Color screening in Quark Gluon Plasma (QGP): An experiment to measure χ_c suppression in PbPb collisions at the CERN SPS

CHIC: Charm in Heavy Ion Collisions

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The Physics case

- **QGP color screening through quarkonium measurements**
  - **Quarkonium color screening** in a Quark Gluon Plasma is a prediction of **lattice QCD**, for instance :

H. Satz, J. Phys. G 32 (2006)

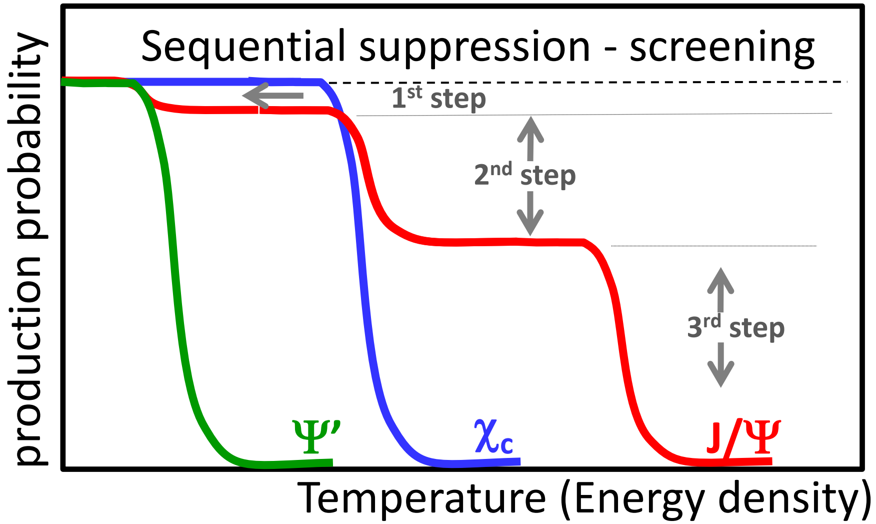
quarkonium dissociation temperature / critical QGP temperature →

state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	>4.0	1.76	1.60	1.19	1.17

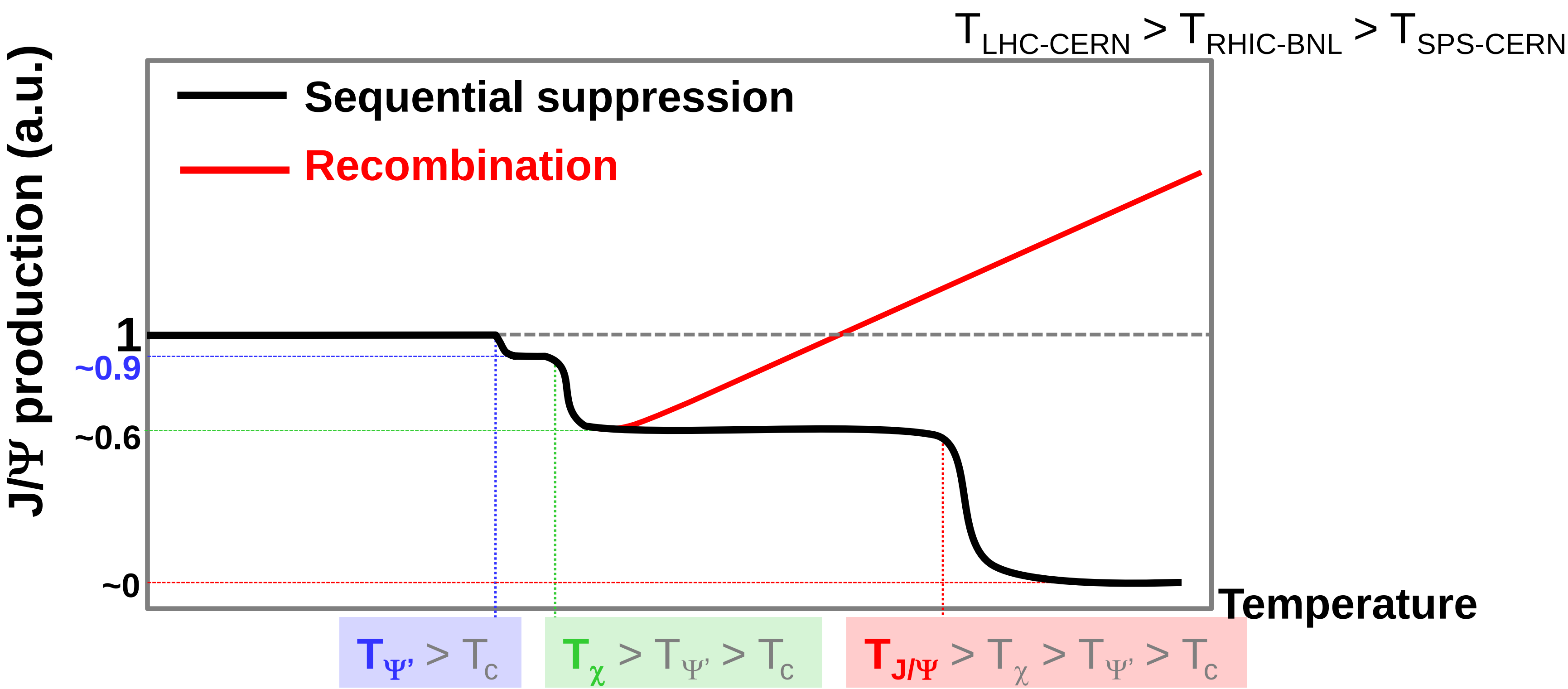
  - Because of feed-downs and different T_d, **sequential suppression** should show up.

Feed-downs contributing to J/Ψ inclusive yield

$$\frac{60\%\ \text{direct } J/\Psi + 30\%\ \chi_c \rightarrow J/\Psi+\gamma + 10\%\ \Psi' \rightarrow J/\Psi + X}{\text{Inclusive } J/\Psi \text{ yield}}$$



- **Other possible QGP effect: $c\bar{c}$ recombination**
  - In a QGP, **c and $\bar{c}$ quarks can combine** to form a J/Ψ.
  - Requires a large number of $c\bar{c}$ pairs ➔ **RHIC** energies? **LHC** energies?



Charmonia in A+A Experimentally

- **Charmonium production in A+A collisions studied at:**
  - SPS (√s=17 GeV) NA38, NA50, NA60 experiments
  - RHIC (√s=200 GeV) PHENIX, STAR experiments
  - LHC (√s=2.76 TeV) ALICE, CMS experiments

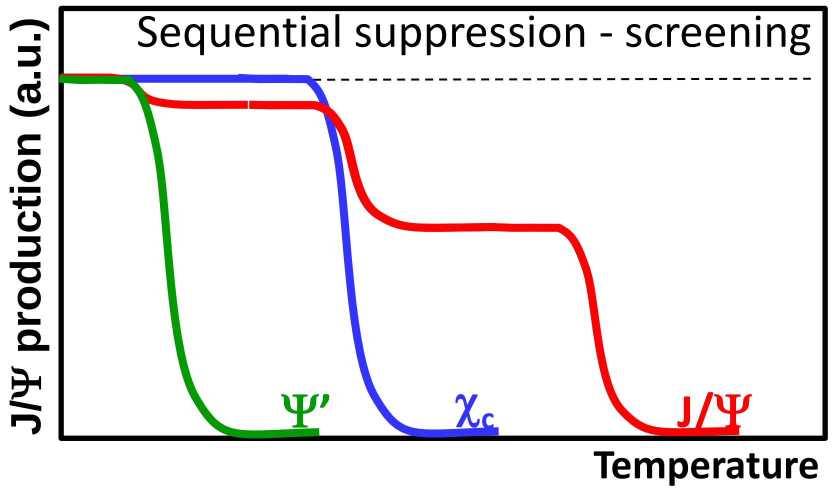
- **Short summary for J/Ψ:**
  - NA50 (PbPb@SPS) observed an *anomalous* suppression
  - PHENIX (AuAu@RHIC) observed a similar suppression (than NA50)
  - ALICE (PbPb@LHC) observed a smaller suppression for low p_T J/Ψ
  - CMS (PbPb@LHC) observed a larger suppression for high p_T J/Ψ

- **Unclear picture :**
  - Observed Hot and Dense Matter effects. For quarkonia, are they due to
    - **color screening ?** Apply in principle at SPS, RHIC and LHC
    - **Recombination ?** Apply at RHIC? LHC?
    - **Both ?**

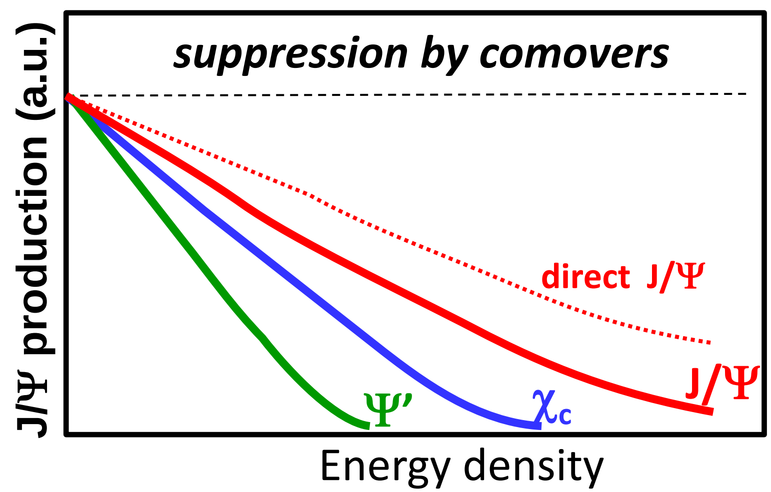
- **To understand Hot and Dense Matter effects on charmonium,**
  - **need to (dis)prove color screening first.**
  - Study of recombination is a second step (at high energies).

Color screening @ SPS

- **How to Test sequential suppression with charmonia ?**
  1. must be in a regime where recombination is negligible ➔ **SPS energies**
  2. **must measure J/Ψ, Ψ', χ_c** :
     - ~30% (resp. ~10%) of inclusive J/Ψ comes from χ_c (resp. Ψ') decay.
     - According to lattice calculations, T_d (Ψ') < T_d (χ_c) < T_d (J/Ψ)
     - **If screening, one should observe a step-like suppression patterns**



- **Alternative scenario: suppression by comoving hadrons**
  – Smooth suppression
  – Same suppression-starting point
  – Slopes related to binding energy : $S_{\Psi'} > S_{\chi} > S_{J/\Psi}$



NA50 results

- **Anomalous suppression at SPS** Eur.Phys.J.C49:559-567,2007

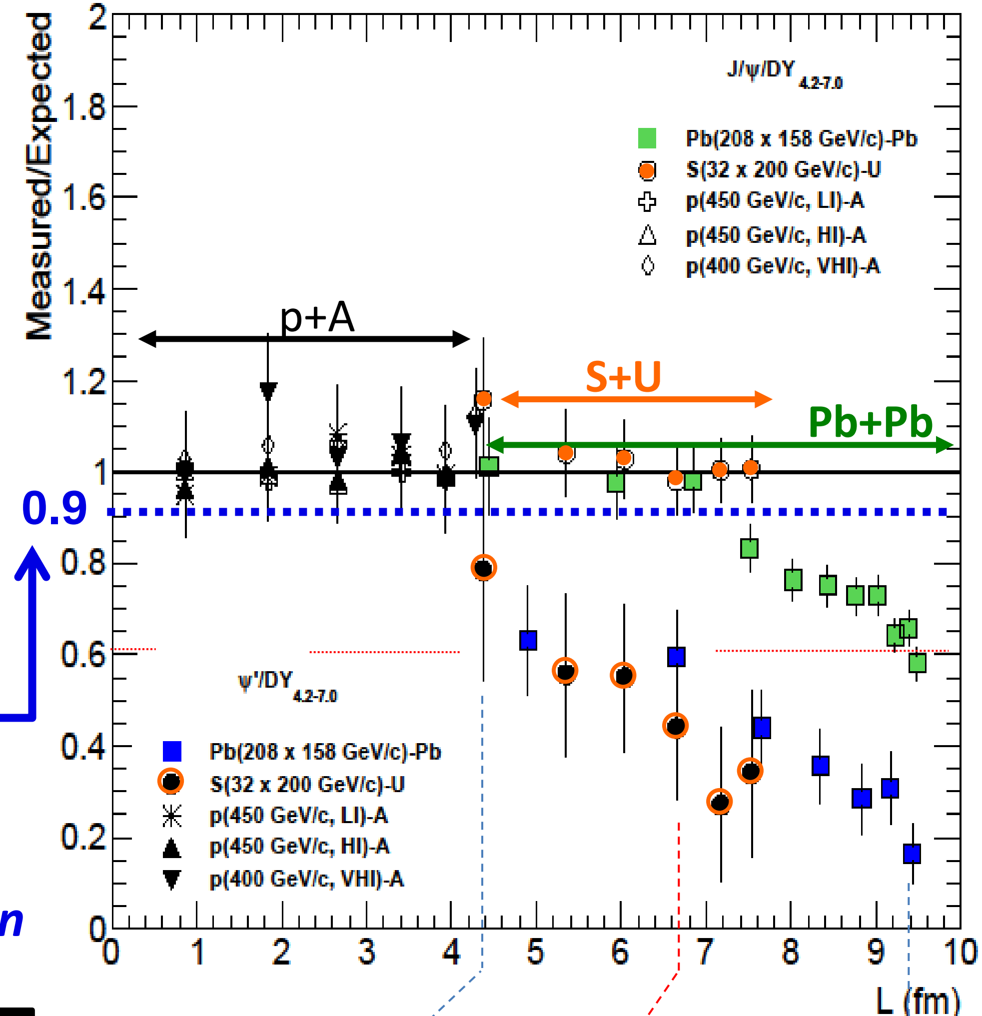
sequential suppression (QGP) ?
or
comovers (no QGP) ?

L = length of nuclear matter seen by quarkonium state

Expected = measured yield in p+A extrapolated to large L

NA50 measured J/Ψ and Ψ', but,

Measuring J/Ψ and Ψ' only is not the answer : *too small Ψ'→ J/Ψ feed-down*



L (fm)	4.37	4.90	6.65	7.65	8.83	9.43
ε (GeV/fm³)	1.04	1.24	2.04	2.53	3.19	3.76

→ need of a larger feed-down fraction
→ Measure χ_c !

Suppression patterns

- **Anomalous suppression at SPS**

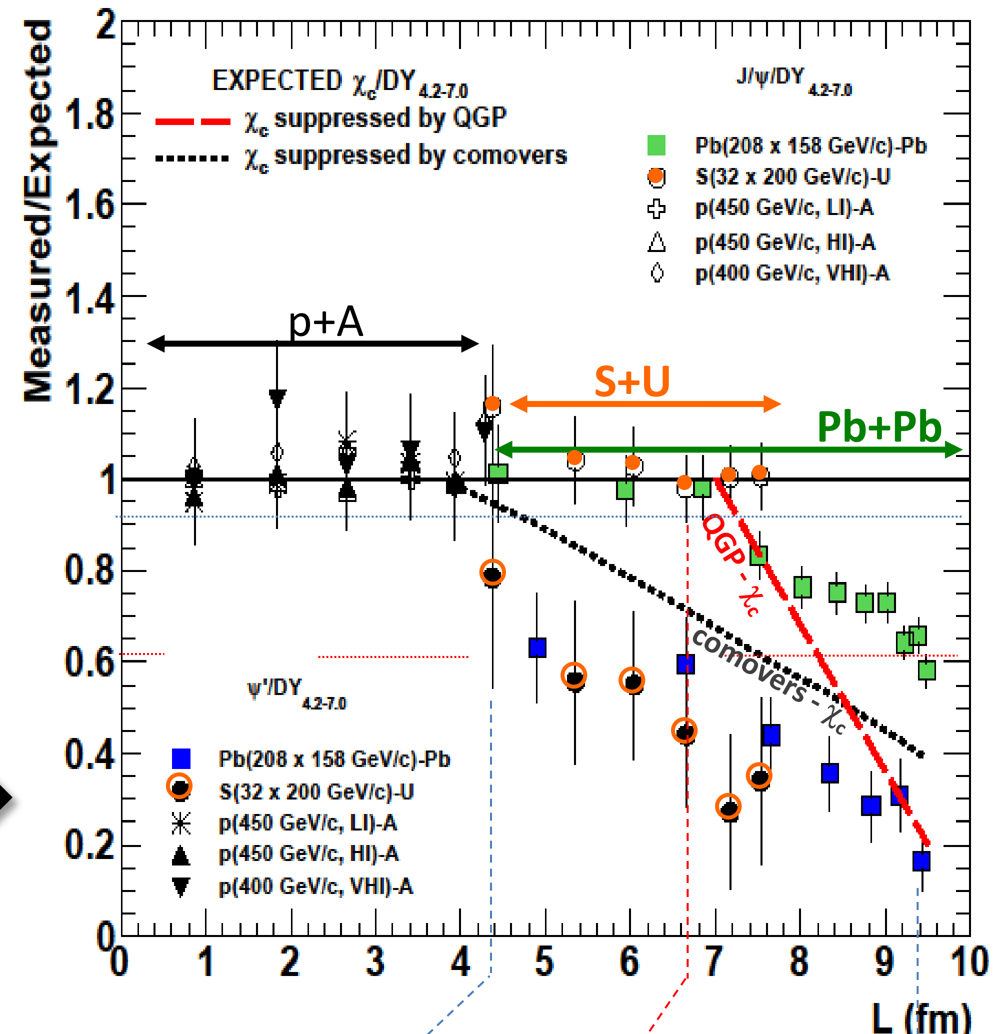
Eur.Phys.J.C49:559-567,2007

sequential suppression (QGP) ?
or
comovers (no QGP) ?

Take advantage of large $\chi_c \rightarrow J/\Psi$ feed-down fraction

$$\frac{60\%\ \text{direct } J/\Psi + 30\%\ \chi_c \rightarrow J/\Psi + \gamma + 10\%\ \Psi' \rightarrow J/\Psi + X}{\text{Inclusive } J/\Psi \text{ yield}}$$

Measuring J/Ψ, Ψ' and χ_c suppression patterns will give the answer



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Apparatus artist view

Primary goal : measure $\chi_c \rightarrow J/\Psi + \gamma$ in Pb+Pb collisions at $\sqrt{s}$ = 17.2 GeV

- **Beam:**

high-intensity 158 GeV/c Pb beam

high-intensity 158/450 GeV/c *p* beam

- **Detector features:**

Vertex detector + Spectrometer

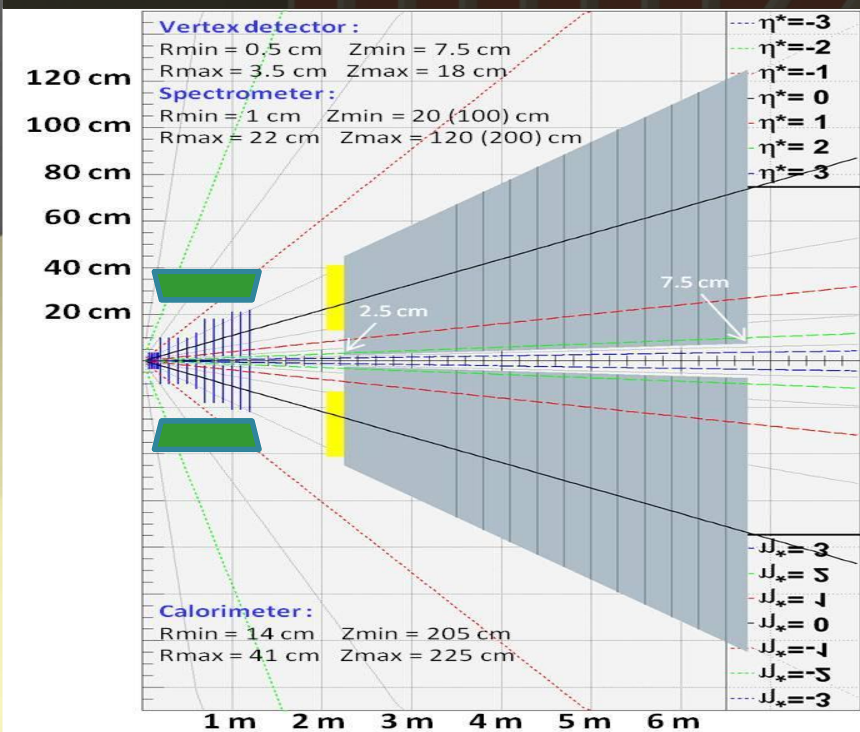
Measures tracks before absorber → very good mass resolution

Ultra-granular calorimeter

Measures low energy γ in high π^0 multiplicity environment

Absorber/trigger

Absorbs π/K → Minimize fake triggers from π/K decays



Instrumented Absorber :

4.5 m thick Fe absorber

→ dimuon trigger rate ~ 0.3 kHz

Could be magnetized to measure muon momentum

Calorimeter:

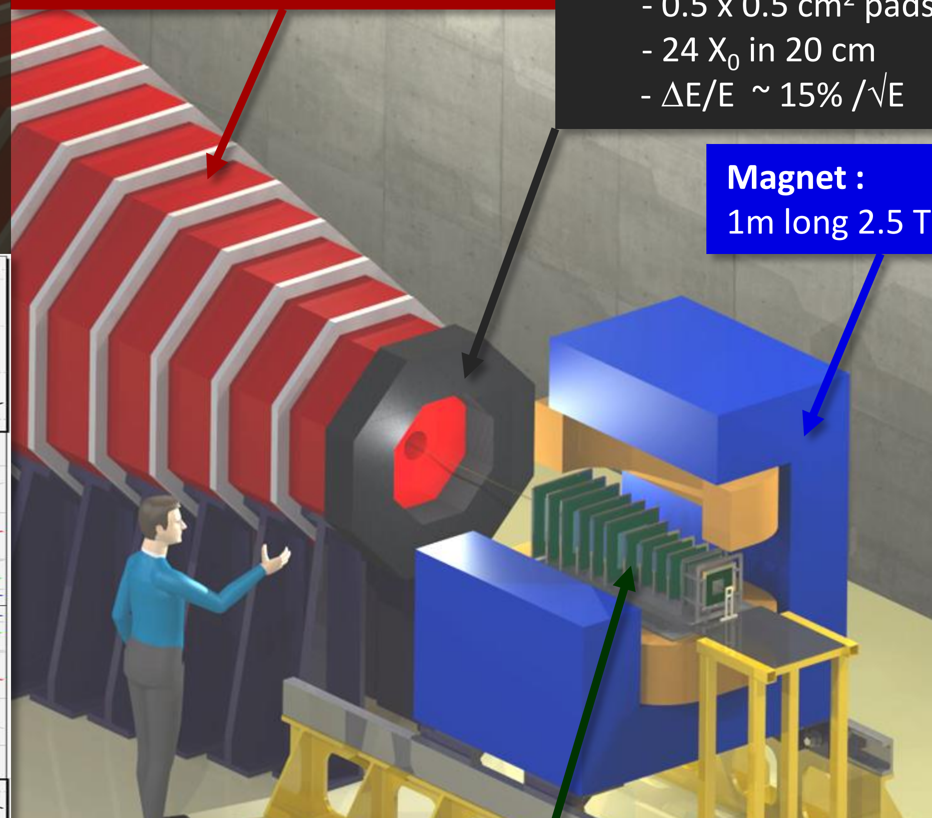
→ ultra-granular EMCal

→ W + Si layers à la CALICE

- 30 layers
- 0.5 x 0.5 cm^2 pads
- 24 X_0 in 20 cm
- $\Delta E/E$ ~ 15% /$\sqrt{E}$

Magnet :

1m long 2.5 T dipole



Estimations based on NA60/CERN telescope performances

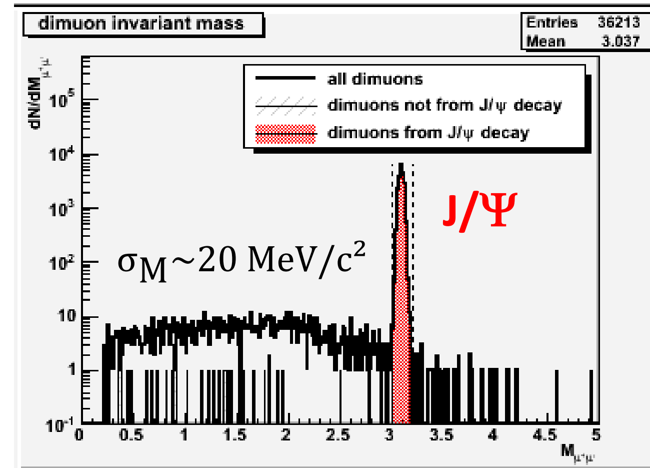
Silicon Spectrometer

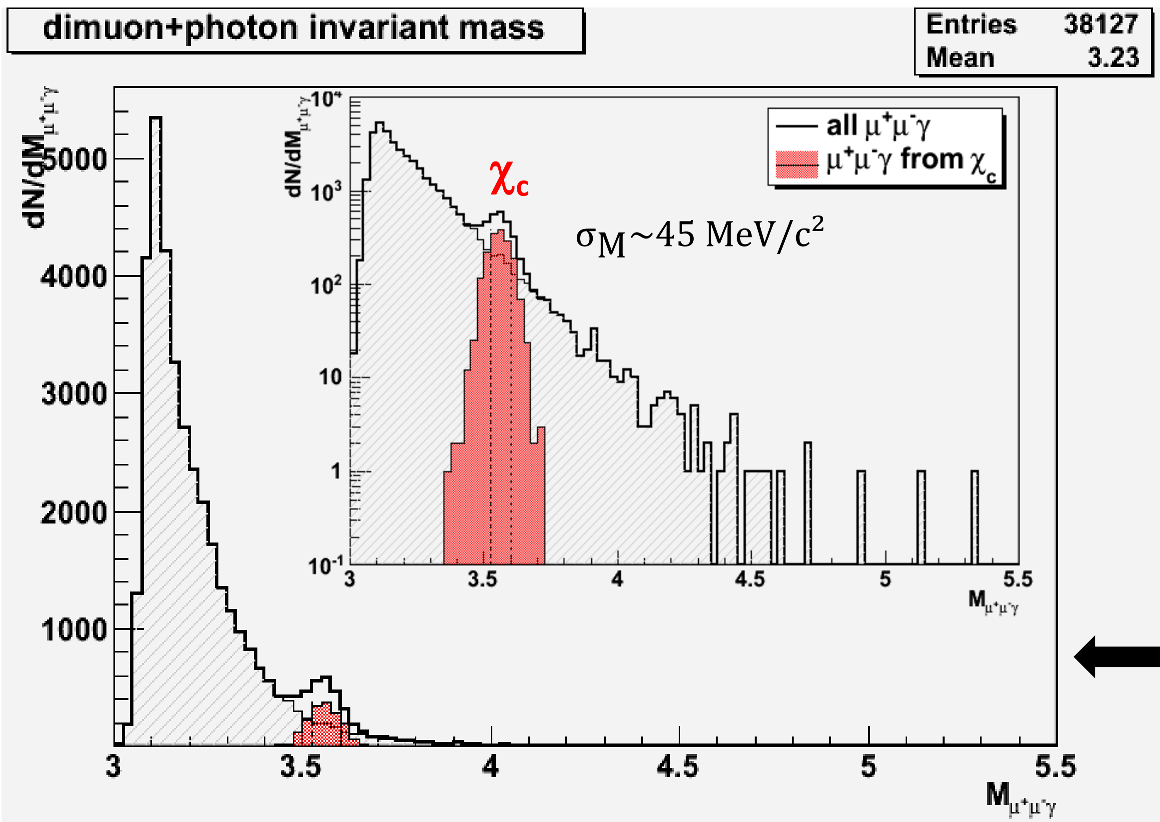
covers 1.5 rapidity unit

$\Delta p/p$ = 1% → J/Ψ mass resolution ~20 MeV/c^2

Expected performances simulation
Signal extraction

- **Typical mass plots** **(~1 week data taking w/ a 10% λ_I Pb target)**
  - 200 000 J/Ψ embedded in Pb+Pb Minbias events produced w/ EPOS
    - 140 000 direct J/Ψ→ $\mu^+\mu^-$ (70%)
    - 60 000 χ_c → J/Ψ γ → $\mu^+\mu^-$ γ (30%)





After acceptance/selection cuts
within $y_{CMS} \in$[-0.5;0.5]
35 000 **J/Ψ→$\mu^+\mu^-$**
→ acc x eff = 17.4%

Including
1700 **χ_c → J/Ψ γ → $\mu^+\mu^-$ γ**
→ acc x eff = 2.8 %

Expected performances — Statistics

- **Typical 40-day Pb+Pb run** **($10^7.s^{-1}$ Pb beam → 10% λ_I Pb target)**
  - ~ 180 000 $J/\Psi \rightarrow \mu^+\mu^-$ recorded
  - 2 extreme numerical scenarios:
    - If χ_c suppressed as J/Ψ: $\frac{\chi_c \text{ yield}}{J/\Psi \text{ yield}} \sim 4\%$

$$\Rightarrow \binom{\text{most periph.}}{\chi_c \text{ yield}} = 16942 \times 4\% = 677$$

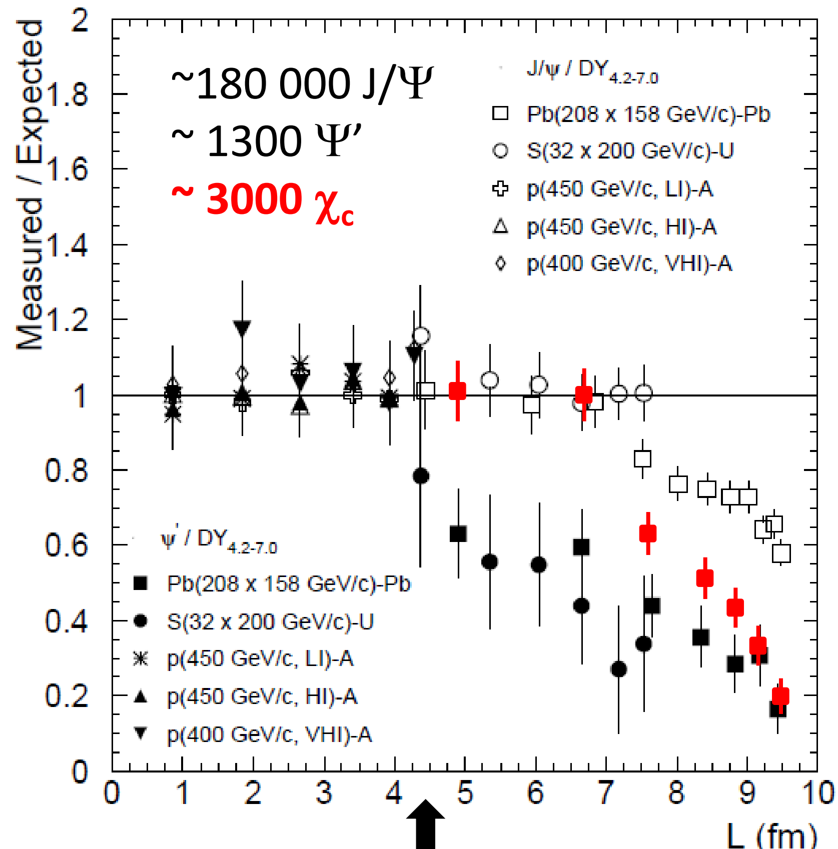
    - If χ_c suppressed as Ψ': $\frac{\chi_c \text{ yield}}{\Psi' \text{ yield}} = 2.18$

$$\binom{\text{most periph.}}{\chi_c \text{ yield}} = 16942 \times 4\% \times 0.6 = 406$$

E_T range (GeV)	ψ'	J/ψ	χ_c as Ψ'	χ_c as J/Ψ
3–20	186 ± 25	16942 ± 146	406	677
20–35	243 ± 31	25229 ± 181	530	1010
35–50	227 ± 35	27276 ± 192	495	1091
50–65	193 ± 36	27681 ± 196	421	1107
65–80	154 ± 36	27315 ± 200	336	1093
80–95	159 ± 37	25111 ± 193	647	1004
95–150	110 ± 40	28570 ± 209	240	1143
			3075	**7125**

NA50 data

Eur.Phys.J.C49:559-567,2007



Expect $3000 < N_{\chi_c} < 7000$

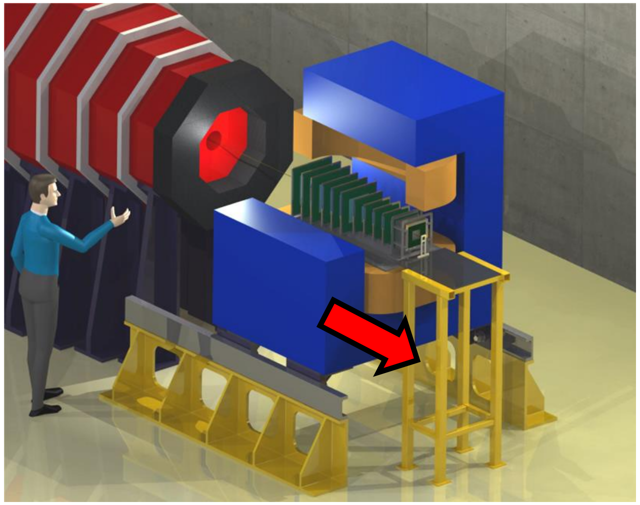
Cold Nuclear Matter

- **A thorough p+A program**
  - **mandatory as reference for hot nuclear matter effects**
  - **Must control (understand) :**
  - charmonium absorption by cold nuclear matter ➔ A dependence
  - Shadowing/anti-shadowing (x_2 scaling)
  - Energy loss, formation time (x_F scaling)

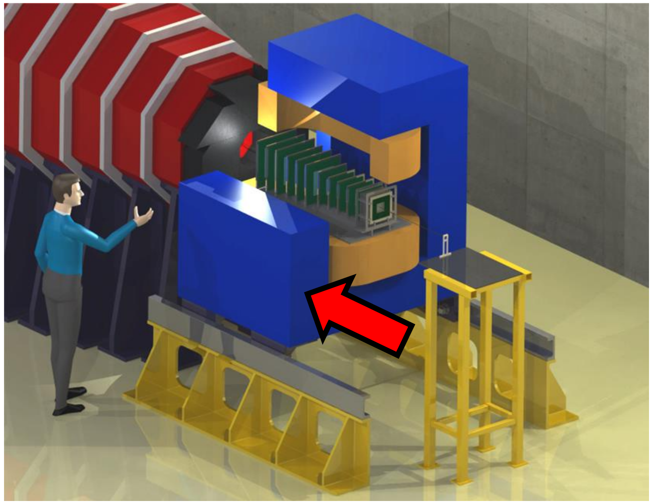
  } ➔ **Need large y_{CMS} range**

- **Two detector configurations to cover $y_{CMS} \in [-0.5 ; 2]$**

Mid-rapidity : $y_{CMS} \in [-0.5 ; 1]$



Forward-rapidity : $y_{CMS} \in [0.5 ; 2]$



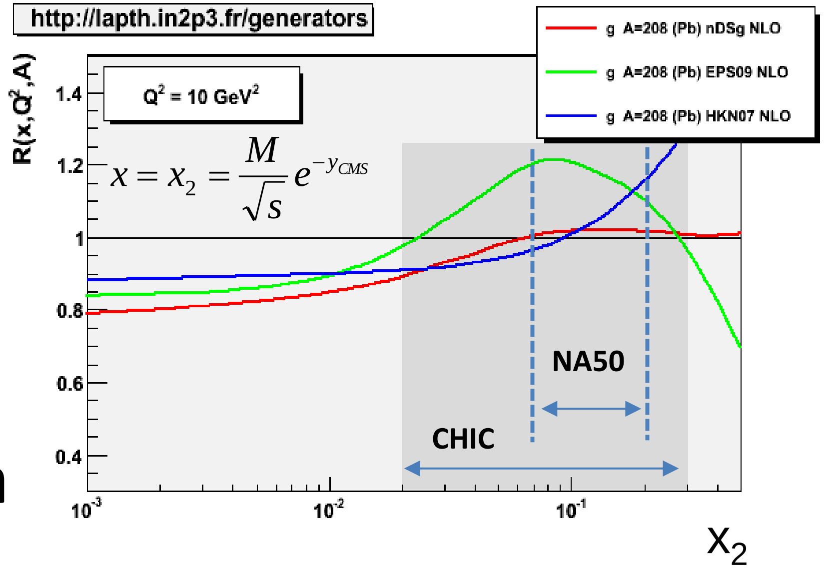
Detector capabilities

- **Two detector configurations to cover y_{CMS} [-0.5; 2]**

J/Ψ, Ψ', χ_c in a large y_{CMS} range

➔ **Large coverage in x_2**

➔ **Large coverage in x_F**



- **Large amount of data**

Typical 1week/target NA50 data taking
(EPJ C33 (2004) 31-40)

Target	size (λ_I)	$< I_{protons} >$ ($\times 10^8$)	Total $N_{protons}$ ($\times 10^{12}$)	$N_{\mu\mu}^{+-}$ (2.7 - 3.5)
Be	60 %	21.7	50.7	368 000
Al	52 %	23.0	63.4	602 000
Cu	28 %	27.0	45.5	762 000
Ag	30 %	24.8	43.8	821 000
W	19 %	23.5	28.5	524 000

– **Study J/Ψ, Ψ', χ_c with several targets**
  - NA50: p+Be, p+Al, p+Cu, p+Ag, p+W, p+Pb

– **Large statistics** required
  - Typical 1week/target NA50 data taking
  - **Current SPS operation: Delivering proton beam to the LHC several months per year**

Significantly larger (than NA50) amount of data available for CHIC

Conclusion

- **Measuring together J/Ψ, Ψ' and χ_c in p+A collisions with several targets will give a thorough control of Cold Nuclear Matter effects**
- **Measuring together J/Ψ, Ψ' and χ_c in A+A collisions at SPS energies will (dis)prove sequential suppression scenario.**
- **The apparatus is well suited to explore other important physics subjects such as open charm or low mass lepton pairs production in heavy ion collisions.**

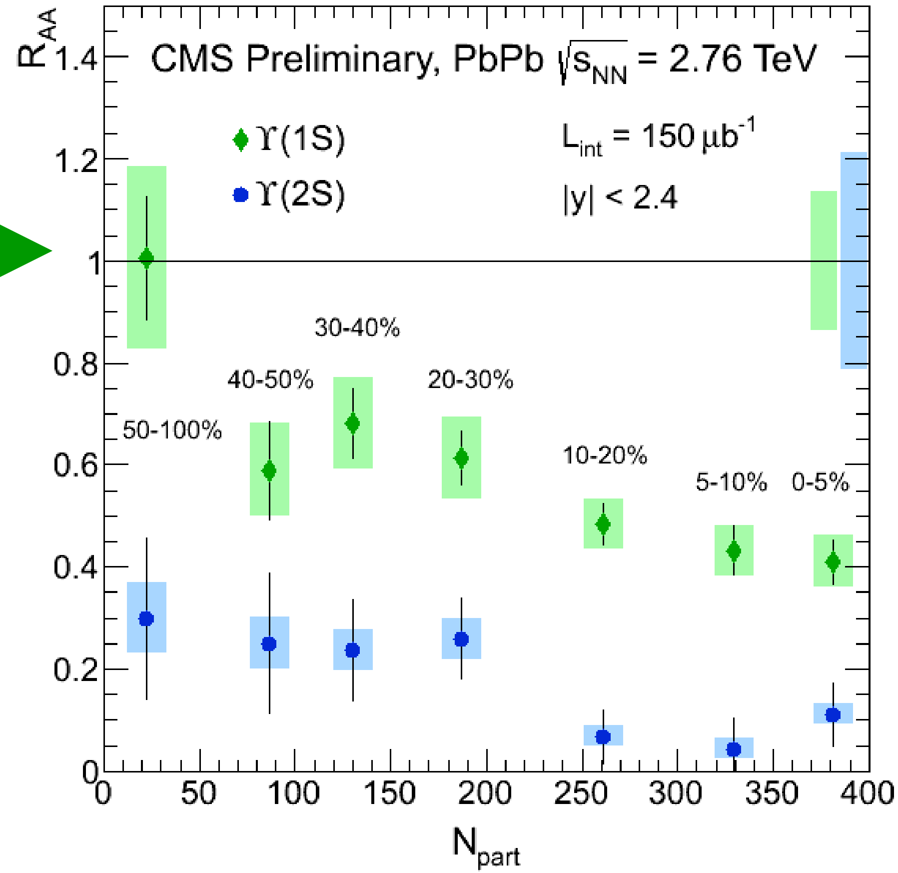
- **Testing sequential suppression scenario at SPS is crucial to fully understand RHIC and LHC results.**

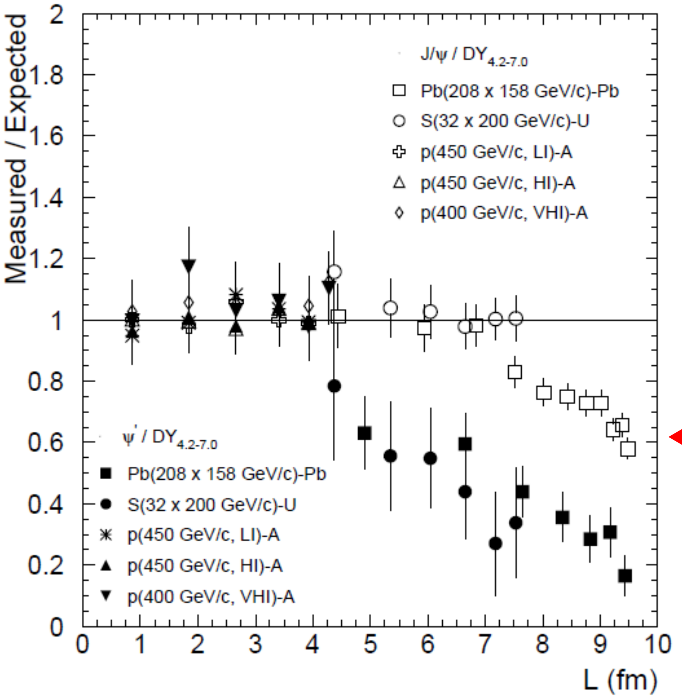
New upsilon results

Results from CMS

"Observation of Sequential ϒ Suppression in PbPb collisions" (at LHC)

PRL109, 222301 (2012)

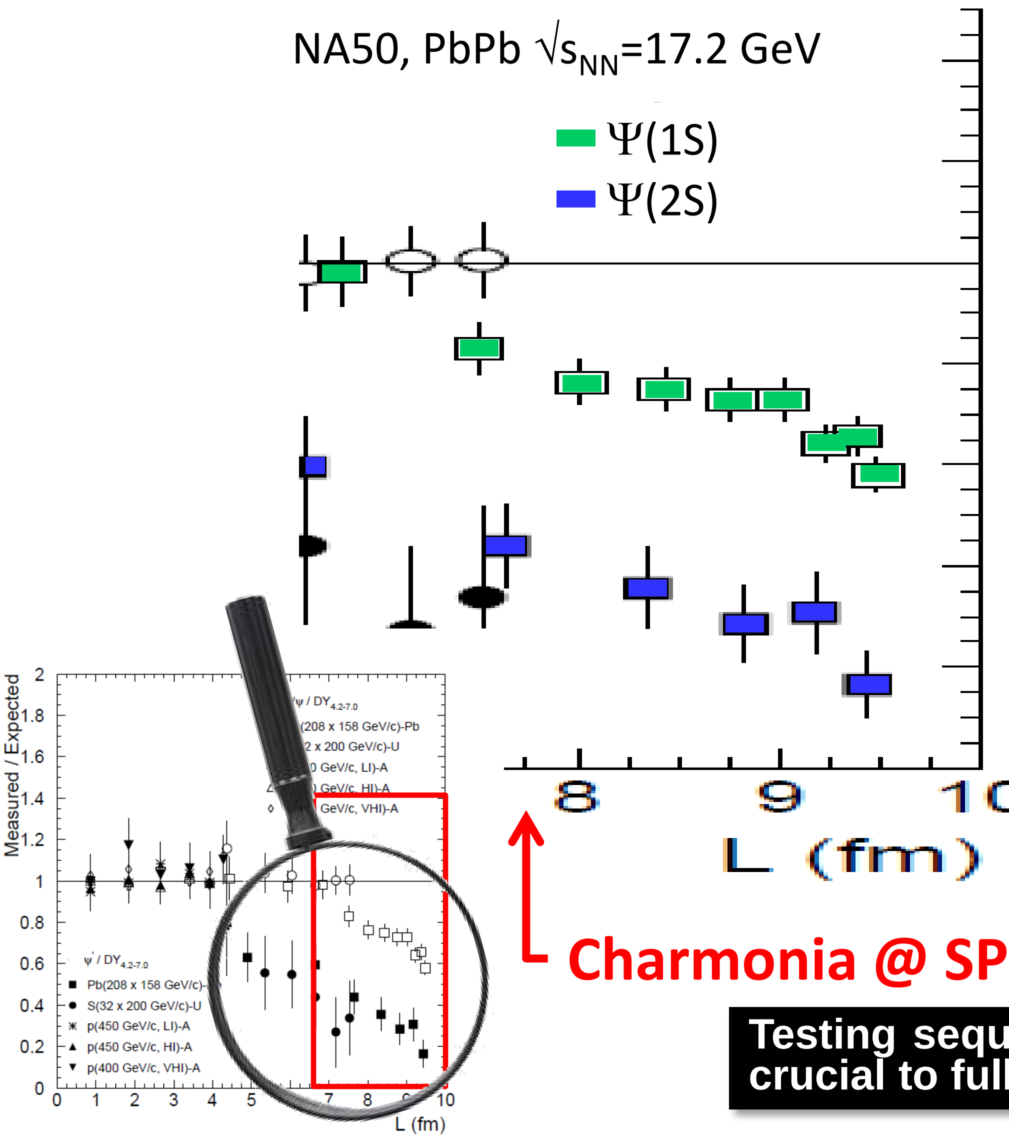


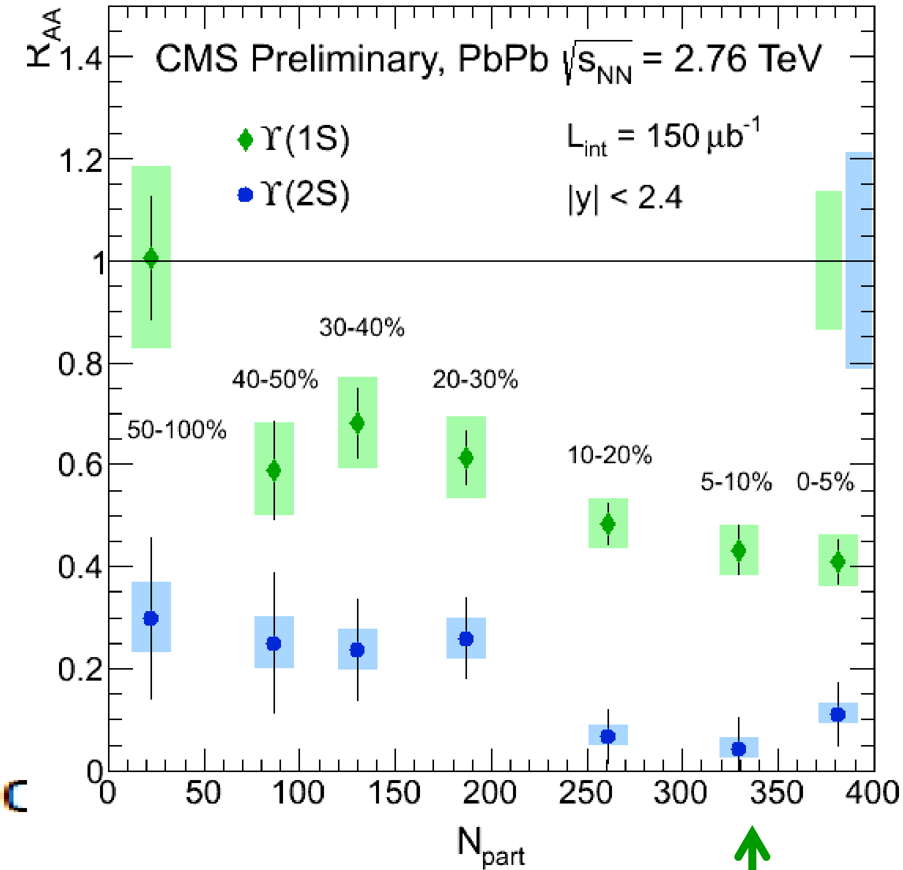


Charmonia @ SPS **bottomonia @ LHC**

Testing sequential suppression scenario at SPS is crucial to fully understand RHIC and LHC results.

J/Ψ@SPS .vs. ϒ@LHC color screening ?





Charmonia @ SPS **bottomonia @ LHC**

Testing sequential suppression scenario at SPS is crucial to fully understand RHIC and LHC results.

Expression of interest

- **Submitted to SPSC** **(oct. 2012)**

Expression of Interest
Submitted to SPSC – oct.2012
CERN-SPSC-2012-031

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH

Expression of Interest

for an experiment to study charm production with proton and heavy ion beams

(CHIC: Charm in Heavy Ion Collisions)

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Draft MINUTES on the 108th Meeting of the SPSC
15-16 January 2013
CERN-SPSC-2013-008

The SPSC has received an expression of interest to study charm production with proton and heavy ion beams. The SPSC recognizes the **strong physics motivation** of a study that addresses **central open questions** about the **color screening** of charmonium in heavy ion collisions and about **cold nuclear matter effects**. For a comprehensive investigation, an extension including open charm production would be desirable.

For further review, the SPSC would require a letter of intent with information about the experimental implementation and the **collaboration** pursuing it.

Project status

- **Current think tank**
  - F. Arleo, E.G. Ferreiro, F. Fleuret, P.-B. Gossiaux, S. Peigné
- **apparatus**
  - **Tracking**
    - Performed upstream of the absorber
    - Needs low detector occupancy → silicon technology
    - **Welcomes group with expertise !**
  - **Calorimetry**
    - Around 400 γ per rapidity unit in central PbPb collisions
    - Need ultragranular calorimetry à la CALICE
    - Lab currently involved : **LLR - Ecole polytechnique (France)**
  - **Trigger**
    - Absorber can be made of Fe (since tracking is performed upstream)
    - Absorber can be magnetized and, since instrumented, can provide momentum information to be matched with the tracker (RPCs?, micromegas?)
    - **Welcomes group with expertise !**

- **Timeline**
  - From T_0 (3 labs involved): ~ 5 Years for full simulation and final design (2 years), construction and installation (2 years), commisionning (1 year)

backup

Mass resolution

- CHIC expected performances for low mass dileptons
  - Tracking performed upstream to the absorber
    - ➔ no multiple scattering due to absorber
    - ➔ momentum resolution affected by magnetic field only:

$$\frac{\Delta P}{P} \propto \frac{1}{BL^2} P$$

  - Momentum resolution
    - With a 1m long 2.5T dipolar magnetic field
      - $\frac{\Delta P_\mu}{P_\mu}$ = 1% for typical muon from J/Ψ (<P_μ> ~10 GeV/c)
      - $\frac{\Delta P_\mu}{P_\mu}$ = 0.7% for typical muon from ω (<P_μ> ~7 GeV/c)
  - Expected mass resolution:
    - J/Ψ: $\frac{\Delta P_\mu}{P_\mu} = 1\%$ ➔ $\frac{\Delta P_\mu}{\sqrt{2}P_\mu} = \frac{\Delta M_{\mu\mu}}{M_{\mu\mu}} = 0.7\%$
    - ω: $\frac{\Delta P_\mu}{P_\mu} = 0.7\%$ ➔ $\frac{\Delta P_\mu}{\sqrt{2}P_\mu} = \frac{\Delta M_{\mu\mu}}{M_{\mu\mu}} = 0.5\%$

$\Delta M_{\mu\mu}^{J/\Psi} \sim 3.097\ \mathrm{GeV}/c^2 \times 0{,}7\% \sim 20\ \mathrm{MeV}/c^2$

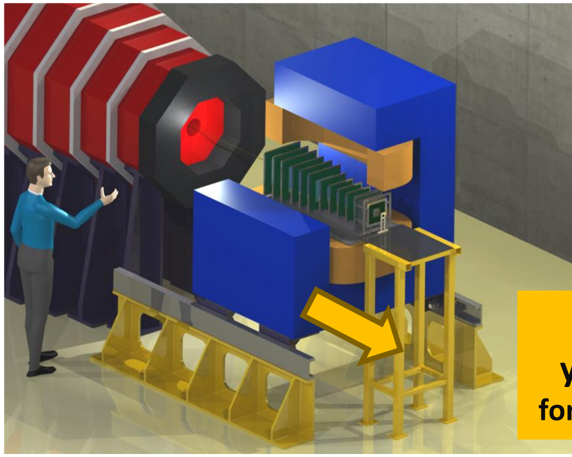
NA50: $\Delta M_{\mu\mu}^{J/\Psi} \sim 90\ \mathrm{MeV}/c^2$

$\Delta M_{\mu\mu}^{\omega} \sim 782.7\ \mathrm{MeV}/c^2 \times 0{,}5\% \sim 4\ \mathrm{MeV}/c^2$

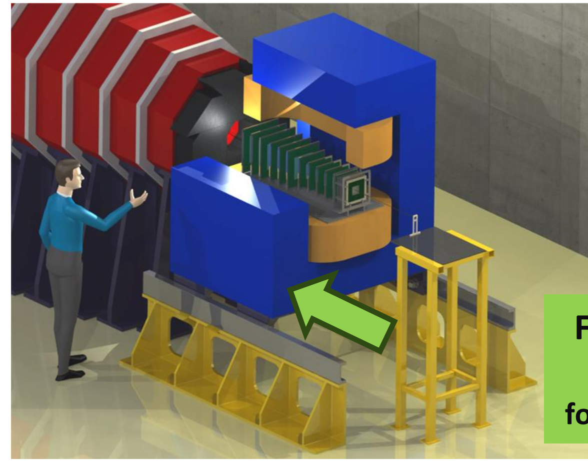
NA60: $\Delta M_{\mu\mu}^{\omega} \sim 20\ \mathrm{MeV}/c^2$

Rapidity coverage

- **Spectrometer acceptance: two detector configurations**



Mid-rapidity
$y_{CMS} \in [-0.5 ; 1]$
for P_{beam} = 158 GeV/c



Forward-rapidity
$y_{CMS} \in [0.5 ; 2]$
for P_{beam} = 158 GeV/c

Depending on the beam energy, different rapidity ranges accessible

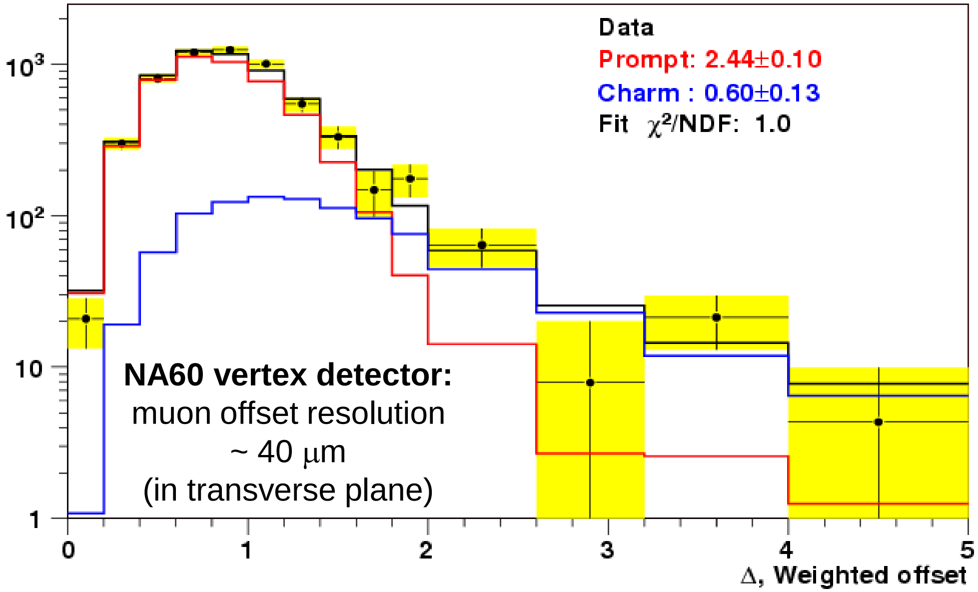
P_{beam} (GeV/c)	$\sqrt{s}$ (GeV)	Rapidity of Center-of-mass	Mid-rapidity		Forward-rapidity	
			y_{CMS} min	y_{CMS} max	y_{CMS} min	y_{CMS} max
158	17.2	2.91	-0.5	1	0.5	2
120	15.1	2.77	-0.36	1.14	0.65	2.14
80	12.3	2.57	-0.16	1.34	0.84	2.34
60	10.7	2.43	-0.02	1.48	0.98	2.48

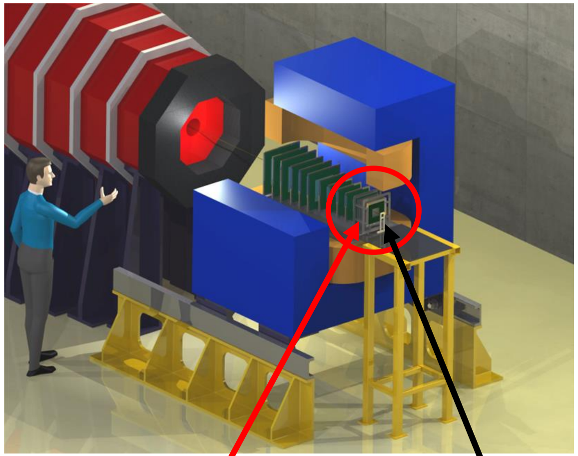
Common coverage: $y_{CMS} \in [0;2]$ **(NA50/NA60 coverage = [0;1])**

Measuring muon offset

- **Use same Strategy as NA60: measure muon vertex**
  - Open charm decay length: $\begin{cases} D^{+/-}: c\tau = 311.8\ \mu m \\ D^0: c\tau = 122.9\ \mu m \end{cases}$
  - P_{lab} = 158 GeV/c → γ=9.2 → $\begin{cases} D^{+/-}: \gamma c\tau = 2.86\ \text{mm} \\ D^0: \gamma c\tau = 1.13\ \text{mm} \end{cases}$

(simulation studies ongoing to estimate CHIC performances)





CHIC: Vertex detector located 7.5 cm downstream from the target
(7 cm for NA60)

target

NA60 capable to separate prompt (red) from charm (blue) contribution

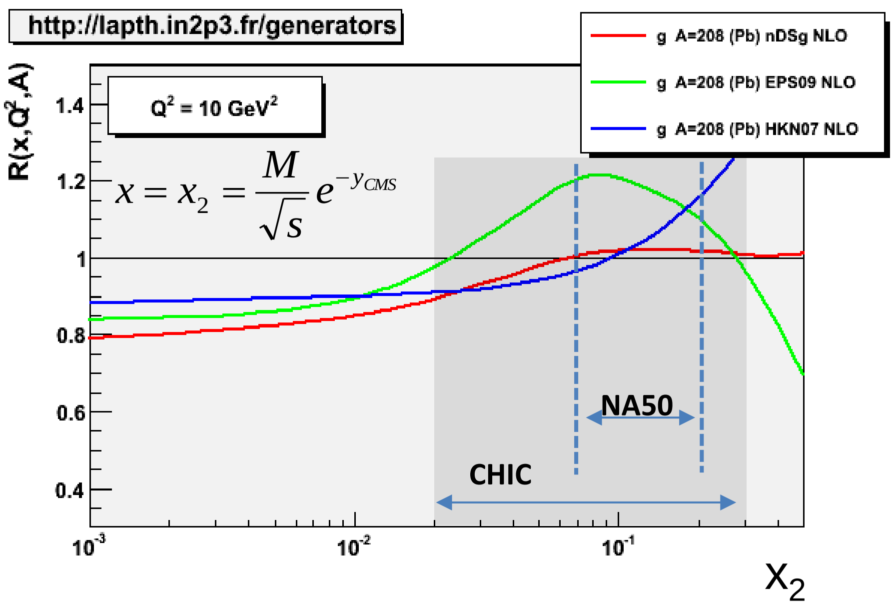
- **In principle, CHIC can measure open charm.**
- **Simulations on-going…**

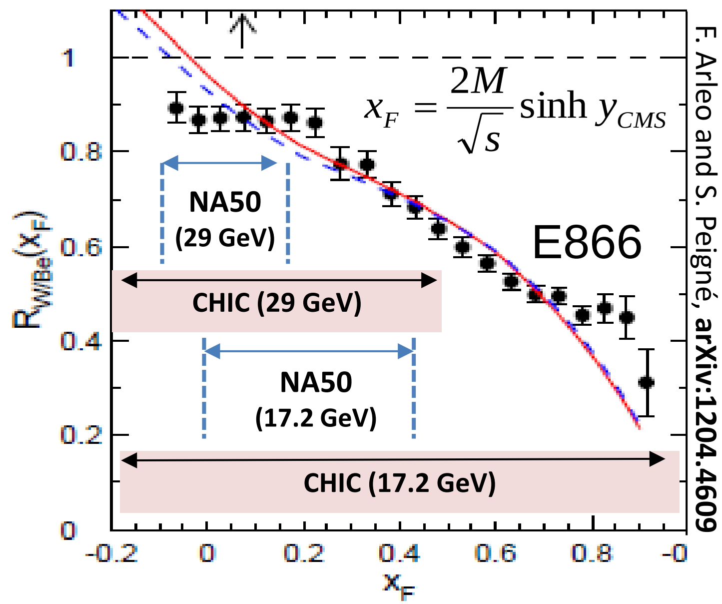
Large rapidity coverage

- **A thorough p+A program**
  - mandatory as reference for hot nuclear matter effects

J/Ψ, Ψ', χ_c in a large y_{CMS} range
→ Large coverage in x_2
→ Large coverage in x_F

E_{beam} ($\sqrt{s}$)	Exp.	y_{CMS}	x_2	x_F
158 GeV (~17 GeV)	NA50	[0;1]	[0.07;0.18]	[0;0.42]
	CHIC	[-0.5;2]	[0.02;0.30]	[-0.19;1]
450 GeV (~29 GeV)	NA50	[-0.4;0.6]	[0.06;0.16]	[-0.09;0.14]
	CHIC	[-0.9;1.6]	[0.02;0.26]	[-0.22;0.51]





Measuring χ_c at SPS

- **Operate a new experiment**
  - Primary goal:

    $\chi_c \rightarrow J/\Psi + \gamma \rightarrow \mu^+ \mu^- \gamma$
  - Beam:

    high-intensity 158 GeV/c Pb beam

    high-intensity 158/450 GeV/c *p* beam
  - Detector features :

    Vertex detector + Spectrometer

    Measures tracks before absorber for very good mass resolution

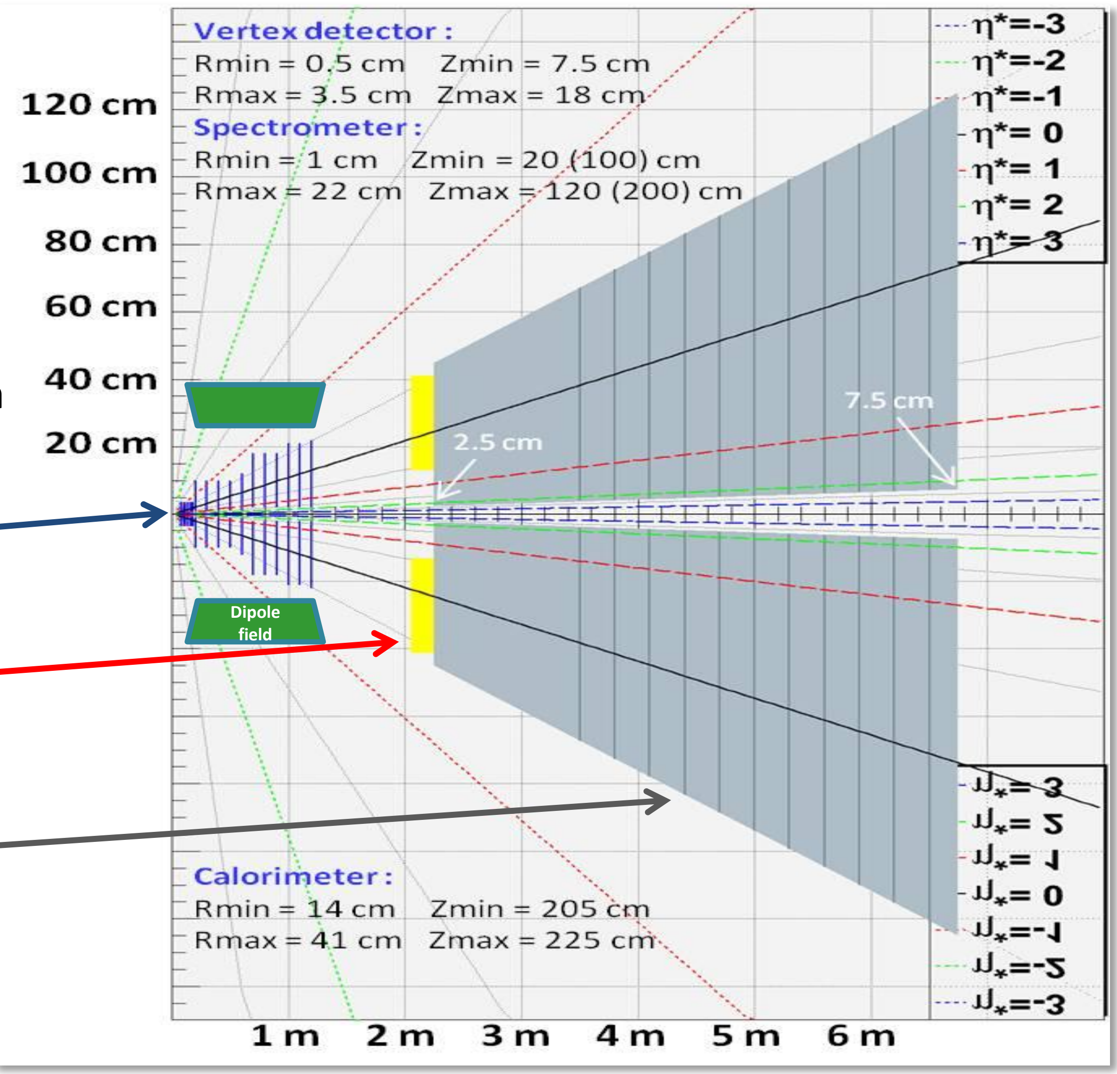
    Ultra-granular calorimeter

    Measures low energy γ in high π^0 multiplicity environment

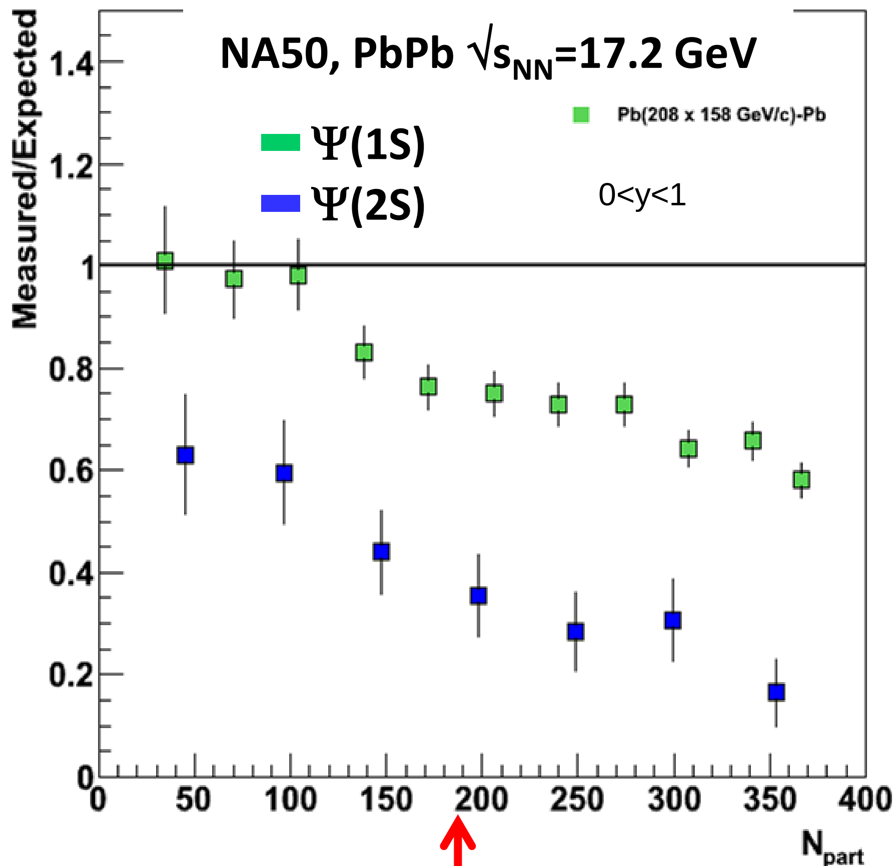
    Absorber/trigger

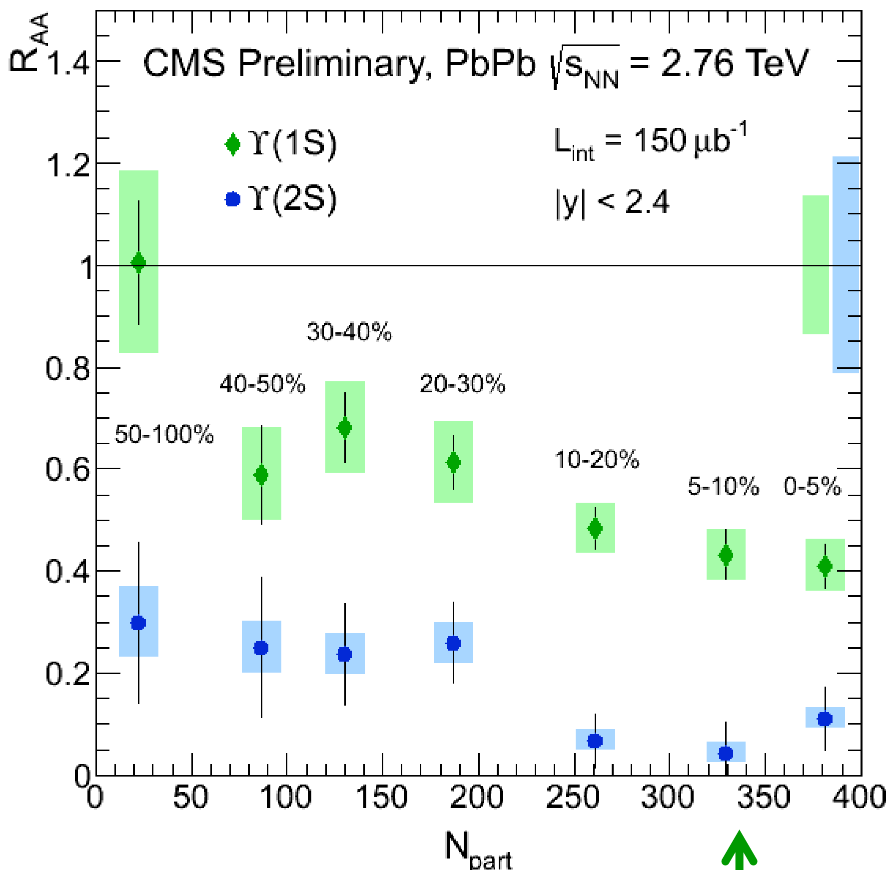
    Absorbs π/K

    Minimize fake triggers from π/K decays



J/Ψ@SPS .vs. Υ@LHC color screening ?





Charmonia @ SPS **bottomonia @ LHC**

On the same axis

CHIC

CERN strategy

Conclusions of the CERN Town meeting on “Relativistic Heavy-Ion Collisions”

CERN - june 29, 2012

“…The town meeting also observed that the CERN SPS would be well-positioned to contribute decisively and at a competitive time scale to central open physics issues at large baryon density. In particular, the CERN SPS will remain also in the future the only machine capable of delivering, heavy ion beams with energies exceeding 30 GeV/nucleon, and the potential of investigating rare penetrating probes at this machine is attractive.”