ATLAS EXPERIMENT
http://atlas.ch

Top quark physics with the ATLAS detector @ LHC

t ?

Università "La Sapienza"- Roma
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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: going differential

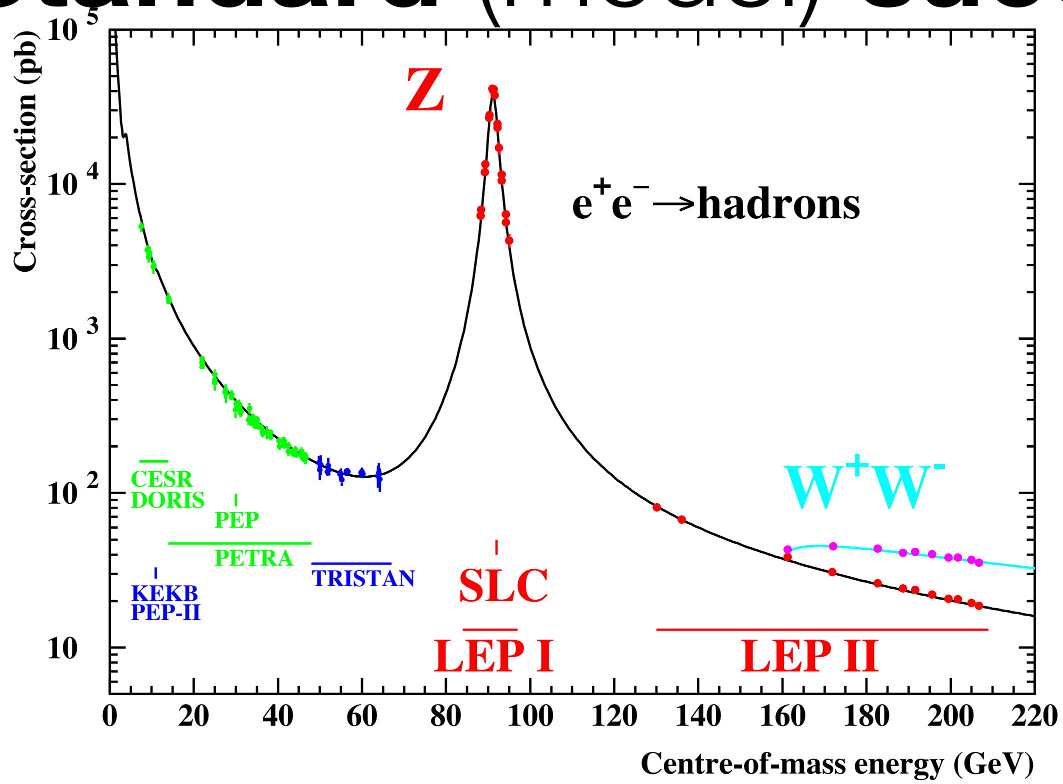
- Measuring **Top Mass**

Recent public results!

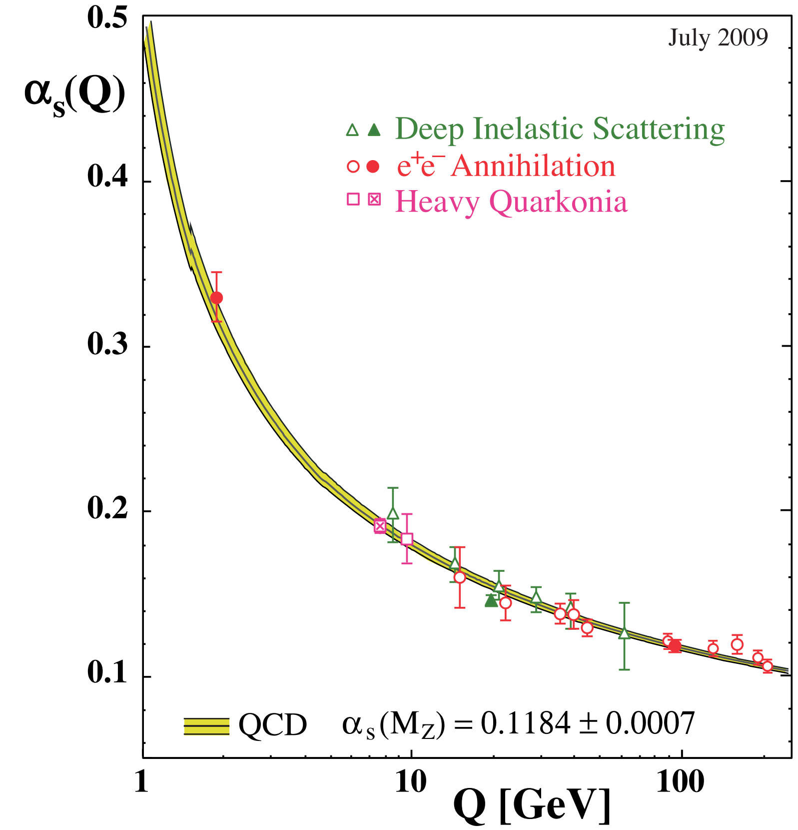
- Top and Higgs

- A view from the Top Beyond SM in Top production

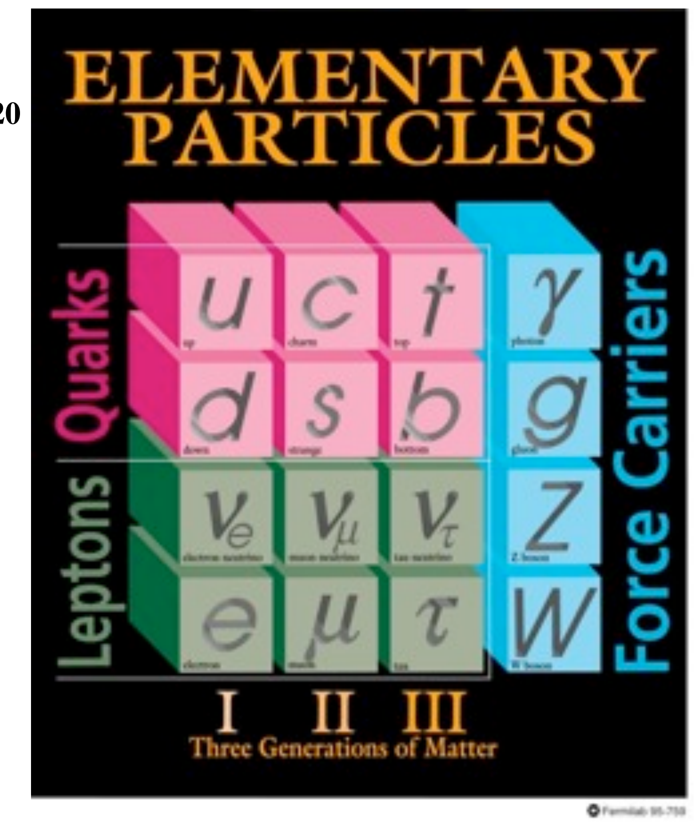
Standard (model) **successes**

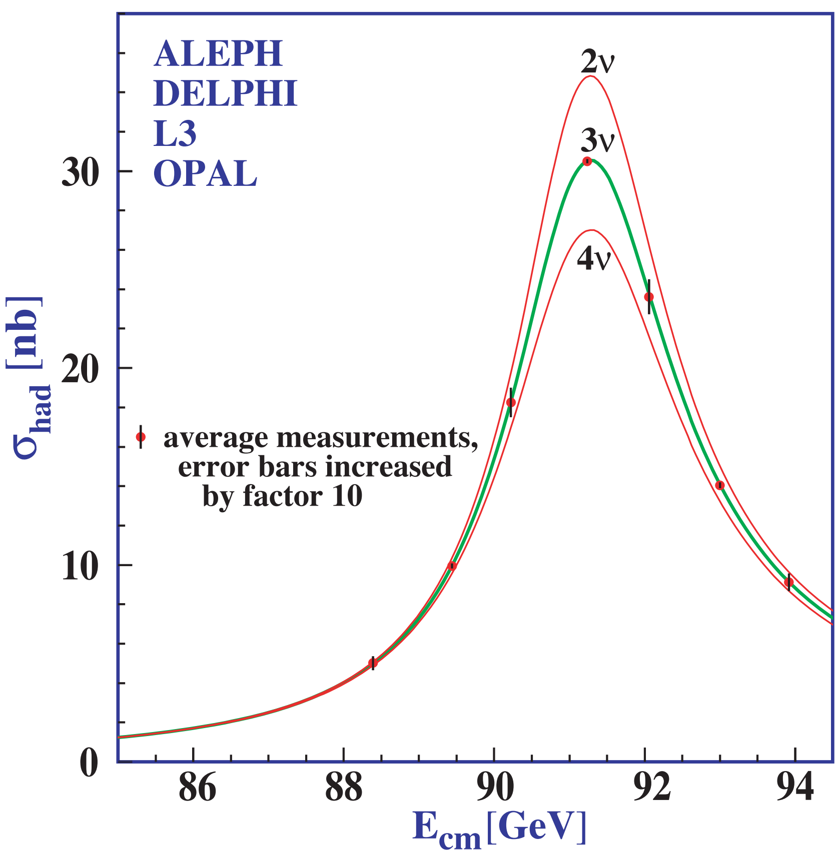


W, Z, bosons unify Electro-weak force



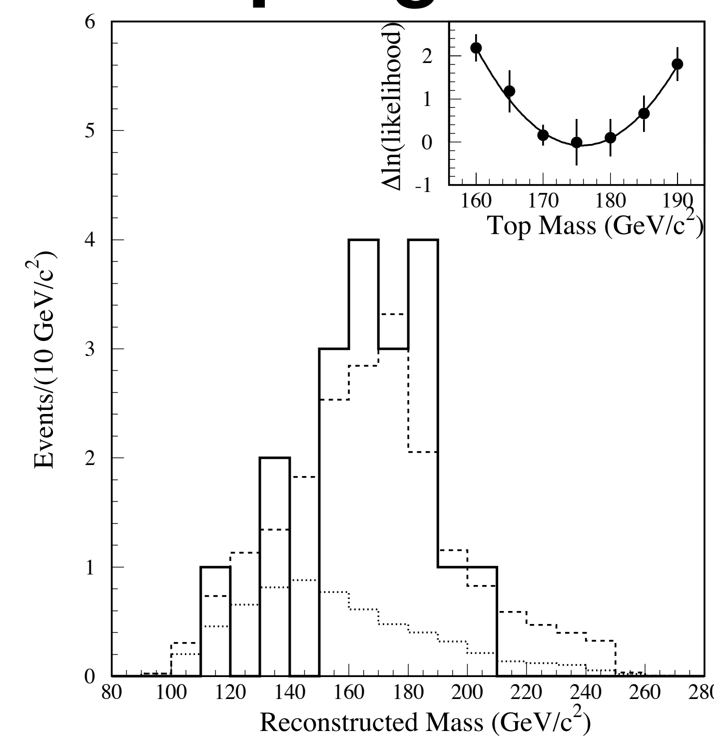
Strong coupling runs





only 3 standard neutrinos

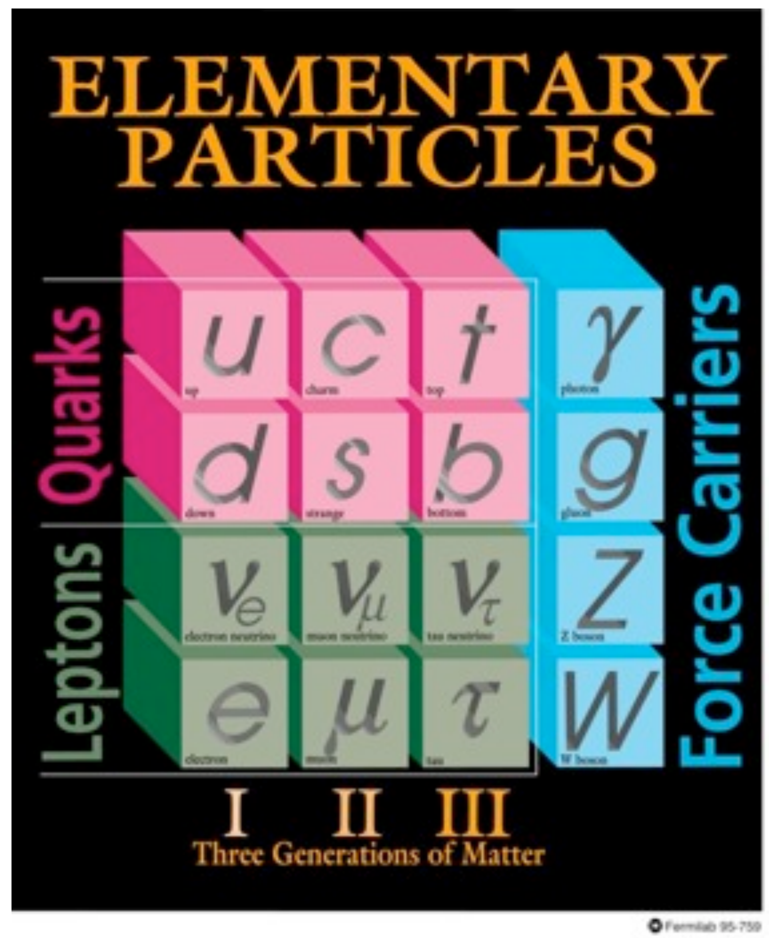
a quick (biased) selection..



Top quark is found

Standard (model) **questions**

- ***How is gravity incorporated?***
- **What is the origin of mass?**



- ***Why 3 generations with different quantum numbers ?***
- ***Why different forces (ranges, strengths)?***
- ***What accounts for the energy balance of the universe?***

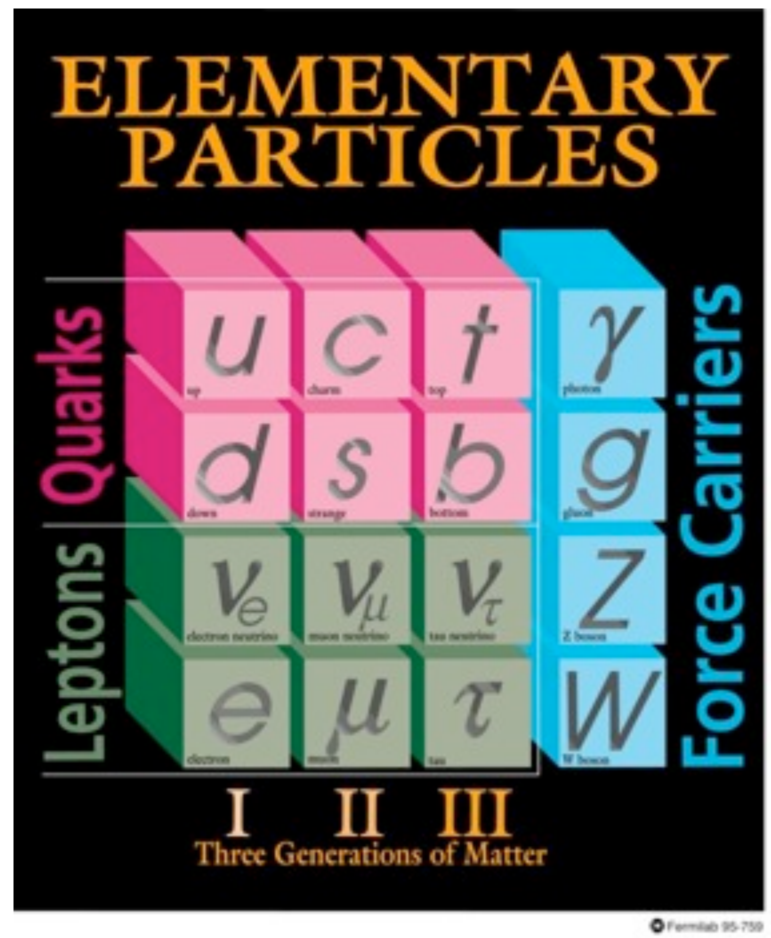
Standard (model) **questions**

- ***What is the origin of mass?***

Higgs**,** SuperSymmetry, New Strong forces..

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

Quantum gravity
Extra dimensions...



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

4th generation...?

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

String theory..

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

Dark matter, Dark energy...

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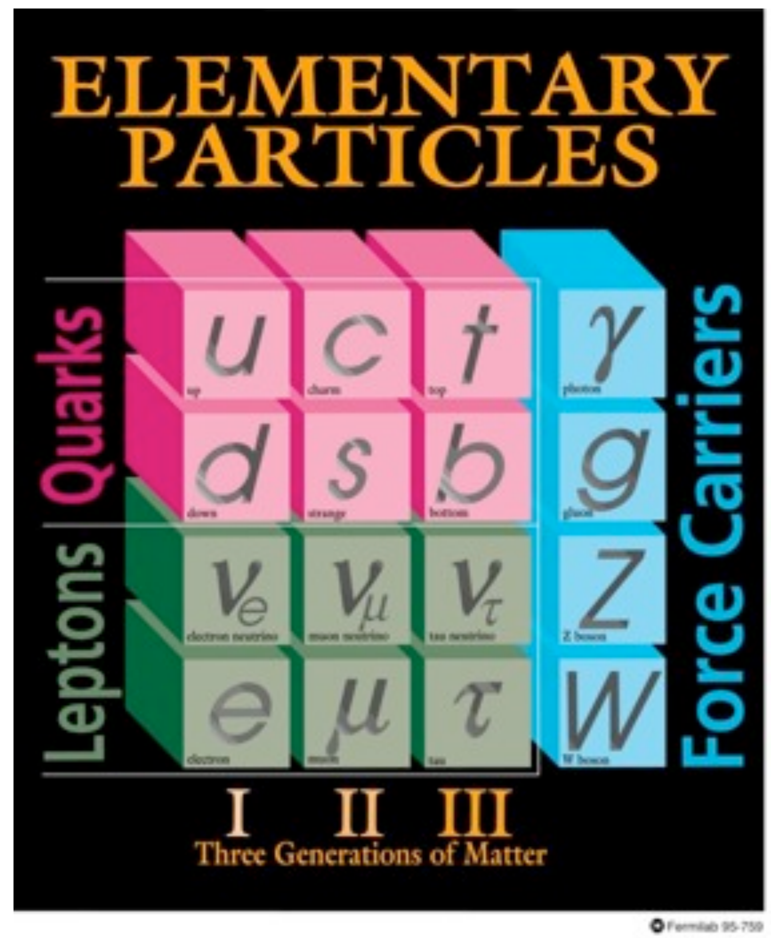

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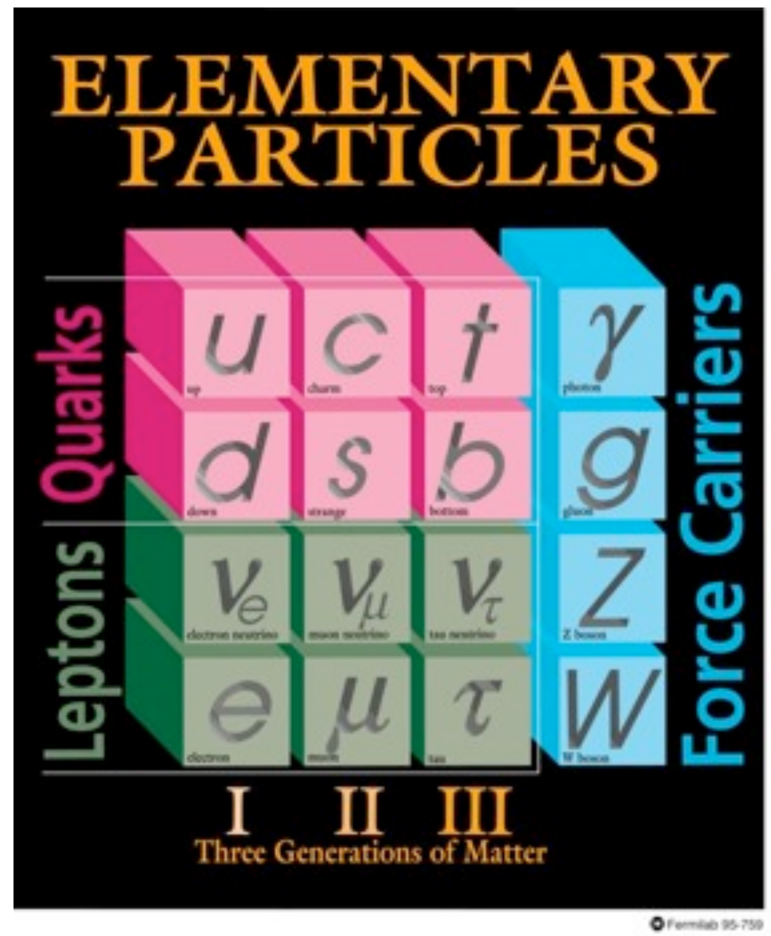

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4th generation...?

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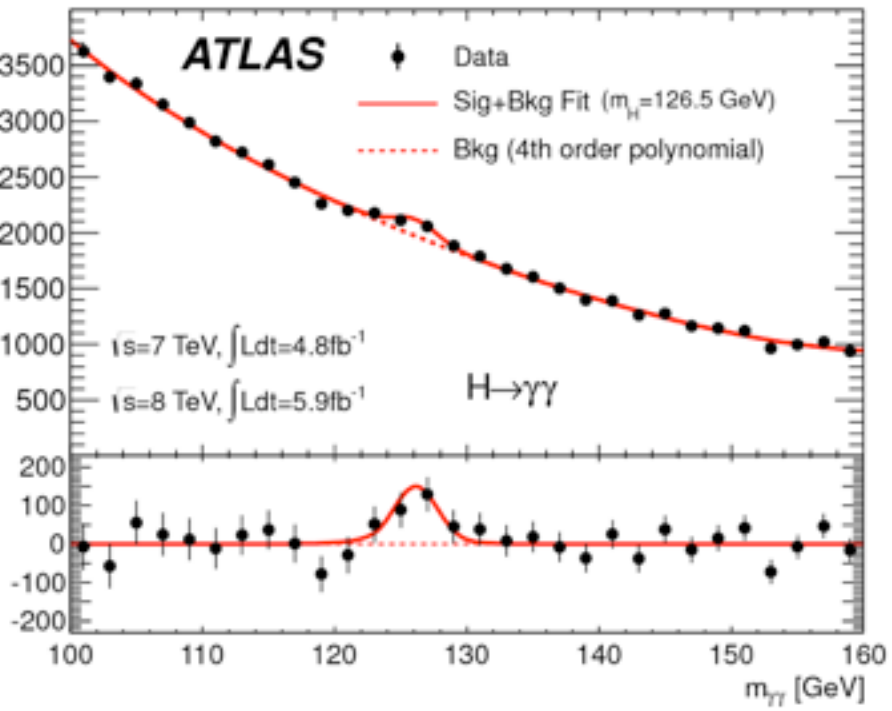
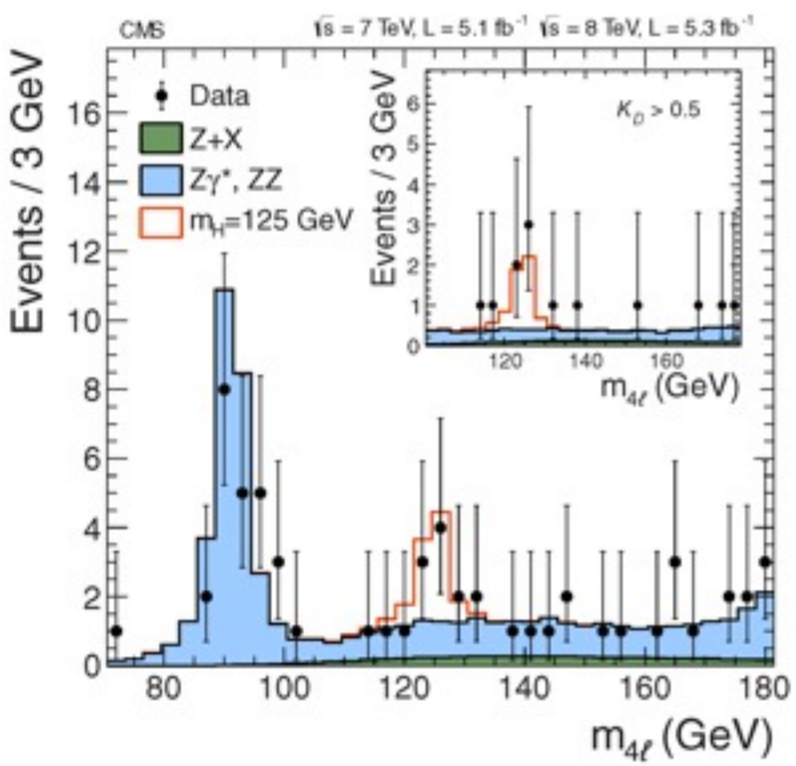
Dark matter, Dark energy...

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

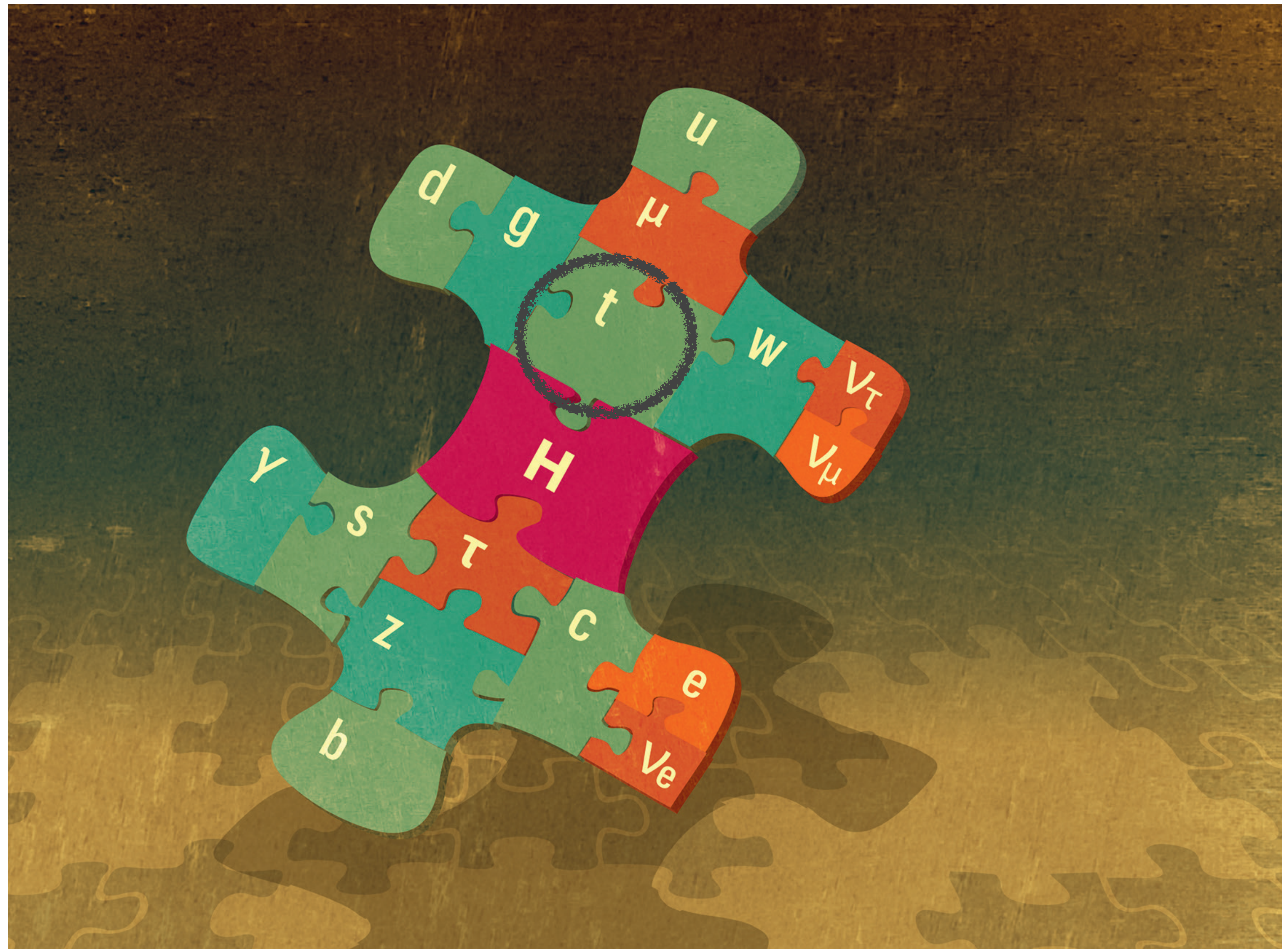
Phys. Lett. B 716 (2012) 1-29



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..

Why Top (quark)?

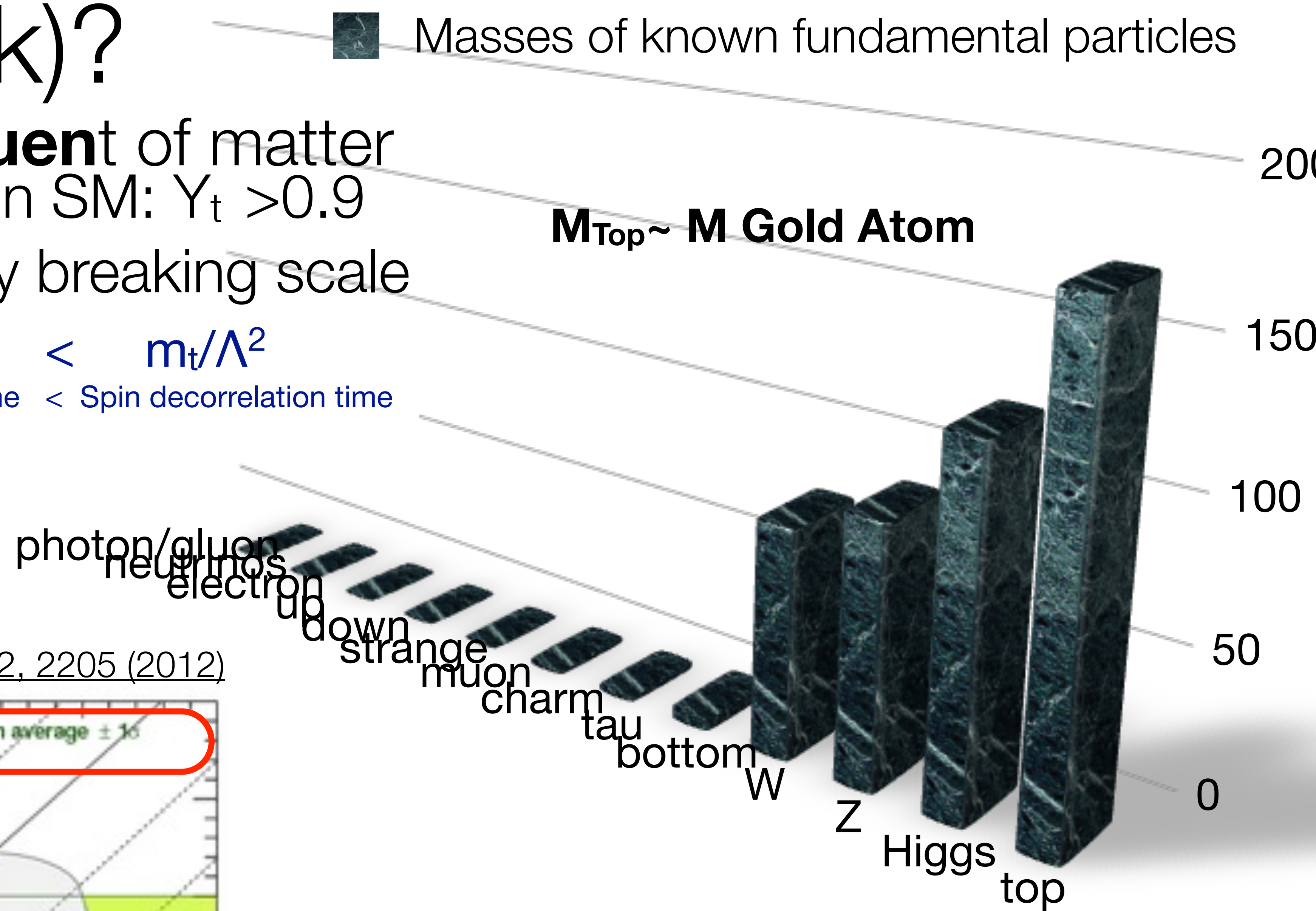
Most massive constituent of matter

Large Yukawa coupling in SM: Y_t >0.9

M_{top}~ electroweak symmetry breaking scale

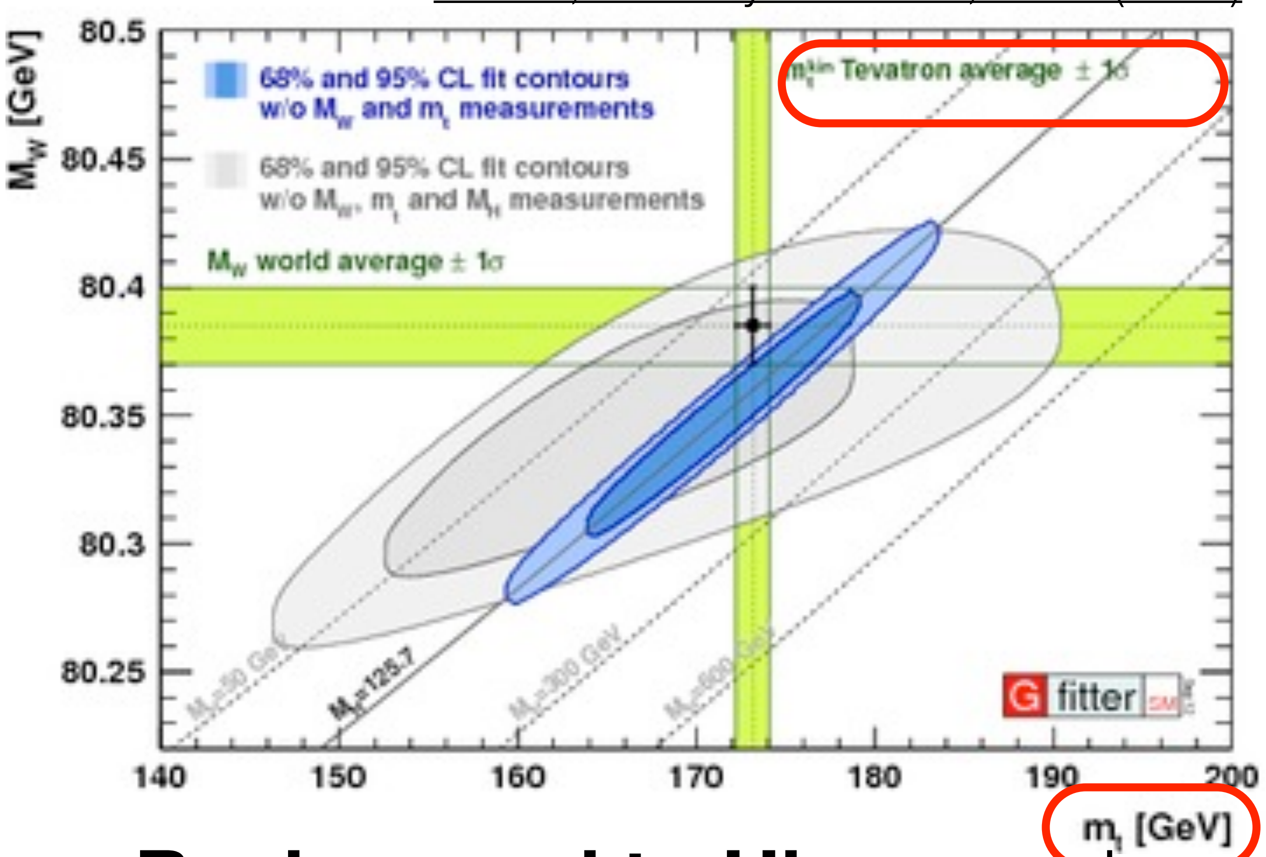
$1/m_t$ < $1/\Gamma_t$ < $1/\Lambda$ < m_t/Λ^2

Production time < Lifetime < Hadronization time < Spin decorrelation time



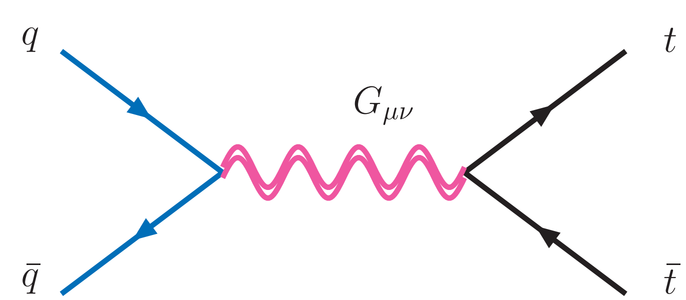
Decay and strong production rate are **tests of standard model**

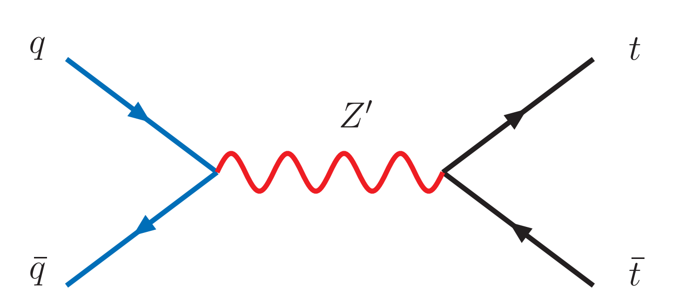
GFitter, Eur. Phys. J. C 72, 2205 (2012)



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

Various scenarios with **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

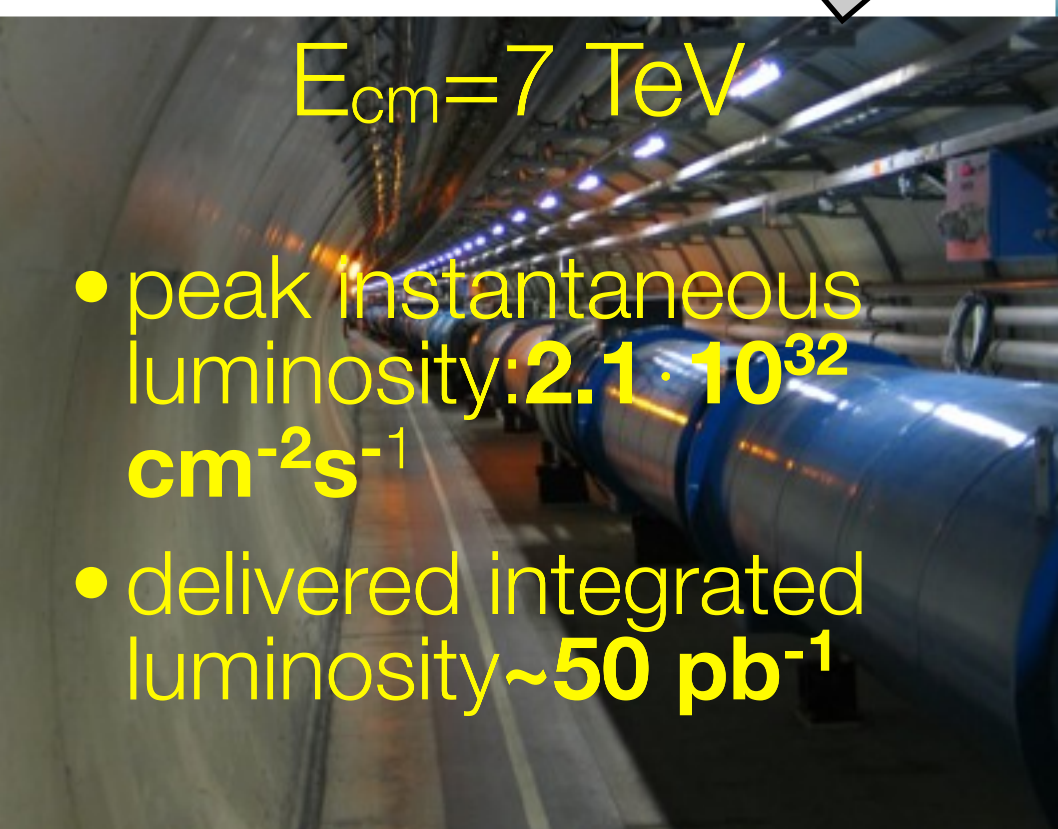
$$\mathcal{L} \propto \frac{N_1 N_2}{\sigma^2}$$

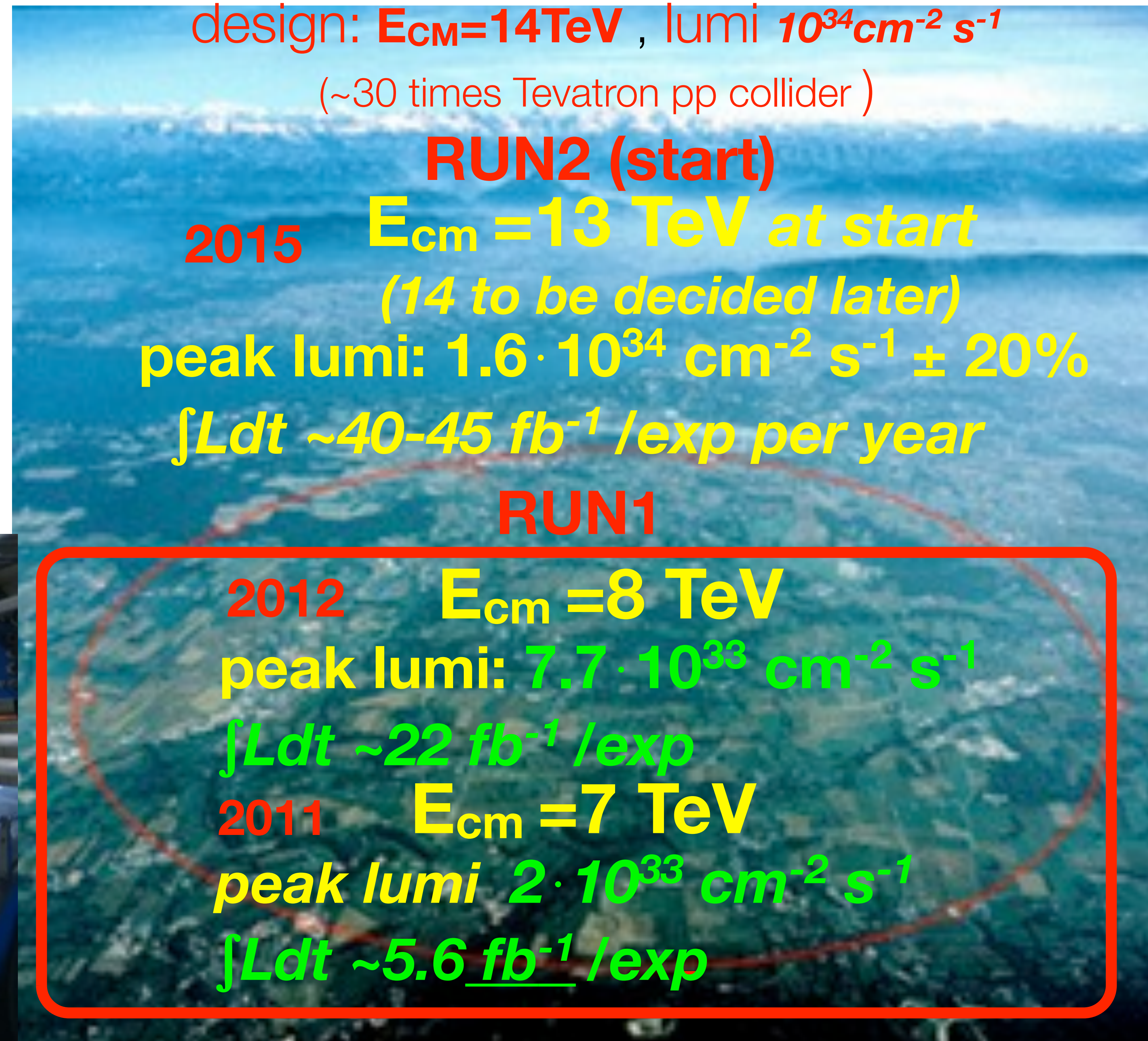
Key parameters:

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

Ad maiora..

2010

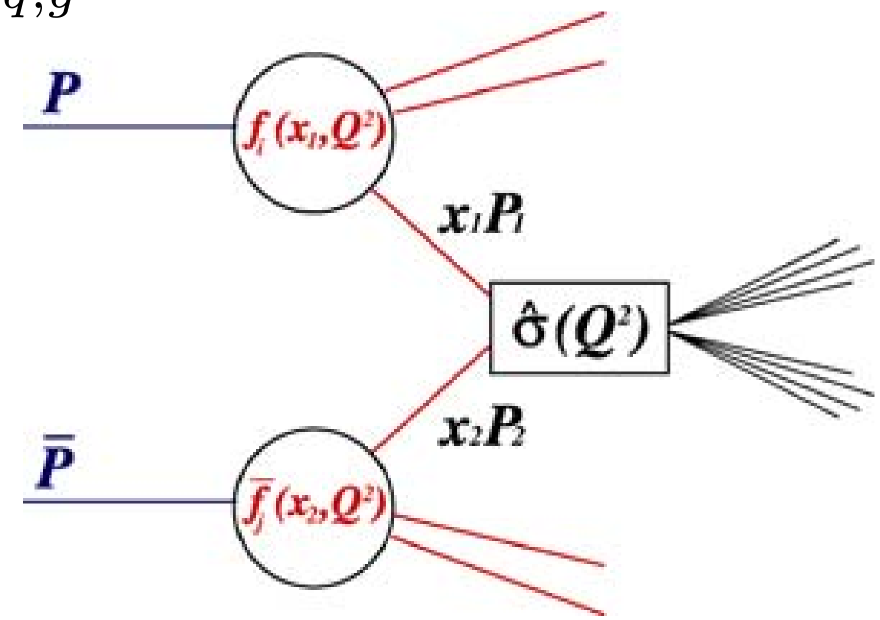




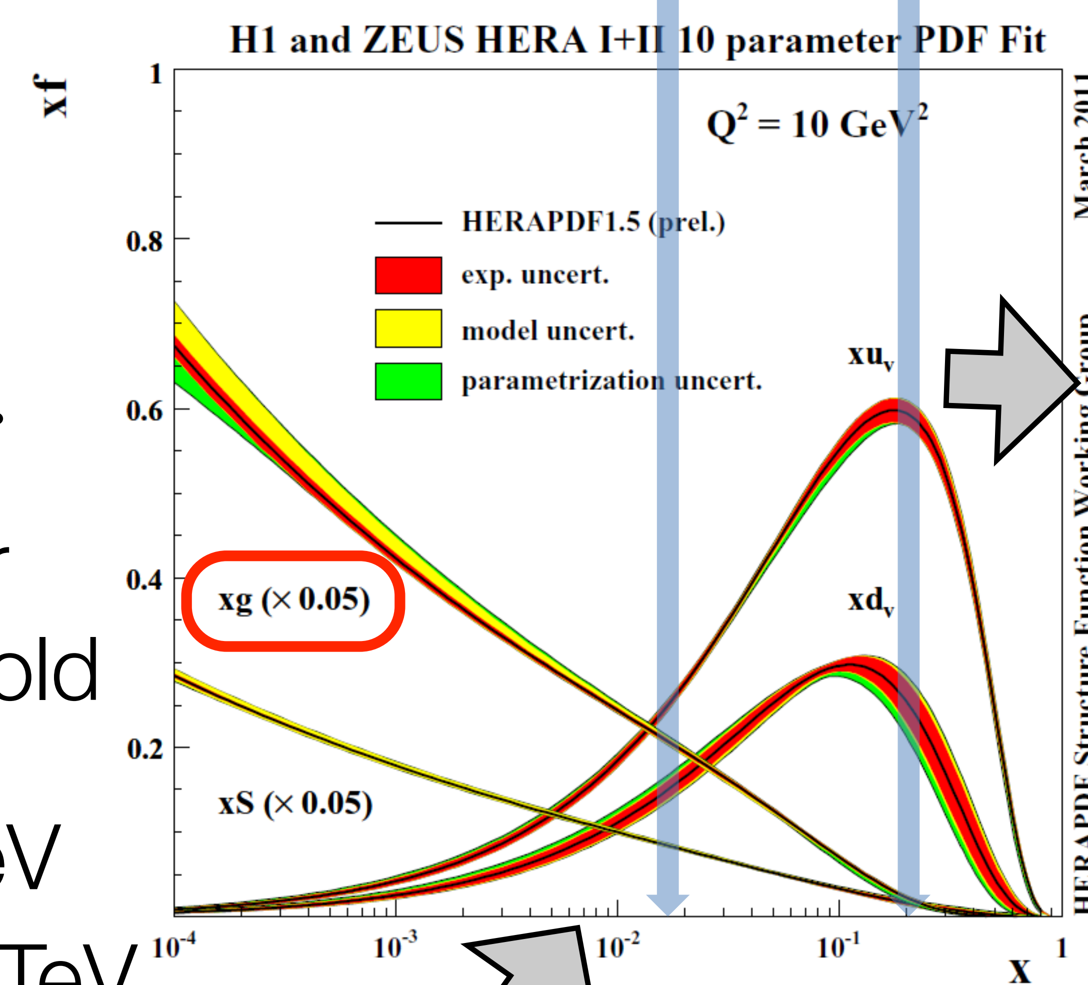
$N_{events}(\Delta t)$= ***∫Ldt*** * cross section

Top quark @ LHC: production(I)

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



	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 x ⇒ typical $x_i x_j$ near threshold

⇒ $x \approx \dfrac{2m_t}{\sqrt{s}} =$ 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

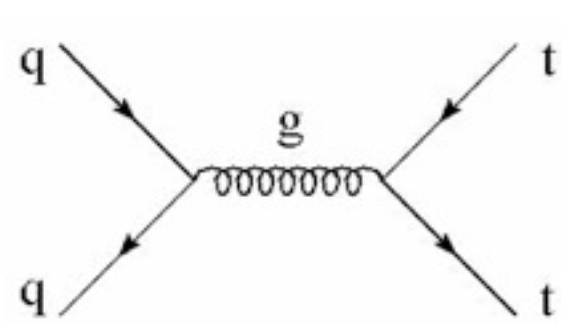
Top quark @ LHC: production (II)

probe low x in pdfs →
(abundant) gluon fusion dominated

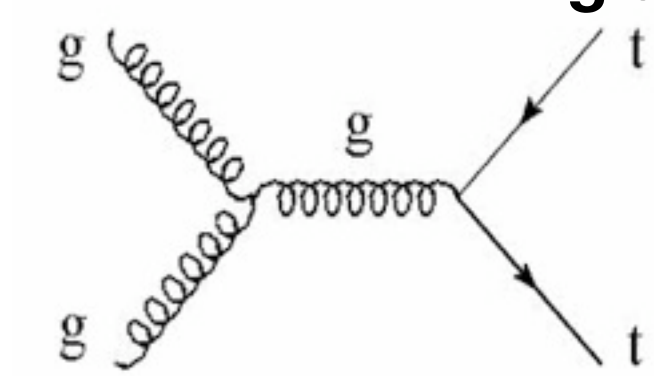
	Tevat	LHC(7)	LHC(14)
gg	~10%	**~85%**	~90%
qq	~90%	**~15%**	~10%

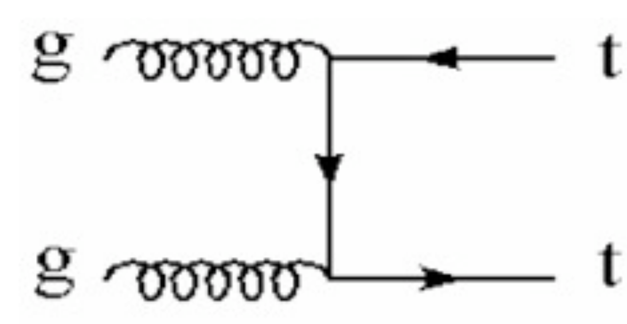
top pairs: strong

qq annihilation



gluon fusion





Czakon,Mitov,Fiedler 2013

NNLO+NNLL accuracy

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

$\sigma_{7TeV} = 172\ ^{+4.4}_{-5.8}\ ^{+4.7}_{-4.8}$ pb

$\sigma_{8TeV} = 245.8\ ^{+6.2}_{-8.4}\ ^{+6.2}_{-6.4}$ pb

scales *PDF*

PDF=MSTW2008nnlo68cl
for m_{top}= 173.3

single top: electroweak

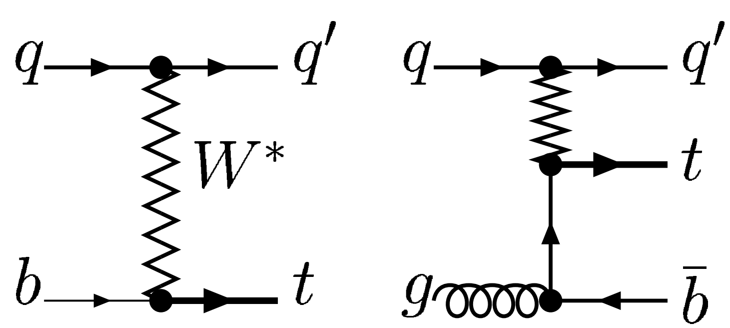
m_{top}= 172.5

Kidonakis 2010,2011

approx NNLO

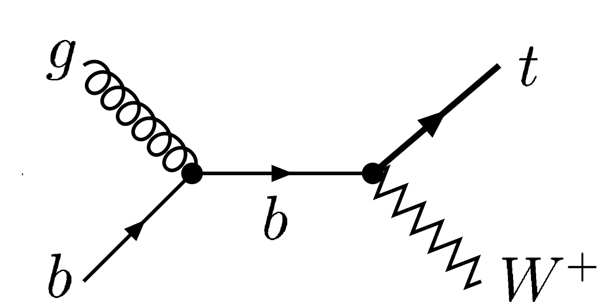
$\delta\sigma_t/\sigma_t$ ~2 to 7%

t chan



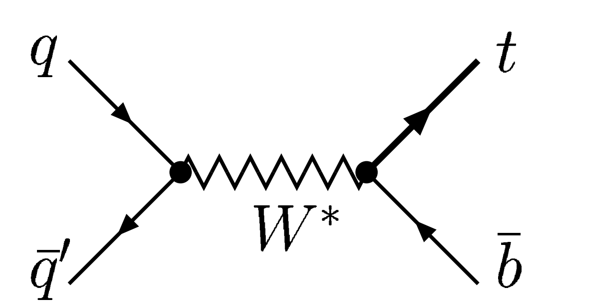
σ_{7TeV} = 64.6 ± 2.4 pb
σ_{8TeV} = 87.8±3.4 pb

Wt chan



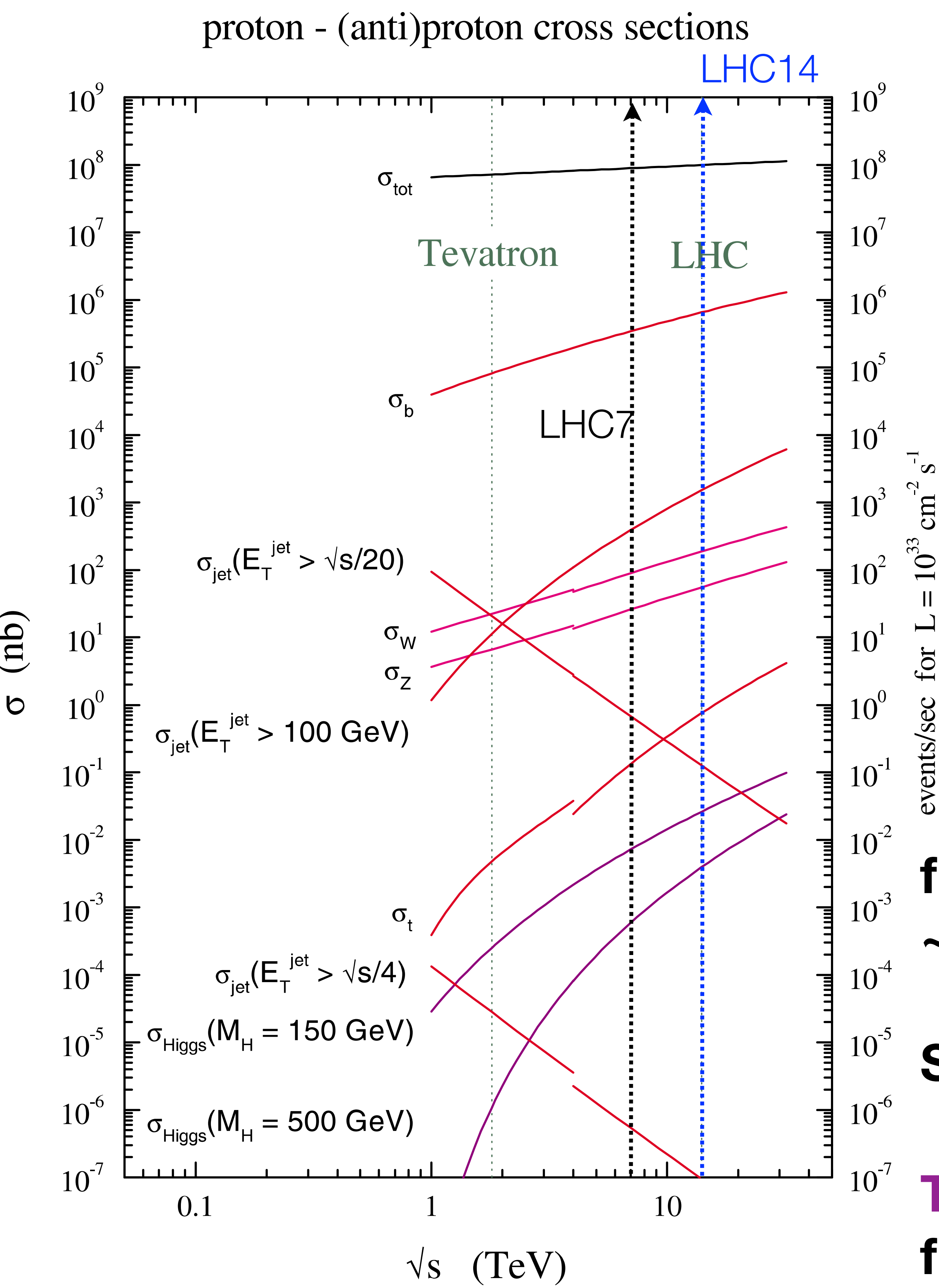
σ_{7TeV} = 15.7 ± 1.1 pb
σ_{8TeV} =22.4±1.5 pb

s chan



σ_{7TeV} = 4.6±0.2 pb
σ_{8TeV} =5.6±0.2 pb

Top @ LHC: in the context



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

√s(TeV)	$\sigma_{tt}(pb)$	$\sigma_{t}(pb)$	tt/t Rate at L= $10^{33}cm^{-2}\ s^{-1}$
1.96 (pp)	~7		
7 (pp)	~172	~65	0.16 (0.06)Hz
8(pp)	~230	~88	0.23 (0.08)Hz
14 (pp)	~900		0.9Hz

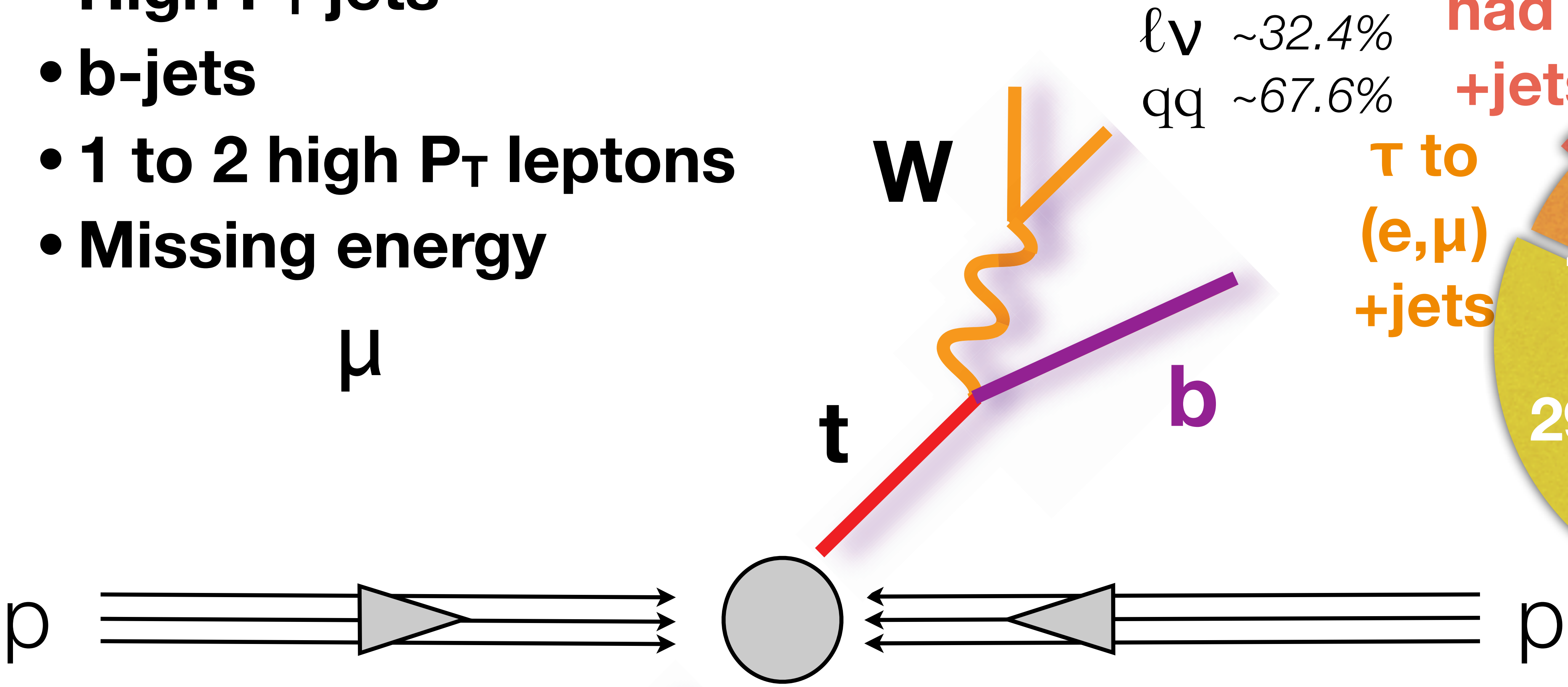
for $\int Ldt$ = 5 fb^{-1} (18fb^{-1}))@7 (8) TeV, expect ~$8 \cdot 10^5$ (~4.5 10^6)tt events

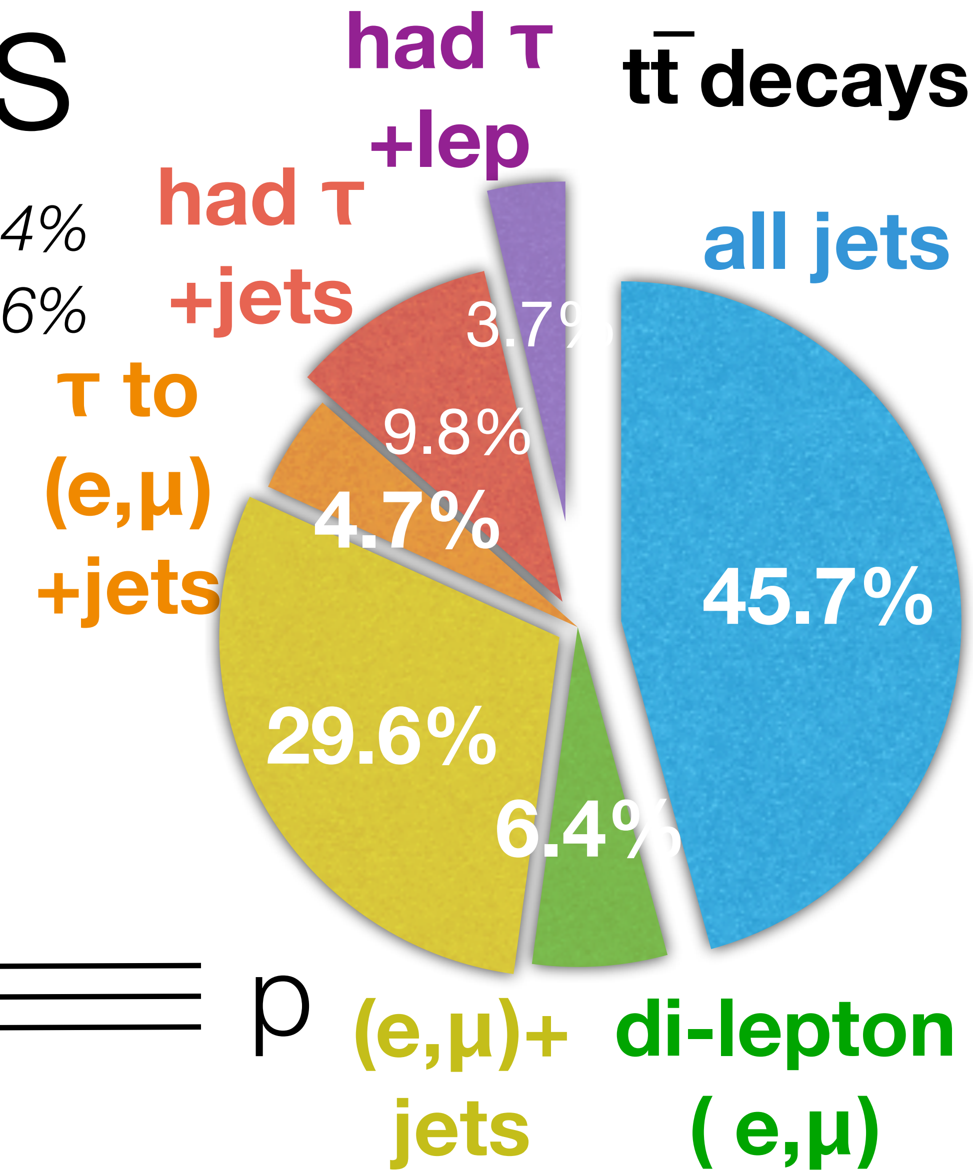
Single top events are ~50%

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

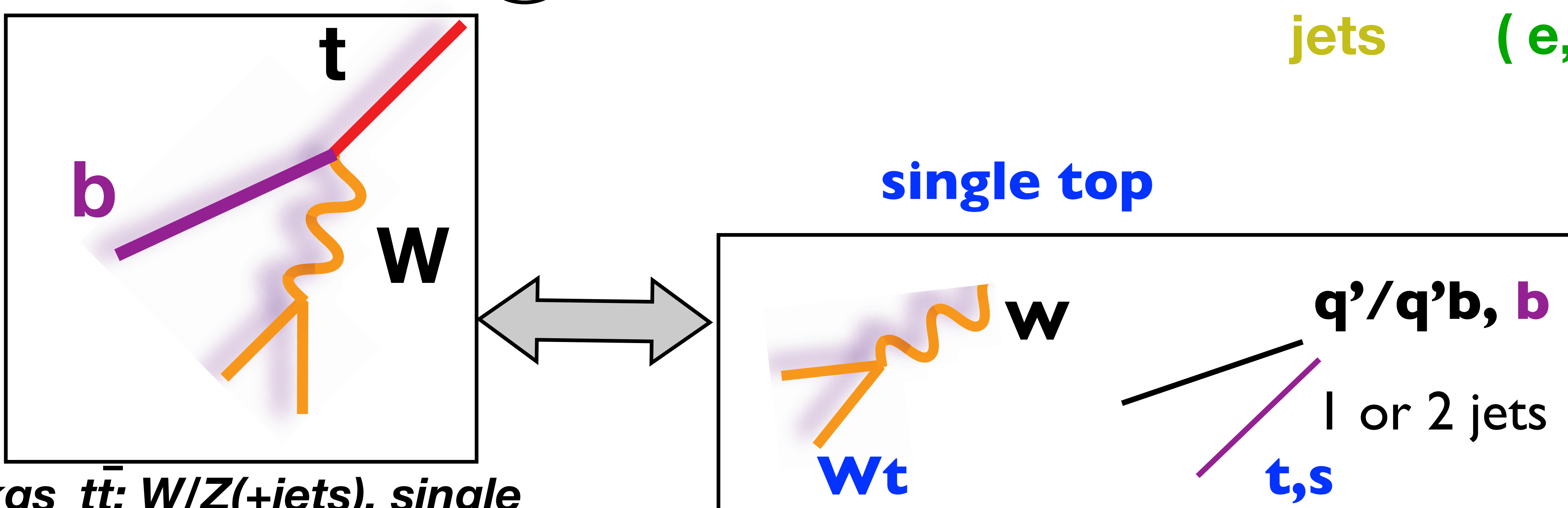
Top signatures

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





single top

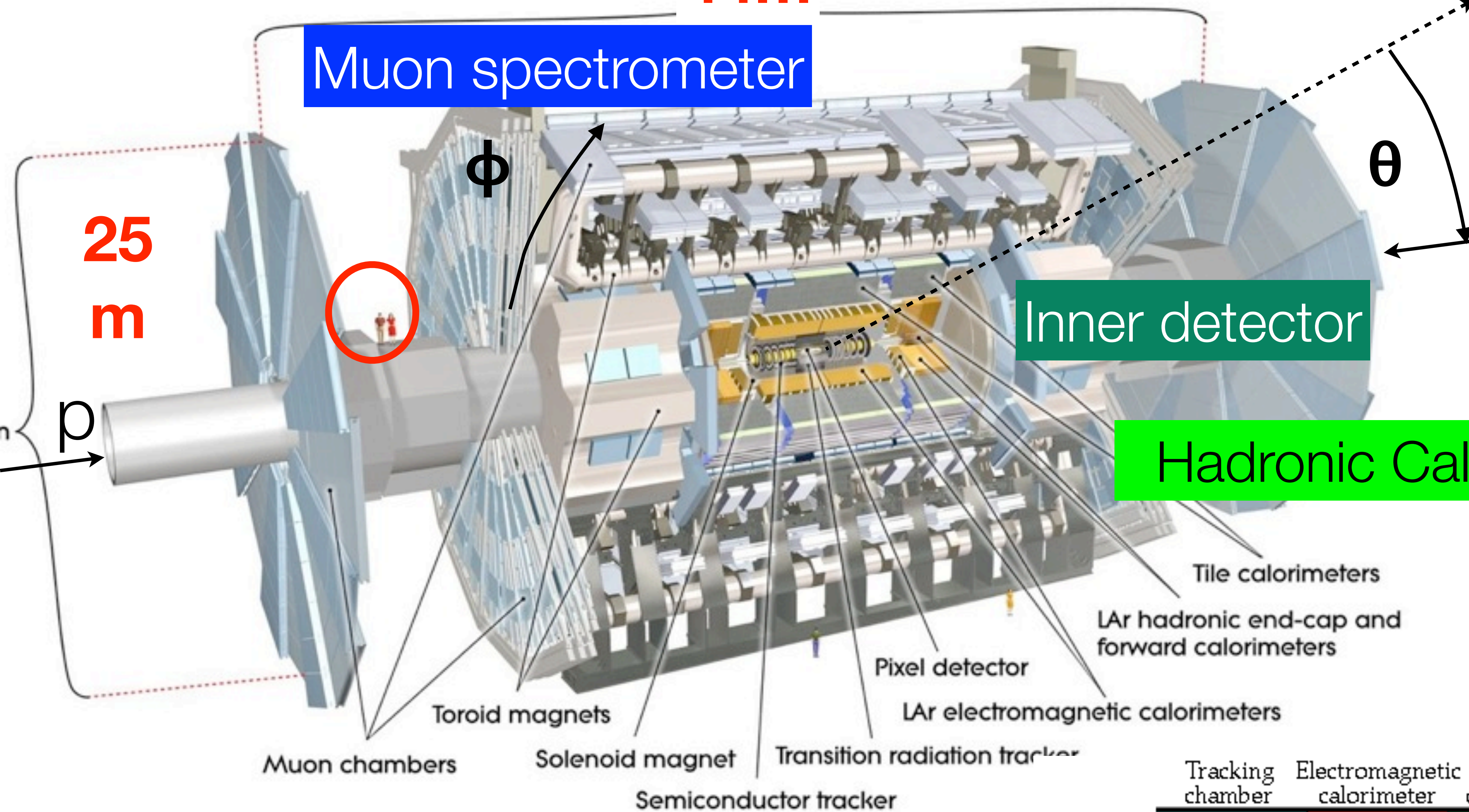


bkgs_$t\bar{t}$: W/Z(+jets), single top, QCD, Di-bosons

bkgs_single_t: $t\bar{t}$ + same bkgs_tt

ATLAS : a *Top* observer...

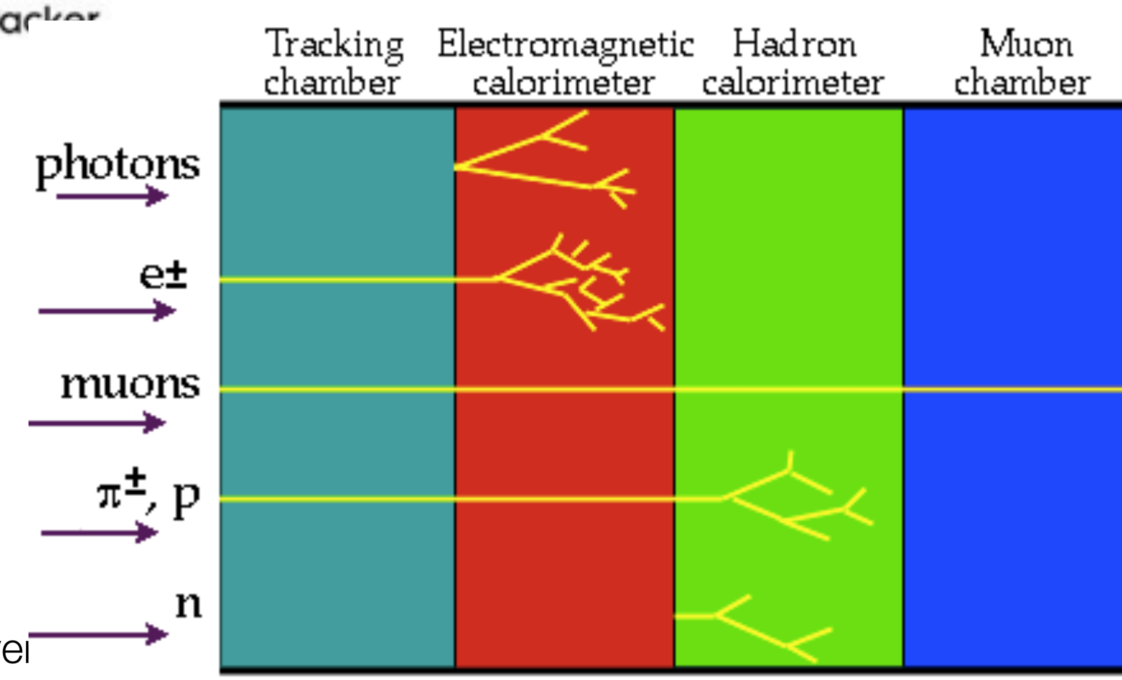
3 trigger levels
for event
selection



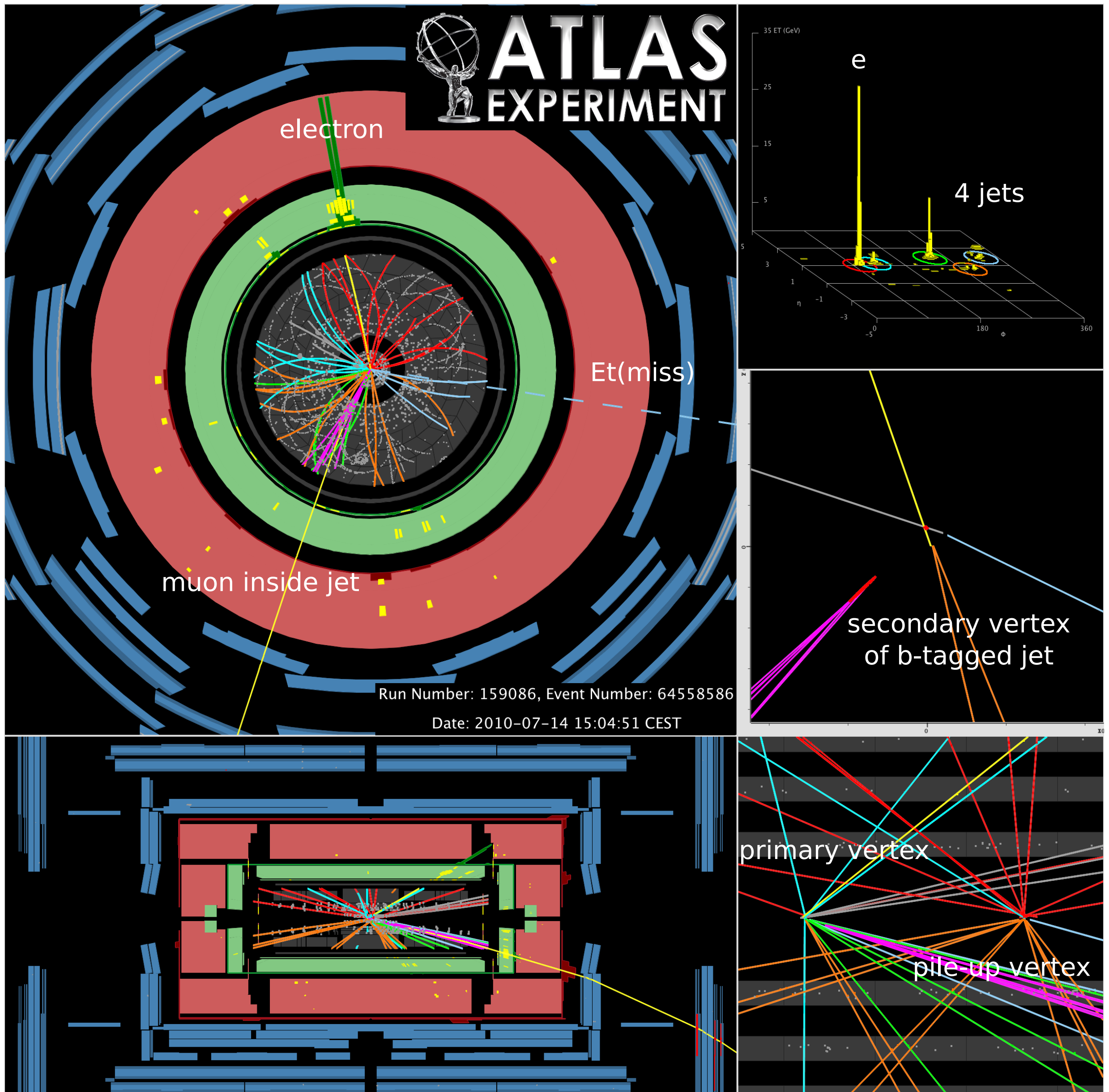
size matters

EM Calorimeters

η = pseudorapidity =-ln (tan(θ/2))



...with excellent performance



e+jets candidate

2010

Total Recorded (Delivered) Lumi:

45.0 (48.1) pb^{-1}

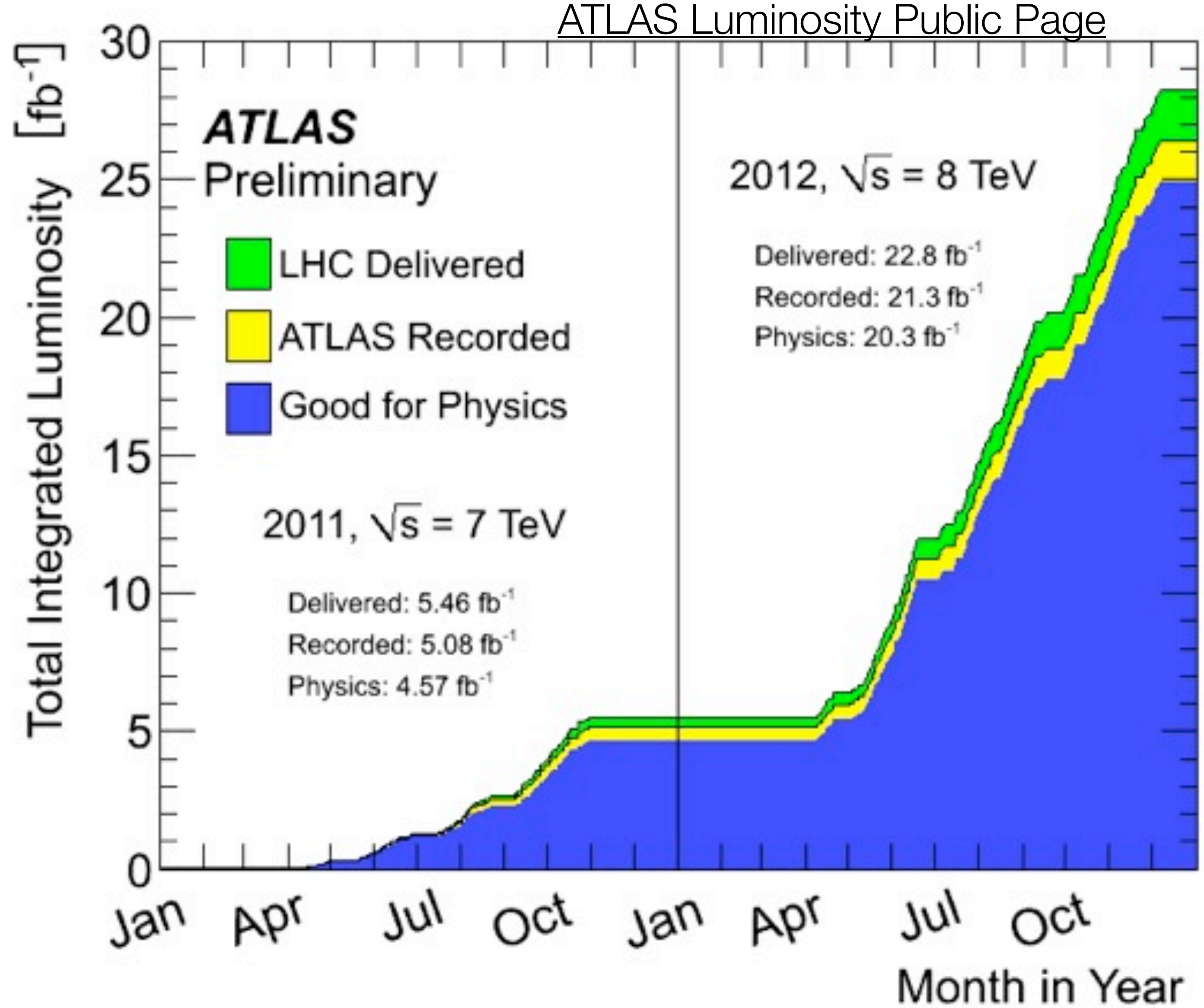
Lumi uncertainty~3.4%

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

2011-2012

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

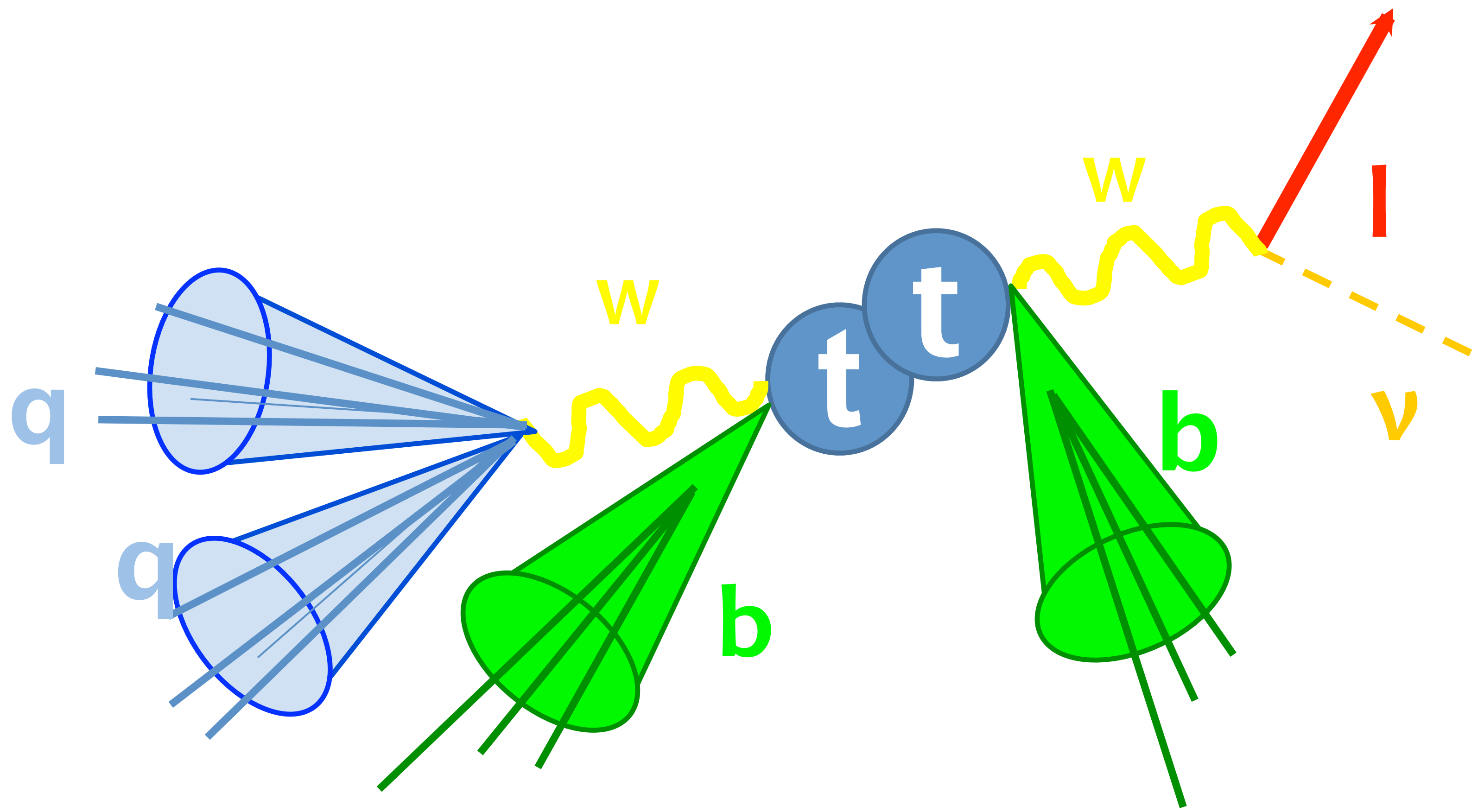
ATLAS Luminosity Public Page



Luminosity uncertainty ~1.8% to 3.1%(prel)

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

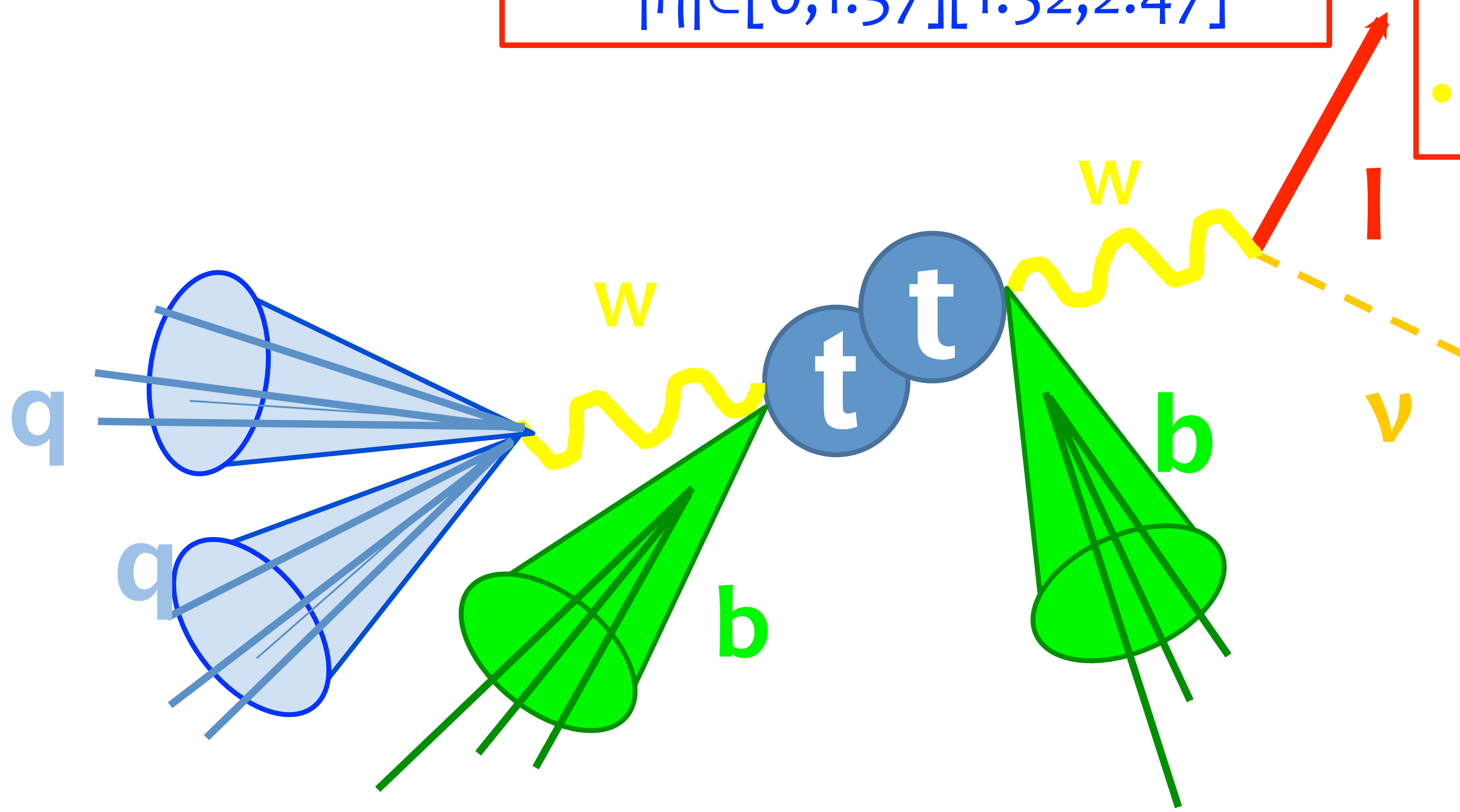
Selection/Ingredients for top quark pairs/single-top



Selection/Ingredients for top quark pairs/single-top

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 $|\eta| < 2.5$



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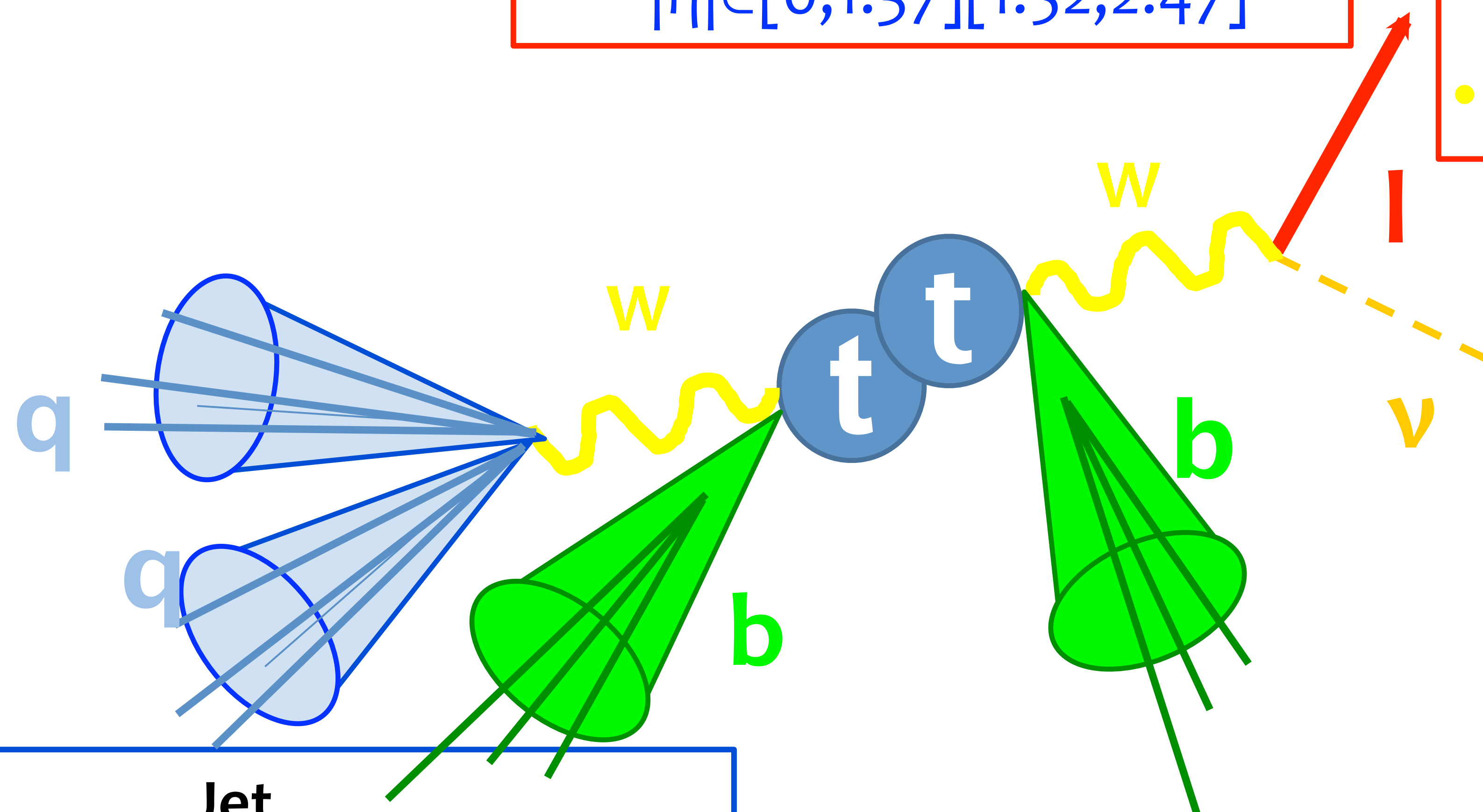

Jet

- Topological clusters, Anti-k_T (R=0.4)
- MC Calibration checked w/data
- $p_T > 25$ (20) GeV, $|\eta| < 2.5$
- (large JVF $=\sum_{\text{jet trk in PV}} p_T / \sum_{\text{jet trk}} p_T$ vs pile-up jets)

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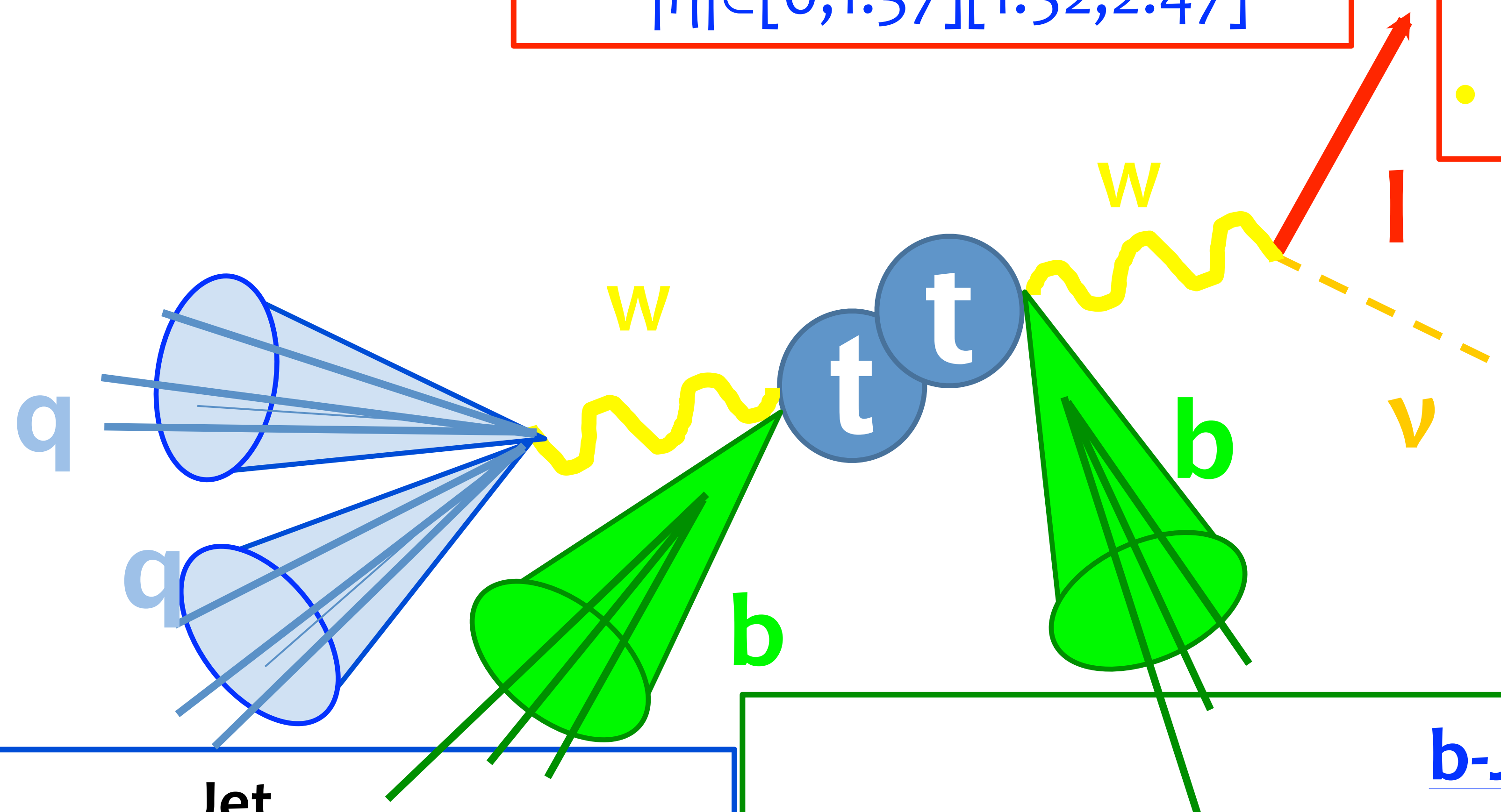

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b-Jet

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

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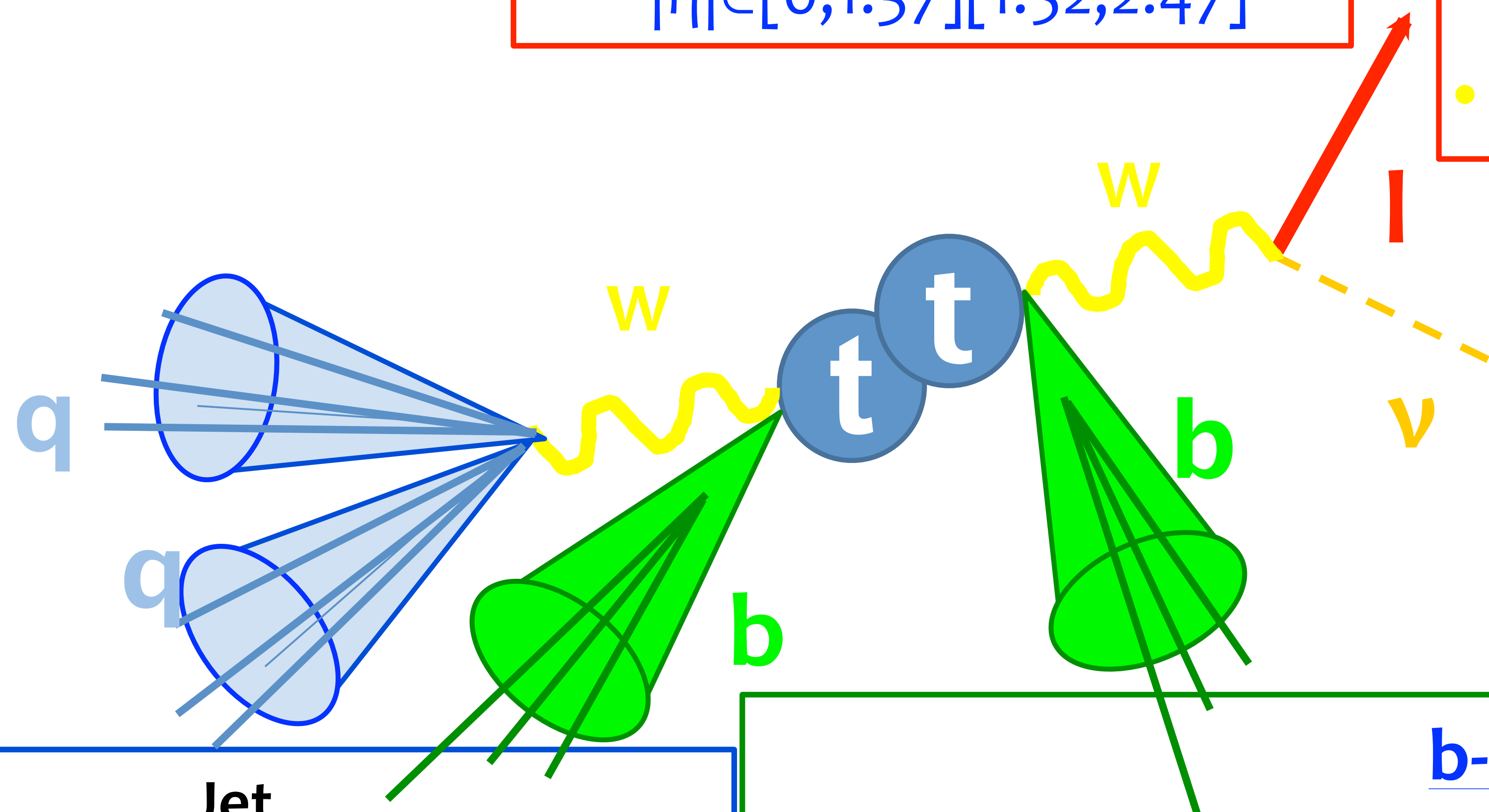

E_T^{miss}
- Vector sum of calo energy deposits
- Corrected for identified objects

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Selection/Ingredients for top quark pairs/single-top

Event cleaning
- Good run conditions
- Primary vertex (PV) with at least 5 tracks
- Bad jet veto
- Cosmic veto (μμ)

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

Muon
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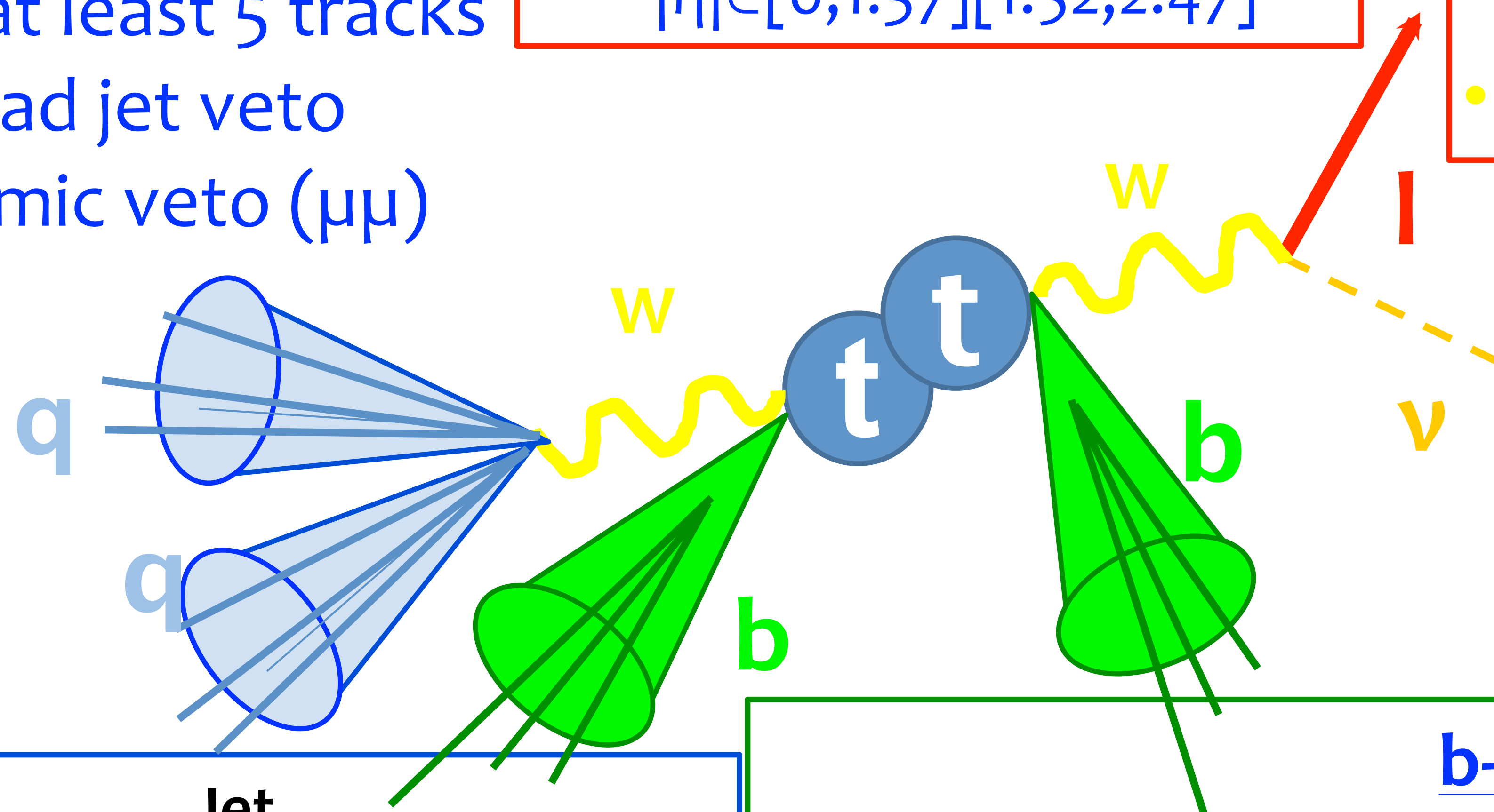

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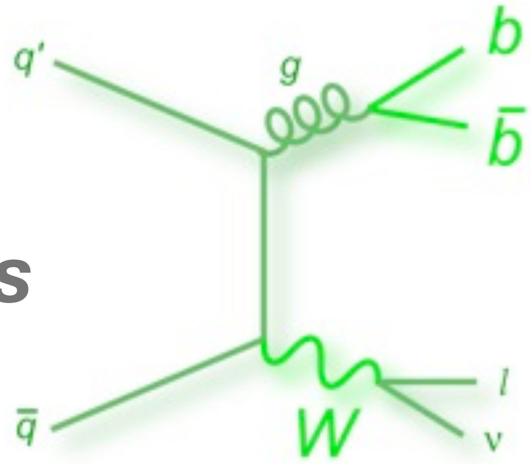
Backgrounds estimates (single lepton+jets)

- ***W+jets***

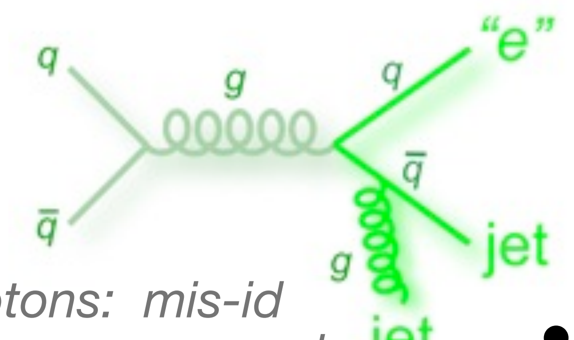


- *simulated shape*
- ***normalization: scale from charge asymmetry of W prod*** *before b-tag, MC extrapolation to b-tagged region*

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

MC *data*

- ***QCD***



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

- *Matrix method*

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

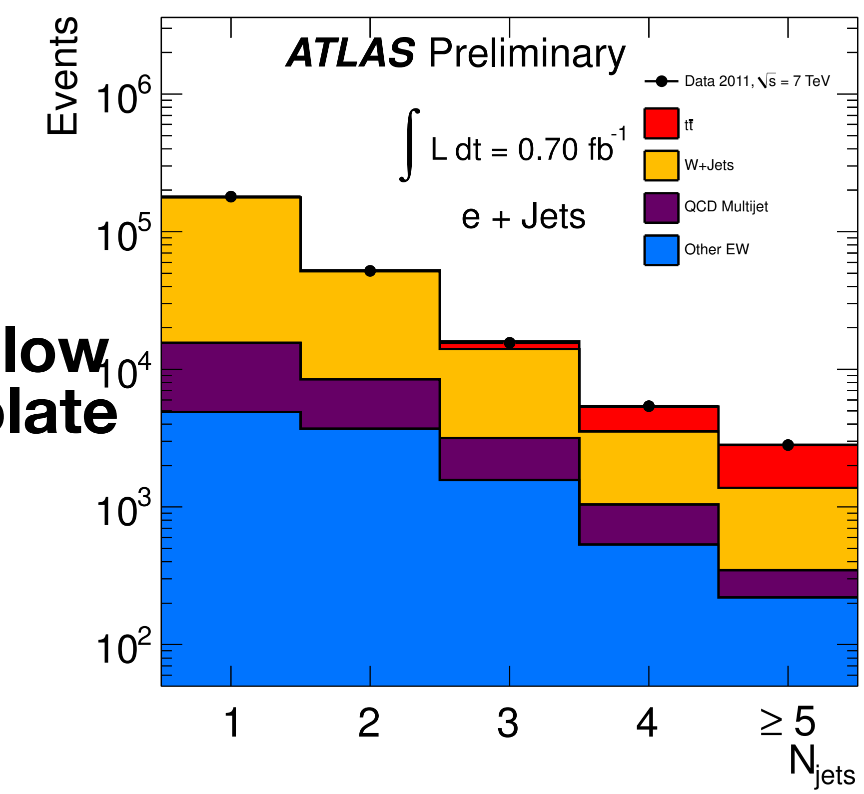
(J Boudreau Top2012)

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

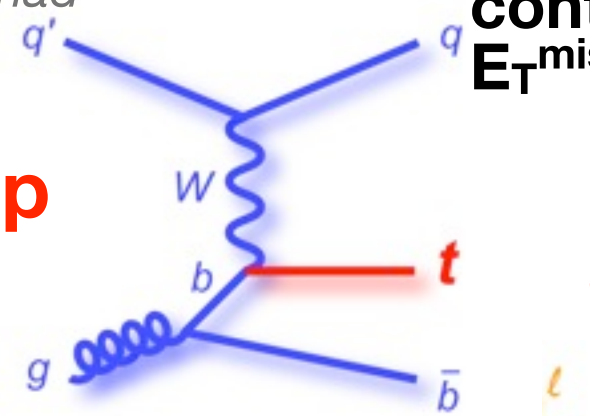
- *Jet template*:**shape from jet triggered events with 1 high em. content jet. Normalize by fitting low E_T^{miss} shape to data and extrapolate**

ATLAS-CONF-2011-121



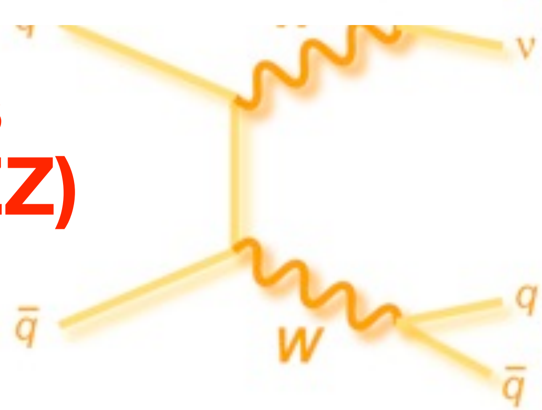
normalizations=fit parameters, estimates are starting points for fit

- **Single top**



Simulated shape+ rate set to SM

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

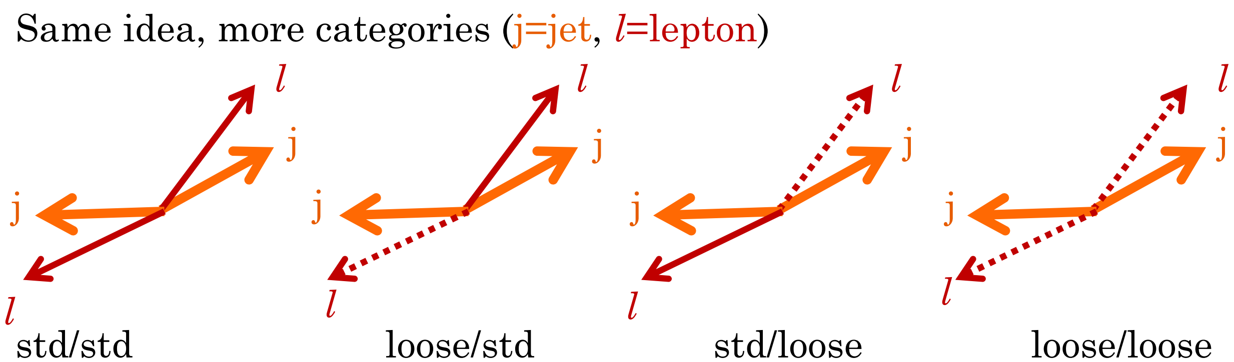


simulated shape+ rate from simul.

Backgrounds (di-lepton)

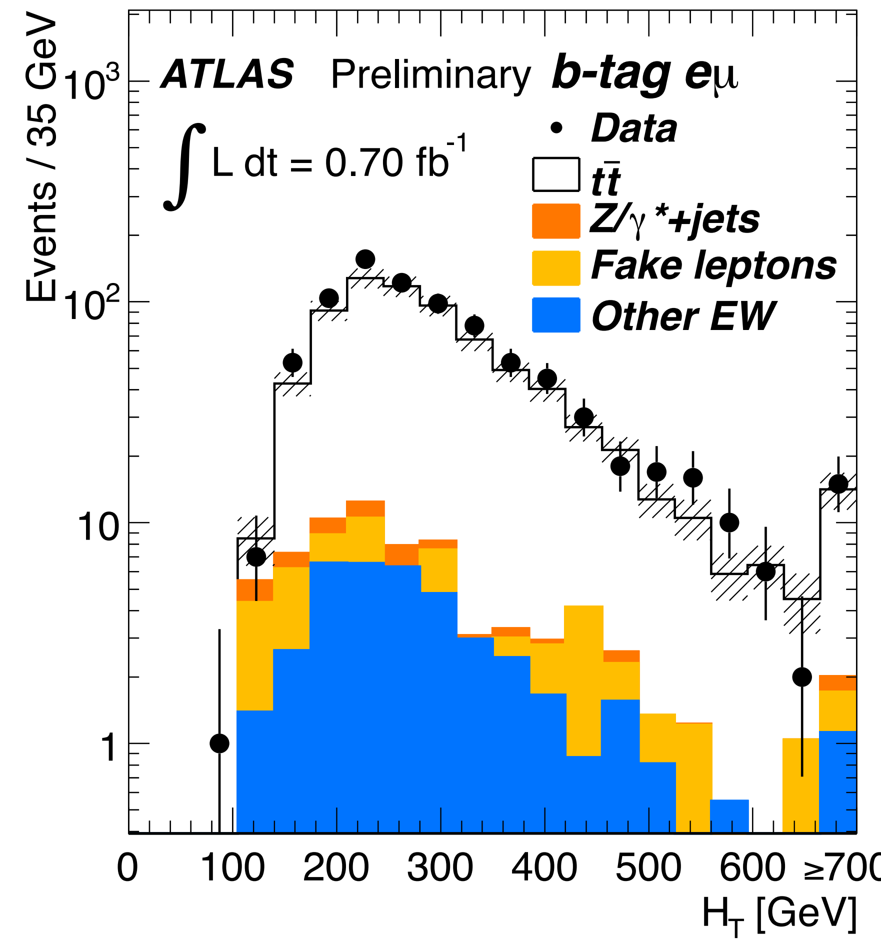
ATLAS-CONF-2011-100

- "Fake" leptons from data
  - Get **probability** for **loose** "fake" and real leptons ***to be in signal region*** **← control samples** enriched with real (in Z window) or "fake" (low E_T^{miss}) leptons
  - **Combine** with **N(di-lep)** for **all loose/tight** pairs→**fake tight** (i.e. signal) **lep**



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

(J Boudreau Top2012)



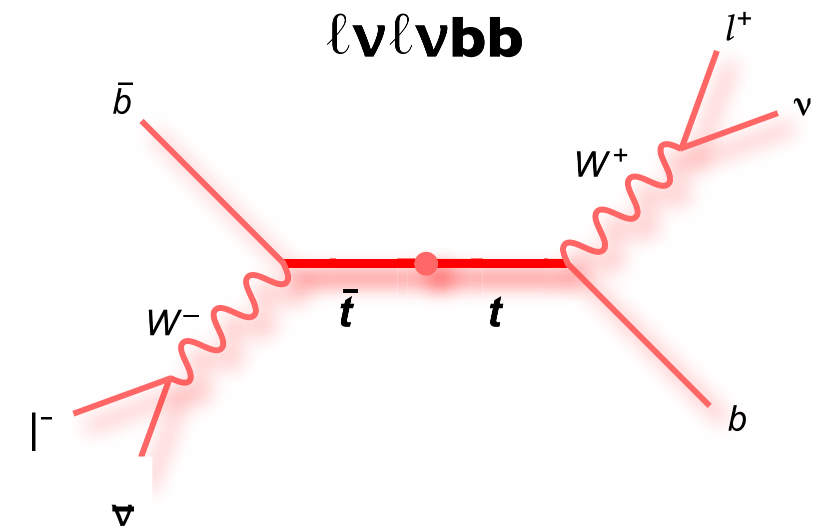
- **Alternative: scale bkg-subtracted N(same sign leptons) in data** with N(opposite sign)/ N(same sign) from simulation

- Z/γ* bkg (ee, μμ) : **scale** non-Z/γ*-bkg-subtracted **data in** Z-mass window **control region with ratio** of N(Z/γ*) in signal region to control region **from simul.**

Producing top quarks

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

$\int Ldt$ ~ **20.3 fb^{-1}** *(2012)*

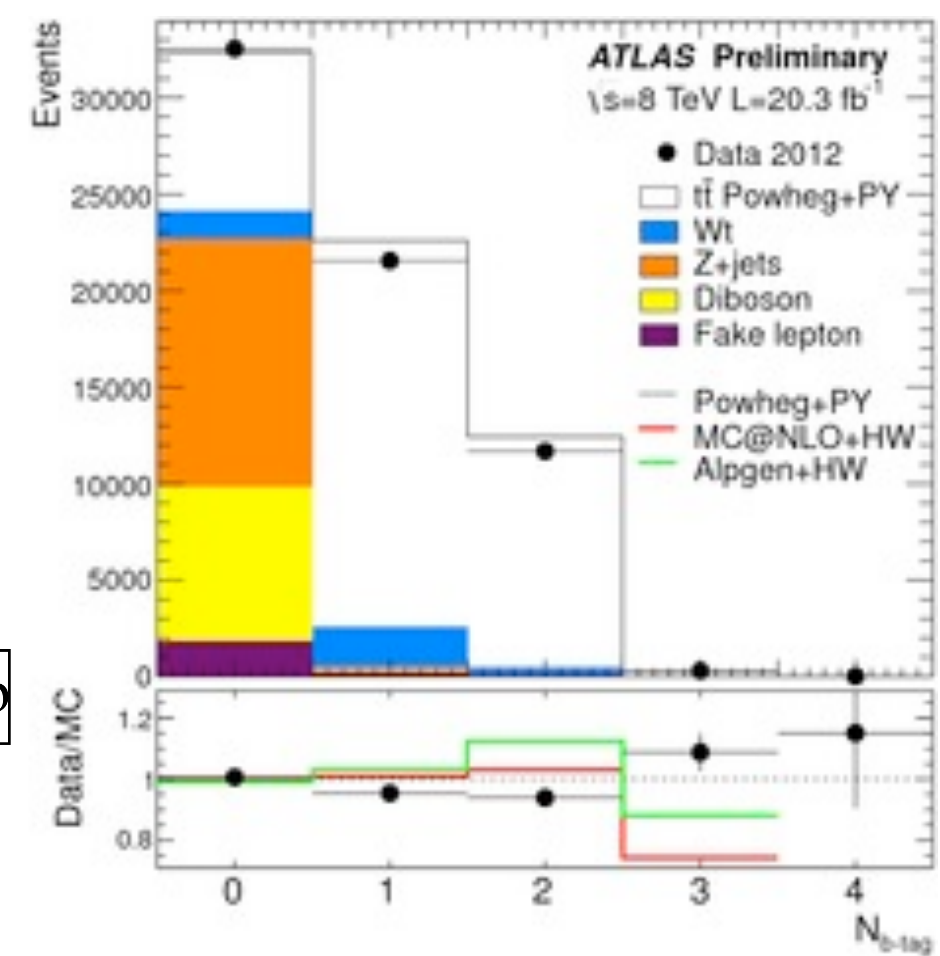


freshly presented at TOP2013 in September

- **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), fake leptons, reduced Z+jets

- **Simultaneous fit for σ_{tt} 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**

ATLAS-CONF-2013-097



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

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

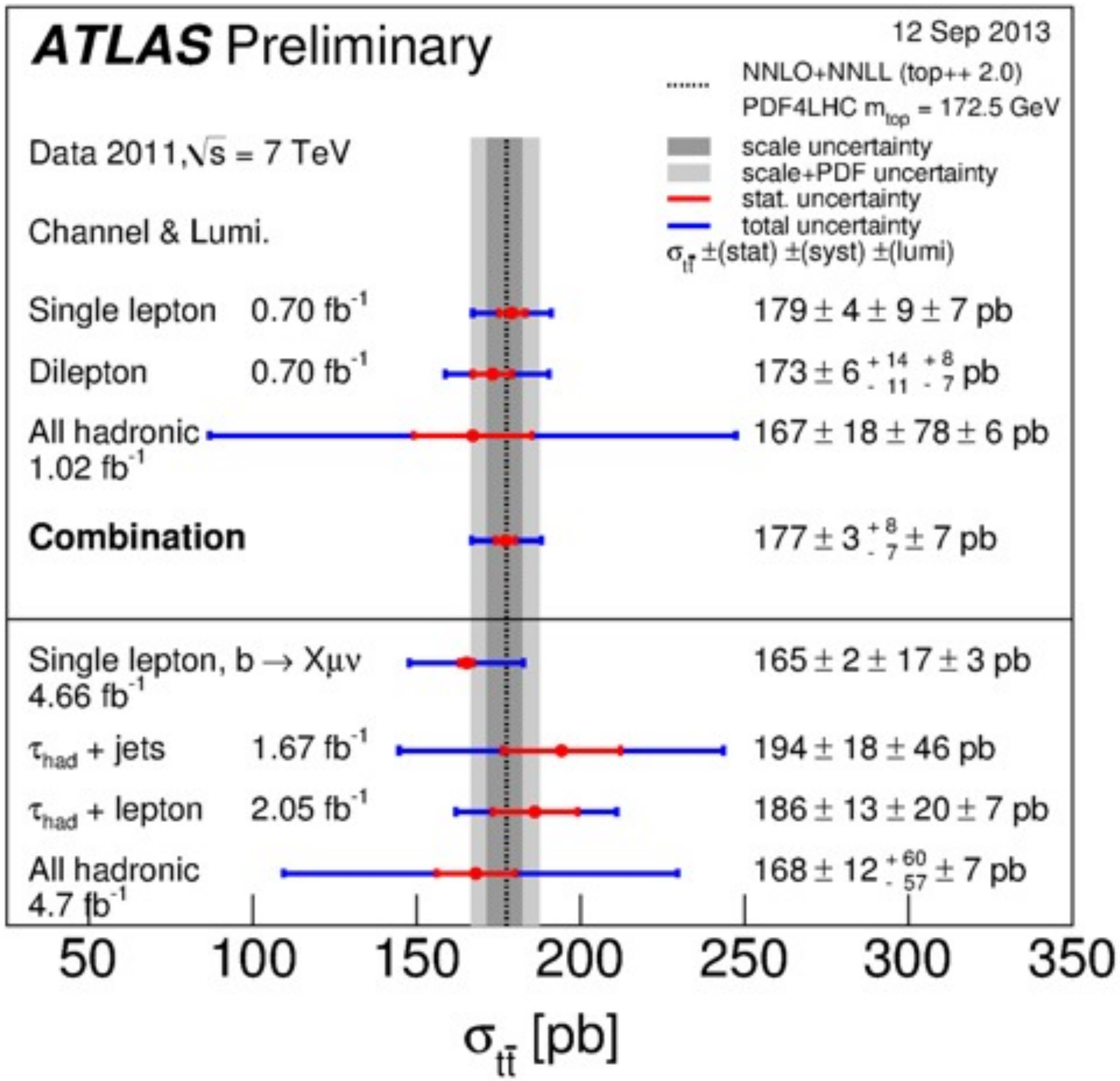
$$\sigma_{t\bar{t}} = 237.7 \pm 1.7\ \text{(stat)} \pm 7.4\ \text{(syst)} \pm 7.4\ \text{(lumi)} \pm 4.0\ \text{(beam energy) pb}$$

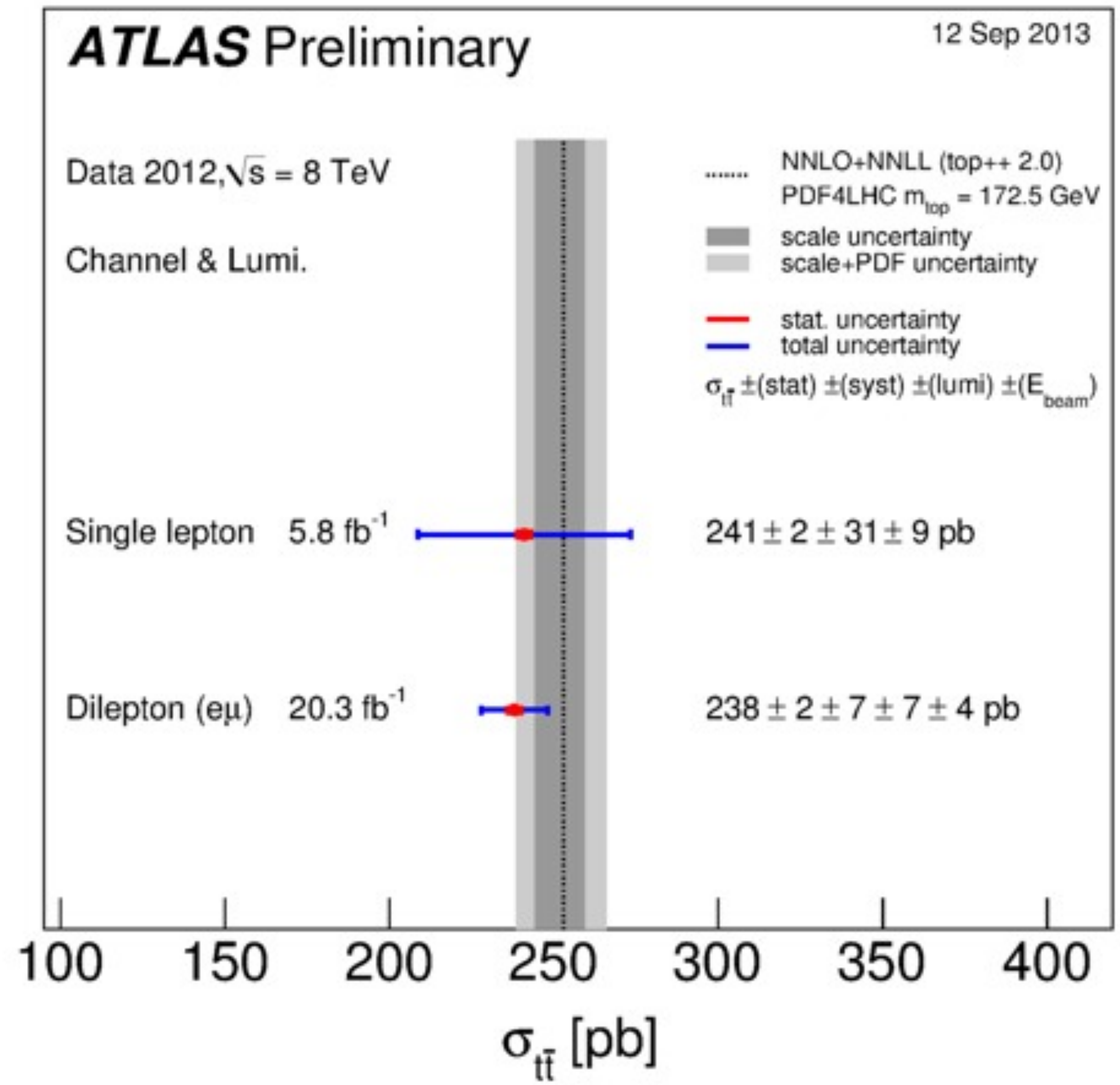
$\delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ ~4.8%

Most precise LHC $\sigma_{t\bar{t}}$ @ 8 TeV!

Inclusive top pair cross section results $\sigma_{t\bar{t}}$

√s = 7 TeV (latest) — *√s = 8 TeV*





- ATLAS relative uncertainty is **~6% (4.8%)** at √s =7 (8) TeV **dominated by systematics. Comparable to theory.**

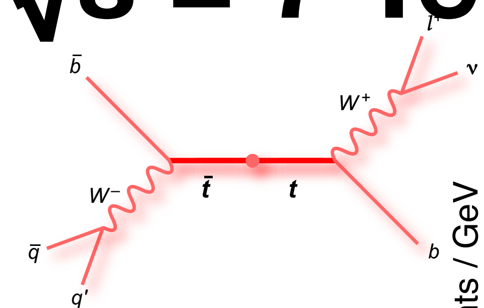
LHC combined @ ***√s = 7 TeV*** ATLAS-CONF-2012-134

$$\sigma_{t\bar{t}} = 173.3 \pm 2.3(\text{stat.}) \pm 9.8(\text{syst.})\ \text{pb}$$

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

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

evolution from EJPC (2013) 73 2261)



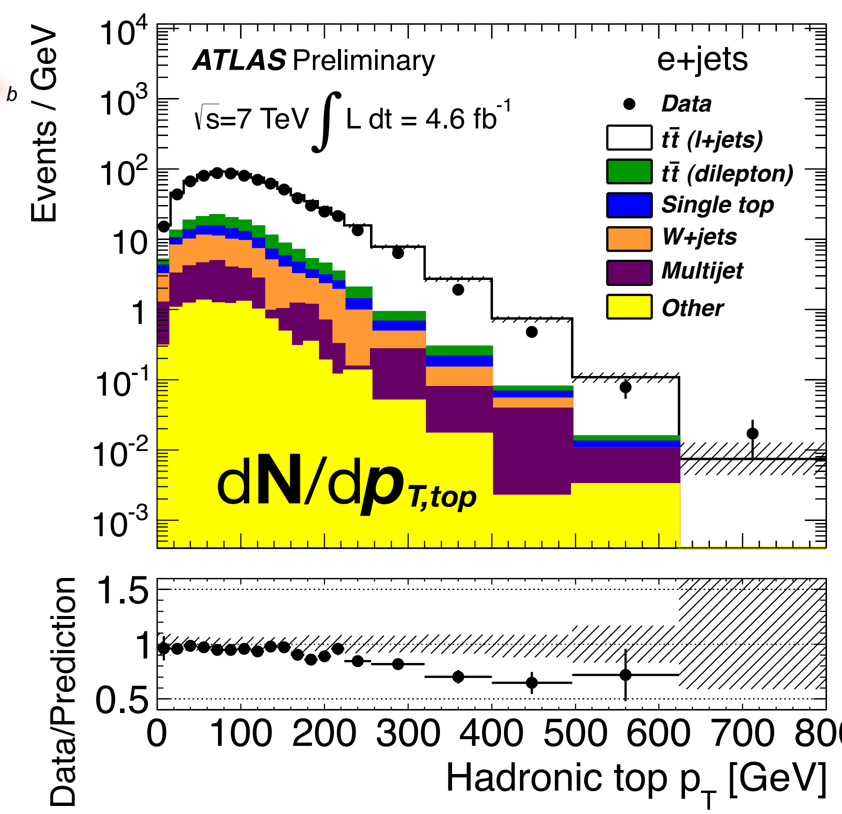
$\int L dt$ = **4.7 fb^{-1}** *(2011)*
qqℓ**νbb**

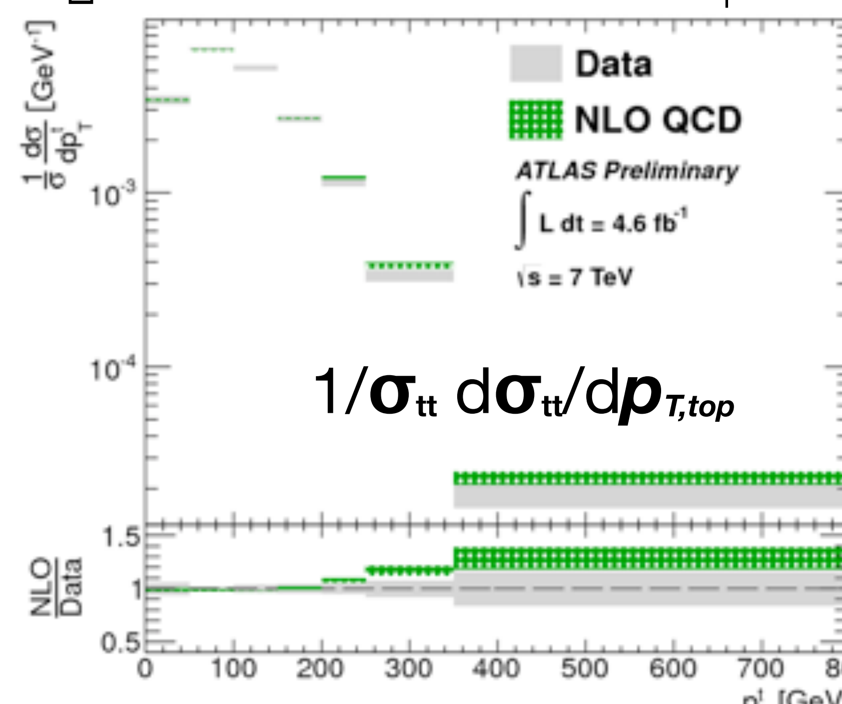
fresh from TOP2013 (September)!

- 1 isol. (e,μ), symmetric E_T and m_T^W cuts, **≥ 4 central jets,** ≥1 b-tag, standard bkg
- **Reconstruct tt with kinematic likel. fit** *(m_t,m_W constraint)* → -log(lkl) > 50
- **Unfold d(N-N$_{bkg}$)/dX to full phase space** *(regularized unfolding, linearity tests),* scale with L and $\boldsymbol{\sigma_{tt}}$ → 1/$\boldsymbol{\sigma_{t\bar{t}}}$ d$\boldsymbol{\sigma_{t\bar{t}}}$/d**X**

$$\sigma_j = \frac{\sum_i M_{ij}^{-1}(N_i - B_i)}{A_j \mathcal{L}}$$

- ***X***= ***p$_{T,top}$*** *(new)*, ***m$_{t\bar{t}}$ y$_{t\bar{t}}$ p$_{T,t\bar{t}}$*** *: compare with MC and calculations!*
- *Typical syst:<7% for **y$_{t\bar{t}}$**, 10-20% **p$_{T,t\bar{t}}$** 2 to 10% for **p$_{T,top}$** , 2% to 5% **m$_{t\bar{t}}$**,*





ATLAS-CONF-2013-099

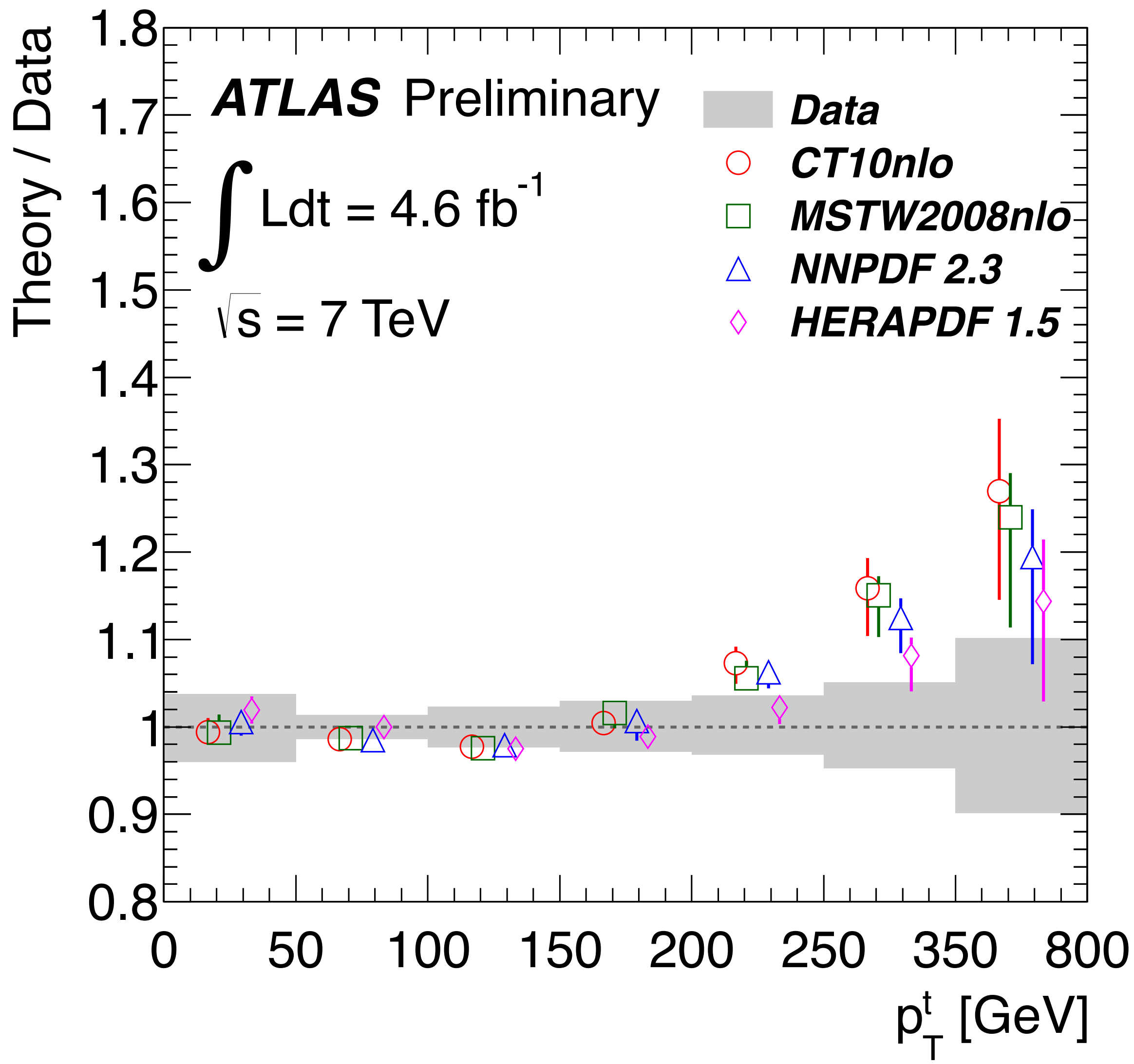
Differential! Test QCD , constrain new (non-)resonant phys. in $t\bar{t}$!

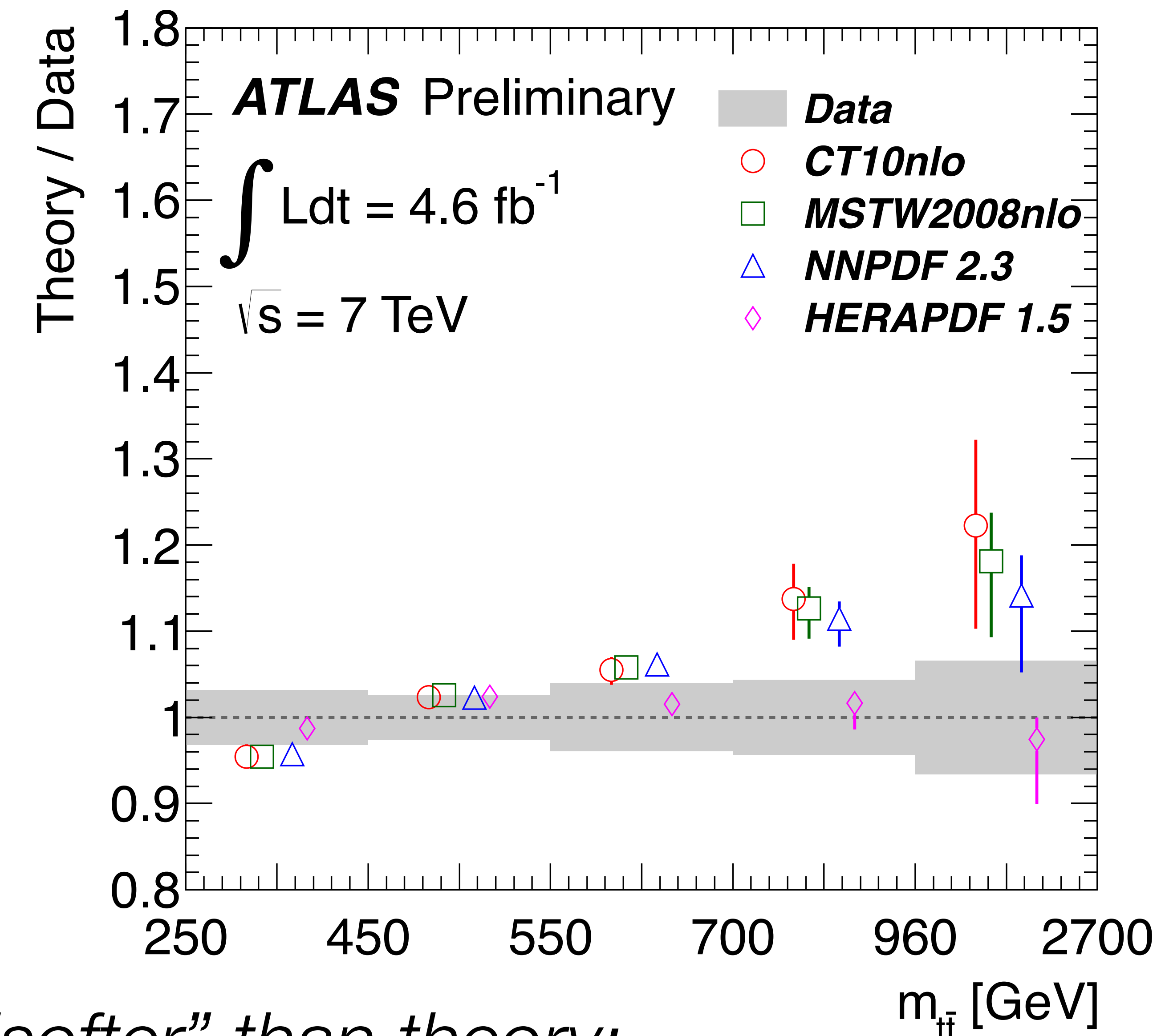
Differential $d\sigma_{tt}/dX$: l+jets $\sqrt{s}$ = 7 TeV

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

qqℓ**νbb**

ATLAS-CONF-2013-099



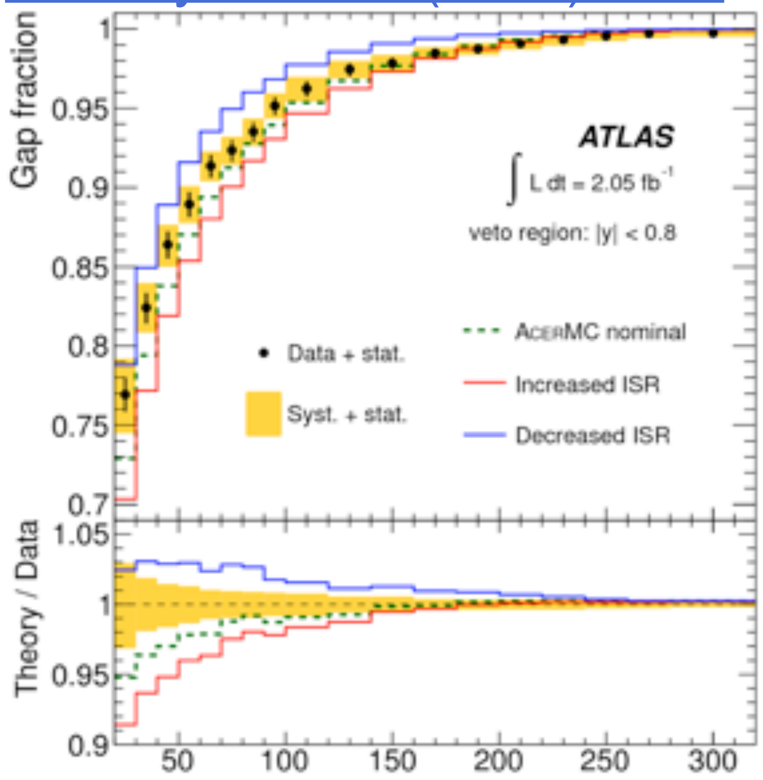


Data tend to be "softer" than theory;
HERA PDF consistent, while some tension is visible with other PDFs
Prediction from from NLO generator

Differential! Test PDF!

Differential σ_{tt}:growing field of action

Eur.Phys.J. C72 (2012) 2043

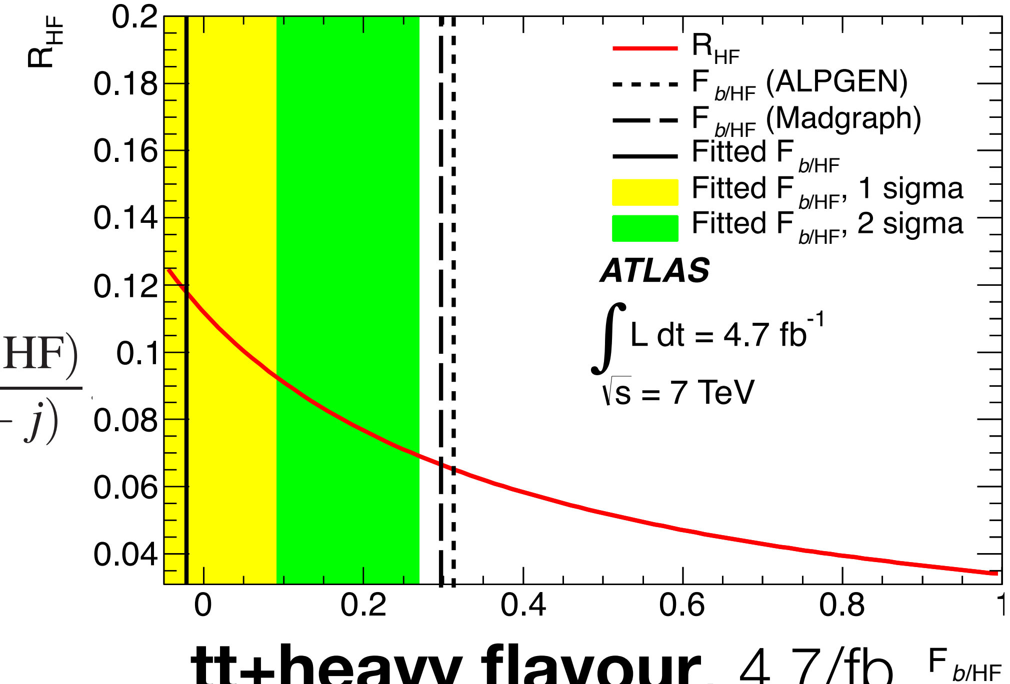


gap fraction (1/σ dσ/dQ), 2/fb

$\sqrt{s}$ = *7 TeV*

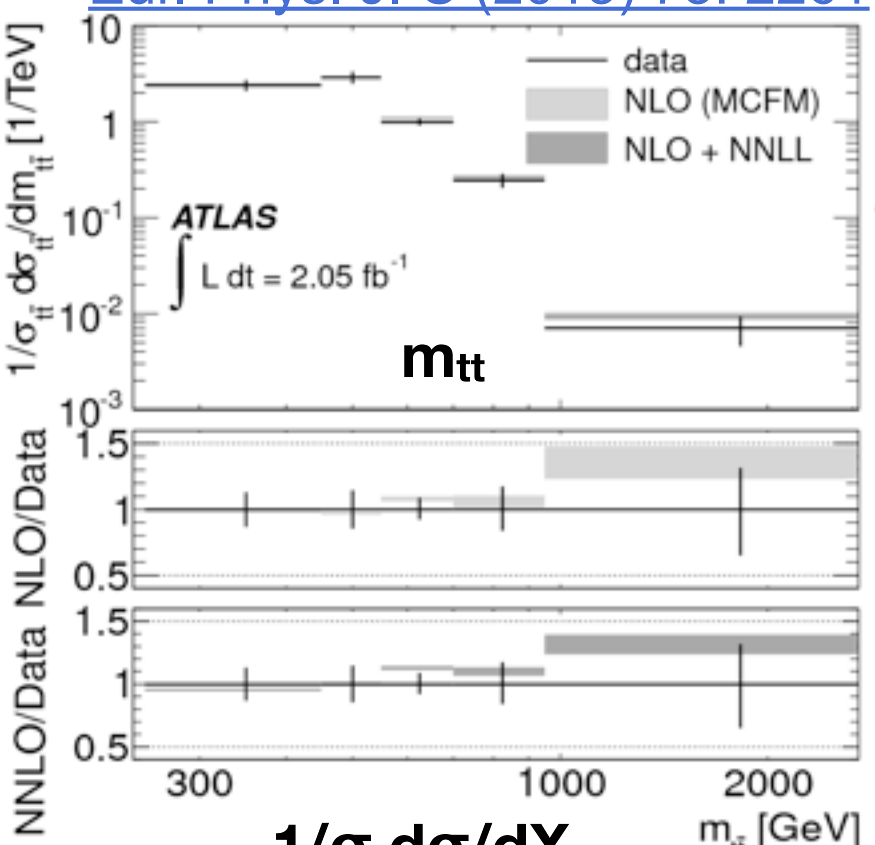
arXiv:1304.6386, submitted to PRD

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



tt+heavy flavour, 4.7/fb

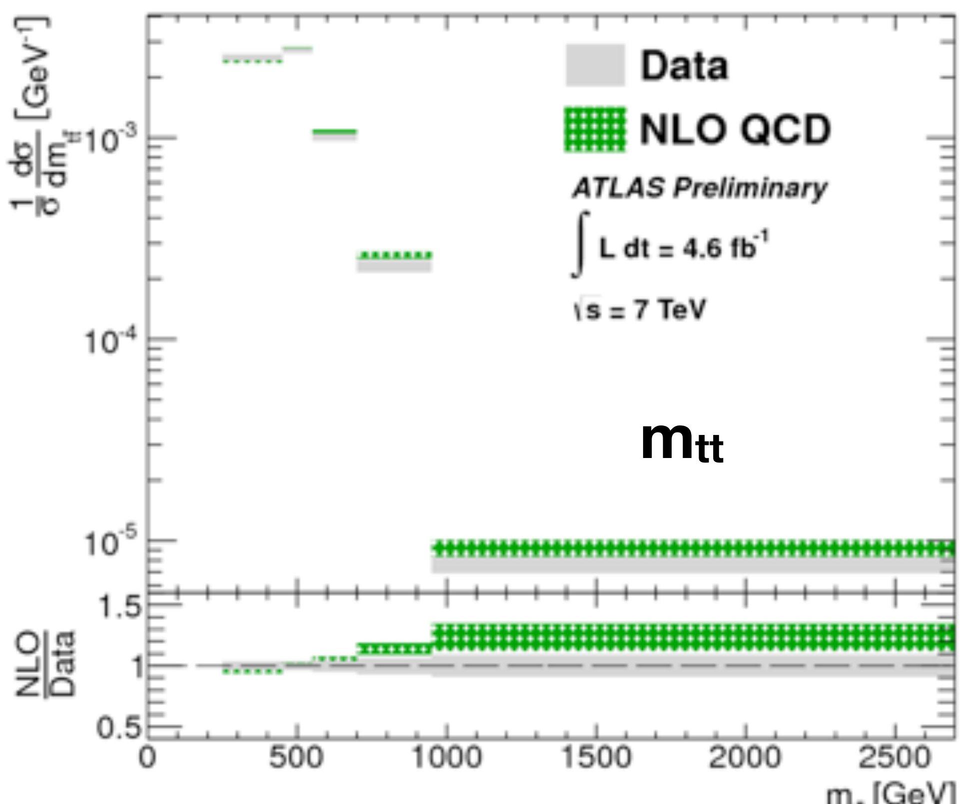
Eur. Phys. J. C (2013) 73: 2261



1/σ dσ/dX,

X=m_{tt} $p_{T,tt}$ $y_{,tt}$ 2/fb

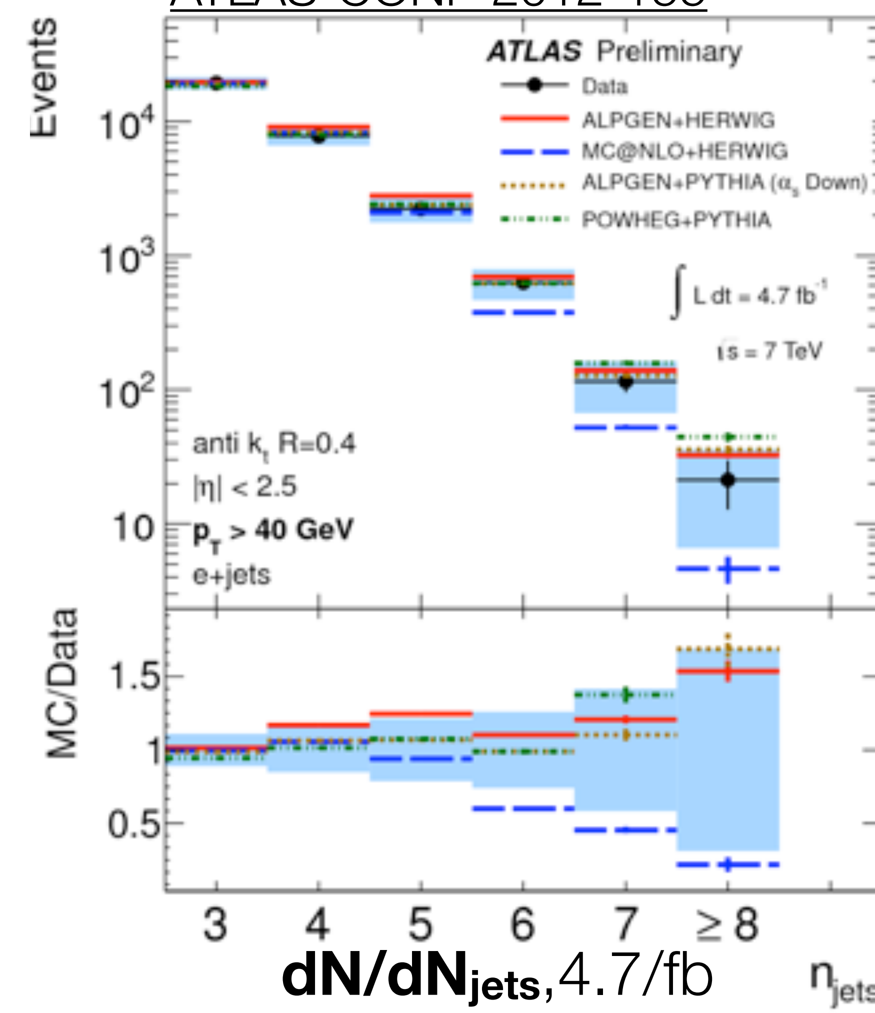
ATLAS-CONF-2013-099



1/σ dσ/dX,

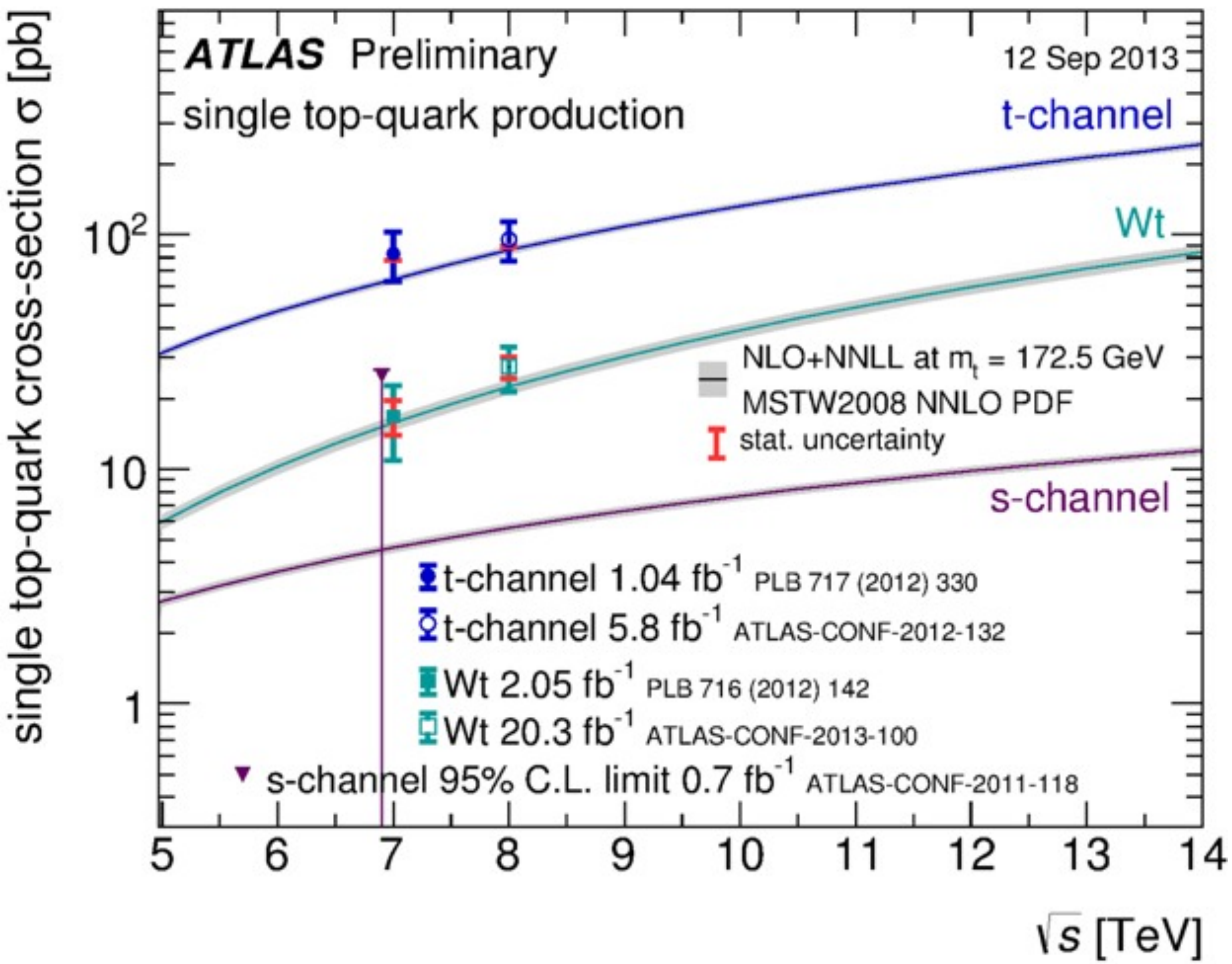
X= $p_{T,top}$ $m_{t\bar{t}}$ $p_{T,t\bar{t}}$ $y_{,t\bar{t}}$ 5/fb

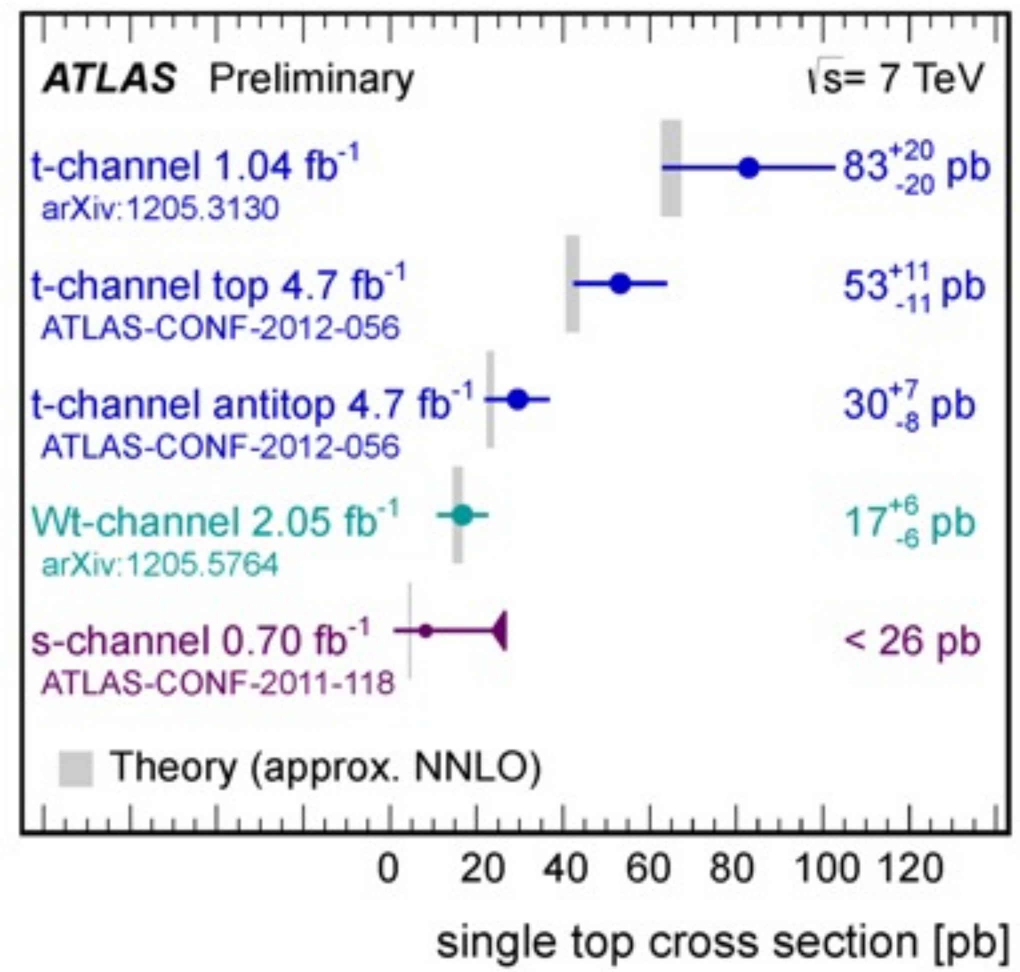
ATLAS-CONF-2012-155



dN/dN$_{jets}$,4.7/fb

Inclusive single top cross section results σ_t

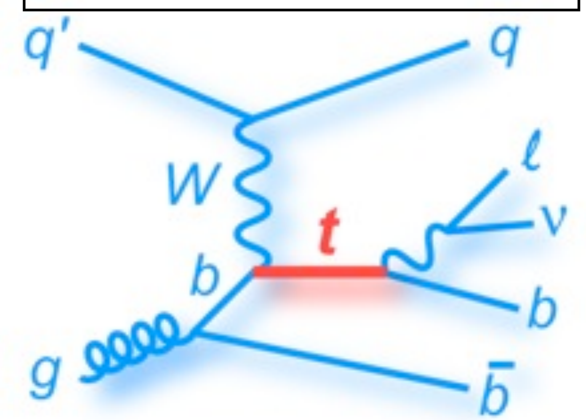


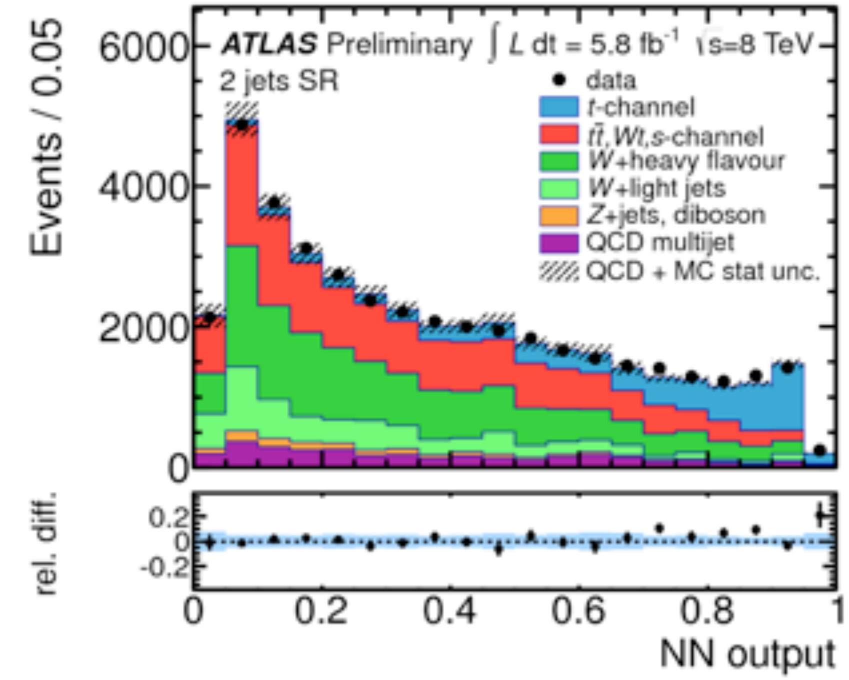


Measuring σ_t single top

- **Observed** in t-chan at **$\sqrt{s}$ =** 7 & 8 TeV

t-chan: $q\ell\nu b(b)$



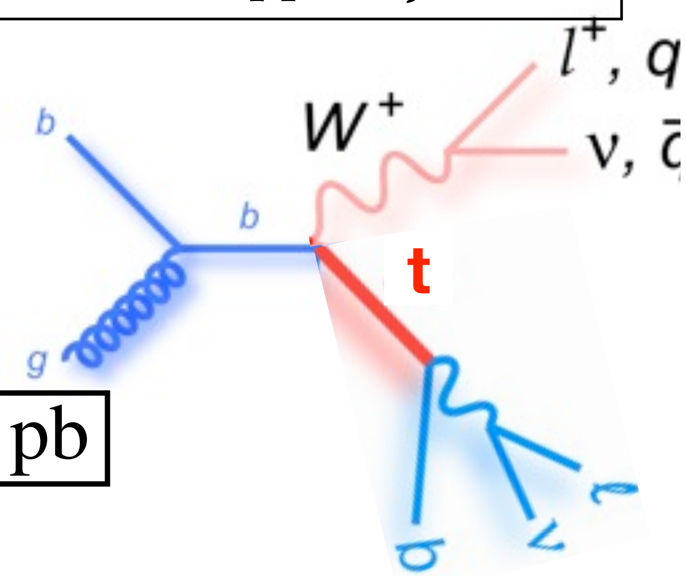


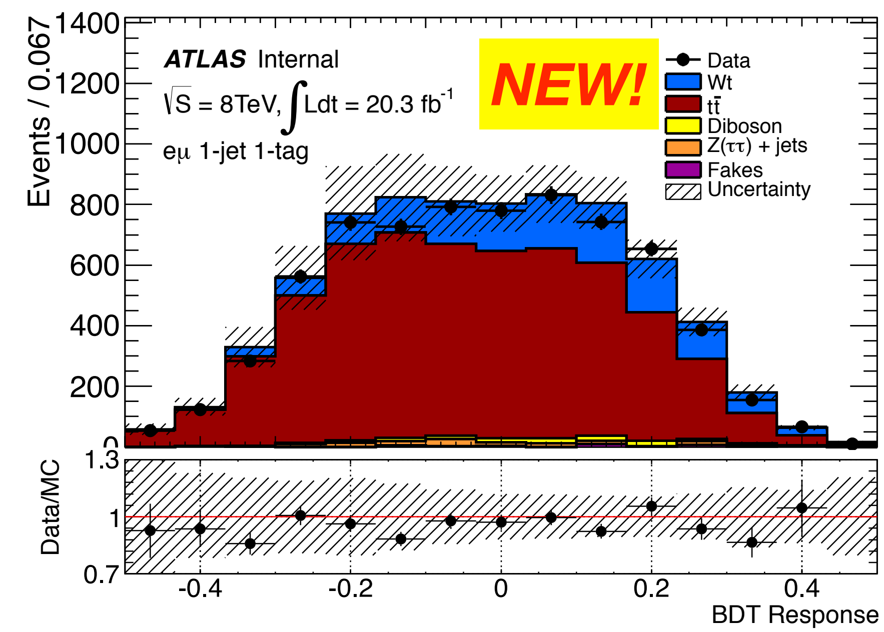
$$\sigma_t = 95 \pm 2\,(\text{stat.}) \pm 18\,(\text{syst.})\,\text{pb}$$

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

@ $\sqrt{s}$ =8 TeV

Wt-chan: $qq\ell\nu b, \ell\nu\ell\nu b$





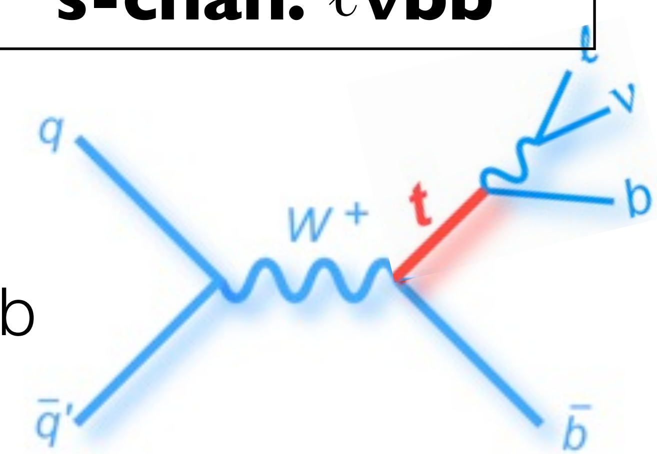
- Wt **evidence** at 8 TeV!

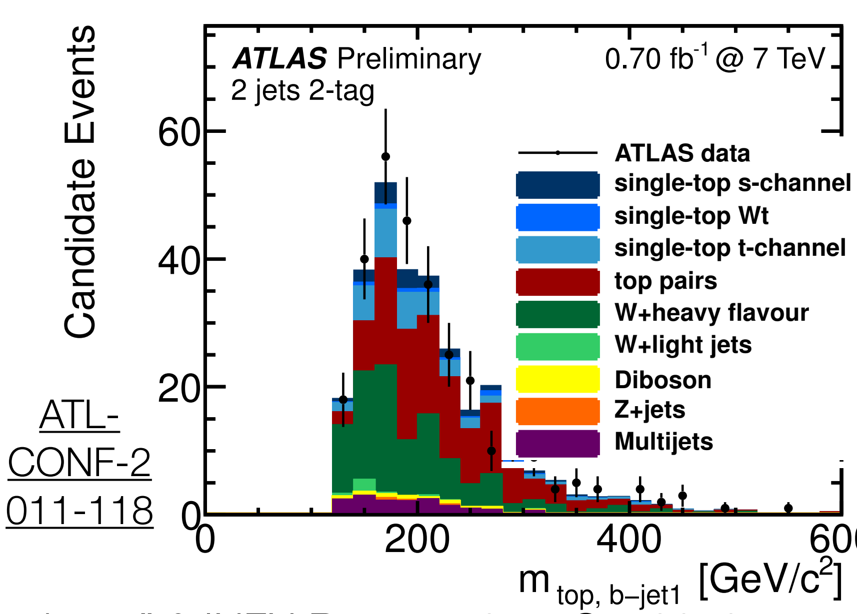
σ_{Wt} =27.2 ± 2.8 (stat) $\pm$ 5.4 (syst) pb

significance: **4.2 s.d.**

$\delta\sigma_{Wt}/\sigma_{Wt}$ ~22%

s-chan: $\ell\nu bb$





ATL-CONF-2011-118

- Have 95% CL obs (exp) upper limit

$$\sigma_t\ (s\text{-channel}) < 26.5\ (20.5)\ \text{pb}$$

$\int L dt$ = **1.0 - 0.7 fb^{-1}** *(2011)* & **5.8 fb^{-1} (2012)**

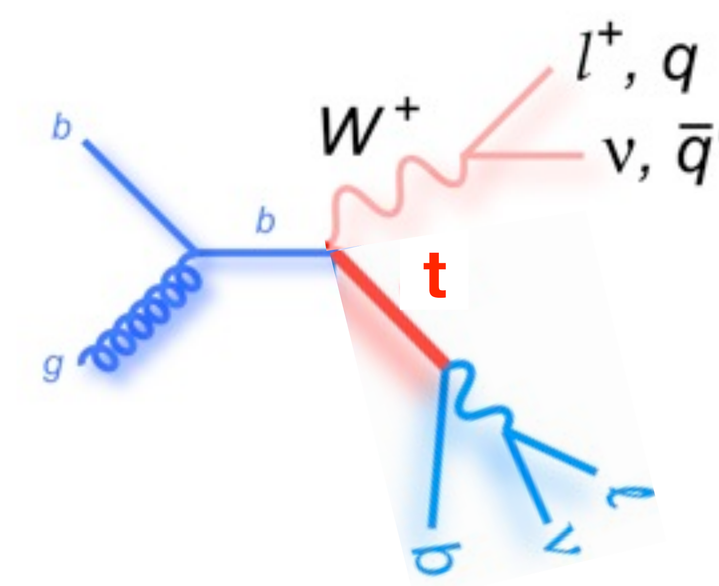
Inclusive σ_t : Wt-channel - $\sqrt{s}$ = 8 TeV

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

ATLAS-CONF-2013-100

fresh from TOP2013!

ℓνℓνb

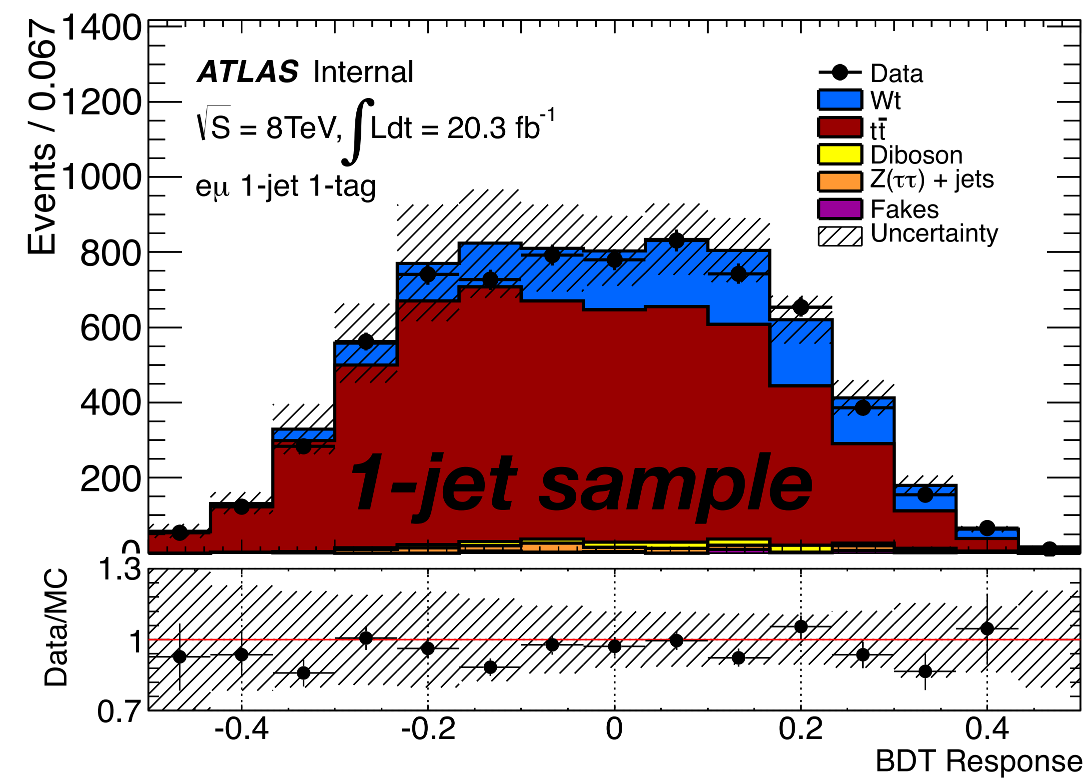


- **OS eμ**, 1 or 2 central high p_T jets, ≥1 b-tag,
- bkg: tt,diboson, Z+jets, data-driven (MM) fake lept.

- **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.*



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

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

- *Assuming $|V_{tb}| >> |V_{ts}|, |V_{td}|$* **determine V_{tb}**

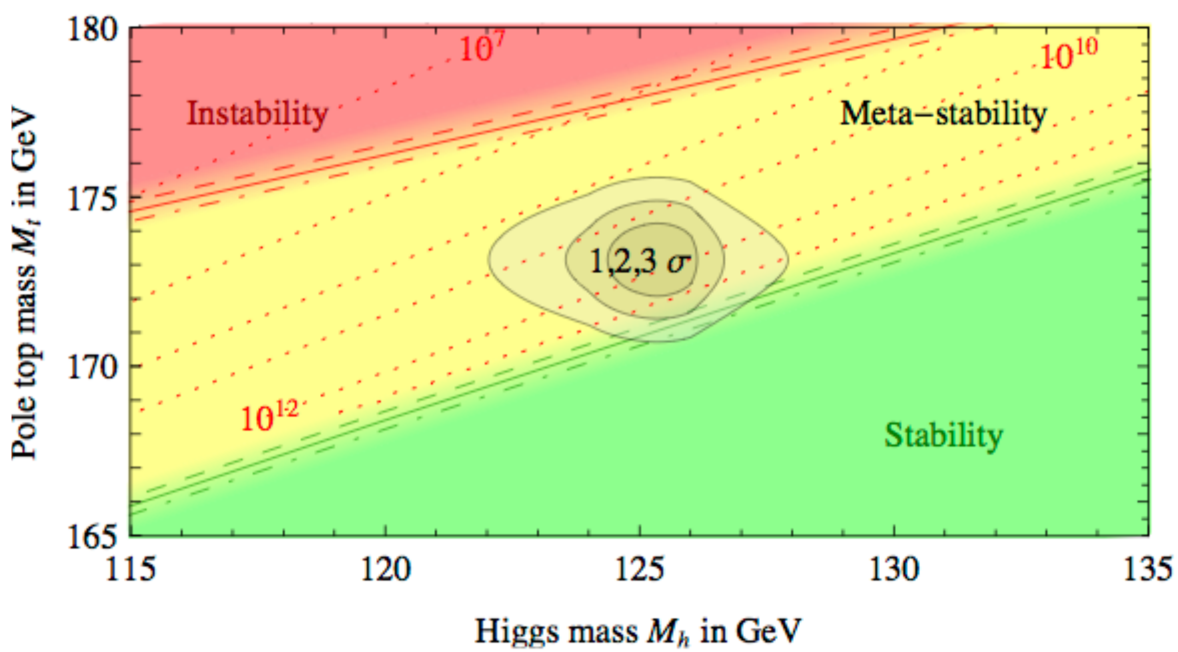
$$|V_{tb}| = 1.10 \pm 0.12$$

If $|V_{tb}|<1$ $|V_{tb}|>0.72$ at 95%CL

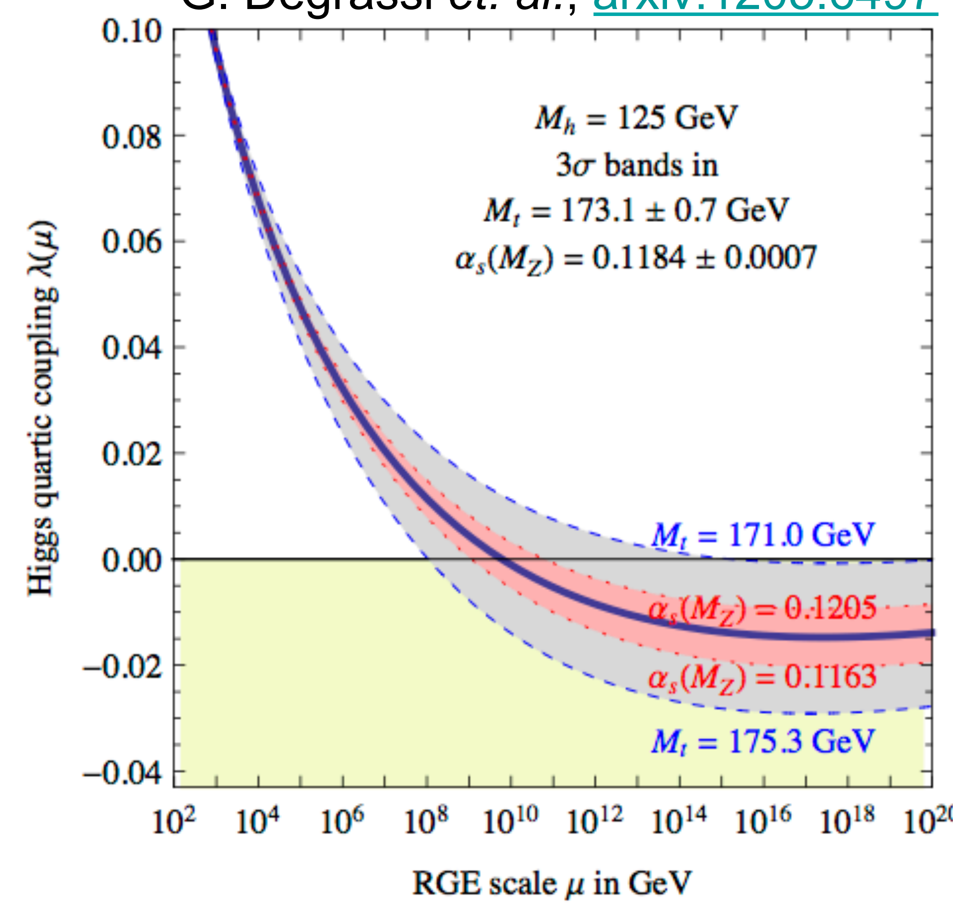
Wt evidence at 8 TeV!

Measuring top mass

i.e. what makes top special



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

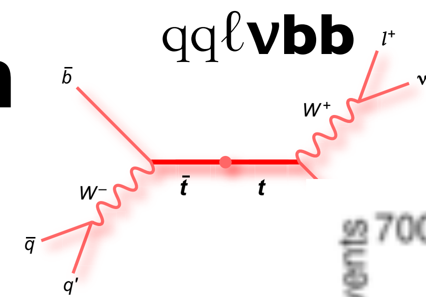


Measuring top mass

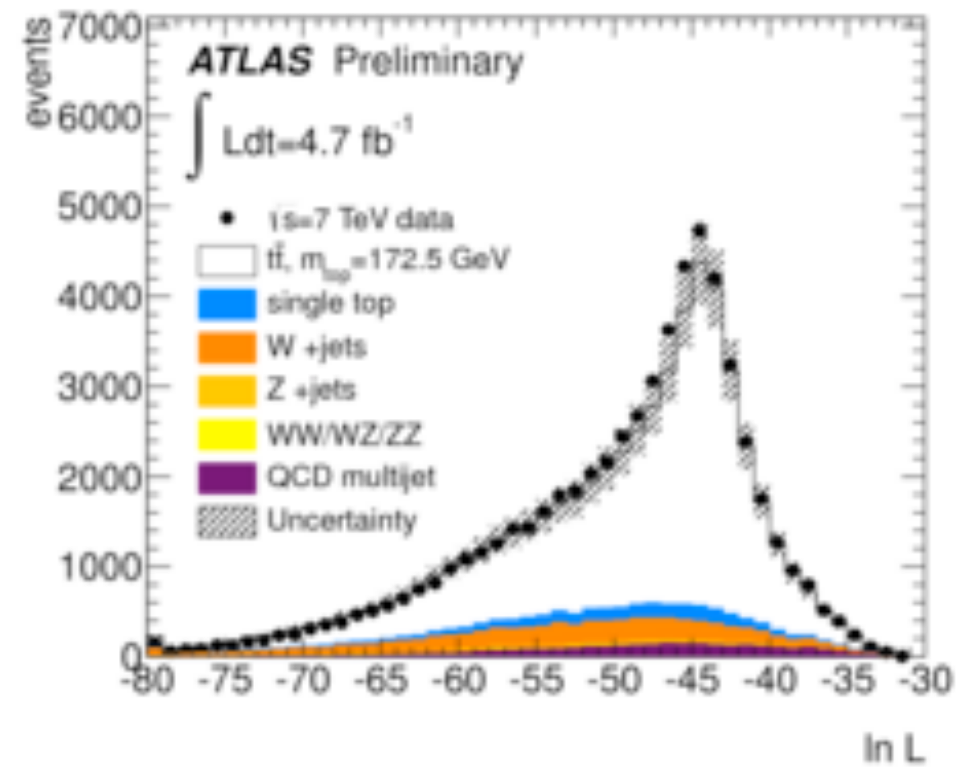
$\int Ldt$ = **4.7 fb^{-1}** *(2011)*

ATLAS-CONF-2013-046

- **Standard single lepton selection**

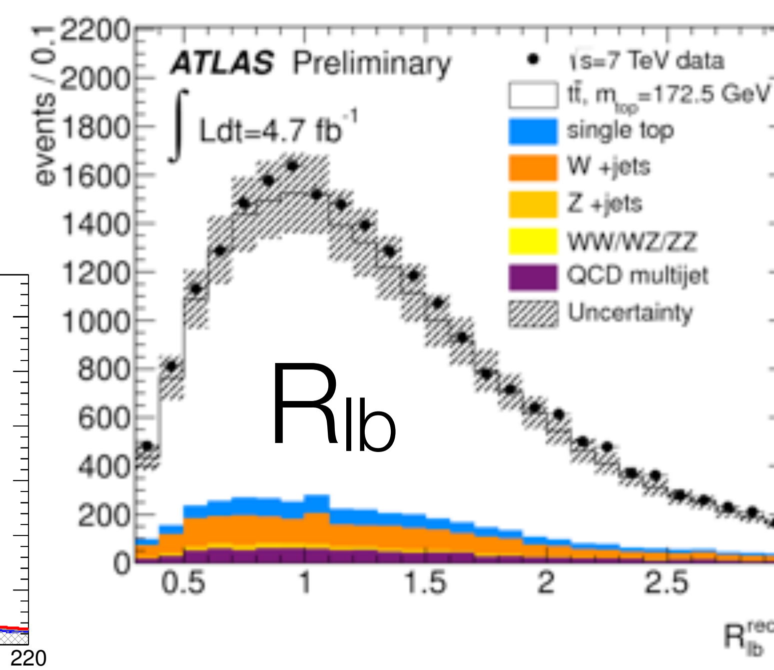


  - *good quality objects, 1 lepton, cuts on E_T, m_T^W, ≥4 jets, at least 1 b-tagged jet*
  - *channel dep analytic shape for bkg,*
  - *W+jets and QCD from data*

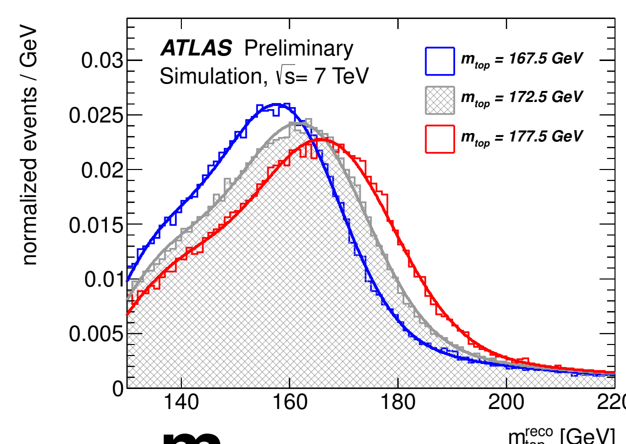


- **Reconstruct m_{top}-sensitive variables Reconstruct LO tt picture with kinematic likel. fit** *($m_{top,HAD}$= $m_{top,LEP}$ + weight for b/mis-tag ,m_W constraint)* → assign jets
  - **$m_{top,reco}$ from fit-assigned & constrained jets**
  - **$m_{W,reco}$ from fit-assigned but unconstrained jets**
  - **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



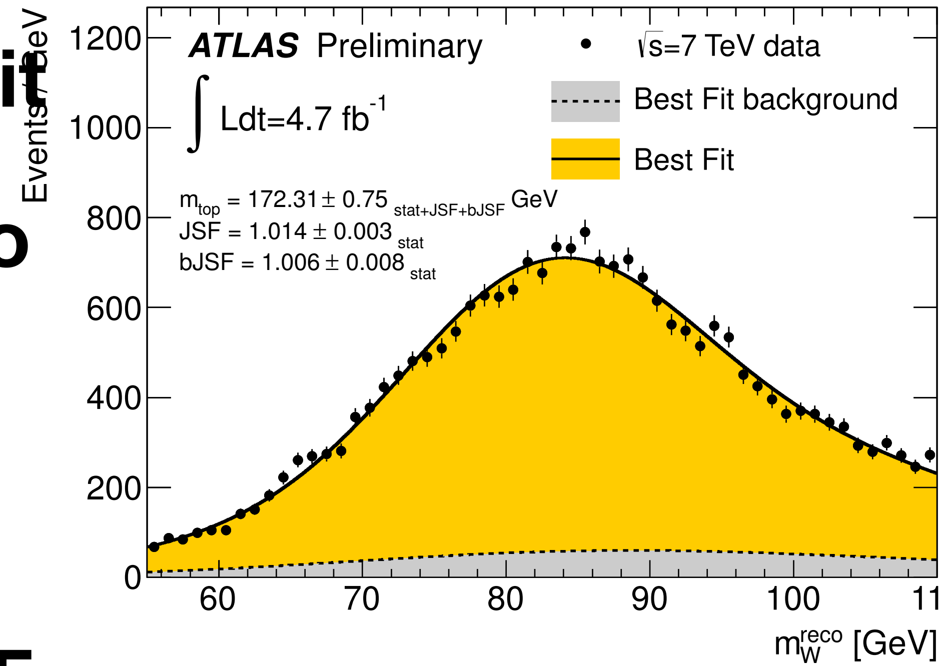
- *Jet energy scale is crucial: different reduction*

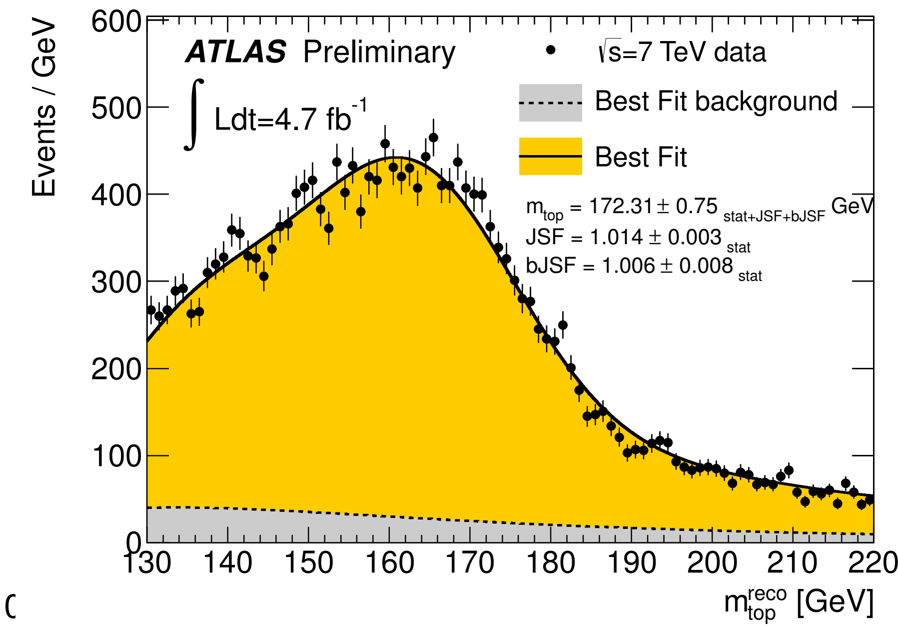
Measuring top mass

$\int Ldt = \mathbf{4.7\ fb^{-1}}$ (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*$\rightarrow$**m_{top},JSF,bJSF**

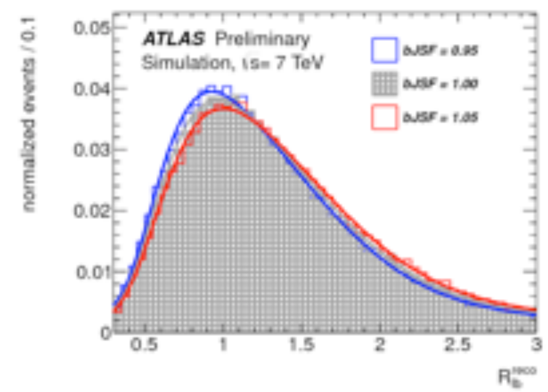


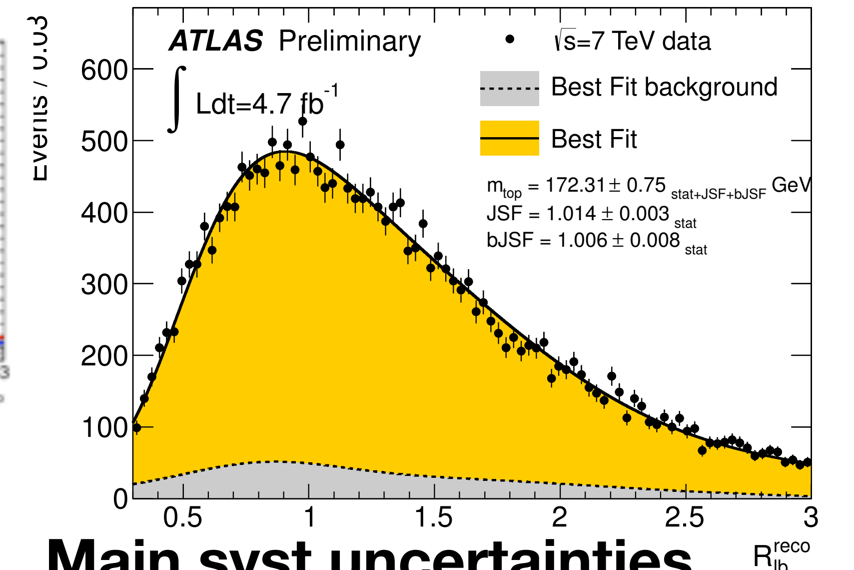


Template dependence

- **$m_{top,reco}$: 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

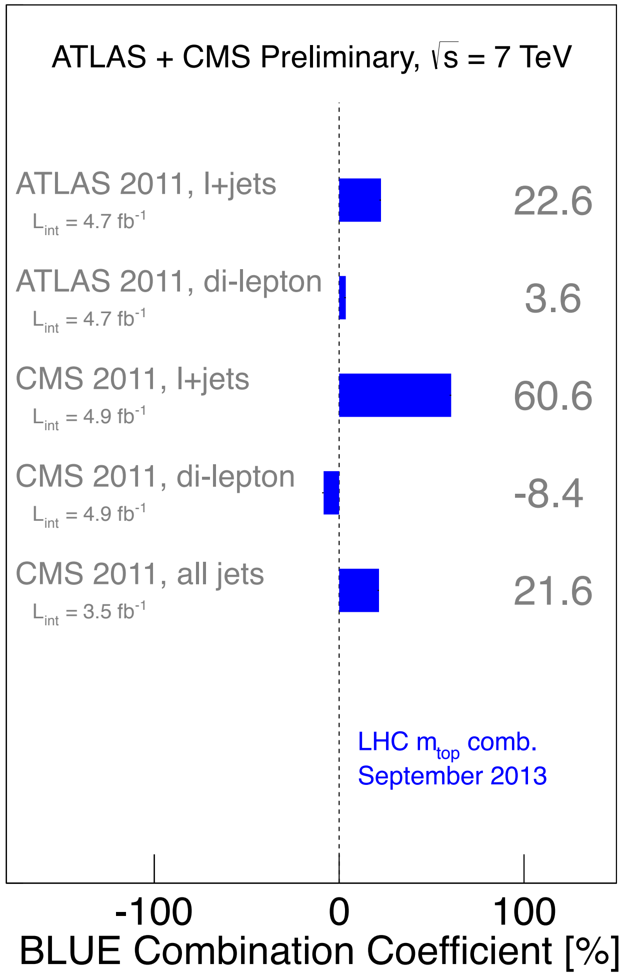
$$m_t = 172.31 \pm 0.75(\mathrm{stat} + \mathrm{JSF} + \mathrm{bJSF}) \pm 1.35(\mathrm{syst})\mathrm{GeV}$$
$$\mathrm{JSF} = 1.014 \pm 0.003(\mathrm{stat}) \pm 0.021(\mathrm{syst})$$
$$\mathrm{bJSF} = 1.006 \pm 0.008(\mathrm{stat}) \pm 0.020(\mathrm{syst})$$

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} @ LHC (Oct 2013)

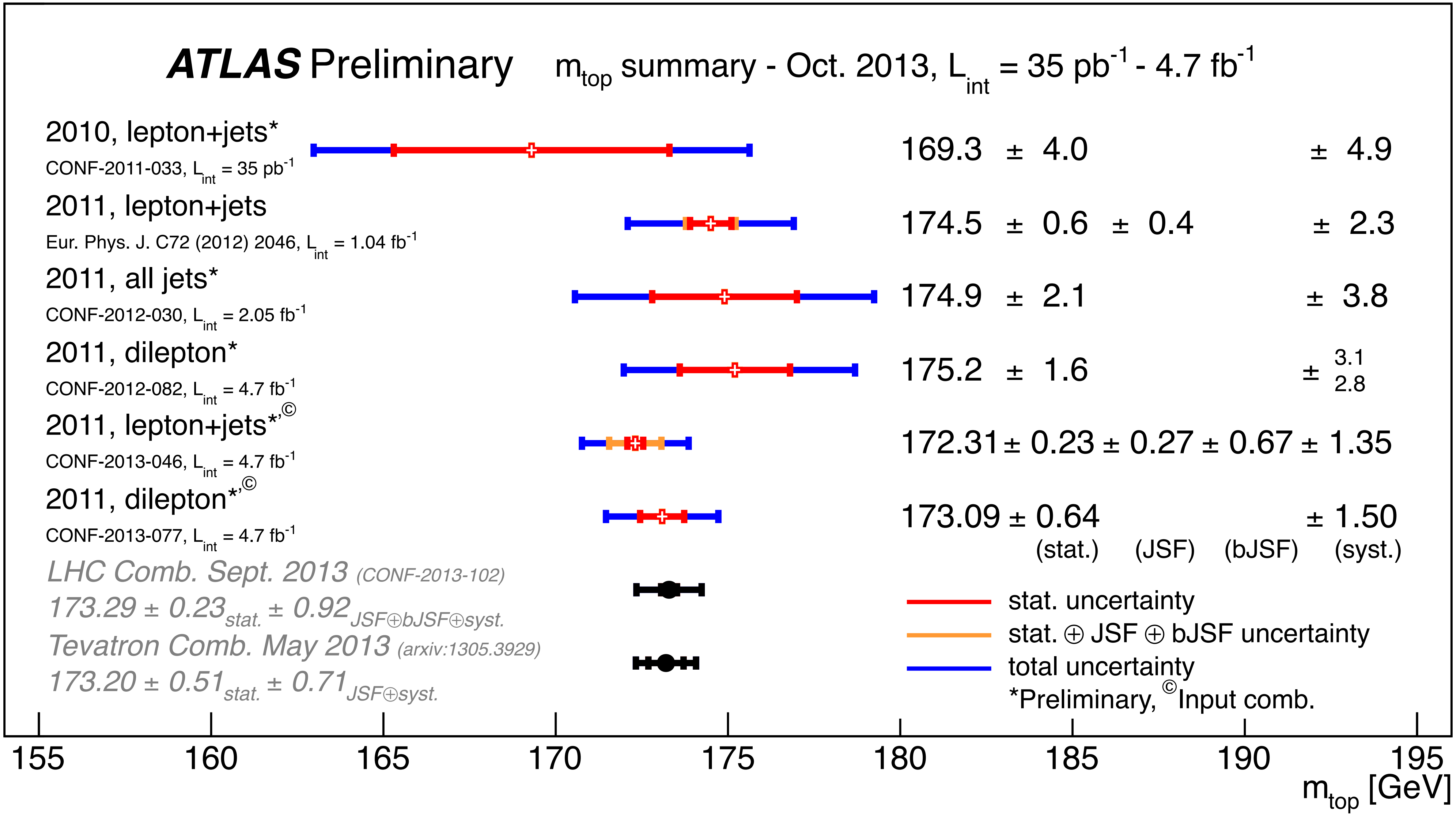


	ATLAS comb.	CMS comb.	LHC comb.
Measured m_{top}	172.65	173.59	173.29
iJES	0.41	0.27	0.26
uncorrelated JES comp.	0.66	0.32	0.29
in-situ JES comp.	0.30	0.08	0.10
intercalib. JES comp.	0.28	0.02	0.07
flavour JES comp.	0.21	0.19	0.16
b-jet energy scale	0.35	0.56	0.43
Monte Carlo simulation	0.40	0.06	0.14
Radiation modelling	0.42	0.28	0.32
Colour reconnection	0.31	0.48	0.43
Underlying event	0.25	0.17	0.17
Proton PDF	0.15	0.07	0.09
Detector modelling	0.22	0.25	0.20
b-tagging	0.66	0.11	0.25
Lepton reconstruction	0.07	0.00	0.01
Background from MC	0.06	0.10	0.08
Background from Data	0.06	0.03	0.04
Method	0.08	0.07	0.06
Multiple Hadronic Interactions	0.02	0.06	0.05
Statistics	0.31	0.29	0.23
Systematics	1.40	0.99	0.92
Total Uncertainty	1.43	1.03	0.95

- ***Systematics dominated***

ATLAS-CONF-2013-102

Status/history on m_{top}



bJSF has stat nature relative to in-situ JES calib

Sept 2013 combinations

ATLAS	$172.65 \pm 0.31_{stat} \pm 1.40_{(b)JSF\oplus\ syst}$
CMS	$173.59 \pm 0.29_{stat} \pm 0.99_{JSF\oplus\ syst}$
LHC	$\mathbf{173.29 \pm 0.23_{stat} \pm 0.92_{JSF\oplus\ syst}}$

ATLAS-CONF-2013-102

CMS-PAS-TOP-13-005

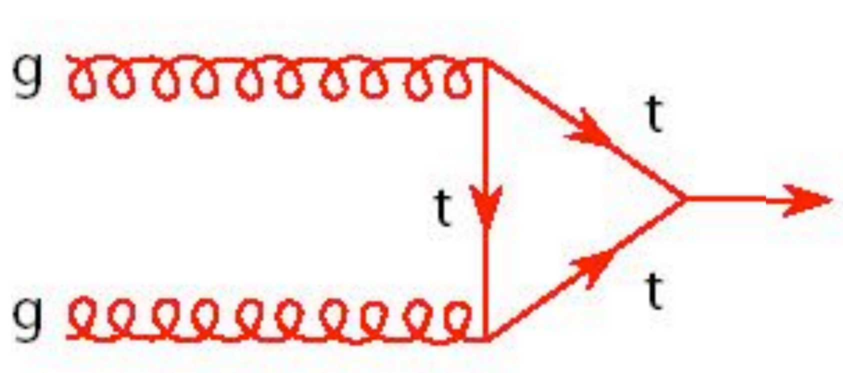
Top and Higgs

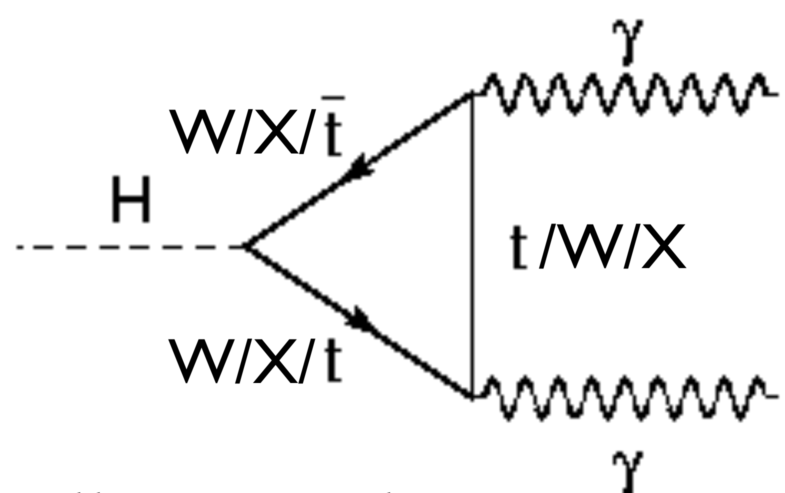
Top-Higgs coupling measurements

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

- Indirect evidence for SM-like Y_t

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

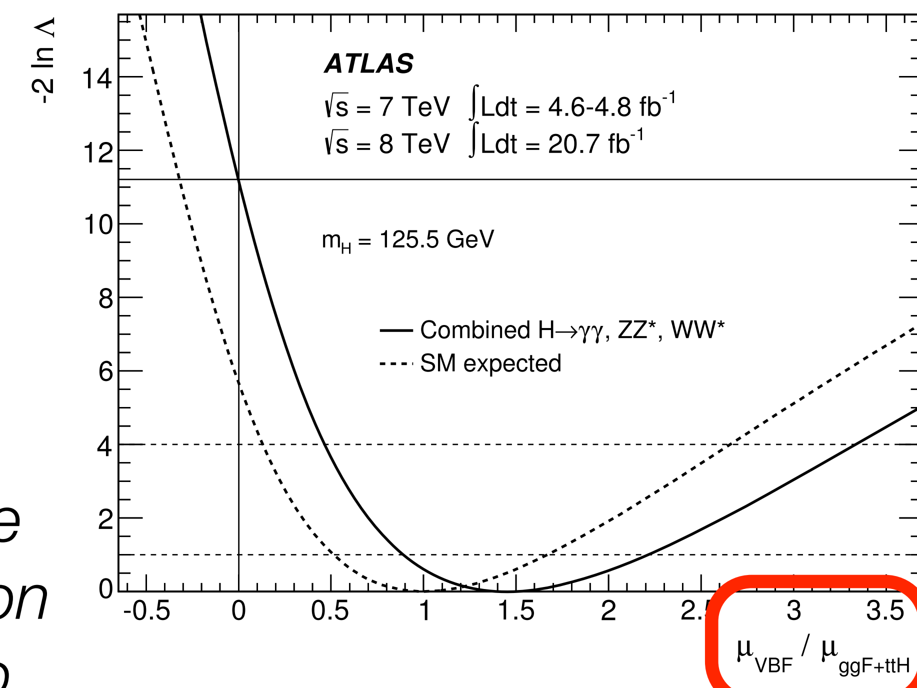




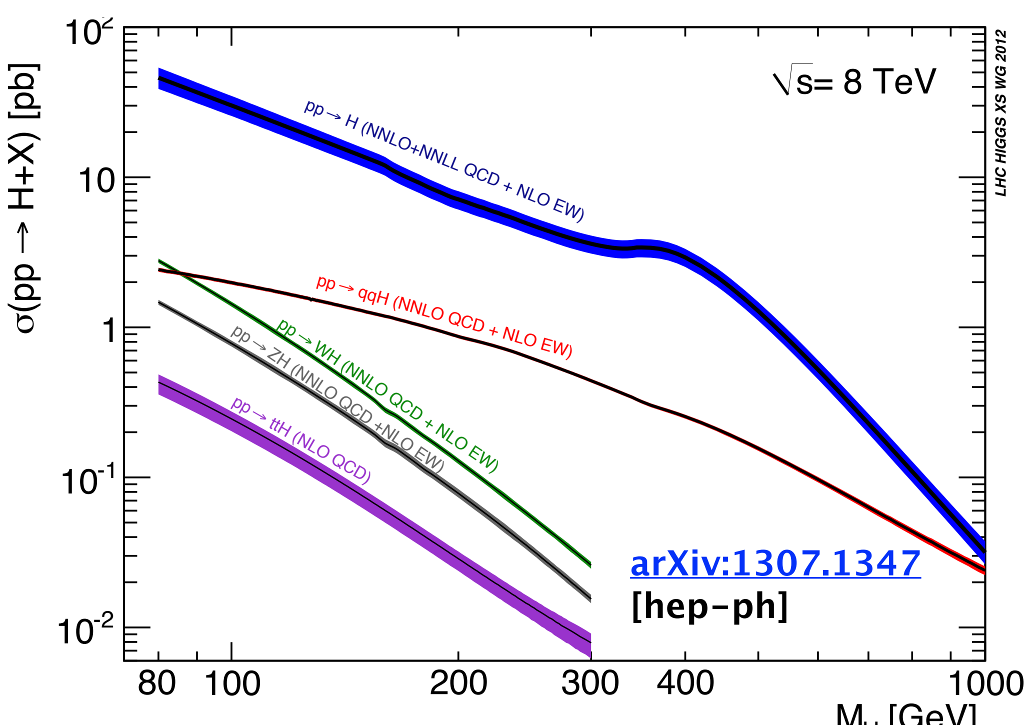
gluon fusion: dominant at LHC

$$\kappa_g^2(\kappa_b,\kappa_t) = \frac{\kappa_t^2 \cdot \sigma_{ggH}^{tt} + \kappa_b^2 \cdot \sigma_{ggH}^{bb} + \kappa_t\kappa_b \cdot \sigma_{ggH}^{tb}}{\sigma_{ggH}^{tt} + \sigma_{ggH}^{bb} + \sigma_{ggH}^{tb}}$$

interference with W boson in decay to photons

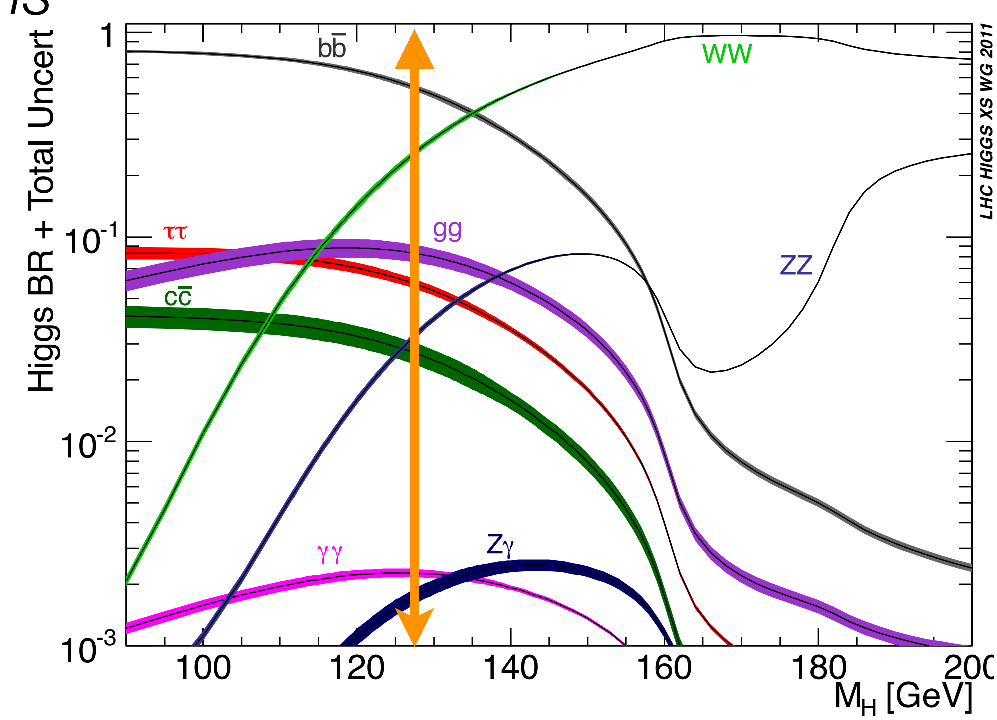


arXiv:1307.1347 [hep-ph]



arXiv:1307.1347 [hep-ph]

ATLAS most recent direct searches use tt̄H with H→bb and H→γγ



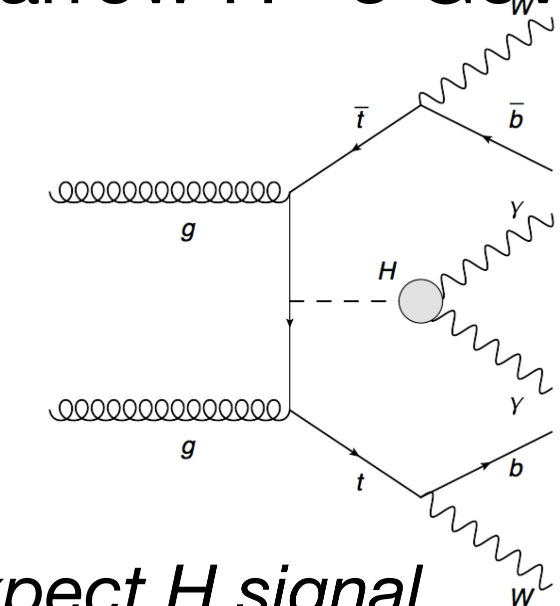
σ (ttH) = 0.13 (0.61) pb @ 8 (14) TeV

Search for $t\bar{t}H$, $H\rightarrow\gamma\gamma$ @ $\sqrt{s}$ = 8 TeV

ATLAS-CONF-2013-080

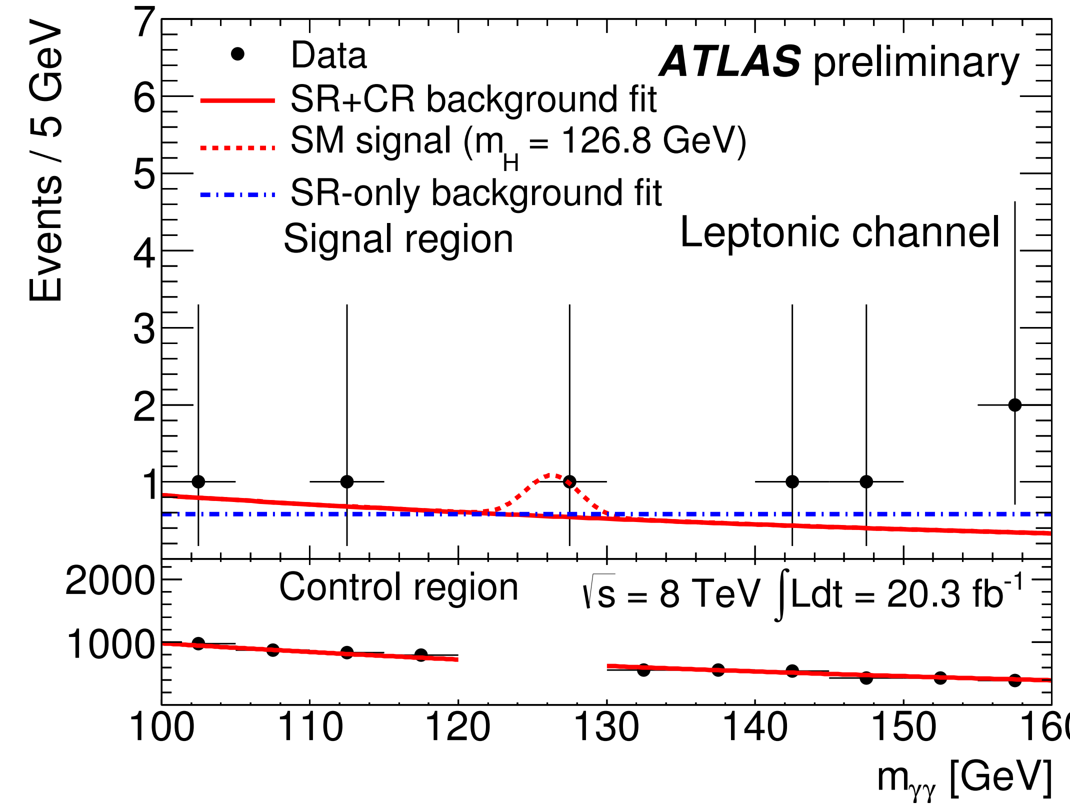
$\int Ldt$ = **20.3 fb^{-1}** *(2012)*

- Low BR: 2 10^{-3}, clean ←narrow H ~3 GeV



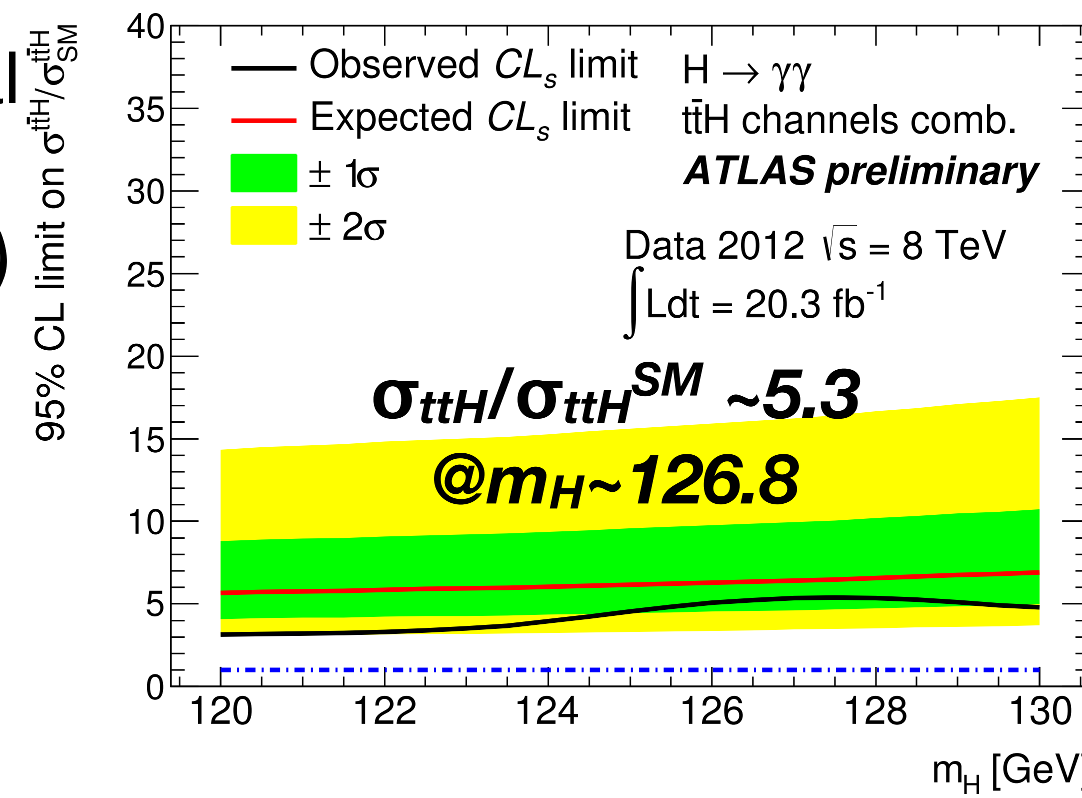
- **Di-photon (γ) trigger**, 2 offline γ (E_T > 40/30 GeV)
- *Leptonic sel*: ≥1 loose p_T lep (e,μ), ≥1 b-tag, E_T^{miss} cut & Z-mass veto
- *Hadronic sel*: ≥6 jets,no lep, ≥2 b-tags

Expect H signal composed of 80% to 90% $t\bar{t}H$



- **Bkg from fit of m(γγ)** to exp. bkg *in signal + side-band of loose γ-ID & isol. control regions* including m_H-dependent Crystal Ball+Gauss signal

- ***δN$_{bkg}$* :*Stat*~50% (~35%) >*Syst*~20% (10%)** *in lep(had) sel*



- Expect 0.55 (0.36) ev, Observe 1 (zero) ev in lep(had):no excess →**95% upper limit for inclusive H and $t\bar{t}H$ σ*BR** *(fixing other H decays to SM)* **including systematics** *in profile likelihood*

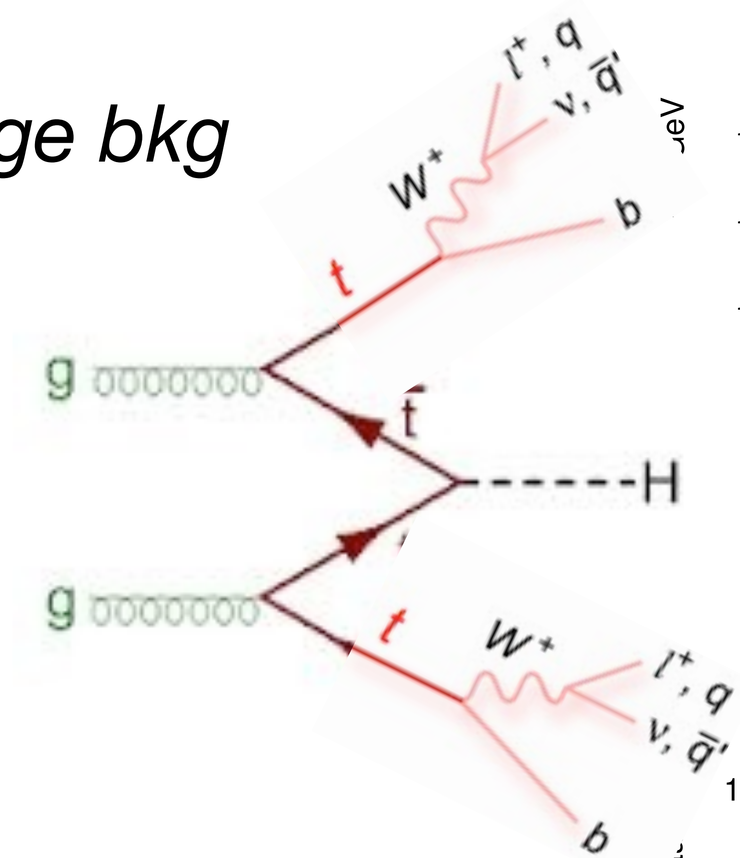
Search for $t\bar{t}H$, $H\to bb$ @ $\sqrt{s}$ = 7 TeV

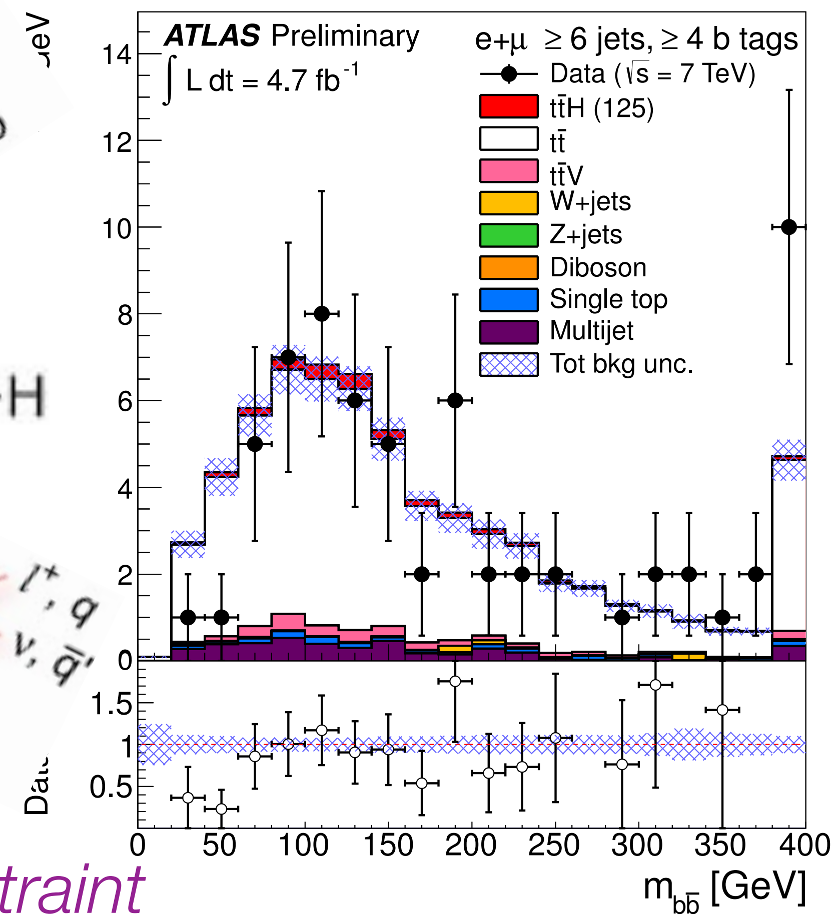
$\int Ldt$ = **4.7 fb^{-1}** *(2011)*

ATLAS-CONF-2012-135

high BR: 57% ,combinatorics, huge bkg

- 1 isol. (e,μ), E_T and m_T^W cuts, **≥ 4 central jets,** ≥1 b-tag, **main bkg: tt+(bb)/jets,** *(from simulation)* ***W +jets*** *(norm from data), data-driven multi-jets*



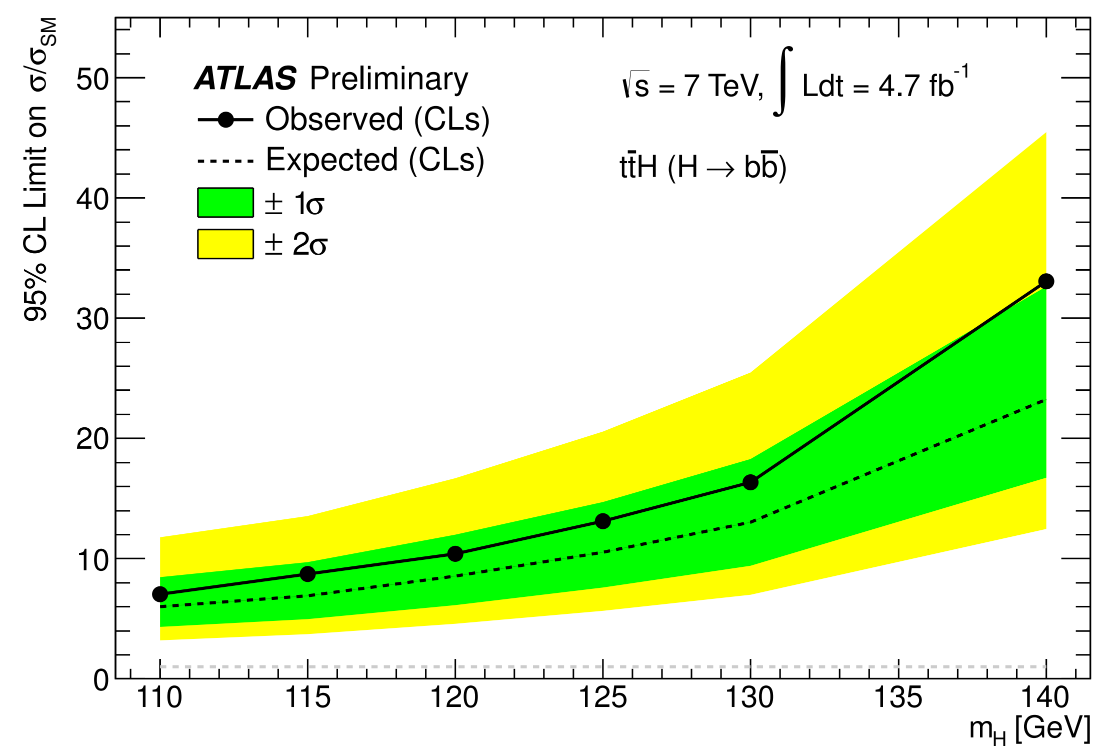


- **Build distributions of**
  - **H_T^{had}** = ∑|$p_{T,jet}$| in *5 jets x 3 or ≥ 4b-tags* **+** *4 jets (0,1, ≥ 2b-tags)+ 5, ≥6 jets (2b-tags)*
  - **m(bb) from kine likelihood fit** to ttbb hypothesis in *6 jets x 3 or ≥ 4b-tags*

signal rich

for syst constraint

- No excess → **Simultaneous** Profile Likelihood (PL) ratio for **H_T^{had} and m(bb) → 95% upper limit for $t\bar{t}$H σ****BR (bb)***) **constraining syst** in **situ** ***as nuisance pars in*** *fits to build* ***PL ratio***

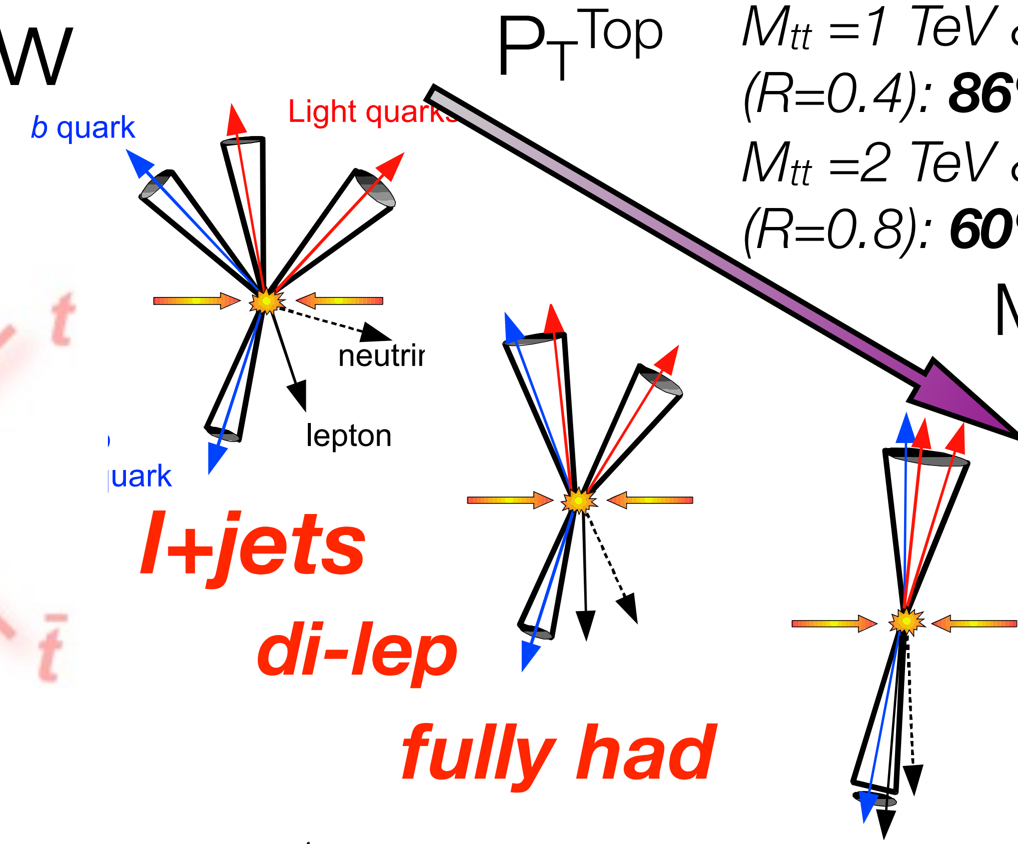


- **Dominant syst: $t\bar{t}$+HF content, b-tag**

Top and New physics

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***

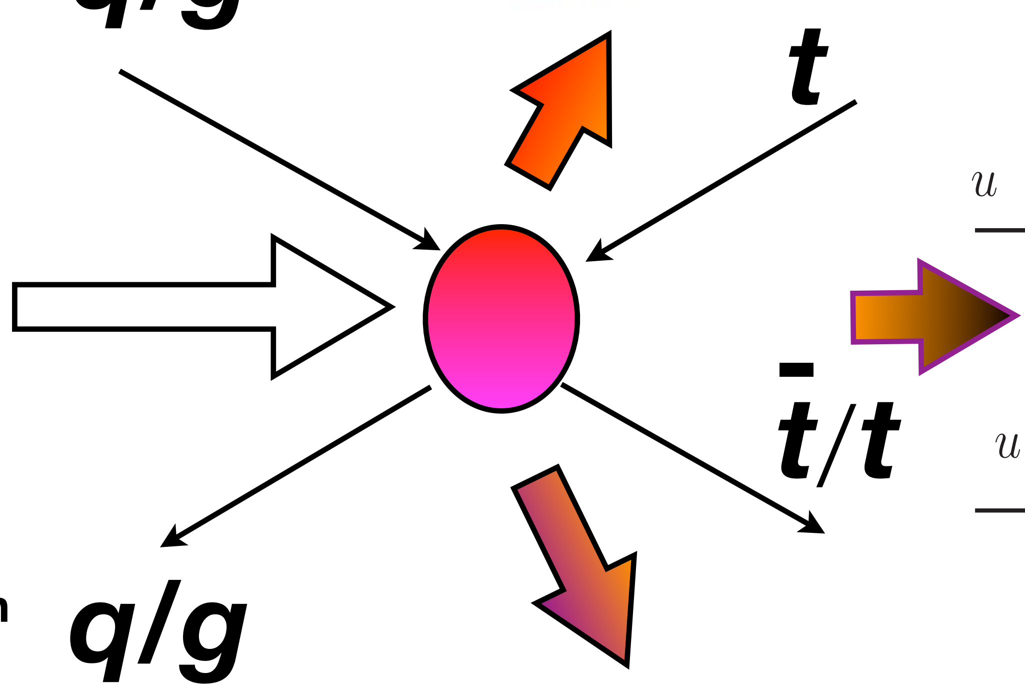
For ΔR=0.8, M_{tt} ~1.7 TeV, P_T ~600 GeV

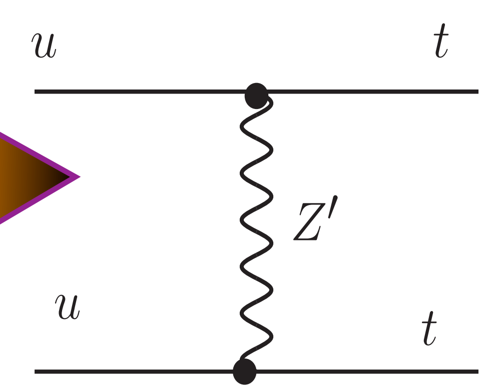
Production cross section

Resonant production

Production kinematics

Spin polarization



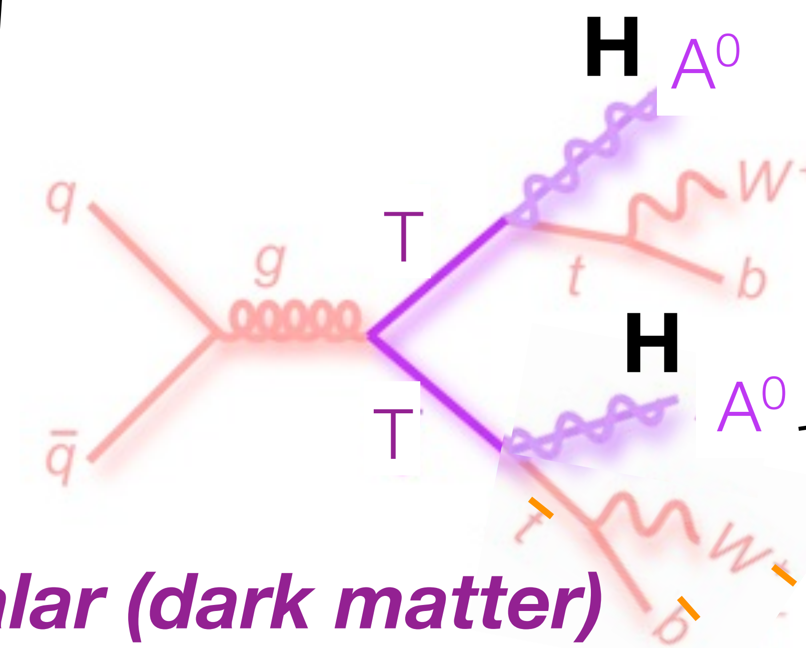


$t/\bar{t}$ charge asymmetry

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}

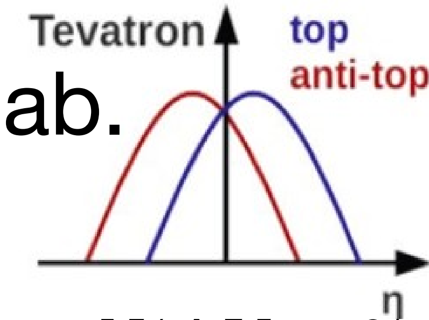
exotic 4th gen, leptoquarks, stop →top +neutralino, UED, little higgs,

top partner + stable scalar (dark matter)

Measure top quarks charge asymmetry

- In $pp/p\bar{p} \to t\bar{t}$: **t/anti-t** have **different** differential distributions (from pQCD). NLO effect in $q\bar{q}$ /qg→$t\bar{t}$/$t\bar{t}q$: 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 discrepancies with SM: i.e. A_{FB} (CDF)~3.4σ SM for m_{tt}> 450 GeV Interference of SM gluon with new phys?***

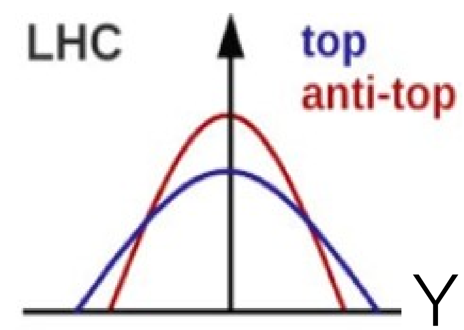
$$A_{FB} = \frac{N(\Delta Y > 0) - N(\Delta Y < 0)}{N(\Delta Y > 0) + N(\Delta Y < 0)}$$

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

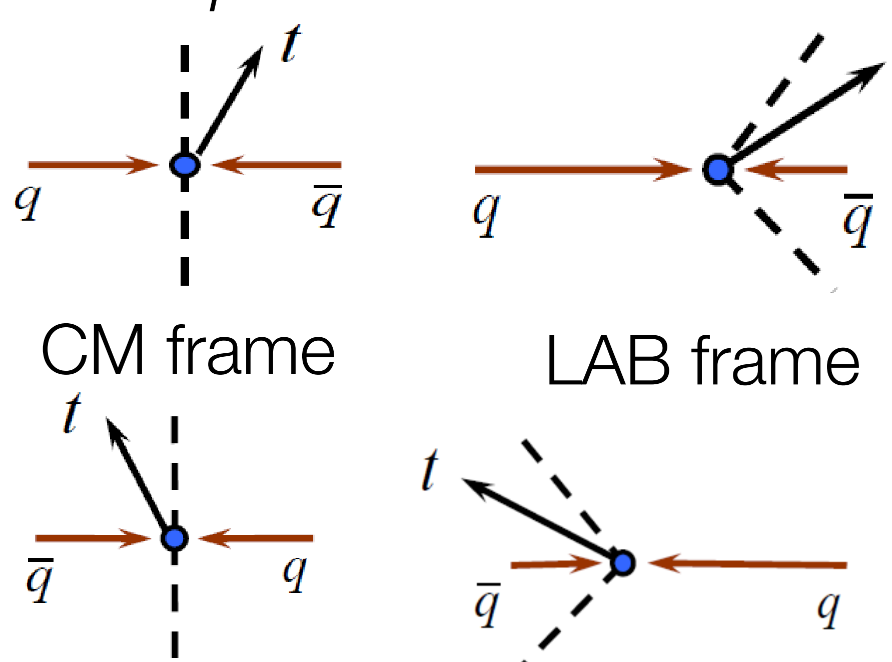
- **At LHC** A_{FB} = 0. Charge asymmetry ⇔ ***t*** emitted along ***q*** direction.

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

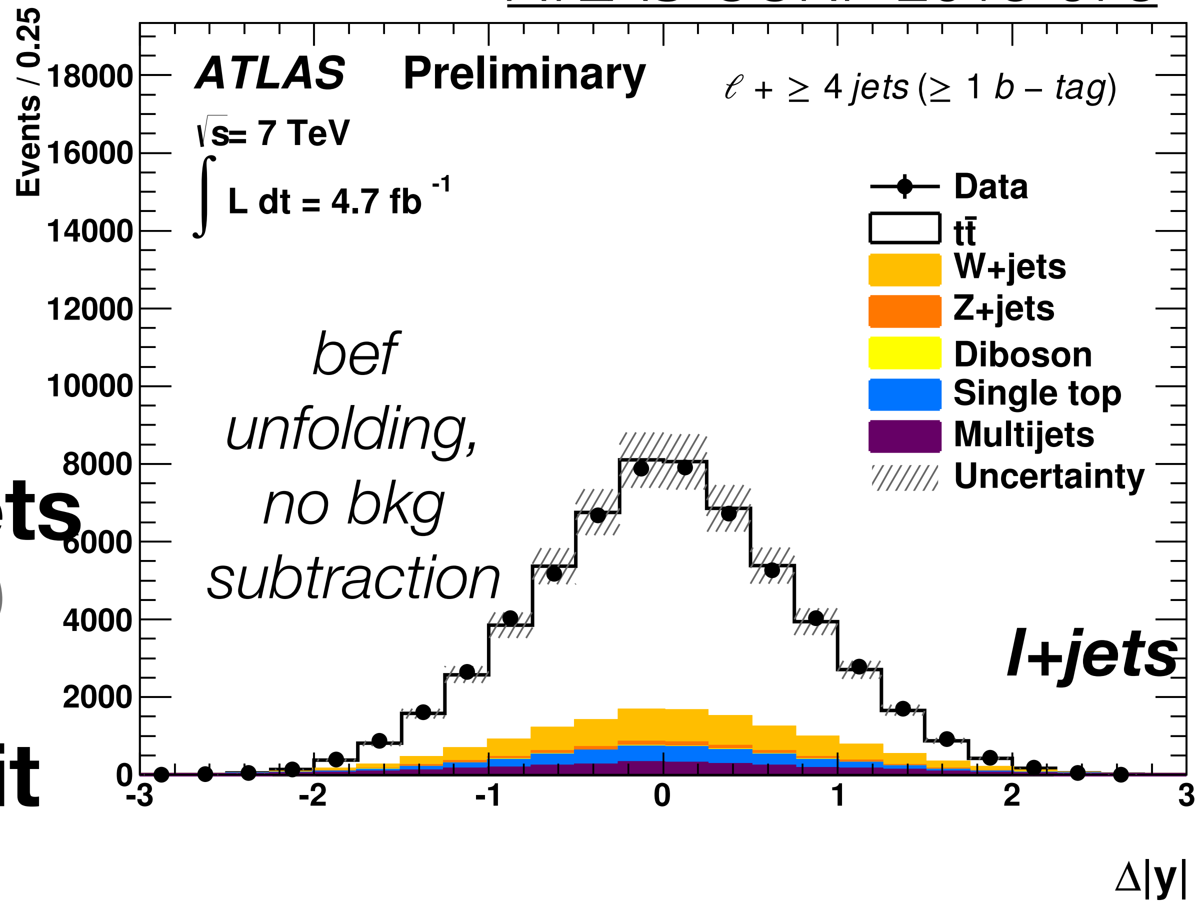
$$A_C^{SM} = 0.0123 \pm 0.0005$$

Measure top quarks charge asymmetry

$\int Ldt$ = **4.7 fb⁻¹** *(2011)*

ATLAS-CONF-2013-078

$qq\ell\nu bb$



- **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 tt̄ 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*

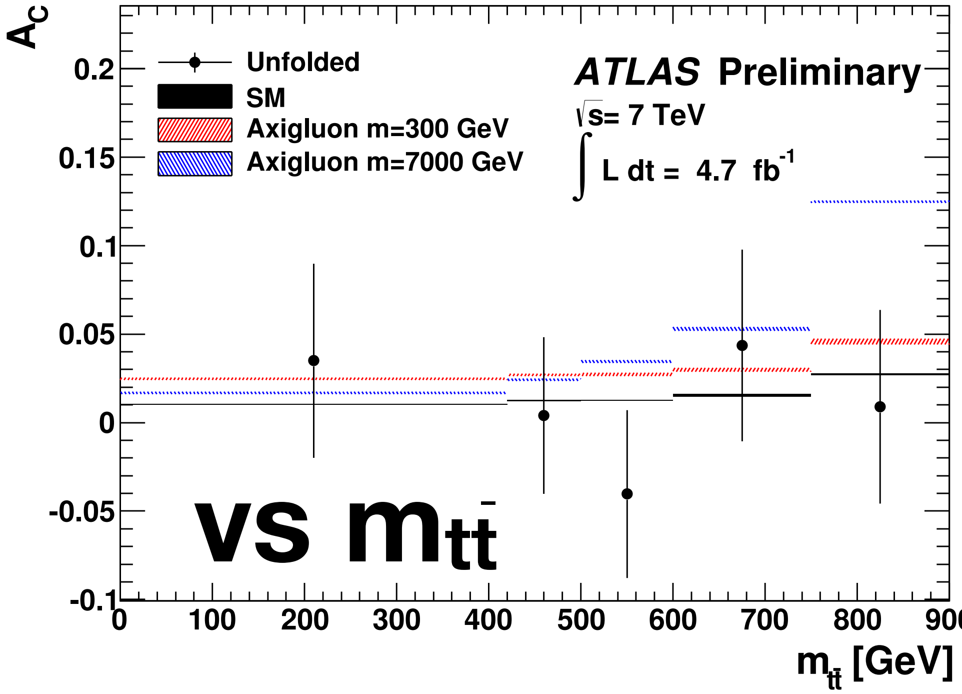
A_C	Data	Theory
Unfolded	0.006±0.010	0.0123±0.0005
Unfolded with $m_{t\bar{t}}$ > 600 GeV	0.018±0.022	$0.0175^{+0.005}_{-0.004}$
Unfolded with $\beta_{z,t\bar{t}}$ > 0.6	0.011±0.018	$0.0202^{+0.006}_{-0.007}$

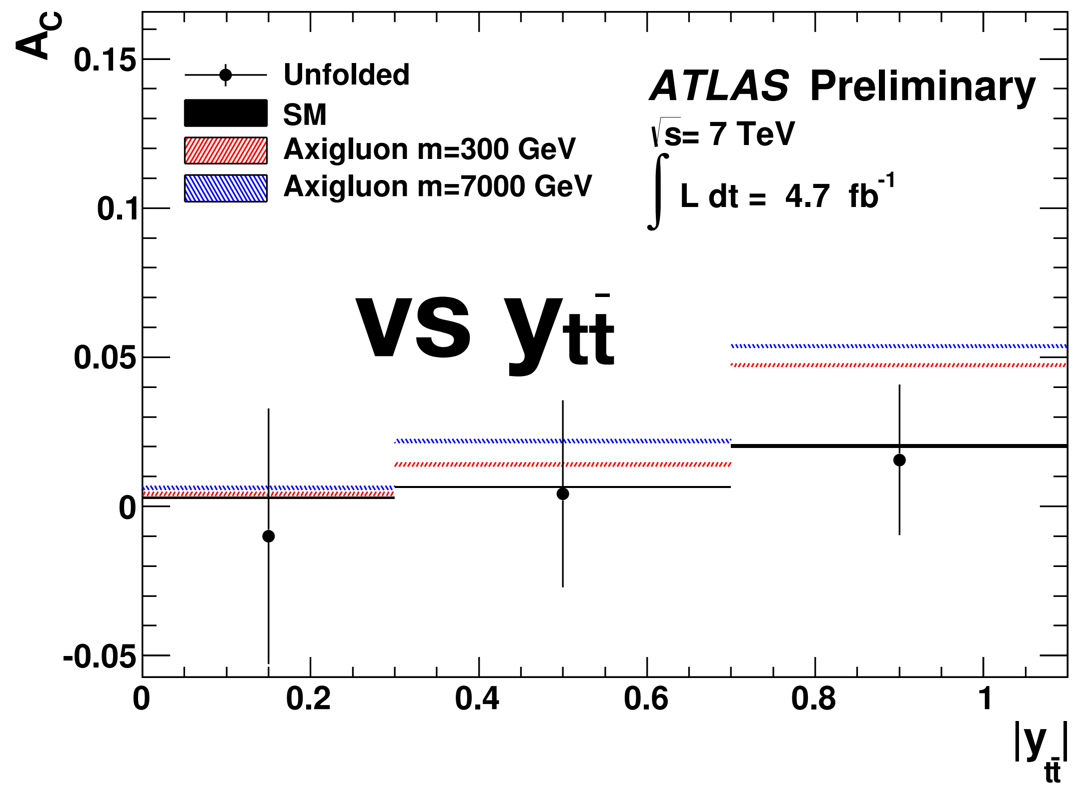
consistent with SM, *stat dominated,main syst: JES and lep. en scale*

Measure top quarks charge asymmetry

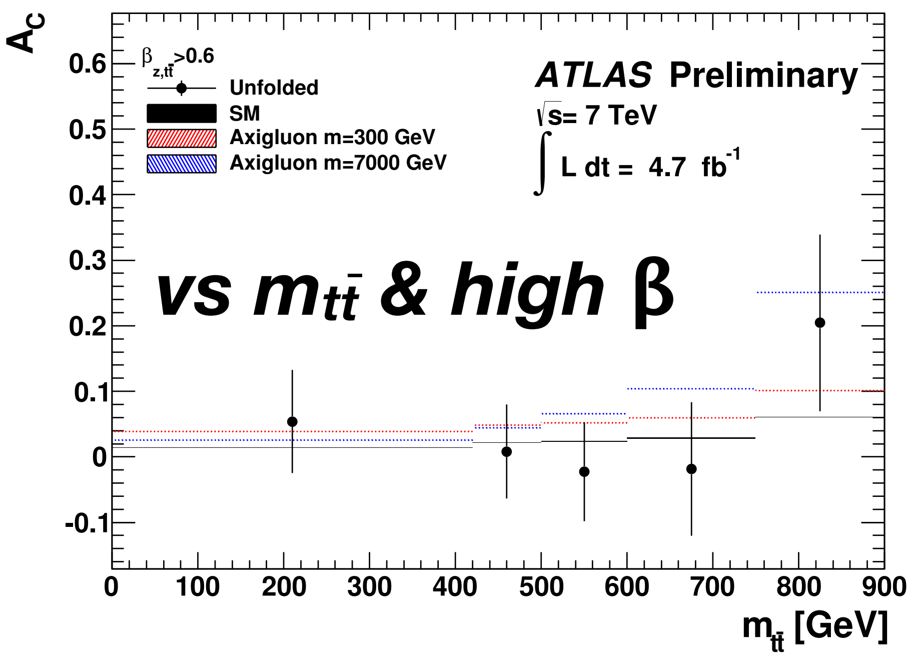
ATLAS-CONF-2013-078

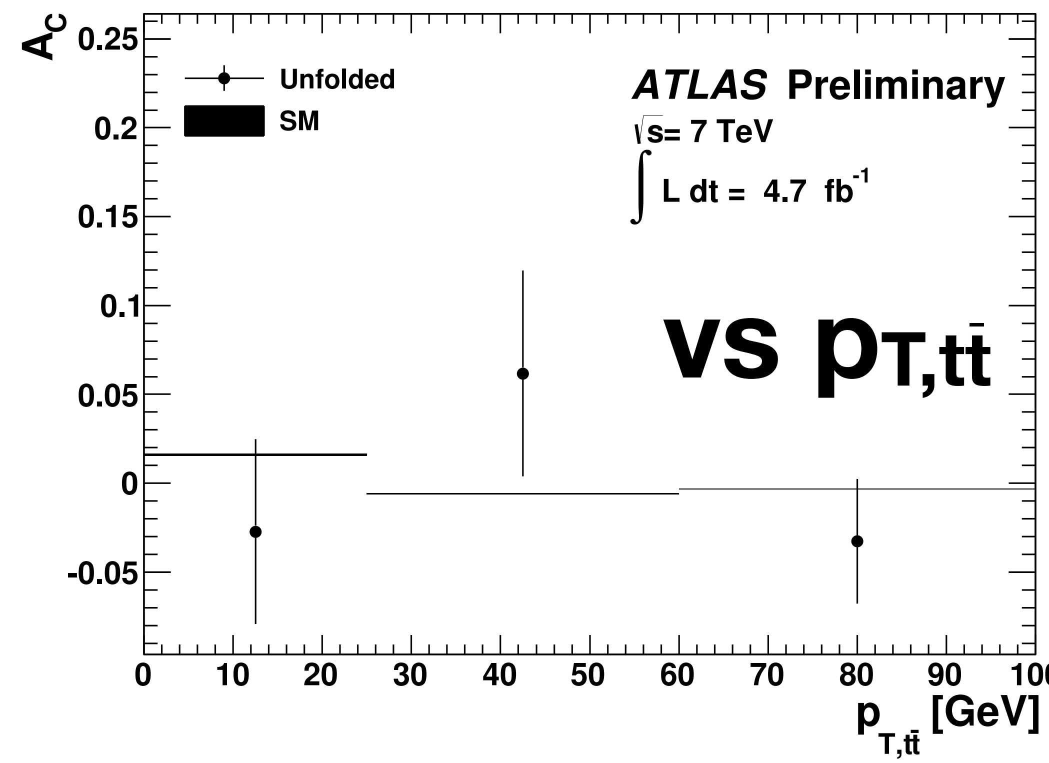
$\int L dt$ = **4.7 fb^{-1}** *(2011)*





"unfolded" uncertainties are (dominant) stat + syst





- **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**

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

ATLAS-CONF-2013-018

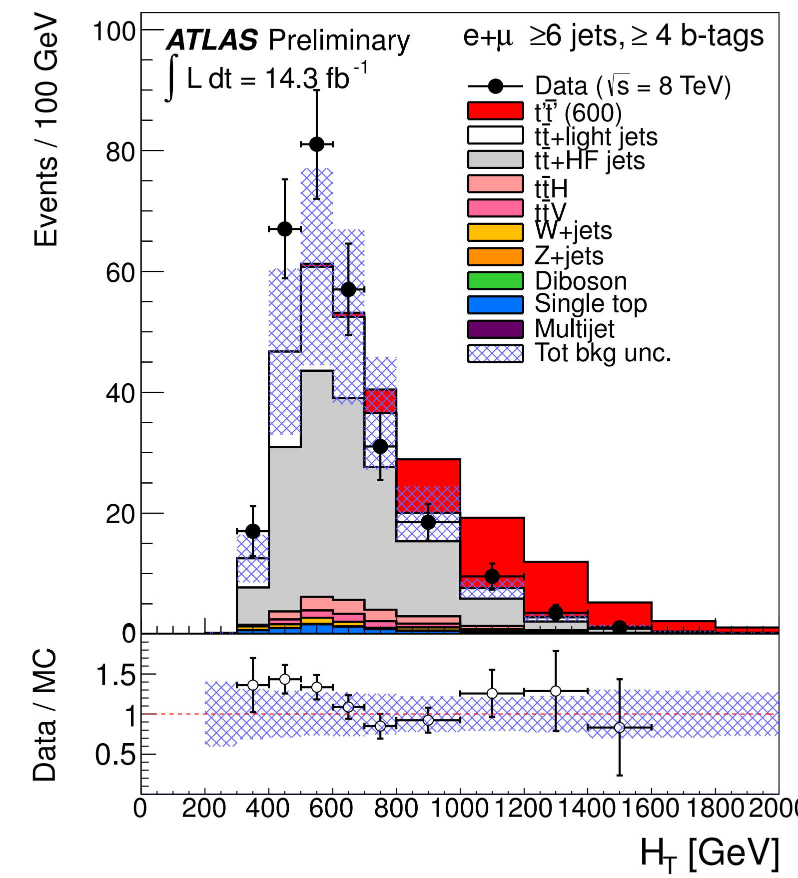
T: to cancel top-induced divergencies of m_H, same EWK SU(2) xU(1) behaviour for both chiralities

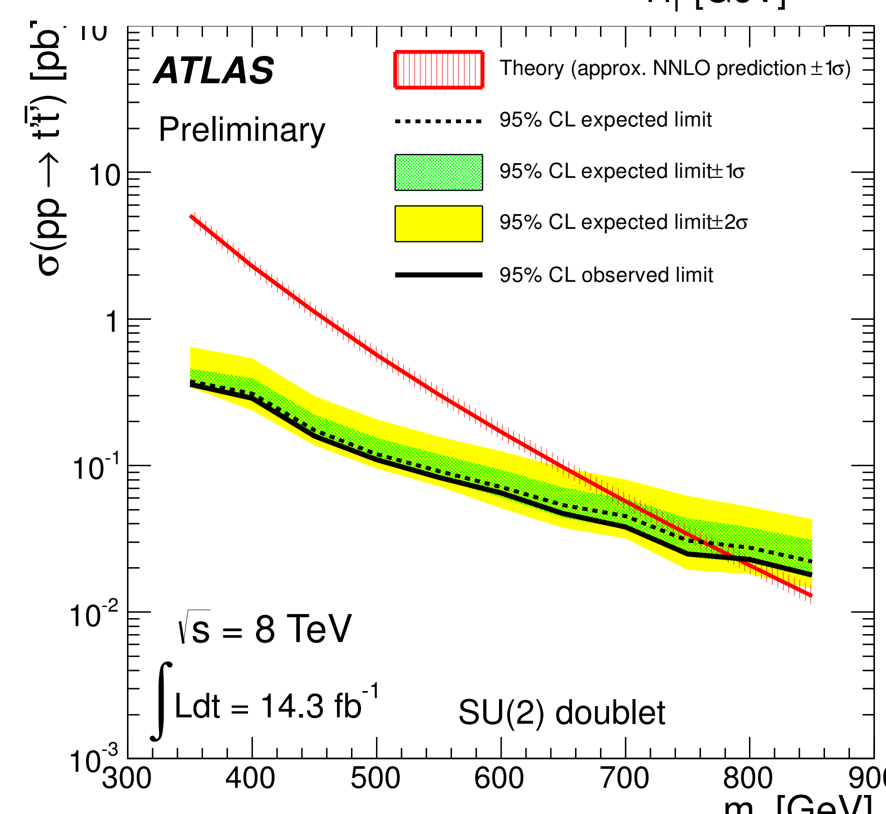
$\int Ldt$ = **14.3 fb^{-1}** *(2012)*

$t'\bar{t}' \rightarrow Ht H\bar{t}, ZtHt$ 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***: $t\bar{t}$+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 $t\bar{t}$+light/HF jets norm. as *nuisance par.***

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





New physics in m_{tt}

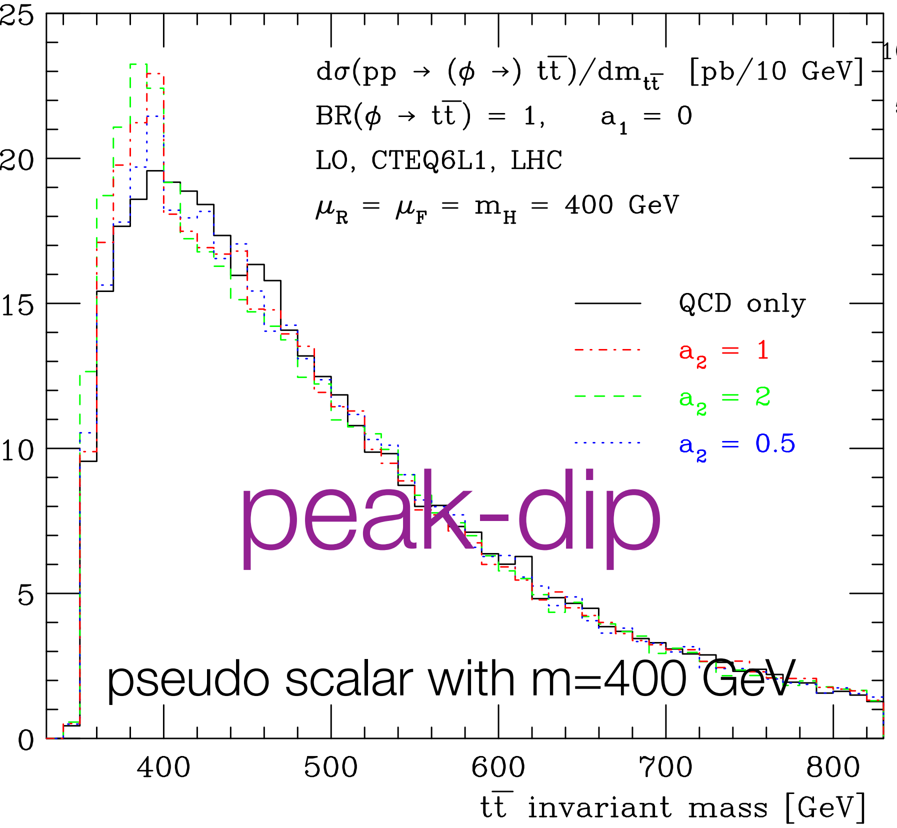
one peak

Z' or

new strong bosons

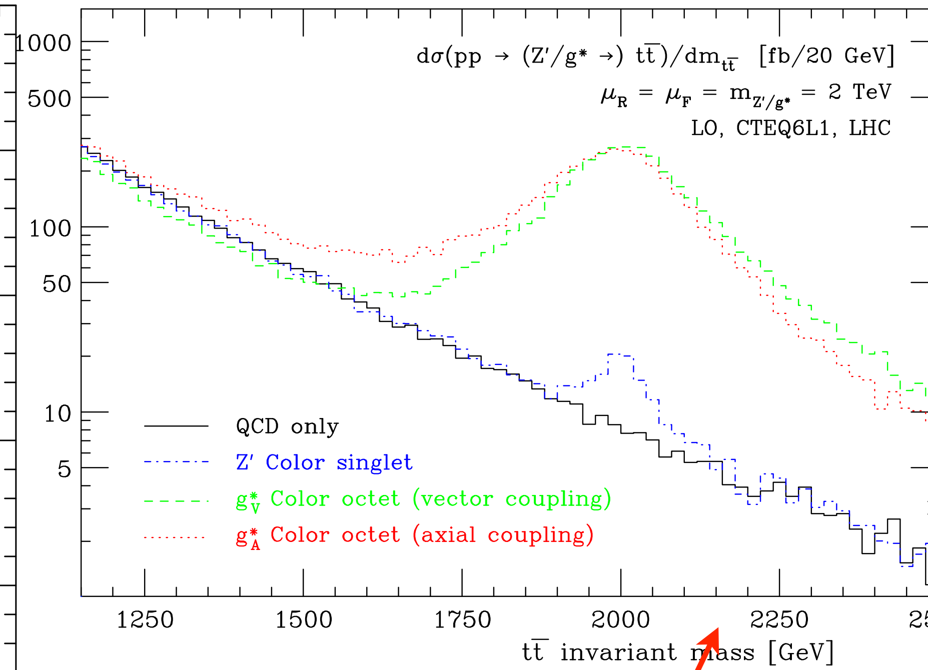
enhancements

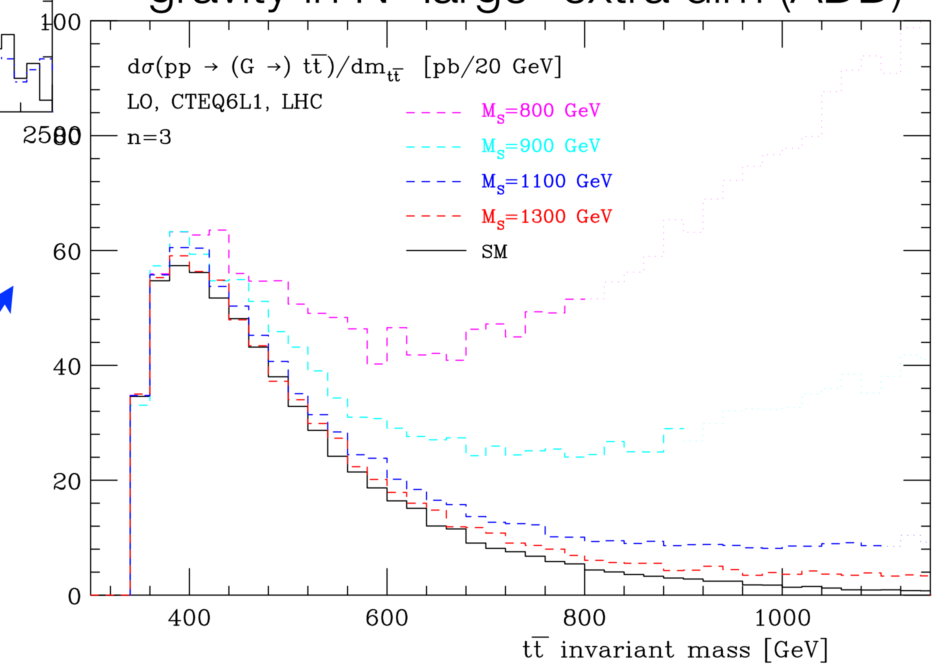
tower of degenerate KK gravitons ; only gravity in N "large" extra dim (ADD)



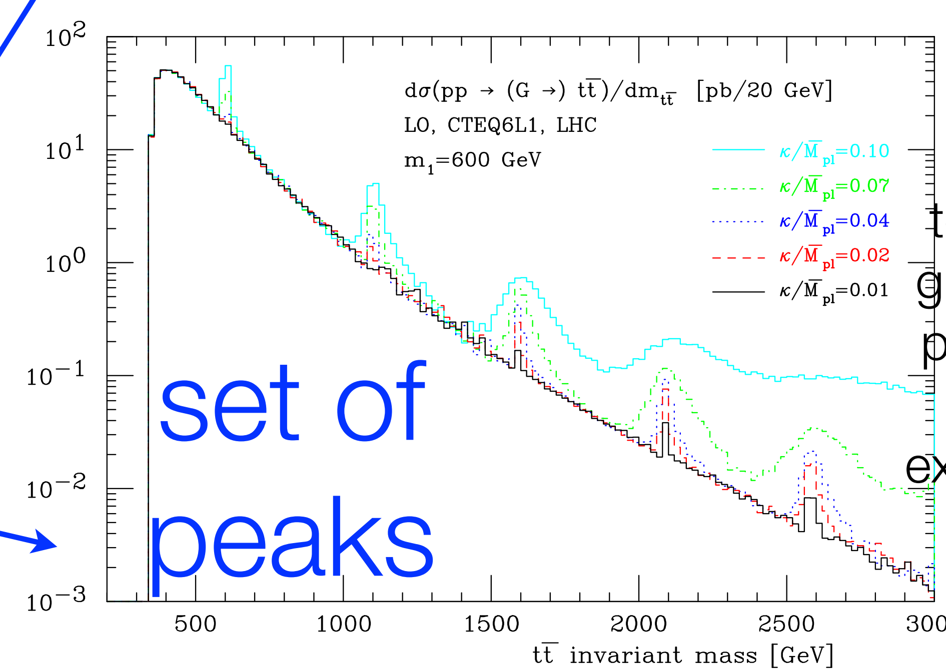
peak-dip

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]



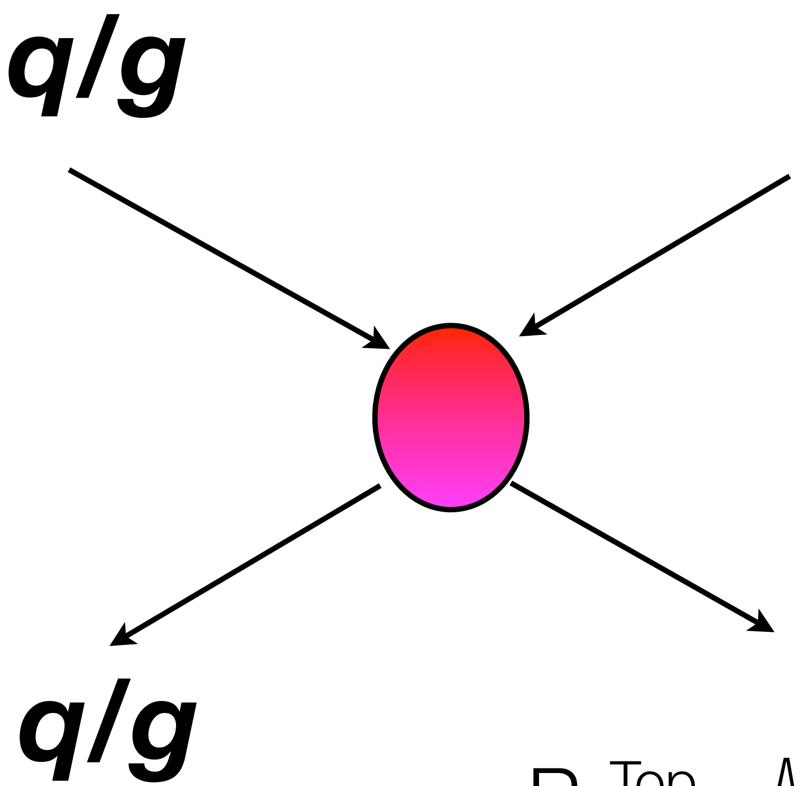
set of peaks

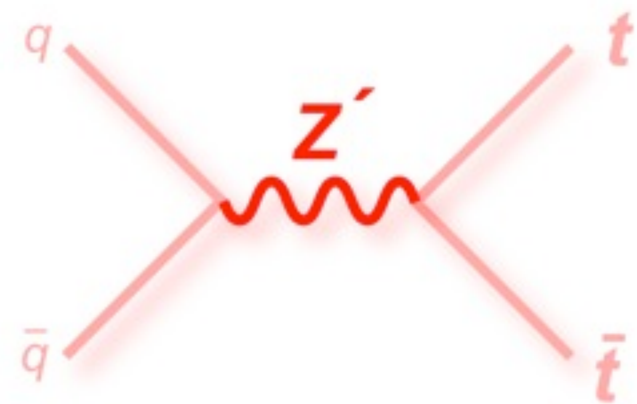
tower of KK gravitons ; all particles in 1 "warped" extra dim (RS)

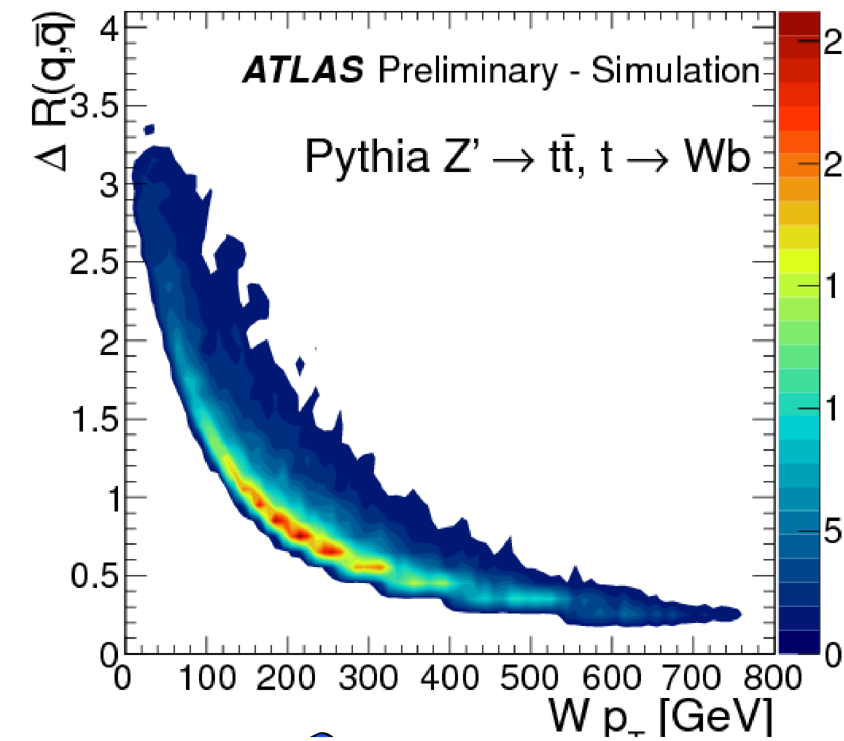
JHEP 0901:047,2009

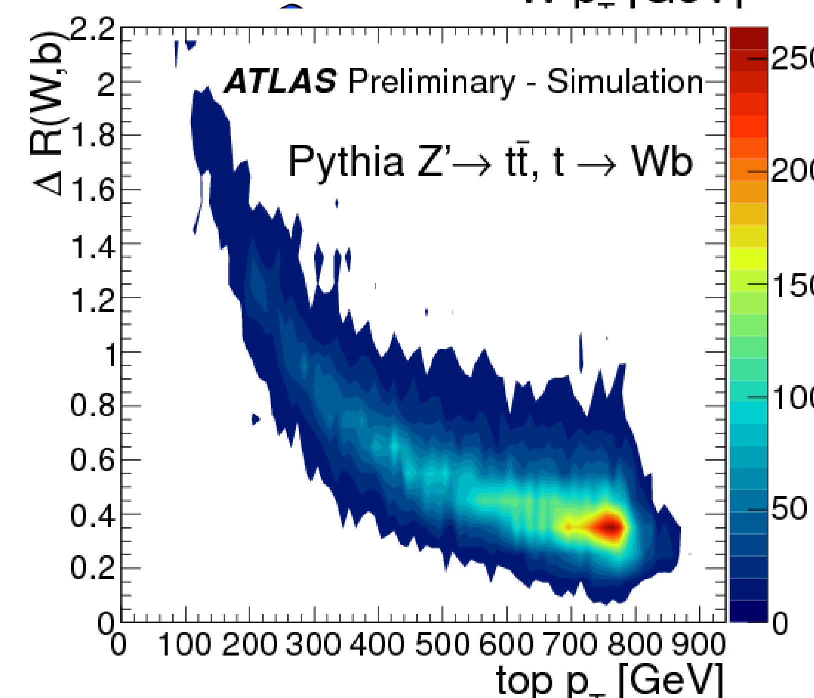
The emergence of boosted tops

ATLAS-CONF-2012-065



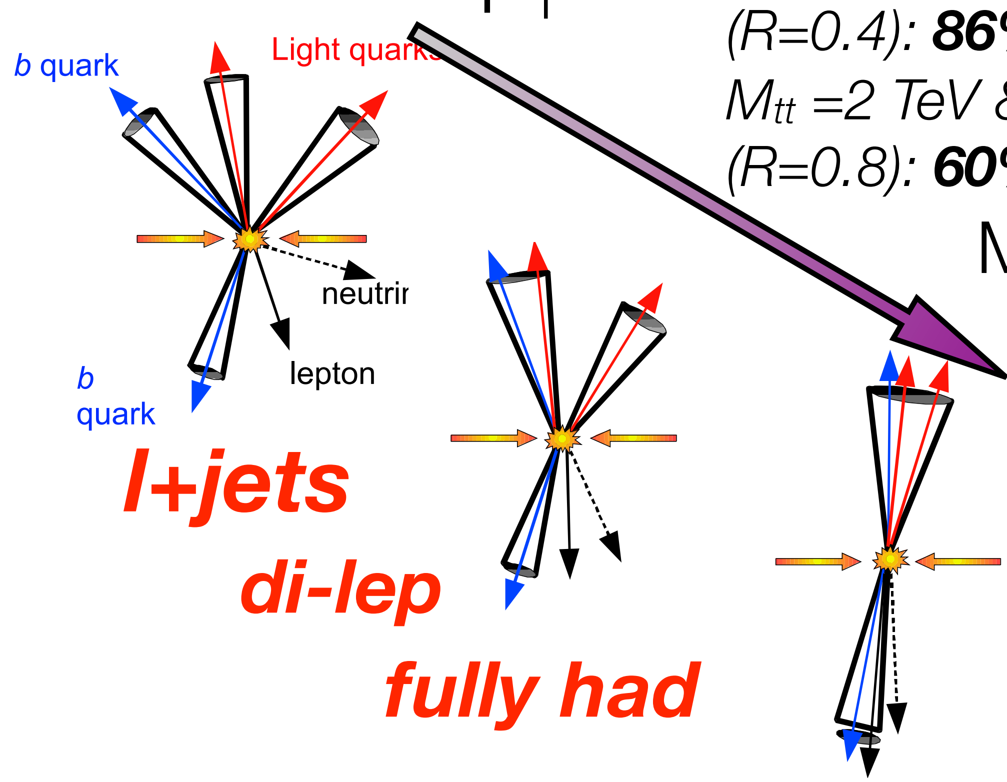






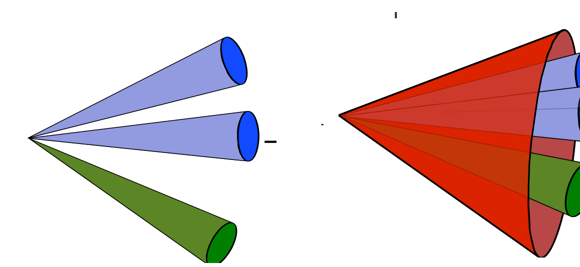
M_{tt} =1 TeV & anti-k_T (R=0.4): ***86% resolved***

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



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

$$\Delta R = 2m/p_T$$



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

$\int L dt$ = **14.3 fb^{-1}** *(2012)* ***$\sqrt{s}$=8 TeV***

ATLAS-CONF-2013-052

qqℓ**νbb**

Resolved selection

- *single lepton trigger*

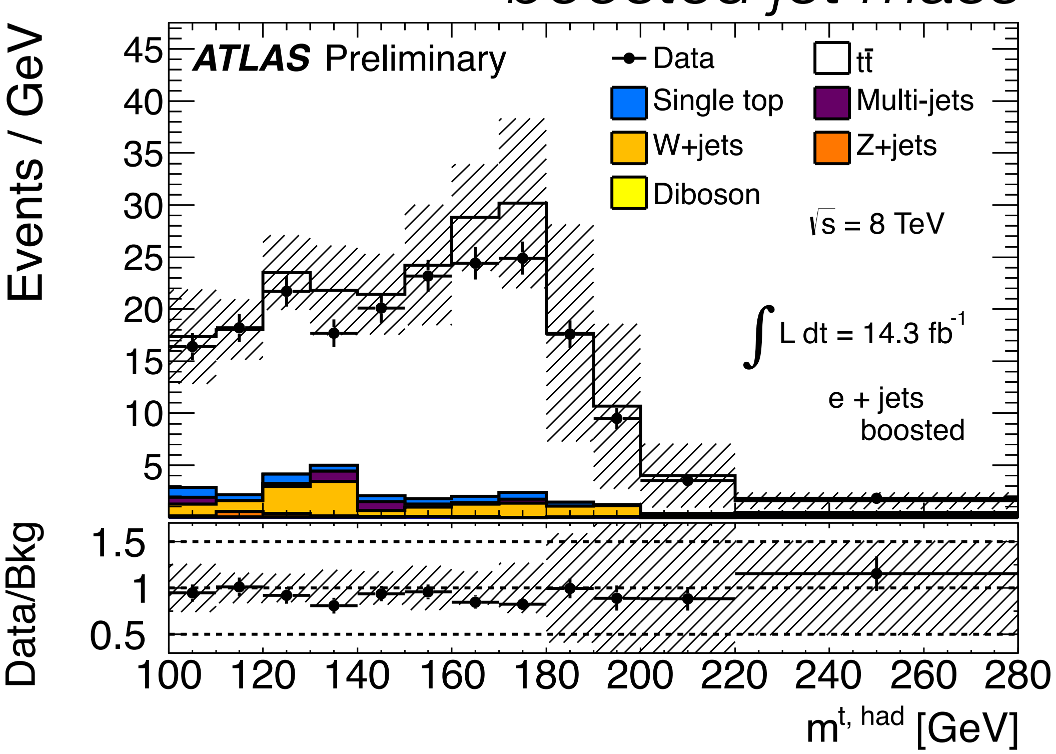
(Fully) Boosted selection

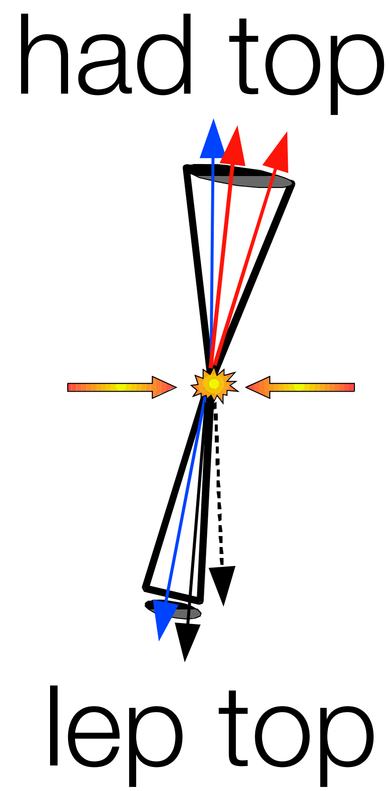
- *trigger on R=1.0 anti-k_T jet with **p_T** > 240 GeV (~100% eff > 350 GeV)*

- *exactly **1 good, high p_T central lepton (e, μ) 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





- *≥ 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*

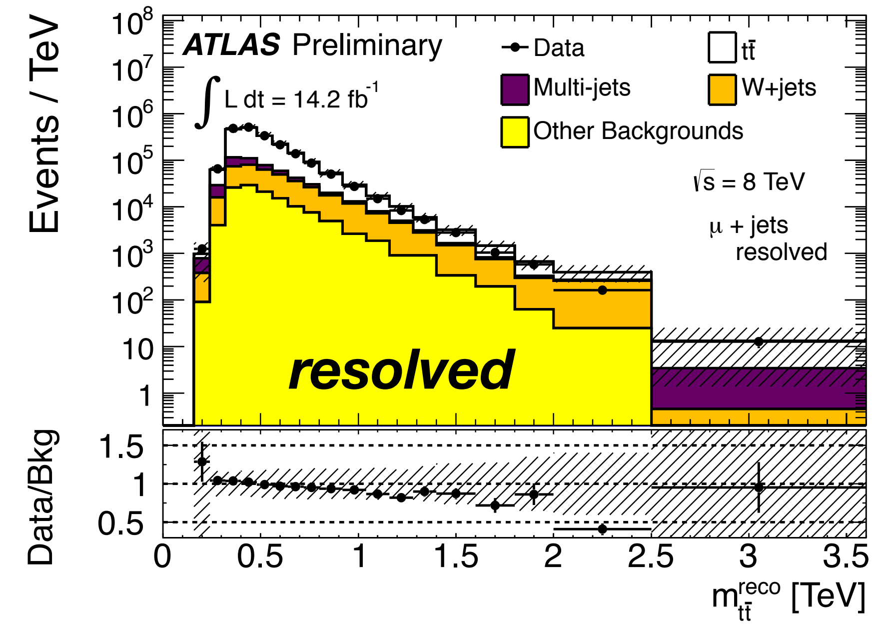
2 exclusive samples: pass boosted, fail boosted & pass resolved

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

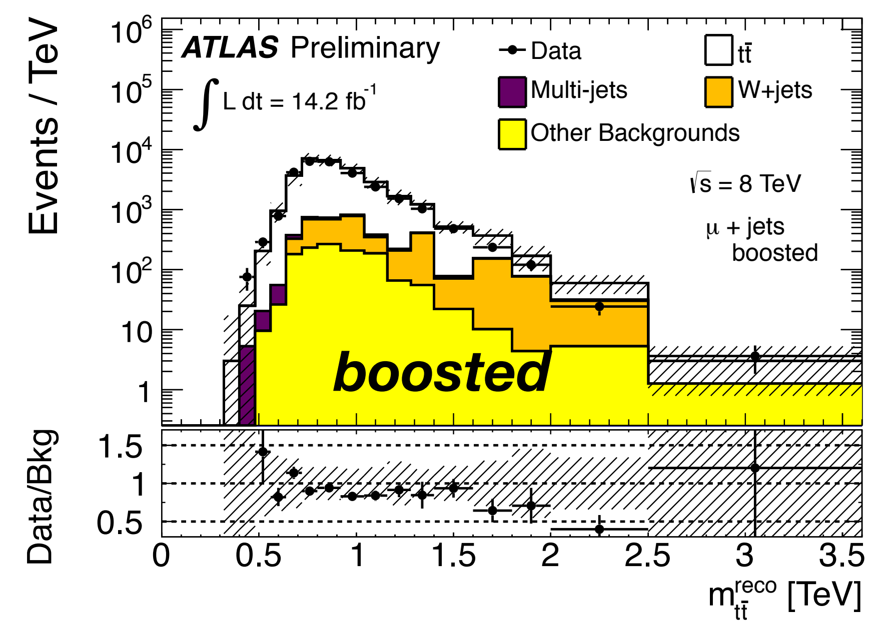
$\int Ldt$ = **14.3 fb^{-1}** *(2011)* $\sqrt{s}$*=8 TeV*   ATLAS-CONF-2013-052

qqℓ**vbb**

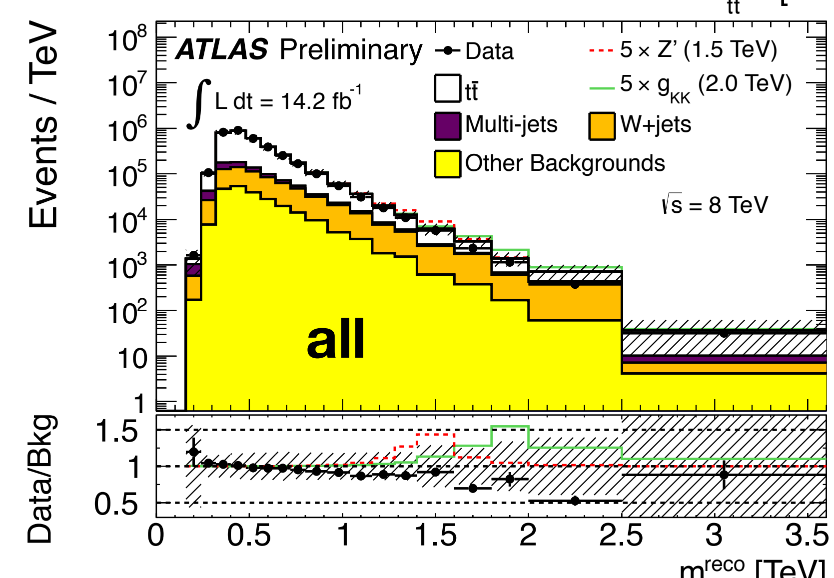
- Data-driven **QCD** (*matrix method, validated in low E_T^{miss}, $m_T(W)$ region, orthogonal to boosted*), **W+jets normalization** (*from charge asymmetry of W production, relaxed p_T, b-tag and **k_T (1 → 2) cuts***)



- **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

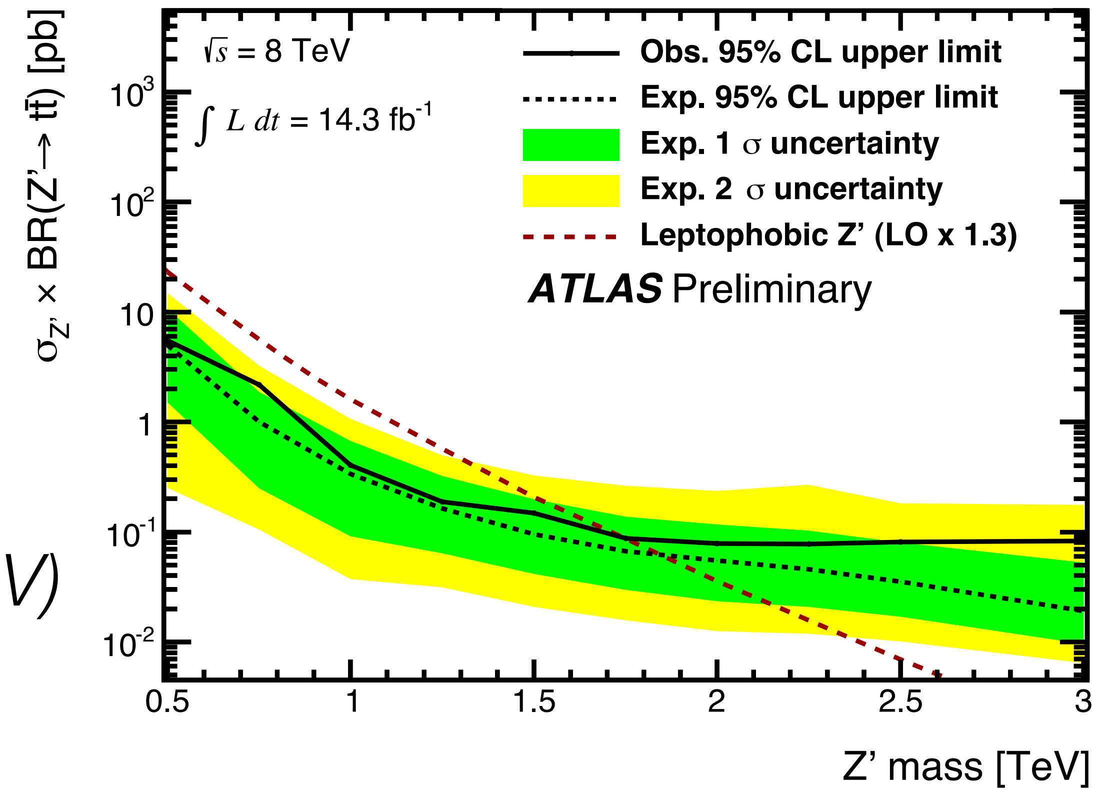


Search for excess in $t\bar{t}$ production vs M_{tt} -single lepton

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

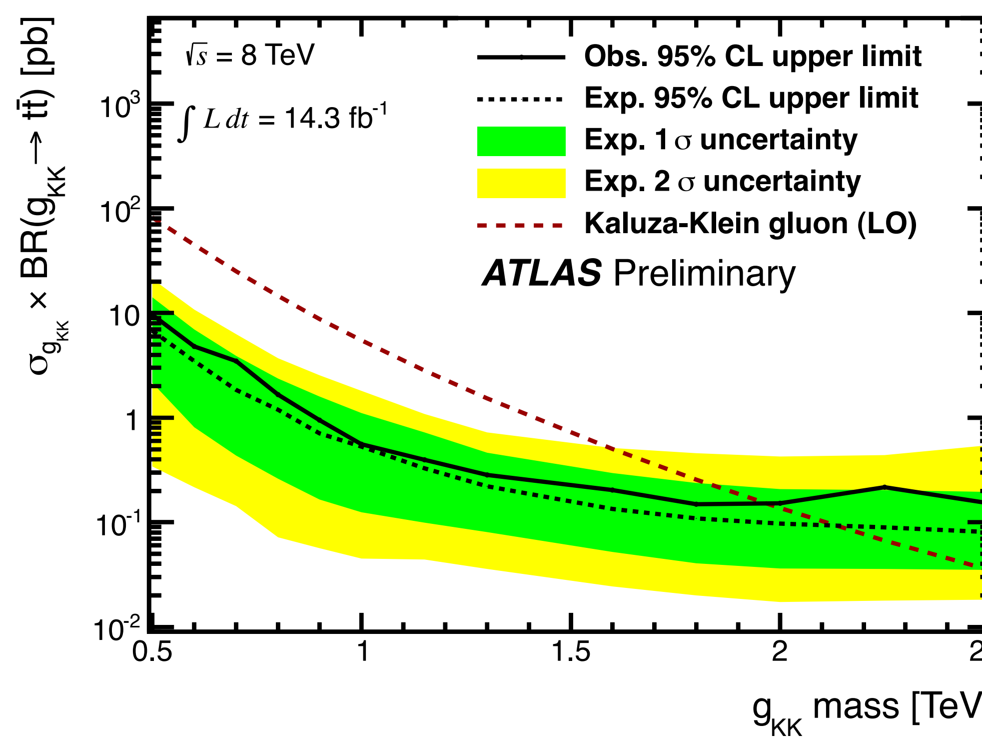
ATLAS-CONF-2013-052

- 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**

Some words on prospects

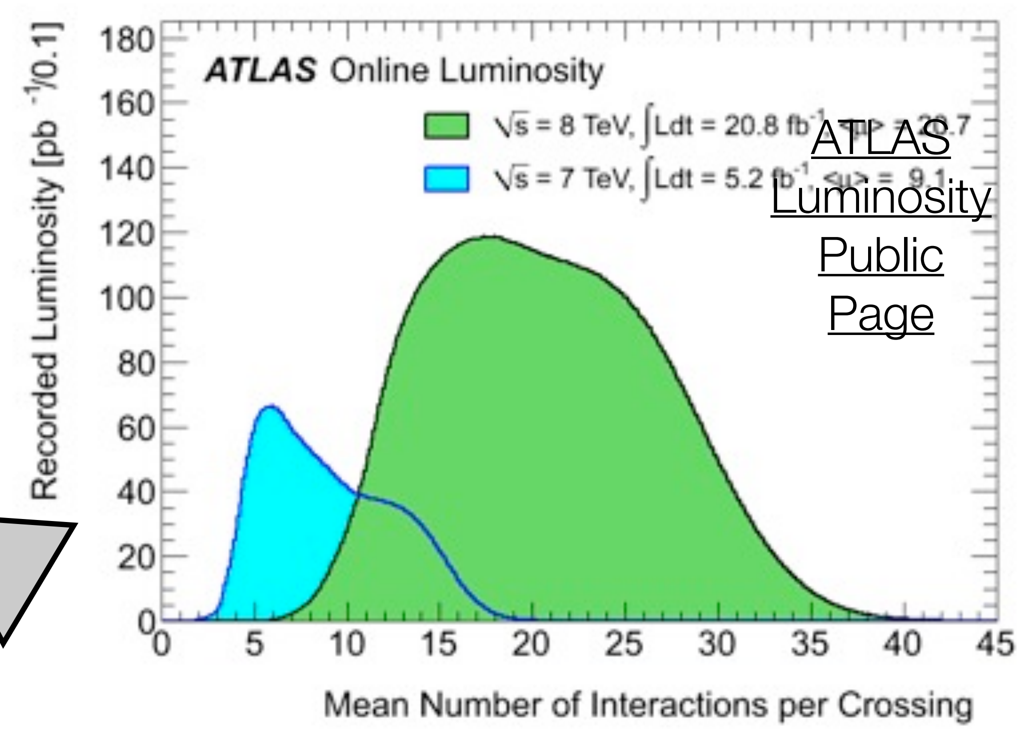
- **Go for precision realm in top production and top mass.** Measurements: mostly **systematics dominated (that's where the work is).**

- **Go for differential xsec measurements** ($d\sigma/dm_{tt}$, $d\sigma/dp_{T,tt}$, $d\sigma/dp_{T,top}$, $d\sigma/dy_{tt}$) to test SM and complement direct searches
- Active effort to **design/develop fiducial measurements** (uniform definition of stable particles after hadronization) **in ongoing/future analyses to reduce theory extrapolations, allow durable comparison with theory** advancements **and combination with CMS**

- **Expect higher statistic searches to extend limits in the TeV/sub pb region**
  - **pile-up** understanding for standard and boosted jets
  - **boosted top regime** will use new tagging/reconstruction techniques, associated syst uncertainties,new triggers

(K Suruliz, TOP2013)

Period	Lumi $[\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	pile-up	$\mathcal{L}_{\mathrm{Int}}$ (fb^{-1})
2012	$7 \cdot 10^{33}$	21	25
2015-2017	$1 \cdot 10^{34}$	25	90
2019-2021	$2 \cdot 10^{34}$	50-80	300
2022-	$5 \cdot 10^{34}$	~ 140	3000



ATLAS Luminosity Public Page

Conclusions

- **Top analysis is in full swing** thanks to the combined performance of LHC & detectors: **a very rich program is already underway.**

- *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.

- The **top mass** is measured at 0.83% (ATLAS)/0.55%(LHC) level. Work is ongoing for LHC and LHC-Tevatron combination.

- **Direct determination of top** quark **coupling to** the newly found **Higgs** boson is still limited by number of events.

- **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

BACK-UP

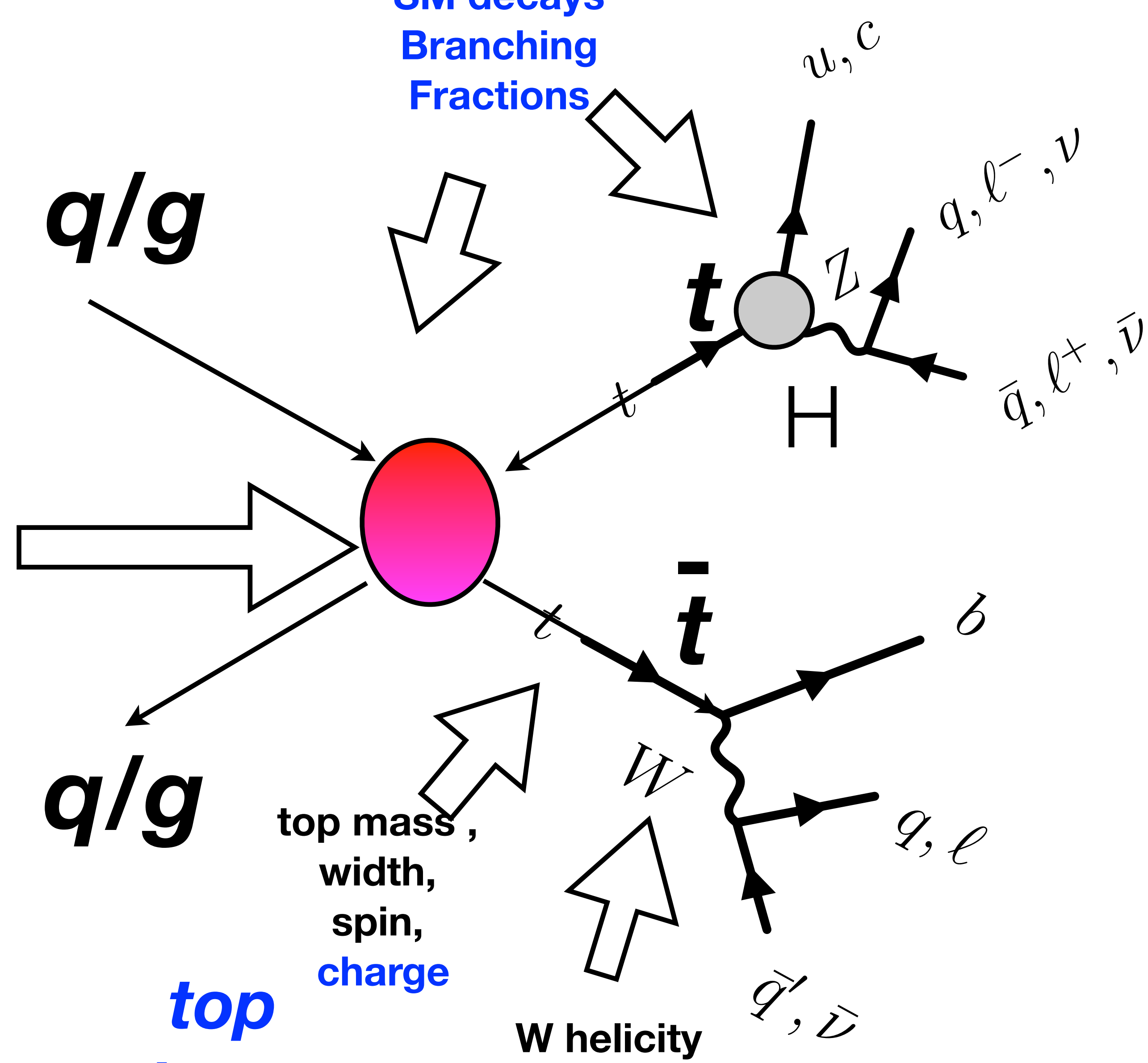
Top **decay** as a window on new physics

Quark Singlet, Two Higgs Doublet, RP SUSY , TopColour assisted Technicolour, Warped (RS) ED

FCNC

inspired by figure
by D Chakraborty

Rare/Non SM decays Branching Fractions



Spin polarization

top charge

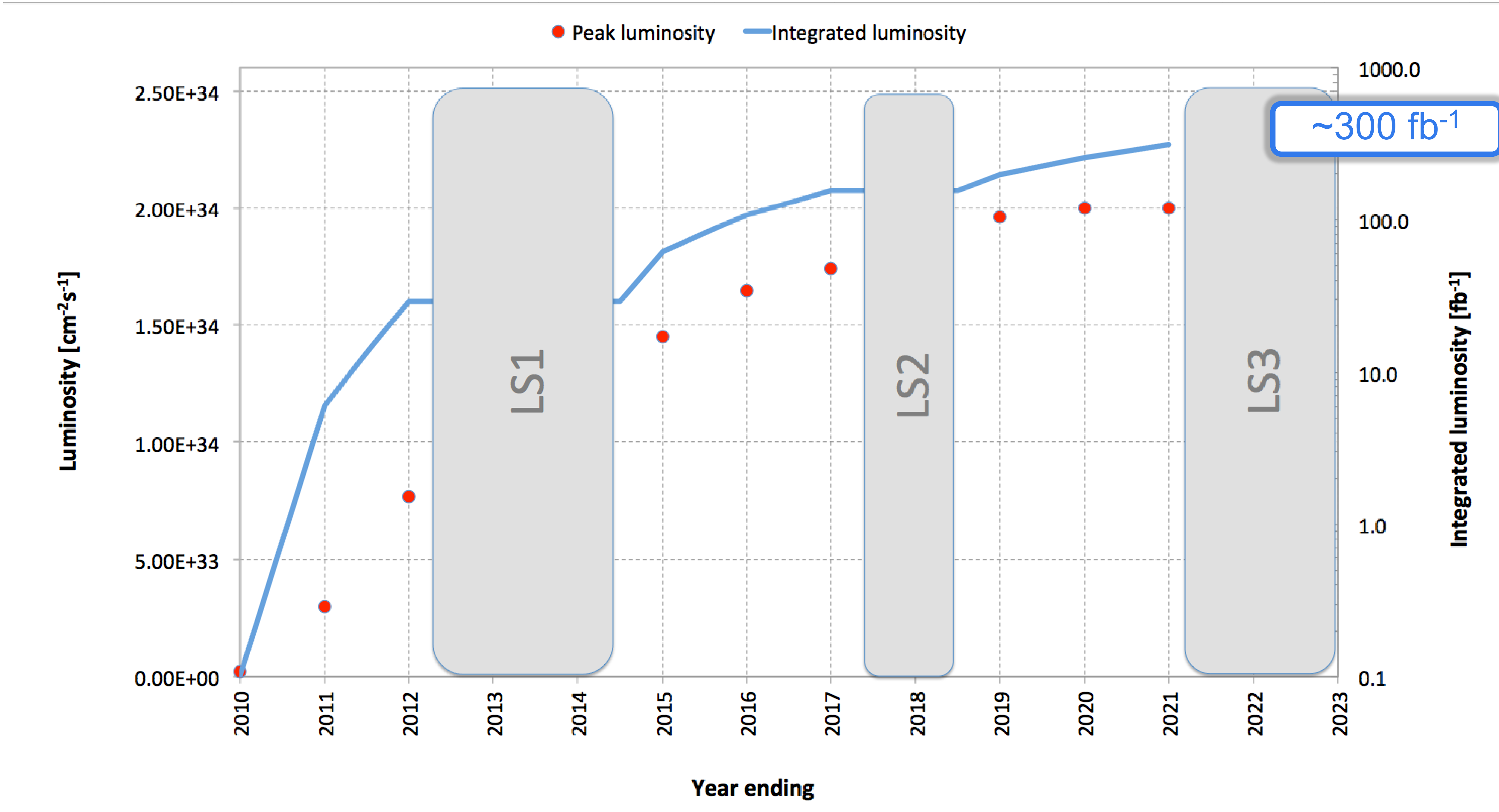
exotic quarks

W helicity Wtb coupling,V (tb)

top polarization and Wtb vertex

LHC

"Baseline" luminosity



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

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Objects

Jet Energy Scale (JES) in ATLAS

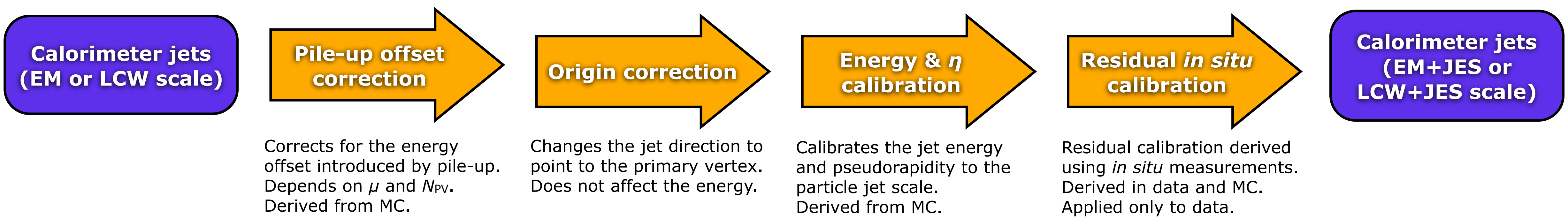
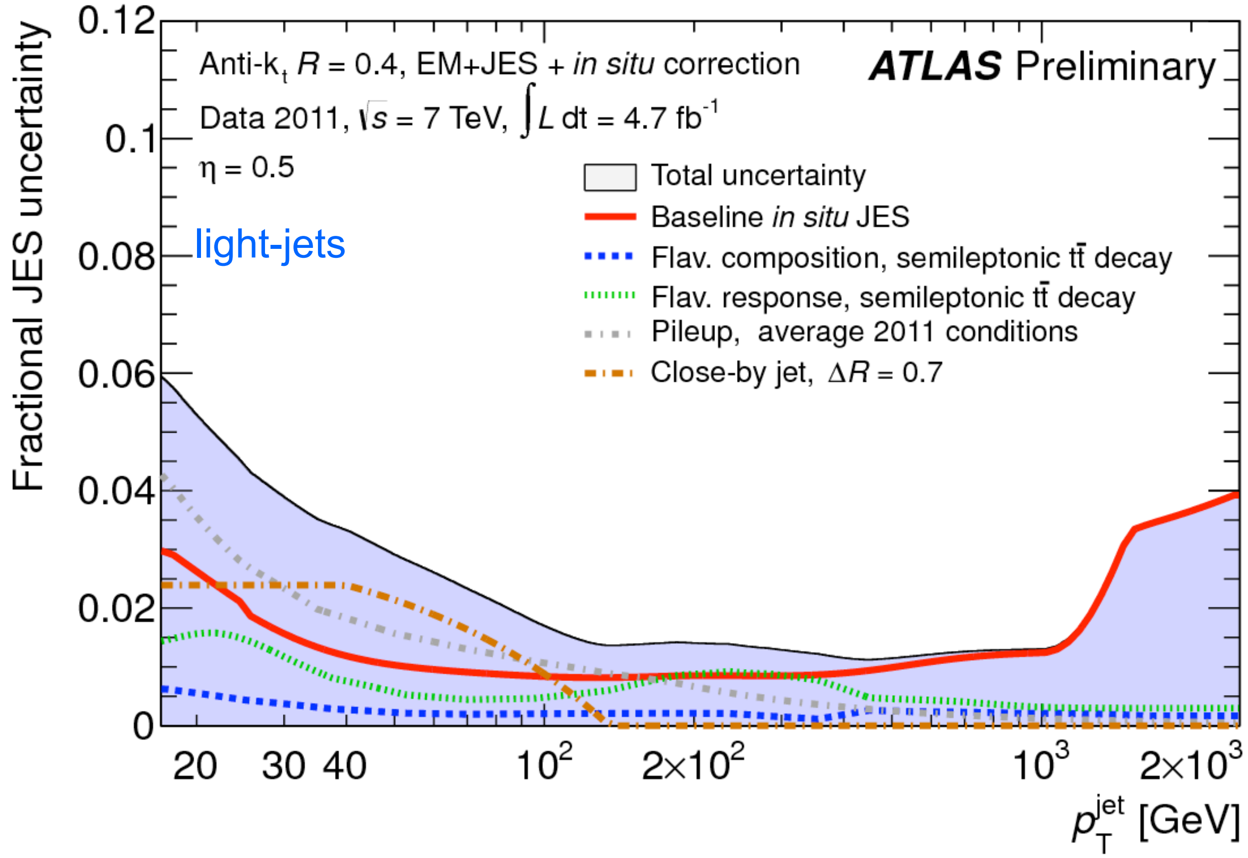
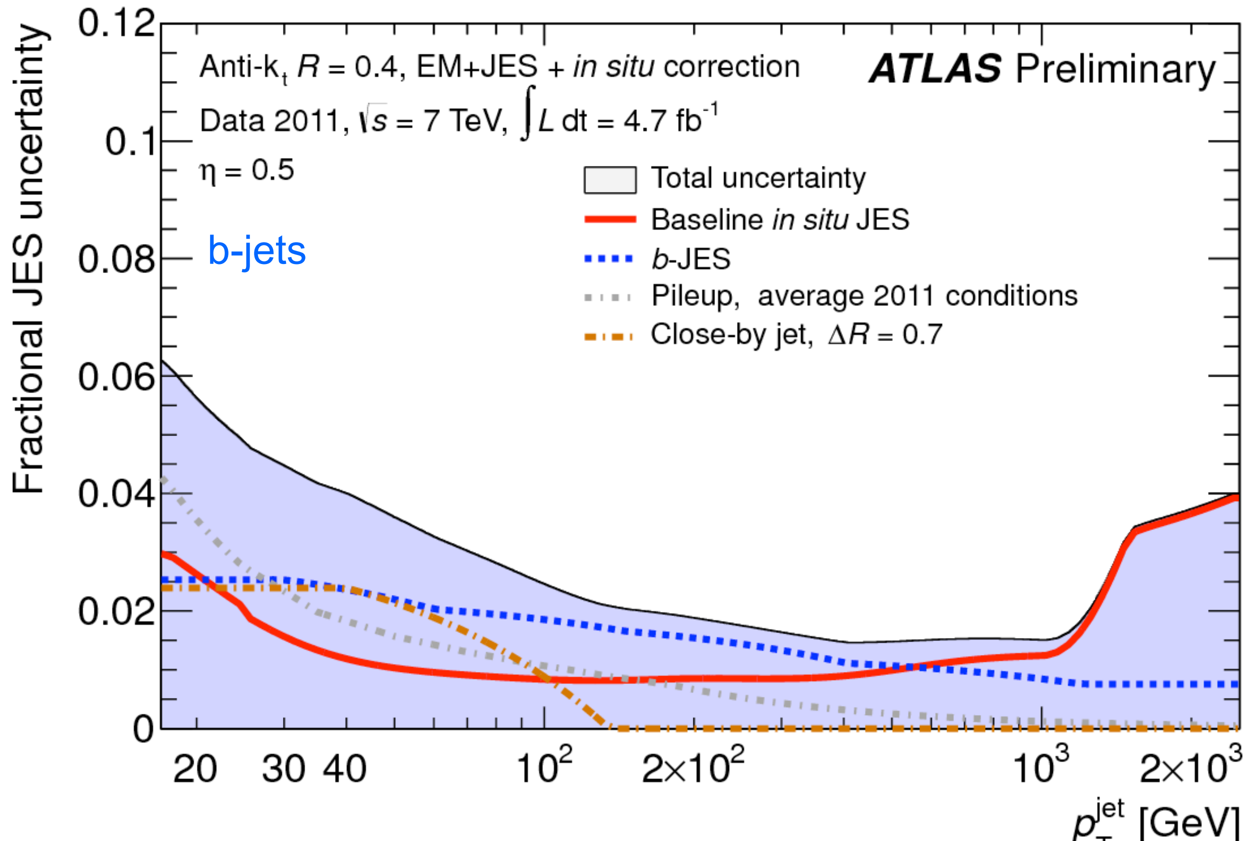


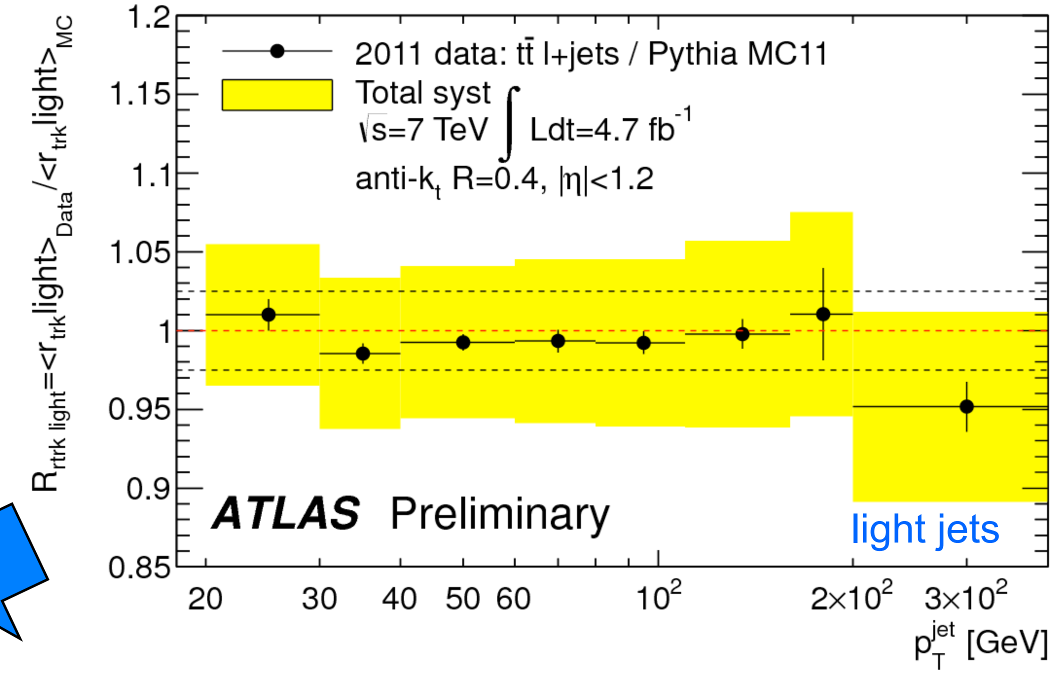
Figure 2: Overview of the ATLAS jet calibration scheme used for the 2011 dataset. The pile-up, absolute JES and the residual *in situ* corrections calibrate the scale of the jet, while the origin and the η corrections affect the direction of the jet.

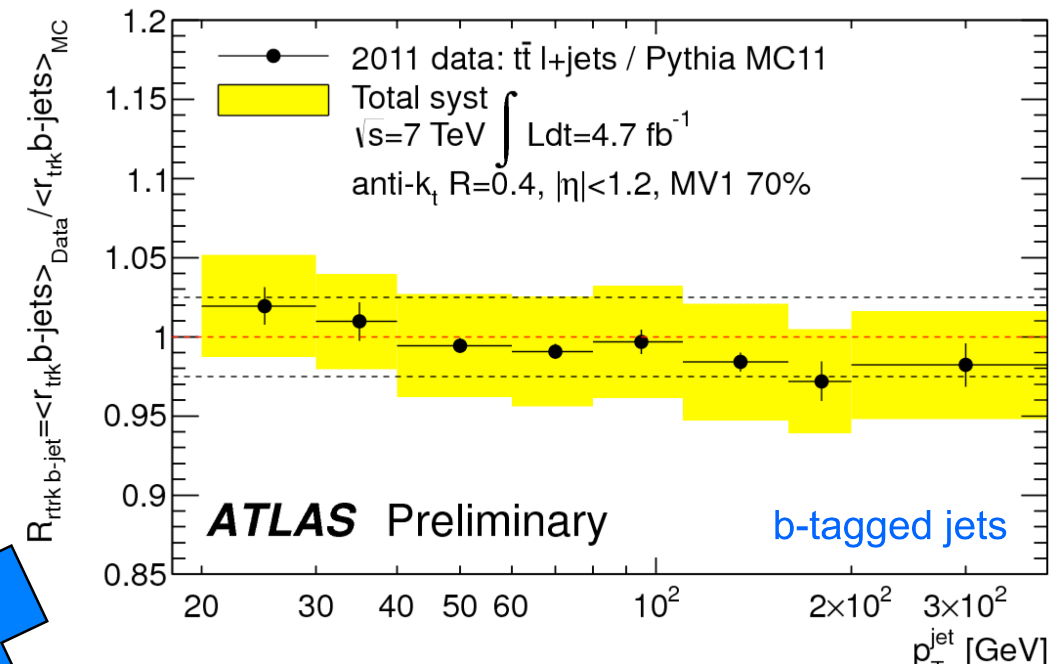
JES in ATLAS

ATLAS-CONF-2013-004

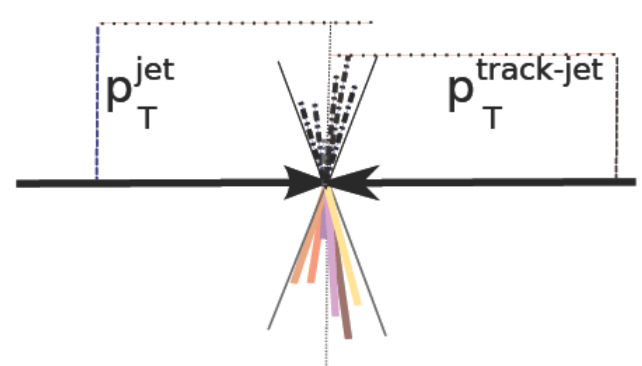








ATLAS-CONF-2013-002



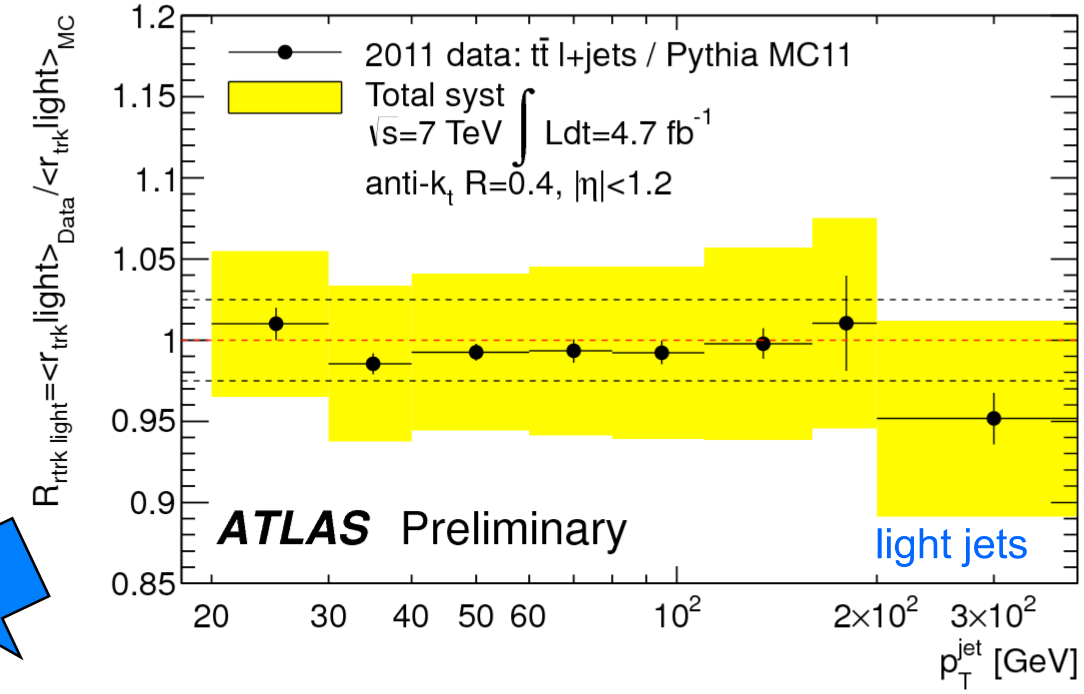
$$r_{\rm trk} = \frac{\sum \vec{p}_T^{\rm \,track}}{p_T^{\rm jet}}$$

$$R_{r_{\rm trk}} \equiv \frac{[< r_{\rm trk} >]_{\rm data}}{[< r_{\rm trk} >]_{\rm MC}}$$

G. Cortiana 33

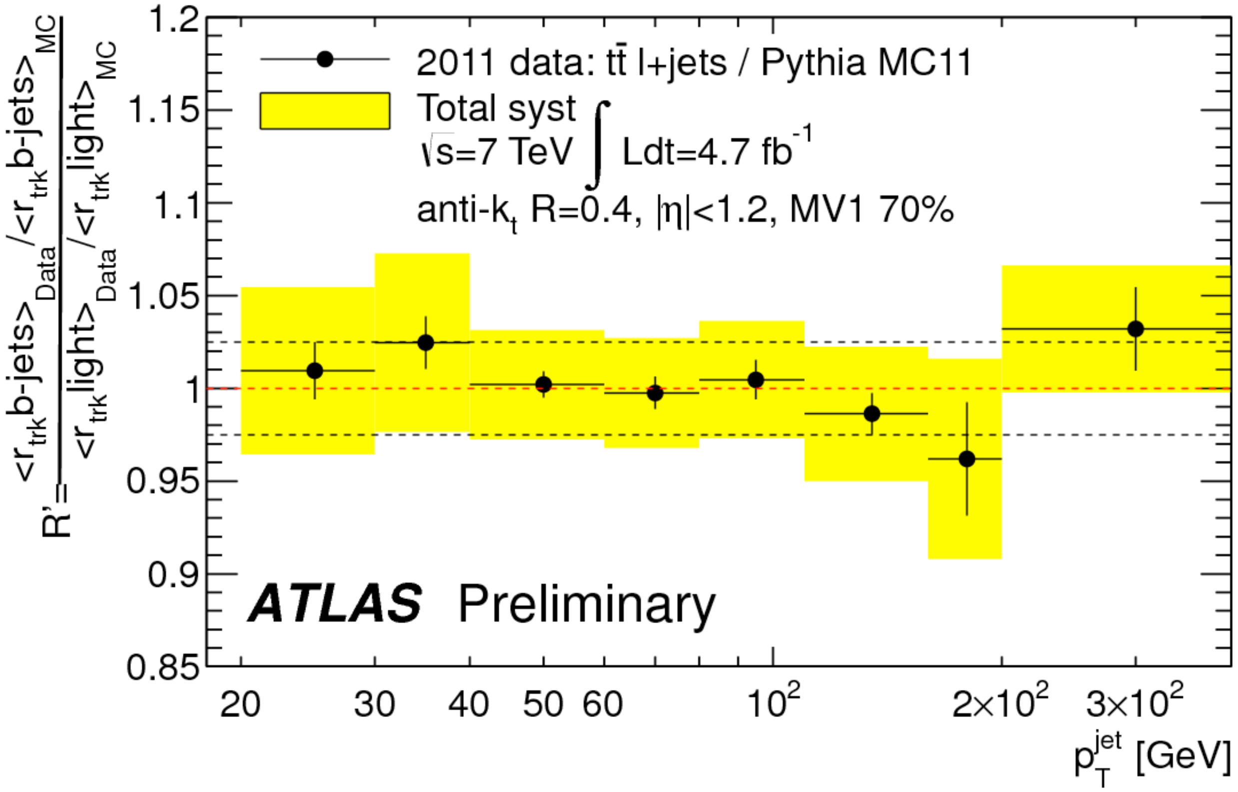
- *Additional topology/flavour uncertainties are specific to top-antitop events*
- *JES validation: use tracks in jets in di-jets and top-anti-top events*

ATLAS-CONF-2013-004

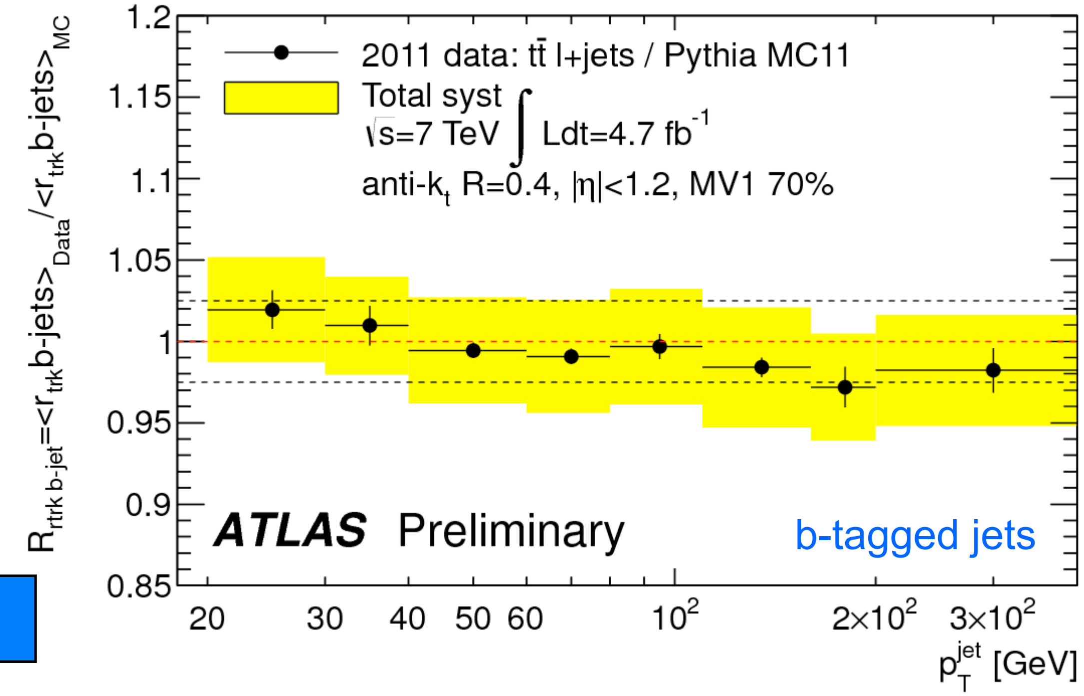


$$R' \equiv \frac{R_{r_{\mathrm{trk,b-jets}}}}{R_{r_{\mathrm{trk,inclusive}}}}$$

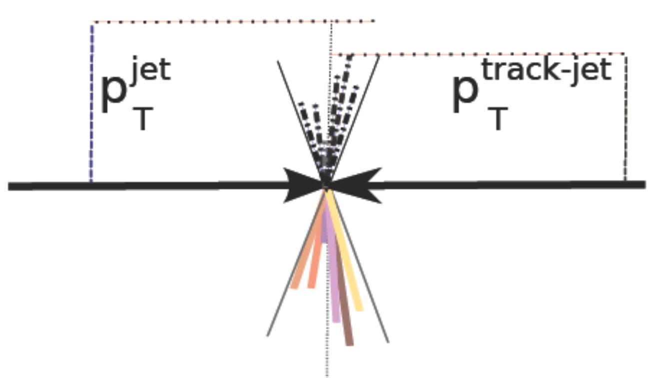
Sensitive to the relative b-to-light jets energy scale



ATLAS-CONF-2013-002



Top quark pair events complement the di-jet studies otherwise limited to intermediate to high p_T ranges due to jet trigger thresholds



$$r_{\mathrm{trk}} = \frac{\sum \vec{p}_T^{\ \mathrm{track}}}{p_T^{\mathrm{jet}}}$$

$$R_{r_{\mathrm{trk}}} \equiv \frac{[< r_{\mathrm{trk}} >]_{\mathrm{data}}}{[< r_{\mathrm{trk}} >]_{\mathrm{MC}}}$$

Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)

CERN Seminar, July 2nd, 2013 *G. Cortiana* 34

Top production

Measurement of $\sigma_{t\bar{t}}$ - LHC Combination @ s = 7 TeV

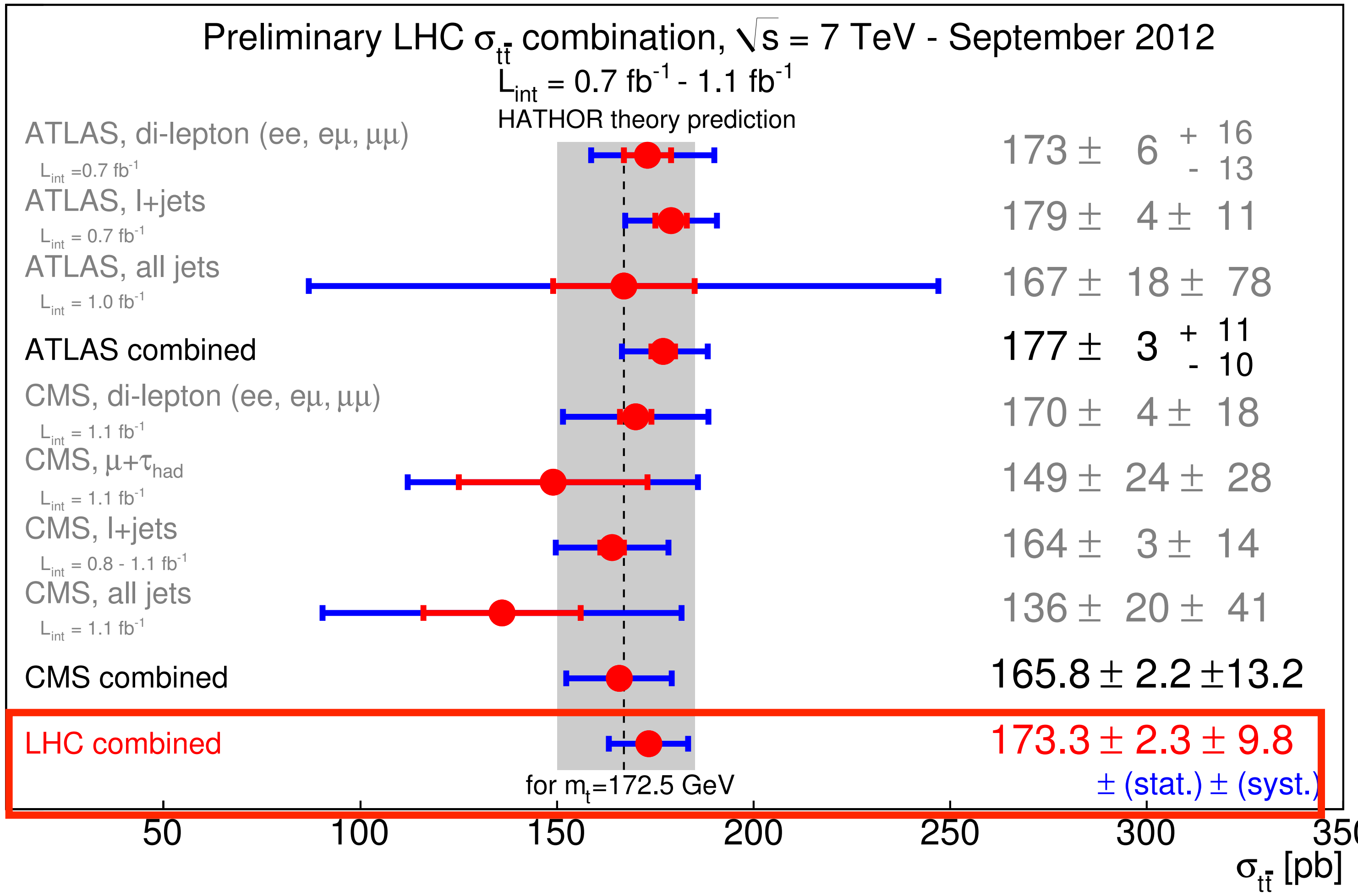
	ATLAS	CMS	Correlation	LHC combination
Cross-section	177.0	165.8		173.3
Uncertainty				
Statistical	3.2	2.2	0	2.3
Jet Enegy Scale	2.7	3.5	0	2.1
Detector model	5.3	8.8	0	4.6
Signal model				
Monte Carlo	4.2	1.1	1	3.1
Parton shower	1.3	2.2	1	1.6
Radiation	0.8	4.1	1	1.9
PDF	1.9	4.1	1	2.6
Background from data	1.5	3.4	0	1.6
Background from MC	1.6	1.6	1	1.6
Method	2.4	n/e	0	1.6
W leptonic branching ratio	1.0	1.0	1	1.0
Luminosity				
Bunch current	5.3	5.1	1	5.3
Luminosity measurement	4.3	5.9	0	3.4
Total systematic	10.8	14.2		9.8
Total	11.3	14.4		10.1

- Combine with best linear unbiased estimator
- Total correlation~30%

ATLAS-CONF-2012-134 & CMS-PAS-TOP-12-003

- Improvement by 7% (11%) w.r.t most precise l+jets channel
- **Final $\delta\sigma/\sigma$~5.8% (10 pb)**

$$\sigma_{t\bar{t}} = 173.3 \pm 2.3(\text{stat.}) \pm 9.8(\text{syst.})\ \text{pb}$$



LHC $\sigma_{t\bar{t}}$ Measurement @ 8 TeV

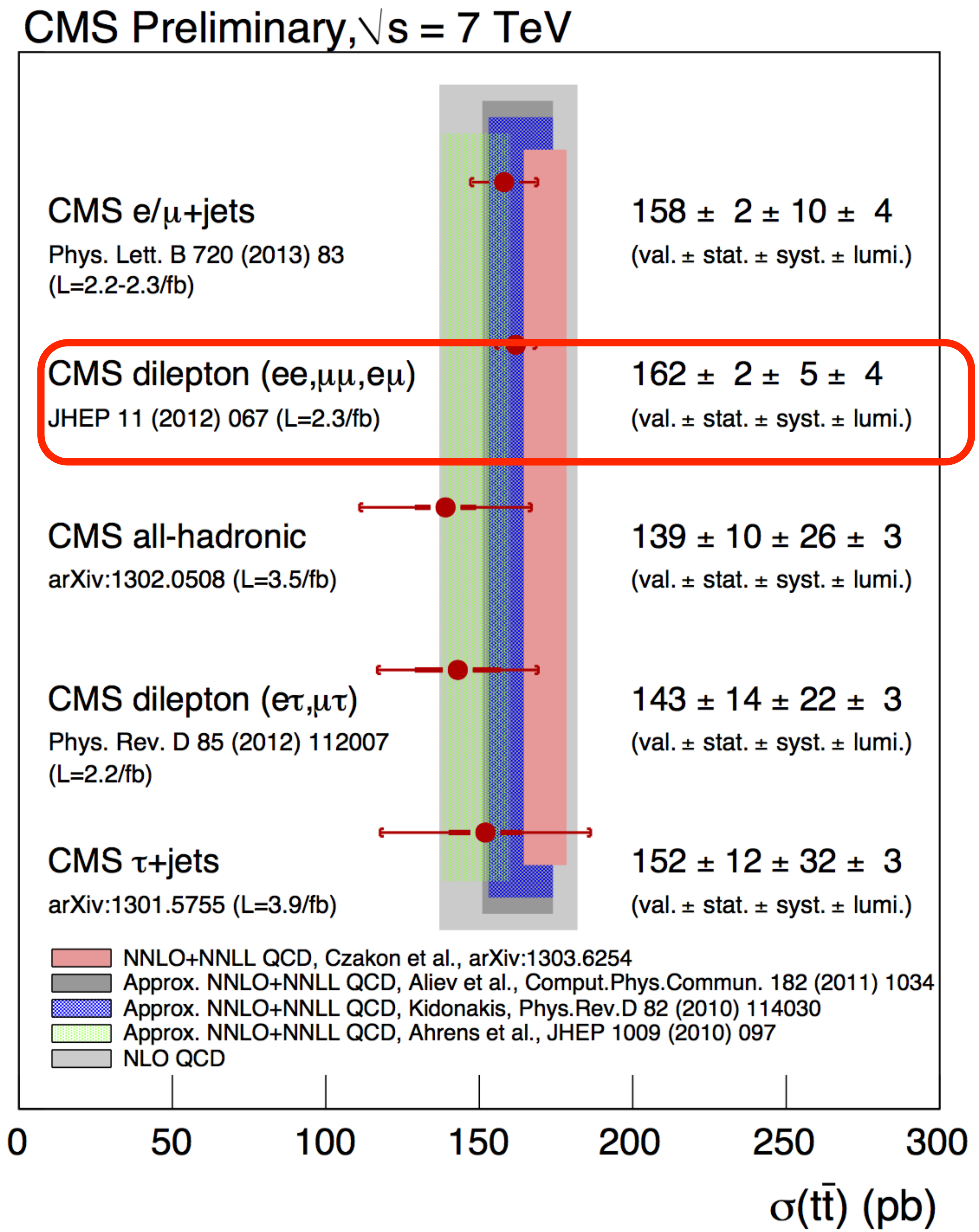
LHC $\sigma_{t\bar{t}}$ measurements at 8 TeV have not been combined yet. Present measurements are:

- **ATLAS dilepton:ATLAS-CONF-2013-097 (20.3 fb^{-1}) Extract signal counting only $e\mu$ events with 1 and 2 b-tagged jets**
  $\sigma_{t\bar{t}} = 238 \pm 2(\text{stat}) \pm 7(\text{syst}) \pm 7(\text{lumi}) \pm 4(\text{b.e.u.})$ pb
- **CMS dilepton:CMS PAS TOP-12-007 (2.4 fb^{-1}) Extract signal from b jet multiplicity, use ee,$\mu\mu$ and $e\mu$**
  $\sigma_{t\bar{t}} = 227 \pm 3(\text{stat}) \pm 11(\text{syst}) \pm 10(\text{lumi})$ pb
- **ATLAS ℓ+jets:ATLAS-CONF-2012-149 (5.8 fb^{-1})**
  $\sigma_{t\bar{t}} = 241 \pm 2(\text{stat}) \pm 31(\text{syst}) \pm 9(\text{lumi})$ pb
- **CMS ℓ+jets:CMS PAS TOP-12-006 (2.8 fb^{-1})**
  $\sigma_{t\bar{t}} = 228 \pm 9(\text{stat}) \pm 29(\text{syst}) \pm 10(\text{lumi})$ pb

Dilepton measurements dominate any combination.

S. Protopopescu, TOP2013

CMS xsec status



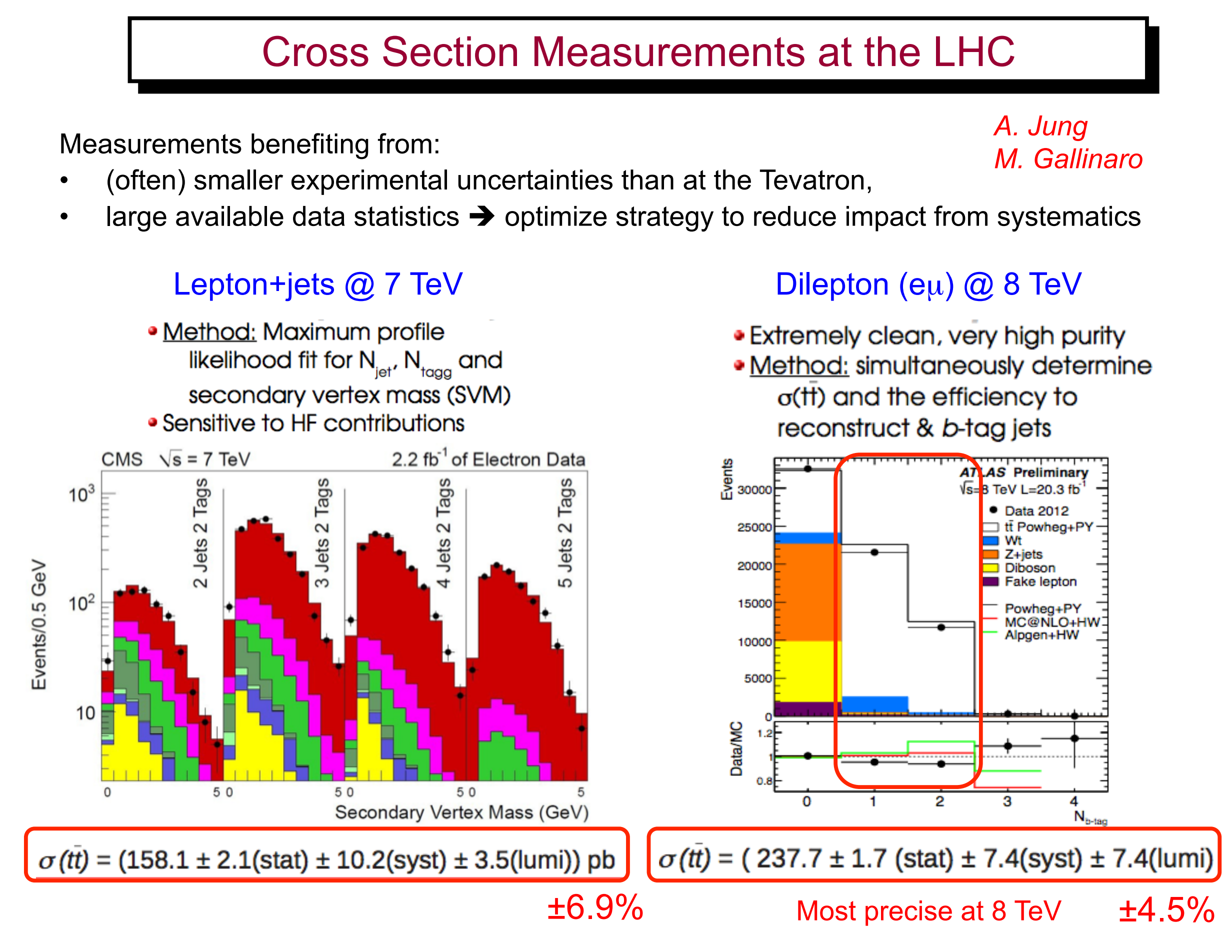
TOP2013: Inclusive $t\bar{t}$ Xsec Session

- 1 theory summary on NNLO + 3 summaries on at LHC +Tevatron on: e\μ final states, τ+hadronic channels, combination

- Fully differential QCD NNLO MC is in the works, possibly including decays in narrow width approximation →*prediction is possible for diff cross sections*

- Tevatron: syst dominated, D0-CDF combined has $\delta\sigma_{tt}/\sigma_{tt}$~5.4% New full stat l+jets result for D0 with $\delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ ~10% (~9.7/fb)

- LHC
  - @7 TeV : no news, CMS dilepton has $\delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ 4.4%, ATLAS has old combination including unrealistic single lepton at from 0.7/fb
  - @8 TeV: ATLAS has most precise measurement: new dilepton with 4.7%.

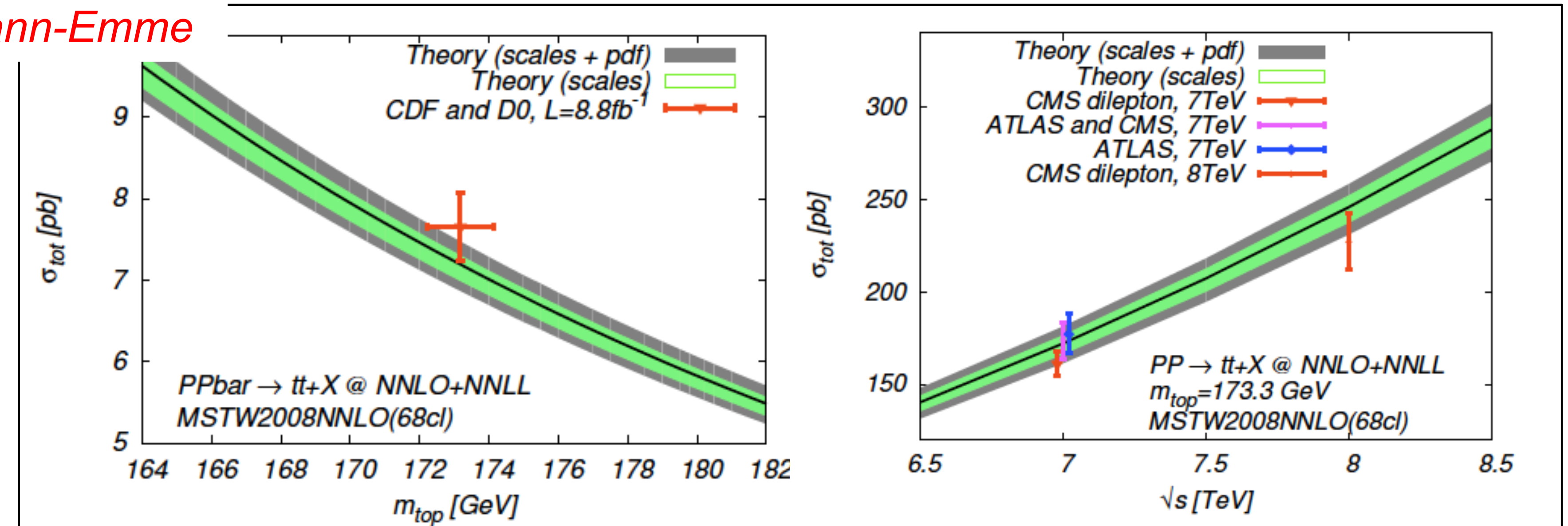


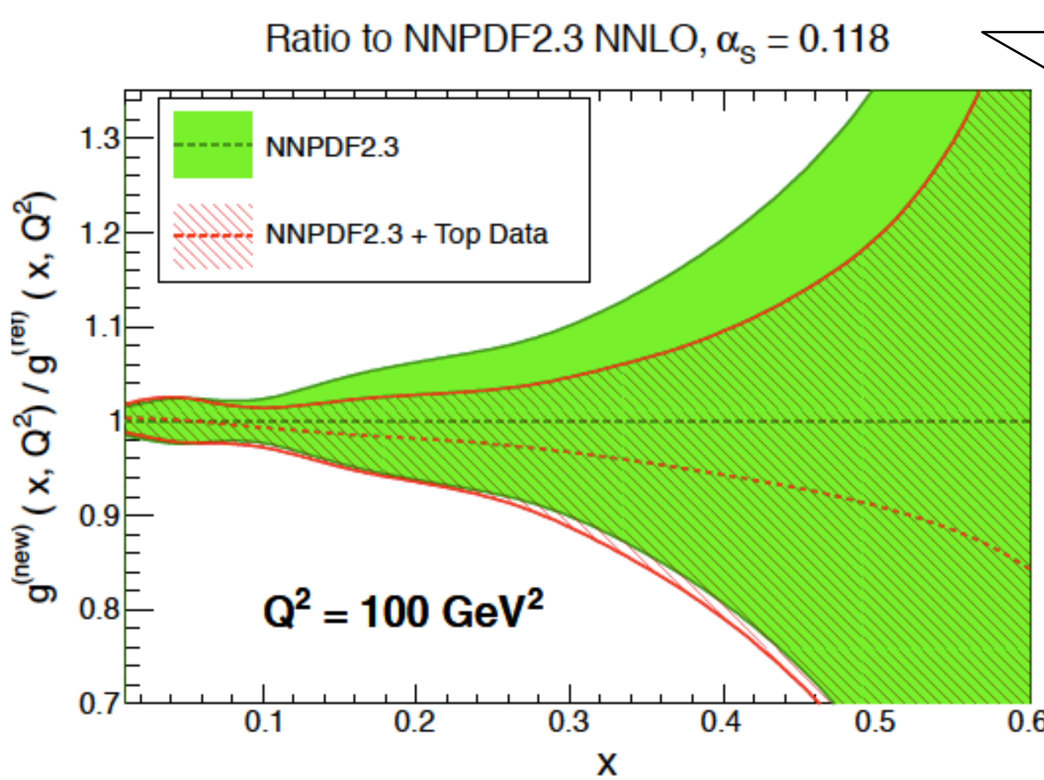
A Juste - Experimental Summary

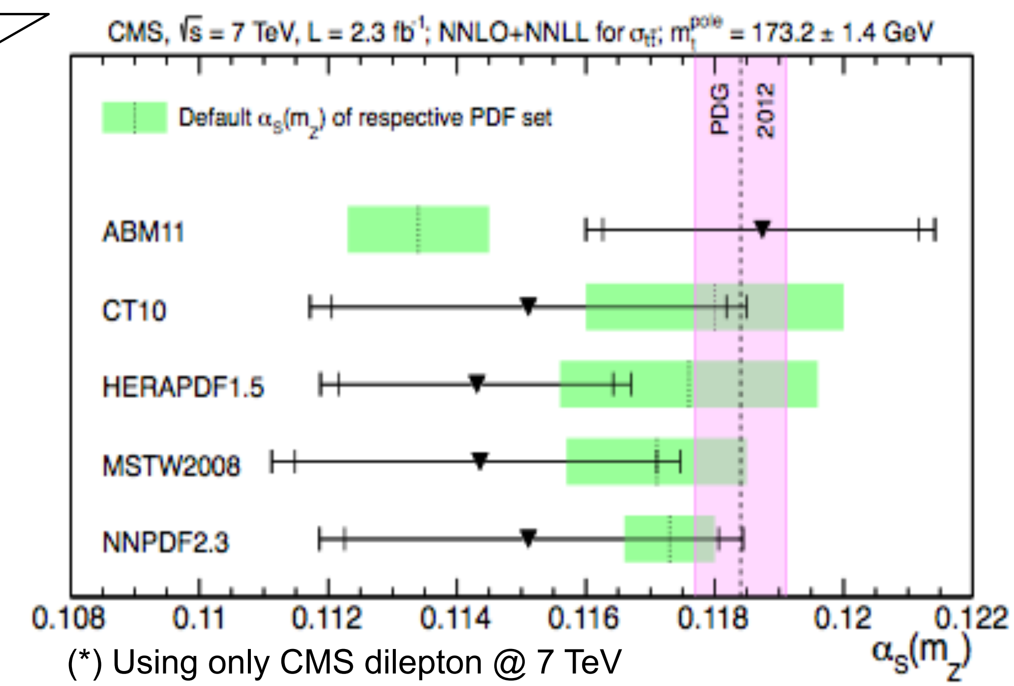
TOP2013: bonuses from precise $t\bar{t}$ cross section

Implications of Precision σ_{tt}

S. Naumann-Emme







(*) Using only CMS dilepton @ 7 TeV

With NNPDF: $\alpha_S(m_Z) = 0.1151^{+0.0033}_{-0.0032}$

Improve gluon PDF at high x

First measurement of α_s at NNLO from a hadron collider

A Juste - Experimental Summary

TOP2013: suggestions on $t\bar{t}$ cross section

What to do with NNLO top cross section?

Baernreuther, Fiedler, Mitov, Czakon

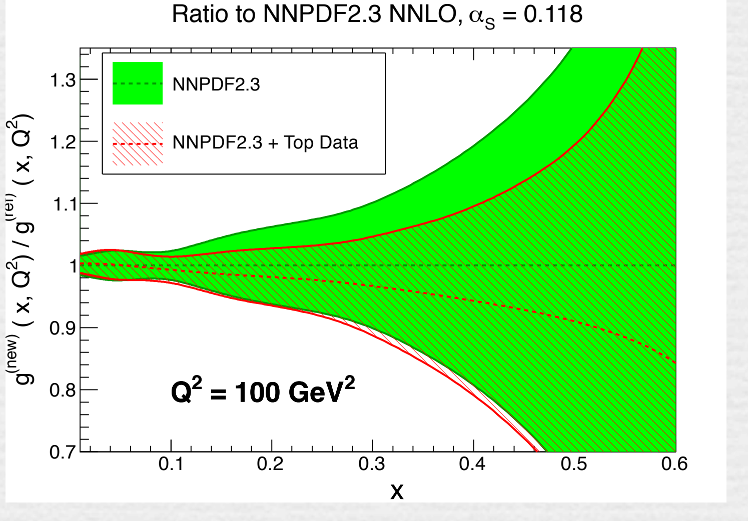
- Establishes trust in QCD production mechanism: it really, really works
- Can check that no stops/vector tops/etc masking as tops are in data [Weiler, Lysak]
- Very competitive extraction of alpha_s

[Naumann-Emme]

$$\alpha_s(m_Z) = 0.115 \pm 0.003$$

- Top quark induction into Hall of PDF Global Fit Data
  - gluon density handle at large x

Czakon, Mitov, Mangano, Rojo



- Not least: encouraging to theorists!

Eric Laenen -Theory summary-TOP2013

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TOP2013: Differential Xsec session

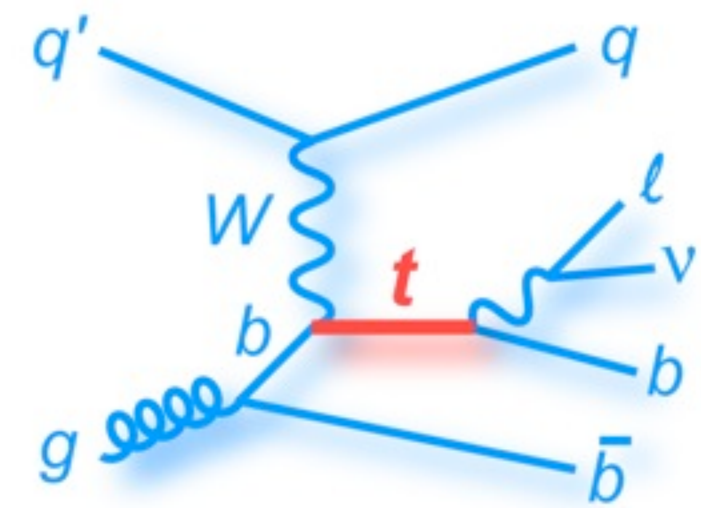
- 1 theory summary + 2 experimental summaries: on kinematic differential cross sections, on jet multiplicities

- Theory: many advancements at NLO (see next page)
- Kinematic diffxsec: data-prediction agreement
  - **$m_{t\bar{t}}$** : ATLAS: o.k. with MCs, NLO & NLO+NNLL are harder (more populated high m_{tt} tails); CMS is o.k. for generators and NLO+NNLL
  - **$p_{T,t\bar{t}}$: ok with MCs and predictions** for ATLAS and CMS
  - **$y_{t\bar{t}}$**: ATLAS: ALPGEN is o.k., other MCs somewhat different ; o.k. for CMS (available in dilepton channel only)
  - **$p_{t,top}$**: some differences between ATLAS and CMS
    - ❖ CMS **o.k. with approx NNLO** (data **is above** MC at low $p_{t,top}$), MCs are different from data at low $p_{t,top}$:
    - ❖ ATLAS: **not o.k. with approx NNLO** (data **is below** MC at low $p_{t,top}$), only POWHEG is o.k. for MCs
  - ATLAS: **ALPGEN is o.k. for $m_{t\bar{t}}$, but not for $p_{t,top}$**
  - **Only common point between ATLAS and CMS is MC@NLO+HERWIG**, CMS has POWHEG+HERWIG (but shows POWHEG+PYTHIA)
- jet multiplicities: no news (CMS has results with ~19.6/fb)

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

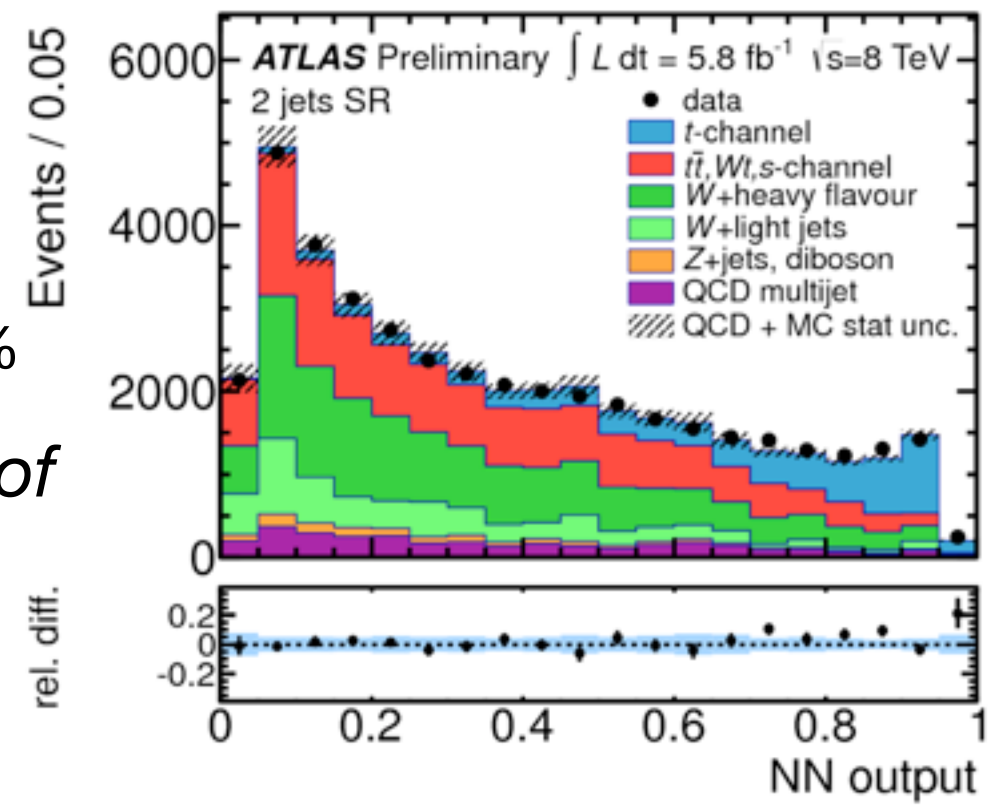
ATL-CONF-2012-132

t-chan: $q\ell\nu b(b)$



- 1 isol. lep (e or μ), 2 or 3 jets with $|\eta|<4.5$, E_T^{miss} cut, large $m_T(W)$* → fake lep veto , 1 b-tag
- bkg: tt/Wt/s-chan, W/Z+jets, data-driven fake lep
- **Extract σ_t** *and bkg norm* **by binned max. likelihood fit of Neural Network (NN) distribution** *(11 kin. vars: jet-lep masses, rapidities)* to data in 2- & 3-jet bins

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



band from MC stat+fakes uncertainty

- Syst dominated (*JES,b-tag and t-chan gen.*)

$$\sigma_t = 95 \pm 2\,(\text{stat.}) \pm 18\,(\text{syst.})\,\text{pb}$$ **$\delta\sigma_t/\sigma_t$** ~19%

- *Assuming $|V_{tb}| >> |V_{ts}|, |V_{td}|$* **determine V_{tb}** ← *ratio of measured to predicted σ_t*

$$|V_{tb}| = 1.04^{+0.10}_{-0.11}$$

If $|V_{tb}|<1$ $|V_{tb}|>0.89$ at 95%CL

- First BLUE ATLAS +CMS combination !

($\int Ldt$ = **5.8 (5.0) fb^{-1}** *(2012)*) ATLAS-CONF-2013-098

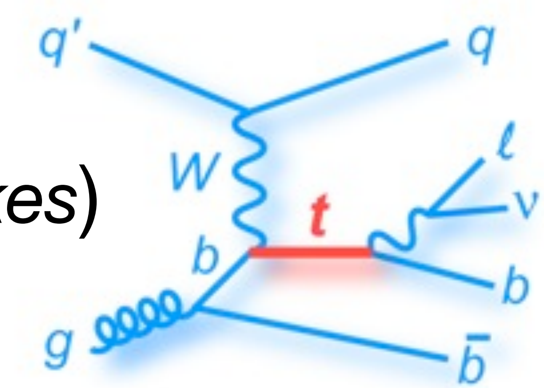
$$\sigma_{\text{t-ch.}} = 85 \pm 4\,(\text{stat.}) \pm 11\,(\text{syst.}) \pm 3\,(\text{lumi.})\,\text{pb}$$ **$\delta\sigma_t/\sigma_t$** ~14%

$$m_T(W) = \sqrt{2p_T(\ell)E_T^{miss}\left[1-\cos\Delta\phi\left(\ell, E_T^{miss}\right)\right]}$$

t-chan is established! First LHC combination

Inclusive σ_t: t-chan $\sqrt{s}$ = 7 TeV

ATL-CONF-2012-056 $\int L dt$ = **4.7 fb^{-1}** *(2011)*

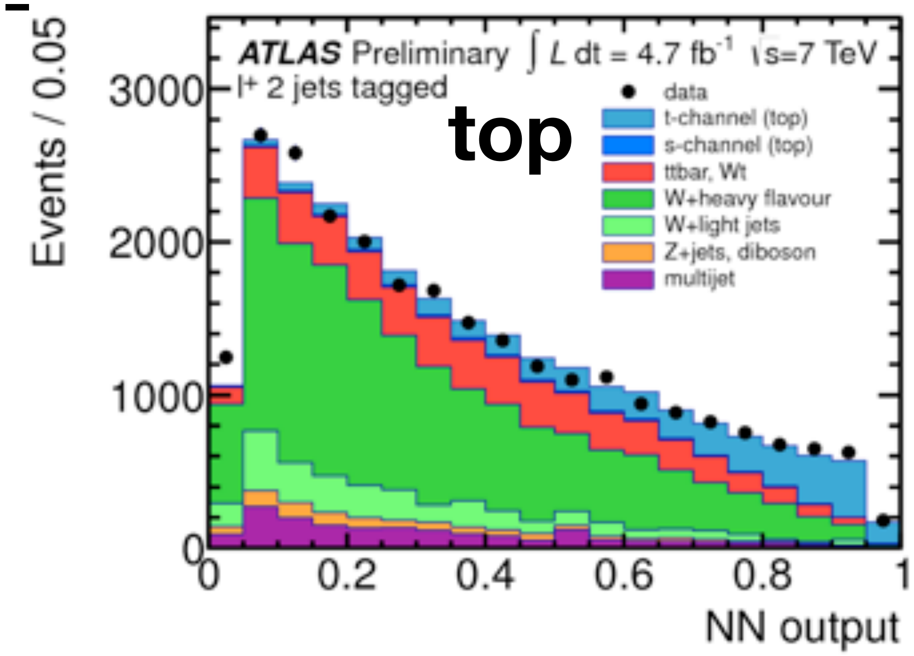


- standard single lepton sel + bkg estimates *(tt/Wt,W+jets,fakes)*

- **Extract σ_t** *and* **$\sigma_{anti\text{-}t}$ by binned max. likelihood fit o***f standard* **NN distribution** to data in 2- & 3-jet bin with pos and neg lep (e,μ)

syst dominated: ISR/FSR, JES

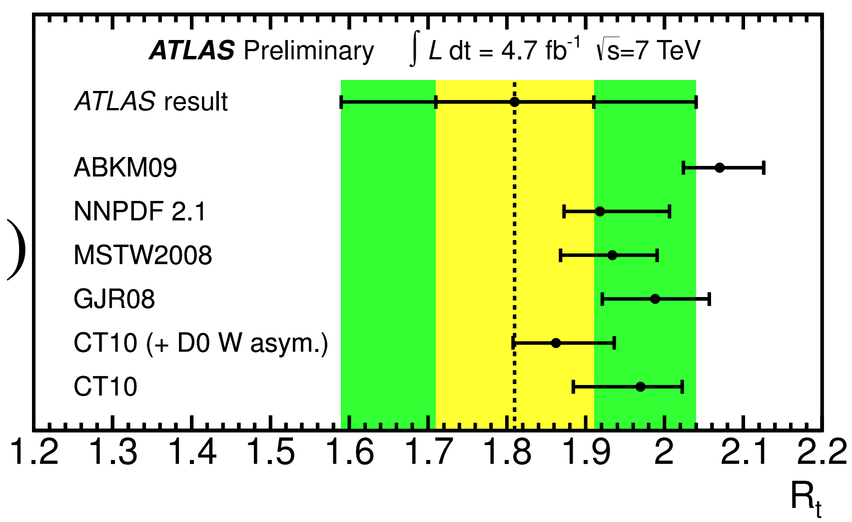
	$\delta\sigma_t/\sigma_t$
$\sigma_t(\bar{t}) = 29.5 \pm 1.5\,(\text{stat.}) \pm 7.3\,(\text{syst.})\,\text{pb}$	~15%
$\sigma_t(t) = 53.2 \pm 1.7\,(\text{stat.}) \pm 10.6\,(\text{syst.})\,\text{pb}$	~12%
$\sigma_t(t+\bar{t}) = 76.2 \pm 2.1\,(\text{stat.}) \pm 9.1\,(\text{syst.})\,\text{pb}$	~12%

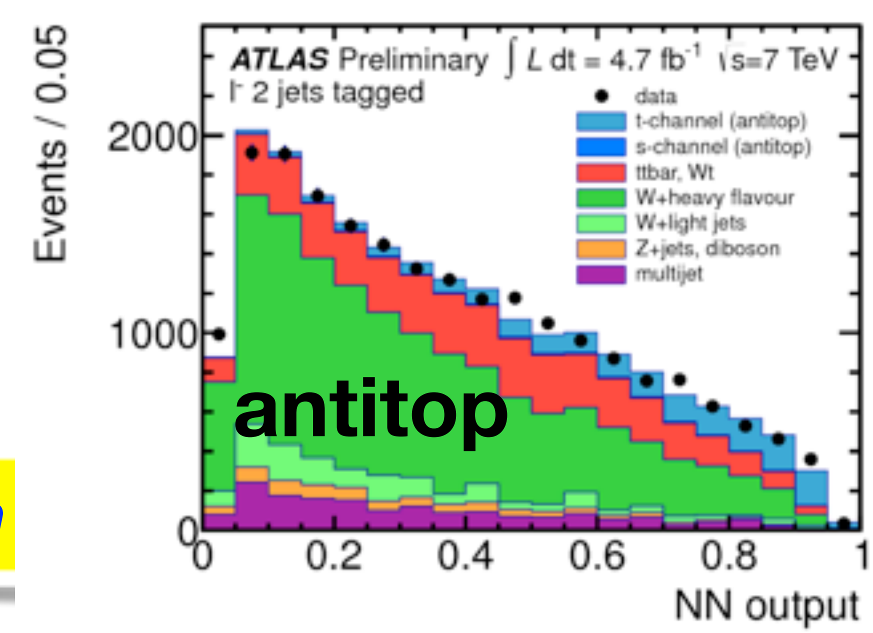


band from MC stat+fakes uncert.

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

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

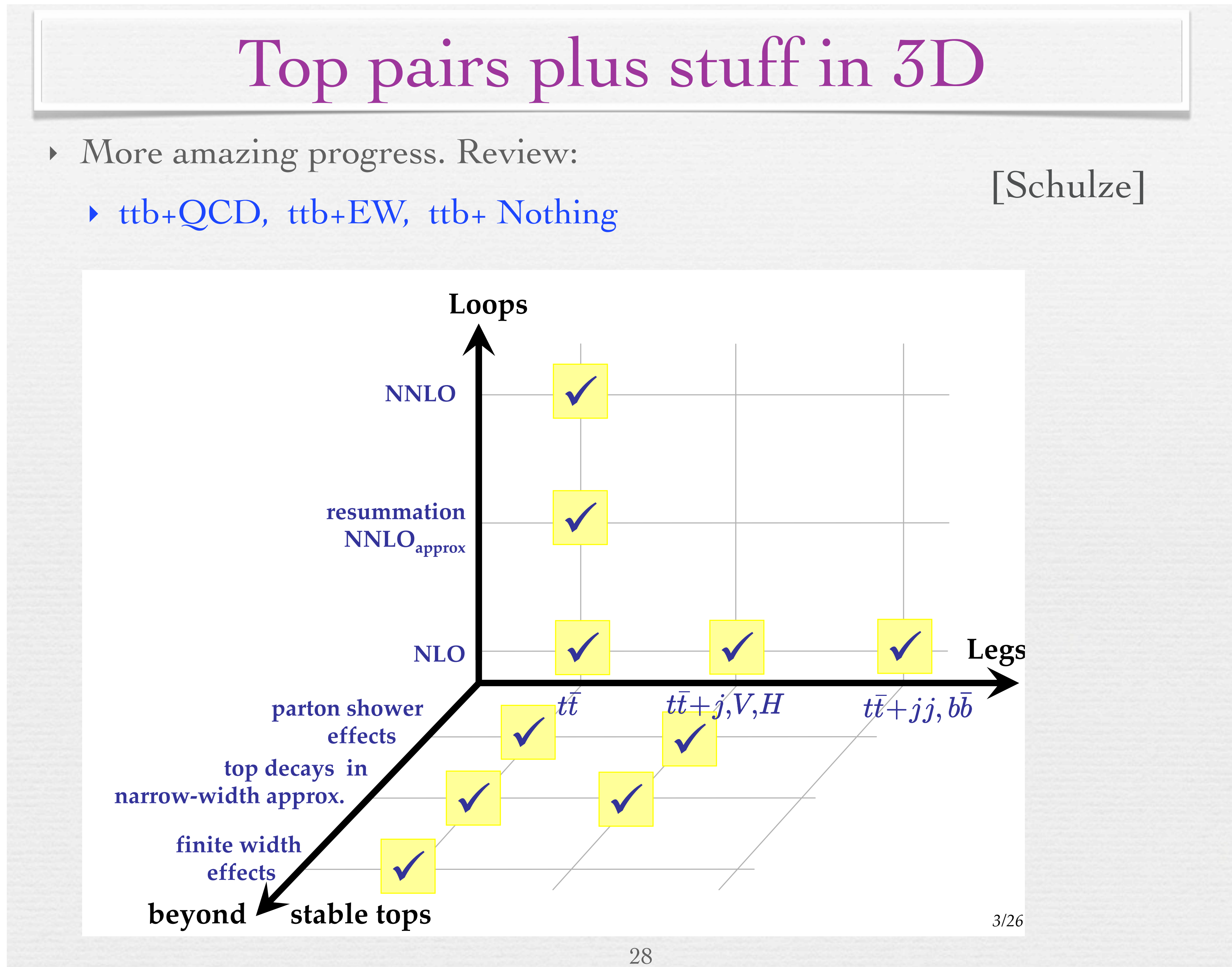




Wealth of t-chan info! Test of EWK top production

TOP2013: Differential Xsec session - Theory intro

Eric Laenen -Theory summary-TOP2013



- $t\bar{t}$+j, $t\bar{t}$+jj, $t\bar{t}$+bb,$t\bar{t}$ +tt : now all available at NLO

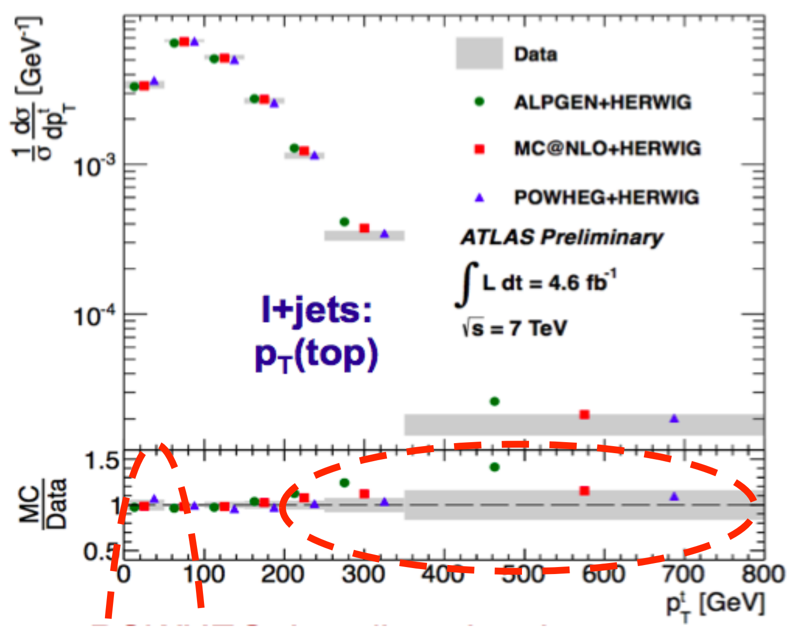
TOP2013: Differential Xsec session

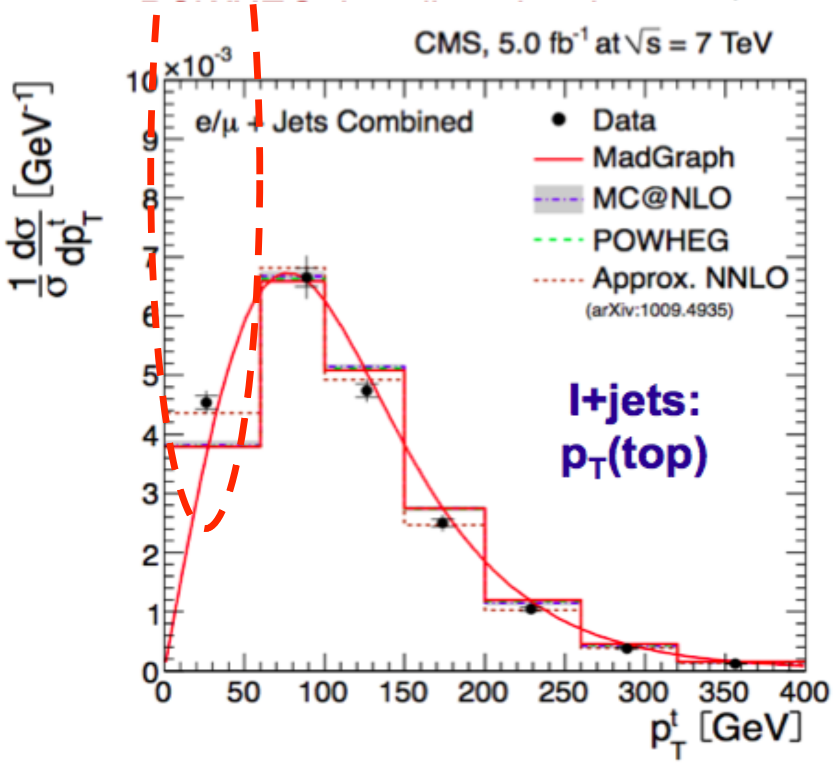
A Juste - Experimental Summary-TOP2013

- Differences are well captured by A. Juste in the summary

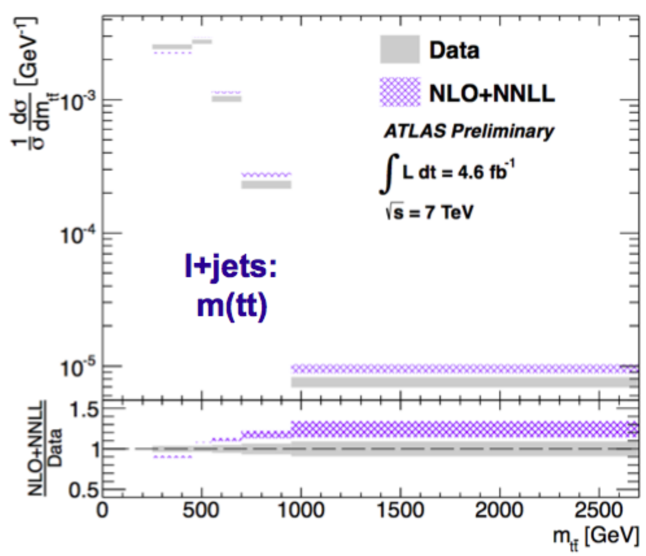
Differential Cross Sections: $p_{T,t}$, m_{tt}

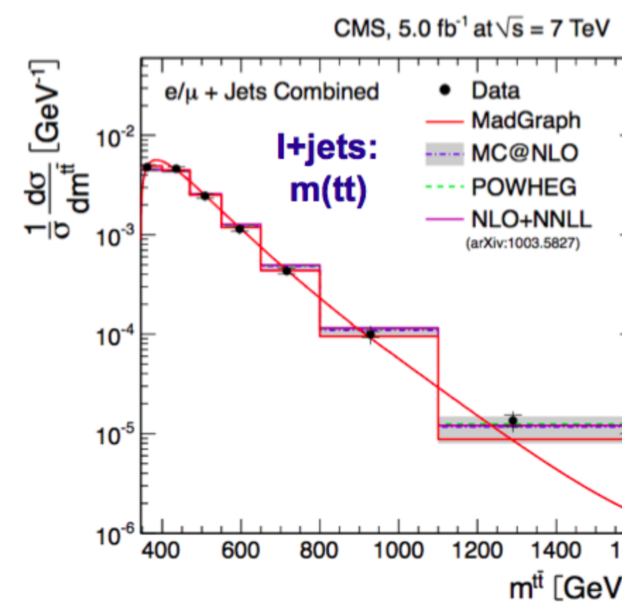
M. Aldaya





- Top p_T: in general softer spectrum in data than predicted by MCs.
- Some tension between ATLAS and CMS in the first bin affects conclusion on agreement with NLO+NNLL prediction.
- Partonic level defined in the same way? Non-perturbative corrections missing?





- m_{tt}: very sensitive to PDFs but also to NP. Beware of EW effects not accounted for!
- Somewhat contradictory conclusions by ATLAS and CMS regarding agreement with NLO+NNLL.

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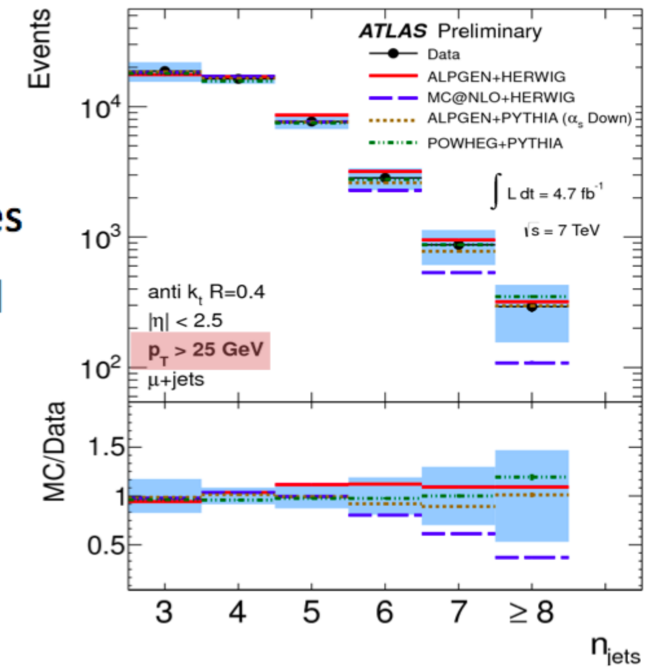
TOP2013: Differential Xsec session

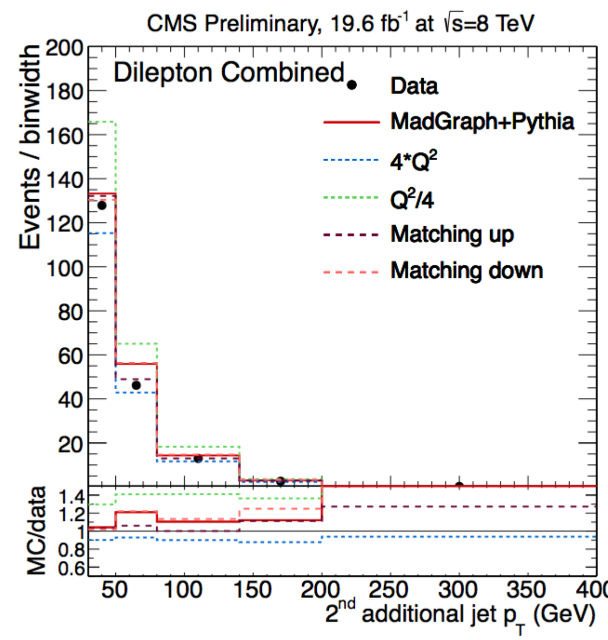
A Juste - Experimental Summary-TOP2013

$t\bar{t}$+jets and $t\bar{t}$+heavy-flavor Cross Sections

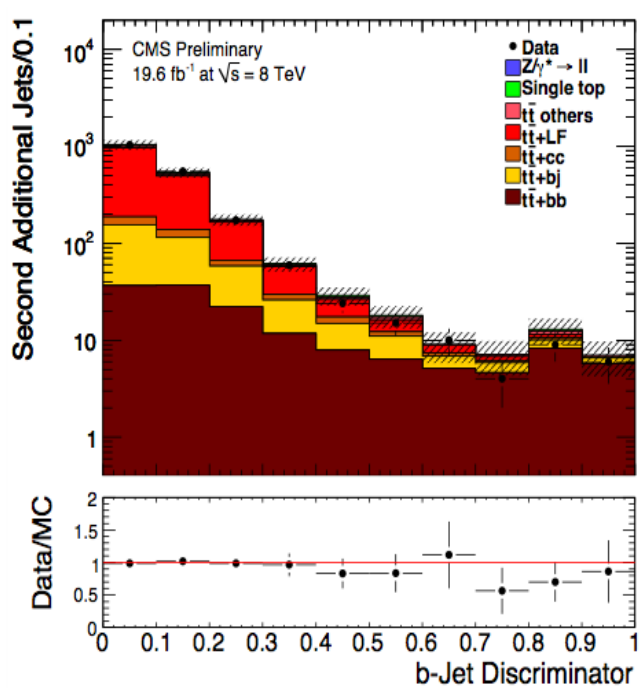
LL.-M. Mir

- Constraint of ISR/FSR @ m_{top} scale
- Test of perturbative QCD @ LHC energies
- $t\bar{t}$+jets important background to $t\bar{t}H$ and other BSM final states
- Anomalous $t\bar{t}$+jets production could signal BSM physics





K. Lannon



- Improved theoretical understanding of $t\bar{t}$+heavy-flavor background critical for $t\bar{t}H$, H→$b\bar{b}$ and other NP searches.
- New measurement of $\sigma(t\bar{t}b\bar{b})/\sigma(t\bar{t}jj)$ by CMS.

Result corrected back to particle level with following phase space:
- Leptons or jets: p_T > 20 (40) GeV; |η| < 2.5
- ΔR(jj) > 0.5; ΔR(lj) > 0.5

8 TeV	20 GeV	40 GeV
Measured	$\frac{\sigma_{t\bar{t}b\bar{b}}}{\sigma_{t\bar{t}jj}} = 2.3 \pm 0.3(\text{stat.}) \pm 0.5(\text{syst.})\%$	$\frac{\sigma_{t\bar{t}b\bar{b}}}{\sigma_{t\bar{t}jj}} = 2.2 \pm 0.4(\text{stat.}) \pm 0.5(\text{syst.})\%$
Madgraph+Pythia	$\frac{\sigma_{t\bar{t}b\bar{b}}}{\sigma_{t\bar{t}jj}} = 1.6 \pm 0.2\%$	$\frac{\sigma_{t\bar{t}b\bar{b}}}{\sigma_{t\bar{t}jj}} = 1.3 \pm 0.2\%$
POWHEG+Pythia	$\frac{\sigma_{t\bar{t}b\bar{b}}}{\sigma_{t\bar{t}jj}} = 1.7 \pm 0.2\%$	$\frac{\sigma_{t\bar{t}b\bar{b}}}{\sigma_{t\bar{t}jj}} = 1.4 \pm 0.2\%$

(Note: errors on predictions include only MC stats)

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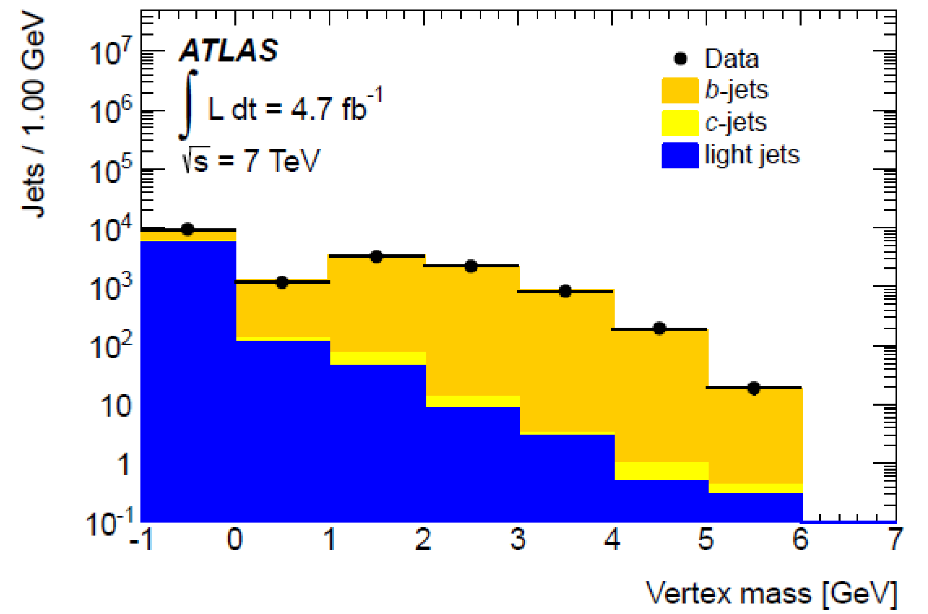
$t\bar{t}$ + heavy flavor quarks ($\sqrt{s}$ = 7 TeV)

NEW: To be submitted to Phys. R. D

- Motivation: $t\bar{t}+b/c+X$ events are main background to $t\bar{t}H(H \to b\bar{b})$
  - $c\bar{c}/b\bar{b}$ are produced in association with top via gluon splitting from ISR/FSR
- Signature: two opposite sign leptons + E_T^{miss} + at least two jets
  - $t\bar{t}$+HF: at least 3 *b*-tagged jets
  - $t\bar{t}$+jets: at least 2 *b*-tagged jets (at least 3 jets)
- Background:
  - Di-boson, Z+jets, single top: rely on simulation
  - fake leptons: data-driven from same sign lepton sample
  - *b*-tag jets from mistagged LH jets:
    - $t\bar{t}$+jets: MC simulation
    - $t\bar{t}$+HF: fit to the vertex mass of b-tagged jets



Vertex mass for b-tagged jets

- Strategy: quote the R_{HF} ratio between the $t\bar{t}$+HF cross section and $t\bar{t}$+jets one in a fiducial volume
  - $$R_{HF} = \frac{\sigma_{fid}^{(t\bar{t}+HF)}}{\sigma_{fid}^{(t\bar{t}+j)}} \Rightarrow \sigma_{fid}^{(t\bar{t}+X)} = \frac{N_X}{\int Ldt \cdot \varepsilon}$$

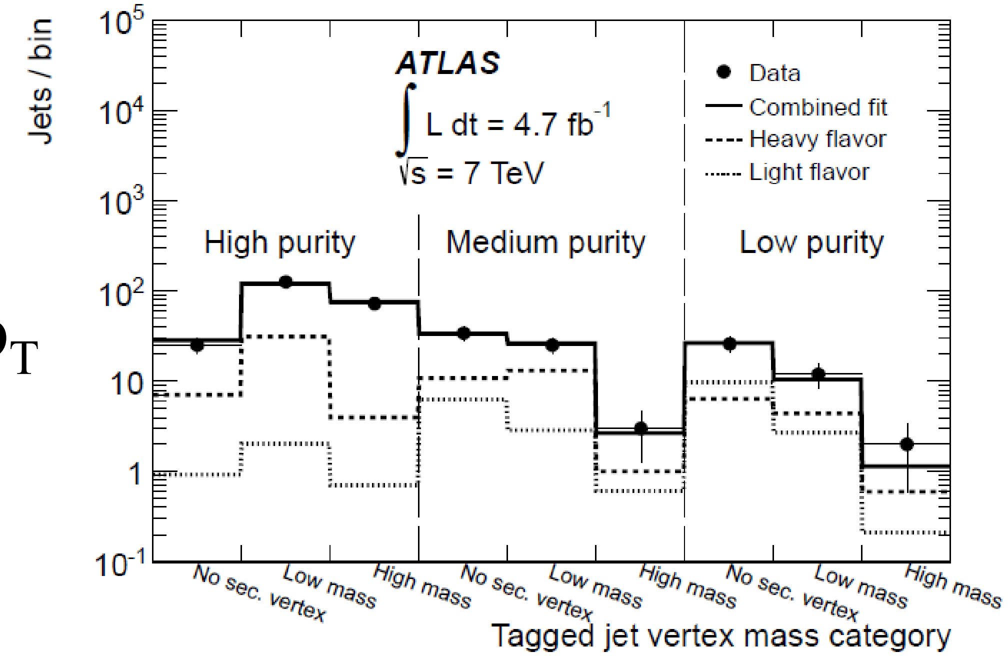
    (C. Bertella @ DIS2013)
    - N_X : the number of additional *b*-tagged jets for the $t\bar{t}$+HF selection; number of selected dilepton events for the $t\bar{t}$+jets selection
    - Fiducial volume: two leptons from top decay with p_T>25(20) GeV for e(μ) and |η|<2.5 and at least 3 (2) *b*-jets for $t\bar{t}$ + HF ($t\bar{t}$ + jets) and at least 3 jets for $t\bar{t}$ +HF

$t\bar{t}$ + heavy flavor quarks ($\sqrt{s}$ = 7 TeV)

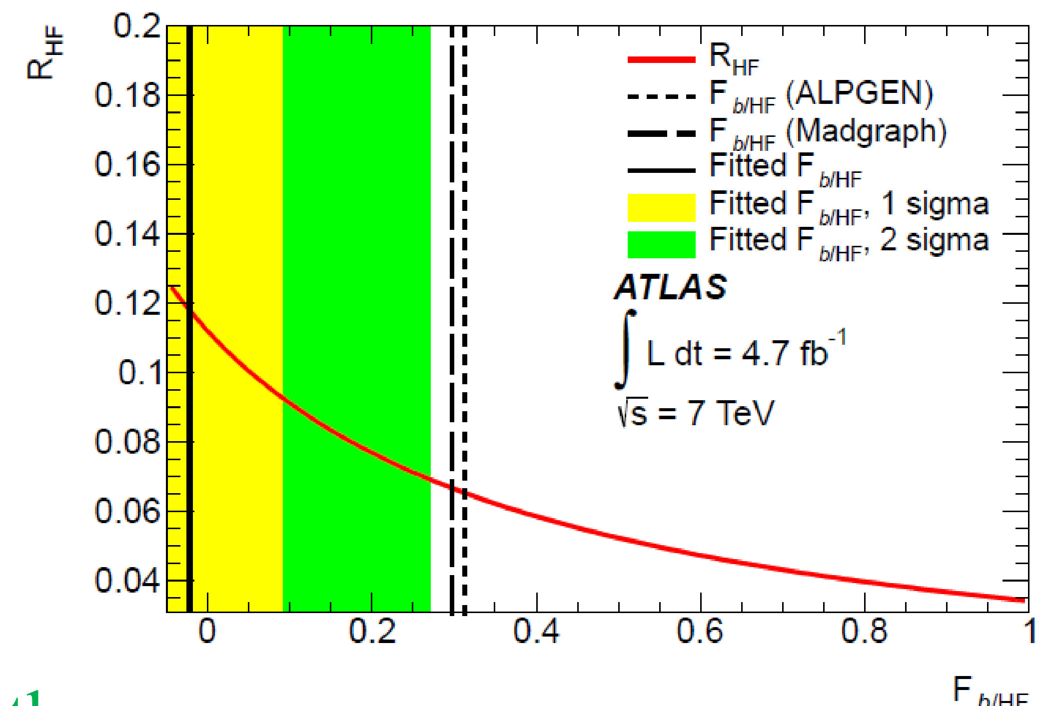
NEW: To be submitted to Phys. R. D

- Fraction of HF jets extracted by a binned maximum likelihood template fit on the vertex mass distribution
  - To increase the sensitivity → 2D p.d.f . (p_T – vertex mass)
  - Three exclusive bins of *b*-jet purity: $\varepsilon_{b\text{-tag}}$ = 60%, 60% to 70%, 70% to 75%
    - To differentiate between *b*'s, light flavor and *c*'s
- σ_{HF} ($t\bar{t}$+HF)= 0.18 ± 0.03(stat.) pb
- σ_{HF} ($t\bar{t}$+jets)= 2.55 ± 0.07(stat.) pb
- R_{HF} = [7.1 ± 1.3(stat.)$_{-2.0}^{+5.3}$ (syst.)] %
  - Dominant uncertainty: fiducial flavor composition
- Result consistent at 1.4σ level with LO SM prediction from ALPGEN and at 0.6σ level with approx. NLO result from POWHEG

(C. Bertella @ DIS2013)



Template fit results to vertex mass



R_{HF} as a function of $F_{b/HF}$, ratio of $t\bar{t}$ events with additional b-quarks to $t\bar{t}$ events with additional c- or b-quarks

Top mass

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

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

set b-JES to 1

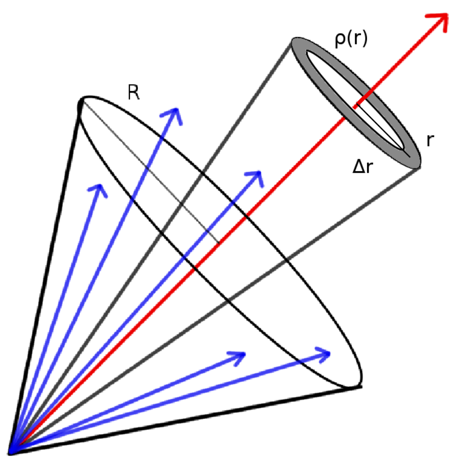
- Larger stat in 3D because of higher dim, but reduced b-JES
- Dominant modelling is reduced by JSF/ b-JSF
- Residual JES from p_T dependence of JES
- b-tag:p_T dependence of scale factors affecting R_{lb}
- Overall: better total syst , bJES absorbed by bJSF, scaling with lumi, uncorrelated in combinations

	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
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
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
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
Total uncertainty	2.05	0.021	1.55	0.021	0.022

top-quark events: MC modelling

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

- Modelling of signal events is crucial for precision measurements
  - analysis calibration
  - event reconstruction
  - definition of the parameter range used for systematic variations of MC samples



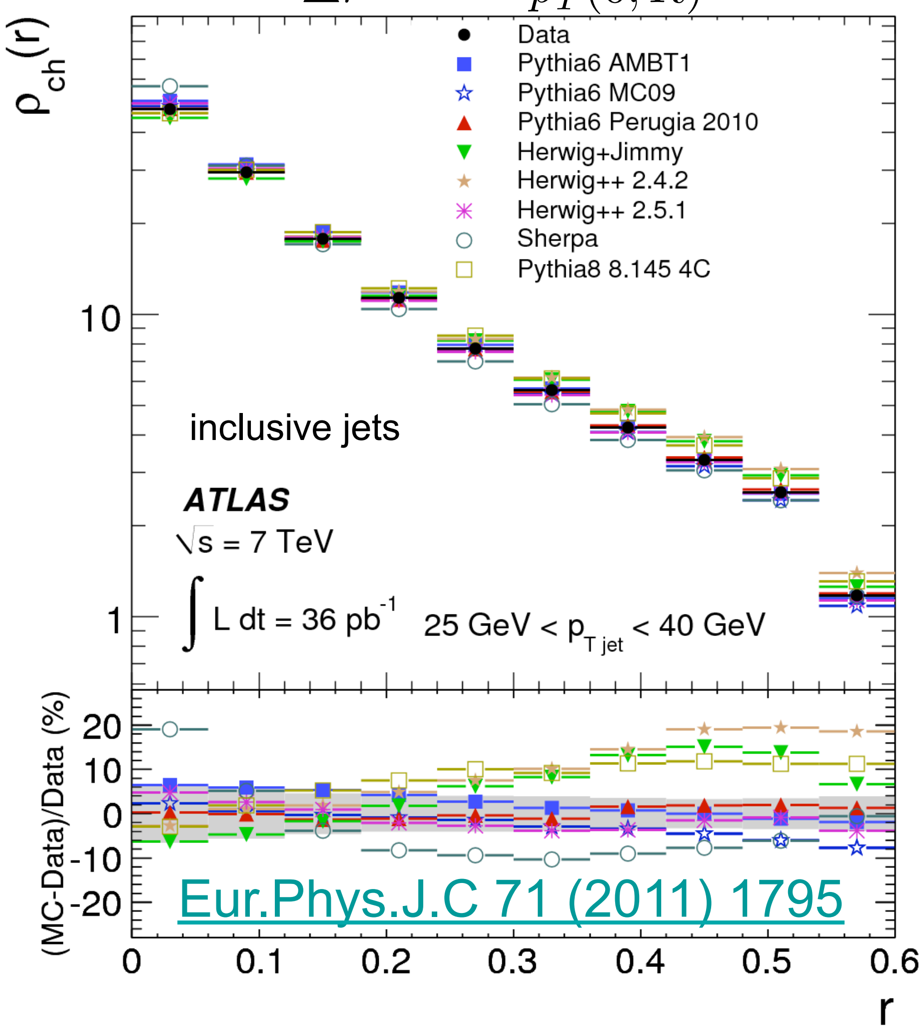
- Jet shapes are sensitive to the details of the parton shower models. (differential/integrated, using calorimeter clusters/tracks)

- Top pair events complement studies from the inclusive jet sample. Possibility to analyse separately b-quark and light-quark jets.

Observable/analysis	Modelling improvements
Jet multiplicity	MC@NLO+Herwig replaced by PowHeg+Pythia
Gap fraction	Reduced parameter range for ISR/FSR systematics
Jet shape	Hadronization: from Herwig to Pythia Perugia tunes

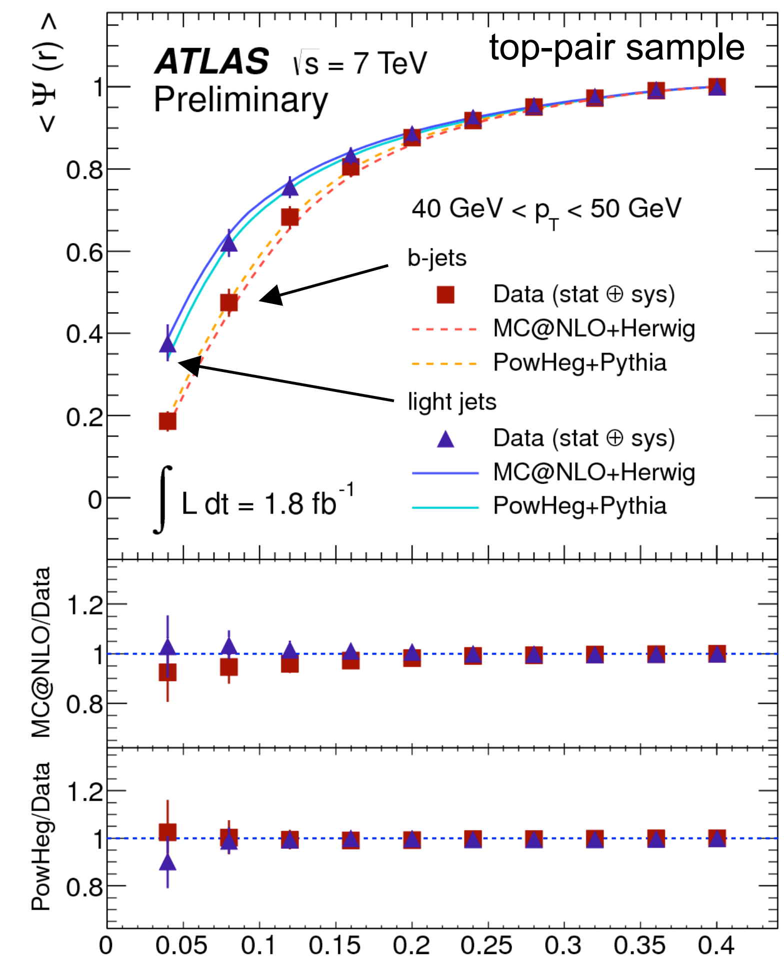
Differential jet shape

$$\rho(r) = \frac{1}{\Delta r}\frac{p_T(r-\Delta r/2, r+\Delta r/2}{p_T(0,R)}$$



Integrated jet shape:

$$\Psi(r) = \frac{p_T(0,r)}{p_T(0,R)}$$



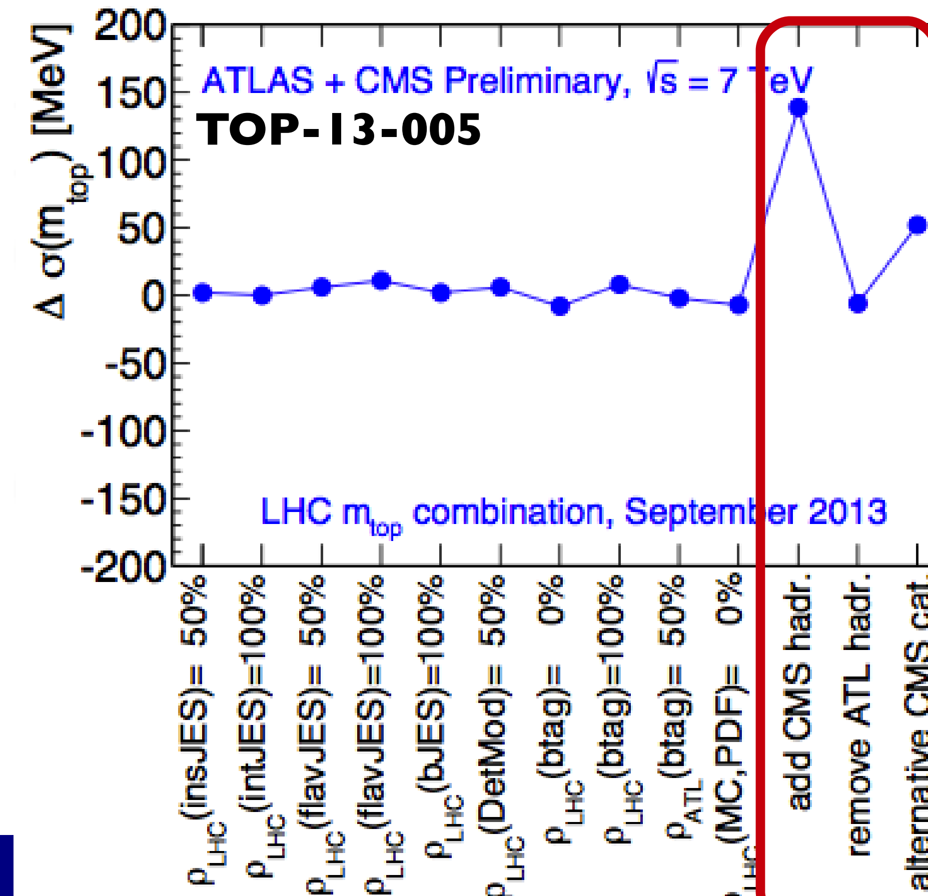
Most relevant correlations: JES

- **Correlation of JES between ATLAS and CMS is split into four groups:**

dJES (uncorr, in-situ γ/Z, intercalib) | aJES (flavour) | bJES (b-specific) | cJES (out-of-cone) | rJES (remainder) + iJES (in-situ)

in-situ γ/Z	Flavor	bJES	Intercalib.	Uncorr.
$\rho_{exp}=1$, $\boldsymbol{\rho_{LHC}=0}$ vary 0 → 0.5	$\rho_{exp}=1$, $\boldsymbol{\rho_{LHC}=0}$ vary 0 → 1	$\rho_{exp}=1$, $\boldsymbol{\rho_{LHC}=0.5}$ vary 0.5 → 1.0	$\rho_{exp}=1$, $\boldsymbol{\rho_{LHC}=0.5}$ vary 0.5 → 1	$\rho_{exp}=0$ or 1, $\boldsymbol{\rho_{LHC}=0}$

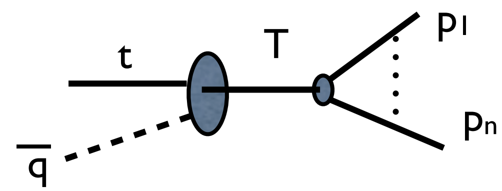
- Robust combination with respect to most variations ▶
- **Three additional cross-checks:**
  - add ttbar-specific hadronization uncertainty in CMS measurements comparing Powheg Pythia vs Herwig
  - remove ATLAS tt-specific hadronization
  - re-categorize CMS bJES uncertainty varying b-fragmentation, semi-leptonic BR, hadronization model



(P. Silva, TOP2013)

Definition of m_{top} from top decays

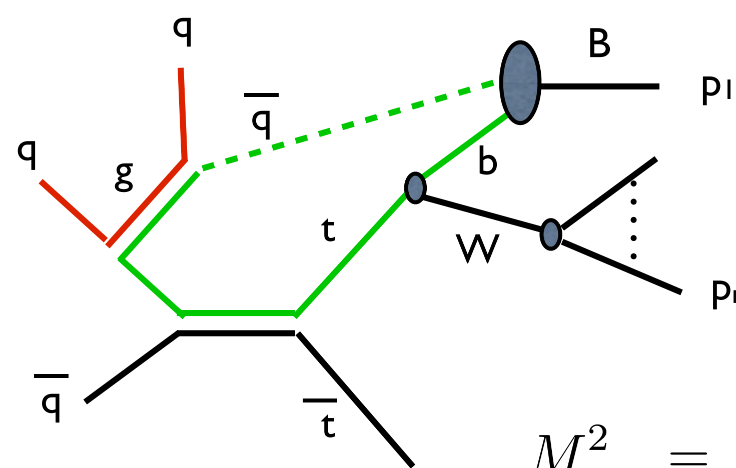
If Γ_{top} were < 1 GeV, top would hadronize before decaying. Same as b-quark



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

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

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

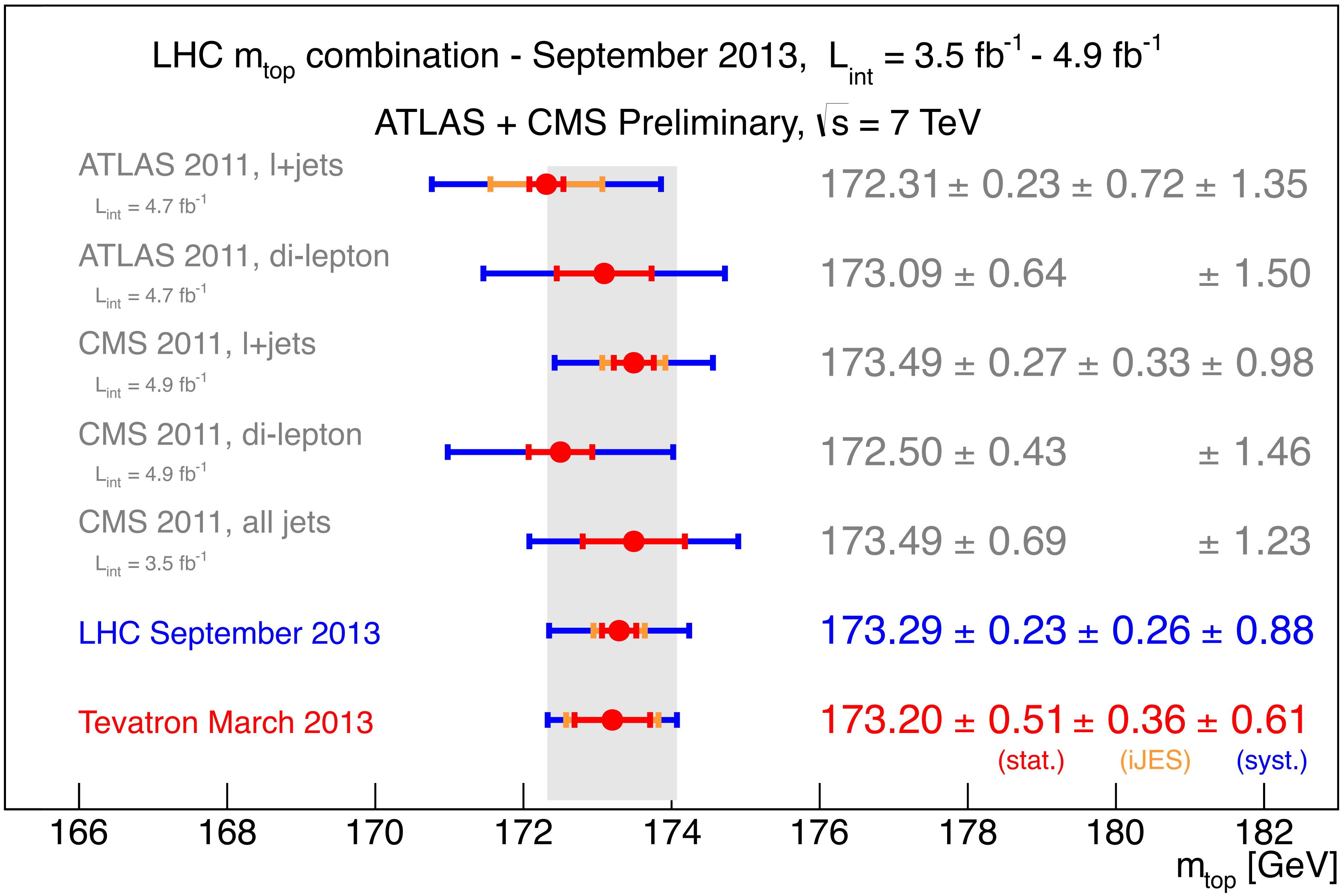
Goal:
- correctly quantify the systematic uncertainty
- identify observables that allow to validate the theoretical modeling of hadronization in top decays
- identify observables less sensitive to these effects

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)

m_{top} @ LHC (Oct 2013)



ATLAS-CONF-2013-102

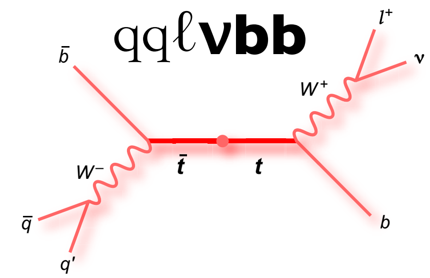
m_{top} @ LHC (Oct 2013)

- LHC Categorization of syst (compared to Tevatron)
- ρ_{exp} (ρ_{LHC})is correlation assumed within same experiment (between different exp)
- ρ_{exp} and ρ_{LHC} only reported for ungrouped categories

Uncertainty Categories			Size [GeV]						Correlation	
			ATLAS		CMS			LHC	ρ_{exp}	ρ_{LHC}
Tevatron	ATLAS	CMS	2011 l+jets	2011 di-l	2011 l+jets	2011 di-l	2011 all jets	comb		
Measured m_{top}			172.31	173.09	173.49	172.50	173.49	173.29		
	Jet Scale Factor		0.27		0.33					
	bJet Scale Factor		0.67							
iJES	Sum (statistical comp.)		0.72		0.33			0.26	0	0
dJES	uncorrelated JES comp.		0.61	0.73	0.24	0.69	0.69	0.29	1	0
	in-situ γ/Z JES comp.		0.29	0.31	0.02	0.35	0.35	0.10	1	0
	intercalib. JES comp.		0.19	0.39	0.01	0.08	0.08	0.07	1	0.5
aJES	flavour JES comp.		0.36	0.02	0.11	0.58	0.58	0.16	1	0.0
bJES	b-jet energy scale		0.08	0.71	0.61	0.76	0.49	0.43	1	0.5
Signal	MC Generator		0.19	0.20	0.02	0.04	0.19			
	Hadronisation		0.27	0.44						
MC	Sum		0.33	0.48	0.02	0.04	0.19	0.14	1	1
	ISR/FSR		0.45	0.37						
		Q^2-scale			0.24	0.55	0.22			
		Jet-Parton scale			0.18	0.19	0.24			
Rad	Sum		0.45	0.37	0.30	0.58	0.33	0.32	1	1
CR	Colour reconnection		0.32	0.29	0.54	0.13	0.15	0.43	1	1
-	Underlying event		0.12	0.42	0.15	0.05	0.20	0.17	1	1
PDF	Proton PDF		0.17	0.12	0.07	0.09	0.06	0.09	1	1
	Jet Resolution		0.22	0.21	0.23	0.14	0.15			
	Jet Reco Efficiency		0.05							
	E_T^{miss}		0.03	0.05	0.06	0.12				
DetMod	Sum		0.23	0.22	0.24	0.18	0.28	0.20	1	0
	b-tagging		0.81	0.46	0.12	0.09	0.06	0.25	1	0.5
LepPt	Lepton reconstruction		0.04	0.12	0.02	0.14		0.01	1	0
Background from MC				0.14	0.13	0.05		0.08	1	1
Background from Data			0.10				0.13	0.04	0	0
Method			0.13	0.07	0.06	0.40	0.13	0.06	0	0
Multiple Hadronic Interactions			0.03	0.01	0.07	0.11	0.06	0.05	1	1
Statistics			0.23	0.64	0.27	0.43	0.69	0.23		
Systematics			1.53	1.50	1.03	1.46	1.23	0.92		
Total Uncertainty			1.55	1.63	1.06	1.52	1.41	0.95		
Comb. Coeff. [%]			22.6	3.6	60.6	-8.4	21.6	χ^2/ndf = 1.8/4		
Pull			-0.80	-0.15	0.41	-0.67	0.19	χ^2 prob = 77%		

Measuring top mass

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



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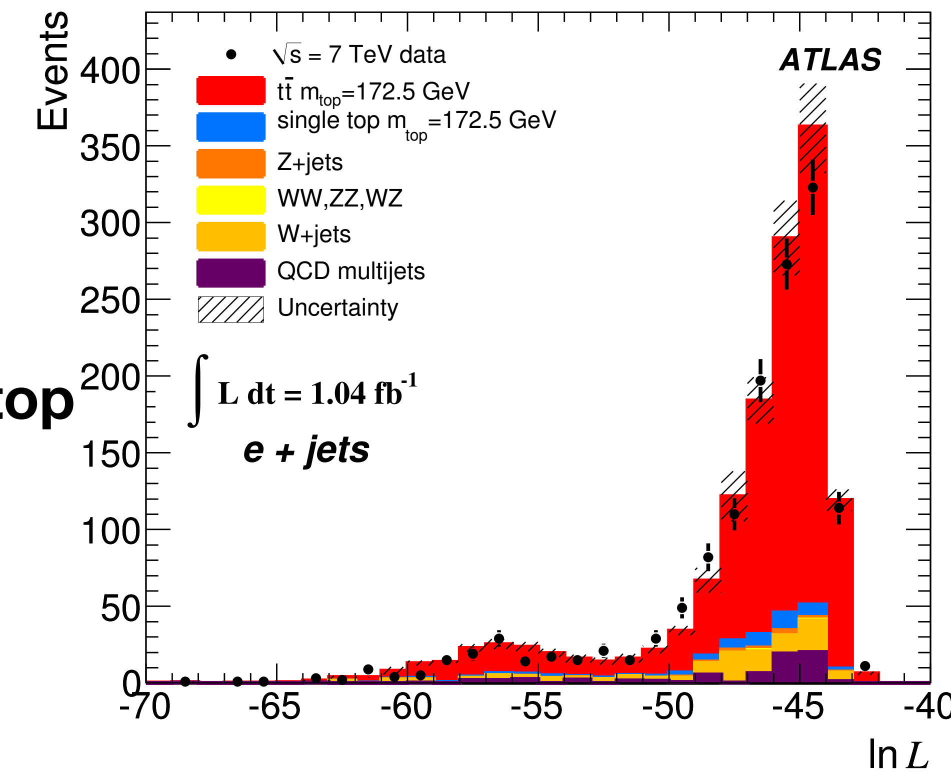
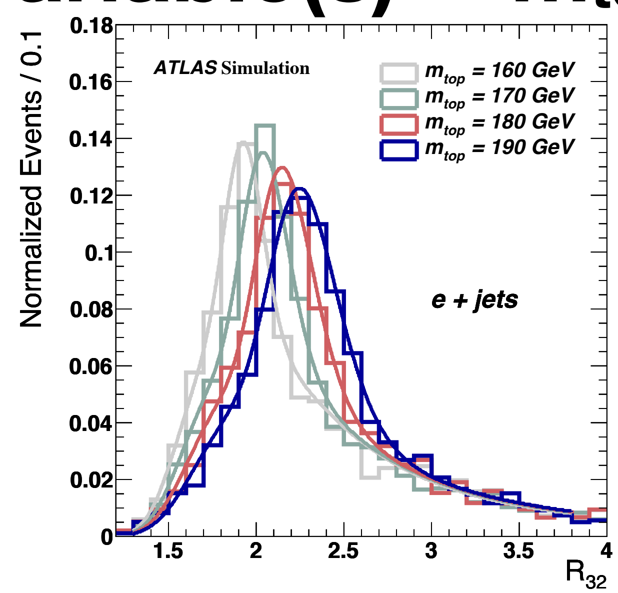
- **Standard single lepton selection**
  - *good quality objects, 1 lepton, cuts on E_T, m_T^W, ≥4 jets, at least 1 b-tagged jet*
- **Reconstruct two m_{top}-sensitive variables**
  - *Jet energy scale is crucial: different reduction*
- **Binned likelihood fit** *of data* **to m_{top}-dependent template(s) of variable(s) →m_{top}**
  - *channel dep analytic shape for bkg,*
  - *W+jets and QCD from data*
- **Compare/Combine**



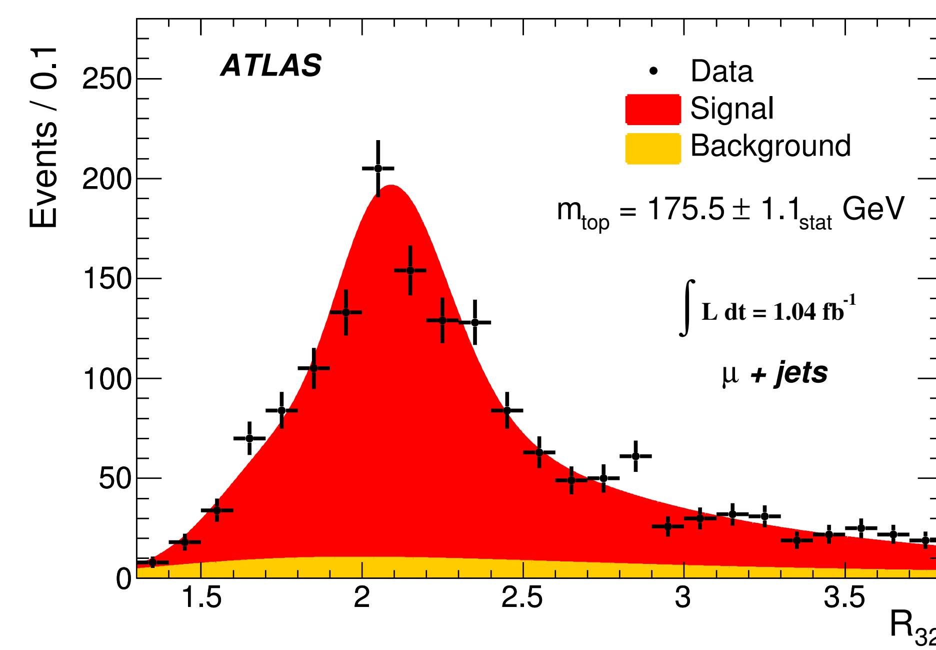


1d R_{32} analysis

- **fit R_{32} = *Ratio of 3-jet (top) to 2-jet (W) masses:*** *assign jets with kinematic likelihood fit using W mass constraint, $m_{top,HAD}$= $m_{top,LEP}$ + weight for b/mis-tag*

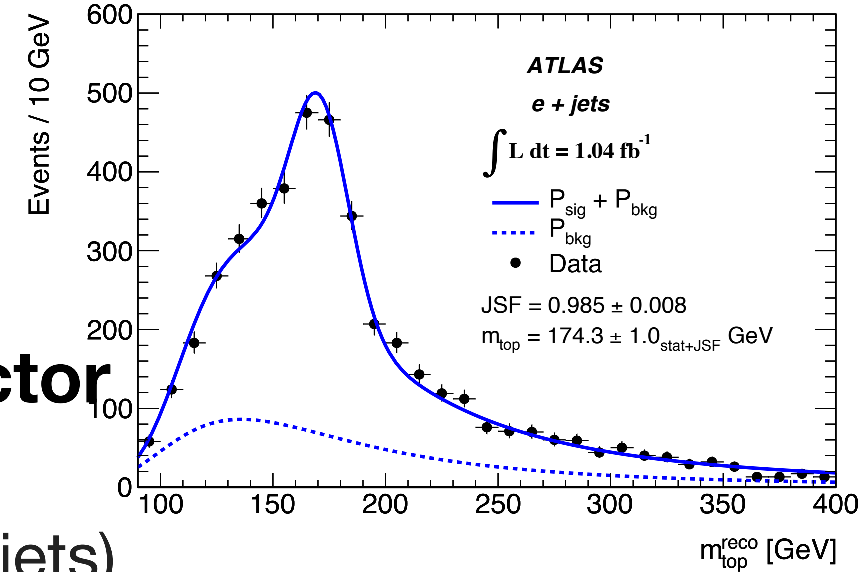
cancel jet syst in ratio

- *Log(L)>-50 , 2-jet mass (60-100)GeV*
- *$p_{T,jet}$ >40 GeV for 3-jet system*



linearity tested with Poisson-fluctuated pseudoexp.

Measuring top mass



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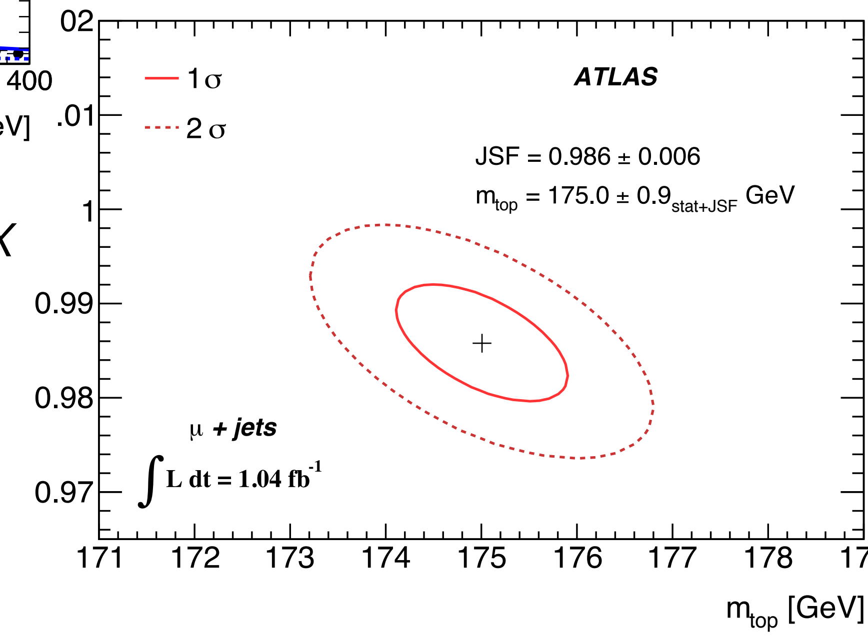
2dM analysis

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

- **fit ($m_{t,reco}$, $m_{w,rec}$): function of global Jet Energy Scaling Factor (JSF)→ $m_{top,JSF}$**
  - use largest p_T 3-jet system (b- +2 l-jets)
    - **$m_{W,rec}$** from 2 light-jets
    - χ^2 with 2 l-jets energies imposing M_W → **$m_{top,rec}$** from **fitted** jets + b-jet
    - scale all jets with same JSF

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

m(2 l-jets)∈ (50,100) GeV

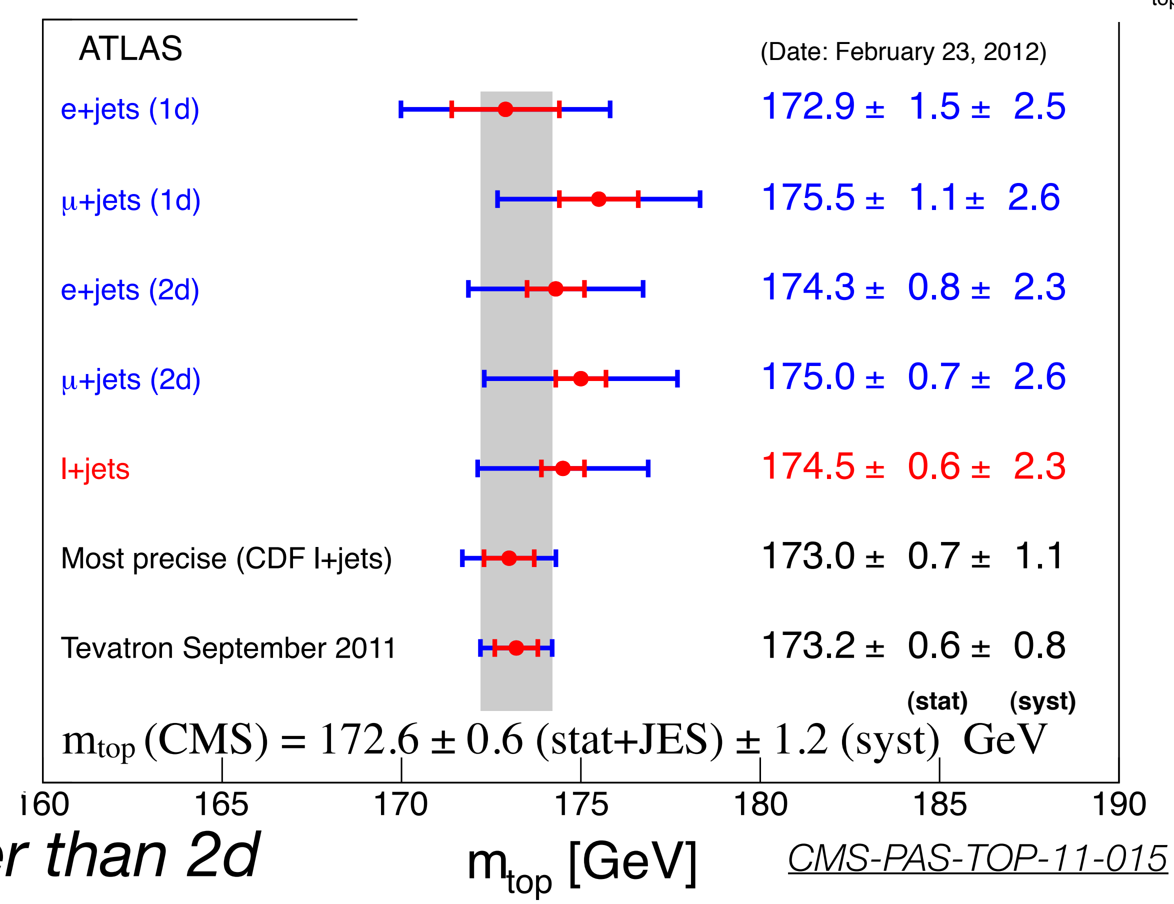


Results

1d R_{32} $m_{top} = 174.4 \pm 0.9_{stat} \pm 2.5_{syst}$ GeV

2dM $m_{top} = 174.5 \pm 0.6_{stat} \pm 2.3_{syst}$ GeV

- ***Systematic dominated! b-JES***
  - *$1dR_{32}$ (GeV) : ISR/FSR (1.4), JES(~1.2), b-JES(~1.16), MCGen (~0.7), Colour Rec (0.6)*
  - *2dM (GeV): **b-JES (~1.6)**, ISR/FSR(~1), JES (~0.66), Colour Rec(0.55), JSF (0.4)*

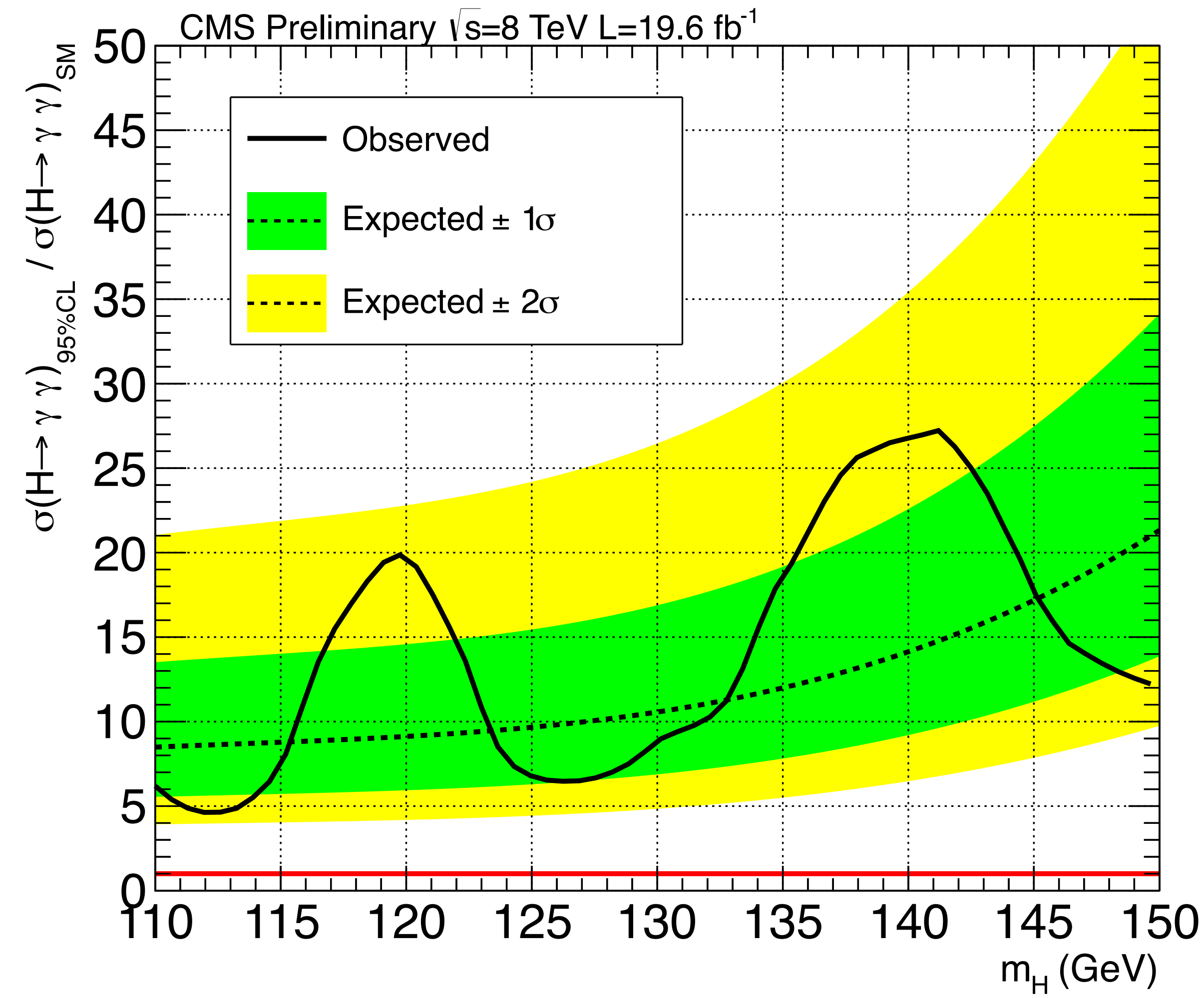


CMS-PAS-TOP-11-015

- *Correl 1d-2d O(15-16%) , combination not better than 2d*

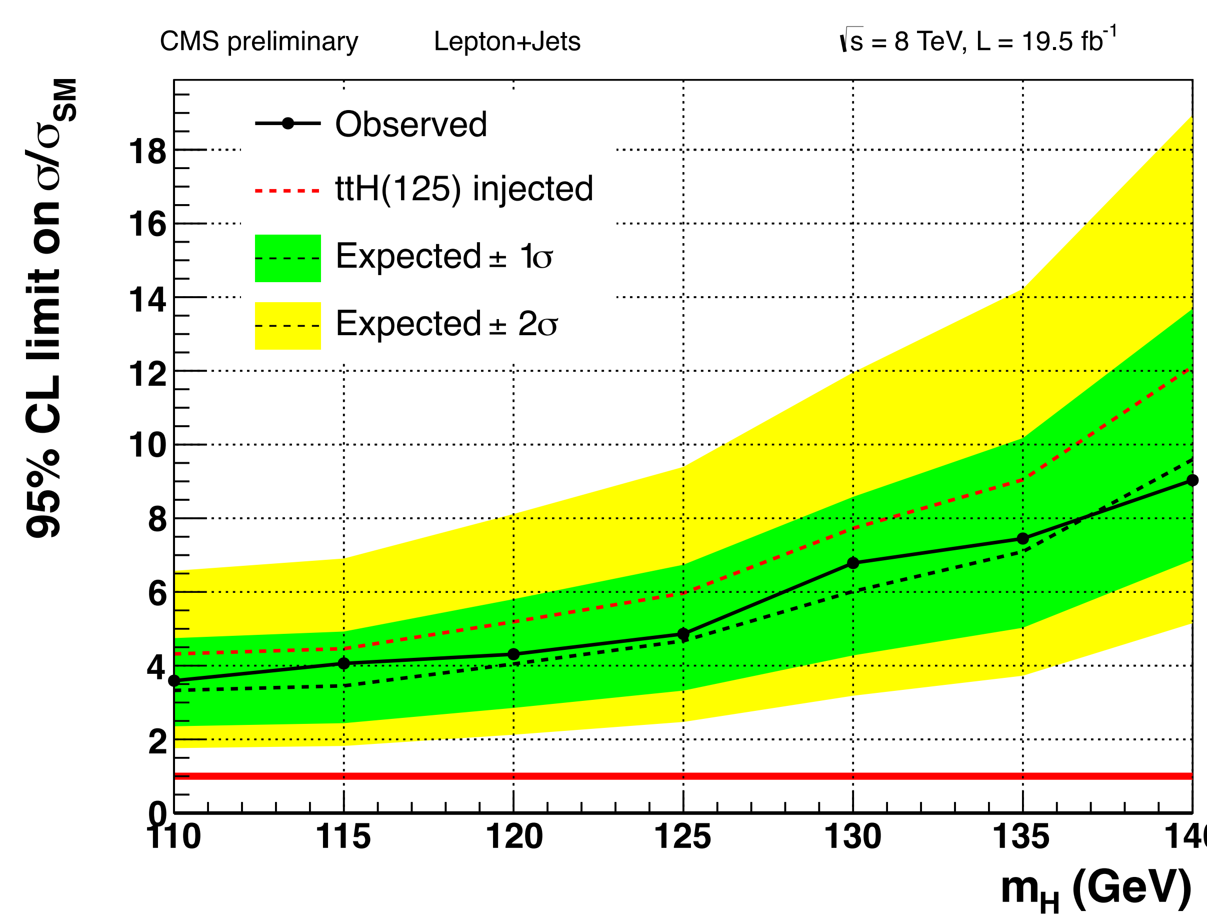
Top and Higgs

CMS limits on $t\bar{t}H$



CMS-PAS-HIG-13-015

- **$t\bar{t}H$, H→γγ @ $\sqrt{s}$ = 8 TeV**



CMS-PAS-HIG-13-018

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

95%CL upper limits on Higgs prod

Higgs Mass	Observed	Expected Median
110 GeV	3.6	3.3
115 GeV	4.1	3.5
120 GeV	4.3	4.0
125 GeV	4.9	4.7
130 GeV	6.8	6.0
135 GeV	7.4	7.1
140 GeV	9.0	9.6

l+jets

Higgs Mass	Observed	Expected Median
110 GeV	6.5	5.8
115 GeV	7.4	6.5
120 GeV	8.2	7.2
125 GeV	9.1	8.2
130 GeV	12.4	10.5
135 GeV	15.0	12.3
140 GeV	18.0	14.1

dilep

$t\bar{t}H$ combination by CMS

ttH Channel	95% CL upper limits on $\mu = \sigma/\sigma_{SM}$ ($m_H = 125.7$ GeV)				
		Expected			
	Observed	Median Signal Injected	Median	68% CL Range	95% CL Range
$\gamma\gamma$	5.4	6.7	5.5	[3.5,8.9]	[2.4,14.1]
$b\bar{b}$	4.5	5.2	3.7	[2.6,5.2]	[2.0,7.0]
$\tau\tau$	12.9	16.2	14.2	[9.5,21.7]	[6.9,32.5]
4l	6.8	11.9	8.8	[5.7,14.2]	[4.0,22.4]
3l	6.7	4.7	3.8	[2.5,5.8]	[1.8,8.7]
Same-sign 2l	9.1	3.6	3.4	[2.3,5.0]	[1.7,7.2]
Combined	4.3	2.9	1.8	[1.2,2.6]	[0.9,3.6]

Charge asymmetry

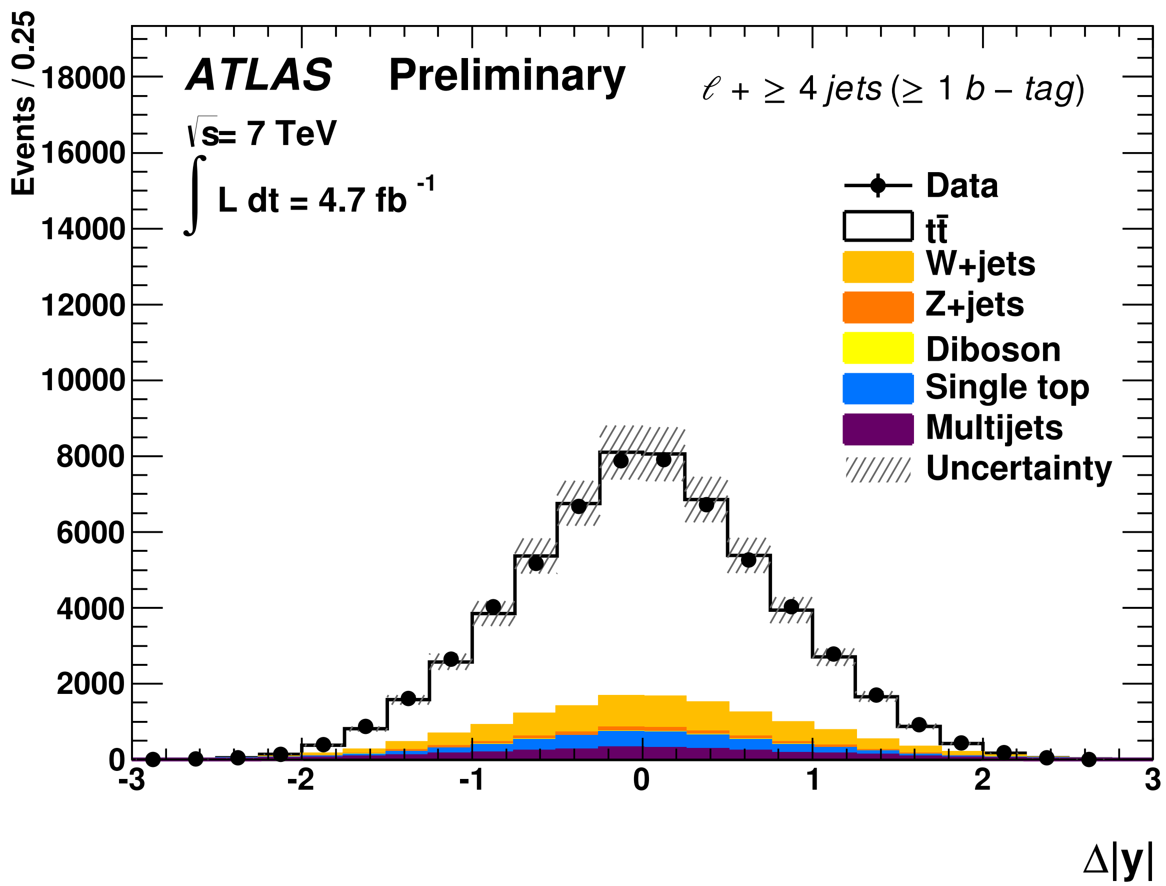
Measure top quarks charge asymmetry

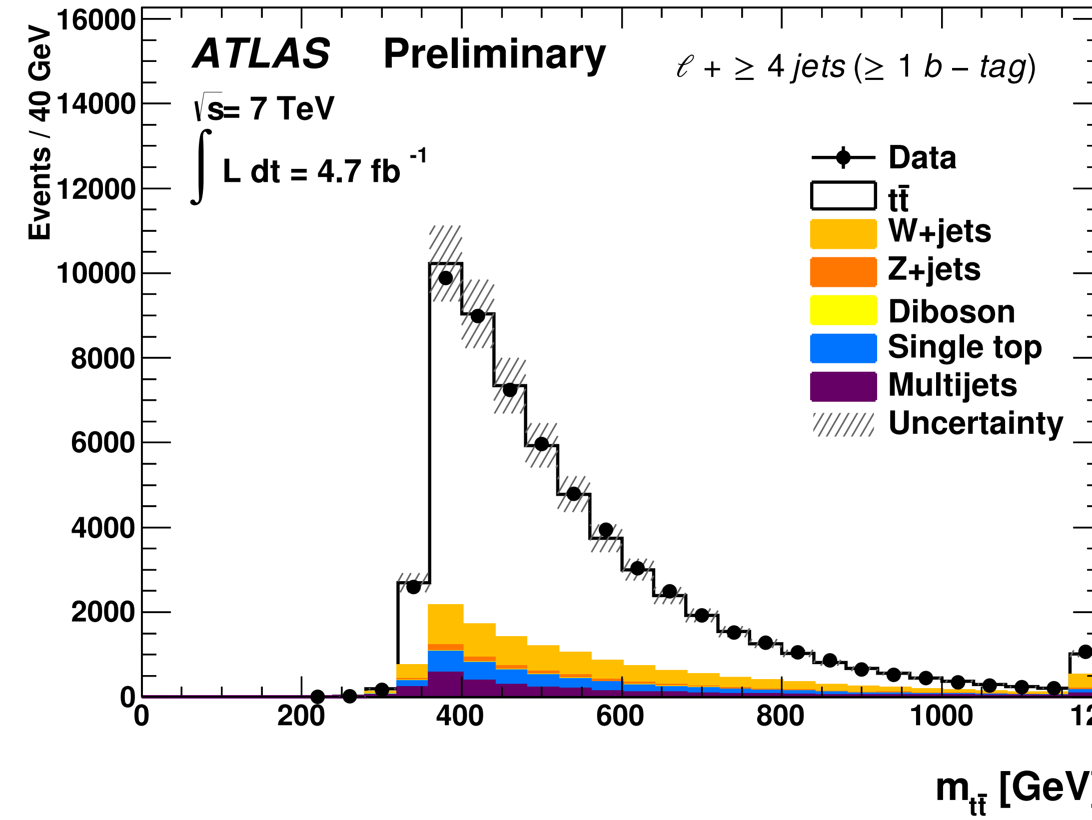
$\int L dt$ = **4.7 fb^{-1}** *(2011)*

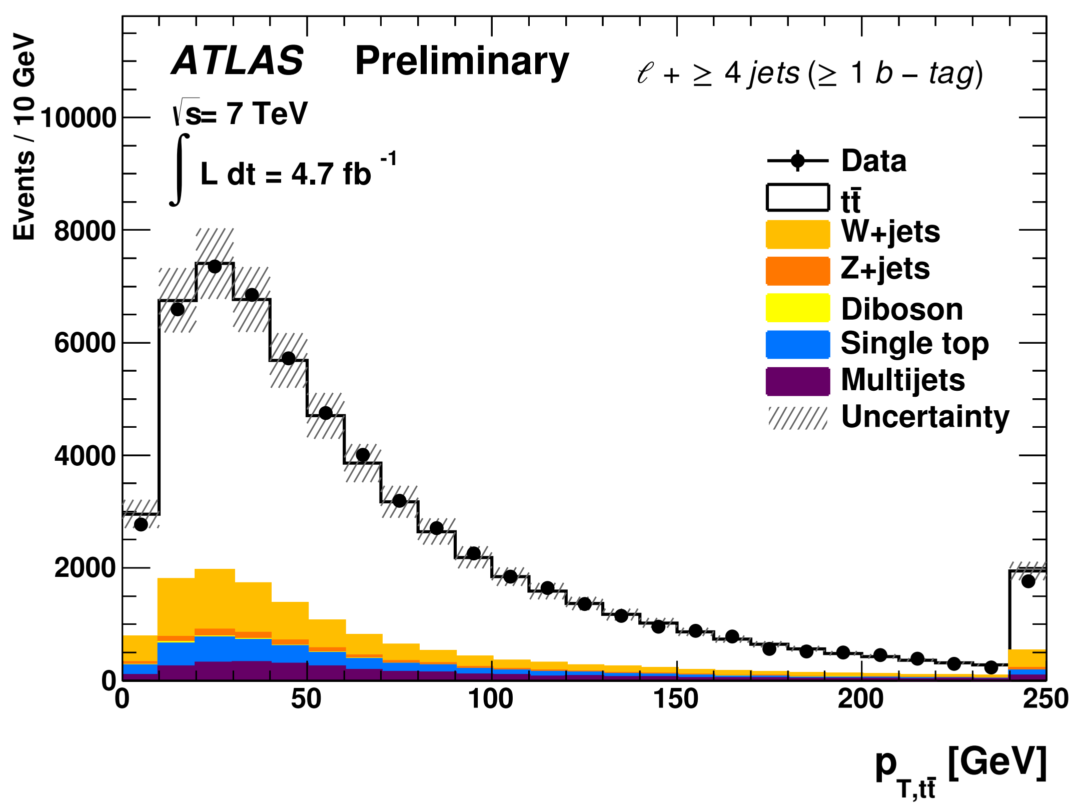
qqℓ**νbb**

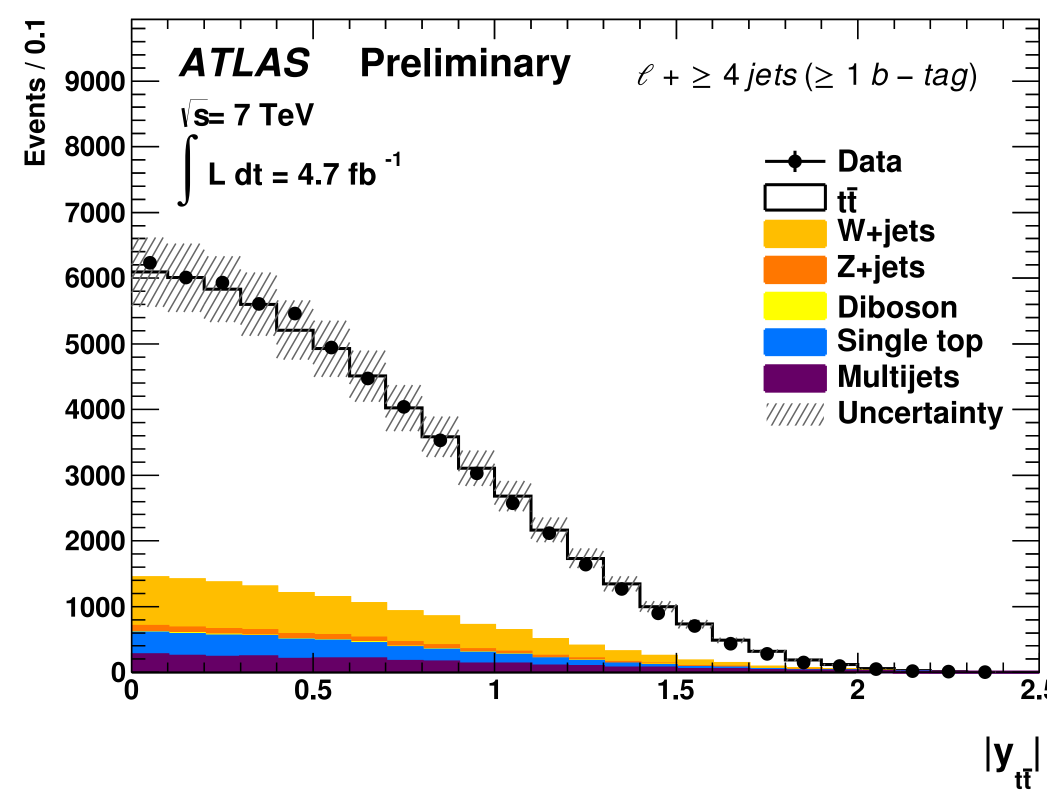
bef unfolding,
no bkg subtraction

ATLAS-CONF-2013-078









CHARGE ASYMMETRY AT LHC @ 7 TEV

SM prediction QCD NLO + EW: $A_C^{|y|} = 1.23 \pm 0.05\,\%$.

[Bernreuther, Si, PRD86 (2012) 034026]

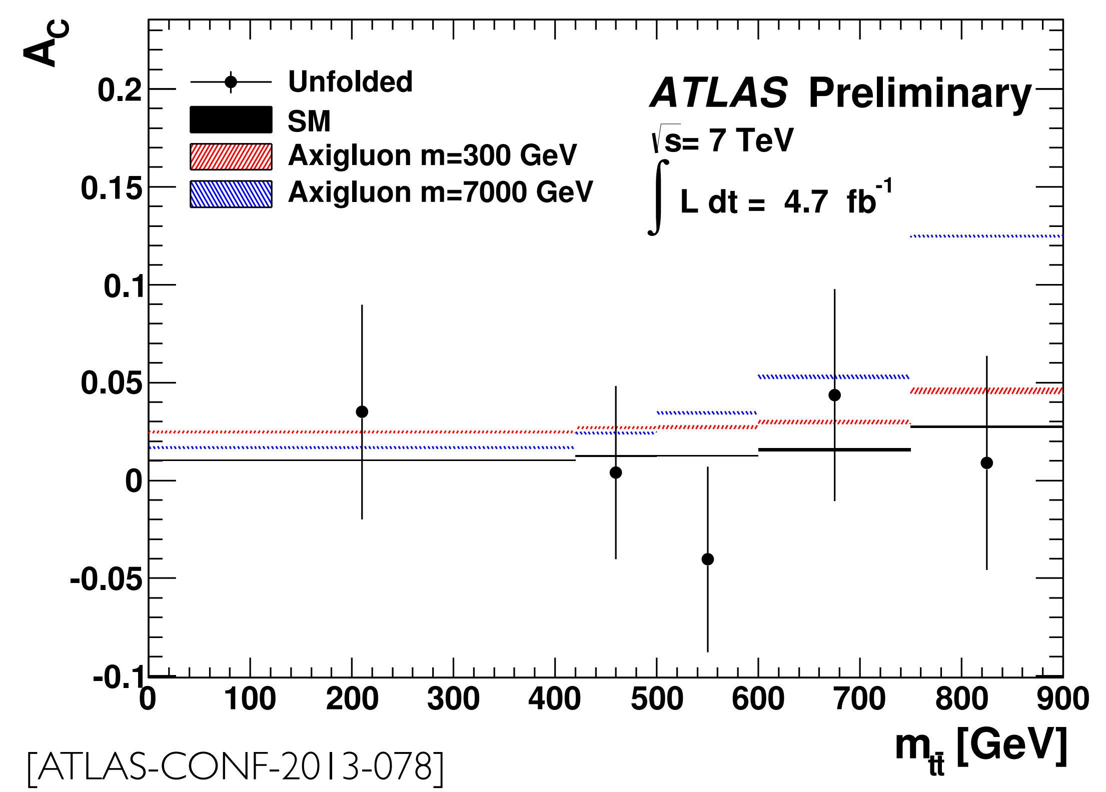
Lepton+jets

CMS: $A_C^{|y|} = 0.4 \pm 1.0 \pm 1.1\,\%$

[CMS, PLB717 (2012) 129]

ATLAS: $A_C^{|y|} = 0.6 \pm 1.0\,\%$

[ATLAS-CONF-2013-078]



[ATLAS-CONF-2013-078]

Dilepton

CMS: $A_C^{|y|} = 5.0 \pm 4.3^{+1.0}_{-3.9}\,\%$

[CMS-PAS-TOP-12-010]

ATLAS: $A_C^{|y|} = 5.7 \pm 2.4 \pm 1.5\,\%$

[ATLAS-CONF-2012-057]

Results are compatible with SM, but significance is limited.

12

(S Westhoff, TOP2013)

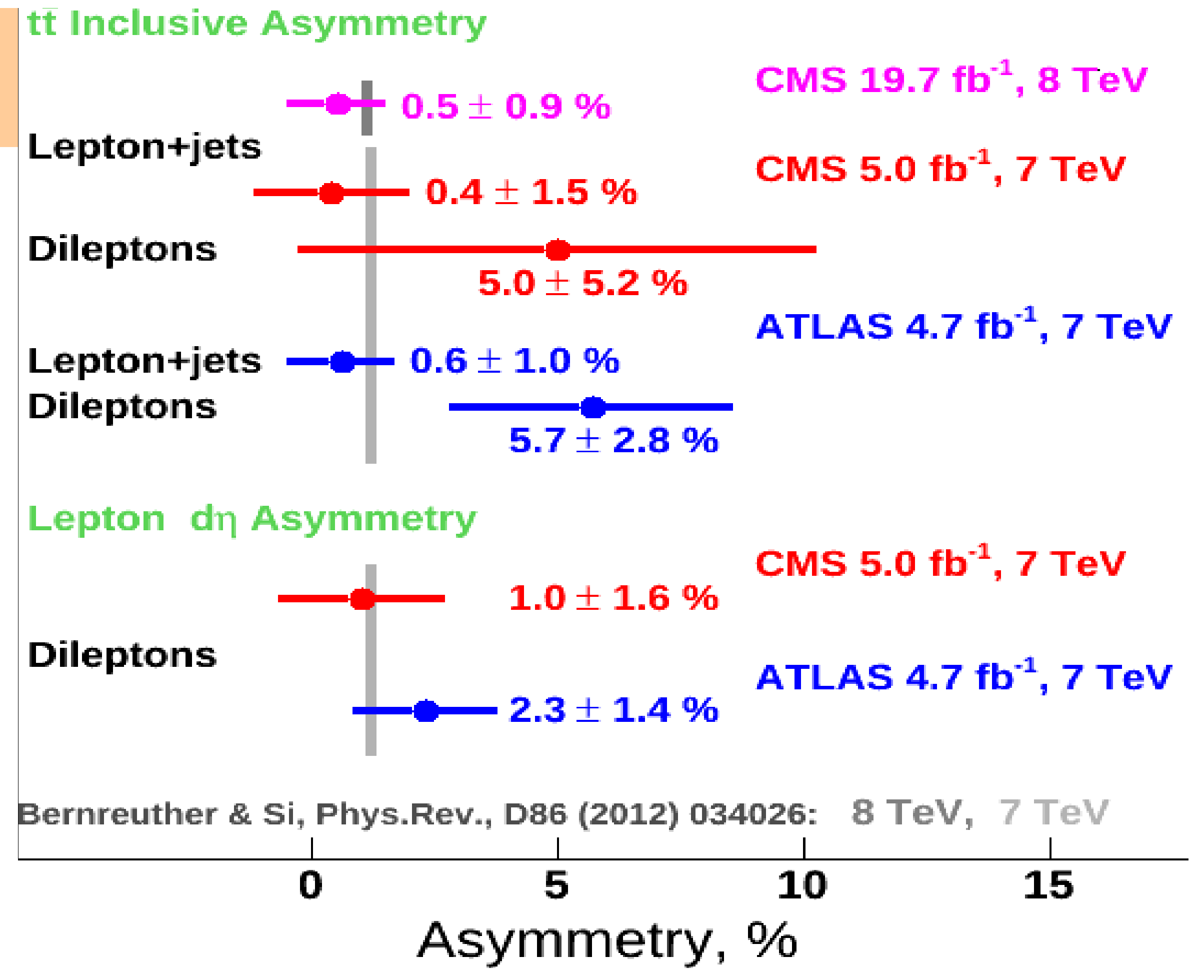
Latest on LHC charge asymmetry

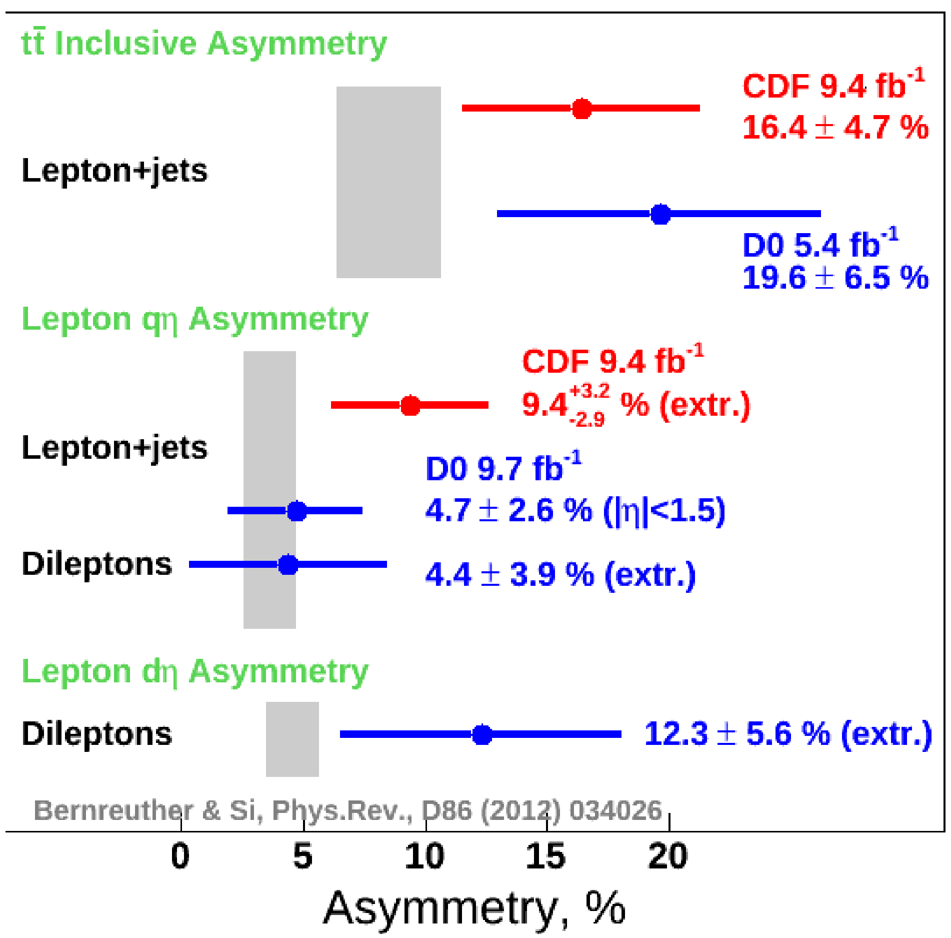
Conclusion

LHC: no deviation from the SM prediction is seen up to now, but precision is start to be limited by the systematic uncertainties (could be improved with more statistics?).

Further progress may be seen in measuring asymmetries in the specific regions of phase space (high velocity, high invariant $t\bar{t}$ mass, ...).

(V. Sharyy , TOP2013)





Tevatron: still some tension between measurements and QCD calculation at the level of 2-3 σ. Differential asymmetry shows an interesting enhancement at high invariant $t\bar{t}$ mass.

Further improvement in precision will be made after finishing the analysis of the full D0 statistics (could expect ~3% precision for the combined inclusive asymmetry)

Tevatron combination is absolutely necessary (including differential asymmetries) in order to make a conclusive statement.

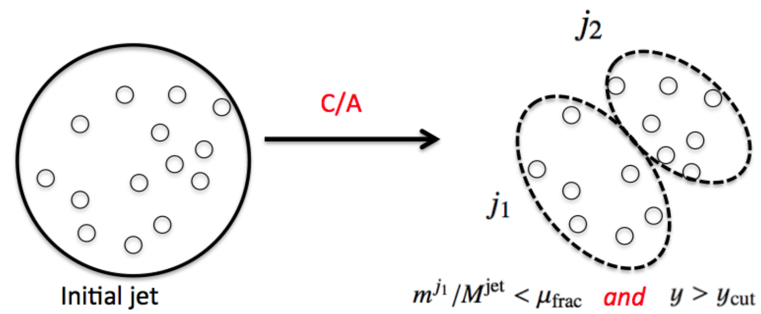
Top resonances

Boosted decays : the issues (II)

ATLAS-CONF-2012-065

- Recover radiations & deal with pile-up: **grooming** vs standard

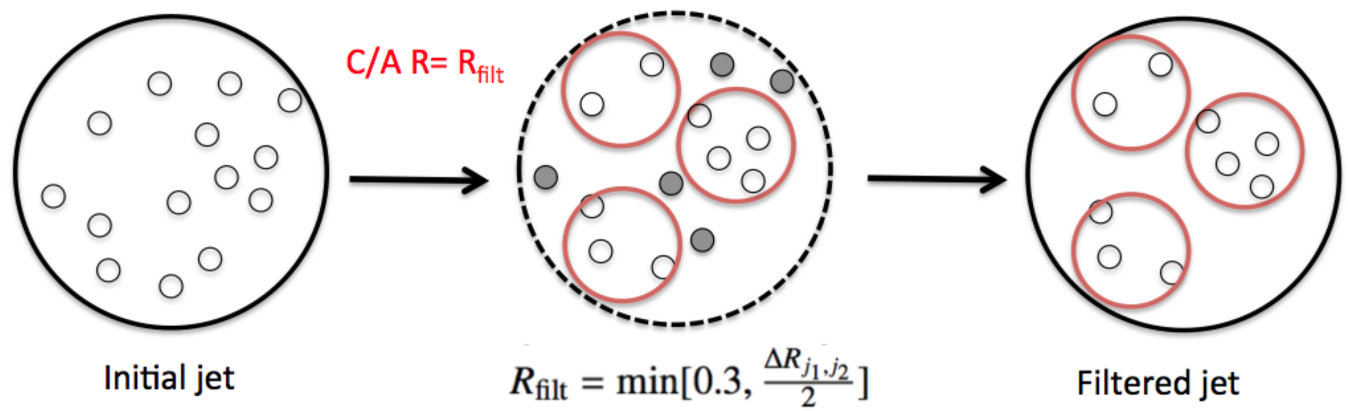
Mass Drop: *undo C/A by 1 step,consider jets with sizeable mass difference between subjet_i and original jet*



standard

- offset corrections
- jet area correction

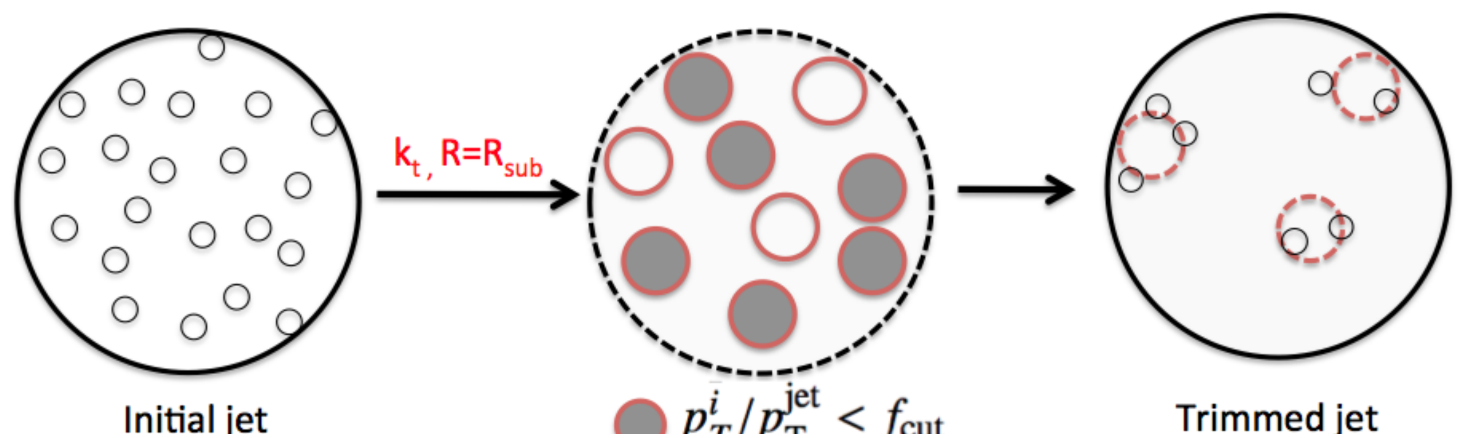
Filter: *recluster with CA,keep only 3 hardest subjets*



Trimming: global

make subjets and

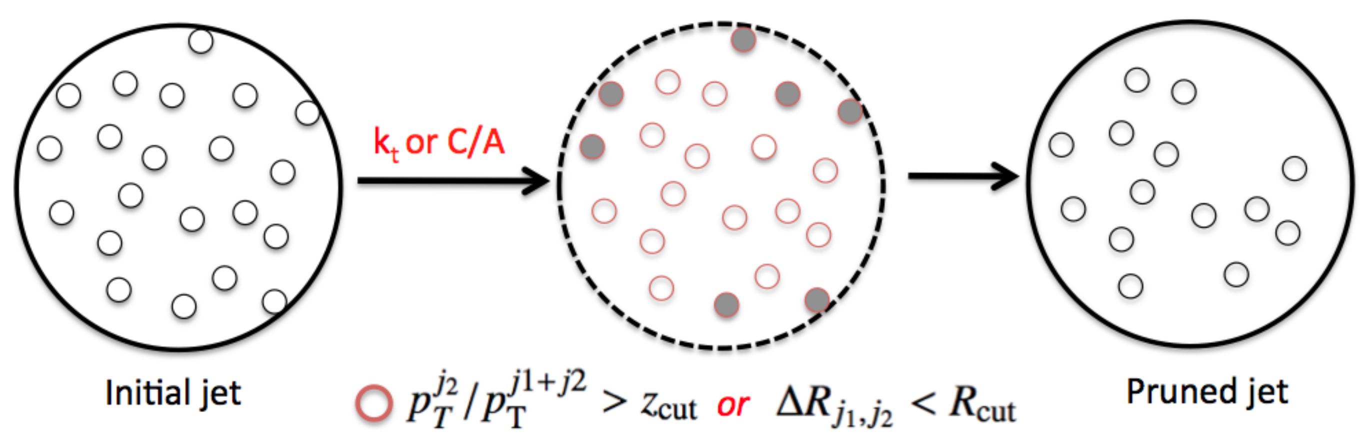
take away soft contrib compared to overall scale



Pruning:local

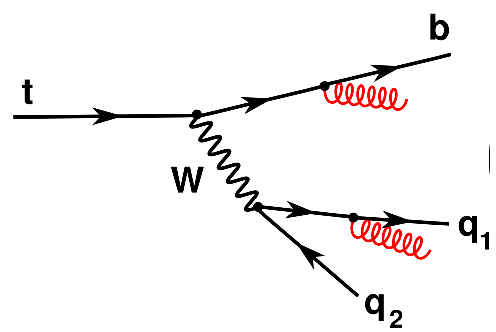
run k_T or CA on constituents

discrad soft elements at each recomb step

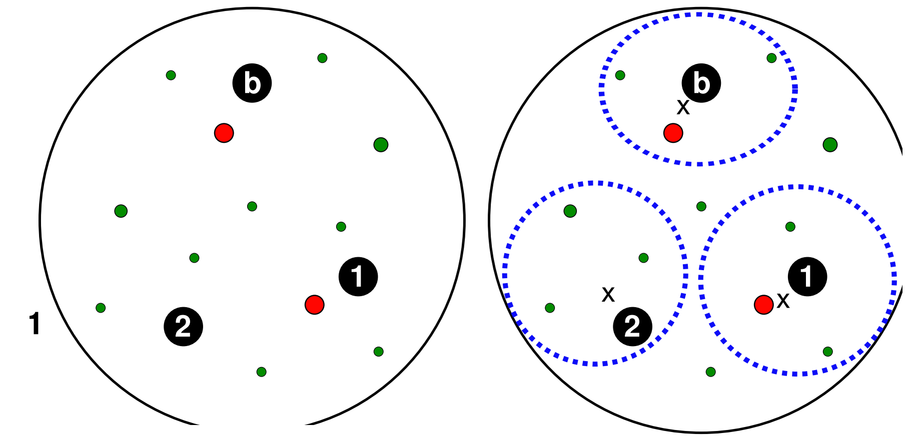


Used taggers: HEPTopTagger : grooming

ATLAS-CONF-2012-065

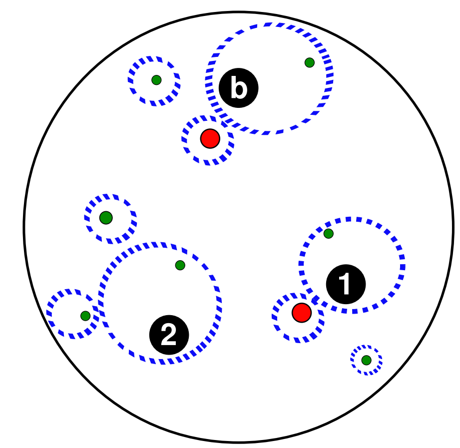


(from S Fleischmann TOP2012)



1 Decompose until $m_{j_i} < 30\,\text{GeV}$ with mass drop requirement $m_{j_i} < \mu\, m_{\text{large jet}}$ *each new subjet is decomposed*

2 Investigate 3 subjets and their constituents

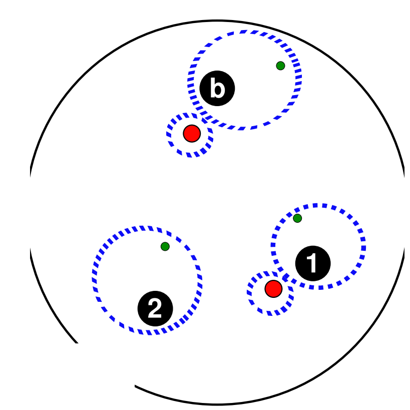


consider all triplets of subjets

3 Re-cluster using C/A with parameter $R = \min(0.3, \min_{ij} \Delta R(j_i, j_j)/2)$

new sub-jets

require total mass in top mass window



4 Use only 5 hardest subjets of last step

5 Build exactly 3 subjets from the selected constituents

if $R_- < \frac{m_{23}}{m_{123}} < R_+$ $\quad 0.2 < \arctan \frac{m_{13}}{m_{12}} < 1.3$ $\quad , \; R_{\pm} = (1 \pm f_W)\frac{m_W}{m_{\text{top}}}$

jet formed by 3 sub-jets is candidate top jet

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

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

ATLAS-CONF-2013-052

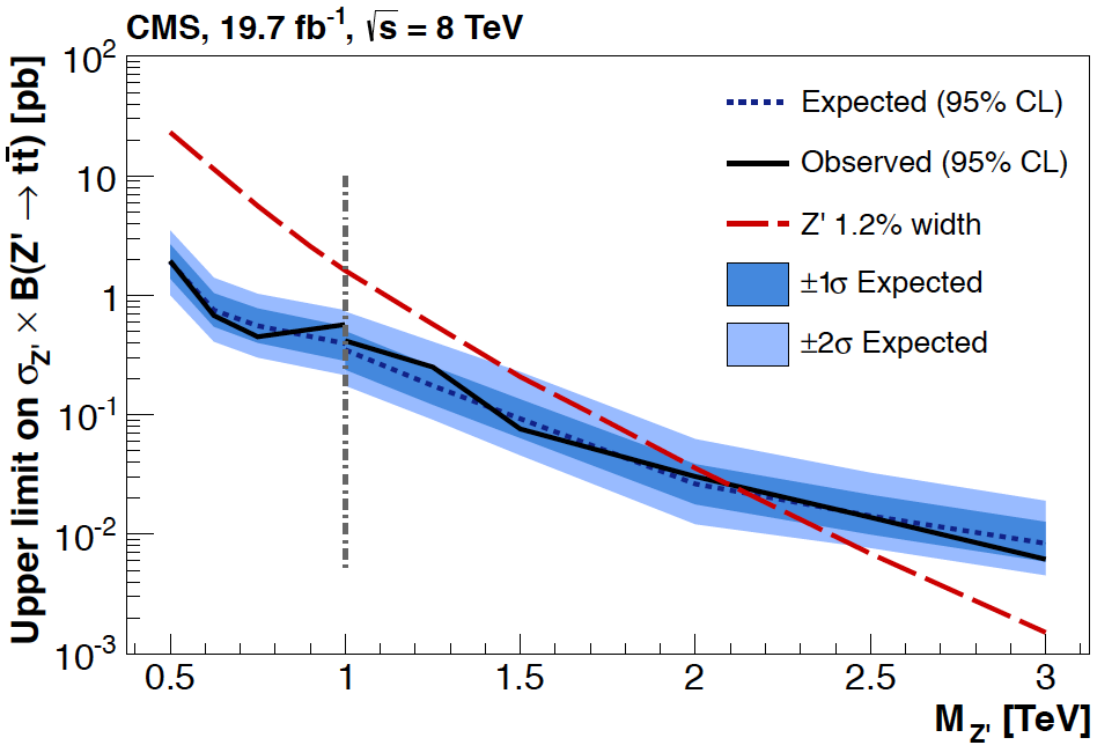
- Syst uncertainties on bkg and Z yields
- Dominant sources are JES, JMS, b-tag and PDF

Systematic Uncertainties	Resolved selection yield impact [%] total bkg.	Resolved selection yield impact [%] Z'	Boosted selection yield impact [%] total bkg.	Boosted selection yield impact [%] Z'
Luminosity	2.9	4	3.3	4
PDF	2.9	5	6	2.9
ISR/FSR	0.2	–	0.7	–
Parton shower and fragm.	5	–	4	–
$t\bar{t}$ normalization	8	–	9	–
$t\bar{t}$ EW virtual correction	2.2	–	4	–
$t\bar{t}$ Generator	1.5	–	1.6	–
W+jets $b\bar{b}$+$c\bar{c}$+c vs. light	0.8	–	1.0	–
W+jets $b\bar{b}$ variation	0.2	–	0.4	–
W+jets c variation	1.1	–	0.6	–
W+jets normalization	2.1	–	1.0	–
Multi-Jet norm, e+jets	0.6	–	0.3	–
Multi-Jet norm, μ+jets	1.8	–	0.3	–
JES, small-radius jets	6	2.2	0.7	0.5
JES+JMS, large-radius jets	0.3	4	17	3.3
Jet energy resolution	1.6	0.4	0.6	0.7
Jet vertex fraction	1.7	2.3	2.1	2.4
b-tag efficiency	4	1.8	3.4	6
c-tag efficiency	1.4	0.3	0.7	0.9
Mistag rate	0.7	0.3	0.7	0.1
Electron efficiency	1.0	1.1	1.0	1.0
Muon efficiency	1.5	1.5	1.6	1.6
All systematic uncertainties	14	9	22	9

CMS latest limits on $t\bar{t}$ resonances

Limits

arXiv: hep-ex:1309.2030



Phase space overlap between resolved and boosted semi-leptonic analysis

Transition point ≈ 1 TeV

Quote resolved result below and boosted result above 1 TeV

Model	Observed Limit	Expected Limit
$Z', \Gamma_{Z'}/M_{Z'} = 1.2\%$	2.1 TeV	2.1 TeV
$Z', \Gamma_{Z'}/M_{Z'} = 10\%$	2.7 TeV	2.6 TeV
RS KK gluon	2.5 TeV	2.4 TeV

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)

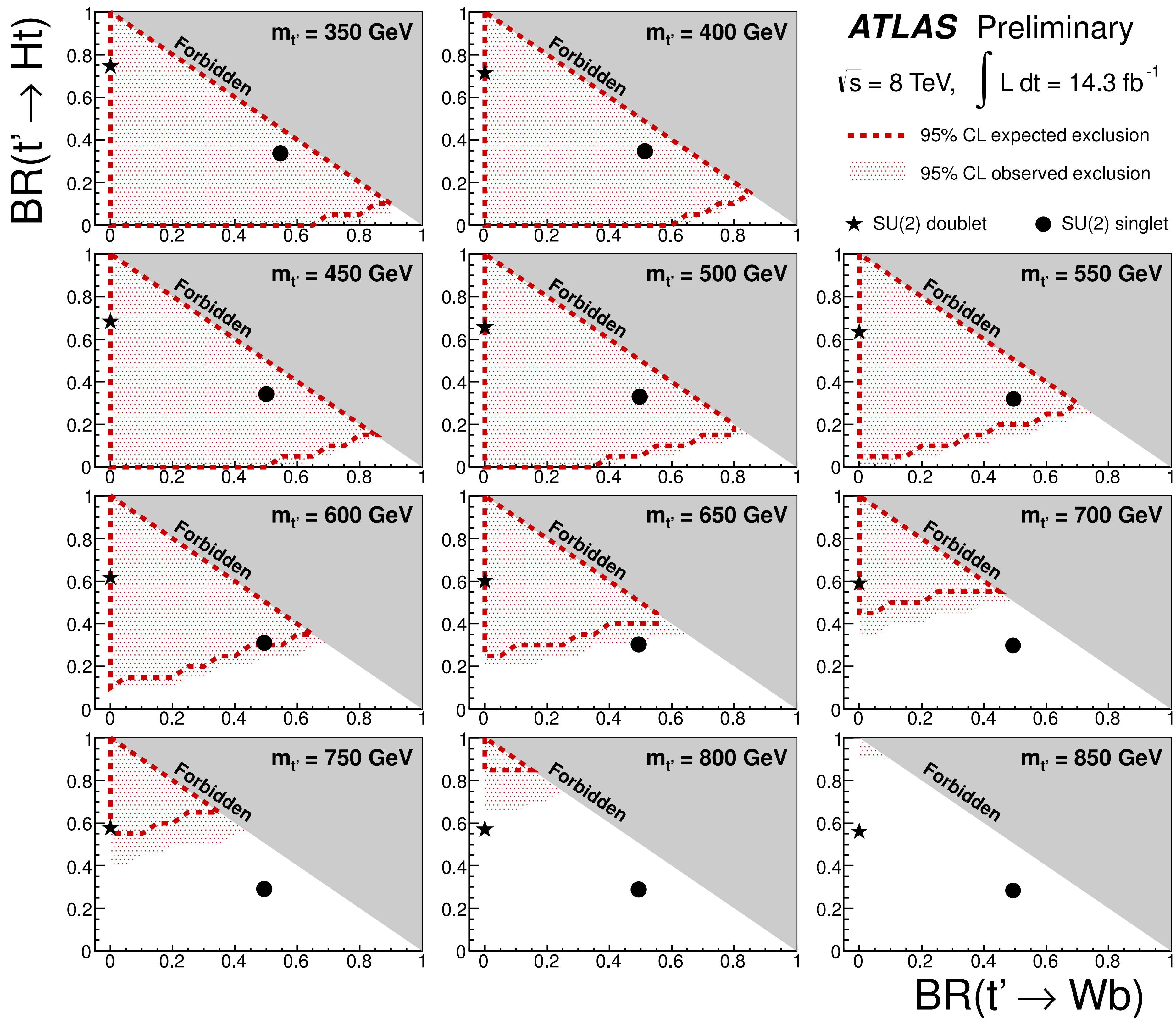
Limit for **$m_{t\bar{t}}$ > 1TeV**: **S < 1.2 at 95% CL** with credible interval of 1.1-2.0 at 68% CL

fully boosted hadronic search @ $\sqrt{s}$ = 8 TeV

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

ATLAS-CONF-2013-018

- Observed (red filled) and expected (red-dashed) explusion regions @95%CL for diferent t' masses
- Default BR from PROTOS are shown for singlet (circle) and doublet (star)
- grey is unphysical



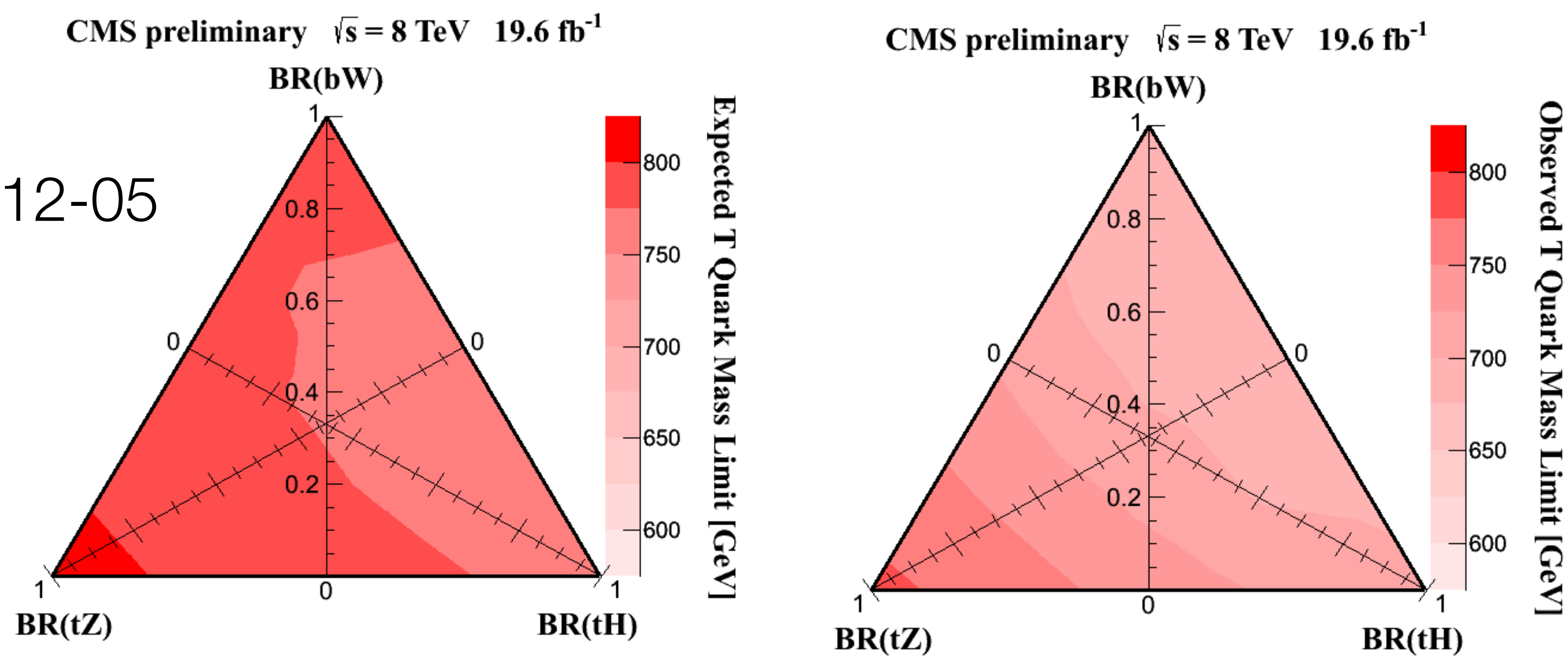
CMS latest limits on vector like quark T

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Limits on T' mass

Expected and observed limits on the T' quark mass for each possible branching ratio

CMS-PAS-B2G-12-05



Greatest sensitivity for T' → tZ decays
Lower limits on m(T'): between 687 and 782 GeV

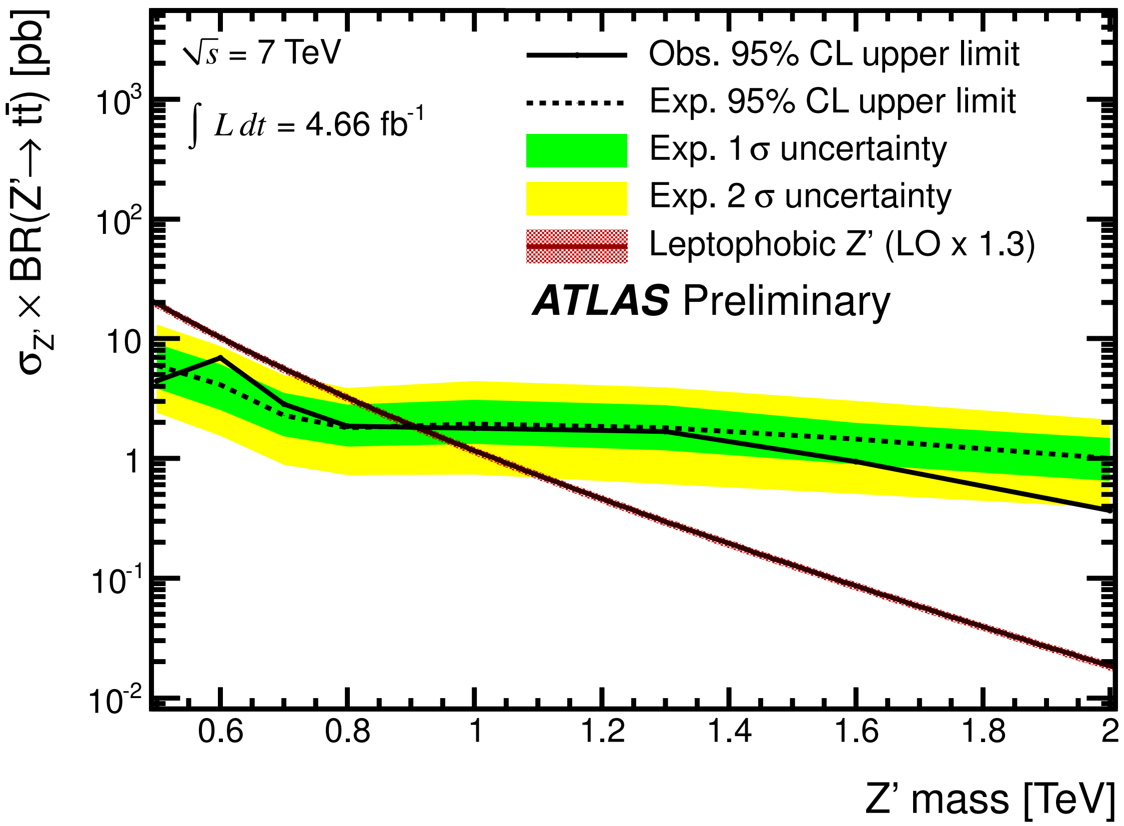
$T_{2/3}$ → tH, tZ, bW | CMS

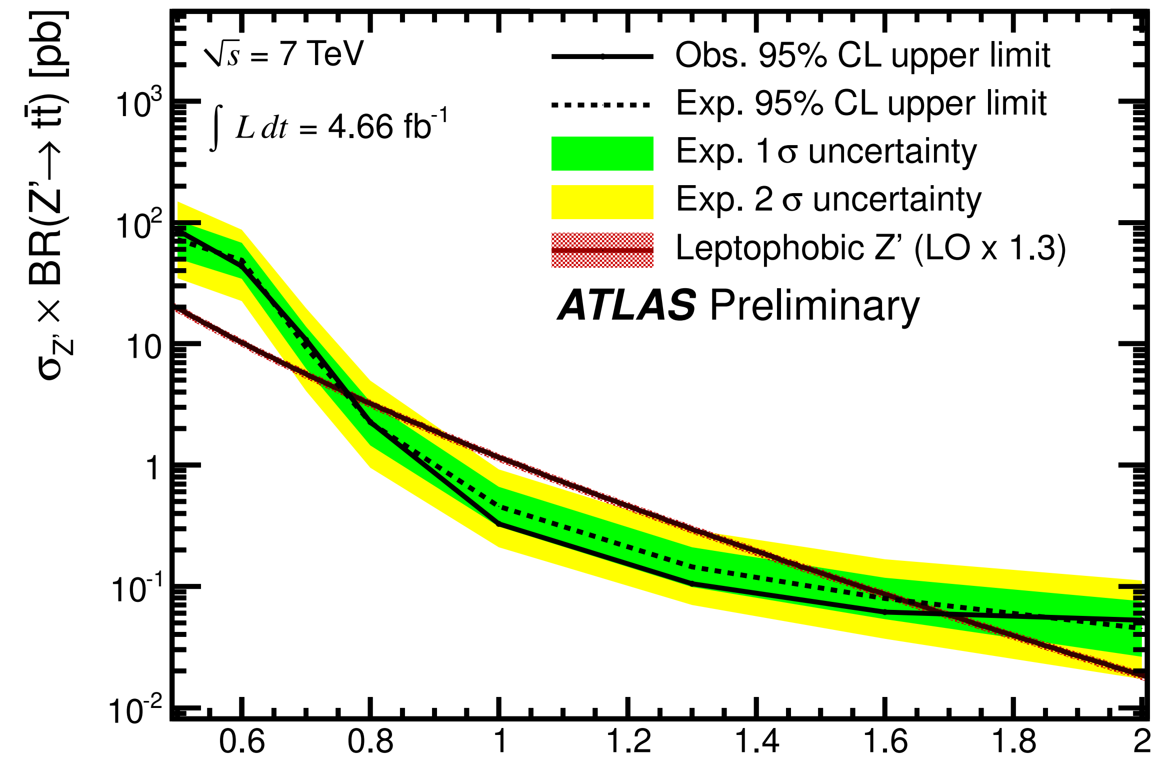
Rebekka Sophie Höing 30

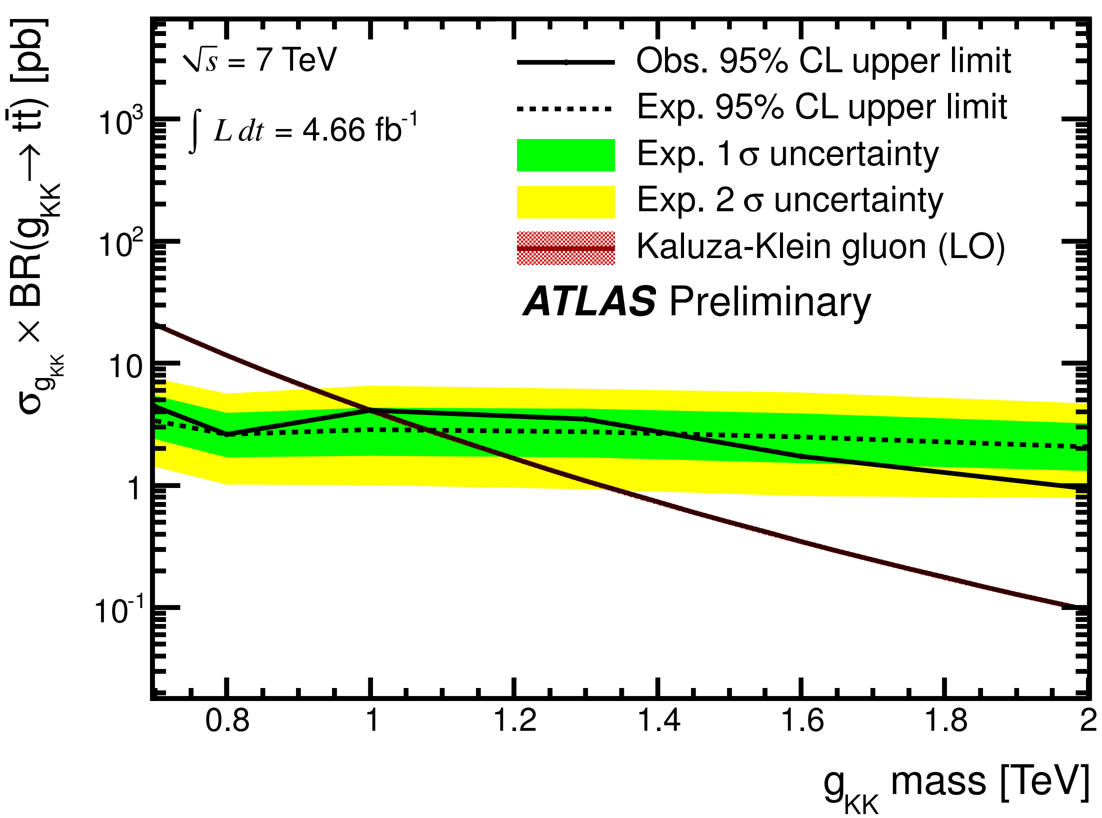
R. Hoing, TOP2013

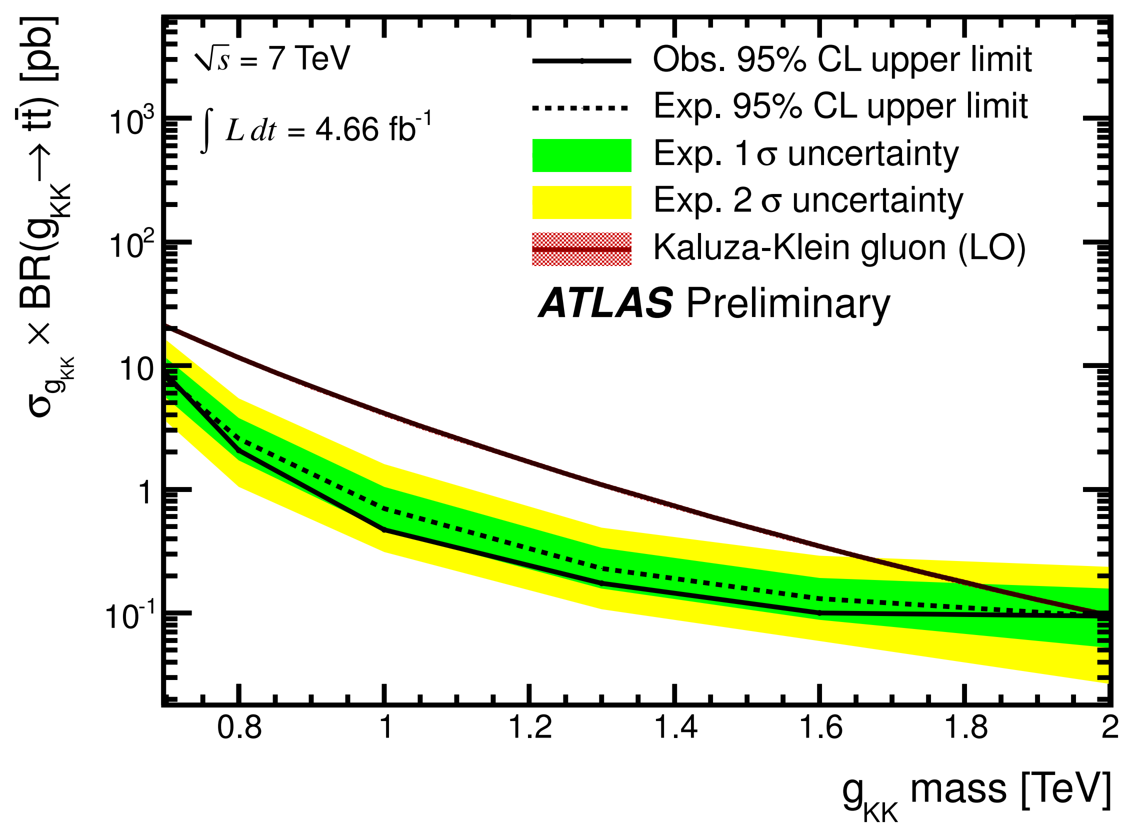
Going boosted extends reach!

Resolved ATLAS-CONF-2012-136 **Boosted**









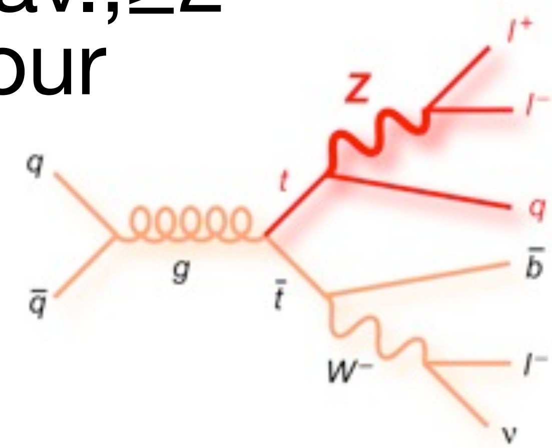
New physics in top decay

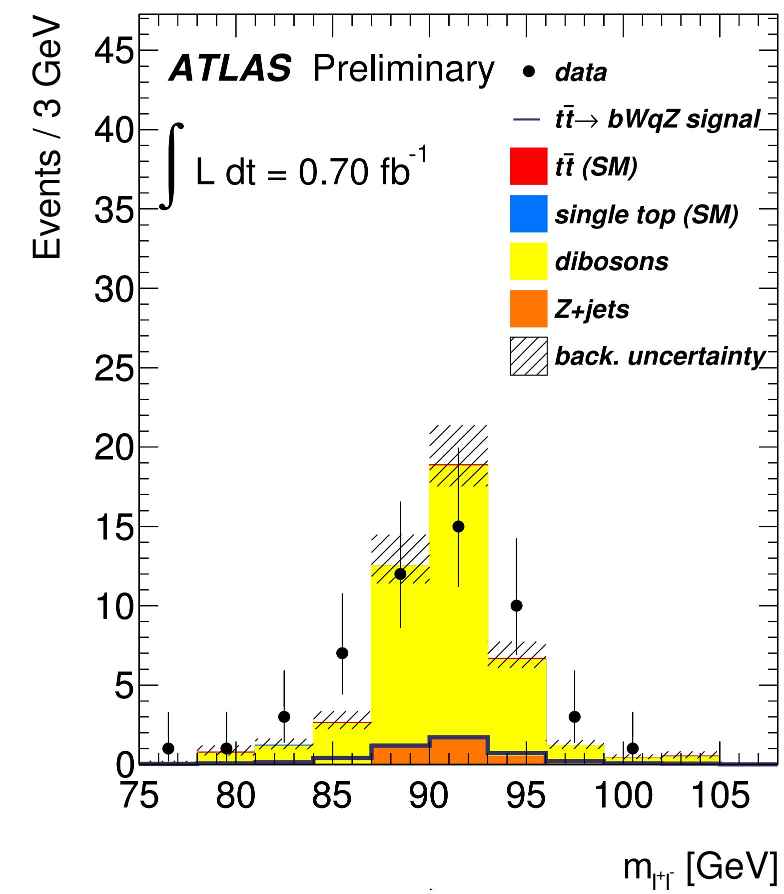
Search for Flavour Changing Neutral Currents in $t\bar{t}$

ATLAS-CONF-2011-154

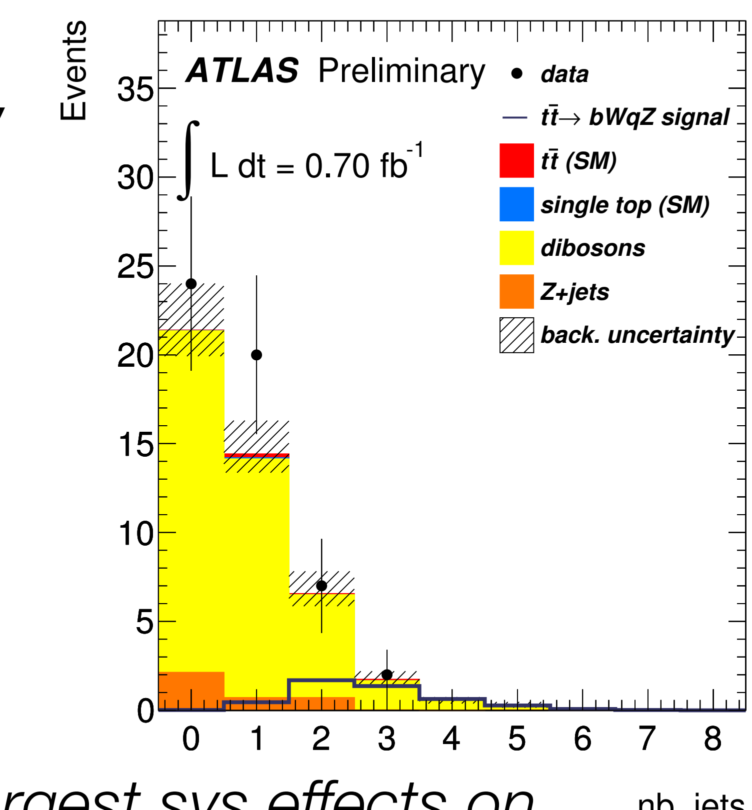
$\int Ldt =$ **0.7 fb^{-1}** *(2011)*

- **single lepton trigger, 3** isolated high p_T **leptons (e,μ)** *from same prim. vertex,* leading lep flav.= trigger flav.,≥2 opposite charge and same flavour
- $|M(\ell^+,\ell^-) - M_Z| < 15$ GeV
- ≥2 jets: *(sub) leading with* p_T *>20 (30) GeV*, large E_T^{miss} *>20 GeV.*





- **Bkg: dominant di-boson from simul.***(WZ,ZZ).* **Data-driven fake lepton (jets) bkgs: 1** *(WW & di-lepton tt from sim., Z+jets from Z-control region)*, **2** *(W +jets and single top)* **and 3** *(QCD and tt) extrapol. from 3 same-sign lep sample*. *Negligible 1fake+$\ell^+\ell^-$*



- **Reconstruct tt→ WbZb with min Least Square** *(m_{top},m_W,m_Z constraint) → $|m_W^{rec}-m_W|$ <30 GeV & $|m_{top}^{rec} - m_{top}|$<40 GeV* → **No excess found→ frequentist 95%CL on BR(t→qZ) =1.1% (exp 1.3%)** *including syst*

largest sys effects on yield:JES,mu trigger, el id

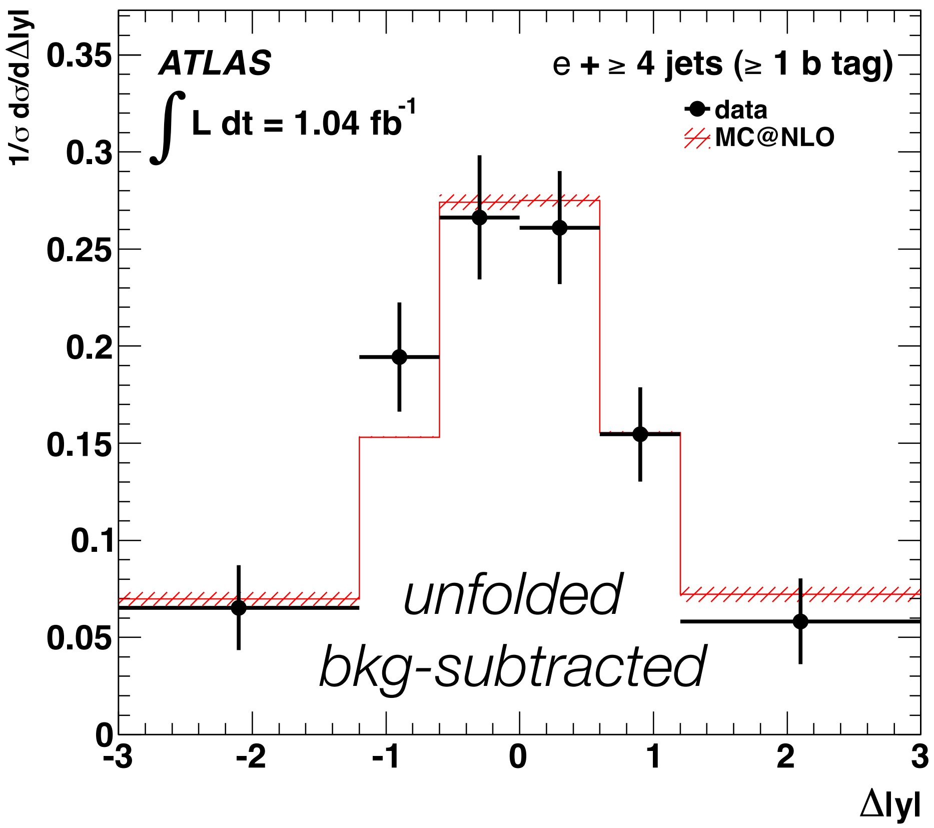
Charged Higgs searches in ATLAS

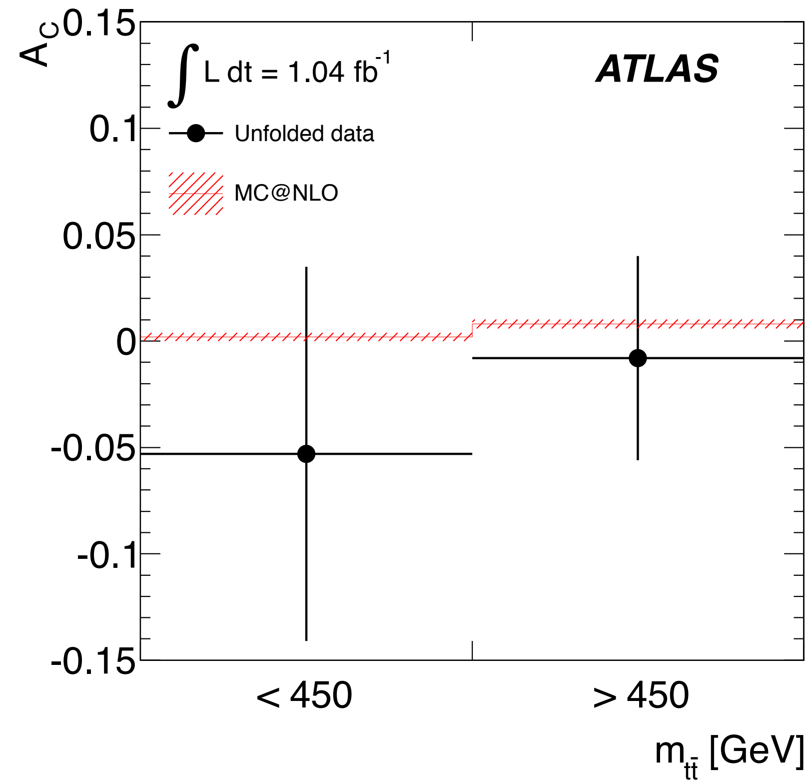
papers

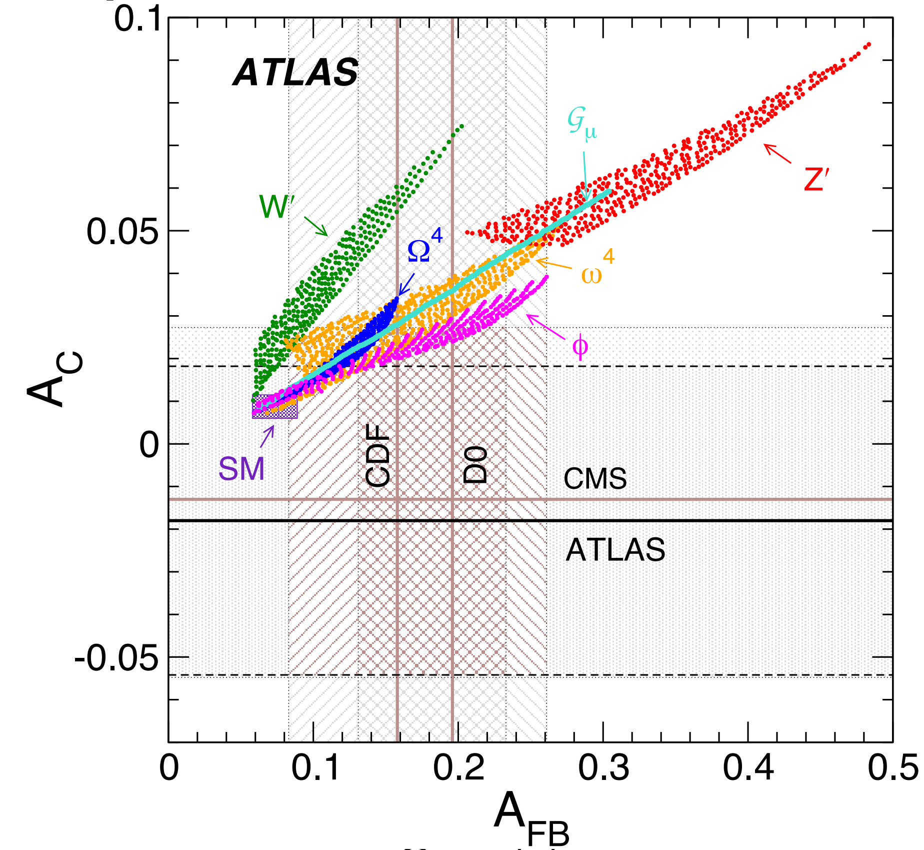
- The European Physical Journal C December 2012, 72:2244, Doubly charged higgs in like-sign dilepton, 4.7/fb
- Journal of High Energy Physics March 2013, 2013:76, lepton universality violation 4/.6/fb
- The European Physical Journal C June 2013, 73:2465, light charged higgs to decaying to cs 4.7/fb

Measure top quarks charge asymmetry

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



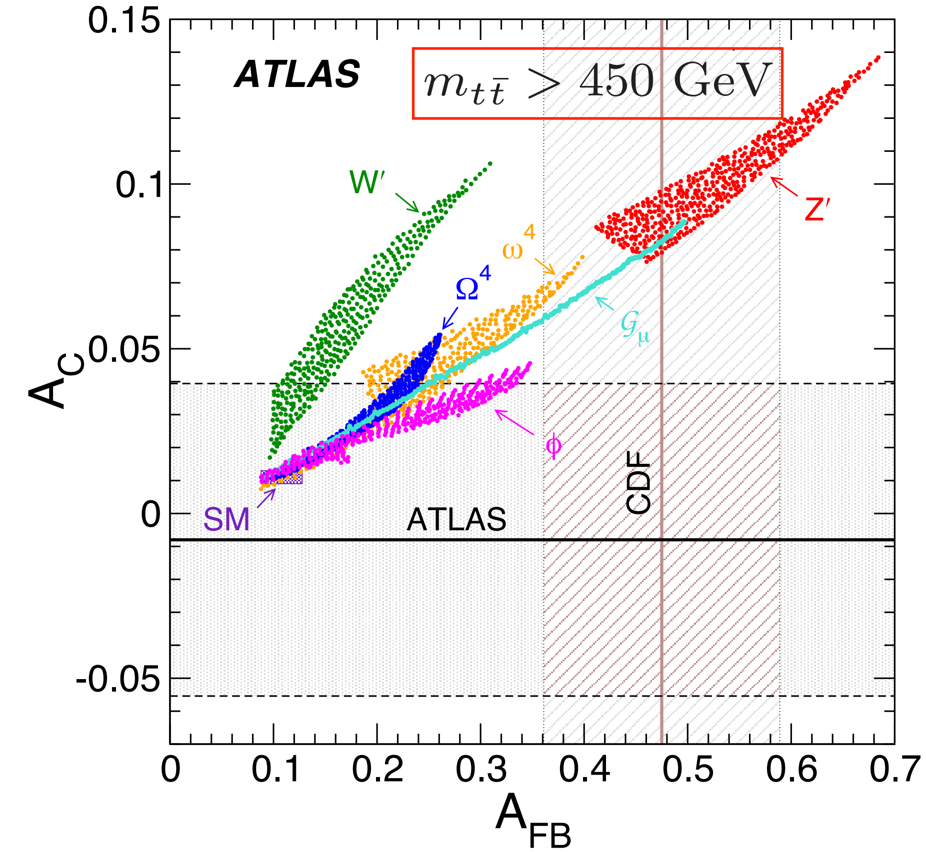




G : axigluon

ϕ*: scalar Higgs-like doublet*

Ω⁴,ω²: charge 4/3 scalar



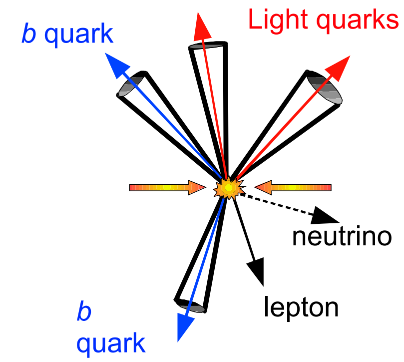
Eur.Phys.J. C72 (2012) 2039

- **Unfold** 2d (dN/dΔ|Y| , $M_{t\bar{t}}$) for det effects *(iterative bayesian)* → **derive A_C vs $M_{t\bar{t}}$**
- **Disfavours flavour changing Z'** *(uu →Z'→tt̄) with rh coupling to us* **and W'** ***with rh coupling to d*** *(dd → W' → tt̄)*

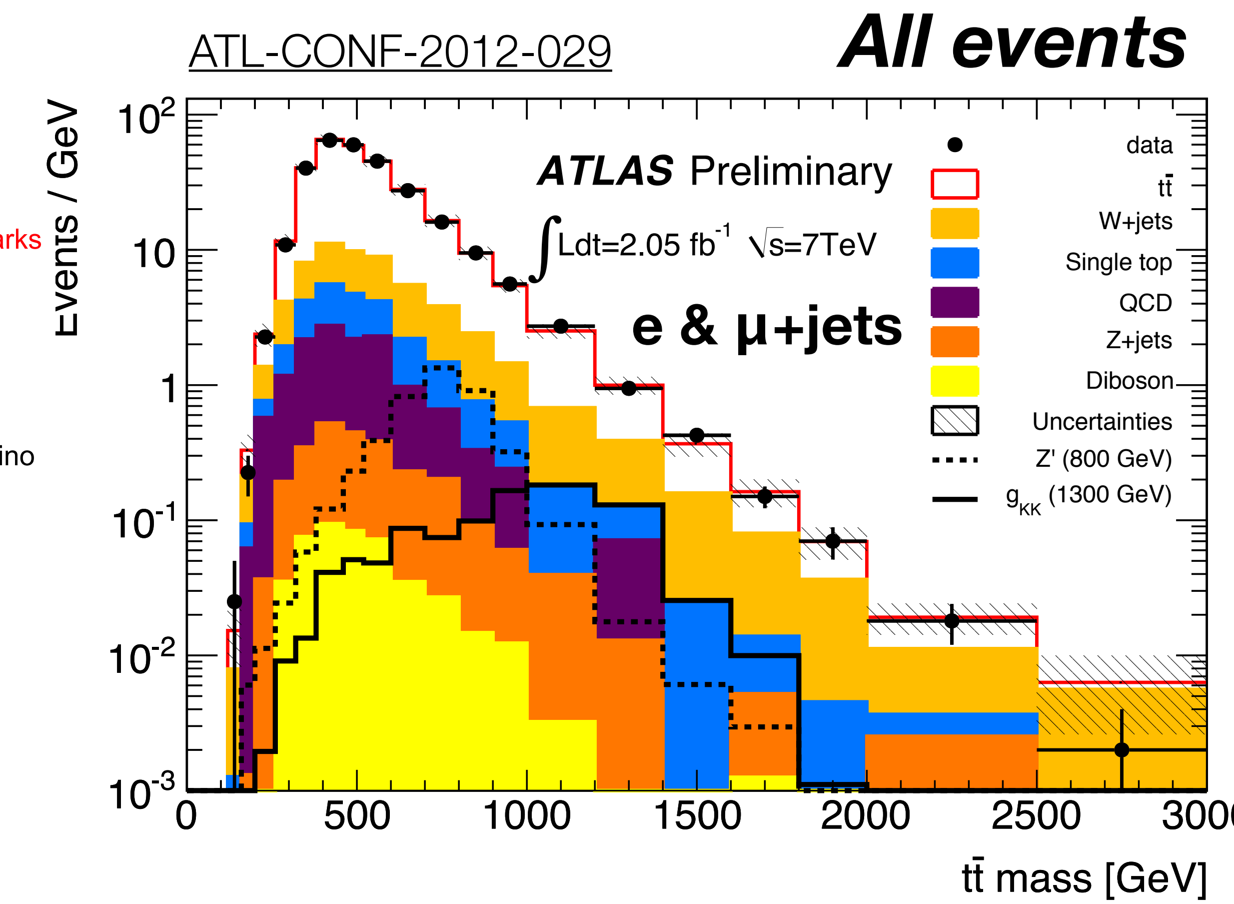
Search for excess in $t\bar{t}$ production vs $M_{t\bar{t}}$ - single-lepton

$\int Ldt$ = **2.05 fb^{-1}** *(2011)*

qqℓ**vbb**

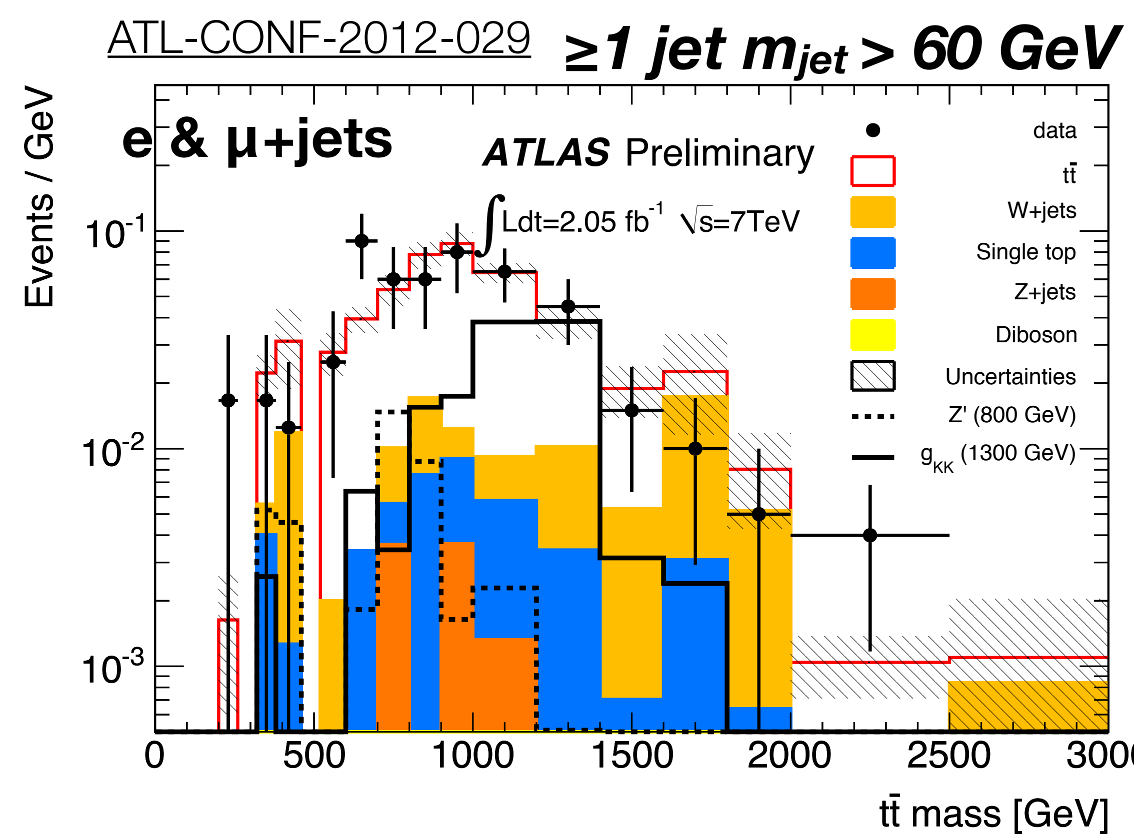


- **A: standard single lep** (e μ)
  sel: ≥4 jets, ≥1 b-tag



- Data-driven **QCD** (*jet template method normalized to low E_T^{miss}*) **W +jets normalization** (*normalization scaling from charge asymmetry of W production)*

- **Reconstruct leptonic W** *from E_T^{miss}, lepton & W mass*, **then M_{tt}**
  - ***sum leptonic W to***
    - ***if ≥1 jet m_{jet} > 60 GeV : high mass jet + closest Dr jet***
    - ***else 4 or 3 leading p_T jets****, exclude too close (in DR (m_{jet})) jets to lepton/other jets. Iterate until 4 or 3 jets remain.*

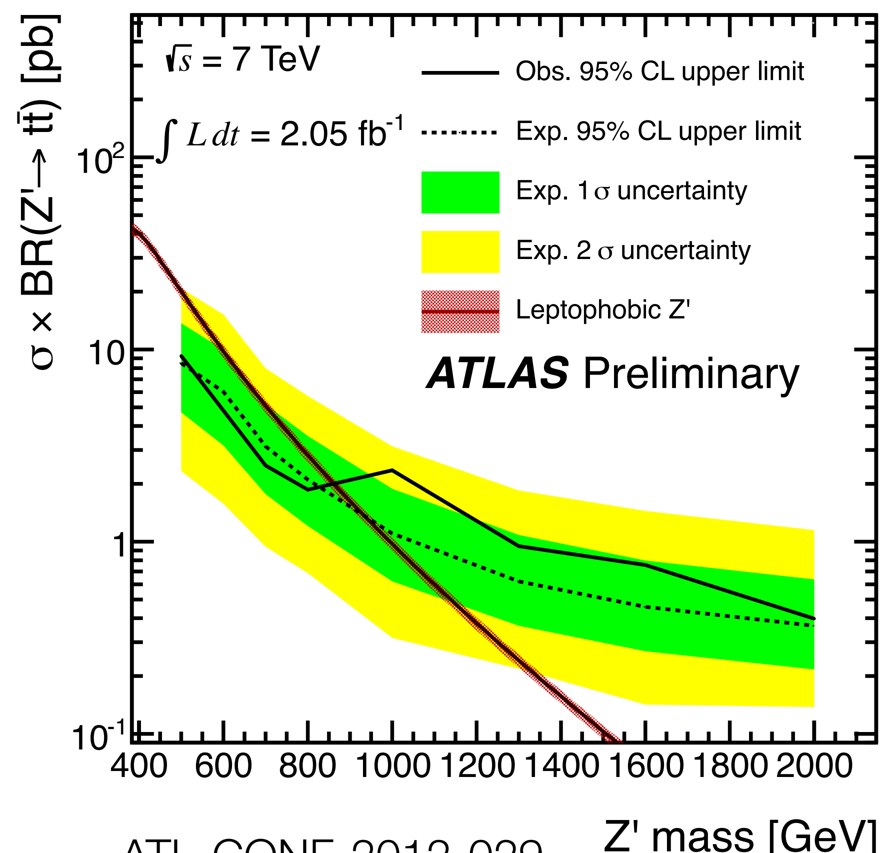


Search for excess in $t\bar{t}$ production vs $M_{t\bar{t}}$ -single lepton

- No excess found → **95% Bayesian credible interval for Z' & RS KKGluon σ*BR, including systematics** *as averaged(A) nuisance pars.*

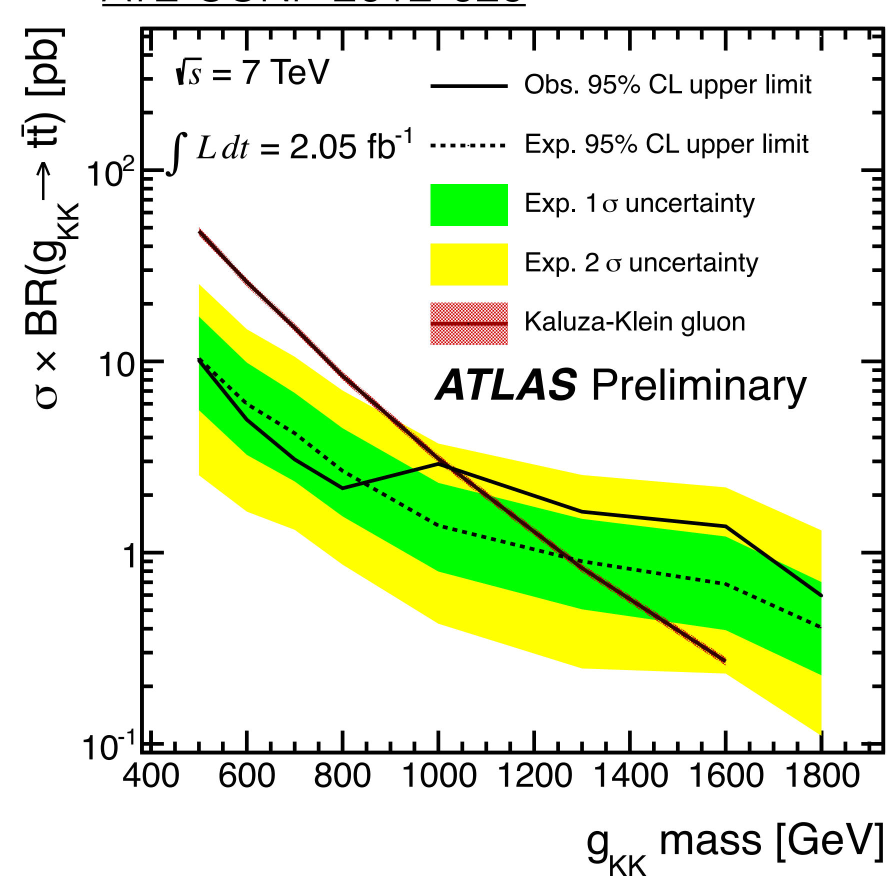
- Upper observed (expected) limit at **95% prob on topcolour Z' σ*BR (with $\Gamma_{Z'}/m_Z$ ~ 1%)**
  - **9.3 pb** *for $m_{Z'}$=500 GeV* **to 0.95 pb** *for $m_{Z'}$=1.3 TeV*
  - *Z' with* **500 GeV <$m_{Z'}$ <860 GeV are excluded at 95% prob**

ATL-CONF-2012-029



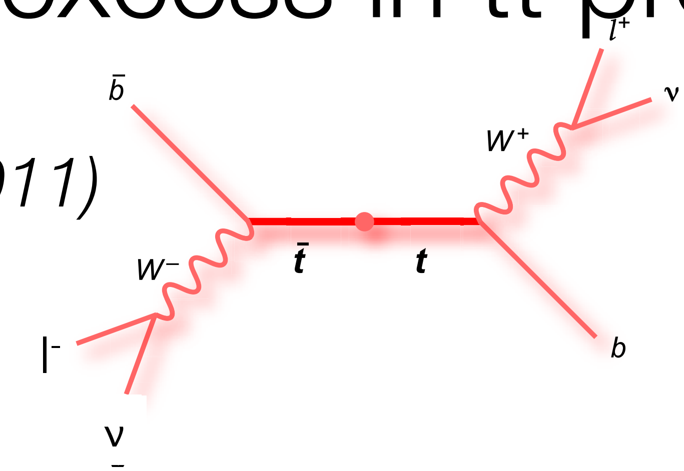
- Upper observed (expected) limit at **95% prob on KKGluon σ*BR**
  - **11.6 pb** *for* **$m_{kkG'}$**=*500 GeV* **to 1.6 pb** *for* **$m_{kkG'}$**=*1.3 TeV*
  - KK Gluons with **500 GeV <m_{kkG} < 1020 GeV are excluded with 95%prob**

ATL-CONF-2012-029

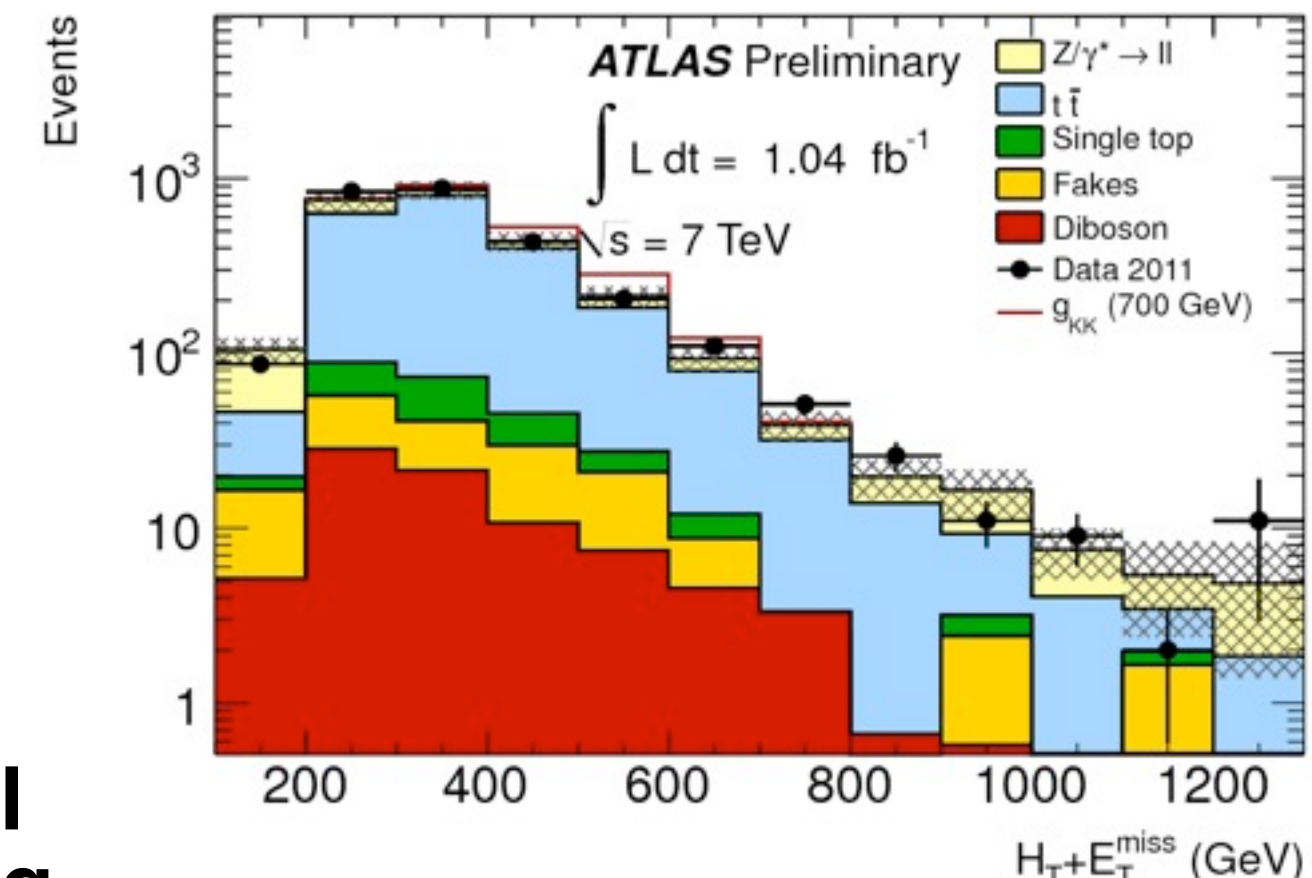


Search for excess in $t\bar{t}$ production - di-lepton

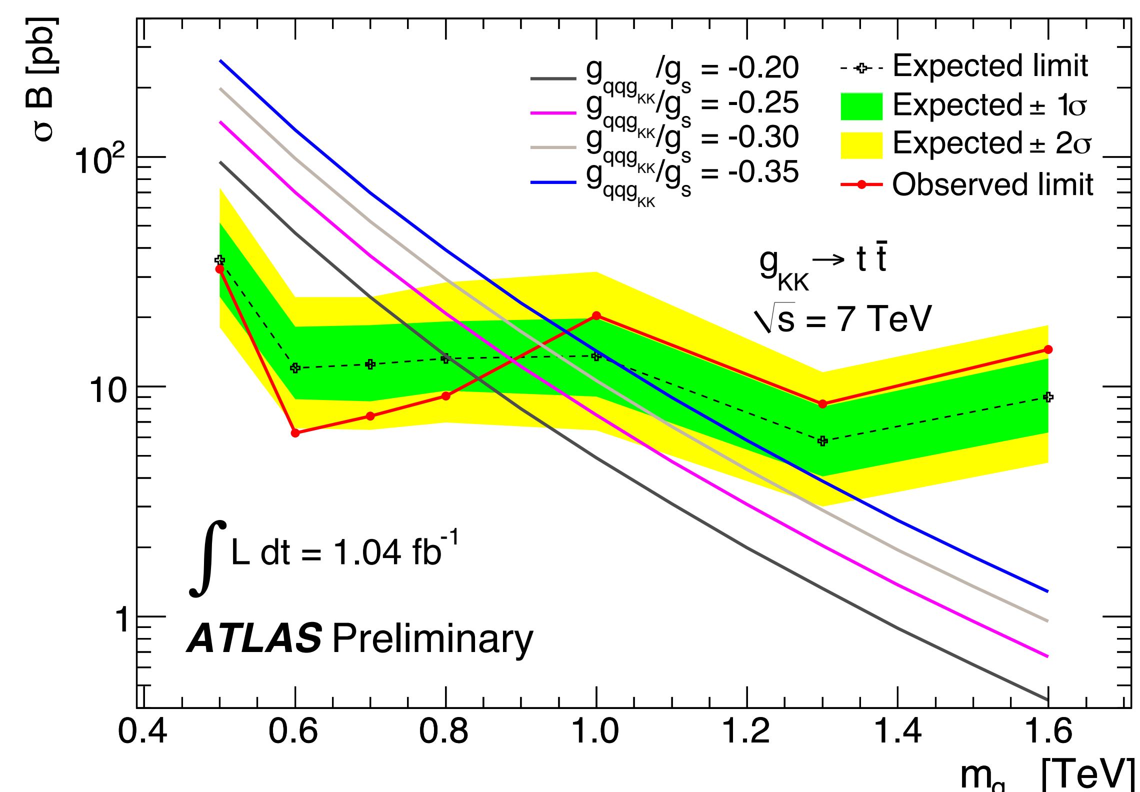
$\int L dt$ = **1.04 fb^{-1}** *(2011)*



ATLAS-CONF-2011-123



- **Standard**: **di-lepton selection** (e,μ) + **data-driven Z/γ*+jets** (*E_T^{miss}-dep Z-window*) and **QCD** bkg estimates
- No excess found in $H_T+E_T^{miss}$ → **95% Bayesian credible interval for RS KKGluon σ*BR including systematics** *as integrated nuisance pars.*
- **Exclude RS KKGluon with M_{KK} below 0.84 TeV** at 95% CL

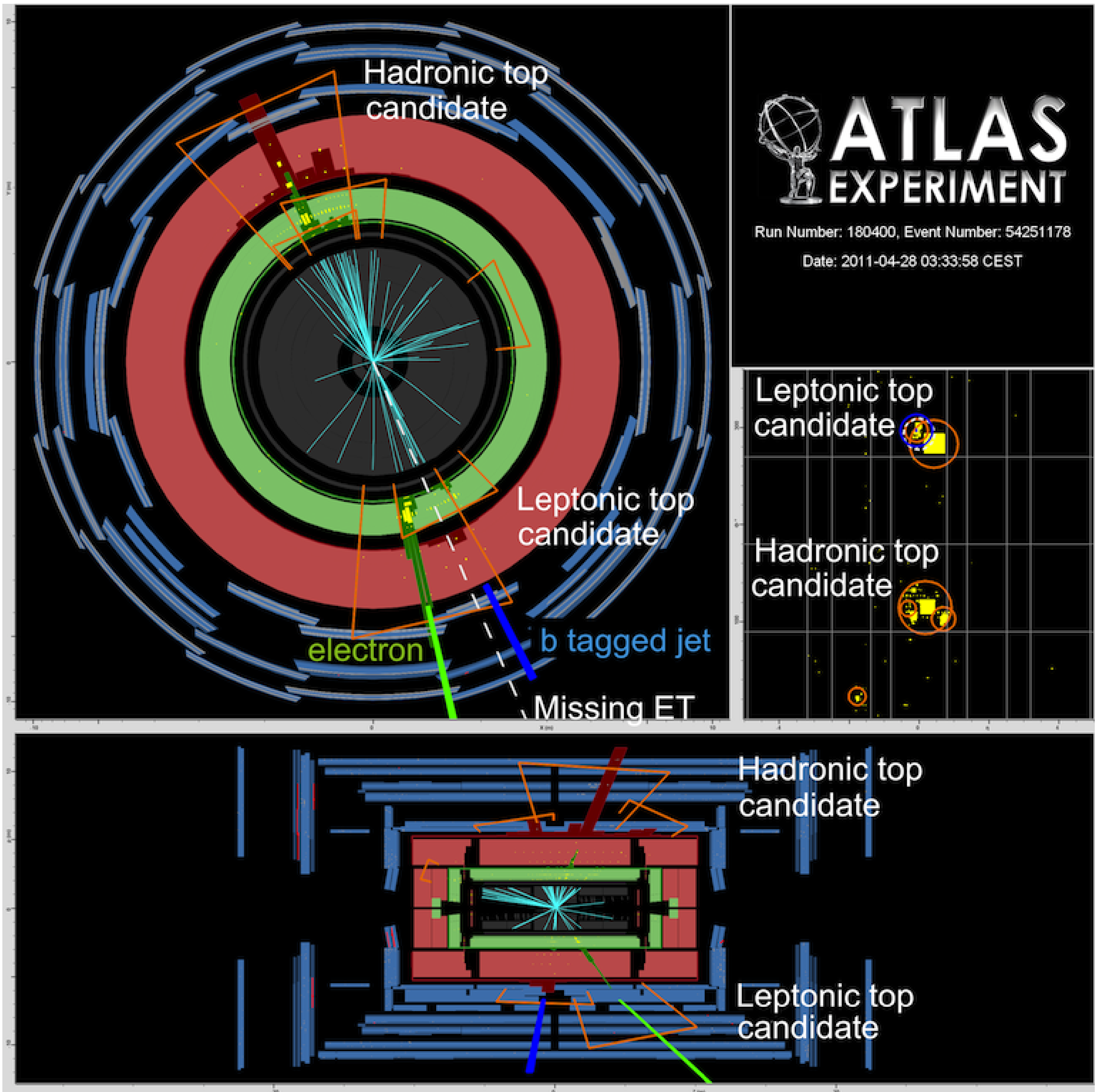


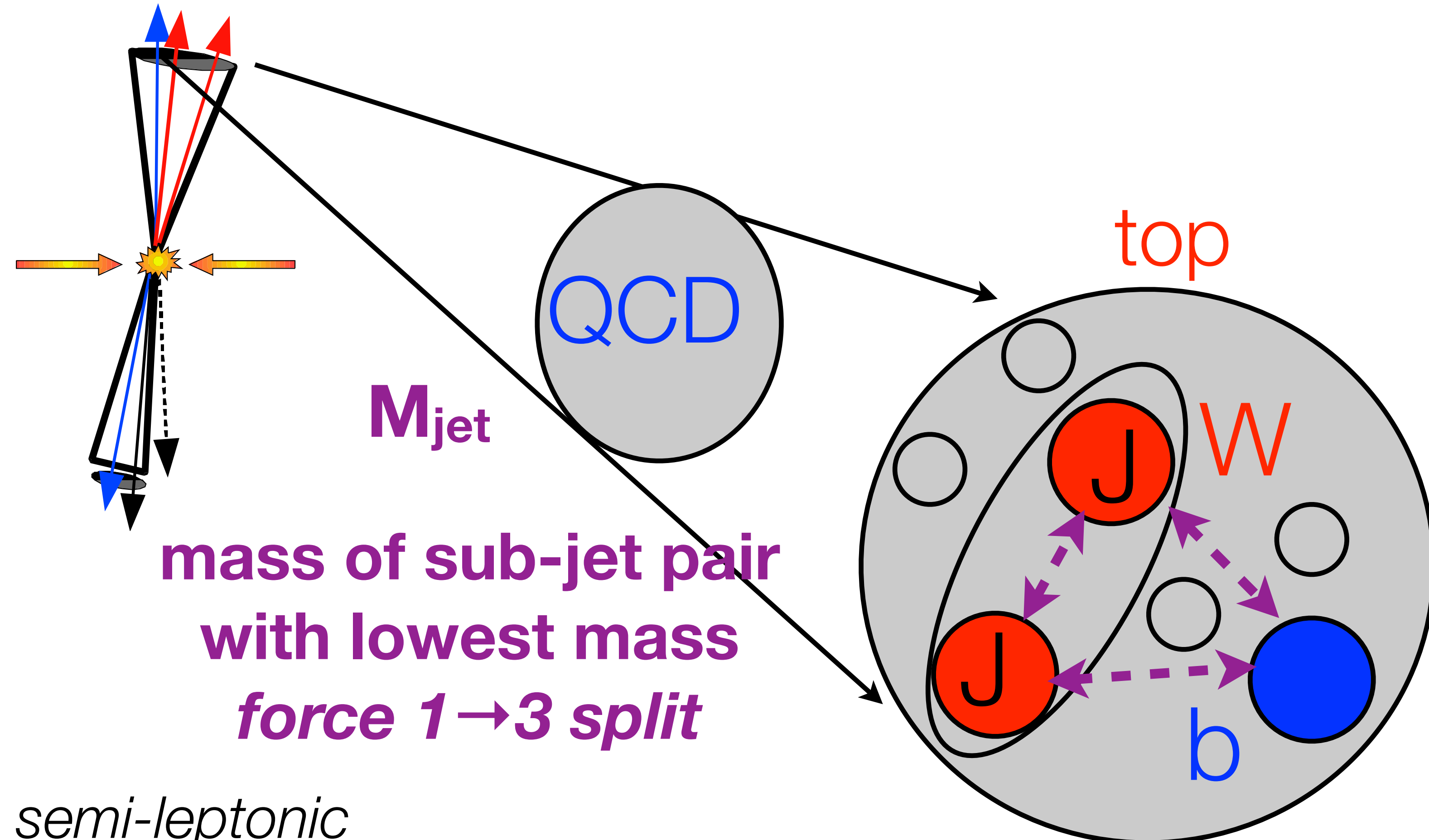
default →

	Mass Limit (TeV)	
$g_{qqg_{KK}}/g_s$	Expected	Observed
-0.20	0.80	0.84
-0.25	0.88	0.88
-0.30	0.95	0.92
-0.35	1.02	0.96

ATL-CONF-2011-087

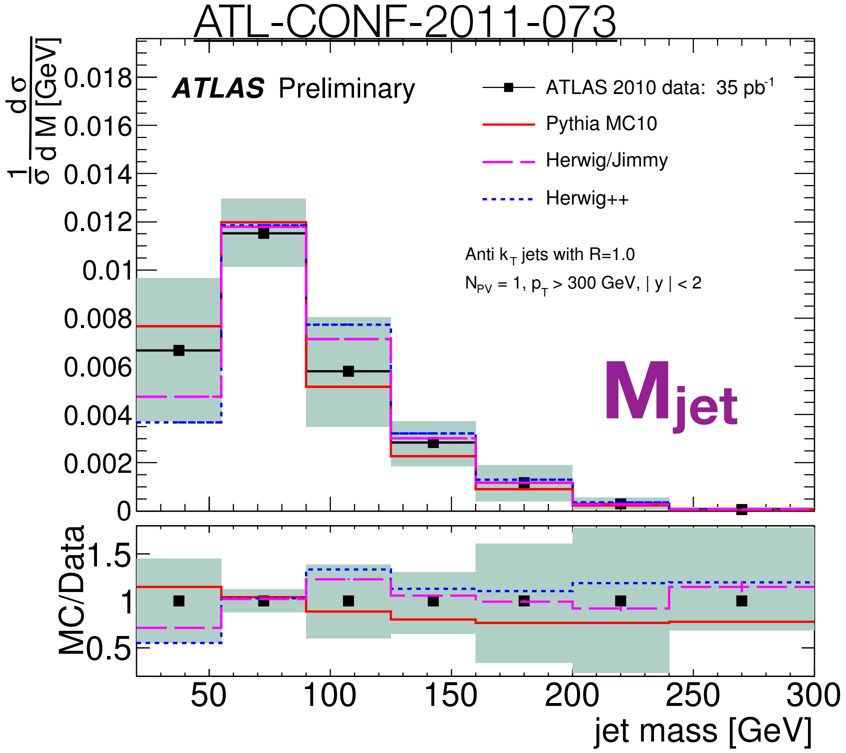
Going Boosted in ATLAS





semi-leptonic di-top-jet candidate

ATL-CONF-2011-073



Tag top jets
Understand substructure of large cone (fat) jets

measured for antik_T with R=1

ATL-CONF-2011-073