b and c production in CMS and ATLAS

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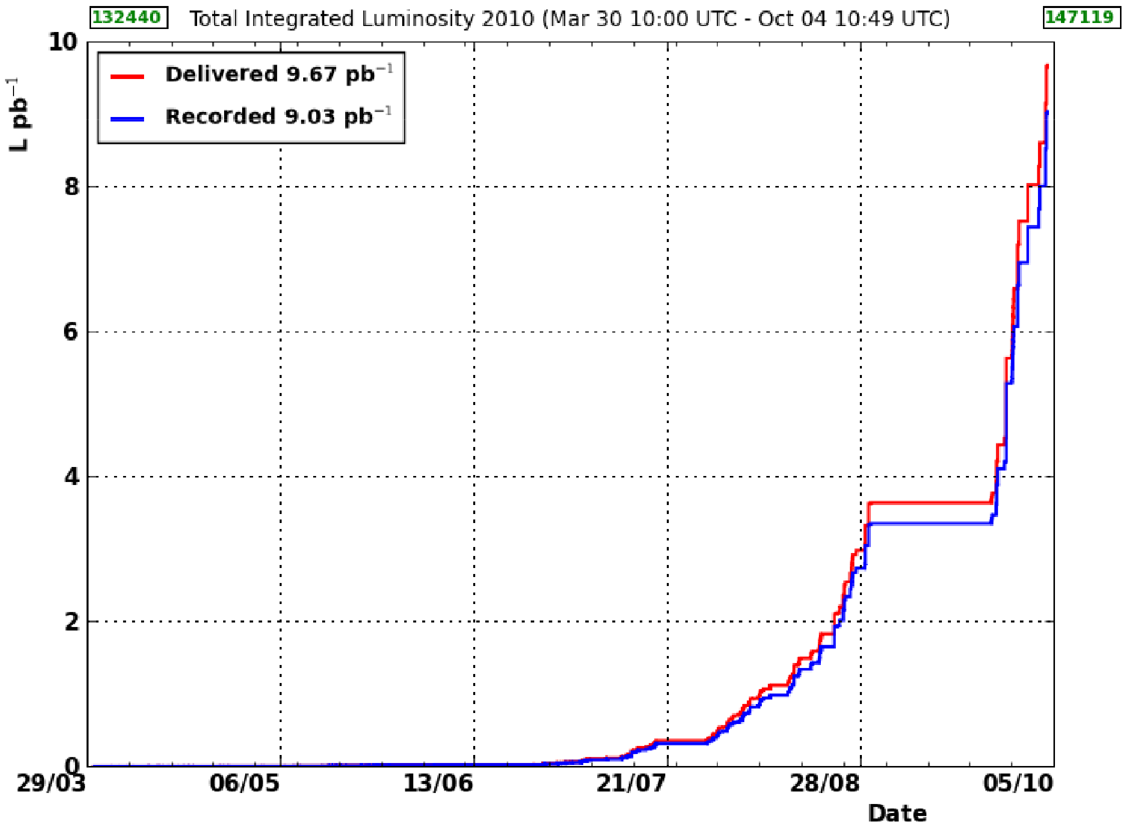
on behalf of CMS and ATLAS collaborations

VII Meeting on B-physics (LAL)

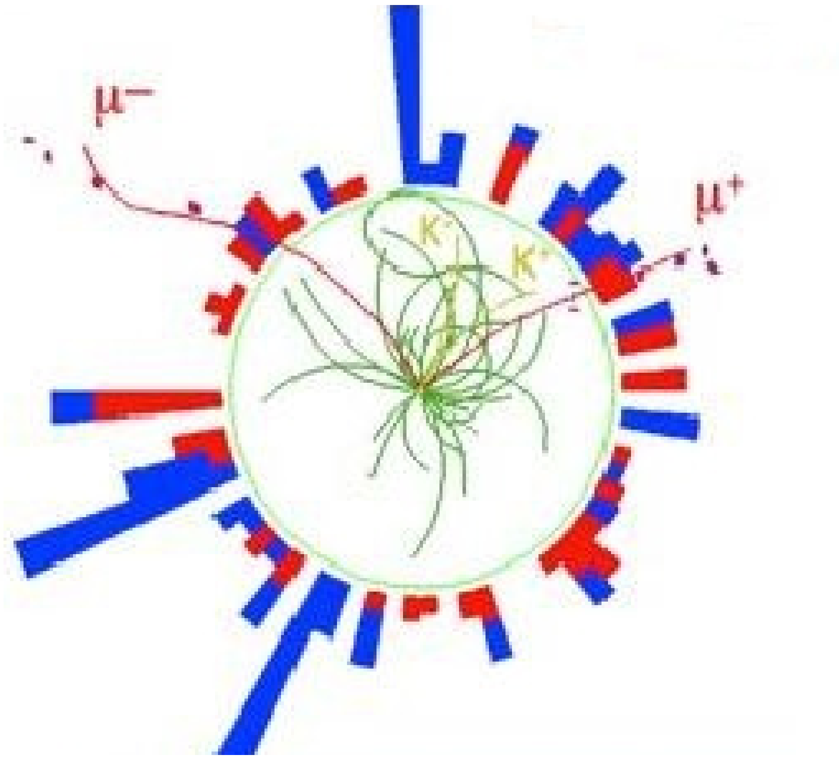
LHC luminosity evolution

- LHC startup in March 2010
- 9.67 pb^{-1} delivered lumi
- 5 pb^{-1} certified lumi
- 6 pb-1 in the last 2 weeks
- Inst. lumi 10^{26} -> 5 $10^{31} cm^{-2}s^{-1}$
- Now up to ~ 500 nb^{-1}/day
- No explosions so far ☺



b and c physics @ LHC

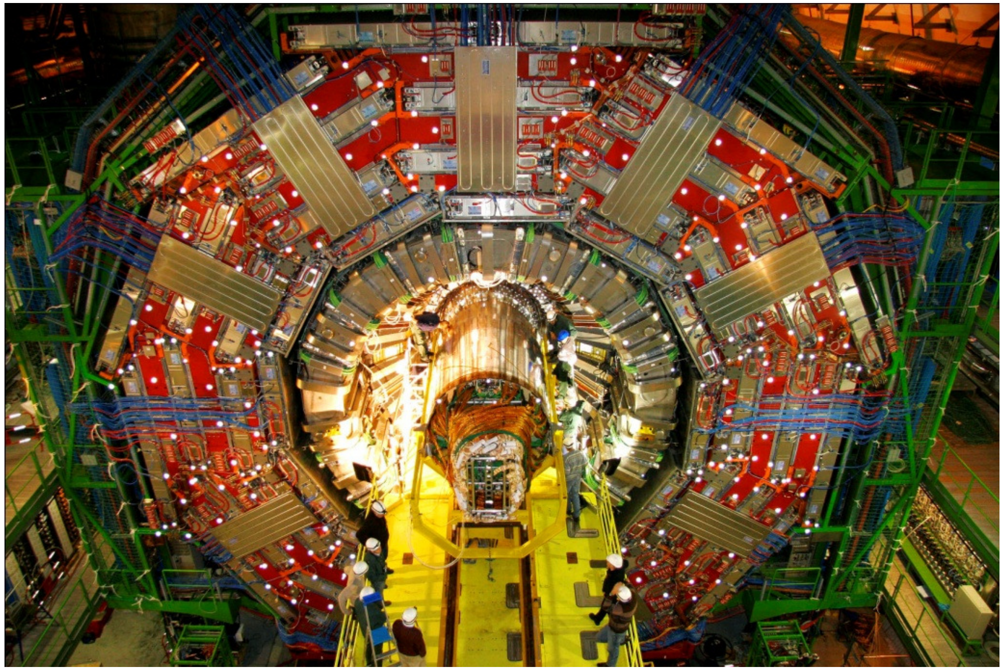
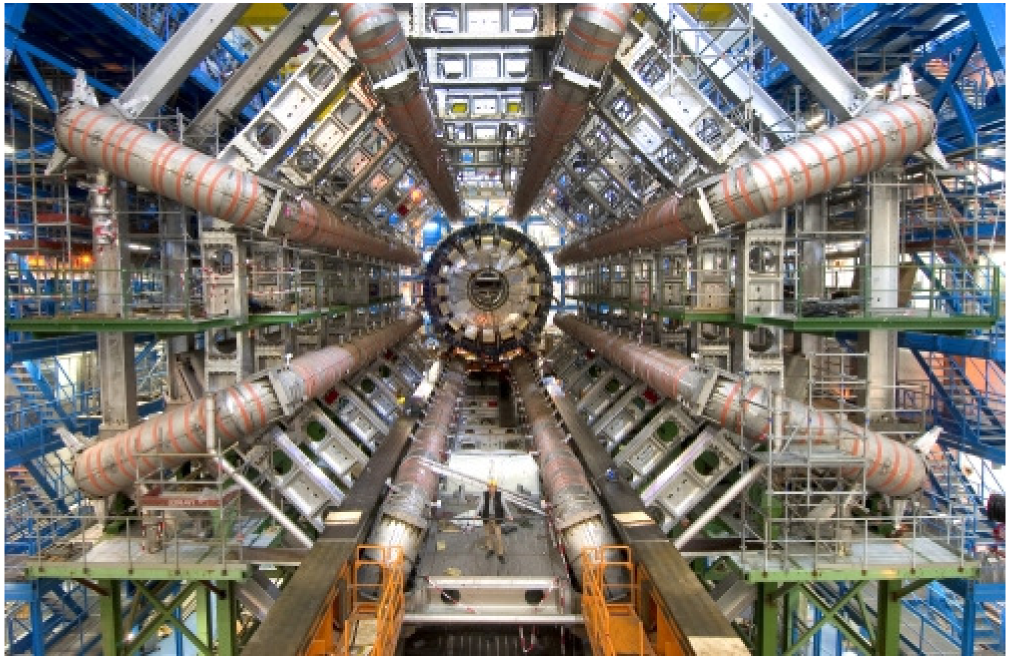
- The study of heavy quark production is of main interest in LHC:
  - *Quarkonia production (J/psi, Y)*
  - *Test of QCD (NRQCD)*
  - *CP violation (B-mesons)*
  - *Higgs (if light enough)*
- Huge programme (already started):
  - *Quarkonia and b cross section* *(already in place)*
  - *Charmed mesons properties (1-100 pb^{-1})*
  - *Quarkonia polarization*
  - *B-mesons properties*
  - *(limits to) BR of rare decays (FCNC) (> 1 fb^{-1})*



$B_s \to J/\psi\ \varphi$ candidate in CMS

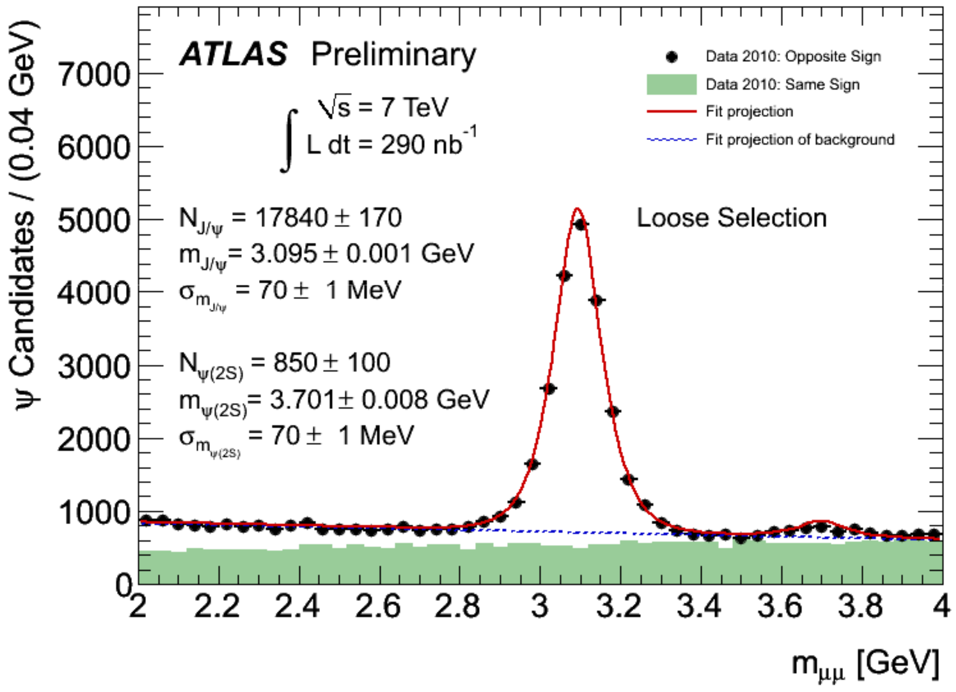
- Need of high performance tracking detectors (b-tagging) and efficient lepton triggers

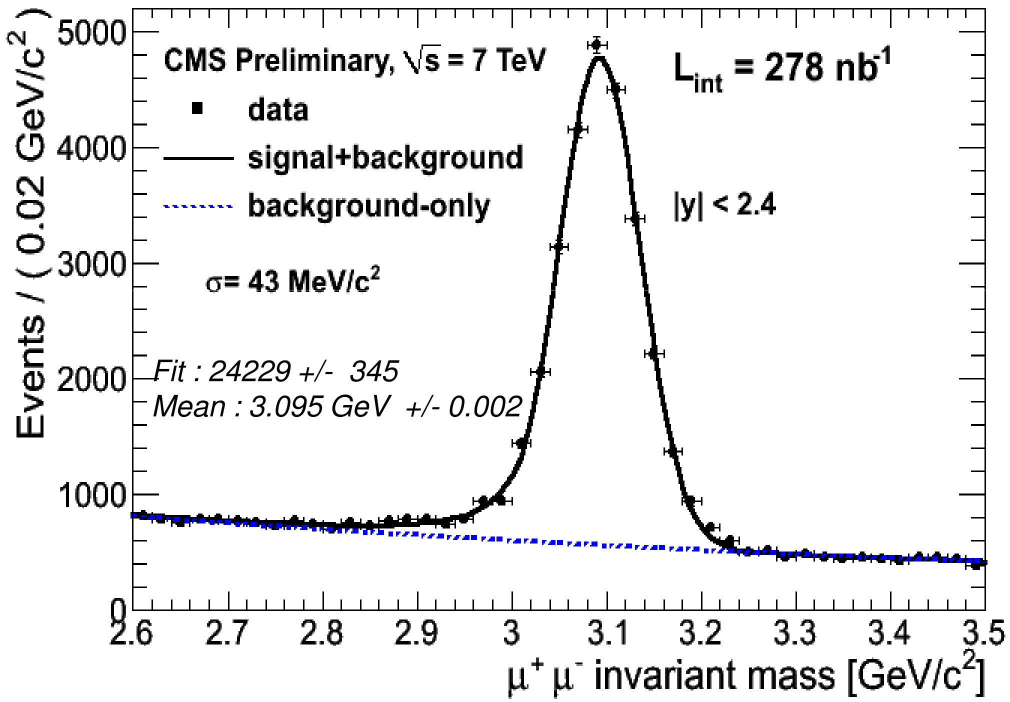
CMS and ATLAS

- Performant inner tracking detectors (based on Si pixels and strips)
- Fast and redundant muon identification system (Mu triggers)
- Extended coverage with respect to Tevatron detectors ($|\eta| \leq 2.5$)
- Very different configuration of B field, in the inner region superconducting solenoids are used by both (2 vs 4 T)
- 3 Levels for trigger decision (L1 Hardware, L2/L3 software)

J/ψ





- Very inclusive trigger paths:
  - *ATLAS: MinBias + L1 single Muon*
  - *CMS: L1 Double Muon + single Mu (pT>3 GeV/c)*
- Pairs of opposite charge muons
- Good primary vertex and secondary vertex by the two muons
- Quality cuts (n° of hits, $\chi 2$ fit ... See backup)

Yields extracted by MLL fits to data:

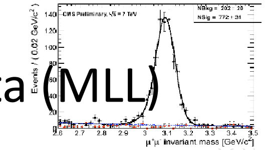
CMS: CB + Exp

ATLAS: Gauss + Linear

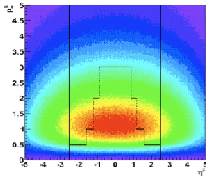
Cross Section

$$\frac{d^2\sigma}{dp_T\,dy} \times B(J/\psi \to \mu\mu) = \frac{N_{fitted}}{L \cdot A \cdot \varepsilon_{trigger} \cdot \varepsilon_{reco} \cdot \Delta p_T \cdot \Delta y}$$

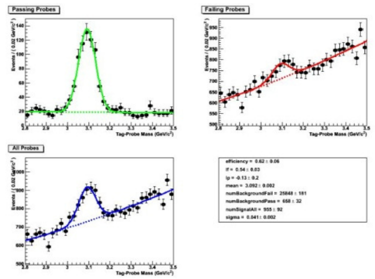
From fit to data (MLL)



from MC

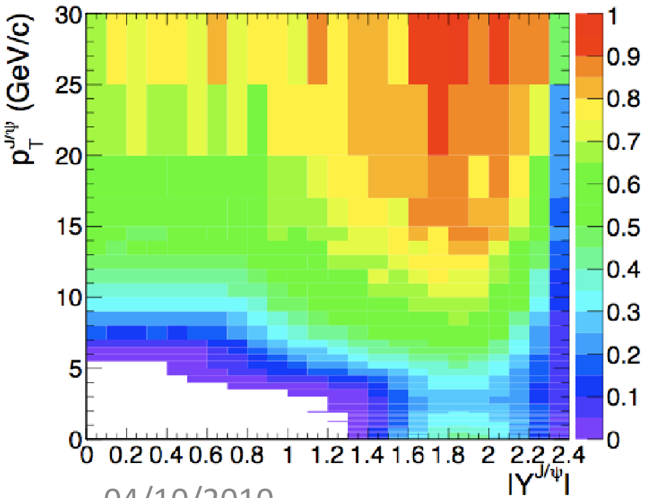


From data , T&P (for CMS)

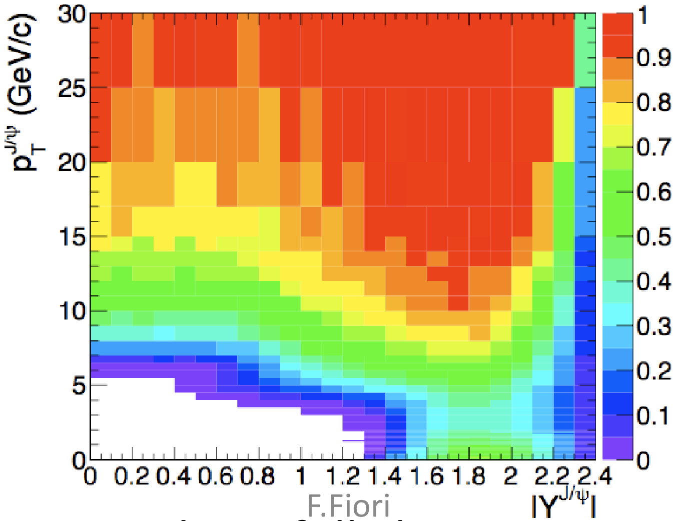


- **ATLAS** weights event by event with 1/Aε (efficiency taken by simulation)
- **CMS** correct the yields in each bin with 1/<A ε>
- The acceptance is strongly dependent by the polarization, 5 scenarios considered:

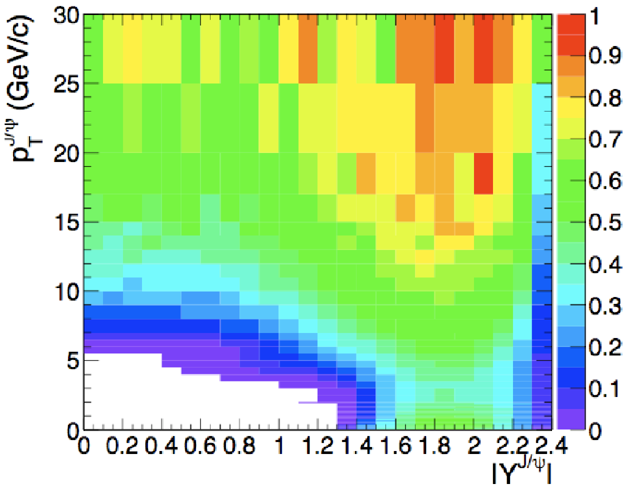
ATLAS include in systematic error , CMS quotes 5 Xsections



isotropic

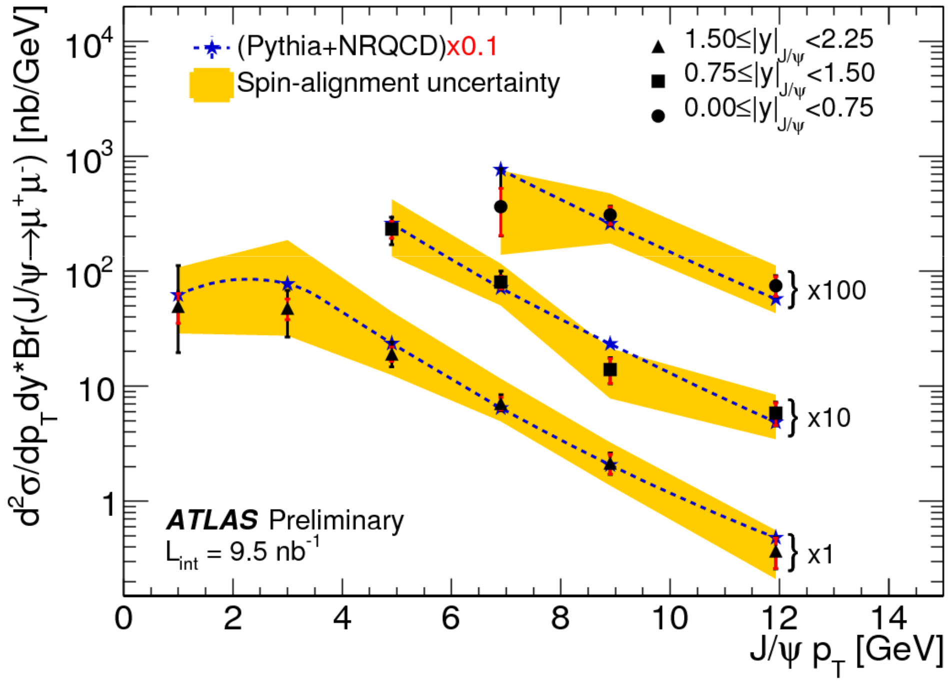


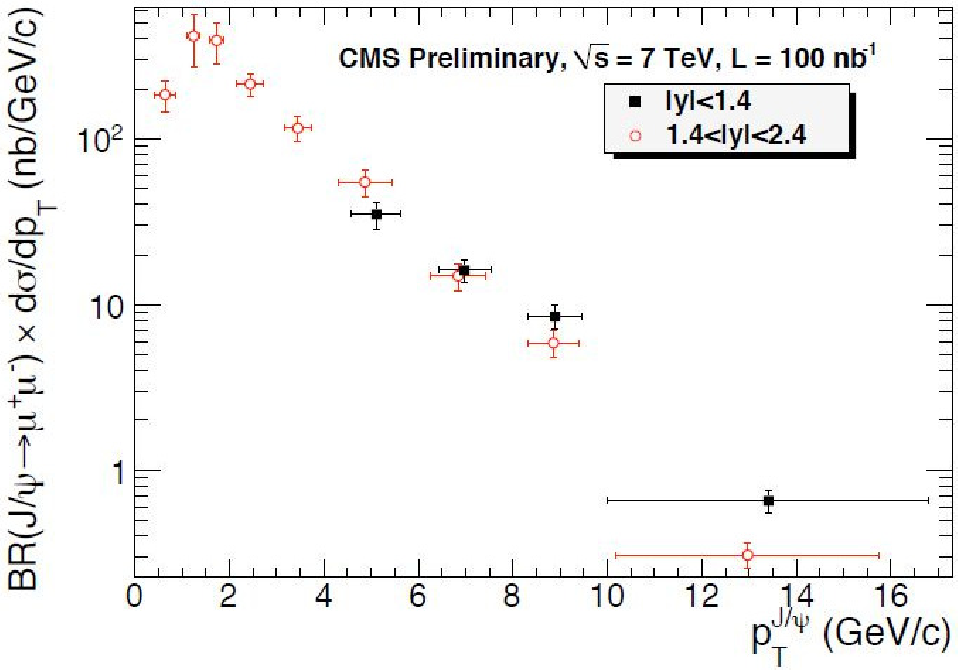
Helicity fully long.



Collins-Soper fully long.

Differential Cross Section





Systematics:

- Signal (background) PDF (1-8%)
- Single Mu efficiencies (10-15%)
- Momentum scale (>1%)
- FSR (1-2%)
- Polarization (not included in sys.)

Total production cross section in 4 < pT<30 and |y| <2.4:

289.1 ±16.7(stat) ±60.1(syst) nb

For details on J/psi see:

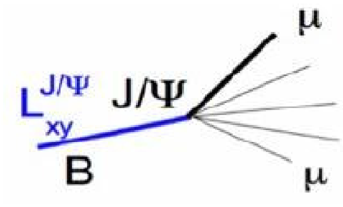
ATLAS

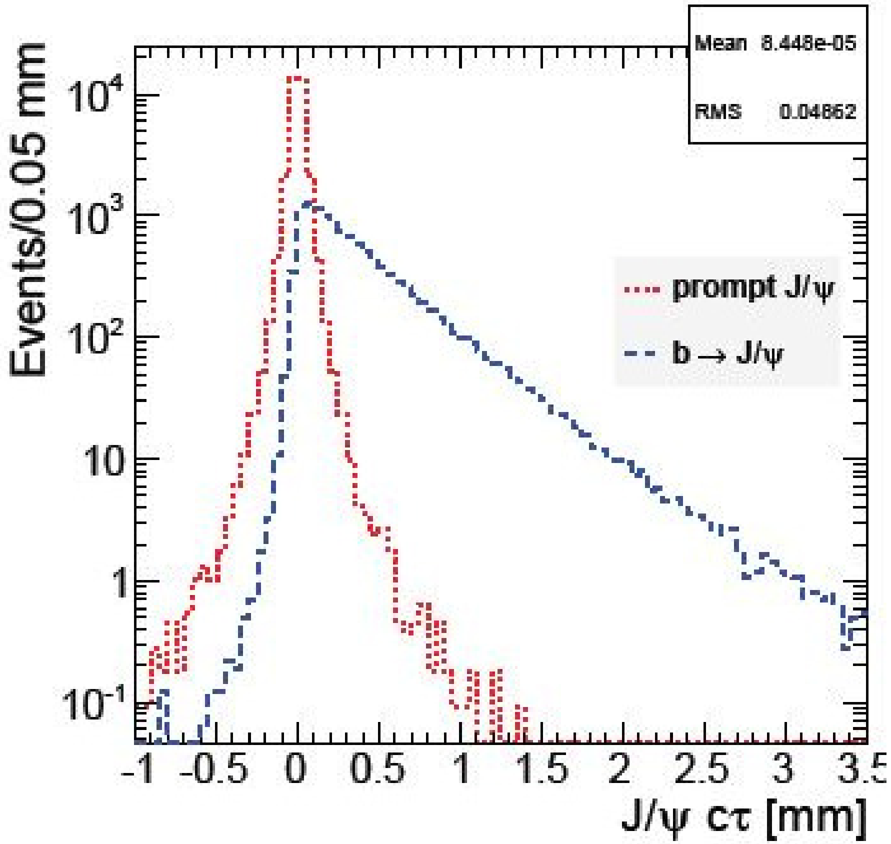
CMS

B-Fraction

pseudo-proper decay length

$$\ell_{xy} = \frac{L_{xy}^{J/\psi} \cdot M^{J/\psi}}{p_T^{J/\psi}}$$





- *Prompt J/ψ: triple Gaussian resolution function*
- *Simultaneus MLL fit to the mass and lifetime distributions*

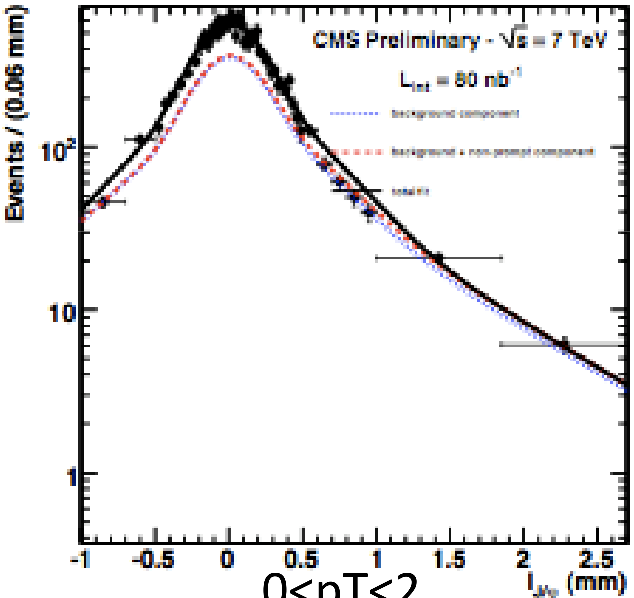
B-hadron component, two approaches:

A. MC template of true pseudo-decay length, convoluted with the same resolution function extracted from prompt decays (used as reference)

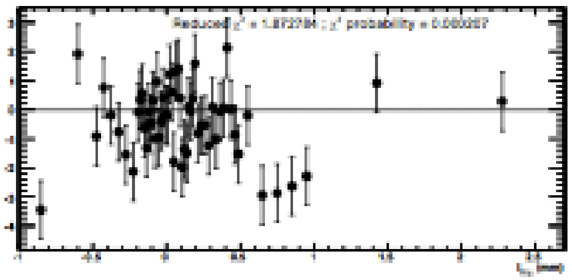
B. Assume a convolution of an exponential decay with two resolution functions:
   - A Boost resolution function to account for differences between the B-hadron and the J/Psi boost
   - Decay length resolution R (assumed to be the same of prompt J/Psi)

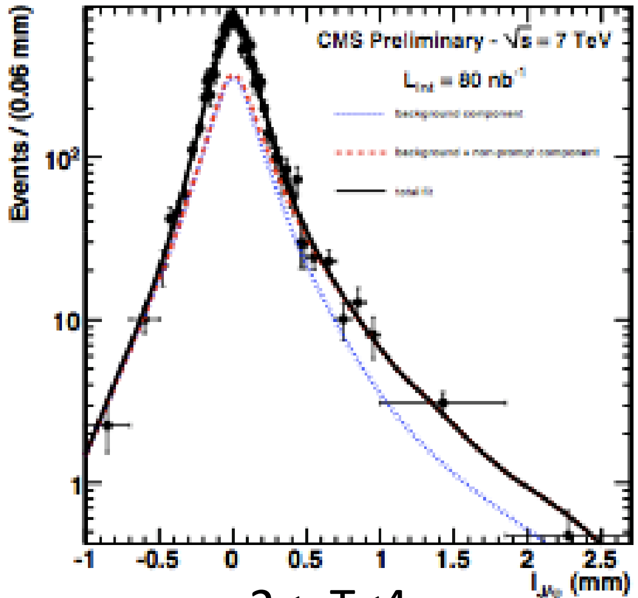
(The difference is taken as systematic)

Lifetime Fits

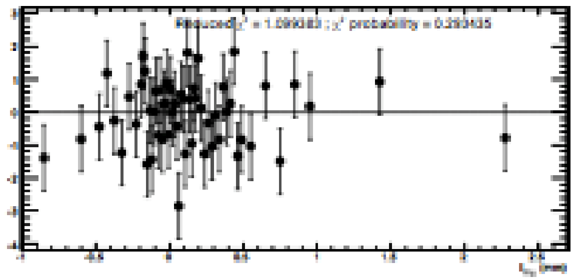


0<pT<2
forward





2<pT<4
forward



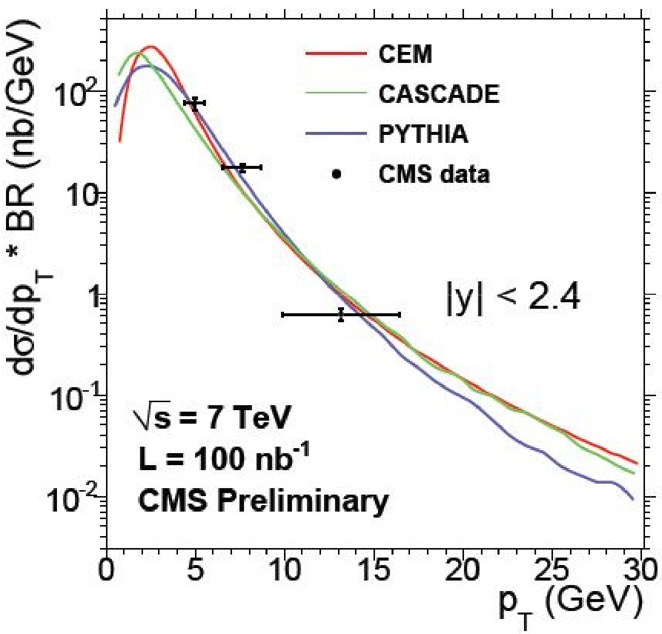
Resolution:

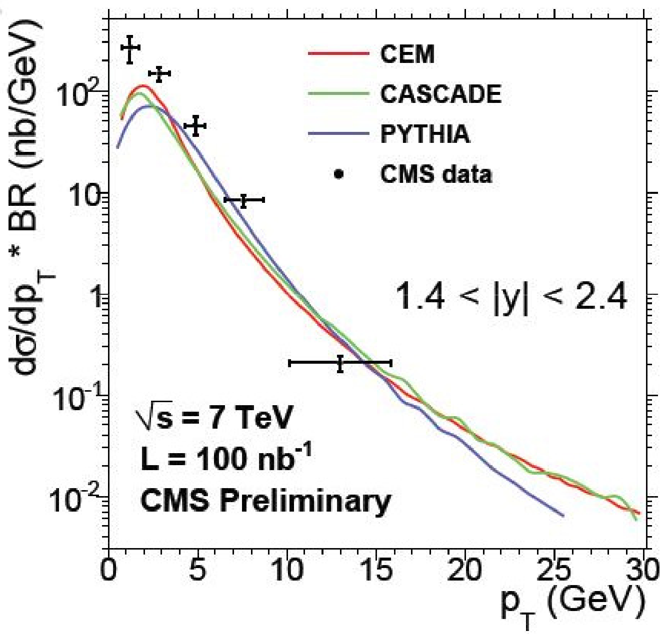
Barrel
pT 4.0-6.0 (85 ± 15) um
pT 6.0-10.0 (46 ± 5) um
pT 10.0-30.0 (39 ± 7) um

Forward
pT0.0-2.0 (253 ± 9) um
pT2.0-4.0 (141 ± 6) um
pT4.0-6.0 (74 ± 4) um
pT6.0-10.0 (55 ± 4) um
pT10.0-30.0 (37 ± 6) um

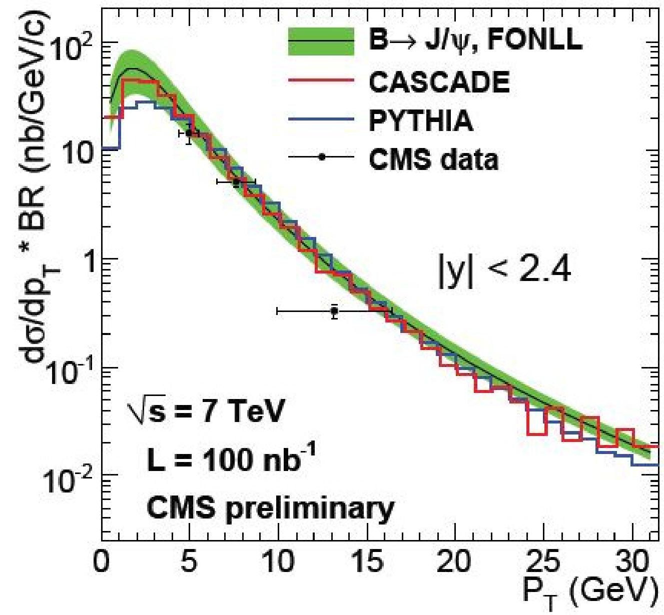
Total cross secion x Br for B hadron decays in 4< pT< 30 and|y|<2.4:
56.1±5.5(stat)±7.2(syst) nb

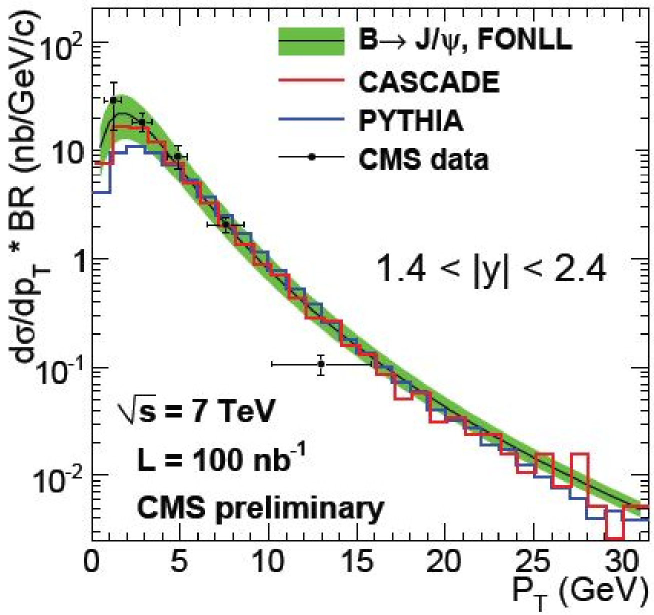
Comparison with predictions





prompt

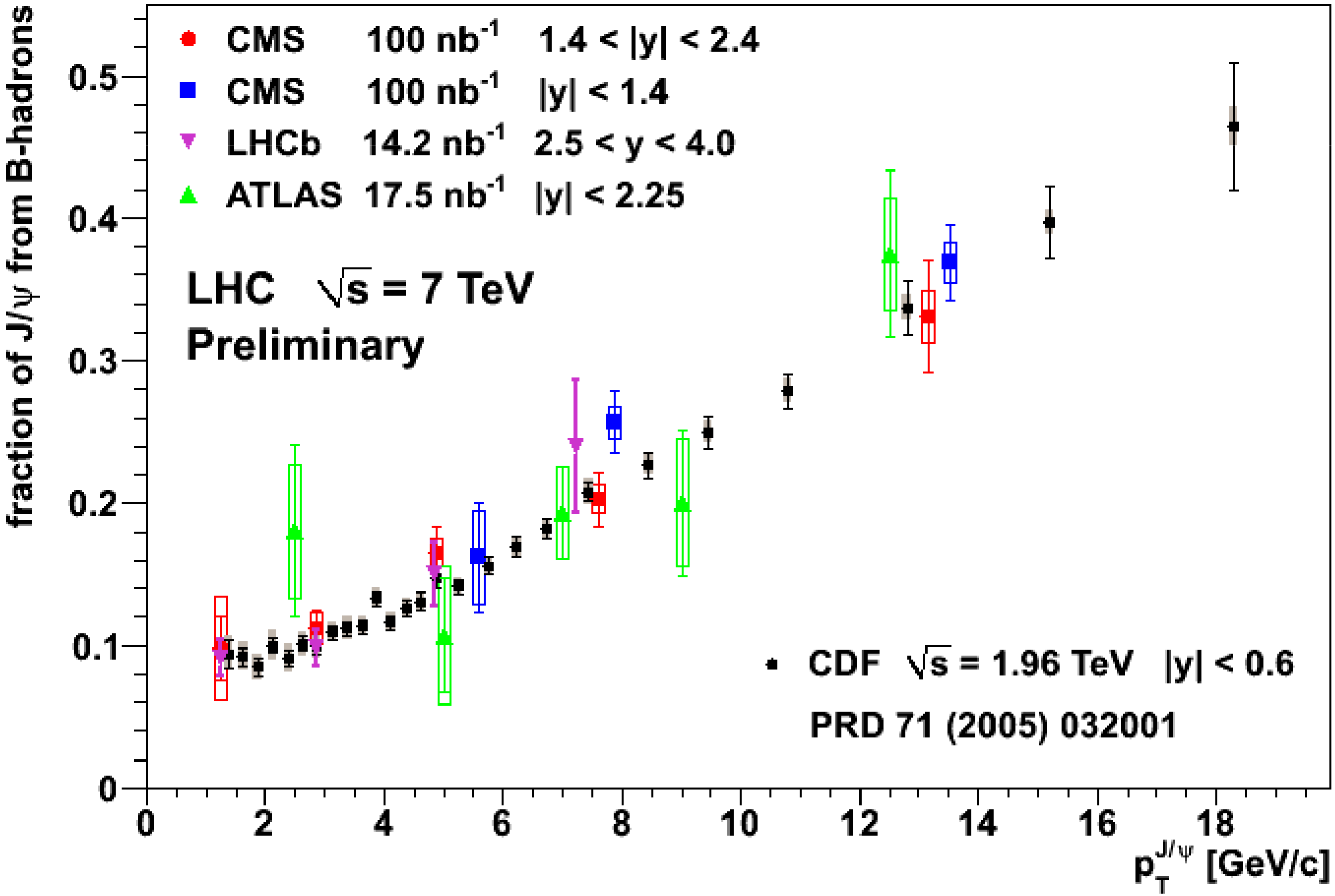




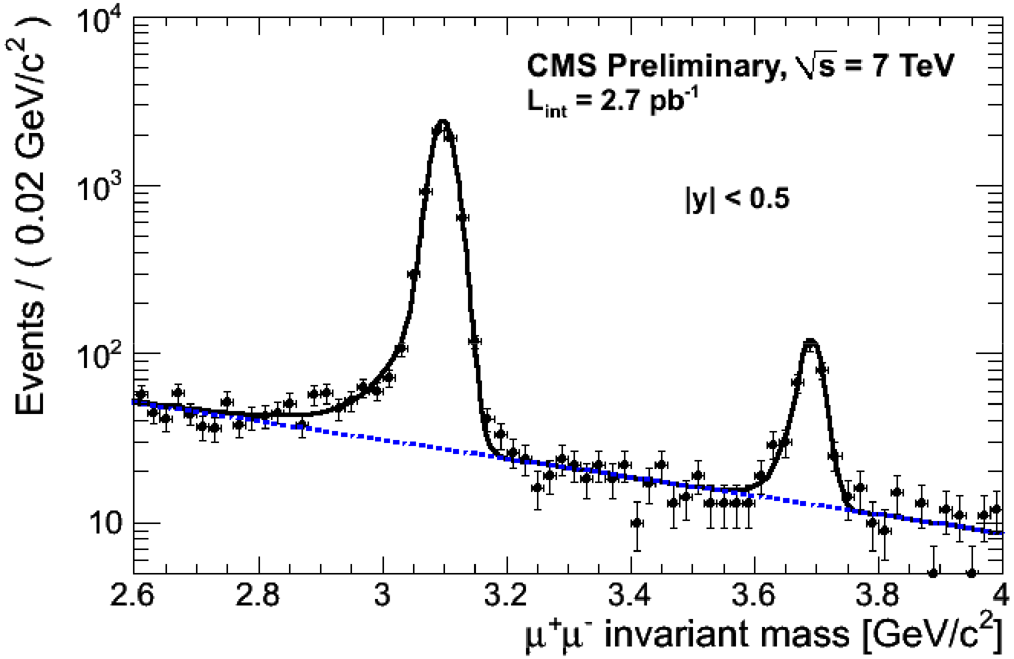
Non prompt

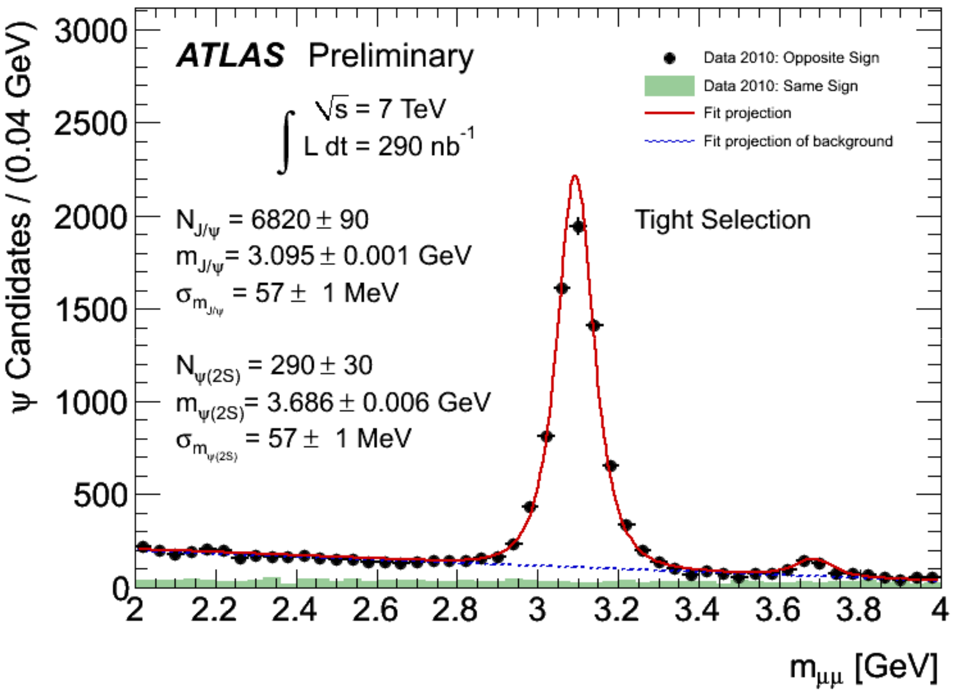
… and with other experiments

compilation by Hermine Woehri



Ψ(2S)

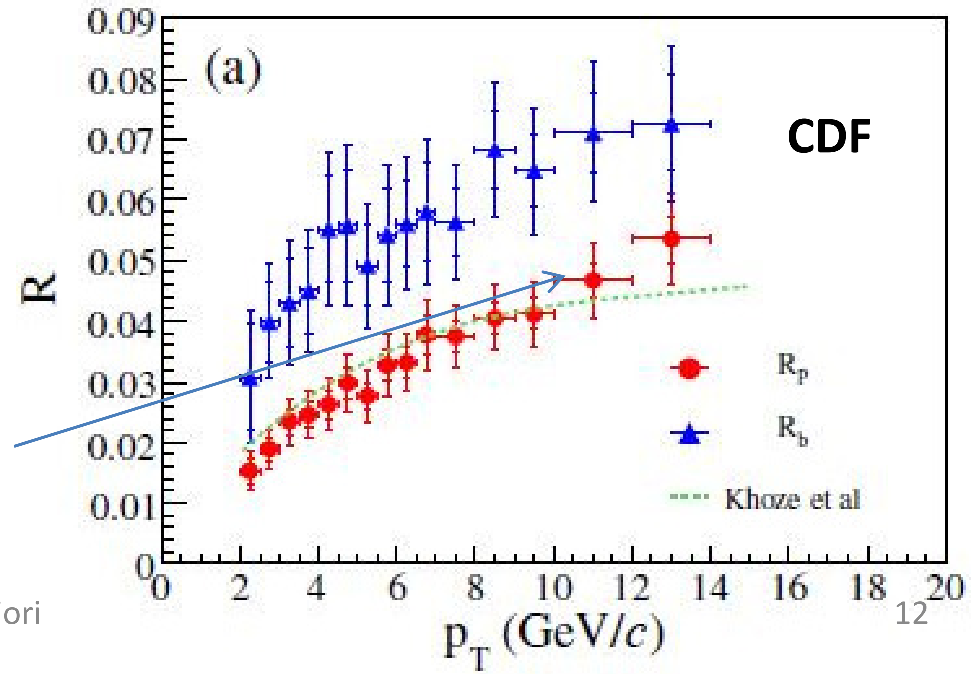




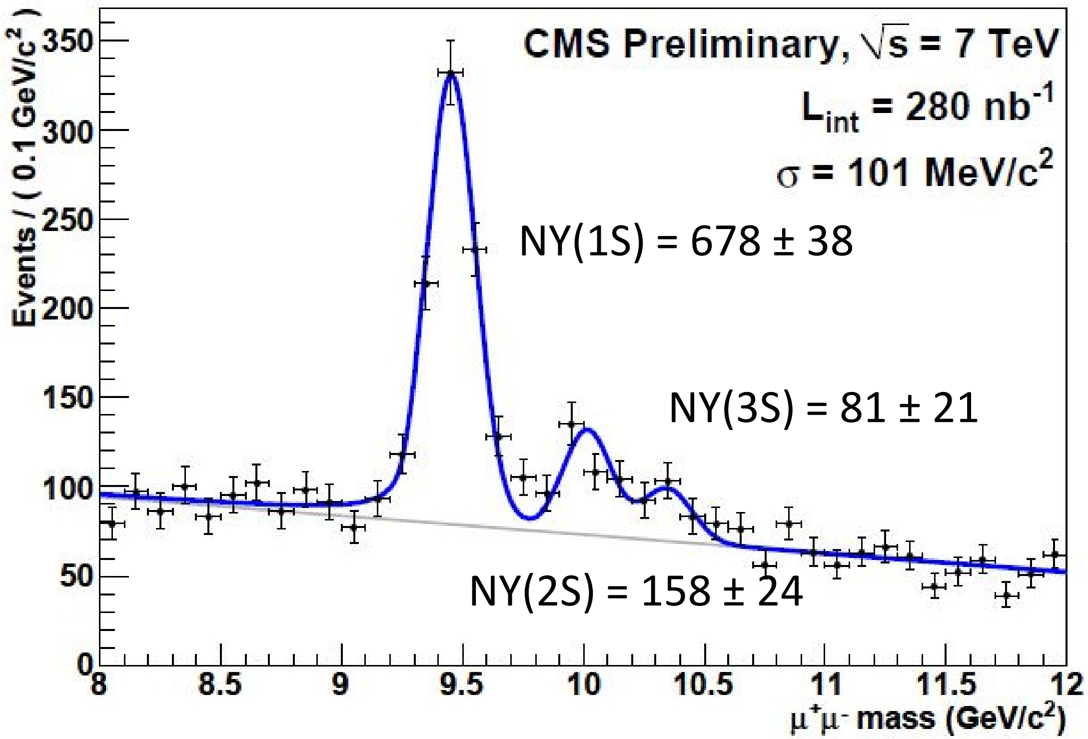
N J/psi: 7010 +/- 108
Resolution J/psi: 20 MeV +/- 0.6
Mean J/psi: 3.097 GeV +/- 0.0003
N psi(2S): 311 +/- 23
Resolution psi(2S): 18 MeV +/- 2
Mean psi(2S): 3.691 GeV +/- 0.001

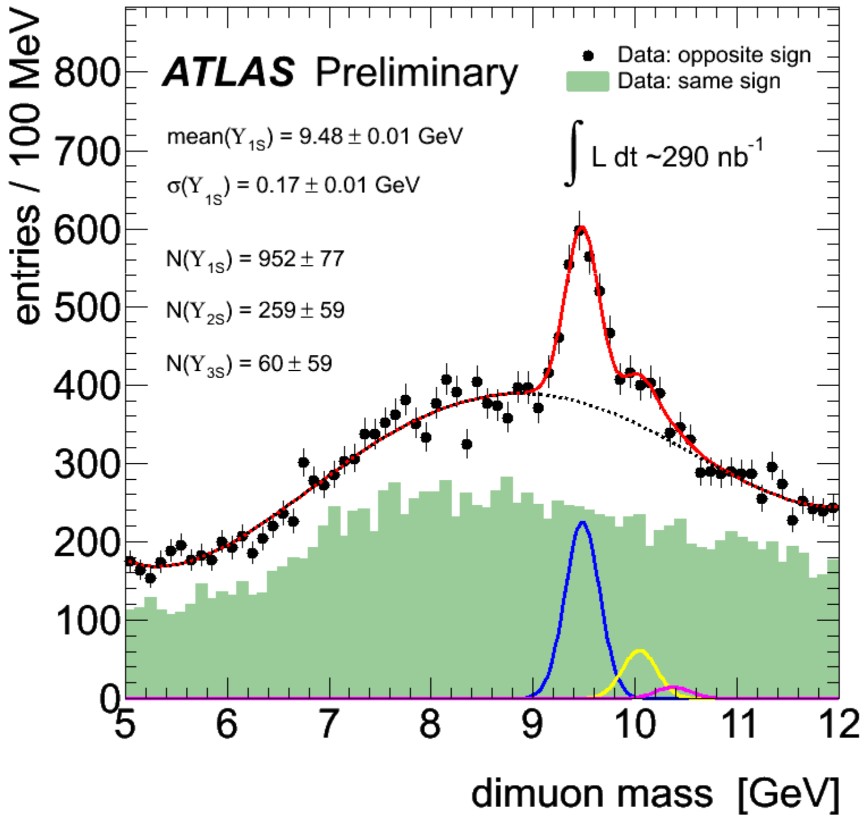
R= N(psi(2S))/N(J/psi):

R_{CMS} = 0.044 ± 0.004 (<p_T>=11.7 GeV/c)
R_{ATLAS} = 0.042 ± 0.005



Y family





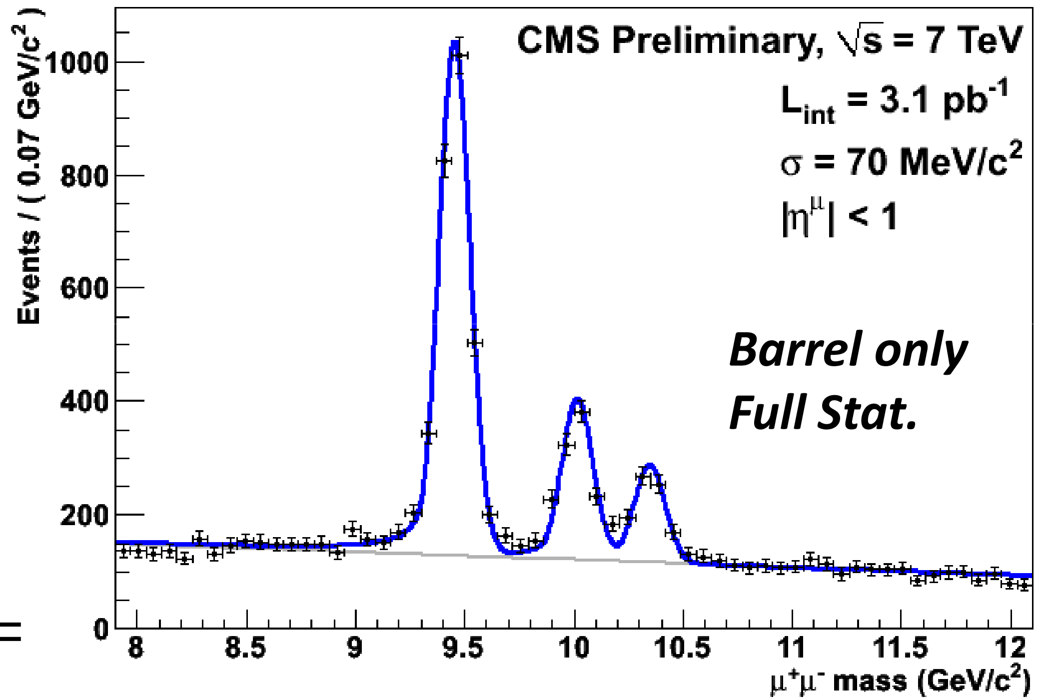
- ✓ Y family well visible in CMS and ATLAS data
- ✓ CMS already published a pT differential cross section
- ✓ The selection of events is the same of the J/psi

Υ production in CMS

Trigger: Double Muon at L1
Fit: 3 Gaussians + Linear

Dominant source of systematics is the efficiency computation (statistical origin)

5 cross sections quoted for the different polarizations

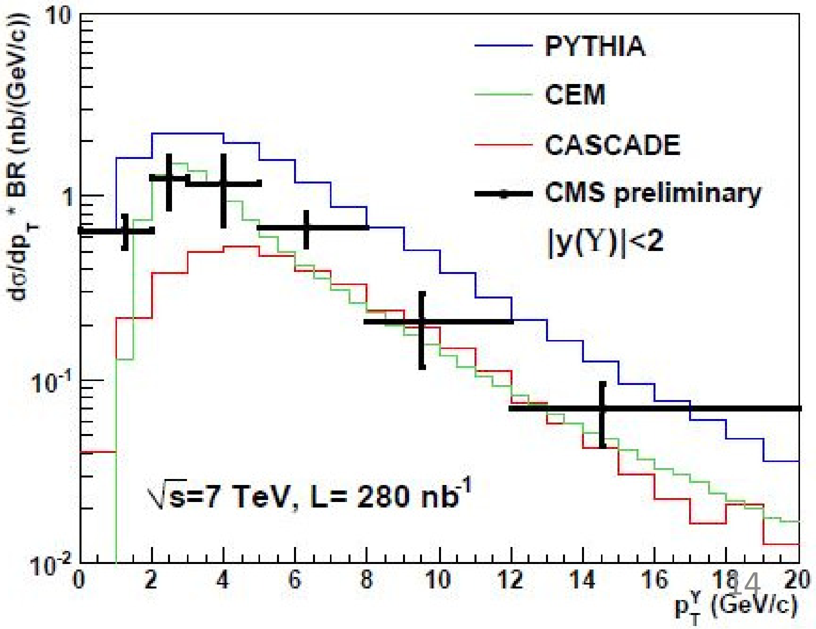


$$\sigma(pp \to \Upsilon(1S)) \cdot Br(\mu^+\mu^-) =$$
$$8.3 \pm (0.5) \pm (0.9) \pm (1.0) nb$$

Stat. Lumi. sys.

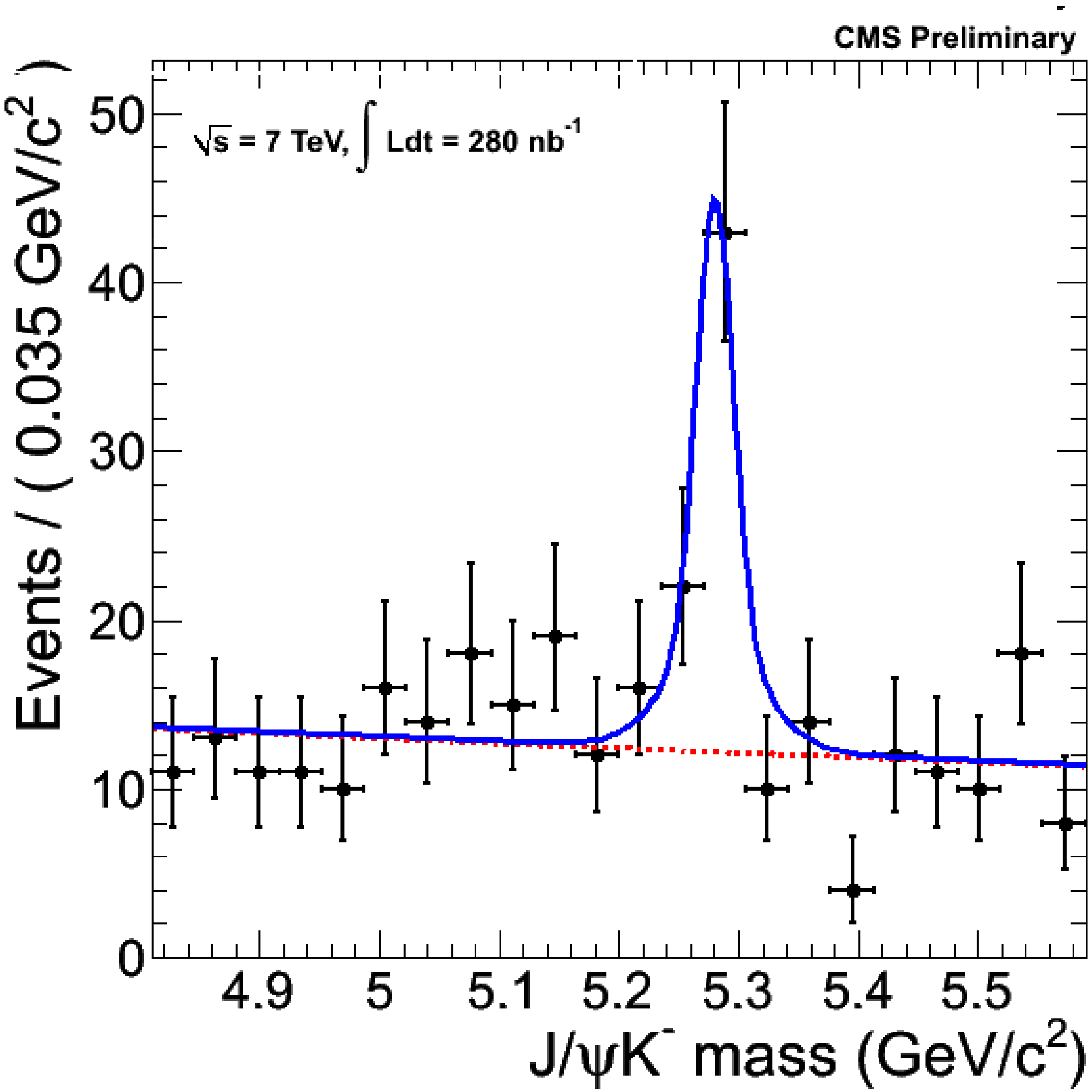
$$B(\Upsilon(1S) \to \mu^+\mu^-) = (2.48 \pm 0.05)\,\%,$$
$$B(\Upsilon(2S) \to \mu^+\mu^-) = (1.93 \pm 0.17)\,\%,$$
$$B(\Upsilon(3S) \to \mu^+\mu^-) = (2.18 \pm 0.21)\,\%.$$

R= $[\sigma(\Upsilon_{2S}) + \sigma(\Upsilon_{3S})]/\sigma(\Upsilon_{1S})$ $R = 0.44 \pm 0.06 \pm 0.07$



Deatails here

B±-mesons in CMS



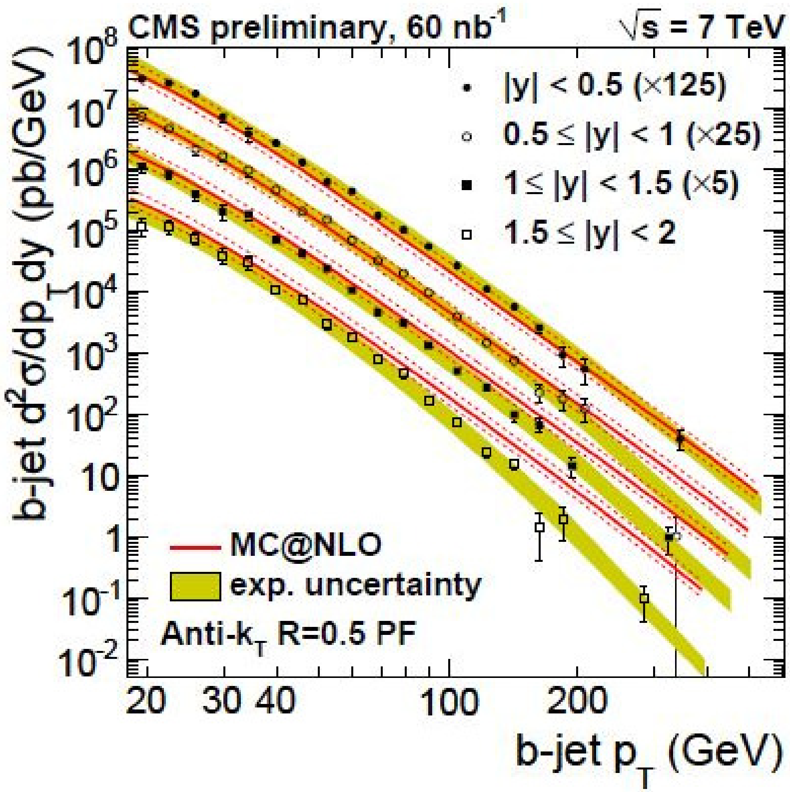
- ❑ Single Mu trigger (pT> 3GeV/c)
- ❑ Opposite sign di-muon combinations, if more than one chose the one with mass closest to the J/psi mass
- ❑ di-muon vertex Probability >0.1%
- ❑ Combine J/psi candidate with tracks (pT>0.9 GeV/c)
- ❑ Kinematic fit with J/psi mass constraint
- ❑ Require vertex probability > 0.1%
- ❑ If multiple candidates/event, choose highest pT B^- candidate
- ❑ cτ(J/ψK)/Δcτ > 1

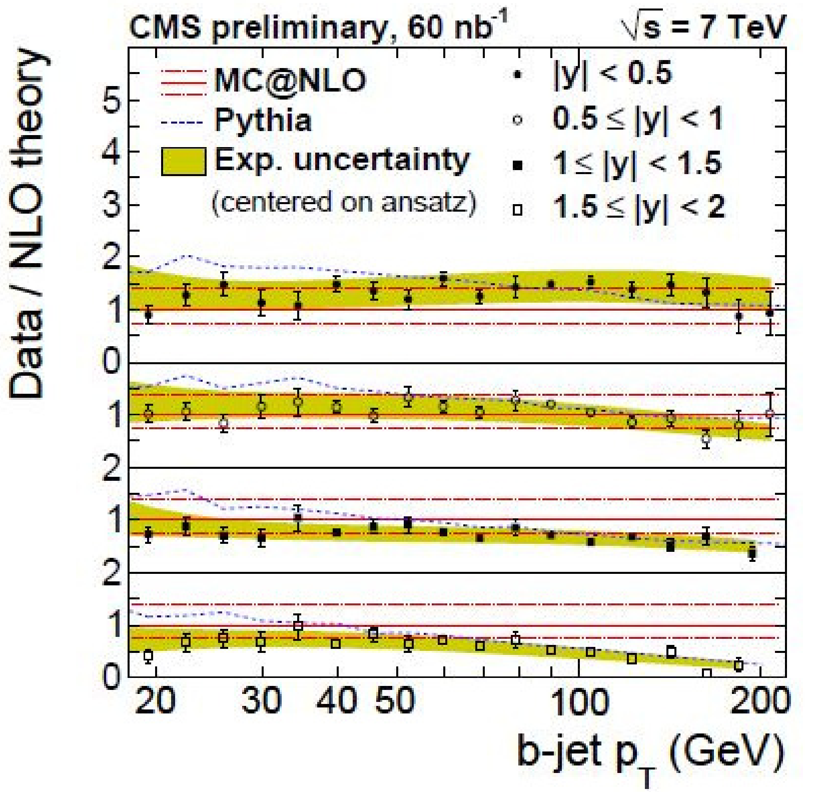
N_sig= 48 ± 8
Mean= 5.280 GeV/c²
Resolution= 32 MeV/c²

Details here

Inclusive b-jet production in CMS

CMS measured a double differential cross section for b-jet production and the ratio to inclusive jet production in the kinematic range |y|<2 and 18 < J_{pT} < 300 GeV/c





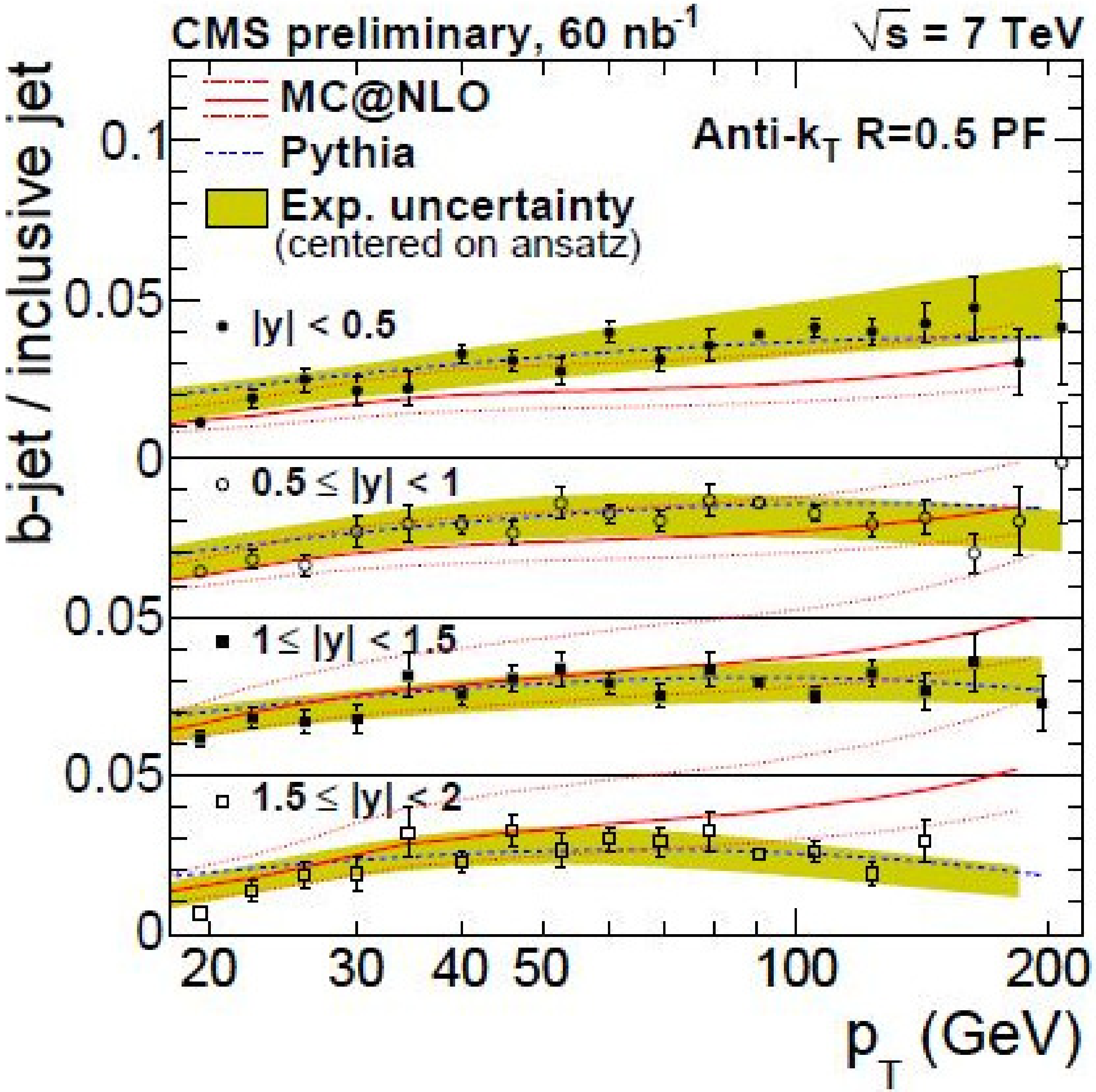
✓ b-tag: The secondary vertex is fitted with at least three charged particle tracks.

✓ A selection on the reconstructed 3D decay length significance is applied, corresponding to about 0.1% efficiency to tag light flavor jets and 60% efficiency to tag b jets at pT = 100 GeV.

✓ Purity and mistag probability taken from MC (Pythia)

✓ Trigger: MinBias + single-jet

b-jets/inclusive-jets

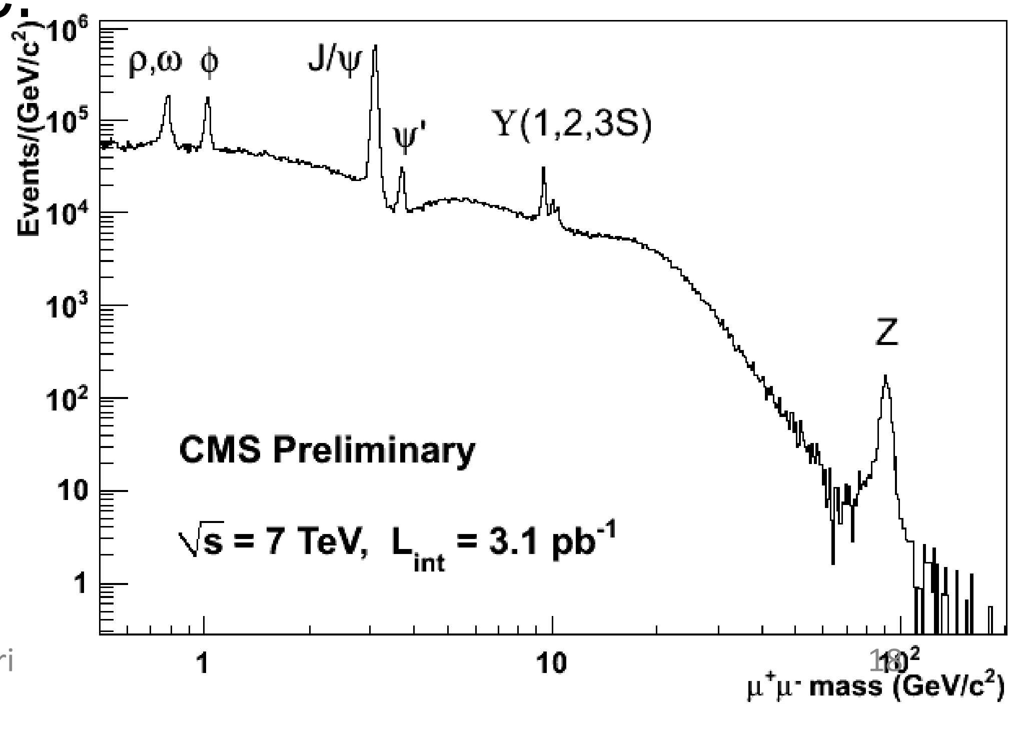


- The ratio reduces the uncertainties on JES and luminosity
- Good agreement with Pythia
- NLO calculations are in agreement at low pT, with very different shape at high pT
- Leading systematics:
  I. b-tagging efficiency (20%)
  II. Mistag (1-10%)

Details here

Conclusions

- After 6 months from the LHC start up ATLAS and CMS have produced good quality physics results
- New results with much more statistics coming soon (weeks)
- J/psi X section measurement in place for both experiments
- More refined B-physics studies require more data however the collaborations seem very reactive.
- The re-discovery of the Standard Model is just started



Back up

Selection I

- **Event selection**:
  - *Good Vertex, Anti Scraping [+L1 tech bits (only for runs<136086)]*
- **Mu selection**:
  - *Use GlobalMuons and TrackerMuons*
    - ***see next slide for selection details***
    - ***No Mu cleaning (does not affect x-section once using trigger bits)***
- **Triggers used:**
  - ***HLT_L1DoubleMuOpen (pT<4 GeV/c) + HLT_Mu3 (pT>4 GeV/c)***
    - ***strategy: keep the loosest unprescaled trigger path and that gives the smallest systematics***
- **Analysis is performed on GG+GT+TT**
  - *In case more than a combination use the GG; if both are GG, GT or TT take the one with larger p_T*
    - ***Given the small number of events the three categories are lumped into a single category.***

Selection II

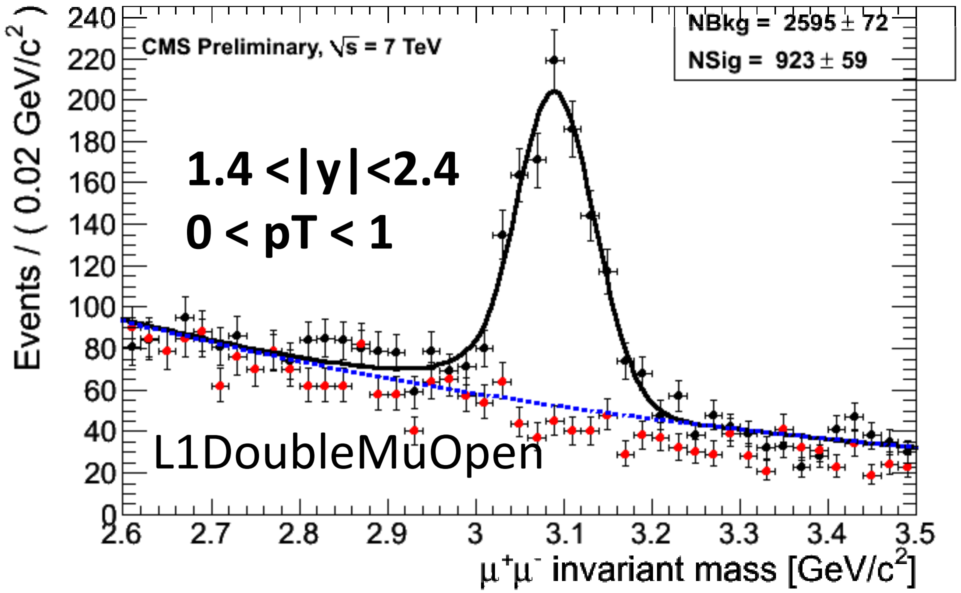
- **Both muons in acceptance**
- **Muon tracker tracks:**
  - *$\chi 2/ndof < 4.0$*
  - *$|d0| < 3.0$ cm (calculated w.r.t. PV)*
  - *$|dz| < 15.0$ cm (calculated w.r.t. PV)*
  - *number of valid hits (pixel + strips) > 11*
  - *number of pixel layers with hits ≥ 2*
- **Global muons:**
  - *$\chi 2/ndof$ (global fit) < 20.0*
  - *number of valid muon hits > 0*
  - *also tracker muons arbitrated and passing TMLastStationAngTight selector*
- **Tracker muons**:
  - *arbitrated and passing TMLastStationAngTight*
- **a secondary vertex must be found with $P(\chi 2) > 0.1\%$**

Mass Fit

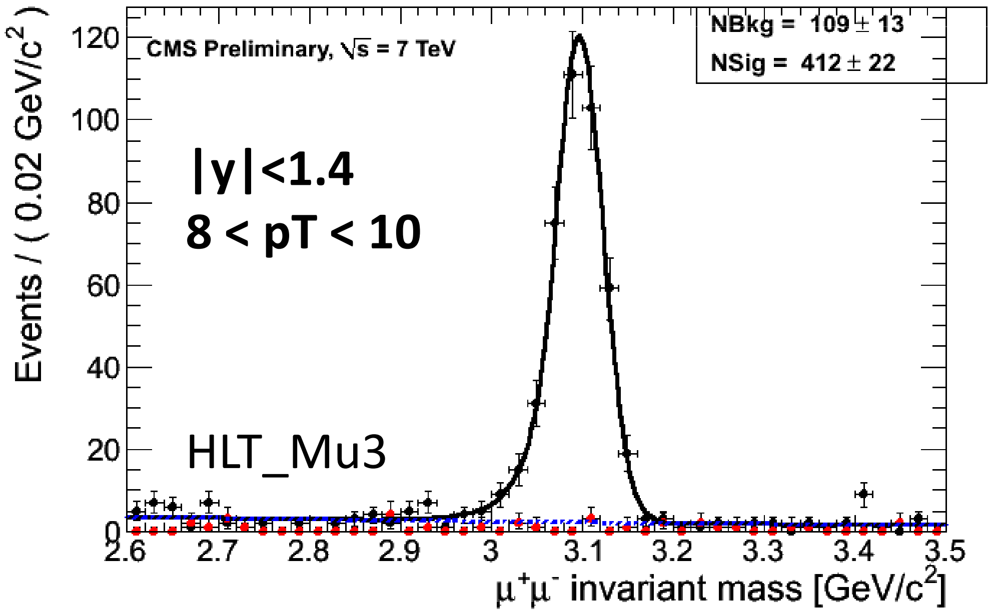
- CB signal + Exponential background

Example of two (very) different bins:

High background level, worse resolution



Practically no background



Fit : 923 +/- 59
Resolution : 45.2 +/- 2.4 MeV/c²
Mean : 3.090 +/- 0.002 GeV/c²
S/B= 1.4

Fit : 412 +/- 22
Resolution : 26.1 +/- 1.4 MeV/c²
Mean : 3.097 +/- 0.001 GeV/c²
S/B= 26.5

we have considered a CB+Gauss for the signal and a linear fit for the background to estimate for systematics

Efficiencies

- Determined by T&P (single muon)

$$\varepsilon_{reco} = \varepsilon_{track} \cdot \varepsilon_{id}$$

- From single mu to J/ψ:

$$\varepsilon_{J/\psi} = \varepsilon_{reco}(\mu^+) \cdot \varepsilon_{reco}(\mu^-) \cdot \varepsilon_{Trigger} \cdot \rho \cdot \varepsilon_{Vertex}$$ ← From data

$$\varepsilon_{Trigger} = \varepsilon_{Trigger}(\mu^+) \cdot \varepsilon_{Trigger}(\mu^-)$$ ← For double Mu trigger

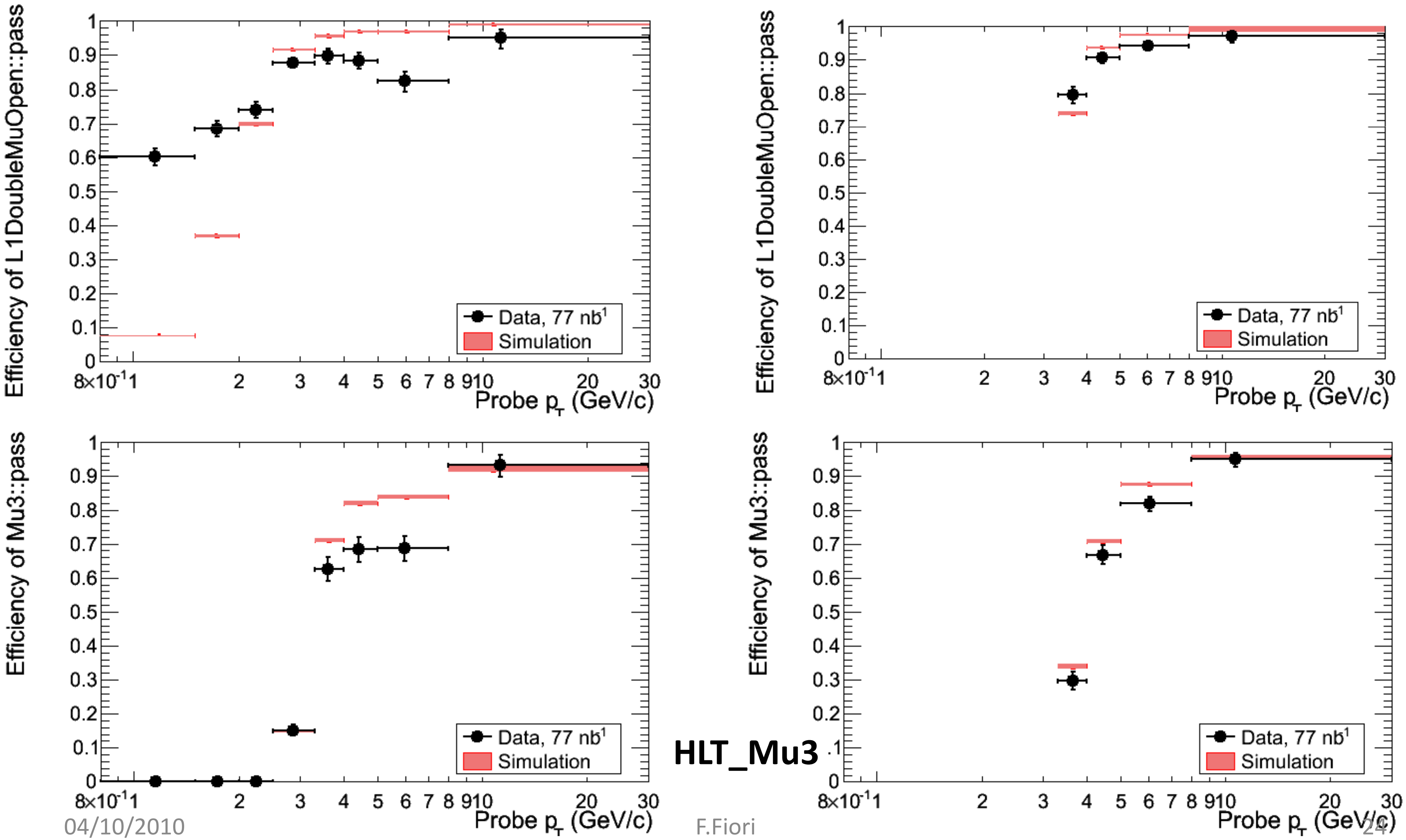
$$\varepsilon_{Trigger} = \varepsilon_{Trigger}(\mu^+) + \varepsilon_{Trigger}(\mu^-) - \varepsilon_{Trigger}(\mu^+) \cdot \varepsilon_{Trigger}(\mu^-)$$ ← For single Mu trigger

All the single muon efficiency computed on data

- Triggers used:
  - L1DoubleMuOpen (Forward region for pT<4 GeV/c)
  - HLT_Mu3 (For pT>4 GeV/c, gives a better S/B)

Trigger efficiency (T&P)

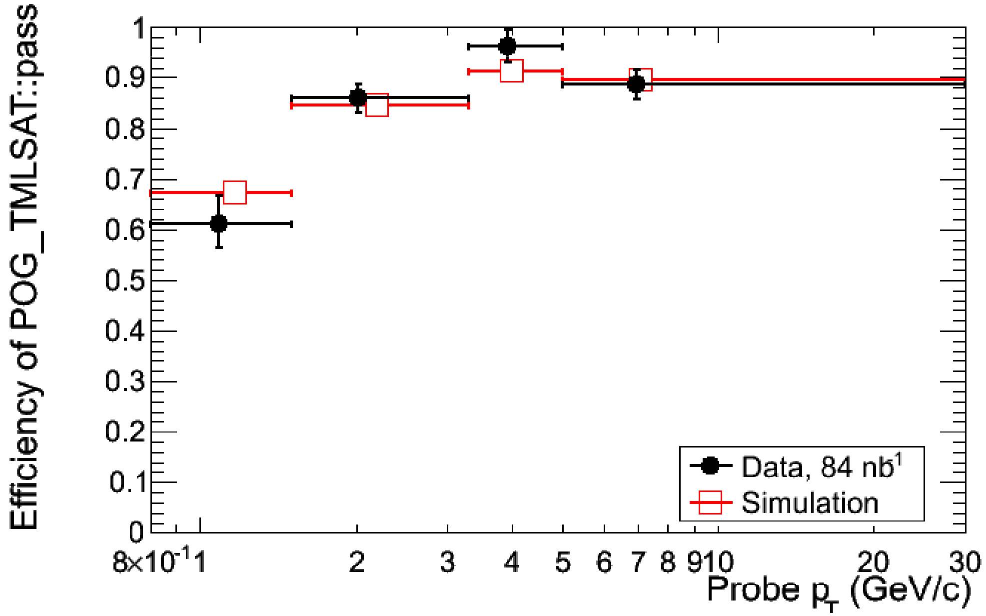
DoubleMuOpen

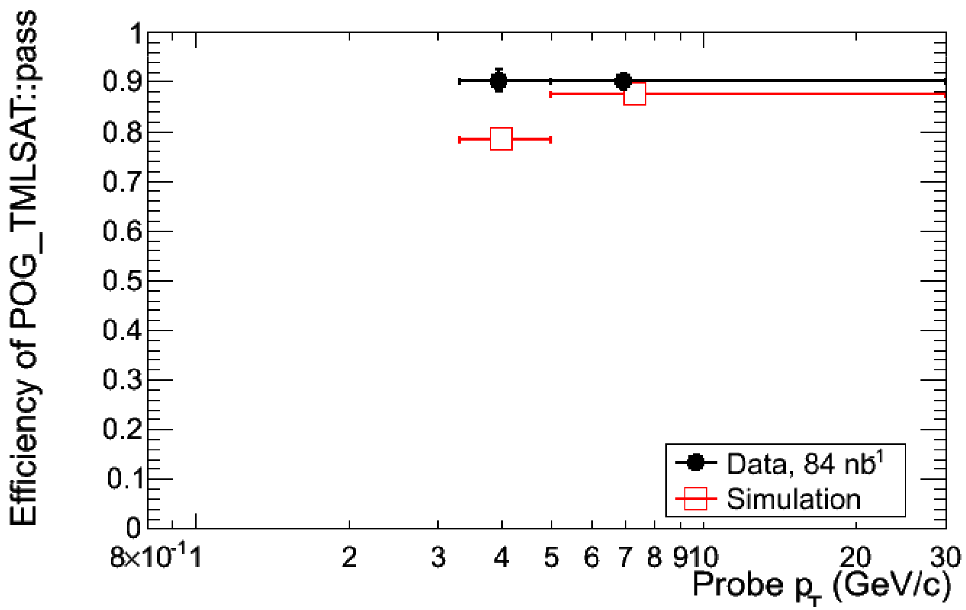


HLT_Mu3

Id and Tracking

- Muon Id





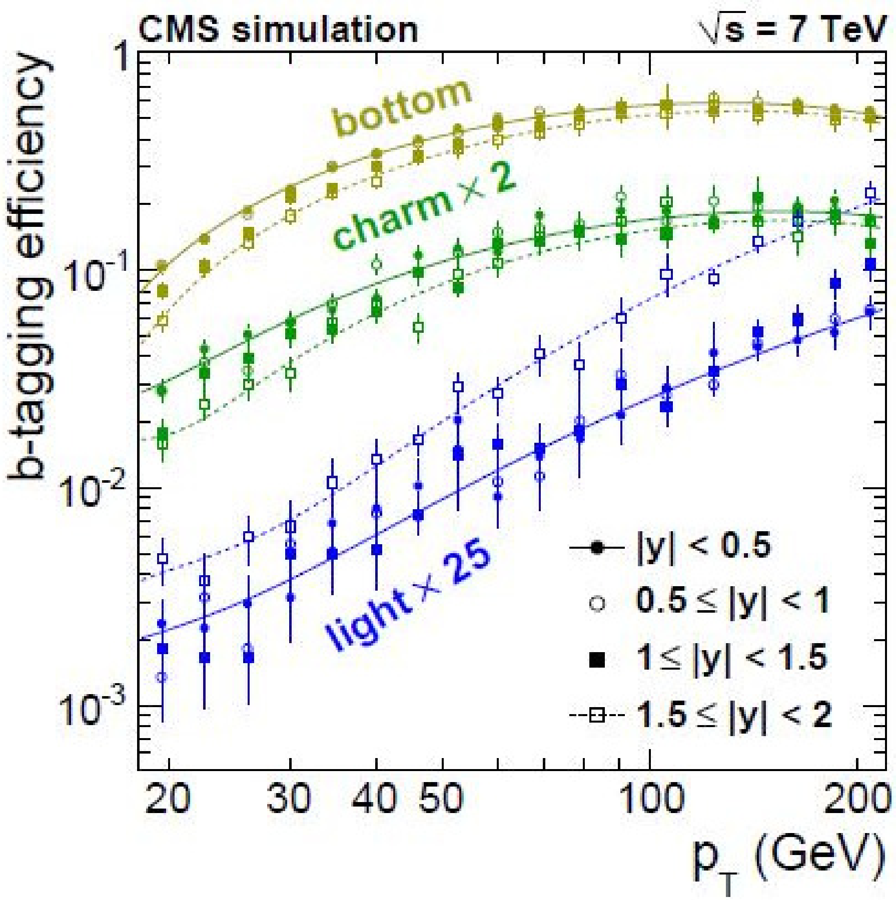
- Tracking: use the T&P from PAS TRK-10-002.
  - assumed that the pT behaviour is the same between the data and MC. Correct for phi-eta dependence.

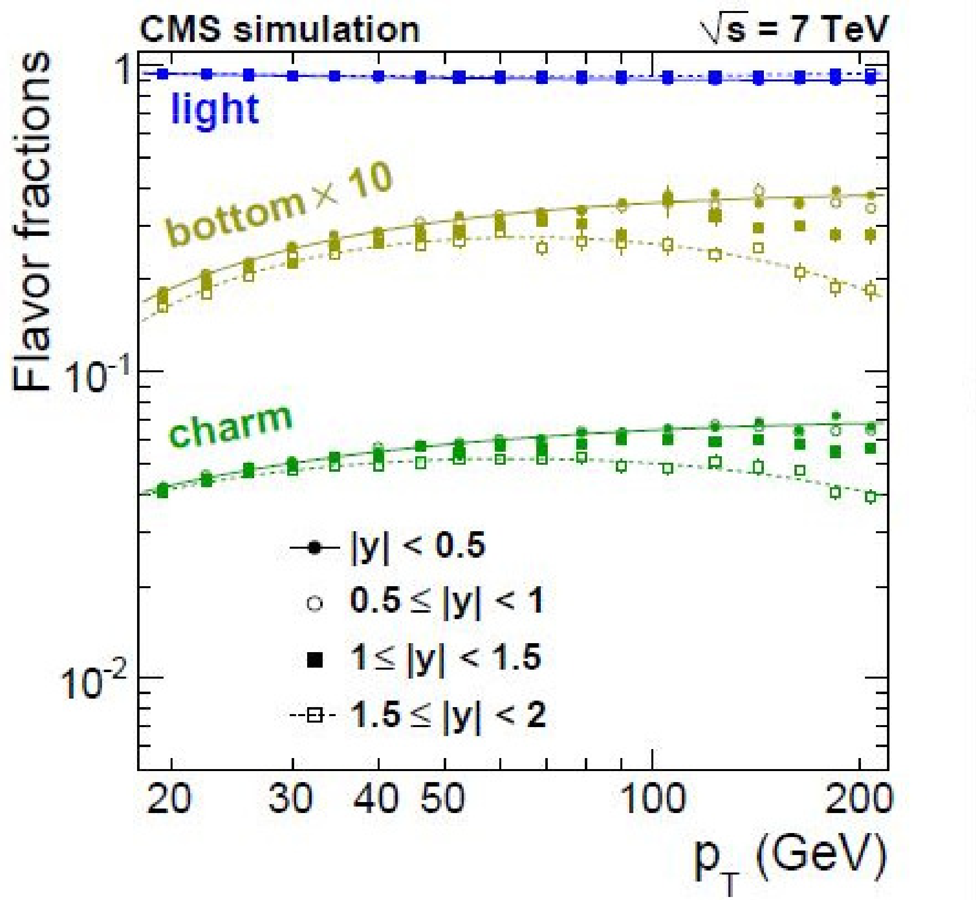
Inclusive Xsection

$p_T^{J/\psi}$ (GeV/c)	$\langle p_T^{J/\psi} \rangle$ (GeV/c)	$BR(J/\psi \to \mu^+\mu^-) \cdot \frac{d\sigma}{dp_T}$ (nb/ GeV/c)				
			Prompt J/ψ polarization			
		null	$\lambda_\theta^{CS} = -1$	$\lambda_\theta^{CS} = +1$	$\lambda_\theta^{HX} = -1$	$\lambda_\theta^{HX} = +1$
			$\lvert y \rvert < 1.4$			
$4-6$	5.11	$34.9 \pm 2.5 \pm 6.0$	45.5 ± 14.6	32.2 ± 6.3	25.5 ± 10.3	42.9 ± 12.1
$6-8$	6.98	$16.18 \pm 0.84 \pm 2.33$	18.84 ± 4.04	15.15 ± 2.58	12.22 ± 4.58	19.30 ± 4.41
$8-10$	8.89	$8.49 \pm 0.45 \pm 1.35$	9.80 ± 1.64	7.97 ± 1.69	6.56 ± 2.84	9.98 ± 1.75
$10-30$	13.41	$0.653 \pm 0.031 \pm 0.097$	0.724 ± 0.099	0.622 ± 0.120	0.543 ± 0.184	0.728 ± 0.101
			$1.4 < \lvert y \rvert < 2.4$			
$0-1$	0.64	$185 \pm 12 \pm 38$	131 ± 67	234 ± 68	134 ± 65	229 ± 63
$1-1.5$	1.24	$419 \pm 40 \pm 138$	298 ± 172	524 ± 205	314 ± 162	501 ± 187
$1.5-2$	1.73	$393 \pm 24 \pm 110$	281 ± 150	490 ± 167	302 ± 136	464 ± 147
$2-3$	2.44	$214 \pm 9 \pm 33$	155 ± 71	265 ± 65	169 ± 58	248 ± 51
$3-4$	3.45	$116 \pm 5 \pm 19$	86 ± 36	141 ± 35	93 ± 30	133 ± 28
$4-6$	4.87	$54.6 \pm 3.0 \pm 10.$	45.0 ± 14.0	62.7 ± 14.6	44.5 ± 13.7	62.0 ± 14.1
$6-8$	6.84	$14.92 \pm 0.64 \pm 2.60$	13.74 ± 2.87	15.95 ± 3.00	12.74 ± 3.38	16.42 ± 3.24
$8-10$	8.86	$5.88 \pm 0.34 \pm 1.00$	5.80 ± 1.09	5.97 ± 1.03	5.18 ± 1.46	6.31 ± 1.01
$10-30$	12.97	$0.307 \pm 0.024 \pm 0.048$	0.309 ± 0.054	0.308 ± 0.054	0.281 ± 0.057	0.323 ± 0.058

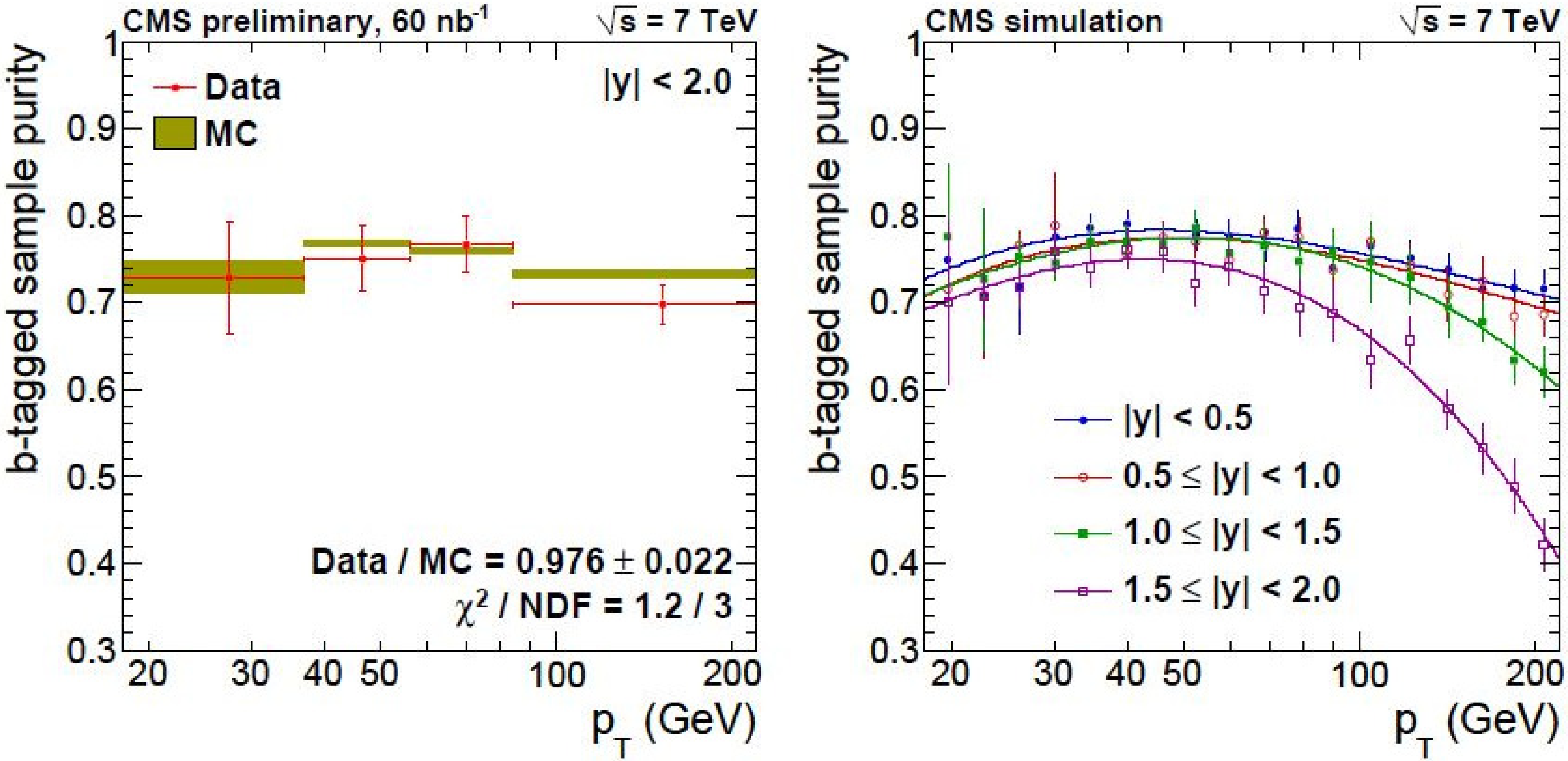
As the data sample grows, it will become possible to measure the polarization and re-evaluate the corresponding cross section.

B-tagging efficiency





Purity


CMS preliminary, 60 nb^{-1}
$\sqrt{s}$ = 7 TeV
|y| < 2.0
Data
MC
Data / MC = 0.976 ± 0.022
χ^2 / NDF = 1.2 / 3
b-tagged sample purity
p_T (GeV)
CMS simulation
$\sqrt{s}$ = 7 TeV
|y| < 0.5
0.5 ≤ |y| < 1.0
1.0 ≤ |y| < 1.5
1.5 ≤ |y| < 2.0
b-tagged sample purity
p_T (GeV)