News From The LHC

Daniele del Re
Sapienza Università & INFN Sezione Roma

SAPIENZA
UNIVERSITÀ DI ROMA

OPEN QUESTIONS IN SM

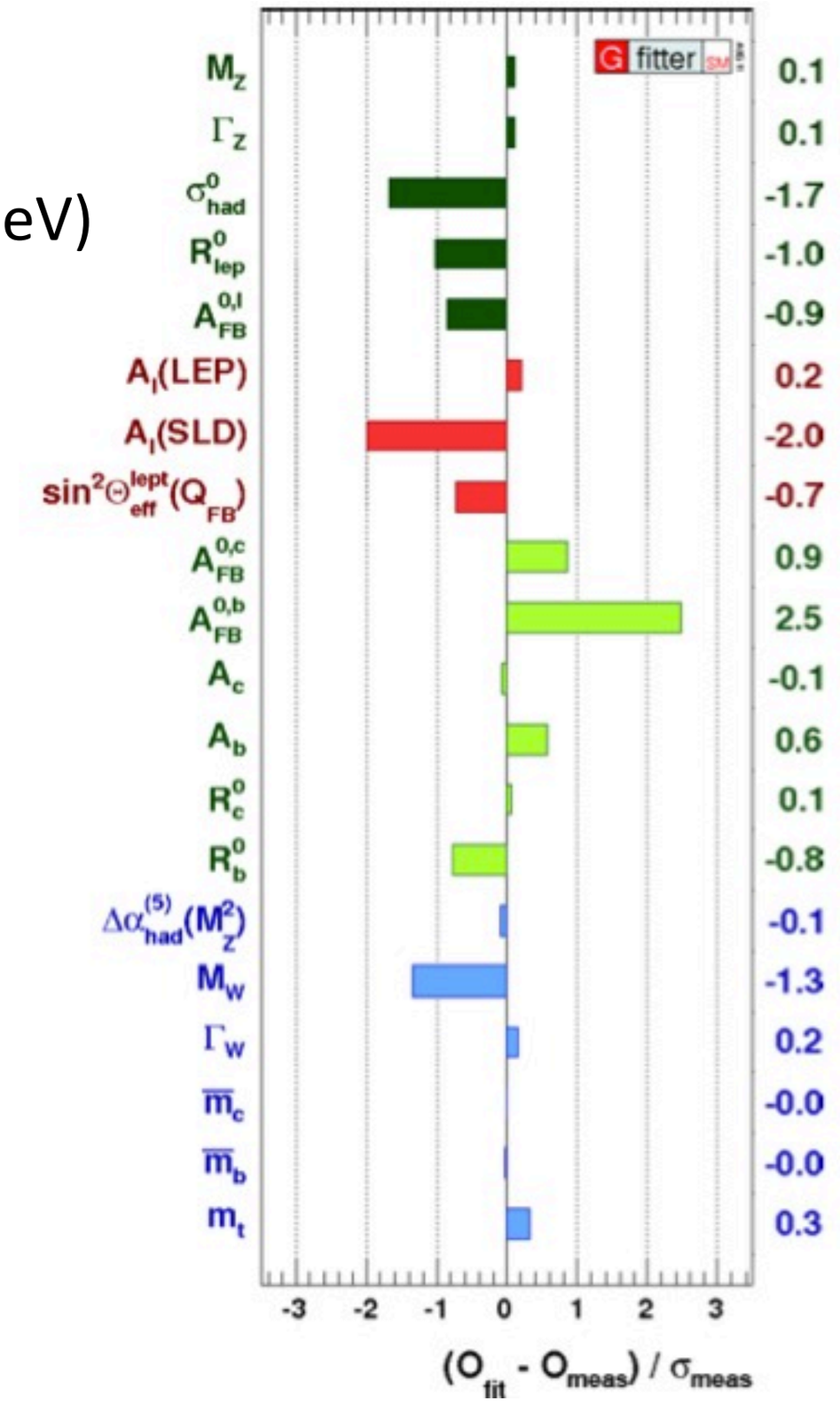
Main open questions in Particle Physics:

- Hierarchy problem: small Higgs mass vs large Planck Mass
- Does Higgs boson exist?
- Origin of Dark Matter
- Flavor puzzle: flavor parameter small and hierarchical
- Neutrino masses
- …

LHC will give an answer to many of those

MULTIPLE WAYS TO CROSSCHECK SM @ LHC

- **search for the Higgs**
  - in the whole mass range O(100GeV÷600GeV)
- **measure SM parameters**
  - e.g. forward-backward asymm., m_t
- **look for deviations in EWK processes**
  - e.g. anomalous triple gauge couplings
- **check for processes beyond SM**
  - e.g. SUSY with missing E_T
- **search for new resonances**
  - e.g. Z′ at large masses

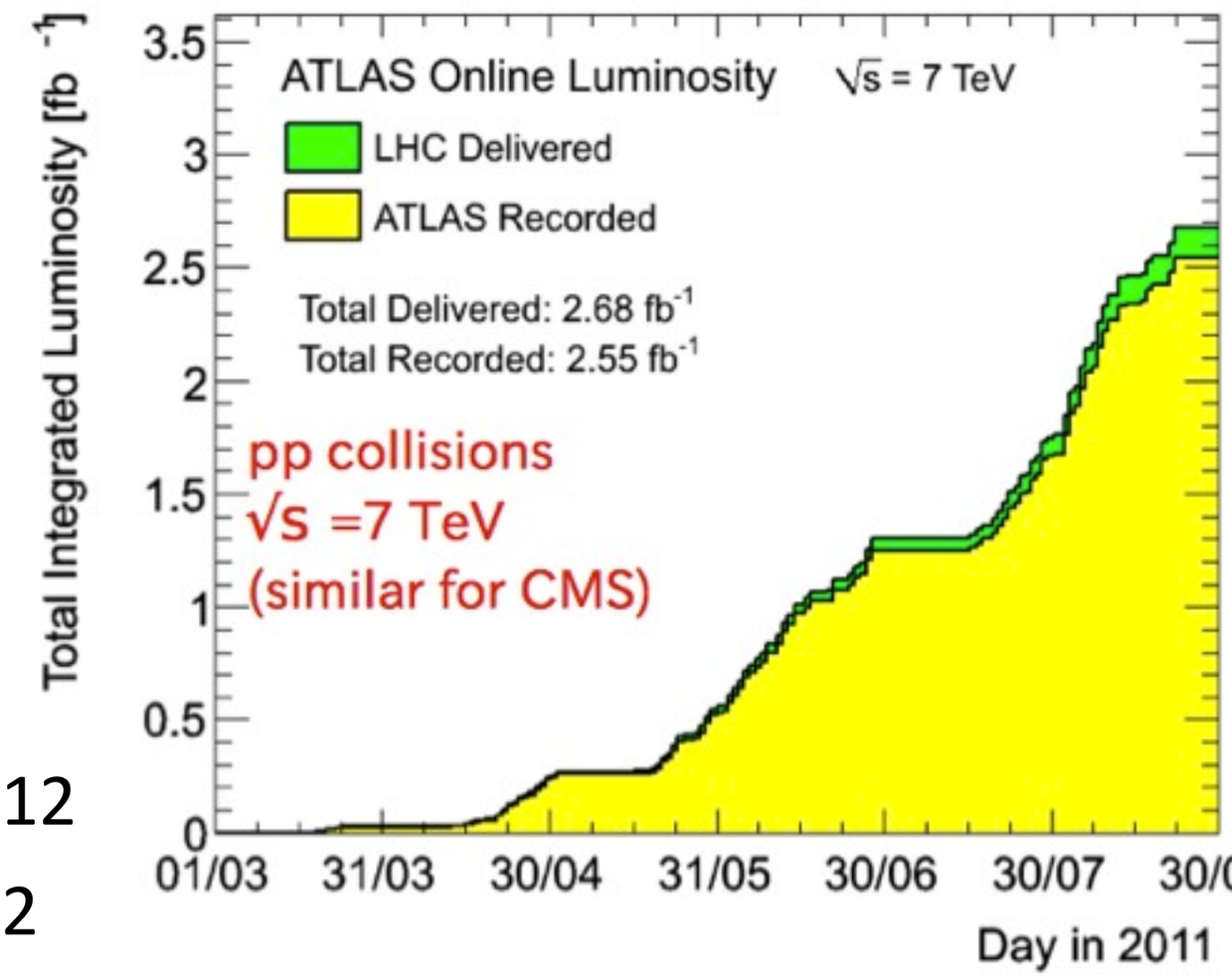


OUTLINE OF THE TALK

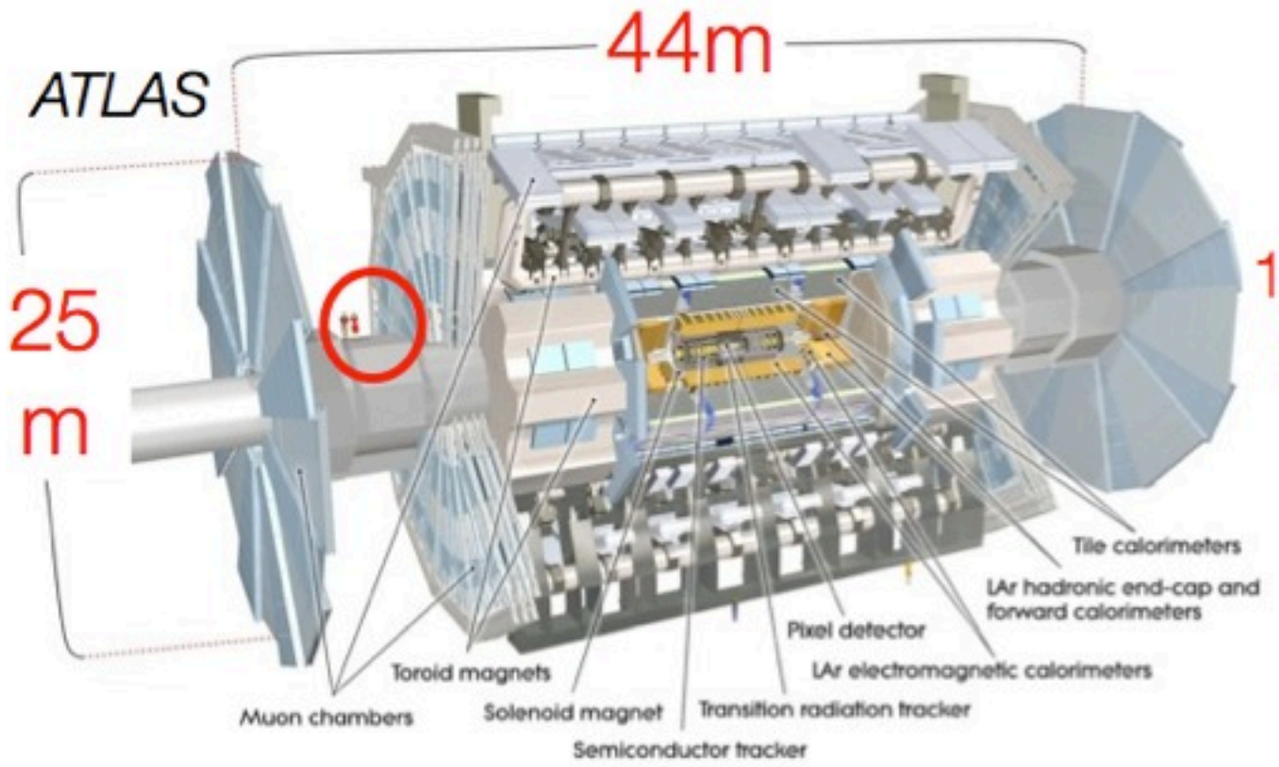
- focus on the **EWK physics results**
  - W/Z
  - Top
  - Higgs
- some flavor of **searches** of physics **beyond SM**
- **DISCLAIMER:**
  - ATLAS/CMS oriented talk
  - small fraction of physics results detailed
- **complete list** of physics output here:
  - **ATLAS**: https://twiki.cern.ch/twiki/bin/view/AtlasPublic
  - **CMS**: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

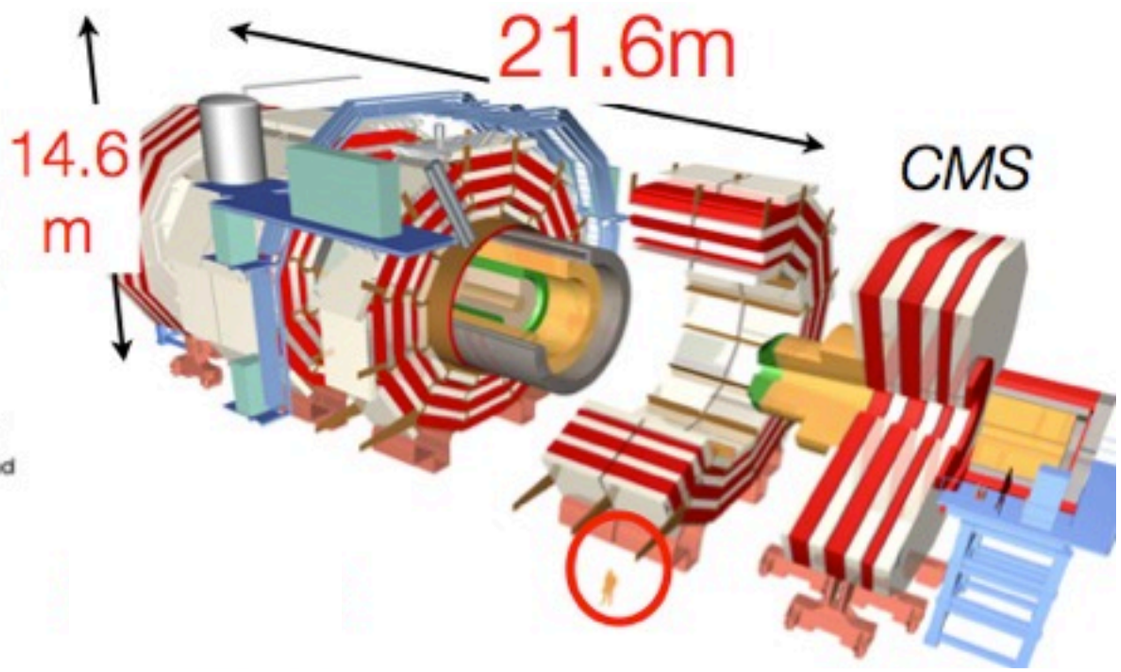
LHC AND INTEGRATED LUMINOSITY

- **pp collisions at 7TeV**
- **great performance, beyond expectations**
  - luminosity peak ~2.2 10^{33} $cm^{-2}s^{-1}$
  - ~80 pb^{-1}/day
  - 50 ns bunch spacing
- **~2.7 fb^{-1} delivered so far**
- **<6-7 collisions> per crossing**
- **Future**:
  - **fast increase** in luminosity
  - O(5-10 fb^{-1}) expected for Moriond12
  - O(30 fb^{-1}) expected for end of 2012



DETECTORS





	ATLAS	CMS
Magnetic Field	solenoid (2 T) + toroid (0.5÷1T)	3.8 T solenoid + return yoke
Tracker	Si pixel, strips + TRT	Si pixel, strips
EM Calorimeter	Pb + LAr	PbWO4 crystals
Had Calorimeter	Fe+scint./Cu+LAr/W+Lar (≥11λ)	Brass+scintillator(≥7λ)/Fe+quartz
Muon	air-toroid muon spectrom.	iron return-yoke muon spectrom.
Trigger	L1+RoI-based HLT	L1+HLT

RECONSTRUCTED OBJECTS: SUMMARY

electrons

- track/calo-cluster match
- isolation to reject jets
- **scale known to 0.3%-1.5%**

muons

- match between tracker and muon detector
- isolation to reject jets
- **scale known to better than 1.0%**

photons

- calo-only+conversions (with tracker)
- isolation to reject jets
- **scale known to better than 1.0% (CMS)**

jets

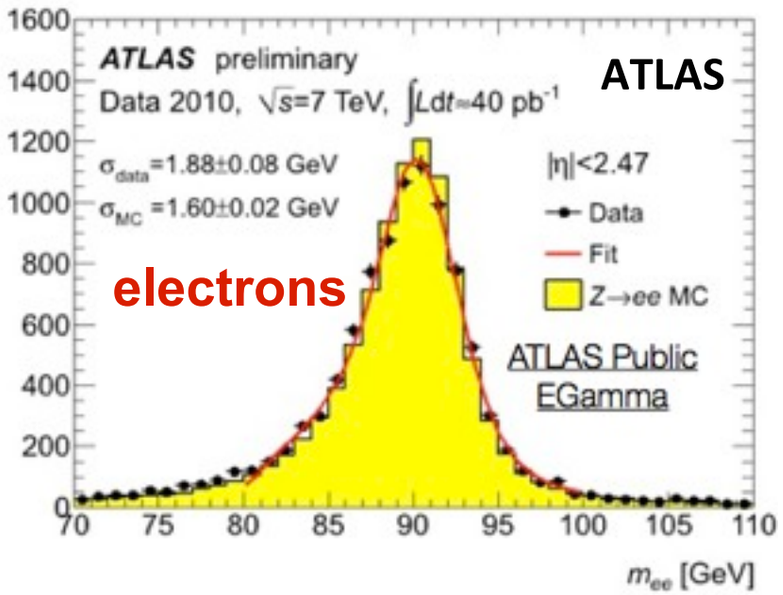
- reconstructed with calorimetric deposits, with tracks or with the whole detector information
- anti-Kt algorithm
- ΔR cone 0.4-0.5
- **scale known to 2%-8% (p_T and η dep.)**

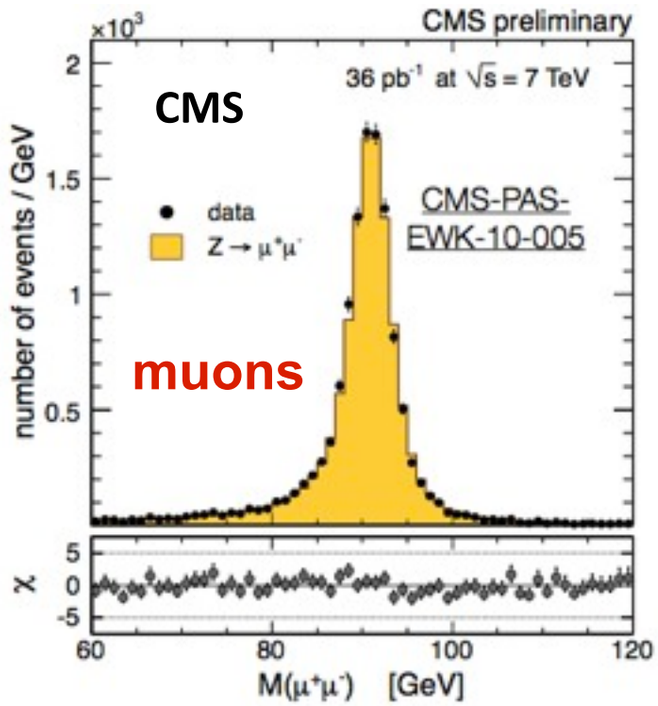
MET

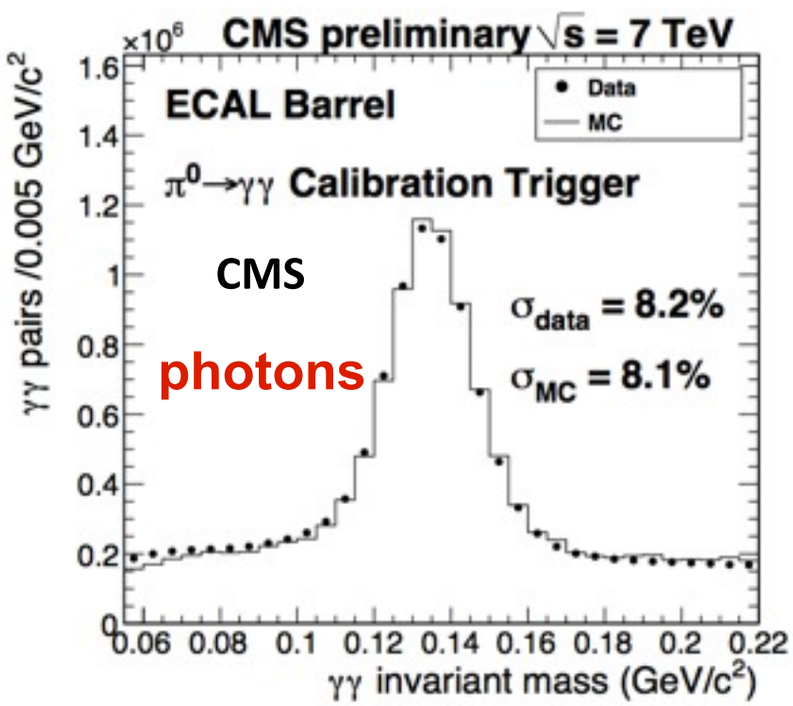
- negative vector sum of
  - -calorimetric objects
  - -(or) tracks
  - -(or) all objects from whole detectors
- projected on the transverse plane
- cleaning to remove detector noise

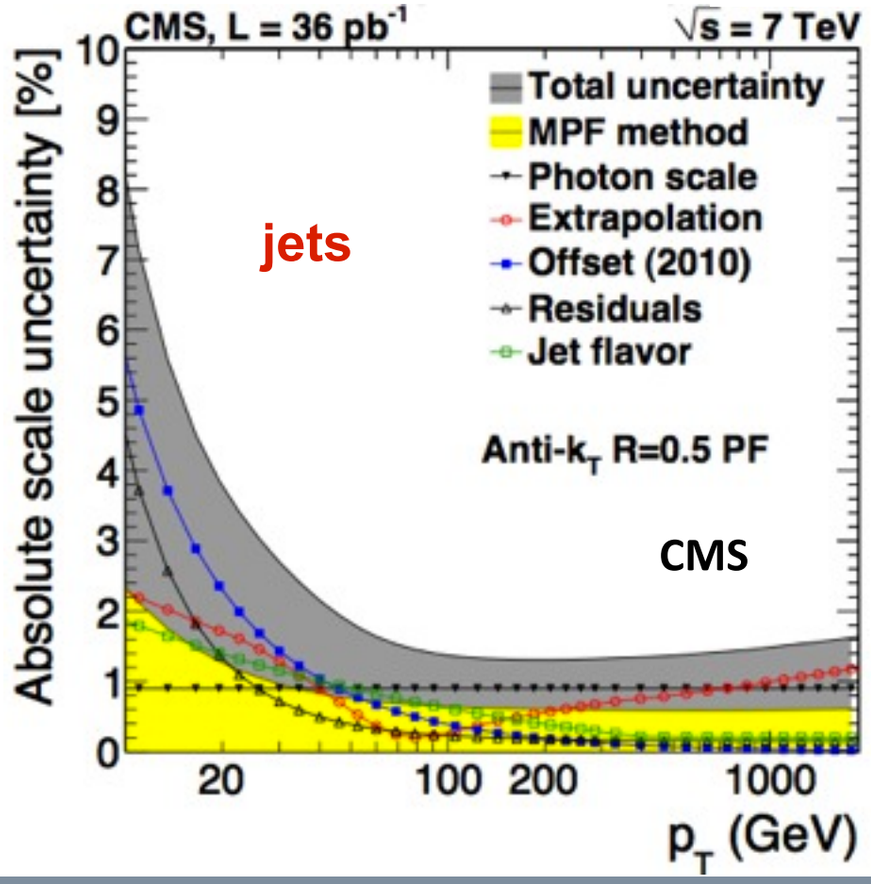
Fantastic detector performance, already close to design

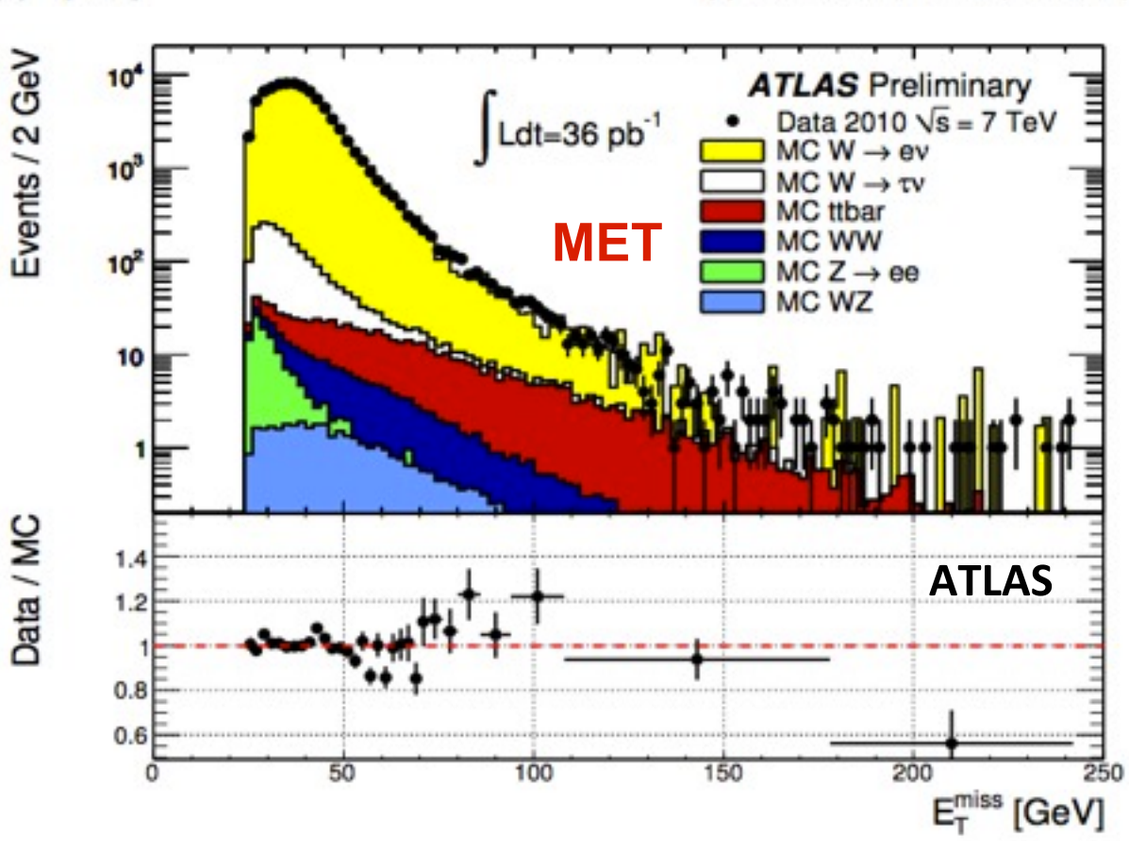
RECONSTRUCTED OBJECTS: CALIBRATION



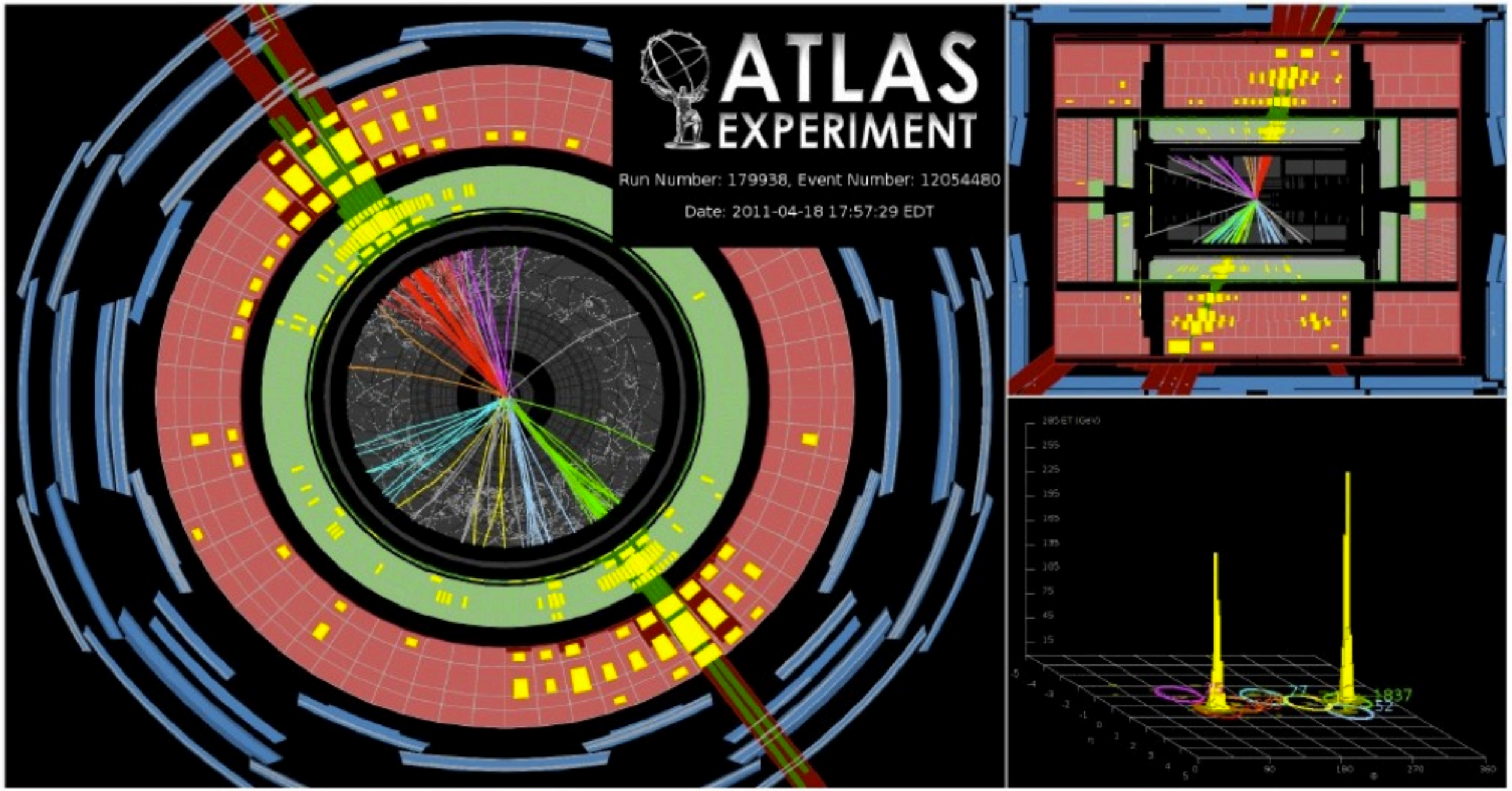






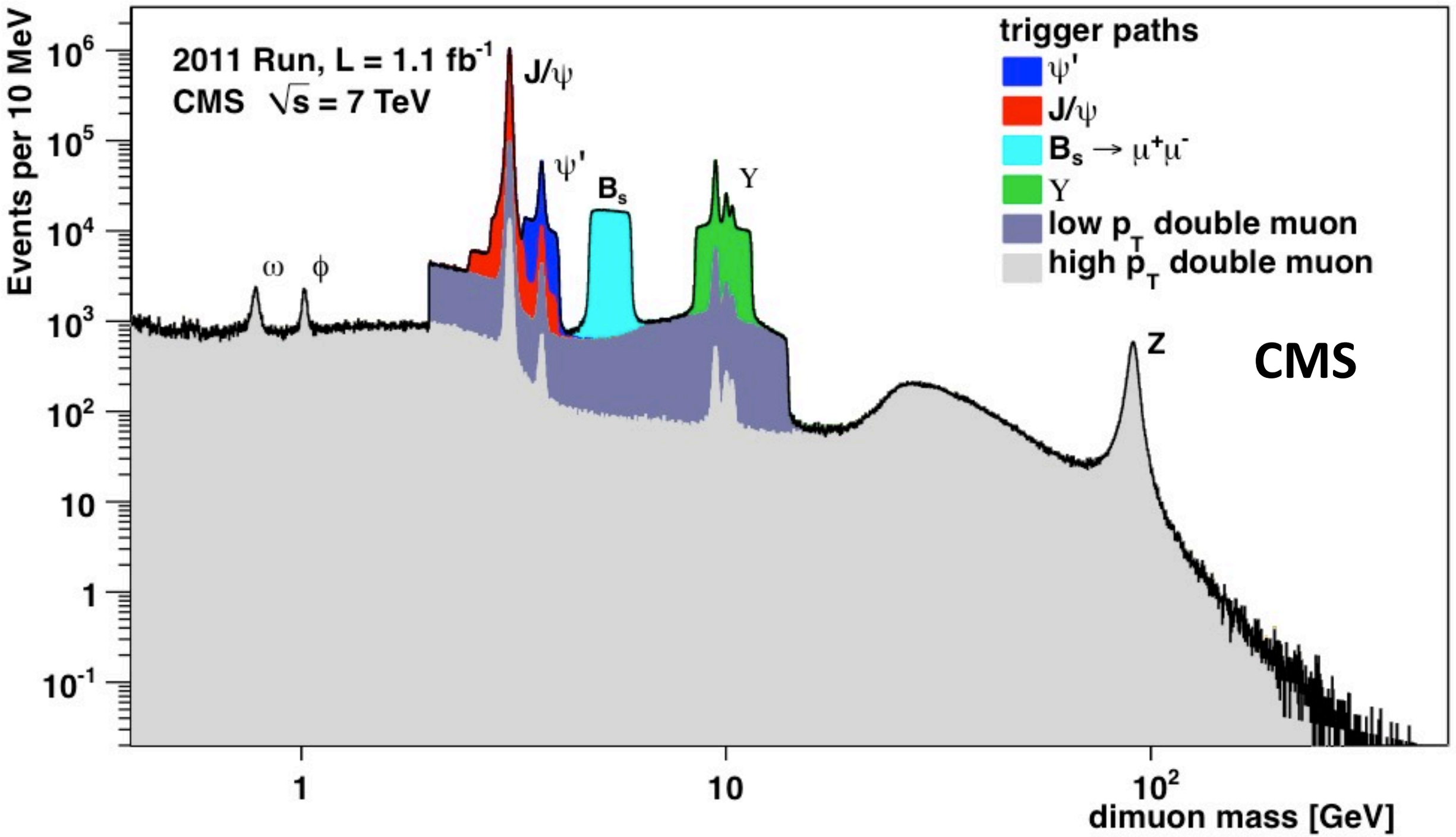


HIGH ENERGY FRONTIER: NICE DISPLAY



m(jet-jet) = 4.0 TeV **Missing E_T = 100 GeV**

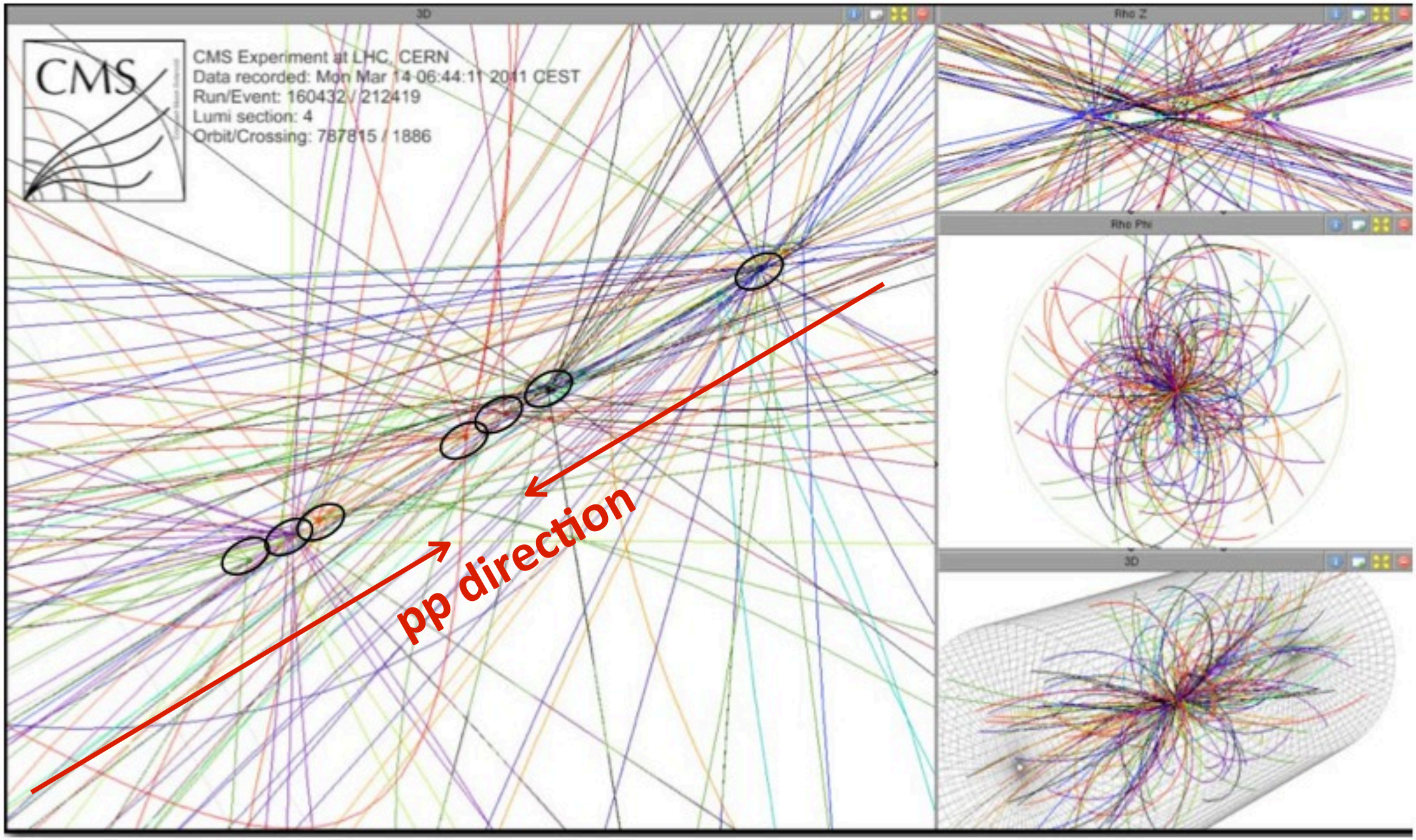
TUNING OF TRIGGERS



Dimuon mass distribution obtained from overlapping several trigger paths.

PILE-UP CHALLENGE

Past: <nPU> ~ 6. Future: <nPU> > 15!



W/Z Physics

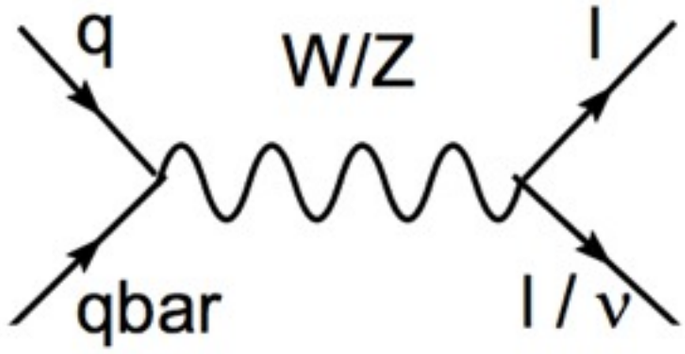
W/Z Physics: Motivations

Precise W/Z measurements important for many reasons:

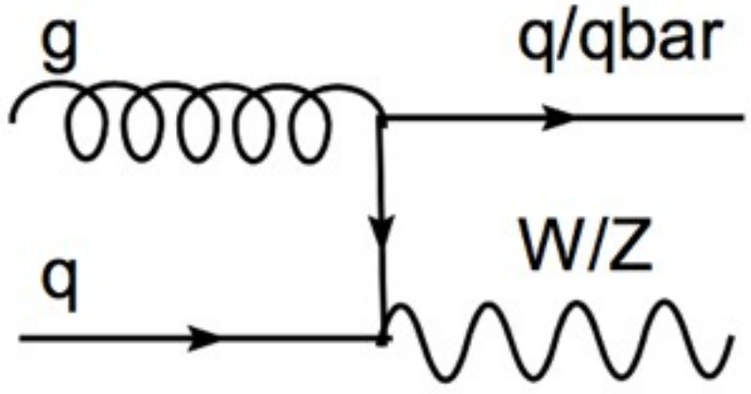
- **deviations from SM as a sign of new physics**, e.g. anomalous TGCs in di-boson production
- **test of perturbative QCD, constrain proton PDFs**
- **understand backgrounds** for new physics searches and Higgs
- **detector and physics objects fine tuning**
  - W, Z: source of isolated high p_T leptons
  - benchmark for lepton reconstruction and identification (understand efficiency, resolution)
- **crosschecks for LHC luminosity**

W AND Z PRODUCTION AND SIGNATURE

LO:



DY



W/Z + jet

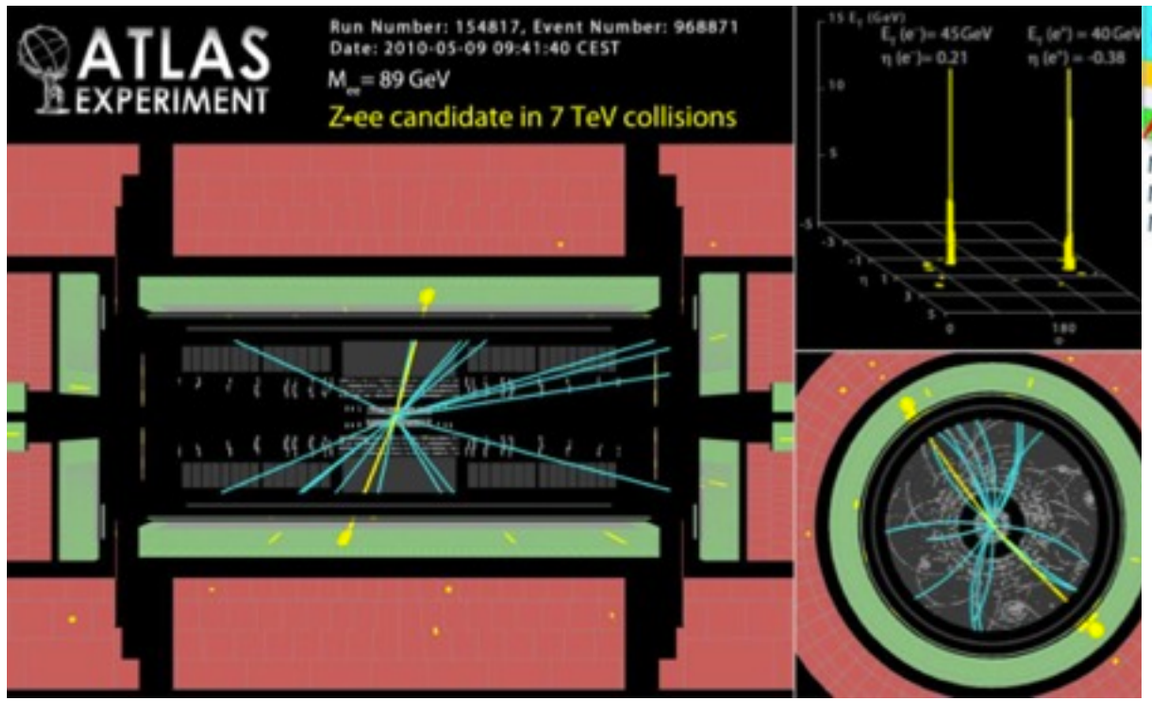
\+ **NLO**

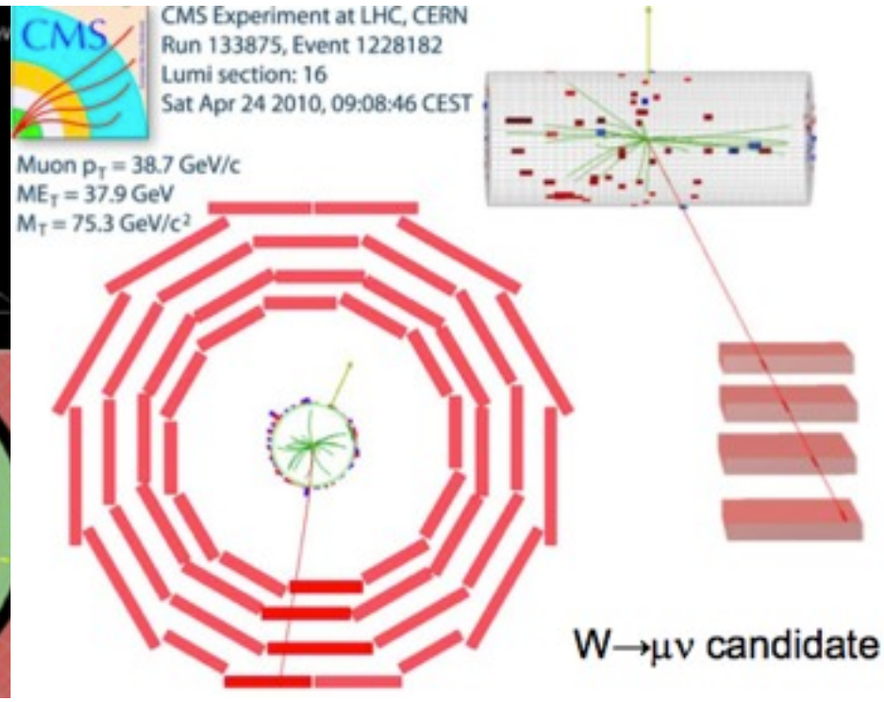
Rate: 10M W per fb^{-1} (#Z ~ 1/10 of the #W)

Signature:

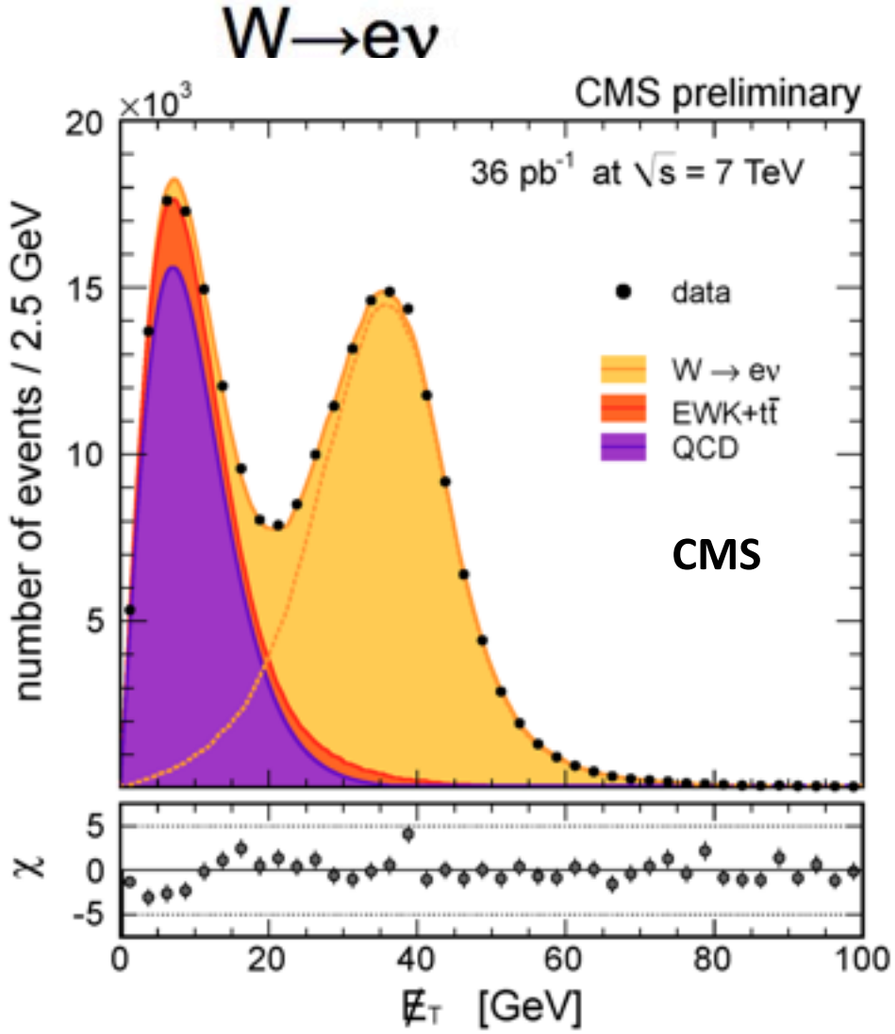
1) ~high p_T and isolated leptons

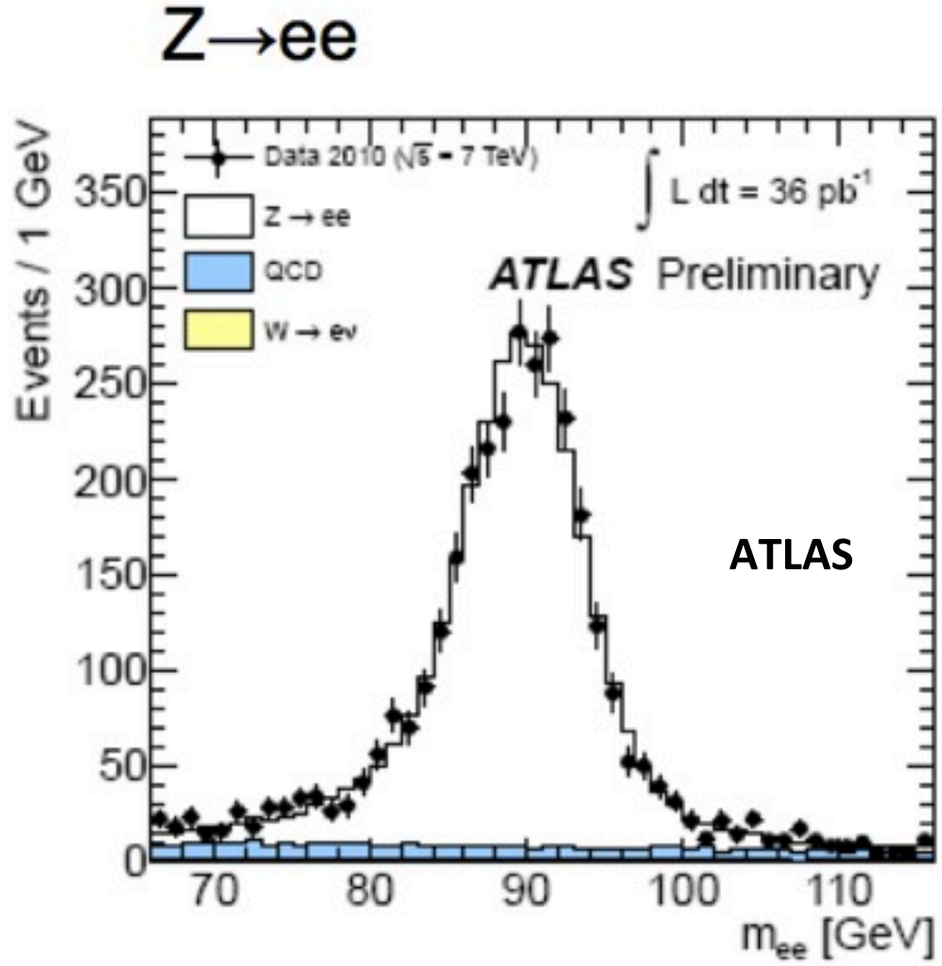
2) missing E_T (W) due to neutrino





W AND Z EXTRACTION AND BACKGROUNDS





use of missing E_T or transverse mass $m_T = \sqrt{2 p_T^e p_T^\nu (1 - \cos(\phi_e - \phi_\nu))}$

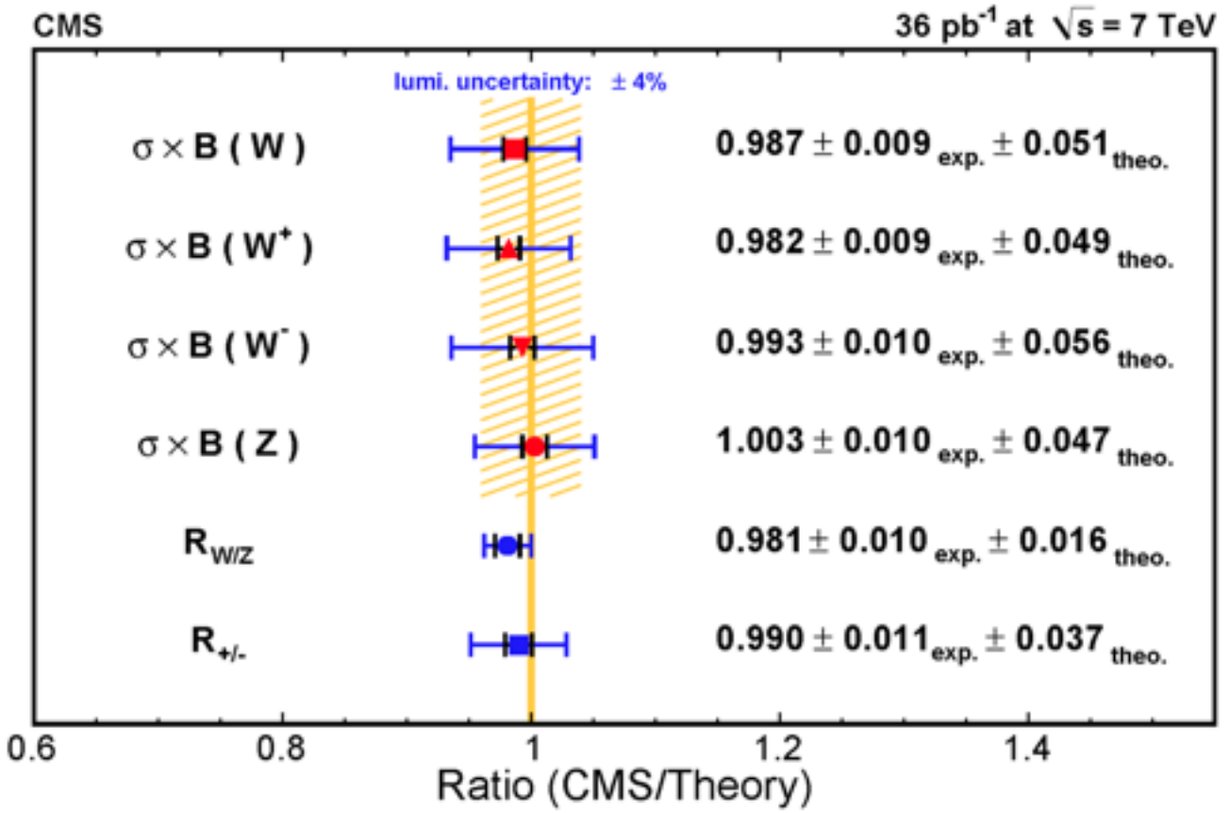
di-lepton invariant mass

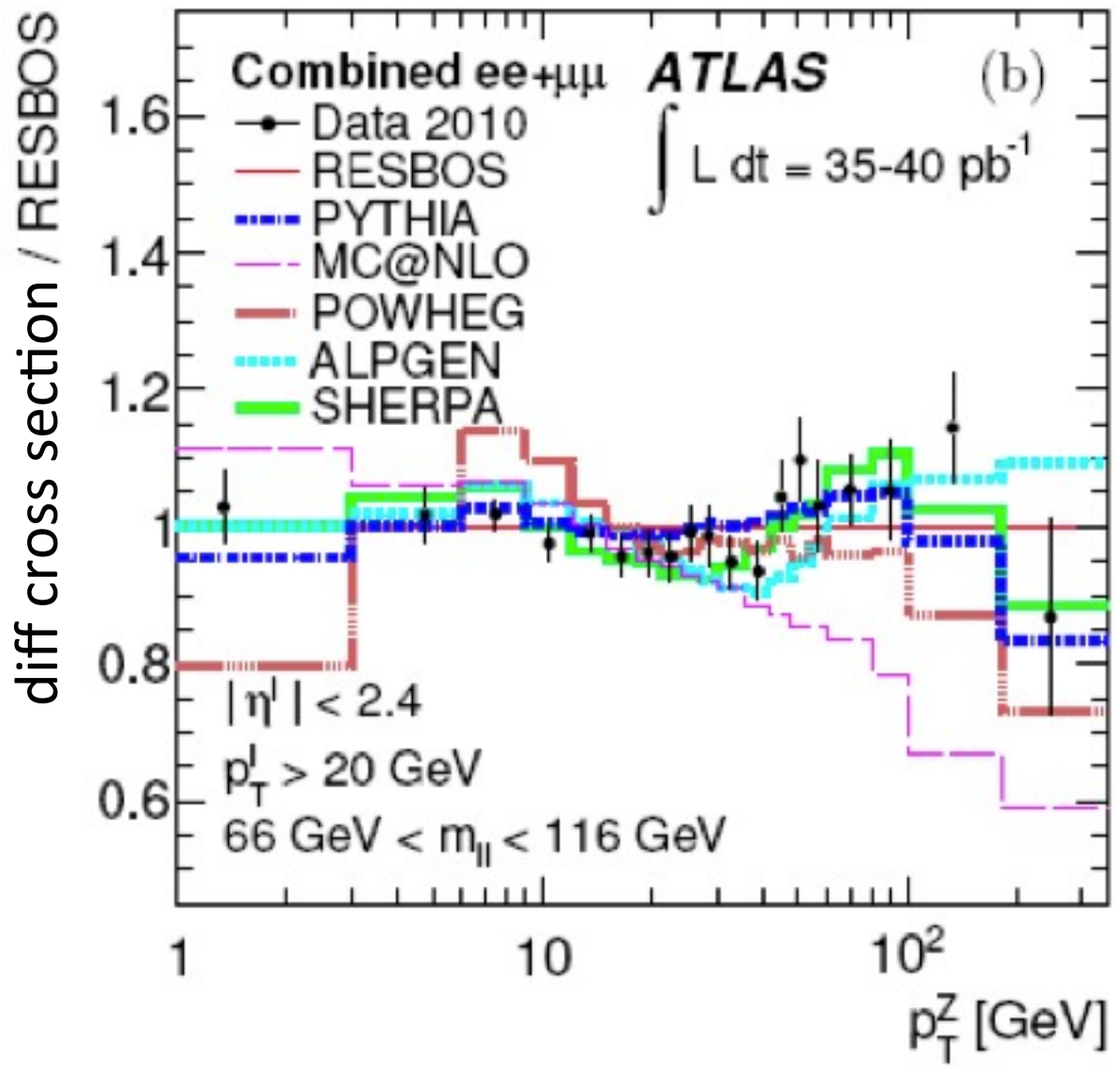
Backgrounds:

QCD (real or fake leptons), EWK WW,WZ,ZZ, W with tau decay, Z with one missing lepton (background to W)

W/Z Cross Section

- **inclusive cross section** (and vs pseudorapidity) **sensitive to PDFs** (due to acceptance cuts)
- **cross section vs p_T sensitive to extra jet radiation**, i.e. to NLO corrections

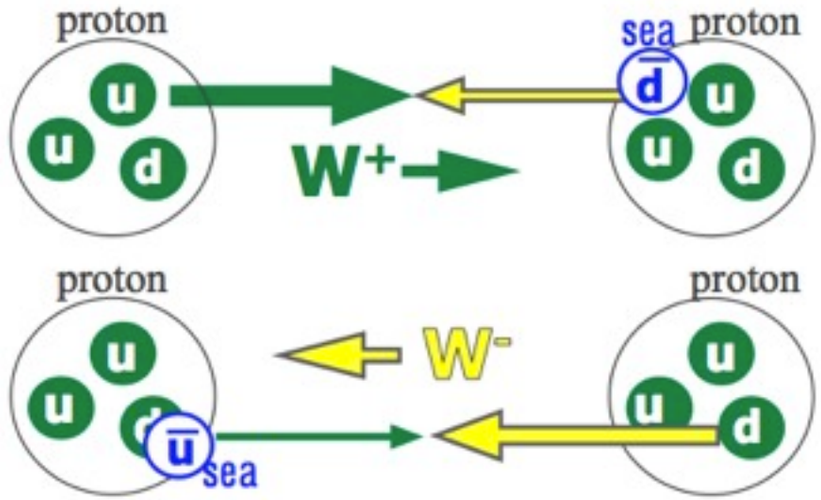




ratio limited by theory systematics
(PDF + fixed order calculation)

CHARGE ASYMMETRY

- at LHC **W charge asymmetry** due to **$N(u_v) > N(d_v) \Rightarrow N(W+) > N(W-)$**



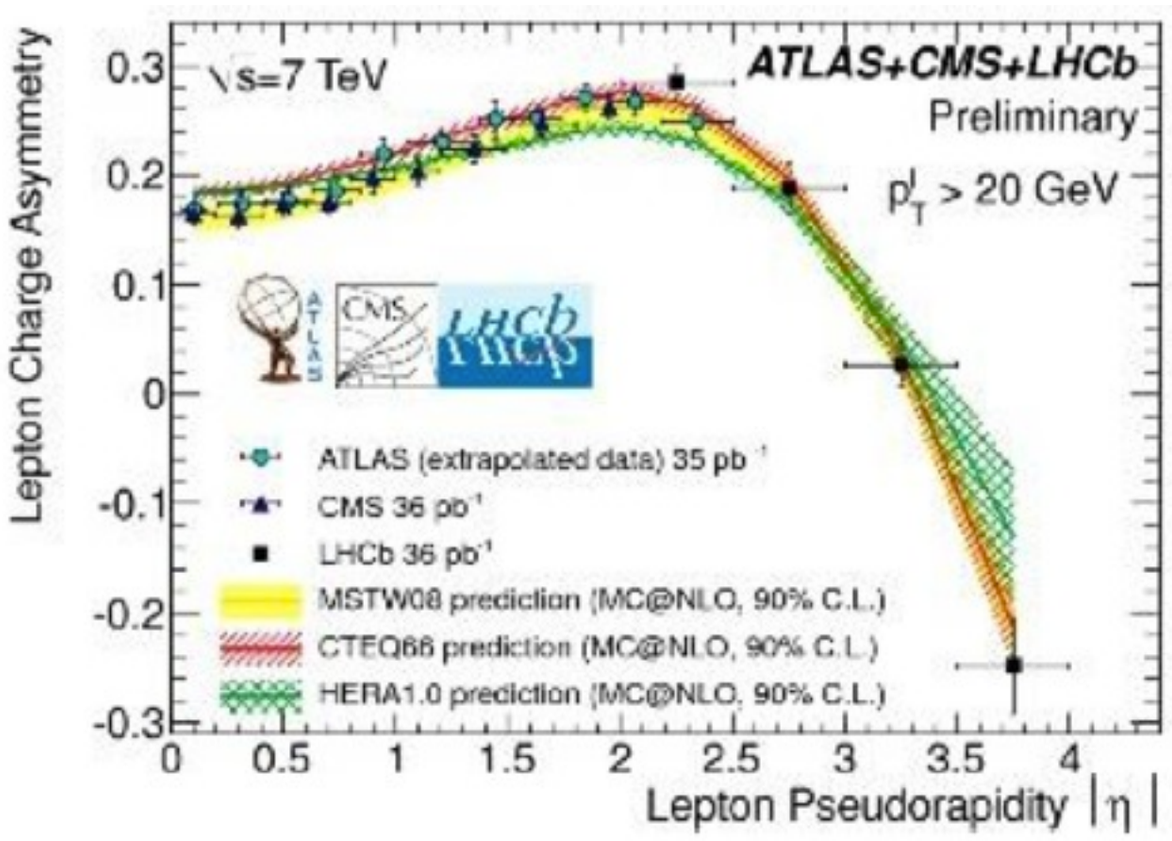
- W pseudo-rapidity cannot be reconstructed ⇒ **lepton asymmetry**

$$\mathcal{A}_{exp}(\eta) = \frac{\frac{dN}{d\eta}(\ell^+) - \frac{dN}{d\eta}(\ell^-)}{\frac{dN}{d\eta}(\ell^+) + \frac{dN}{d\eta}(\ell^-)}$$

- **inclusive** measured to be

  1.43 ± 0.05 (CMS)

- **asymmetry vs pseudorapidity** to check **u/d ratio and sea antiquark densities** in different ranges of x

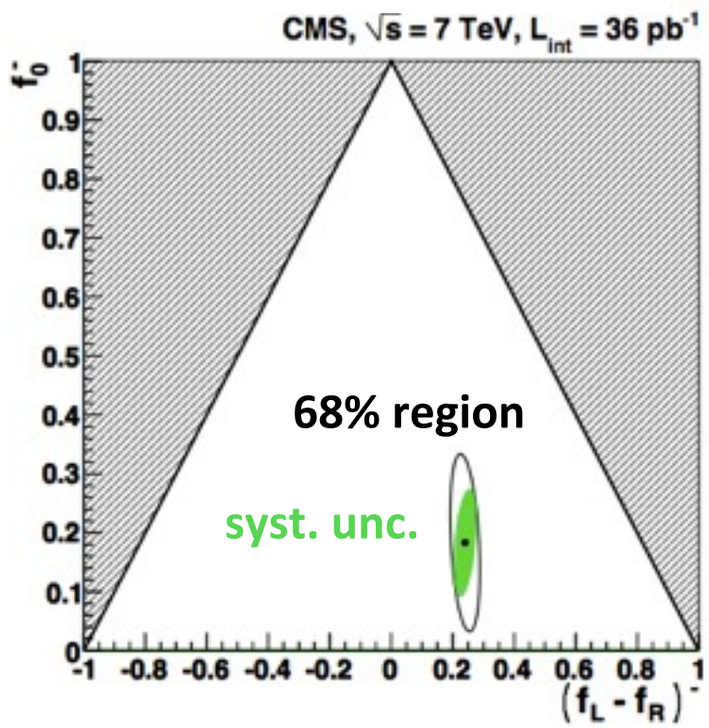


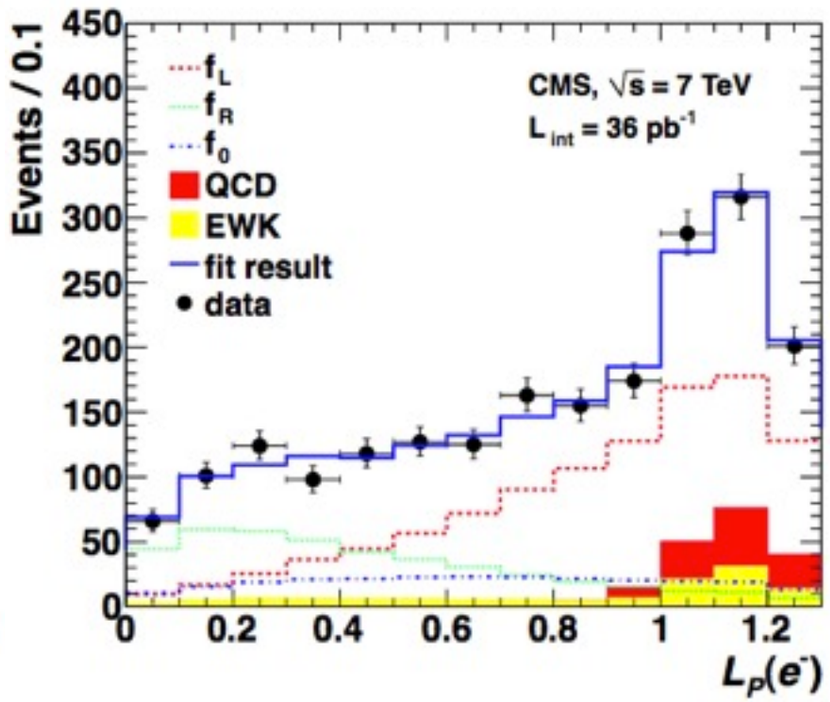
W POLARIZATION

- at LHC dominant high p_T **W+jet production mechanism is qg → Wq**
- combining with **V-A** nature of weak interactions

  ⇒ **W is polarized**: left handed
- **cosθ*** (angle of the lepton in the W rest frame with respect to the W direction in the lab) **cannot be measured** (p_z unknown)

⇒ **use of** $L_P = \dfrac{\vec{p}_T(\ell) \cdot \vec{p}_T(\mathrm{W})}{|\vec{p}_T(\mathrm{W})|^2}$





DRELL-YAN FB ASYMMETRY

$$A_{\mathrm{FB}} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

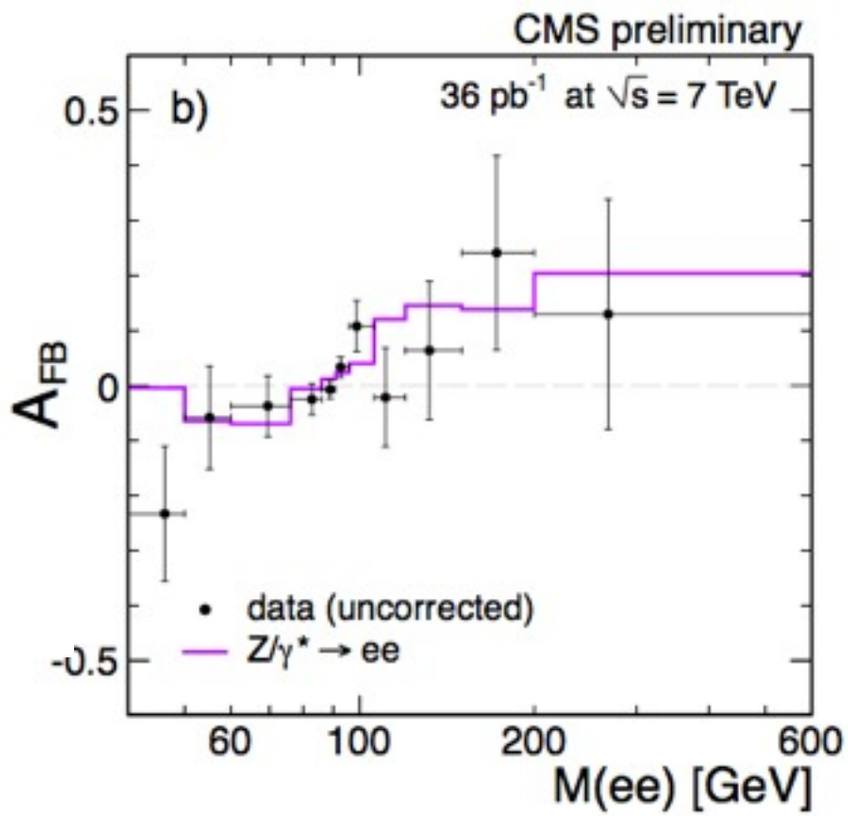
where σ_F for $\cos\theta^*_{CS}>0$
σ_B for $\cos\theta^*_{CS}<0$

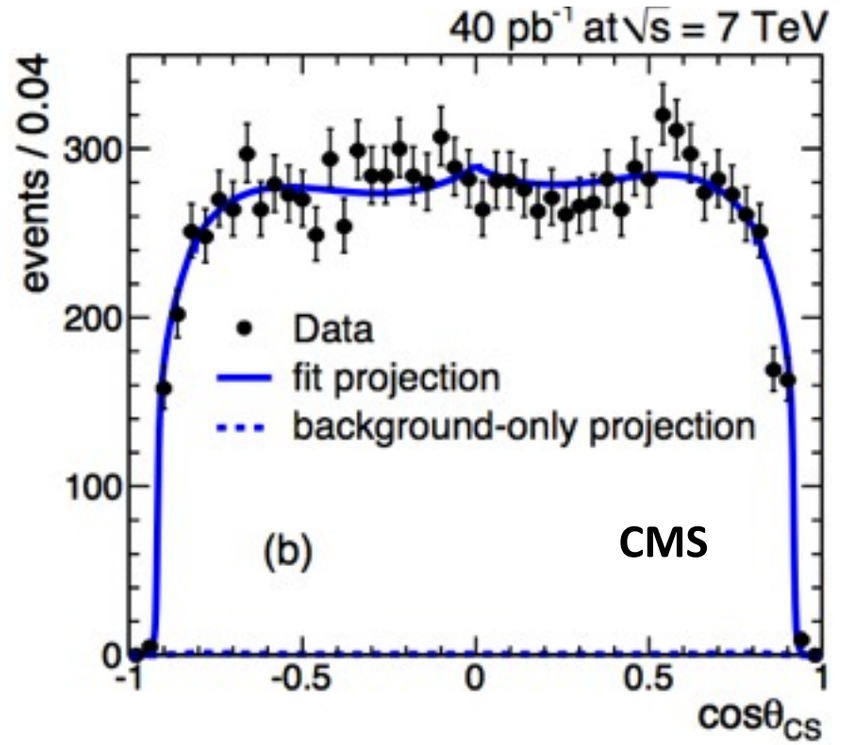
θ^*_{CS} = so called **Collins-Soper angle** calculated with respect to direction closer to dilepton direction

- **sensitive to $\sin^2\theta_W$**
- in **bins of M_{ll} and** lookin$_g$ at the **full kinematics**

$$\sin^2\theta_{\mathrm{eff}} = 0.2287 \pm 0.0020(\mathrm{stat.}) \pm 0.0025(\mathrm{syst.})$$

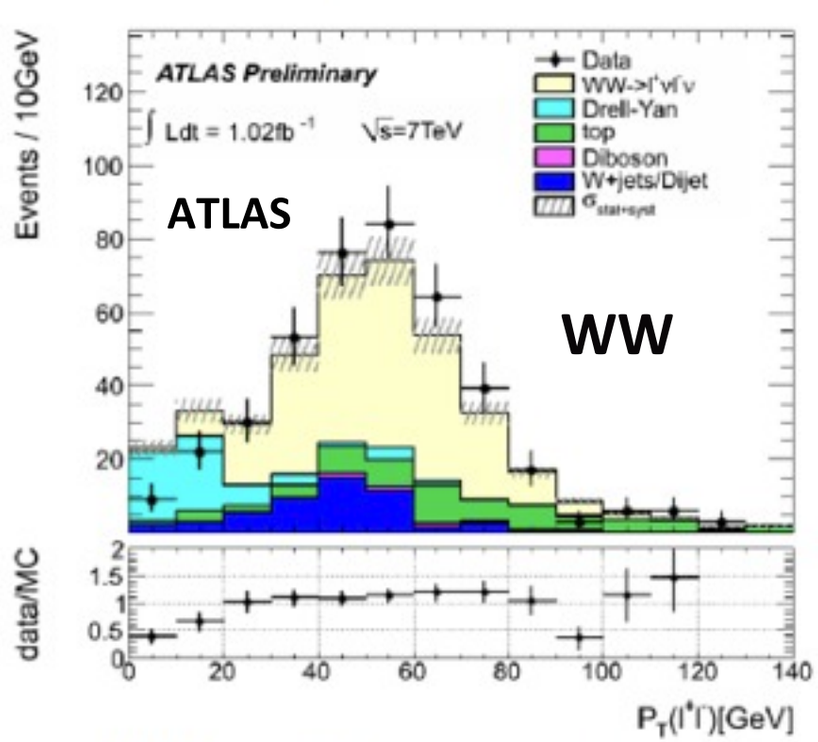
to be compared with (world ave.) 0.23153±0.00016
(D0 exp) 0.2309±0.0010





ZZ/WW/ZW Cross Section

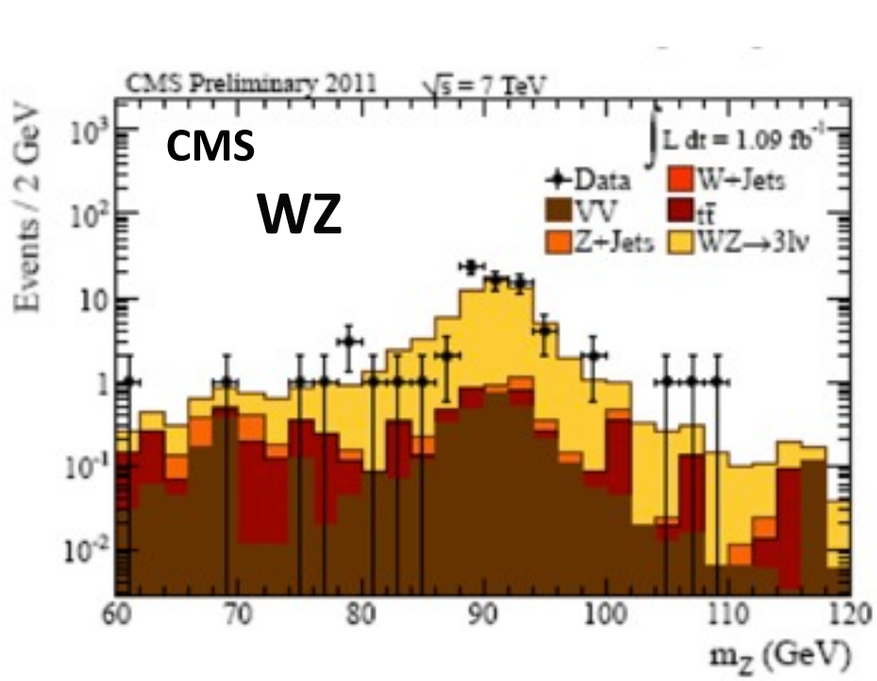
- **fundamental test** of the Standard Model
  - self interaction between ewk bosons, triple gauge couplings (TGC)
- **probe for new physics** (resonances, anomalous TGC)
- **backgrounds for Higgs** searches (high mass)



$\sigma(WW) = 48.2 \pm 4.0(stat)$

ATLAS $\pm 6.4(syst) \pm 1.8(lumi)\ pb$

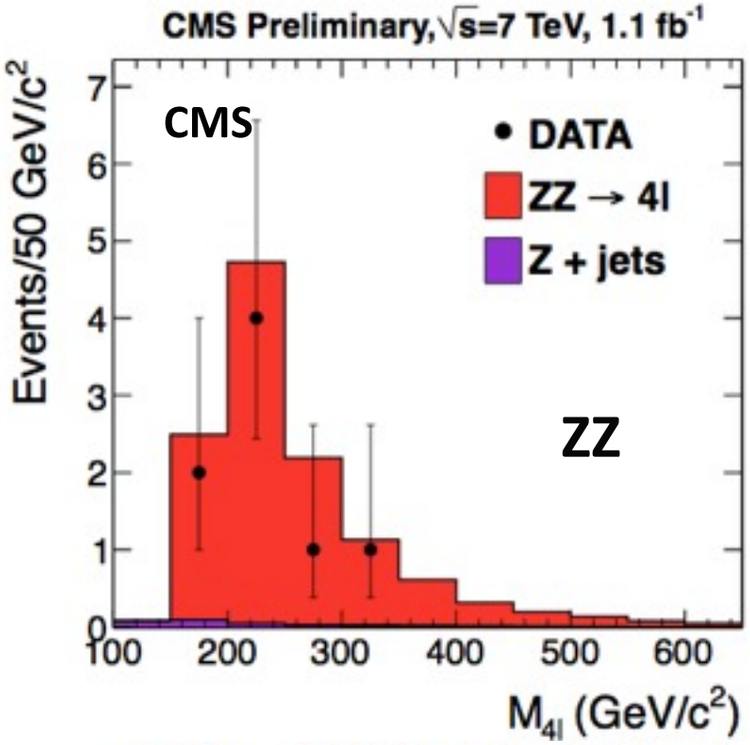
(NLO expected $46 \pm 3\ pb$)



$\sigma(WZ) = 17.0 \pm 2.4(stat)$

CMS $\pm 1.1(syst) \pm 1.0(lumi)\ pb$

(NLO expected $19.790 \pm 0.088\ pb$)

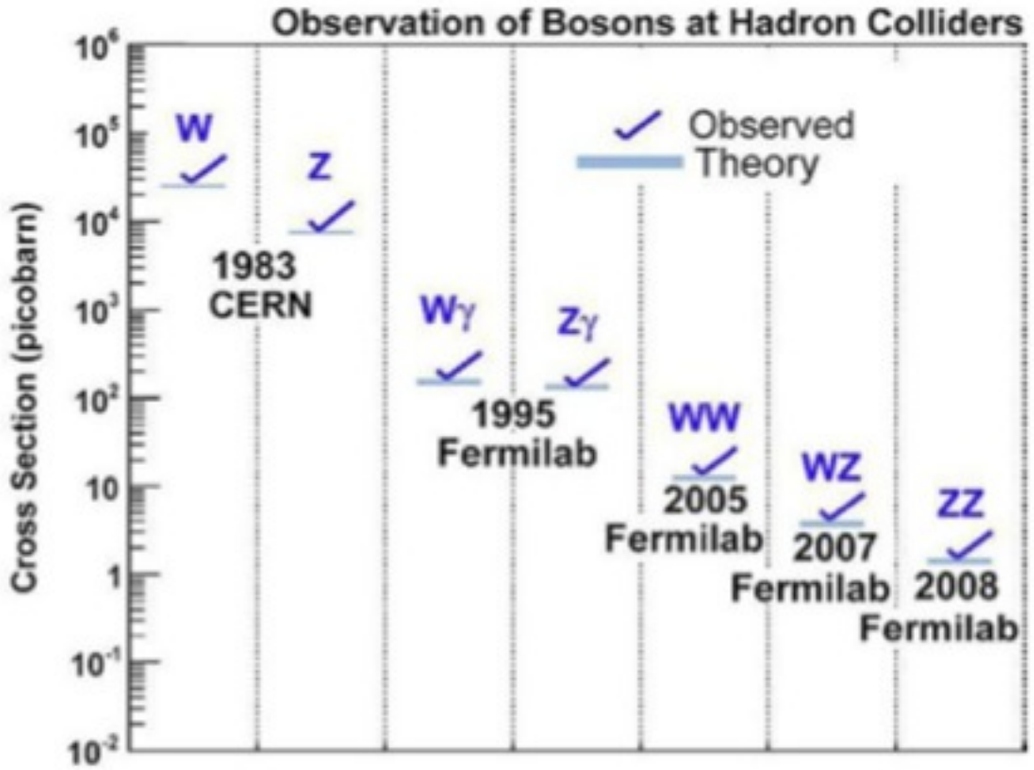


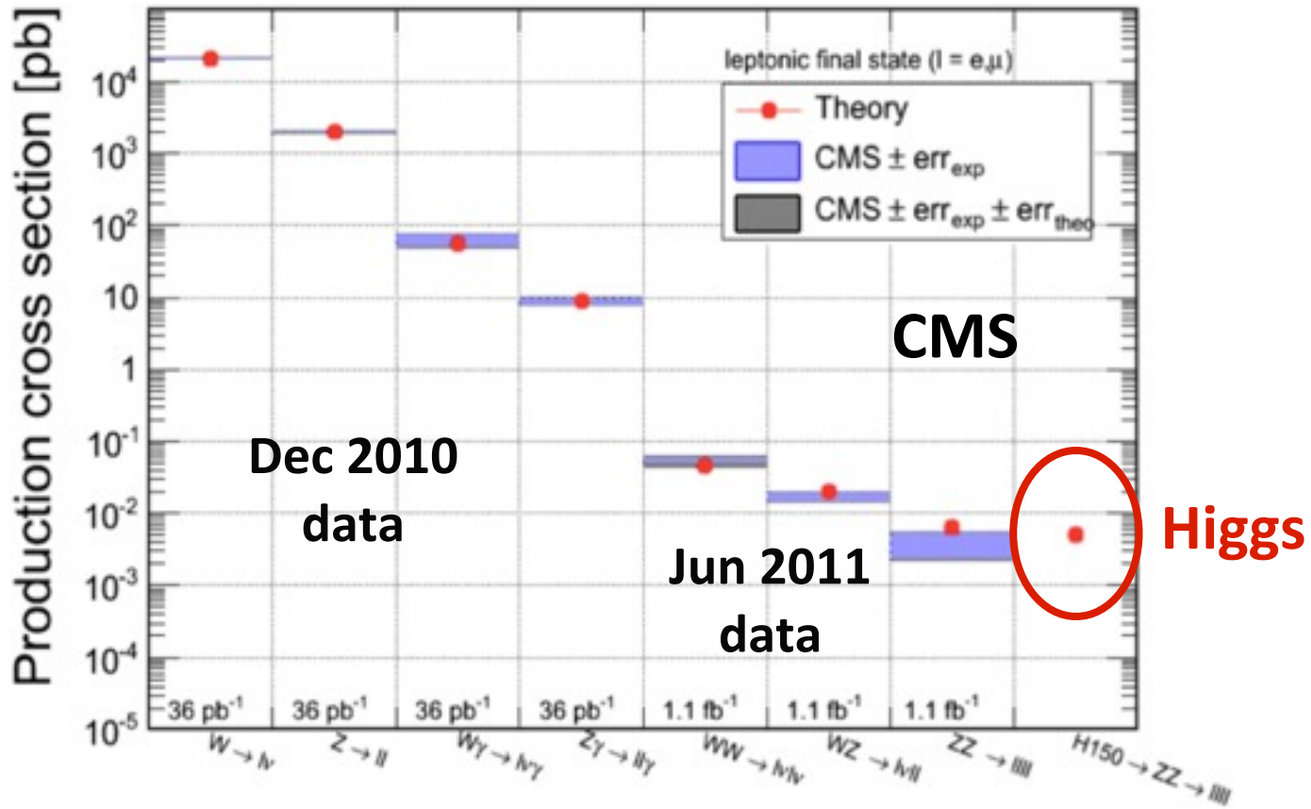
$\sigma(ZZ) = 3.8^{+1.5}_{-1.2}(stat) \pm 0.2(syst)$

CMS $\pm 0.2(lumi)\ pb$

(NLO expected $6.4 \pm 0.6\ pb$)

LHC: FROM EWK PHYSICS TO HIGGS





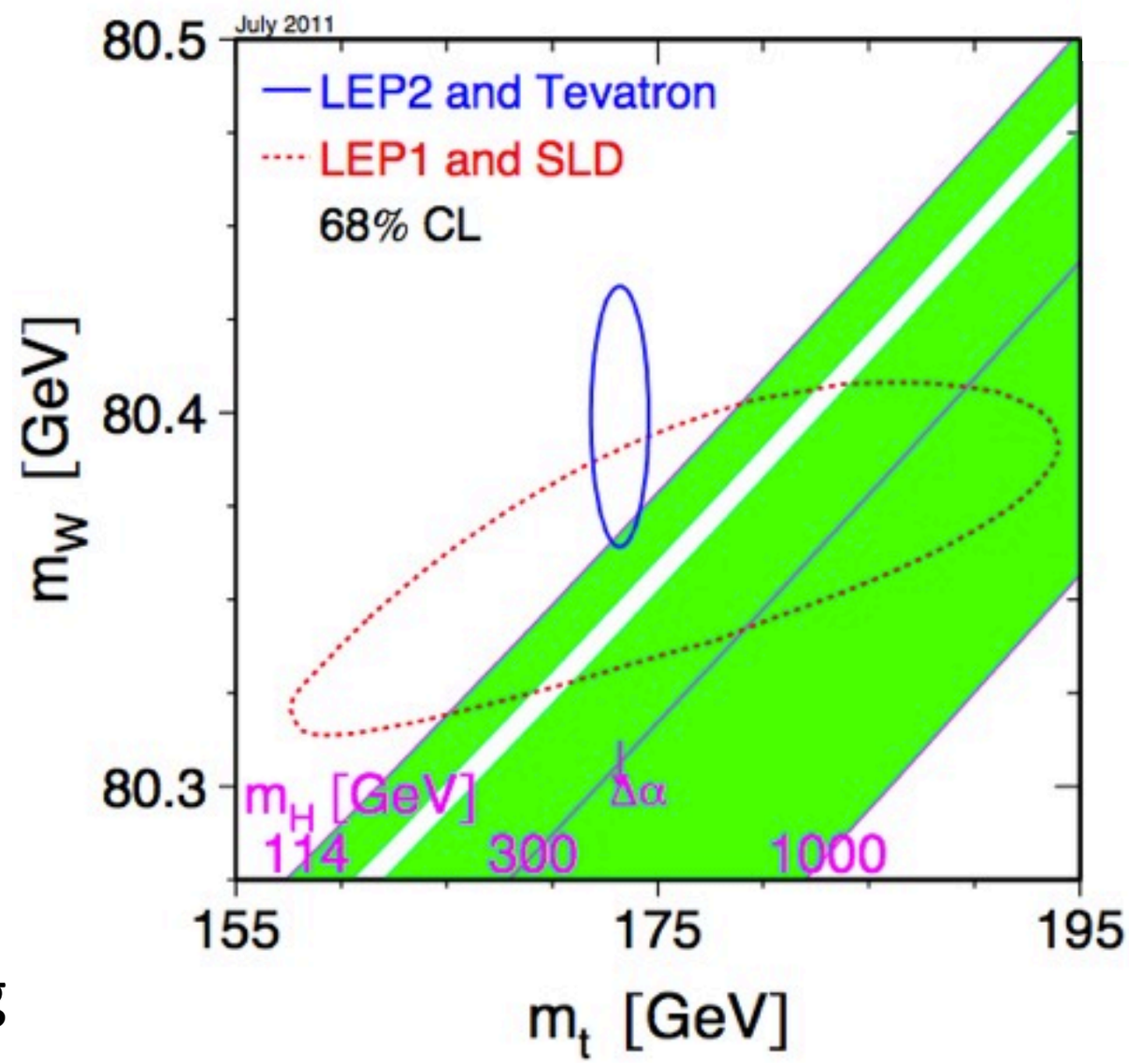
25 years

6 months

Top Physics

TOP PHYSICS: MOTIVATIONS

- **most massive** constituent of matter
- **M(top) ~ EW breaking scale**
- decay and strong **production rate as tests of SM**
- **coupling to the Higgs ~ 1**
  - Special role in EWK symmetry breaking?
- various **scenarios with direct/ indirect coupling to new physics**
  - from extra dimensions to new strong forces

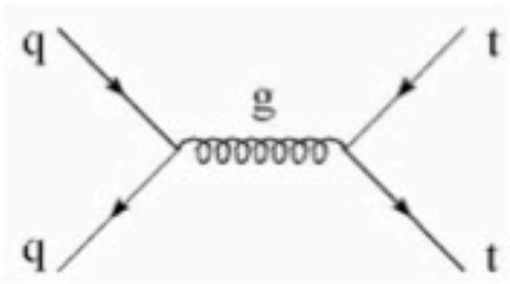


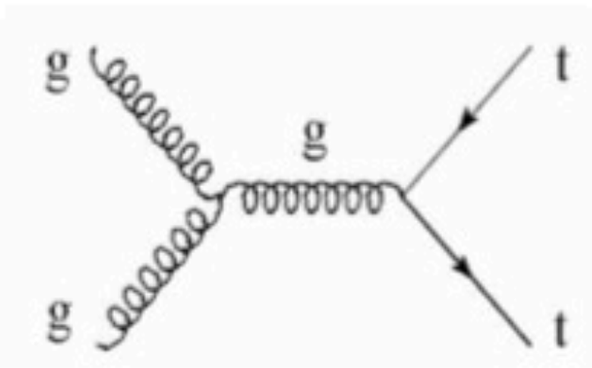
TOP PRODUCTION

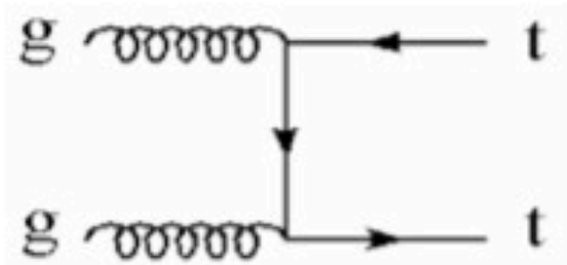
probe low x in pdfs →gluon fusion dominated

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

top pairs: strong





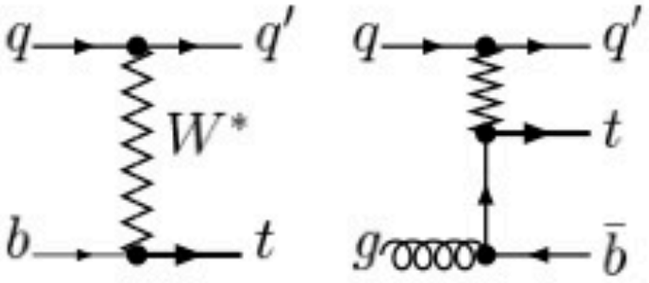


Aliev et al 2011
Beneke et al 2010
Langefeld Moch Uwer 2009
Moch,Uwer 2008

$\sigma = 165^{+11}_{-11}$ pb

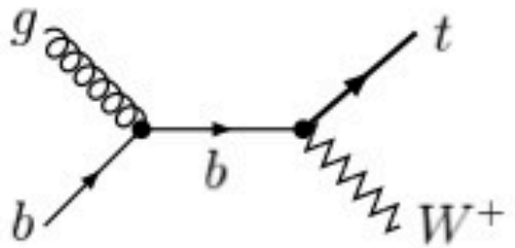
single top: electroweak

t chan



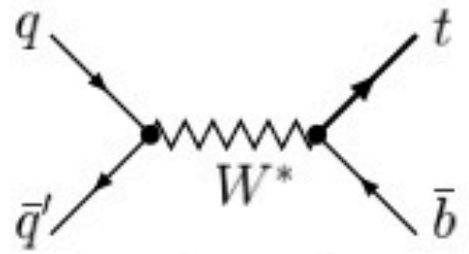
$\sigma = 64^{+3}_{-3}$ pb

Wt chan



$\sigma = 15.7^{+1.3}_{-1.4}$ pb

s chan

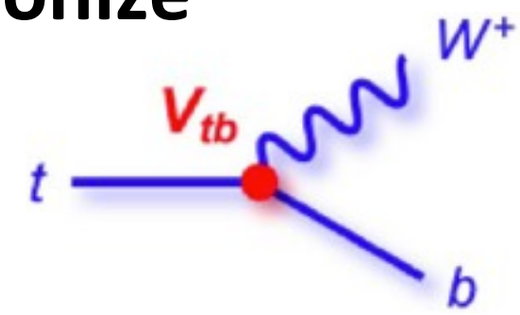


$\sigma = 4.6 \pm 0.3$ pb

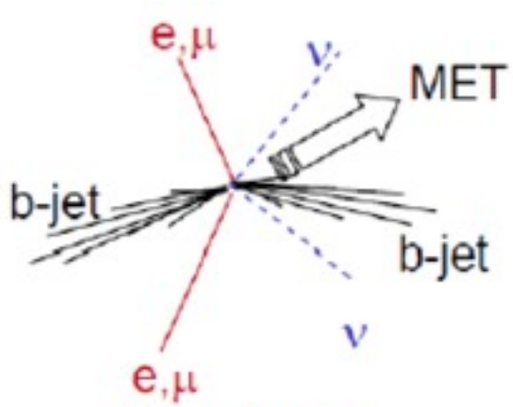
Kidonakis 2010

TOP PAIR SIGNATURES AND SELECTION

- **top decays before it can hadronize**
  - almost exclusively **t→Wb**



- **top pair event classification**

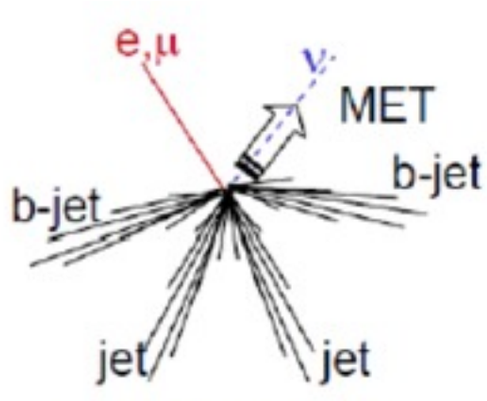


dileptons

BR ~ 5%

background small

mainly Z+jets,EW

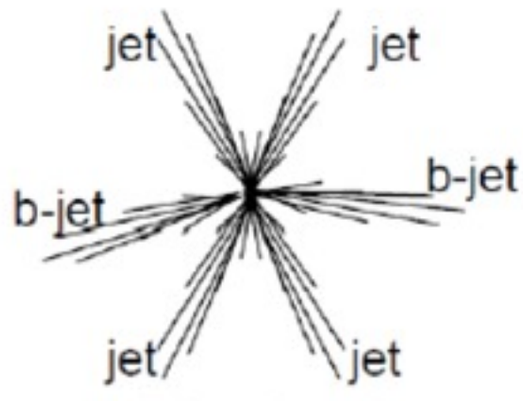


lepton + jets

BR ~ 30%

background moderate

mainly W+jets

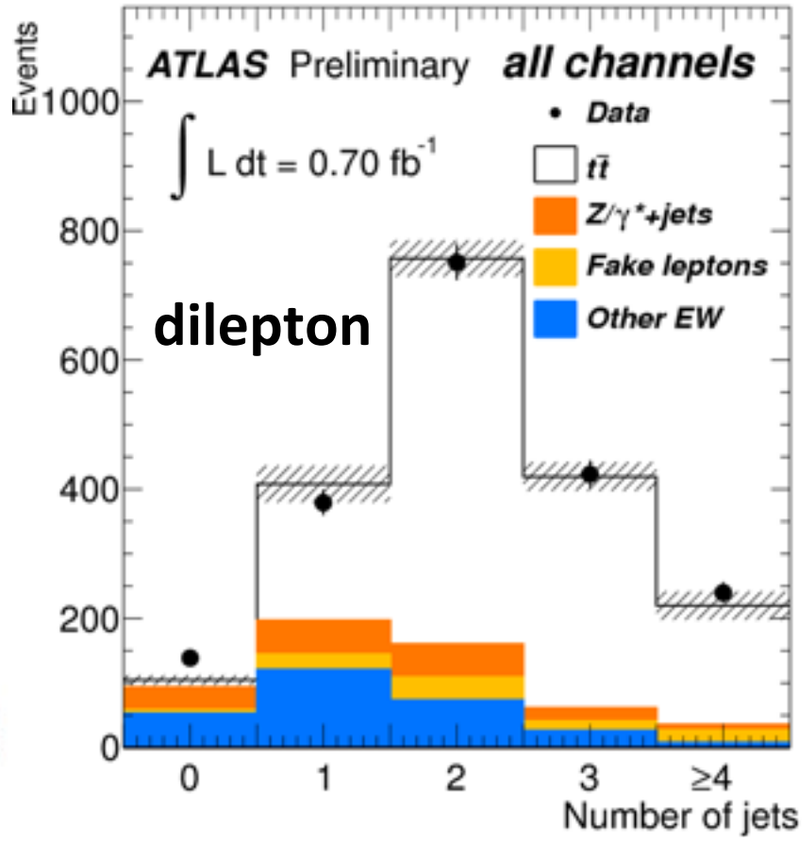


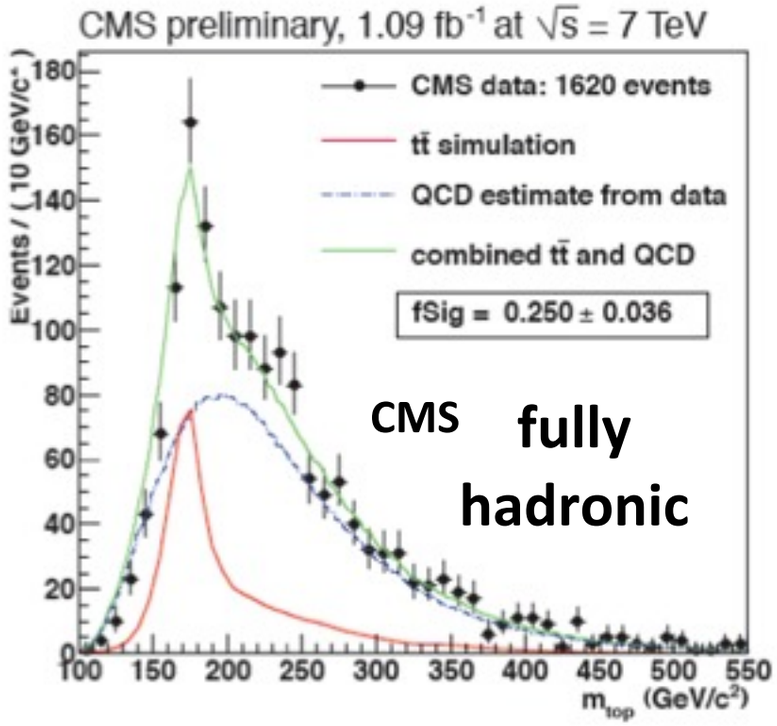
all hadronic

BR ~ 46%

background high

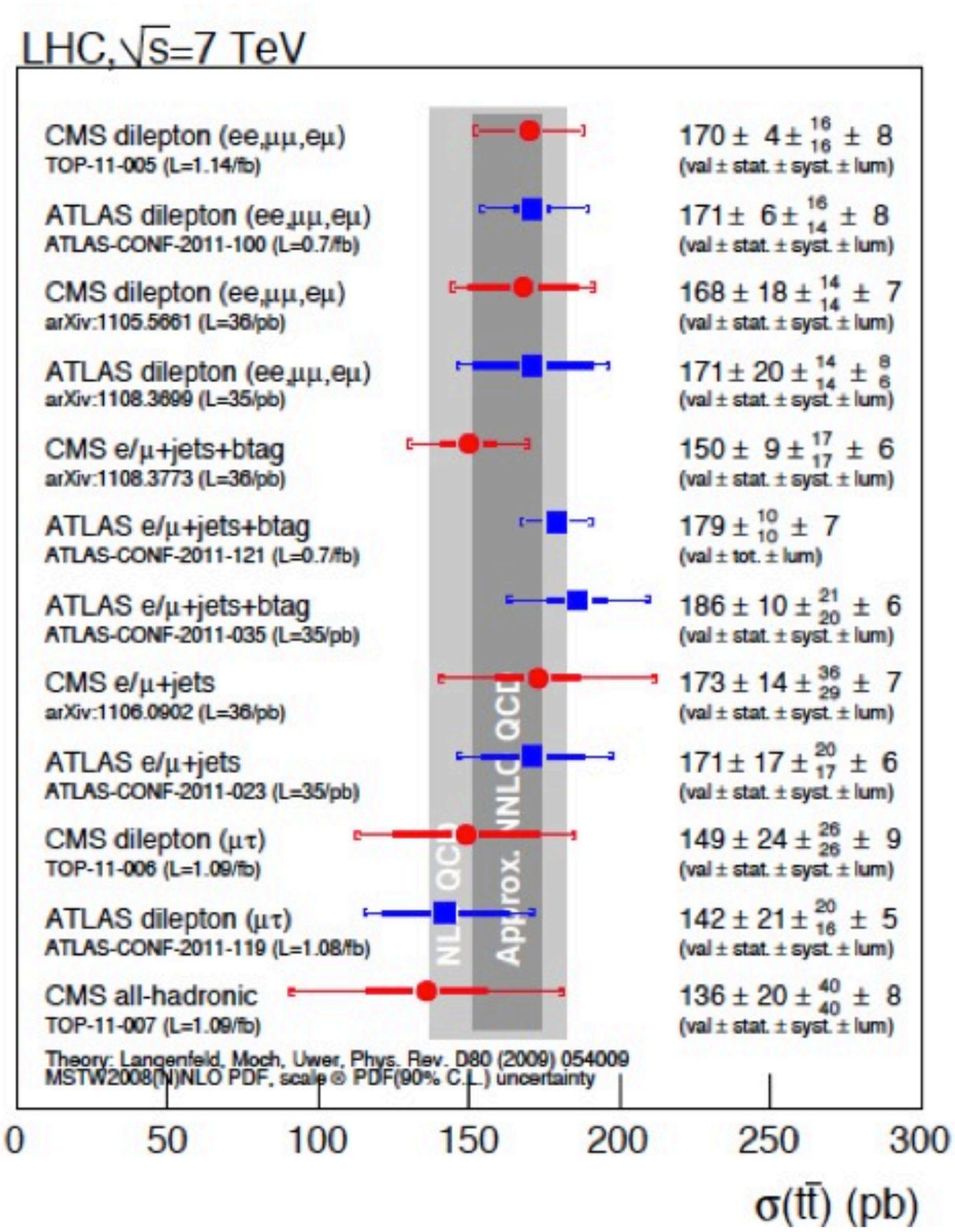
mainly QCD





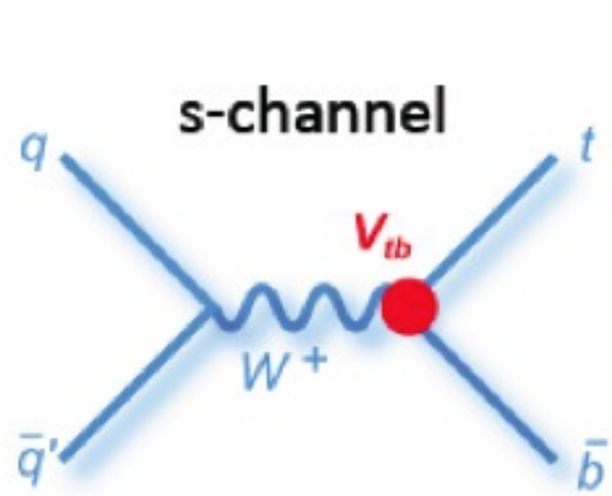
TOP PAIR CROSS SECTION

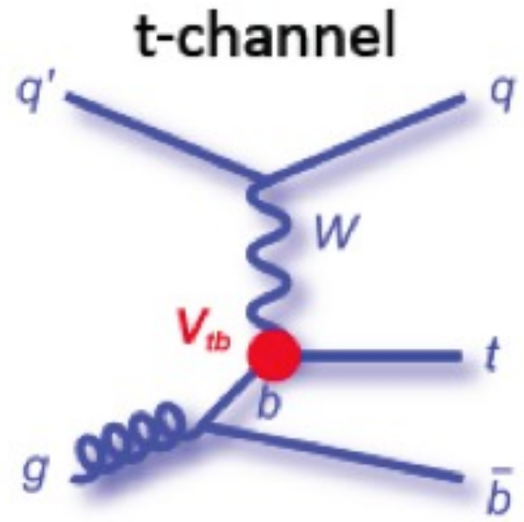
- measurements using **different signatures** with similar performance from both experiments performed
- **most precise measurement now at ~7% uncertainty**
- **combination not yet there** but can be as low as 5%
- **NNLO calculation to be challenged**
- also **sensitive to PDFs**

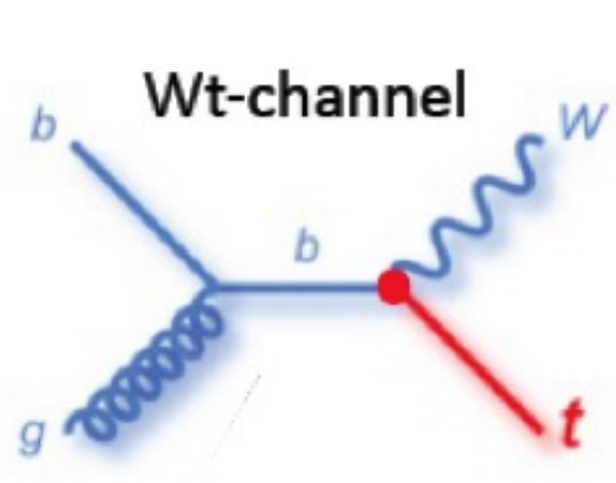


SINGLE TOP

- challenging because of **small cross section and large bkg**
- **measurement of V_{tb}, b-parton in proton, anomalous couplings**
- **s-channel even more challenging at LHC**
- require leptons+(b)jets+MET







For M_t = 172.5 GeV	σ_{tb}	σ_{tqb}	σ_{tW}
pp @ 7 TeV	4.6 ± 0.3 pb	64.6 +3.3 -2.6 pb	15.7 ± 1.4 pb
	large at Tevatron		small at Tevatron

SINGLE TOP RESULTS

t-channel "seen" by both experiments

ATLAS: $\sigma_t = 90^{+9}_{-9}(\text{stat})\,^{+31}_{-20}(\text{syst})$

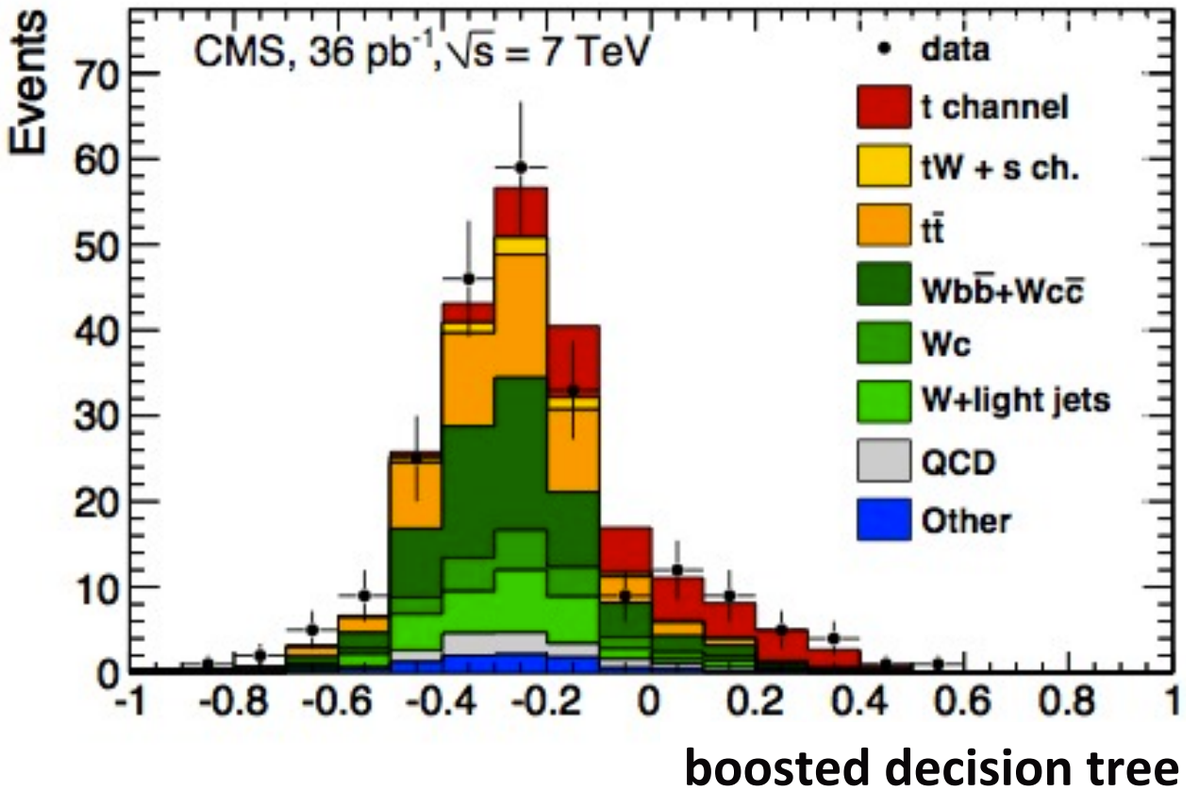
CMS: $\sigma = 83.6 \pm 29.8\,(stat+syst) \pm 3.3\,(lumi)\,pb$

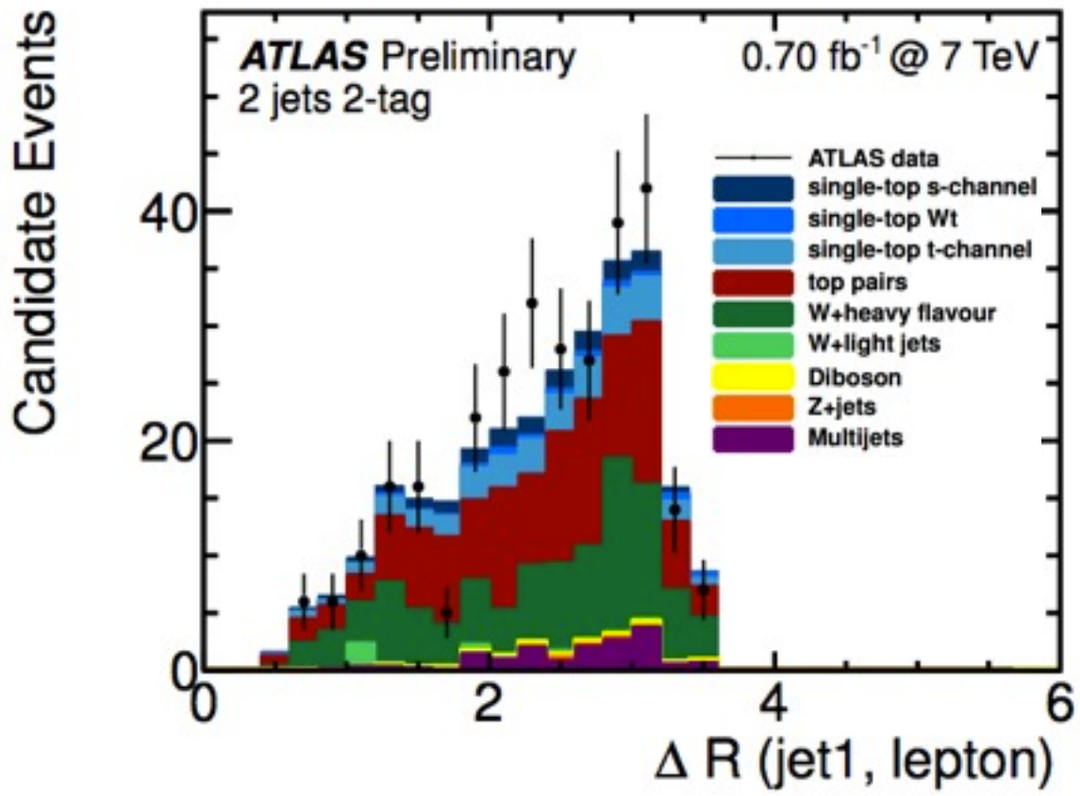
not enough sensitivity for s-channel and Wt production

ATLAS

s-channel: $\sigma_s < 26.5$ pb

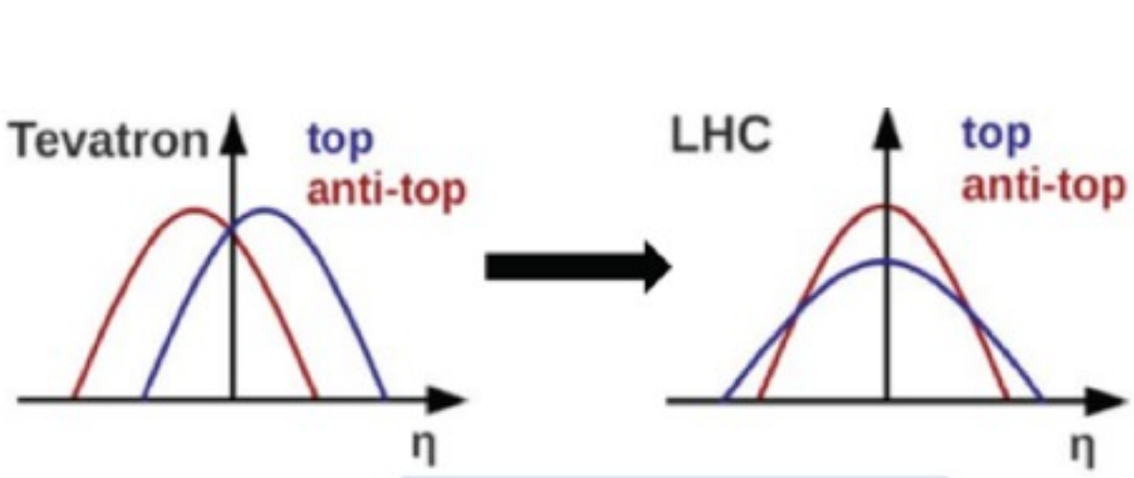
Wt: $\sigma(pp \to Wt + X) < 39.1$ pb (obs.)

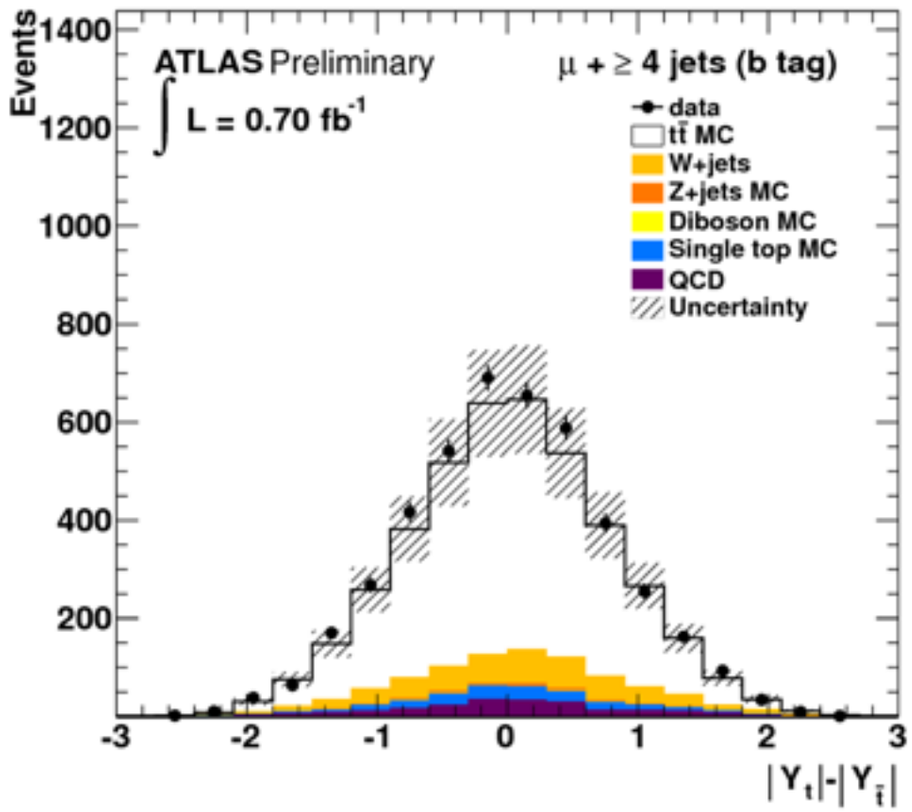




TOP CHARGE ASYMMETRY

- **at leading order** in SM, quark pair production **symmetric under charge conjugation**
- **at higher orders asymmetry appears** (sensitive to NP)
- **wider pseudorapidity distribution for top compared to anti-top**





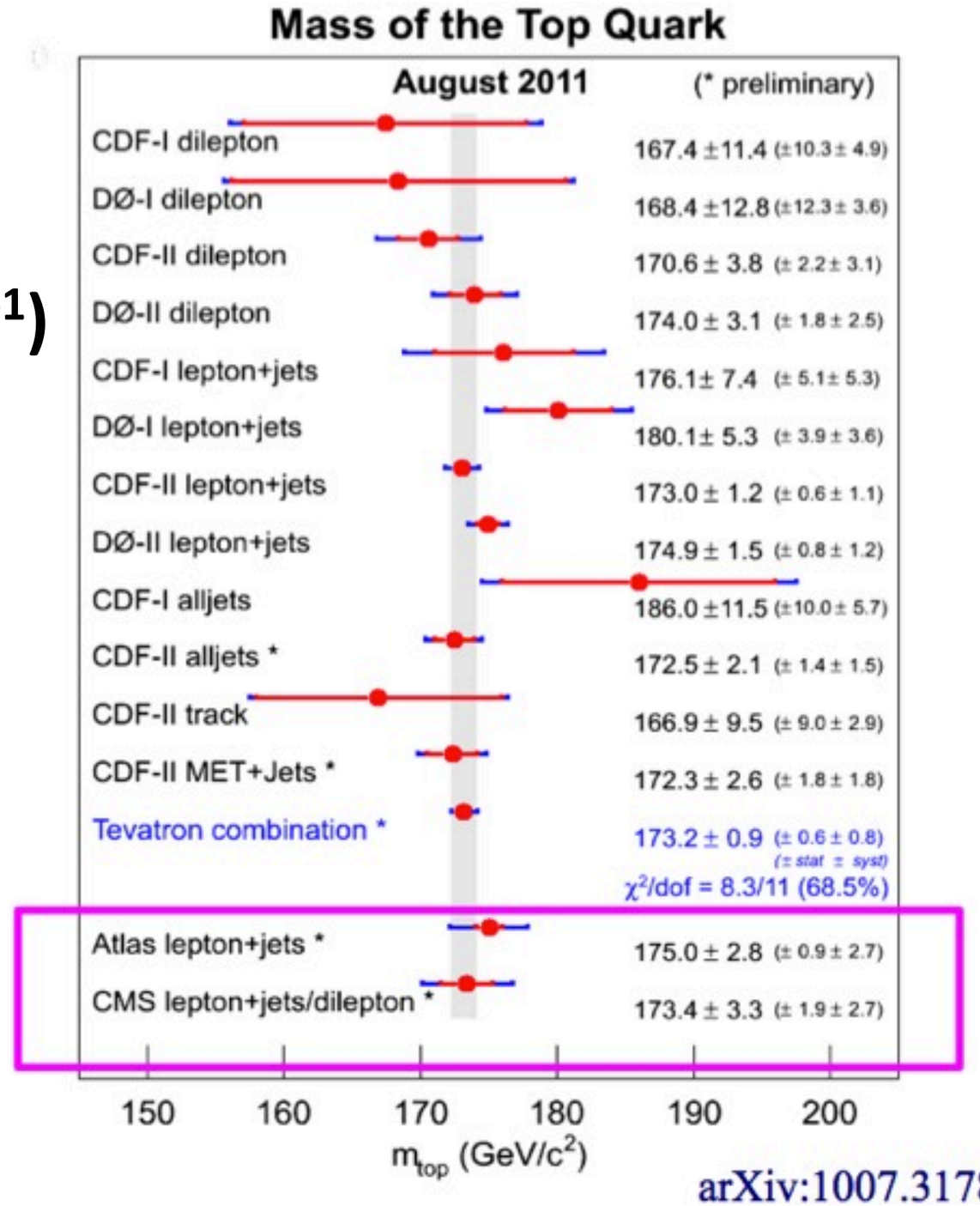
$$A_C = \frac{N(\Delta|Y| > 0) - N(\Delta|Y| < 0)}{N(\Delta|Y| > 0) + N(\Delta|Y| < 0)} \qquad \Delta|Y| = |Y_t| - |Y_{\bar{t}}|$$

$$\text{CMS} \quad A_C^{\eta} = -1.6 \pm 3.0(stat)^{+1.0}_{-1.9}(syst)\% \qquad A_C^{\eta}(\text{theory}) = 1.3\ \%$$

$$\text{ATLAS} \quad A_C^{y} = -2.4 \pm 1.6(stat) \pm 2.3(syst)\% \qquad A_C^{y}(\text{theory}) = 0.6\ \%$$

Top Mass

- done in **dilepton and lepton + jets modes**
- **full sample not yet used (36-700pb^{-1})**
- **statistical** error already **similar to Tevatron**
- need to **work on systematics**. Main contributions:
  - jet energy scale
  - ISR/FSR



BSM Searches

SUSY AS A POSSIBLE SM EXTENSION

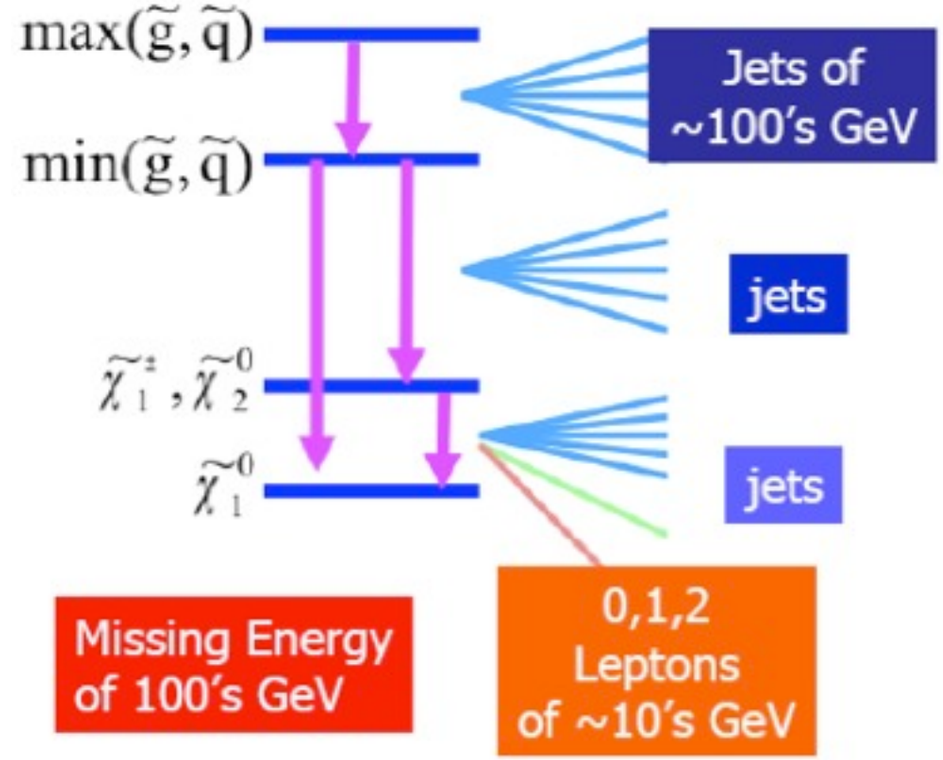
- **new symmetry between fermions and bosons** (every SM particle has a partner differing by 1/2 in spin)
- **solves hierarchy and other SM problems**
- **SUSY particles** produced **in pairs**
- **stable and neutral lightest SUSY particle** (LSP)
  - good candidate for **Dark Matter**

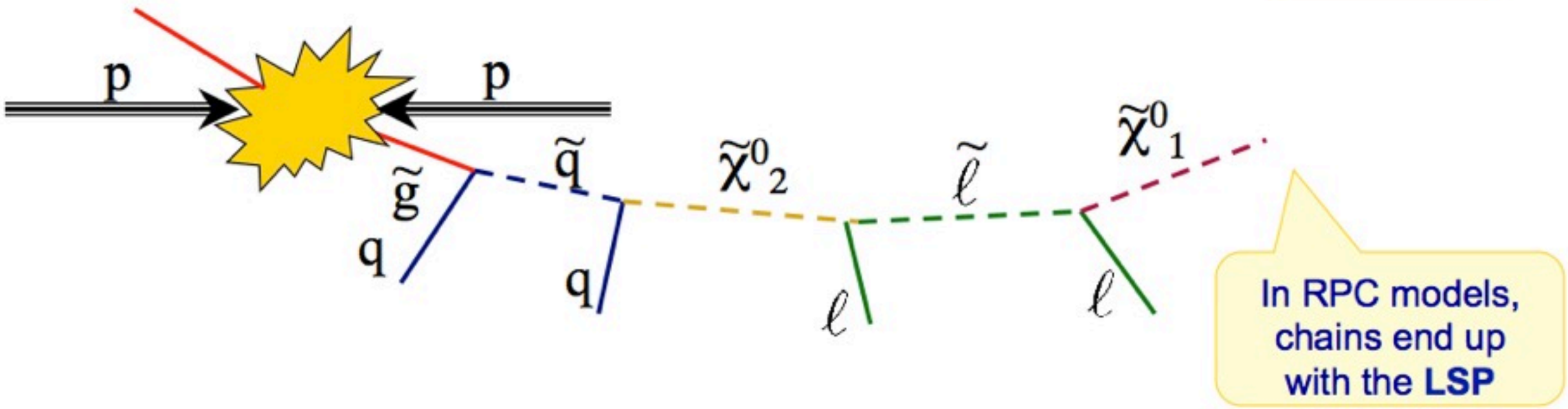
SM Particles	SUSY Particles		
quarks: q	q	squarks: $\tilde{q}$	
leptons: l	l	sleptons: $\tilde{l}$	
gluons: g	g	gluino: $\tilde{g}$	
charged weak boson: $W^{\pm}$	$W^{\pm}$	Wino: $\tilde{W}^{\pm}$	$\tilde{\chi}^{\pm}_{1,2}$ chargino
Higgs: H^0	$H^{\pm}$	charged higgsino: $\tilde{H}^{\pm}$	
	h^0, A^0, H^0	neutral higgsino: $\tilde{h}^0, \tilde{A}^0,$	$\tilde{H}^0$ higgsino
neutral weak boson: Z^0	Z^0	Zino: $\tilde{Z}^0$	$\tilde{\chi}^0_{1,2,3,4}$ neutralino
photon: γ	γ	photino: $\tilde{\gamma}$	

SUSY: SIGNATURE

Event topology:

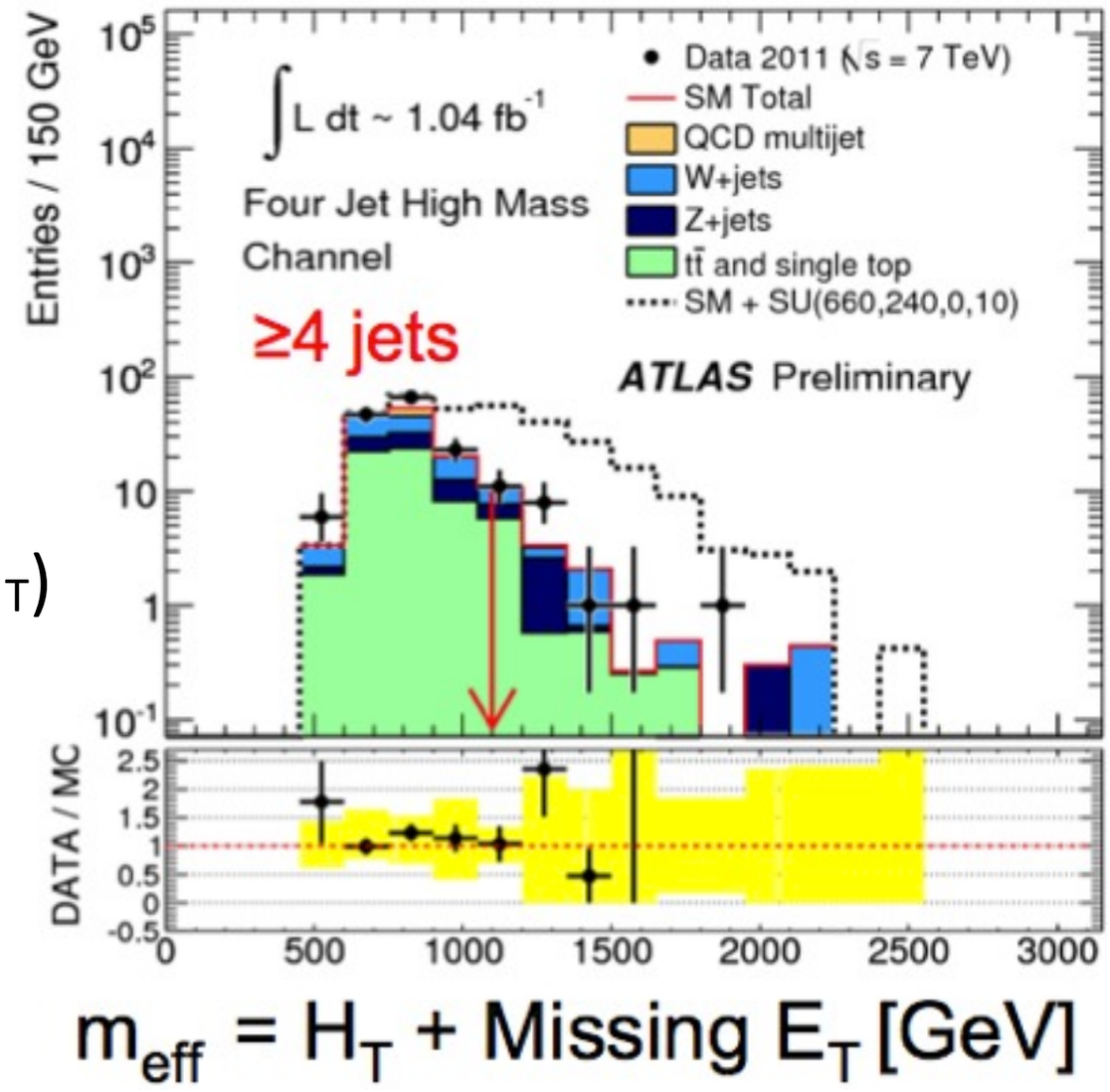
- **high p_T jets** from squark-gluino decays
- **large missing E_T** from LSP
- **high p_T leptons** from sgaugino/slepton
- **high p_T b-jets, τ-jets** depending on models





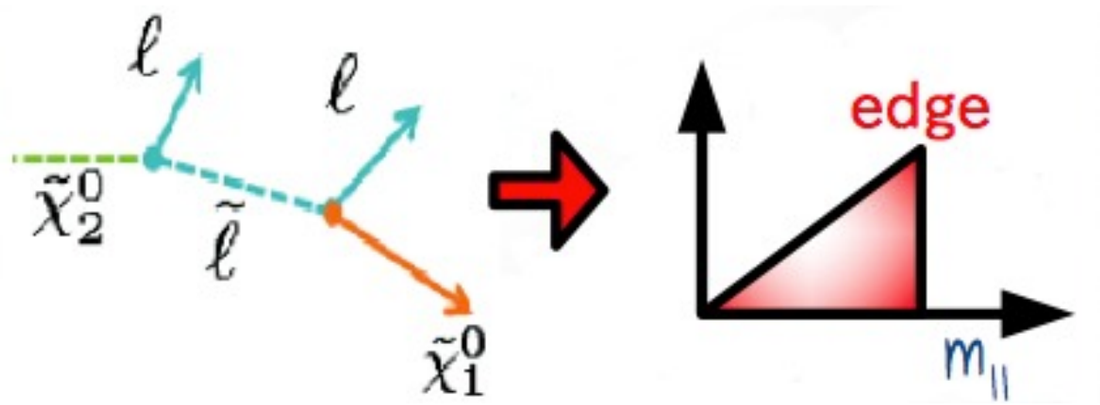
SEARCHES IN JETS + MET

- **strong production of massive particles**
  - require high p_T jets
  - leptons are vetoed
- **different techniques:**
  - large missing E_T
  - large jet hadronic transverse energy (H_T)
  - large jet multiplicities (large cascades)
  - QCD topology rejection
- **striking signature** from SUSY

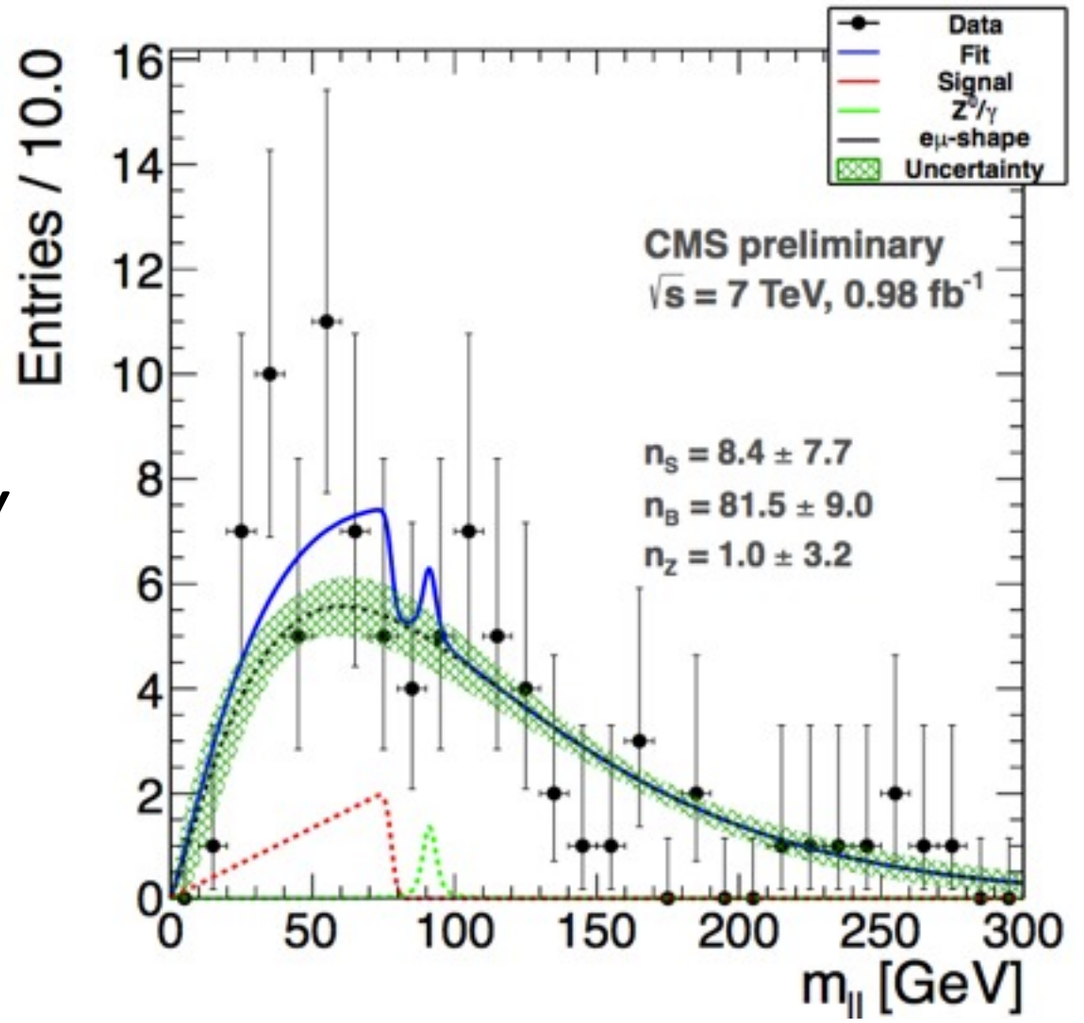


SEARCHES IN LEPTONS + MET

- **require leptons + MET**



- **different lepton selections**
  - 1 lepton
  - 2 opposite-sign leptons (same cascade)
  - 2 same-sign leptons with same or opposite flavor (opposite cascades)



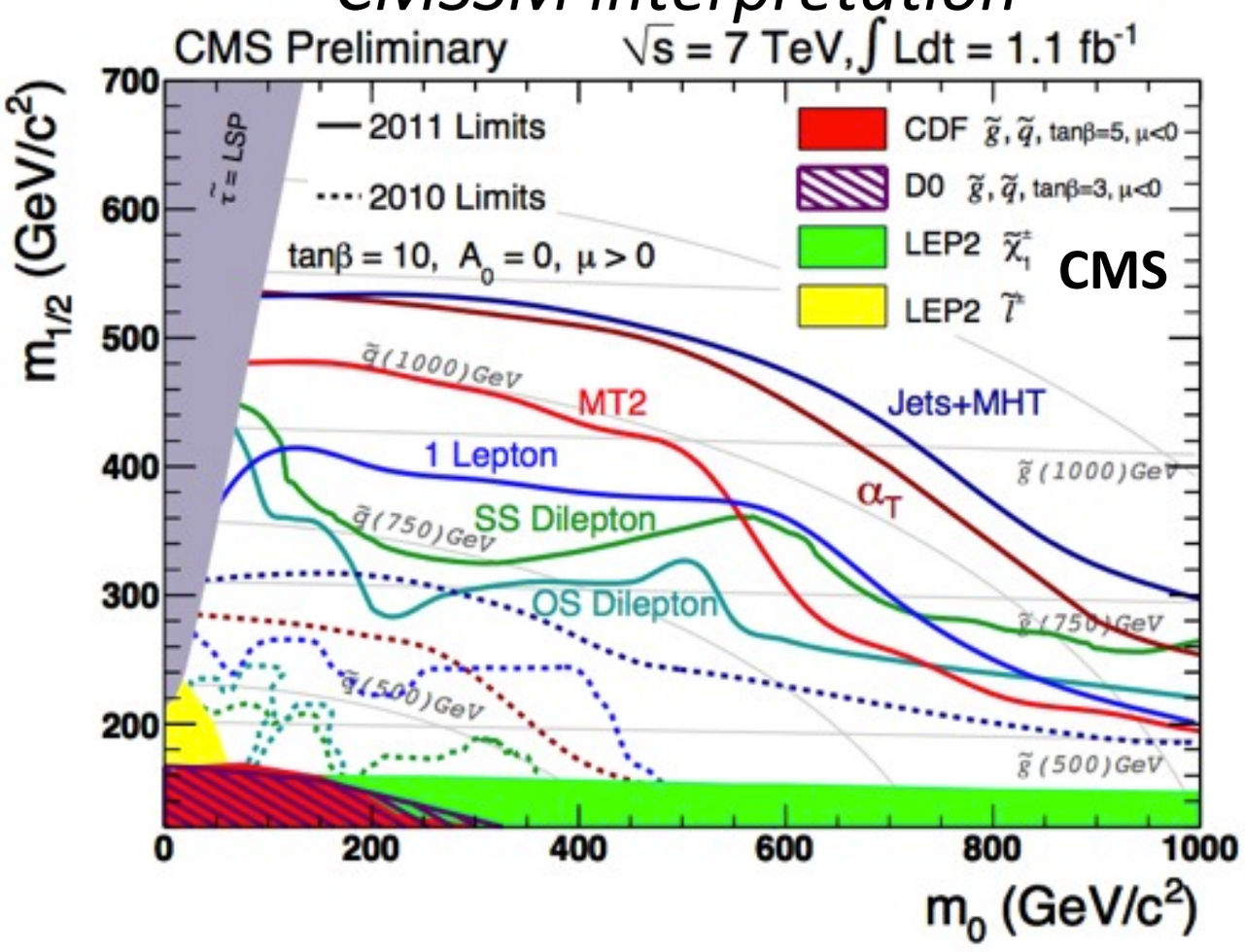
- use **kinematic constraint** of the SUSY cascade to identify signal

- **less stringent limits than fully hadronic but complementary**

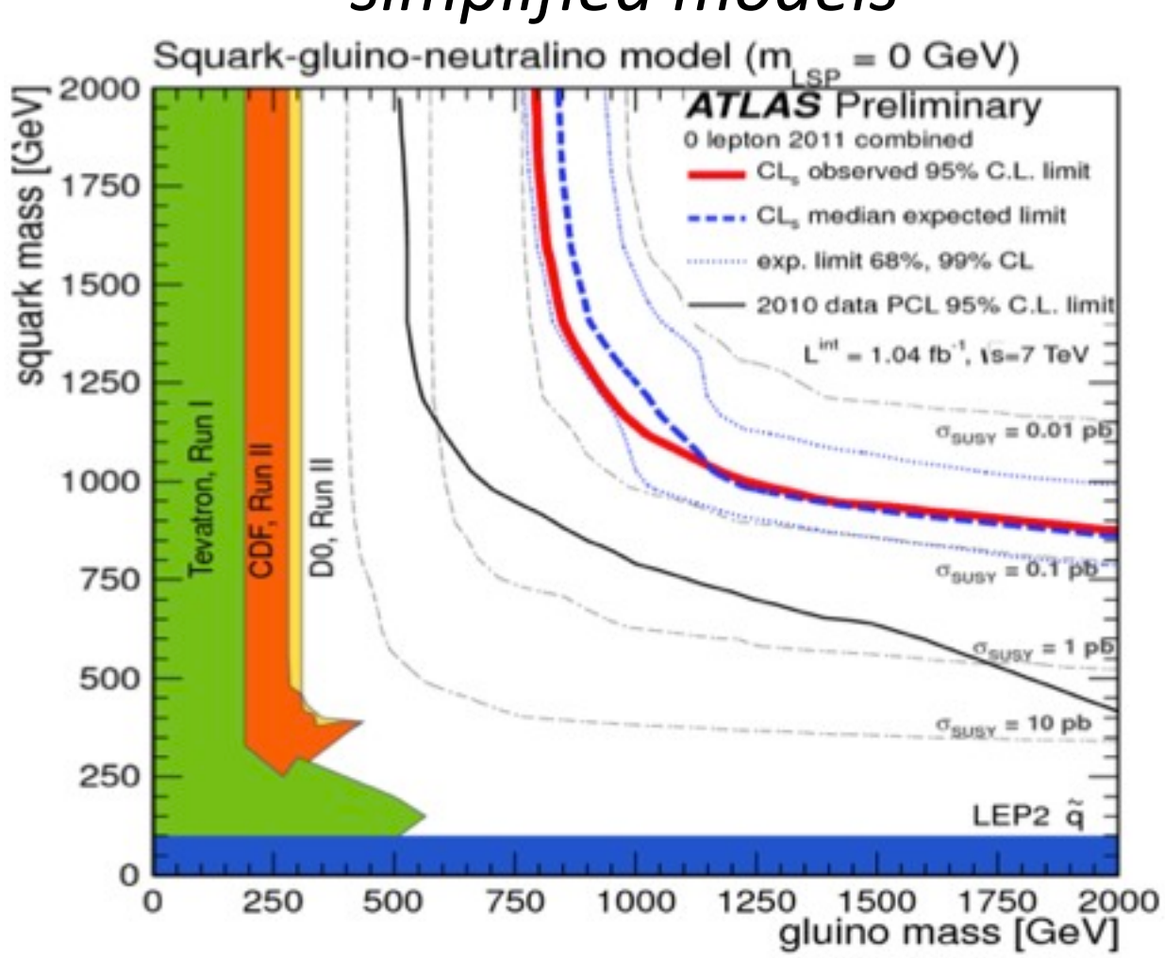
SUMMARY OF SUSY RESULTS

- **no hints of SUSY so far**
- much more stringent limits than for previous experiments
  - **limits at 1TeV for m(squark)=m(gluino)**
- x10 statistics helps but limited by 7TeV energy

CMSSM interpretation

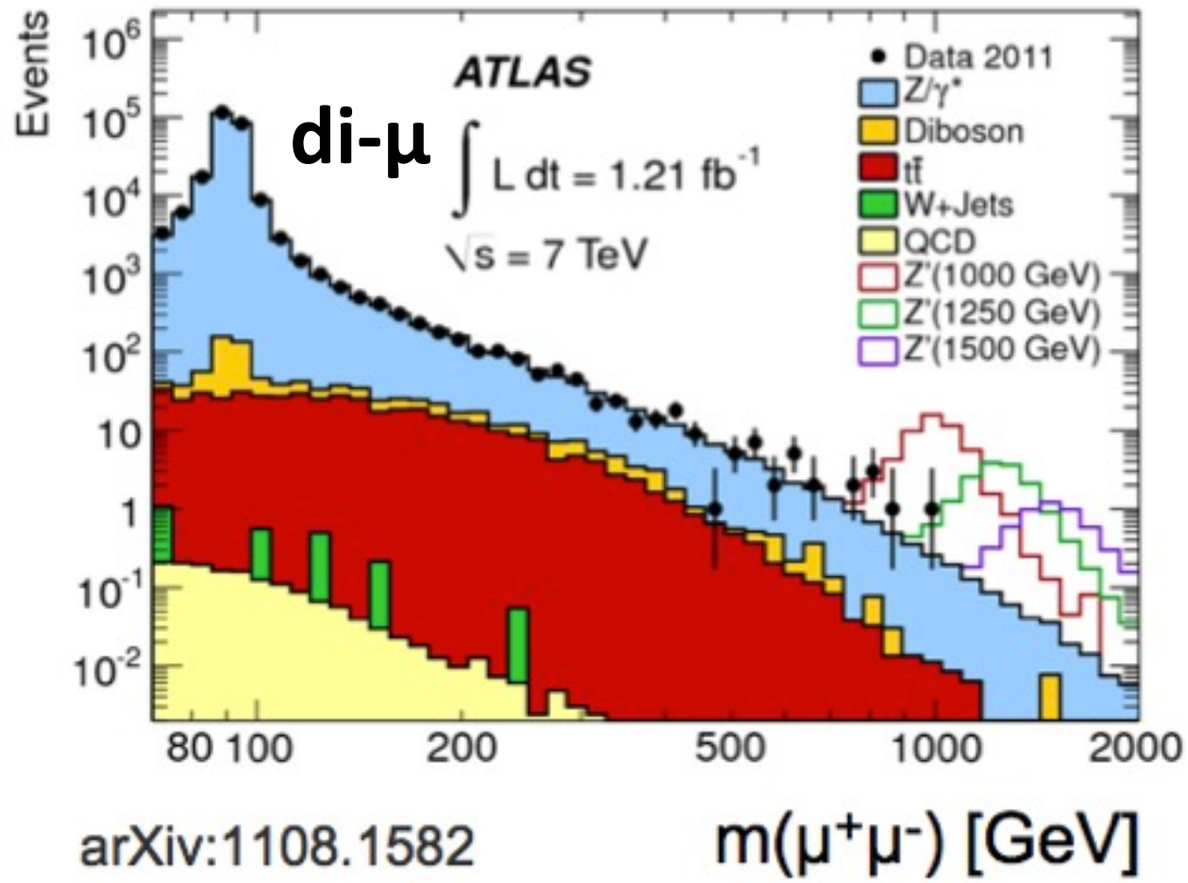


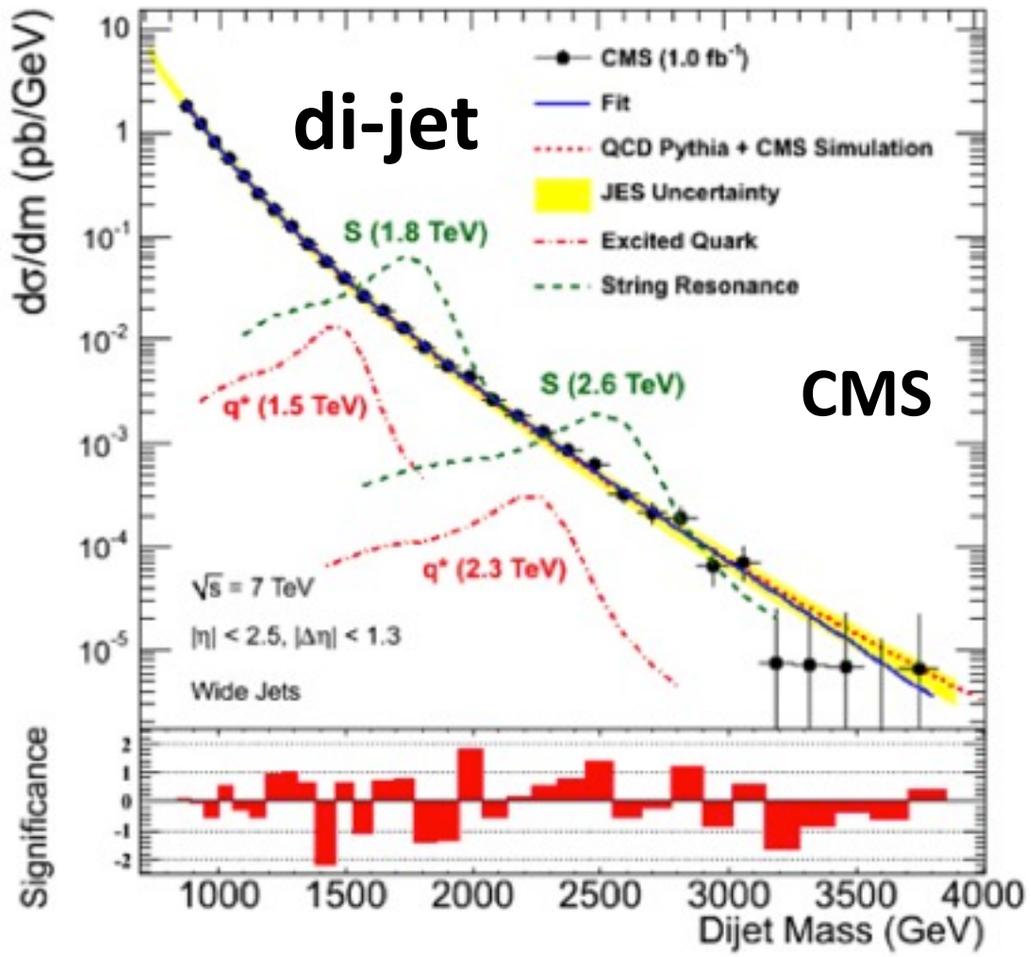
simplified models



SEARCHES FOR HEAVY RESONANCES

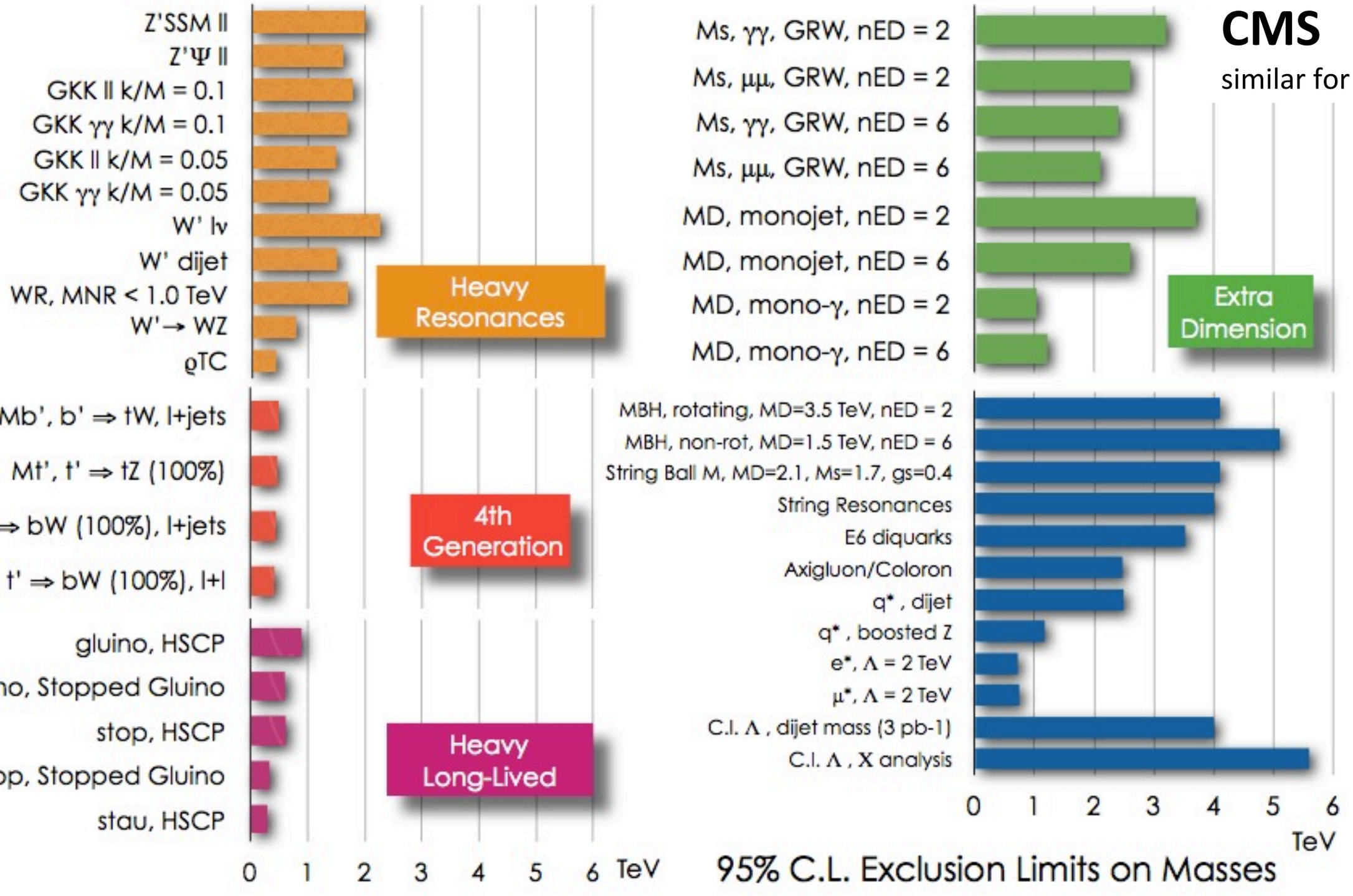
- **predicted by numerous extensions of SM**
  - sequential SM, GUT-inspired theories, technicolor, Kaluza-Klein ED
- **relatively clean with good S/B and identified by a peak!**
- care for **energy/momentum reconstruction above 1 TeV**
- **no peak so far**





ALL EXOTICA SEARCHES

- Full list, **to have a feeling of the scanned phase-space**



CMS

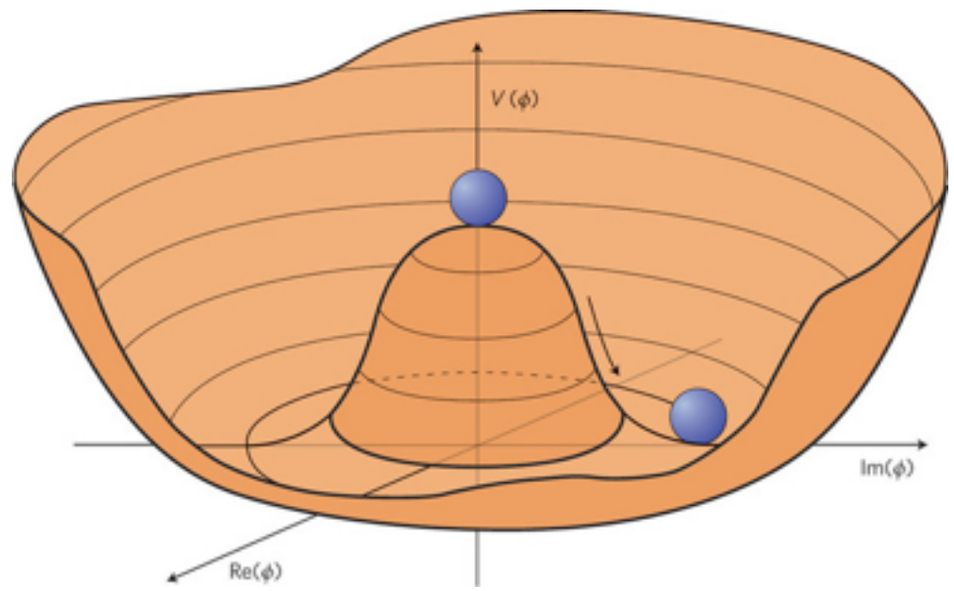
similar for ATLAS

Higgs Physics

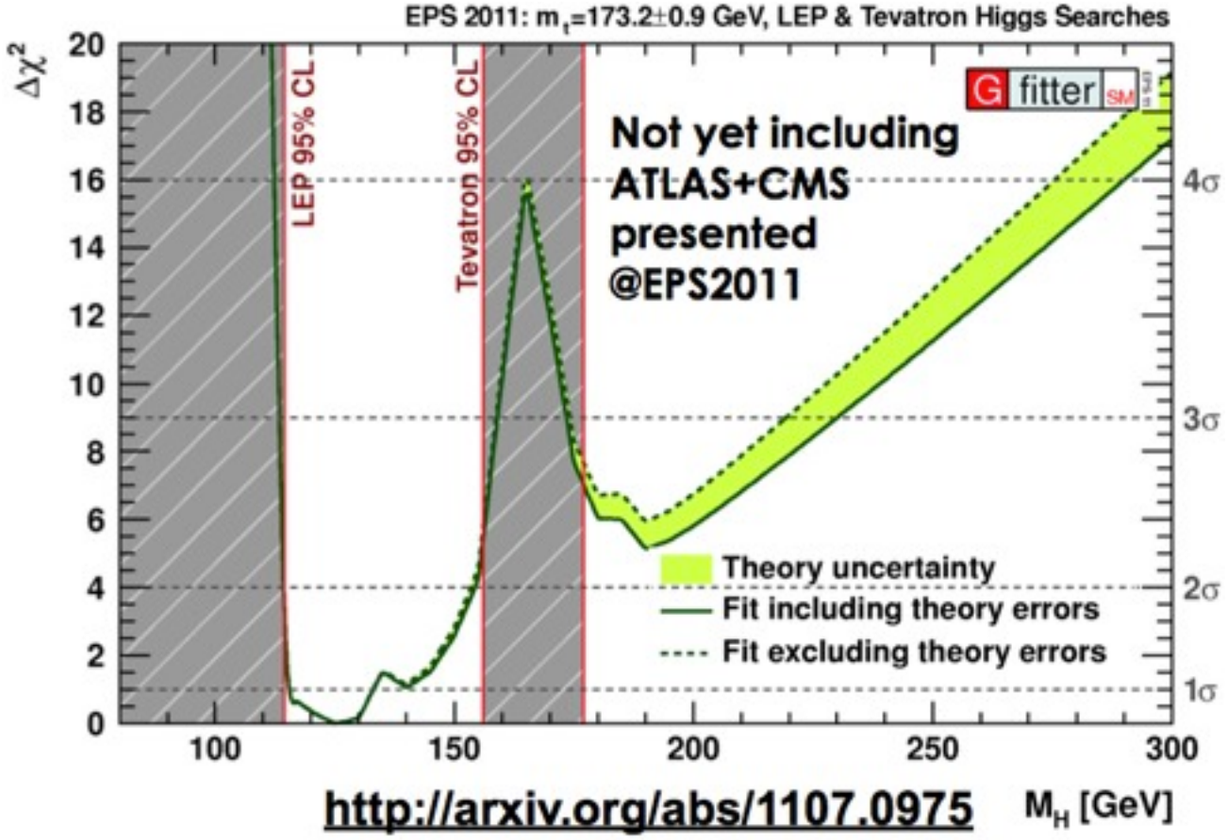
HUNTING THE HIGGS

- in SM **electroweak symmetry broken via the Higgs mechanism**

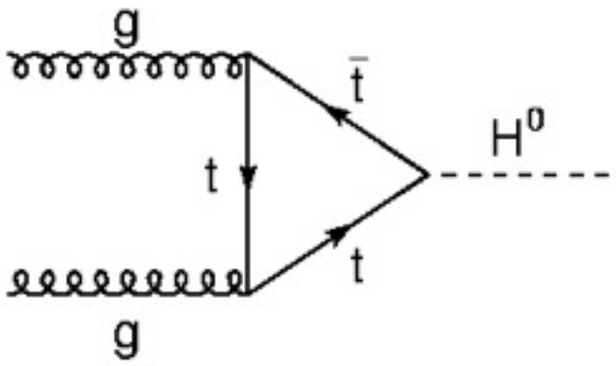
$$V(|\phi|) = \mu|\phi|^2 + \lambda|\phi|^4$$

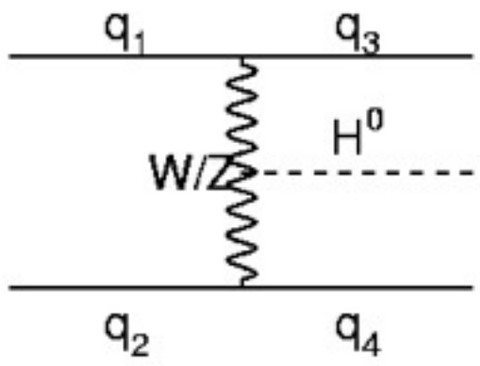


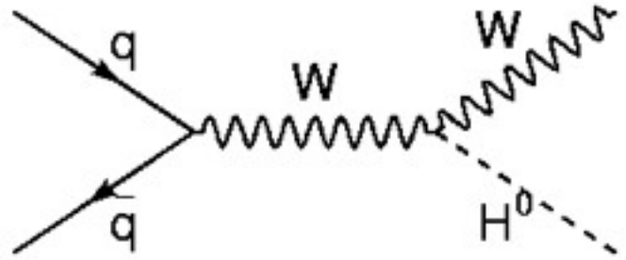
- **W and Z bosons acquire mass, photon** remains **massless**
- **Higgs not yet seen**
- **limits** for the Higgs bosons from **direct searches and global EW fits**

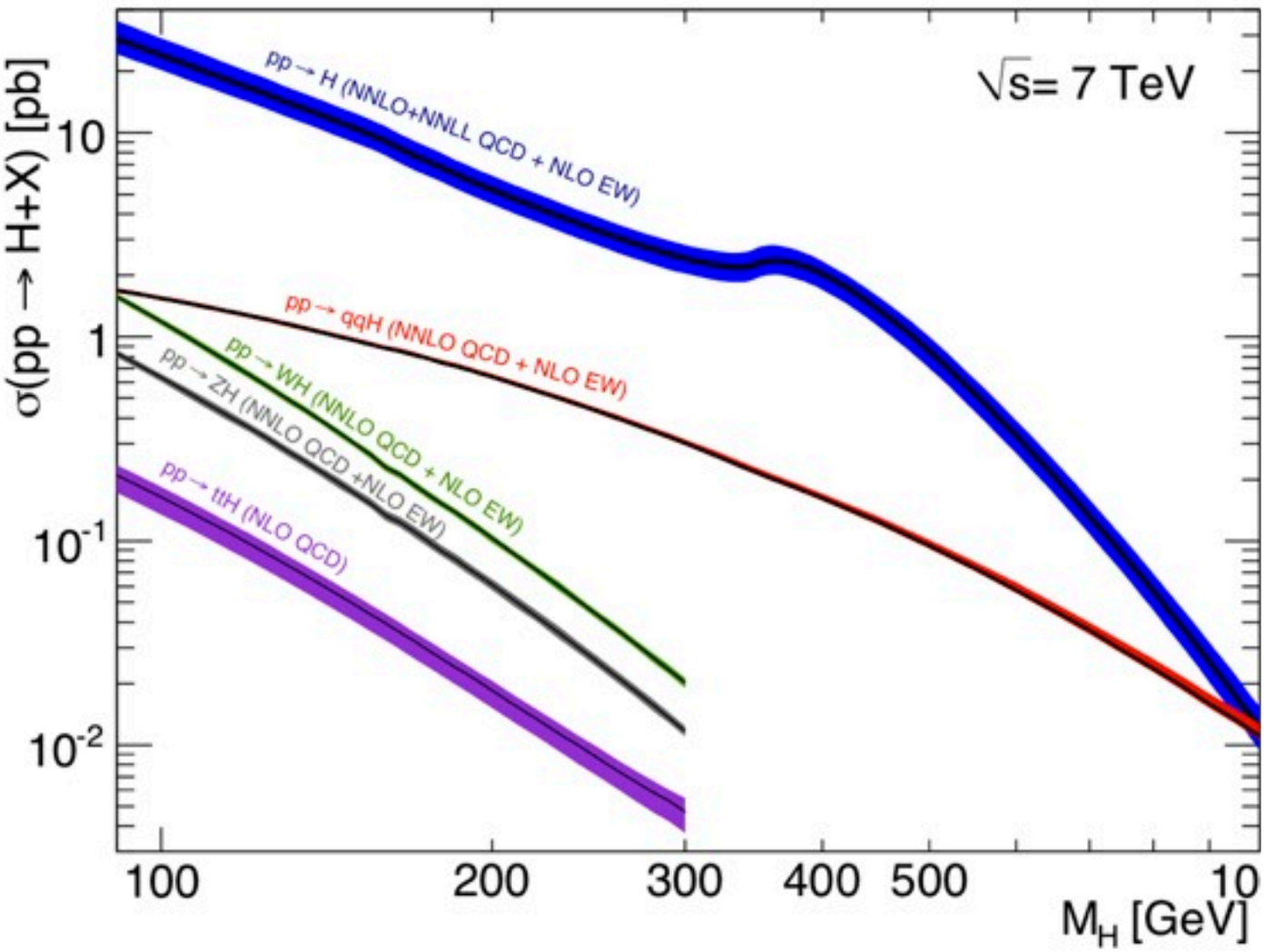


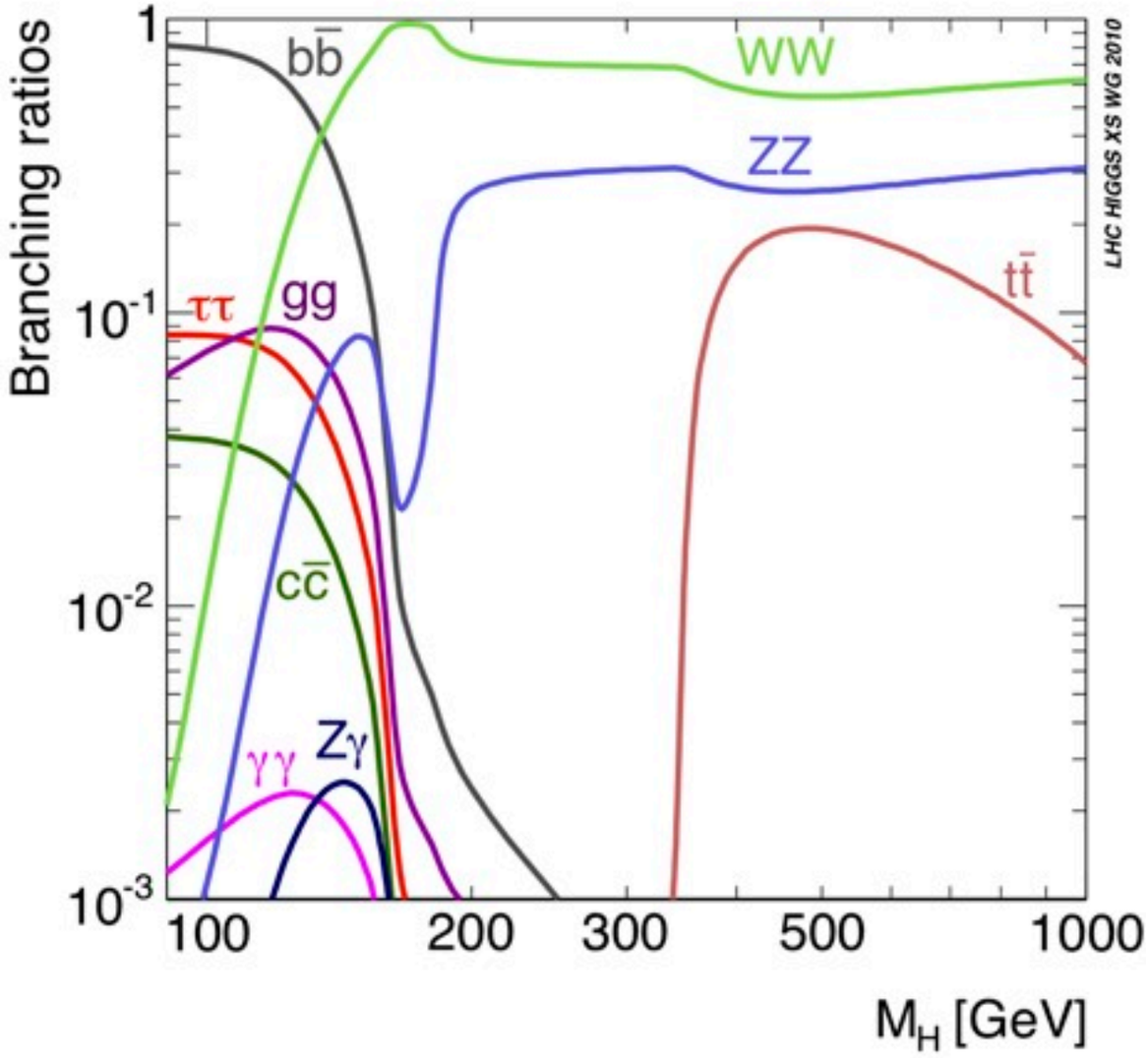
Higgs Cross Sections @ LHC and BR



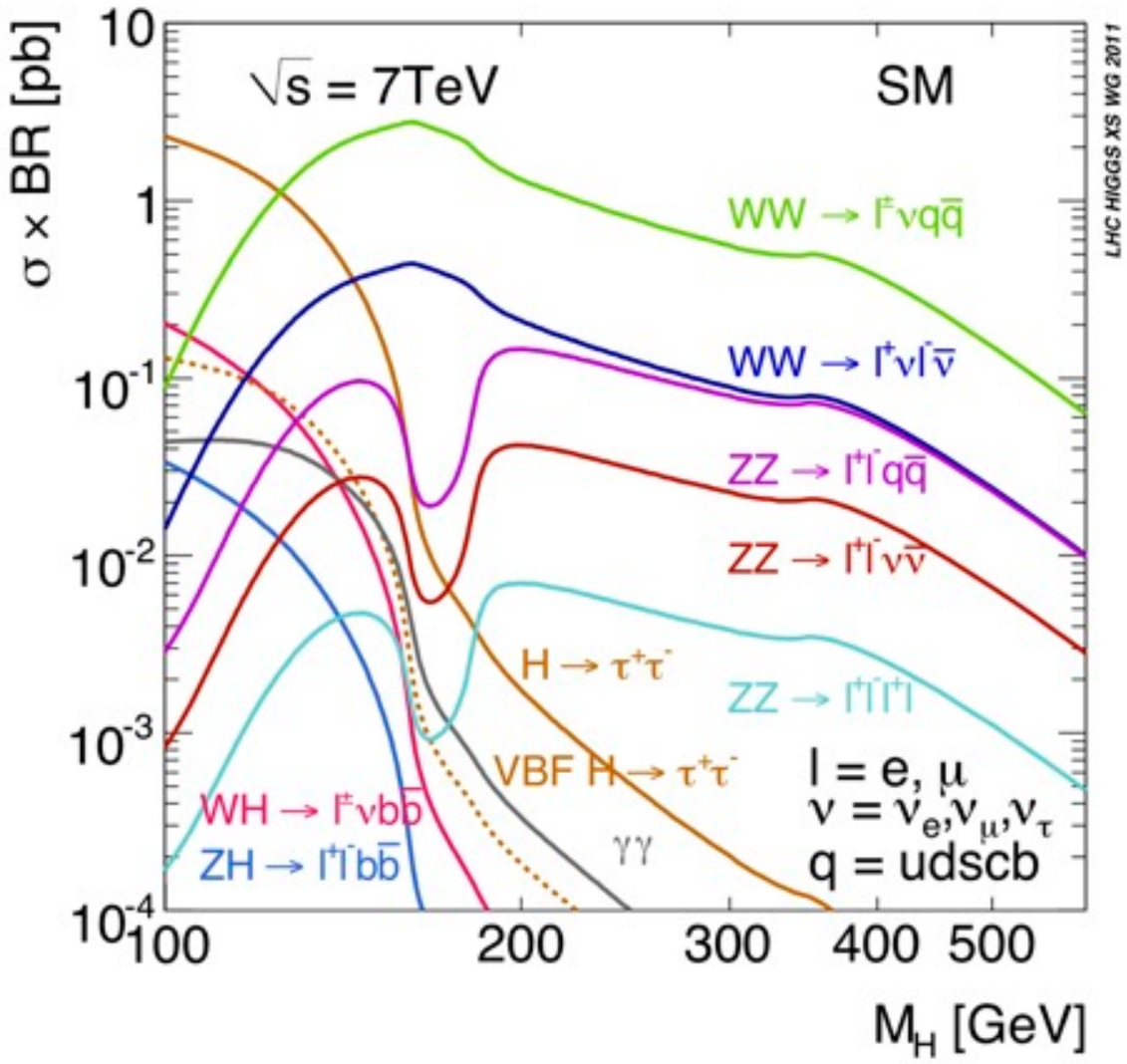








Higgs Cross Sections @ LHC and BR

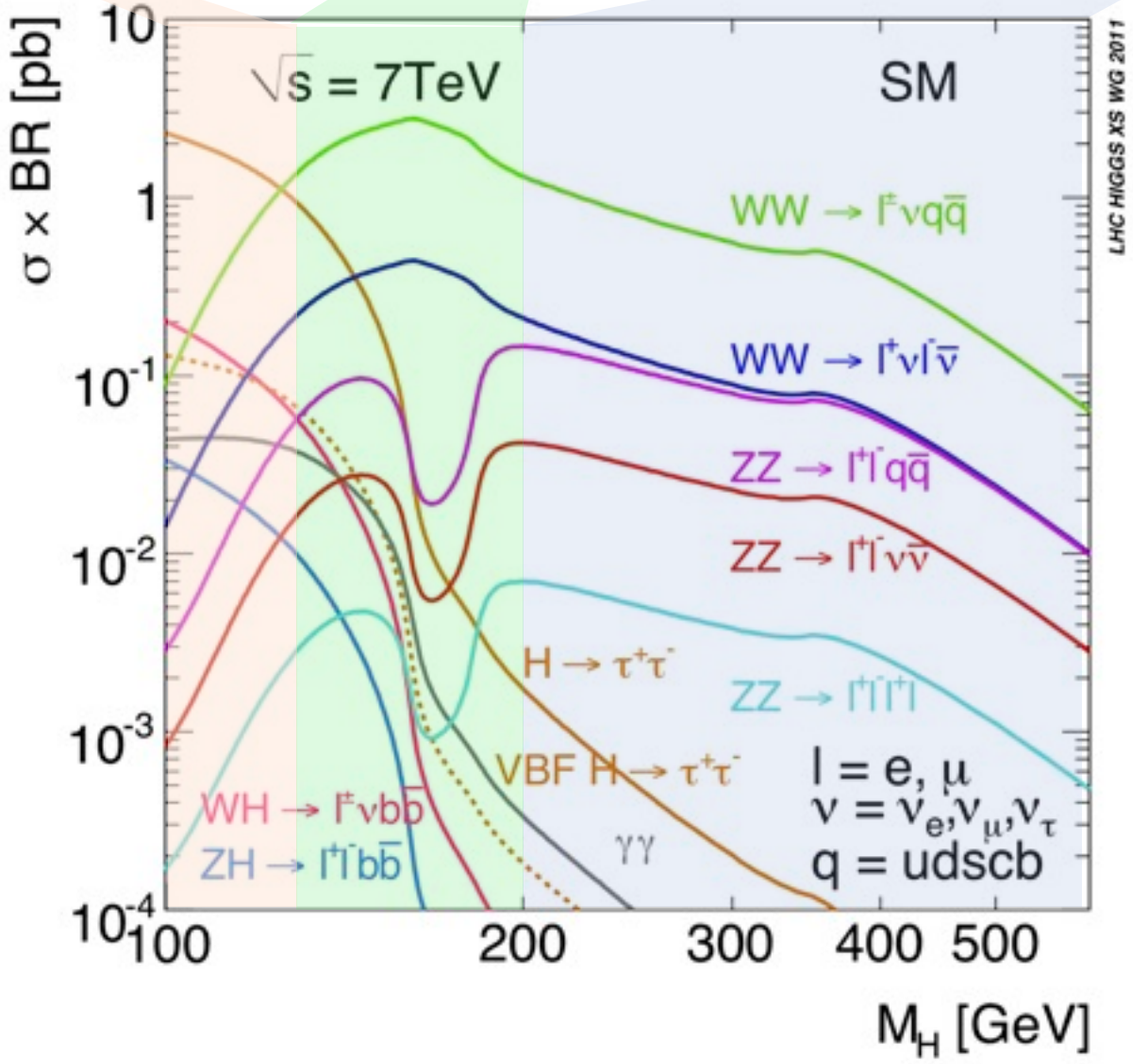


Higgs Cross Sections @ LHC and BR

M_H<130GeV
H→γγ dominates

130GeV<M_H<200GeV
H→WW dominates

M_H>200GeV
H→ZZ dominates

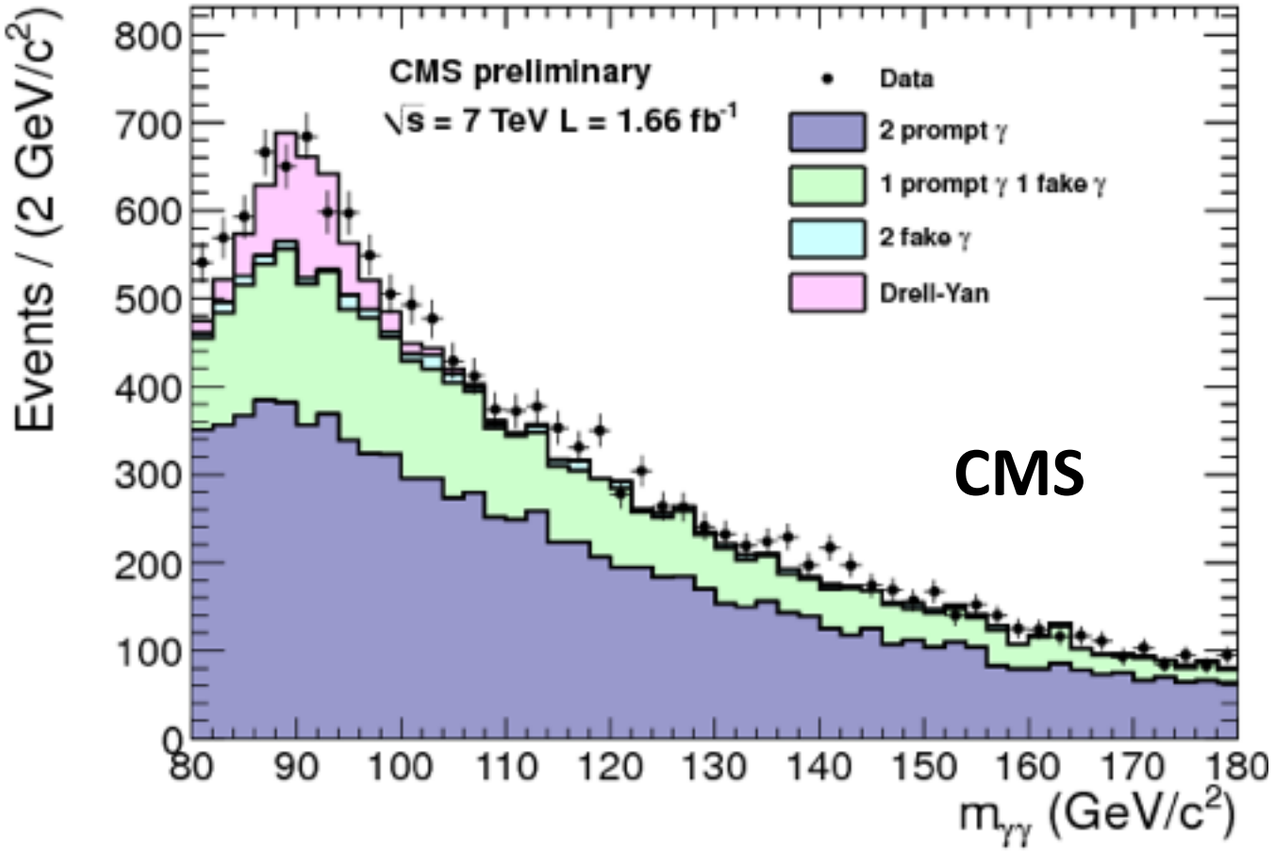


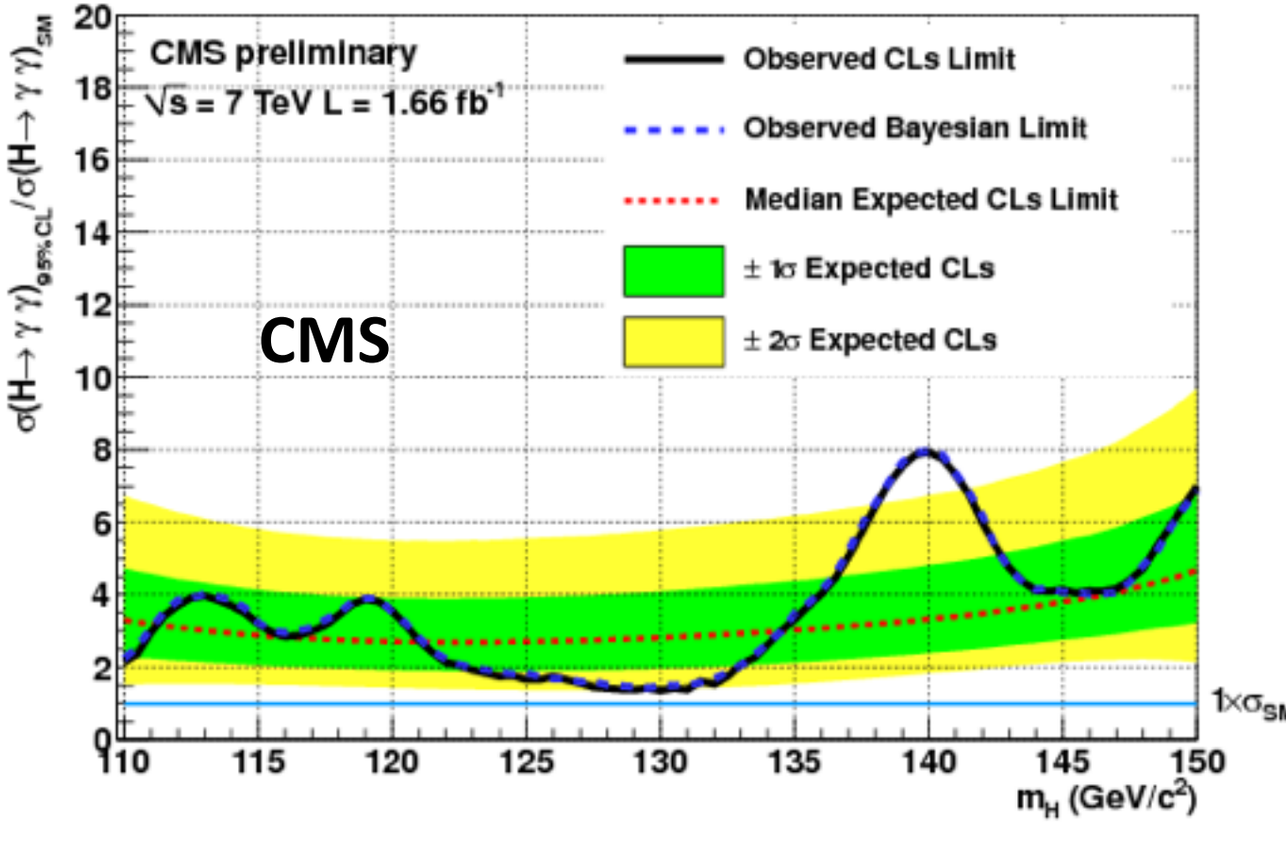
BACKGROUNDS, SIGNATURE, AND S/B

mode	backgrounds	signature	S/B
H→γγ	born/box diphoton QCD photon+ jet	two photons peak in inv. mass	low O(0.1)
H→WW	ttbar drell-yan pp→WW	two leptons with opposite charge MET	medium O(1)
H→ZZ	pp→ZZ	four leptons with right charge peaks in inv. mass (Z and Higgs)	high >1

$H \rightarrow \gamma\gamma$

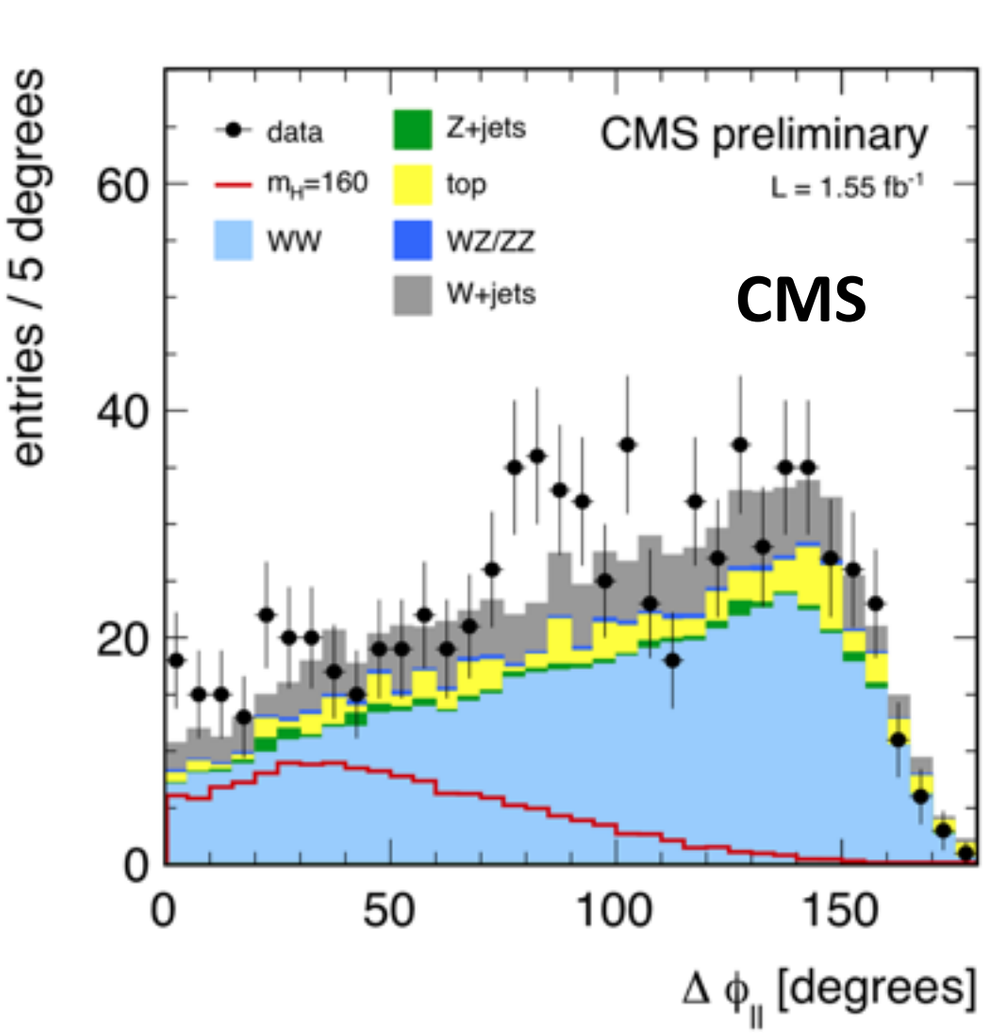
- **crucial** channel in the mass **region preferred by EWK fit**
- **sensitivity** to either excluded or see Higgs **not reached yet**
  - exclusion at about **3xSM**
- **with O(10fb^{-1})** possible to give **a final answer**

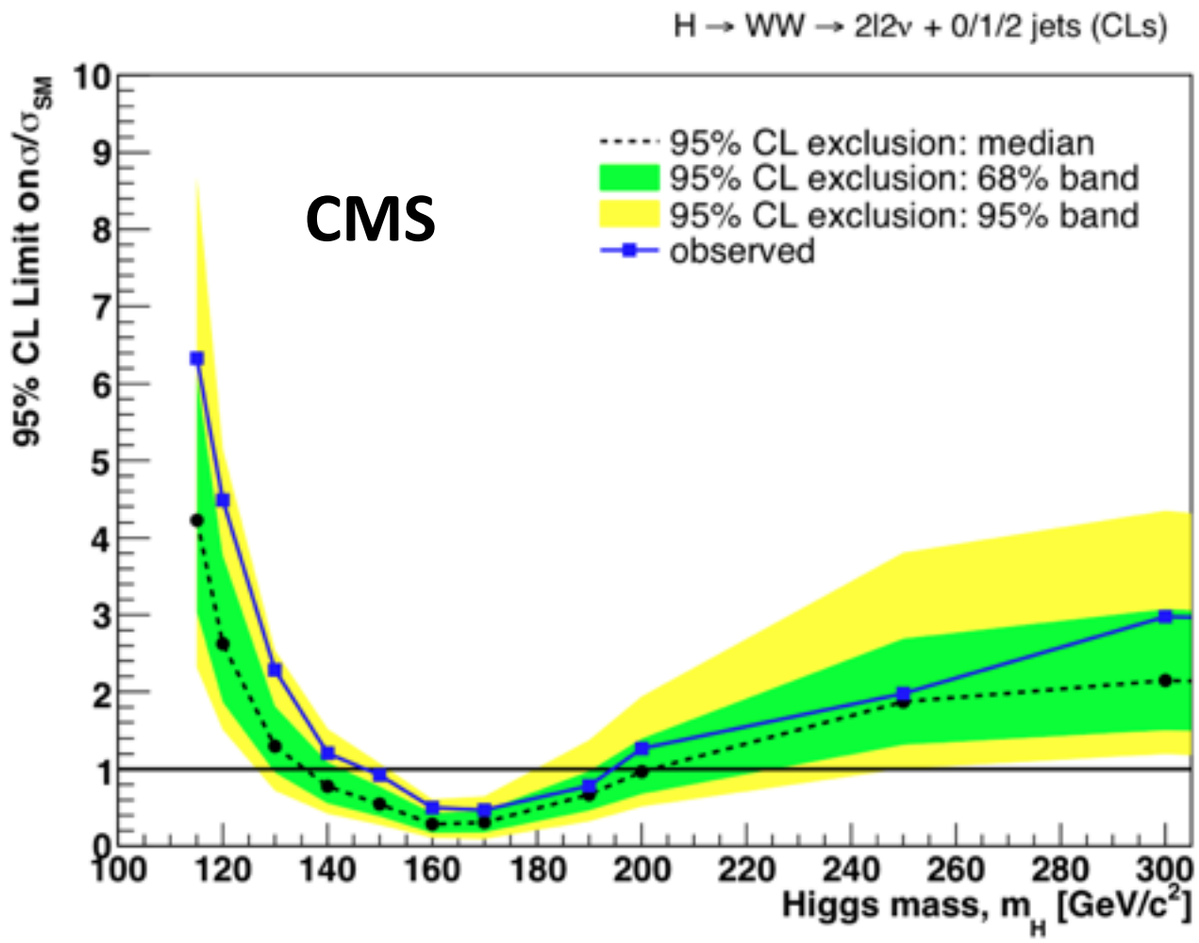




$H \rightarrow WW$

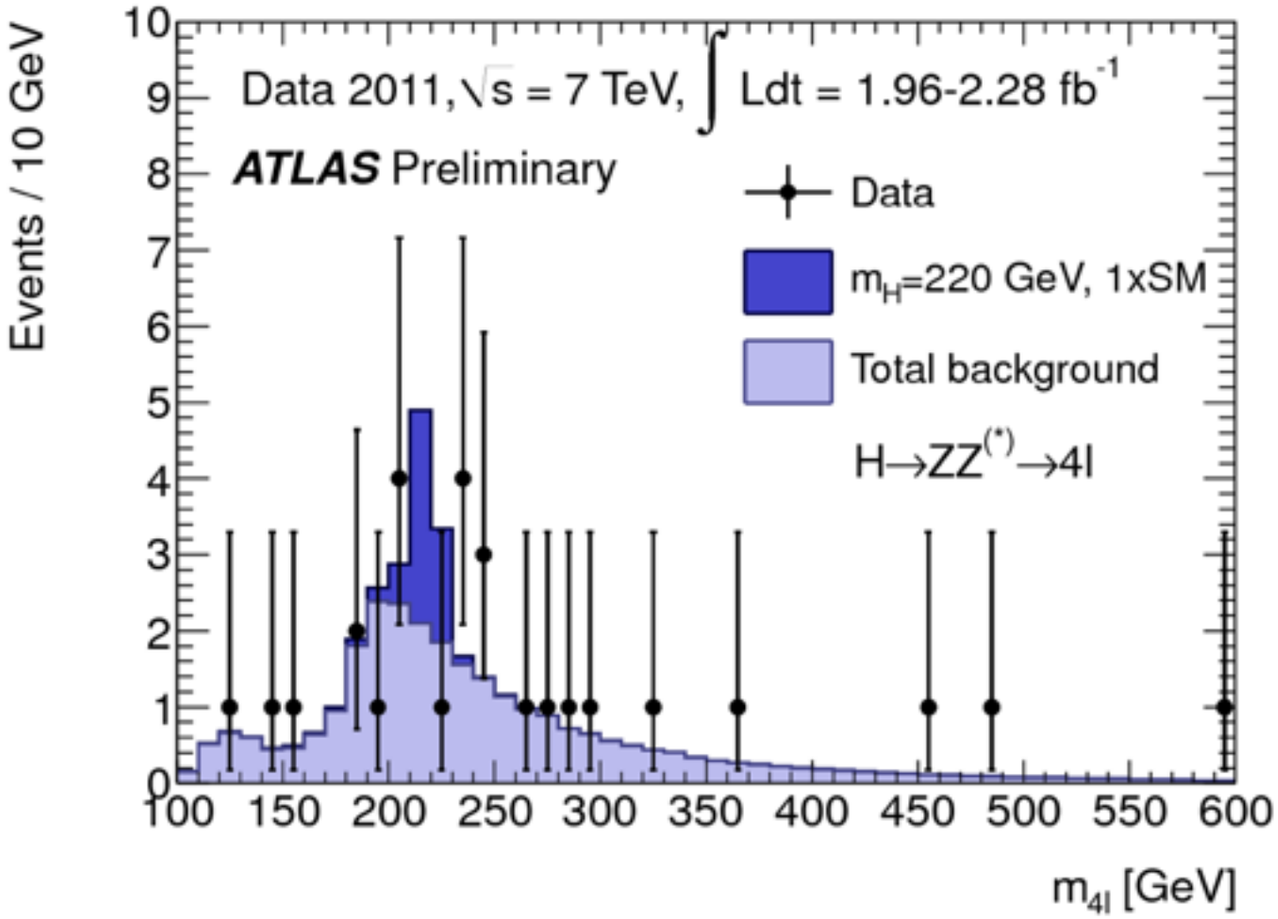
- **best** channel for exclusion in the **intermediate mass region**
  - but **tough for discovery** since no peak
- MET and topology requirements (e.g. $\Delta\phi$ between leptons)
- **exclusion in 140GeV<M_H<200GeV**

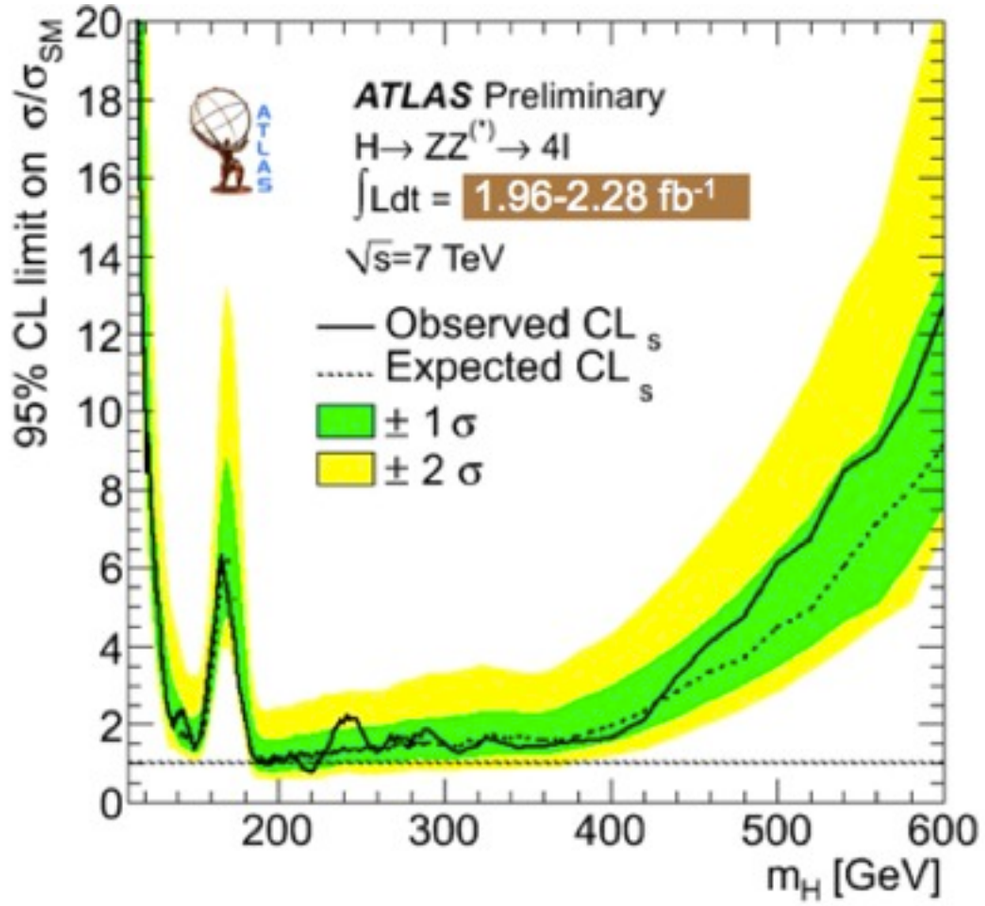




H → ZZ

- **very clean** signature (peak over ZZ SM) **but low statistics**
  - **best channel** for discovery at **high masses**
- **sensitivity (>200GeV)** already **reached**
- exclusion in **combination with other ZZ modes** (e.g. 2l2ν)

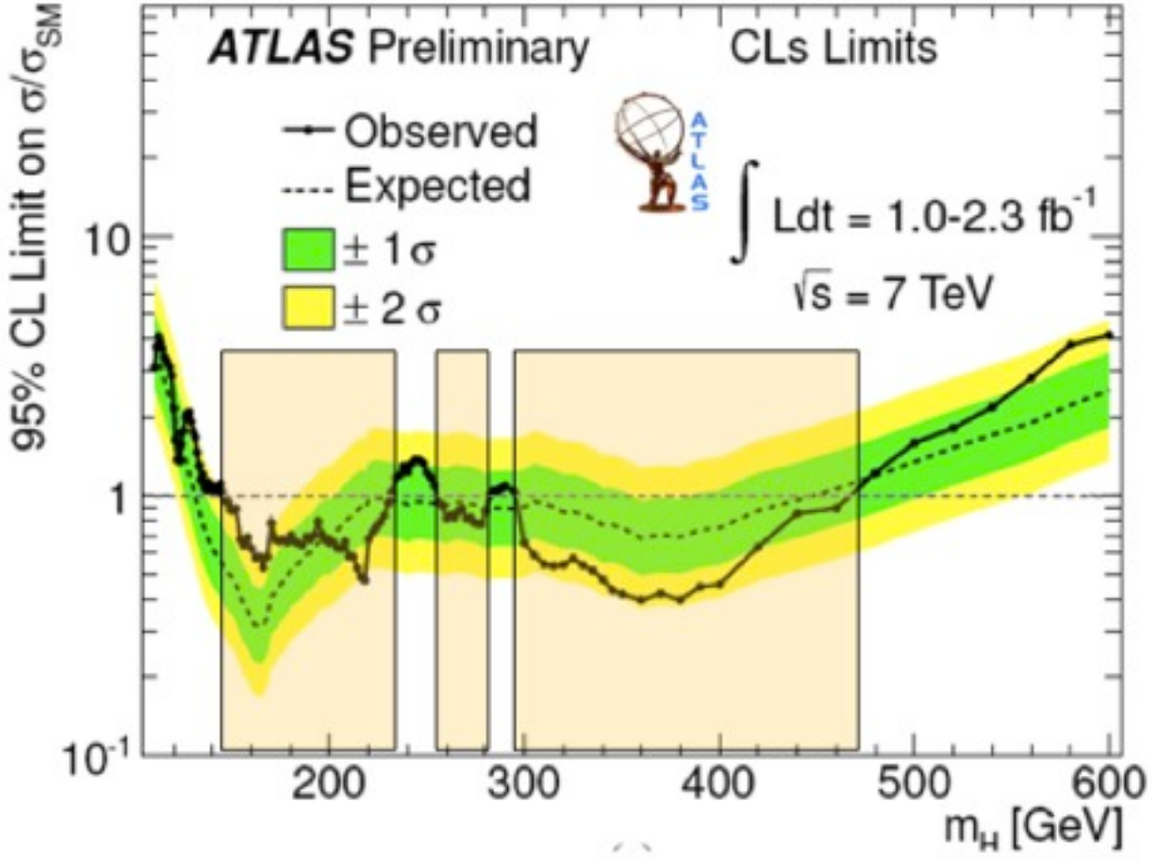


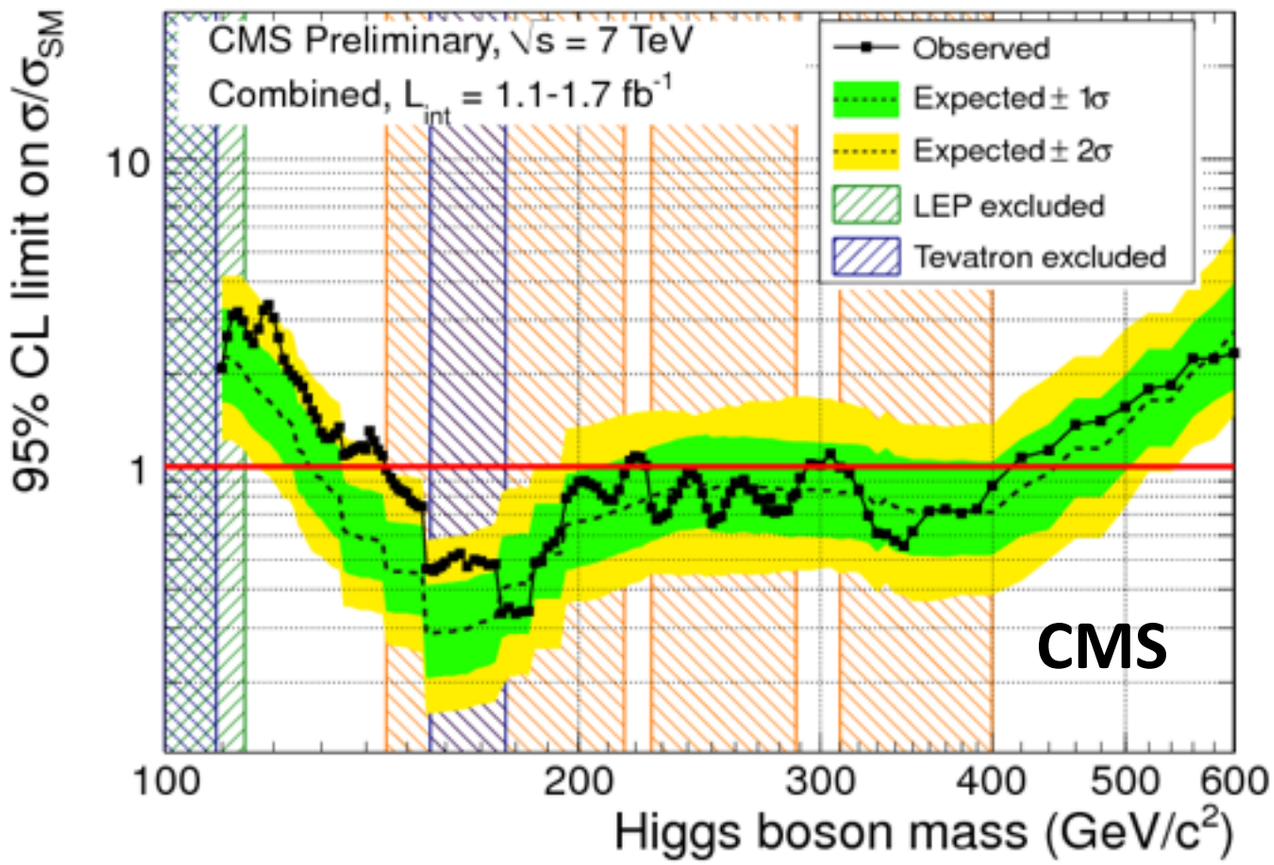


HIGGS COMBINATION: UPPER LIMIT

- final limits **combining more than 10 channels**
- **ATLAS-CMS combination in progress**
- expect that at 95% confidence level Higgs is excluded in region

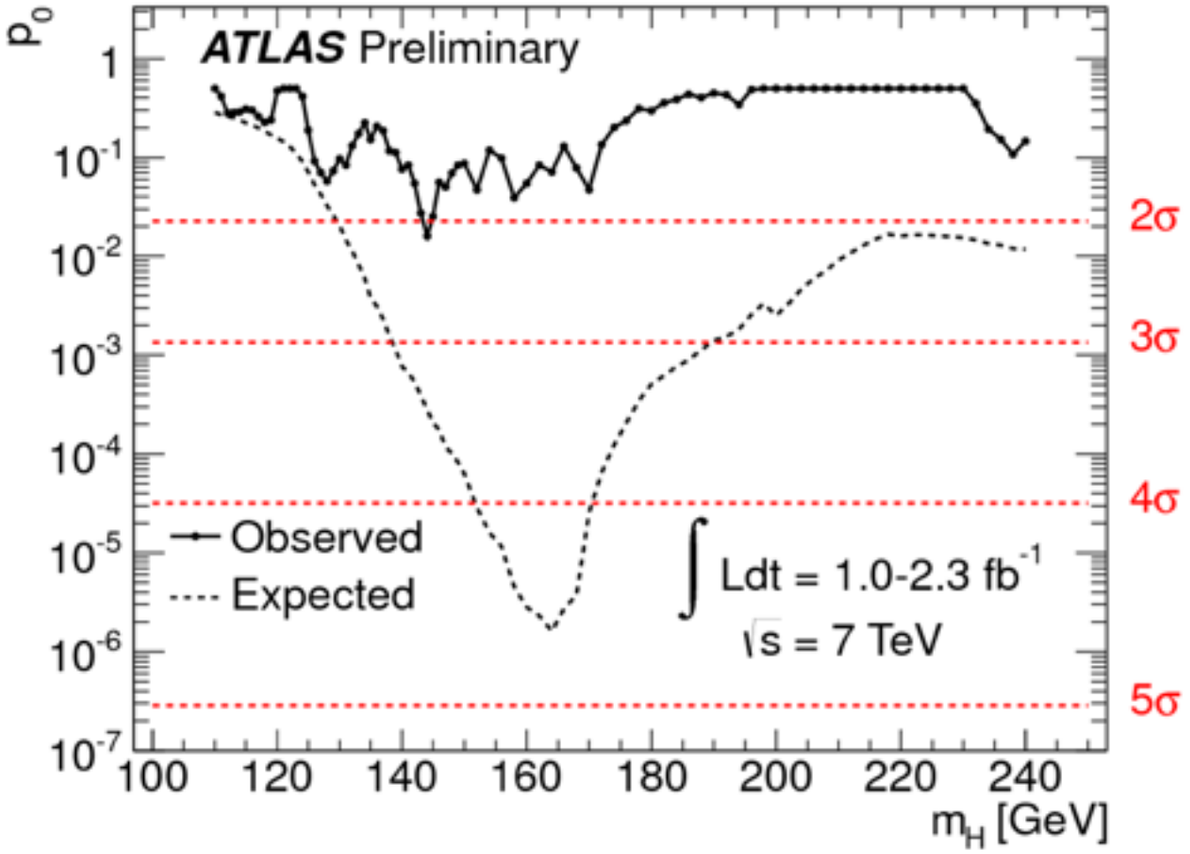
  140GeV<M_H<450GeV

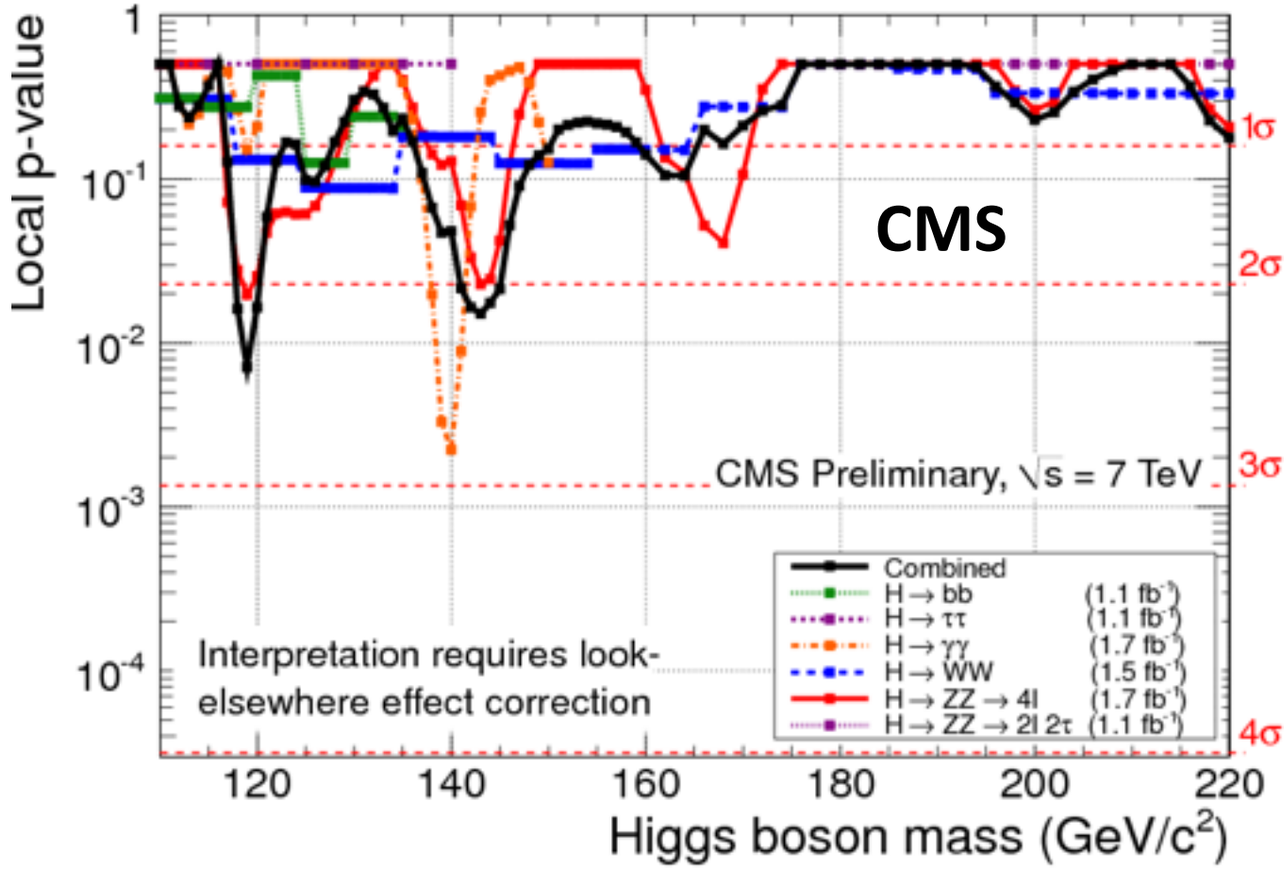




HIGGS COMBINATION: P-VALUE

- **p-value** = probability that data are consistent with a background-only hypothesis
- **no significant excess yet...**

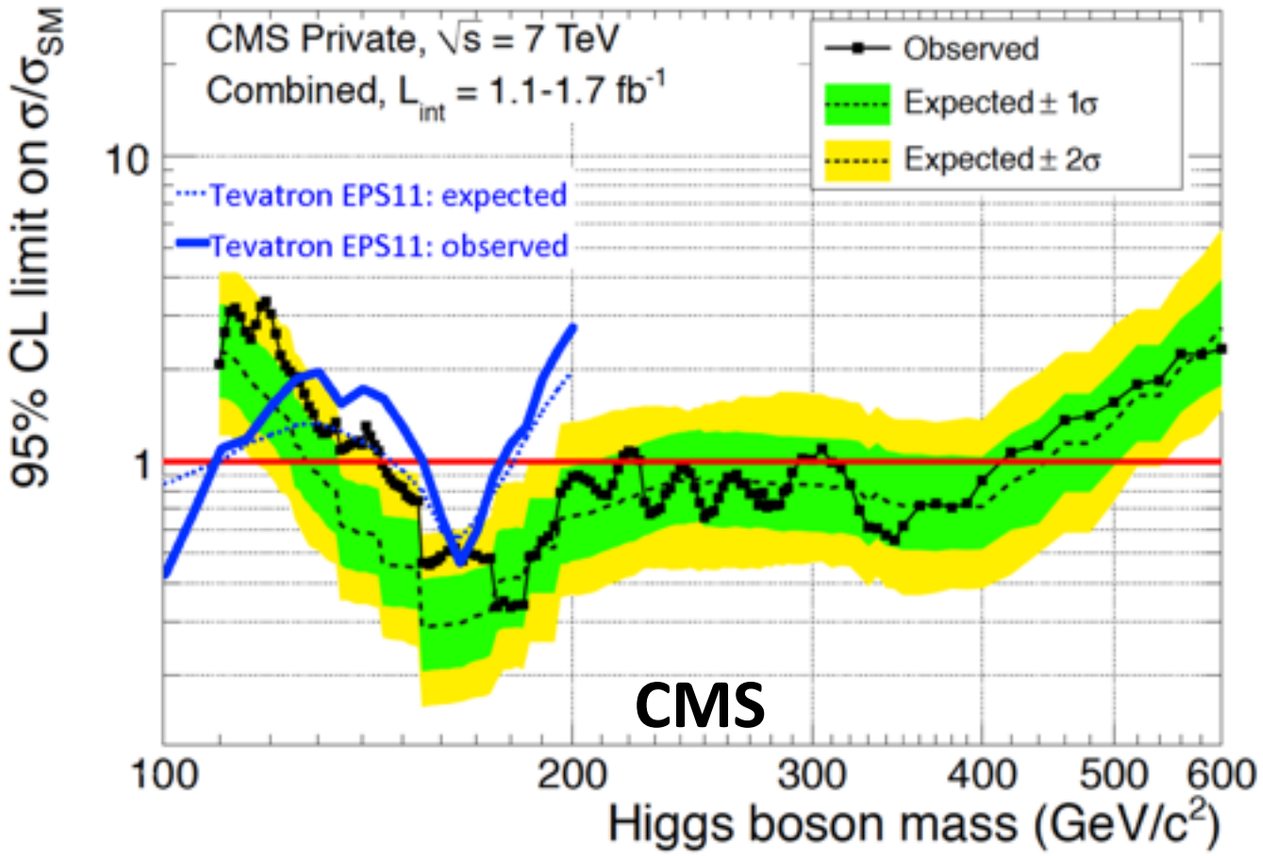




HIGGS: CONCLUSIONS AND PERSPECTIVES

- **Tevatron results are almost superseded** (except for very low mass)
- Higgs with **large mass (>140GeV) is unlikely**
  - excluded with a decent CL by LHC
- **tough job at low masses**
  - major player will be $H \rightarrow \gamma\gamma$

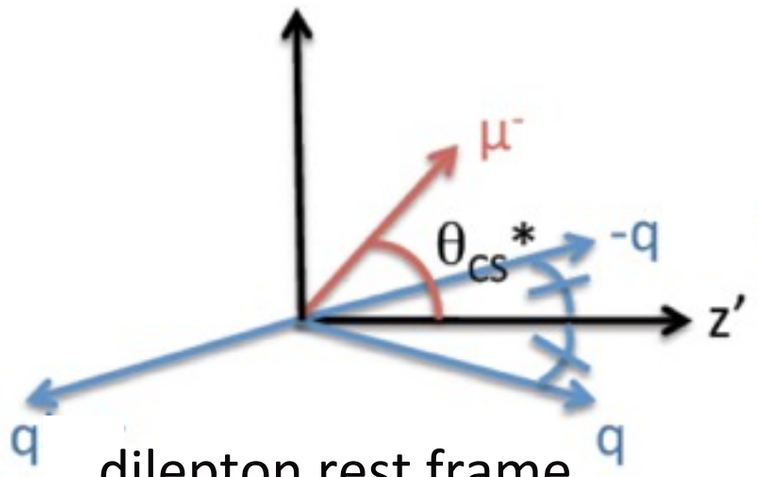
- **Personal view:**
  - O($10fb^{-1}$) enough to exclude on the whole range
    ⇒ ~Moriond 2012
  - end of 2012 for a final answer



CONCLUSIONS

- **LHC is doing great. >2fb^{-1} so far. Fast increase expected**
- **Fantastic performance of ATLAS and CMS**
  - physics objects and trigger already deeply understood
- **Wide physics output (>100 ATLAS+CMS papers)**
  - EWK and Top physics already at precision level
  - extensive searches of physics beyond SM
  - Higgs hunting providing world-best exclusions
- **Short summary of searches**
  - no hint of new physics or Higgs. Exclusion at 95% CL:

SUSY ($m_{squark}=m_{gluino}$)	**<1TeV**
New Gauge Bosons (Sequential SM)	**<2TeV**
Higgs	**140GeV<M_H<450GeV**



dilepton rest frame