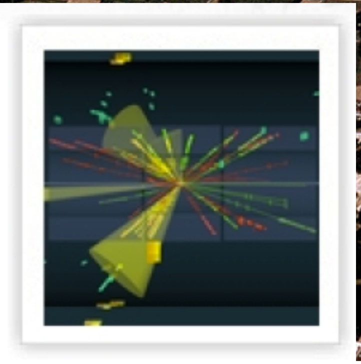
The ATLAS and CMS Experiment

Albert De Roeck
CERN, Geneva, Switzerland
Universiteit Antwerpen, Belgium
IPPP Durham, UK
UC Davis, USA



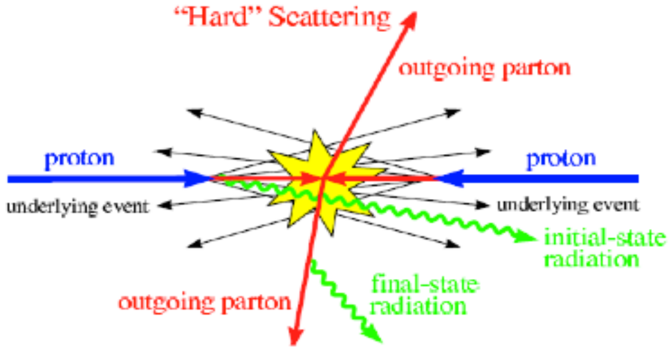
Taller de Altas Energías 2010
2010, Aug 31 -- Sep 11

Lecture Plan

- Introduction
- The LHC Collider
  - Introduction to the LHC
- The experimental challenges at the LHC
  - The experimental solutions
- The “general purpose” experiments
  - The CMS experiment
  - The ATLAS experiment
- First performance results of the experiments
- First physics with the ATLAS and CMS experiments
  - QCD, B-physics
  - EWK/Searches and the outlook

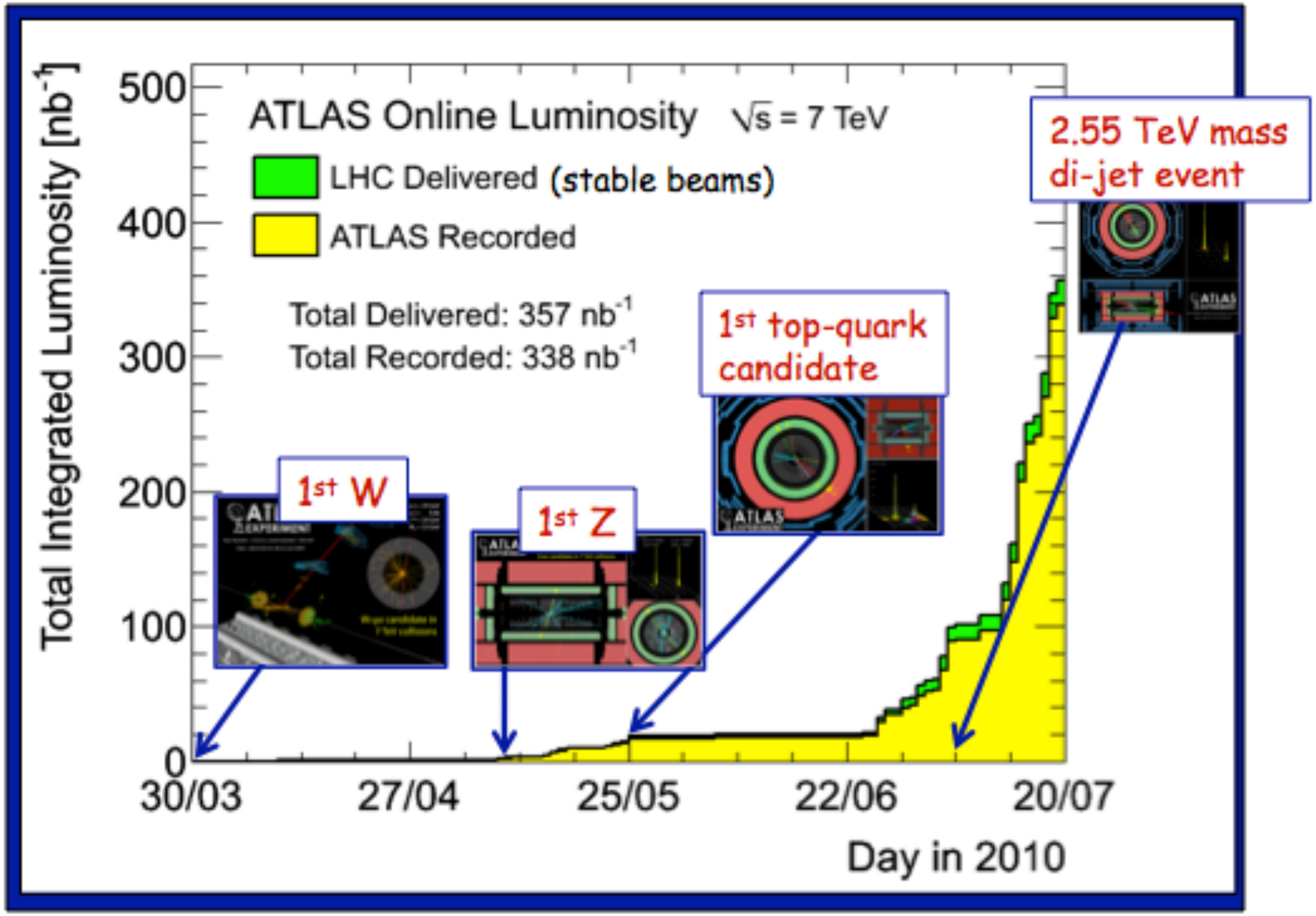
Physcis Results obtained so far:

- Studies of general characteristics of minimum bias events (our future pile-up)
- Study of the underlying event with a hard scattering
- Resonances/known particles
- Jet physics & QCD
- B-physics
- W,Z boson production at 7 TeV
- Top at 7 TeV
- Searches for new physics
- …

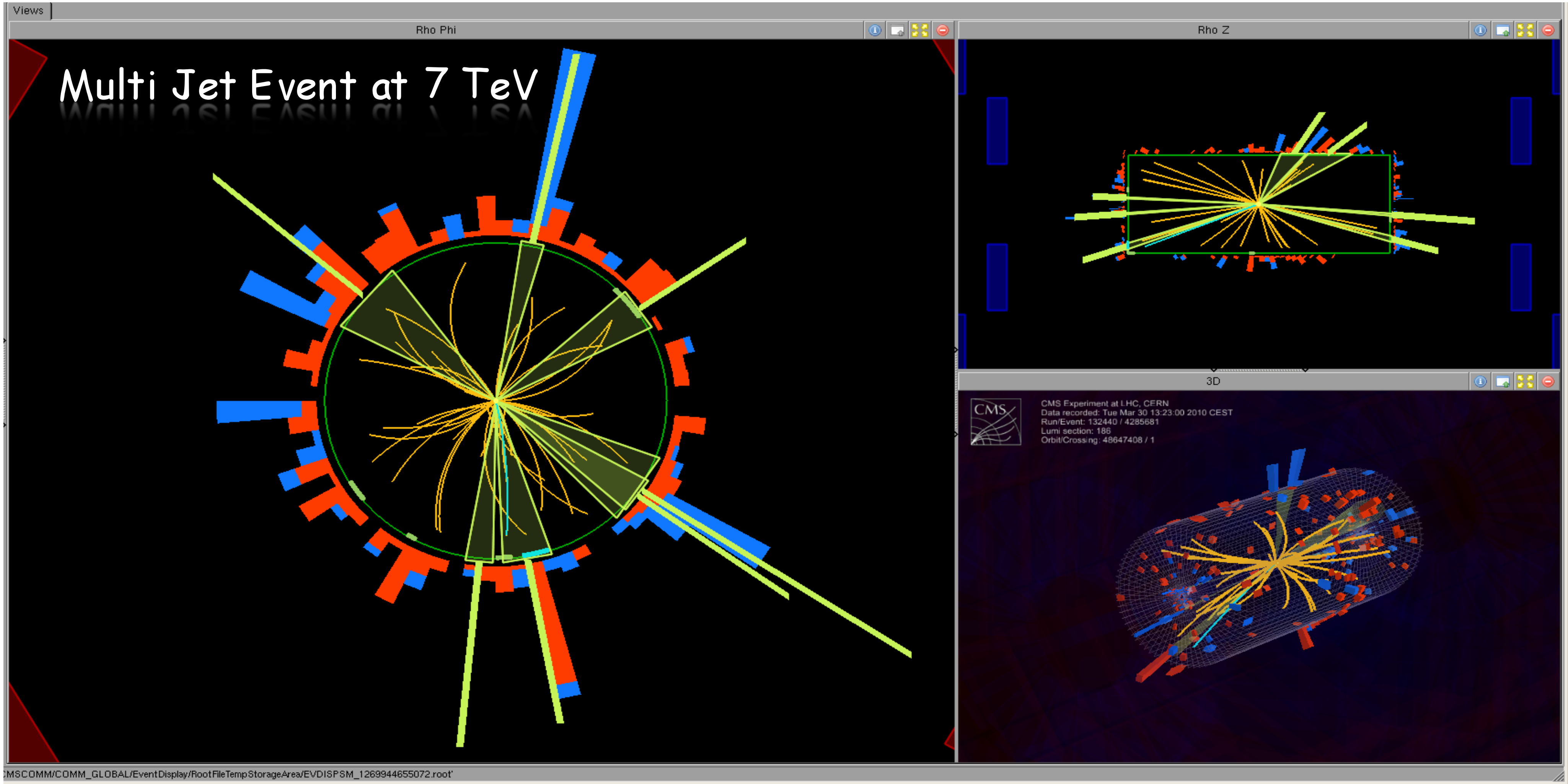


Underlying event

Luminosity & Physics



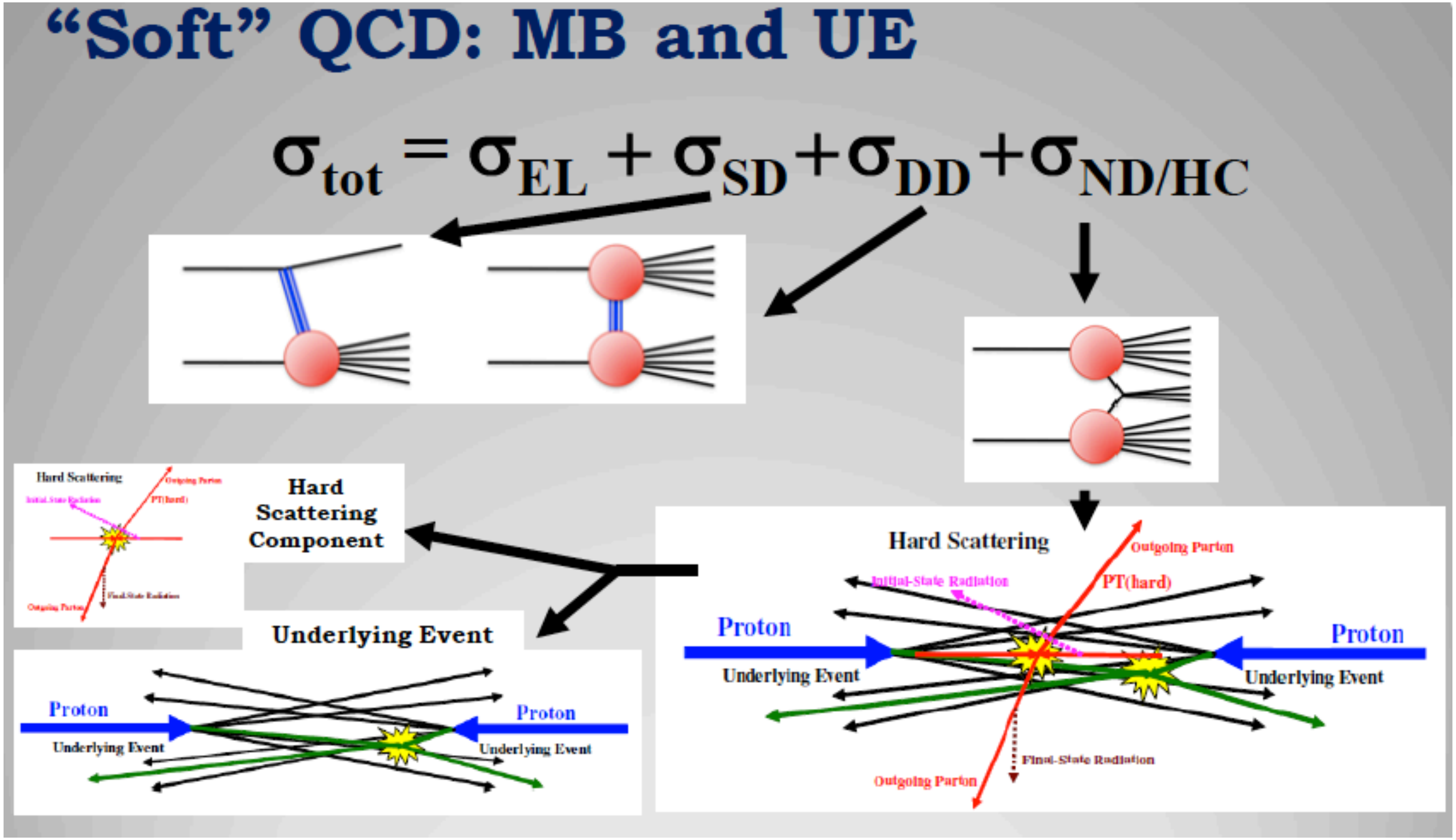
First Collisions at 7 TeV



What are the characteristics of events at 7 TeV

Number of particles? Correlations between particles? Jets? Heavy flavors?

Event Types



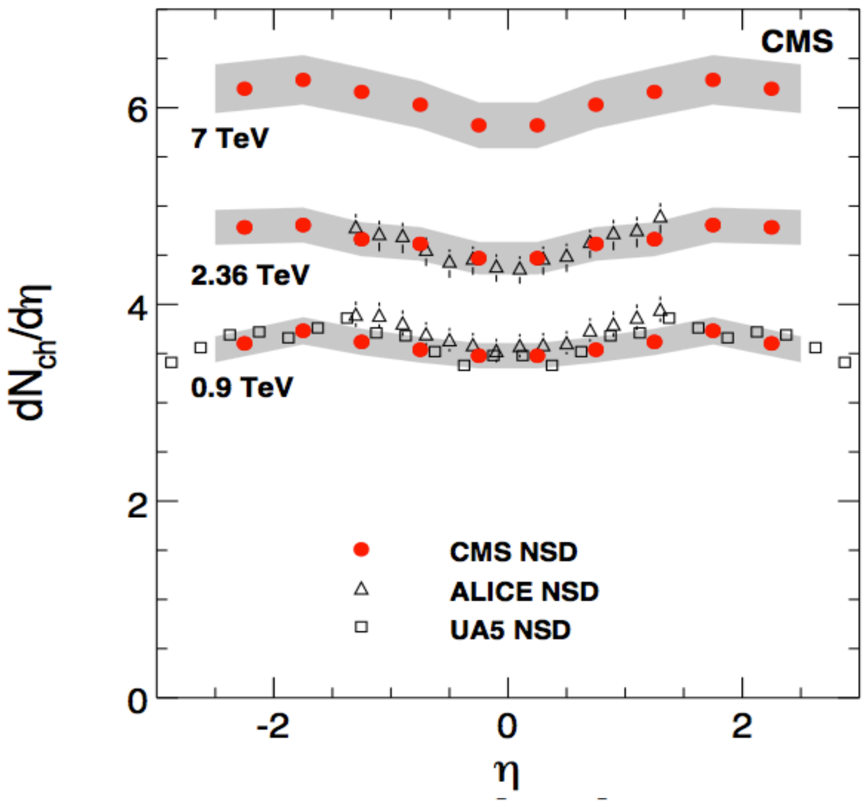
…Not always easy to classify individual events

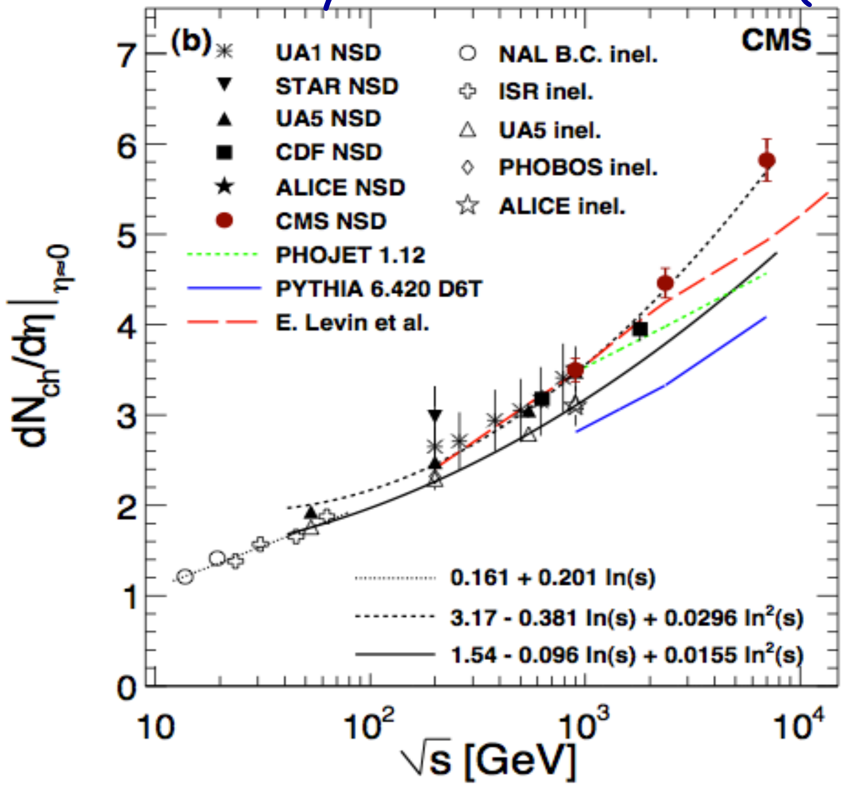
Charged Particles

pseudo-rapidity density of charged hadrons at √s = 7 TeV

Minimum bias events   Non-Single Diffractive event selection

Phys. Rev. Lett. : 105 (2010)





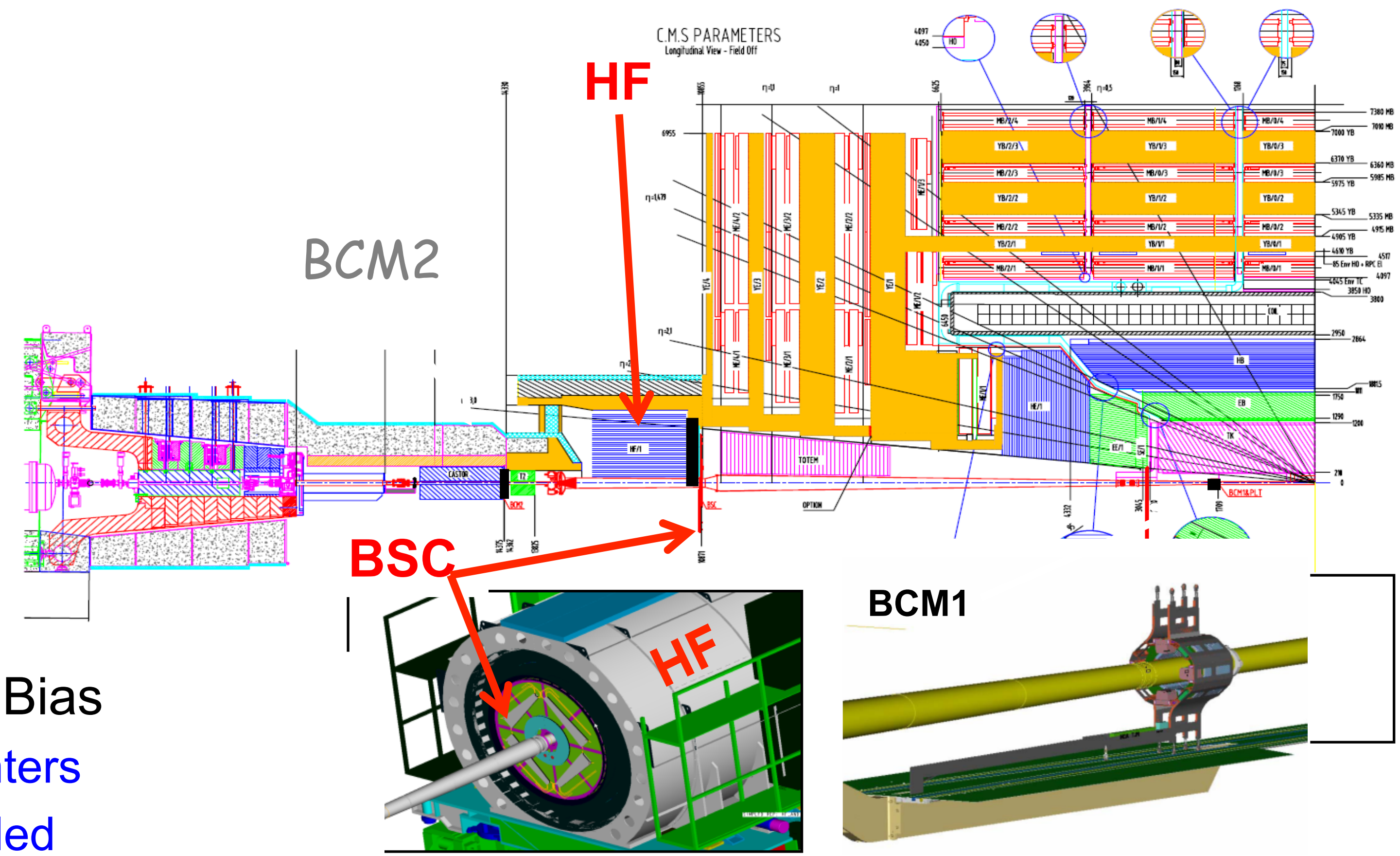
Rise of dN/dη in data stronger than currently used models

Triggers at Start-up

7 TeV Start up:

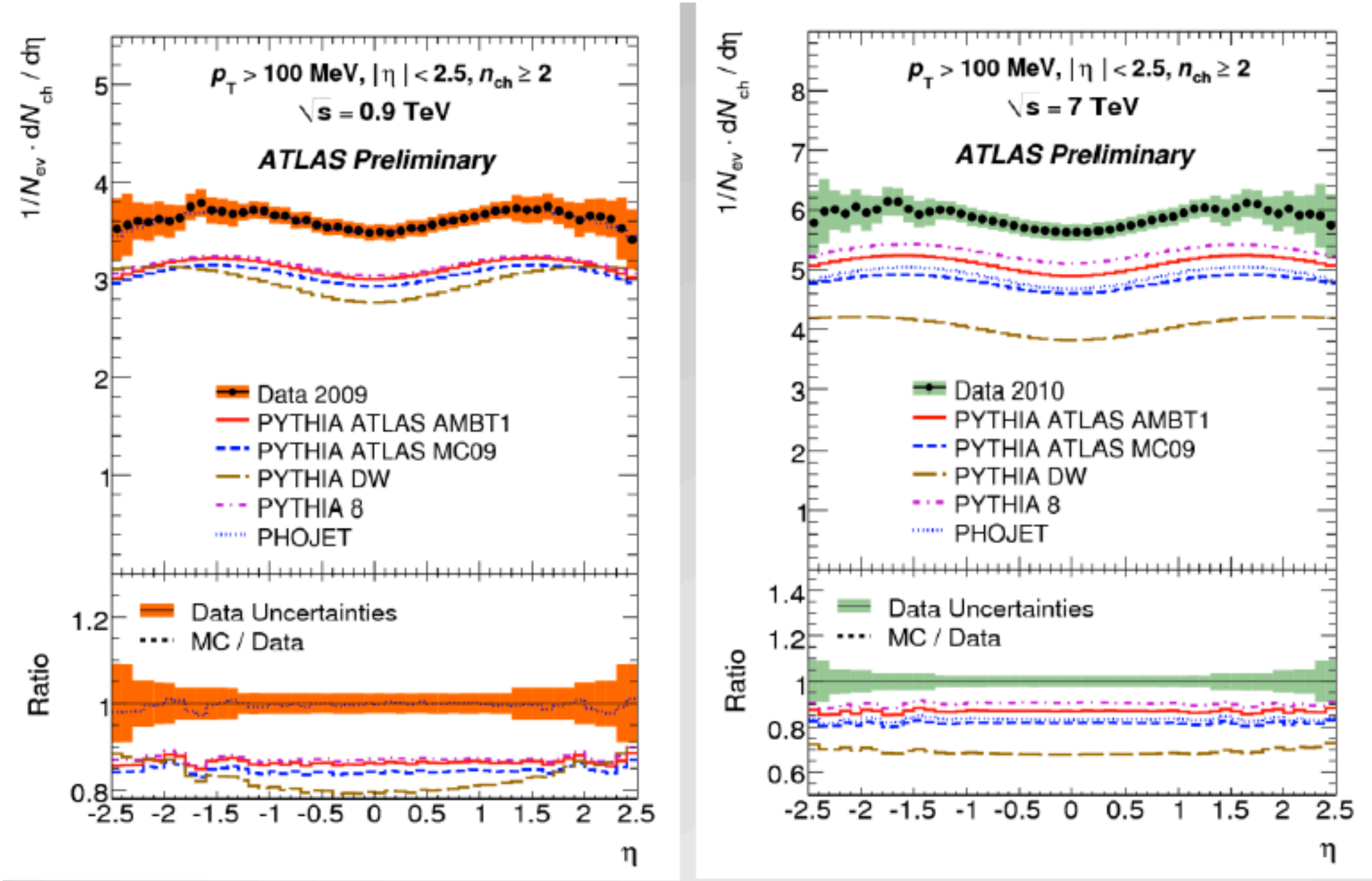
Work horse trigger = minimum bias triggers

- Hadronic Forward
  - HF: $2.5 \leq |h| \leq 5.$
- Beam Scintillator planes
  - BSC: ± 10.5 m from IP
- Beam Pick-up Timing
  - BPTX: ± 175 m from IP
- Trigger: Min Bias & Zero Bias
  - L1 Beam Scintillator Counters
  - L1 Trigger "BPTX" prescaled
- Minimum Bias selection:
  - BSC (OR 2 planes) + vertex: ϵ ~ 90%
  - HF (E > 3 GeV both sides): ϵ ~ 90%
    - Combined high ϵfficiency



Now with squeezed beams, deploy the full trigger menu

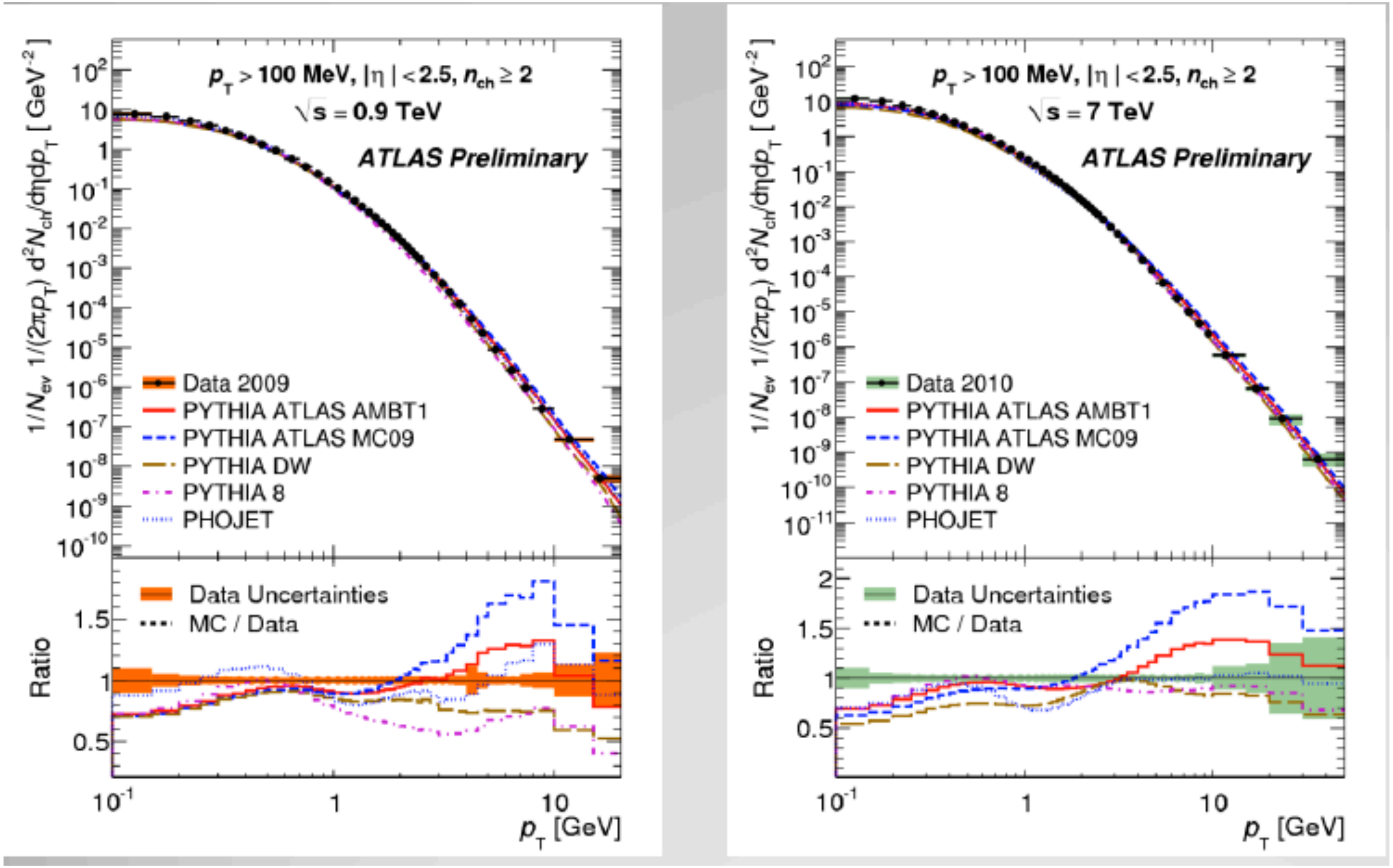
Charged Particles



No corrections for diffractive components :particle density as observed

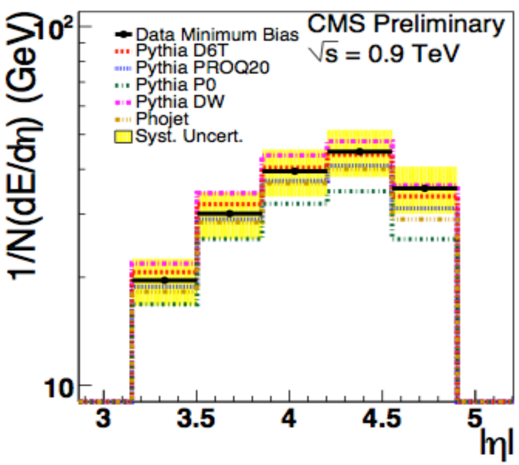
Charged Particles

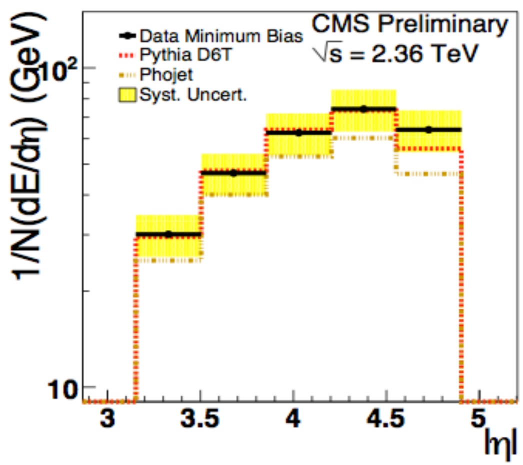
P_T spectra & comparison with models

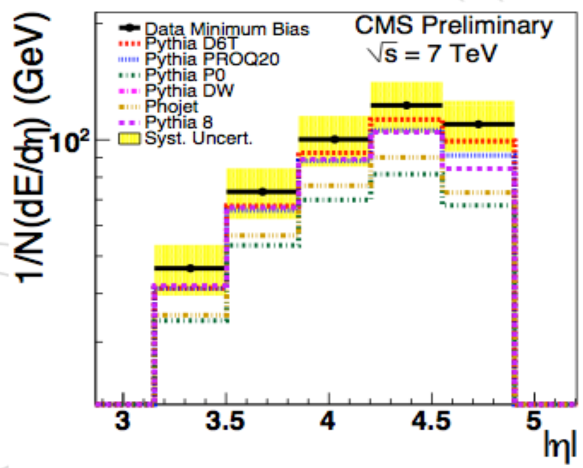


Forward Energy Flow

- MinBias event selection
- Energy flow at different CM energies

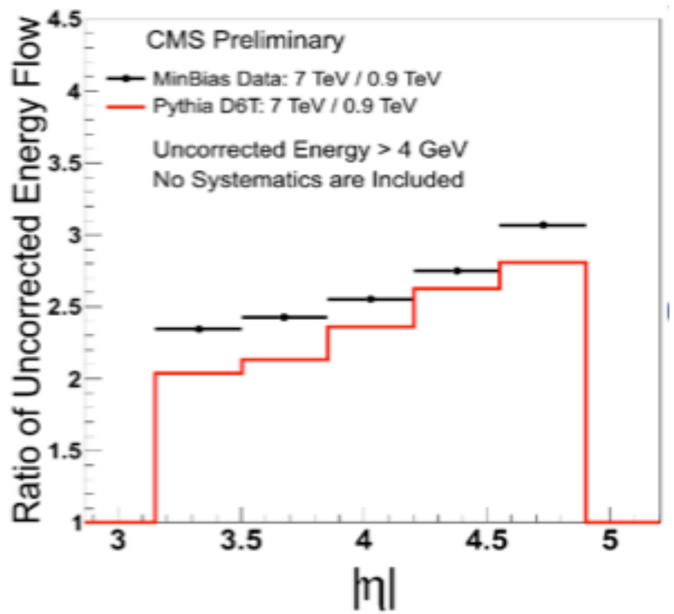






- Ratio of the energy flow at different energies

$$R_{Eflow}^{\sqrt{s_1},\sqrt{s_2}} = \frac{\frac{1}{N_{\sqrt{s_1}}}\frac{\Delta E_{\sqrt{s_1}}}{\Delta\eta}}{\frac{1}{N_{\sqrt{s_2}}}\frac{\Delta E_{\sqrt{s_2}}}{\Delta\eta}}$$

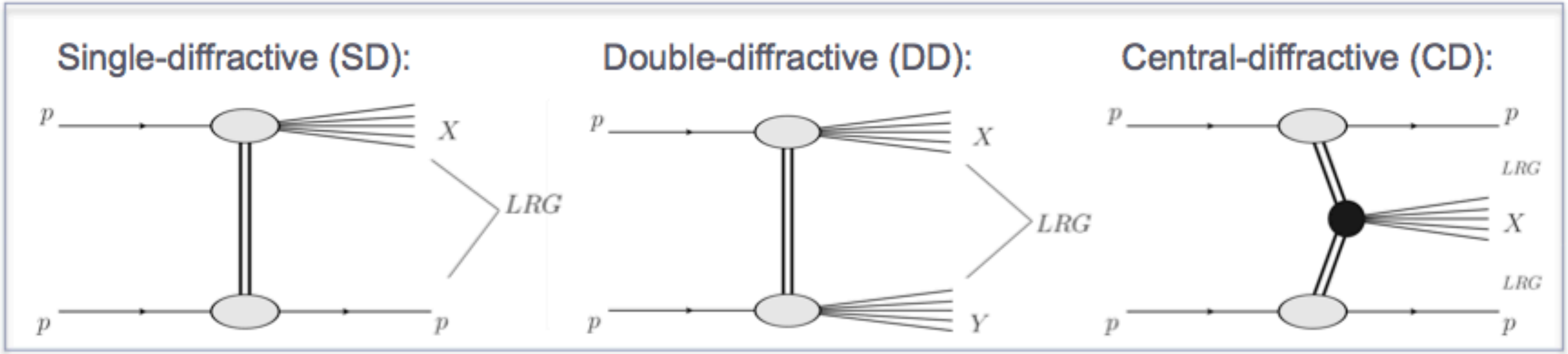


Similar rise with collision energy as seen in dN/dη analysis

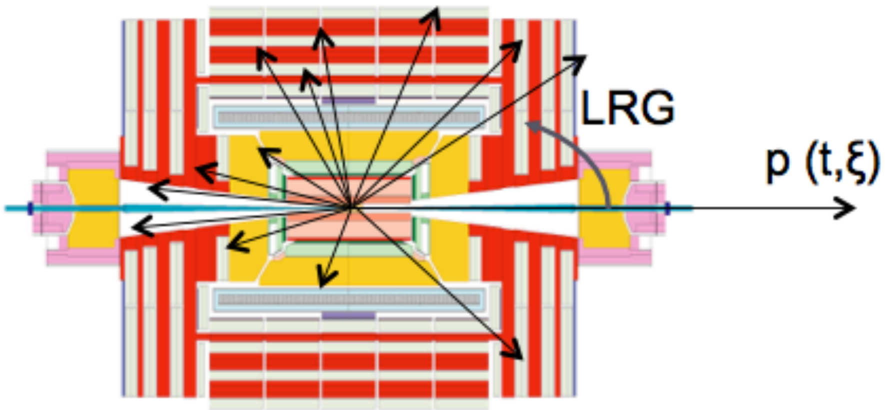
Comparison of the Experiments

- ATLAS selectes minimum bias events without separating diffractive components
  - Least Model dependend but hard to compare with other data as the measurement depends on the choosen phase space
  - Favoured by MC builders
- ALICE & CMS exclude single diffraction, which has a model dependence (in practice it is not large)
  - Favoured by model phenomenologists
- Future: we will release the measurements with both methods

The Diffractive component



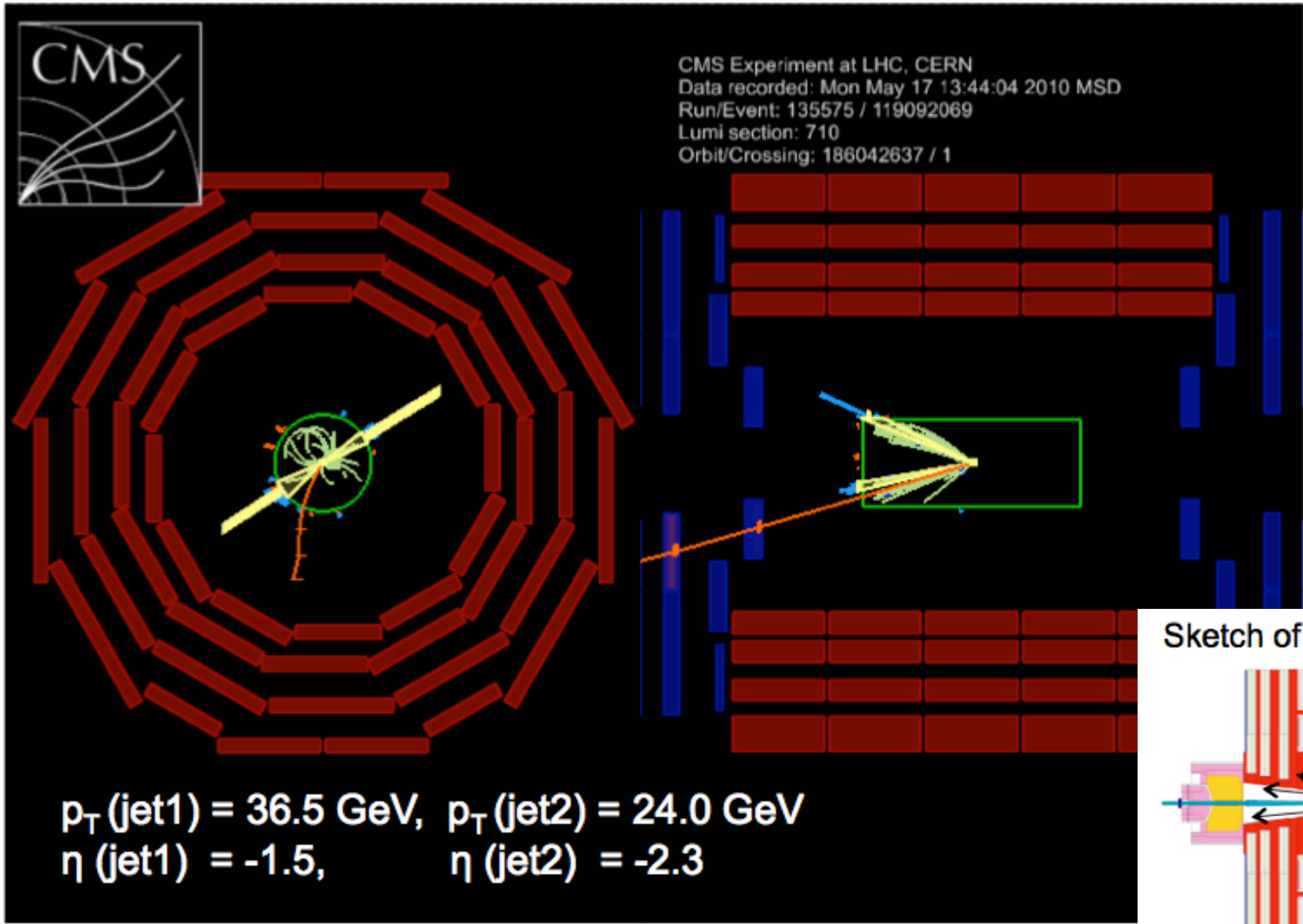
Sketch of single-diffractive event:

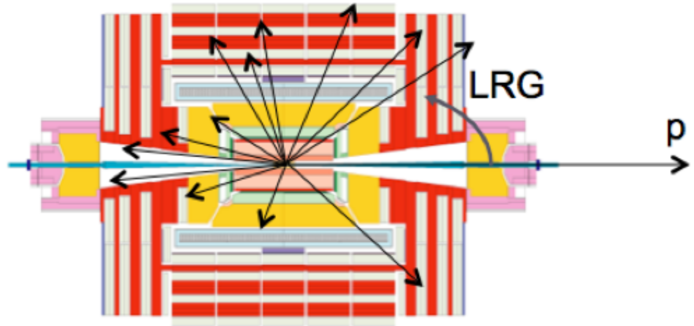


LRG: Large Rapidity Gap

- Diffractive events correspond to large fraction of the hadron-hadron cross section;
- Modeling of soft diffraction generator specific;
- Defining and constraining diffractive component (and their evolution with √s) important ingredient in the tuning of MC generators at the LHC.

Example Diffractive Event

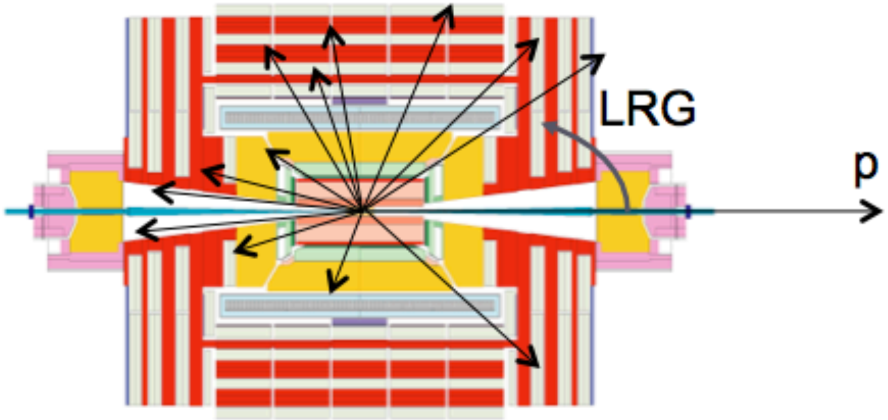


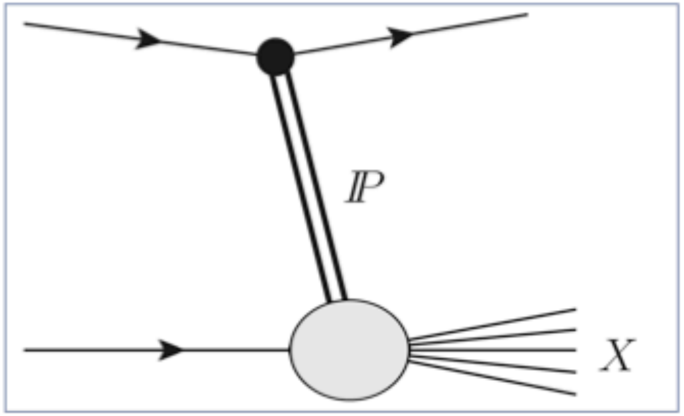


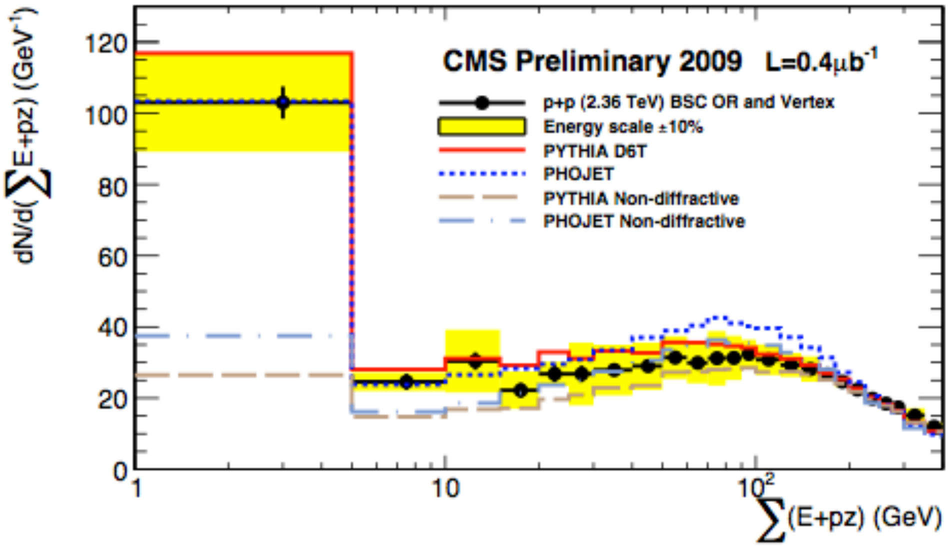
We see diffractive events in the data !!

Diffraction in the data

Sketch of single-diffractive event:





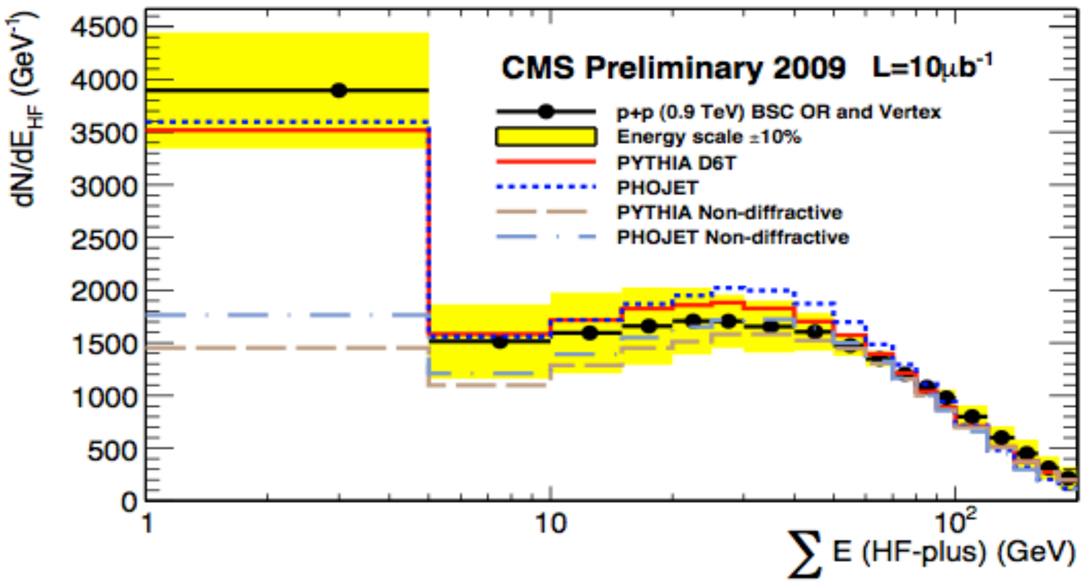


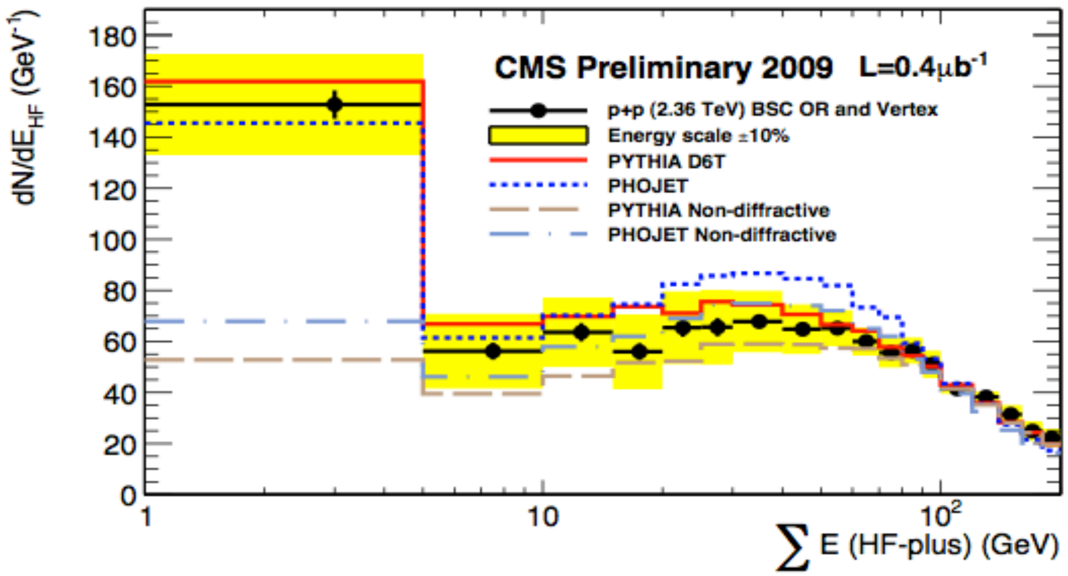
$\Sigma\,(E \pm p_z)$ related to the momentum loss of the scattered proton. One expects a (diffractive) peak at low values of this variable ($\sigma \sim 1/\xi$).

Main systematic effect due to ±10% energy scale variation.

N.B. All plots are uncorrected

Evidence for Diffraction





Energy in the most forward Calorimeter (HF)
3<|η| 5

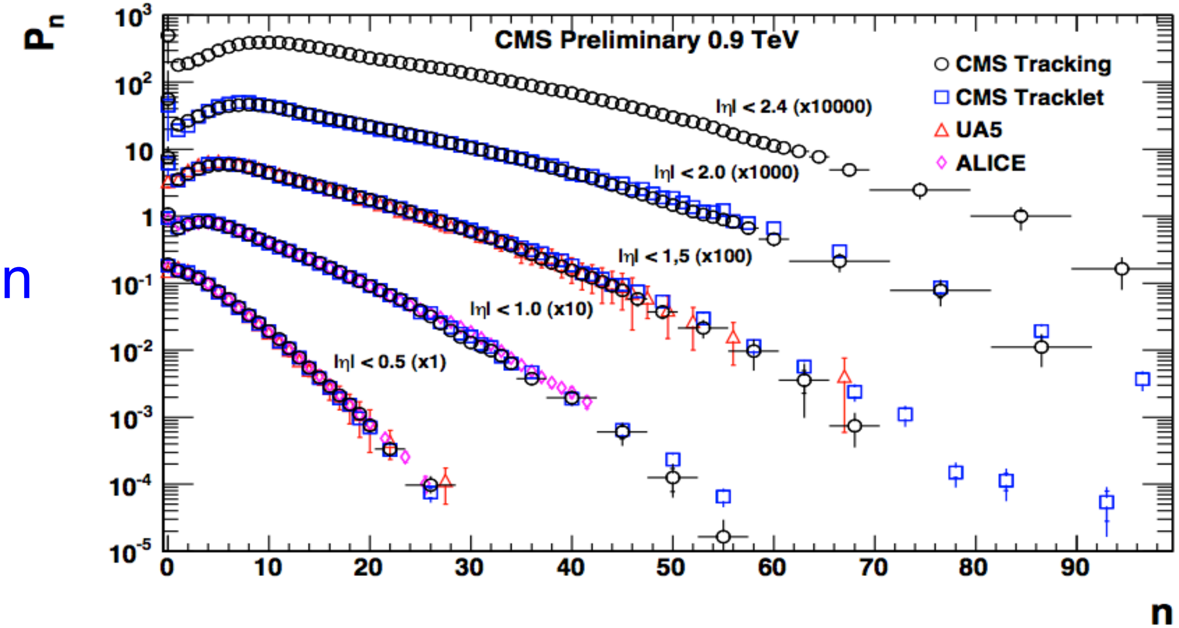
Low energy indicates the presence of a rapidity gap

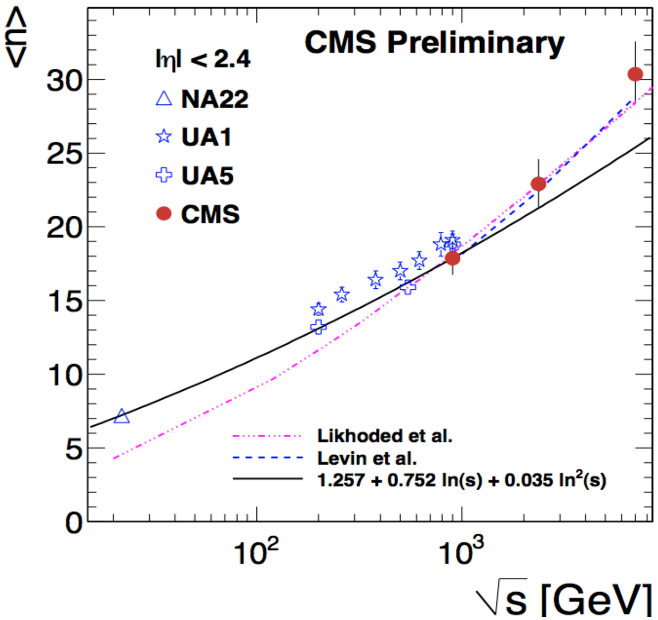
Consistent with the MC expectations

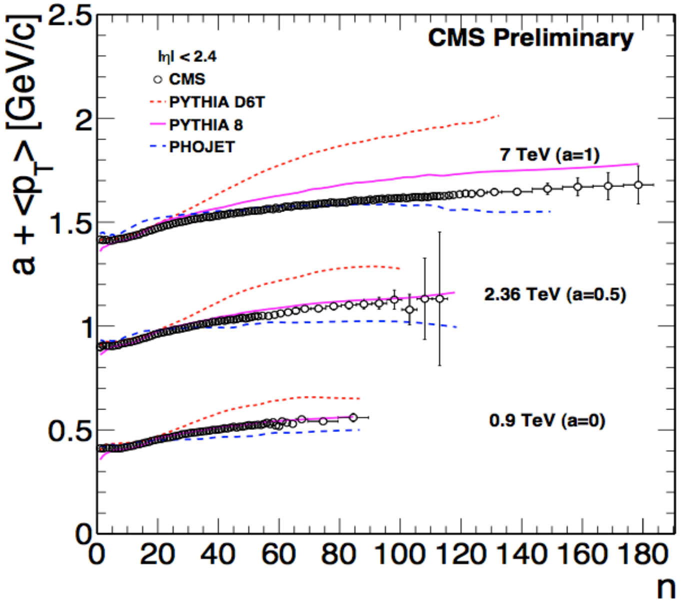
Multiplicity Distributions

Charged particle multiplicity
of the events

- Minimum Bias event selection
- Unfolded charged particle multiplicity distributions (down to p_T = 0 GeV/c)
- <pT> versus multiplicity

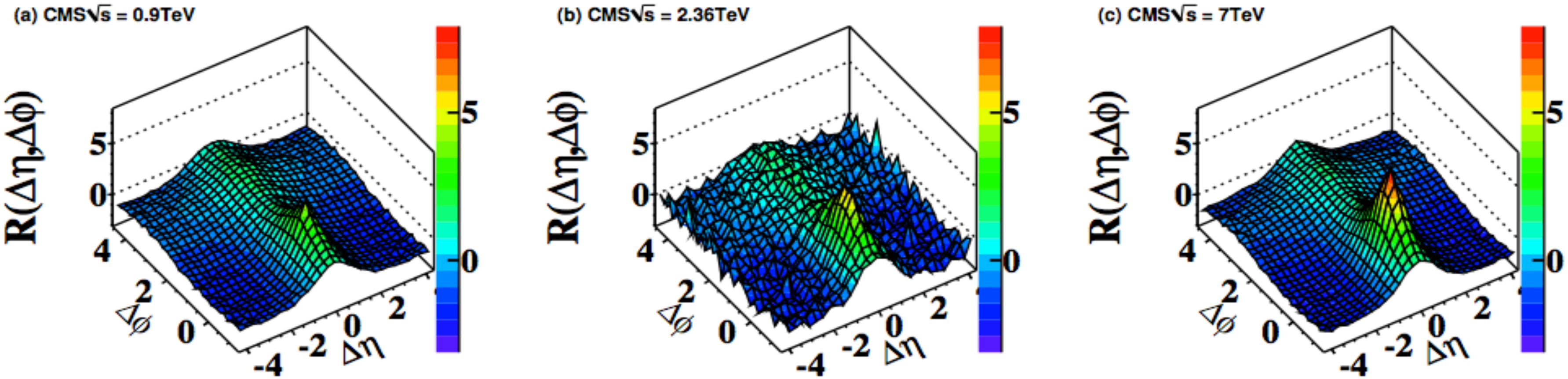






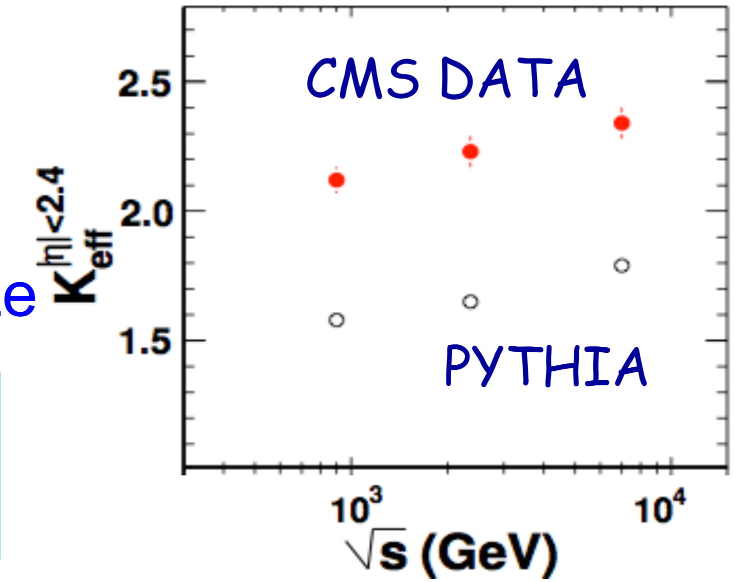
Two Particle Correlations

Two particle angular correlations



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

Effective cluster size



Short range correlations

Cluster size not described by eg PYTHIA

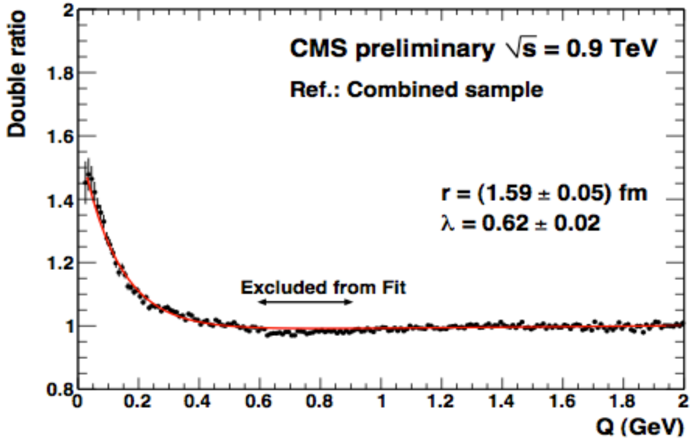
Bose Einstein Correlations

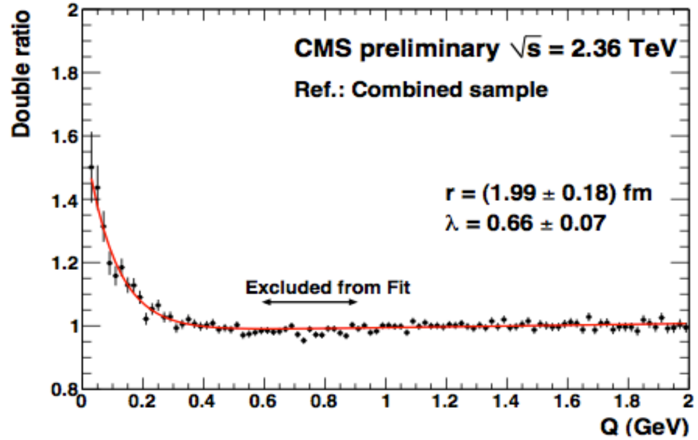
Correlations between two identical bosons (pions) √s = 0.9 and 2.36 TeV

$Q^2 = -(p1-p2)^2$

$$R(Q) = C\left[1 + \lambda\Omega(Qr)\right] \cdot (1 + \delta Q). \qquad \Omega(Qr) = e^{-Qr},$$

- MinBias events
- Use 7 reference samples
- Combination of all ref. samples





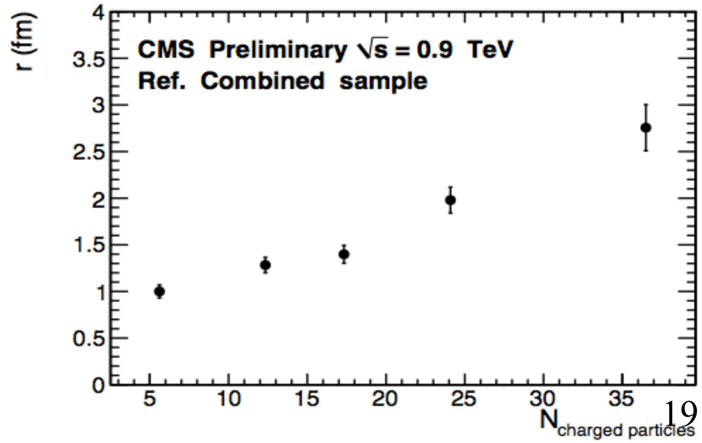
√s = 0.9 TeV $r = 1.59 \pm 0.05$ (stat.) ± 0.19 (syst.) fm and $\lambda = 0.625 \pm 0.021$ (stat.) ± 0.046 (syst.)

√s = 2.36 TeV $r = 1.99 \pm 0.18$ (stat.) ± 0.24 (syst.) fm and $\lambda = 0.663 \pm 0.073$ (stat.) ± 0.048 (syst.)

Multiplicity dependence

Results of fits to 0.9 TeV data

Multiplicity range	P-value	C	λ	r (fm)
2 - 9	9.7×10^{-1}	0.90 ± 0.01	0.89 ± 0.05	1.00 ± 0.07 (stat.)± 0.05 (syst.)
10 - 14	3.8×10^{-1}	0.97 ± 0.01	0.64 ± 0.04	1.28 ± 0.08 (stat.)± 0.09 (syst.)
15 - 19	2.7×10^{-1}	0.96 ± 0.01	0.60 ± 0.04	1.40 ± 0.10 (stat.)± 0.05 (syst.)
20 - 29	2.4×10^{-1}	0.99 ± 0.01	0.59 ± 0.05	1.98 ± 0.14 (stat.)± 0.45 (syst.)
30 - 79	2.8×10^{-1}	1.00 ± 0.01	0.69 ± 0.09	2.76 ± 0.25 (stat.)± 0.44 (syst.)



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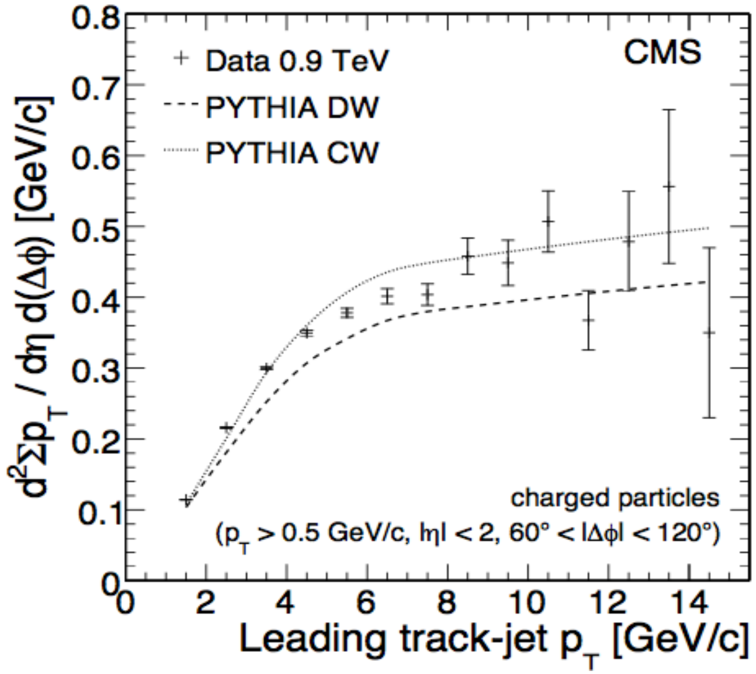
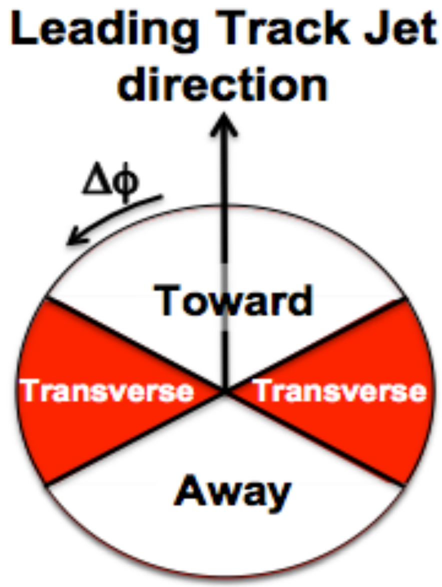
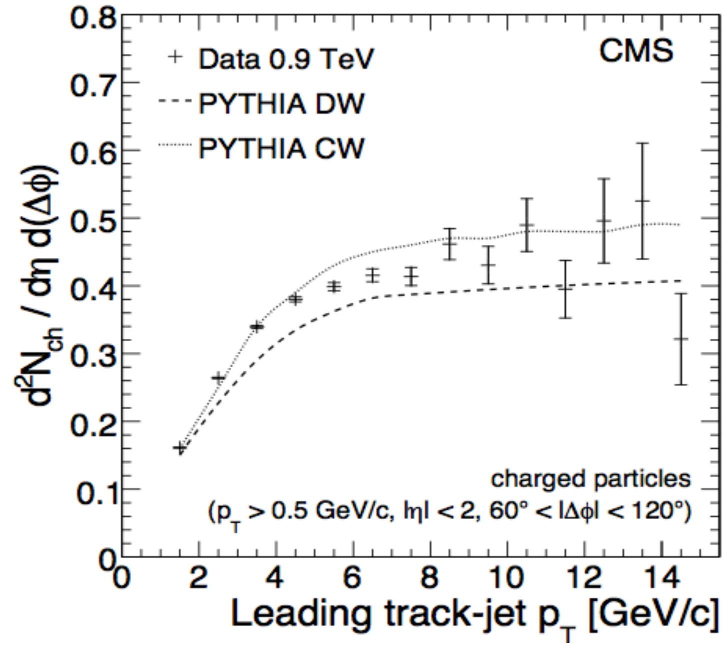
Underlying Event Studies

Underlying event activity at √s = 0.9

- MinBias event selection, with additional requirement of a ‘hard’ scattering via a track jet with p_T > 3 GeV
- Study the particle density and scalar p_T sum in the transverse region, for particles with |η| < 2 and p_T > 0.5 GeV (uncorrected data)





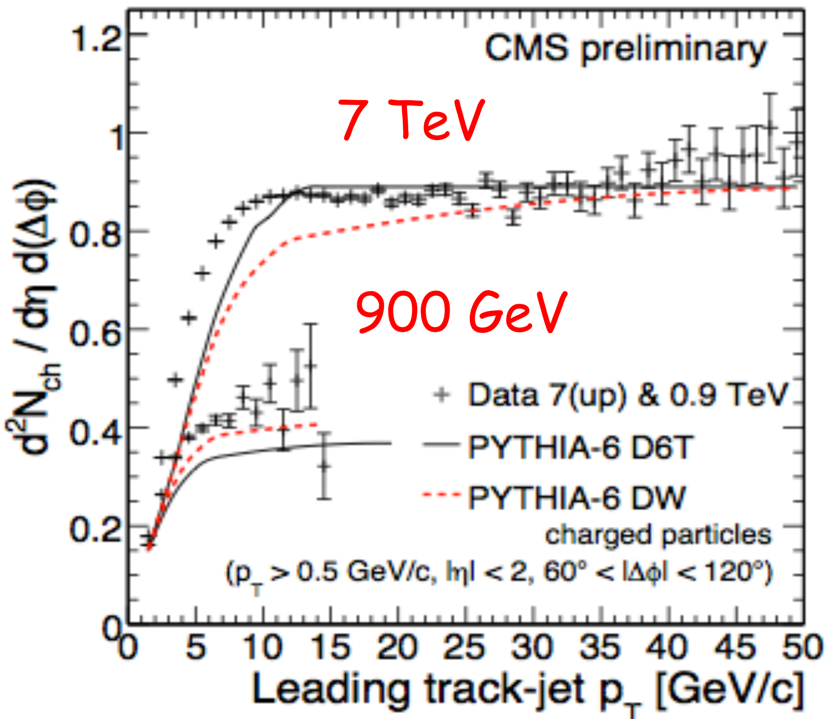


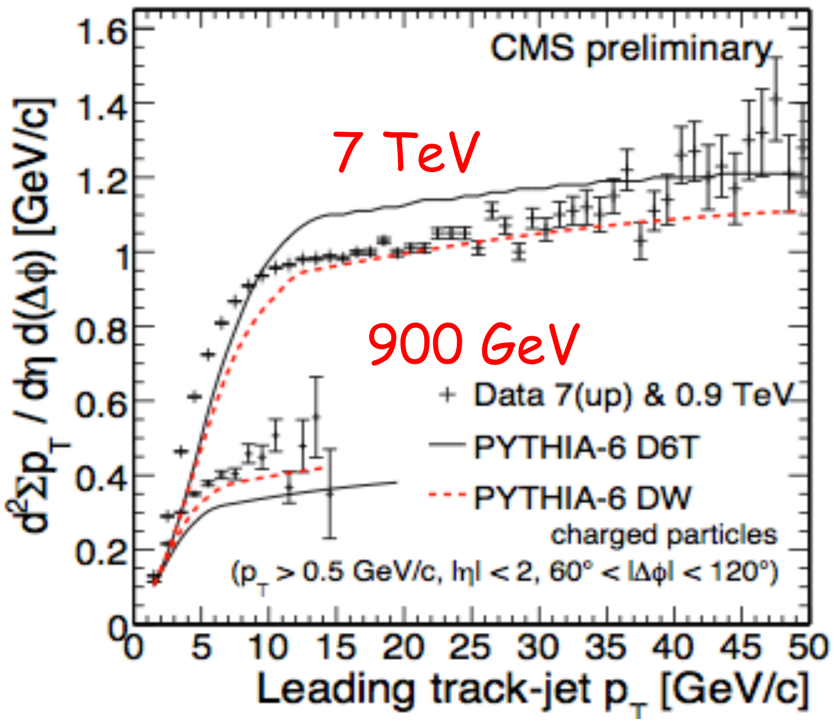
Model Comparison: DW = Standard Tune CW = New Tune (p_{T0}= 1.8 GeV, ε= 0.3)

More food for MC model tuning…

Underlying Event Studies

- MinBias event selection
- Analysis of the 7 TeV data

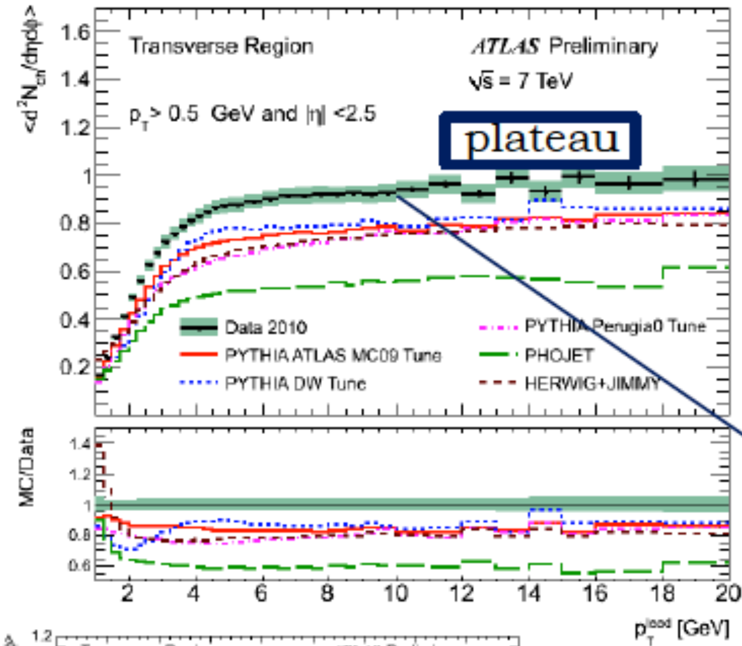


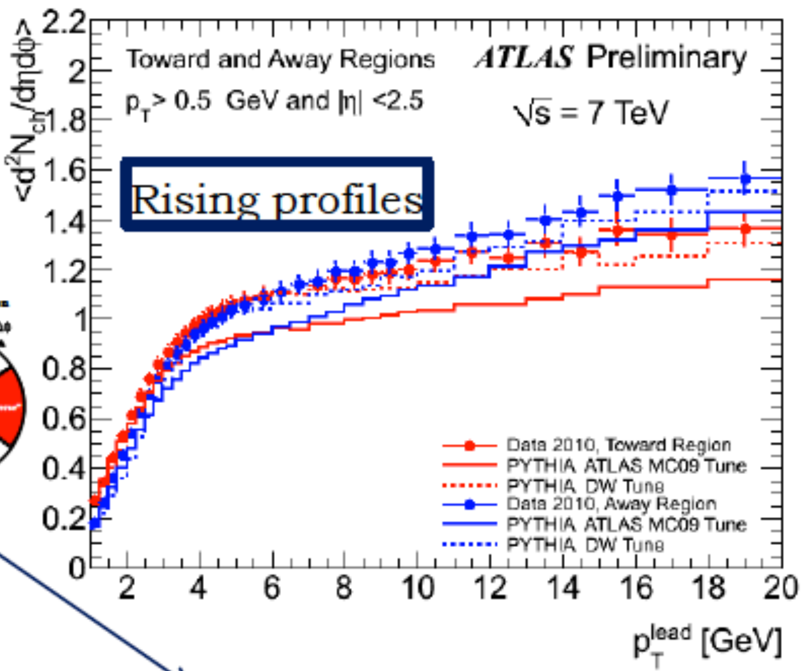


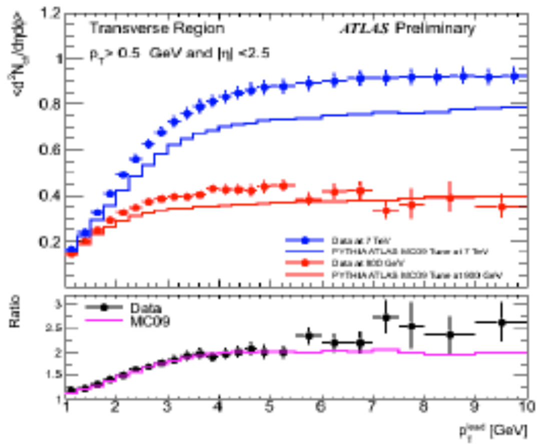
- Also: Jet Area/Median Approach Analysis

Underlying event activity increases with factor ~2 at 7 TeV
Significant increase of multi-parton interactions?

Underlying Event Studies







Roughly twice the particle density compared to minimum bias measurements.

UE more active than predicted.

ATLAS-CONF-2010-081

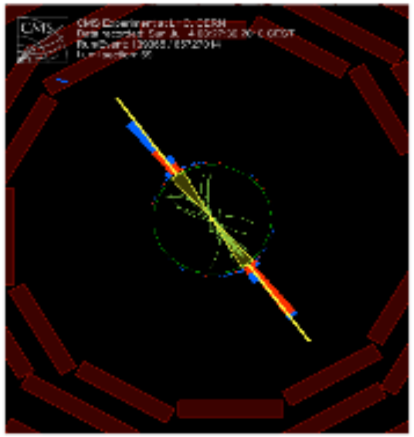
Event Shapes

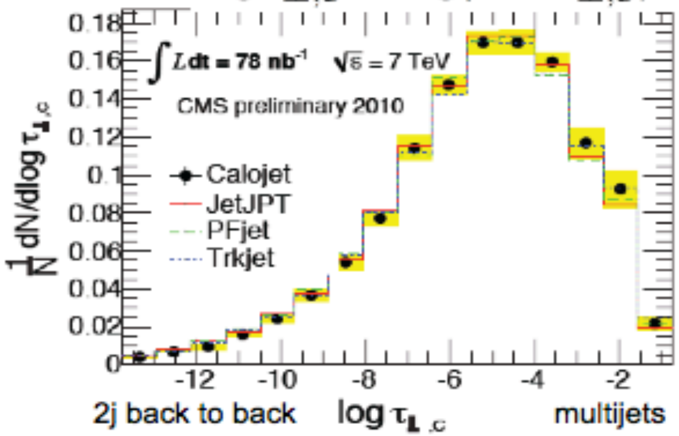
Hadronic Event Shape

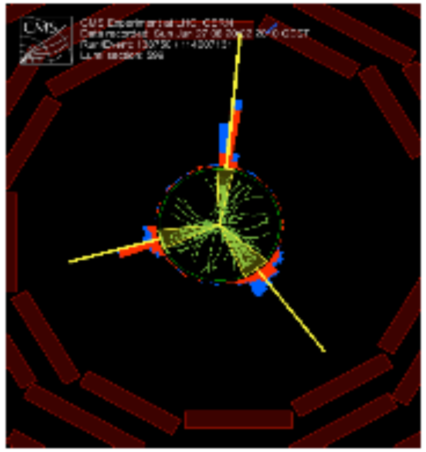
- **Central transverse thrust**

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

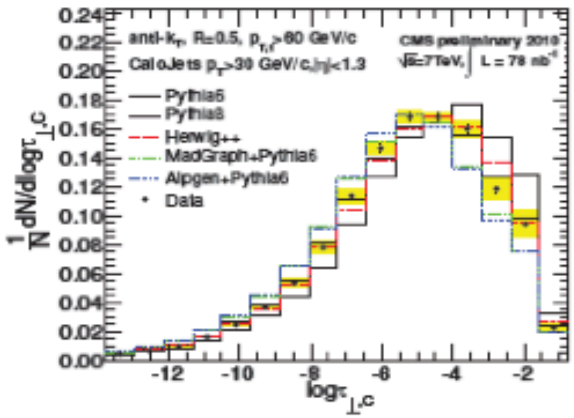
$$\log \tau_{\perp,C} = \log(1 - T_{\perp,C})$$







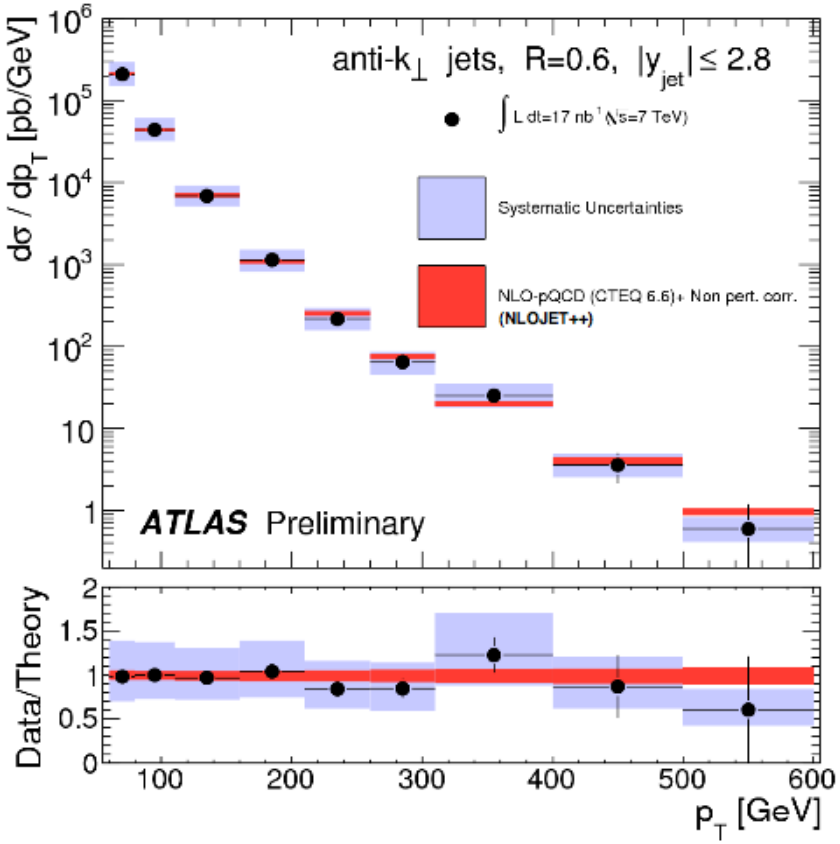
- 4 jet types in very good agreement
- $p_T^{leading}$>60 GeV, $|\eta_{j1j2}|$<1.3, p_T>30 GeV, $|\eta|$<1.3,
  → JES dominant syst, JER and position resolution (±10%)



Inclusive Jet Cross Sections

❑ Inclusive jet cross-section (~Tevatron x 100)

- Restricted to 17 nb^{-1} (no pile-up contamination) and p_T^{jet}>60 GeV and $|y^{jet}|$<2.8
- Correct measured jets to particle level using parton-shower MC (Pythia, Herwig):
  ➔ Compare to NLO pQCD prediction corrected from hadronization and underlying event
- Theoritical uncertainties on σ (PDF, α_S, scale): ■
  ✓ **10%** over measurable p_T range y~0
  ✓ Increase to **30-40%** at |y|~2.8
- Experimental uncertainties on σ: ■
  ✓ **30-40%** dominated by Jet Energy Scale
  ✓ 11% from Luminosity not included

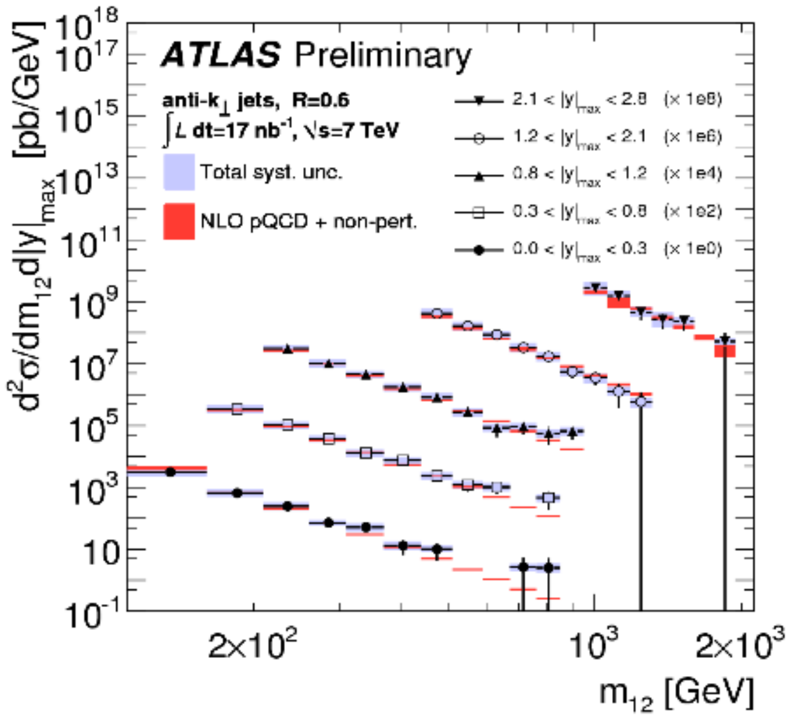


Good agreement data-MC over 5 orders of magnitude

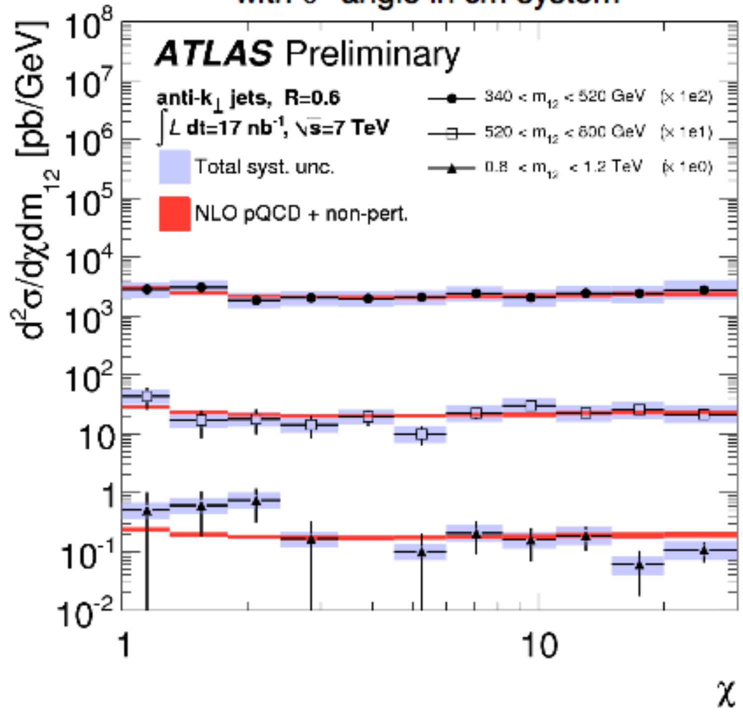
Di-jet Cross Sections

❑ Dijet cross-section

- Main jet : p_T>60 GeV. Sub-leading jet: p_T>30 GeV



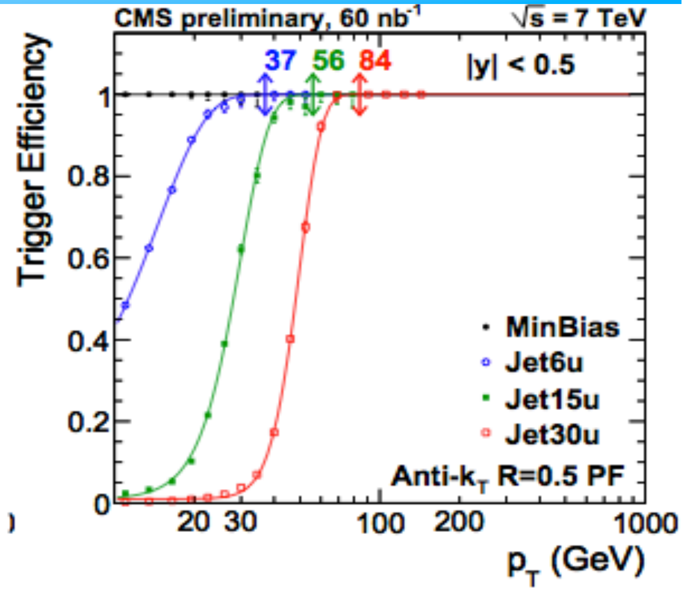
χ= exp(|y1-y2|) ~ (1+cos θ*)/(1-cos θ*)
with θ* angle in cm system

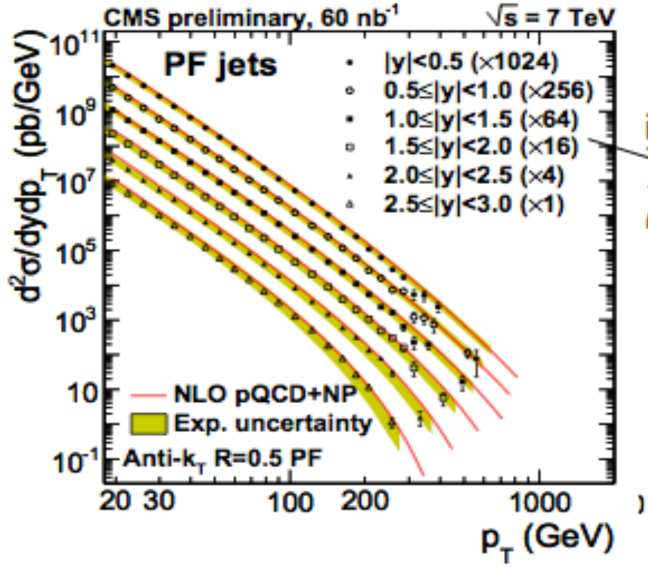


Good agreement data-MC in all rapidity and mass regions

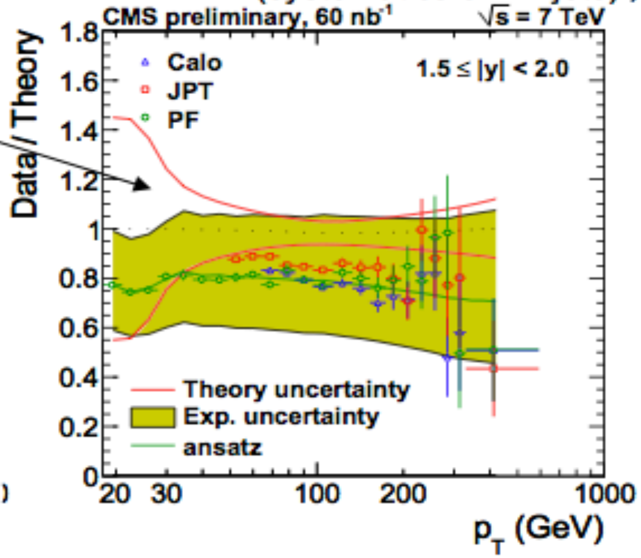
Jet Cross Sections

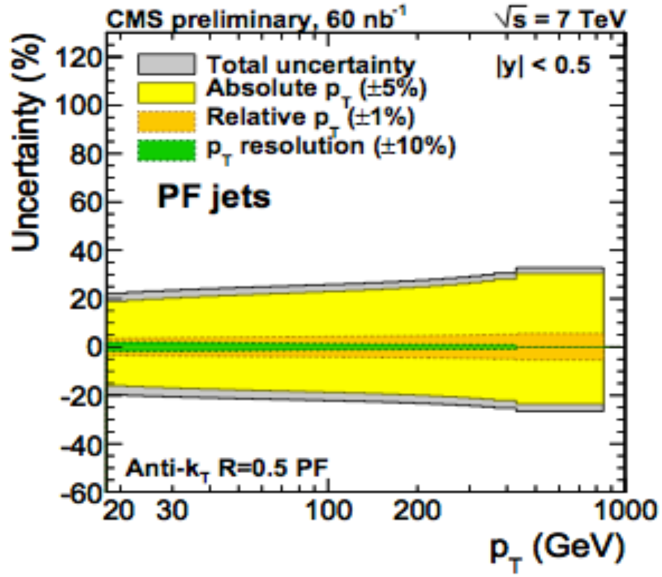
- Triggers: min.bias + single jet > 6,15,30 GeV
  combined exclusively at ~99% turn-on
- Resolution unfolding → hadron level
- Agreement with NLO using CTEQ6.6
  non-perturb. correction from Pythia-Herwig average
  PDF uncertainty comparing different PDF sets
  μ_f, μ_r uncertainty: pT/2 → 2 pT





(systematics of PF jets)

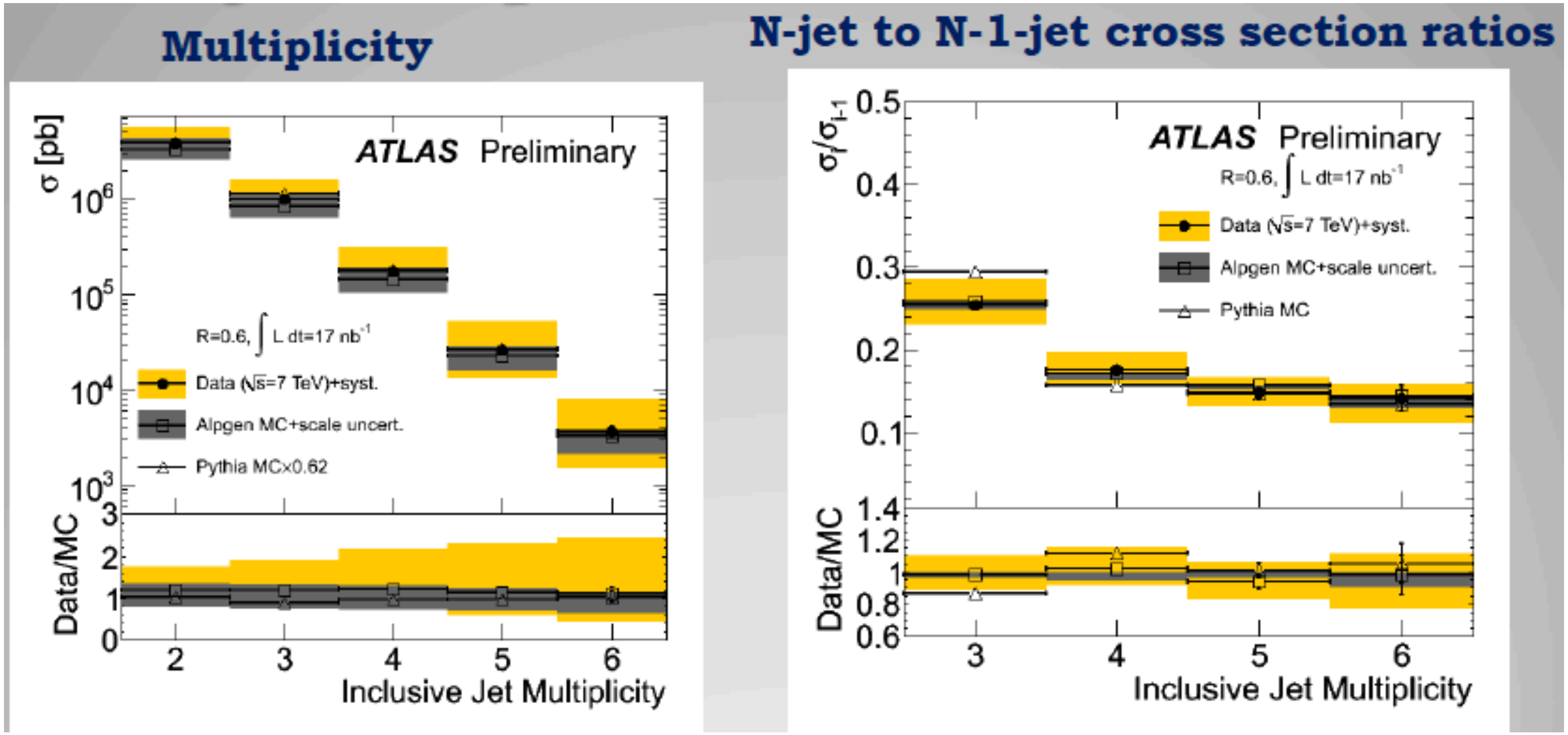




- Few % difference in JES between algos → 10% on the xsec

Anti-K_T jet algorithm with R=0.5

Jet Multiplicity

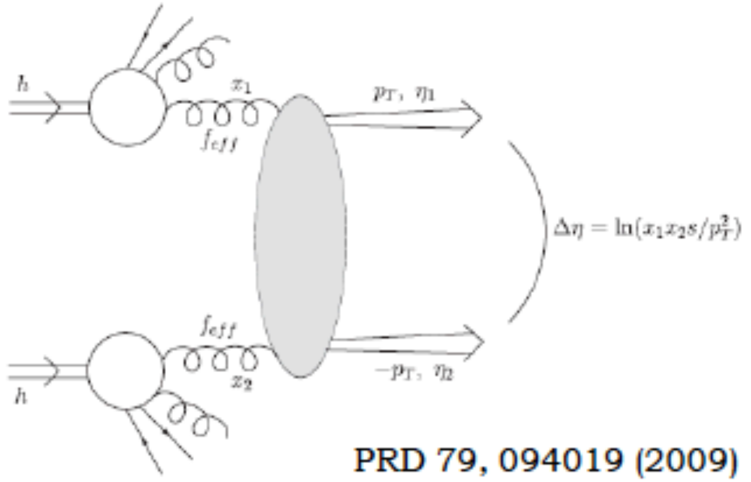


Data are more or less as expected, but still large experimental errors…

More Di-jet Studies

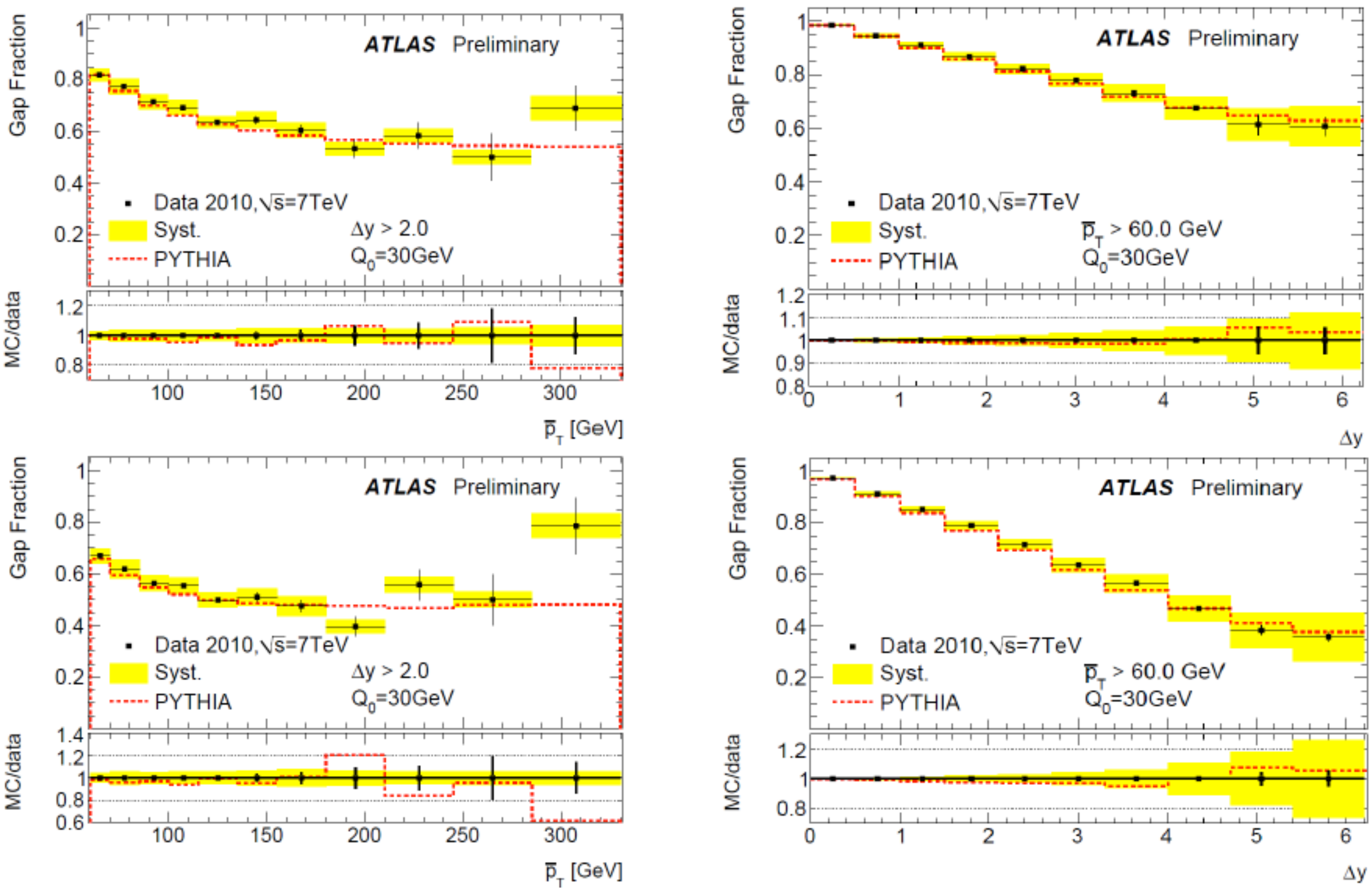
Dijet Production with a Jet Veto

- Measures the fraction of dijet events in that do not contain an additional jet in the rapidity region bounded by the dijet system.
- Requirement: Two good anti-kt jets (R=0.6) with average p_T > 60 GeV, Each with p_T > 30 GeV, within rapidity |y| < 4.5 and rapidity separation Δy > 2. Forward calorimeter is used in this measurement.



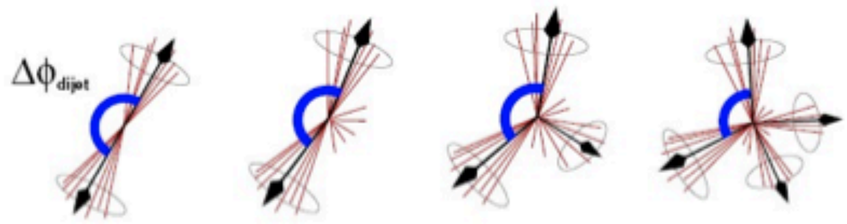
PRD 79, 094019 (2009)

Di-jets + Central Gap events

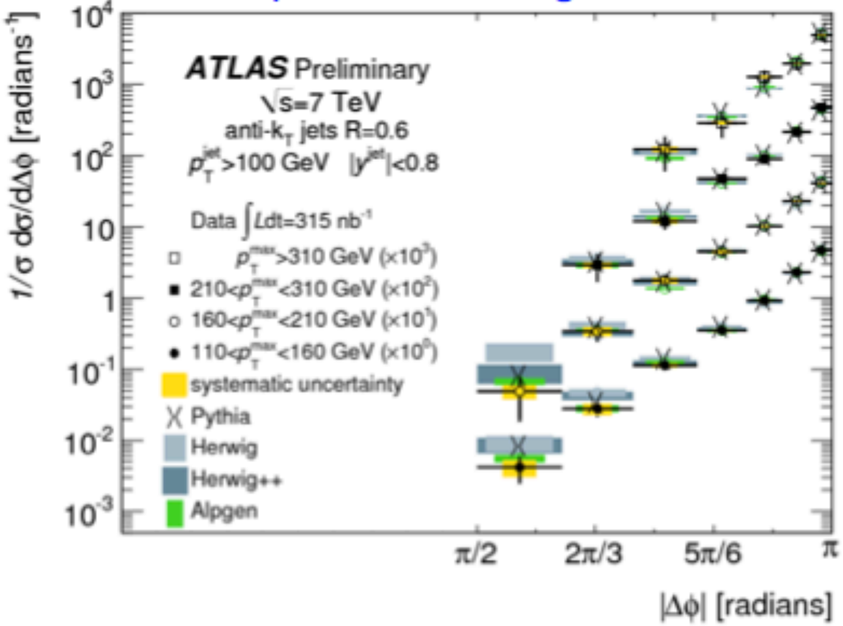


Azimuthal Decorrelations

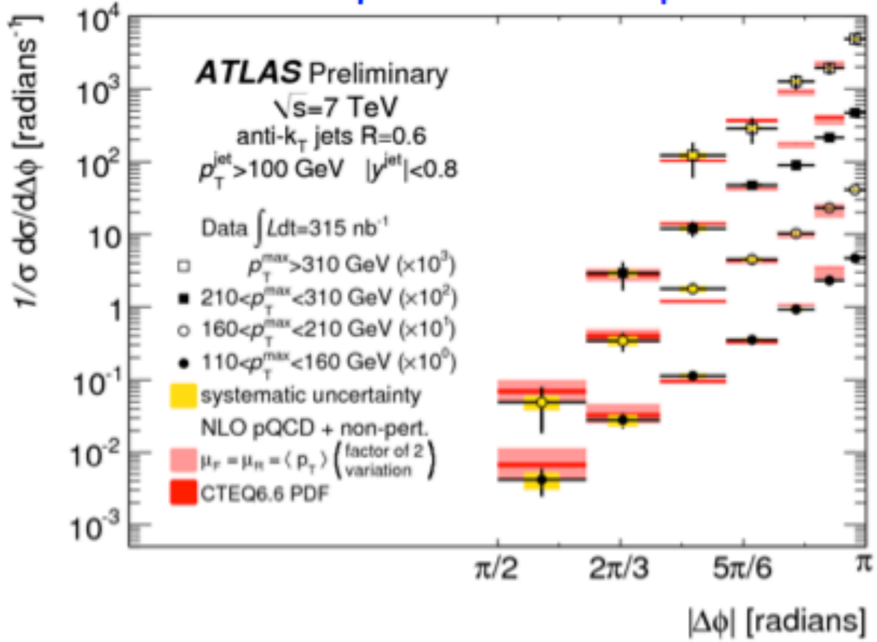
Angle between leading jets sensitive to higher-order QCD radiation without explicit 3rd jet reconstruction



Comparison to MC generators



Comparison to NLO pQCD



Good agreement for both Alpgen and NLO pQCD

Azimuthal Decorrelations

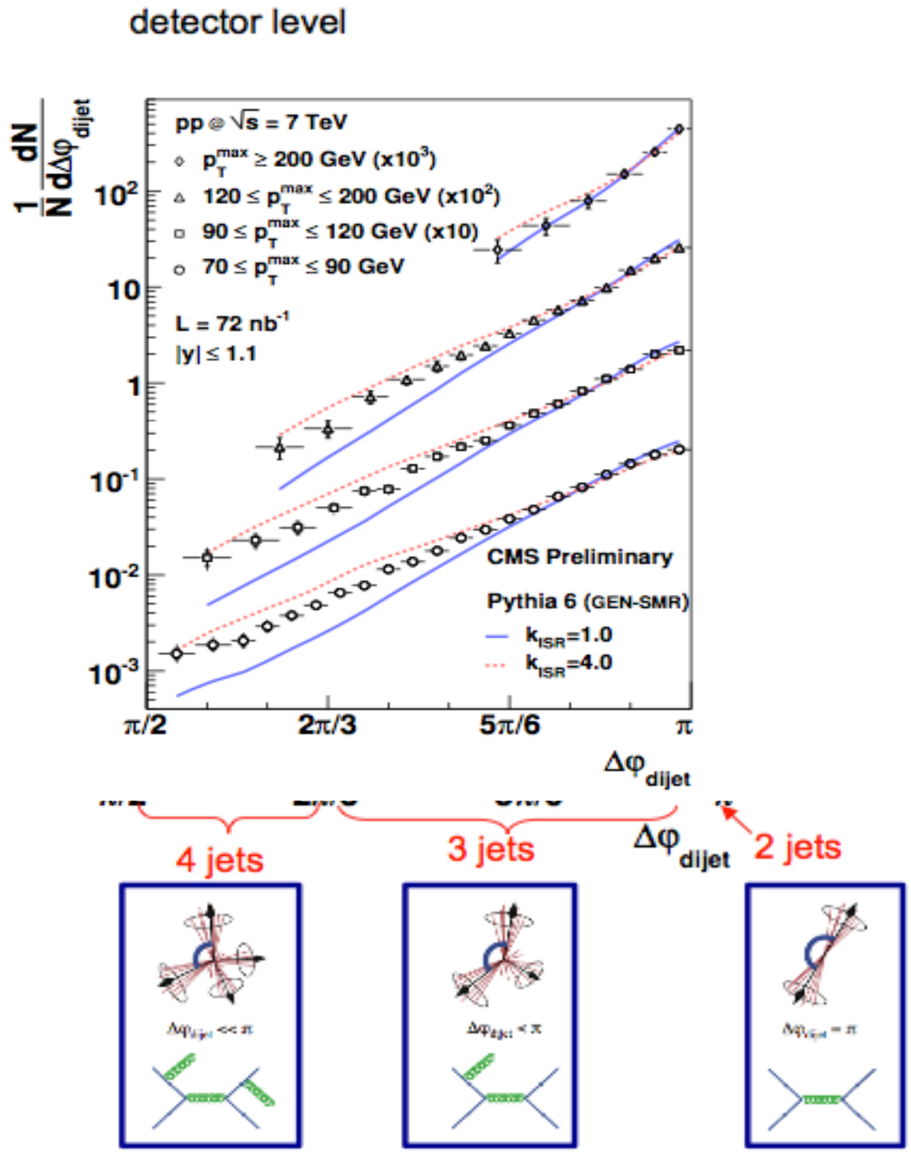
Dijet Azimuthal Decorrelations

- $\Delta\varphi_{dijet} = |\varphi_{jet1} - \varphi_{jet2}|$

  sensitive to higher order QCD radiation effects

- Madgraph underestimates low $\Delta\phi$ (multi-jet) region

- High sensitivity to ISR, much less to FSR

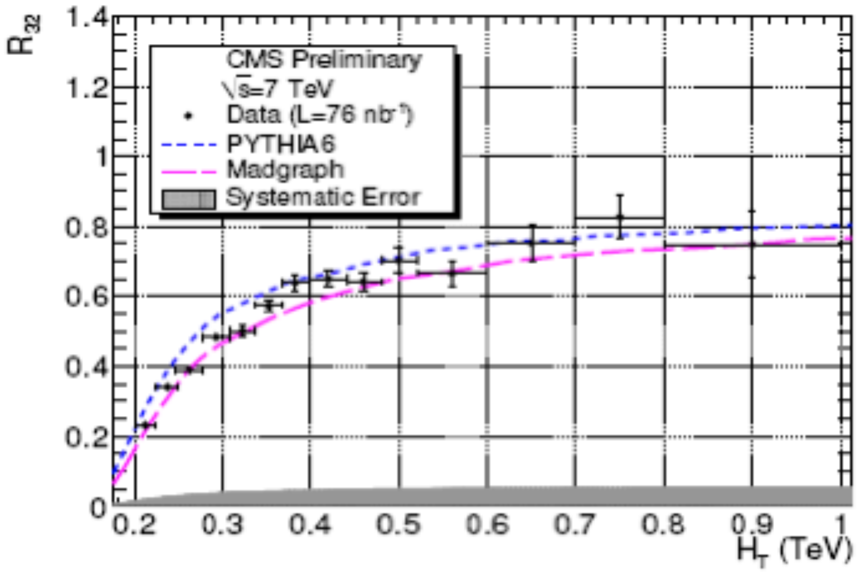


3 to 2 jet ratios

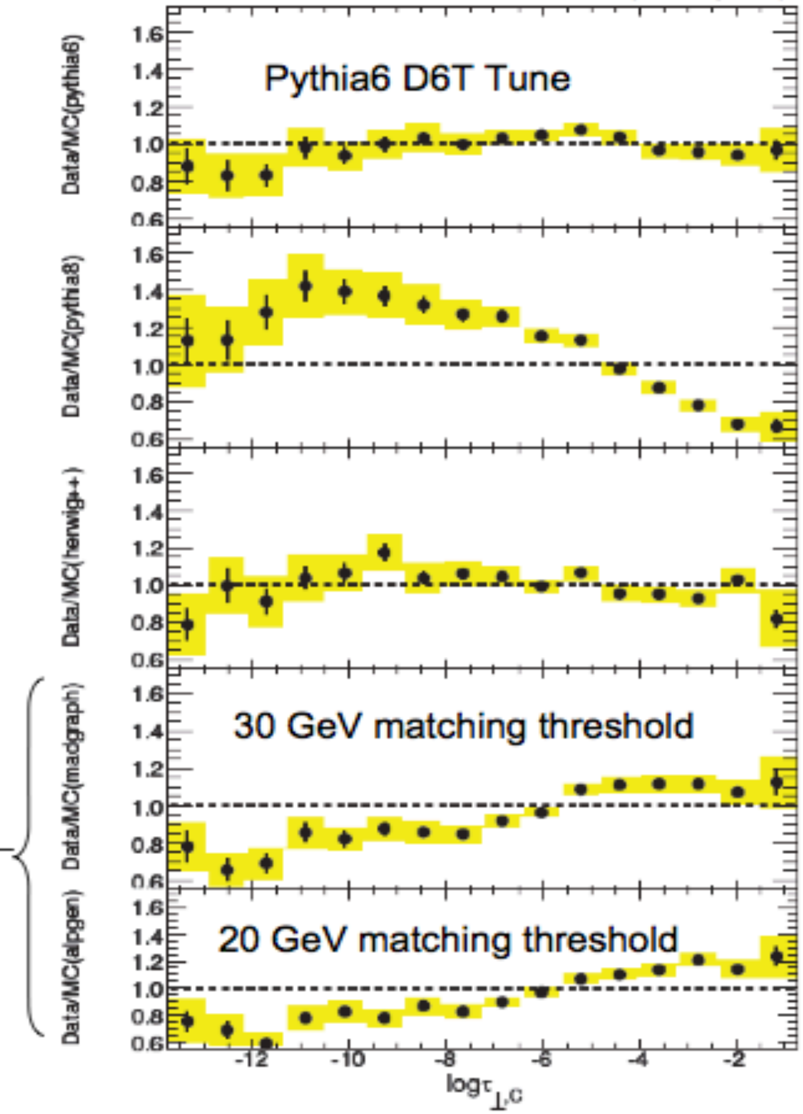
2j → 3j results

- **Hadronic event shape:**
  ME MC underestimate 3jets region
  - same bahviour for higher $p_T^{leading}$
  - improves for higher jet multiplicity

- **3j / 2j VS H_T:**
  not conclusive yet



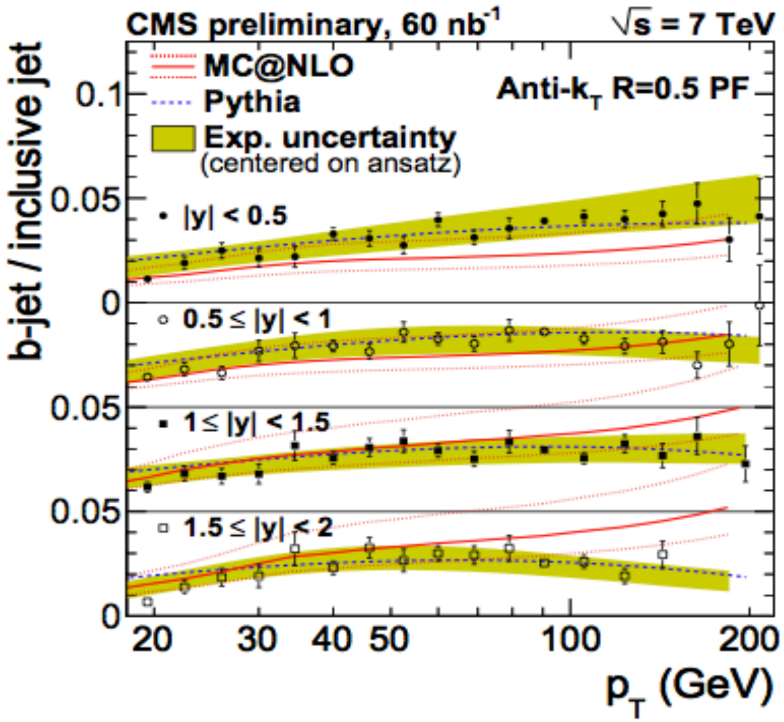
detector level (calo jets)



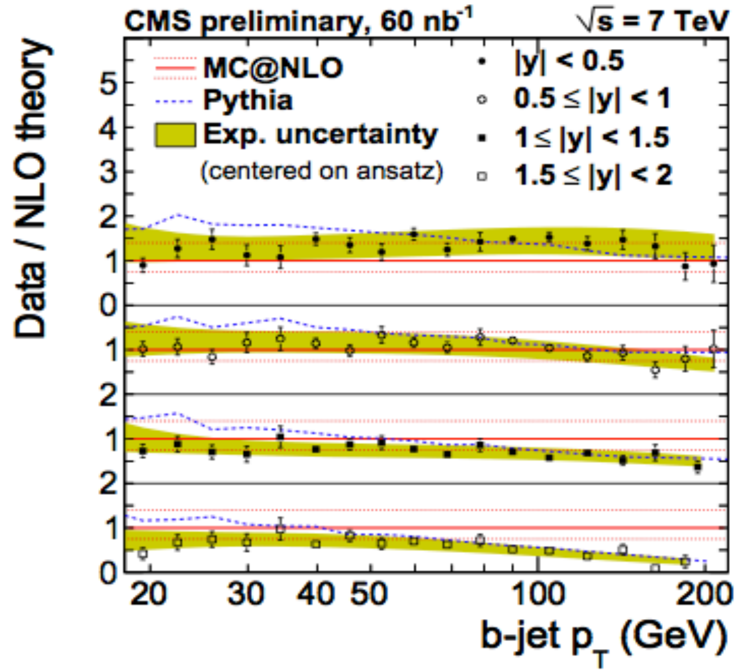
b-jet Cross Sections

b-jet dσ/dp_T

- ❑ Ratio to inclusive → partial syst cancellation
  - b-tag efficiency ~ 20%
  - JES b-jets VS LF jets ~1%



❑ b-jet xsec

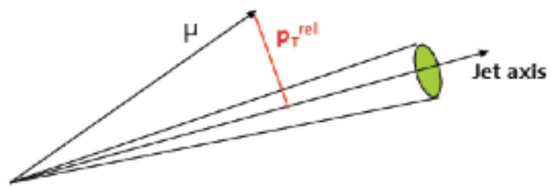


- ❑ Comparison to theory:
  - b-jets from MC@NLO (CTEQ5M)
  - inclusive jets from NLO (CTEQ6.6M)

→ reasonable agreement with NLO **but different p_T, η shapes**

b-Production Cross Sections

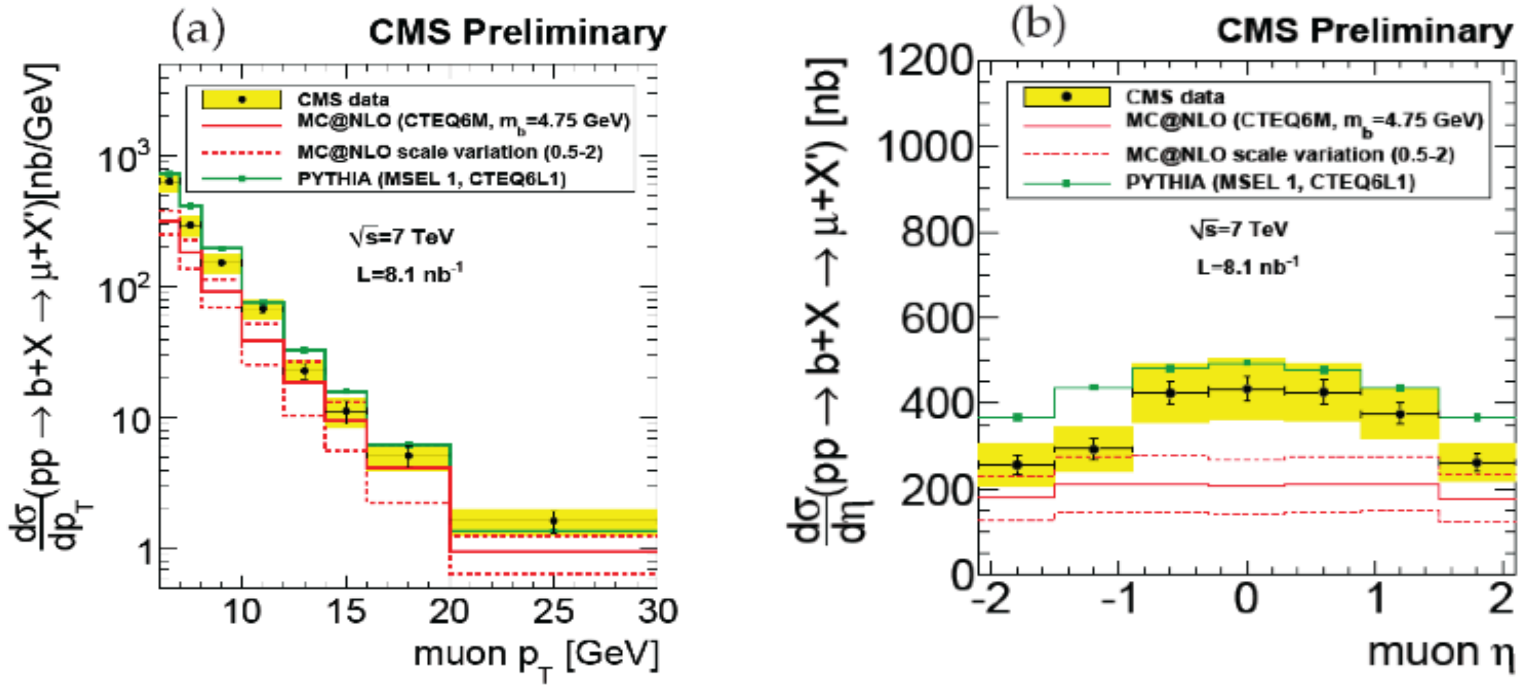
$b \rightarrow \mu + X$



- Measurement from p^T_{rel} distribution fit with b and cudsg templates (p_T^μ>6 GeV, $|\eta^\mu|$<2.1)

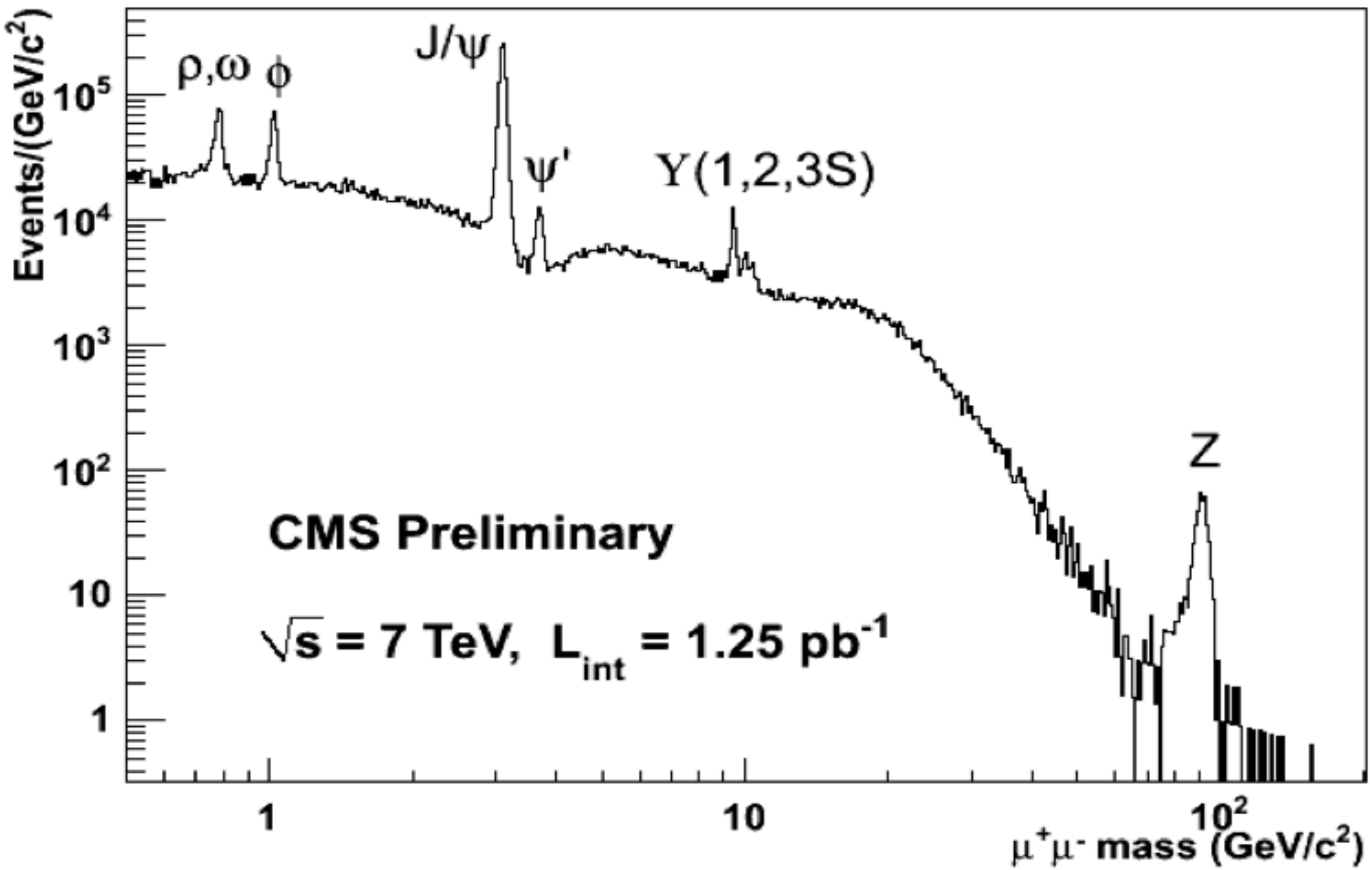
$$\sigma = (1.48 \pm 0.04_{\text{stat}} \pm 0.22_{\text{syst}} \pm 0.16_{\text{lumi}})\ \mu\text{b}.$$

$$\sigma_{\text{MC@NLO}} = [0.84^{+0.36}_{-0.19}(\text{scale}) \pm 0.08(m_b) \pm 0.04(\text{pdf})]\ \mu\text{b}.$$



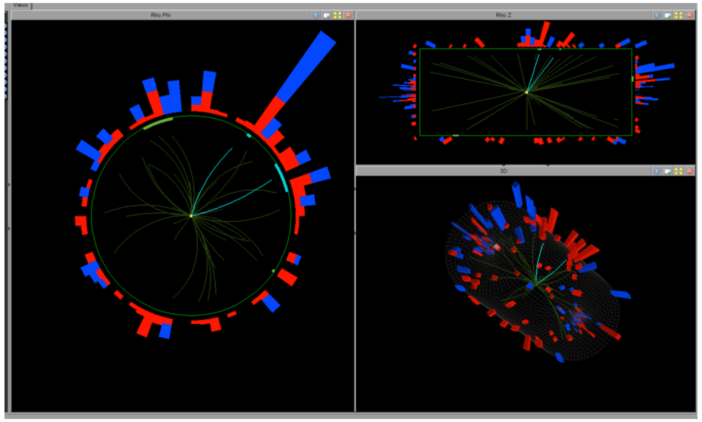
- Same results as inclusive b-jets: **NLO underestimates xsec at low η and low p_T**

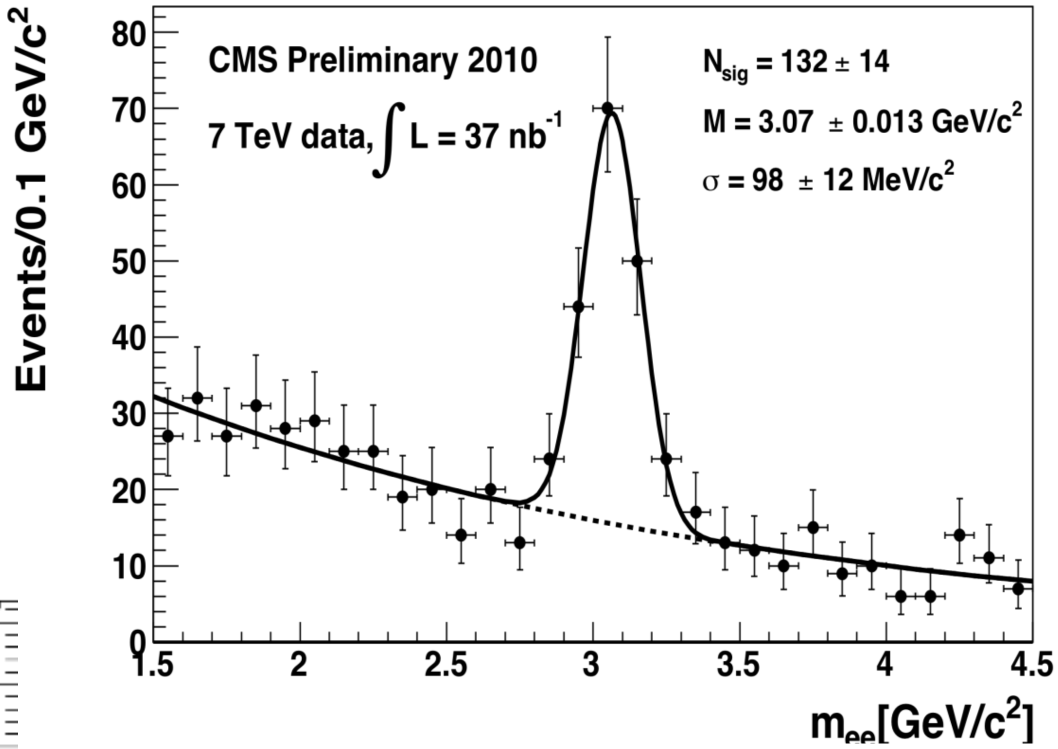
Resonances → μμ

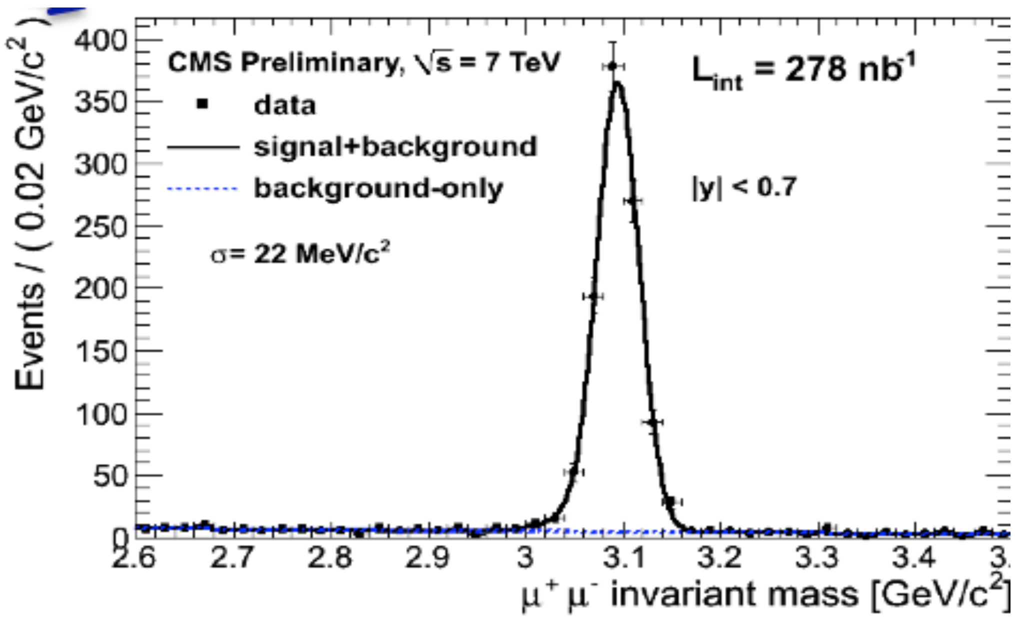


Remember: CMS = Compact Muon Solenoid!!

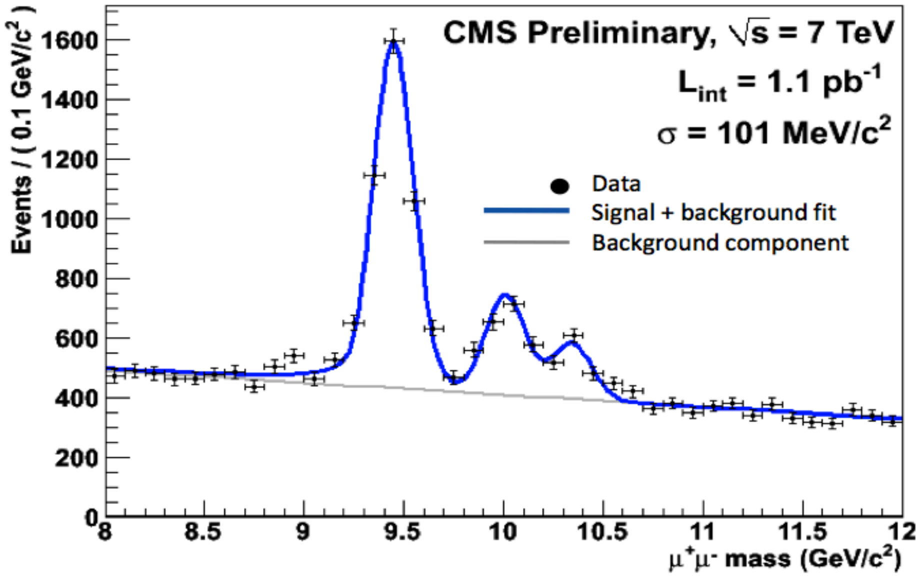
J/ψ → μμ and ee




CMS Preliminary 2010
7 TeV data, $\int L = 37\ nb^{-1}$
N_{sig} = 132 ± 14
M = 3.07 ± 0.013 GeV/c^2
σ = 98 ± 12 MeV/c^2
Events/0.1 GeV/c^2
m_{ee}[GeV/c^2]

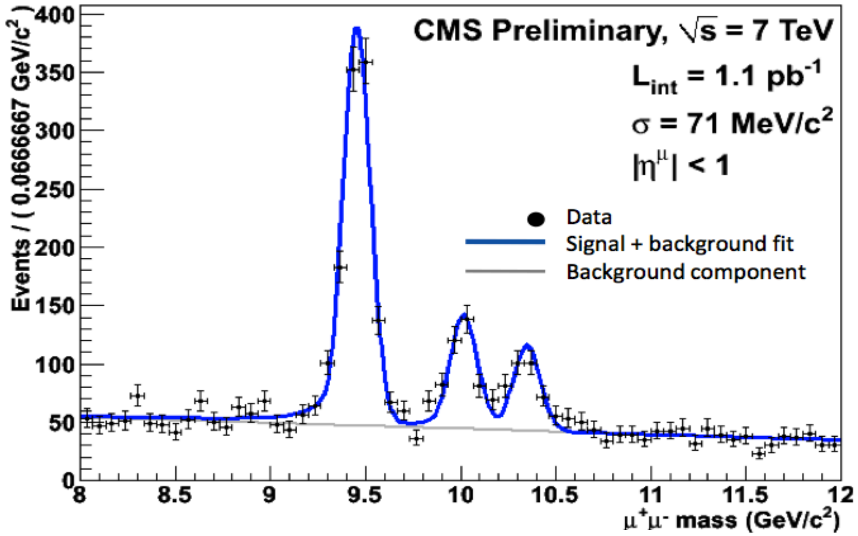

CMS Preliminary, $\sqrt{s}$ = 7 TeV
data
signal+background
background-only
σ= 22 MeV/c^2
L_{int} = 278 nb^{-1}
|y| < 0.7
Events / (0.02 GeV/c^2)
$\mu^+\mu^-$ invariant mass [GeV/c^2]

Υ → μμ



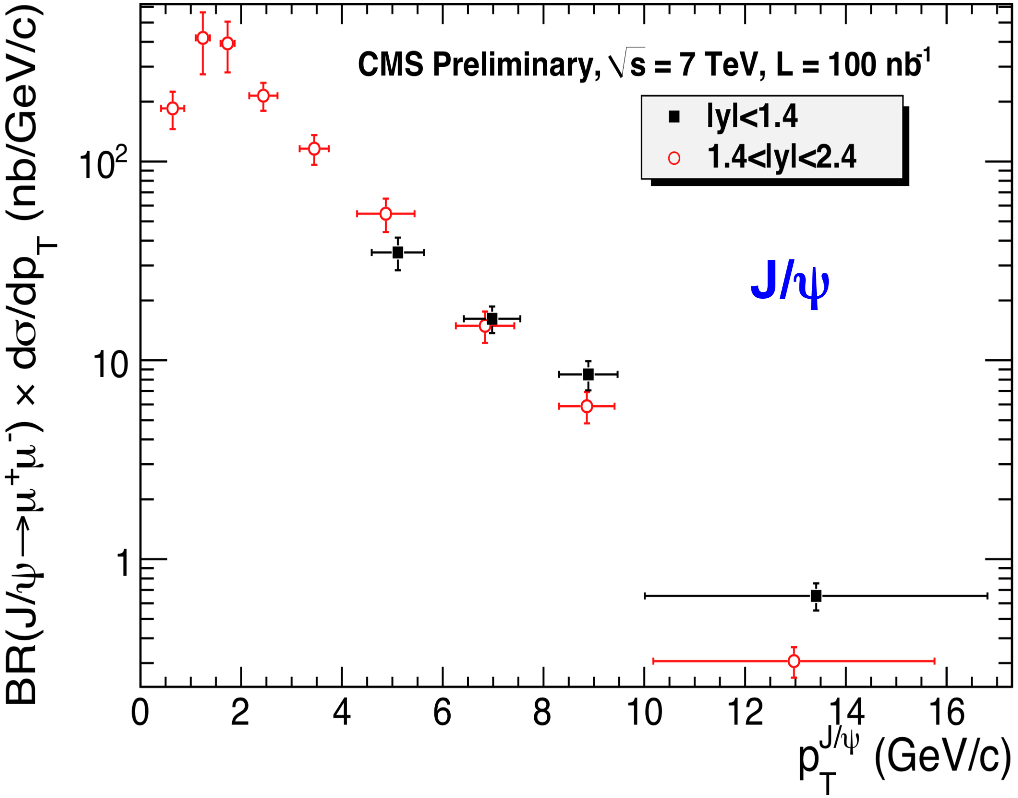
Signal events Υ(1S) = 3106 83
Signal events Υ(2S) = 893 57
Signal events Υ(3S) = 508 51

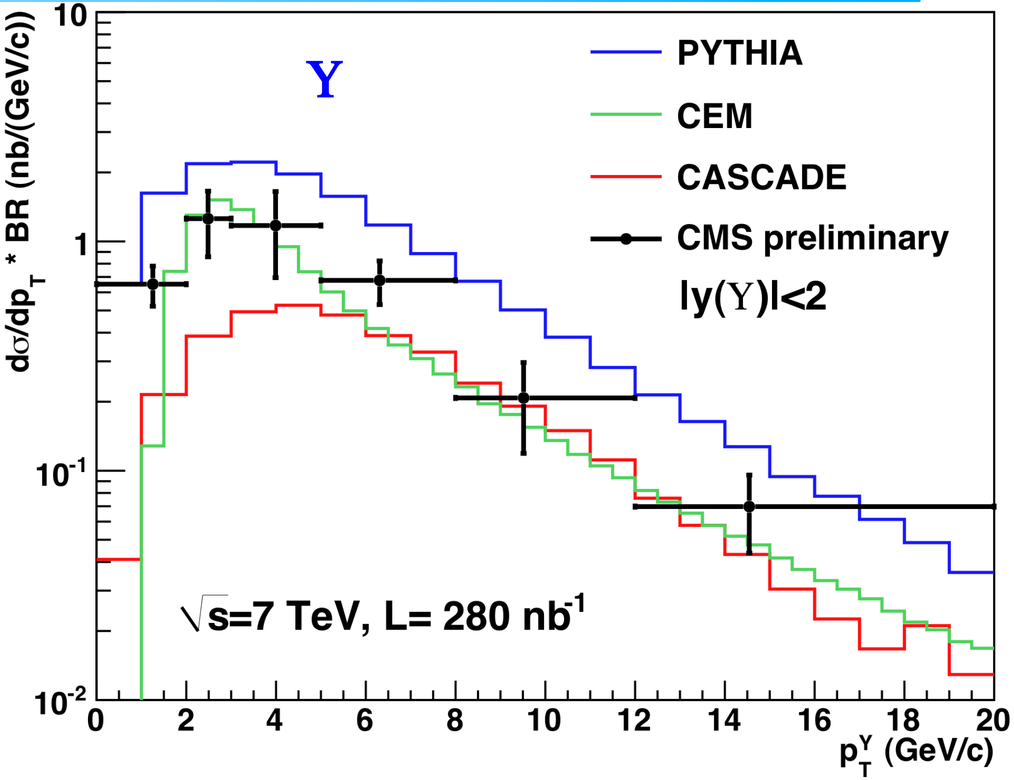
Muons in the barrel detectors only



Signal events Υ(1S) = 979 38
Signal events Υ(2S) = 278 24
Signal events Υ(3S) = 212 22

J/ψ(Υ)→μ+μ- Differential/Total Cross Section





Differential cross sections as a function of p_T (in the null polarization scenario).

The total cross sections are: (p_T between 4-30 GeV and $|\eta|<2.4$)

σ(pp→J/ψ + X)·BR(J/ψ→μ+μ−) = (289.1 ± 16.7(stat) ± 60.1(syst)) nb

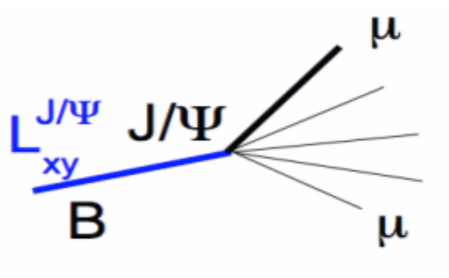
and ($|\eta|<2.0$)

σ(pp →Υ(1S)+X)·B(Υ(1S)→μ+ μ−)=(8.3±0.5(stat)±0.9(syst) ±1.0(lum))nb

The systematic uncertainties are dominated by the statistical precision of the muon efficiency determination from data and by the uncertainty on the luminosity.

Fraction of J/ψ→μ+μ- from B Hadron decays

Traditional approach: the B transverse decay length used to separate the prompt from the non-prompt component

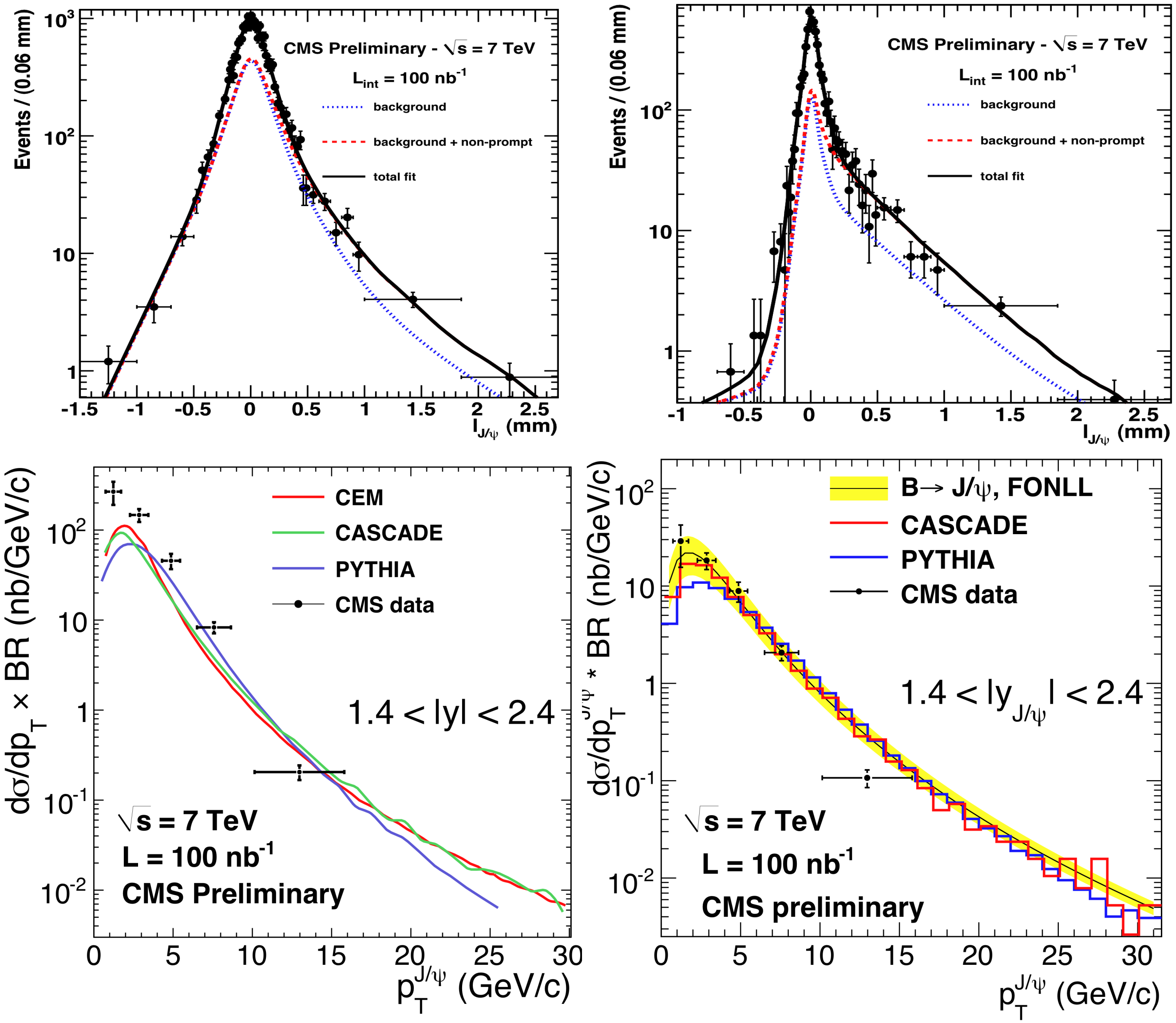


and to measure the prompt (non-prompt) differential cross section.

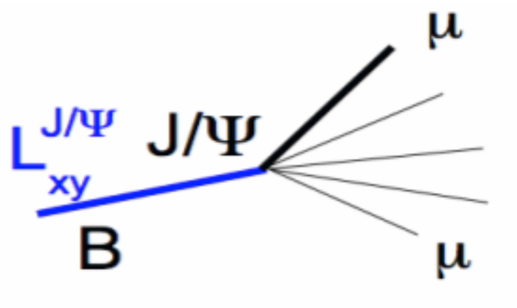
Non prompt cross section:

BR(J/ψ→μ+μ−)· σ(pp→bX→ J/ψ+X’) = (56.1 ± 5.5(stat) ± 7.2(syst))nb

(p_T>4GeV/c and |y| <2.4)



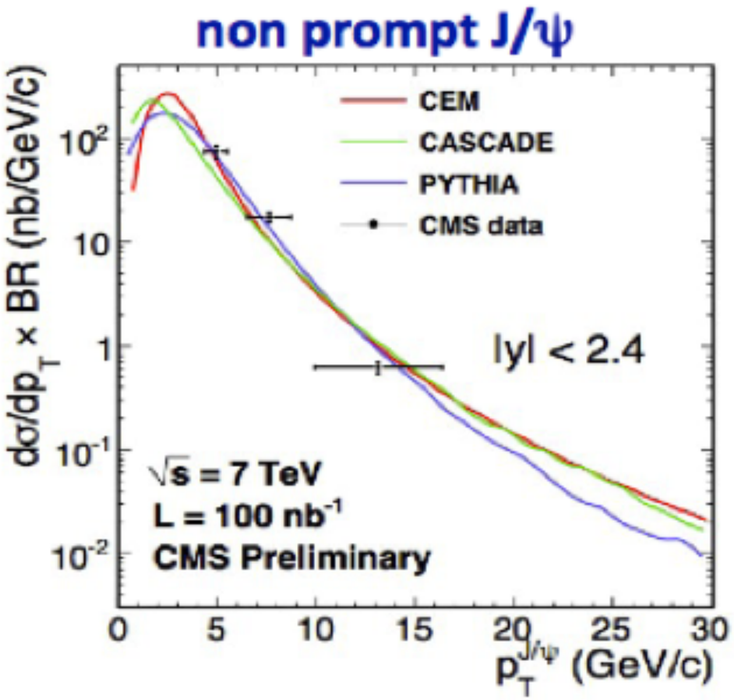
J/ψ from B-hadrons

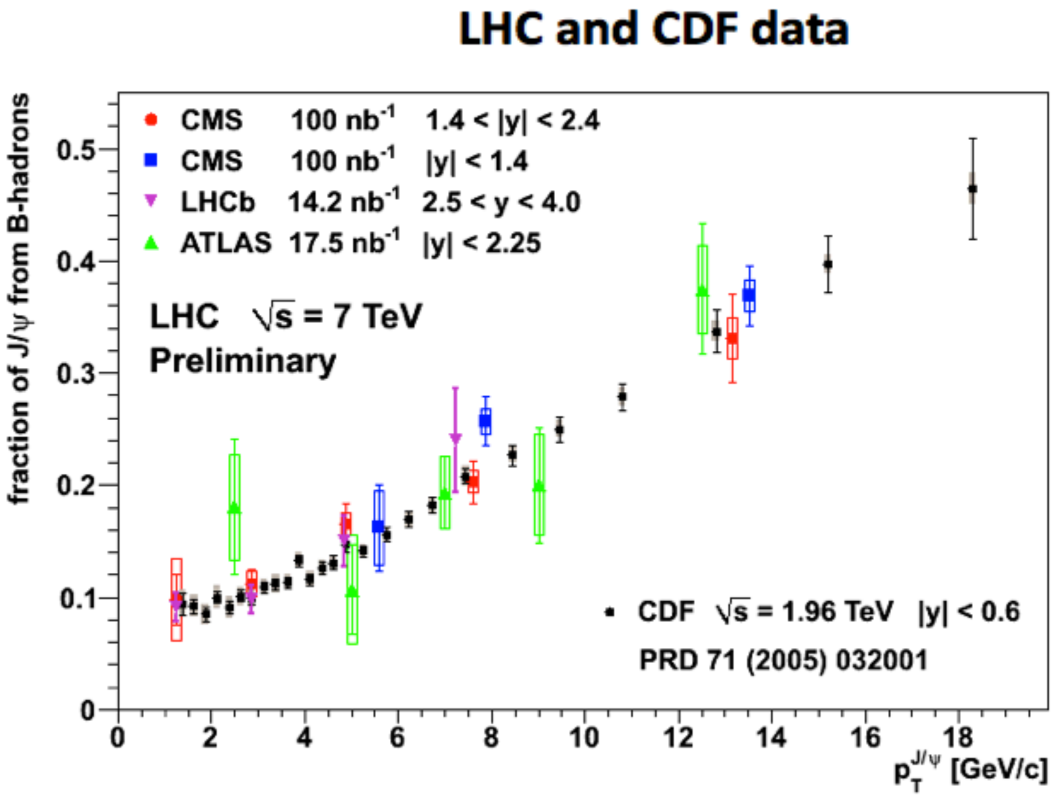


Non prompt J/ψ :

σ_{NP}* BR= **56.1±5.5(stat)±7.2(syst) nb**

(p_T within 4-30GeV/c, |η|<2.4)

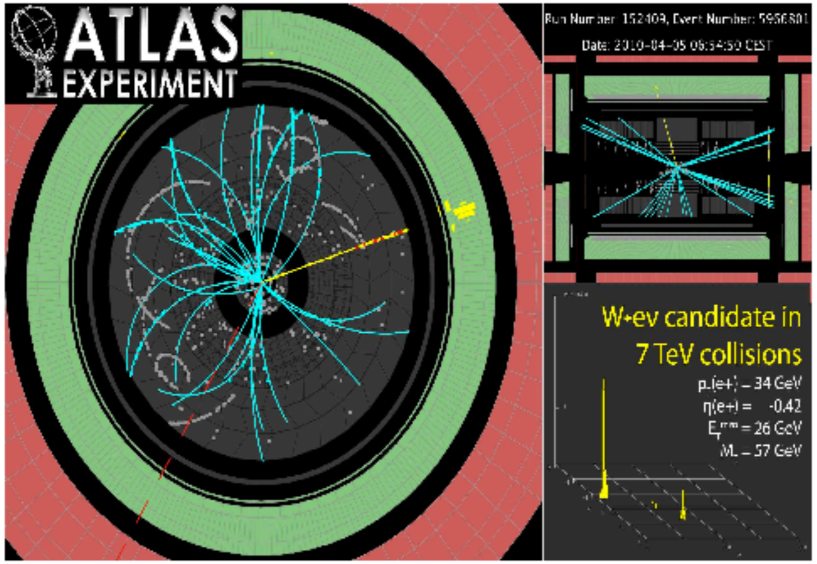


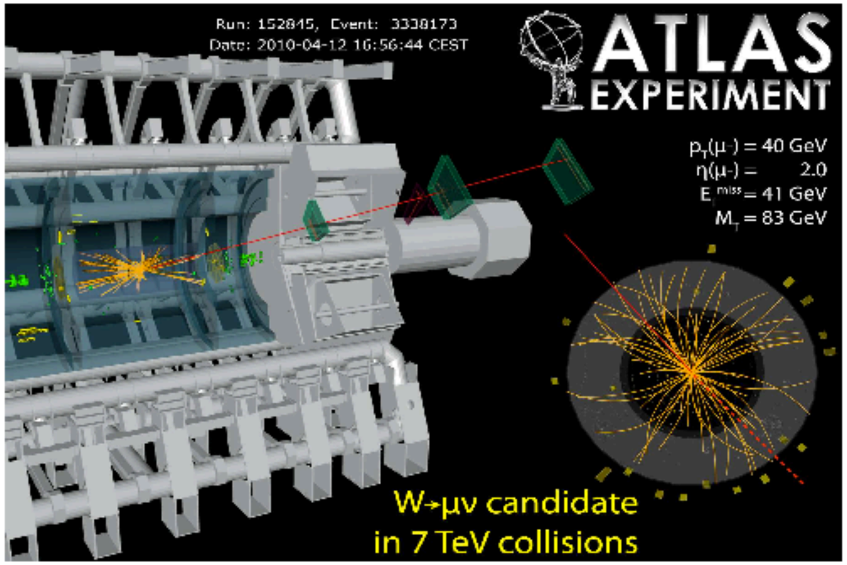


Production of heavy bosons:W/Z

❑ Fundamental milestone in the rediscovery of the Standard Model

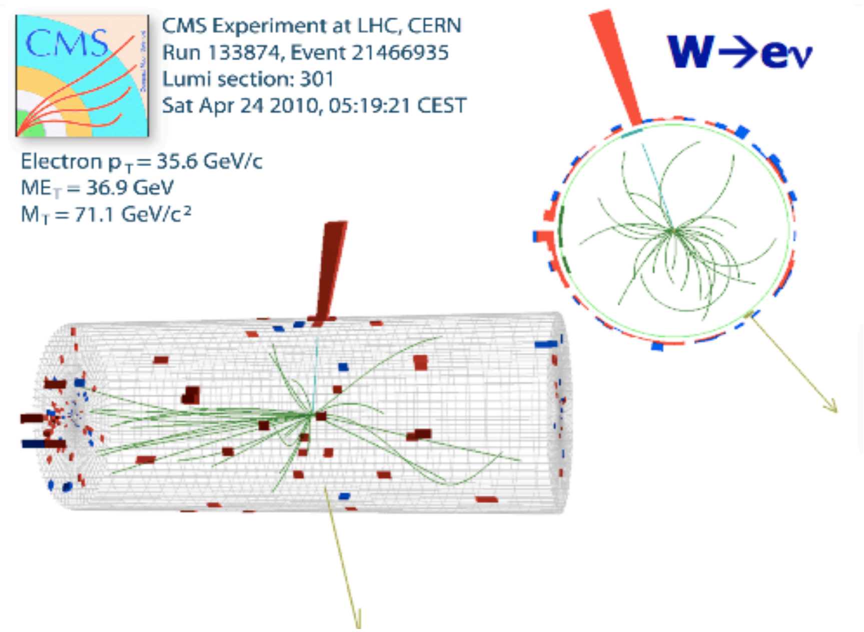
- W powerfull tool to constraints the PDF
- Among dominant source for New physics and top (W+4 jets)
- High statistics sources of pure high pT leptons
  - ➔ EM calo calibration (E/p), Muon Spectrometer aligment / Toroidal field mapping

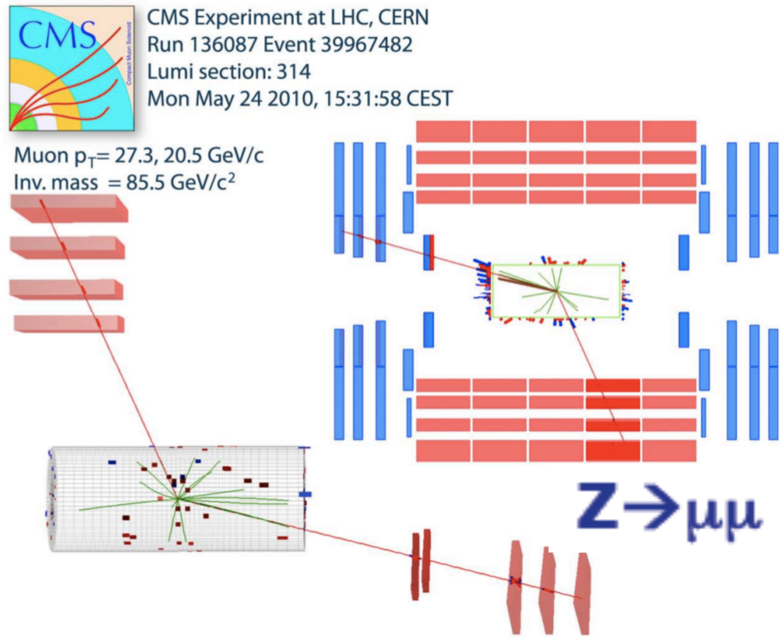


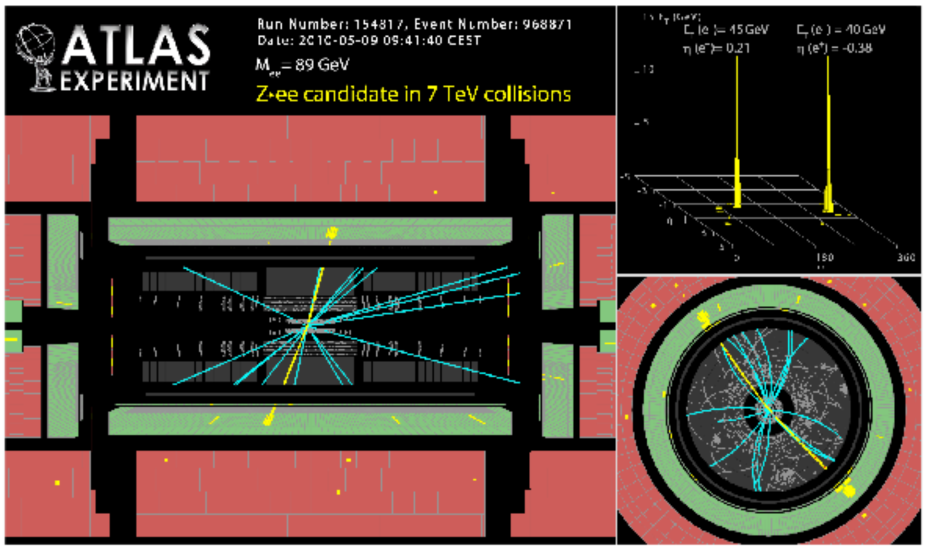


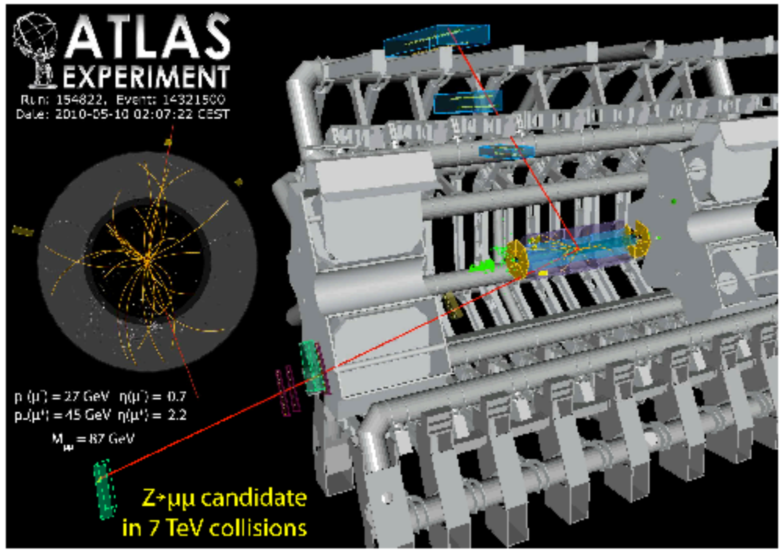
Very clean signatures !

Production of heavy bosons:W/Z



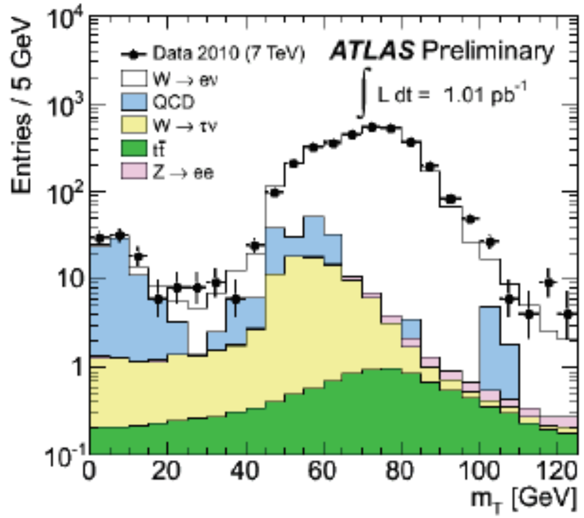


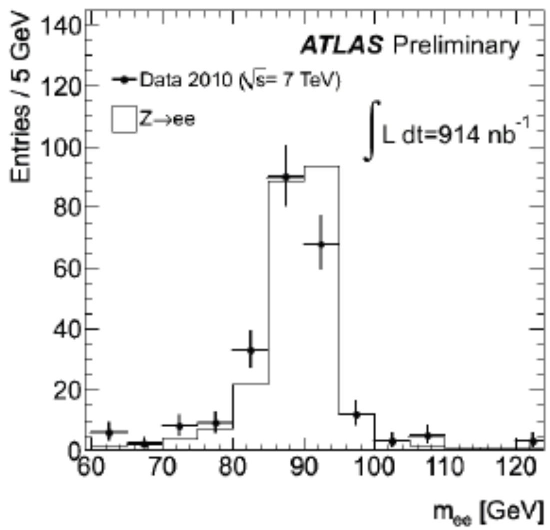




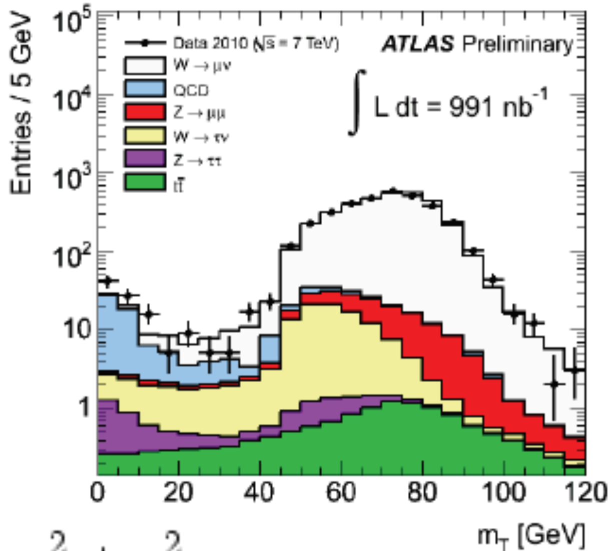
ATLAS W/Z Studies

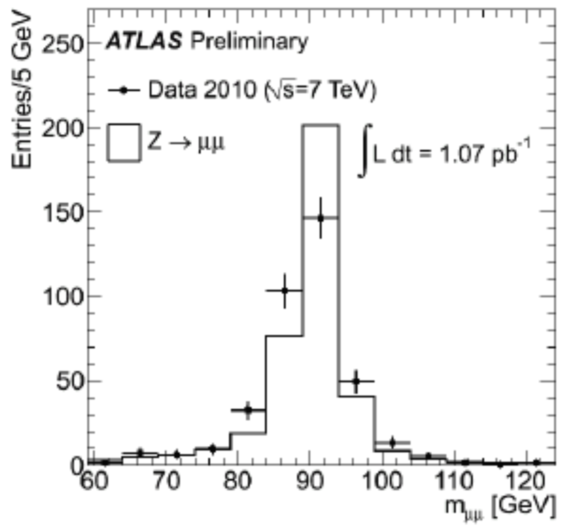
electron channel





muon channel





$$m_T^2 = m^2 + p_x^2 + p_y^2$$

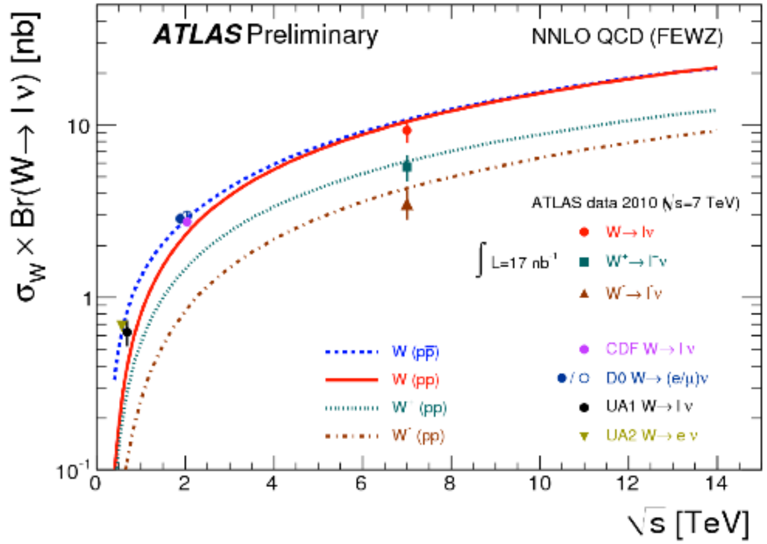
W cross section

❑ Total cross-section measurement at L_{int}=17 nb^{-1}: 46 (72) W→eν(μν)

- MC geometrical and kinematic acceptance: A_W~ 47±1.5%
- Systematics on reconstruction efficiency (C_W):

$$\sigma(W \rightarrow l\nu) = \frac{N_W^{sig}}{A_W C_W L_{int}}$$

Uncertainty	Electron	Muon
Trigger	<0.5%	4%
Material effect	4%	--
Identification	6%	4%
E Scale+Resolution	2%	4%
E_T^{miss} Scale+Resolution	2%	2%
Total	8%	7%
C_W	(65.6±5.3)%	(81.4±5.6)%



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

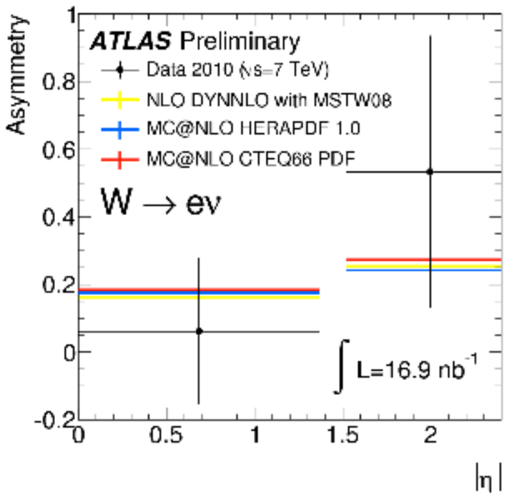
- Compatible with Standard Model expectations (10.5±0.4 nb)
- Combined measurement dominated by luminosity systematics at 17 nb^{-1} !

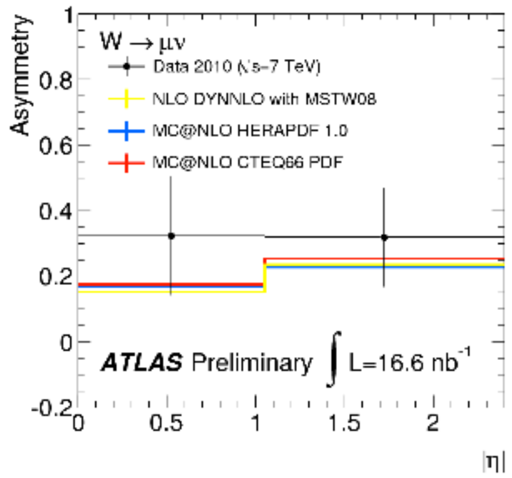
W Asymmetry

- **Asymmetry (A) → Measured the difference in W+/W- production**
  - Most systematics cancel in the ratio
  - Sensitive to valence quark distributions (x ~10^{-3}-10^{-1}) → A vs η to distinguish between PDF

$$A = \frac{\sigma(W \to \ell^+\nu) - \sigma(W \to \ell^-\nu)}{\sigma(W \to \ell^+\nu) + \sigma(W \to \ell^-\nu)} \neq 0$$

A (W→ eν) = 0.21 ± 0.18 (stat) ± 0.01 (syst)
A (W→ μν) = 0.33 ± 0.12 (stat) ± 0.01 (syst)
NNLO theory prediction: A~0.2





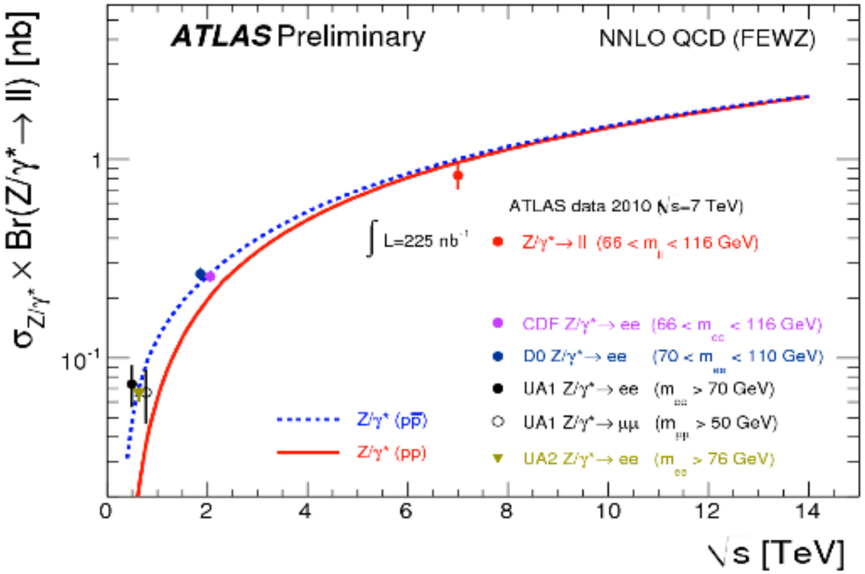
Statistically limited up to few pb^{-1}

Z cross section

- **Total cross-section measurement at L_{int}~225 nb^{-1}: 46 (79) Z→ee(μμ)**
  - MC geometrical and kinematic acceptance: A_Z~ 46.5±1.4%
  - Systematics on reconstruction efficiency (C_Z):

$$\sigma(Z/\gamma^* \to ll) = \frac{N_Z^{sig}}{A_Z C_Z L_{int}}$$

Uncertainty	Electron	Muon
Trigger	<0.5%	2%
Identification	10%	7%
Material effect	8%	--
E Scale+Resolution	2%	1%
Pile-up	2%	--
Total	14%	7%
C_Z	(64.5±9.0)%	(79.7±5.3)%



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

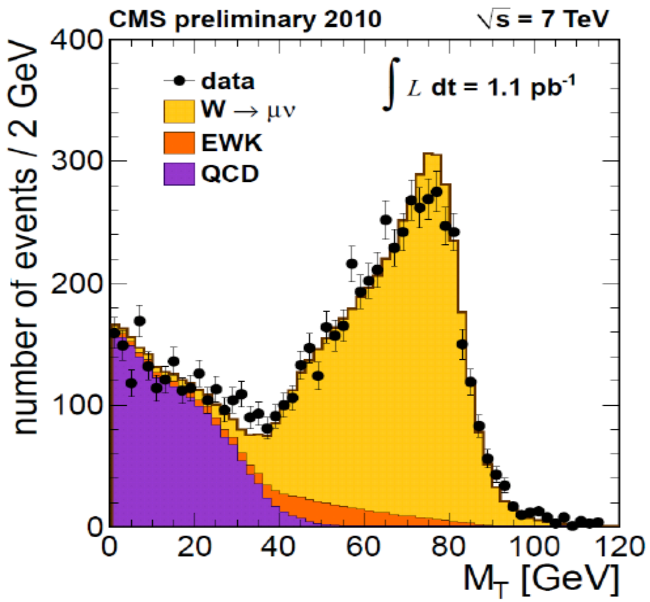
- Compatible with Standard Model expectations (0.99±0.04 nb)
- Combined measurement dominated by luminosity systematics at 225 nb^{-1} !

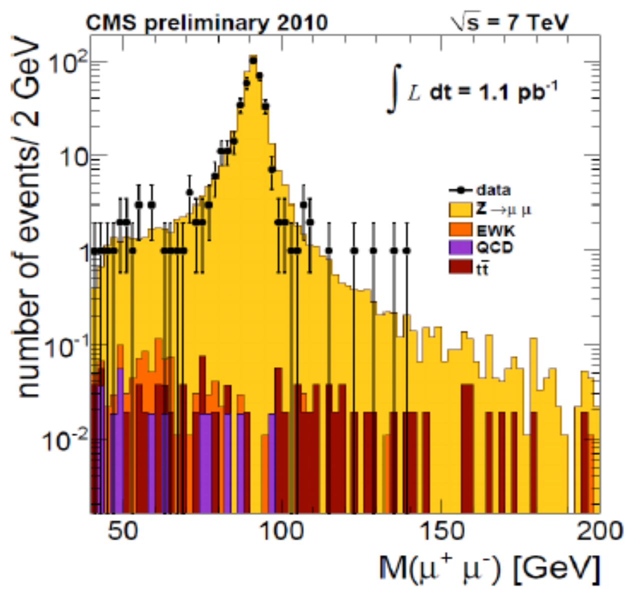
CMS: W/Z Production (muon channel)

- Kinematics
  - For W, $p_T > 9$ GeV, $|\eta| < 2.1$
  - For Z, $p_T > 20$ GeV, one $|\eta| < 2.4$
- Good quality muon track
  - Hits in pixels, strip tracker, muon system)
  - χ^2/dof < 10
- Z measurement requires only track isolation of 3 GeV in a cone
- For W measurement, use a relative isolation in a cone of $\Delta R < 0.3$:

Source	W channel (%)	Z channel (%)
Muon reconstruction/identification	3.0	2.5
Trigger efficiency	3.2	0.7
Isolation efficiency	0.5	1.0
Muon momentum scale/resolution	1.0	0.5
$\not{E}_T$ scale/resolution	1.0	-
Background subtraction	3.5	-
PDF uncertainty in acceptance	2.0	2.0
Other theoretical uncertainties	1.4	1.6
TOTAL (without luminosity uncertainty)	6.3	3.8
Luminosity	11.0	11.0

Simultaneous fits to backgrounds and signal contributions. QCD background shapes obtained using data. EWK background shapes and signal from MC.





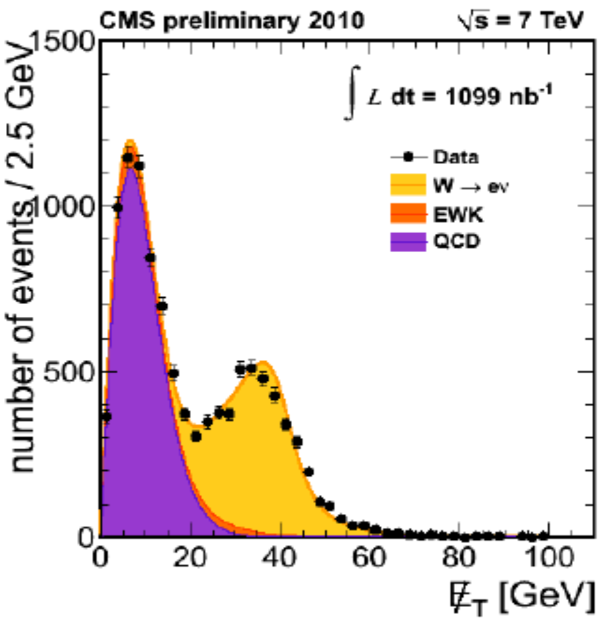
W/Z Production (electron channel)

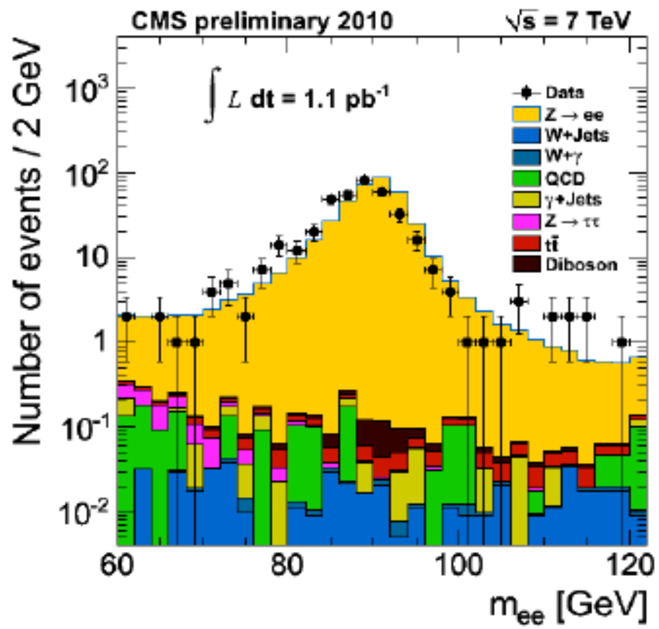
- Kinematics
  $p_T > 20$ GeV
  $0.0 < |\eta| < 1.442$
  $1.566 < |\eta| < 2.5$
- Specialized track reconstruction to deal with potential large bremsstrahlung
- Electron identification requirements on shower shape variables
- Isolation requirements in tracker ECAL, HCAL

W: 75% efficiency
Z: 90% efficiency
QCD background shapes from data, EWK background and signal shapes from MC

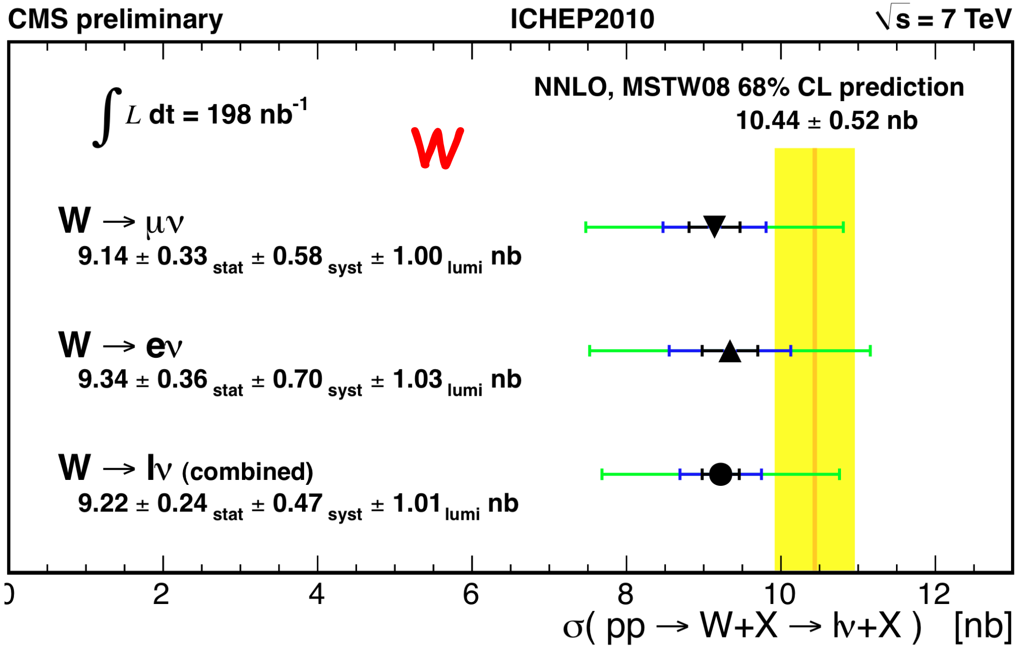
4530 W's
389 Z's

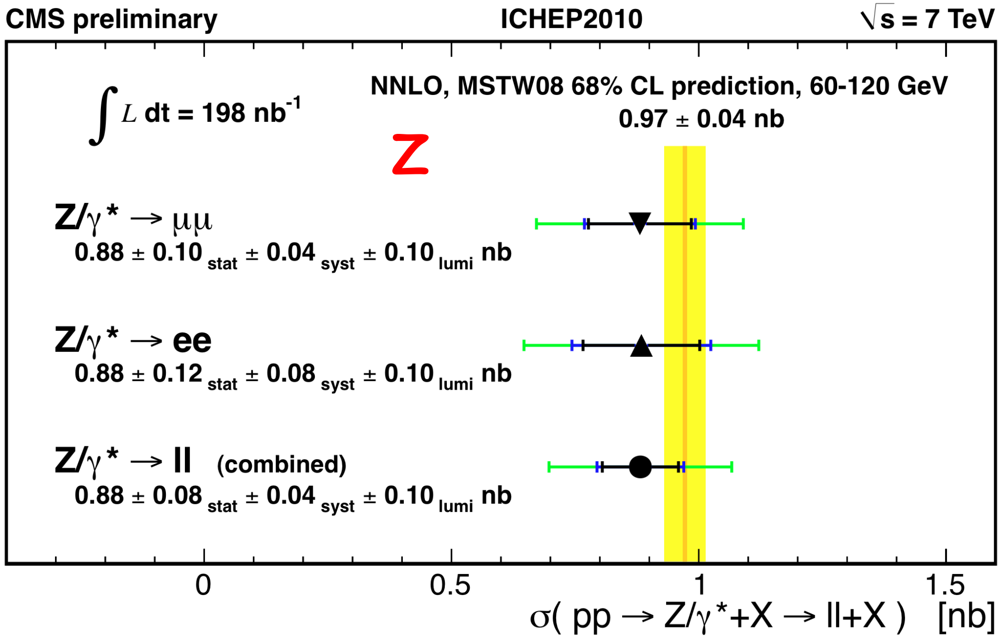
Source	W channel (%)	Z channel (%)
Electron reconstruction/identification	6.1	7.2
Trigger efficiency	0.6	-
Isolation efficiency	1.1	1.2
Electron momentum scale/resolution	2.7	-
$\not{E}_T$ scale/resolution	1.4	-
Background subtraction	2.2	-
PDF uncertainty in acceptance	2.0	2.0
Other theoretical uncertainties	1.3	1.3
TOTAL (without luminosity uncertainty)	7.7	7.7
Luminosity	11.0	11.0



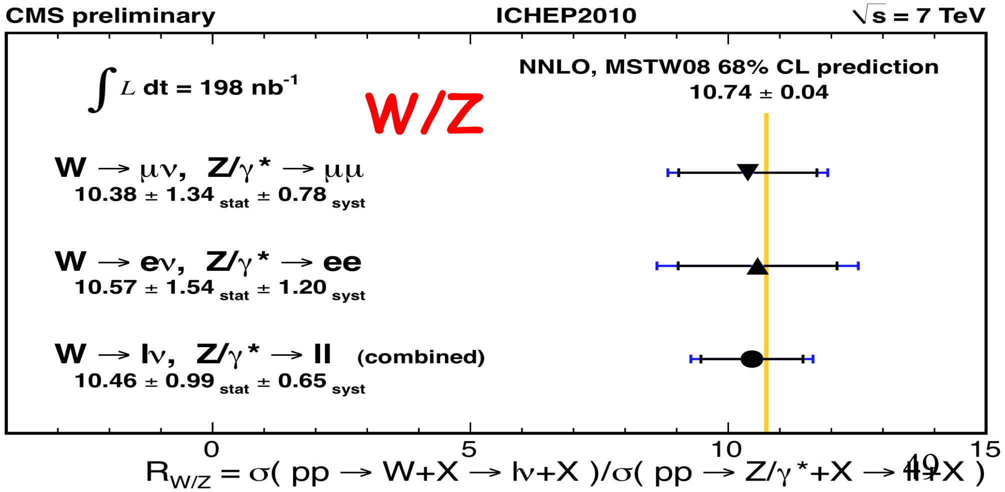


W/Z Production Cross Sections

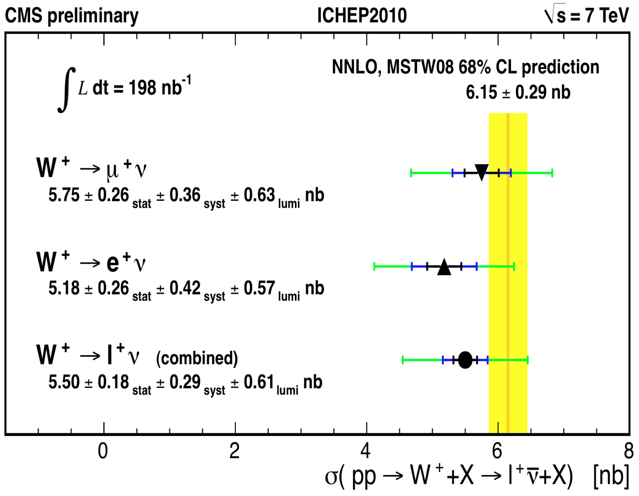


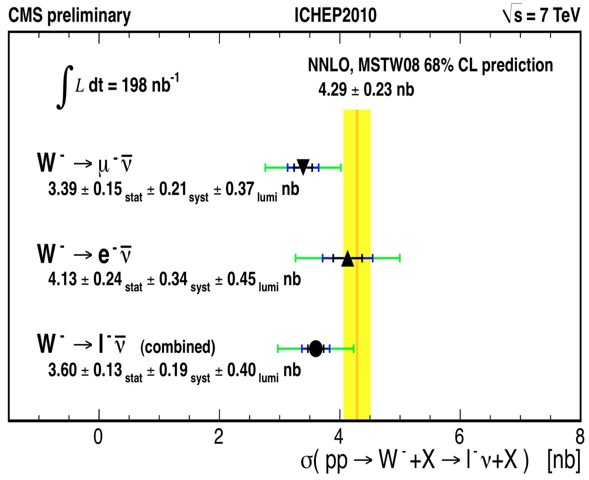


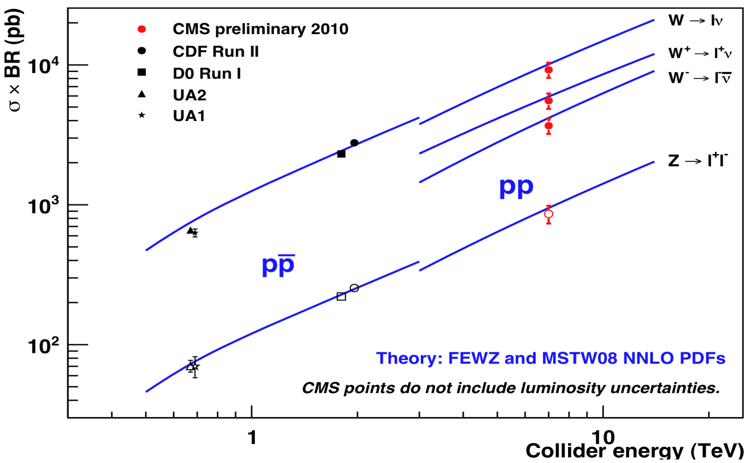
Note: ~all major components of the measurements (efficiency, background, systematic errors etc) are carefully evaluated using data driven methods.



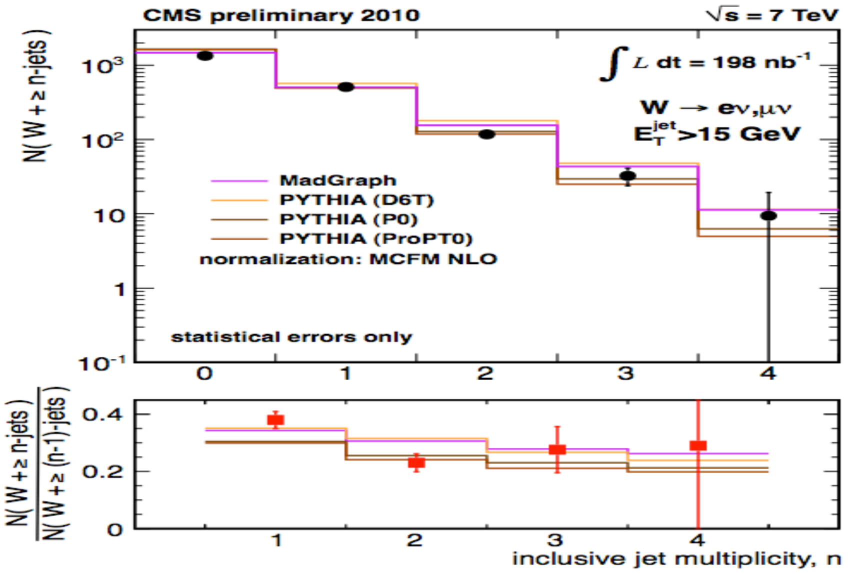
Charge Asymmetry and W+jets







W+jets

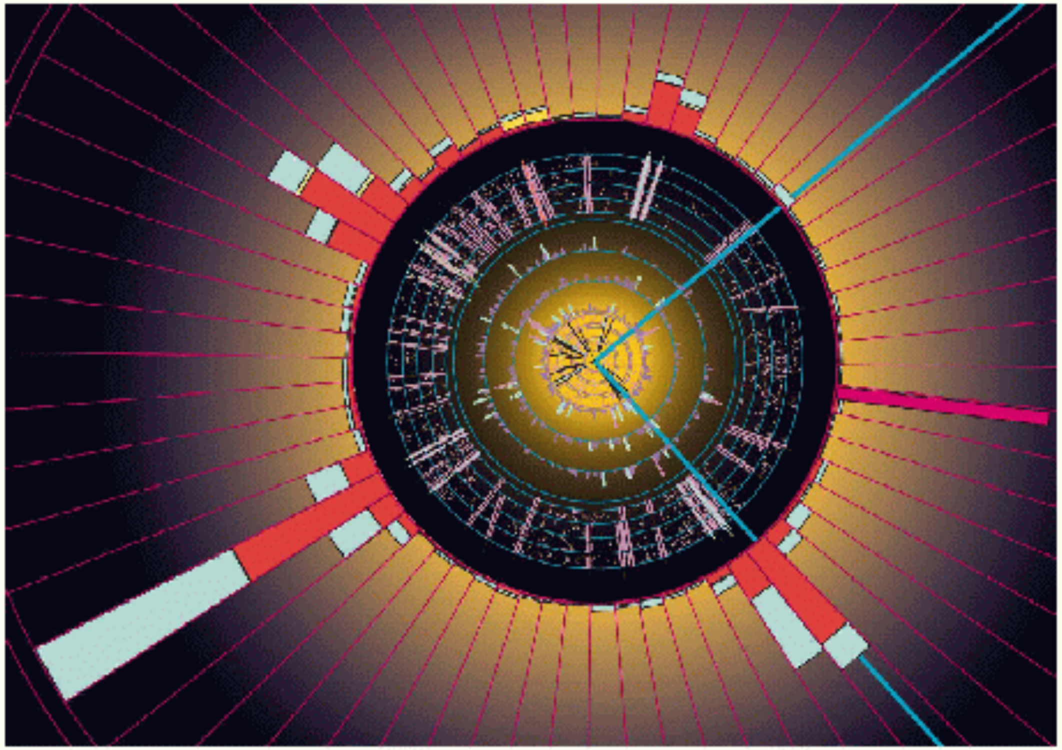


…And now we deploy everything for hunting the top

Discovery of the Top Quark

Recent Steps

The Last Quark



Top Quark discovered at Fermilab

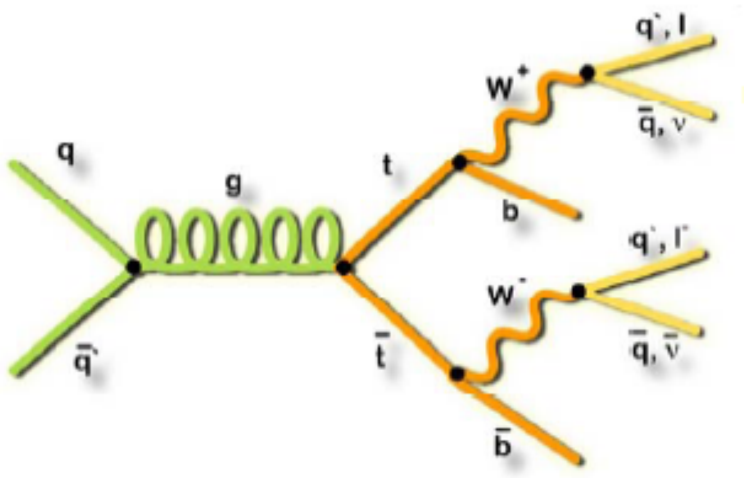
1994

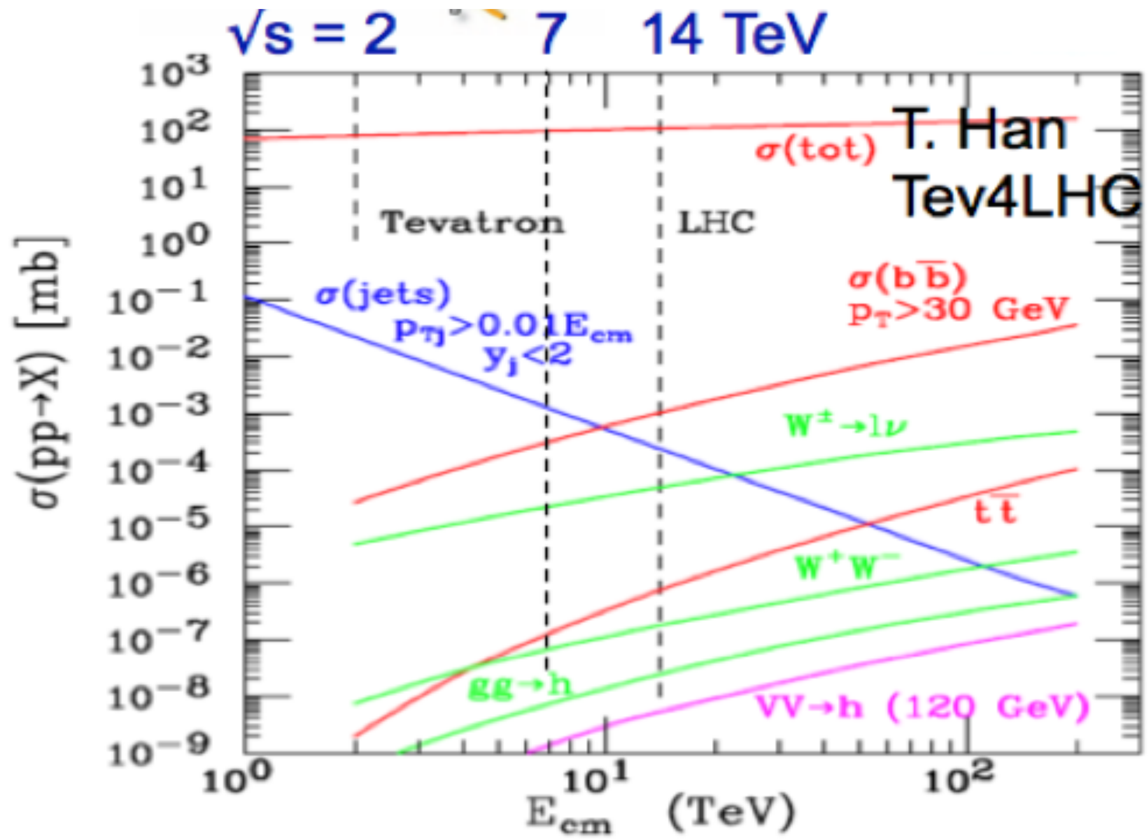
Top mass

174 +/- 5 GeV

i.e. this quark
is as heavy as
a gold nucleus

Top Quarks at the LHC



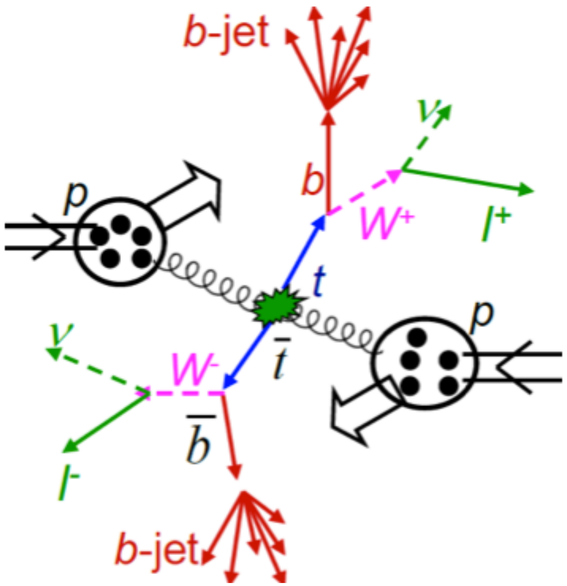


- Precise SM measurements
- A window to new physics
- In many new physics scenarios (e.g. SUSY) top is dominant BG
- Great tool to calibrate detector
  - Jet energy scale, b-jet eff.

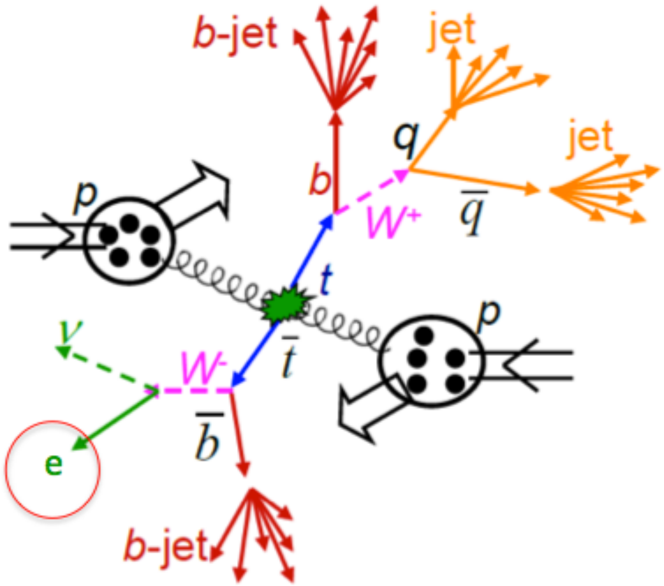
TOP is the gateway to New Physics…!!

Top Channels Studied so far

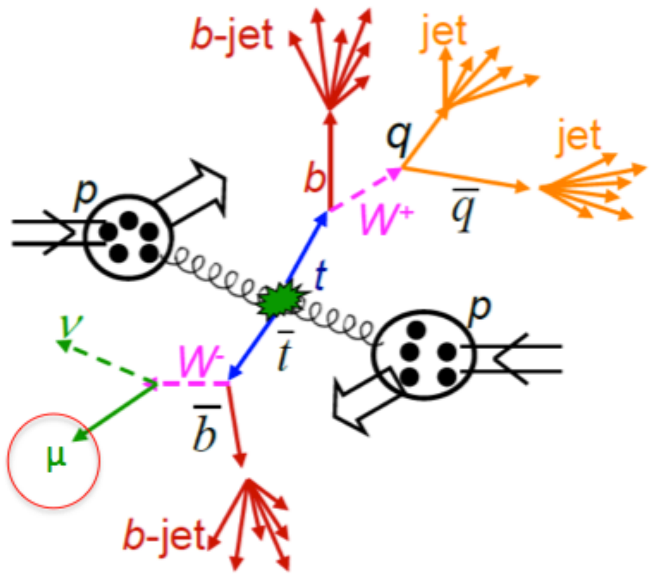
2 leptons + MET
2 (or more) jets



Electron + MET +
4 (or more) jets



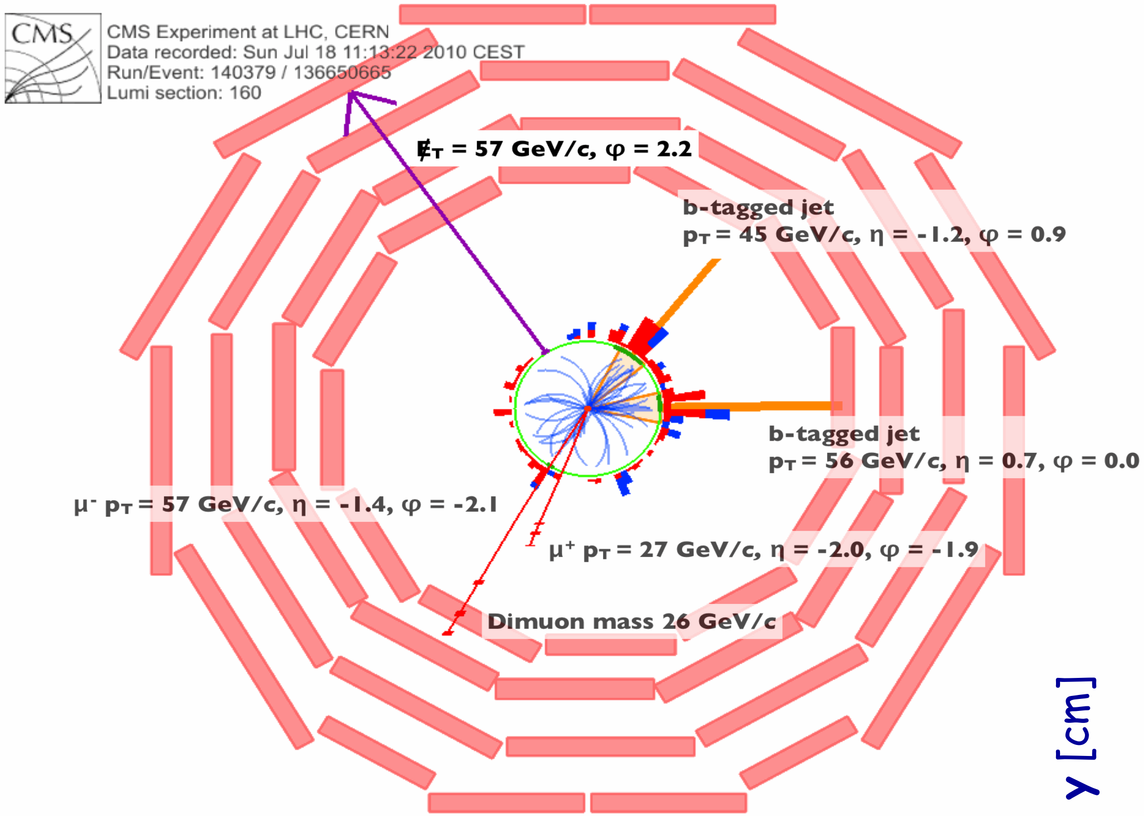
Muon + MET +
4 (or more) jets



Note: always 2 b-jets

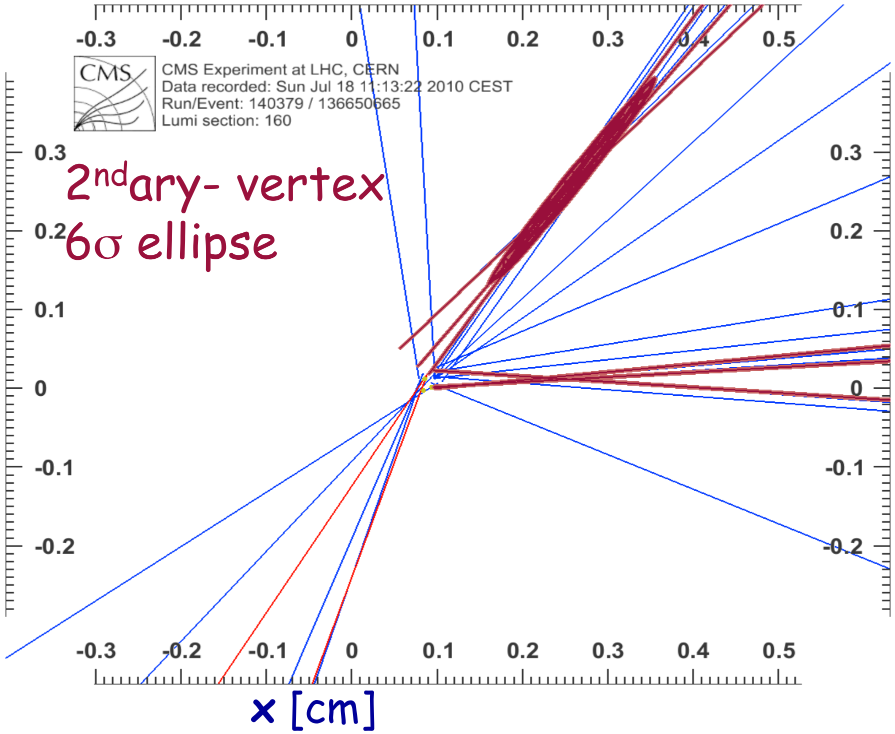
MET = missing transverse energy

Top signals in CMS



μμ +Jets candidate event.

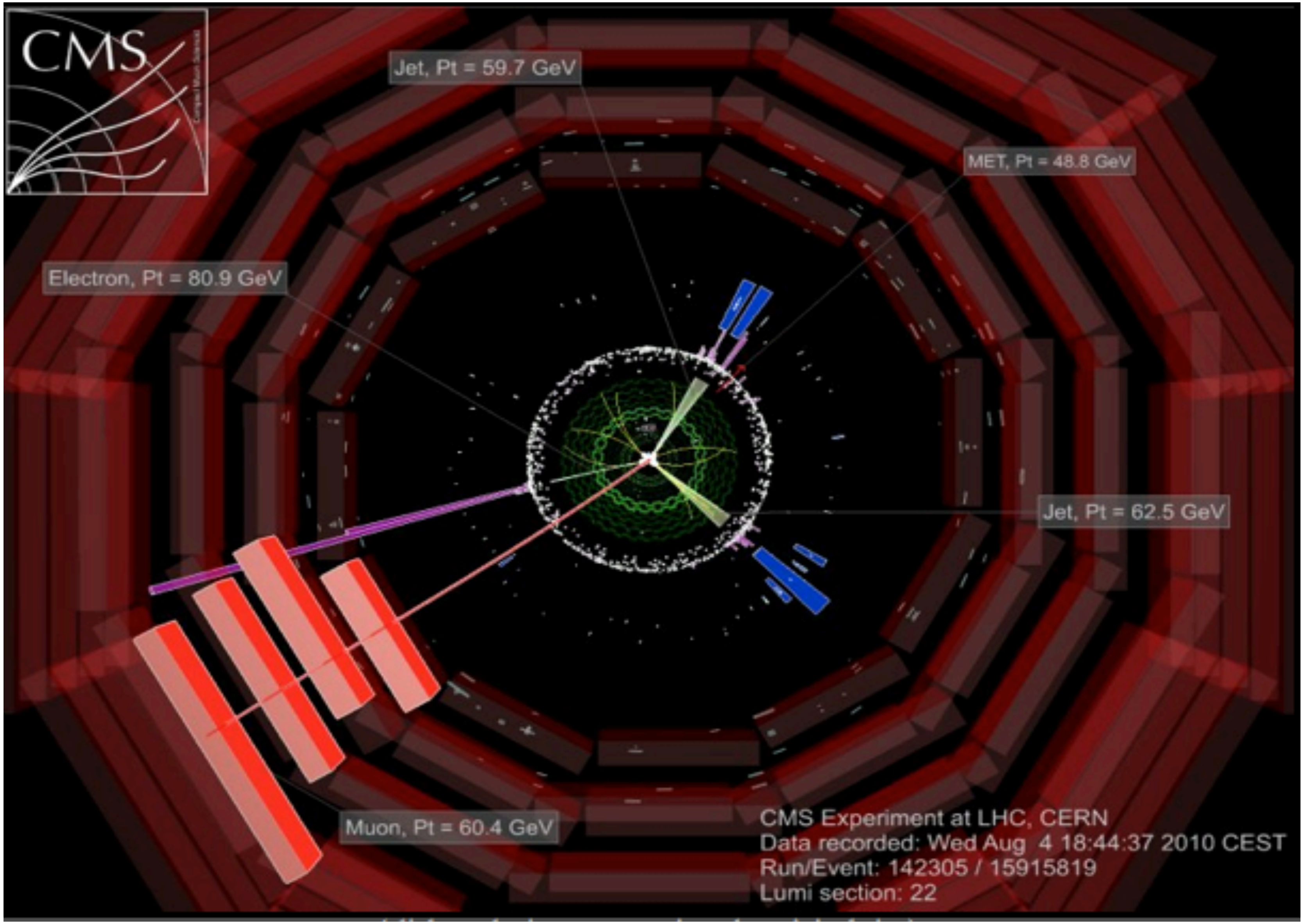
2 muons with opposite charge
2 jets, both with good/clear b-tags
(and secondary vertices!)
significant MET (>50 GeV)



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

0.84 pb^{-1} of data analyzed

Top candidate (muon+electron+ 2 jets)



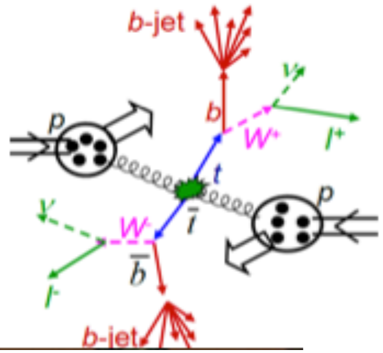
Top Selections

DILEPTON

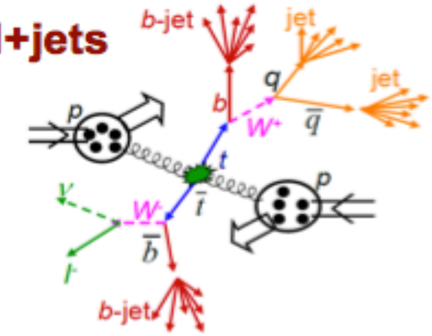
- Single lepton triggers
  - μ+X (Pt>9 GeV,) e+X (Pt>15 GeV)
- Two isolated, opposite charge leptons (ee,mumu,emu)
  - Pt>20 GeV, |eta|<2.5(mu),2.4(e)
  - Rel. isolation < 0.15

$$\text{Rel.isol.} = \frac{\sum_{R<0.3} p_T^{\text{track}} + \sum_{R<0.3} p_T^{\text{ECAL}} + \sum_{R<0.3} p_T^{\text{HCAL}}}{p_T(\text{lepton})}$$

- Z-boson veto
  - |M(ll)-M(Z)|>15 GeV
- Missing Et (MET)
  - Using calorimeter & tracking
  - MET>30(20) GeV in ee,mumu (emu)
- Jets
  - Anti-Kt (R=0.5)
  - Using calorimeter & tracking
  - Pt>30 GeV, |eta|<2.4
  - Expect >=2 jets for ttbar



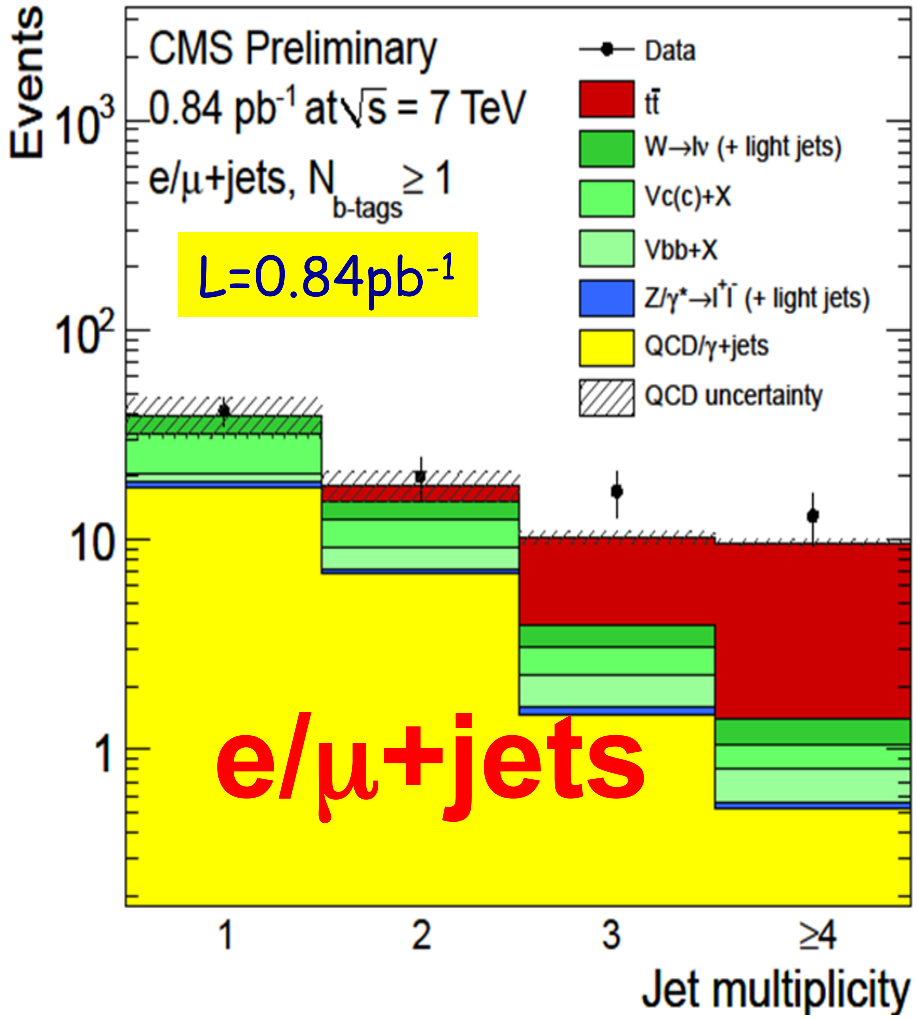
LEPTON+jets



- Considered modes:
  - e+jets
  - mu+jets
- Single lepton triggers
- Exactly one isolated lepton
  - Muons: Pt>20 GeV, |eta|<2.1
  - Electrons: Pt>30 GeV, |eta|<2.4
- Missing Et (MET)
- Not used in event selection, but to reconstruct transverse Mass
- Jets
  - Anti-Kt (R=0.5)
  - Pt>30 GeV, |eta|<2.4
  - Expect >=4 jets for ttbar
  - No b-tagging in baseline selection

Lepton+ Jets Top Selection

Using the full statistics currently validated ($0.84pb^{-1}$) and **requiring at least 1 jet b-tagged** (secondary vertex tagger with ≥2 tracks; high efficiency with ~1% fake rate)



For N(jets)≥3 we count

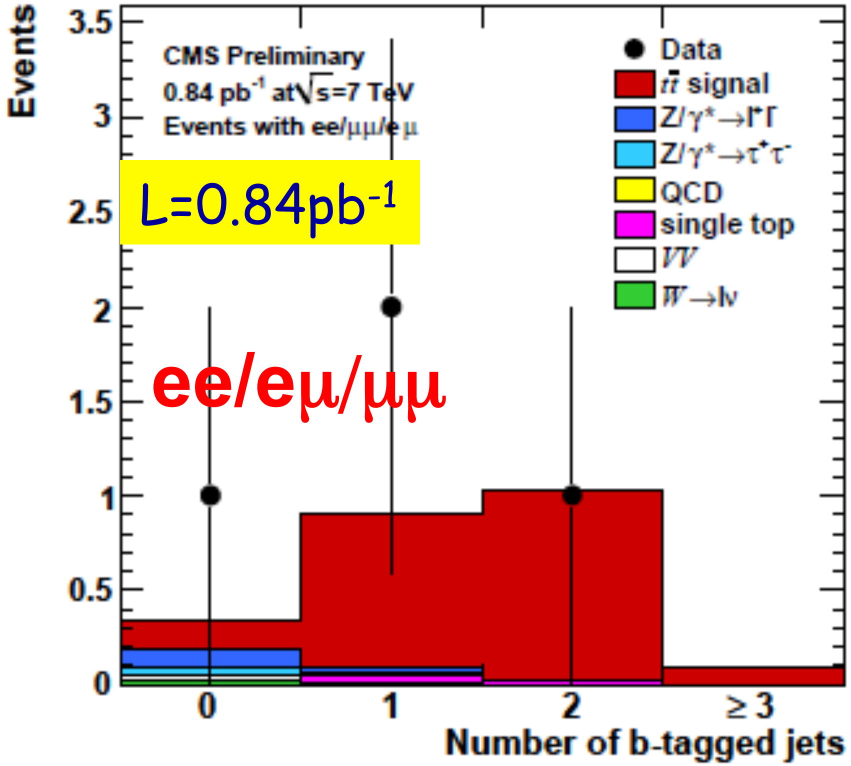
30 signal candidates over a predicted background of 5.3

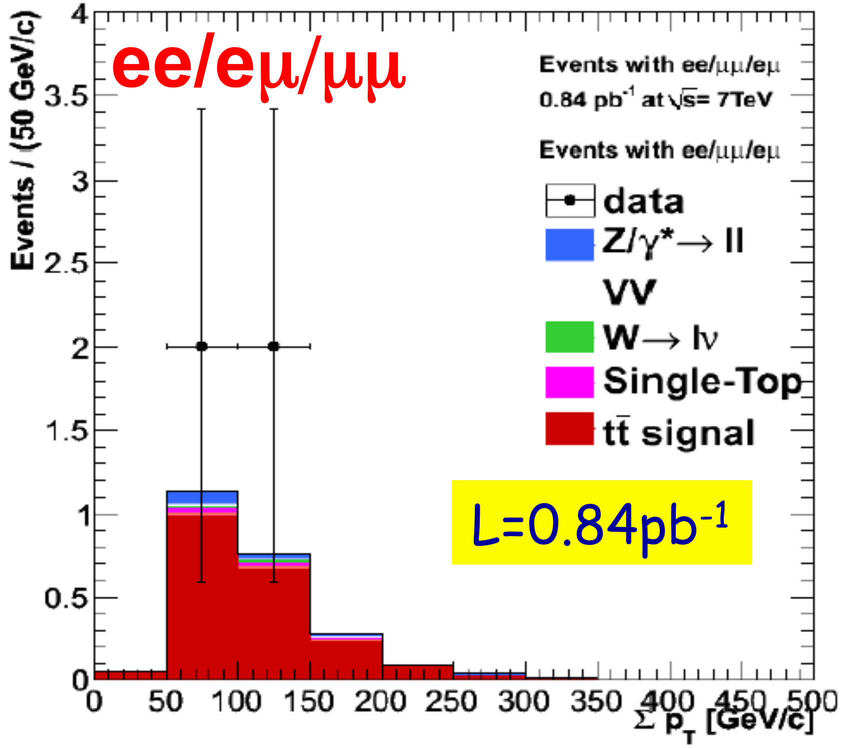
15 expected signal event

t-tbar events are observed in CMS at a rate consistent with NLO cross section, considering experimental (JES, b-tagging) and theoretical (scale, PDF, HF modelling, …) uncertainties.

Di-Lepton+ Jets Top Selection

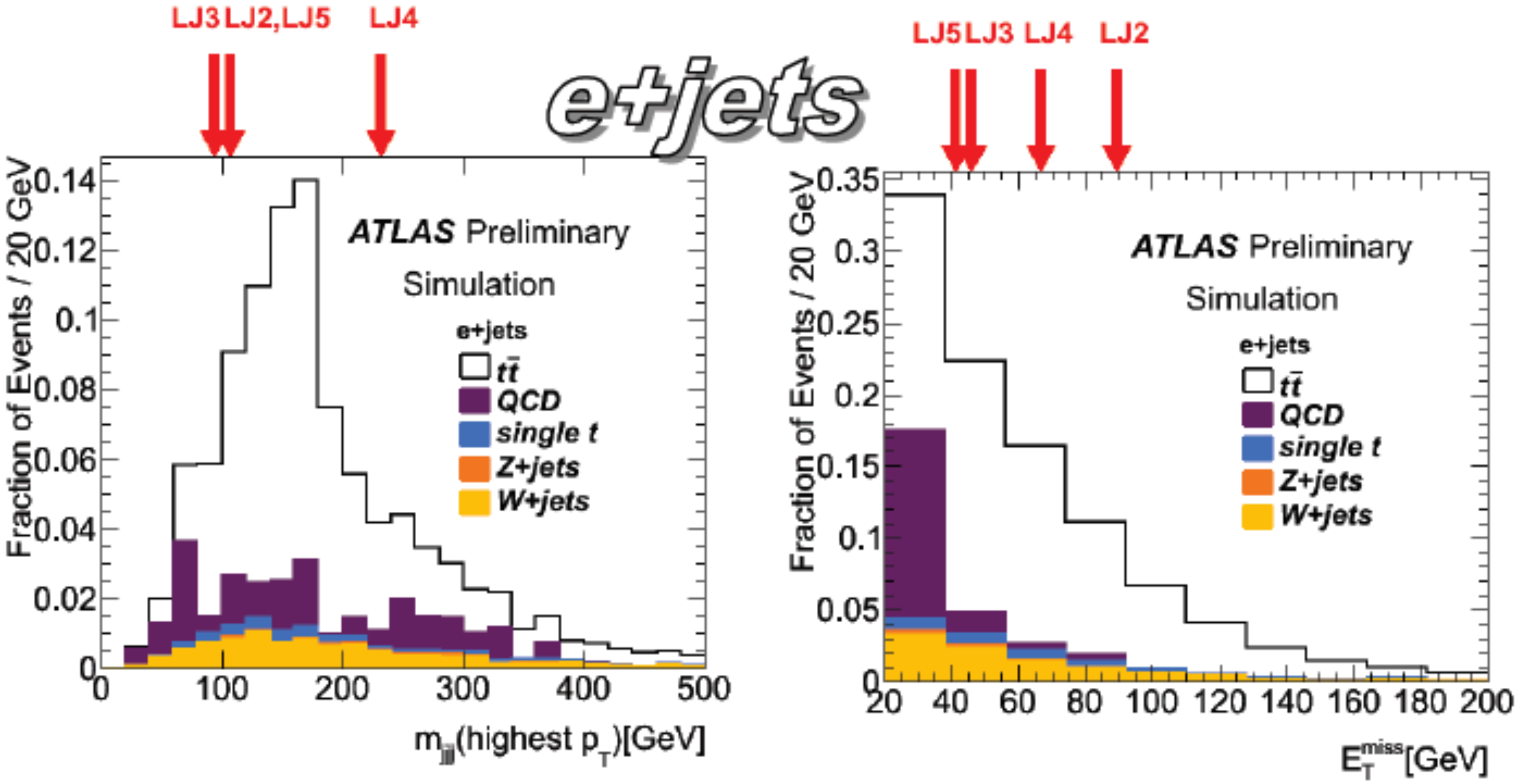
- Full selection applied: Z-bosonVeto, |M(ll)-M(Z)|>15 GeV
- MET >30 (20) GeV in ee,μμ, (eμ); N(jets)≥2



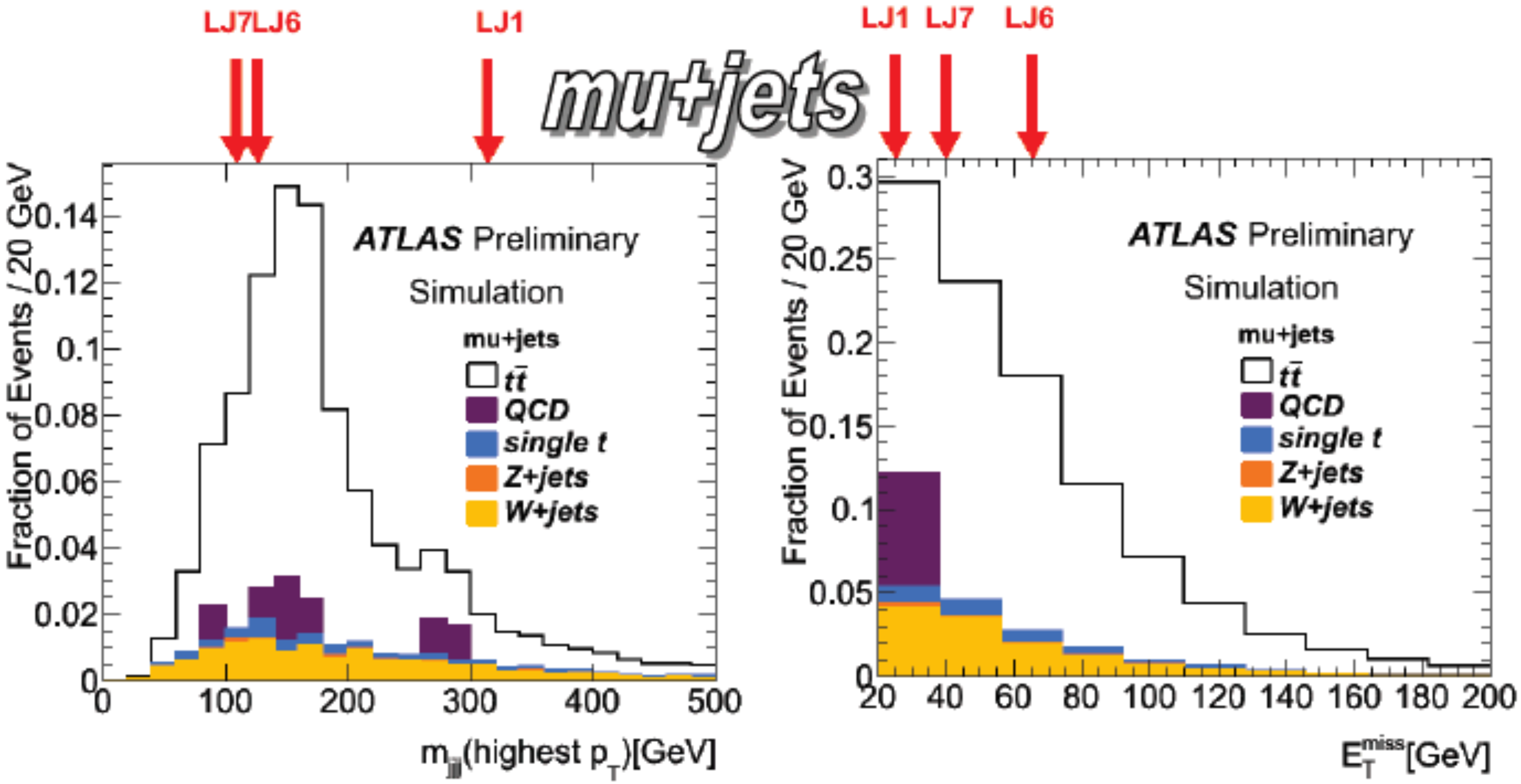


4 ttbar candidates (1eμ, 1ee, 2μμ) over a negligible background.
Top signal at LHC established.
First cross sections will come soon!

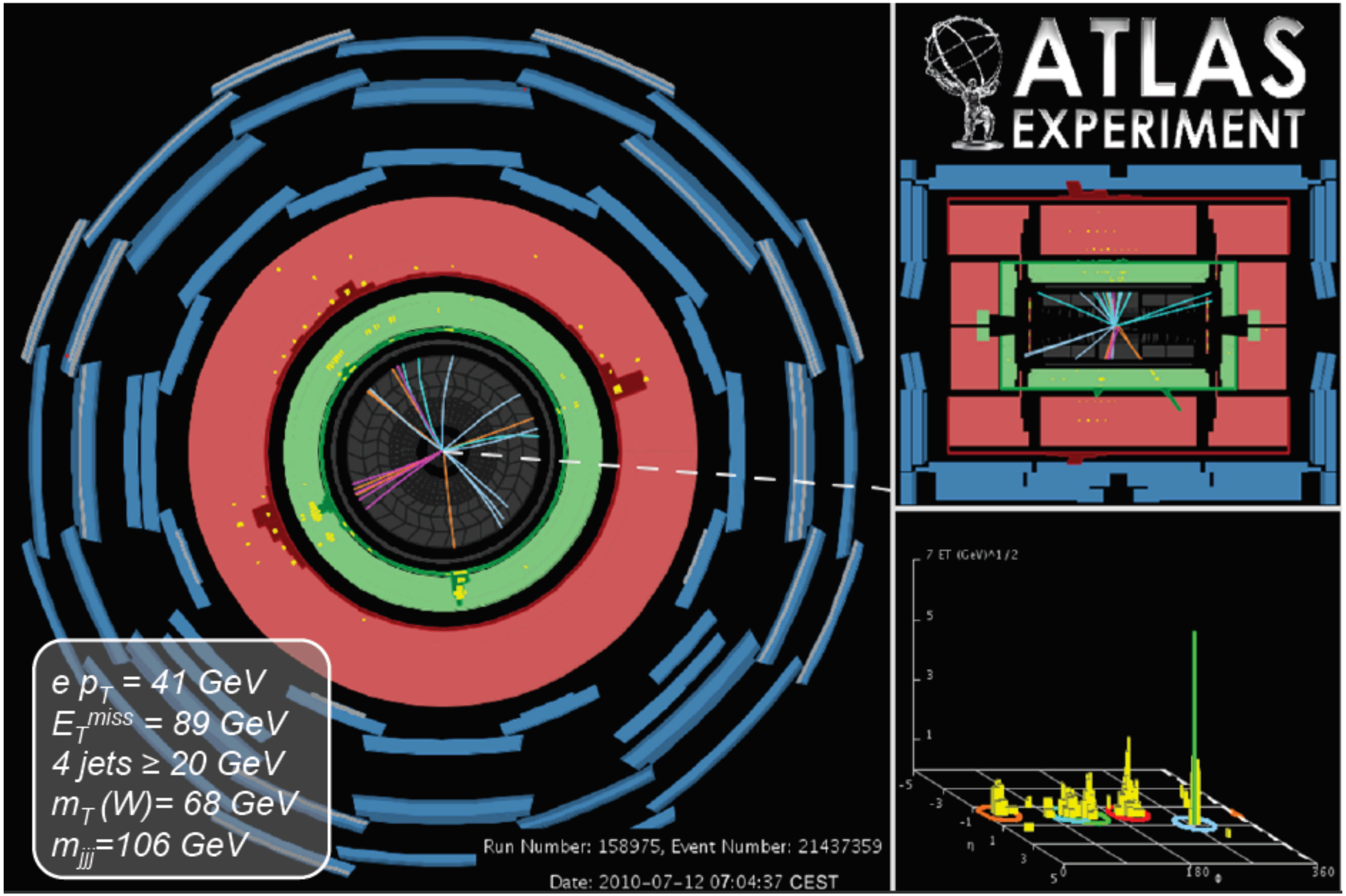
Top candidates: e+ jets



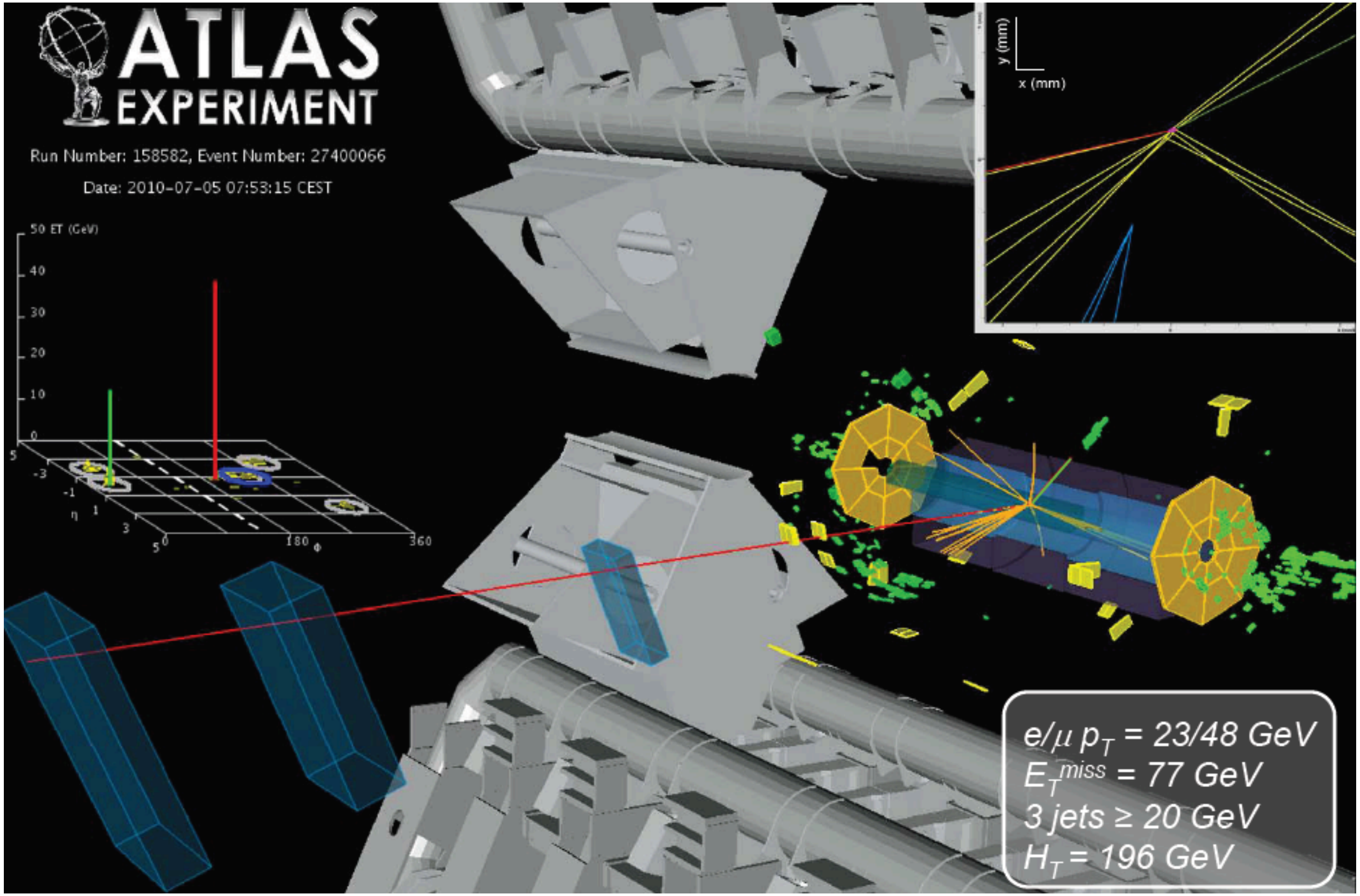
Top candidates: muon+ jets



e+jet event candidate (LJ2)

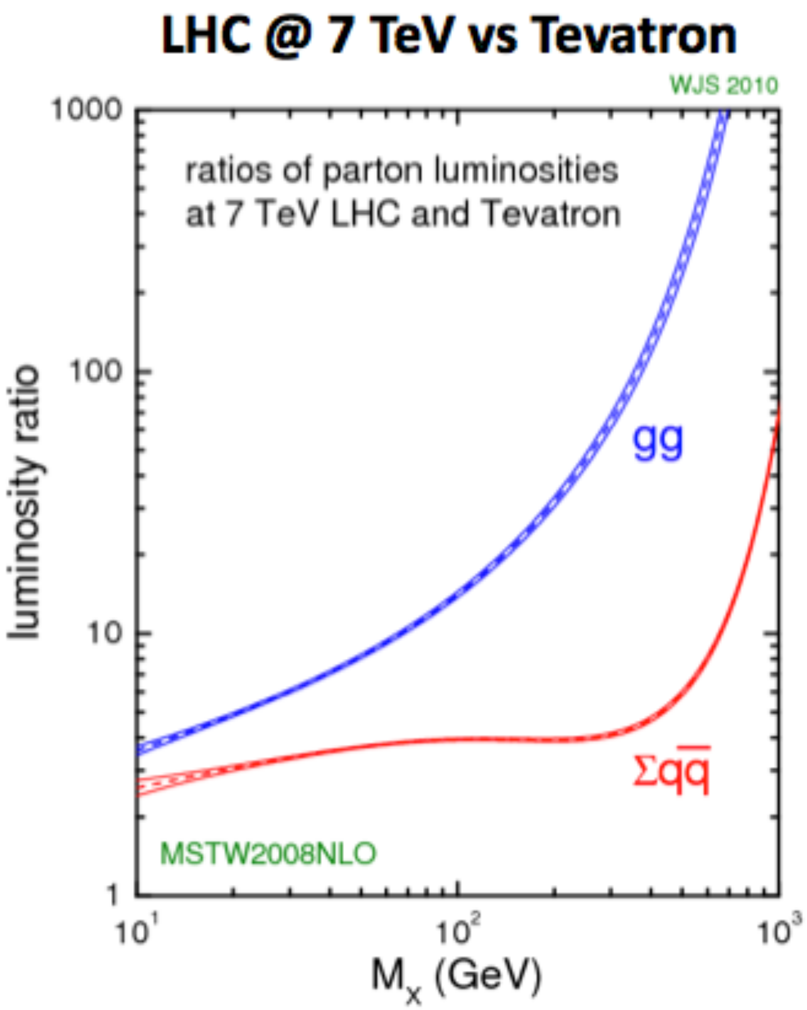


Muon + Electron + Jets Candidate



In all,Top observed in CMS and ATLAS: first top in Europe!!

Searches for New Physics



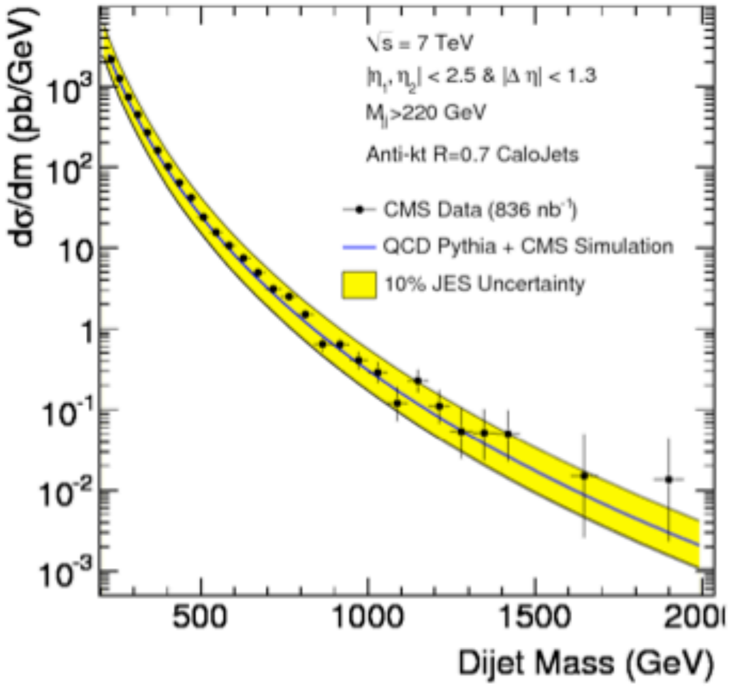
How fast can we expect the LHC to take over from the Tevatron?

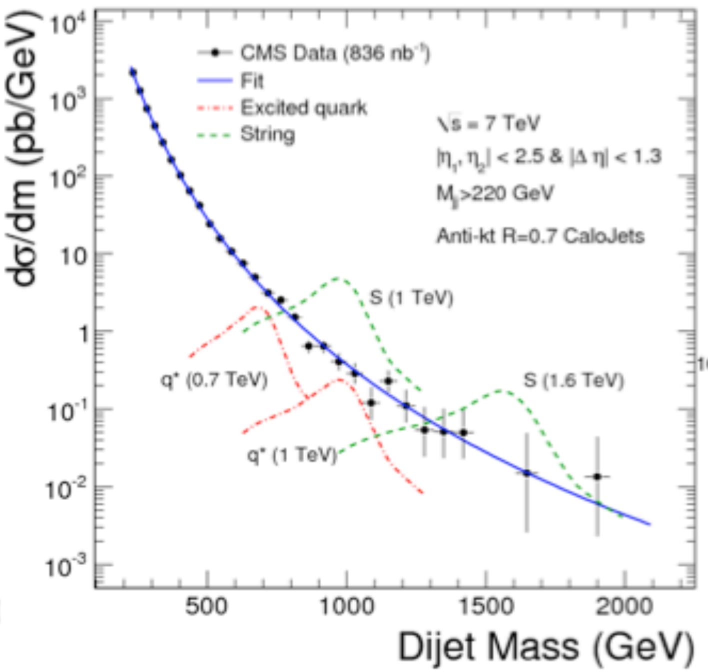
Look at the parton luminosities

The power of the higher energy!!!

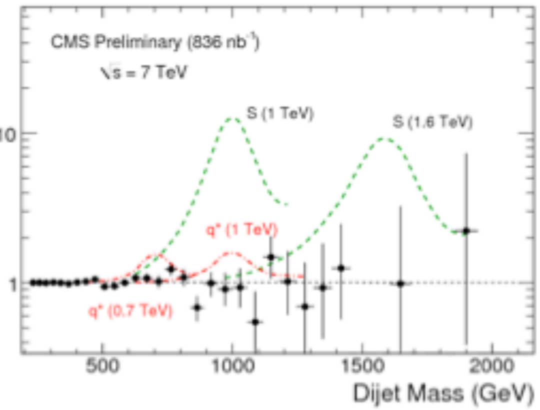
Exploring New Territory: Di-jets

Measured dijet mass differential cross section for $|h_1,h_2|<2.5$ and $|\eta_1,\eta_2|<1.3$.
The distribution is sensitive to the coupling of any new massive object to quarks and gluons.





L=0.84pb^{-1}



95% CL mass limits:

String resonances >2.1TeV **Excited quarks >1.14TeV**

Axigluons/Colorons >1.06TeV **E_6 Diquarks>0.58 TeV.**

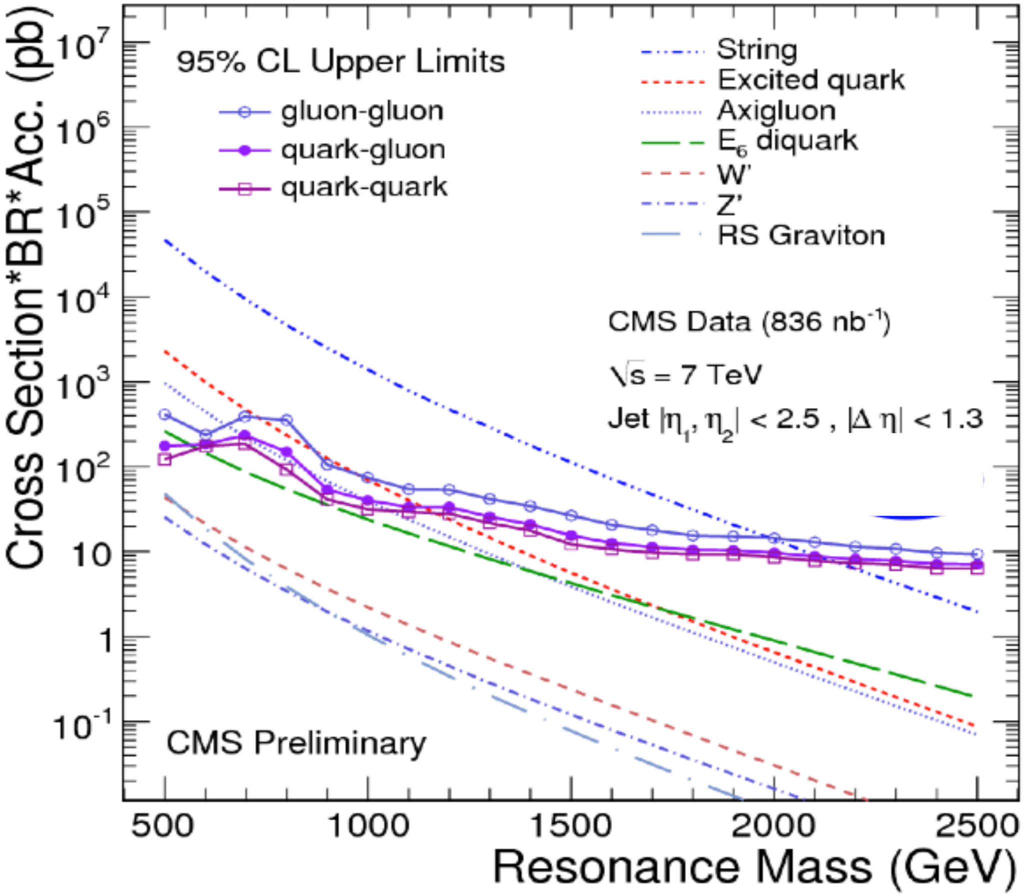
Exploring New Territory: Di-jets

new massive objects that couple to quarks (q) and gluons (g) → di-parton resonance
qq, qg, gg → resonant structures in the di-jet

Several model of quark compositeness:

Model Name	X	Color	J^P	$\Gamma/(2M)$	Final-state Partons
String	S	mixed	mixed	0.003-0.037	$qq, q\bar{q}, gg$ and qg
Axigluon	A	Octet	1^+	0.05	$q\bar{q}$
Coloron	C	Octet	1^-	0.05	$q\bar{q}$
Excited Quark	q*	Triplet	$1/2^+$	0.02	qg
E_6 Diquark	D	Triplet	0^+	0.004	qq
RS Graviton	G	Singlet	2^+	0.01	$q\bar{q}$, gg
Heavy W	W'	Singlet	1^-	0.01	$q\bar{q}$
Heavy Z	Z'	Singlet	1^-	0.01	$q\bar{q}$

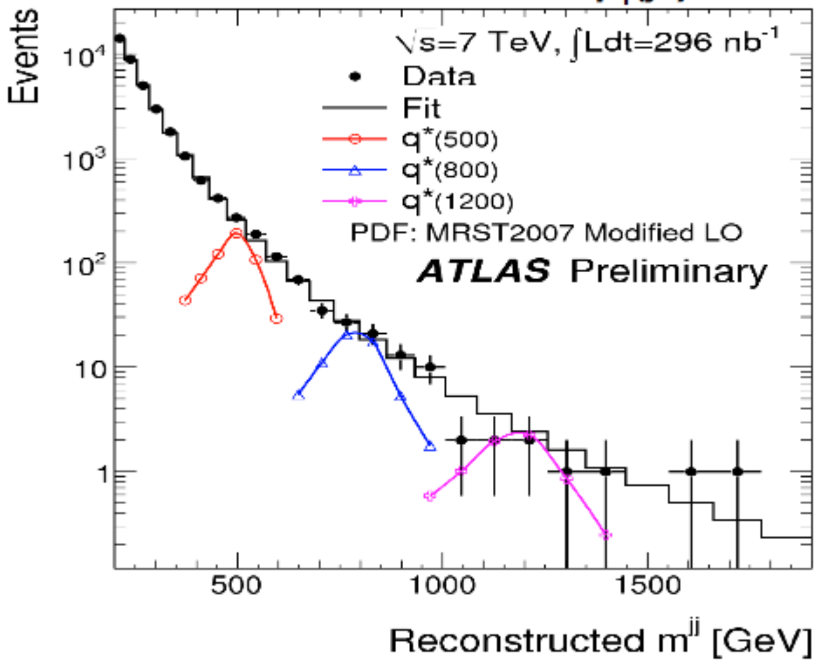
Model	95% C.L. Mass Limit (TeV) using CTEQ6L	
	CMS (836 nb^{-1})	CDF (1.13 fb^{-1})
String	2.10	1.4
q*	1.14	0.87
Axigluon/ Coloron	1.06	1.25
E_6 Diquark	0.58	0.63

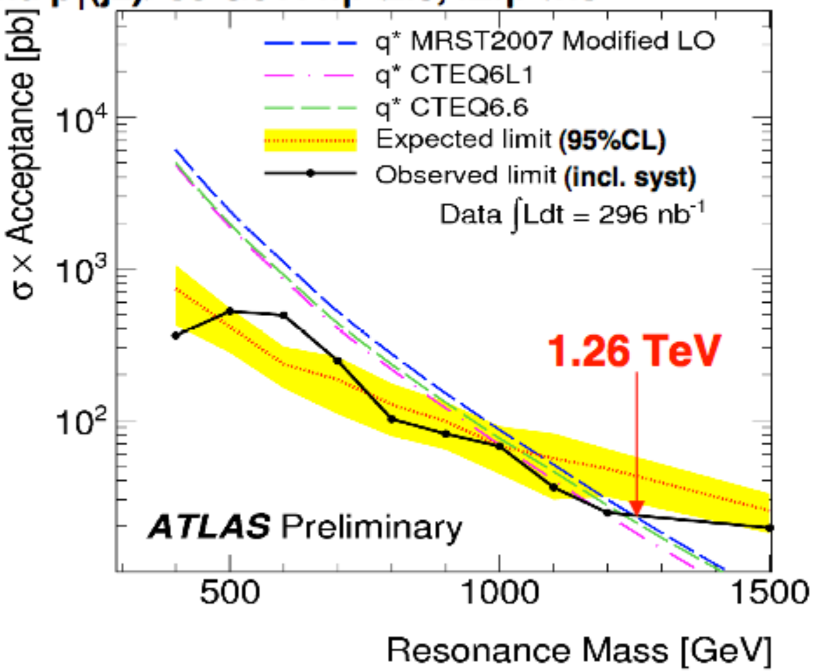


Exploring New Territory: Di-jets

- **Search for excited quarks (q*→jj) on full ICHEP data sample**
  - Signal is searched as deviation from smooth monotonic function
  - Systematics considered: luminosity, Jet Energy scale, background fit

To enhance S/√B: $p_T(j1)>80$ GeV and $p_T(j2)>30$ GeV: $|\eta|<2.5$, $|\Delta\eta|<1.3$



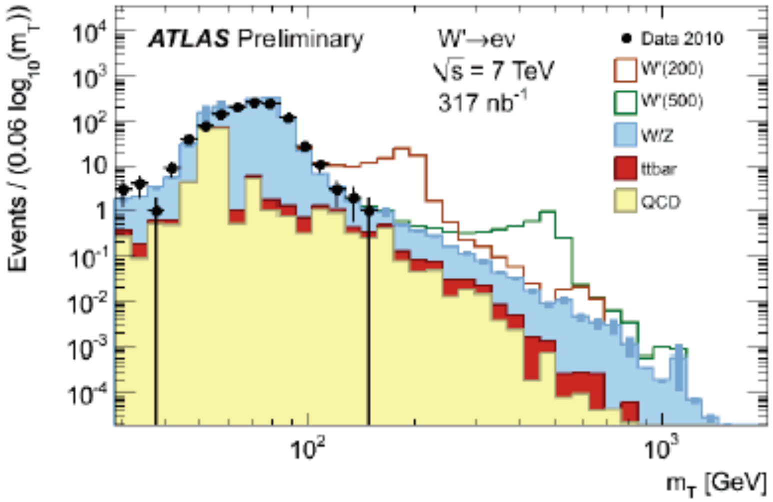


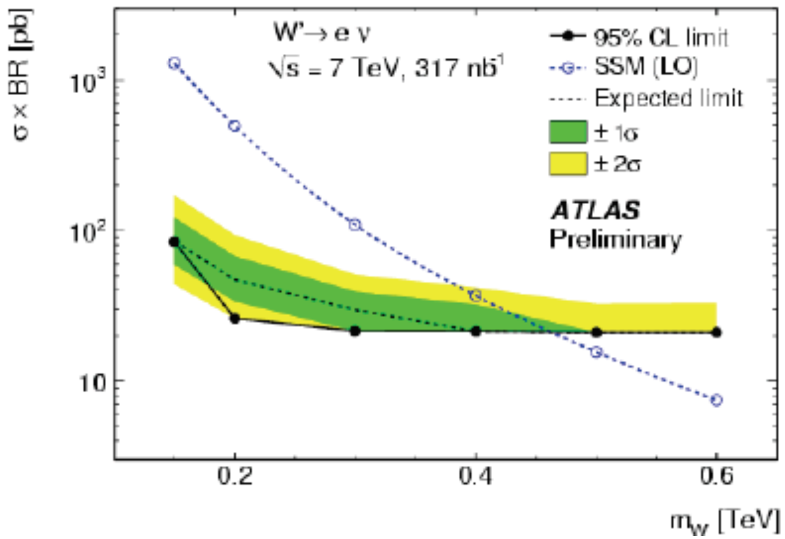
0.4< M(q*) <1.26 TeV excluded at 95% CL (*CDF latest: 0.26 < M(q*)<0.87 GeV*)

Search for W'

- Analysis exercised with 317 nb-1 of data
- Data consistent with SM predictions
- Current limit that can be set (electrons): 465 GeV
- Current results support estimates from previous MC sensitivity studies

electron channel





But maybe the "New World" is far more weird than what we thought sofar…

Recent developments in many models lead to the possible existence of heavy particles that have unusual long lifetimes

These can decay in the middle of the detector (nanoseconds) or live even much longer eg seconds, hours, days…

This leads to very special detector signatures!

Long Lived Particles in Supersymmetry

Split Supersymmetry

- Assumes nature is fine tuned and SUSY is broken at some high scale
- The only light particles are the Higgs and the gauginos

  - Gluino can live long: sec, min, years!

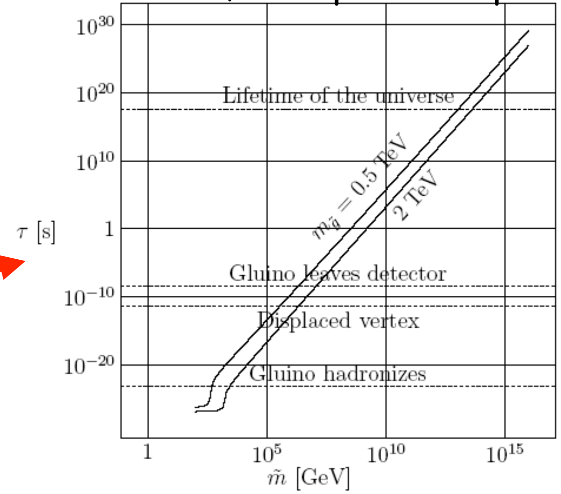
  - R-hadron formation (eg: gluino+ gluon): slow, heavy particles containing a heavy gluino. Unusual interactions with material eg. with the calorimeters of the experiments!

Gravitino Dark Matter and GMSB

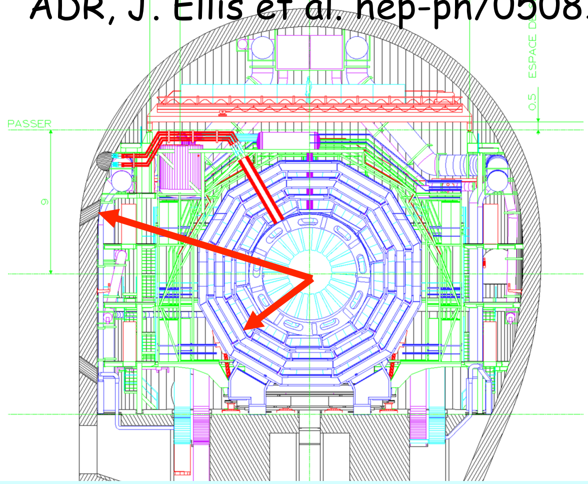
- In some models/phase space the gravitino is the Lightest supersymetric particle (LSP)
- ⇒ NLSP (neutralino, stau lepton) can live 'long'
- ⇒ non-pointing photons

⇒Challenge to the experiments!

Arkani-Hamed, Dimopoulos hep-th/0405159



K. Hamaguchi,M Nijori,ADR hep-ph/0612060
ADR, J. Ellis et al. hep-ph/0508198

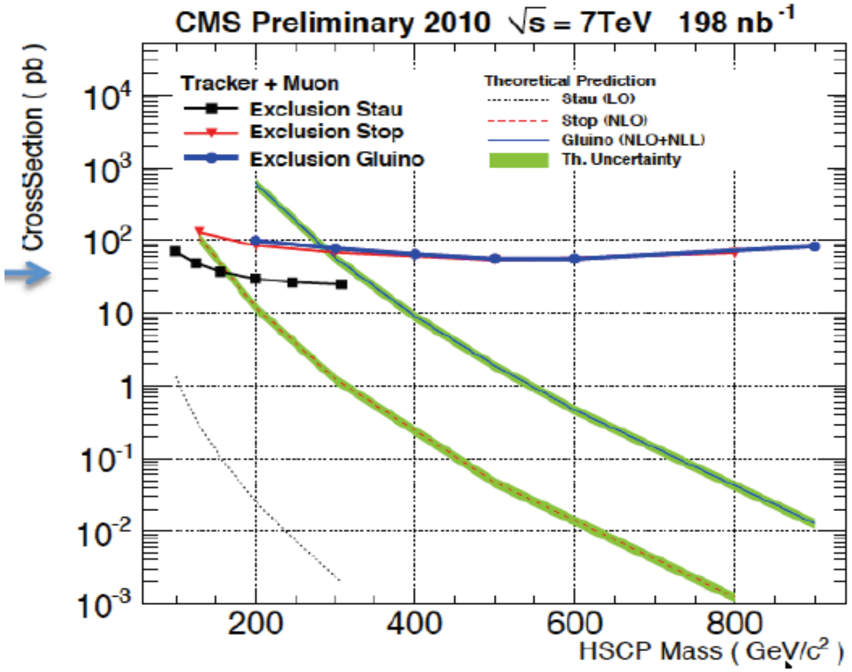


Sparticles stopped in the detector,walls of the cavern, or dense 'stopper' detector. They decay after hours---months…

Searches for Heavy Stable Charged Particles

Example:
Heavy Stable
Charged Particles

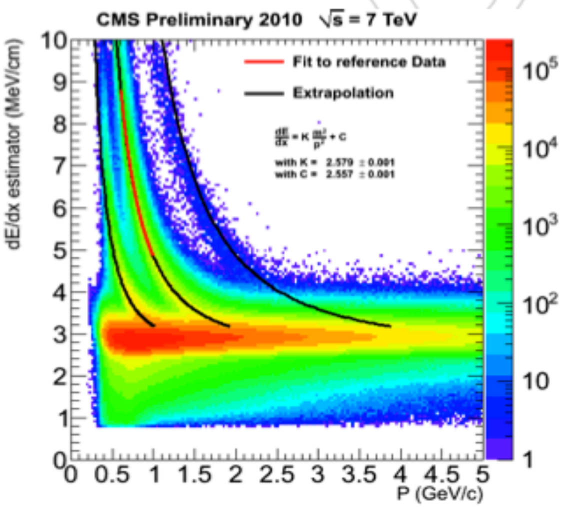
Eg heavy stable
gluino (R-hadron)
or stop/stau

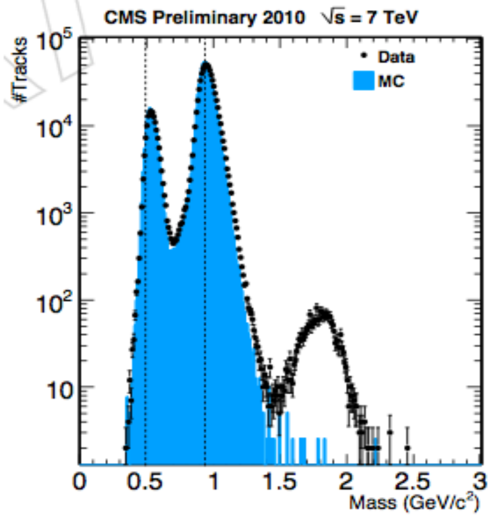


First search limits
using tracker de/dx
and muon
identification

Result for 198 nb^{-1}
0 events after cuts

95% CL limits
on production cross
sections of a few
100 pb in the 200-300
GeV mass range
Eg. Gluinos> 284 GeV





Stopped R-hadrons or Gluinos!

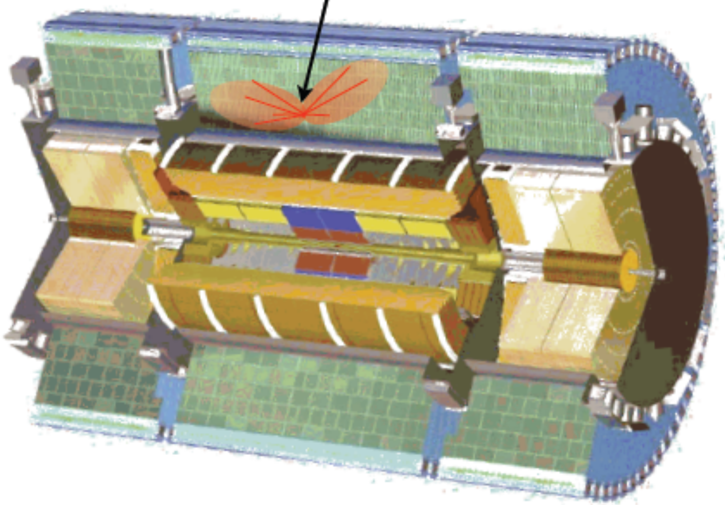
The R-hadrons may loose so much energy that they simply stop in the detector

Long Lived Gluinos

$\tau_{\tilde{g}} > 100$ ns

looking for stopped gluinos that later decay

100s GeV Unbalanced $= \not{E}_T$

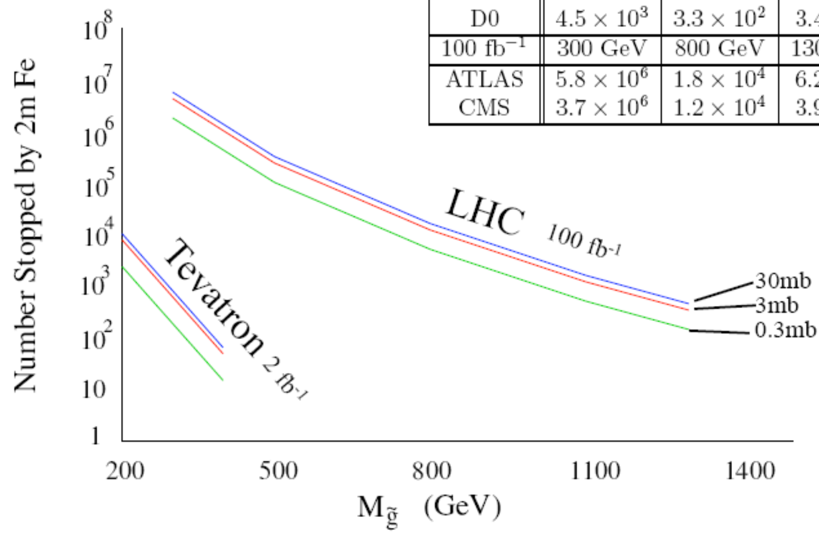


Uncorrelated with any beam crossing

No tracks going to or from activity

Total Number of Stopped Gluinos

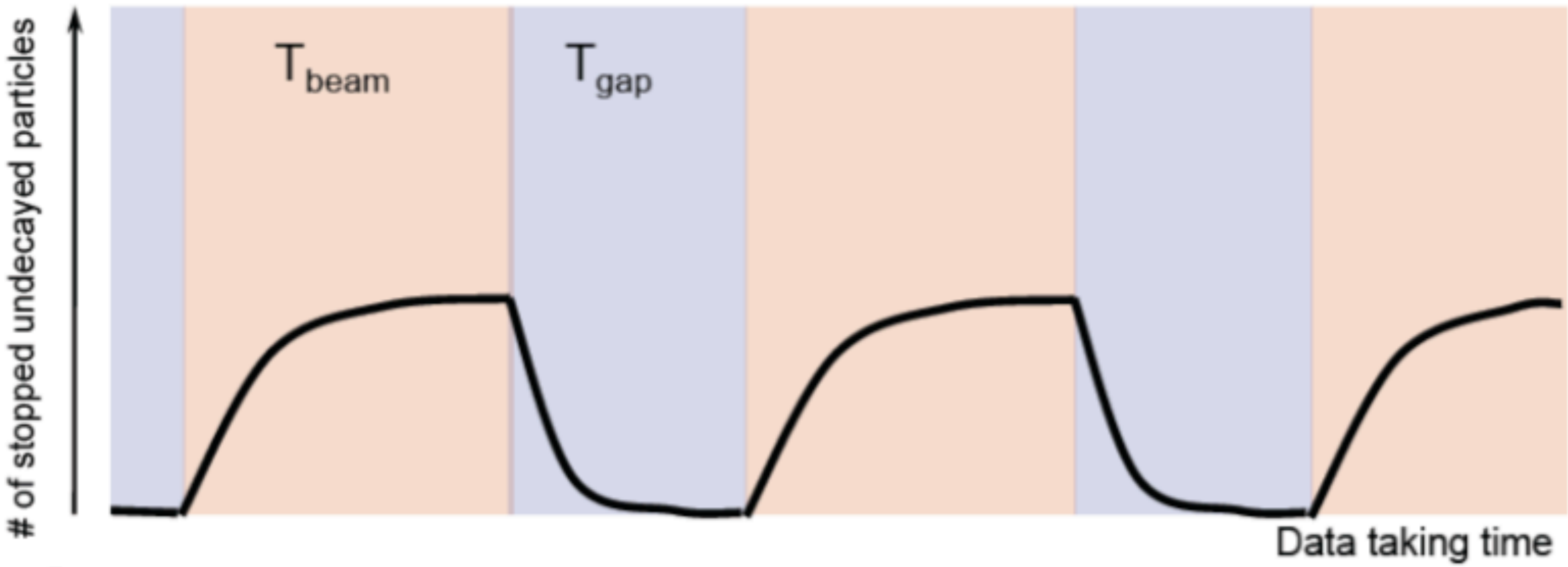
Arvanitaki, Dimopoulos, Pierce, Rajendran, JW hep-ph/0506242



2 fb^{-1}	200 GeV	300 GeV	400 GeV
CDF	4.1×10^3	3.1×10^2	3.3×10^1
D0	4.5×10^3	3.3×10^2	3.4×10^1
100 fb^{-1}	300 GeV	800 GeV	1300 GeV
ATLAS	5.8×10^6	1.8×10^4	6.2×10^2
CMS	3.7×10^6	1.2×10^4	3.9×10^2

$\Rightarrow$ Special triggers needed, asynchronous with the bunch crossing

Stopped gluinos



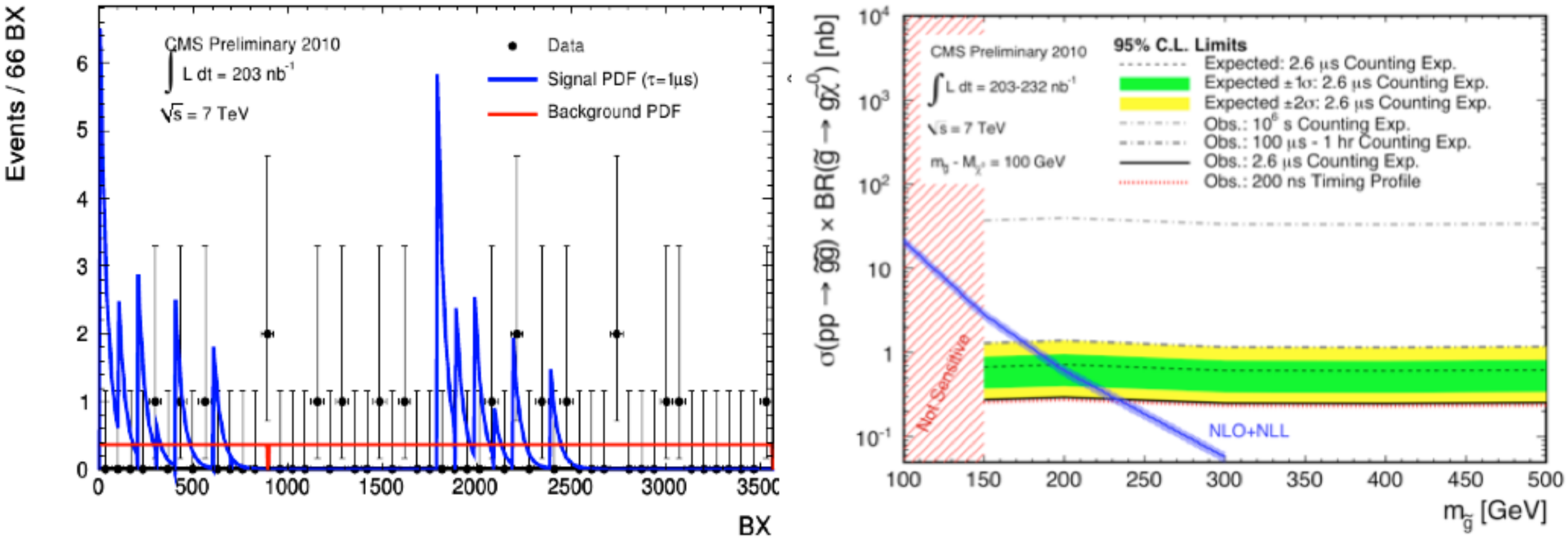
- Basic idea: R-hadrons can loose enough energy in the detector to stop somewhere inside (usually calorimeters)
- Sooner or later they must decay Eg when there is no beam!
- Trigger: (jet) && !(beam)
- Only possible backgrounds: cosmics and noise

Can be studied in the experiments with cosmic data

Stopped Gluinos

Search for HSCP that stop in the detectors
and decay a long time afterwards (nsec, sec, hrs…)

Searches for Stopped Gluino



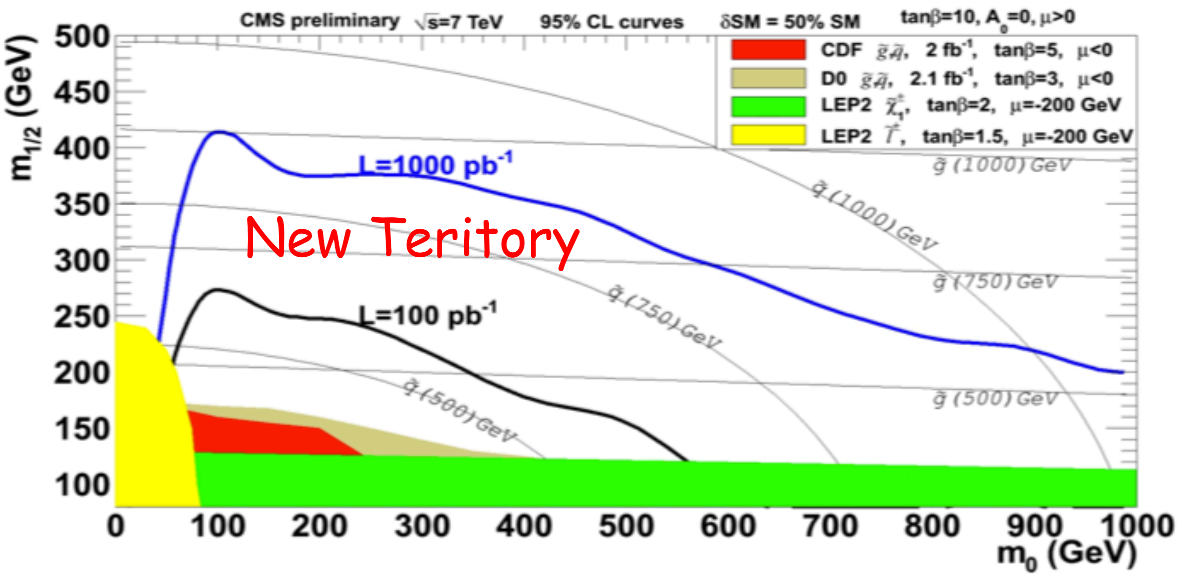
- gluino, hadronized into a charged R-hadron, can stop and decay in the calorimeter
- trigger on large "out-of-collision" energy depositions
- sensitive to the large lifetimes
- assume $BR(\tilde{g} \to g\tilde{\chi}^0) = 100\%,\ M_{\tilde{g}} - M_{\tilde{\chi}^0} > 100\ GeV$
- CMS'2010 95% CL limits on gluino lifetime $\tau_{\tilde{g}}$:
  - counting experiment excludes $\tau_{\tilde{g}}$ within [120ns, 6μs]
  - time profile analysis improves low limit down to 75ns

Gluino masses are excluded:

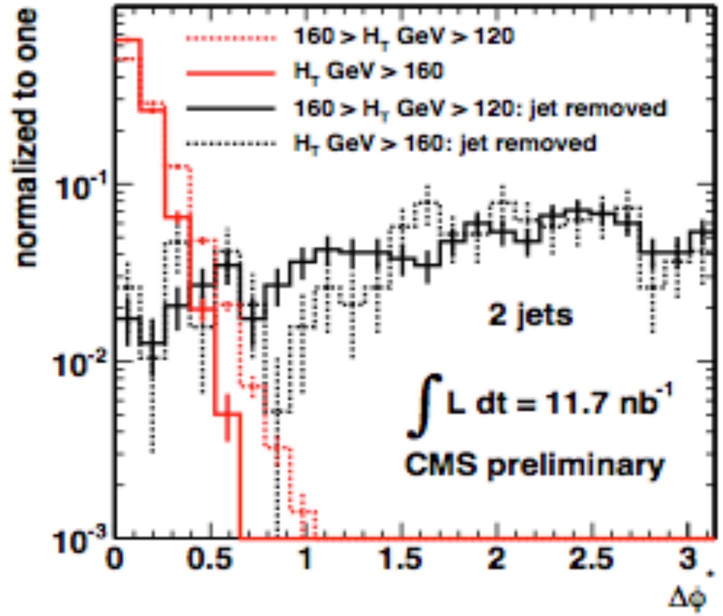
<229GeV (τ=200ns)
<225GeV (τ=2.6μs).

Preparing for SUSY Searches

Sensitivity to SUSY will come soon



Data driven methods in place



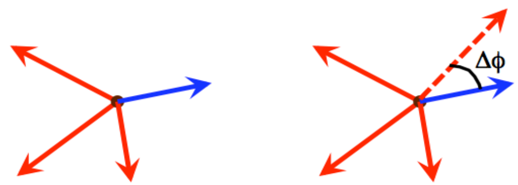
m_0 amd $m_{1/2}$ are universal scalar and gaugino masses at the GUT scale

$$\Delta\phi^* \equiv \min_k(|\Delta\phi((\sum_{i=0}^{i=n} -\vec{j}_i) + \vec{j}_k, \vec{j}_k)|)$$

100 pb^{-1} = end of 2010

1000 pb^{-1} = end of 2011

Δφ* is min over all jet partitions

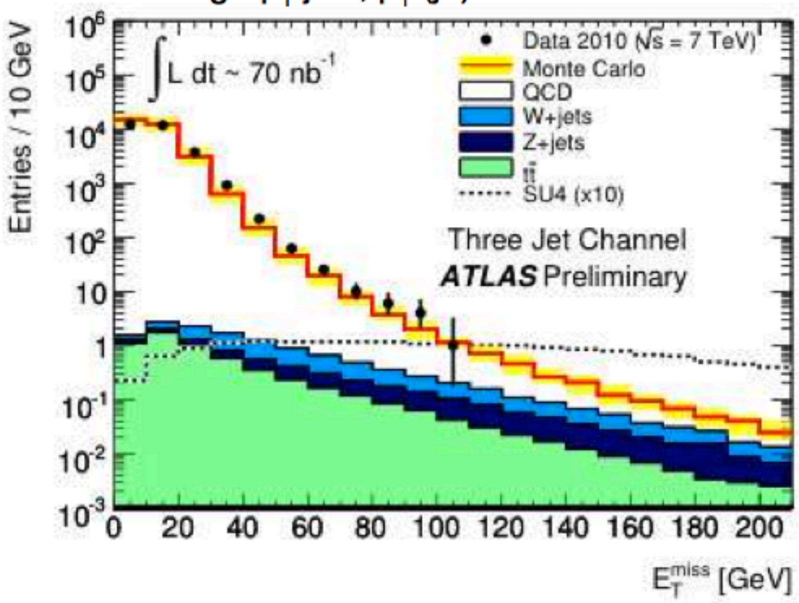


A Higgs discovery will likely need more data…

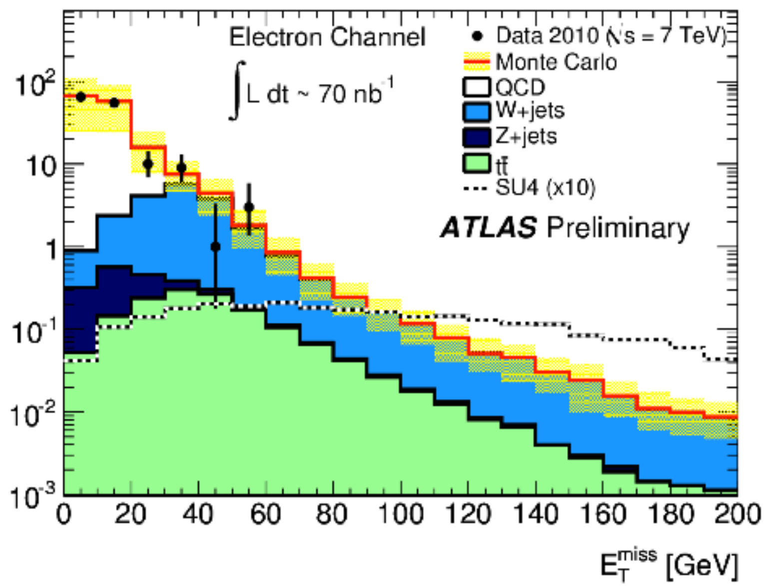
Searches for Supersymmetry

- **First task: Understand backgrounds !**
  - Some examples in SUSY-like searches

Jets + E_T^{miss} channel:
≥ 3 high-p_T jets, p_T (j1) > 70 GeV

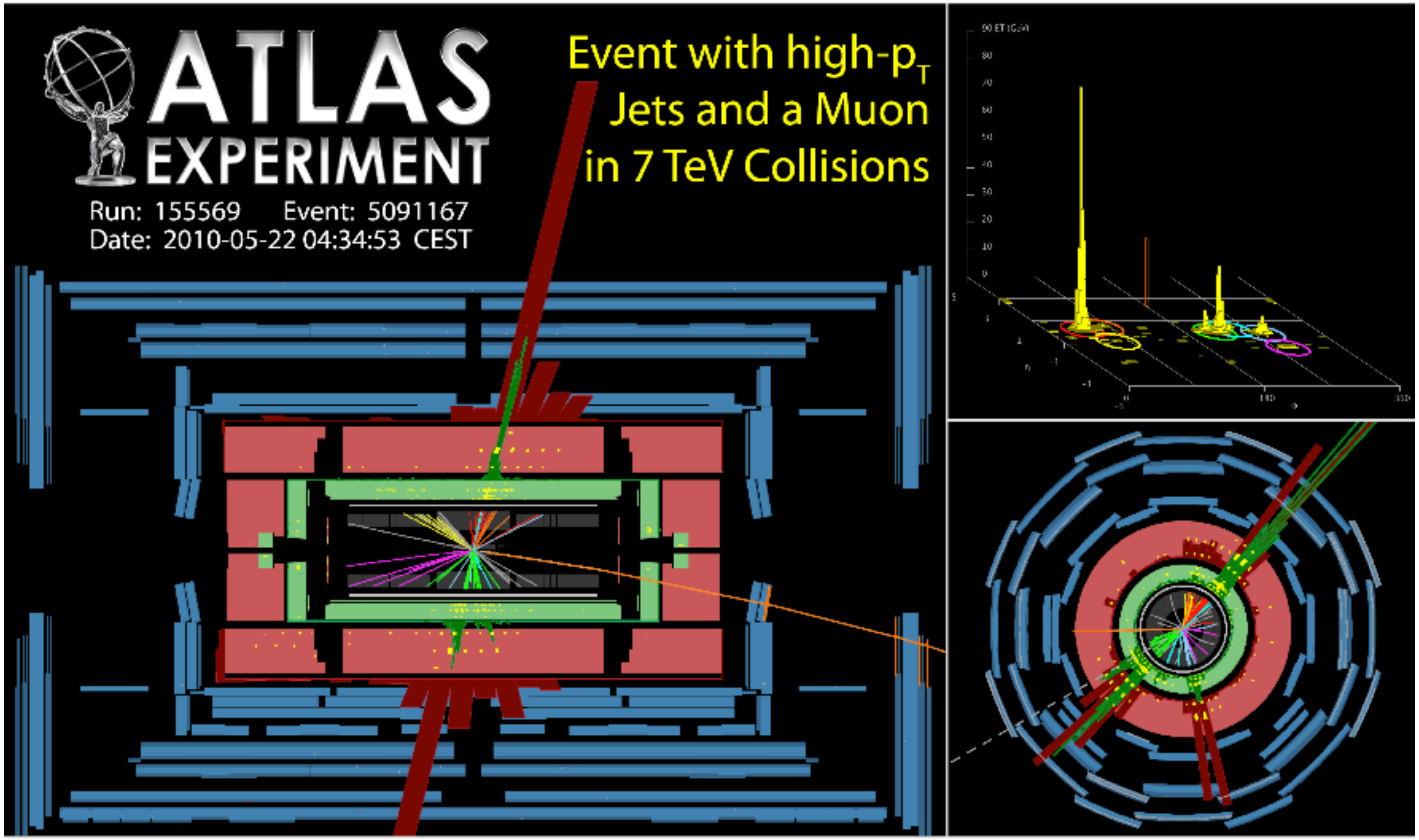


1 electron + Jets + ETmiss channel:
p_T (el) > 20 GeV, ≥ 2 high-p_T jets



Meanwhile be prepared to set competitive limits with > 1pb⁻¹ data

An Interesting Event…



A few weeks back…

It's On: Early Interpretations of ATLAS Results in Jets and Missing Energy Searches

Daniele S. M. Alves,[1,2] Eder Izaguirre,[1,2] and Jay G. Wacker[1]

[1] *Theory Group, SLAC National Accelerator Laboratory, Menlo Park, CA 94025*
[2] *Physics Department, Stanford University, Stanford, CA 94305*

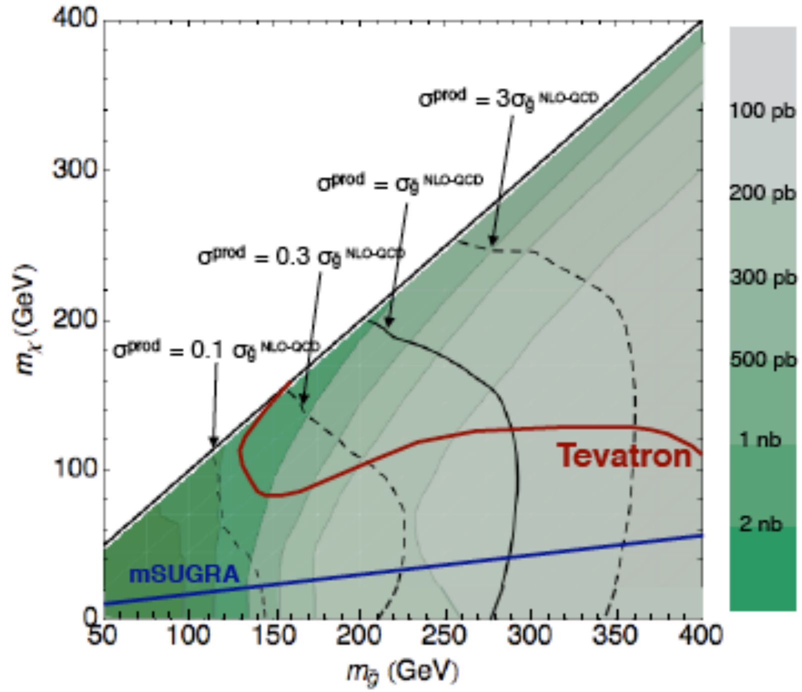
4/8/2010

The first search for supersymmetry from ATLAS with 70 nb^{-1} of integrated luminosity sets new limits on colored particles that decay into jets plus missing transverse energy. For gluinos that decay directly or through a one step cascade into the LSP and two jets, these limits translate into a bound of $m_{\tilde{g}} \geq 205$ GeV, regardless of the mass of the LSP. In some cases the limits extend up to $m_{\tilde{g}} \simeq 295$ GeV, already surpassing the Tevatron's reach for compressed supersymmetry spectra.

ATLAS Data for the summer conference

Cut	Topology	$1j + \not{E}_T$	$2^+j + \not{E}_T$	$3^+j + \not{E}_T$	$4^+j + \not{E}_T$
1	p_{T1}	> 70 GeV	> 70 GeV	> 70 GeV	> 70 GeV
2	p_{Tn}	≤ 30 GeV	> 30 GeV $(n = 2)$	> 30 GeV $(n = 2, 3)$	> 30 GeV $(n = 2 - 4)$
3	$\not{E}_{T\,\mathrm{EM}}$	> 40 GeV	> 40 GeV	> 40 GeV	> 40 GeV
4	$\Delta\phi(j_n, \not{E}_{T\,\mathrm{EM}})$	none	$[> 0.2, > 0.2]$	$[> 0.2, > 0.2, > 0.2]$	$[> 0.2, > 0.2, > 0.2,$ none$]$
5	$\not{E}_{T\,\mathrm{EM}}/M_{\mathrm{eff}}$	none	> 0.3	> 0.25	> 0.2
	N_{Pred}	46^{+22}_{-14}	6.6 ± 3.0	1.9 ± 0.9	1.0 ± 0.6
	N_{Obs}	73	4	0	1
	$\sigma(pp \to \tilde{g}\tilde{g}X)\epsilon\|_{95\%\ \mathrm{C.L.}}$	663 pb	46.4 pb	20.0 pb	56.9 pb

$pp \to \tilde{g}\tilde{g}X$



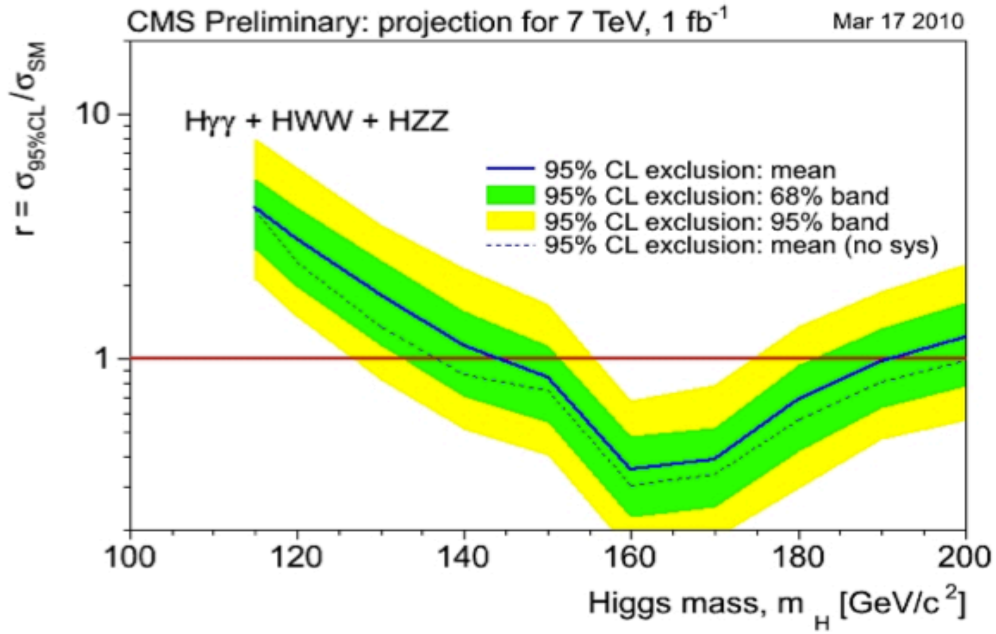
70 nb^{-1} only!!

Low luminosity but can already exclude some special SUSY regions with LHC

…And the Search for the Higgs

- Sizeable integrated luminosity is needed before significant insights can be made in SM Higgs search.
- However, even with moderate luminosity per experiment, Higgs boson discovery is possible in particular mass regions.

Example Reach by end of 2011



- If the Higgs exist: LHC will discover it after 3-4 years of operation
- If the Higgs does not exist: LHC should see other new effects

Summary

- CMS and ATLAS are very well advanced with the detector commissioning and calibration
- The experiments records physics data, following a well defined scheme, evolving with luminosity, for triggers and datasets and data distribution.
- Physics papers being completed on the 7 TeV collisions. Lots of results for ICHEP2010 on QCD, EWK, B-physics, and observation of the top. The first searches for new physics have started, and some go already beyond the limits of the Tevatron.
- CMS and ATLAS are ready for the 'real game' ie searches for new physics, and for the Higgs

and maybe soon…

END