Charmonium production at LHC

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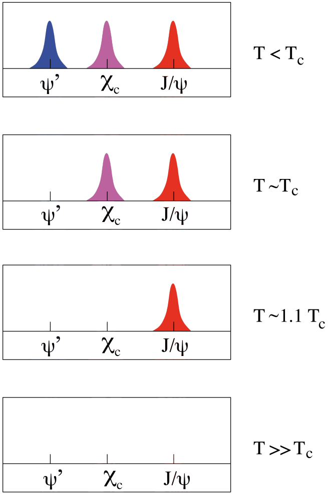
Quarkonia study: motivation

- study the **deconfined** state of the matter **Q**uark **G**luon **P**lasma
  $\hookrightarrow$ **color screening** of static potential between heavy quarks
  $\hookrightarrow$ quarkonia **melting** above certain temperature/energy density threshold: **thermometer** of the medium
- probe of low-x gluon structure
  $\hookrightarrow$ production via **gluon-gluon** fusion
  $\hookrightarrow$ Bjorken-x values as low as $\sim 10^{-5}$: strong nuclear gluon shadowing
  $\hookrightarrow$ **gluon saturation**: non-linear QCD evolution



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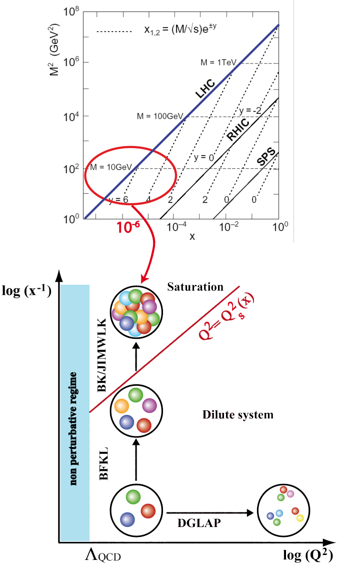
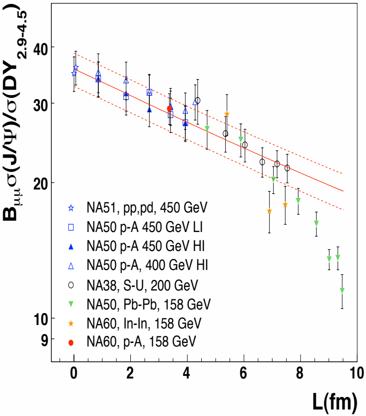
quarkonia: probe of QCD media



J/ψ at SPS

- **normal nuclear absorption** describes very well p-p, p-A, S-U and peripheral In-In and Pb-Pb data
- the **survival probability** evolves as $\exp(-\sigma_{abs}\rho_0 L)$
  - L: nuclear matter thickness
  - ρ_0: nuclear density
  - σ_{abs}=4.18±0.35 mb
- **anomalous suppression** in Pb-Pb and In-In collisions for $N_{part} > 80$
- **new** results



[EPJ C39:335,2005]

J/ψ behaves as the predicted golden signature of the QGP !

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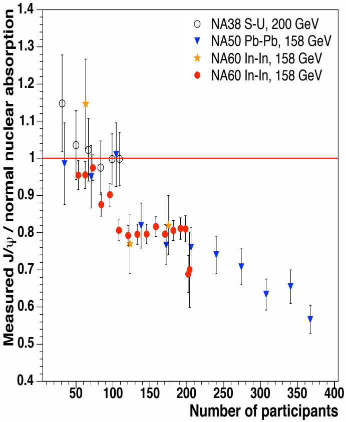

[Nucl.Phys.A774:711-714,2006]

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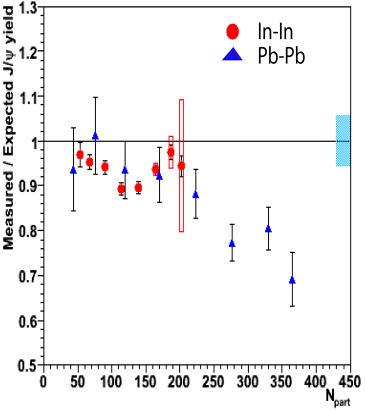

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J/ψ at RHIC

- comparison via **nuclear modification factor** $R_{AA} = \frac{dN_{AA}/dydp_t}{N_{coll}\, dN_{pp}/dydp_t}$
- **first surprise** $\rightsquigarrow$ similar suppression at SPS and at RHIC: R_{AuAu}@RHIC(y$\sim$0)$\approx R_{PbPb}$@SPS
  - obvious differences between two systems: energy densities, x_{Bj}, σ_{abs}, ...
- **second surprise** $\rightsquigarrow$ the suppression is larger at forward than at mid-rapidities: R_{AuAu}@RHIC(y$\sim$1.7) $<$ R_{AuAu}@RHIC(y$\sim$0)
  - energy density smaller in forward rapidity
  - regeneration, coalescence ?
  - saturation, shadowing ?
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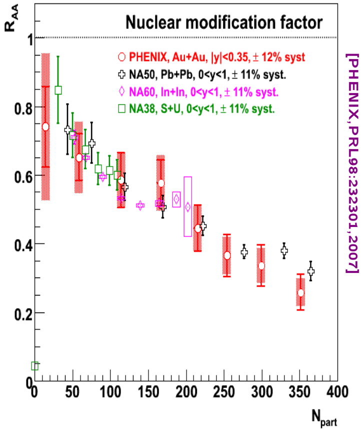

[PHENIX,PRL98:232301,2007]

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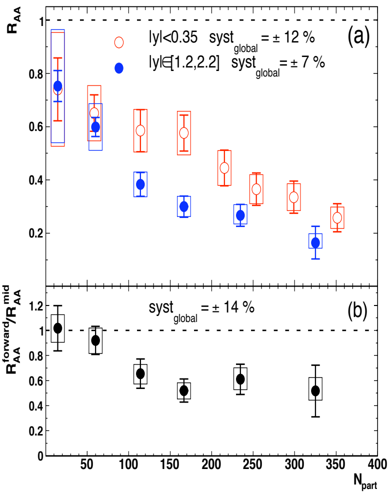

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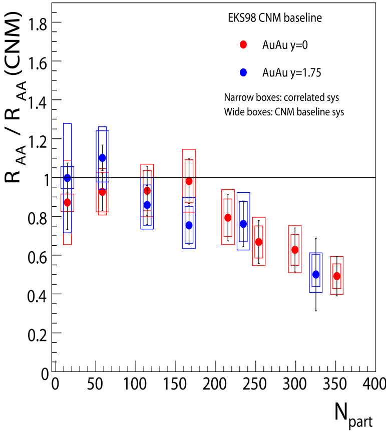
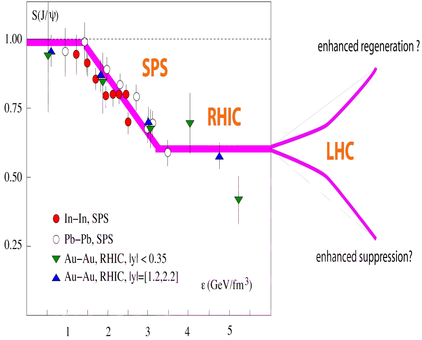


J/ψ at LHC (1)

- big step in $\sqrt{s}$: LHC ≈ RHIC × **28**
- probe **unexplored** Bjorken-x region
- **large** statistics expected
- **regeneration** or **suppression**?
- prediction: depends strongly on the **open charm** cross section
- **secondary** vs **prompt** J/ψ
- **data taking strategy**
  1 LHC year = 10^7s p-p ($3 \cdot 10^{30}$cm^{-2}s^{-1})
  + 10^6s A-A ($5 \cdot 10^{26}$cm^{-2}s^{-1})

  ↪ **p-p**: reference for p-A and A-A **(PDF, quarkonia production mechanisms, fragmentation function, CGC)**
  ↪ **p-A**: disentangle between initial and final state effects **(shadowing, CGC, Cronin effect)**
  ↪ **A-A**: study of the hot and dense medium **(quarkonia suppression/regeneration, secondary J/ψ, thermal enhancement, energy loss mechanism, in medium hadronisation)**



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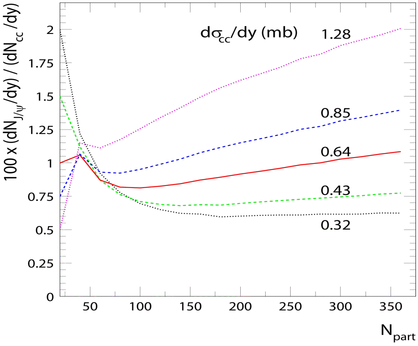


J/ψ at LHC (2)

- **experiments:** ALICE, ATLAS, CMS and LHCb
- **detection channels:** e^+e^- and $\mu^+\mu^-$
- **experimental challenges:**

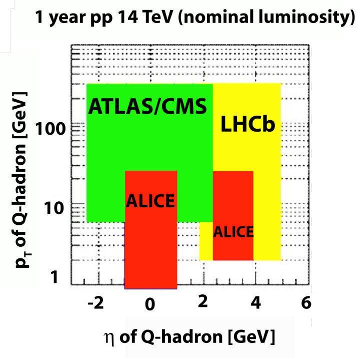
  $\hookrightarrow$ $B \rightarrow J/\psi\ (\psi') + X$

  $\hookrightarrow$ energy loss of heavy quarks

  $\hookrightarrow$ normalization

  - Drell-Yan **not** available for normalization (quarkonia from gg fusion at LHC; small D-Y cross section at LHC)
  - W, Z, **but** ... different production mechanisms, large difference in mass between bosons and quarkonia
  - open heavy flavour, **but** ... energy loss, thermal charm production

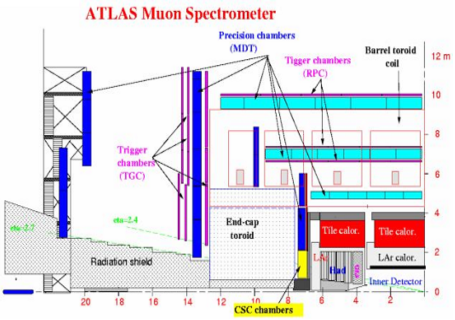
  $\hookrightarrow$ **complex** combinatorial background



Measuring quarkonia in ATLAS: $\mu^+\mu^-$

Excellent muon detection capabilities for $|\eta| < 2.7$

- detectors for muon detection
  $\hookrightarrow$ **MDT**: **M**onitored **D**rift **T**ubes (barrel and endcaps)
  $\hookrightarrow$ **CSC**: **C**athode **S**trip **C**hambers (endcaps)
  $\hookrightarrow$ **RPC**: **R**esistive **P**lates **C**hambers (barrel trigger)
  $\hookrightarrow$ **TGC**: **T**hin **G**ap **C**hambers (endcaps and barrel trigger)
- magnetic field: barrel toroid: $\sim$ 0.5-1 T
- di-muon trigger: **p_T ($\mu_{1,2}$) > 4 GeV/c**
- muon track resolution:
  $\hookrightarrow$ MDT: $\sim$ 300 μm
  $\hookrightarrow$ CSC: $\sim$ 50-70 μm
- momentum measurement using MDT + CSC: p_T resolution (10 GeV/c) **$\sim$ 1.5 - 2%**

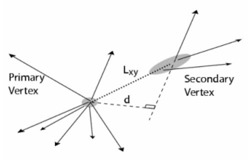


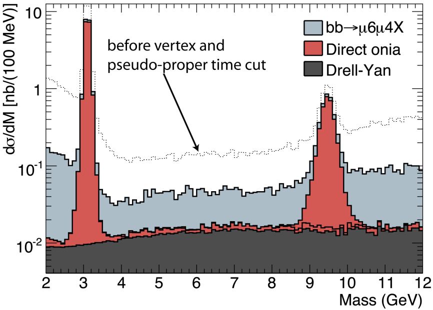
ATLAS: J/ψ @ p-p collisions

- **17000 J/ψ** per 1 pb^{-1}
- separation of **prompt** and **indirect** J/ψ using the radial displacement L_{xy} of two-track vertex from the beamline
  $\hookrightarrow$ pseudo-proper time decay t_0

$$t_0 = \frac{L_{xy} \cdot M_{J/\psi}}{p_T(J/\psi) \cdot c_{light}}$$

$\hookrightarrow$ $t_0 = 0$ for prompt J/ψ





- mass resolution $\sim$ **54 MeV/c^2**
- **S/B = 60**

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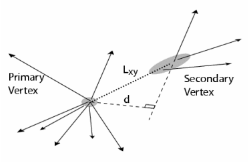

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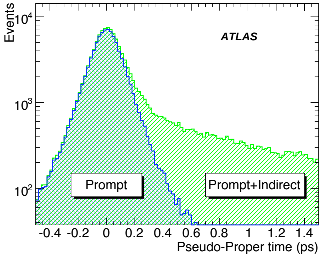
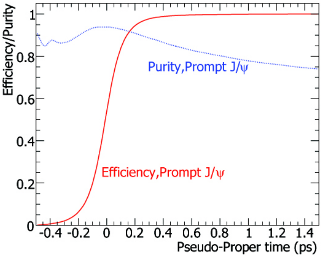
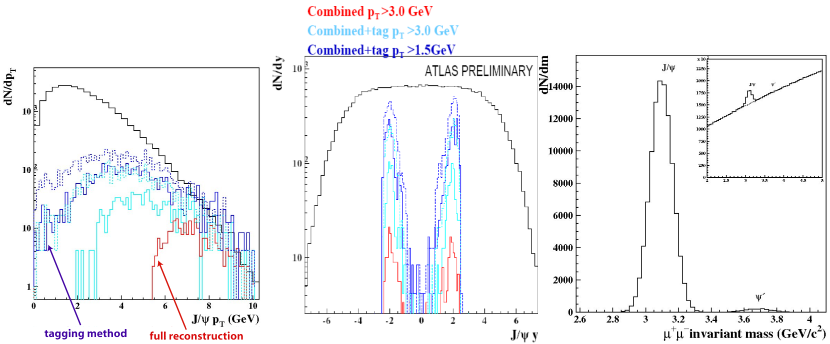




ATLAS: J/ψ @ Pb-Pb collisions

- **130000 J/ψ** per month (0.5 nb^{-1})
- low acceptance due to **minimum** muon p_T cut **1.5 GeV/c**
- two methods considered:
  ↪ both muons fully reconstructed
  ↪ tagging method for one muon
- mass resolution ∼ **68 MeV/c^2**
- **S/B ∼ 0.15**

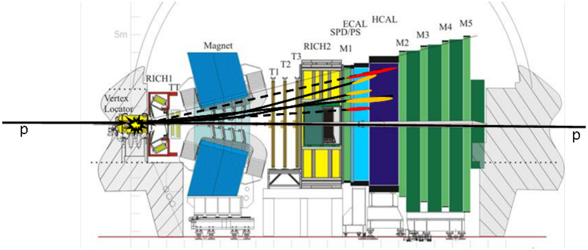


Measuring quarkonia in LHCb: only p-p collisions

- angular coverage 15 - 300 mrad: **$2 < \eta < 5$**
- nominal luminosity: $\sim 2\times 10^{32}$ cm^{-2}s^{-1}
- muon system: 5 stations (M1,..,M5)
  ↪ 1368 **M**ulti-**W**ire **P**roportional **C**hambers (**MWPC**) for M2,...,M5
  ↪ 12 triple-**GEM** for M1 (**G**as-**E**lectron **M**ultiplier)
- integrated magnetic field: $\sim$ 4 T m

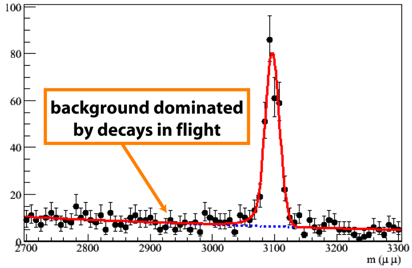
J/ψ **selection**

- pair of good quality tracks coming from a common vertex
  ↪ **vertex** χ^2/dof $<$ 6 and **track** χ^2/dof $<$ 5
- both tracks identified as muons
- one track with **$p_T > 1.5$ GeV/c**



LHCb: J/ψ @ p-p collisions

- J/ψ signal in 19.3 million minimum bias events
- fit with **Crystal-Ball** function: **Gaussian** J/ψ + **exponential** background
- mass resolution **$\sim$11 MeV/c^2**
- **S/B $\sim$ 4**
- expected 3.2×10^6 events in 5 pb^{-1} at 8 TeV
- **efficiency** correction estimated using Monte Carlo



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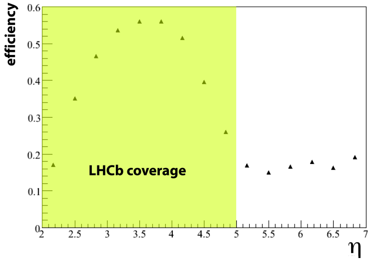
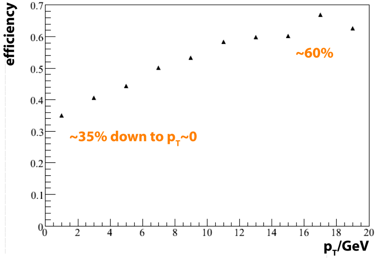


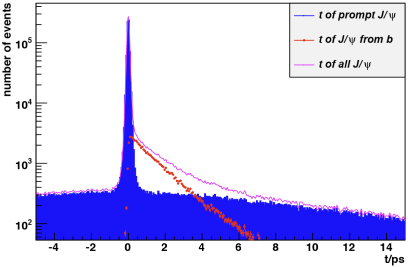


LHCb: identifying prompt J/ψ

- $\sim$ **8%** J/ψ come from b decays
- approximation of the proper time of the b quark in the forward direction

$$t = \frac{dz}{p_z^{J/\psi}} \times m^{J/\psi}$$

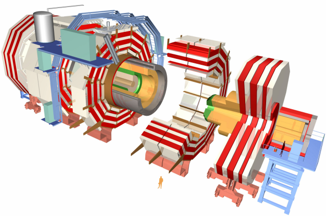
$\hookrightarrow$ **prompt Gaussian component**: J/ψ produced in the primary vertex
$\hookrightarrow$ **prompt background**: extracted from the J/ψ mass sidebands
$\hookrightarrow$ **exponential component**: J/ψ's produced from b decays
$\hookrightarrow$ **long tail**: due to the association of the J/ψ to the wrong primary vertex

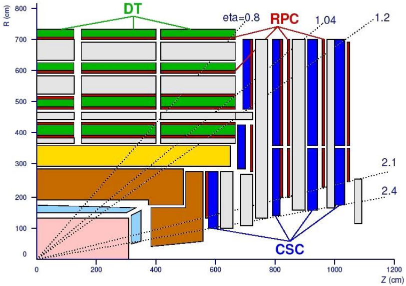


Measuring quarkonia in CMS

Ideally suited to study quarkonia production in the di-muon channel.

- detectors for muon detection
  ↪ **DT**: **D**rift **T**ubes (central barrel)
  ↪ **CSC**: **C**athode **S**trip **C**hambers (endcap)
  ↪ **RPC**: **R**esistive **P**lates **C**hambers (barrel and endcap, trigger)
- large rapidity coverage $\mid \eta \mid <$**2.4**
- strong magnetic field $\sim$ **4 T** ($\sim$ **1.8 T**)
- matching between tracks in the muon chambers and in the silicon tracker
- $\mathbf{p}_T$ resolution (10 GeV/c) $\sim$ **0.8 - 2%**
- minimum μ momenta:
  ↪ barrel $\mid \eta \mid < 0.8$: $\mathbf{p}_T^{\mu} >$ **3.5 GeV/c**
  ↪ endcap: $\mathbf{p}_L^{\mu} >$ **4.0 GeV/c**





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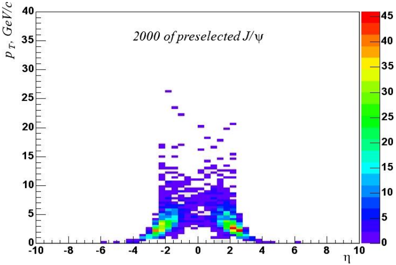
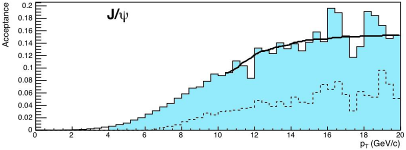
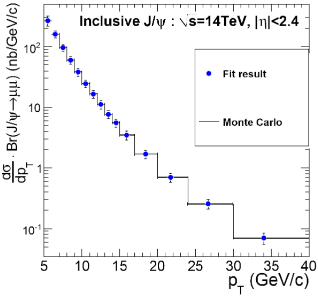
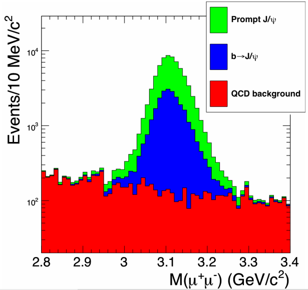




CMS: J/ψ @ p-p collisions

- $\sim$ **25000** J/ψ per 1 pb^{-1} (1-2 days)
- expected p_T spectrum after 3 pb^{-1} ($\sim$ 75000 J/ψ)
- J/ψ yield is extracted by fitting the dimuon mass distribution, separating the signal peak from the underlying background continuum
- observed J/ψ yield:
  $\hookrightarrow$ **direct** J/ψ
  $\hookrightarrow$ decays **from B hadrons**
  $\hookrightarrow$ decays **from χ_c and ψ'**
- **non-prompt fraction** estimated using the pseudo proper decay length





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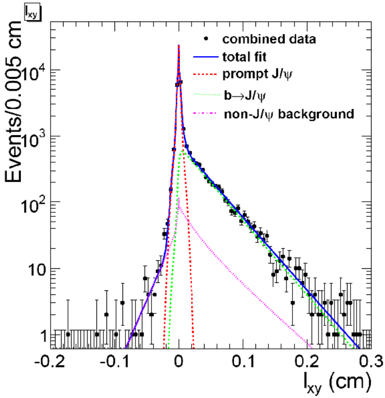
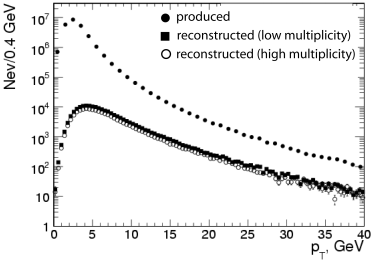


CMS: J/ψ @ Pb-Pb collisions

- 0.5 nb^{-1}: **one month** at 4×10^{26} $cm^{-2}s^{-1}$ and 50% machine operation efficiency, assuming **no** quarkonia suppression

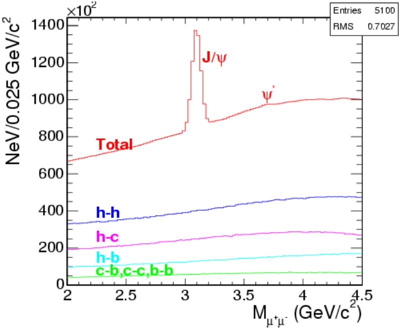
$dN_{ch}/d\eta\ \|_{\eta=0}$	$\Delta\eta$	S/B	$N(J/\psi)$
2500	$\|\eta\|<2.4$	1.2	184000
2500	$\|\eta\|<0.8$	4.5	11600
5000	$\|\eta\|<2.4$	0.6	146000
5000	$\|\eta\|<0.8$	2.8	12600

- transverse momentum spectrum **up to 40 GeV/c**



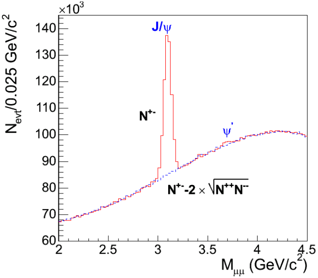
CMS: J/ψ @ Pb-Pb collisions

- signal + background
  $\hookrightarrow$ integrated luminosity: 0.5 nb^{-1}
  $\hookrightarrow$ **high multiplicity** setting:
  $dN_{ch}/d\eta\ |_{\eta=0} = 5000$
  $\hookrightarrow$ background:
  - **90 %** from $\pi^{\pm}/K^{\pm} \rightarrow \mu + X$
  - **open heavy flavour** (D,B) meson decays (BR∼18% (38%) for c(b))
- J/ψ like-sign subtraction
  $\hookrightarrow$ the **best** case:
  $dN_{ch}/d\eta\ |_{\eta=0} = 2500$ and $|\ \eta\ | < 0.8$
  $\hookrightarrow$ the **worst** case:
  $dN_{ch}/d\eta\ |_{\eta=0} = 5000$ and $|\ \eta\ | < 2.4$
- mass resolution ∼ **35 MeV/c^2**

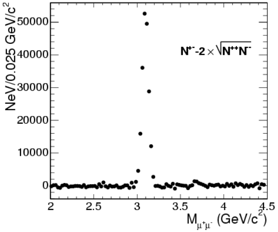


CMS: J/ψ @ Pb-Pb collisions

- signal + background
  $\hookrightarrow$ integrated luminosity: 0.5 nb^{-1}
  $\hookrightarrow$ **high multiplicity** setting:
  $dN_{ch}/d\eta\ |_{\eta=0} = 5000$
  $\hookrightarrow$ background:
  - **90 %** from $\pi^{\pm}/K^{\pm} \rightarrow \mu + X$
  - **open heavy flavour** (D,B) meson decays (BR∼18% (38%) for c(b))



- J/ψ like-sign subtraction
  $\hookrightarrow$ the **best** case:
  $dN_{ch}/d\eta\ |_{\eta=0} = 2500$ and $|\ \eta\ |<0.8$
  $\hookrightarrow$ the **worst** case:
  $dN_{ch}/d\eta\ |_{\eta=0} = 5000$ and $|\ \eta\ |<2.4$



- mass resolution $\sim$ **35 MeV/c^2**

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- signal + background
  - $\hookrightarrow$ integrated luminosity: 0.5 nb^{-1}
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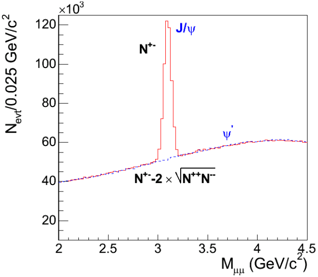
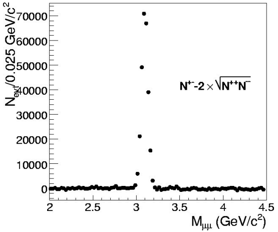
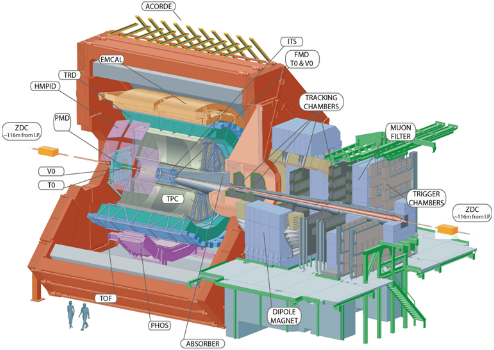
- mass resolution ∼ **35 MeV/c^2**





Measuring quarkonia in ALICE

- covers **central** ($|\eta| < 0.9$) and **forward** ($-4.0 < \eta < -2.5$) regions
- coverage extends to $\mathbf{p_T \sim 0}$ for quarkonia
- **channels**: electronic, muonic and hadronic
- high precision **vertexing** in the central barrel
- **detection channels:** e^+e^- and $\mu^+\mu^-$

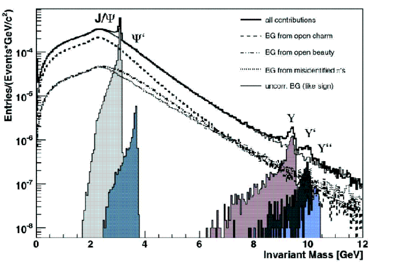


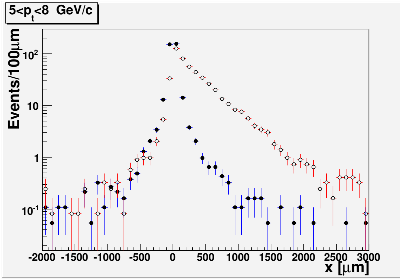
ALICE: quarkonia to dielectrons for $|\eta|<0.9$

- tracking (**ITS**, **TPC**, **TRD**) + vertexing (**ITS**) + electron identification (**TPC**, **TRD**) + trigger (**TRD**)
- **expected statistics** 1 month of 10 % central Pb-Pb, $dN_{ch}/dy = 3000$, L=5 x 10^{26} $cm^{-2}s^{-1}$, 2 x 10^8 events, $M\pm1.5\sigma$

state	S(x10^3)	B(x10^3)	S/B	$S/\sqrt{S+B}$
J/ψ	121.1	88.2	1.4	265
Υ	1.3	0.8	1.6	28
Υ'	0.46	0.8	0.6	13

- **secondary vs prompt J/ψ**
  - $\sim$ 22(39) % of J/ψ (ψ') come from beauty hadron decay
  - J/ψ originating from B decays are produced at large distance from the primary vertex
- mass resolution **$\sim$30 MeV/c^2**





ALICE: quarkonia to dimuons for $-4<\eta<-2.5$

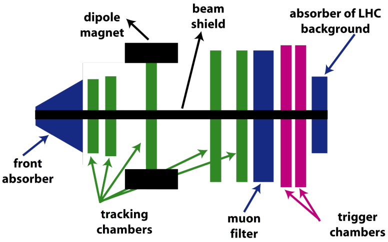
- **muon spectrometer**
  ↪ absorbers
  ↪ tracking system
  ↪ trigger chambers
  ↪ dipole magnet $\sim$ **0.7 T**

- **expected statistics**
  1 month central Pb-Pb (0 <b<3 fm),
  L=5 x 10^{26} $cm^{-2}s^{-1}$, $M\pm2\sigma$

state	S($x10^3$)	B($x10^3$)	S/B	$S/\sqrt{S+B}$
J/ψ	130	680	0.20	150
ψ'	3.7	300	0.01	6.7
Υ	1.3	0.8	1.7	29
Υ'	0.35	0.54	0.65	12
Υ''	0.20	0.42	0.48	8.1

  - J/ψ: large statistics, p_T=0-20 GeV/c
  - ψ': poor significance
  - Υ, Υ': p_T=0-8 GeV/c
  - Υ'': 2-3 runs needed

- mass resolution **$\sim$70 MeV/c^2**



ALICE: quarkonia to dimuons for -4<η<-2.5

- **muon spectrometer**
  ↪ absorbers
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  ↪ trigger chambers
  ↪ dipole magnet ~ **0.7 T**

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  1 month central Pb-Pb (0 <b<3 fm),
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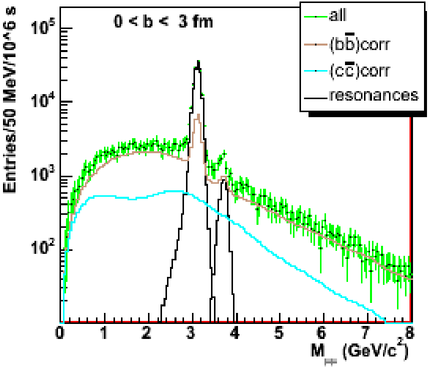
- mass resolution **~70 MeV/c^2**

J/ψ family
Uncorrelated bkg subtracted

[ALICE PPR Vol.2]



ALICE: suppression scenario

dimuon channel, **statistics**: 1 month Pb-Pb collisions, $L=5\cdot10^{26}$ $cm^{-2}s^{-1}$

assumptions

no nuclear absorption
no energy loss of b quarks
no combinatorial bkg

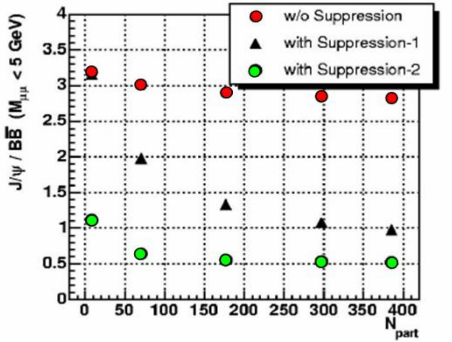
with suppression-1

T_c=270 MeV
T_D/T_c=1.7 for J/ψ
T_D/T_c=4.0 for Υ

with suppression-2

T_c=190 MeV
T_D/T_c=1.21 for J/ψ
T_D/T_c=2.9 for Υ

[ALICE PPR Vol.2]



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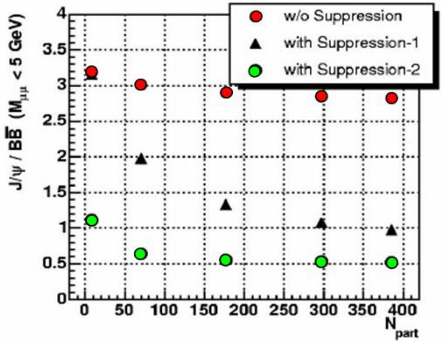
[ALICE PPR Vol.2]



Ability to distinguish between different suppression scenarios !

Conclusions

- quarkonia are a **powerful** tool to probe the QCD in p+p, p+A and A+A collisions:
  ↪ p+p (vacuum production): production picture, polarization
  ↪ A+A: sensitive probe of QGP properties
  ↪ p+A: cold nuclear matter effects
  ↪ produced via gg fusion: probe of low-x QCD
- LHC will help to **clarify** the quarkonia production picture
- **large** statistics of quarkonia are expected at LHC
- ALICE/ATLAS/CMS have complementary capabilities
- charmonia performance

ALICE $\mu^+\mu^-$	ALICE e^+e^-	CMS $\mu^+\mu^-$	ATLAS $\mu^+\mu^-$
70 MeV/c^2	30 MeV/c^2	35 MeV/c^2	68 MeV/c^2

- **more** analysis not discussed here...