# An experiment to measure $\chi_c$ suppression at the CERN SPS

## CHIC: **C**harm in **H**eavy **I**on **C**ollisions

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# Charmonia in A+A

# The Physics case

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

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

| 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.
- **Experimentally**
  - $J/\Psi$ production in A+A collisions is (has been) 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
  - **Unclear overall picture :**
    - Hot and Dense Matter effects are due to Quarkonium screening ? Recombination ? Both ?
    - Moreover, Cold Nuclear Matter effects must be better controlled (understood)
  - To understand Hot and Dense Matter effects, **need to answer color screening question first.** (Recombination occurs at high energies)

# Testing color screening

## Testing sequential suppression with charmonia :

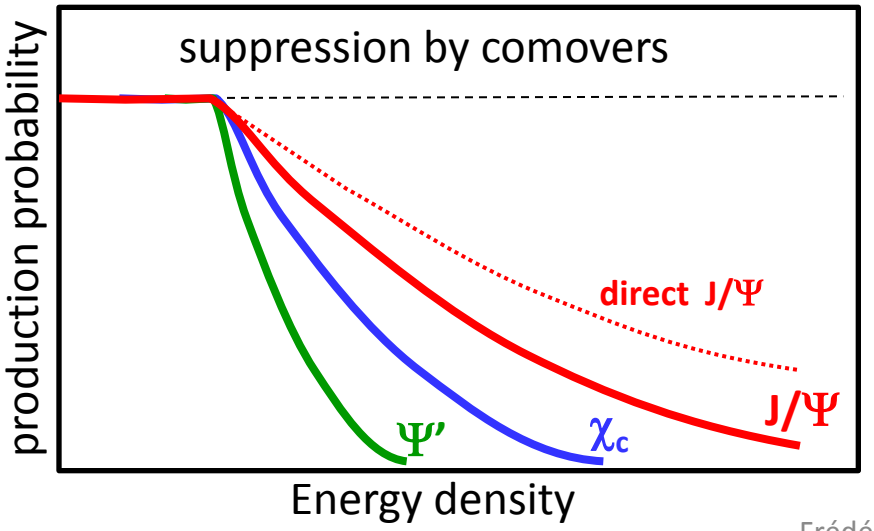
1. must be in a regime where recombination is negligible ➔ **SPS energies**
2. must measure the suppression pattern of **several related states**, for instance:
   - ~30% of the inclusive J/Ψ yield comes from $\chi_c$ decay.
   - According to lattice calculations, $T_d(\chi_c) < T_d(J/\Psi)$
   - **If screening, one should observe a gap in suppression patterns**

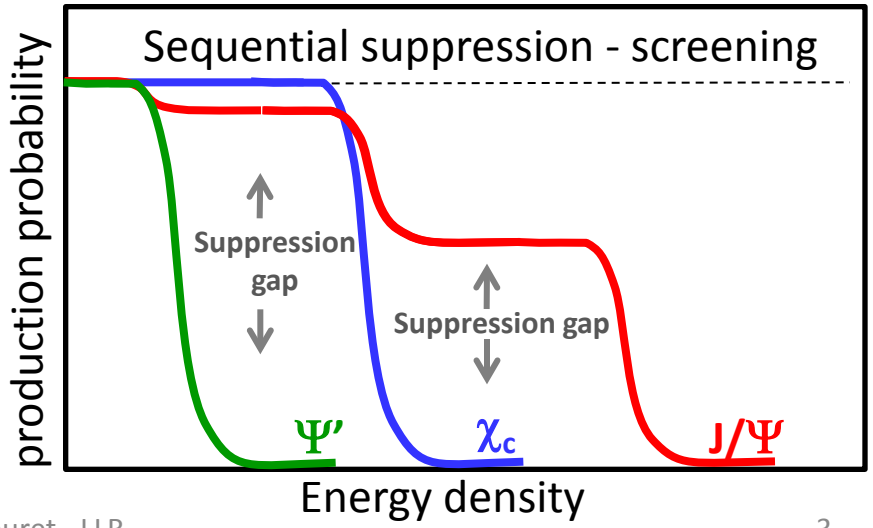
– *Alternative scenario: suppression by comoving hadrons*

– *Smooth suppression*

– *Same starting point*

– *Slopes related to binding energy : $S_{\Psi'} > S_{\chi} > S_{J/\Psi}$*



# Sequential suppression

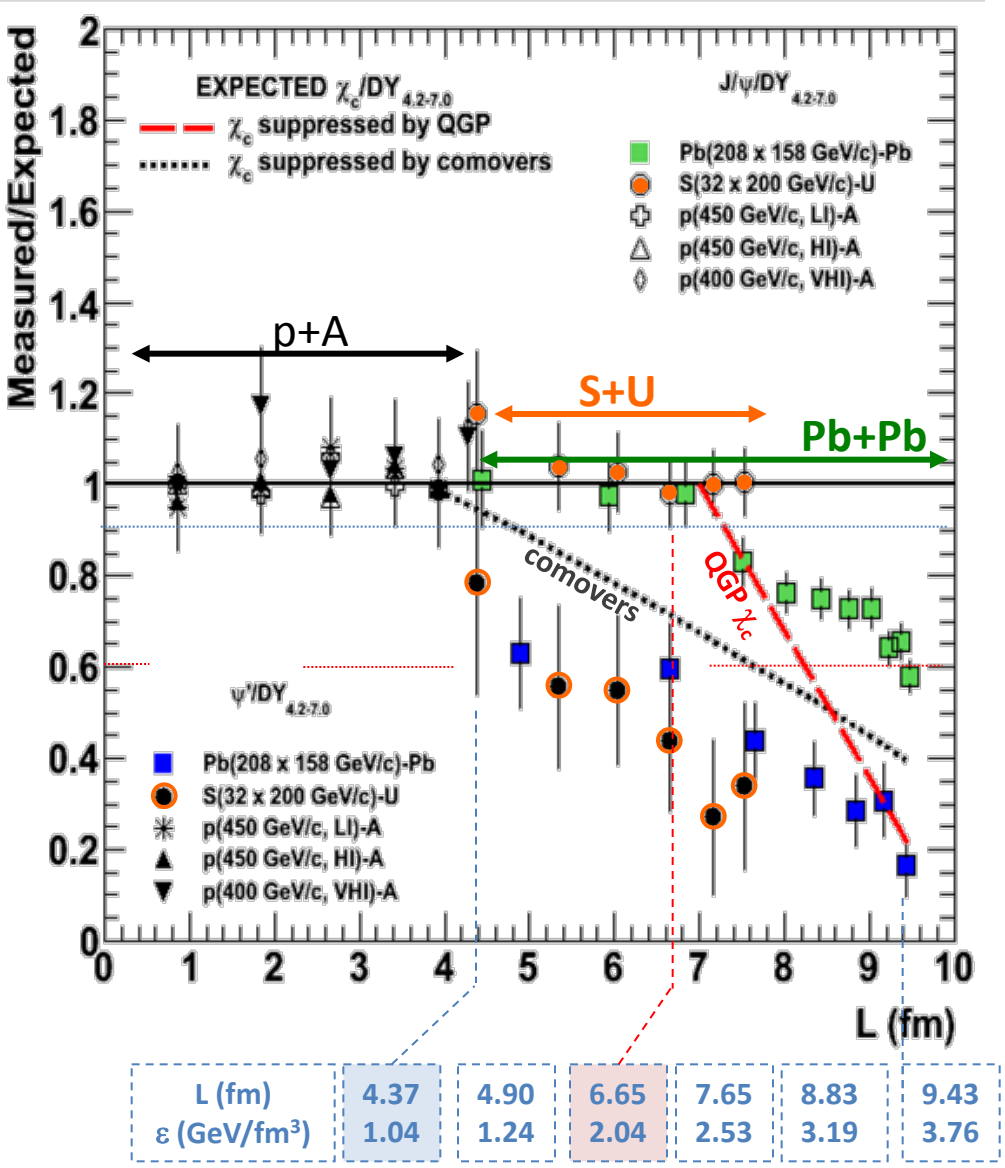
- **Anomalous suppression at SPS** [Eur.Phys.J.C49:559-567,2007]

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

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

Measuring Ψ' only is not the answer :
*too small feed-down*
➔ need of a larger feed-down fraction

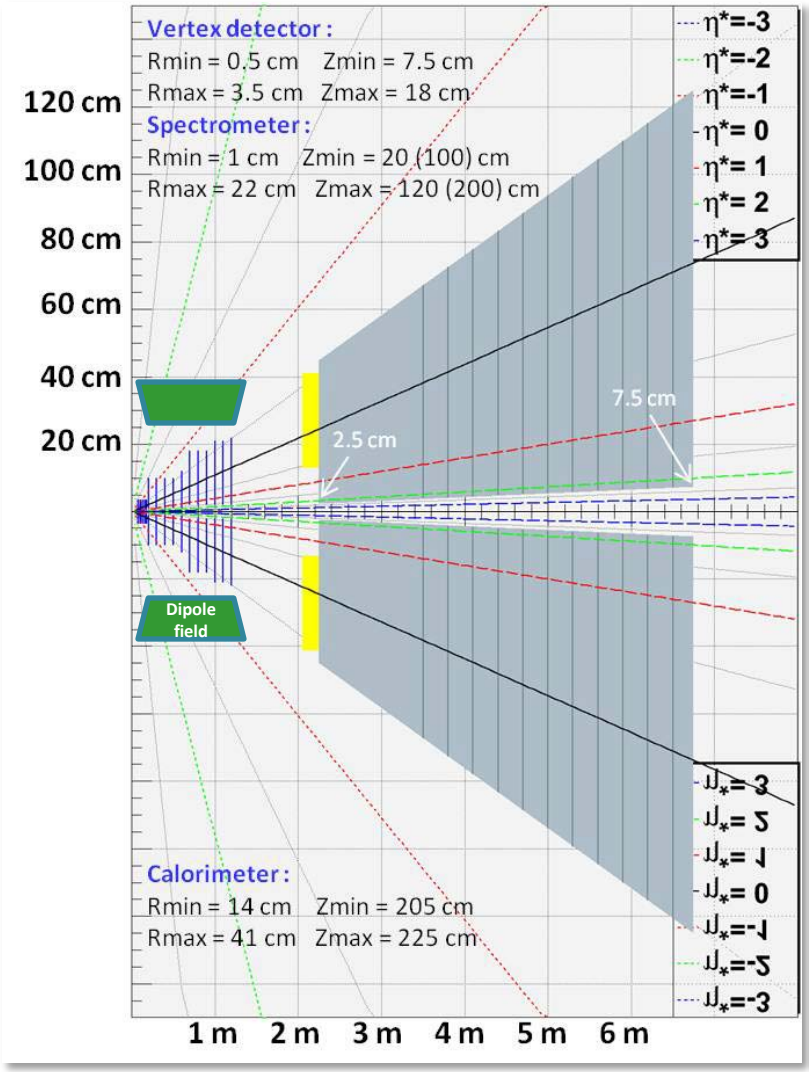
**Measuring J/Ψ, Ψ' and $\chi_c$ suppression patterns will give the answer**




| 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 |

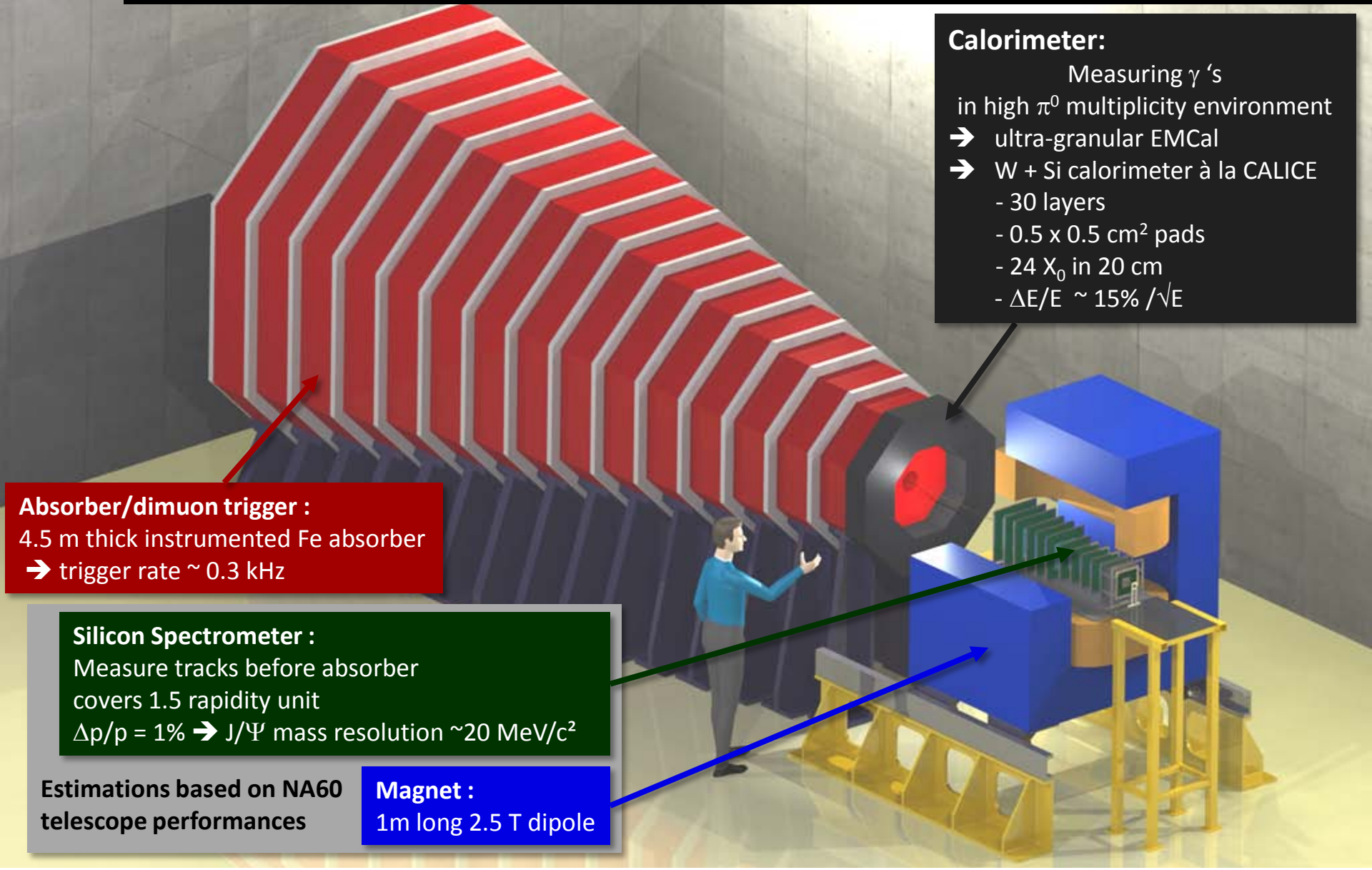
# Measuring $\chi_c$ at SPS

- **Operate a new experiment at SPS**
  - Primary goal : $\chi_c \rightarrow J/\Psi + \gamma \rightarrow \mu^+ \mu^- \gamma$
    - With high intensity 158 GeV/c Pb beam
    - With high intensity 158/450 GeV/c proton beam
  - Detector features :
    1. **Vertex + Spectrometer**
       - » Measure tracks before absorber for very good mass resolution
    2. **Calorimeter**
       - » Measure low energy $\gamma$ in high $\pi^0$ multiplicity environment
    3. **Absorber/trigger**
       - » **Absorb** $\pi$/K
       - » Minimize fake triggers from $\pi$/K decays



# Apparatus

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



**Calorimeter:**
Measuring $\gamma$ 's
in high $\pi^0$ multiplicity environment
➔ ultra-granular EMCal
➔ W + Si calorimeter à la CALICE
- 30 layers
- 0.5 x 0.5 cm² pads
- 24 $X_0$ in 20 cm
- $\Delta E/E$ ~ 15% /$\sqrt{E}$

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

**Silicon Spectrometer :**
Measure tracks before absorber
covers 1.5 rapidity unit
$\Delta p/p$ = 1% ➔ J/$\Psi$ mass resolution ~20 MeV/c²

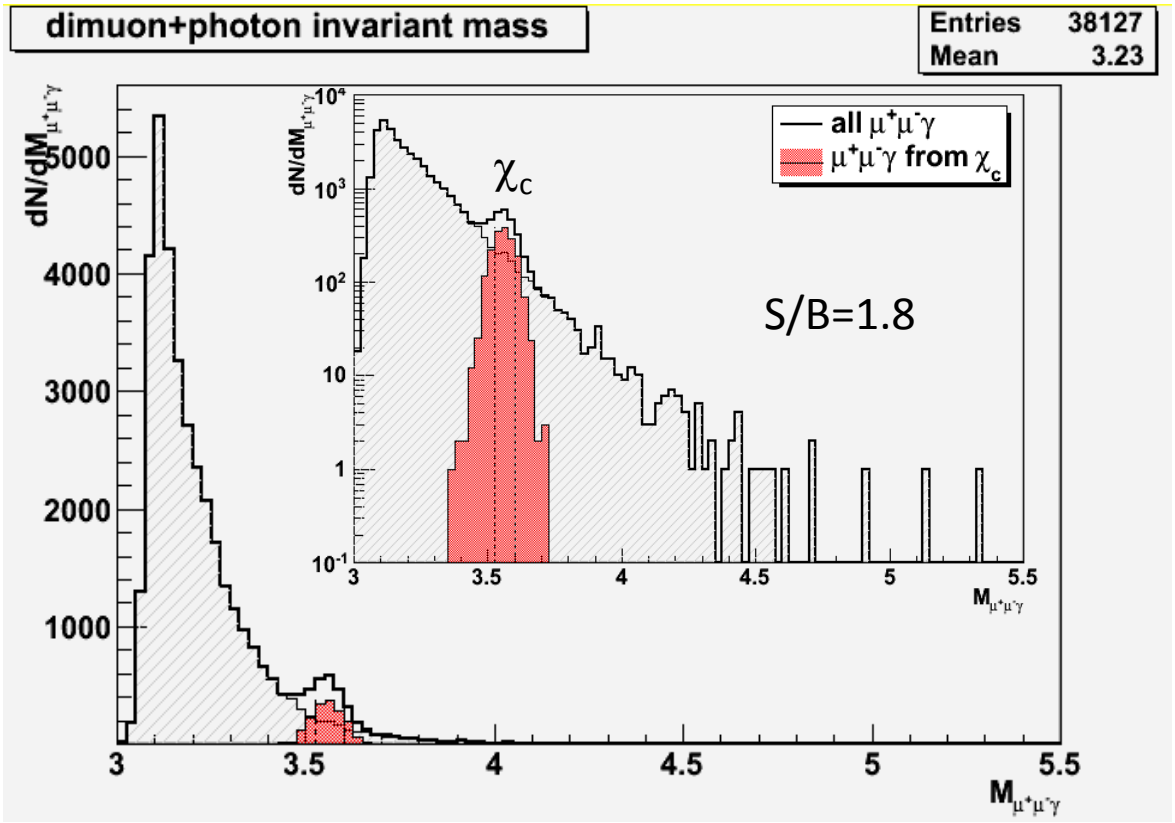
**Estimations based on NA60 telescope performances**

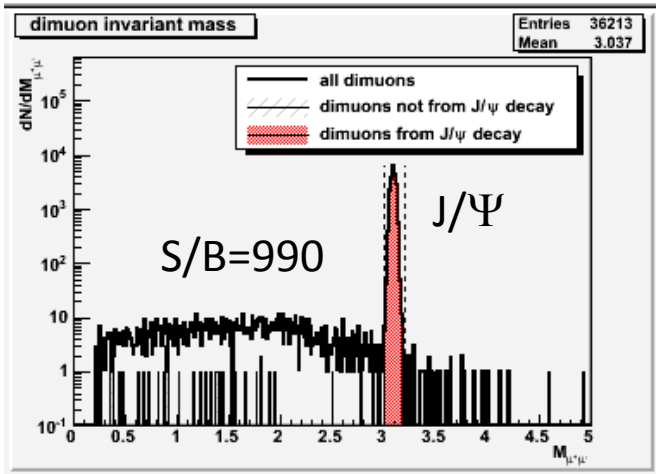
**Magnet :**
1m long 2.5 T dipole

# Expected performances

# Signal extraction

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




After acceptance and selection cuts:

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

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

# Expected performances

# Statistics

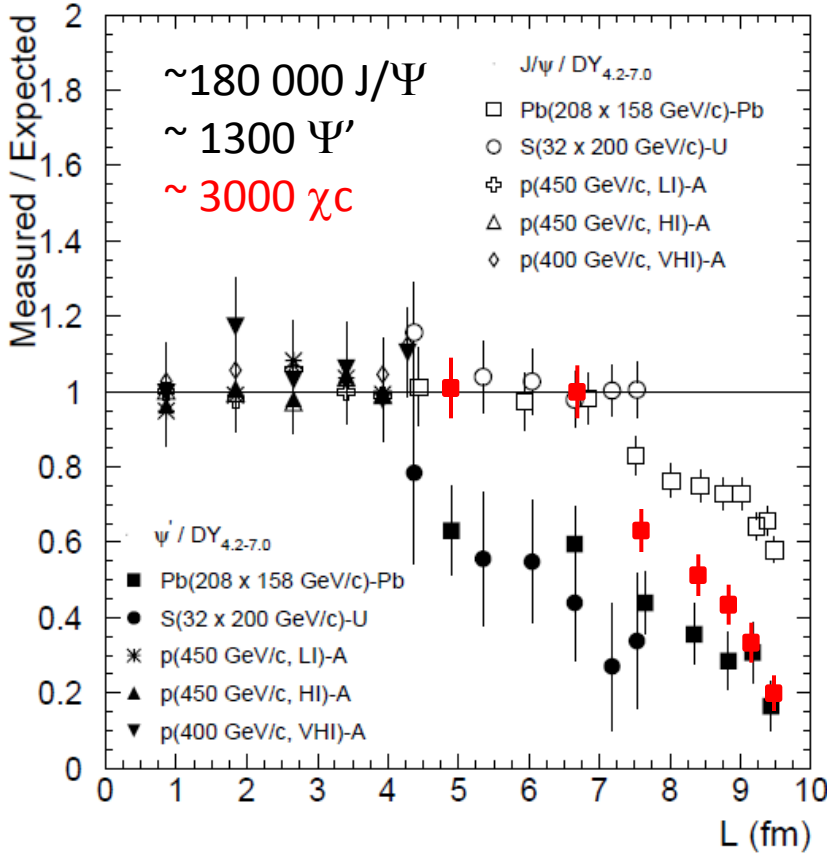
- **Typical one month Pb+Pb run**
  - ~ 200 000 inclusive $J/\Psi \rightarrow \mu^+\mu^-$ expected
  - 2 extreme scenarios:

- If $\chi_c$ suppressed as J/Ψ $\quad \dfrac{\chi_c \text{ yield}}{J/\Psi \text{ yield}} \sim 4\%$

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

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

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




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

| $E_T$ range (GeV) | $\psi'$ | J/$\psi$ | $\chi_c$ as Ψ' | $\chi_c$ 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** |

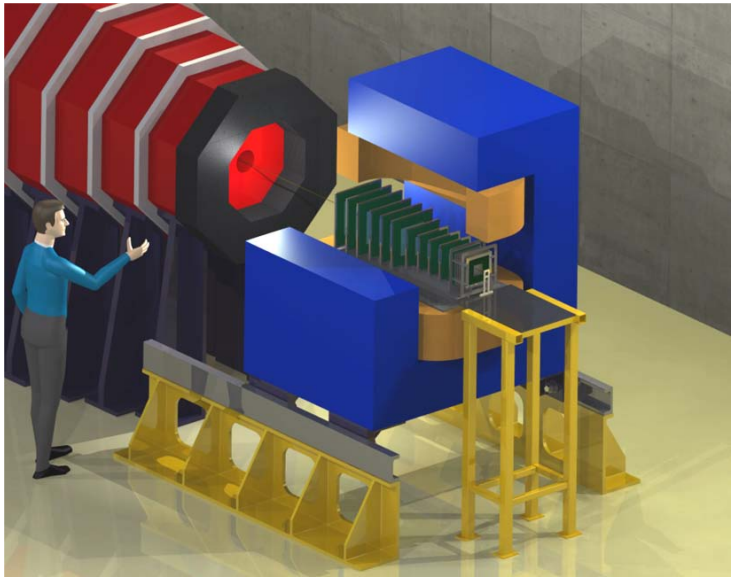
# p+A program investigate Cold Nuclear Matter

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

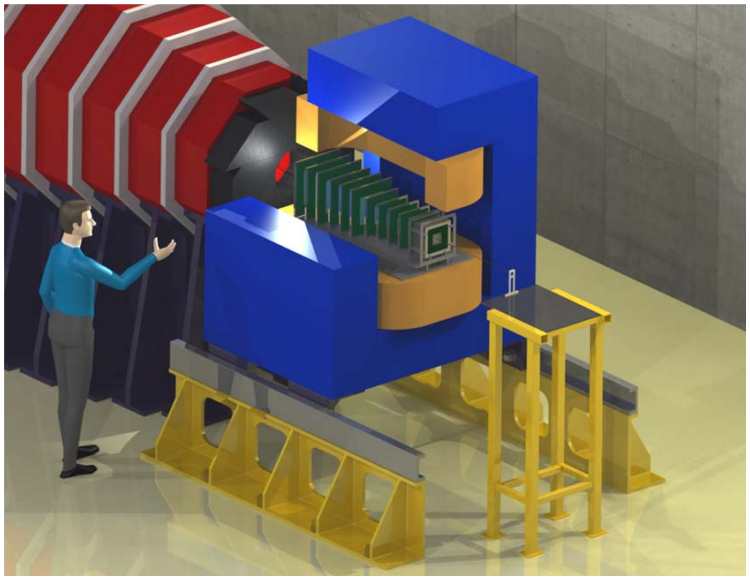
- **Must control (understand) :**
  - charmonium absorption by cold nuclear matter ➔ A dependence
  - Shadowing/anti-shadowing ($x_2$ scaling)
  - Energy loss (saturation)… ($x_F$ scaling)

  ➔ **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 : $y_{CMS} \in [0.5 ; 2]$**

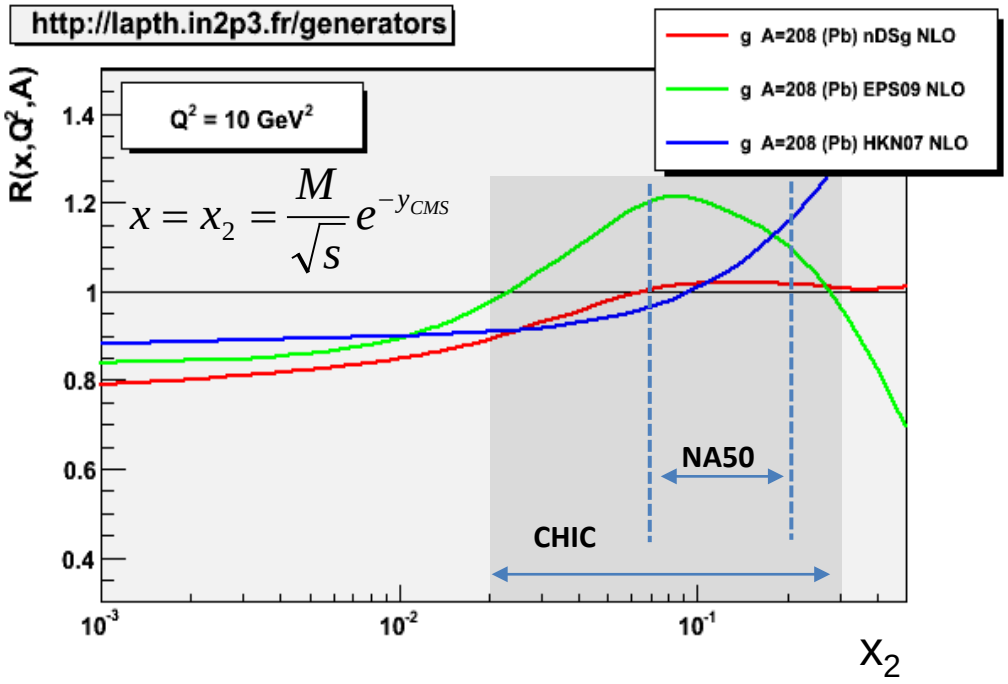


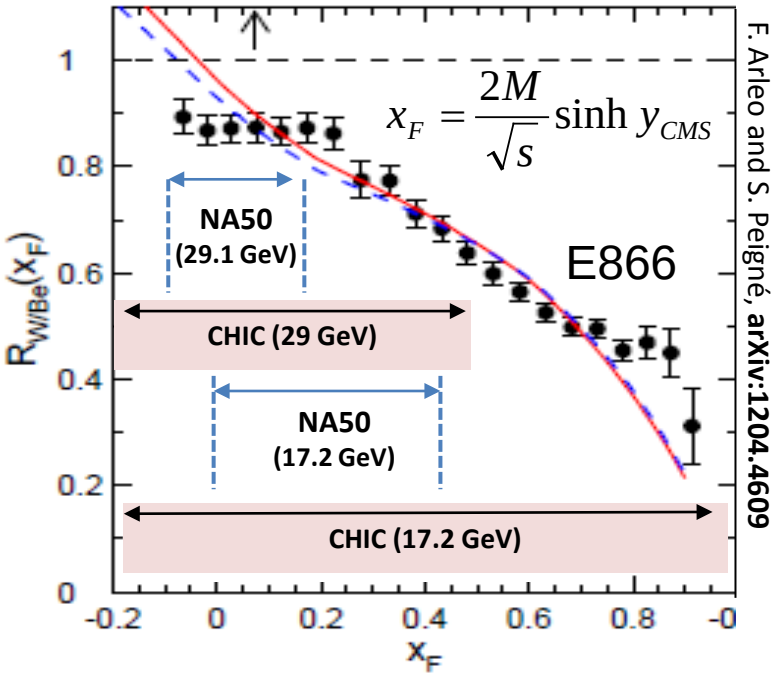
# p+A program investigate Cold Nuclear Matter

**A thorough p+A program requires**

- **J/Ψ, Ψ', $\chi_c$ with several targets**
  (NA50: p+Be, p+Al, p+Cu, p+Ag, p+W, p+Pb)
- **J/Ψ, Ψ', $\chi_c$ in a large $y_{CMS}$ range**
- **Large statistics** (in principle, can run with proton beam several months per year)

| $E_{beam}$ ($\sqrt{s}$) | 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] |



# Conclusion

- **Measuring together J/Ψ, Ψ' and $\chi_c$ in p+A collisions with several targets will give a thorough control of Cold Nuclear Matter effects**

- **Measuring together J/Ψ, Ψ' and $\chi_c$ 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.**

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

# New upsilon results

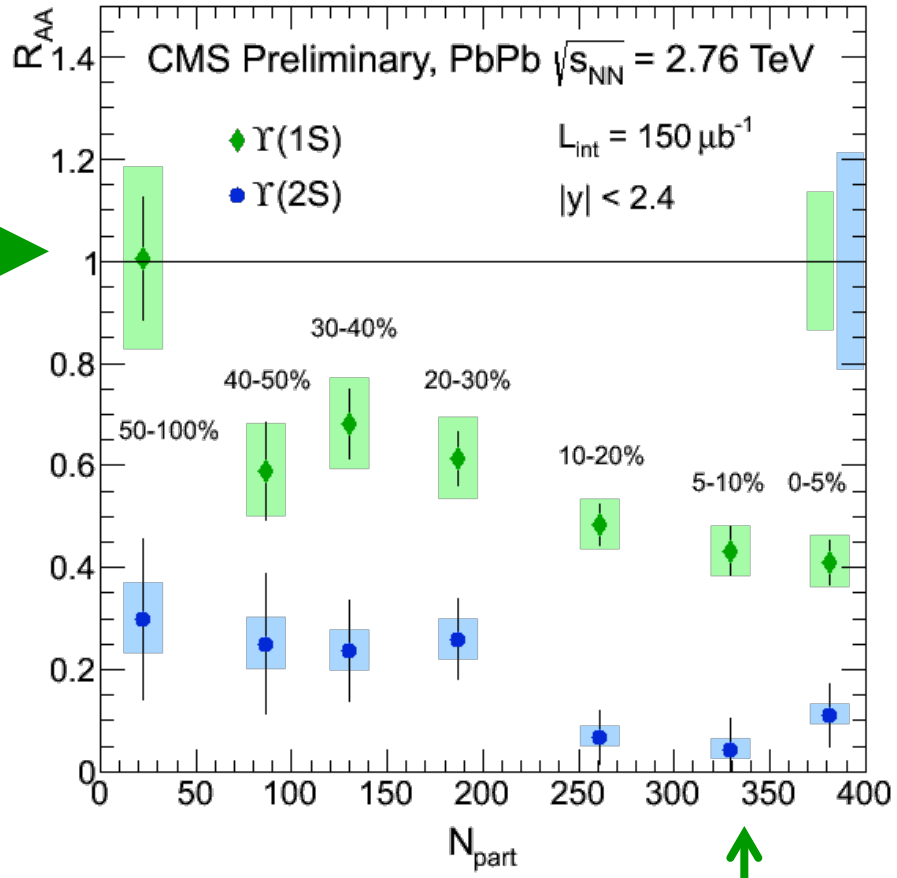
## Beautiful results from CMS

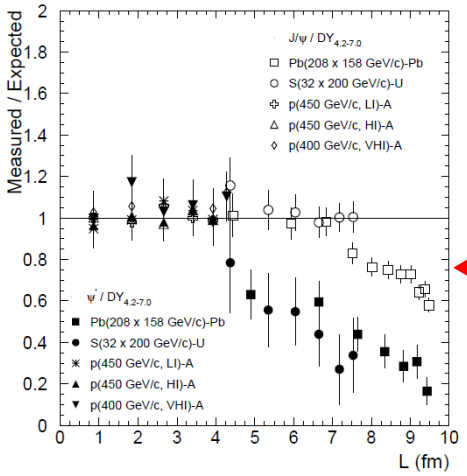
(Camelia Mironov, HP2012)

◉Suppression pattern as expected in the sequential melting scenario

$\Upsilon(3S)>\Upsilon(2S)>\Upsilon(1S)$

$$\frac{\Upsilon(3S)}{\Upsilon(1S)}|_{PbPb} < 0.07\ (95\%C.L.)$$



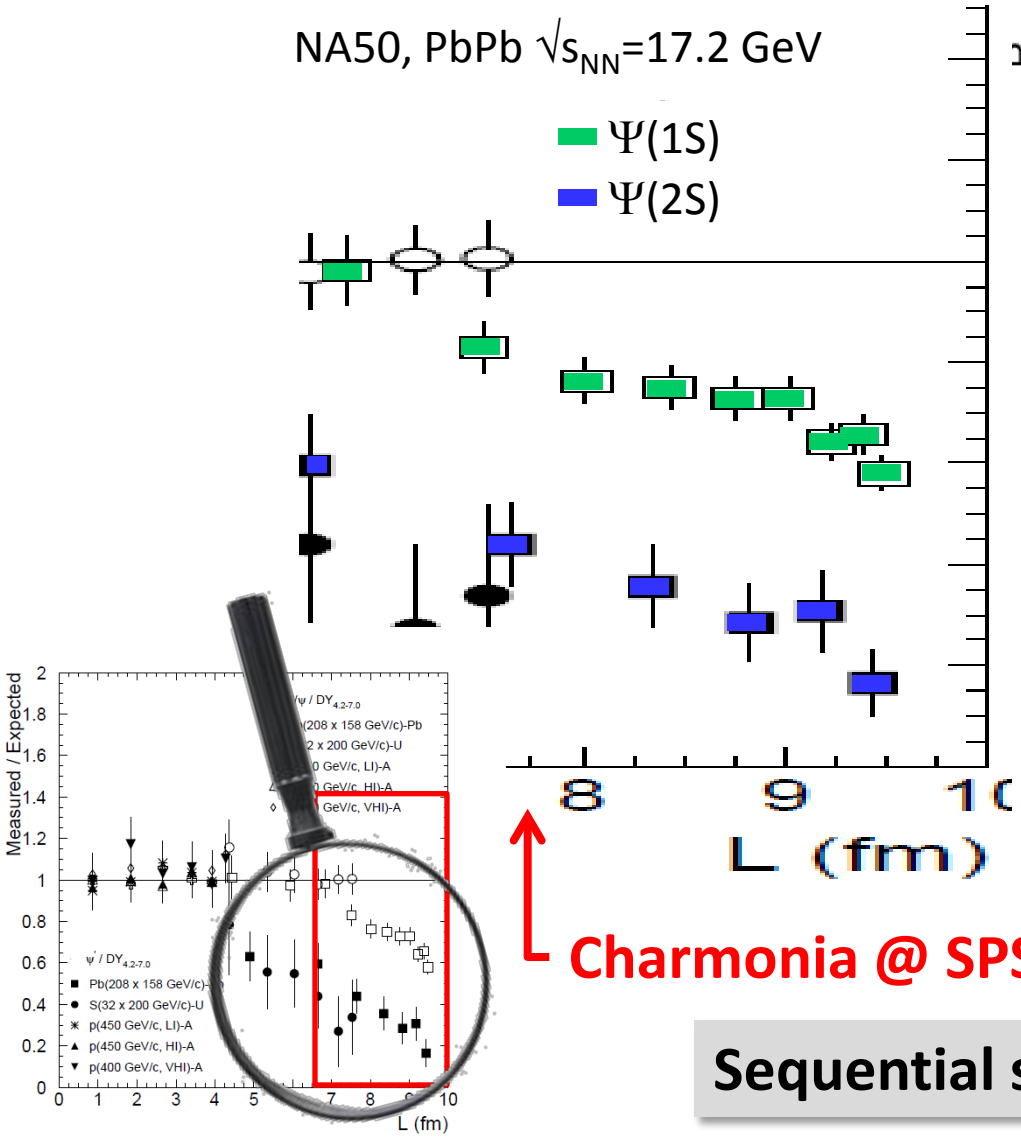



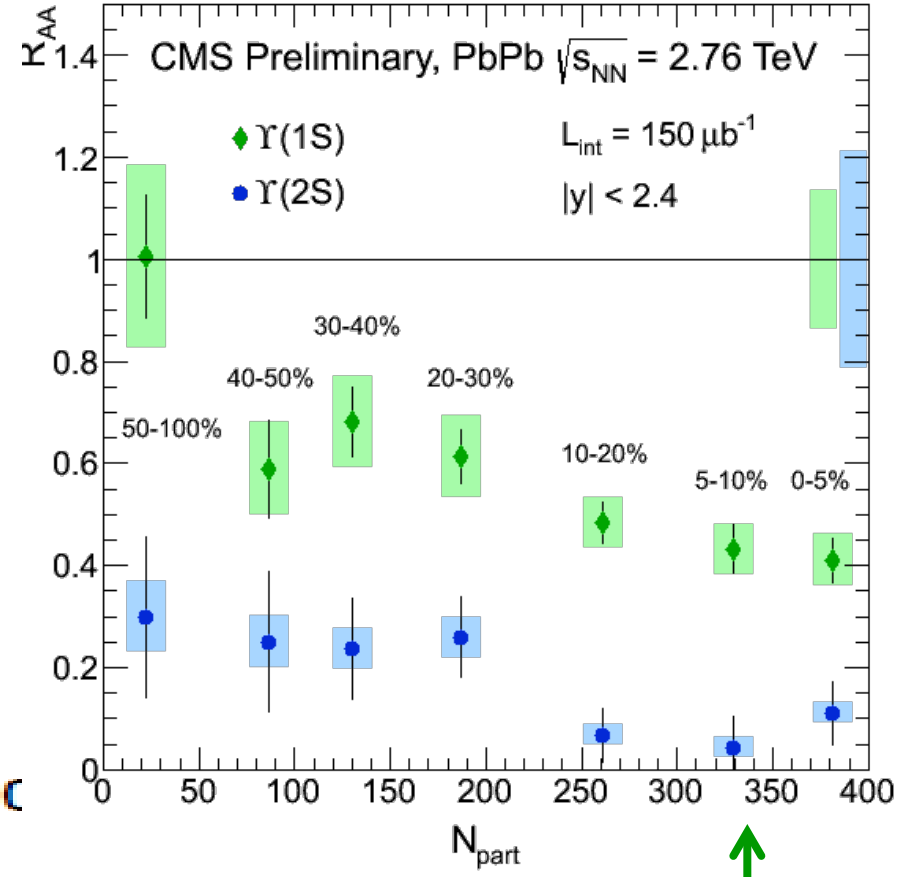

Charmonia @ SPS

bottomonia @ LHC

**Sequential suppression ?**

# J/Ψ@SPS .vs. Υ@LHC sequential suppression ?



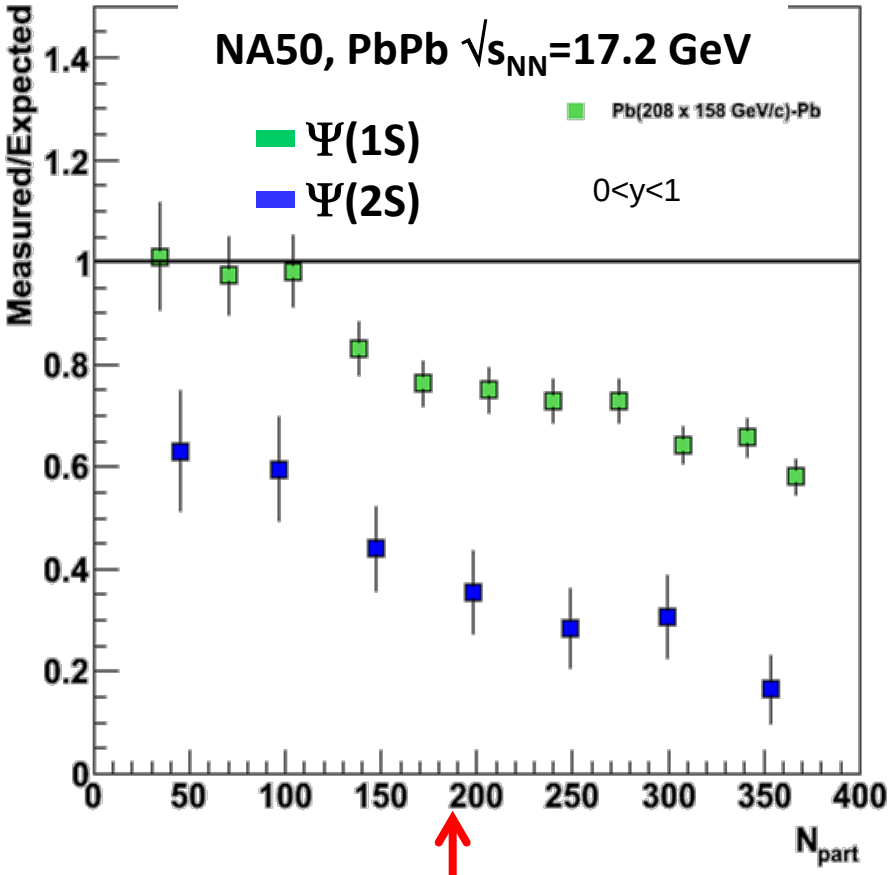



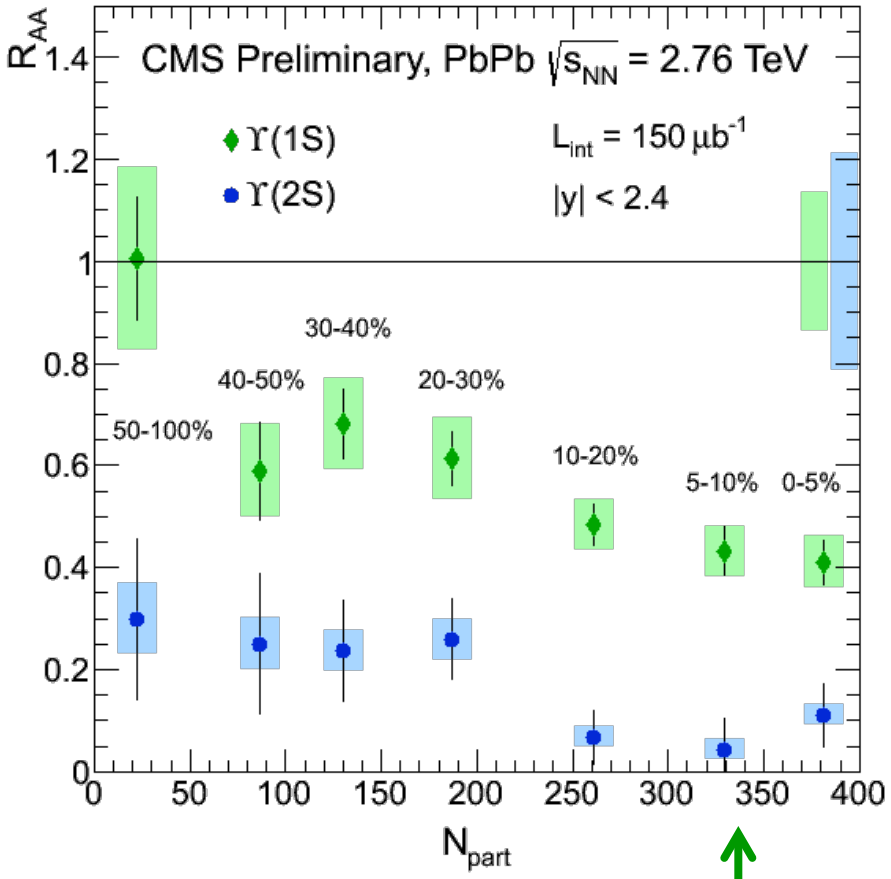

Charmonia @ SPS

bottomonia @ LHC

**Sequential suppression ?**

# J/Ψ@SPS .vs. Υ@LHC sequential suppression ?



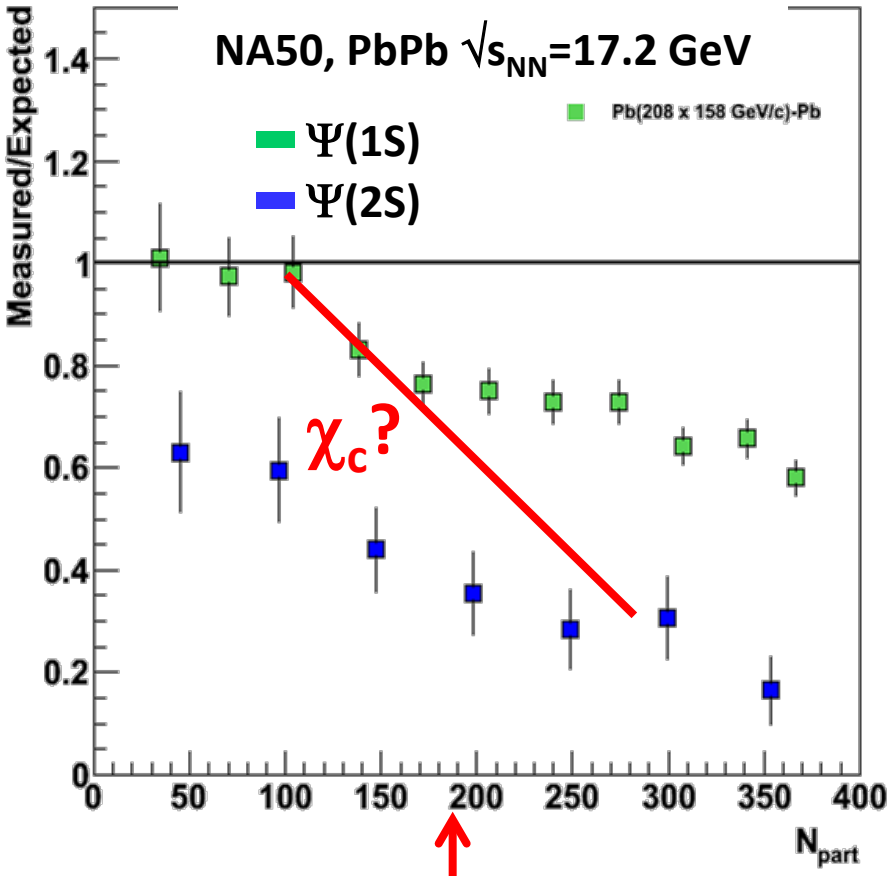



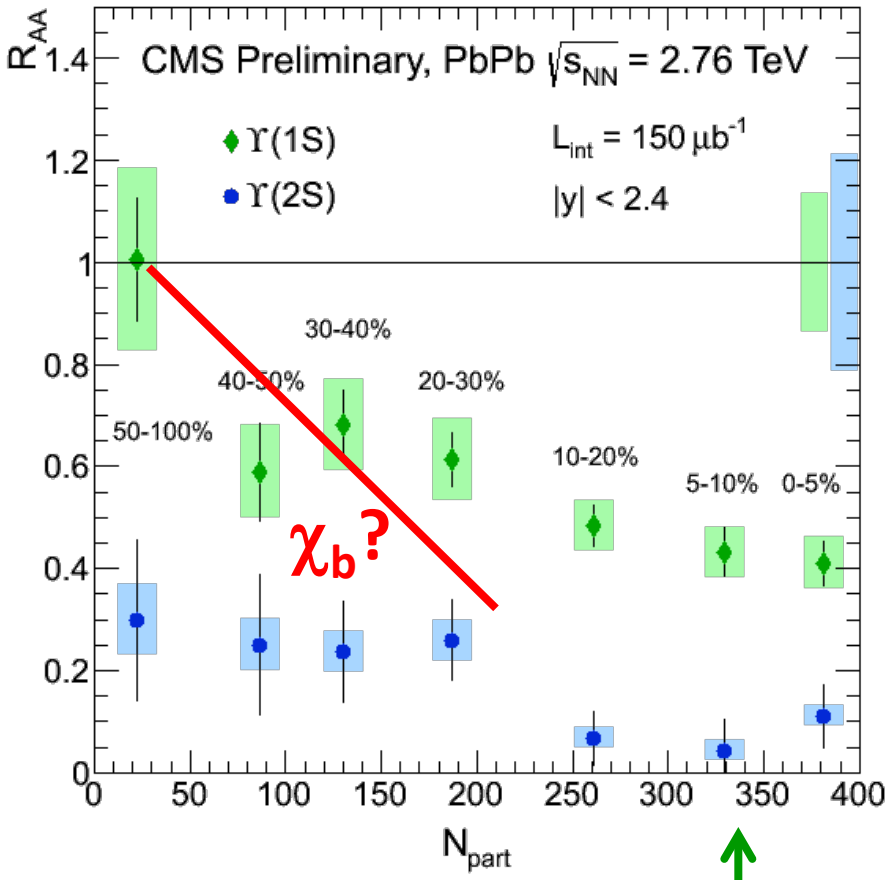

Charmonia @ SPS

bottomonia @ LHC

**On the same axis**

# J/Ψ@SPS .vs. Υ@LHC sequential suppression ?




Charmonia @ SPS

bottomonia @ LHC

**Let's measure $\chi_c$ at SPS !**

# CERN strategy

## Conclusions of the Town meeting "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."**

# Expression of interest

- **To be submitted to SPSC**

## 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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