The first six months of 7 TeV physics at the LHC

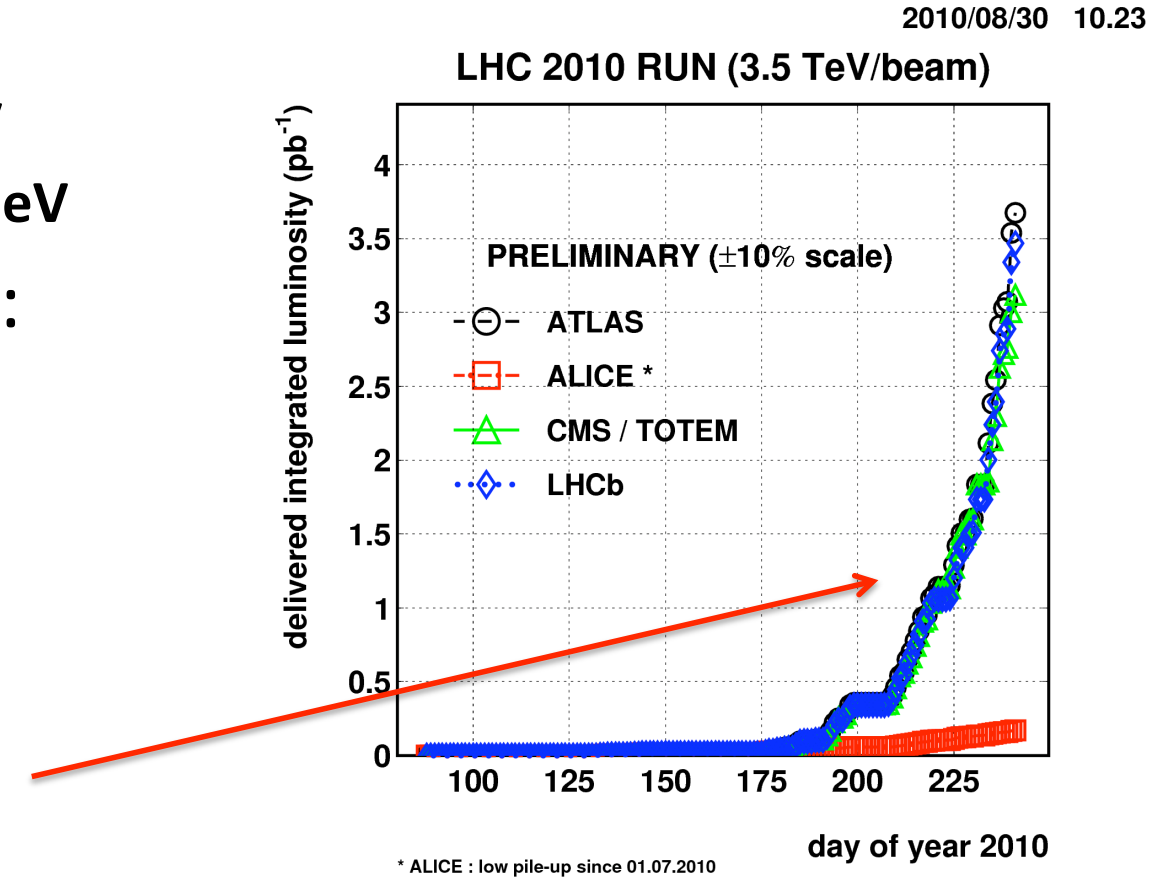
Roberto Tenchini

INFN - Pisa

I have taken most results from CMS …

Statistics available now at the LHC (per experiment)

- 2009 run:
  - About **10 μb^{-1} at 900 GeV**
  - About **half μb^{-1} at 2360 GeV**
- 2010 till today, 7 TeV :
  - **> 3.5 pb^{-1}**
  - **public results with up to 830 nb^{-1}**



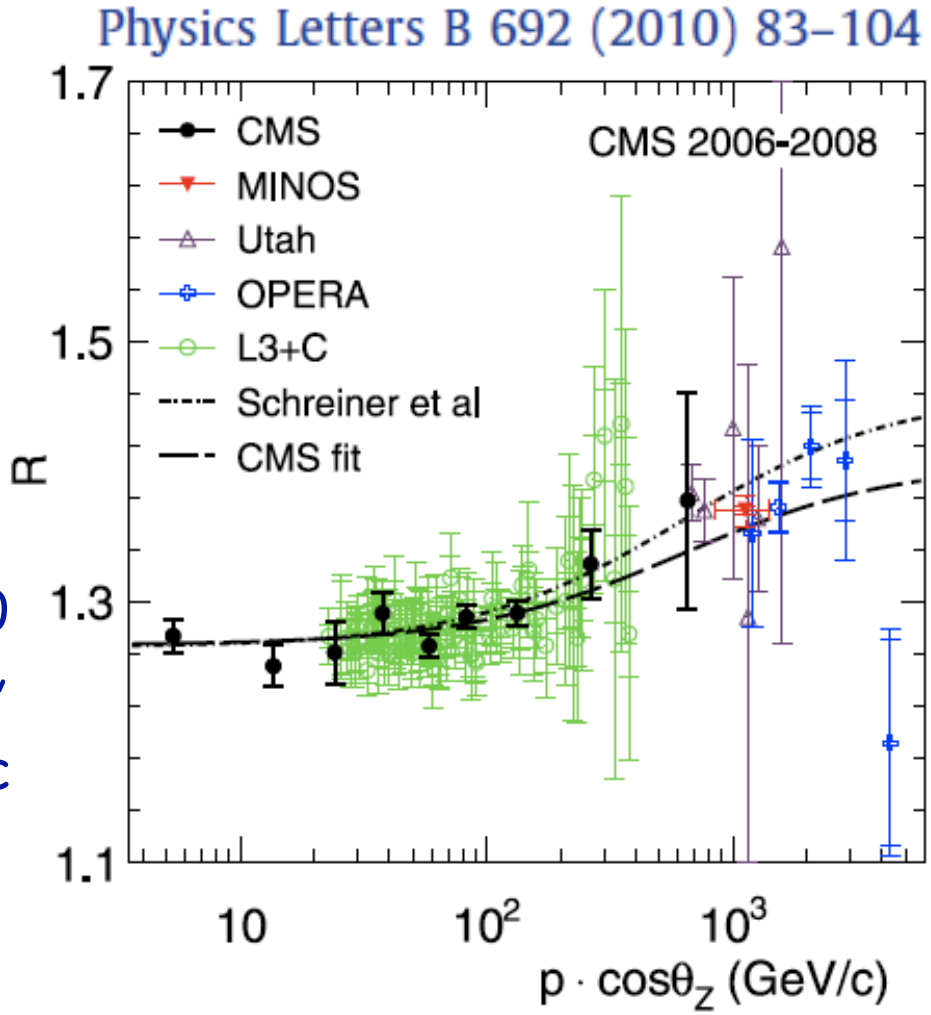
- Important jumps

in luminosity

(we are at **10^{31} $cm^{-2}s^{-1}$** aim to reach soon 10^{32})

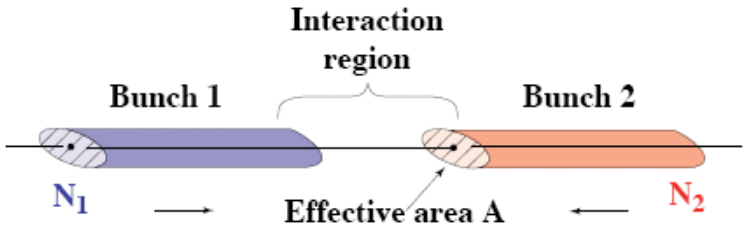
Physics commissioning

- We started well … we owe a lot to **cosmic rays**
- They even provided physics measurements for next PDG
- **Nature, Vol. 6, No 9, Sept 2010**: " ahead of high-energy proton collisions, from cosmic-data-taking runs in 2006 and 2008 **CMS has achieved the most precise measurement so far**, for muons of momenta lower than 100 GeV/c, of the **muon charge ratio**, which is the ratio of the number of positively charged atmospheric muons to the number of negatively charged ones arriving at the Earth's surface."



How well do we know the absolute luminosity ? Van Der Meer scans

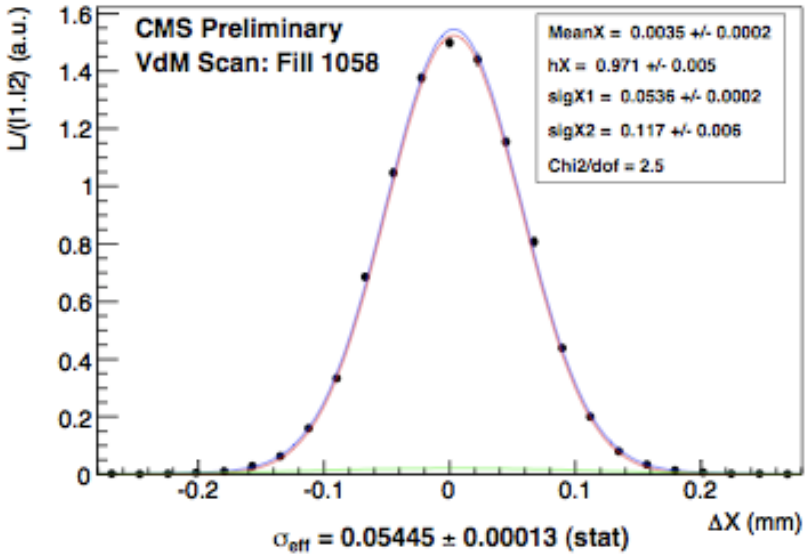
$$\mathcal{L} = \frac{N_1 N_2 f}{A_{\text{eff}}}$$



Beam intensities and crossing frequency are known with good accuracy
The effective overlap area A can be determined by scans in separation

- The present uncertainty (11%) dominated by the knowledge of the beam currents.
- Event counts with “Monte Carlo cross sections” give consistent results

CMS-PAS-EWK-2010-004

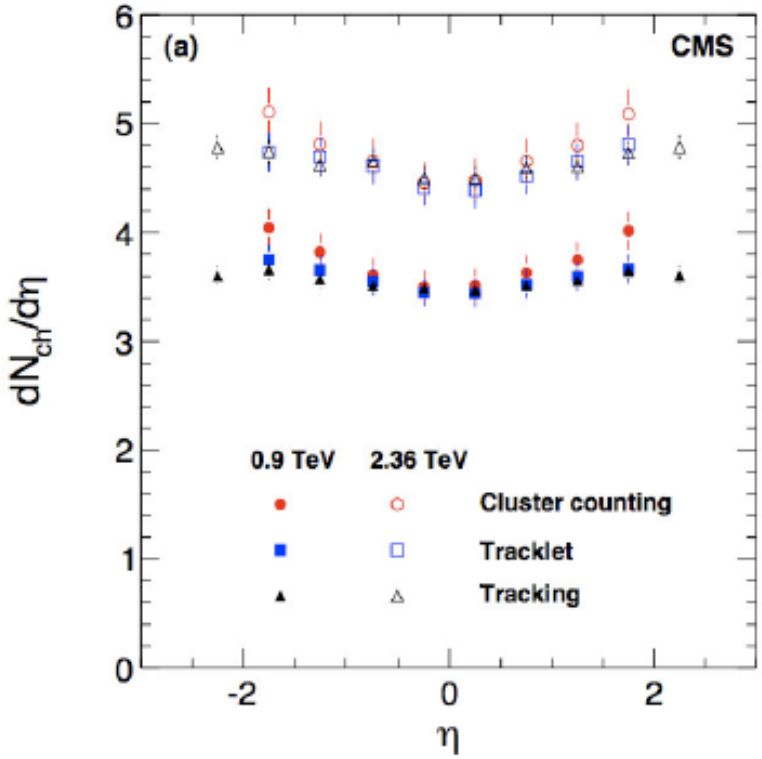


Soft Physics

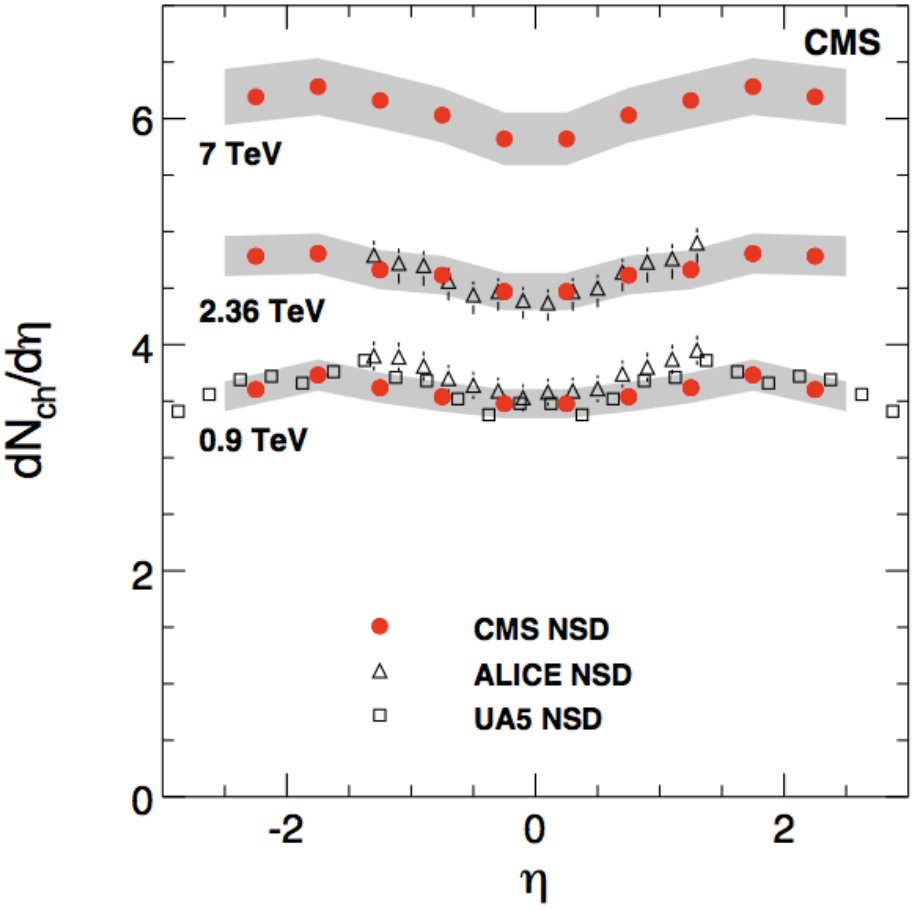
- At nominal luminosity (**10^{34}**) 25 inelastic collisions will be superimposed to the interesting events (**pileup**)
- The initial phase (**10^{28} - 10^{31}**) was the right moment to study their properties: we had "**minimal trigger bias**"
- We need also to **tune** the general properties of our **Monte Carlo generators**
- We have also to "**calibrate**" the **Heavy Ion** collisions with pp seen by the same apparatus

The dN/dη distribution

Three methods:
1) Cluster counting (pt down to 30 MeV)
2) Tracklets
3) Full tracking

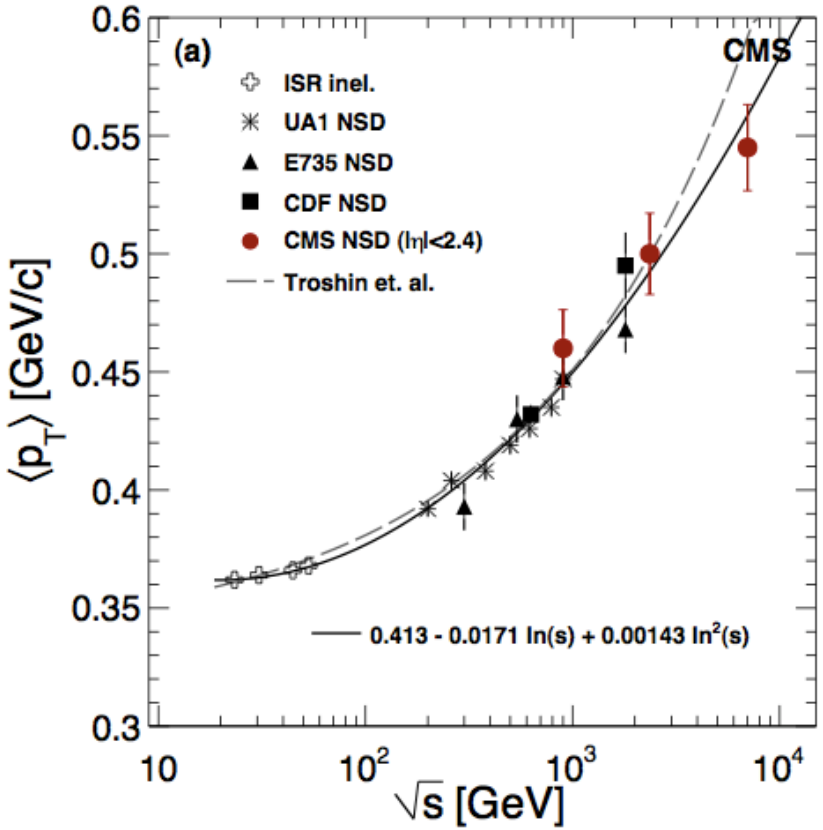


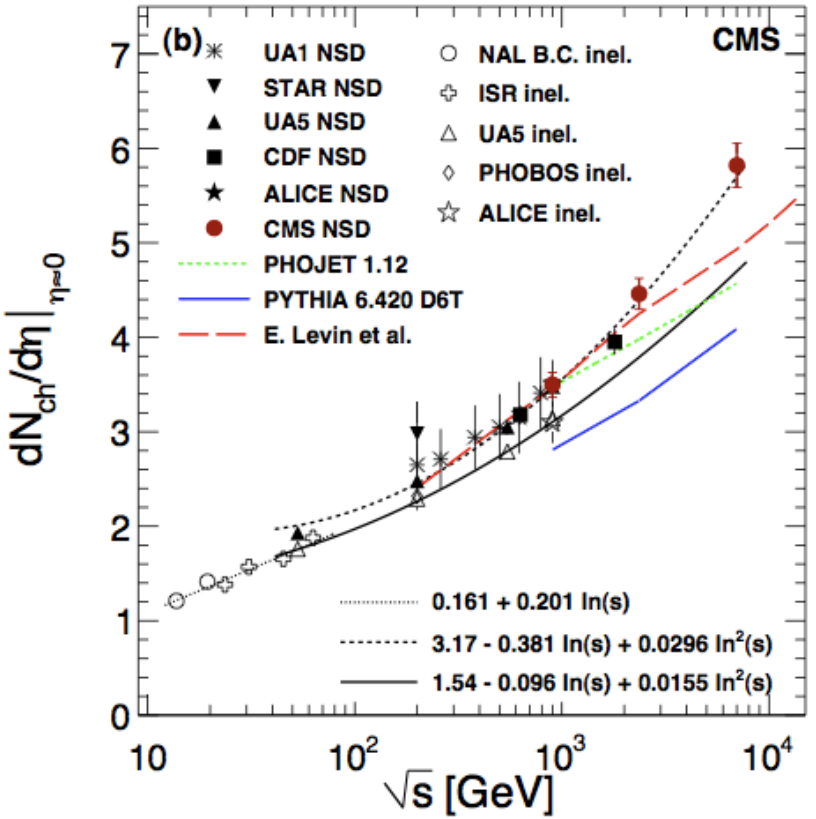
Phys. Rev. Lett. : 105 (2010) , pp. 022002



Correction for Single diffractive dissociation ~ 5% controlled with data

Charged hadrons vs sqrt(s)

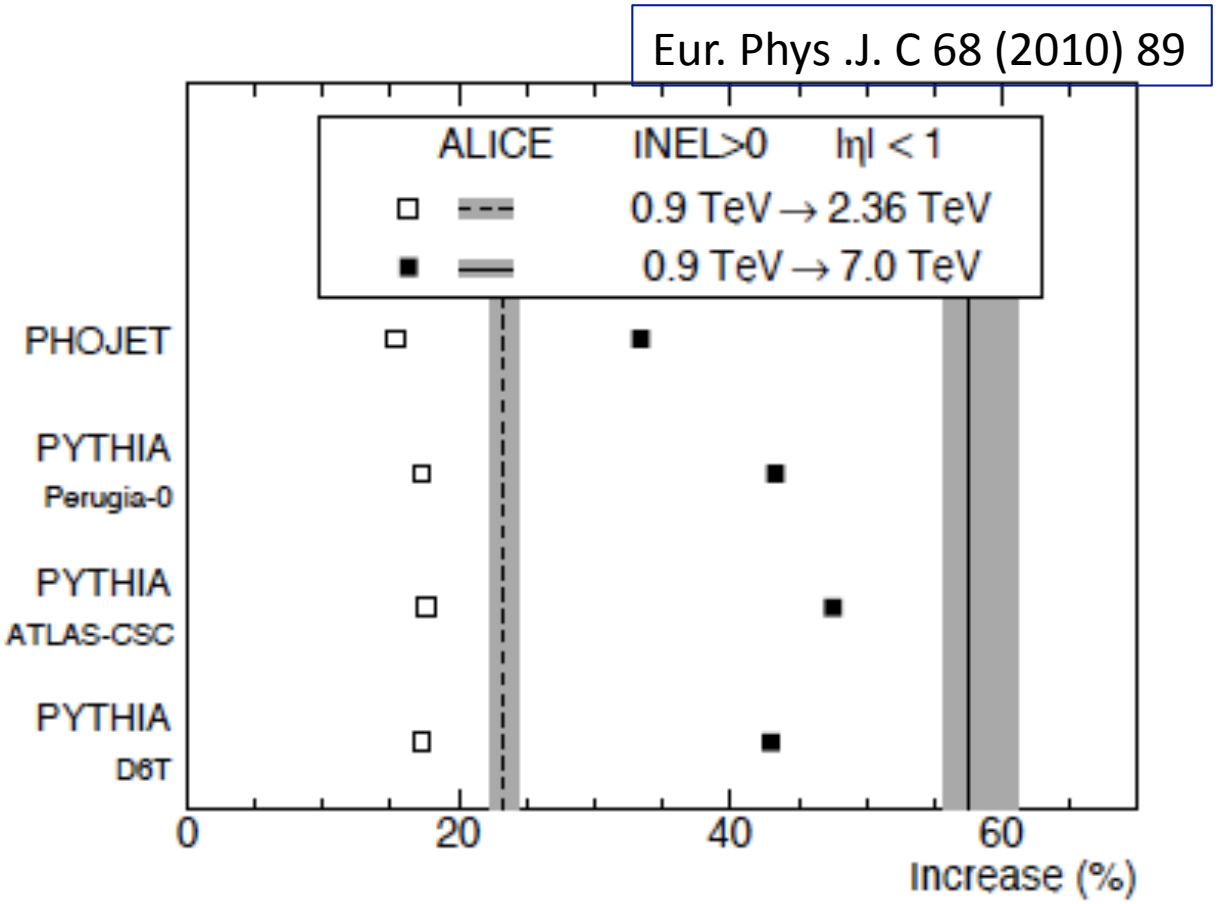




Rise of dN/dη in data stronger than currently used models

Relative increase of multiplicity larger than models prediction

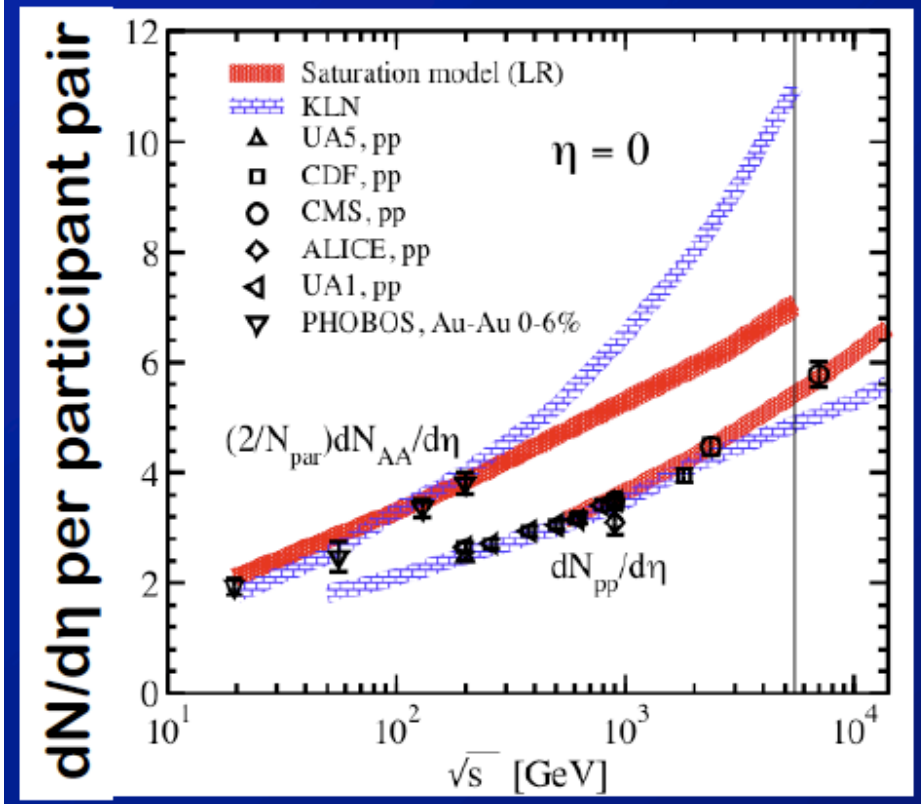
Eur. Phys .J. C 68 (2010) 89

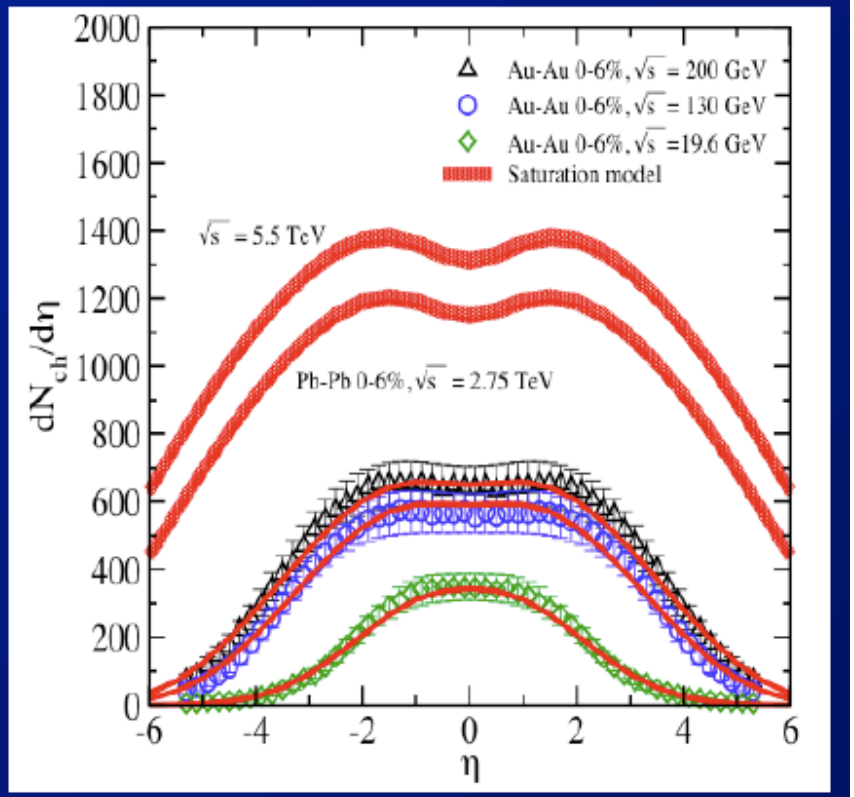


Plenary talk of B. Cole at ICHEP 2010

"Hot off the Press"

Levin and Rezaeian, arXiv:1007.2430v2

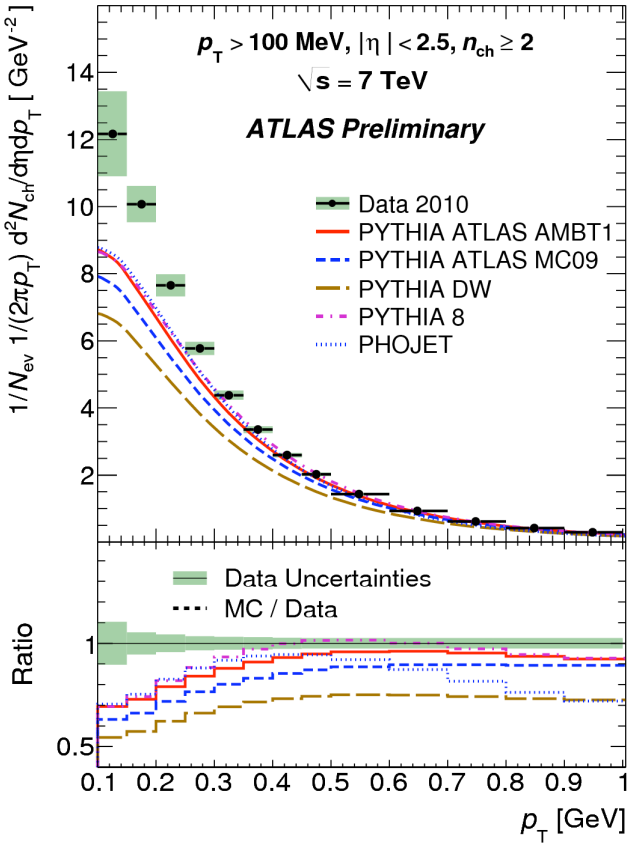




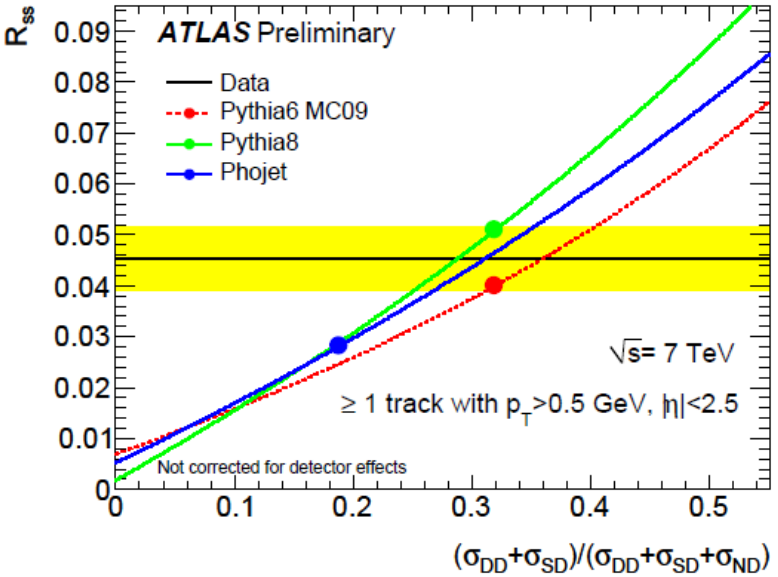
- p-p prediction at 7 TeV confirmed by CMS

New ATLAS measurement, focusing on diffraction (ICHEP 2010)

- Analysis extended to lower momentum region (p_T>100MeV, n_{ch}≥2)
- Luminosity – 190 μb^{-1} (10 M events)
- Data-MC agreement is worse at low p_T – larger diffractive component which was not used in MC tune.



Probe diffractive part of cross-section:
Min. Bias Scintillator - require activity on one-side of detector ONLY

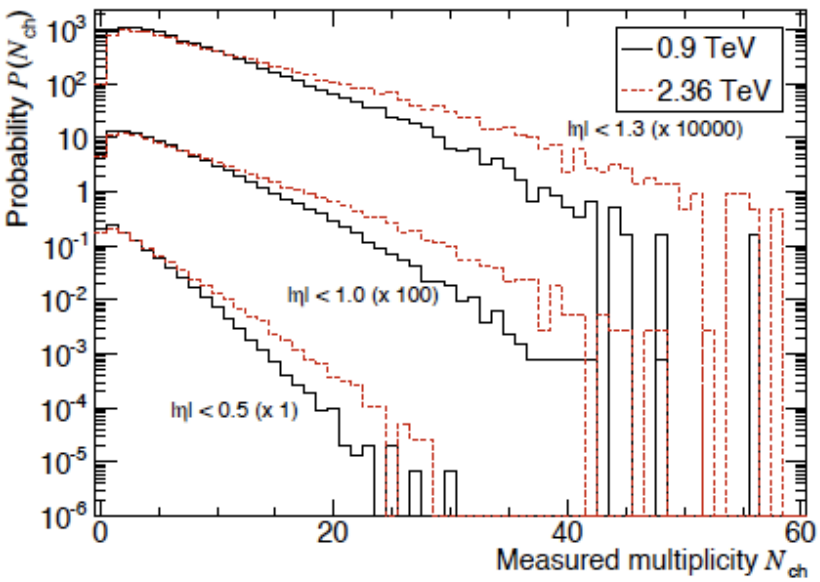


- Pythia 6 and 8 describe rate of diffractive events well
- Phojet best description of track distributions

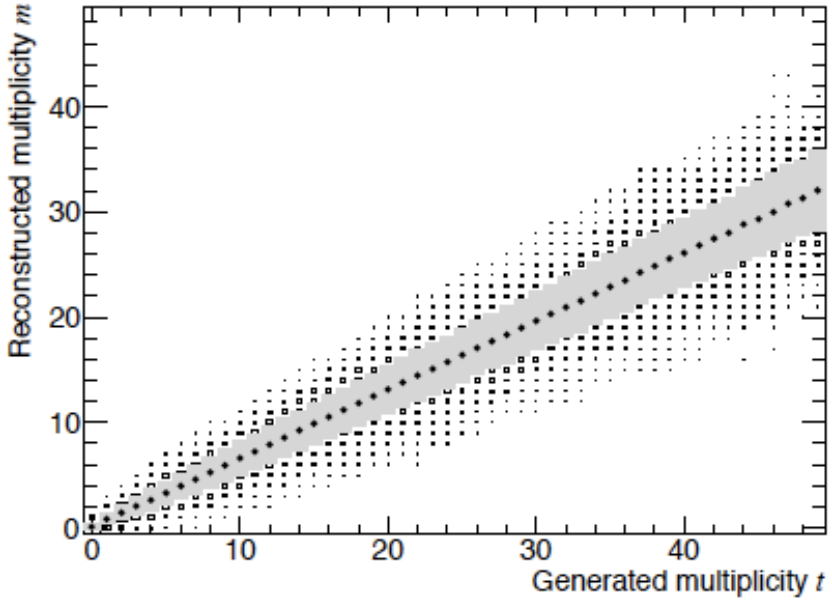
ATLAS-CONF-2010-046
ATLAS-CONF-2010-047

Multiplicity distributions (example from ALICE)

Eur. Phys .J. C 68 (2010) 89



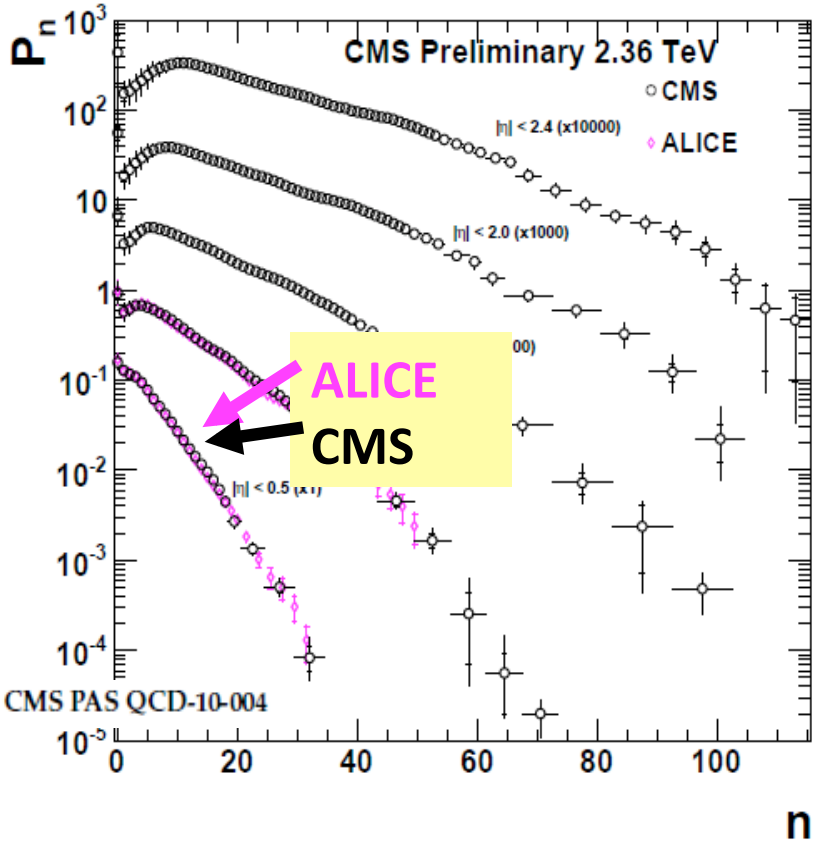
Raw measurements

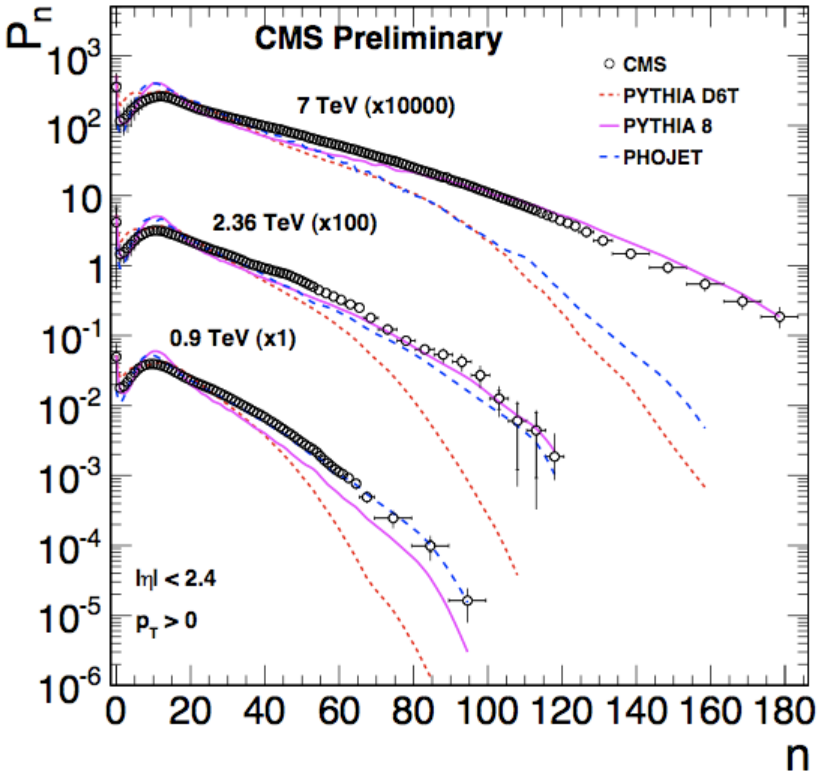


Unfolding

Test KNO scaling:
distribution <Nch>P(z), where z = Nch/<Nch>, independent of energy.

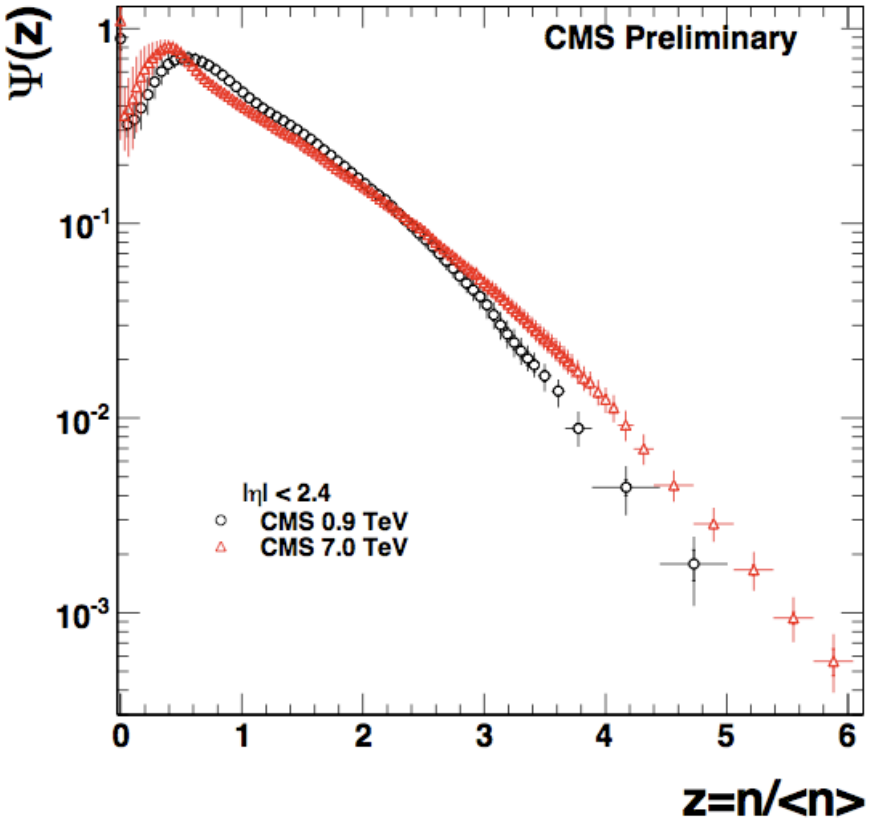
Multiplicity distributions (Alice and CMS, ICHEP2010)



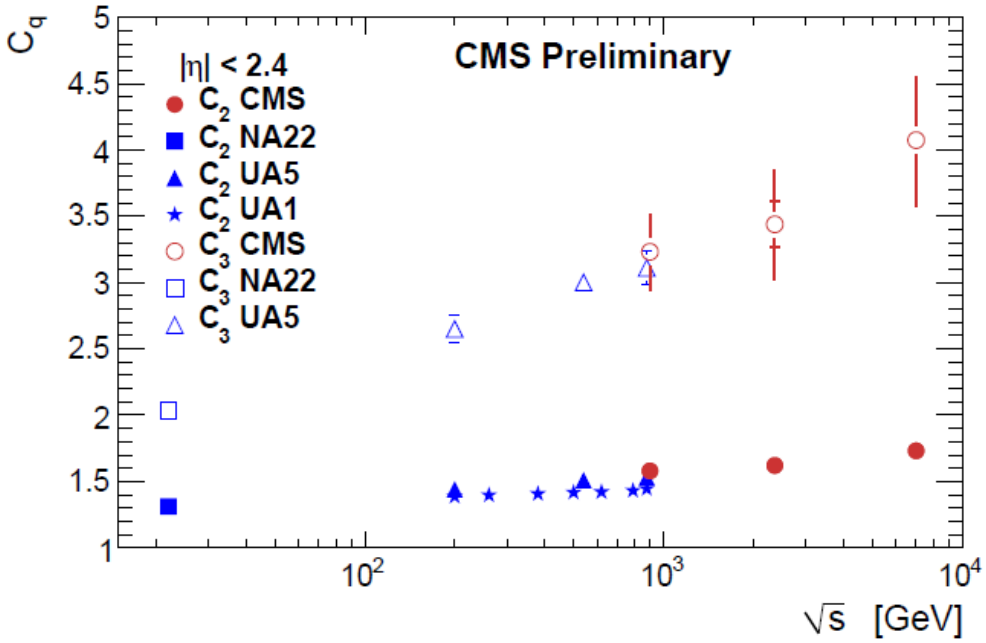


Experiments agree, but need to work on Monte Carlo tunes !

KNO scaling violations

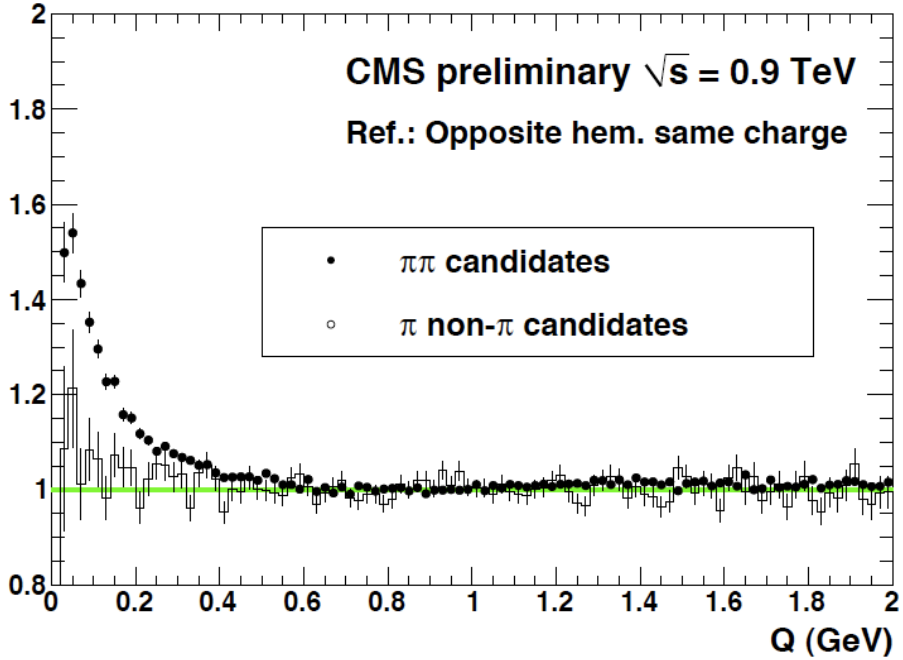


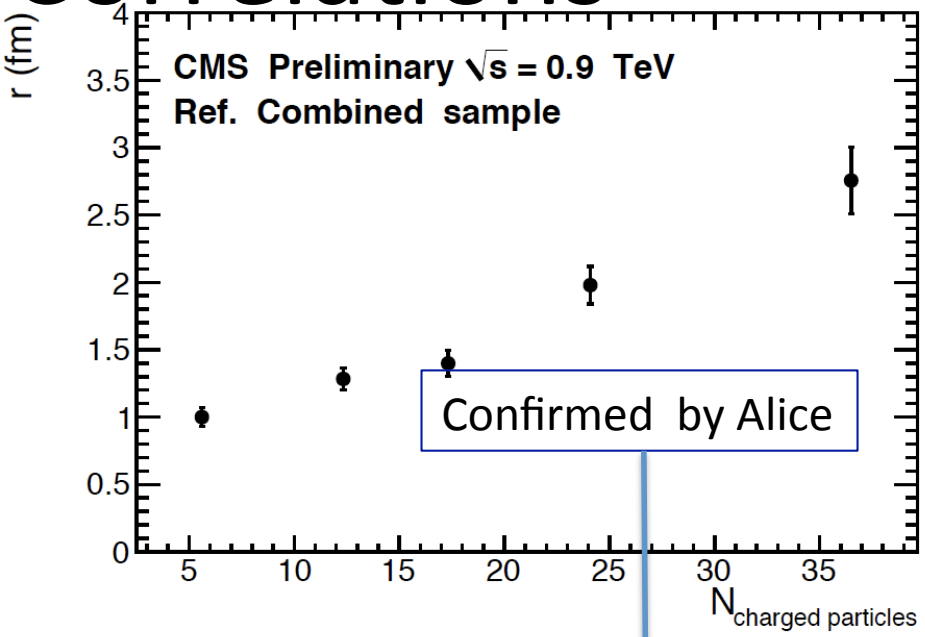
KNO: normalized multiplicity moments Cq=<n^q>/<n>^q independent of s

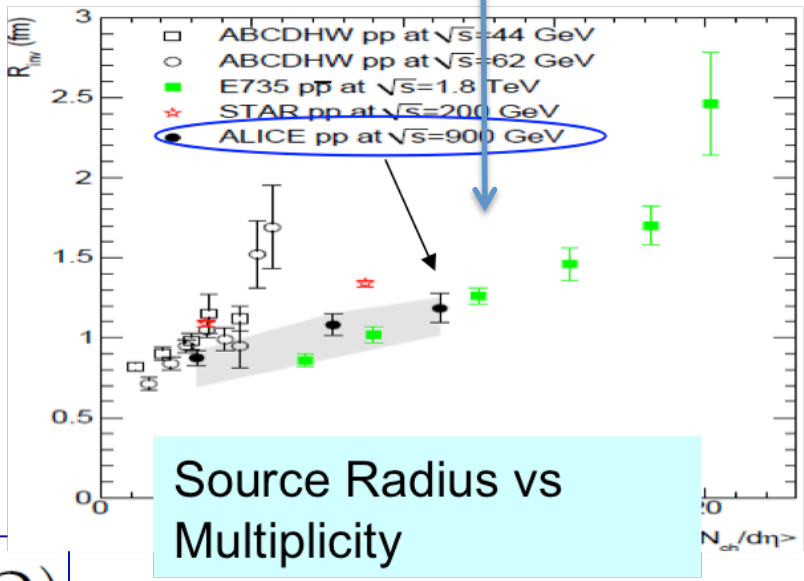


Bose-Einstein Correlations

Phys. Rev. Lett. : 105 (2010) , pp. 032001







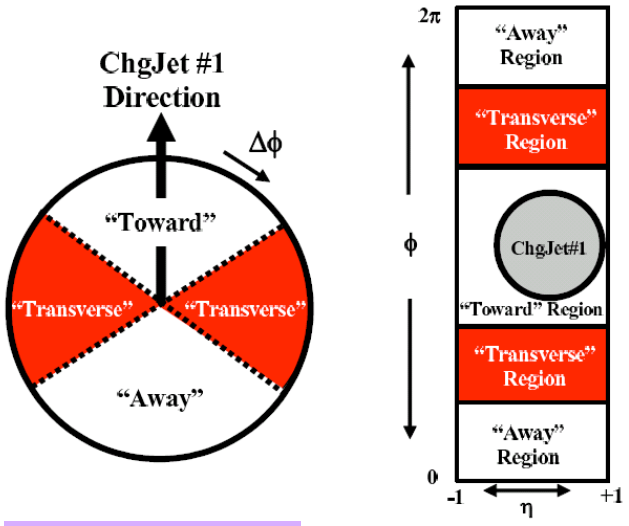
$$Q = \sqrt{-(p_1 - p_2)^2} = \sqrt{m_{inv}^2 - 4m_\pi^2}$$

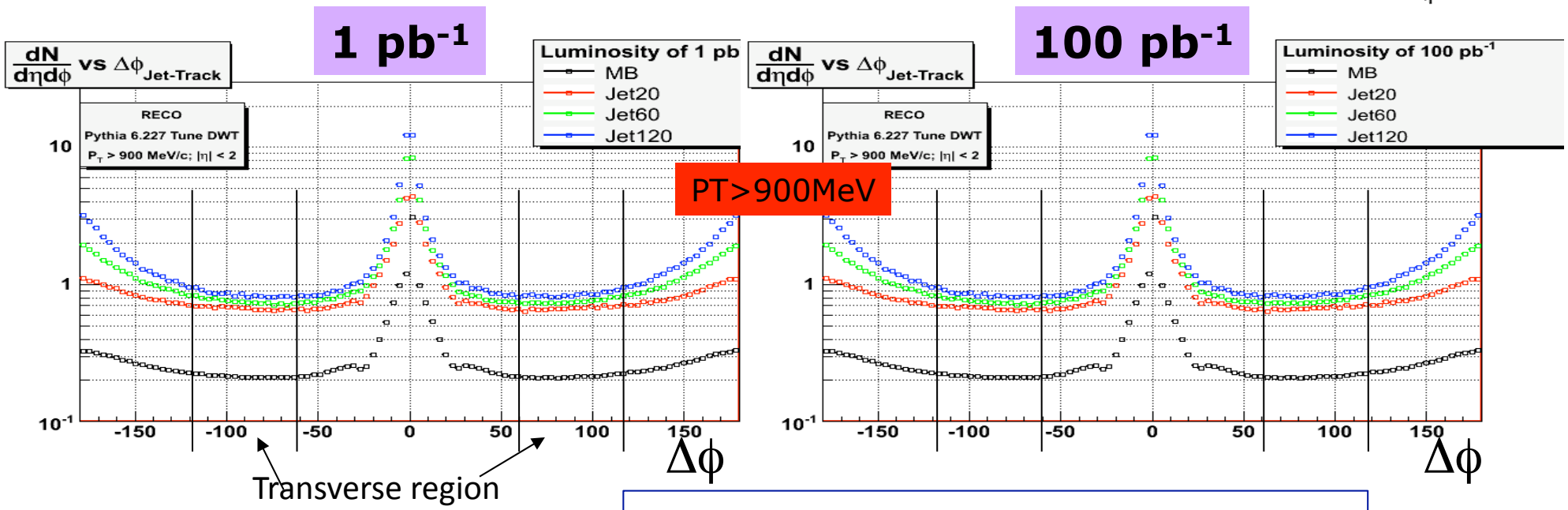
$$R(Q) = C\left[1 + \lambda\Omega(Qr)\right] \cdot (1 + \delta Q)$$

Event structure (UE)

- Minimum-bias & jet events
  - measure underlying event activity

Main observables:
+ dN/dηdϕ, charged density
+ d(P_T^{sum})/dηdϕ, energy density

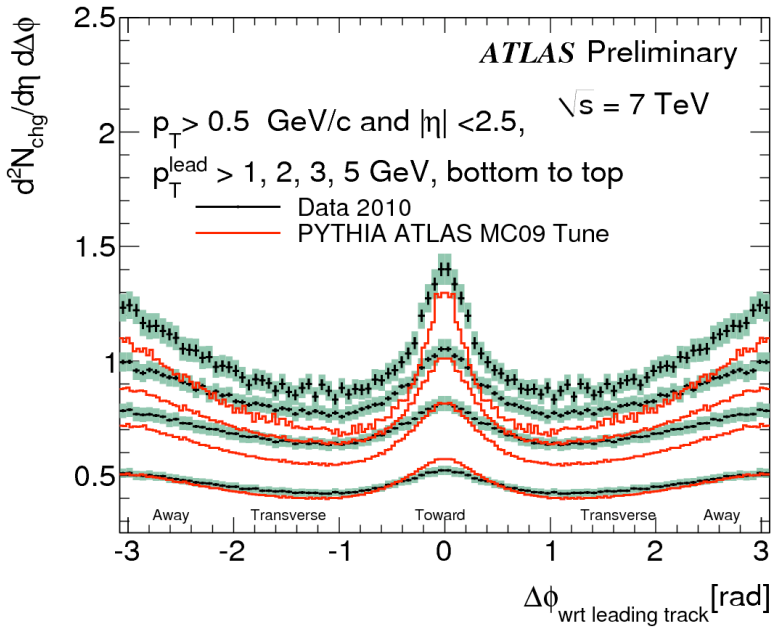




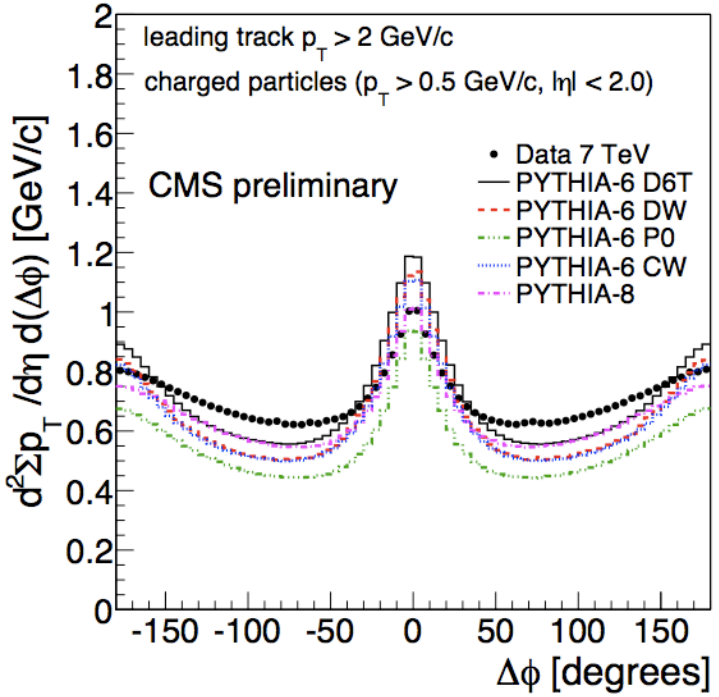
MONTE CARLO Examples

Underlying event at 7 TeV

ATLAS-CONF-2010-029



CMS-PAS-QCD-2010-010



- ATLAS provides detector-corrected distributions
- CMS analysis done also for track-jets

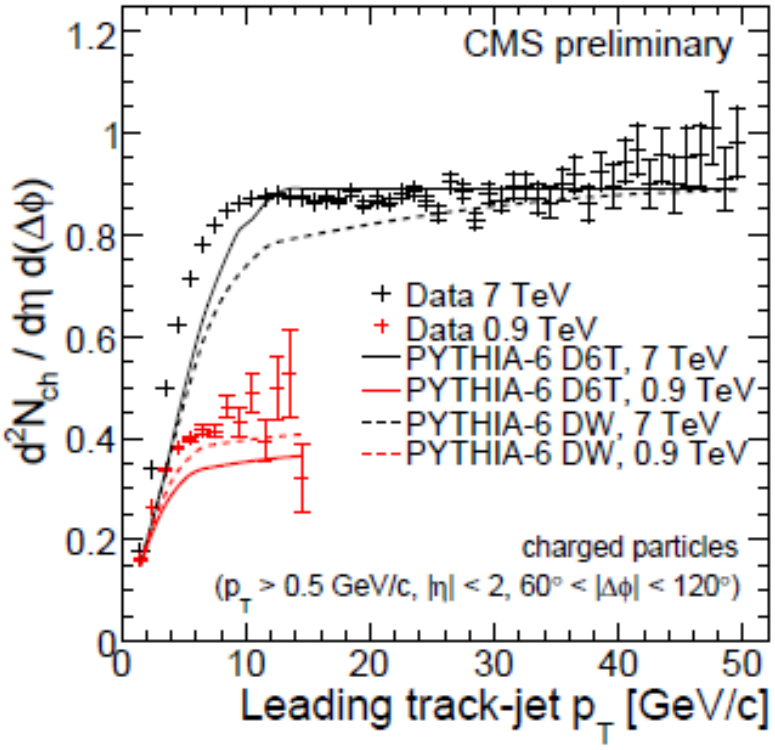
Underlying event studies

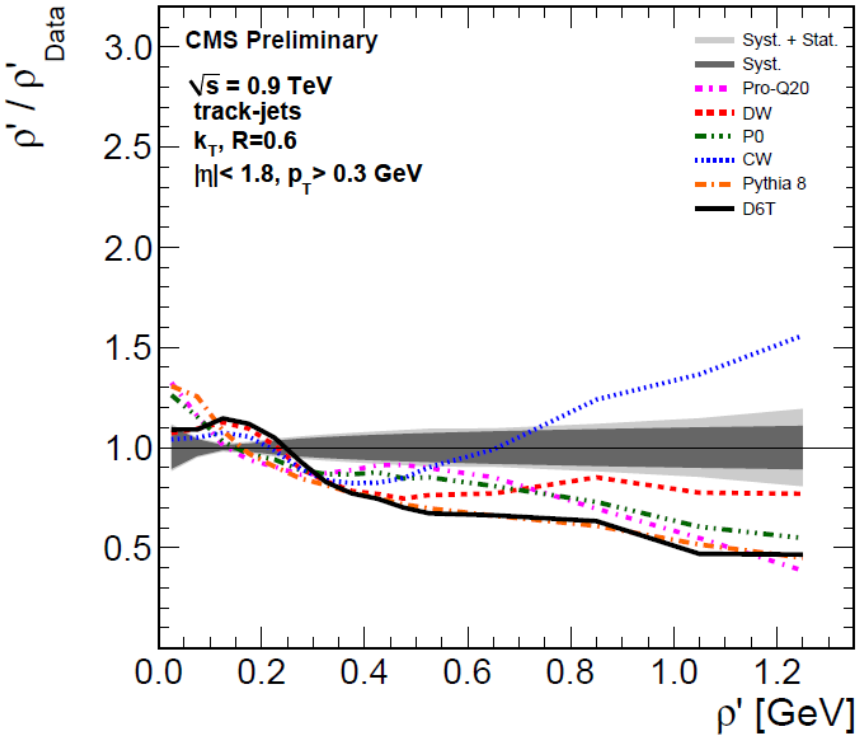
Energy dependence not well described by models which are consistent with Tevatron data

CMS QCD-10-005: New approach (Cacciari, Salam, Sapeta)

Median of jet Pt / jet area

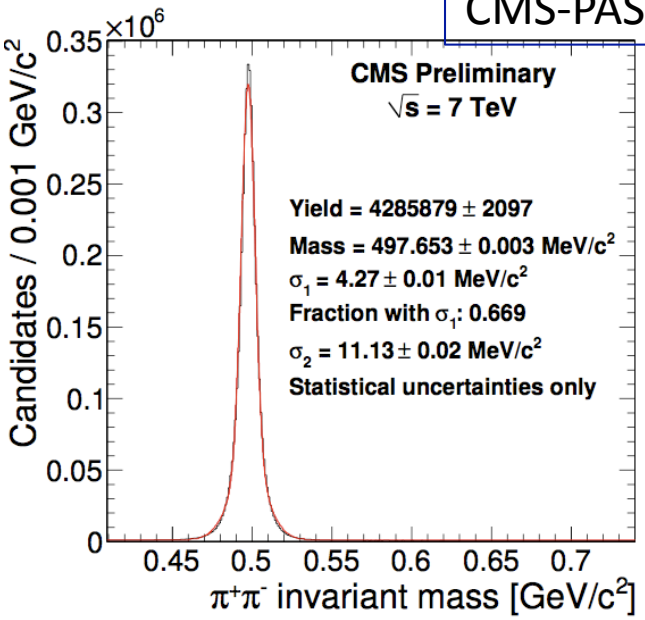
$$\rho' = \underset{j \in \text{physical jets}}{\text{median}} \left[\left\{ \frac{p_{\mathrm{T}j}}{A_j} \right\} \right] \cdot C$$

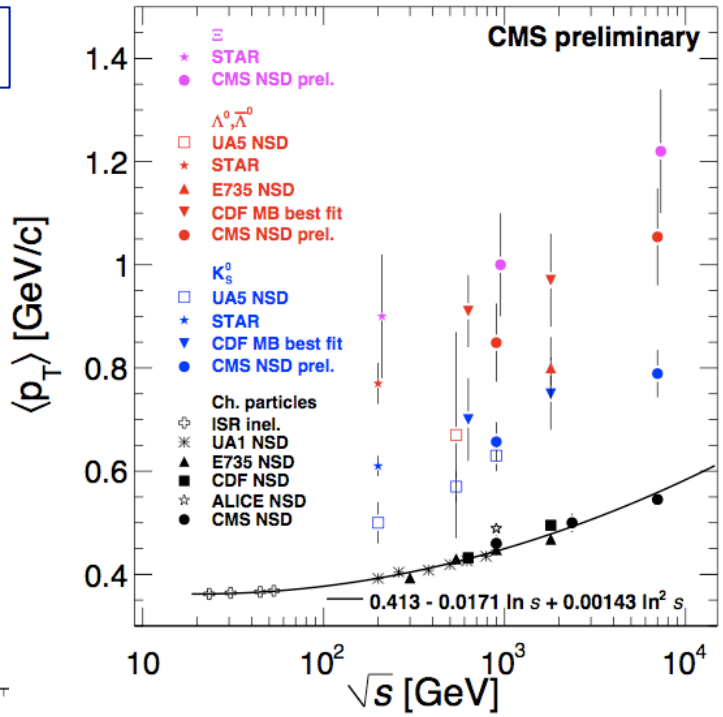


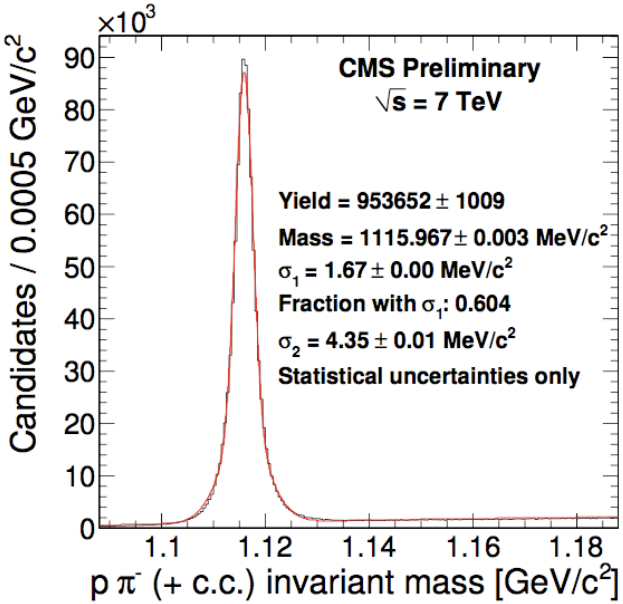


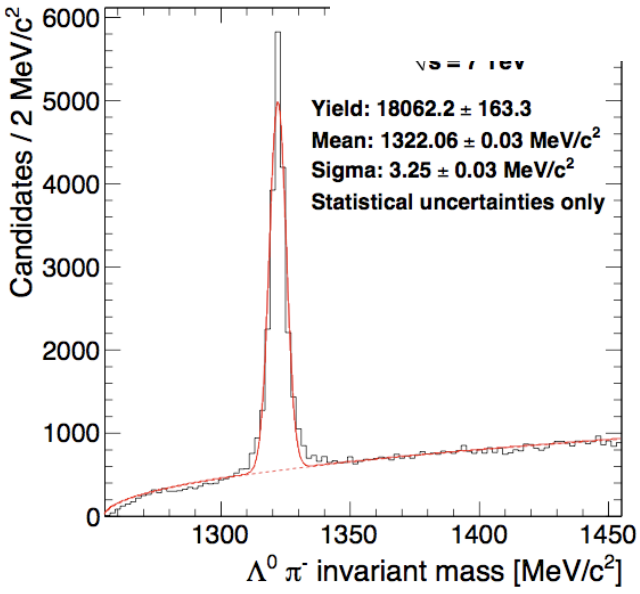
Spectra of particles with strangeness

CMS-PAS-QCD-2010-007



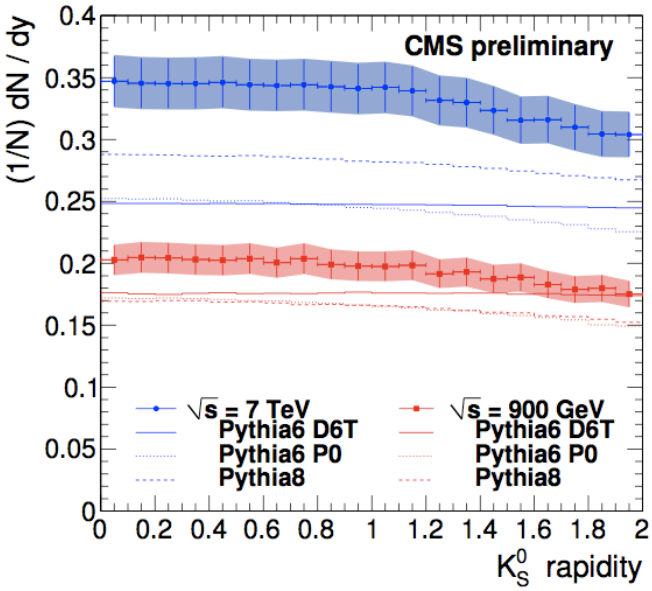


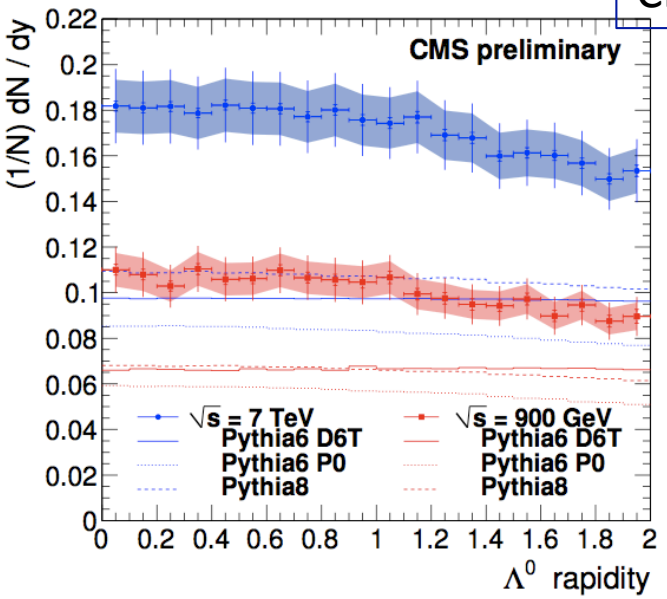


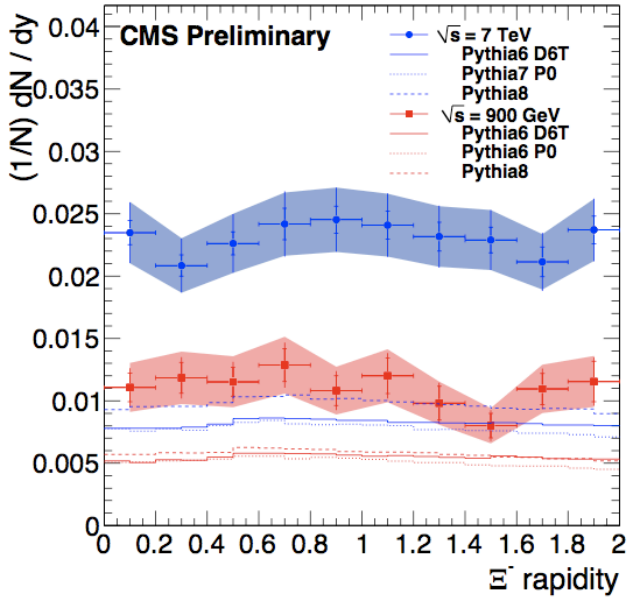


Spectra of particles with strangeness

CMS-PAS-QCD-2010-007

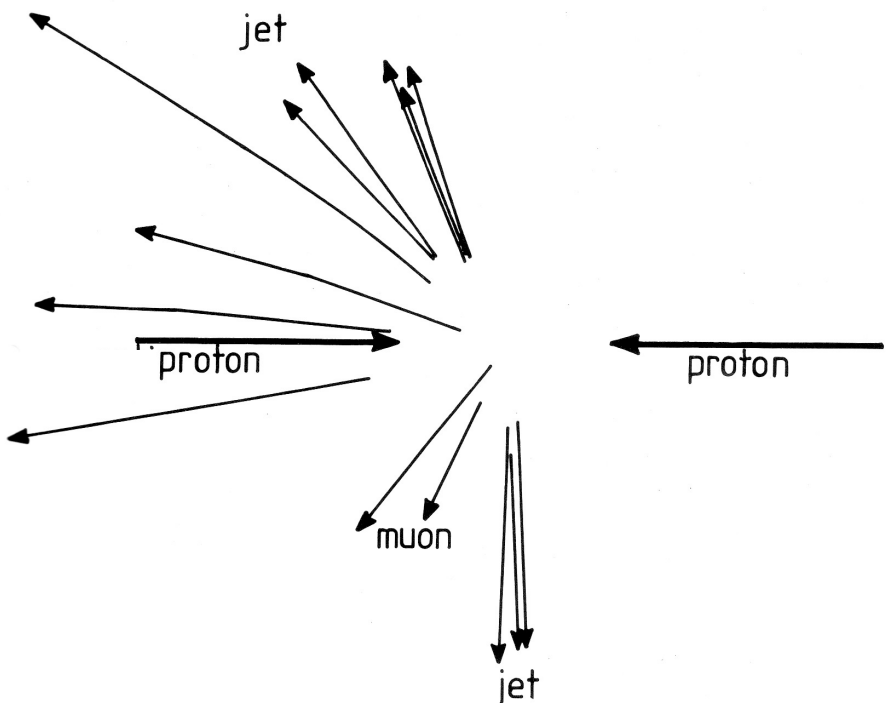






- Increase of strangeness production strongly underestimated by the simulation
- The discrepancy increases with centre-of-mass energy, mass, and strangeness

Jet Physics

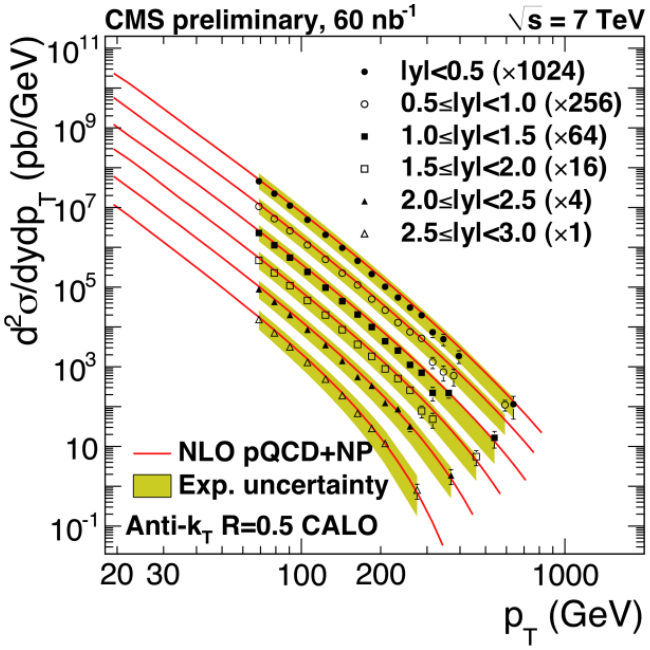


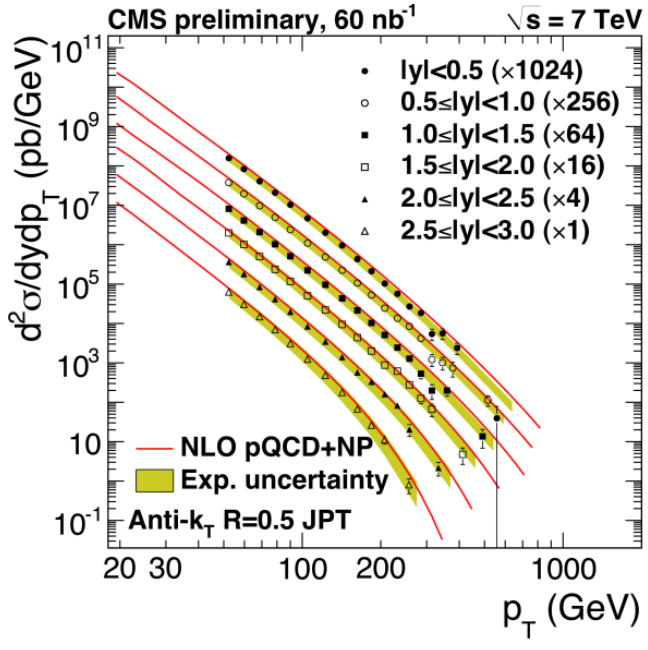
Jet physics has started: inclusive jet cross sections

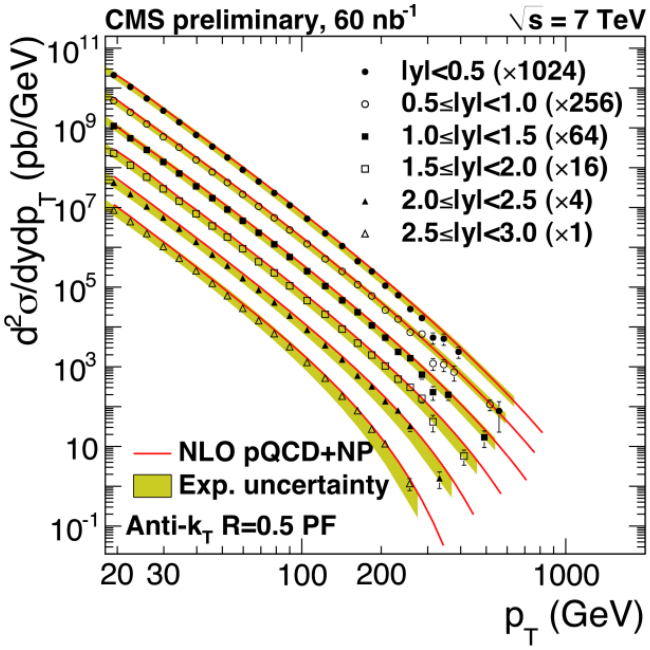
- L=60nb-1, measure cross section in various rapidity bins for Pt=18 … O(500) GeV, using three jet types
  - Calo, JPT, particle flow

CMS-PAS-QCD-2010-011

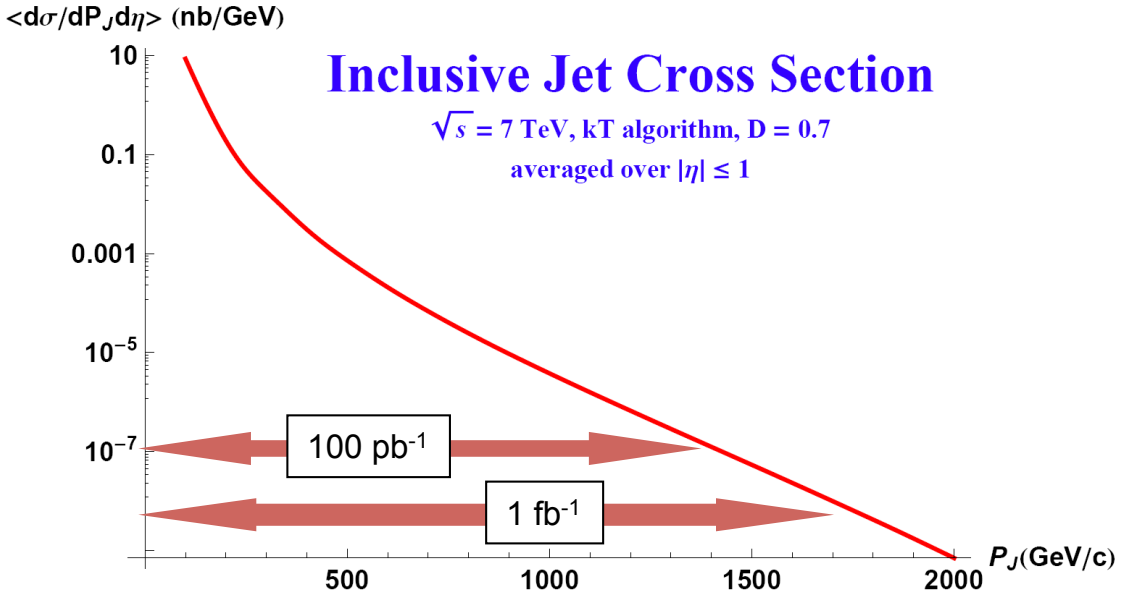
- Good agreement between methods, and with NLO QCD







Jet Physics has started



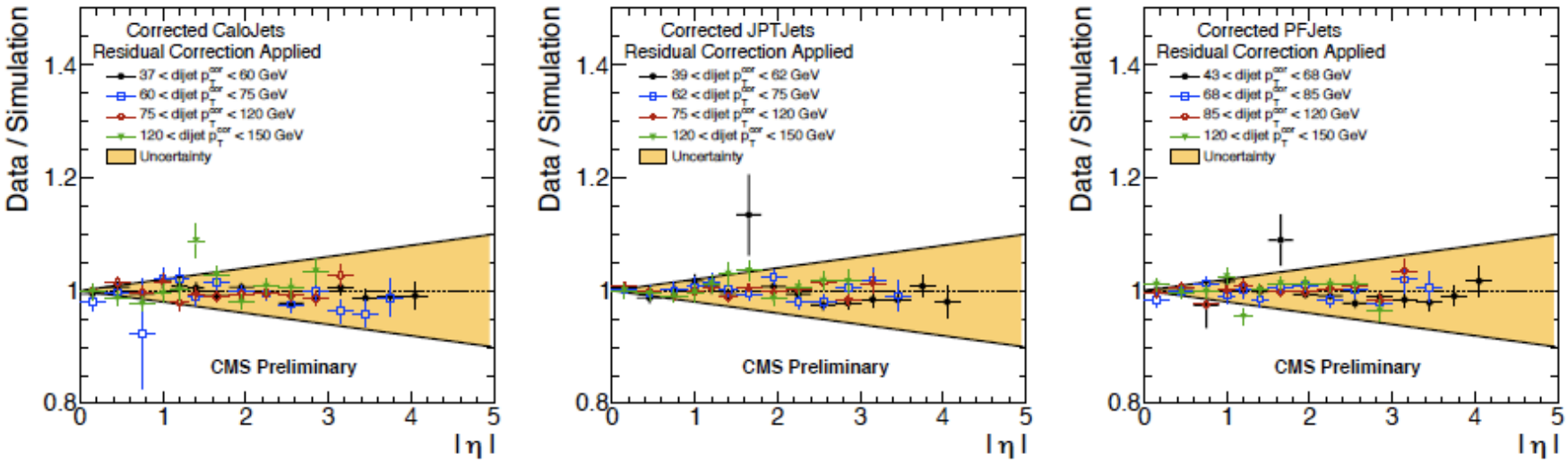
NLO QCD jet spectrum – no detector effects included

Thanks to Steve Ellis for making this

- Expect to reach jets with E_T's of around 1.4 TeV after the first 100 pb^{-1}
- Also, jets with E_T's of around 1.7 TeV after the first fb^{-1}
- Reminder: as a rule of thumb, the sensitivity to a contact interaction Λ is roughly 4x the E_T of the most energetic jet.

Jet corrections

- Relative corrections (jet equalization) from di-jet balancing



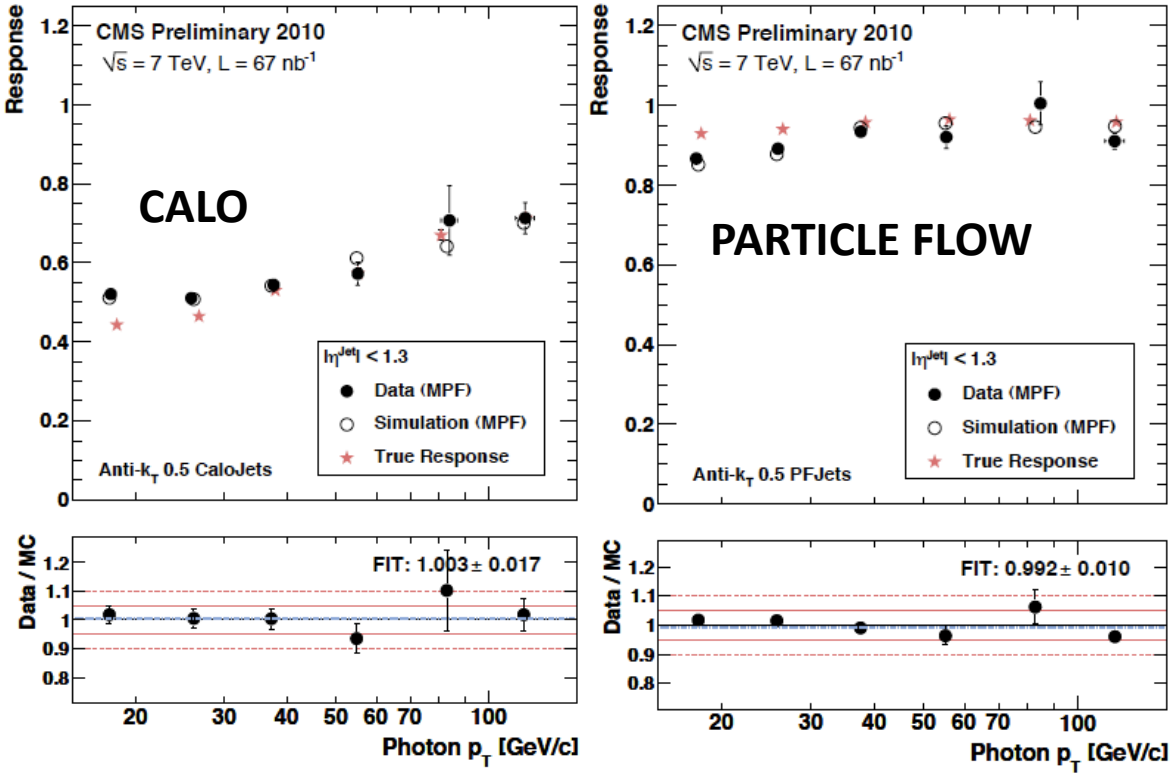
CMS-PAS-JME-2010-003

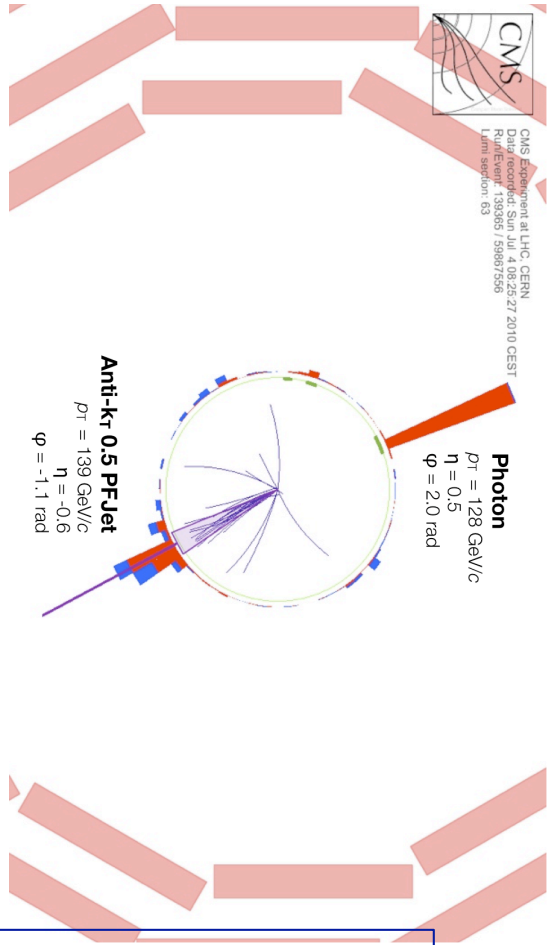
CMS: For relative corrections take 2%|eta| as uncertainty

Jet corrections

- Absolute calibration from γ+jet events

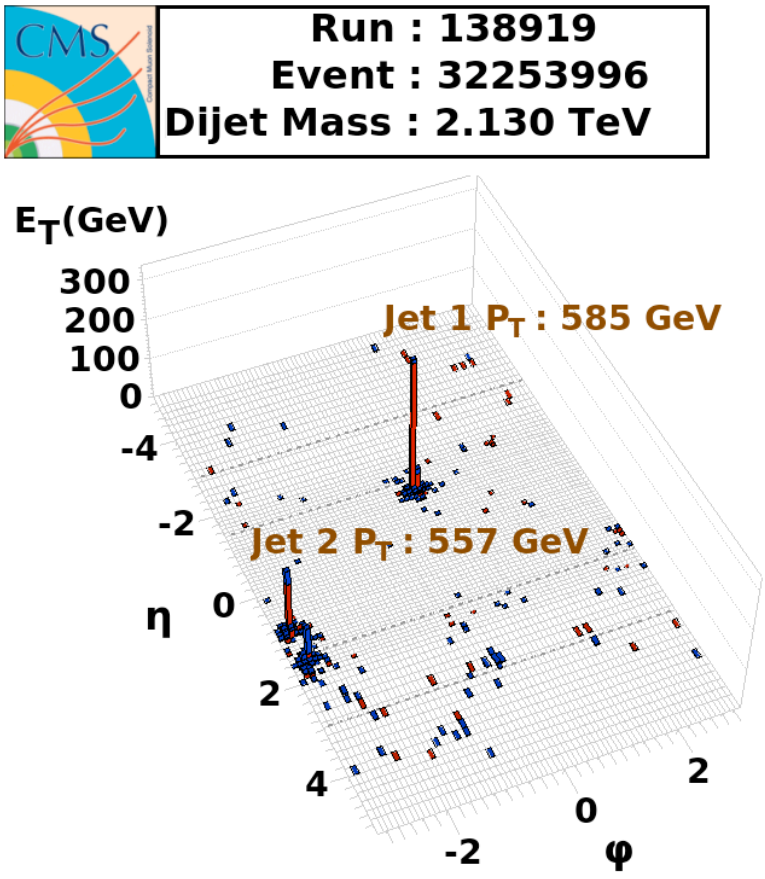
CMS-PAS-JME-2010-003

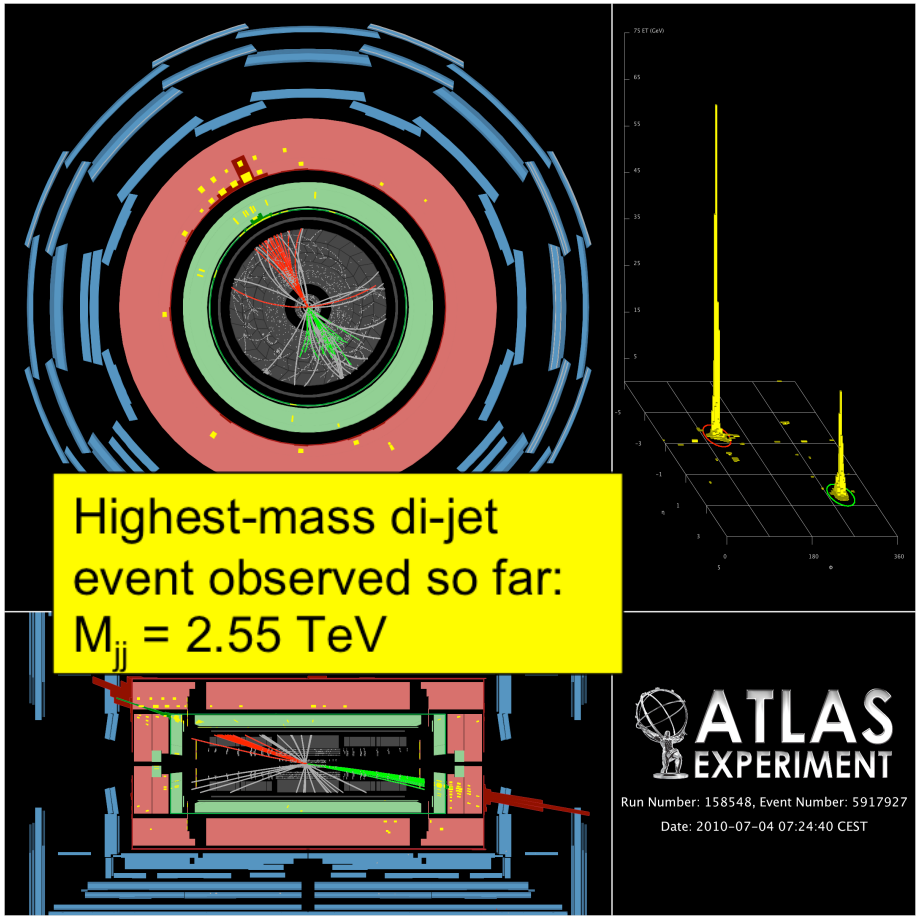




CMS: For absolute correction take 10% for CALO and 5% for PF as uncertainty
ATLAS: 7% uncertainty for CALO

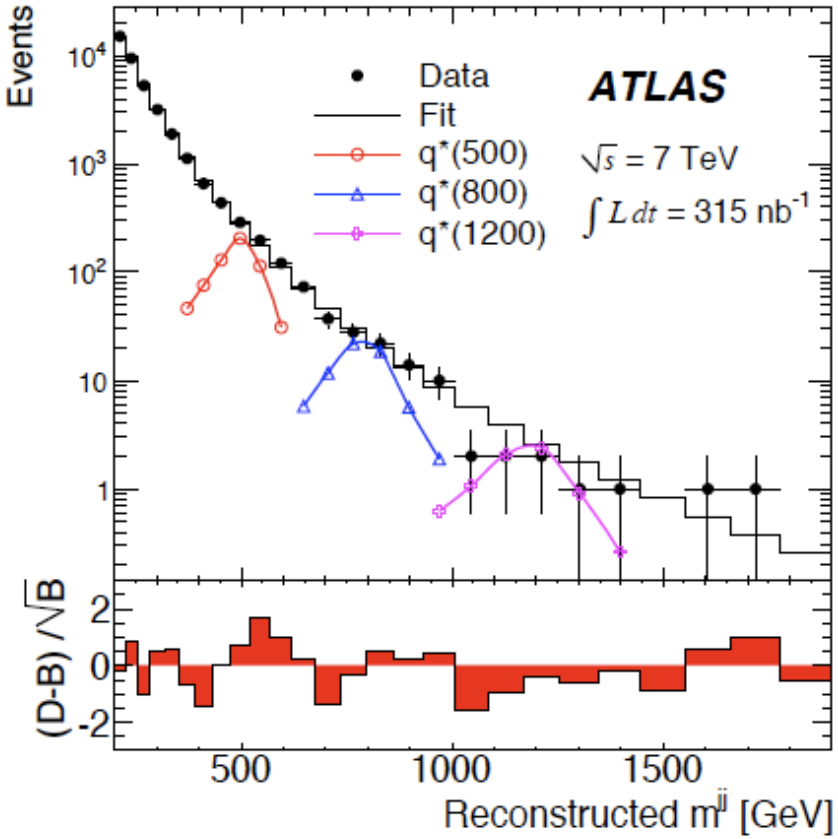
Di-jet mass and search for resonances



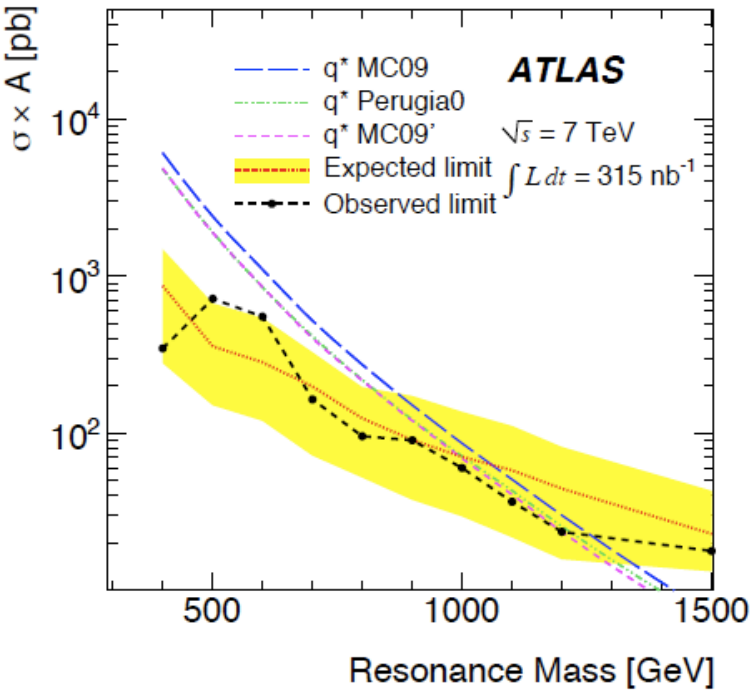


Search for excited quarks (ATLAS)

- Published just after ICHEP (arXiv:1008.2461)



$0.40 < m_{q^*} < 1.26$ TeV excluded

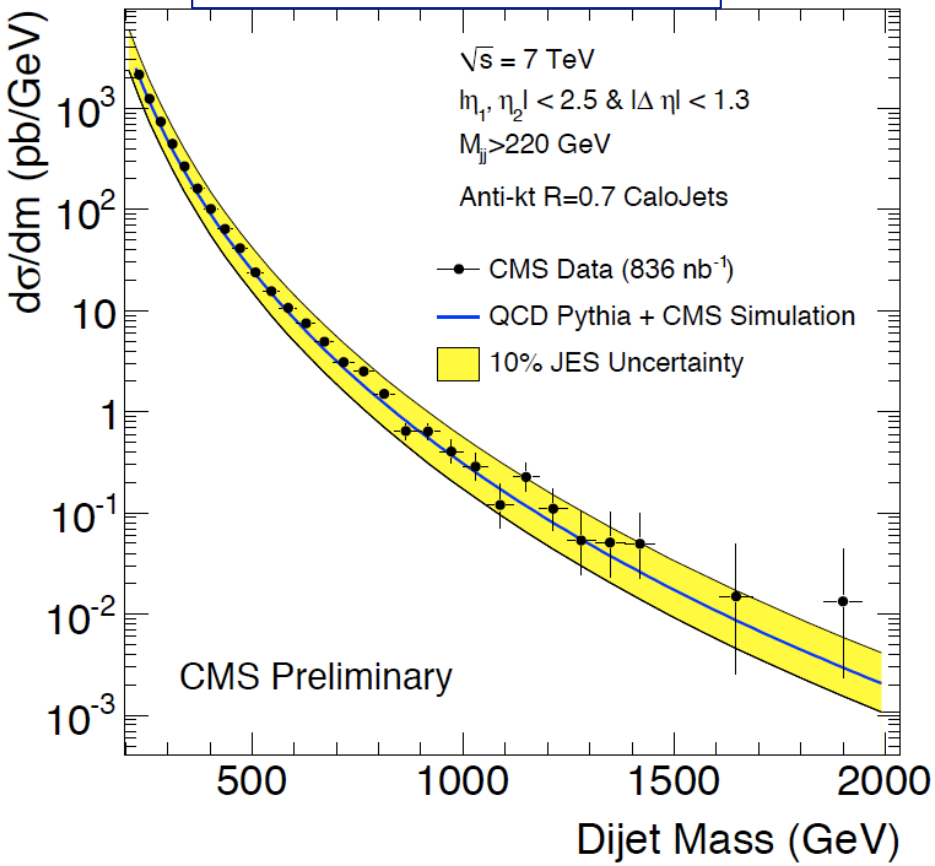


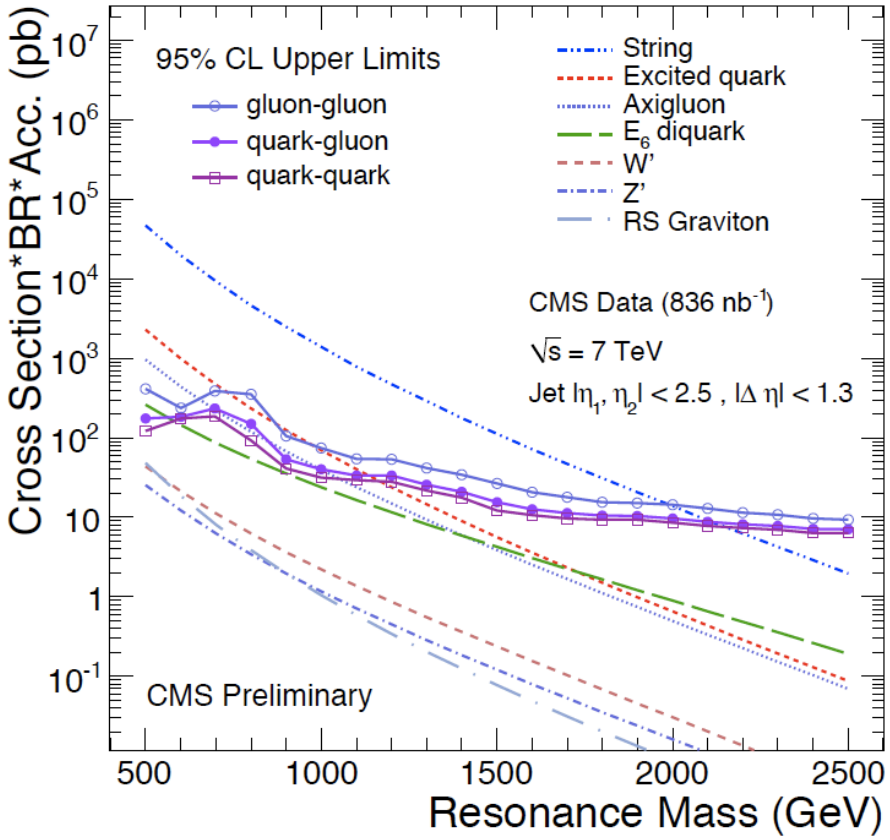
Limit from Tevatron is m_q* > 0.87 TeV,

Search for di-jet resonances (CMS)

- Recent update with 830 nb-1

CMS-PAS-EXO-2010-010

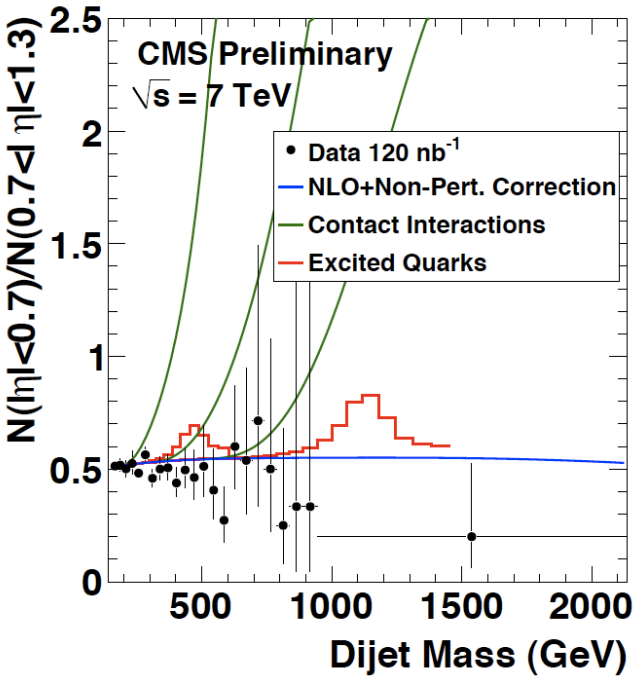


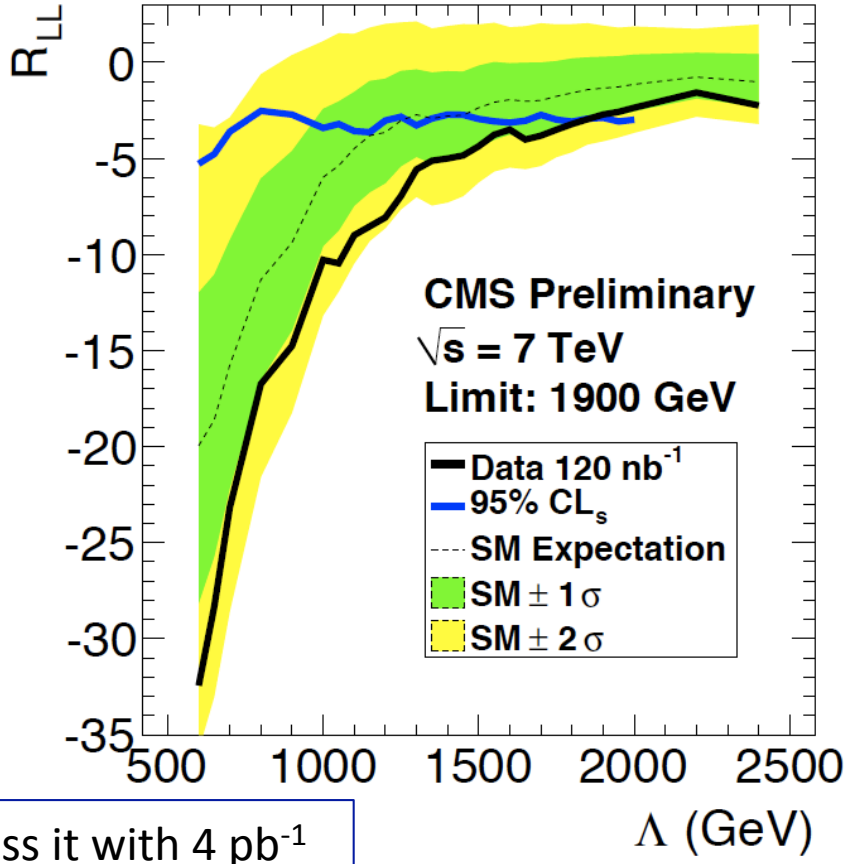


Limit on contact interactions

- Di-jet centrality ratio (jets at $|\eta|<0.7$ vs $0.7<|\eta|<1.3$)

CMS-PAS-EXO-2010-002



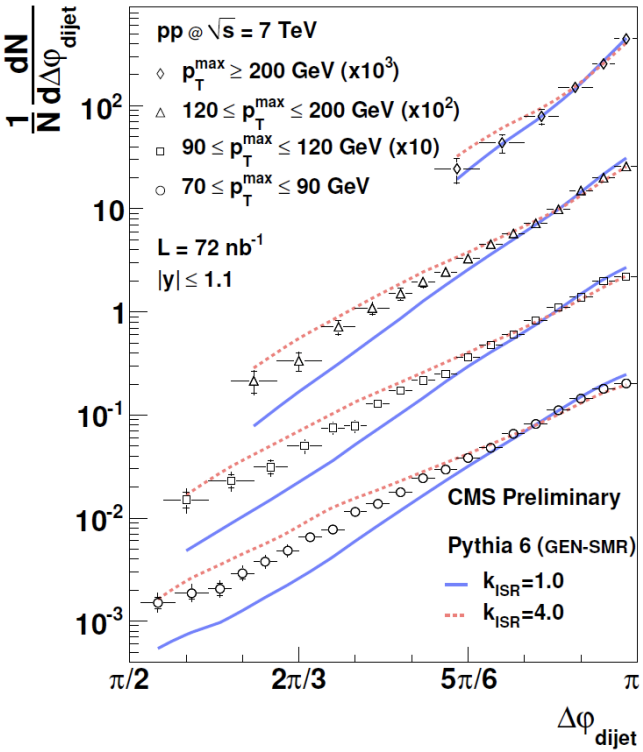


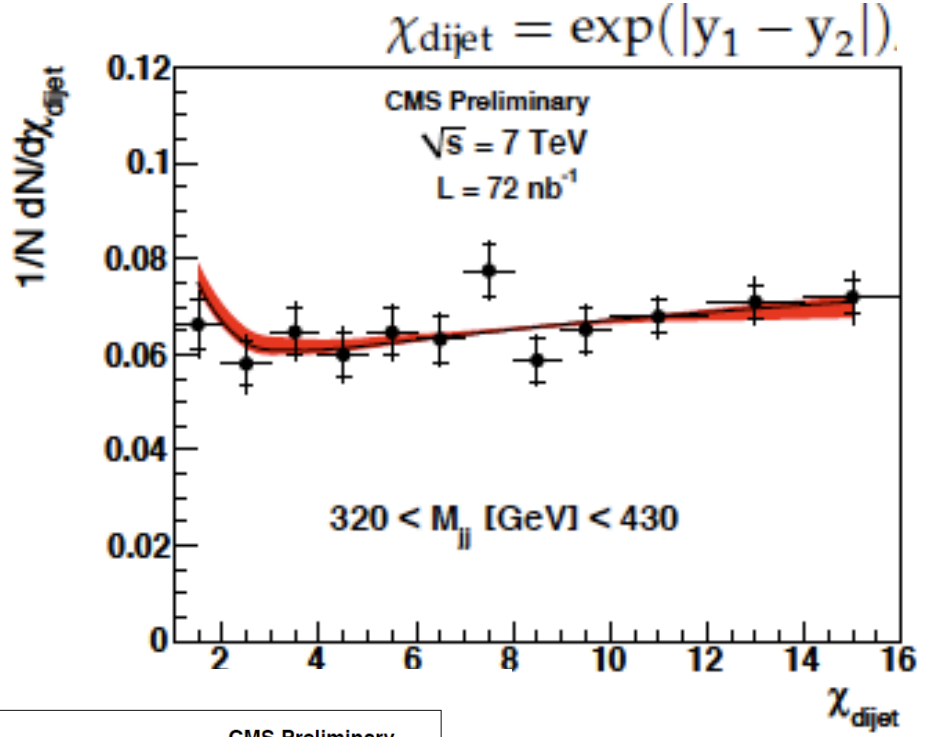
Limit from Tevatron is $\Lambda > 2.8$ TeV, we will surpass it with 4 pb^{-1}

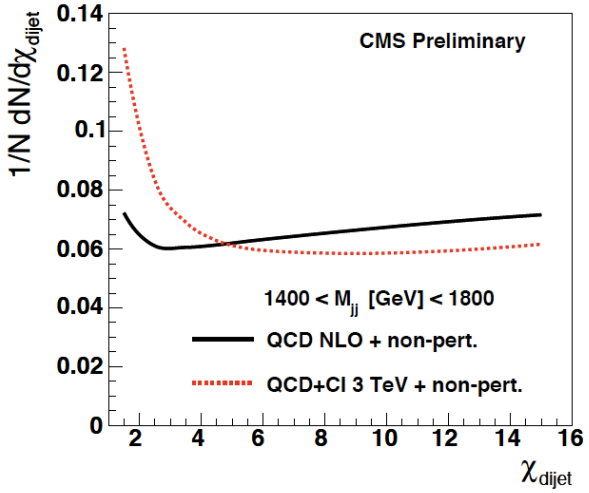
Di-jet angular distributions

CMS-PAS-QCD-2010-015

- Measure azimuthal difference between two leading jets.
- Testing ground for pQCD
- Sensitive to new physics







Sensitive at contact interactions with $\Lambda \sim 3$ TeV with 2 pb-1

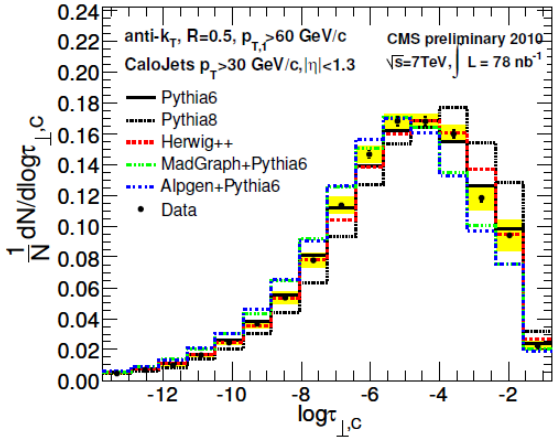
Event shape studies

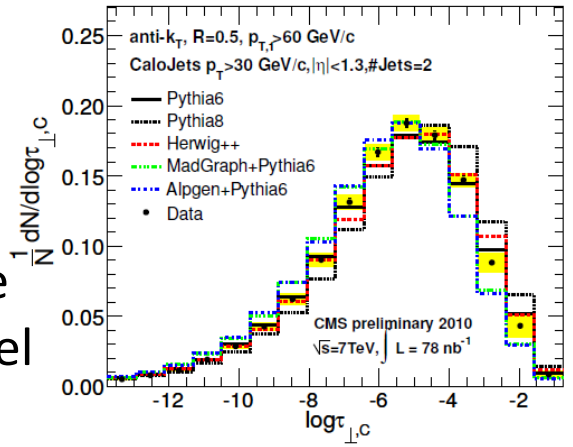
CMS-PAS-QCD-2010-013

- 7TeV data, 80nb-1
- Event shapes not affected by JES uncertainty (only indirectly due to jet counting)
- Model comparisons
  - Best agreement with PYTHIA6 and HERWIG++
  - ALPGEN/MADGRAPH more peaked at delta-phi=180, smaller R3/2 -> shift of event shapes to smaller values
  - Difference P6-P8 cannot be accounted by shower model

Central transverse thrust

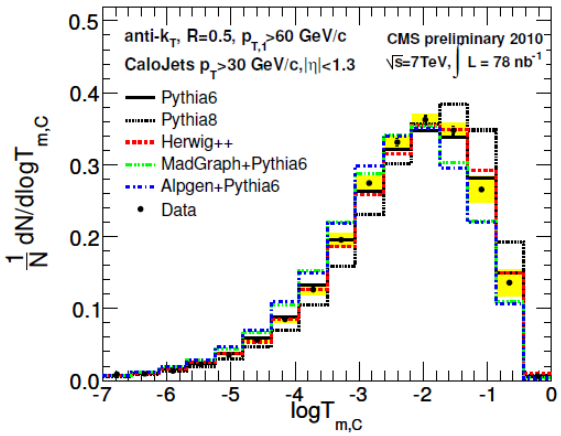
$$T_{\perp,\mathcal{C}} \equiv \max_{\vec{n}_T} \frac{\sum_{i\in\mathcal{C}} |\vec{p}_{\perp,i} \cdot \vec{n}_T|}{\sum_{i\in\mathcal{C}} p_{\perp,i}}$$

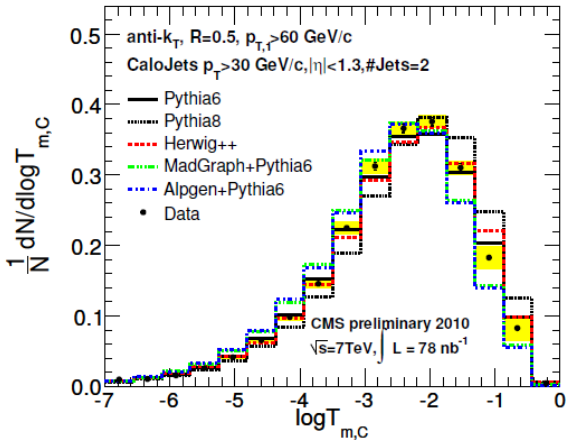




Central thrust minor

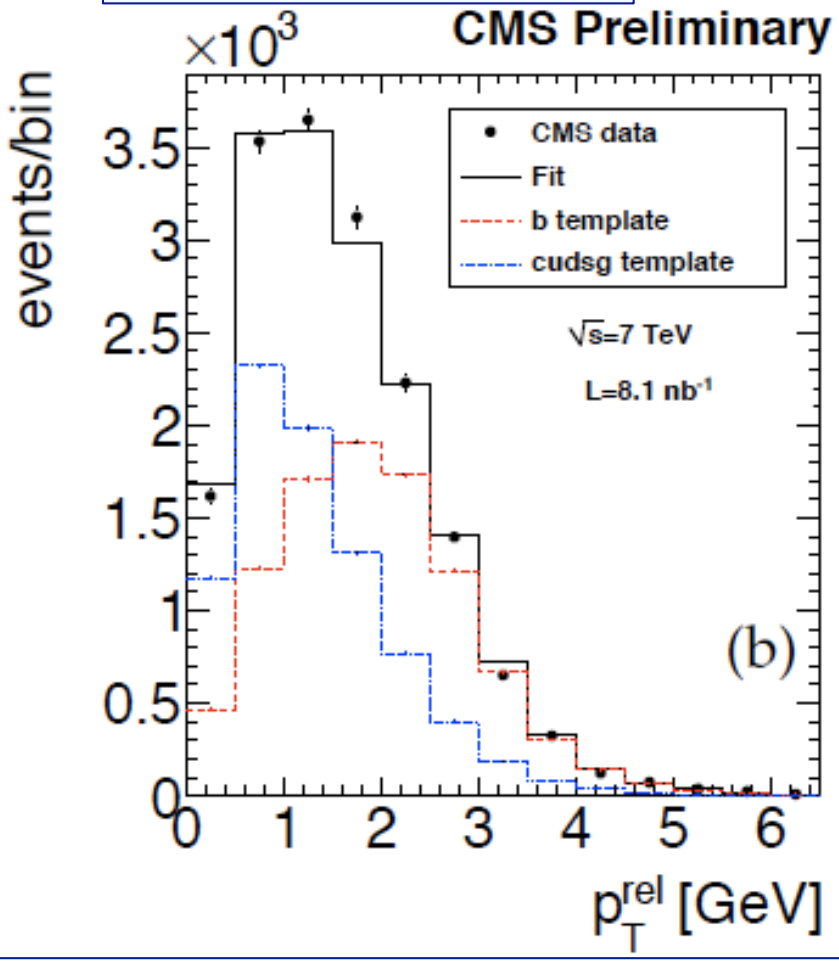
$$T_{m,\mathcal{C}} \equiv \frac{\sum_{i\in\mathcal{C}} |\vec{p}_{\perp,i} \times \vec{n}_{\mathrm{T},\mathcal{C}}|}{\sum_{i\in\mathcal{C}} p_{\perp,i}}$$

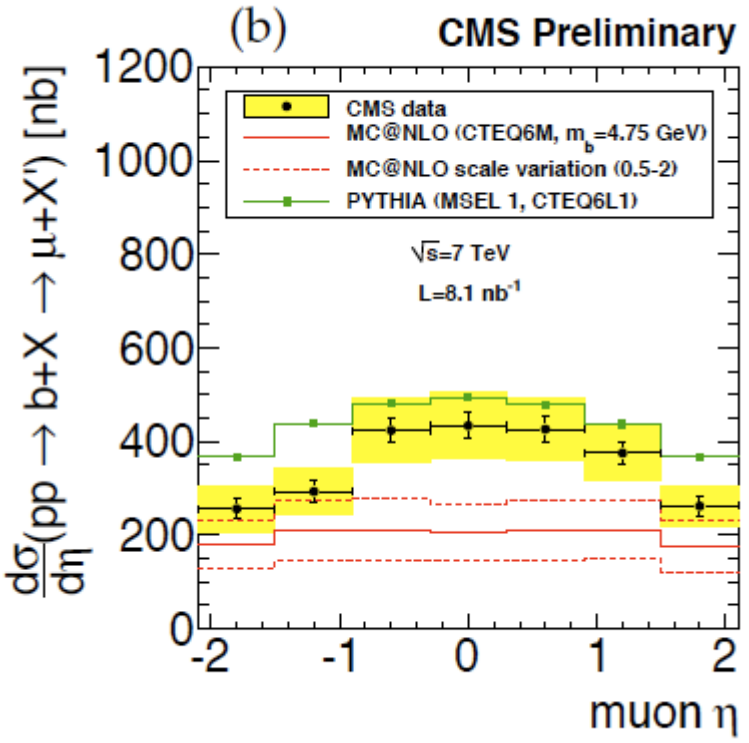




First b cross section measurements at 7 TeV : lepton tagging

CMS-PAS-BPH-2010-007

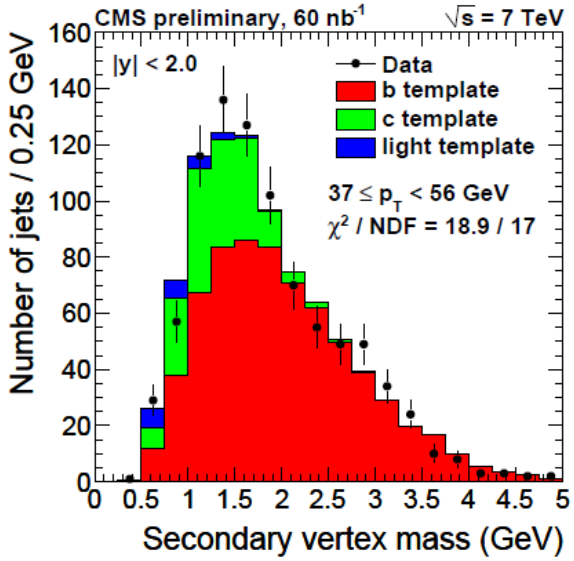


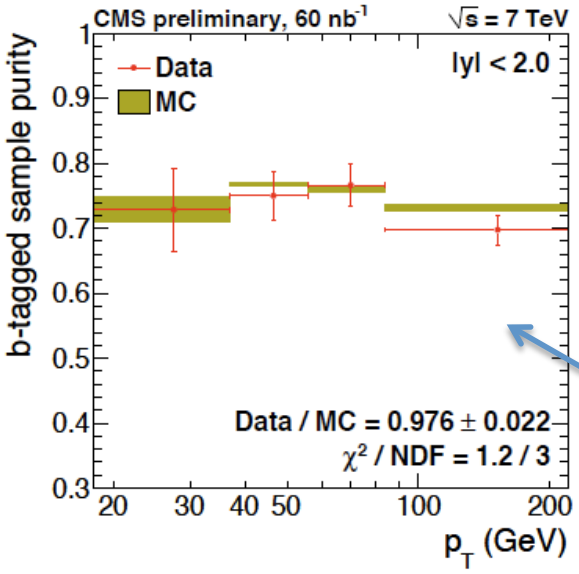


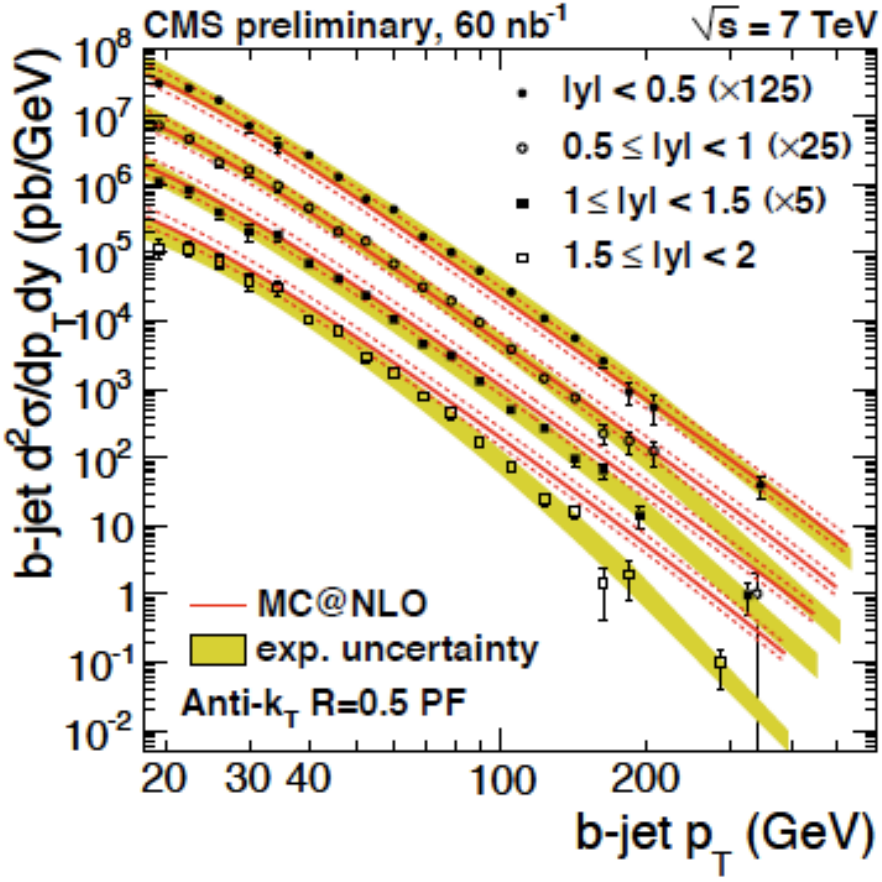
$$\sigma(pp \to b + X \to \mu + X', p_{\perp}^{\mu} > 6\,\mathrm{GeV}, |\eta^{\mu}| < 2.1) = (1.48 \pm 0.04_{\mathrm{stat}} \pm 0.22_{\mathrm{syst}} \pm 0.16_{\mathrm{lumi}})\,\mu\mathrm{b}.$$

First b cross section measurements at 7 TeV : lifetime tagging

CMS-PAS-BPH-2010-009



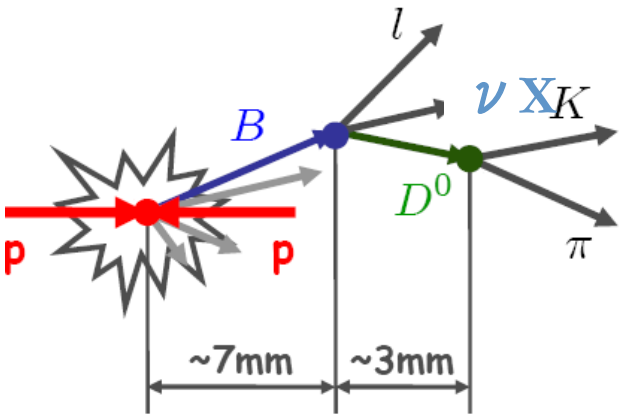


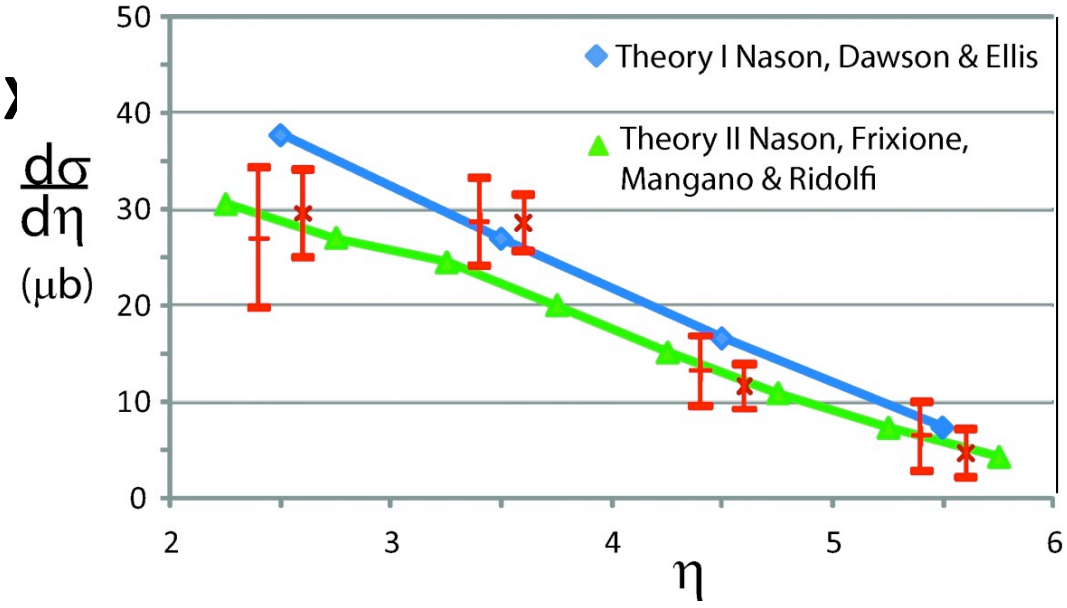


Efficiency and purity determined from data

b cross section measurements at 7 TeV

LHCb, using b → D^0 μ ν) events

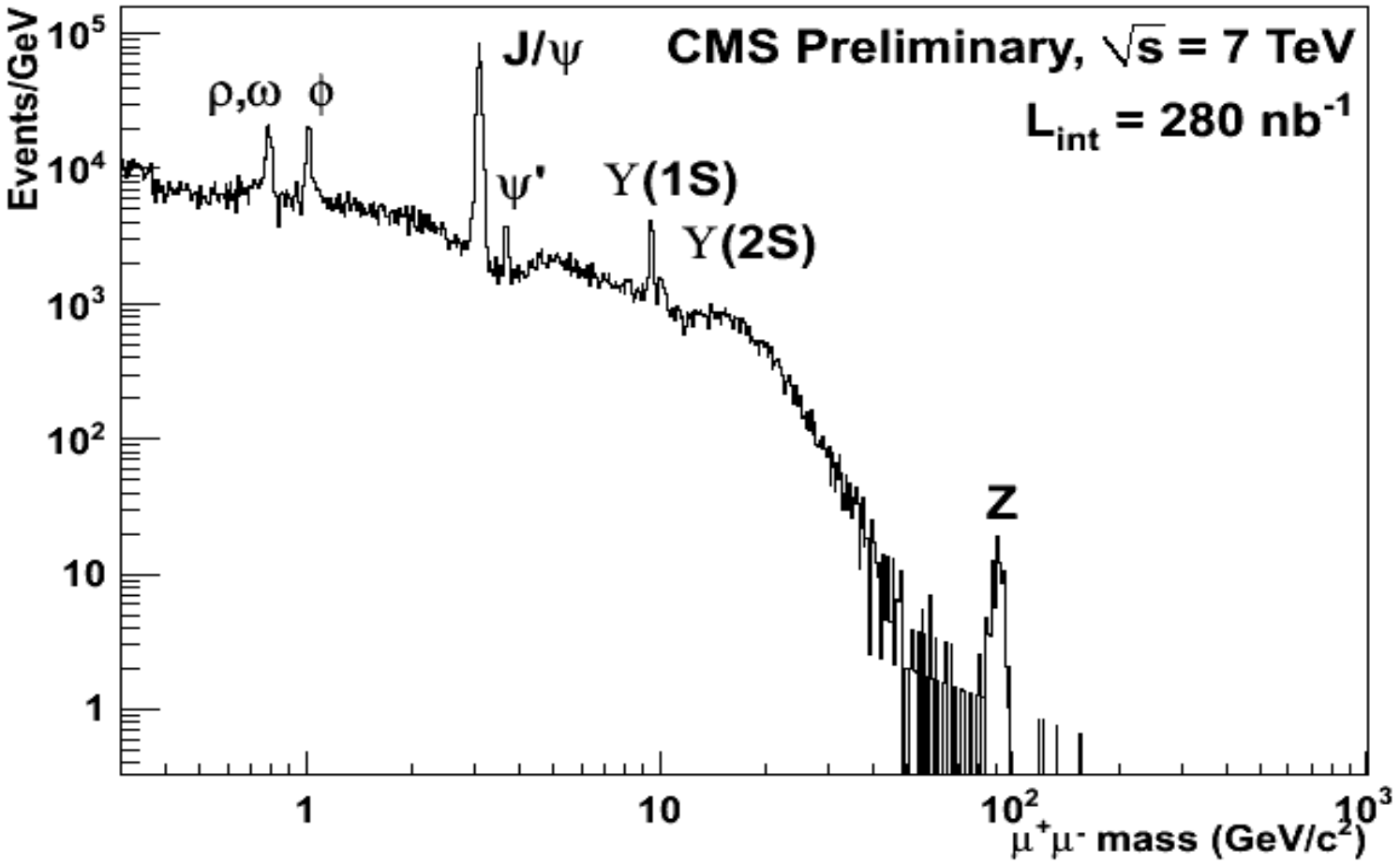




η	LHCb
2-6	74.9±5.3±12.8 μb
all	282±20±48 μb

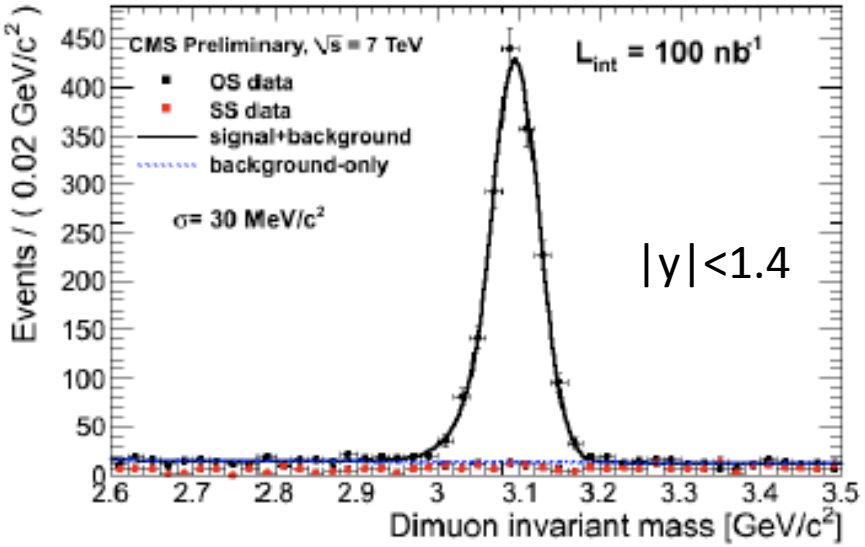
CMS: **238 *μb*** *from the MC@NLO*
Global scale factor for
30 < pT < 150 GeV and |y| < 2.0
0.99 ± 0.02(stat) ± 0.21(syst)

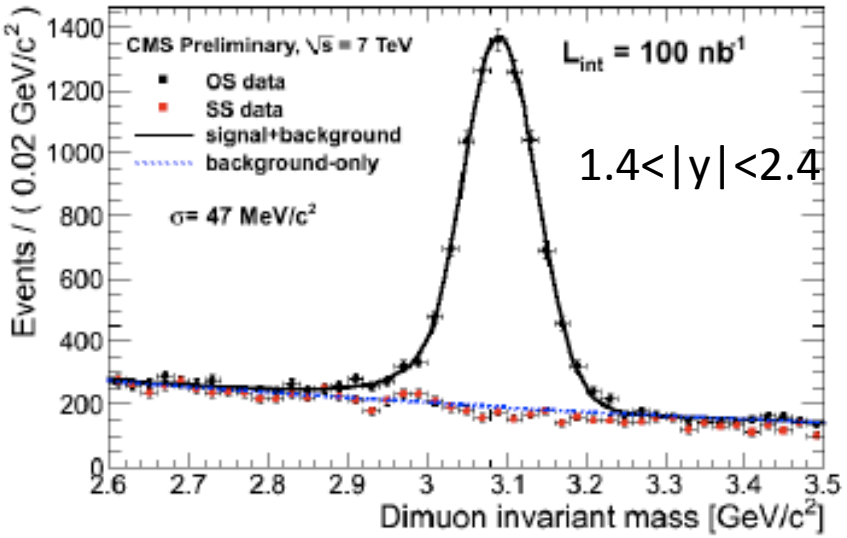
Dilepton resonances at 7 TeV



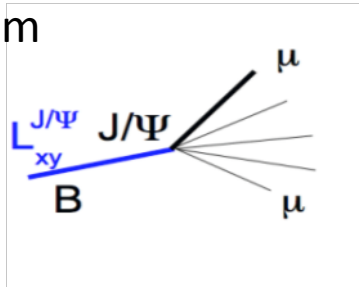
$J/\psi \rightarrow \mu^+\mu^-$

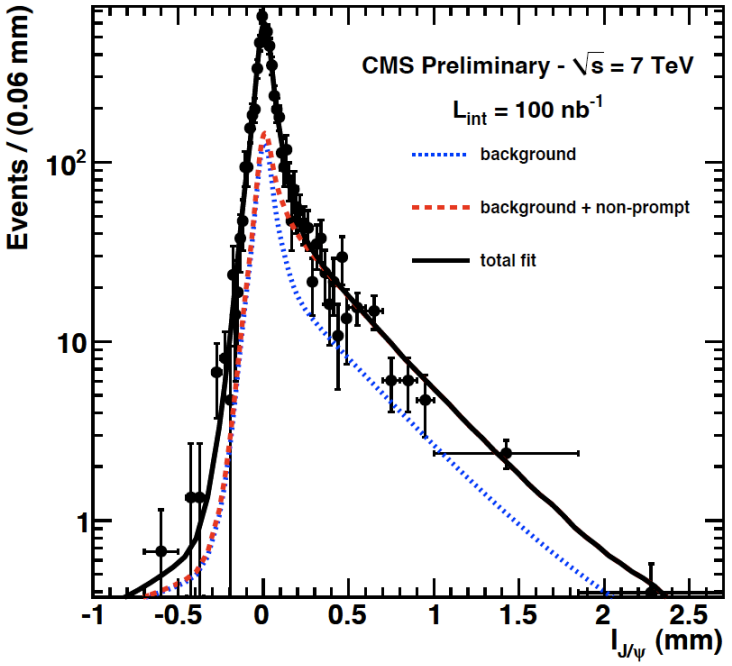
CMS-PAS-BPH-2010-002





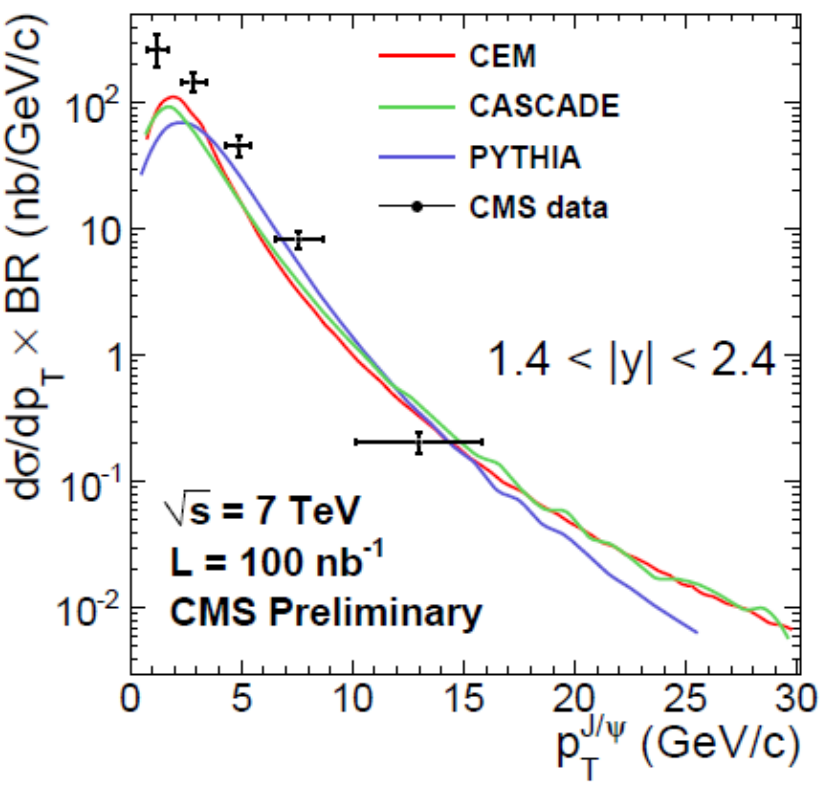
Separate prompt and B – decay contributions from decay length

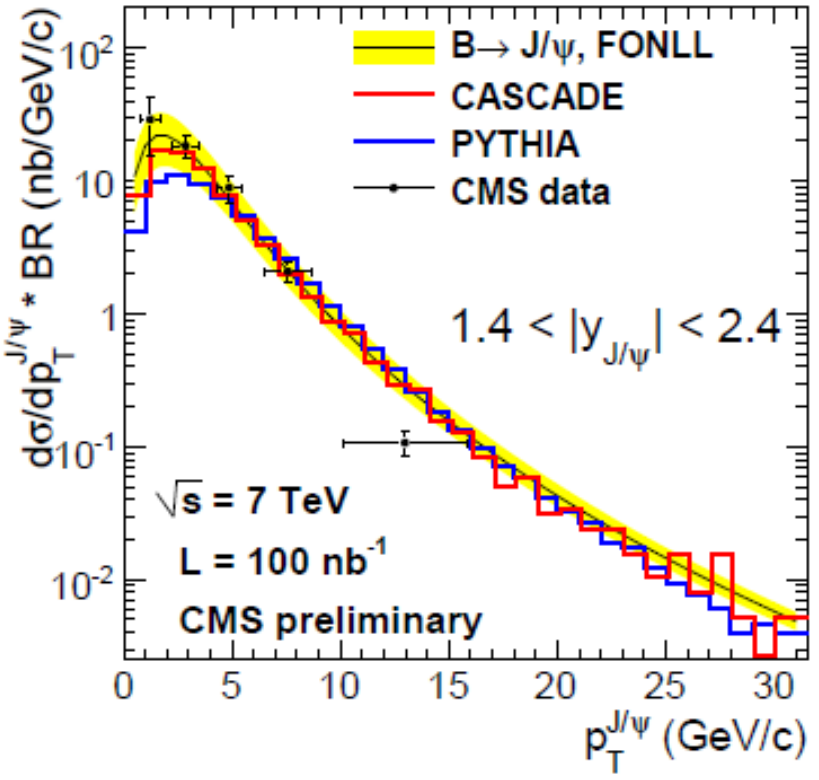




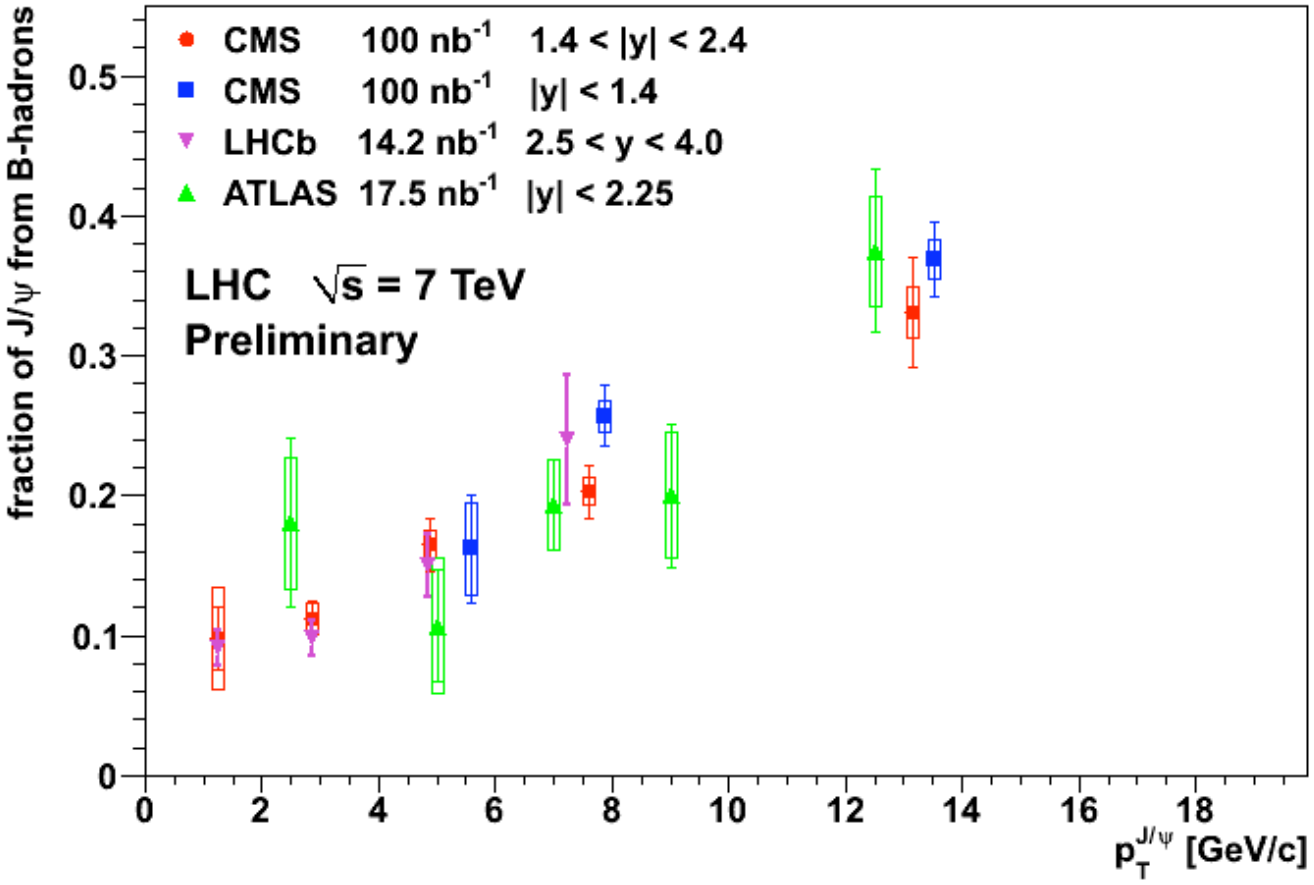
Separate prompt J/ψ and measure cross section

CMS-PAS-BPH-2010-002

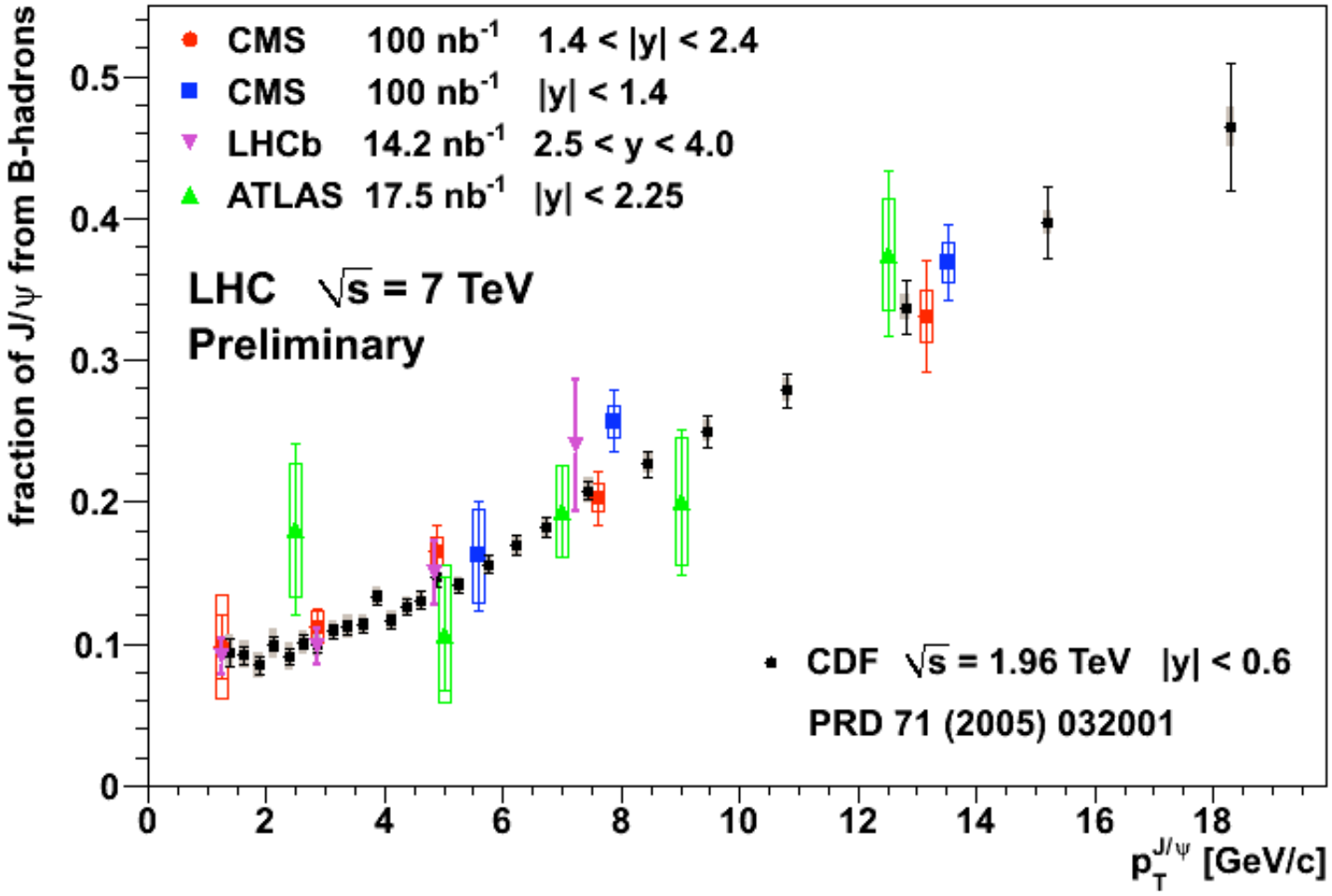




Fraction of non-prompt J/ψ from LHC exp at ICHEP

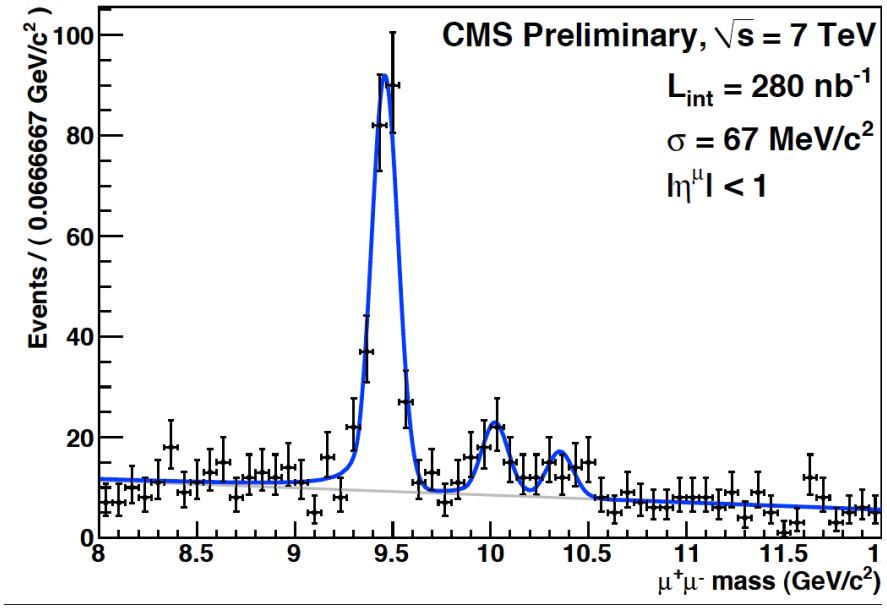


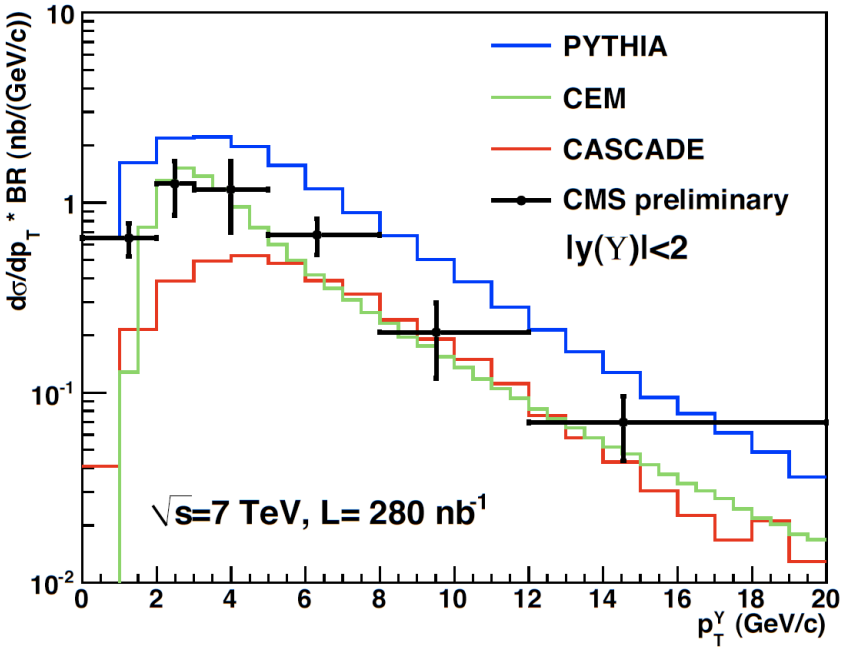
Fraction of non-prompt J/ψ
7 TeV vs 1.96 TeV



First Upsilon measurements at 7 TeV

CMS-PAS-BPH-2010-003



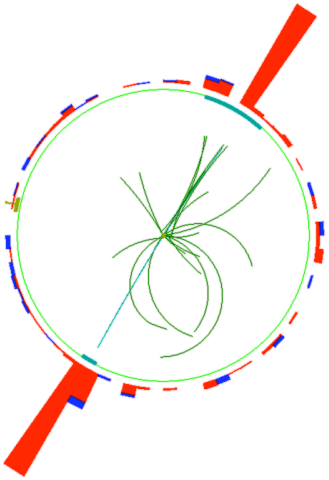


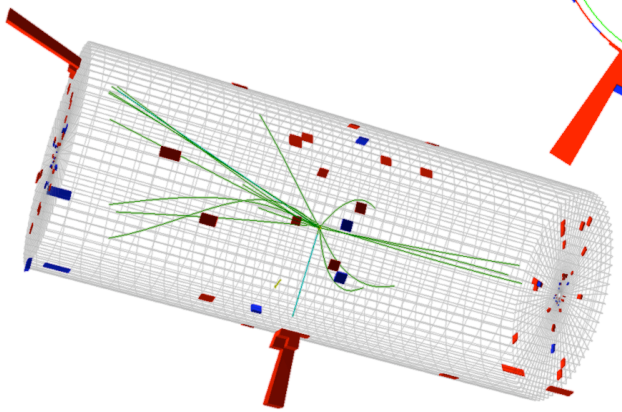
$$\sigma(pp \to \Upsilon(1S)X) \cdot \mathcal{B}(\Upsilon(1S) \to \mu^+\mu^-) = (8.3 \pm (0.5)_{\text{stat.}} \pm (0.9)_{\text{lumi.}} \pm (1.0)_{\text{syst.}})\ \text{nb},$$

$$[\sigma(pp \to \Upsilon(2S)X) + \sigma(pp \to \Upsilon(3S)X)]/\sigma(pp \to \Upsilon(1S)X) = 0.44 \pm 0.06 \pm 0.07$$

CMS Experiment at LHC, CERN
Run 133877, Event 28405693
Lumi section: 387
Sat Apr 24 2010, 14:00:54 CEST

Electrons p_T = 34.0, 31.9 GeV/c
Inv. mass = 91.2 GeV/c^2



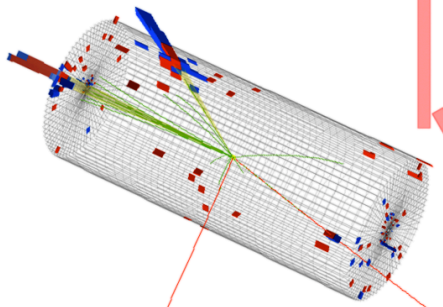


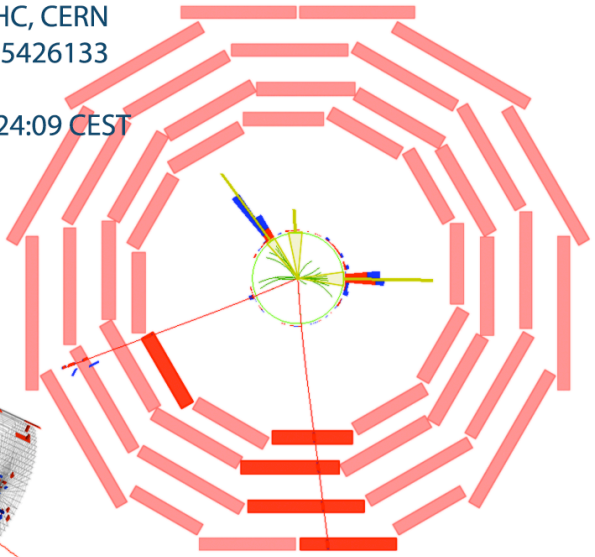
$Z \rightarrow ee$

CMS Experiment at LHC, CERN
Run 135149, Event 125426133
Lumi section: 1345
Sun May 09 2010, 05:24:09 CEST

Muon p_T= 67.3, 50.6 GeV/c
Inv. mass = 93.2 GeV/c^2

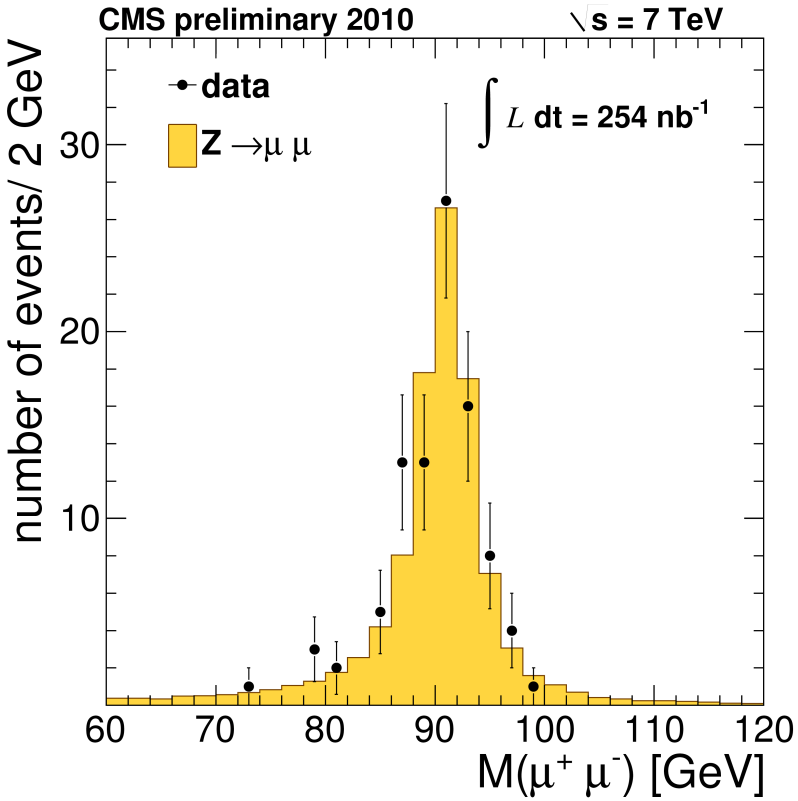
$Z \rightarrow \mu\mu$

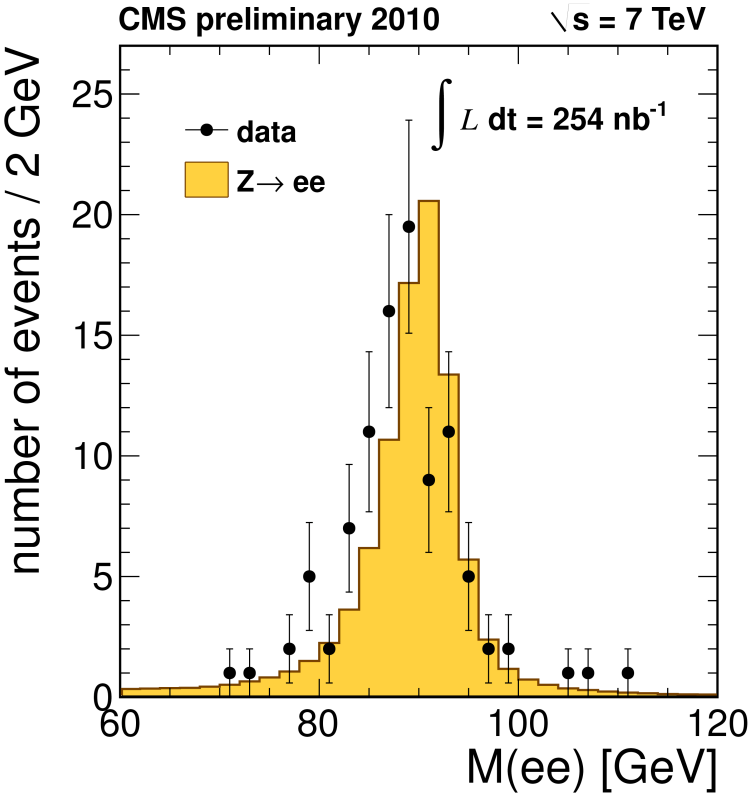




Z production at 7 TeV

CMS-PAS-EWK-2010-002



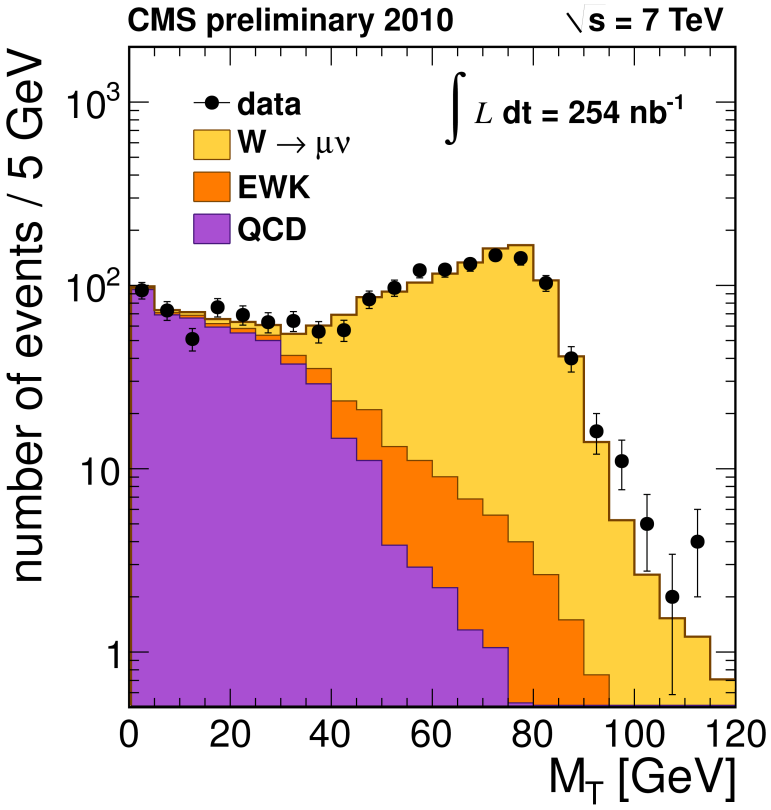


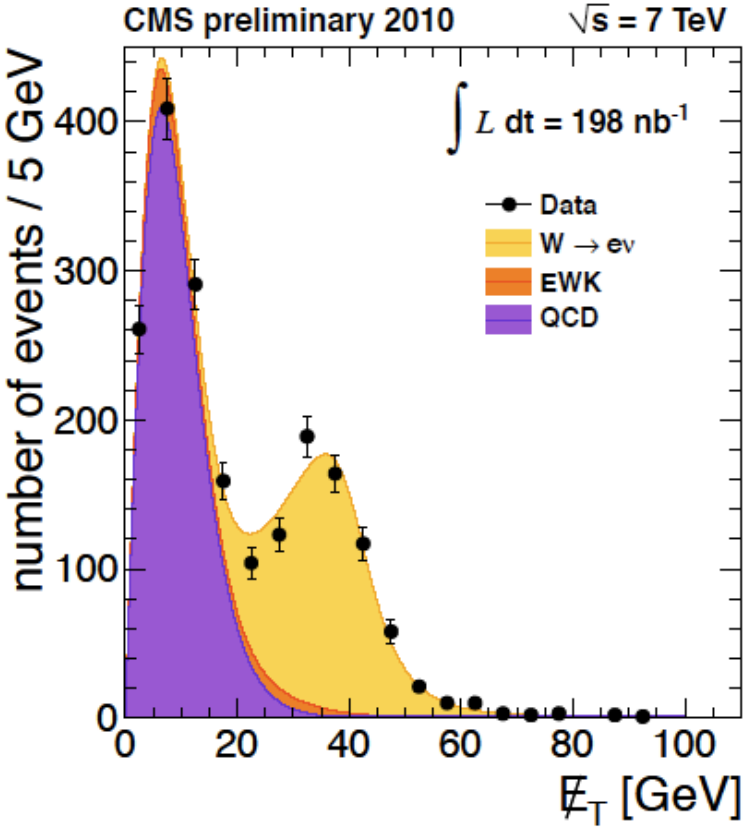
$$\sigma(\mathrm{pp} \rightarrow \mathrm{Z}(\gamma^*) + \mathrm{X} \rightarrow \ell^+\ell^- + \mathrm{X}) = 0.882^{+0.077}_{-0.073}(\mathrm{stat.})^{+0.042}_{-0.036}(\mathrm{syst.}) \pm 0.097(\mathrm{lumi.})\ \mathrm{nb}$$

ATLAS

σ (Z → ll) = 0.83 ± 0.07 (stat) ± 0.06 (syst) ± 0.09 (lumi) nb

W production at 7 TeV





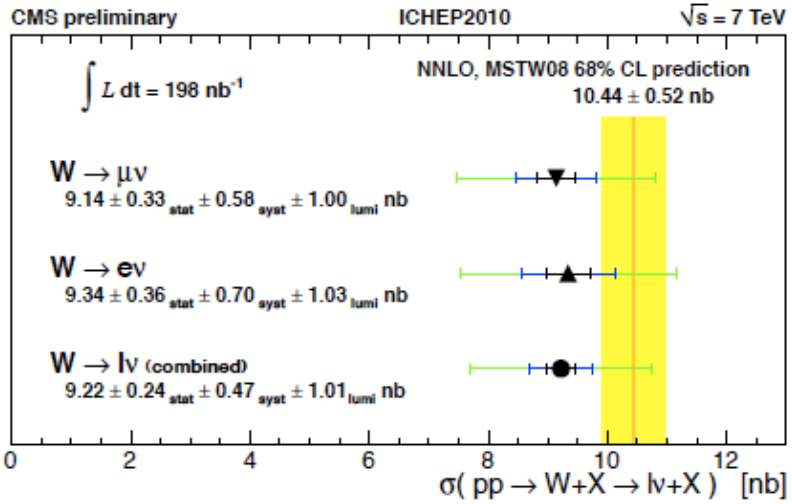
$$\sigma(\mathrm{pp} \rightarrow W + X \;\; \ell\nu + X) = 9.22 \pm 0.24(\mathrm{stat.}) \pm 0.47(\mathrm{syst.}) \pm 1.01(\mathrm{lumi.})\ \mathrm{nb},$$

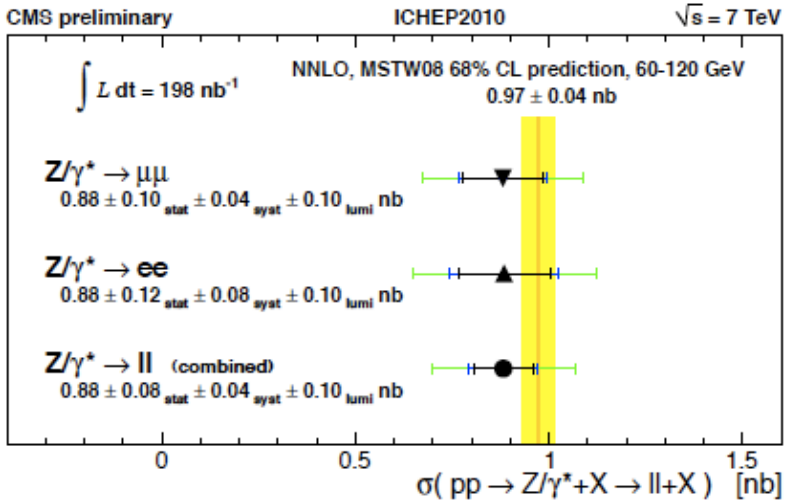
ATLAS

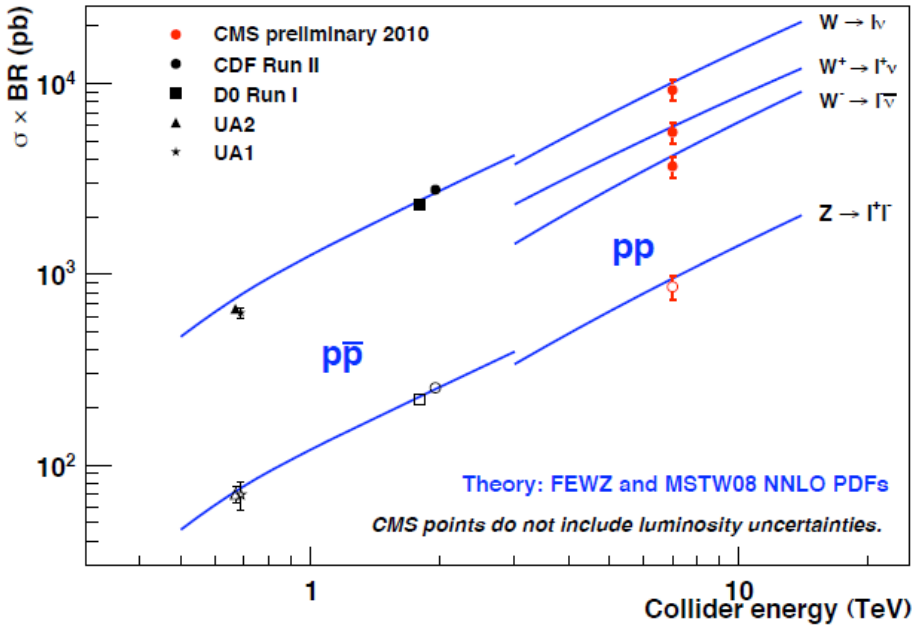
σ (W → lν) = 9.3 ± 0.9 (stat) ± 0.6 (syst) ± 1.0 (lumi) nb

CMS-PAS-EWK-2010-002

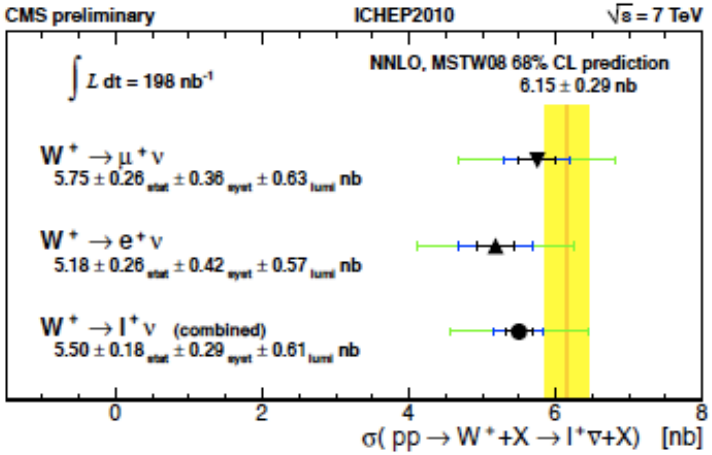
W, Z cross sections (CMS, ICHEP)

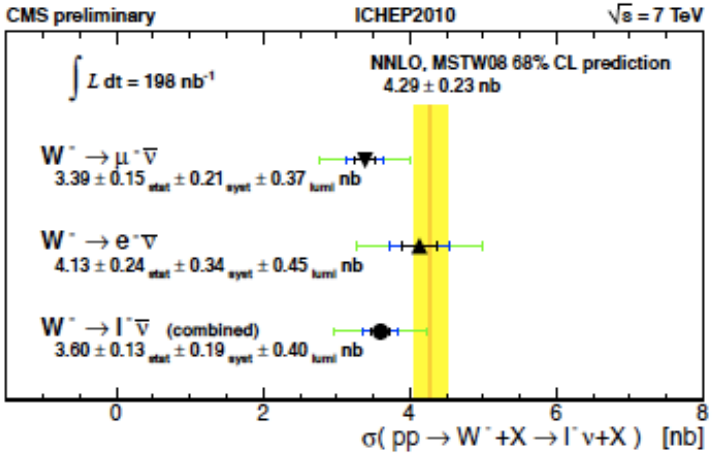


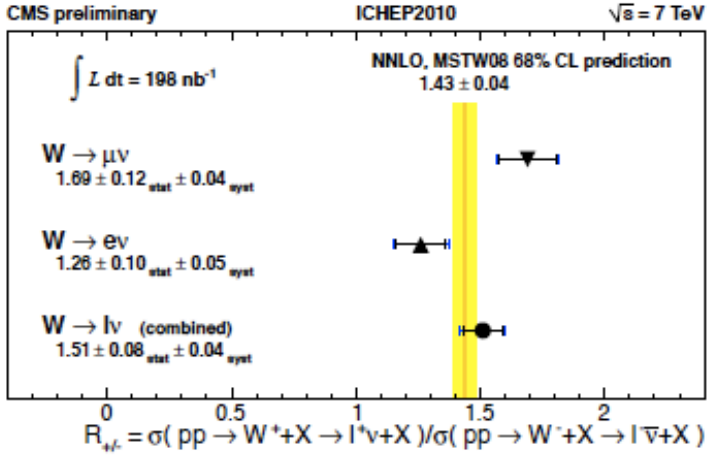




The W charge ratio (CMS, ICHEP)



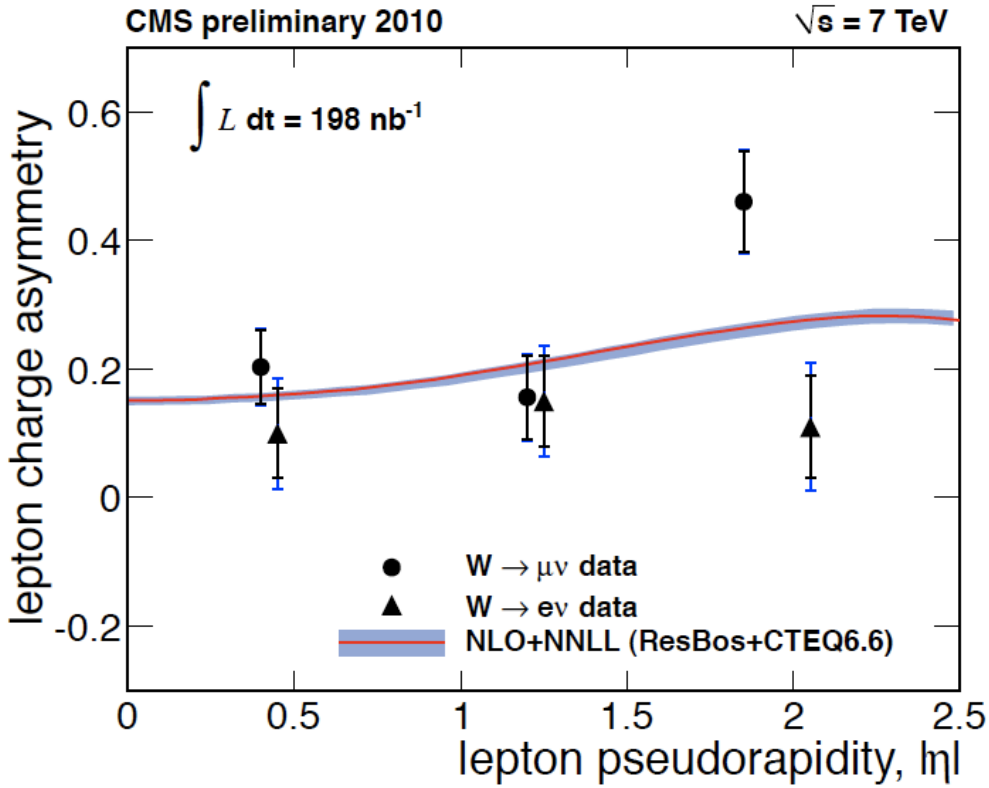




CMS-PAS-EWK-2010-002

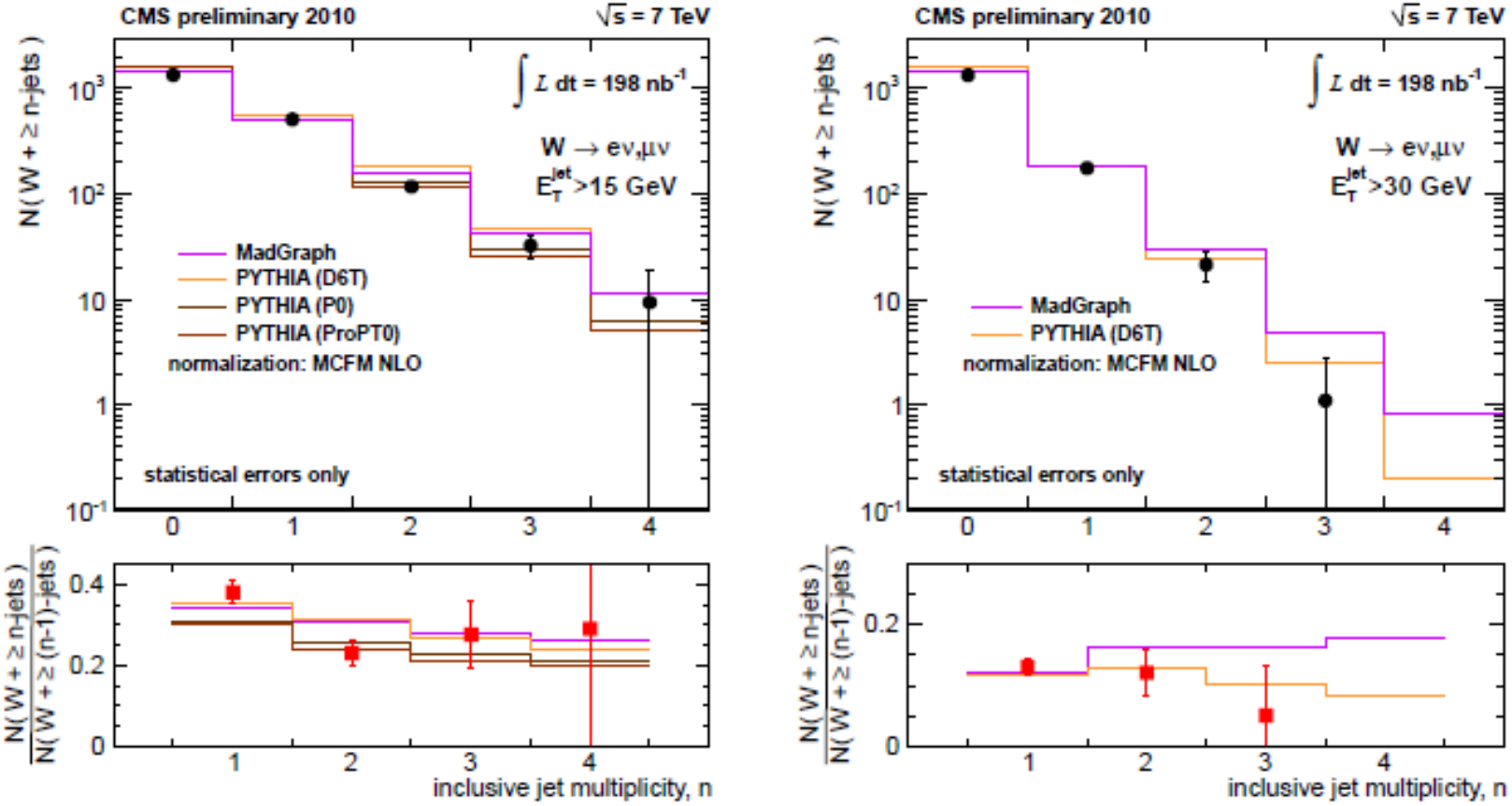
The W charge ratio

CMS-PAS-EWK-2010-002



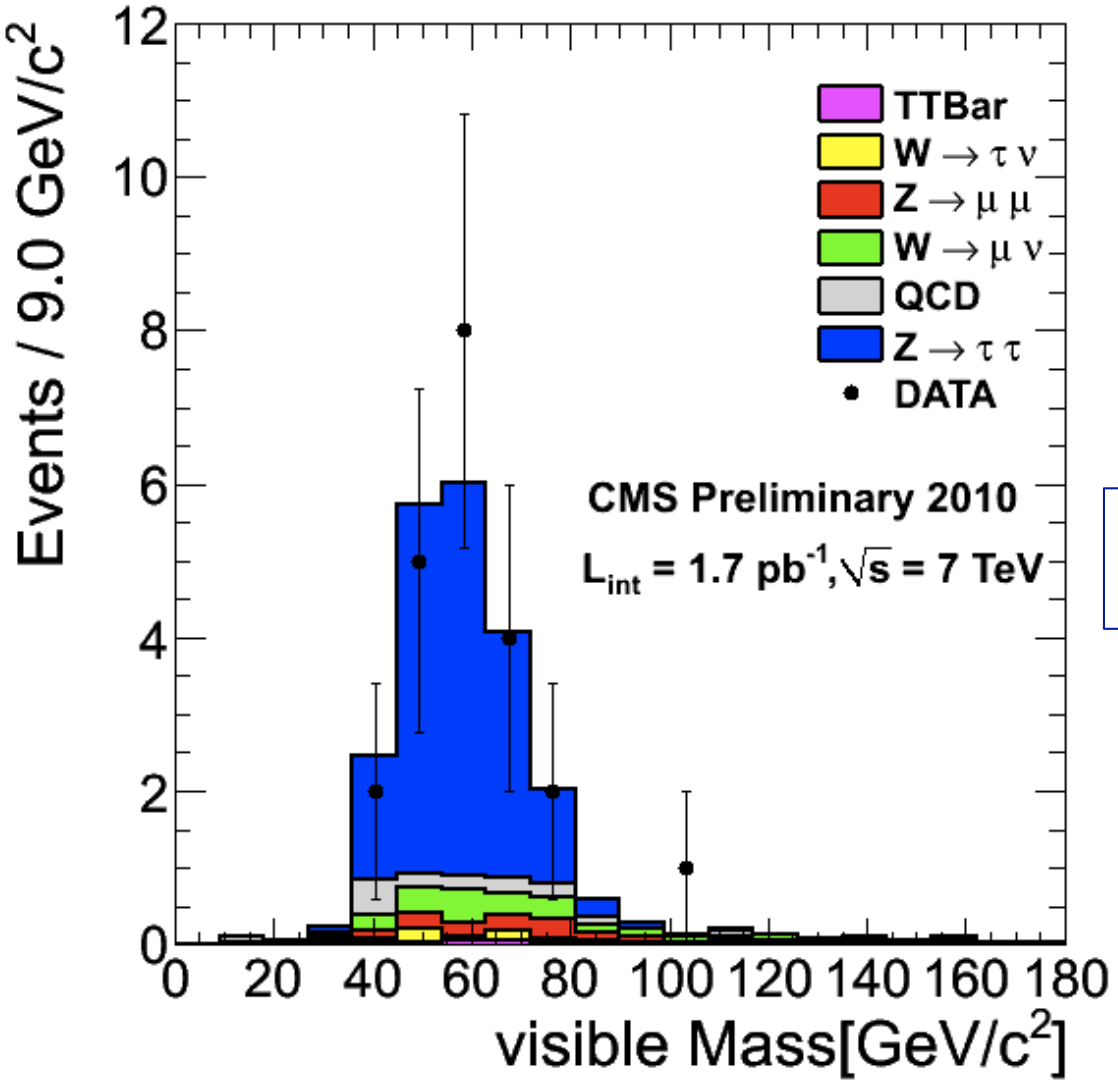
Will be a powerful tool to constraint the PDF, together with other W,Z distributions

W + jets



Agreement with simulation within stat. errors

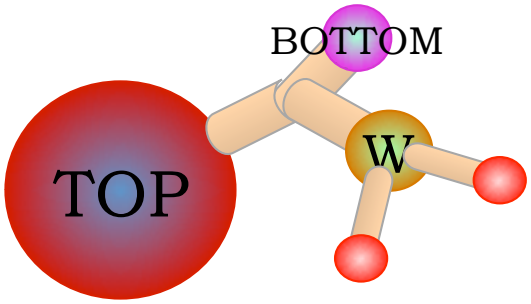
NEW: Z→ ττ from CMS



One tau hadronic decay, the other decays to muon

Same selection as described in CMS-PAS-PFT-2010-004

The birth of a top factory !



Early measurement

- Establish the ttbar cross section at 7 TeV

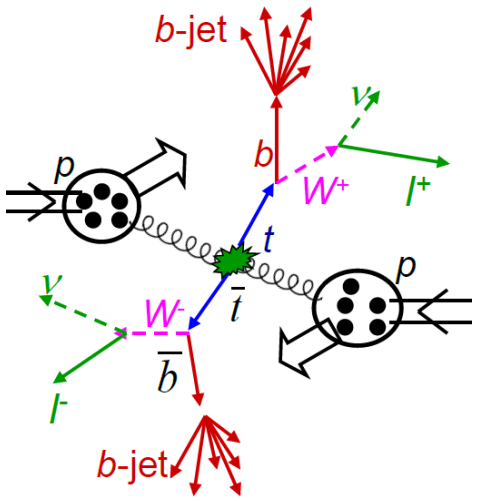
→Check the gluon PDF !

With more luminosity and understood detectors expect a rich program of top physics al LHC

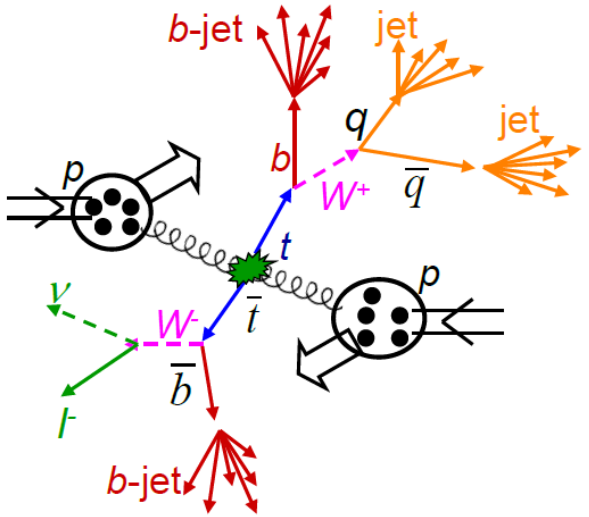
- single top production
- ttbar resonances
- top rare decays
- single top and ttbar spin measurement
- …. eventually precision mass measurement

ttbar selection

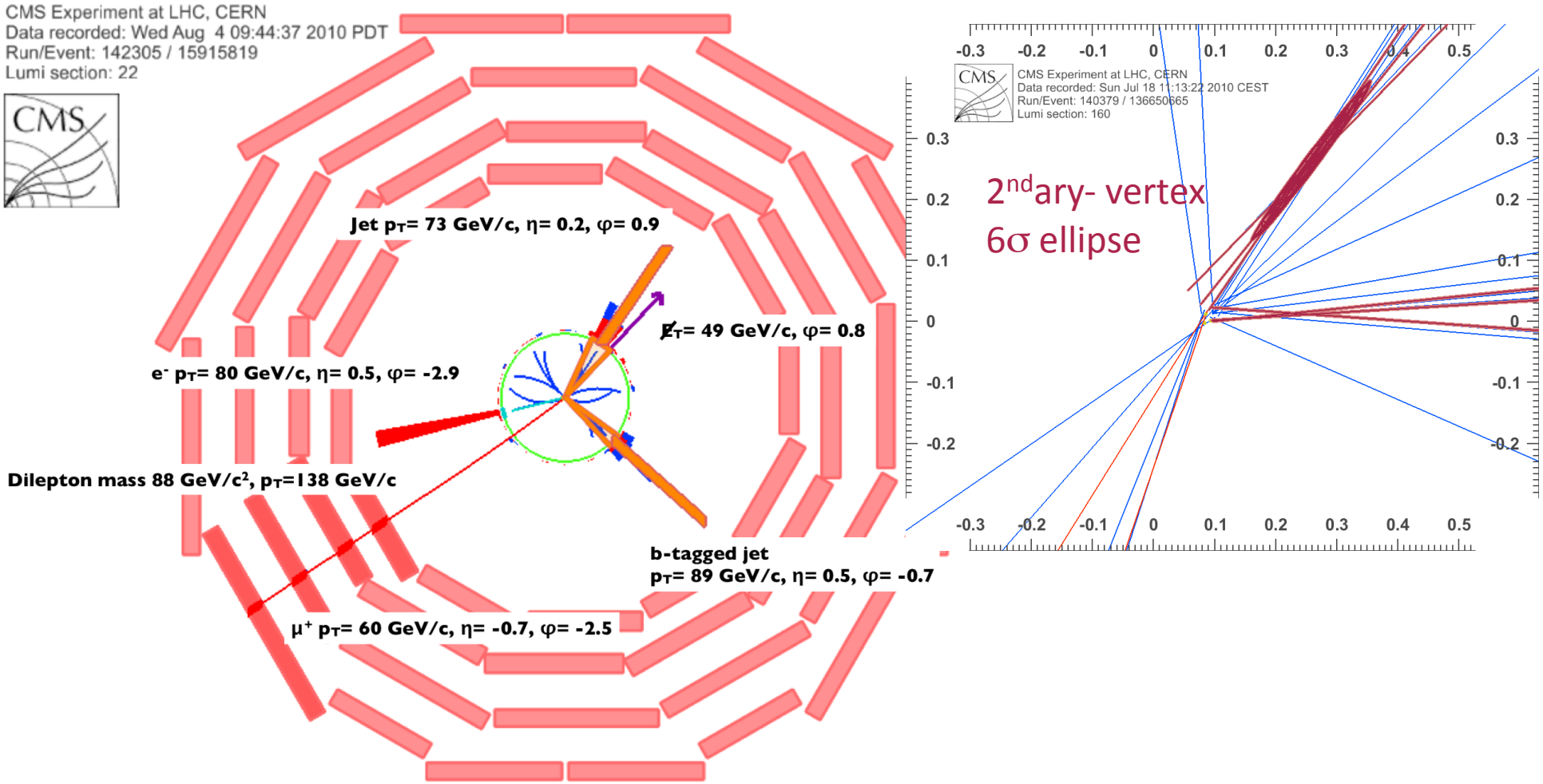
- Dilepton
  - 2 isolated, opposite charge leptons, Pt>20 GeV, Z-Veto
  - Jets with Pt>30 GeV (expect >=2 for Top)
  - tcMET>30 (20) GeV in ee,mumu (emu)
  - >=2 JPT jets, Pt>30 GeV



- Lepton+Jets
  - One isolated high pt e (Pt>30 GeV) or mu (Pt>20 GeV)
  - Jets with Pt>30 GeV (expect >=4 for Top)

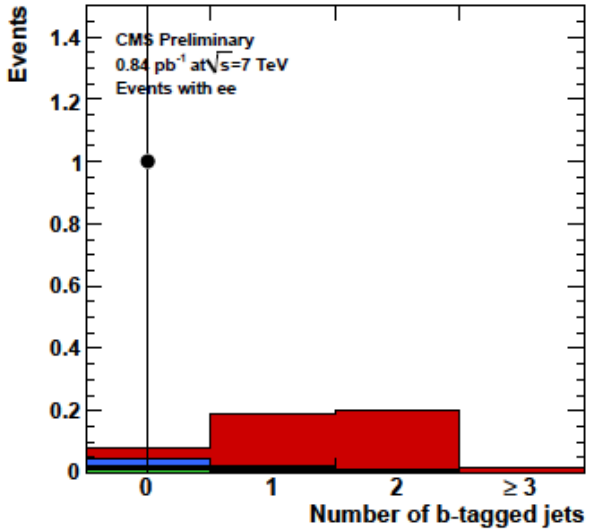


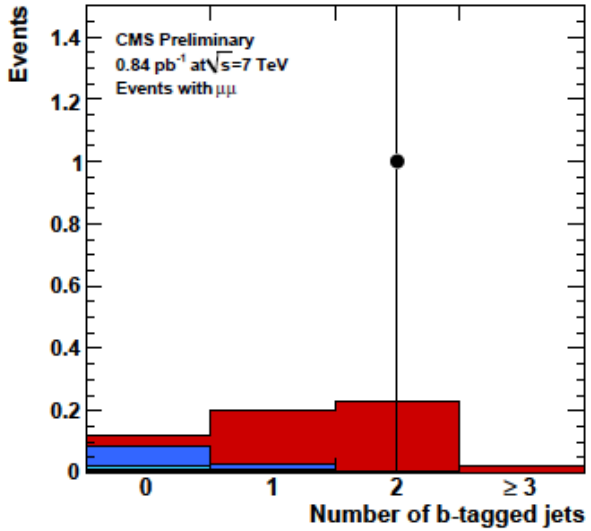
e+mu dilepton candidate event

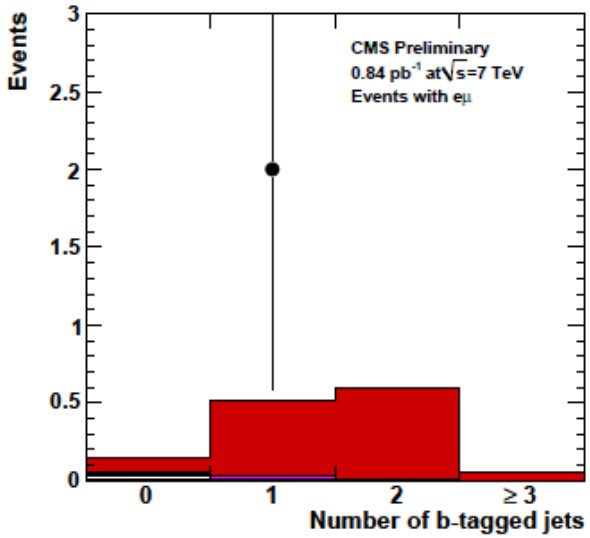


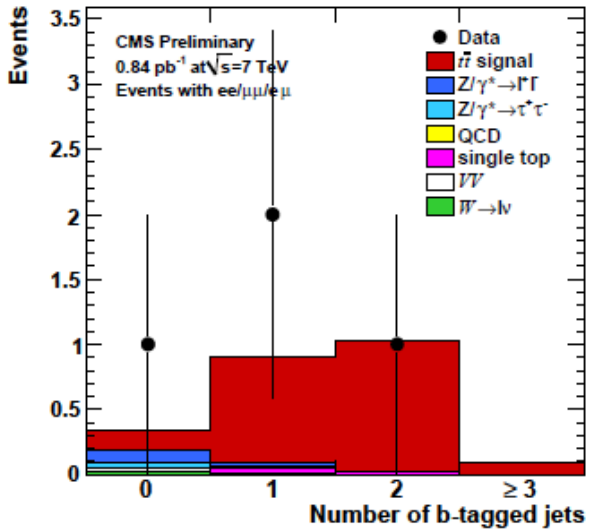
di-leptonic channel, b-tag multiplicity

With Z-veto, MET, N(jets)>=2 cuts applied

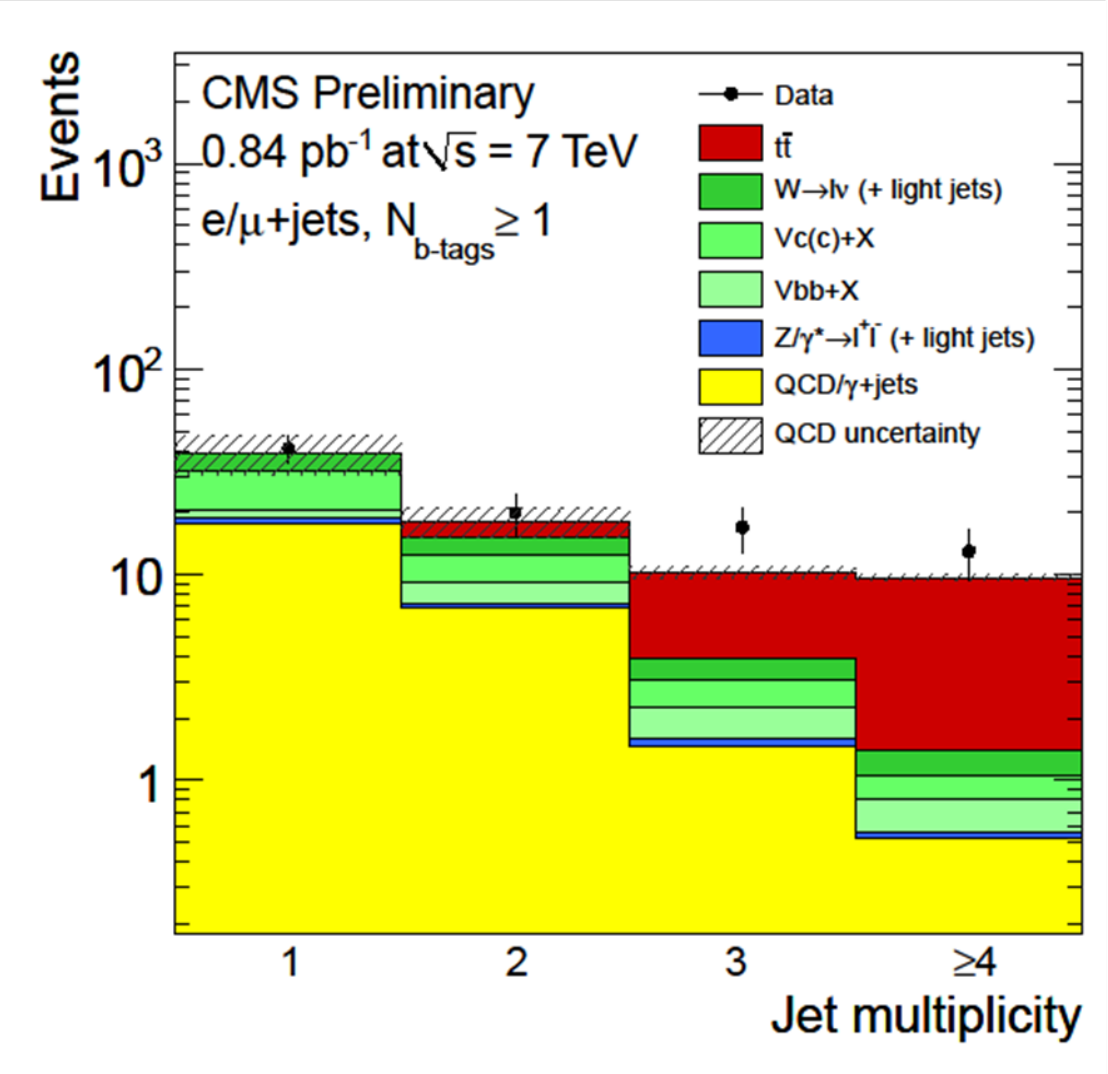








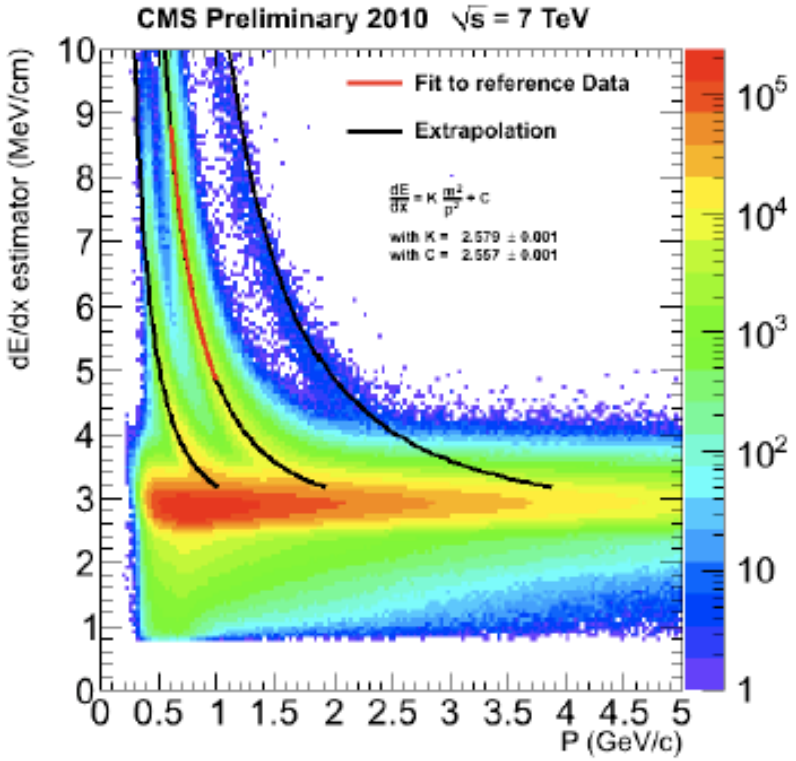
Semileptonic channel, electrons and muons combined, b-tagging



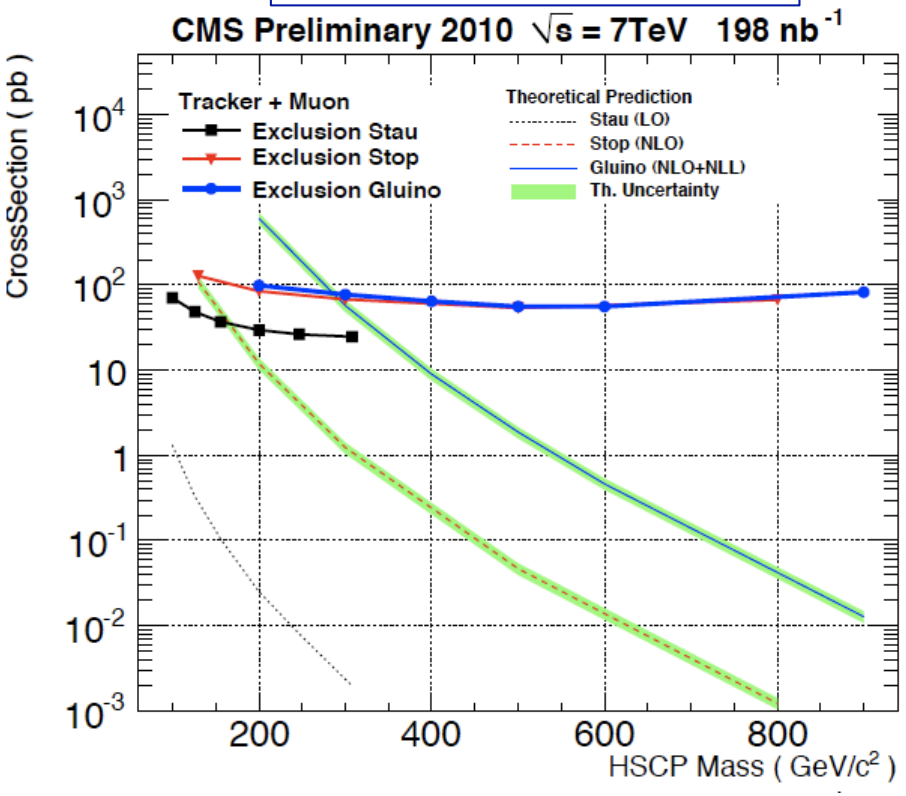
Exotic searches

Heavy Stable Charged Particles

- A very early analysis: dE/dx and possibly Time-of-Flight based
- dE/dx part is well understood from cosmic runs
- Sensitivity beyond the Tevatron with as little as 1 pb^{-1} of data



CMS-PAS-EXO-2010-004

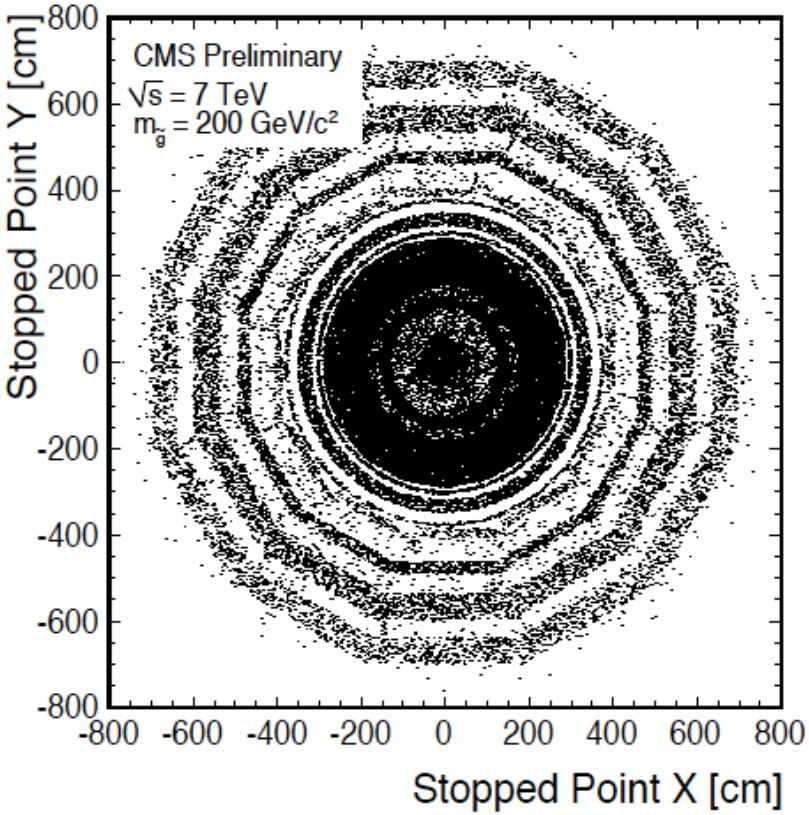


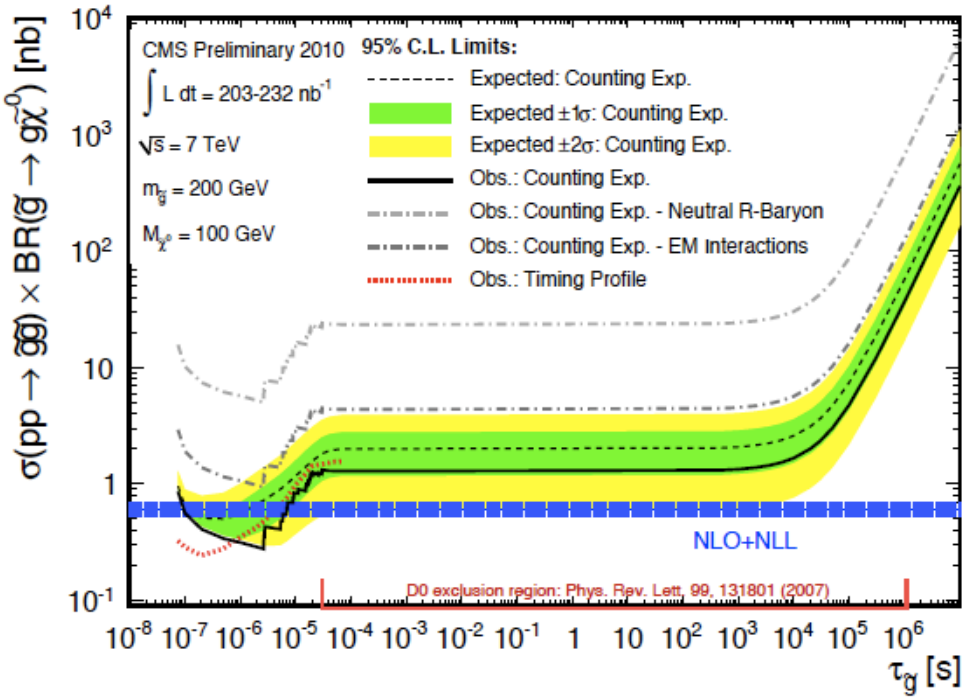
Search for Stopped Gluinos

CMS-PAS-EXO-2010-003

- Searched for long-lived gluinos that stops in CMS and decays producing a signal in HCAL
- Used the gaps between crossing in the LHC beam structure
- Explored a region uncovered at Tevatron,

exclude lifetimes from 75 ns - 6 μs for $m_{\tilde{g}} = 200\ \mathrm{GeV}/c^2$





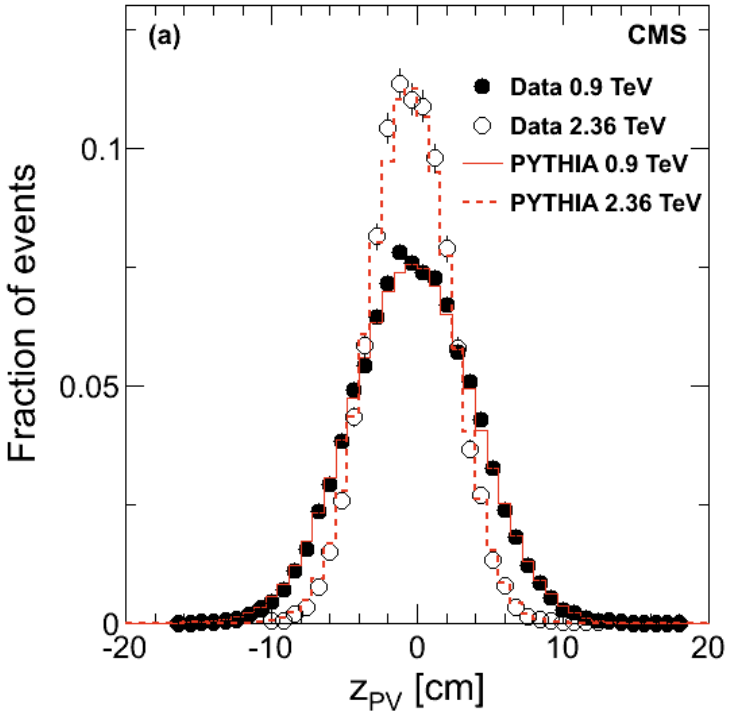
Achievements of LHC exp (summer 2010)

- Physics commissioning (in advanced progress)
- Soft Physics (many results)
- Jet Physics (starts being interesting !)
- EWK Physics (W and Z cross section, properties)
- B (and charm) physics at 7 TeV (cross sections)
- Top Physics (the birth of a top factory)
- Search for New Physics (entering a new land)

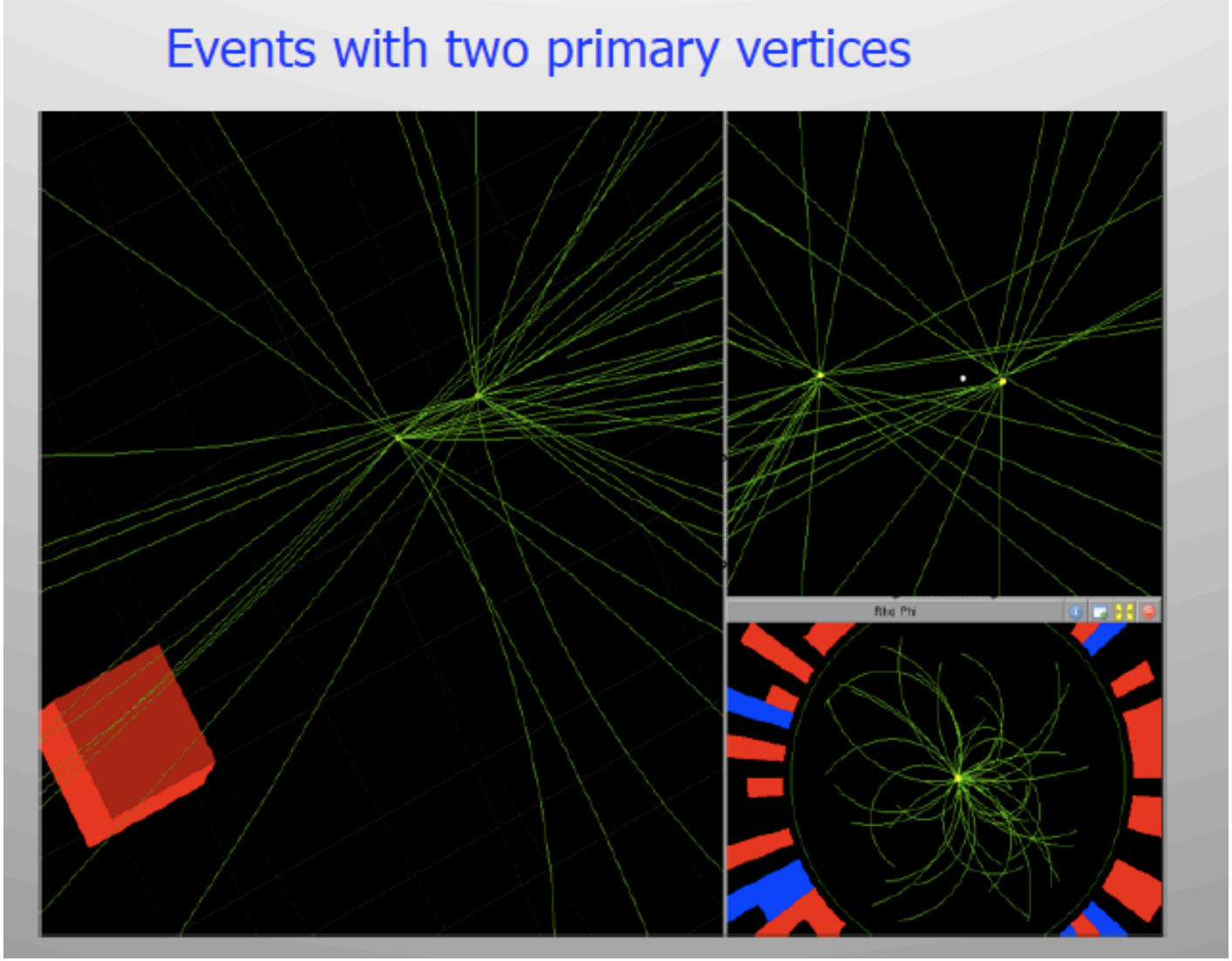
Backup

Example : dN/dη from CMS

- Event selection:
- – >3 GeV total energy on both sides in the Forward Calorimeter (HF)
- – Beam Halo rejection (BSC)
- – Beam background rejection
- – Collision vertex
- Measure NSD $|\eta| < 2.5$
- Efficiencies:
  - NSD: ~**86 %**
  - SD: ~19 %
  - DD: ~34 %

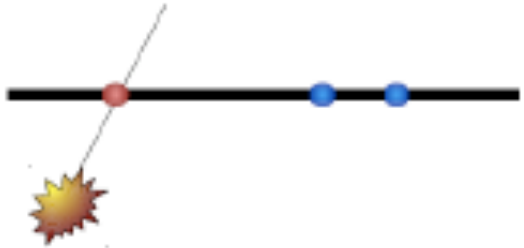


Events with multiple primary vertexes were rare at that luminosity



Cluster counting method

- Counting hits (clusters of pixels)in the pixel barrel layers
- Cluster length ~ |sinh(η)|
- Corrections for loopers,weak decays, secondaries
- Independent result for 3 pixel layers
- Immune to detector misalignment
- Sensitive to beam background

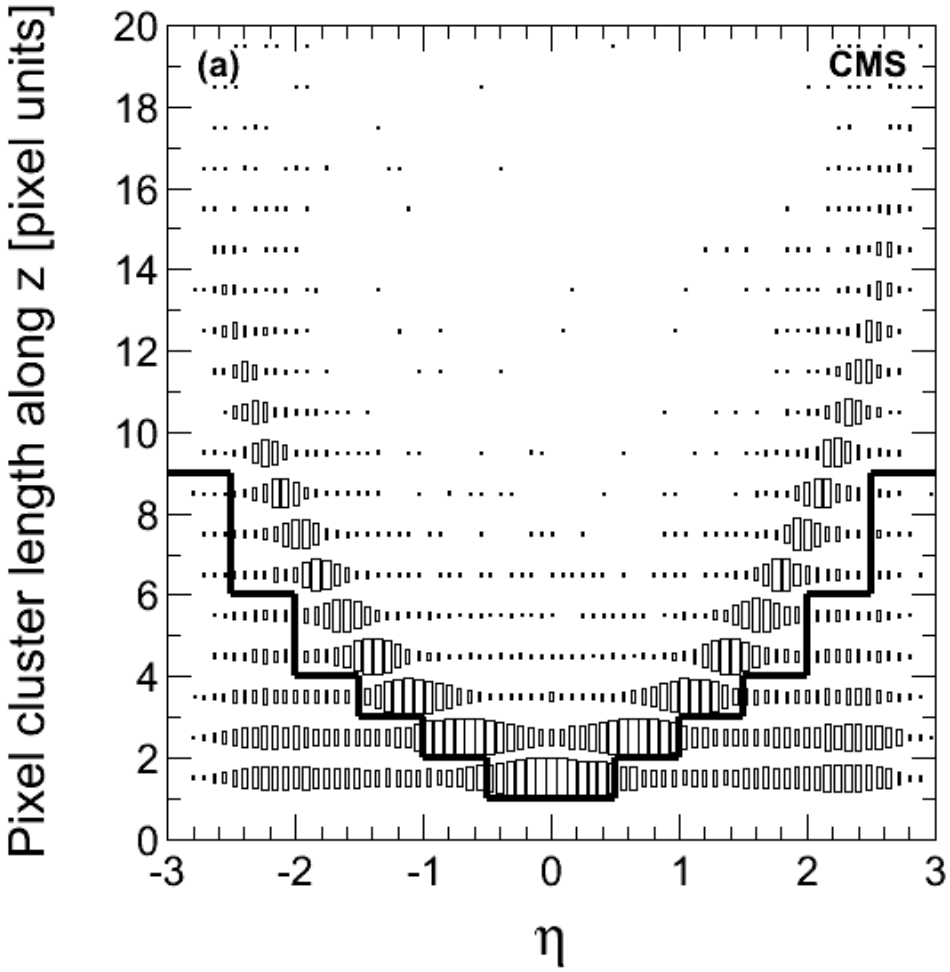


Can measure pt down to 30 MeV !!

Cluster counting method (II)

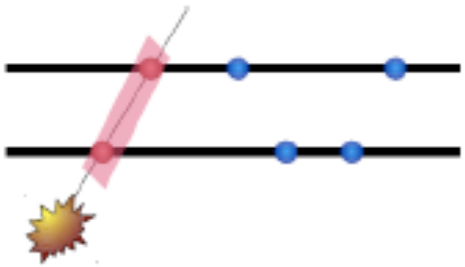
Pixel cluster length along the beam direction as a function of η. The solid line shows the cut applied.

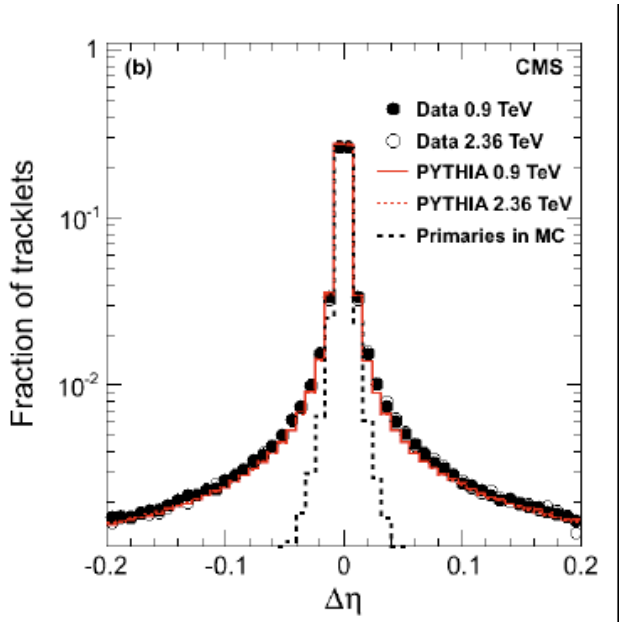
$$\eta = -\ln(\tan(\vartheta/2))$$



Tracklet method

- Tracklets: pairs of clusters on different pixel barrel layers
- The $\Delta\eta$ and $\Delta\varphi$ correlations are used to separate the signal
- A side-band in $\Delta\varphi$ is used to subtract combinatorial background
- Corrections for efficiency, weak decays, secondaries Independent result for all 3 layer pairs
- Less sensitive to beam background

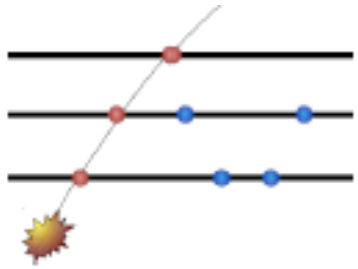




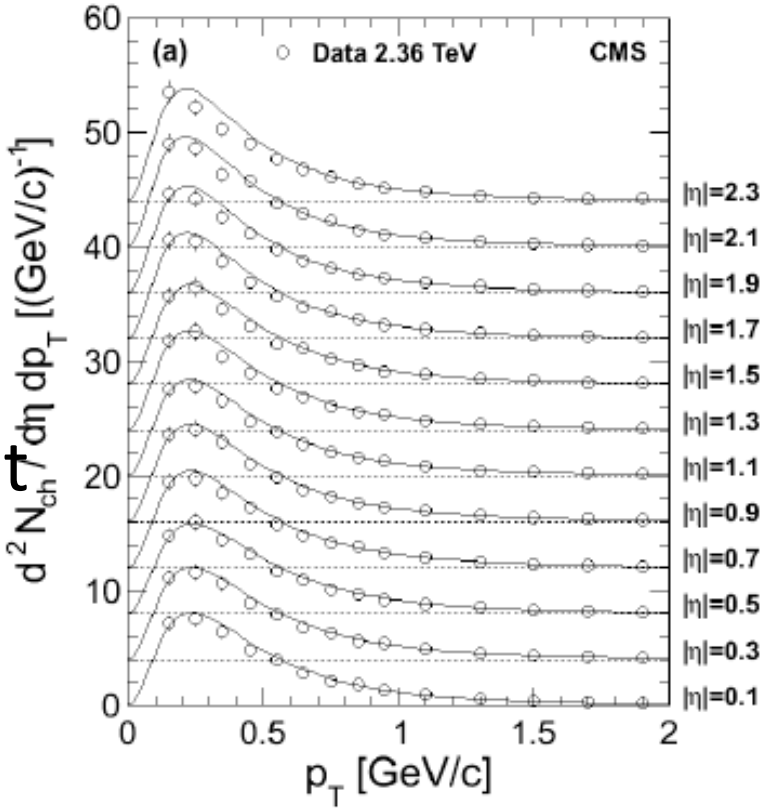
The $\Delta\eta$ distribution of the two clusters of the tracklets

Can measure pt down to 50 MeV

Tracking method



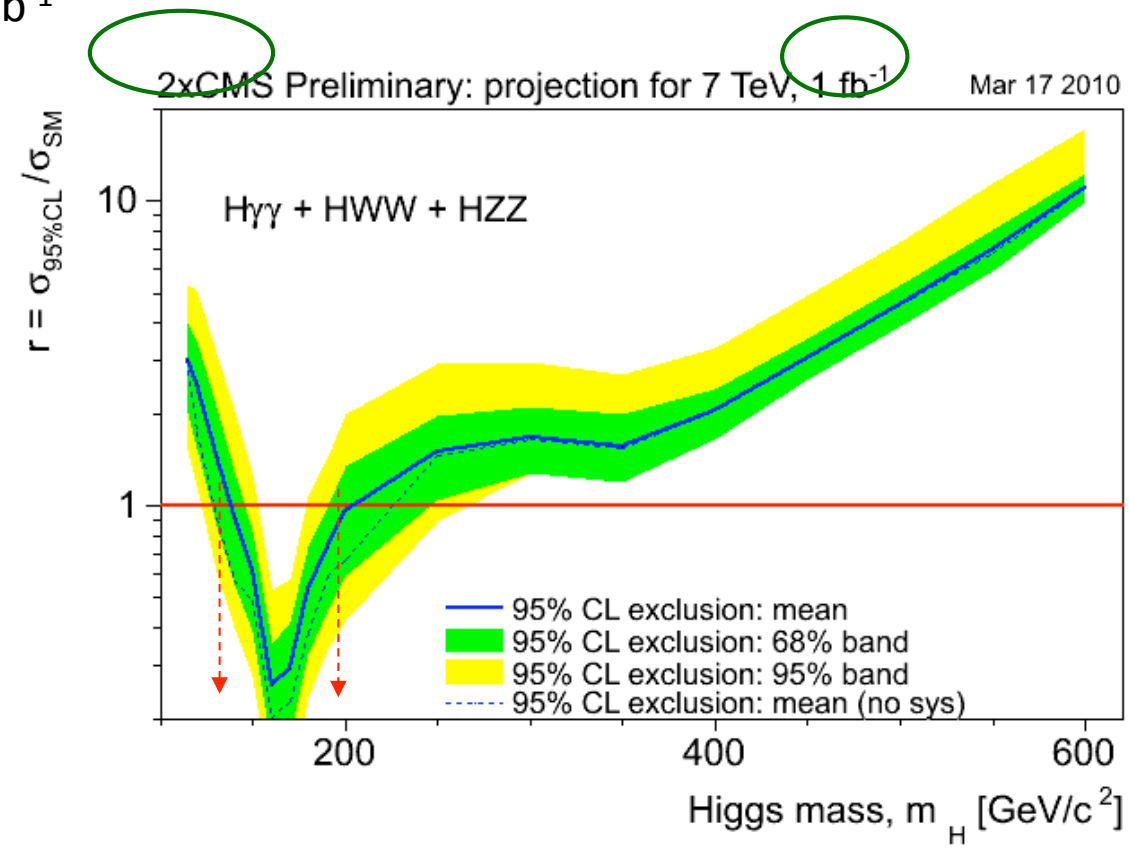
- Uses all pixel and strip layers
- Builds particle trajectories Iteratively
- Low fake rate achieved with cleaning based on cluster
- Compatibility with beam spot and primary vertex required
- Immune to background
- More sensitive to beam spot position and detector alignment



Differential yield of charged hadrons in the range $|\eta|<2.4$ The η bins are shifted by four units vertically.

Standard Model Higgs: Combined

1fb^{-1}

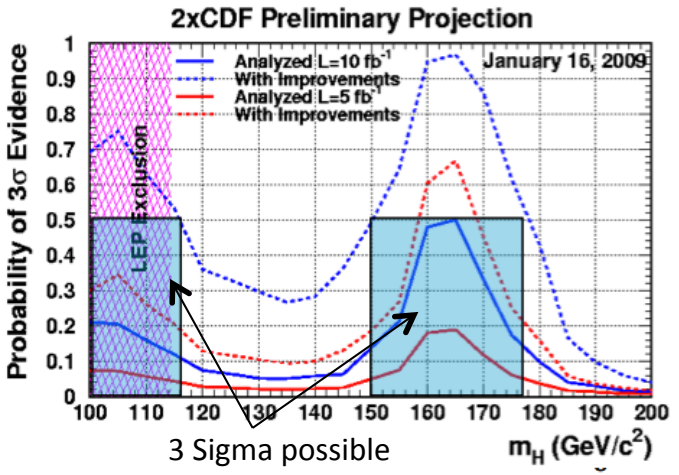


SM Higgs expected excluded range approx: **140-200 GeV**
discovery range approx: **160-170 GeV**

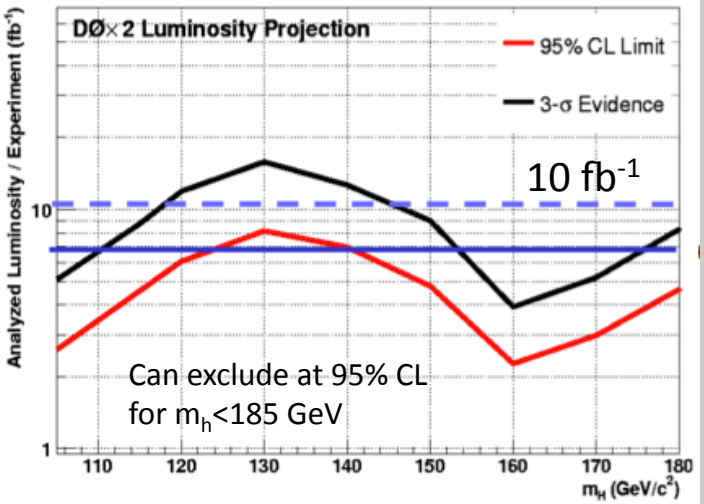
LHC starts to take over from the Tevatron at Higgs masses above 140 GeV!

TEVATRON Projection

2xCDF

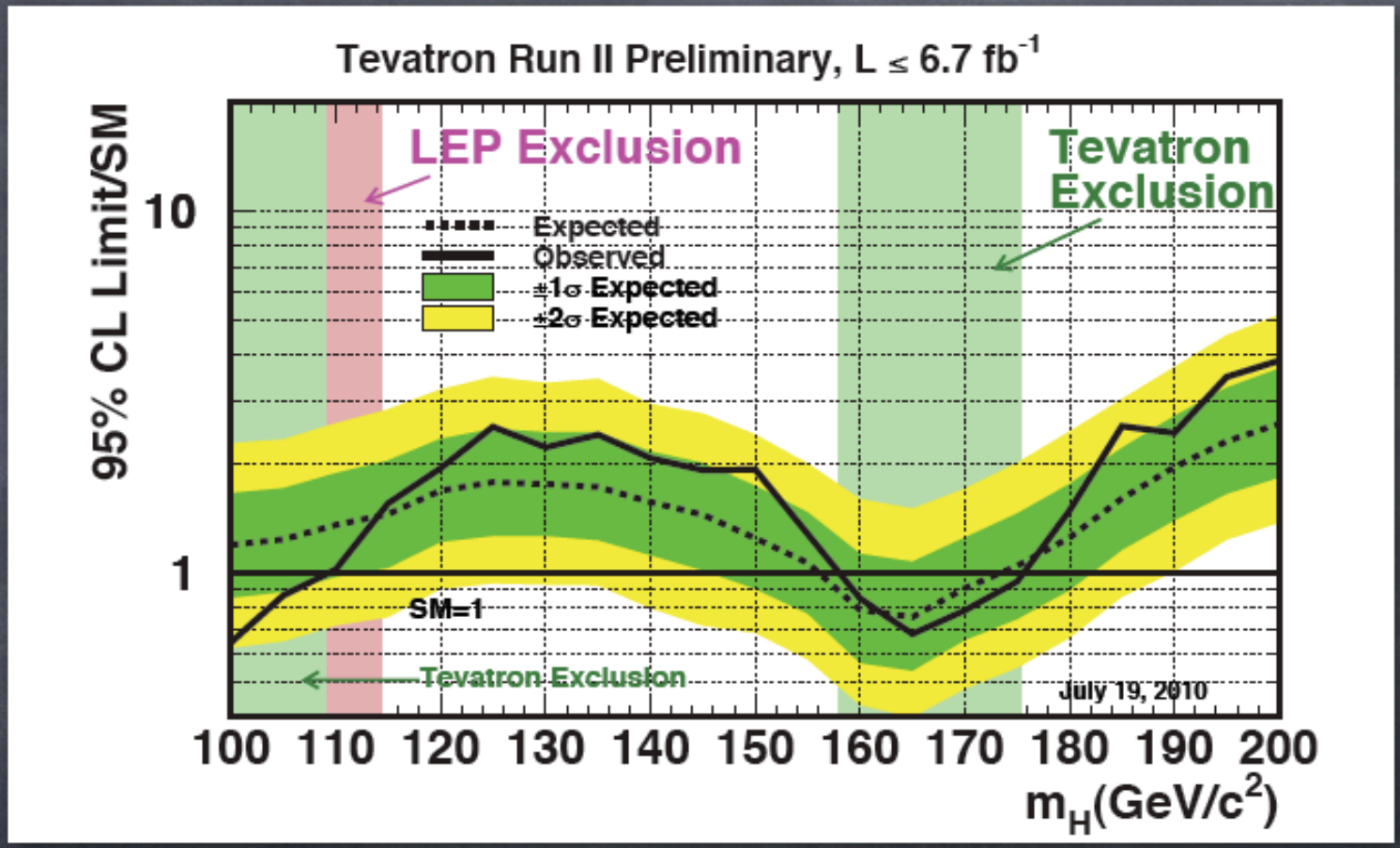


2xD0



Tevatron combination

"Expected sensitivity"



- High mass 95% CL exclusion :
  - 158 < m_H < 175 GeV
    - 4 times previous (162 - 166 GeV)
    - Expected (156 < m_H < 175 GeV)

e+mu dilepton candidate event