LATEST RESULTS FROM THE LHC

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Results from

1. Soft Particle Production
- Charged Hadron Multiplicities
- Strange Hadrons and Hyperons
- Angular Correlations

2. QCD Phenomena
- Di-Muon Production
- D Meson Production
- J/Ψ Production
- B-Production
- Jet Physics

3. B-Physics
- B Hadrons, Lifetime
- Prospects for B -> $\mu\mu$
- B Oscillations

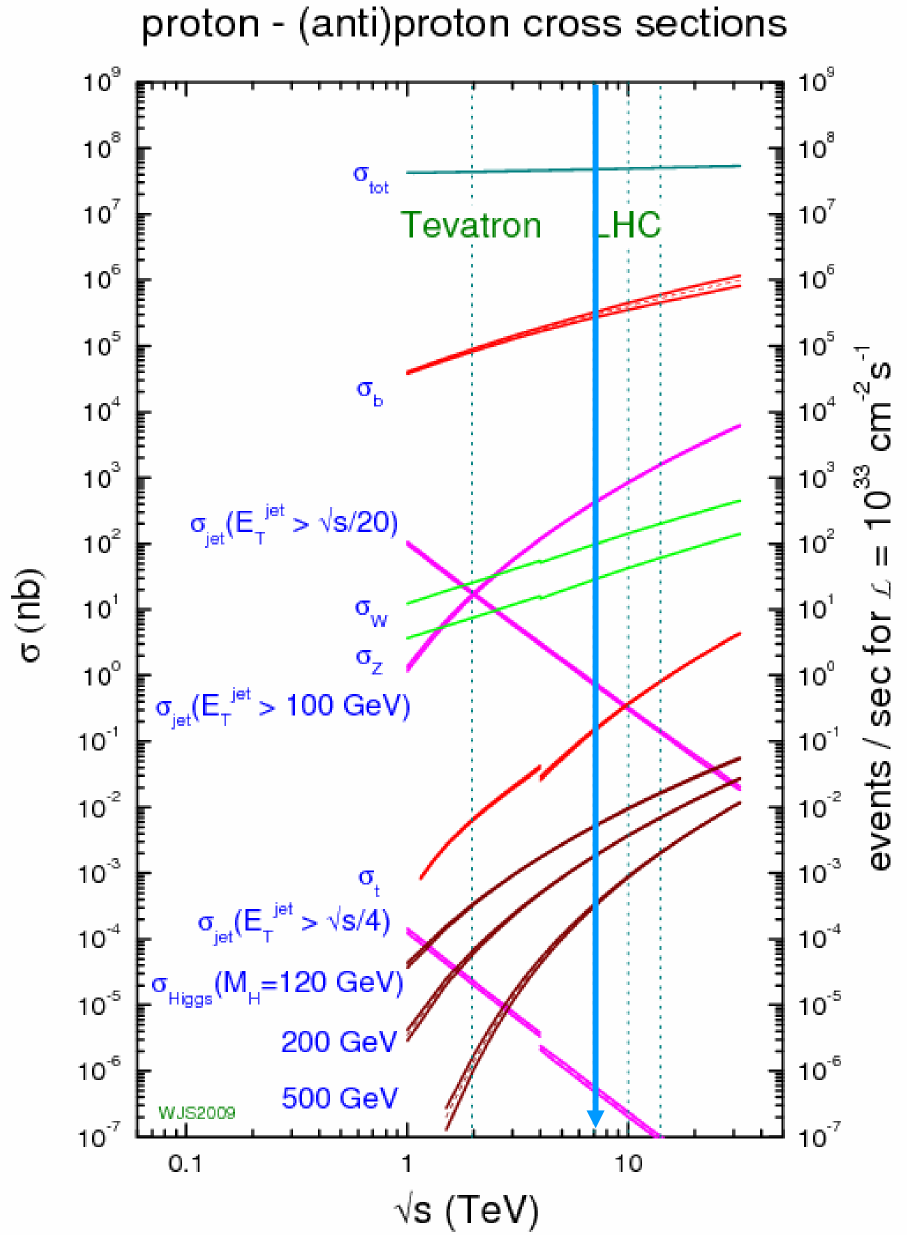
4. Electroweak Physics
- W/Z Production

5. Top Quark Physics
- Top Quark Evidence

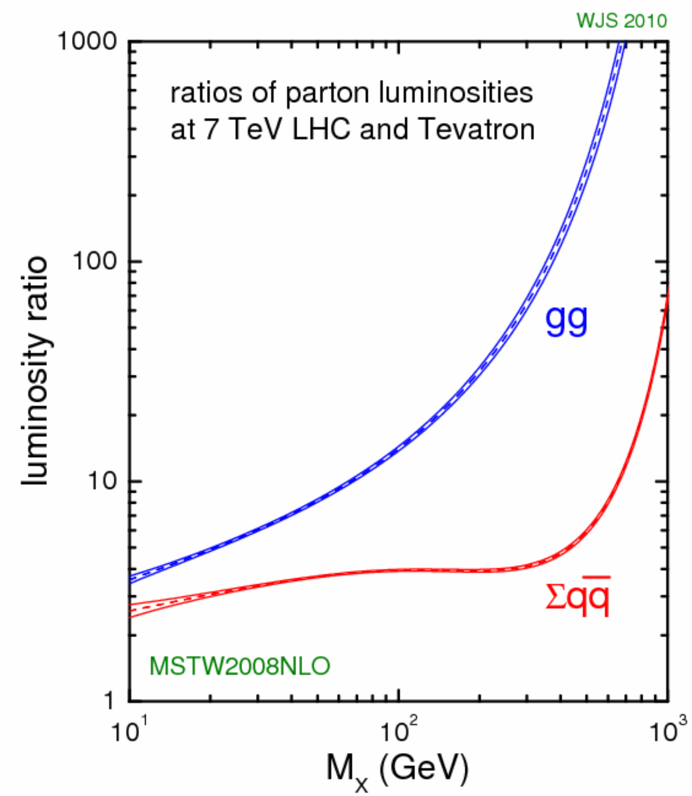
6. Physics beyond the Standard Model
- W‘
- Di-Jet Resonances
- Compositness
- Search for SUSY

Most results from 103rd LHCC http://indico.cern.ch/conferenceDisplay.py?confId=105780

Cross Sections



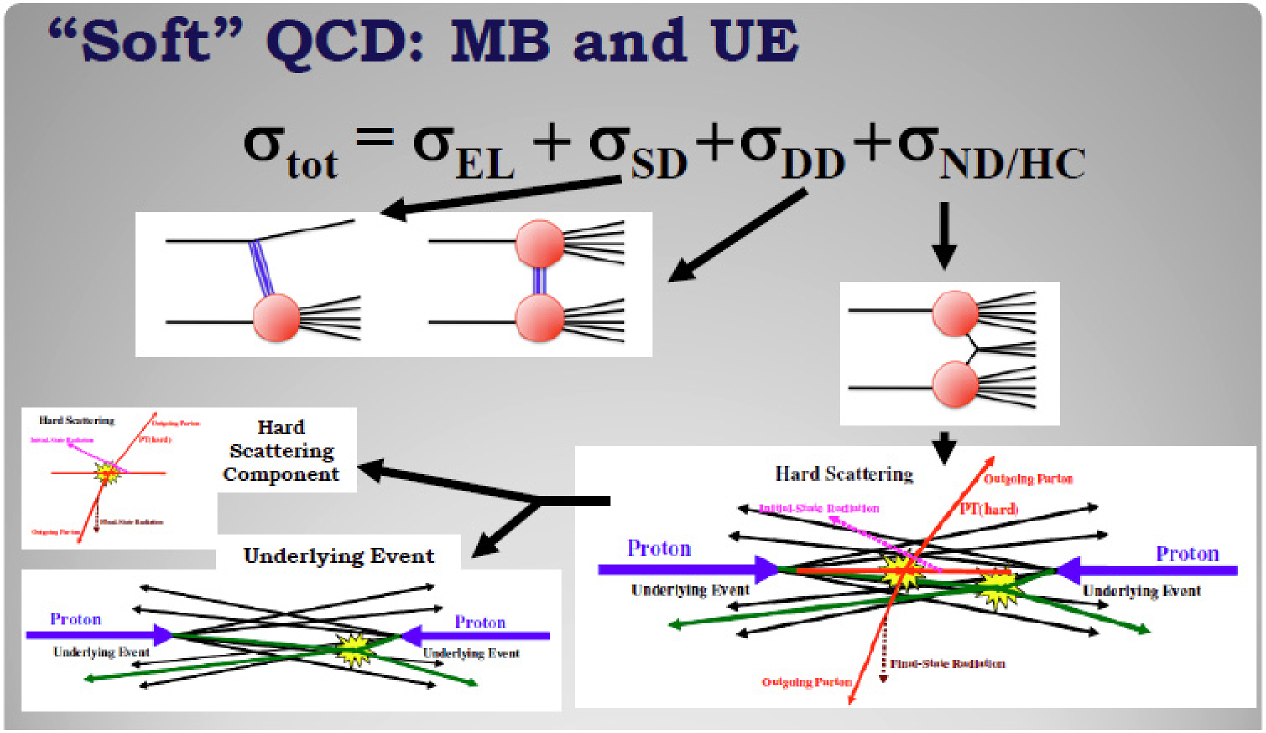
LHC @ 7 TeV vs Tevatron



x 20 gain in luminosity @ M_{top}

1. SOFT PARTICLE PRODUCTION

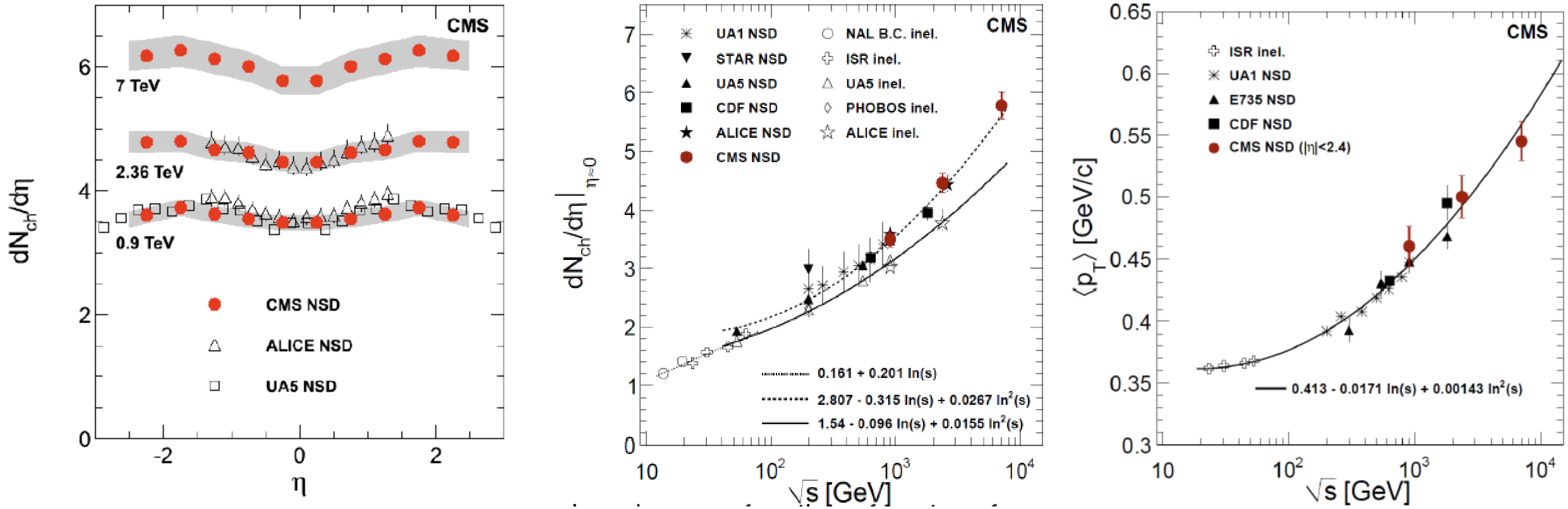
- Charged Hadron Multiplicities
- Strange Hadrons and Hyperons
- Angular Correlations



Minimum-bias: events collected with (ideally) totally inclusive trigger, in principle contains all types of interactions proportionally to their natural production rate.
Underlying event: “connected” with the hard scattering.

1.1 Charged Hadron Multiplicities

Minimum bias events: soft QCD (p_T tracks down to 50 MeV)
Non single-diffractive event selection (correction 6%→2.5% systematic error)



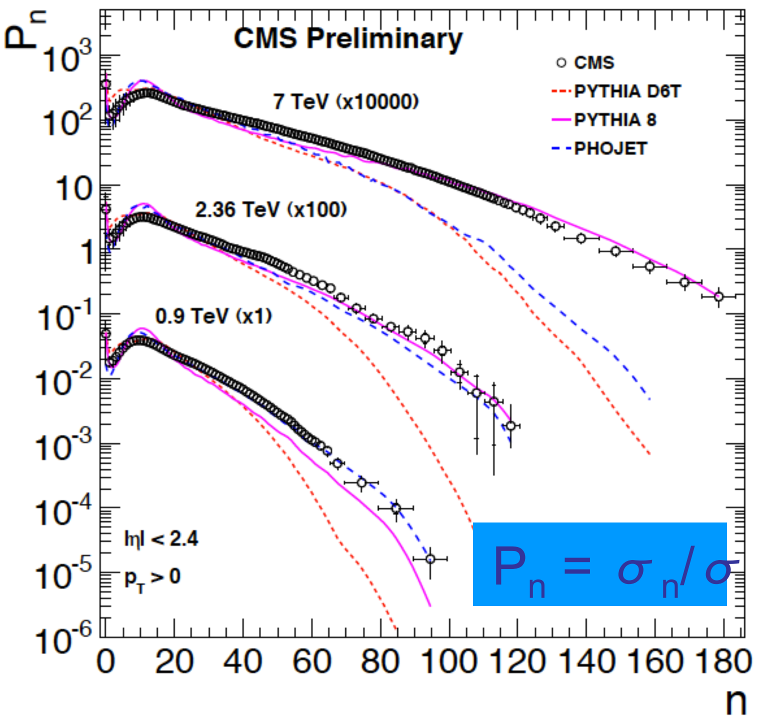
N_{ch} at $|\eta|<0.5$

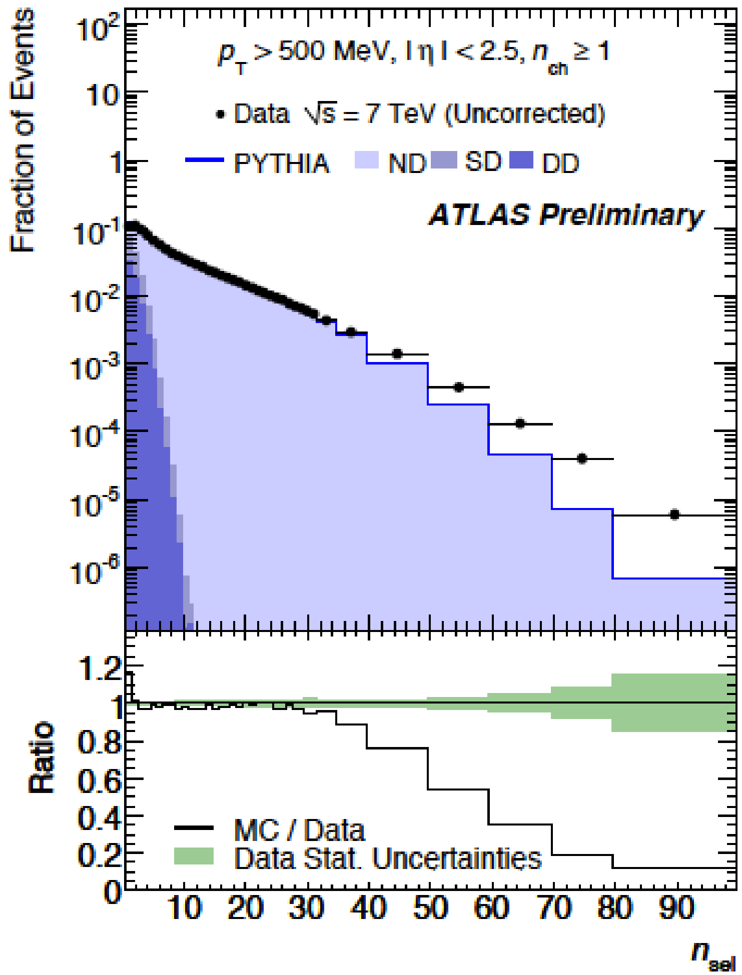
0.9 TeV: $3.48 \pm 0.02\ (\text{stat.}) \pm 0.13\ (\text{syst.})$

2.36 TeV: $4.47 \pm 0.04\ (\text{stat.}) \pm 0.16\ (\text{syst.})$

7.0 TeV: $5.78 \pm 0.01(\text{stat}) \pm 0.23(\text{syst})$

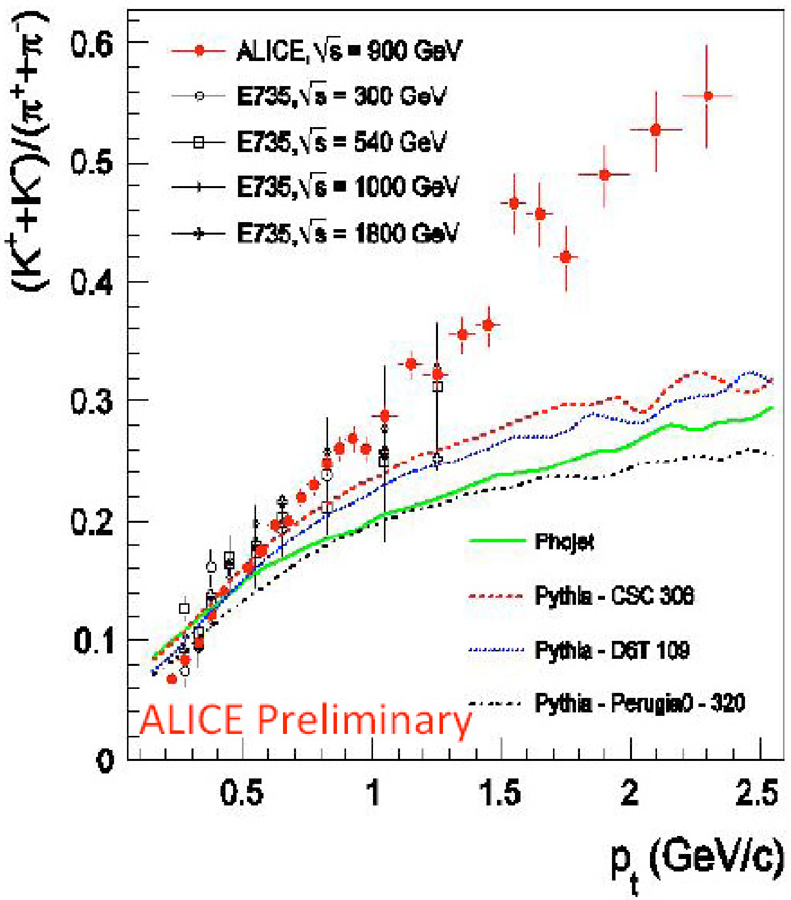
Charged Multiplicity Distributions

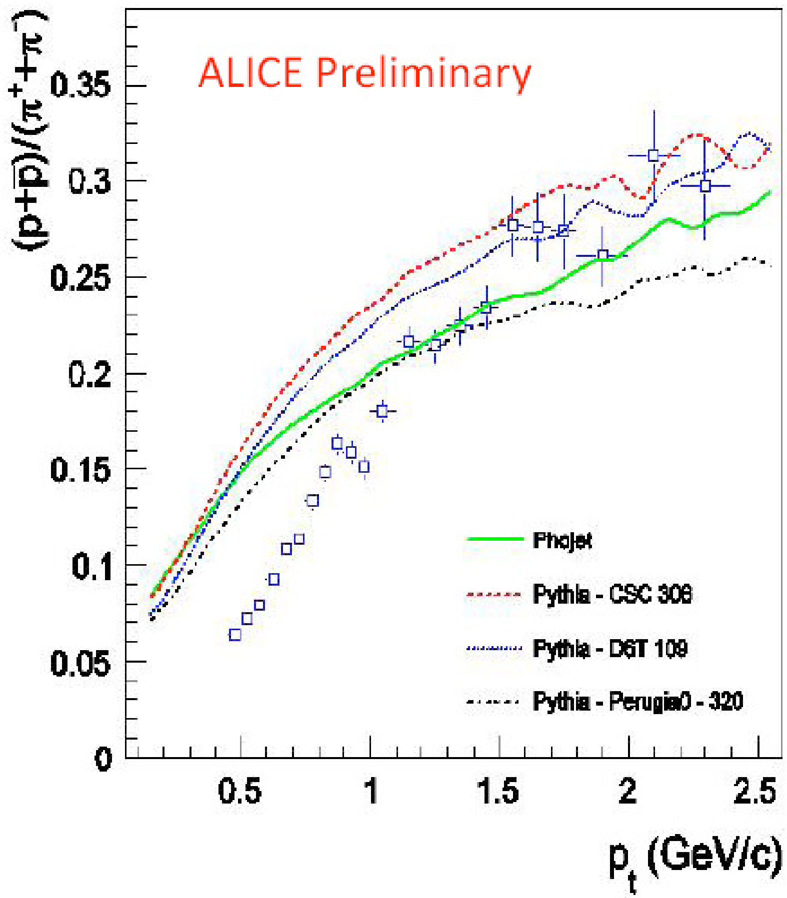




Distributions not well described by our event generators:
Tuning is needed

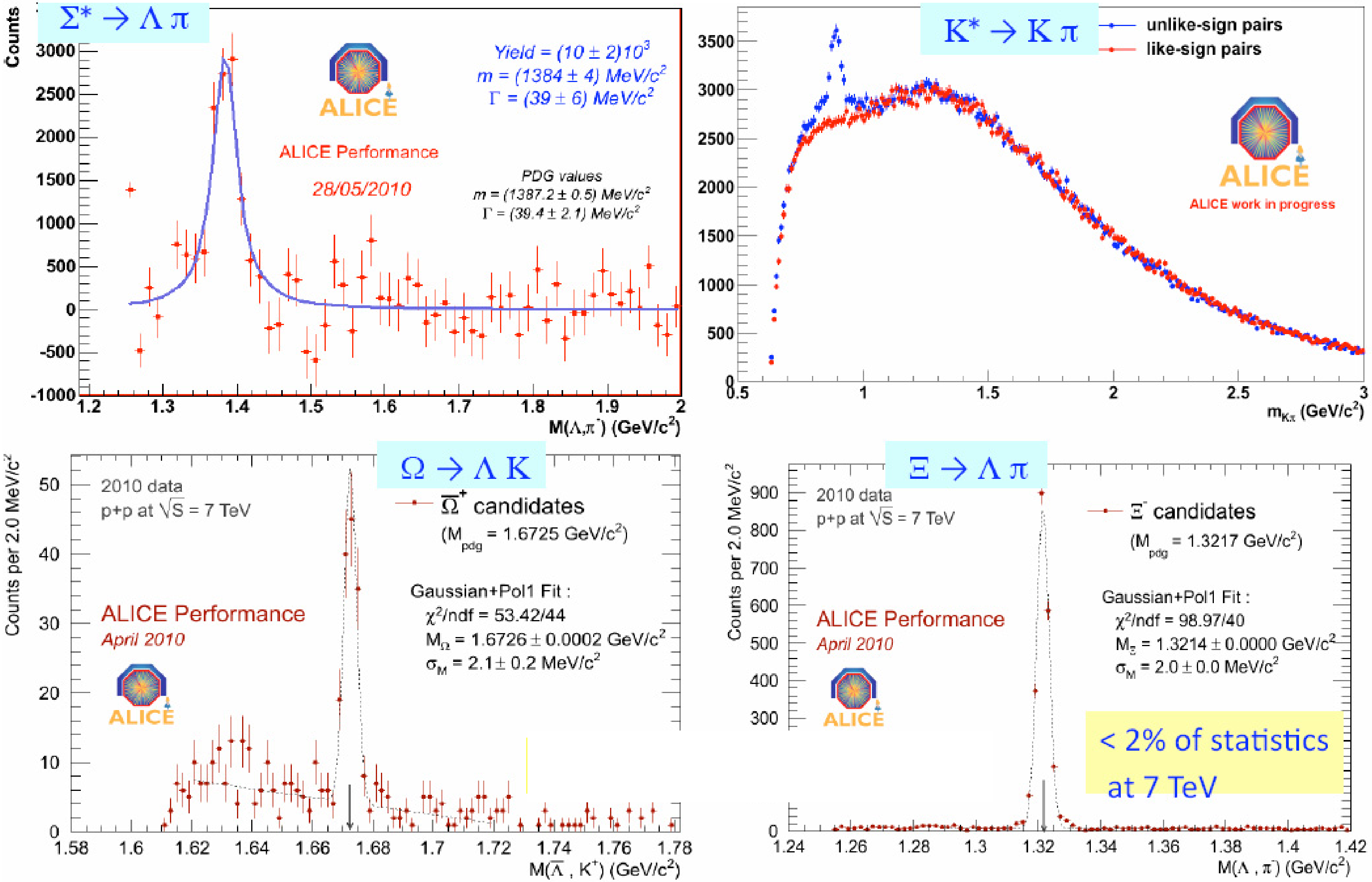
Particle Ratios vs p_t



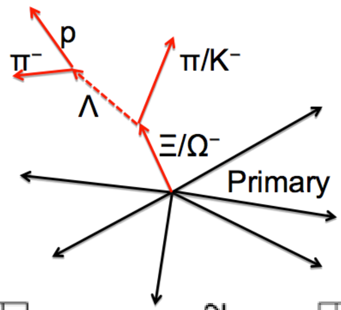


Poor agreement with models, at higher p_T for K/π and lower p_T for p/π

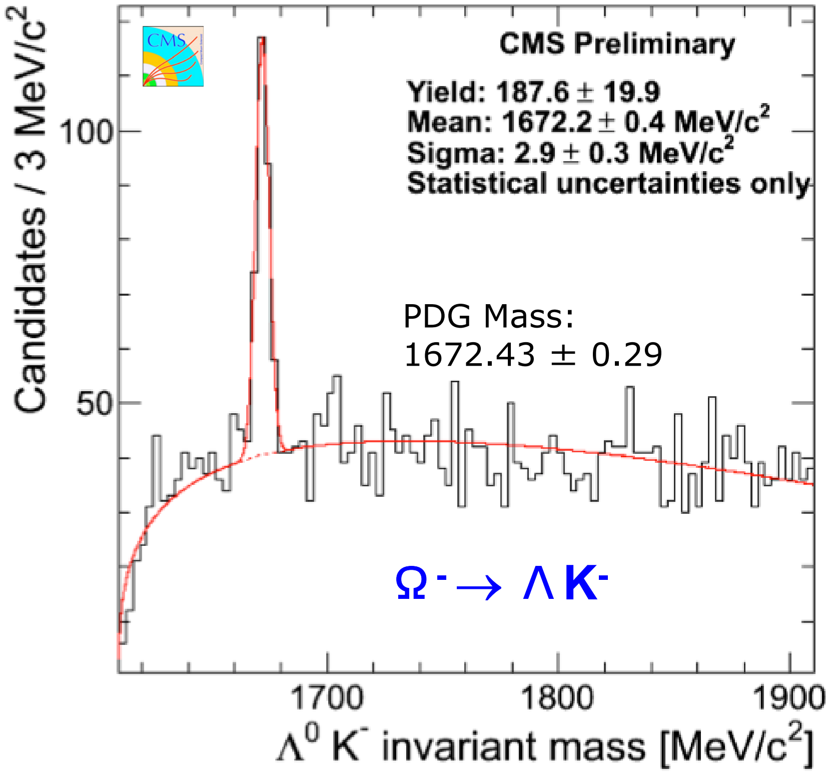
1.2 Strange Hadrons and Hyperons

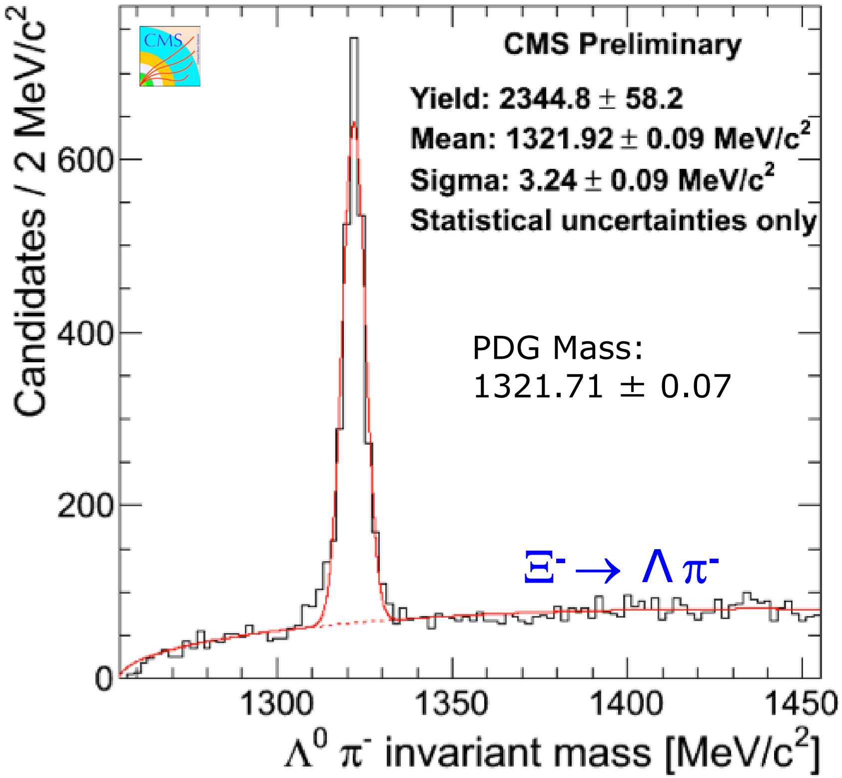


- Tracks displaced from primary vertex ($d_{3D} > 3\sigma$)
- Common displaced vertex ($L_{3D} > 10\sigma$)



Invariant mass distribution for different combinations ($\Omega^{\pm} \to \Lambda K^{\pm}$ or $\Xi^{\pm} \to \Lambda \pi^{\pm}$) fit to a common vertex.

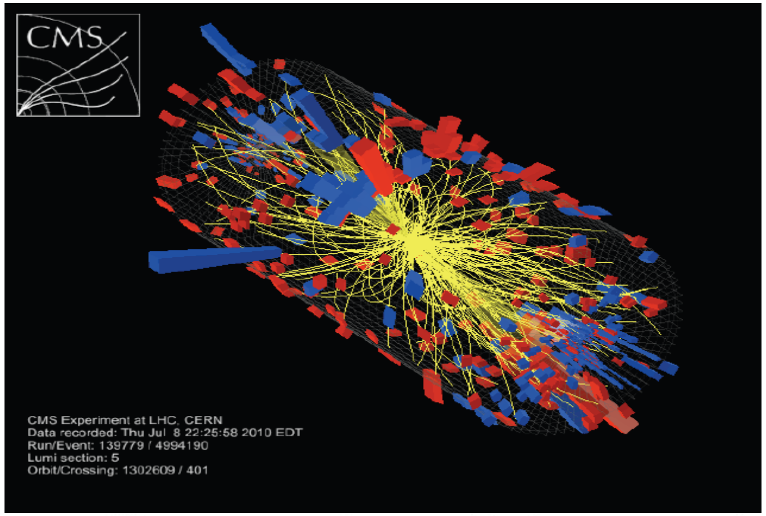




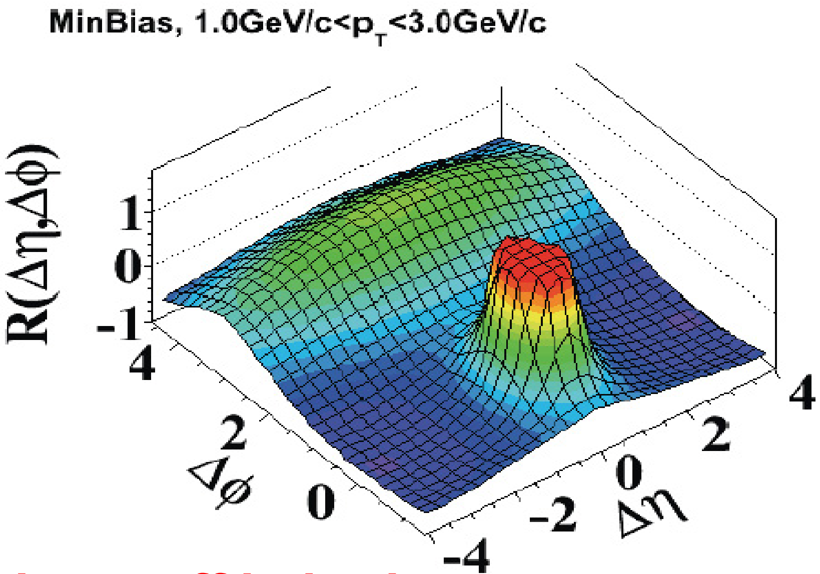
Mass accuracy at the level of 10^{-4} ➔ good alignment of Si-strip and pixels

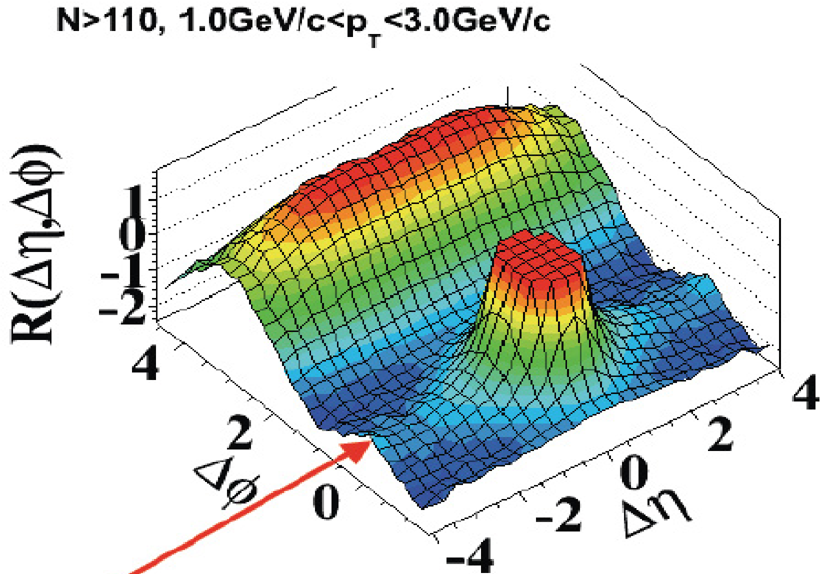
1.3 Observation of Long Range Correlations

$$R(\Delta\eta,\Delta\varphi) = \left\langle (N-1)\left(\frac{S_N(\Delta\eta,\Delta\varphi)}{B_N(\Delta\eta,\Delta\varphi)} - 1\right)\right\rangle_N$$



MinBias

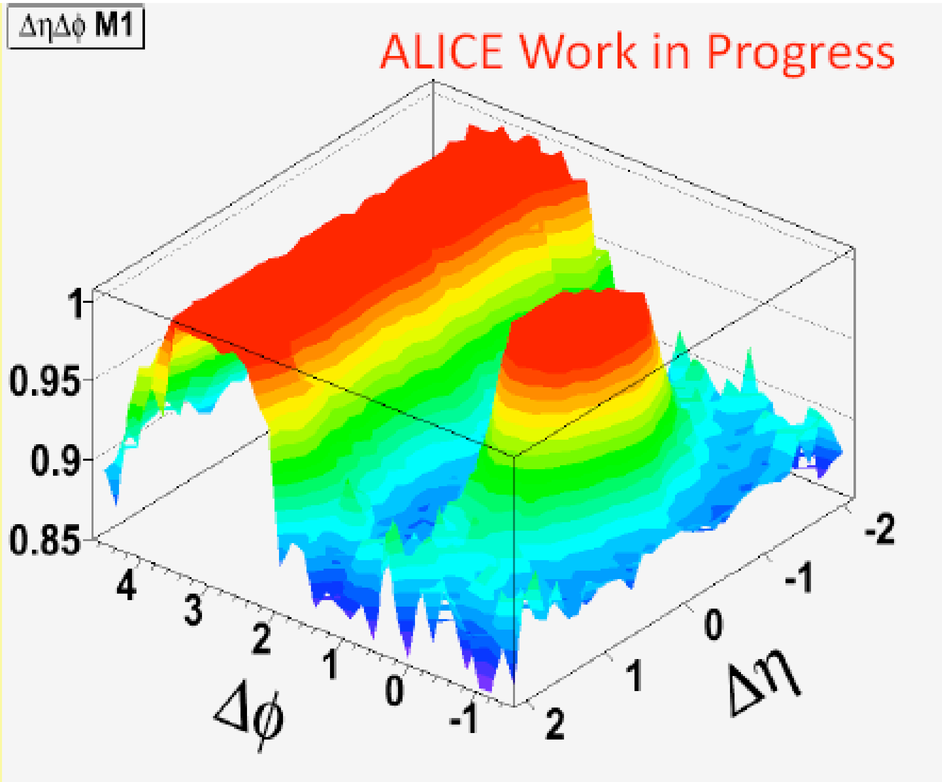




Peak cut-off in both distributions

Long range same side correlations: arXiv:1009.4122

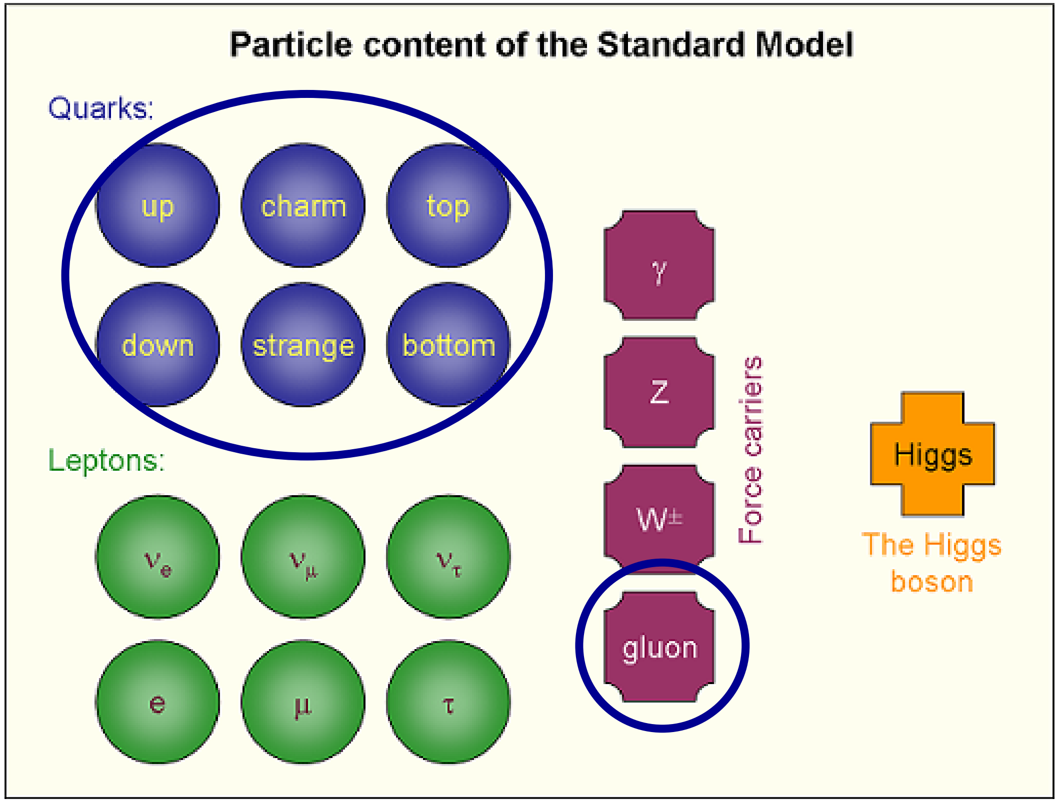
Nearside Longitudinal Structure?



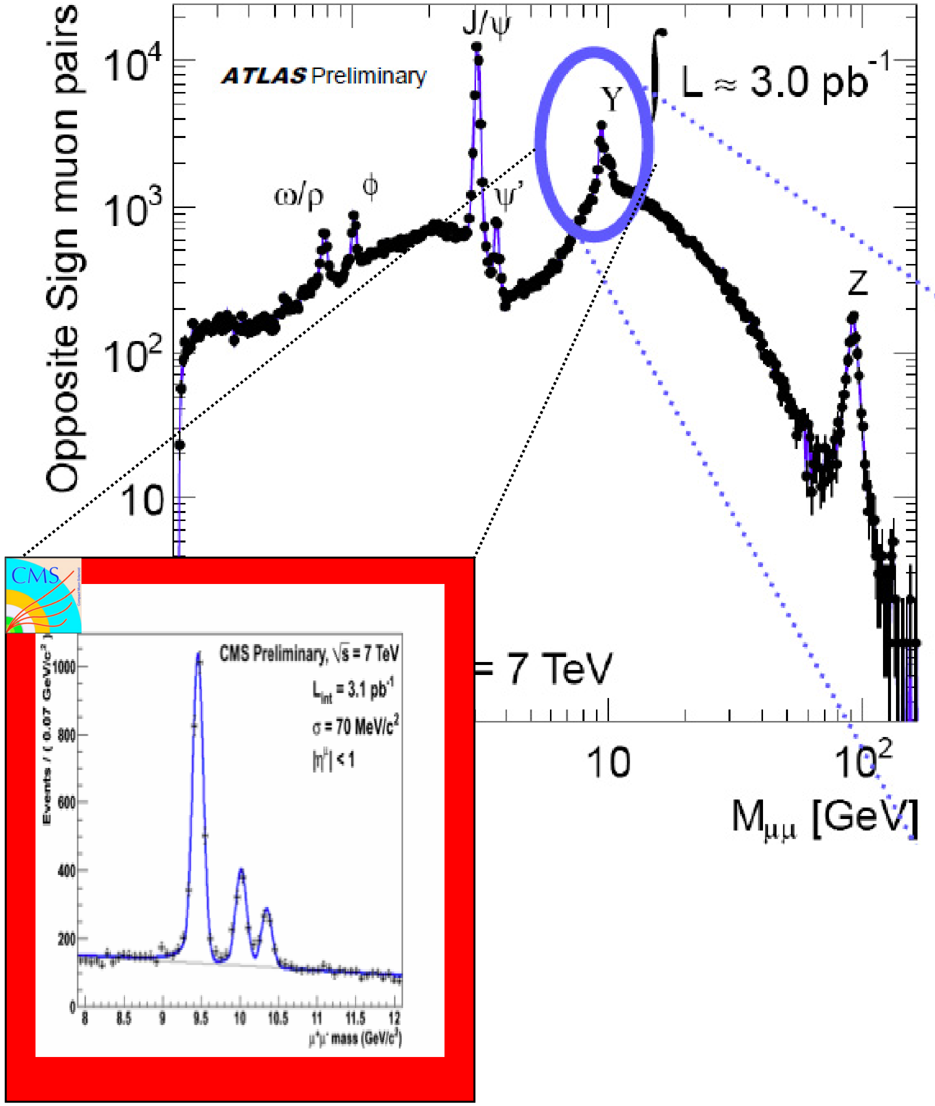
5 - 6 x <M> , p_T > 1.5 GeV

2. QCD PHENOMENA

- Di-Muon Production
- D Meson Production
- J/Ψ Production
- Bottom Production
- Jet Physics

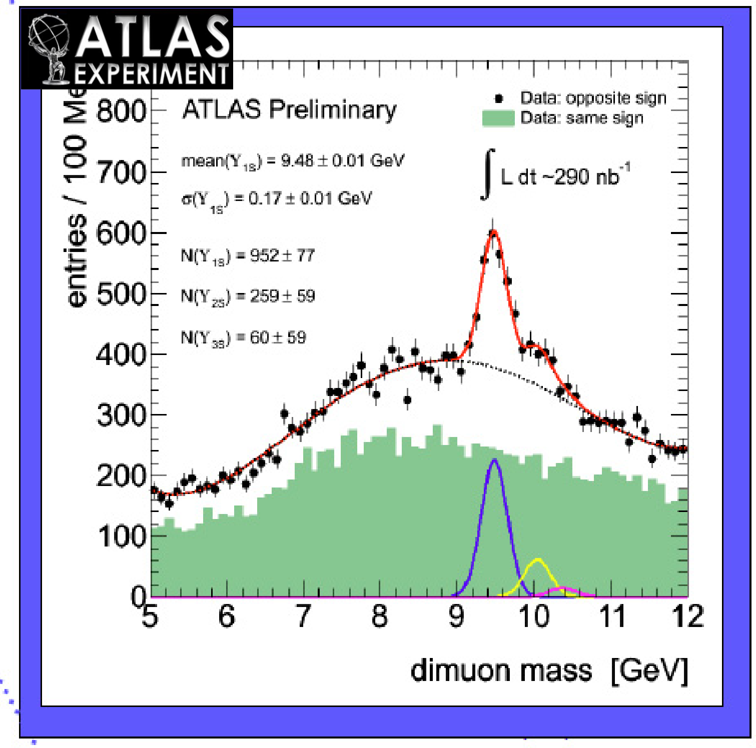


2.1 Di-Muon Production



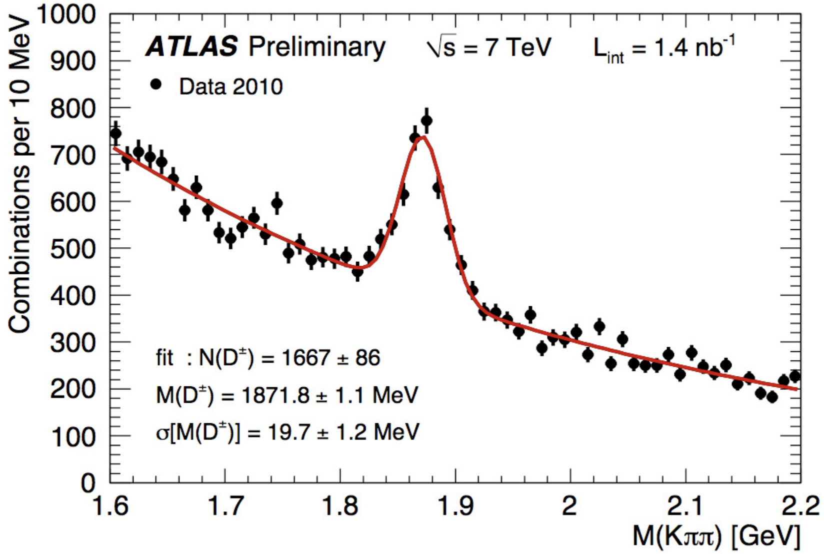
Simple analysis:

- LVL1 muon trigger with p_T ~ 6 GeV threshold
- 2 opposite-sign primary muons reconstructed by combining tracker and muon spectrometer

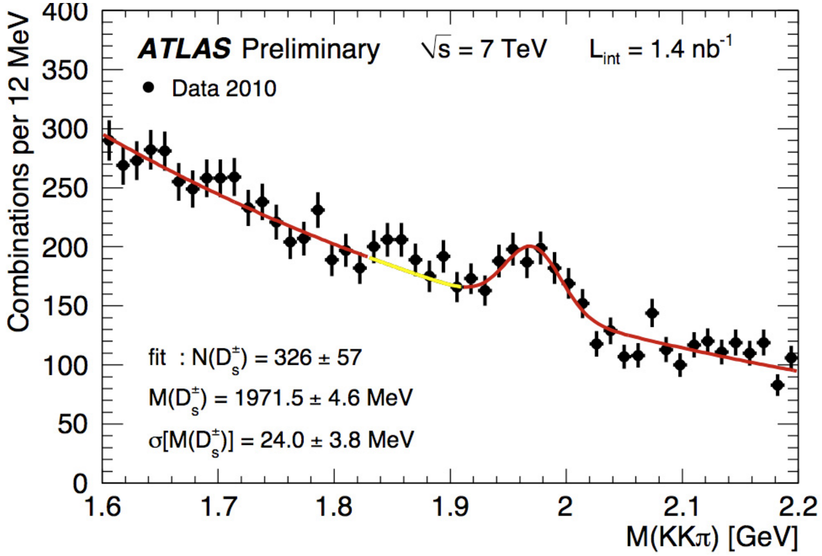


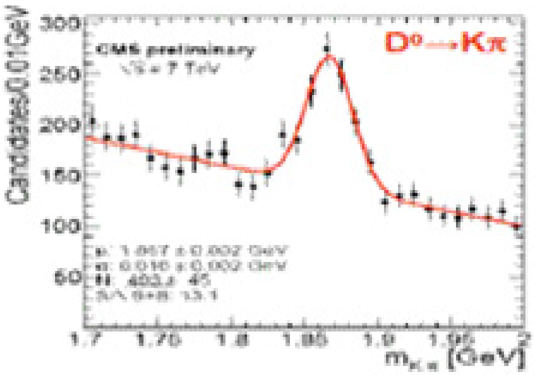
2.2 D Meson Production

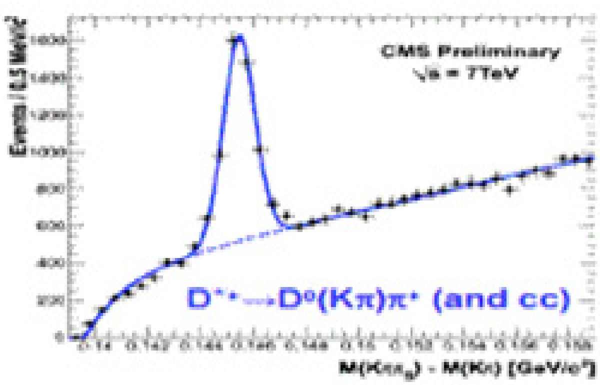
$D^+ \rightarrow K^- \pi^+ \pi^+$

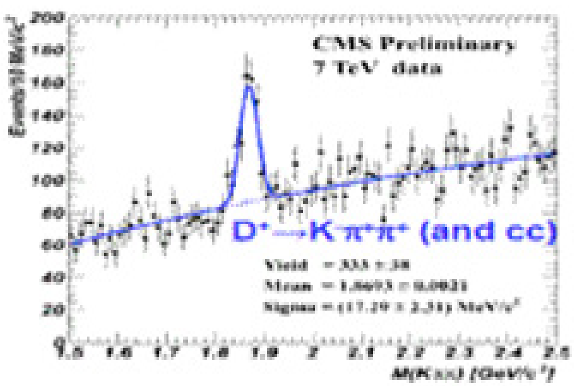


$D_s^+ \rightarrow \Phi\ \pi^+ \rightarrow (K^+ K^-)\, \pi^+$



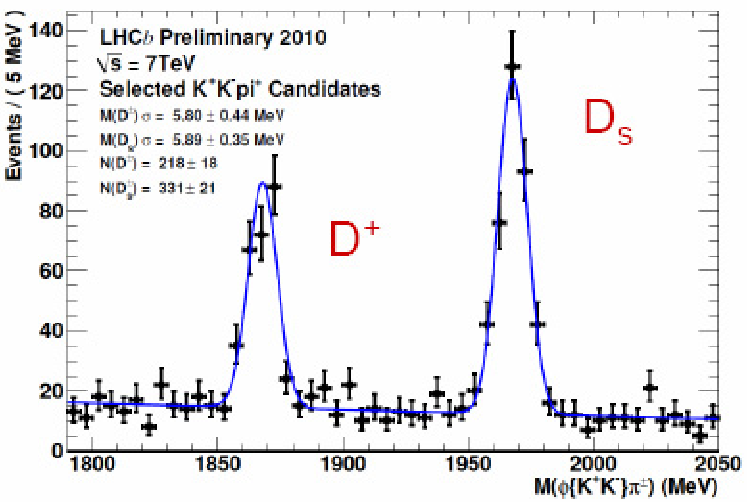


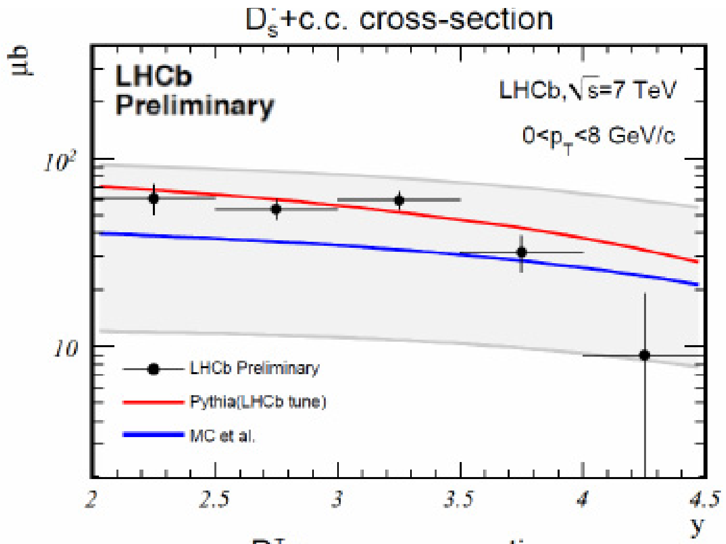


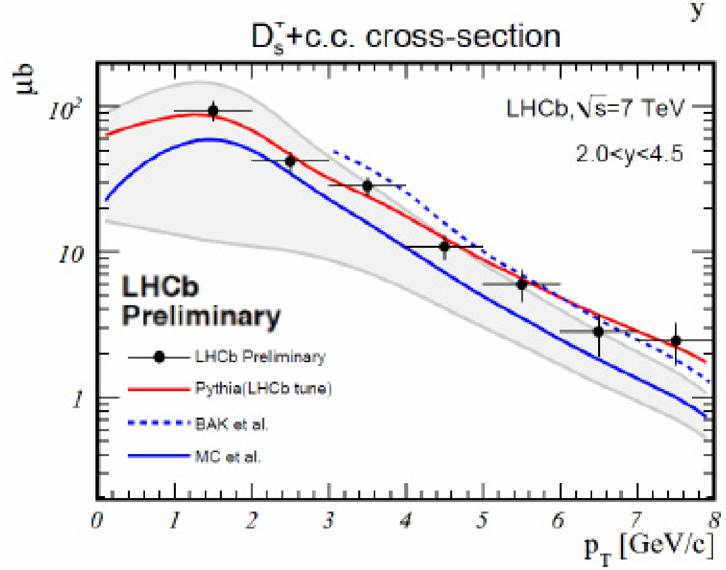


Measurement of D Cross Section

- First measurement at √s=7 TeV.
- Measure cross section vs y, p_T in ~2 nb^{-1}, with open trigger.
- Impact parameter distribution used to separate prompt $D^{0,+}$,D^+, D_s from secondary.
- Good agreement with expectations!

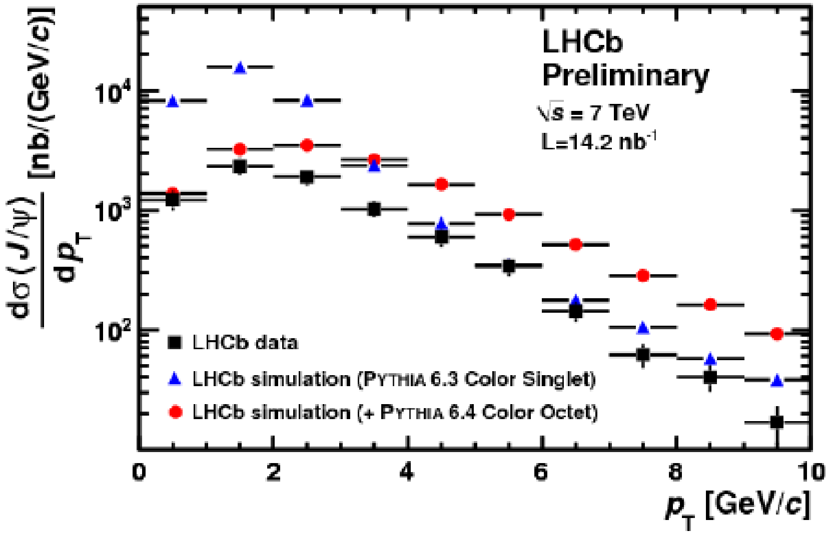






2.3 J/Ψ Production

- Preliminary cross section measurement with ~14 nb^{-1} (ICHEP):



- Scale and shapes not well described by colour singlet nor by octet models→ new studies are coming.

- Inclusive J/ψ production:

  $\sigma(2.5<y<4, p_T<10\ GeV/c) = 7.65 \pm 0.19 \pm 1.10^{+0.87}_{-1.27}\ \mu b$

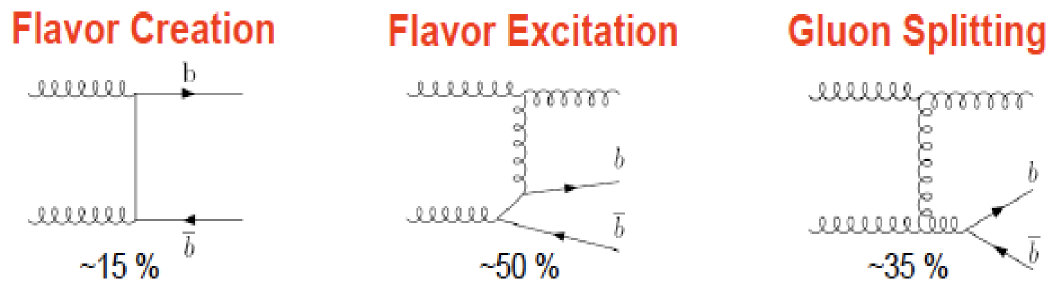
- J/ψ production from b:

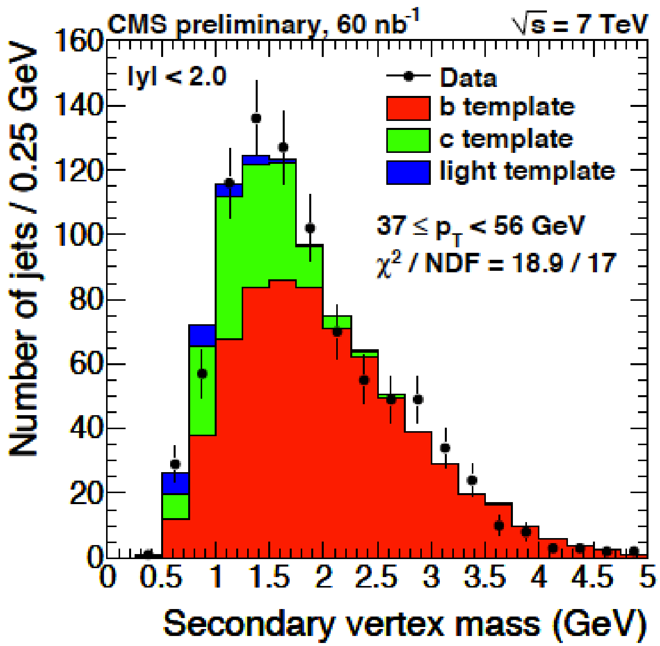
  $\sigma(2.5<y<4, p_T<10\ GeV/c) = 0.81 \pm 0.06 \pm 0.13\ \mu b$

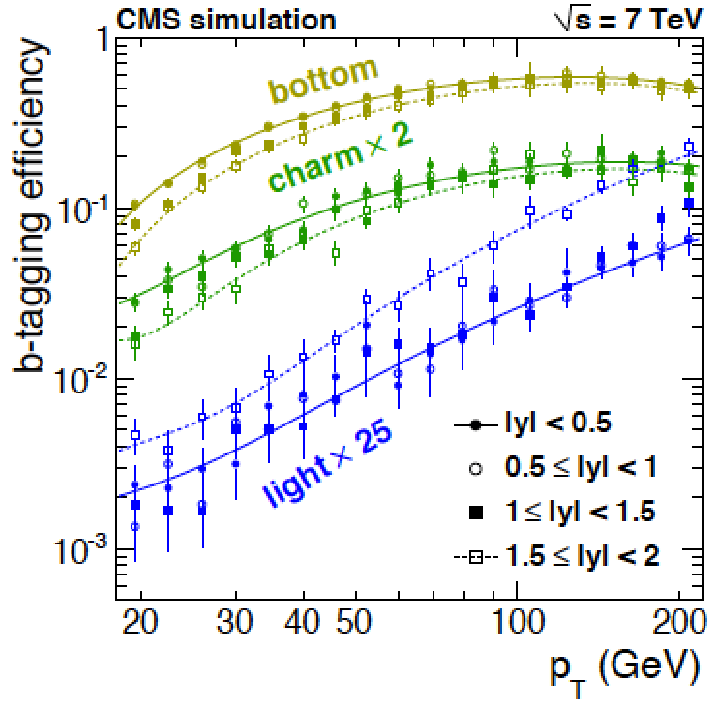
2.4 Bottom Hadron Production and Tagging

> Sources of B at the LHC: FEX and GS are higher order, but dominate at the LHC!

- B tagging with various algos;
- Invest purity and c mistag rate e.g. with template fit to secondary vertex mass.

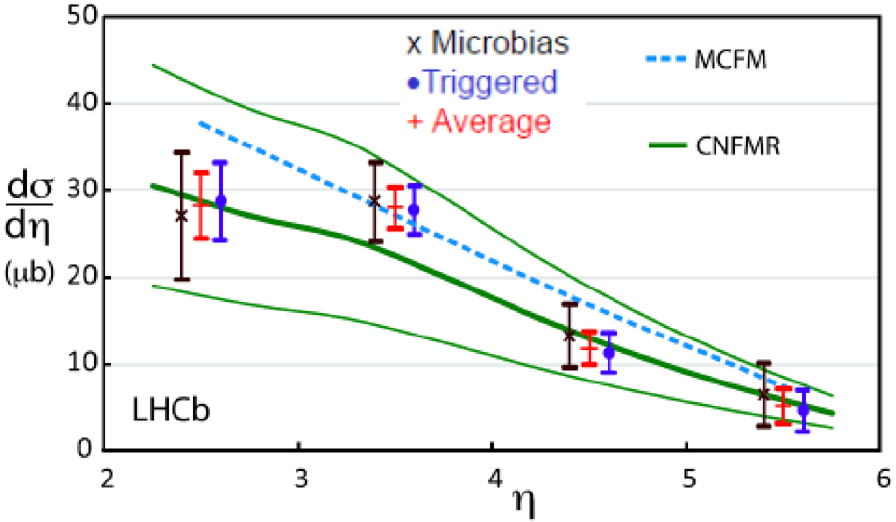






Bottom Hadron Cross Section

Cross section in four η bins, open trigger (~3 nb^{-1}) and muon trigger sample (~12 nb^{-1}) submitted to PLB (arXiv:1009.2731)



Shapes and scales agree well with expectation. Validates QCD predictions at LHC energies

$\sigma\ (pp \rightarrow H_b X\ ) = 75.3 \pm 5.4 \pm 13.0\ \mu b$ for $2<\eta<6$, any p_T, $\sqrt{s}=7$ TeV

Extrapolating to 4π with PYTHIA 6.4: **$\sigma(pp \rightarrow b\bar{b}X) = 284 \pm 20 \pm 49\ \mu b$**

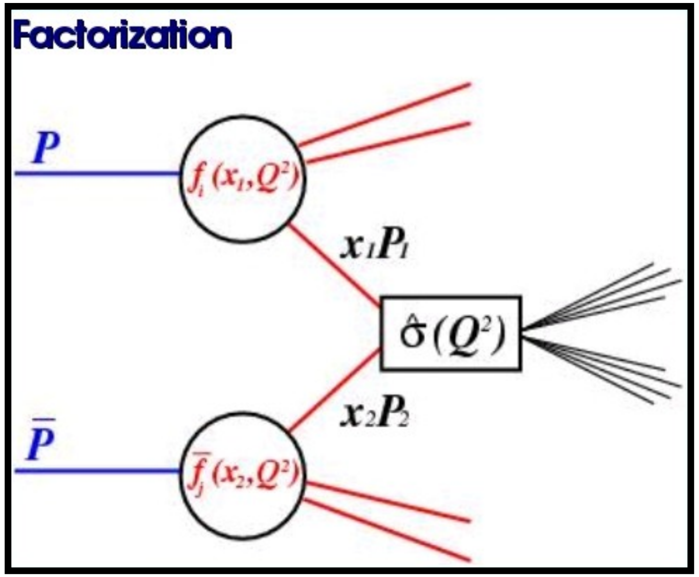
Averaging with prel. result from b→J/ψ: **$\sigma(pp \rightarrow b\bar{b}X) = 292 \pm 15 \pm 43\ \mu b$**

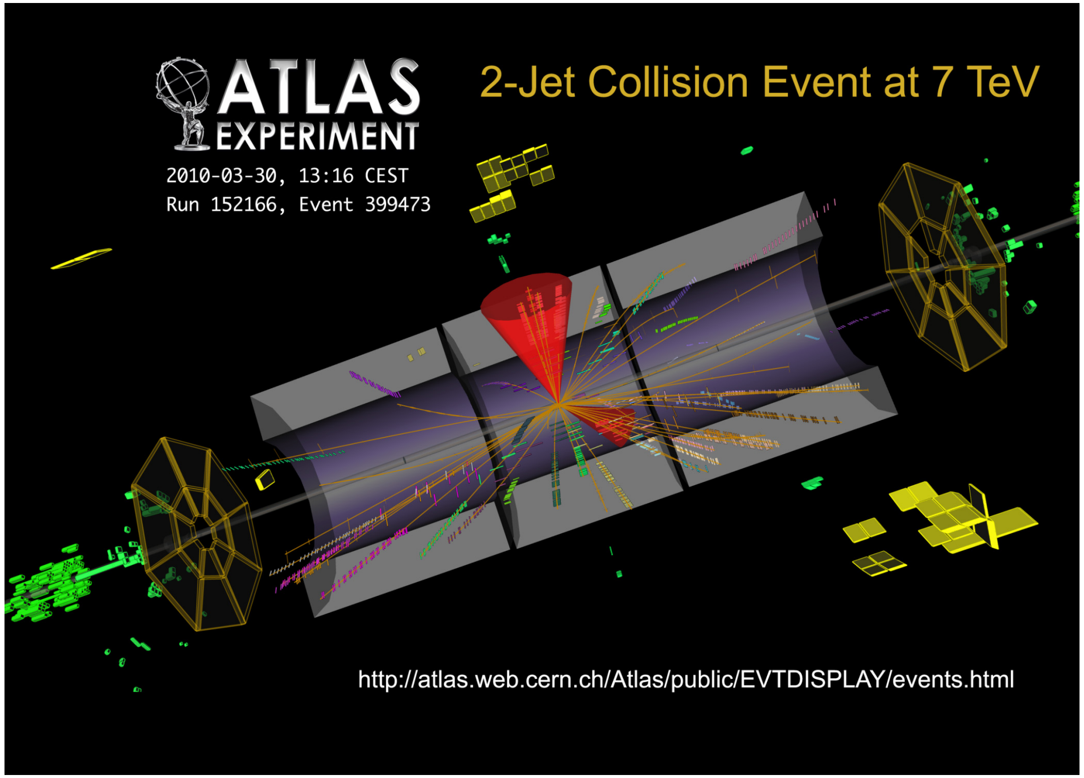
Theory: MCFM 332 μb, NFMR 254 μb

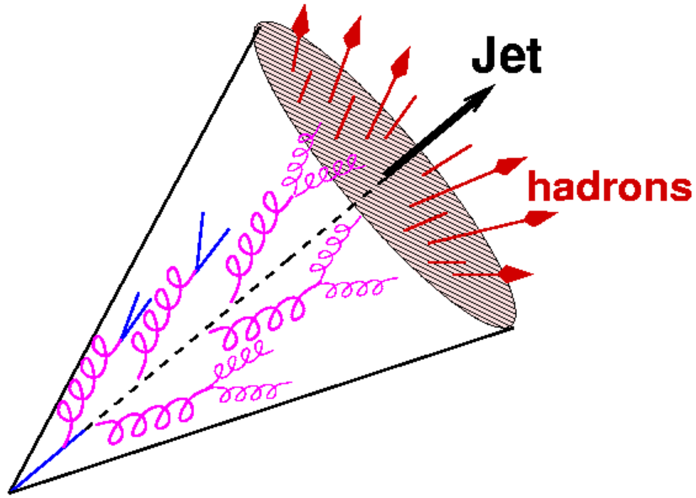
→ b rate (at least) as high as assumed in LHCb sensitivity studies.

2.5 Jet Physics

$$\sigma(s) = \sum_{ij} \iint dx_1 dx_2 f_{i/p}(x_1,\mu) f_{j/p}(x_2,\mu) \hat{\sigma}_{ij}$$

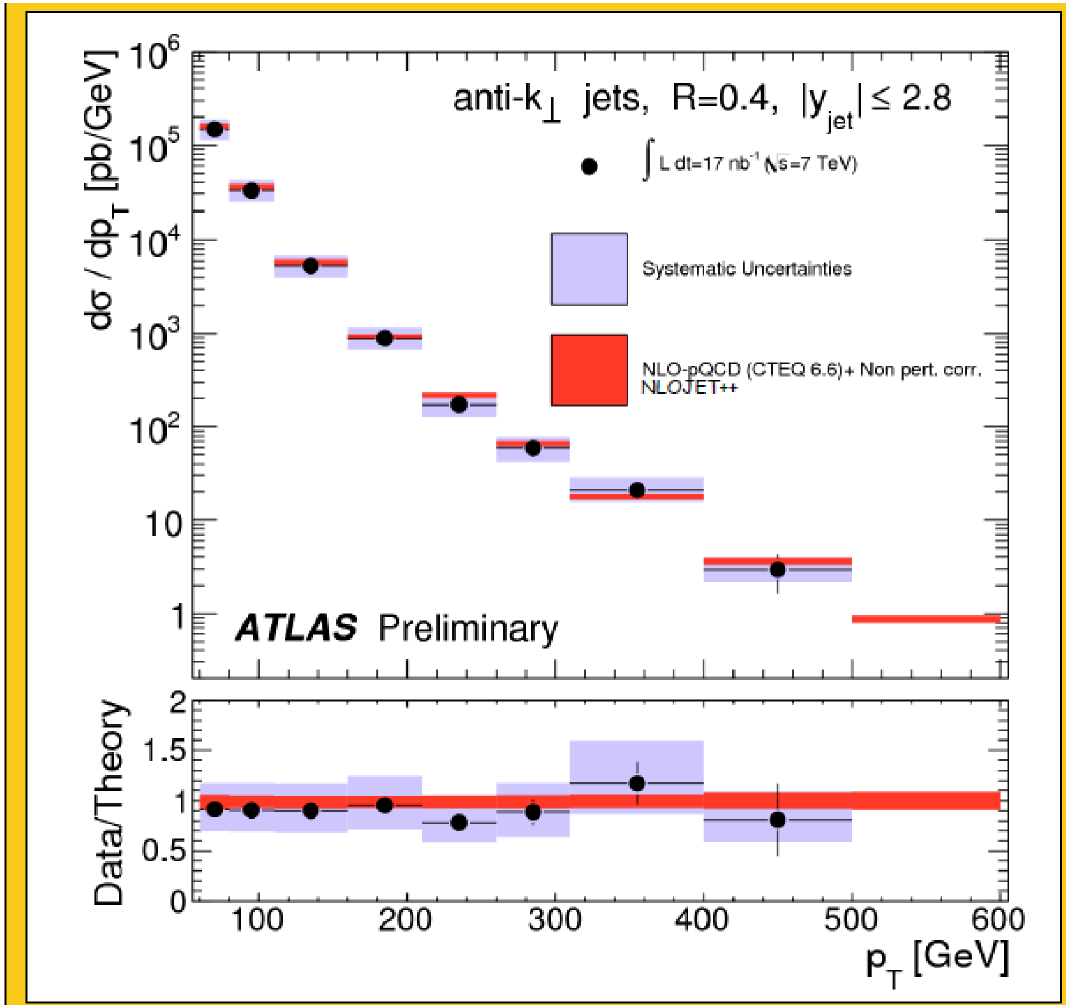






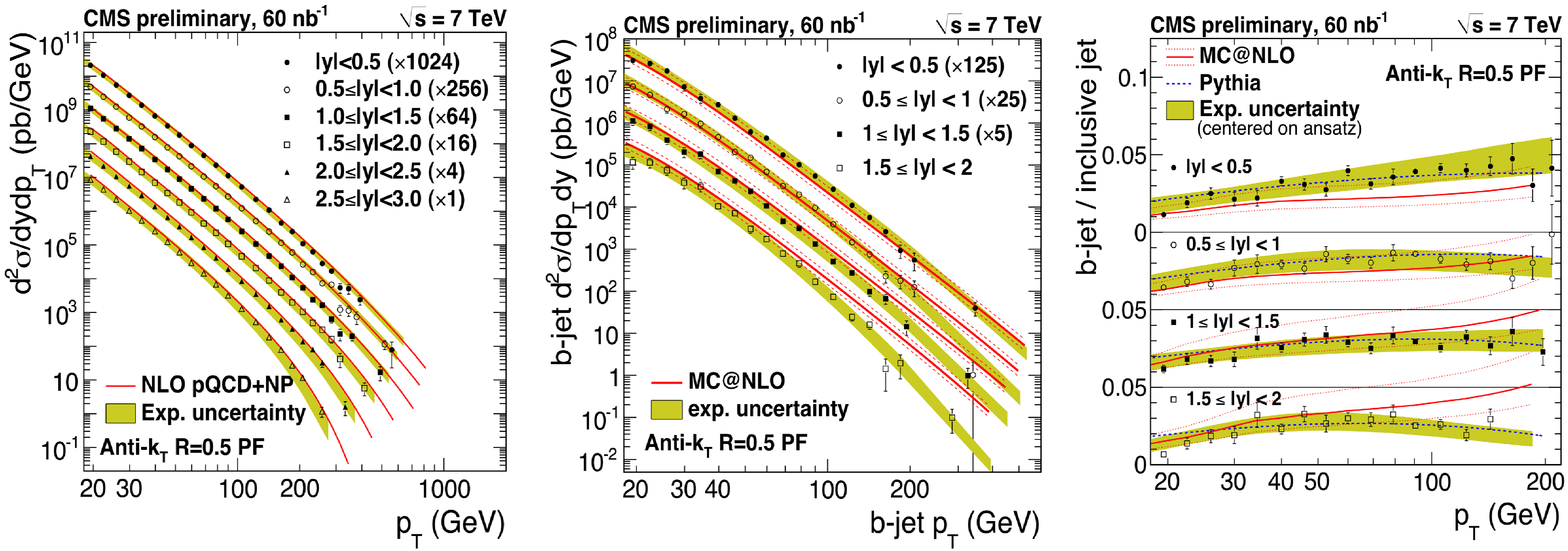
Inclusive Jet Cross Sections

- Observed jets corrected to particle-level using parton-shower MC (Pythia, Herwig)
  - justified by detailed comparison studies and good agreement with data
- NLO QCD comparison after corrections for hadronization and underlying event
- Theoretical uncertainty: ~20% (up to 40% at large |y|) from variation of PDF, α_s, scale
- Experimental uncertainty: ~30-40% dominated by Jet Energy scale (known to ~7%)
  - Luminosity (11%) not included



Good agreement with QCD over 5 orders of magnitude

Inclusive jet p_T spectra have been produced with three different jet approaches
All results are in good agreement with NLO theory
With Particle Flow approach distributions can be extended to a low p_T value of 18GeV.

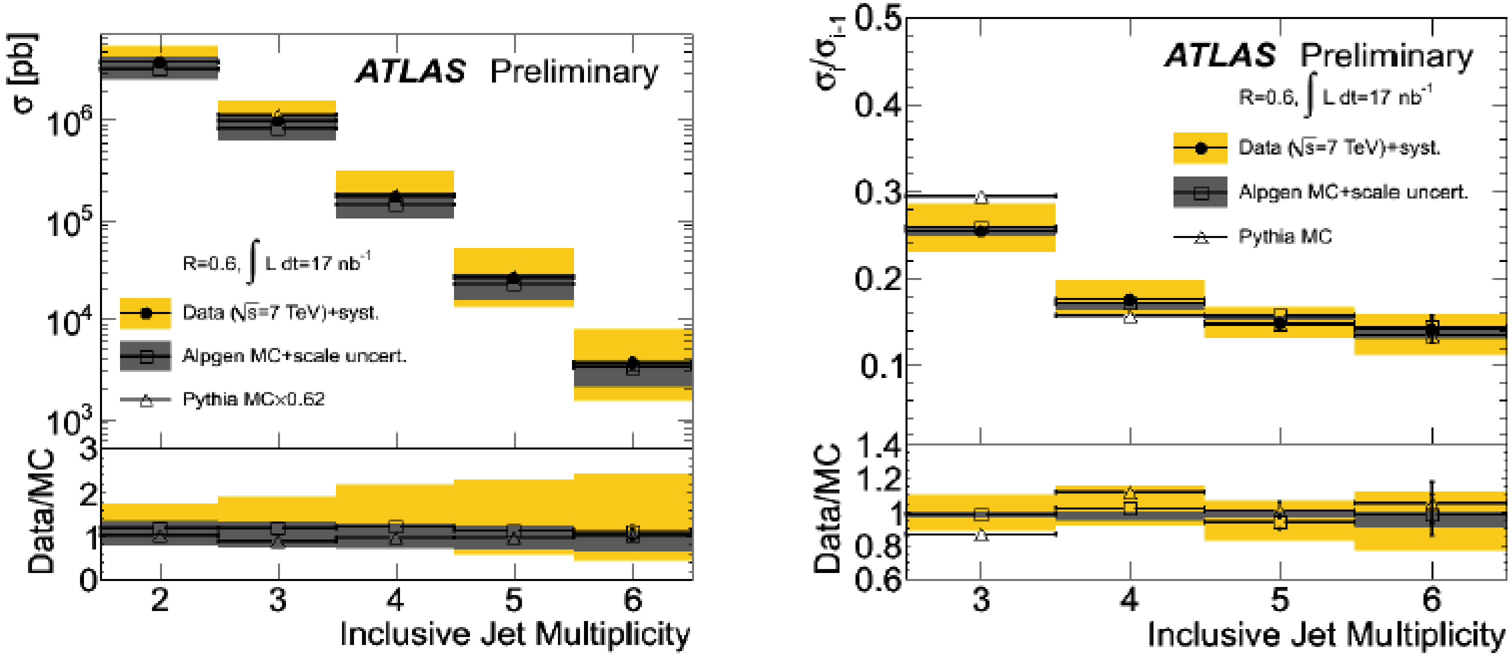


b-jets

High Purity ~ 0.7 using Secondary Vertex Tagger

Higher order emissions also measured directly

$p_T(jet_1)>60$ GeV, $p_T(jet_{2,3,..})>30$ GeV, $|y_{jet}|<2.8$

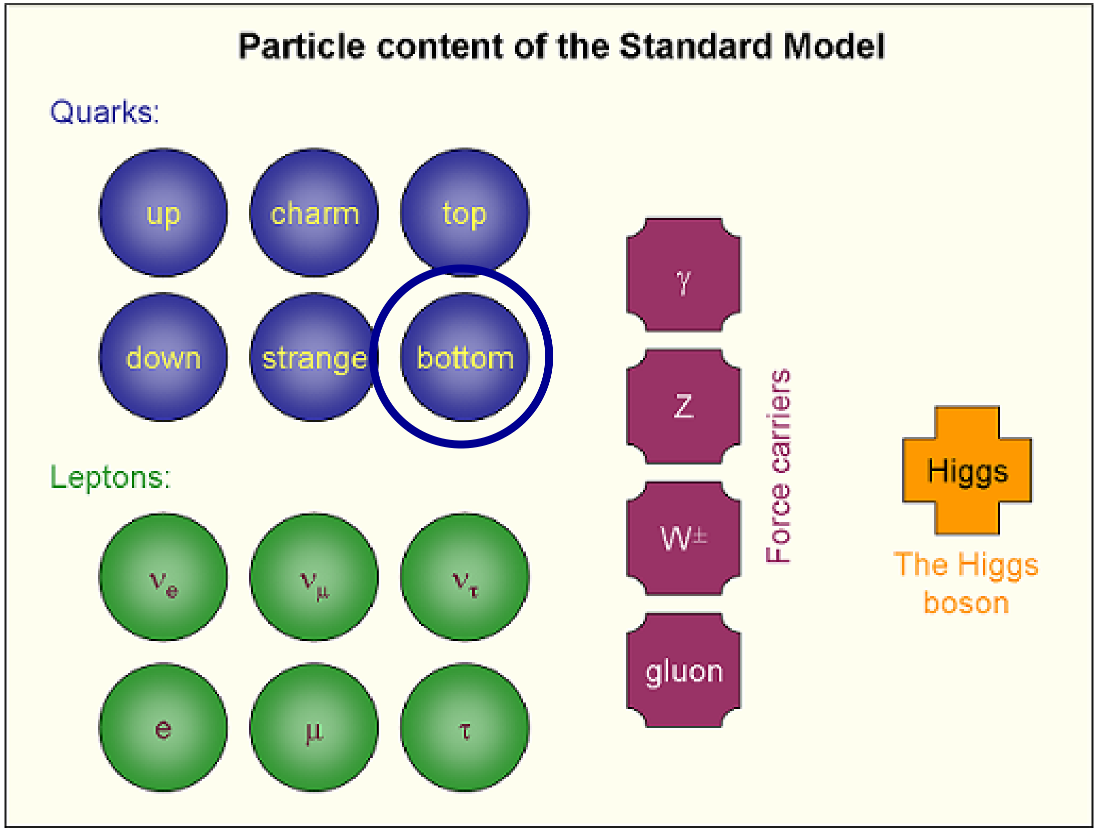


Cross sections as function of p_T(jet) and Σp_T(jet) measured as well

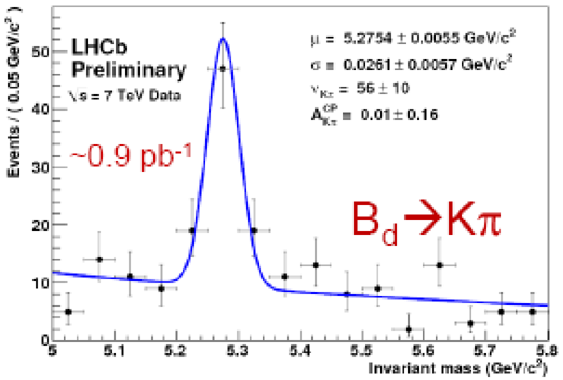
Alpgen found to give good description of data

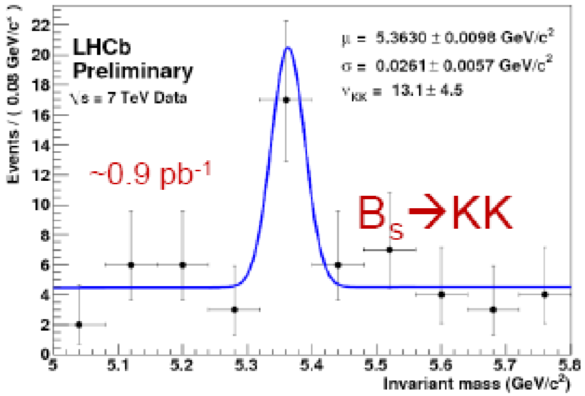
3. B-PHYSICS

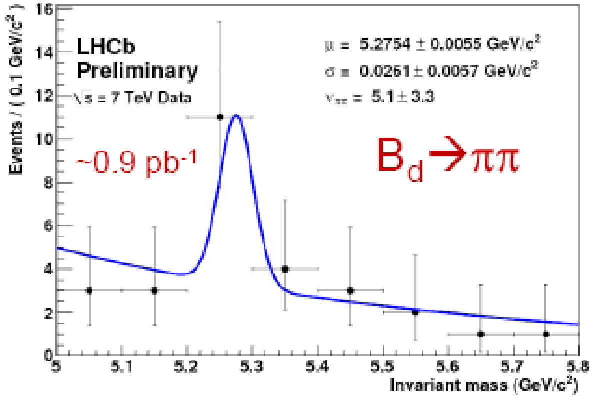
- B Hadrons, B Lifetime
- Prospects for $B \to \mu\mu$
- B Oscillations

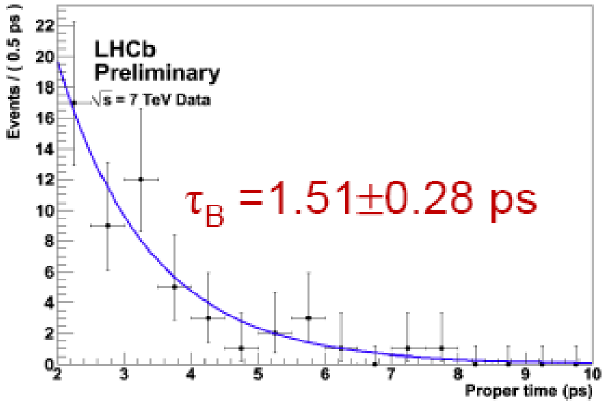


- Two body charmless B decays are core to LHCb programme: γ angle, loop effects etc.
- Crucial use of PID from RICH and very good mass resolution.







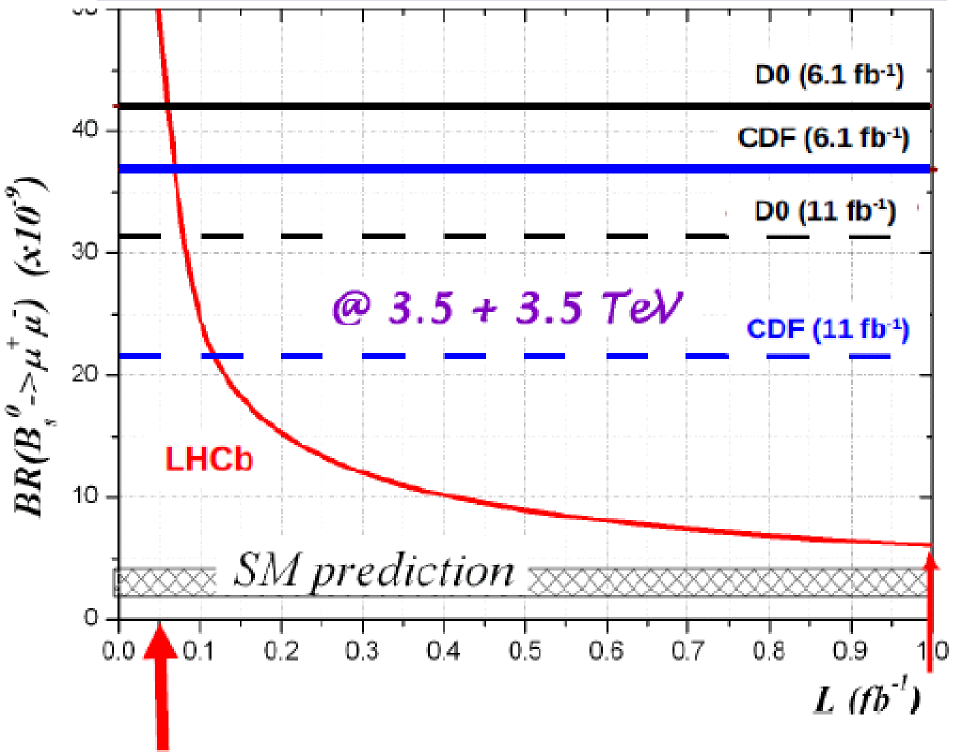


Yields so far ~match expectations. In 2011 running will get largest world samples both in B^0 and B_s.

1.2 Prospects for $B_s \rightarrow \mu\mu$

Very rare decay in SM, well predicted $BR(B_s \rightarrow \mu\mu) = (3.35 \pm 0.32) \times 10^{-9}$.

Exclusion limit at 90% CL at $\sqrt{s}$=7TeV

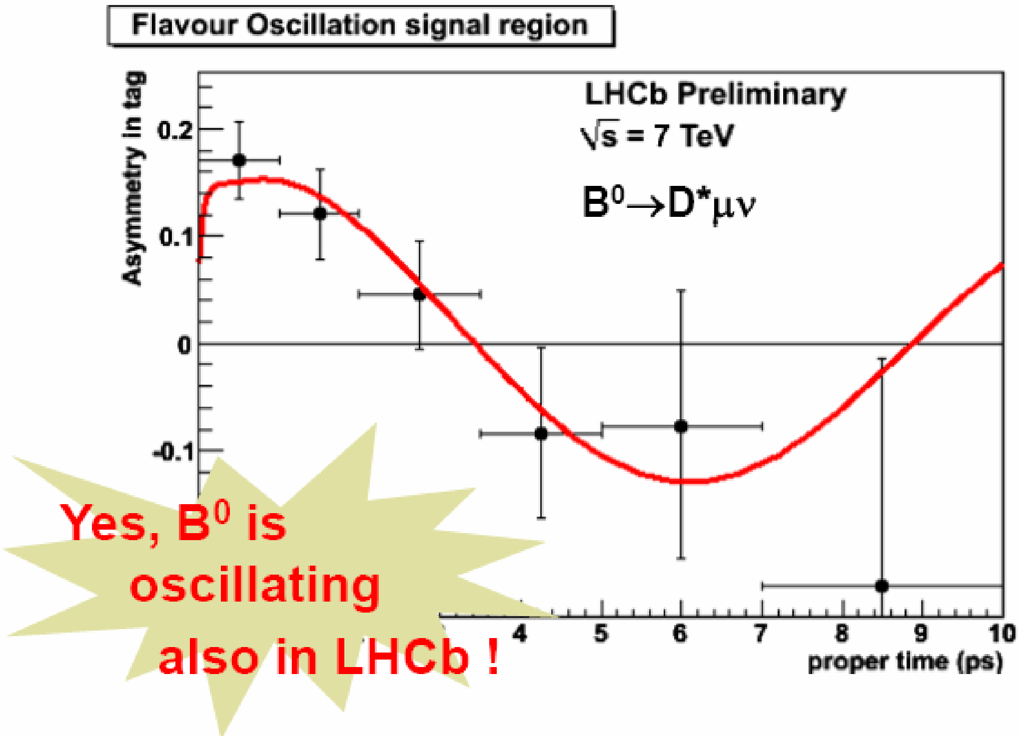


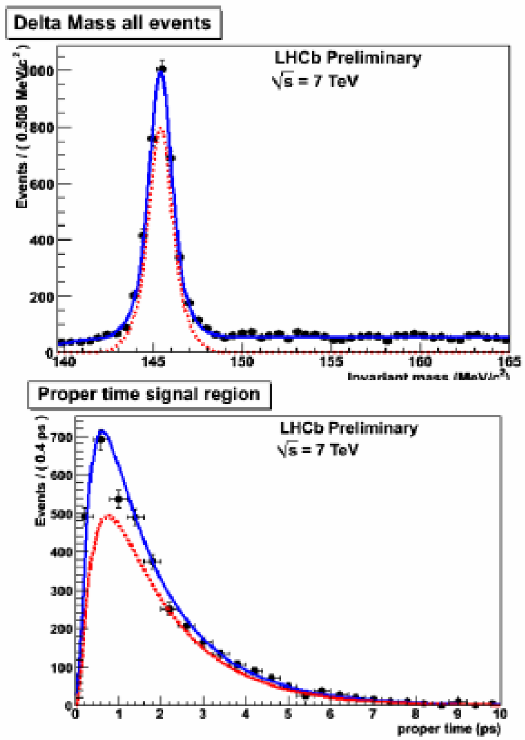
approaching new limit possible already with 50 pb^{-1}

- Sensitive to NP, in particular new scalars.
  In MSSM: $BR \propto \tan^6\beta / M_H^2$

- Sensitivity from MC assuming measured $b\bar{b}$ cross-section
- Expectation being confirmed by tests on data.

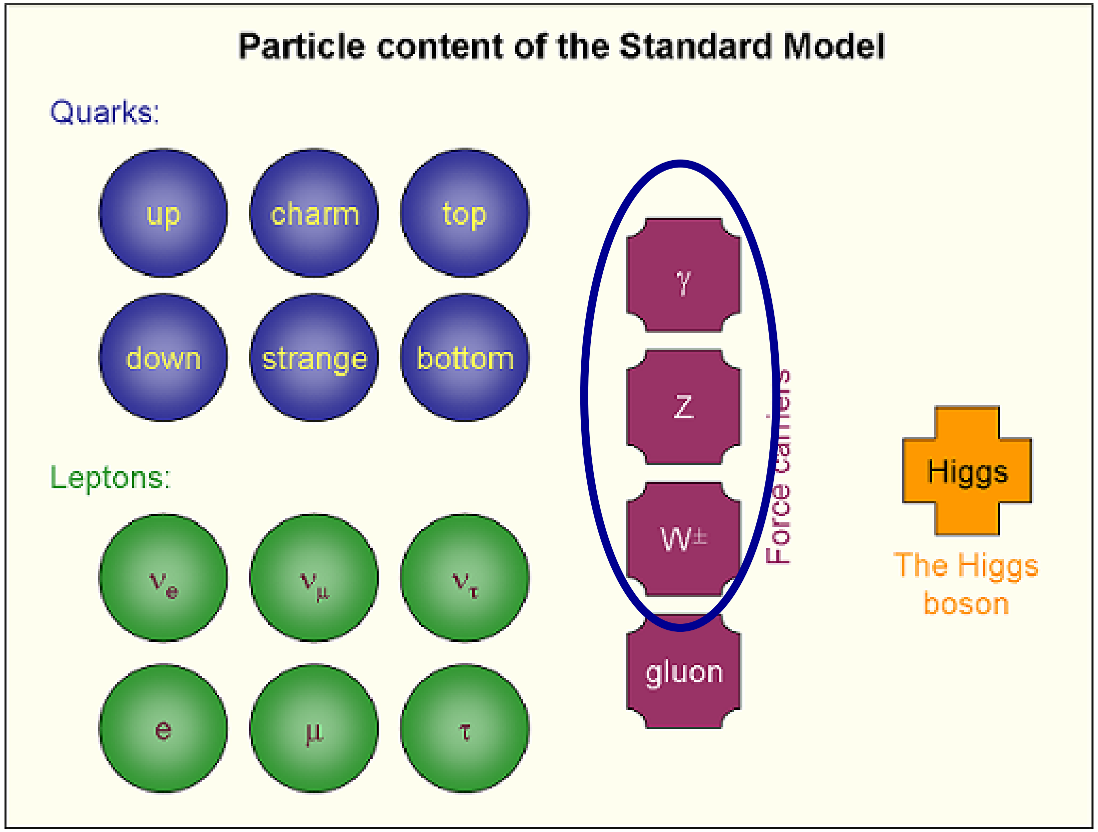
- First signal of flavour oscillation from $B^0_d \to D^{*-}(D^0\pi^-)\mu^+\nu$ events .





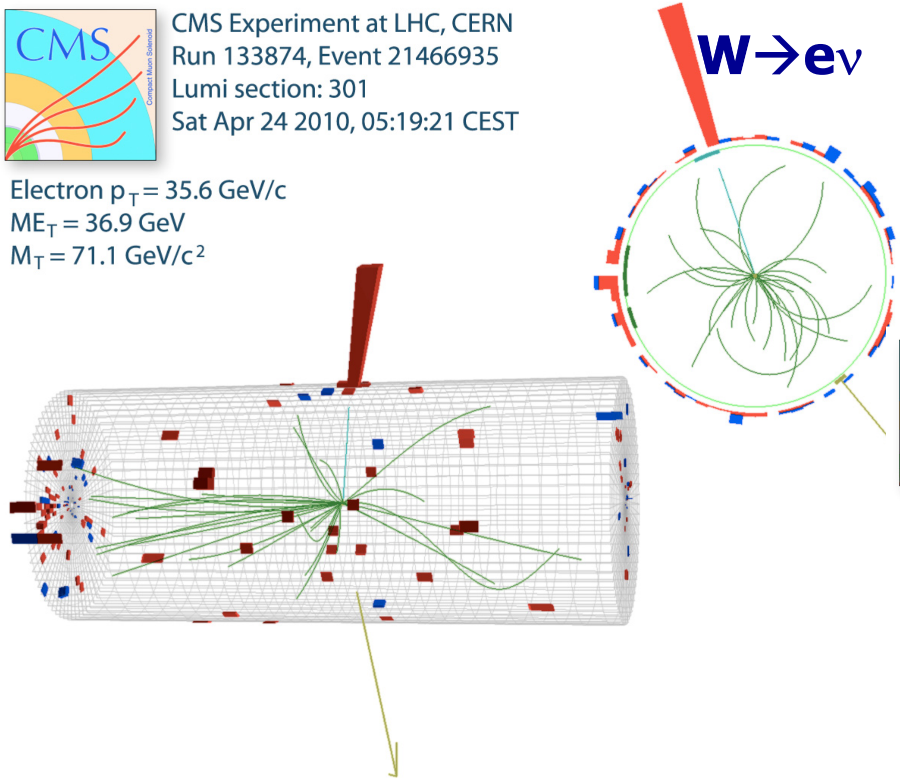
- "Out of the box" un-calibrated tagging performance (algorythm tuning, tagger combination etc..) already at 60% of expected performance.

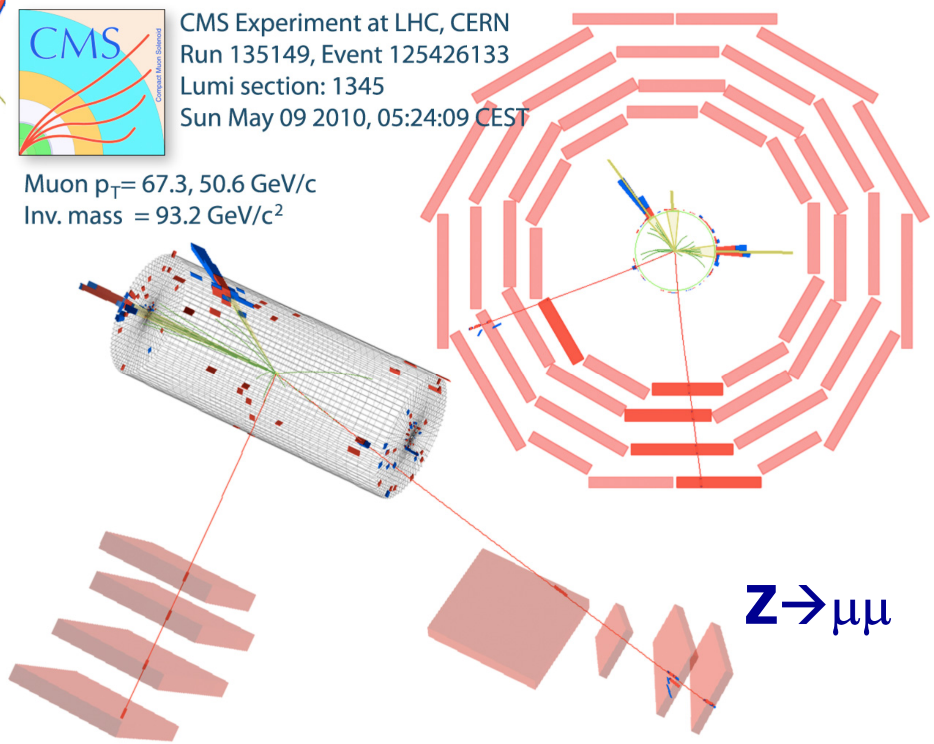
- W/Z Boson Production



W/Z candidates

W→eν

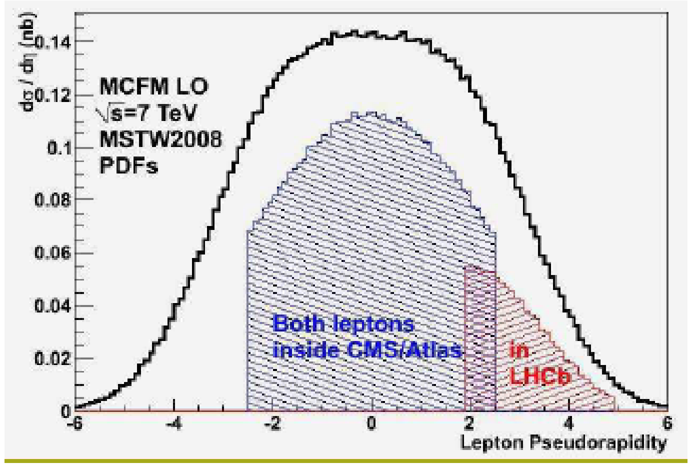




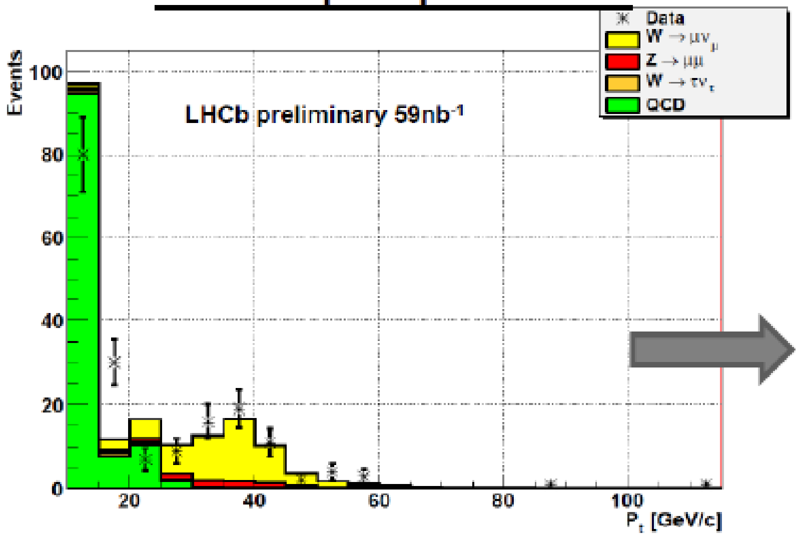
Z→μμ

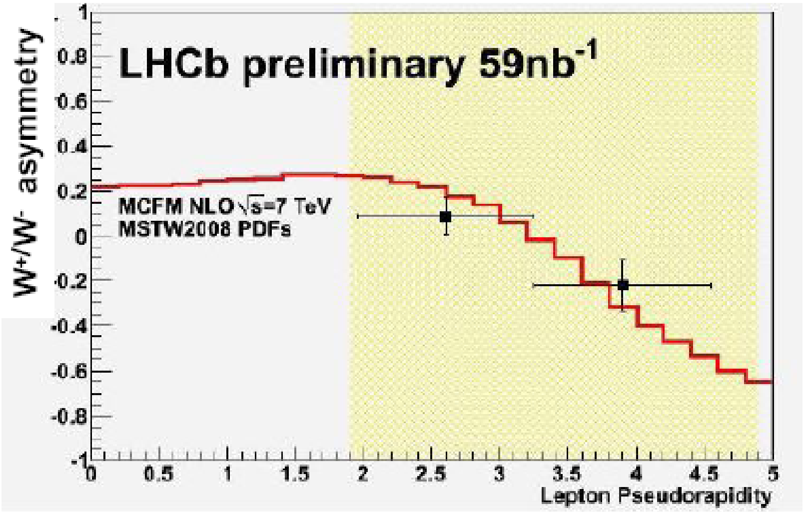
Charge Asymmetry of W Bosons

- Unique LHCb η coverage, allows for interesting W,Z production studies
- First result: charge asymmetry in $W^{\pm} \rightarrow \mu^{\pm} \nu$ events

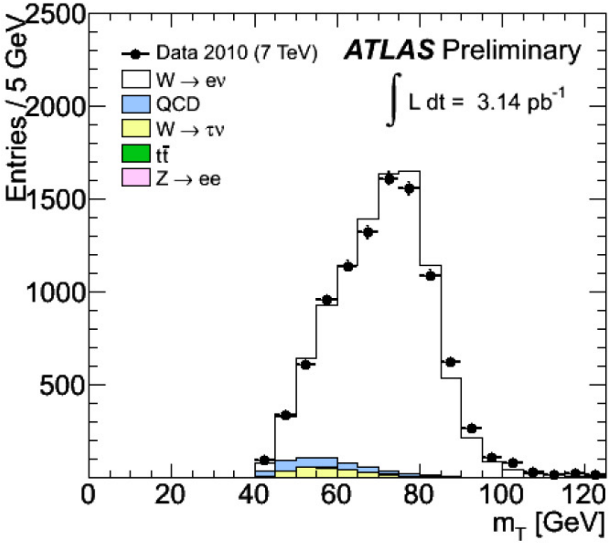


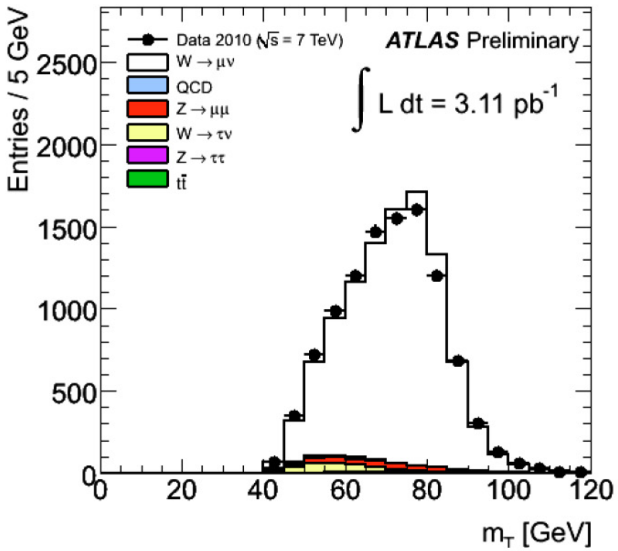
Muon pt spectrum





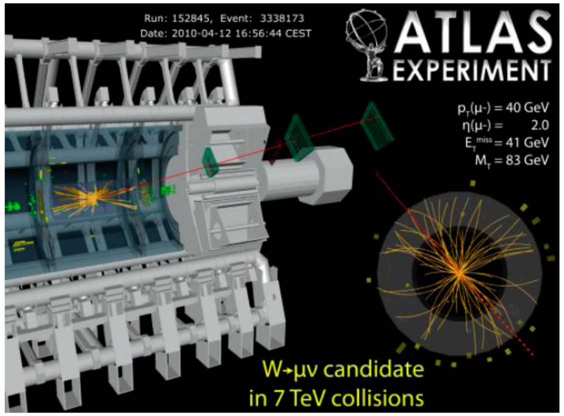
Mass Distributions of IVB

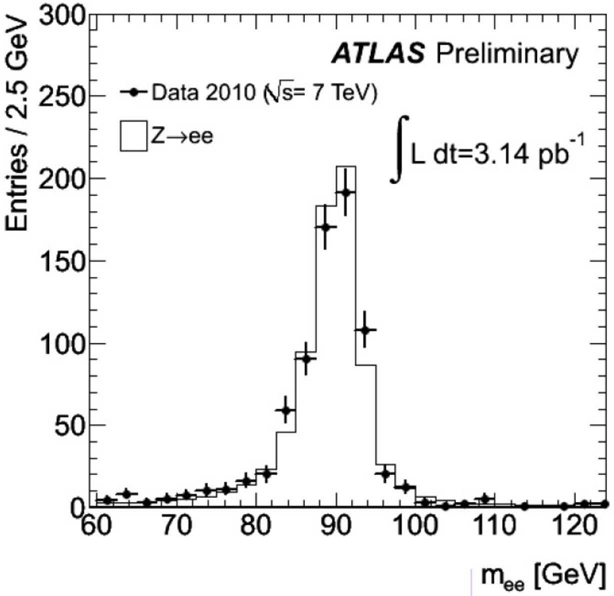


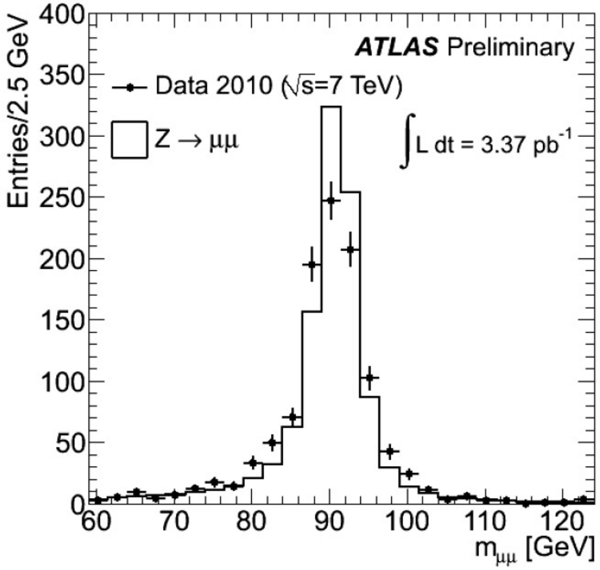


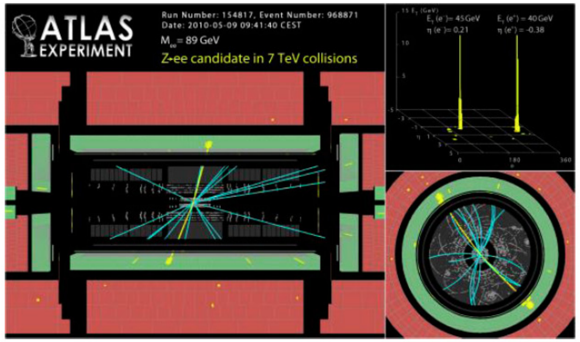
ATLAS has collected ~10^4 W's and ~10^3 Z's per channel.

Yield is between Tevatron 1A and 1B datasets.)



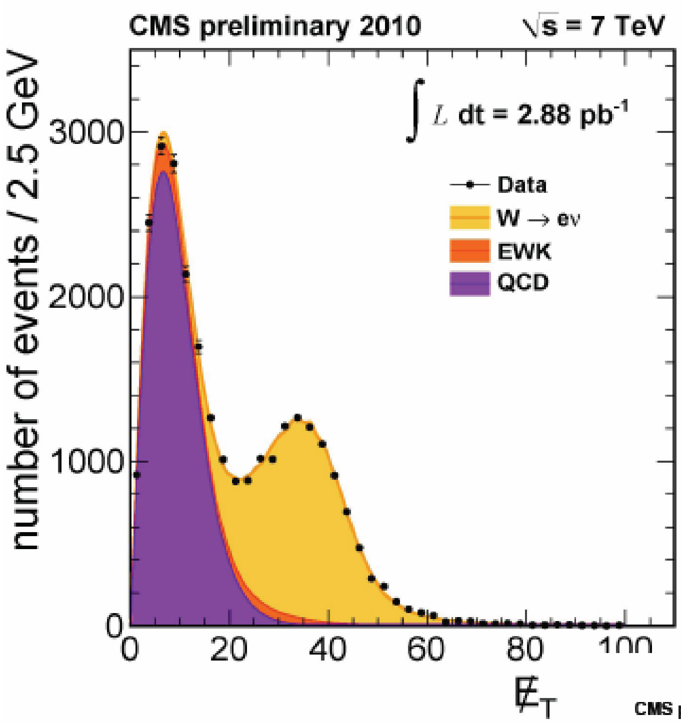


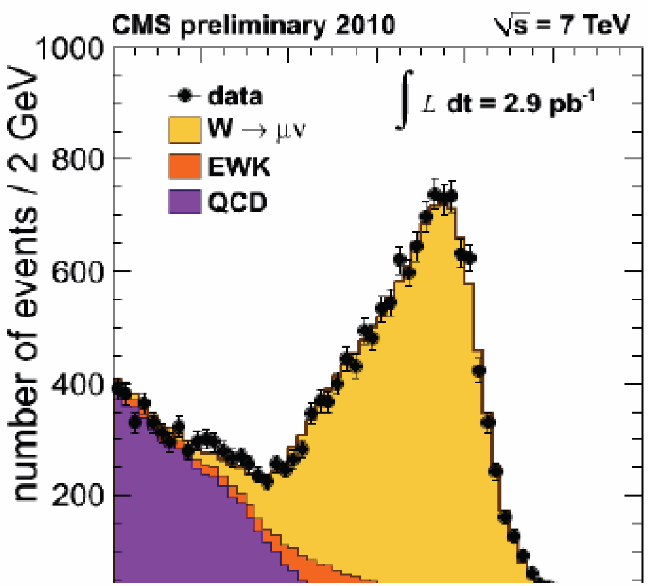


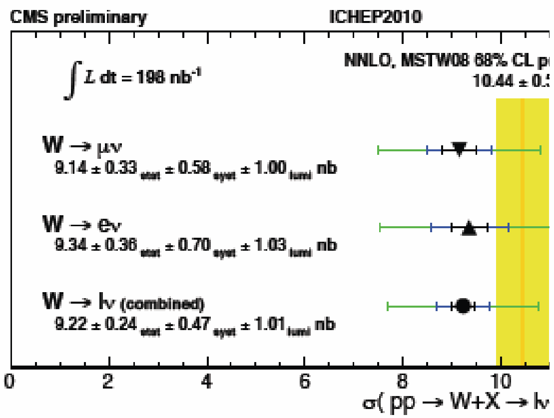


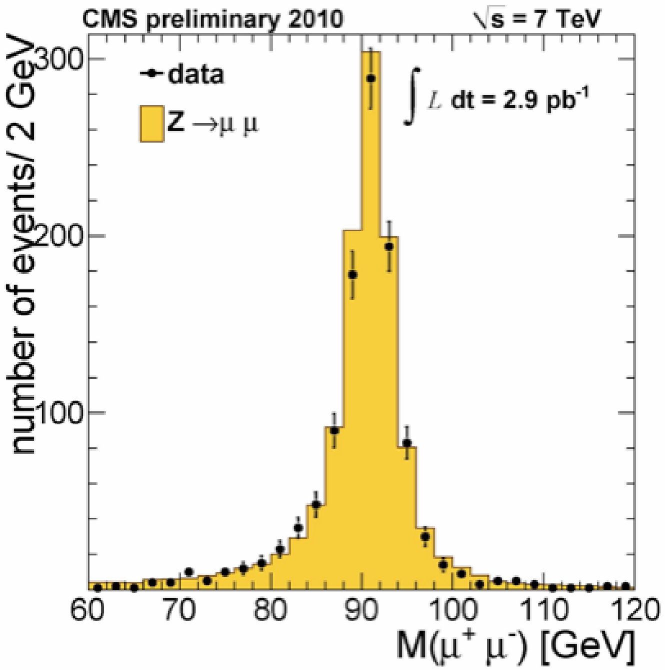
$$m_T = \sqrt{2 p_T^{\ell} p_T^{\nu} (1 - \cos(\phi^{\ell} - \phi^{\nu}))}$$

Data driven background shapes

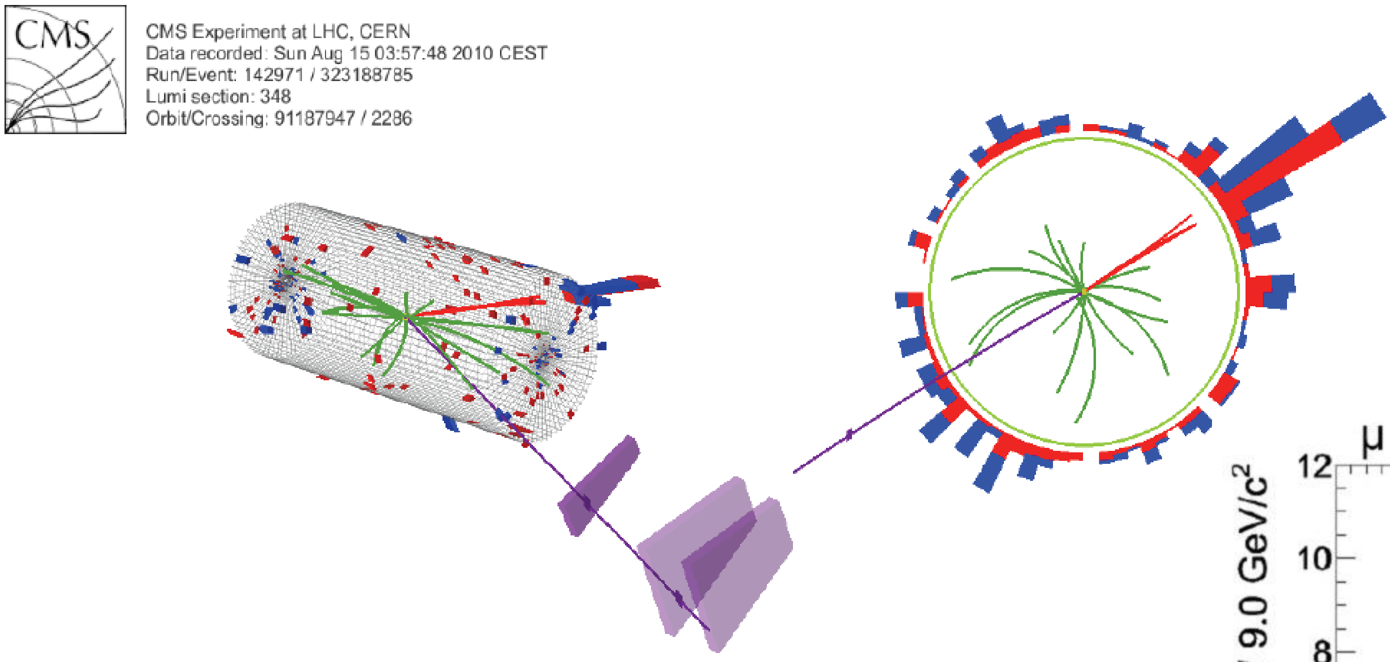






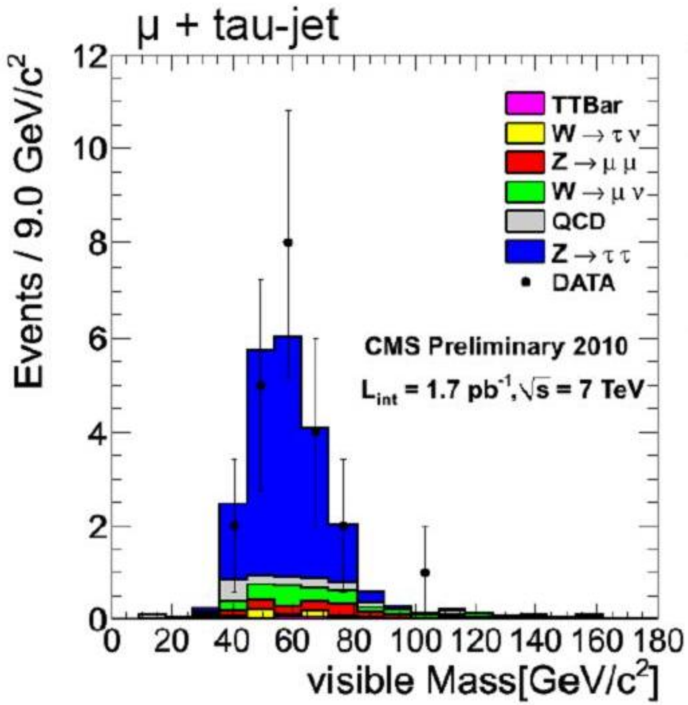


$Z \rightarrow \tau \tau$

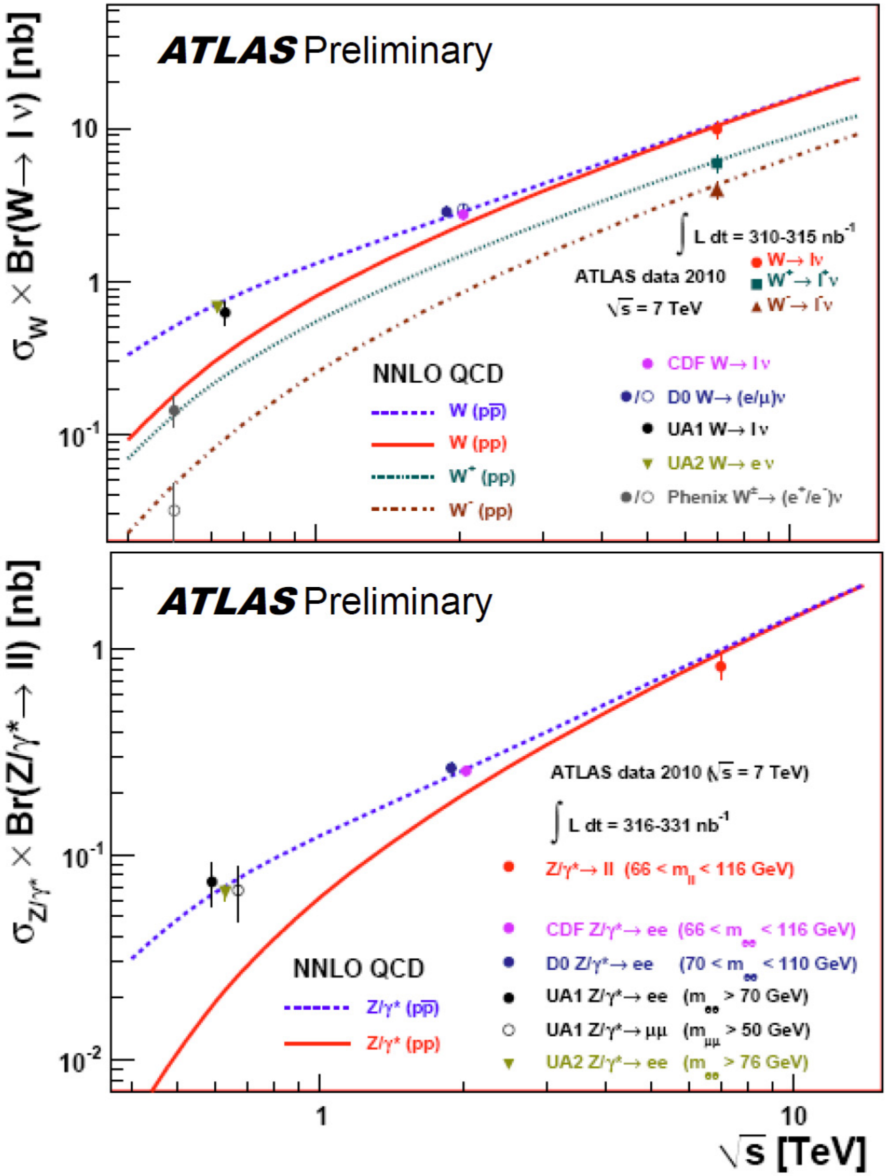


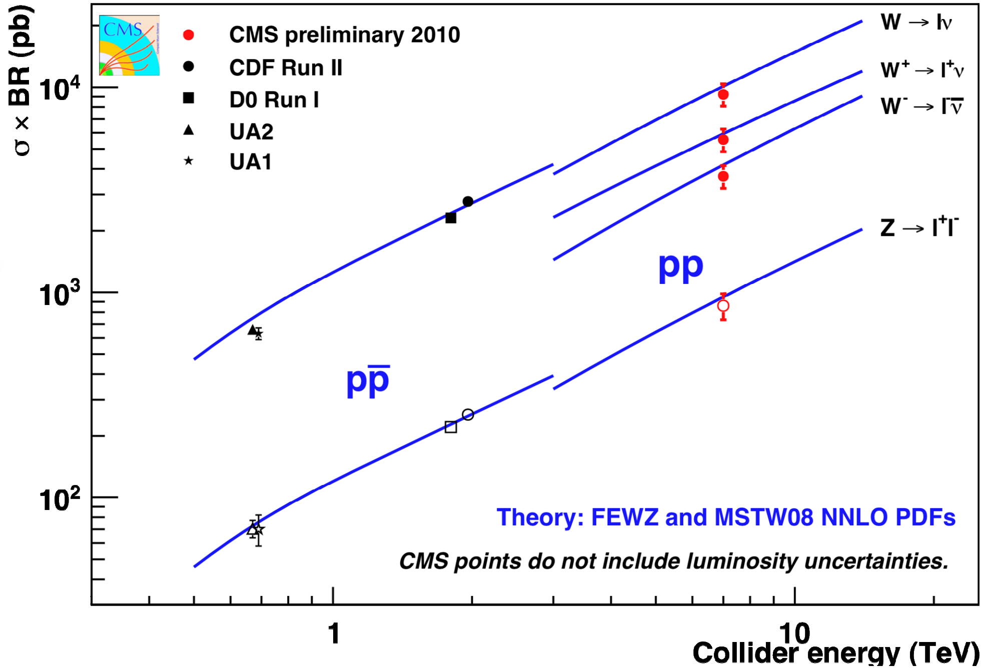
μ Pt = 32.4 GeV/c
η = 1.7

τ Pt = 37.4 GeV/c
η = 1.5
Mass = 1.2GeV/c²



Cross Sections of W and Z



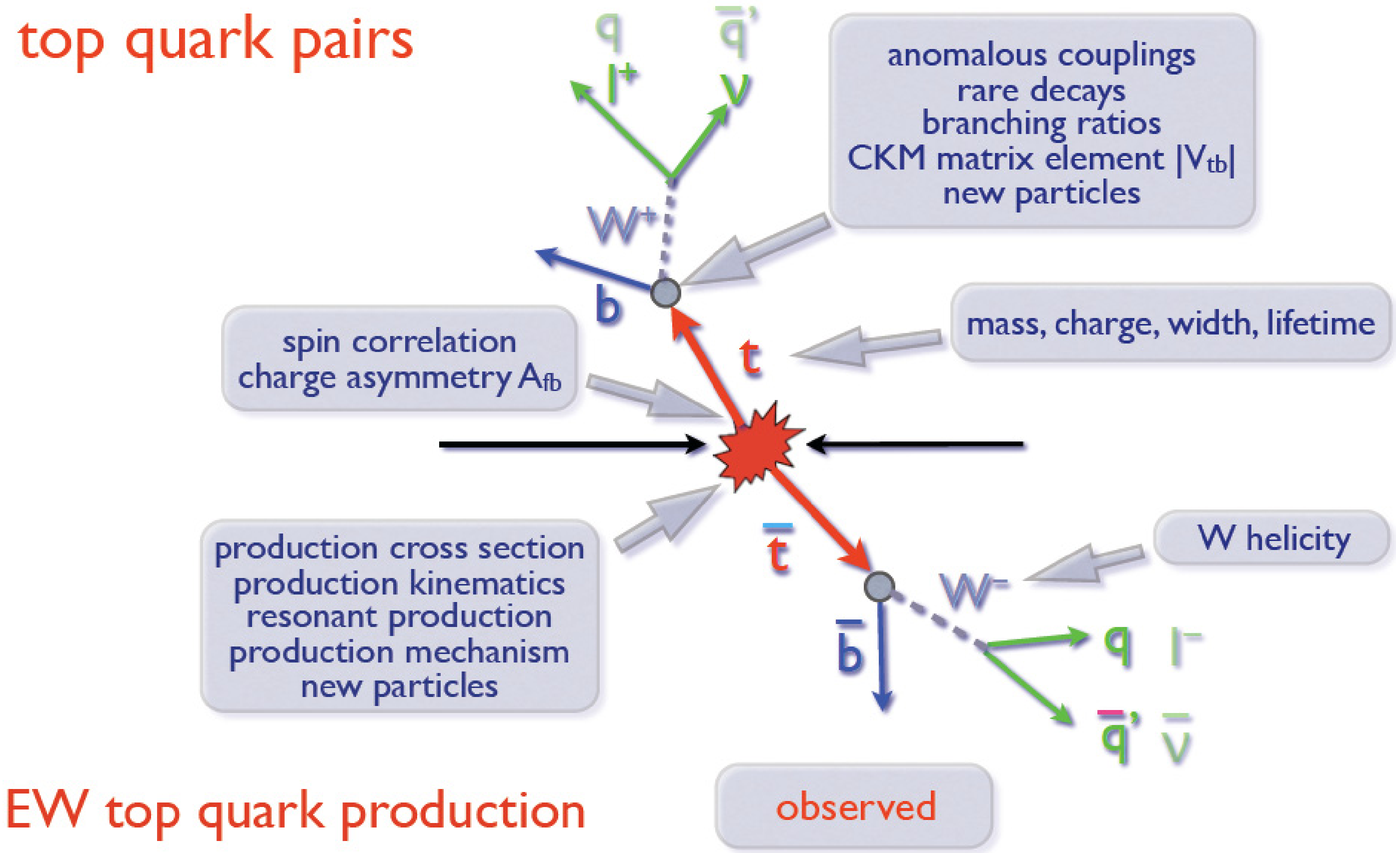


About 20% systematic and statistical uncertainty, lumi 11%.

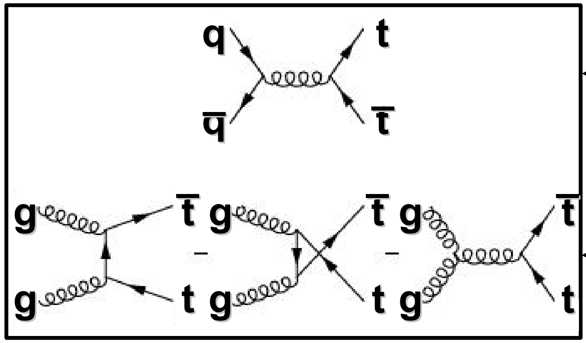
5. TOP QUARK PHYSICS

The mother of physics:

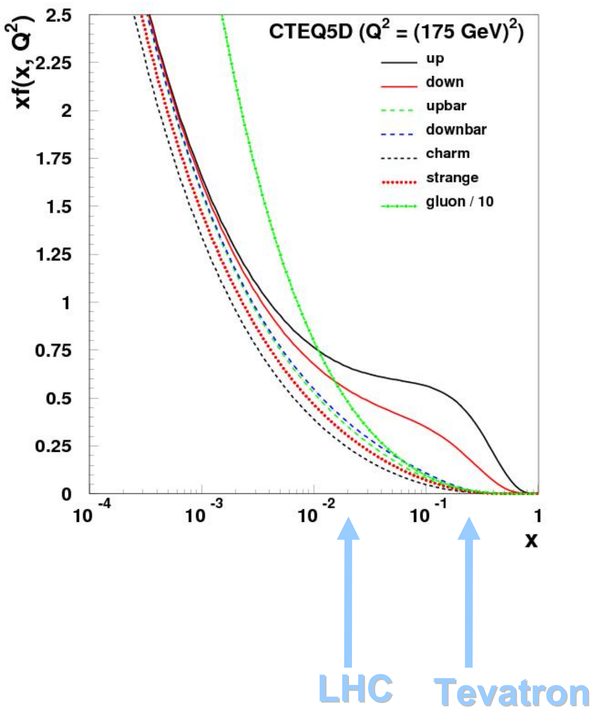
- Precise SM measurements
- A window to new physics (decay product, anomalies)
- Great tool to calibrate detector: Jet energy scale, b-jet efficiency
- In many new physics scenarios (e.g. SUSY) top is dominant BG

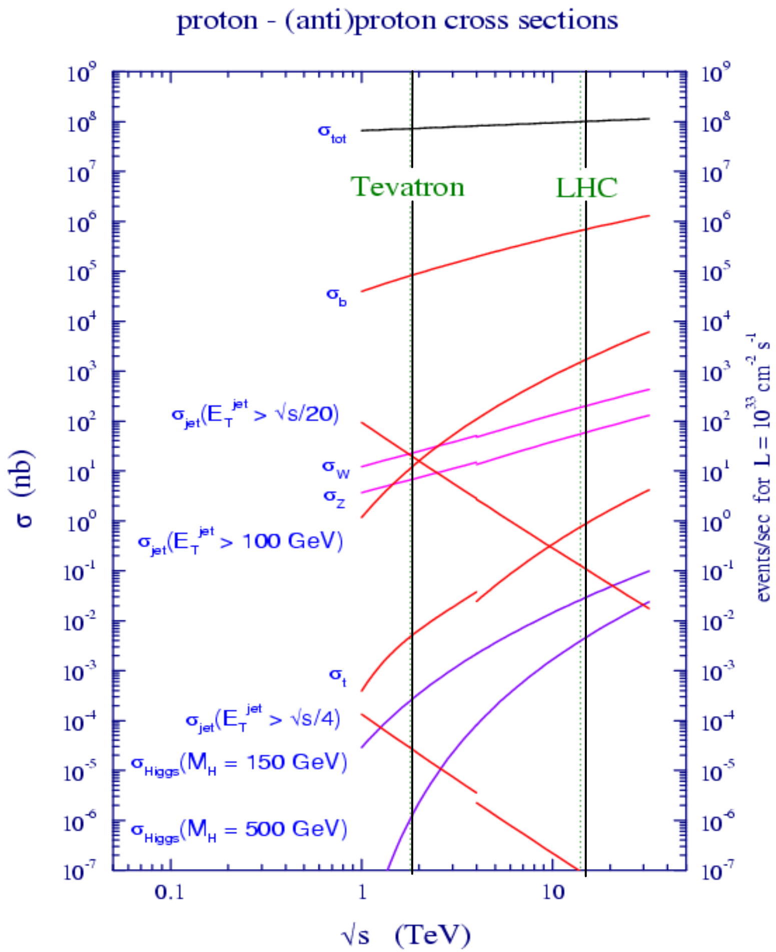


Pair Production of Top Quarks



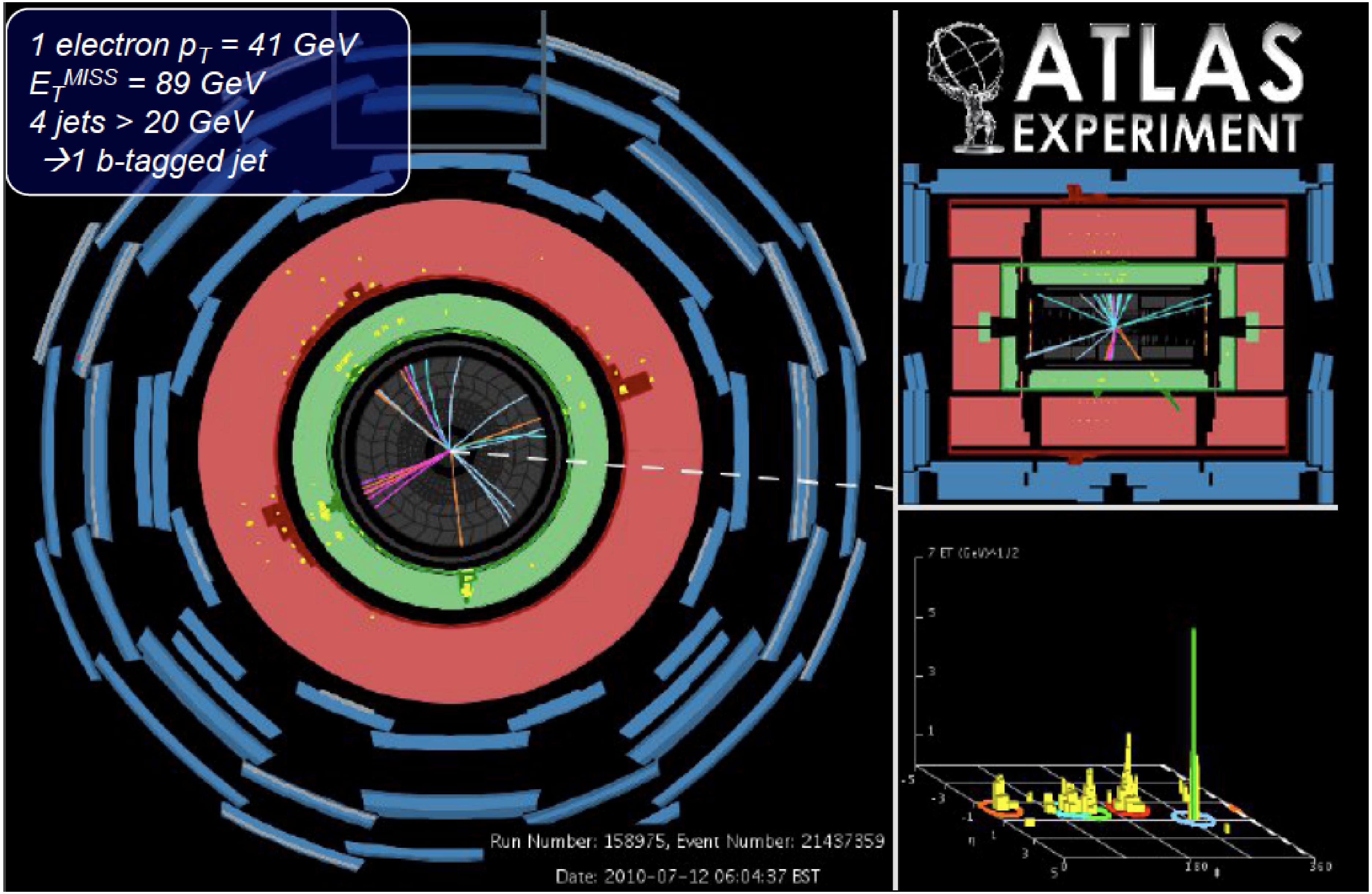
	TEV	LHC
$q\bar{q} \to t\bar{t}$	~85%	~15%
$gg \to t\bar{t}$	~15%	~85%



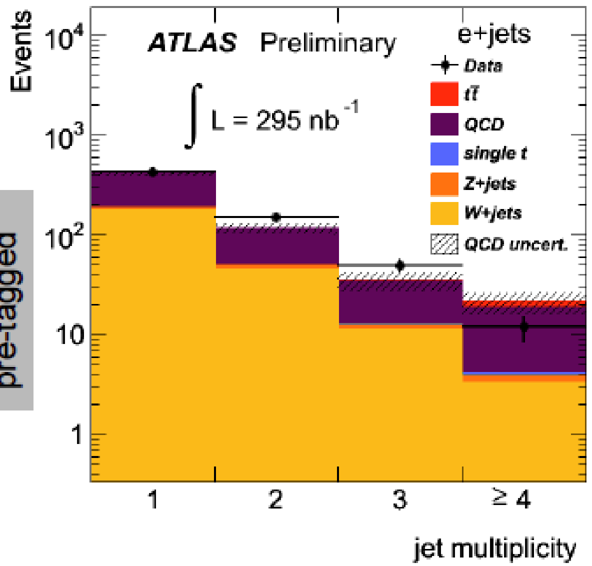


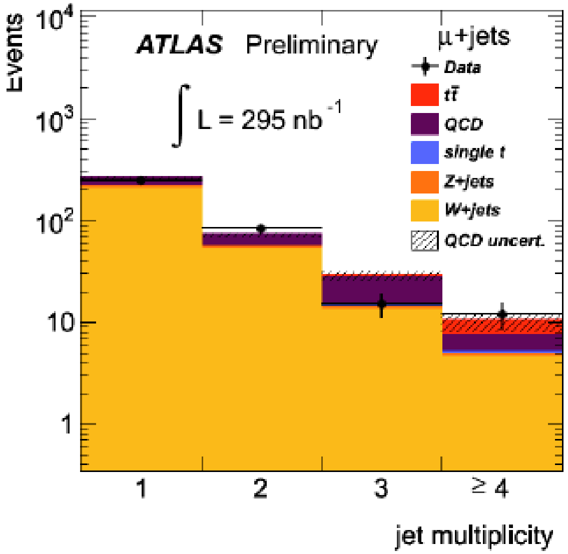
9/2010: See a few dozen candidates at ATLAS and CMS

2011: Expect more tt Events at LHC than at Tevatron


1 electron p_T = 41 GeV
E_T^{MISS} = 89 GeV
4 jets > 20 GeV
→1 b-tagged jet
ATLAS
EXPERIMENT
Run Number: 158975, Event Number: 21437359
Date: 2010-07-12 06:04:37 BST

pre-tagged



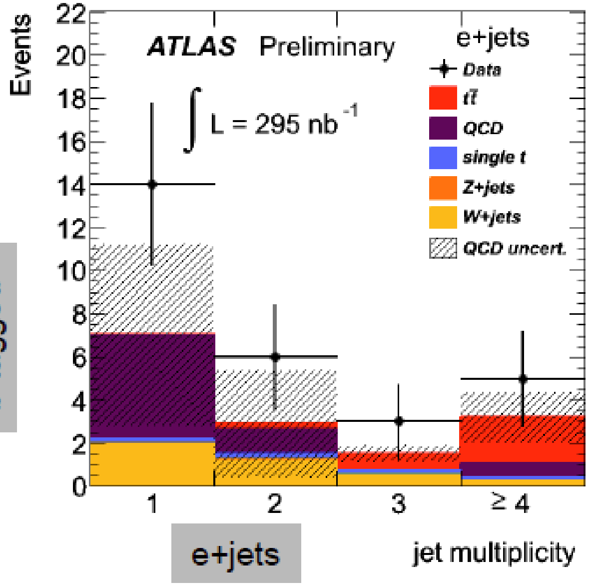


The QCD background here is data-driven (these plots use the matrix method).

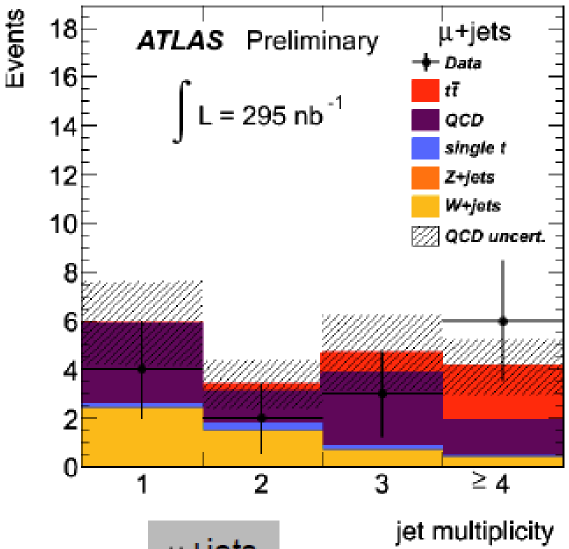
The single top and W/Z+jets backgrounds are taken from Monte Carlo: MC@NLO and ALPGEN

In parallel, we are using the 3 pb^{-1} of data taken so far to quantify the backgrounds

b-tagged

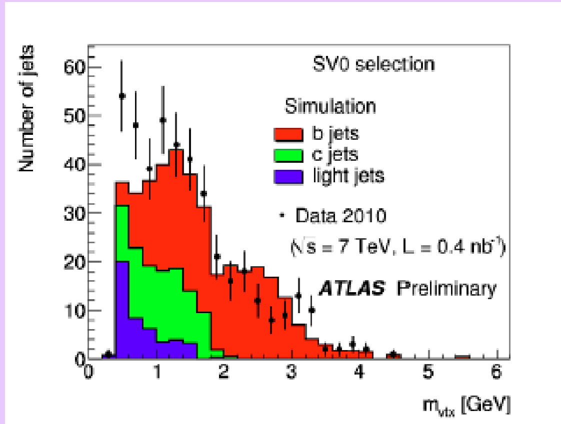


e+jets

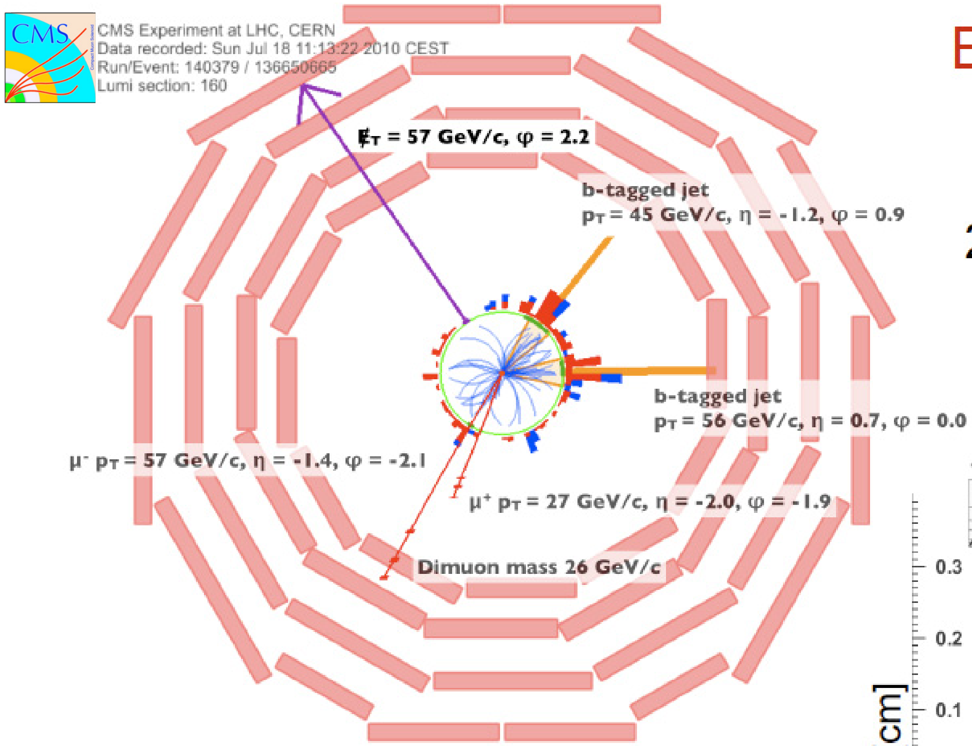


μ+jets

Jets are b-tagged by the SV0 algorithm.

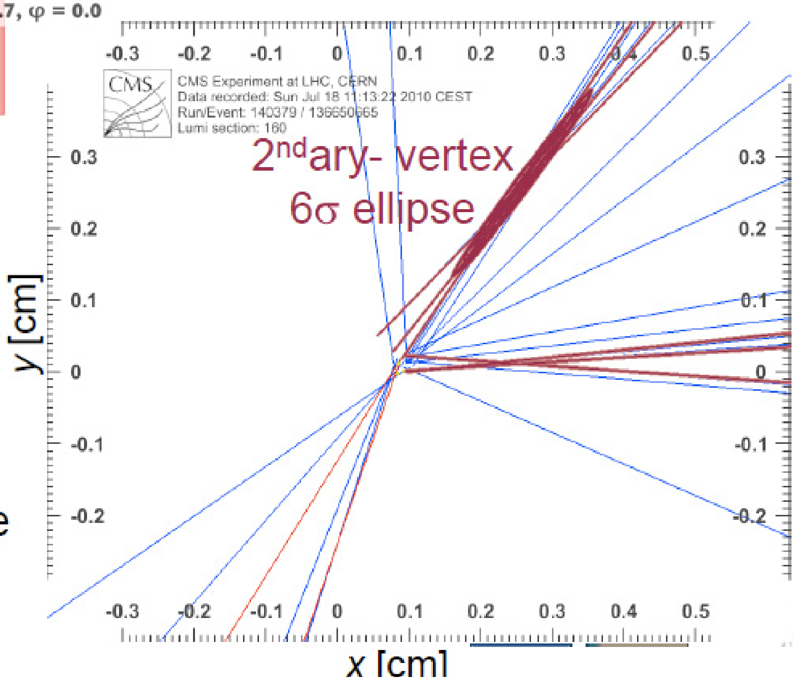


$\mu\mu$ +Jets Candidate Event *(from July 18)*



Event passes all cuts of full selection:

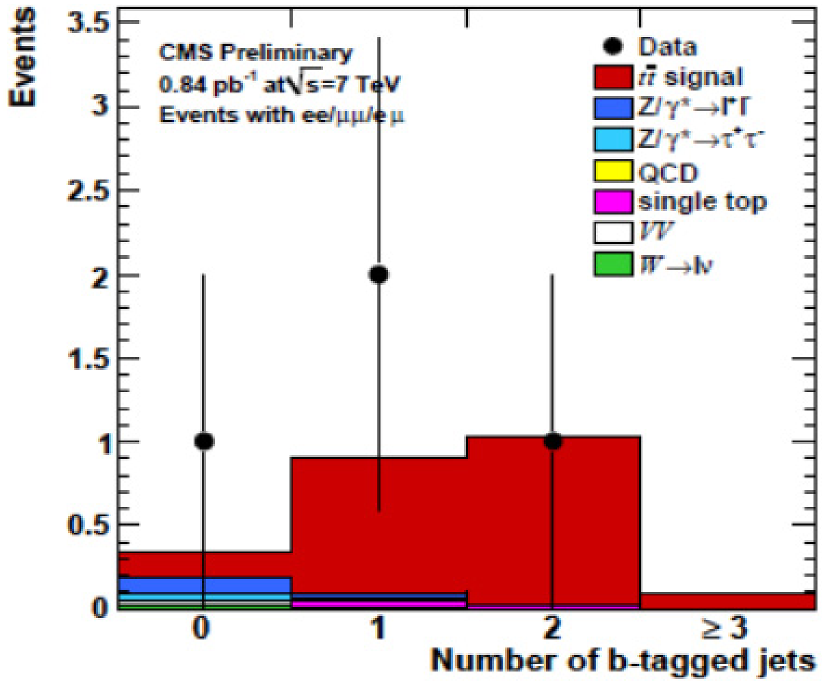
2 muons with opposite charge
2 jets, both w/ good/clear *b*-tags
(and secondary vertices!)
significant MET (>50 GeV)

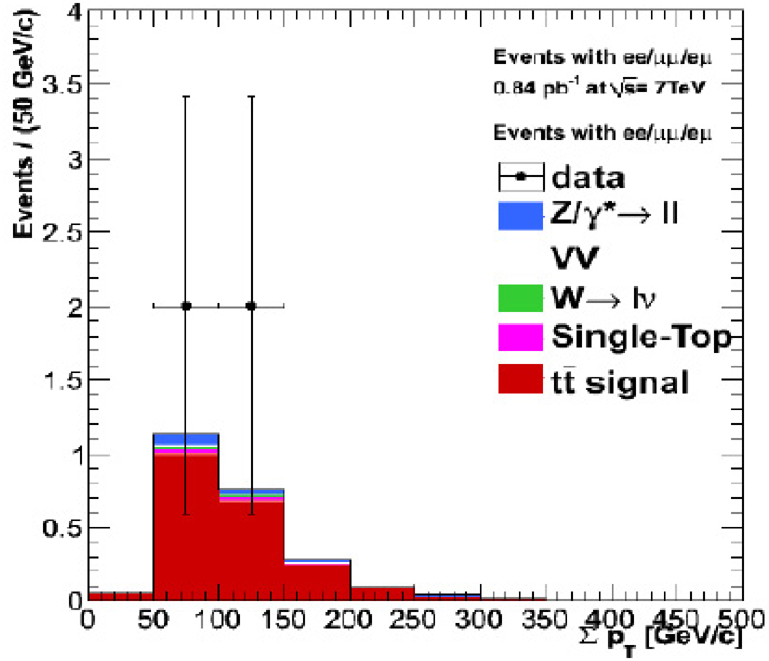


$m(\mu\mu) = 26\ \mathrm{GeV}/c^2$

Preliminarily reconstr. mass is in the range 160–220 GeV/c^2 (consistent with m_{top})

Top-Antitop Signal in Di-Lepton Mode

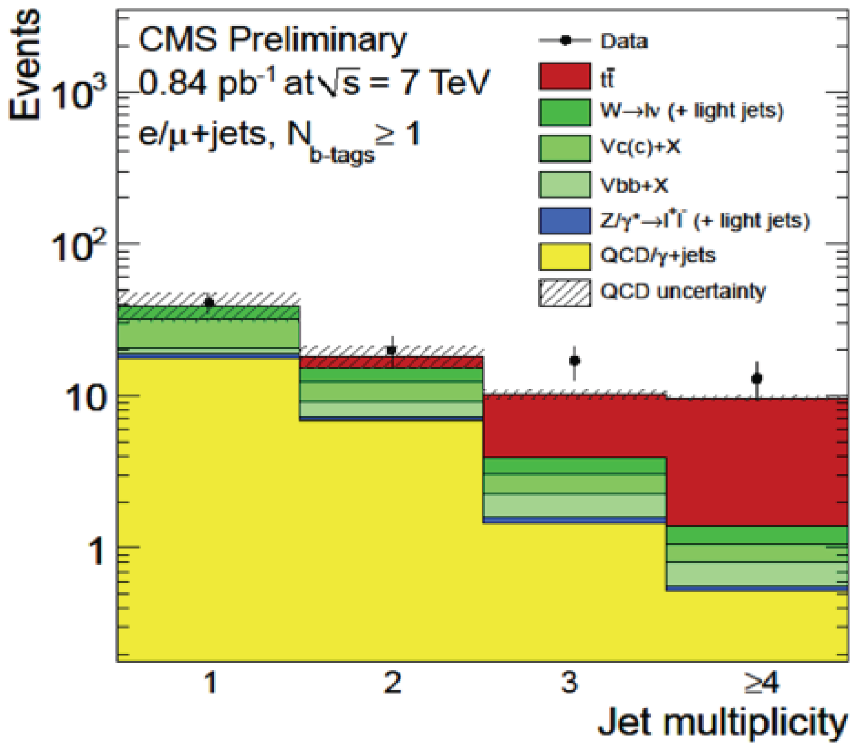




- Full selection applied: Z-bosonVeto, |M(ll)-M(Z)|>15 GeV
- MET >30 (20) GeV in ee,μμ, (eμ); N(jets) ≥2
- 4 tt candidates (1 eμ, 1 ee, 2 μμ) over a negligible background.
- Top signal at LHC established.

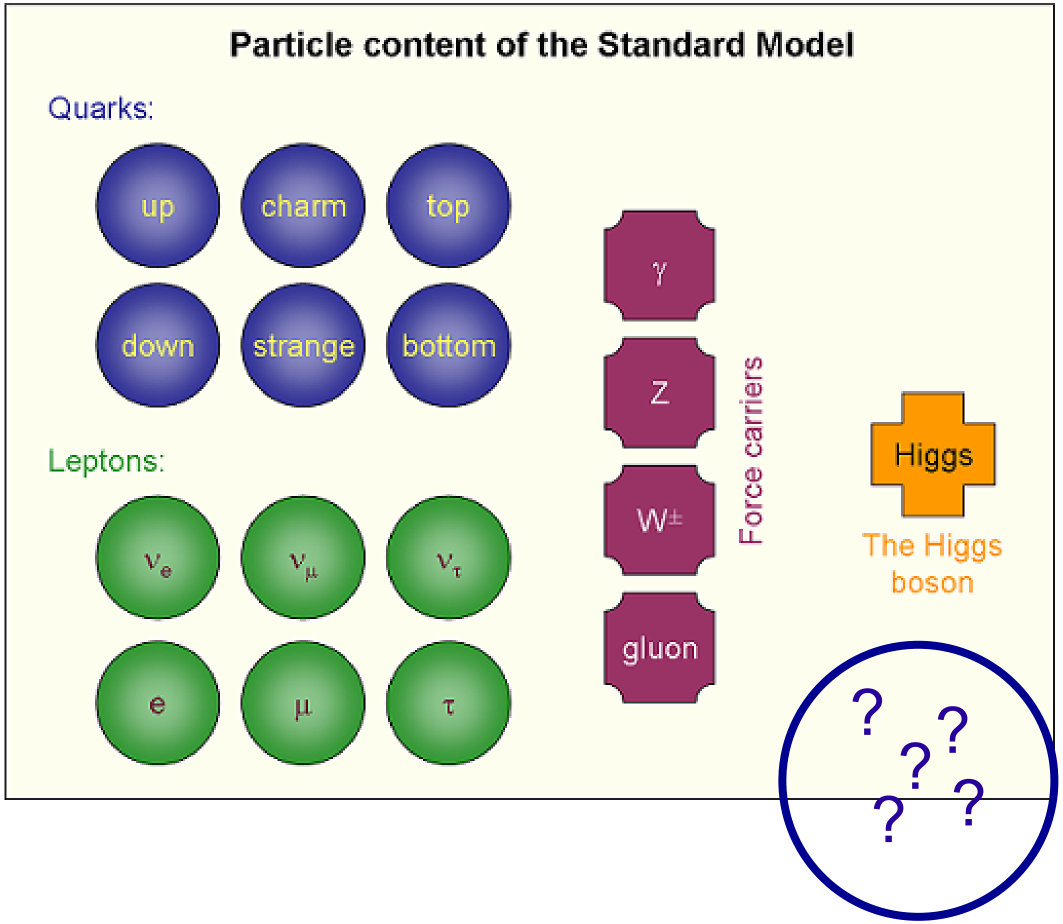
Top-Antitop Signal in Lepton-Jets Mode

- Using $0.84 pb^{-1}$ and requiring at least 1 secondary vertex tagger with ≥2 tracks;
  - ~50% efficiency ~1% fake rate
- N(jets)≥3
  - 30 signal candidates over a predicted background of 5.3
- tt rate consistent with NLO cross section
  - Up to experimental (JES, b-tagging) and theoretical (scale, PDF, HF modeling,

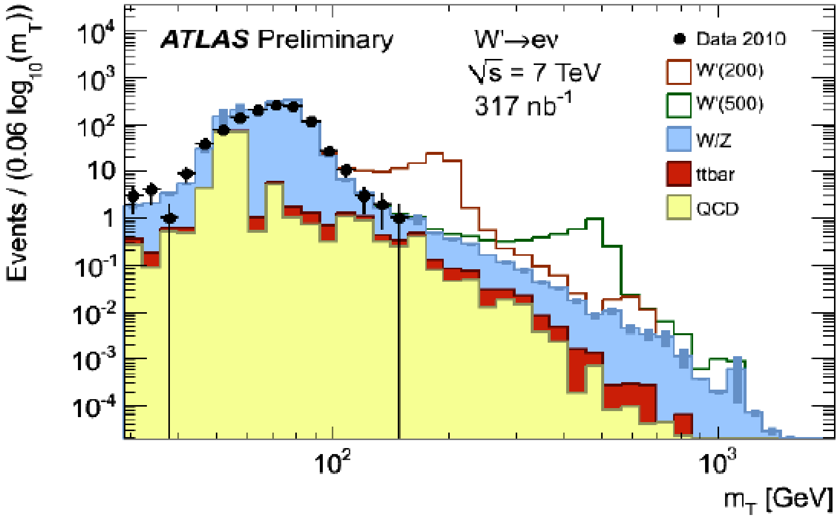


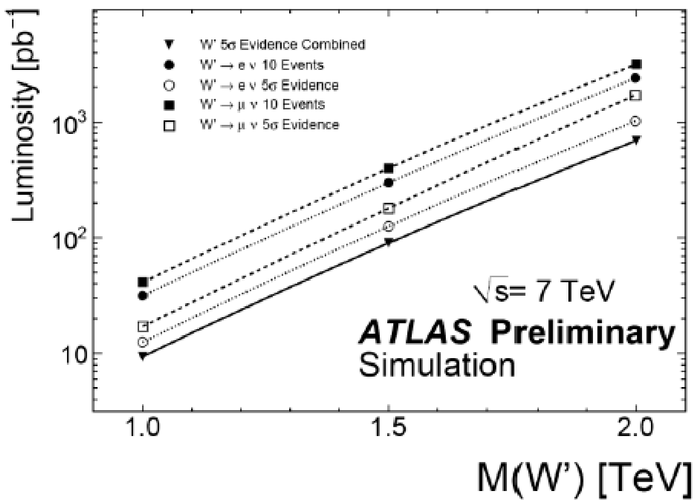
6. SEARCH FOR NEW PHYSICS

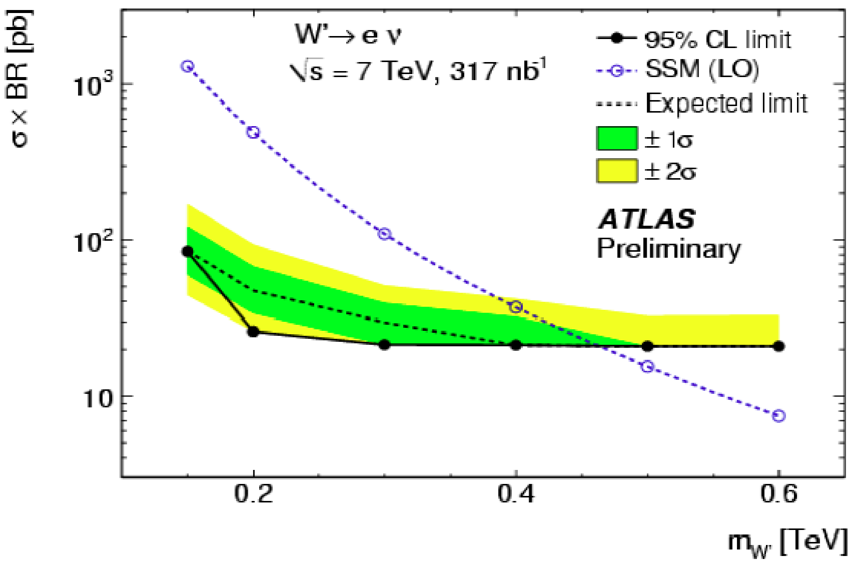
- Search for W'
- Di-Jet Resonances
- Quark Compositness
- SUSY Prospects

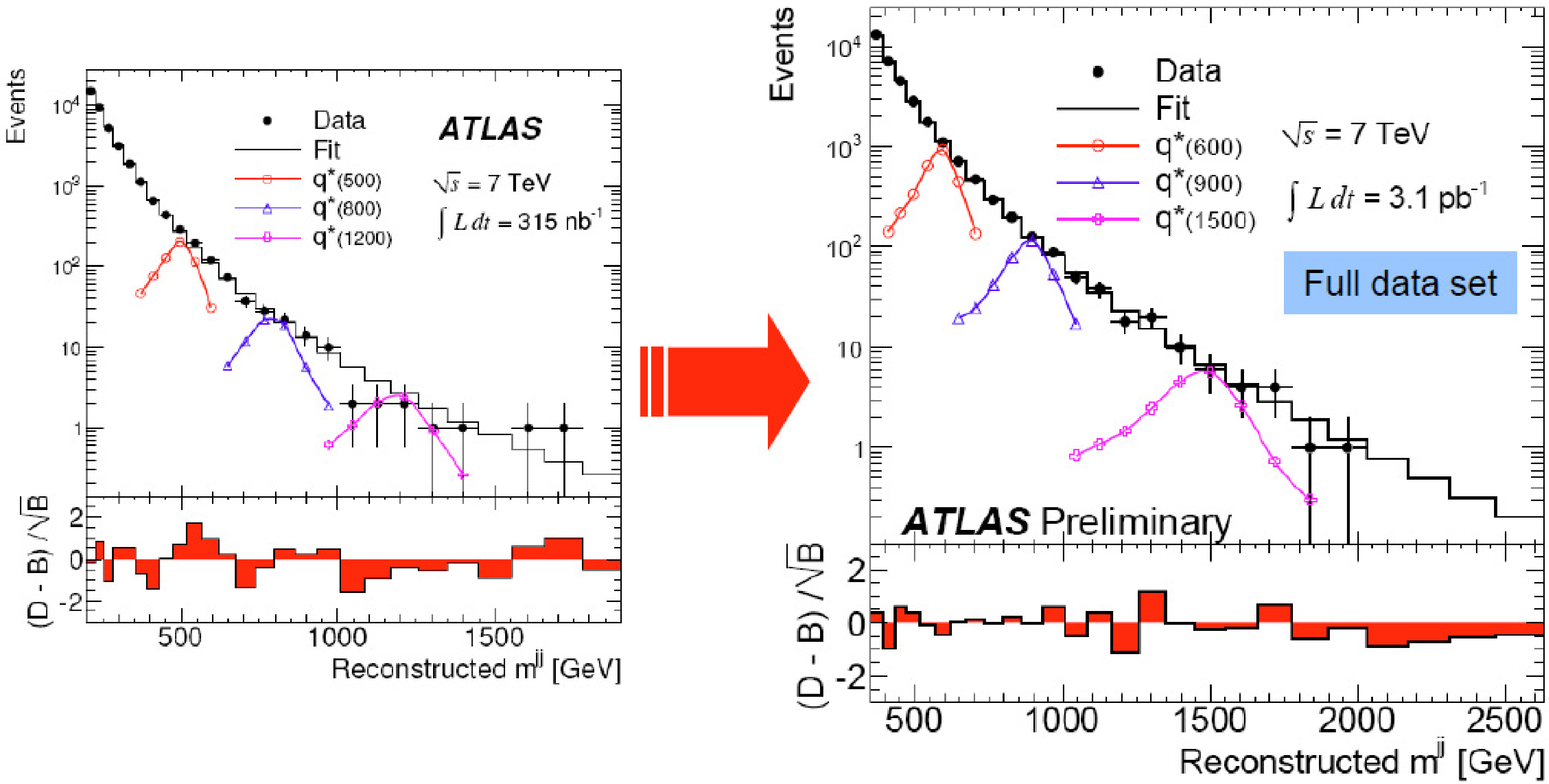


- Analysis uses 317 nb-1 of data
- Data consistent with SM predictions
- Current limit that can be set (electrons): 465 GeV
  - Present Tevatron limit is 1 TeV
- Current results support estimates from previous MC sensitivity studies
  - Extend sensitivity around 5 pb^{-1}
  - Discovery potential at 10-20 pb^{-1}

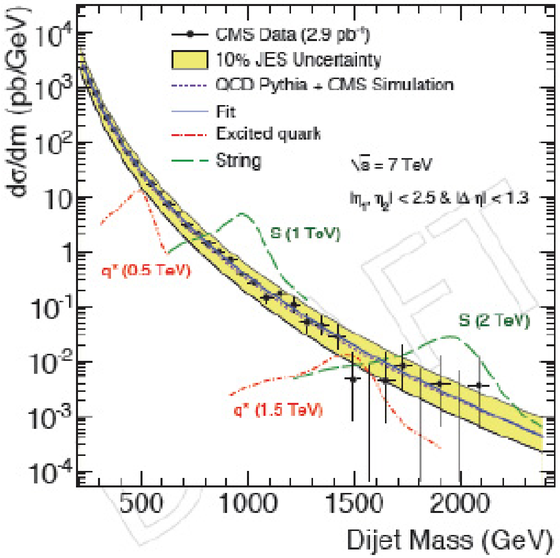


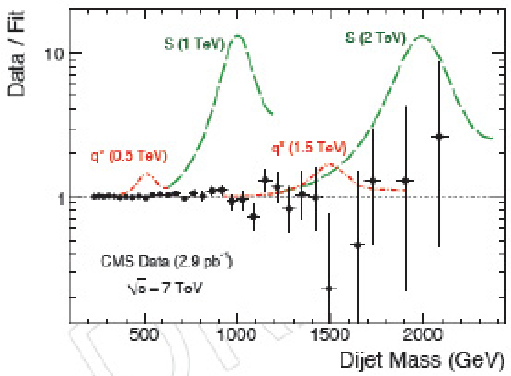


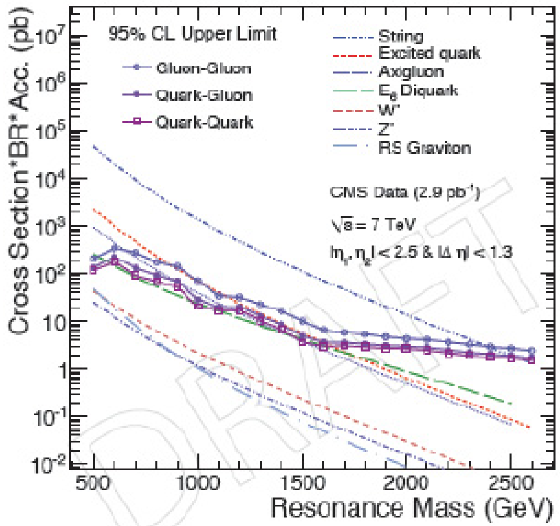




- With 10x as much data the expected limit moves from 1.06 TeV to 1.51 TeV and the observed limit moves from 1.26 TeV to **1.53 TeV**.
  - We raised the jet requirement to $p_T(j_1)$ > 150 GeV to match the evolving trigger.





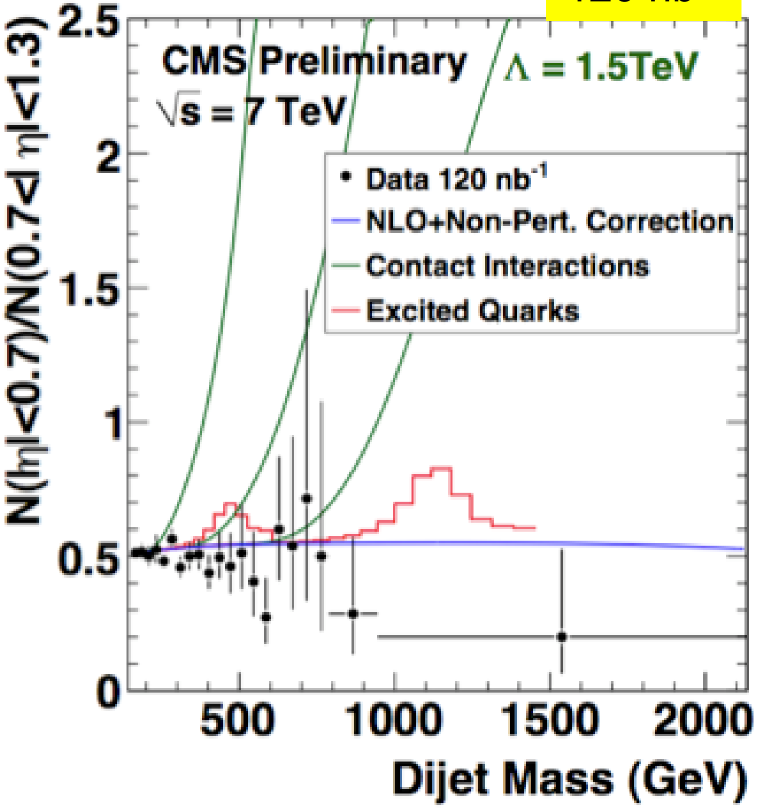


- Search for narrow resonances in di-jet final states.
  - Differential cross section for $|\eta_1,\eta_2|<2.5$ and $|\Delta\eta_{12}|<1.3$.
    - Sensitive to coupling of any new massive object to quarks and gluons.
  - 95% CL mass limits
    - String resonances >2.5 TeV, Excited quarks >1.58 TeV
    - Axigluons/Colorons >1.17 TeV

a. Measuring centralicity:

$$R = \frac{N(|\eta| < 0.7)}{N(0.7 < |\eta| < 1.3)}$$

120 nb^{-1}



- Roughly flat for t-channel QCD
- Rises for quark contact interactions

Data agree well with NLO + non-purturbative corrections:

Limit on the contact interaction scale Λ

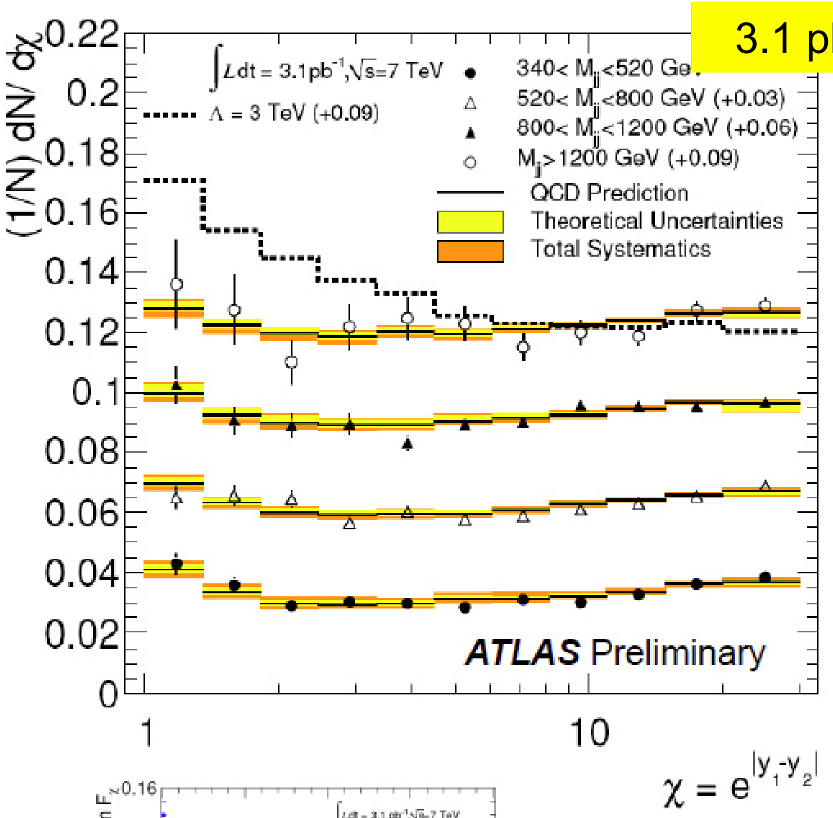
Λ< 1.9 TeV at 95% C.L.

(Tevatron excludes Λ<2.8 TeV)

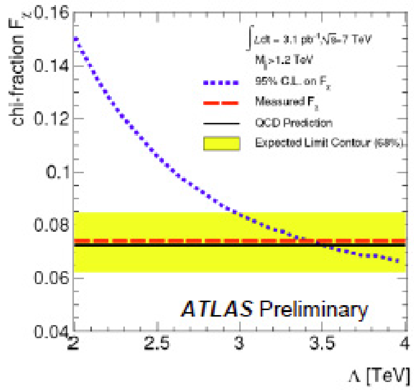
b. Measuring angular distributions:

- Angular distributions are sensitive to s-channel vs. t-channel (QCD) production of dijets
  - The variable χ is convenient – it's flat for Rutherford scattering, and almost flat for QCD
  - s-channel exchange peaks at low χ.
- We require (depending on mass bin)
  - $p_T(j_1) > 80\text{-}150$ GeV (trigger)
  - $p_T(j_2) > 30$ GeV (reconstruction)
  - $|y_1 + y_2| < 1.5$
  - $|y_1 - y_2| < 4.9$

  } Makes acceptance in χ relatively flat.
- No significant deviation from QCD is observed
  - Expressed as our benchmark, a contact interaction Λ, this works out to $\Lambda > 3.4$ TeV (at 95%), with an expected sensitivity of 3.5 TeV
  - Previous best limit is from D0, $\Lambda > 2.8$ TeV

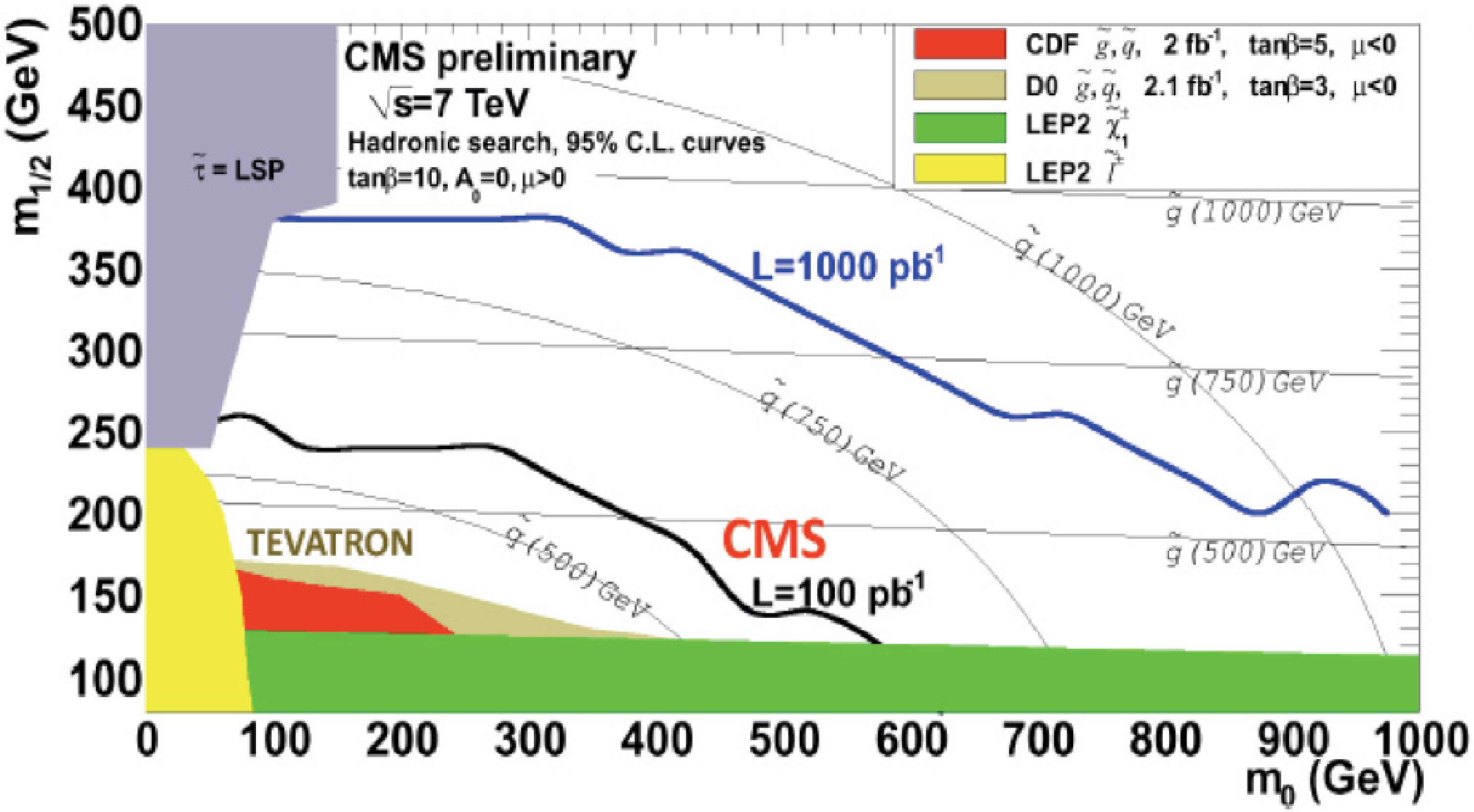


3.1 pb^{-1}



$\Lambda_{qqqq} > 3.4$ TeV

- 7 TeV data of less than 100 pb^{-1} should provide sensitivity to SUSY parameter space well beyond current Tevatron limits.
- Sensitivity strongly depends on the understanding of the SM backgrounds.



SUMMARY

- Data taking (and machine performance) is very smooth.
- Detectors are wonderful instruments! So far all four large experiments are covering almost all topics.
- Begin to “rediscover SM” at Hadron Colliders.
- Begin with searches for new physics – partially surpassing Tevatron already! Higgs, however, still far away!
- Very promising prospects: up to 1fb^{-1} in 2011 looks realistic.

We are entering the TEV area

One Word of Caution

Tiny signal to background and the huge level of expectations may lead to false discoveries.

Some examples I experienced (not all were published):

SPPS Collider:
- Centauro Events (1982)
- Diffactive Top Production (1984)
- SUSY in Mono Jets (1984)
- EWK Top Production (1984)

Tevatron:
- Top at 140 GeV (1993)
- Compositnes in Jet pt distributions (1996)
- 170 GeV Higgs into muons (2000)
- Multi-Higgs production into taus (2008)

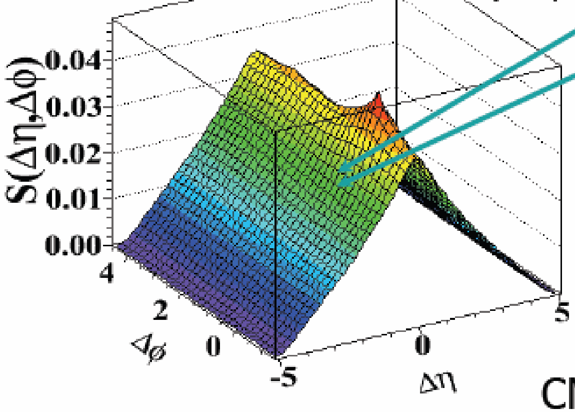
LHC:
- **I hope this will stay empty !**


DAS LETZTE, DAS ICH VERSTANDEN HABE, WAR "HEUREKA"!
OH

Definition of Two-Particle Correlations

Signal distribution:

$$S_N(\Delta\eta,\Delta\varphi) = \frac{1}{N(N-1)}\frac{d^2N^{signal}}{d\Delta\eta d\Delta\varphi}$$

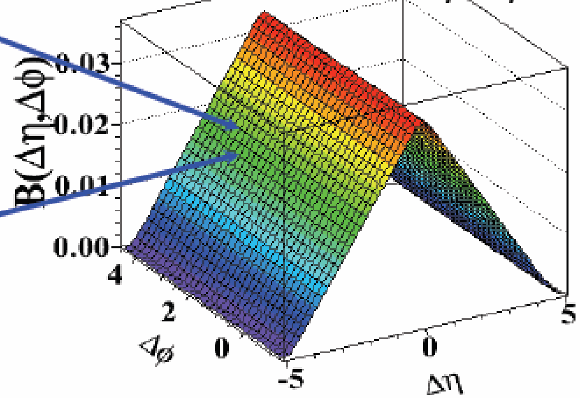


Event 1

Event 2

Background distribution:

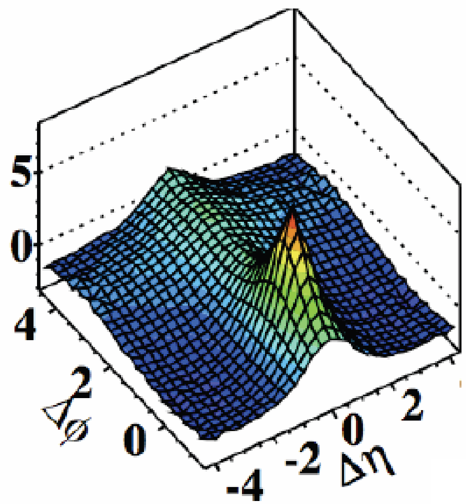
$$B_N(\Delta\eta,\Delta\varphi) = \frac{1}{N^2}\frac{d^2N^{bkg}}{d\Delta\eta d\Delta\varphi}$$



CMS pp 7TeV

$$\Delta\eta = \eta_1 - \eta_2$$

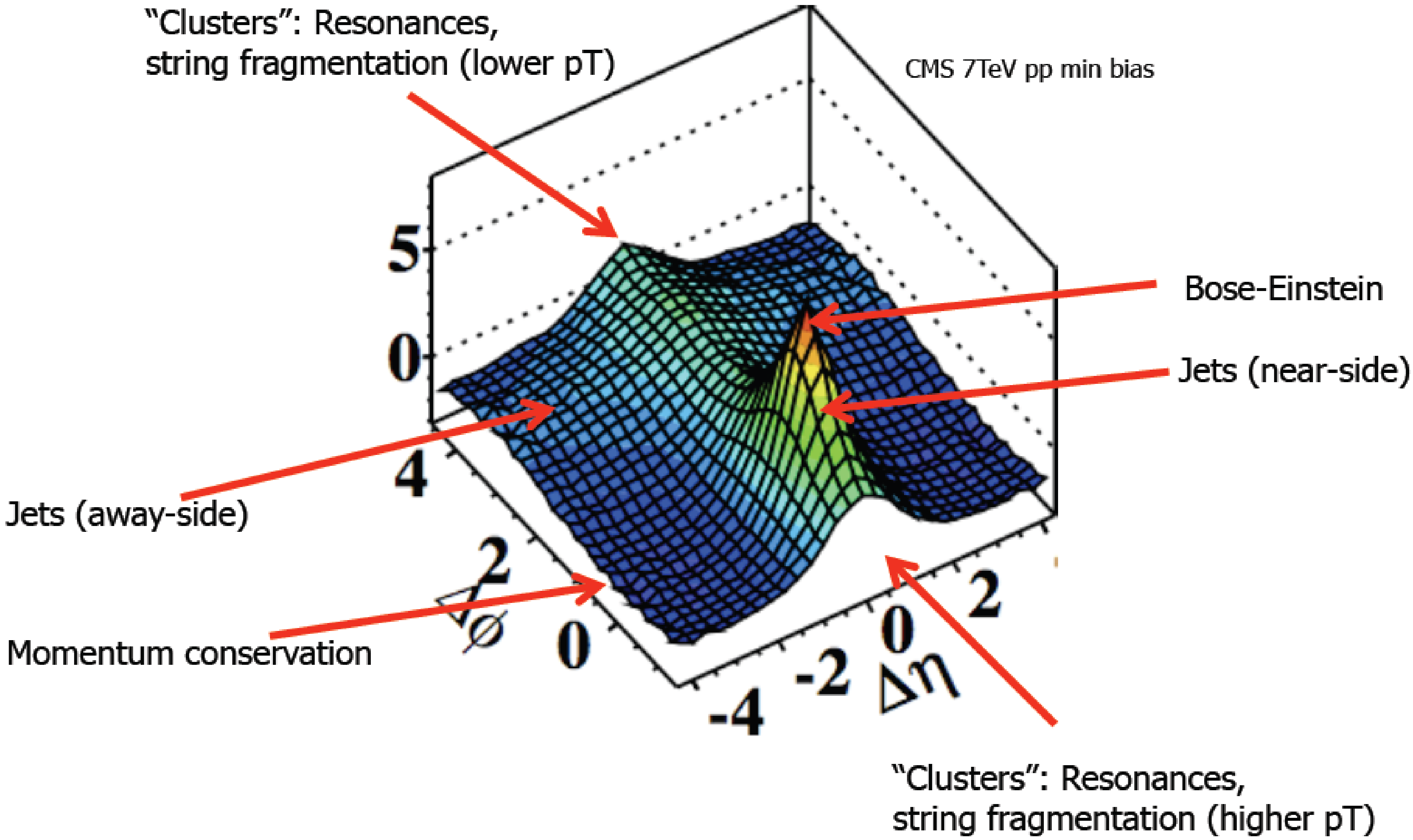
$$\Delta\varphi = \varphi_1 - \varphi_2$$



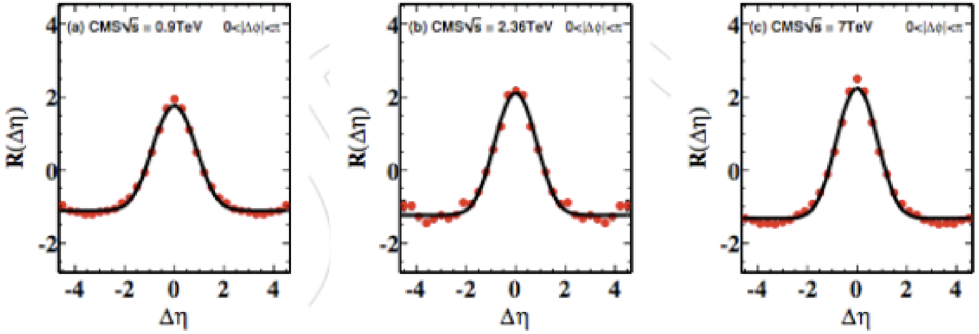
$$R(\Delta\eta,\Delta\varphi) = \left\langle (N-1)\left(\frac{S_N(\Delta\eta,\Delta\varphi)}{B_N(\Delta\eta,\Delta\varphi)} - 1\right)\right\rangle_N$$

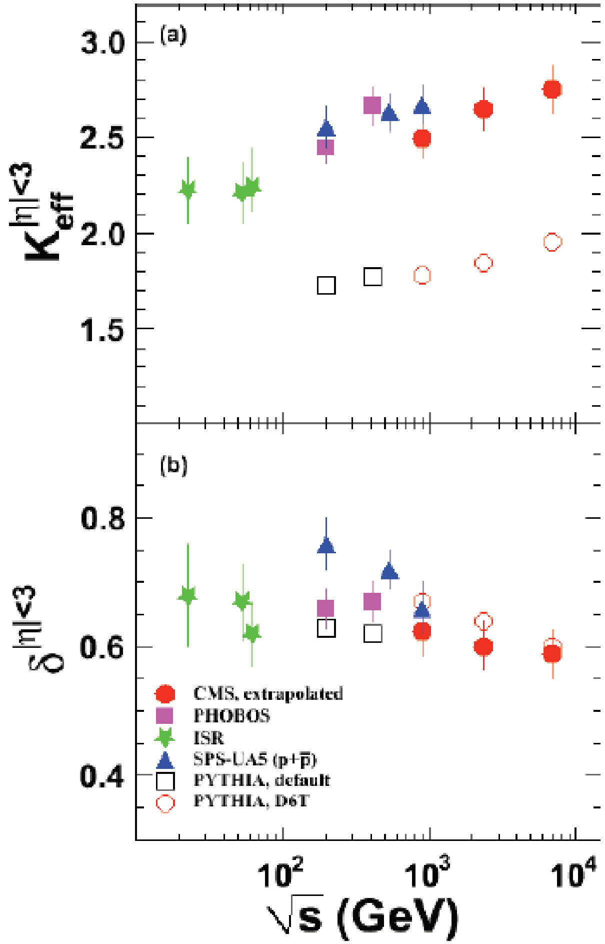
p_T-inclusive two-particle angular correlations in MinBias collisions

G. Tonelli and G. Roland, CMS, CERN seminar 21. Sept 2010


"Clusters": Resonances,
string fragmentation (lower pT)
CMS 7TeV pp min bias
Bose-Einstein
Jets (near-side)
Jets (away-side)
Momentum conservation
"Clusters": Resonances,
string fragmentation (higher pT)
5
0
4
2
0
Δφ
-4
-2
0
2
Δη

1D "Projection" to $\Delta\eta$ axis





K_{eff}: Number of correlated particles

δ: Extend of correlation in $\Delta\eta$

PYTHIA describes the energy dependence

Underestimates the cluster size K_{eff}