Quarkonium in the ALICE Muon Spectrometer

Roberta Arnaldi

INFN Torino

- The ALICE Muon Spectrometer
- Feasibility studies in pp and PbPb
- First quarkonium measurements in pp@7TeV

Physics motivations

pp collisions

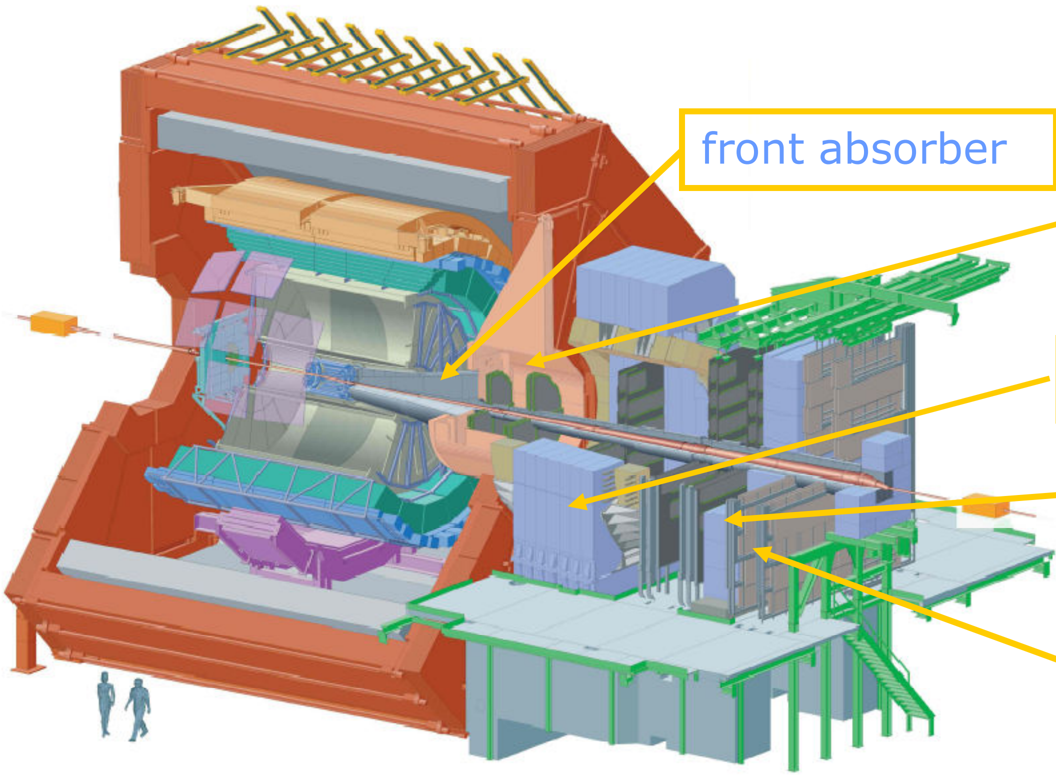
- provide a reference for nuclear collisions results
- provide information on production models (CSM, NRQCD, CEM…). Relevant observables are:
  - quarkonia cross sections
  - p_T differential distributions ← down to p_T~0 GeV/c in the ALICE muon spectrometer
  - y differential distributions
  - polarization
- rapidity acceptance of the ALICE muon spectrometer allows to access gluon PDFs at very small x ($<10^{-5}$)

AA collisions

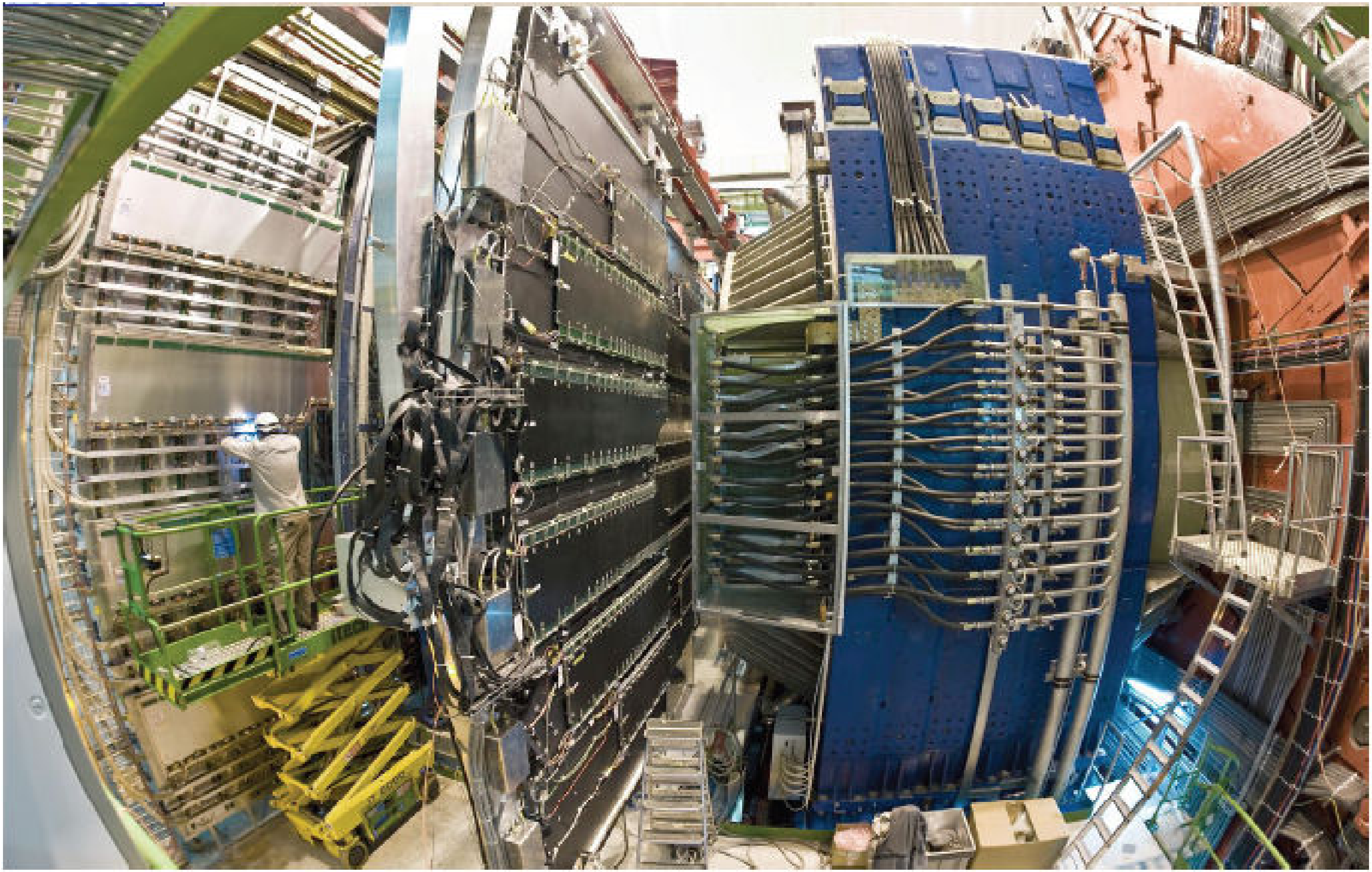
- quarkonium is a well known signature for QGP formation. New scenarios open thanks to the high LHC energy:
  - factor 10 (100) increase in charmonia (bottomonia) σ with respect to RHIC → bottomonium physics will be accessible
  - high charm quark multiplicity (N_{CC}~100) → J/ψ regeneration (not yet well defined at RHIC) might become dominant

The experimental apparatus

- The forward muon spectrometer measures quarkonium in the $\mu^+\mu^-$ decay channel, in the rapidity region $2.5 < \eta < 4$
- It is designed in order to have:
  - large geometrical acceptance → to increase dimuon statistics
  - acceptance down to $p_T \sim 0$ → where direct J/ψ production dominates
  - good mass resolution → to separate the Υ family
  - tracking/trigger high granularity read-out → to cope with the high multiplicity



The Muon Spectrometer



Simulation inputs

Simulations for quarkonium production are based on

- CEM calculations with MRST HO PDF

  m_c=1.2 GeV/c^2, μ=2m_c ← for J/ψ
  m_b=4.5 GeV/c^2, μ=2m_b ← for ϒ

  Inclusive cross section, assuming higher resonances feed-down

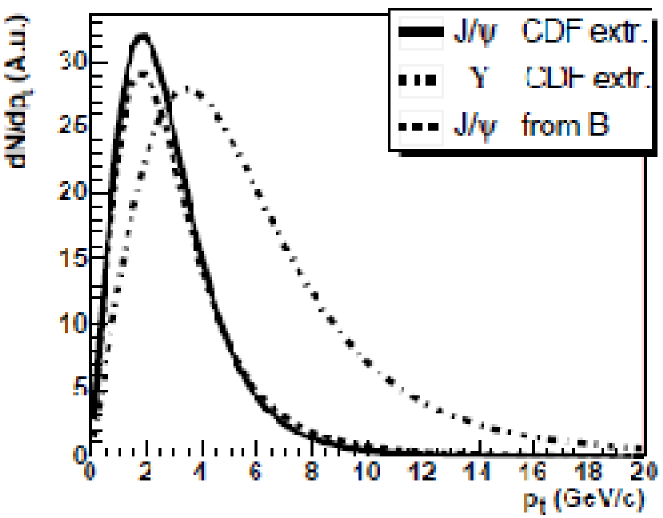
CEM predictions, with these parameters, are in agreement with Tevatron data for the ϒ, but they underestimate by a factor ~2 the $\sigma_{J/\psi}$ → J/ψ yields from these simulations may represent a pessimistic estimate

5.5 TeV → $\sigma_{pp}^{J/\psi}$ = 31 μb → σ_{pp}^{Υ} = 0.50 μb

14 TeV → $\sigma_{pp}^{J/\psi}$ = 53.4 μb → σ_{pp}^{Υ} = 1.12 μb

- $\sigma_{PbPb}^{J/\psi}$ obtained assuming
  - binary scaling (Glauber model)
  - nuclear shadowing (using EKS98 parametrization)

- y, p_T differential distributions obtained from CEM predictions and from the extrapolation of the CDF data at √s=2TeV, respectively



(ALICE-INT-2006-029, ALICE-INT-2008-016)

J/ψ from B decay are also included

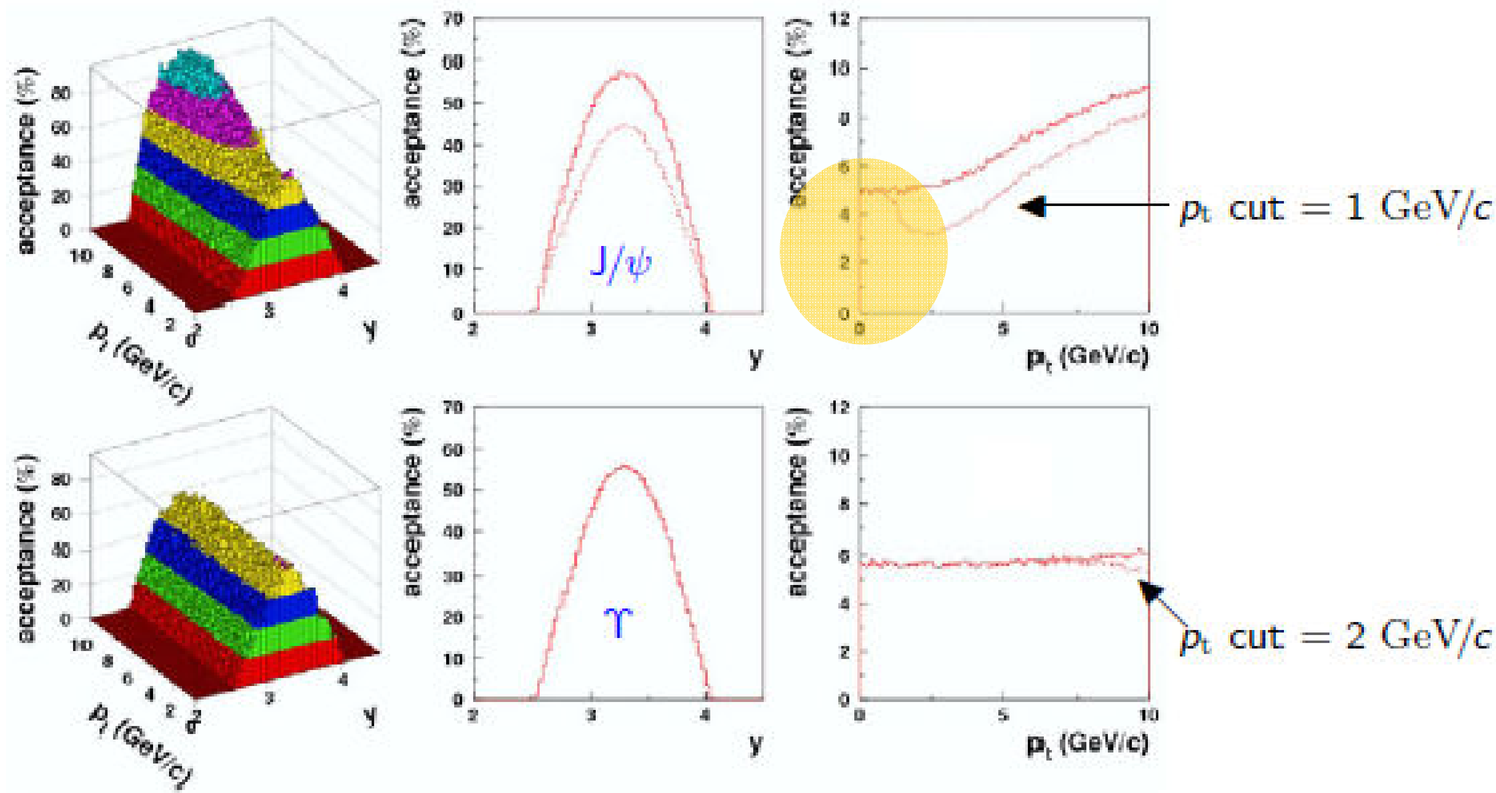
Acceptances

- Computed generating and reconstructing resonances according to realistic y, p_T distributions and assuming no quarkonium polarization

Acc. integrated over y, p_T (values sensitive to the input distributions):

$A_{J/\psi} \sim 4.46\%$

$A_{\Upsilon} \sim 4.41\%$



- A p_T cut on single muons can be implemented at the trigger level, to decrease the soft combinatorial background to the muon trigger
→ ~ 20% effect on the integrated J/ψ acceptance for 1GeV/c cut

- The combined efficiency in the MS acceptance, taking into account tracking/trigger efficiency is ~ 70% for the J/ψ and ~85% for the ϒ

Dimuon background

Background consists of

- Correlated dimuons
  → both muons originate from the same heavy quark pair

$$\mu + X \leftarrow D \quad D \rightarrow X + \mu$$

$$\mu + D \leftarrow B \quad B \rightarrow D + \mu$$

$$\mu + X \hookleftarrow \qquad \hookrightarrow X + \mu$$

- Uncorrelated dimuons
  → combination of decay muons from uncorrelated sources

From CEM σ and PYTHIA simulation

(tuned to reproduce NLO pQCD)

- Muons from π and K decay (uncorrelated bck)
  → simulation based on HIJING assuming a pessimistic estimate of $dN_{ch}/d\eta|_{\eta=0} \sim 8000$
  → muons produced after a first hadronic interaction in the absorber (secondary π, K decays) <10% (after p_T and vertex cut)

Pb-Pb @ 5.5 TeV: expected yields

- Expected yields for the yearly ALICE Pb-Pb data taking period

  Time = 10^6 s
  L = 5 10^{26} $cm^{-2}s^{-1}$

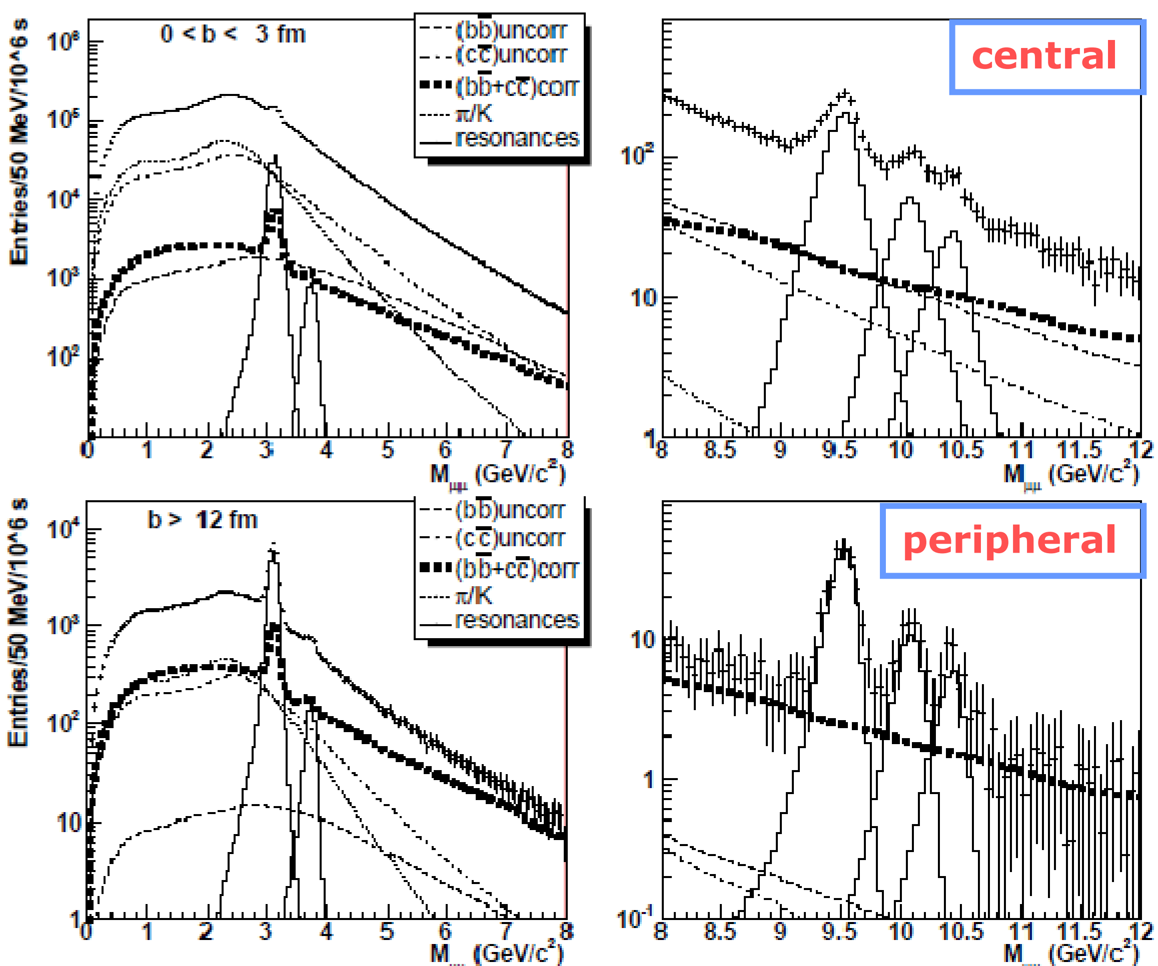
- Number of expected events (integrated over centrality)

  assuming no medium effects apart from shadowing and no enhancement in the quarkonium production due to statistical hadronization or cc recombination

	J/ψ	$\psi(2S)$	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
N. ev.	7 10^5	2 10^4	7 10^3	2 10^3	1 10^3

Pb-Pb @ 5.5 TeV: inv. mass spectra

- J/ψ region → strong background centrality dependence (uncorrelated bck dominates)
- ϒ region → weaker background centrality dependence (correlated bck dominates)



- Mass resolution:

  J/ψ ~ 70MeV

  ϒ ~ 100MeV

  → the ϒ states can be clearly separated

Uncorrelated background can be subtracted through event mixing techniques

Pb-Pb@5.5TeV: centrality dependence

		S [x10³]	S/B	S/√(S+B)
J/ψ	c1	134	0.20	150
	c2	238	0.27	220
	c3	202	0.49	250
	c4	97	1.09	220
	c5	22	3.14	130

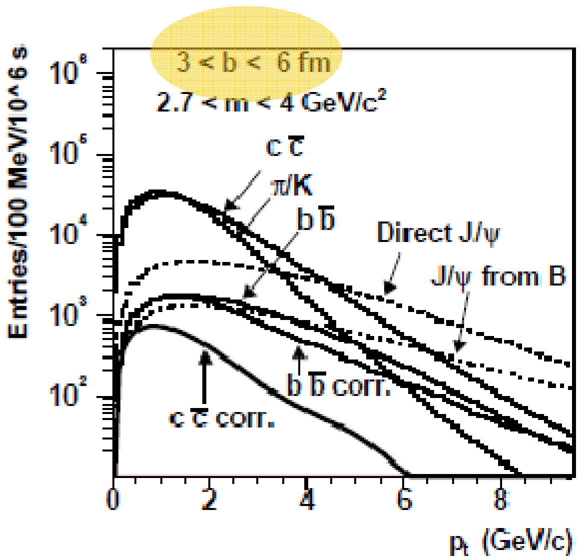
		S [x10³]	S/B	S/√(S+B)
ψ′	c1	3.8	0.01	6.7
	c2	6.7	0.02	11
	c3	5.6	0.03	13
	c4	2.6	0.06	12
	c5	0.62	0.18	9.7

		S [x10³]	S/B	S/√(S+B)
ϒ	c1	1.3	1.7	29
	c2	2.4	2.3	41
	c3	2.0	3.6	39
	c4	0.95	6.3	29
	c5	0.21	9.5	15

- In one month of data taking the J/ψ and ϒ centrality dependence can be studied
- ϒ: reduced bck compensates the smaller number of signal events, wrt the J/ψ → reasonable significance values
- Worst situation for the ψ(2S): background similar to the J/ψ, but rate of signal events similar to the ϒ
- ϒ(2S), ϒ(3S): small statistics, i.e. S~ 2000 (1000) integrated over centrality

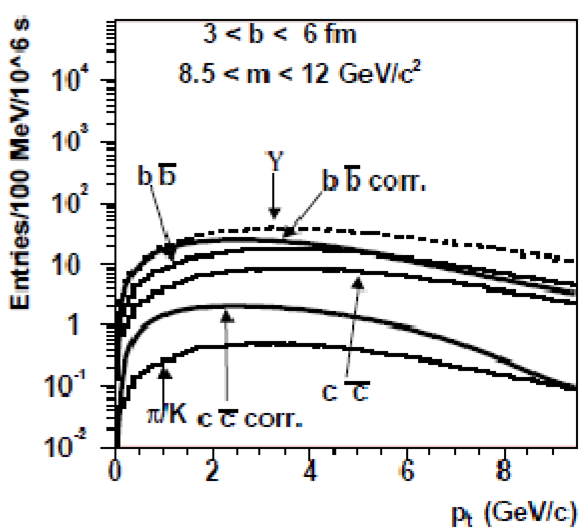
Pb-Pb @ 5.5 TeV: p_T dependence

- The p_T dependence of the quarkonium yields can be studied vs centrality



	p_T (GeV/c)	S [x10³]	S/B	S/√(S+B)
J/ψ	0-2	79	0.13	94
	2-4	79	0.40	150
	4-6	46	1.31	161
	6-8	20	3.09	123
	8-20	14	6.85	108

- worse S/B at low p_T, due to the harder J/ψ tail with respect to other contributions
- more than 1000 J/ψ with p_T>8 GeV/c even for b>12 fm



	p_T (GeV/c)	S [x10³]	S/B	S/√(S+B)
ϒ	0-2	0.28	2.2	15
	2-4	0.62	2.1	21
	4-6	0.56	2.2	19
	6-8	0.36	2.4	16
	8-20	0.54	2.9	20

- constant S/B.
- several centrality bins can be summed to improve statistics (also for ϒ(2S), ϒ(3S), ψ′)

Pb-Pb@5.5 TeV: suppression studies

Mechanisms affecting the quarkonium yields have been introduced:

- absorption in cold nuclear matter
  → assuming values of absorption cross sections between 0 – 10 mb

- suppression in QGP
  → assuming a sequential melting and different T_c and T_{diss} values

	J/ψ	ψ(2S)	ϒ(1S)	ϒ(2S)	ϒ(3S)
T_d/T_c	1.7	1.1	4.0	1.4	1.14
T_d/T_c	2.1	1	2.9	1.1	1

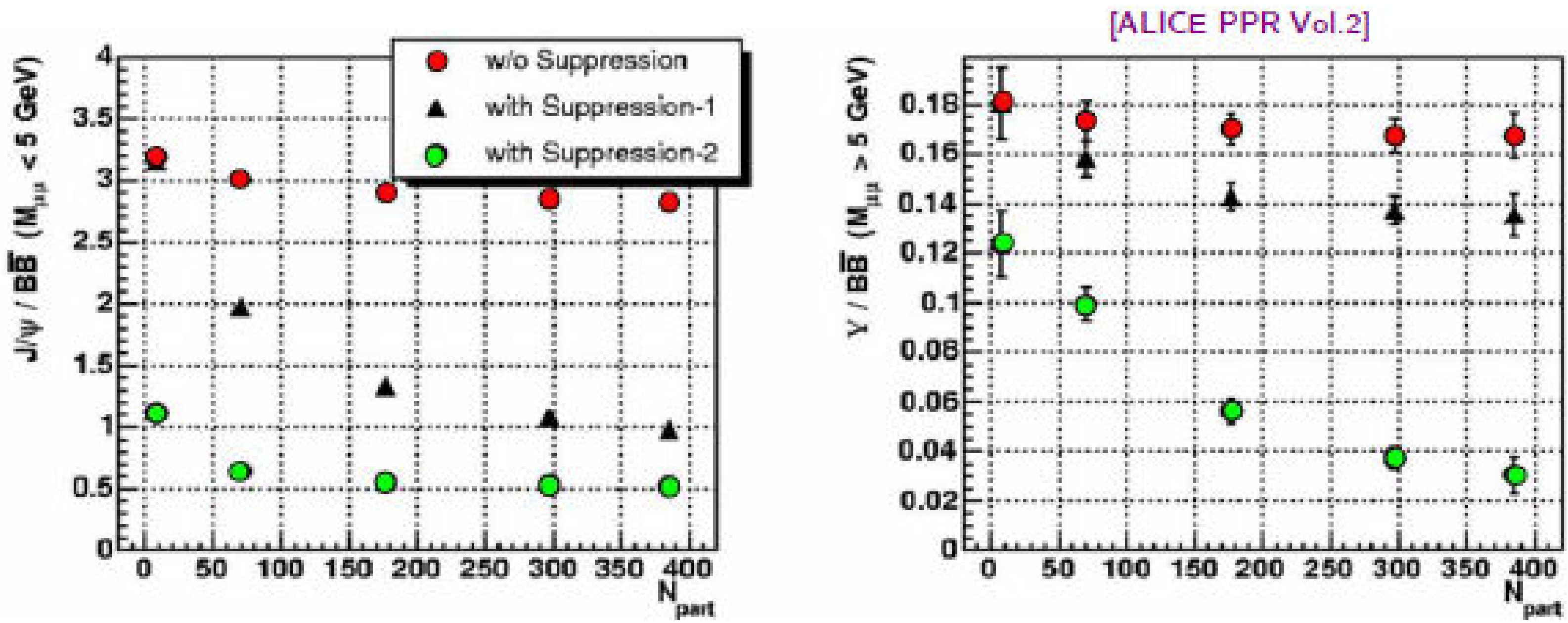
Suppression 1: T_c~270MeV
Suppression 2: T_c~190MeV

in the Suppression 1 scenario the prompt ϒ will not melt, while they do in the suppression 2 scenario

- enhancement (statistical hadronization/recombination)
  → not yet included

Pb-Pb@5.5 TeV: suppression studies

- Combining the different ingredients, several suppression scenarios are foreseen



  - Data are normalized to beauty production, assuming that B hadrons are not affected by cold/hot medium effects (apart from shadowing). No systematic on the evaluation of the QGP influence on beauty production is included

- The statistics collected in one year data taking should allow to disentangle between the proposed theoretical scenarios for the quarkonium behaviour in the hot medium

Normalizations

normalization	advantages	disadvantages
Drell-Yan	• same approach used at SPS	• different production mechanism (qq) • low DY cross section
R_{AA} (R_{CP})	• easy • same approach already used at RHIC	• $\sigma_{pp}^{J/\psi}$ not available at 5.5TeV → need extrapolation • cold/hot effects not disentangled → pA needed to study cold matter effects (as SPS,now starting at RHIC)
Higher resonances (eg: ψ'/ψ…)	• same prod. process • detector ineffic. cancel out	• difficult because of higher resonances low statistics and/or high background level
Open heavy flavor	• same production mechanism	• open heavy flavor may be affected by the hot medium (energy loss)
Electroweak bosons	• no hot medium effects	• production dominated by qq collisions • different Q^2 domain • Z^0 statistics

Quarkonium polarization

pp collisions

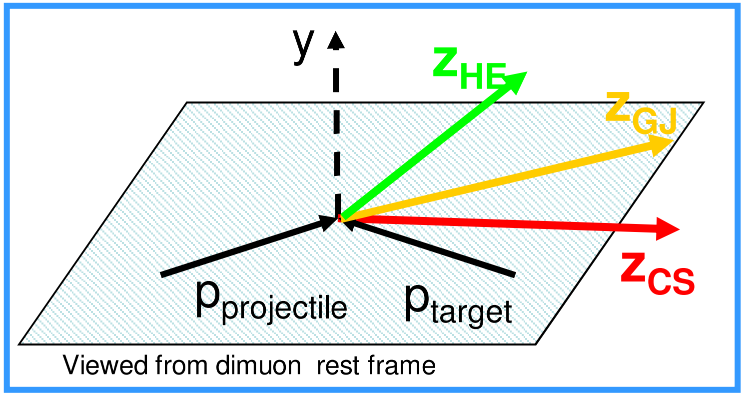
- important tool for the study of quarkonium production mechanisms
- extremely debated topic because of inconsistencies between theoretical models and experimental data

AA collisions

- influence of deconfined phase not yet studied in detail (see anyway D.Kharzeev Phys. Rev. C68 061902 (2003))

Recent studies have pointed out the importance of the choice of the polarization frame (E.Braaten et al arXiv:0812.3727, P.Faccioli et al. arXiv:0902.4462)

- the degree of polarization may depend on the chosen frame
- polarization results can be compared only if the same frame is adopted



J/ψ polarization is measured from the full angular distribution of the decay leptons (usually μ and ν terms are neglected)

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta\, d\phi} = \left(1 + \lambda\cos^2\theta + \mu\sin 2\theta\cos\phi + \frac{\nu}{2}\sin^2\theta\cos 2\phi\right)$$

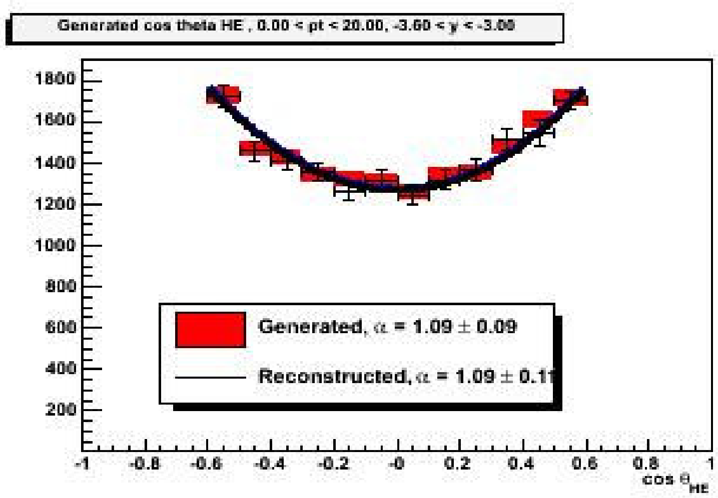
Pb-Pb@5.5 TeV: polarization

Quarkonium polarization will be studied

- in different reference frames (helicity, Collins-Soper)
- as a function of centrality or p_T

Preliminary results obtained neglecting azimuthal contribution ($\mu,\nu=0$)

$$\frac{dN}{d\cos\vartheta} \sim 1 + \alpha\cos^2\vartheta$$

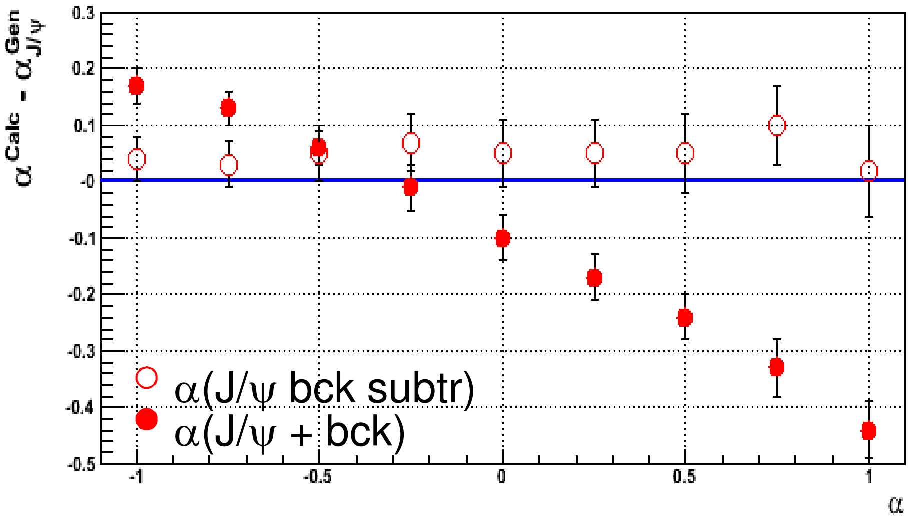


Different analysis techniques have been investigated, in order to estimate the degree of polarization

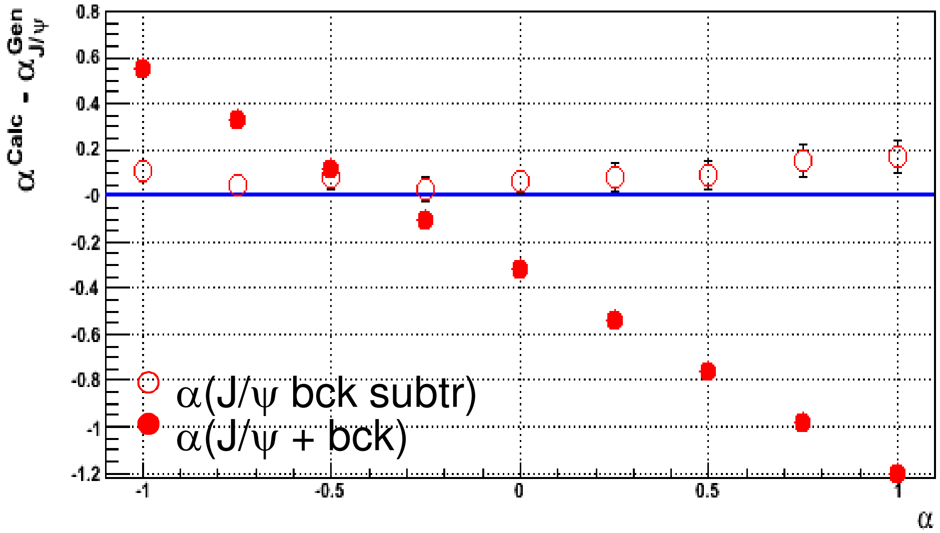
- 3D acceptance correction
- comparison with MC templates (CDF approach)

Pb-Pb@5.5 TeV: J/ψ polarization

S/B= 3.13 peripheral Pb-Pb

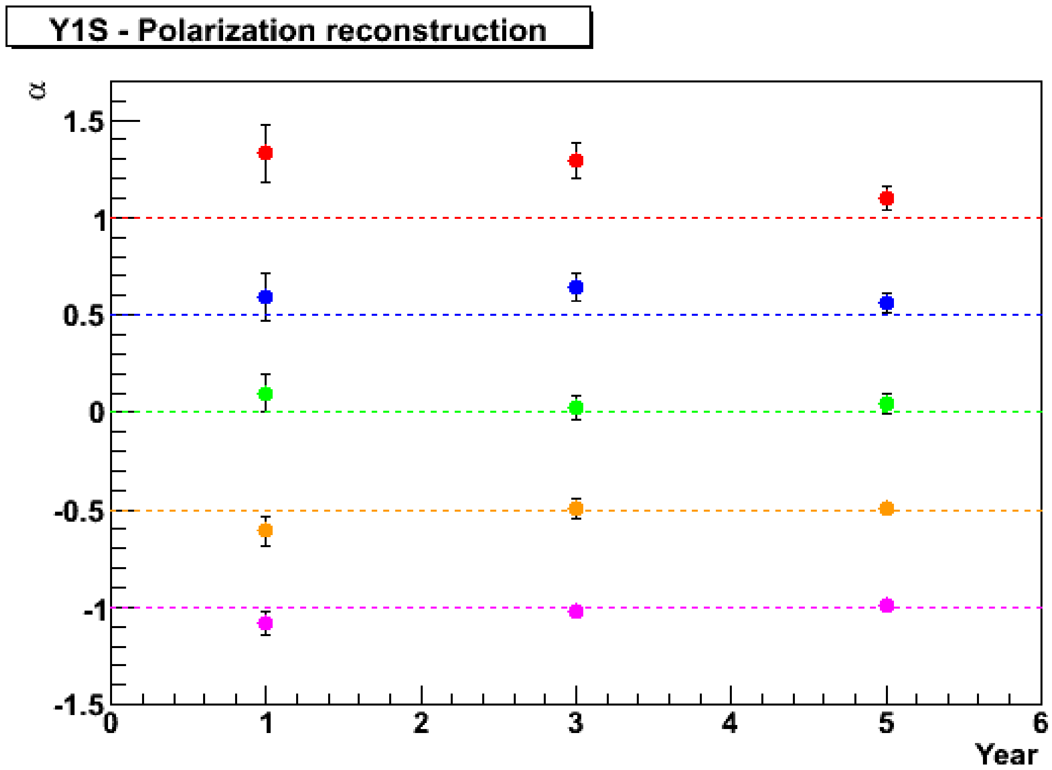


S/B= 0.2 central Pb-Pb



- background subtraction techniques required
  → the background clearly washes out the original J/ψ polarization
- large J/ψ statistics
  → enough to perform a study vs. centrality or p_T
- absolute statistical error ~±0.05 for all centralities (for peripheral, smaller statistics compensated by the smaller background)

Pb-Pb@5.5 TeV: Υ polarization



- in 1 year of data taking → we can extract the Υ(1s) polarization integrated over centrality with an error of ~0.1
- Integrating over some years of data taking → the p_T or centrality dependence of the polarization can be investigated

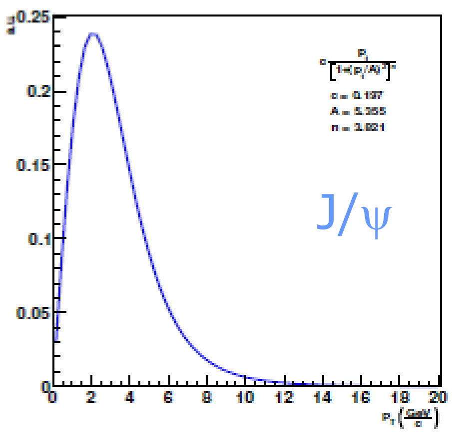
p-p collisions @ √s = 14TeV

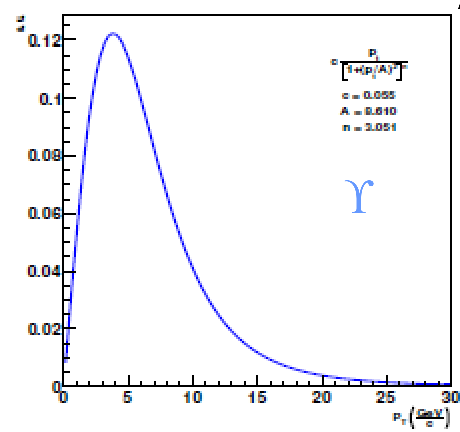
- Quarkonia yields have been computed assuming

  Time = 10^7 s (1 year data taking)
  L = 3 10^{30} $cm^{-2}s^{-1}$

- simulations performed with the same inputs as those for PbPb

ALICE-INT-2006-029

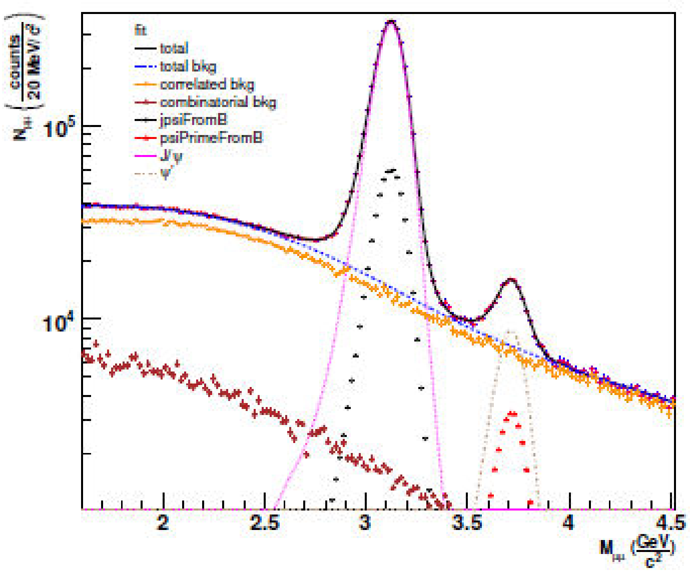


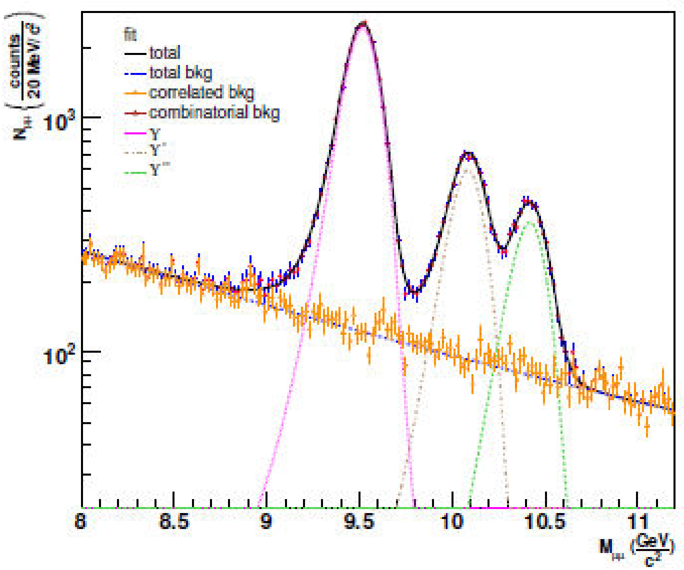


- Number of expected events

	J/ψ	ψ(2S)	ϒ(1S)	ϒ(2S)	ϒ(3S)
N. ev.	3 10^6	7 10^4	3 10^4	7 10^3	4 10^3

p-p @√s=14TeV: inv. mass spectrum





- Spectrum is dominated by correlated background (due to the low multiplicity, the uncorrelated contribution is small)

	S [x10³]	S/B	S/√(S+B)
J/ψ	2807	12	1610
ψ'	75	0.6	170
ϒ	27	10.4	157
ϒ'	6.8	3.4	73
ϒ''	4.2	2.4	55

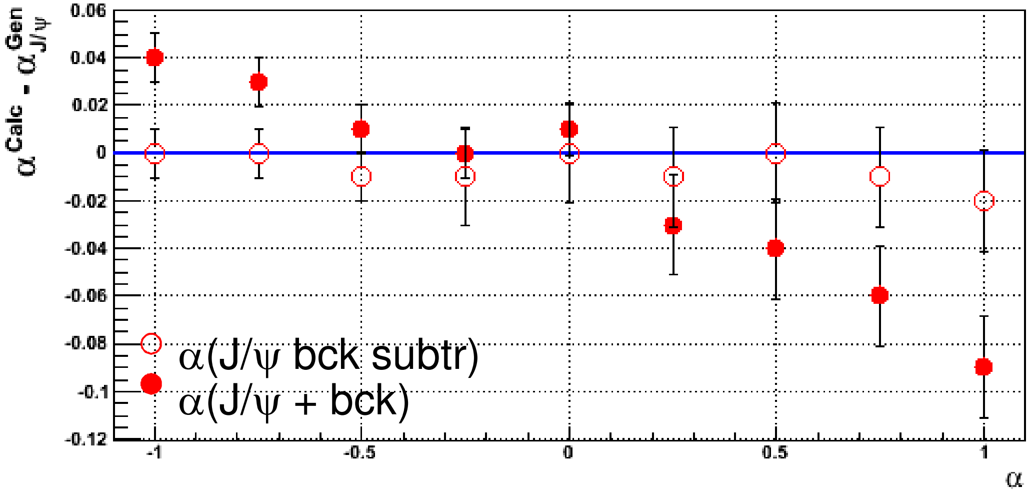
- It will be possible to study J/ψ p_T differential distribution with reasonable statistics up to 20 GeV/c

- The large ϒ statistics will allow a study of its differential distributions

p-p @$\sqrt{s}$=14TeV: J/ψ and ϒ polarization

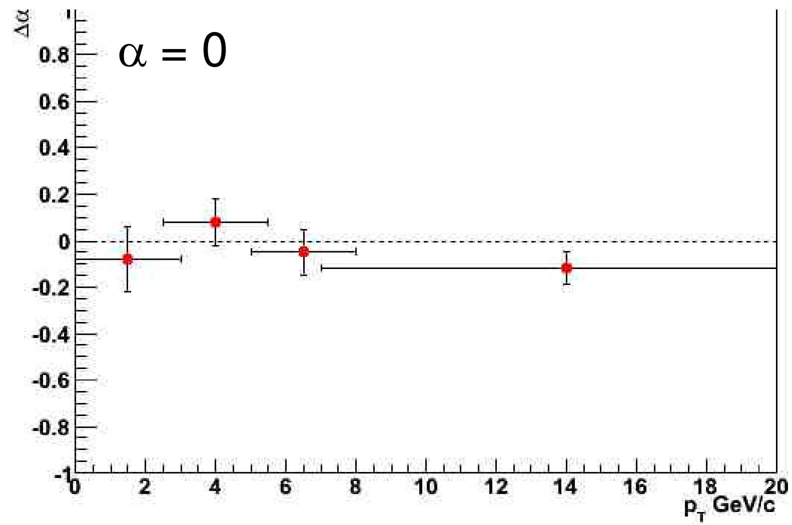
J/ψ

- bias on the evaluation of the J/ψ polarization due to the background is not very large (as expected)
- with 200K J/ψ, the error on $\alpha_{J/\psi}$ is < 0.02



ϒ

- with the available ϒ statistics we can evaluate the polarization with a statistical error between 0.05 – 0.11
- statistical errors, for the p_T dependence of the polarization, vary between 0.03 -0. 2
- ALICE expected statistics in 1 year ~ 3 times ϒ CDF statistics (Run I, 3 yr)

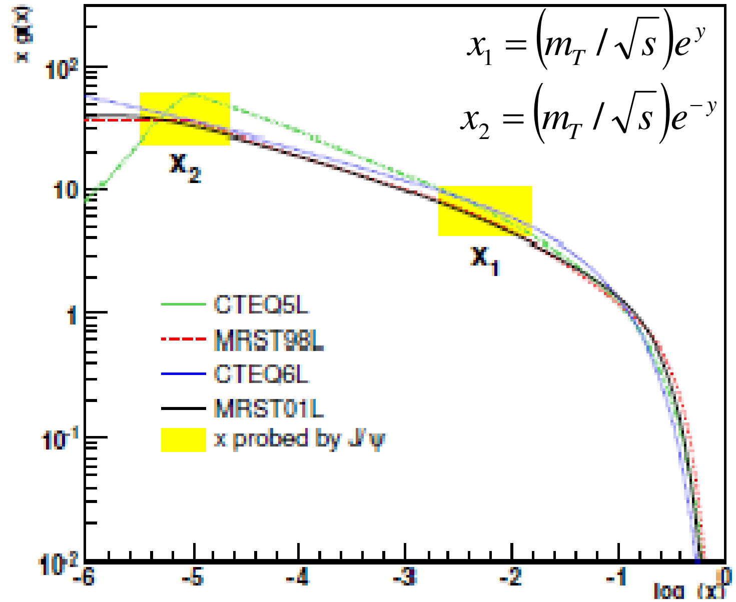


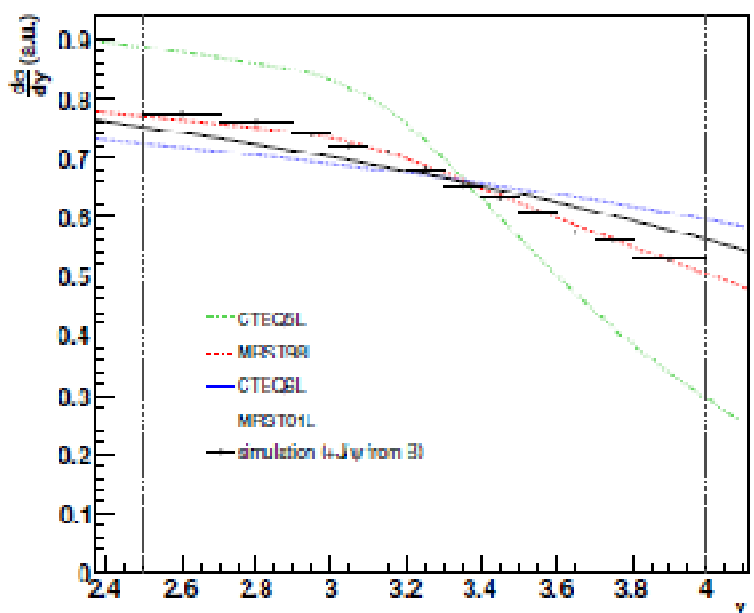
p-p @√s=14TeV: low x region

- gluon PDF distributions have large uncertainties at very low x, since they rely on extrapolations (no data available in this region)

- LO CEM calculations show that the shape of the quarkonium rapidity distribution is strictly related to the PDF. Since the region 2.5<y<4 corresponds to x < 10^{-5}
  → it will be possible to put constraints on the gluon PDF at low x

- the accuracy if the data collected in the muon spectrometer will be good enough to discriminate between the different models





First data - p-p @$\sqrt{s}$ = 7 TeV

From the recent Chamonix workshop: a very long pp run at 7 TeV is foreseen.

the statistics collected during the whole long run will, of course, allow to study all the resonances with good accuracy

But what can we already measure after a short data taking period?

Assuming at the beginning:

$L = 2.3\ 10^{29}\ cm^{-2}\ s^{-1}$

$\varepsilon_{LHC} = 12\%$

the expected number of collected events will be:

	J/ψ	ψ(2S)	Υ(1S)	Υ(2S)	Υ(3S)
6 days	10^3	20	10	3	2
60 days	10^4	200	100	30	20

In the medium term ALICE will reach $L = 3\ 10^{30}\ cm^{-2}\ s^{-1}$
It might be possible to run without ALICE slow detectors and reach an even higher luminosity

First data – possible scenarios

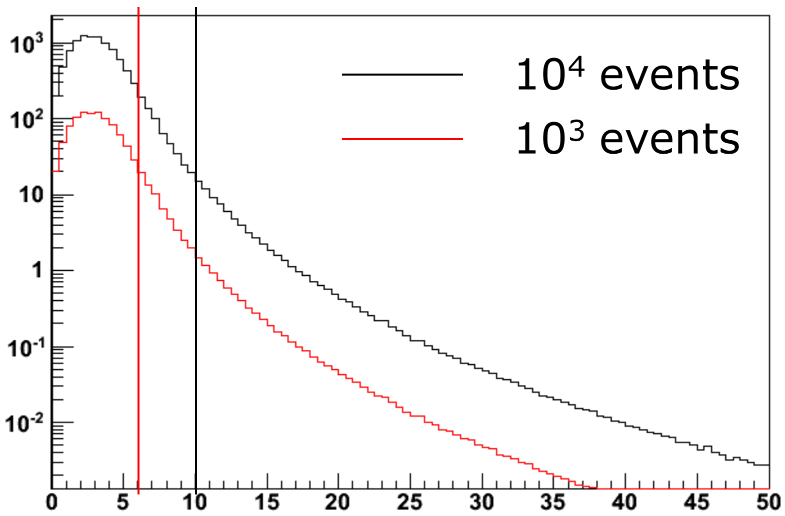
Which measurements can be performed with this initial statistics?

- J/ψ integrated production cross section
- J/ψ differential cross sections
- J/ψ polarization (vs. p_T)

depending, of course, on data taking conditions, i.e. on the number of collected events

With 10^4 J/ψ:

- production cross section
- differential p_T distribution up to $p_T \sim 10$ GeV/c
- integrated polarization value (statistics might not be enough to study the its p_T dependence)



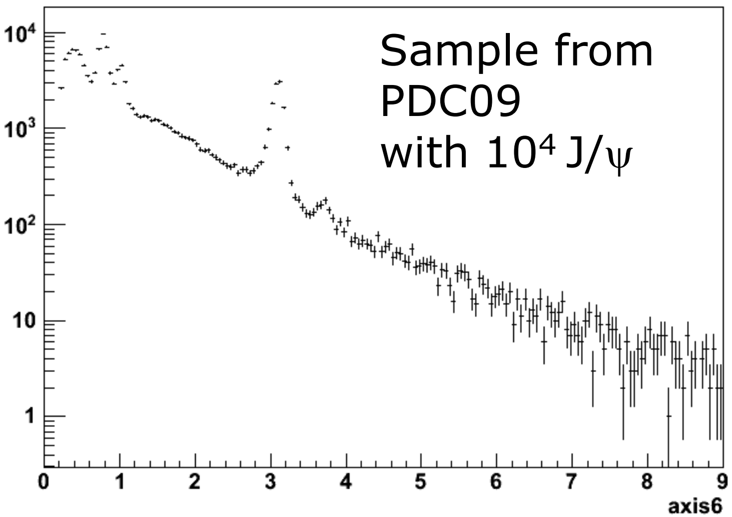
With 10^3 J/ψ:

- production cross section
- lower p_T reach (~6 GeV/c)
- no polarization

First data – production cross section

- J/ψ integrated production σ is doable also with a limited statistics
  - Possible normalization to the absolute luminosity → maybe not available from the very beginning
  - Alternative: measure J/ψ multiplicity per inelastic pp collision and multiply by the inelastic pp cross section (either from theory or TOTEM)

$\sigma_{J/\psi}$ will be affected by <15-20% error if the J/ψ polarization is neglected in the acceptance correction → a polarization measurement will reduce this error



- Other resonances cross sections:
  - we expect ~200 $\psi(2S)$, interesting since they are not affected by charmonium feed-down.
  - may be enough for an integrated cross section (if mass resolution is good)

J/ψ from B decay

- Feed-down from B, ψ' and χ_c is the most limiting issue for theory comparison

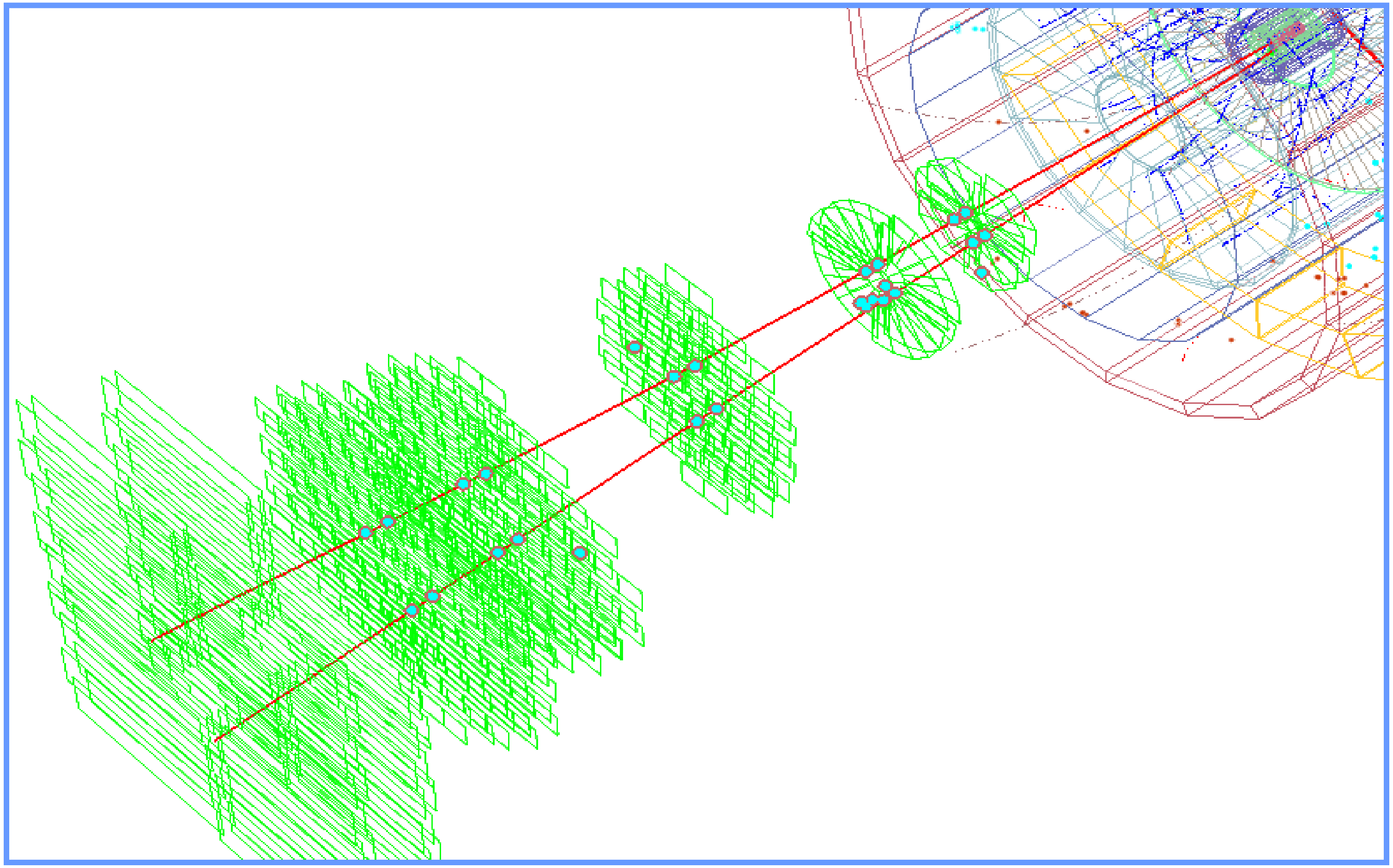
- Prompt and secondary J/ψ cannot be distinguished in the Muon Spectrometer acceptance (because of the multiple scattering in the absorber)
  Therefore we must rely on:
  - Theoretical models to estimate the J/ψ contribution from B have rather large uncertainties
  - Experimental measurements:
    - → 3 muon events in ALICE muon spectrometer
    - → B cross section from ALICE single muon
    - → B cross section from ALICE single e (extrap. at forward η)

- Most of the measurements may be affected by large systematic. More precise results probably not available at the beginning

  - First results might only be inclusive J/ψ cross section

First ALICE dimuons!

- First “real” dimuons seen in ALICE in pp at $\sqrt{s}$=900GeV, even if out of the ~20 observed dimuons… not yet a J/ψ!



Conclusions

- The ALICE Muon Spectrometer is designed to measure quarkonium in the muon channel in the rapidity region $2.5 < \eta < 4$, down to $p_T \sim 0$ GeV/c

- After one Pb-Pb data taking period at 5.5TeV, we should be able to discriminate between different suppression scenarios

- The incoming pp data taking period at 7TeV should allow measurements of J/ψ
  - production cross section
  - differential distributions
  - polarization

  helping to discriminate between different production mechanisms.

  Production cross section measurements should be feasible also for $\psi(2S)$ and Υ.

- The pp run @ 900GeV has shown the first dimuons in the Muon Spectrometer!
  We are just waiting for new data!!!!

Backup

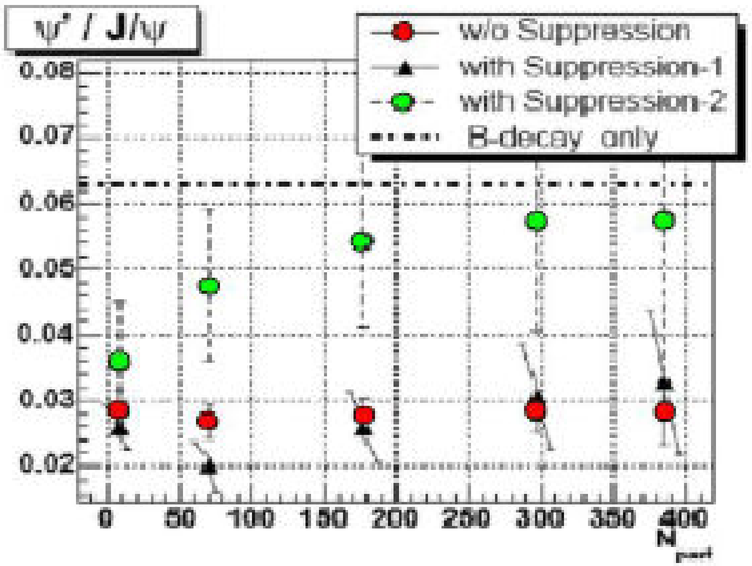
Muon Spectrometer

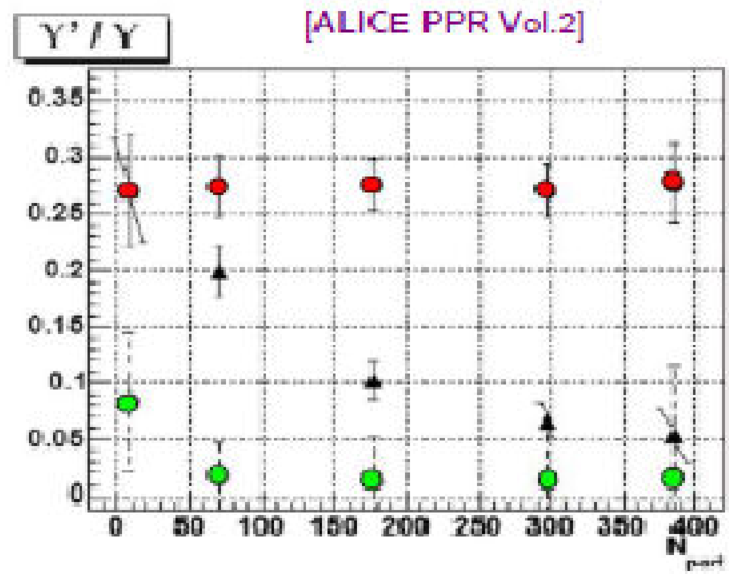
Muon detection		
Polar, azimuthal angle coverage	$2 \leqslant \theta \leqslant 9, 2\pi$	
Minimum muon momentum	4 GeV/c	
Resonance detection	J/ψ	Υ
Pseudo rapidity coverage	$4.0 \leqslant \eta \leqslant 2.5$	$4.0 \leqslant \eta \leqslant 2.5$
Transverse momentum range	$0 \leqslant p_t$	$0 \leqslant p_t$
Mass resolution	70 MeV	100 MeV
Front absorber		
Longitudinal position (from IP)	$-5030mm \leqslant z \leqslant -900mm$	
Total thickness (materials)	10λ (carbon-concrete-steel)	
Dipole magnet		
Nominal magnetic field, field integral	0.7 T, 3 Tm	
Free gap between poles	$2.972 - 3.956$ m	
Overall magnet length	4.97m	
Longitudinal position (from IP)	-z = 9.87m (centre of the dipole yoke)	
Tracking chambers		
Number of stations, number of planes per station	5, 2	
Longitudinal position of stations	-z = 5357, 5860, 9830, 12920, 14221 mm	
Anodecathode gap (equal to wire pitch)	2.1 mm for st. 1; 2.5 mm for st. 2 5	
Gas mixture	$80\% Ar/20\% CO_2$	
Pad size st. 1 (bending plane)	$4 \times 6, 4 \times 12, 4 \times 24 mm^2$	
Pad size st. 2 (bending plane)	$5 \times 7.5, 5 \times 15, 5 \times 30 mm^2$	
Pad size st. 3, 4 and 5 (bending plane)	$5 \times 25, 5 \times 50, 5 \times 100 mm^2$	
Max. hit density st. 15 (central PbPb×2)	$5.0, 2.1, 0.7, 0.5, 0.6 \cdot 10^{2}$ hits cm^{2}	
Spatial resolution (bending plane)	$\simeq 70$ μm	

Tracking electronics	
Total number of FEE channels	1.09×10^6
Shaping amplifier peaking time	1.2 μs
Trigger chambers	
Number of stations, planes per station	2, 2
Longitudinal position of stations	-z = 16 120, 17 120 mm
Total number of RPCs, total active surface	$72, \sim 150 m^2$
Gas gap	single, 2 mm
Electrode material and resistivity	Bakelite^{TM}, $\rho = 24 \times 10^9$ cm
Gas mixture	$Ar/C_2H_2F_4$/i-butane/SF_6 ratio 49/40/7/1
Pitch of readout strips (bending plane)	10.6, 21.2, 42.5 mm (for trigger st. 1)
Max. strip occupancy bend. (non bend.) plane	3%(10%) in central Pb-Pb
Maximum hit rate on RPCs	3 (40) Hz cm^{-2} in Pb-Pb (Ar-Ar)
Trigger electronics	
Total number of FEE channels	2.1×10^4
Number of local trigger cards	234 + 2

Pb-Pb@5.5TeV: suppression studies(2)

Other possible approach for suppression studies: ψ'/ψ, Υ'/Υ





Advantages:

- similar cold nuclear matter effects
- detector inefficiencies should cancel out

ψ'/ψ

- large error bars from the ψ' fit
- ratio less sensitive to the suppression scenarios due to the B decay contribution (assumed not to be affected by the medium)

Υ'/Υ

- ratio allows to disentangle the different scenarios

First data – theory comparison

- Several theorists have been contacted, in order to have **CSM, CEM** (R. Vogt), **NRQCD** calculations to be compared with our results

- J.P. Lansberg will kindly provide LO CSM calculations for
  - → Direct J/ψ, p_T integrated, cross section
  - → Differential p_T distributions

NLO calculations → still to be understood at low p_T

- Crucial to control feed-downs for data-theory comparison!
- Important to study ψ' production cross section