Top quark physics with the ATLAS detector at the LHC

INFN Sezione di Pisa
Università di Pisa
1st April 2014

Francesco Spanò

ROYAL HOLLOWAY UNIVERSITY OF LONDON

francesco.spano@cern.ch

ATLAS EXPERIMENT
http://atlas.ch

t

Outline

- **Why top quark ?**

- **The tools of the trade**
  - **LHC:** a *Top* factory at work
  - **The ATLAS detector**: a *Top* observer

- Measuring **top quark production: top pair,** *single top*

- Measuring **top quark properties:mass**

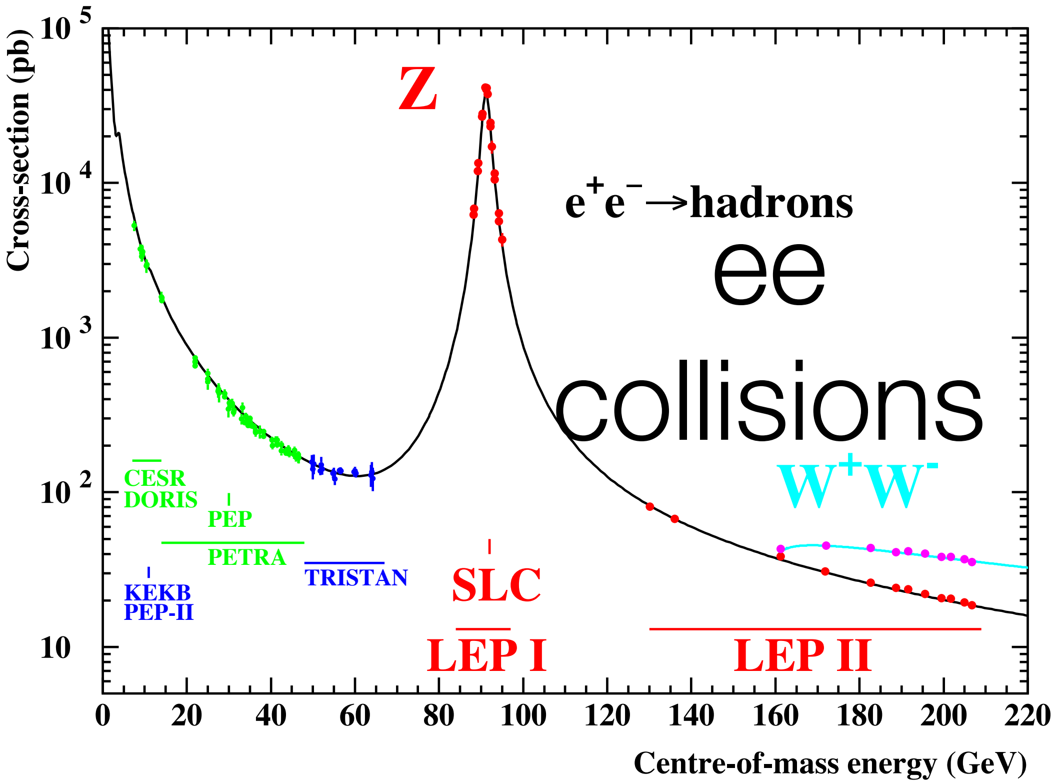
- Measuring **top quark and Higgs coupling**

Latest highlights!

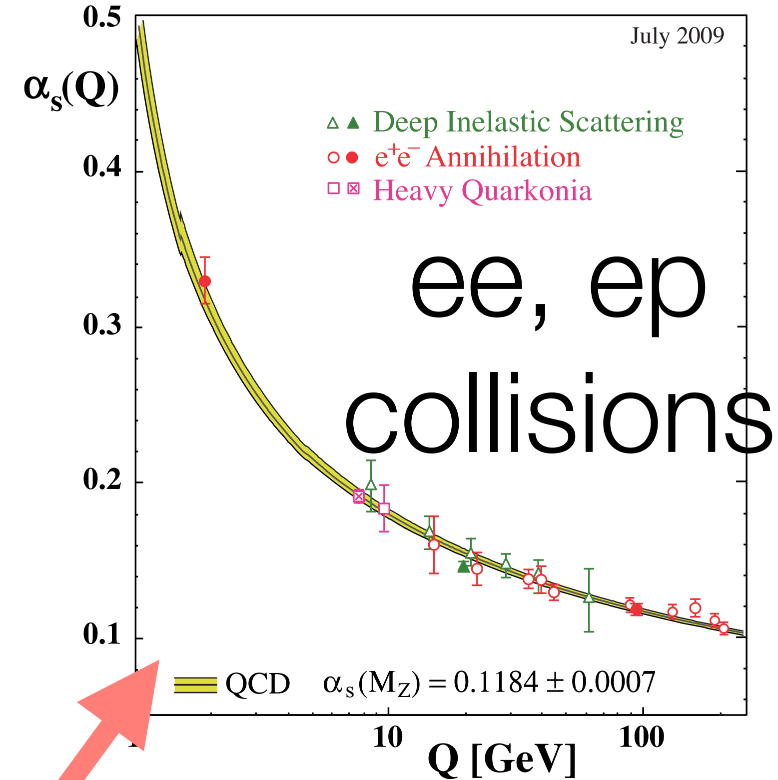
- Top pair production as a **window on new physics**
  - **The emergence of boosted tops**

- Conclusions

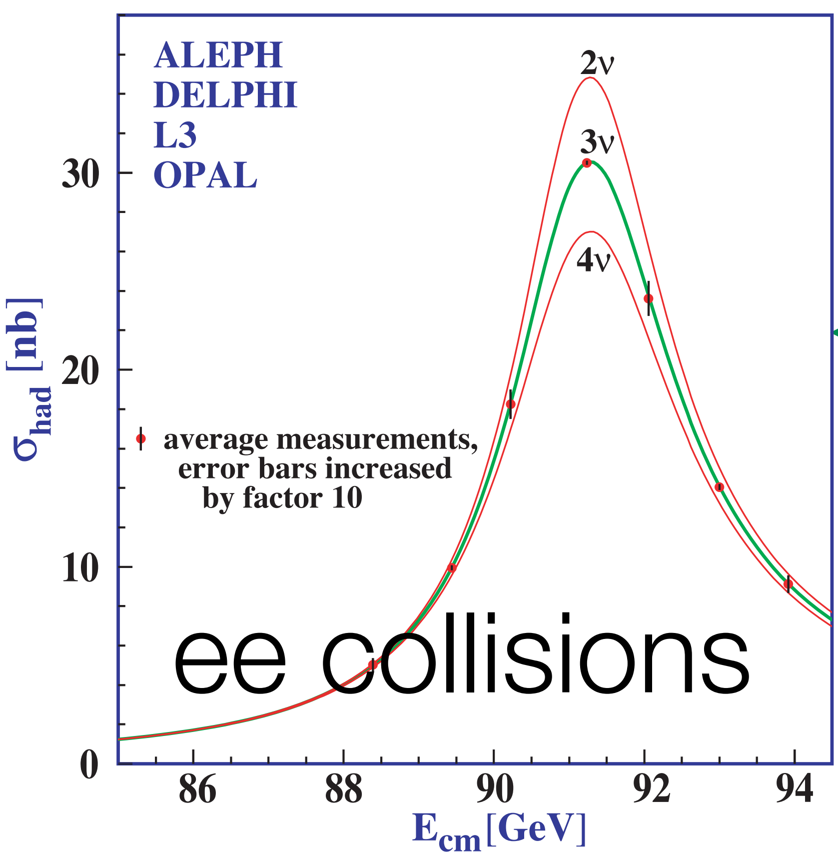
Standard (model) **successes** *at colliders*

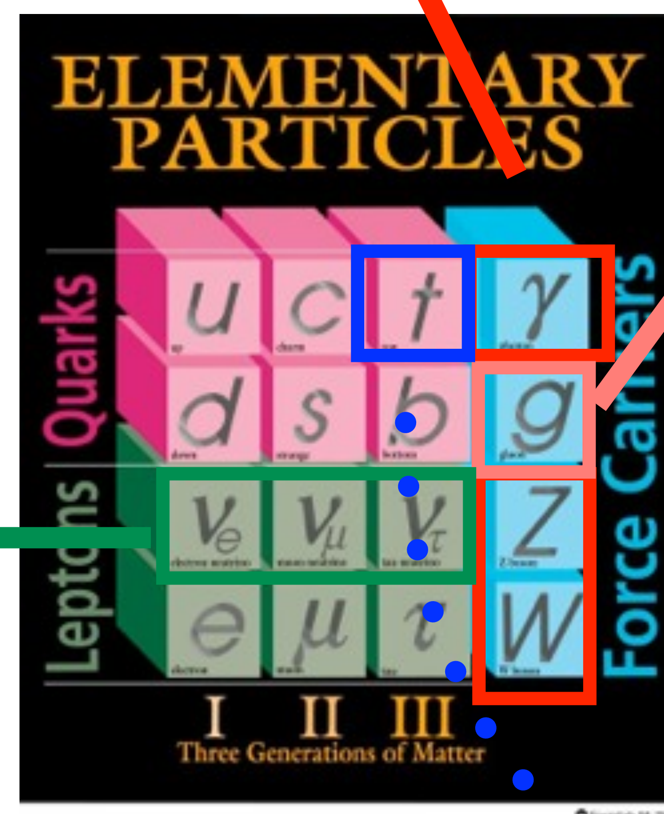


Electromagnetic force unified to Weak: electrons annihilate to W, Z, in addition to photons

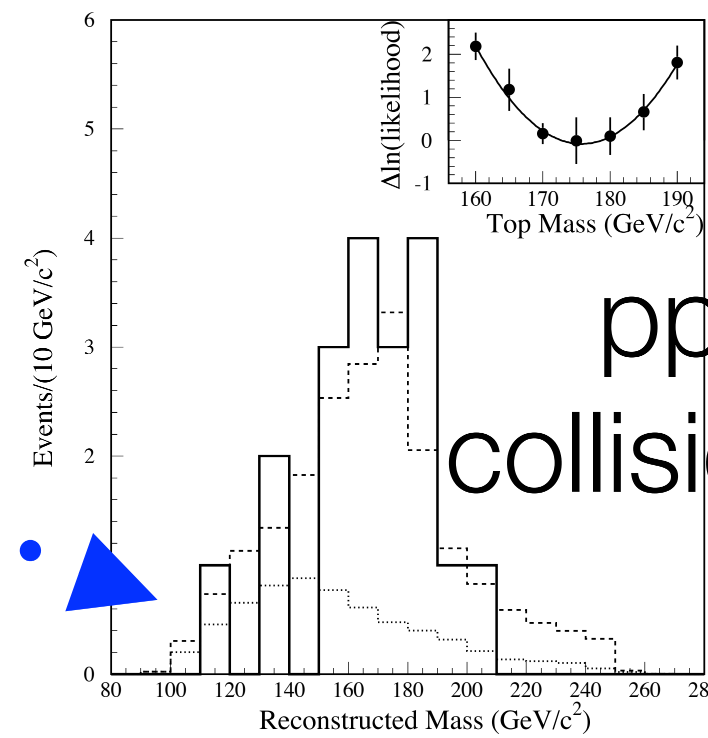


Strong interaction strength changes with momentum exchange





The known micro-world



there are only 3 standard neutrinos

a quick (biased) selection..

Top quark is found

Standard (model) **questions**

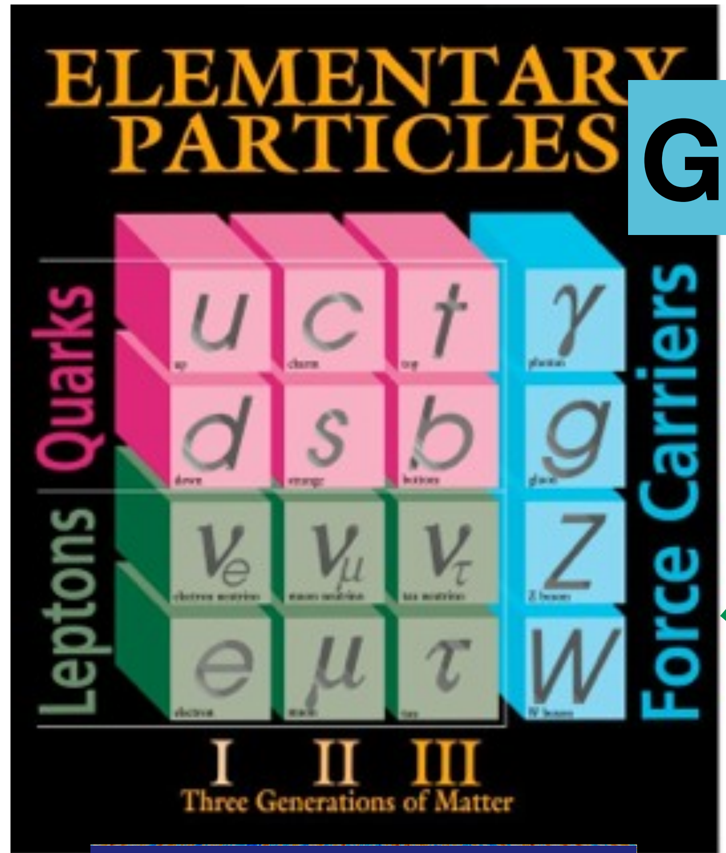
See for instance arXiv:0312096v1[hep-ph]

- *What is the **origin of mass**? Why are symmetries of **forces** different from those of **particles**?*

- *How is **gravity** incorporated?*

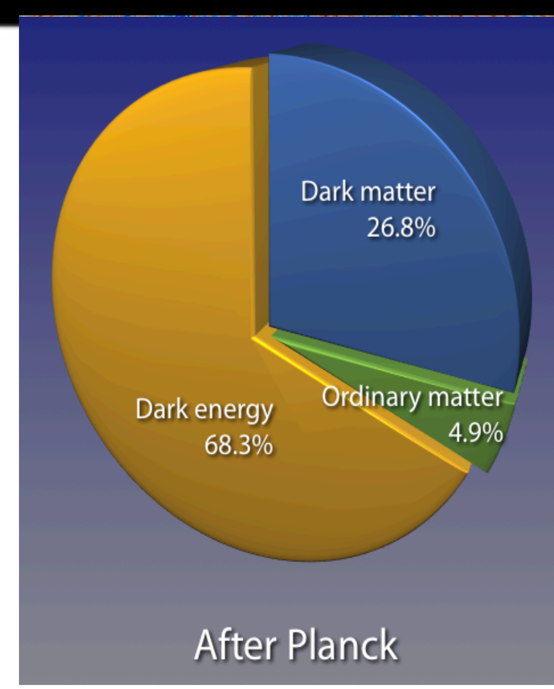
2/3

-1/3



- *Why **different forces** (ranges, strengths)?*

- *Why **3 generations of matter** with different quantum numbers ?*



(P. Natoli, Cosmology with Planck, LaThuile 2014)

- ***What** accounts for the energy balance of the universe?*

Standard (model) **questions**

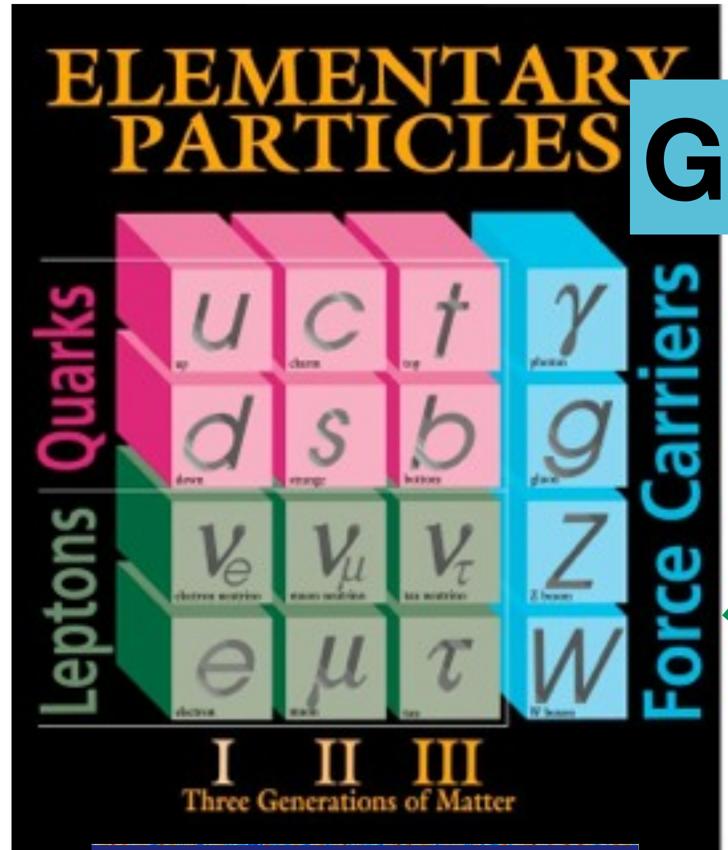
See for instance arXiv:0312096v1[hep-ph]

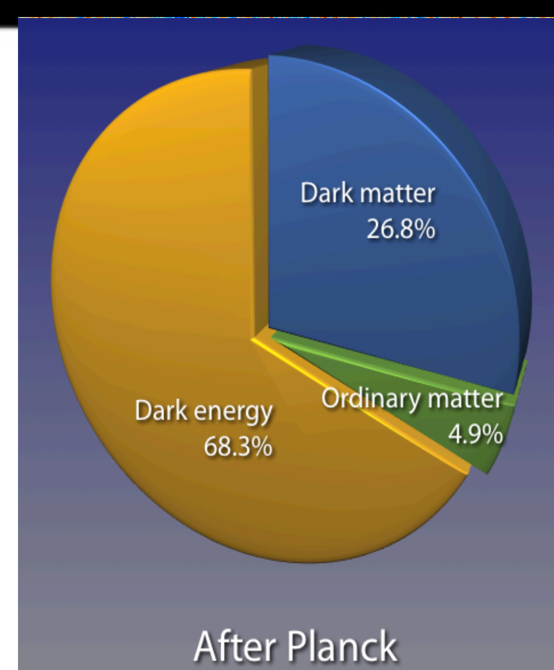
- ***What is the origin of mass? Why are symmetries of forces different from those of particles?***

Higgs, SuperSymmetry, New Strong forces..

- ***How is gravity incorporated?***

Quantum gravity
Extra dimensions...





- ***Why different forces (ranges, strengths)?***

String theory..

- ***Why 3 generations of matter with different quantum numbers ?***

4th generation...?

(P. Natoli, Cosmology with Planck, LaThuile 2014)

- ***What accounts for the energy balance of the universe?***

Dark matter, Dark energy...

Standard (model) **questions**

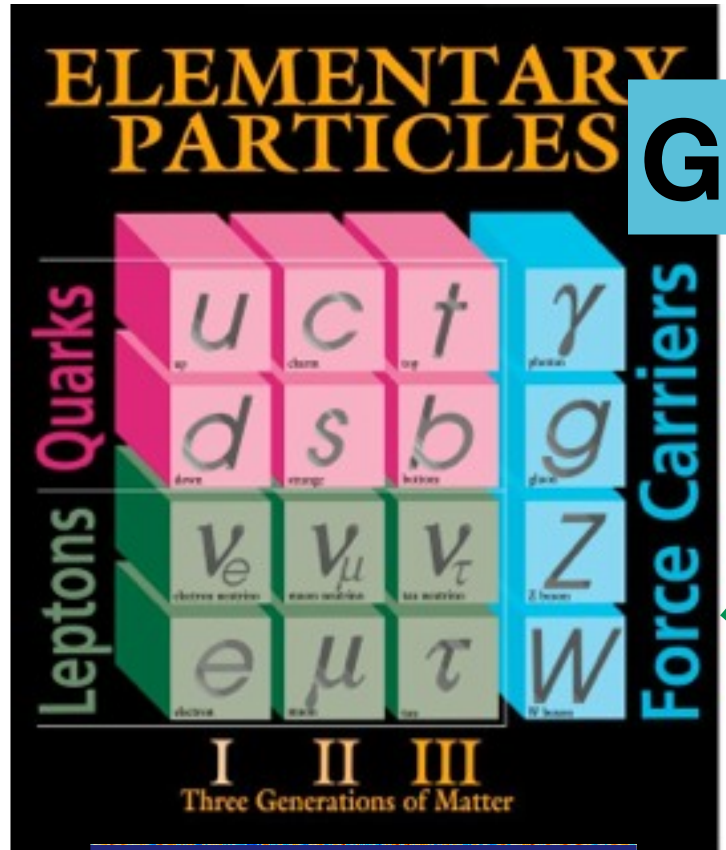
See for instance arXiv:0312096v1[hep-ph]

- ***What is the origin of mass? Why are symmetries of forces different from those of particles?***

Higgs, SuperSymmetry, New Strong forces..

- ***How is gravity incorporated?***

Quantum gravity Extra dimensions...

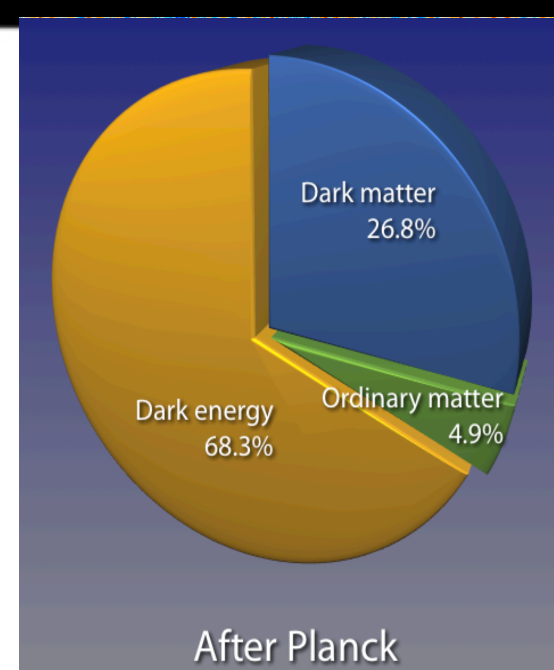


- ***Why different forces (ranges, strengths)?***

String theory..

- ***Why 3 generations of matter with different quantum numbers ?***

4th generation...?



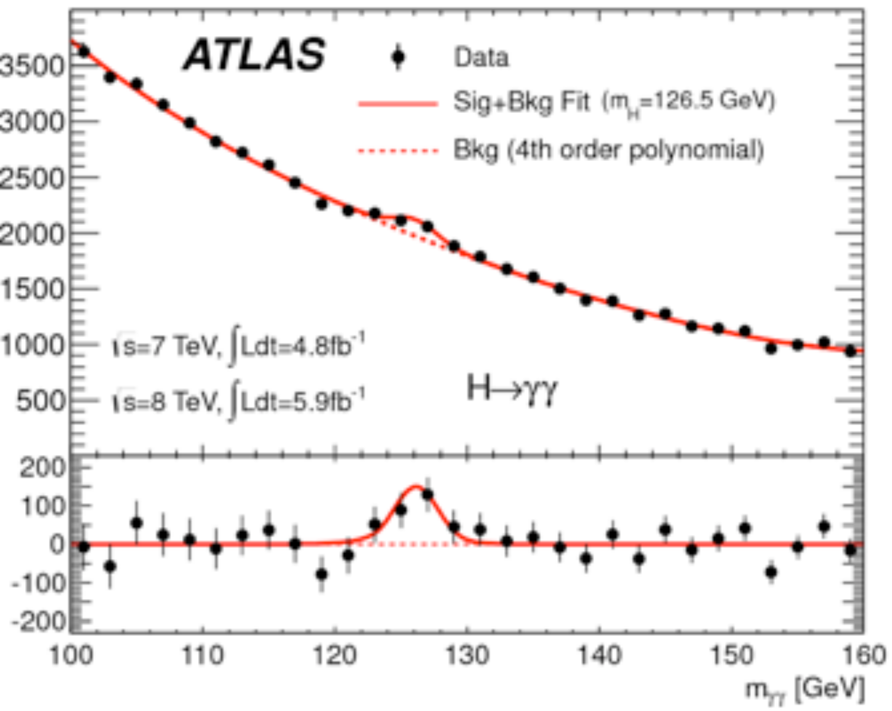
(P. Natoli, Cosmology with Planck, LaThuile 2014)

- ***What accounts for the energy balance of the universe?***

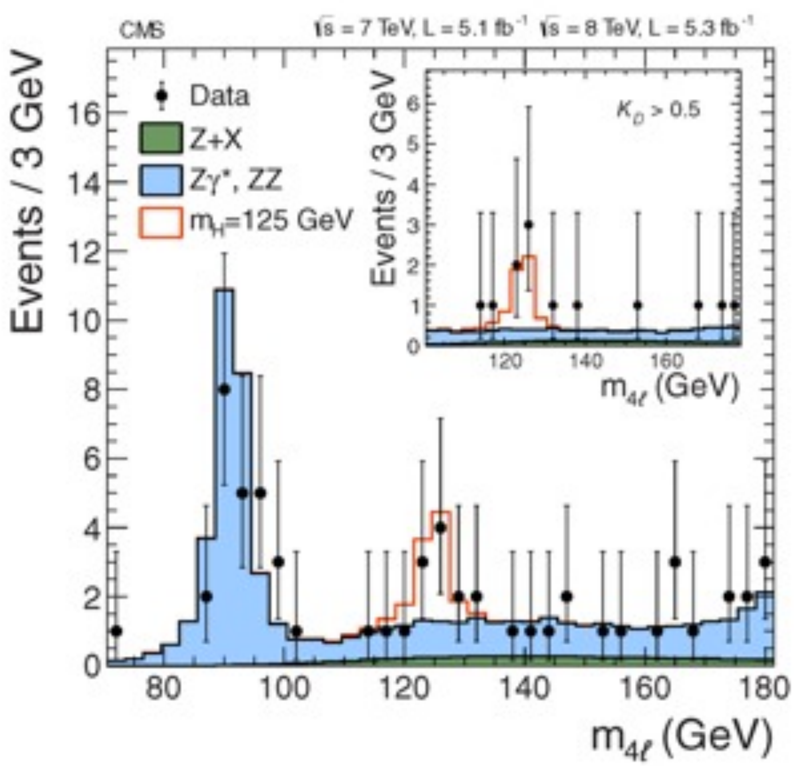
Dark matter, Dark energy...

Standard (model) **successes: scalar boson is observed!**

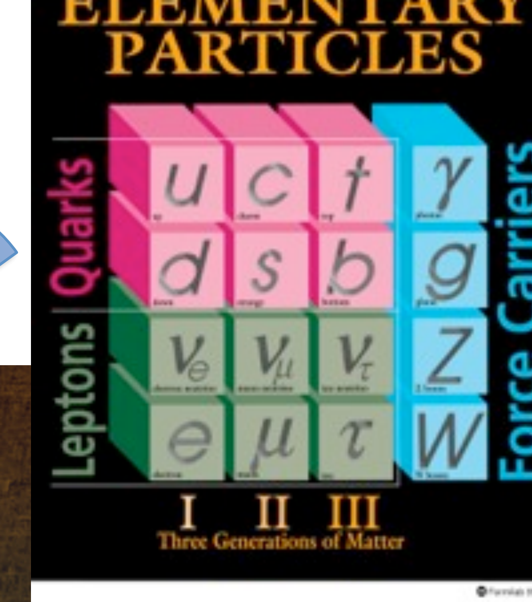
[*Phys. Lett. B 716 (2012) 1-29*]

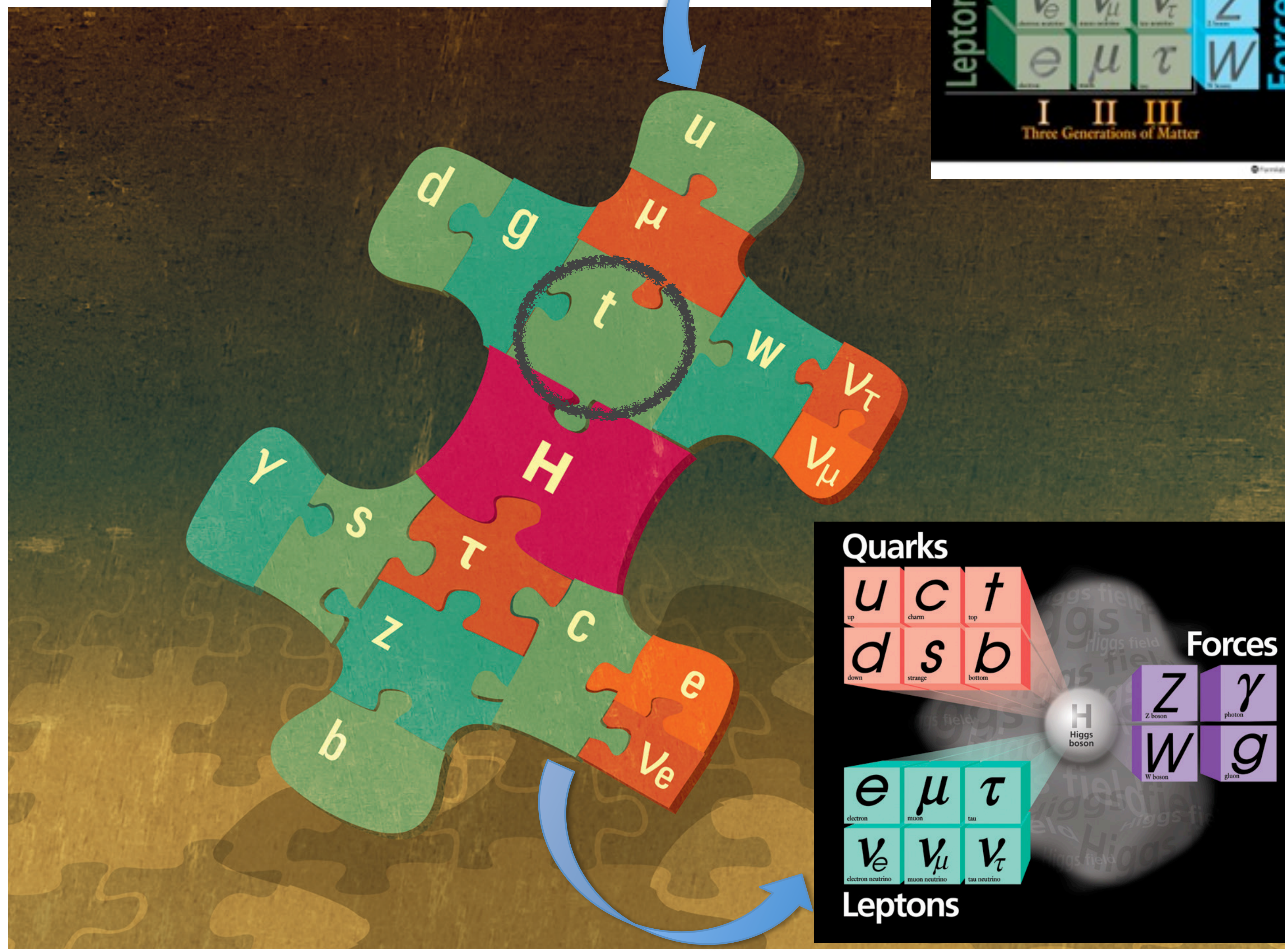


[*Phys. Lett. B 716 (2012) 30*]



Nobel for Phys 2013 - InfoForPublic





Even if the Higgs particle has completed the Standard Model puzzle, the Standard Model is not the final piece in the greater cosmic puzzle.

The puzzle is not complete..

Standard (model) **questions**

See for instance arXiv:0312096v1[hep-ph]

- *What is the **origin of mass**? Why are symmetries of **forces** different from those of **particles**?*

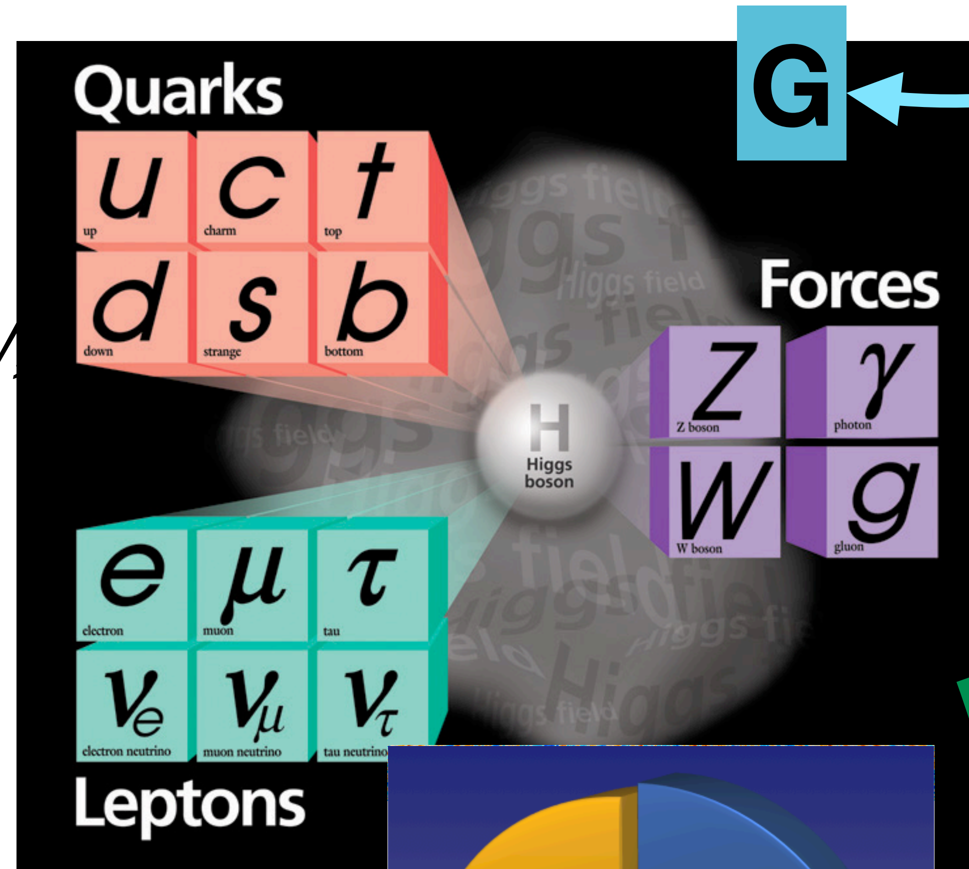
***Higgs,** SuperSymmetry*

New Strong forces..

- *How is **gravity** incorporated?*

Quantum gravity

Extra dimensions...



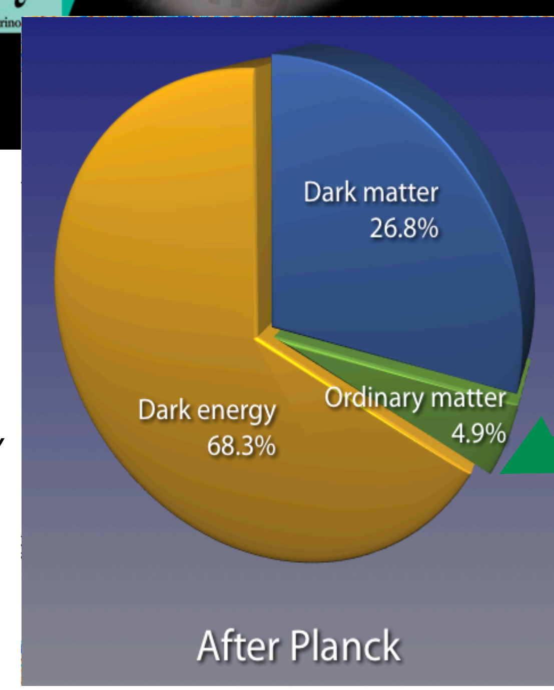
- *Why **3 generations of matter** with different quantum numbers ?*

4th generation...?

- *Why **different forces** (ranges, strengths)?*

String theory..

(P. Natoli, Cosmology with Planck, LaThuile 2014)



- ***What accounts for the energy balance of the universe?***

Dark matter, Dark energy...

Why Top (quark)?

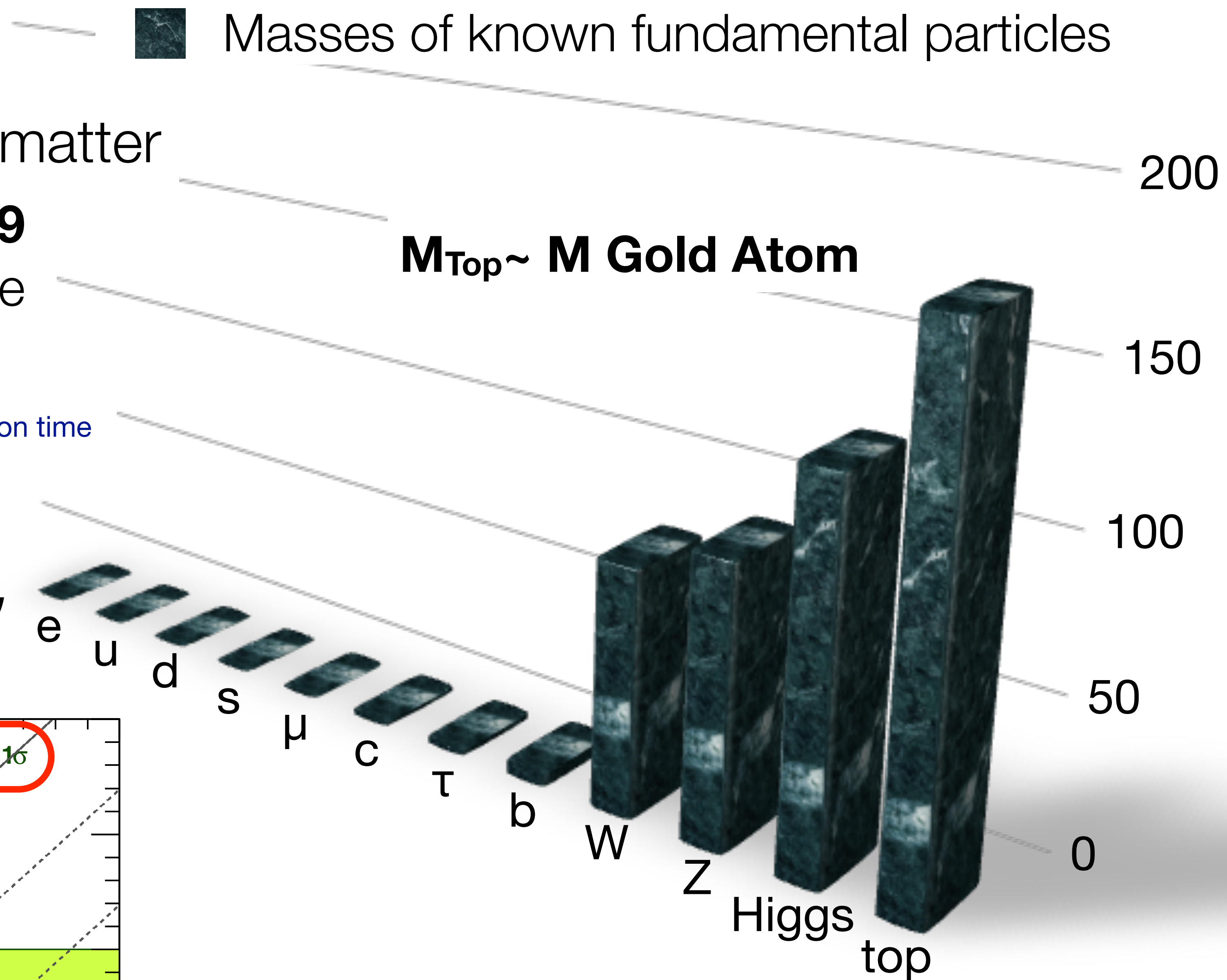
Most massive known **constituen**t of matter

Largest coupling to Higgs in SM: Y_t >0.9

M_{top}~ electroweak symmetry breaking scale

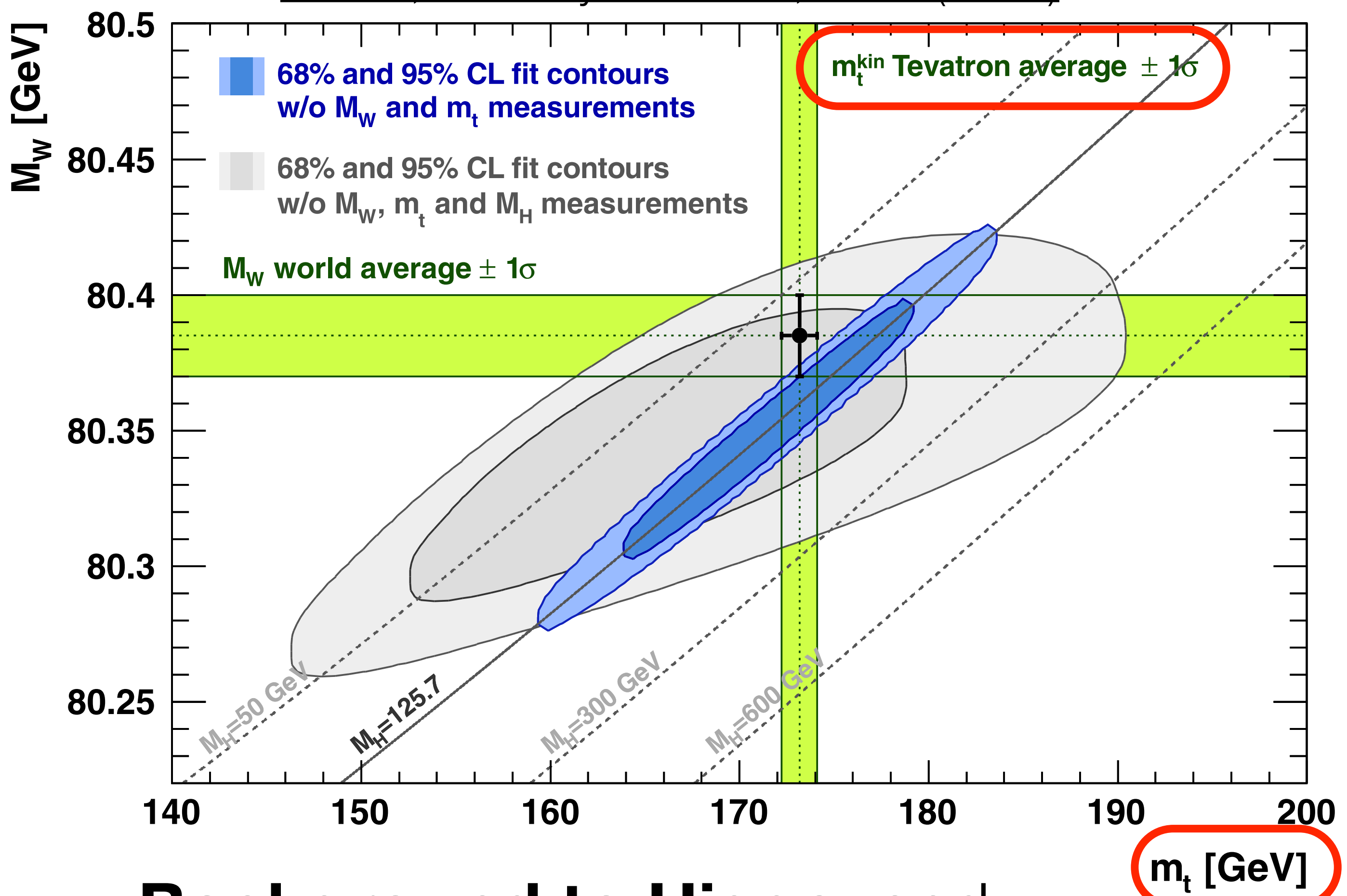
$1/m_t$ < $1/\Gamma_t$ < $1/\Lambda$ < m_t/Λ^2

Production time < Lifetime < Hadronization time < Spin decorrelation time



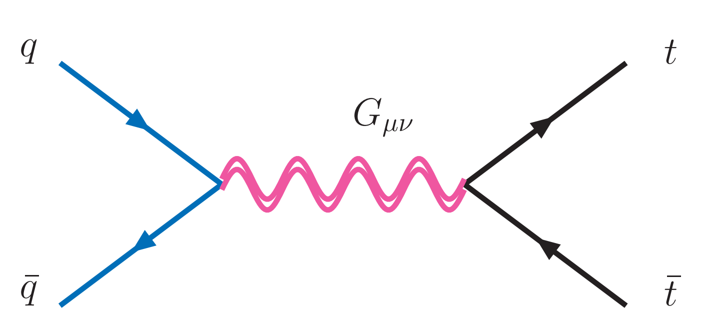
Strong, EWK production and decay rate test standard model

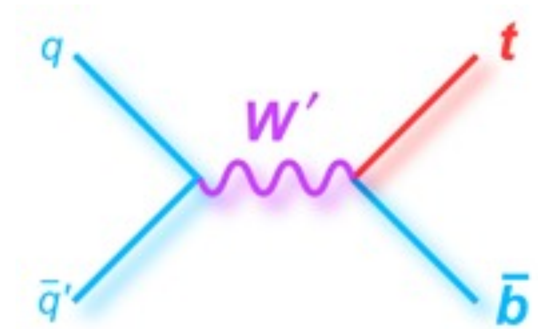
GFitter, Eur. Phys. J. C 72, 2205 (2012)



Background to Higgs and possible **new physics** (SUSY,..)

In many scenarios top quark has **direct/ indirect coupling to new physics:** from extra dimensions to new strong forces





LHC : a *Top* producer

counter-rotating high intensity proton bunches colliding at center of mass energy (E_{cm} or $\sqrt{s}$) = 7 TeV in 27 Km tunnel

E_{cm}(Tevatron)= 1.96 TeV

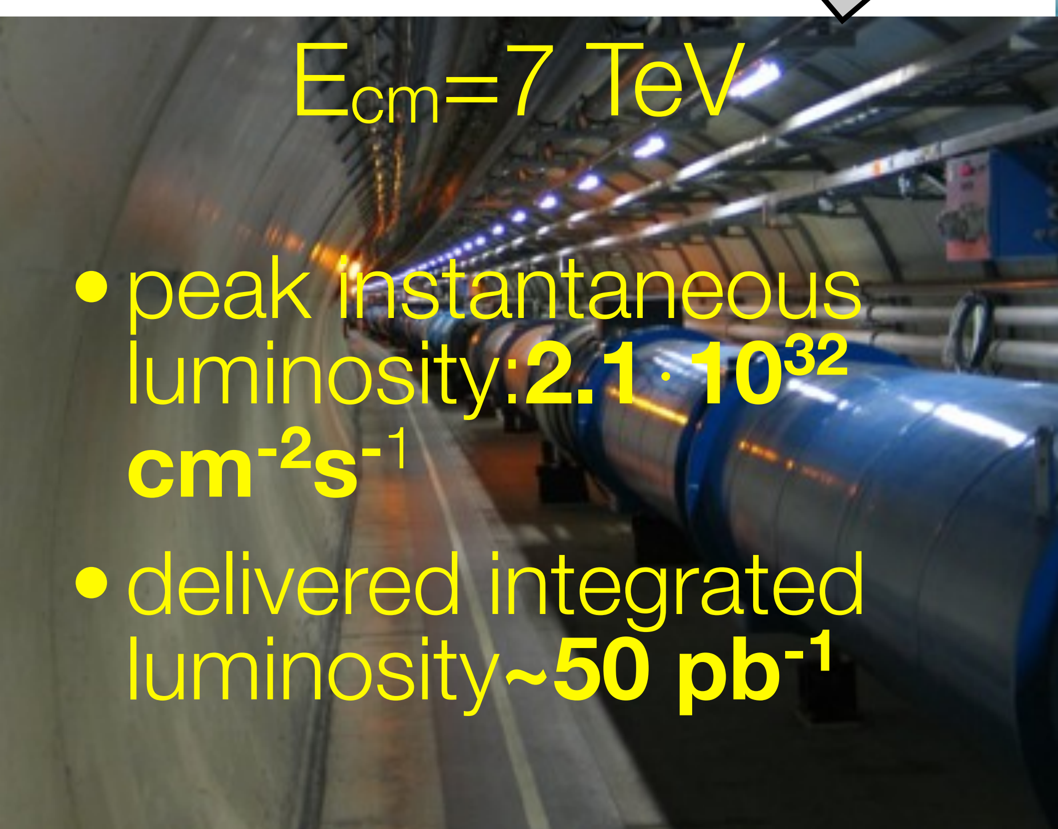
$$\mathcal{L} \propto \frac{N_1 N_2}{\sigma^2}$$

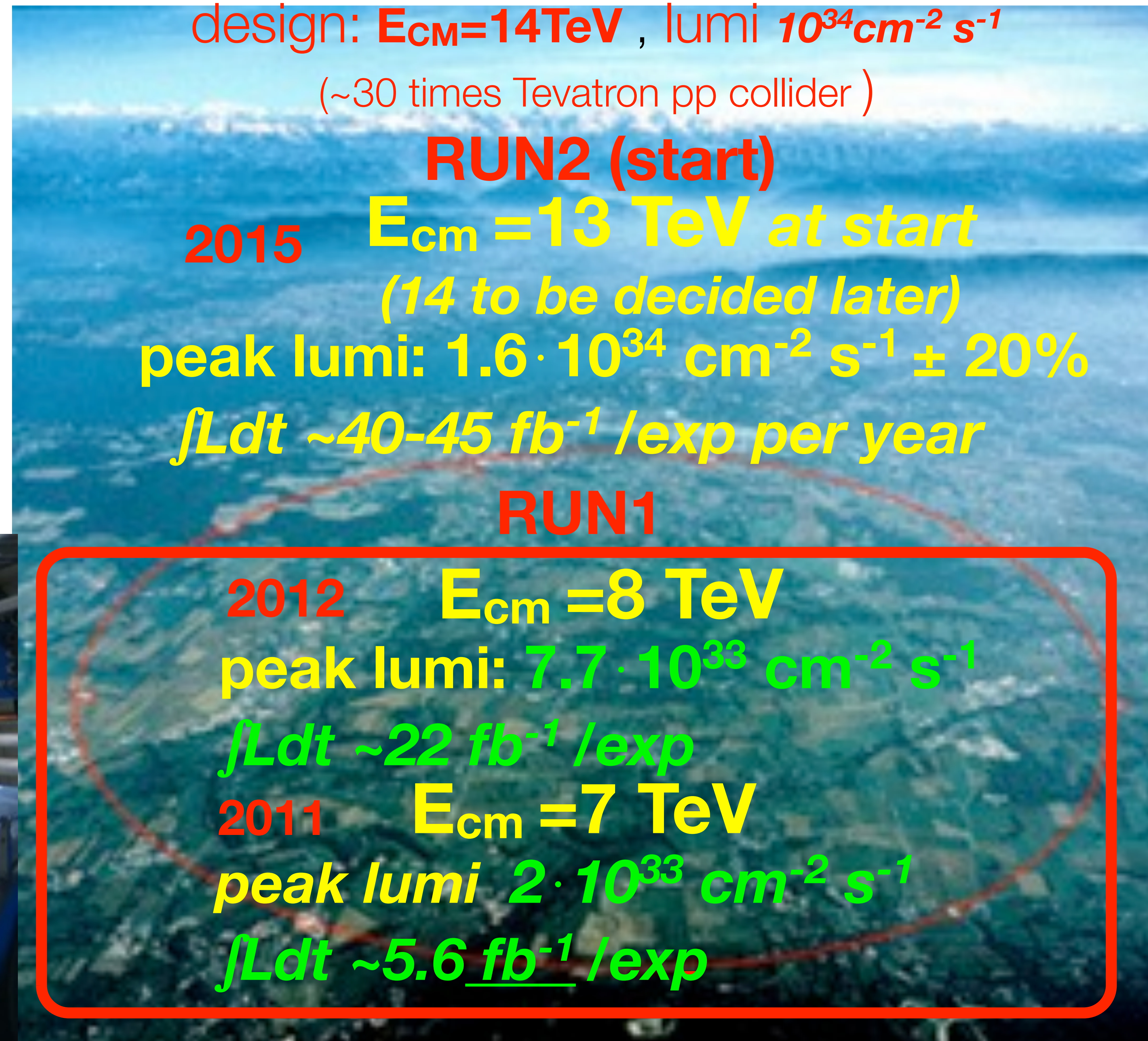
Key parameters:

- N_i = bunch intensity
- n_b = number of bunches
- σ = colliding beam size

Ad maiora..

2010

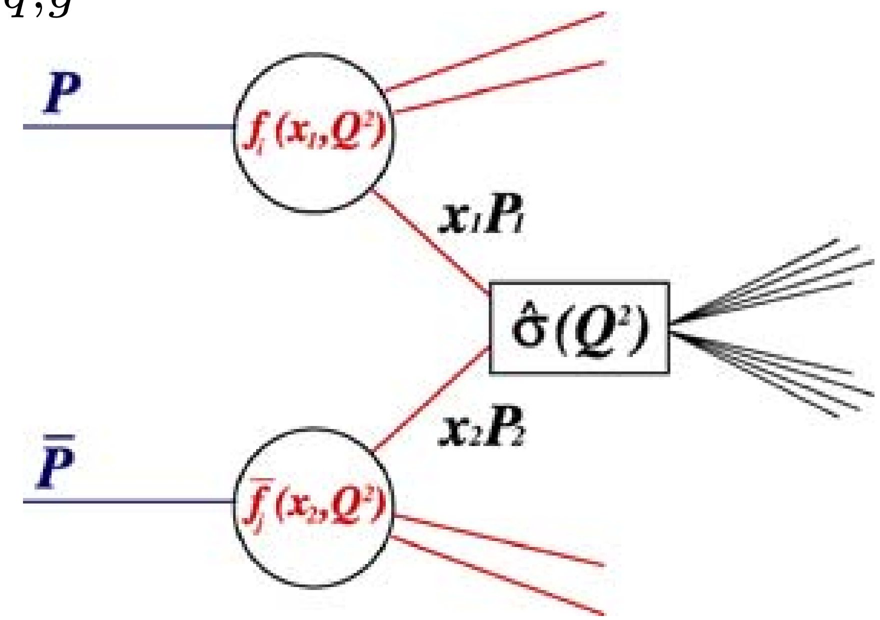




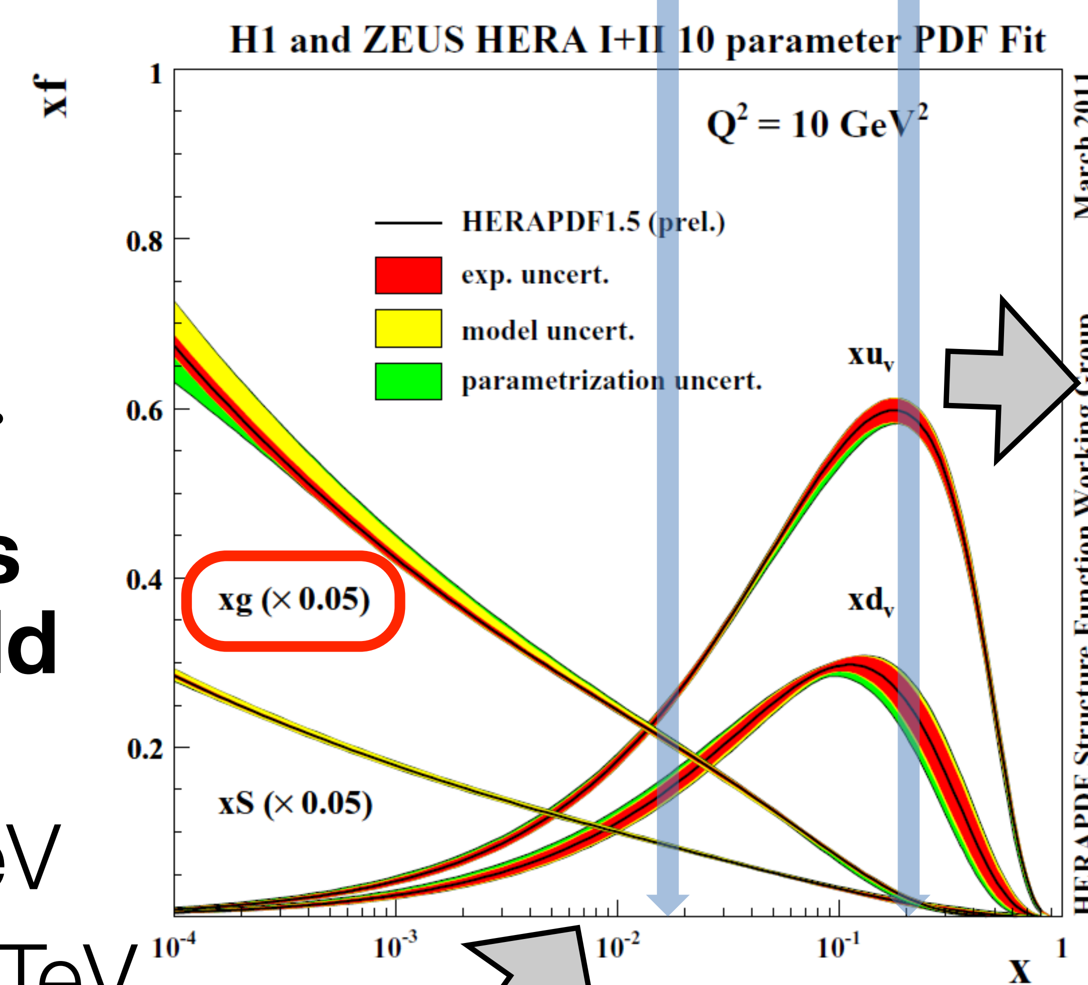
$N_{events}(\Delta t) = \int L dt$ * cross section

Top quark @ LHC: production

$$\sigma^{t\bar{t}}(\sqrt{s}, m_t) = \sum_{i,j=q,\bar{q},g} \int dx_i dx_j f_i(x_i, \mu^2) \bar{f}_j(x_j, \mu^2) \quad \hat{\sigma}^{ij\to tt}(\rho, m_t^2, x_i, x_j, \alpha_s(\mu^2), \mu^2)$$



	LHC(14)	LHC(7)	Tev(1.9)
gg	~90%	~85%	~10%
qq	~10%	~15%	~90%



To produce $t\bar{t}$

~massless partons

$\hat{s} \geq 4m_t^2$ ⇒ $x_i x_j = \hat{s}/s \geq 4m_t^2/s.$

$f_i(x)$ falls with larger ŝ

lower ŝ ← lower x_i, x_j

⇒ **typical $x_i x_j$ is near threshold low ŝ**

⇒ $x \approx \frac{2m_t}{\sqrt{s}} =$ 0.19 @ Tevatron √s=1.8 TeV

0.18 @ Tevatron √s=1.96 TeV

(0.048, 0.043, 0.025) @ LHC with √s=(7, 8,14) TeV

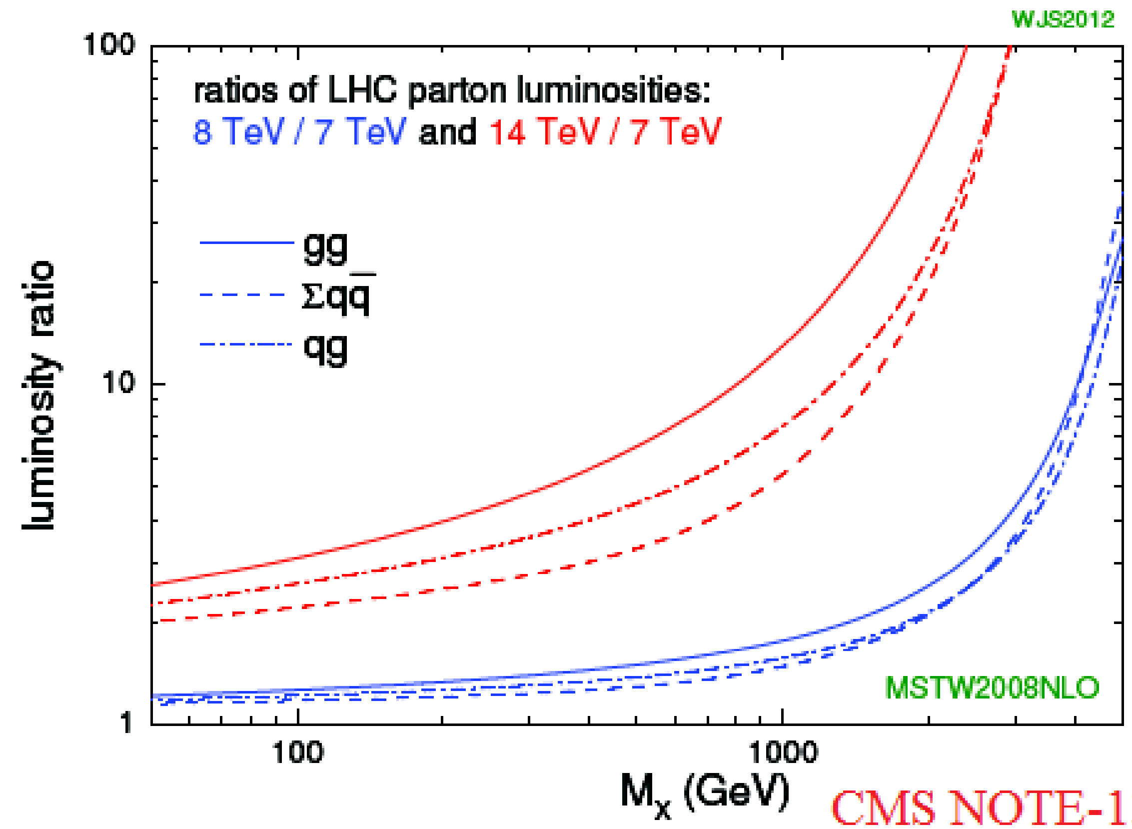
Top quark @ LHC: production (II)

(formulas from Campbell et al, hep/ph 0611148)

$$\sigma = \sum_{i,j}\int_0^1 dx_1\, dx_2\, f_i(x_1,\mu)\, f_j(x_2,\mu)\, \hat{\sigma}_{ij} = \sum_{i,j}\int \left(\frac{d\hat{s}}{\hat{s}}\, dy\right)\left(\frac{dL_{ij}}{d\hat{s}\, dy}\right)(\hat{s}\,\hat{\sigma}_{ij}) \sim \sum_{i,j}\frac{\Delta\hat{s}}{\hat{s}}\left(\frac{dL_{ij}}{d\hat{s}}\right)(\hat{s}\,\hat{\sigma}_{ij})$$

$$\frac{dL_{ij}}{d\hat{s}\, dy} = \frac{1}{s}\,\frac{1}{1+\delta_{ij}}\left[f_i(x_1,\mu) f_j(x_2,\mu) + (1 \leftrightarrow 2)\right]$$

- Different **x-range and center of mass** dependence incorporated in **Parton luminosities**→
  - **gg→X** dominated processes **grow more than qq →X** ones
  - **larger gains at high multi-TeV masses** ~up to O(100)



CMS NOTE-13-002

$R^{th,nnpdf}$ = 14TeV to 8 TeV xsec ratios

JHEP{1208},2012

Cross Section	$R^{\rm th,nnpdf}$	$\delta_{\rm PDF}$(%)	δ_{α_s} (%)	$\delta_{\rm scales}$ (%)
$t\bar{t}/Z$	2.12	$\pm$ 1.3	$-0.8-0.8$	$-0.4-1.1$
$t\bar{t}$	3.90	$\pm$ 1.1	$-0.5-0.7$	$-0.4-1.1$
Z	1.84	$\pm$ 0.7	$-0.1-0.3$	$-0.3-0.2$
W^+	1.75	$\pm$ 0.7	$-0.0-0.3$	$-0.3-0.2$
W^-	1.86	$\pm$ 0.6	$-0.1-0.3$	$-0.3-0.1$
W^+/W^-	0.94	$\pm$ 0.3	$-0.0-0.0$	$-0.0-0.0$
W/Z	0.98	$\pm$ 0.1	$-0.1-0.0$	$-0.0-0.0$
ggH	2.56	$\pm$ 0.6	$-0.1-0.1$	$-0.9-1.0$
$t\bar{t}(M_{tt}\geq 1\ \mathrm{TeV})$	8.18	$\pm$ 2.5	$-1.3-1.1$	$-1.6-2.1$
$t\bar{t}(M_{tt}\geq 2\ \mathrm{TeV})$	24.9	$\pm$ 6.3	$-0.0-0.3$	$-3.0-1.1$
$\sigma_{\rm jet}(p_T\geq 1\ \mathrm{TeV})$	15.1	$\pm$ 2.1	$-0.4-0.0$	$-1.9-2.4$
$\sigma_{\rm jet}(p_T\geq 2\ \mathrm{TeV})$	182	$\pm$ 7.7	$-0.3-0.2$	$-5.7-4.0$

- **Cross section in"tails" increase differently** than the overall value

thanks to K. Suruliz, TOP2013

Top quark @ LHC: production (II)

pp collisions

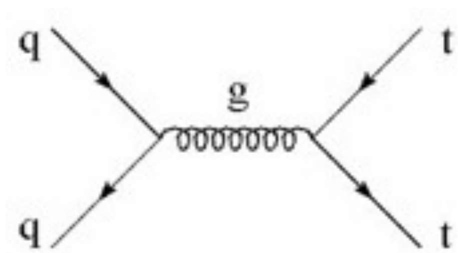
probing lower x than Tevatron → (abundant) gluon fusion dominated

	Tevatron	LHC(7)	LHC(14)
gg	~10%	**~85%**	~90%
qq	~90%	**~15%**	~10%

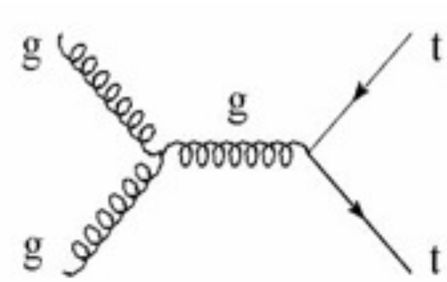
m_{top}= 172.5

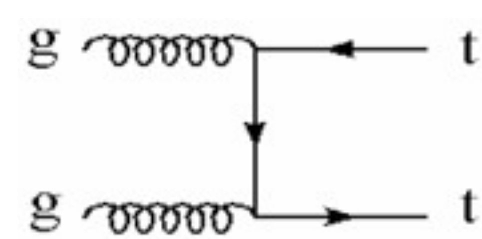
top pairs*: *strong

qq annihilation



gluon fusion





At Tevatron

$\sigma_{t\bar{t}} \sim 7$ pb
$\sigma_t \sim 3.5$ pb

Czakon,Mitov,Fiedler 2013

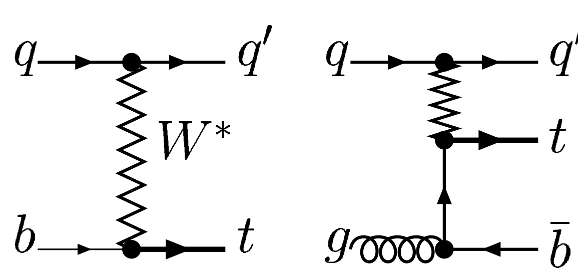
NNLO+NNLL accuracy

$\delta\sigma_{tt}/\sigma_{tt}$ ~4%

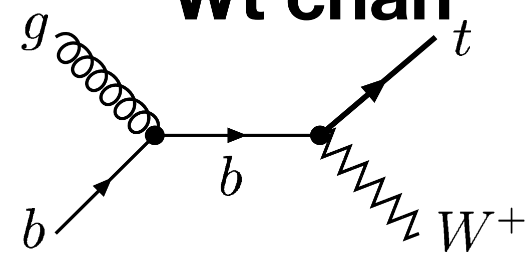
σ_{7TeV} (pb)	**$172^{+4.4}_{-5.8}{}^{+4.7}_{-48}$**
σ_{8TeV} (pb)	**$245^{+6.2}_{-8.4}{}^{+6.2}_{-6.4}$**
σ_{13TeV} (pb)	**~741**

single top:* *electroweak

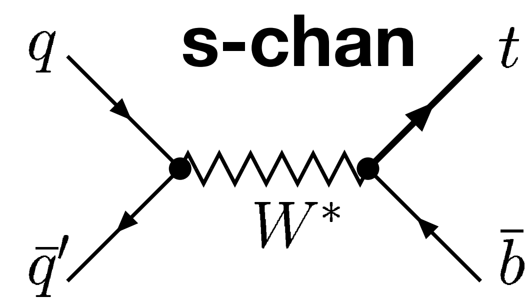
t-chan



Wt chan



s-chan



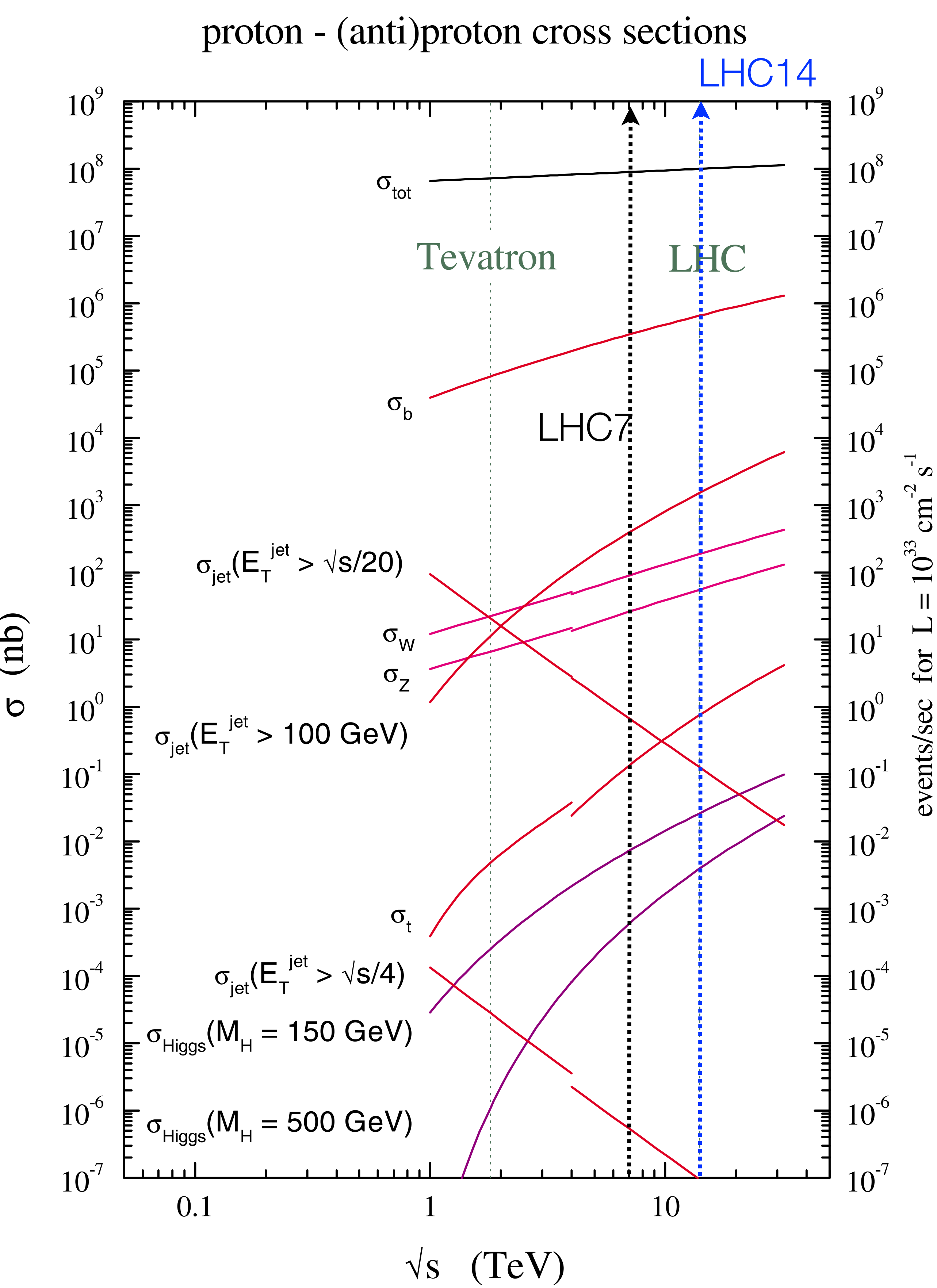
Kidonakis 2010,2011

approx NNLO

$\delta\sigma_t/\sigma_t$ ~2 to 7%

	t-chan	Wt chan	s-chan
σ_{7TeV} (pb)	**64.6±2.4**	**15.7±1.1**	**4.6±0.2**
σ_{8TeV} (pb)	**87.8±3.4**	**22.4±1.5**	**5.6±0.2**
σ_{13TeV} (pb)	**~213**	**~71.7**	**~10.9**

Top @ LHC: in the context



t and $t\bar{t}$ cross section

√s(TeV)	σ_{tt}(pb)	σ_t(pb)
1.96(pp̄)	~7	3.5
7(pp)	~172	~85
8(pp)	~245	~115
13(pp)	~740	~296
14(pp)	~900	~338

$t\bar{t}$(t) Rate at L= 10^{33}cm^{-2} s^{-1}

0.17 (0.08)Hz
0.24 (0.12)Hz
0.74 (0.30)Hz
0.90 (0.33)Hz

LHC is a TOP FACTORY

~5.4M (~0.96 M) $t\bar{t}$ events produced by LHC in 2012 (2011)

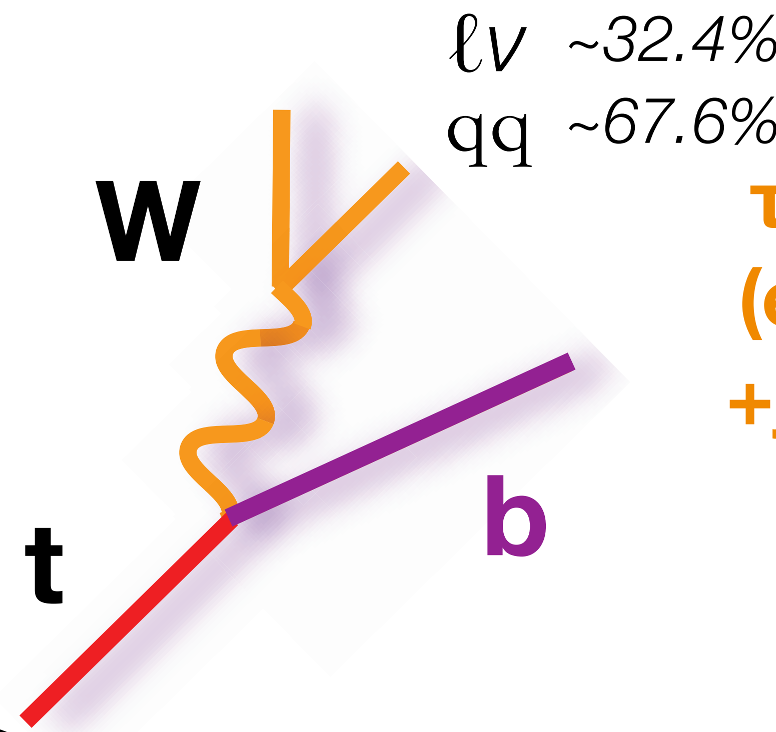
for ∫Ldt = 100fb^{-1} @13 (14) TeV, expect ~59.2 10^6 (~72 10^6) $t\bar{t}$ events

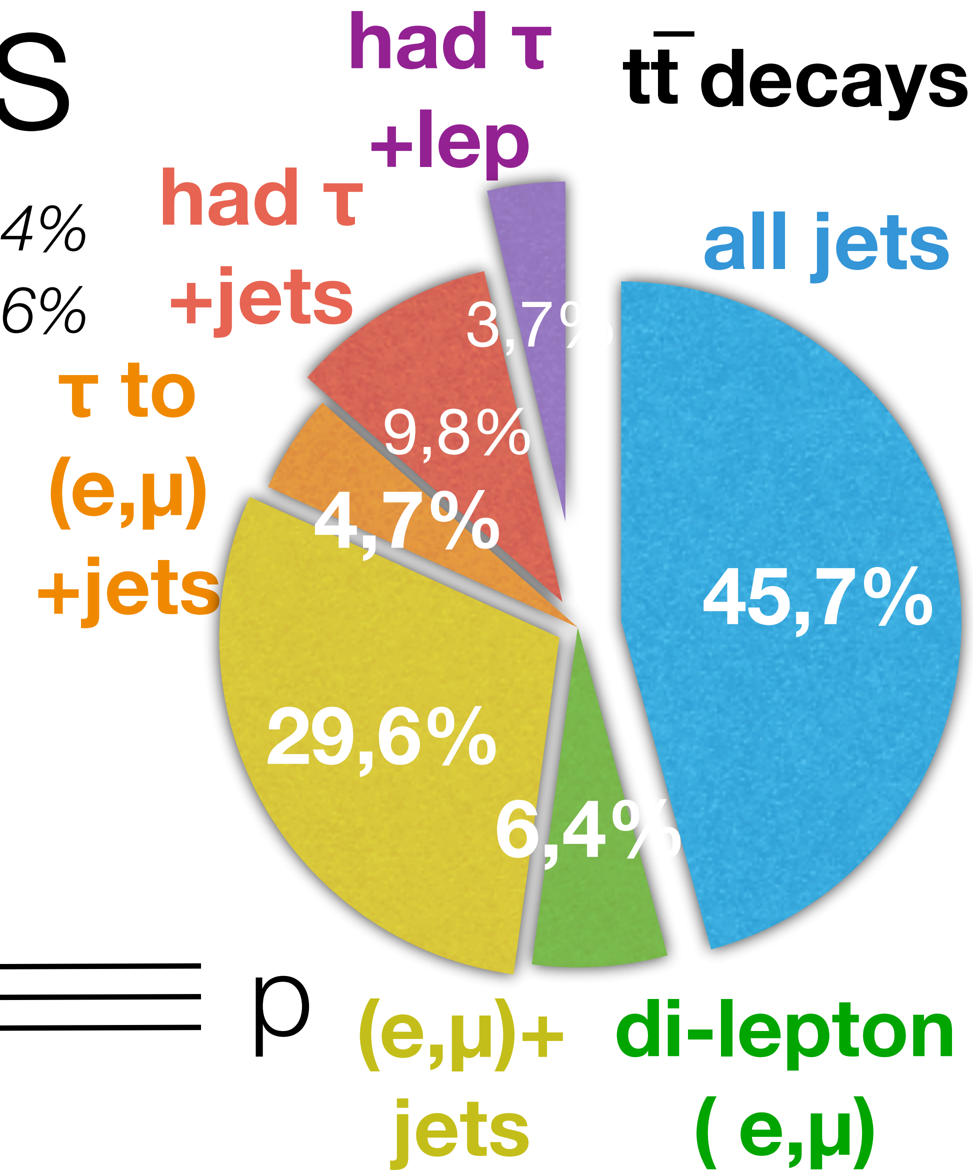
Single top events are ~50%

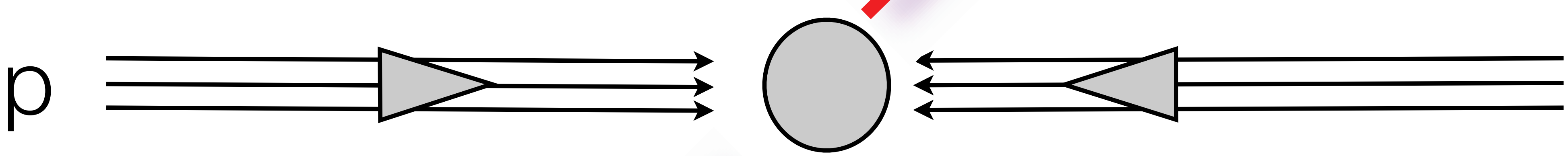
Tevatron (lower energy collider): ∫Ldt =9.4 fb^{-1} on tape, expect ~ 6.6·10^4 events

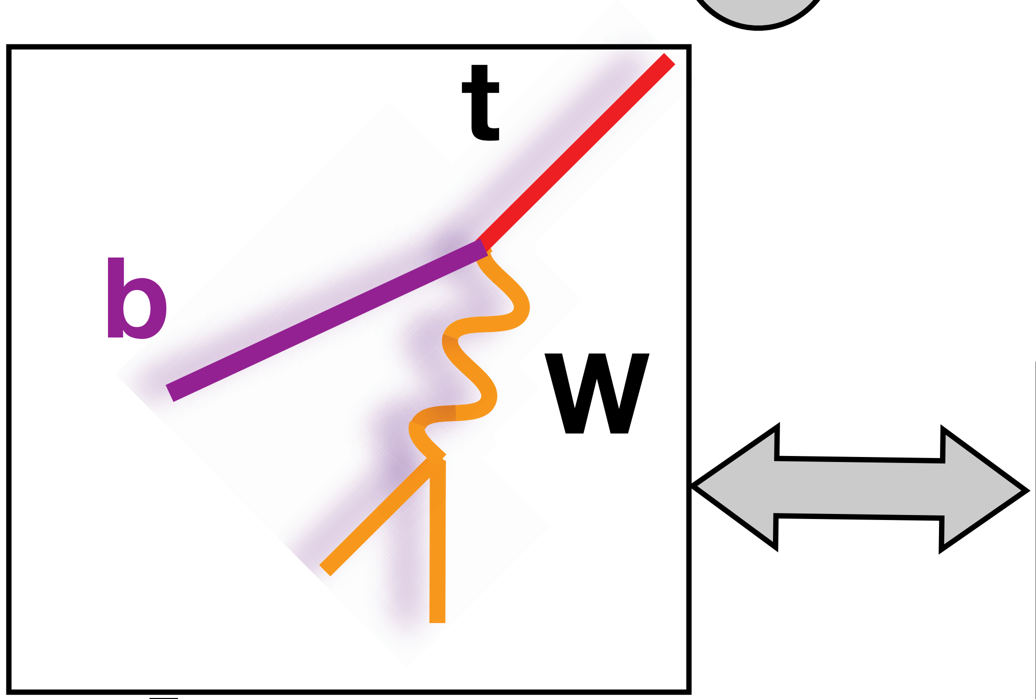
Top signatures

- **High P_T jets**
- **b-jets**
- **1 to 2 high P_T leptons**
- **Missing energy**

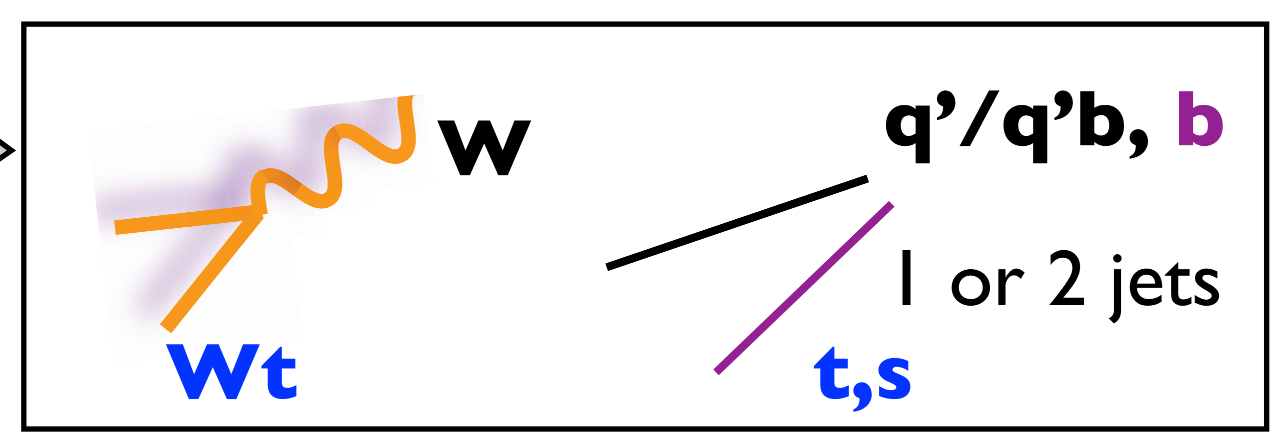








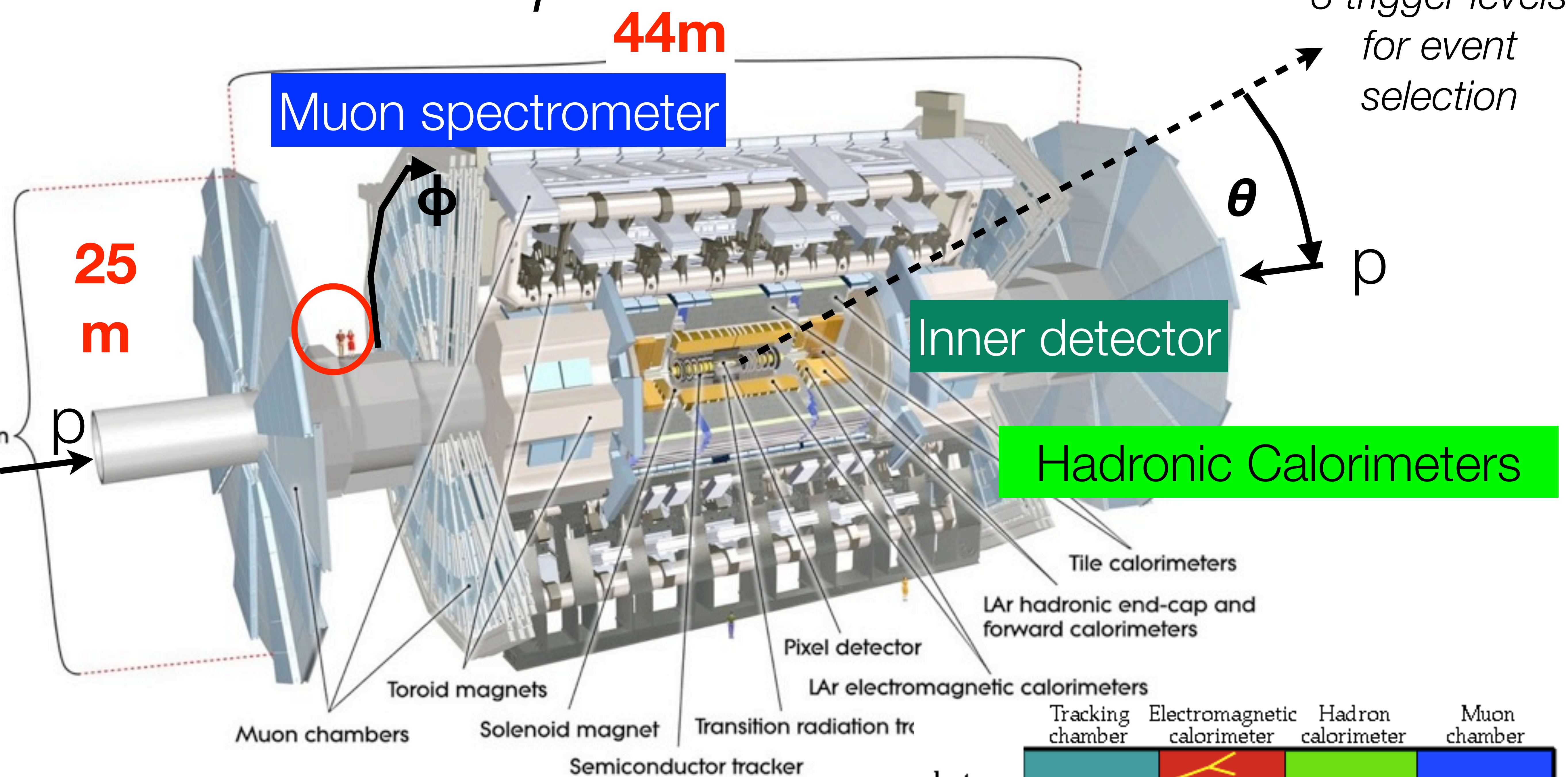
single top



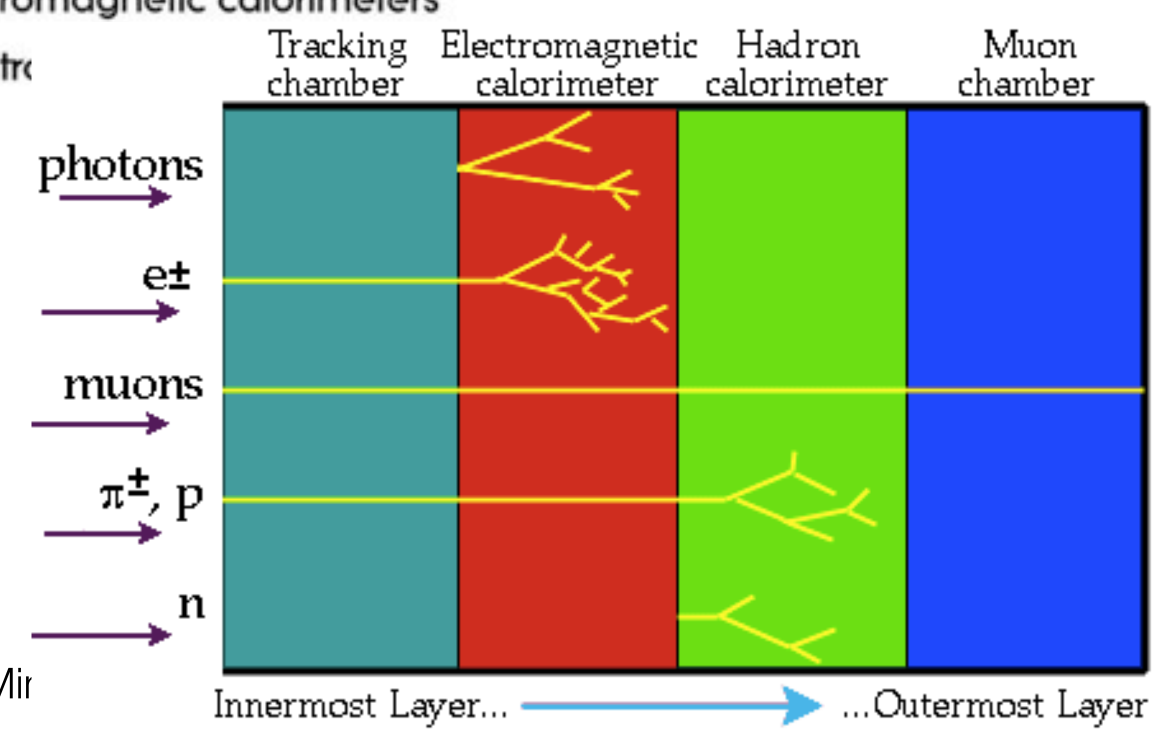
bkgs_tt̄: W/Z(+jets), single top, QCD, Di-bosons

bkgs_single_t: tt̄ + same bkgs_tt̄

ATLAS : a *Top* observer

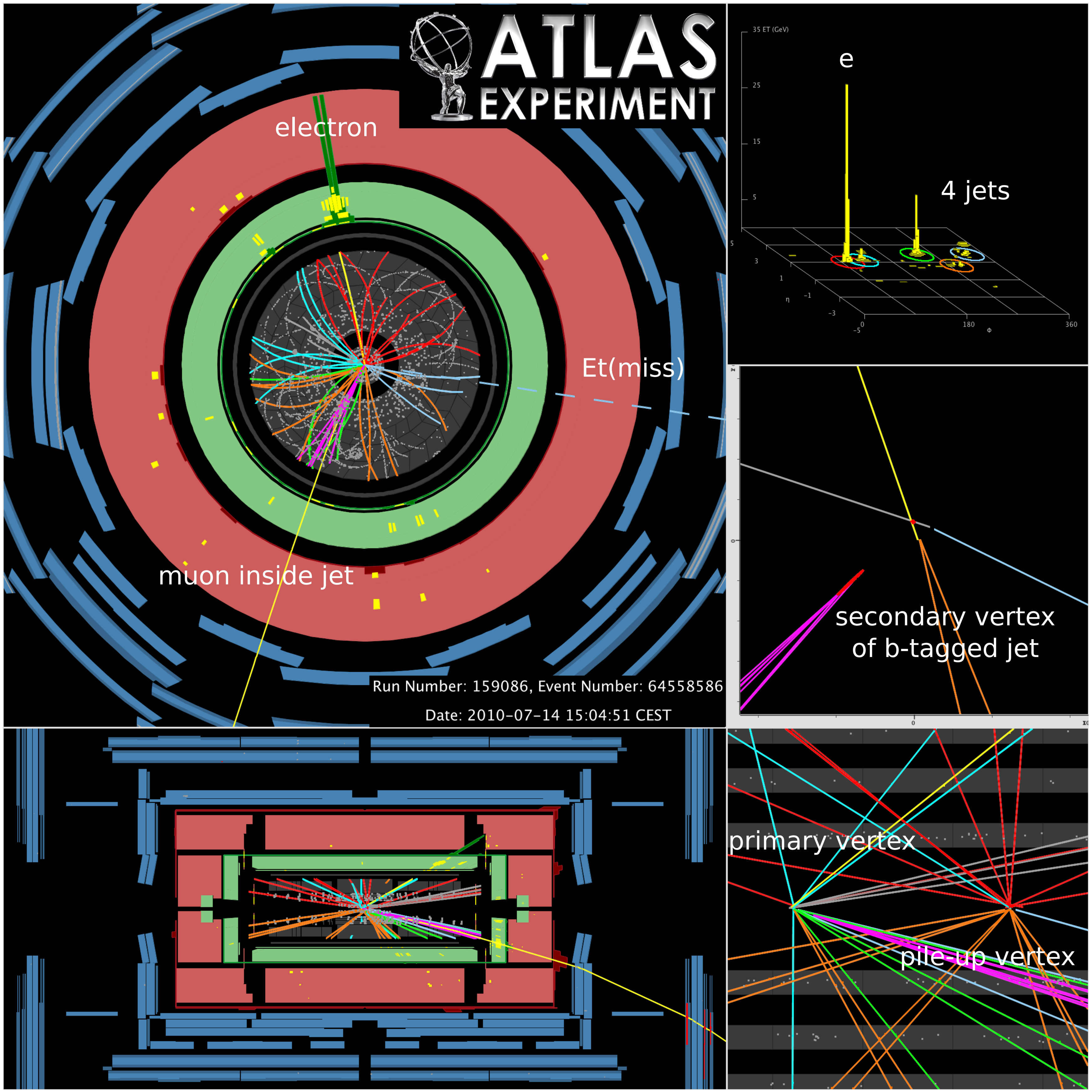


size matters



η = pseudorapidity =-ln (tan(θ/2))

ATLAS **:** *Top* observer.....



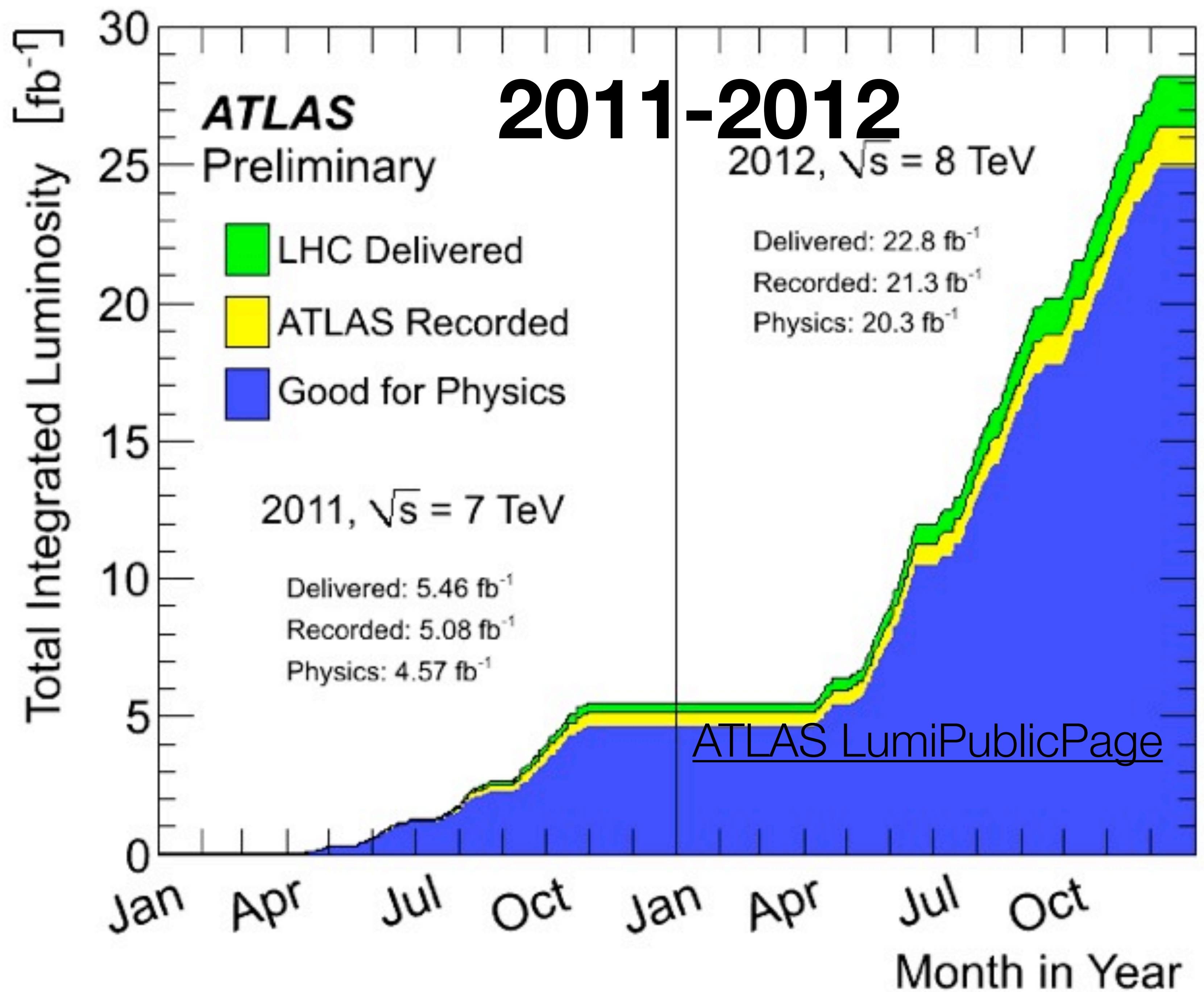
Top quark events are real commissioning tool: full detector at play!!

e+jets candidate

...with excellent data taking performance

Analyses use : 4.7 fb^{-1} (2011) to 20.3 fb^{-1} (2012)

Lumi uncertainty
~1.8% to 3.1%(prel)



ATLAS (2010)

Total Recorded (Delivered) Lumi: **45.0 (48.1) pb^{-1}**
Lumi uncertainty~3.4%

Data sample for first top paper~3 pb^{-1}

...In a harsh environment

Number of Interactions per Crossing

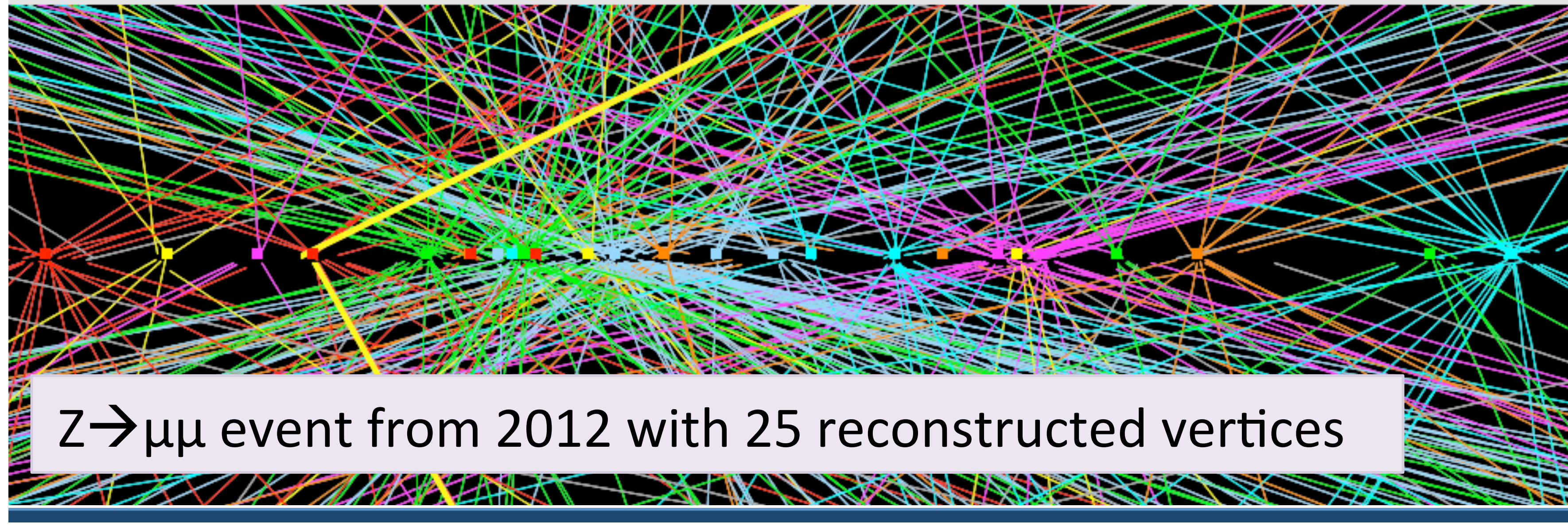
Shown is ***the luminosity-weighted distribution of the mean number of interactions per crossing for the 2011 and 2012 data.***

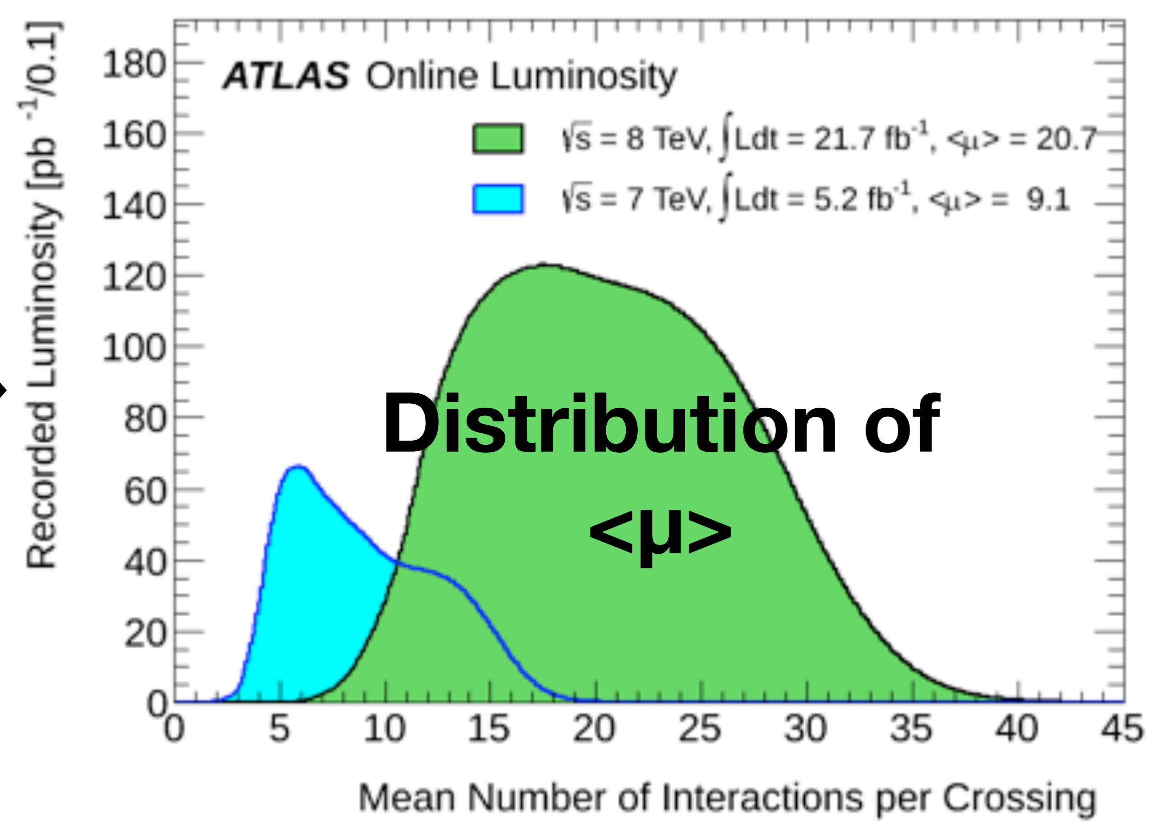
This shows the full 2011 run and 2012 data taken between April 4th and Novemebr 26th The integrated luminosities and the mean mu values are given in the figure. The mean number of interactions per crossing corresponds ***the mean of the poisson distribution on the number of interactions per crossing calculated for each bunch.*** *It is calculated from the instantaneous per bunch luminosity as* $\boldsymbol{\mu = L_{bunch} \times \sigma_{inel} / f_r}$ *where* L_{bunch} *is the per bunch instantaneous luminosity,* σ_{inel} *is the inelastic cross section which we take to be 71.5 mb for 7TeV collisions and 73.0 mb for 8TeV collisions,* n_{bunch} *is the number of colliding bunches and* f_r *is the LHC revolution frequency. More details on this can be found in arXiv:1101.2185.*

Example ATLAS LumiPublicPage

- Running with 50ns bunch spacing (instead of 25ns)
  - → double pile-up for same luminosity
- Has to be fought and mitigated at all levels:
  - Trigger, reconstruction of physics objects, isolation cuts, etc.
  - Data processing: CPU time for reconstruction…

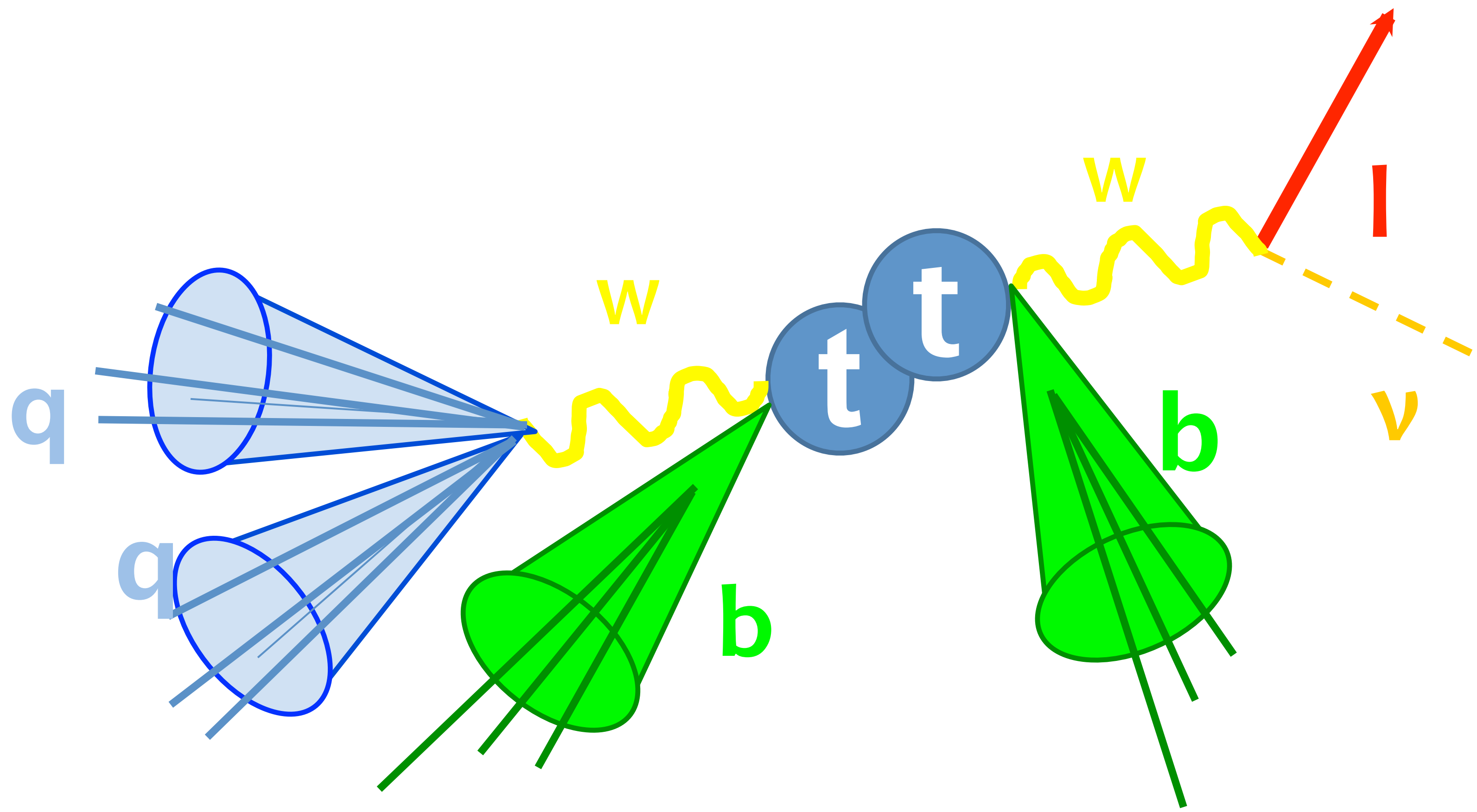
M. Aleksa TOP2012





Selection/Ingredients for top quark pairs/single-top

ATLAS (CMS is similar)



Selection/Ingredients for top quark pairs/single-top

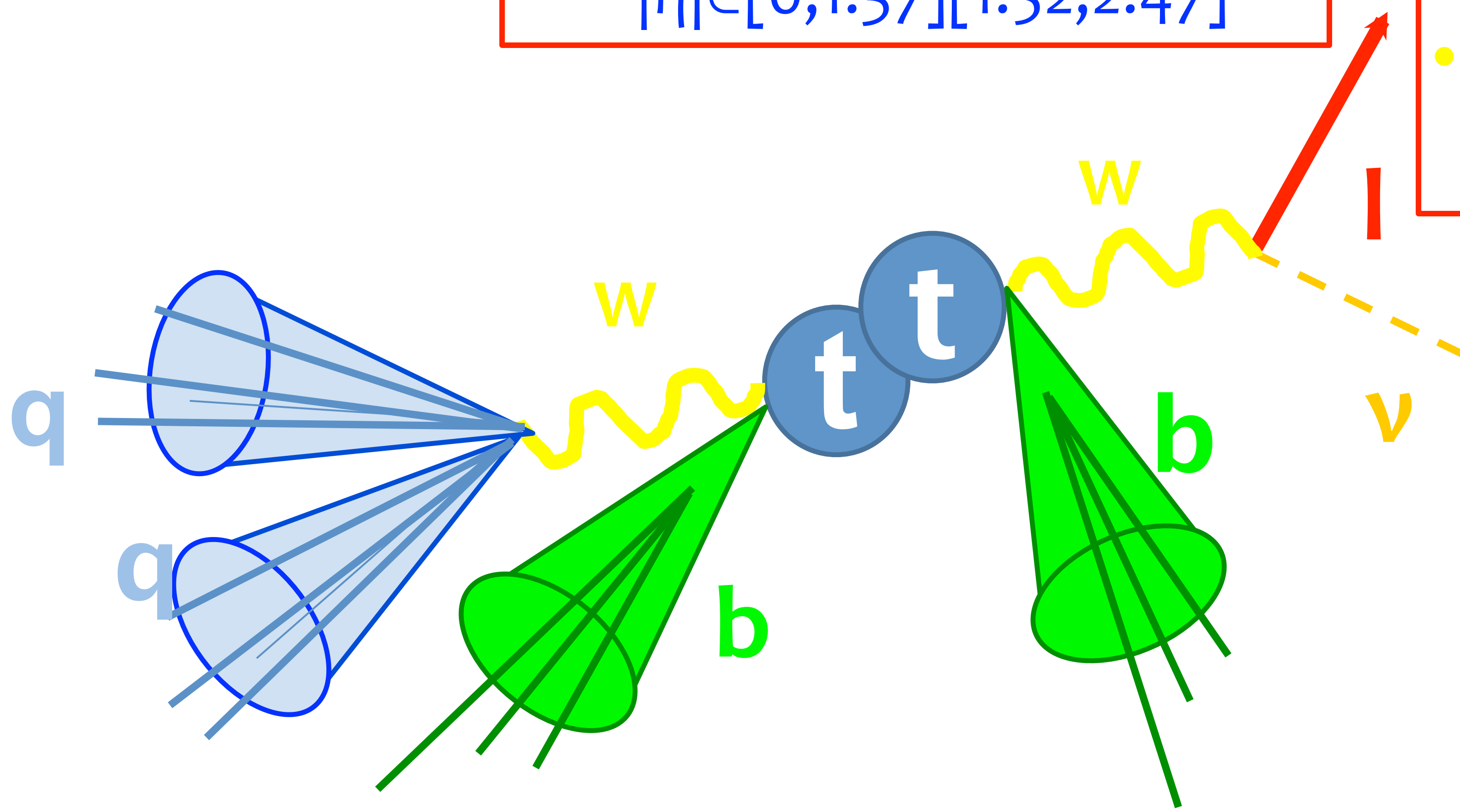
ATLAS (CMS is similar)

Electron

- Good isolated calo object
- Matched to track
- $E_T > 25$ GeV
- $|\eta| \in [0;1.37][1.52;2.47]$

Muon

- Segments in tracker and muon detector
- Calo and track isolation
- $p_T > 20$ GeV $|\eta| < 2.5$ (2.1 for CMS)

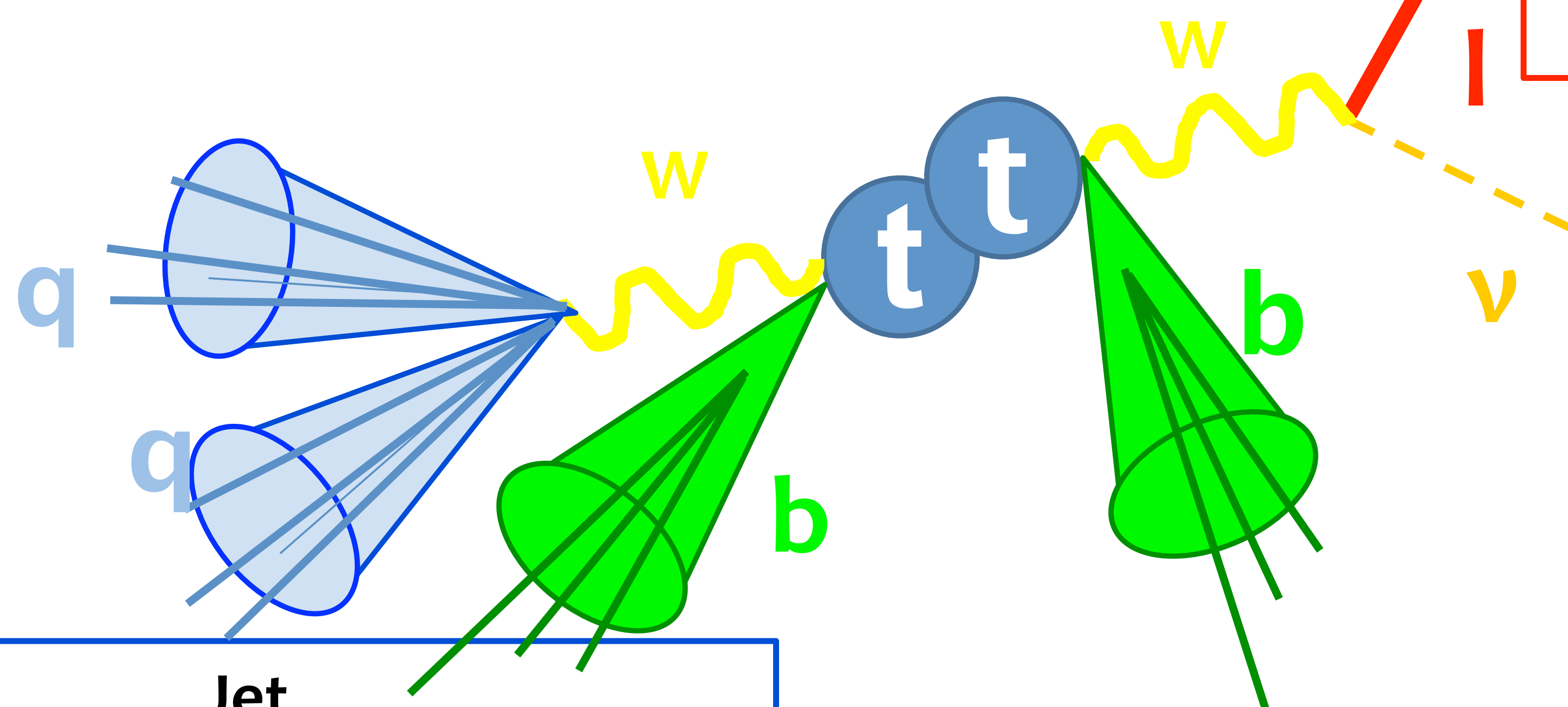


Selection/Ingredients for top quark pairs/single-top

ATLAS (CMS is similar)

Electron
- Good isolated calo object
- Matched to track
- E_T>25 GeV
- $|\eta|\in[0;1.37][1.52;2.47]$

Muon
- Segments in tracker and muon detector
- Calo and track isolation
- p_T > 20 GeV $|\eta|$ < 2.5 (2.1 for CMS)



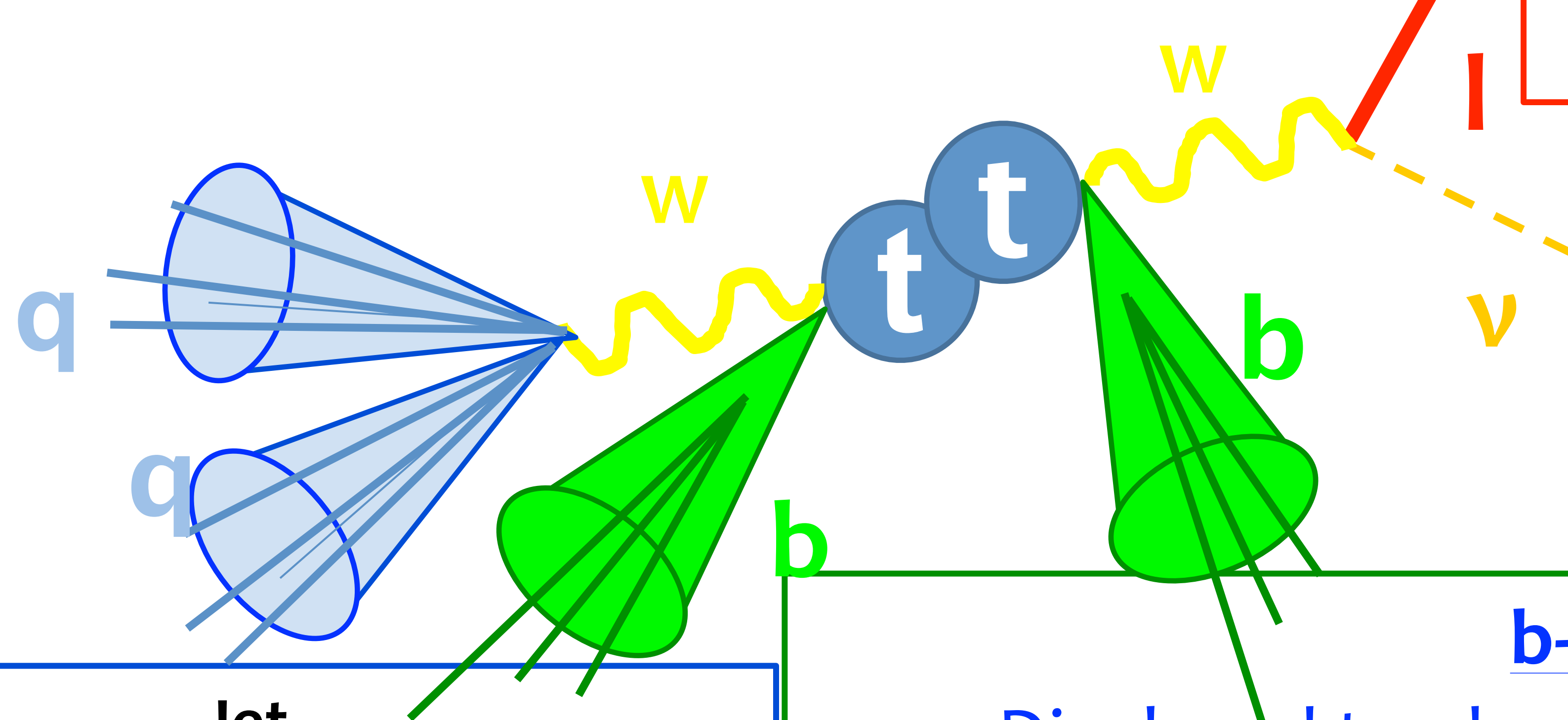
Jet
- Topological clusters, Anti-k_T (R=0.4 (0.5 for CMS)), MC Calibration checked w/data
- p_T > 25 (20) GeV (30 for CMS), $|\eta|$ < 2.5
- (large JVF $=\sum_{\text{jet trk in PV}} p_T/\sum_{\text{jet trk}} p_T$ vs pile-up jets, CMS: use particle flow to remove charged hadrons not from prim verted)

Selection/Ingredients for top quark pairs/single-top

ATLAS (CMS is similar)

Electron
- Good isolated calo object
- Matched to track
- E_T>25 GeV
- $|\eta|\in[0;1.37][1.52;2.47]$

Muon
- Segments in tracker and muon detector
- Calo and track isolation
- $p_T > 20$ GeV $|\eta| < 2.5$ (2.1 for CMS)



Jet
- Topological clusters, Anti-k_T (R=0.4 (0.5 for CMS)), MC Calibration checked w/data
- $p_T > 25$ (20) GeV (30 for CMS), $|\eta| < 2.5$
- (large JVF $=\sum_{\text{jet trk in PV}} p_T / \sum_{\text{jet trk}} p_T$ vs pile-up jets, CMS: use particle flow to remove charged hadrons not from prim verted)

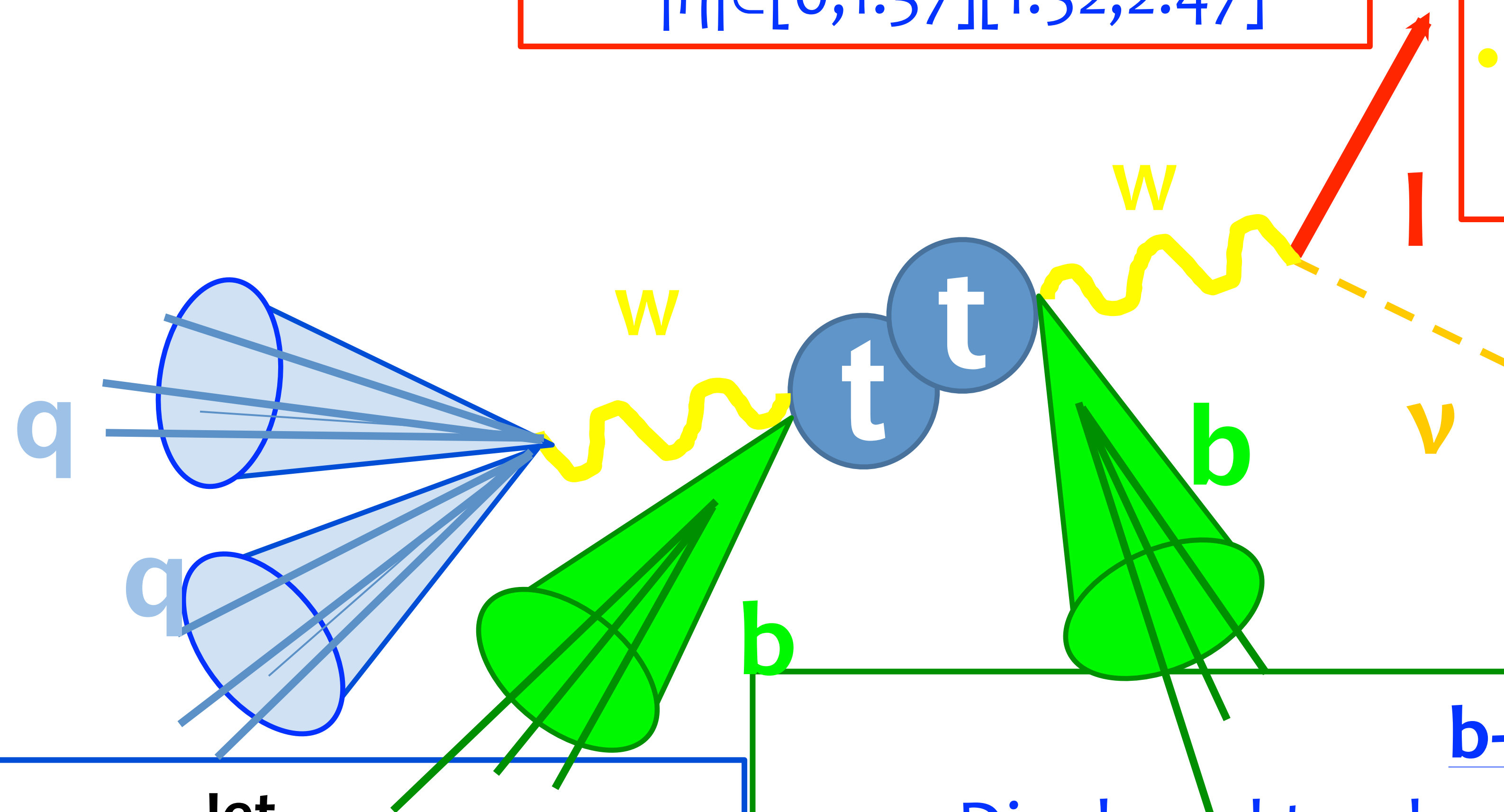
b-Jet
- Displaced tracks or secondary lepton
- SV0: reconstruct sec.vertex
- JetProb: track/jet compatibility with prim. vertex
- IP3D+SV1 +/or JetFitter: advanced lkl/NN taggers

Selection/Ingredients for top quark pairs/single-top

ATLAS (CMS is similar)

Electron
- Good isolated calo object
- Matched to track
- E_T>25 GeV
- $|\eta| \in [0;1.37][1.52;2.47]$

Muon
- Segments in tracker and muon detector
- Calo and track isolation
- p_T > 20 GeV $|\eta|$ < 2.5 (2.1 for CMS)



E_T^{miss}
- Vector sum of calo energy deposits
- Corrected for identified objects

Jet
- Topological clusters, Anti-k_T (R=0.4 (0.5 for CMS)), MC Calibration checked w/data
- p_T > 25 (20) GeV (30 for CMS), $|\eta|$ < 2.5
- (large JVF $=\sum_{\text{jet trk in PV}} p_T / \sum_{\text{jet trk}} p_T$ vs pile-up jets, CMS: use particle flow to remove charged hadrons not from prim verted)

b-Jet
- Displaced tracks or secondary lepton
- SV0: reconstruct sec.vertex
- JetProb: track/jet compatibility with prim. vertex
- IP3D+SV1 +/or JetFitter: advanced lkl/NN taggers

Selection/Ingredients for top quark pairs/single-top

ATLAS (CMS is similar)

Event cleaning

- Good run conditions
- Primary vertex (PV)with at least 5 tracks
- Bad jet veto
- Cosmic veto ($\mu\mu$)

Electron

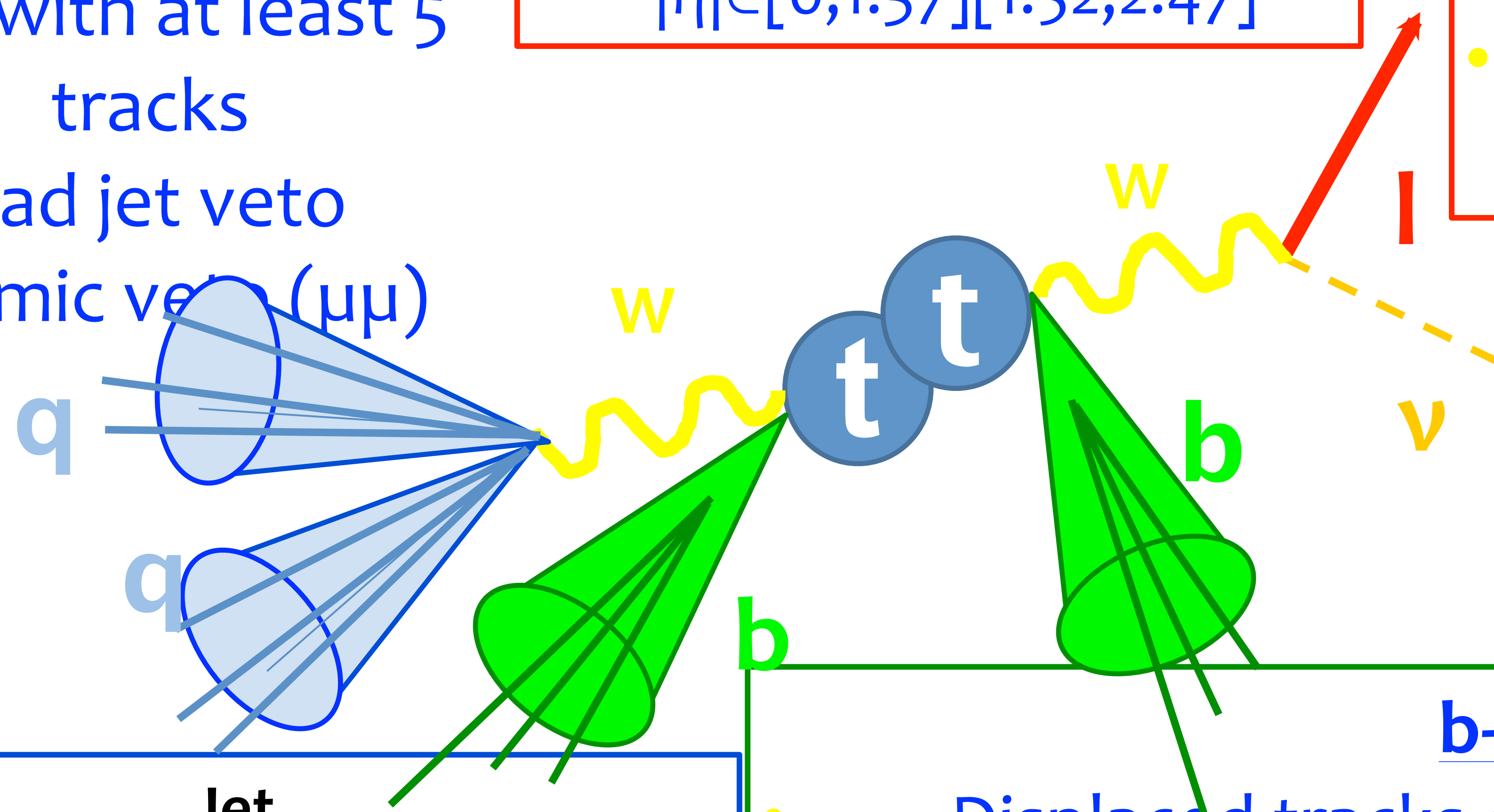
- Good isolated calo object
- Matched to track
- E_T>25 GeV
- $|\eta|\in[0;1.37][1.52;2.47]$

Muon

- Segments in tracker and muon detector
- Calo and track isolation
- p_T > 20 GeV $|\eta|$ < 2.5 (2.1 for CMS)

E_T^{miss}

- Vector sum of calo energy deposits
- Corrected for identified objects



Jet

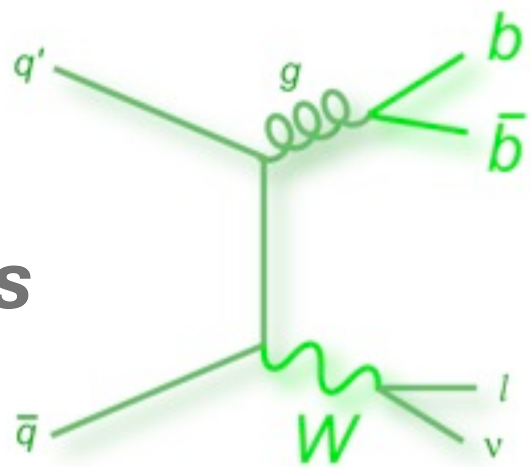
- Topological clusters, Anti-k_T (R=0.4 (0.5 for CMS)), MC Calibration checked w/data
- p_T > 25 (20) GeV (30 for CMS), $|\eta|$ < 2.5
- (large JVF $=\sum_{\text{jet trk in PV}} p_T / \sum_{\text{jet trk}} p_T$ vs pile-up jets, CMS: use particle flow to remove charged hadrons not from prim verted)

b-Jet

- Displaced tracks or secondary lepton
- SV0: reconstruct sec.vertex
- JetProb: track/jet compatibility with prim. vertex
- IP3D+SV1 +/or JetFitter: advanced lkl/NN taggers

Backgrounds estimates *(tt single lepton+jets, single top t,s-chan)*

- ***W+jets***

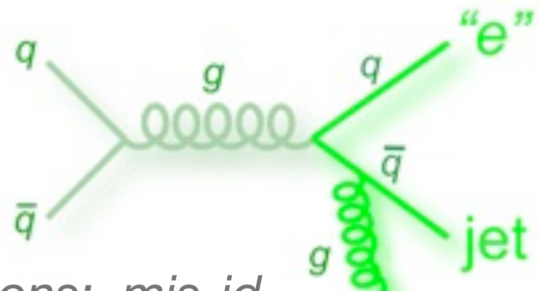


- *simulated shape*
- ***normalization: scale from charge asymmetry of W prod*** *before b-tag, MC extrapolation to b-tagged region*

$$N_{W^+} + N_{W^-} = \left(\frac{r_{MC}+1}{r_{MC}-1}\right)(D^+ - D^-)$$

MC *data*

- ***QCD***



- *"Fake" leptons: mis-id jets, $\gamma \rightarrow e^+e^-$, non-prompt leptons (b/c-decays), punch-through had*

- *Matrix method*

$$N^{\text{loose}} = N^{\text{loose}}_{\text{real}} + N^{\text{loose}}_{\text{fake}},$$
$$N^{\text{std}} = rN^{\text{loose}}_{\text{real}} + fN^{\text{loose}}_{\text{fake}}$$

r is the marginal efficiency of standard cuts.
f is the same, for background sources
Both can be measured in pure or background event subtracted samples

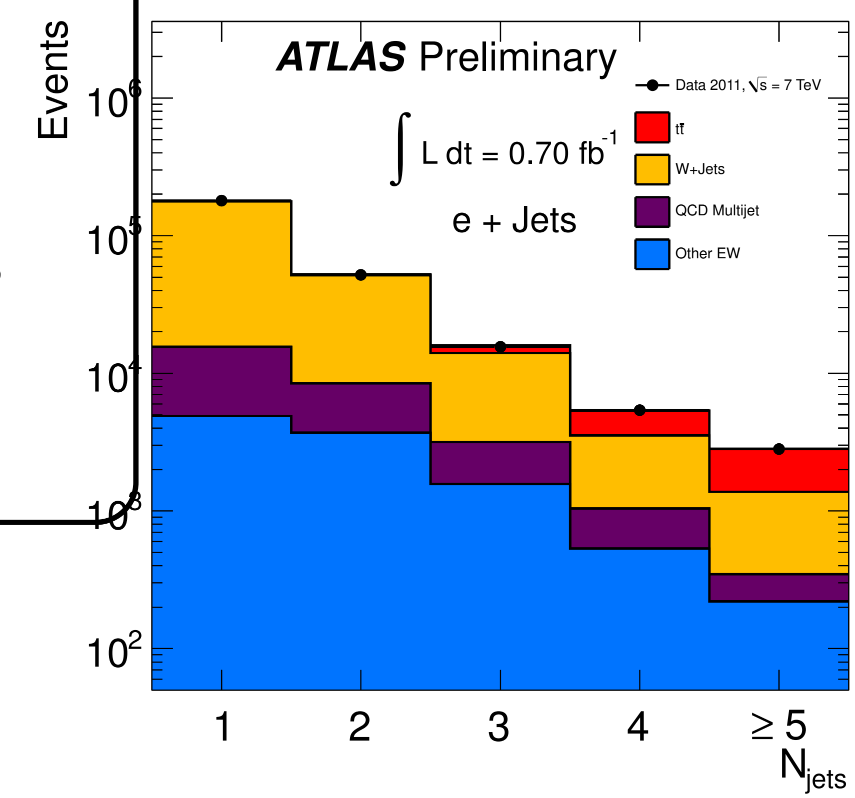
- *Jet template*

Shape from jet triggered events with 1 high em. content jet.

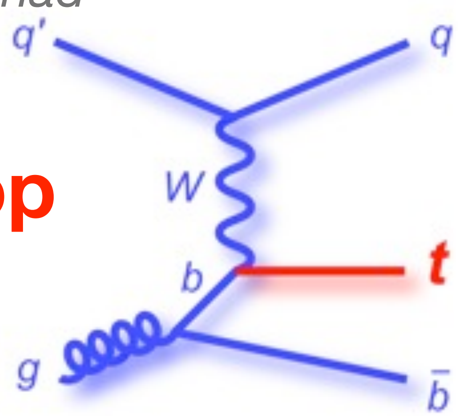
Normalize by fitting low E_T^{miss} shape to data and extrapolate

(J Boudreau, Top2012)

ATLAS-CONF-2011-121



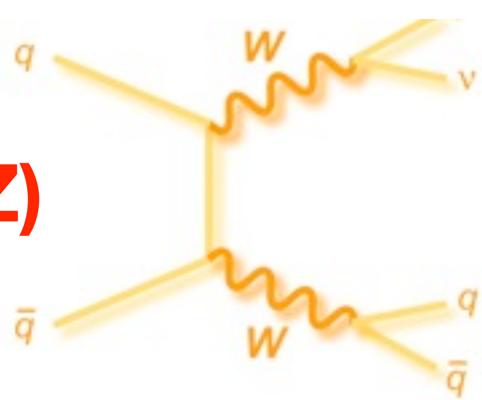
- **Single top**



Simulated shape+ rate set to SM

normalizations=fit parameters, estimates are starting points for fit

Di-bosons (WW,WZ,ZZ)



simulated shape+ rate from simul.

Backgrounds *(tt di-lepton, Wt single top)*

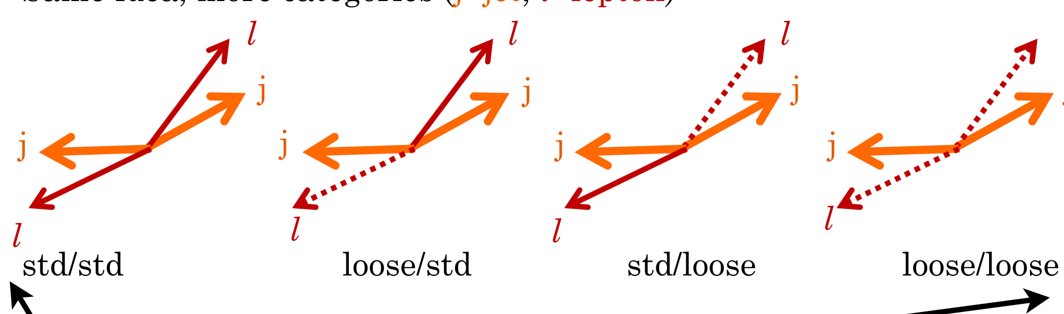
- ***Fake leptons** : generalize single lepton estimate*
  - Get **r** and **f** : **probability** for **loose** "fake" and real **leptons** ***to pass standard sel.*** ← **control samples** enriched with real (in Z window) or **"fake" (low E_T^{miss})** leptons
  - **Combine** with **N(di-lep)** for **all loose "fake" & real** pairs→**fake standard lepton content**

ATLAS-CONF-2011-100

(J Boudreau, Top2012)

Same idea, more categories (j=jet, l=lepton)

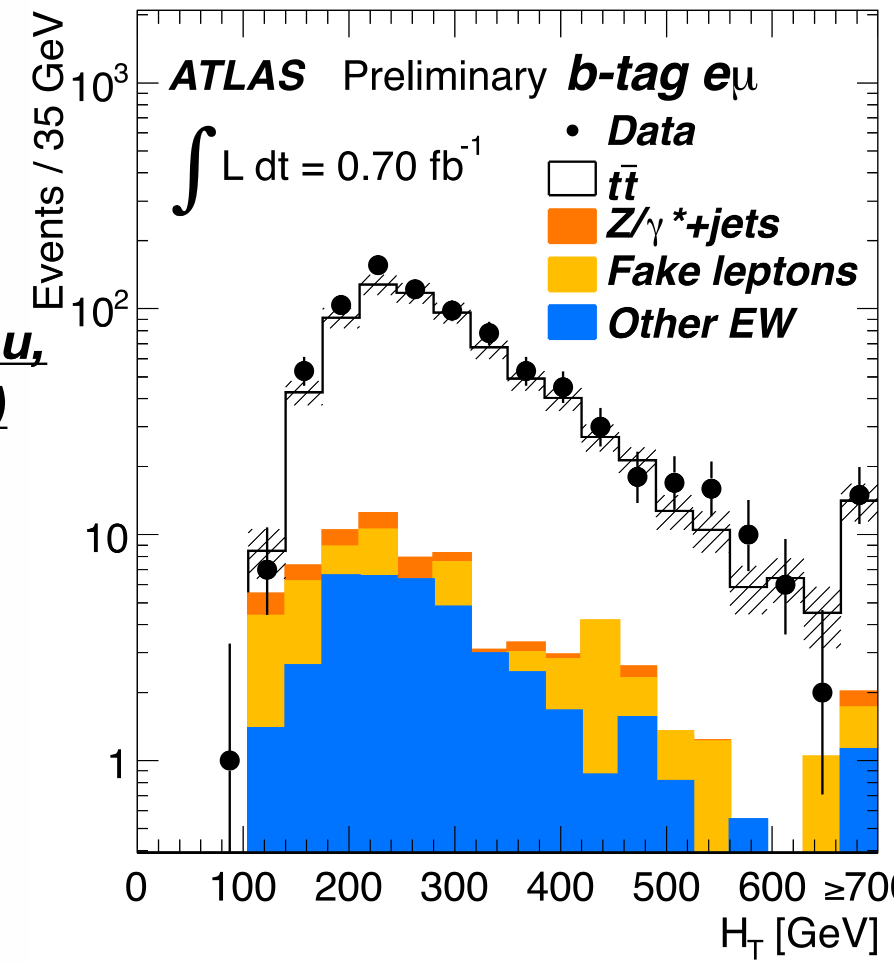
di-lep topologies



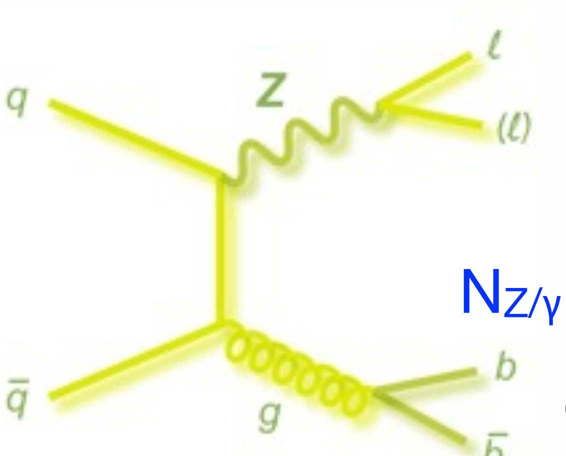
loose, standard

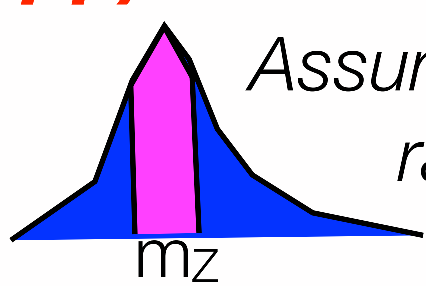
$$\begin{pmatrix} N^{l,l} \\ N^{l,s} \\ N^{s,l} \\ N^{s,s} \end{pmatrix} = \begin{pmatrix} 1 & 1 & 1 & 1 \\ r_2 & f_2 & r_2 & f_2 \\ r_1 & f_1 & r_1 & f_1 \\ r_1 r_2 & r_1 f_2 & f_1 r_2 & f_1 f_2 \end{pmatrix} \circ \begin{pmatrix} N^{l,l}_{r,r} \\ N^{l,l}_{r,f} \\ N^{l,l}_{f,r} \\ N^{l,l}_{f,f} \end{pmatrix}$$

real,fake in loose



- ***Z/γ* bkg (ee, μμ)***





Assume constant Zdata/Z MC ratio in/out Z window

$$N_{Z/\gamma}\,(SR) = [\mathrm{Data}(CR) - \mathrm{NonZBkg}(CR)]\,\frac{MC_{Z/\gamma}\,(SR)}{MC_{Z/\gamma}\,(CR)}$$

CR (SR)=in (out of) Z mass window

What we study about the top quark

inspired by figure
by D Chakraborty

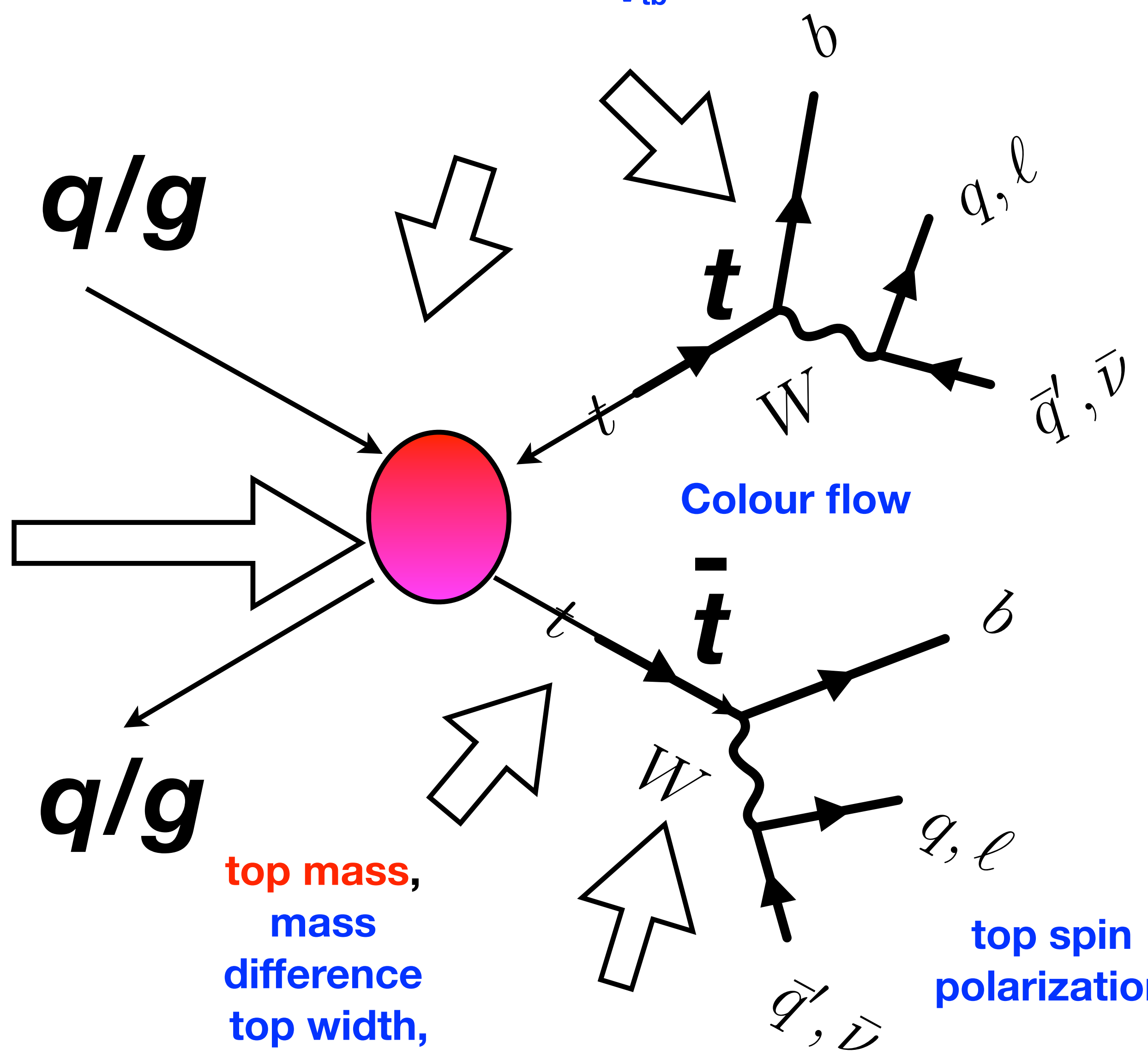
Discuss Today

Branching Fractions
V_{tb}

Production cross section double and single top

Resonant production & New phys

Production kinematics



Spin correlation

Charge asymmetry

top mass, mass difference top width, spin, charge lifetime

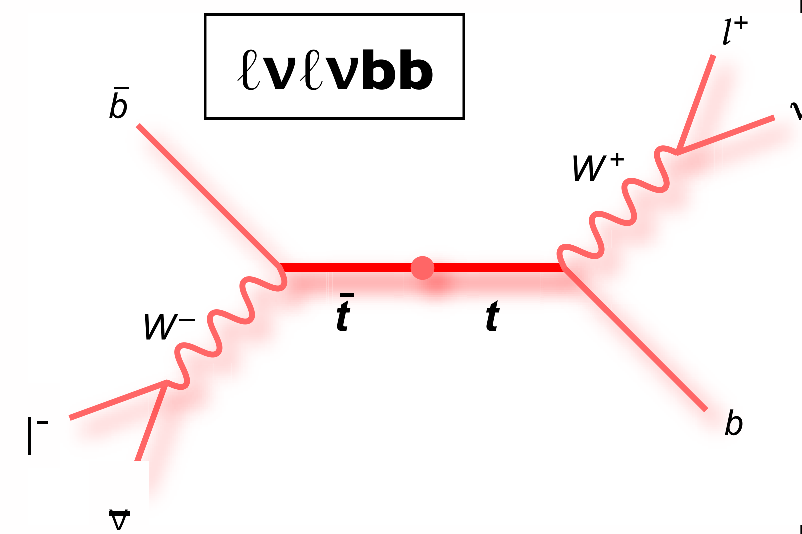
top spin polarization

W helicity
Wtb coupling,V(tb)

Defining feature: Top Production

Inclusive $\sigma_{t\bar{t}}$: dilepton - $\sqrt{s}$ = 8 TeV

$\int L dt \sim$ **20.3 fb^{-1}** *(2012)*

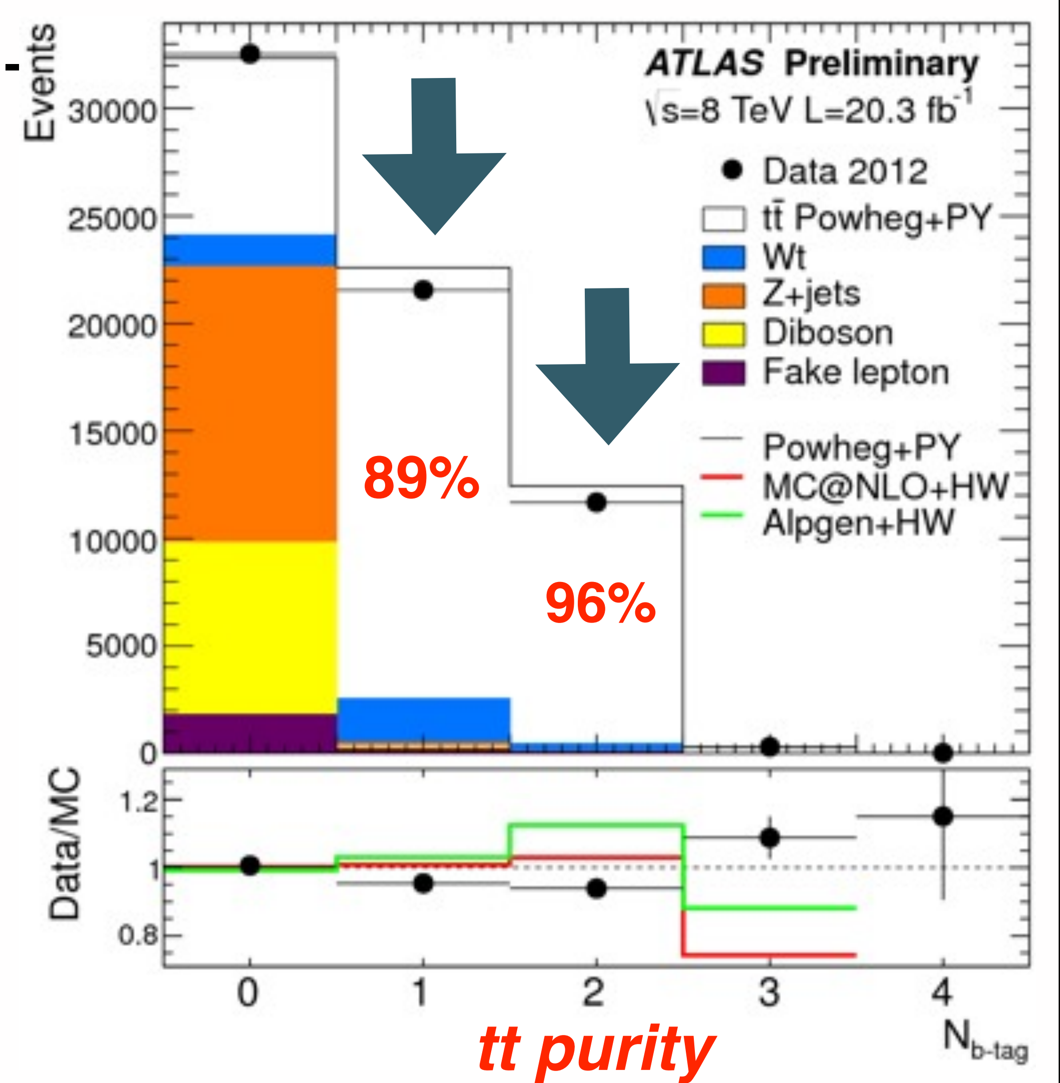


- **Require opposite sign (OS) eμ** no H_T,E_T^{miss} cuts, no lep isolation *minimal use of jet/E_T^{miss} info*
- **Bkg: single top** (Wt) *(from simul.)*, **data-driven fake leptons** *(extrapolated from same sign lep. sample)*, **Z+jets** *(extrapolated from Z→μμ sample)*

ATLAS-CONF-2013-097

- **Simultaneous fit for $\sigma_{t\bar{t}}$ and ε_b, efficiency to select, reco and b-tag a jet in** 1-b-tag and 2-b-tag samples→**minimize jet & b-tag syst**

$$N_1 = L\sigma_{t\bar{t}}\, \epsilon_{e\mu} 2\epsilon_b(1 - C_b\epsilon_b) + N_1^{\rm bkg}$$
$$N_2 = L\sigma_{t\bar{t}}\, \epsilon_{e\mu} C_b {\epsilon_b}^2 + N_2^{\rm bkg}$$

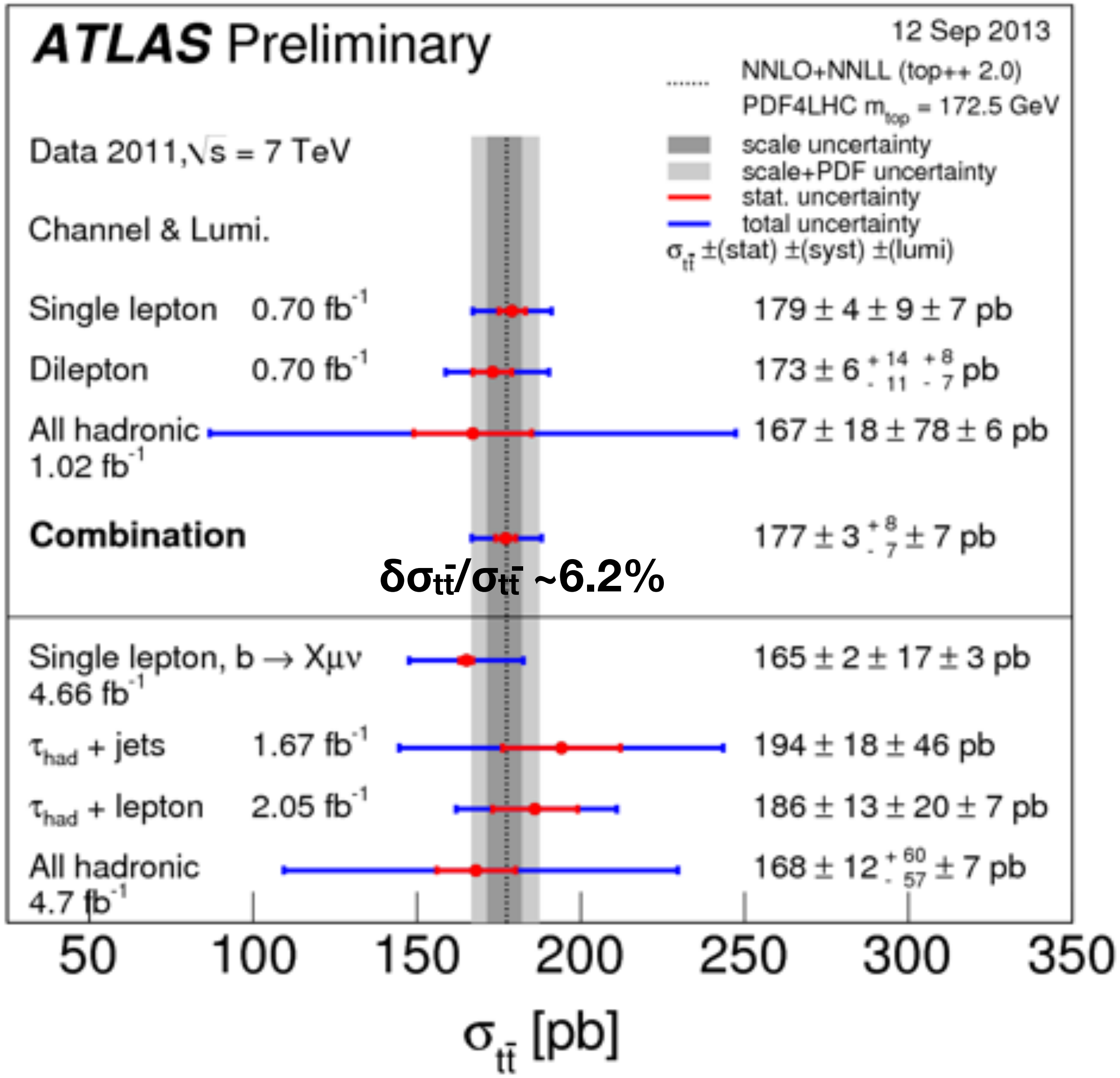


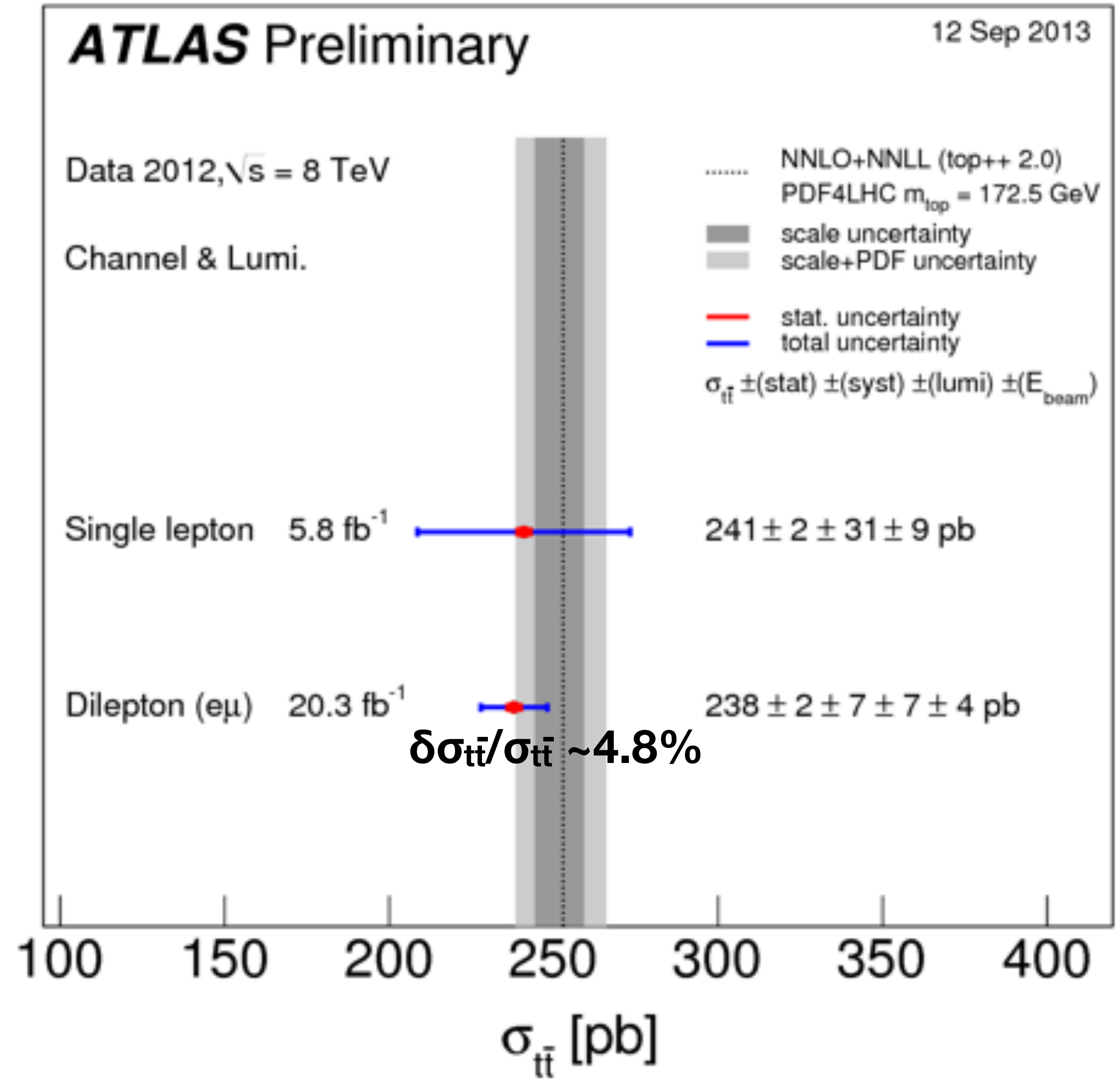
- **Dominated by "External" Syst:** *Lumi ~3.1%, E_b~1.7%, tt modelling ~1.5% Elec. ID/isol ~1.4%*

$$\sigma_{t\bar{t}} = 237.7 \pm 1.7\ \text{(stat)} \pm 7.4\ \text{(syst)} \pm 7.4\ \text{(lumi)} \pm 4.0\ \text{(beam energy) pb}$$

$\delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ ~4.8%

Inclusive $\sigma_{t\bar{t}}$ - Summary at $\sqrt{s}$ = 7 & 8 TeV





LHC (ATLAS+CMS) combined $\sigma_{t\bar{t}}$ @ 7 TeV

$$\sigma_{t\bar{t}} = 173.3 \pm 2.3\ (\text{stat.}) \pm 7.6\ (\text{syst.}) \pm 6.3\ (\text{lumi.})\ \text{pb}$$

ATLAS-CONF-2012-134

CMS-PAS-TOP-12-003

$\delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ ~5.8%

- **Systematics dominated, comparable to theory uncertainty**

Going differential for σ_{tt} !

test of SM QCD tt production & kine (generators & had scheme)

Why?

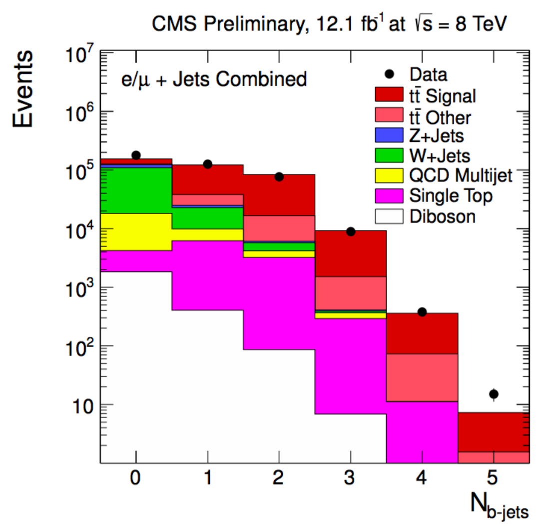
complementary in searches for new forces, dimensions

provide info on Parton Dist Functions

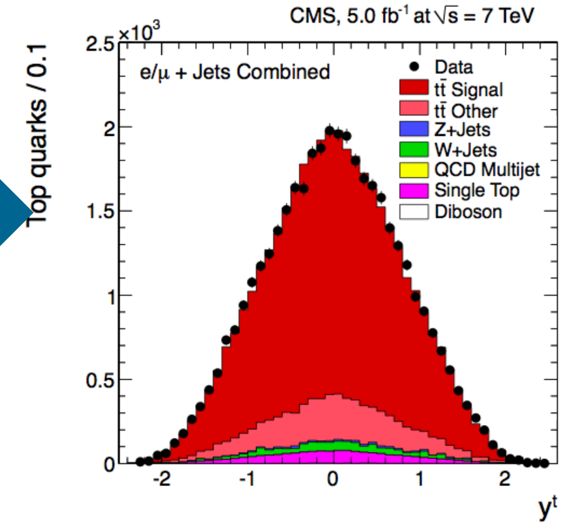
M. Aldaya, FS TOPLHCWG open session 28-29th Nov. 2013

Measure σ(tt̄) as a function of kinematic distributions of **top, top pairs, b-jets, leptons, and lepton pairs**

(1) Event selection



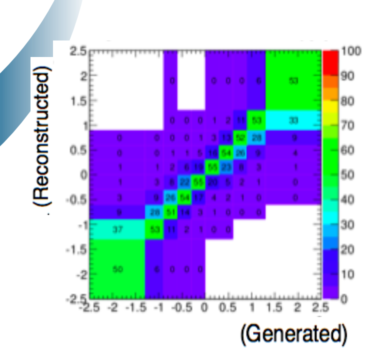
(2) tt̄ kinematic reconstruction



(3) Bin-wise cross section measurement

- Subtract background
- Unfolding: correct for detector effects and acceptance

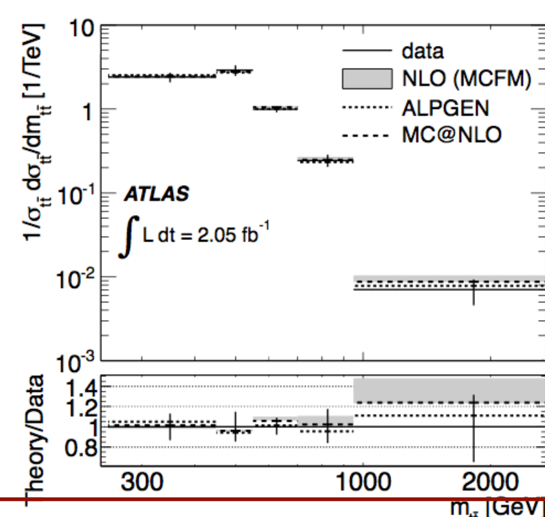
$$\frac{1}{\sigma}\frac{d\sigma^i}{dX} = \frac{1}{\sigma}\frac{N^i_{\text{Data}} - N^i_{\text{BG}}}{\Delta^i_X \epsilon^i L}$$



Response matrix

(4) Differential tt̄ cross sections

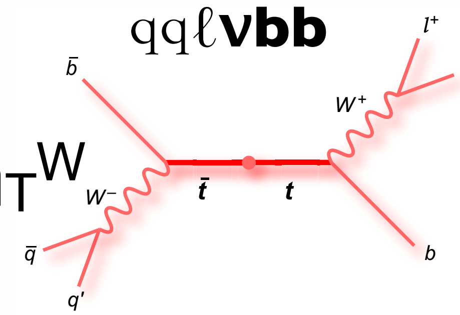
- Normalised to in-situ measured σ(tt̄)
- 'Visible' or extrapolated to full phase space
- Compare to theory predictions



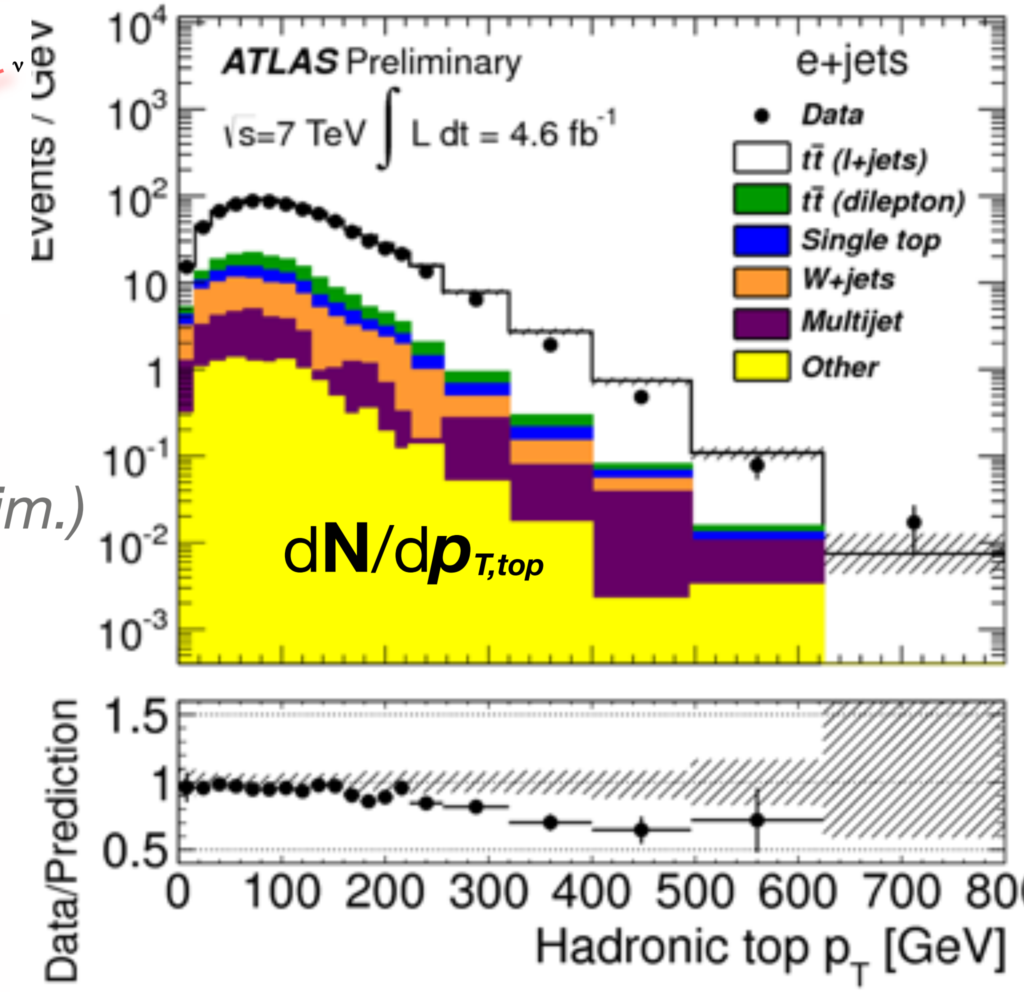
Differential $d\sigma_{t\bar{t}}/dX$: l+jets $\sqrt{s}$ = 7 TeV

$\int L dt$ = **4.7 fb^{-1}** *(2011)*

ATLAS-CONF-2013-099



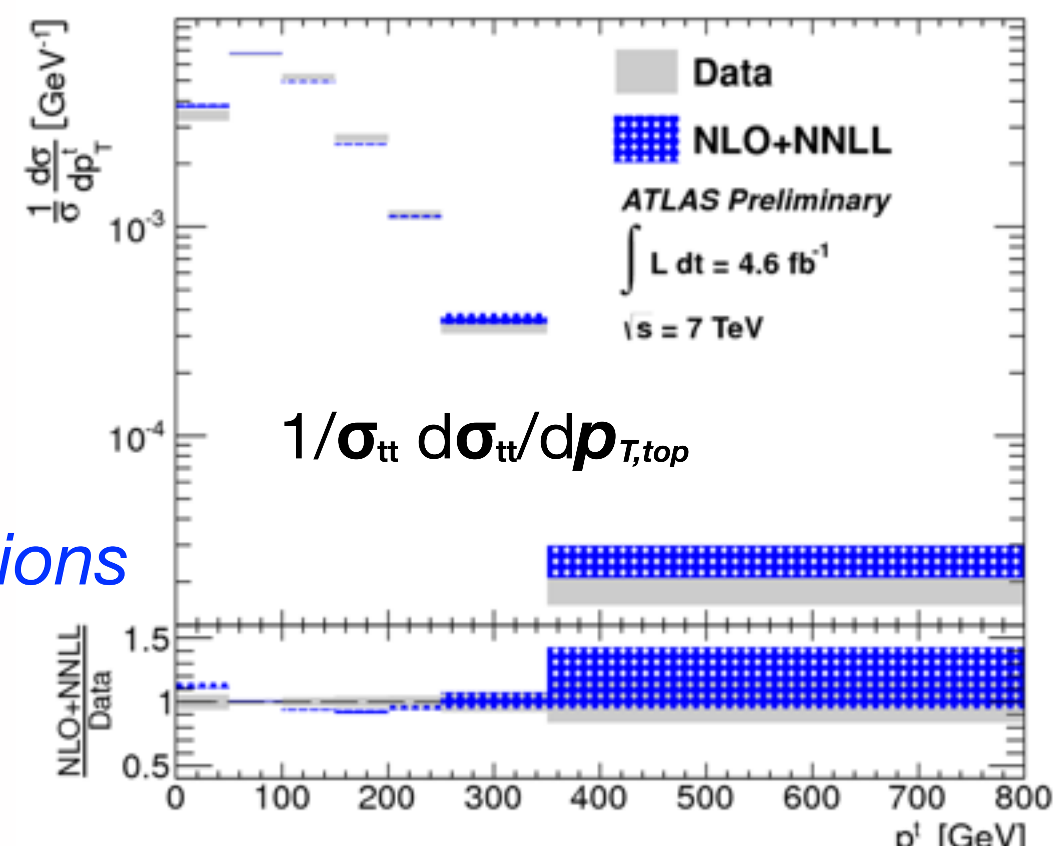
- 1 isol. (e,μ), symmetric E_T and m_T^W cuts, **≥ 4 central jets,** ≥1 b-tag
- **Data-driven W+jets** *(normalize pre-tag with W^+/W^- asymmetry, extrapol. b-tag prob from 2-jet-bin)* **fake lep.** *(loose/tight matrix method),* ***single top, dibosons*** *(from sim.)*



- **Reconstruct $t\bar{t}$ with kinematic likel. fit** *(m_t,m_W constraint)* → cut on quality of kine fit
- **Unfold d(N-N$_{bkg}$)/dX to full phase space** *(regularized unfolding, linearity tests),* scale with L and $\sigma_{t\bar{t}}$ → $1/\sigma_{t\bar{t}}\, d\sigma_{t\bar{t}}/dX$

$$\frac{d\sigma}{dX_j} \equiv \frac{1}{\Delta X_j} \cdot \frac{\sum_i \mathcal{M}_{ji}^{-1}[D_i - B_i]}{\mathrm{BR} \cdot \mathcal{L} \cdot \epsilon_j}$$

$X = p_{T,top}$, $m_{t\bar{t}}$, $|y|_{t\bar{t}}$, $p_{T,t\bar{t}}$



- **Combine (e,μ)+jets channels** with minimal covariance estimator (BLUE) *including correlations*
  - ***Propagate syst uncertainties through unfolding:*** *modify migration matrix & acceptances, fix data*

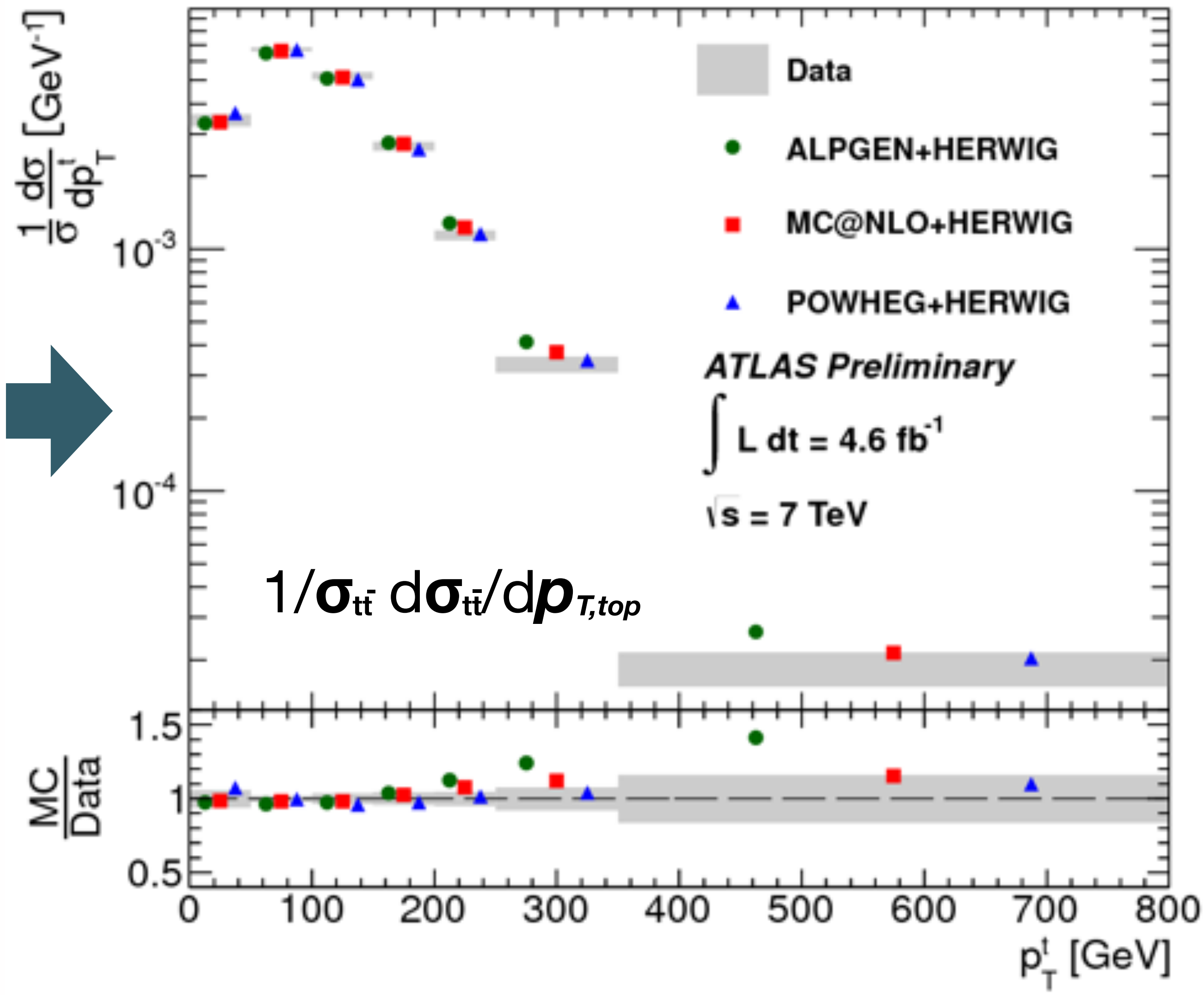
Differential $d\sigma_{t\bar{t}}/dX$: l+jets $\sqrt{s}$ = 7 TeV

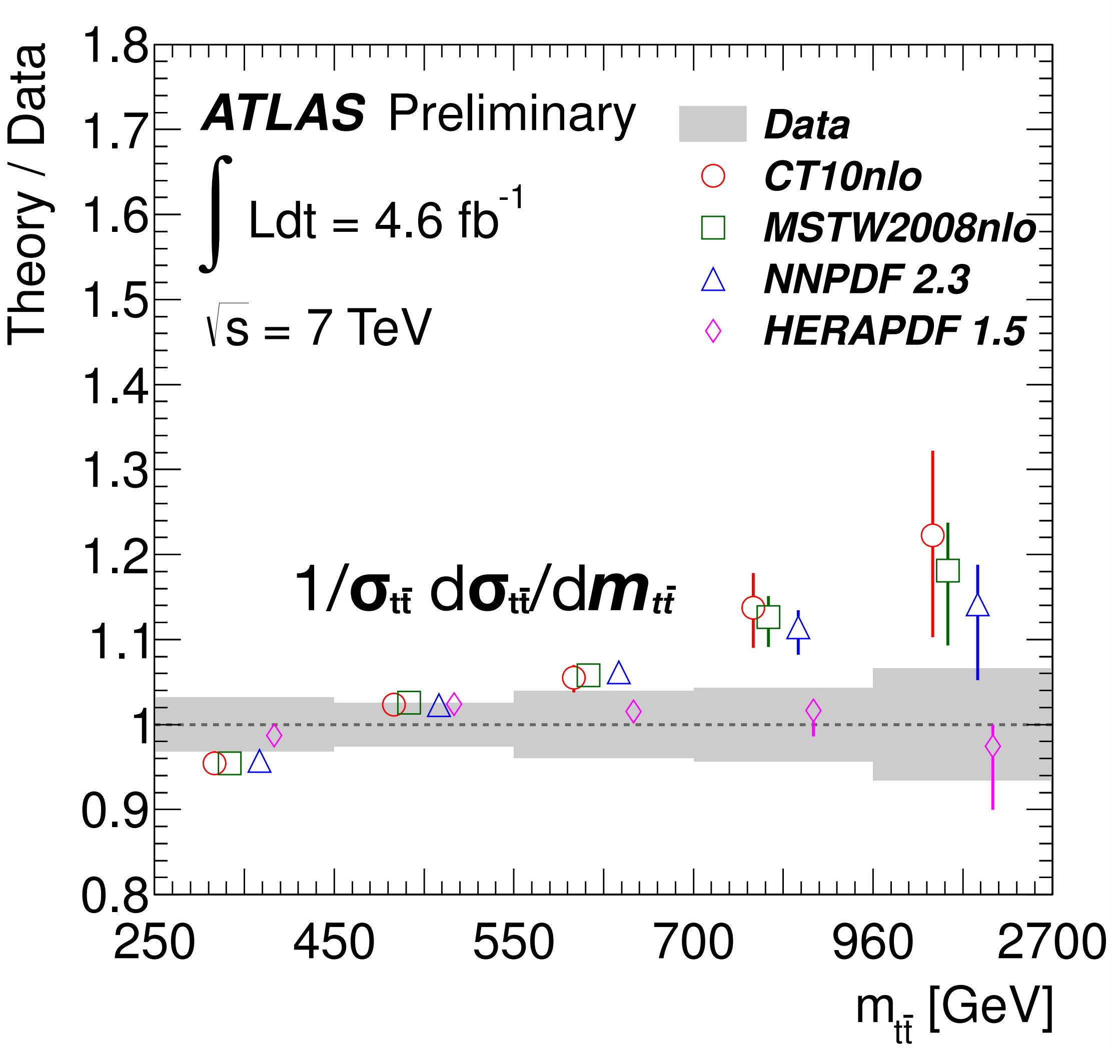
$\int Ldt$ = **4.7 fb^{-1}** (2011)

- ***Syst dominated***: <7% for $y_{t\bar{t}}$, 10-20% $p_{T,t\bar{t}}$, 2% to 11% for $p_{T,top}$, 3% to 6% $m_{t\bar{t}}$

Compare with MC, NLO & approx NNLO

- **$p_{T,top}$ spectrum is softer than most predictions for $p_{T,top}$ >200 GeV**





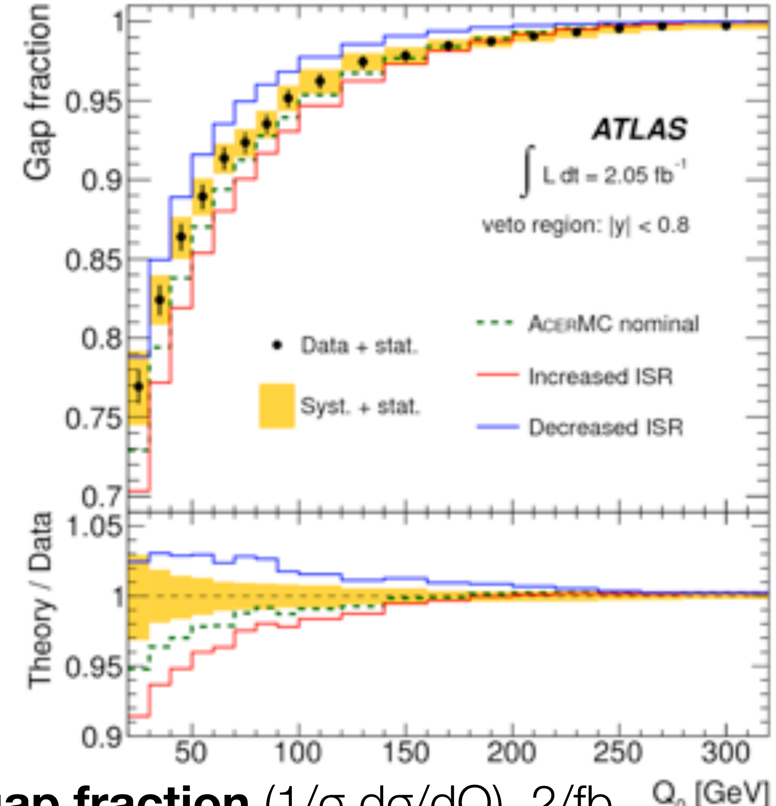
Compare with different PDF sets

- **Data show sensitivity to PDF with some preference for HeraPDF**

ATLAS-CONF-2013-099

Differential σ_{tt}:growing field of action

Eur.Phys.J. C72 (2012) 2043

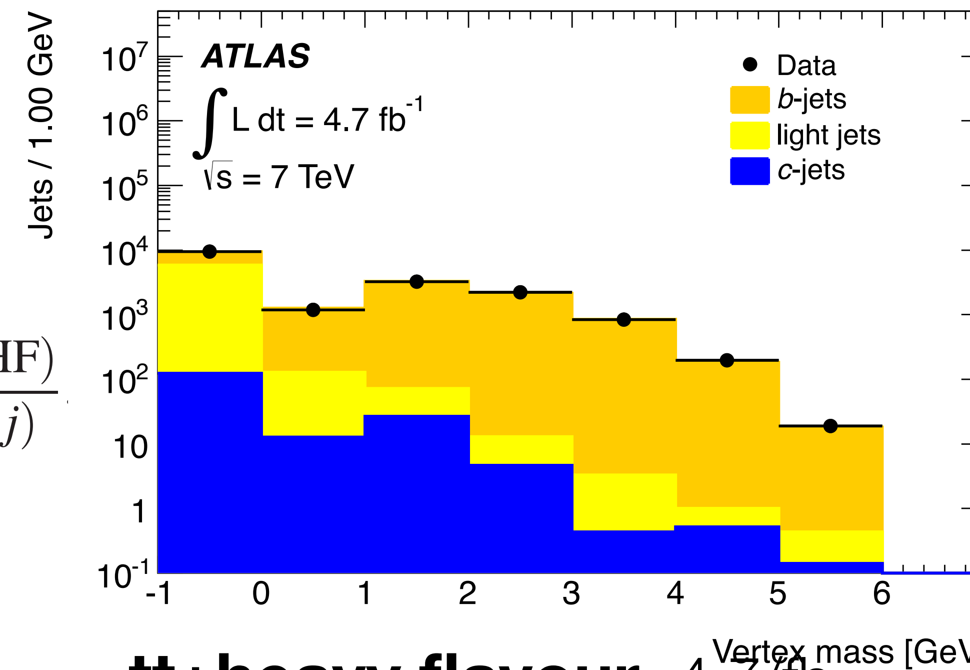


gap fraction (1/σ dσ/dQ), 2/fb

√s = 7 TeV

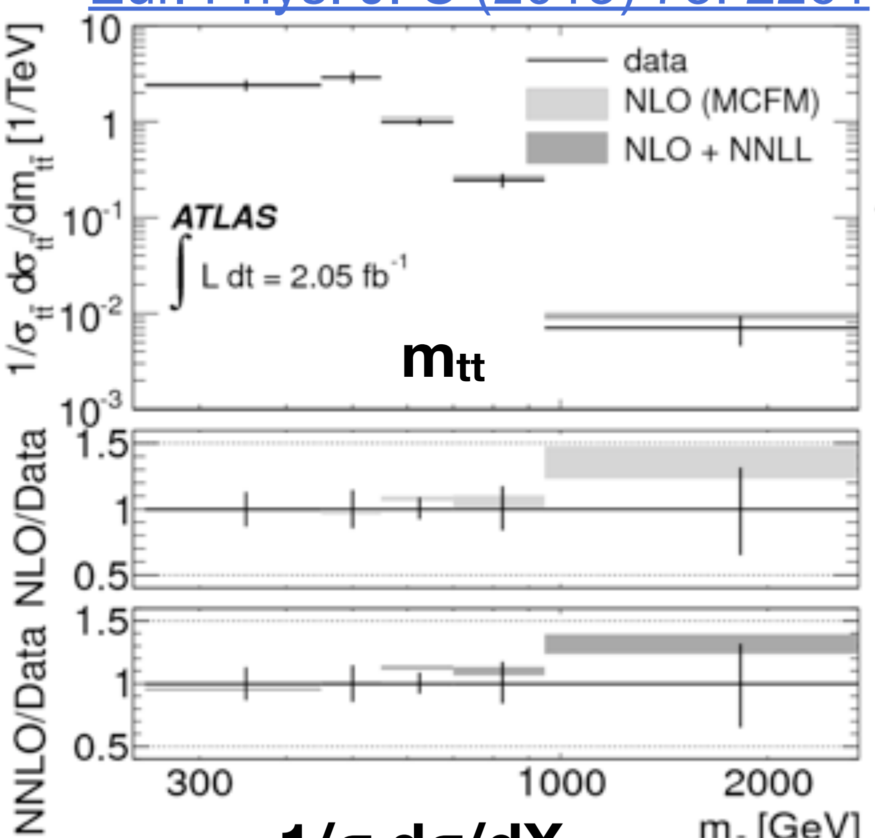
arXiv:1304.6386, accepted by PRD

$$R_{HF} = \frac{\sigma_{fid}(t\bar{t}+HF)}{\sigma_{fid}(t\bar{t}+j)}$$



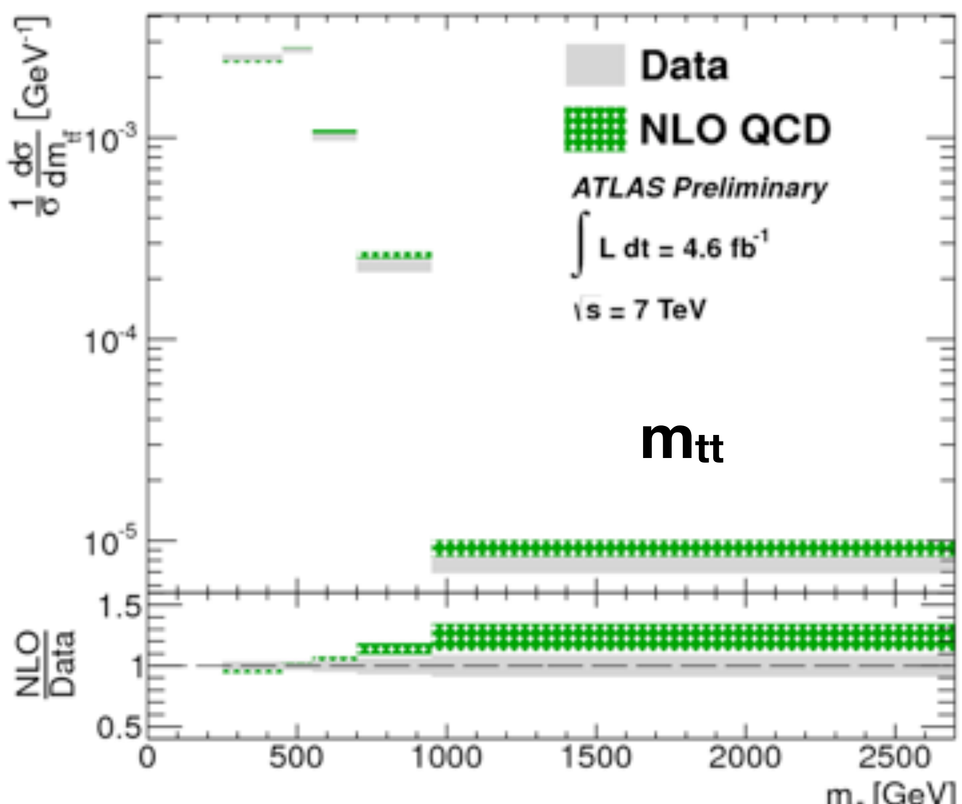
tt+heavy flavour, 4.7/fb

Eur. Phys. J. C (2013) 73: 2261



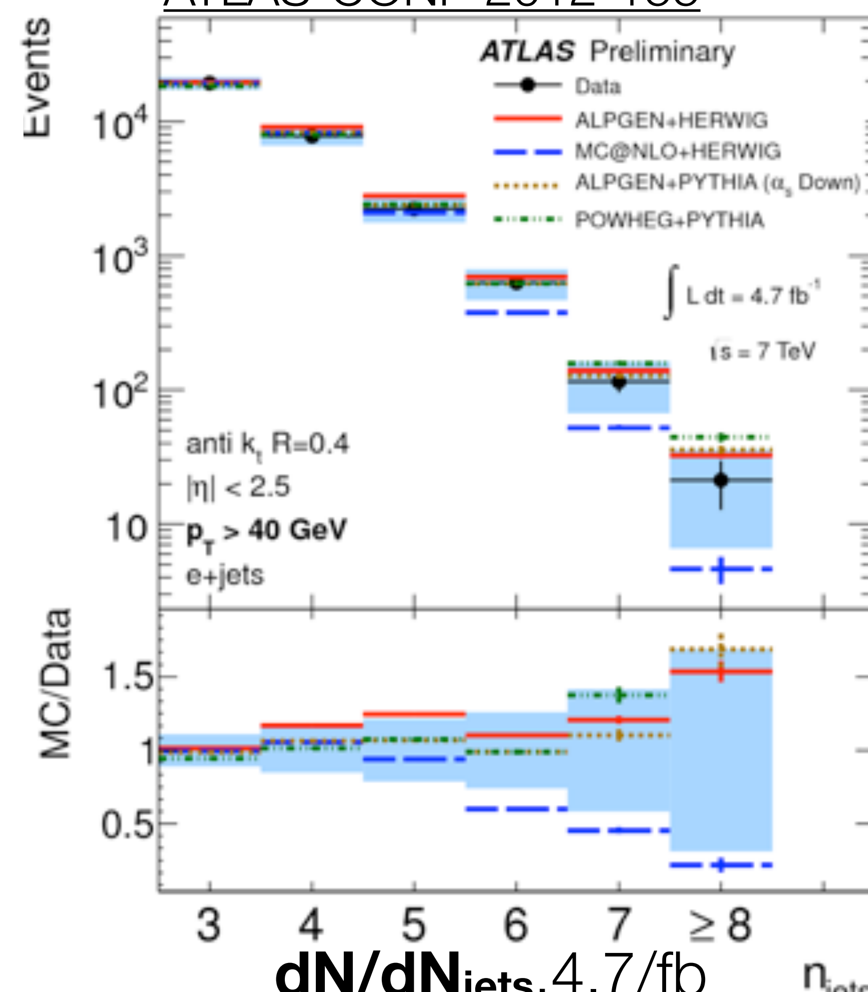
1/σ dσ/dX,
X=mtt pT,tt y,tt 2/fb

ATLAS-CONF-2013-099



1/σ dσ/dX,
X= pT,top mtt pT,tt y,tt 5/fb

ATLAS-CONF-2012-155

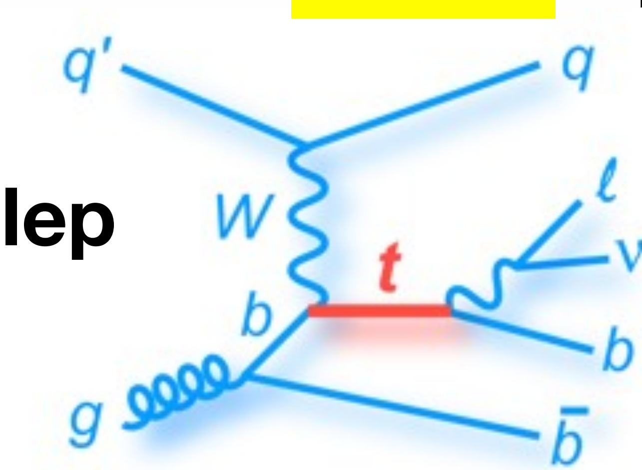


dN/dNjets,4.7/fb

Inclusive and fiducial σ_t: t-chan $\sqrt{s}$ = 8 TeV

NEW!

- **1 isol. lep** (e or μ), **2 jets** with $|\eta|<4.5$, large E_T^{miss} and $m_T(W)$* → fake lep. veto, **1 b-tag,** *additional lepton iso*
- Bkg: *simulated* $t\bar{t}$/Wt/s-chan, W/Z+jets, **data-driven fake lep** *(el-like jet template or sample with inverted muon quality cuts)*



- **Extract number of t-chan events, ν_t, by binned max. likelihood fit** *of* **Neural Network output** to data *(11 kin. vars: jet-lep masses, $\sum_{jet,lep} p_T + E_T^{miss}$, jet rapidities)*

ATLAS-CONF-2014-007

$\int L dt$ = **20.3 fb^{-1}** *(2012)*

- **Calculate cross section with fiducial efficiency**

fiducial: *apply ~**reco cuts to particle level** jets, brem-corrected truth e, μ,ν from W, b-jet is tagged with b-hadron*

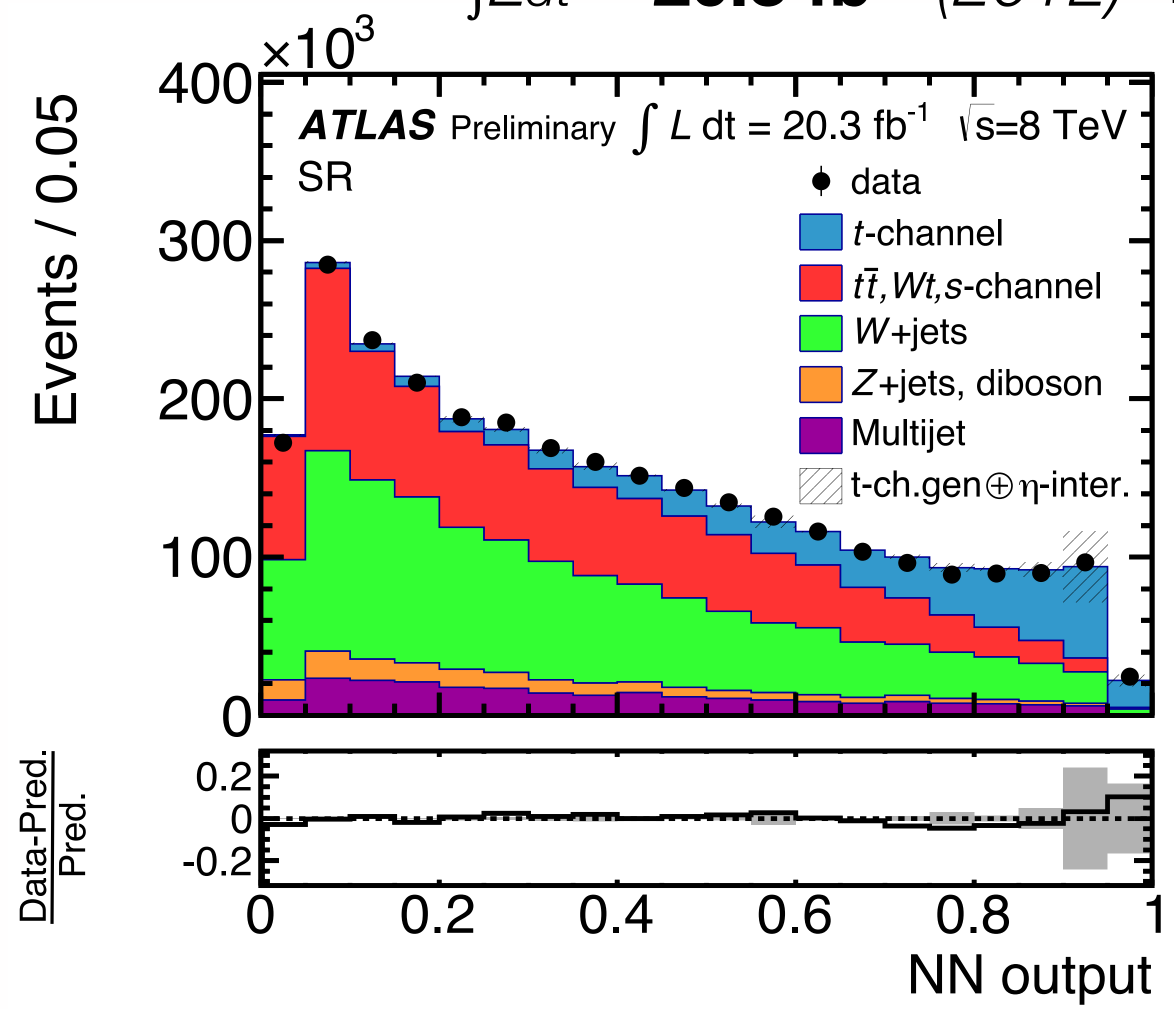
$$\sigma_{\rm fid} = \frac{\epsilon_{\rm corr,sel}}{\epsilon_{\rm corr,fid}} \cdot \frac{\hat{\nu}}{\mathcal{L}} = R_f \cdot \frac{\hat{\nu}}{\mathcal{L}},$$

$$\sigma_{\rm fid} = 3.37 \pm 0.05\,({\rm stat.}) \pm 0.47\,({\rm syst.}) \pm 0.09\,({\rm lumi.})\ {\rm pb}$$

$\delta\sigma_t/\sigma_t$ ~14%

syst dominated

JES from detector intercalibration ~7.9%, t-chan generator~7.9%

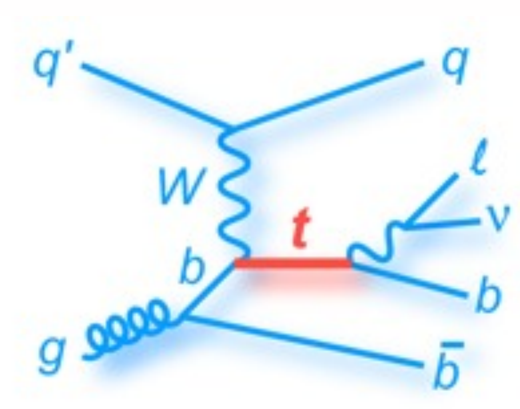


$^{*}\ m_{\rm T}(W) = \sqrt{2\left[p_{\rm T}(\ell)E_{\rm T}^{\rm miss} - \vec{p}_{\rm T}(\ell)\cdot\vec{E}_{\rm T}^{\rm miss}\right]},$

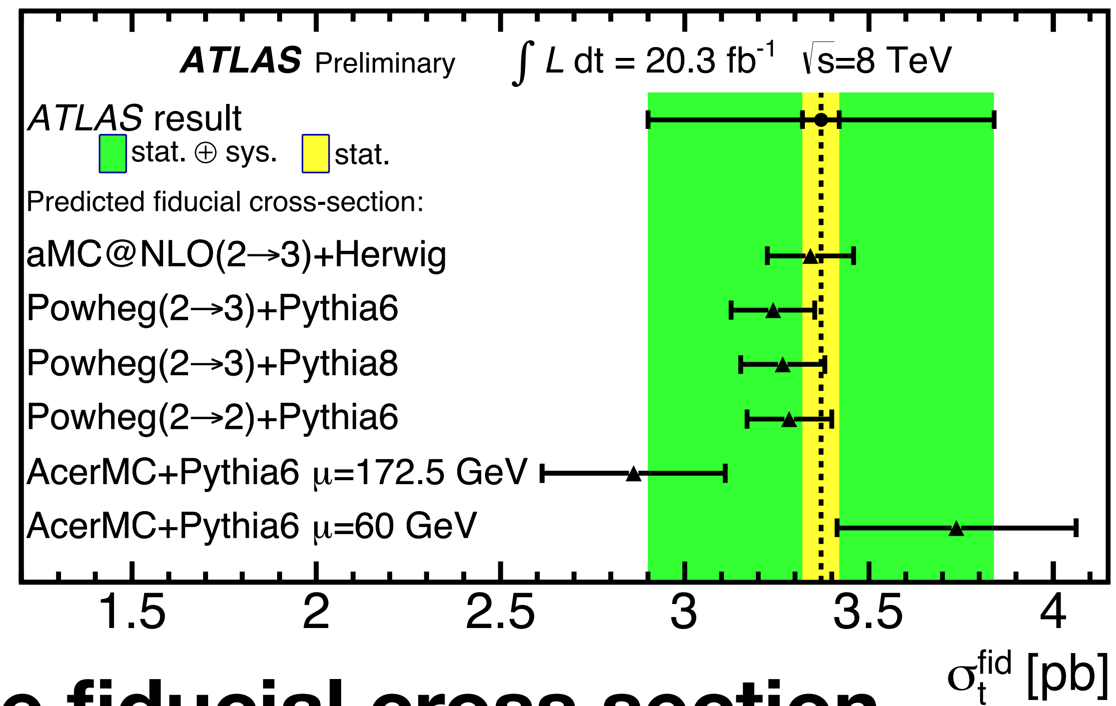
Inclusive and fiducial σ_t: t-chan $\sqrt{s}$ = 8 TeV

NEW!

- **Compare result with predictions** of LO/NLO generators



PDF & scale uncertainty uncertainty



ATLAS-CONF-2014-007

$\int L dt$ = **20.3 fb^{-1}** *(2012)*

- **Extrapolate the fiducial cross section to the full phase space**

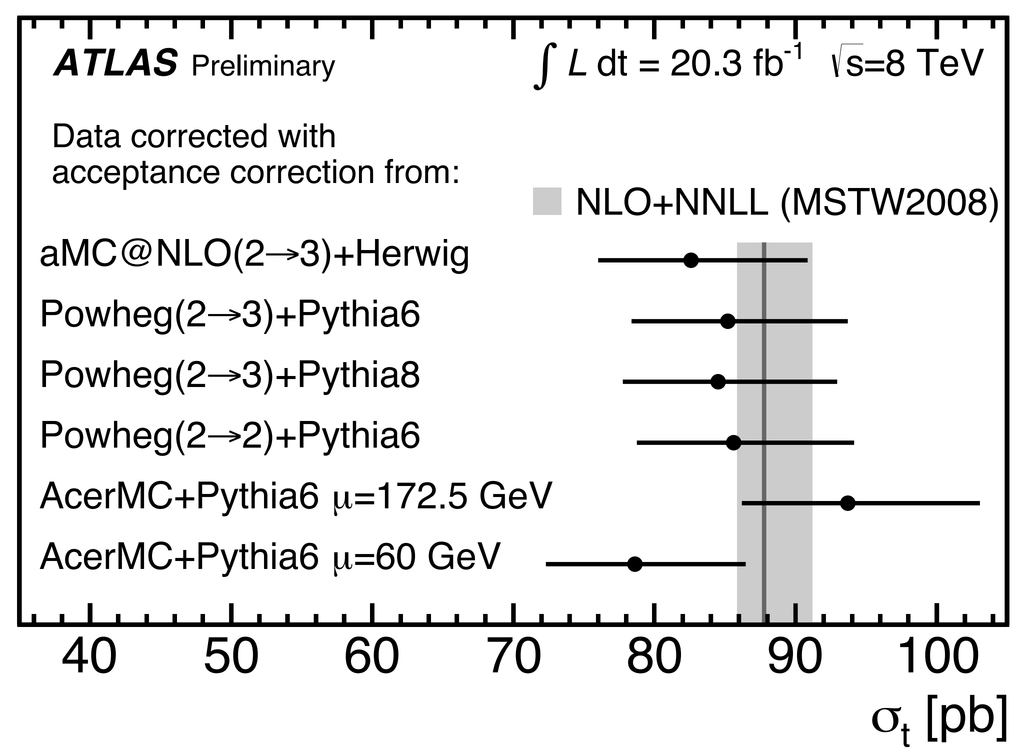
$$\sigma = \frac{1}{\epsilon_{\text{fid}}} \cdot \sigma_{\text{fid}}$$

particle level selection efficiency

aMC@NLO corrected

$$\sigma_t = 82.6 \pm 1.2\,(\text{stat.}) \pm 11.4\,(\text{syst.}) \pm 3.1\,(\text{PDF}) \pm 2.3\,(\text{lumi.})\ \text{pb}$$

$\delta\sigma_t/\sigma_t$ ~14.6% *other full space get to 17%*



- **Determine** If $|V_{tb}|<1$ $|V_{tb}| > 0.80$ at 95% C.L.

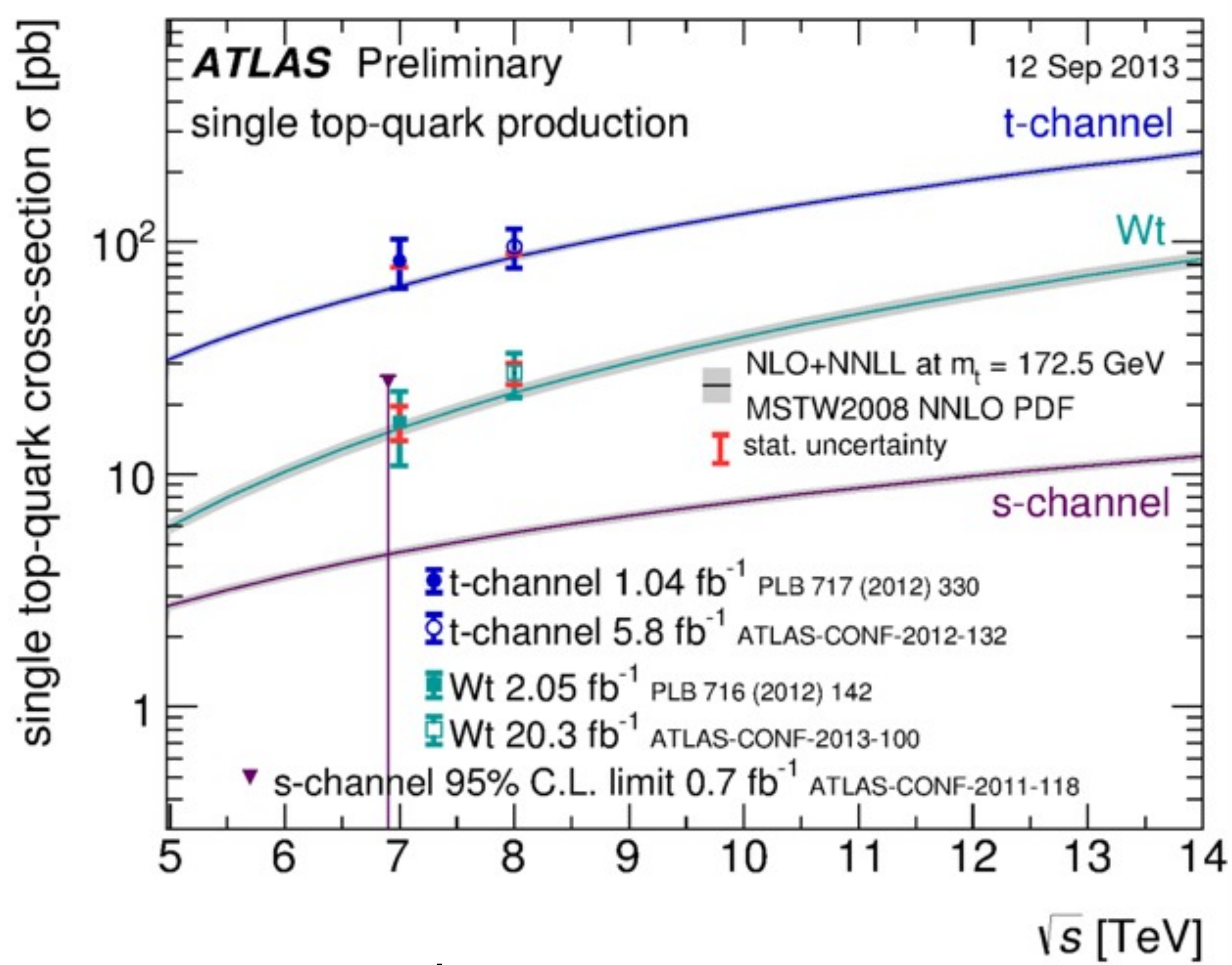
$$|V_{tb}| = 0.97 \pm 0.01\,(\text{stat.})^{+0.06}_{-0.07}\,(\text{syst.}) \pm 0.06\,(\text{gen. + PDF})^{+0.02}_{-0.01}\,(\text{theor.}) \pm 0.01\,(\text{lumi.}) = 0.97^{+0.09}_{-0.10}$$

Inclusive σ_t - Summary at $\sqrt{s}$ = 7 & 8 TeV

At $\sqrt{s}$ =7 and 8 TeV

- **Observation of t-channel**
  - **$\delta\sigma_t/\sigma_t$** ~19% to 25%
- **Evidence on Wt channel**
  - **$\delta\sigma_{Wt}/\sigma_{Wt}$** ~20% to 30%

- Limit on s-channel at $\sqrt{s}$ =7 TeV



- First ATLAS + CMS combination at $\sqrt{s}$ = 8 TeV !

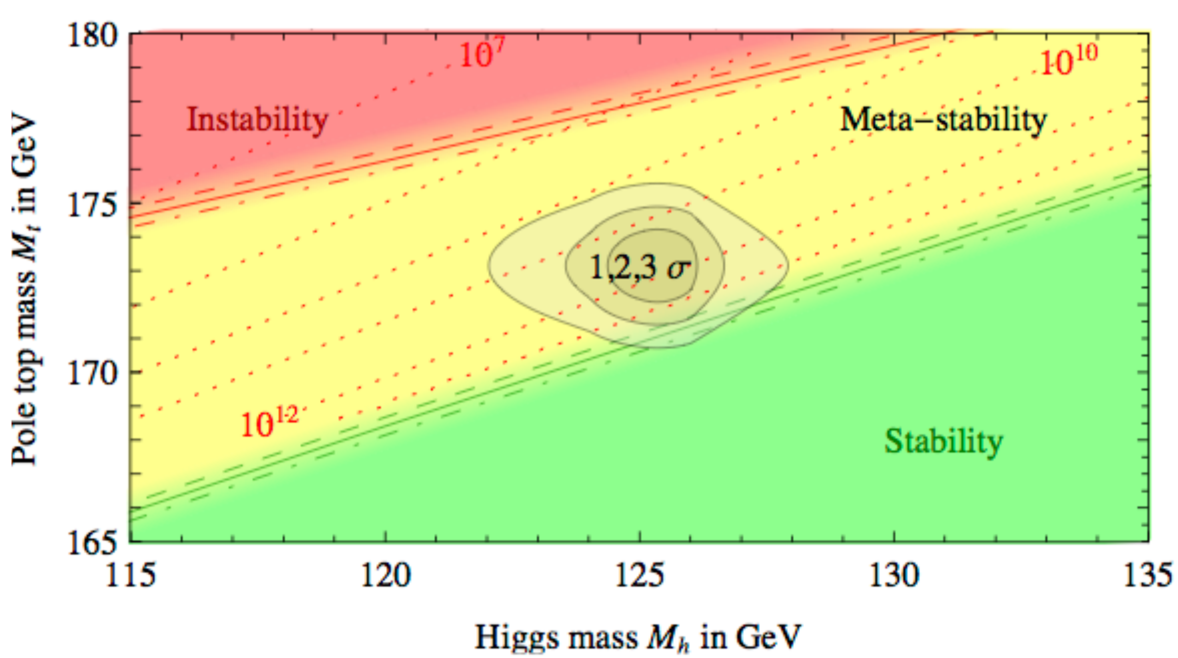
$\sigma_{\text{t-ch.}} = 85 \pm 4\,(\text{stat.}) \pm 11\,(\text{syst.}) \pm 3\,(\text{lumi.})\,\text{pb}$ $\int L dt$ = **5.8 (5.0) fb^{-1}** *(2012))*

$\delta\sigma_t/\sigma_t$ ~14%

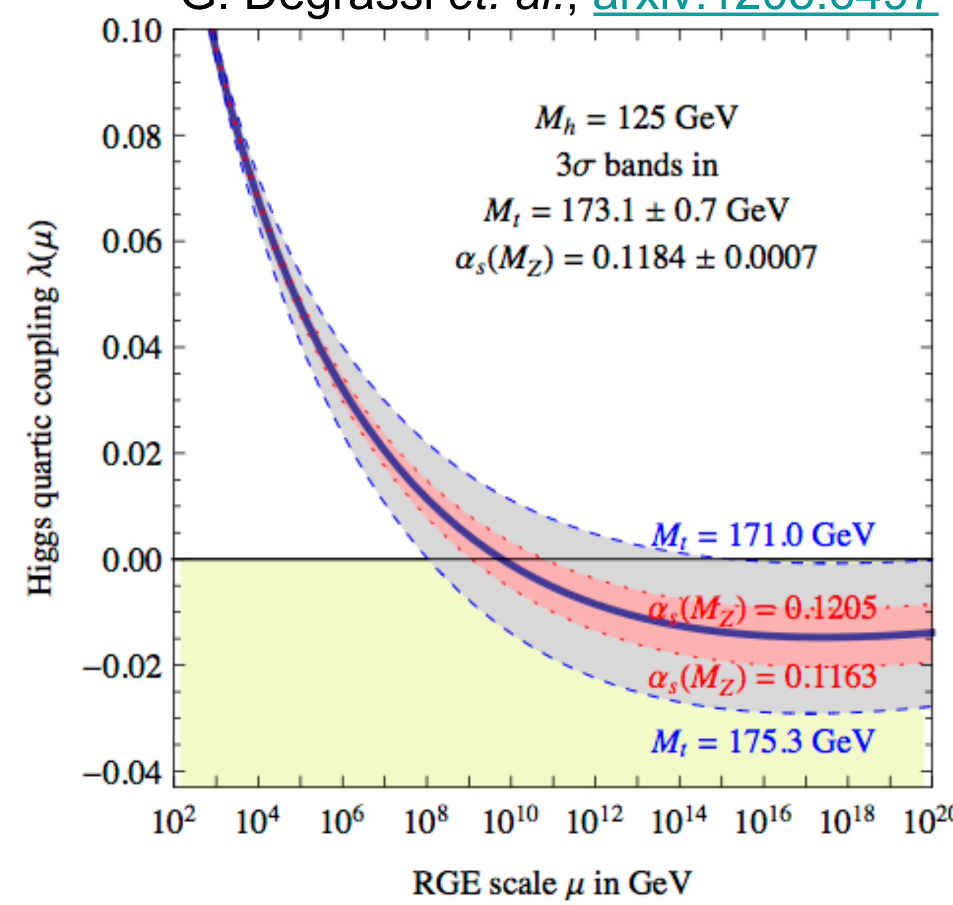
ATLAS-CONF-2013-098
CMS-PAS-TOP-12-002

Measuring top mass

i.e. what makes top special



G. Degrassi *et. al.*, arxiv:1205.6497



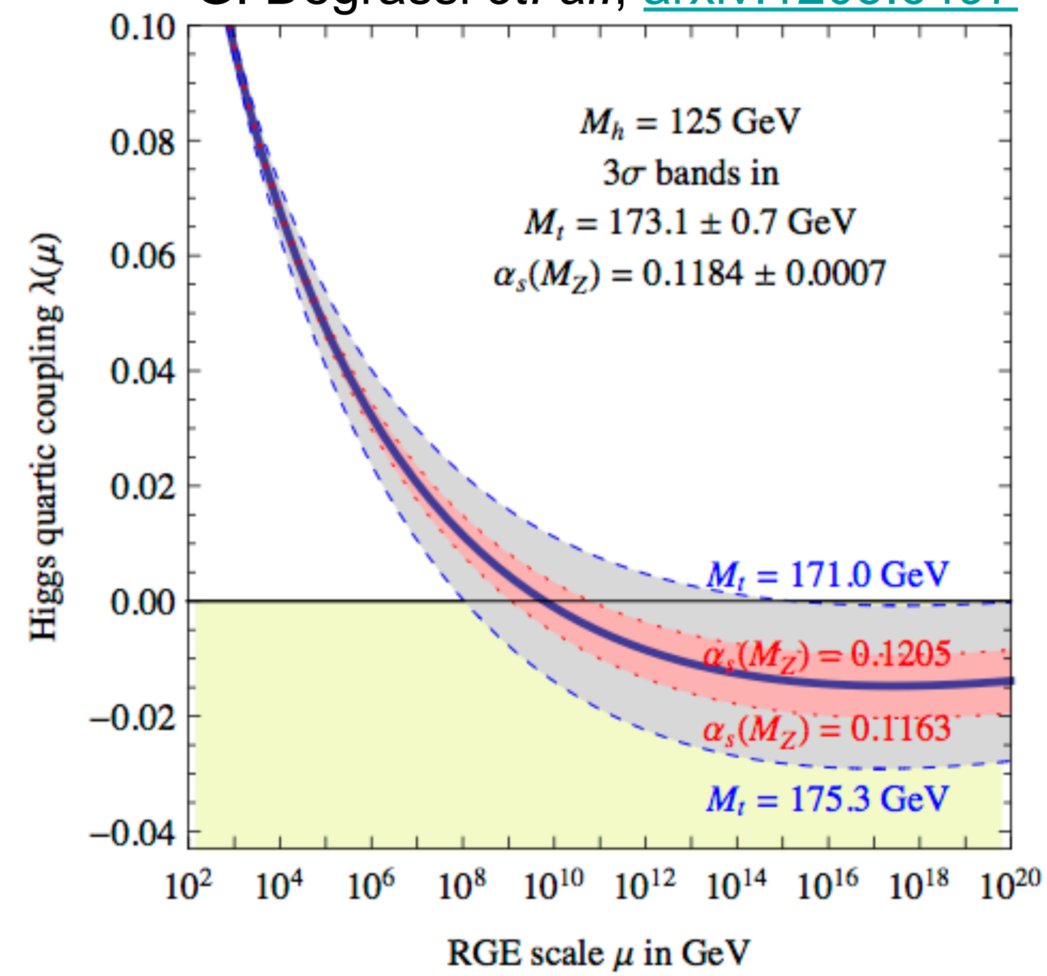
Higgs potential stability

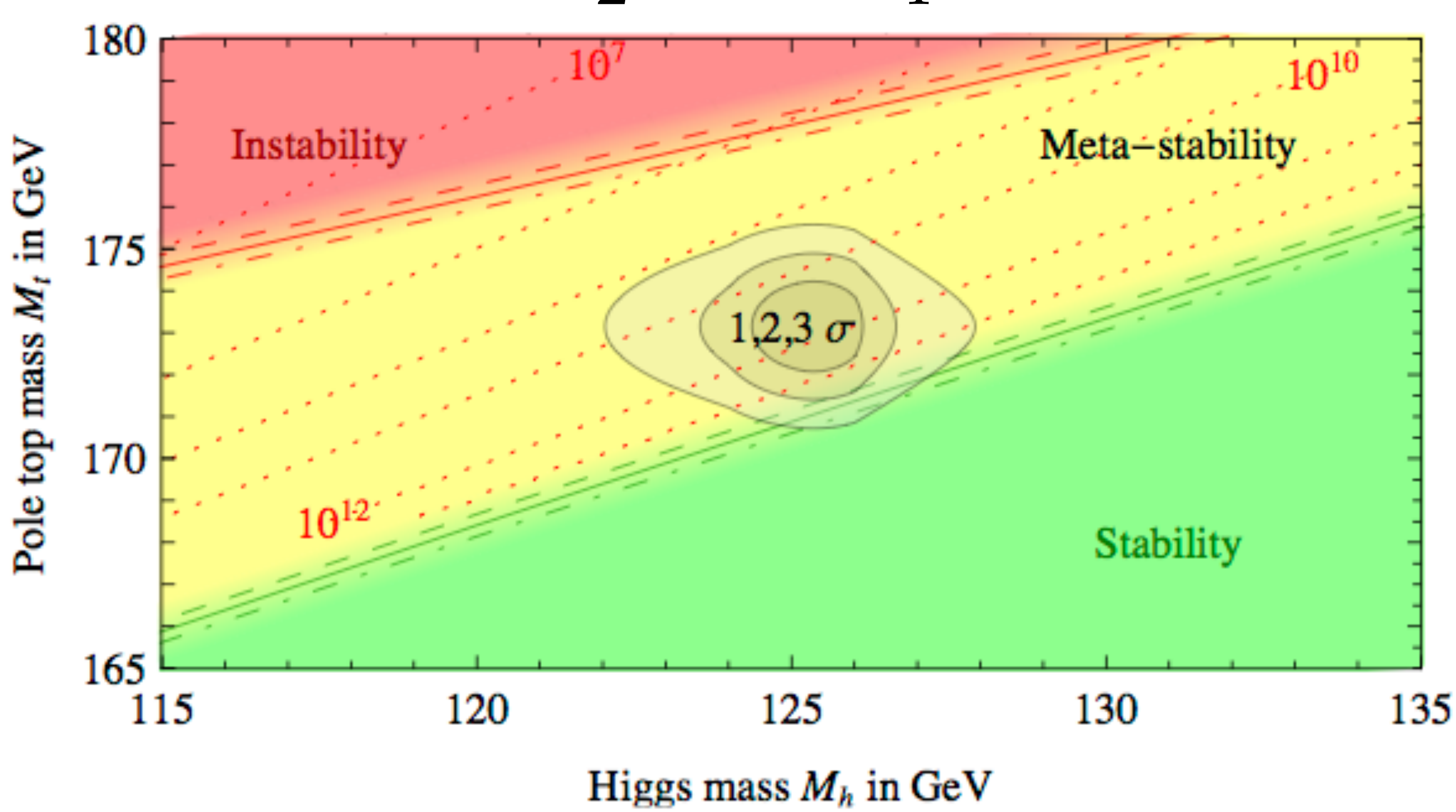
(G. Cortiana's CERN seminar, 2nd July 2013)

- The current experimental values of m_H and m_{top} are very intriguing from the theoretical point of view:
  - the Higgs quartic coupling could be rather small, vanish or even turn negative at a scale slightly smaller than the Planck scale.
  - if $\lambda(\mu)>0$
    the electroweak vacuum is a global minimum
  - if $\lambda(\mu)<0$
    the electroweak vacuum becomes metastable (does not become unstable over the age of the universe)

$$V = \frac{1}{2}\mu^2\Phi^2 + \frac{1}{4}\lambda\Phi^4$$

G. Degrassi *et. al.*, arxiv:1205.6497



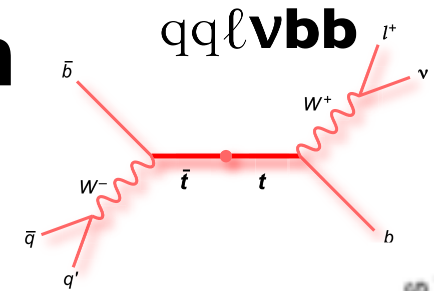


- Even in the absence of direct evidences for new physics at the LHC, the experimental information on m_H and m_{top} gives us useful hints on the structure of the theory at very short distances
- Renewed interest for precision m_{top} measurements

G. Cortiana 42

Measuring top mass

$\int L dt$ = **4.7 fb^{-1}** *(2011)*

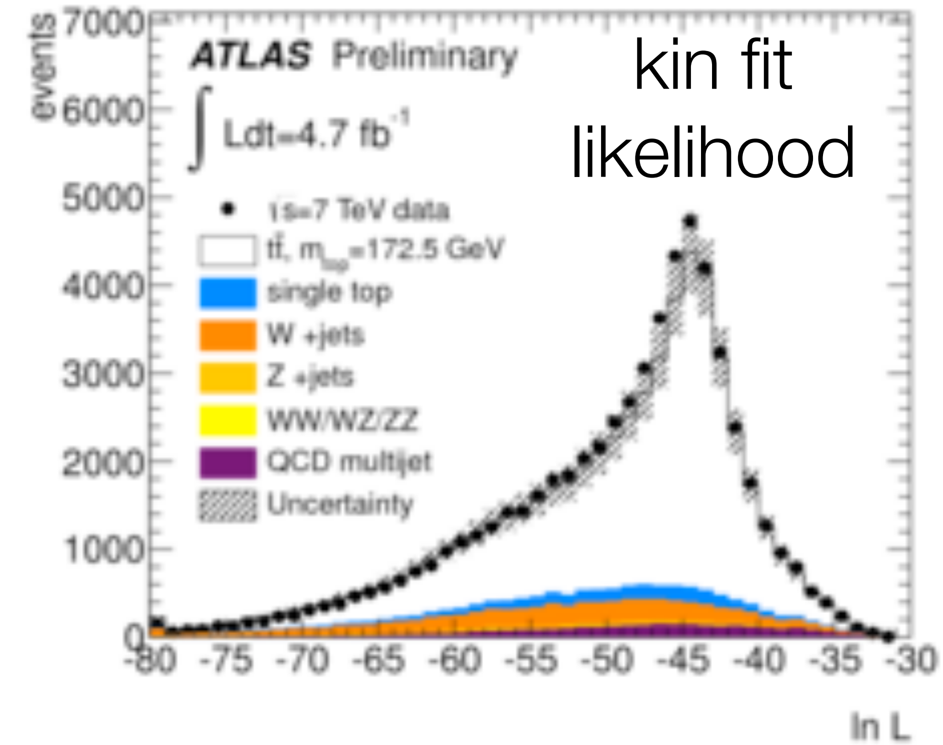


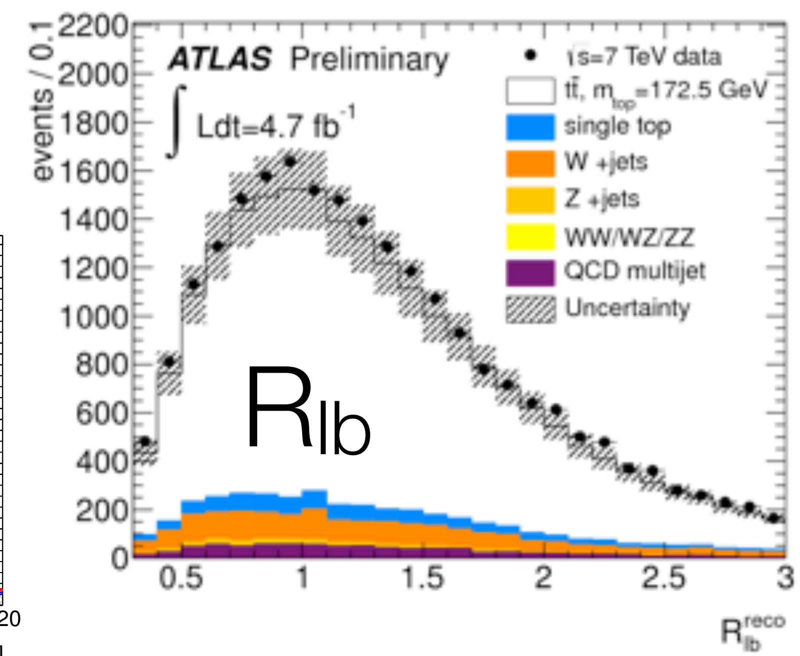
ATLAS-CONF-2013-046

- **Standard single lepton selection**
  - *good quality objects, 1 lepton, cuts on E_T, m_T^W, ≥4 jets, at least 1 b-tagged jet*
  - *channel dep analytic shape for bkg,*
  - *W+jets and QCD from data*

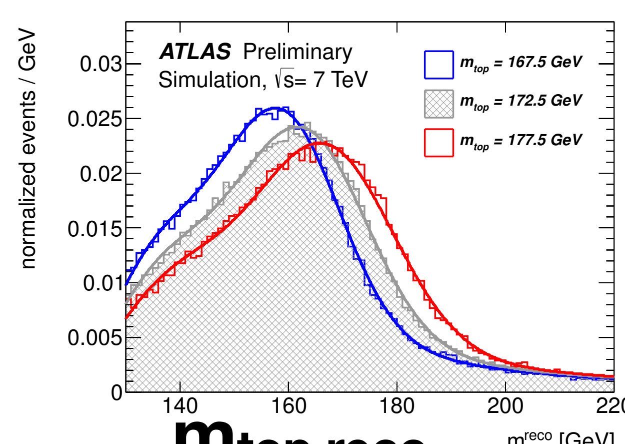
- **Reconstruct m_{top}-sensitive variables Reconstruct LO tt picture with kinematic likel. fit** *($m_{top,HAD}$= $m_{top,LEP}$ + weight for b/mis-tag ,m_W constraint)* → assign jets
  - **$m_{top,reco}$ from fit-assigned & constrained jets**
  - **$m_{w,reco}$ from fit-assigned but unconstrained jets**
  - **R_{lb} (1 or 2 btag) = $\alpha \sum_{b\text{-tag}} p_{T,b\text{-tag}} / (p_{T,Wjet1}+p_{T,Wjet2})$**

    α=2 for 1-btag and α=1 for 2 b-tag





- **Build simulated template(s)** of variables as a function of
  - m_{top}
  - global jet en. scale factor (JSF)
  - relative b-to-light jet energy scale factor (truth matched):b-JSF



$m_{top,reco}$

Jet energy scale is crucial

Measuring top mass

$\int Ldt$ = **4.7 fb^{-1}** *(2011)*

ATLAS-CONF-2013-046

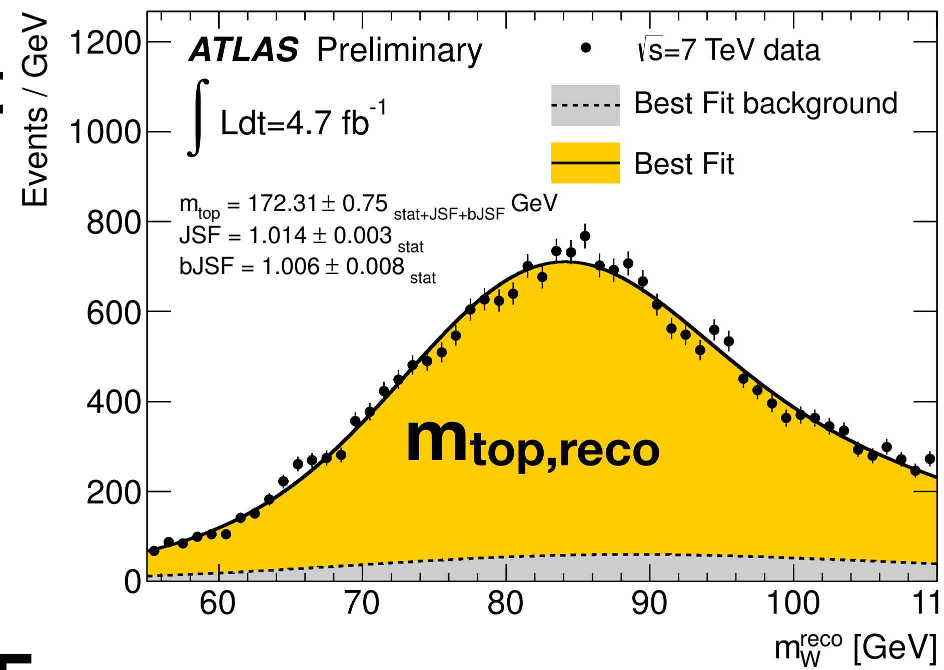
- **Unbinned likelihood fit** *of data in windows of* $m_{W,rec}$, $m_{top,reco}$ *and* R_{lb} **to 3 analytic template(s)** *derived by fit to MC*→**m_{top},JSF,bJSF**

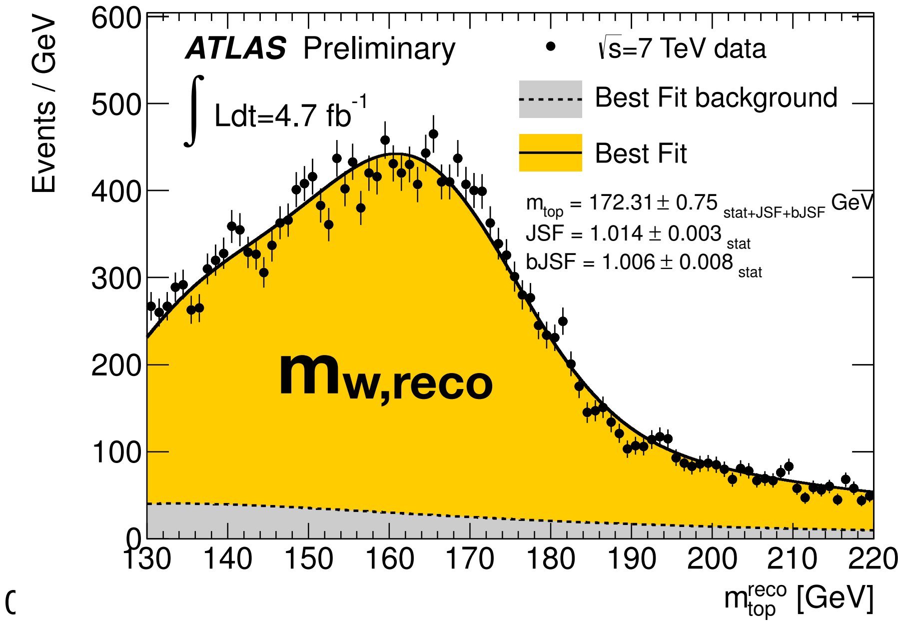
Template dependence

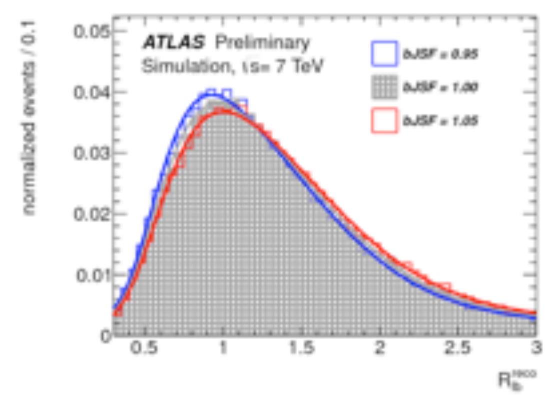
- **$m_{top,reco}$: m_{top}, JSF,b-JSF**
- **$m_{w,reco}$: JSF**
- **R_{lb}: m_{top}, b-JSF**

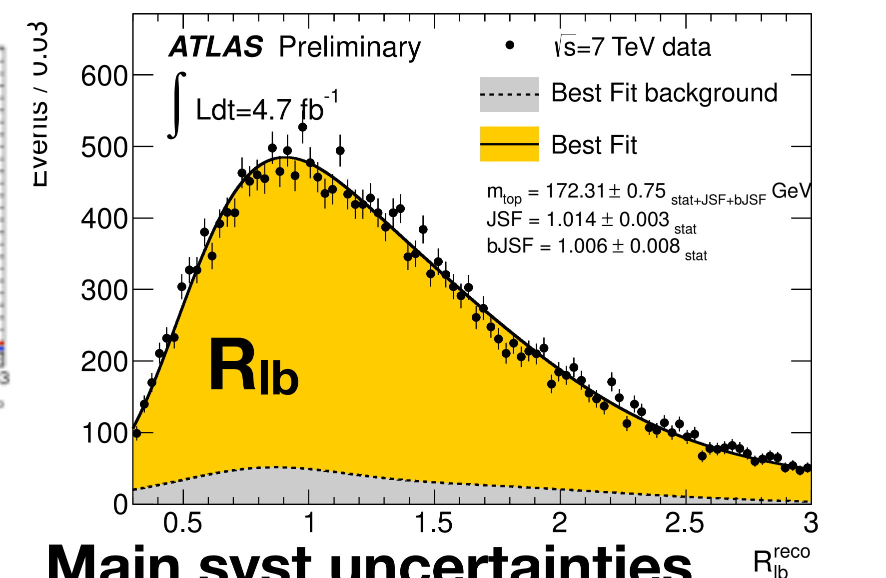
variables correlations at 15% level

reduce JES *by in-situ fix to W mass + transfer uncertainty to JSF, bJSF*









$$m_t = 172.31 \pm 0.75(\mathrm{stat} + \mathrm{JSF} + \mathrm{bJSF}) \pm 1.35(\mathrm{syst})\mathrm{GeV}$$
$$\mathrm{JSF} = 1.014 \pm 0.003(\mathrm{stat}) \pm 0.021(\mathrm{syst})$$
$$\mathrm{bJSF} = 1.006 \pm 0.008(\mathrm{stat}) \pm 0.020(\mathrm{syst})$$

Main syst uncertainties

Description	Value [GeV]
Statistics	0.23
JSF (stat)	0.27
bJSF (stat)	0.67
Hadronisation	0.27
Colour reconnection	0.32
ISR/FSR	0.45
Jet energy scale	0.79
b-tagging	0.81
Total systematic	**1.35**

- ***Systematic dominated!*** ***b-JES reduced by 40% w.r.t to previous measurement.***
  - ***b-JES*** (starting from reduced baseline), *reduction ISR/FSR modelling (jet activity), jets are dominant, modelling is still important*

m_{top} @ ATLAS with 3D template: uncertainties

(thanks to G. Cortiana's CERN seminar, 2nd July 2013)

set b-JES to 1

- Larger stat in 3D because of higher dim, but reduced b-JES
- Dominant modelling is reduced by JSF/ b-JSF
- Residual JES from p_T dependence of JES
- b-tag:p_T dependence of scale factors affecting R_{lb}
- Overall: better total syst , bJES absorbed by bJSF, scaling with lumi, uncorrelated in combinations

ATLAS-CONF-2013-046

	2d-analysis		3d-analysis			
	m_{top} [GeV]	JSF	m_{top} [GeV]	JSF	bJSF	
Measured value	172.80	1.014	172.31	1.014	1.006	
Data statistics	0.23	0.003	0.23	0.003	0.008	
Jet energy scale factor (stat. comp.)	0.27	n/a	0.27	n/a	n/a	
bJet energy scale factor (stat. comp.)	n/a	n/a	0.67	n/a	n/a	
Method calibration	0.13	0.002	0.13	0.002	0.003	
Signal MC generator	0.36	0.005	0.19	0.005	0.002	
Hadronisation	1.30	0.008	0.27	0.008	0.013	reduced
Underlying event	0.02	0.001	0.12	0.001	0.002	
Colour reconnection	0.03	0.001	0.32	0.001	0.004	
ISR and FSR (signal only)	0.96	0.017	0.45	0.017	0.006	reduced
Proton PDF	0.09	0.000	0.17	0.000	0.001	
single top normalisation	0.00	0.000	0.00	0.000	0.000	
W+jets background	0.02	0.000	0.03	0.000	0.000	
QCD multijet background	0.04	0.000	0.10	0.000	0.001	
Jet energy scale	0.60	0.005	0.79	0.004	0.007	
b-jet energy scale	0.92	0.000	0.08	0.000	0.002	reduced
Jet energy resolution	0.22	0.006	0.22	0.006	0.000	
Jet reconstruction efficiency	0.03	0.000	0.05	0.000	0.000	
b-tagging efficiency and mistag rate	0.17	0.001	0.81	0.001	0.011	
Lepton energy scale	0.03	0.000	0.04	0.000	0.000	
Missing transverse momentum	0.01	0.000	0.03	0.000	0.000	
Pile-up	0.03	0.000	0.03	0.000	0.001	
Total systematic uncertainty	2.02	0.021	1.35	0.021	0.020	reduced
Total uncertainty	2.05	0.021	1.55	0.021	0.022	

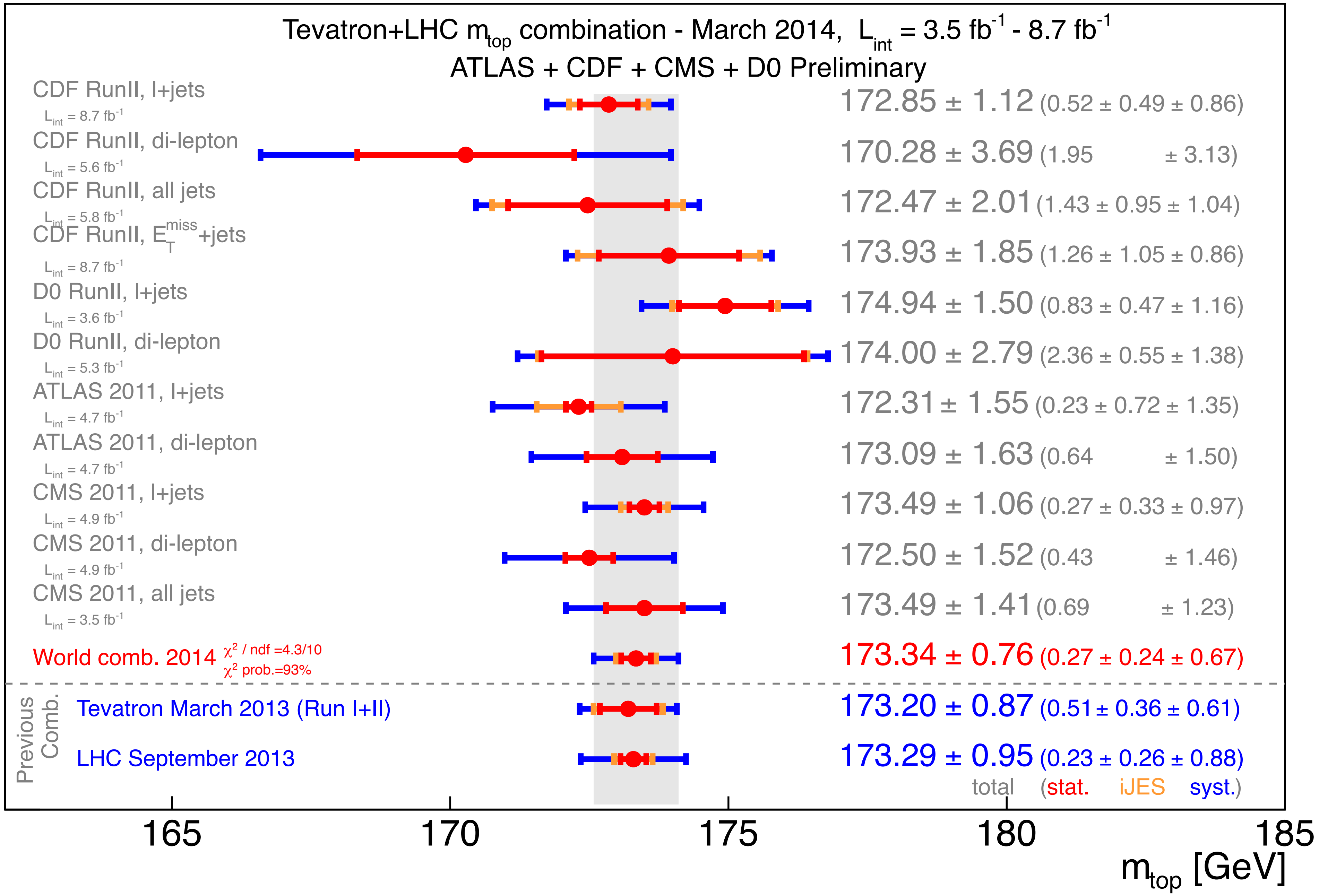
First M_{top} World average

NEW!

- **First combination** of m_{top} from **1.96 TeV $p\bar{p}$ & 7 TeV pp** collisions

arxiv:1403.4427[hep-ex]

- Tevatron: up to 8.7/fb
- LHC: up to 4.9/fb
- Use most precise measurement in each channel by each experiment
- **δm_{top} reduced** by
  - **28%** w.r.t. most precise single input
  - **13%** w.r.t to previous most precise combination
- **Systematics dominated**
  - tt modelling
  - energy scale of light and b-jets



m_{top} = 173.34± 0.27(stat) ± 0.71(syst) GeV

$\delta m_{top} / m_{top}$ ~0.44%

First M_{top} World average : uncertainties & correlations

NEW!

arxiv:1403.4427[hep-ex]

GeV

Uncertainty	World Combination
m_{top}	173.34
Stat	0.27
iJES	0.24
stdJES	0.20
flavourJES	0.12
bJES	0.25
MC	0.38
Rad	0.21
CR	0.31
PDF	0.09
DetMod	0.10
b-tag	0.11
LepPt	0.02
BGMC	0.10
BGData	0.07
Meth	0.05
MHI	0.04
Total Syst	0.71
Total	0.76

- Major effort to classify **uncertainties** & define **correlations**

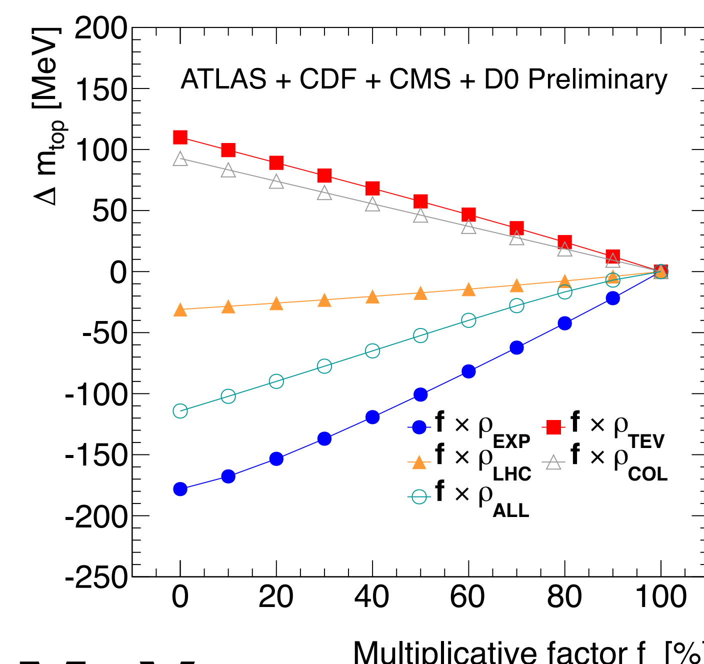
- Vary correlation scenarios **(m_{top}, δm_{top}) stable** within uncertainties

within same experiment — *within same collider* — *between colliders*

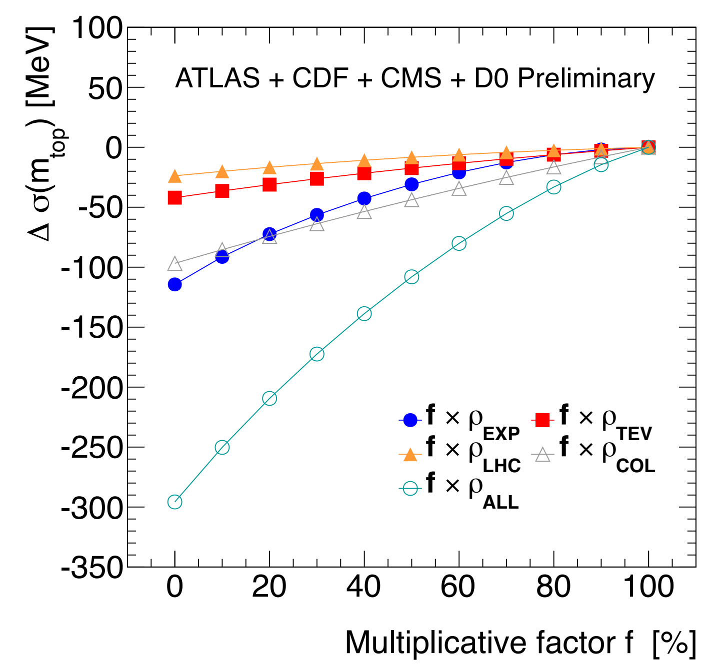
	ρ_{EXP}				ρ_{LHC}	ρ_{TEV}	ρ_{COL}	
	ρ_{CDF}	ρ_{D0}	ρ_{ATL}	ρ_{CMS}			$\rho_{ATL-TEV}$	$\rho_{CMS-TEV}$
Stat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
iJES	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
stdJES	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
flavourJES	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
bJES	1.0	1.0	1.0	1.0	0.5	1.0	1.0	0.5
MC	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Rad	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.5
CR	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
PDF	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.5
DetMod	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
b-tag	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
LepPt	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
BGMC†	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BGData	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Meth	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MHI	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0

11 input columns combined with

MeV



MeV

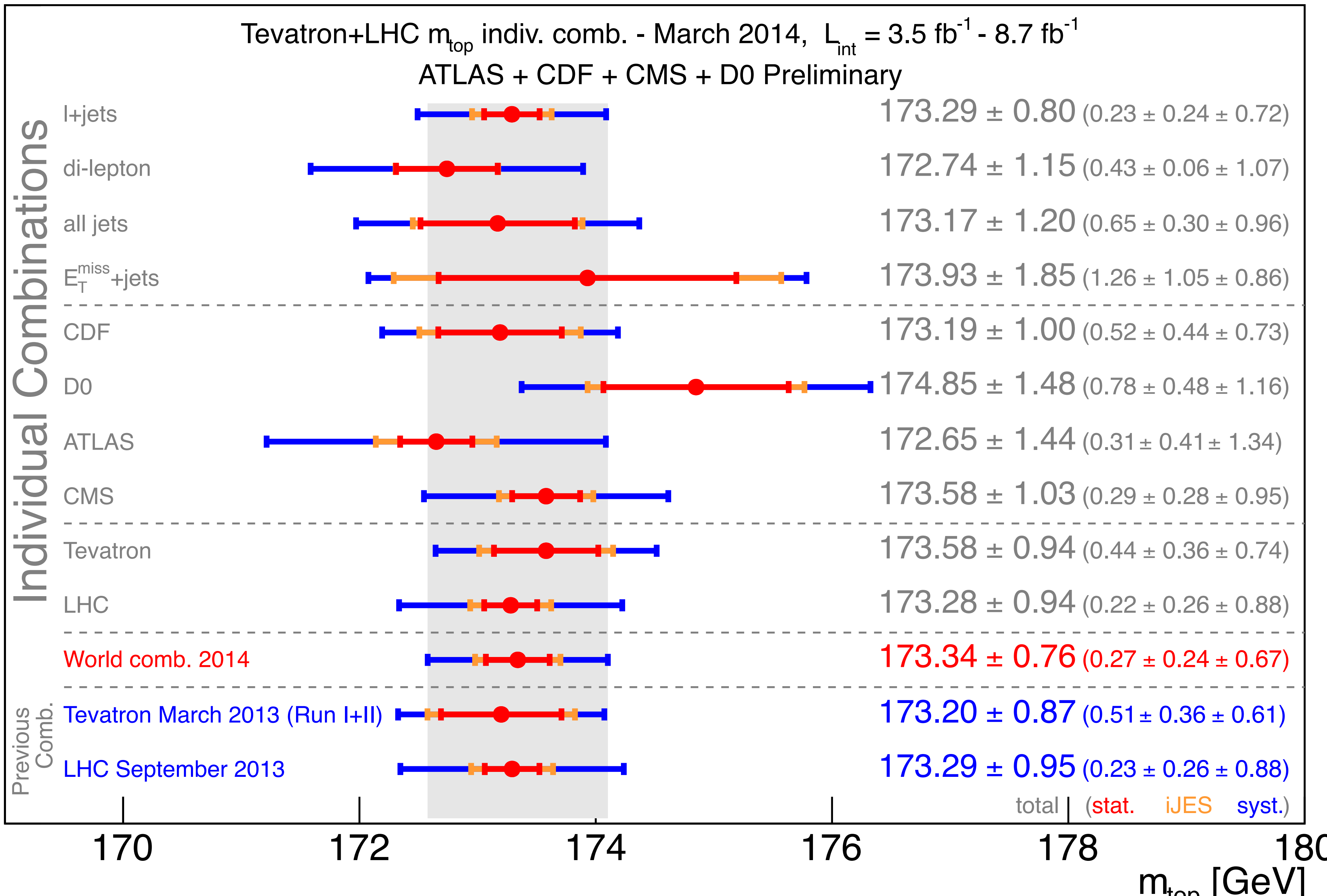


First M_{top} World average : consistency

NEW!

- Combine by allowing different top masses for different data sets
  - *for inst. 4 parameter fit (m^{l+jets} $m^{di\text{-}l}$ $m^{alljets}$ m^{ETmiss})instead of 1 m_{top}*
- Keep correlations, check consistency

arxiv:1403.4427[hep-ex]



per final state

per experiment

per collider

All measurements are very well consistent

Measuring Top and Higgs coupling

Top, Higgs and BSM

Discovery of Higgs

EWK mechanism gives mass to fermions:
m_f =(Yukawa coupling for f)*(vev)/$\sqrt{2}$

Measure/Study top-Higgs coupling

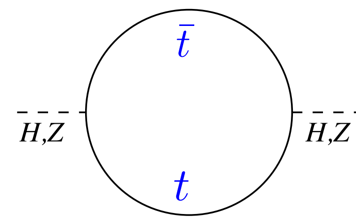
look beyond: Naturalness to alleviate Hierarchy problem = fine tuning to renormalize Higgs mass
Here be dragons

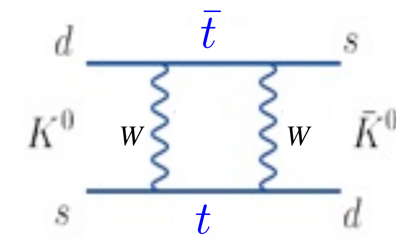
Top and BSM: a "natural" view

Standard Model (SM): top coupling to Higgs is perturbative but LARGE: $y_t \simeq 1$

Quantum effects (virtual tops) => dramatic impact on EW & flavor phys.: $\frac{2N_c\, {y_t}^2}{16\pi^2} \simeq 5\%$

(Gilad Perez, CKM2012)

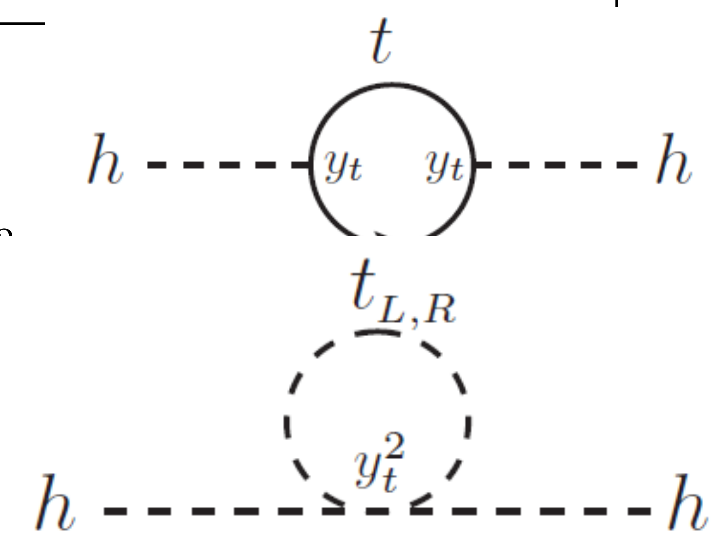




Higgs mass has quantum corrections

(Gian Giudice: arXiv 1307.7879)
$$\frac{\delta m_h^2}{m_h^2} = \frac{3G_F}{4\sqrt{2}\pi^2}\left(\frac{4m_t^2}{m_h^2} - \frac{2m_W^2}{m_h^2} - \frac{m_Z^2}{m_h^2} - 1\right)\Lambda^2 = \left(\frac{\Lambda}{500\ \text{GeV}}\right.$$

top quark gives largest contrib $\frac{\delta m_h^2}{m_h^2} \sim \left(\frac{\tilde{m}_t}{400\,\text{GeV}}\right)^2$



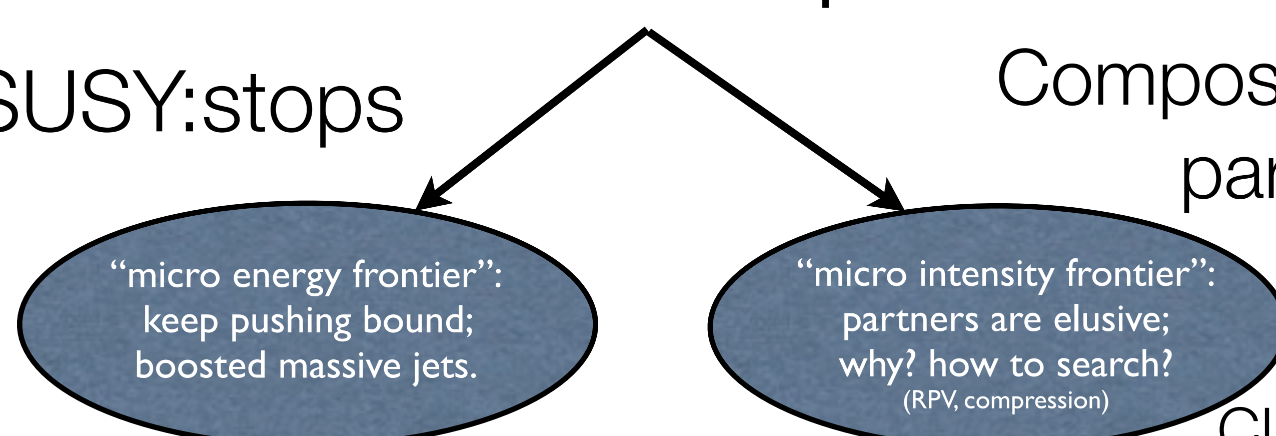
UV corrections from particles coupling to Higgs are additive and uncorrelated with M_h so if scale is about 500 GeV they are larger than M_h

If naturalness is a guide: need top partners to avoid fine tuning m_H in renormalization

LHC8: where are the partners ⁇

SUSY:stops

Composite Higgs:T partners

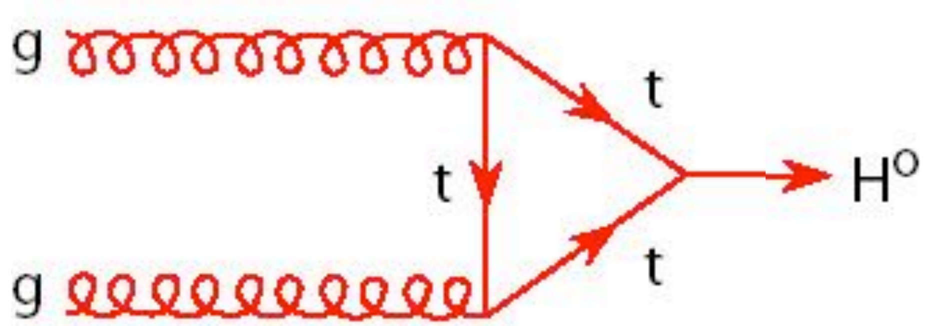


(figure from Gilad Perez, CLICMeeting, Oct2013)

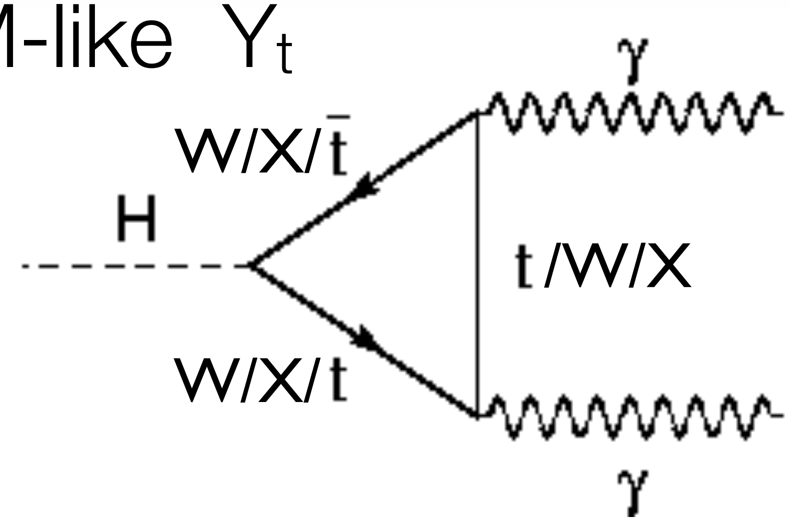
Top-Higgs coupling measurements

- In SM : top Yukawa coupling (Y_t) >0.9, m_{top} ~ coupling
- measure Y_t : Test nature of newly found boson & EWK sym. break.

- Direct evidence for decay to taus (fermions)
- Indirect evidence for SM-like Y_t

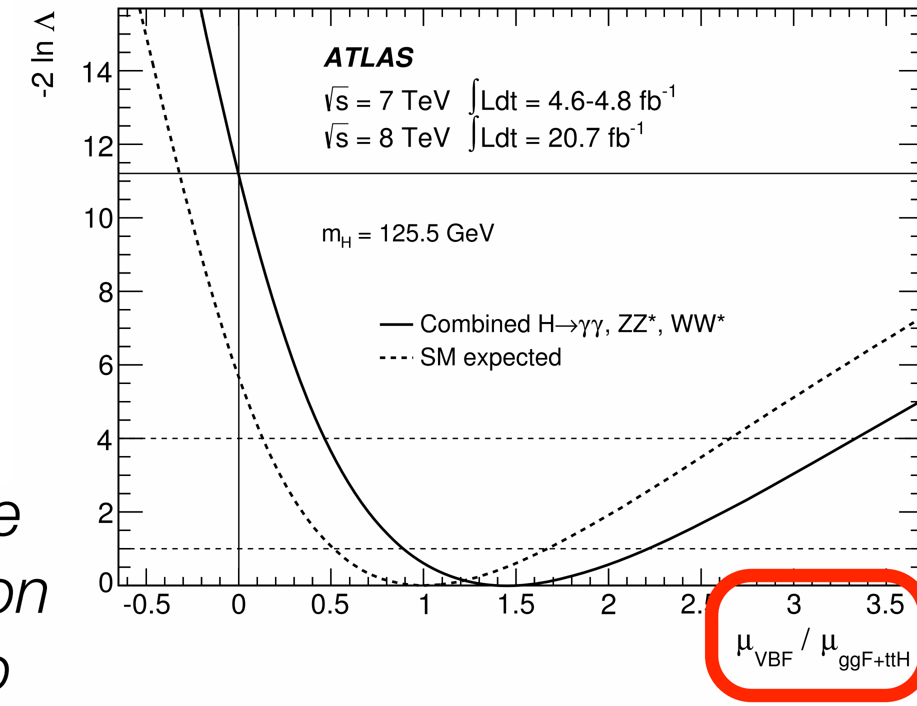


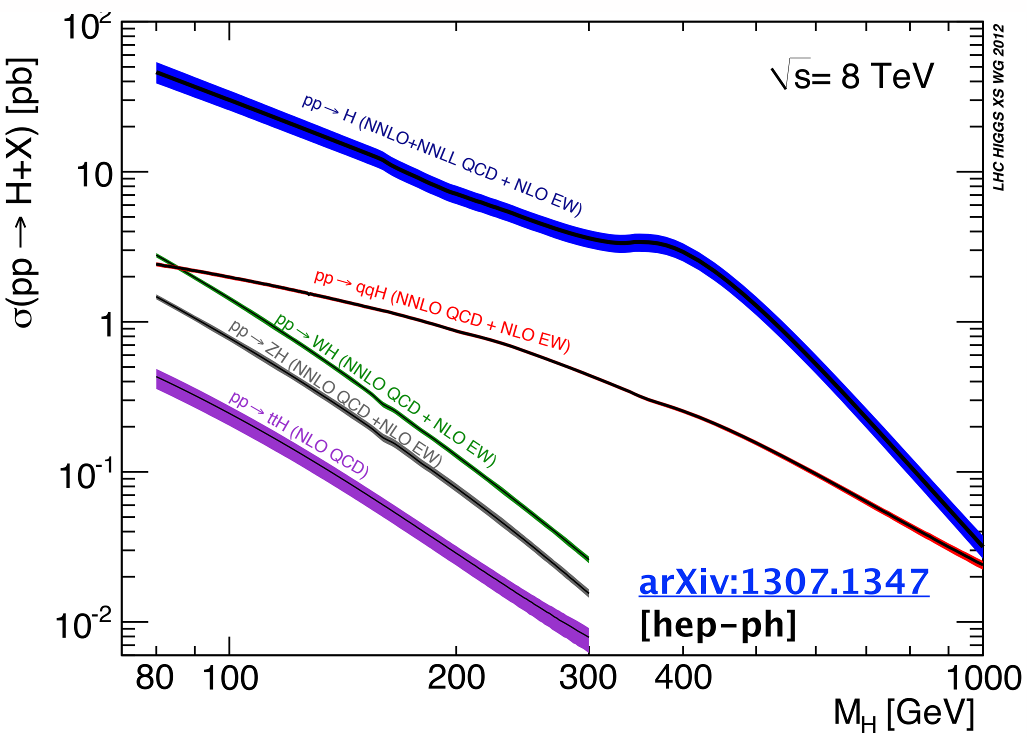
gluon fusion: dominant at LHC



interference with W boson in decay to photons

[Phys. Lett. B 726 (2013), pp. 88-119](#)



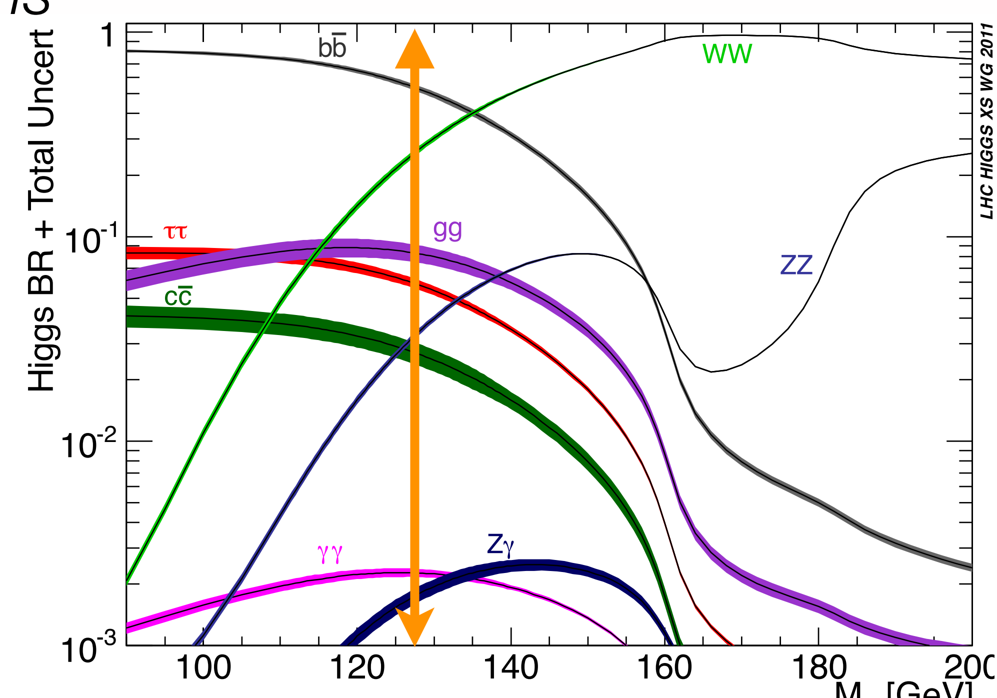


arXiv:1307.1347 [hep-ph]

σ (ttH) = 0.13 (0.63) pb @ 8 (14) TeV

Most recent direct searches use ttH with H→bb and H→γγ

arXiv:1307.1347 [hep-ph]



Search for $t\bar{t}H$, $H \rightarrow bb$ @ $\sqrt{s}$ = 7 TeV

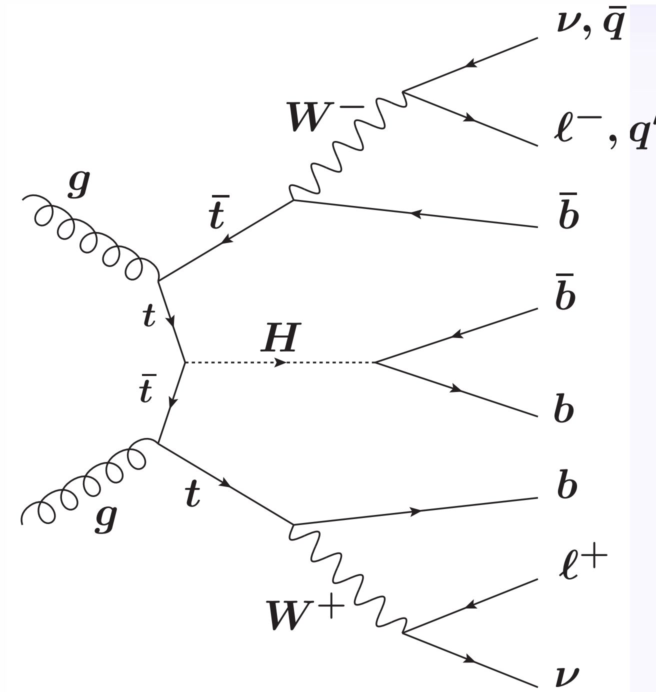
NEW!

*high H → **bb** BR: 57%, combinatorics, huge bkg*

ATLAS-CONF-2014-011

Two selections

- 1 isol. (e,μ), E_T and m_T^W cuts,4 to **≥ 6 central jets, 2 to ≥** 4 b-tag,
- 2 opposite sign lep (e,μ), 2 to **≥ 4 jets, 2 to ≥** 4 b-tag

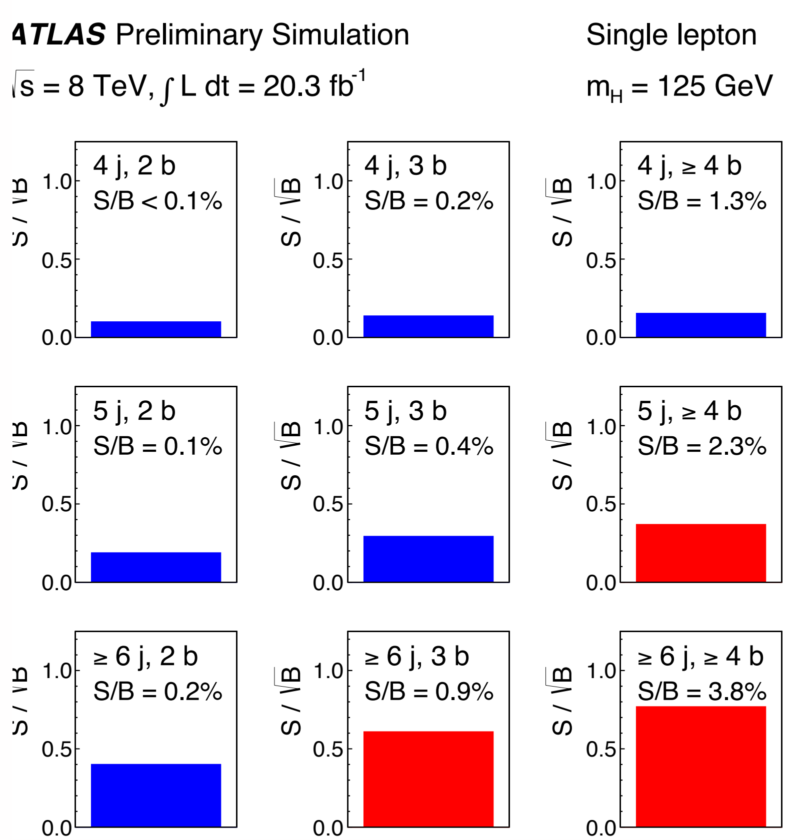


- **main bkg: tt+(bb)/ jets,** *(from simulation +data-driven corrections)* ***W+jets*** *(norm from data), data-driven multi-jets*

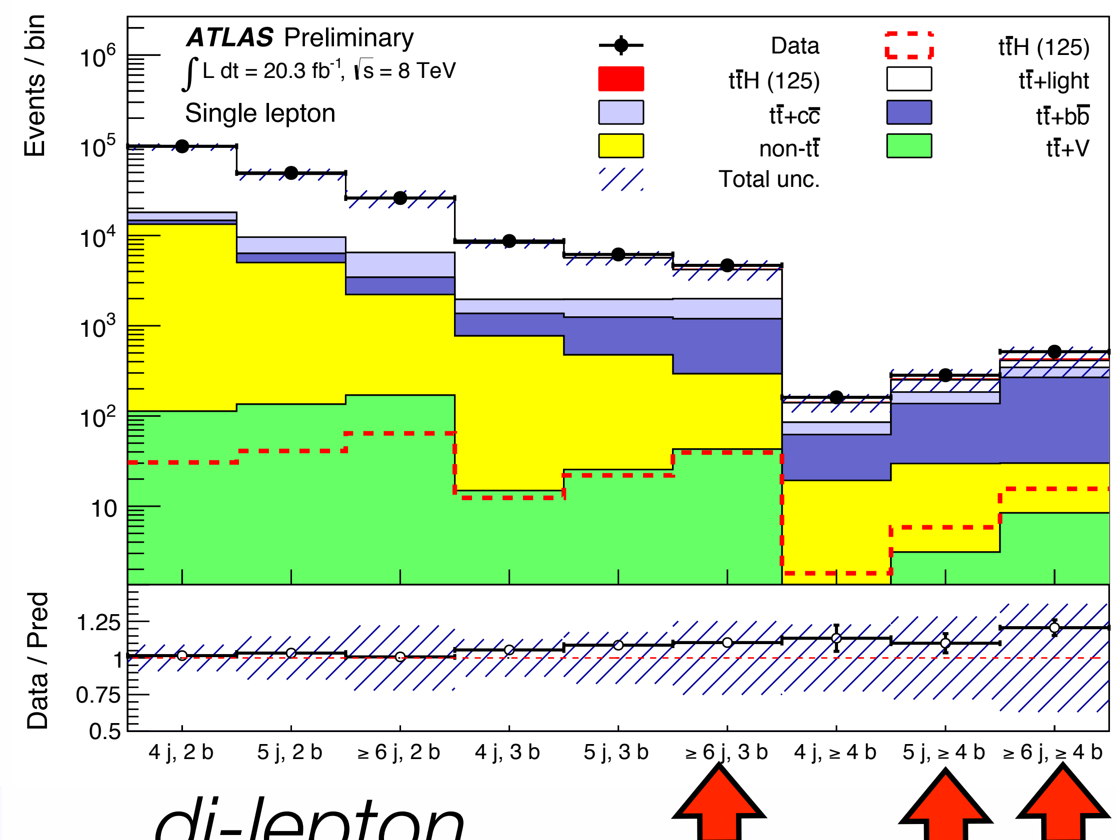
- **Separate events in 9 regions with different b-tag and jet multiplicities**

for syst/bkg constraint

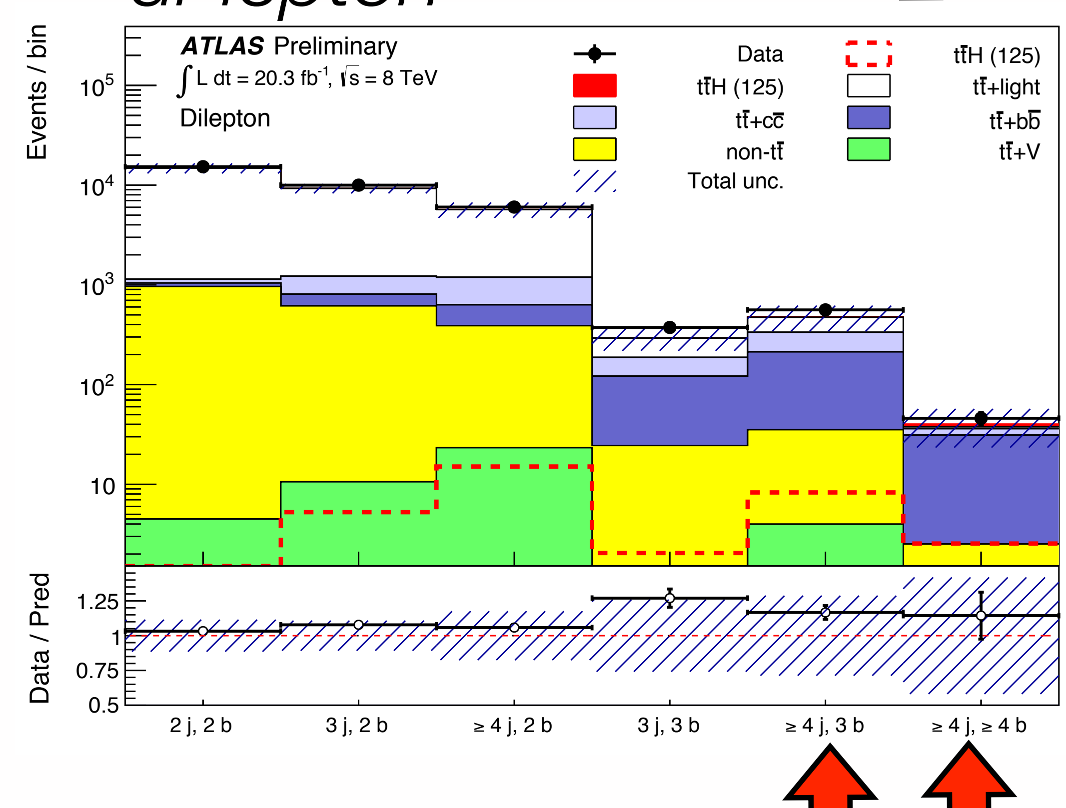
signal rich



single lepton



di-lepton



Search for **$t\bar{t}H$, H→bb** @ $\sqrt{s}$ = 8 TeV

NEW!

- **Build signal-bkg discriminating variable in each region**

	2 *b*-tags	3 *b*-tags	$\geq$ 4 *b*-tags
4 jets	H_T^{had}	H_T^{had}	H_T^{had}
5 jets	H_T^{had}	NN	NN
$\geq$ 6 jets	H_T^{had}	NN	NN

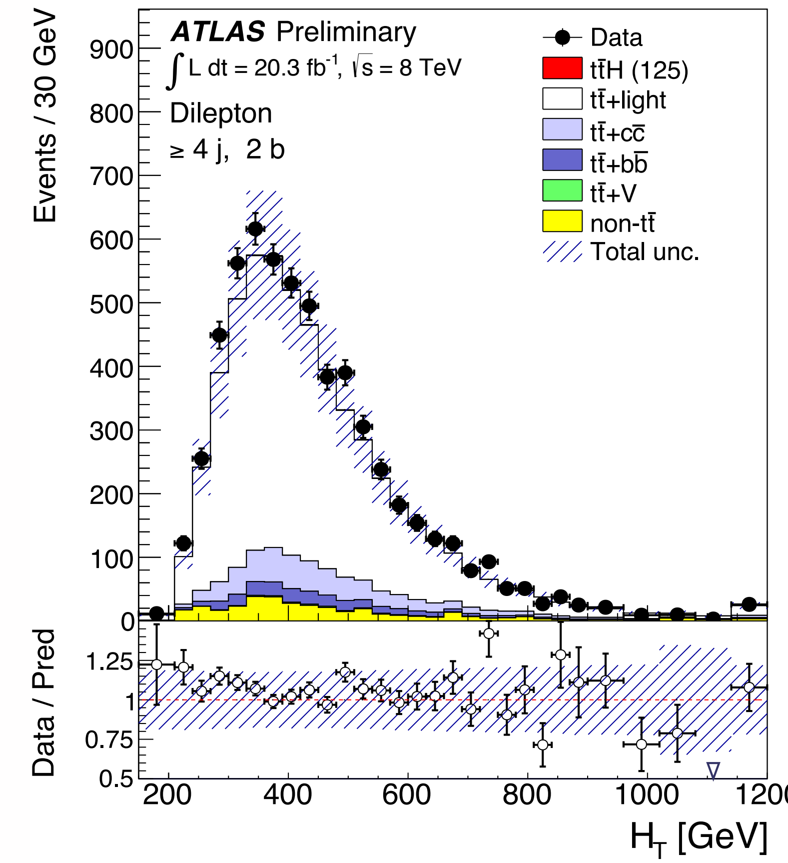
single lepton

	2 *b*-tags	3 *b*-tags	$\geq$ 4 *b*-tags
2 jets	H_T		
3 jets	H_T	NN	
$\geq$ 4 jets	H_T	NN	NN

dilepton

(E. Le Menedu, Moriond EWK 2014)

ATLAS-CONF-2014-011



- **Signal depleted regions**:
  - $\mathbf{H_T^{had}} = \sum |p_{T,jet}|$ for single lep
  - $\mathbf{H_T} = \sum |p_{T,jet}| + \sum |p_{T,lep}|$ for dilep

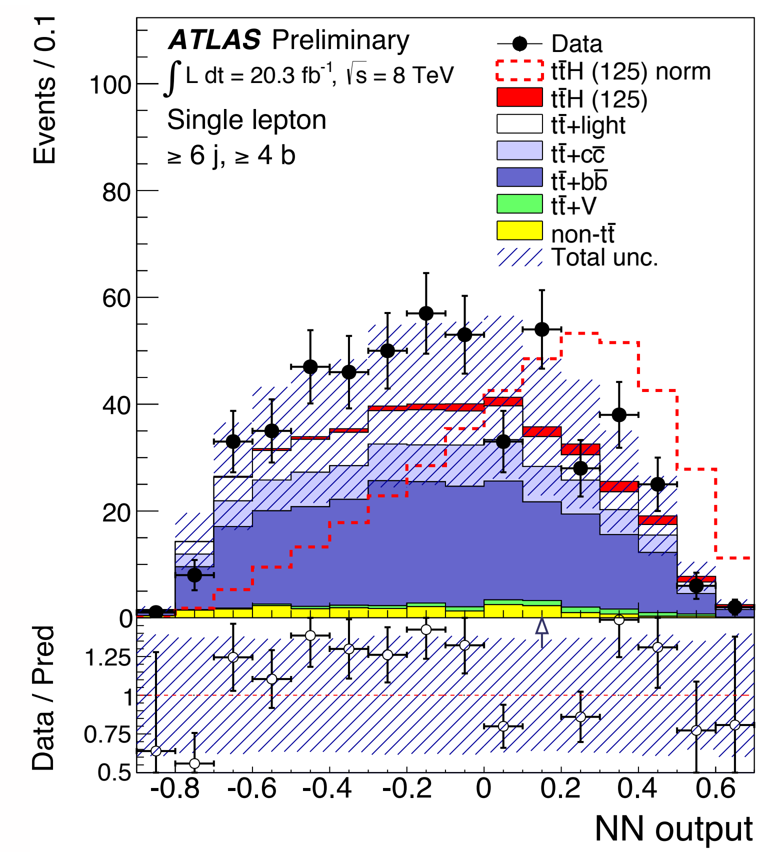
- **l+jets, 5 jets, 3 b-tags**
- **Signal rich regions**

Neural Network

- **Train on 10 region- & channel-dep variables**
  - **object kinematics, global event variables: H_T, $N_{jets,\ pT>40GeV}$**
  - **object pair: M(b,b),Angles(b,b) event shapes**

to separate tt+bb from tt+light jets

to separate ttH from tt+jets in each region



Search for **ttH, H→bb** @ $\sqrt{s}$ = 8 TeV

NEW!

ATLAS-CONF-2014-011

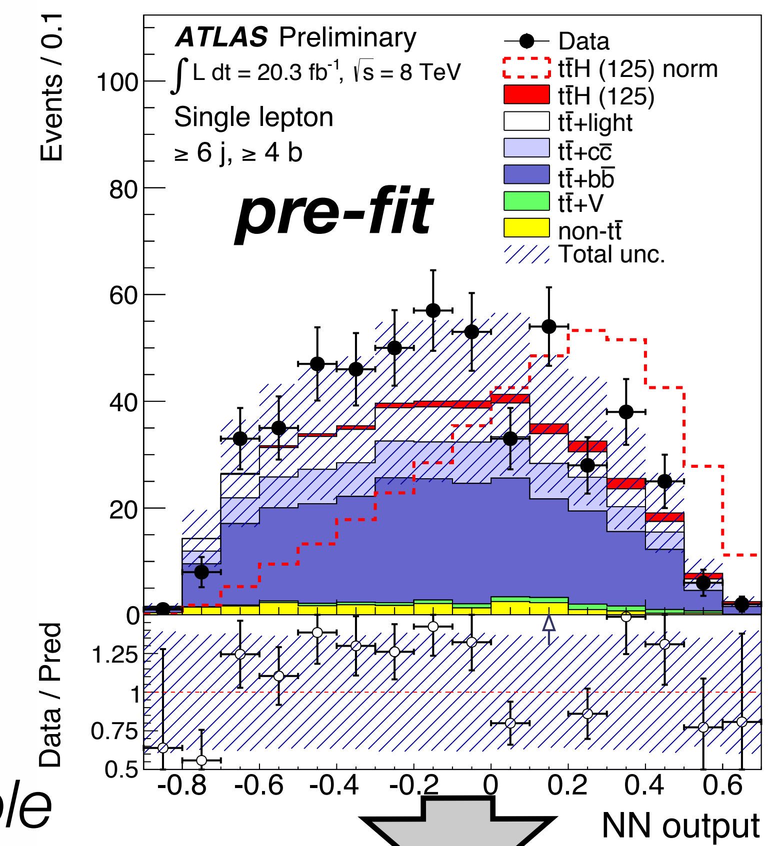
- **Derive likelihood L** for distributions of all discriminating variables **in all (15) regions** in the signal (ttH)+ background hypothesis

product over all bins

$$\mathcal{L}(\text{data}\,|\,\mu,\theta) = \text{Poisson}\,(\,\text{data}\,|\,\mu\cdot s(\theta)+b(\theta)\,)\cdot p(\tilde{\theta}|\theta)$$

$\mu=\sigma_{obs}/\sigma_{SM}$

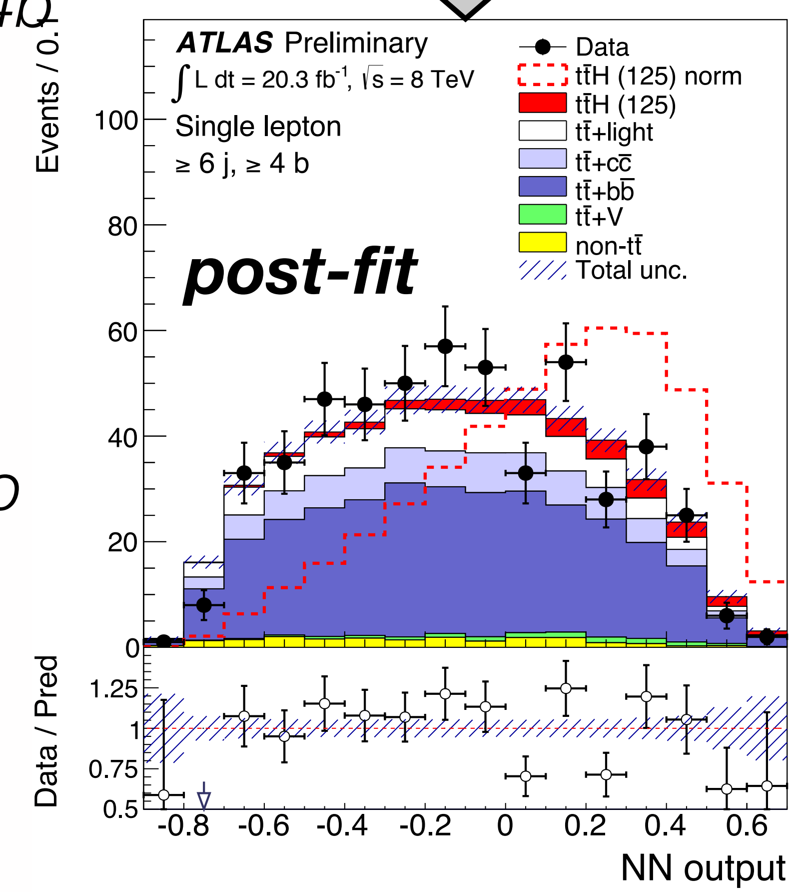
  - $\tilde{p}(\theta|\theta)$: Gaussian or log-normal distributions for nuisance parameters → effect of syst uncertainties



- **Maximize global L versus μ, *θ* →extract signal strength μ_{fit}, θ_{fit}** i.e. constrain syt uncertaintie and bkg normalization (b(*θ*))

example in 6j,4b

- Consistent single lepton and dilepton results. **Uncertainty reduced by factor 5-6 in most sensitive regions**



signal normalized to fitted μ

- Main syst uncertainties:
  - jet energy scale
  - b-tagging efficiency
  - **modelling of tt+jets bkg** (data-reweighting, hadronization,generator)

Search for ttH, H→bb @ $\sqrt{s}$ = 8 TeV

NEW!

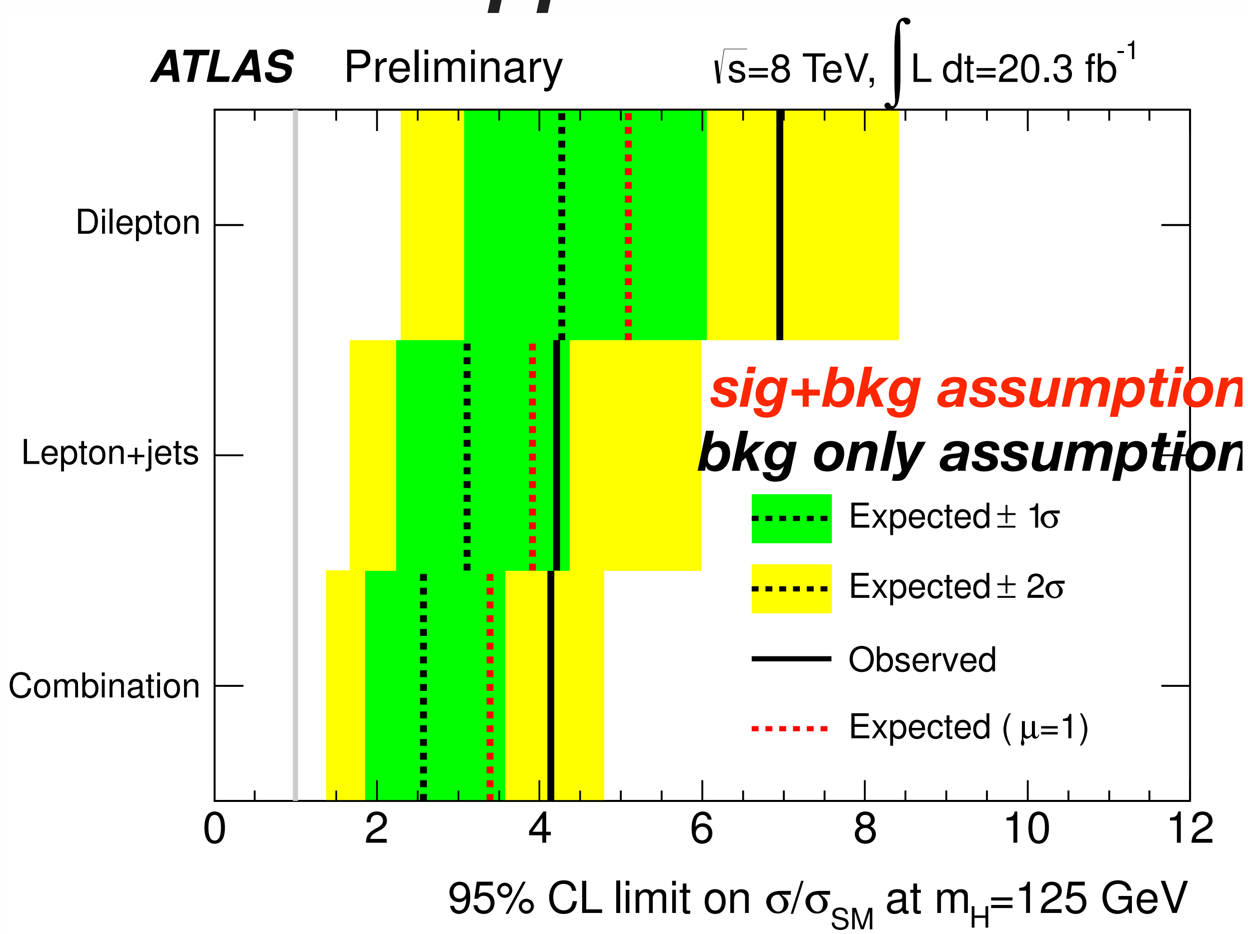
Given model for probability distributions for signal, bkg, systematic uncertainties (det⊗theory) build **likelihood-based variable f(μ) to**

- in the bkg only hypothesis (μ=0), **derive** the probability to observe a more discrepant f-value than the observed one → **test bkg hypothesis**
- in the sig+bkg hypothesis, **derive [0,upper limit] interval** that covers the "true" **μ** value 95% of the times→ **test signal hypothesis**

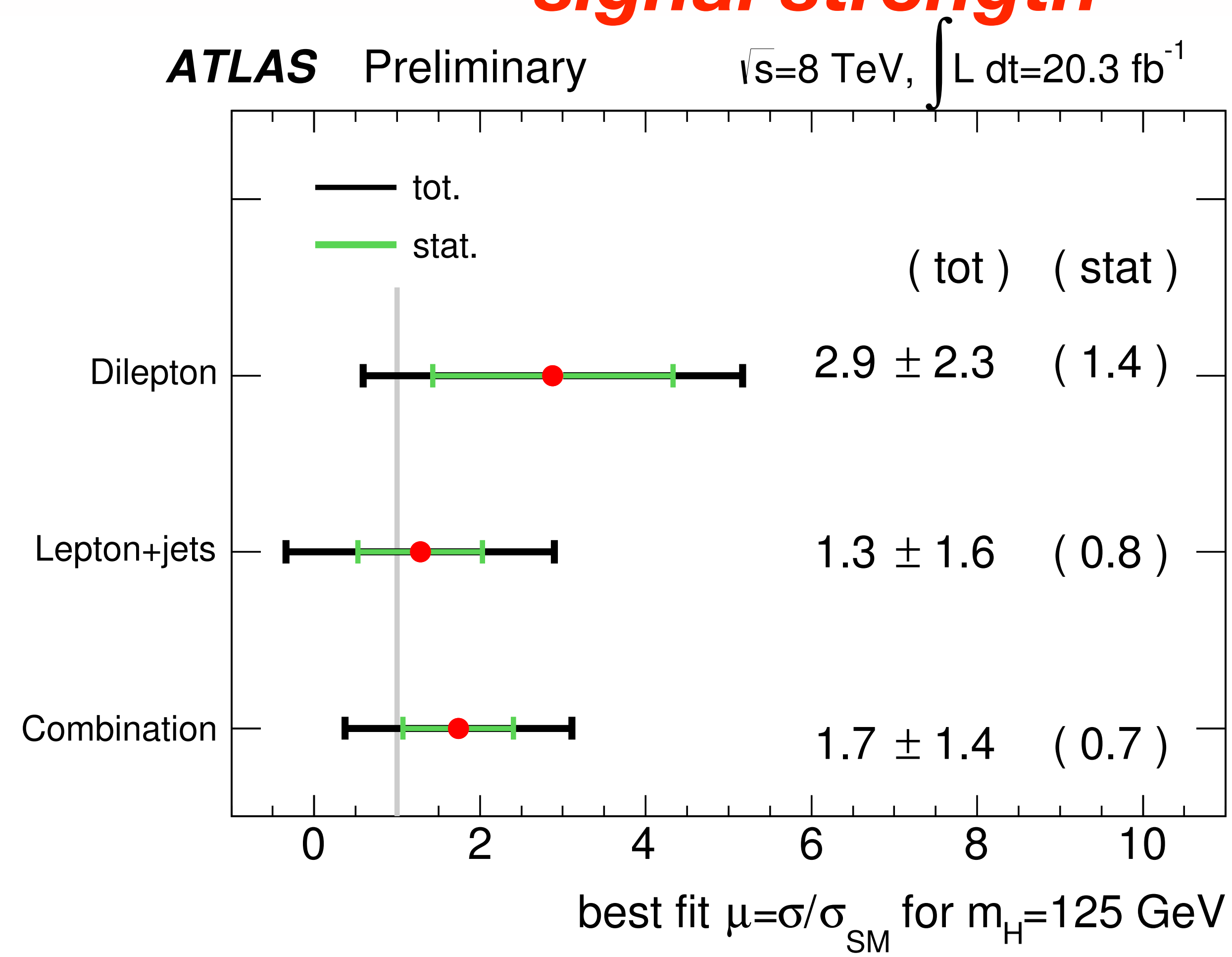
- Estimate **signal strength** from maximum likelihood fit

ATLAS-CONF-2014-011

upper limit



signal strength



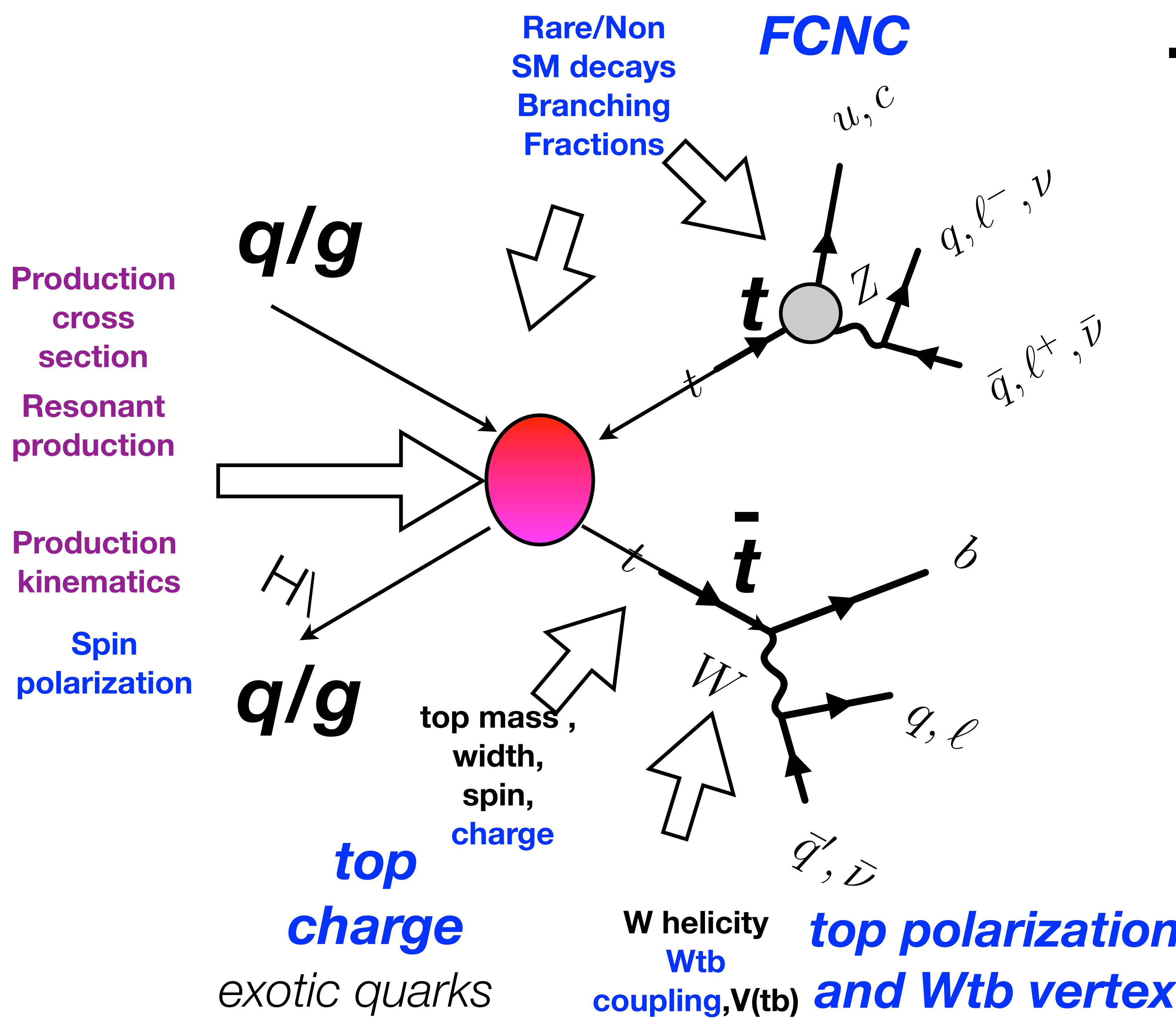
95% CL Observed (Expected) upper limit 4.1 (2.6)x SM, μ_{best}= 1.7 ± 1.4

Top and New physics

Top quark as a window on new physics

inspired by figure
by D Chakraborty

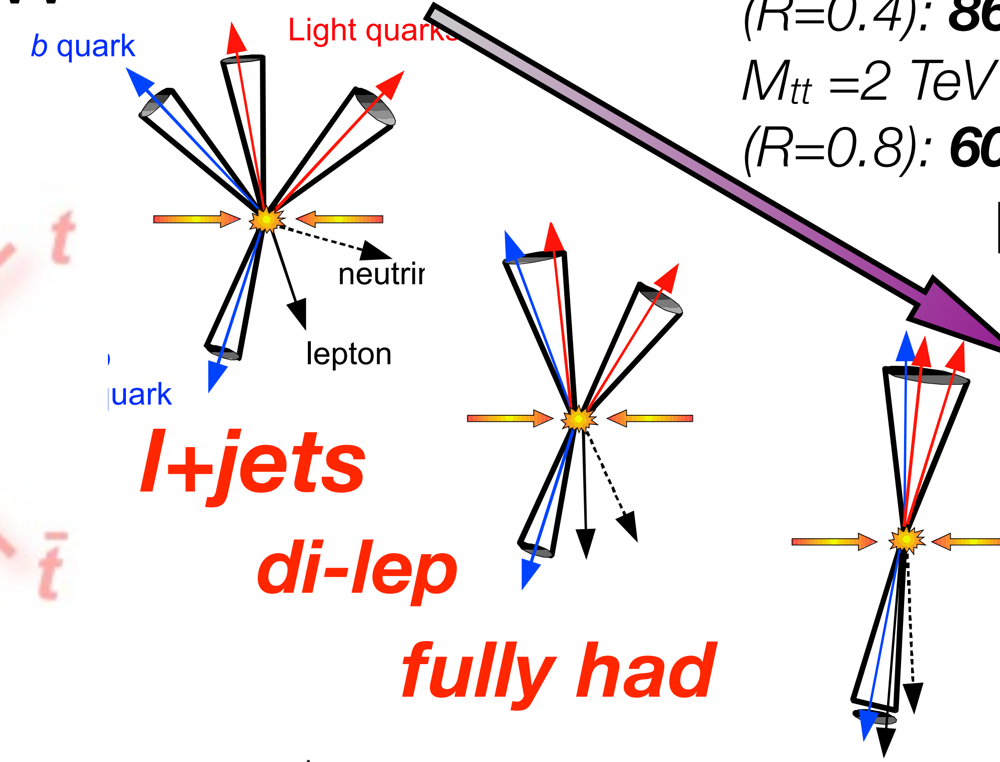
TODAY



i.e.
Beyond the Standard model

Top **production** as a window on new physics

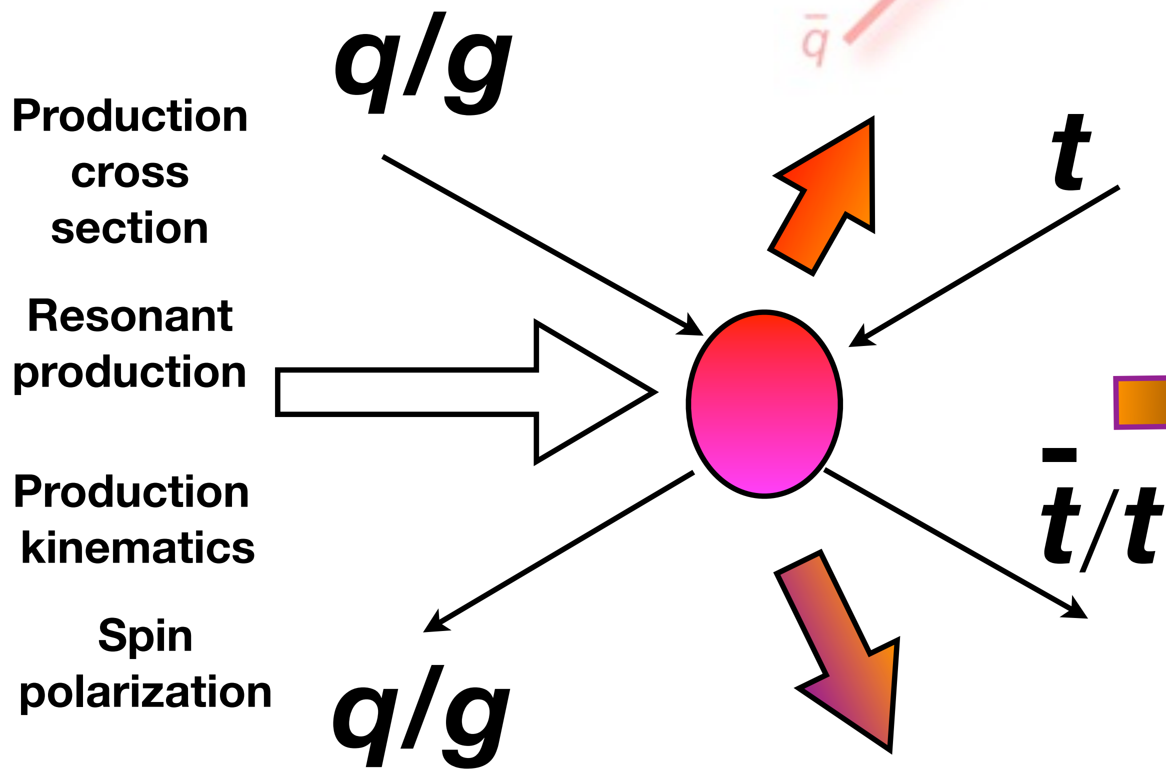
by no means exhaustive list of models!

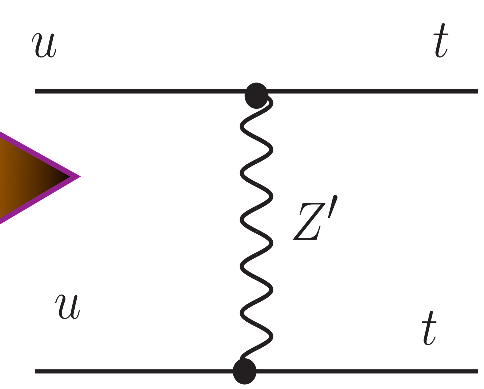


*M_{tt} =1 TeV & anti-k_T (R=0.4): **86% resolved***

*M_{tt} =2 TeV & antikt (R=0.8): **60% boosted***

For ΔR=0.8, M_{tt} ~1.7 TeV, P_T ~600 GeV



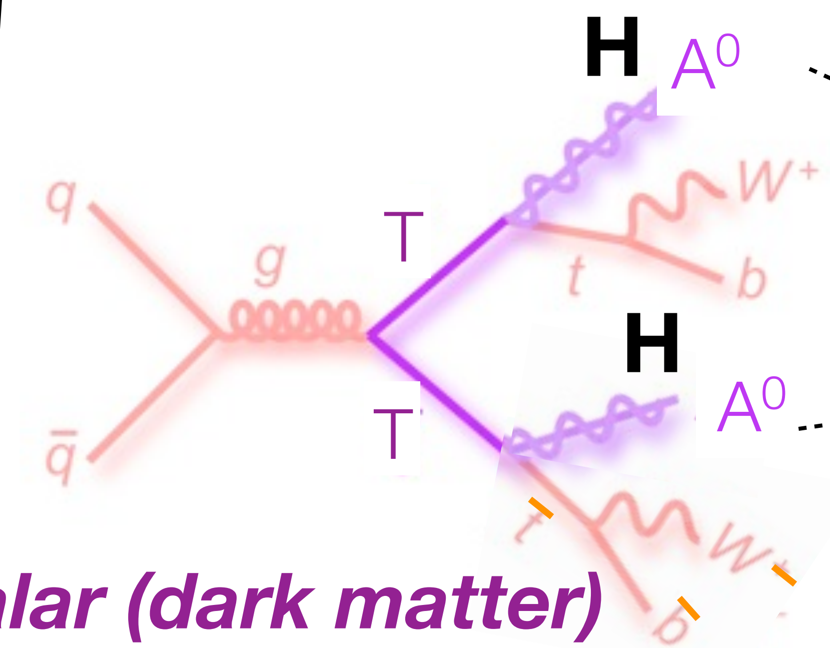


t/t̄ charge asymmetry

color octect vector, color singlet Z’, color triplet scalars

Same sign top pair

4th gen, FCNC, left-right symmetric, higgs triplets, SUSY, UED, little higgs



tt+jets/E_T^{miss}

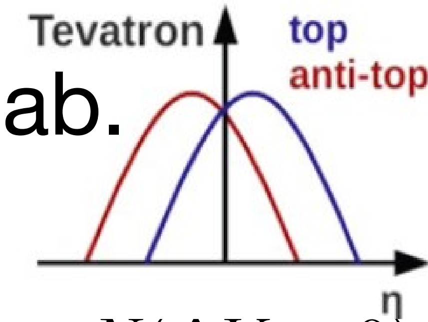
exotic 4th gen, leptoquarks, stop →top +neutralino, UED, little higgs,

top partner + stable scalar (dark matter)

Measure top quarks charge asymmetry

- In pp/p$\bar{p}$→t$\bar{t}$: **t/anti-t** have **different** differential distributions (from pQCD). NLO effect in q$\bar{q}$ /qg→tt/t$\bar{t}$g: interference of amplitudes that are ***relatively odd*** under t ⇔ anti-t exchange.

- **At Tevatron** (q$\bar{q}$~85%) it manifests as FB asymmetry in lab.



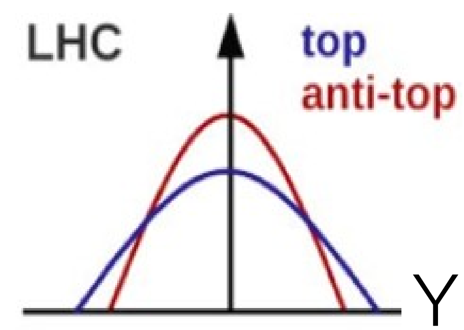
- ***Observe some tension with SM (CDF somewhat higher than expected)***
Interference of SM gluon with new phys?

$$A_{FB} = \frac{N(\Delta Y > 0) - N(\Delta Y < 0)}{N(\Delta Y > 0) + N(\Delta Y < 0)}$$

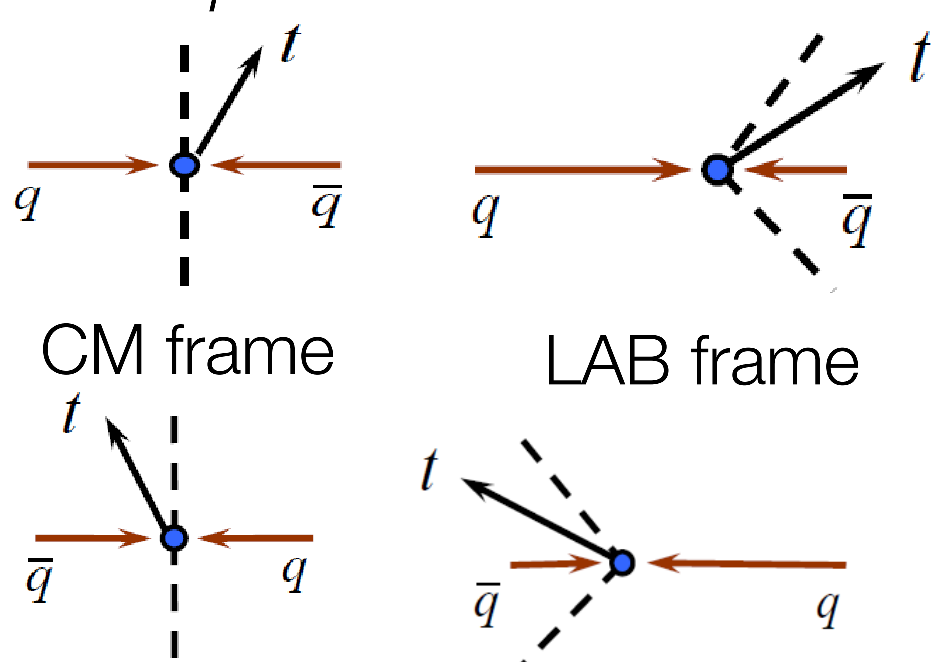
where $\Delta Y = Y_t - Y_{\bar{t}}$

- **At LHC** A_{FB} = 0. Charge asymmetry ⇔ ***t*** emitted along ***q*** direction.

- As generally z(**q**) > z(**anti-q**), **t is more forward than anti-t in LAB frame** *z = proton momentum fraction*



t/anti-t figures by K.Suruliz (U Sheffield)



$$A_C = \frac{N(\Delta|Y| > 0) - N(\Delta|Y| < 0)}{N(\Delta|Y| > 0) + N(\Delta|Y| < 0)}$$

where $\Delta|Y| = |Y_t| - |Y_{\bar{t}}|$

$$A_C^{SM} = 0.0123 \pm 0.0005$$

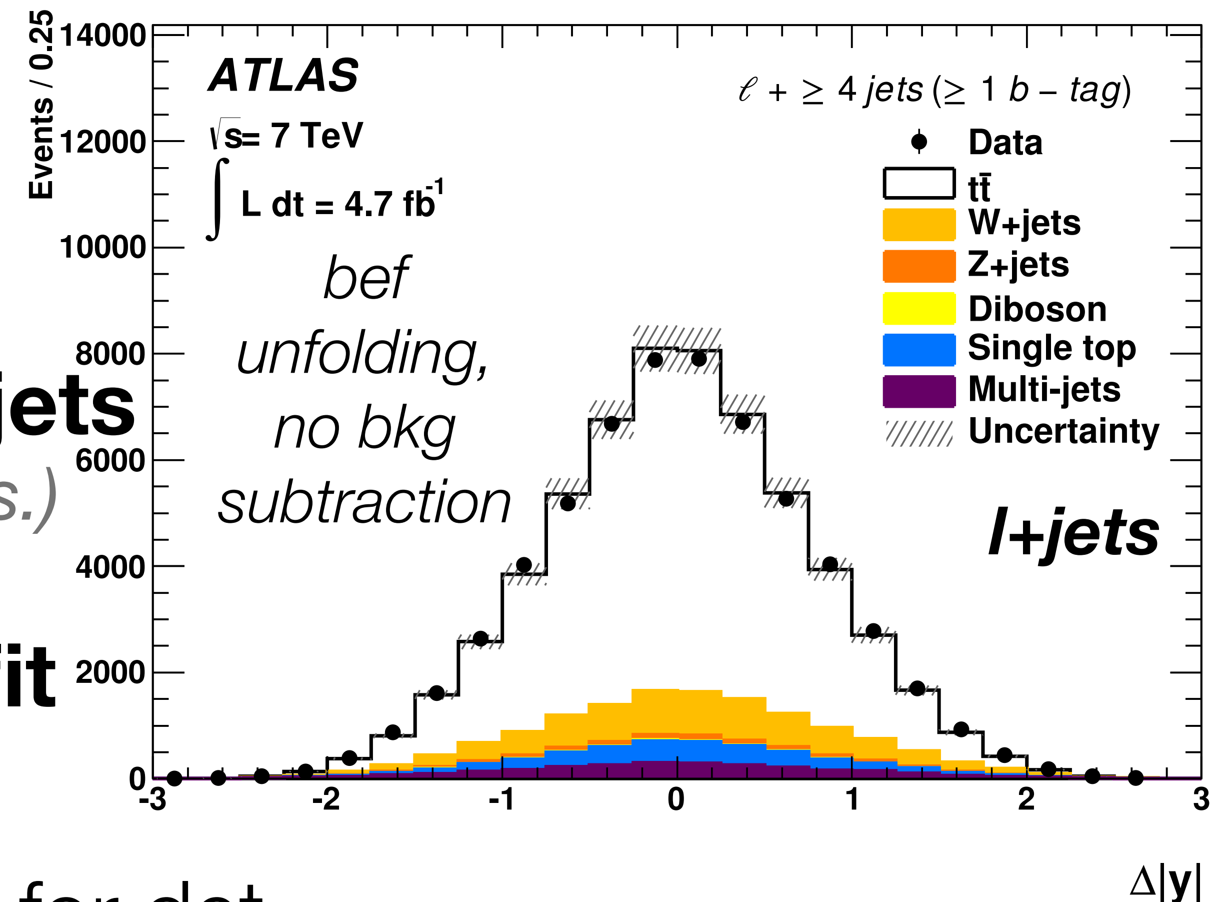
Measure top quarks charge asymmetry

$\int L dt$ = **4.7 fb^{-1}** *(2011)*

$qq\ell\nu bb$

JHEP02(2014)107

- **Standard single lepton selection**
  - *good quality objects, 1 lepton, cuts on E_T, m_T^W, ≥4 jets, at least 1 b-tagged jet*



- Data-driven **QCD** (*matrix method*), **W+jets normalization** (*from W asymmetry meas.)*

- **Reconstruct $t\bar{t}$ with kinematic lkl fit** *(m_{top},m_W constraint)* → Δ|Y| distribution

- **Subtract bkg and unfold** dN/dΔ|Y| for det effects *(regularized "Bayesian" unfolding):* → **derive A_C**

$$p(\mathbf{T}|\mathbf{D},\mathcal{M}) \propto \mathcal{L}(\mathbf{D}|\mathbf{T},\mathcal{M}) \cdot \pi(\mathbf{T})$$

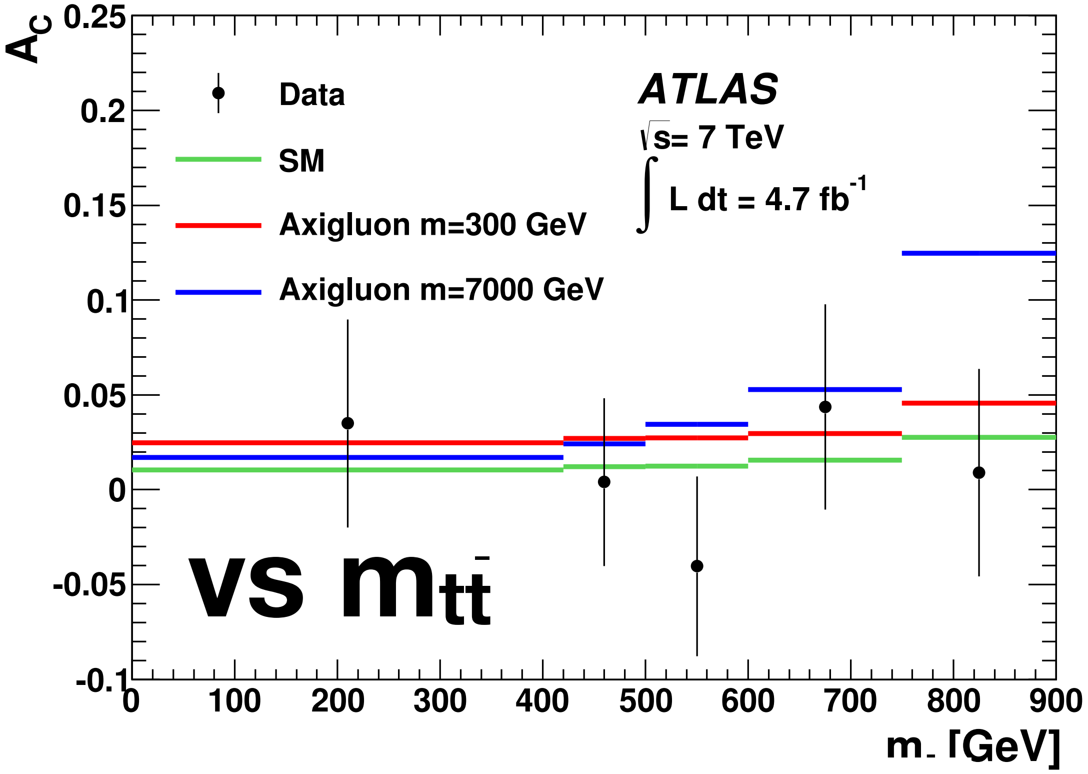
T= spectrum, **D**=data, **M**=migration model, **π**=prior, *flat= no reg,*

- **Combine e and μ chan** ***marginalizing posterior w.r.t. syst***

A_C	Data	Theory
Unfolded	0.006±0.010	0.0123±0.0005
Unfolded with $m_{t\bar{t}} > 600$ GeV	0.018±0.022	$0.0175^{+0.0005}_{-0.0004}$
Unfolded with $\beta_{z,t\bar{t}} > 0.6$	0.011±0.018	$0.020^{+0.006}_{-0.007}$

consistent with SM, *stat dominated ,main syst: JES and lep. en scale & res*

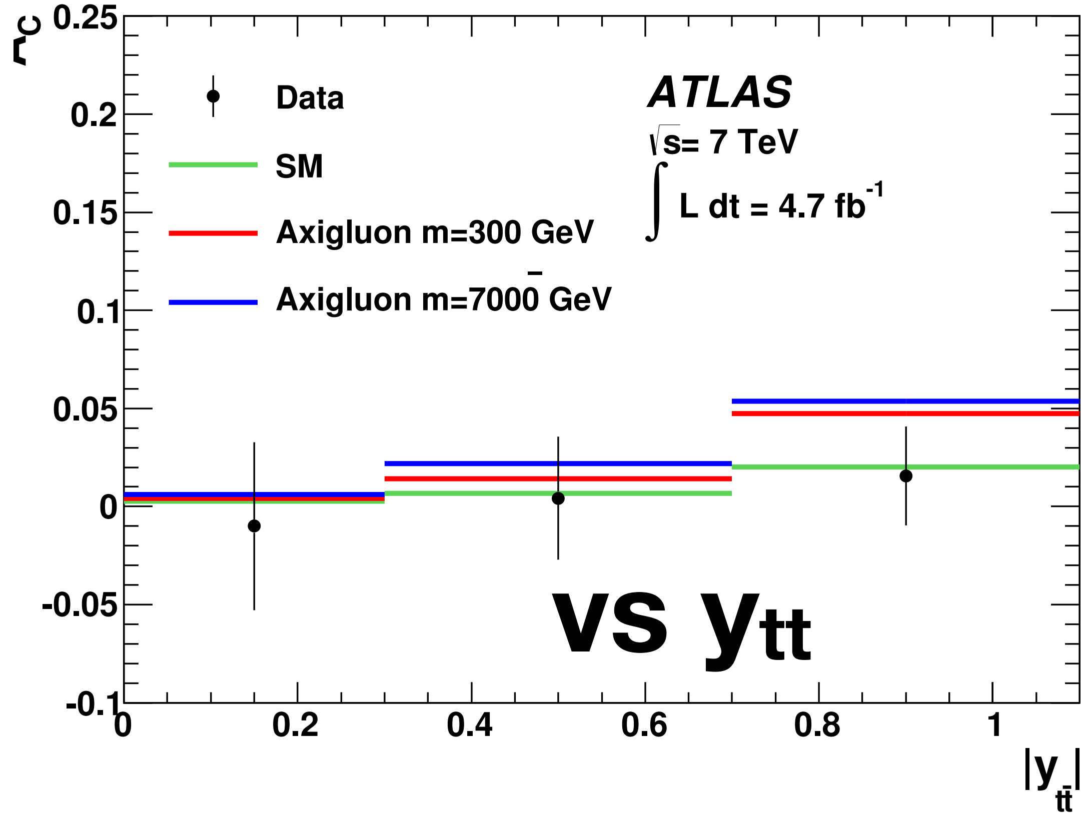
Measure top quarks charge asymmetry

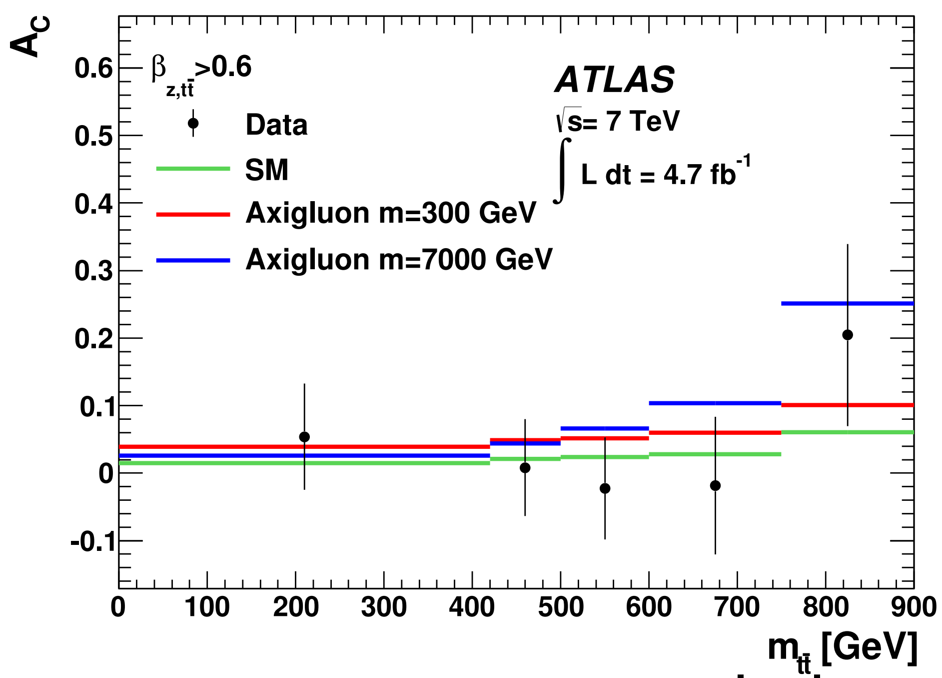


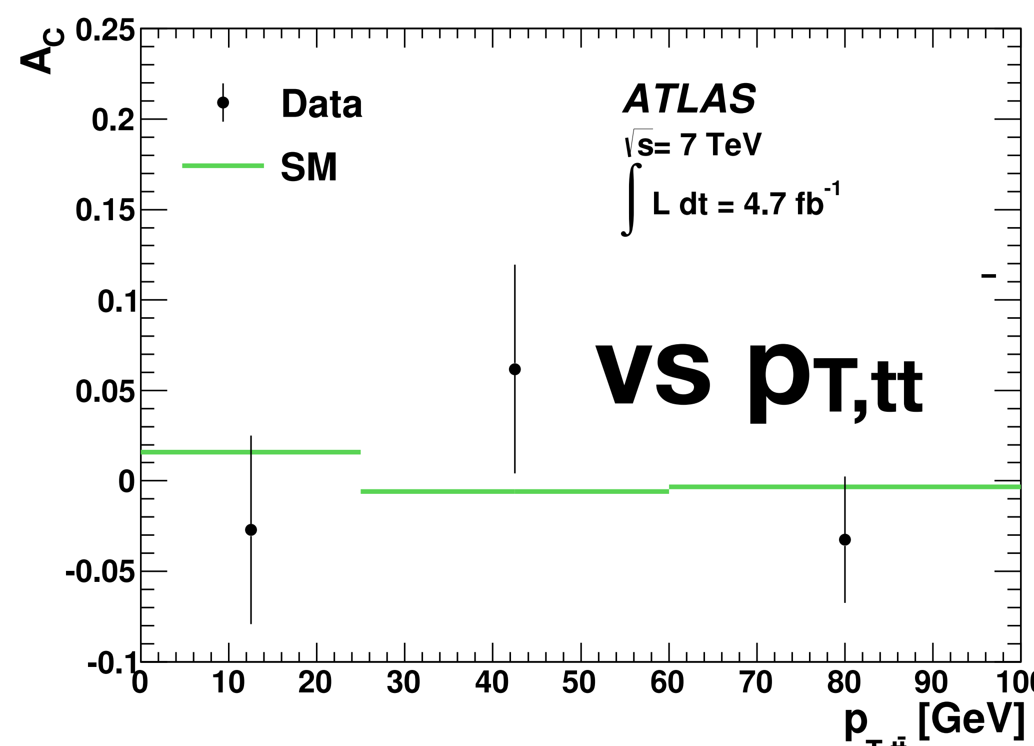
$\int L dt$ = **4.7 fb^{-1}** *(2011)*

JHEP02(2014)107

"unfolded" uncertainties are (dominant) stat + syst (JES, lep en/res)







- **Unfold** 2d (dN/dΔ|Y| , X) with **X=$m_{t\bar{t}}$, $y_{t\bar{t}}$** , *(unregularized)* **$p_{T,t\bar{t}}$,** *(regularized)* for det effects *for bayesian)* → **derive A_C vs X**
- **No deviation from SM are observed**

LHC combination of charge asymmetry at s=7 TeV

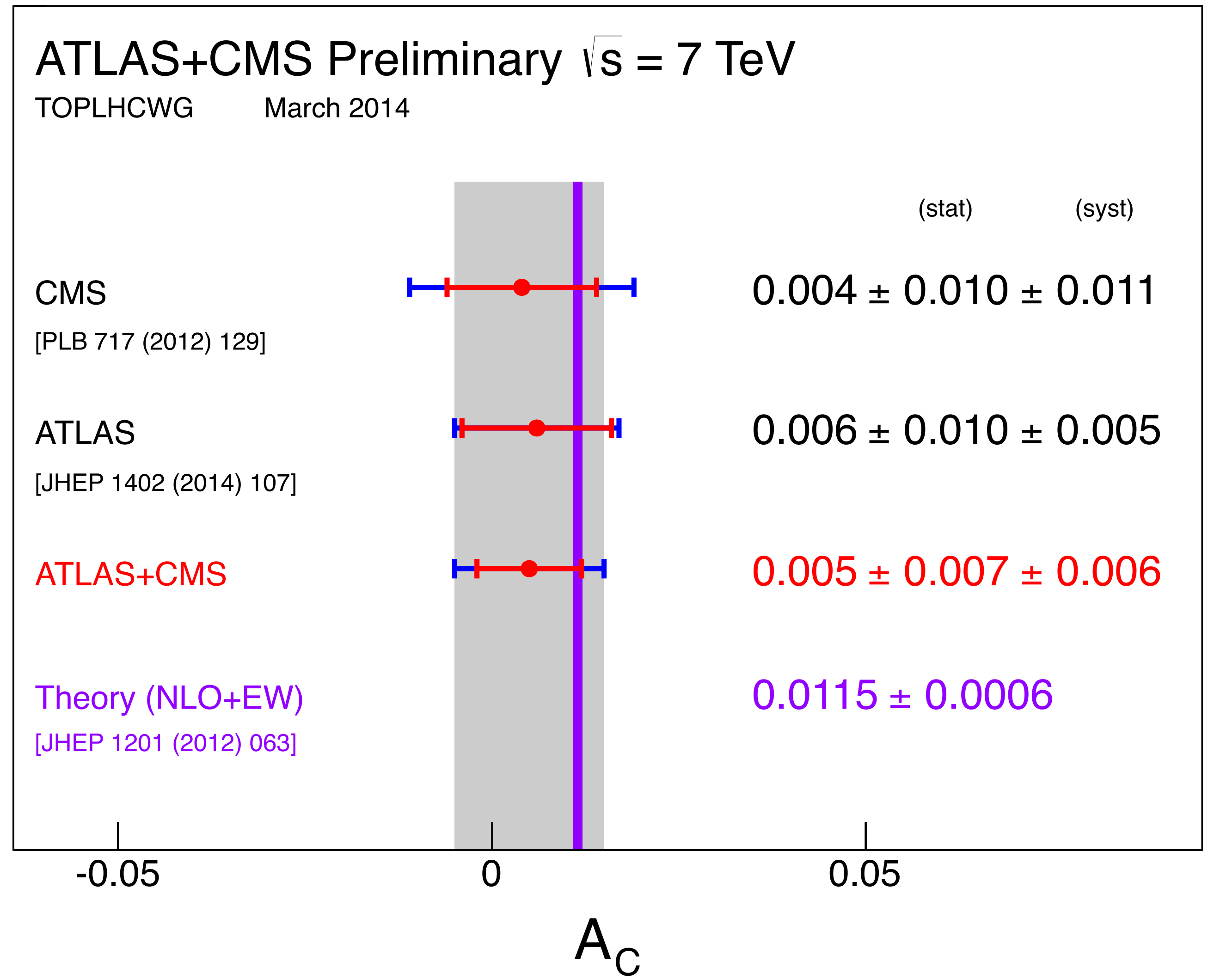
$\int L dt$ = **4.7 -5.0 fb^{-1}** *(2011)* ATLAS-CONF-2014-012

- Two measurements
- l+jets selection
- Full reconstruction of tt topology
- **Unfold Δ|Y| distribution** with different regularized schemes: *bayesian inspired (A), generalized matrix inversion (C)*

A=ATLAS,C=CMS

6% overall correlation

NEW!



- **Combine** with minimal covariance estimator (BLUE) ***including correlations***
  - *1 for PDF and tt modelling,0.5 for W+jets model, 0 for the rest)*
  - **Marginalization: no unique uncertainty decomposition→ don't use marginalized ATLAS result, but syst from change in mean posterior for each source**

- **Results are stable for different correlation scenarios** *(individual corr. changes, simultaneous scaling of correlated values)*
- Stat ~ Syst

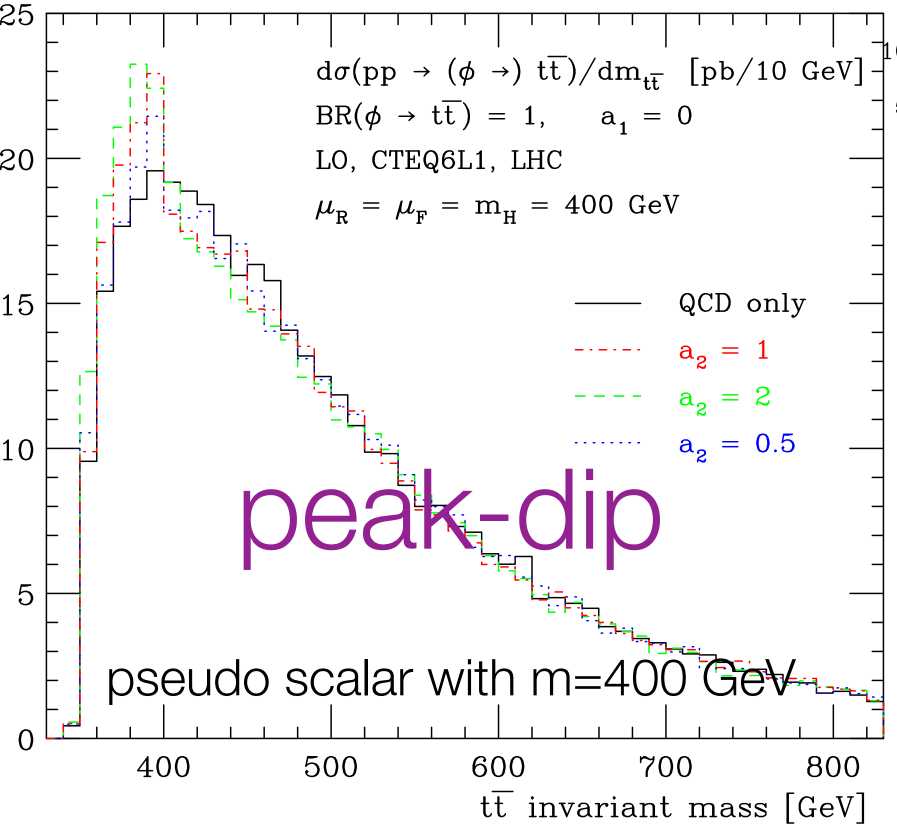
New physics in m_{tt}

one peak

Z' or
new strong bosons

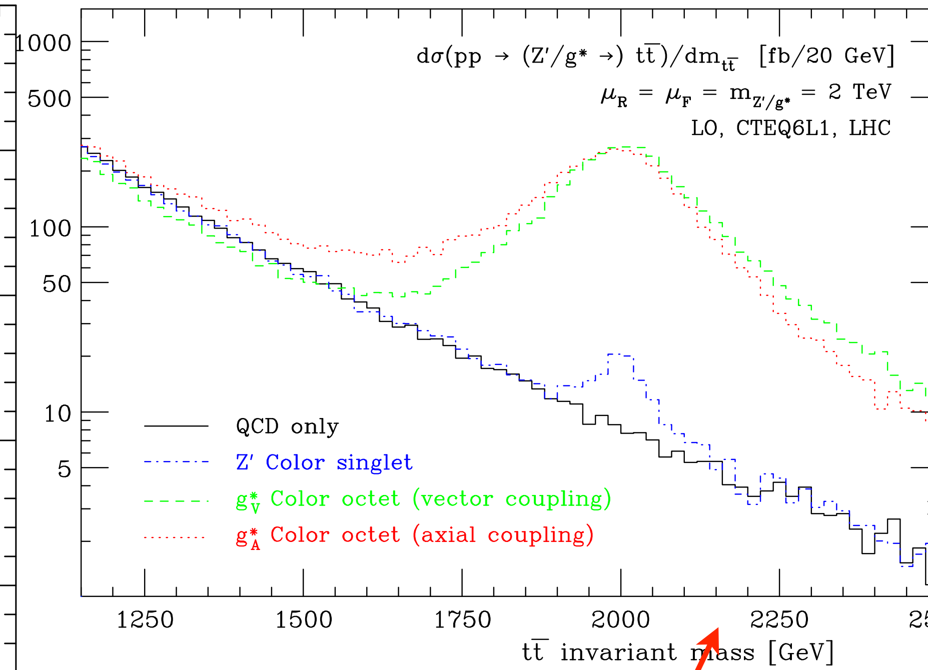
enhancements

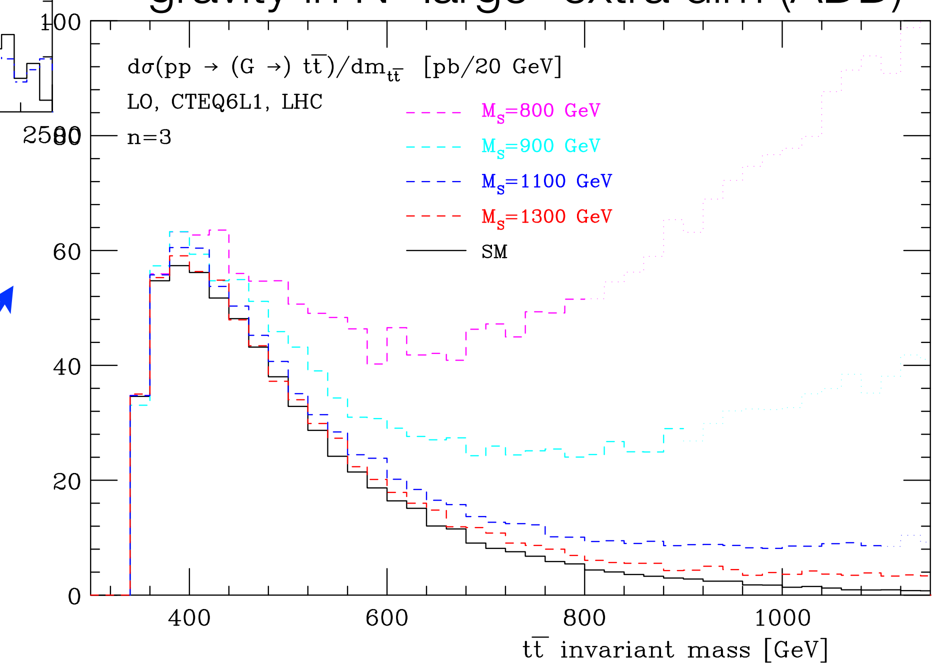
tower of degenerate KK gravitons ; only gravity in N "large" extra dim (ADD)



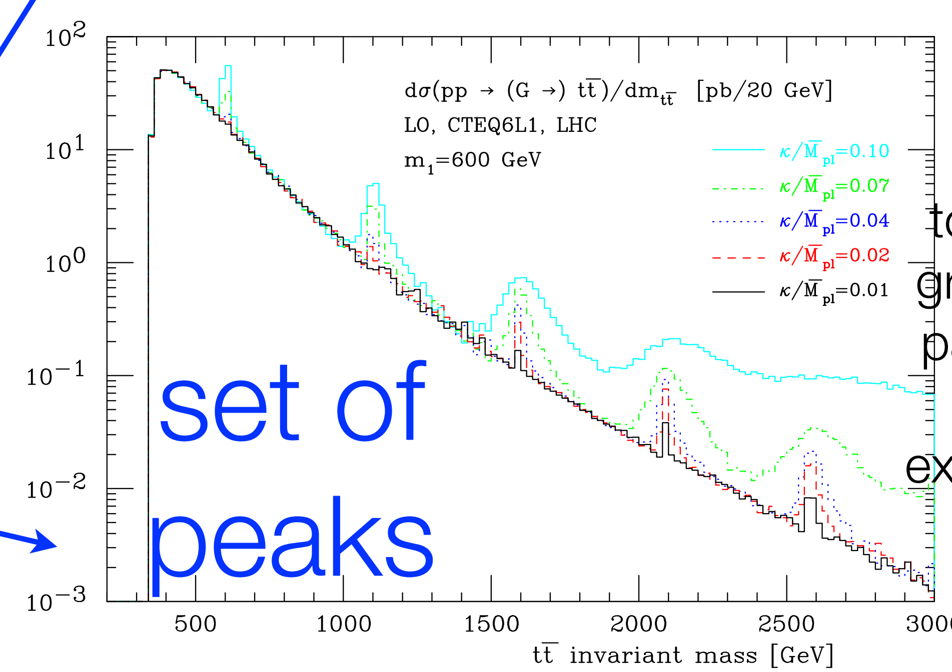
peak-dip

pseudo scalar with m=400 GeV





Spin	color	parity $(1, \gamma_5)$	some examples/Ref.
0	0	(1,0)	SM/MSSM/2HDM, Ref. [51, 52, 53]
0	0	(0,1)	MSSM/2HDM, Ref. [52, 53]
0	8	(1,0)	Ref. [54, 55]
0	8	(0,1)	Ref. [54, 55]
1	0	(SM,SM)	Z'
1	0	(1,0)	vector
1	0	(0,1)	axial vector
1	0	(1,1)	vector-left
1	0	(1,-1)	vector-right
1	8	(1,0)	coloron/KK gluon, Ref. [56, 57, 58]
1	8	(0,1)	axigluon, Ref. [57]
2	0	–	graviton "continuum", Ref. [17]
2	0	–	graviton resonances, Ref. [18]



set of peaks

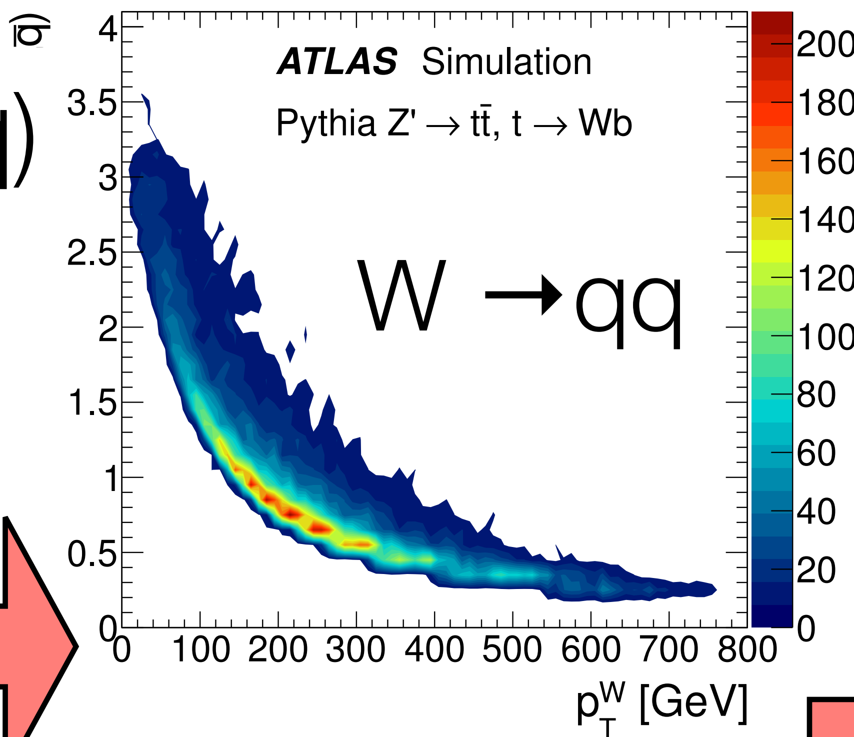
tower of KK gravitons ; all particles in 1 "warped" extra dim (RS)

JHEP 0901:047,2009

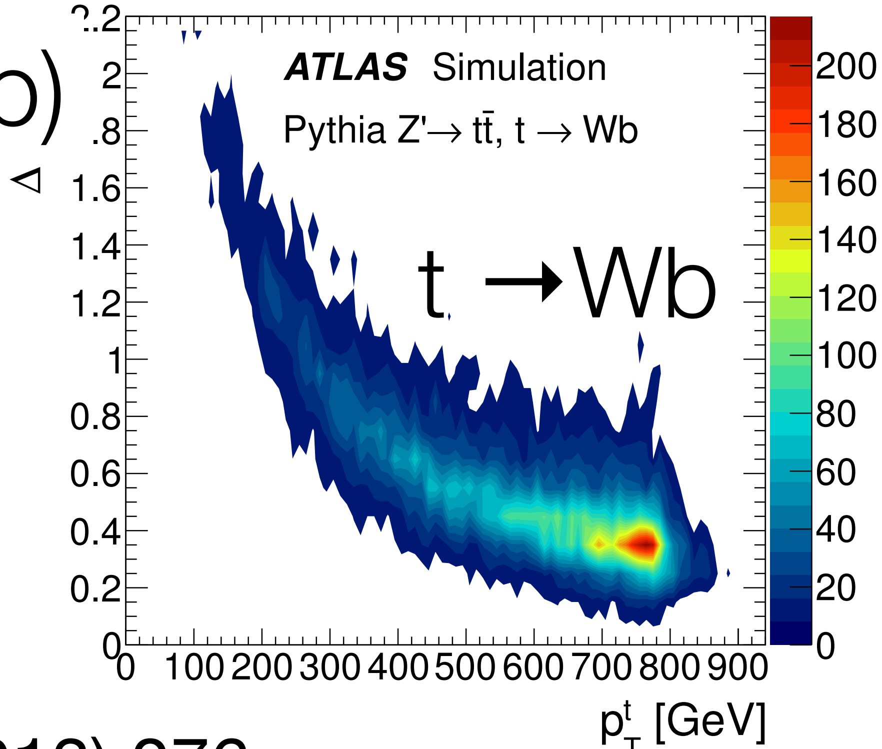
The emergence of boosted tops

$\Delta R(i,j \text{ from } X \rightarrow i,j) \sim 2m_X(i,j)/p_{T,X}$

ΔR(q,q)



ΔR(W,b)



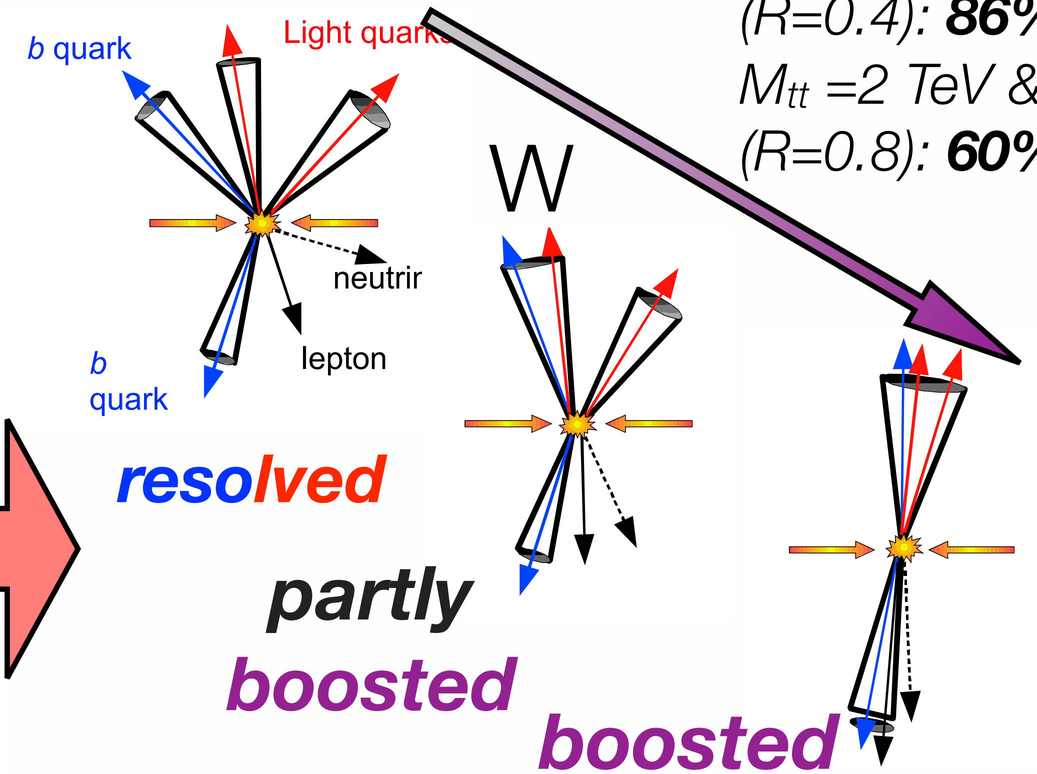
Reduced efficiency for "resolved" reco

M_{tt}

P_T^{Top}

*M_{tt} =1 TeV & anti-k_T (R=0.4): **86% resolved***

*M_{tt} =2 TeV & antikt (R=0.8): **60% boosted***



For ΔR=0.8, M_{tt} ~1.7 TeV, P_T ~600 GeV

*Need to **distinguish top-jet from light q-, gluon**-initiated jets: **di-jets** bkg **overwhelming** fully had tt decays*

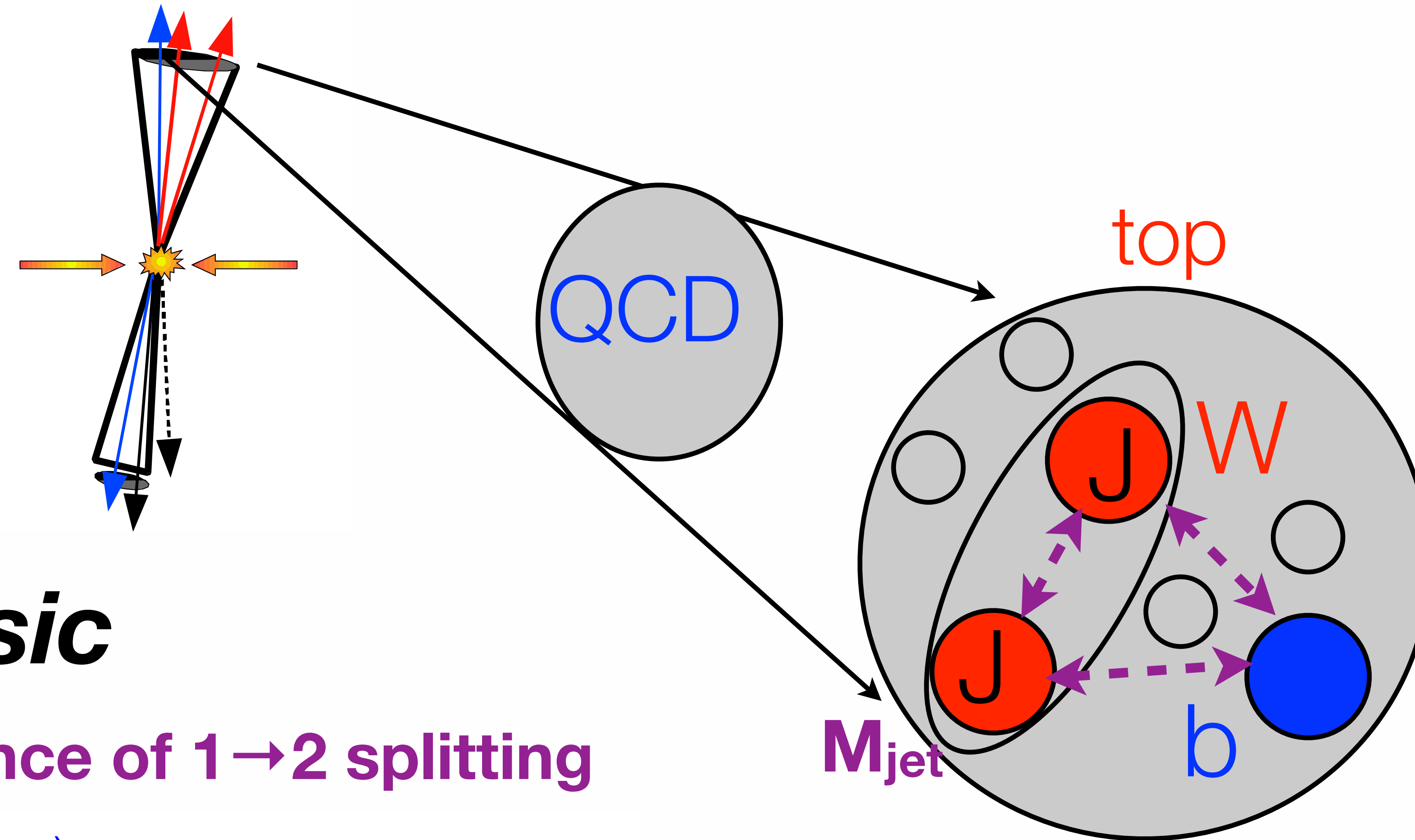
Pile up & soft activity degrade identification & energy estimate

JHEP 1309 (2013) 076

How **to tag** a boosted hadronic top quark?

Look into the jet substructure

(see Jose Juknevich, TOP2013)



Basic

*Use **jet mass** and* **k_T distance of 1→2 splitting**

- Splitting scales (ATLAS tagger) Butterworth, Cox, Forshaw (hep-ph/021098)
  - Read off k_T scales of the (next-to-)next-to-last clusterings
  - Place cuts on jet mass and splitting scales

Radiation based

Discard soft coherent radiation ("grooming") to reveal boosted objects:redefine jets

Example

- HEPTopTagger Plehn, Spannowsky, Takeuchi, Zerwas (1006.2833)
  - **Mass-drop tagger** divides jet into subjets
  - **Filtering** removes UE/Pileup contamination
  - Choose pairing based on **mass criteria**

Prong/pattern based

Recognize energy pattern in unchanged jet

Example

- Top Template Tagger Almeida et al. (1006.2035)
  - Discriminates heavy jets using their energy distributions
  - Compares the energy flow within a jet with the flow of selecte partonic decays (templates)

How **to tag** a boosted hadronic top quark? (II)

Performance figures of merit

efficiency to tag top jet vs **rejection against light-gluon jet**

sensitivity to energy from superposed collisions (pile-up)

efficiency to **select the top final state** vs bkg

ATLAS-CONF-2014-003

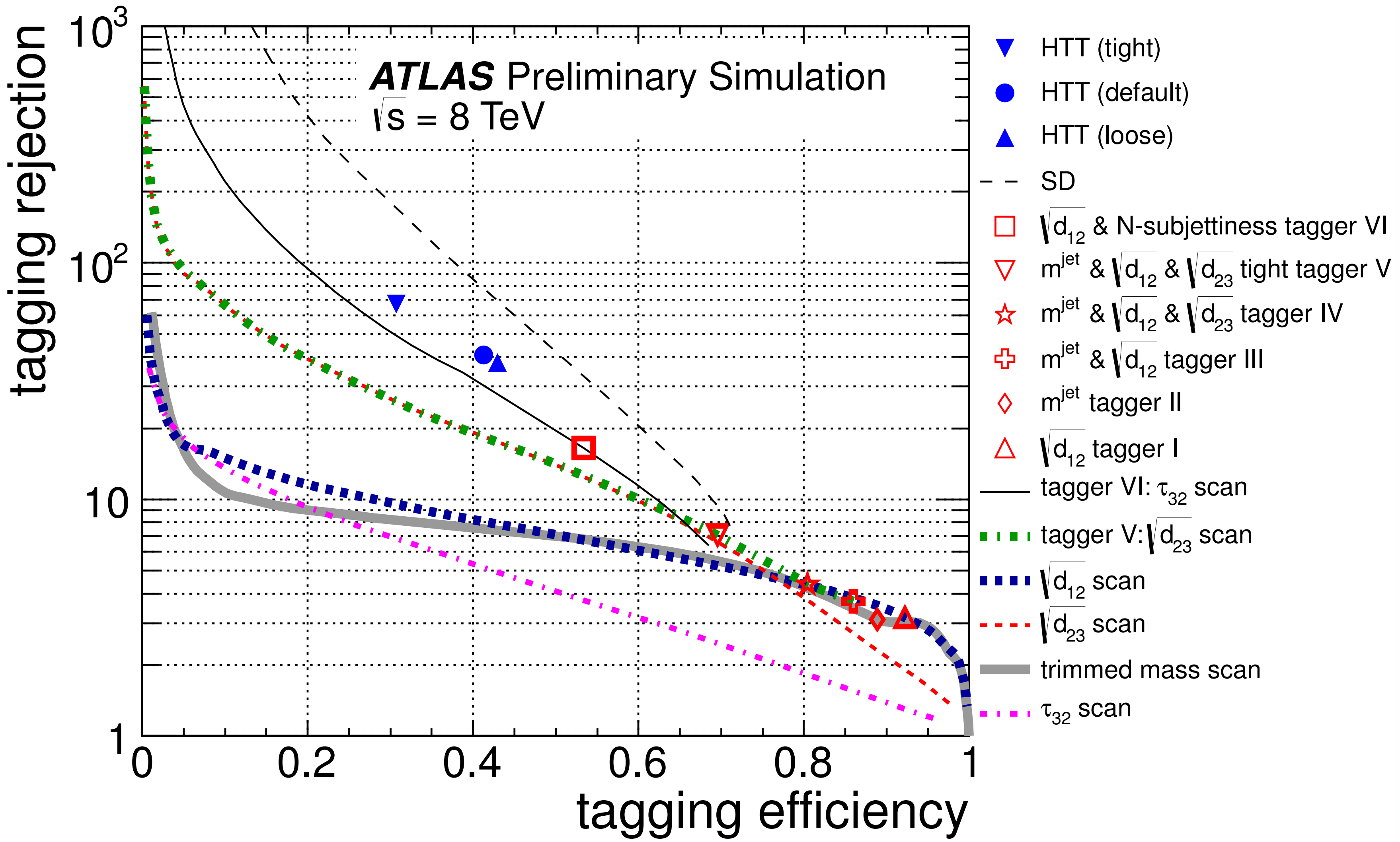


Figure 7: Comparison of expected top jet tagging efficiency and light quark/gluon jet rejection. All substructure taggers and scans use trimmed anti-k_t $R = 1.0$ jets, except the HEPTopTagger (HTT) that uses C/A $R = 1.2$. The same $Z' \to t\bar{t}$, $m_{Z'} = 1.75$ TeV signal samples and multijet background samples and selection are used for all taggers. Systematic uncertainties are not considered for any of the algorithms.

“Boosted” Search for excess in $t\bar{t}$ production vs $M_{t\bar{t}}$ - *single-lepton*

∫Ldt = **14.3 fb^{-1}** *(2012)* ***√s=8 TeV***

ATLAS-CONF-2013-052

$qq\ell$**νbb**

Resolved selection

- *single lepton trigger*

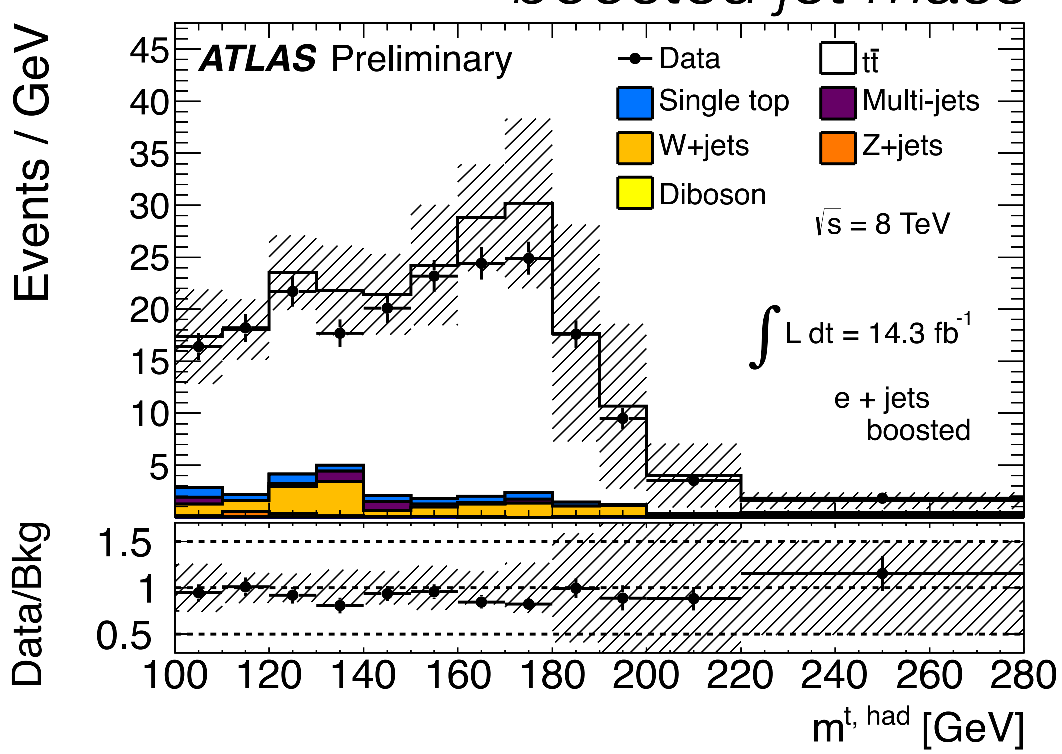
(Fully) Boosted selection

- *trigger on R=1.0 anti-k$_T$ jet with **p$_T$** > 240 GeV (~100% eff > 350 GeV)*

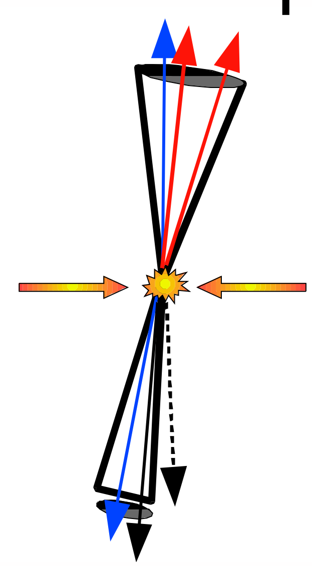
- *exactly* ***1 good, high p$_T$ central lepton (e,) with p$_{T\ dep}$ isolation***

- *≥ 3 (4) good anti-k$_T$ (R=0.4) jets if ≥ 1 (no) jet with m$_{jet}$ > 60 GeV*

boosted jet mass



had top



lep top

- *≥ 1 anti-k$_T$ (R=0.4) jet with ΔR(lep,jet)<1.5,closest jet → **b-jet for leptonic top***

*≥ 1 anti-k$_T$ (R=1.0) jet with **large** ΔR**(jet,jet for** lep **top)** ≥ 1.5, **large p$_T$** ≥ 300 GeV, **large m$_{jet}$**>100 GeV, **large k$_T$ (1 → 2) scale** (> 40 GeV) after shedding soft rad (trimmimg) → **lead “fat” jet is had top***

- ***tops in opposite hemisphere*** *→ Δϕi(lep,had t-jet)>2.3, ΔR(lept b-jet, had t-jet)>1.5*

- *≥ 1 anti-k$_T$ (R=0.4) b-tagged jet*

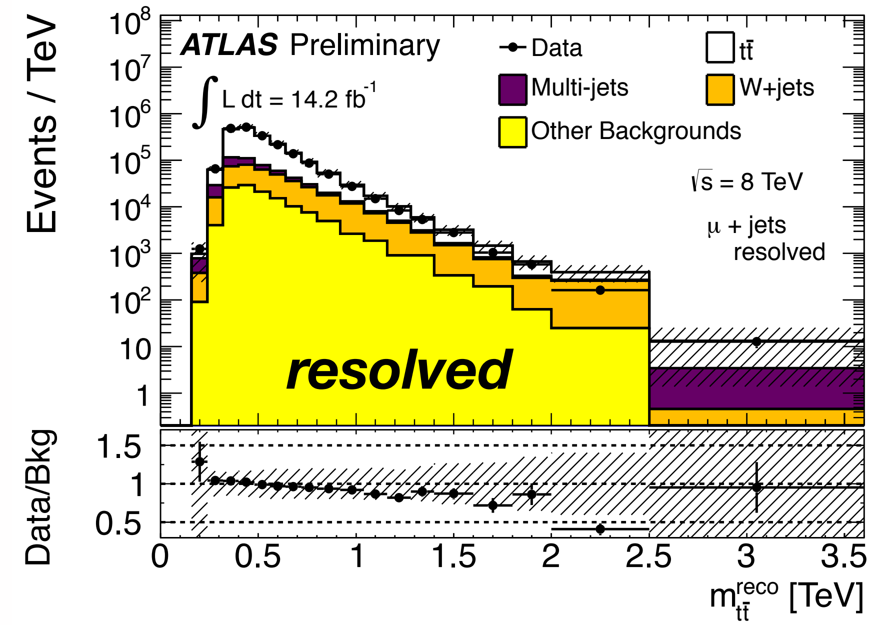
2 exclusive samples: pass boosted , fail boosted & pass resolved

“Boosted” Search for excess in $t\bar{t}$ production vs $M_{t\bar{t}}$ -*single-lepton*

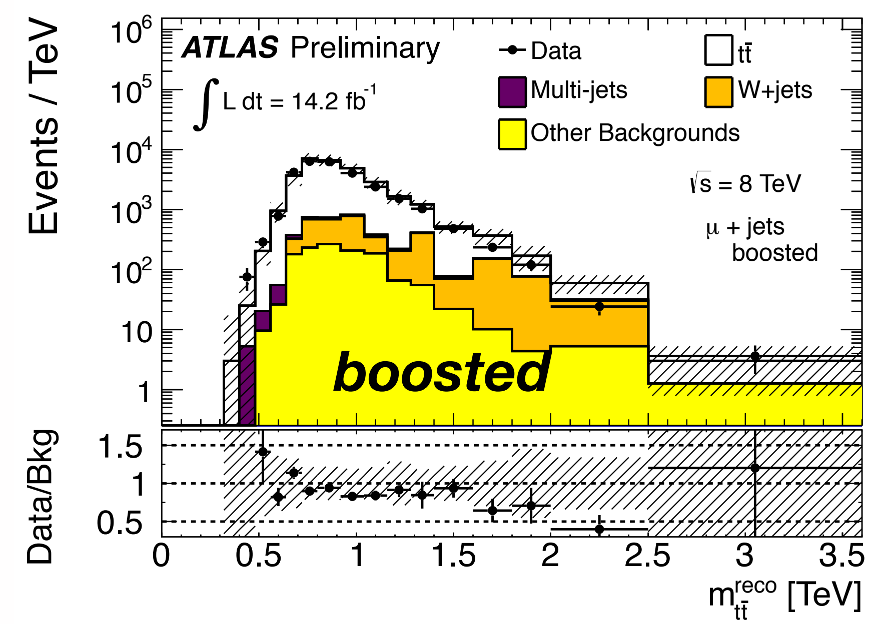
$\int Ldt$ = **14.3 fb^{-1}** *(2012)* $\sqrt{s}$*=8 TeV*   ATLAS-CONF-2013-052

qqℓ**vbb**

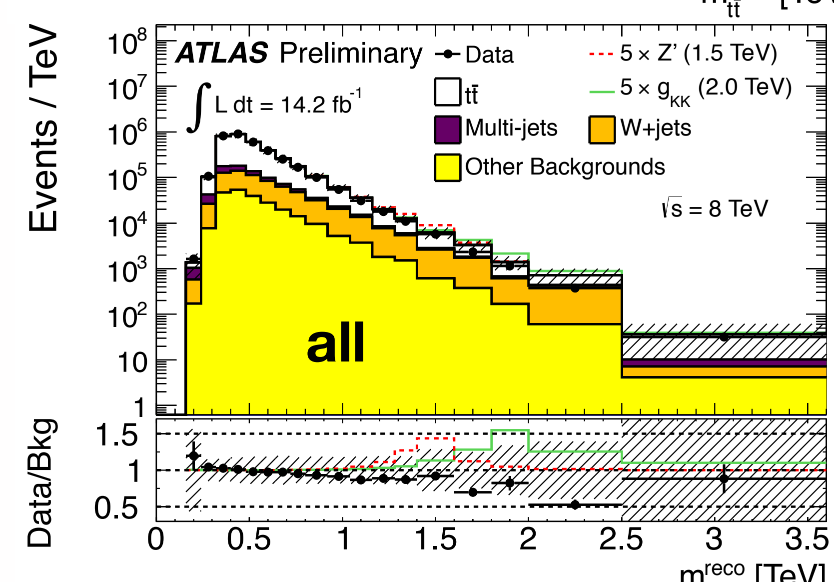
- Data-driven **QCD** (*matrix method, validated in low E_T^{miss} , $m_T(W)$ region, orthogonal to boosted*), **W+jets normalization** (*from charge asymmetry of W production, relaxed p_T , b-tag and **k_T (1 → 2) cuts***)



- **Resolved M_{tt}: sum of top 4-momenta from** four jet assignment, lep and ν with minimal least squared sum, imposing W, top mass and similar $p_{T,top}$ constraints
  - ❖*p_z (ν) from W mass constraint*
  - ❖*all selected jets are used*
  - ❖*if jet with m_{jet} >60 GeV, allow qq and qb merging*



- **Boosted M_{tt}:** from had t-jet + high p_T lepton**,** p_z (ν) from W mass constraint, leptonic b-jet



Search for excess in $t\bar{t}$ production vs M_{tt} -single lepton

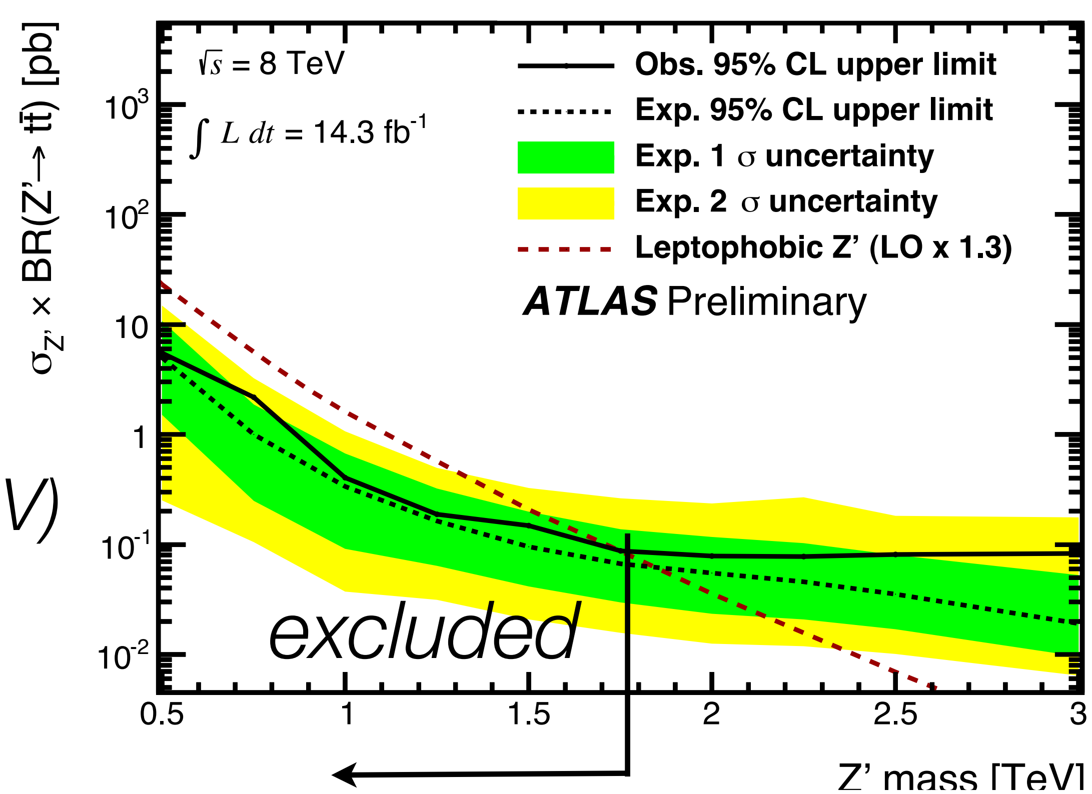
$\int L dt$ = **14.3 fb^{-1}** *(2011)* $\sqrt{s}$=8TeV

ATLAS-CONF-2013-052

- No excess found → **95% upper observed limit (Bayesian credible interval) for Z' & RS KKGluon *σ*BR*. *Combine 4 spectra (2 chan x 2 sel)* including systematics** *as marginalized nuisance pars, flat prior.*

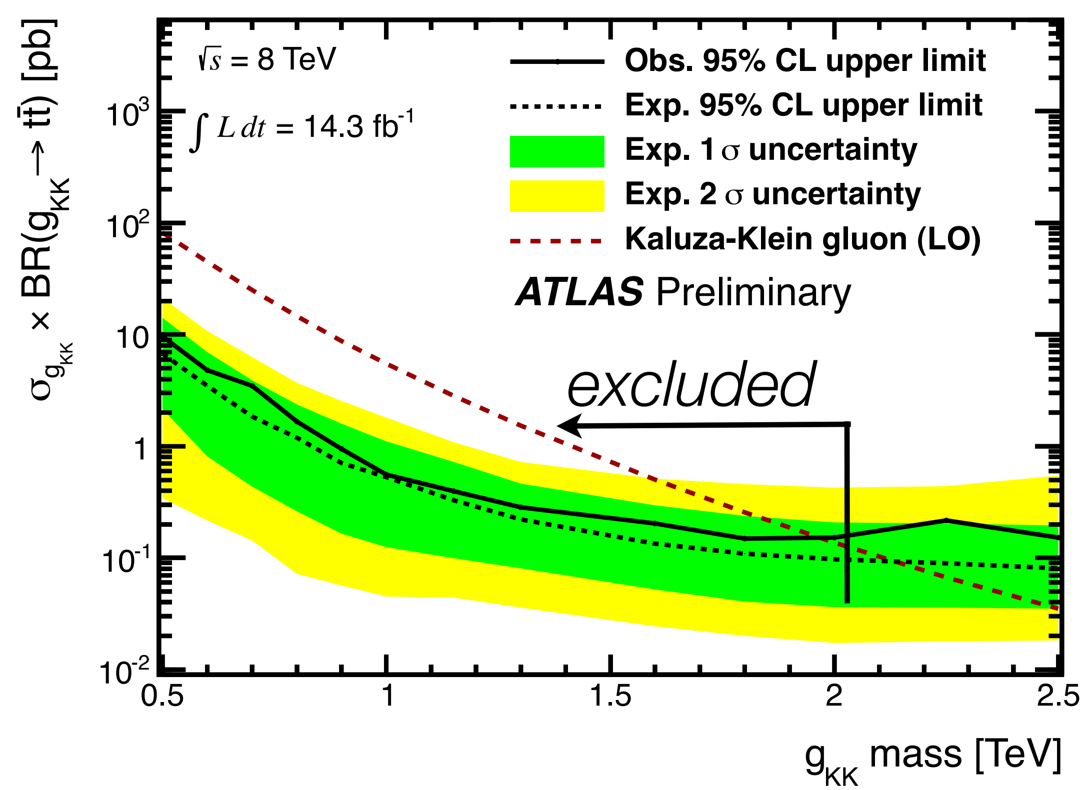
- **Limit on Topcolour Z' *σ*BR* (with $\Gamma_{Z'}/m_Z$ ~ 1%) : 5.3 pb** *($m_{Z'}$=500 GeV)* **to 0.08 pb** *($m_{Z'}$=3 TeV)*

Z' with **500 GeV <$m_{Z'}$ <1.8 TeV are excluded at 95% prob**



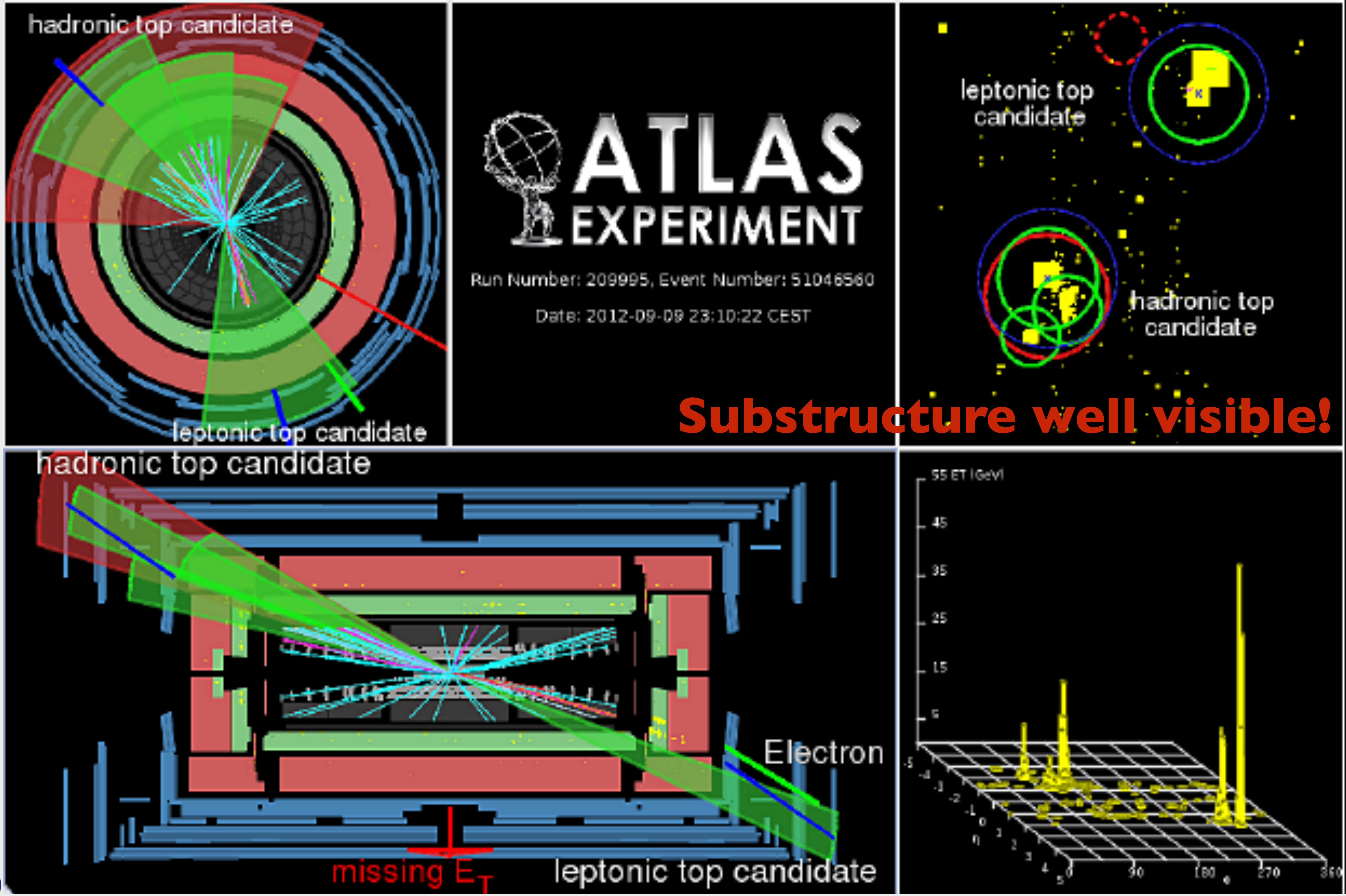
- Limit on **KKGluon *σ*BR* (with Γ_{KKG}/m_{kkG} ~ 15%): 0.56 pb** *($m_{kkG'}$= 1 TeV)* **to 0.15 pb** *($m_{kkG'}$=2.5 TeV)*

KK Gluons with **500 GeV < m_{kkG} < 2.0 TeV are excluded with 95%prob**



Top-tagged Event Display

P. Azzi
(Moriond EWK 2014)



Substructure well visible!

Patrizia Azzi MoriondEWK14 13

putting it all together: **boosted ttH**?

Plehn,Spannowsky, Salam
Phys.Rev.Lett. 104 , 111801 (2010)

p_T reach of Higgs and top quark is definitely larger than their masses →potential for boosted configs

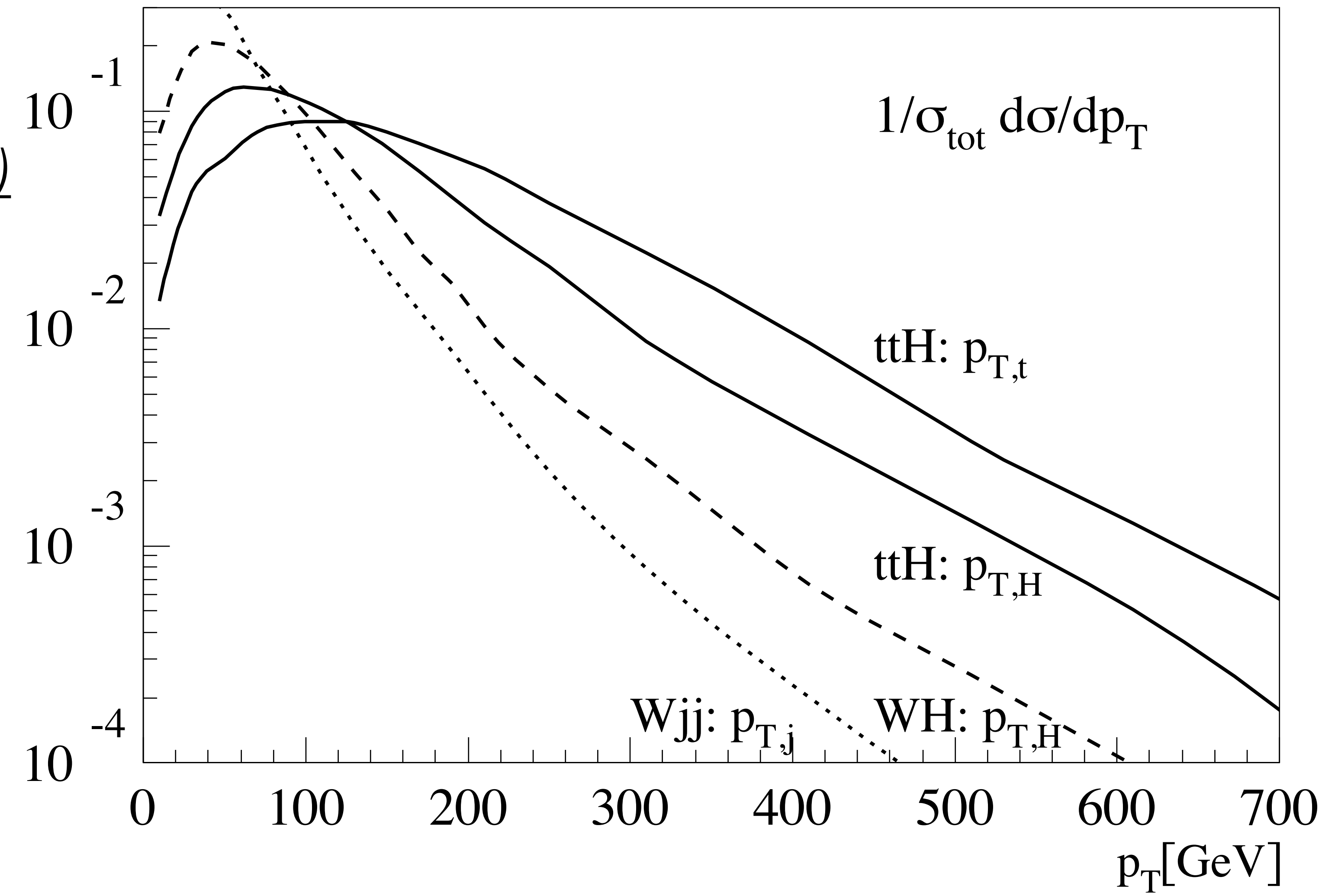


FIG. 1: Normalized top and Higgs transverse momentum spectra in $t\bar{t}H$ production (solid). We also show $p_{T,H}$ in W^-H production (dashed) and the p_T of the harder jet in W^-jj production with $p_{T,j} > 20$ GeV (dotted).

- Cons: lower rates →to be explored in Run2 and beyond
- Pros: much less severe combinatorial bkg, improve $S/\sqrt{B}$

Conclusions

- **Top analysis is in full swing** thanks to the combined performance of LHC & detectors: **a very rich program is under way.**
- *By exploiting the LHC top quark factory* (~6M $t\bar{t}$, ~3M single top events produced by LHC in 2011+2012) **ATLAS is testing top strong and electroweak inclusive production at unprecedented precision**
  - $\delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ ~4.7% compared to ~4% prediction uncertainty (NNLO+NNLL)
  - $\delta\sigma_{t}/\sigma_{t}$ ~12% to 15%: still space for improvement
- **Differential cross sections measurements test SM tt production and complement new physics searches in completely new phase space** with 10% to 50% relative unc. Expect higher reach in Multi TeV region with reduced syst uncertainties, due to parametrization/understanding of more phase space corners & improvement in MC generators (NNLO).
- The **top mass** is measured at 0.83% (ATLAS)/**0.55%**(LHC)/**0.44%**(World) level. Work is ongoing for LHC and LHC-Tevatron combination. Expect sub-GeV precision if progress is made on syst uncertainties exploiting differential info.
- **Direct determination of top** quark **coupling to** the newly found **Higgs** boson is still limited by number of events. Run2 expects observation with high luminosity.
- **New physics** connected to top quark by resonances/asymmetries and top rare decays to HIggs boson **is being searched in previously unexplored TeV/sub pb regions** of mass and cross sections: reach to be extended greatly in multi-TeV region with pile-up mitigation technqiues & improved syst uncertainties

BACK-UP

top properties

Top quark @ LHC: production

pp collisions

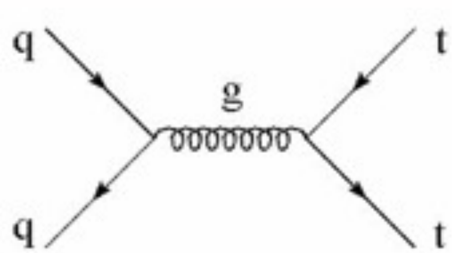
probing lower x than Tevatron →
(abundant) gluon fusion dominated

	Tevatron	LHC(7)	LHC(14)
gg	~10%	**~85%**	~90%
qq	~90%	**~15%**	~10%

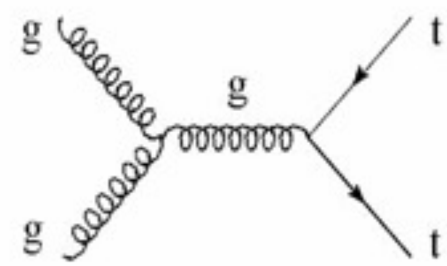
m_{top}= 172.5

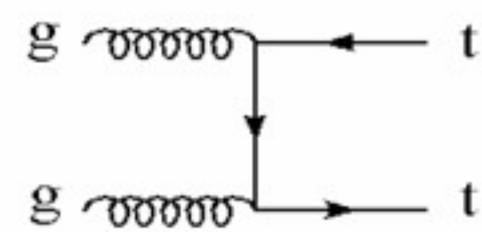
top pairs*: *strong

qq annihilation



gluon fusion





At Tevatron

$\sigma_{t\bar{t}} \sim 7\ pb$
$\sigma_t \sim 3.5\ pb$

Czakon,Mitov,Fiedler 2013

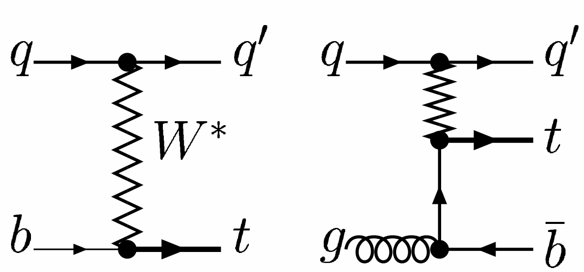
NNLO+NNLL accuracy

$\delta\sigma_{tt}/\sigma_{tt}$ ~4%

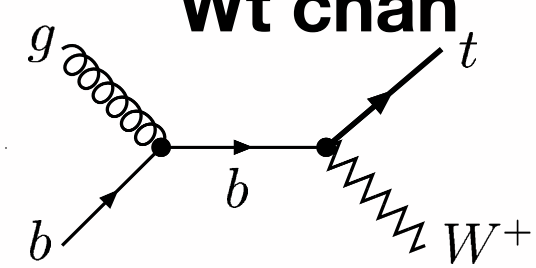
σ_{7TeV} (pb)	$172^{+4.4}_{-5.8}{}^{+4.7}_{-48}$
σ_{8TeV} (pb)	$245^{+6.2}_{-8.4}{}^{+6.2}_{-6.4}$

single top: electroweak

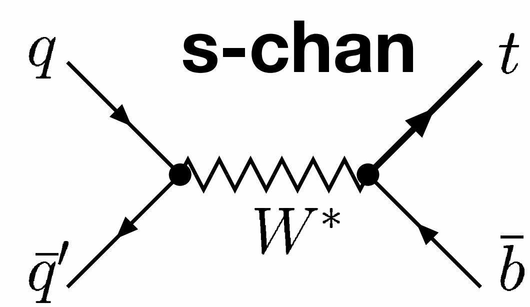
t-chan



Wt chan



s-chan



Kidonakis 2010,2011

approx NNLO
$\delta\sigma_t/\sigma_t$ ~2 to 7%

	t-chan	Wt chan	s-chan
σ_{7TeV} (pb)	64.6±2.4	15.7±1.1	4.6±0.2
σ_{8TeV} (pb)	87.8±3.4	22.4±1.5	5.6±0.2

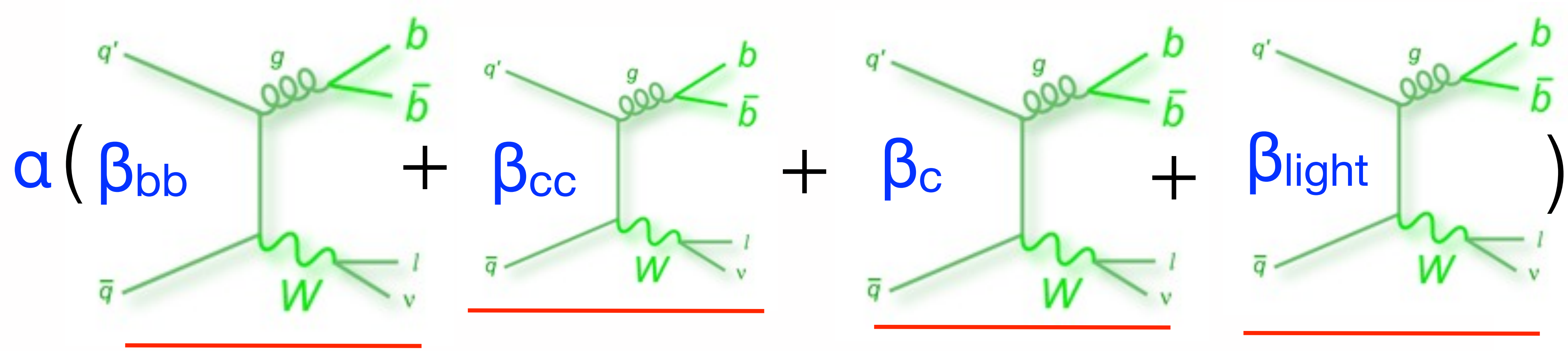
signal and backgrounds

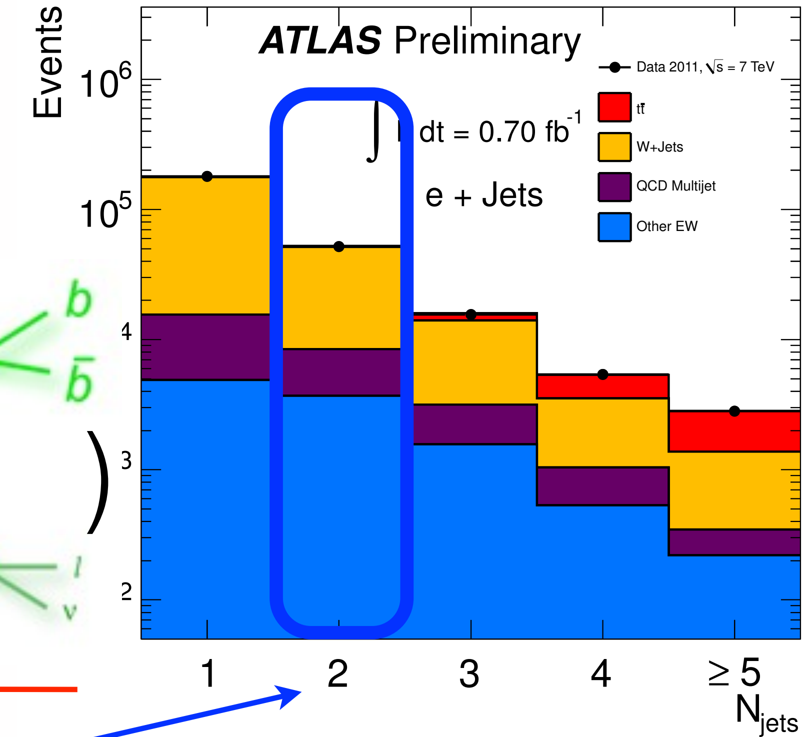
Backgrounds - single lepton+jets - **full scale example**

- ***W+jets***

simulated shapes

data-driven overall norm and flavour fractions





- Iterate: **use events with 1lep + large E_T^{miss} +2 jets to derive α and β_{xx} before b-tagging**
    1. *Derive* α ***as ratio of asymmetric production of W^+ and W^- is well known*** *(more u-quarks than d-quarks) in W+2jets events, no b-tag*

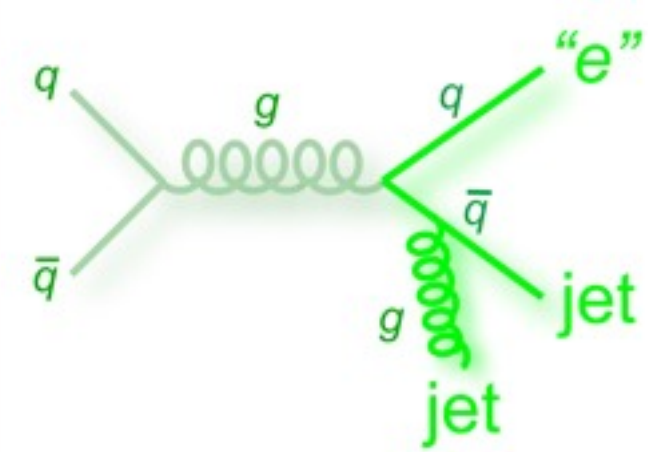
$$N_{W^+} + N_{W^-} = \frac{(N^{MC}_{W^+} + N^{MC}_{W^-})}{(N^{MC}_{W^+} - N^{MC}_{W^-})}(D^+ - D^-) = \left(\frac{r_{MC} + 1}{r_{MC} - 1}\right)(D^+ - D^-),$$

    2. *Derive* β_{xx} *from 3 equations using 2 data samples with positive and negative leptons in W+2 jet bin with standard sel & no b-tag + 1 normalization condition*
    3. *Derive* α *as in 1, but in r_{MC} use β_{xx} from step 2*
- Extrapolate shape and norm from 2 jets channel to **any jet multiplicity b-tagged** channel with

$$W^n_{\geq 1tag} = W^n_{pretag} \cdot f^{2j}_{tag} \cdot f^{2\to n}_{tag}$$

Backgrounds estimates *(tt single lepton+jets, single top t,s-char*

- ***Fake leptons***



"Fake" leptons: mis-id jets, $\gamma \to e^+e^-$, non-prompt leptons (b/c-decays), punch-through had

- *Matrix method* **(J Boudreau, Top2012)**

$$N^{\rm loose} = N^{\rm loose}_{\rm real} + N^{\rm loose}_{\rm fake},$$
$$N^{\rm std} = r N^{\rm loose}_{\rm real} + f N^{\rm loose}_{\rm fake}$$

r is the marginal efficiency of standard cuts.
f is the same, for background sources

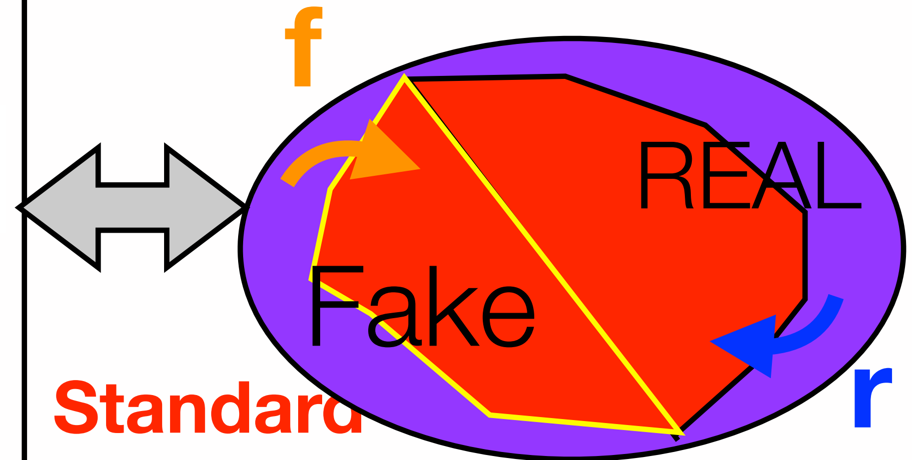
Both can be measured in pure or background event subtracted samples

- *Jet template*

Shape from jet triggered events with 1 high em. content jet.

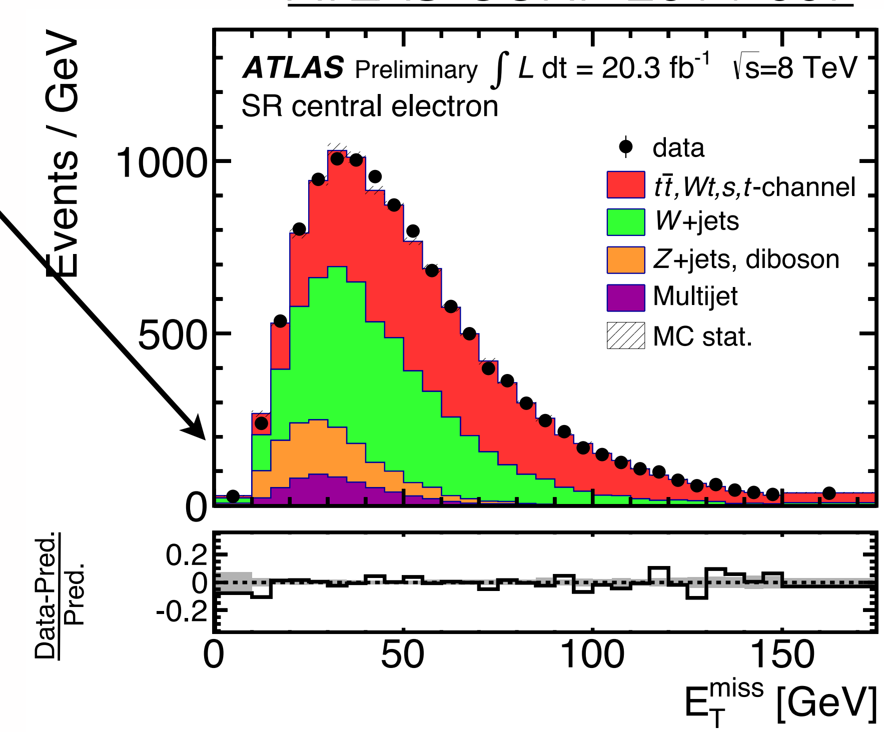
Normalize by fitting low E_T^{miss} shape to data and extrapolate

Loose selection=relax lepton isolation & identification

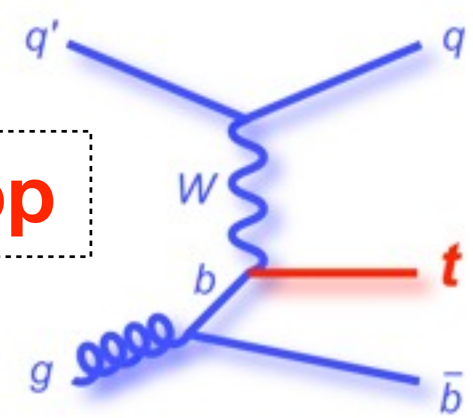


Standard selection

ATLAS-CONF-2014-007

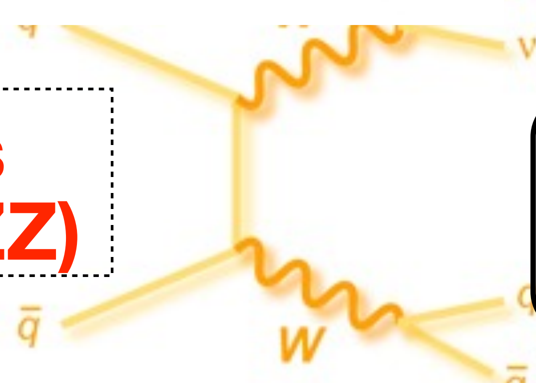


- **Single top**



Simulated shape+ rate set to approx NNLO

- **Di-bosons (WW,WZ,ZZ)**



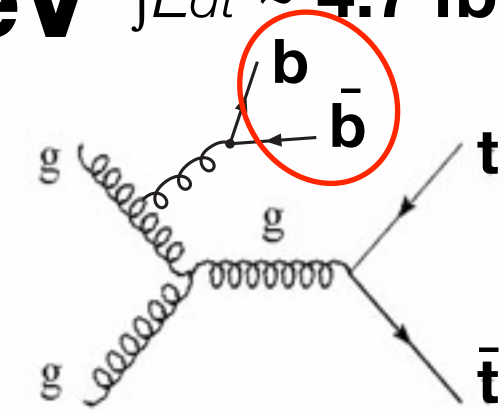
Simulated shape+ rate set to SM

normalizations=fit parameters, estimates are starting points for fit

top production

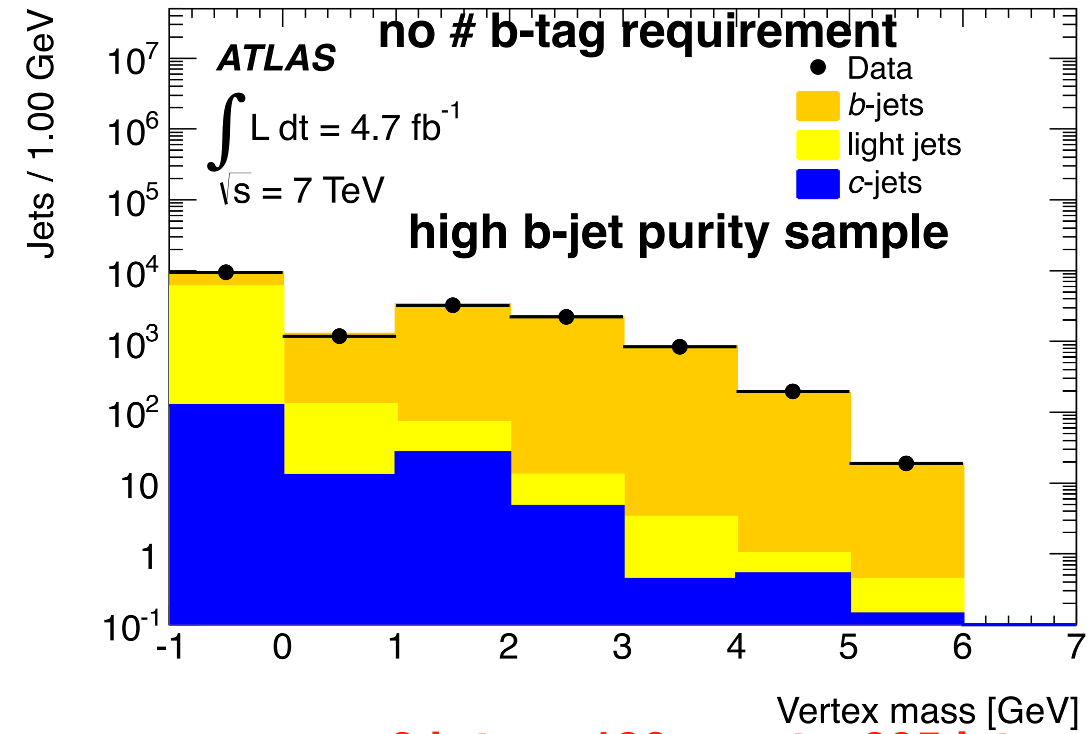
Inclusive $\sigma_{t\bar{t}+heavy\ flavour}$:dilepton-$\sqrt{s}$ =7 TeV $\int Ldt \sim$ 4.7 fb^{-1} *(2011)*

$t\bar{t}$ + b/c+X (HF) is main bkg to $t\bar{t}$+H,H→$b\bar{b}$



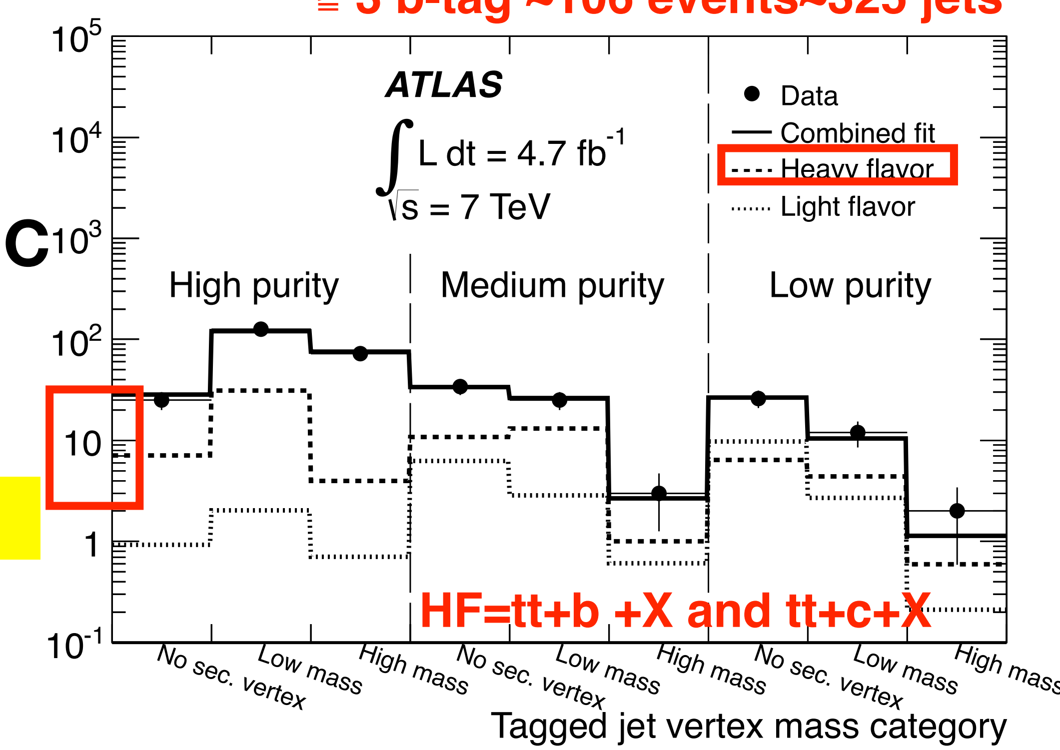
- 2 **OS leptons,** ≧ **2 jets,** ee,μμ: high E_T^{miss} cut & $M(\ell\ell) \neq m_Z$, eμ: high $H_T = \sum_{jets,lepts} p_T$ - **Bkg:** *as in dilepton inclusive*

- In ≧ **3 b-tag ev. calculate** $\sigma_{fid}(t\bar{t}+\mathrm{HF}) = \frac{N_{HF}}{\int \mathscr{L}dt \cdot \varepsilon_{HF}}$;
  - **N_{HF} =#b-tags from combined HF = 79±26←Max lkl. fit of templates** *(tt̄, bkg, HF, mis-tag)* **to displaced vertex mass of b-tags & jet p_T** in 3 b-tag purity bins
    large uncertainty on b- to c- separation →measure only HF
  - **ε_{HF}: from N_{HF} to #ev. with ≧3 true b-/c-jets (2 top b-jets)←MC**



≧ 3 b-tag ~106 events~325 jets

- **In ≧ 3 jets & ≧ 2 b-tags ev. get** $\sigma_{fid}(t\bar{t}+j) = \frac{N_j}{\int \mathscr{L}dt \cdot \varepsilon_j}$
  - **N_j = #events with $t\bar{t}$ + ≧ 1 jet =1541±41** ←cut & count
  - **ε_{HF}: from N_{HF} to #ev. with ≧3 true jets (2 top b-jets)←MC**

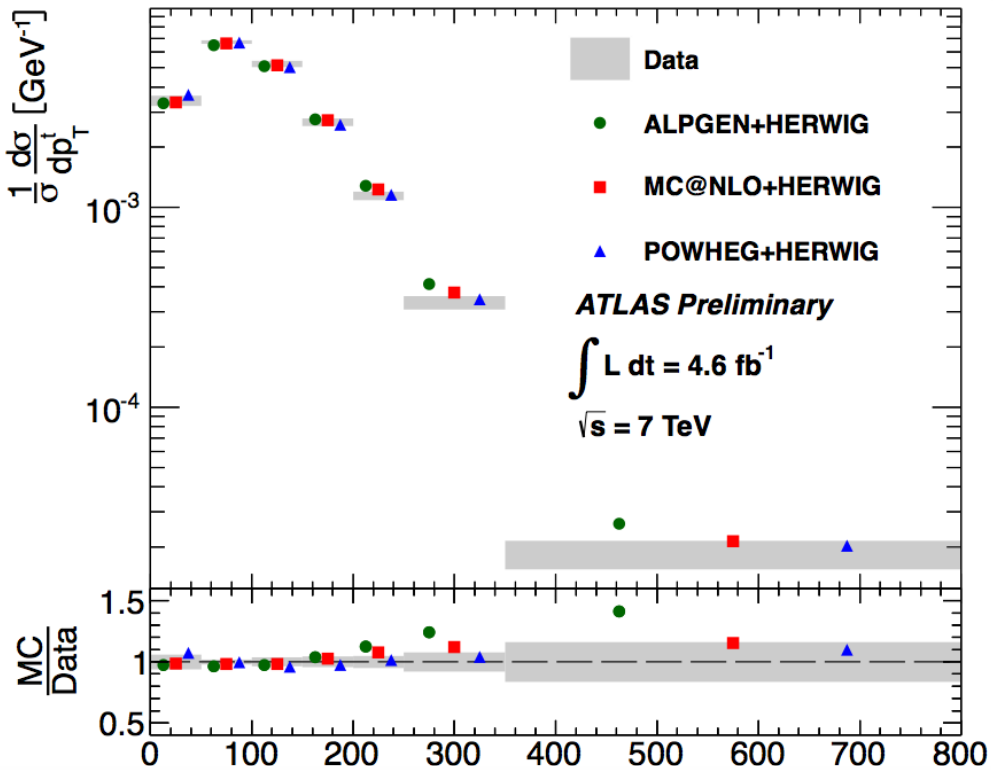


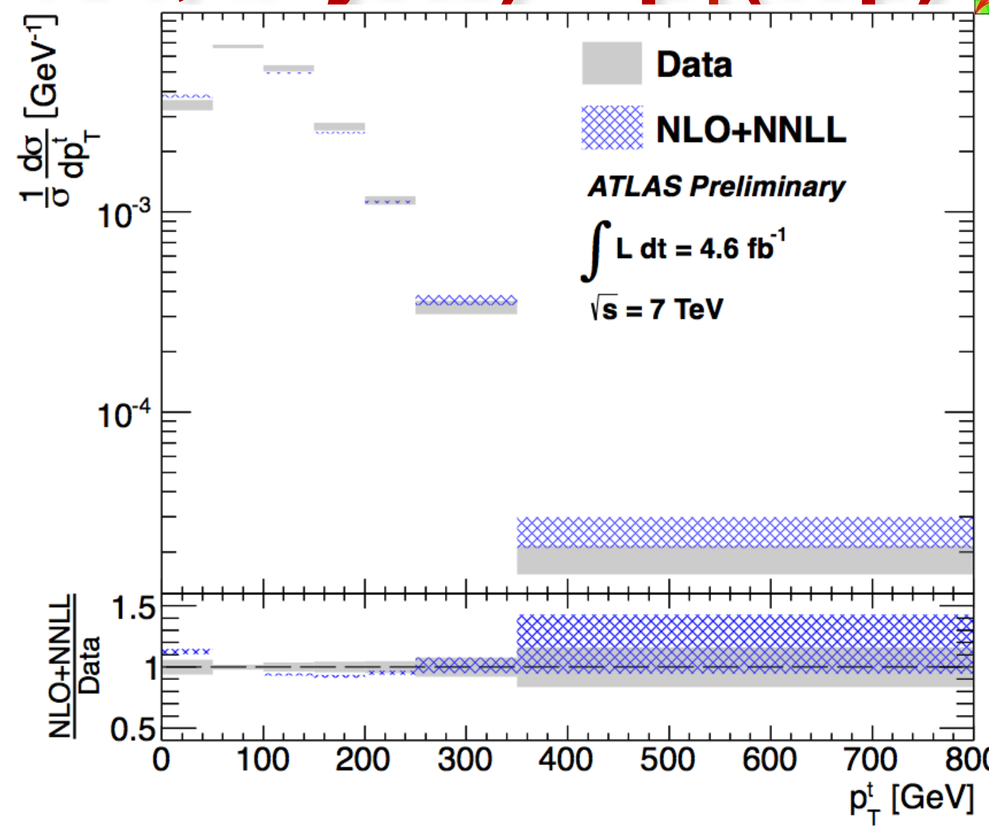
$$R_{HF} = \frac{\sigma_{fid}(t\bar{t}+\mathrm{HF})}{\sigma_{fid}(t\bar{t}+j)} = [6.2 \pm 1.1(stat) \pm 1.8\ (syst)]\%$$

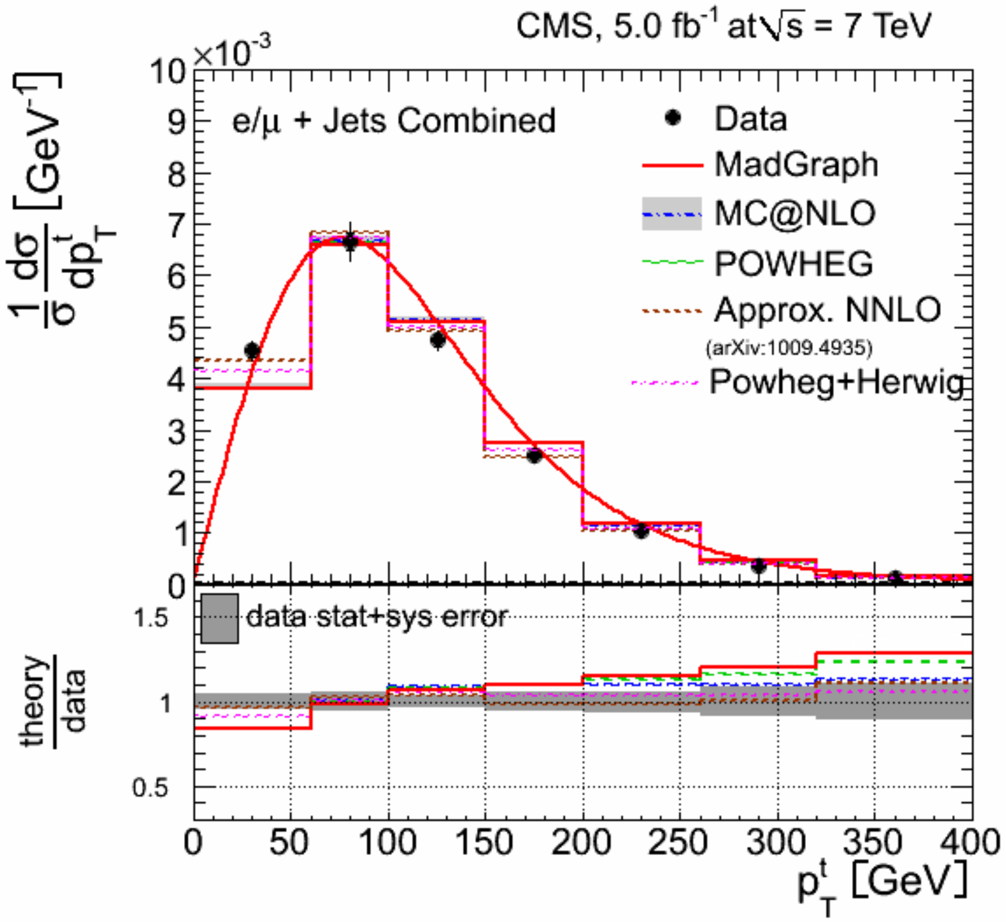
SM: 3.4% (ALPGEN) , 5.2% (POWHEG)

- **Syst dominated:** *c-tagging (21%),fragm. (10%) flavour comp. (6%),* arXiv:1304.6386, submitted to PRD

Results: ATLAS & CMS (7 TeV, ℓ+jets) – p_T(top)







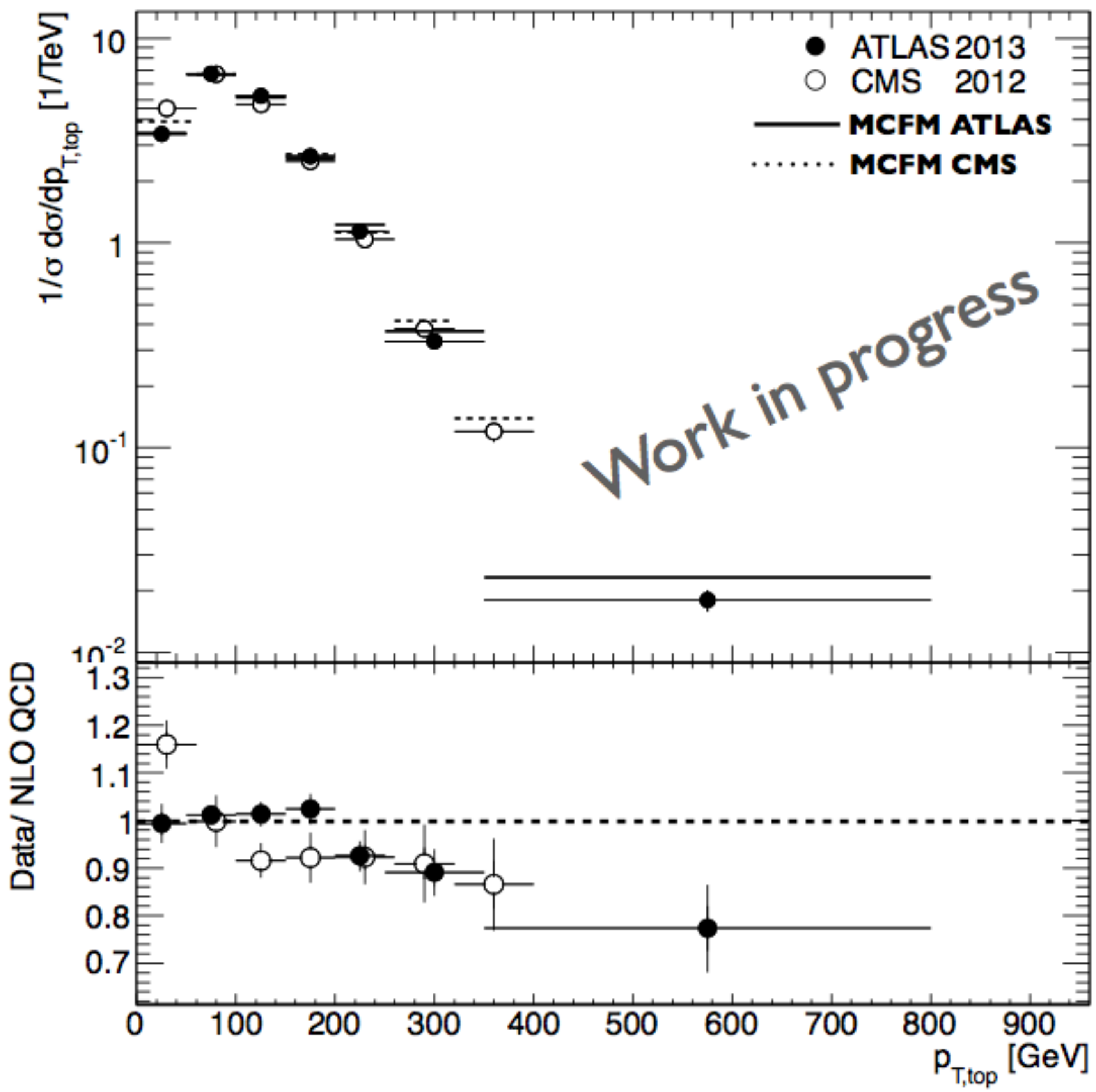
- Powheg+Herwig describes ATLAS & CMS data reasonably well over the full p_T range
- **p_T(top) < 200 GeV: disagreement btw ATLAS & CMS**
  - CMS: softer spectrum in data, best described by Approx. NNLO
  - ATLAS: disagreement with Approx. NNLO
- CMS: Similar behaviour for dileptons, both at 7 & 8 TeV

16 TOPLHCWG, 28.11.13

M. Aldaya, F.Spanò (for ATLAS & CMS) TOPLHCWG open session 28-29th Nov. 2013

Results: ATLAS & CMS (7 TeV, ℓ+jets) – p_T(top)

- First attempt at direct data comparison: data/NLO prediction (MCFM)



p_T(top) < 200 GeV:

- Disagreement between ATLAS & CMS data
- ATLAS result in agreement with MCFM

p_T(top) > 200 GeV:

- Good agreement between ATLAS & CMS data
- ATLAS & CMS in disagreement with MCFM

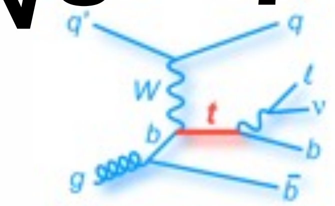
<u>M. Aldaya, F.Spanò (for ATLAS & CMS) TOPLHCWG open session 28-29th Nov. 2013</u>

$\sigma_t/\sigma_{\bar{t}}$: t-chan $\sqrt{s}$ = 7 TeV

$\int L dt$ = **4.7 fb^{-1}** *(2011)*

ATLAS-CONF-2012-056

$q\ell\nu$**b(b)**



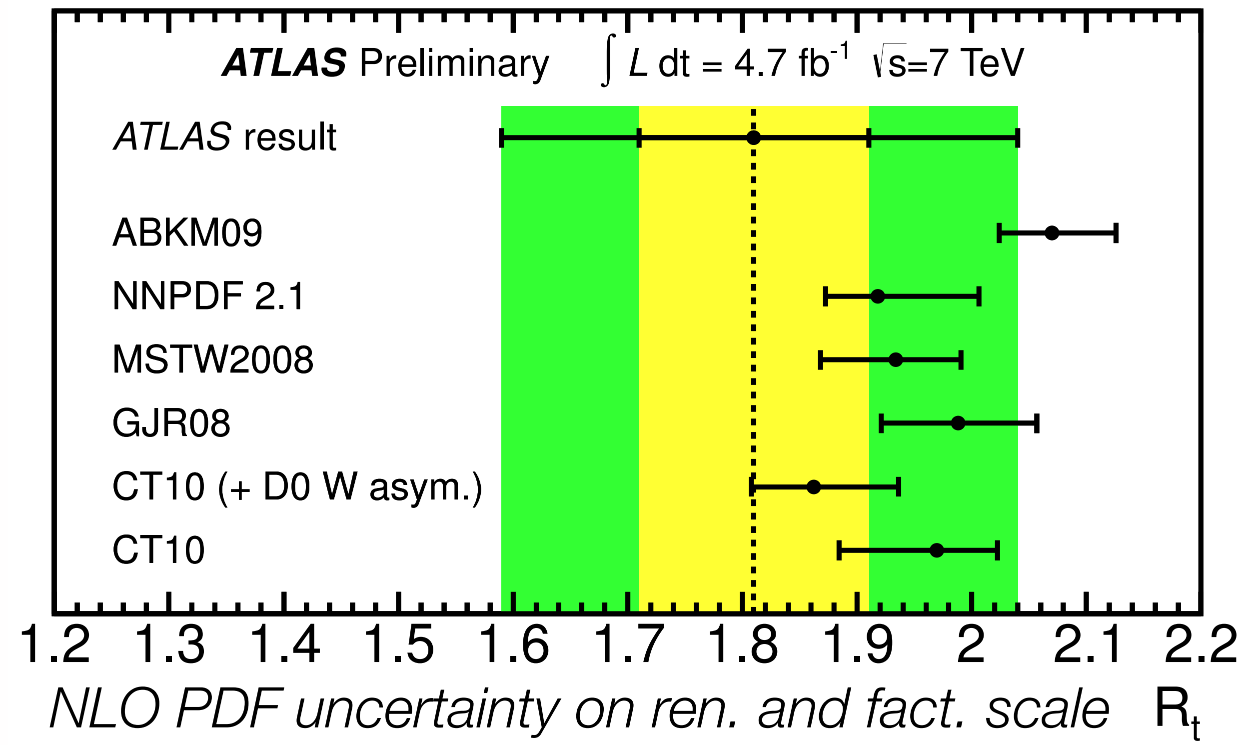
- **Calculate R$_t$ =σ_t / $\sigma_{anti\text{-}t}$** (**sensitive to u/d PDFs**) *including corr→reduce* **δR**

syst dominated: ISR/FSR~4% JES~4%, fakes

$$R_t = 1.81 \pm 0.10\,(\text{stat.})\,^{+0.21}_{-0.20}\,(\text{syst.})$$

δR/R~13%

stat ~ spread of predictions ~ uncertainty on pred.



Inclusive σ_t : t-channel -$\sqrt{s}$ = 8 TeV

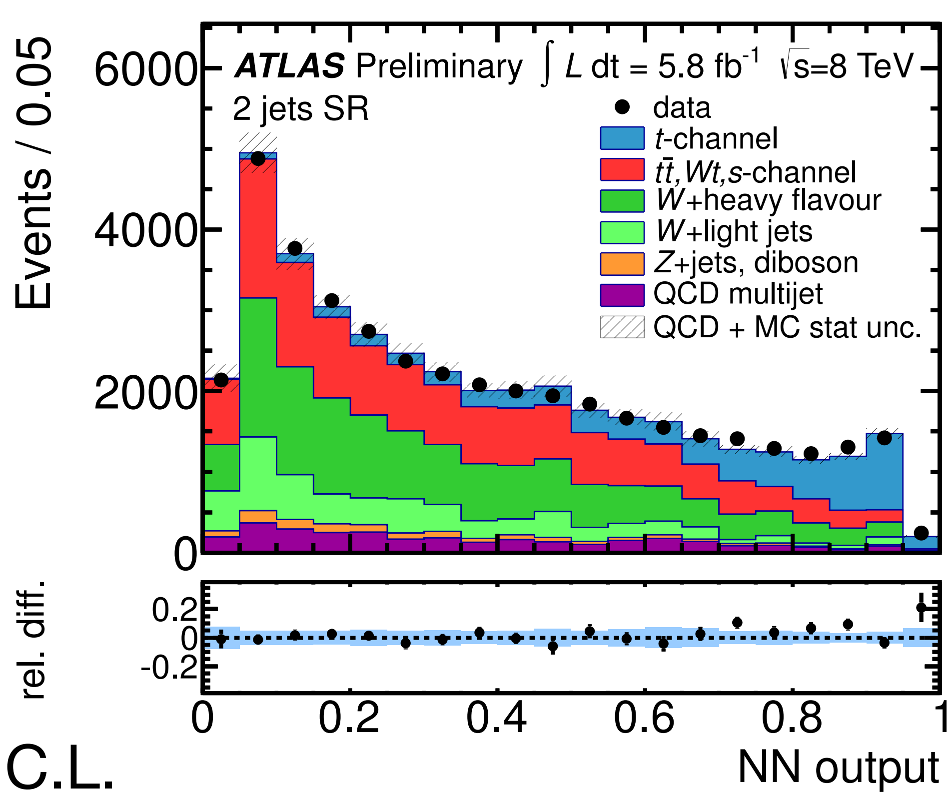
$\int L dt$ = **5.8 fb^{-1}** *(2012)*

ATL-CONF-2012-132

- same selection and bkg estimate as $\sqrt{s}$ = 7 TeV
- **Extract σ_t** *and bkg norm* **by max. lkl fit of NN distribution** *(11 kin. vars: jet-lep masses, $\sum_{jet,lep} p_T$ + E_T^{miss}, jet rapidities)* to data in 2- & 3-jet bins

$$\sigma_t = 95 \pm 2\,(\text{stat.}) \pm 18\,(\text{syst.})\,\text{pb}$$

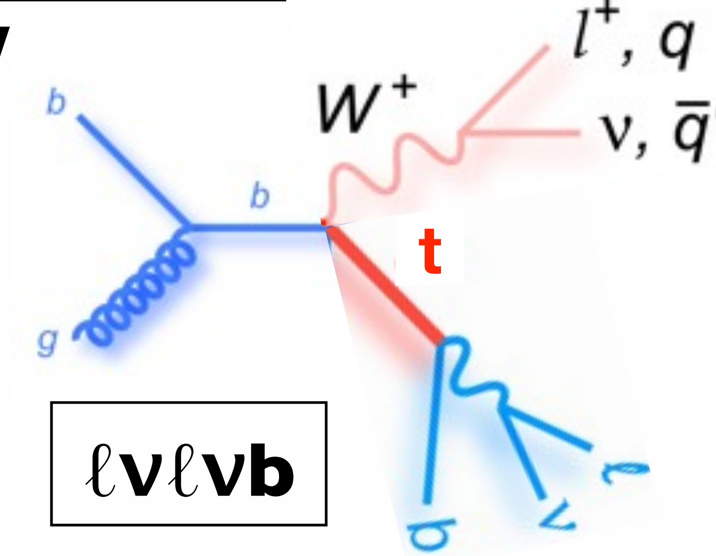
$\delta\sigma_t/\sigma_t$ ~19%



band: MC stat+fakes uncertainty

- Syst. dominated (*I/FSR~9%,JES~7%,b-tag eff~ 8%*)
- **Determine** $|V_{tb}| = 1.04^{+0.10}_{-0.11}$ If $|V_{tb}|$<1 $|V_{tb}|$ > 0.80 at 95% C.L.

Inclusive σ_t : Wt-channel - $\sqrt{s}$ = 8 TeV

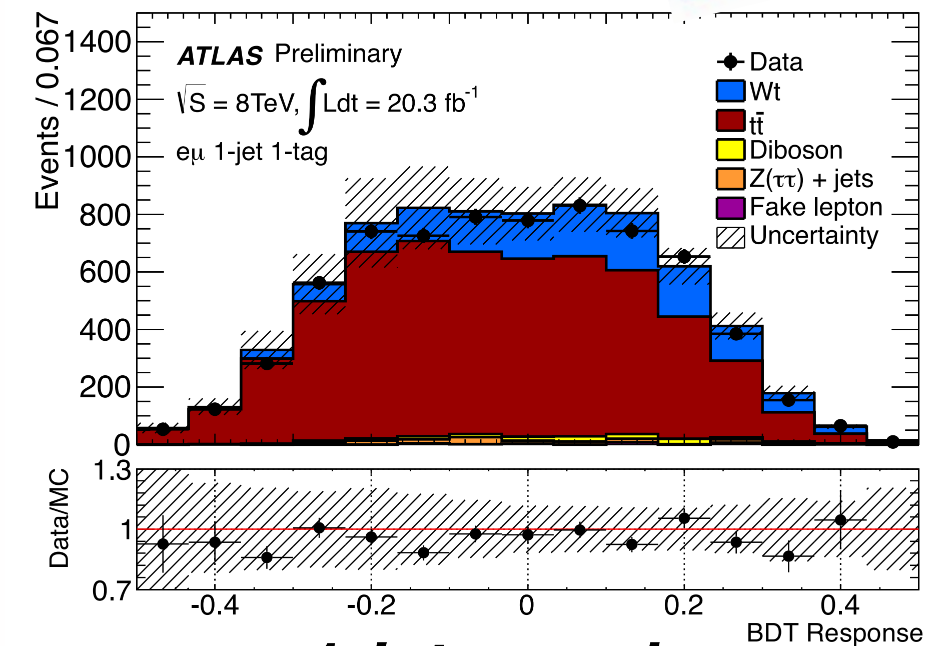


ATLAS-CONF-2013-100 $\int L dt$ = **20.3 fb^{-1}** *(2012)*

- **OS eμ**, 1 or 2 central high p_T jets, ≥1 b-tag,
- Bkg: $t\bar{t}$,diboson, Z+jets, data-driven *(matrix method)* fake lept.

ℓνℓνb

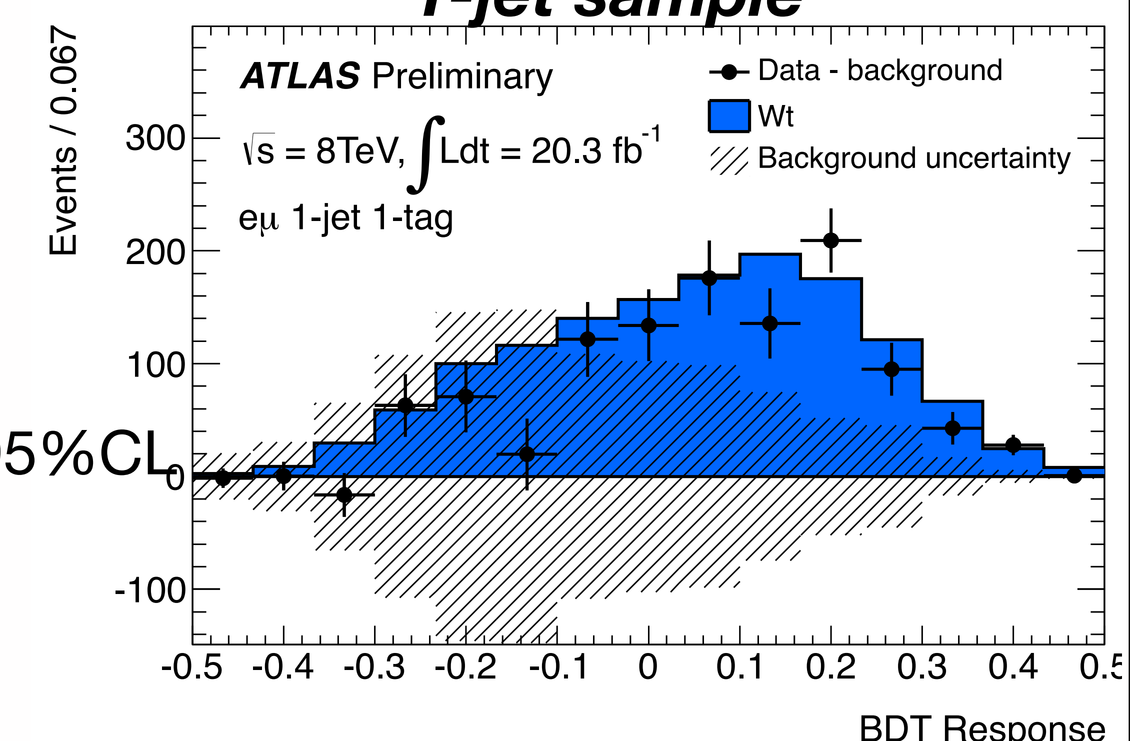
- **Extract σ_{Wt}** *and bkg norm* **by** *simultaneous* **binned max. likelihood fit of Boosted Decision Tree outputs** *in 1 and 2-jet bin (with 19 and 20 kine vars)*



Syst dominated

- *Syst: Wt(tt) gen+ had 11%(~7.5%) b-tag eff.~8%, ISR/FSR (~5.9%) and b-jet en. scale (~5.0%). Profile b-tag, 1 comp of JES and soft JES.*

1-jet sample



σ_{Wt} = 27.2 ± 2.8 (stat) ± 5.4 (syst) pb

significance: **4.2 s.d.** **$\delta\sigma_{Wt}/\sigma_{Wt}$** ~22%

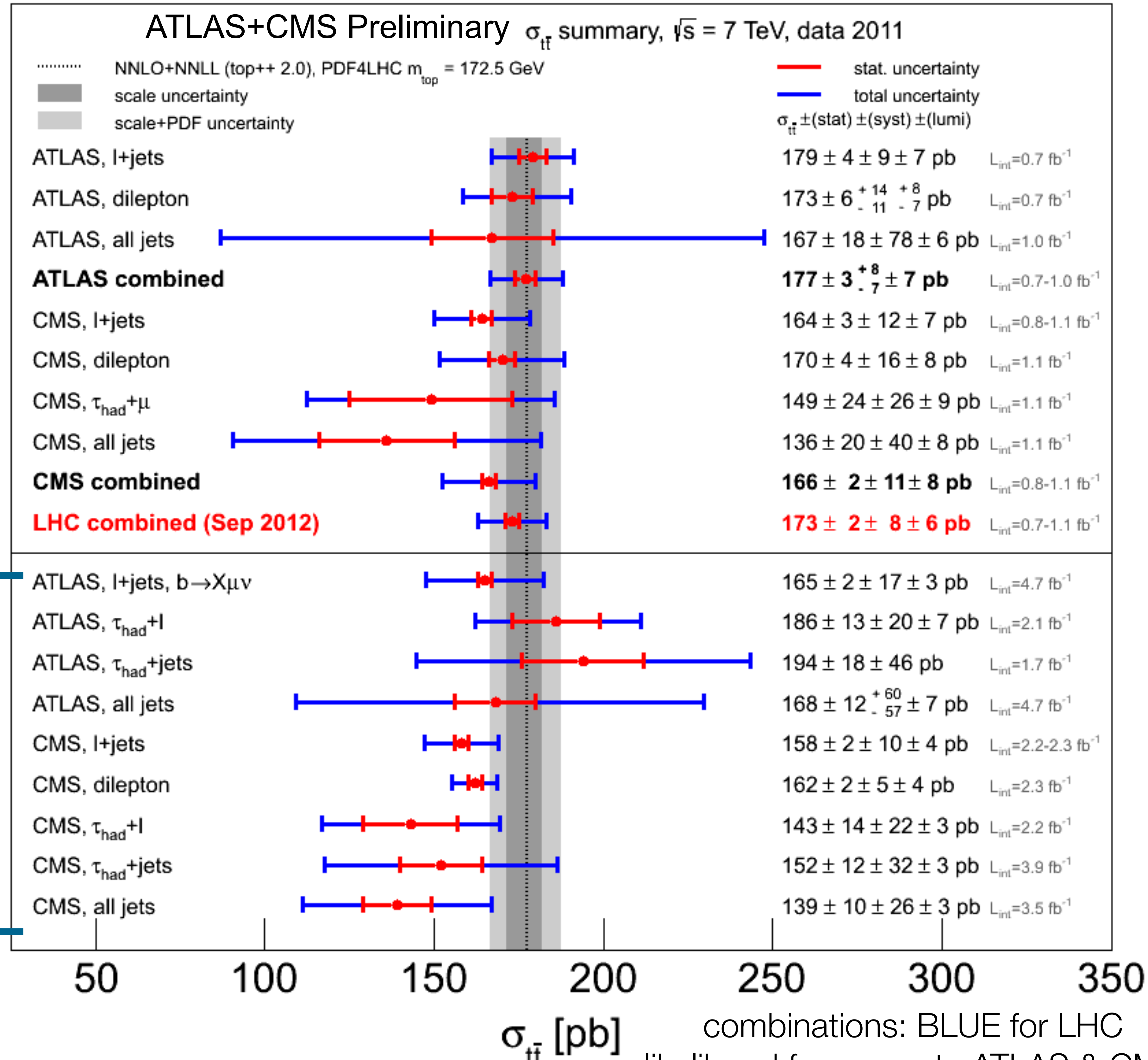
- **Determine** $|V_{tb}| = 1.10 \pm 0.12$ If $|V_{tb}|<1$ $|V_{tb}|>0.72$ at 95%CL

Wt evidence at 8 TeV!

Summary of LHC σ(tt̄) results @ 7 TeV

Using
m_{top} = 172.5 GeV
as a temporary fix until experiments provide parametrisation for the mass dependence

New or updated measurements, not included in current LHC combination



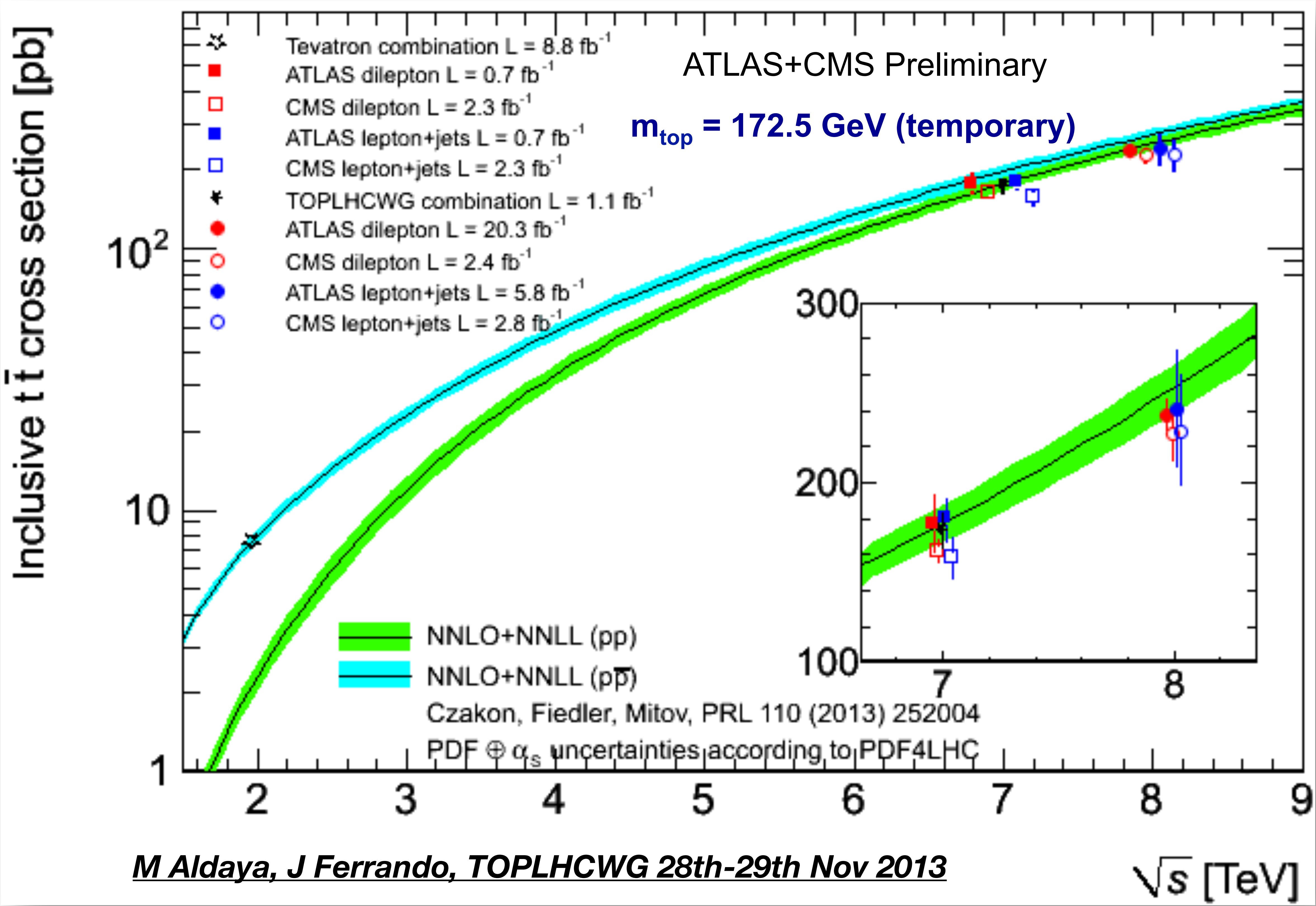
combinations: BLUE for LHC
likelihood for separate ATLAS & CMS

Plan for future combinations:

- Provide LHC combination at 7 TeV with updated results
- Combine 8 TeV results as soon as updated CMS measurement is released

M. Aldaya **_M Aldaya, J Ferrando, TOPLHCWG 28th-29th Nov 2013_** TOPLHCWG, 28.11.13

σ($t\bar{t}$) as a function of √s



M Aldaya, J Ferrando, TOPLHCWG 28th-29th Nov 2013

M. Aldaya 16 TOPLHCWG, 28.11.13

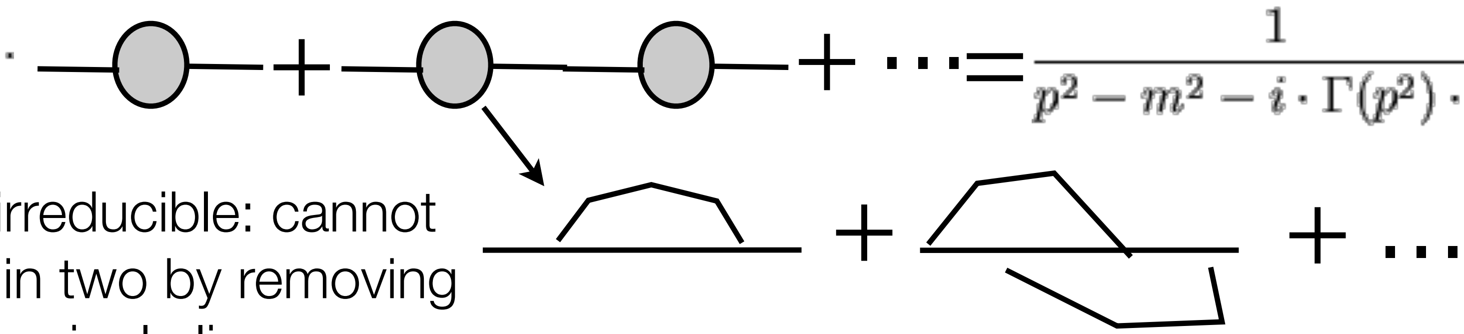
top mass

Top mass definition(I)

- **Mass is a parameter in Lagrangian that undergoes renormalization to take into account higher order corrections (self energy)**
  - *redefinition of physical amplitudes as a function of parameters depending on a cut-off that limits the integration range of integrals which would go to infinity*
  - *the bare parameters encode the high energy degrees of freedom*

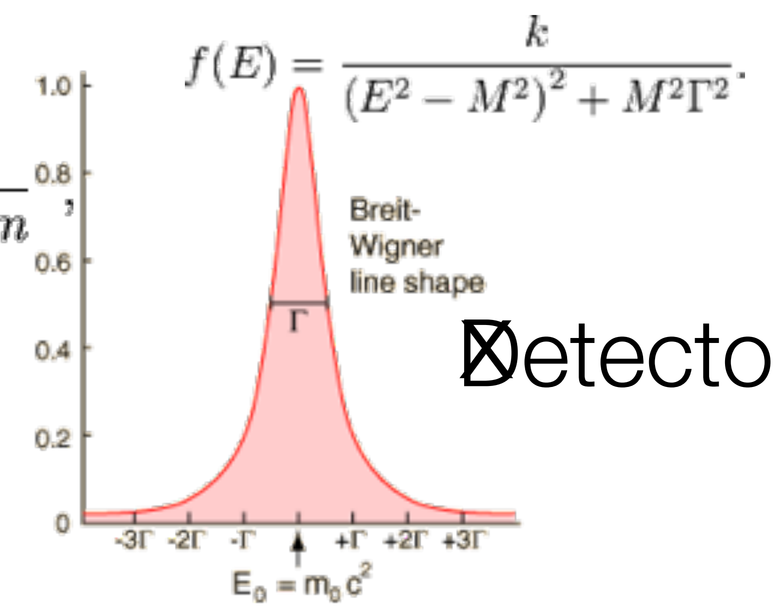
propagator to amplitude: higher order sel-energy corrections

$$\frac{1}{p^2-m^2} \cdot$$



$$= \frac{1}{p^2 - m^2 - i\cdot\Gamma(p^2)\cdot m},$$

1 part irreducible: cannot be split in two by removing a single line



Detector

- **Self energy corrections shift the "bare" mass**: $m_0 \rightarrow m_0 + \Sigma(m_0)$
  - $\Sigma(m_0)$ is finite term +divergent part
- **Renormalization changes $m_0 \rightarrow m_{ren} + \Sigma(m_{ren})$ where $\Sigma(m_{ren})$ is finite** as one subtracts the divergent part
- **Renormalization implies choice of scheme** i.e. what to keep fixed.

Phys.Rept. 504 (2011) 145-233

Phys.Rept. 504 (2011) 145-233

Top mass definition(II)

- **Rapidity of convergence in perturbative regime depends on renormalization scheme** (even if results don't)
- QCD is only asymptotically convergent : scheme should be acceptable in non pert regime too + no infinite order in perturbative regime

Typical renormalization scheme

- **Long distance** scheme ~ **Pole mass**: operative definition as real part of pole position in complex momentum space; imagine taking free particle to infinity, and measuring mass (impossible for QCD, top is coloured and confined); closer to collider measurement
- **Short distance** ~ Minimal Subtraction ($\overline{MS}$): subtract the divergent term of corrections + universal constant; do not touch finite part.
- Mass difference between any two schemes is calculable as perturbative series in α_s

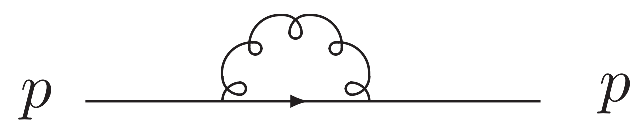
$$m_{pole} = \overline{m}(\overline{m}) \left(1 + \frac{4}{3}\frac{\overline{\alpha}_s(\overline{m})}{\pi} + 8.28\left(\frac{\overline{\alpha}_s(\overline{m})}{\pi}\right)^2 + \cdots\right) + O(\Lambda_{QCD})$$

F Maltoni Lake Louise2014

- *Difference involves integral of alpha_s over a region where it becomes large so the series does not converge : the ambiguity is of order Λ_{QCD}*

Top mass: LHC combination $m_t = 173.3 \pm 0.23 \pm 0.29$ GeV, but what mass?

Subtraction of the UV divergences in the self energy $\Sigma(p)$



Renormalized propagator: $S^{-1}(p) = -i[\not{p} - m_t^0 + \Sigma^R(p, m_t^0, \mu)]$

Mass is solution of equation $\not{p} - m_t + \Sigma^R(p, m_t, \mu) = 0$

Pole mass:

$$\Sigma^R(p) = 0 \ \ \text{and} \ \ \frac{\partial \Sigma^R}{\partial \not{p}} = 0 \ \ \text{for} \ \ \not{p} = m$$

$\overline{\text{MS}}$ mass $\bar{m}_t(\mu)$– dimensional regularization $D = 4 - 2\epsilon$

$$\Sigma(p) = \frac{i\alpha_S C_F}{4\pi} \left\{ \left[\frac{1}{\epsilon} - \gamma + \ln 4\pi + A(m_t^0, p, \mu) \right] \not{p} - \left[4 \left(\frac{1}{\epsilon} - \gamma + \ln 4\pi \right) + B(m_t^0, p, \mu) \right] m_t^0 \right\}$$

Counterterm to subtract $(1/\epsilon + \gamma_E - \ln 4\pi)$

Relation with the pole mass (coefficients c_i depending on $\ln[\mu^2/\bar{m}_t(\mu)^2]$)

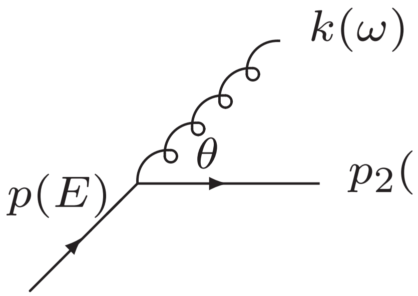
$$m_t = \bar{m}_t(\mu) \left[1 + \alpha_S(\mu) c_1 + \alpha_S^2(\mu) c_2 + \ldots \right]$$

– Typeset by FoilTEX – G Corcella, ATLAS Italia Workshop,Jan2014 11

Top mass definition(III)

- **MS calculation shows faster convergence** for tt cross section, top width..Possibly use it to define top mass.
- What do we measure though?
- A third quantity: the Monte Carlo mass.   resulting from decay products, form hadronization and colour effects. Expect it to be close to the pole mass.
- Understanding the ambiguity (1 GeV, hundreds of MeV) is the object of current studies.

Top mass measurement driven by parton shower generators



$$dP = \frac{\alpha_S}{2\pi}\, P(z)dz\, \frac{dQ^2}{Q^2}\, \Delta_S(Q^2_{\max}, Q^2)$$

Q^2: ordering variable

$\Delta_S(Q^2_{\max}, Q^2)$: no radiation in $[Q^2, Q^2_{\max}]$ (soft/collinear virtual corrections)

$$\Delta_S(Q^2_{\max}, Q^2) = \exp\left[-\frac{\alpha_S}{2\pi}\int_{Q^2}^{Q^2_{\max}} \frac{dQ'^2}{Q'^2}\int_{z_{\min}}^{z_{\max}} dz P(z)\right]$$

HERWIG : $Q^2 = E^2(1-\cos\theta) \simeq E^2\theta^2/2$ (angular ordering);

PYTHIA: $Q^2 = p^2$ **or** k_T^2

$\alpha_S(k_T^2)$ with two-loop evolution in HERWIG and one-loop in PYTHIA

Total cross section LO thanks to unitarity $(1 = R + V)$

Distributions equivalent to threshold LL resummation, + some NLLs

$\Lambda \to \Lambda_{\rm MC} = \Lambda \exp(4K\beta_0)$: NLL Sudakov form factor at large x (Catani, Marchesini and Webber)

– Typeset by FoilTEX – G Corcella, ATLAS Italia Workshop,Jan2014 12

m_t

All time classic

Top-quark Mass

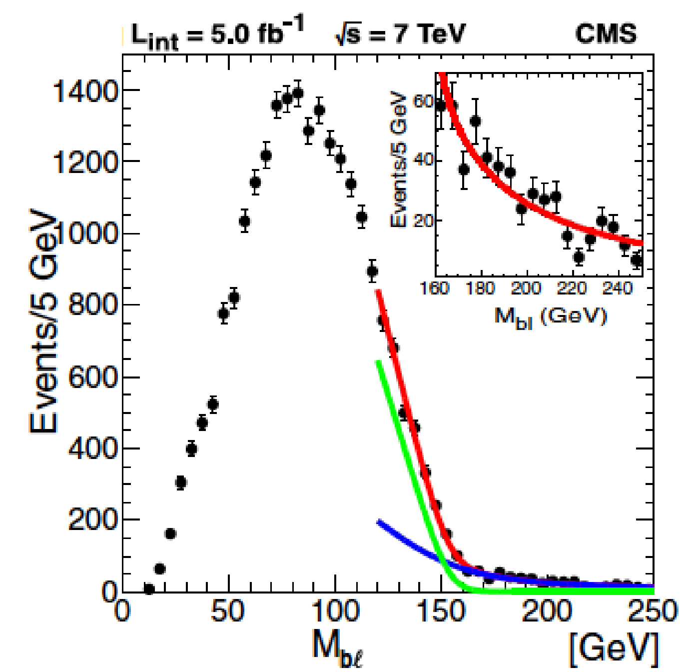
Several strategies for top mass measurement:

1. Template and Matrix Element Methods. Still LO in their essence, yet calibrated to NLO MC simulations. MC mass is closely related to the pole mass (=suffers of the same NP uncertainties). MEM: automation [Artoisenet et al. 2010] and first steps towards NLO [Campbell et al. 2012]

2. More exclusive final state observables, such as the m (J/psi, lepton)[Kharchilava '99], [Chierici, Dierlamm CMS NOTE 2006/058]. Statistically limited.

3. End point method [CMS, 2013] : m_{T2}, simple and resilient.

$$M_{b\ell}^{max} = \sqrt{m_b^2 + \left(1 - \frac{m_\nu^2}{M_W^2}\right)(E_W^* + p^*)(E_b^* + p^*)}$$



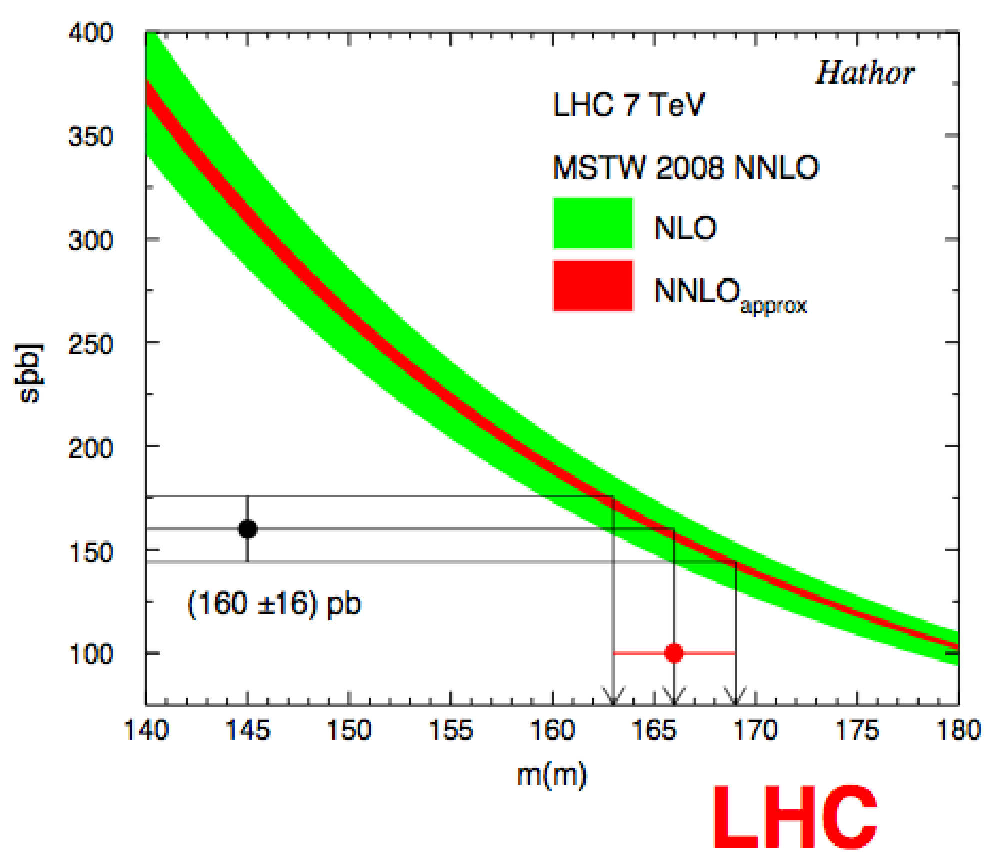
Top-quark Mass

mt
All time classic

Several strategies for top mass measurement:

3. Extraction of m^{MSbar} from the cross section

[Langenfeld, Moch, Uwer 2009, Beneke, Falgari, Klein, Schwinn `11 Ahrens, Ferroglia, Neubert, Pecjak, Yang `11]

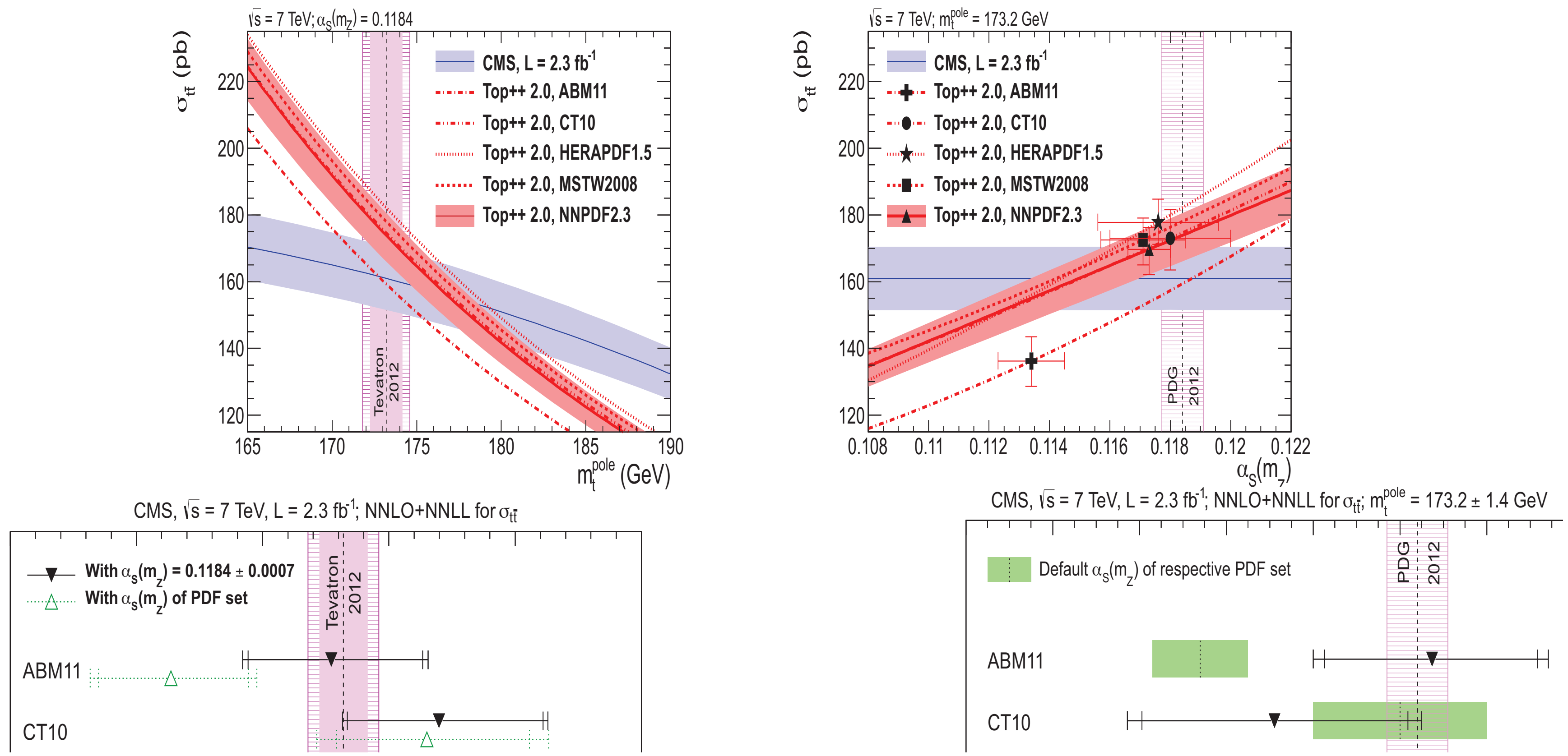


- Not competitive right now due uncertainties in the cross section measurement, to the slope and the TH uncertainty band.
- $\Delta m/m \sim 3\%$

The total inclusive NNLO+NNLL $t\bar{t}$ cross section can be used to extract m_t and α_s
consistency with theoretical definitions, small perturbative and non-perturbative
very little impact of width effects

Disadvantage: mild dependence on m_t implies large errors on the extracted value

Found result (CMS): $m_t^{\rm pole} = 176.7^{+3.8}_{-3.4}$ GeV agrees with the 'Monte Carlo' mass



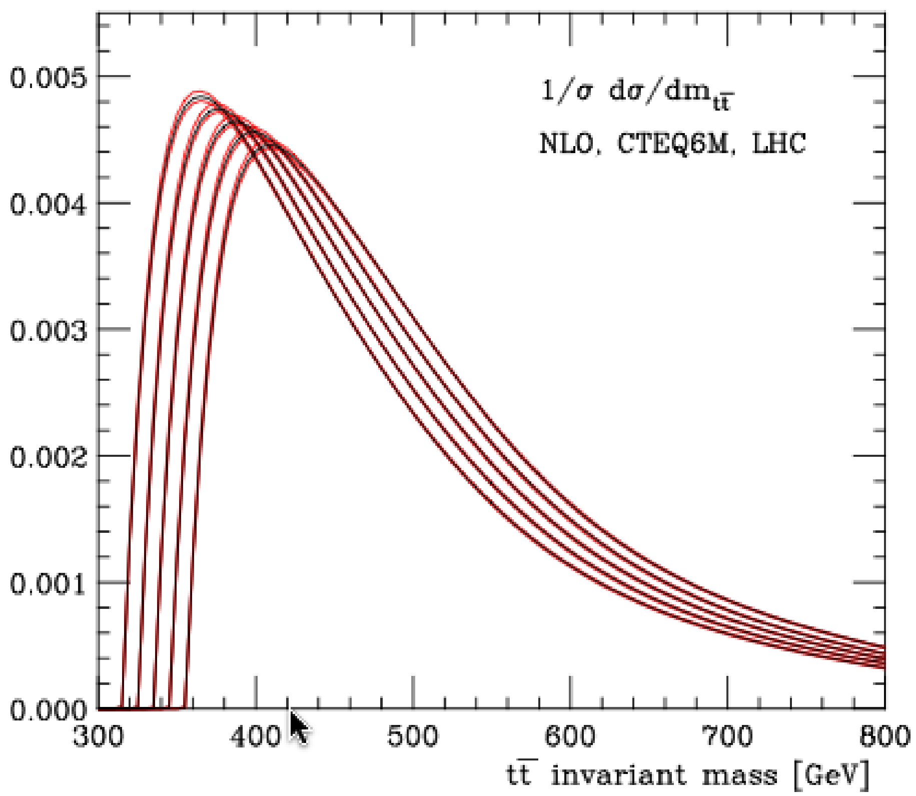
G Corcella, ATLAS Italia Workshop,Jan2014

Top-quark Mass

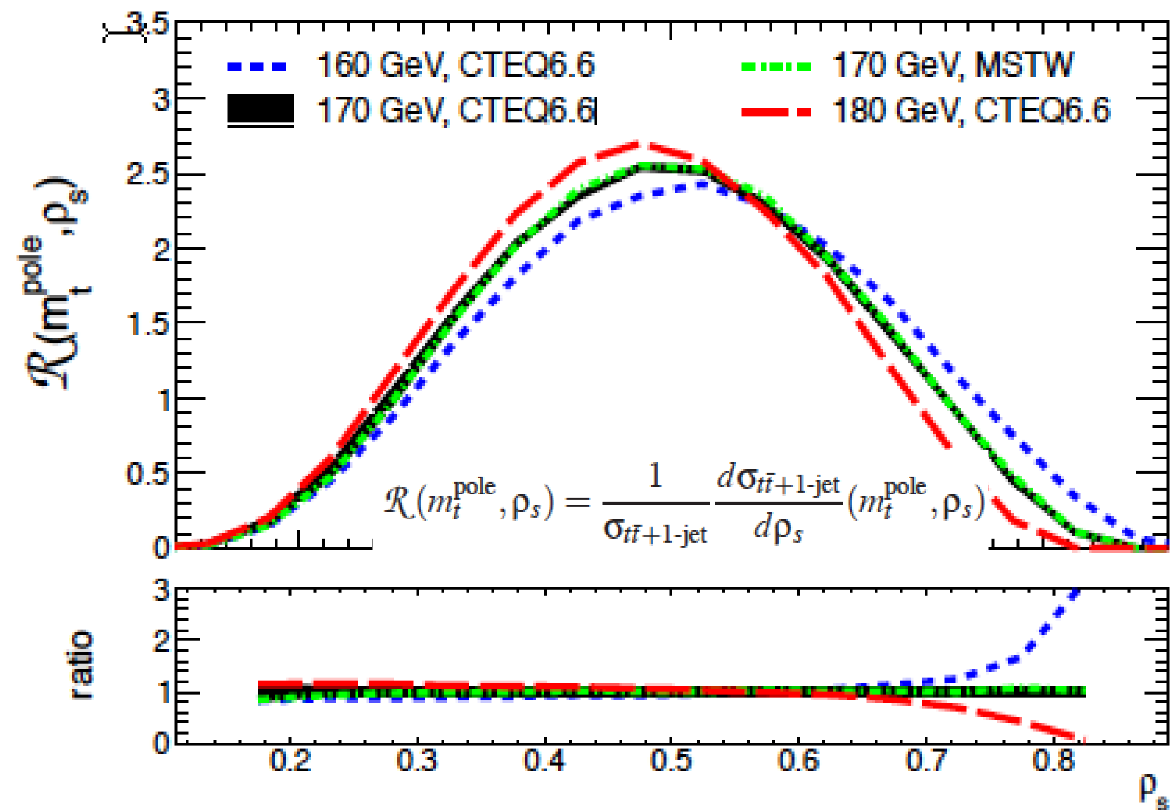
Several strategies for top mass measurement:

4. Extraction of m_{top} from distributions:

[Frederix, FM 2009]



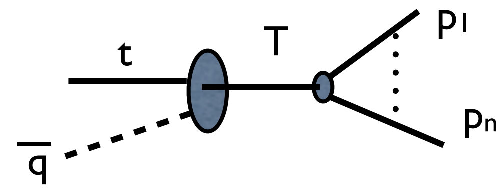
[Alioli et al. 2013]



Difficult roads, yet worth to be explored! Boosted states and single-top production could also be used to independently assess the impact of non-perturbative corrections.

Top mass Definition (III)

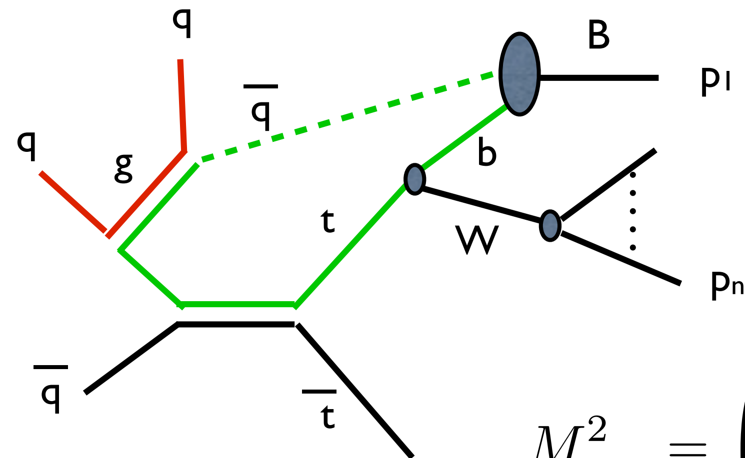
If Γ_{top} were < 1 GeV, top would hadronize before decaying. Same as b-quark



$$m_T^2 = \left(\sum_{i=1,\ldots,n} p_i\right)^2$$

m_t = $F_{\text{lattice/potential models}}$ (m_T, α_{QCD})

But Γ_{top} is > 1 GeV, top decays before hadronizing. Extra antiquarks must be added to the top-quark decay final state in order to produce the physical state whose mass will be measured



$$M_{exp}^2 = \left(\sum_{i=1,\ldots,n} p_i\right)^2$$

As a result, M_{exp} is not equal to m^{pole}_{top}, and will vary in each event, depending on the way the event has evolved.

The top mass extracted in hadron collisions is not well defined below a precision of $O(\Gamma_{top})$~ 1 GeV

Goal:
- correctly quantify the systematic uncertainty
- identify observables that allow to validate the theoretical modeling of hadronization in top decays
- identify observables less sensitive to these effects

Conclusions

- To the level of 250-500 MeV, it is justified to consider m_{MC}=m_{pole}
- Dynamics "on the W side" extremely stable against all that happens on the b-side: try to exploit lepton endopoints, or other related observables
- Absolute effects of b-jet recombination in the few-GeV range, most of it controlled by perturbative effects, thus unaffected by NP uncertainties

(M. Mangano TOP2013)

TOP-QUARK MASS

m_t

All time classic

Open issues/suggestions/prospects:

- Evaluate systematic uncertainties from showering/hadronization/color recombination to go from pole mass to "MC" mass. [Skands and Wicke 2007]
- Study top mass determination in other contexts: as a function of pt of the top in ttbar, from single-top,...
- Study new variables that are more resilient to QCD effects (such as those constructed out of the leptons).
- Consider the opportunities coming from very high statistics samples.

Experimental analyses employ Monte Carlo parton showers which are not NLO QCD calculations, but LO+LL (soft/collinear), with some NLLs, neglect Γ_t and depend on a few tunable non-perturbative parameters $(x_1, \ldots x_n)$

However, the reconstruction relies on final-state observables, then one would expect the extracted 'Monte Carlo mass' ($m_{\rm MC}$ mimicks the pole mass)

In the SCET framework (Hoang and Stewart) m_t can be identified with the jet mass at the shower cutoff $Q_0 \sim \mathcal{O}(1\ \mathrm{GeV})$ and is in fact close to the pole mass:

$$m_{\rm pole} = m_J(\mu) + e^{\gamma_E}\Gamma_t \frac{\alpha_S(\mu) C_F}{\pi}\left(\ln\frac{\mu}{\Gamma_t} + \frac{1}{2}\right) + \mathcal{O}(\alpha_S^2)$$

Ongoing study

Other strategy to address the meaning of the top mass (G.C. and M.L.Mangano):

Hadronize the top quark, i.e. meson states $T^{\pm,0} \sim t\bar{u}, t\bar{d}$ and let them decay according to the spectator model, i.e. $t \to bW$ with a spectator light quark and $W \to \ell\nu$

Showers from b and spectator quarks

Invariant mass $m(Wb_{\rm jet})$ mimicks the top mass

Relate meson mass to pole or $\overline{\rm MS}$ top masses via lattice, NRQCD, etc.

Work carried out within the LPCC and TOPLHCWG: hope of results for next meetings

G Corcella, ATLAS Italia Workshop,Jan2014

top and new physics

Search for vector-like quark @ $\sqrt{s}$=8 TeV

ATLAS-CONF-2013-018

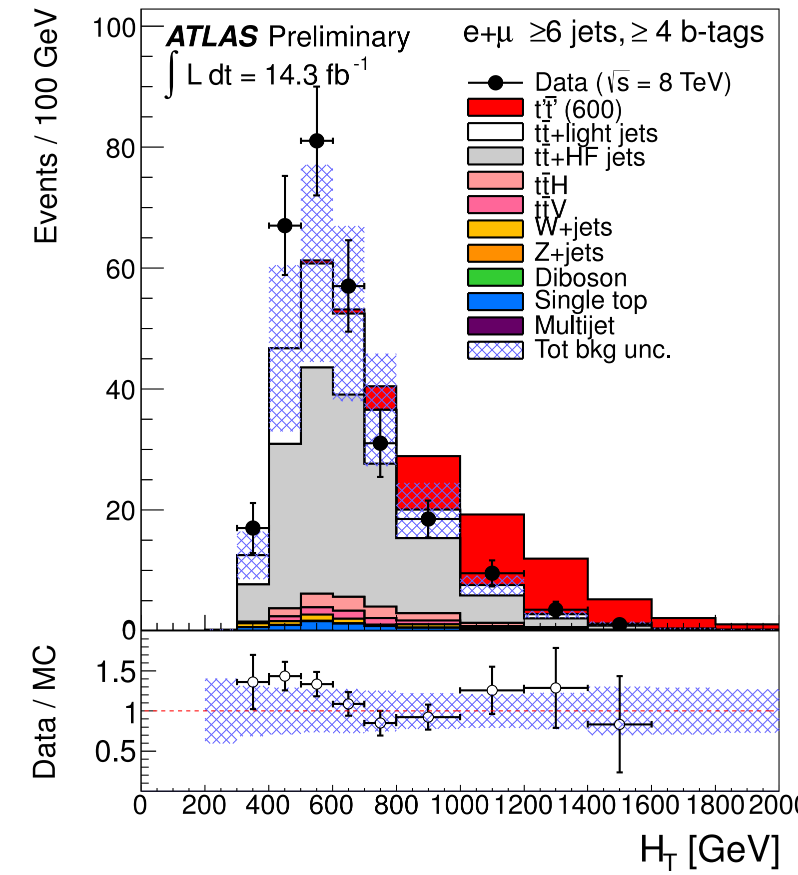
T: to cancel top-induced divergencies of m_H, same EWK SU(2) xU(1) behaviour for both chiralities

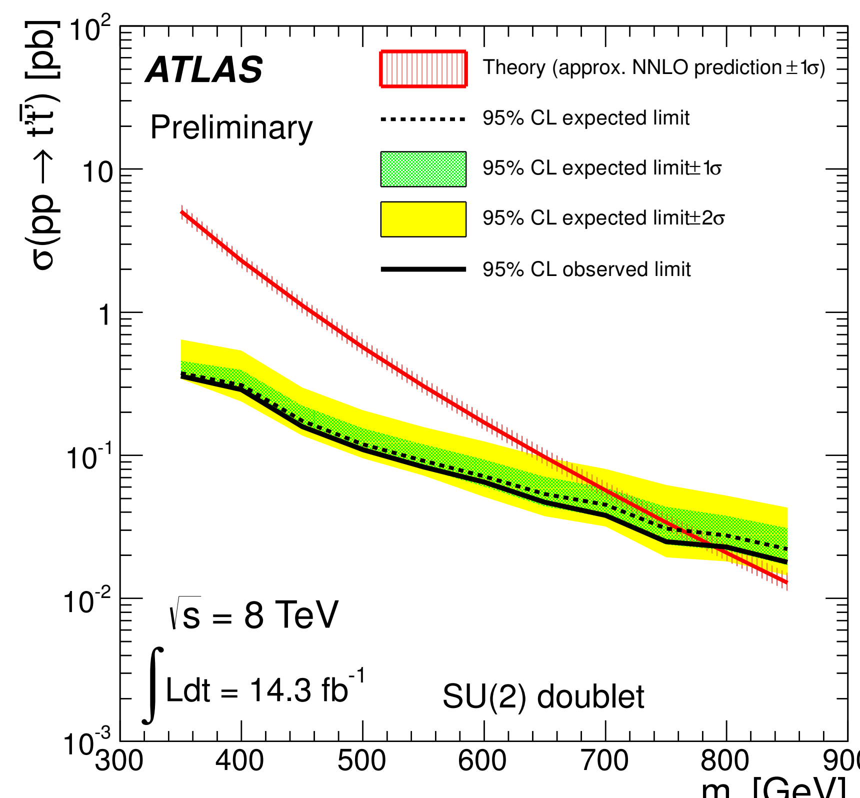
$\int L dt$ = **14.3 fb^{-1}** *(2012)*

$t'\bar{t}' \rightarrow Ht H\bar{t}, ZtHt$ and $WbHt$ & $H \rightarrow bb$

- 1 isol. (e,μ), symmetric E_T and m_T^W + E_T cuts, **≥ 6 central jets,** ≥2 b-tag
- **Data-driven *tt + heavy/light jets*** *(norm, scale factors by fit to low b-tag, H_T regions),* ***W+jets*** *(norm from charge asymm.) and* ***multi-jets bkg***
- **Build H_T** = $\sum |p_{T,jet}| + E_T^{miss} + p_{T,lep}$ ←*more energetic leptons and jets in t' signal*) in *2,3,≥ 4b-tags*
- **Dominant syst in bkg yield***: tt+HF content, b/c-tag, JES, phys modeling*
- No excess →**95% CL upper limit for *σ* (t't') *and BR(t'→Wb) vs BR(t' →Ht) from lkl ratio for* H_T including syst + constraining tt+light/HF jets norm. as *nuisance par.***

Weak-isospin doublet (singlet) t' with **$m_{t'}$ < 790 (640) GeV are excluded at 95%CL**



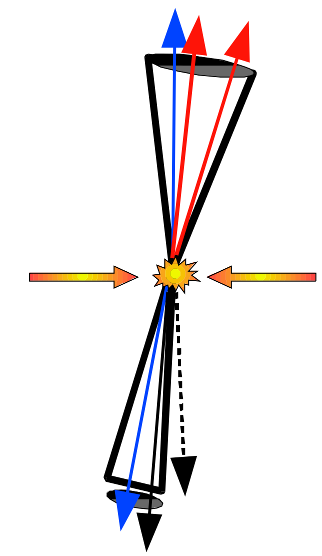


"Boosted" Search for excess in tt production vs M_{tt} -*all had*

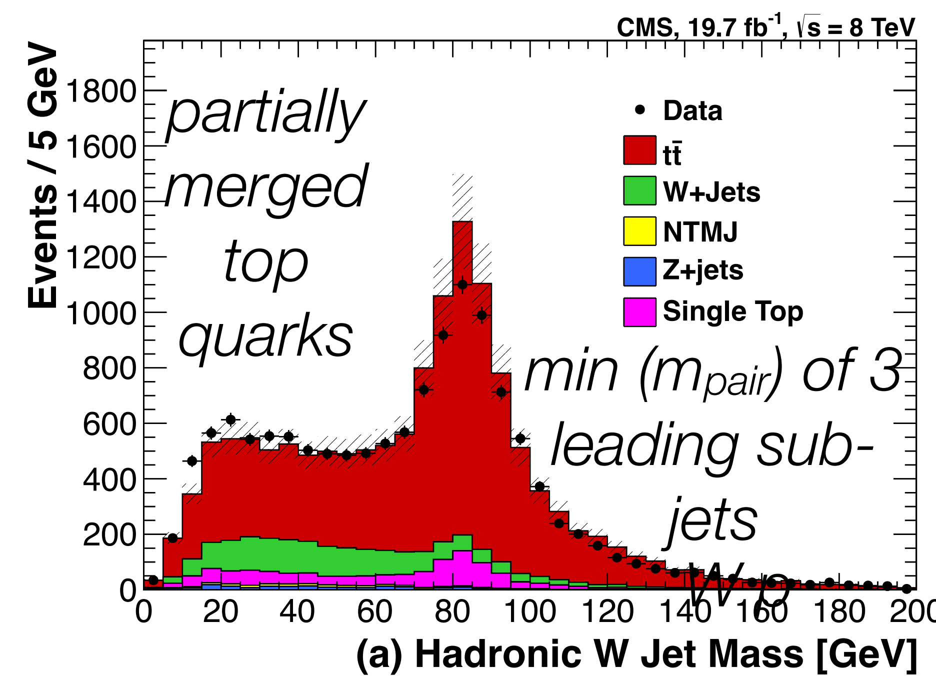
qqqq**bb** [Phys. Rev. Lett. 111 (2013) 211804](#)

- *trigger: Sum p_T R=0.5 anti-k_T jets >750 GeV*

- ***"1+1"***: **2** fat (R=**0.8**) Cambridge-Aachen **(CA) jets**
  - **p_T>400 GeV & back-to-back (|Δϕ|** *>π/2)*
  - **top-tagged** (*m_{jet} ~m_{top} ,$N_{sub\text{-}jets}$ after p_T-based declustering = 3 or 4, min($m_{2\ sub\text{-}jets}$) > 50 GeV*)

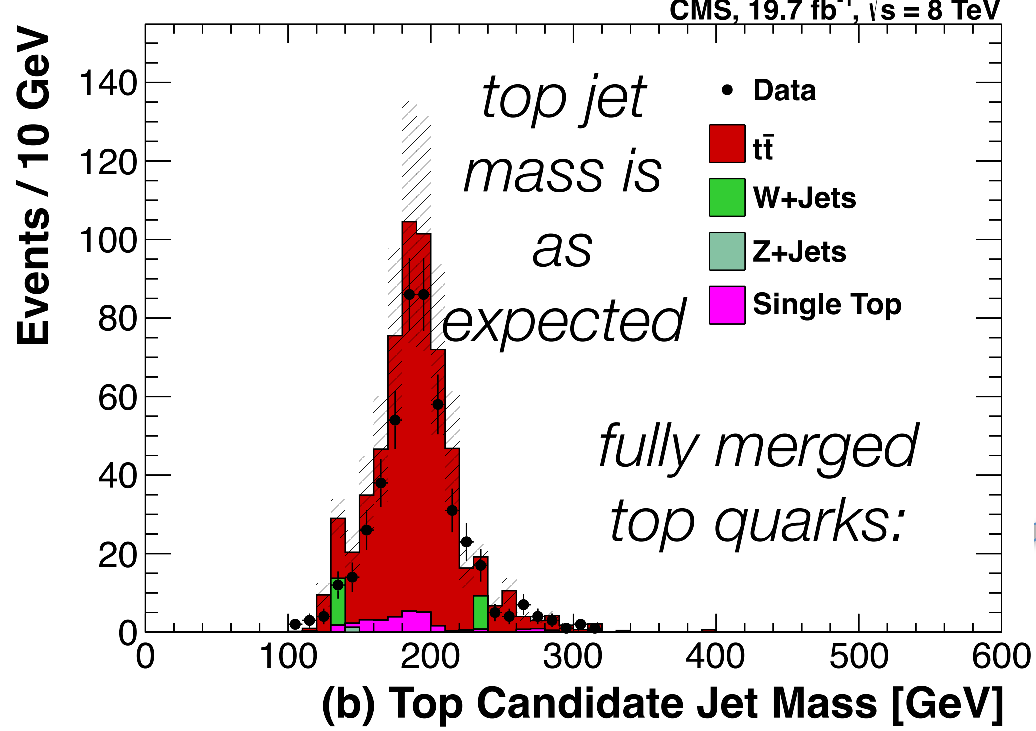


∫Ldt = **19.7fb⁻¹**
(2012) √s=8 TeV

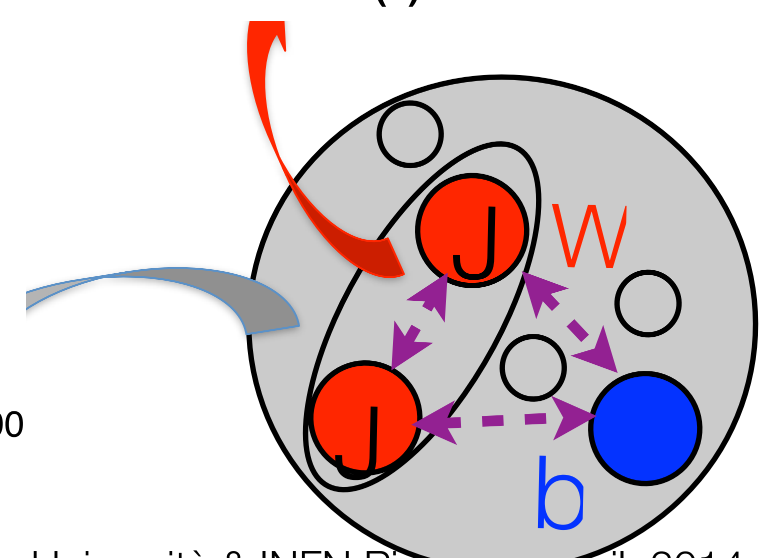


validatiom i**n mu+jets** sample with leading jet with p_T>200GeV

JES scale for subjets & jets with W peak, W sel eff



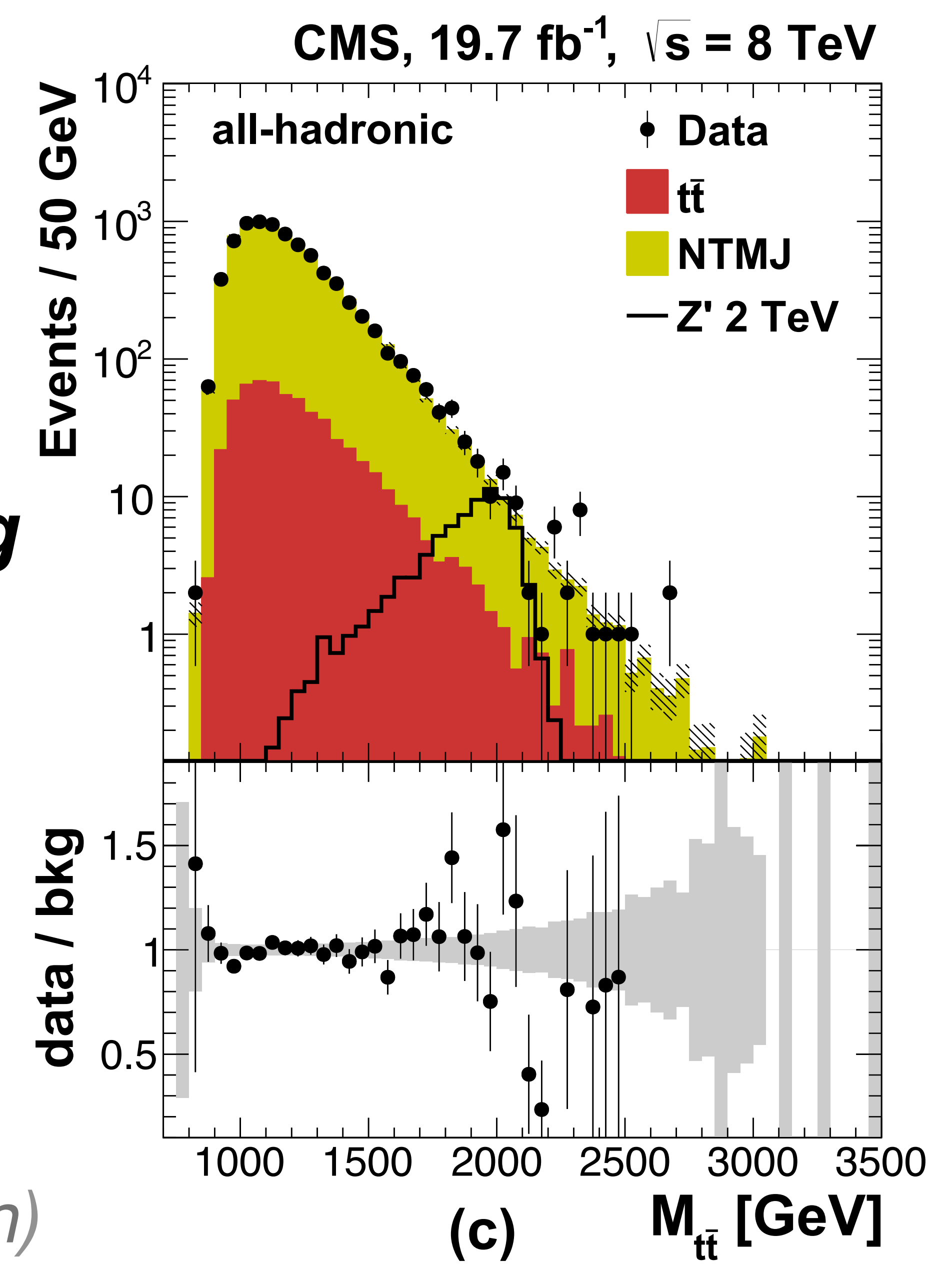
- ***"1+2"*: ≥3 R=0.8 CA jets**
  - **leading top-tagged jet** with **p_T>350 GeV**
  - **2nd**(3rd) **pruned** *(discard soft,wide-angle clusters)* **jet** with **p_T>200 (30**) GeV, **large Δϕ**$_{>2.1(1.7)}$ **from 1st**
  - **j2 is W-tag** (*m_{jet} ~m_W ,2 sub-jets,max($m_{sub\text{-}jet}$)/m_{jet} <0.4),* **m(j2,j3)~m_{top}**



“Boosted” Search for excess in $t\bar{t}$ production vs $M_{t\bar{t}}$ -*all had*

$\int Ldt$ = **19.7 fb^{-1}** *(2012)* $\sqrt{s}$=8 TeV   qqqq**bb**   Phys. Rev. Lett. 111 (2013) 211804

- Data-driven **Non-Top Multi-jet (NTMJ) bkg**
  - *in events with 2 leading fat jets with p_T >400 GeV + **1** (random) **inverted top-tag** (min(m_2 sub-jets) <30 GeV): count number of times other jet is top-tagged → **prob. to mis-top-tag light parton jet vs jet p_T***
  - *in events with 2 leading fat jets with p_T >400 GeV + **1** (random) **top-jet: apply mis-top-tag rate as function of non-top-tagged jet p_T***
    - ***set mass of non-top-tagged jet to random value** from simulated NTMJ ← vs kine bias as $m_{top\text{-}jet}^{sig\ region}$ > $m_{non\text{-}top\text{-}jet}^{pre\text{-}tag}$*
  - *assume no signal is present in pre-tag sample → correct by subtracting simulated signal events passing NTMJ procedure*
- **tt bkg from simulation***(shape and normalization)*



- **Boosted M_{tt}: mass of four momentum sum of two top-tagged jets**

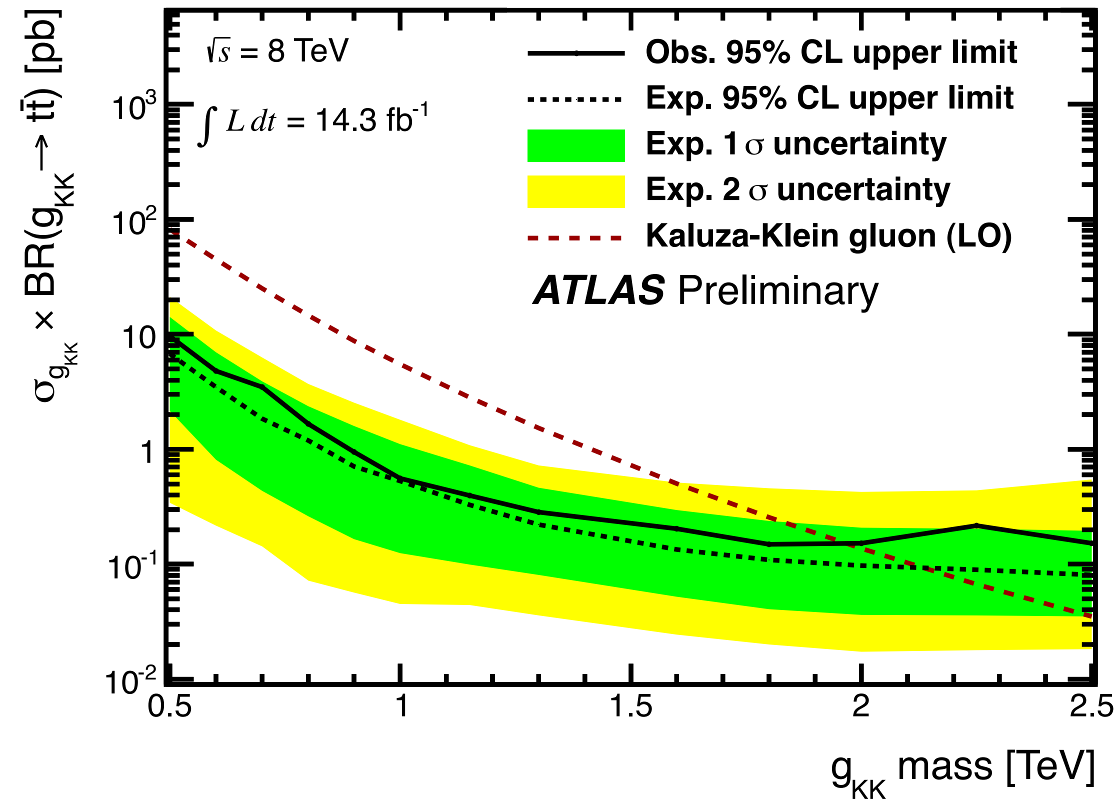
Search for excess in $t\bar{t}$ production vs M_{tt} -single lepton

$\int Ldt$ = **14.3 fb^{-1}** *(2011)* $\sqrt{s}$=*8TeV*

A=ATLAS,C=CMS

ATLAS-CONF-2013-052

- ***ATLAS***: Limit on **KKGluon *σ*BR* (with Γ_{KKG}/m_{kkG} ~ 15%) 0.56 pb** *($m_{kkG'}$= 1 TeV)* **to 0.15 pb** *($m_{kkG'}$=2.5 TeV)*



KK Gluons with **500 GeV < m_{kkG} < 2.0** *(A)* **, m_{kkG} < 2.5 TeV** *(C)* **are excluded with 95%prob**

Phys. Rev. Lett. 111 (2013) 211804

CMS

Spin-zero resonance:

Mass	Limit
500 GeV	0.8 pb
750 GeV	0.3 pb

Non-resonant enhancement:**ratio S** = (SM + BSM tt) / (SM tt)

Limit for $m_{t\bar{t}}$ > 1TeV: **S < 1.2 at 95% CL** with credible interval of 1.1-2.0 at 68% CL

Prospects for resonance searches (II)

- Perform parallel differential cross section measurements: complementary to specific searches

- Trigger: maximize collection of larger data set with dedicated boosted triggers (iso/non-iso/mini-iso lepton+jets, fat-jet)

- Selection & Reco:
  - **use boosted configuration to enhance selection efficiency** at highest top quark p_T. **Include more performant top taggers**
  - low tt mass: **use matrix element techniques** to get a handle on comb bkg

- Stat: reduced with higher lumi

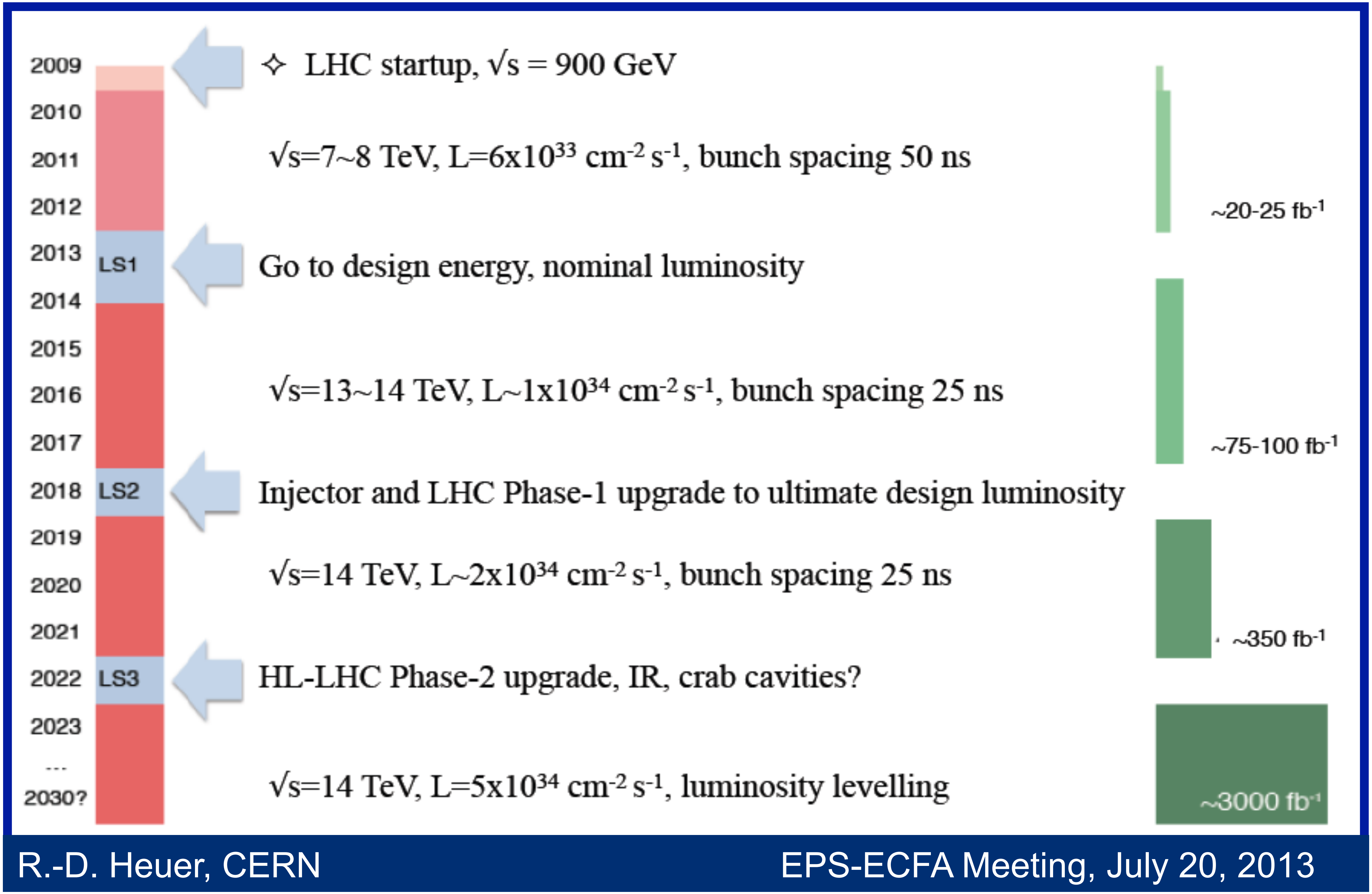
- Syst: use differential information

The close future

tt cross section prospects for 13 TeV

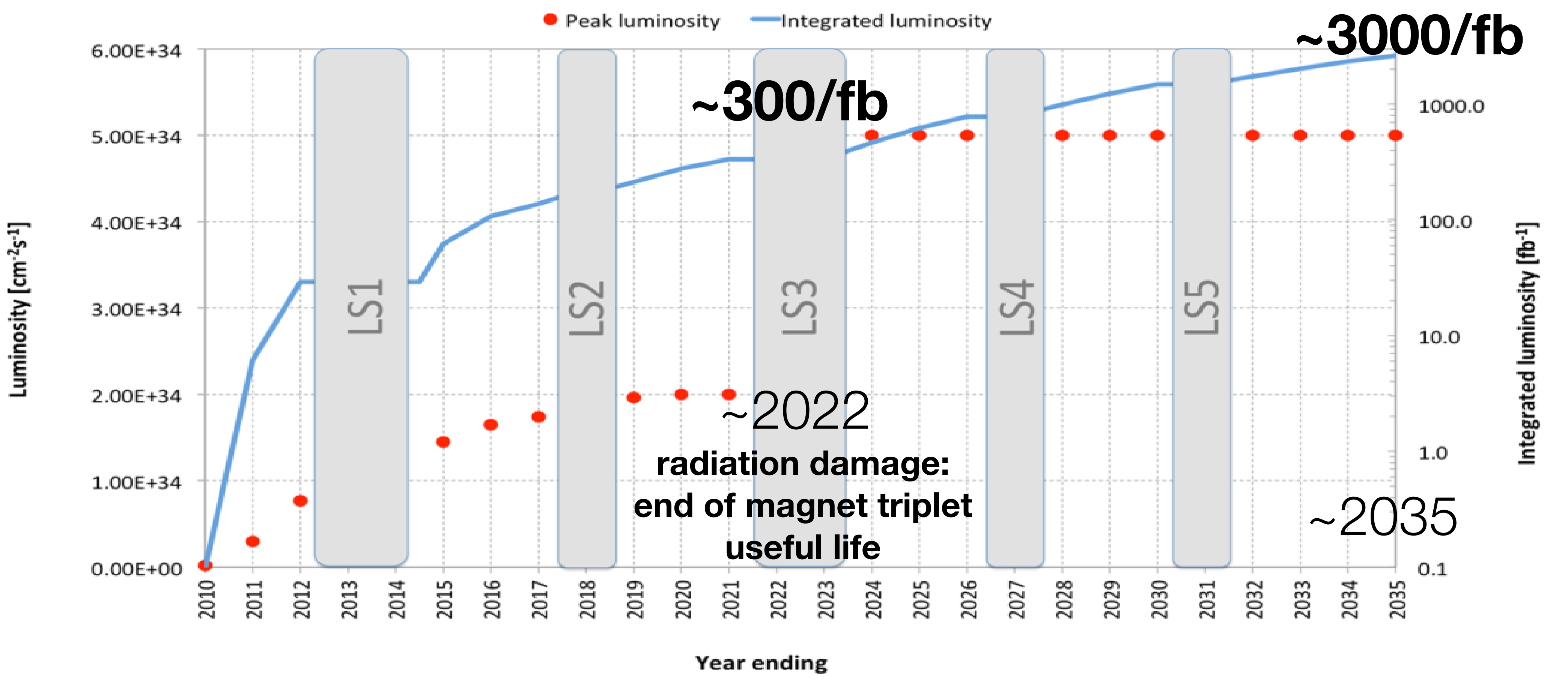
- Increase in luminosity & cross section will enhance signal, backgrounds, possibly better S/B; even though samples are already extremely pure
- More **particle level** vs parton level **measurements**
- Combination will improve uncertainty by using uncorrelated uncertainties
- Measurements are dominated by systematic uncertainties 2 strategies
  - **Use larger data sample to reduce syst uncertainties,**
    - ❖ generator modelling: crucial harmonization in LHC to achieve combined result
    - ❖ ISR/FSR
    - ❖ Fragmentation: tune simulation/hadronization models/
    - ❖ improve PDF measurements particularly high x gluons and feed-it back
    - ❖ **de-sensitize analysis to sys uncertainty**
- differential cross section
  - increase in data size plays crucial role to allow testing low cross section regions
  - **focused syst studies as above in each diffxsec bin interplay with bin and unfolding optimization**
  - enhance selection efficiency in higher, boosted configuration by tagging scheme

LHC: beyond 2015



The plan of HL-LHC (baseline)

Frédérick Bordry,ECFA HL LHC ExpWorkshop October 2013



Levelling at 5 10^{34} cm^{-2} s^{-1}: 140 events/crossing in average, at 25 ns; several scenarios under study to limit to 1.0 → 1.3 event/mm

(“Pile-up at HL-LHC and possible mitigation” Stephane Fartoukh on Wed. 2nd Oct.)

Total integrated luminosity of 3000 fb^{-1} for p-p by 2035, with LSs taken into account and 1 month for ion physics per year.

The High Luminosity LHC
Frédérick Bordry
ECFA High Luminosity LHC Experiments Workshop – 1st October 2013

36

- **LS1 [2013-2014] : 1st beams in 2015**
- **Run 2 : 13 TeV – 25 ns – up to 1.7 10^{34} $cm^{-2}.s^{-1}$, 40-45 fb^{-1} per year**
- **LS2 (higher intensity - LIU) [2018 or 2019]**
- **Run 3 (up to ~2.0 10^{34} $cm^{-2}.s^{-1}$)**

300 fb^{-1} before LS3

HL-LHC: start construction in LS2 (2018) (cryo & collimators), install hardware in LS3 (~2022)

Summary of prospects for underlying picture

Run 1: $\sqrt{s}$ =7/8 TeV

Run2 and beyond ($\sqrt{s}$ = 13/14 TeV)

- L = 20/fb (5/fb) @ $\sqrt{s}$=8 (7)TeV

increased E_{CM} , lumi & data/set

- ***∫Ldt*** ~90/fb by 2018, **~300/fb** by 2020**: O(250 M) tt events**, ~3000/fb by 2035
- **Larger xsec increase for gg→X** dominated processes, **more at high multi-TeV masses** ~up to O(100)

- <μ>~20

Higher pile-up

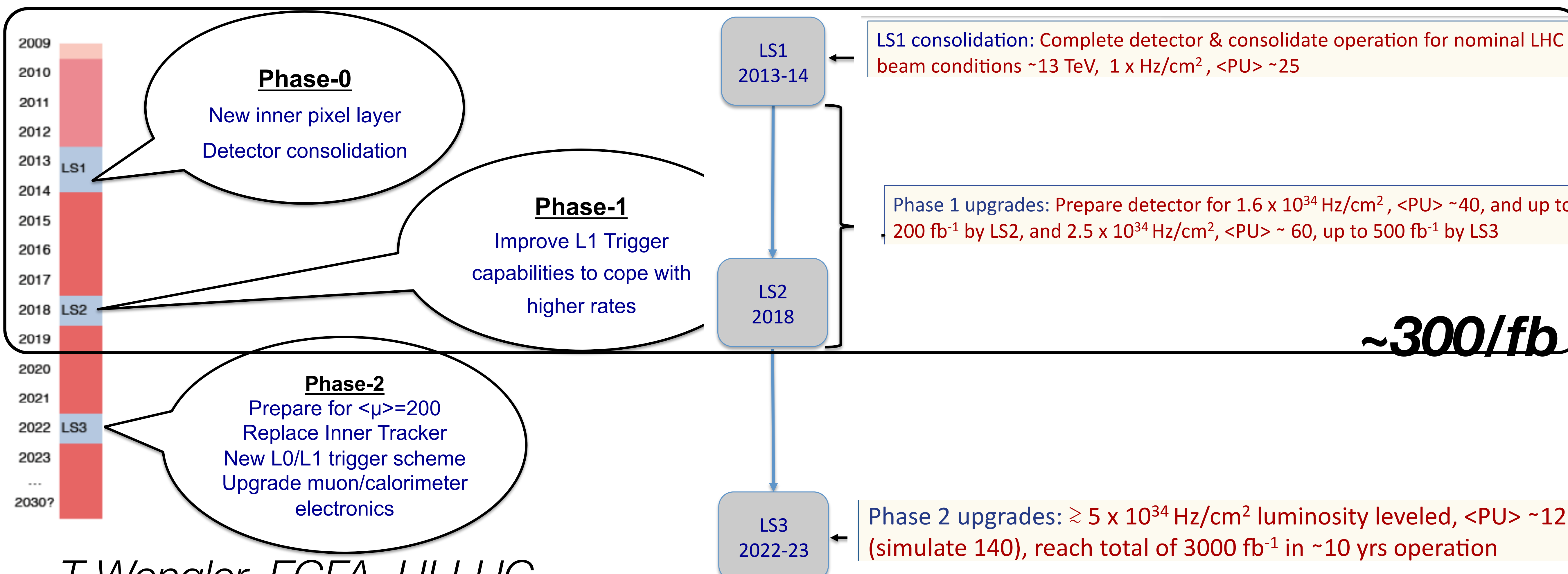
- <μ>~140
- **higher rates** for trigger
- **Worse jet resolution** (1 GeV per vertex), larger jet multiplicity
- **Worse b-tagging performance**, fake primary vertex, pile-up & fake tracks

ATLAS & CMS in run 2 & beyond

- The first detector requirement is easy to state
  - *Have one that is not dead*
- Due to radiation damage, LHC detectors will **not survive beyond ~500 fb^{-1}**
  - *Must **replace** inoperable elements*
    - **Tracking detectors, endcap calorimeters (CMS)**
  - *Must **upgrade** electronics to cope with increased rates (esp. trigger)*

C. Hill. et al.
ECFA HLLHC
Workshop Oct 2013

ATLAS — CMS



T Wengler, ECFA HLLHC workshop, Oct2013

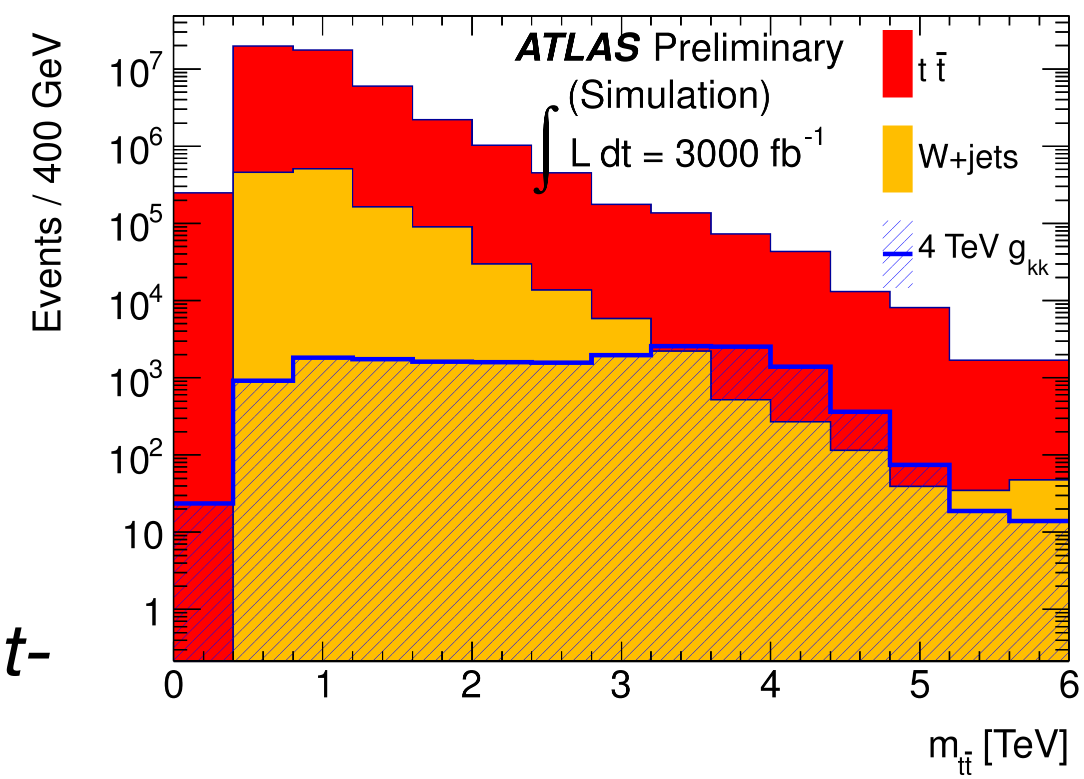
J Spalding, ECFA HLLHX Workshop , Oct 2013

Prospects for resonance searches (I) ‣ATLAS-PHYS-PUB-2013-003

- Upgraded ATLAS fully simulated events with **high pile-up (<μ>=140)** at **$\sqrt{s}$=14 TeV** up to **$\int Ldt$= 3000/fb**

Simplified ATLAS boosted l+jets sel.

- *exactly* ***1 good, high p_T central lepton firing trigger***
- *≥ 1 anti-k_T (R=1.0) jet.* ***large p_T*** *≥ 250 GeV,* ***large m_{jet}****>120 GeV, →* ***lead "fat" jet is had top***
- *≥ 1 anti-k_T (R=0.4) jet with ΔR(jet,had t-jet)>1.0,one with highet p_T →* ***b-jet for leptonic top***
- ***tops in opposite hemisphere*** *→ ΔR(lep,had t-jet)>1.0, ΔR(lept b-jet, had t-jet)>1.5*
- *E_T^{miss}>50 GeV*



- **M_{tt}:** from had t-jet + high p_T lepton, p_z (ν) from W mass constraint, leptonic b-jet

model	300 fb^{-1}	1000 fb^{-1}	3000 fb^{-1}
g_{KK}	4.3 (4.0)	5.6 (4.9)	6.7 (5.6)
Z'_{topcolor}	3.3 (1.8)	4.5 (2.6)	5.5 (3.2)

USE STAT uncertainties ONLY inclusion of syst will reduce reach

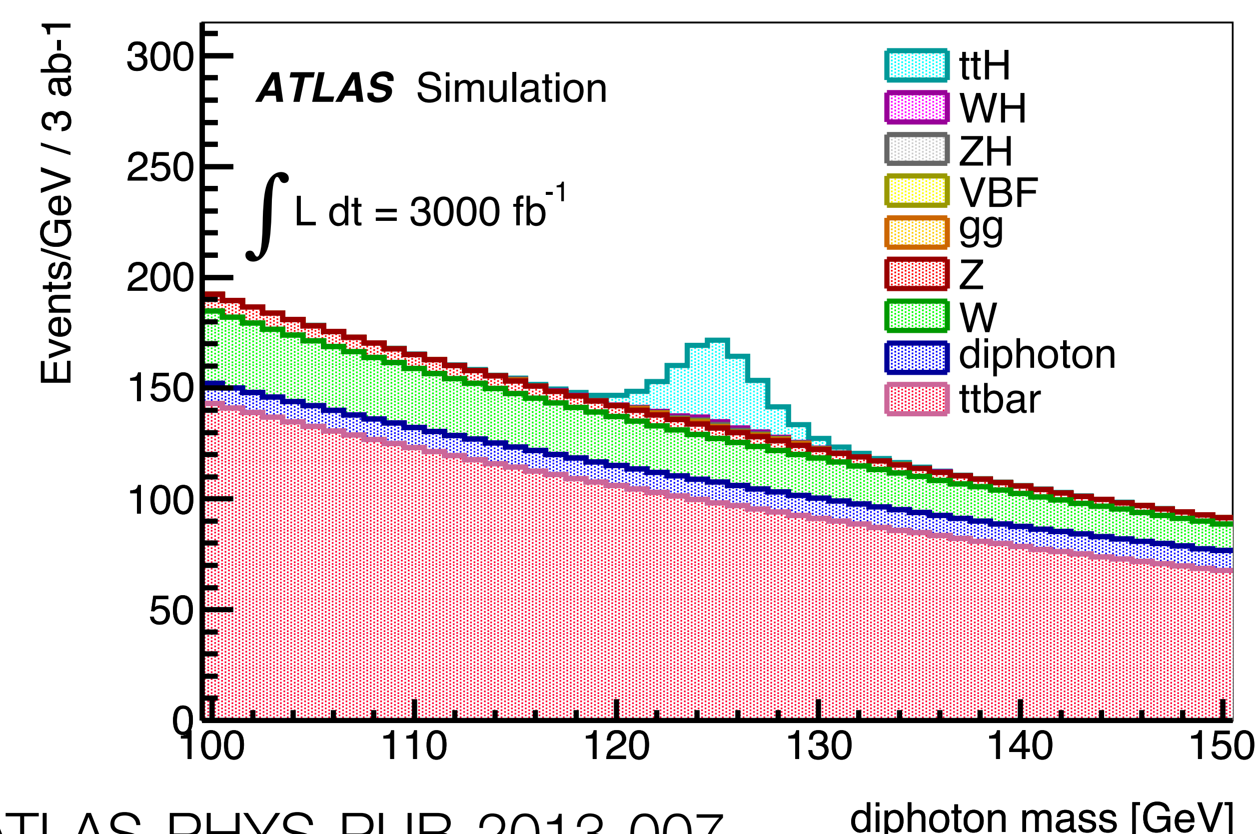
Expected limits in absence of signal, in TeV, for l+jets (dilepton) channel @14 TeV LHC

Prospects on ttH: example on

- ttH is a top target for observation at 13-14 TeV running
- First stage of run2: factor 5 improvement in stat sensitivity
  - Factor 5-6 more integrated lumi compared to run 1
  - Factor 4.7 increase in signal cross section between 8 TeV and 14 TeV
  - Bkg rise more slowly ; tt production ~ factor 3.6 increase between 8 and 14 TeV

Figure 2: Expected diphoton mass distribution in the single lepton ttH channel for $\sqrt{s}$=14 TeV and $\mathcal{L} = 3000\,\mathrm{fb}^{-1}$.

Full simulation
for 14 TeV LHC
for H**γγ**
clean signal; S/B~20%



ATLAS-PHYS-PUB-2013-007