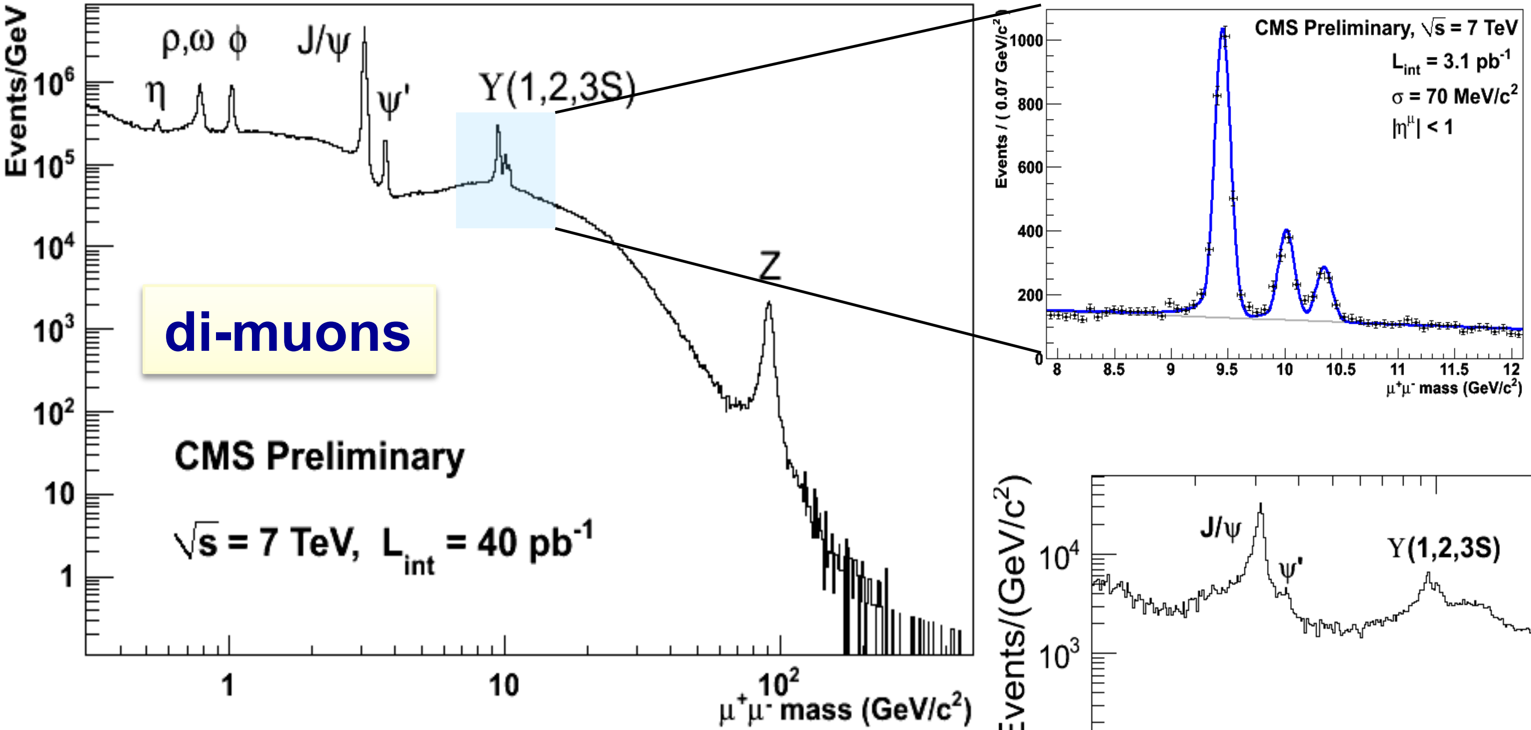
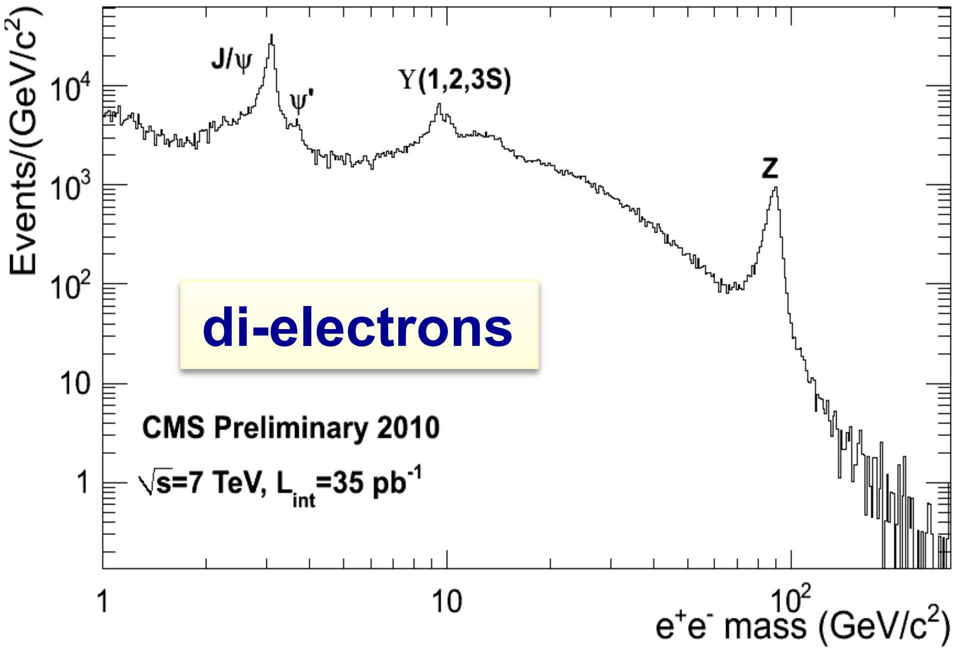
Heavy flavors

Dilepton mass spectrum at 7 TeV

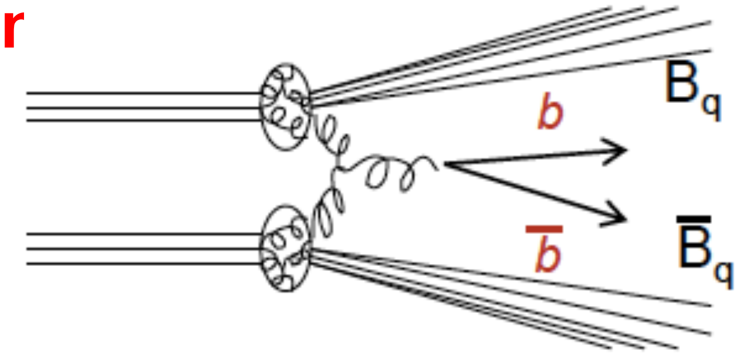


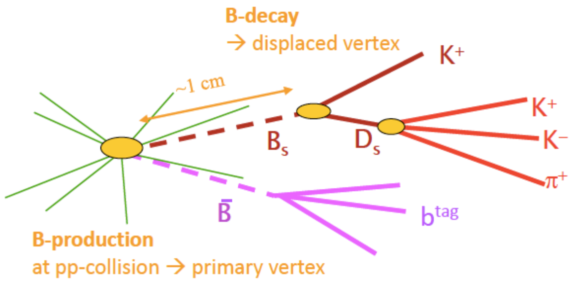


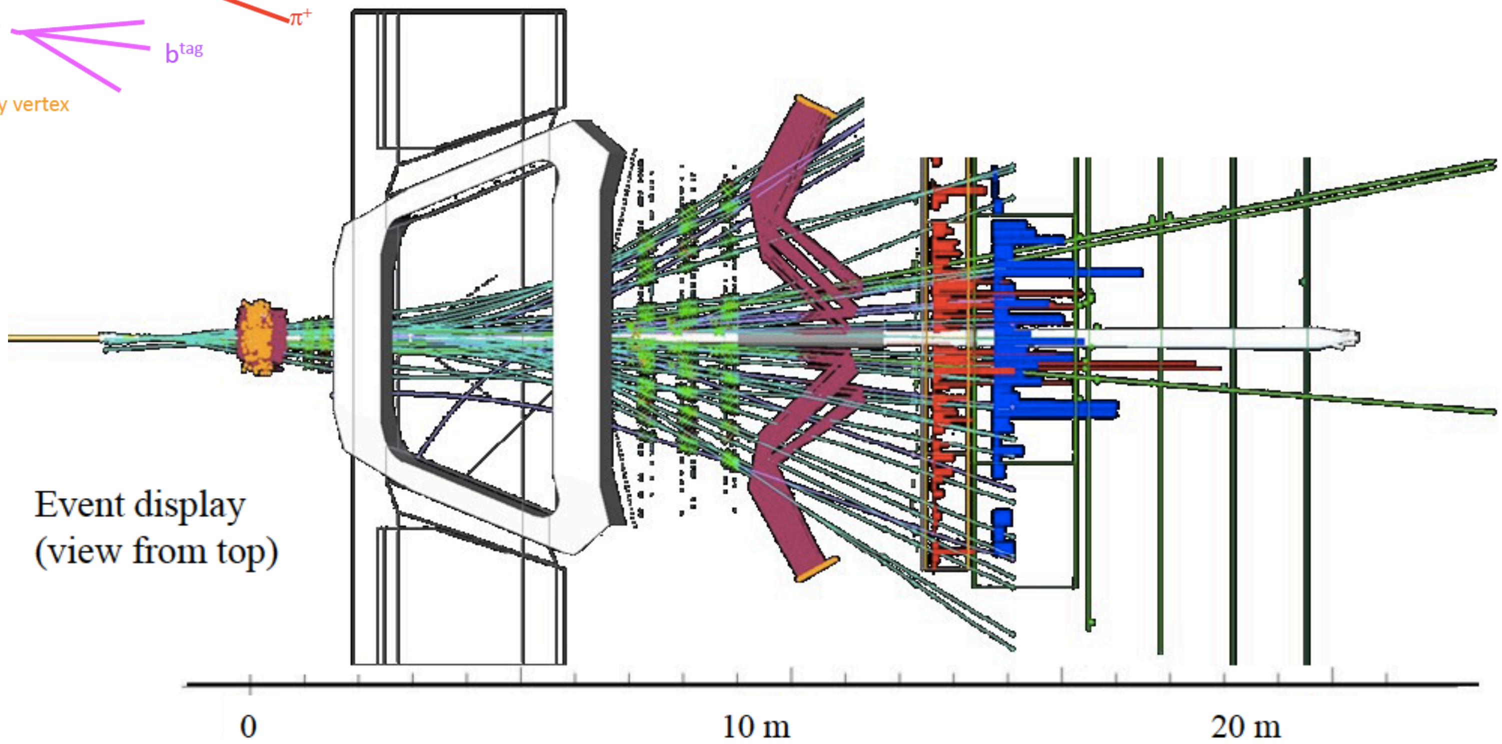
Demonstration of (high) quality of electron and muon reconstruction

And of course, from LHCb

- **B-quark production cross sectior**
  - **It's also very forward-peaked**
  - **LHCb: cover 2<|η|<6 region**

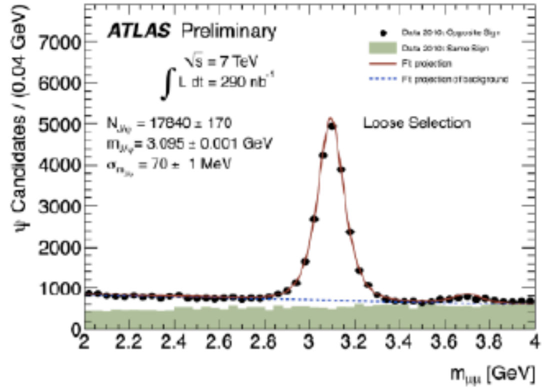


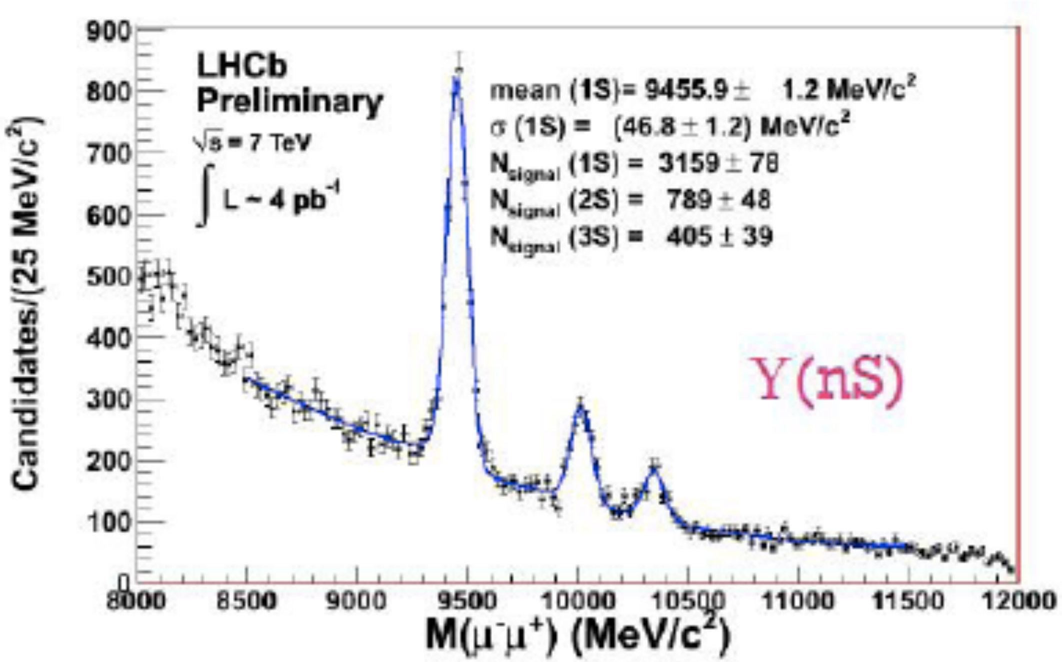


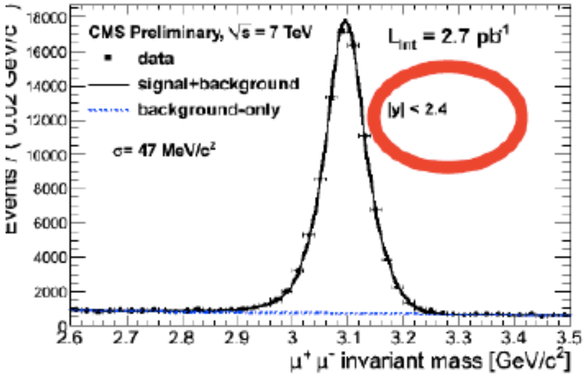


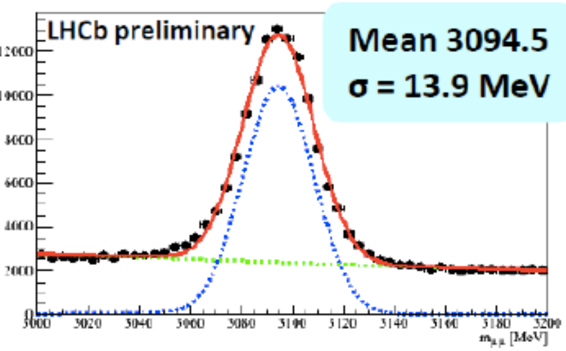
And LHCb…

	ATLAS	CMS	LHCb
σ (MJ/ψ)	70 MeV	47 MeV	14 MeV

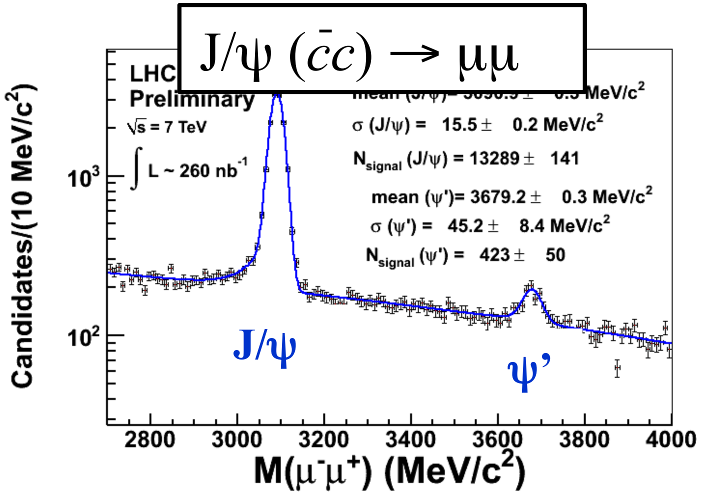


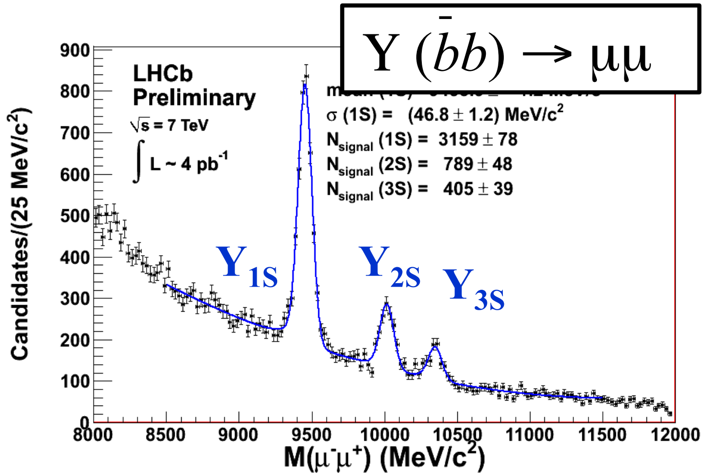


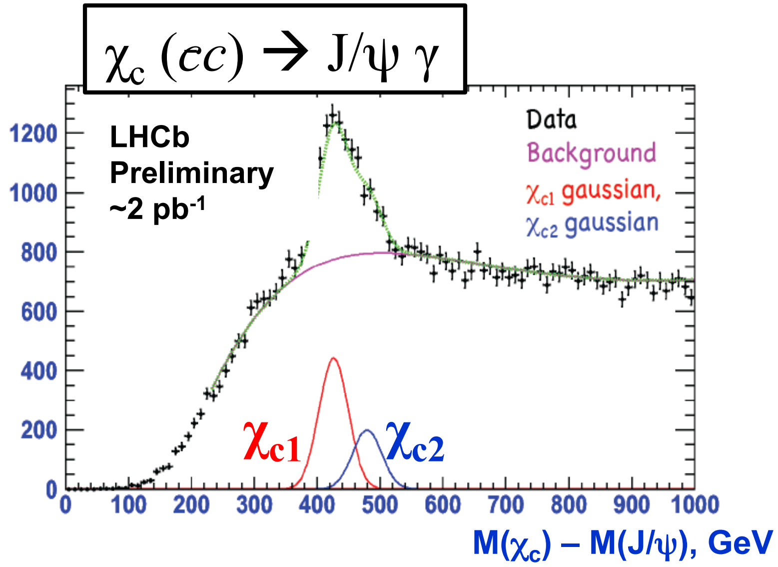


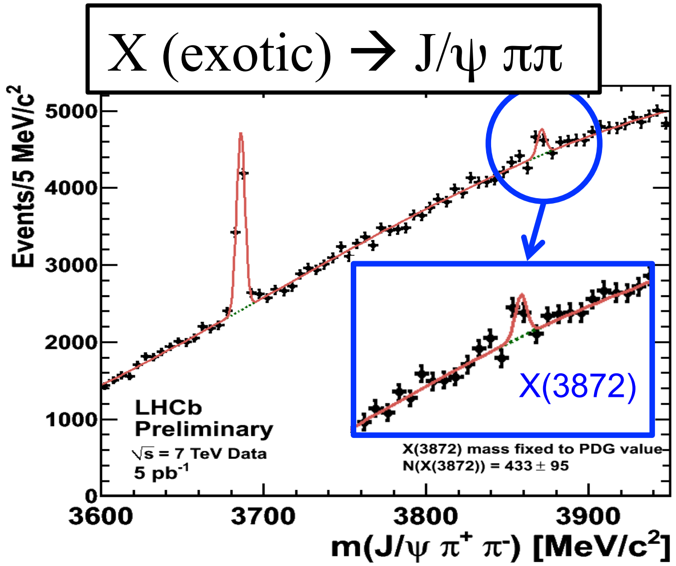


LHCb: onia


J/ψ (c̄c) → μμ
LHCb
Preliminary
√s = 7 TeV
∫ L ~ 260 nb⁻¹
σ (J/ψ) = 15.5 ± 0.2 MeV/c²
N_signal (J/ψ) = 13289 ± 141
mean (ψ')= 3679.2 ± 0.3 MeV/c²
σ (ψ') = 45.2 ± 8.4 MeV/c²
N_signal (ψ') = 423 ± 50
J/ψ
ψ'
Candidates/(10 MeV/c²)
M(μ⁻μ⁺) (MeV/c²)

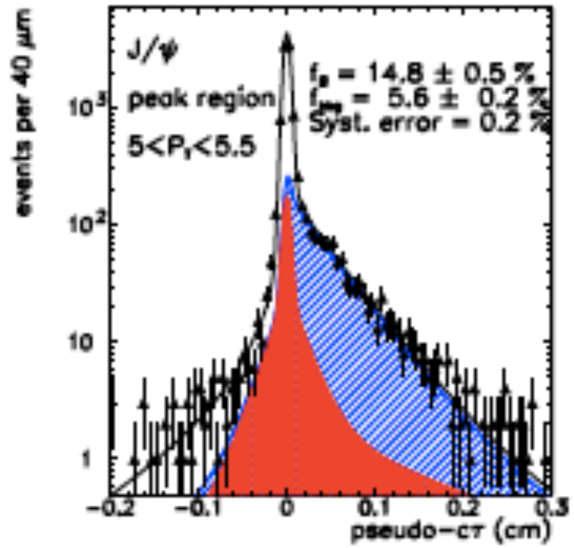

Υ (b̄b) → μμ
LHCb
Preliminary
√s = 7 TeV
∫ L ~ 4 pb⁻¹
σ (1S) = (46.8 ± 1.2) MeV/c²
N_signal (1S) = 3159 ± 78
N_signal (2S) = 789 ± 48
N_signal (3S) = 405 ± 39
Υ1S
Υ2S
Υ3S
Candidates/(25 MeV/c²)
M(μ⁻μ⁺) (MeV/c²)

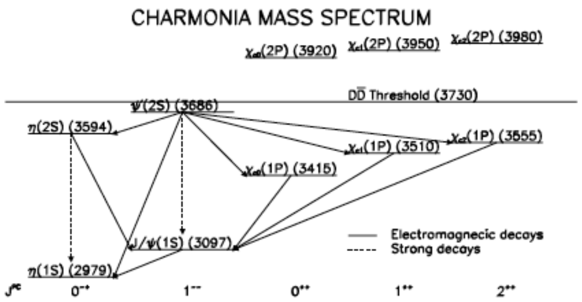

χc (cc) → J/ψ γ
LHCb
Preliminary
~2 pb⁻¹
Data
Background
χc1 gaussian,
χc2 gaussian
χc1
χc2
M(χc) – M(J/ψ), GeV


X (exotic) → J/ψ ππ
X(3872)
LHCb
Preliminary
√s = 7 TeV Data
5 pb⁻¹
X(3872) mass fixed to PDG value
N(X(3872)) = 433 ± 95
Events/5 MeV/c²
m(J/ψ π⁺ π⁻) [MeV/c²]

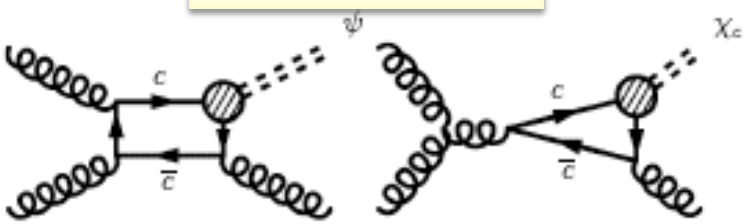
Onia – why they're interesting

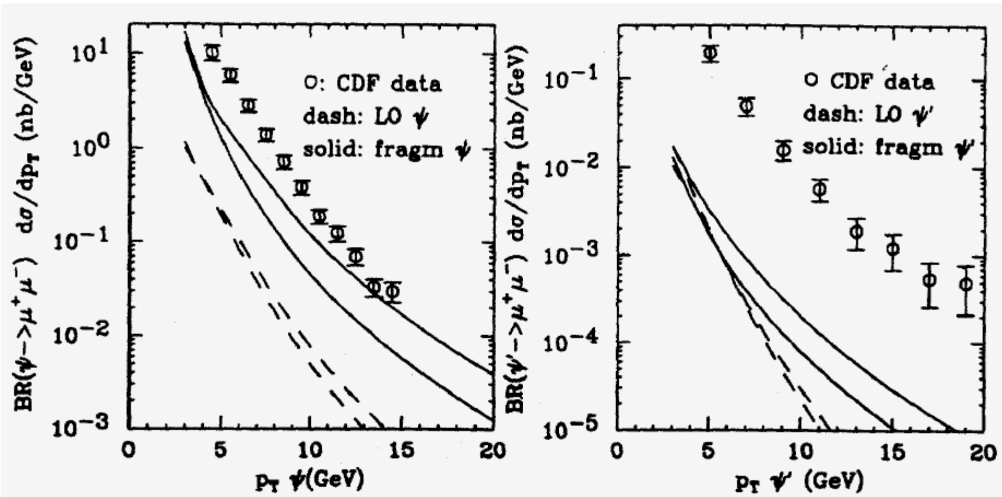
- **It all started with CDF in Run I: very large prompt J/ψ component**
  - Advent of SVX meant one could separate the J/ψ from b decays and "prompt" production
  - And it was not due to χ_c cascades: same "problem" in ψ(2S):





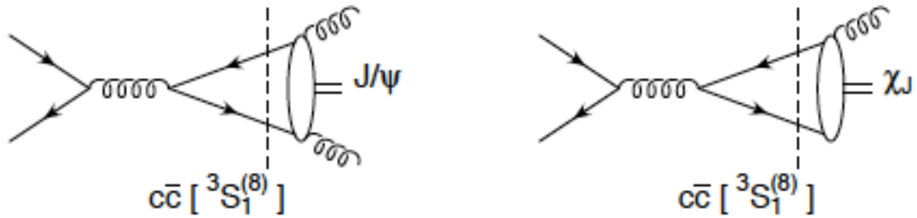
Color Singlet





NRQCD, color octet, etc

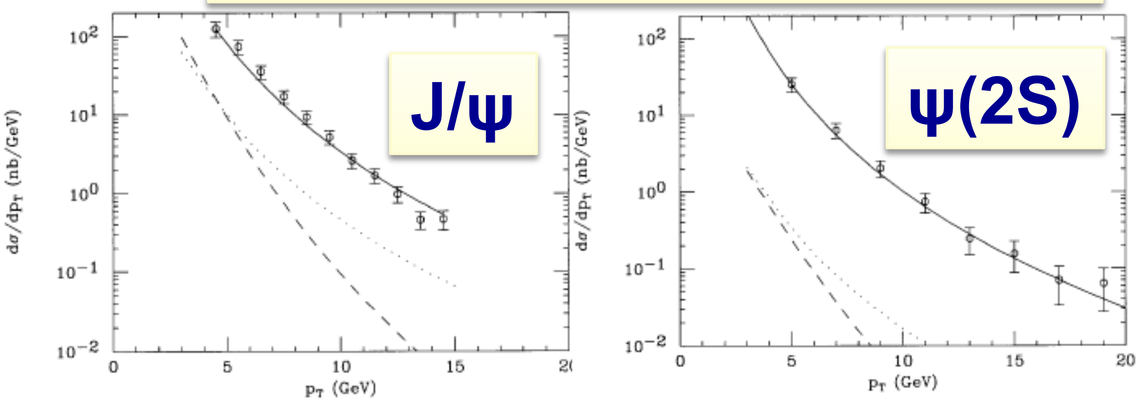
- **Color octet: bleed only color, so no need for singlet to form hadron**

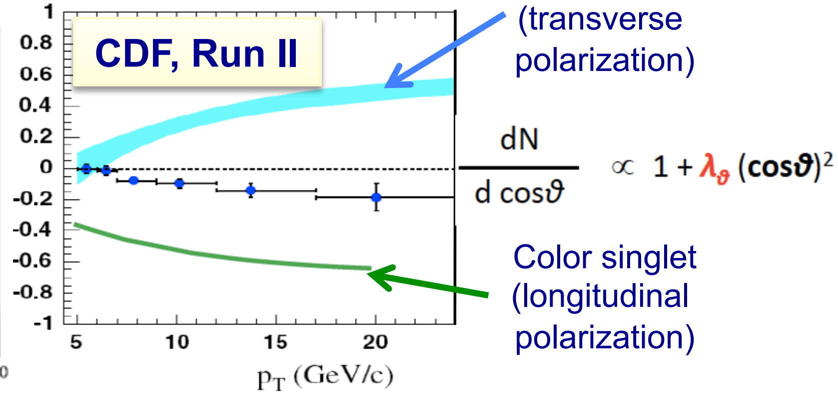


  - **Implies a much larger cross section (any gluon-gluon initial state → gluon in final state, gluon fragmentation → ψ)**
  - **"bonus": non-perturbative, so normalization floats ☺**
  - **"sign": charmonium should be polarized.**

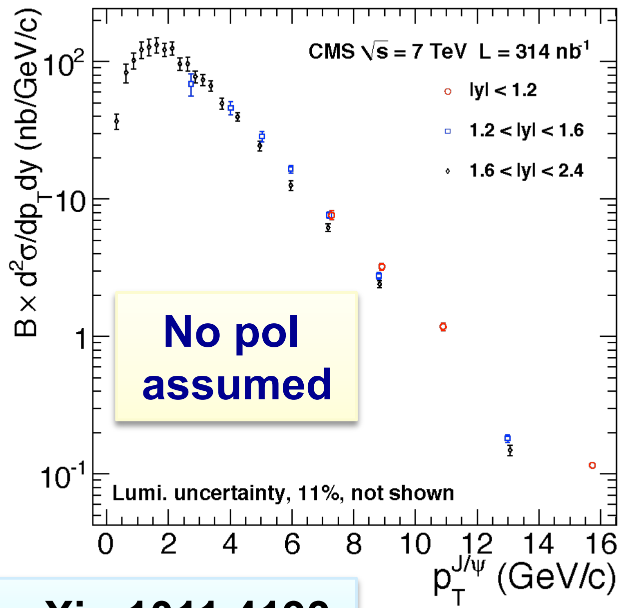
Normalizing direct+COM to data

Or not?



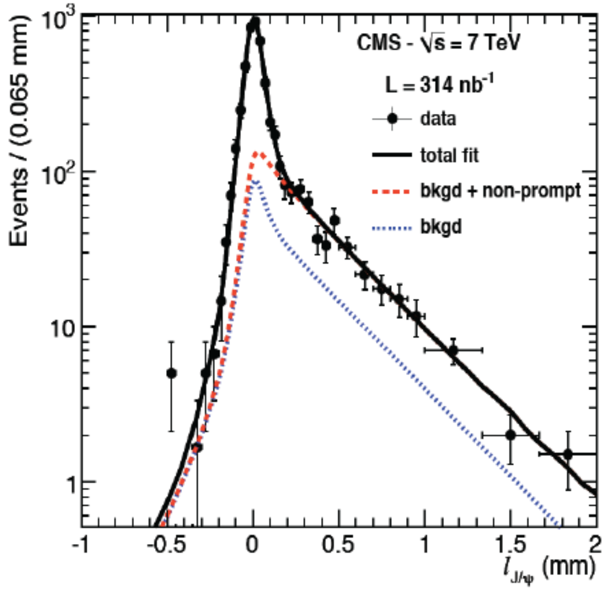


J/ψ Production (I)



No pol assumed

arXiv:1011.4193

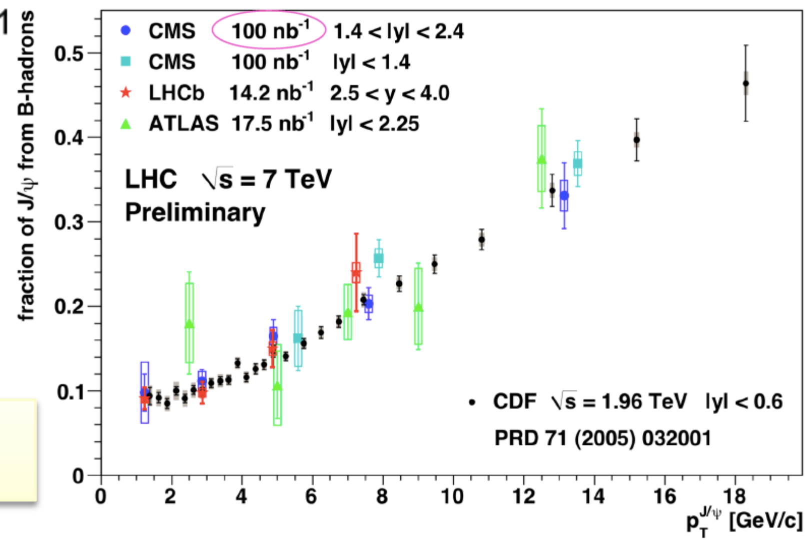


6.5<pT<10 GeV/c, 1

+ATLAS+LHCb

$$\sigma(pp \to \Psi X)\bullet \mathrm{BR}(\Psi \to \mu^+\mu^-) = 70.9 \pm 2.1 \pm 3.0 \pm 7.8 \text{ nb}$$

$$\sigma(pp \to bX \to \Psi X)\bullet \mathrm{BR}(\Psi \to \mu^+\mu^-) = 26.0 \pm 1.4 \pm 1.6 \pm 2.9$$

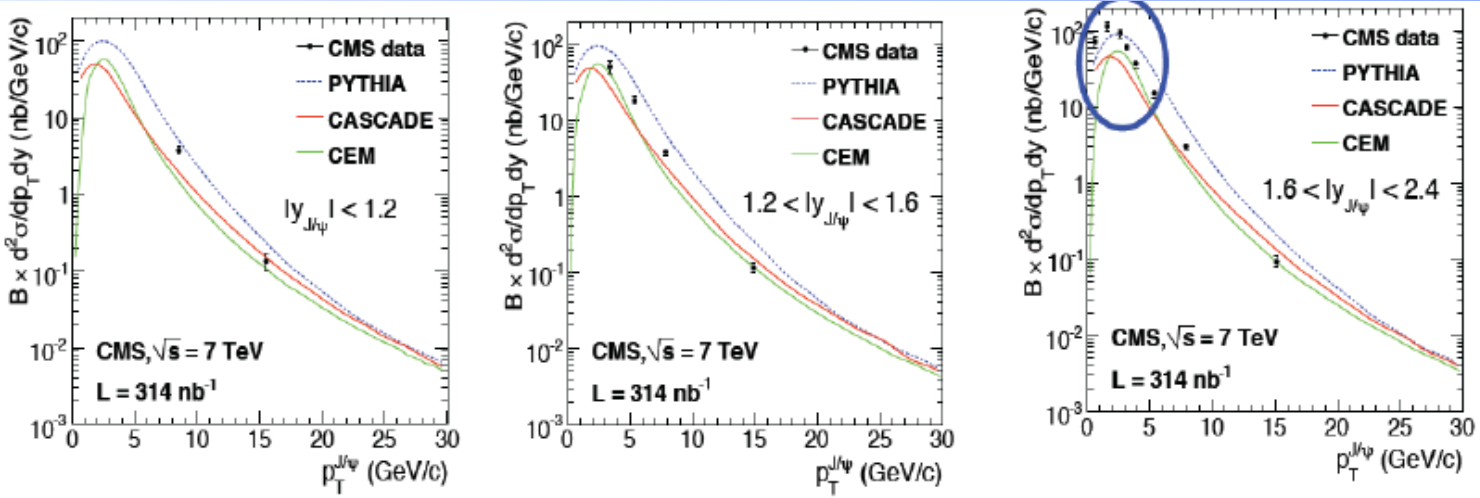


Fraction of J/ψ from b decays

Independent of y and E_{cm} (!?)

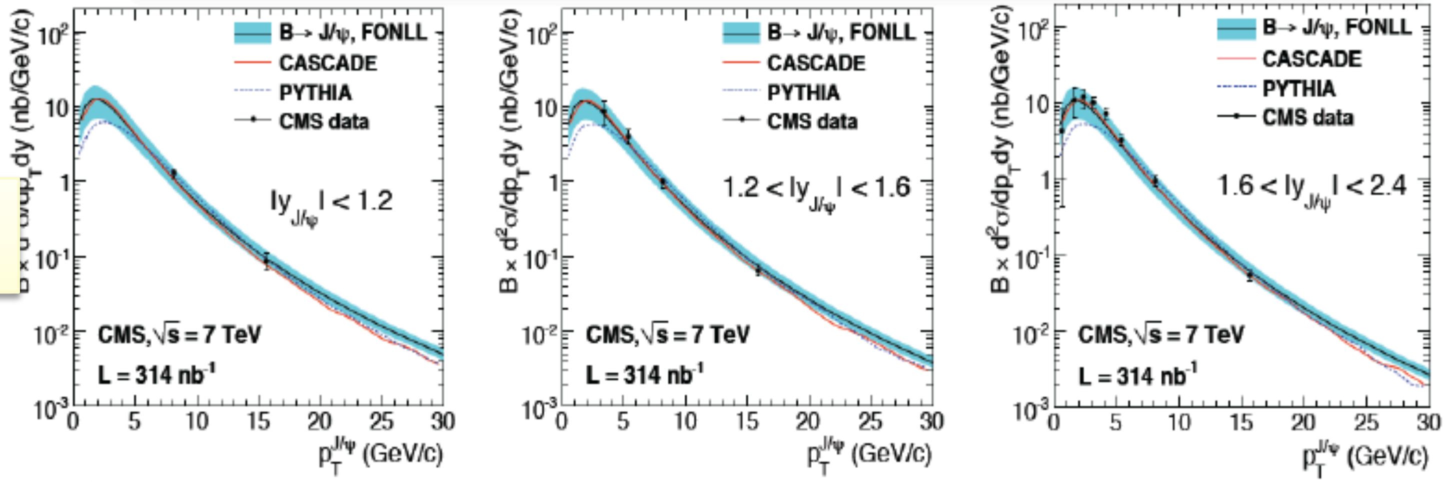
J/ψ Production (II)

Prompt



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

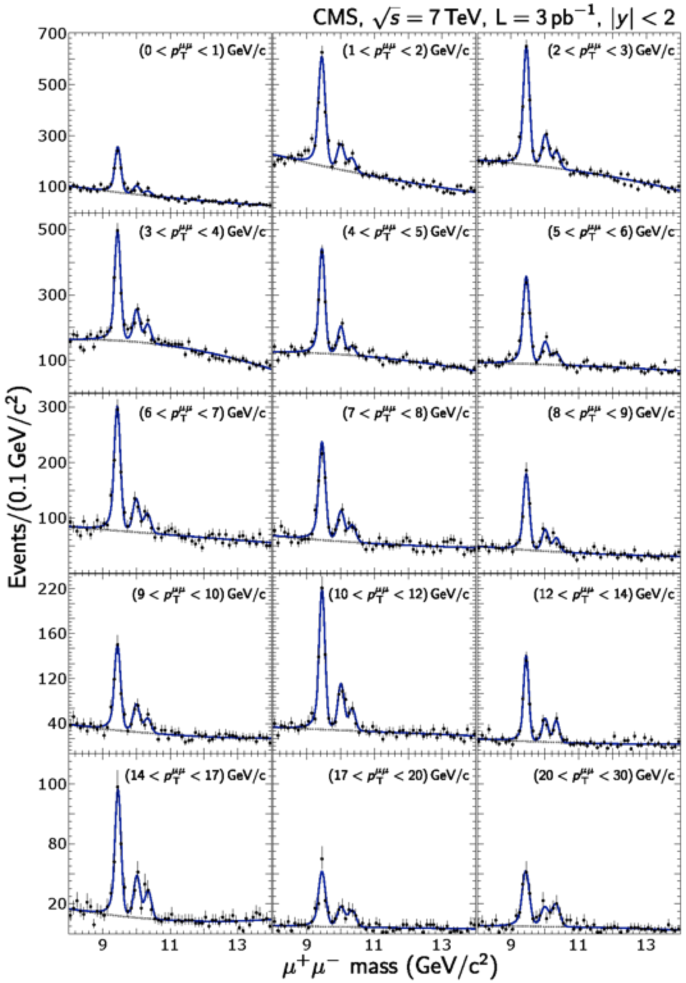
B→J/ψ X

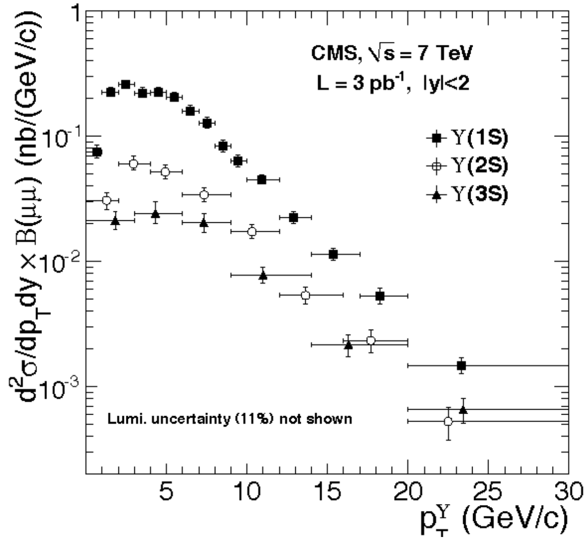


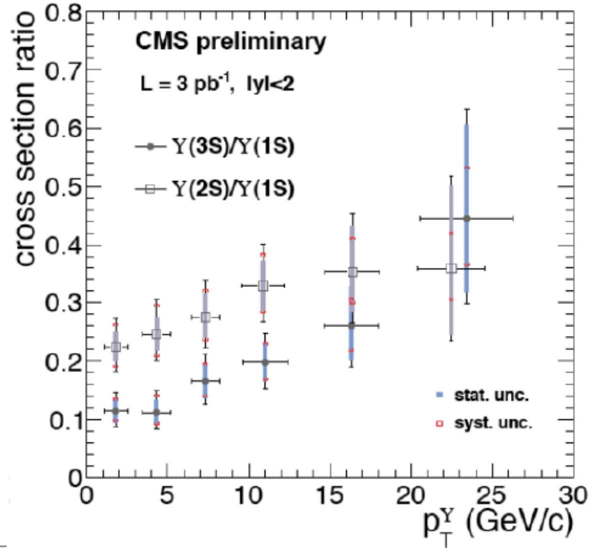
$$\sigma(pp \to bX \to J/\psi X) \cdot BR(J/\psi \to \mu^+\mu^-) = 26.0 \pm 1.4\ (\text{stat}) \pm 1.6\ (\text{syst}) \pm 2.9\ (\text{luminosity})\ \text{nb}$$

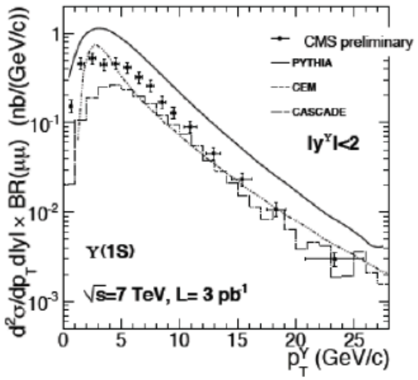
Upsilon Production

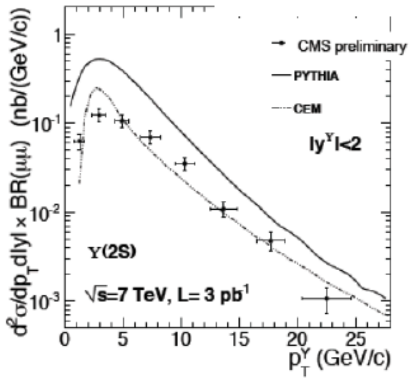
arXiv:submit/ 0170551

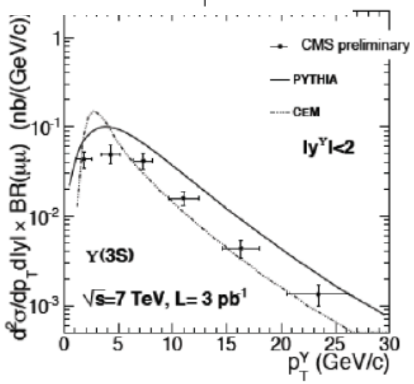










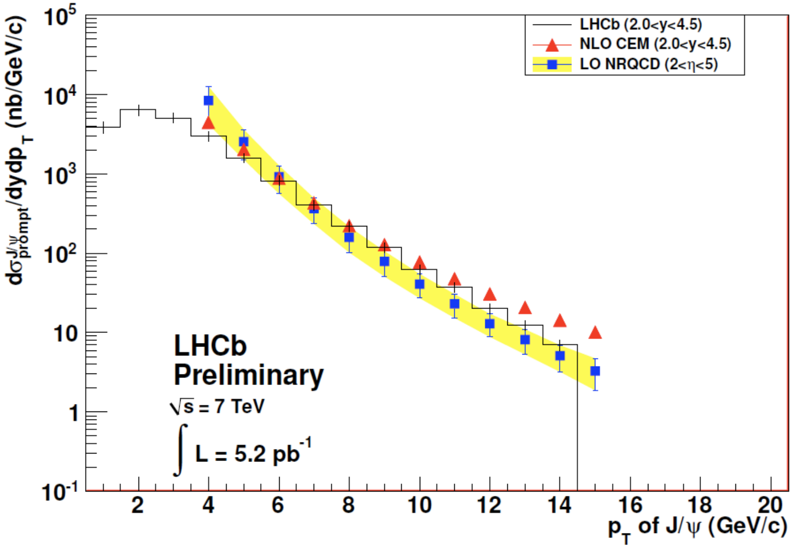


$$\sigma(pp \to \Upsilon(1S)X) \cdot \mathcal{B}(\Upsilon(1S) \to \mu^+\mu^-) = 7.37 \pm 0.13(\text{stat.})^{+0.61}_{-0.42}(\text{syst.}) \pm 0.81(\text{lumi.})\,\text{nb}\,,$$

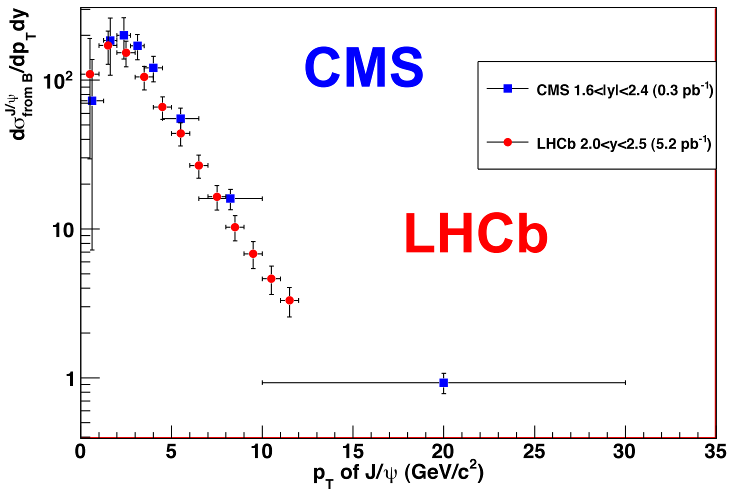
$$\sigma(pp \to \Upsilon(2S)X) \cdot \mathcal{B}(\Upsilon(2S) \to \mu^+\mu^-) = 1.90 \pm 0.09(\text{stat.})^{+0.20}_{-0.14}(\text{syst.}) \pm 0.24(\text{lumi.})\,\text{nb}\,, \quad (7)$$

$$\sigma(pp \to \Upsilon(3S)X) \cdot \mathcal{B}(\Upsilon(3S) \to \mu^+\mu^-) = 1.02 \pm 0.07(\text{stat.})^{+0.11}_{-0.08}(\text{syst.}) \pm 0.11(\text{lumi.})\,\text{nb}\,. \quad (8)$$

Charm(onium) production: LHCb

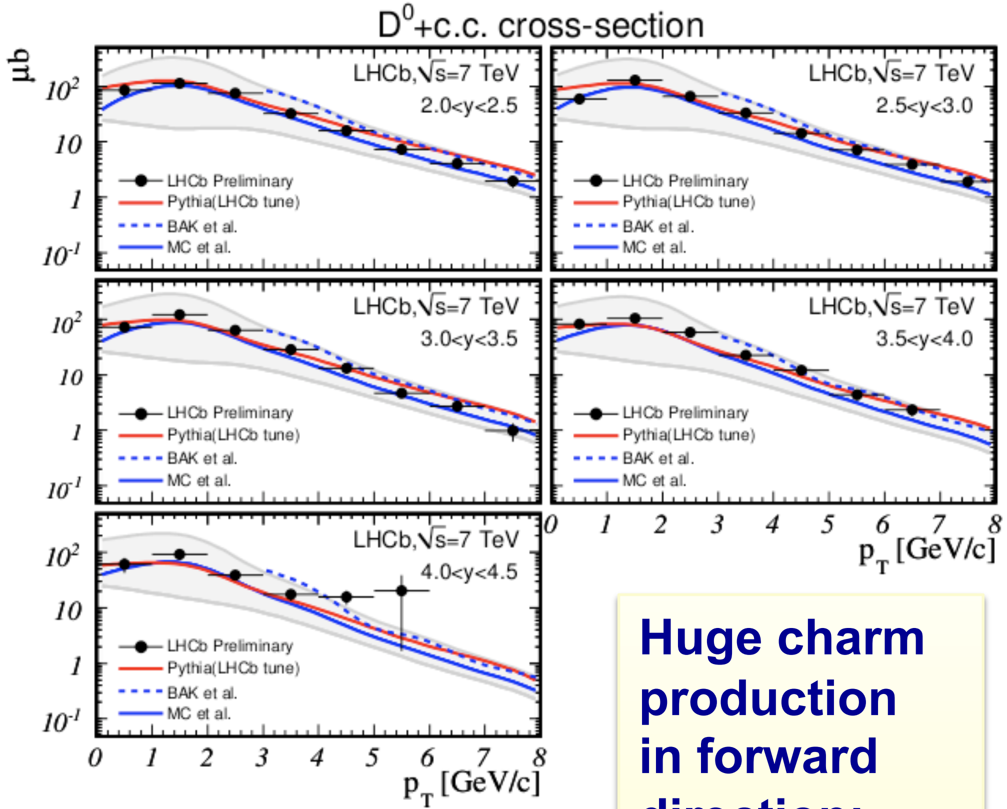


$\sigma_{prompt}(J/\psi,\ P_t<14\ \mathrm{GeV/c},\ 2<y<4.5) =$
$= (\ 10.8 \pm 0.05 \pm 1.51^{+1.69}_{-2.25}\ )\ \mu b$



Open charm cross-sections

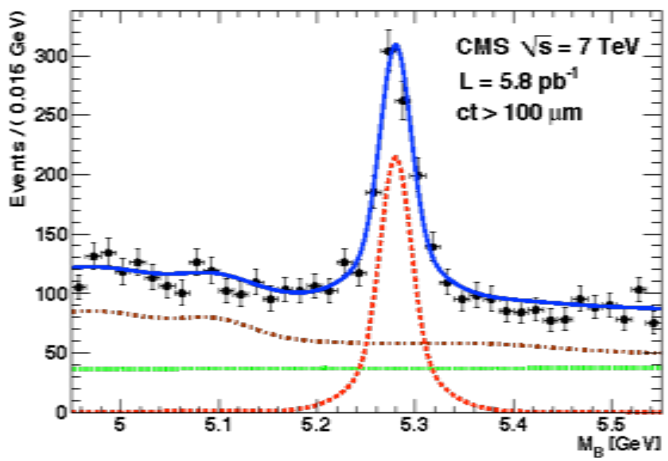
(D*, D^0, D^+, D_s and Λ_c)

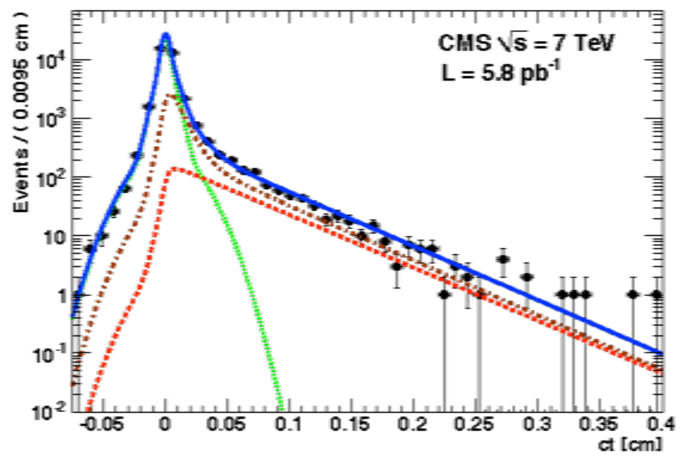


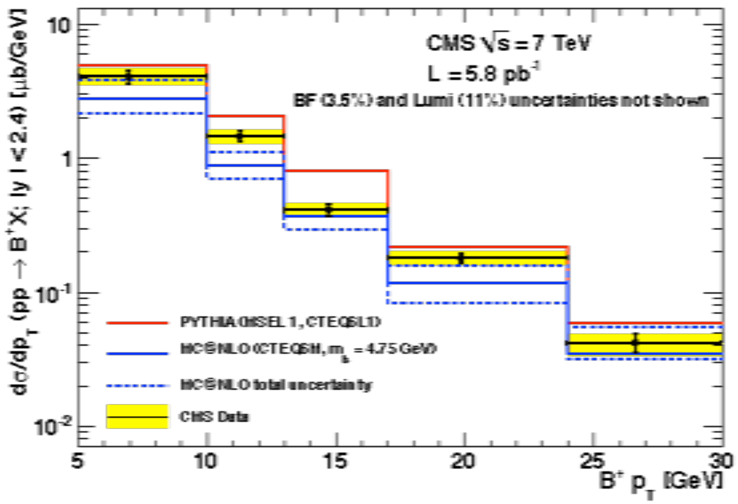
Huge charm production in forward direction: ~20 × b

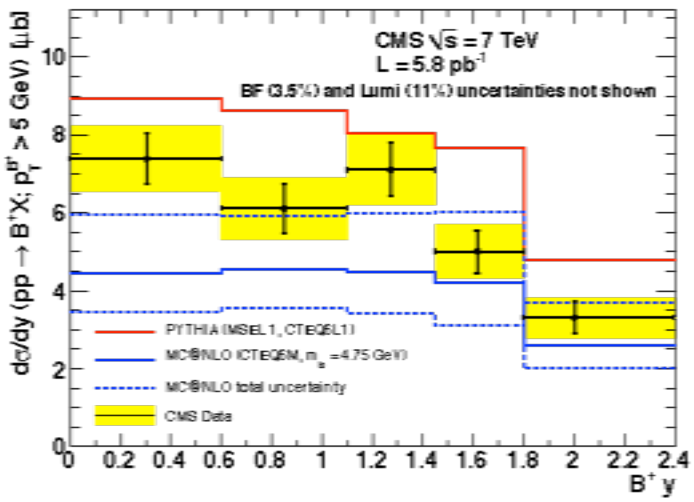
$B^+ \to \psi K$ Production

arXiv:0172289









bb-cross section

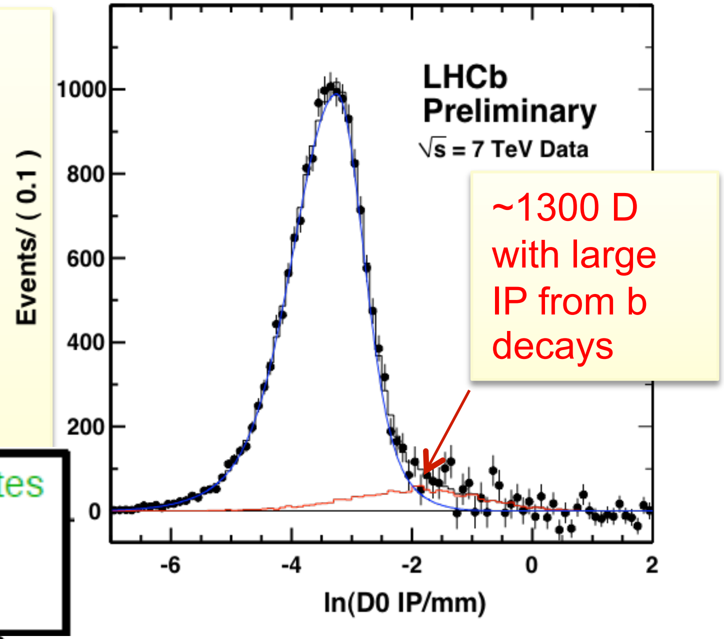
Start from D0 sample. Then:

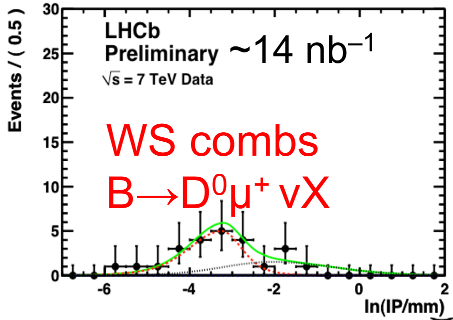
semileptonic B decays: $\mu + D^0 \rightarrow K^- \pi^+$

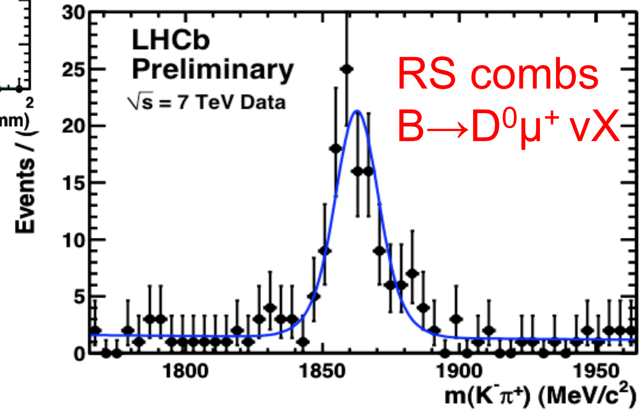
fit sideband-subtracted D^0 IP distribution

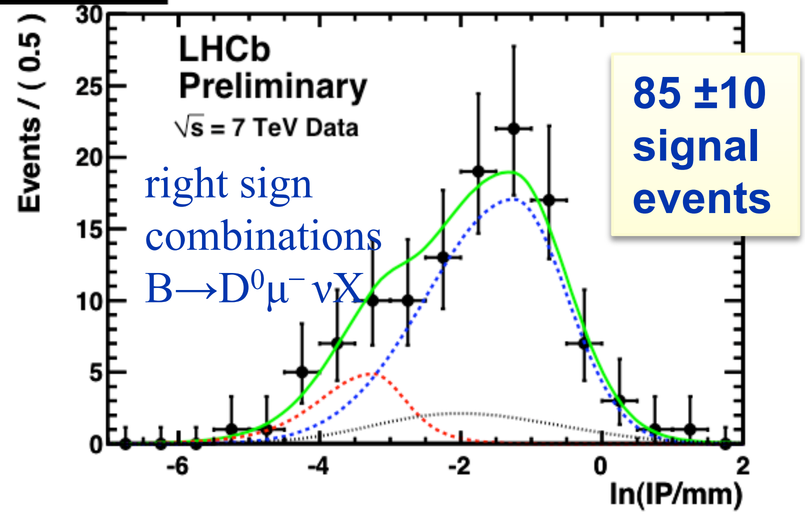
Form wrong-sign (WS) combs: $B \rightarrow D^\circ \mu^+ \nu X$

Form right-sign (RS) combs: $B \rightarrow D^\circ \mu^- \nu X$

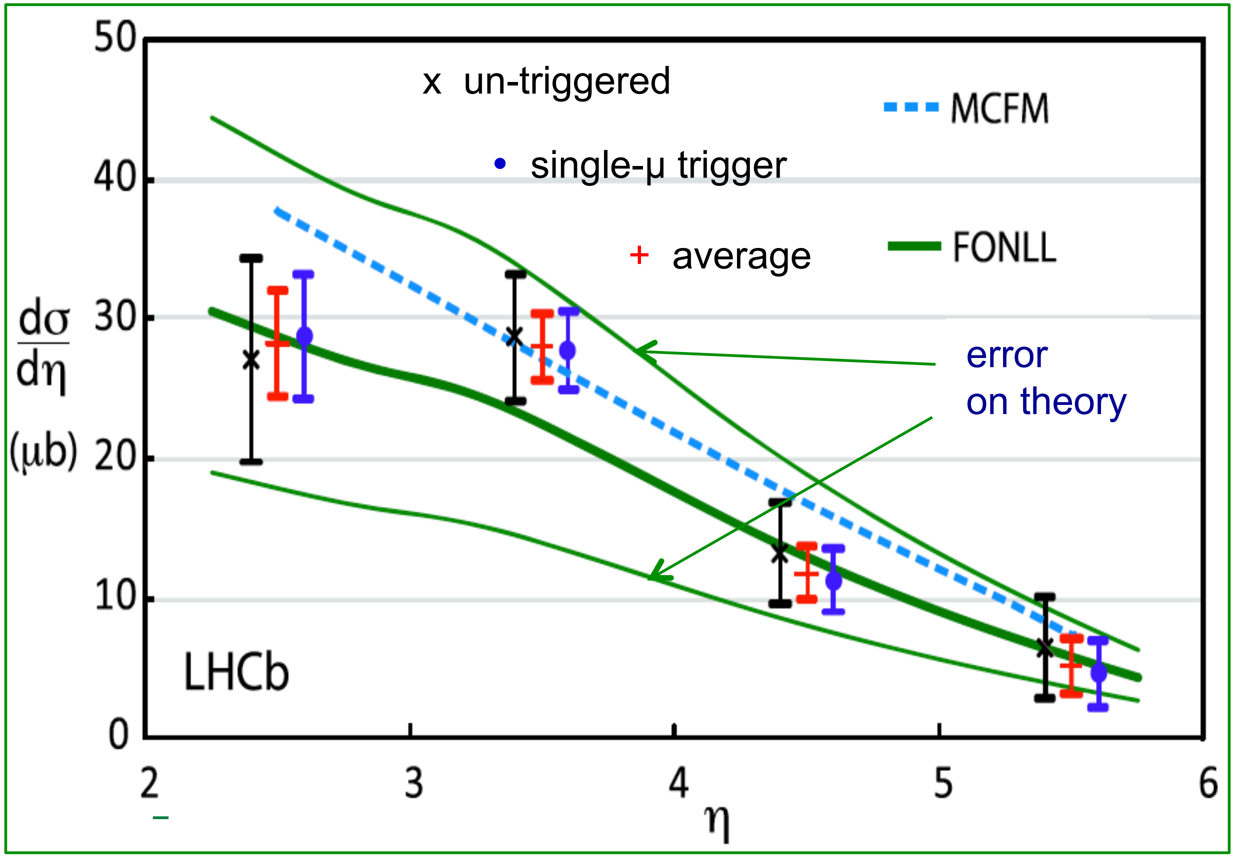








bb cross section



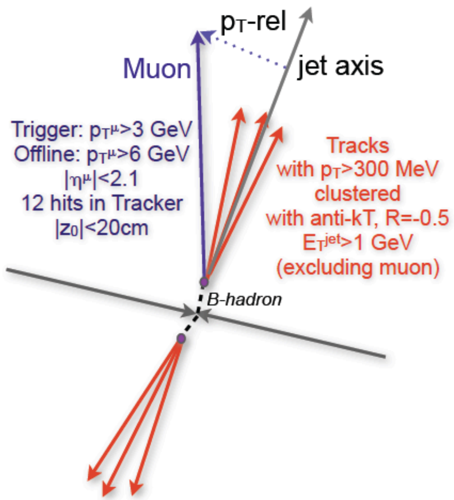
From $B^0 \rightarrow D^0 X^+ \mu^- \nu$; $D^o \rightarrow K^- \pi^+$

$$\sigma(pp \to b\bar{b}X) = 284 \pm 20 \pm 49\,\mu\text{b}\,.$$

In perfect agreement with $B \rightarrow J/\psi X$

$$\sigma(pp \to b\bar{b}X) = 295 \pm 4 \pm 48\,\mu\text{b}$$

Inclusive b cross section from muons

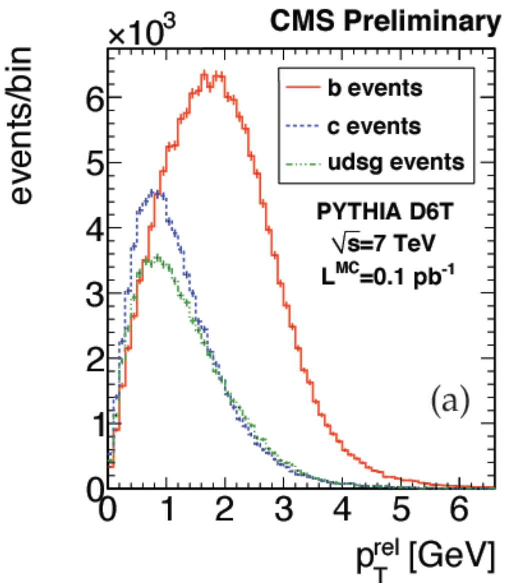


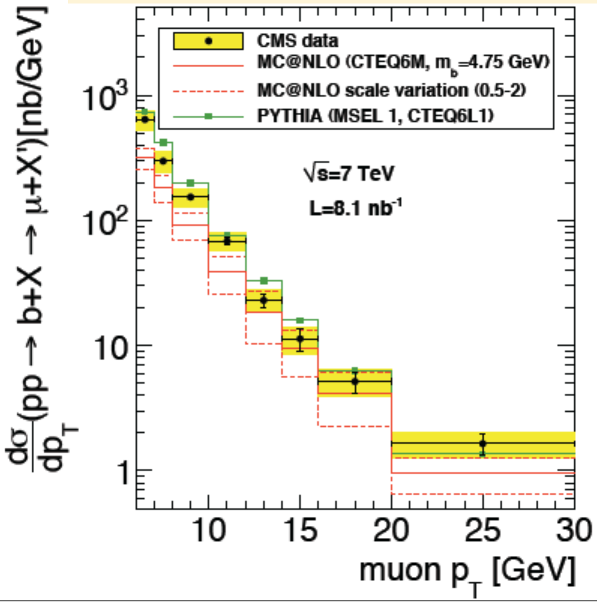
- **Muons in jets; multiply by b fraction (from P_T^{rel} fit)**
  - **Largest expt uncert: fake muon "model" (ptrel) & und event**
  - **MC@NLO: discrepancy at low p_T; low η**

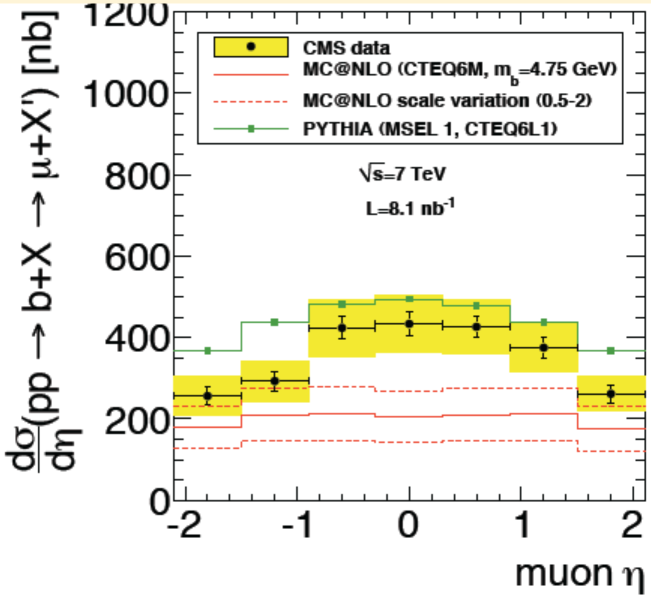
$\sigma = (1.48 \pm 0.04_{\text{stat}} \pm 0.22_{\text{syst}} \pm 0.16_{\text{lumi}})\ \mu b$ **Measured visible cross section**

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

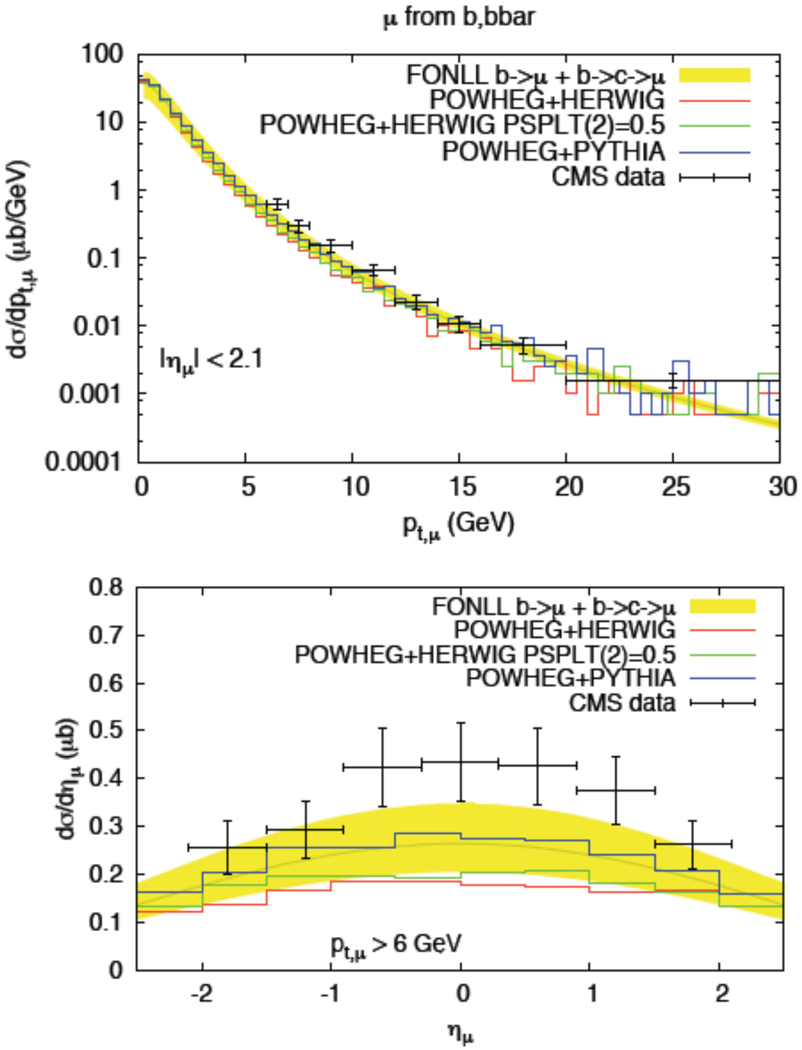
$\sigma_{\text{MC@NLO}} = [0.84^{+0.36}_{-0.19}(\text{scale}) \pm 0.08(m_b) \pm 0.04(\text{pdf})]\ \mu b$ ($\mu_F=\mu_R=p_T$)

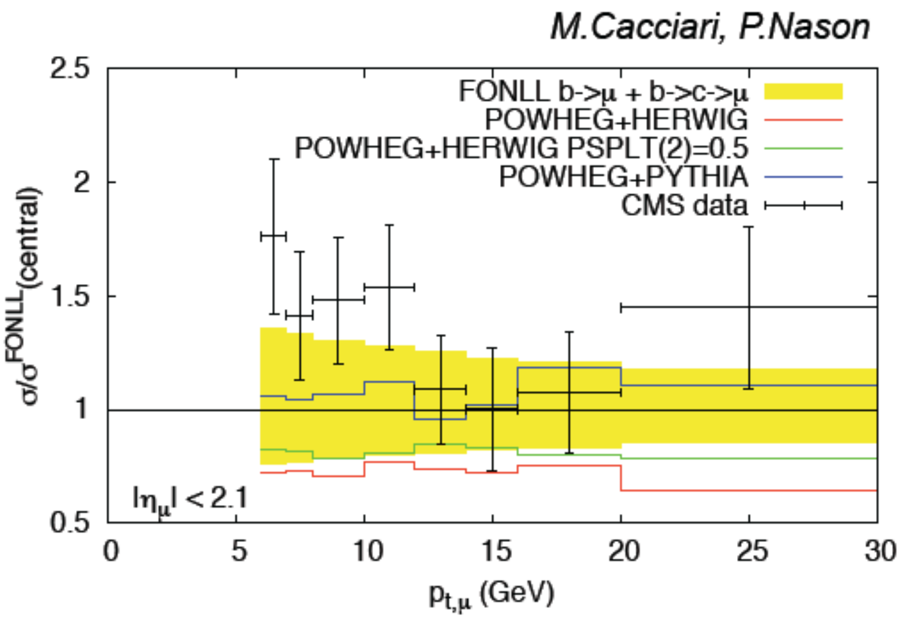






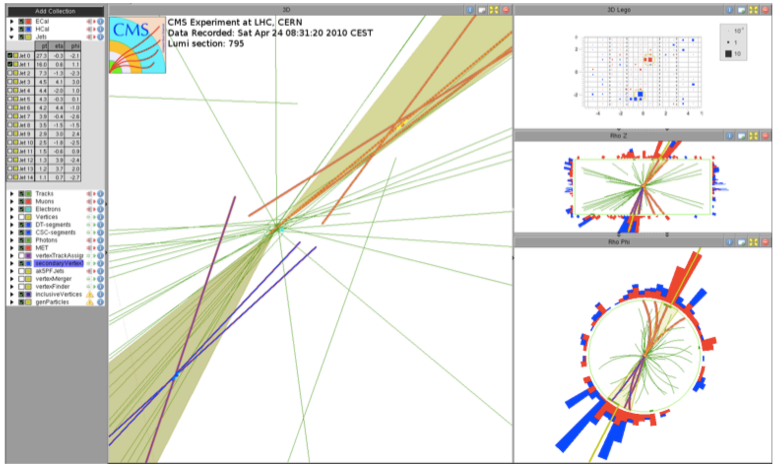
b cross section

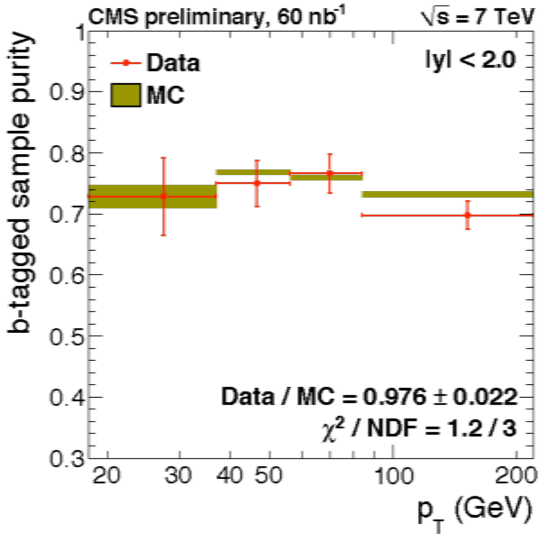


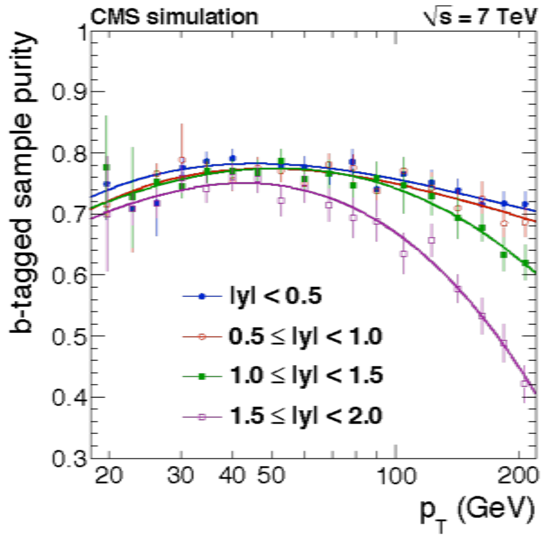


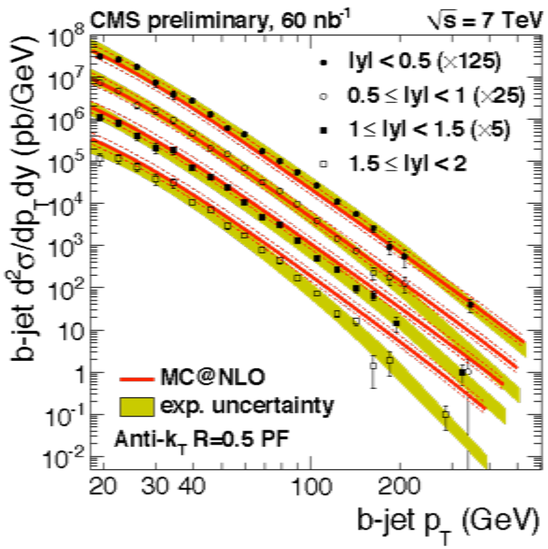
CMS PAS BPH-10-009
Jul 2010

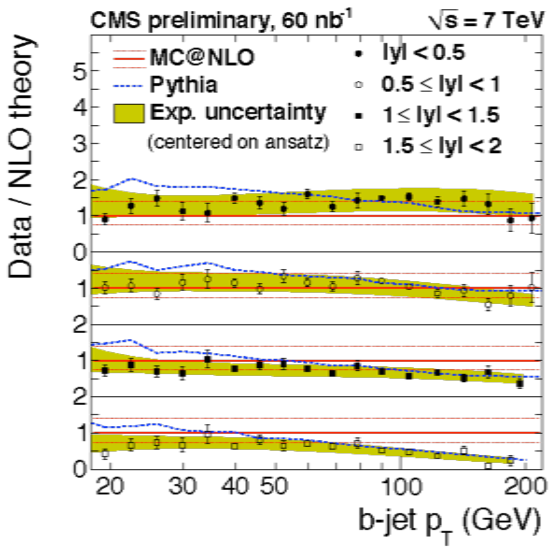
b-Jet Production

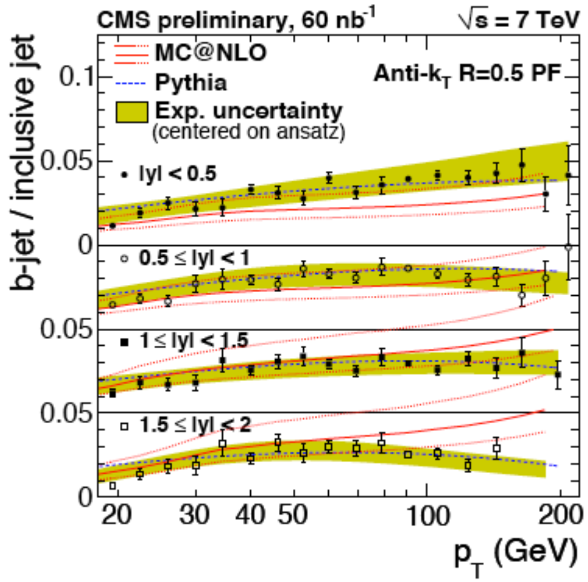






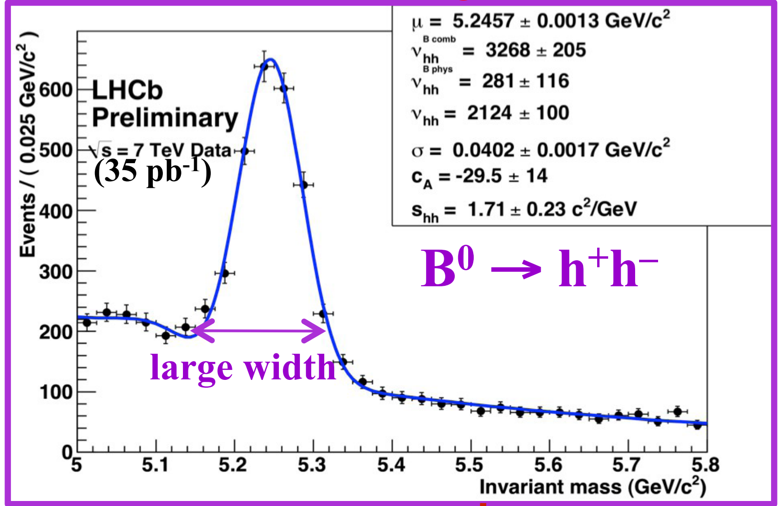




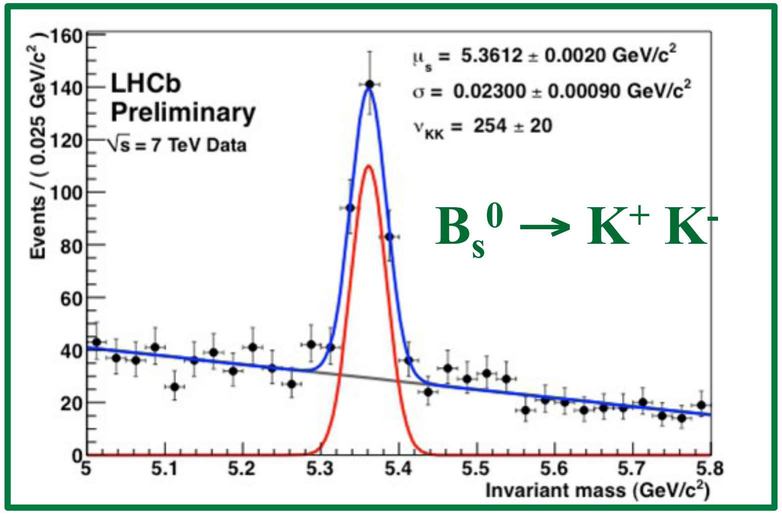


LHCb: particle Identification on B→hh

No particle ID: any 2 hadrons

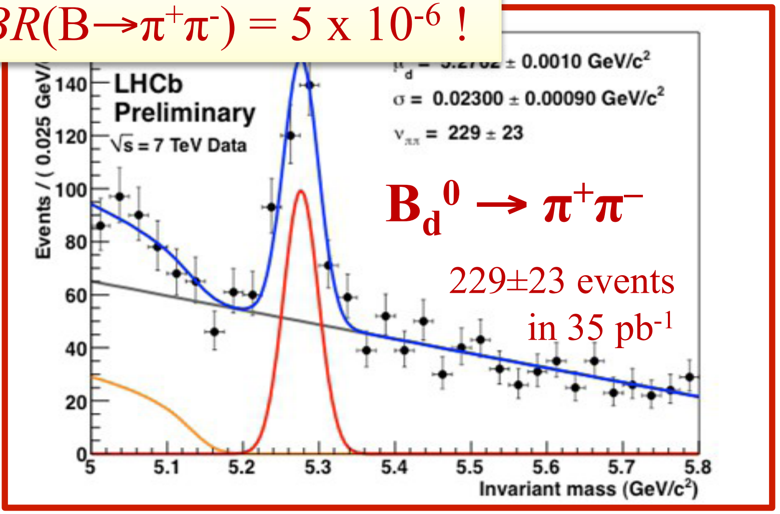


particle ID: 2 Kaons



particle ID: 2π

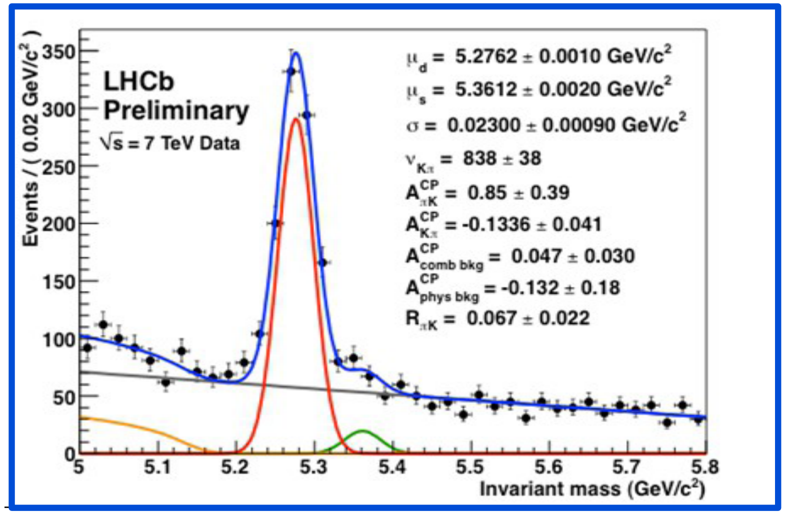
BR(B→π+π-) = 5 x 10-6 !



particle ID: 1π+1K

$B_d^0 \to K\pi$ & $B_s^0 \to K\pi$

(will get as many Kπ in <1 fb^{-1} as Belle in 1000 fb^{-1})



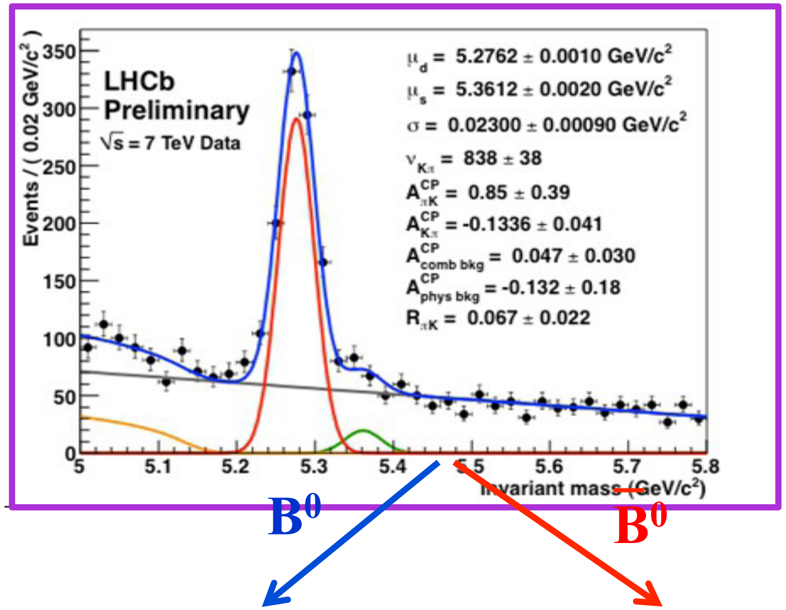
Expectations 2011:
LHCb: 6500 ev./fb^{-1}
(CDF: 1100 ev./fb^{-1})

(raw) evidence for direct CP violation

$B_d^0 \rightarrow K\pi$

&

$B_s^0 \rightarrow K\pi$

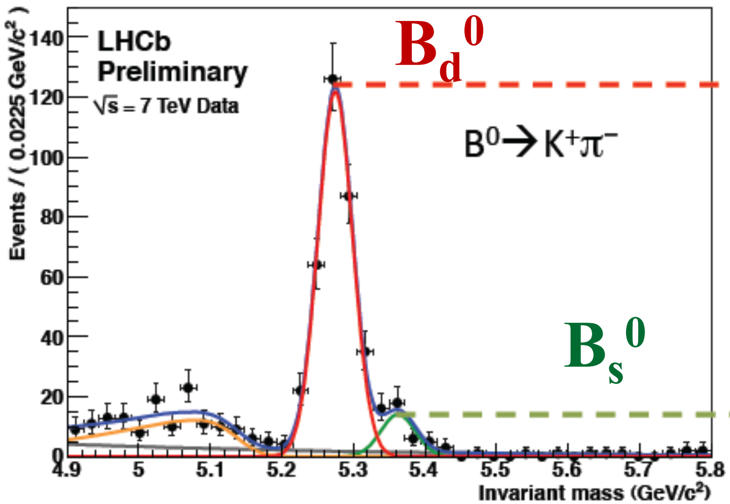


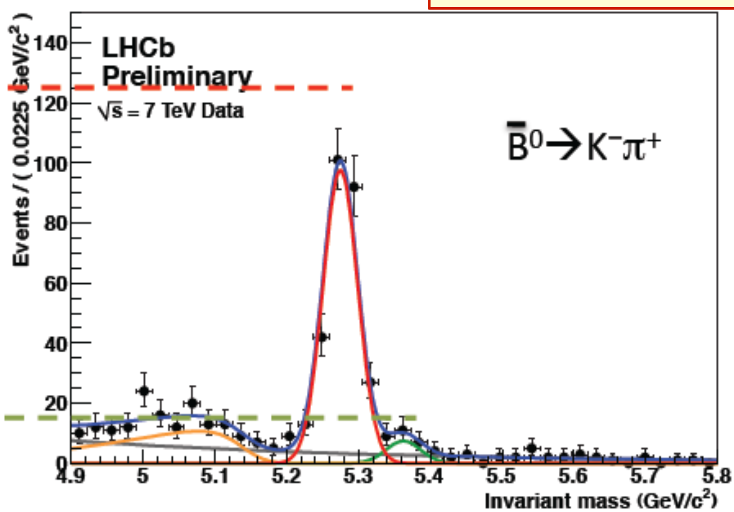
B_s^0/B_d^0 yield = (10.7±2.0)%,

$A_{CP}(B_d^0)$=-0.134±0.041
(HFAG: -0.098±0.012)

$A_{CP}(B_s^0)$=0.43±0.17
(CDF: 0.39±0.15±0.08 in 1 fb^{-1})

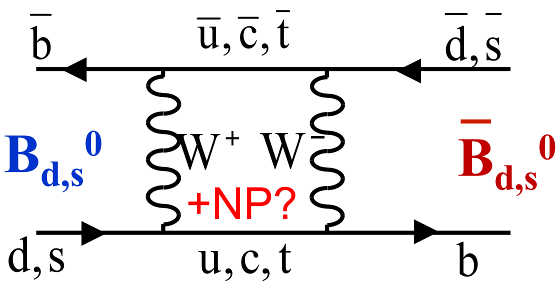
- only raw asymmetries
- not accounted for production & detector asymmetries
- not a physics result yet!

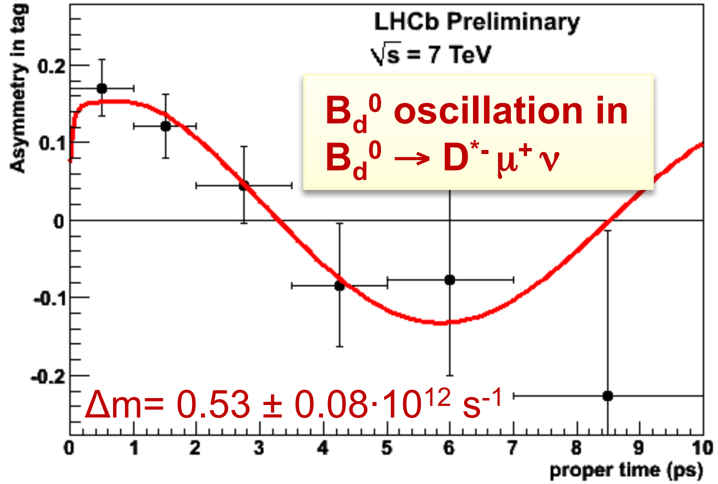




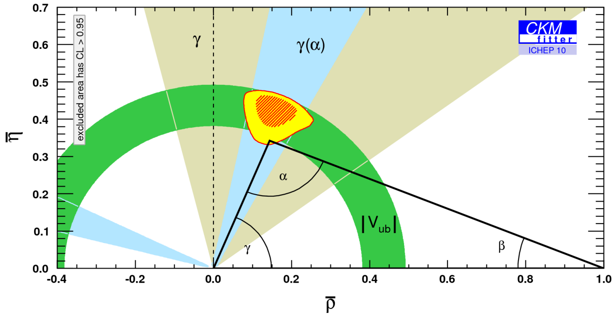
EWK aspects of B physics

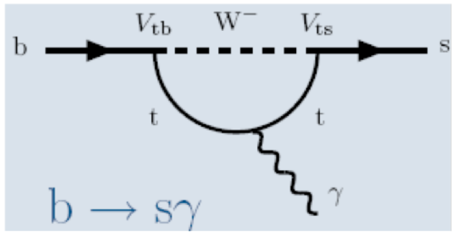
- **Foremost: mixing (test flavor-tagging; time-resolution)**





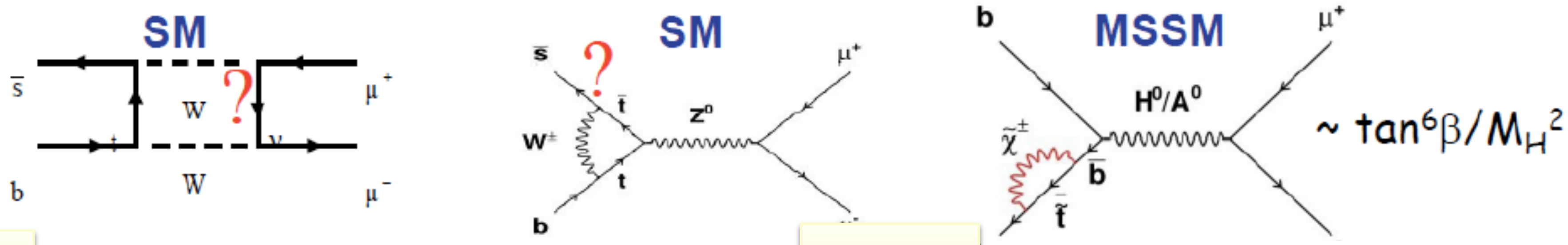
- **What's "left" in the post-factory era:**
  - **CP violation**
    - B_s oscillation phase φ_s
    - CKM angle γ
    - CP asymmetries in charm sector
  - **Rare Decays**
    - FB asymmetry in B→K*μμ and B_s→φγ, φee
    - Effective FCNC: B_s→μμ, D→μμ



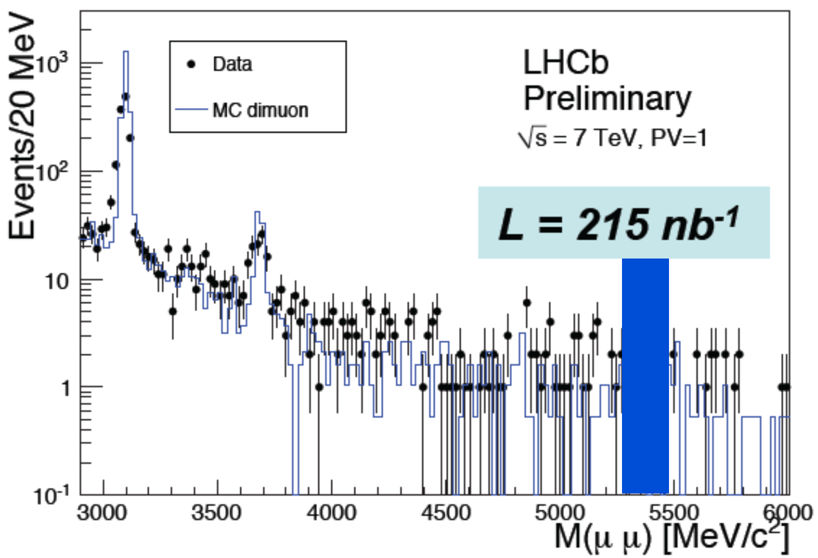


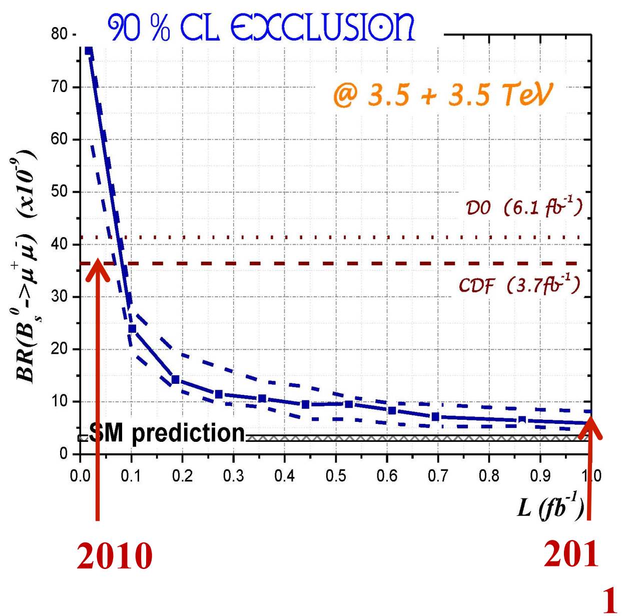
What is coming next

- $B_s \to \mu\mu$: probe of new physics



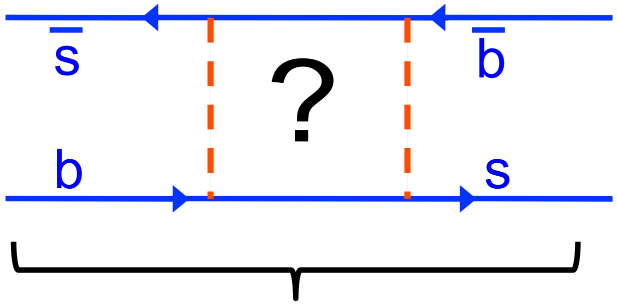
SM: $BR(B_s \to \mu^+\mu^-) = (3.6 \pm 0.3) \times 10^{-9}$ **CDF:** $BR(B_s \to \mu^+\mu^-) < 3.6 \times 10^{-8}$



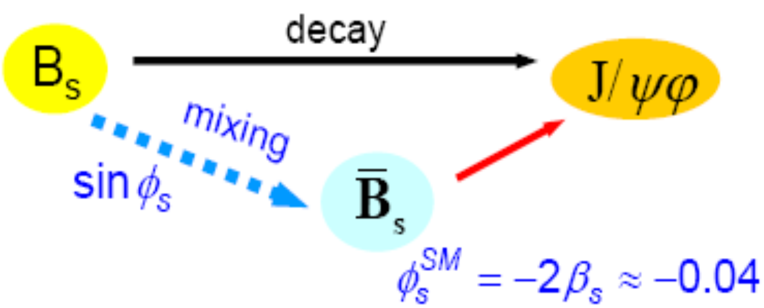


β_s (from $B_s \rightarrow J/\psi\phi$)

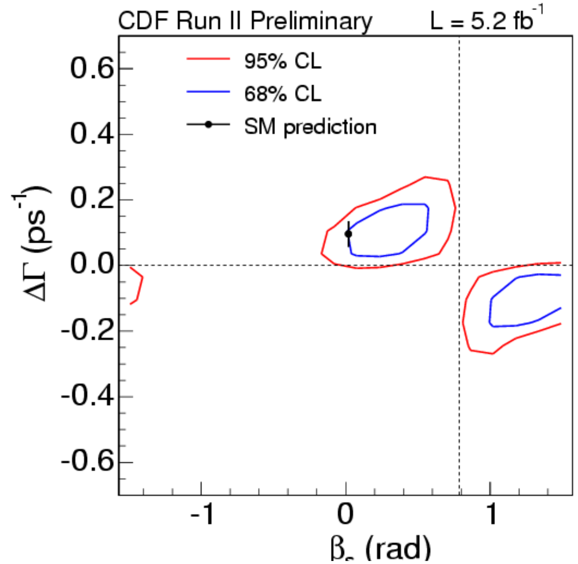
- **Measurement reserved for hadron collider expts**

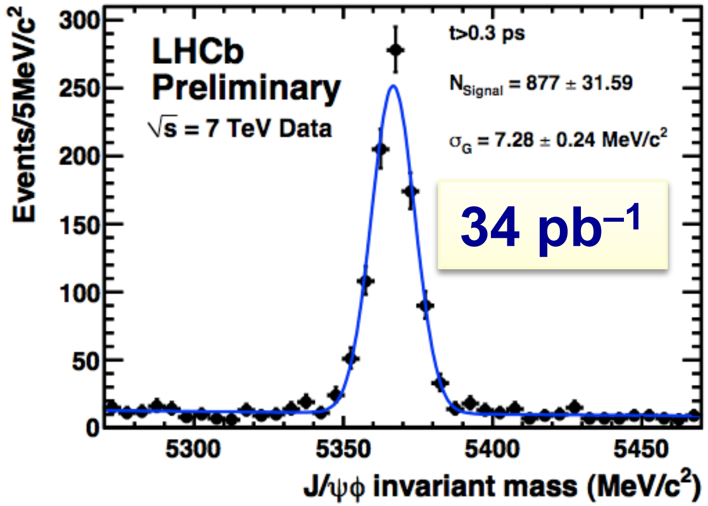


Δm_s , $\Delta\Gamma$, phase ϕ_s



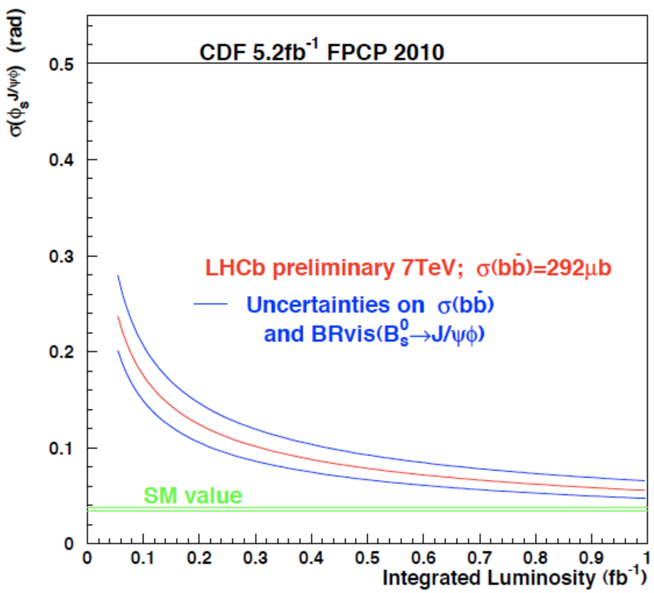
$$A_{CP}(t) \rightarrow \sin\phi_s$$



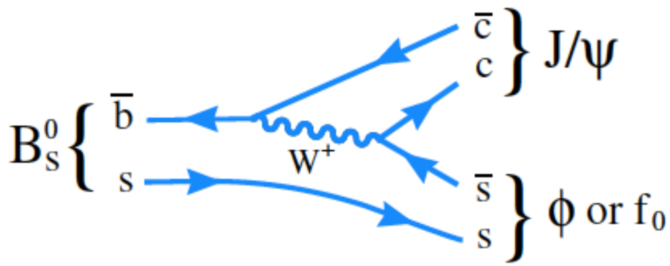


Measuring β_s

- **Sensitivity to βs:**
  - # of Bs→J/ψφ candidates seen in data: 50kevts/fb^{-1}
  - τ resolution in data: currently worse than σ_τ = 0.040 ps (assumed below); nevertheless, adequate for Δm_s ~ 17.7 ps^{-1}.



- **The issue with J/ψφ: not a CP eigenstate**
  - So need angular analysis (as a function of ct) to get S,P,D decomposition
  - A better mode: J/ψf^0 with $f^0 \to \pi^+\pi^-$ (CP even eigenstate)

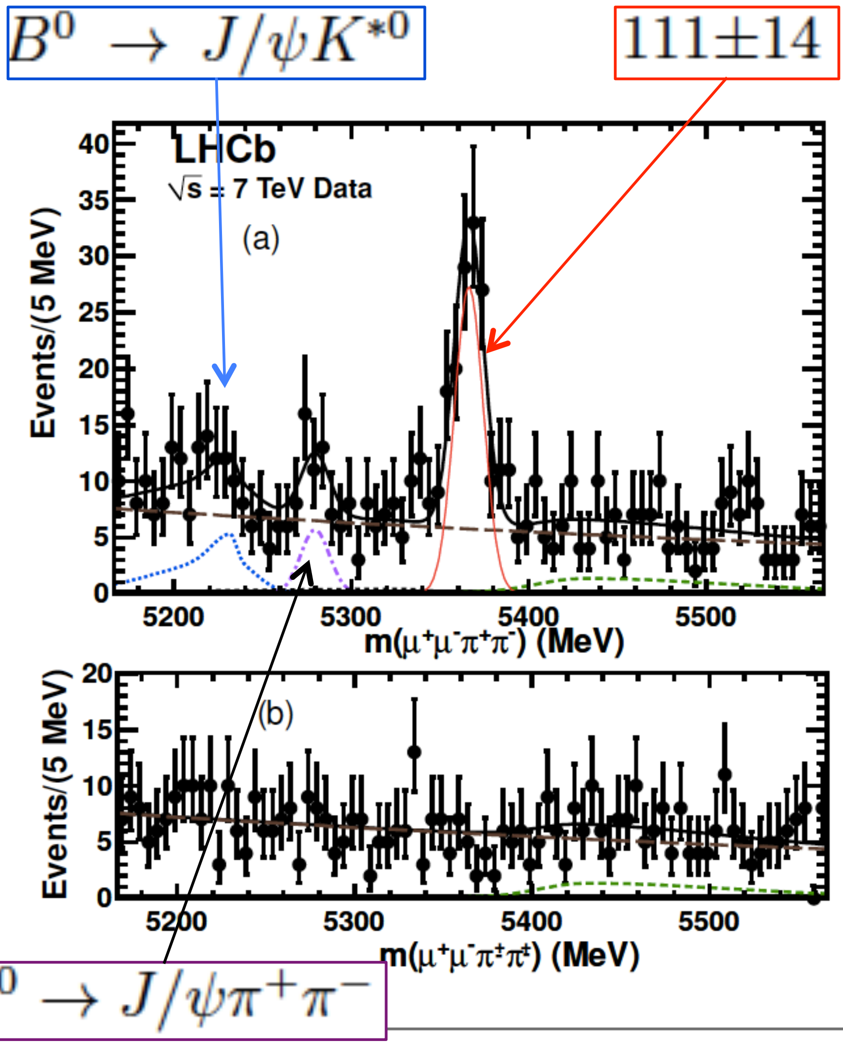


$$R_{f_0/\phi} \equiv \frac{\Gamma(B_s^0 \to J/\psi f_0,\ f_0 \to \pi^+\pi^-)}{\Gamma(B_s^0 \to J/\psi\phi,\ \phi \to K^+K^-)} \approx 20\%.$$

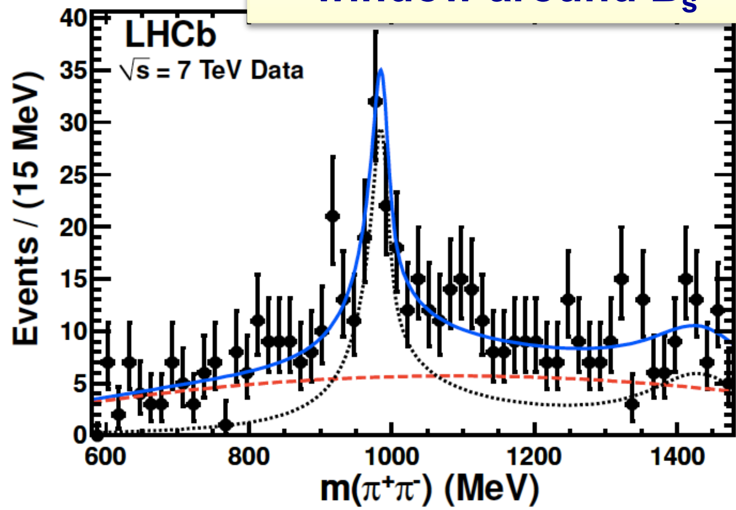
  - LHCb: 635±26 J/ψφ; σ_m~7MeV

Observation of $B_s \to J/\psi f^0(980)$

- **Announced yesterday ☺ by LHCb**



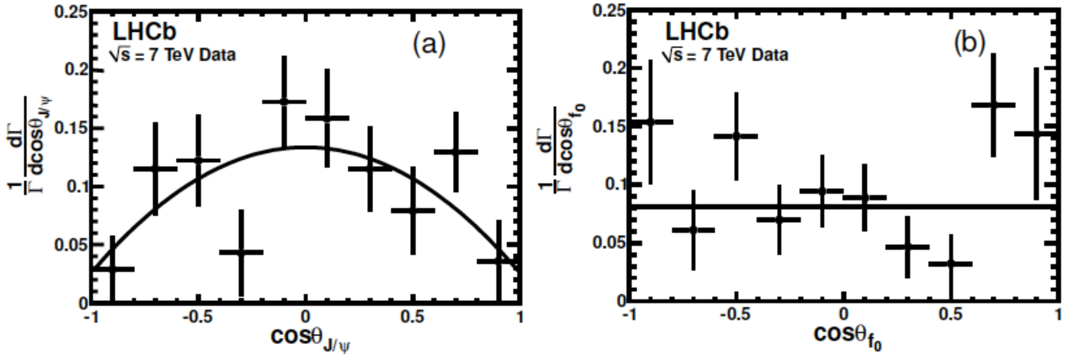
π⁺π⁻ mass in 30 MeV window around B_s



$$1 - \alpha \cos^2 \theta_{J/\psi}$$

$$\alpha = 0.81 \pm 0.21$$

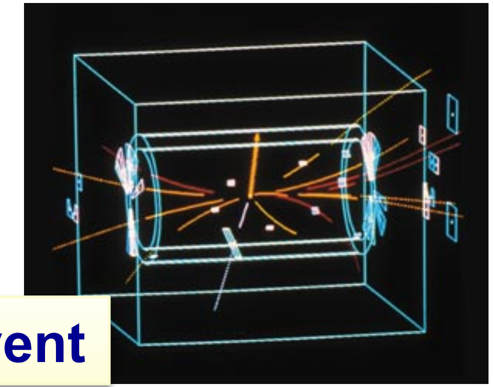
J/ψ: longitud. polar; (S(f⁰)=0)



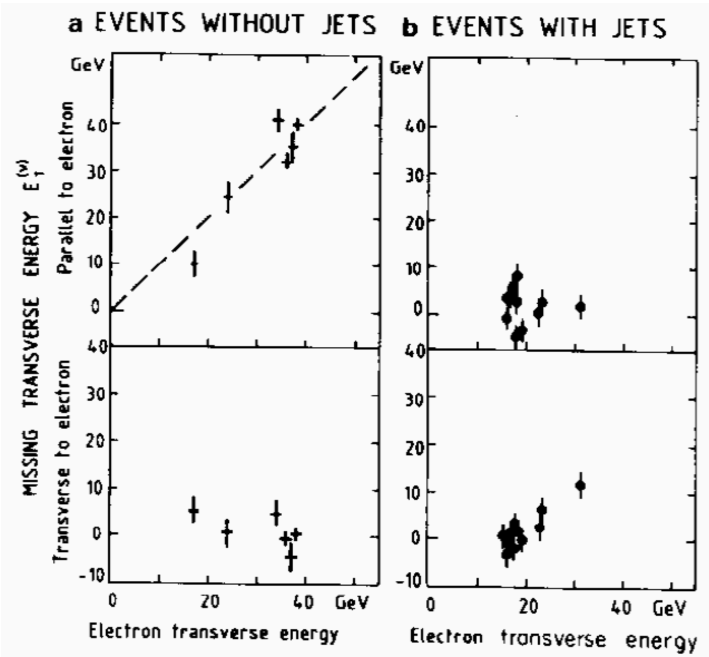
Electroweak probes

Reminder of things past

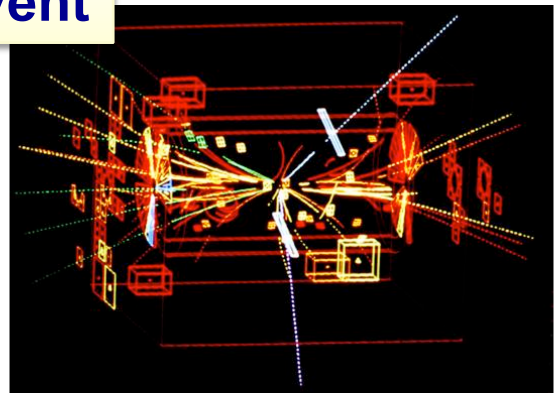
- **First time a hadron collider produced W & Z's at CERN:**

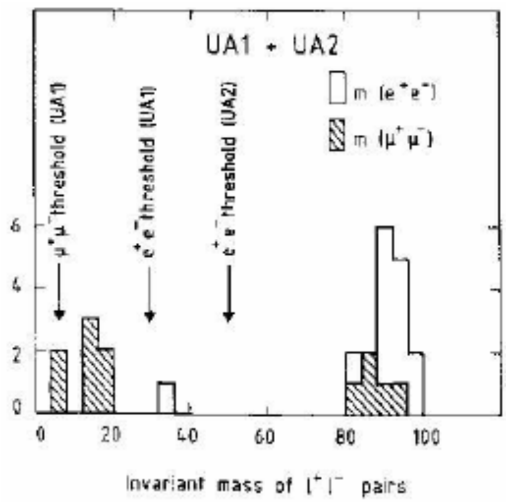


First W event



First Z event





Perhaps what the W' and Z' will look like at the LHC? (after scaling E/p by factor 20?)

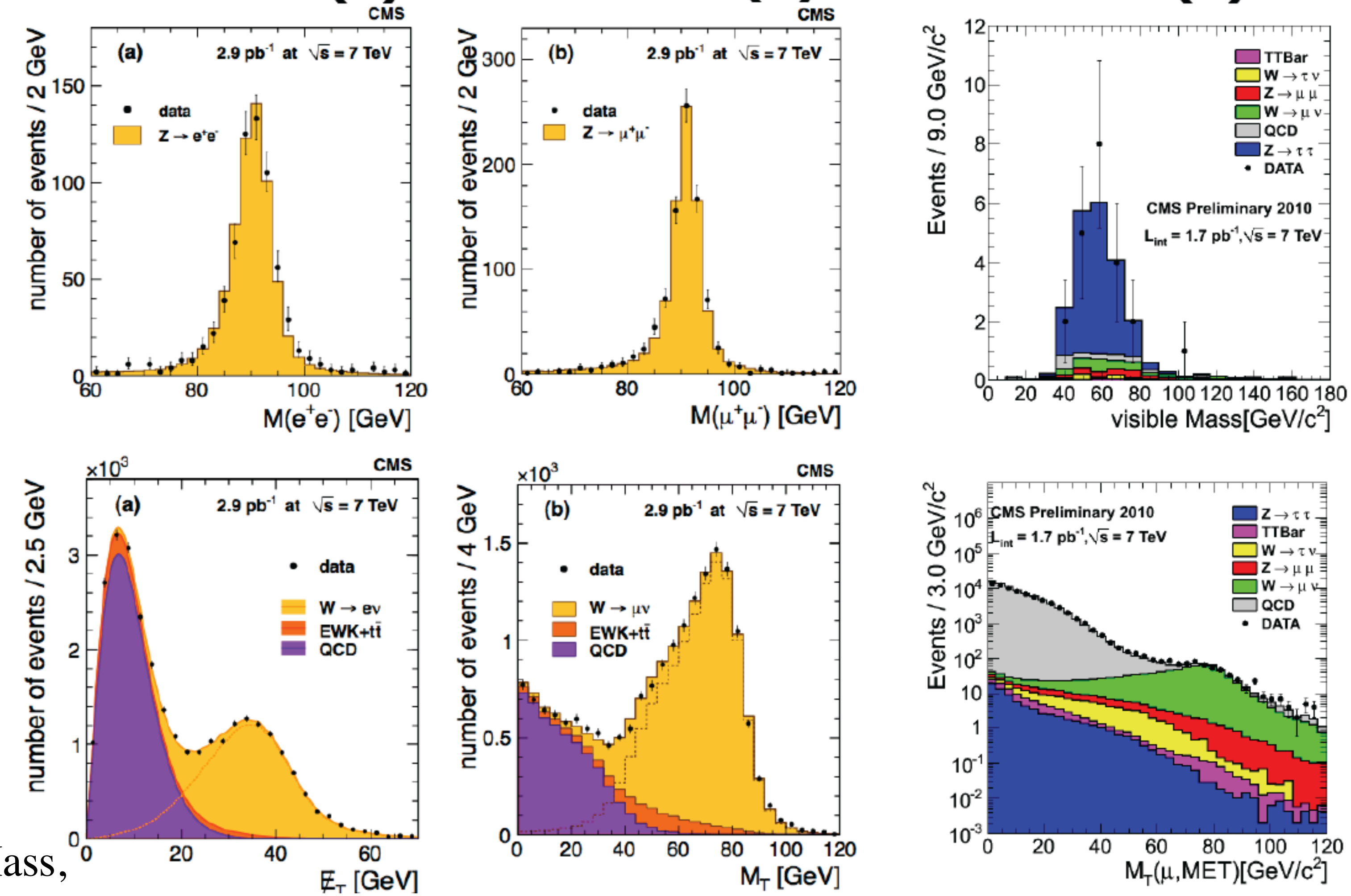
Things have since evolved significantly…

W/Z production at 7 TeV

electron(s) muon(s) tau(s)

Z Boson

W Boson



Transverse Mass,

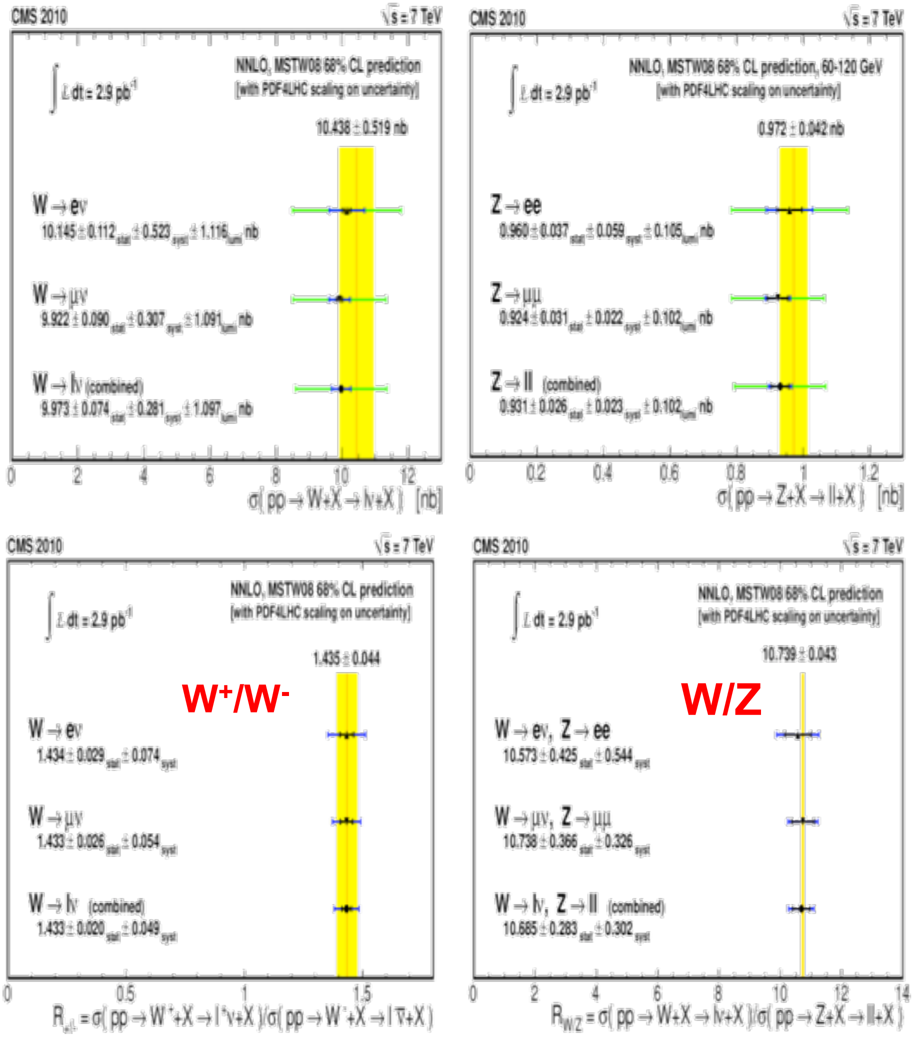
$$M_T = \sqrt{2E_T^{\mu}E_T^{miss}(1 - \cos\Delta\phi_{e,miss}}$$

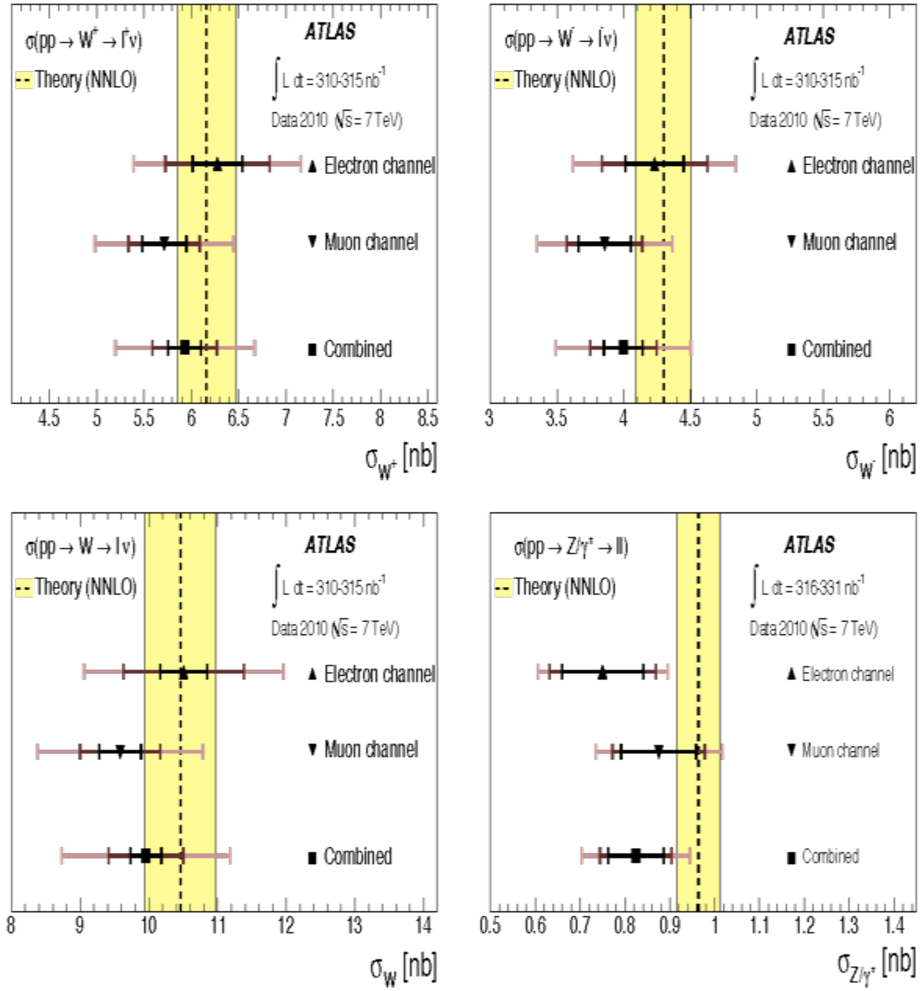
W & Z Cross section

arXiv:1012.2466

$$\sigma\left(W^{+}\right)/\sigma\left(W^{-}\right) \approx 1.4$$

arXiv:1010.2130

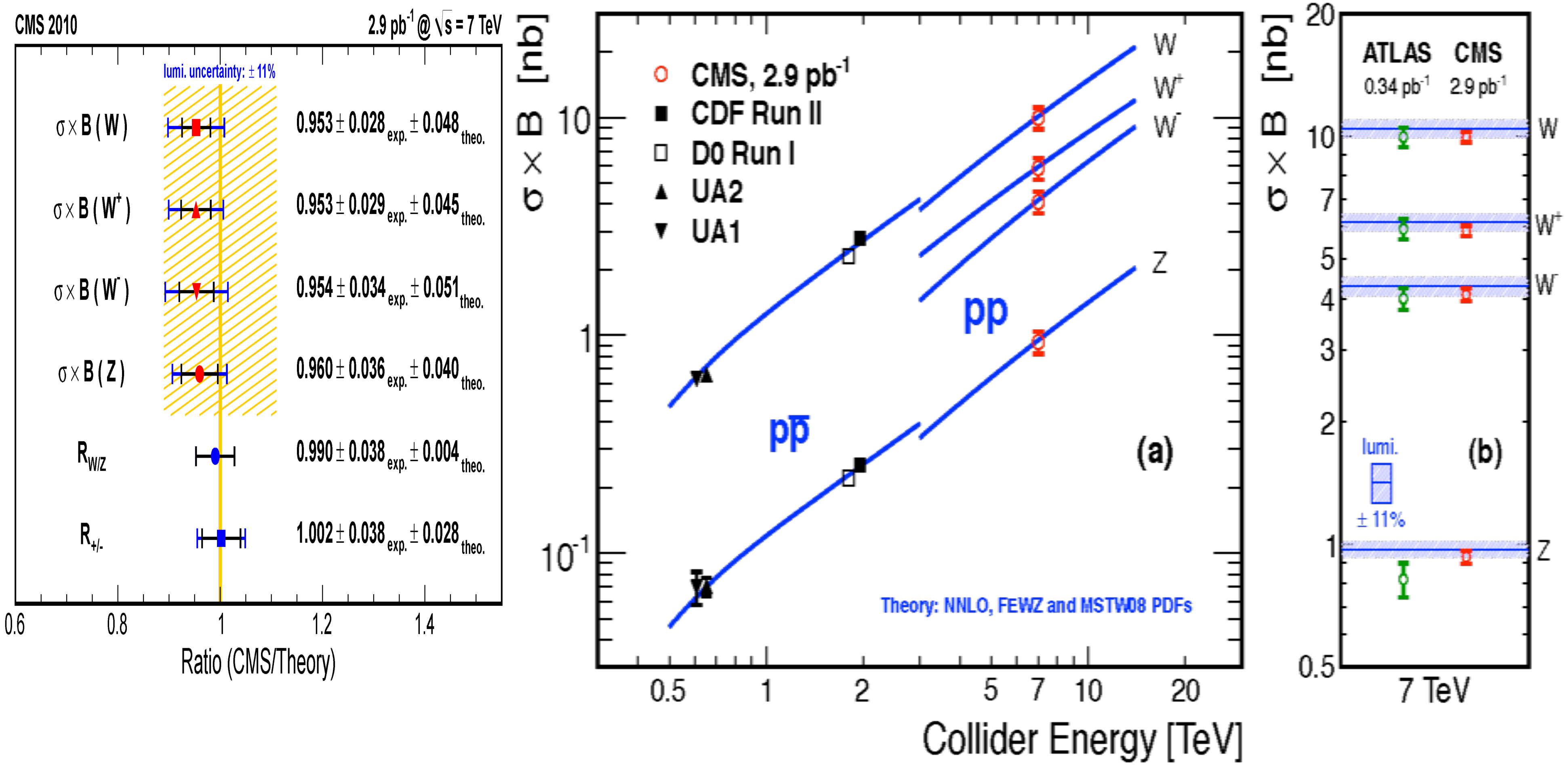




W, Z Cross Section vs √s

- **Baseline measured. Next: need high stats**

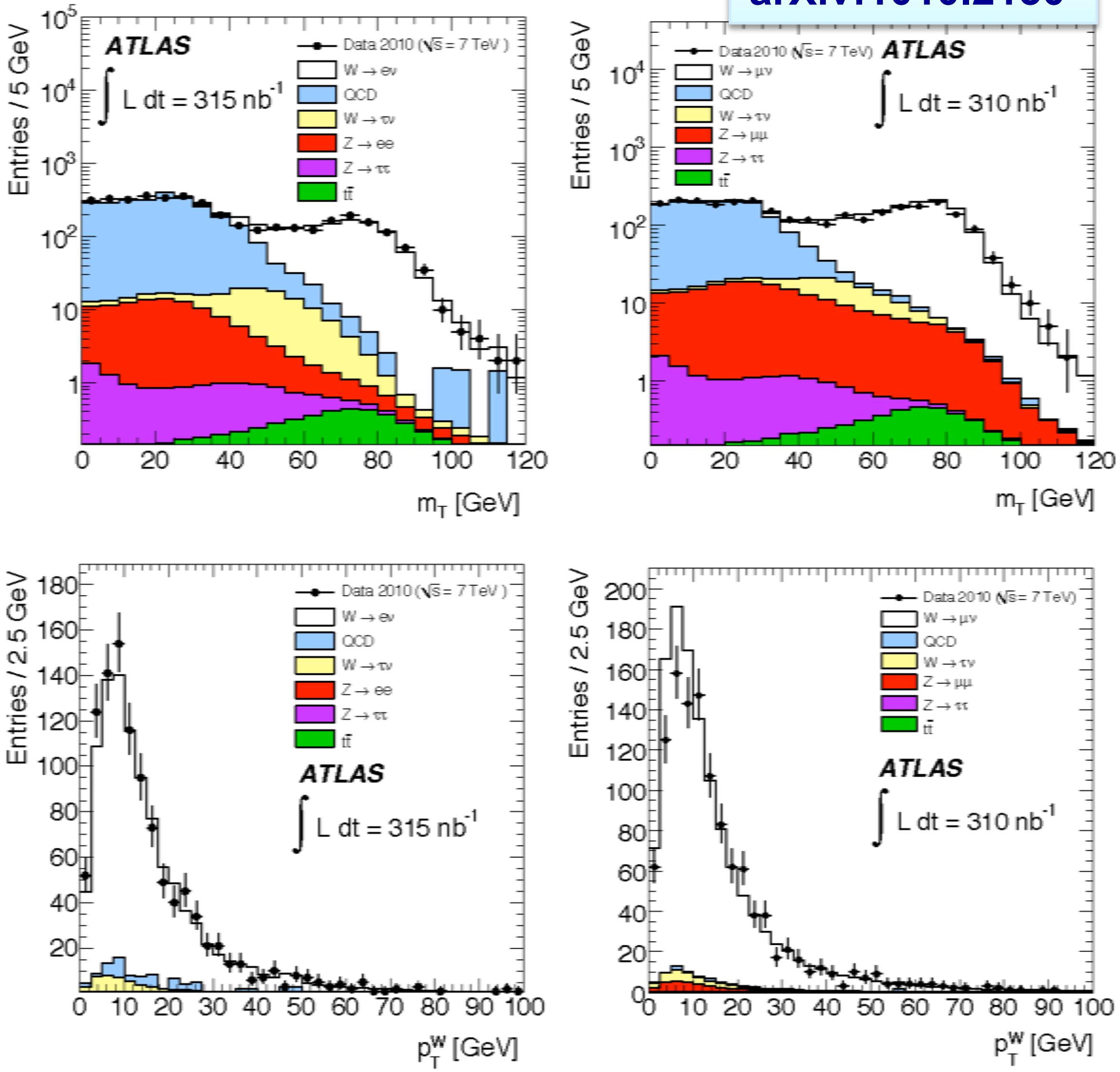
arXiv:1012.2466



W Signal and P_T Spectrum

arXiv:1010.2130

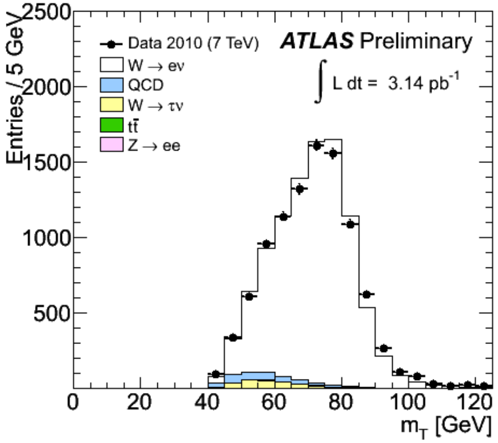
- At low P_T: test for soft QCD – as well as gluon resum-mation
- At high P_T: the interesting region where new physics (should) also lies (lie)
- Measurement relies on (very good) resolution for ME_T



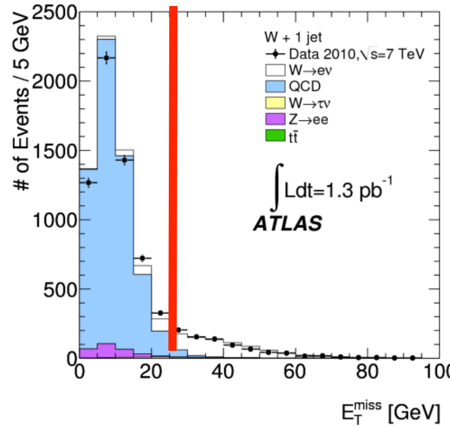
W + Jets: Multiplicity

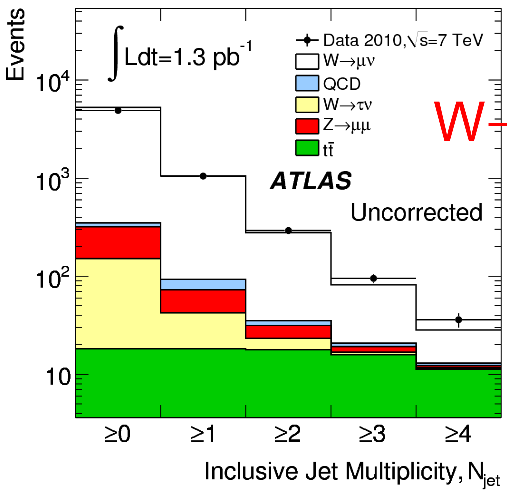
arXiv:1012.5382

- e/μ: p_T>20, |η|<2.4; jets: p_T>20, |η|<2.8
  - E_T^{miss}>25 GeV, M_T > 40 GeV

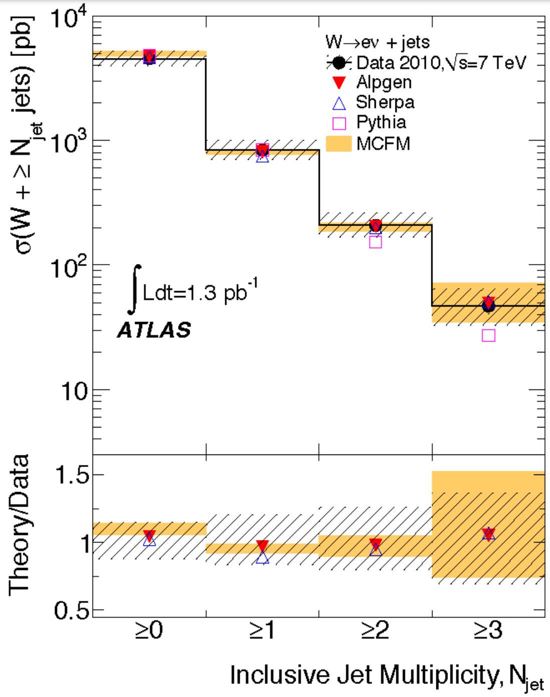


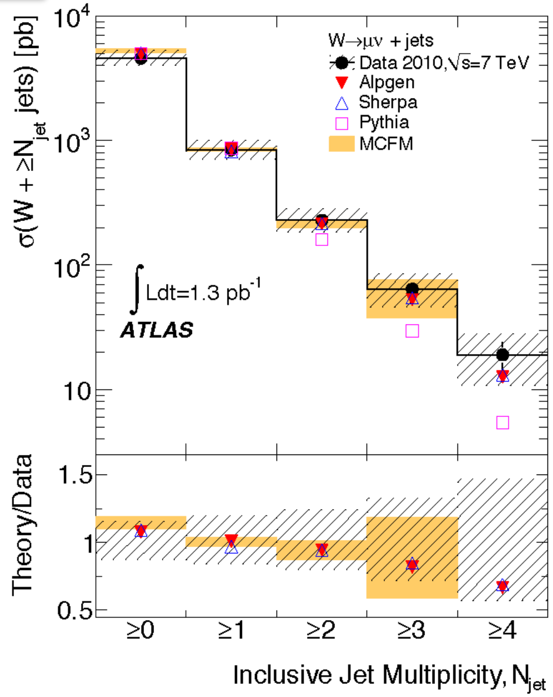
W+jets from simulation
tt from simulation
QCD multijet from data
Z→ee/Z→μμ from simulation





W→μν

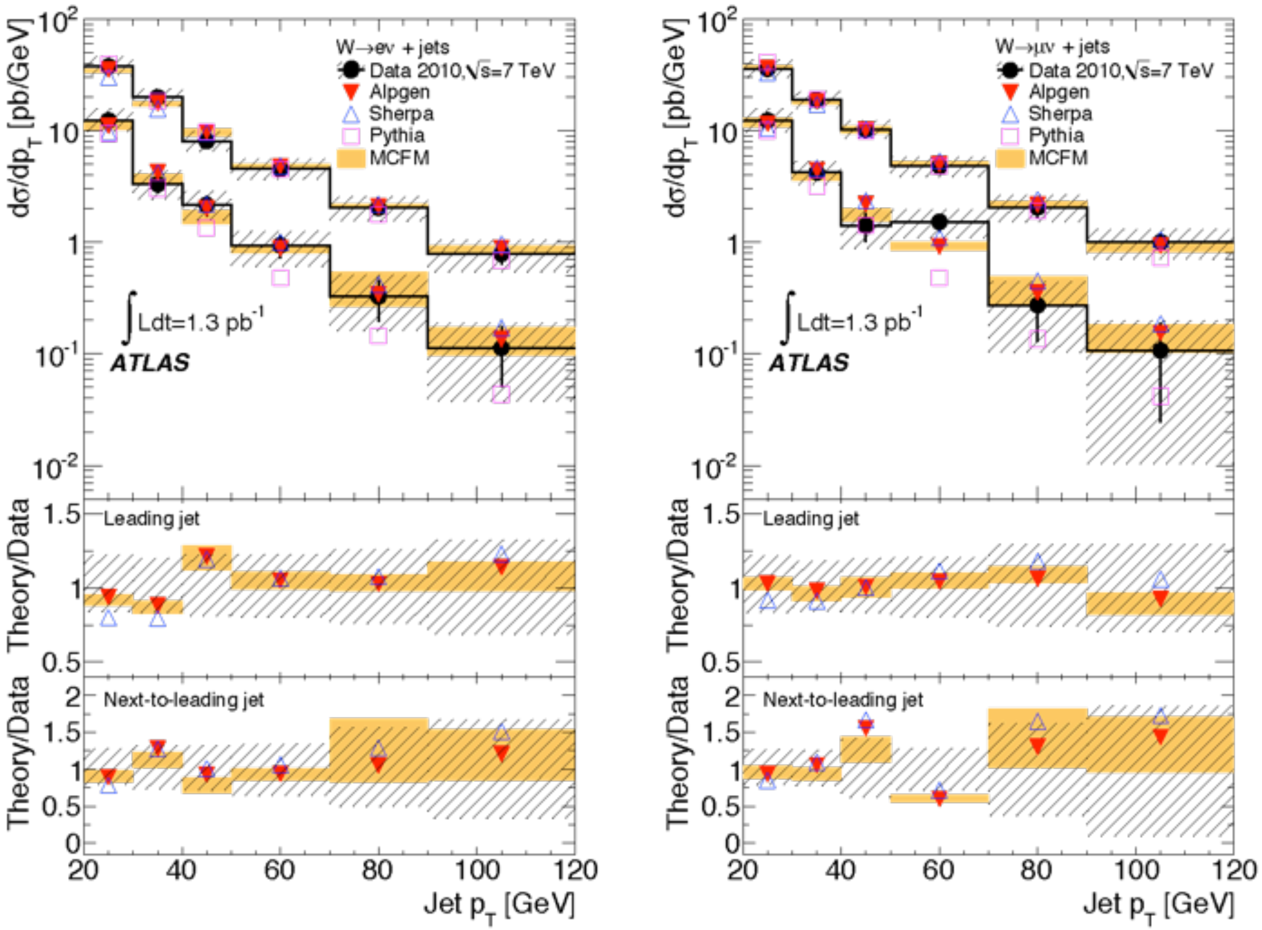




W + Jets P_T

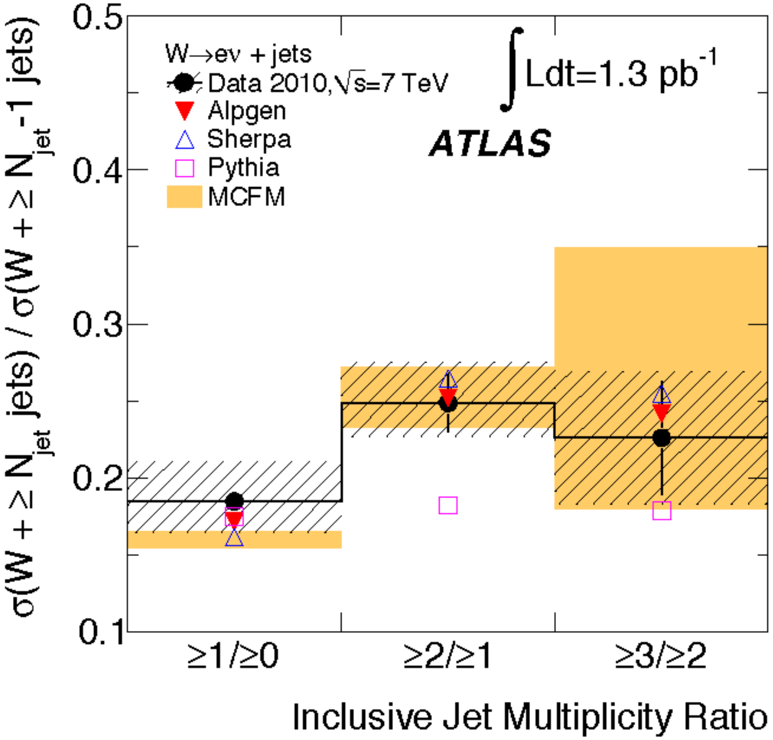
- **Tails in P_T(W) enter in several searches – from SUSY to exotica**

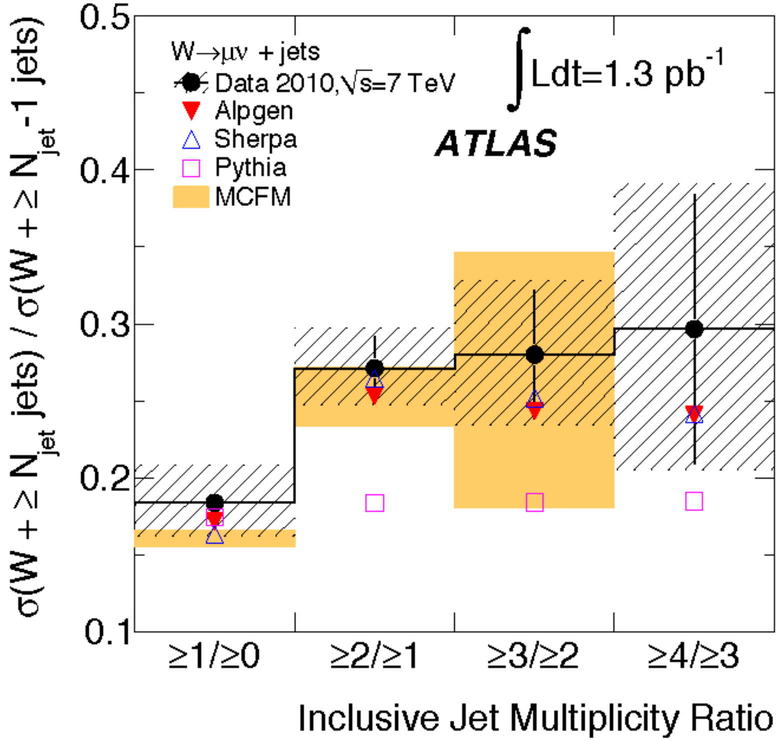
arXiv:1012.5382



W + Jets Ratio

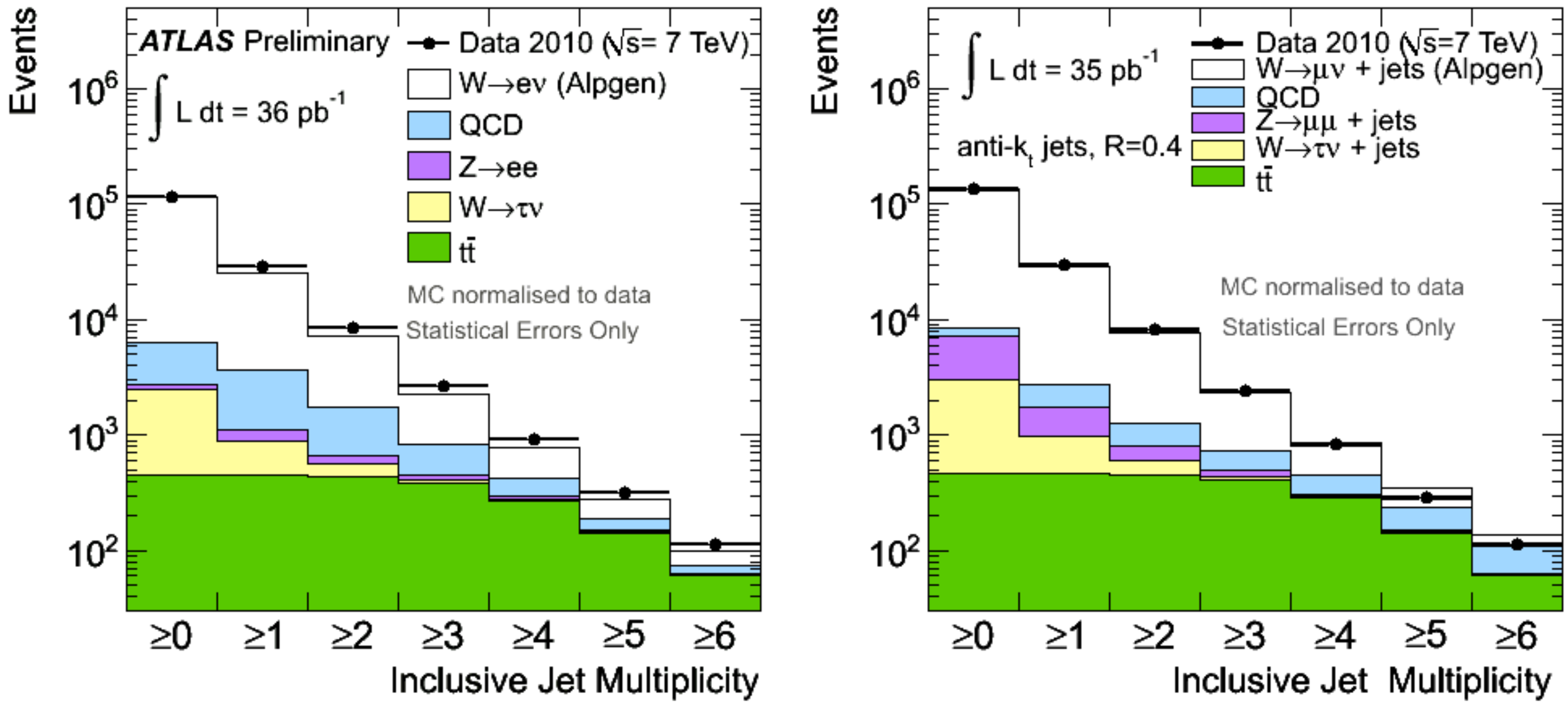
arXiv:1012.5382





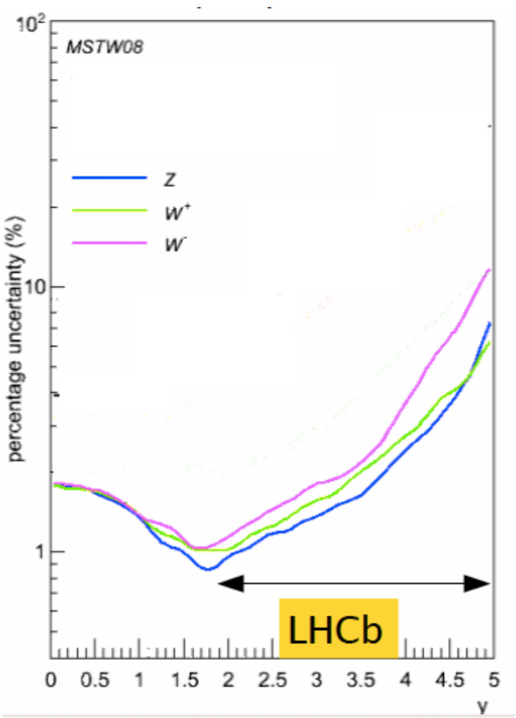
Early study comparing to NLO QCD event generators
Clearly, x30 more data already available
Expect new results (W and Z) for Winter Confs

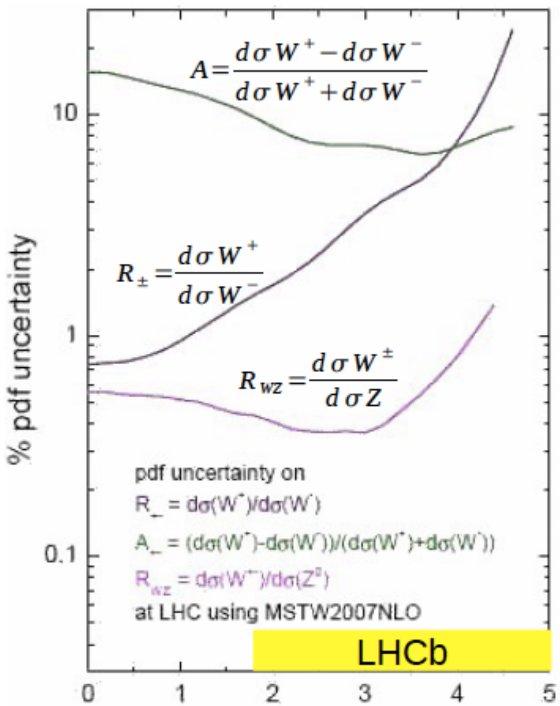
Parenthesis: yesterday's update

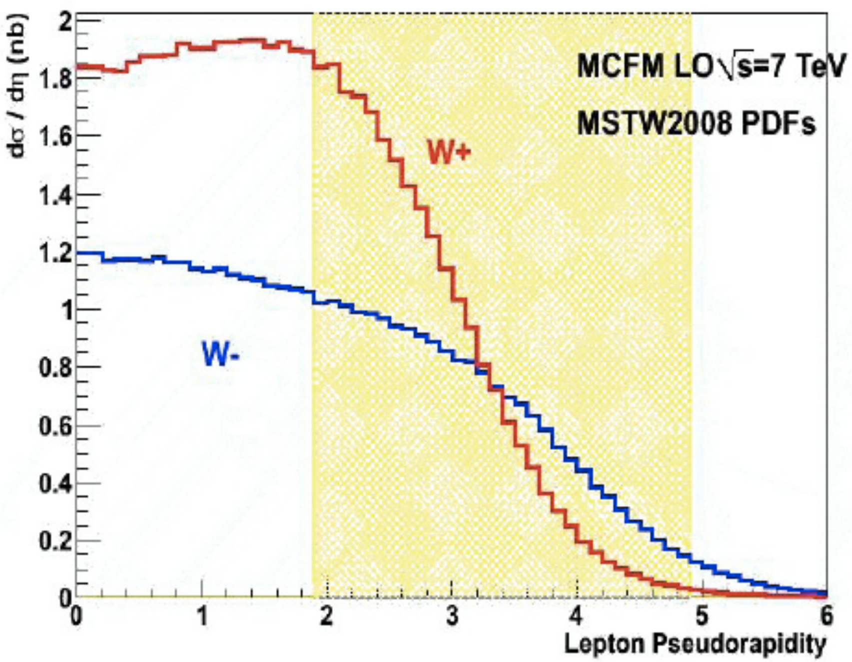


W & Z production in the forward region

- **σ: known to NNLO (1%). Largest uncertainty: pdf**
  - From 1% at central rapidity to ~8-10% at y=5
- **Ratios: syst-free; probe pdfs:**
  - W+/W- probes d_v/u_v; Asymmetry, A_W, probes difference btw d_v & u_v; R_{WZ}: ~no dependence on pdfs

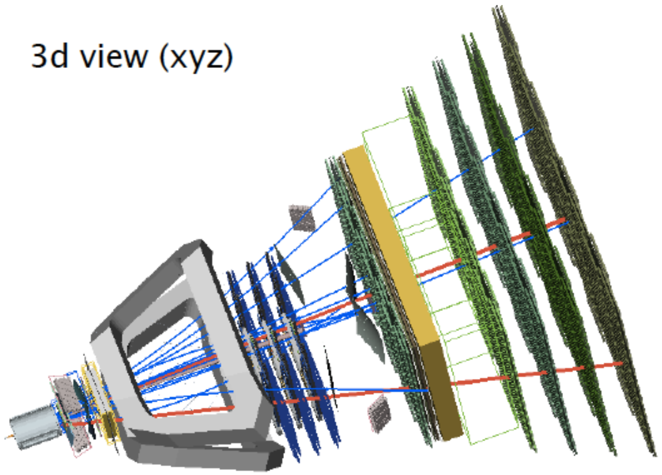




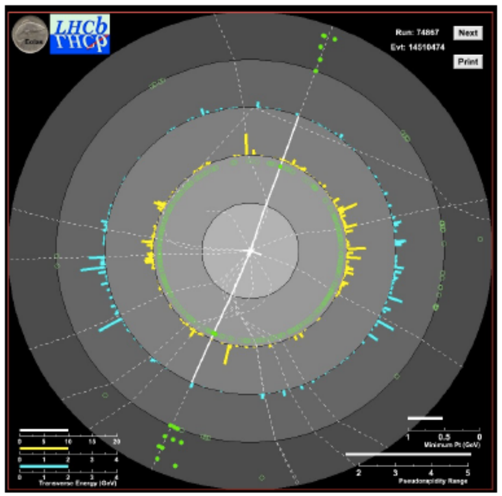


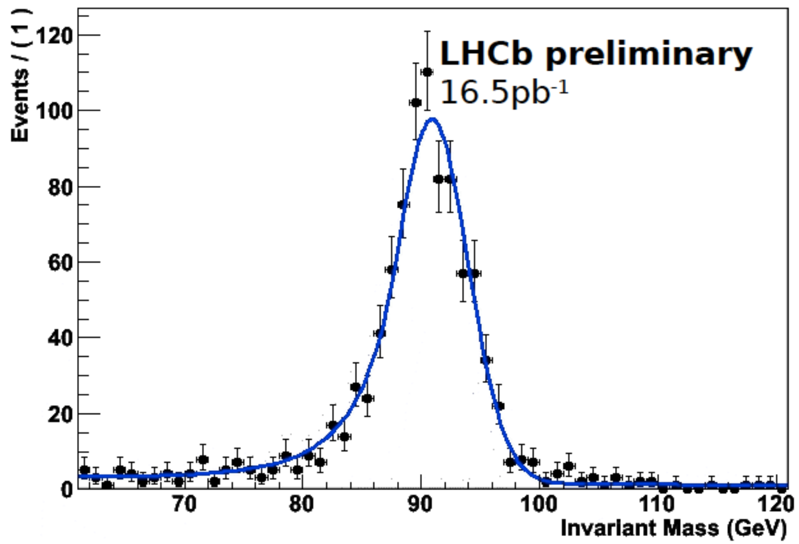
W & Z production in the forward region (I)

3d view (xyz)



φ–z view (Radius=z)





Trigger: Single μ, p_T > 10 GeV

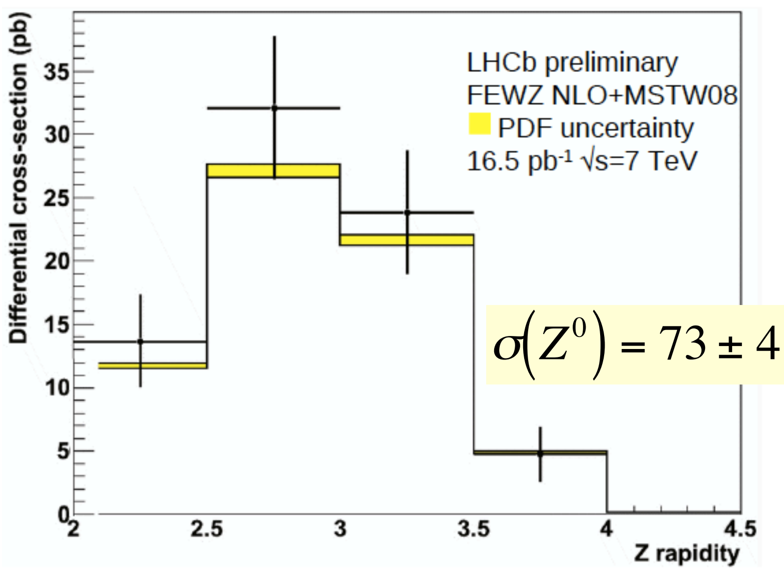
Muon: two good muons

p_T> 20 GeV

2.0 < y_μ 4.5

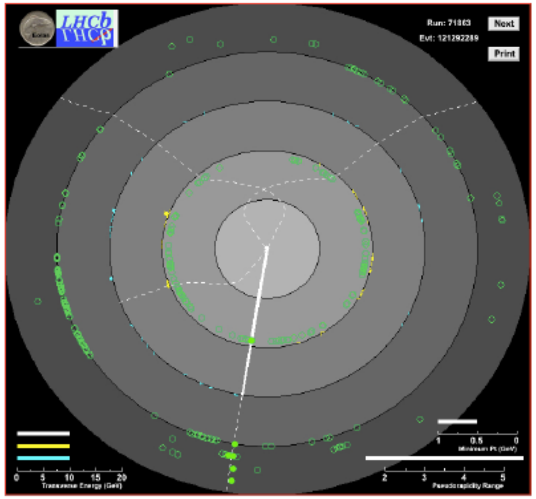
Z: 81 < M(μμ) < 101 GeV

Events N_Z = 833 N_{Bkg} = 1.2±1.2

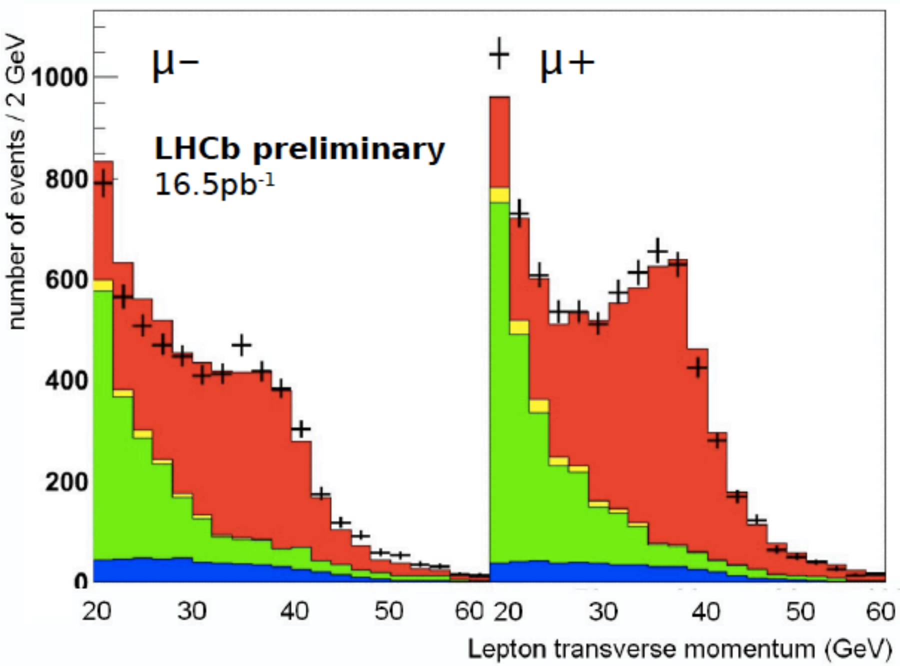


$$\sigma(Z^0) = 73 \pm 4 \pm 7 \ \ \text{pb}$$

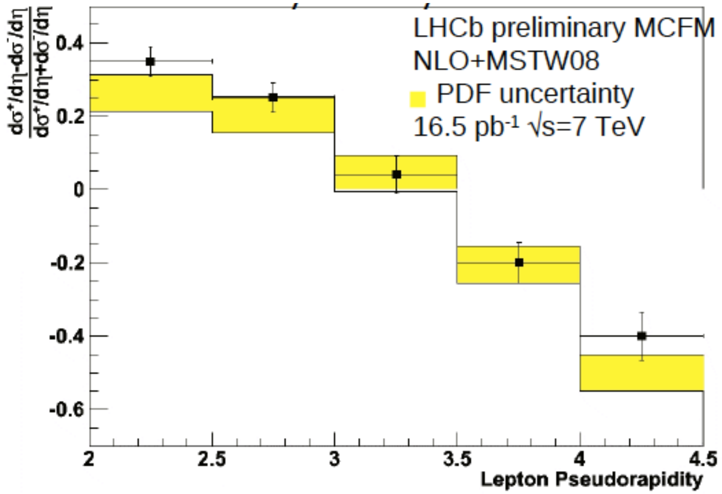
W & Z production in the forward region (II)



2<y<4.5	W^+	W^-
N_{cand}-N_{bkg}	4817±165	3480±161
σ(W) [pb]	1007±48±100	682±40±68

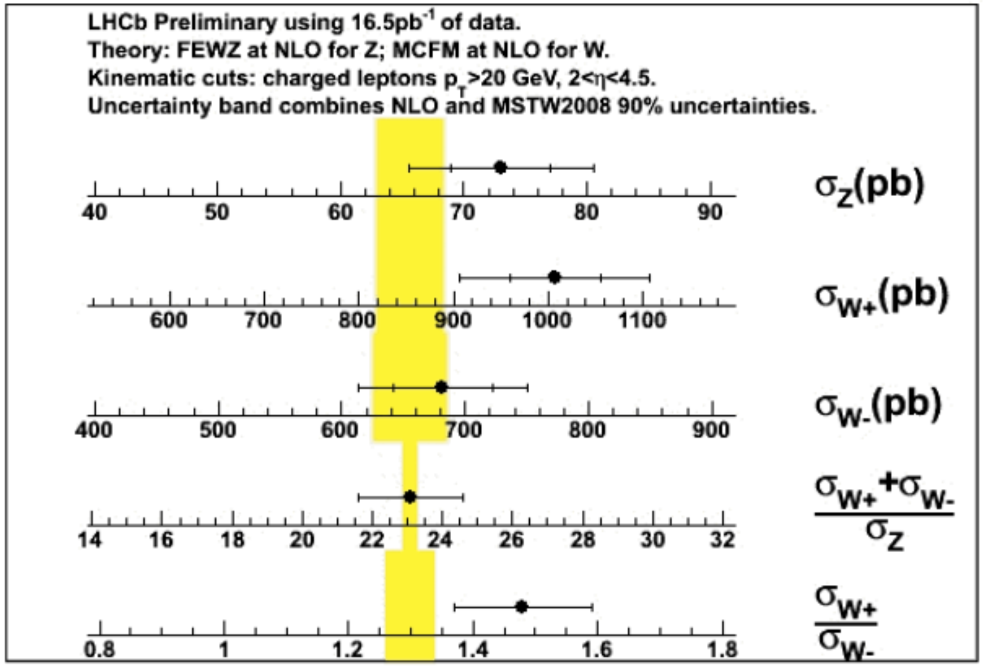


$$A_\mu = \frac{\sigma(W^+ \to \mu^+ \nu_\mu) - \sigma(W^- \to \mu^- \bar{\nu}_\mu)}{\sigma(W^+ \to \mu^+ \nu_\mu) + \sigma(W^- \to \mu^- \bar{\nu}_\mu)}$$



W & Z production in the forward region (III)

- **Summary of measurements**
  - **Will affect the pdfs**



Summary (II)

- **Numerous heavy-flavor production studies**
  - Charmonia: fraction from B mesons consistent across experiments, energies and rapidity (!)
  - Large prompt production (not only cc but bb as well): at LHC as well. Crucial next step: measure polarization.
  - B-> J/ψ X cross sections in agreement with theory
  - Rapidity distributions [CMS]: some disagreement with theory; better at NLO
- **W & Z physics:**
  - Clear signals in electron and muon channels
  - Early studies of production mechanism (P_T(W)) and accompanying jet multiplicity, spectra etc. Good description by QCD (but statistical errors quite large)
  - Nice W/Z signal also in forward region (LHCb). Can probe pdfs