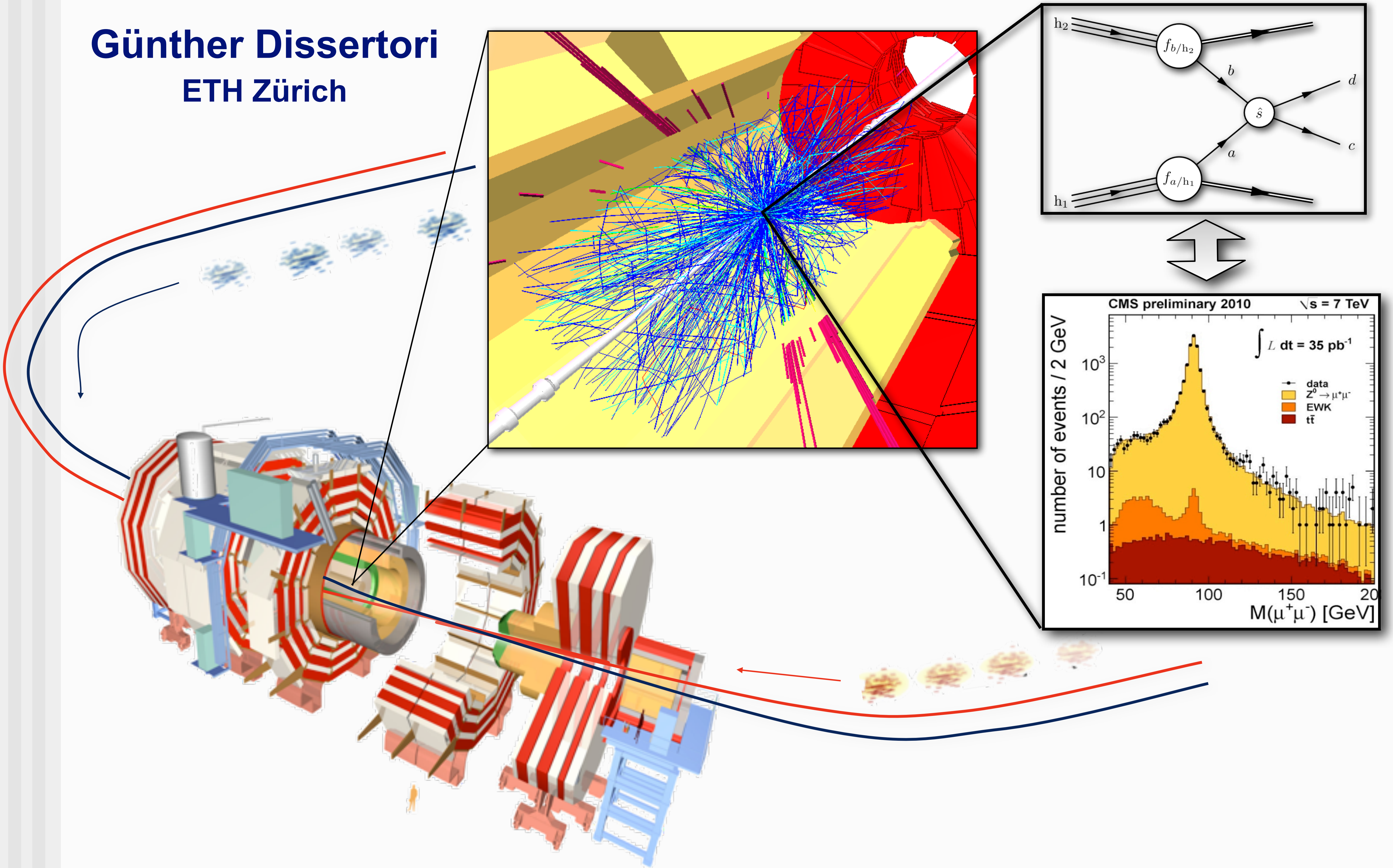
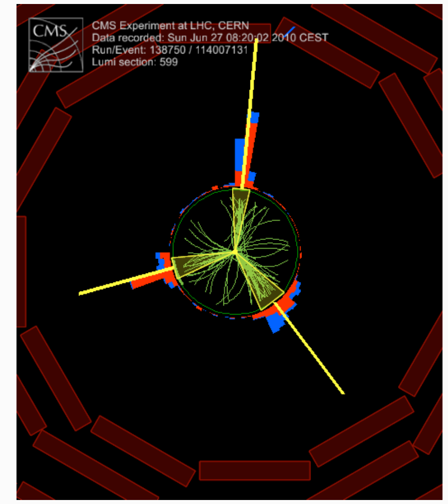
Recent SM Results from CMS

Günther Dissertori

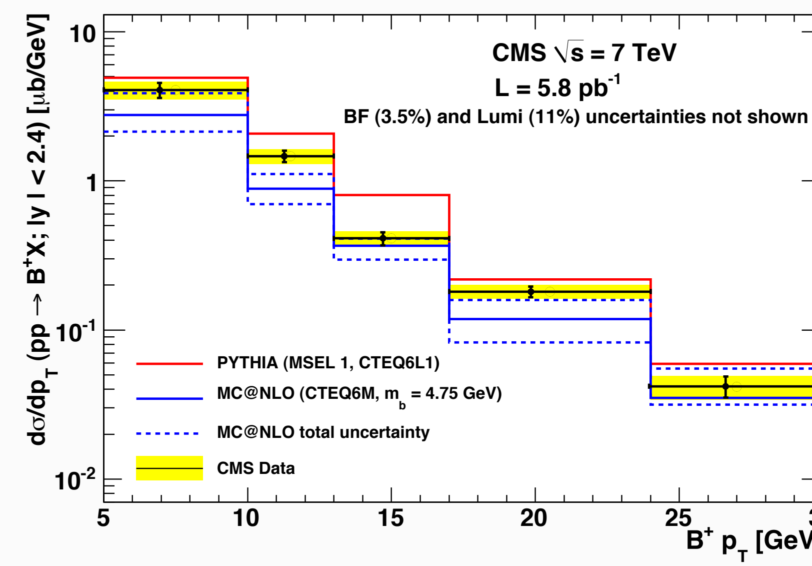
ETH Zürich

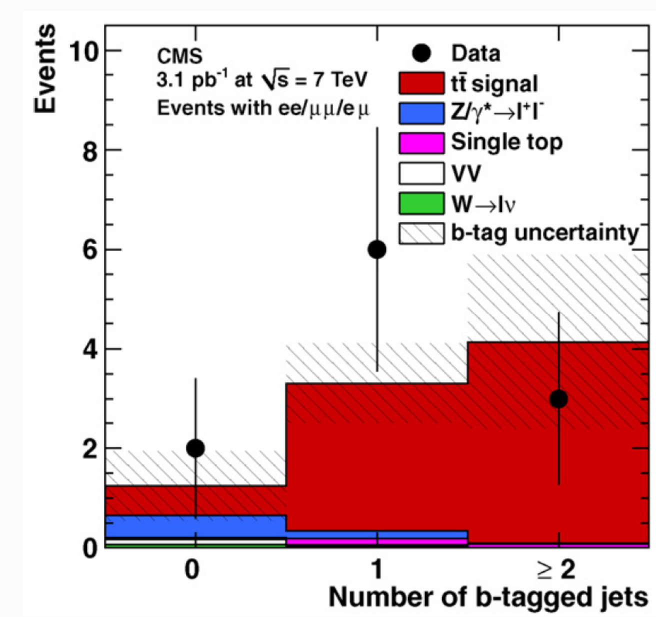


Outline

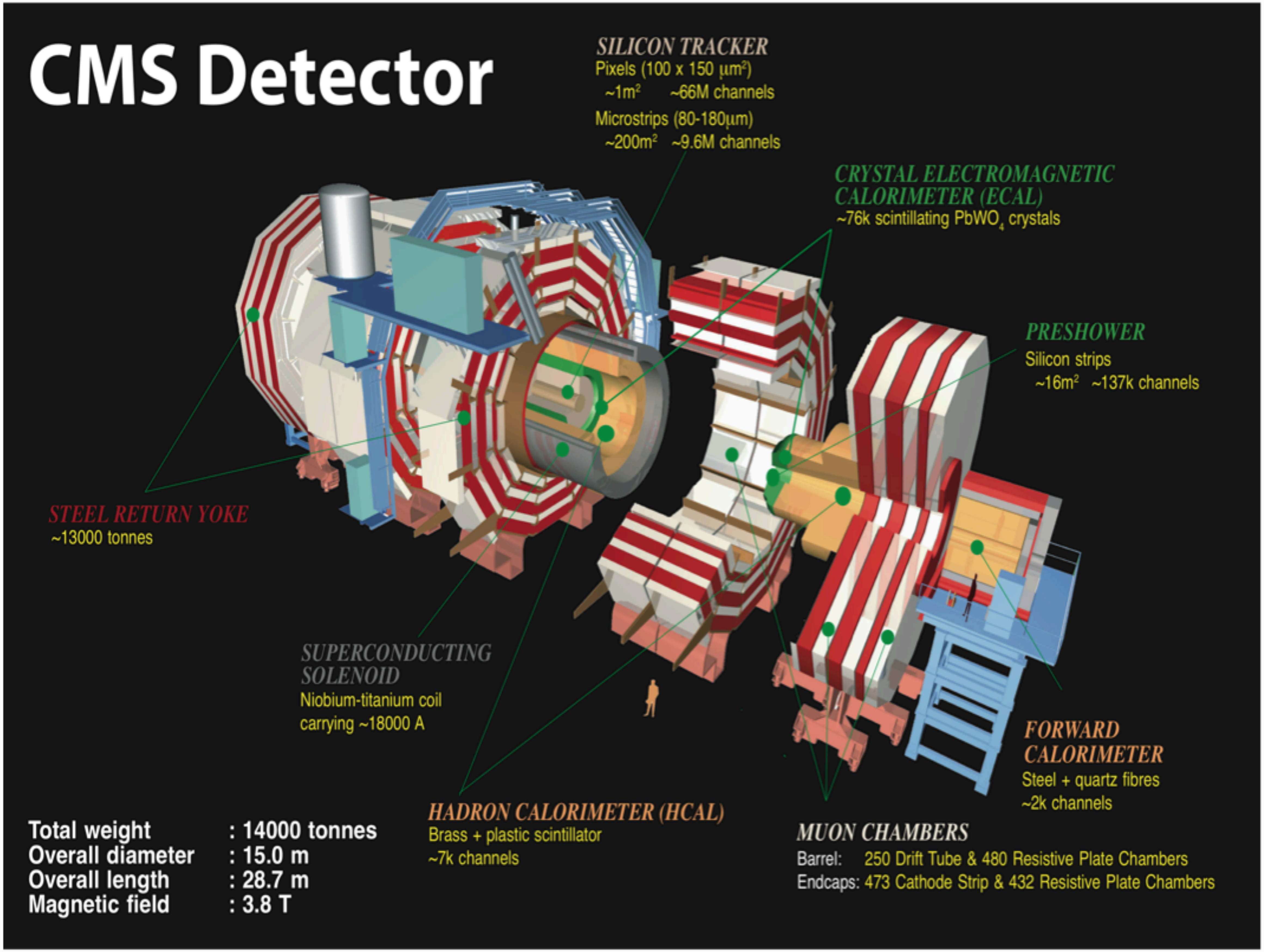


- Introduction
  - CMS operations
  - Very short : Ingredients (Jets, Pflow, ...)
- High-p_T QCD
  - Incl jet cross section
  - Di-jet observables
  - Multi-jet studies
- “Heavy” Quark production
  - Strangeness and Quarkonia
  - b-production
  - top-production
- W and Z production
- Conclusions
- **Note:**
  Nothing on low-pt QCD, UE, FWD, Heavy Ions.
  Focus on the very recent results



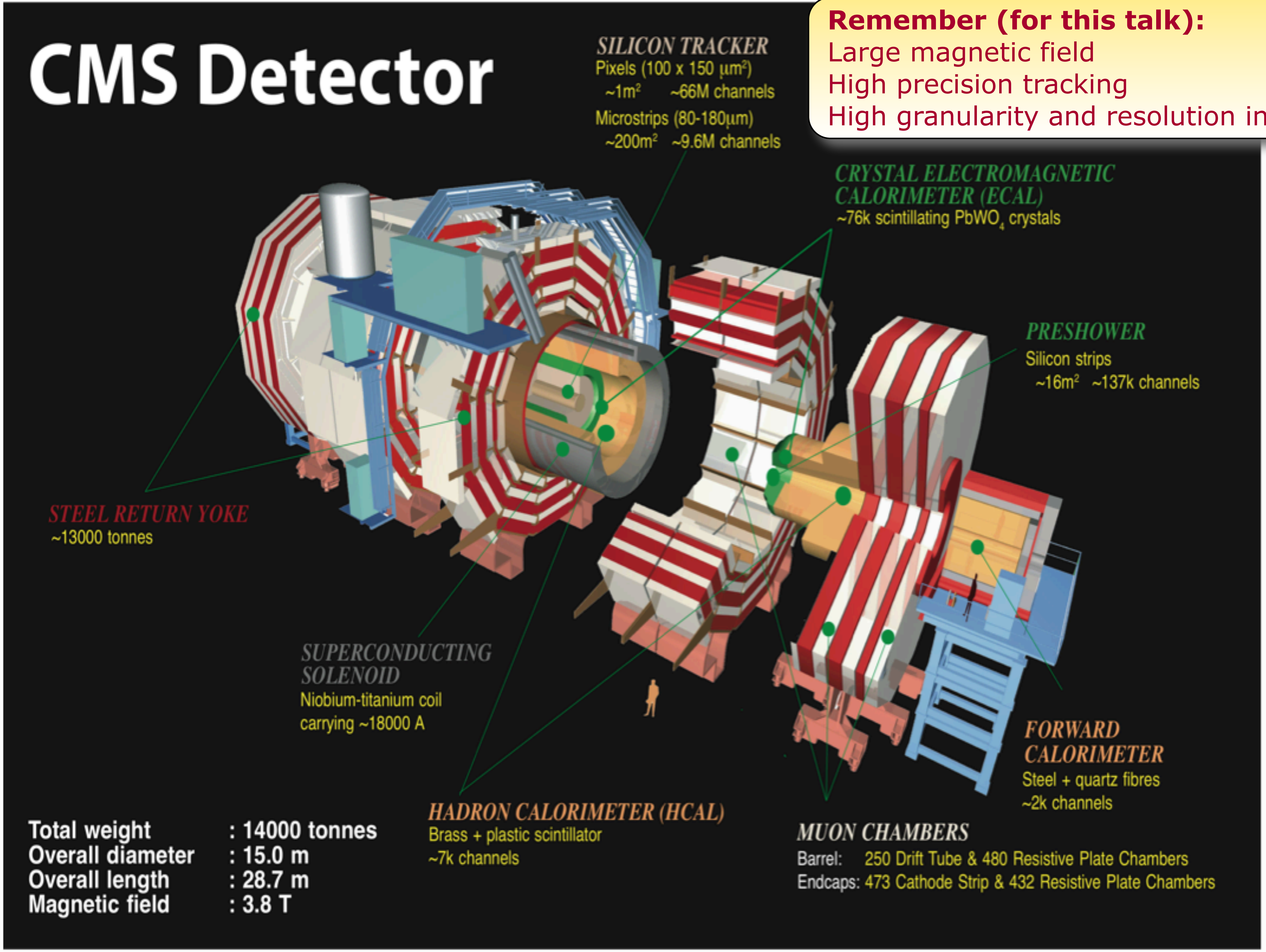


The CMS Detector

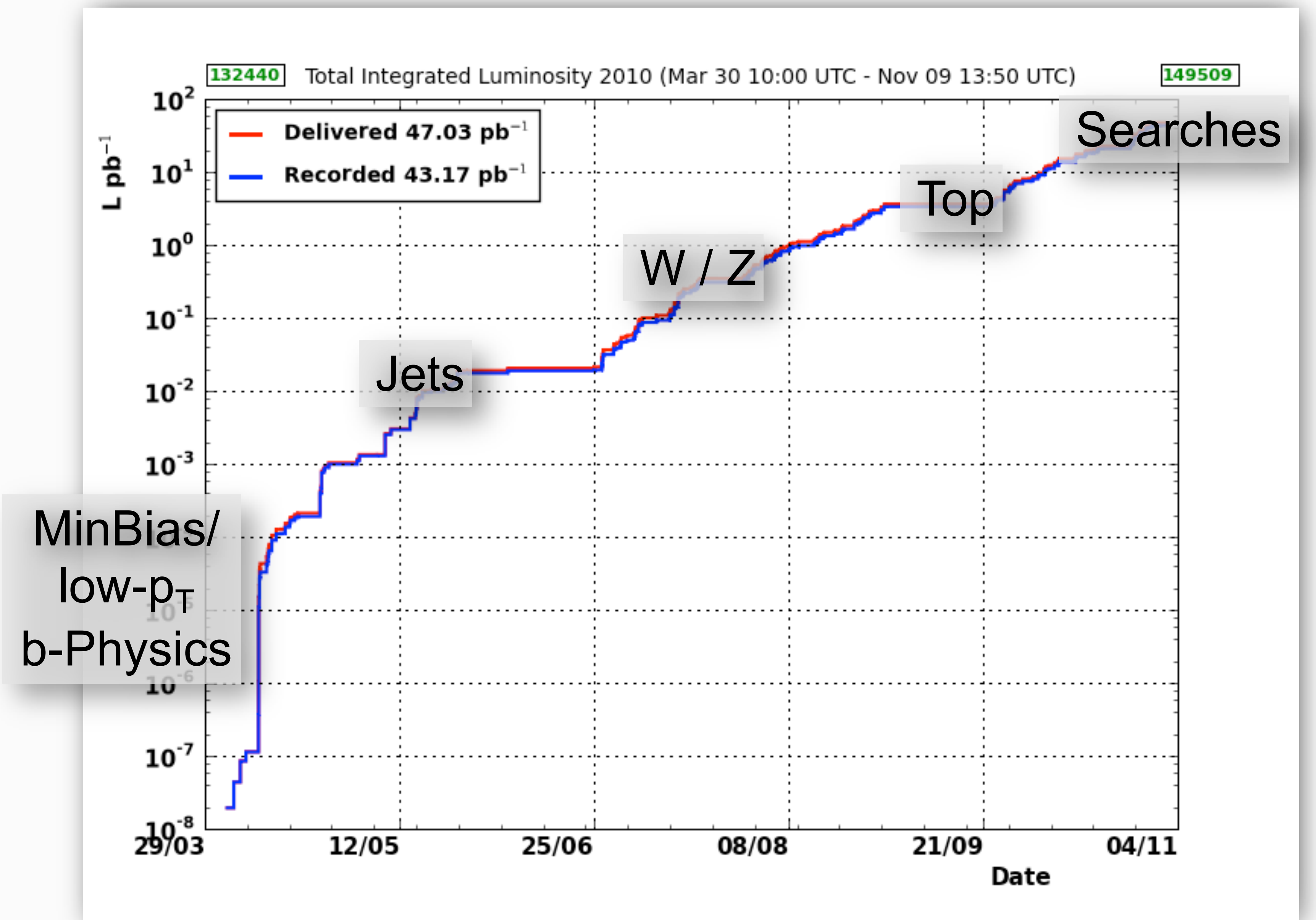


The CMS Detector

Remember (for this talk):
Large magnetic field
High precision tracking
High granularity and resolution in ECAL



Integrated Luminosity 2010 (pp running)



Reliable operations with **47 pb^{-1}** delivered by LHC
CMS recorded **43 pb^{-1}**. Overall data taking larger than **90%**
~85% recorded with all subdetectors in perfect conditions.
Note: all subdetectors have **at least 98%** of all channels operational!

The Ingredients for the preparation of our menu:

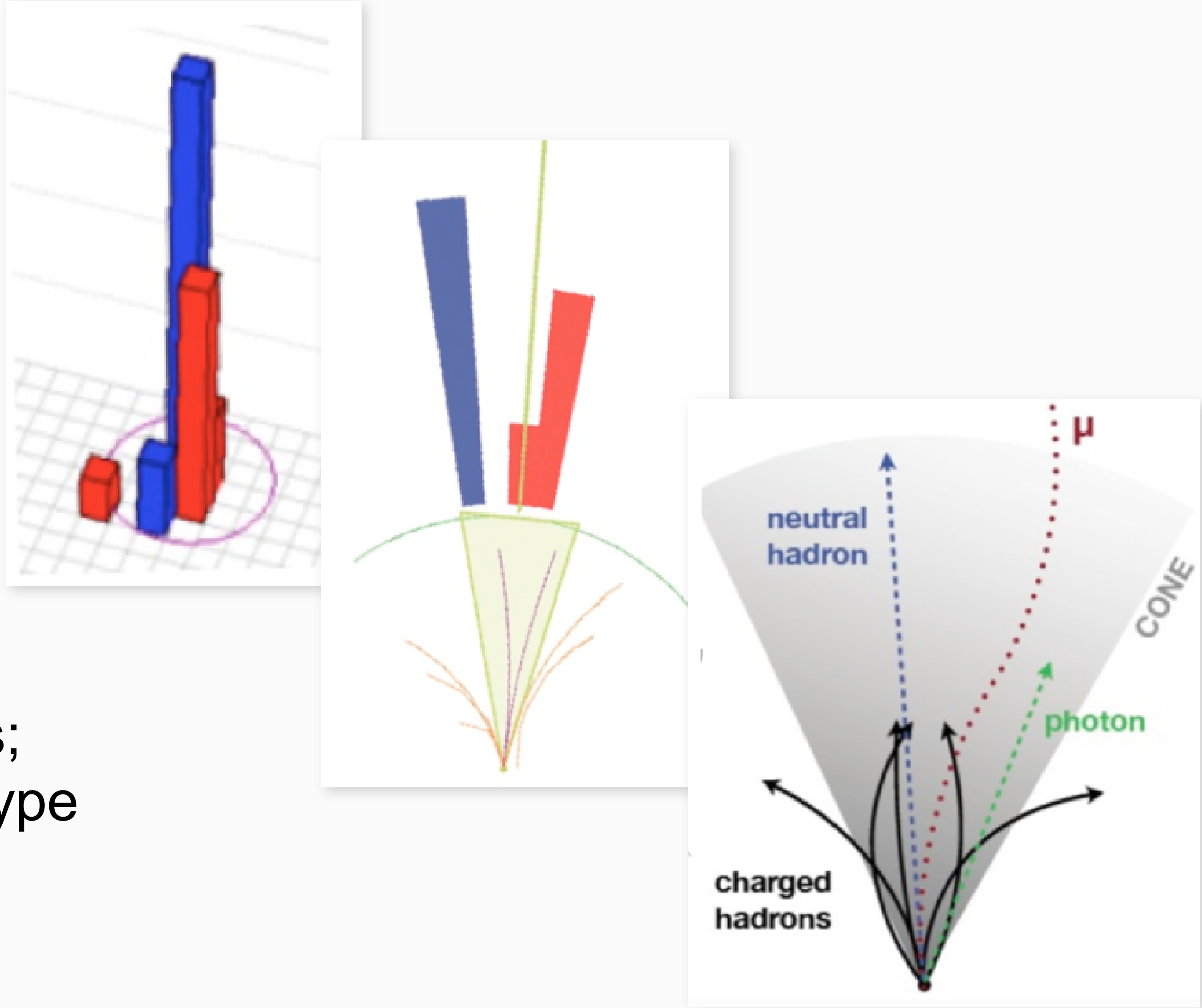
Trigger and object reconstruction

Observed so far:
Excellent performance in Physics Object Reconstruction
(Tracks, Electrons, Muons, Jets, MET, Particle Flow)

in the following, only some statements about Pflow, since rather specific to CMS

Jet Reconstruction

- CalorimeterJet (calojet)
  - from energy depositions grouped HCAL & ECAL
- Jet Plus Tracks (JPT)
  - Calorimeters jets corrected with tracker momentum
- Particle Flow Jets (PFJ):
  - Reconstructed particles using information from all sub-detectors; separate calibration per particle type
- TrackJets
  - from tracks only



- Jet Algorithms:
  - Default for p+p collisions is anti-KT with R = 0.5
  - Also implemented: KT, SiSCone

Jet Reconstruction

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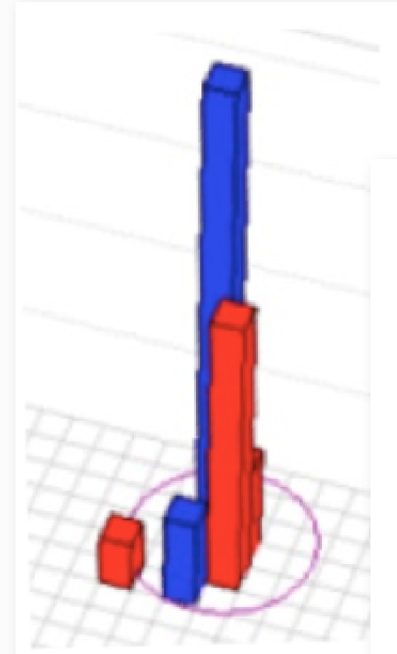

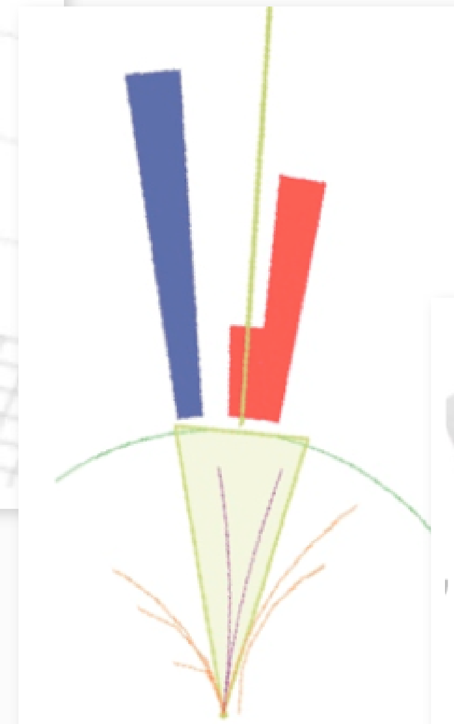

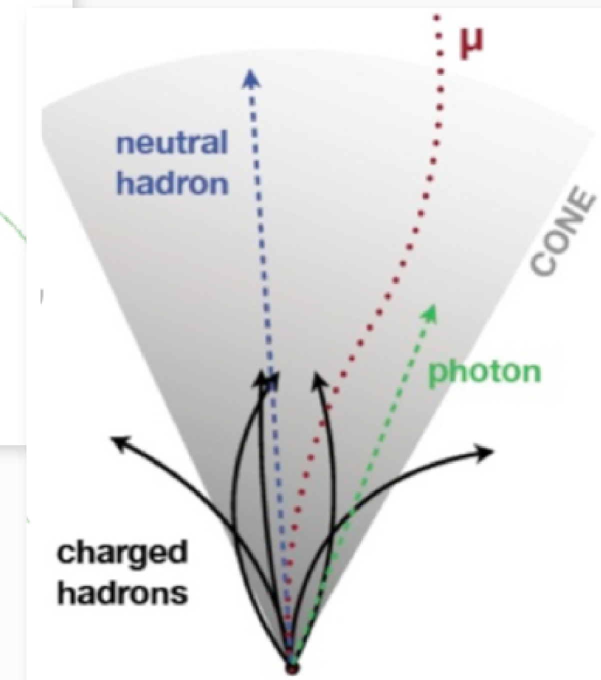

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  - Default for p+p collisions is anti-KT with R = 0.5
  - Also implemented: KT, SiSCone

Using different inputs allows CMS to study and constrain experimental systematics for good understanding of jet identification, resolutions and energy scale

CMS performance: PF jets

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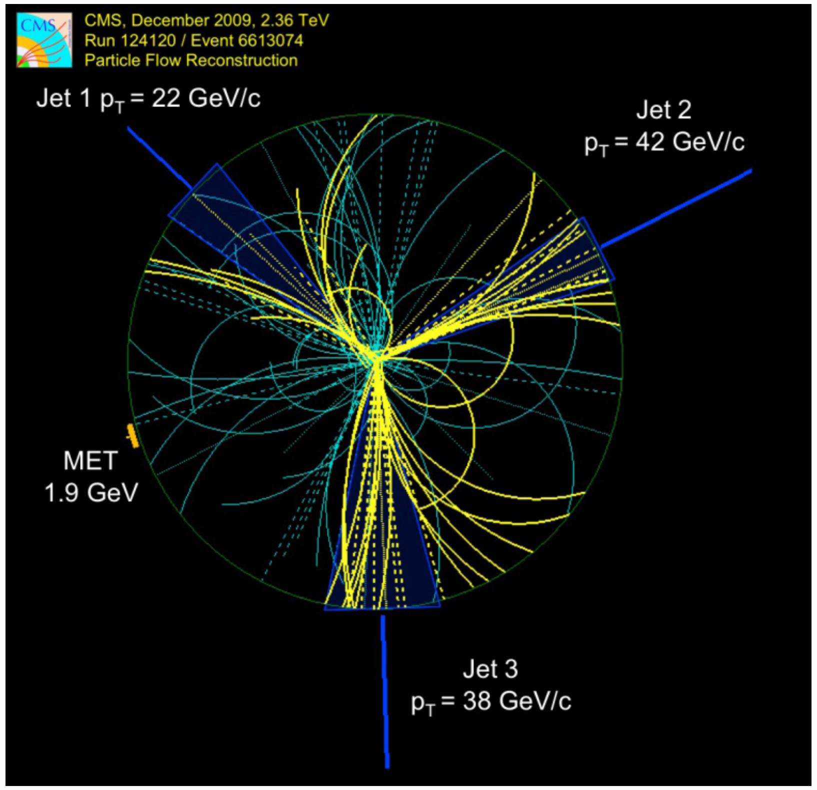

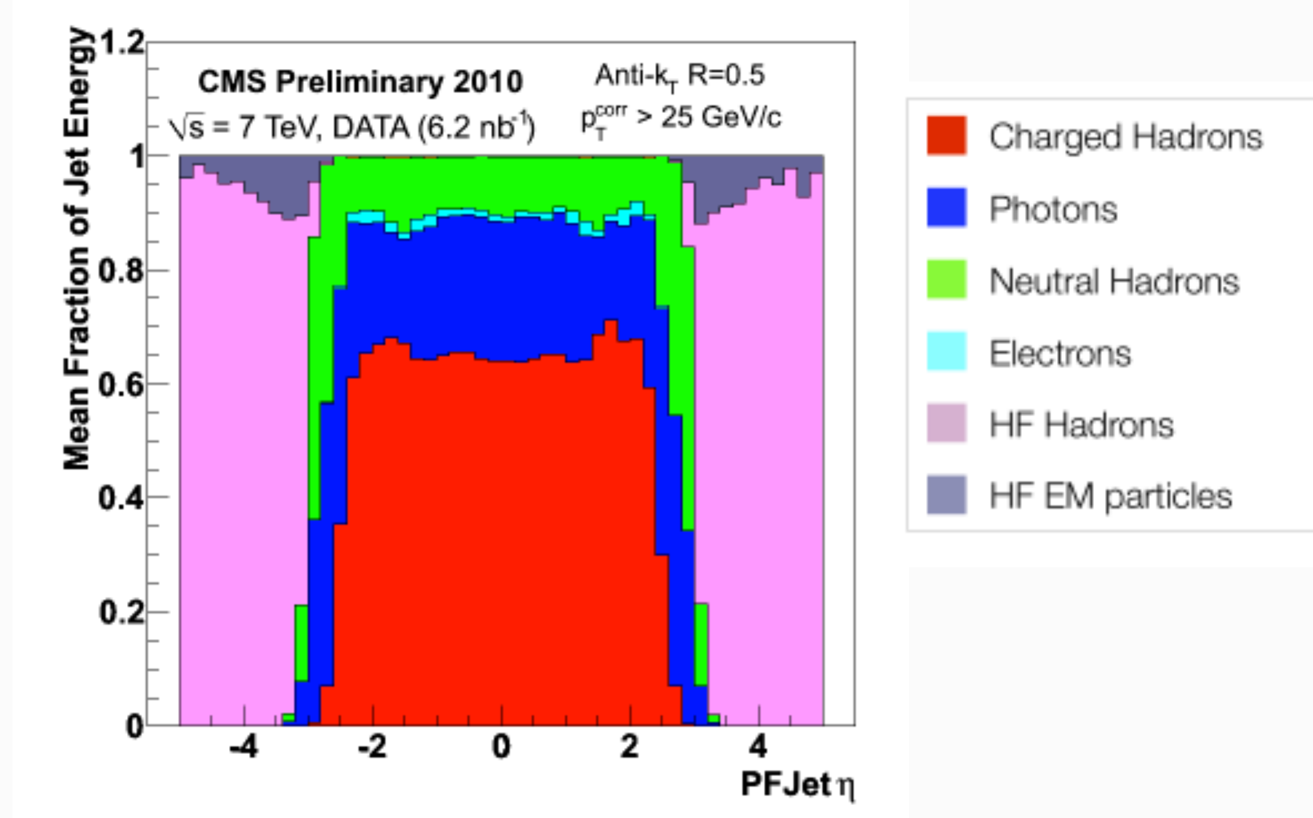

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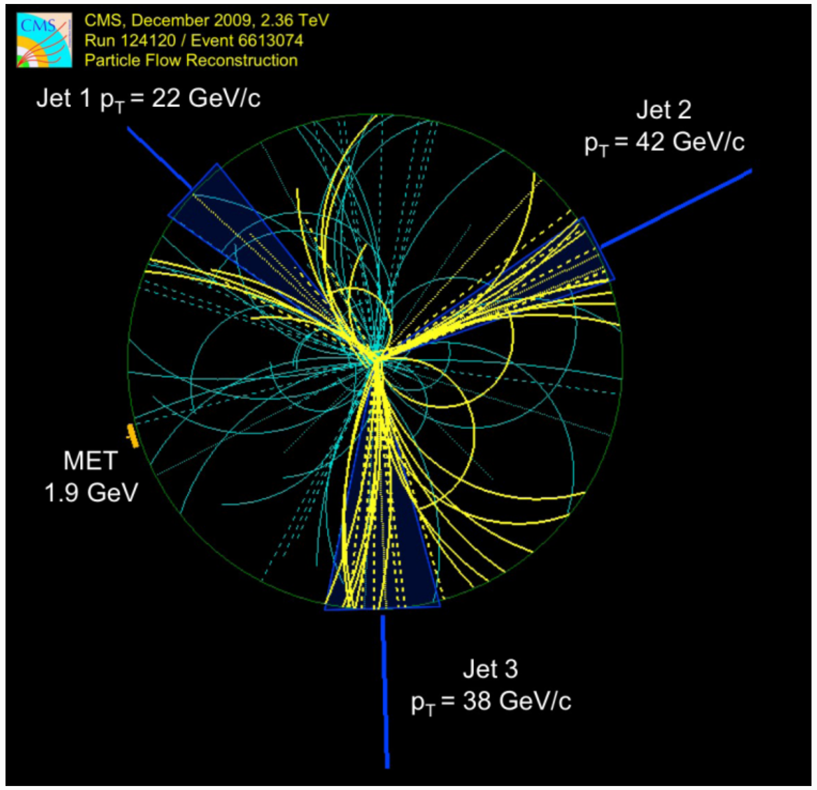
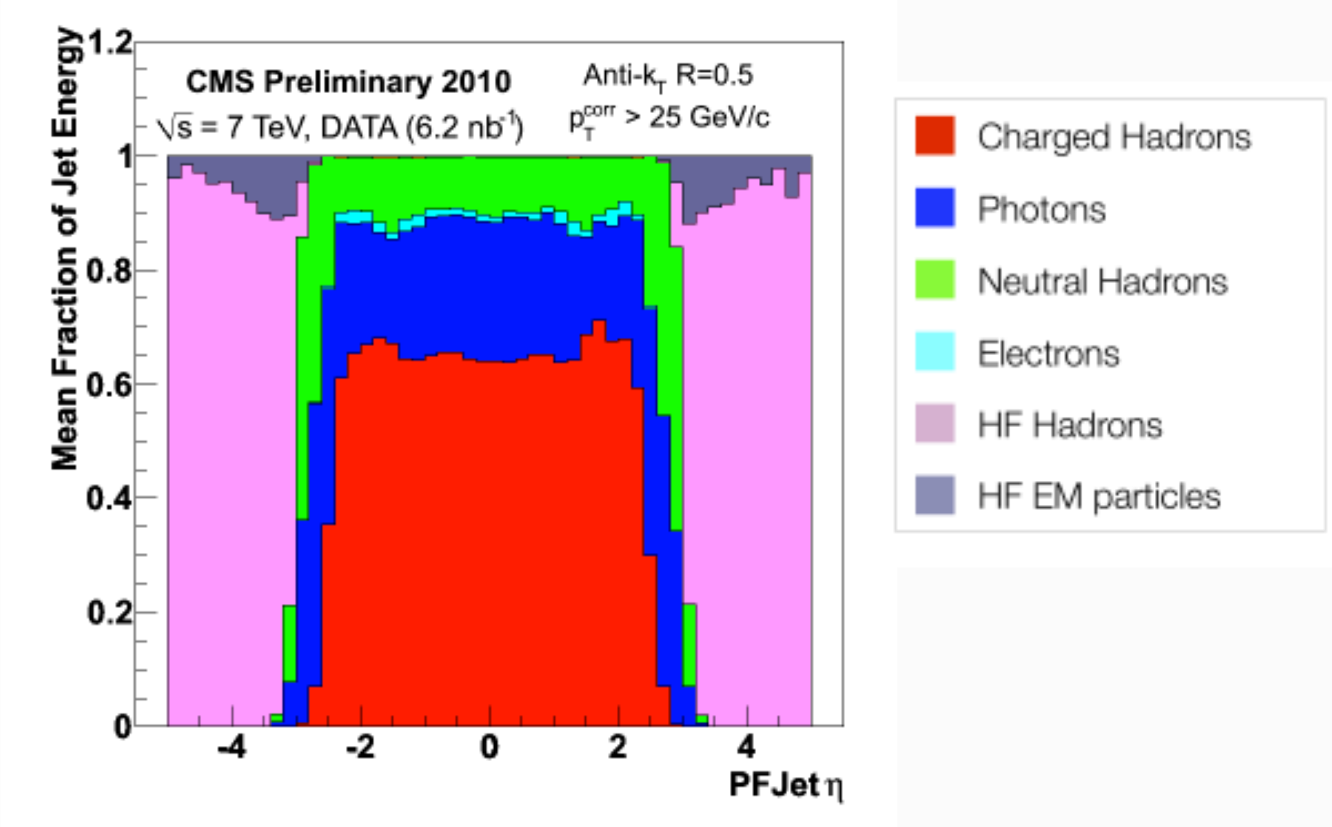
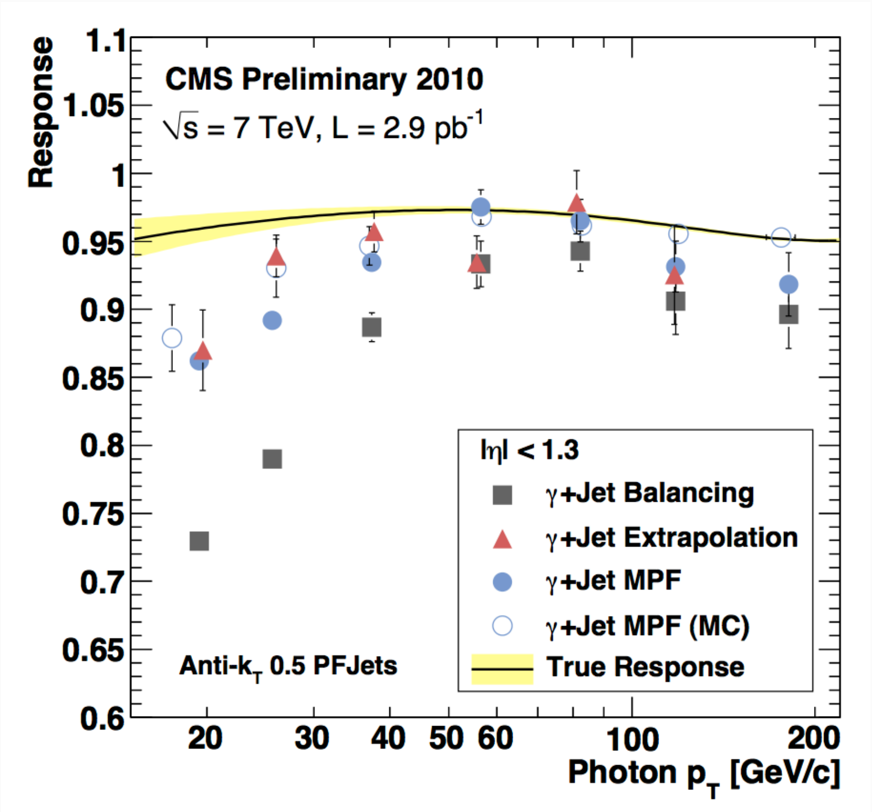




PAS JME-10-010



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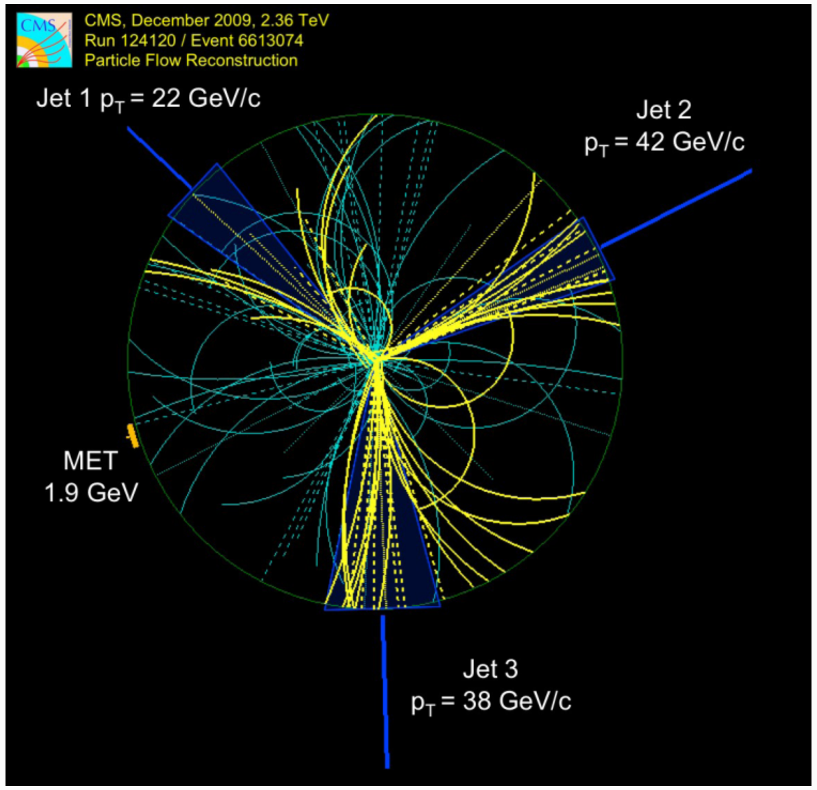

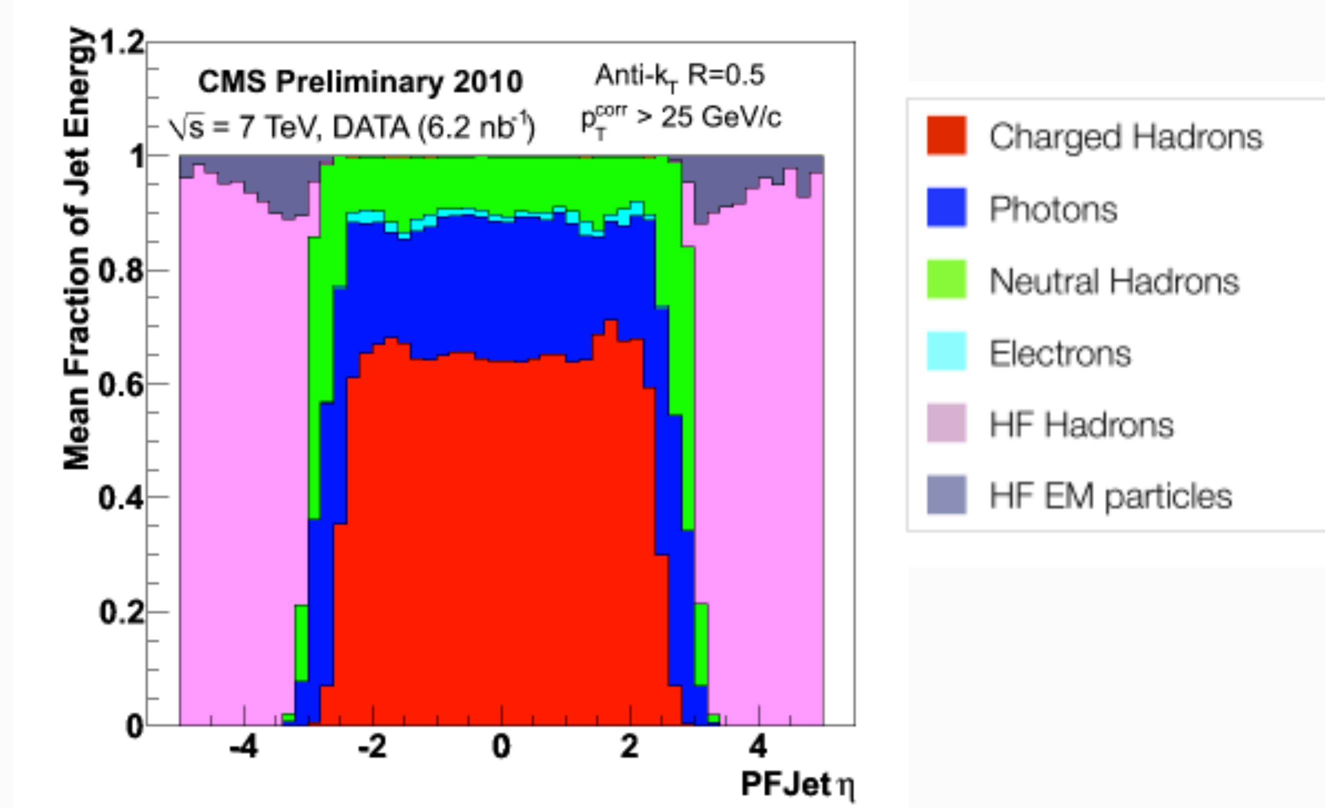

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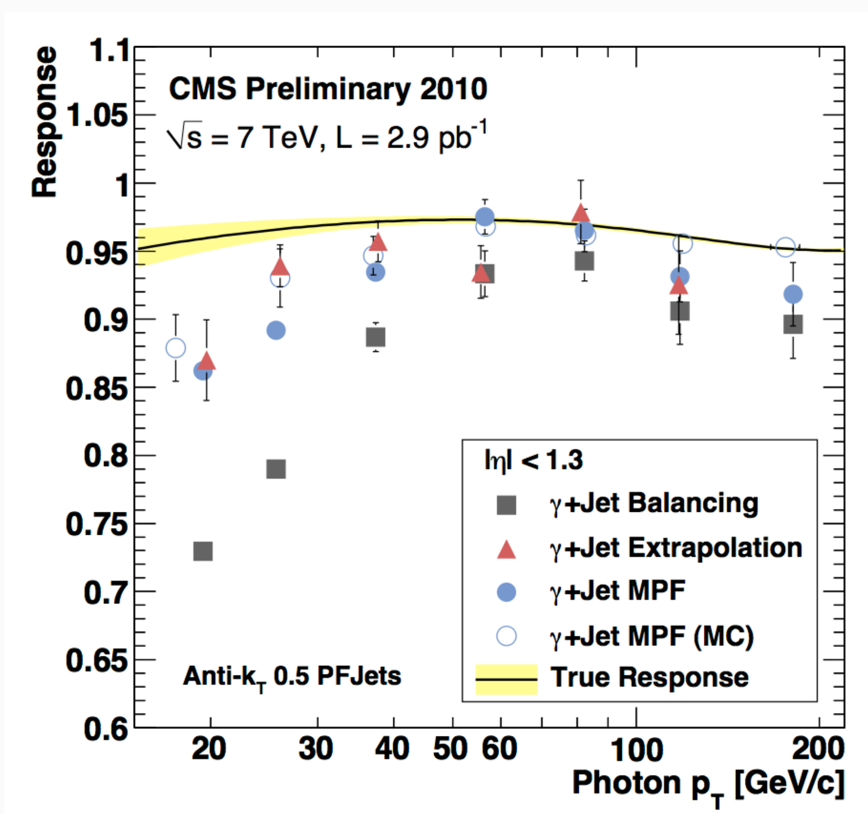
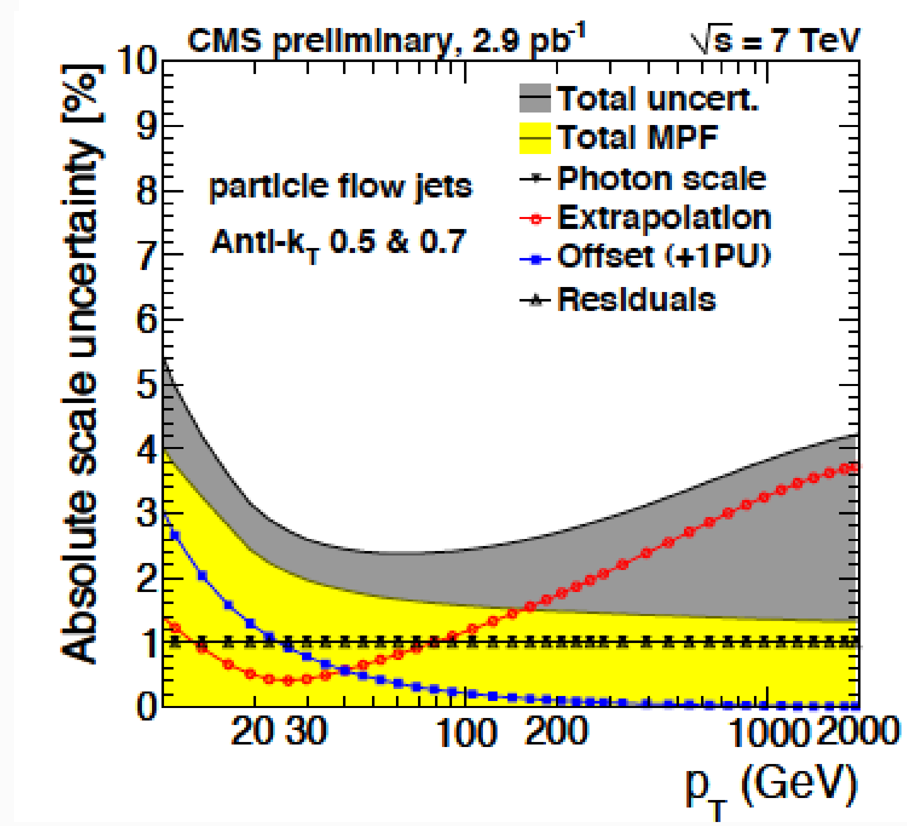
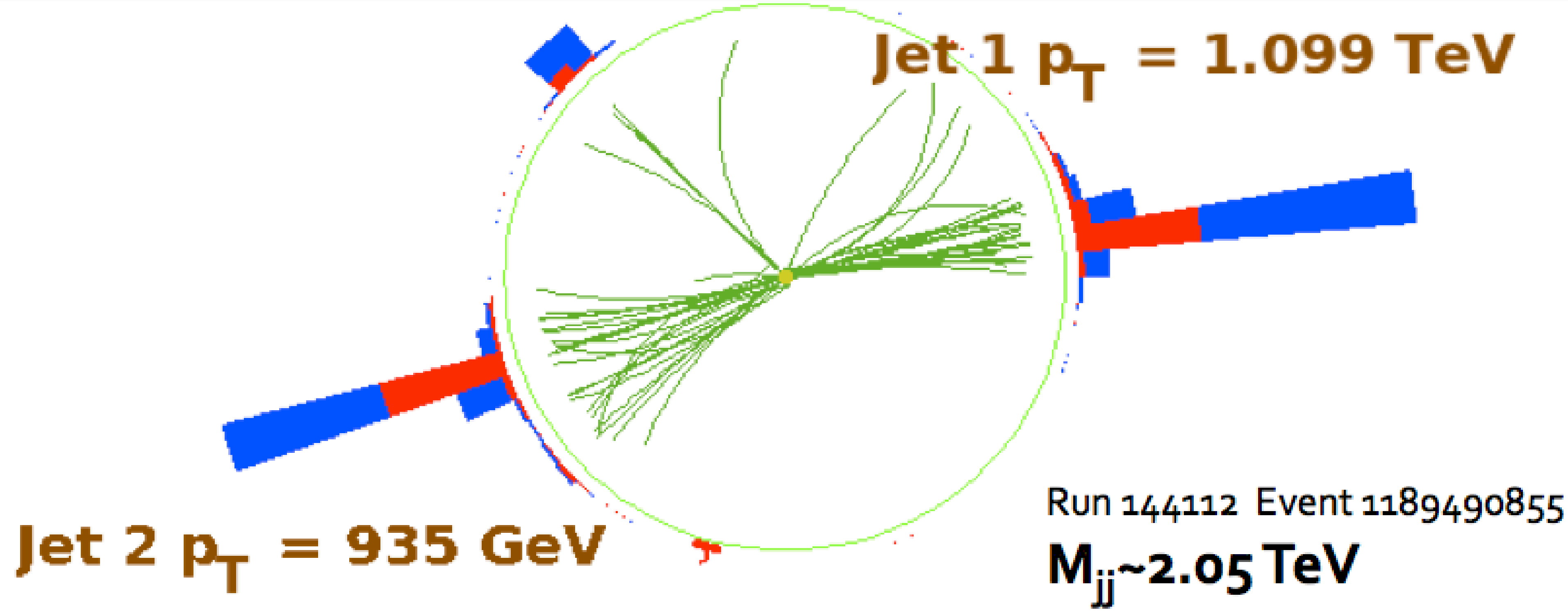




- Jet performance matches simulation very well, PF JEC uncertainties: 3-5 %

High-Pt QCD



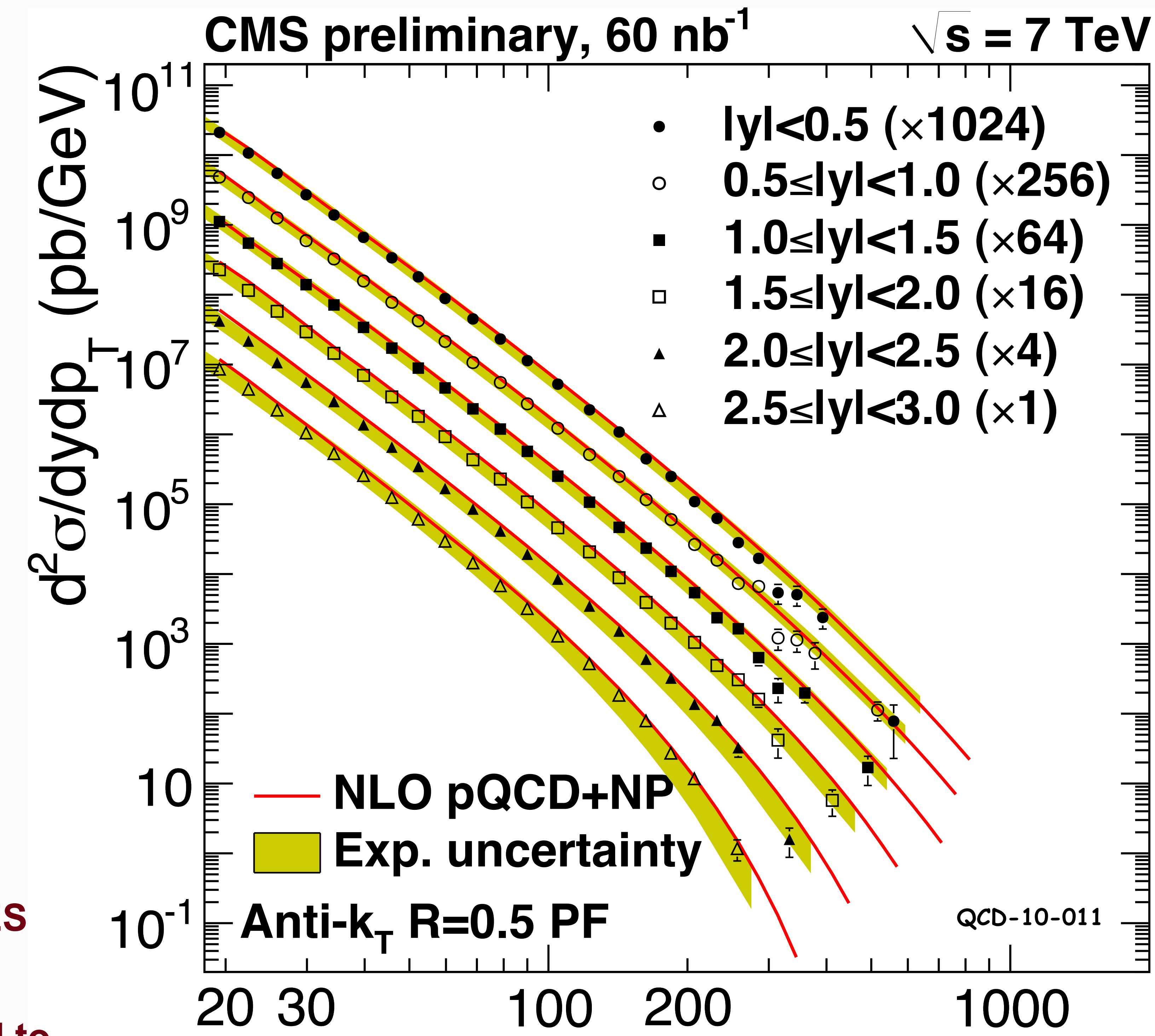
A high mass dijet event satisfying $\Delta\eta < 1.3$
Current highest mass dijet pair: ~2.7 TeV in 3.1 pb^{-1} of data

Inclusive jet cross section

- Inclusive jet p_T spectra are in **good agreement with NLO** theory for all reconstruction types
- Extending to very low p_T thanks to novel reconstruction methods (Particle Flow)
- Low p_T reach limited from theory side by non-perturbative corrections

Down to pt=20 GeV and 5% JES

Preliminary result being updated to full 2010 dataset and 3% Jet Energy Scale



$x_T = p_T/\sqrt{s} = 0.005$

How to reduce uncertainties?

ETH Institute for Particle Physics

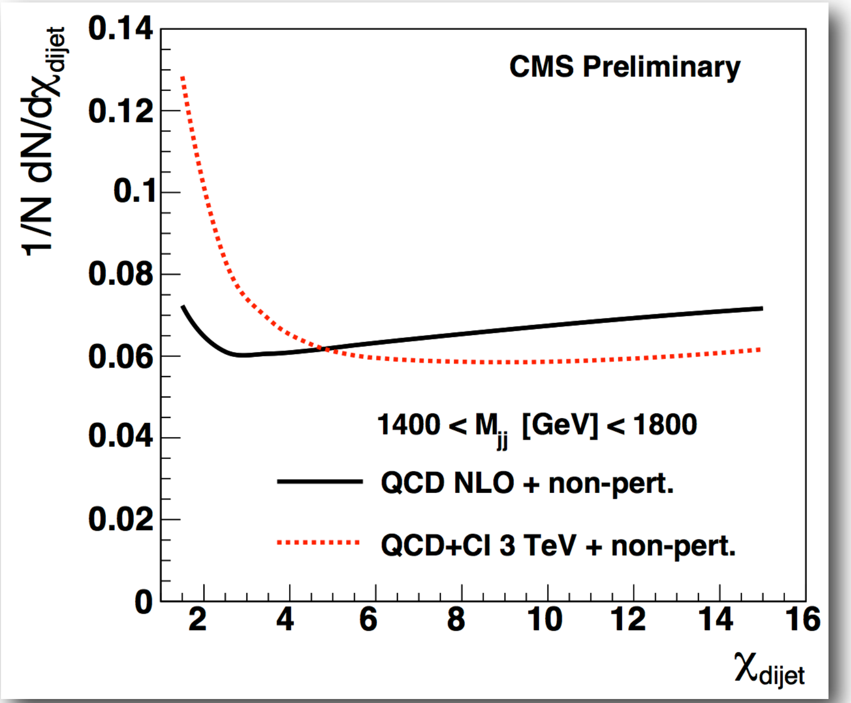
- Look at angular correlations as function of di-jet mass

$$\chi_{dijet} = \exp\left(\left|y_1 - y_2\right|\right)$$

probes parton scattering with light dependency on PDF

• flat for t-channel gluon exchange

• new physics → excess at low χ



- no lumi uncertainty
- very weak JES uncertainty
- Sensitivity up to Λ=5 TeV with 2010 data; Tevatron limits Λ > 2.8-3 TeV

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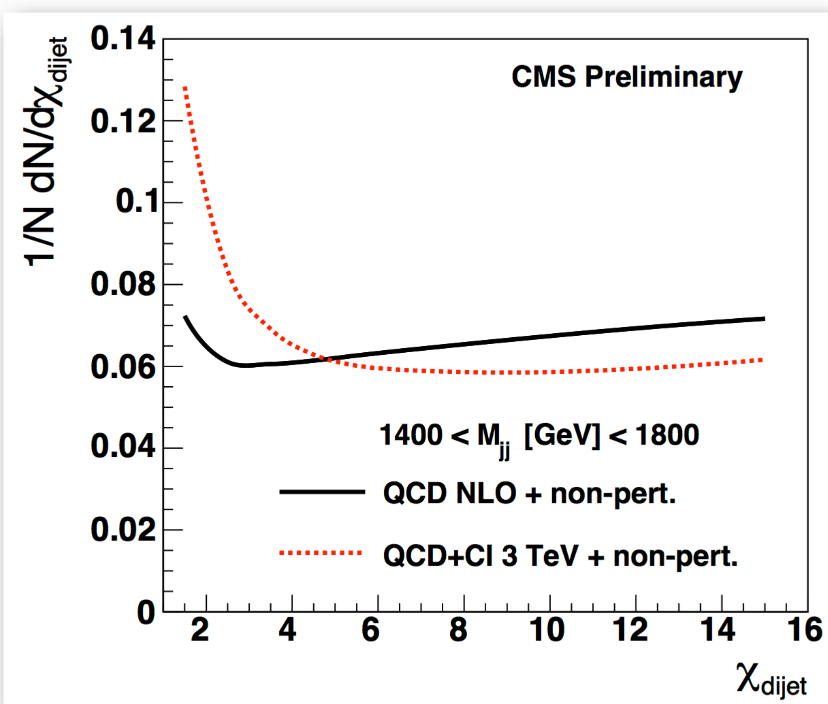

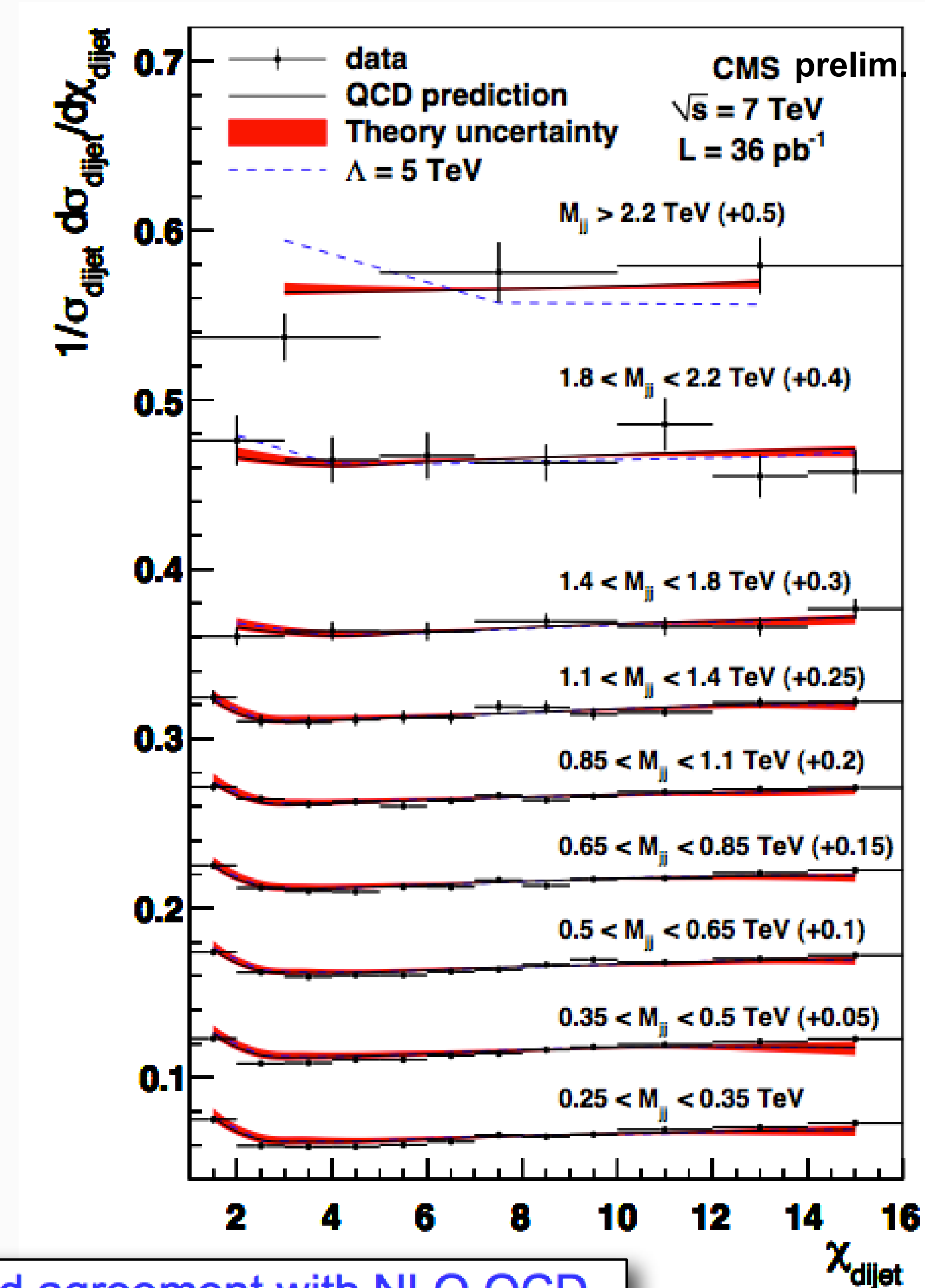

NEW !

Corrected for det.effects

Good agreement with NLO QCD predictions in $0.25 < M_{jj} < 2.2$ TeV

- no lumi uncertainty
- very weak JES uncertainty
- Sensitivity up to Λ=5 TeV with 2010 data; Tevatron limits Λ > 2.8-3 TeV

Observed limit with systematics:
Λ > 5.6 TeV
Expected limit with systematics:
$\Lambda > 5.0^{+0.4}_{-0.5}$ TeV

Correlations in Azimuth

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

  sensitive to higher order QCD radiation effects

- **High sensitivity to ISR, much less to FSR**
- **Independent of luminosity**
- **Weakly dependent on Jet Energy Scale**

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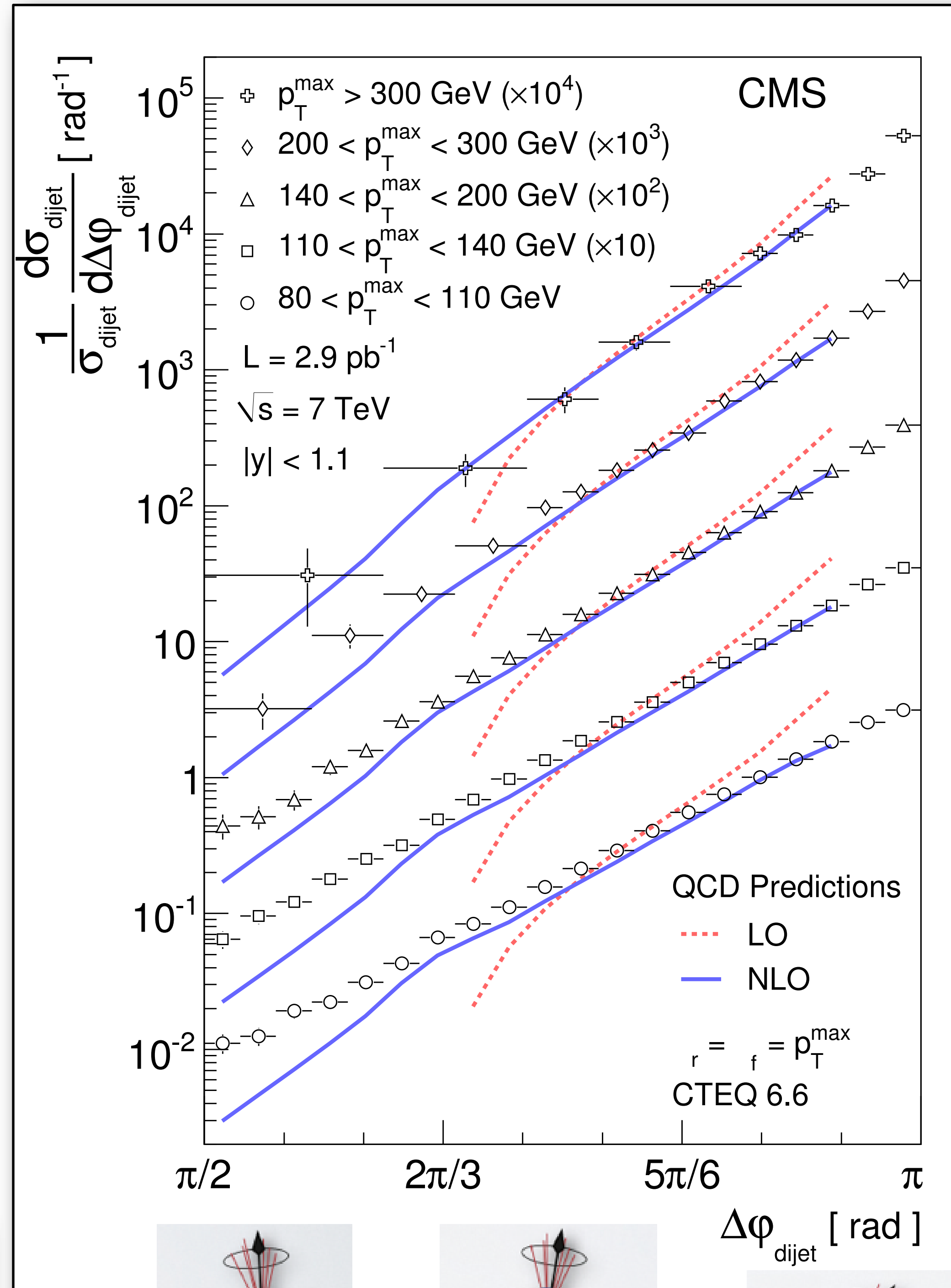

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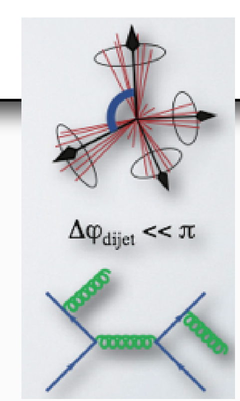
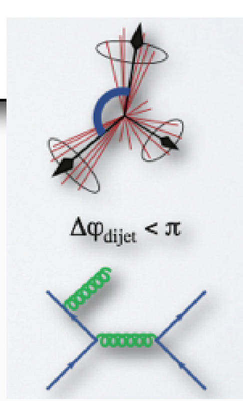
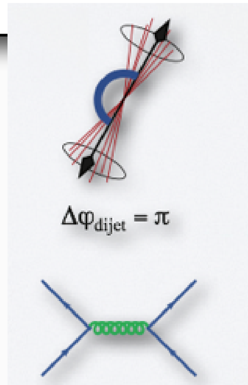
NLO predictions give a better agreement than LO, but they undershoot the data for $\Delta\varphi < 2\pi/3$ (in this region 2→4 LO)







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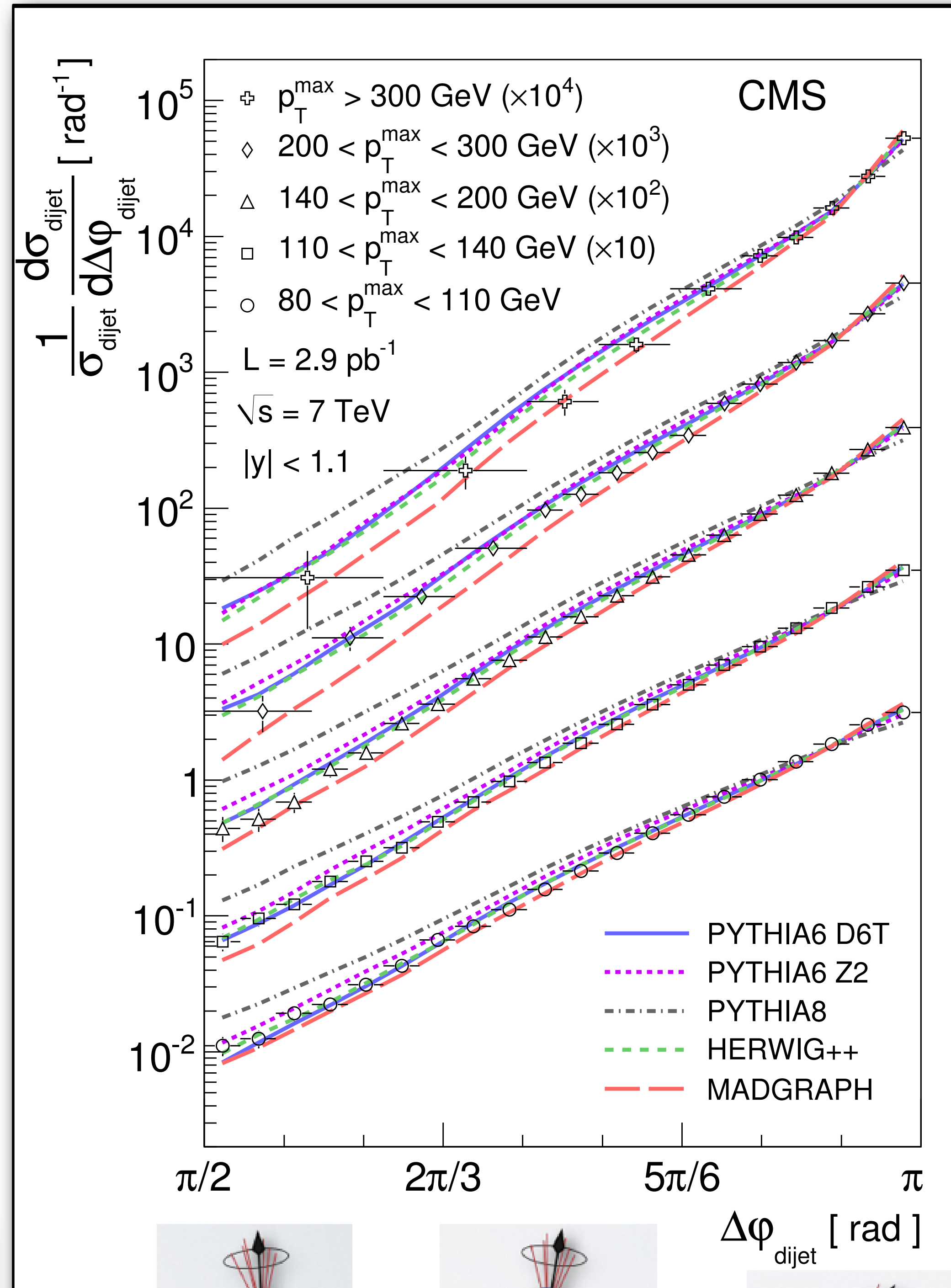

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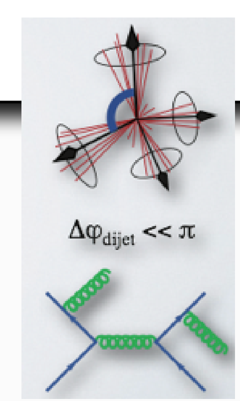
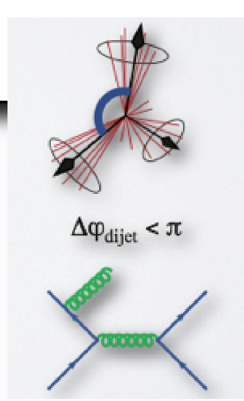
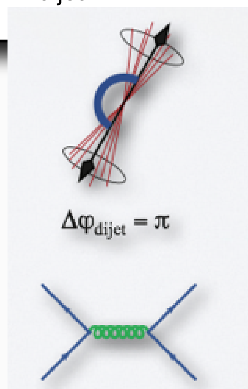
Pythia6 and Herwig++ are in reasonable agreement with data

MadGraph (Pyhtia8) predicts less (more) decorrelation than what is observed in data. Both could be tuned to agree with data by changing the ISR parameters.







Hadronic Event Shapes

CMS PAS QCD-10-013

- **Central transverse thrust**

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

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

robust against choice of jet reconstruction, as well as JEC and JER uncertainties

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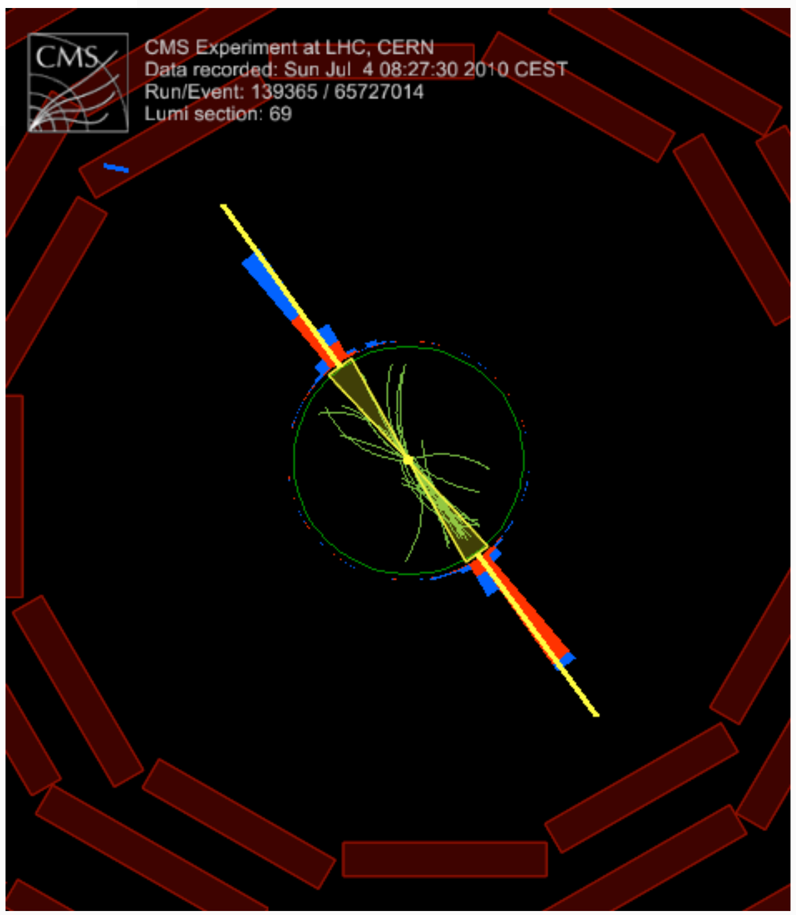

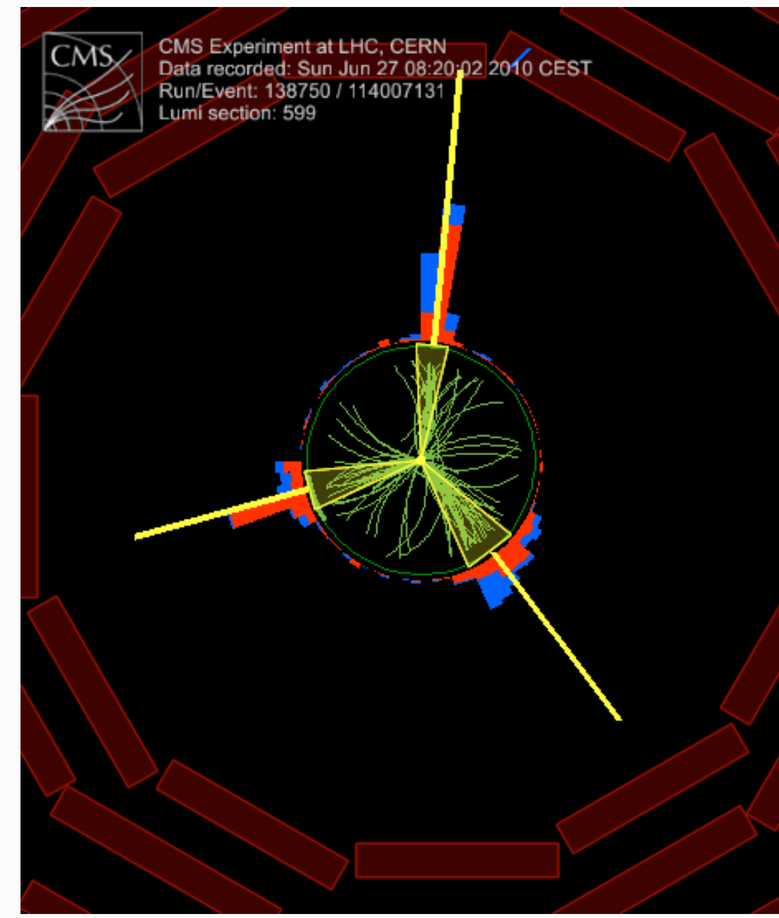

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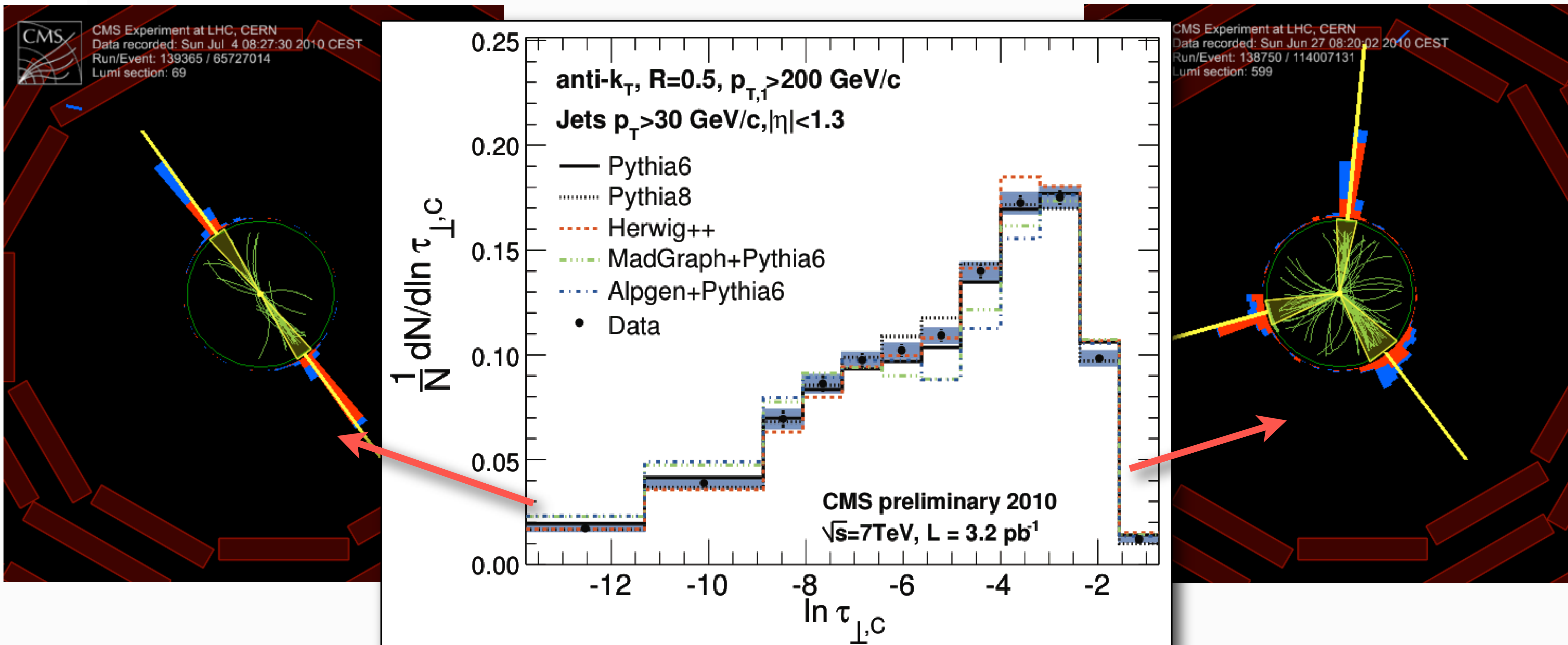


NEW !

Corrected for det.effects, using SVD unfolding!

Similar conclusions to phi de-correlation study:
PY6, PY8 and HW++ predict data rather well.
ALPGEN and MadGraph overestimate the fraction of back-to-back di-jet events, and underestimate 3-jet contrib.

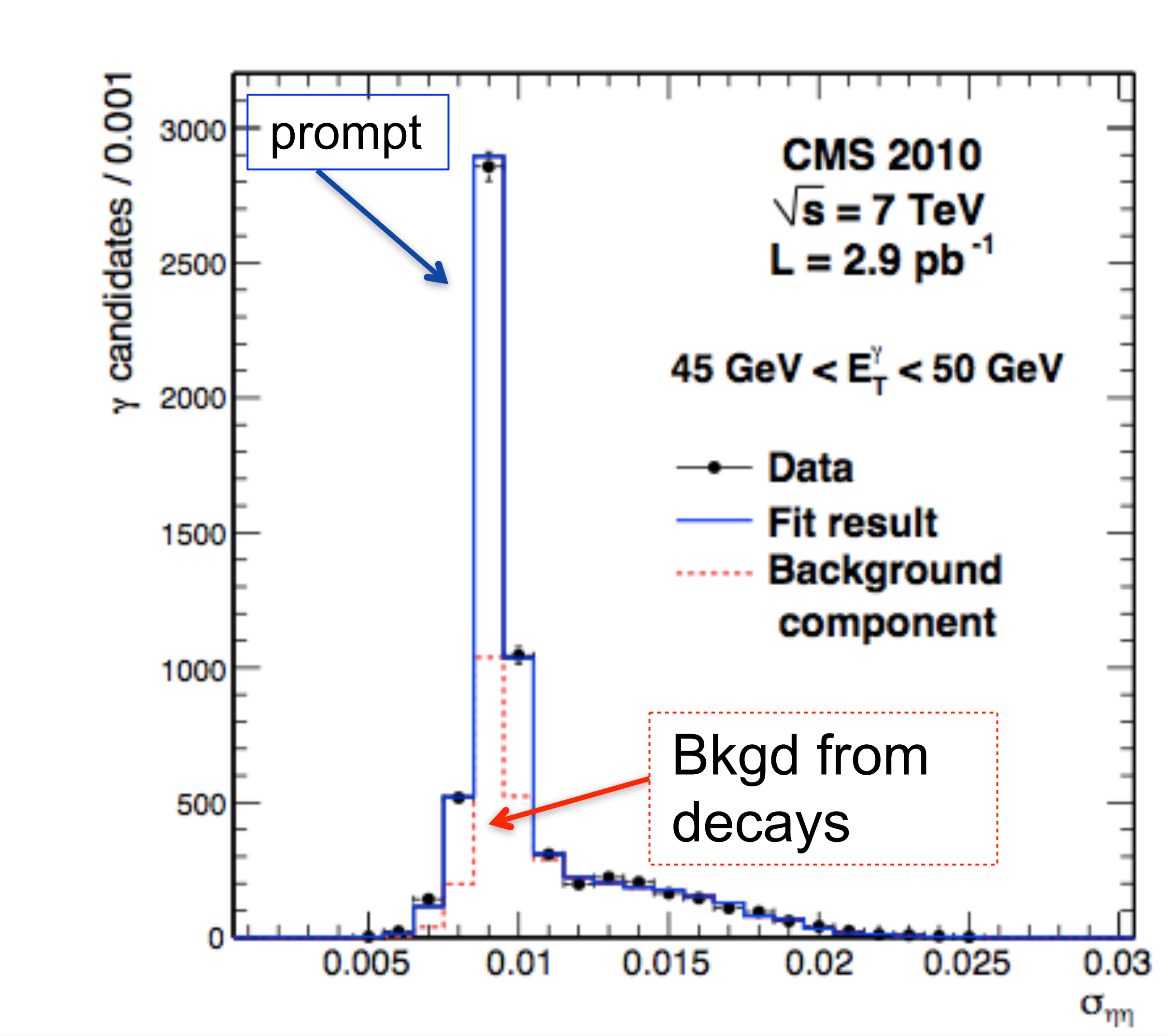
QCD: prompt γ production

arXiv 1012.0799

$$\sigma_{\eta\eta}^2 = \frac{\sum\limits_{\substack{crystal-i \\ in\, 5x5 \\ around mx}} \omega_i (\eta_i - \bar{\eta})^2}{\sum\limits_{crystal-i} \omega_i}$$

Discr. variable: $\sigma_{\eta\eta}$

$$\omega_i = \max\left(0, 4.7 + \ln\left(E_i / E_{5x5}\right)\right)$$



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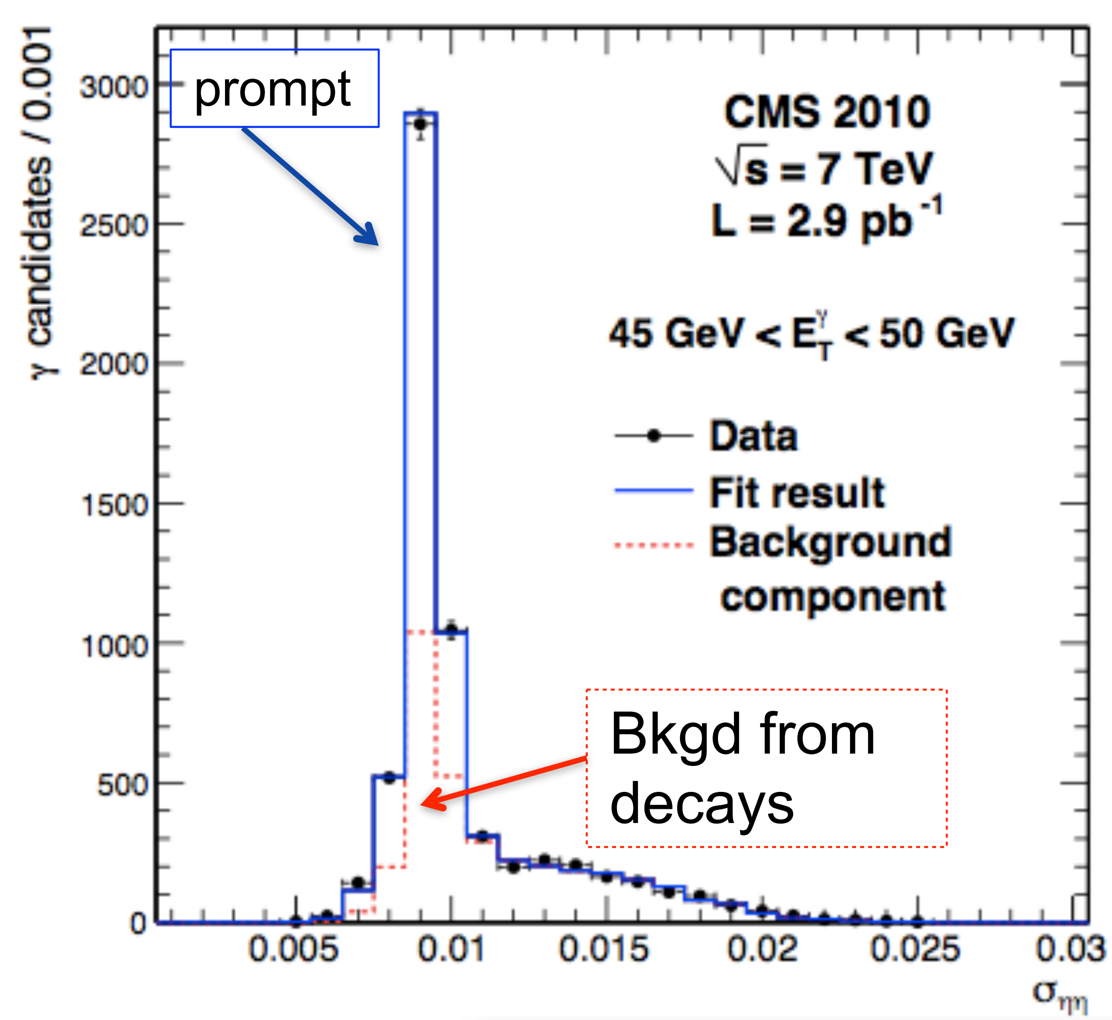
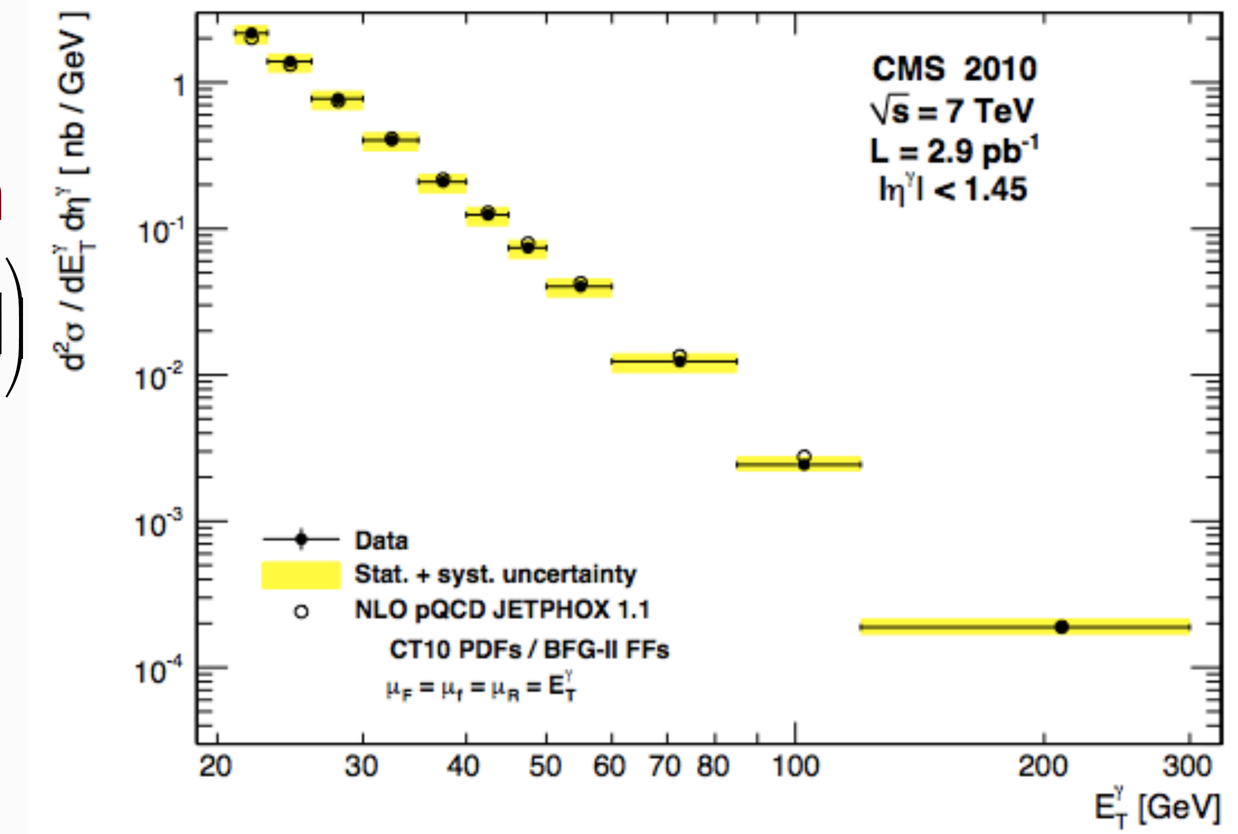
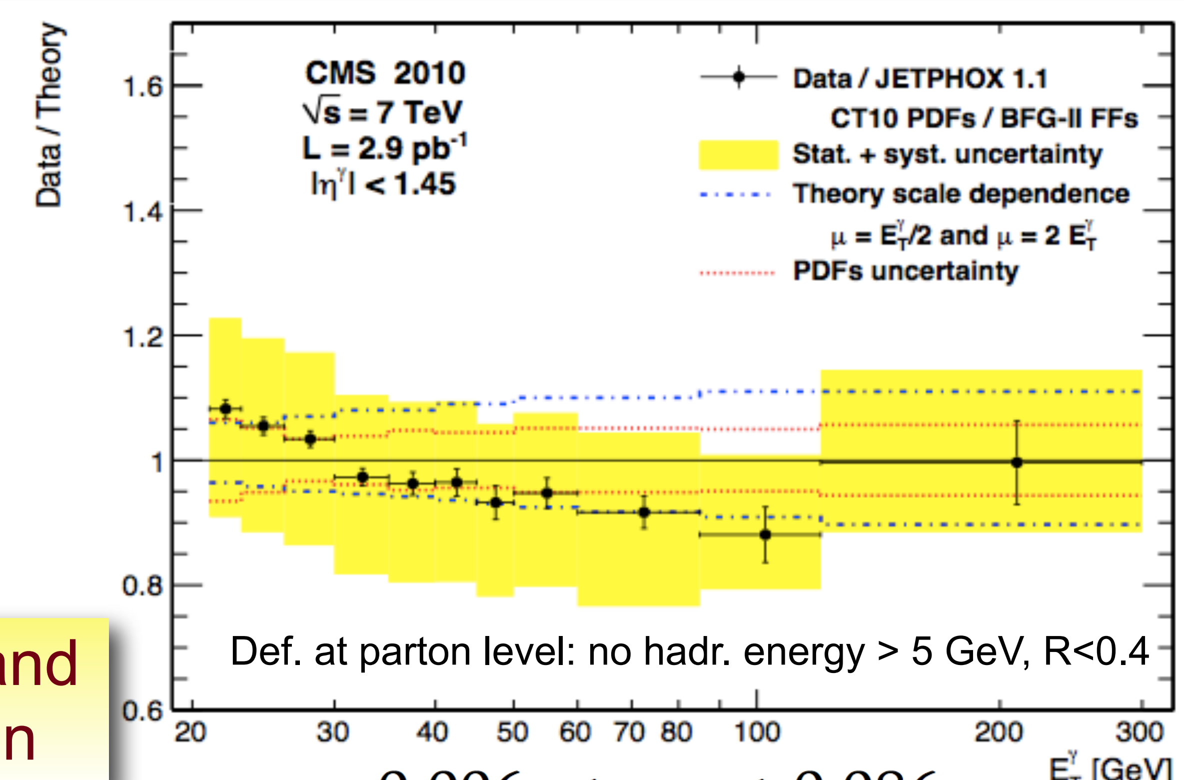




Lumi error (11%) not included



$0.006 < x_T < 0.086$

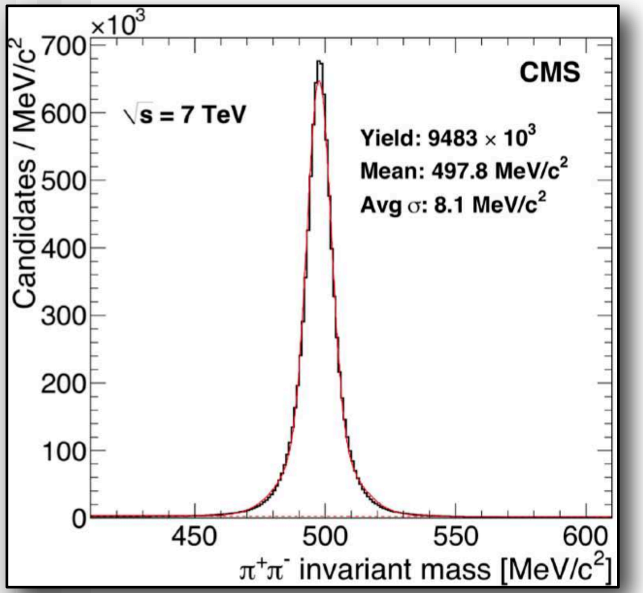
Measurement at higher Q^2 and lower $x_t = 2E_t/\sqrt{s}$ than Tevatron

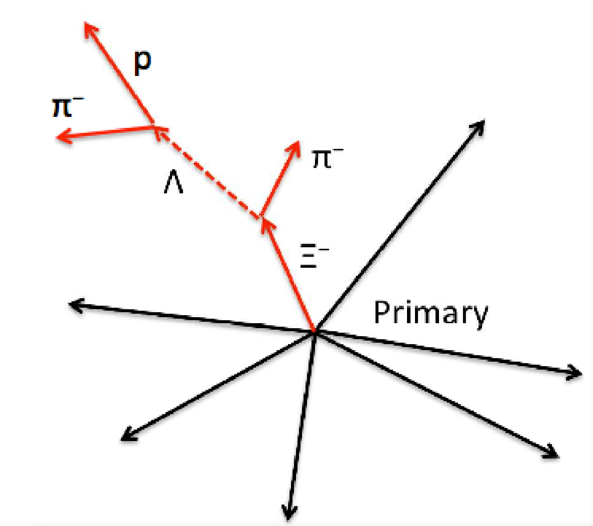
Production of “heavy” quarks:

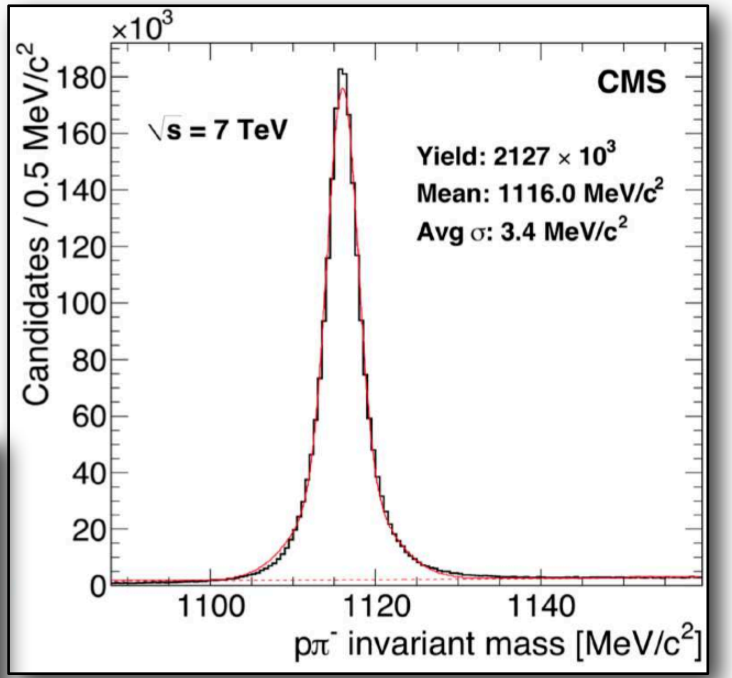
s → Quarkonia → b → top

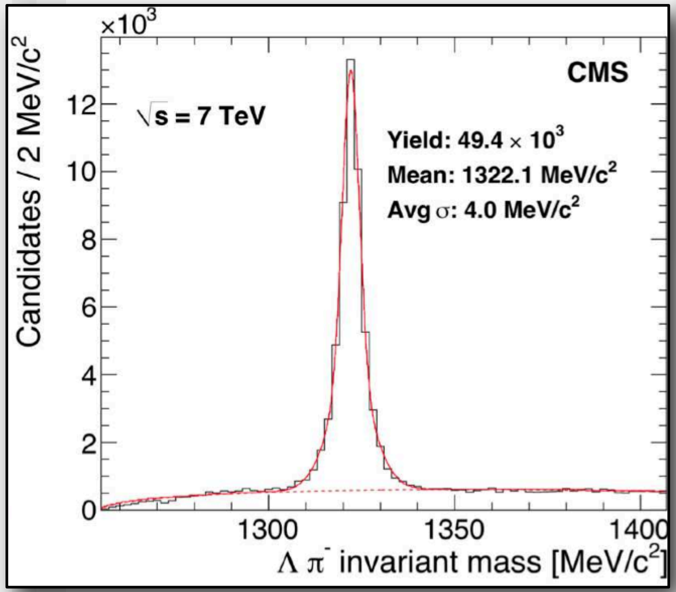
Strangeness Production

- Reconstruction of K_S, Λ, Ξ^-



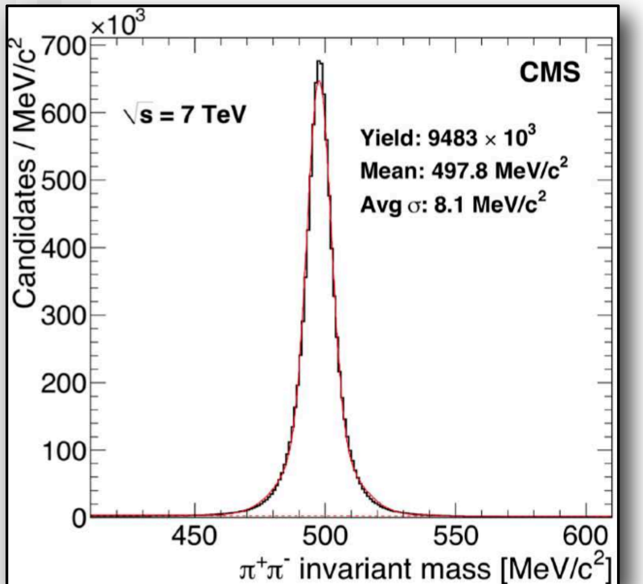


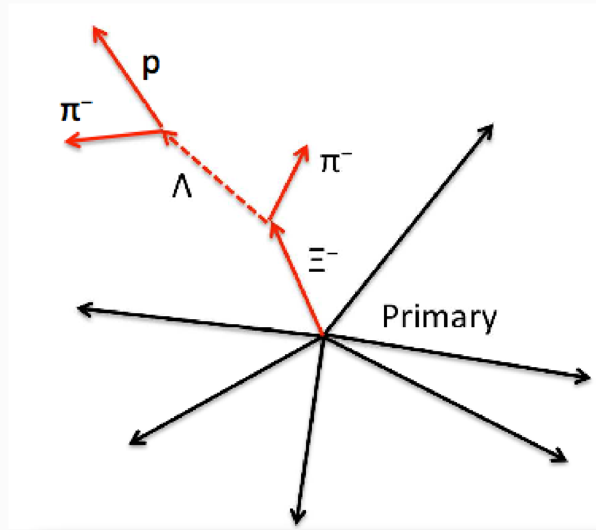


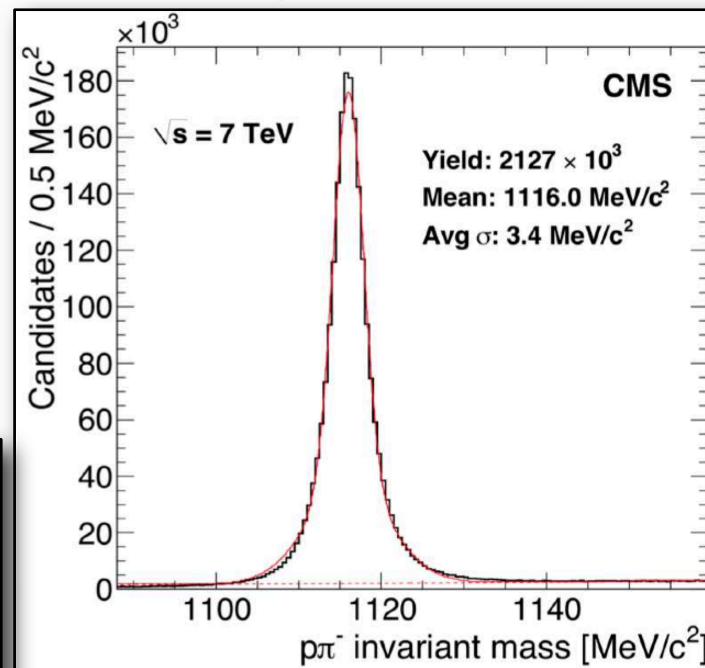


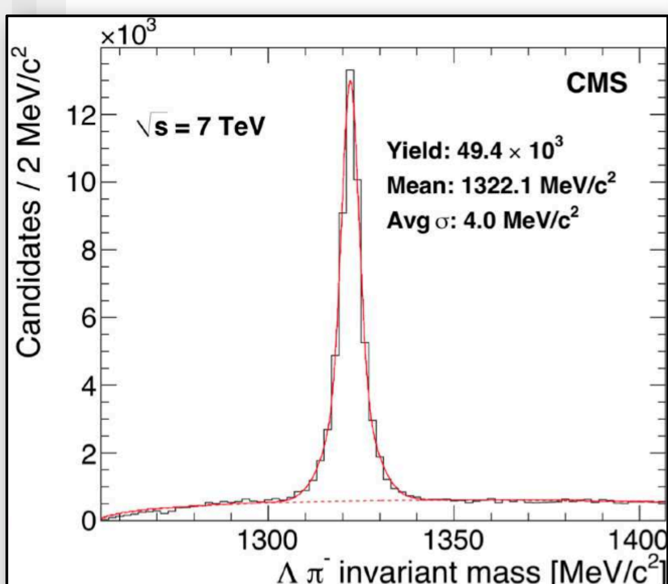
Strangeness Production **NEW !**

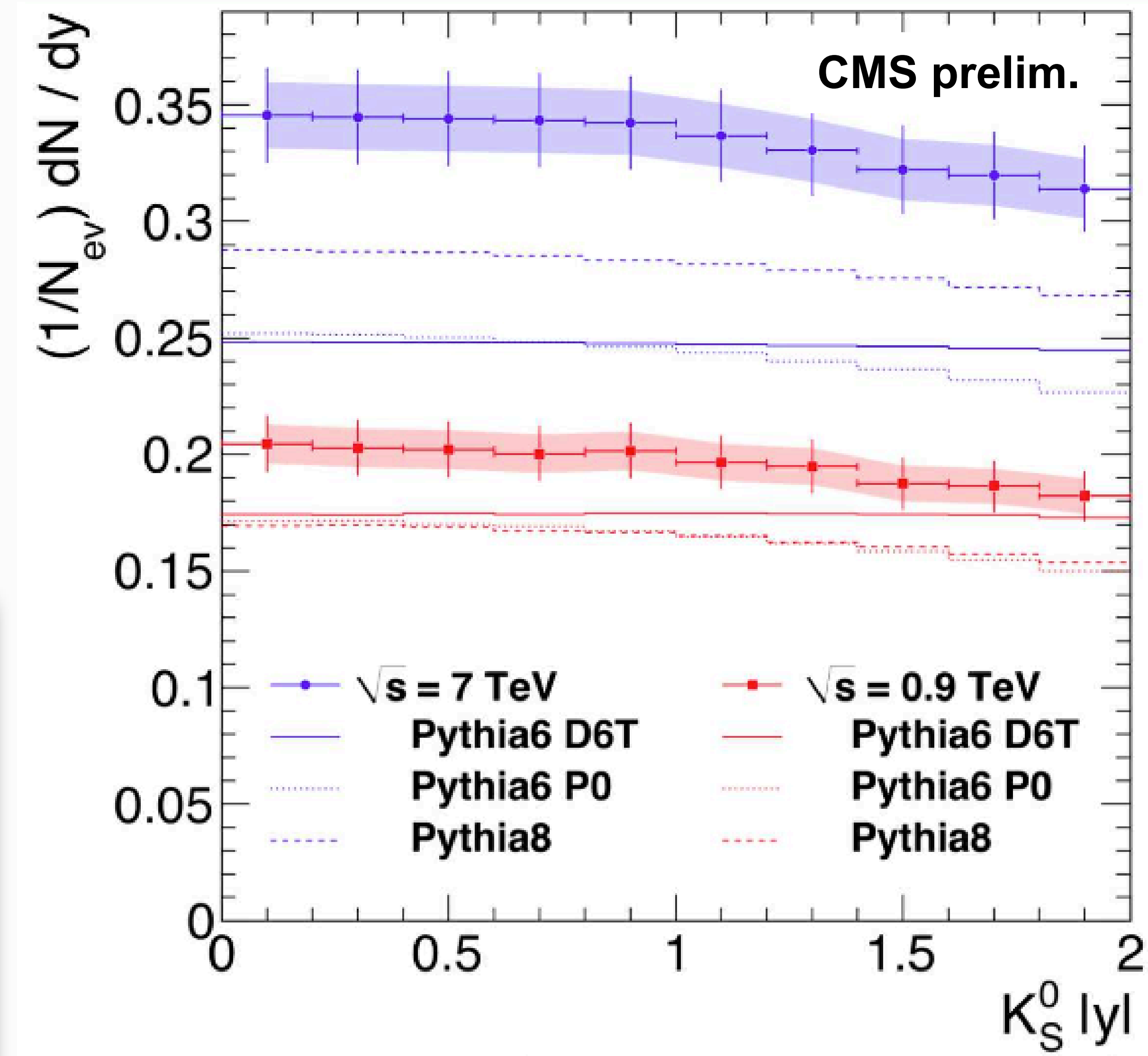
- Reconstruction of K_S, Λ, Ξ^-







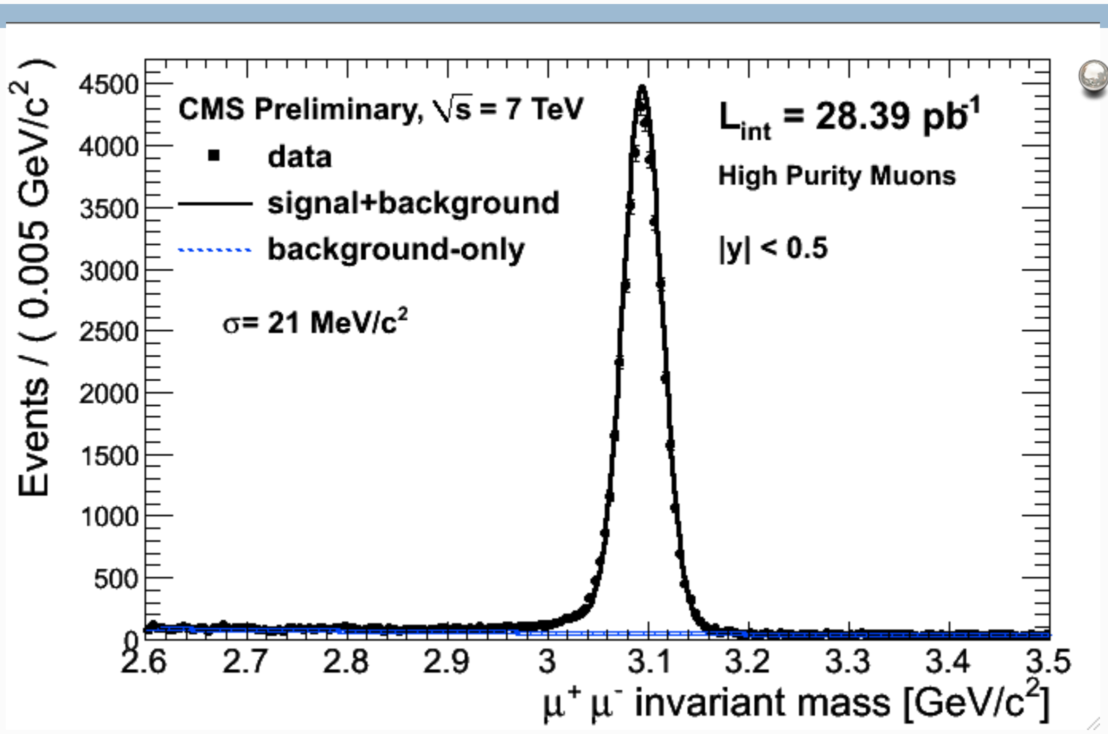




Particle	dN/dy@y=0(MC)/dN/dy@y=0(data)	
	0.9 TeV	7 TeV
K_S	0.852±0.005±0.061	0.719±0.001±0.052
Λ	0.609±0.007±0.070	0.518±0.002±0.060
Ξ	0.475±0.021±0.071	0.374±0.021±0.071

Striking diff. Data-MC, increases with strangeness content

J/ψ production cross sections



Acceptance strongly dependent on polarization!

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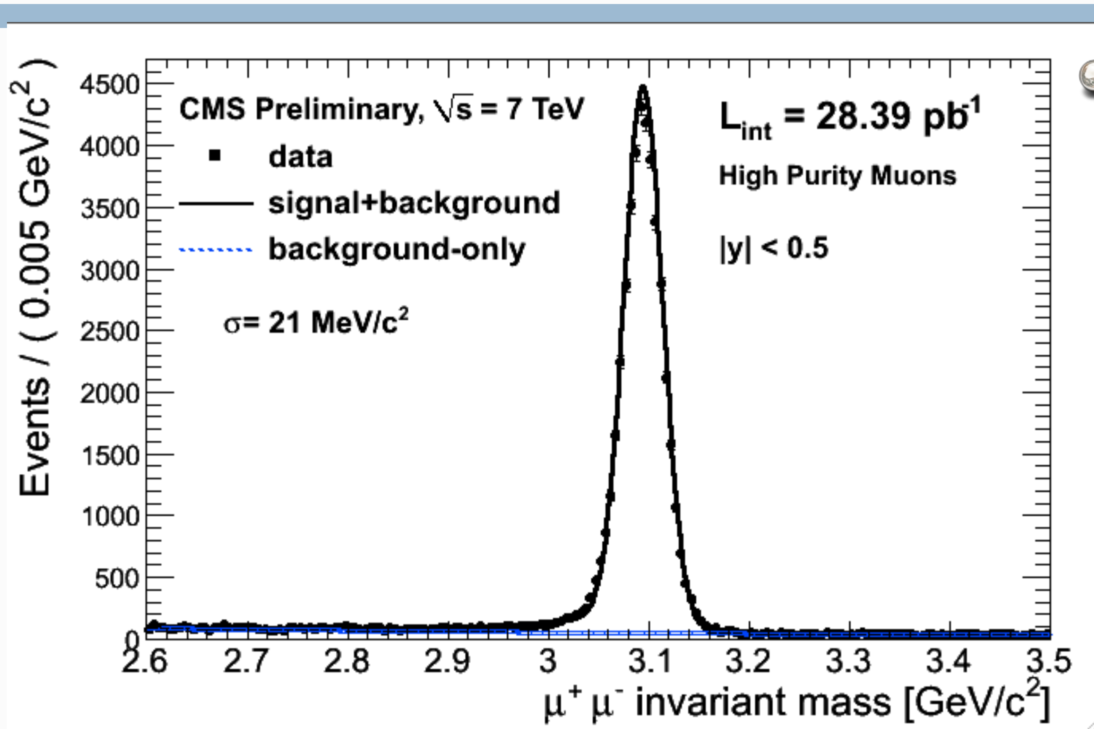

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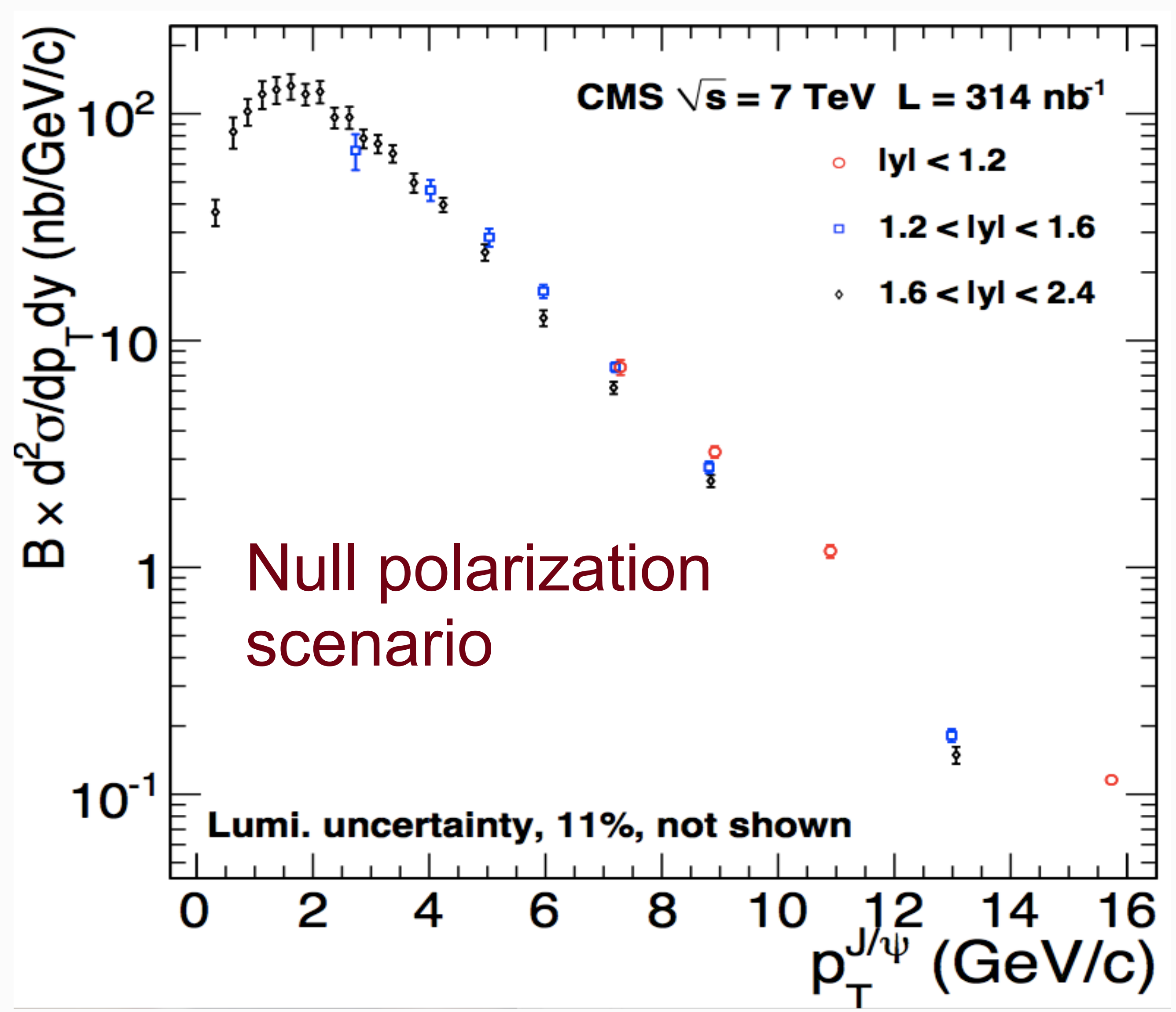


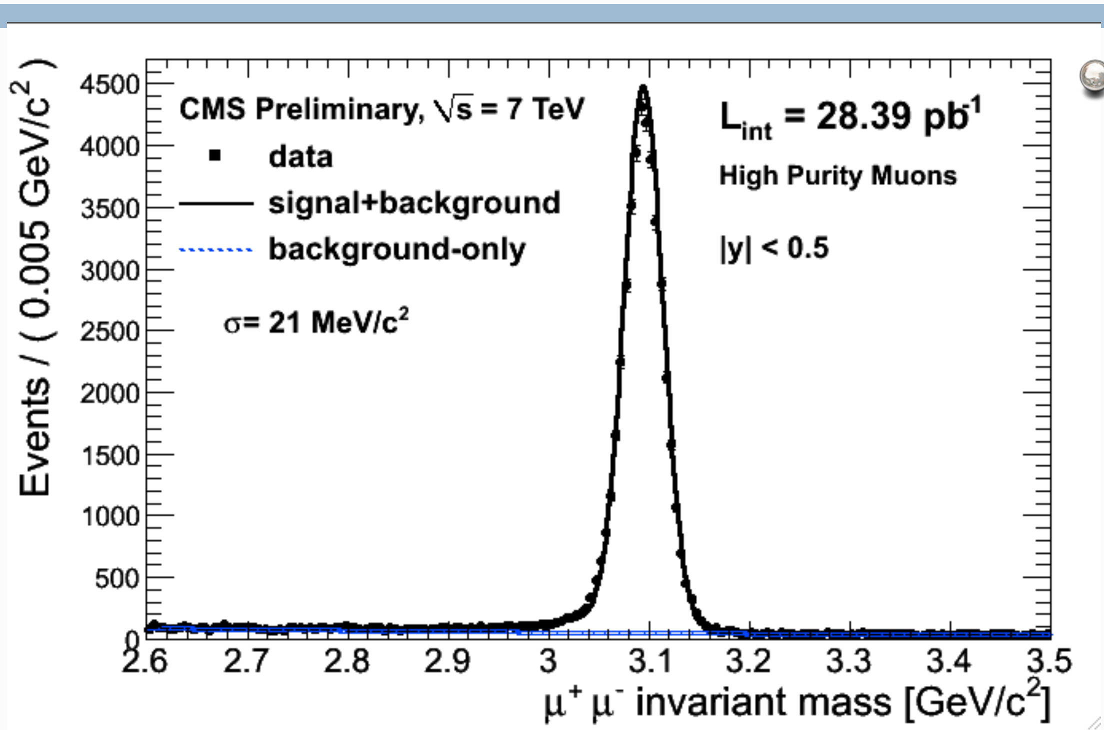
for transverse momenta between 6.5 and 30 GeV/c and $|y| < 2.4$

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

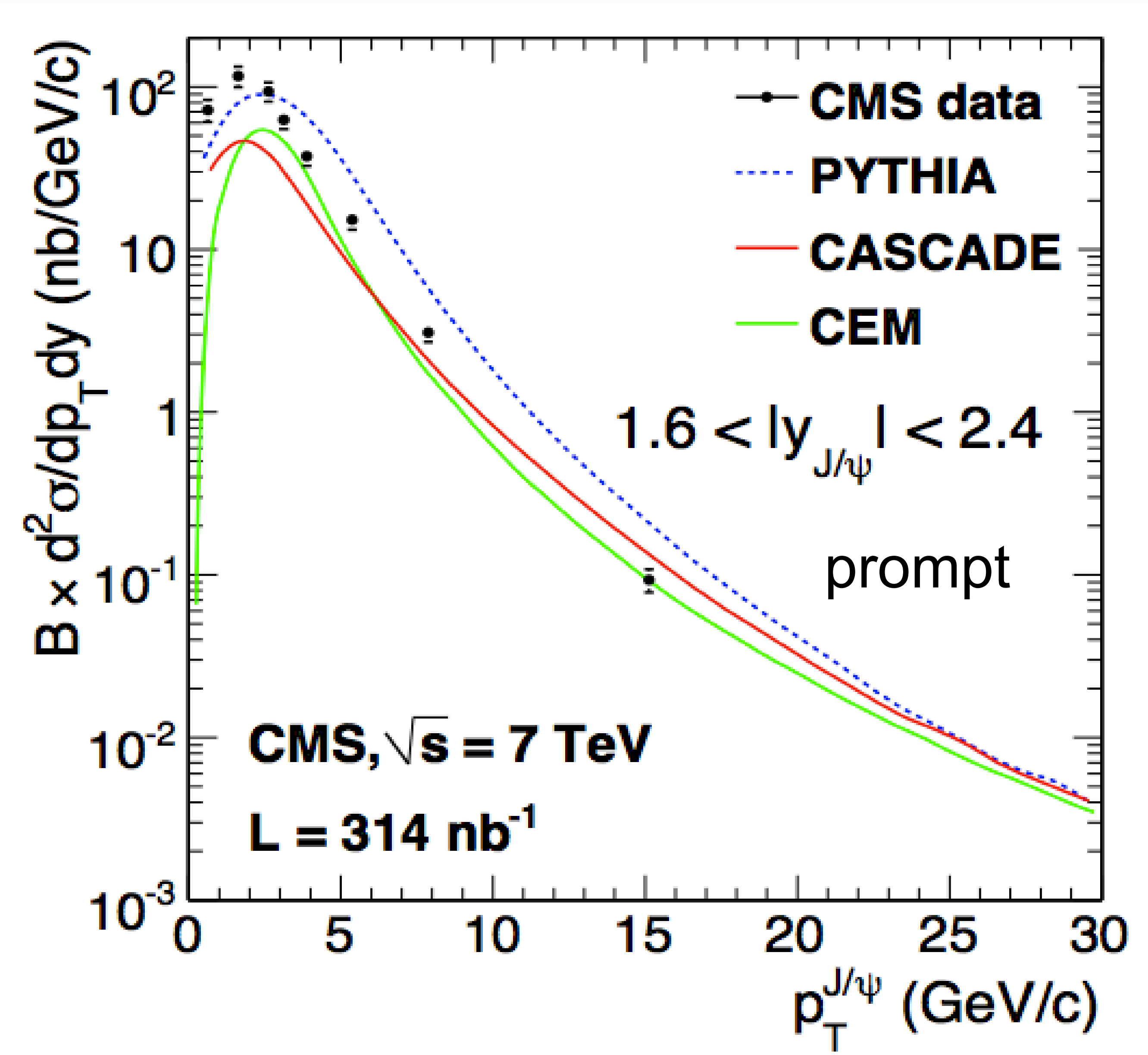
$$BR(\mathrm{J}/\psi \to \mu^+\mu^-) \cdot \sigma(\mathrm{pp} \to bX \to \mathrm{J}/\psi X) = 26.0 \pm 1.4 \pm 1.6 \pm 2.9\ \mathrm{nb}$$

arXiv 1011.4193

J/ψ production cross sections



Acceptance strongly dependent on polarization!



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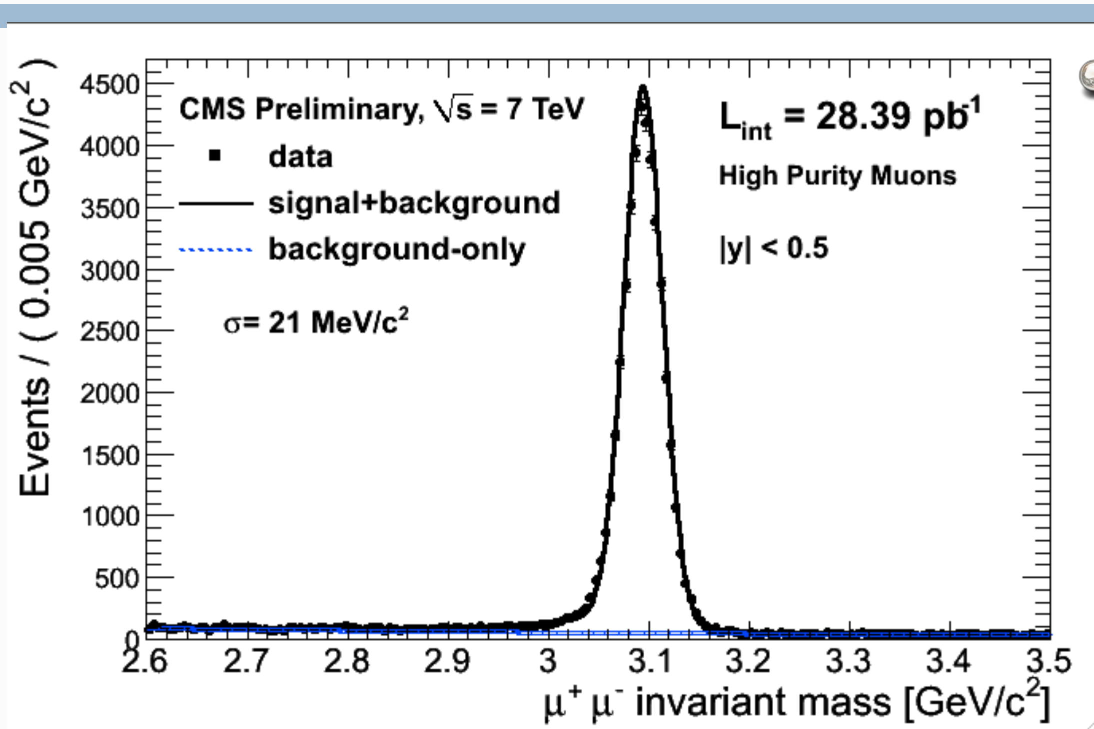

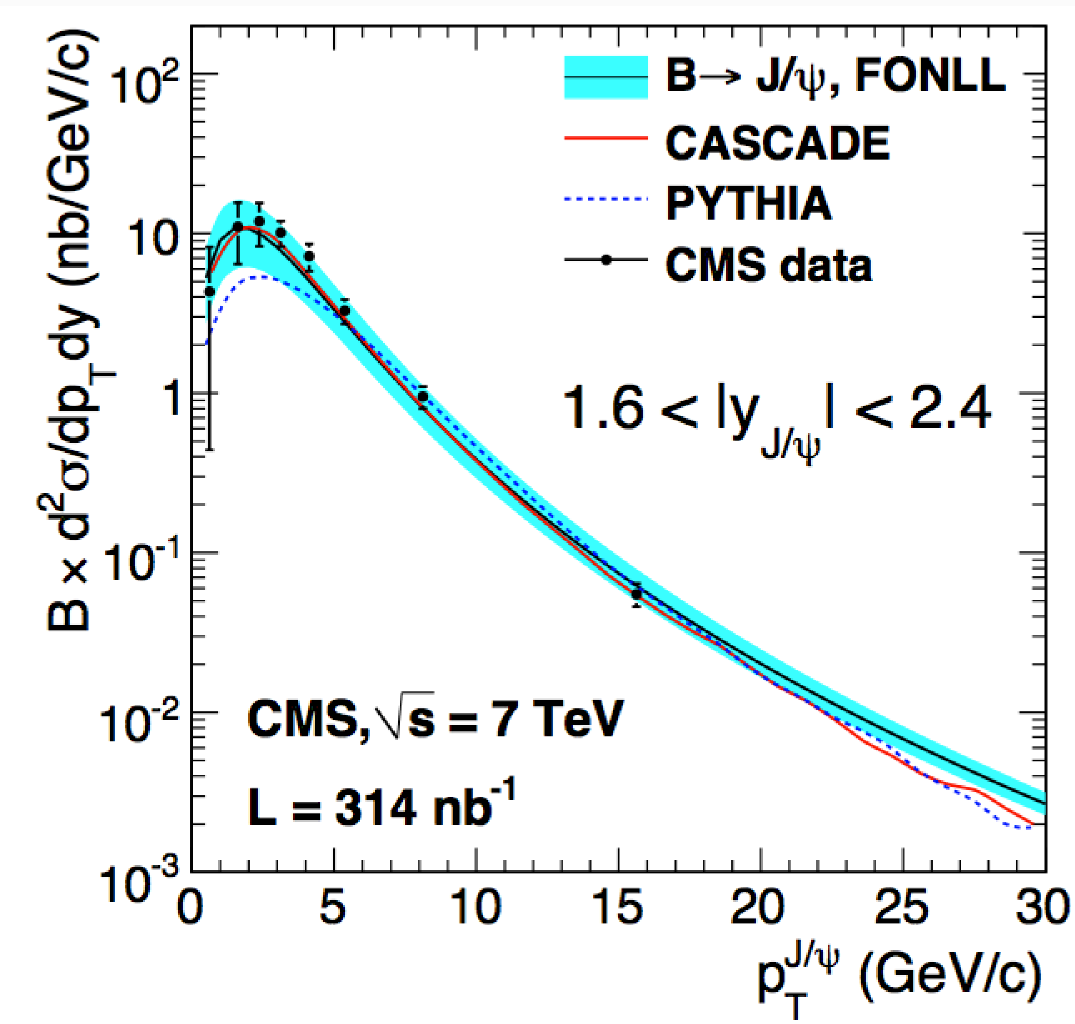

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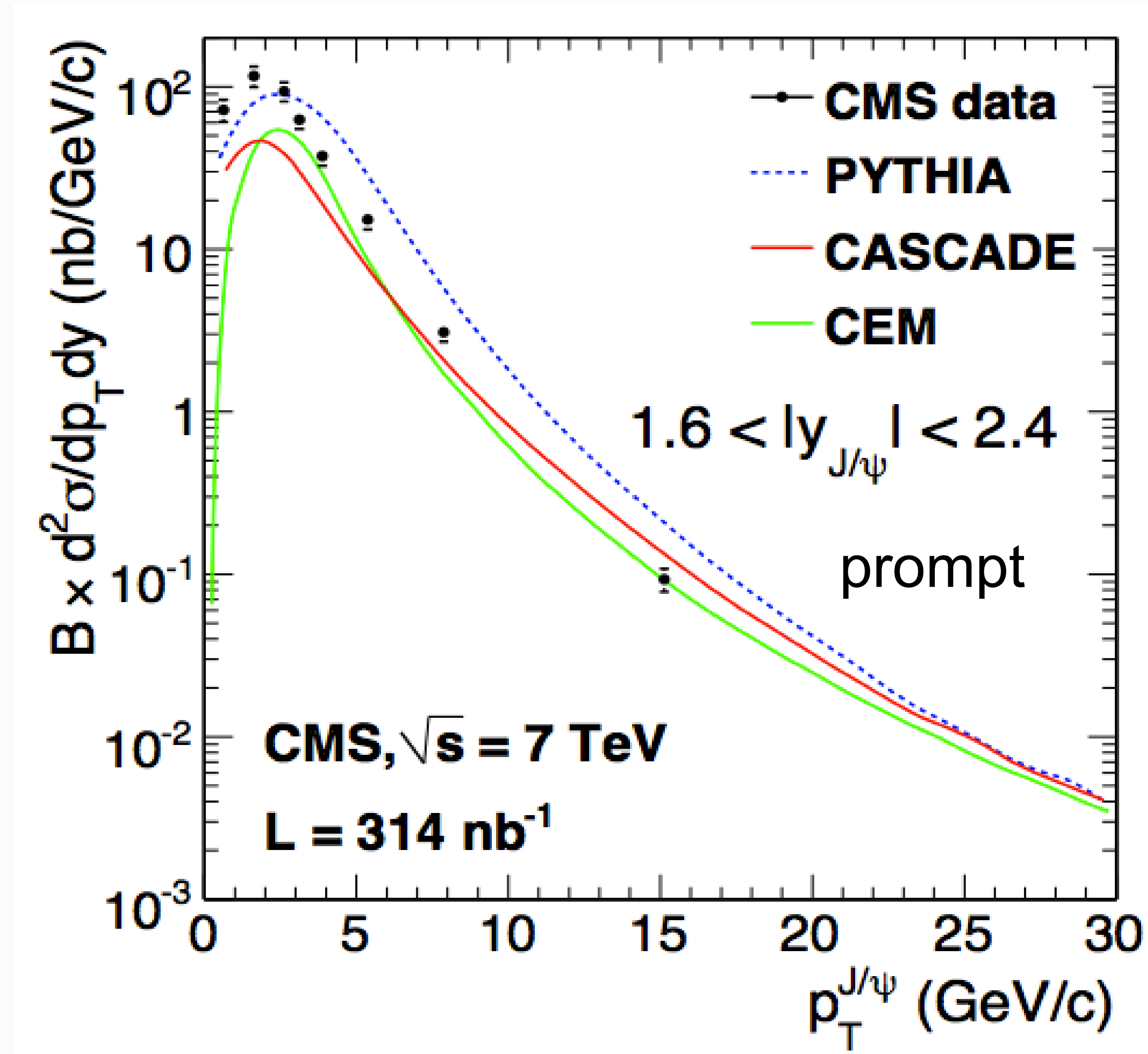

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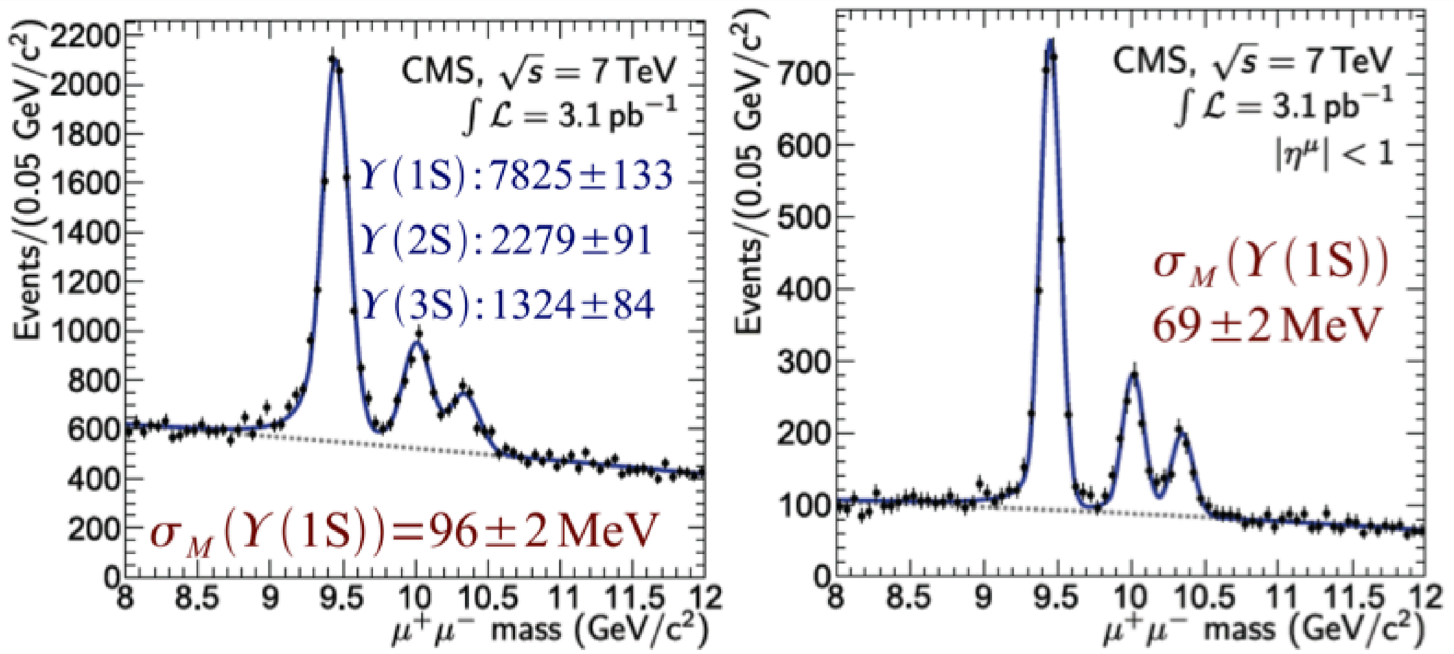
arXiv 1011.4193

Υ production

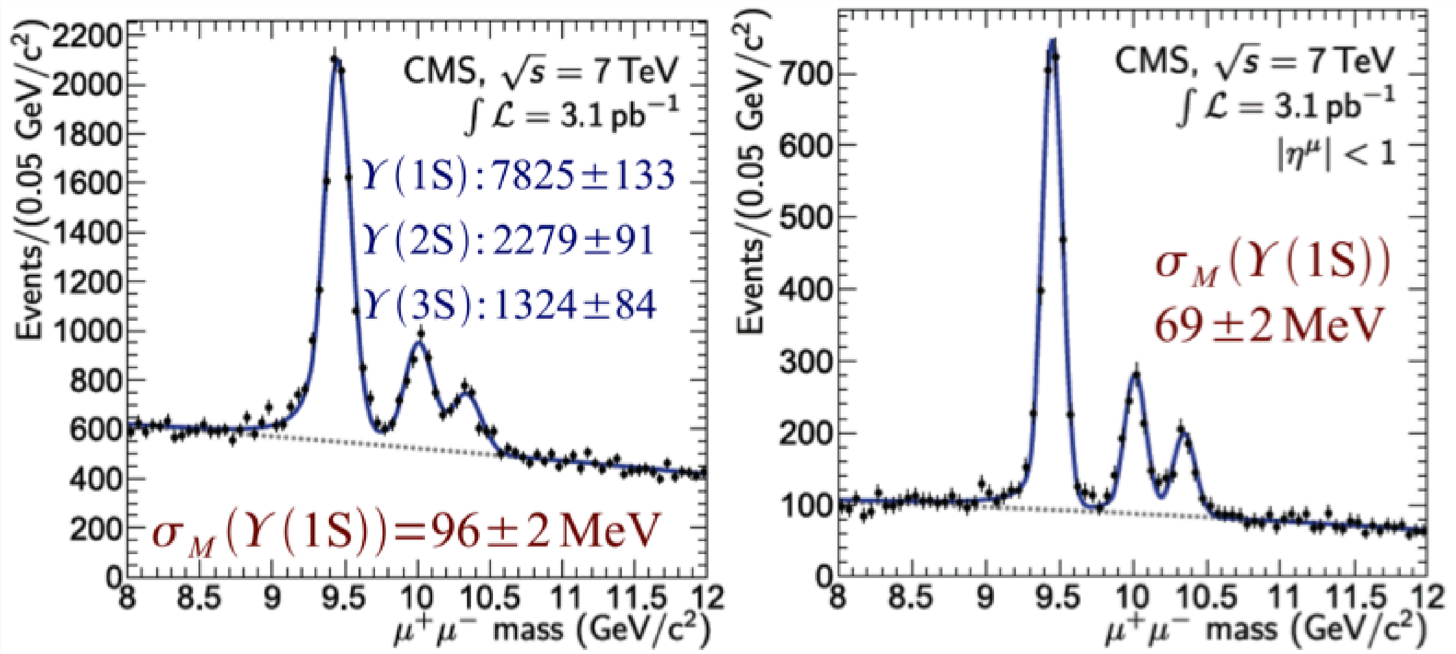
arXiv 1012.5545



(2S,3S) vs 1S mass difference fixed to PDG value in the fit

Υ production

arXiv 1012.5545



(2S,3S) vs 1S mass difference fixed to PDG value in the fit

Also measured:
2S/3S over 1S ratio

Polarization not included: +- 20 % effect

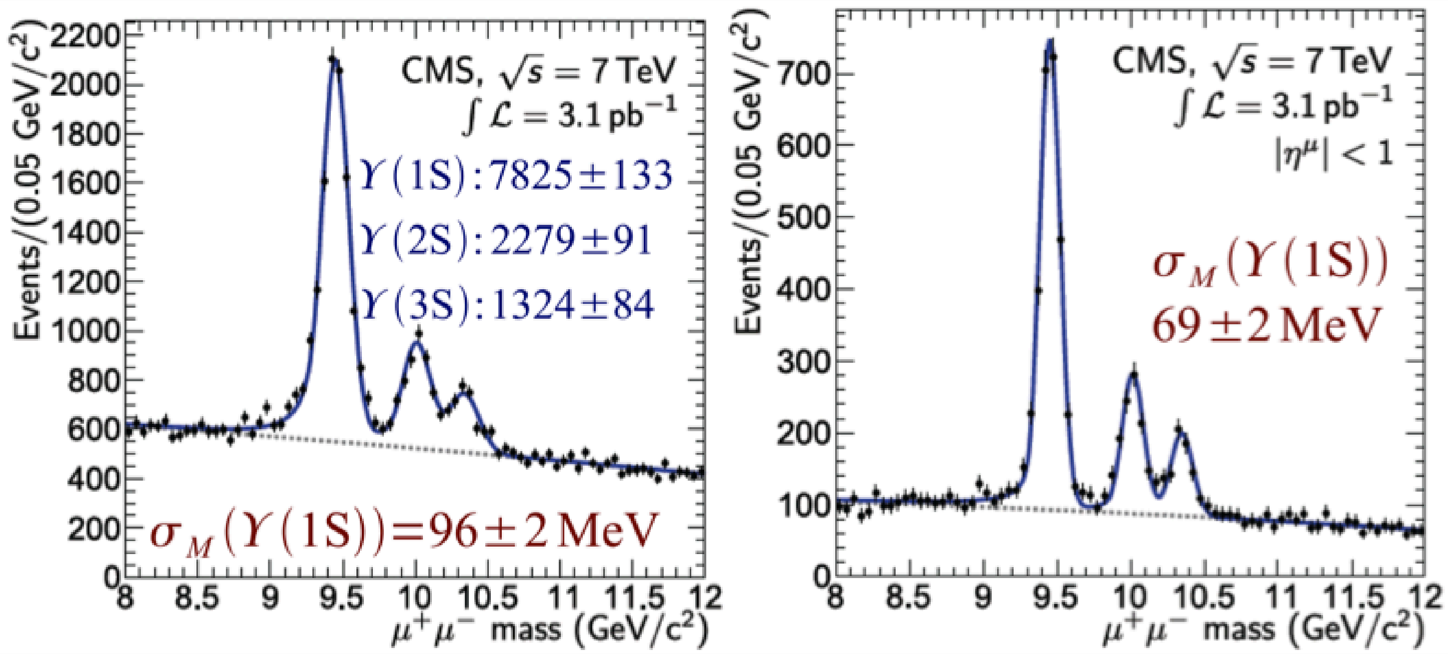
$$\sigma(pp \to \Upsilon(1S)X) \cdot \mathcal{B}(\Upsilon(1S) \to \mu^+\mu^-) = (7.49 \pm 0.13(\text{stat.})^{+0.67}_{-0.49}(\text{syst.}) \pm 0.82(\text{lumi.}))\ \text{nb},$$

$$\sigma(pp \to \Upsilon(2S)X) \cdot \mathcal{B}(\Upsilon(2S) \to \mu^+\mu^-) = (1.93 \pm 0.08(\text{stat.})^{+0.19}_{-0.14}(\text{syst.}) \pm 0.21(\text{lumi.}))\ \text{nb},$$

$$\sigma(pp \to \Upsilon(3S)X) \cdot \mathcal{B}(\Upsilon(3S) \to \mu^+\mu^-) = (1.04 \pm 0.07(\text{stat.})^{+0.12}_{-0.09}(\text{syst.}) \pm 0.11(\text{lumi.}))\ \text{nb}.$$

Υ production

arXiv 1012.5545



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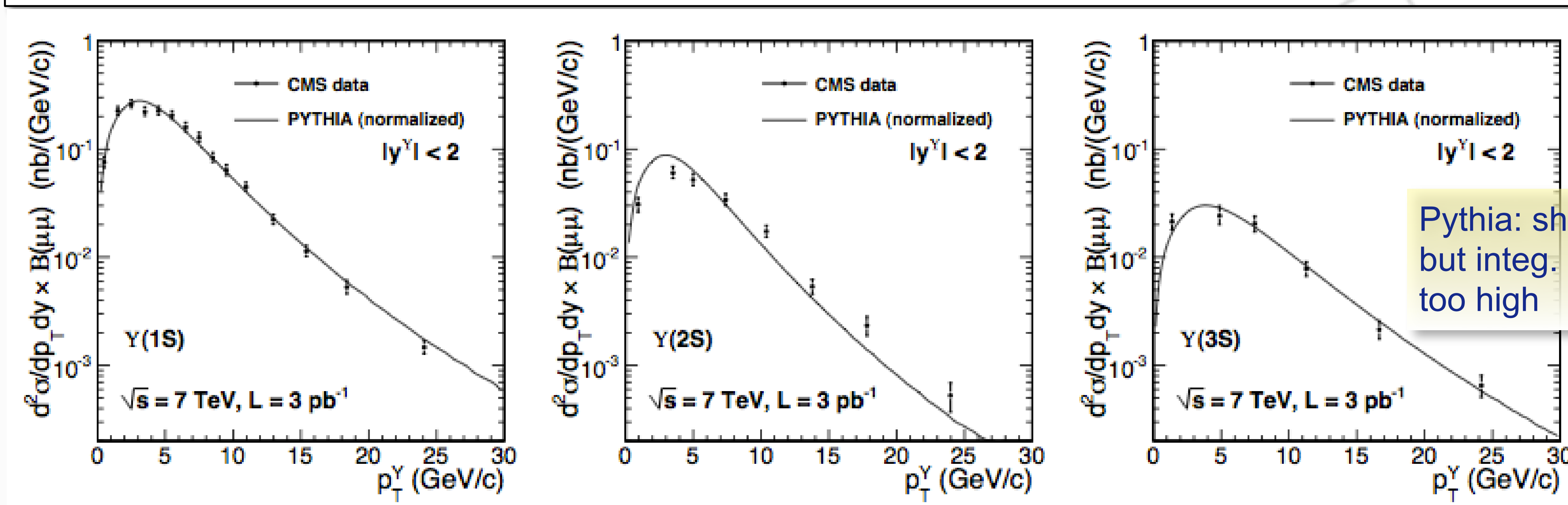


Pythia: shape ok, but integ. x-sec 2x too high

B-quark identification

ETH Institute for Particle Physics

- **Identification with semi-leptonic decay into muons**
  - Low momentum (3 GeV) single-muon trigger thresholds at CMS startup; Method based on p_T^{rel} of muon to nearest jet
  - Can probe inclusive beauty production at low momentum

CMS-PAS-BPH-10-007

- **Secondary vertex identification**
  - Exploit high precision of pixel tracker and long B hadrons lifetimes
  - Efficient secondary vertex reconstruction for E_T^{jet}>20 GeV
  - Excellent for b-jet studies at larger momenta
  - Inclusive secondary vertex finder as a powerful tool for angular correlation studies

CMS-PAS-BPH-10-009

CMS-PAS-BPH-10-010

- **B-hadron exclusive decay reconstruction**
  - Competitive performance in J/ψ X decay channels with J/ψ → mu^+mu^-
  - First published result: $B^+ \rightarrow J/\psi\ K^+$ differential cross section

CERN-PH-EP-2010-087

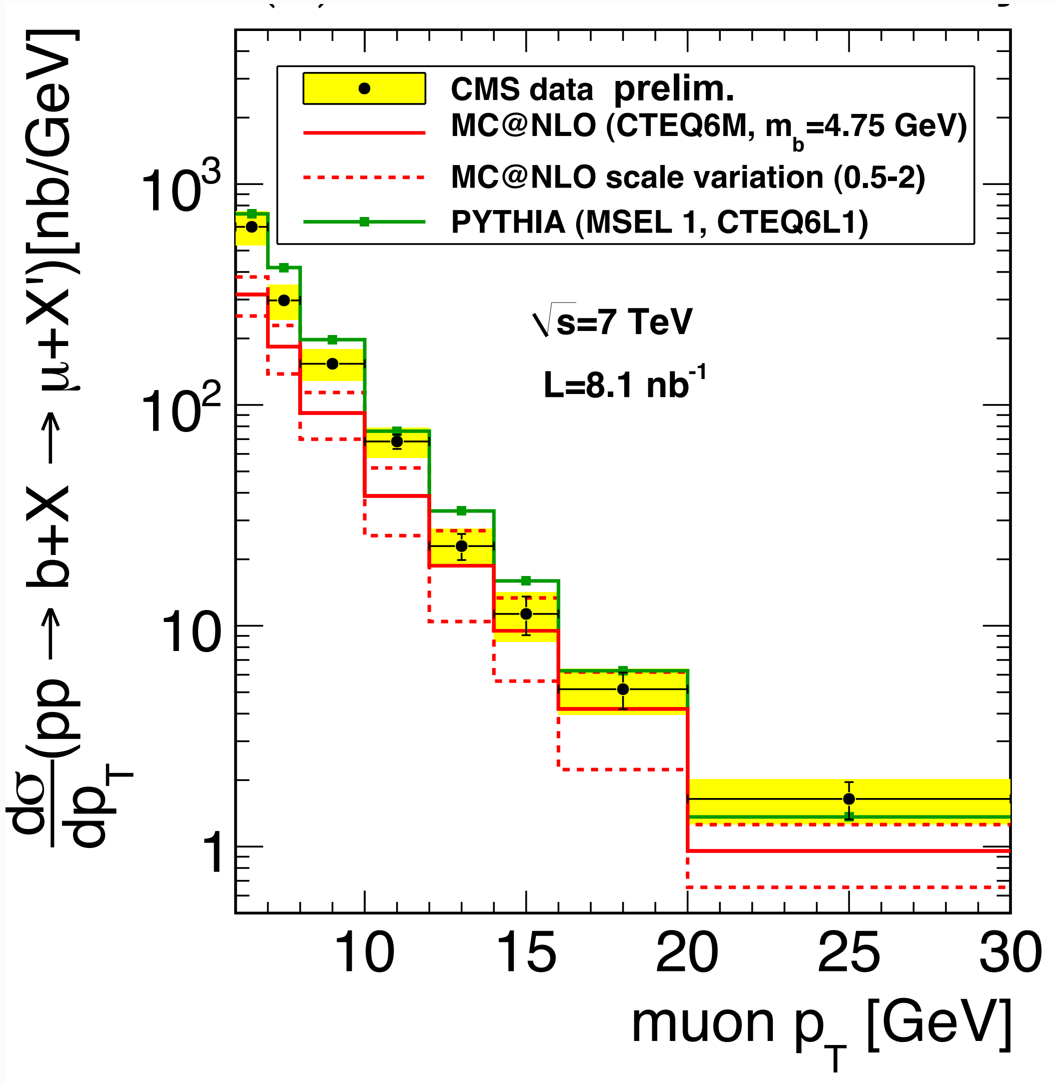
ICHEP2010 results

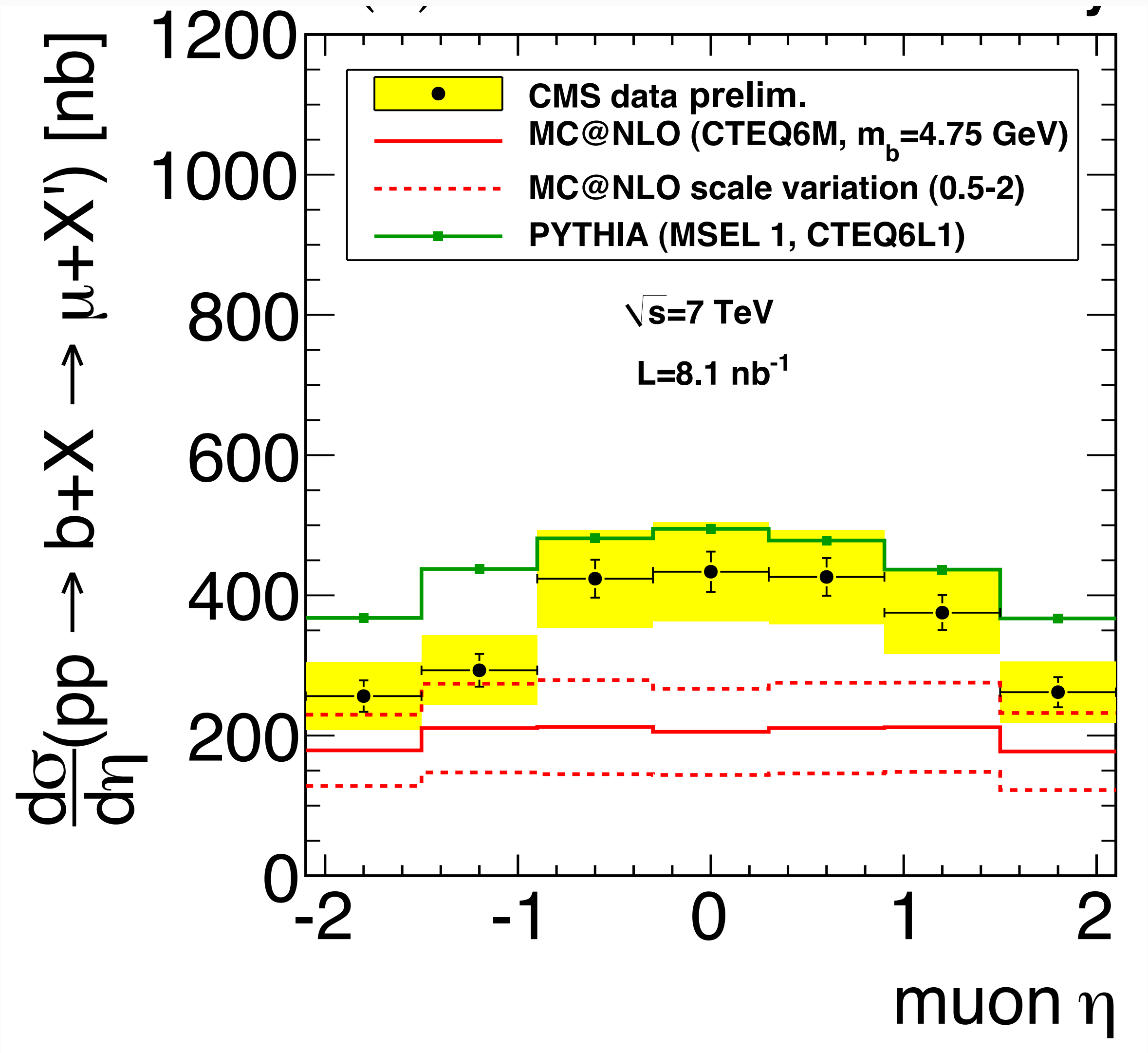
New results!

from: V. Chiochia, Pauli-Workshop, Zurich, Jan 2011

Differential cross sections

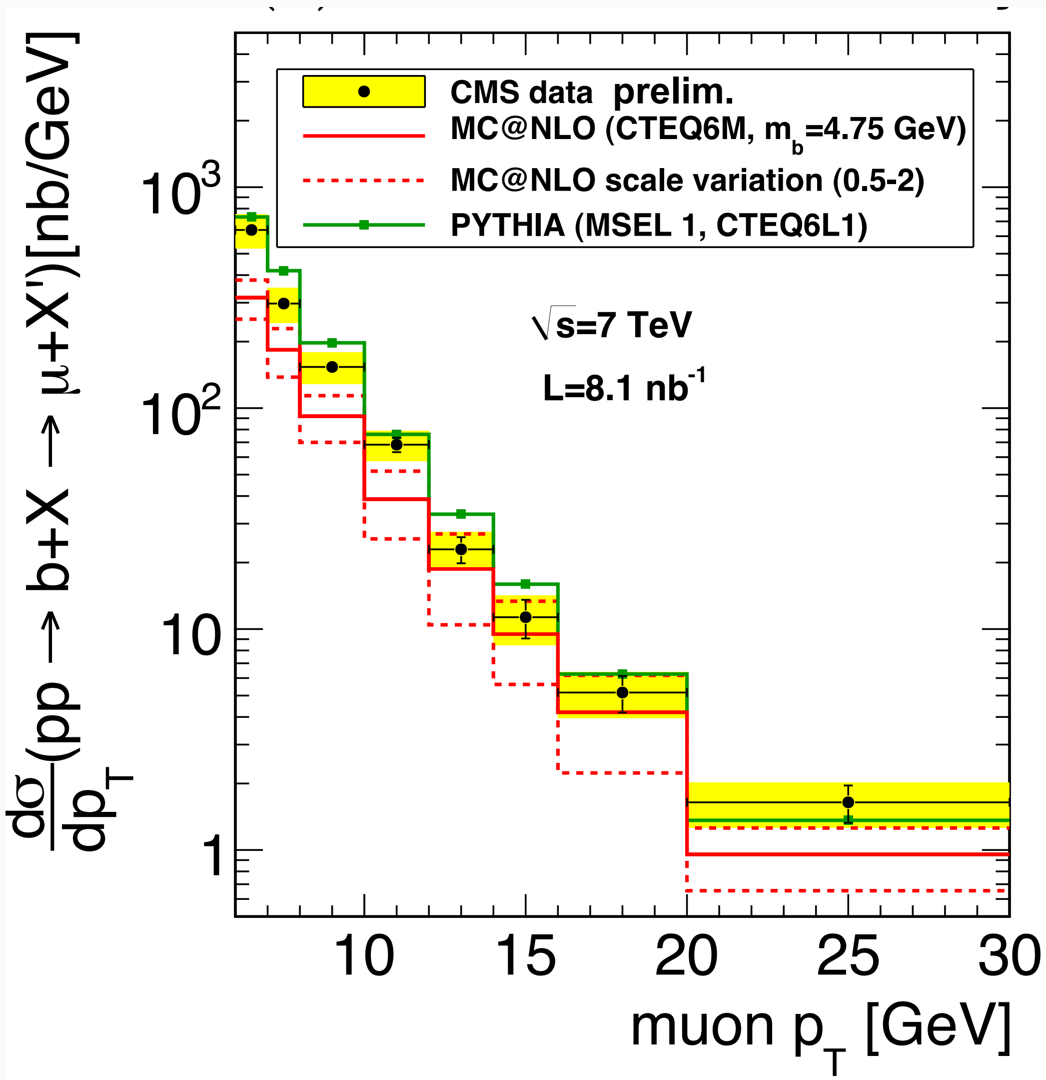
BPH-10-007

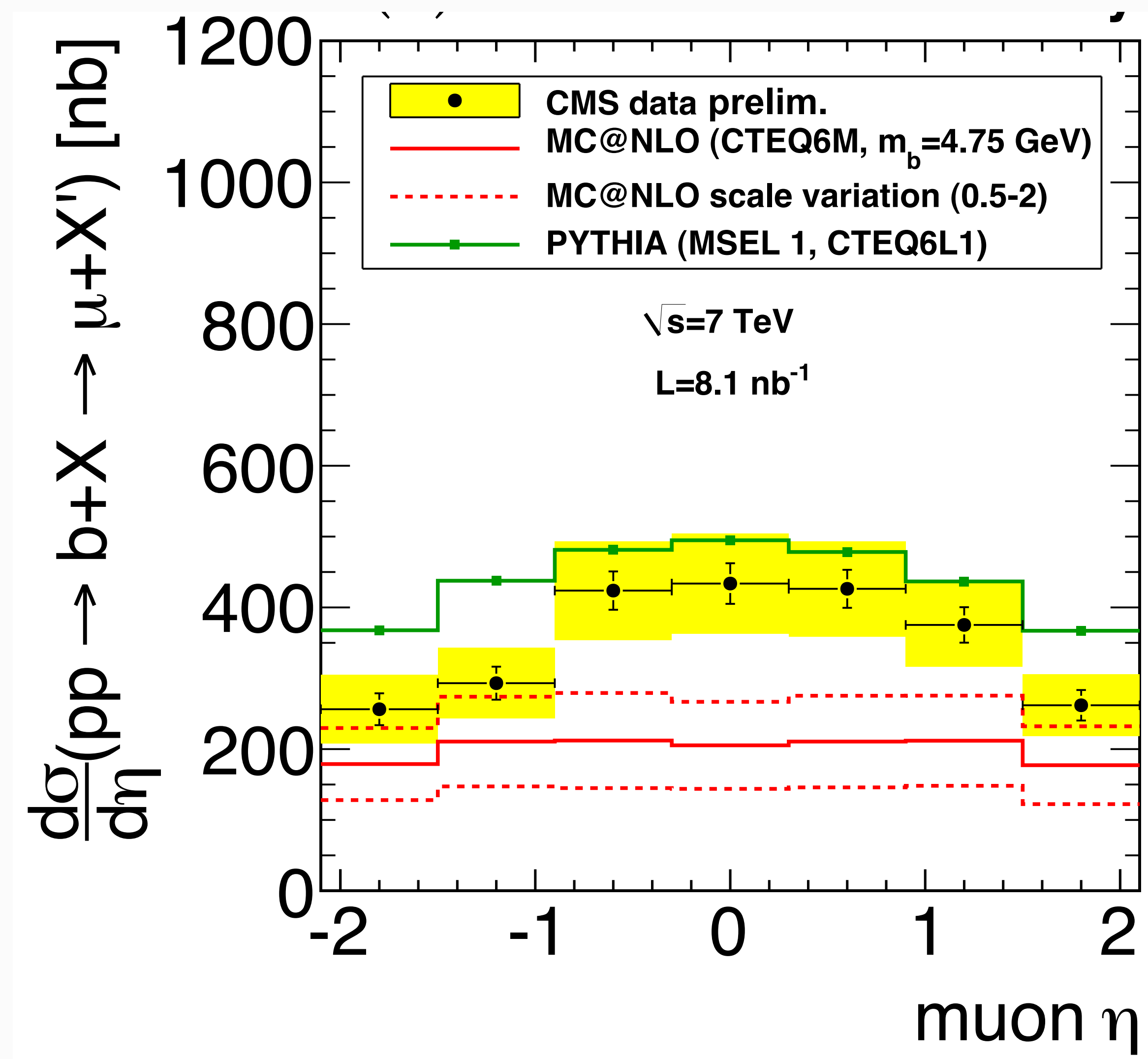




Differential cross sections

BPH-10-007





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

Measured visible cross section $p_{t,\mu} > 6$ GeV $|\eta_\mu| < 2.1$

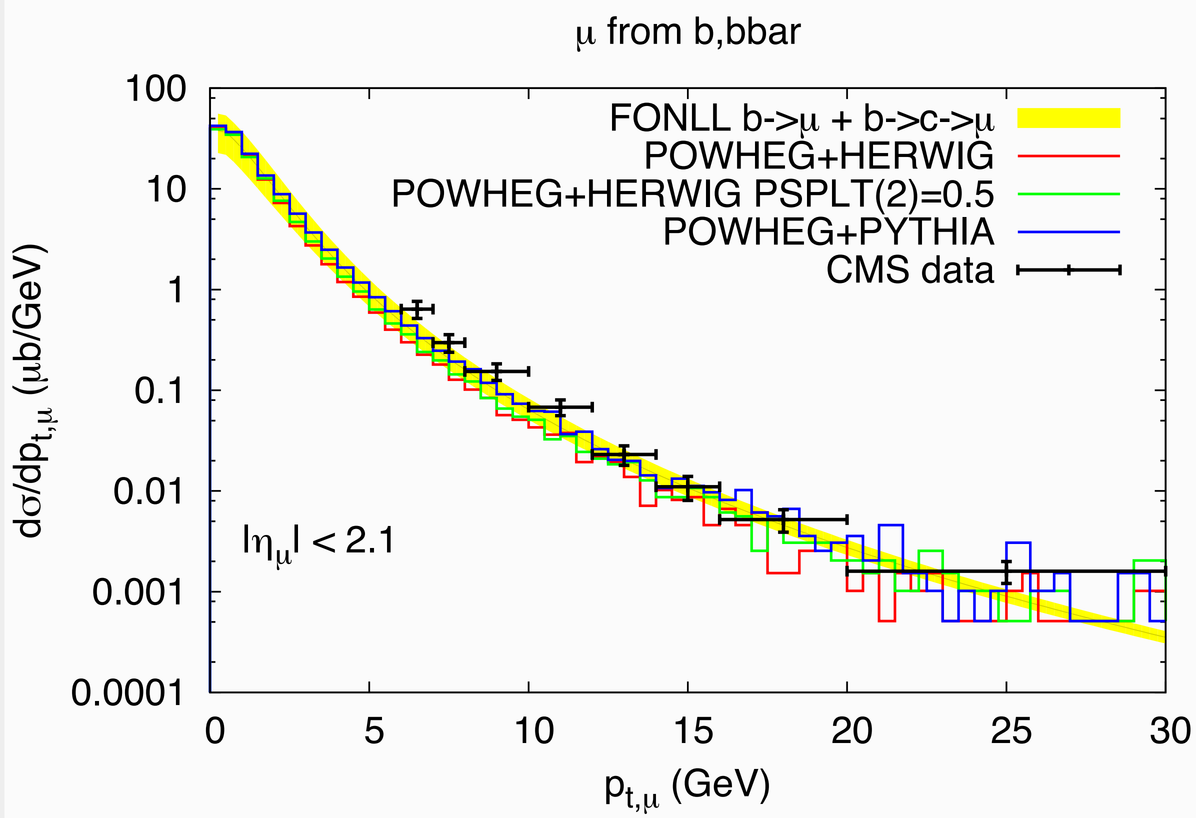
$$\sigma_{\mathrm{PYTHIA}} = 1.8\ \mu\mathrm{b}$$

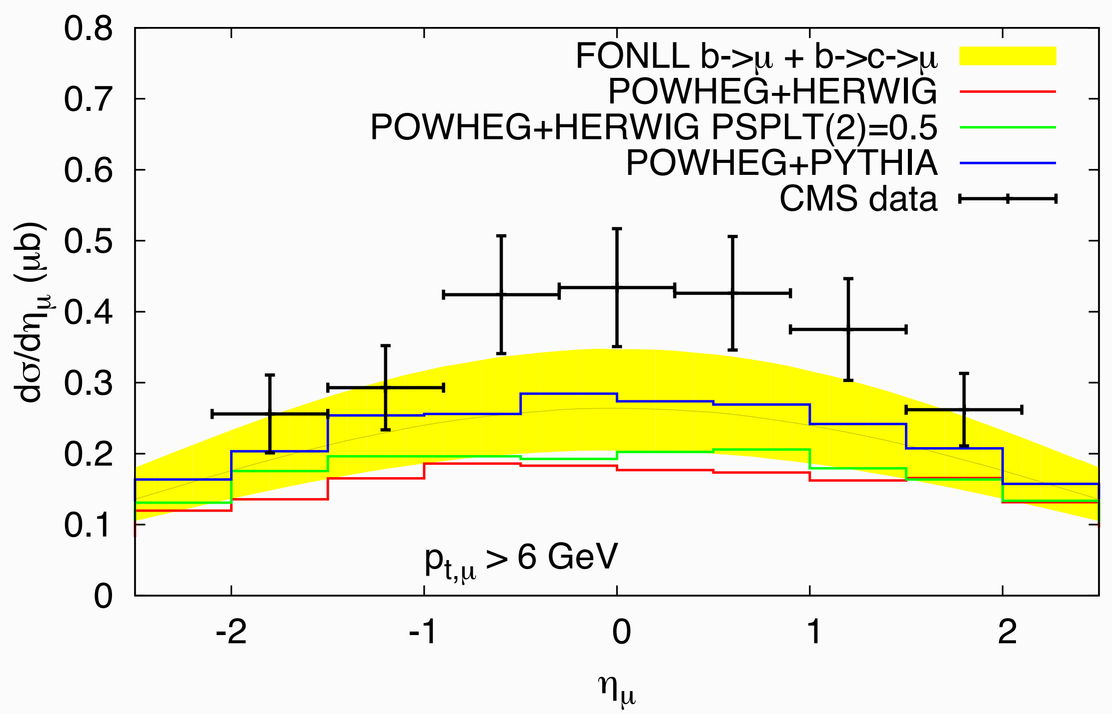
$$\sigma_{\mathrm{MC@NLO}} = [0.84^{+0.36}_{-0.19}(\mathrm{scale}) \pm 0.08(m_b) \pm 0.04(\mathrm{pdf})]\ \mu\mathrm{b}$$ $(\mu_F=\mu_R=p_T)$

Experimental uncertainties (15-20%) dominated by modeling of fake muons and underlying event

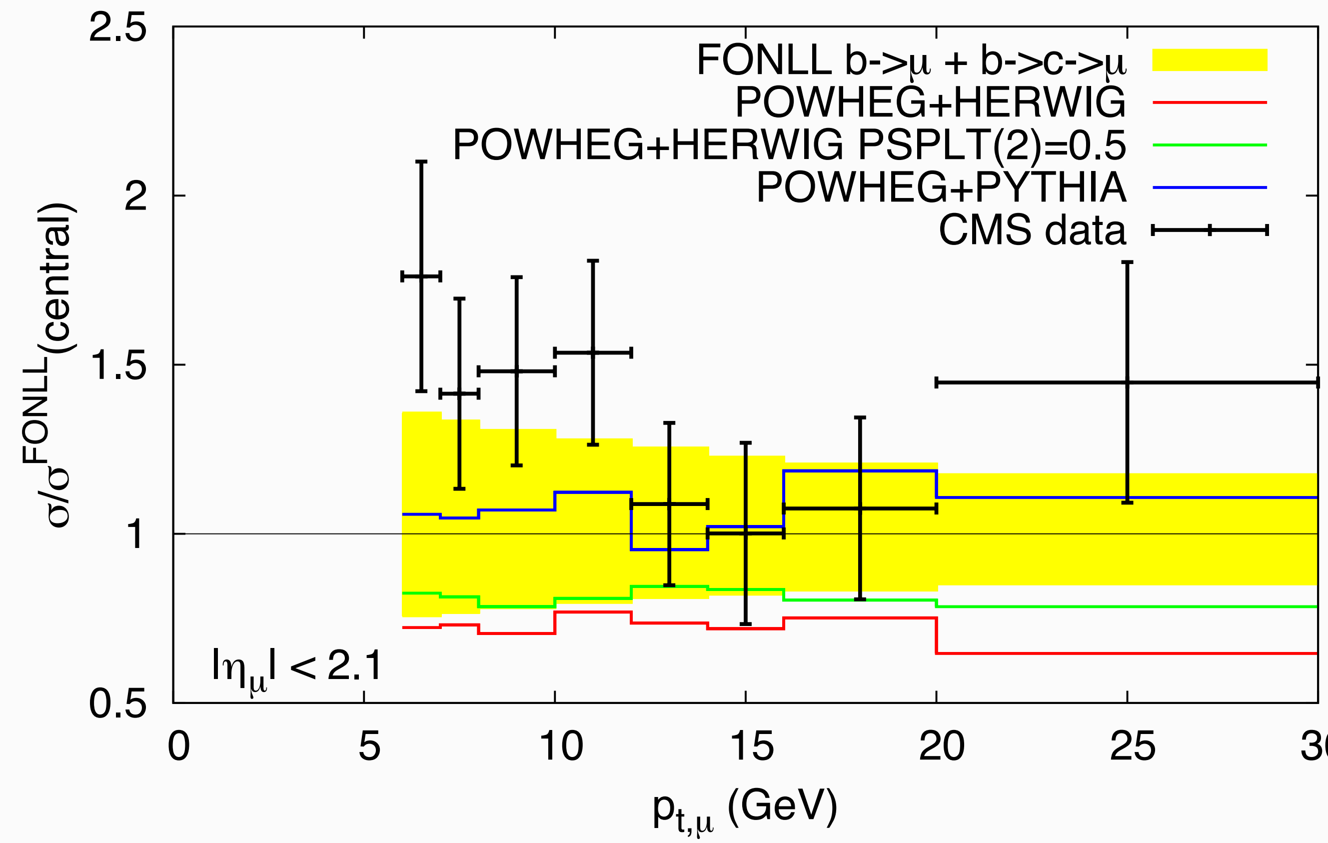
MC@NLO: larger discrepancies at low p_T^{muon} and central region

FONLL and POWHEG





M.Cacciari, P.Nason

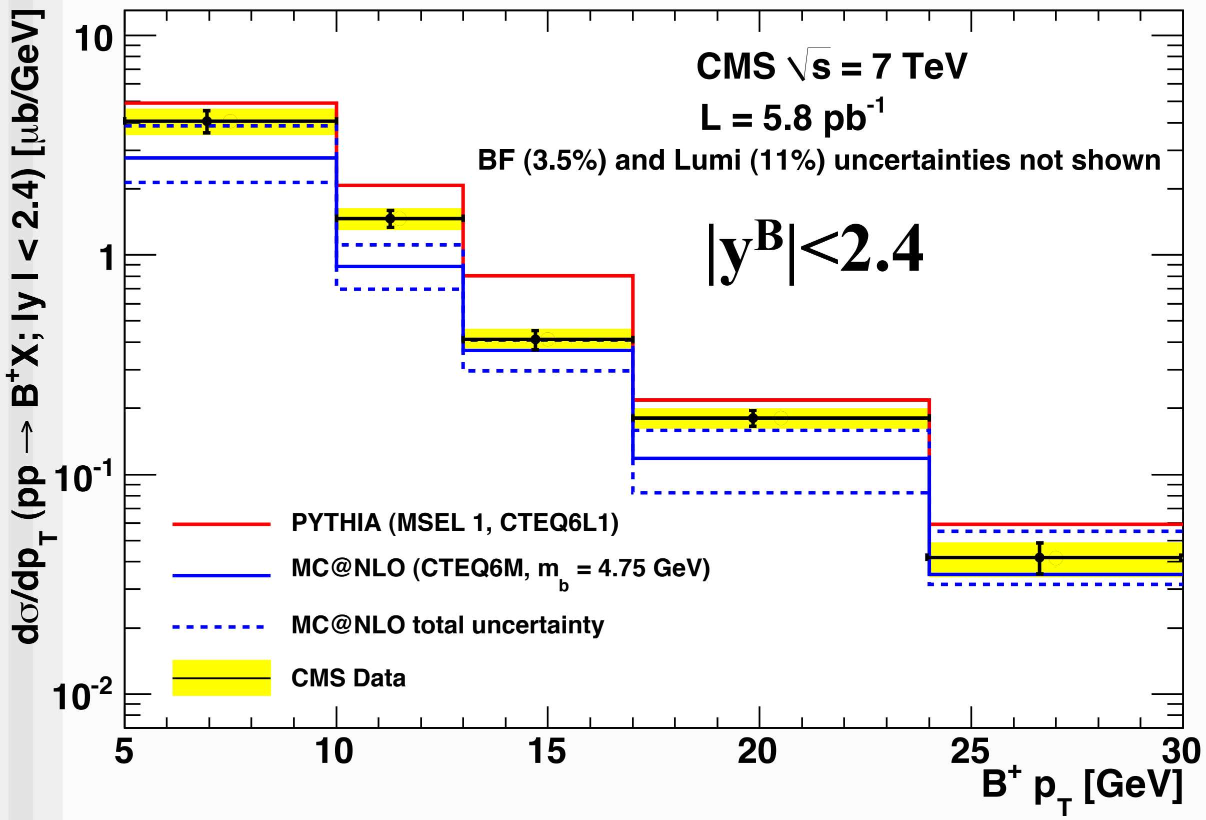


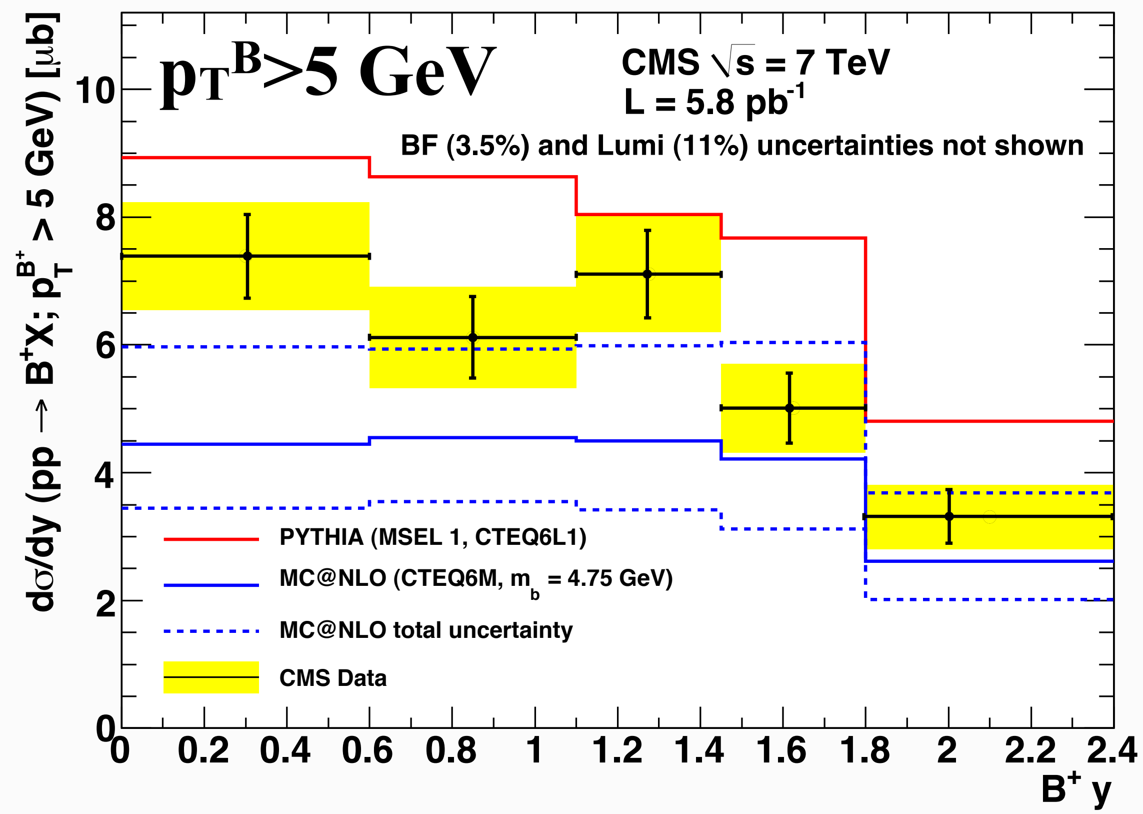
from: V. Chiochia, Pauli-Workshop, Zurich, Jan 2011

$B^+ \to J/\psi\, K^+$

arXiv:1101.0131

- Signal extracted from simultaneous fit to invariant mass and lifetime distributions





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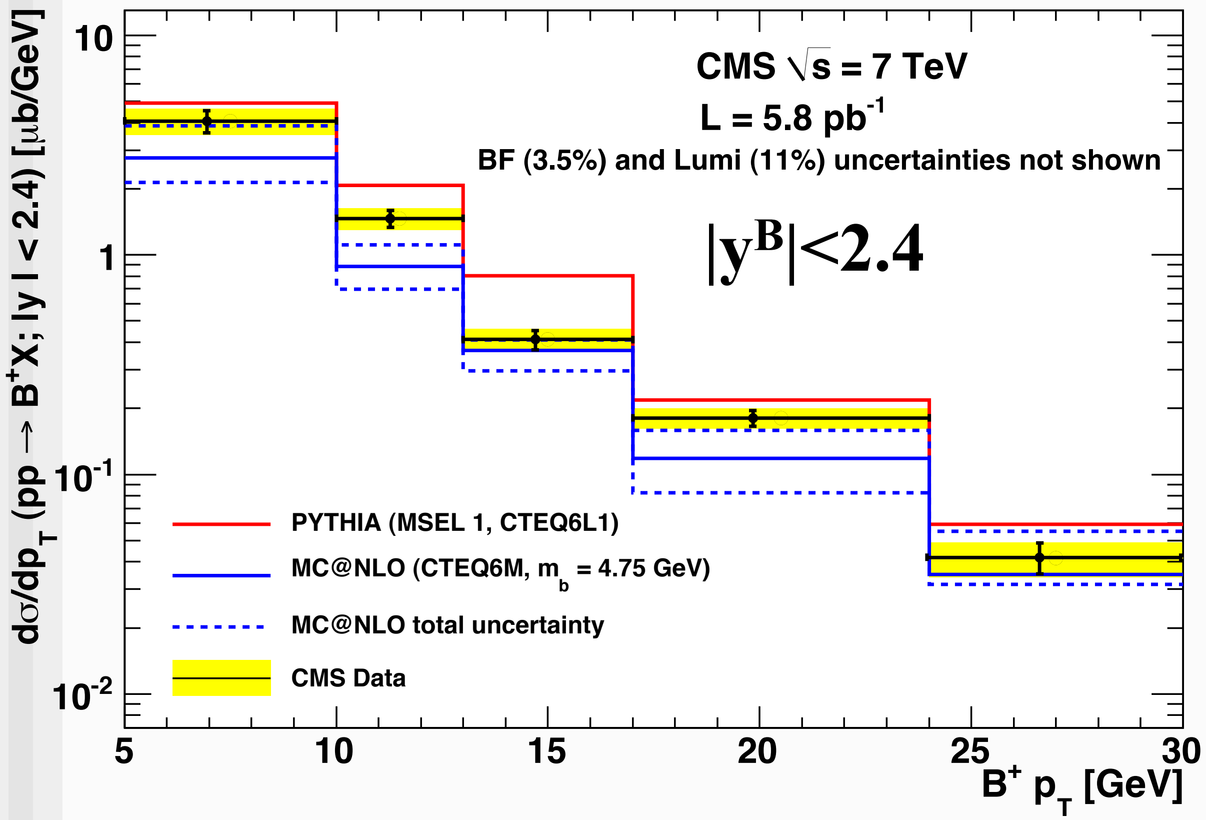
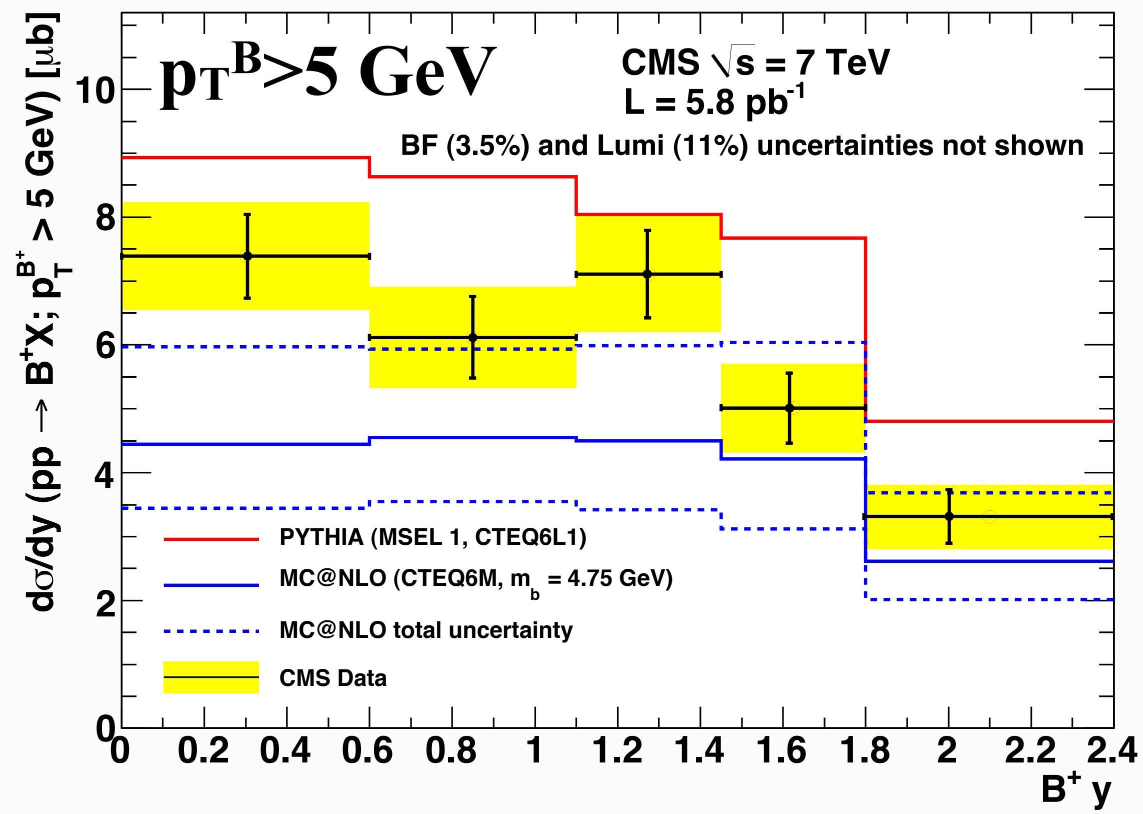




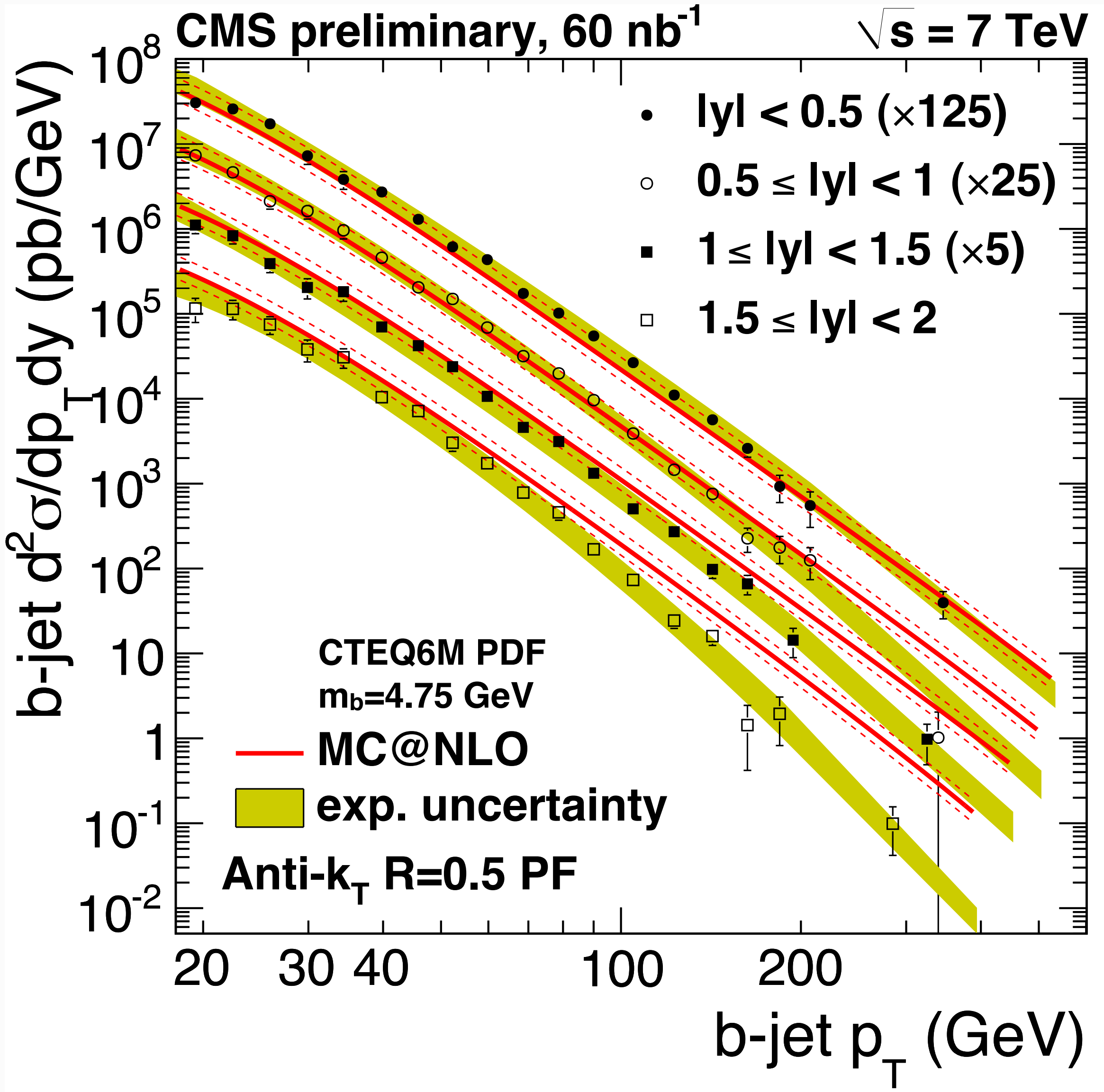
$pp \to B^+X \quad p_T^B > 5$ GeV, $|y^B| < 2.4$

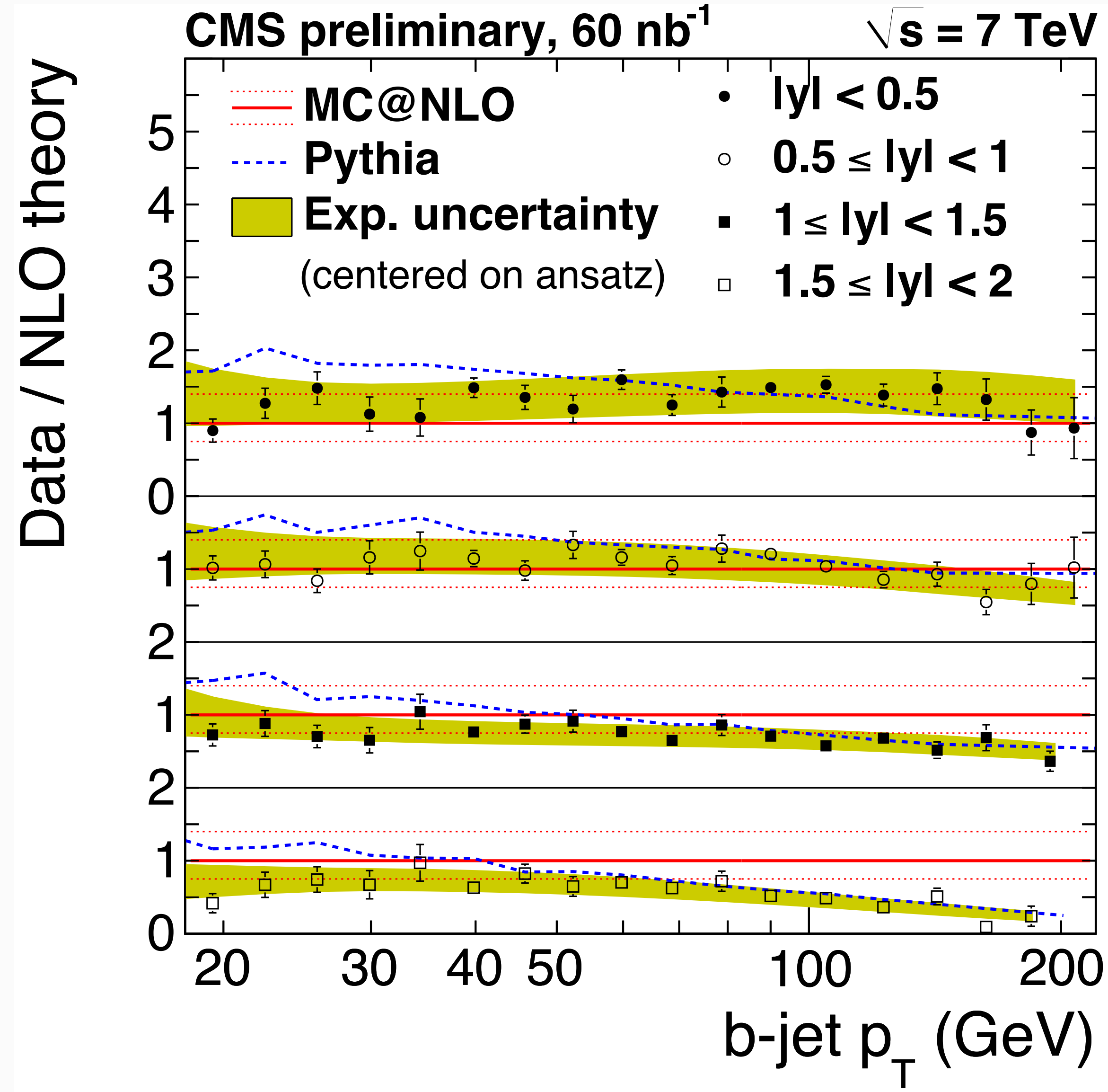
$28.1 \pm 2.4 \pm 2.0 \pm 3.1\ \mu b$	**Measured visible cross section**
$19.1^{+6.5}_{-4.0}\,(\mathrm{scale})^{+1.7}_{-1.4}\,(\mathrm{mass}) \pm 0.6\,(\mathrm{PDF})\ \mu b$	**MC@NLO**
$36.2\ \mu b$	**Pythia**

Experimental uncertainties (~7%) dominated by fit PDF shapes and tracking efficiency
BF (3.5%) and luminosity (11%) uncertainties not shown in figures

Inclusive b-jet production

BPH-10-009





- Experimental uncertainties (~20%) dominated by b-tagging efficiency and jet energy scale
- MC@NLO uncertainties dominated by scale variations (+40%,-25%) and b-quark mass (+17%,-14%)

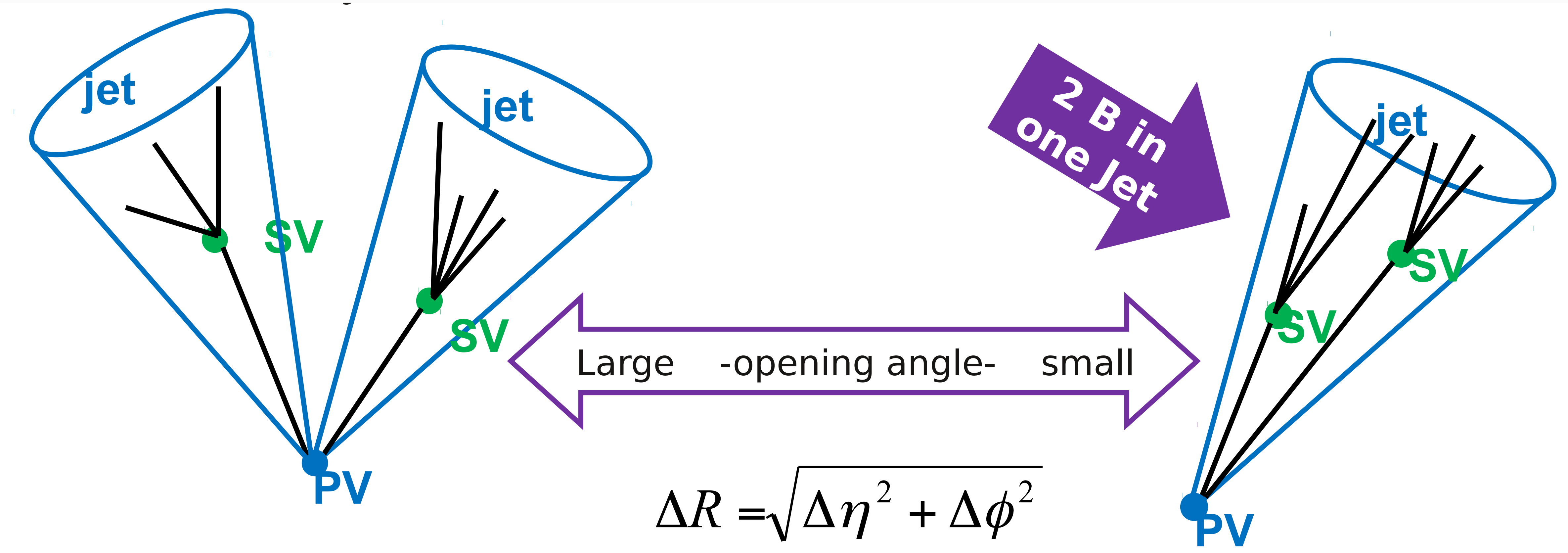
- Generally good agreement with Pythia above 40 GeV
- Shape differences with MC@NLO at large p_T and forward region

from: V. Chiochia, Pauli-Workshop, Zurich, Jan 2011

B-hadron angular correlations NEW !

ETH Institute for Particle Physics

- **Motivation**:
  - What fraction of the b-quark cross section is given by collinear b pair production?
  - How does this fraction evolve with the hardness of the scattering process?
- **Experimental problem:**
  - Measurements based on tagged jets have finite resolution due to jet clustering sizes
- **New technique:**
  - Reconstruct B-hadron momentum from primary and secondary vertices
  - Secondary vertex finder seeded with high IP tracks, jet independent
  - Tertiary vertices from chain decays (b→c) merged into a single B candidate



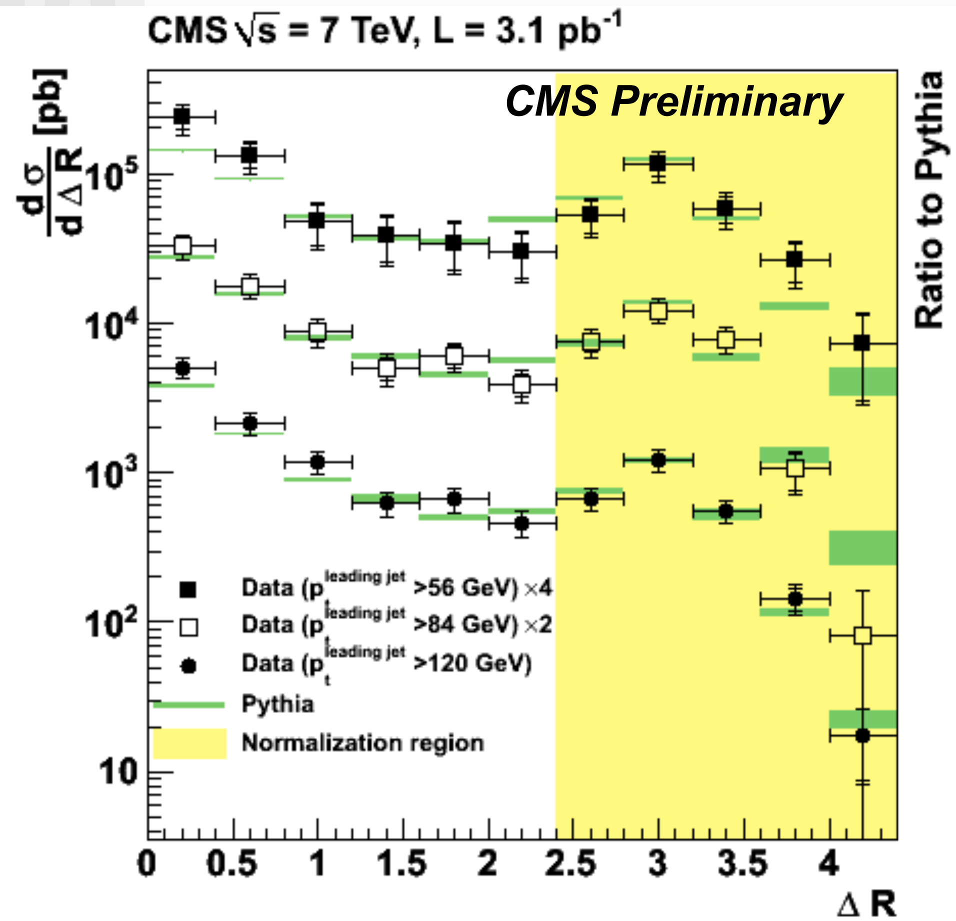
$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

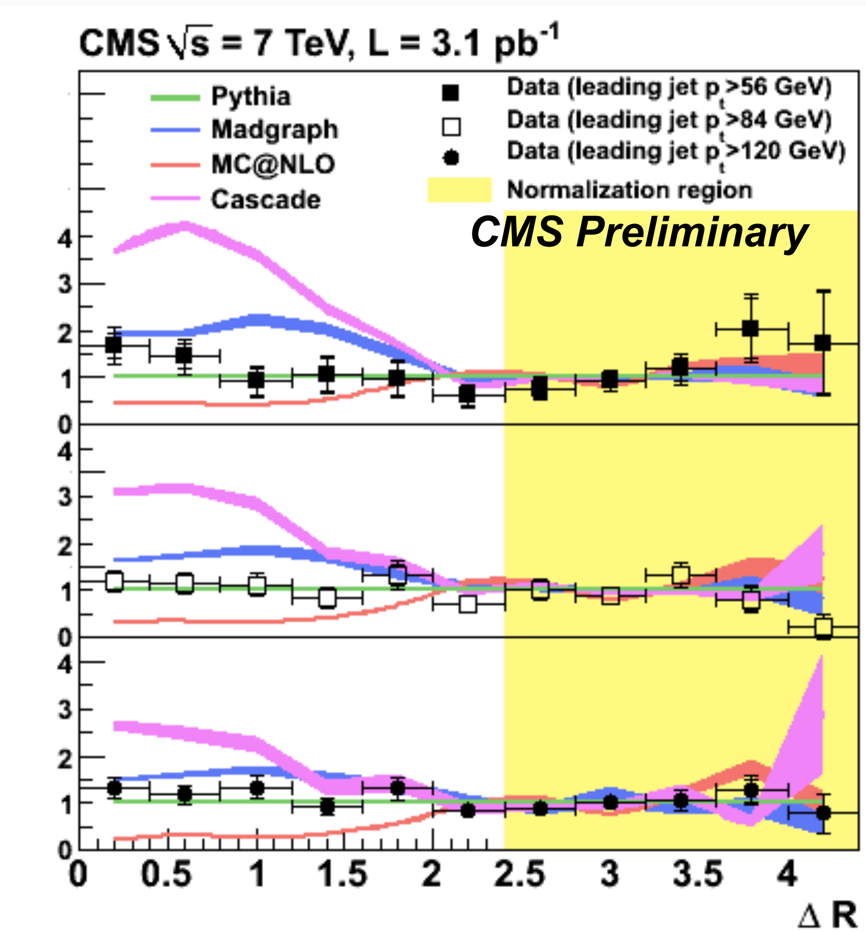
from: V. Chiochia, Pauli-Workshop, Zurich, Jan 2011

Angular correlations: results

NEW !

ETH Institute for Particle Physics





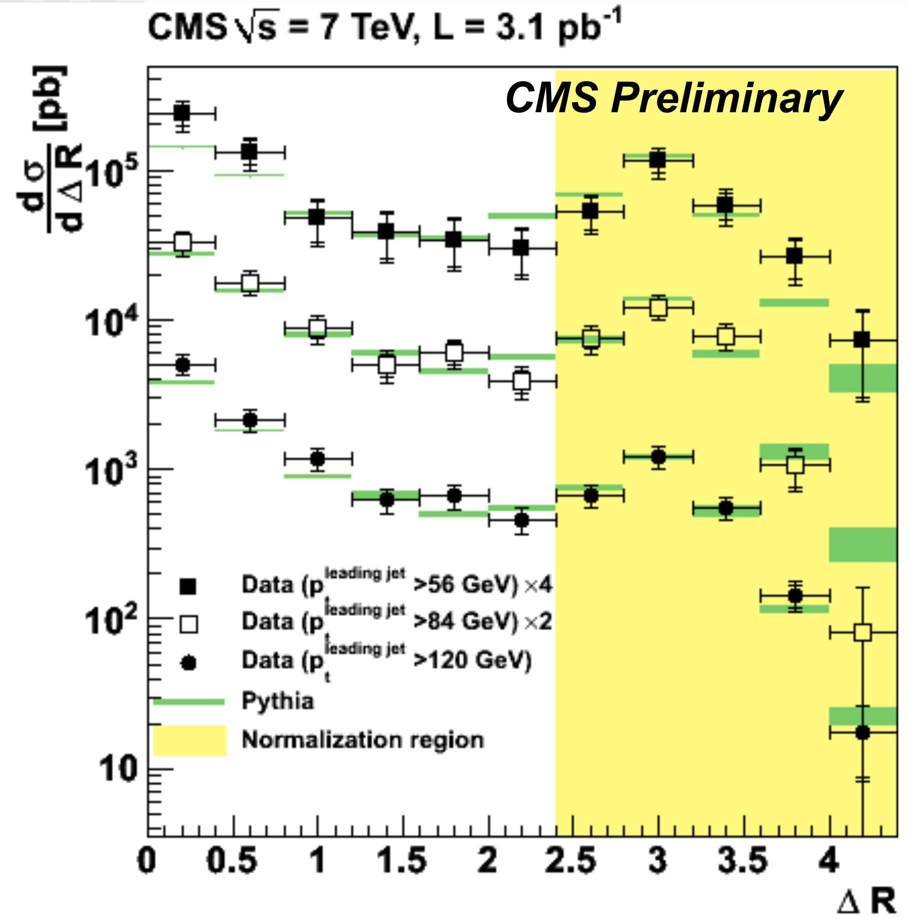
$p_T(B)>15$ GeV, $|\eta(B)|<2$, $|\eta(\text{lead.jet})|<3$

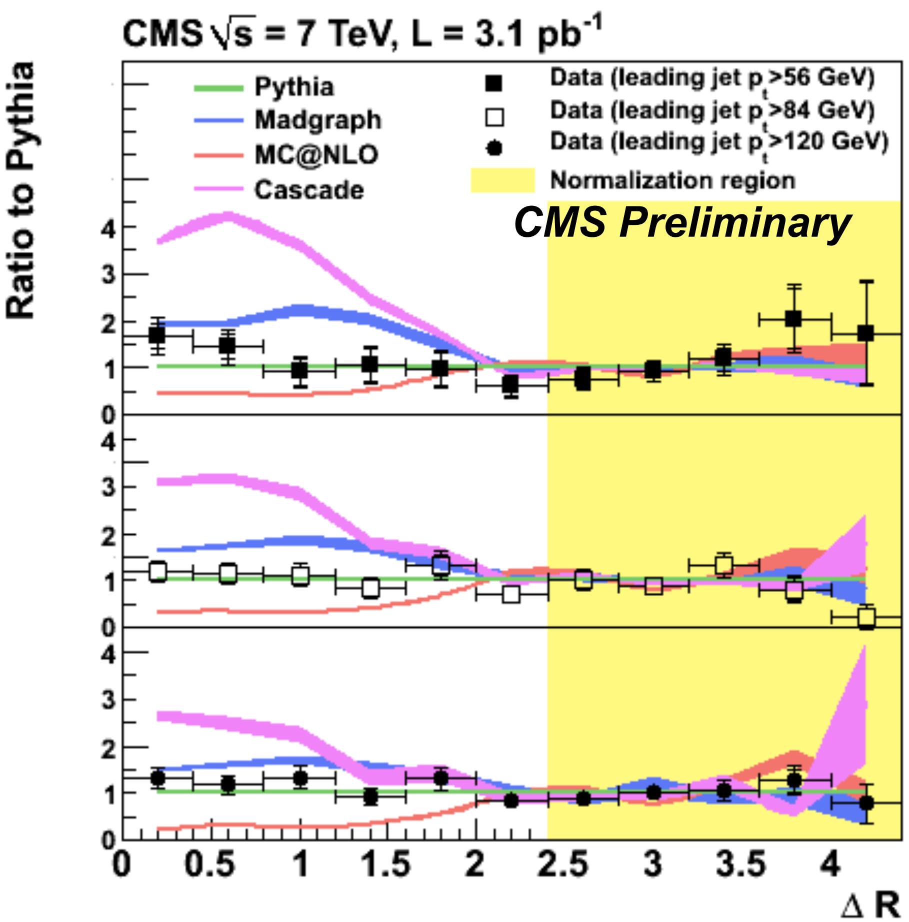
MC normalized to yellow region for shape comparison
in the collinear BB region

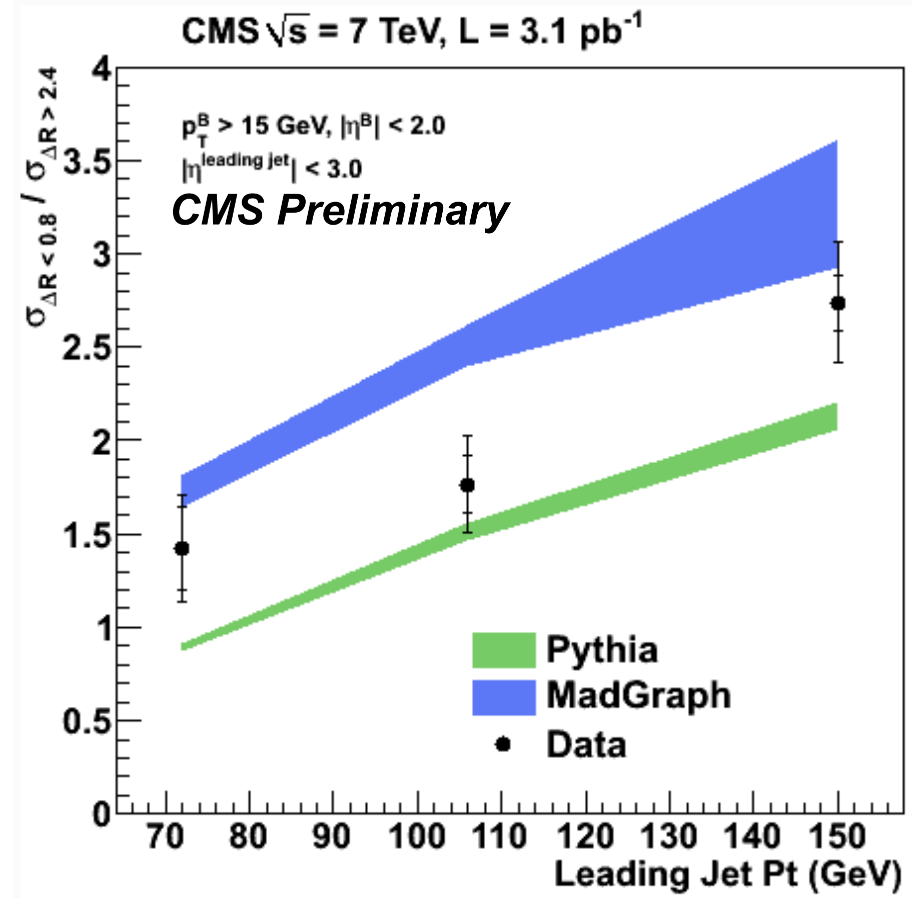
from: V. Chiochia, Pauli-Workshop, Zurich, Jan 2011

Angular correlations: results

NEW !







$p_T(B)>15$ GeV, $|\eta(B)|<2$, $|\eta(\text{lead.jet})|<3$

MC normalized to yellow region for shape comparison in the collinear BB region

Ratio of collinear over back-to-back region

- Sizable fraction of total BB cross section from collinear B-hadron pairs
- Fraction of collinear BB production increases with leading jet p_T
- Data points between Pythia and Madgraph MC. MC@NLO and CASCADE below and above the data, respectively

from: V. Chiochia, Pauli-Workshop, Zurich, Jan 2011

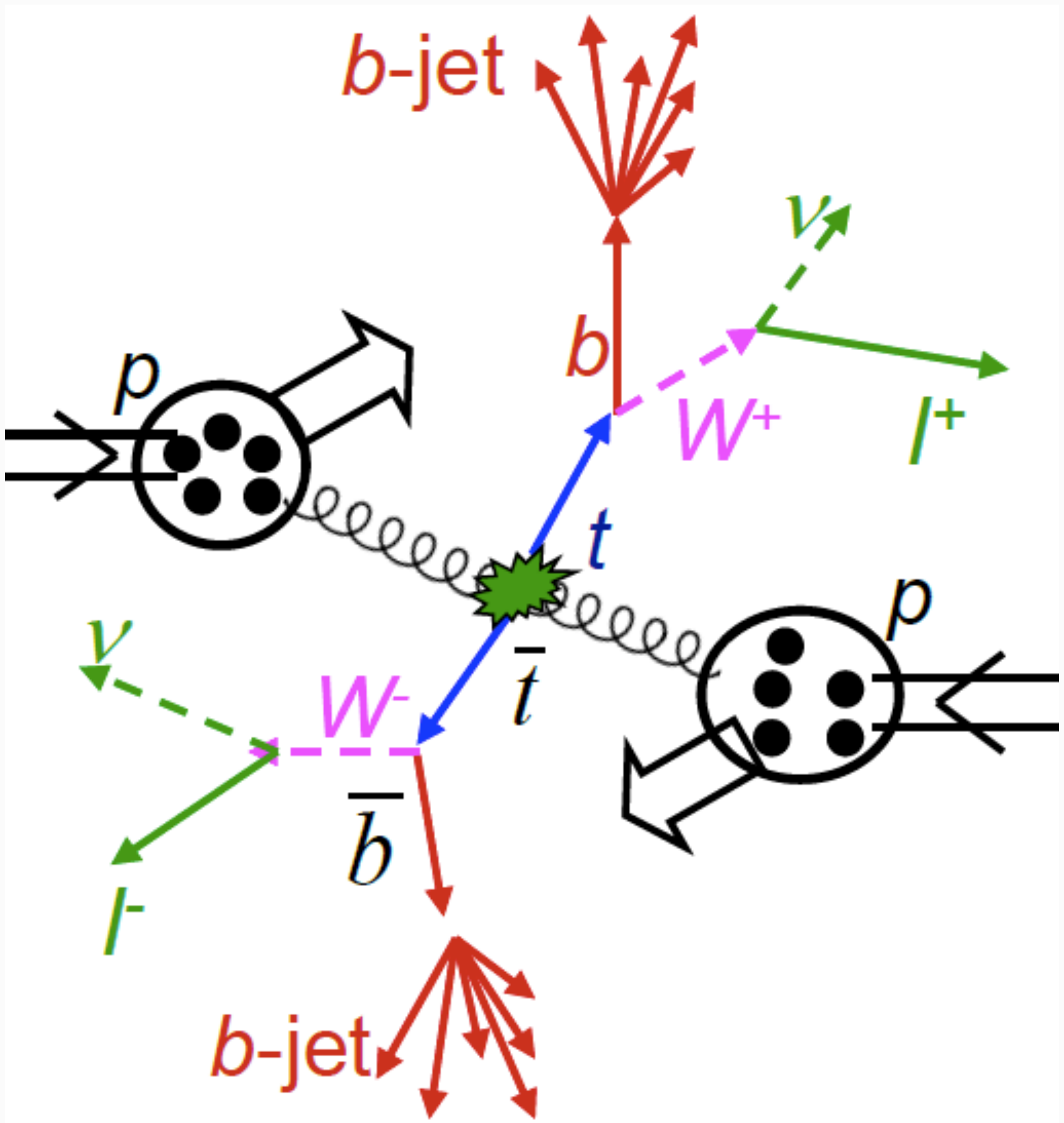
Top prod. : Di-lepton channel

ETH Institute for Particle Physics

- Using 3 pb^{-1} data sample
  - Expect ~10 events signal

Phys. Lett. B 695 (2011) 424-443

- Dilepton features:
  - less frequent but easy to see
  - Clean final states, eμ the cleanest
- Cut and count method
- Selection
  - Online: Single e OR μ trigger
  - Offline
    - Two opposite-charge leptons p_T>20 GeV
    - Lepton isolation
    - Two or more jets (anti-Kt 0.5) with p_T>30 GeV
    - MET > 30(20) GeV ee,μμ (eμ)
    - Veto $M_{dilepton}$ near Z in ee,μμ: |Mass-91| > 15GeV
- Backgrounds
  - Non-W/Z e/μ from j→ l rate in QCD dijets
    - "jet→ e/μ": Includes fakes and b/c->e/μ
  - DY in ee/μμ normalized to events near Z
  - MC for the rest: dibosons, tW, DY→ ττ



from: S. Krutelyov, Pauli-Workshop, Zurich, Jan 2011

Results

Phys. Lett. B 695 (2011) 424-443

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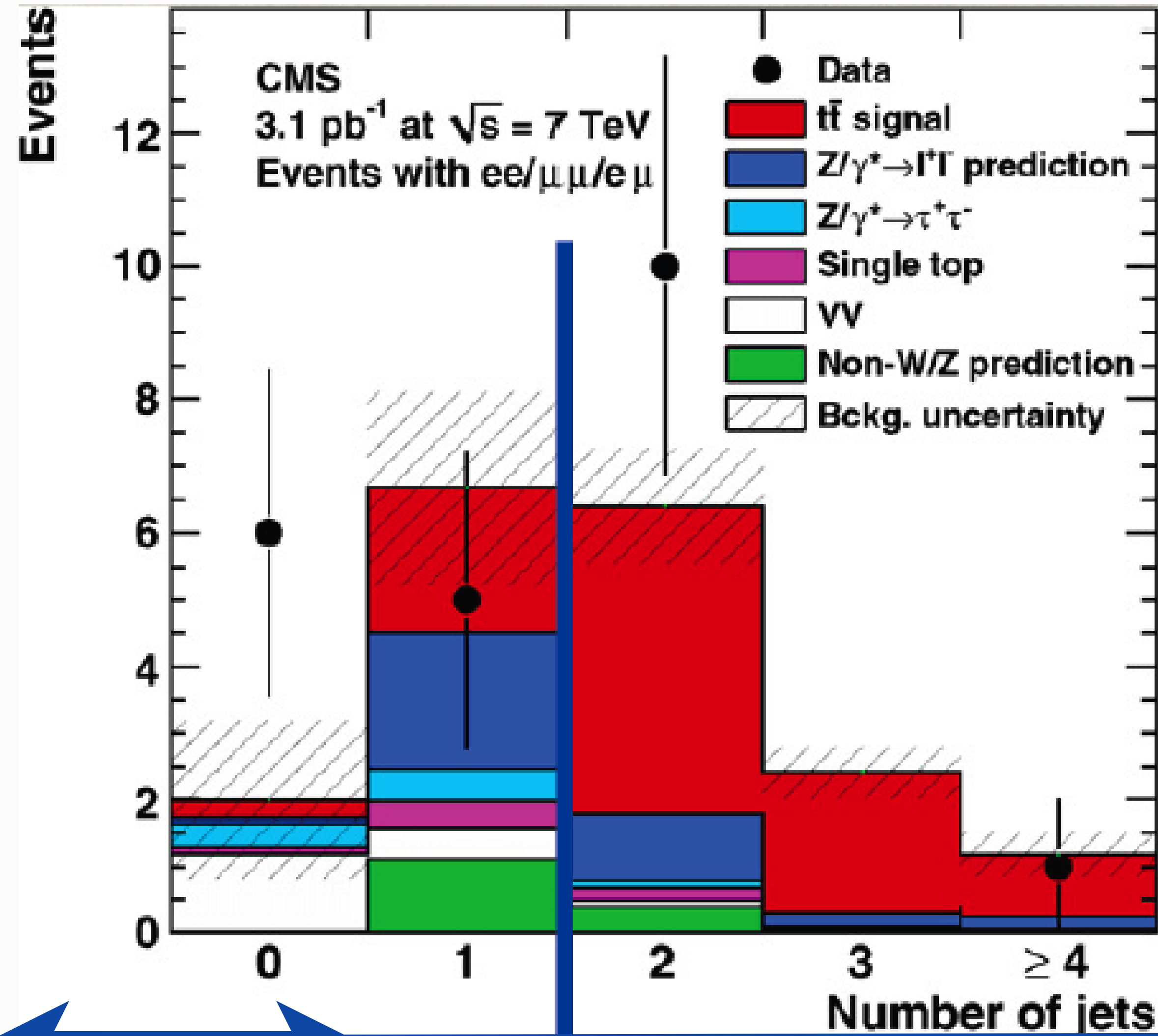
Source	Events
Expected tt	7.7 ± 1.5
Dibosons	0.13 ± 0.07
Single Top	0.25 ± 0.13
DY (τ)	0.18 ± 0.09
DY (e,μ)	1.4 ± 0.5 ± 0.5
Non-W/Z	0.1 ± 0.5 ± 0.3
Total Bkg	2.1 ± 1.0
Total (incl. top)	9.8 ± 1.8
Data	11



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

- The measurement is dominated by statistical uncertainty
- x10 more data available now ==> x2-3 more precision expected

Top-like properties of selected events

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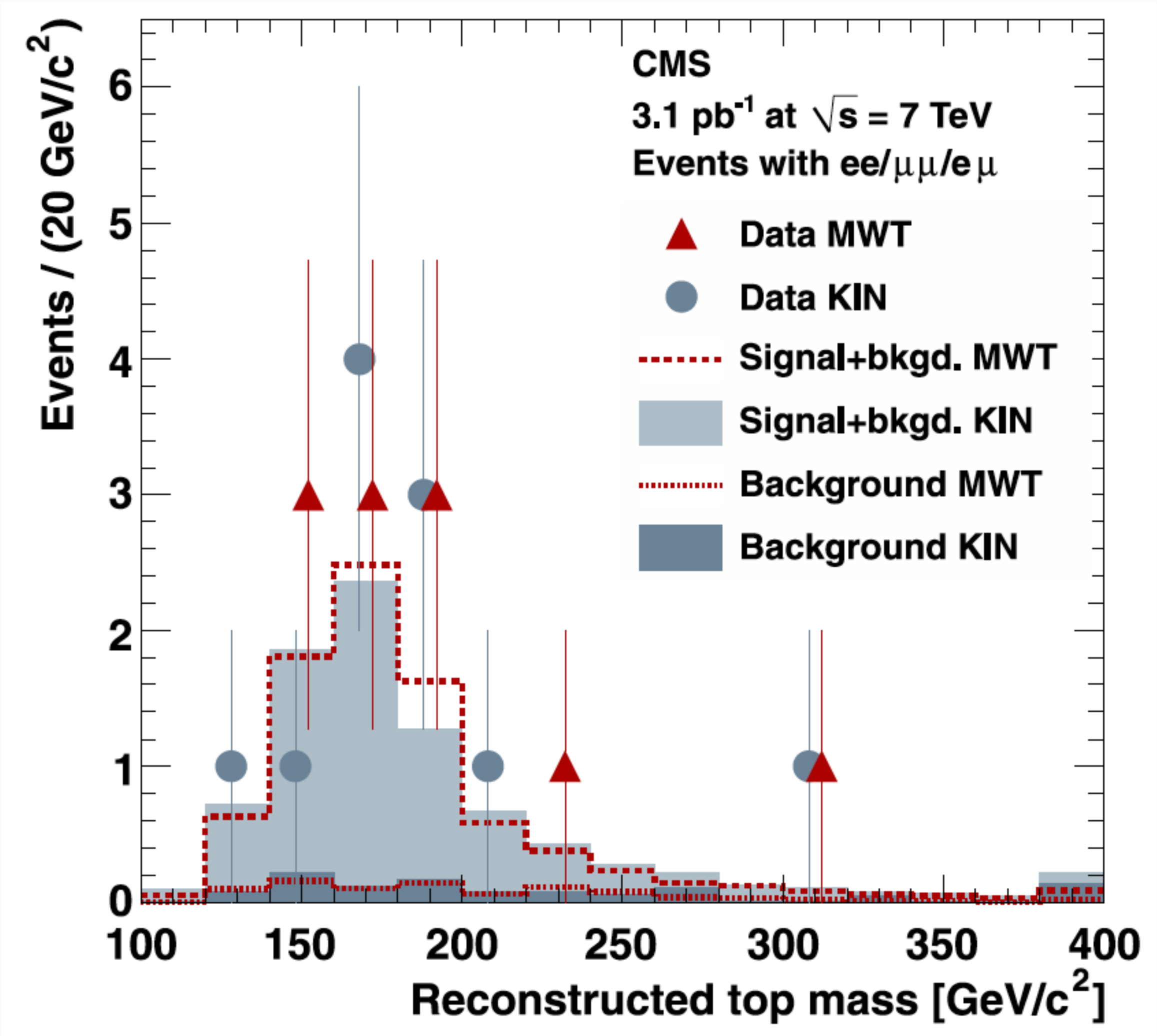
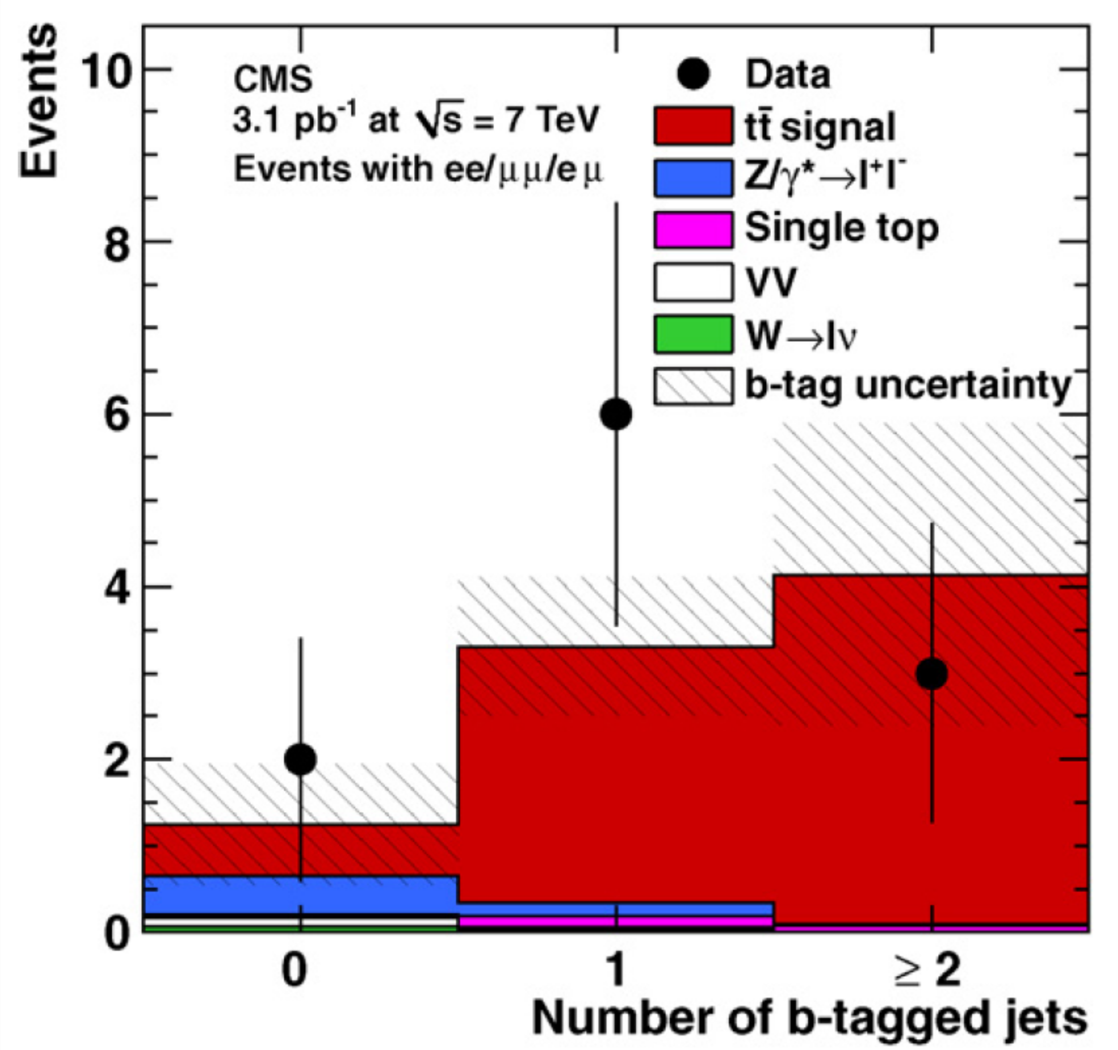
11 events pass full selection: $3\ e^+e^-,\ 3\ \mu^+\mu^-,\ 5\ e^\pm\mu^\mp$
2.1±1.0 backgrounds

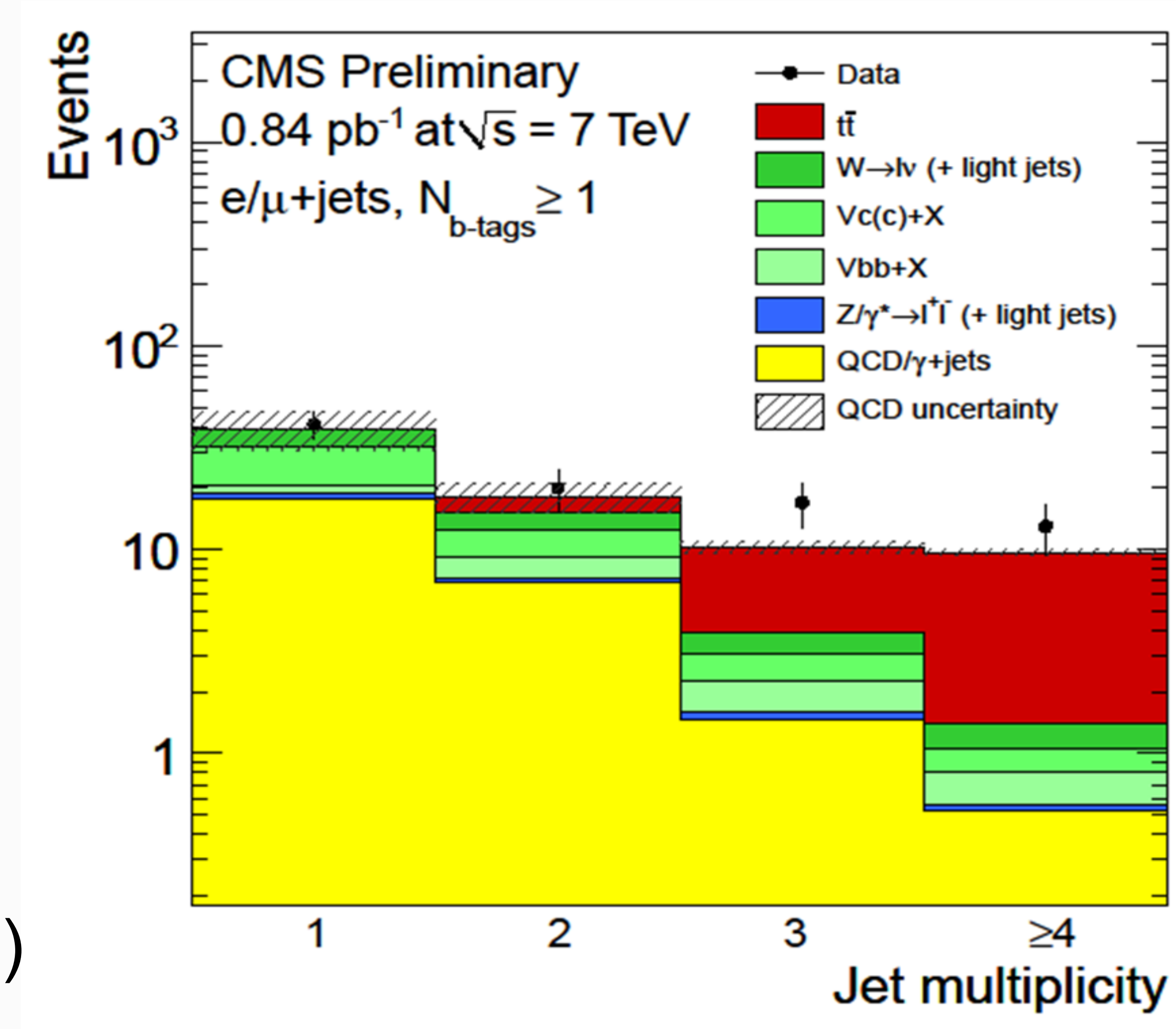




- Reconstructed top mass: includes all event information, gives a global view of consistency. Two methods of reconstruction (different type of constraints) applied to find the solution.
- Multiplicity of b-tagged jets: confirms high rate of b-tags as expected from top

t-tbar : lepton+jets

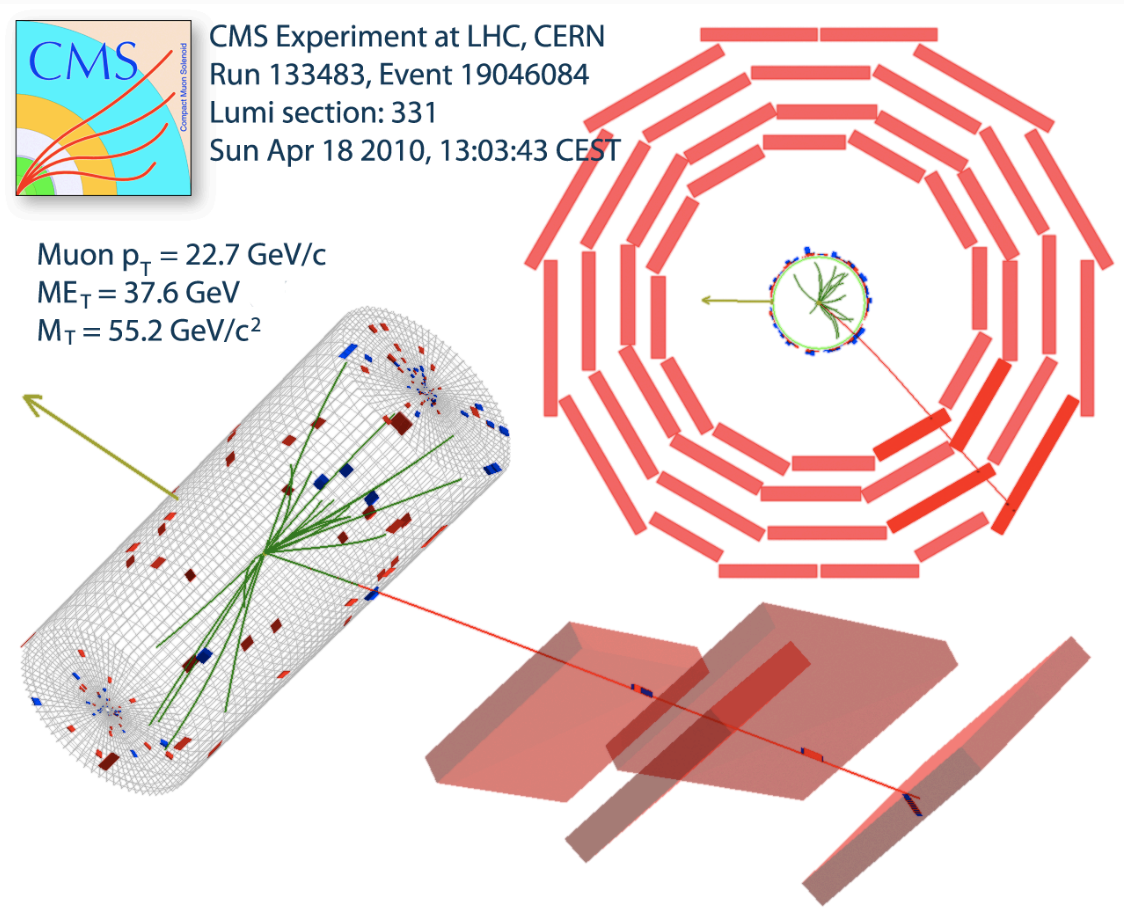
- Using 0.84 pb^{-1} and requiring at least 1 secondary vertex tagger with ≥2 tracks;
  - ~50% efficiency
    ~1% fake rate
- N(jets)≥3
  - 30 signal candidates over a predicted background of 5.3
- ttbar rate roughly consistent with NLO cross section
  - Up to experimental (JES, b-tagging) and theoretical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

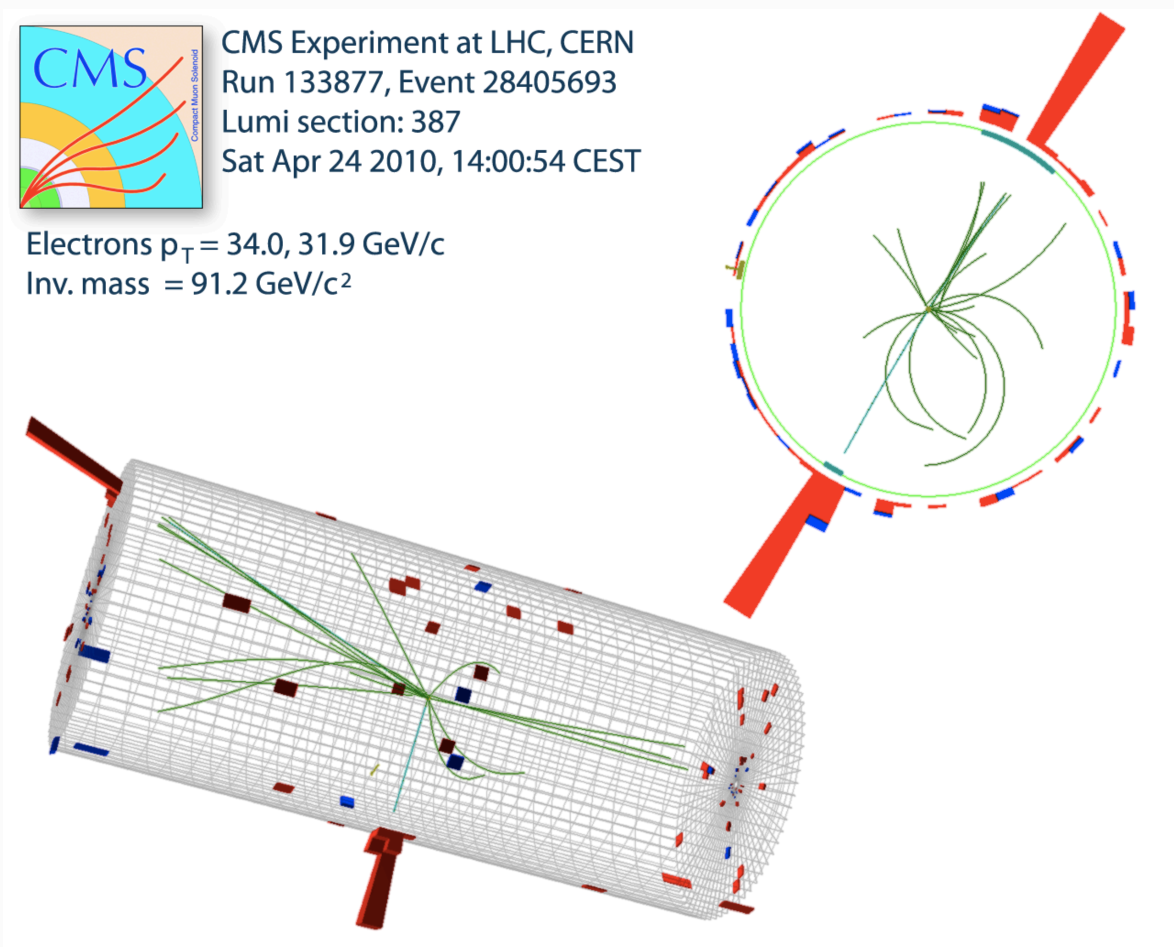


based on early data PAS TOP-10-004 and update to it shown at HCP2010
Update coming soon....

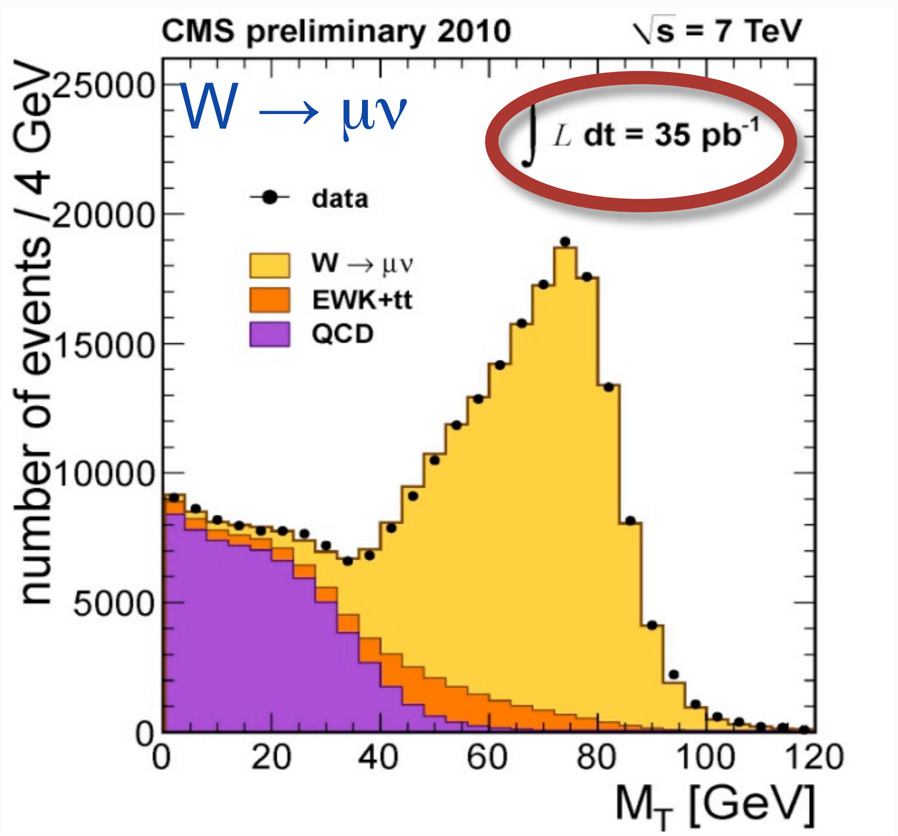
from: S. Krutelyov, Pauli-Workshop, Zurich, Jan 2011

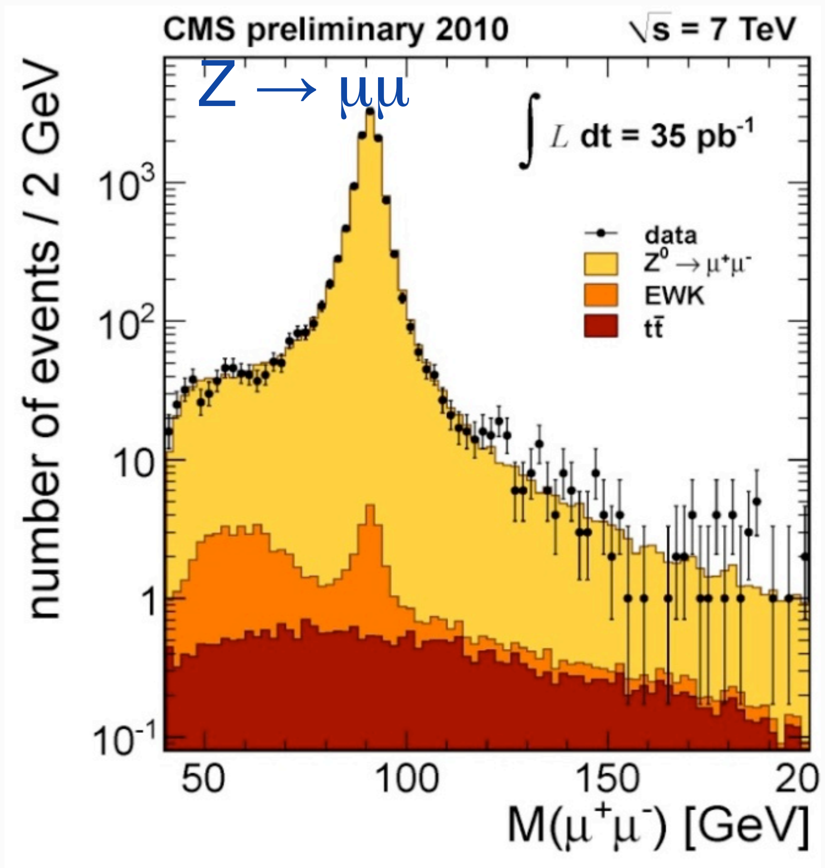
W and Z production

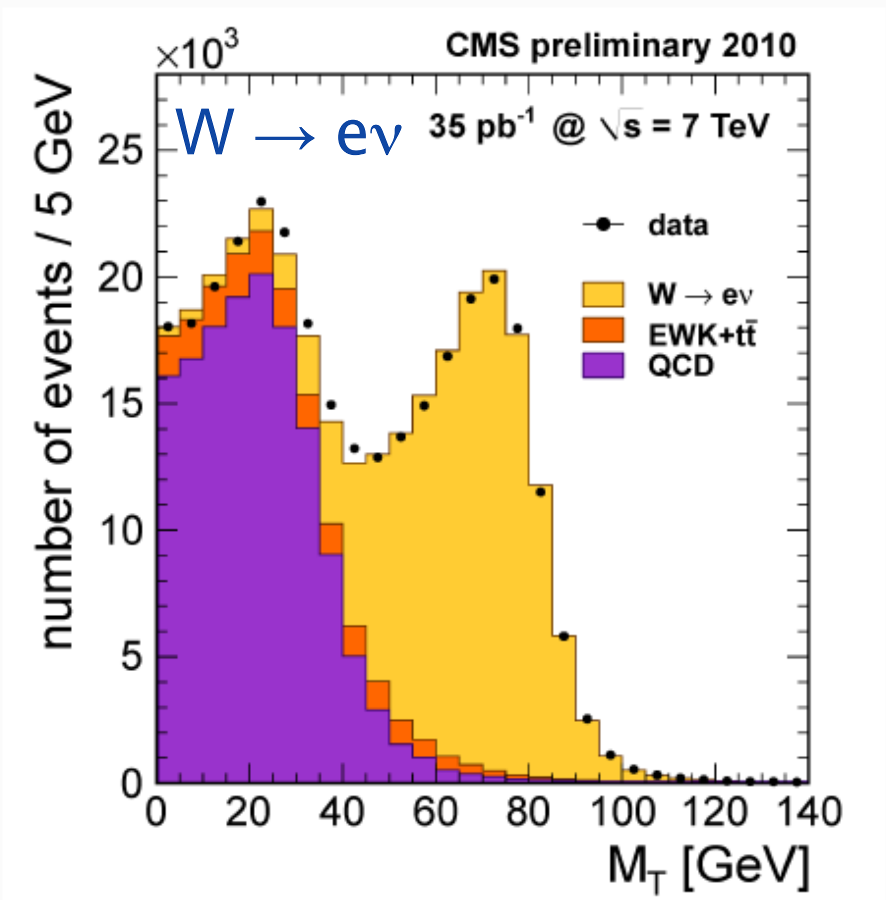


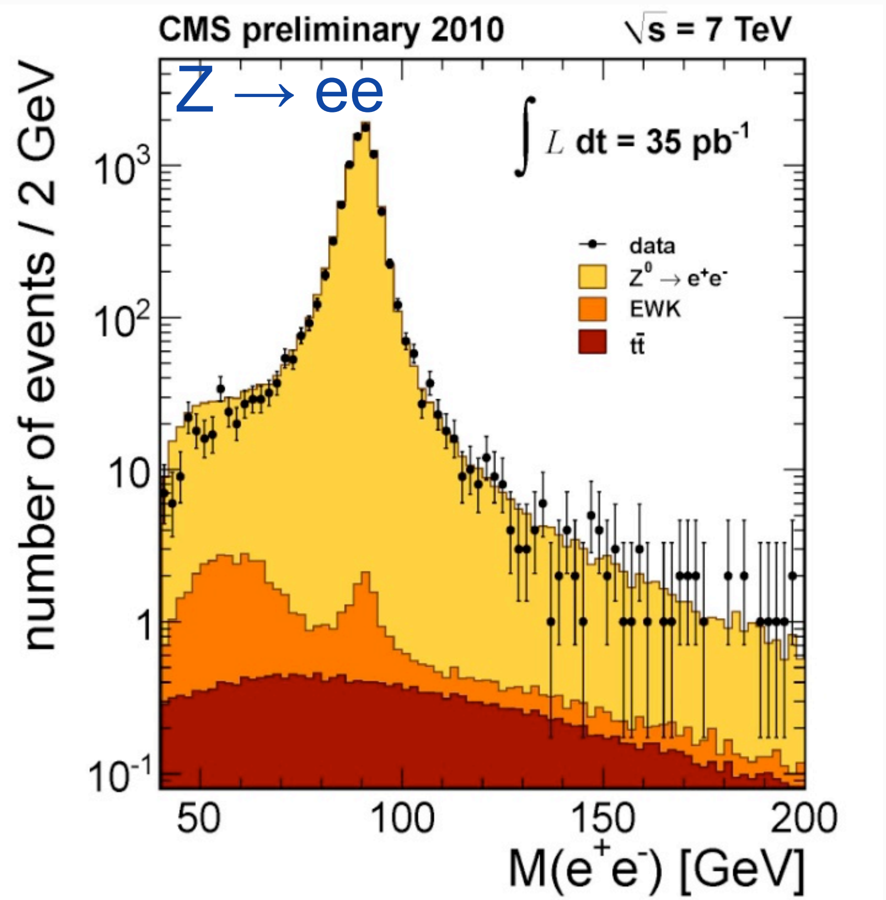


W and Z in e/μ channels







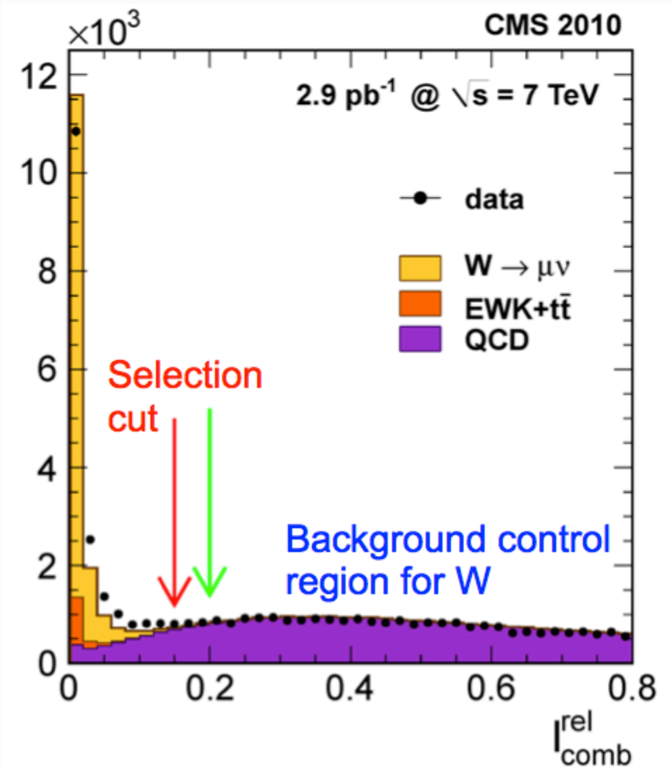


W/Z cross-sections

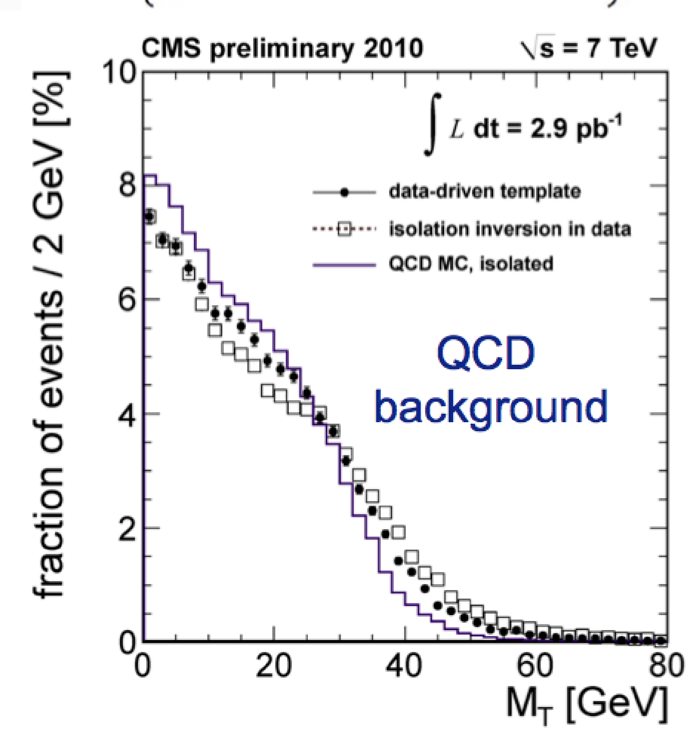
arXiv:1012.2466

ETH Institute for Particle Physics

- Published results for 3/pb, analysis of full 2010 sample ongoing
- Data-driven eff. and background estimations, such as T&P, isolation cut inversion



$$I^{\rm rel}_{\rm comb} = \left\{ \sum (p_T(tracks) + E_T(em) + E_T(had)) \right\} / p_T(\mu)$$

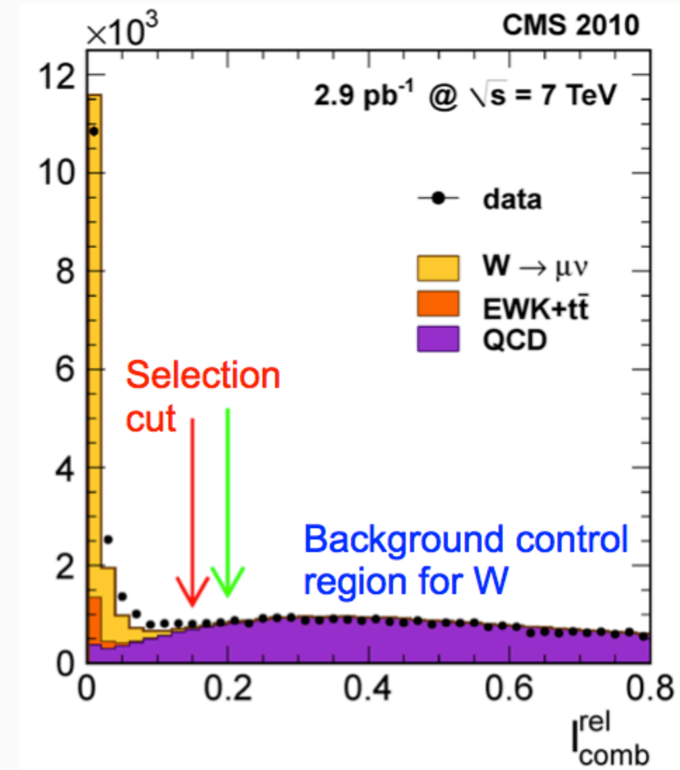


W/Z cross-sections

arXiv:1012.2466

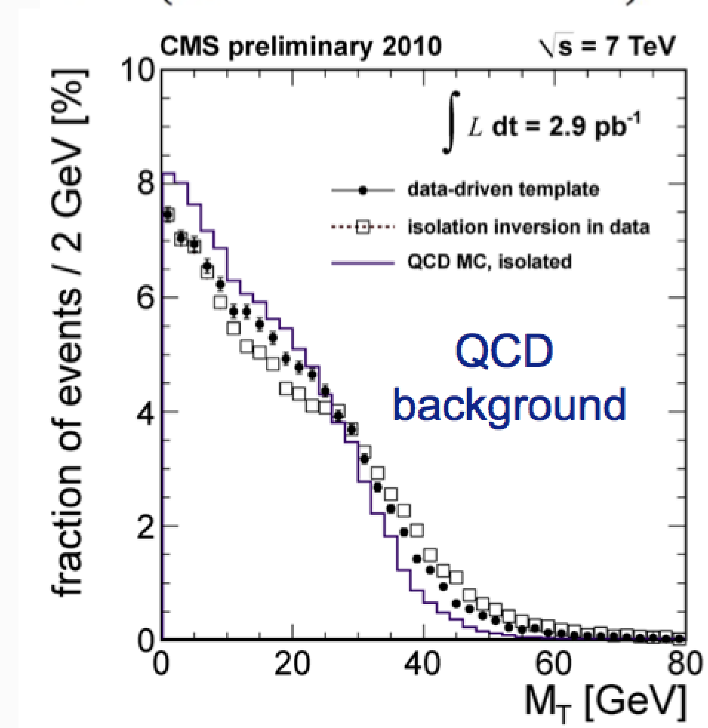
- Published results for 3/pb, analysis of full 2010 sample ongoing
- Data-driven eff. and background estimations, such as T&P, isolation cut inversion

Source	$W \to e\nu_e$	$W \to \mu\nu_\mu$	$Z \to e^+e^-$	$Z \to \mu^+\mu^-$
Lepton reconstruction & identification	3.9	1.5	5.9	0.5
Momentum scale & resolution	2.0	0.3	0.6	0.2
$\not{E}_T$ scale & resolution	1.8	0.4	n/a	n/a
Background subtraction/modeling	1.3	2.0	0.1	$0.2 \oplus 1.0$
PDF uncertainty for acceptance	0.8	1.1	1.1	1.2
Other theoretical uncertainties	1.3	1.4	1.3	1.6
Total	5.1	3.1	6.2	2.3



$$I^{rel}_{comb} = \left\{ \sum (p_T(tracks) + E_T(em) + E_T(had)) \right\} / p_T(\mu)$$

- Accept. ~ 52-57 % (40-43 %) for W (Z)
- Estimated using POWHEG + CTEQ6.6
- Acceptance: PDF syst. from comparing CTEQ6.6, MSTW08NLO, NNPDF2.0

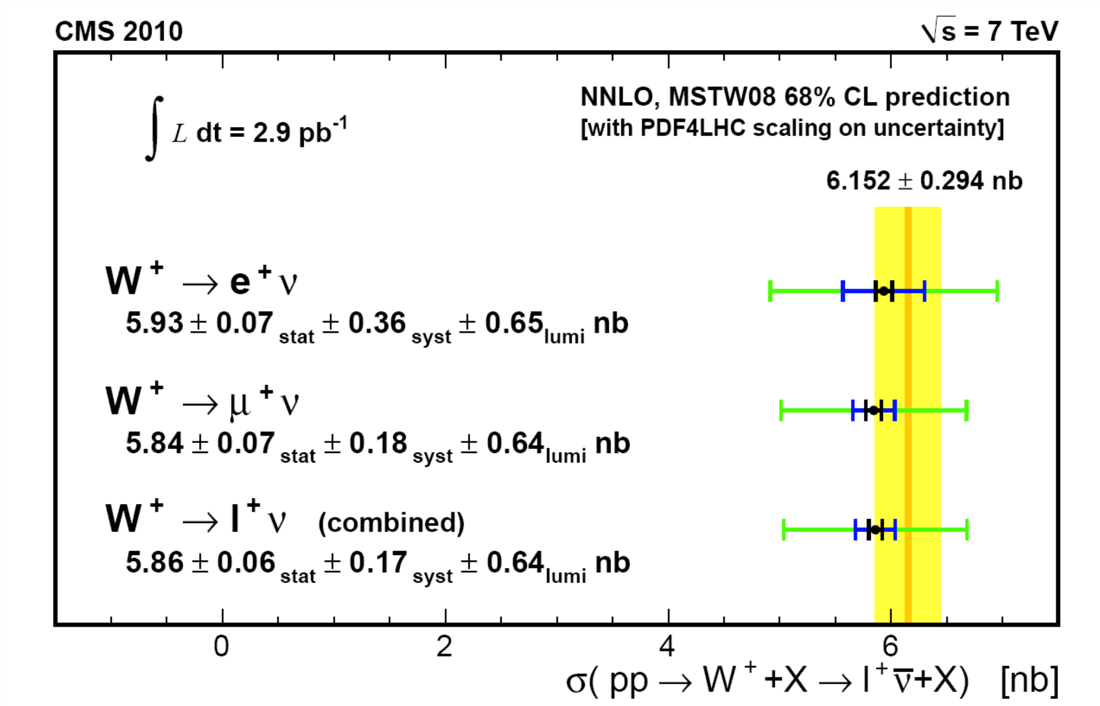


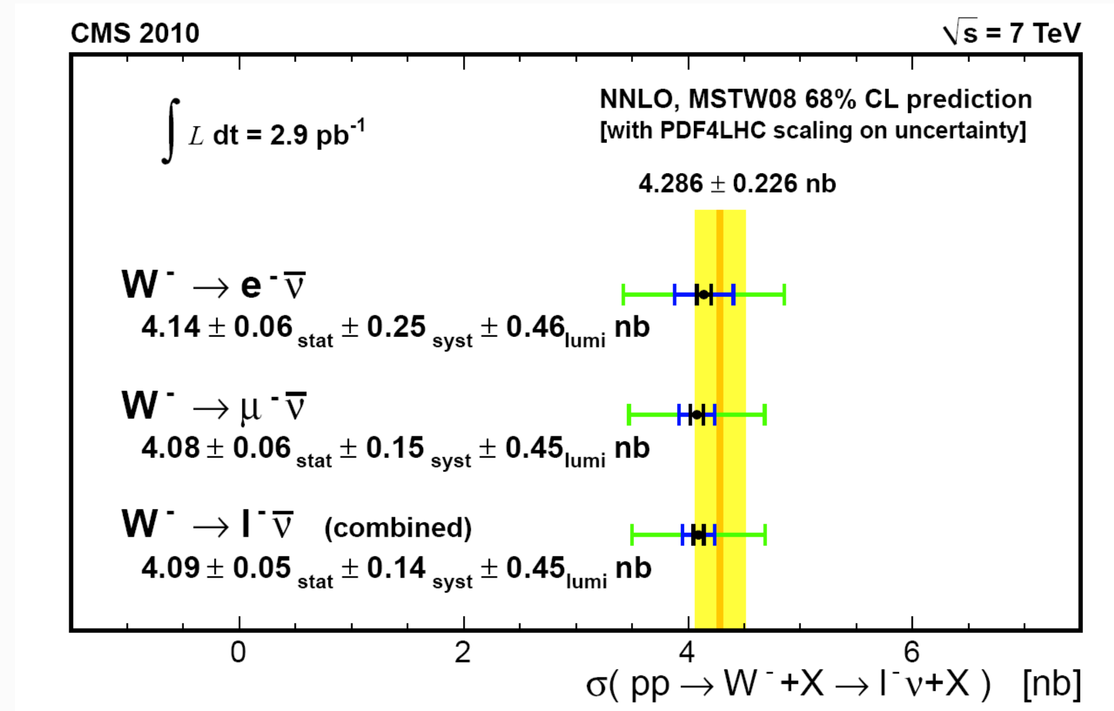
- **Note**: x-sec results also reported within the finite acceptance only!

Comparison with Theory

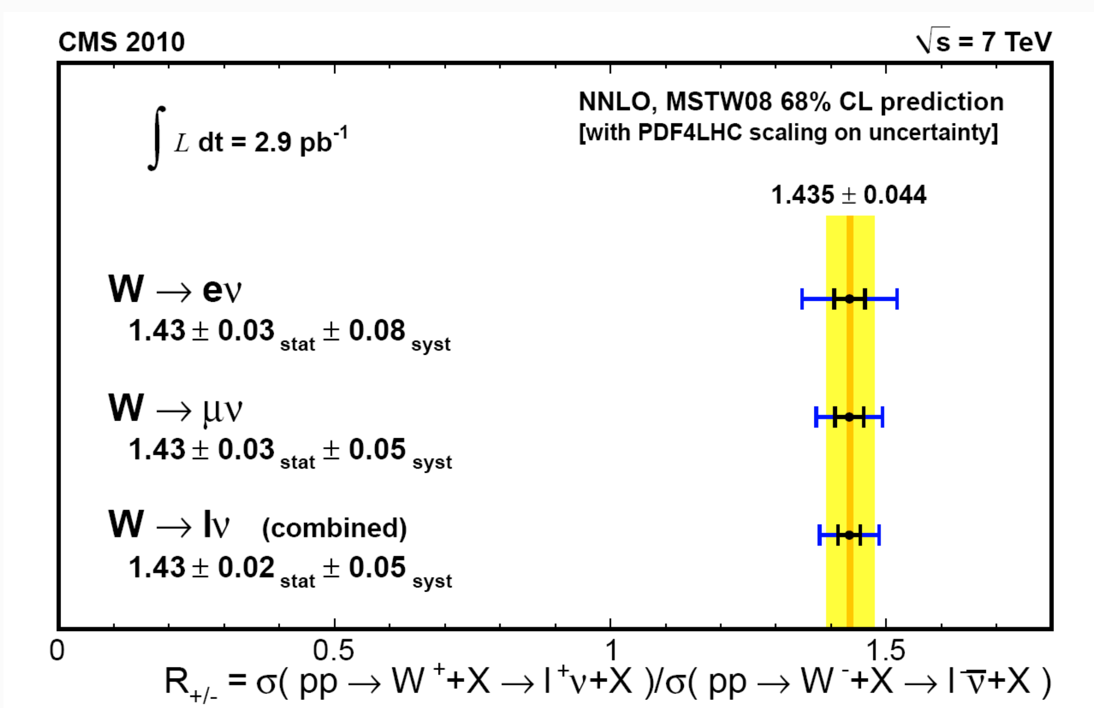
arXiv:1012.2466

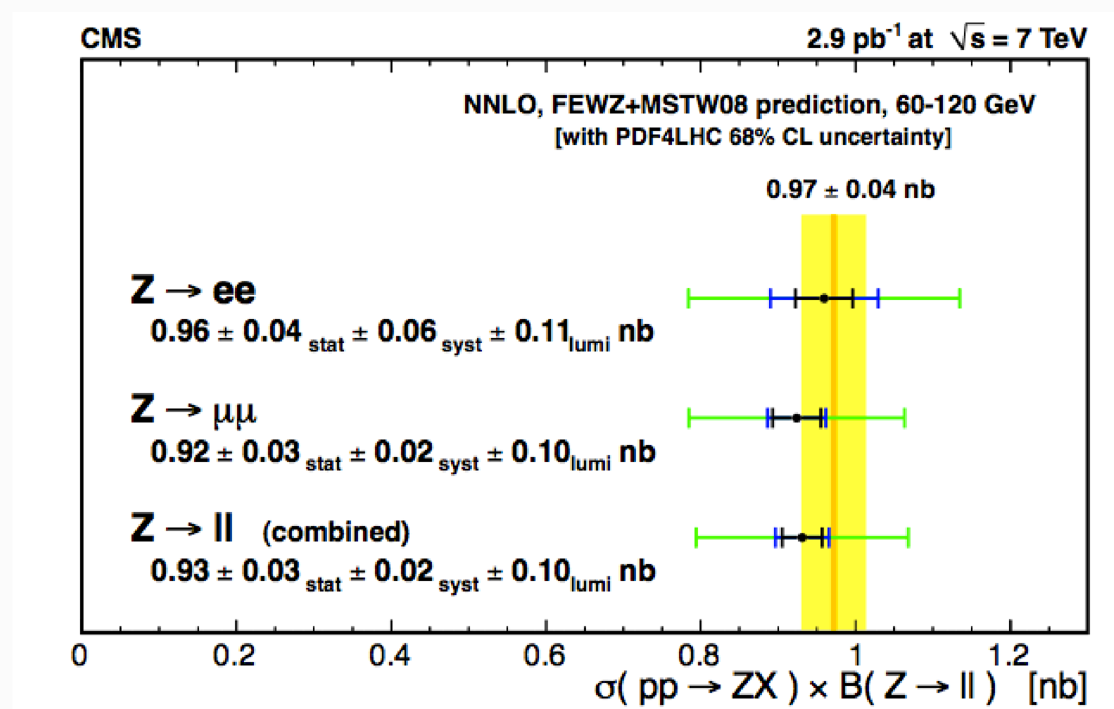
ETH Institute for Particle Physics





- Theory pred. from NNLO (FEWZ) + MSTW08 PDFs
- Theory PDF uncertainties : MSTW08,CTEQ6.6,NNPDF2.0, PDF4LHC prescription

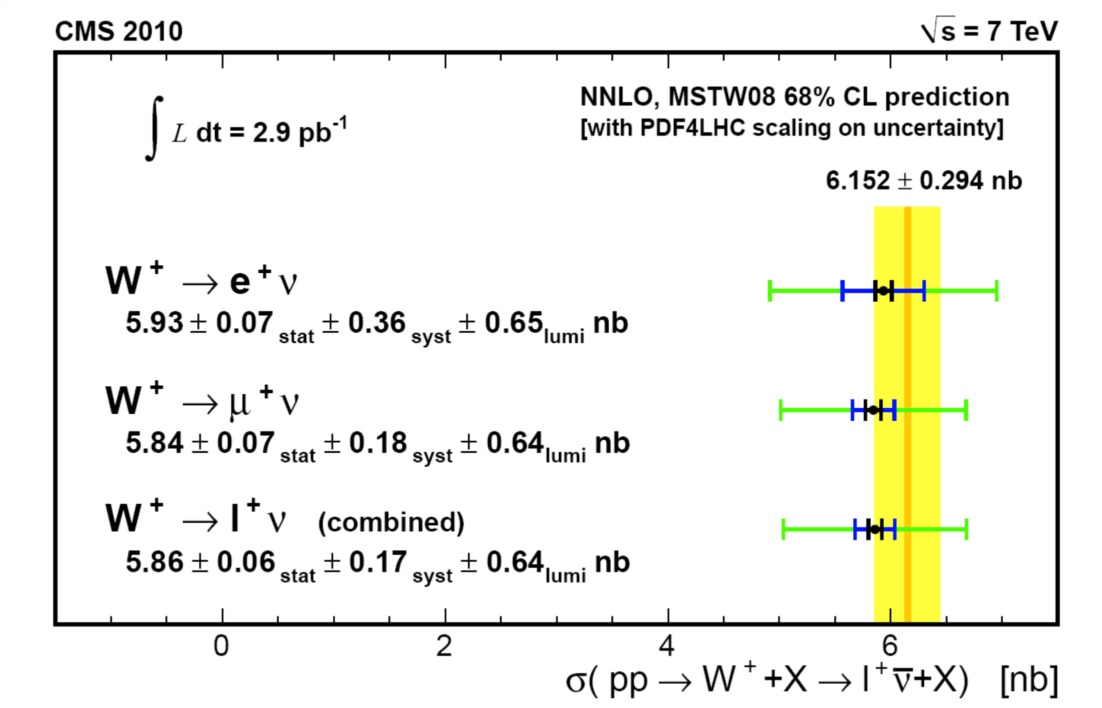


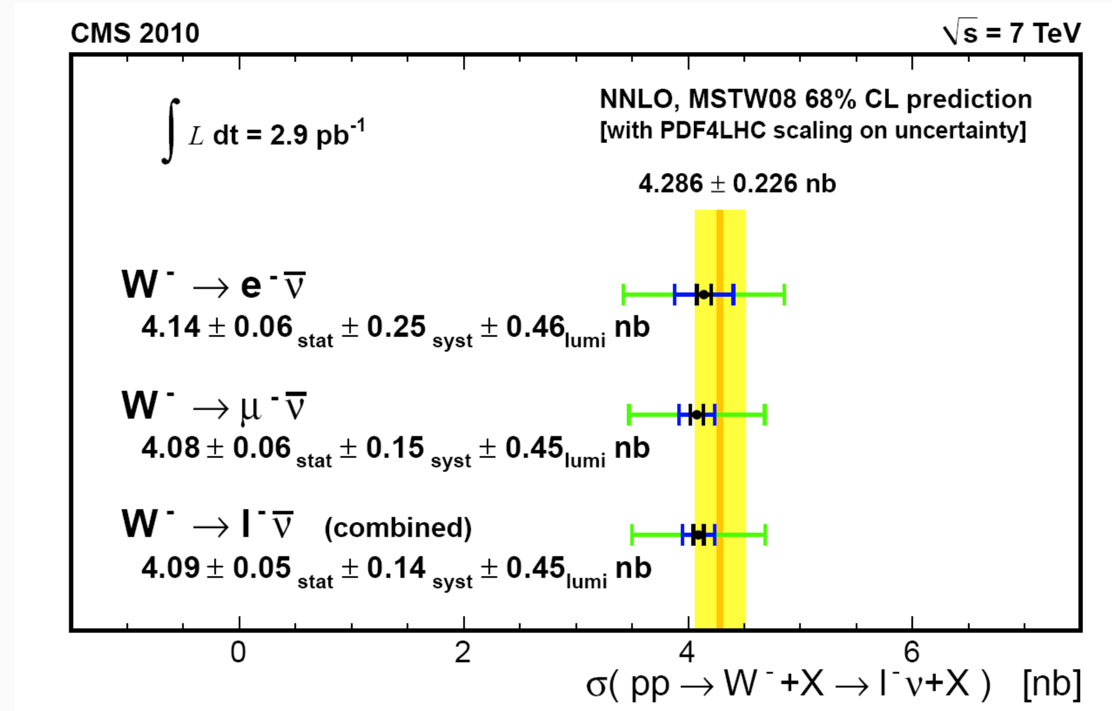


Comparison with Theory

arXiv:1012.2466

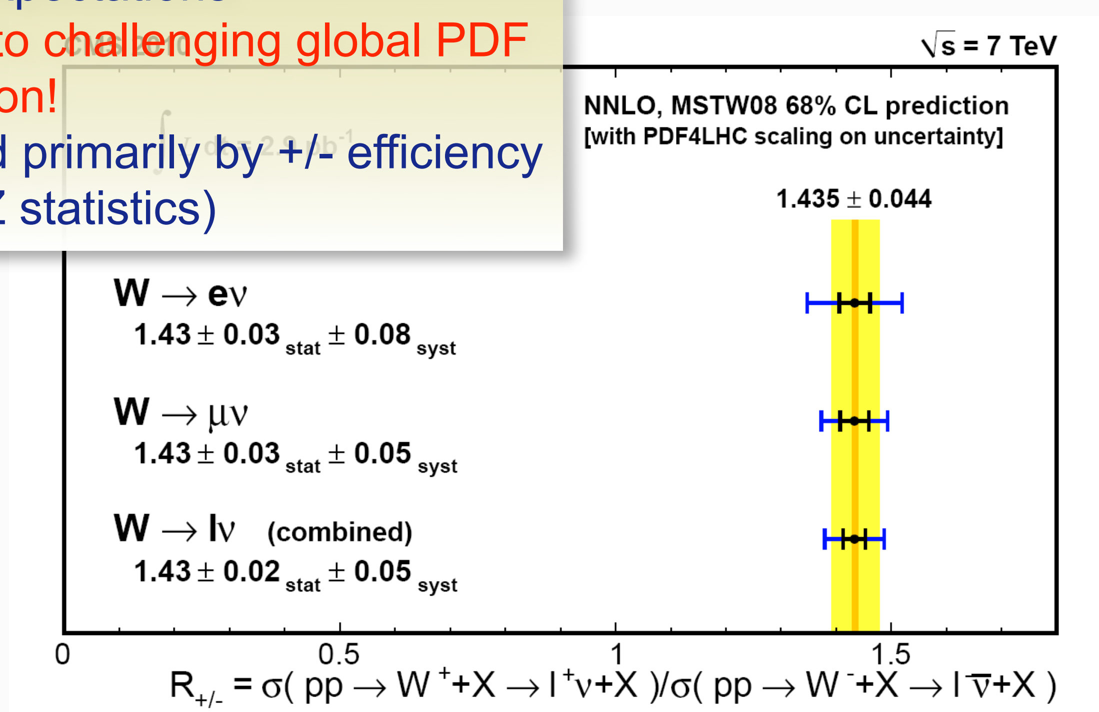
ETH Institute for Particle Physics

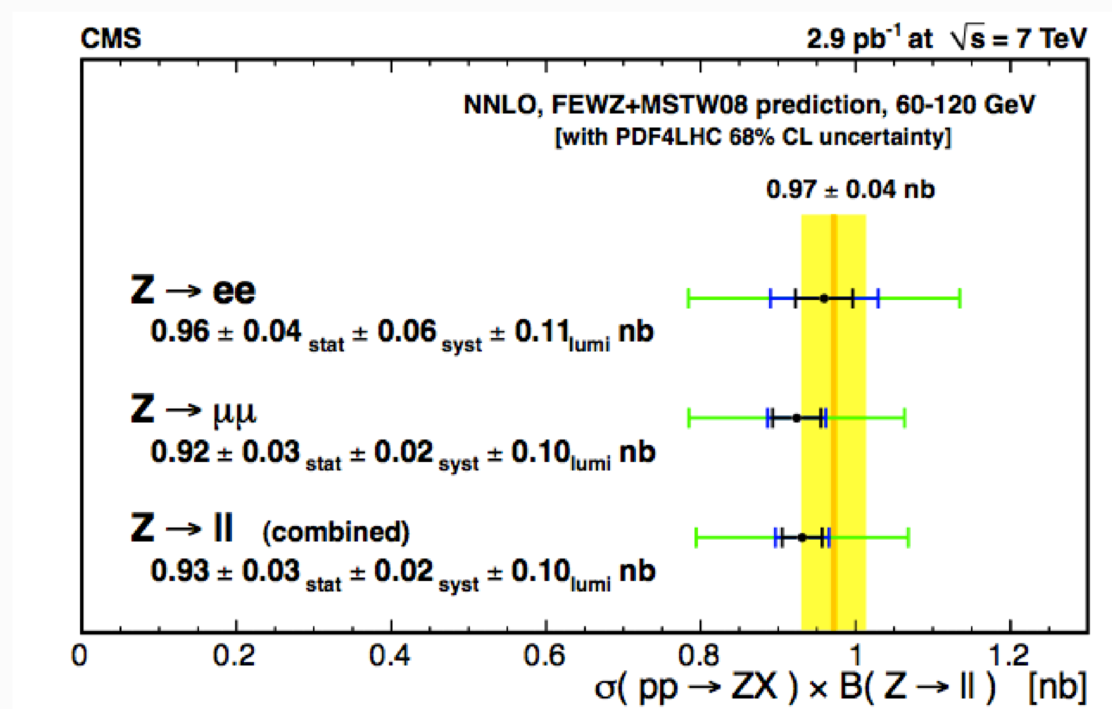




- Theory pred. from NNLO (FEWZ) + MSTW08 PDFs
- Theory PDF uncertainties : MSTW08,CTEQ6.6,NNPDF2.0, PDF4LHC prescription

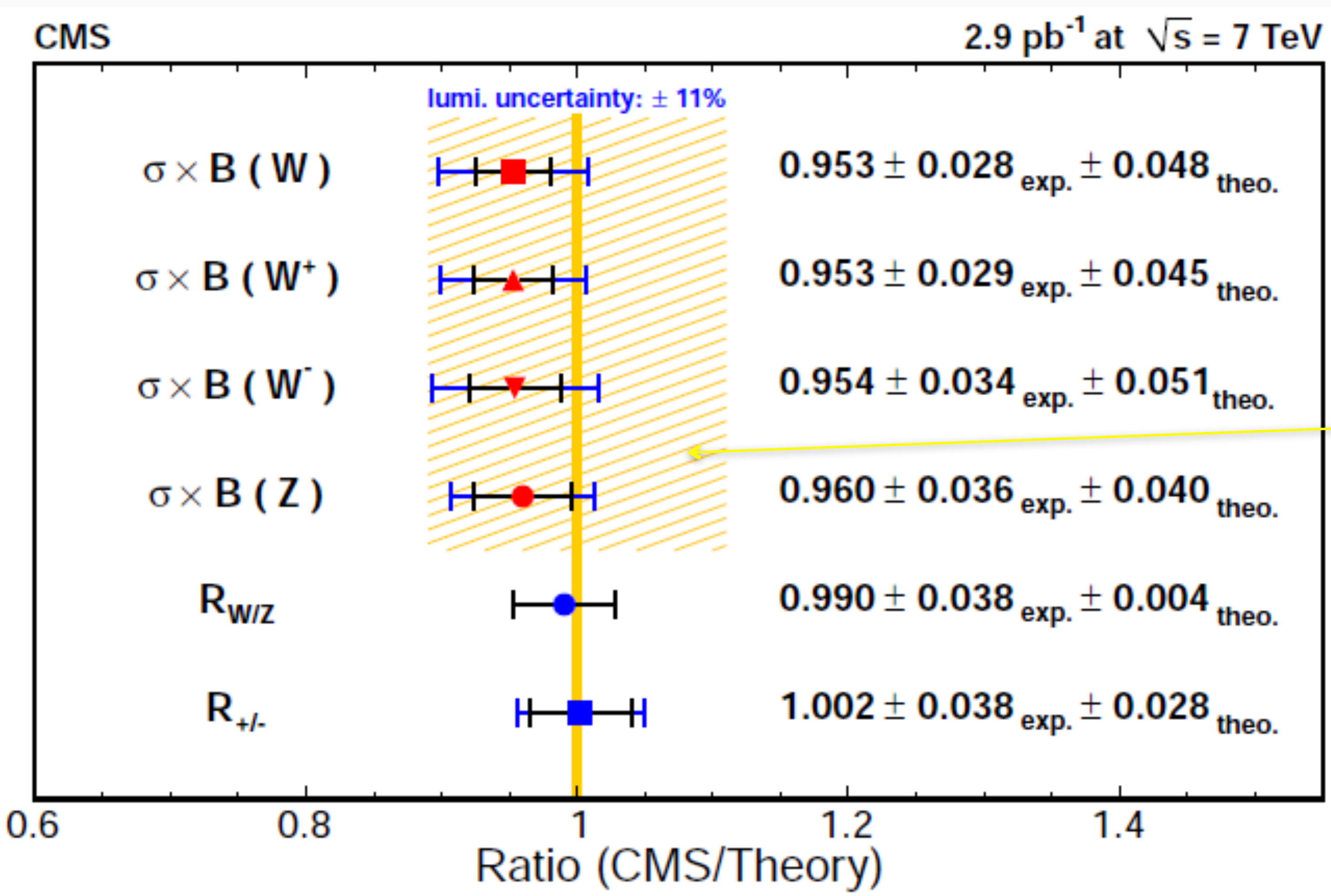
W+ and W- consistent with PDF expectations
Close to challenging global PDF precision!
Limited primarily by +/- efficiency ratio (Z statistics)





Comparison with Theory

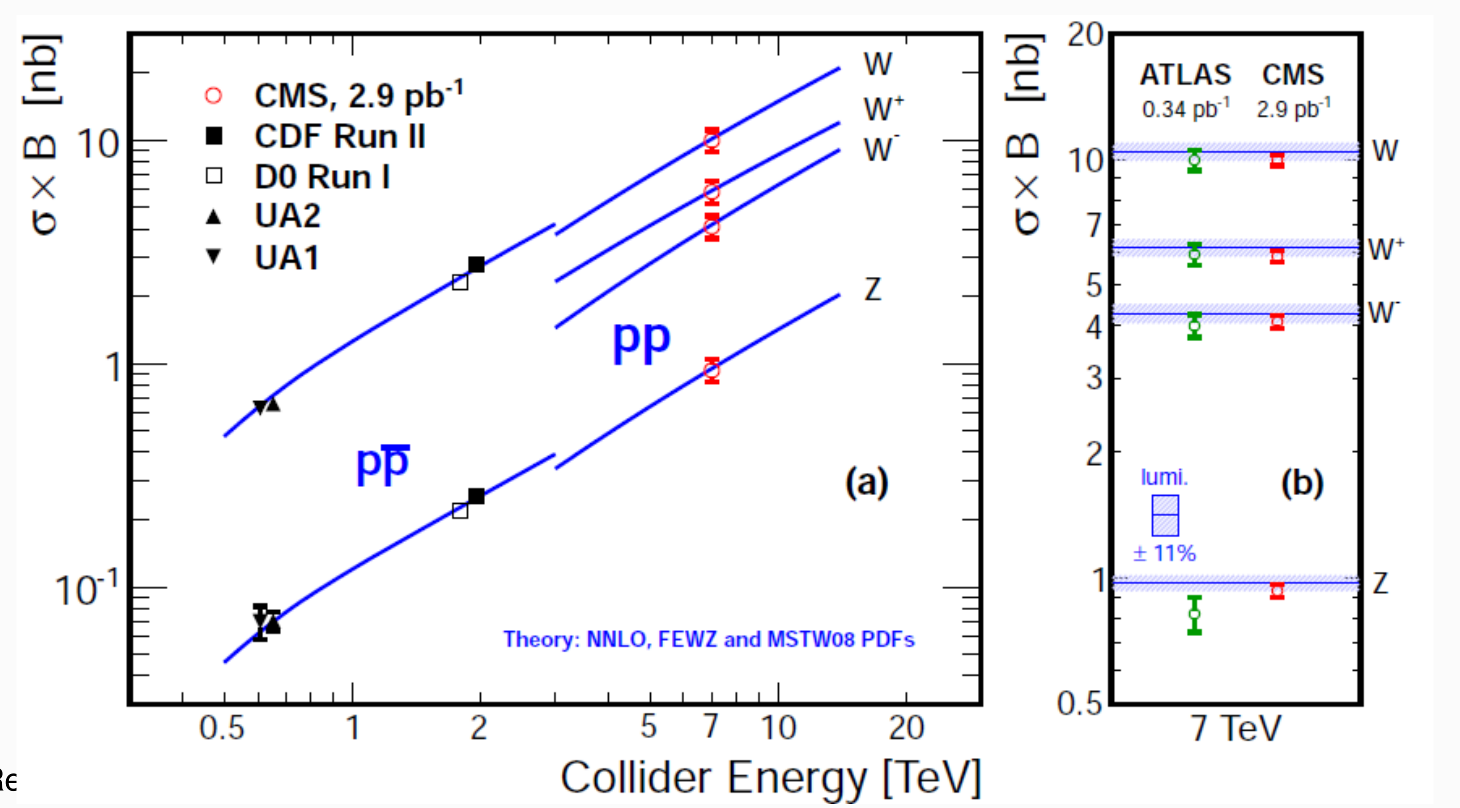
arXiv:1012.2466



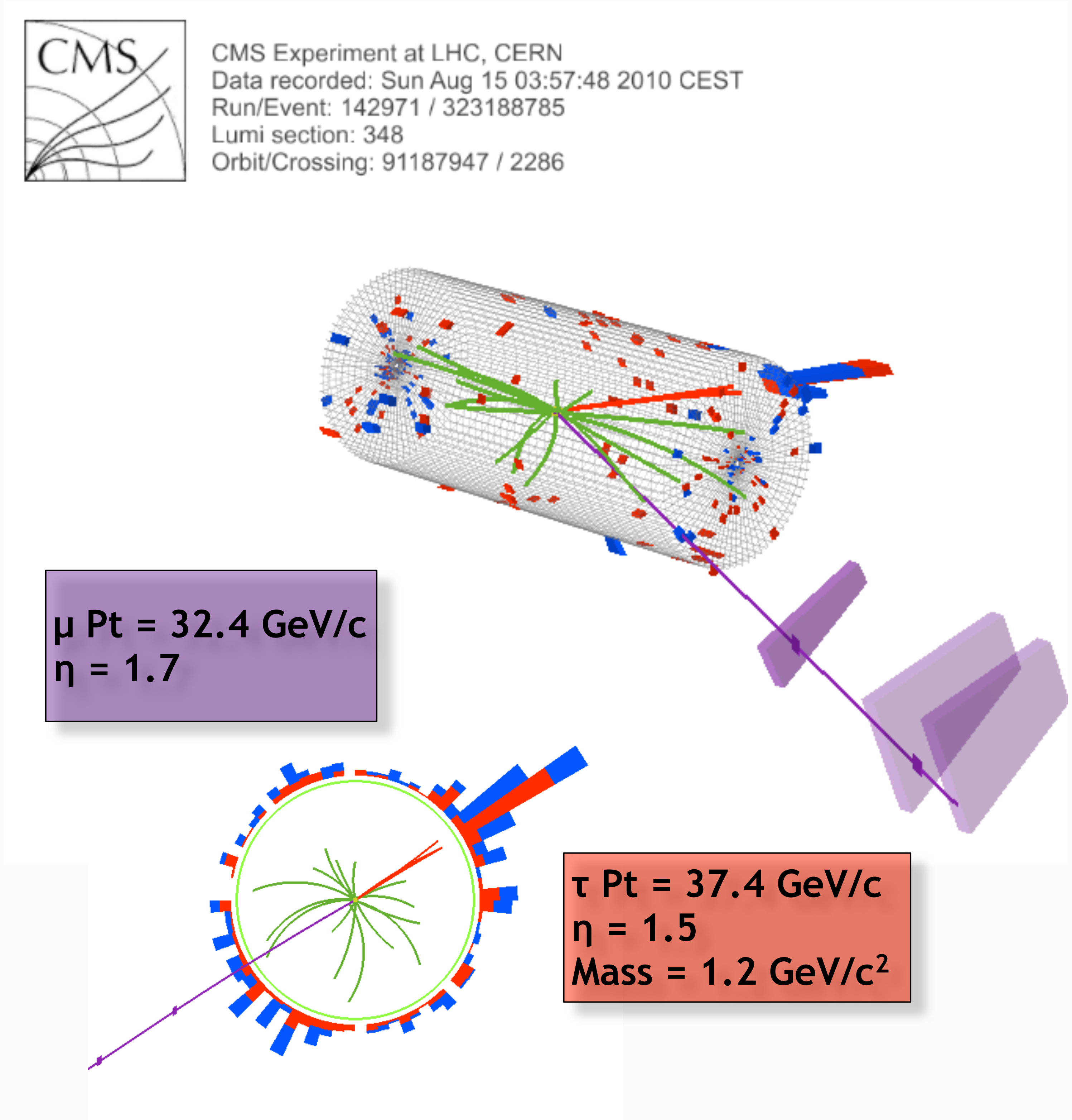
Lumi error

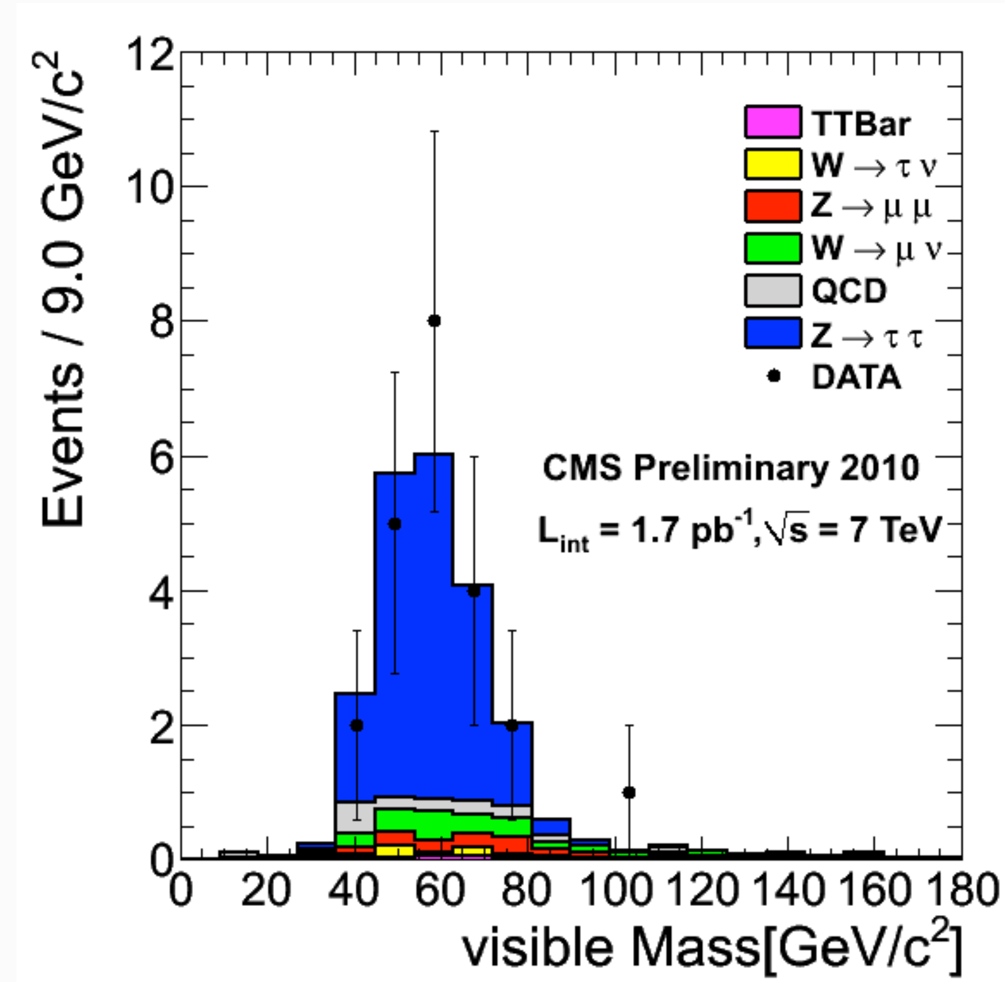
Clearly Lumi is the area with largest potential of improvement

- W cross section non-lumi error 2.9%
- Z cross section non-lumi error 3.9%
- W/Z ratio total error 3.8%
- Internally consistent across channels
- Everywhere close to systematics limited



$Z \to \tau\tau \to \tau\text{-jet}\ \mu$





from: G. Rolandi, Paris, Dec 2010

Conclusions

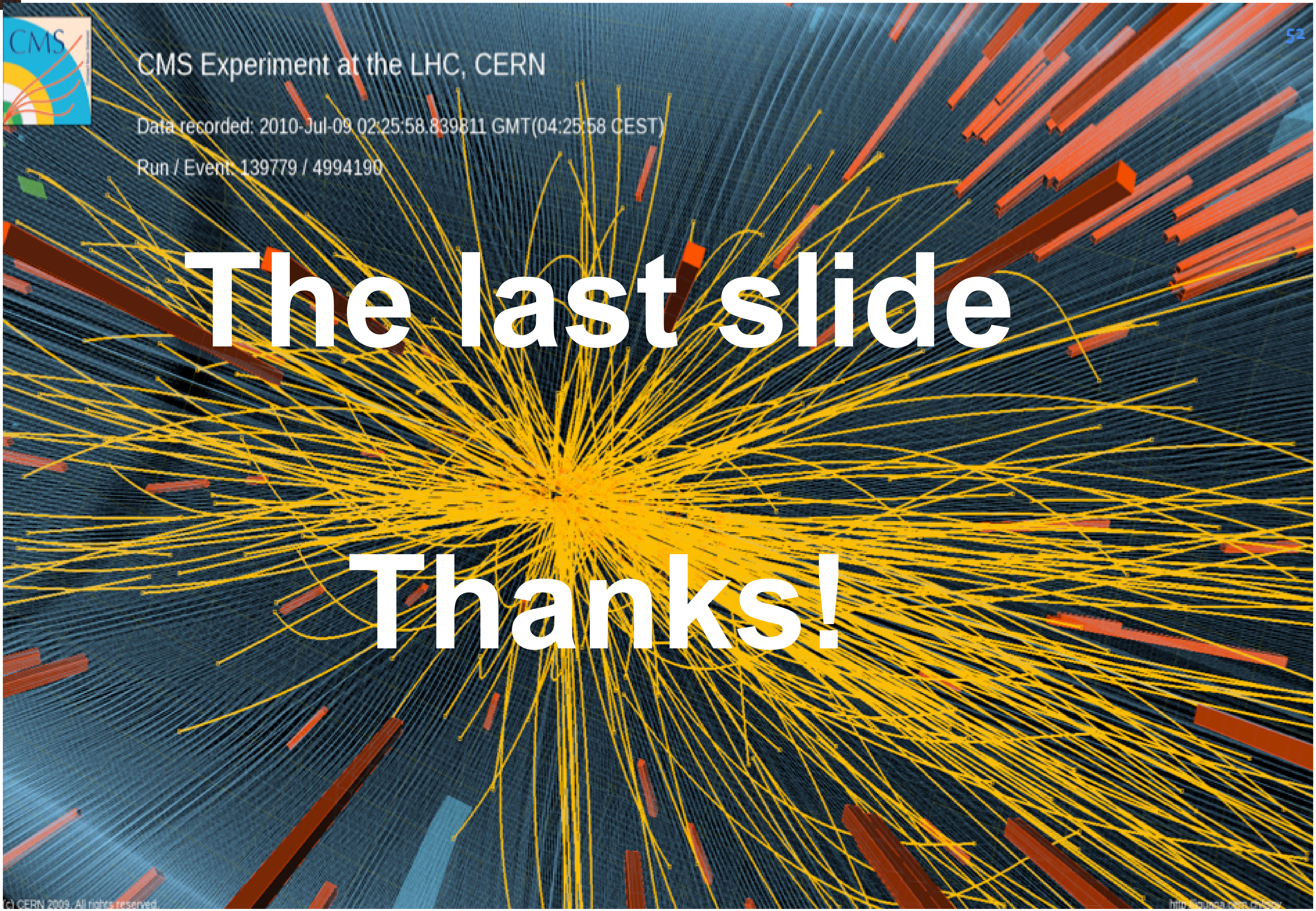
Summary

- The CMS experiment at the LHC performs extremely well

- The first year at 7 TeV has already given us a sample big enough to seriously test and challenge the SM

- The speed, at which the two experiments deliver results, and their quality, is really impressive

The last slide



Thanks!

References (CMS results)

Gateway to collection of all CMS Results:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

Thanks to...

- Input taken from (talks by)
  - G. Rolandi
  - S. Krutelyov
  - V. Chiochia
  - M. Konecki

- Thanks to the organizers for the kind invitation!!