



# 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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- 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 \(2006\)](#)

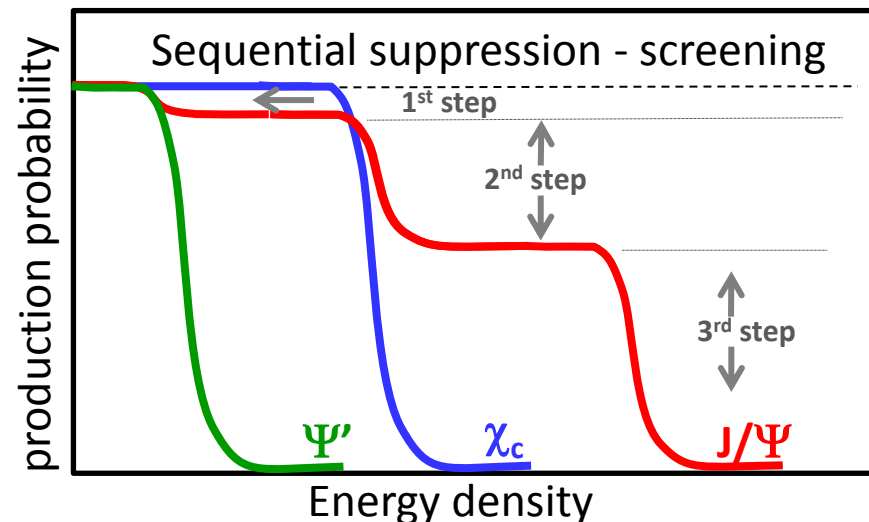
quarkonium dissociation temperature  
critical QGP temperature →

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

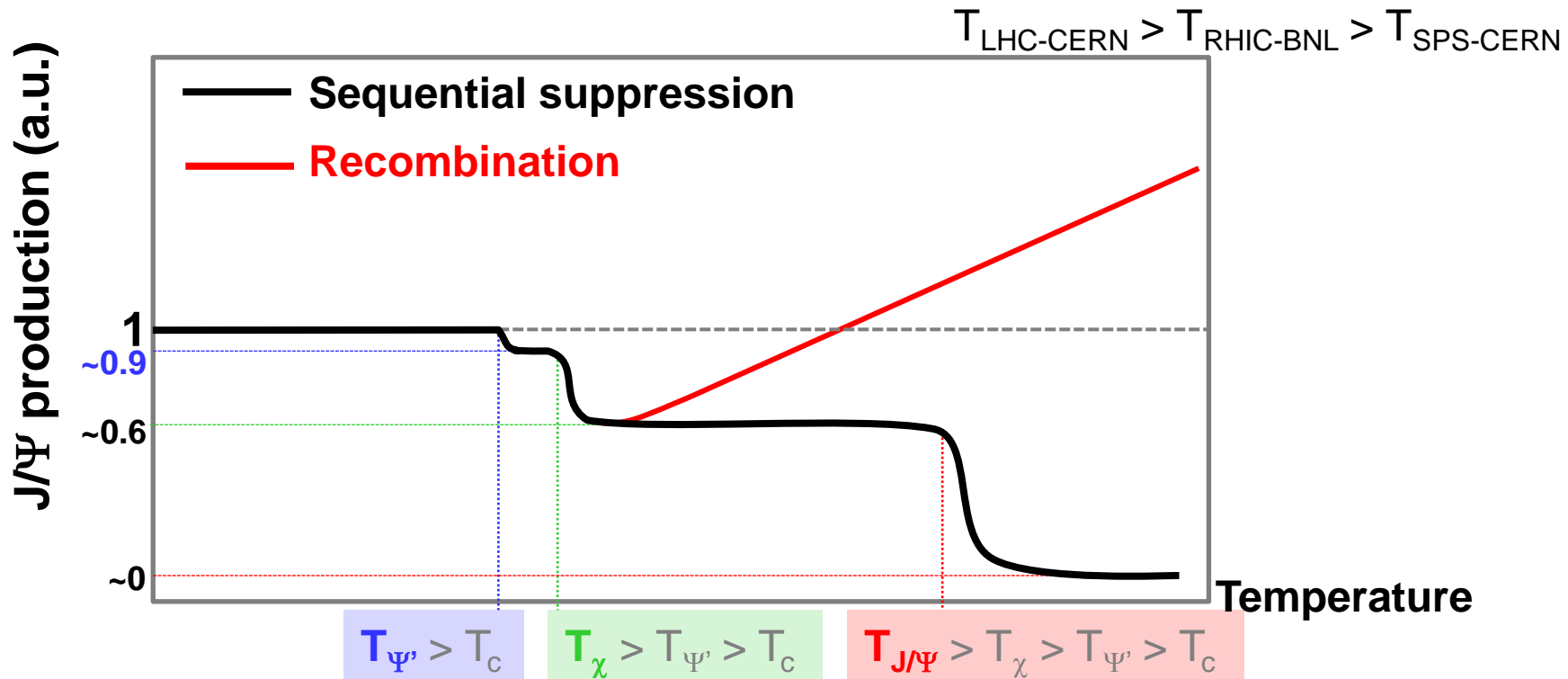
- Because of feed-downs and different  $T_d$ , **sequential suppression** should show up.

*Feed-downs contributing to J/Ψ inclusive yield*

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



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



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

–	NA50	(PbPb@SPS)	observed an <i>anomalous</i> suppression
–	PHENIX	(AuAu@RHIC)	observed a similar suppression (than NA50)
–	ALICE	(PbPb@LHC)	observed a smaller suppression for low $p_T$ $J/\Psi$
–	CMS	(PbPb@LHC)	observed a larger suppression for high $p_T$ $J/\Psi$
  
  - **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 higher energies).

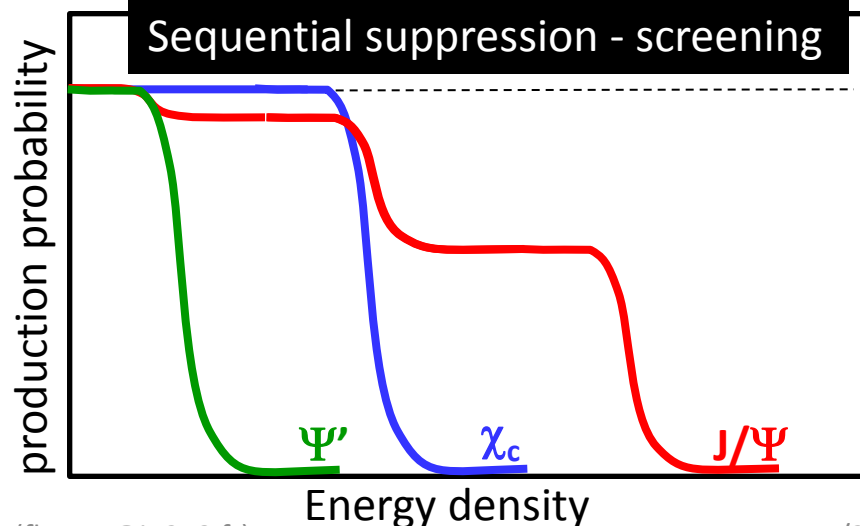
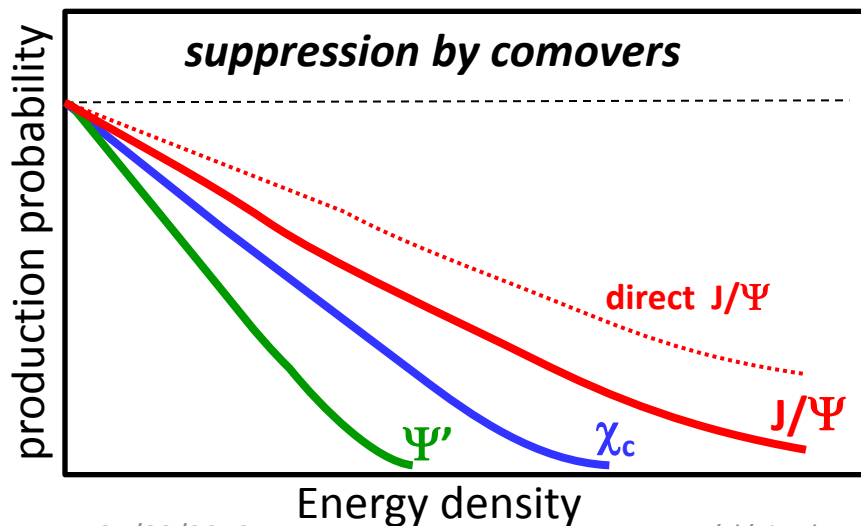
## How to Test sequential suppression with charmonia ?

1. must be in a regime where recombination is negligible → **SPS energies**
2. **must measure** the suppression pattern of  $J/\Psi$ ,  $\Psi'$ ,  $\chi_c$  :
  - ~30% (resp. ~10%) of the inclusive  $J/\Psi$  yield comes from  $\chi_c$  (resp.  $\Psi'$ ) decay.
  - According to lattice calculations,  $T_d(\Psi') < T_d(\chi_c) < T_d(J/\Psi)$

**• If screening, one should observe a step-like suppression patterns**

– *Alternative scenario: suppression by comoving hadrons*

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



- Anomalous suppression at SPS

[Eur.Phys.J.C49:559-567,2007](#)

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

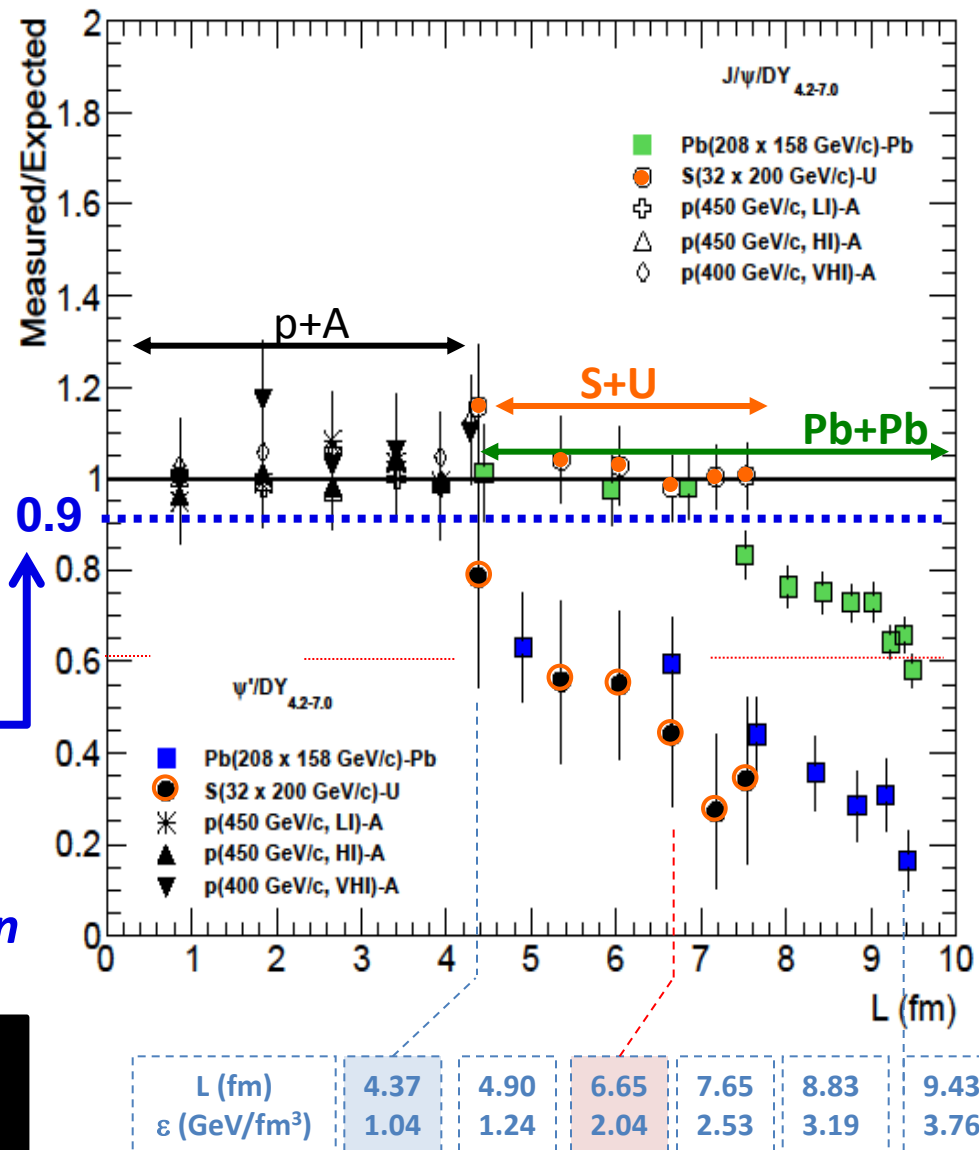
60% direct  $J/\Psi$   
+ 30%  $\chi_c \rightarrow J/\Psi + \gamma$   
+ 10%  $\Psi' \rightarrow J/\Psi + X$   
**Inclusive  $J/\Psi$  yield**

use  $J/\Psi$  feed-downs to discriminate

NA50 measured  $J/\Psi$  and  $\Psi'$ , but,

Measuring  $J/\Psi$  and  $\Psi'$  only is not the answer : *too small  $\Psi' \rightarrow J/\Psi$  feed-down*

→ need of a larger feed-down fraction  
→ Measure  $\chi_c$  !



- Anomalous suppression  
at SPS

[Eur.Phys.J.C49:559-567,2007](http://arxiv.org/abs/0705.3801)

## Expectations in comovers scenario

### Binding energy

state	$\eta_c$	$J/\psi$	$\chi_{c0}$	$\chi_{c1}$	$\chi_{c2}$	$\psi'$
mass [GeV]	2.98	3.10	3.42	3.51	3.56	3.69
$\Delta E$ [GeV]	0.75	0.64	0.32	0.22	0.18	0.05

Taking breakup cross-sections:

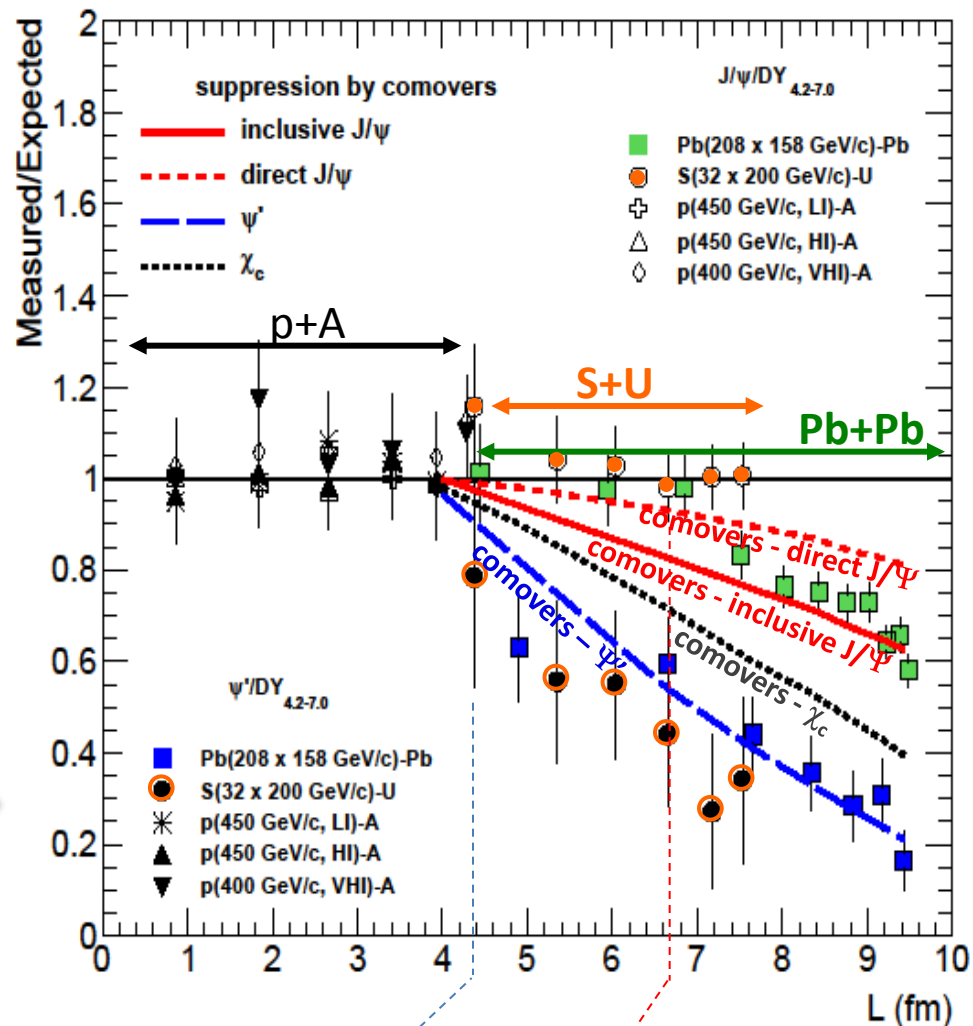
- comovers-direct  $J/\Psi = 0.2$  mb
- comovers -  $\chi_c = 1.0$  mb
- comovers -  $\Psi' = 2.0$  mb

60% direct  $J/\Psi$

+ 30%  $\chi_c \rightarrow J/\Psi + \gamma$

+ 10%  $\Psi' \rightarrow J/\Psi + X$

**Inclusive  $J/\Psi$  yield**



L (fm)	4.37	4.90	6.65	7.65	8.83	9.43
$\epsilon$ (GeV/fm <sup>3</sup> )	1.04	1.24	2.04	2.53	3.19	3.76

- Anomalous suppression at SPS

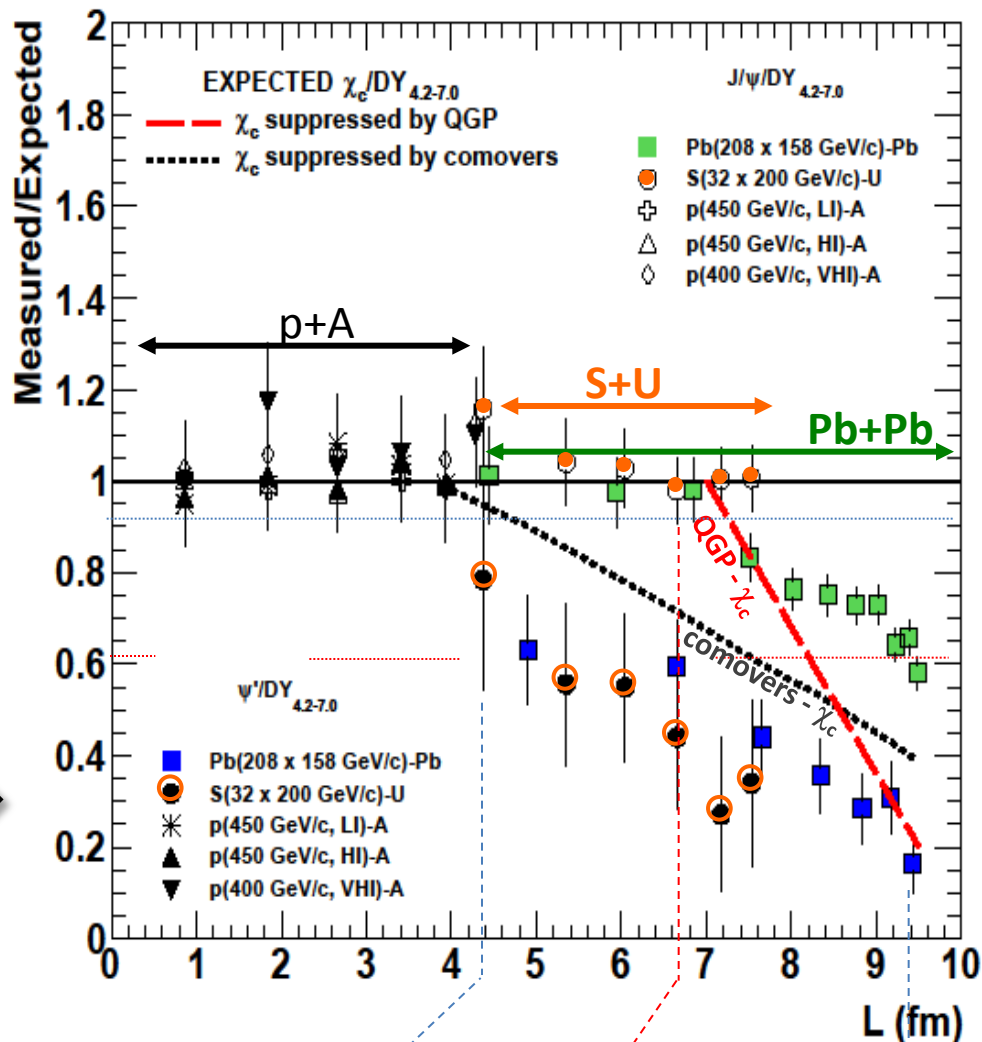
[Eur.Phys.J.C49:559-567,2007](http://arxiv.org/abs/0705.3801)

*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**

Take advantage of large  $\chi_c \rightarrow J/\Psi$  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
$\epsilon$ (GeV/fm <sup>3</sup> )	1.04	1.24	2.04	2.53	3.19	3.76



- 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

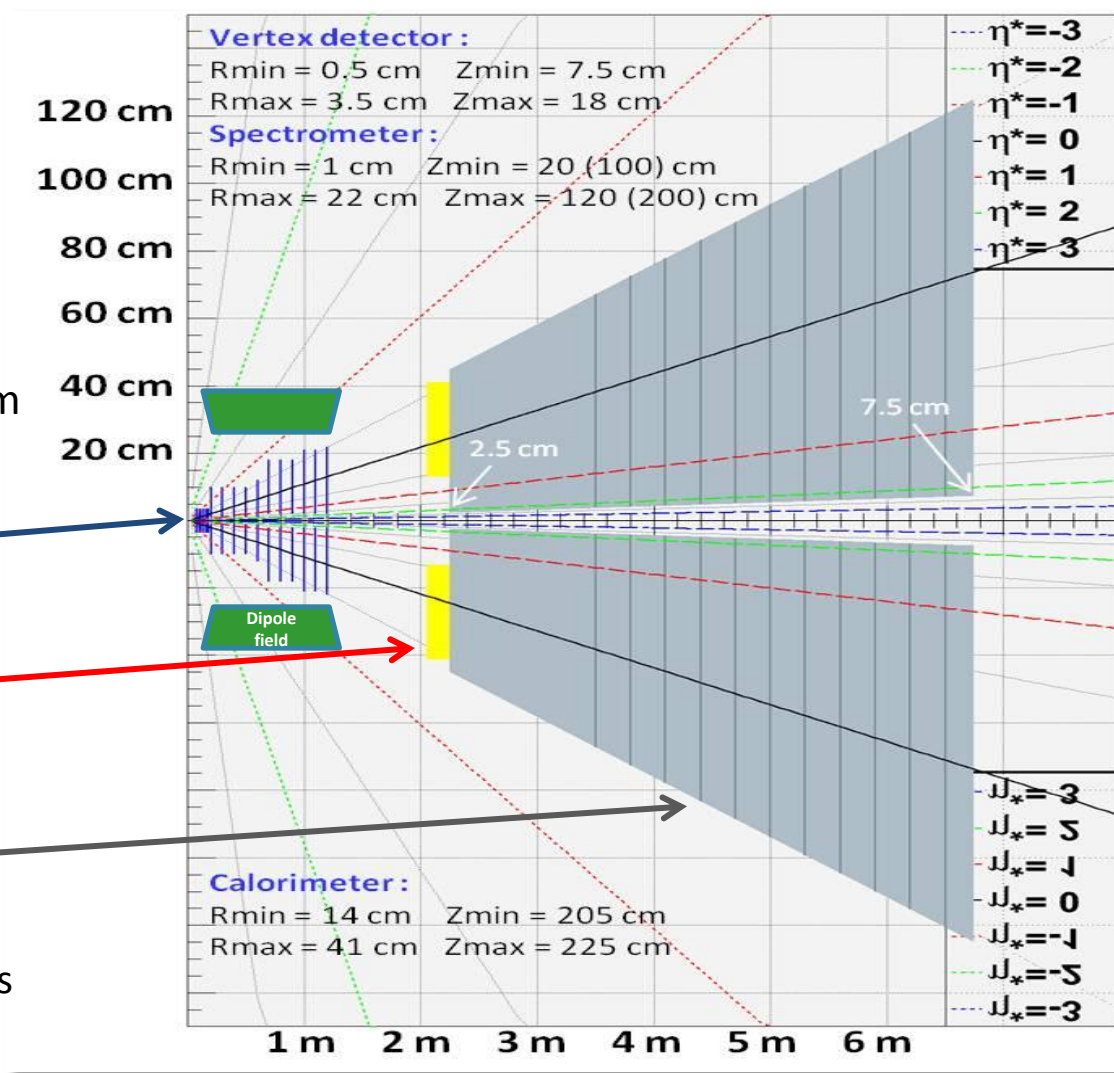
Ultra-granular calorimeter

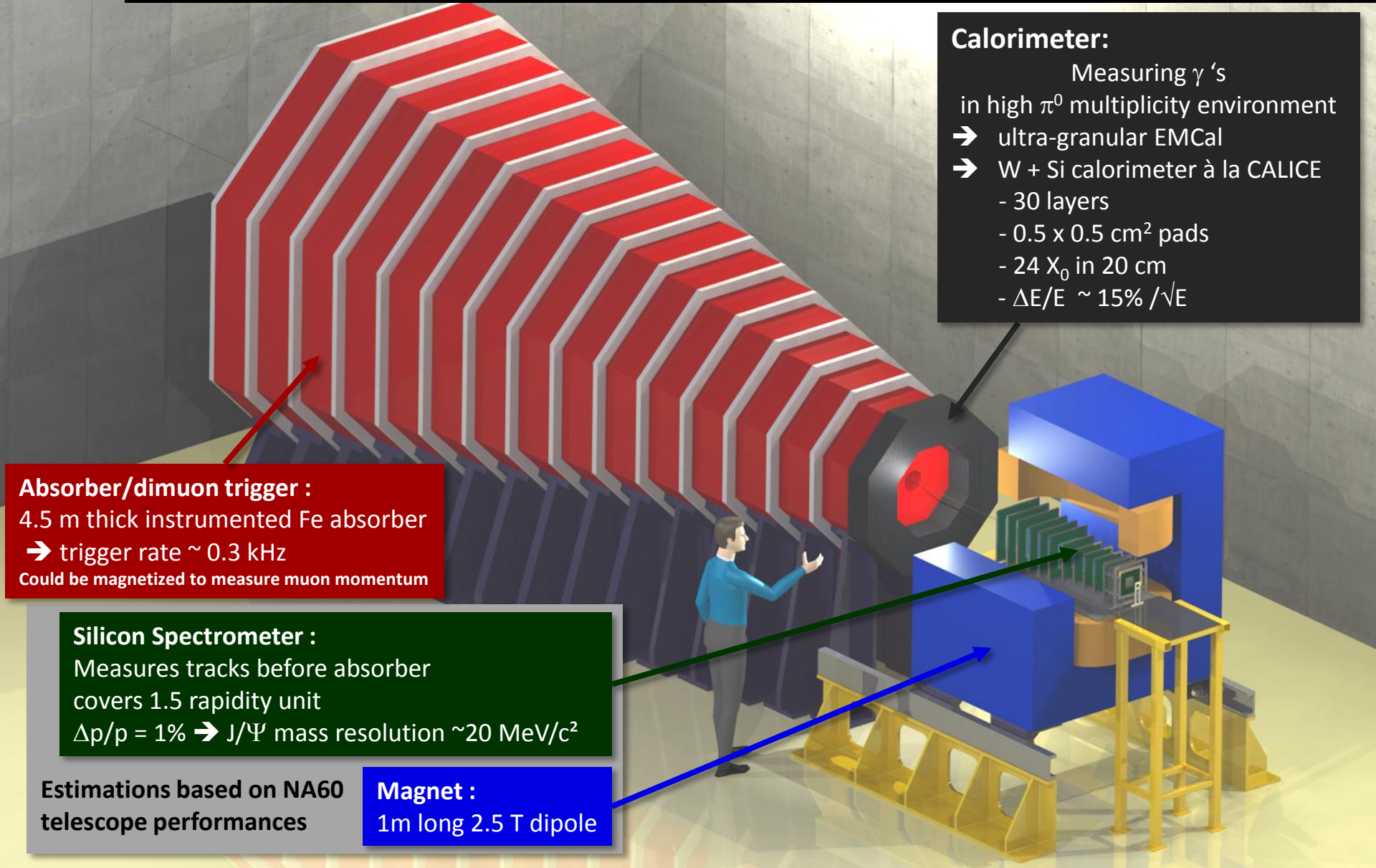
Measures low energy  $\gamma$  in high  $\pi^0$  multiplicity environment

Absorber/trigger

Absorbs  $\pi/K$

Minimize fake triggers from  $\pi/K$  decays





**Calorimeter:**  
 Measuring  $\gamma$ 's  
 in high  $\pi^0$  multiplicity environment  
 → ultra-granular EMCal  
 → W + Si calorimeter à la CALICE  
 - 30 layers  
 -  $0.5 \times 0.5$  cm<sup>2</sup> pads  
 -  $24 X_0$  in 20 cm  
 -  $\Delta E/E \sim 15\% / \sqrt{E}$

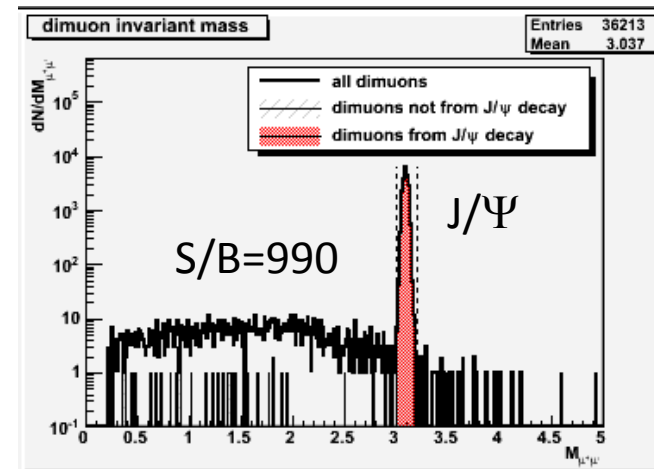
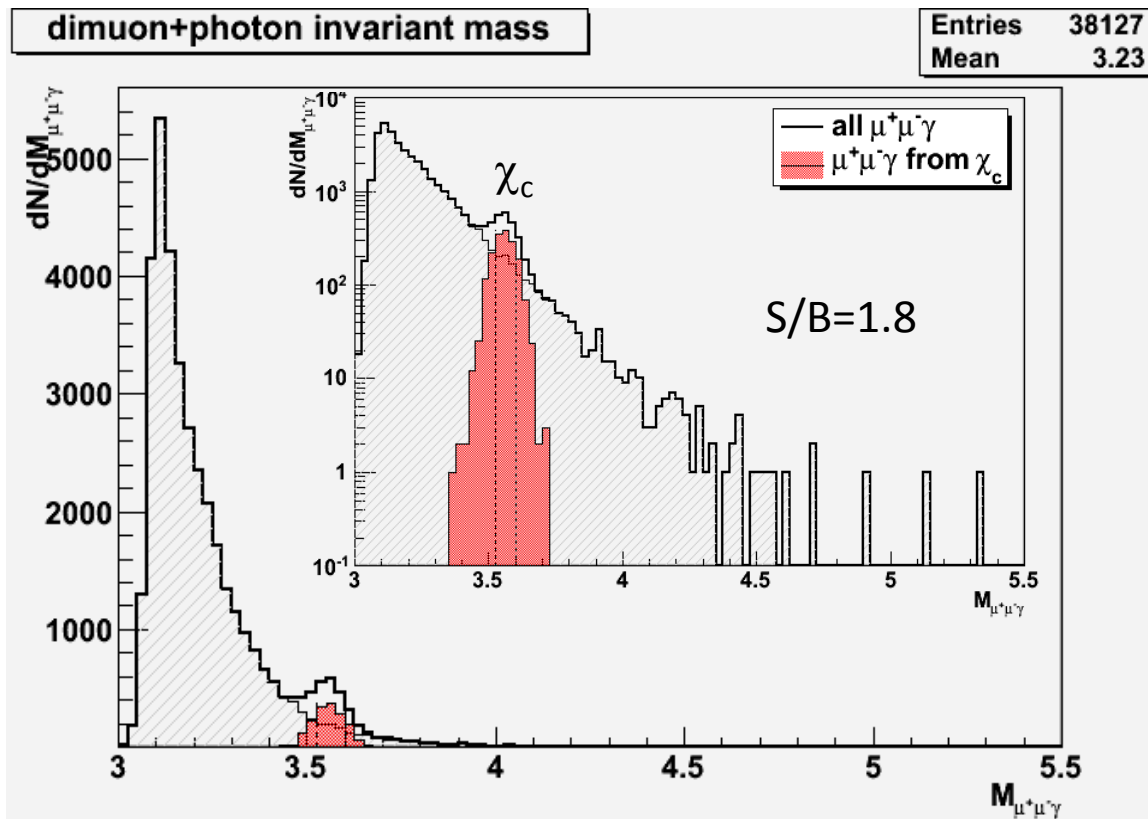
**Absorber/dimuon trigger :**  
 4.5 m thick instrumented Fe absorber  
 → trigger rate  $\sim 0.3$  kHz  
 Could be magnetized to measure muon momentum

**Silicon Spectrometer :**  
 Measures tracks before absorber  
 covers 1.5 rapidity unit  
 $\Delta p/p = 1\% \rightarrow J/\Psi$  mass resolution  $\sim 20$  MeV/c<sup>2</sup>

Estimations based on NA60  
telescope performances

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

- Typical mass plots (~1 week data taking w/ a 10%  $\lambda_1$  Pb target)
  - 140 000  $J/\Psi$  produced in Pb+Pb (70%)
  - 60 000  $\chi_c$  produced in Pb+Pb (30%)
 (embedded in Pb+Pb Minbias events produced w/ EPOS)



After acceptance and selection cuts:

- 35 000  $J/\Psi$   
 → acc x eff = 17.4%  
 mass resolution  $\sim 20 \text{ MeV}/c^2$
- 1700  $\chi_c$   
 → acc x eff = 2.8 %  
 mass resolution  $\sim 45 \text{ MeV}/c^2$

- **Typical 40-day Pb+Pb run**
  - ~ 180 000  $J/\Psi \rightarrow \mu^+\mu^-$  expected
  - 2 extreme numerical scenarios:

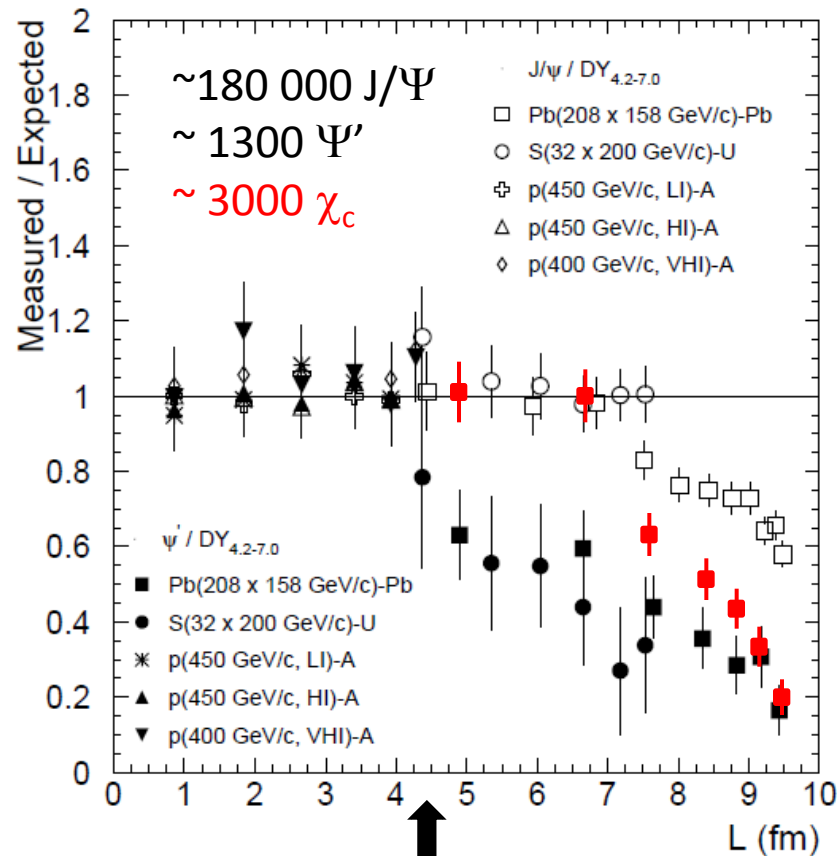
• If  $\chi_c$  suppressed as  $J/\Psi$   $\frac{\chi_c \text{ yield}}{J/\Psi \text{ yield}} \sim 4\%$

→  $\left( \begin{matrix} \text{most periph.} \\ \chi_c \text{ yield} \end{matrix} \right) = 16942 \times 4\% = 677$

• If  $\chi_c$  suppressed as  $\Psi'$   $\frac{\chi_c \text{ yield}}{\Psi' \text{ yield}} = 2.18$

↑  $\left( \begin{matrix} \text{most periph.} \\ \chi_c \text{ yield} \end{matrix} \right) = 16942 \times 4\% \times 0.6 = 406$

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



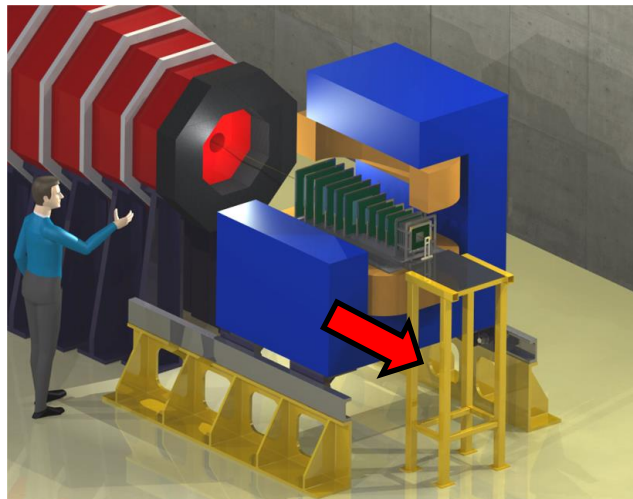
**Expect  $3000 < N_{\chi_c} < 7000$**

- 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)

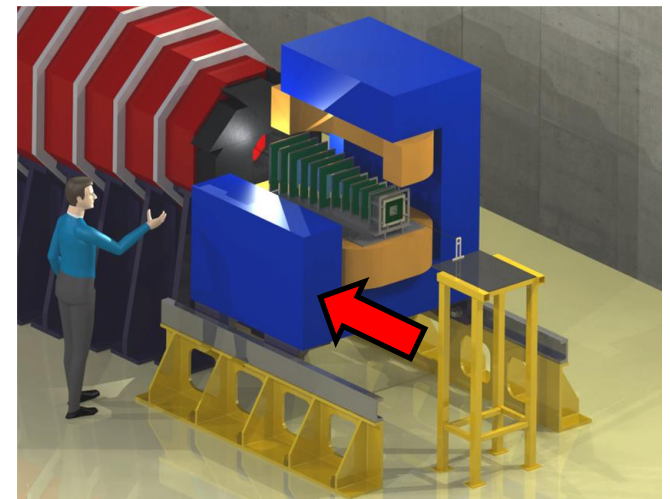
→ Need large  $y_{\text{CMS}}$  range

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

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



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



- A thorough p+A program

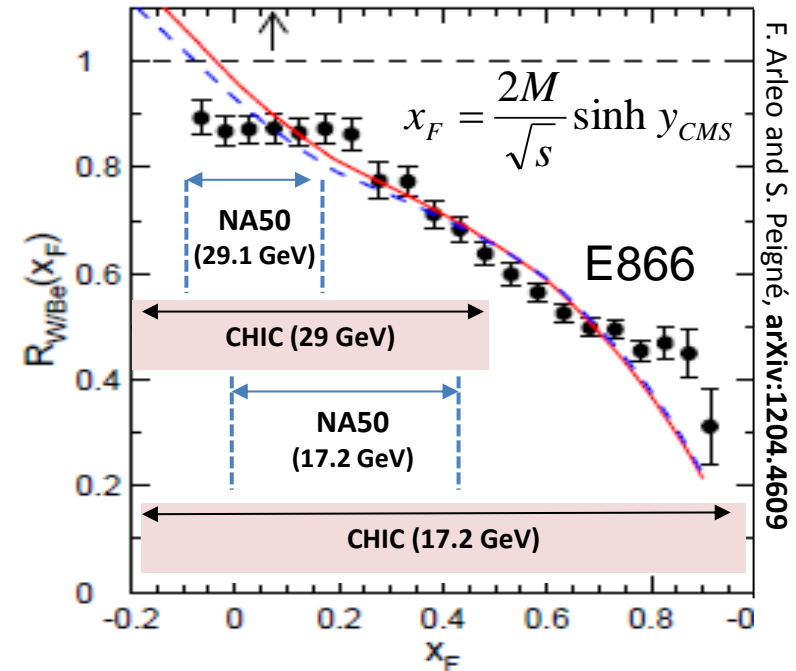
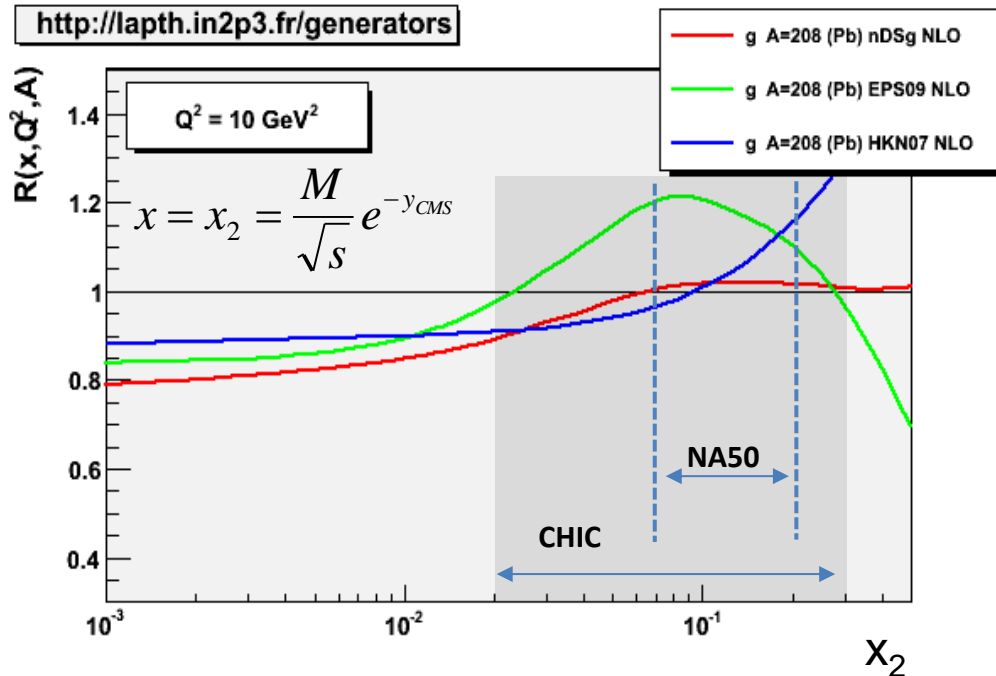
$J/\Psi, \Psi', \chi_c$  in a large  $y_{CMS}$  range

→ 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]



F. Arleo and S. Peigné, arXiv:1204.4609

- A thorough p+A program

- $J/\Psi$ ,  $\Psi'$ ,  $\chi_c$  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 ( $\lambda_I$ )	$\langle I_{protons} \rangle$ ( $\times 10^8$ )	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



- 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  $J/\Psi$  ( $\langle P_\mu \rangle \sim 10$  GeV/c)

- $\frac{\Delta P_\mu}{P_\mu} = 0.7\%$  for typical muon from  $\omega$  ( $\langle P_\mu \rangle \sim 7$  GeV/c)

- Expected mass resolution:

- $J/\Psi$ :  $\frac{\Delta P_\mu}{P_\mu} = 1\% \Rightarrow \frac{\Delta P_\mu}{\sqrt{2}P_\mu} = \frac{\Delta M_{\mu\mu}}{M_{\mu\mu}} = 0.7\%$

- $\omega$ :  $\frac{\Delta P_\mu}{P_\mu} = 0.7\% \Rightarrow \frac{\Delta P_\mu}{\sqrt{2}P_\mu} = \frac{\Delta M_{\mu\mu}}{M_{\mu\mu}} = 0.5\%$

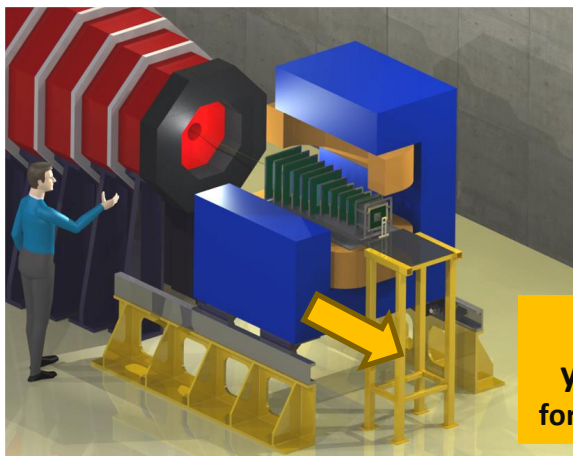
$$\Delta M_{\mu\mu}^{J/\Psi} \sim 3.097 \text{ GeV}/c^2 \times 0,7\% \sim 20 \text{ MeV}/c^2$$

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

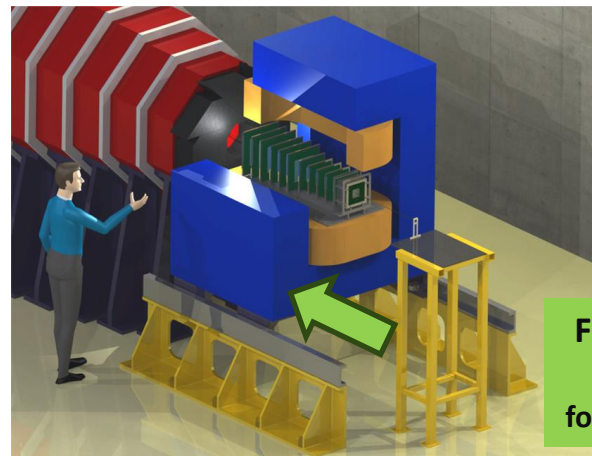
$$\Delta M_{\mu\mu}^\omega \sim 782.7 \text{ MeV}/c^2 \times 0,5\% \sim 4 \text{ MeV}/c^2$$

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

- Spectrometer acceptance: two detector configurations



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



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

Depending on the beam energy, different rapidity ranges accessible

$P_{\text{beam}}$ (GeV/c)	$\sqrt{s}$ (GeV)	Rapidity of Center-of-mass	Mid-rapidity		Forward-rapidity	
			$y_{\text{CMS}} \text{ min}$	$y_{\text{CMS}} \text{ max}$	$y_{\text{CMS}} \text{ min}$	$y_{\text{CMS}} \text{ max}$
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

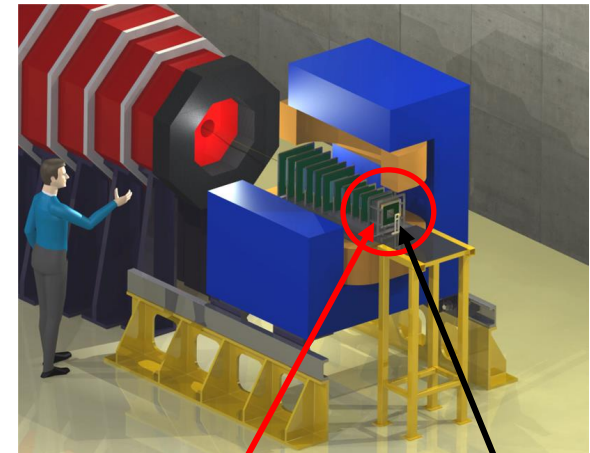
**Common coverage:  $y_{\text{CMS}} \in [0;2]$  (NA50/NA60 coverage =  $[0;1]$ )**

- Use same Strategy as NA60: measure muon vertex

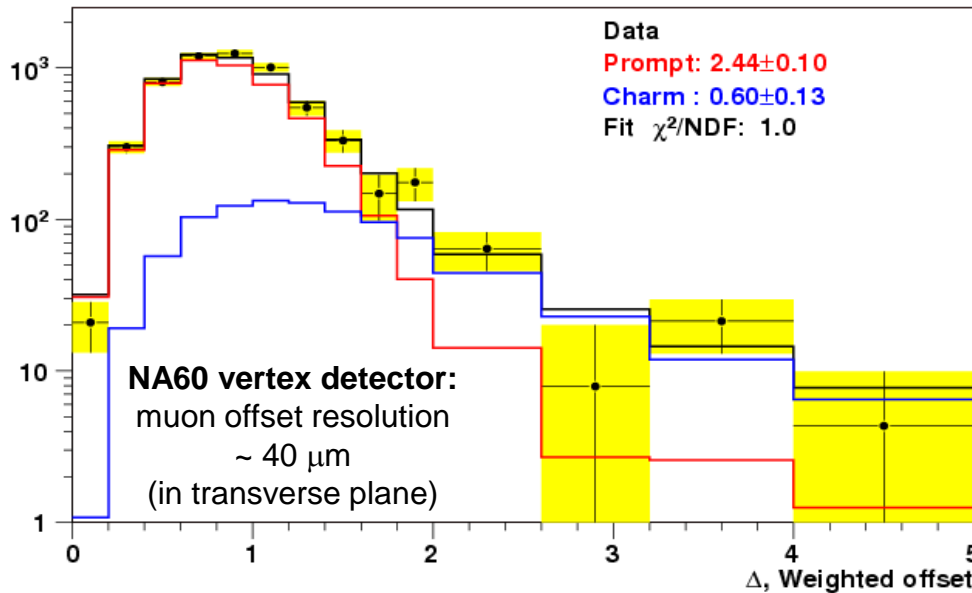
– Open charm decay length:  $\begin{cases} D^{+/-}: c\tau = 311.8 \mu\text{m} \\ D^0: c\tau = 122.9 \mu\text{m} \end{cases}$

–  $P_{\text{lab}} = 158 \text{ GeV}/c \rightarrow \gamma = 9.2 \rightarrow \begin{cases} D^{+/-}: \gamma c\tau = 2.86 \text{ mm} \\ D^0: \gamma c\tau = 1.13 \text{ mm} \end{cases}$

(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...

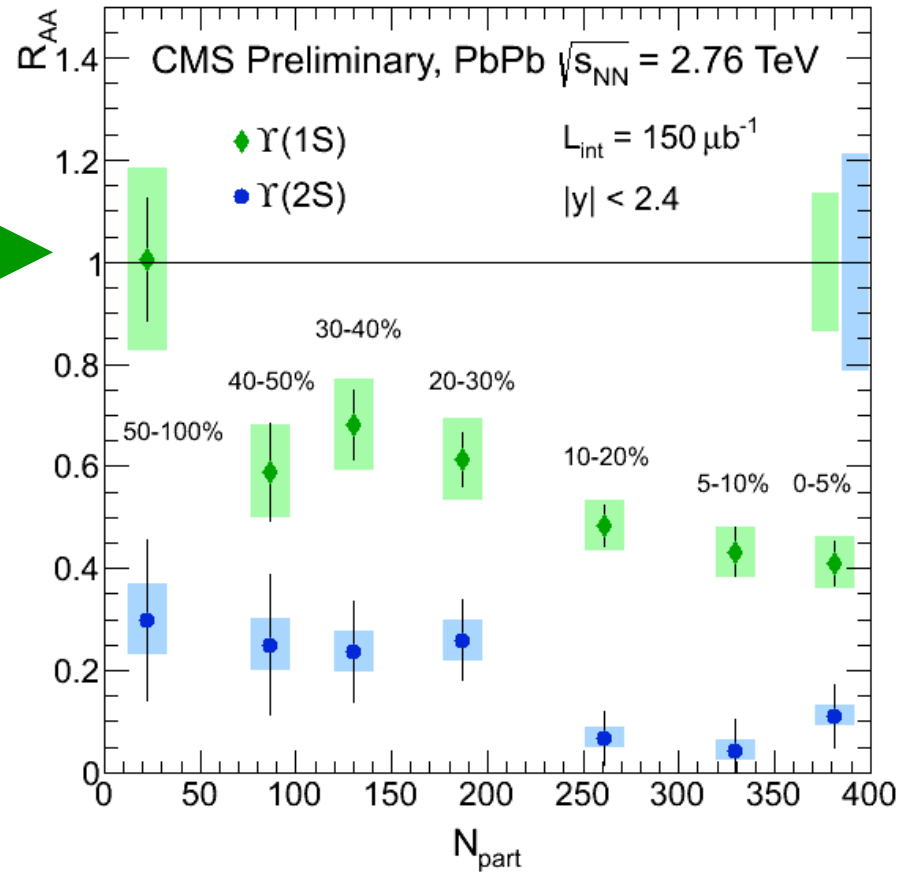
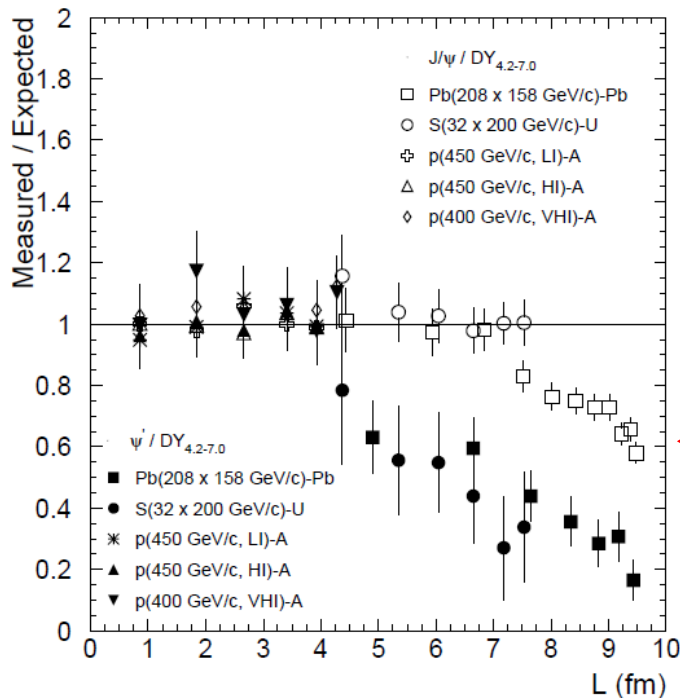
# Conclusion

- Measuring together  $J/\Psi$ ,  $\Psi'$  and  $\chi_c$  in p+A collisions with several targets will give a thorough control of **Cold Nuclear Matter effects**
- Measuring together  $J/\Psi$ ,  $\Psi'$  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.
- **Testing sequential suppression scenario at SPS is crucial to fully understand RHIC and LHC results.**

## Results from CMS

### "Observation of Sequential $\Upsilon$ Suppression in PbPb collisions" (at LHC)

*PRL 109, 222301 (2012)*

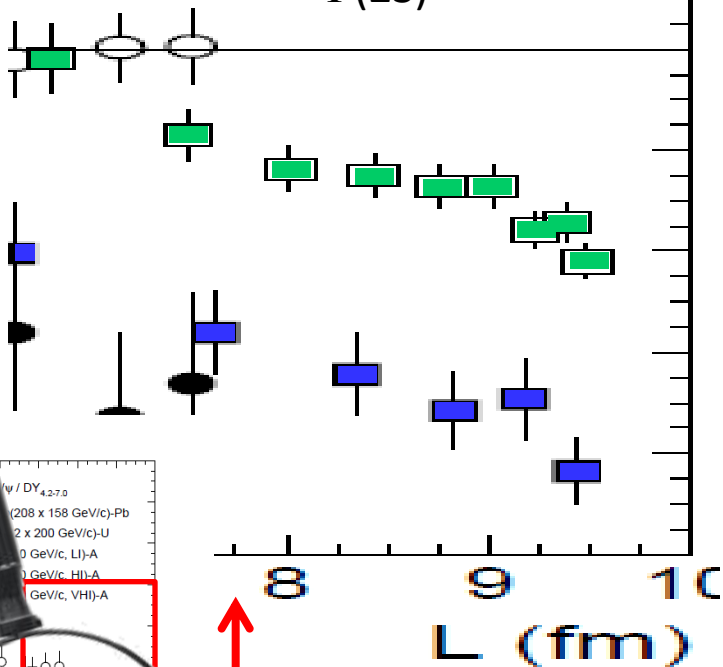


Charmonia @ SPS

bottomonia @ LHC

NA50, PbPb  $\sqrt{s_{NN}}=17.2$  GeV

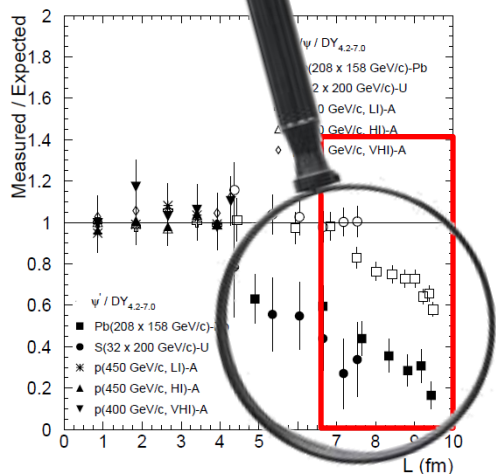
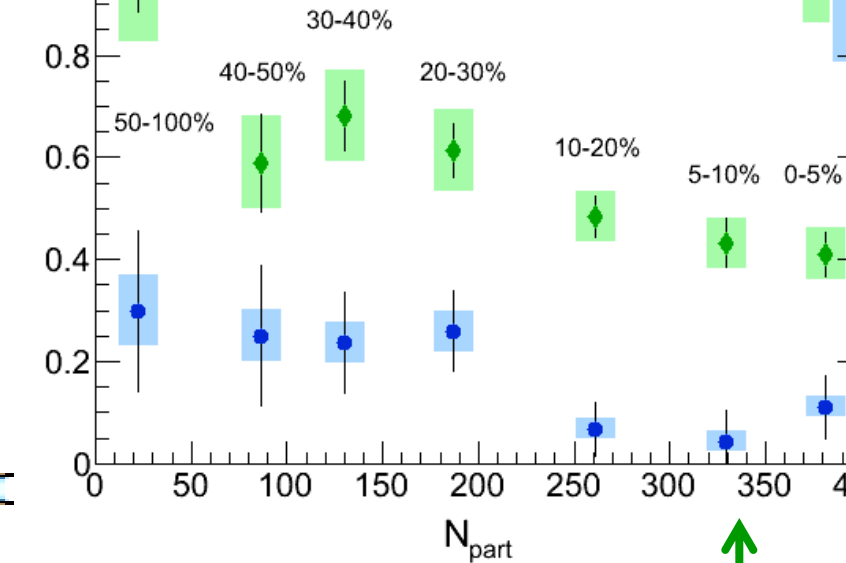
■ Ψ(1S)  
■ Ψ(2S)



CMS Preliminary, PbPb  $\sqrt{s_{NN}} = 2.76$  TeV

◆ Υ(1S)  
● Υ(2S)

$L_{int} = 150 \mu b^{-1}$   
 $|y| < 2.4$



**Charmonia @ SPS**

**bottomonia @ LHC**

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

## 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

- 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-ECI-018  
 20V 30/2012

### 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  $\chi_c$  decays should now be achievable. Together with recent measurements made at RHIC and at LHC on  $J/\psi$  and  $\Upsilon$  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  $\chi_c$ . 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.



## 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.



- **People involved**

- 1 experimentalist : F. Fleuret

- 4 theoreticians : 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  $\gamma$  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**

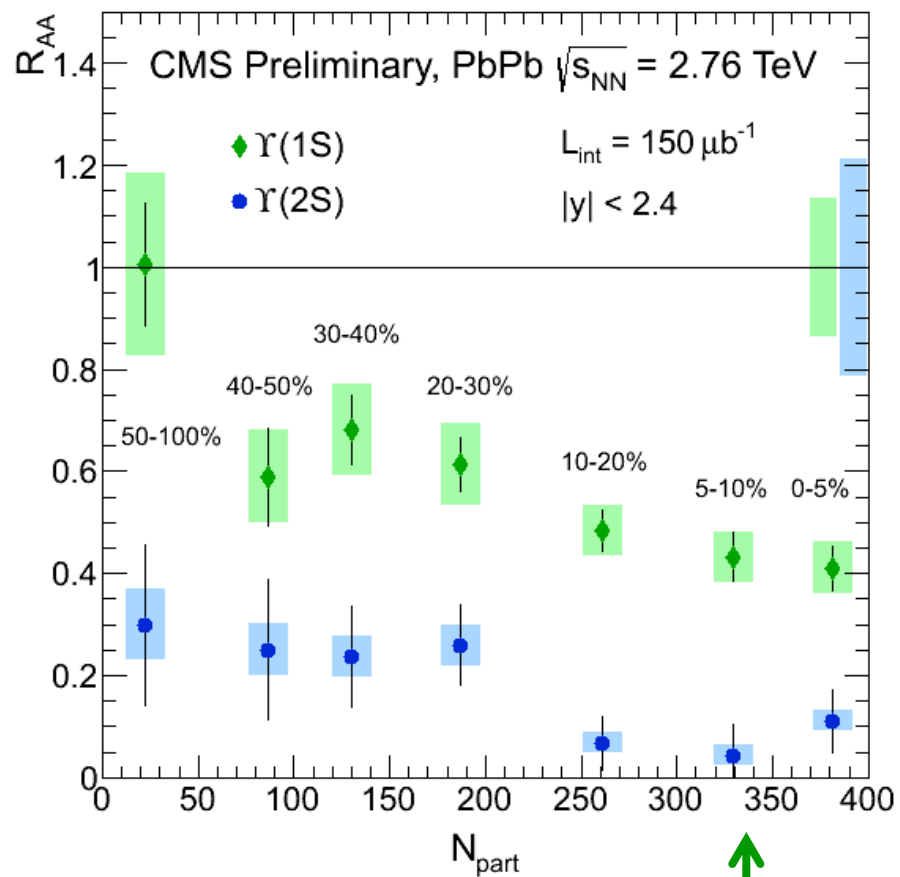
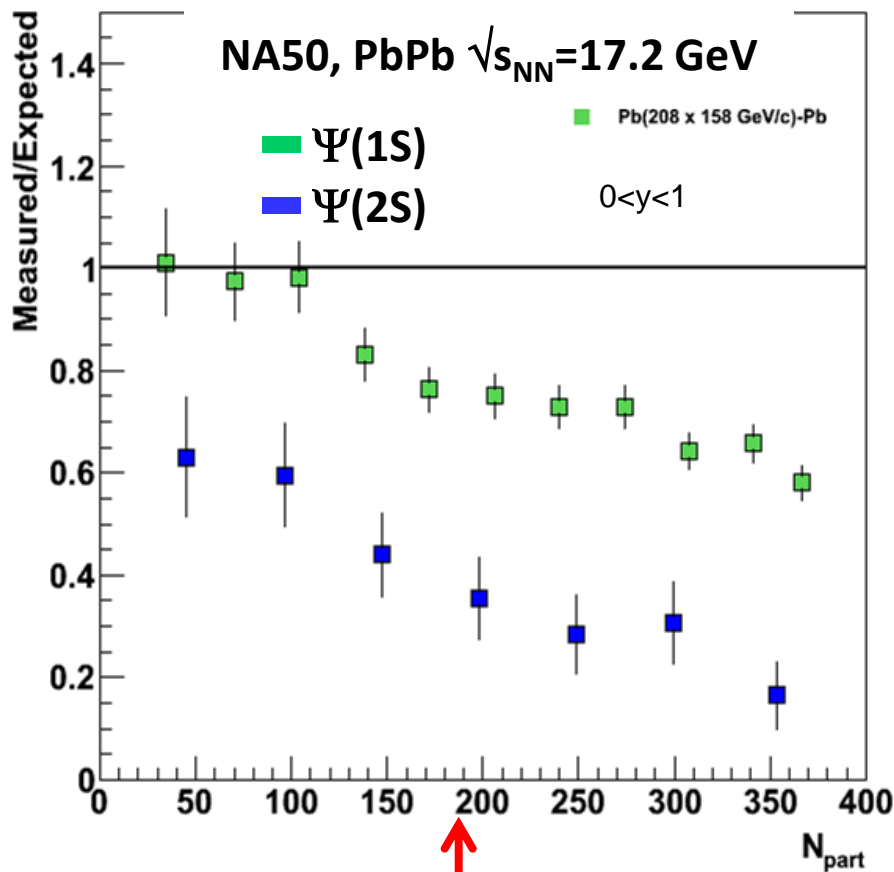
- **Timeline**

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

WE NEED YOU !!  
JOIN US !



# backup



↑ Charmonia @ SPS

↑ bottomonia @ LHC

**On the same axis**