An experiment to measure χ_c suppression 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)

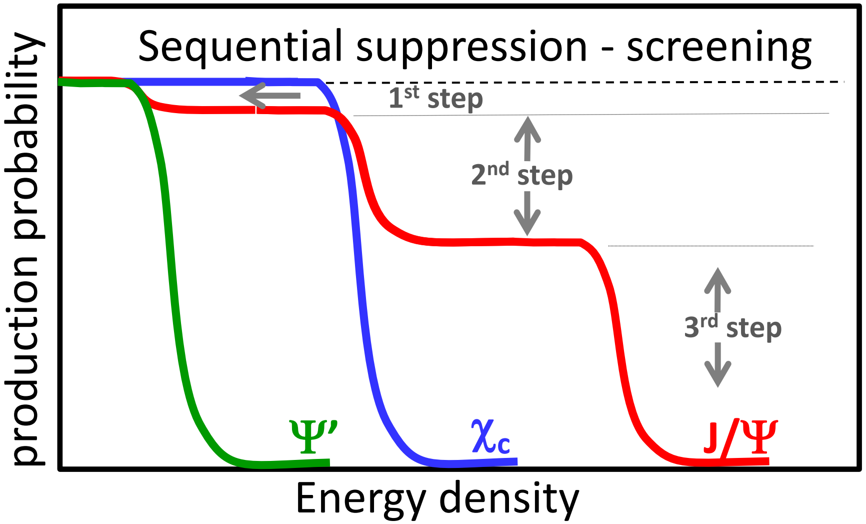
quarkonium dissociation temperature / critical QGP temperature →

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.

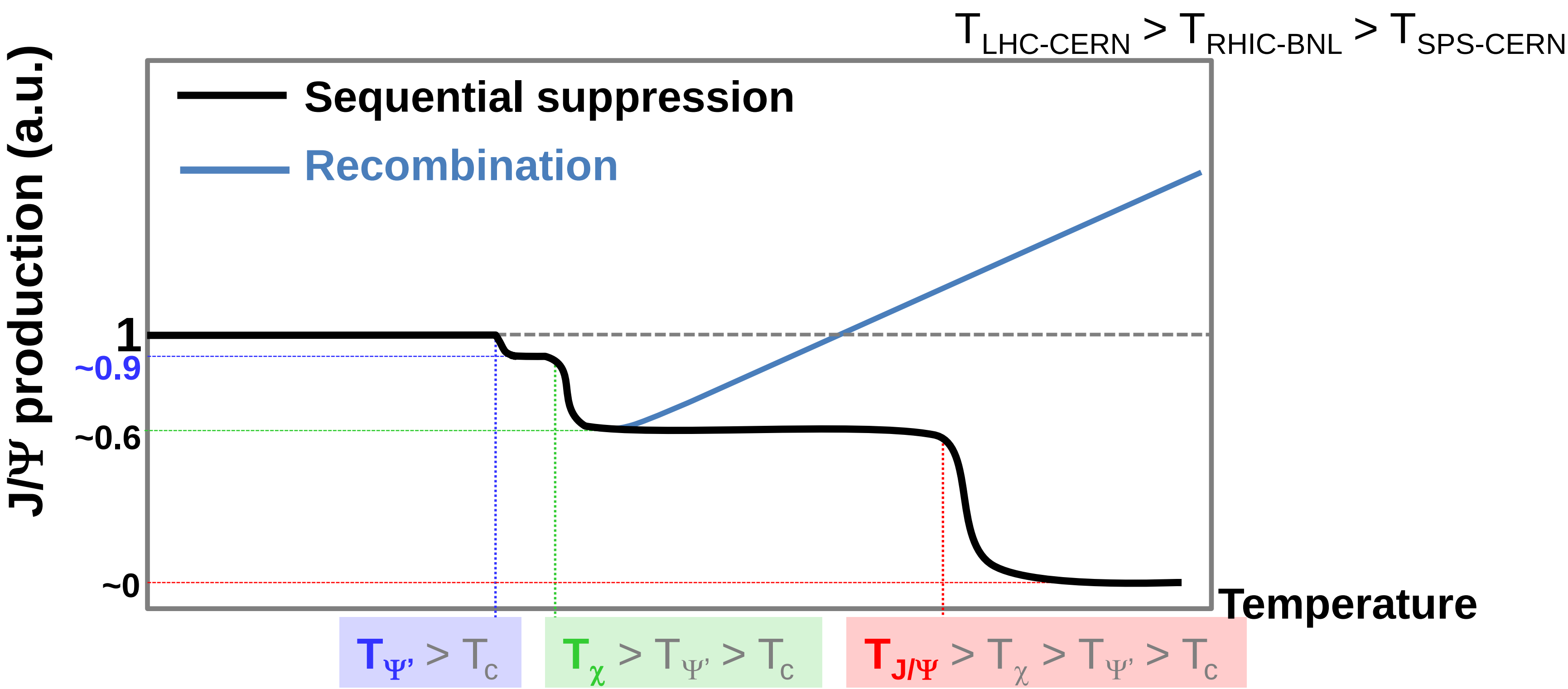
Feed-downs contributing to J/Ψ inclusive yield

60% direct J/Ψ
+ 30% $\chi_c \rightarrow J/\Psi+\gamma$
+ 10% Ψ' → J/Ψ + X
Inclusive J/Ψ yield



The Physics case

- **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?



Experimentally

- **Charmonium production in A+A collisions studied at:**
  - SPS ($\sqrt{s}$~17 GeV) : NA38, NA50, NA60 experiments
  - RHIC ($\sqrt{s}$~200 GeV) : PHENIX, STAR experiments
  - LHC ($\sqrt{s}$~2.76 TeV) : ALICE, CMS experiments

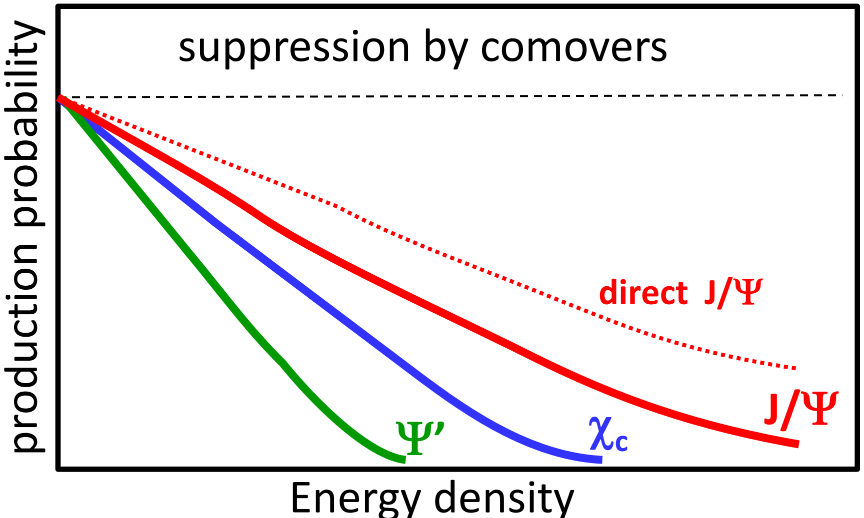
- **Short summary for J/Ψ:**
  - NA50 (PbPb@SPS) observed an *anomalous* suppression
  - PHENIX (AuAu@RHIC) observed a similar suppression (than NA50)
  - ALICE (PbPb@LHC) observed a smaller suppression for low p_T J/Ψ
  - CMS (PbPb@LHC) observed a larger suppression for high p_T J/Ψ

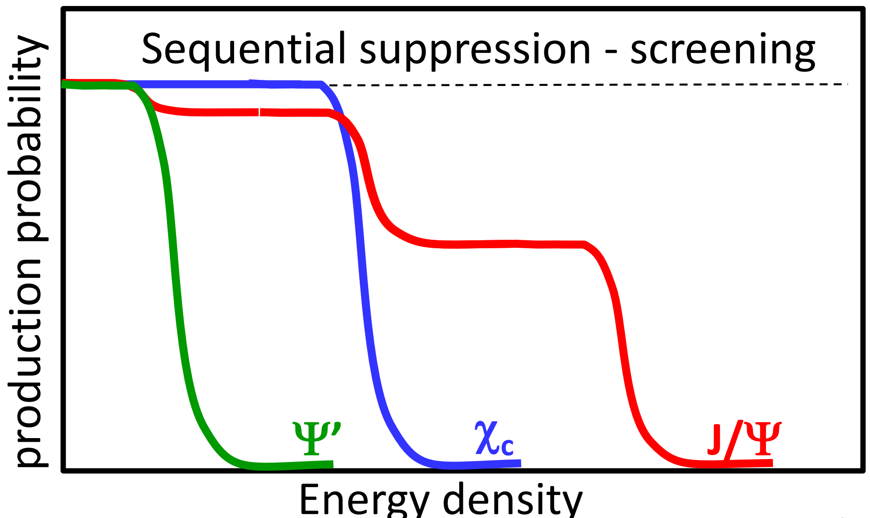
- **Unclear picture :**
  - Observed Hot and Dense Matter effects. For quarkonia, are they due to
    - **color screening ?** Apply in principle at SPS, RHIC and LHC
    - **Recombination ?** Apply at RHIC? LHC?
    - **Both ?**

- **To understand Hot and Dense Matter effects on charmonium,**
  - **need to confirm color screening scenario first.**
  - Recombination study is a second step (at higher energies).

Color screening

- **How to Test sequential suppression with charmonia ?**
  1. must be in a regime where recombination is negligible → **SPS energies**
  2. must measure the suppression pattern of **several related states**, for instance:
     - ~30% of the inclusive J/Ψ yield comes from χ_c decay.
     - According to lattice calculations, $T_d(\chi_c) < T_d(J/\Psi)$
     - **If screening, one should observe a step-like suppression patterns**
  - *Alternative scenario: suppression by comoving hadrons*
    - *Smooth suppression*
    - *Same 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) ?

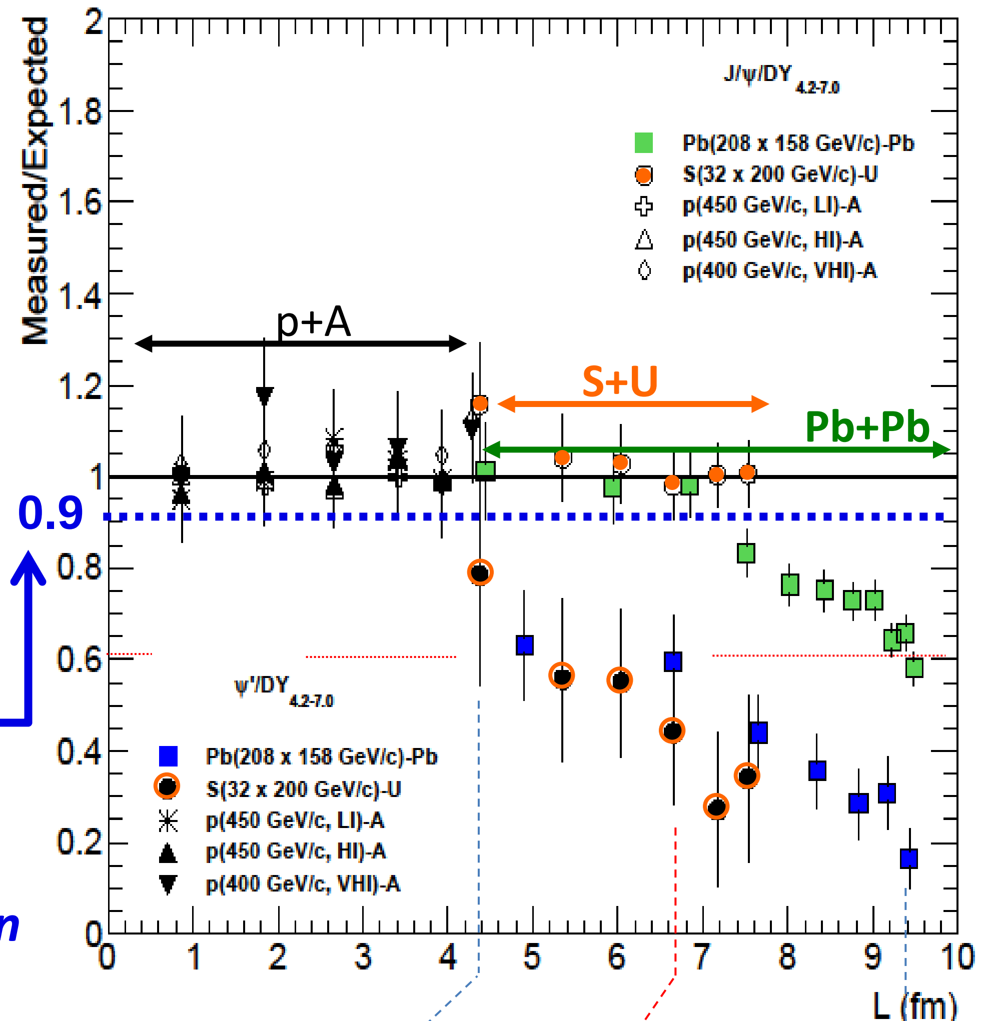
use J/Ψ feed-downs to discriminate

60% direct J/Ψ
+ 30% $\chi_c \rightarrow J/\Psi+\gamma$
+ 10% Ψ' → J/Ψ + X
Inclusive J/Ψ yield

NA50 measured J/Ψ and Ψ', but,

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

0.9



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 !

Comovers

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

Expectations in comovers scenario

Binding energy

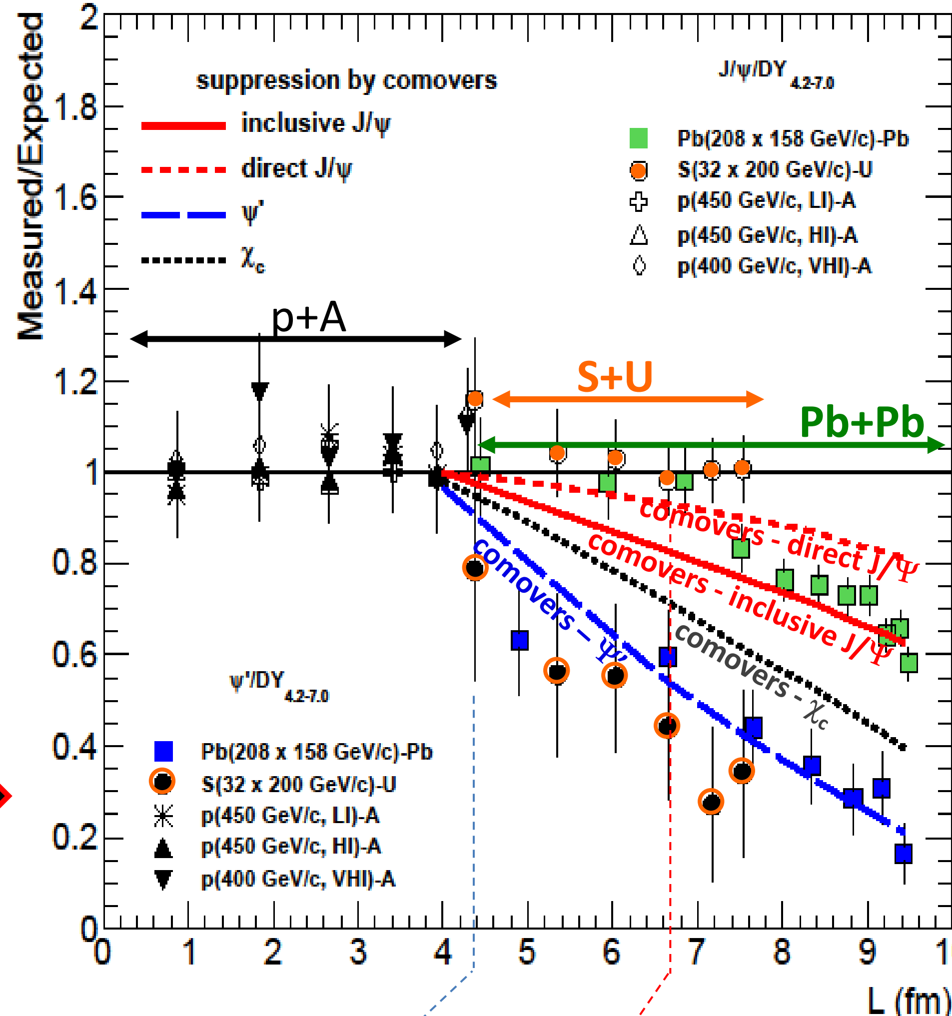
state	η_c	J/ψ	χ_{c0}	χ_{c1}	χ_{c2}	ψ'
mass [GeV]	2.98	3.10	3.42	3.51	3.56	3.69
ΔE [GeV]	0.75	0.64	0.32	0.22	0.18	0.05

Taking breakup cross-sections:

- **comovers-direct J/Ψ = 0.2 mb**
- **comovers – χ_c = 1.0 mb**
- **comovers – Ψ' = 2.0 mb**

and considering feed-downs

60% direct J/Ψ
+ 30% $\chi_c \rightarrow J/\Psi+\gamma$
+ 10% $\Psi' \rightarrow J/\Psi + X$
Inclusive J/Ψ yield



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

Suppression patterns

- **Anomalous suppression at SPS**

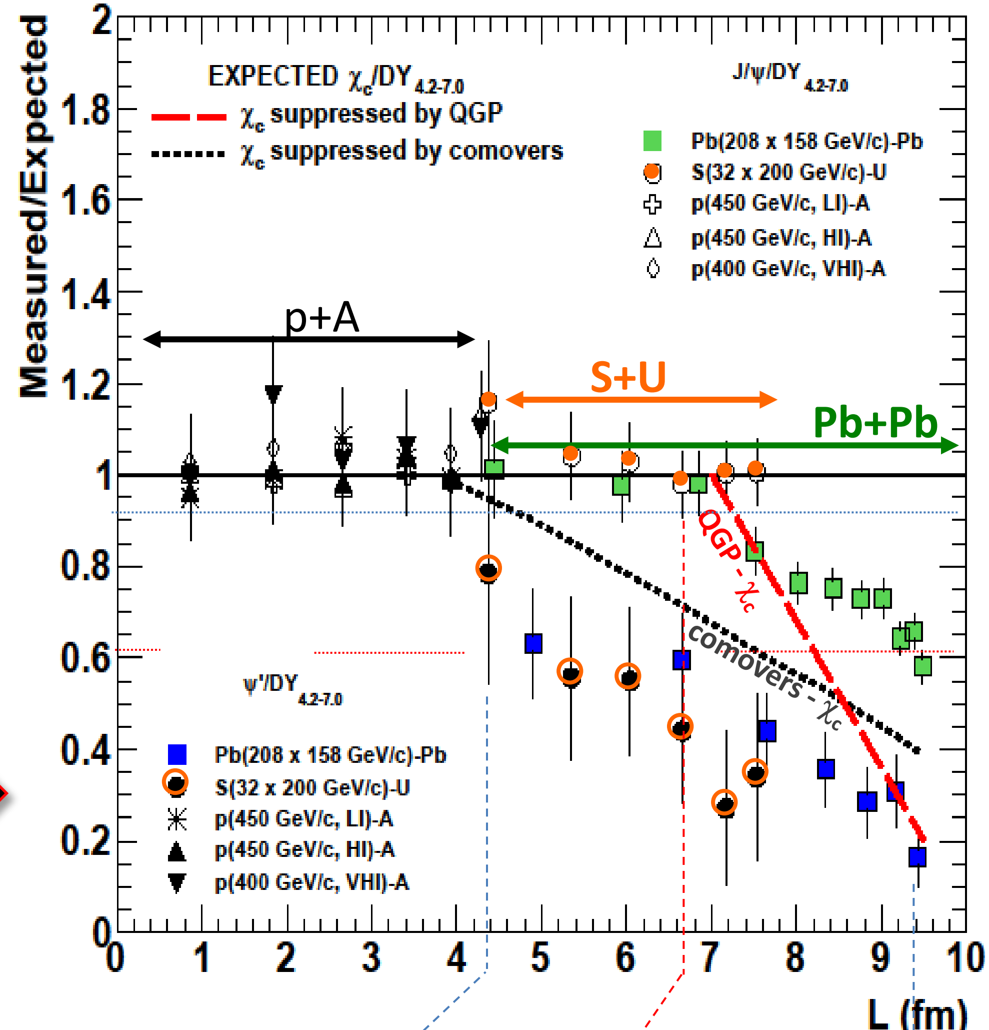
Eur.Phys.J.C49:559-567,2007

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



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

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

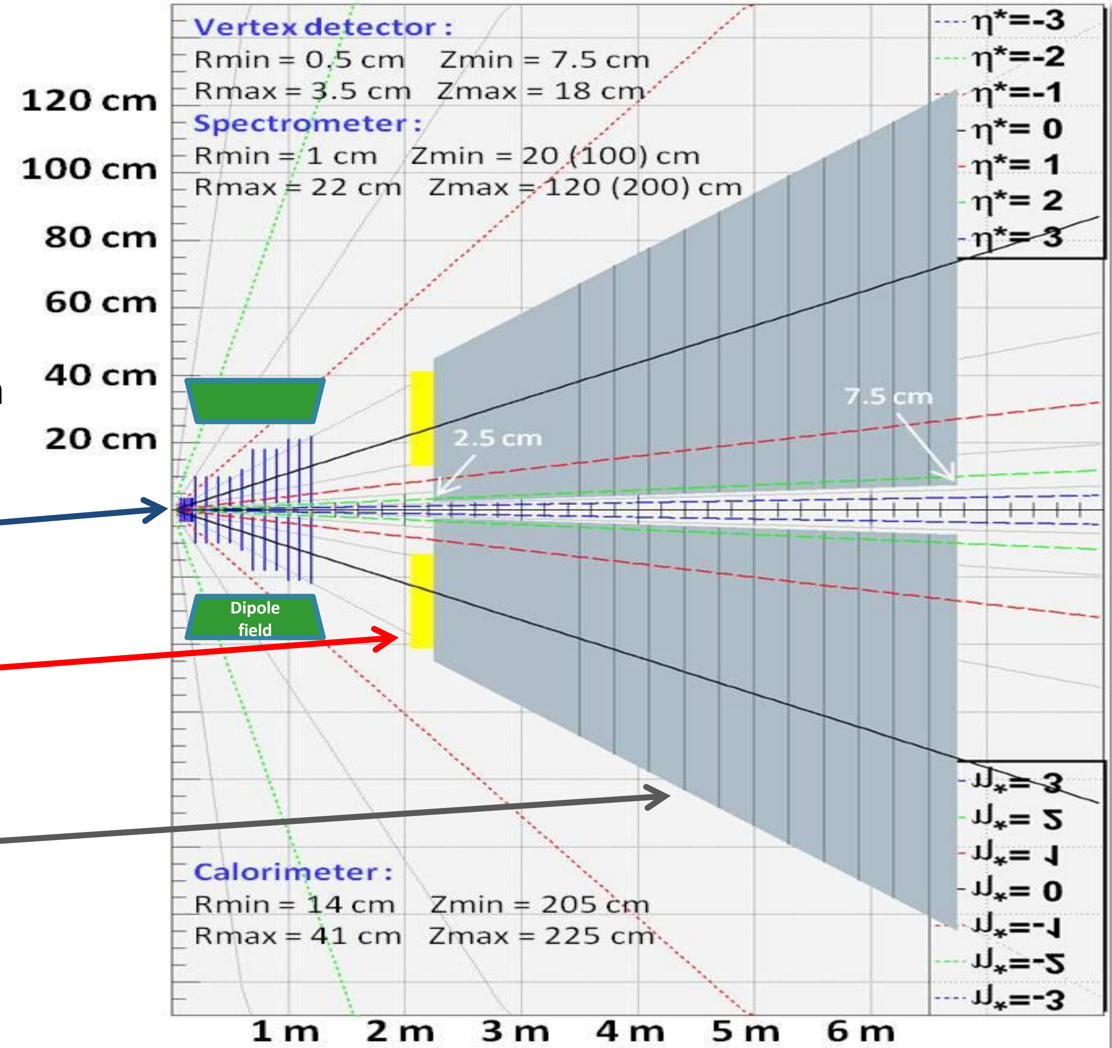
    Ultra-granular calorimeter

    Measures low energy γ in high π^0 multiplicity environment

    Absorber/trigger

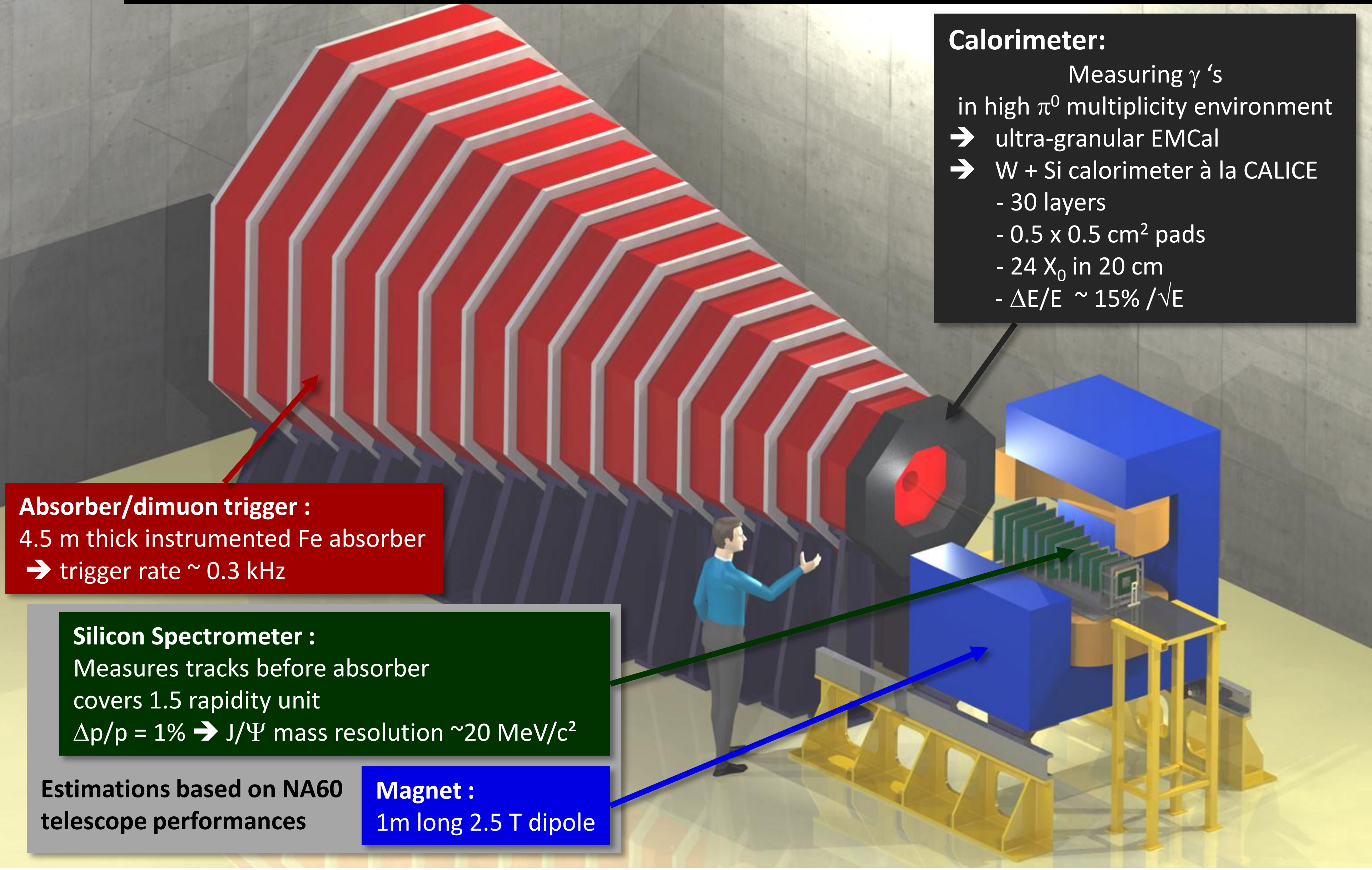
    Absorbs π/K

    Minimize fake triggers from π/K decays



Apparatus artist view

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



Calorimeter:

Measuring γ 's
in high π^0 multiplicity environment
➔ ultra-granular EMCal
➔ W + Si calorimeter à la CALICE
- 30 layers
- 0.5 x 0.5 cm^2 pads
- 24 X_0 in 20 cm
- $\Delta E/E \sim 15\% / \sqrt{E}$

Absorber/dimuon trigger :
4.5 m thick instrumented Fe absorber
➔ trigger rate ~ 0.3 kHz

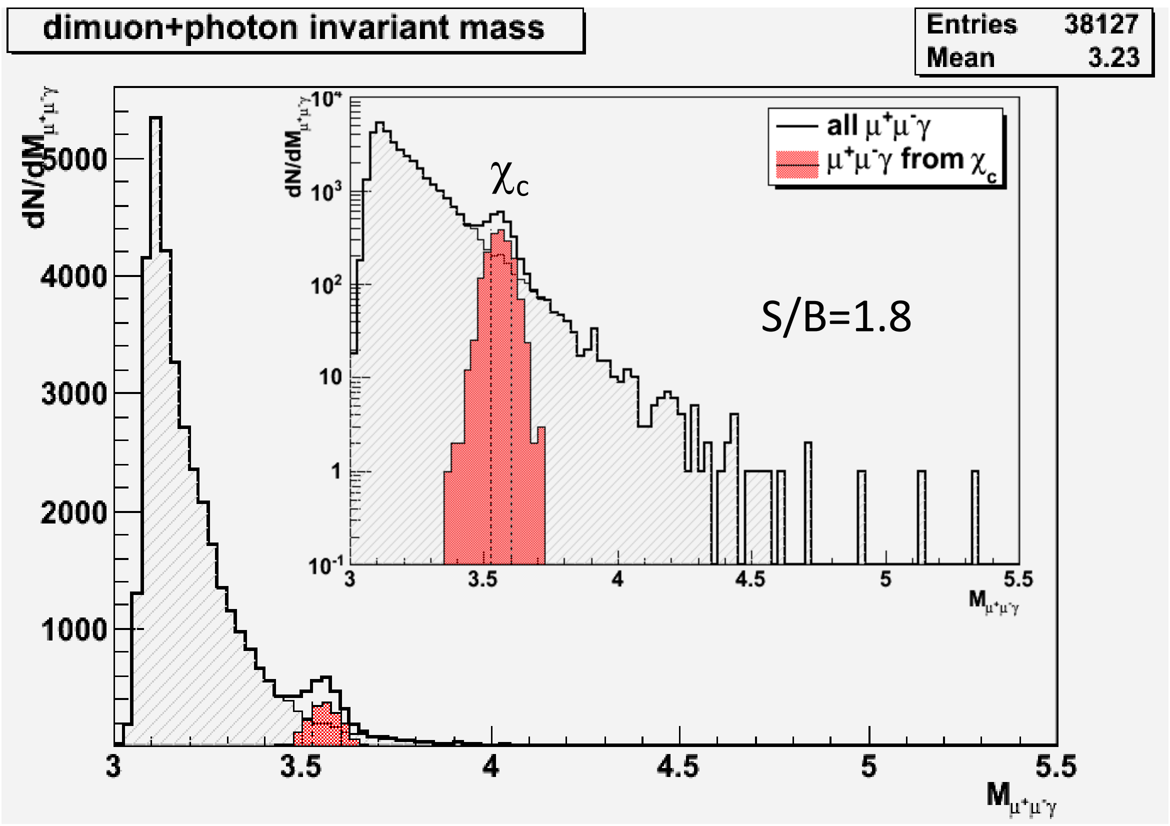
Silicon Spectrometer :
Measures tracks before absorber
covers 1.5 rapidity unit
$\Delta p/p = 1\%$ ➔ J/Ψ mass resolution ~20 MeV/c^2

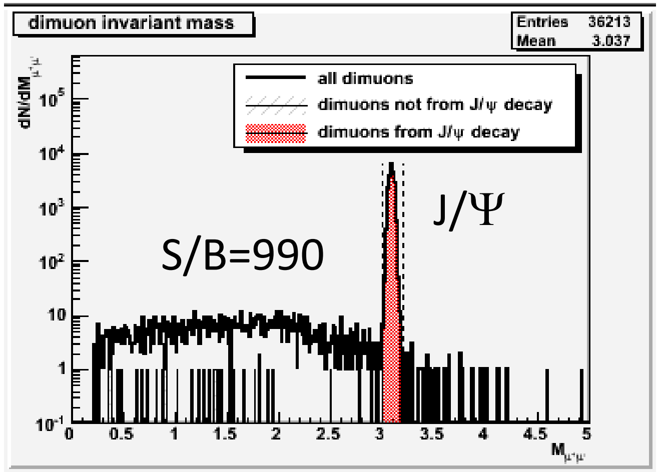
Estimations based on NA60 telescope performances

Magnet :
1m long 2.5 T dipole

Signal extraction

- **Typical mass plots** **(5 days data taking w/ a 10% λ_I Pb target)**
  - 200 000 Pb+Pb minBias EPOS events
    - 140 000 events with J/Ψ embedded (70%)
    - 60 000 events with χ_c embedded (30%)





After acceptance and selection cuts:

• 35 000 **J/Ψ**
➔ **acc x eff = 17.4%**
mass resolution ~ 20 MeV/c²

•1700 χ_c
➔ **acc x eff = 2.8 %**
mass resolution ~ 45 MeV/c²

Expected performances — Statistics

- **Typical 40-day Pb+Pb run**
  - ~ 180 000 inclusive $J/\Psi \rightarrow \mu^+\mu^-$ expected
  - 2 extreme numerical scenarios:
    - If χ_c suppressed as J/Ψ $\frac{\chi_c \text{ yield}}{J/\Psi \text{ yield}} \sim 4\%$

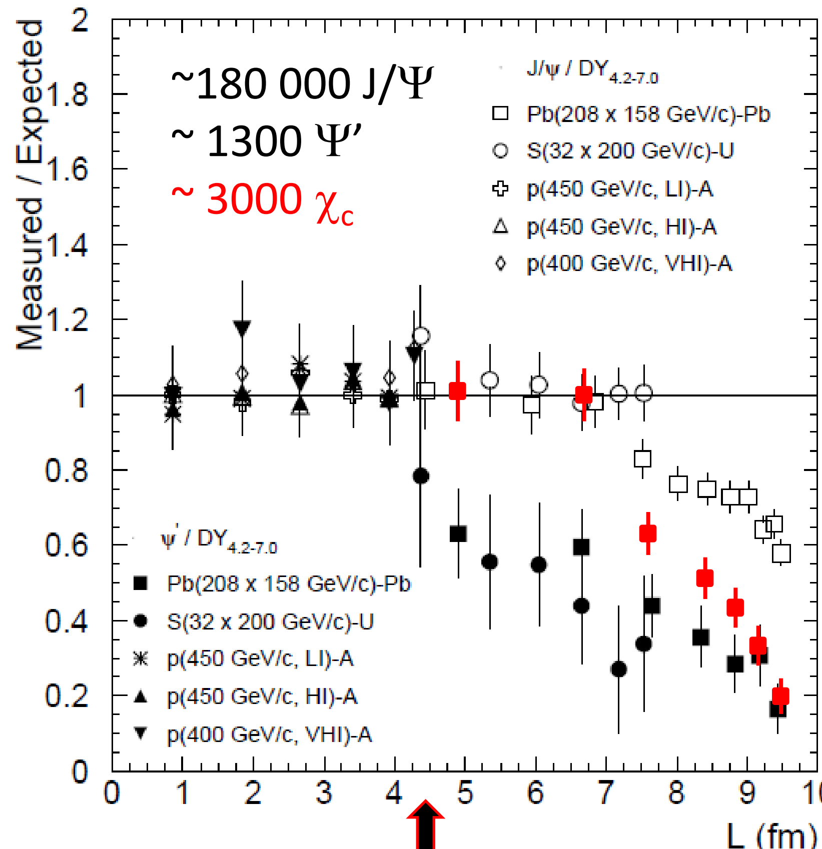
$$\rightarrow \begin{pmatrix}\text{most periph.}\\ \chi_c \text{ yield}\end{pmatrix} = 16942 \times 4\% = 677$$

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

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

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

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**



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

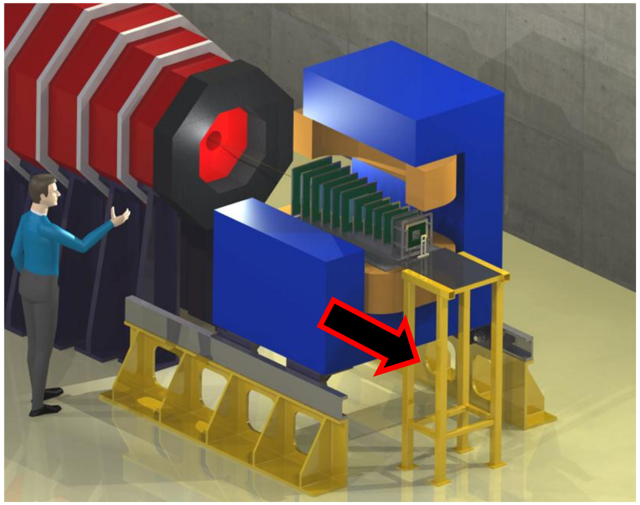
Cold Nuclear Matter

- **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 (saturation)… (x_F scaling)

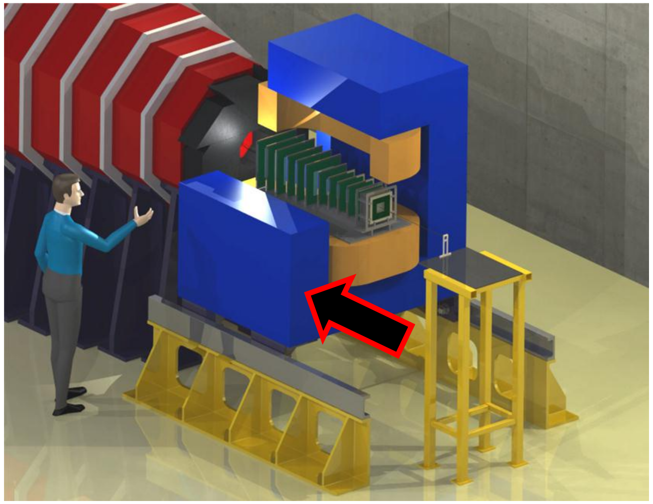
  } ➔ **Need large y_{CMS} range**

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

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



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

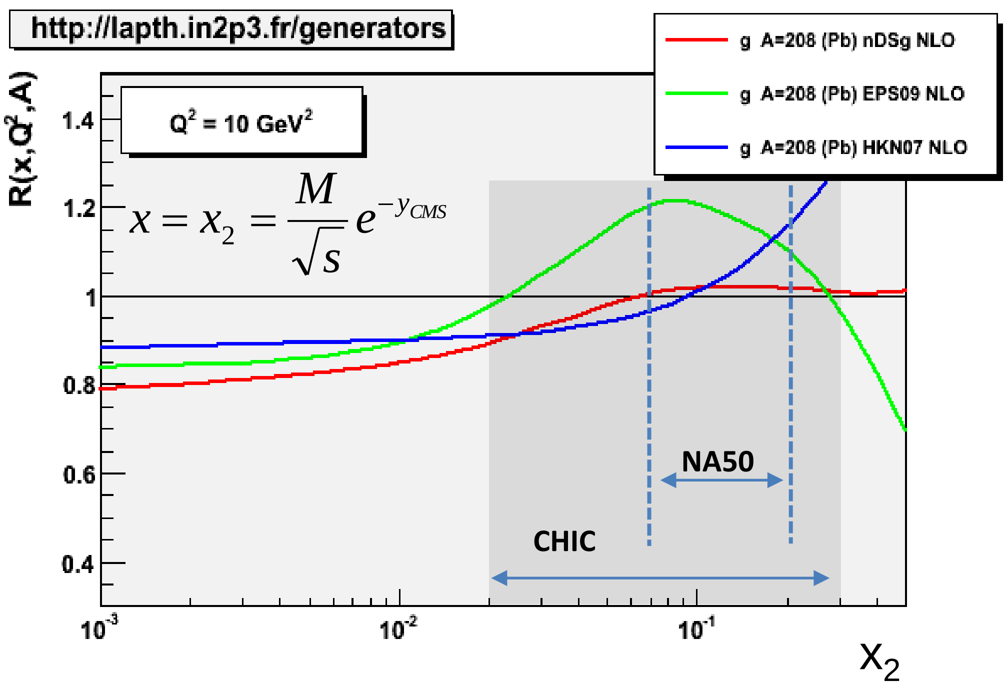


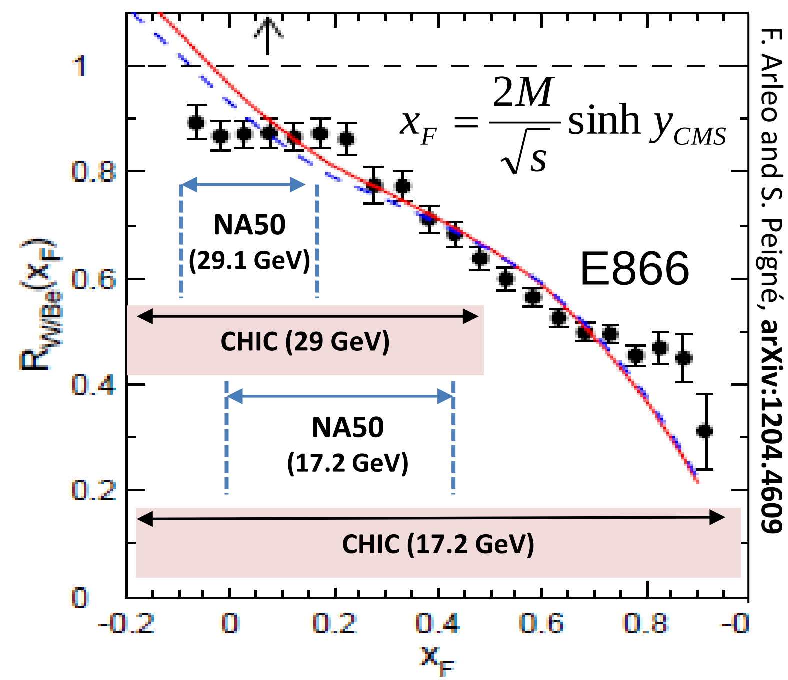
Large rapidity coverage

- **A thorough p+A program**

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]





High statistics

- **A thorough p+A program**
  - **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 (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)	Length (cm)
Be	60 %	21.7	50.7	368 000	13.0
Al	52 %	23.0	63.4	602 000	12.0
Cu	28 %	27.0	45.5	762 000	7.5
Ag	30 %	24.8	43.8	821 000	7.5
W	19 %	23.5	28.5	524 000	4.5

- Current SPS operation:
  - Delivering proton beam to the LHC several months per year

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

other physics opportunities

Low mass dileptons

Energy scan capabilities

Open charm measurement

Frédéric Fleuret - LLR (fleuret@in2p3.fr)

Mass resolution

- **CHIC expected performances for low mass dileptons**
  - Tracking performed upstream to the absorber
    - ➔ no multiple scattering due to absorber
    - ➔ momentum resolution determined 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: $\frac{\Delta P_\mu}{P_\mu} = 0.7\%$ ➔ $\frac{\Delta P_\mu}{\sqrt{2} P_\mu} = \frac{\Delta M_{\mu\mu}}{M_{\mu\mu}} = 0.5\%$

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

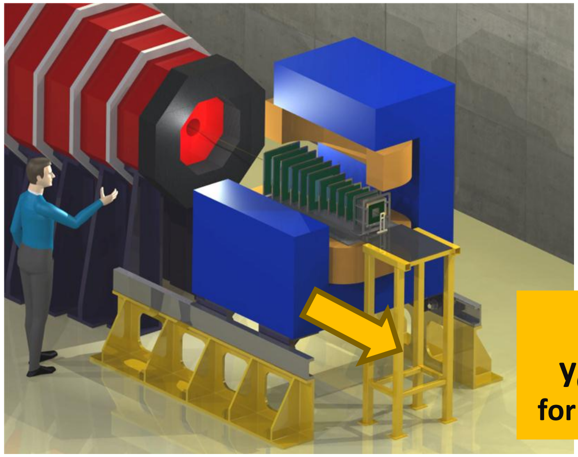
NA50: $\Delta M_{\mu\mu}^{J/\Psi} \sim 90\ \mathrm{MeV}/c^2$

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

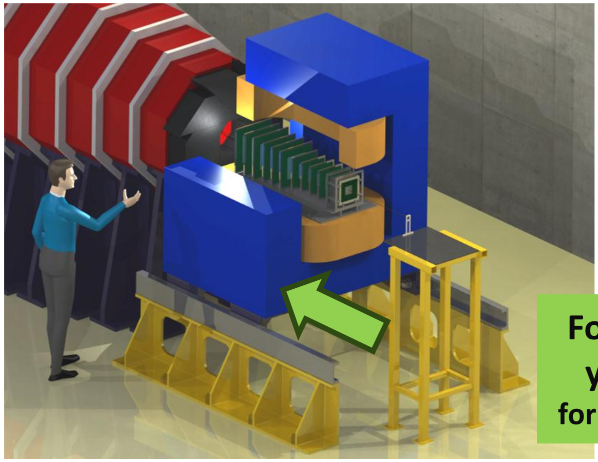
NA60: $\Delta M_{\mu\mu}^{\omega} \sim 20\ \mathrm{MeV}/c^2$

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

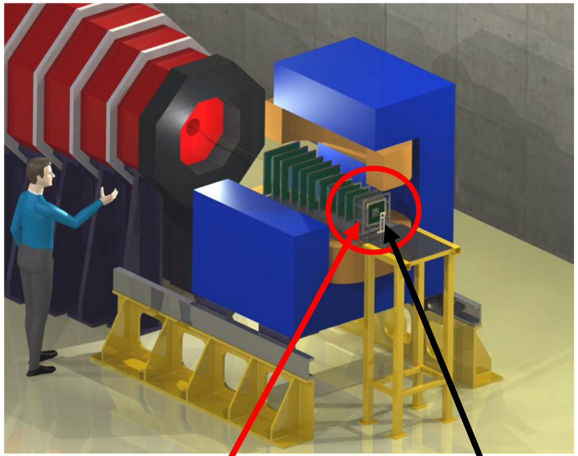
P_{beam} (GeV/c)	$\sqrt{s}$ (GeV)	Rapidity of Center-of-mass	Mid-rapidity		Forward-rapidity	
			y_{CMS} min	y_{CMS} max	y_{CMS} min	y_{CMS} max
158	17.2	2.91	-0.5	1	0.5	2
120	15.1	2.77	-0.36	1.14	0.65	2.14
80	12.3	2.57	-0.16	1.34	0.84	2.34
60	10.7	2.43	-0.02	1.48	0.98	2.48

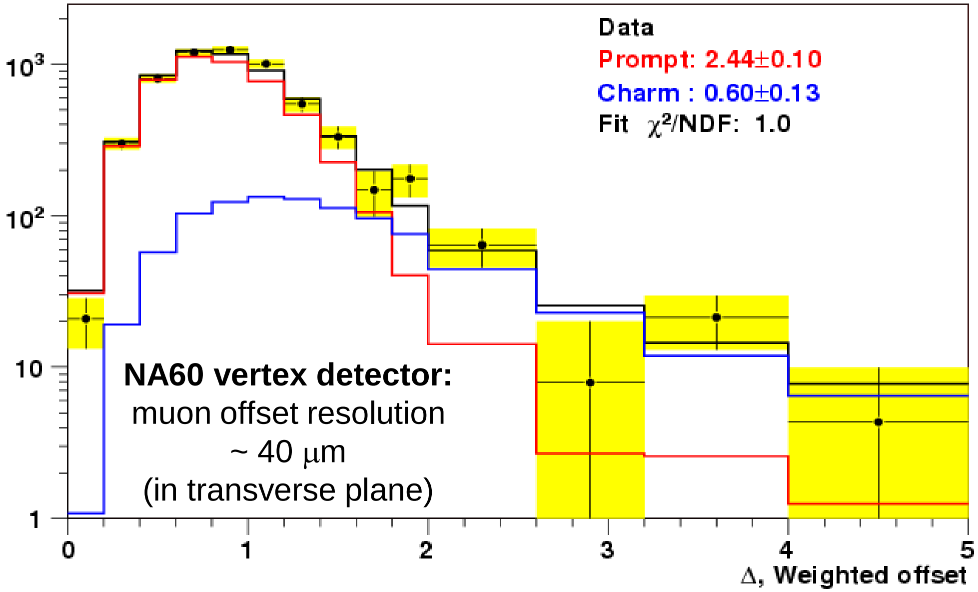
Common coverage: $y_{CMS} \in [0;2]$ **(NA50/NA60 coverage = [0;1])**

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 ➔ $\begin{cases} D^{+/-}: \gamma c\tau = 2.86\ \mathrm{mm} \\ D^0: \gamma c\tau = 1.13\ \mathrm{mm} \end{cases}$

(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

Thanks to advanced CMOS technology expect better performance for CHIC

Conclusion

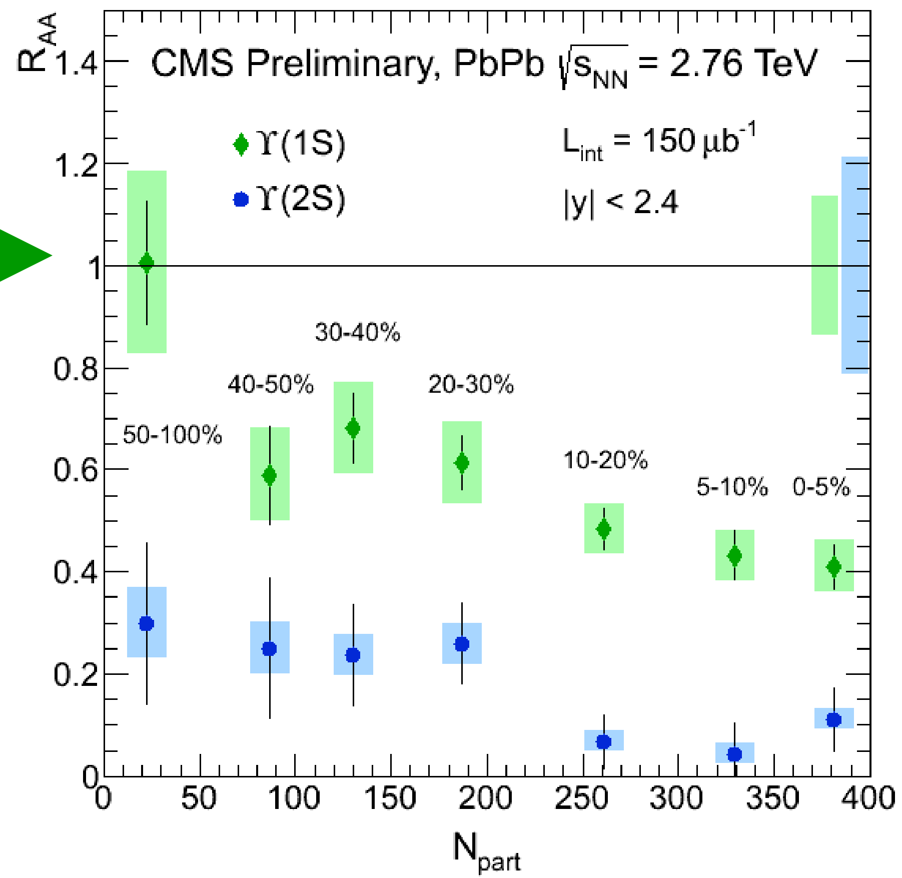
- **Measuring together J/Ψ, Ψ' and χ_c in p+A collisions with several targets will give a thorough control of Cold Nuclear Matter effects**
- **Measuring together J/Ψ, Ψ' and χ_c in A+A collisions at SPS energies will (dis)prove sequential suppression scenario.**
- **The apparatus is well suited to explore 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.**

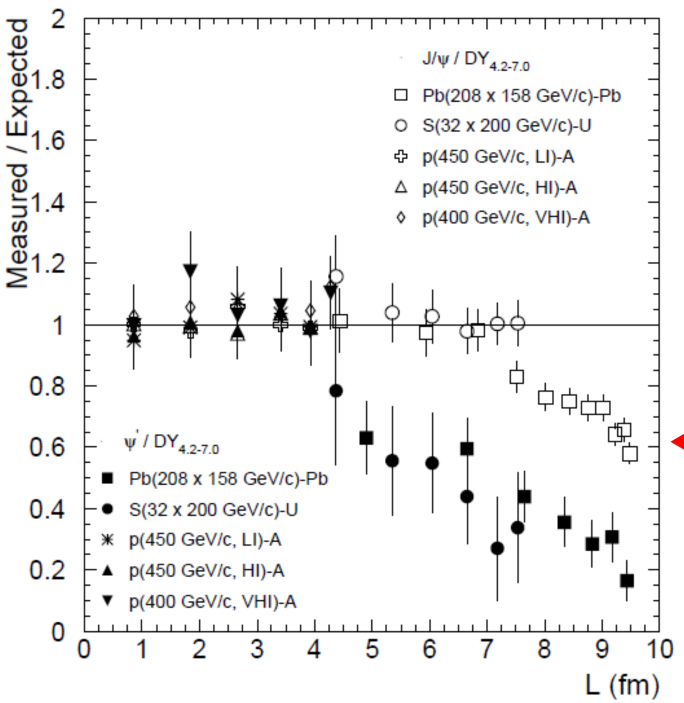
New upsilon results

Results from CMS

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

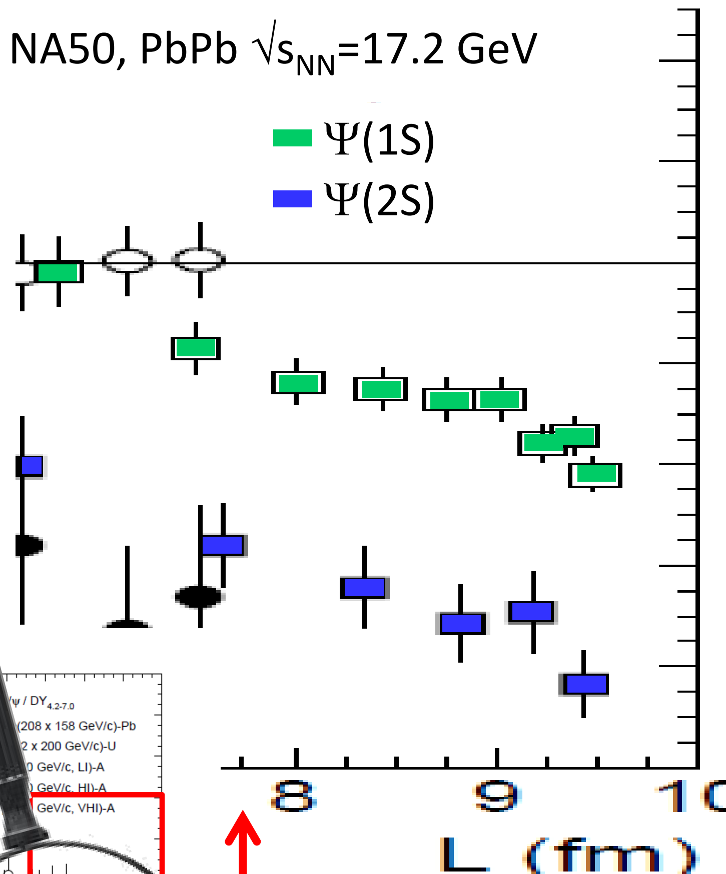
PRL109, 222301 (2012)

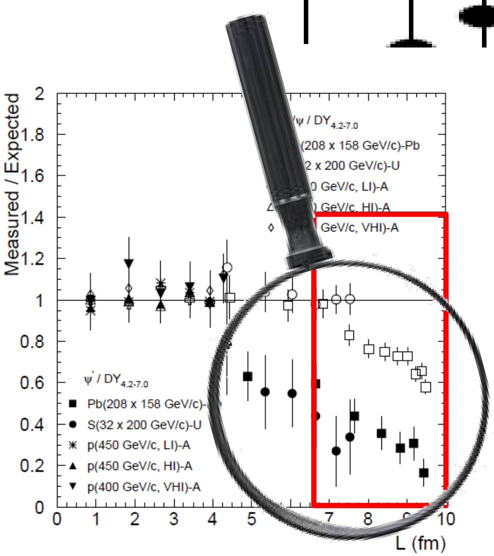


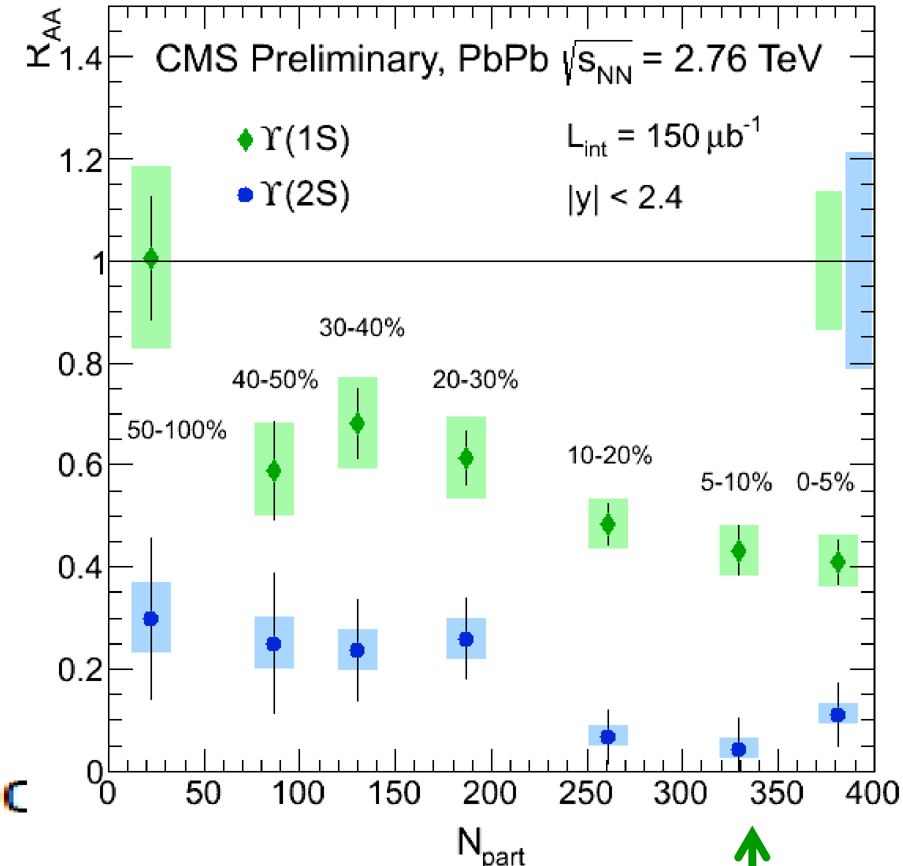


Charmonia @ SPS   bottomonia @ LHC

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.

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."

➔ October 2012: Submission of an Expression of Interest to the SPSC

Expression of interest

- **Submitted to SPSC (october 2012)**

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH

CERN-SPSC-2012-031

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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CERN-SPSC-2012-031 / SPSC-EOI-008
20/10/2012

Abstract

We propose an experiment to perform a systematic study of charmonia production in heavy ion collisions at SPS. Taking advantage of significant advances in electromagnetic calorimetry, the measurement of low energy photons from χ_c decays should now be achievable. Together with recent measurements made at RHIC and at LHC on J/ψ and Υ production, such a measurement will offer the opportunity to use quarkonia as a direct test of phase transition and lattice QCD calculations. In a one month data taking one can expect the collection of thousands of χ_c. This new and dedicated experiment is designed to also study, under optimal conditions, Cold Nuclear Matter (CNM) effects in a larger rapidity range than previously explored by the NA50/NA60 experiments. This measurement of nuclear effects in absence of Quark Gluon Plasma formation will provide a clear and unambiguous reference for the study of Hot and Dense Matter (HDM) effects, a reference which is today needed to deduce an unambiguous interpretation of the results already obtained.

Feedback from SPSC referees

January 2013

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.

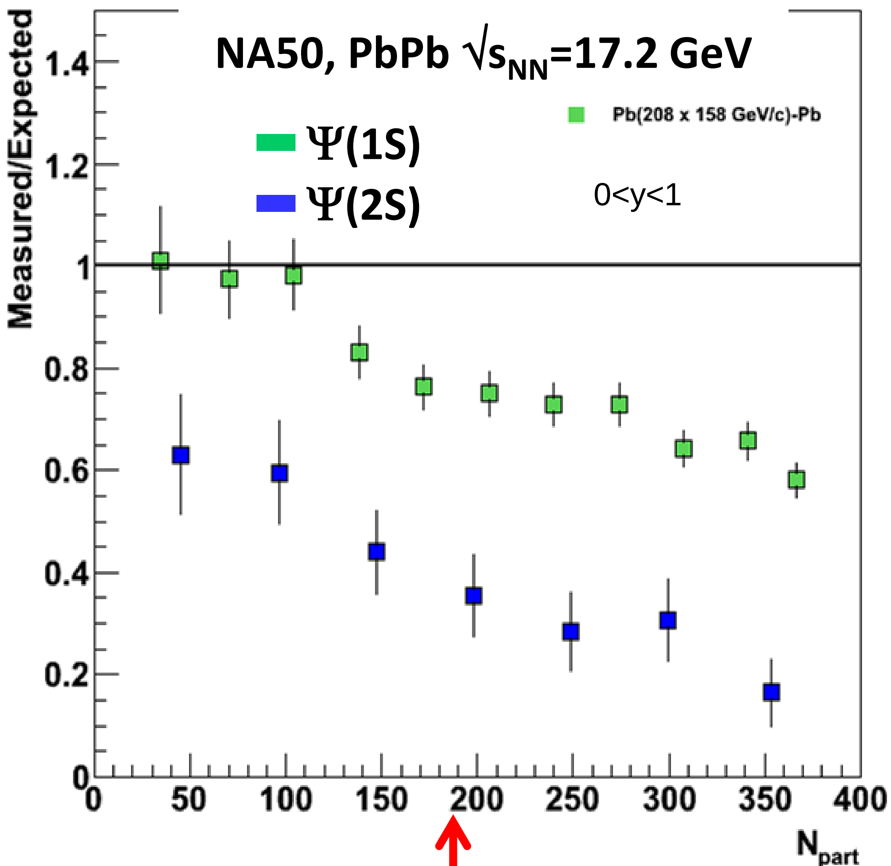
Close and open issues

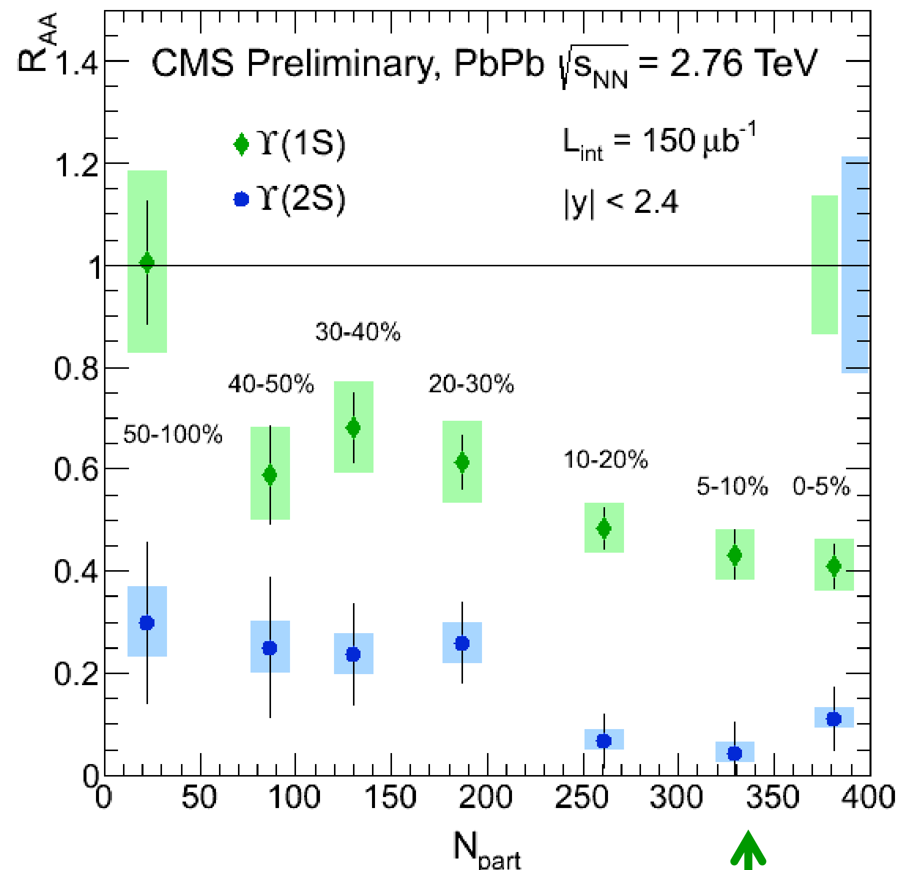
- **People involved**
  - 1 experimentalist : F. Fleuret
  - 4 theoricists : F. Arleo, E.G. Ferreiro, P.-B. Gossiaux, S. Peigné
- **apparatus**
  - Tracking
    - In the current design, tracking is performed upstream to the absorber.
    - Keeping low occupancy ➔ silicon technology : CMOS ?
    - Lab currently involved : **none**
  - Calorimetry
    - Around 400 γ per rapidity unit in central PbPb collisions
    - Need ultragranular calorimetry à la CALICE
    - Lab currently involved : **LLR**
  - 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?)
    - Lab currently involved : **none**

- **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

J/Ψ@SPS .vs. Υ@LHC color screening ?





Charmonia @ SPS **bottomonia @ LHC**

On the same axis