



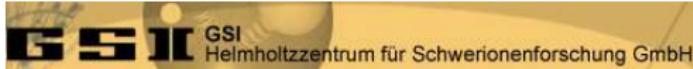
Bottomonium production in pp collisions at $\sqrt{s} = 7$ TeV with the CMS experiment

– QWG11 GSI, Darmstadt –

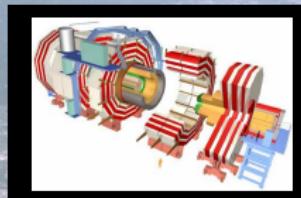
on behalf of CMS Collaboration

Adrian Perieanu

I. Physikalisches Institut B, RWTH-Aachen
4th October 2011

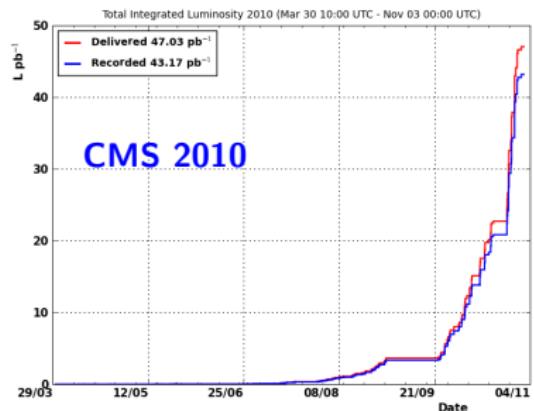


Outline

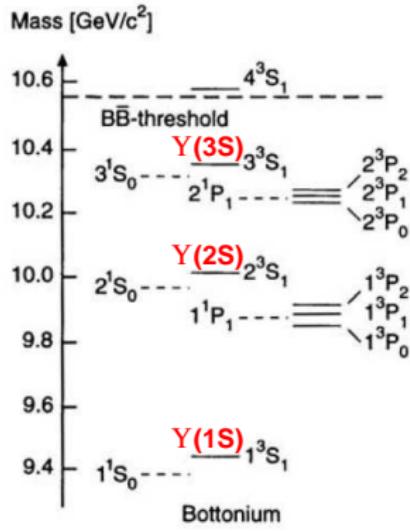


CMS

- 1 Motivation
- 2 CMS Detector
- 3 Event Selection
- 4 $\Upsilon(nS)$ Cross-Sections
- 5 Outlook 2011

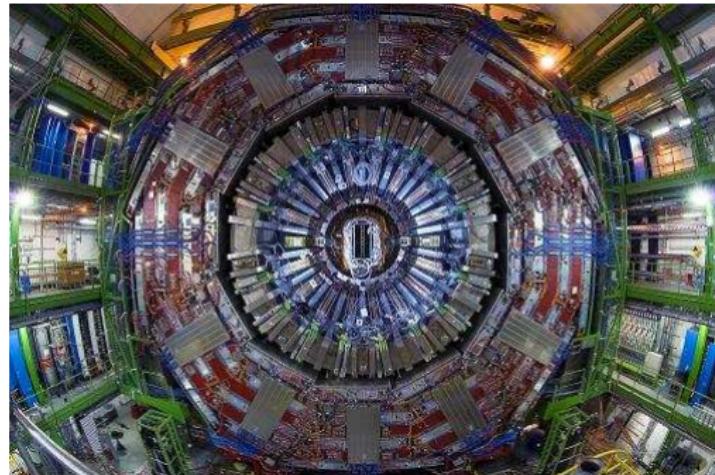


Motivation



J^{PC} 0^{-+} 1^{--} 1^{+-}

- production mechanism of $b\bar{b}$ states ($\Upsilon(nS)$)
 - at $\sqrt{s} = 7$ TeV
 - at large p_T
- measure polarization
 - lack of theories that successfully explain polarization and differential cross-section simultaneously



- understand CMS detector using $\Upsilon(nS) \rightarrow \mu^+\mu^-$ decay channel
 - tracking reconstruction
 - muon identification
 - p calibration
 - trigger

CMS Detector

Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons

STEEL RETURN YOKE
~13000 tonnes

SILICON TRACKER
Pixels (100 x 150 μm^2)
~1m² ~66M channels
Microstrips (80-180 μm)
~200m² ~9.6M channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76k scintillating PbWO₄ crystals

PRESHOWER
Silicon strips
~16m² ~137k channels

SUPERCONDUCTING SOLENOID
Niobium-titanium coil carrying ~18000 A

HADRON CALORIMETER (HCAL)
Brass + plastic scintillator
~7k channels

FORWARD CALORIMETER
Steel + quartz fibres
~2k channels

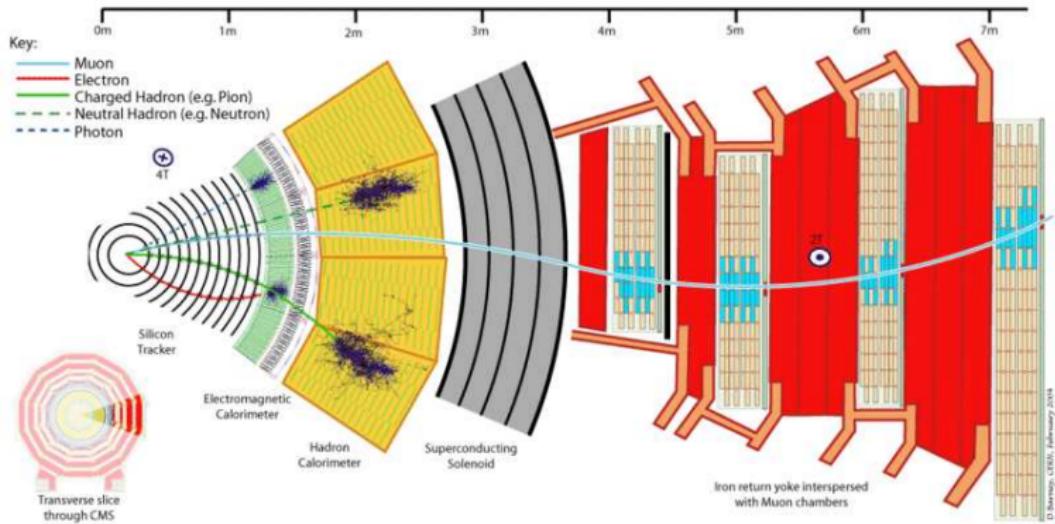
Total weight : 14000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

Barrel: 250 Drift Tube & 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip & 432 Resistive Plate Chambers

Muon Reconstruction

Muons in CMS:

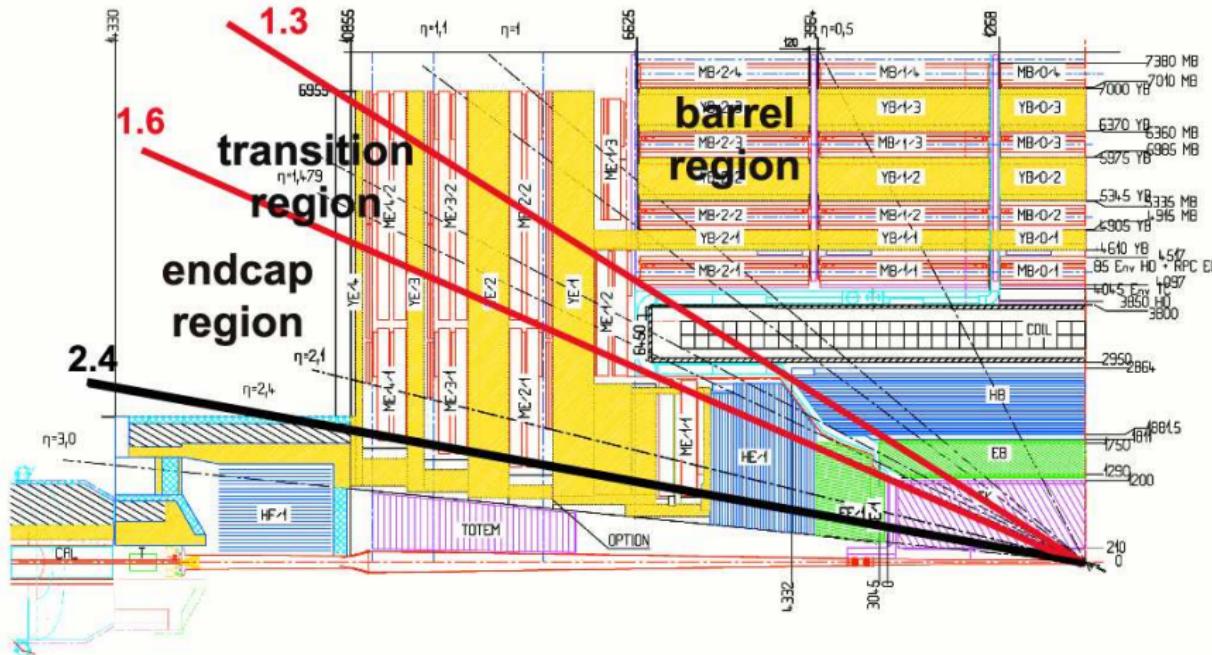
track reconstructed in silicon tracker, associated with compatible signal in muon detectors



- **Global:** track segment in muon chamber matched with track in silicon tracker
- **Tracker:** track in silicon tracker matched to at least one muon station signal
- **Stand Alone:** track only in muon chambers

- **Coverage:**
 - Tracking System $|\eta| < 2.5$
 - Muon Detectors $|\eta| < 2.4$
- $B: 3.8 \text{ T}$
- **Tracking System Resolution:**
$$\sigma_{p_T}/p_T \approx 0.015\% p_T \oplus 0.5\%$$

CMS Geometry



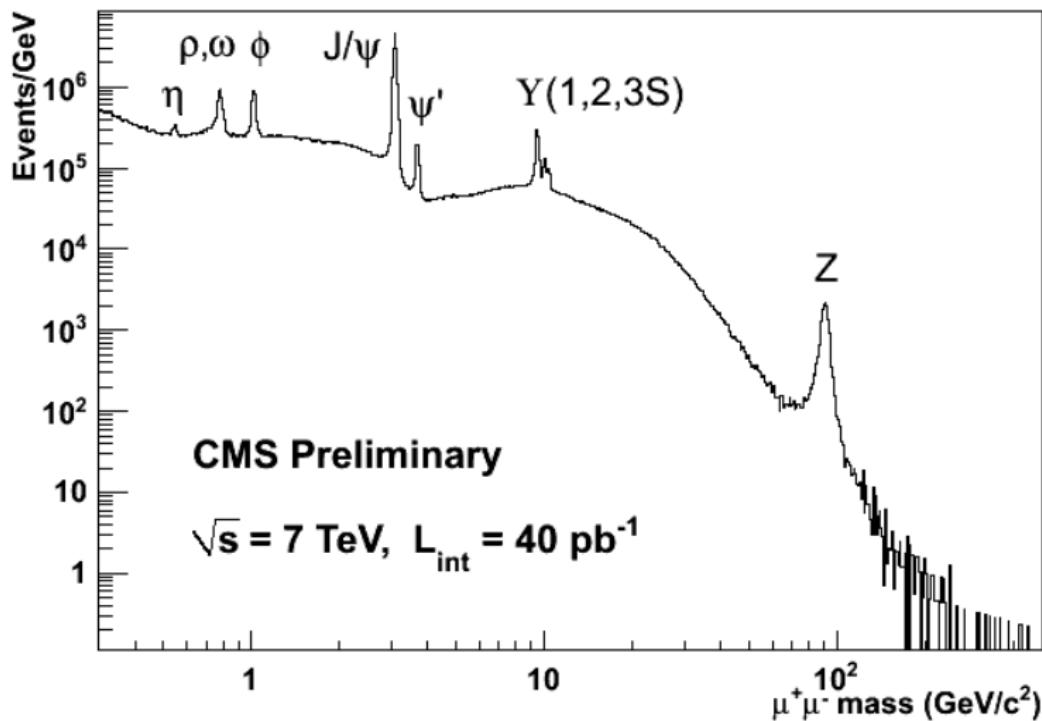
- single muon cuts are applied in bins of pseudorapidity (closer to the detector geometry)
- Upsilon p_T differential cross sections are measured in bins of rapidity

Cross-Section

$$\frac{d^2\sigma(pp \rightarrow \Upsilon(nS)X)}{dp_T dy} \cdot \mathcal{BR}(\Upsilon(nS) \rightarrow \mu^+ \mu^-) = \frac{N_{\Upsilon(nS)}(\mathcal{A}, \epsilon)}{\int L \cdot \Delta p_T \cdot \Delta y}$$

- $N_{\Upsilon(nS)}(\mathcal{A}, \epsilon)$ - corrected signal yield for acceptance \mathcal{A} and efficiency ϵ
- $\int L$ - integrated luminosity
- Δp_T - Υ transverse momentum bin width
- Δy - Υ rapidity bin width
- $\mathcal{BR}(\Upsilon(nS) \rightarrow \mu^+ \mu^-)$ - branching ratio

Welcome to diμdorado !



- how are $\Upsilon(nS) \rightarrow \mu^+\mu^-$ selected?

Event Selection

- **High Level Trigger:**

- coincidence of two muon signals
- later restricted also to
 $M_{\mu^+\mu^-} \in [1.5; 14.5] \text{ GeV}/c^2$

- **Muon Acceptance Cuts:**

$$\begin{array}{ll} p_T \mu > 3.5 \text{ GeV}/c & |\eta_\mu| < 1.6 \\ p_T \mu > 2.5 \text{ GeV}/c & 1.6 < |\eta_\mu| < 2.4 \end{array}$$

- **Vertex Quality:**

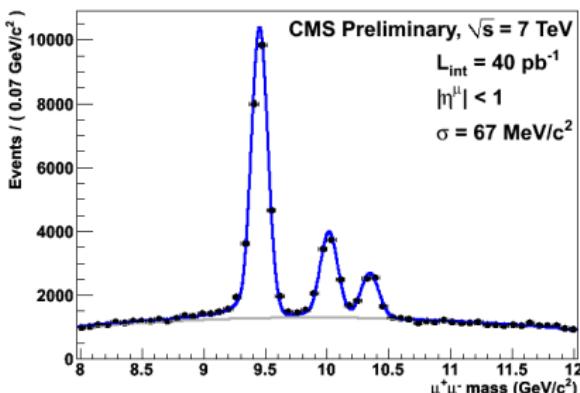
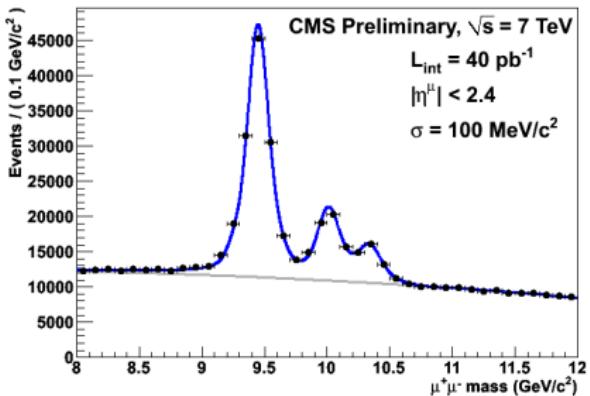
- $P(\chi^2) > 0.1\%$
- best di-muon candidate
(if more than one di-muon pair)

- **Track Quality Cuts:**

- ≥ 12 hits in Tracker detector
- ≥ 1 hit in Pixel layer
- $\chi^2/\text{ndf} < 5$
- cylinder of
 $r \leq 0.2 \text{ cm}$ and $l \leq 25 \text{ cm}$
around primary vertex and
parallel to beam line

- $|\gamma\tau| < 2.0$

- **Yield:** "Crystal Ball" ansatz with
relative $\Upsilon(nS)$ mass differences fixed



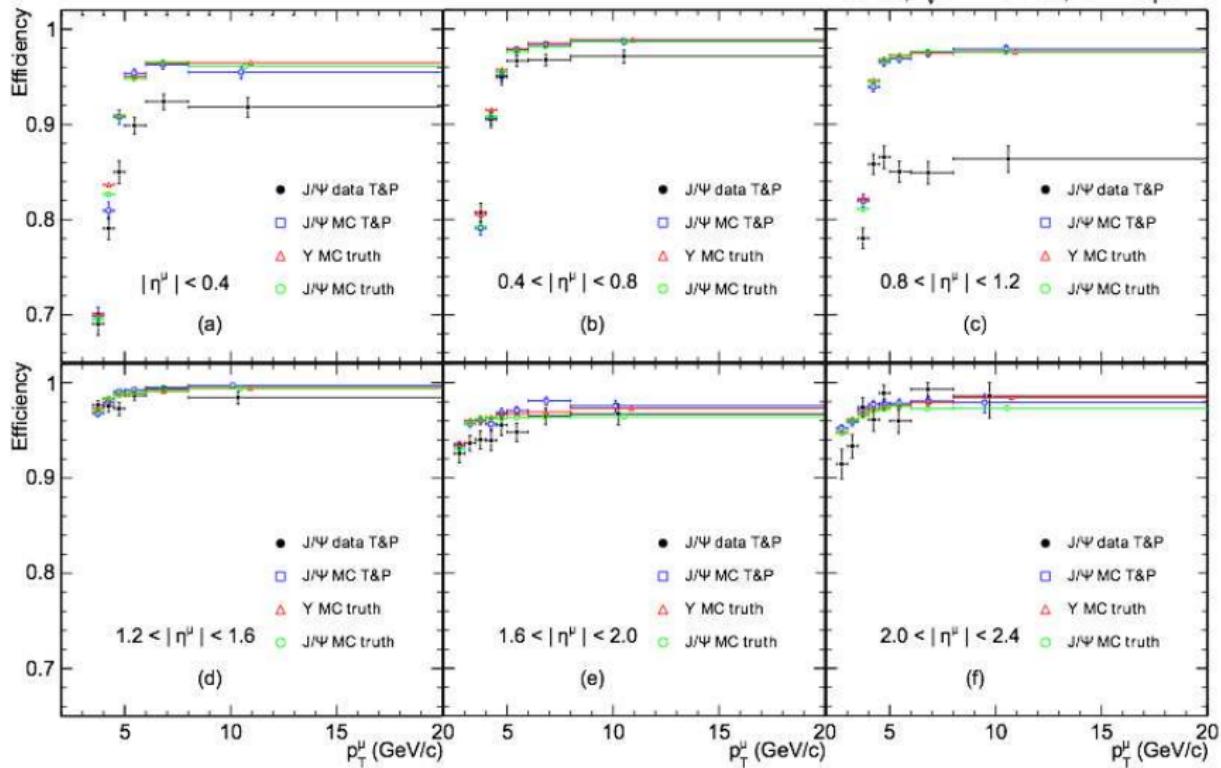
Efficiencies

$$\varepsilon = \varepsilon_{trigger} \times \varepsilon_{\mu ID} \times \varepsilon_{track}$$

- $\varepsilon_{trigger}$ - an identified muon is matched to a muon trigger object (Tag & Probe)
see slide 11
- $\varepsilon_{\mu ID}$ - reconstructed Tracker track of a muon is identified as a muon in offline selection (Tag & Probe)
see slide 12
- ε_{track} - a Tracker track of a muon in CMS acceptance is found in a pp collision event (Track Embedding)
 - $\varepsilon_{track}^{Embedding}$: $(99.64 \pm 0.05)\%$, flat as a function of p_T and η
 - efficiency of track quality criteria (Tag & Probe): $(98.66 \pm 0.05)\%$

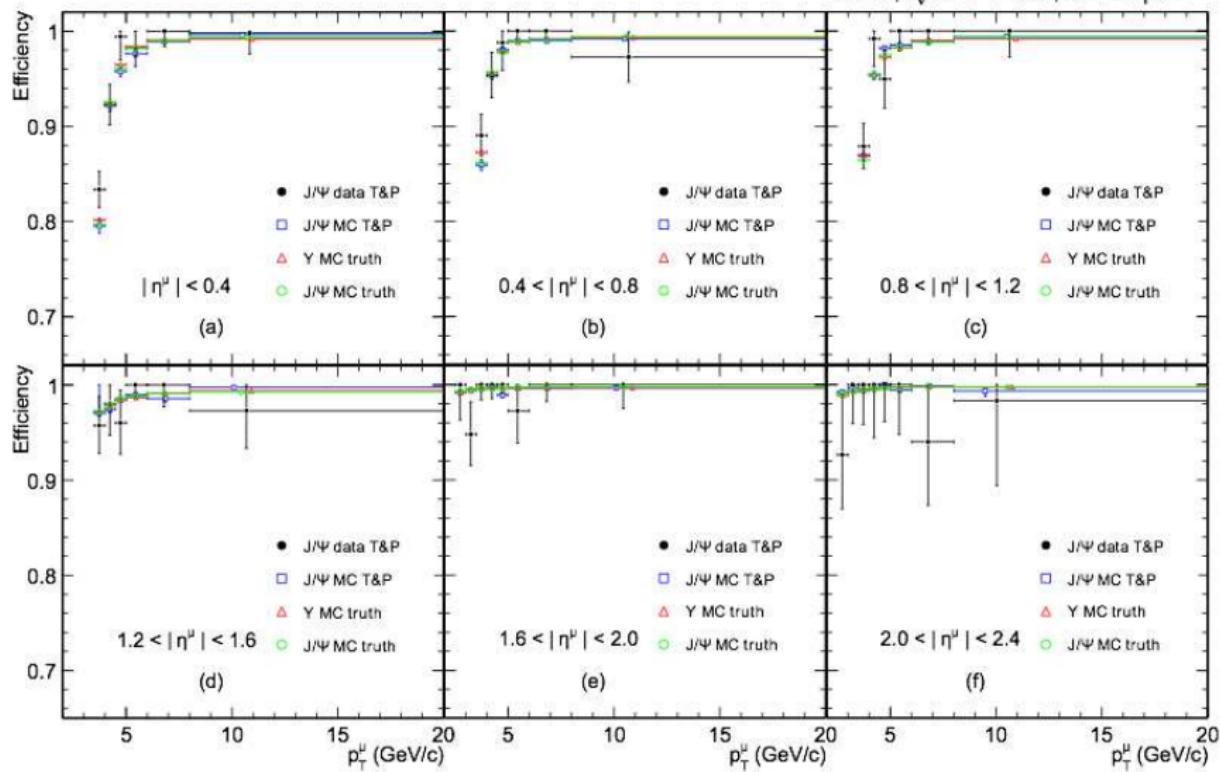
Efficiencies: $\varepsilon_{trigger}$

CMS, $\sqrt{s} = 7 \text{ TeV}, L = 3 \text{ pb}^{-1}$



Efficiencies: $\varepsilon_{\mu} ID$

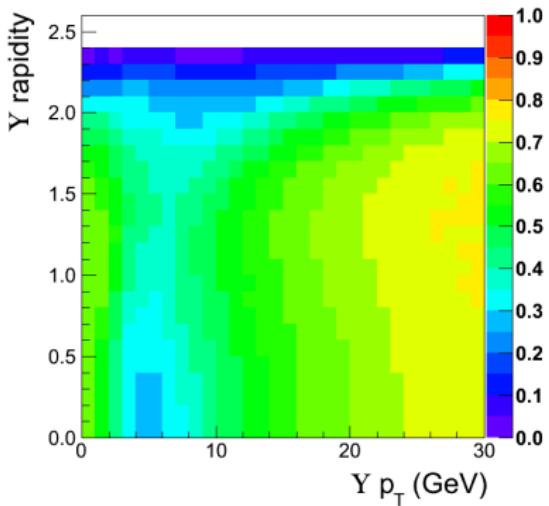
CMS, $\sqrt{s} = 7 \text{ TeV}$, $L = 3 \text{ pb}^{-1}$



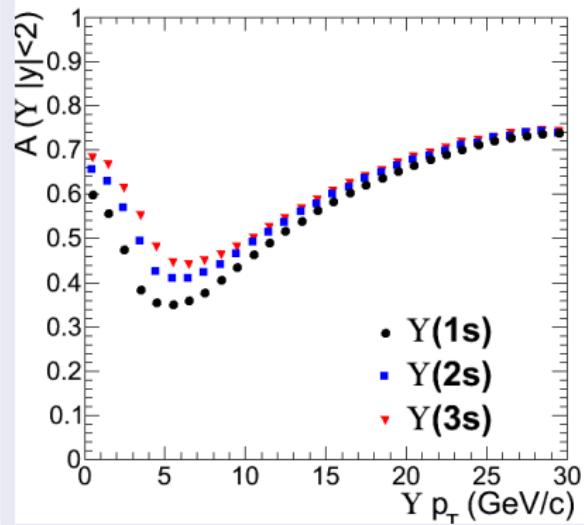
Acceptance

- evaluated using Monte Carlo simulations
- probability that both muons from the upsilon decay leave a detectable track limited by the geometrical and kinematical acceptance

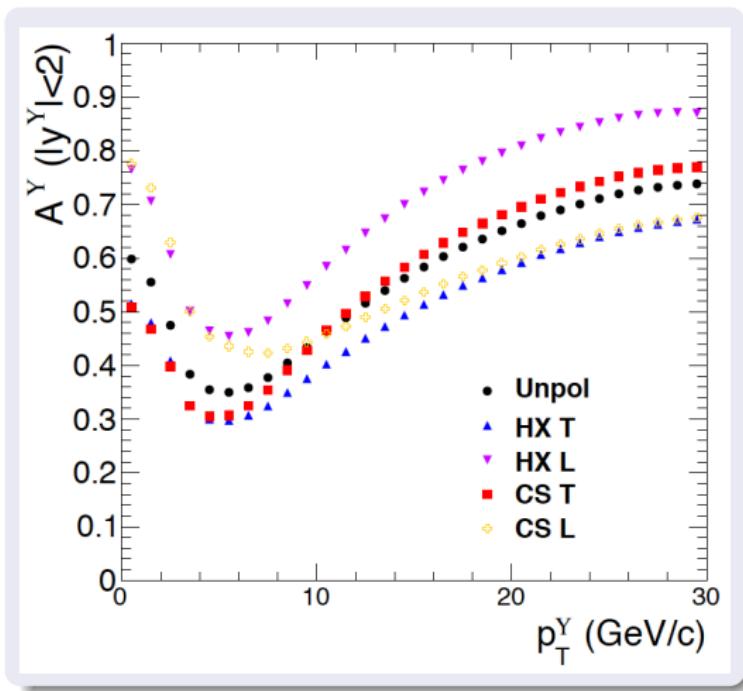
$\Upsilon(1S)$ Unpolarized production



Unpolarized production



Acceptance



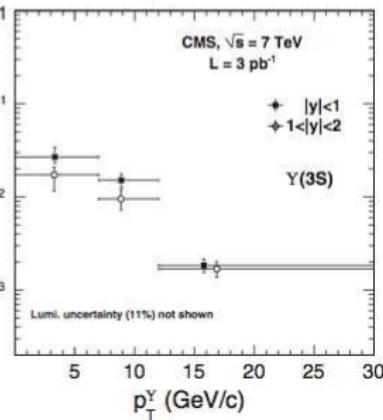
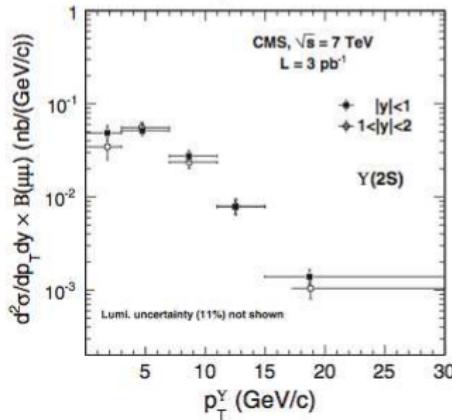
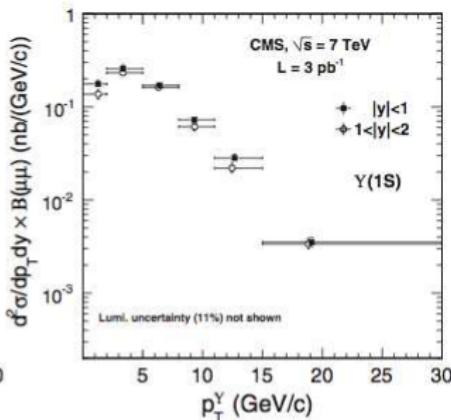
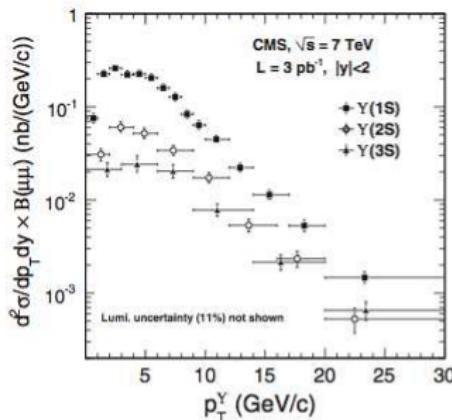
- polarization influences muon angular distributions
- evaluated also for transverse (T) and longitudinal (L) polarization scenarios in the helicity (HX) and Collins-Soper (CS) frames

Systematics

$ y $	\mathcal{A}	$\varepsilon_{trigger, \mu ID}$	S_p	A_{pT}	A_{Vtx}	A_{FSR}	T&P	$\varepsilon_{J/\psi, \Upsilon}$	BG	add.
0.0 - 2.0	0.5	7.5(4.6)	0.3(0.3)	0.6	0.7	0.7	0.0	0.9	0.5	3.0
0.0 - 0.4	0.6	6.8(4.9)	0.4(0.4)	0.7	0.3	0.7	0.6	1.5	0.1	3.0
0.4 - 0.8	0.6	6.8(4.7)	0.4(0.4)	0.6	0.3	0.7	0.3	1.1	5.4	3.0
0.8 - 1.2	0.5	7.5(4.9)	0.3(0.3)	0.6	1.0	0.7	0.1	0.7	2.9	3.0
1.2 - 1.6	0.5	7.7(4.0)	0.2(0.2)	0.6	1.2	0.6	0.2	0.5	4.0	3.0
1.6 - 2.0	0.6	9.3(4.0)	0.0(0.1)	0.6	0.9	0.6	0.9	0.6	5.0	3.0

- \mathcal{L} - luminosity estimation 11% (4% for 2011 data)
- \mathcal{A} - estimation of the acceptance
- $\varepsilon_{trigger, \mu ID}$ - trigger and muon efficiencies
- S_p - imperfect knowledge of the momentum scale
- A_{pT} - production p_T spectrum
- A_{Vtx} - efficiencies of the vertex-quality criterion
- A_{FSR} - modeling of FSR
- $\varepsilon_{J/\psi, \Upsilon}$ - bias from using J/Ψ to determine single-muon efficiencies instead of Υ (used for the first 3 pb^{-1})
- BG - background PDF
- add. - signal PDF, fit, tracking efficiency and effects arising from the efficiency binning

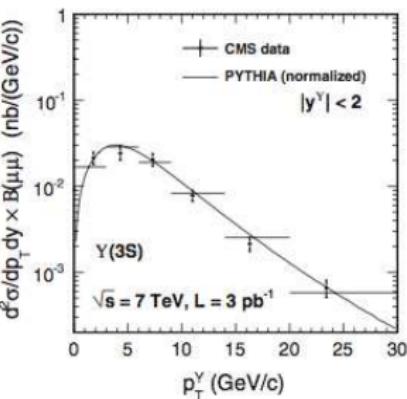
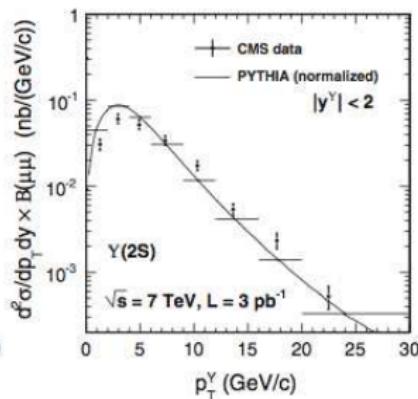
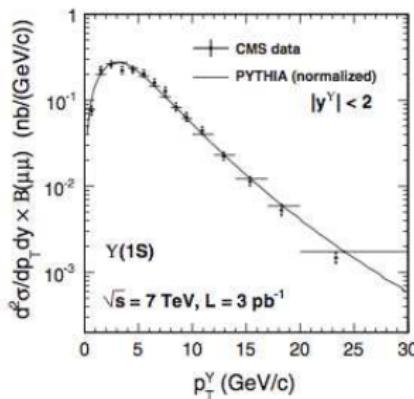
$\Upsilon(nS)$ Cross-Sections



- results for $\int \mathcal{L} = 3 \text{ pb}^{-1}$
- update of published results for $\int \mathcal{L} = 39 \text{ pb}^{-1}$ to be approved soon
- comparison with new calculations (e.g. NRQCD) will also be shown

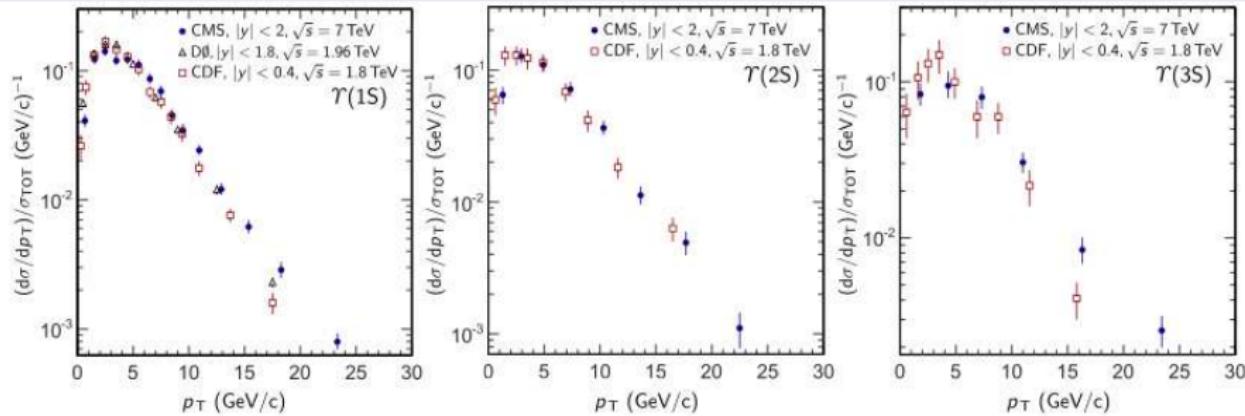
$\Upsilon(nS)$ Cross-Sections

Comparison with Pythia



$\Upsilon(nS)$ Cross-Sections

Comparison with Tevatron Measurements



$\Upsilon(nS)$ Cross-Sections

Integrated production cross sections for $|y| < 2$ range

measurements assume unpolarized $\Upsilon(nS)$ production:

- $\sigma(pp \rightarrow \Upsilon(1S)X) \cdot \mathcal{BR}(\Upsilon(1S) \rightarrow \mu^+ \mu^-) = 7.37 \pm 0.13 \text{ (stat.)}^{+0.61}_{-0.42} \text{ (syst.)} \pm 0.81 \text{ (lumi.) nb}$
- $\sigma(pp \rightarrow \Upsilon(2S)X) \cdot \mathcal{BR}(\Upsilon(2S) \rightarrow \mu^+ \mu^-) = 1.90 \pm 0.08 \text{ (stat.)}^{+0.20}_{-0.14} \text{ (syst.)} \pm 0.24 \text{ (lumi.) nb}$
- $\sigma(pp \rightarrow \Upsilon(3S)X) \cdot \mathcal{BR}(\Upsilon(3S) \rightarrow \mu^+ \mu^-) = 1.02 \pm 0.07 \text{ (stat.)}^{+0.11}_{-0.08} \text{ (syst.)} \pm 0.11 \text{ (lumi.) nb}$

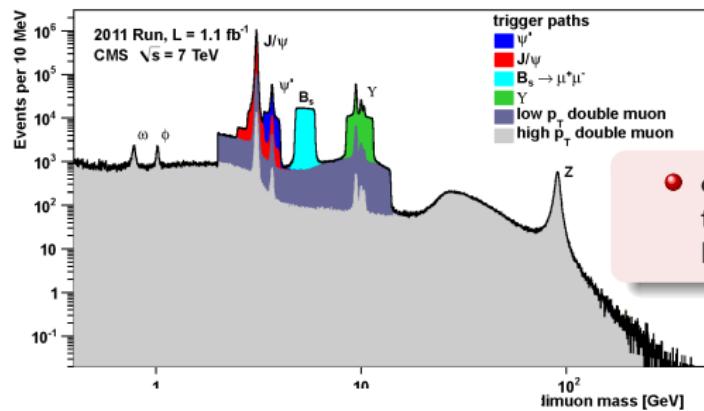
fully-transverse or fully-longitudinal polarization:

$\pm 20\%$ change in cross-section

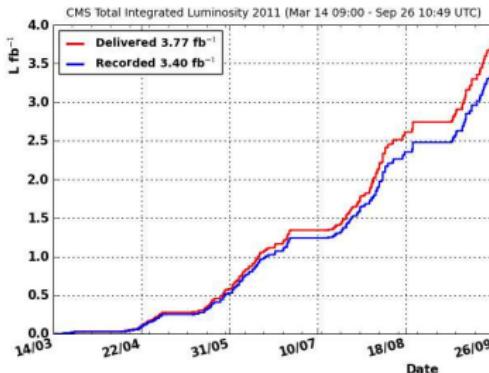
results published in Phys. Rev. D 83, 112004 (2011)

results from Pb-Pb collisions in CMS will be presented by Camelia Mironov on 6th of October

Outlook 2011: where is CMS standing now?

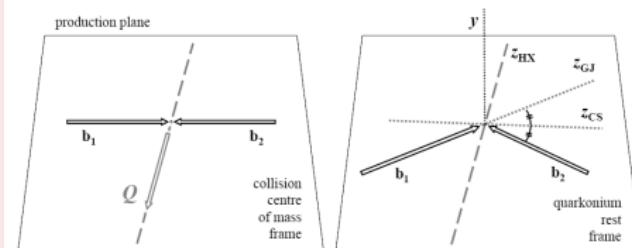


- clever dedicated triggers with cuts that evolve with the increase in luminosity



- already at 3.4 fb^{-1} and still more luminosity to come for this year

- differential cross-sections measured
- it's time to measure the polarization



Back-Up Slides

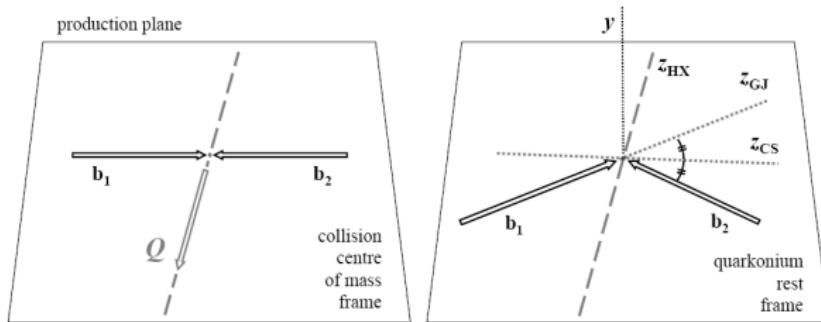
References

<http://prd.aps.org/abstract/PRD/v83/i11/e112004>
<http://cms-physics.web.cern.ch/cms-physics/public/TRK-10-002-pas.pdf>
<http://prl.aps.org/abstract/PRL/v88/i16/e161802> **CDF**
<http://prl.aps.org/abstract/PRL/v94/i23/e232001> **D0**
<http://cdsweb.cern.ch/record/1279145>

Quarkonium Polarization

- alignment of the decaying particle spin with its direction of motion
⇒ two muons get emitted in different angular configurations:

$$W(\cos\theta, \varphi) \propto \frac{1}{3+\lambda_\theta} (1 + \lambda_\theta \cos^2\theta + \lambda_\varphi \sin^2\theta \cos 2\varphi + \lambda_{\theta\varphi} \sin 2\theta \cos \varphi)$$

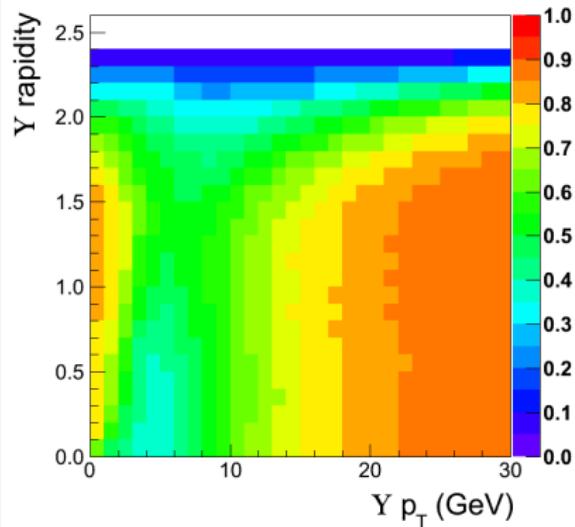


different reference frames:

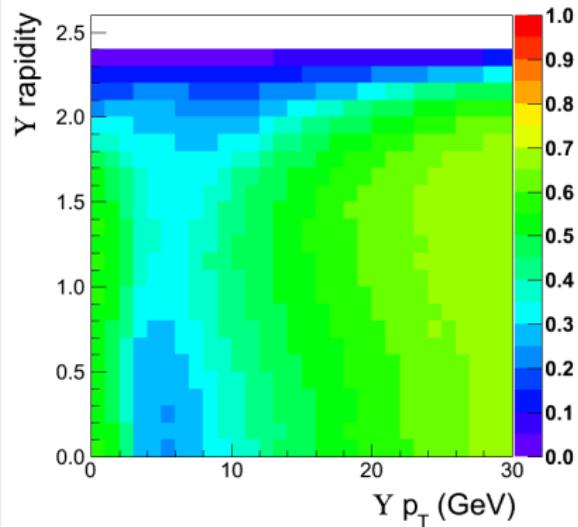
- Helicity frame (HX): own flight/momentum direction of the quarkonium
- Collins-Soper frame (CS): bisecting angle between one beam and the opposite of the other beam
- Gottfried-Jackson frame (GJ): direction of the momentum of one of the two colliding beams

Acceptance: Helicity Frame

$\Upsilon(1S)$: fully longitudinal polarization

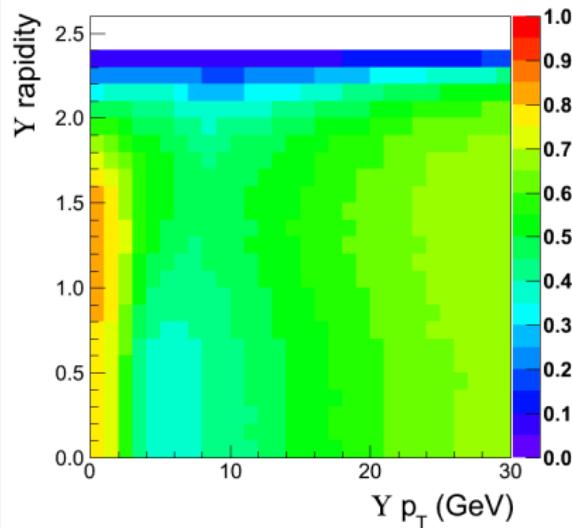


$\Upsilon(1S)$: fully transverse polarization

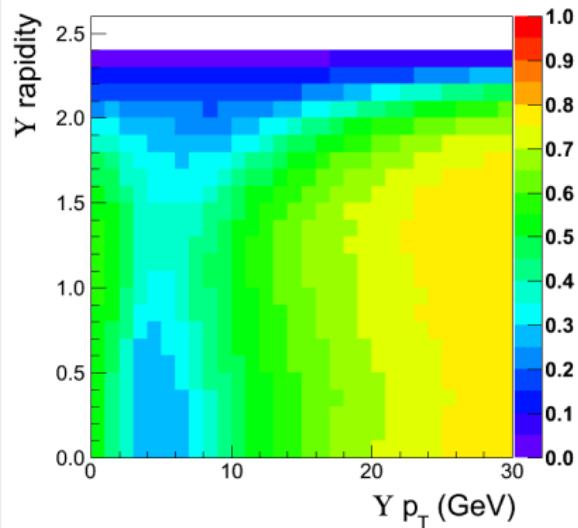


Acceptance: Collins-Soper Frame

$\Upsilon(1S)$: fully longitudinal polarization



$\Upsilon(1S)$: fully transverse polarization

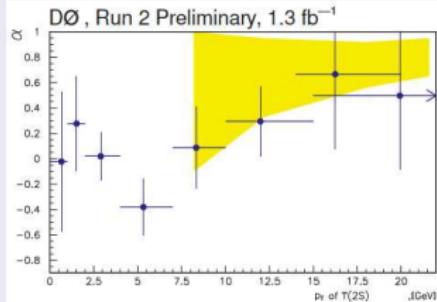
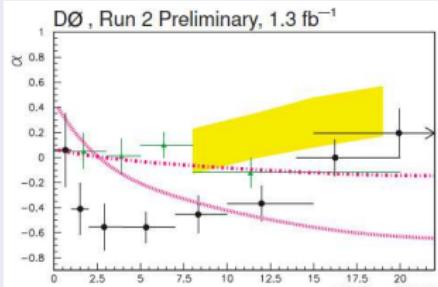


Crystal Ball function (PDF)

$$f(x; \alpha, n, \bar{x}, \sigma) = N \cdot \begin{cases} \exp\left(-\frac{(x-\bar{x})^2}{2\sigma^2}\right), & \text{for } \frac{x-\bar{x}}{\sigma} > -\alpha \\ A \cdot (B - \frac{x-\bar{x}}{\sigma})^{-n}, & \text{for } \frac{x-\bar{x}}{\sigma} \leq -\alpha \end{cases}$$

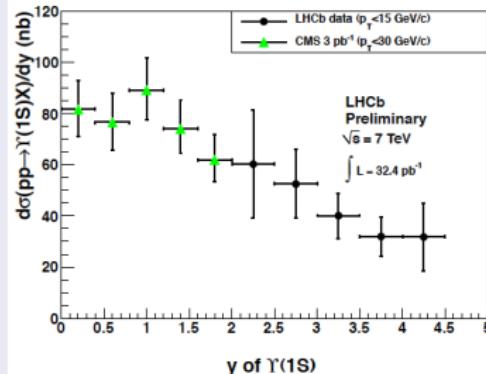
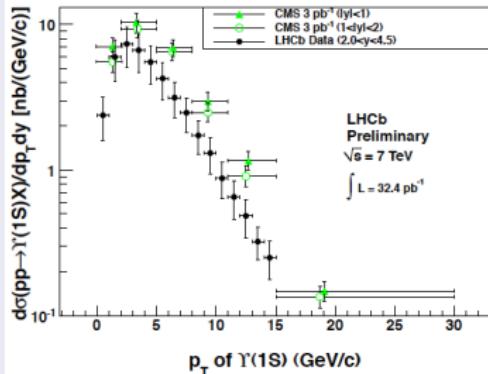
- $A = \left(\frac{n}{|\alpha|}\right)^n \cdot \exp\left(-\frac{|\alpha|^2}{2}\right)$,
- $B = \frac{n}{|\alpha|} - |\alpha|$,
- N is a normalization factor
- α, n parameters fitted from MC simulation
- N, \bar{x} and σ are parameters which are fitted with the data

D0 & CDF vs. Theory



- CDF: green triangles
- D0: black circles
- NRQCD predictions: yellow band
- kt-factorization limit cases: magenta curves
- <http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B50/>

LHCb & CMS



- CMS: green triangles
- LHCb: black circles
- complementarity in rapidity
- <http://cdsweb.cern.ch/record/1333963> LHCb-CONF-2011-016