Experimental Conference Summary

PLHC 2012

June 4 - 9, 2012

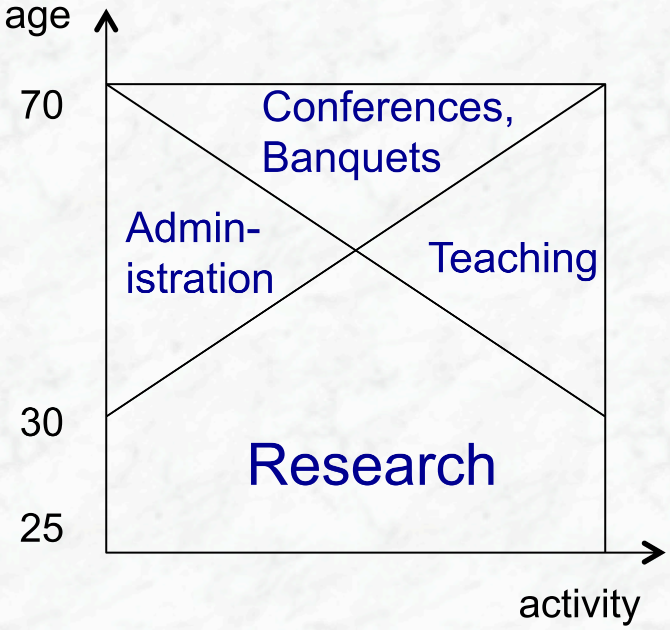
Physics at LHC -2012

Vancouver, BC

Karl Jakobs
Physikalisches Institut
Universität Freiburg / Germany

- At this conference more than 70 experimental talks were given
- I do not attempt to summarize all results in detail and I had to make a selection; I would in no way be capable of giving justice and fair credit to the fantastic amount of work presented during this week (I will also not quote any names of speakers)
- My apologies to those speakers whose results I have omitted

  It is not intended as a reflection of the relative importance !



The role of the LHC

1. Explore the **TeV mass scale**

- What is the origin of the electroweak symmetry breaking ?
  Does the Higgs boson exist?

- Search for physics Beyond the Standard Model
  (Low energy supersymmetry, other scenarios…,)

Look for the "expected", but we need to be open for surprises

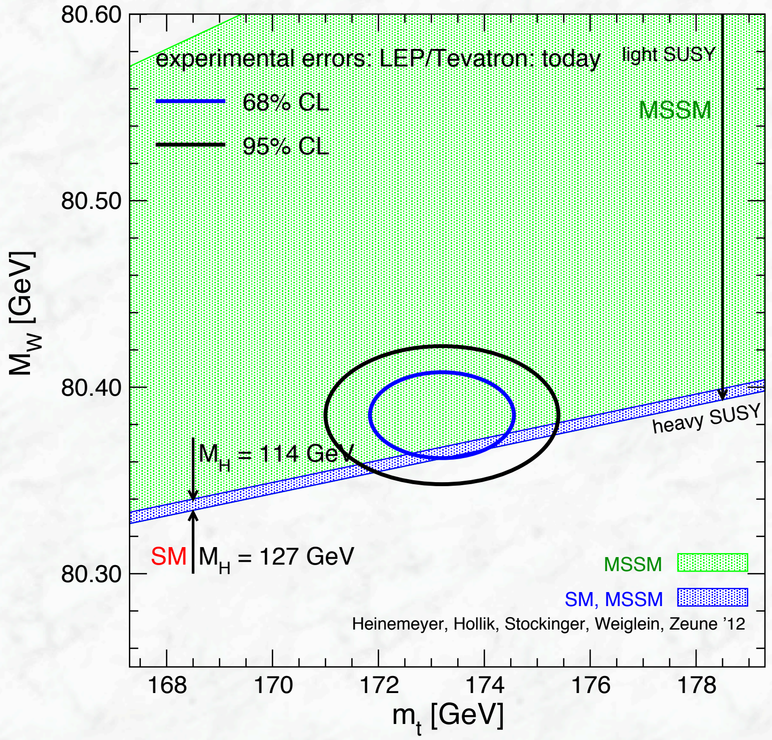
→ perform as many searches (inclusive, exclusive…) for as many final states as possible

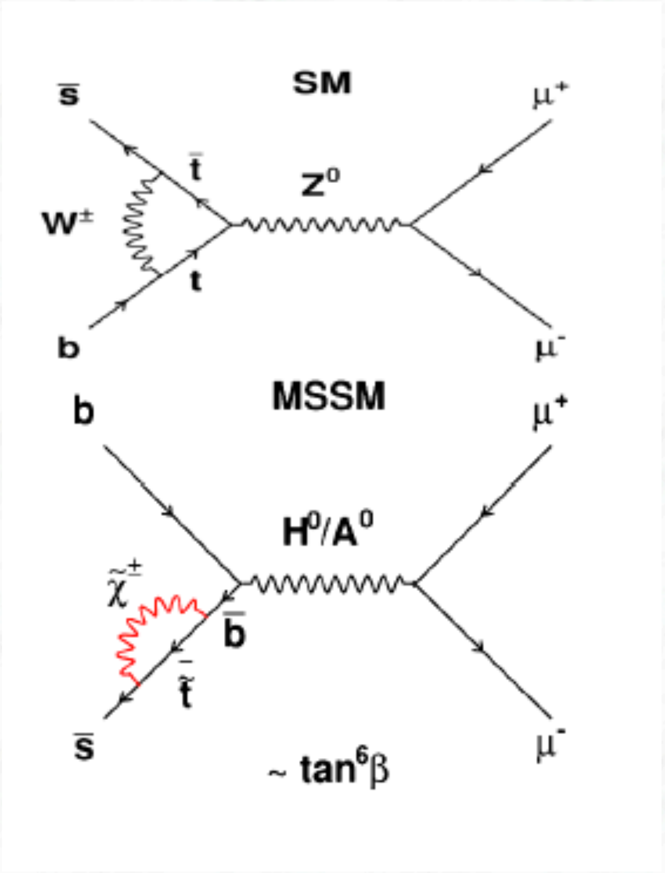
2. Precise tests of the Standard Model

- There is much sensitivity to physics beyond the Standard Model in the precision area (loop-induced effects, probe energy scales far beyond direct reach)
  → precise measurements, search for rare processes

Two important examples:

2012





Ultimate test of the Standard Model:

compare direct prediction of the Higgs boson mass with direct observation

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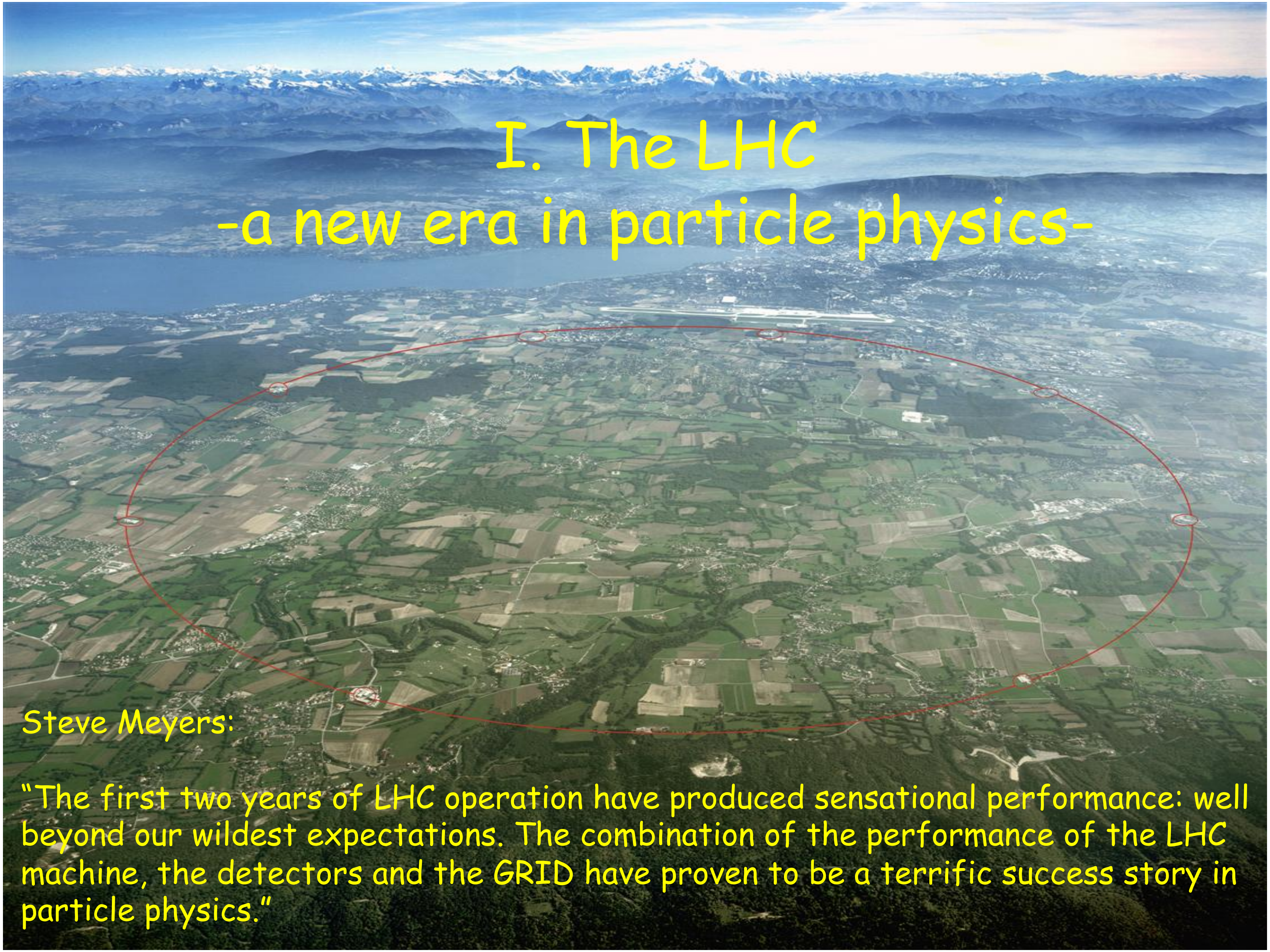
2. Precise tests of the Standard Model

- There is much sensitivity to physics beyond the Standard Model in the precision area (loop-induced effects, probe energy scales far beyond direct reach)
  → precise measurements, search for rare processes

→ Guidance to theory and Future Experiments

Many theoretical models for physics Beyond the Standard Model

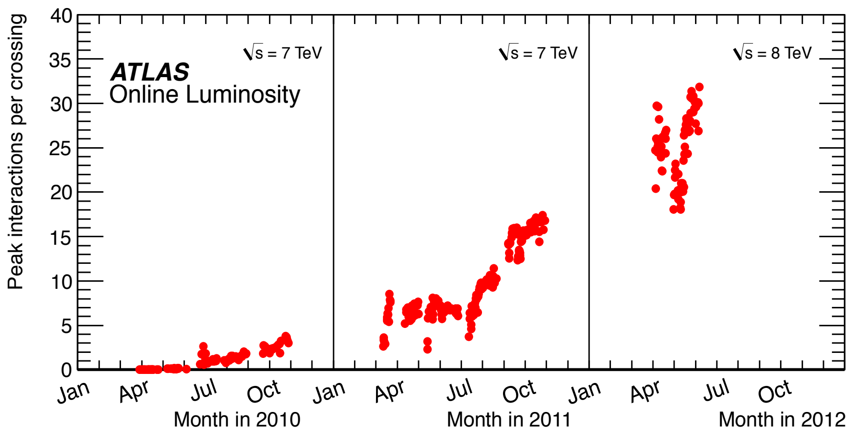


I. The LHC
-a new era in particle physics-

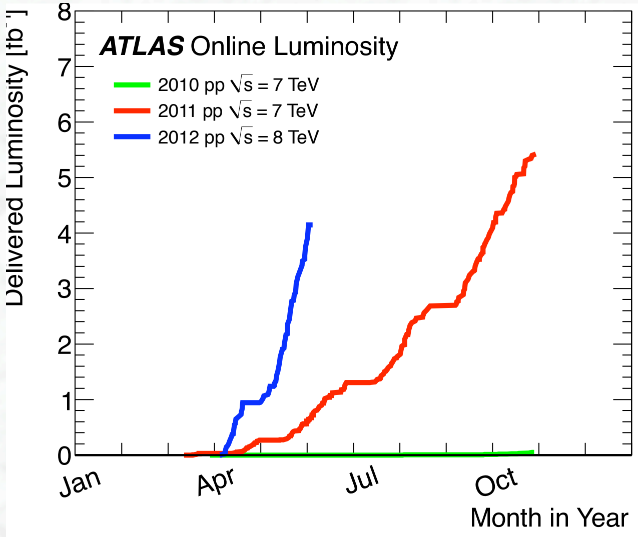
Steve Meyers:

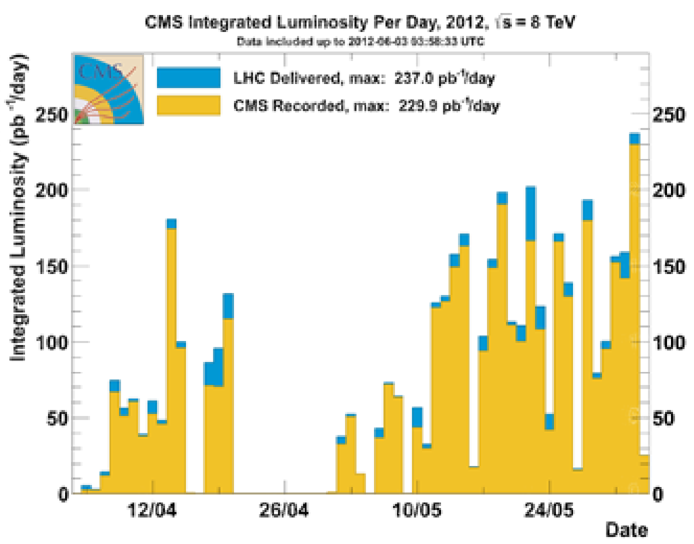
"The first two years of LHC operation have produced sensational performance: well beyond our wildest expectations. The combination of the performance of the LHC machine, the detectors and the GRID have proven to be a terrific success story in particle physics."

A few facts to back this up:



- World record on instantaneous luminosity on 22. April 2011: 4.67 10^{32} cm^{-2} s^{-1} (Tevatron record: 4.02 10^{32} cm^{-2} s^{-1})
- 2011: collect per day as much int. luminosity as in 2010
- 2012: now regularly above 6 10^{33} $cm^{-2}s^{-1}$, record ~6.6 10^{33} $cm^{-2}s^{-1}$





- Very rapid rise in luminosity
- + good machine stability → high integrated luminosities

Completion of an era: Tevatron

Accelerator Innovations

- First major SC synchrotron
- Industrial production of SC cable (MRI)
- Electron cooling
- New RF manipulation techniques

But Tevatron is still in the game:

- W mass
- H → bb
- B physics
- …

and developing

- GRID pioneers

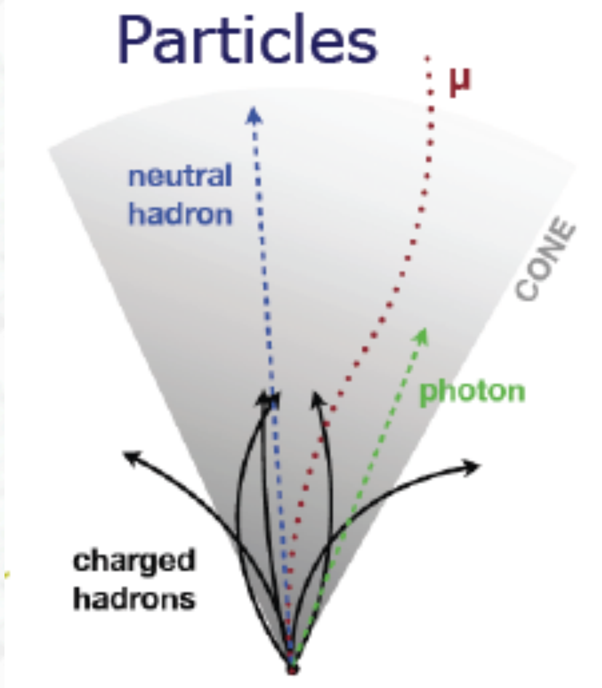
ajor iscoveries

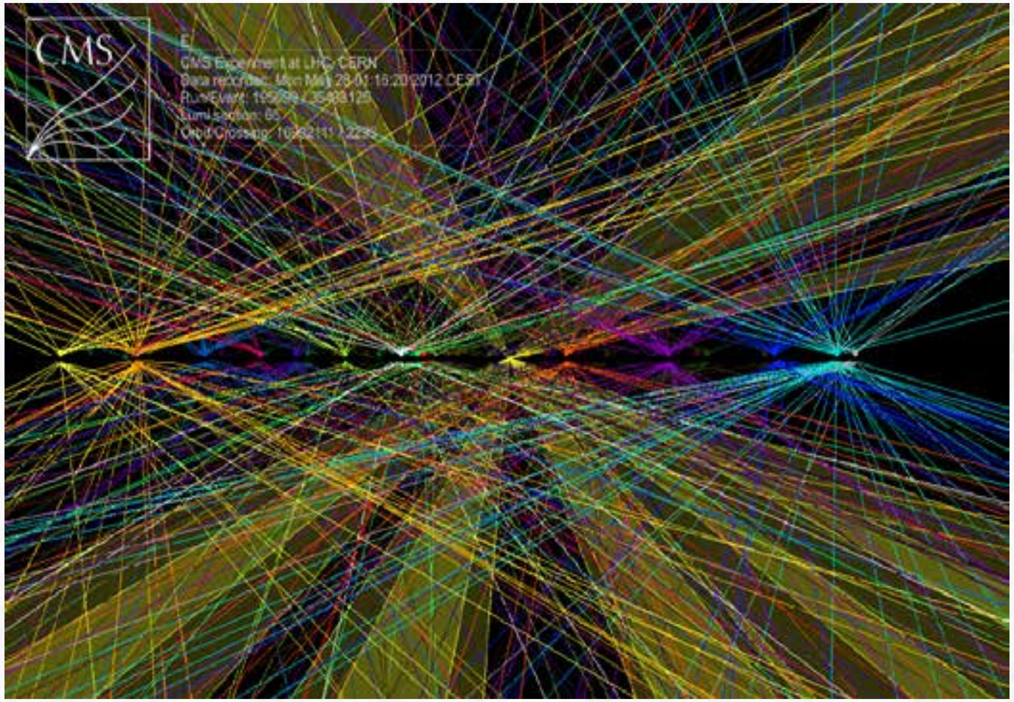
Top quark
B_s mixing
Precision W and Top mass → Higgs mass prediction
Direct Higgs searches
Ruled out many exotica

The next generation

- Fantastic training ground for next generation
- More than 500 Ph.D.s
- Produced critical personnel for the next steps, especially LHC

II. Detector Performance



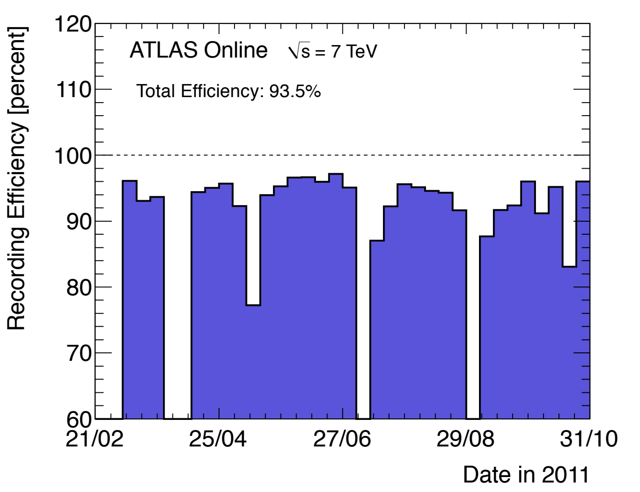


Detector performance is impressive:

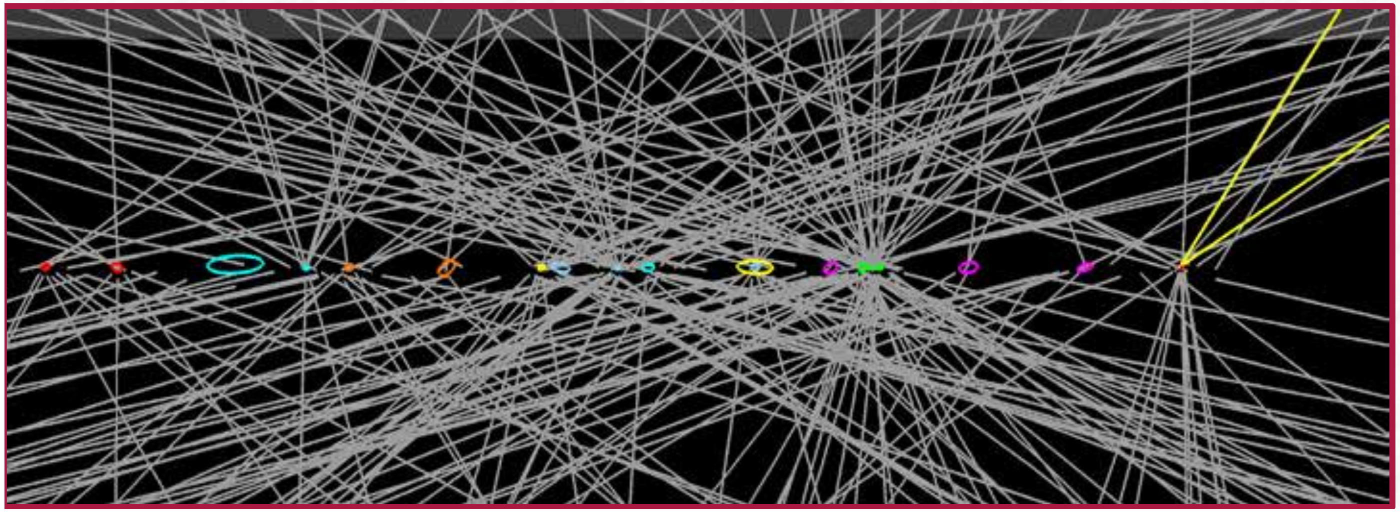
- Very high number of working channels (> 99% for many sub-systems) in all experiments;

- Data taking efficiency is high (> 94%)

- Impressive reconstruction capabilities for physics objects (e, γ, μ, τ, jets, b-tagging, E_T^{miss})



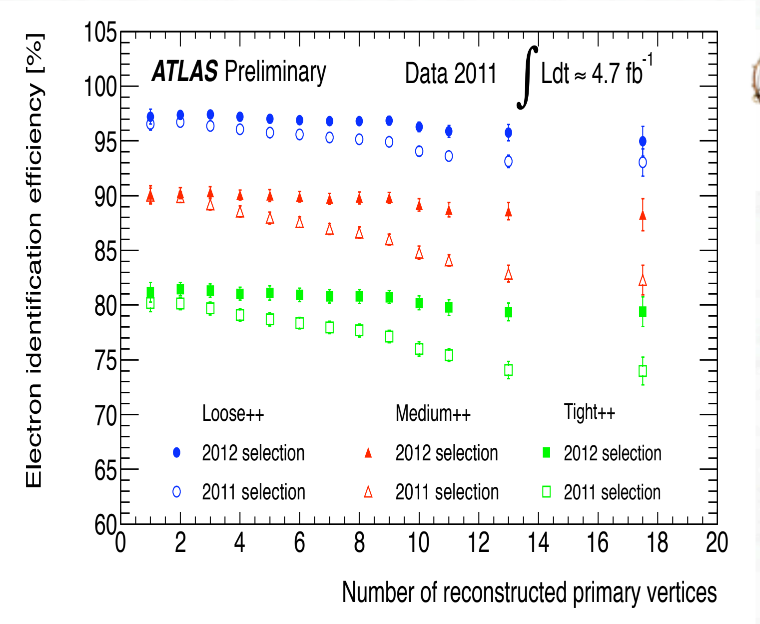
Have been optimized to cope with the ever increasing number of pile-up interactions (impressive examples shown here)



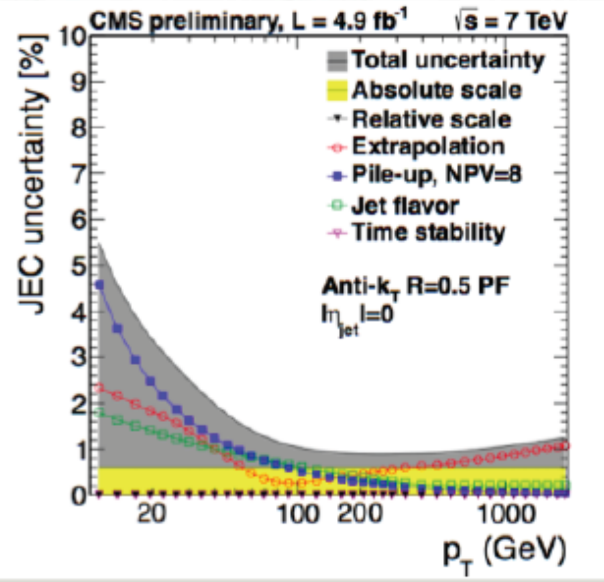
An event with 20 reconstructed vertices

(error ellipses are scaled up by a factor of 20 for visibility reasons)

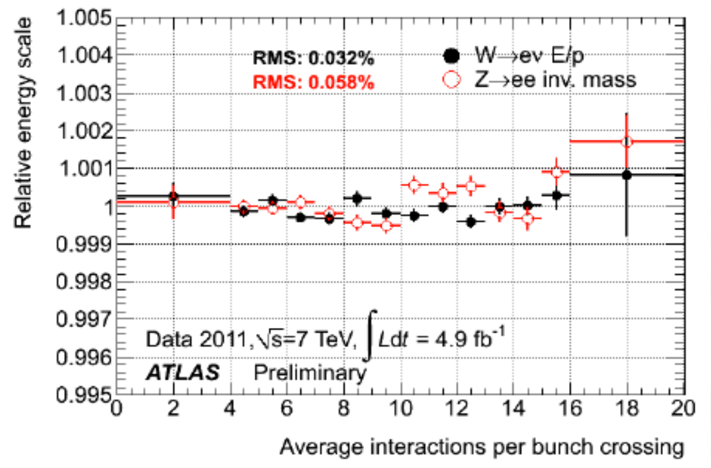
Some performance figures from 2011 data:

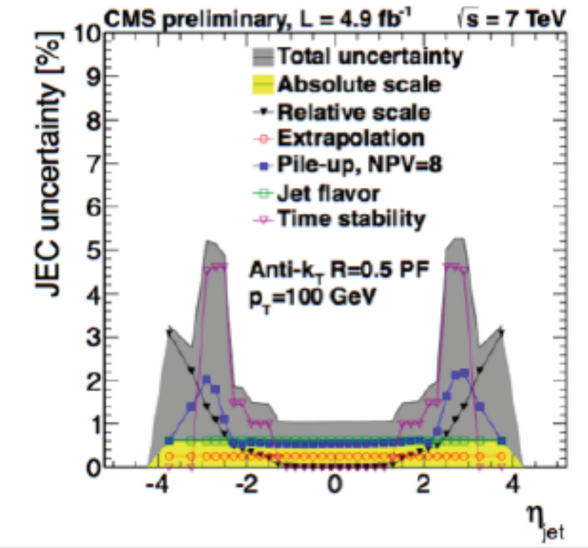


Electron ID efficiency in ATLAS

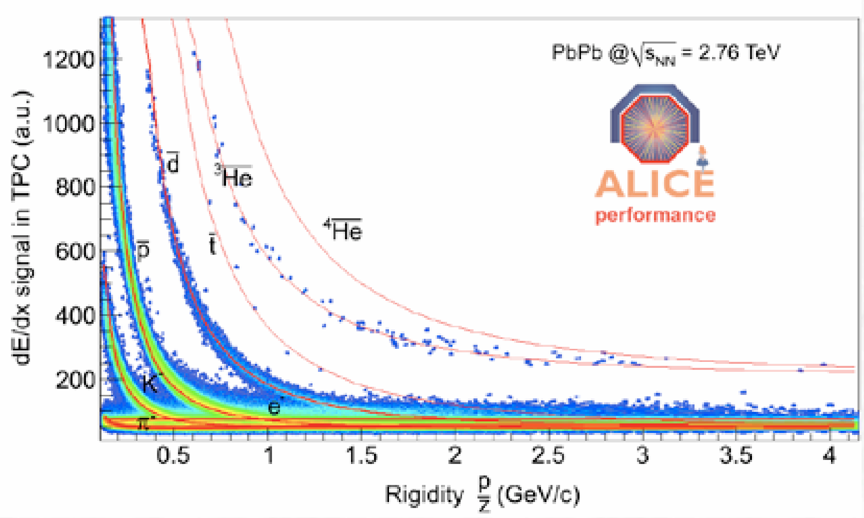


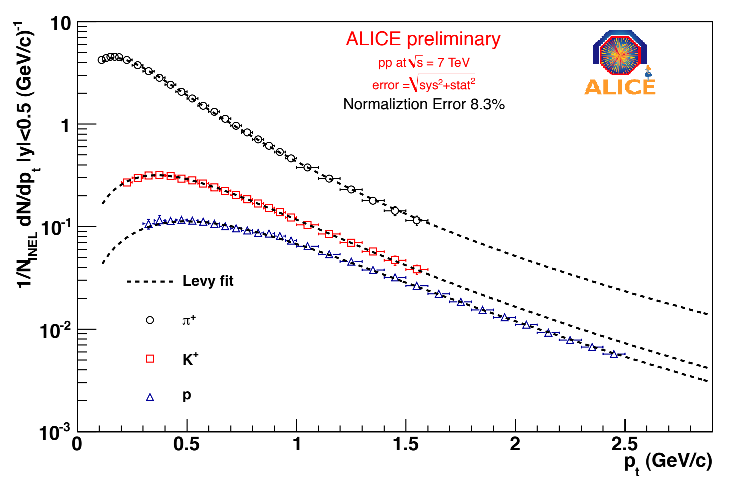
Jet energy scale, E-flow in CMS



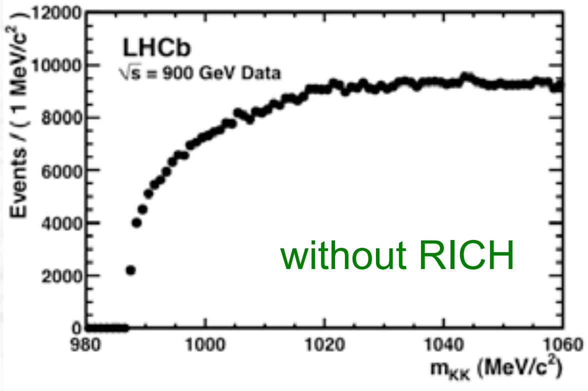


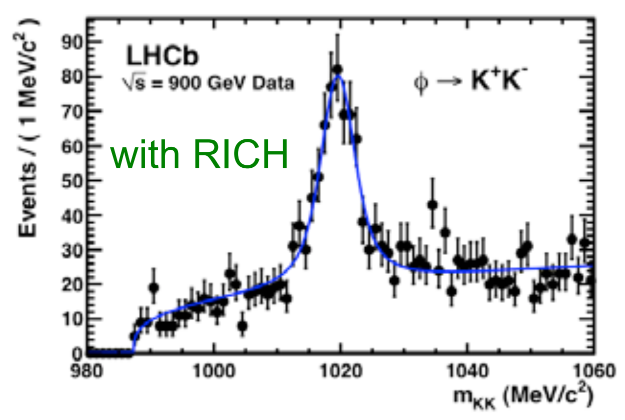
Particle Identification in ALICE and LHCb:



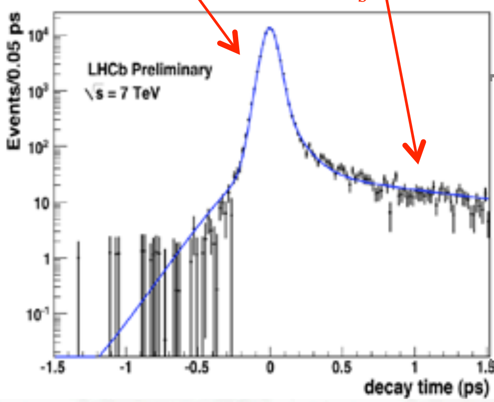


LHCb: Search for $\phi \rightarrow K^+K^-$





Prompt J/ψ $B_s \rightarrow J/\psi\ \phi$



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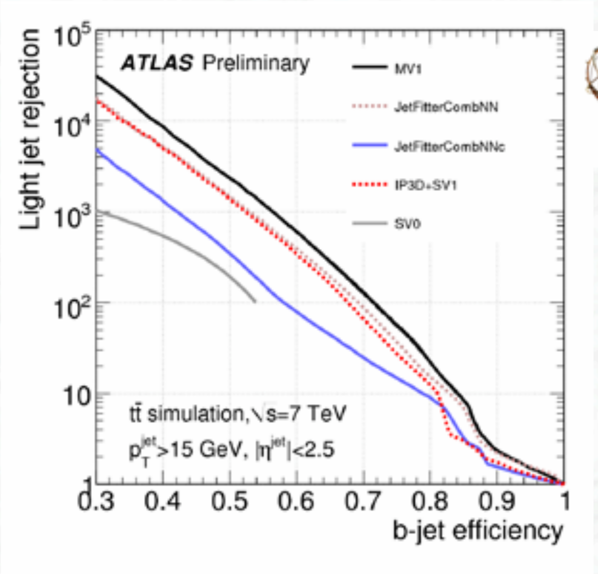
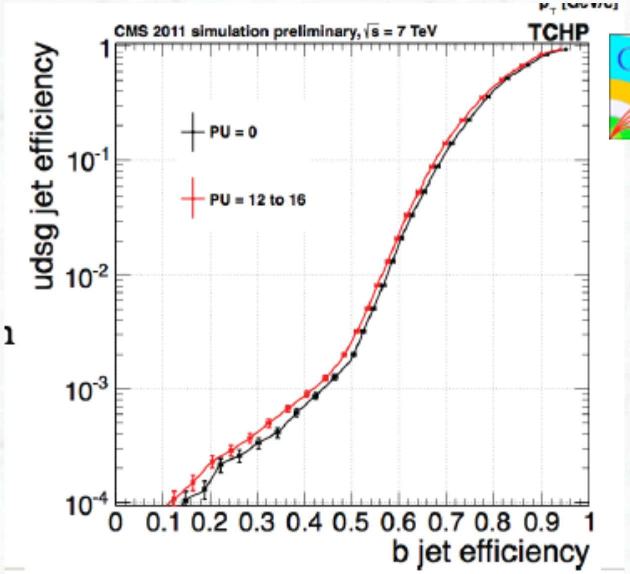
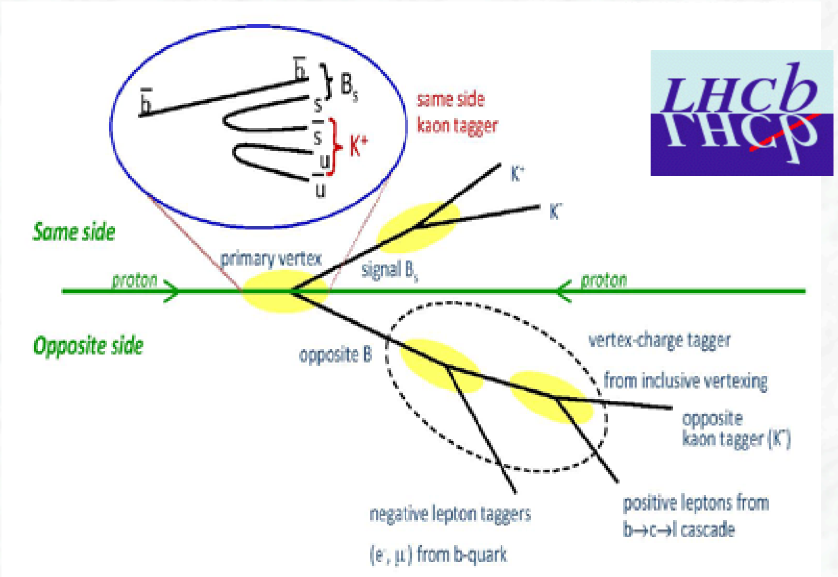
Proper time resolution: 45 fs

b-tagging performances in ATLAS and CMS:
extremely important for many physics analyses (Higgs, SUSY, SM, ….)





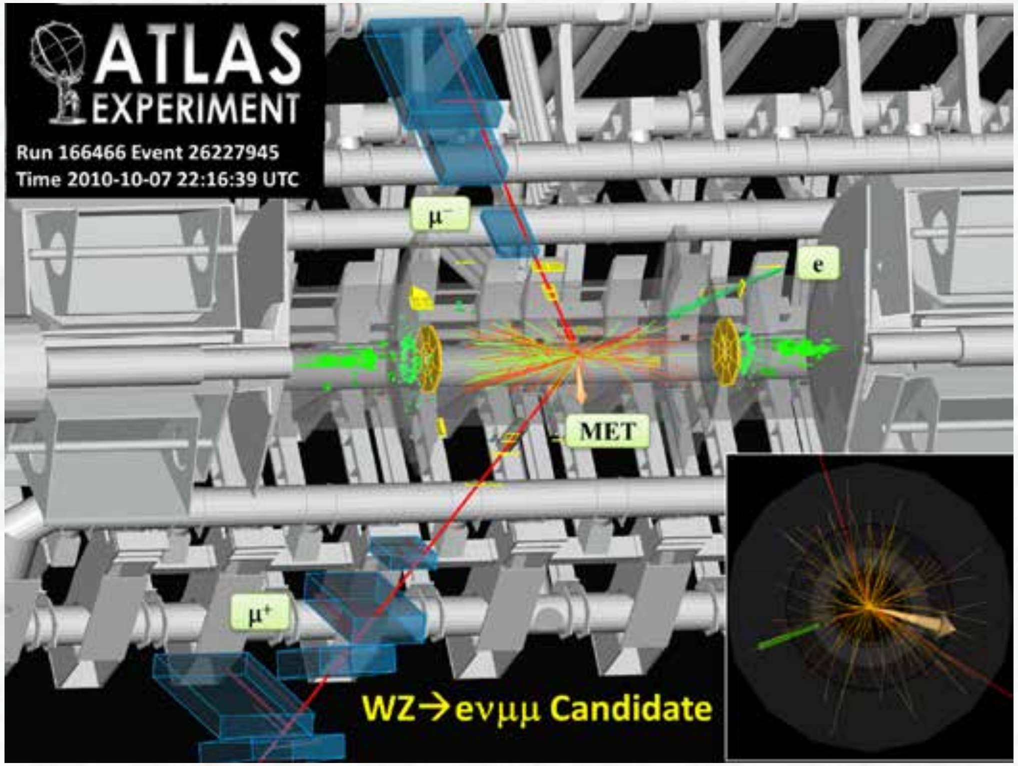


- Reconstruction of the original flavour (B, Bbar) of the reconstructed B meson (important for mixing and CP analyses)

- Performance calibrated from control channels, e.g.

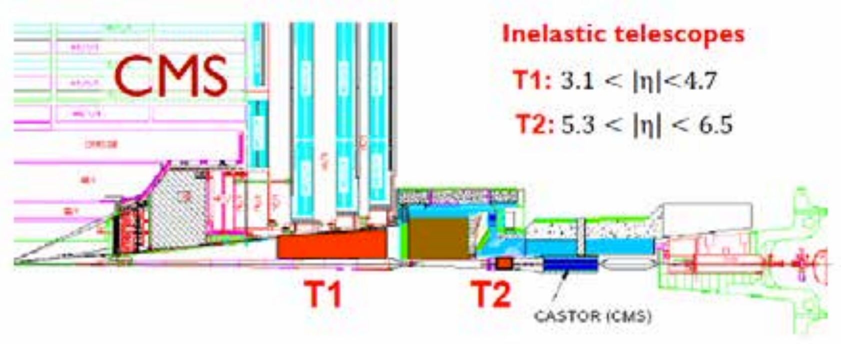
- Effective efficiencies 2.1-3.5% (opp. side) and 0.7% – 1.3% (same side) dep. on analysis

Physics Results



Total, elastic and inelastic pp cross sections at 7 TeV

- Domain of the TOTEM experiment
  Detectors in the CMS forward regions



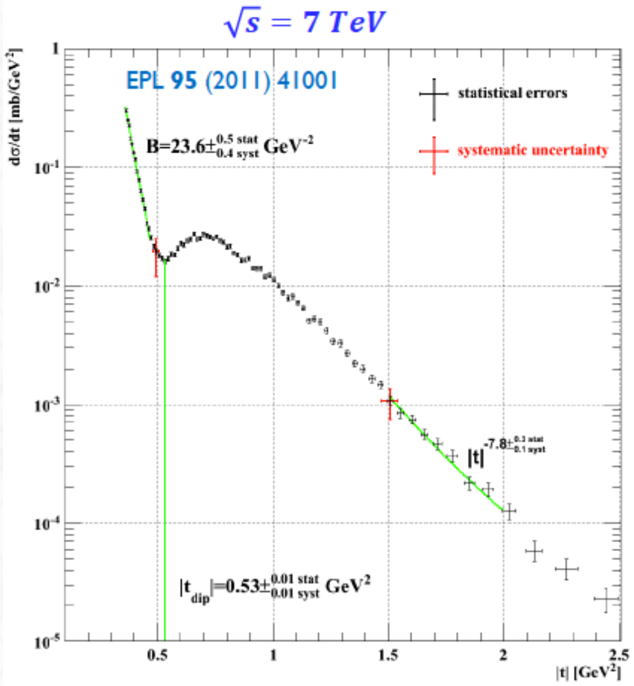
Inelastic telescopes

T1: $3.1 < |\eta| < 4.7$

T2: $5.3 < |\eta| < 6.5$

Elastic scattering: $d\sigma_{el}/dt$

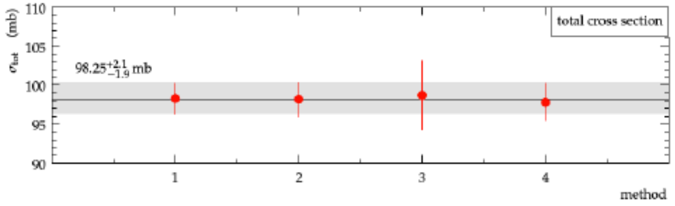
$0.36<|t|<2.5\ \mathrm{GeV}^2$



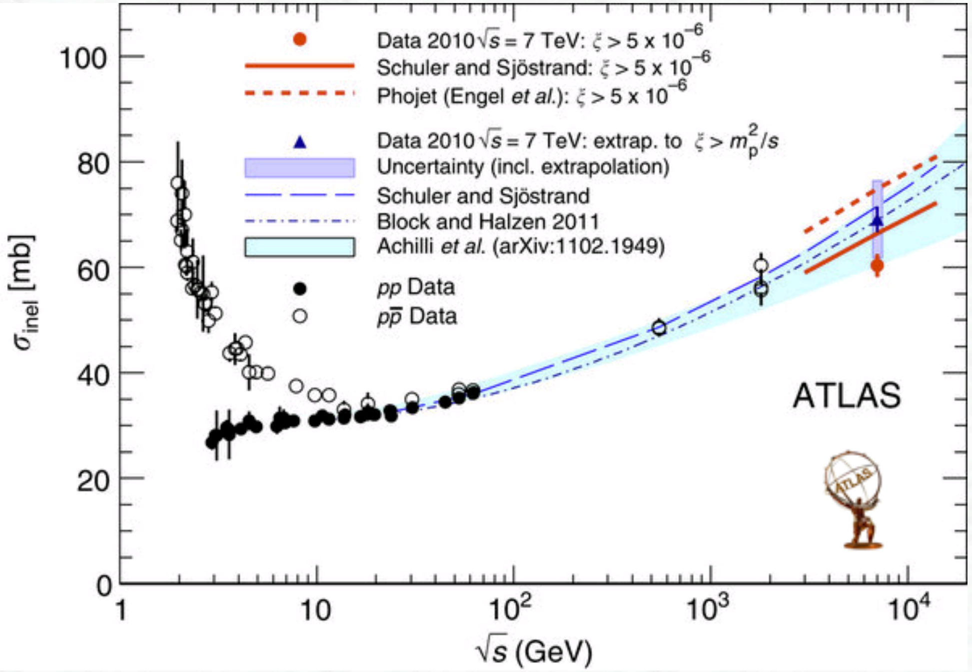
$$\frac{d\sigma_{el}}{dt} \propto e^{-B|t|}$$

Total cross section
(four methods give consistent results)

1. (*low*) Luminosity + Elastic scattering + Optical theorem
   $\sigma_{tot} = 98.3 \pm^{2.2}_{2.0}\ mb$
2. (*high*) Luminosity + Elastic scattering + Optical theorem
   $\sigma_{tot} = 98.2 \pm^{2.4}_{2.2}\ mb$
3. (*high*) Luminosity + Elastic scattering + Inelastic scattering
   $\sigma_{tot} = 98.7 \pm 4.4\ mb$
4. Elastic scattering + Inelastic scattering + Optical theorem
   $\sigma_{tot} = 97.8 \pm^{2.9}_{2.4}\ mb$



Inelastic pp cross section at 7 TeV:



ALICE:

σ_{inel}= (72.7 ± 1.1 (stat) ± 5.1 (model)) mb

ATLAS:

σ_{inel}= (69.1 ± 2.4 (stat) ± 6.9 (model)) mb

CMS:

σ_{inel} = (64.5 ±1.1 (stat) ± 3.0 (model)) mb

TOTEM:

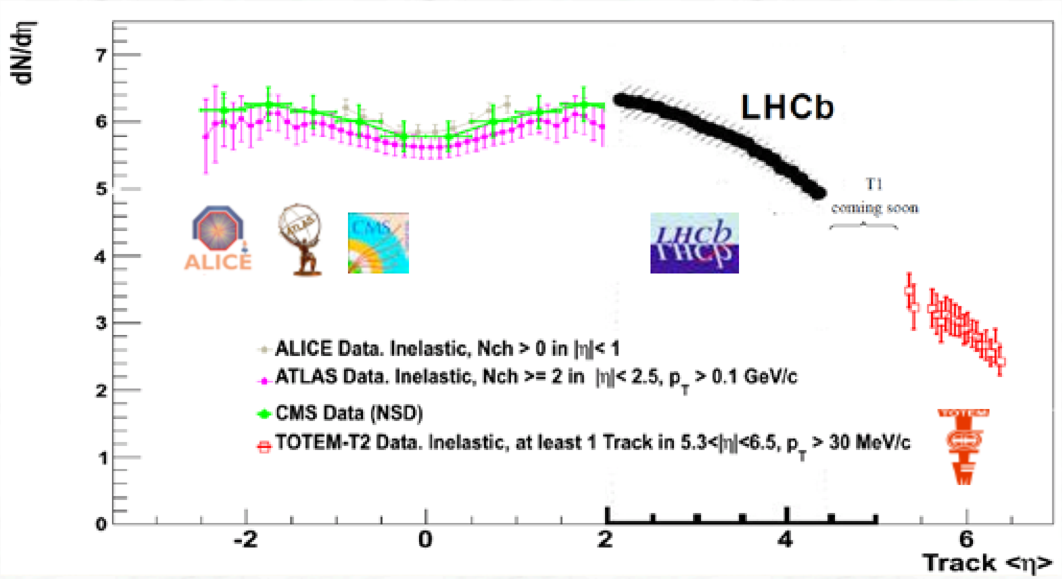
σ_{inel} = (73.5 ± 0.5 (stat) $\pm^{1.8}_{-1.3}$ (syst)) mb

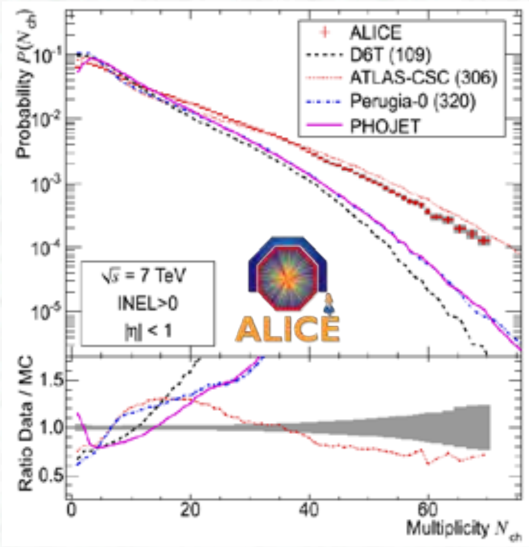
- The inelastic cross section was also measured by ALICE, ATLAS and CMS; Good agreement among the experiments, within systematic uncertainties

- Measurement require the subtraction of diffractive components and acceptance extrapolations;
  The associated model dependence (e.g. Donnachie-Landshoff) constitutes the largest systematic uncertainty

Soft Physics and diffraction

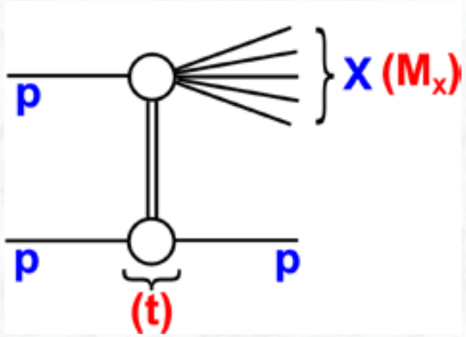
- Measurements of soft inelastic collisions and diffractive processes are important for any modeling of the underlying event or pile-up processes
- LHCb and Totem experiments extend the measurements far into the forward region



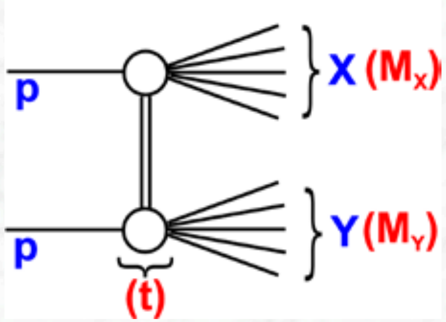


- General behaviour: experiments agree well among each other, however, Monte Carlo models underestimated inclusive particle production;

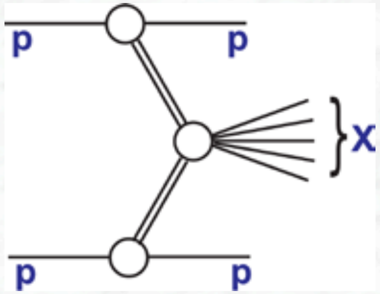
A Monte Carlo tuning that describes simultaneously all observables is still missing



single diffractive

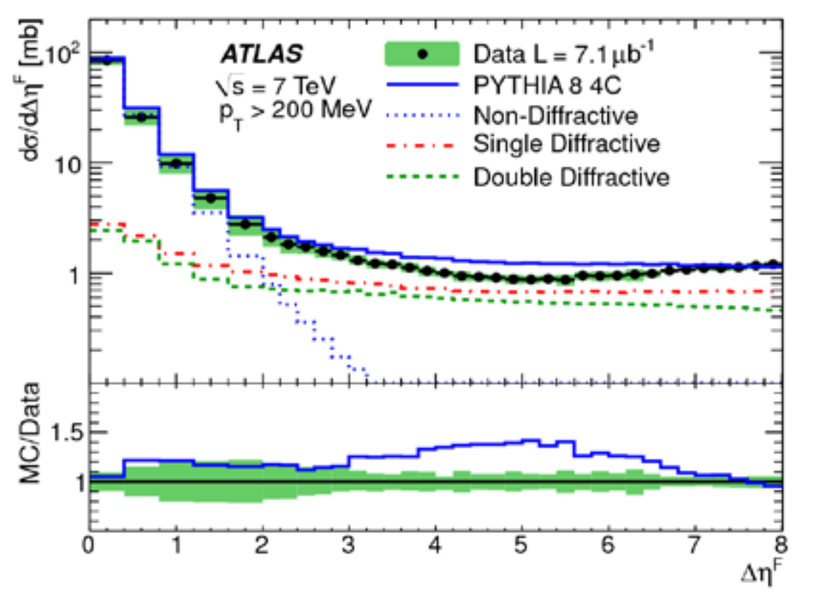


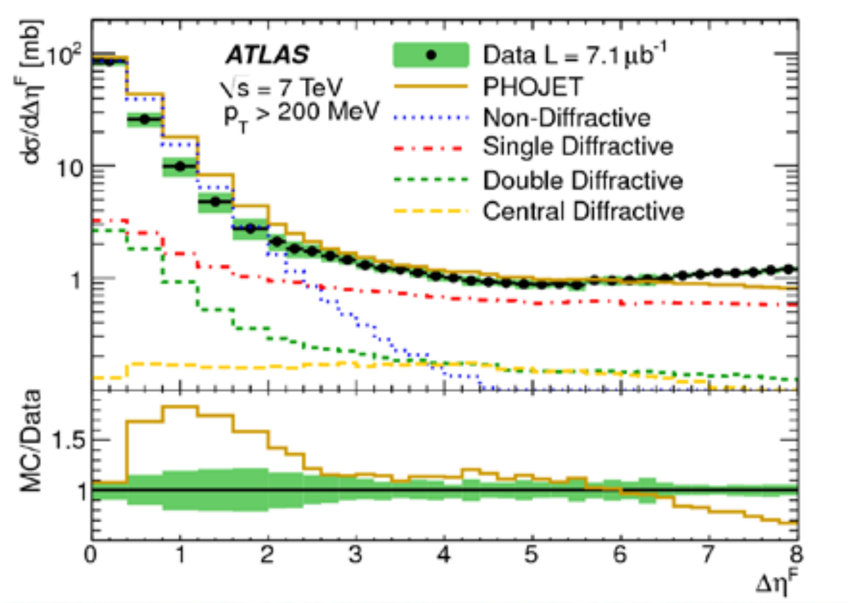
double diffractive



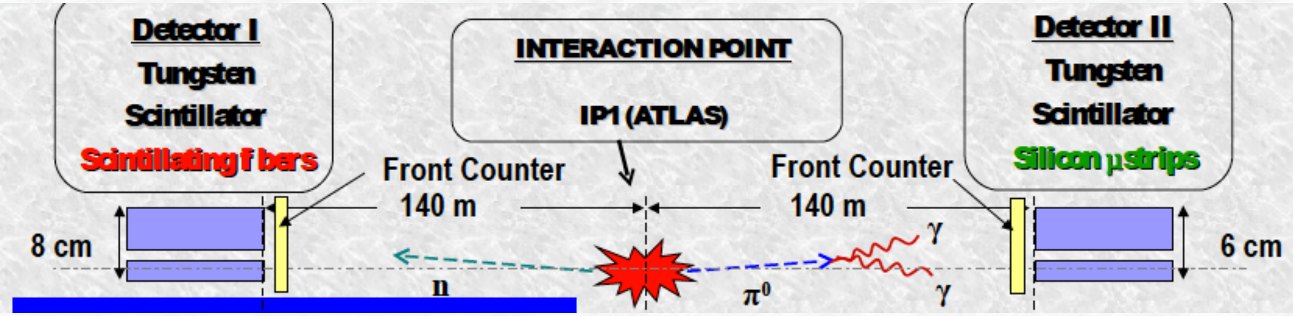
central diffractive

- Disentangle the various diffractive components by studying rapidity gaps;
- Model description needs tuning

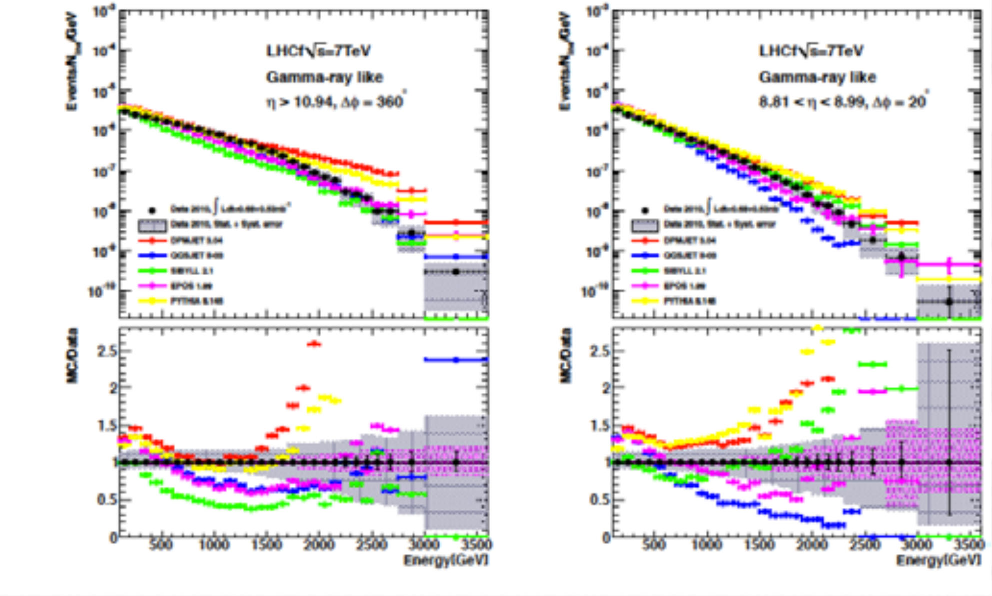


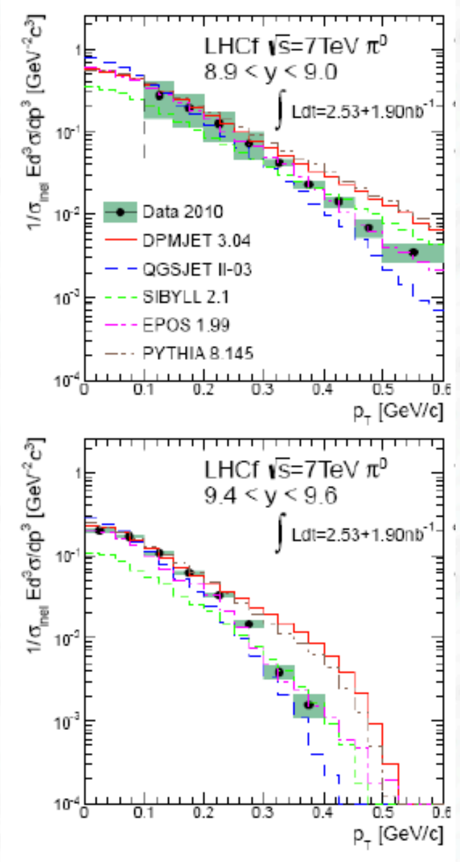


Particle production in the extreme forward region



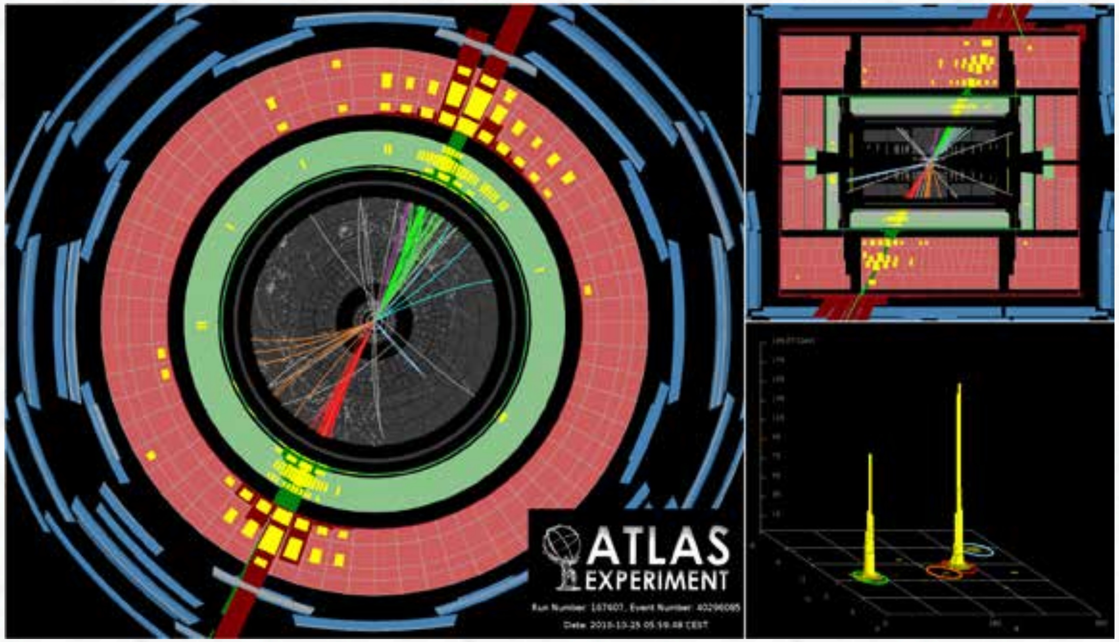
- Single photon and π^0 spectra, compared to models:





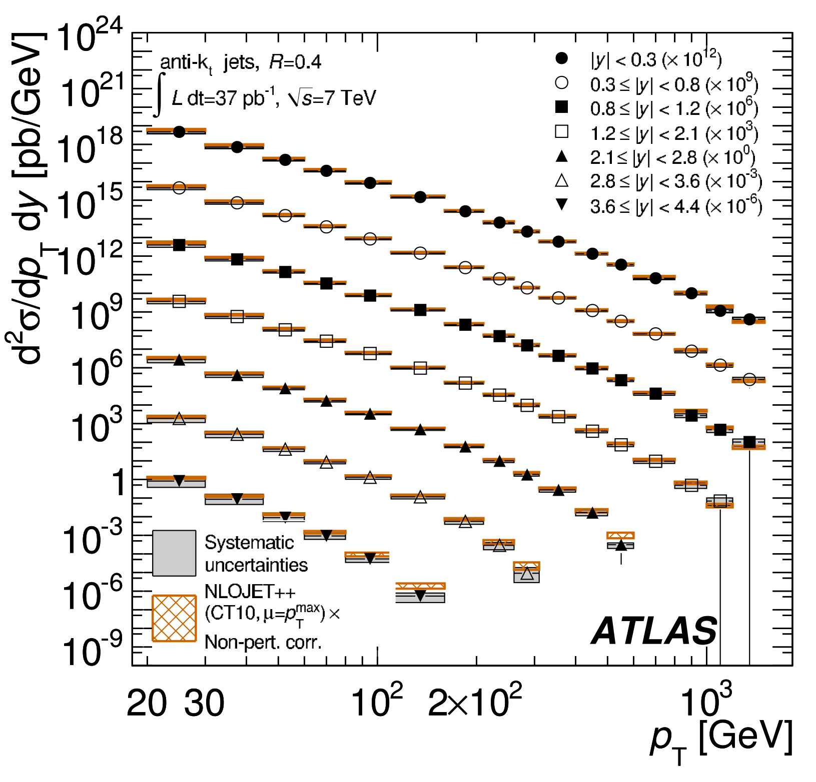
- Important input for astro-particle physics experiments

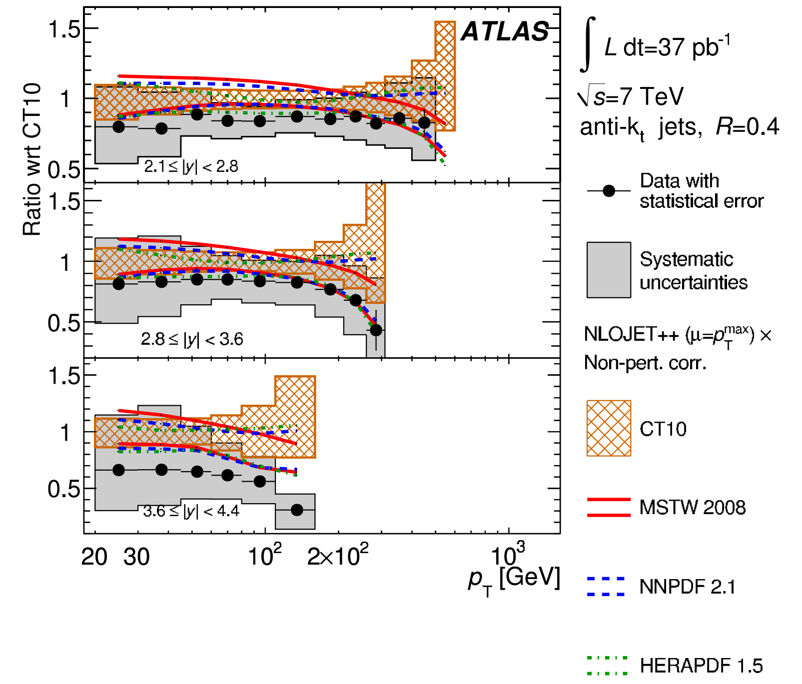
Hard processes:
Tests of perturbative QCD



- Jet production
- W/Z production
- Production of Top quarks
- Heavy hadrons
  (Onia and B hadrons)
- Quark-gluon plasma

Double differential cross sections, as function of p_T and rapidity y (full 2010 data set)

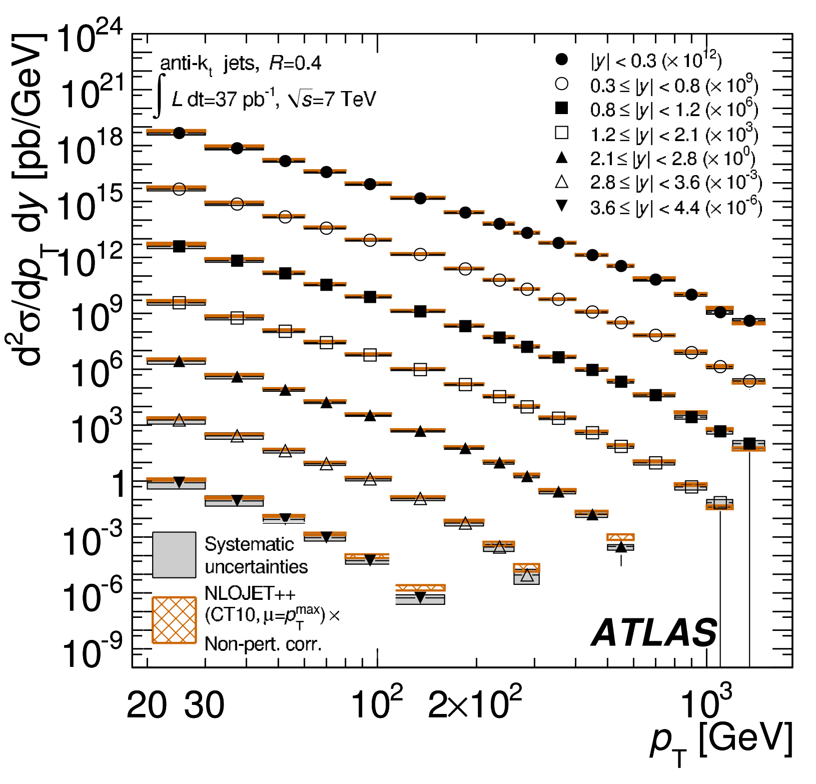


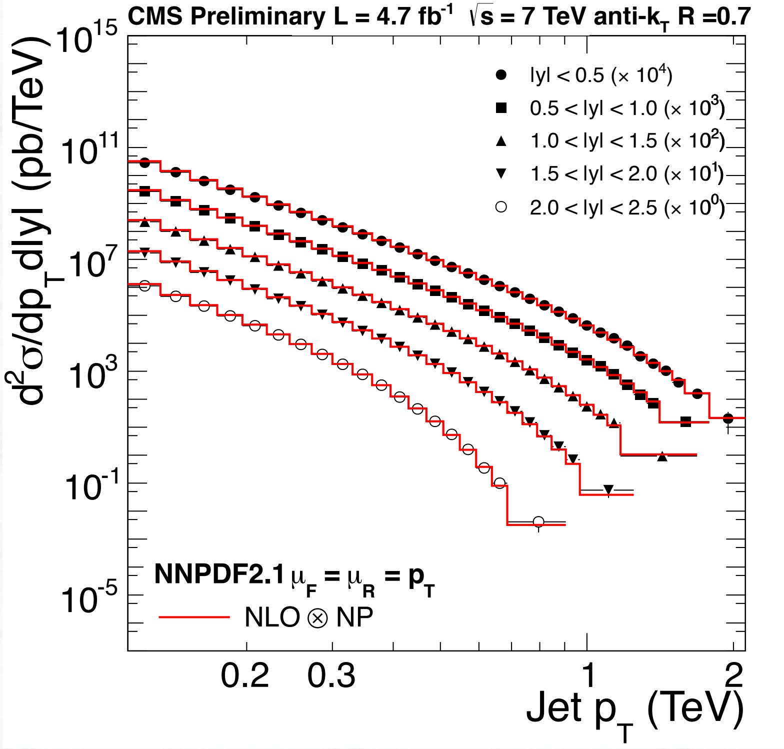


somewhat larger deviations in the forward region

- Data are well described by NLO pert. QCD calculations (NLOJet++)
- Experimental systematic uncertainty is dominated by jet energy scale uncertainty
- Theoretical uncertainties: renormalization/ factorization scale, pdfs, α_s, …, uncertainties from non-perturbative effects

Double differential cross sections, as function of p_T and rapidity y: (full 2010 data set)

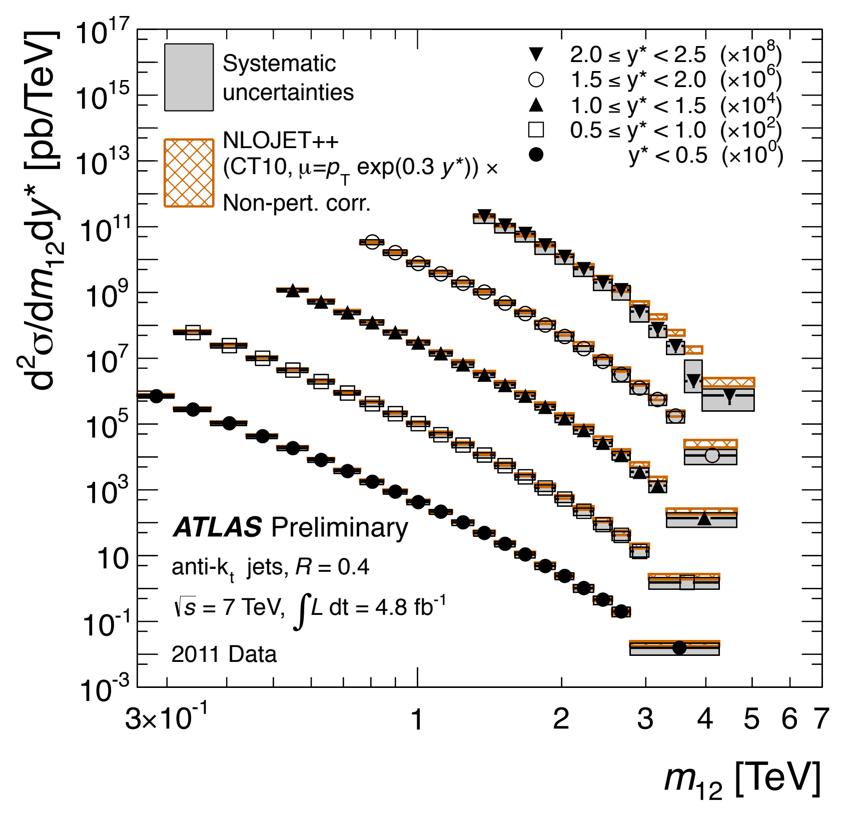


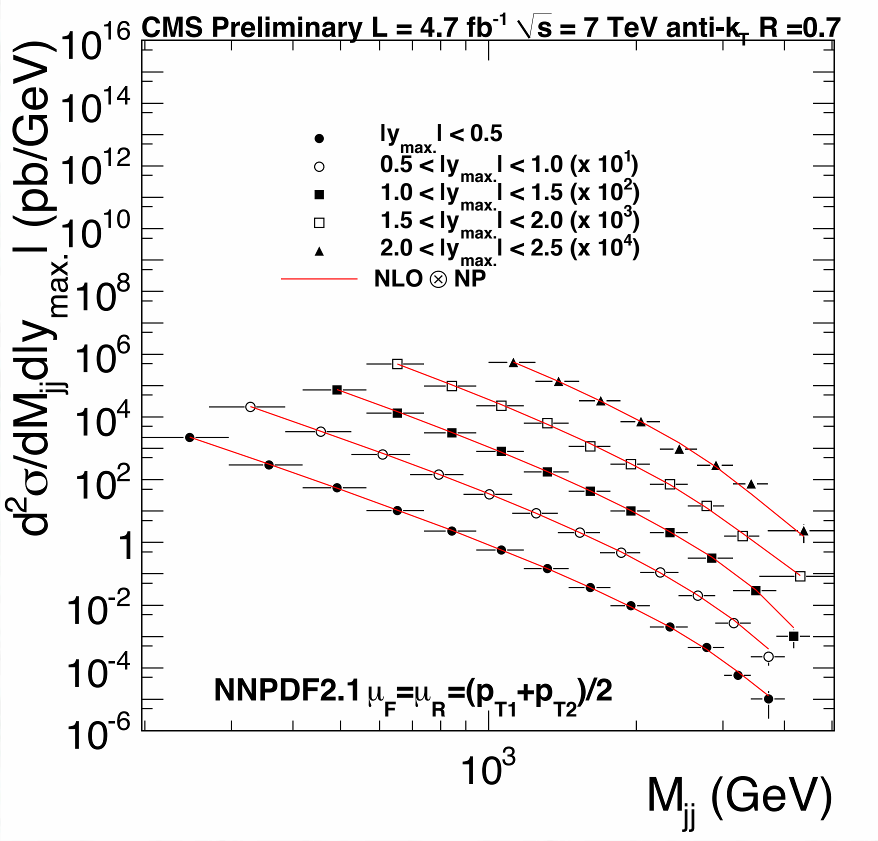


CMS: include full 2011 data set;
comparison up to 2 TeV (central rapidities)

- Data are well described by NLO pert. QCD calculations (NLOJet++)
- Experimental systematic uncertainty is dominated by jet energy scale uncertainty
- Theoretical uncertainties: renormalization/ factorization scale, pdfs, α_s, …, uncertainties from non-perturbative effects

Invariant di-jet mass spectra





Important for: - Test of QCD

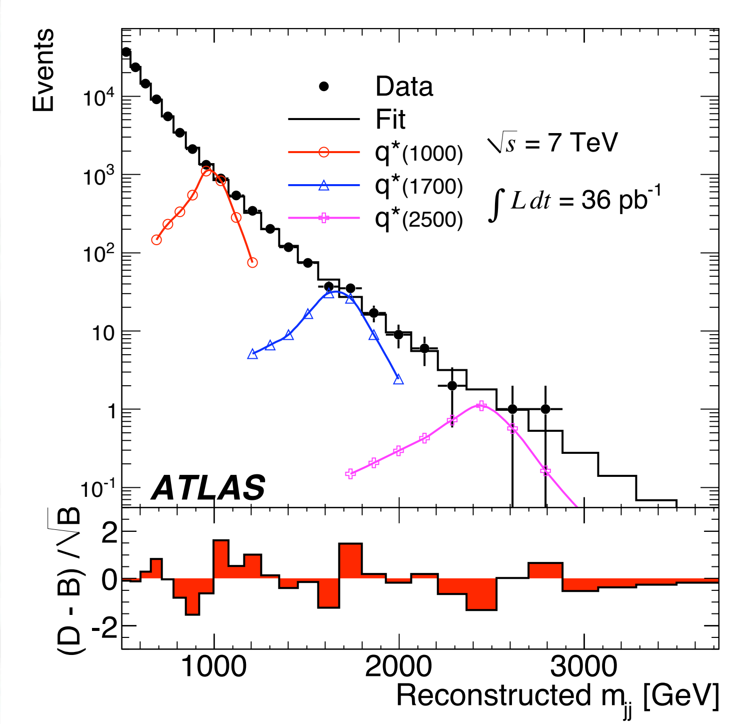
- Search for new resonances decaying into two jets (→ next slide)

In addition to QCD test: Sensitivity to New Physics

- Di-jet mass spectrum provides large sensitivity to new physics

  e.g. Resonances decaying into qq, excited quarks q*, ….

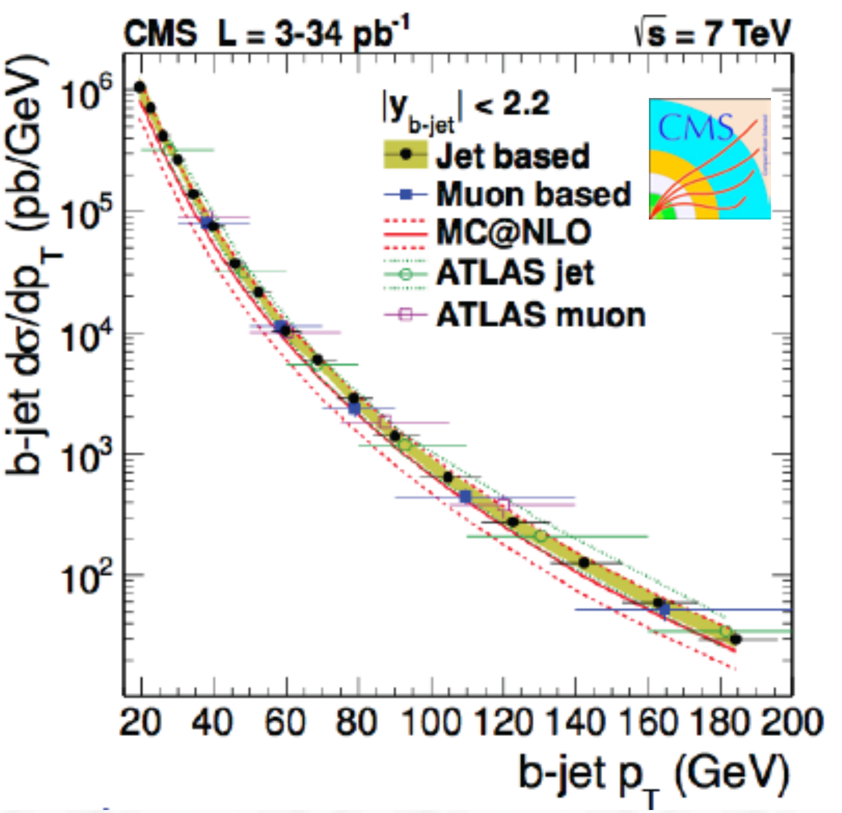
- Search for resonant structures in the di-jet invariant mass spectrum



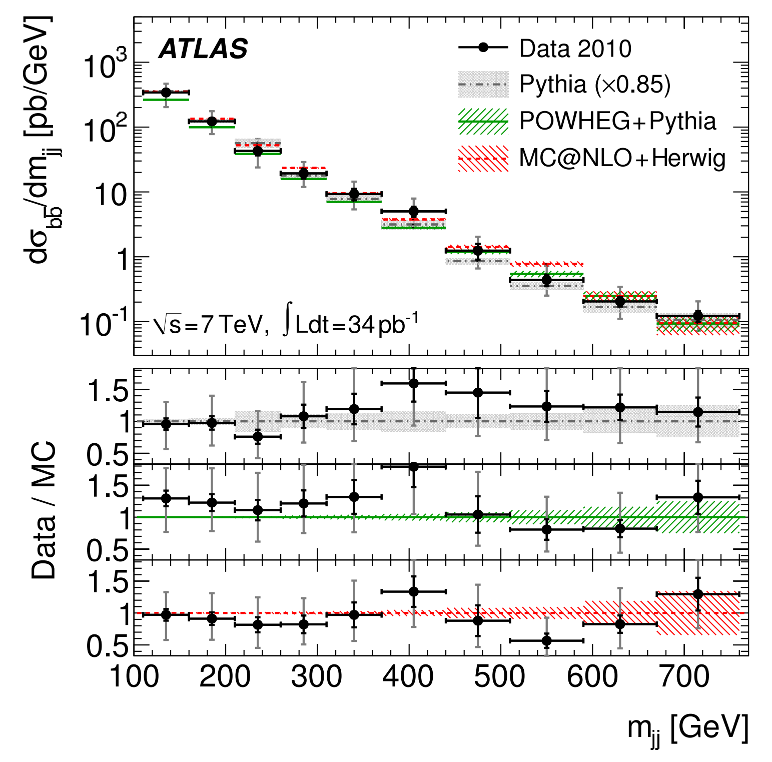
CDF (Tevatron), L =1.13 fb^{-1}: $0.26 < m_{q^*} < 0.87$ TeV

ATLAS (LHC), L = 0.000315 fb^{-1} exclude (95% C.L) q* mass interval
$0.30 < m_{q^*} < 1.26$ TeV
L = 0.036 fb^{-1}: $0.60 < m_{q^*} < 2.64$ TeV

Inclusive b and bb-cross sections



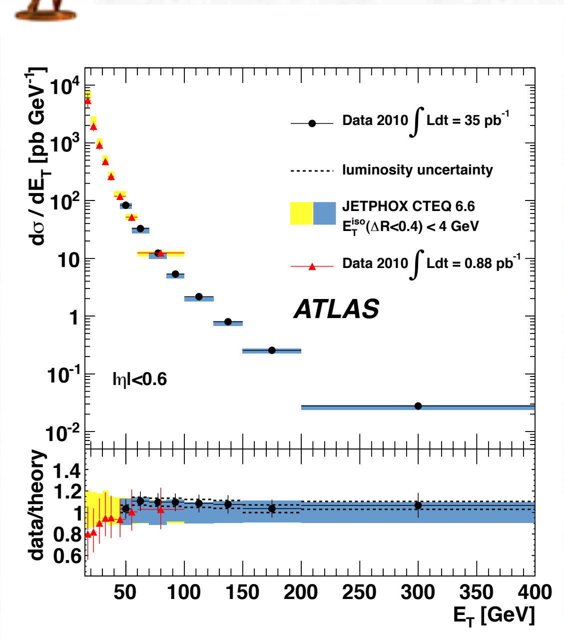
inclusive b-jet production

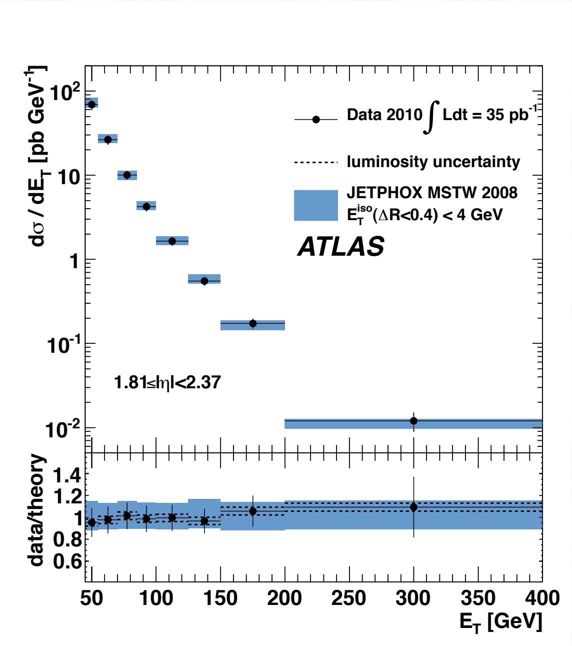


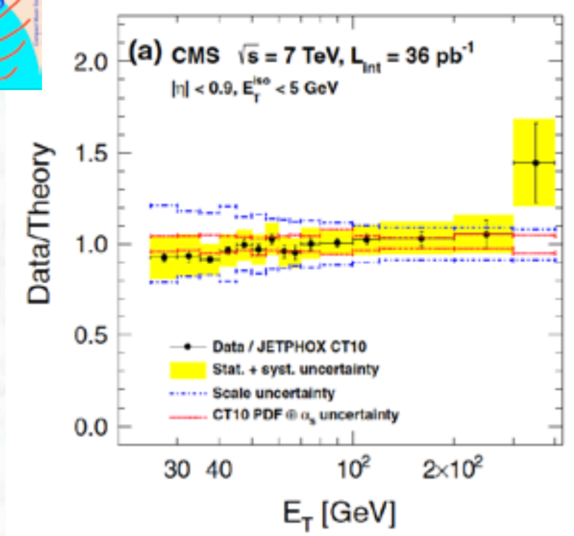
bb di-jet cross section as function of mass

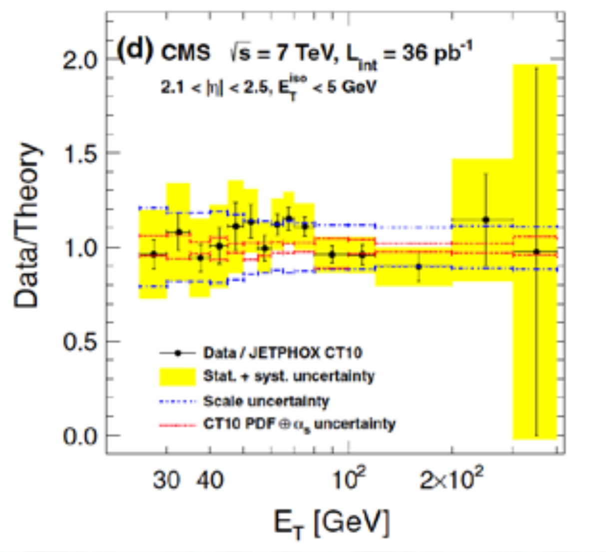
Also good agreement found for the more challenging inclusive b and bb di-jet cross sections (limited to central region, tracker acceptance)

Direct γ production (γ + jet)







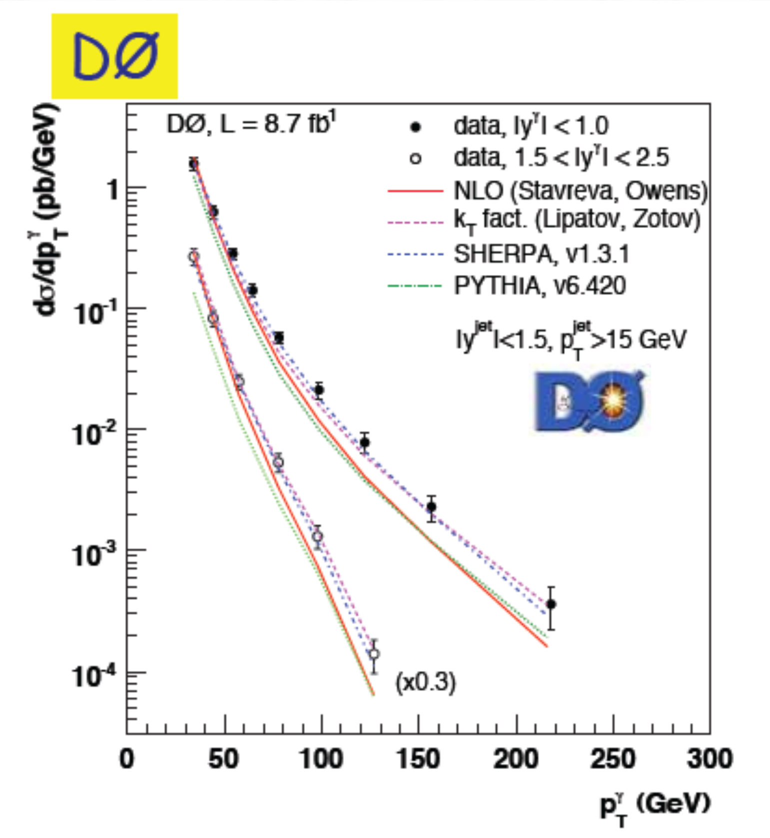


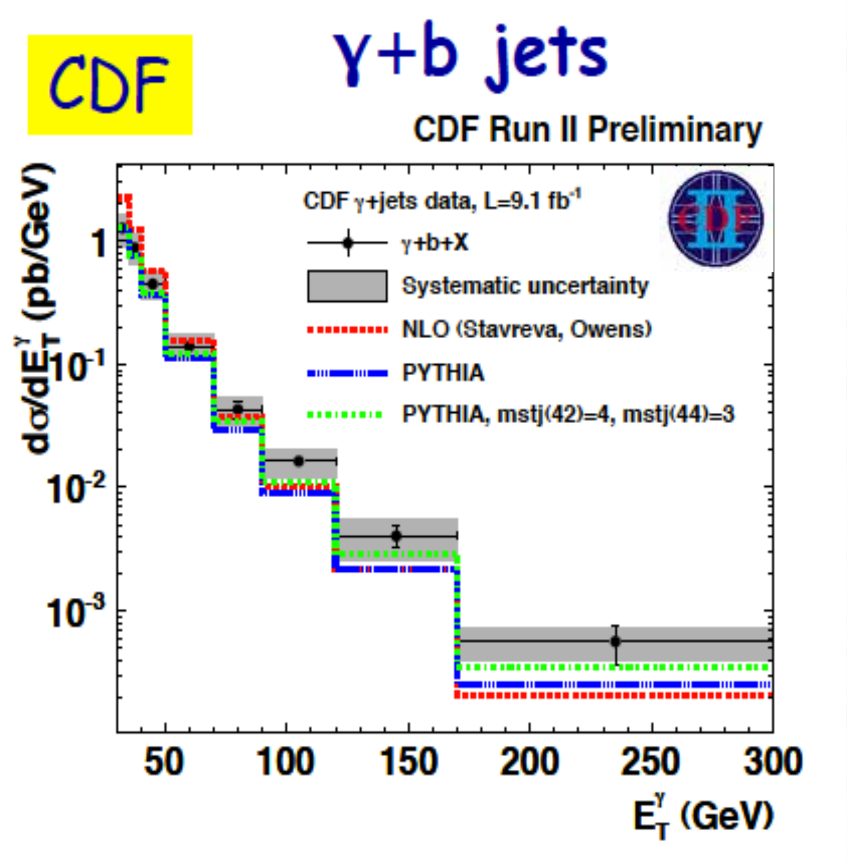
In general good agreement, (within uncertainties, dominated by systematics, e.g. π^0 background, contributions from fragmentation, pdfs, …)

Similar ratios (data / theory) found as function of pseudorapidity in ATLAS and CMS

S. Wolbers

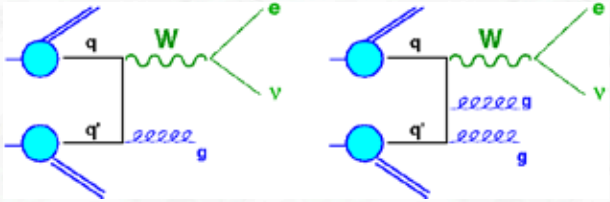
γ + b jet production at the Tevatron

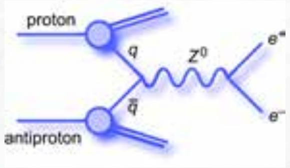




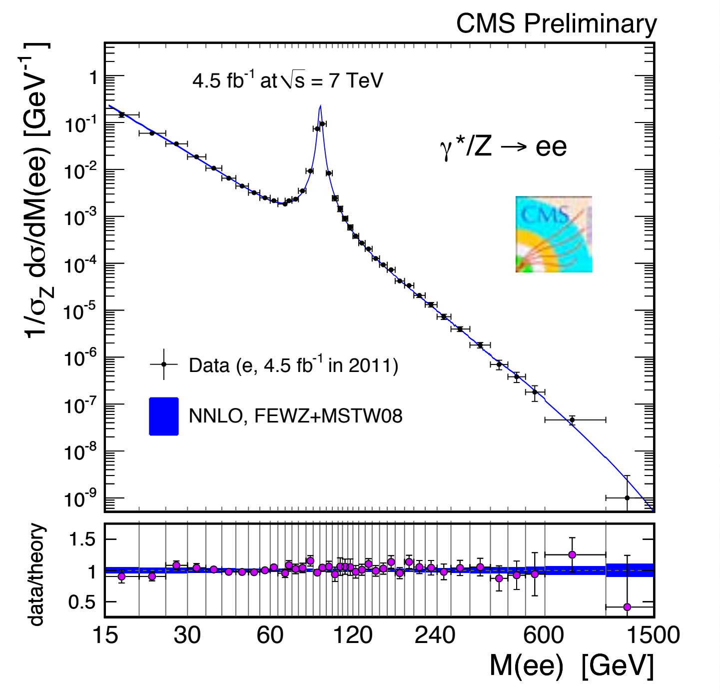
- NLO calculation describe data well in low p_T region
- Larger deviations at high p_T (large NNLO contributions ??)

QCD in W/Z (+ jet) production



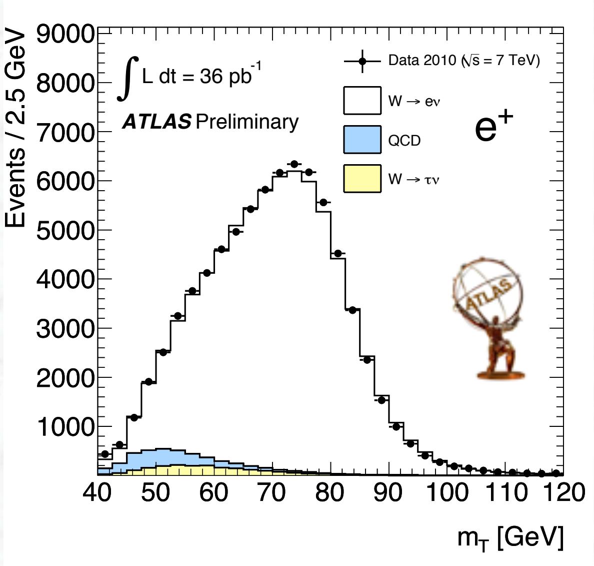


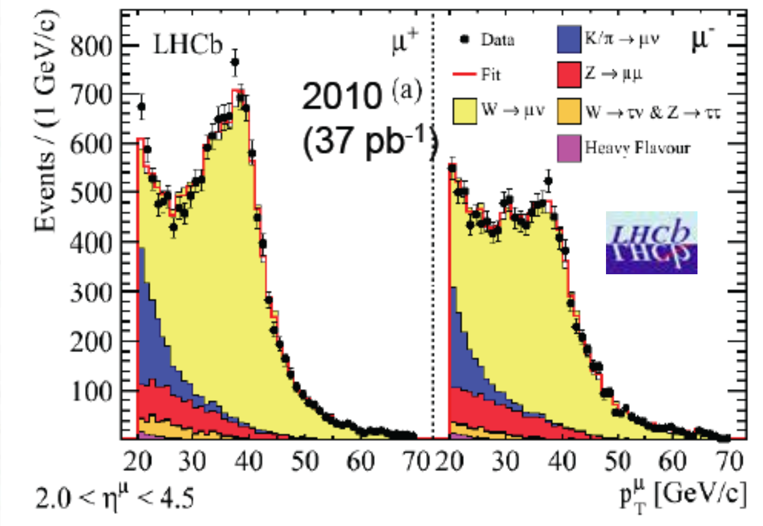
QCD at work



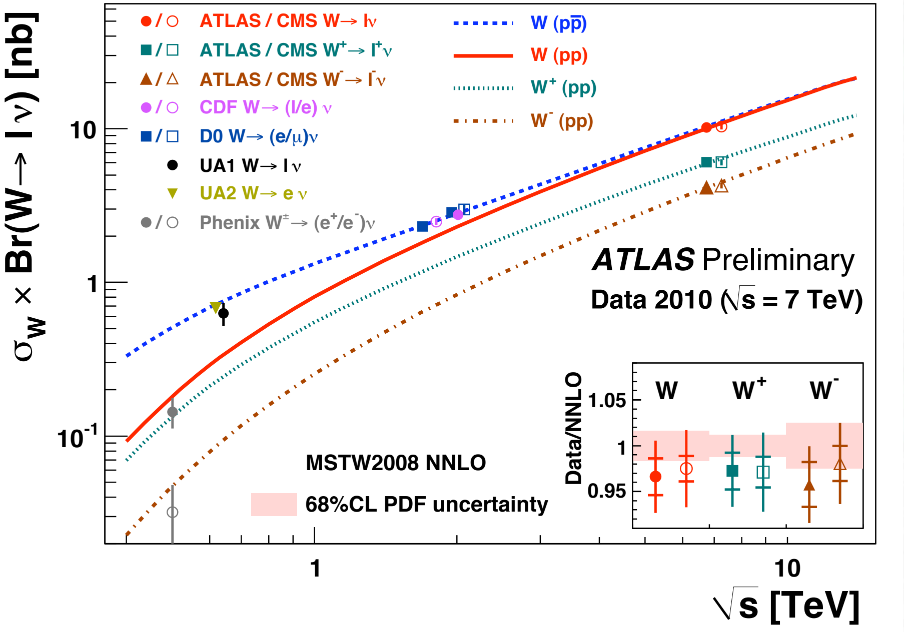
- Drell-Yan pair production measured over large mass range (normalized to Z peak)

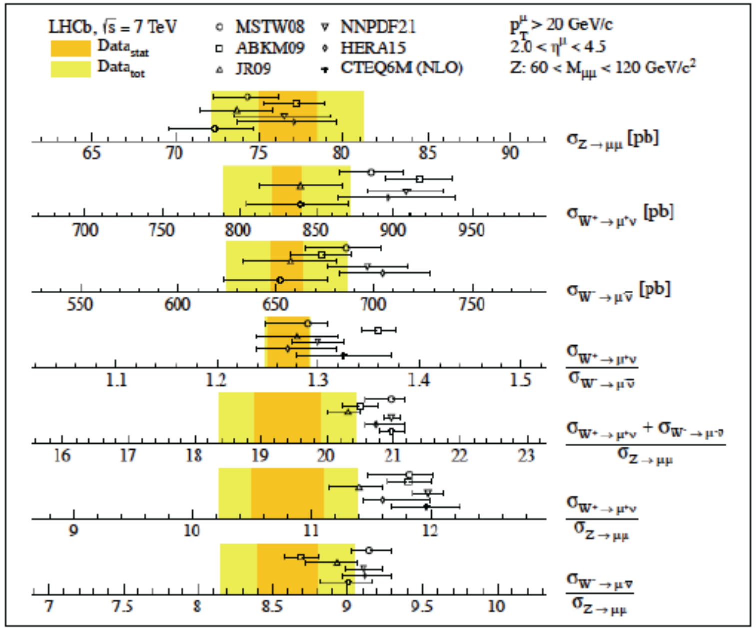
- Clear signals, measurements extend into the forward rapidity region by LHCb





W cross sections at the LHC





LHCb-PA

$Z \rightarrow \mu\mu$

$W^+ \rightarrow \mu\nu$

$W^- \rightarrow \mu\nu$

W+/W-

W/Z

W+/Z

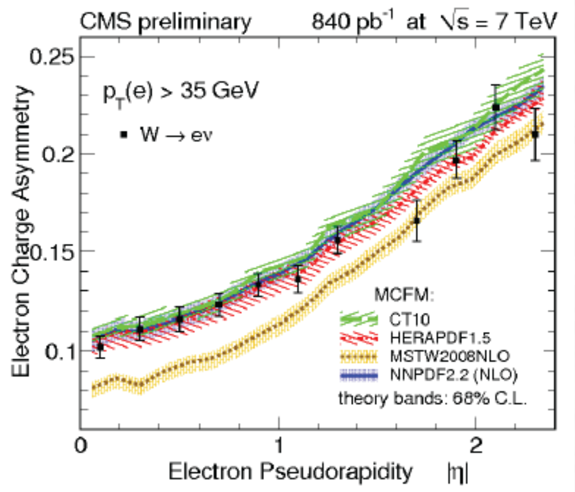
W-/Z

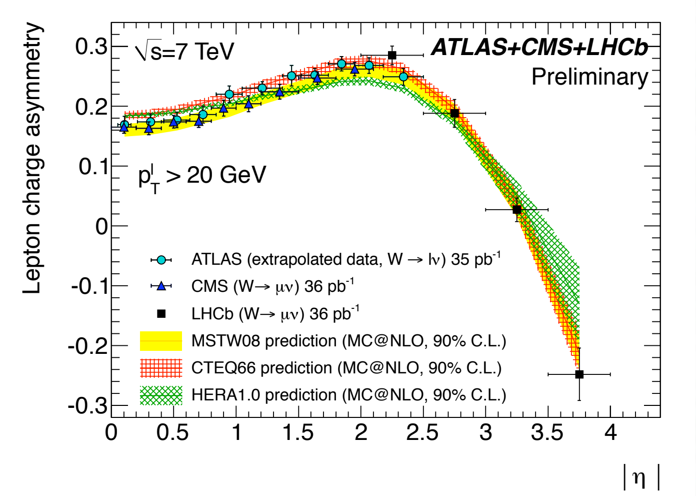
also in the forward region

- Theoretical NNLO predictions in very good agreement with the experimental measurements (for pp, ppbar and as a function of energy)
- Precision is already dominated by systematic uncertainties
- Good agreement as well between experiments

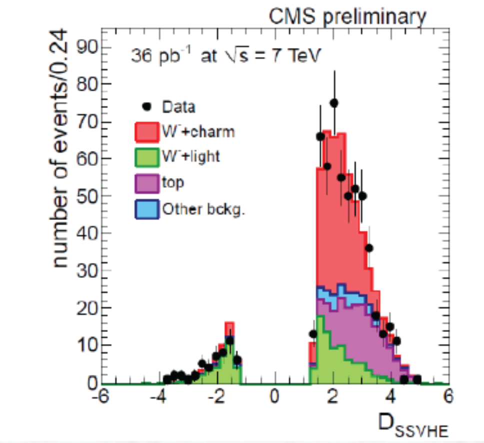
Differential measurements start to constrain pdfs

(i) Lepton charge asymmetries



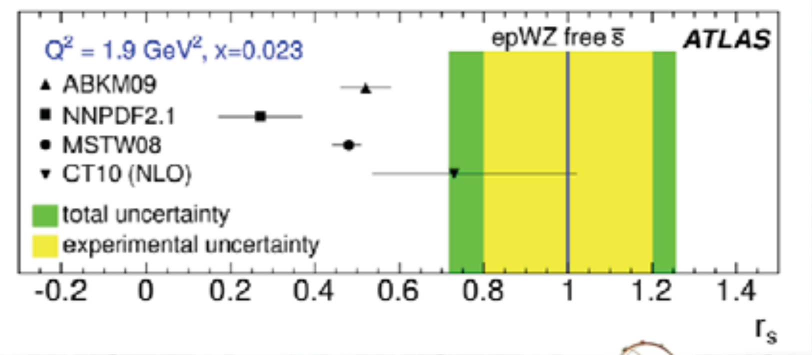


(ii) Flavour separated W+jet production



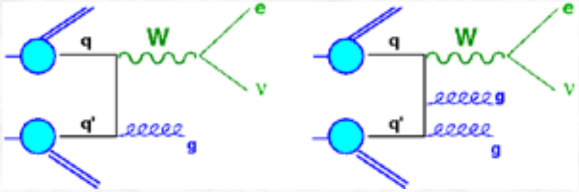
e.g. W+c production

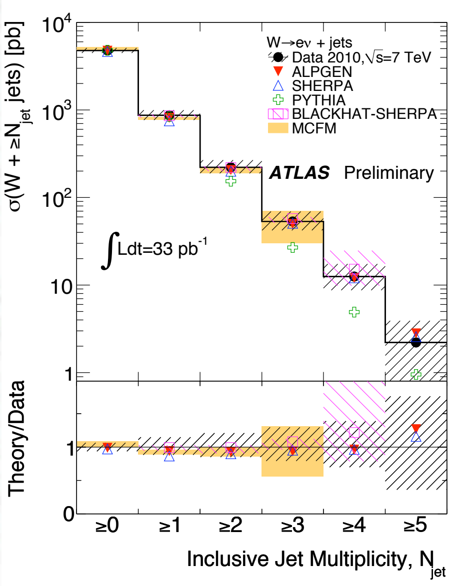
(iii) Extraction of s/sbar from global fit to ATLAS W/Z differential measurements



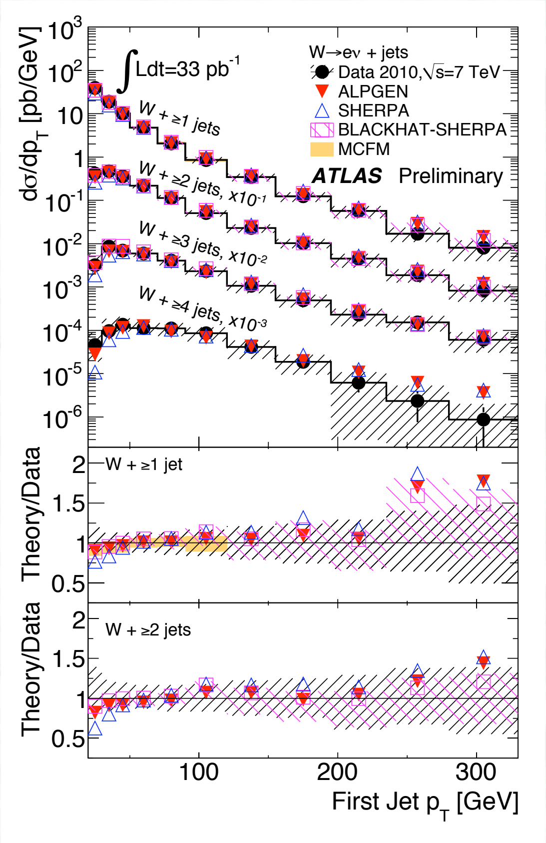
$r_s = 0.5\,(s + \text{sbar}) / \text{dbar}$

W/Z + jet cross section measurements

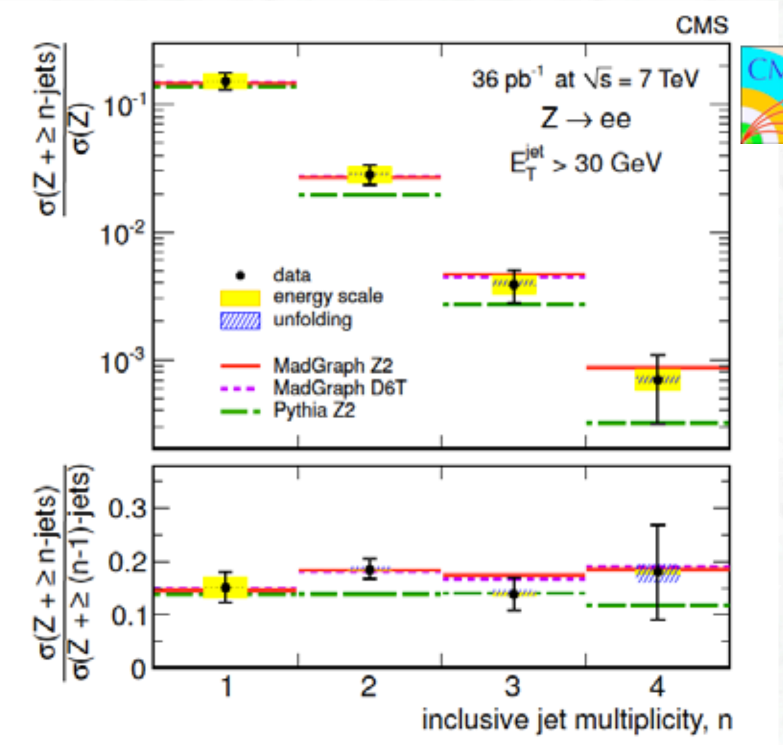




Jet multiplicities
in W+jet production



p_T spectrum of
leading jet



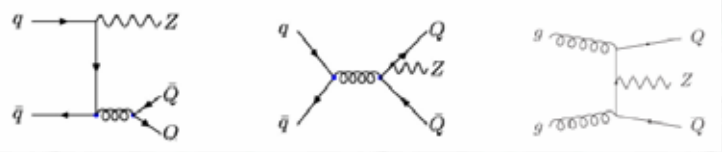
- Impressive description of jet multiplicities and kinematic properties up to high jet multiplicities

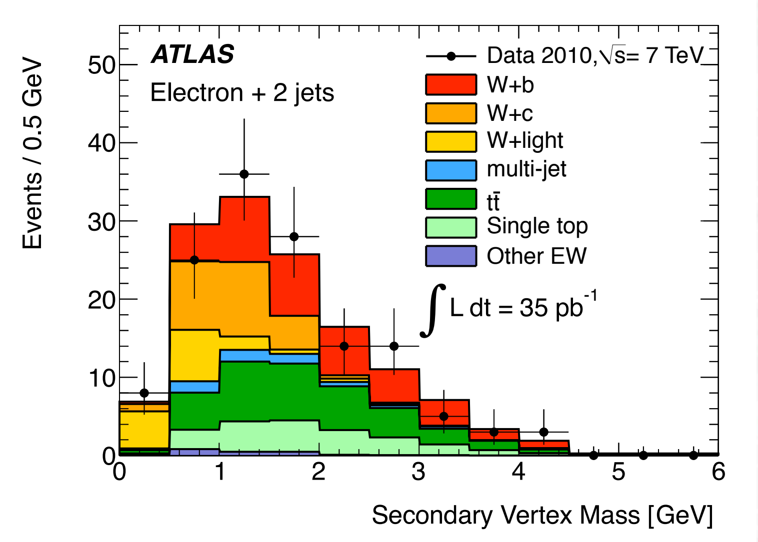
- Impressive progress on NLO calculations for higher jet multiplicity (NLO W+5 jet in reach)

W + b jets

- Important background for many studies (Higgs, SUSY, top)
- Measurements at the Tevatron exceed NLO prediction

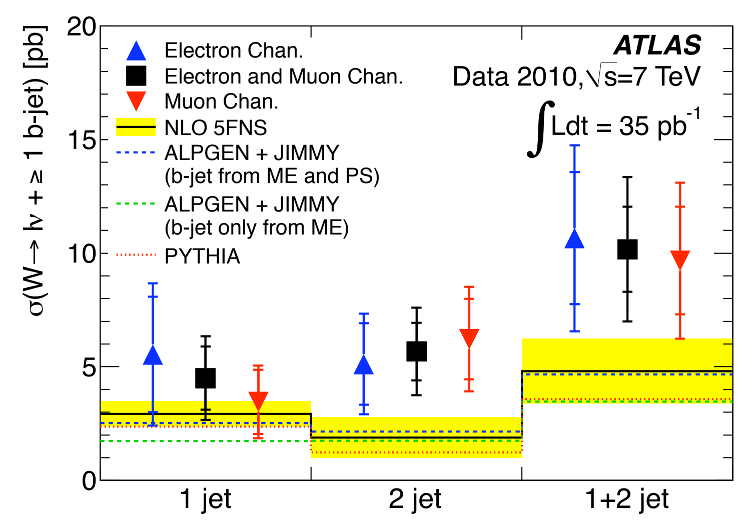
- Measured by ATLAS using 2010 data sample
  - studied W + 1 jet and W + 2 jets
  - require at least one b-tagged jet





W→ e ν + 2 jets

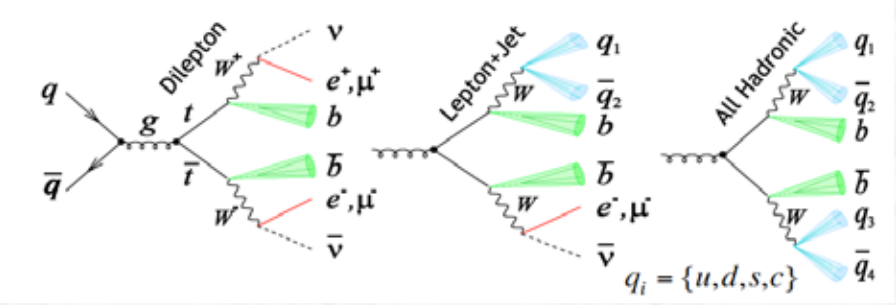
Distribution of the mass of the particles associated to the secondary vertex for b-tagged jets

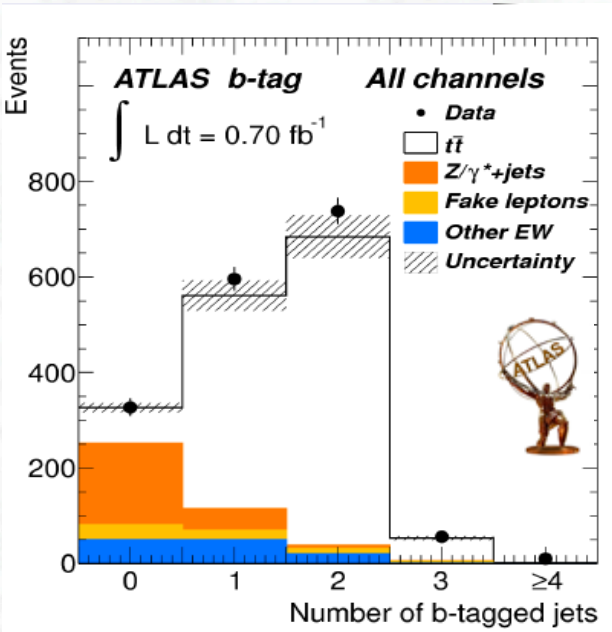


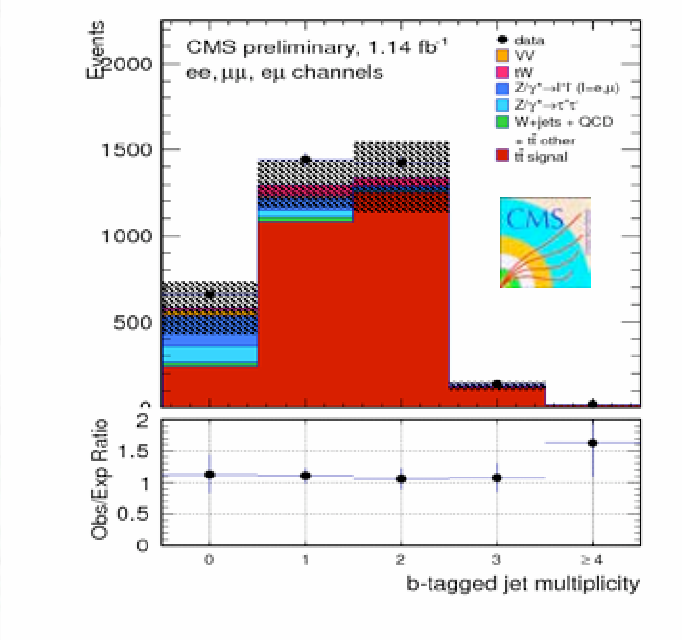
Results from e and μ combined. Measurements ~1.5σ above NLO prediction, but still consistent within uncertainties

Top Quark pair production

Pair production: qq and gg-fusion

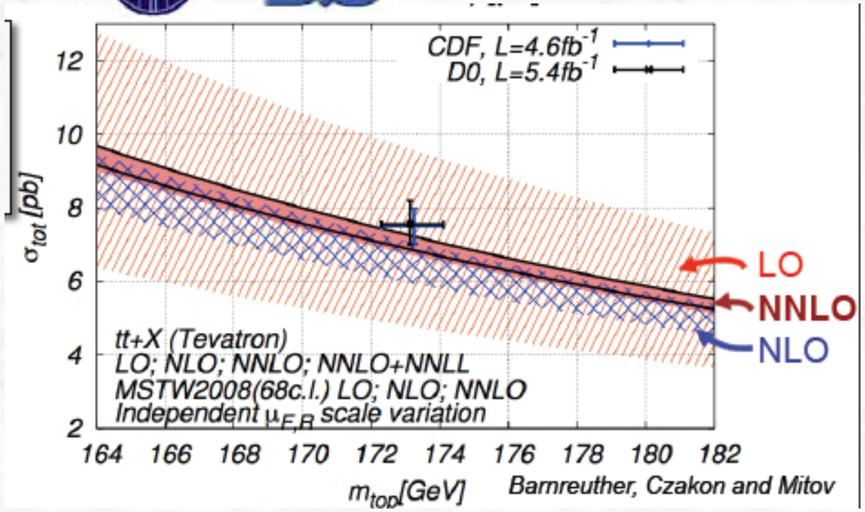


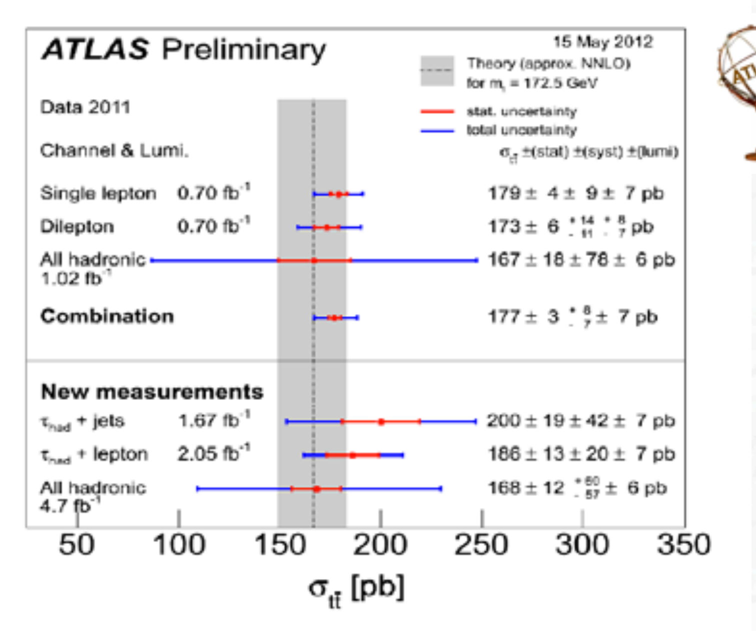


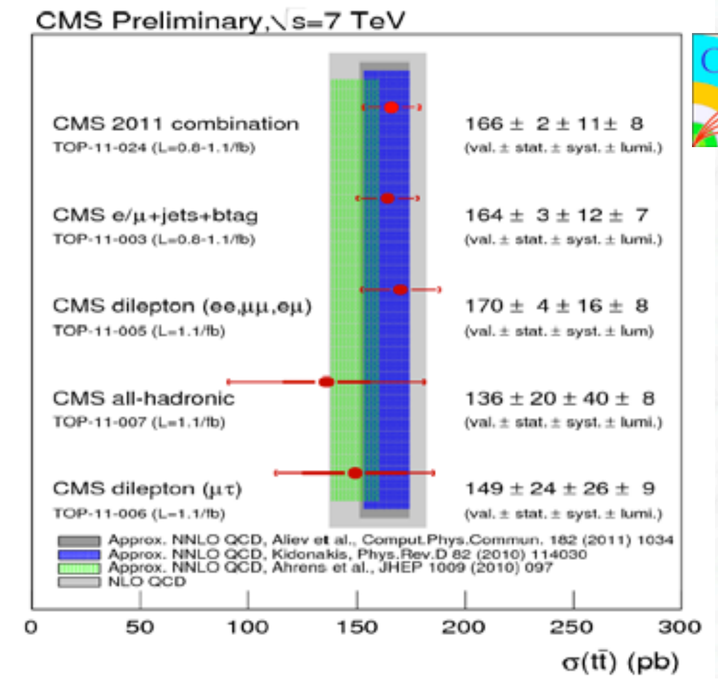


b-tag multiplicity in l-jet events ...and.. in di-lepton events

Top cross section measurements



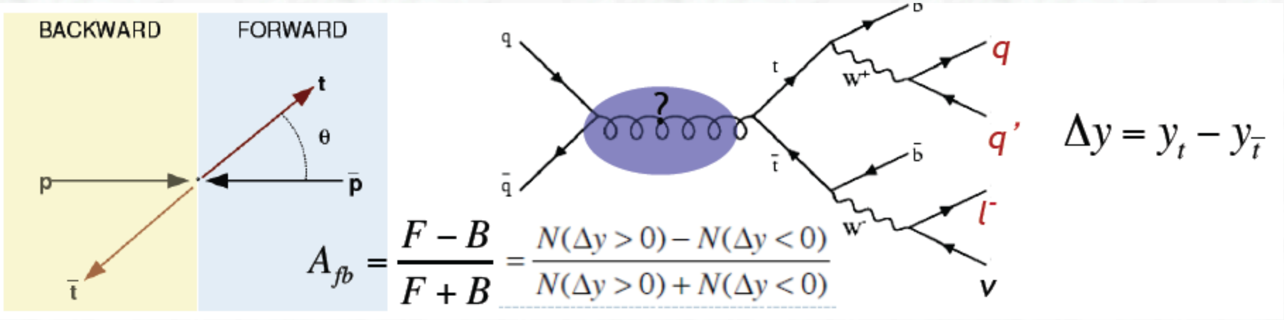




- Measurements at the Tevatron and at the LHC are well described by approx. NNLO calculations
- Precision reached at the Tevatron: 6.4%
- LHC experiments have already reached a comparable precision (6.2%)

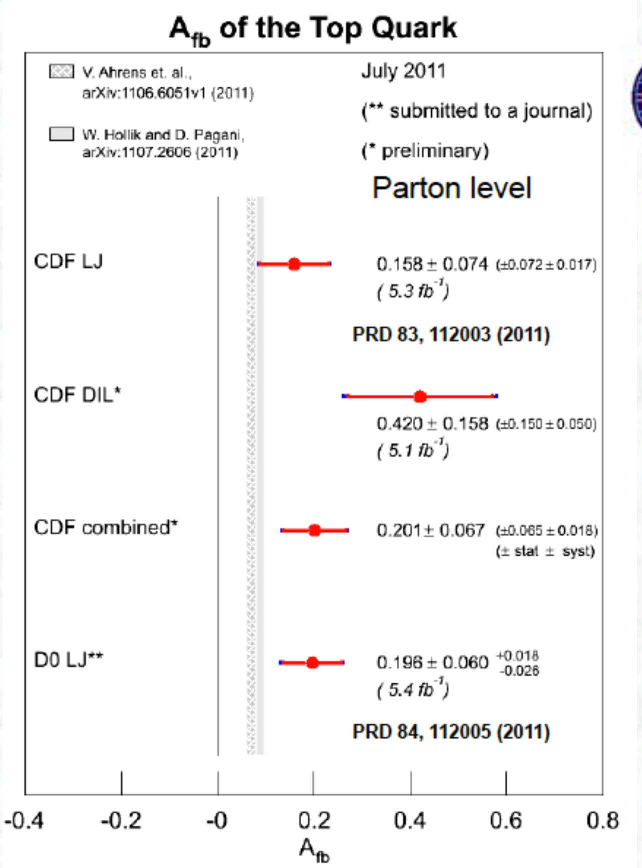
  (large dataset, still potential to reduce the already dominant systematic uncertainties)

Top properties according to expectations, except maybe A_{FB} (Tevatron)



$$\Delta y = y_t - y_{\bar{t}}$$

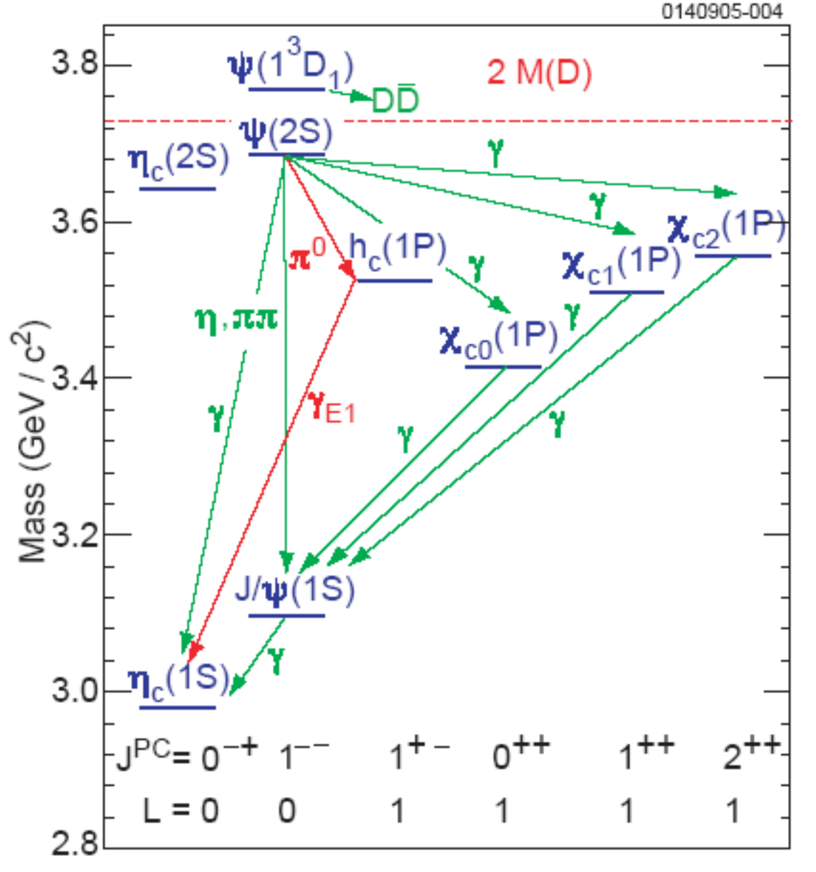
$$A_{fb} = \frac{F-B}{F+B} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$



Needs clarification:

More data, improved theoretical calculations

Charmonium and Bottomonium states



Is this for the LHC ?

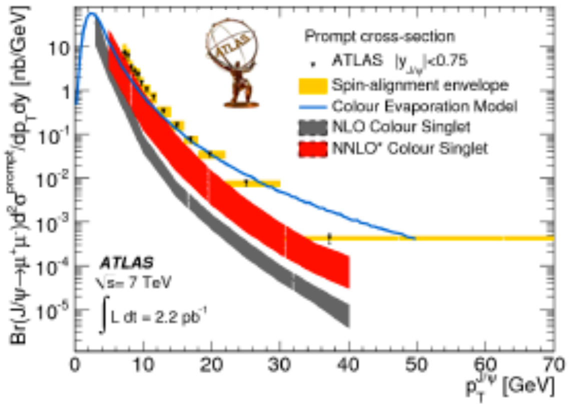
-except for ALICE and LHCb-

Yes, all experiments at the Tevatron and LHC have observed these states, measured production cross sections and have even discovered new ones

use $\mu\mu$ decays and γ-signatures

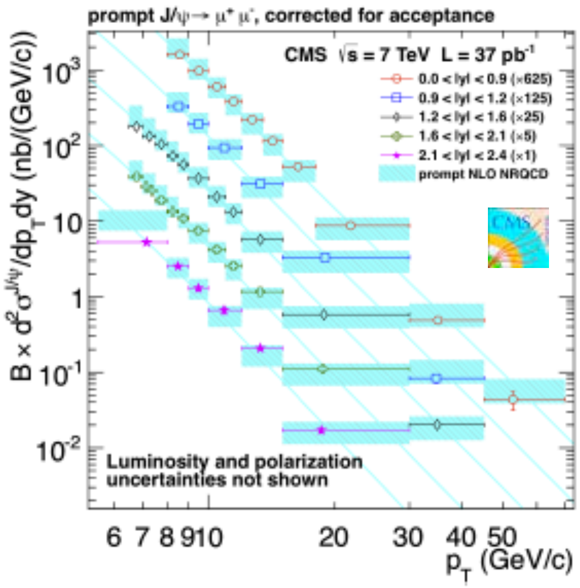
Charmonium production:

ATLAS data vs. CS



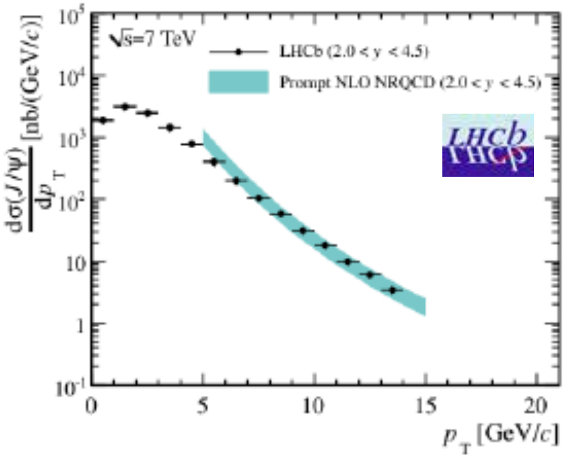
Nucl. Phys. B 850 (2011) 387-444

CMS data vs. CS+CO



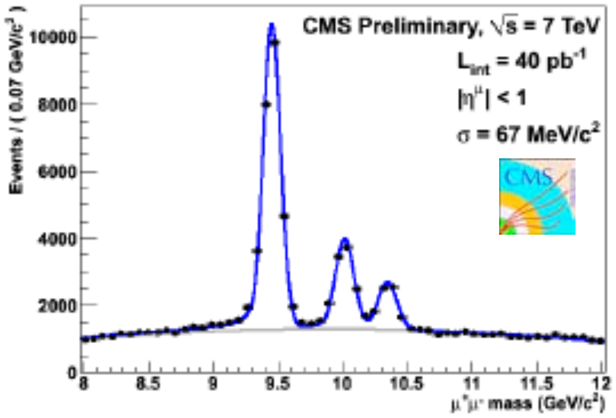
JHEP 02 (2012) 011

LHCb data (5.2 pb^{-1}) vs. CS+CO



EPJC 71(2011)1645

- Production reasonably well described by NLO QCD calculations
- Simple colour singlet model not adequate
- Similar conclusions for bottomonium states
- Polarization is still not understood, further measurements needed

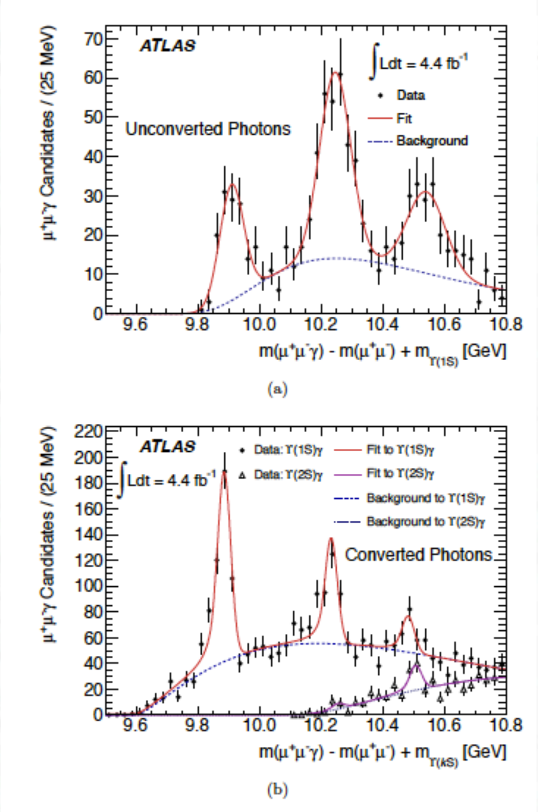


PRD 83 112004 (2011)

New heavy meson or baryon states

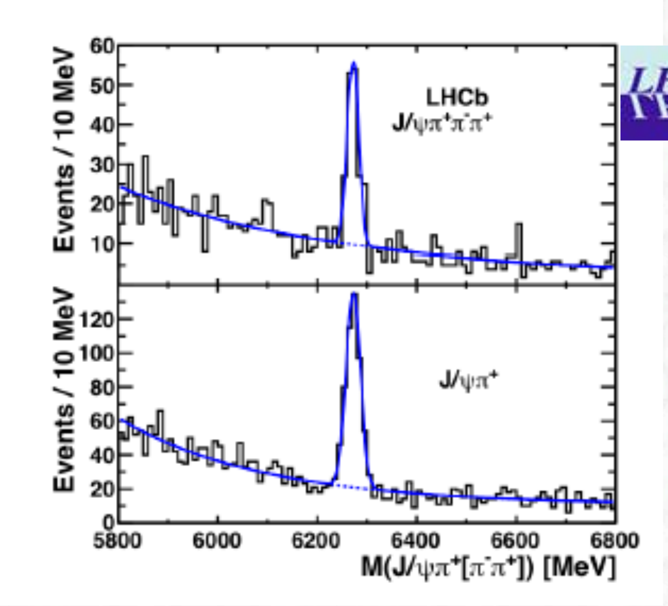
χ_b (3P)

- First observation by ATLAS:
  χ_b (3P) → Υ(1S)+ γ
  and Υ(2S)+ γ



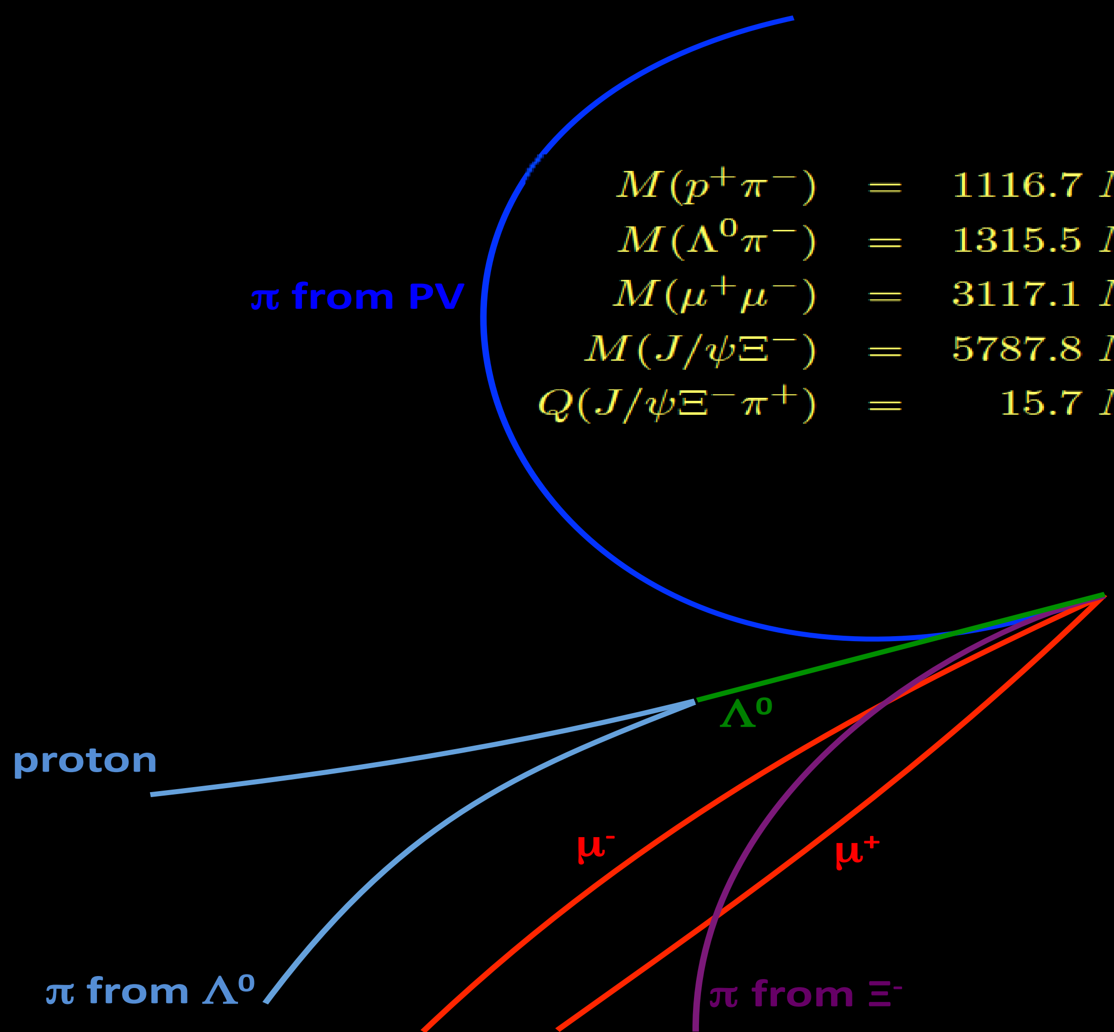
B^+_c

- First observed by CDF in B^+_c → J/ψ lν
- Observed in B^+_c → J/ψ π (LHCb, ATLAS) and J/ψ πππ (LHCb)

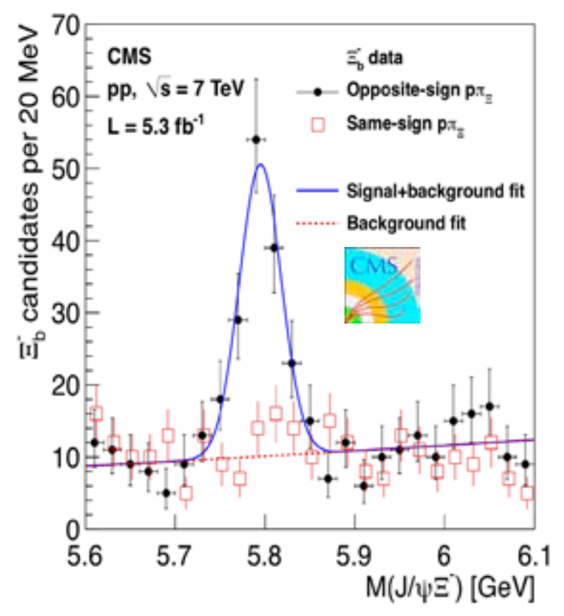


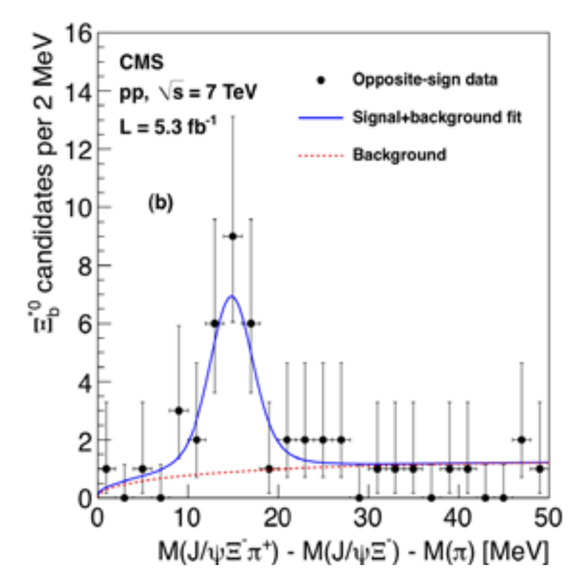
- Many other states by LHCb (B_s^{**}, Λ_b^{0*}, …)

$\Xi_b^{*0} \rightarrow \Xi_b^- \pi^+ \rightarrow \Xi^- J/\psi\, \pi^+ \rightarrow \Lambda \pi^- \mu^+ \mu^- \pi^+ \rightarrow p^+ \pi^- \pi^- \mu^+ \mu^- \pi^+$



$$
\begin{aligned}
M(p^+\pi^-) &= 1116.7\ MeV\\
M(\Lambda^0\pi^-) &= 1315.5\ MeV\\
M(\mu^+\mu^-) &= 3117.1\ MeV\\
M(J/\psi\Xi^-) &= 5787.8\ MeV\\
Q(J/\psi\Xi^-\pi^+) &= 15.7\ MeV
\end{aligned}
$$





Candidate Ξ_b^{*0} event with 3 secondary and ~10 primary vertices