Status and Prospects of LHC Experiments

Physics Results

Gregor Herten

University of Freiburg

HGF Alliance "Terascale"

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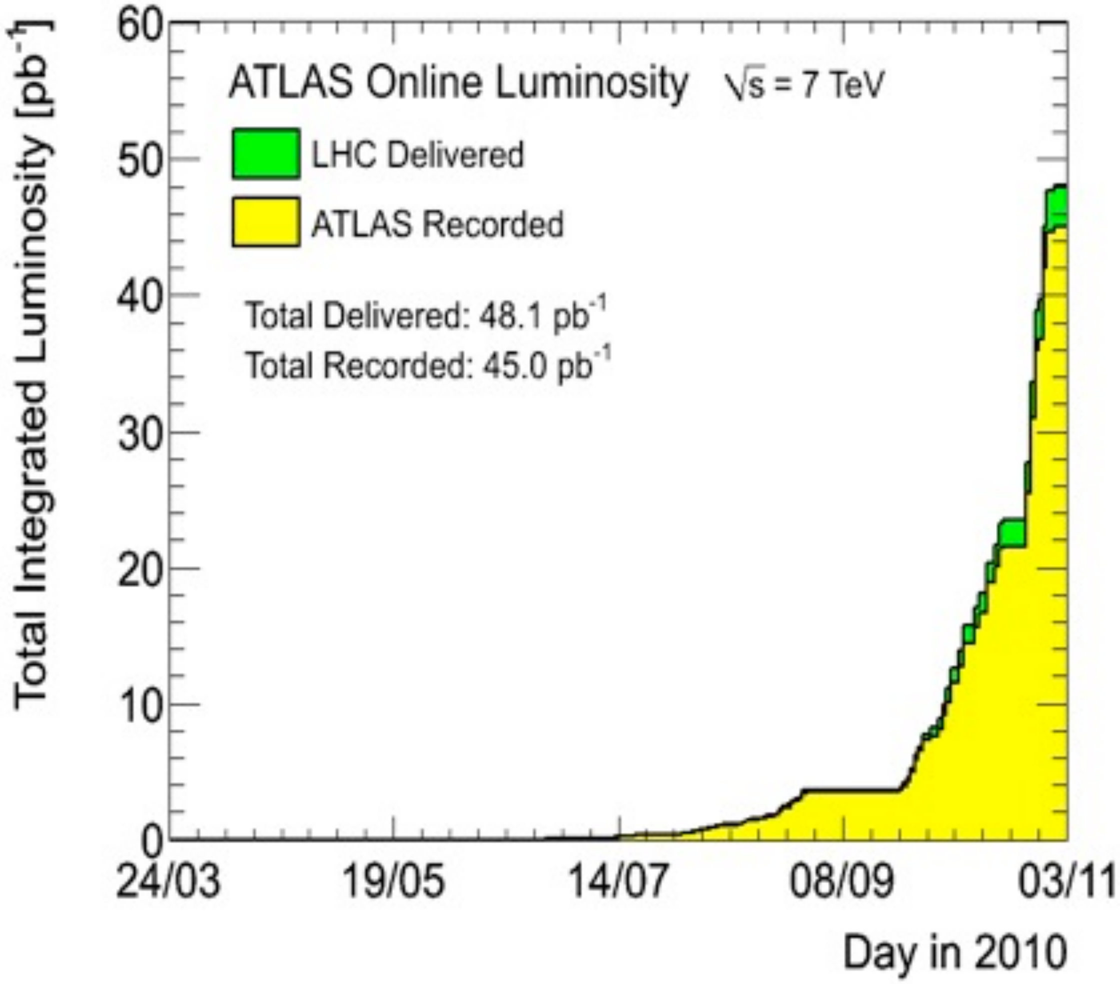
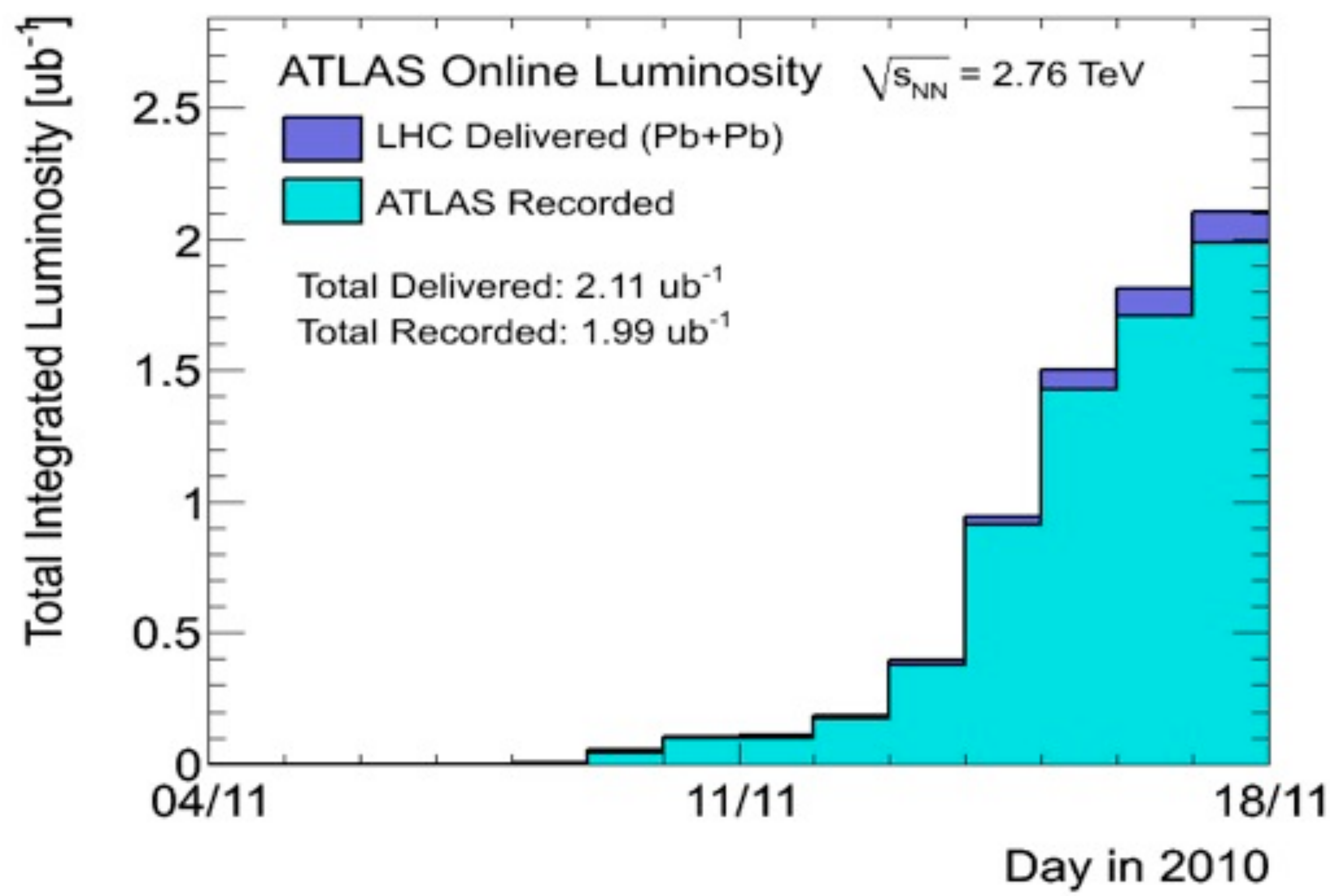
Outline

1. Luminosity and Detector Performance
2. Heavy Ion Physics
3. Soft QCD
4. Exclusive Hadron Decays
5. Jets
6. Electroweak and Top Physics
7. Search for New Particles

Remark:
Material is taken from published results and LHCC presentation (17. Nov. 2010.)

Luminosity





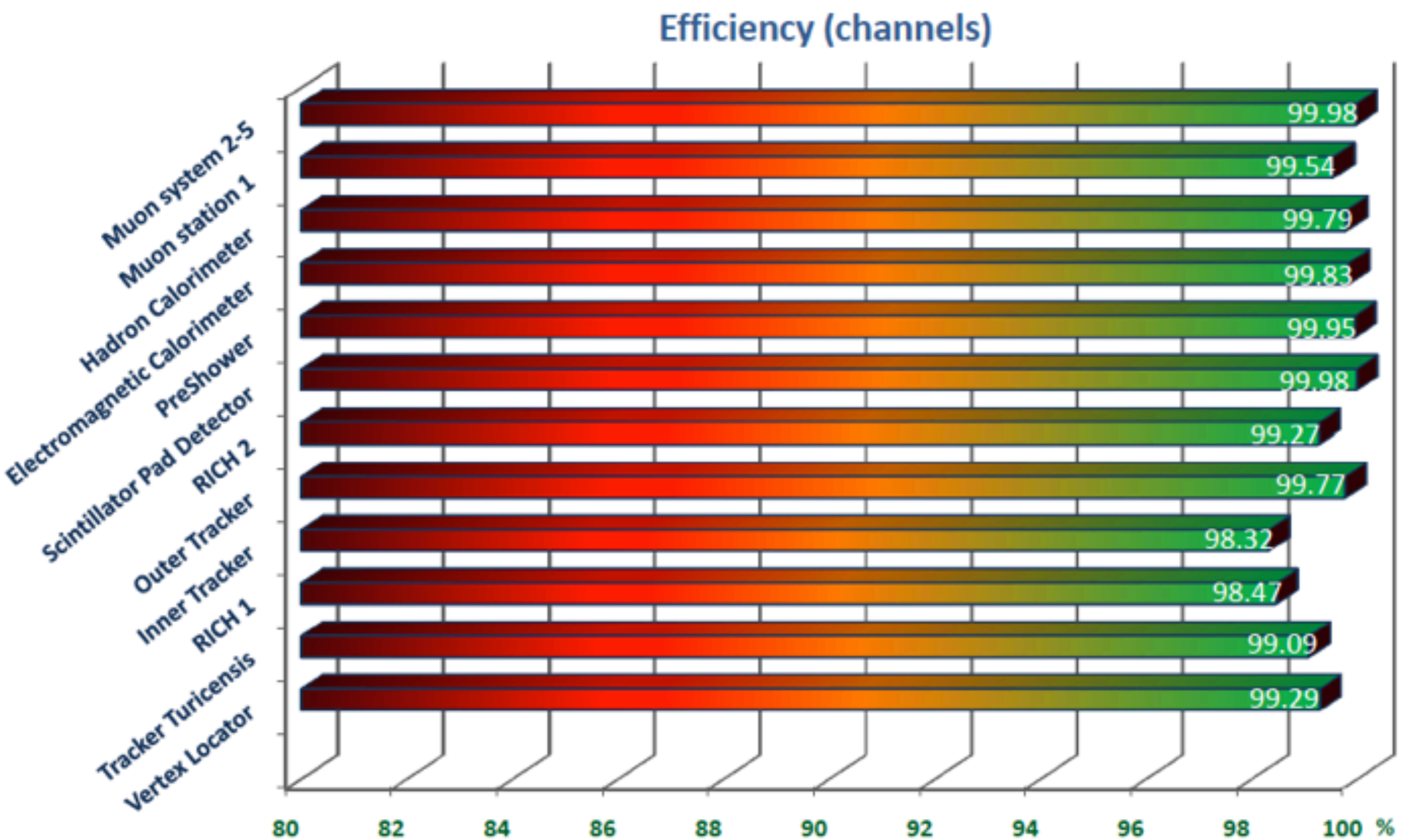
24 out of 48 pb^{-1} delivered in one week of pp running!

Peak L of 2.1×10^{32} $cm^{-2}s^{-1}$; Max. average 4 interactions per BC

Error of luminosity measurement: 11% already dominating error for many cross section measurements.

In Heavy Ion Run: Total luminosity now about 7 μb^{-1}; Cross section 8 barn.

Data Taking Efficiencies

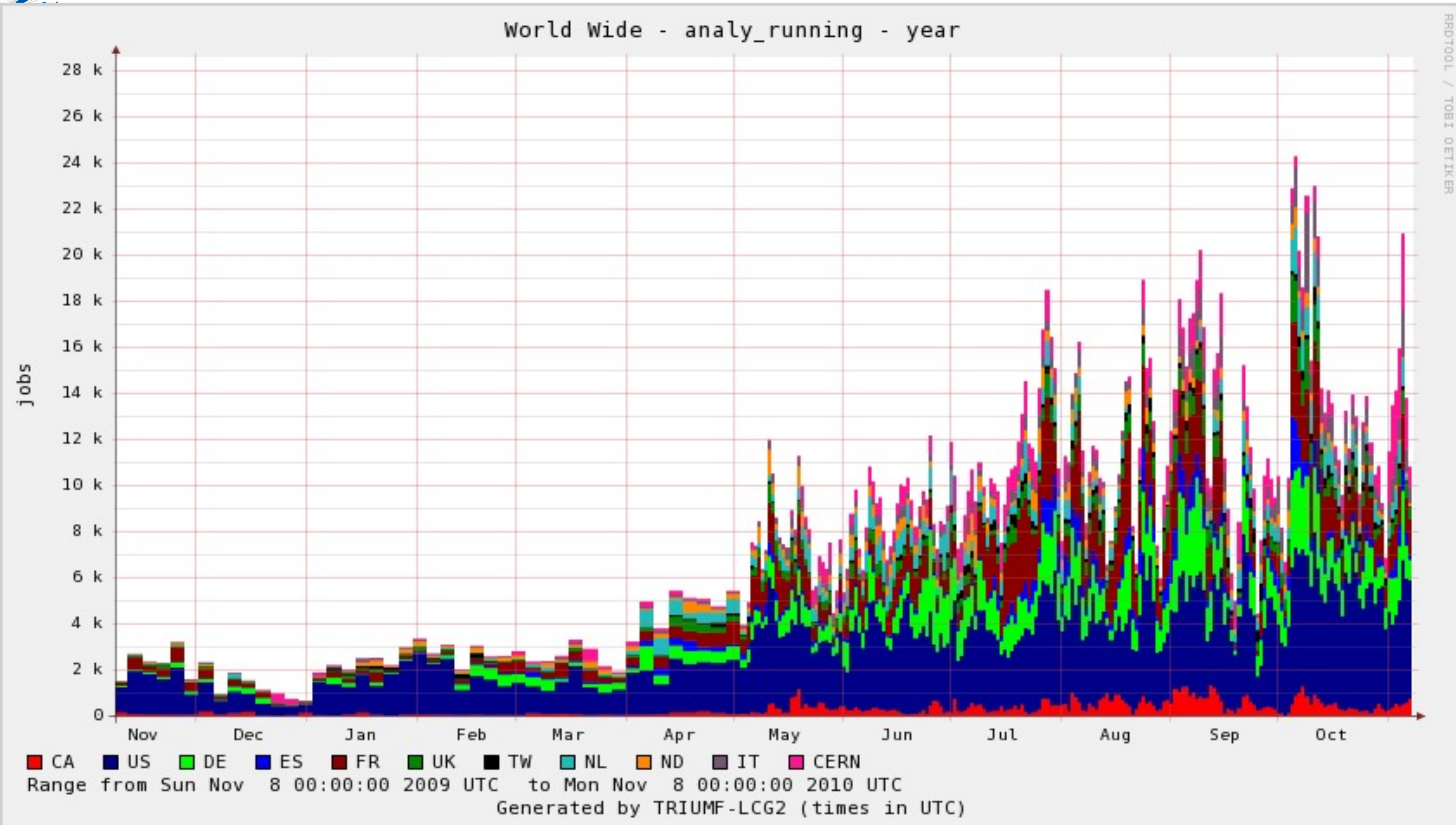


Example: LHCb

Efficiencies close to 100%

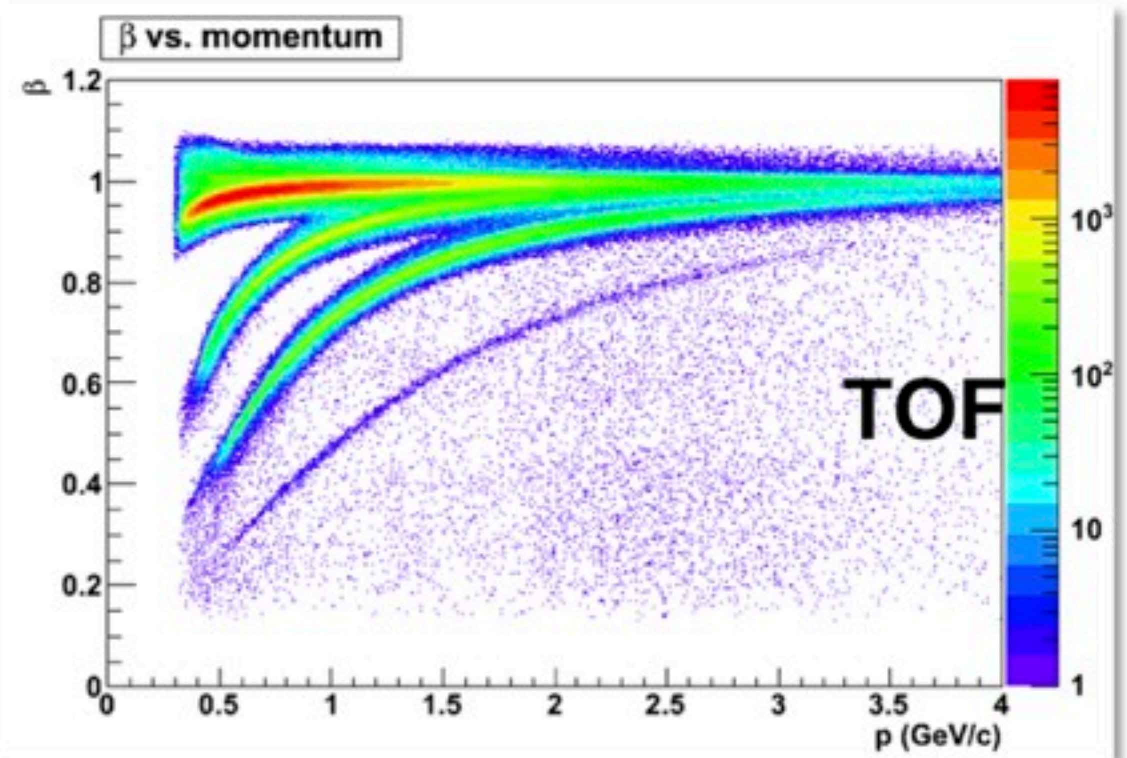
The other LHC experiments have similar detector efficiencies: > 90% for all sub-detectors.

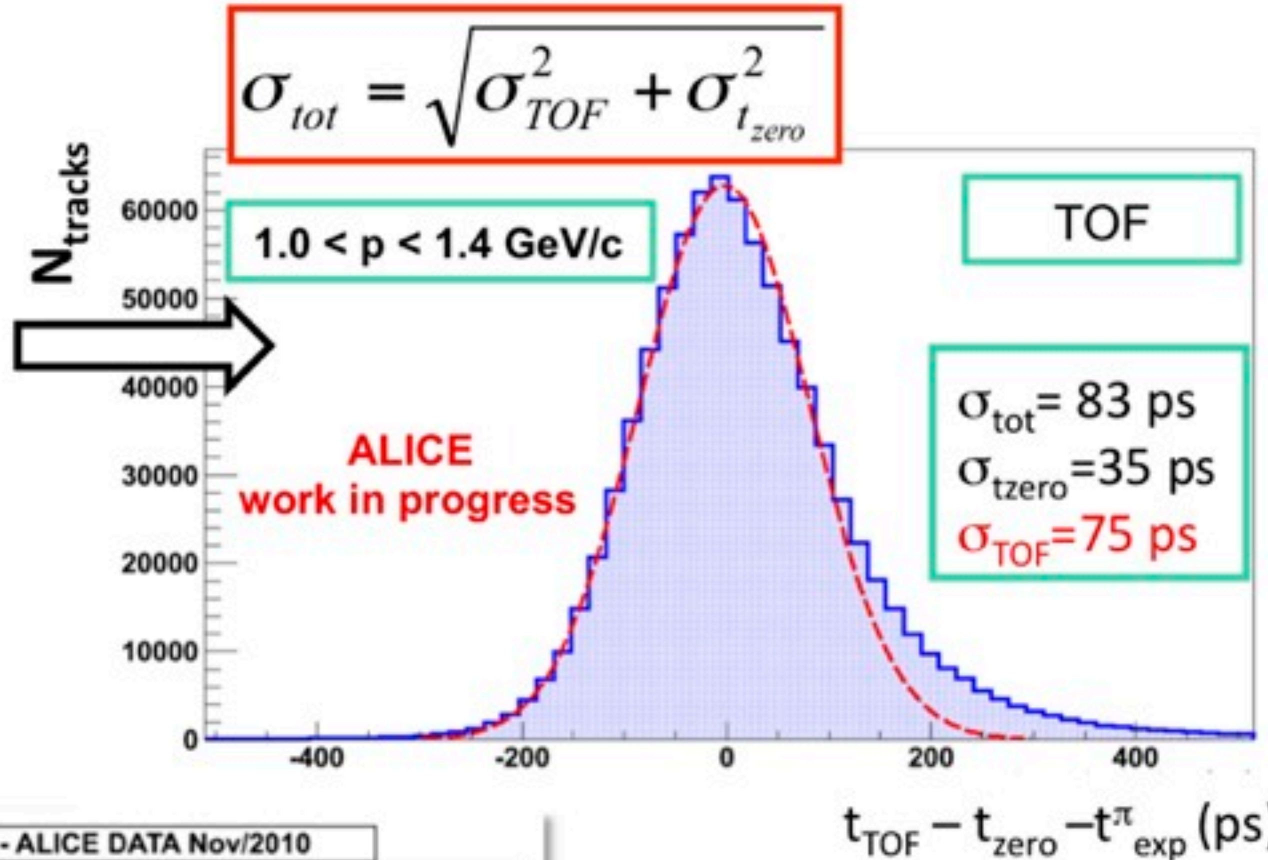
Computing: GRID Jobs (Example ATLAS)

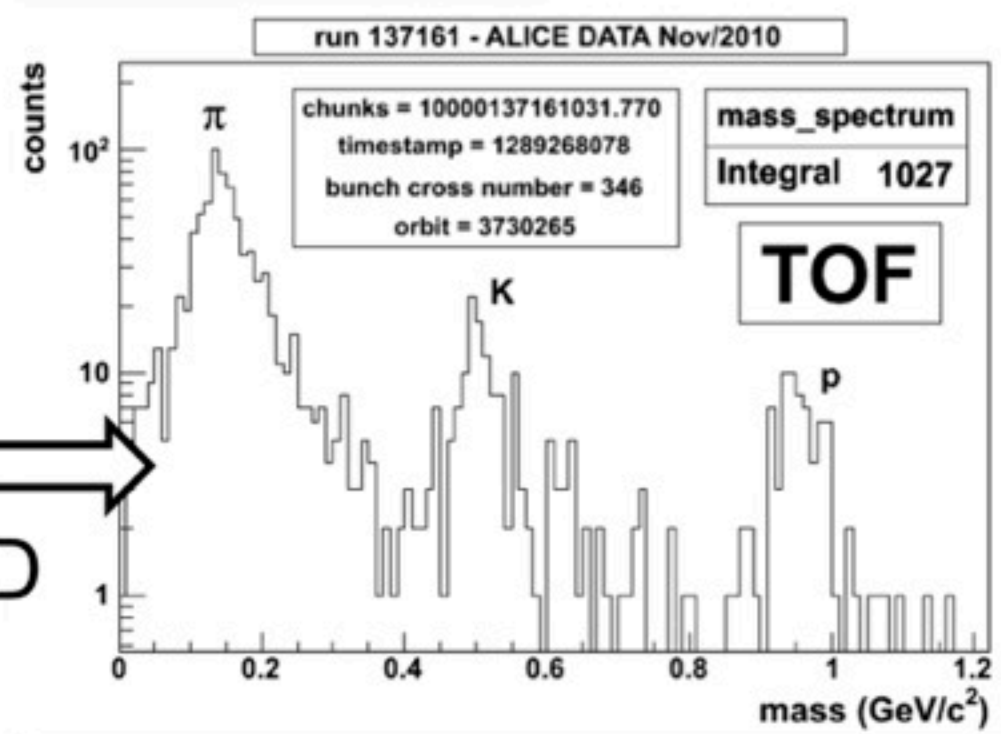


More then 1000 users. Huge increase of number of jobs. Higher than expected network traffic.

ALICE Pb-Pb Collisions : Particle ID



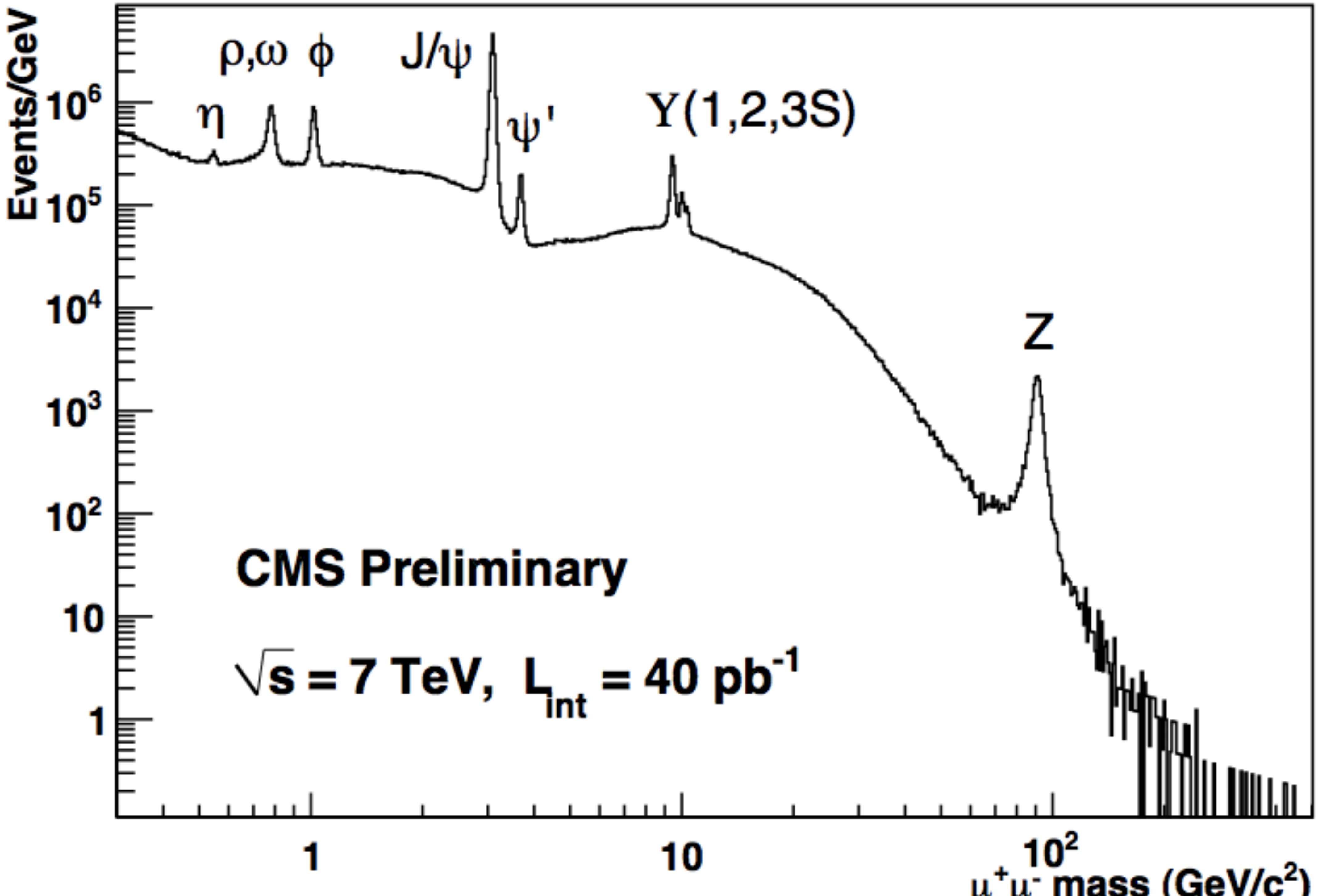




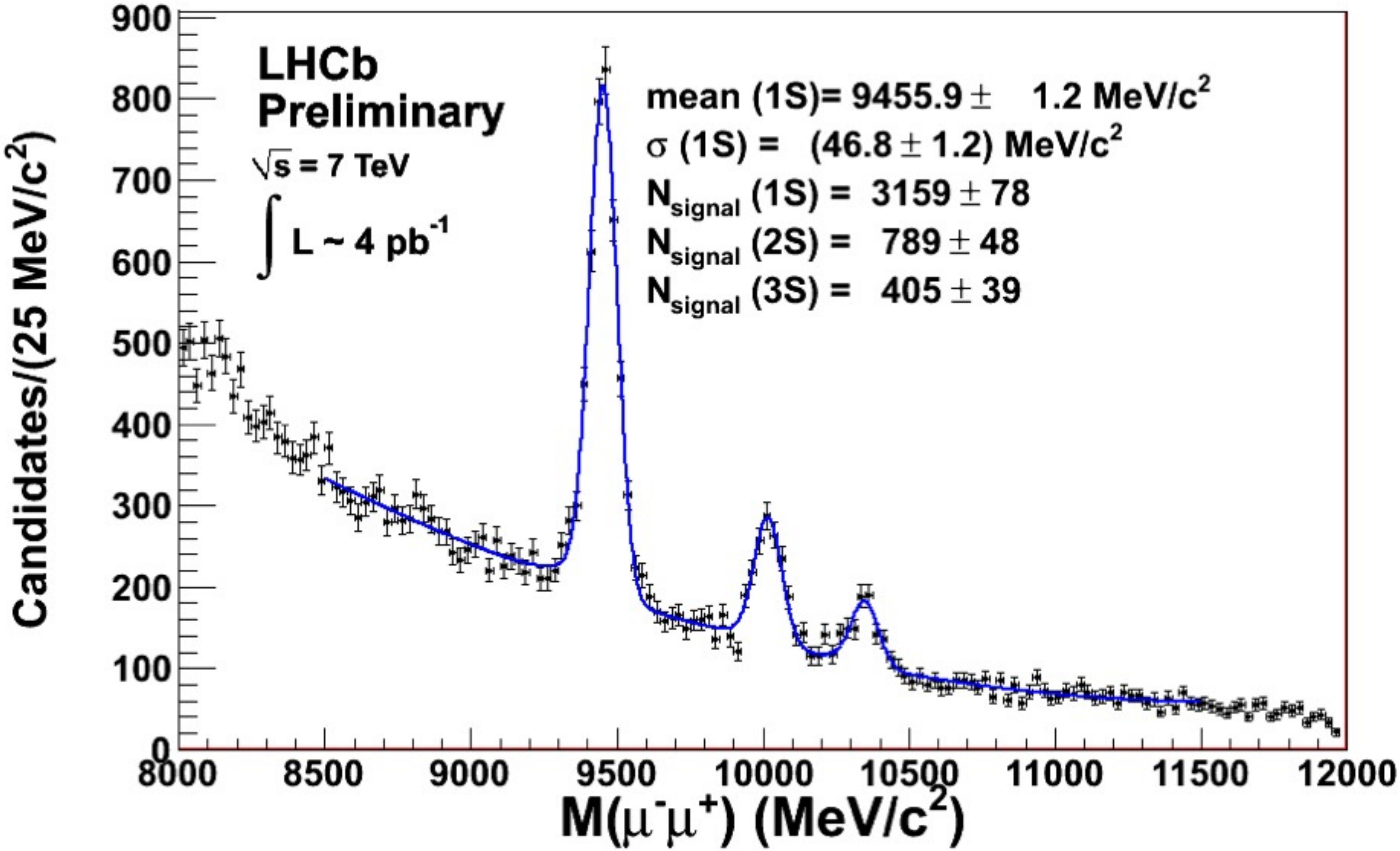
A single Pb-Pb collision!
Event-by-event PID

<80 ps (design) resolution seems within reach!

Detector Performance: CMS inclusive Di-Muon

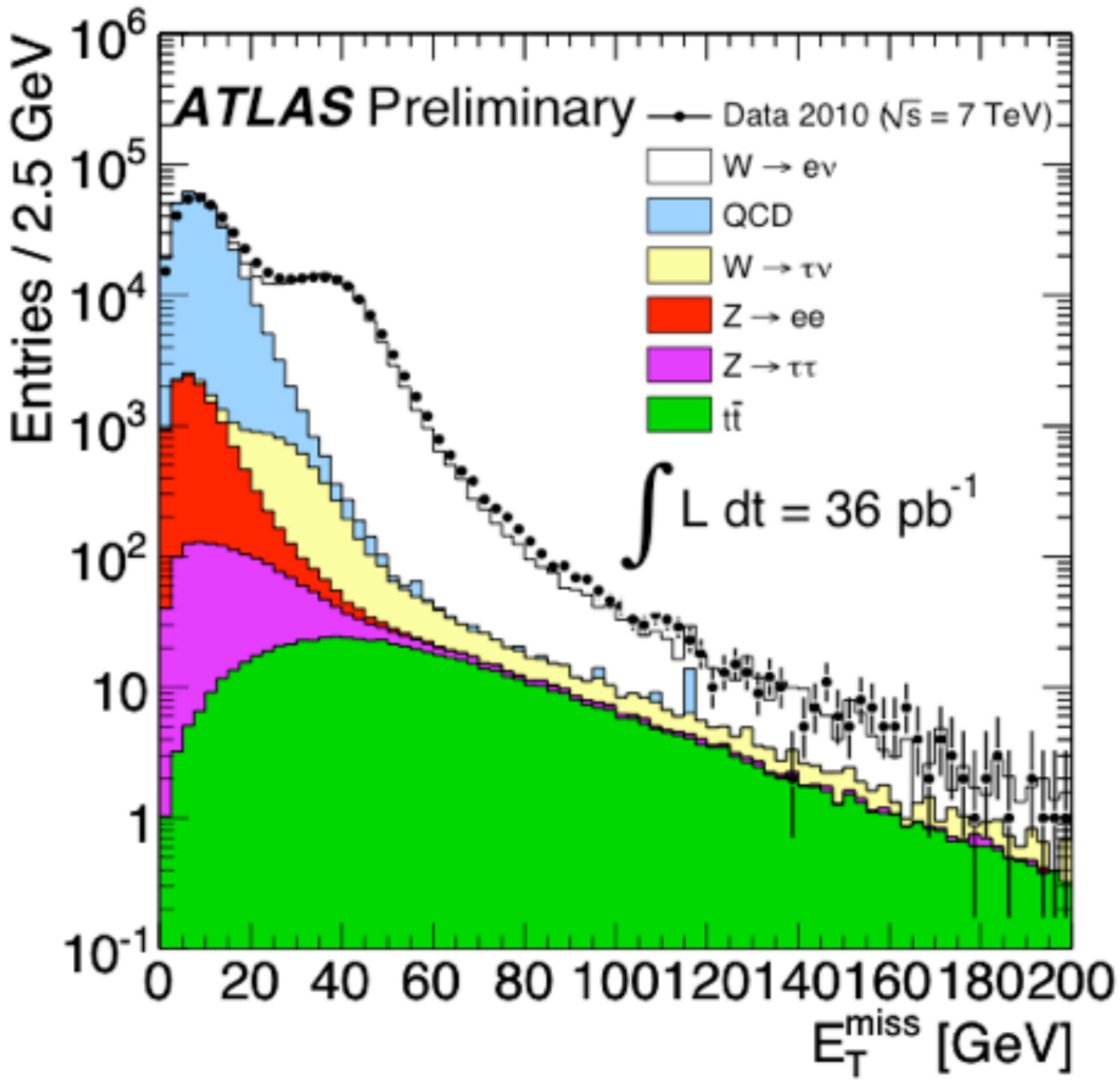


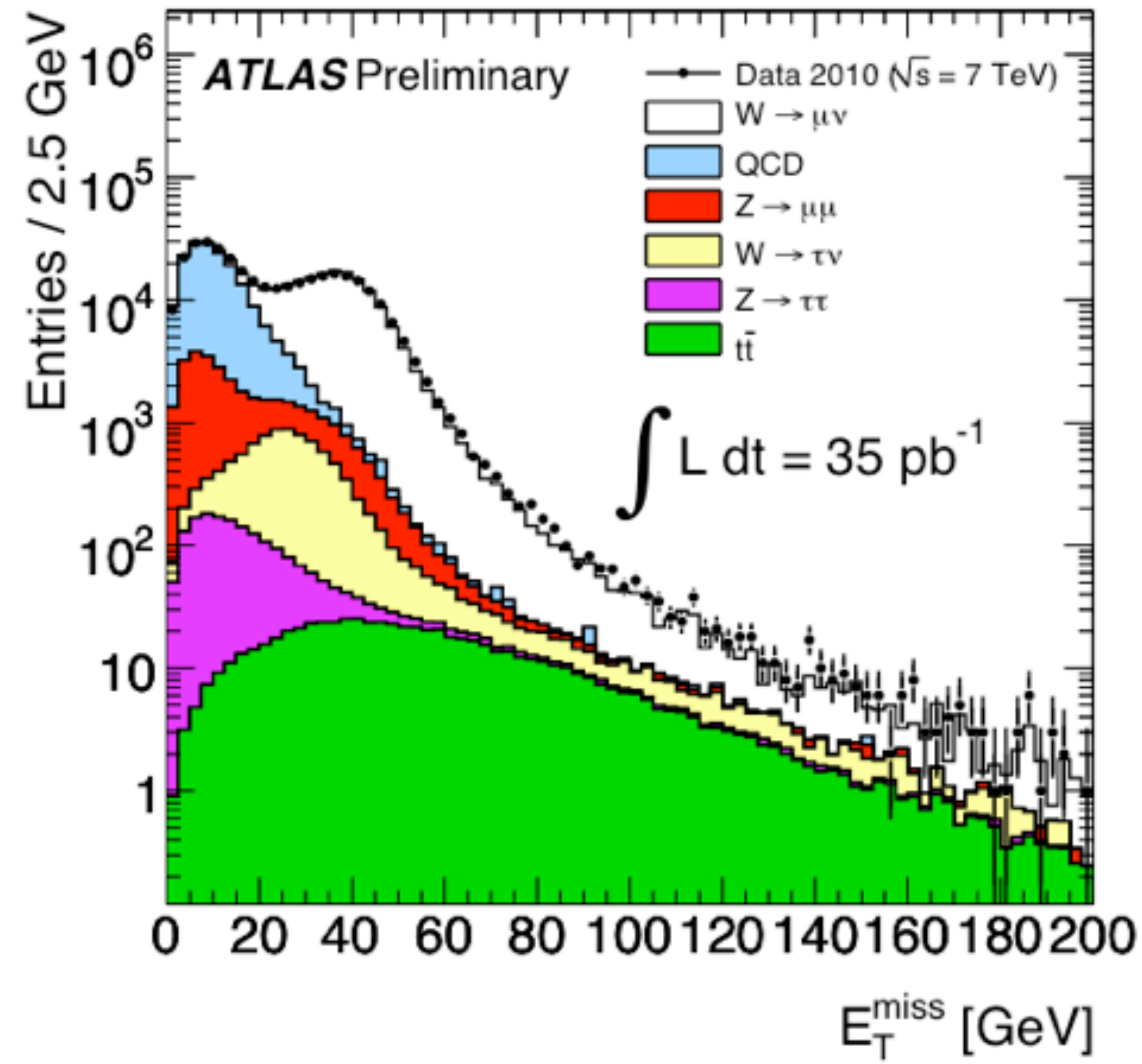
LHCb Di-Muons



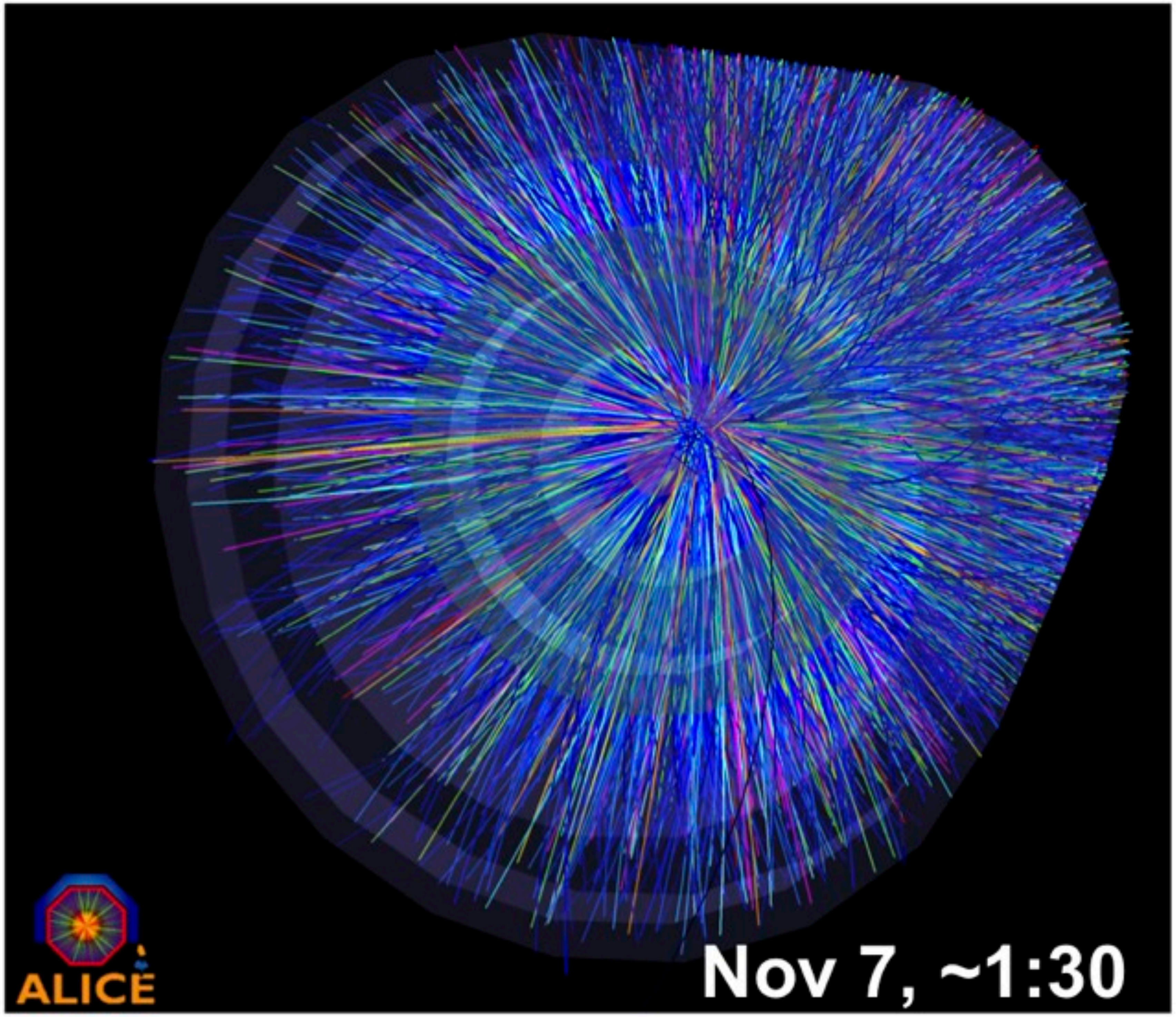
Detector Performance: ATLAS Transverse Missing Energy

E_T^{miss} distribution for events with e or μ with p_T>20 GeV





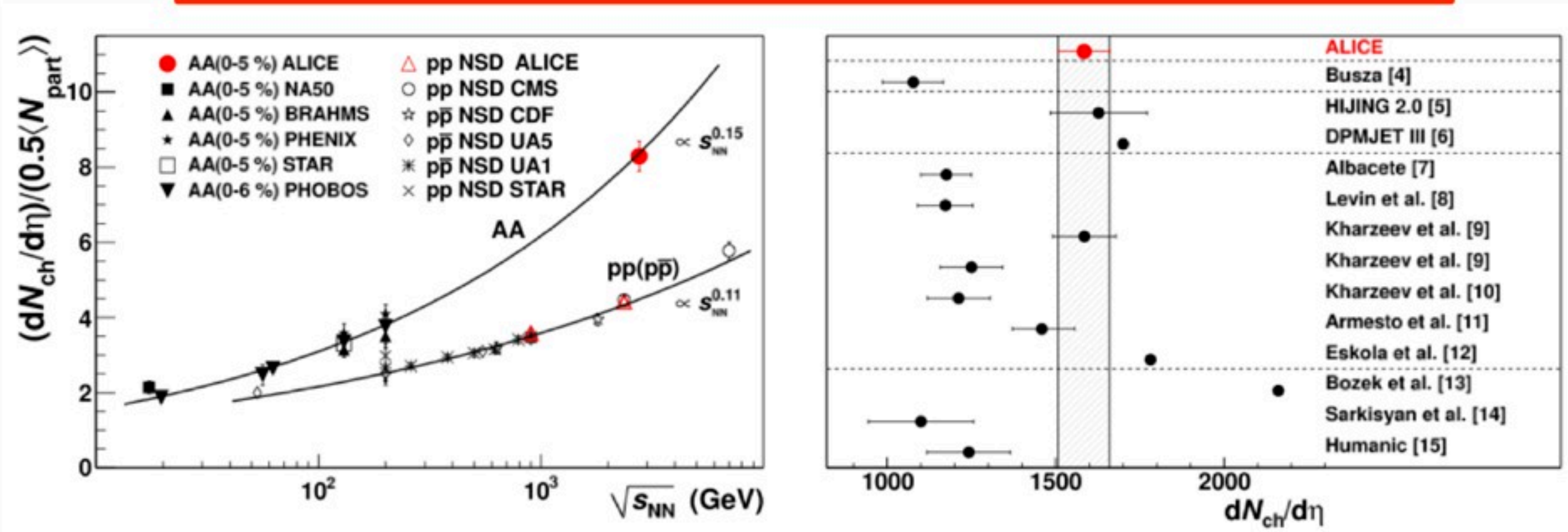
Heavy Ion Physics: ALICE event



Multiplicities of several 1000 observed, highest about 10 000 tracks (ATLAS)

Heavy Ion Physics: ALICE multiplicity

$$\boxed{dN_{ch}/d\eta = 1584 \pm 4\ (stat.) \pm 76\ (syst.)}$$

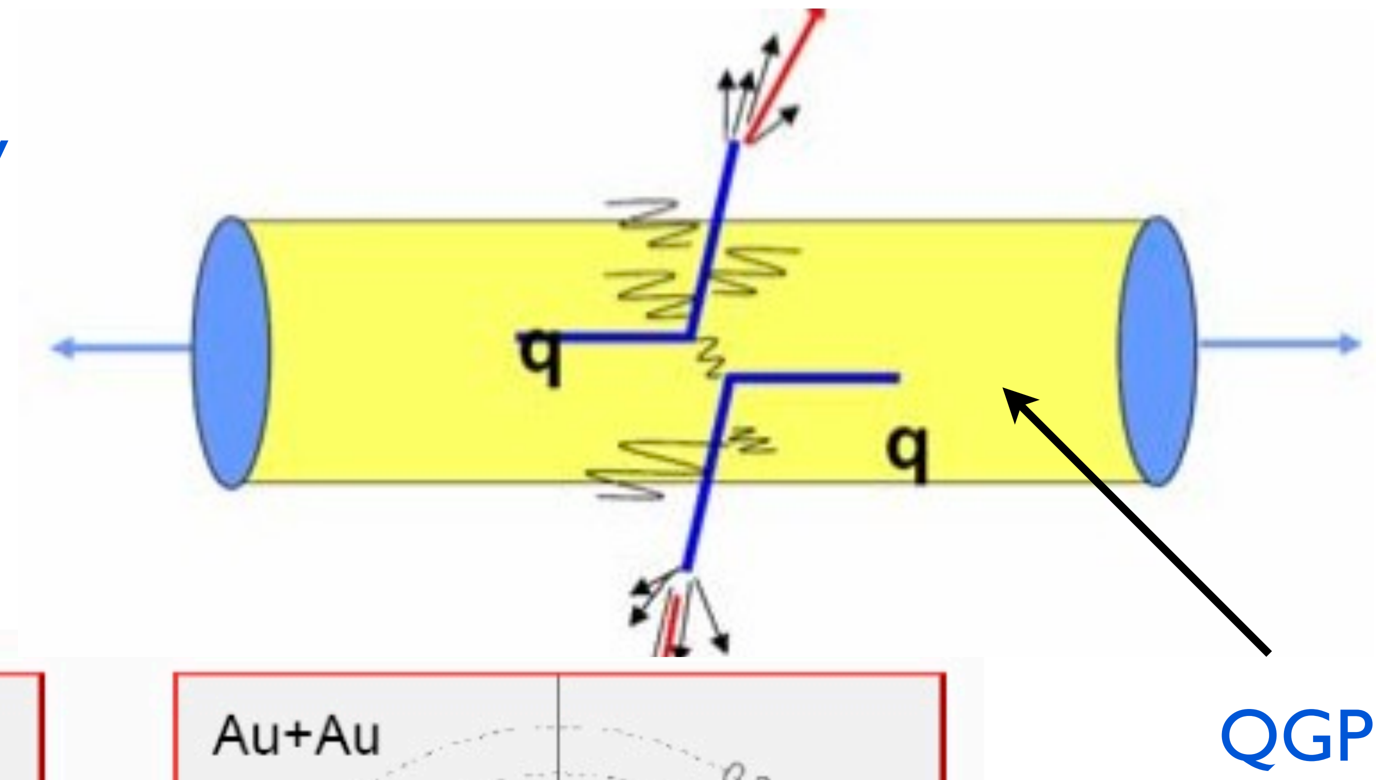


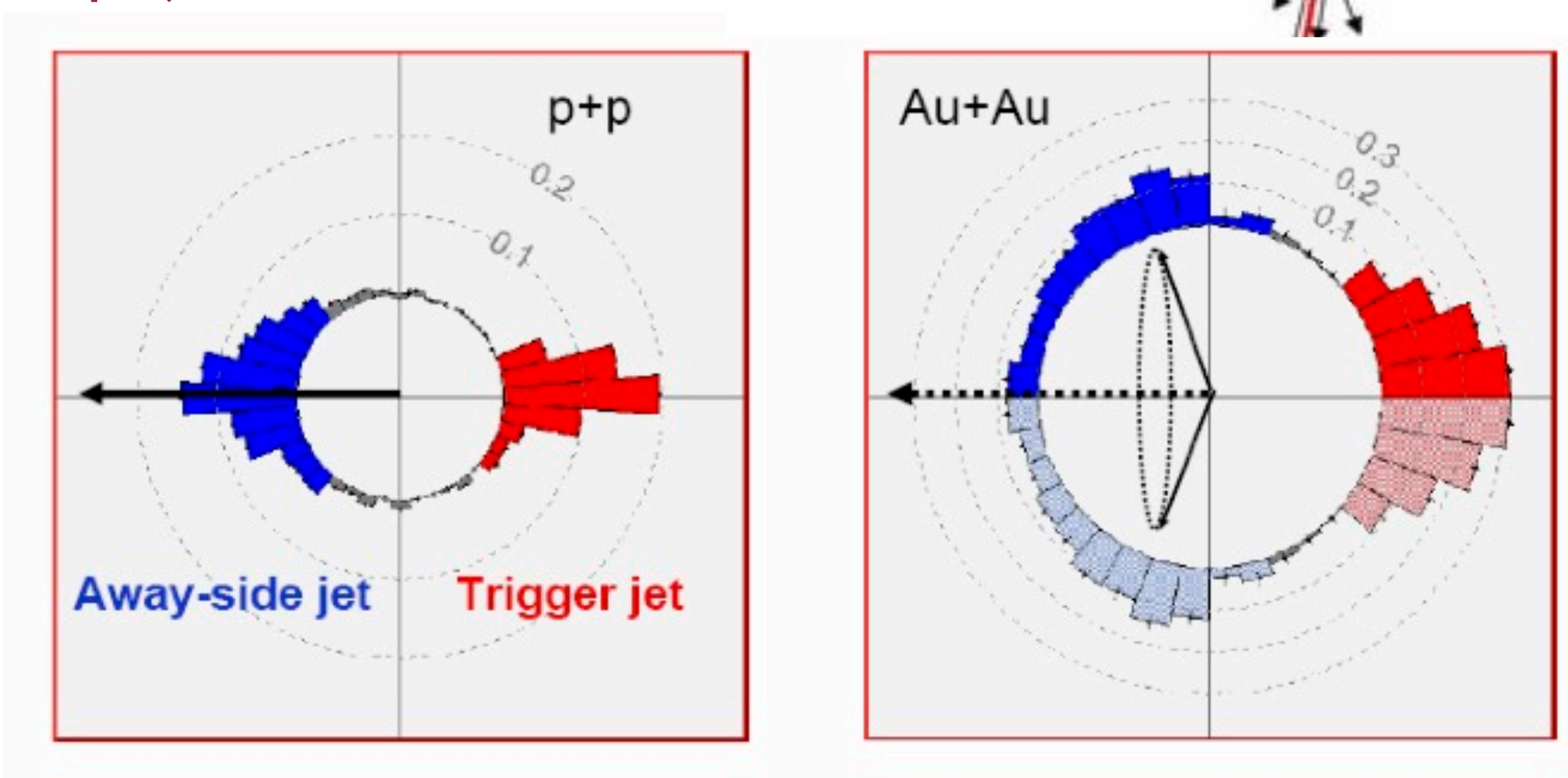
- Increase by factor 1.9 wrt pp at same energy
- Increase by factor 2.2 wrt RHIC Au-Au 200 GeV
- Extrapolation based on RHIC data and limiting fragm. underpredicts
- pQCD-inspired MCs (Hijing, DPMJet) consistent with data
- Some of the models based on intial state saturation underpredict

Heavy Ion Physics: ATLAS Jet Quenching

One expects that quarks loose energy in dense colored quark gluon plasma (jet quenching).

2-jet events at edge of QGP:
Expect high pt-jet on one side and broad low pt-jet on other side.



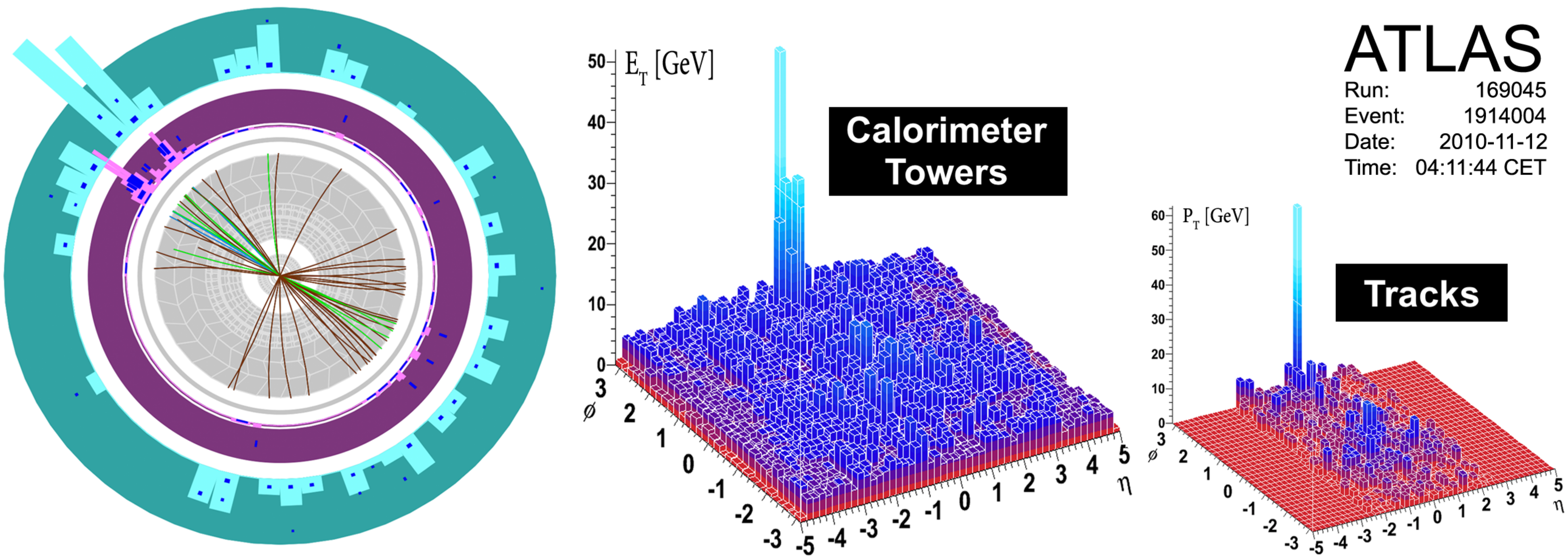


Lost energy of away-side jet is redistributed to angles away from 180° and low transverse momenta $p_T < 2$ GeV/c

ATLAS: Observation of Asymmetric Jets

p_t > 2.6 GeV
and > 0.7 GeV (ECAL)
and > 1.0 GeV (HCAL)

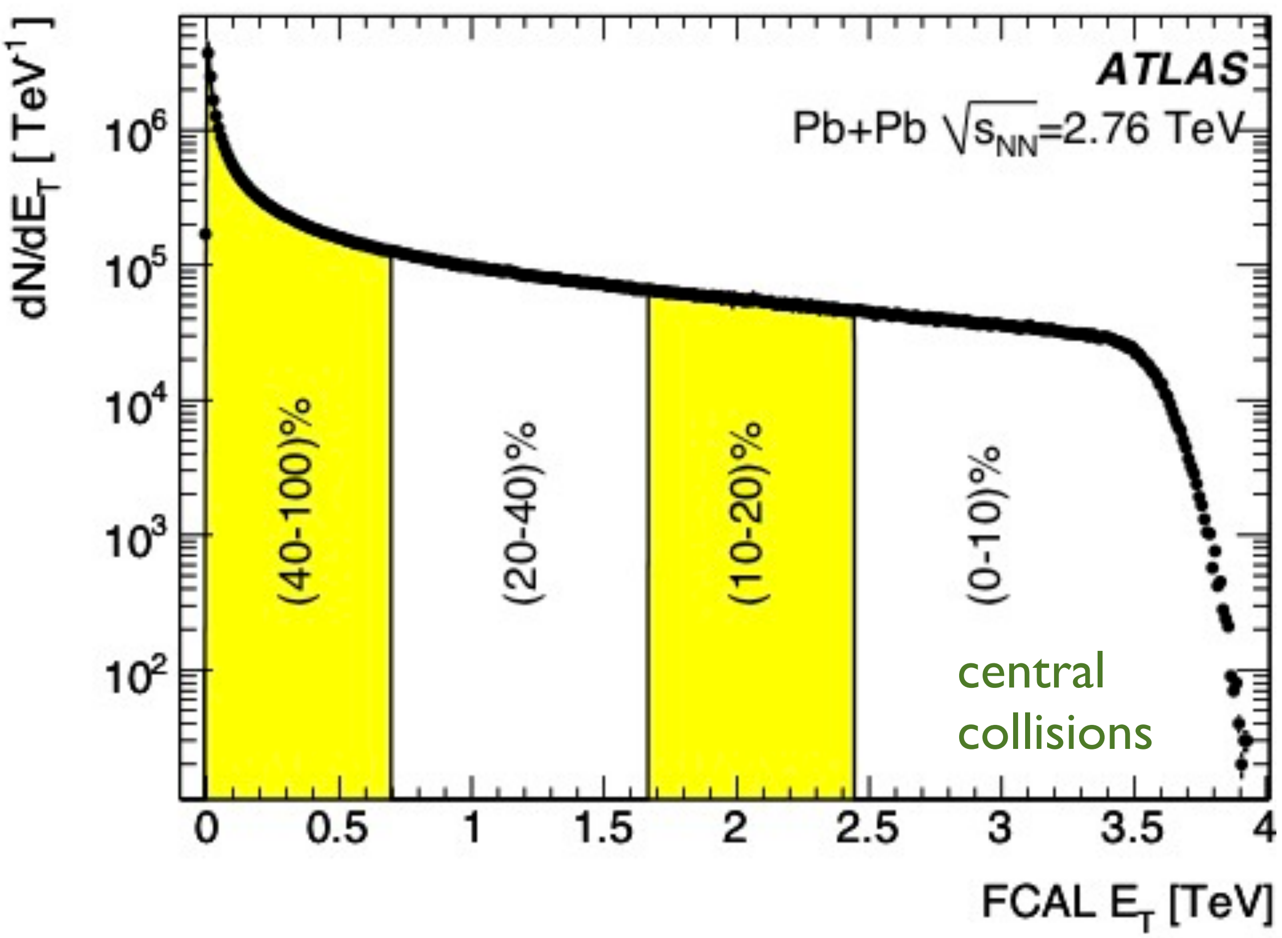
E_T = 100 GeV

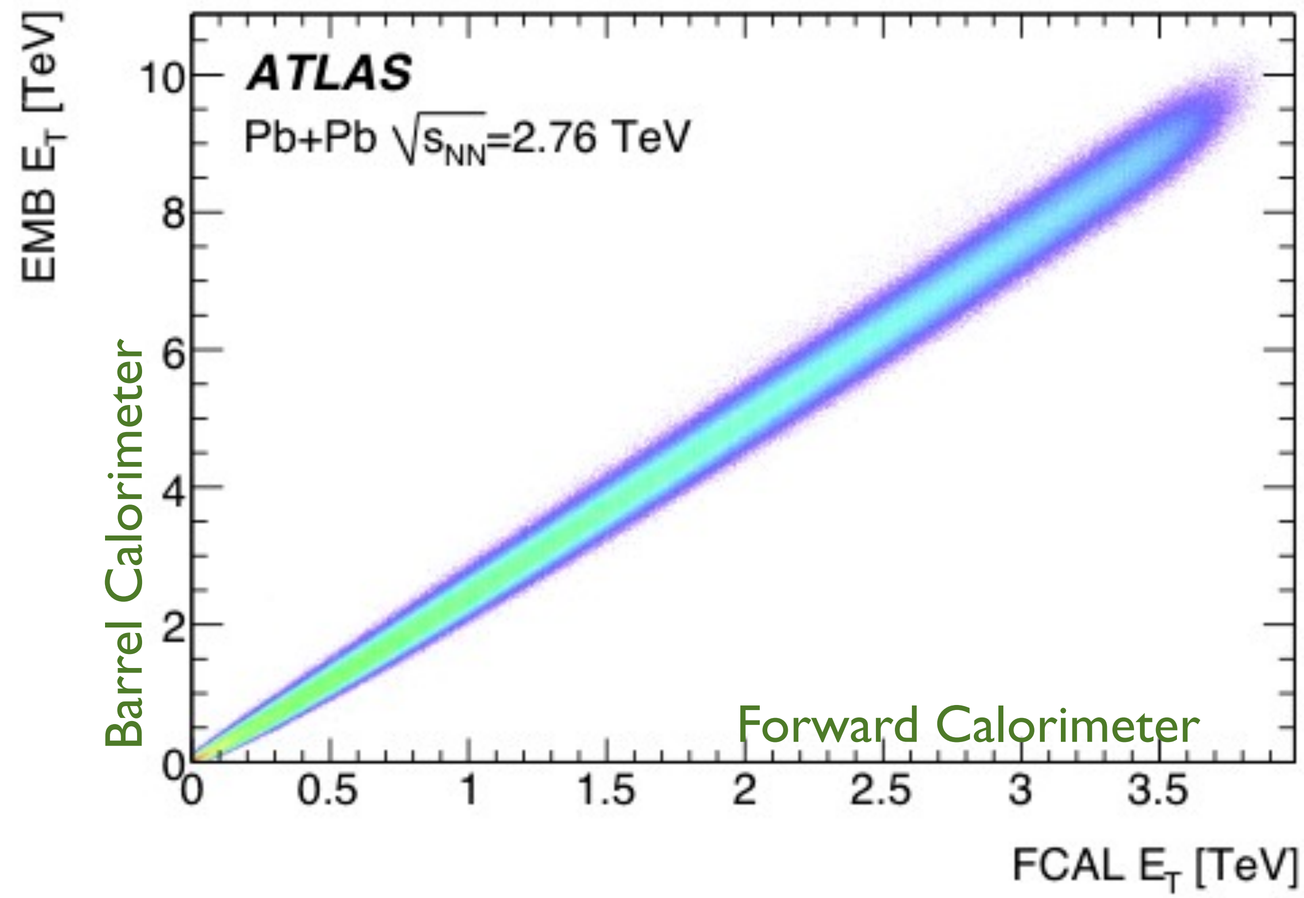


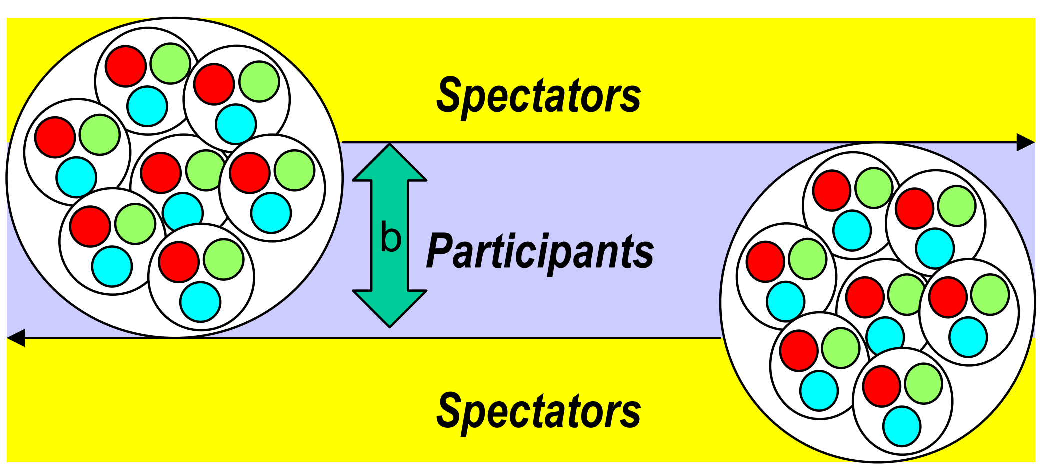
Many events with asymmetric di-jets are observed. By selecting only high pt-tracks one can observe high pt-jet and broad low-pt jet on opposite side.

ATLAS: Observation of Asymmetric Jets

peripheral ⟷ central







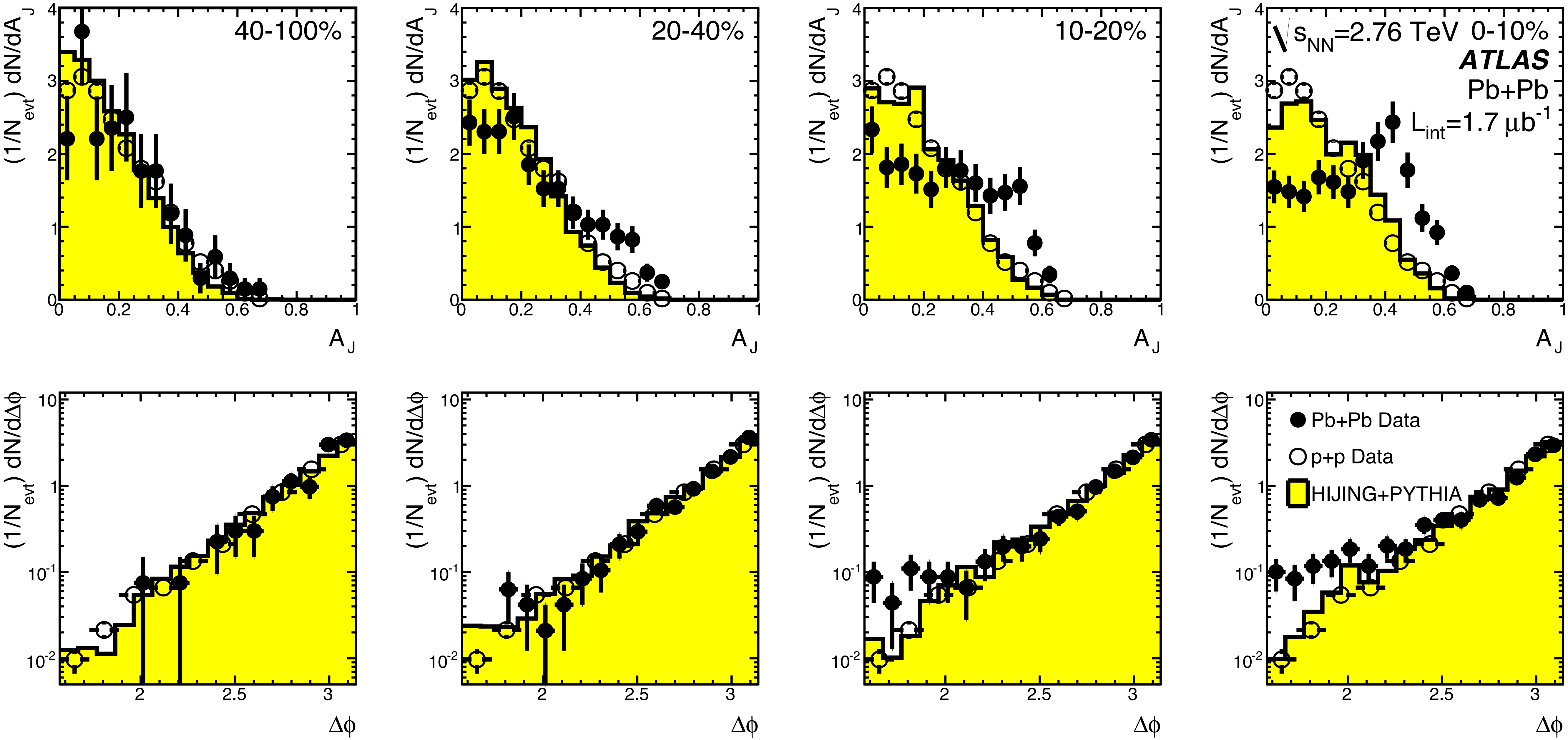
Central Collision = high multiplicity

The impact parameter can not be measured directly - good measure of "centrality" is particle multiplicity (total energy).

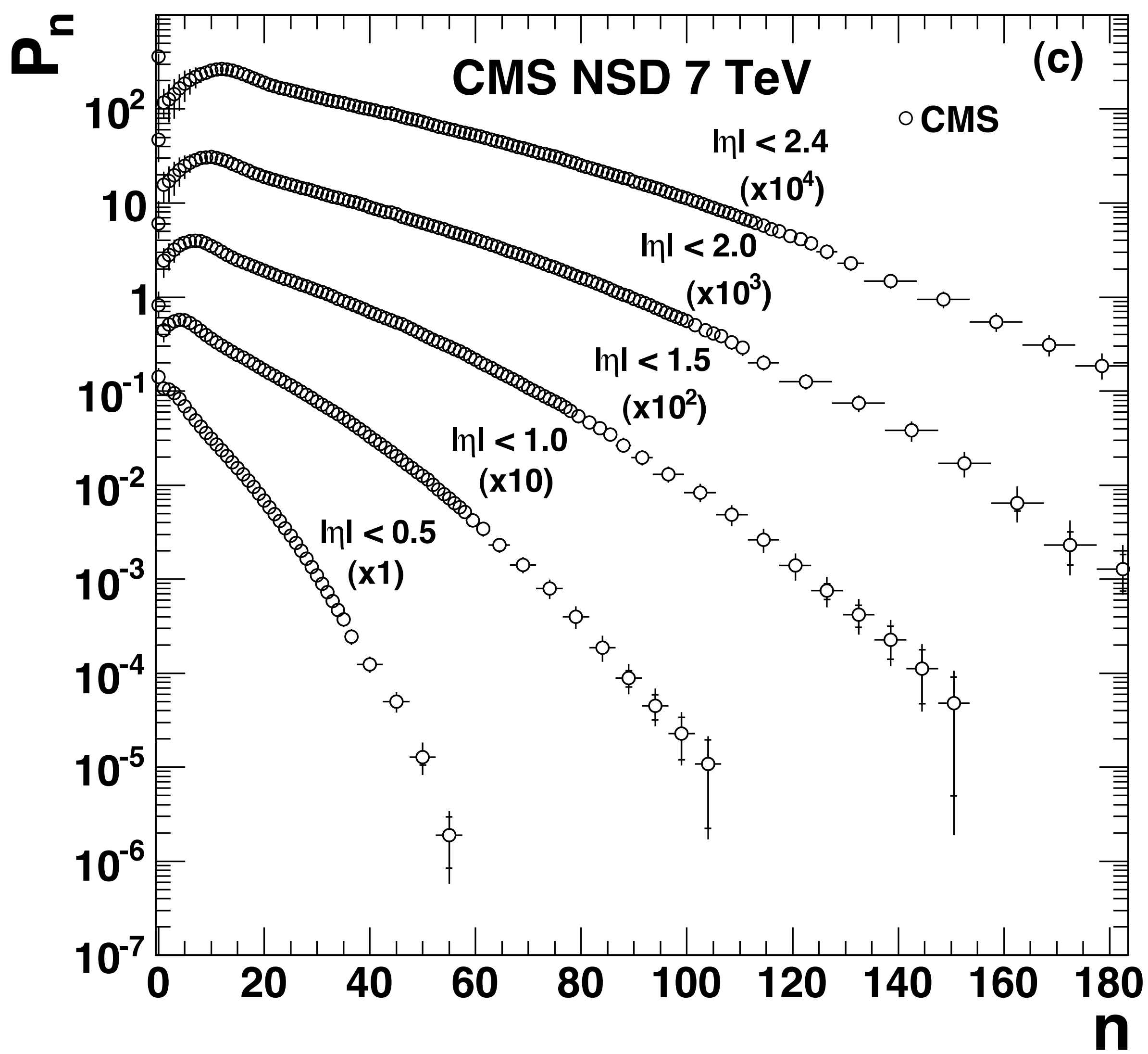
Forward calorimeter energy used as measure of centrality (to avoid bias).

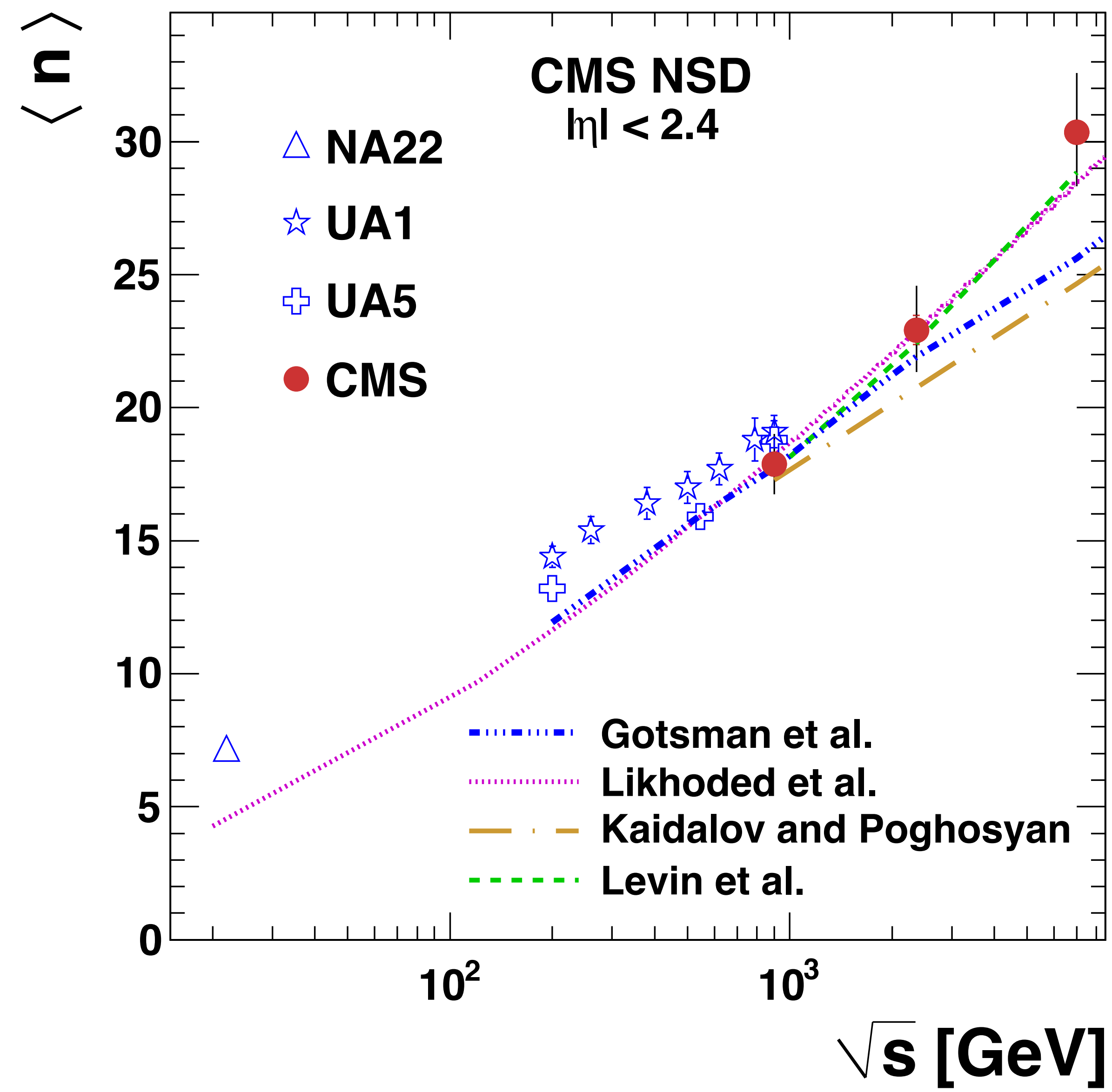
ATLAS: Observation of Asymmetric Jets

Di-Jet Asymmetry $A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}, \Delta\phi > \frac{\pi}{2}$



Peripheral collisions (left): agreement with HIJING (contains no jet quenching)
Central collisions (right): strong jet quenching (large asymmetry) observed



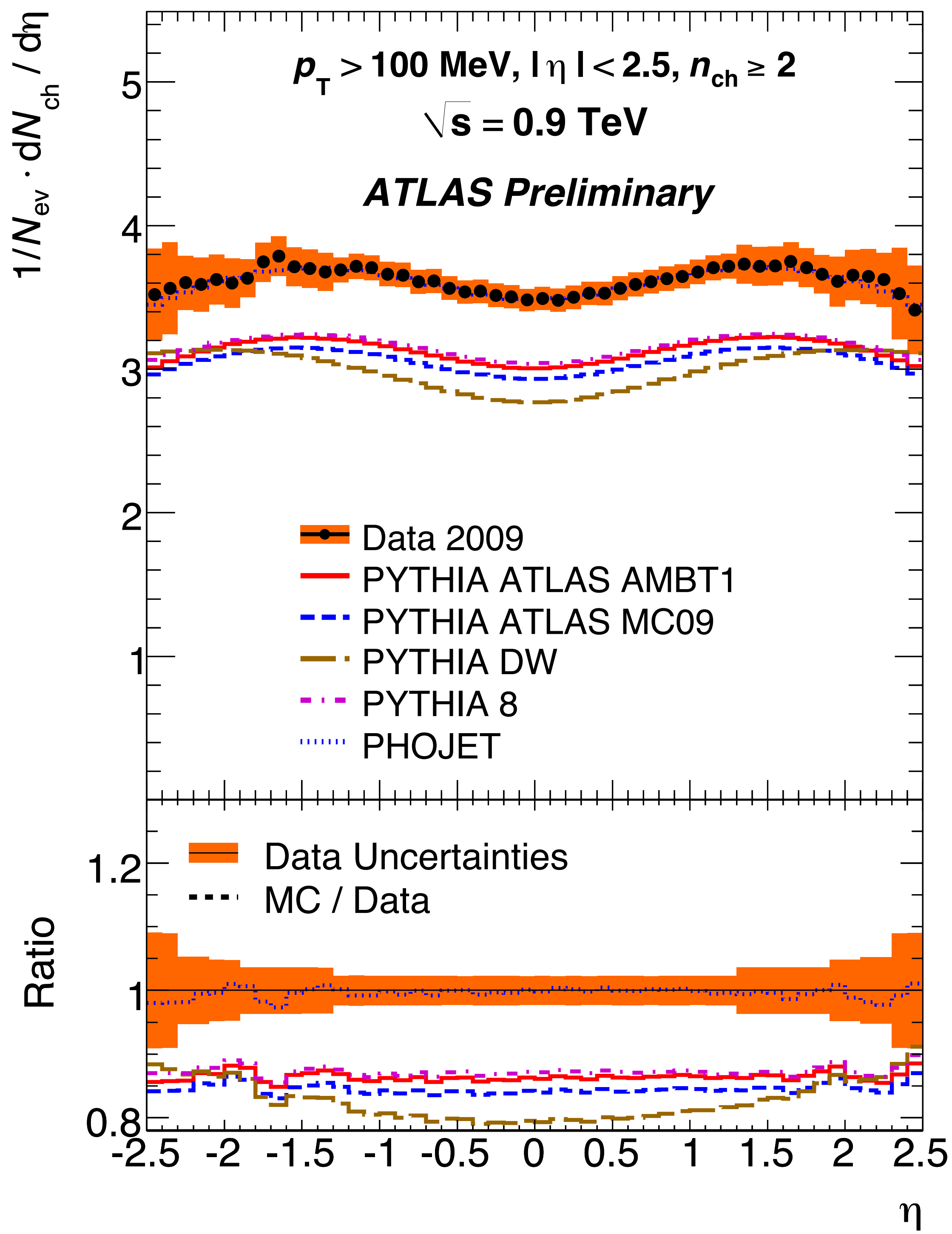


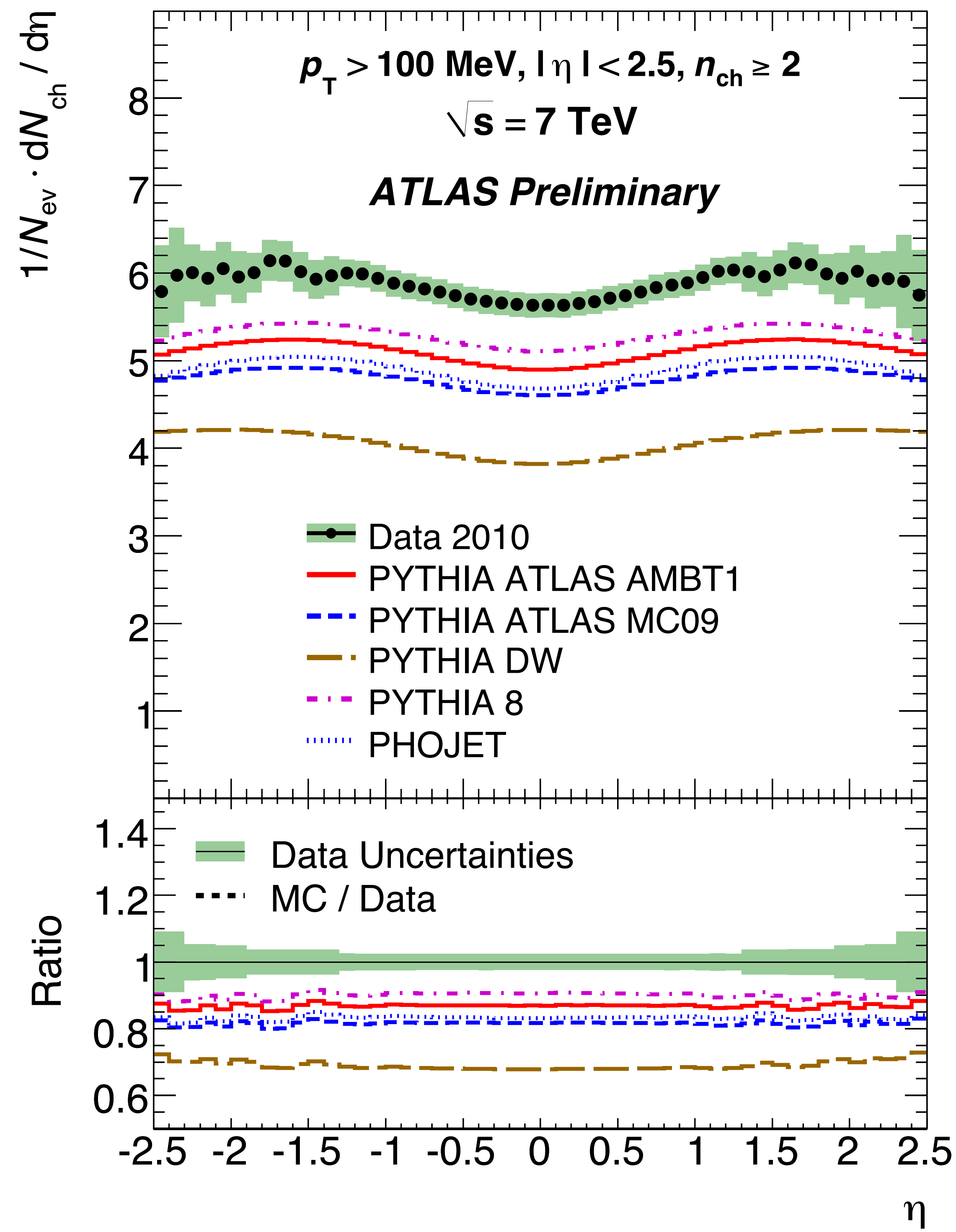
P_n: Probability to find n primary charged particles in a min. bias event.

Mean charged hadron multiplicity.

NSD: Non Single Diffractive Events

ATLAS: Minimum Bias - Charged particle multiplicity





Soft QCD: Long Range Two-Particle Correlations

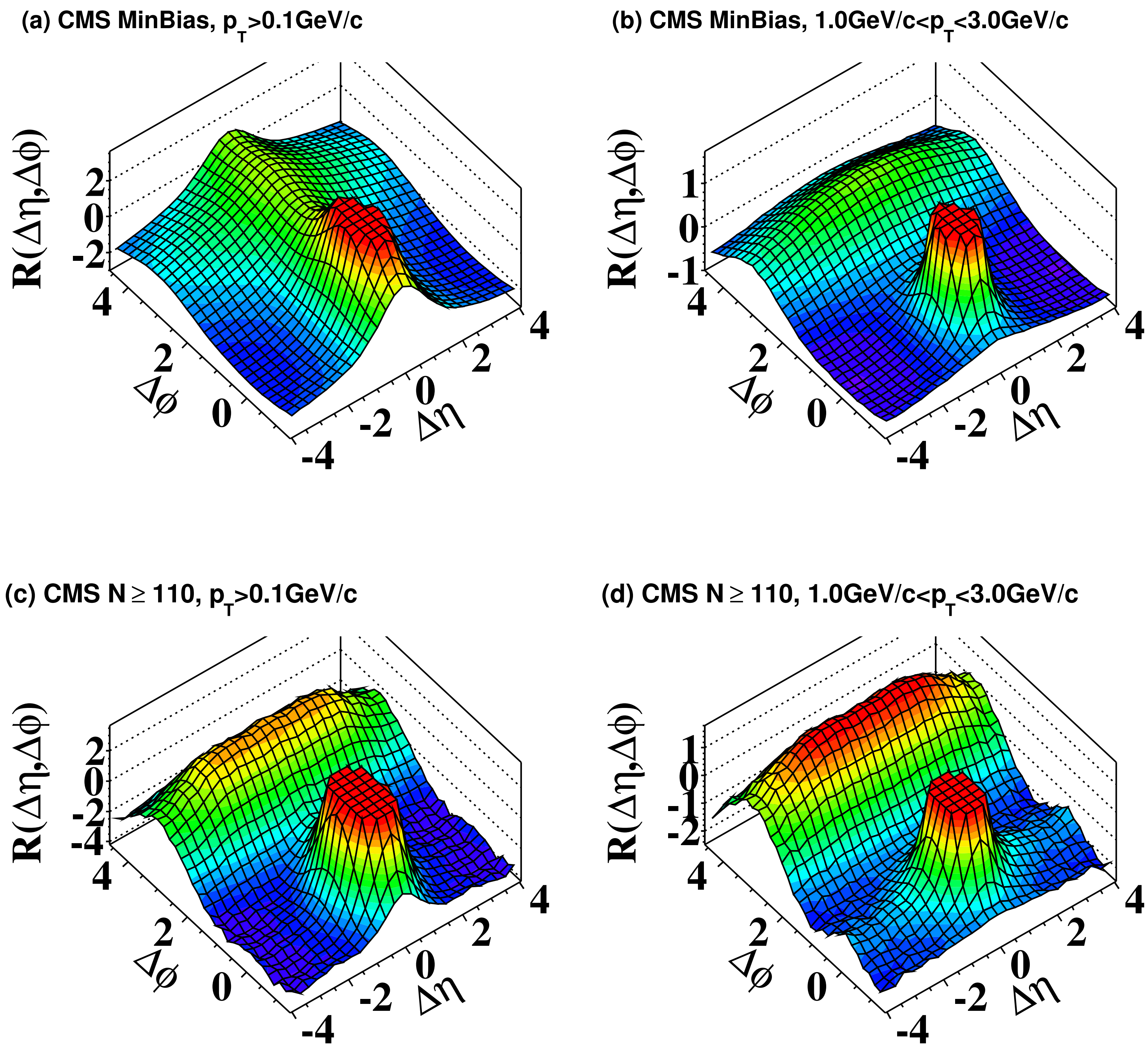
Two-particle correlation functions

Ecms = 7 TeV

Same side correlations (ridge structure) observed for high multiplicity events at $\Delta\varphi \simeq 0$.

Most evident in the intermediate p_t range.

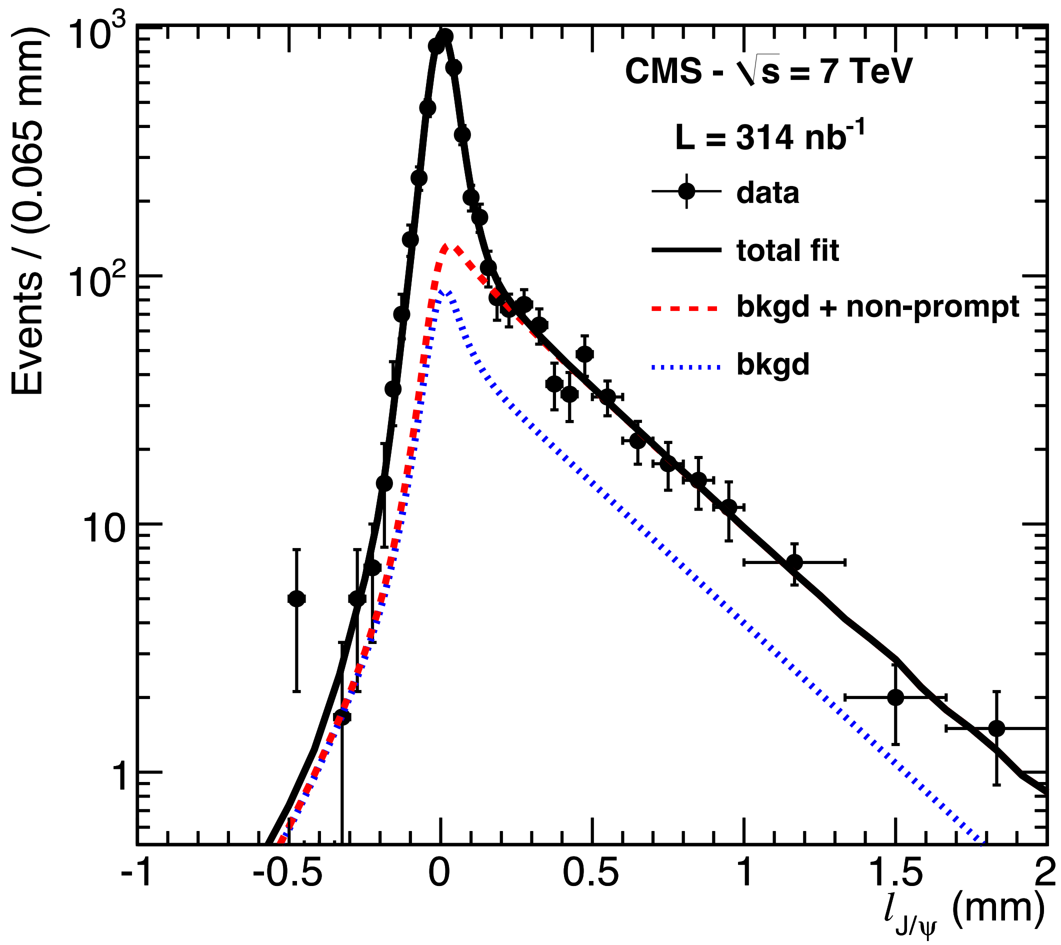
Observed structure resembles features seen in Heavy Ion collisions.



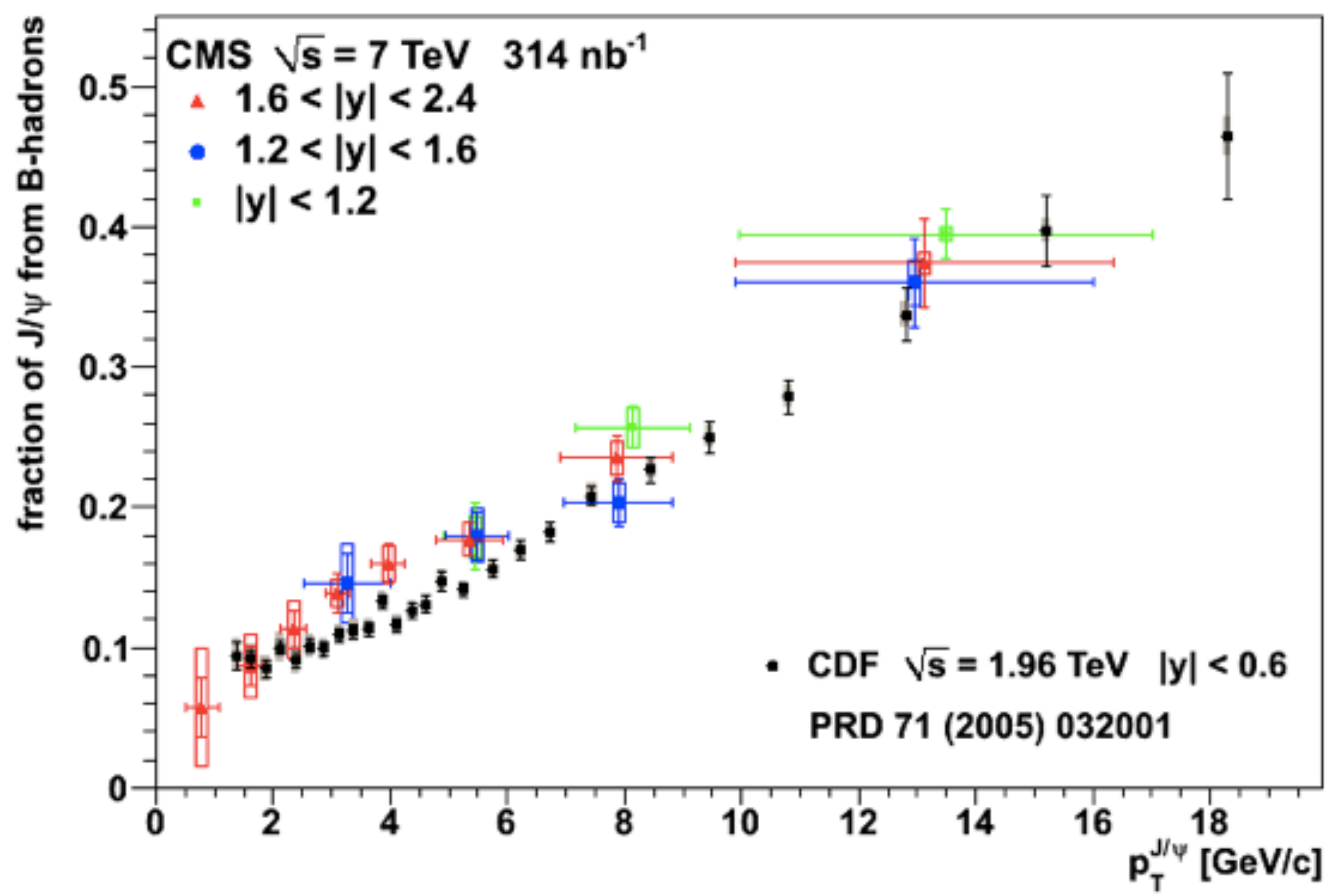
CMS: Prompt and non-prompt J/ψ production

Transverse J/ψ flight distance

$6.5 < p^{J/\psi} < 10$ GeV/c,
$1.6 < |y| < 2.4$



Fraction of J/ψ from B-decay measured from fit to decay length spectrum.



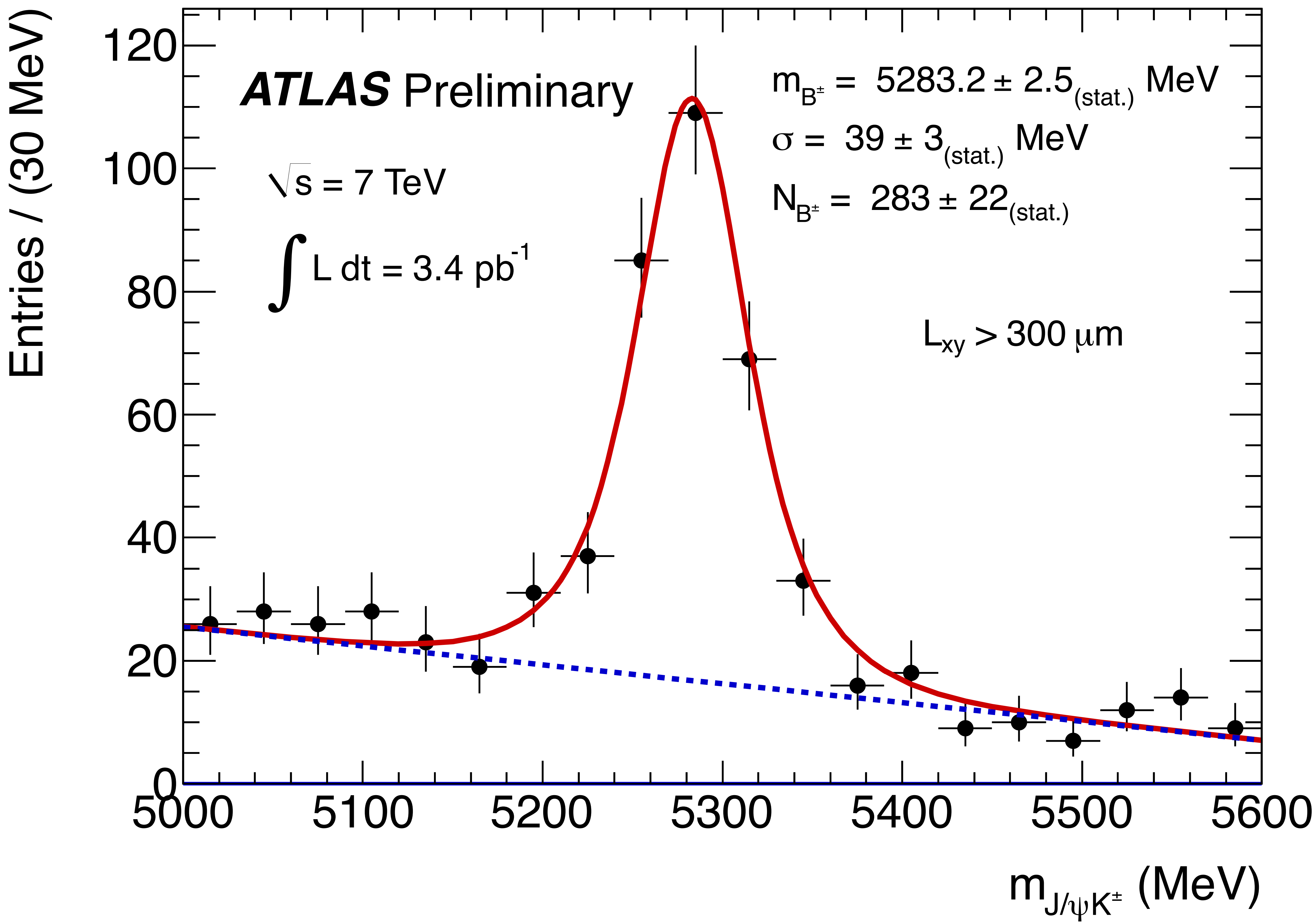
Unpolarized scenario :

$$\sigma(pp \to \mathrm{J}/\psi + X) \cdot \mathrm{BR}(\mathrm{J}/\psi \to \mu^+\mu^-) = 70.9 \pm 2.1(\mathrm{stat}) \pm 3.0(\mathrm{syst}) \pm 7.8(\mathrm{luminosity})\ \mathrm{nb}$$

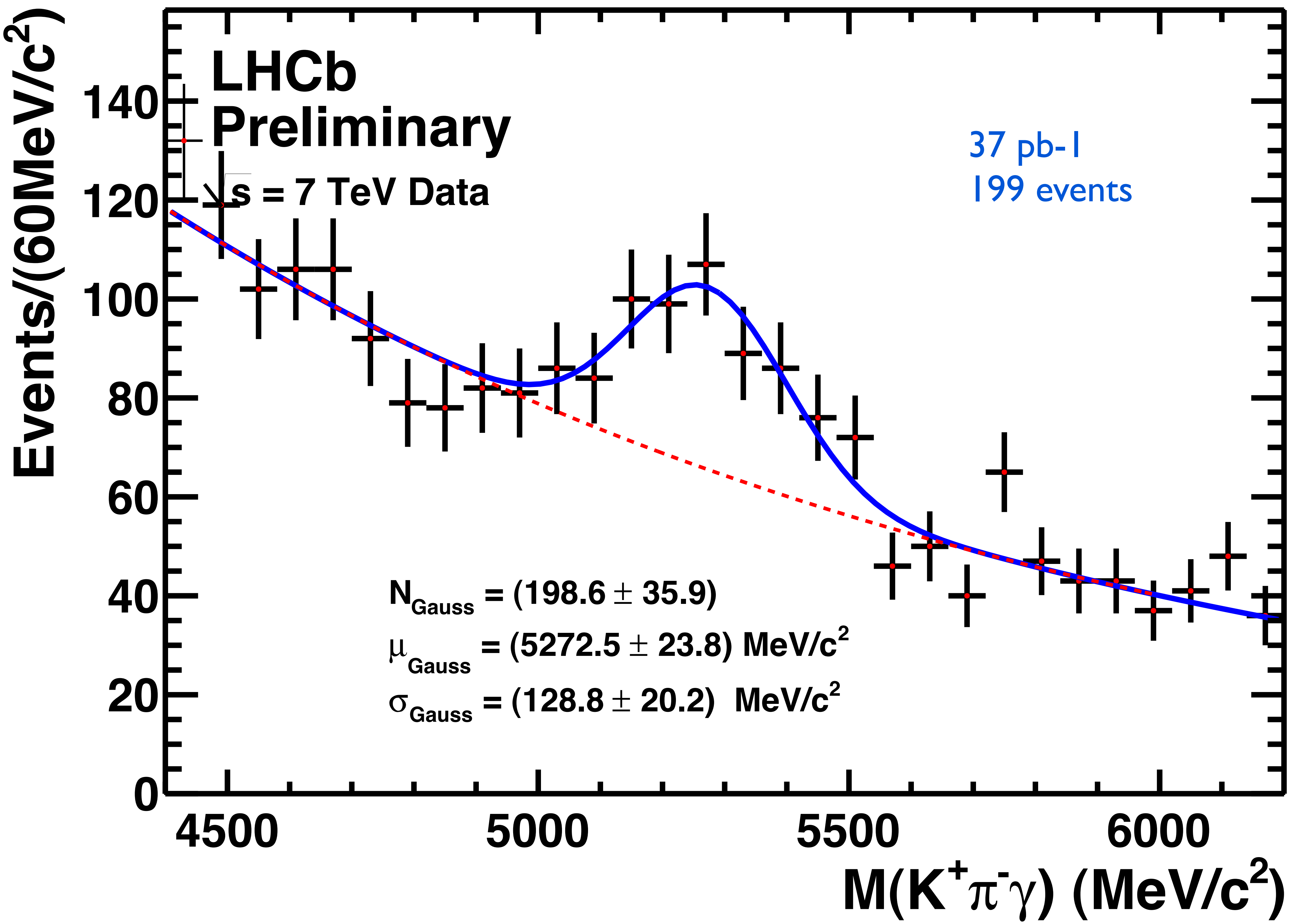
$$\sigma(\mathrm{pp} \to bX \to \mathrm{J}/\psi X) \cdot \mathrm{BR}(\mathrm{J}/\psi \to \mu^+\mu^-) = 26.0 \pm 1.4\ (\mathrm{stat}) \pm 1.6\ (\mathrm{syst}) \pm 2.9\ (\mathrm{luminosity})\ \mathrm{nb}$$

for $6.5 < p_{\mathrm{T}} < 30\,\mathrm{GeV}/c$ and $|y| < 2.4$

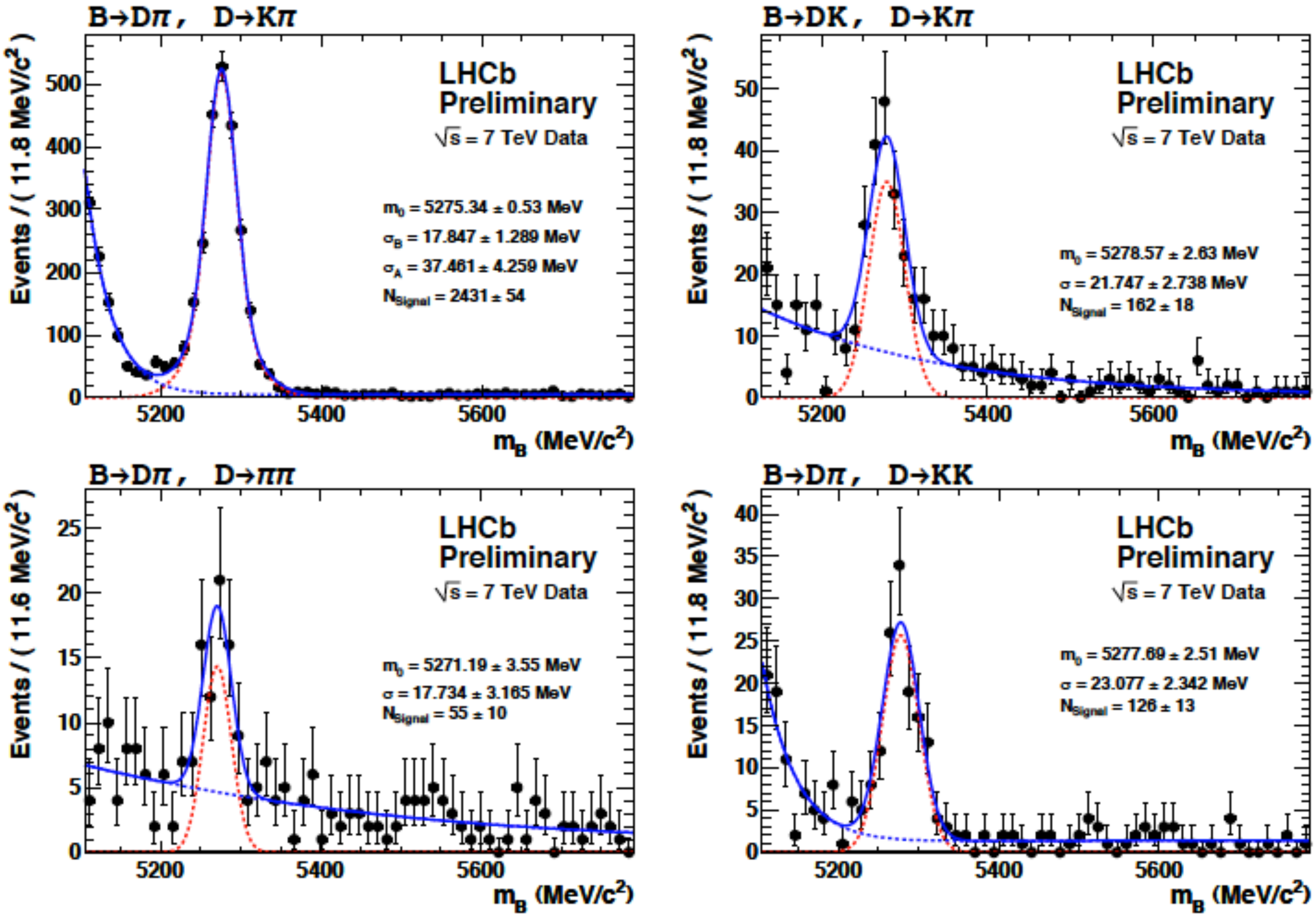
ATLAS: Exclusive $B^+ \to J/\psi\, K^+$



LHCb: Exclusive B-decays $B^o \rightarrow K^{*o}\gamma$



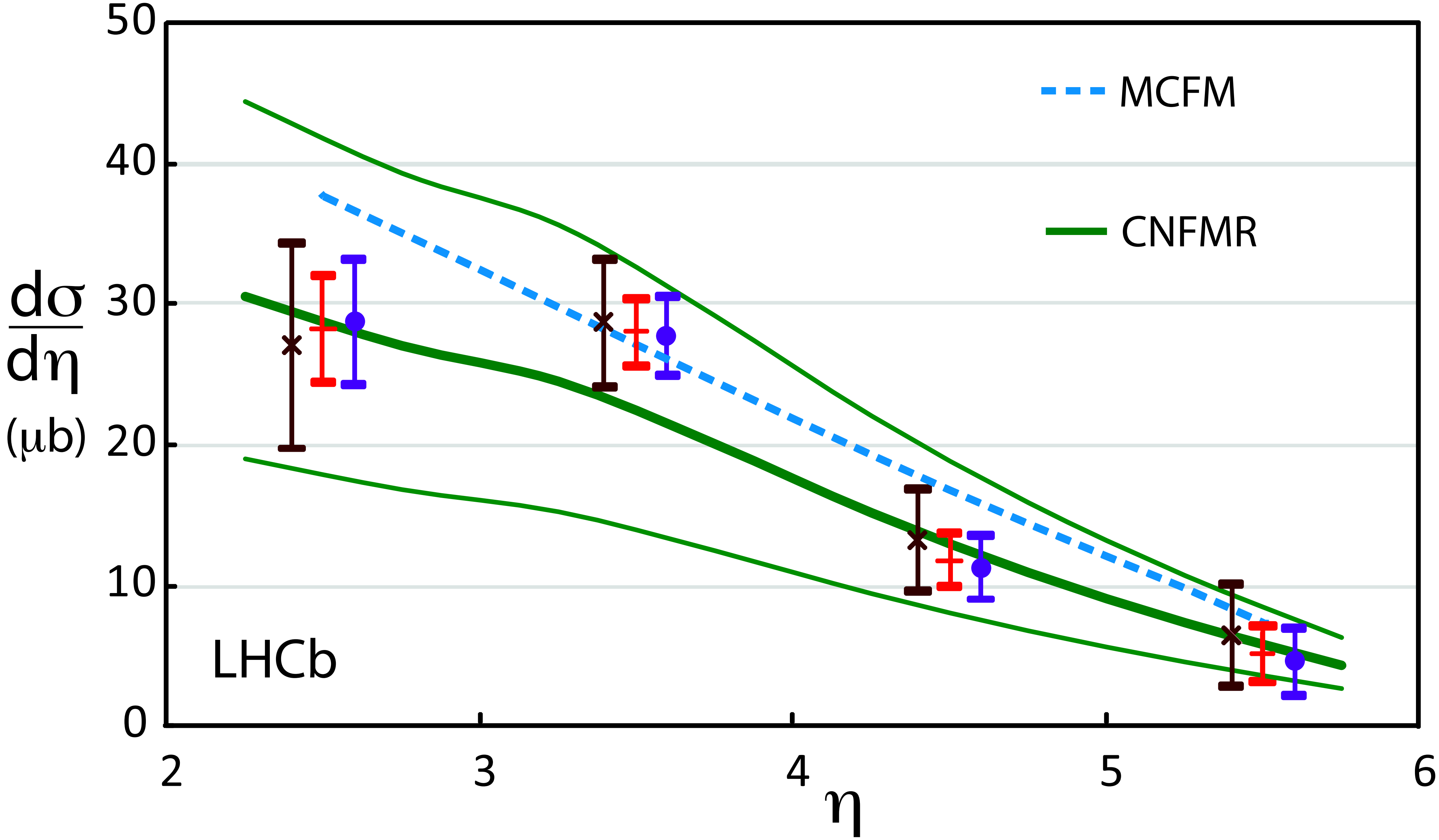
LHCb: Exclusive B Decays



LHCb: bb cross section

B contribution measured from decay length.

decay chain $b \to D^0 X \mu^- \nu$, $D^0 \to K^- \pi^+$



microbias $(\times)$

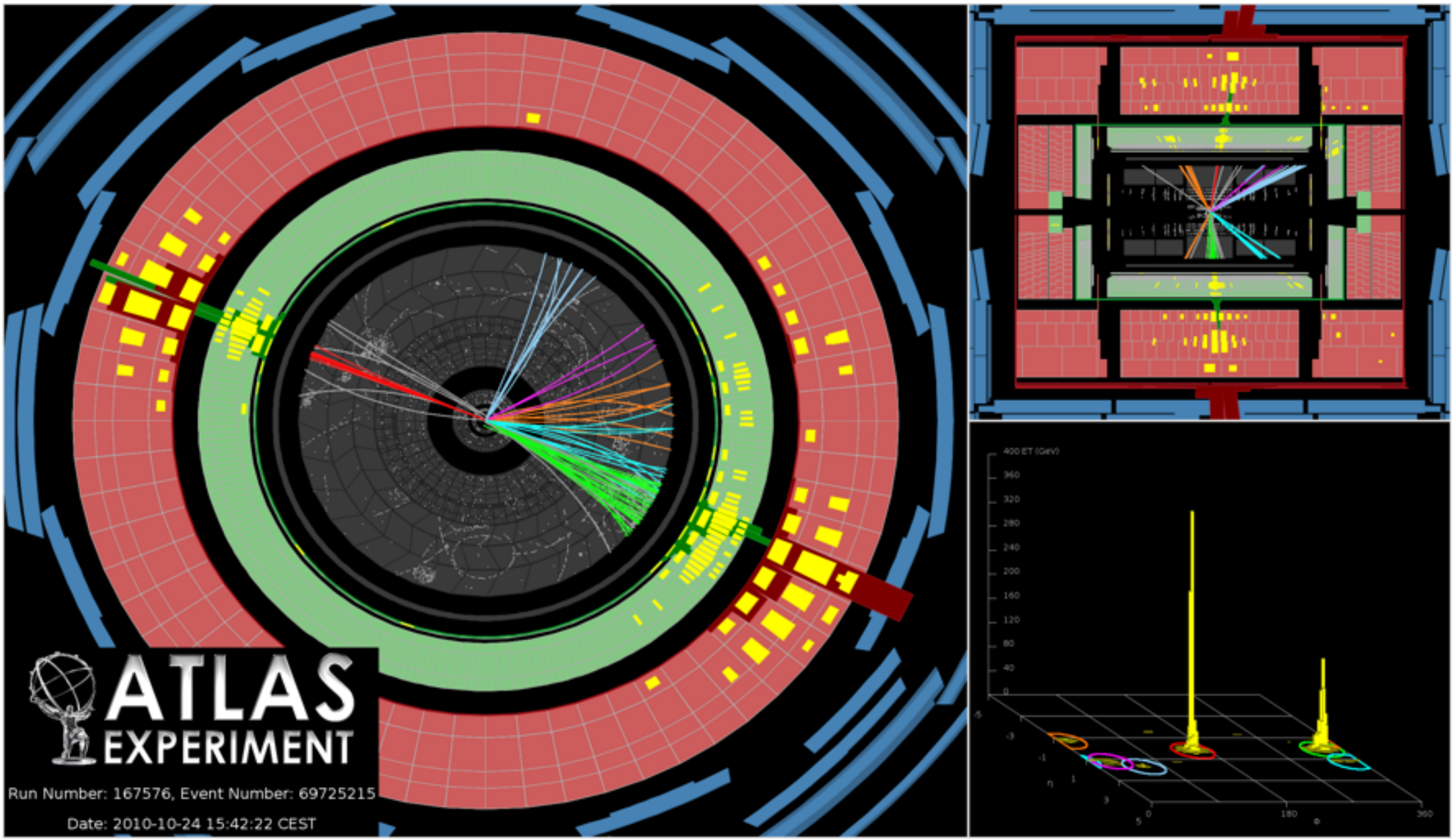
triggered $(\bullet)$

average $(+)$

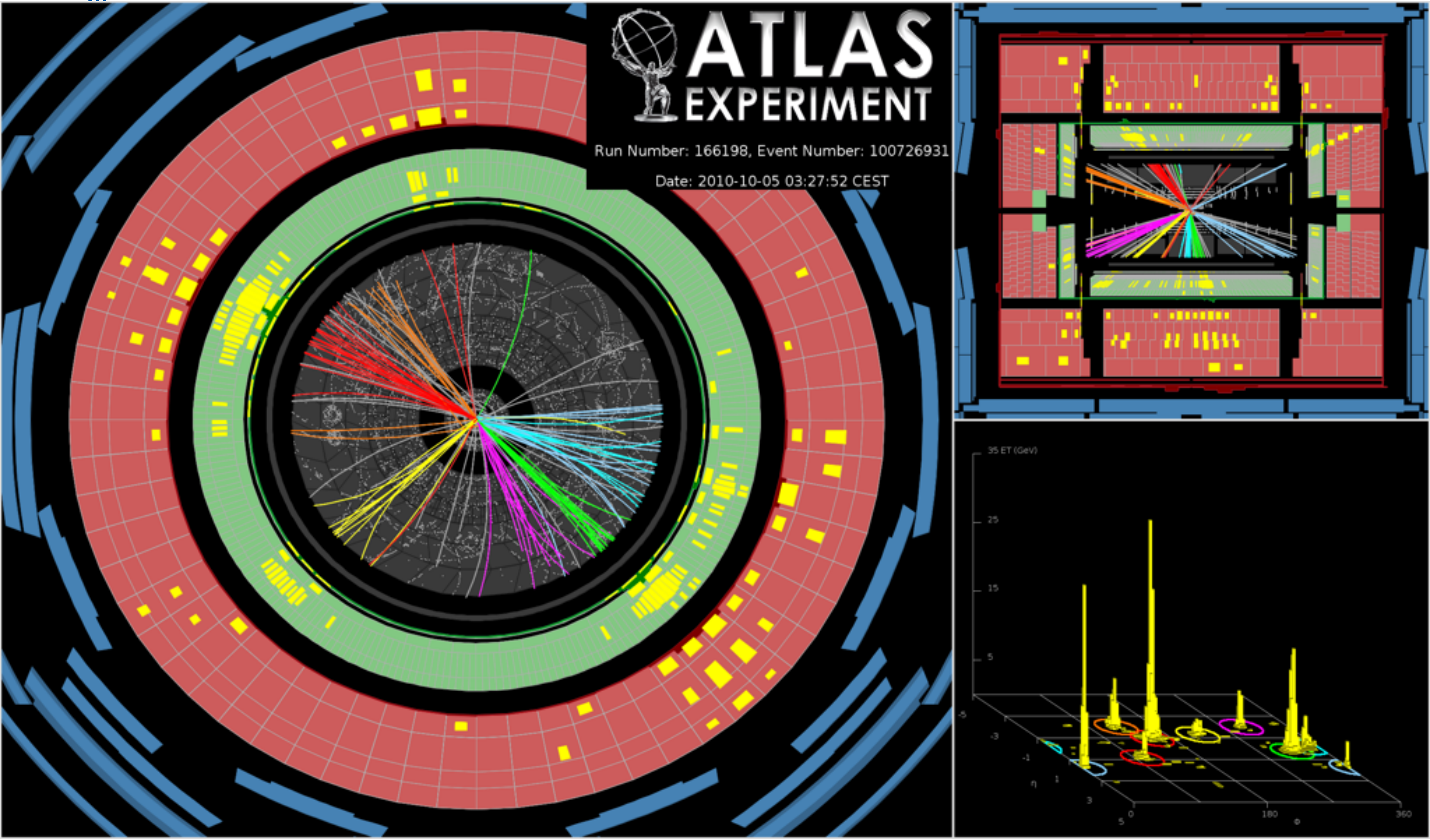
total $b\bar{b}$ cross-section $\quad \sigma(pp \to b\bar{b}X) = (284 \pm 20 \pm 49)\ \mu\text{b}$

Highest pT jet event

p_T jet1=1.3 TeV (also
p_T jet2=1.2 TeV, m_{jj}=2.6 TeV)

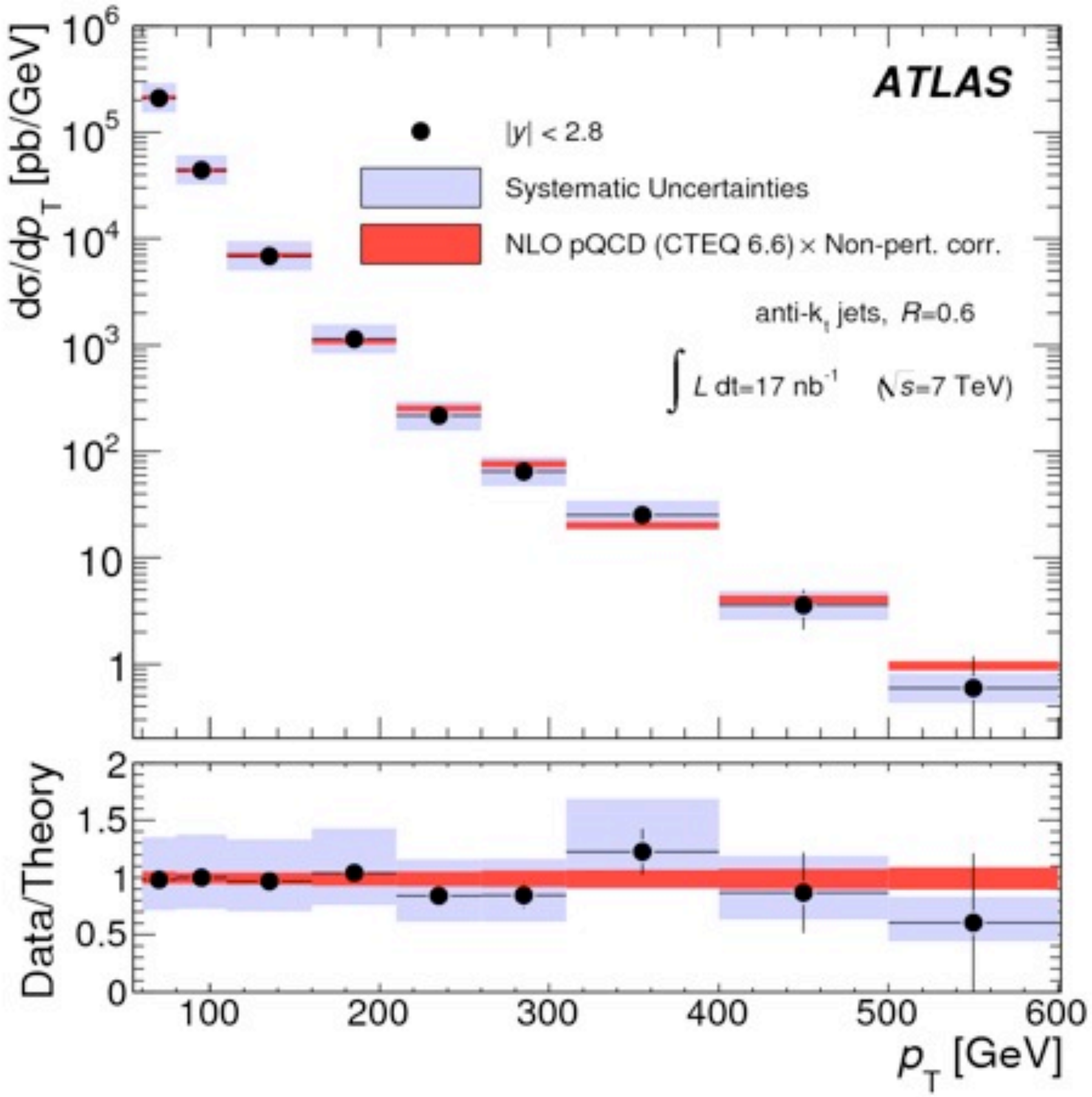


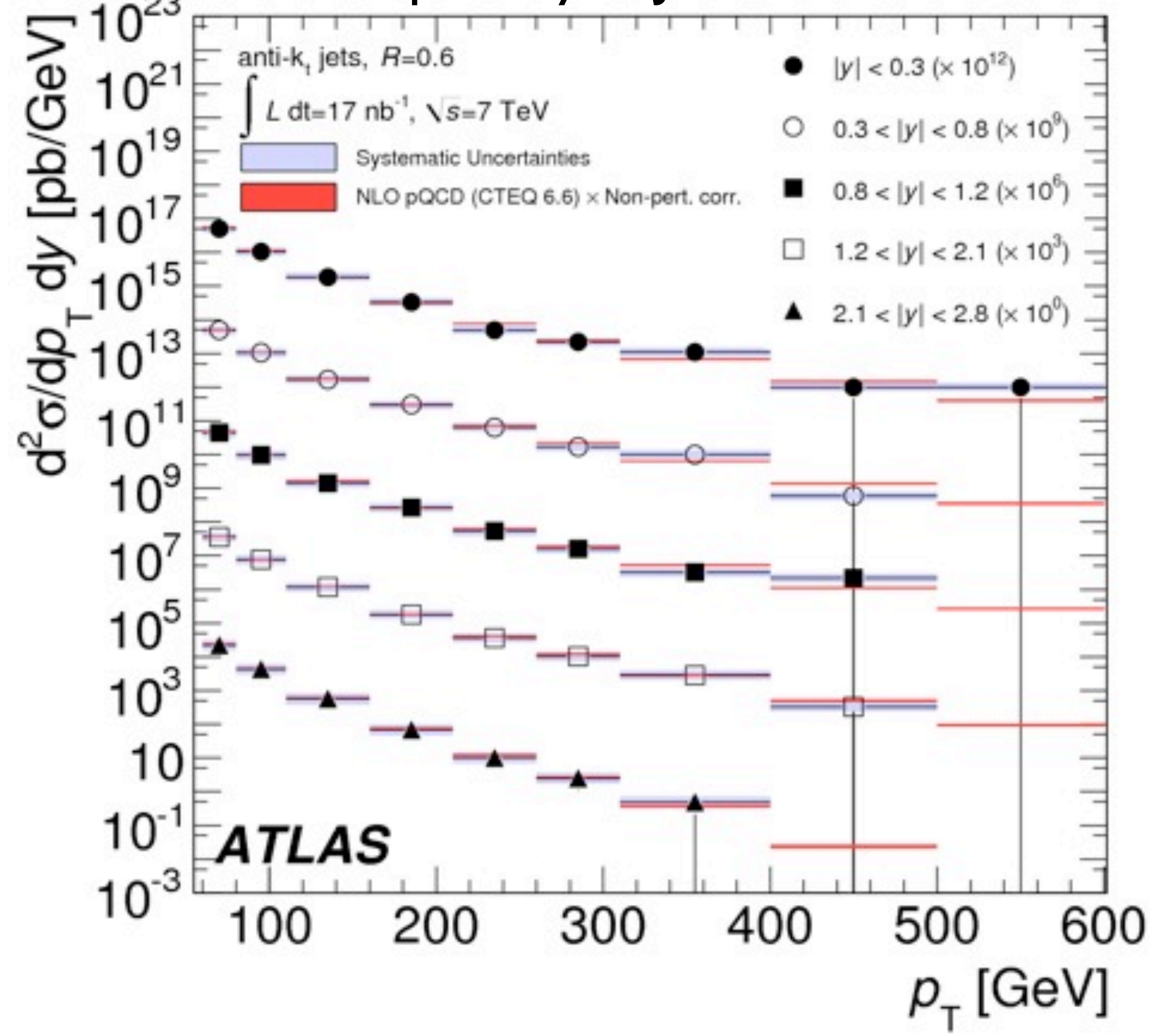
8-jet event


ATLAS
EXPERIMENT
Run Number: 166198, Event Number: 100726931
Date: 2010-10-05 03:27:52 CEST

Inclusive Jet Cross Section

Accepted by EPJC arXiv:1009.5908





Measurement of inclusive jet and dijet cross sections in proton-proton collisions at 7 TeV centre-of-mass energy with the ATLAS detector

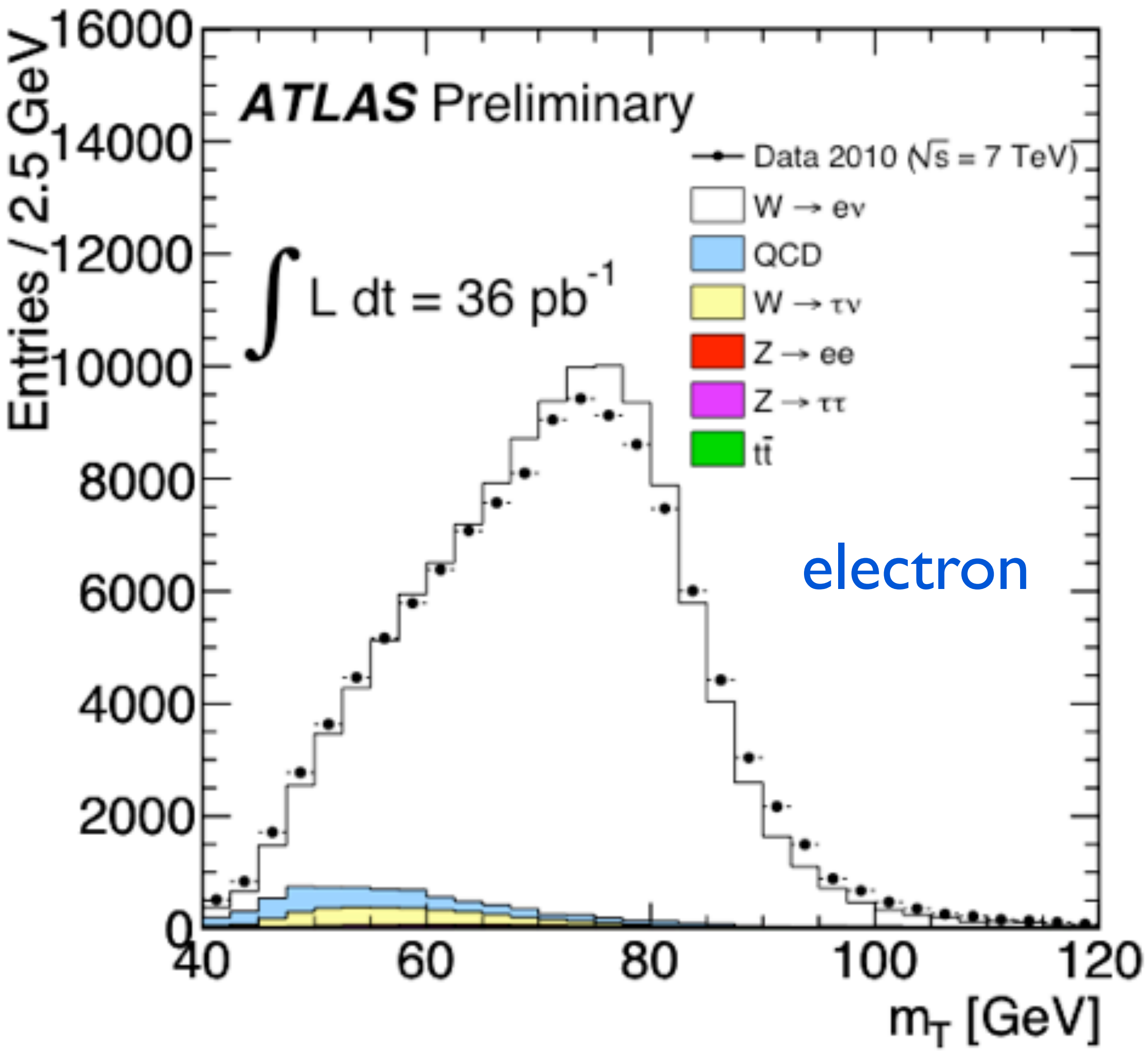
Uncertainty dominated by Jet Energy Scale (at present ~7%)

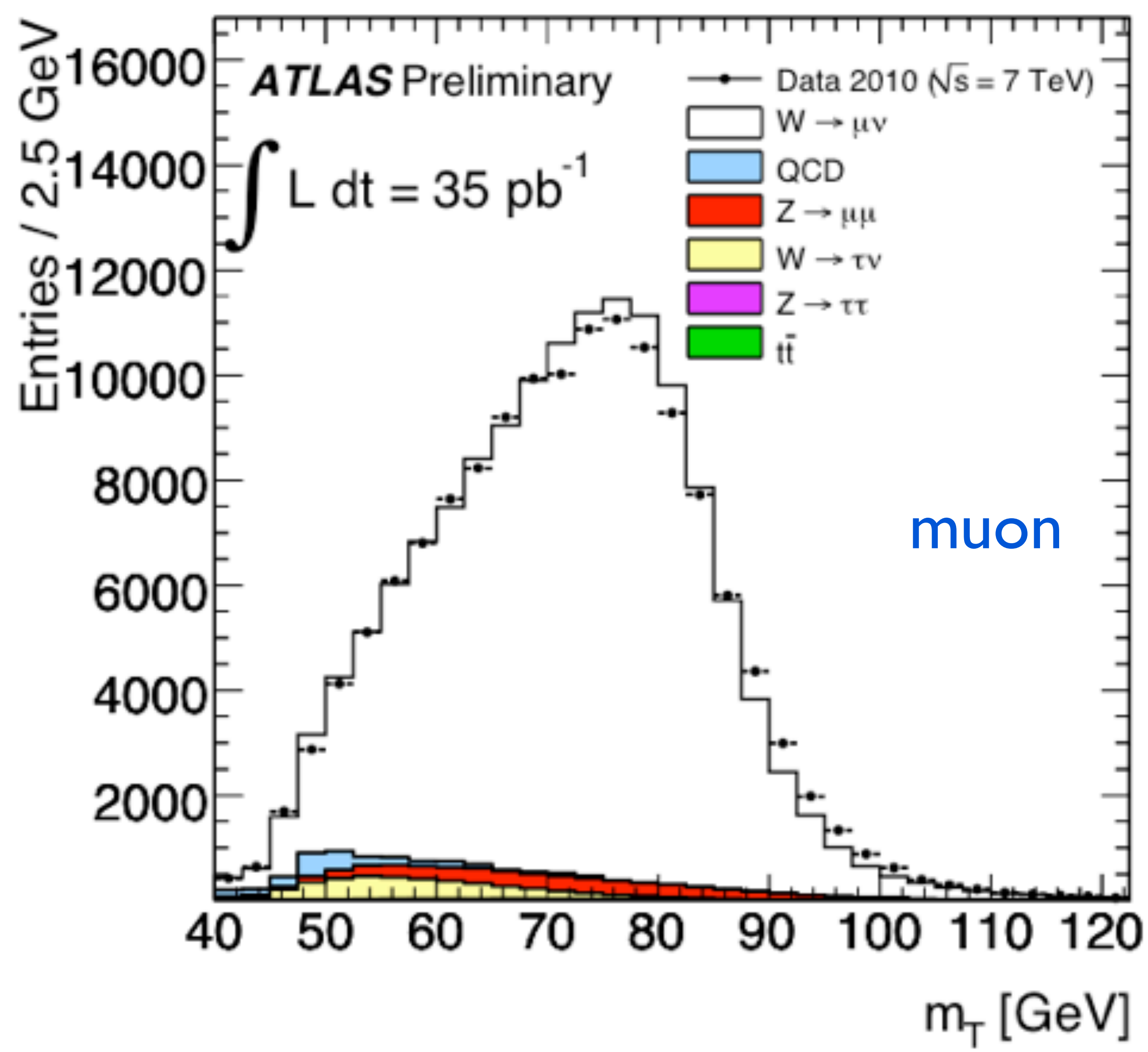
Electroweak: W Transverse Mass

e or μ with p_T>20 GeV, E_T^{miss}>25GeV

MC normalised to data

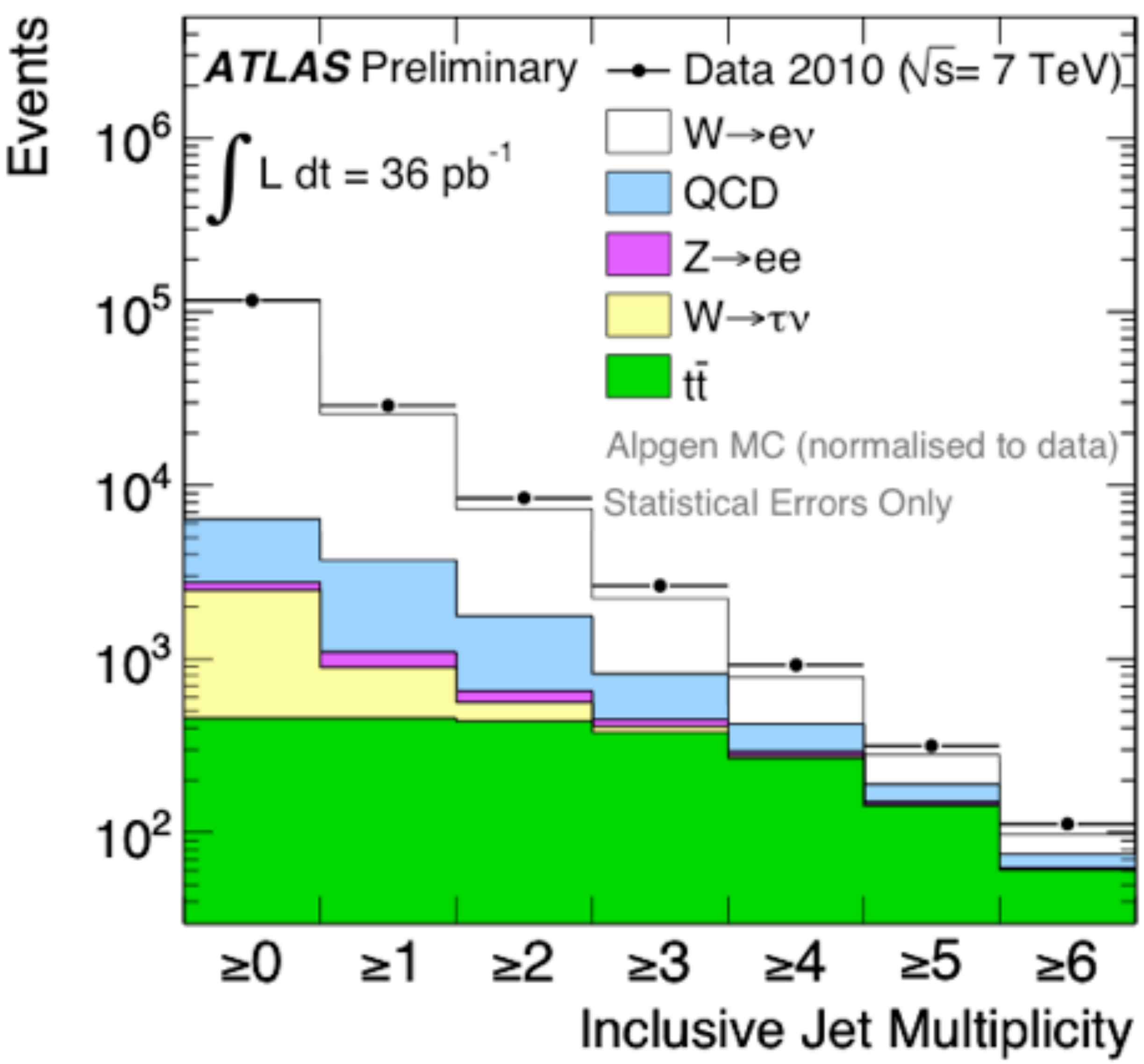
119k electron and 135k muon candidates

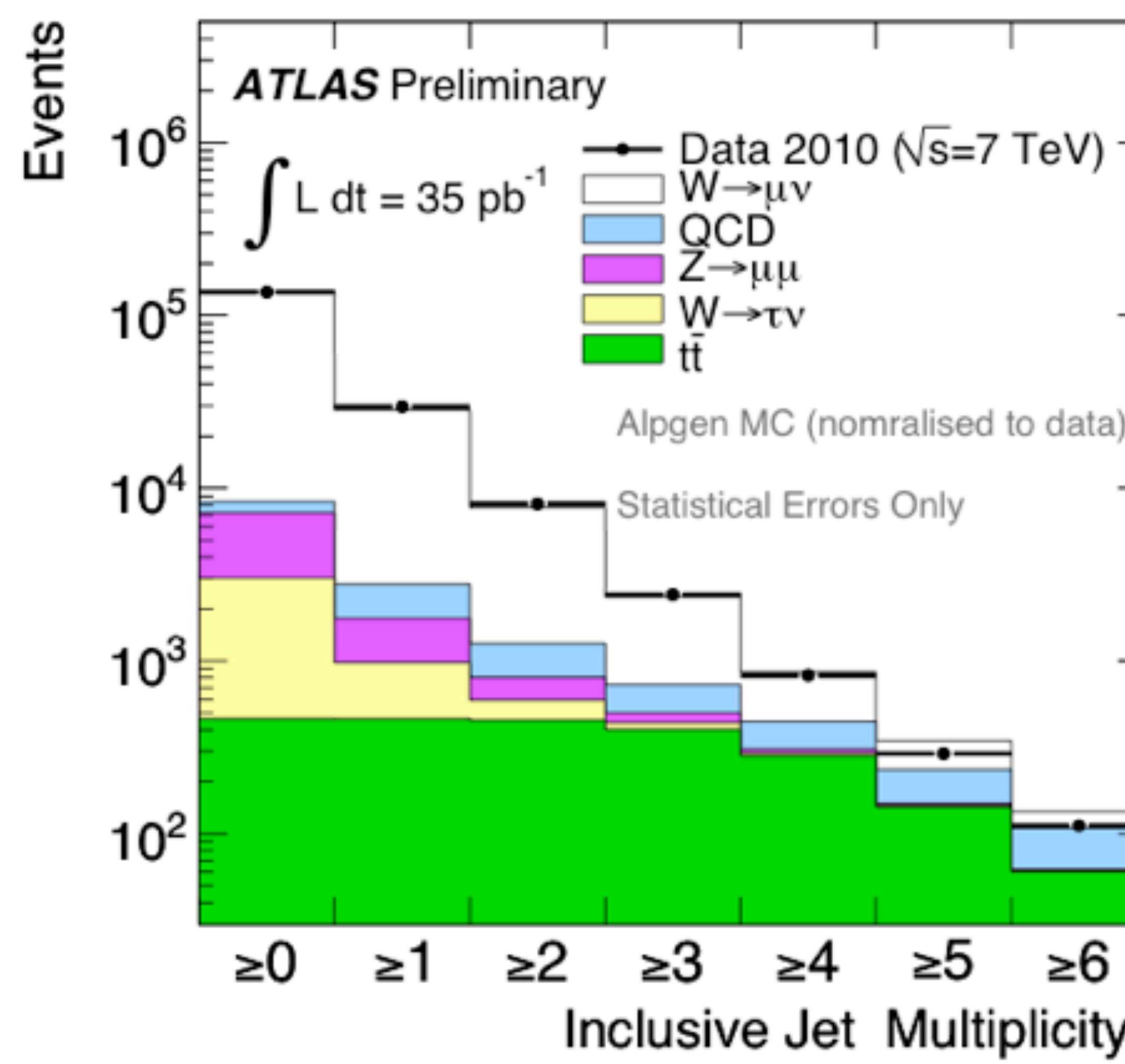




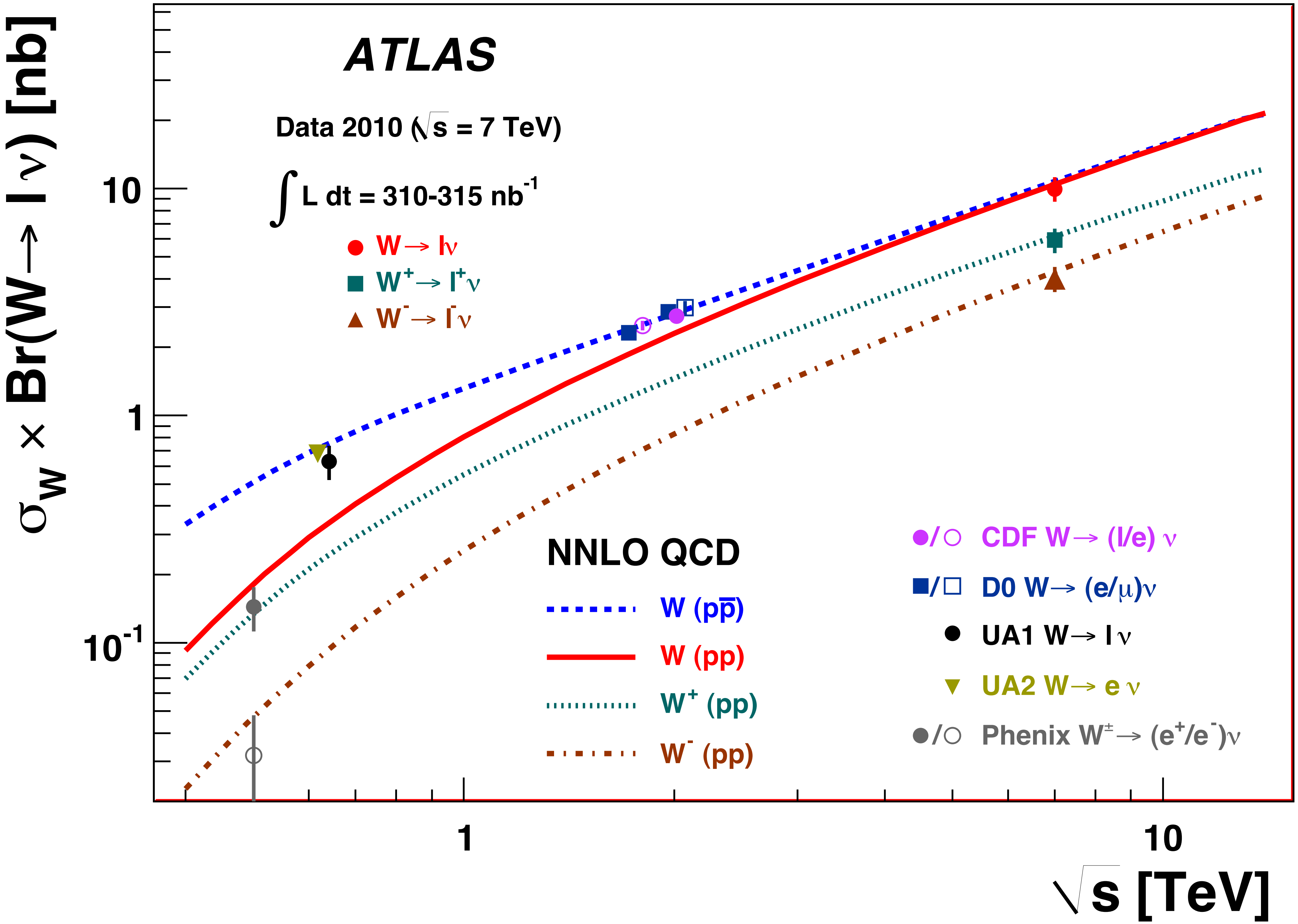
Distribution of number of jets in selected W events.

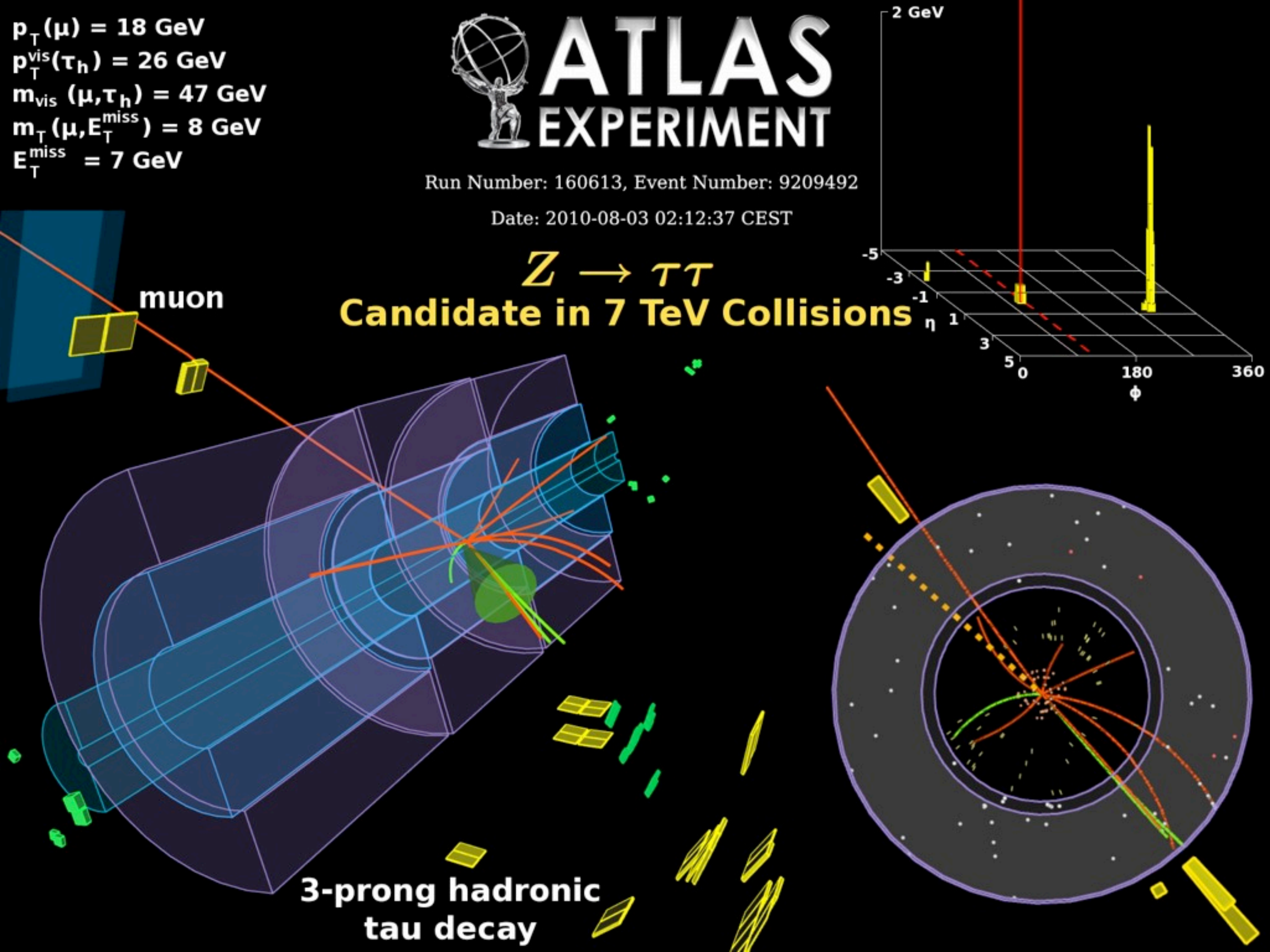
Stat errors only, with ALPGEN MC normalised to data





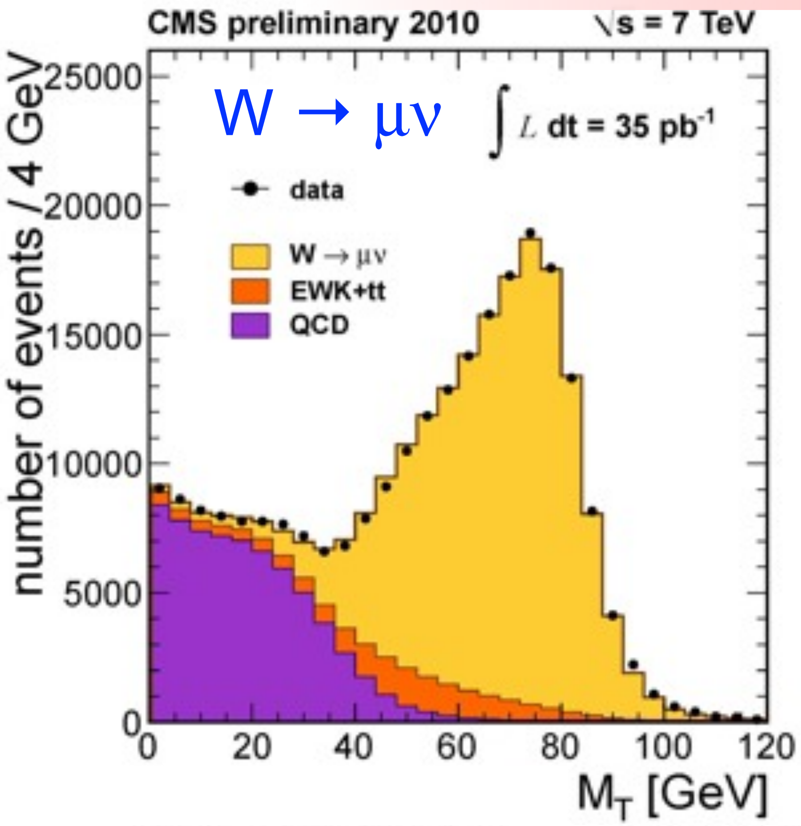
W cross section

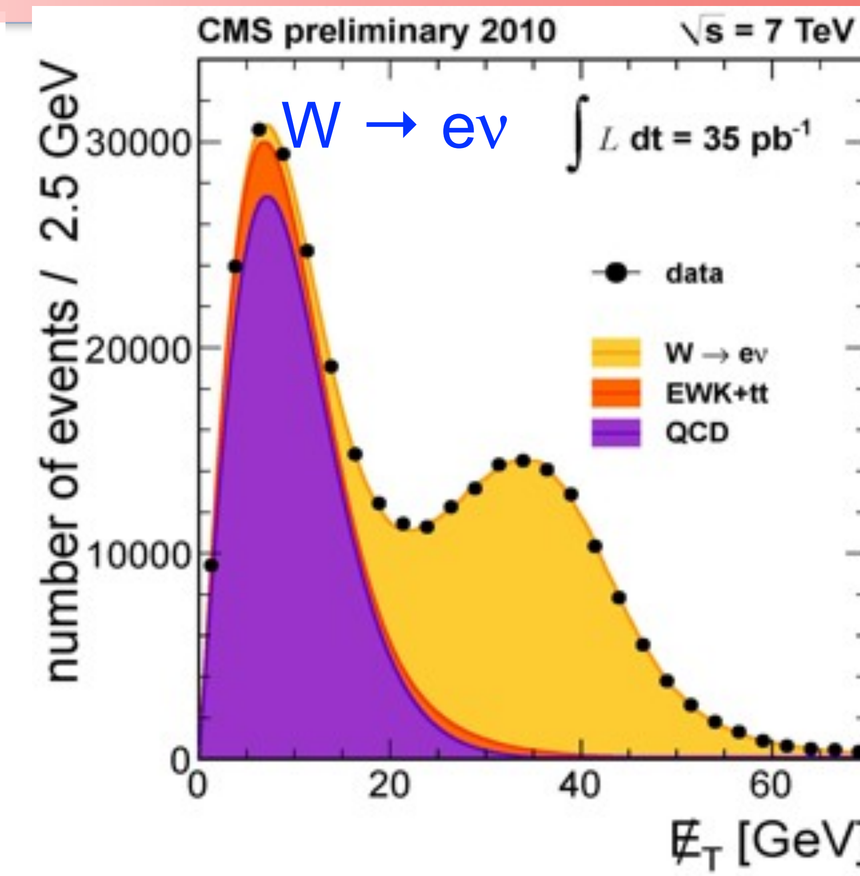




$p_T(\mu)$ = 18 GeV
$p_T^{vis}(\tau_h)$ = 26 GeV
$m_{vis}(\mu,\tau_h)$ = 47 GeV
$m_T(\mu,E_T^{miss})$ = 8 GeV
E_T^{miss} = 7 GeV
ATLAS EXPERIMENT
Run Number: 160613, Event Number: 9209492
Date: 2010-08-03 02:12:37 CEST
$Z \rightarrow \tau\tau$
Candidate in 7 TeV Collisions
muon
3-prong hadronic tau decay
2 GeV
η
φ

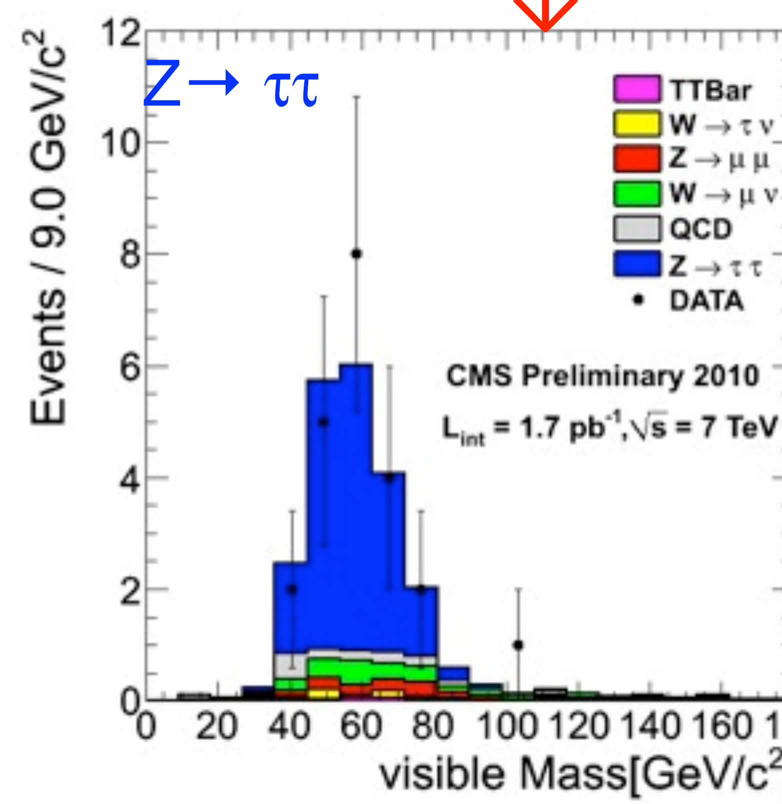
W and Z

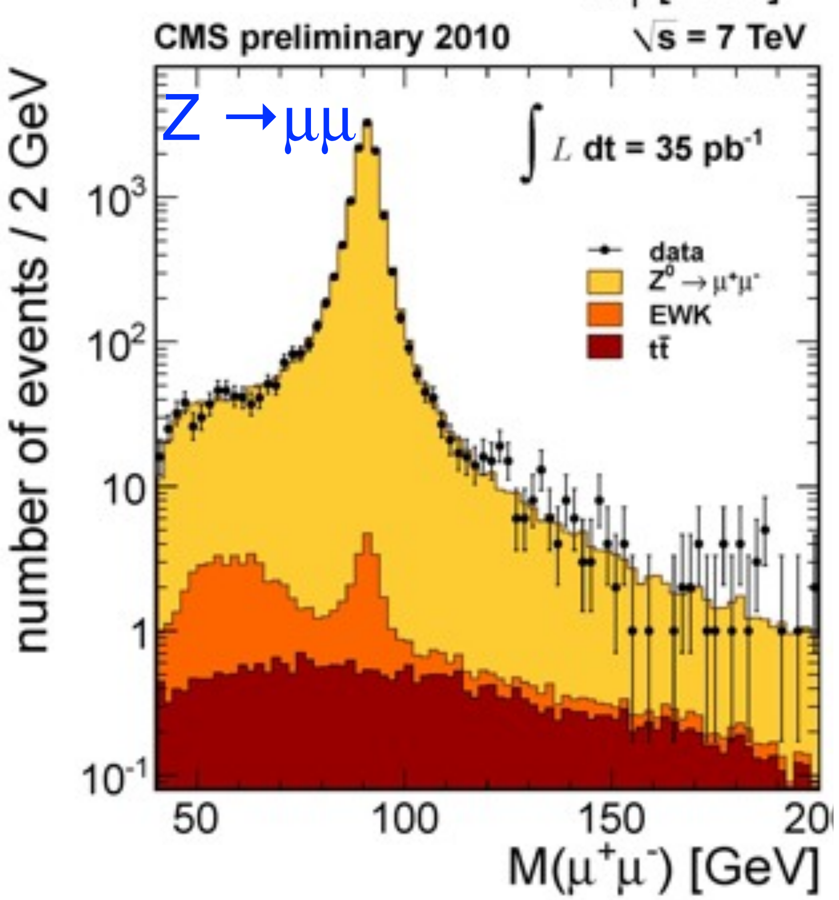


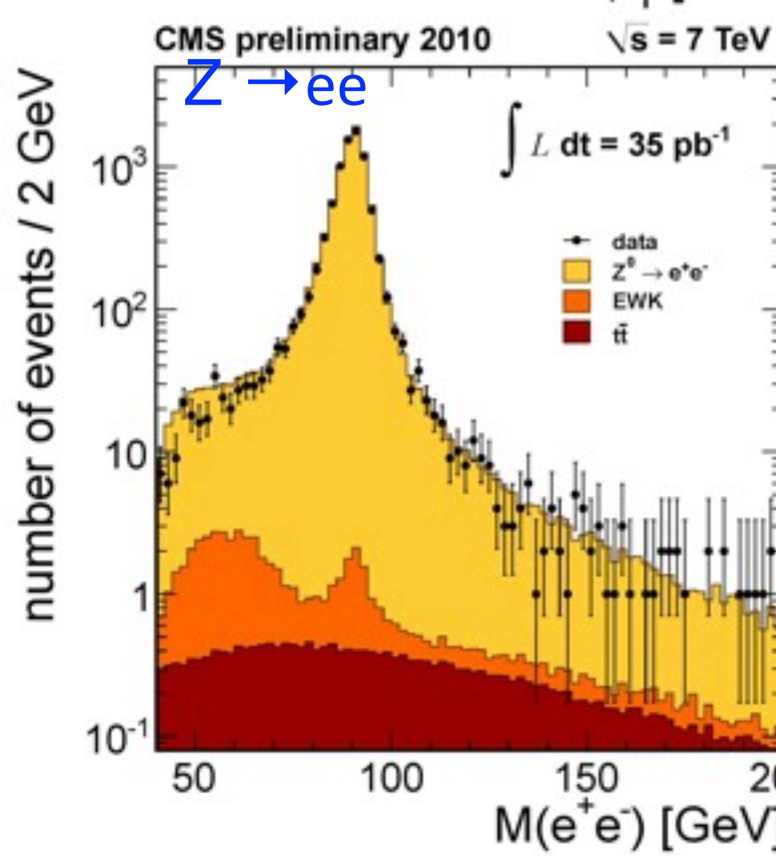


← W ($35pb^{-1}$)

Z→ ττ



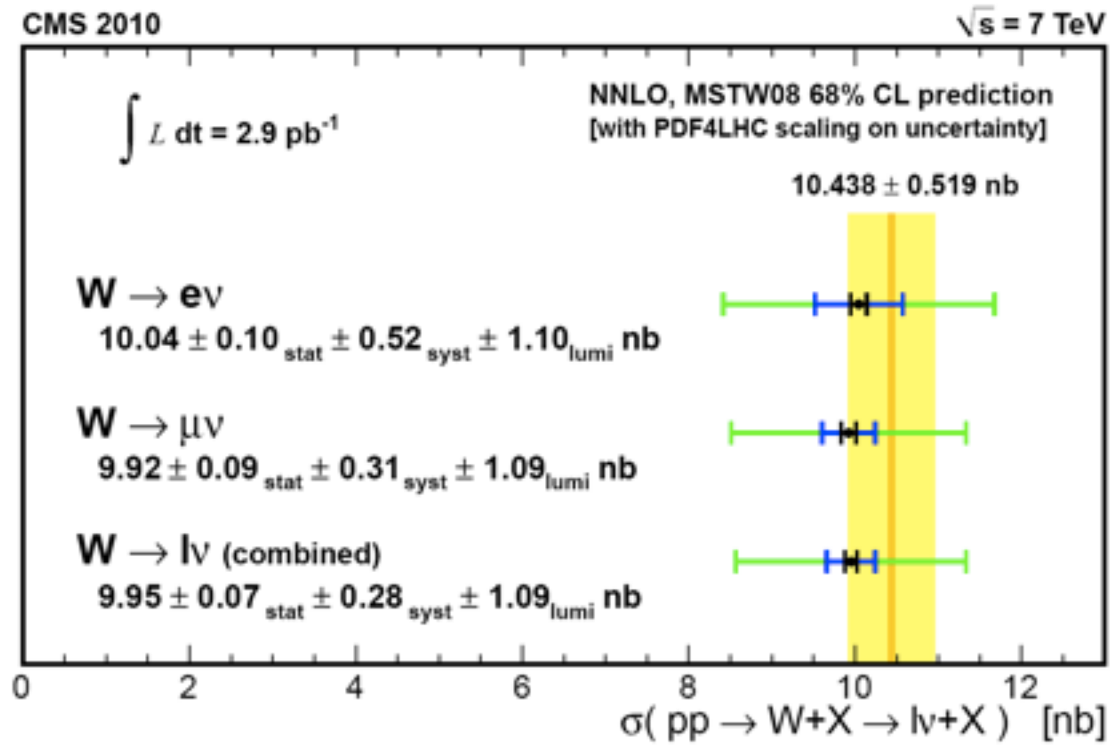


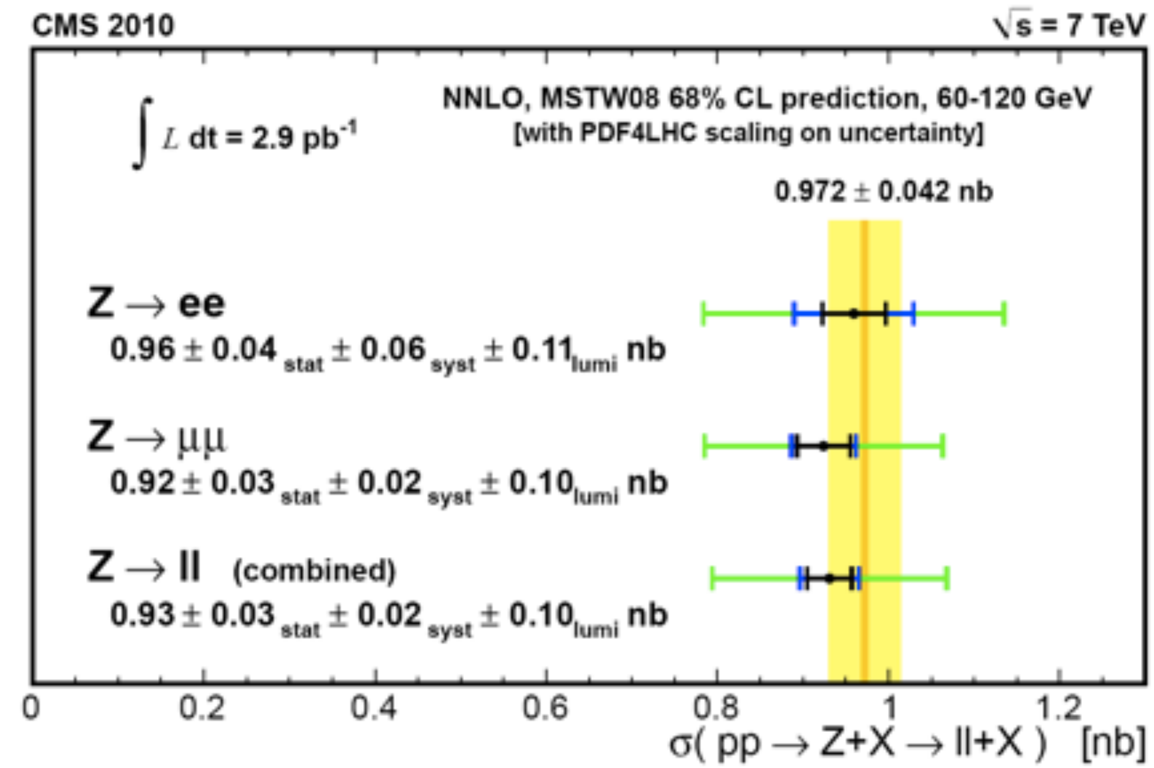


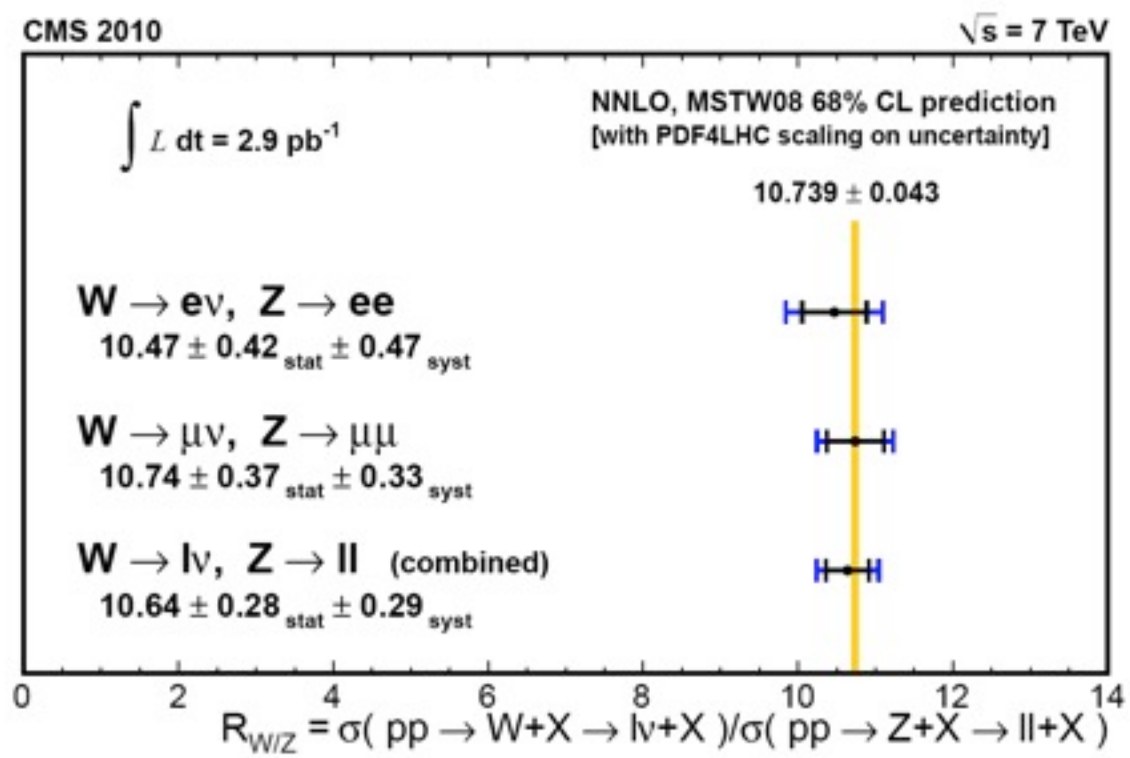
← Z ($35\ pb^{-1}$)

Electroweak: Z & W cross sections

Z and W cross sections and ratios

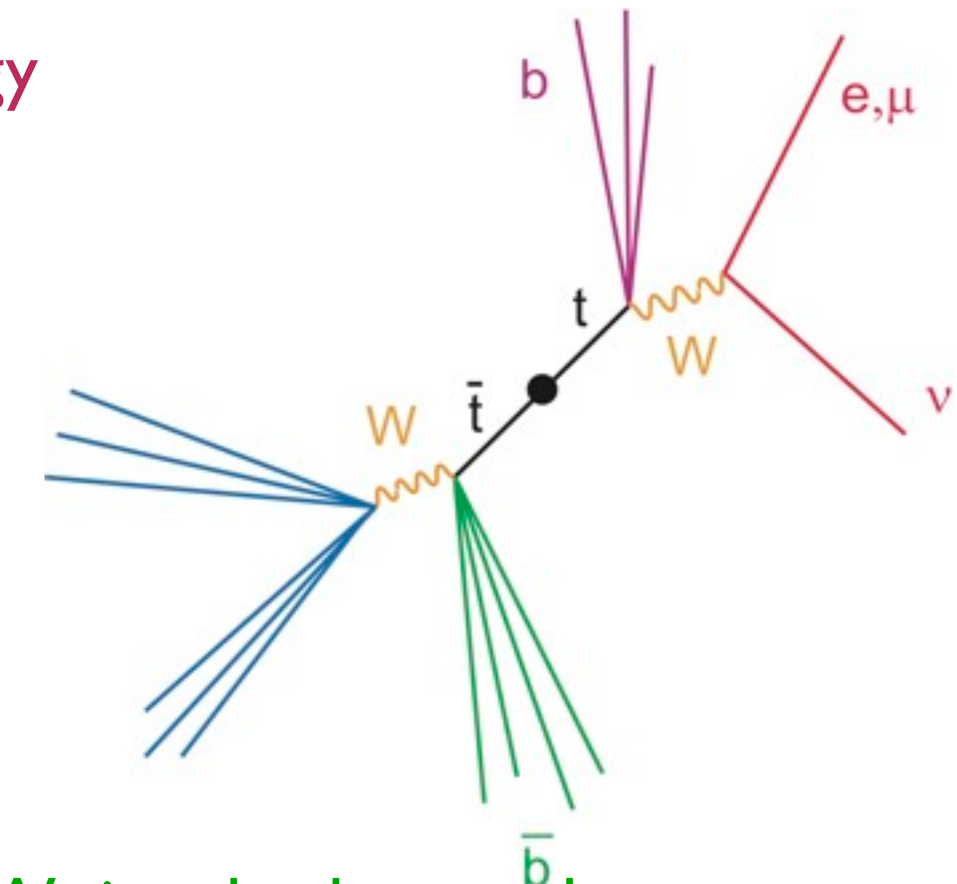






Measurement of Top Cross Section

- Complete set of ingredients to investigate production of ttbar, which is the next step in verifying the SM at the LHC:
  - e, μ, E_T^{miss}, jets, b-tag
- Assume all tops decay to Wb: event topology then depends on the two W decays.
- Of interest:
  - lepton (e or μ), E_T^{miss}, jjbb (37.9%)
  - dilepton (ee, $\mu\mu$ or eμ), E_T^{miss}, bb (6.46%)



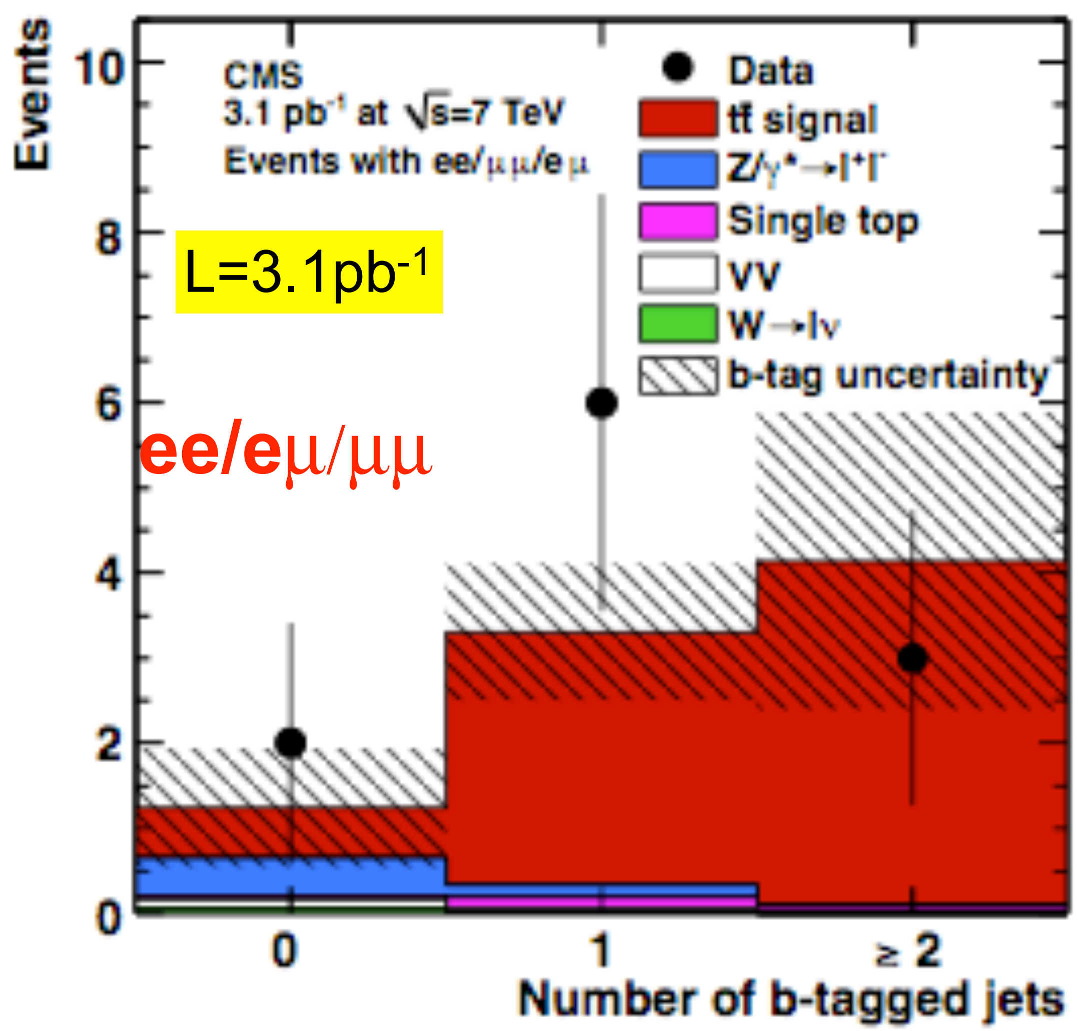
- Data-driven methods to control QCD and W+jets backgrounds
- Counting experiment, with simultaneous likelihood fit to all channels to derive the combined cross section.

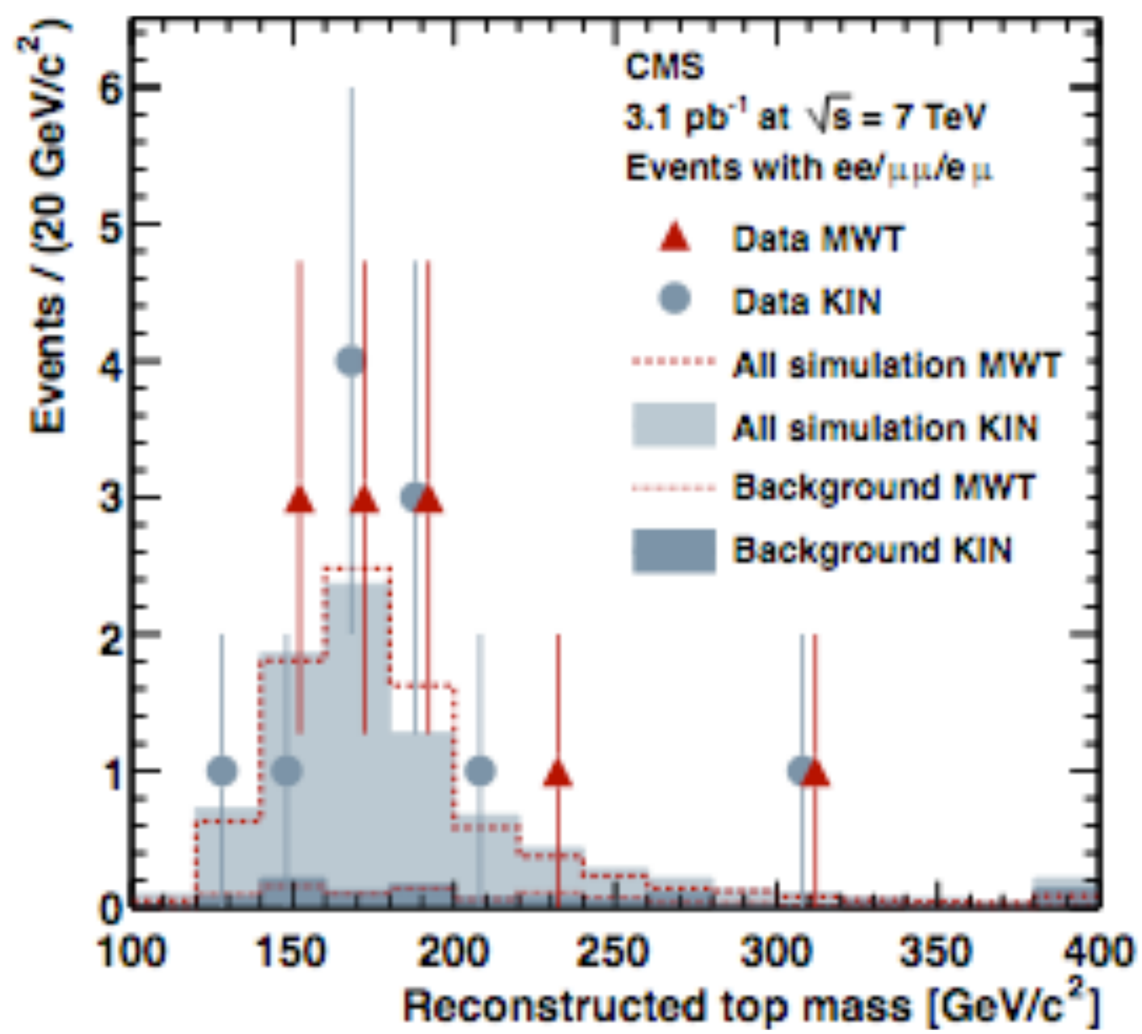
Top

Full selection applied: Z-Veto, |M(ll)-M(Z)|>15 GeV

MET >30 (20) GeV in ee,μμ, (eμ); N(jets)≥2

$\sigma(pp \to t\bar{t}) = 194 \pm 72(stat.) \pm 24(syst.) \pm 21(lumi.)$ pb





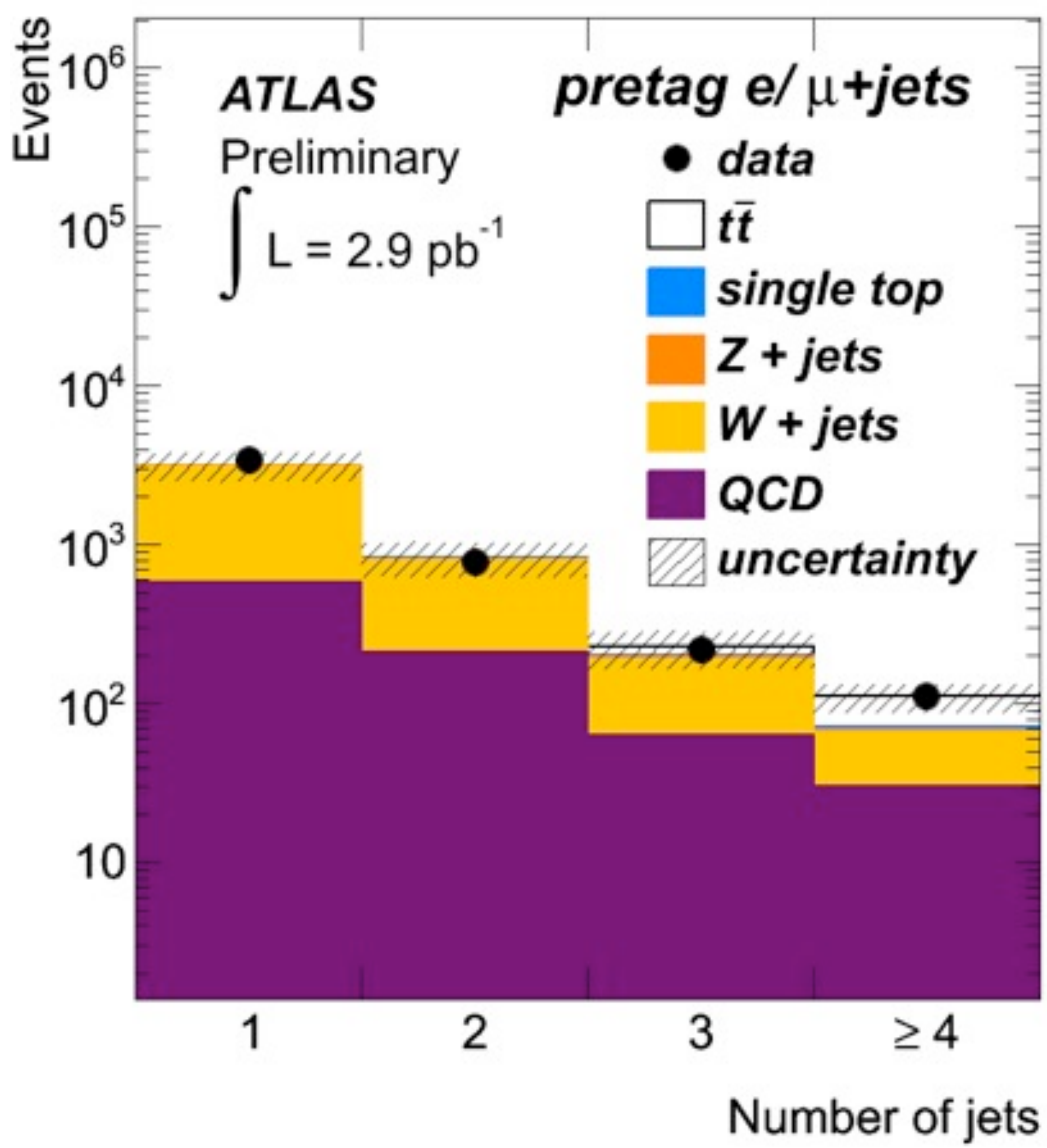
Submitted toPL-B arXiv:1010.5994

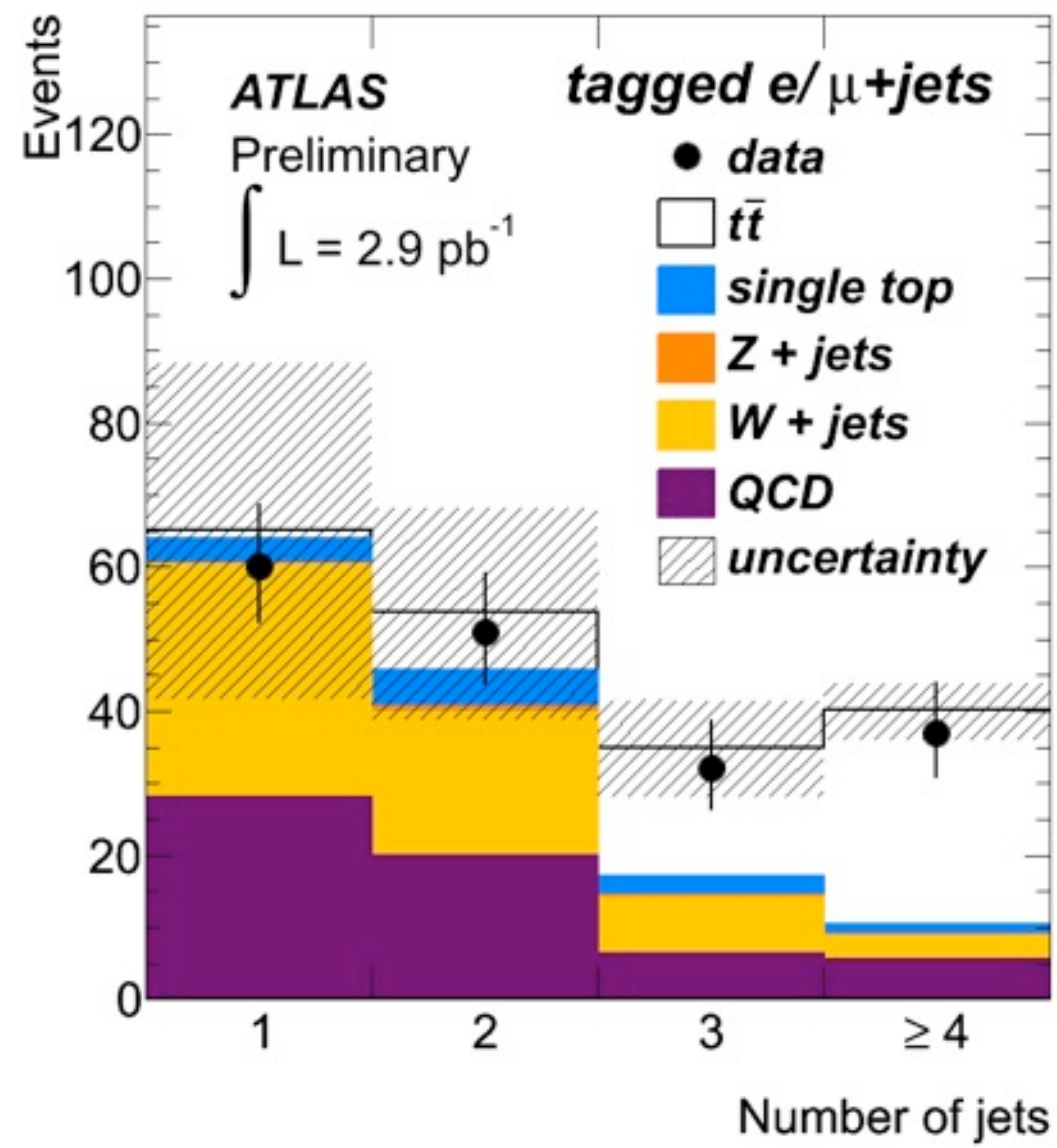
Single lepton channel

1 e or μ with p_T>20 GeV, E_T^{miss}>20 GeV, $E_T^{miss}+m_T(W)$>60 GeV

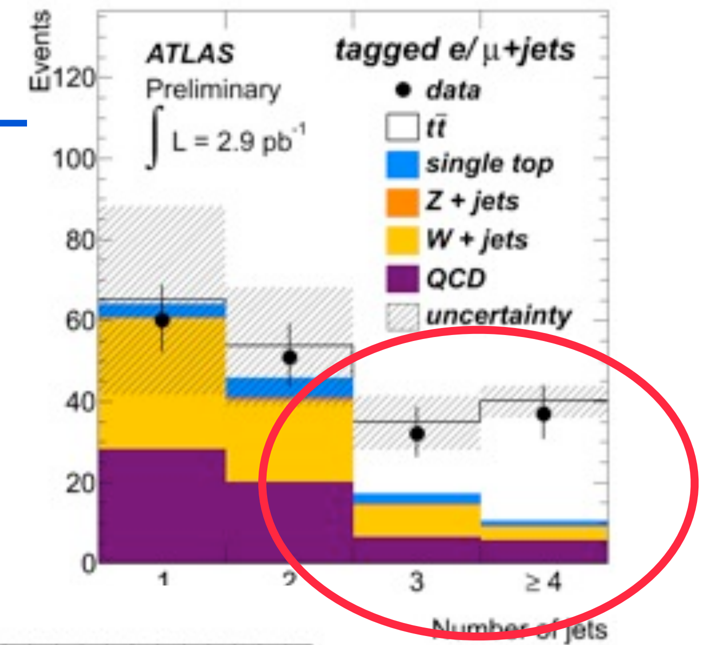
N_{jets} with p_T>25 GeV, with no b-tag requirement or at least one b-tag

Signal defined to have 4 or more jets, and at least 1 b-tag

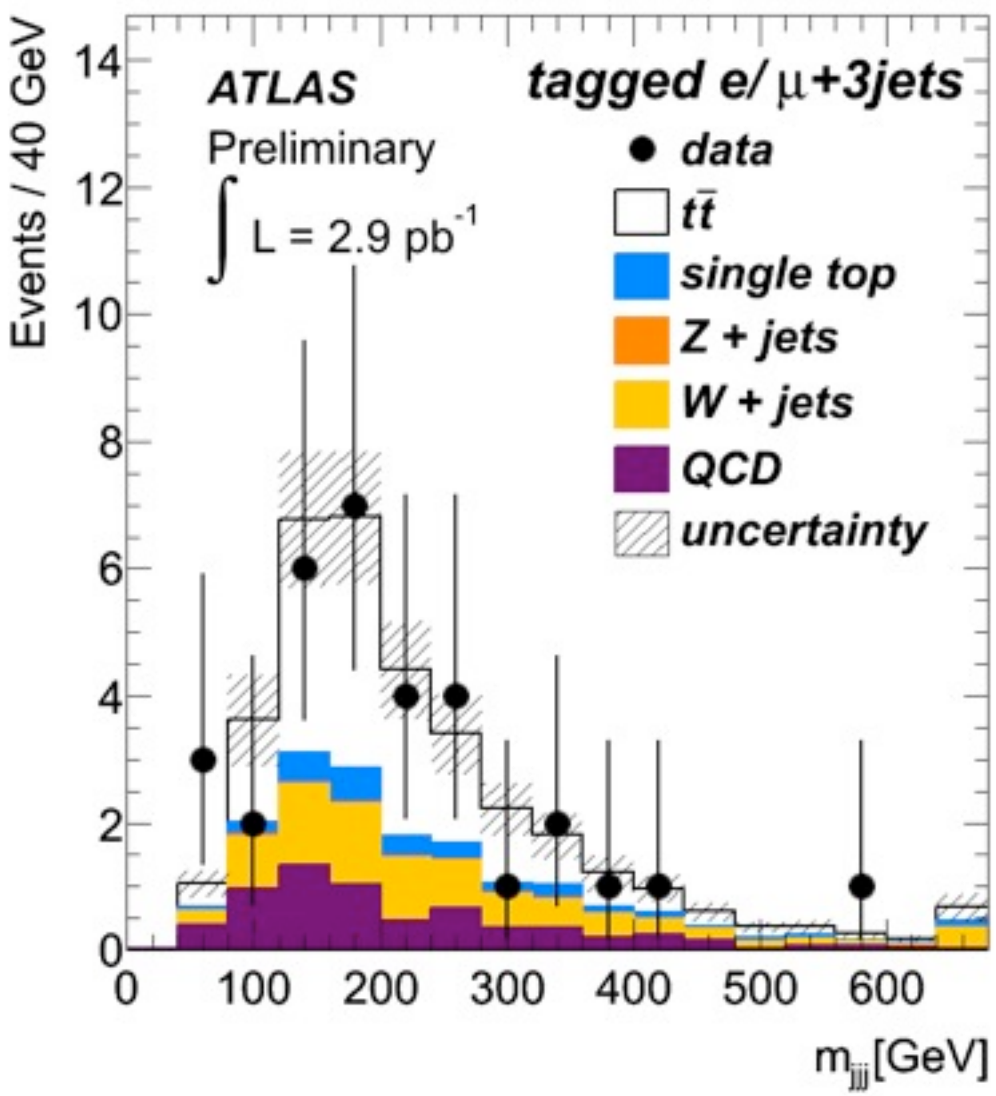


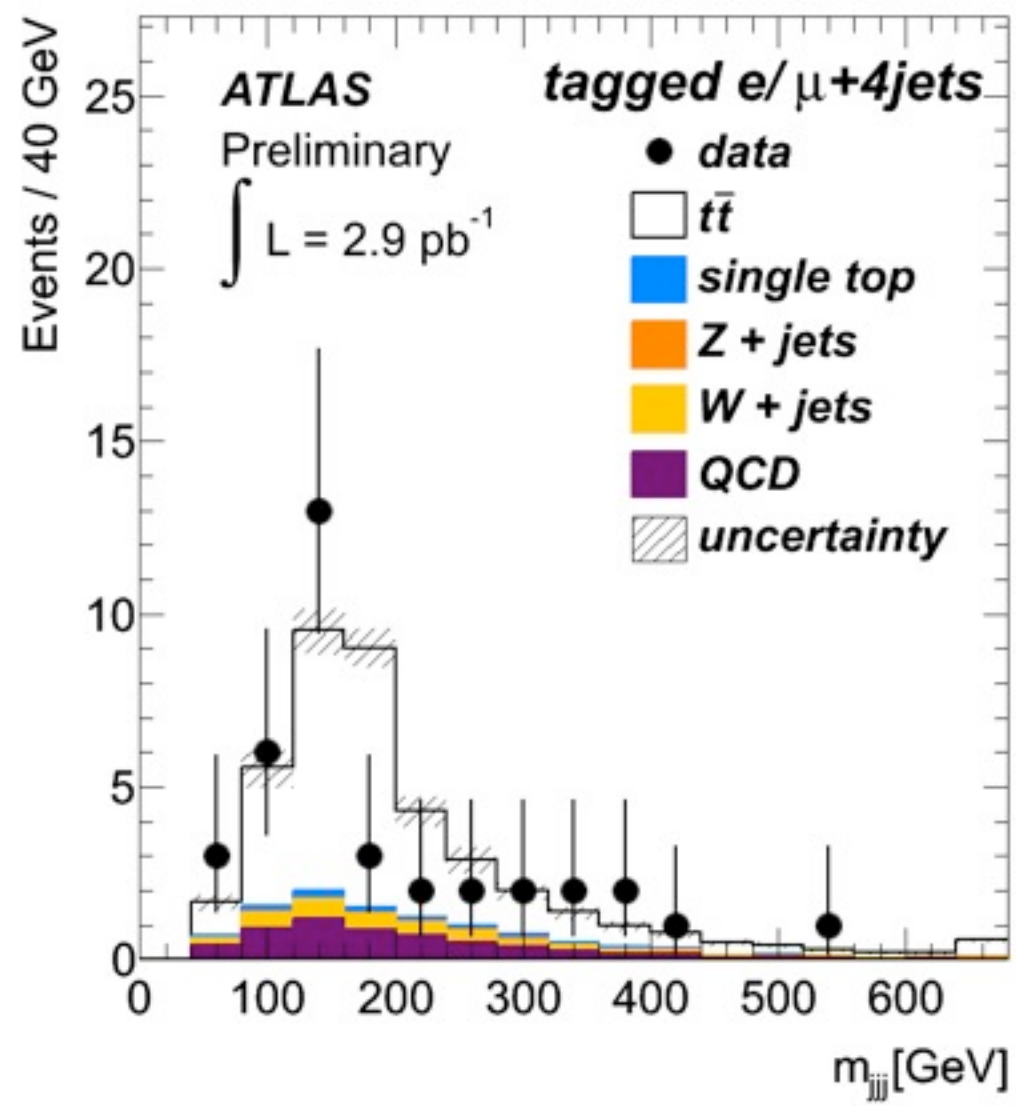


Cross Check of 3-jet Mass



Invariant mass of the highest p_T 3-jet combination for tagged 3 and 4 jet events used in cross-check analyses. Agrees with top hypothesis.

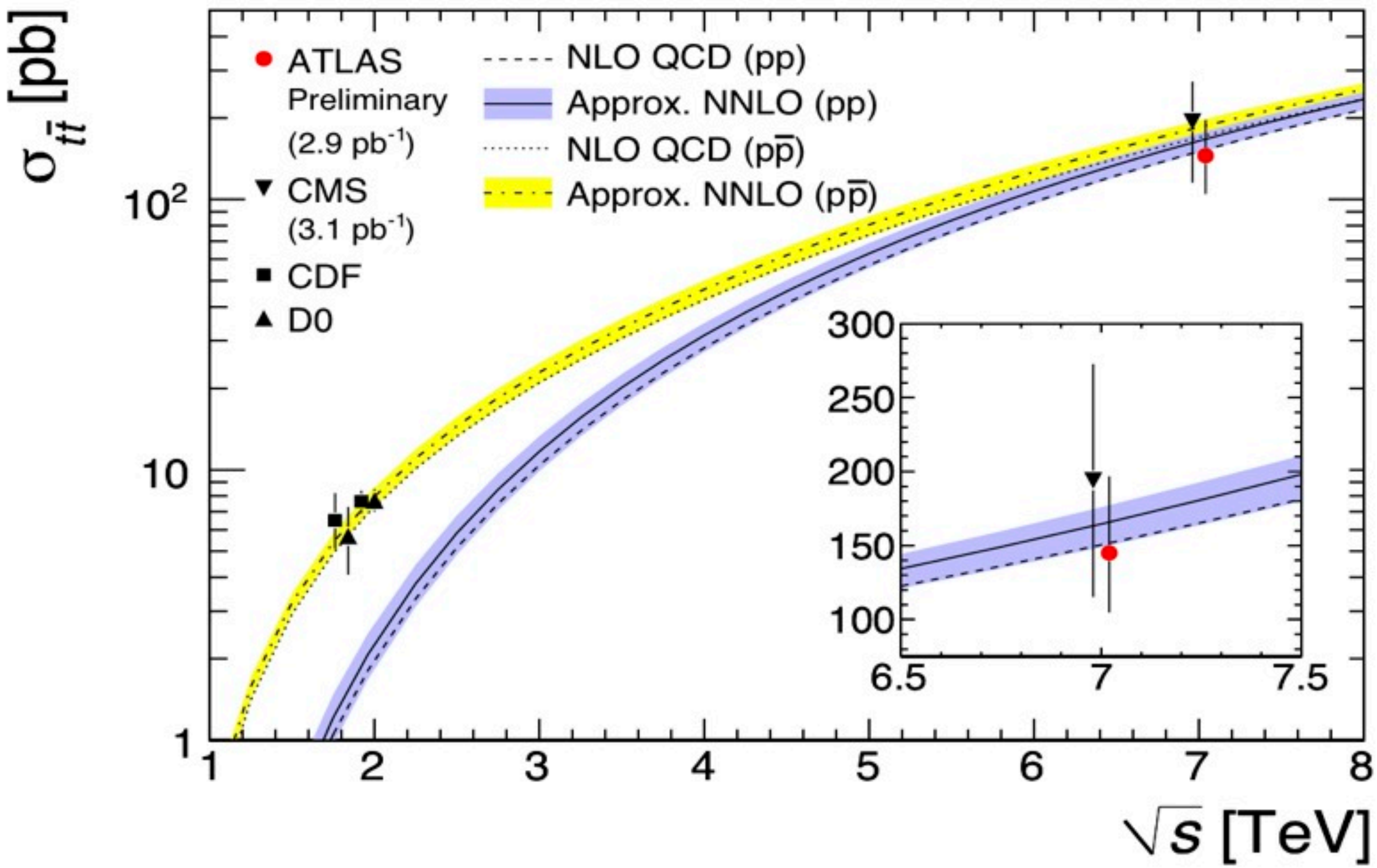




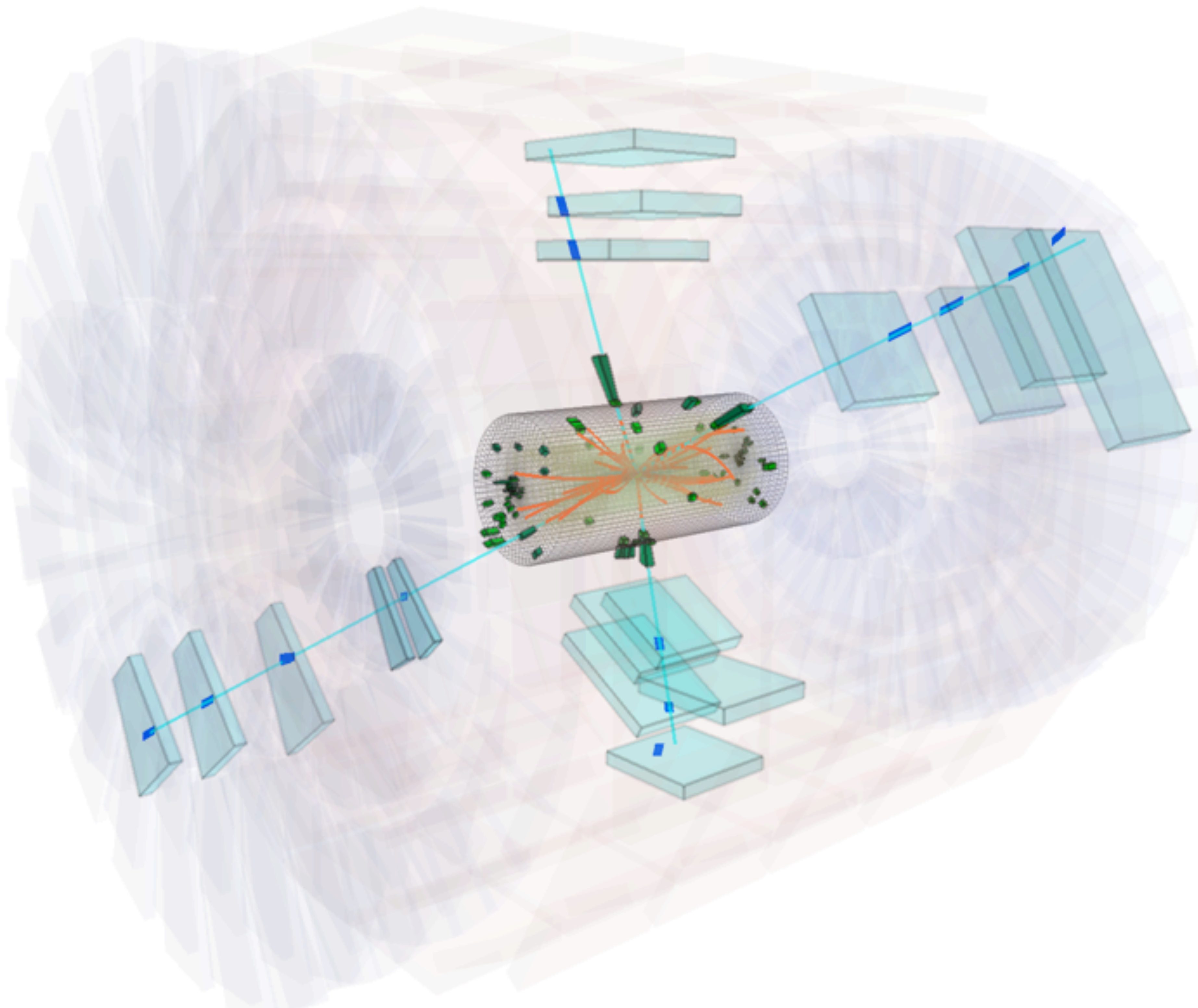
Top Production Cross Section

Combining all channels, $\sigma_{t\bar{t}} = 145 \pm 31^{+42}_{-27}$ pb

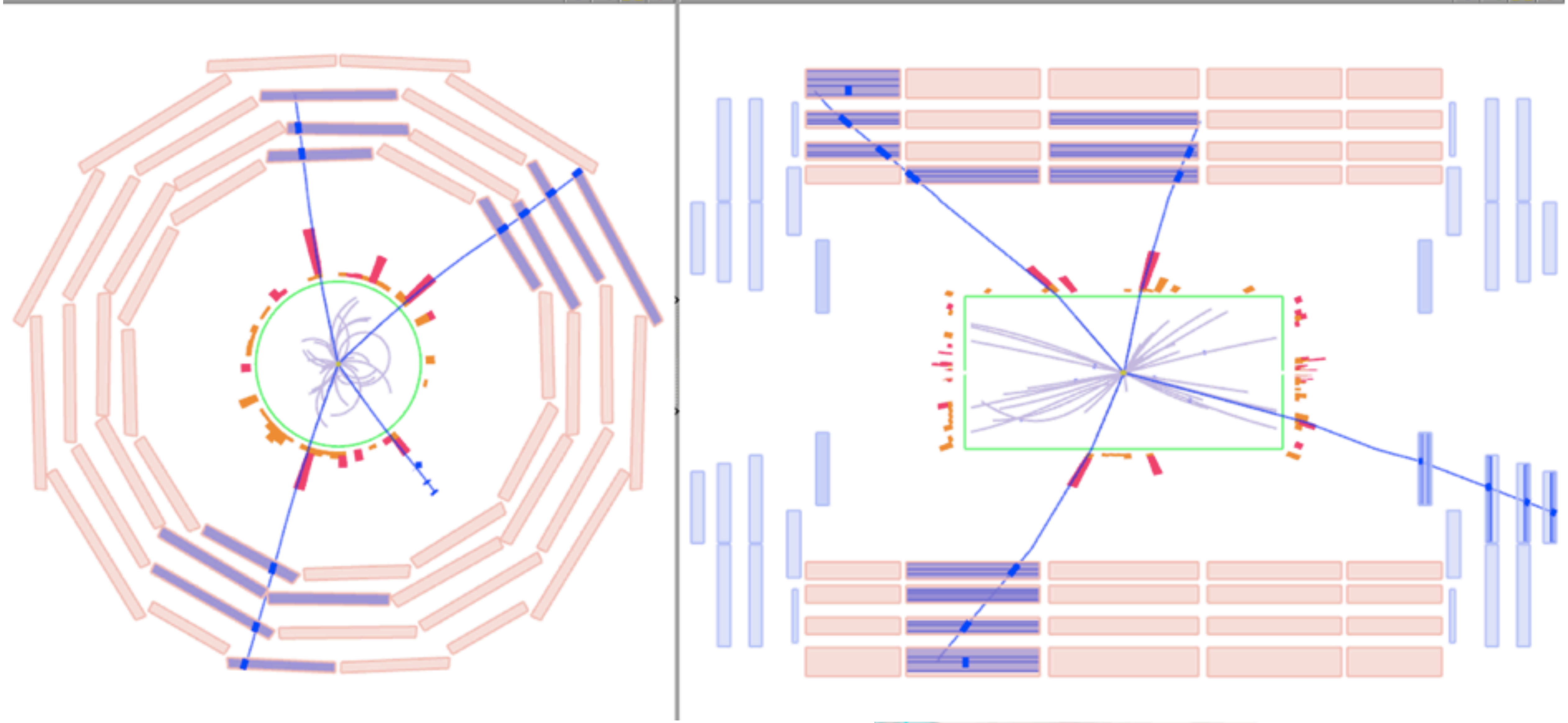
Significance of ~4.8σ w.r.t. background only hypothesis.



A beautiful ZZ event



A beautiful ZZ event

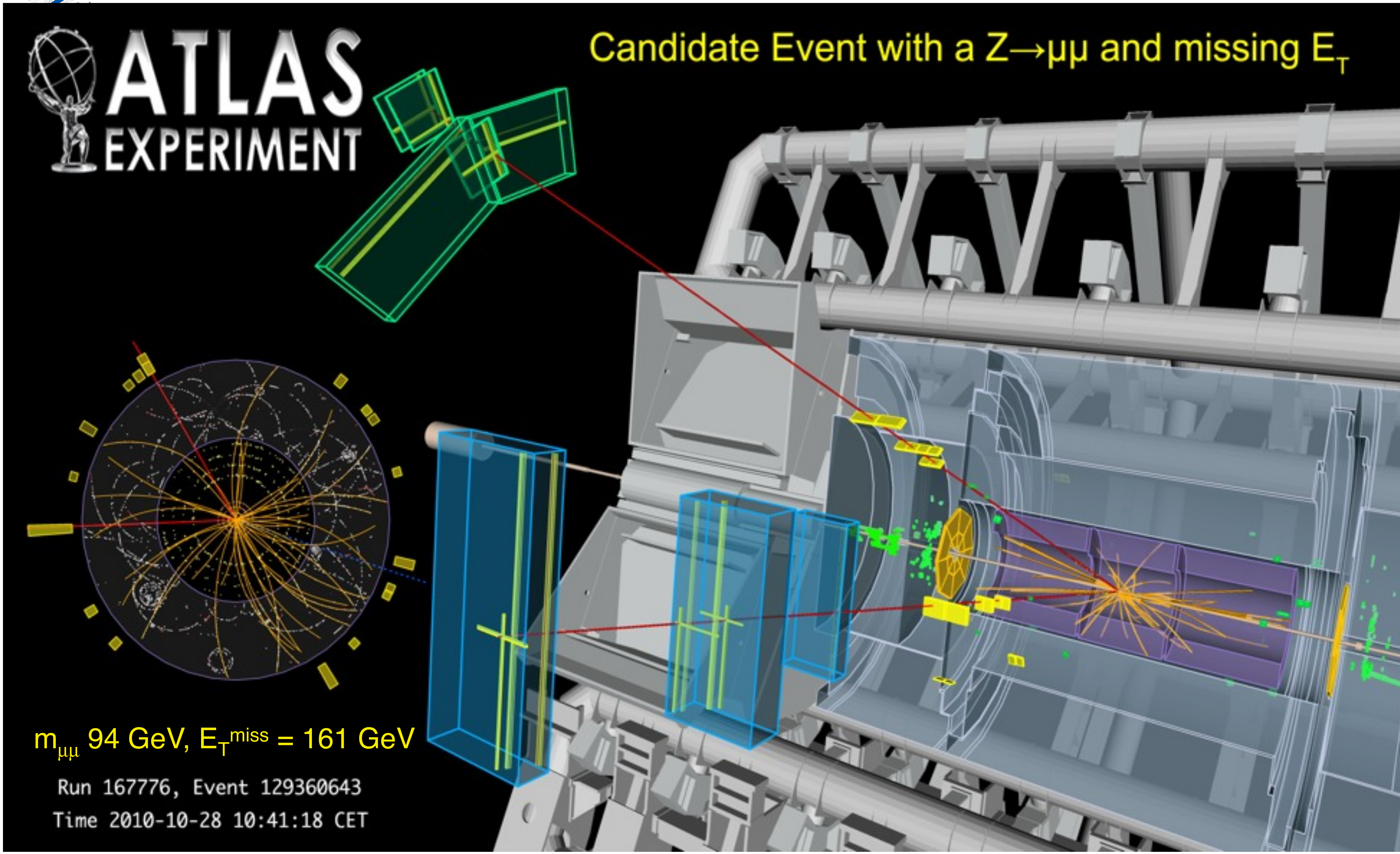


Invariant Masses

$\mu_0 + \mu_1$: 92.15 GeV (total(Z) p_T 26.5 GeV, ϕ -3.03),
$\mu_2 + \mu_3$: 92.24 GeV (total(Z) p_T 29.4 GeV, ϕ +.06),
$\mu_0 + \mu_2$: 70.12 GeV (total p_T 27 GeV),
$\mu_3 + \mu_1$: 83.1 GeV (total p_T 26.1 GeV).

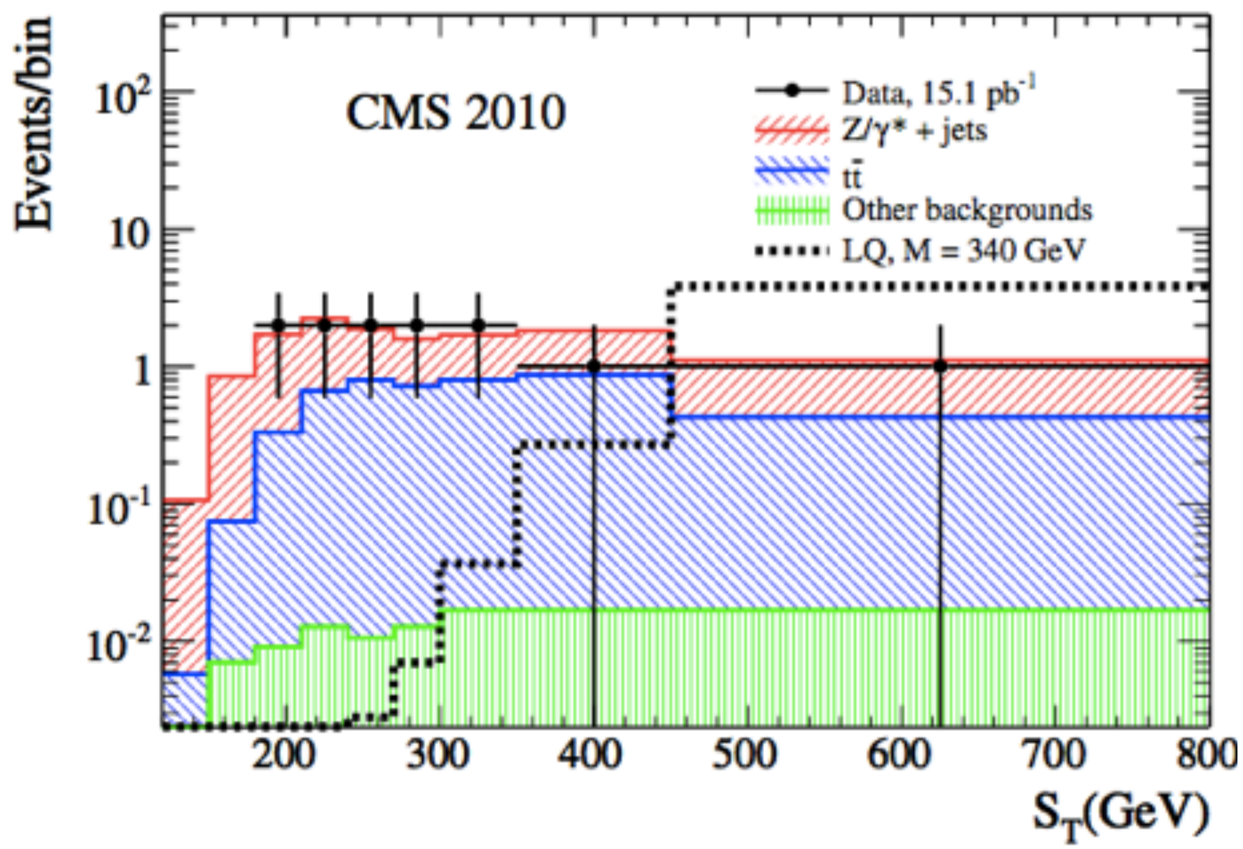
Invariant Mass of 4μ: 201 GeV

ATLAS : ZZ → μμ νν Candidate

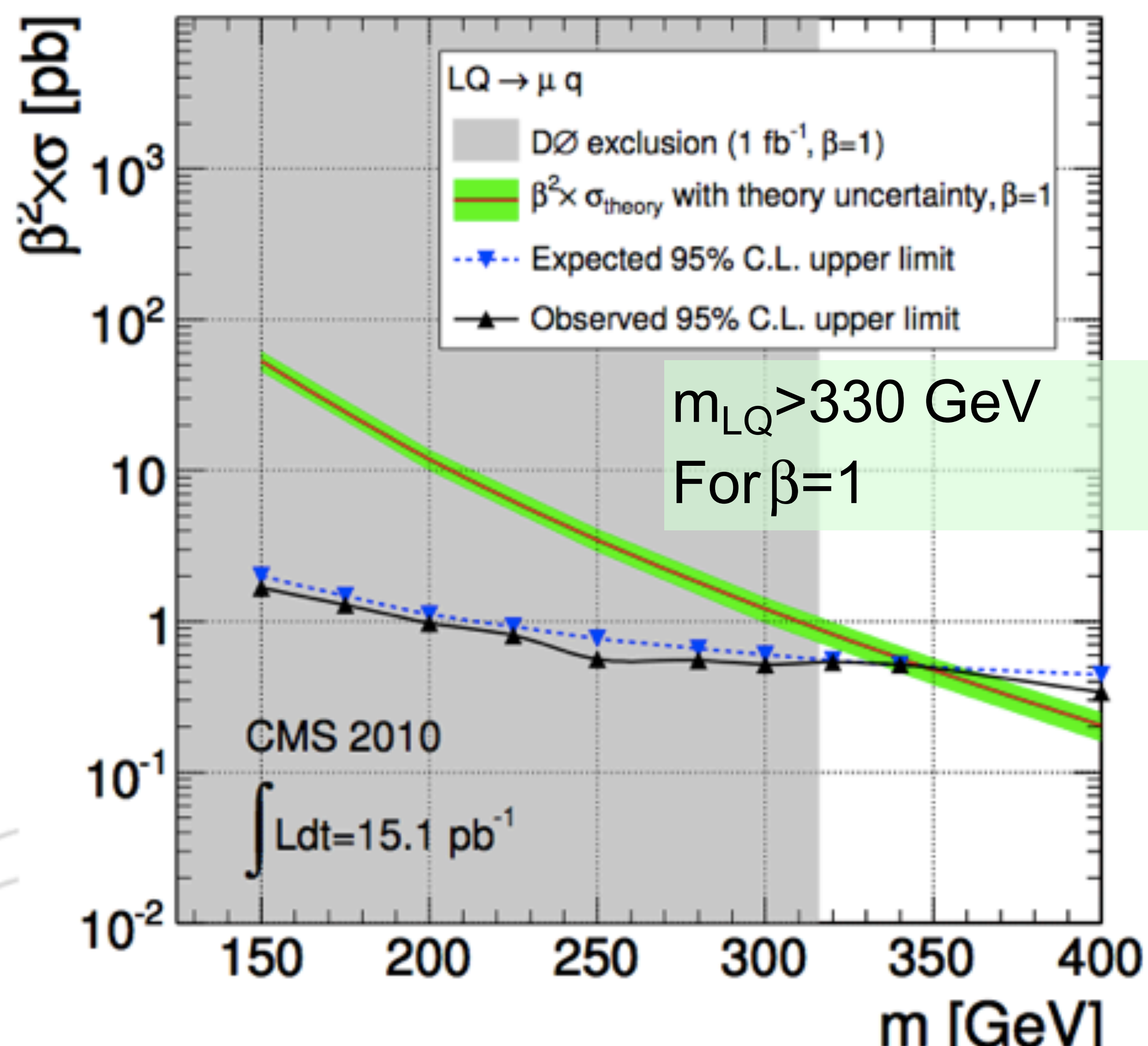


Leptoquark search

- Search for pair produced LQ decaying β % in μ+jet

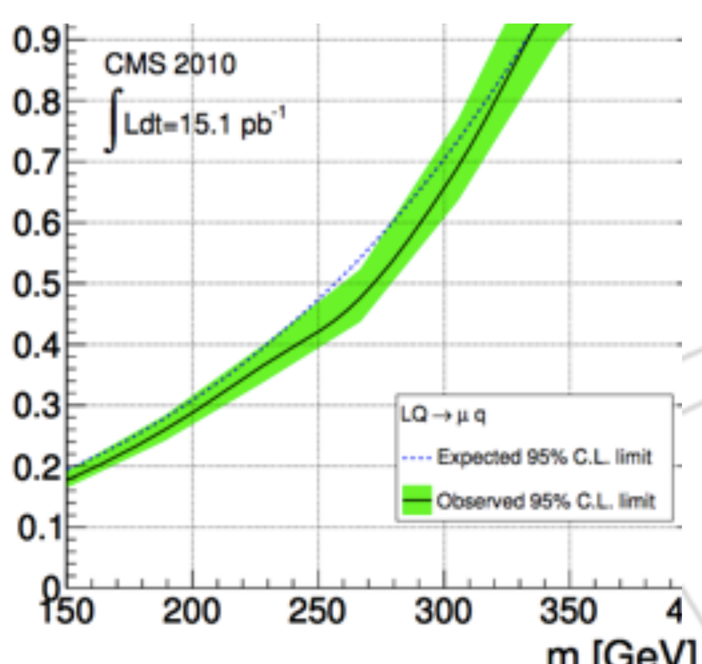


Final discrim. variable $S_T = \sum_{\mu_{1,2}} p_t^{\mu} + \sum_{Jet_{1,2}} p_t^{jet}$



m_{LQ}>330 GeV
For β=1

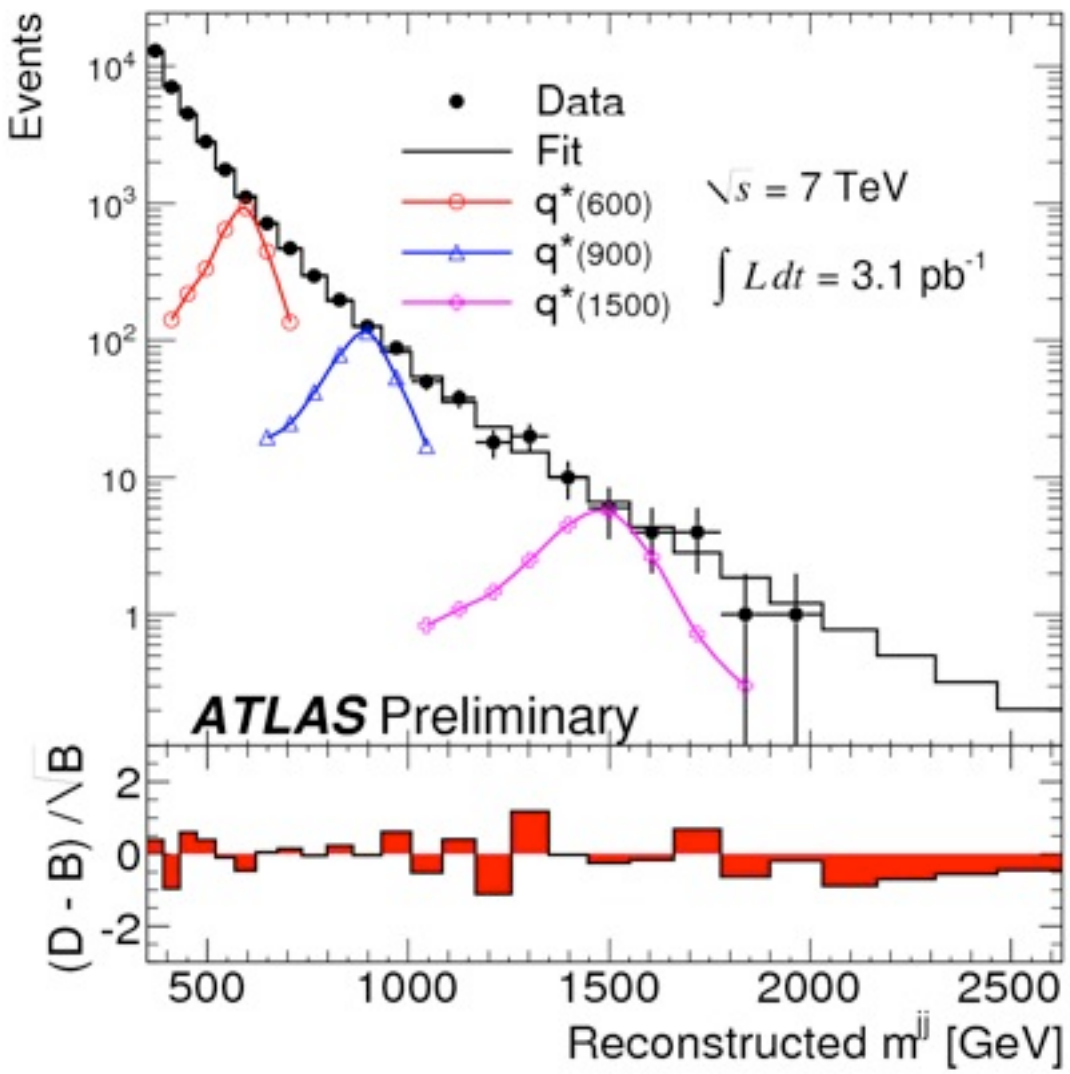
As a function of β

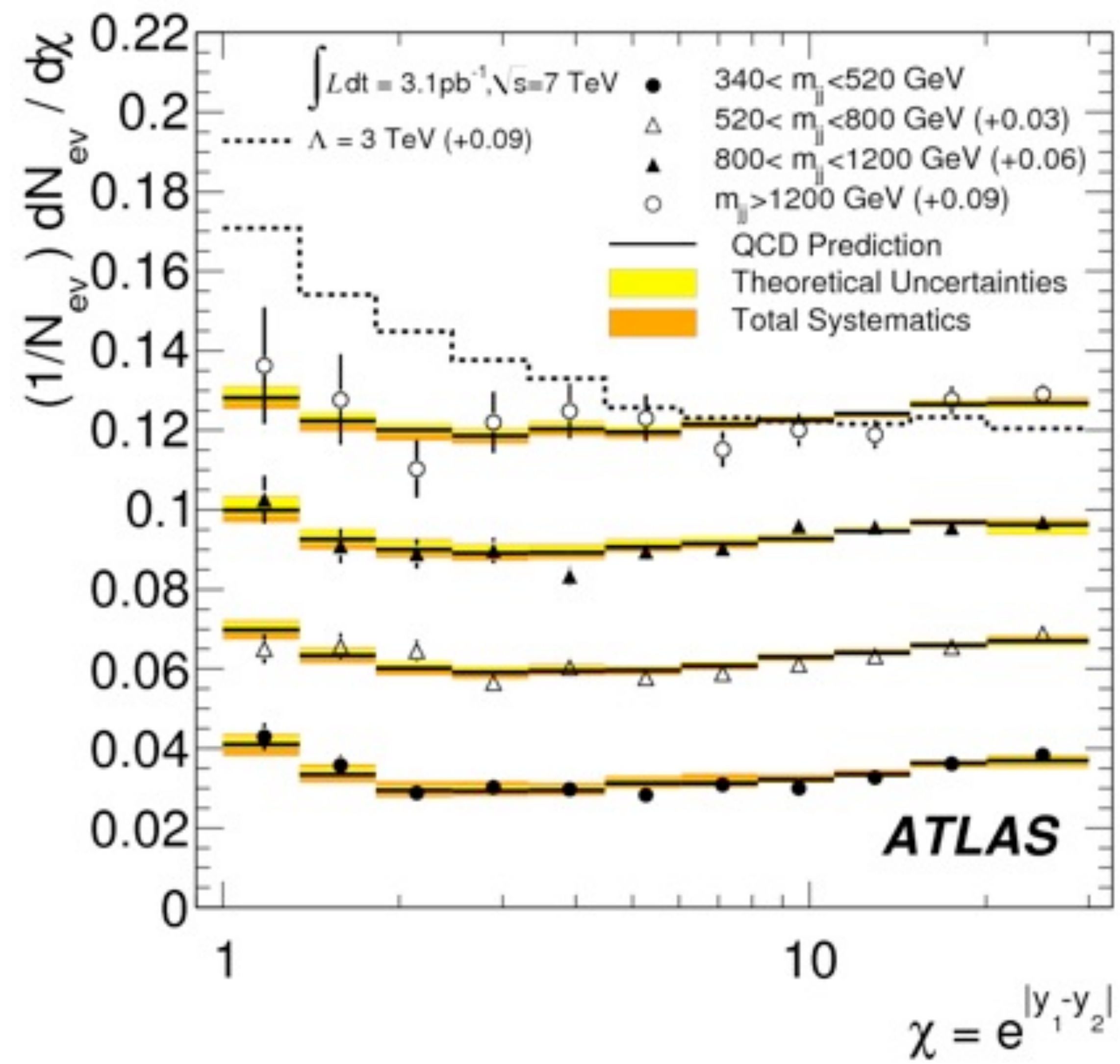


ATLAS: Dijet mass & angular distributions: $3pb^{-1}$

excluded:
0.50 < m(q*) < 1.53 TeV @ 95% CL

Quark contact interactions with scale Λ < 3.4 TeV @ 95% CL



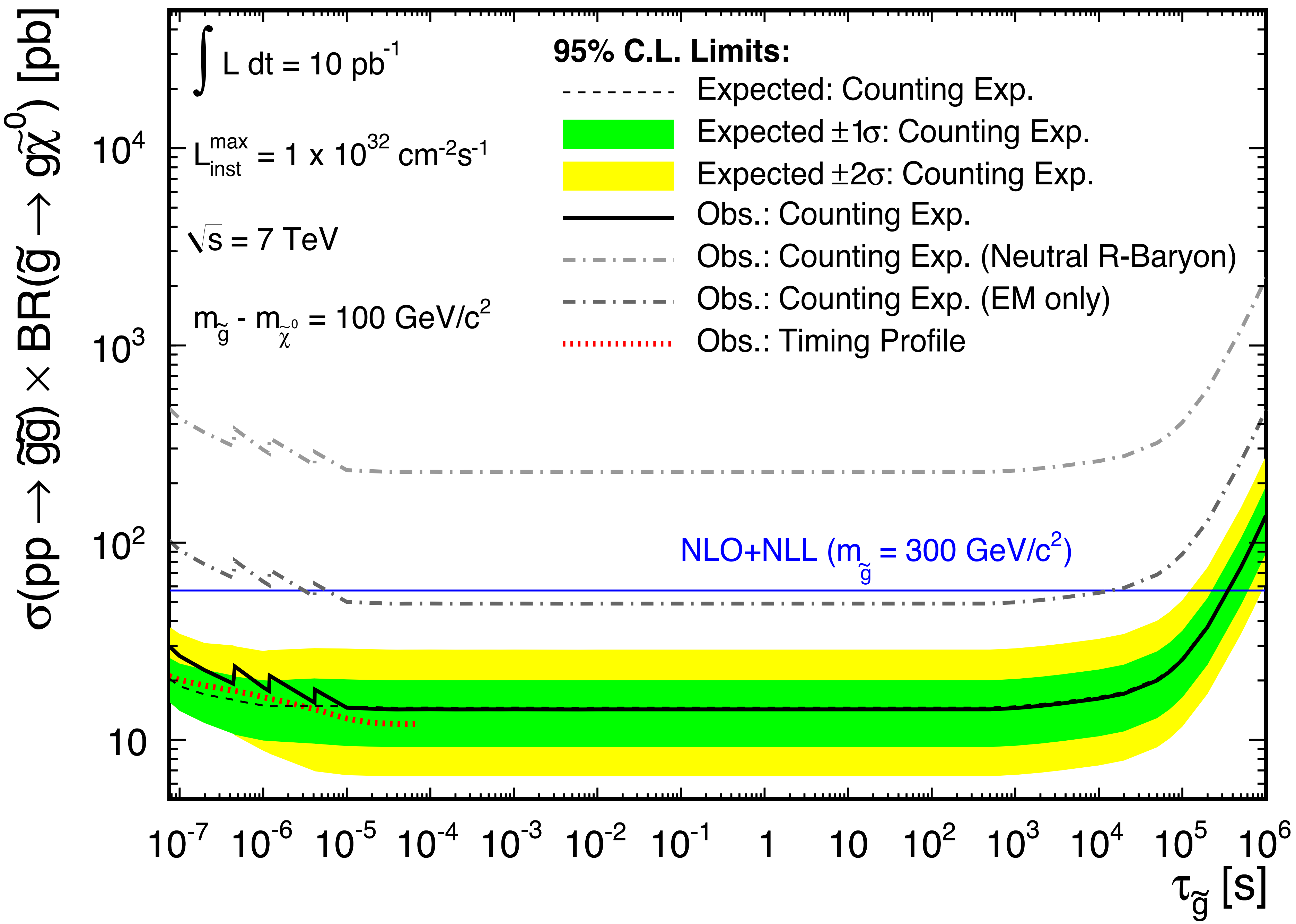


Search for New Particles in Two-Jet Final States in 7 TeV Proton-Proton Collisions with the ATLAS Detector at the LHC, Phys. Rev. Lett. 105, 161801 with 315 nb^{-1}

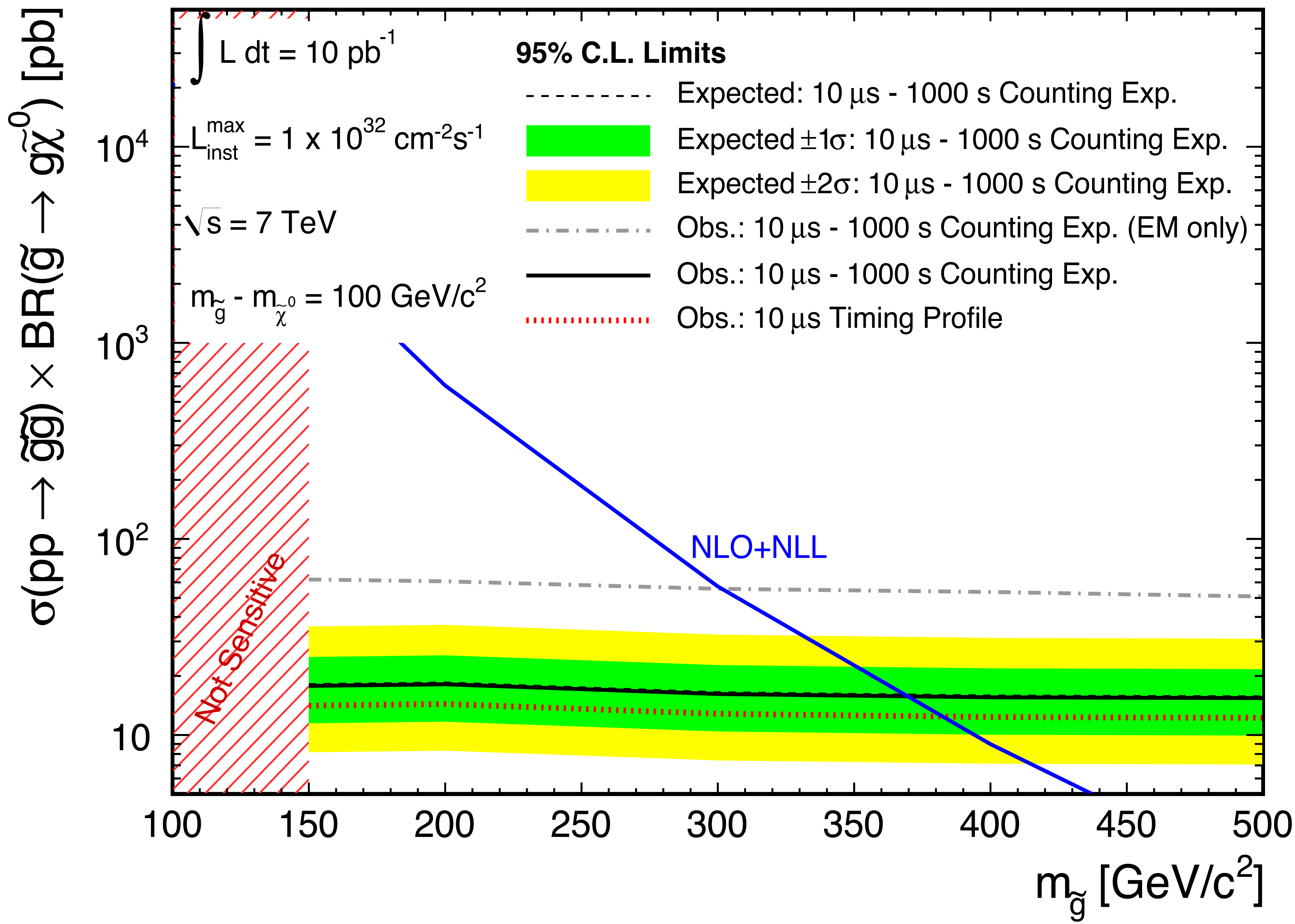
Search for Quark Contact Interactions in Dijet Angular Distributions in in 7 TeV Proton-Proton Collisions with the ATLAS Detector at the LHC, Accepted by PLB

CMS: Limits on Stopped Gluinos

Search for decays of stopped long lived R-hadrons (gluino-meson, gluino-baryon, gluino-gluon bound states) during time intervals without LHC crossing.



CMS: Limits on Stopped Gluinos



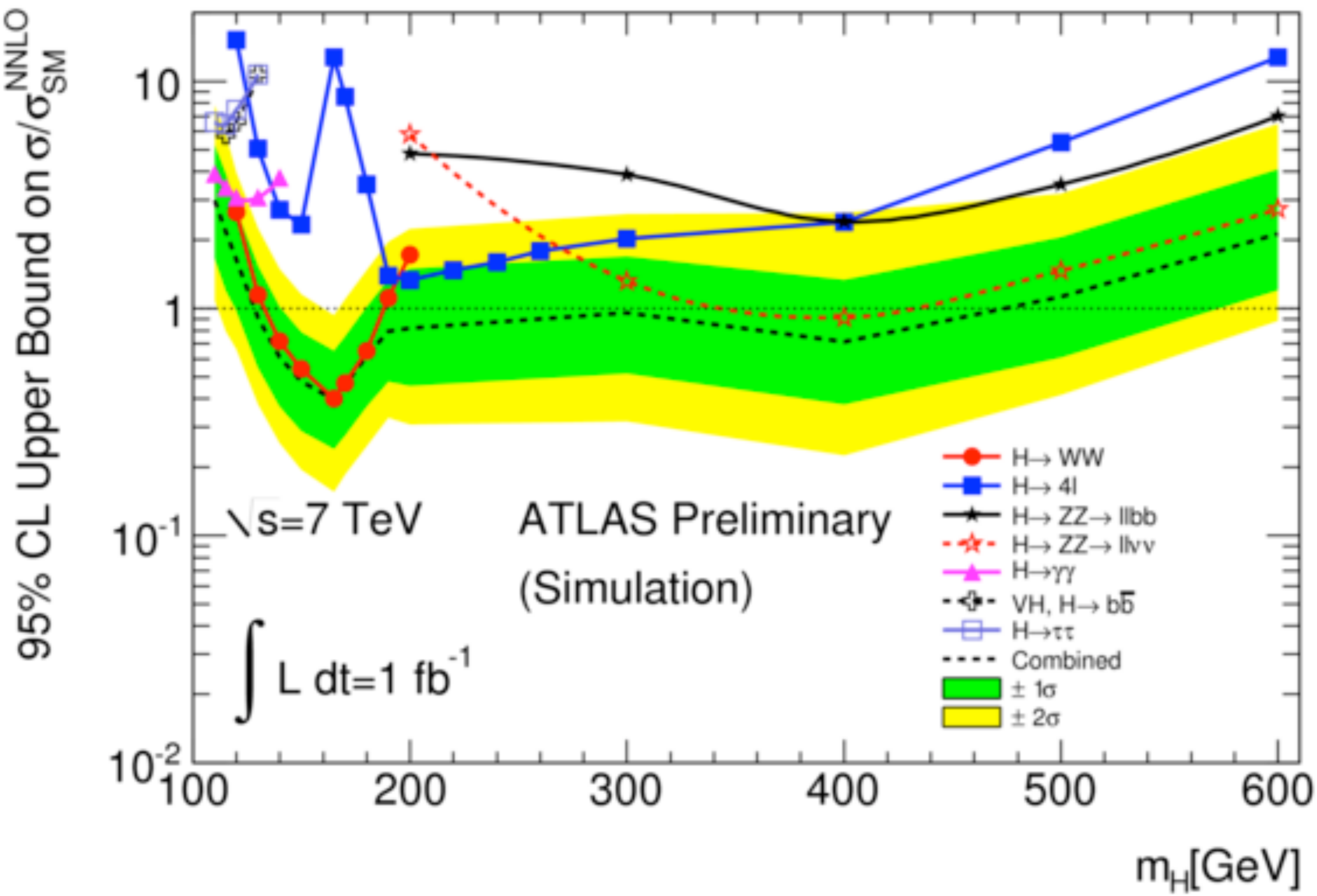
Conclusions: Welcome to the Terascale !

- 2010 was a very successful year for LHC experiments
- Luminosity increased steadily up to 2 x10^{32} /cm^2 sec. Great prospects for 2011.
- All LHC experiments were able to publish results within a very short time. Detectors understood, grid computing works, good agreement between data and simulations, promising situation for future analysis.
- First physics results in all areas: soft QCD, jet physics, electroweak, top, searches and heavy ion collisions.
- LHC starts to exceed sensitivities of Tevatron experiments.
- 2011 with 1 fb^{-1} at 7 or 8 TeV will be exciting !

Backup slides

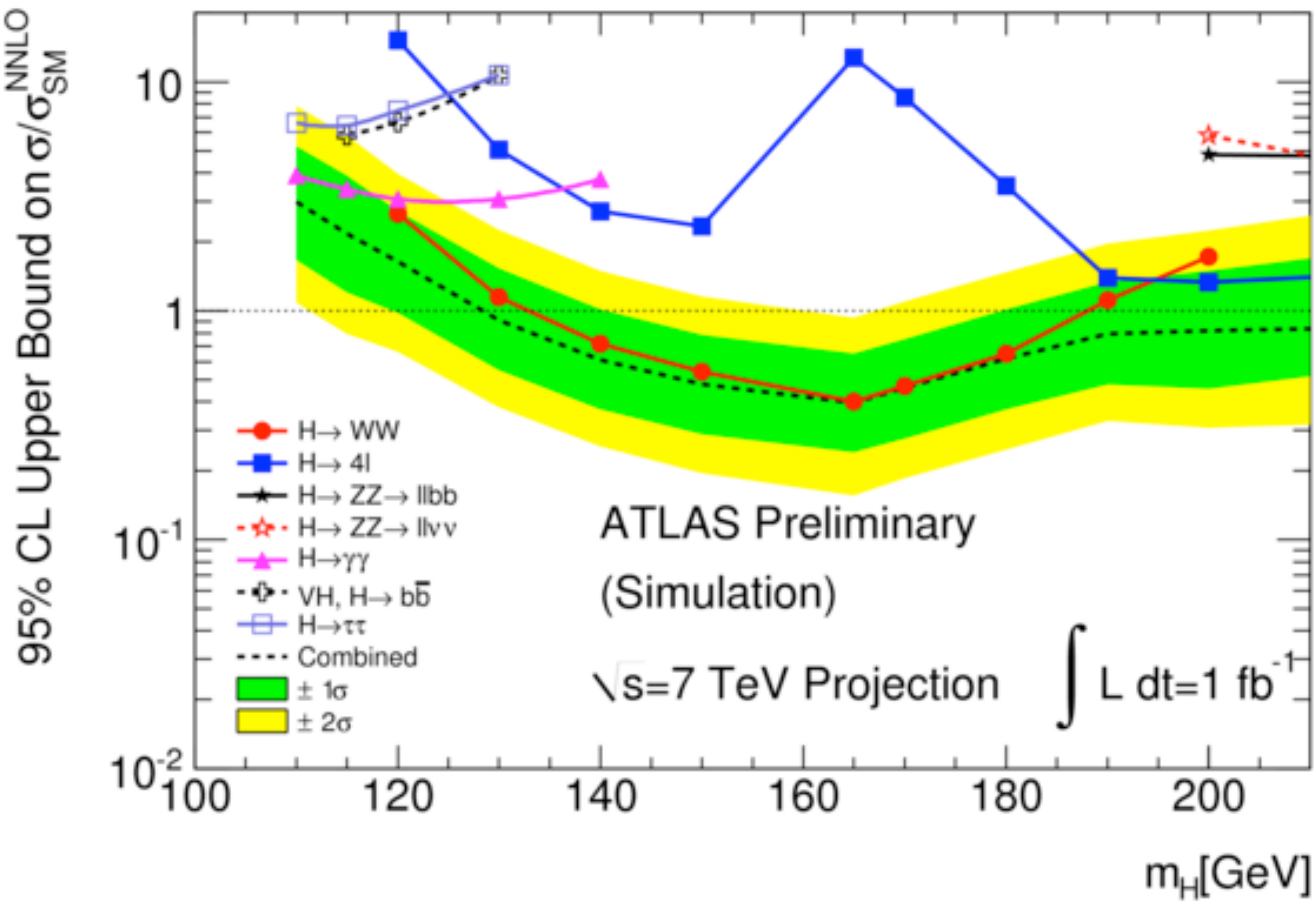
7 TeV, 1 fb^{-1}

129-460 GeV has >50% chance of exclusion

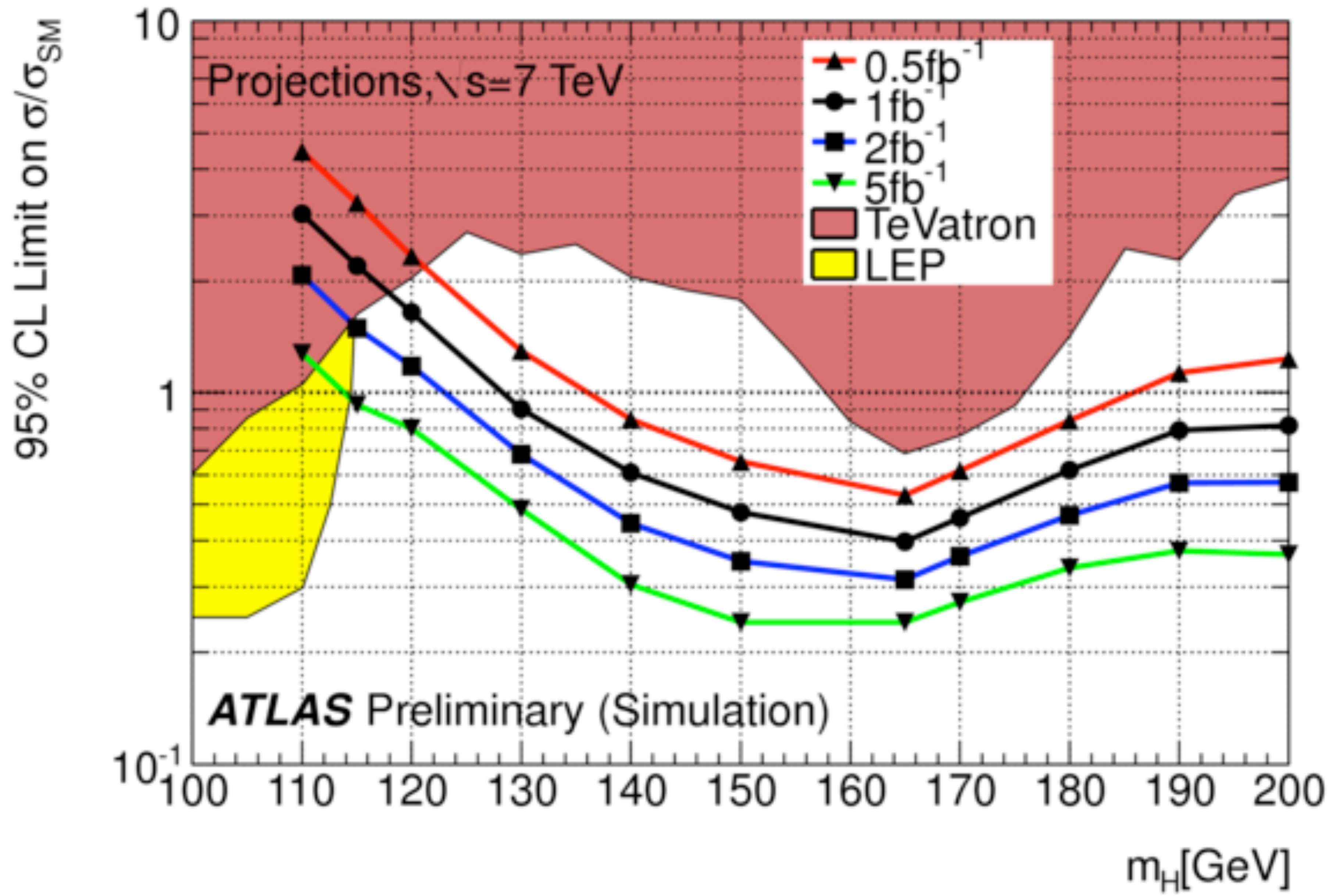


7 TeV, 1 fb^{-1}

$\tau\tau$, bb and $\gamma\gamma$ channels all contribute in low mass region



More integrated luminosity

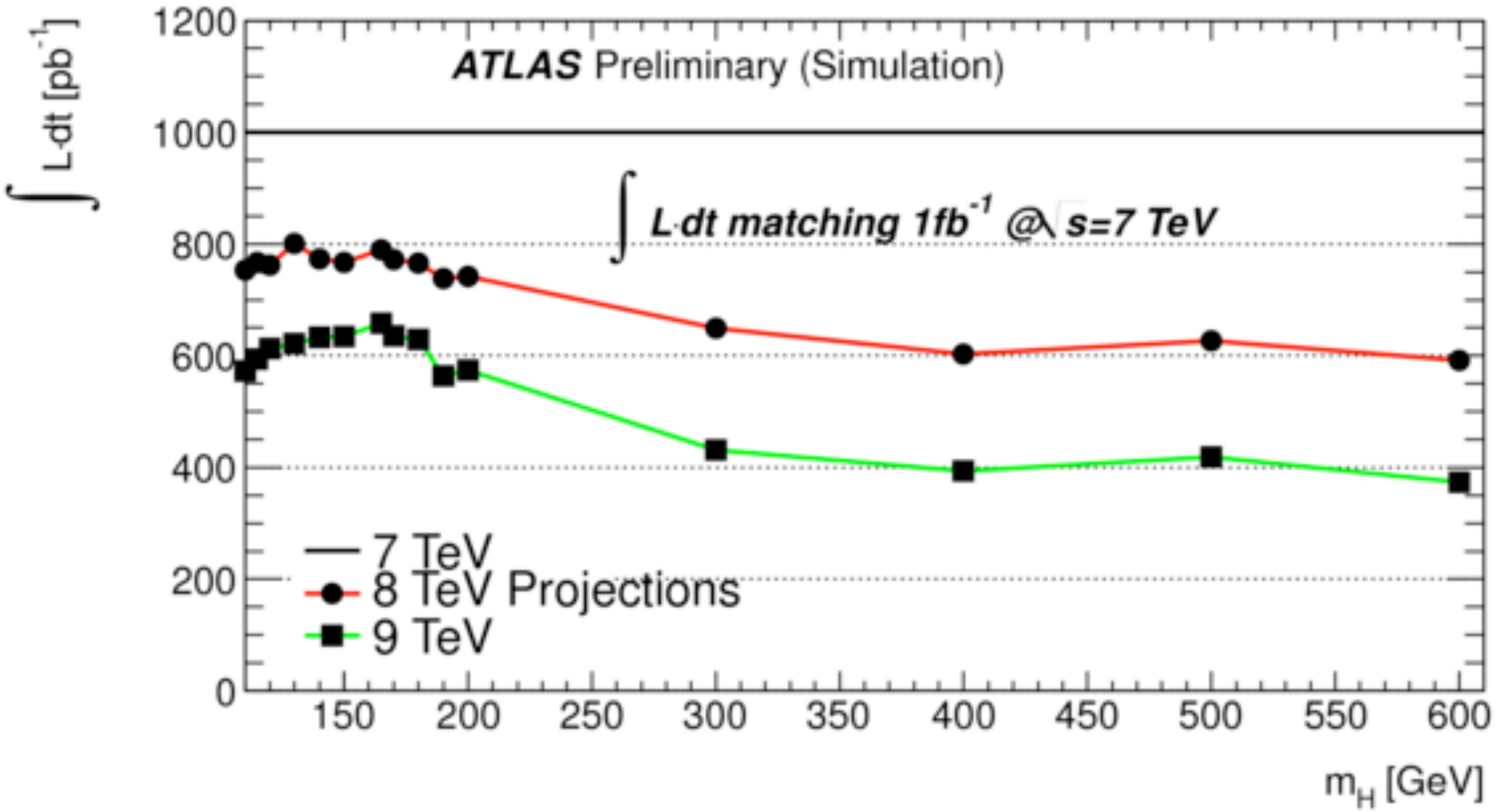


5fb^{-1} enough to close gap with LEP at 7 TeV

Expected 3σ observation from 123 to 550 GeV

Higher centre-of-mass energy

- Compare integrated luminosity at 8 or 9 TeV which gives same median sensitivity as 1 fb^{-1} at 7 TeV
- At 8 TeV, require 20% less integrated luminosity



4 μ mass

PAS HIG 008-3