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SFB 676 – Project B2

Recent Results from CMS

Christian Sander, *University of Hamburg*
on behalf of the CMS Collaboration

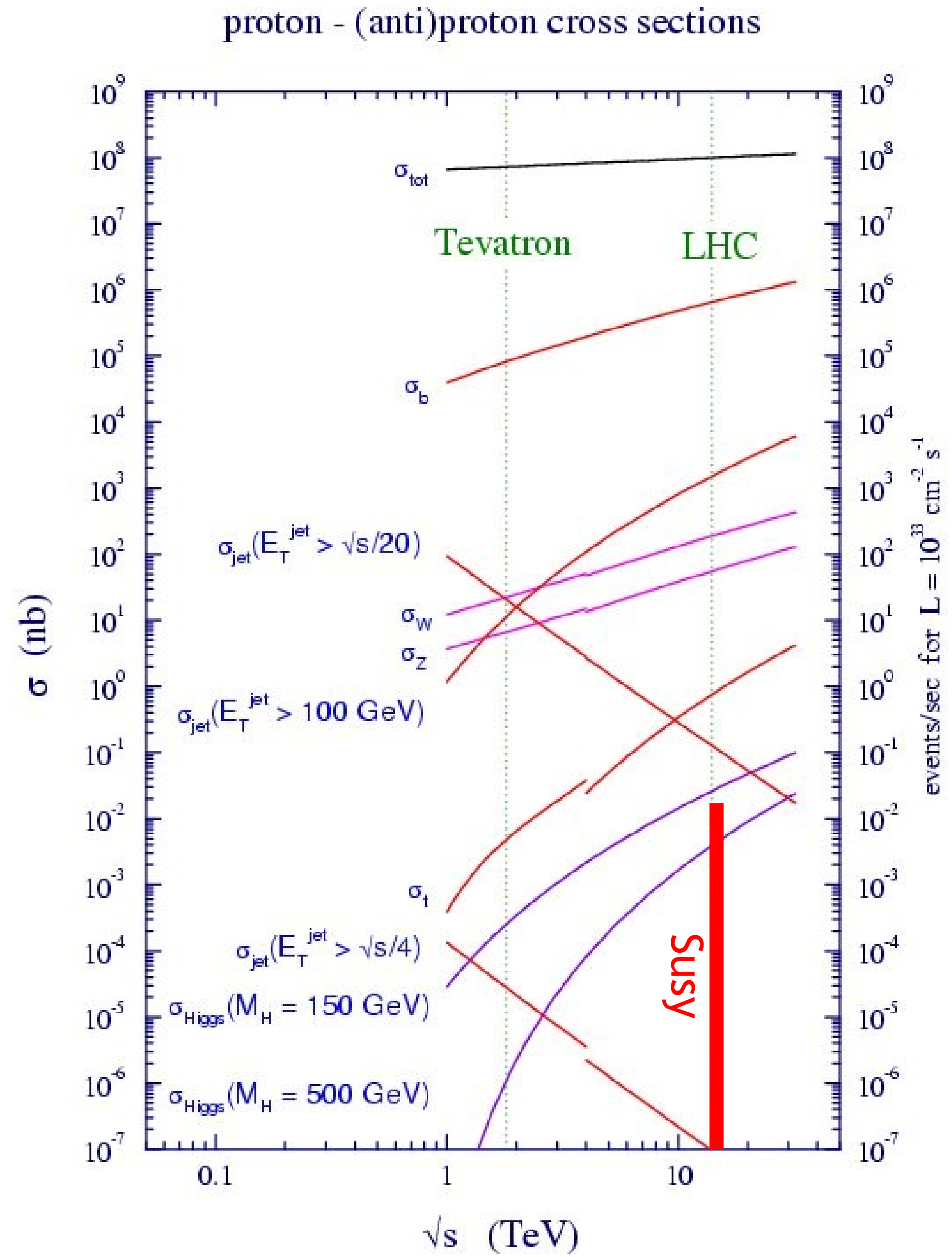
Bonn 23rd - 28th August 2010 18th International Conference on Supersymmetry and Unification of Fundamental Interactions

Outline

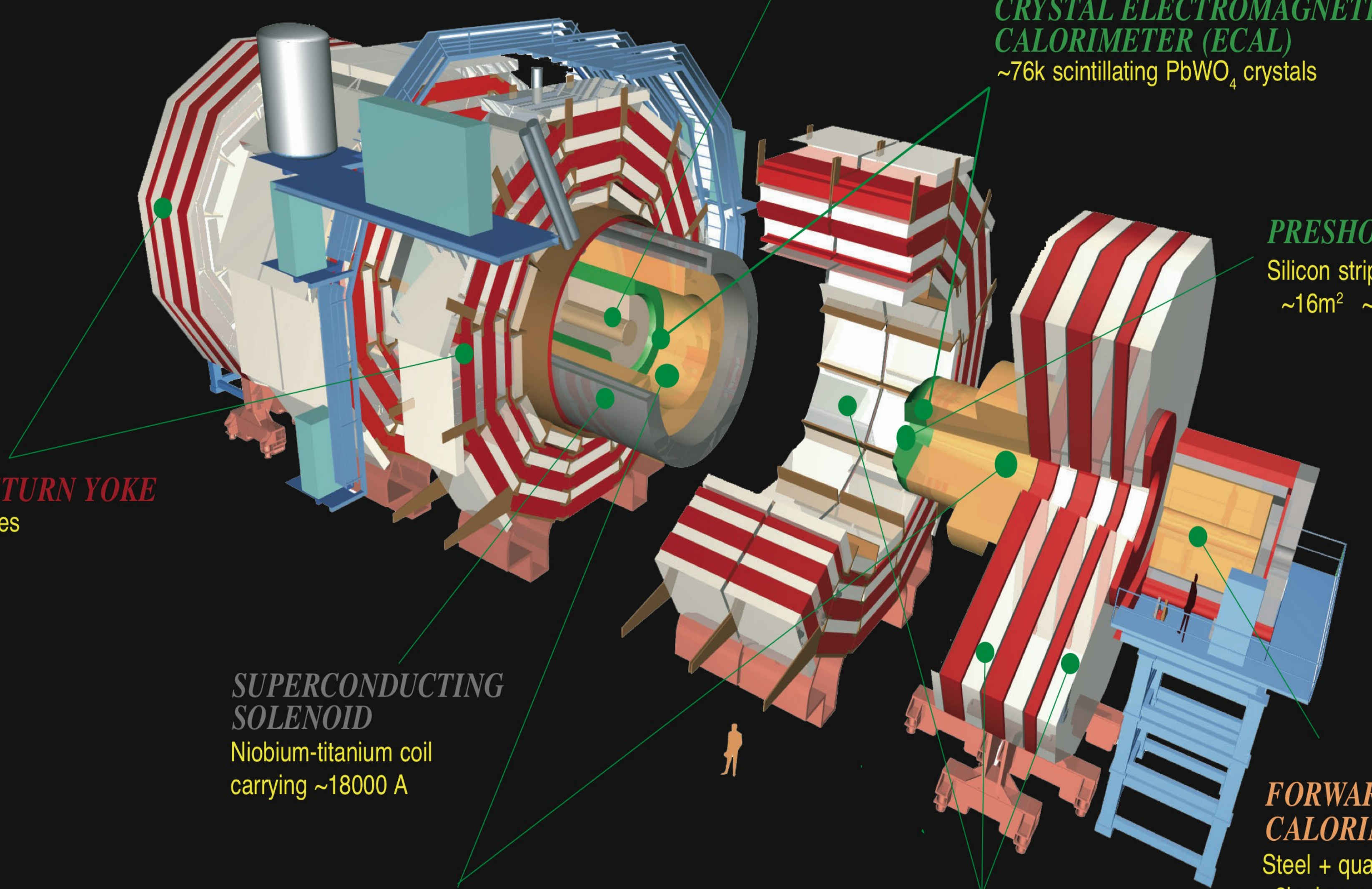
- Introduction
- QCD
  - Soft QCD
  - Jet cross sections
  - Quarkonia (J/ψ and Υ) production
- Electroweak: W and Z production
- Top
- Conclusion and Outlook

Motivation

- SM well established except for missing Higgs boson
- New physics expected at TeV scale
- Measurement and understanding of SM processes important for:
  - Commissioning and calibration of detectors
  - Understanding the background for BSM searches; cross sections of SM orders of magnitude larger than typical BSM models, e.g. supersymmetry
  - Indirect BSM searches by deviations using precision measurements



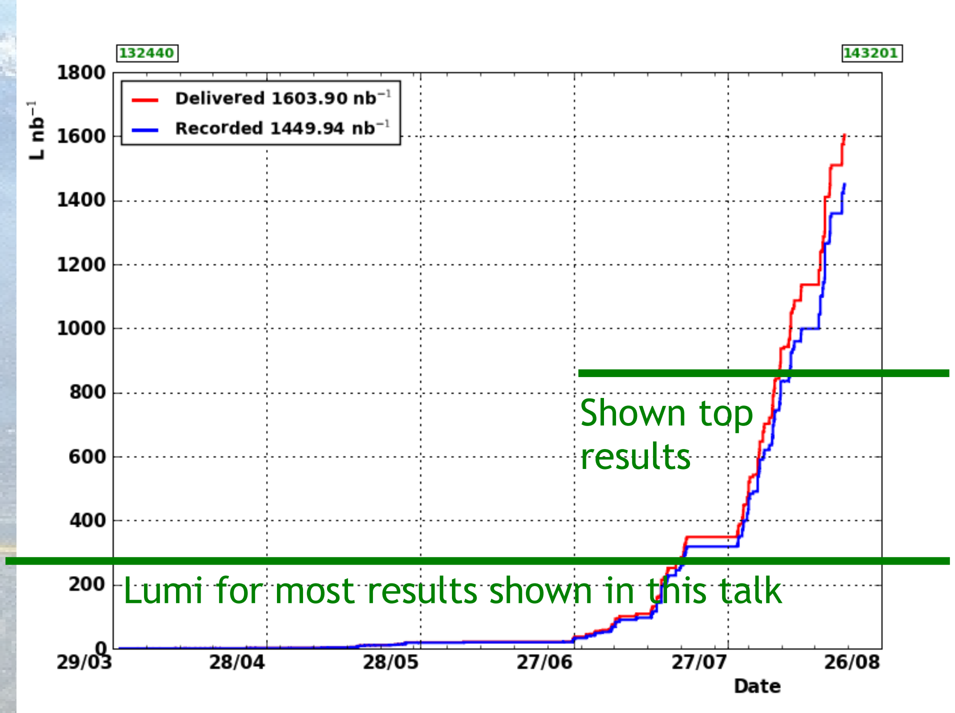
CMS Detector

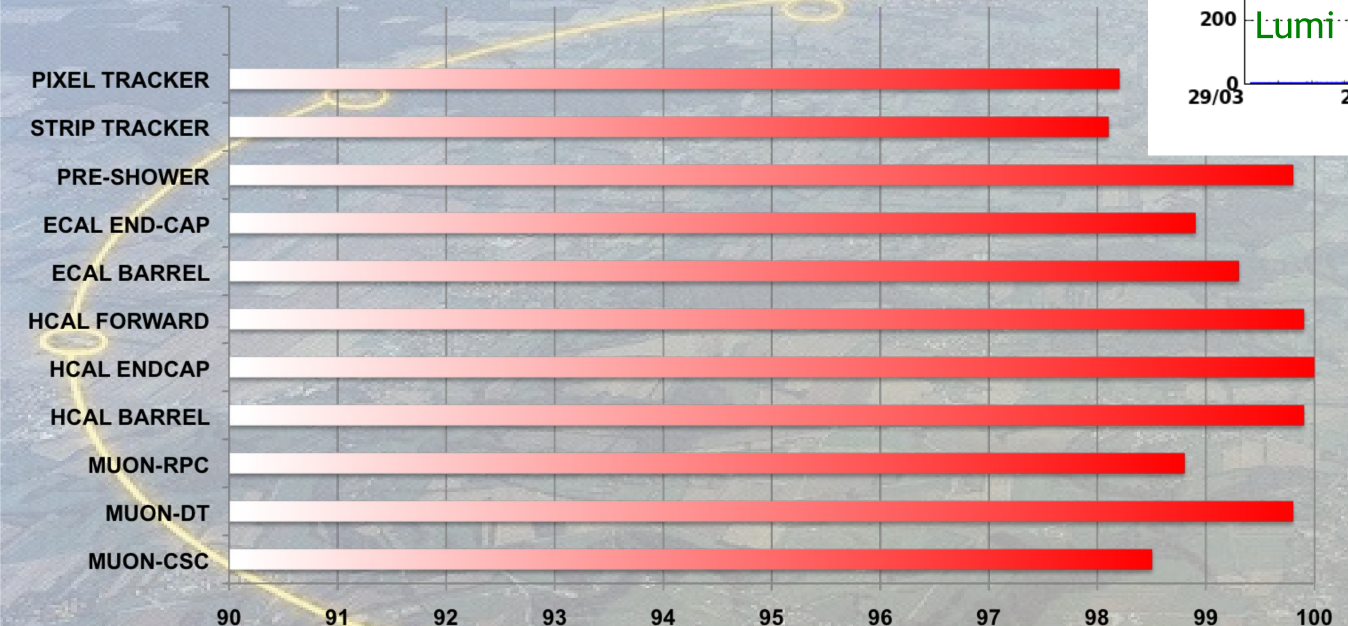


Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

2009: Data taking at √s=900 GeV and 2.36 TeV
Since 30th March: √s=7 TeV

Record Luminosity: 4×10^{30} cm^{-2} s^{-1}
Goal for end 2010: 10^{32} cm^{-2} s^{-1}
Design: 10^{34} cm^{-2} s^{-1}





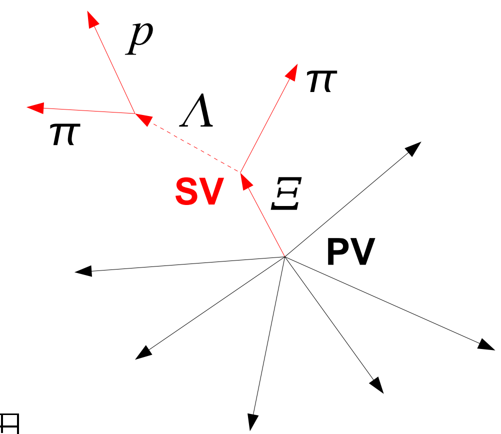
	MUON-CSC	MUON-DT	MUON-RPC	HCAL BARREL	HCAL ENDCAP	HCAL FORWARD	ECAL BARREL	ECAL END-CAP	PRE-SHOWER	STRIP TRACKER	PIXEL TRACKER
Series1	98.5	99.8	98.8	99.9	100	99.9	99.3	98.9	99.8	98.1	98.2

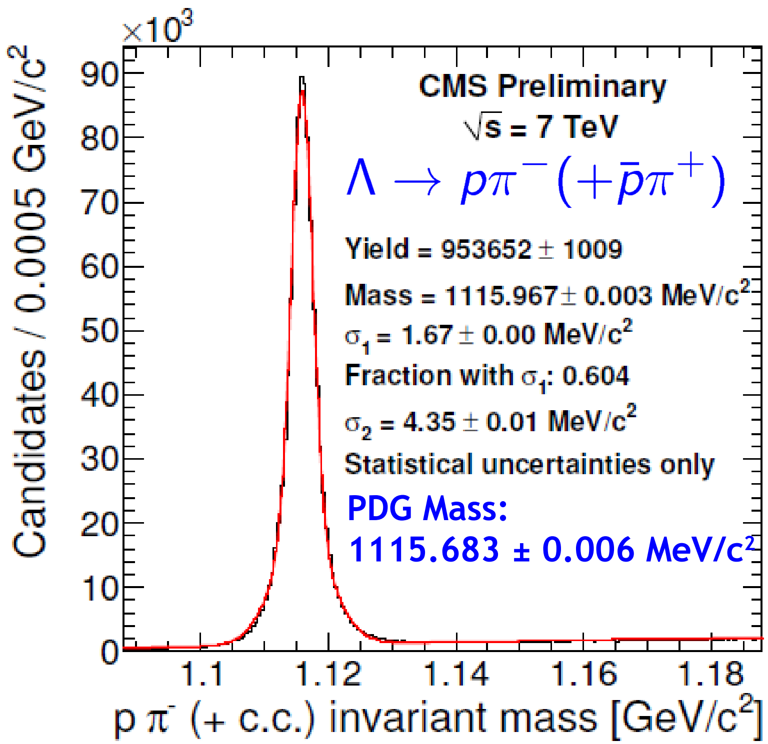
All subdetector components operation at the level >98%

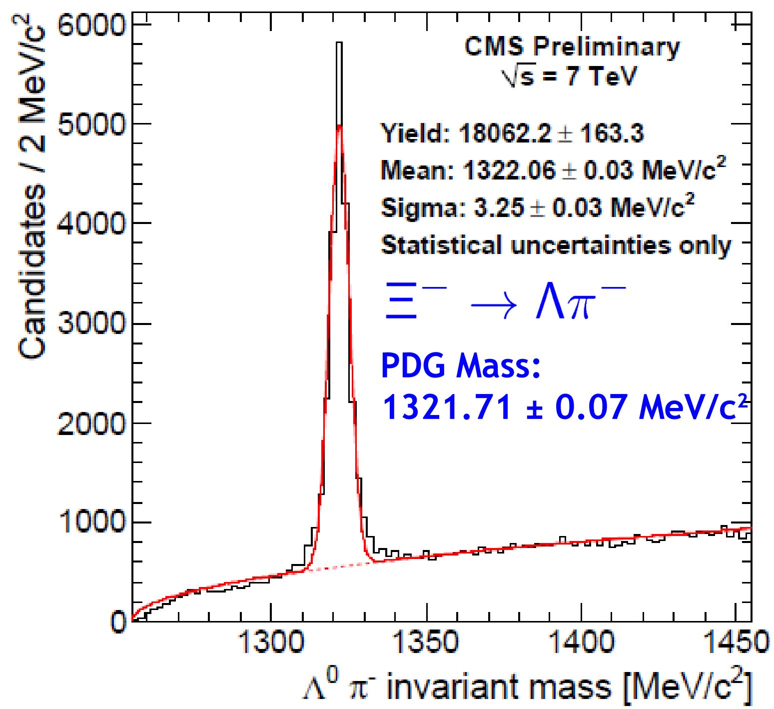
Detector Performance - Example: Tracker

Measurement of strange particle mass resonances: **CMS PAS QCD-10-007**

- Λ baryon candidate: Two tracks of opposite charge; assign lower p_T to m_π; secondary tracks: $d_{3D}>3\,\sigma$; SV
- Ξ baryon candidate: Λ candidate combined with 3rd negative secondary track; SV of Ξ separated from PV by > 4 σ; points back to PV within 3 σ



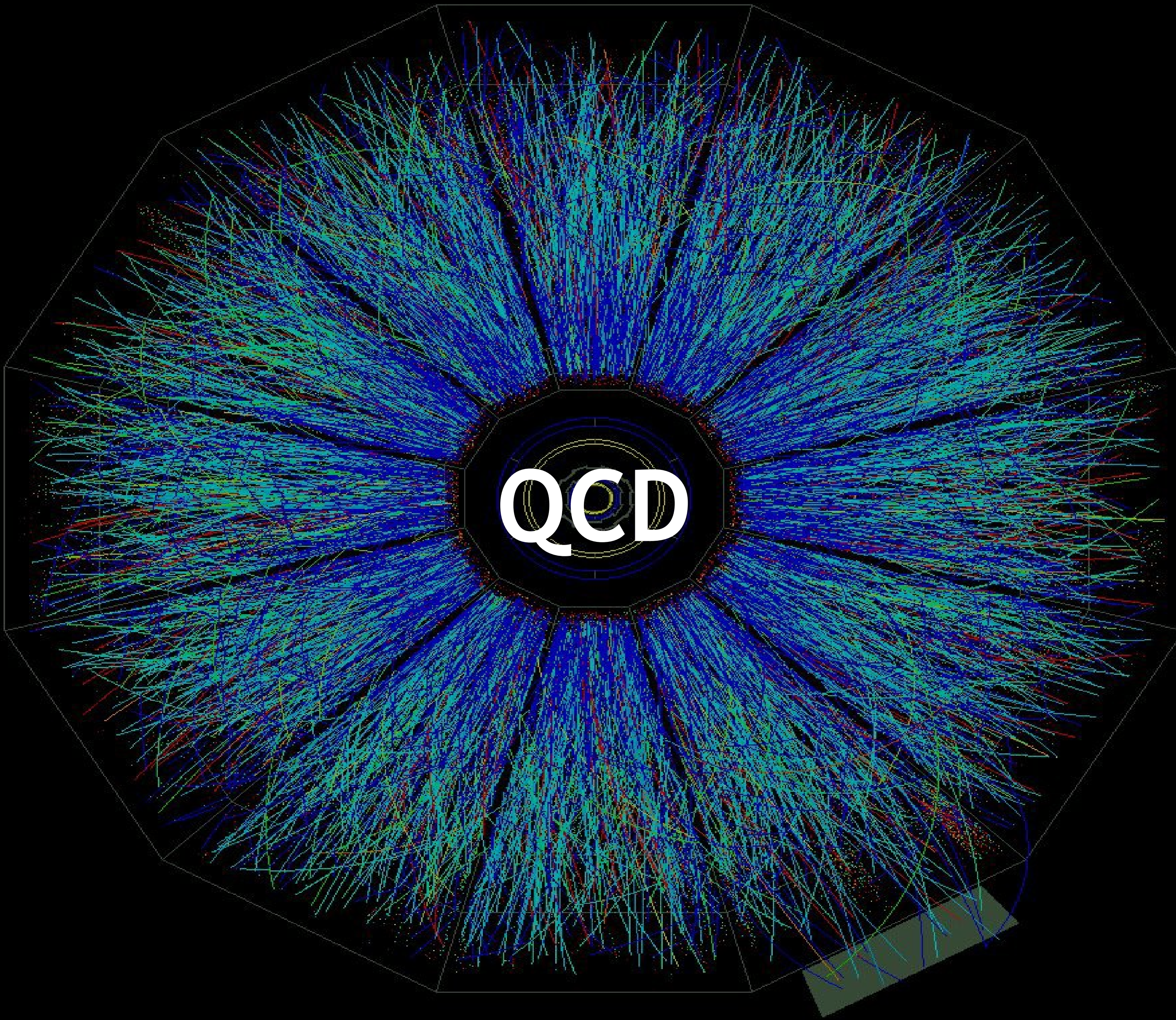




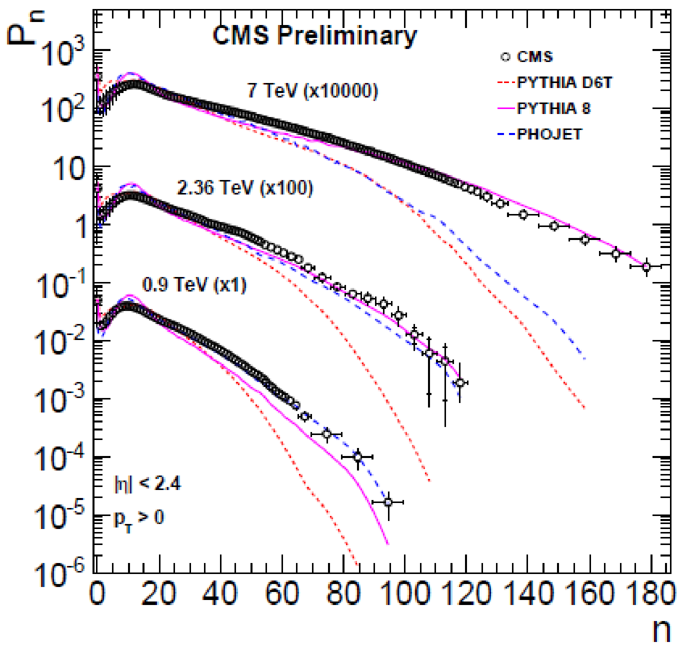
No systematic uncertainties

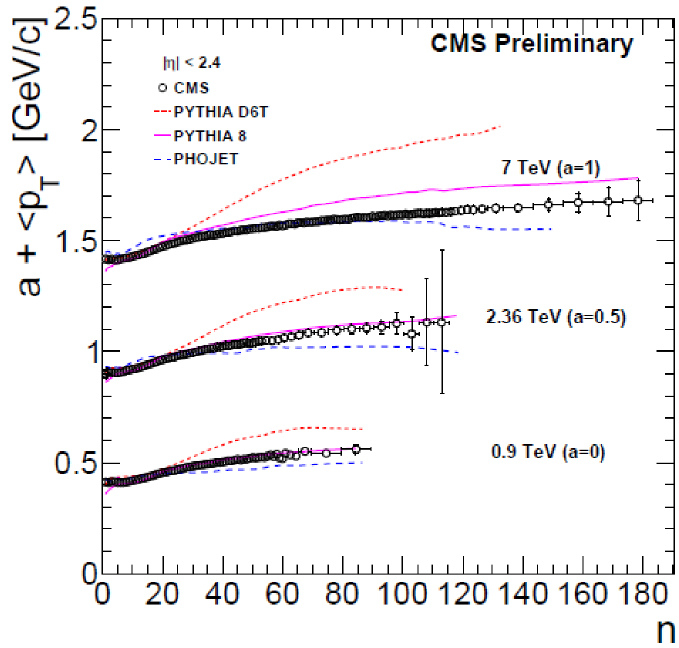
Mass accuracy at the level 10^{-4} → Very well aligned Si-strip and pixel tracker

QCD



Charged Particle Multiplicity



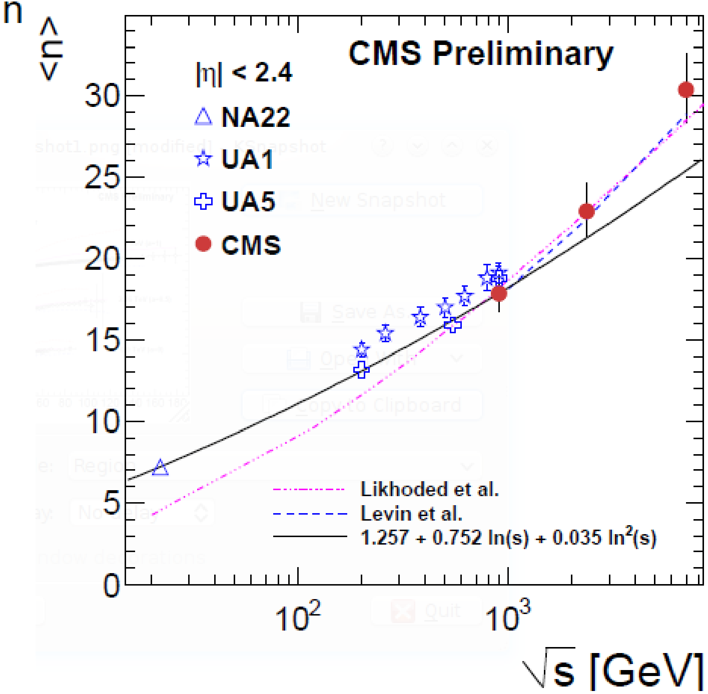


- Rise of particle density in data stronger than in model predictions
- Reduced impact on high p_T physics

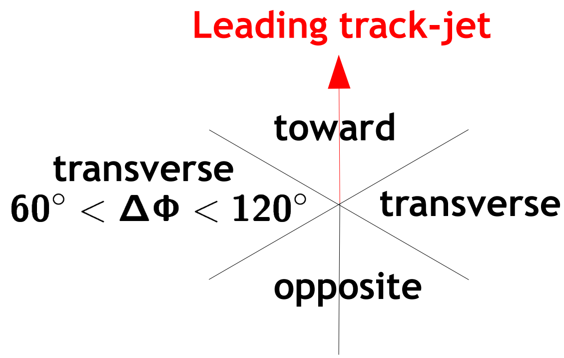
Measurement at 900 GeV, 2.36 TeV and 7 TeV:

- Scaling of particle multiplicity $\langle n \rangle$ and average momentum $\langle p_T \rangle$ tests soft QCD
- All tested models fail to describe n and $\langle p_T \rangle$ distributions at all $\sqrt{s}$ (too few low momentum particles)

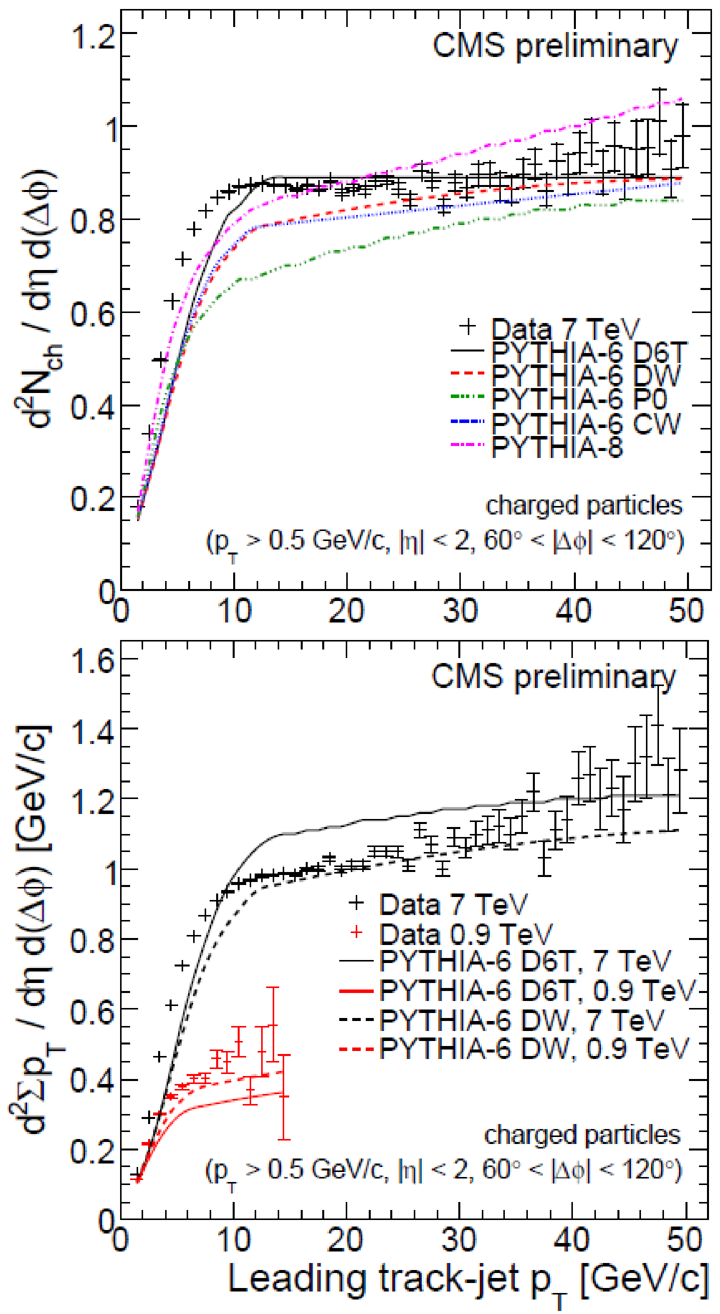
→ **MC generator tuning needed**



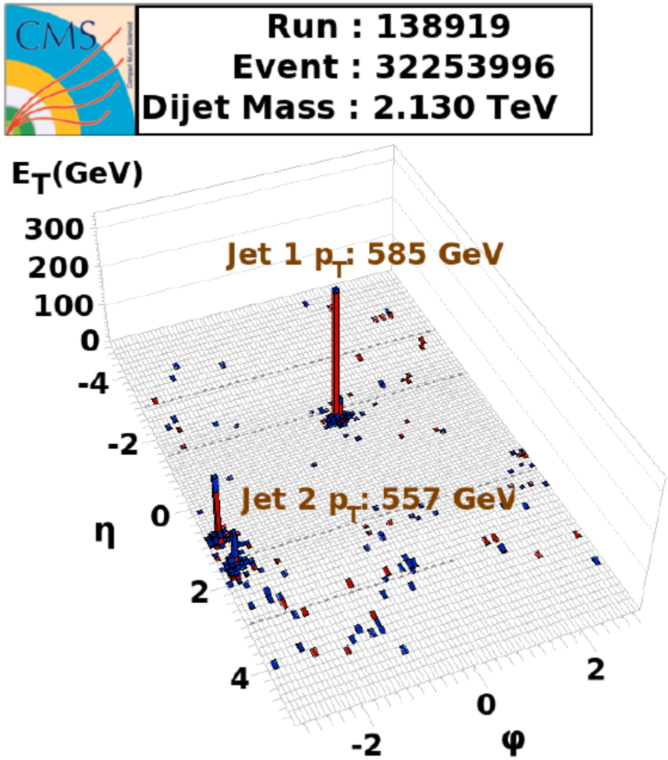
CMS PAS QCD-10-004

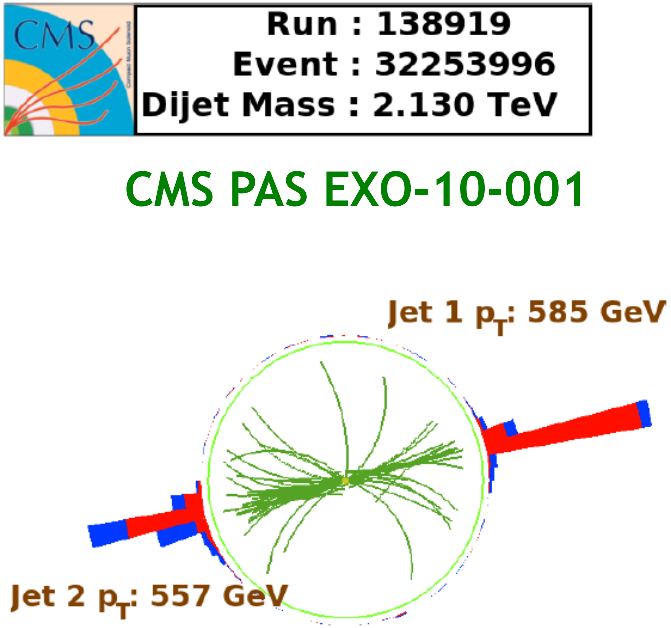


- Underlying event (UE) = multiple particle interaction (MPI) + beam-beam remnants (BBR)
- New 7 TeV data essential for understanding of UE and MPI at high scales (relevant for SM precision measurements and searches)
- UE expected to increase with scale of leading parton (smaller impact angles) and $\sqrt{s}$ (increasing parton densities at given scale)
- Tested models underestimate track mult. and Σp_T at low leading jet p_T ➔ **MC generator tuning needed**

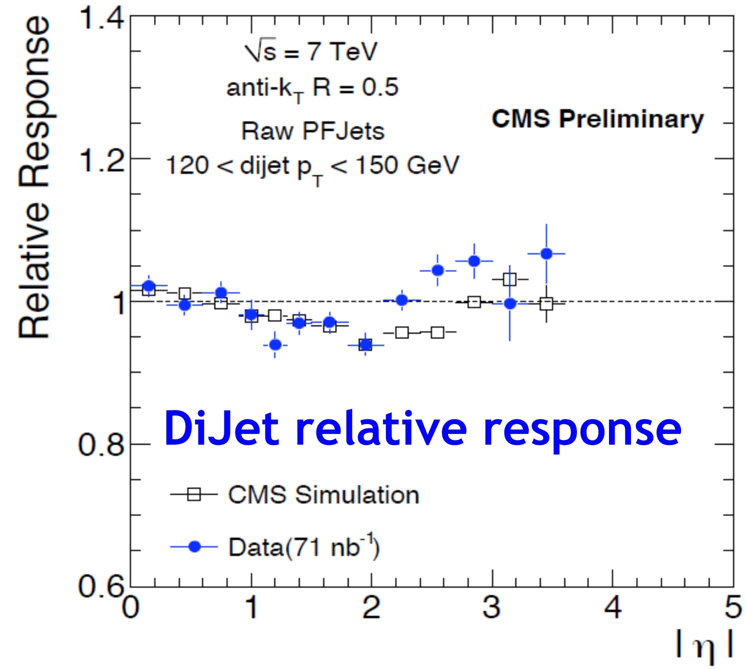


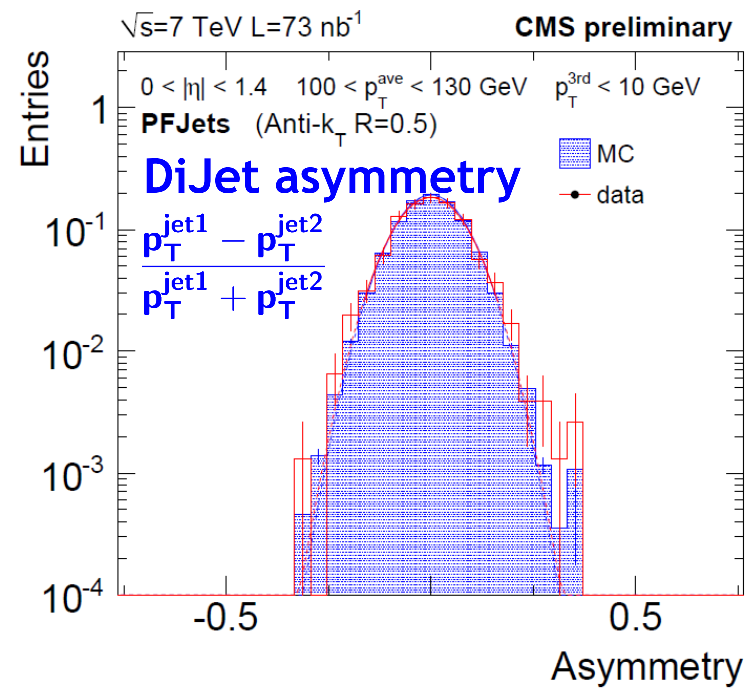
CMS PAS QCD-10-005





CMS PAS EXO-10-001





- **Calorimeter jets:** Uses only calorimeter deposition for reconstruction
- **Jet+Track jets:** Improves calorimeter jets by using accurate measurements of associated tracks
- **Particle Flow jets:** Aims to reconstruct each particle in the events using all detectors, prior to jet clustering

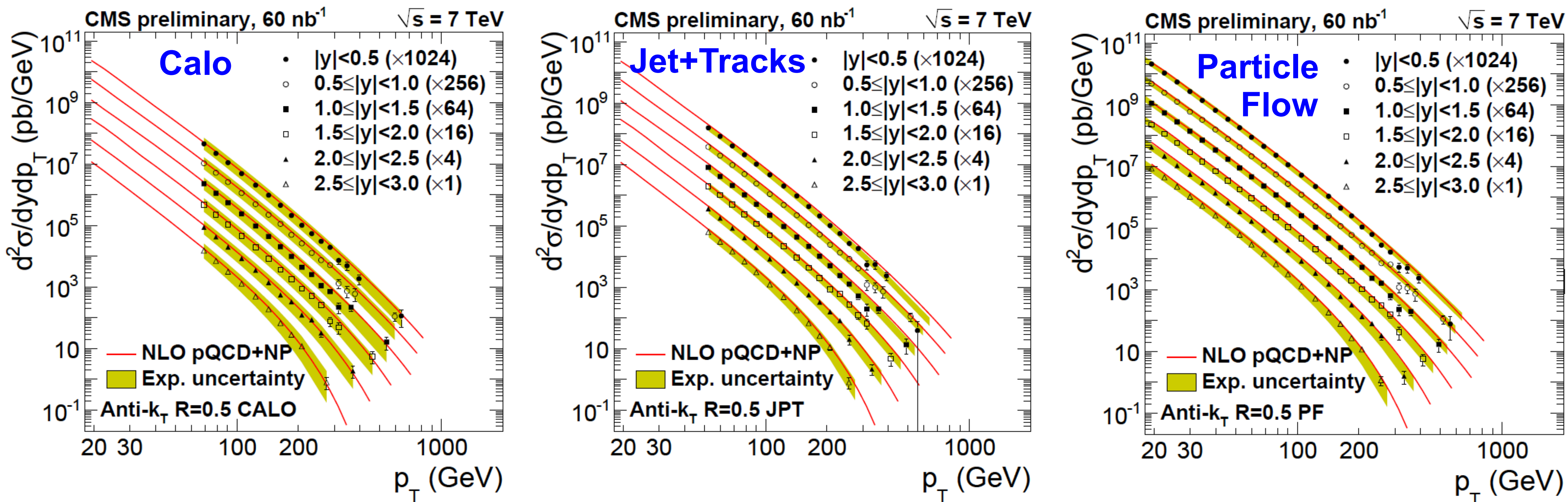
CMS PAS JME-10-003

Inclusive Jet Production

CMS PAS QCD-10-011

- Inclusive jet p_T spectra for all three jet approaches used in CMS (Calorimeter, Jet+Tracks, ParticleFlow)
- Systematic uncertainties dominated by luminosity (~11%) and absolute jet energy scale (JES) uncertainty (~20% to ~80% depending on jet approach and p_T); minor contributions from relative JES and p_T resolution
- For particle flow jets the distributions can be extended down to 18 GeV !!!

All results in good agreement with NLO* theory



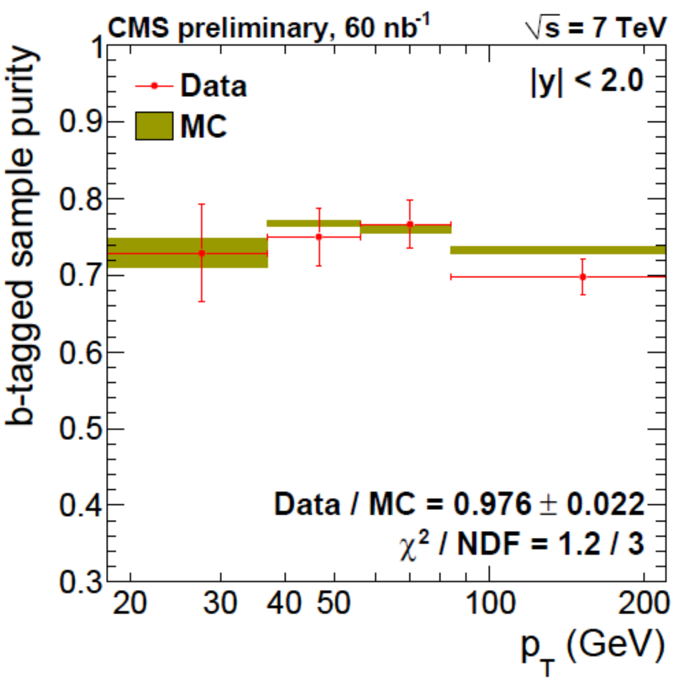
* NLOJET++ within fastNLO framework and CTEQ-6.6 pdfs

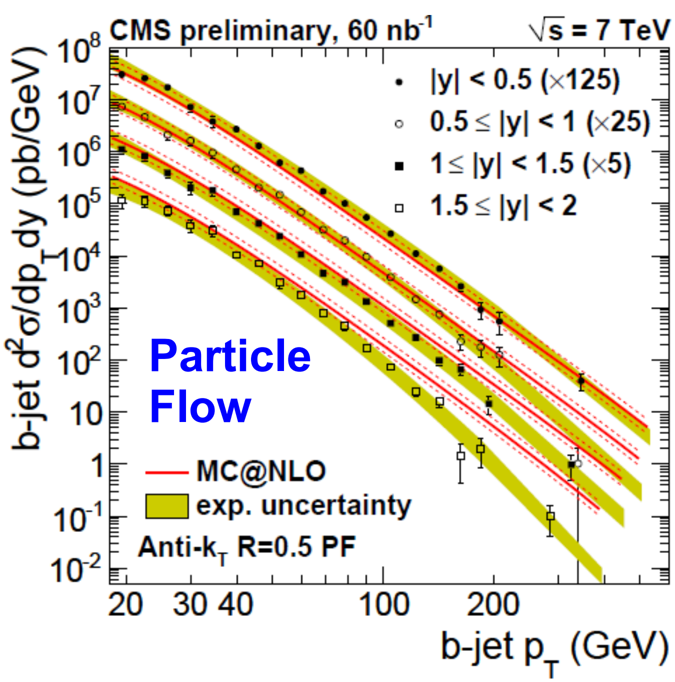
b Jets Production

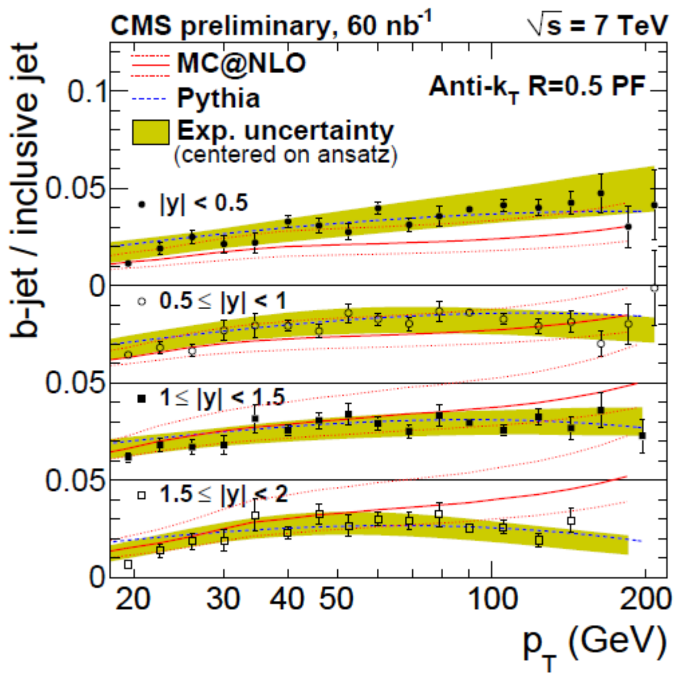
CMS PAS BPH-10-009

- Test of implemented *b*-tagging tools (here: high purity version of the SV Tagger)
  - Purity of *b*-tagged sample extracted from fit to mass of the SV with templates
  - *b*-tagging efficiency from MC; data driven uncertainty (~20%) from semi-muonic *b*-decays using template fit
  - Mistag rate from negative tails of the *b*-tag distributions
- Ratio of *b*-incl. to jet-incl. cross section cancels out common systematic uncertainties

Reasonable agreement with MC@NLO (CTEQ6M) but discrepancies in p_T and y shapes

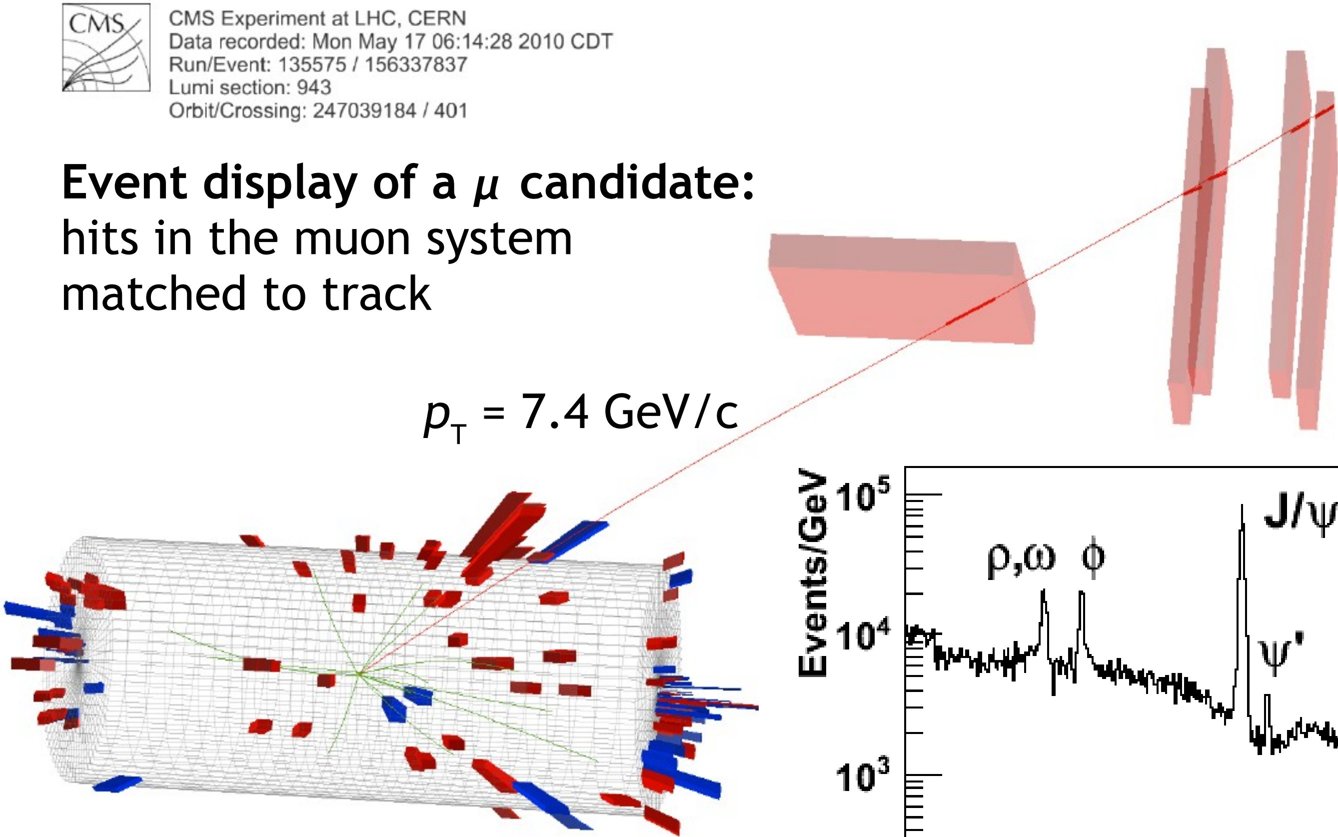




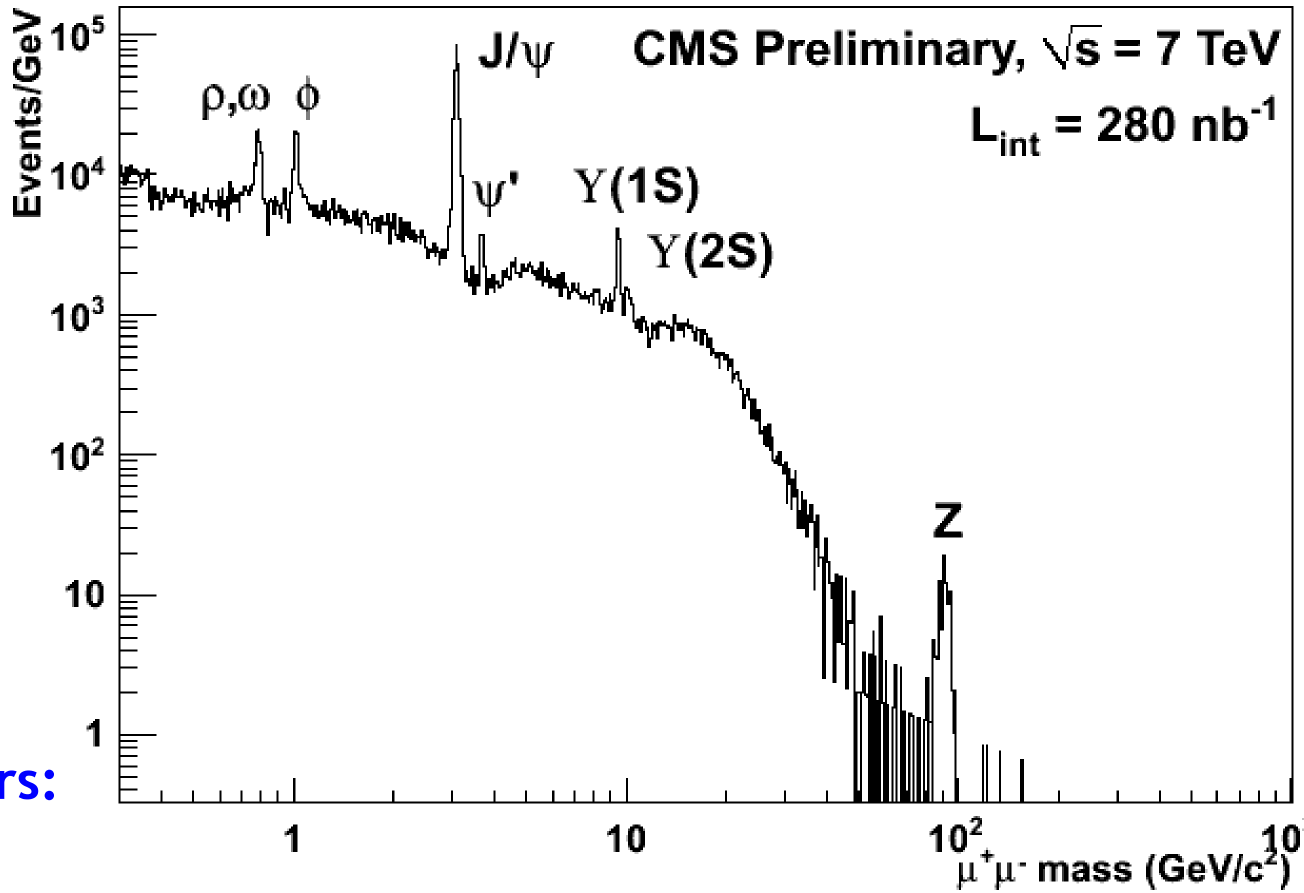


CMS PAS MUO-10-002

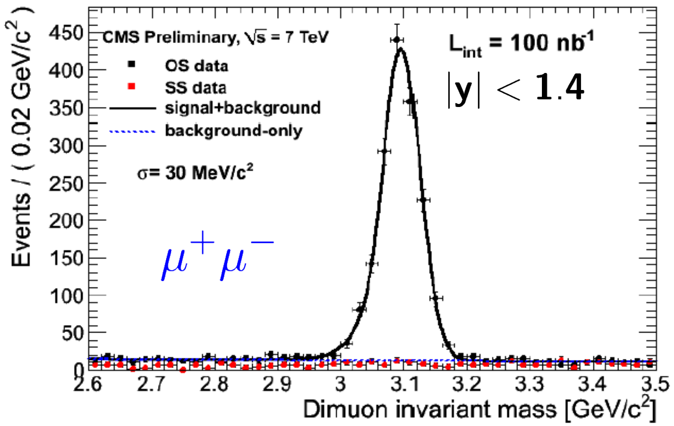
Event display of a μ candidate:
hits in the muon system
matched to track

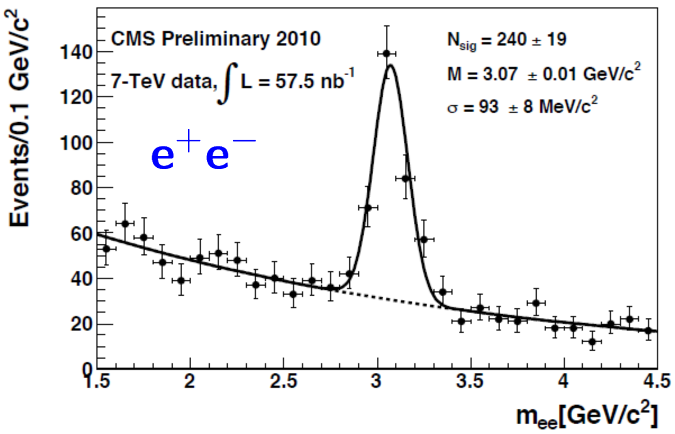


Full invariant mass spectrum of opposite charge muon pairs:

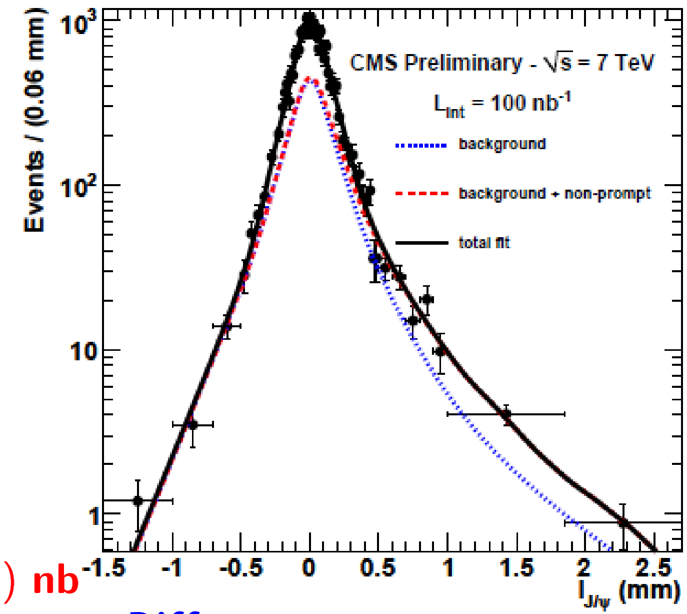


J/ψ Production

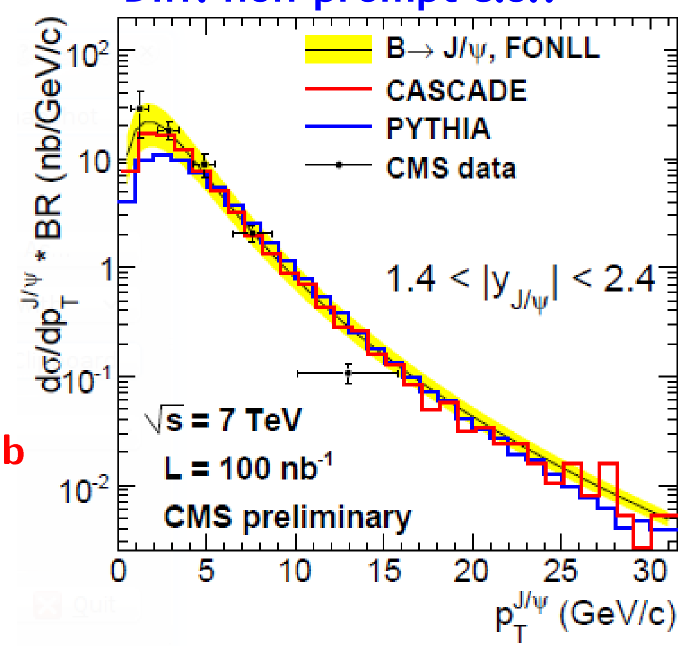




Transverse decay length:



Diff. non-prompt c.s.:



- J/ψ reconstruction in μ and e channel
- Total cross section for inclusive production in μ channel:

$$\mathbf{Br(J/\Psi \to \mu^+\mu^-) \cdot \sigma(pp \to J/\Psi + X) = (289.1 \pm 16.7(stat) \pm 60.1(syst))\ nb}$$

  (systematic uncertainty dominated by statistical precision of the muon efficiency determination from data)

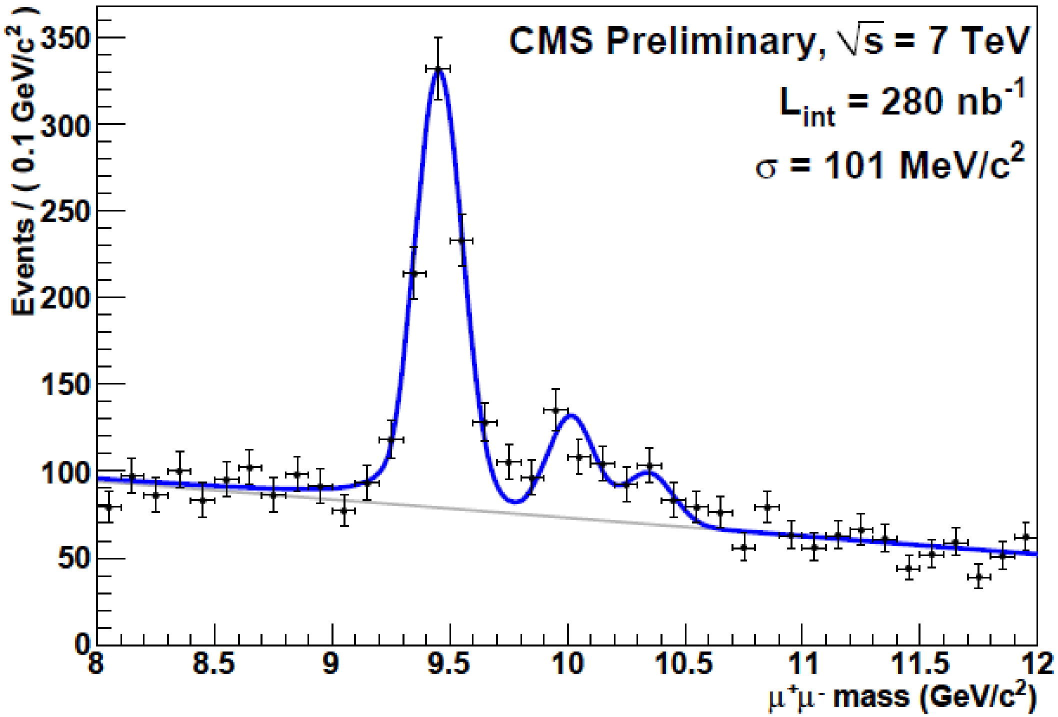
- Unbinned max. likelihood (ML) fit to transverse decay length to **disentangle prompt** (direct production or decay from heavier charmonium states) **and secondary production** (B hadron decays)
- Cross section for non-prompt production in μ channel:

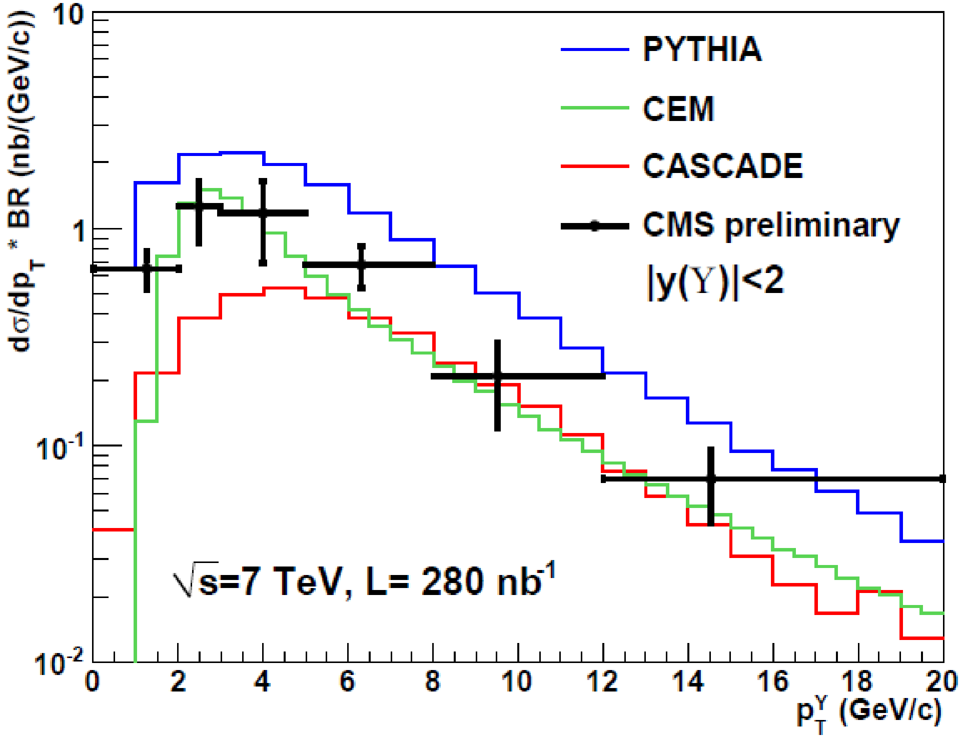
$$\mathbf{Br(J/\Psi \to \mu^+\mu^-) \cdot \sigma(pp \to Y \to J/\Psi) = (56.1 \pm 5.5(stat) \pm 7.2(syst))\ nb}$$

Reasonable agreement with prediction

CMS PAS QCD-10-002

Υ Production





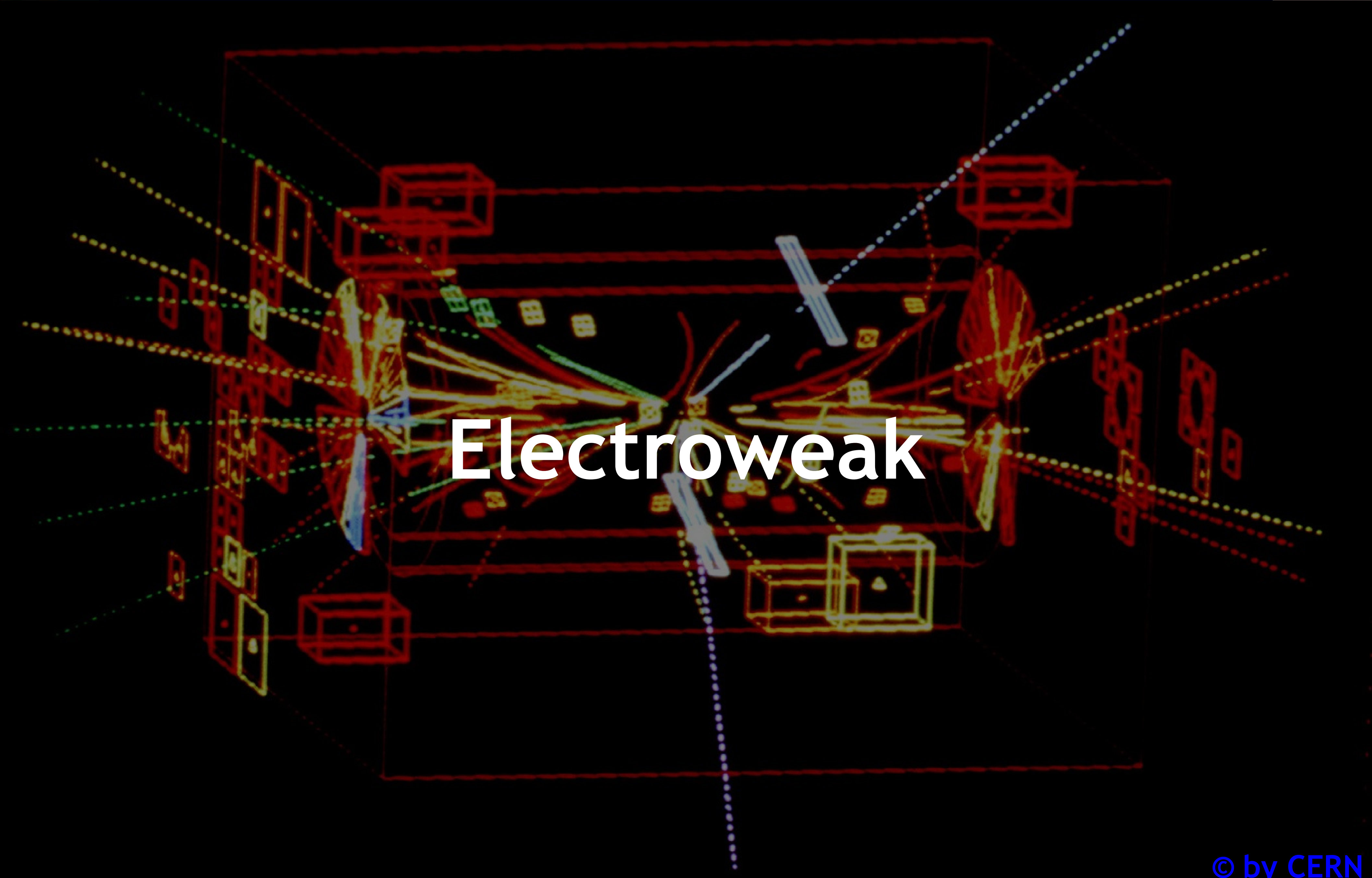
- Υ(1S) resonance identified; Υ(2S) and Υ(3S) will be resolved with more statistics (already: di-muon mass resolution σ=67 MeV/c^2 for $|\eta_\mu|$<1.0)
- Total cross section ($y_{\Upsilon(1S)}$<2.0):

  $$\mathbf{Br(\Upsilon(1S) \rightarrow \mu^+\mu^-) \cdot \sigma(pp \rightarrow \Upsilon(1S) + X) = (8.3 \pm 0.5(stat) \pm 1.0(syst) \pm 0.9(lumi))\ nb}$$

- Differential cross section measured and compared with theoretical predictions

CMS PAS QCD-10-003

Electroweak



© by CERN

W/Z in μ Channel

CMS PAS EWK-10-002

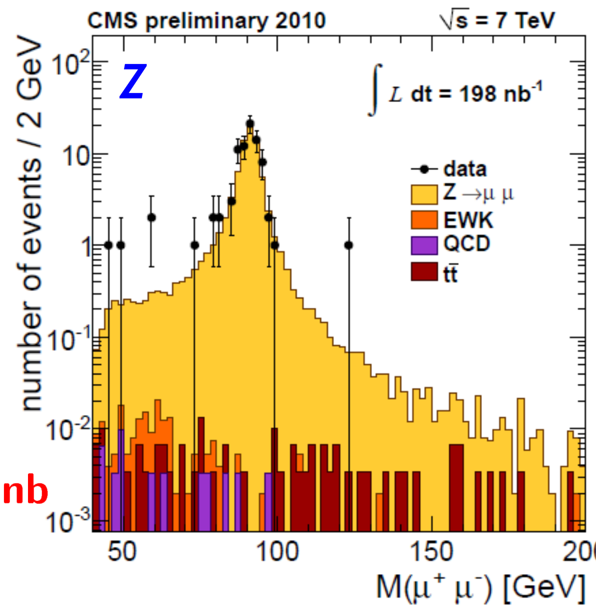
- **Selection:** Trigger P_T>9 GeV/c; leading μ (ID: tracker-μ system match, fit quality, punch through veto): $|\eta|$<2.1; P_T>20GeV/c; rel. combined isolation (tracker+ECAL+HCAL)< 0.15
  ***W*:** Drell-Yan rejection (veto on 2nd μ with P_T>10GeV/c)
  ***Z*:** looser ID and isolation (tracker only) for 2nd μ
- ***W*:** Binned ML fit to M_T with templates from MC (EWK) and data (QCD: inverted isolation cut)

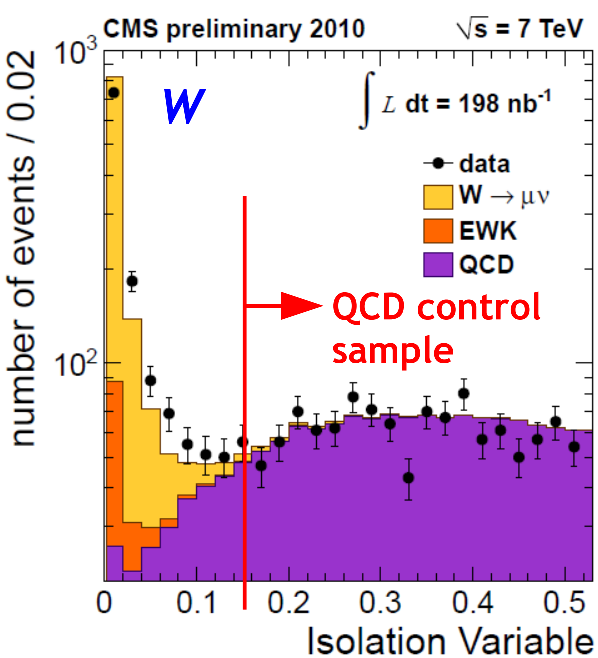
$$M_T^2 = 2\left(E_T^{\mu} \not{E}_T^{PF} - p_T^{\mu} \cdot \not{p}_T^{PF}\right) \leq m_W^2$$

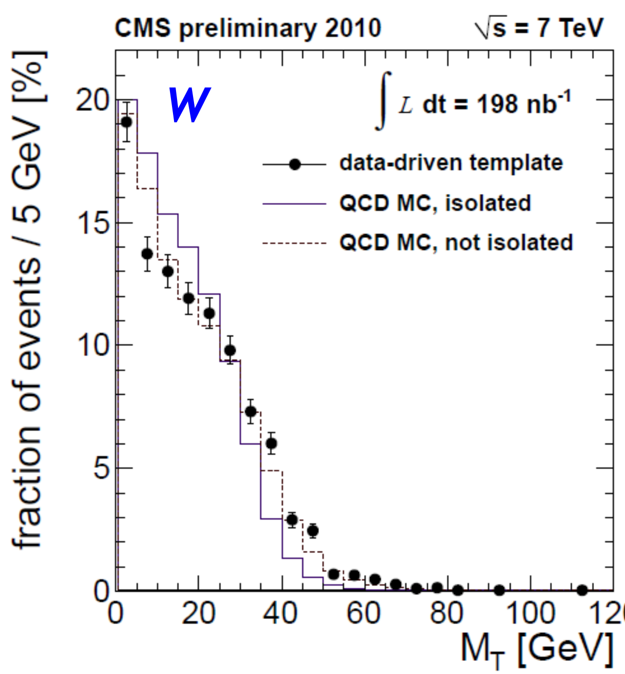
- **Cross sections:**

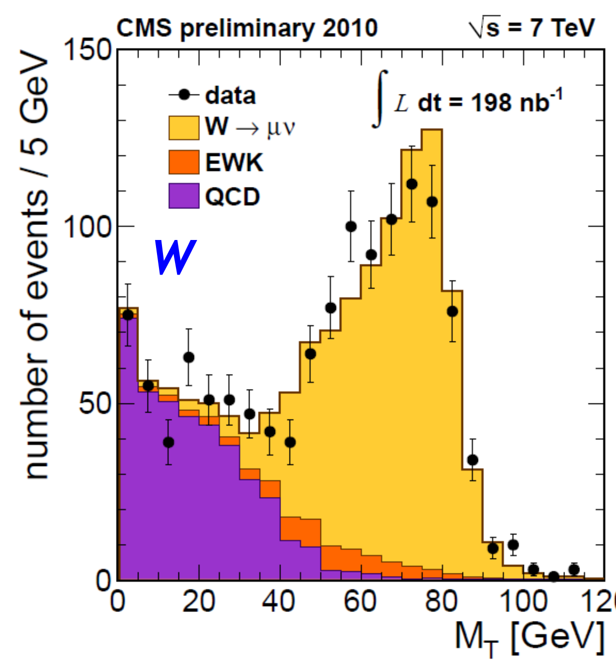
$$\sigma(pp \to Z(\gamma^*) + X \to \mu\mu + X) = (0.881^{+0.104}_{-0.097}(stat)^{+0.042}_{-0.034}(syst) \pm 0.097(lumi))\ nb$$

$$\sigma(pp \to W + X \to \mu\nu + X) = (9.14 \pm 0.33(stat) \pm 0.58(syst) \pm 1.0(lumi))\ nb$$









W/Z in e Channel

- **Selection:** Trigger $P_T(e)$>15 GeV/c; leading *e* (ID: tracker-ECAL match, EM fraction, shower shape, conversion veto): $|\eta|<2.5$; P_T>20GeV/c; relative combined isolation (tracker+ECAL+HCAL)<0.15; optimized for efficiency (***W*:** 75% and ***Z*:** 90%)
- **Cross sections:**

$$\sigma(\mathbf{pp} \rightarrow \mathbf{Z}(\gamma^*) + \mathbf{X} \rightarrow \mathbf{ee} + \mathbf{X}) = (\mathbf{0.884}^{+0.118}_{-0.108}(\mathbf{stat})^{+0.076}_{-0.059}(\mathbf{syst}) \pm \mathbf{0.097}(\mathbf{lumi}))\ \mathbf{nb}$$

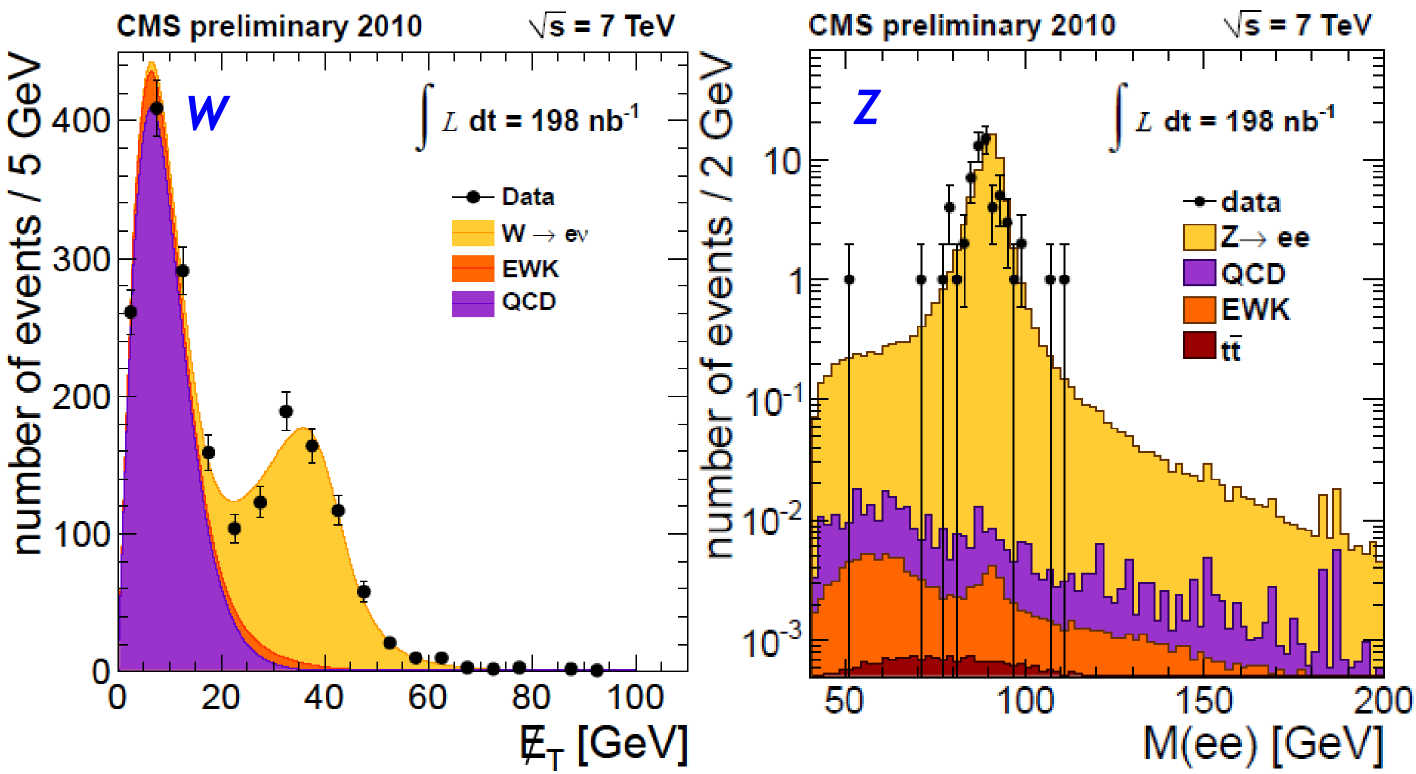
$$\sigma(\mathbf{pp} \rightarrow \mathbf{W} + \mathbf{X} \rightarrow \mathbf{e}\nu + \mathbf{X}) = (\mathbf{9.34} \pm \mathbf{0.36}(\mathbf{stat}) \pm \mathbf{0.70}(\mathbf{syst}) \pm \mathbf{1.03}(\mathbf{lumi}))\ \mathbf{nb}$$

- ***W* signal extraction:** unbinned ML fit to MET distribution; shape of EWK template from MC, QCD shape: modified Rayleigh distribution

$$\mathbf{x} \cdot \exp\left(-\frac{\mathbf{x}^2}{2(\sigma_0 + \sigma_1 \cdot \mathbf{x})^2}\right)$$

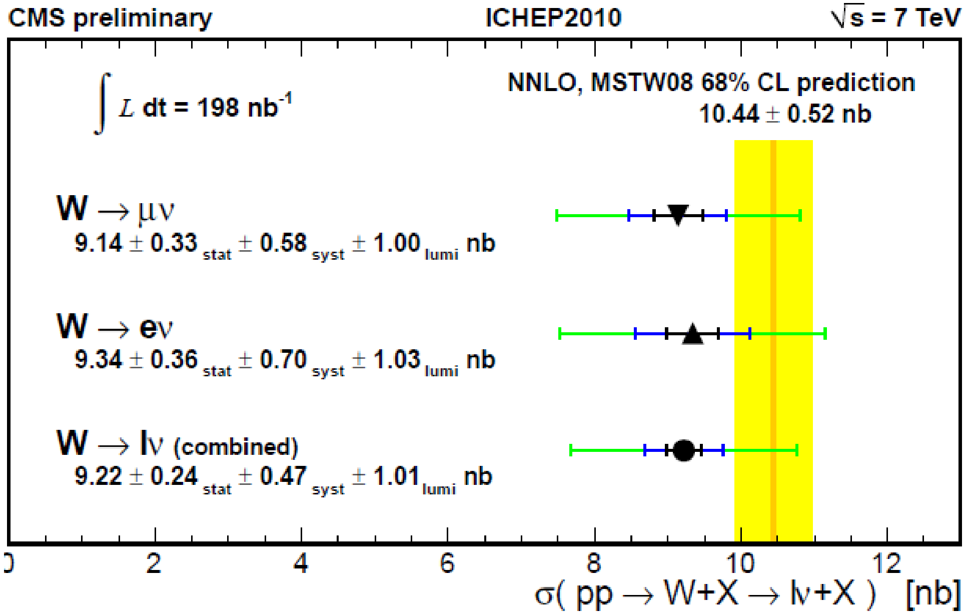
σ_1 fitted from data

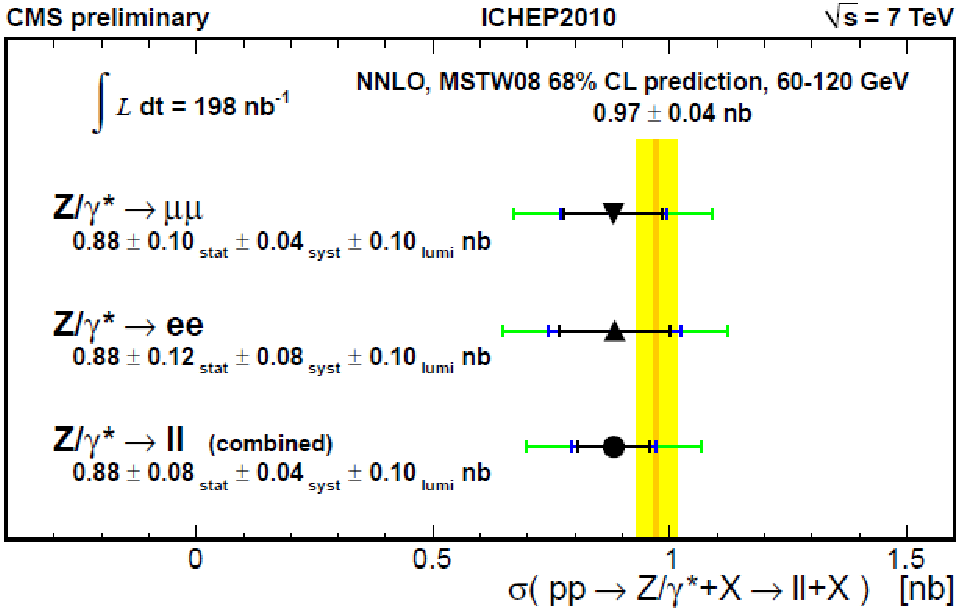
- ***Z* signal extraction:** cut & count



CMS PAS EWK-10-002

W/Z Cross Sections





CMS PAS EWK-10-002

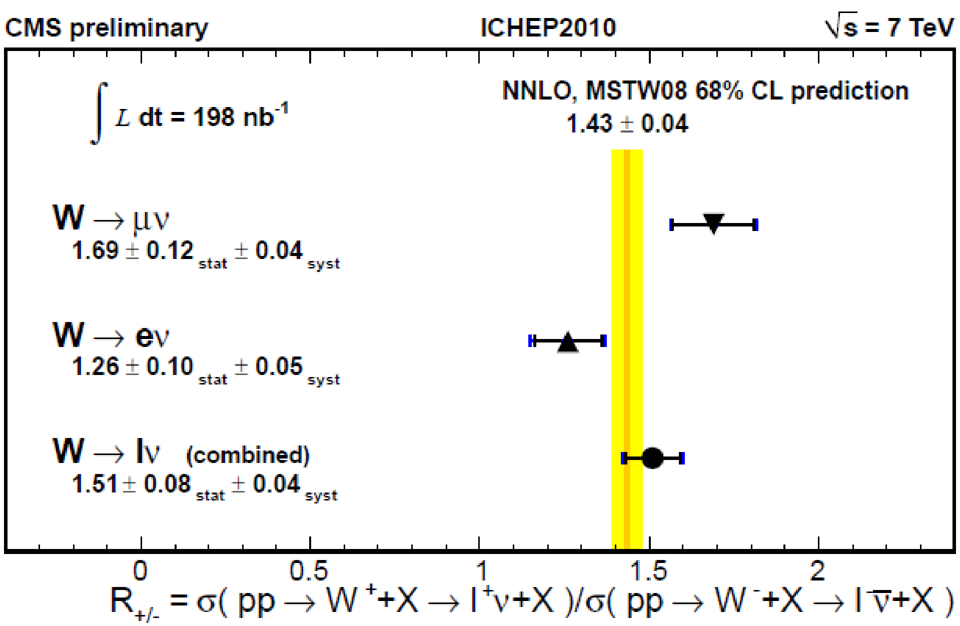
Systematic uncertainties: μ channel

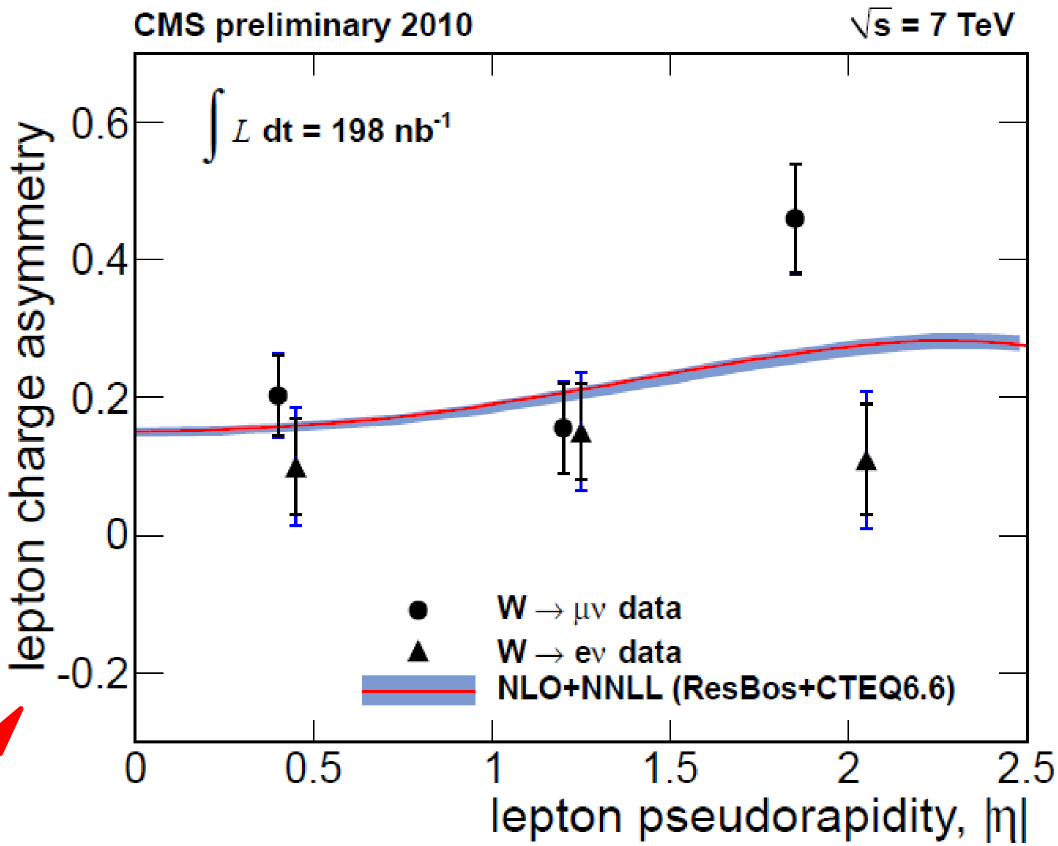
Source	W channel (%)	Z channel (%)
Muon reconstruction/identification	3.0	2.5
Trigger efficiency	3.2	0.7
Isolation efficiency	0.5	1.0
Muon momentum scale/resolution	1.0	0.5
$\not{E}_T$ scale/resolution	1.0	-
Background subtraction	3.5	-
PDF uncertainty in acceptance	2.0	2.0
Other theoretical uncertainties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

Systematic uncertainties: e channel

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

All cross sections for the e and μ final state in agreement with NNLO prediction





$$\mathbf{A}(\eta) = \frac{\mathbf{d}\sigma^{(+)}/\mathbf{d}\eta - \mathbf{d}\sigma^{(-)}/\mathbf{d}\eta}{\mathbf{d}\sigma^{(+)}/\mathbf{d}\eta + \mathbf{d}\sigma^{(-)}/\mathbf{d}\eta}$$

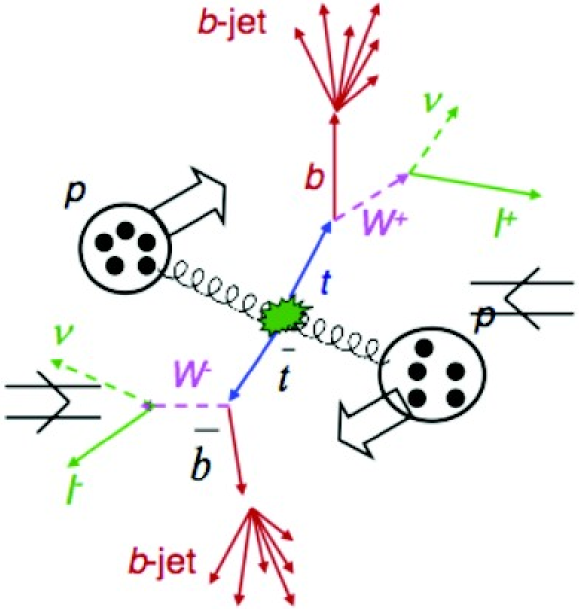
Different parton content in protons (up, down)

- ➔ Charge dependent production cross section
- ➔ Lepton charge asymmetry as function of η:

Constraints on pdfs expected with 10 pb^{-1}

CMS PAS EWK-10-002


Top
from Flickr by Stig Nygaard



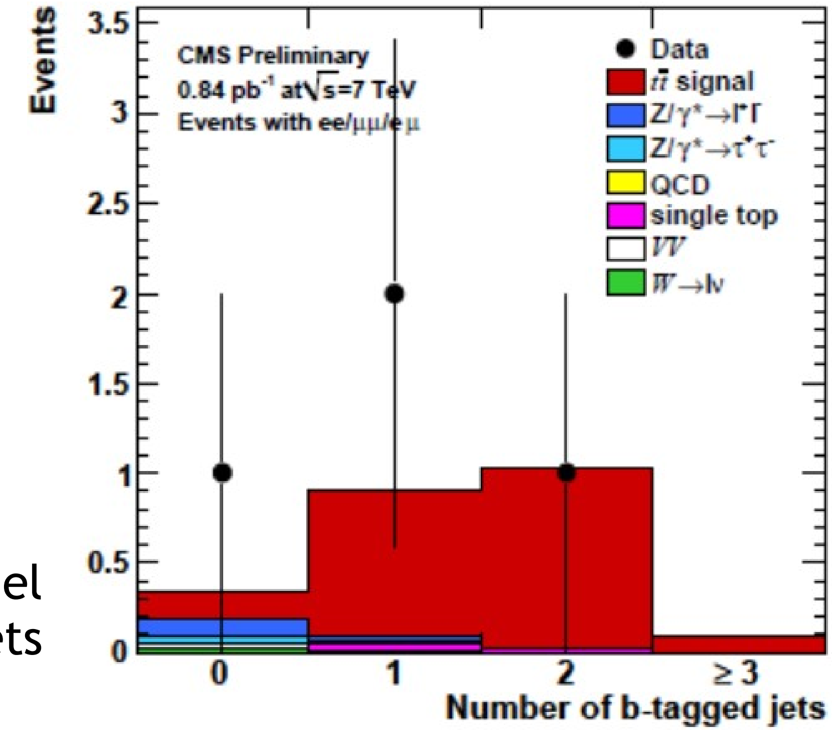
Selection:

- Trigger: $P_T(\mu)$>9 GeV/c, $P_T(e)$>15 GeV/c
- Good primary vertex
- Exactly two prompt isolated leptons P_T>20 GeV/c, $|\eta|$<2.5 (2.4) for $\mu(e)$, rel. combined isolation < 0.15
- Track corrected MET > 30(20) GeV/c for $ee/\mu\mu$ ($e\mu$)
- Z boson veto m_{ll} < 76 GeV/c^2 or m_{ll} > 106 GeV/c^2
- Anti k_T (D=0.5) Jet-Plus-Track jets $|\eta|$<2.4, E_T>30 GeV/c

Very small background (in particular for large MET and additional b-tags)

Recent luminosity update (250 nb^{-1} → **840 nb^{-1}**):

Still small statistics, but increasing number of candidates in all channels!

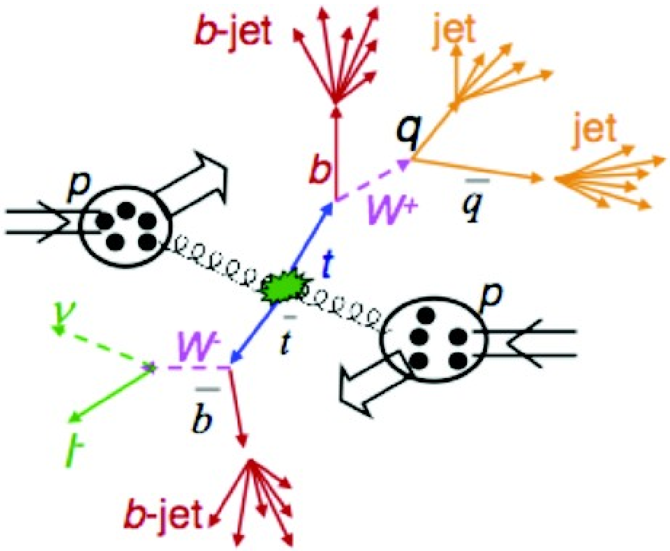


$ee/\mu\mu/e\mu$ channel + 2 jets

CMS PAS TOP-10-004

Selection:

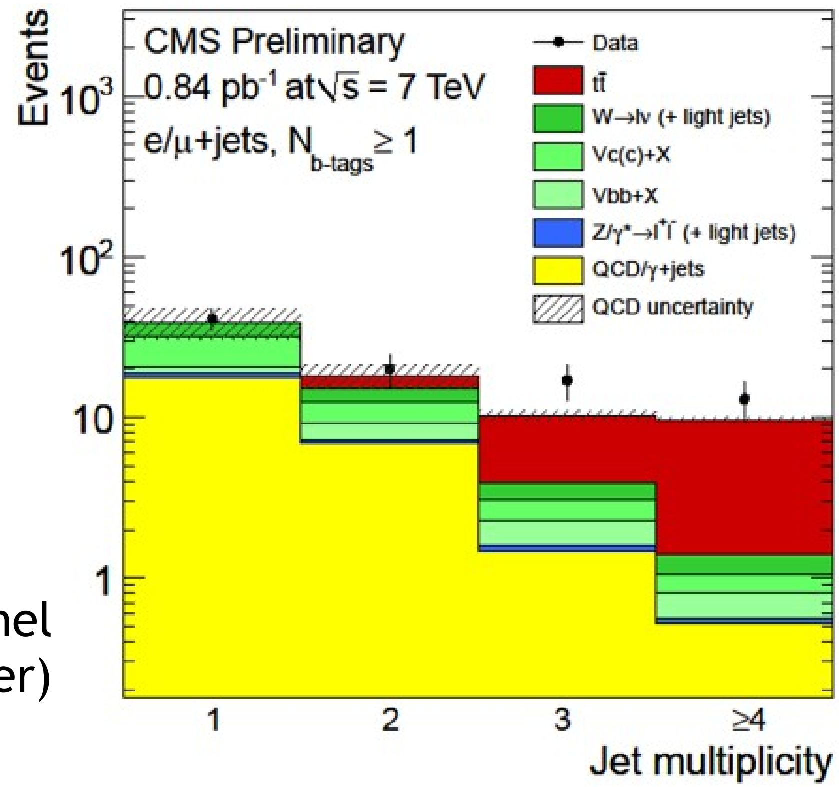
- Trigger: $P_T(\mu)$>9 GeV/c, $P_T(e)$>20 GeV/c
- Good primary vertex
- Exactly one prompt isolated leptons
  - P_T>20 (30) GeV/c, $|\eta|$<2.1 (2.4) for $\mu(e)$
  - rel. combined isolation < 0.05 (0.1) for $\mu(e)$
- Anti k_T (D=0.5) calorimeter jets $|\eta|$<2.4, E_T>30 GeV/c



If additional *b*-tag required:
→ very low background at high jet multiplicity ($N \geqslant 3$)

Recent luminosity update (250 nb^{-1} → **840 nb^{-1}**):

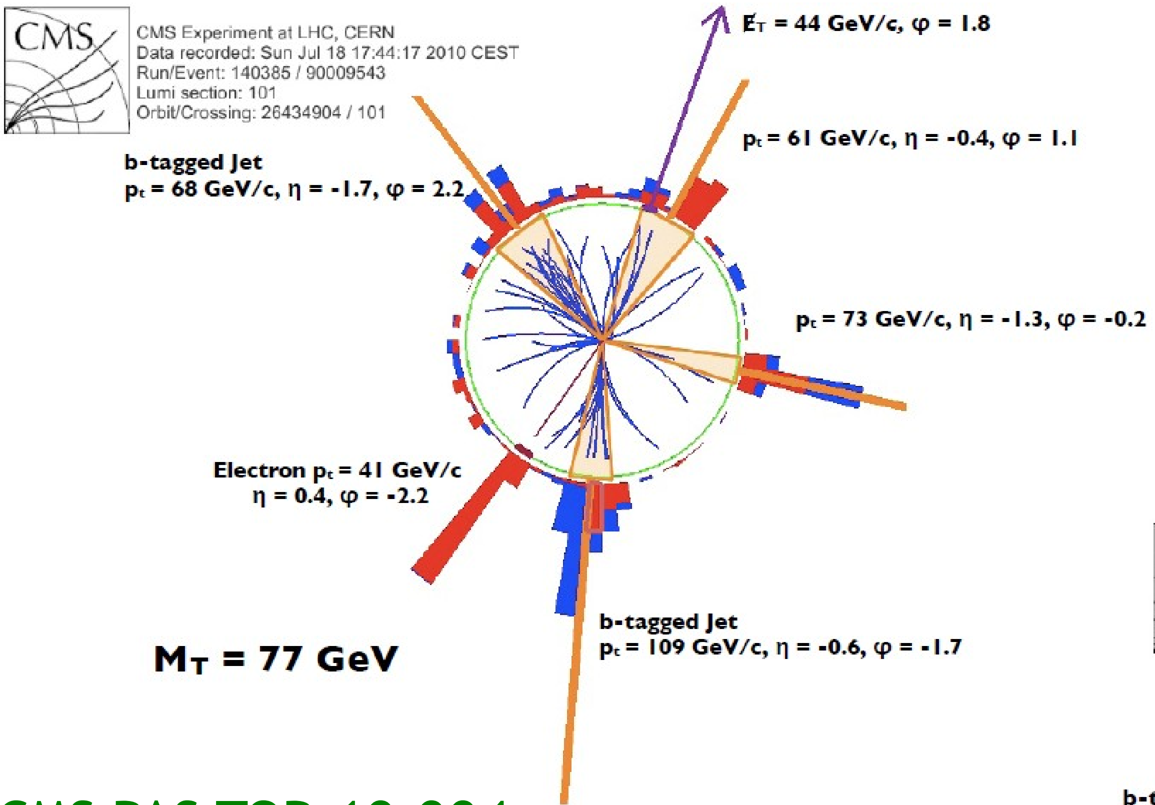
Number of candidates in combined analysis in good agreement with MC prediction!

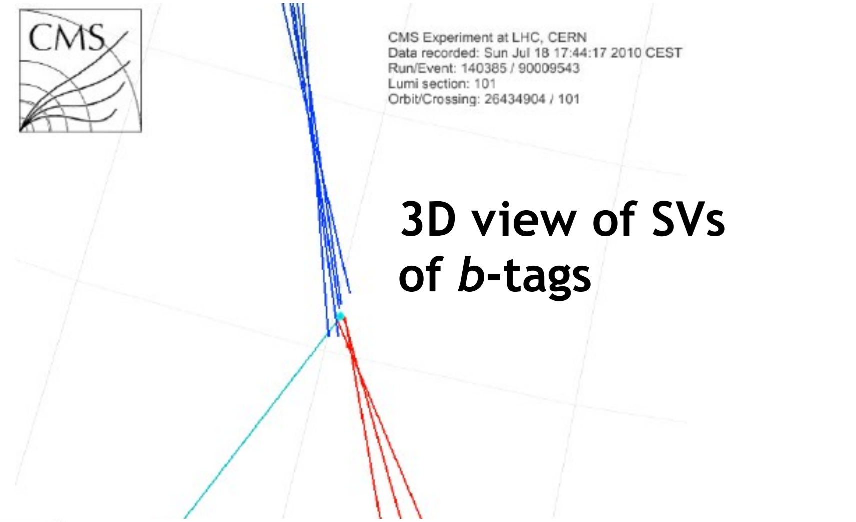


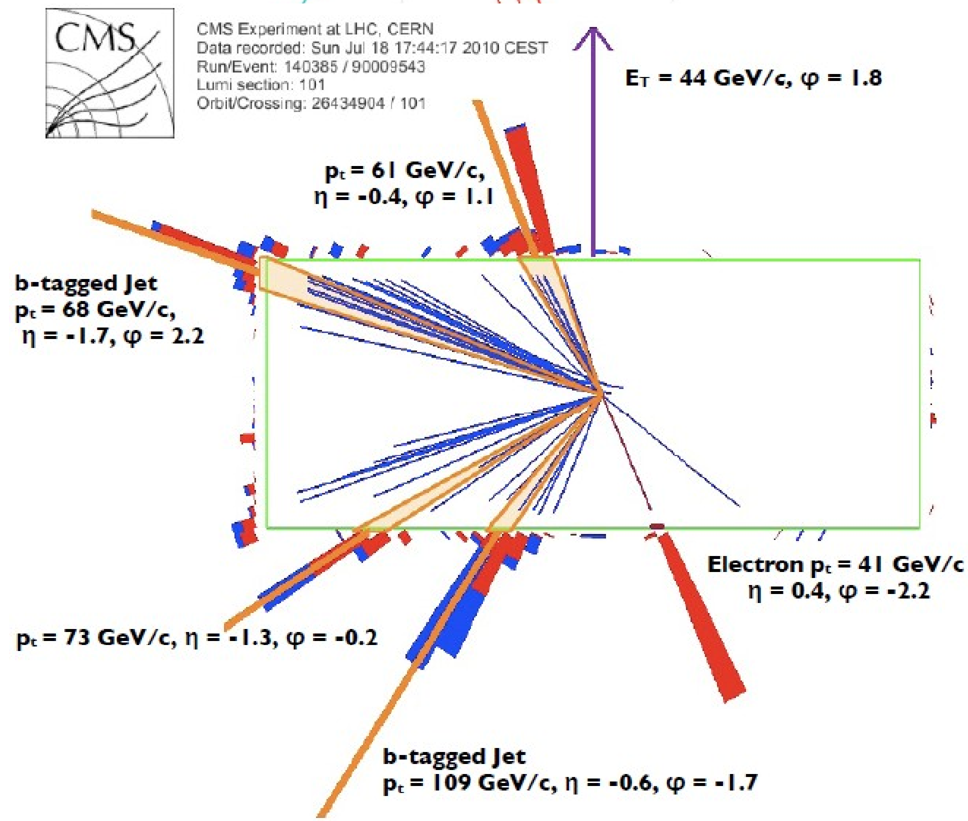
e/μ + jets channel
+ one b-tag (SV tagger)

CMS PAS TOP-10-004

Semi-Leptonic Top Candidate







CMS PAS TOP-10-004

- One electron + four jets (two with good *b*-tag) + MET
- Survives all selection cut
- M_T=77 GeV/c^2 compatible with *W* hypothesis
- Mass of two untagged jets: m_{jj} = 102 GeV/c^2
- Three jet mass: m_{jjb} = 208 / 332 GeV/c^2

Summary and Outlook

- LHC has started and is delivering data at rapidly increasing rate
- CMS is fully operational and all detector components show good performance
- First QCD measurements have been performed: some of them to understand and calibrate the detector, others are new measurements at high energies which test MC generators and pdfs
- Electroweak gauge bosons have been produced and their cross sections have been measured and compared to predictions for different channels
- First top candidates have been reconstructed in various channels
- More data ($\times$ ~10) recorded than used for presented results and much^x more expected in the future
- CMS is prepared for BSM searches (see plenary talk tomorrow by M. Pierini and all the parallel contributions)

All shown results and much more can be found at:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

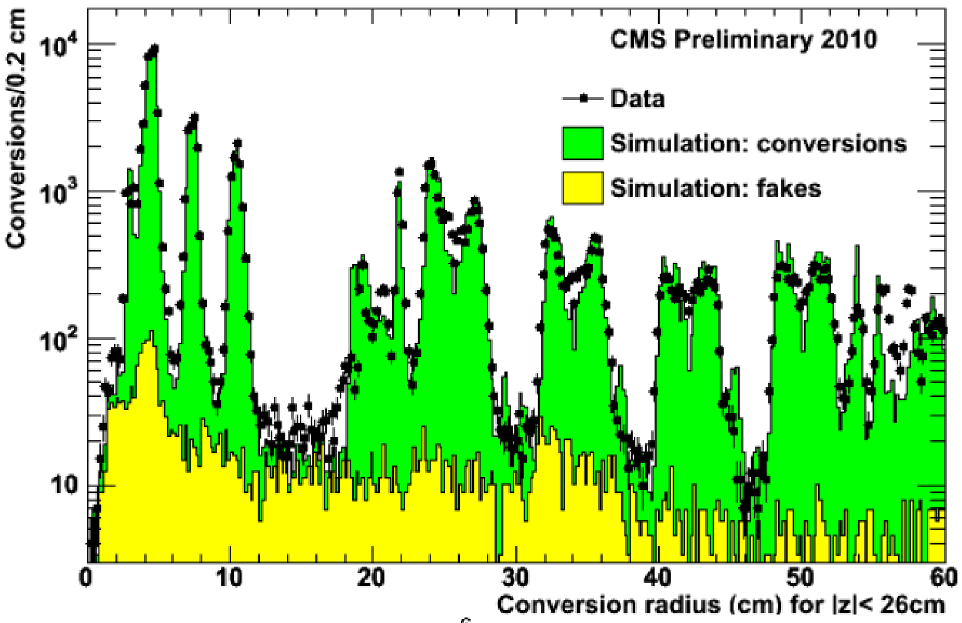
Backup

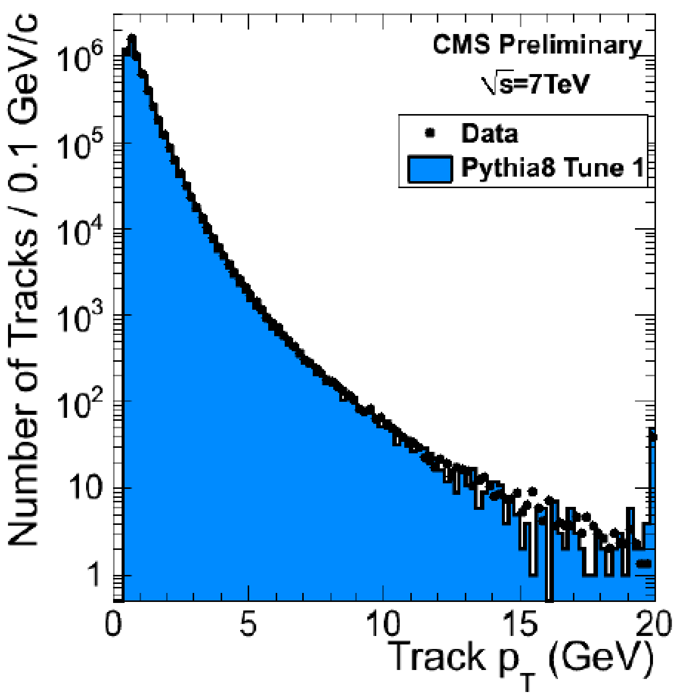
- Material budget from simulation in good agreement with data

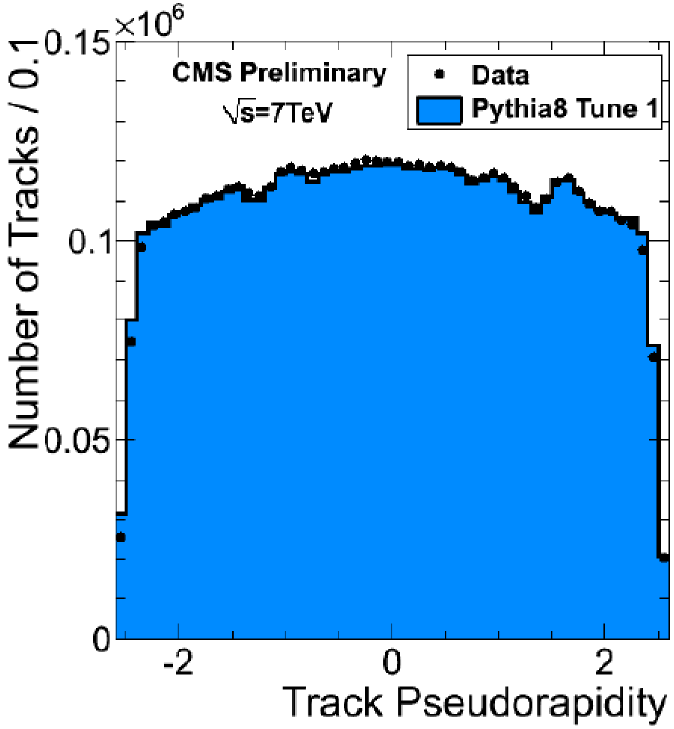
CMS PAS TRK-10-003

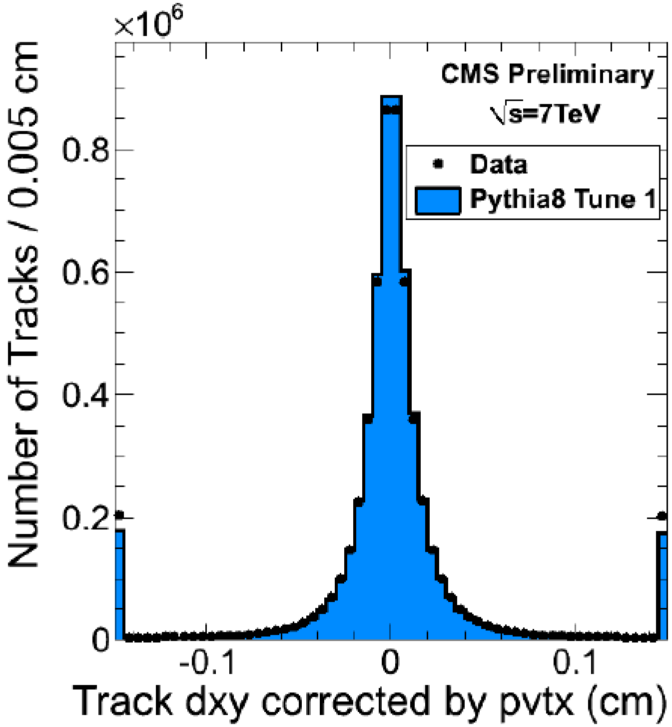
- Good agreement of data with predictions for all studied distributions

CMS PAS TRK-10-005

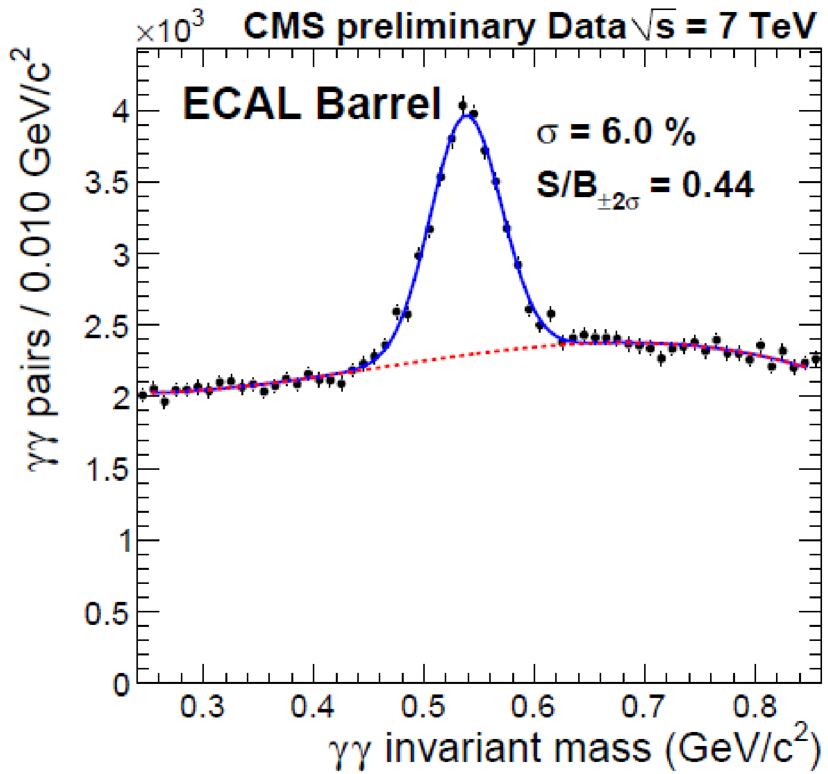


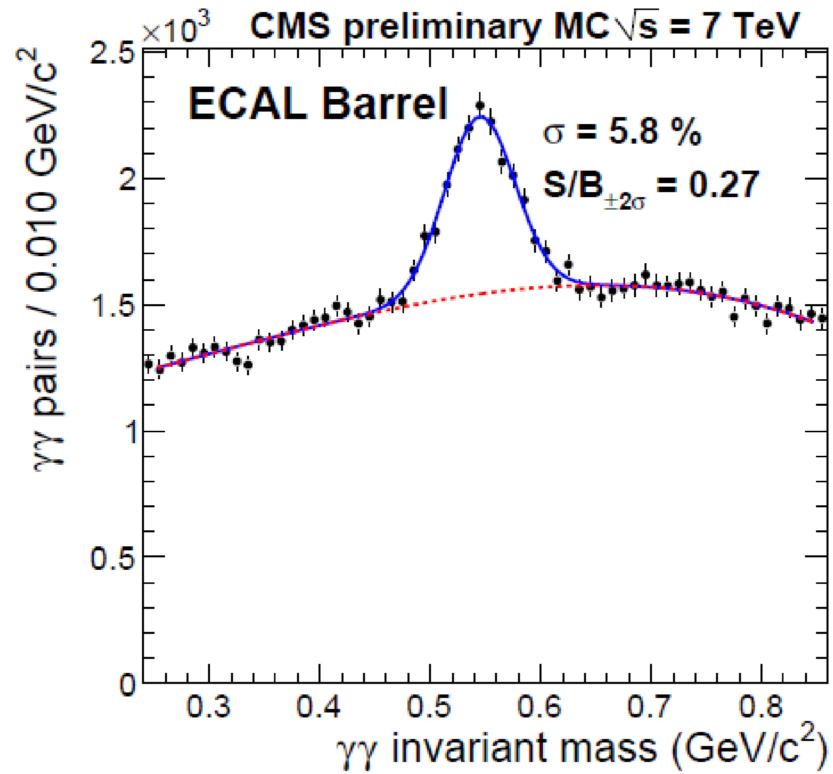






e/γ



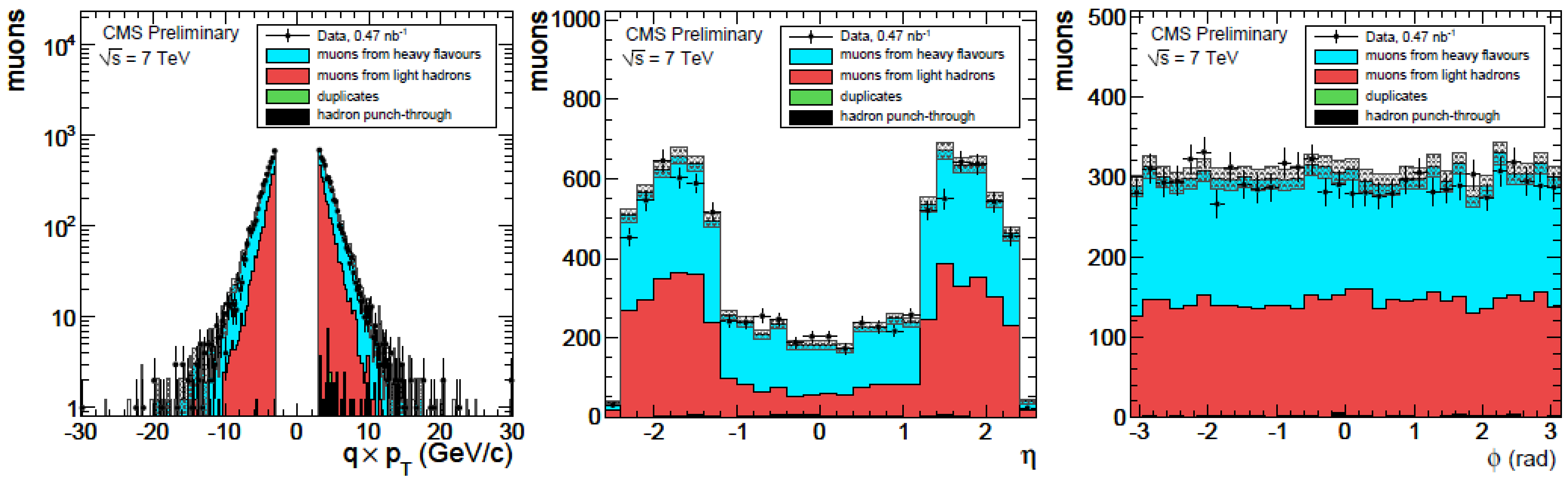


- Using $\pi^0/\eta \rightarrow \gamma\gamma$ to calibrate ECAL
- ECAL response agree with simulation within 1% in the barrel and 3% in the endcap

π^0 peak	Data (MeV/c^2)	MC (MeV/c^2)	Data/MC - 1
EB−	134.53 ± 0.03	135.14 ± 0.02	(-0.45 ± 0.03) %
EB+	133.78 ± 0.03	134.94 ± 0.02	(-0.86 ± 0.03) %
EB	134.16 ± 0.02	135.07 ± 0.02	(-0.68 ± 0.02) %
EE−	138.5 ± 0.3	134.8 ± 0.3	$(+2.8 \pm 0.3)$ %
EE+	137.0 ± 0.3	134.2 ± 0.3	$(+2.1 \pm 0.3)$ %
EE	137.8 ± 0.2	134.5 ± 0.2	$(+2.5 \pm 0.2)$ %
η peak	Data (MeV/c^2)	MC (MeV/c^2)	Data/MC - 1
EB−	539.4 ± 0.9	543.3 ± 0.7	(-0.7 ± 0.2) %
EB+	536.5 ± 1.0	543.7 ± 0.7	(-1.3 ± 0.2) %
EB	537.8 ± 0.6	543.3 ± 0.5	(-1.0 ± 0.1) %

CMS PAS EGM-10-003

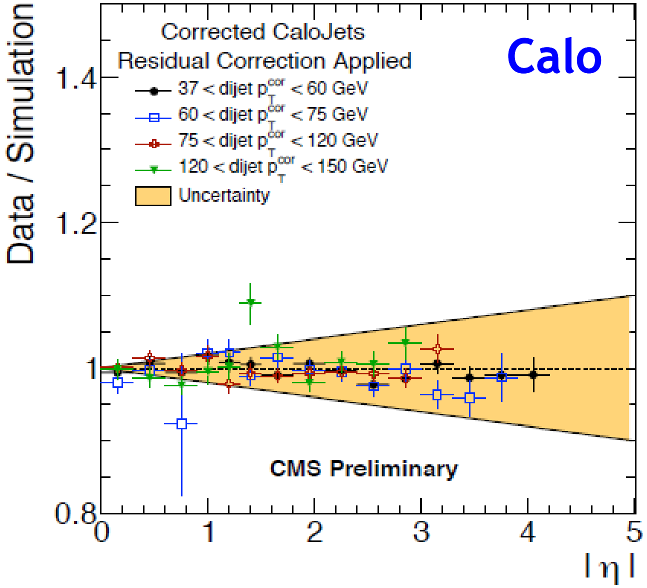
- Muon identification efficiencies and kinematic variables have been studied in detail using minimum bias events and dimuon resonances
- Distributions dominated by light hadron decay (red); excellent agreement with MC prediction including heavy flavor decays (blue); small fraction of punch-through (black) and fakes (green)

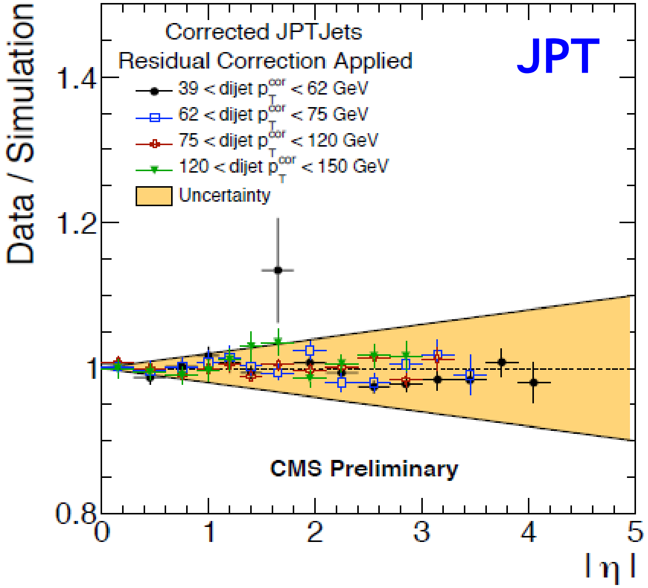


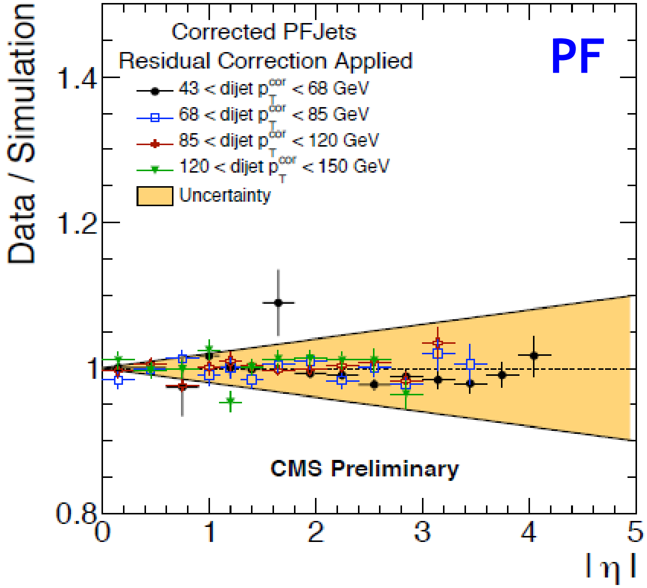
CMS PAS MUO-10-002

CMS PAS JME-10-003

- Jet Algorithm: Anti k_T (D=0.5)
- Three different jet approaches implemented: calorimeter jets, jet + tracks, particle flow
- Jet Energy Correction performed using MC vs data on single particle response, dijet p_T balance, photon+jet balance
- Current physics analysis use a 10% (5%) JEC uncertainties for CALO jets (JPT and PFjets), with an additional 2% uncertainty per unit rapidity



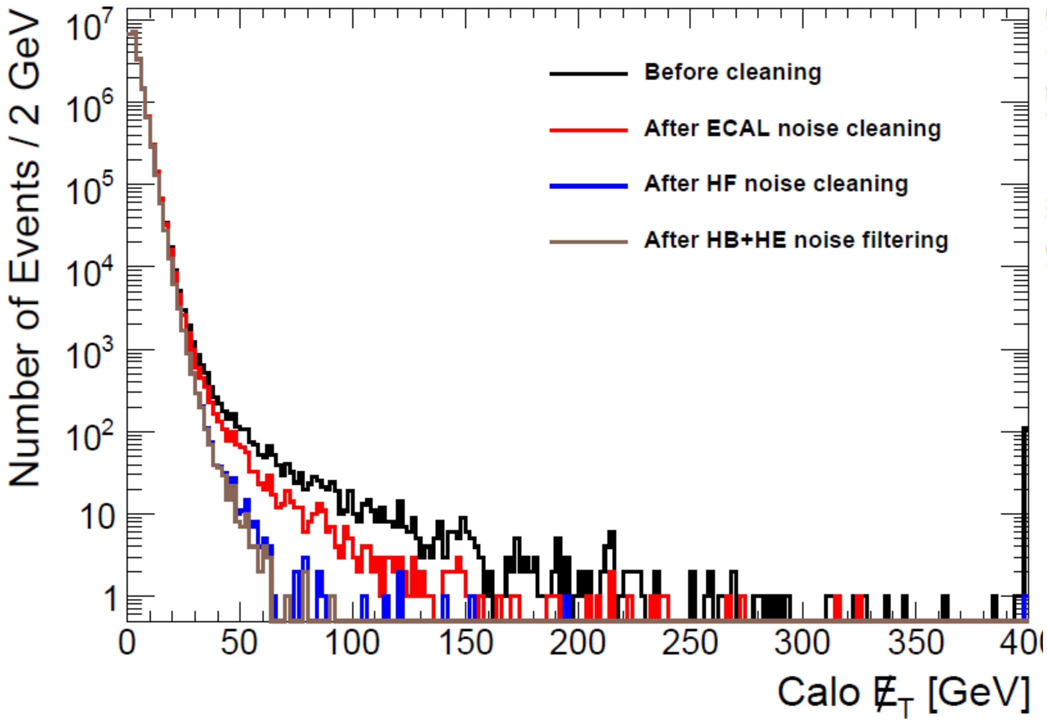


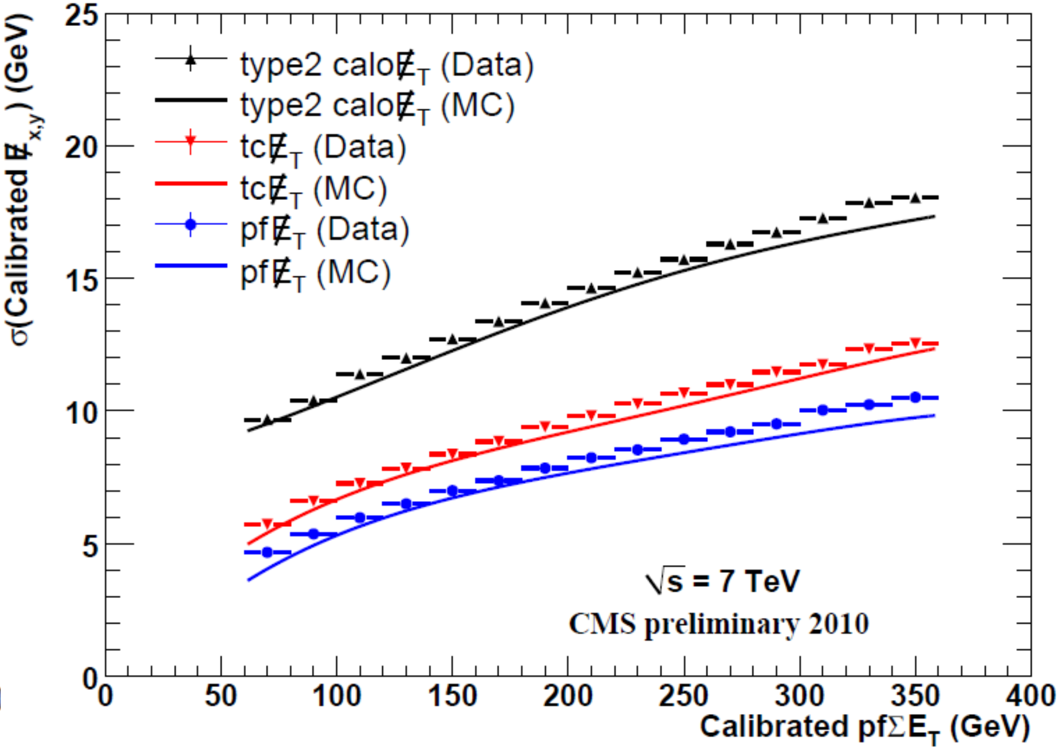


Plots show Data/MC ratio for relative response optained from dijet dijet p_T balance; MC jets corrected with MC-truth JEC; Jets in data with additional residual correction of 2%

Assumed uncertainty on JES looks conservative

CMS PAS JME-10-005





- Three approaches on MET: calorimeter, track corrected and particle flow
- Excellent resolution and small non-gaussian tails
- Understanding all sources of erratic noise is very important for cleaning the distributions

MET ready for physics

CMS PAS BTV-10-001

- Four different b-tagging algorithms implemented:
  - Track counting (TC): requires *N* tracks with minimum significance of impact parameter
  - SSV: at least one secondary vertex from two tracks ("high efficiency") or two tracks ("high purity")
  - Jet probability algorithm combines information from all selected tracks in a jet
  - Lepton based tagging algorithm identifies *b*-hadrons via semi-leptonic decays (low efficiency but high purity)

Agreement of data and MC prediction generally quite close
***b*-tagging algorithms well understood and validated**