

An experiment to measure χ_c suppression at the CERN SPS

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

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

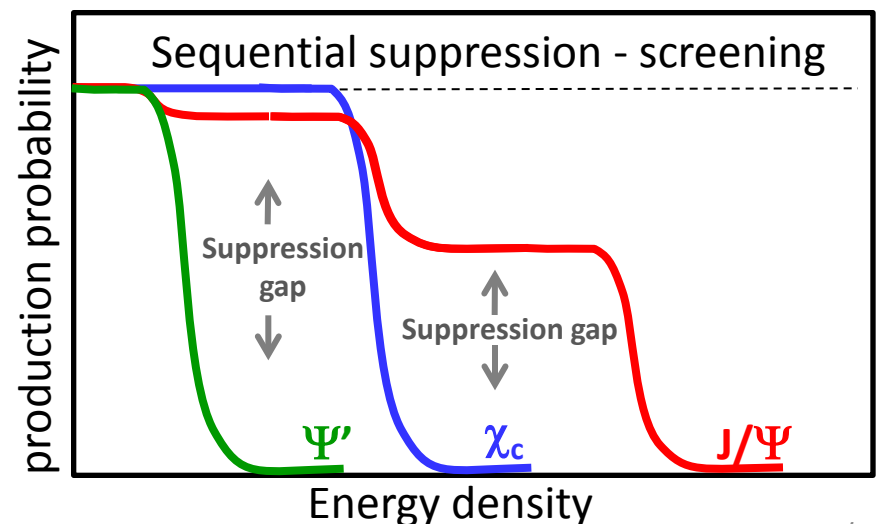
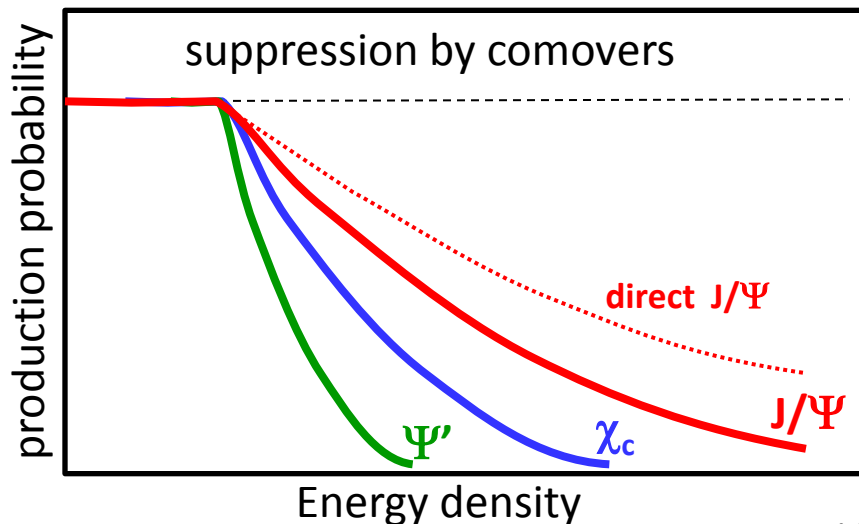
[H. Satz, J. Phys. G 32 \(2006\)](#)

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/Ψ production in A+A collisions is (has been) 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
 - **Unclear overall picture :**
 - **Hot and Dense Matter effects due to color 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 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 gap in suppression patterns**
- *Alternative scenario: suppression by comoving hadrons*
- *Smooth suppression*
 - *Same starting point*
 - *Slopes related to binding energy : $S_{\Psi'} > S_{\chi} > S_{J/\Psi}$*



- Anomalous suppression at SPS

[Eur.Phys.J.C49:559-567,2007](https://arxiv.org/abs/hep-ex/0607007)

sequential suppression (QGP) ?

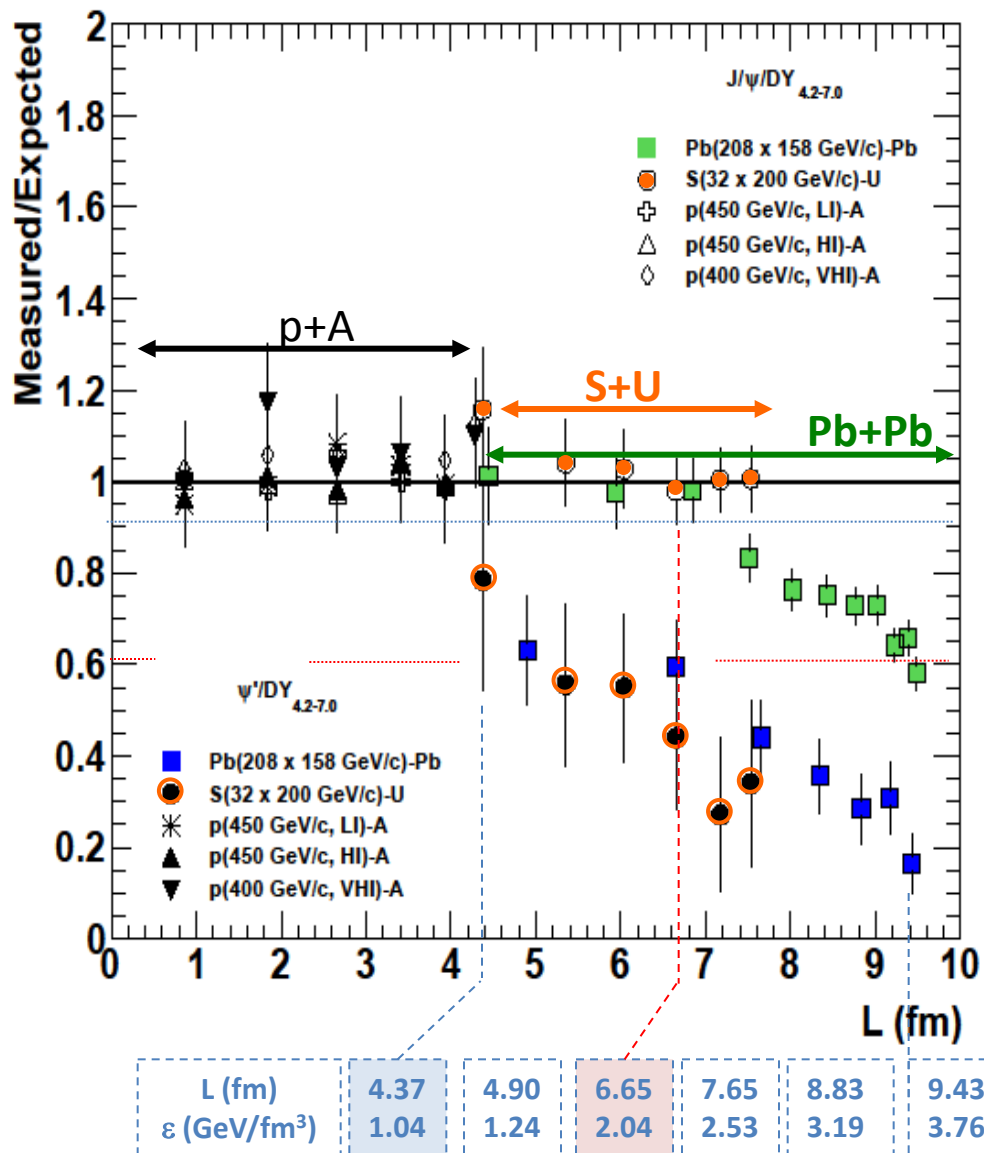
or

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



- Anomalous suppression at SPS

[Eur.Phys.J.C49:559-567,2007](https://arxiv.org/abs/hep-ex/0305025)

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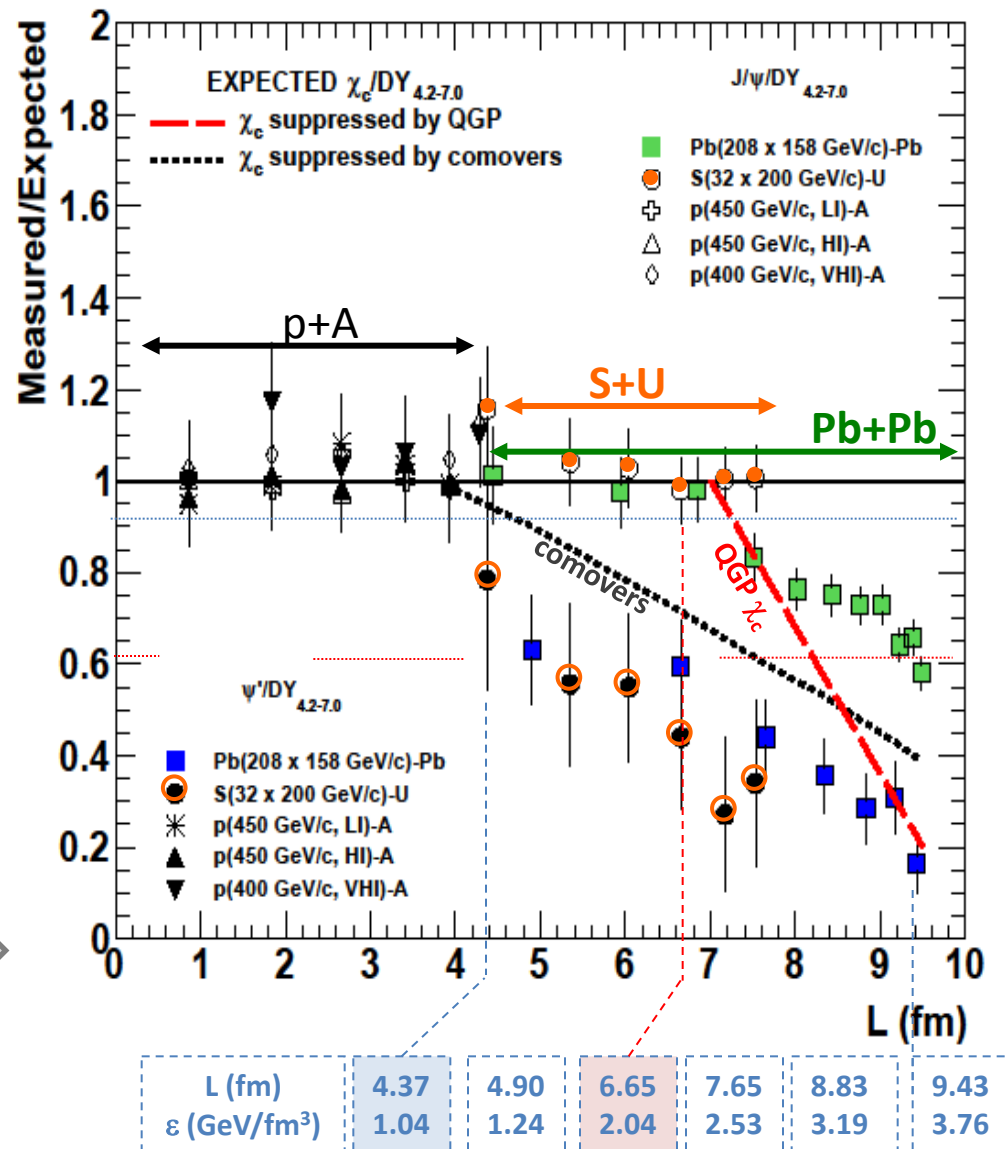
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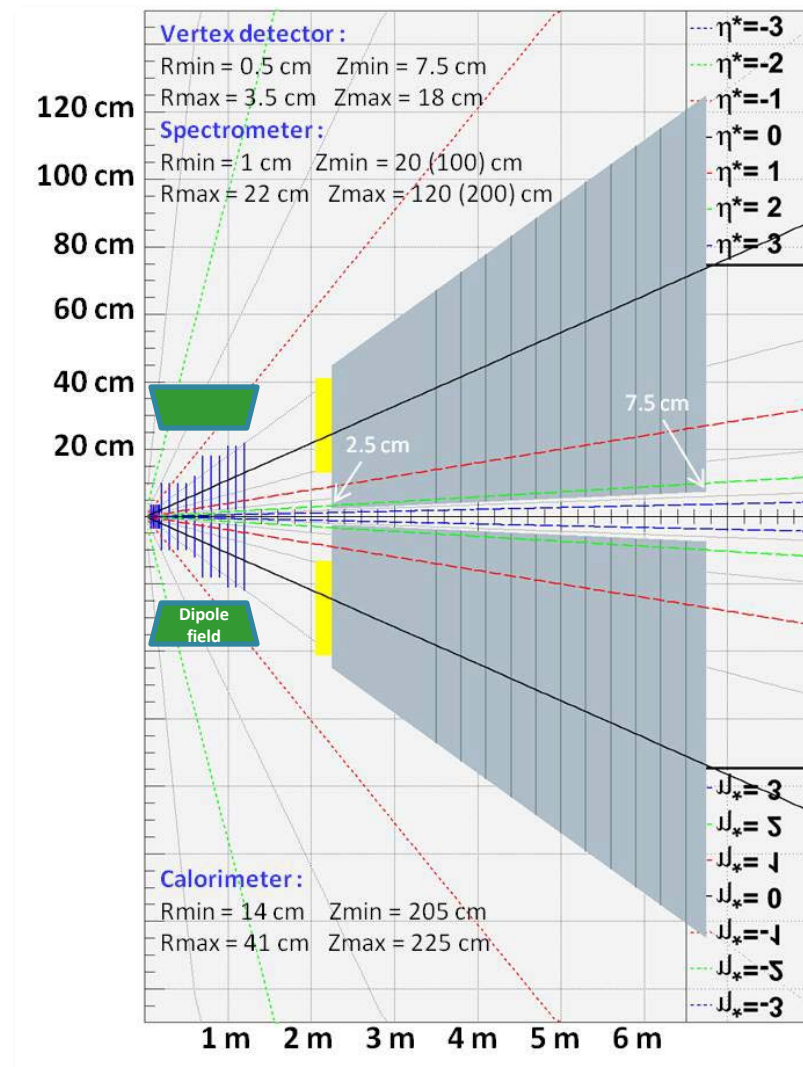
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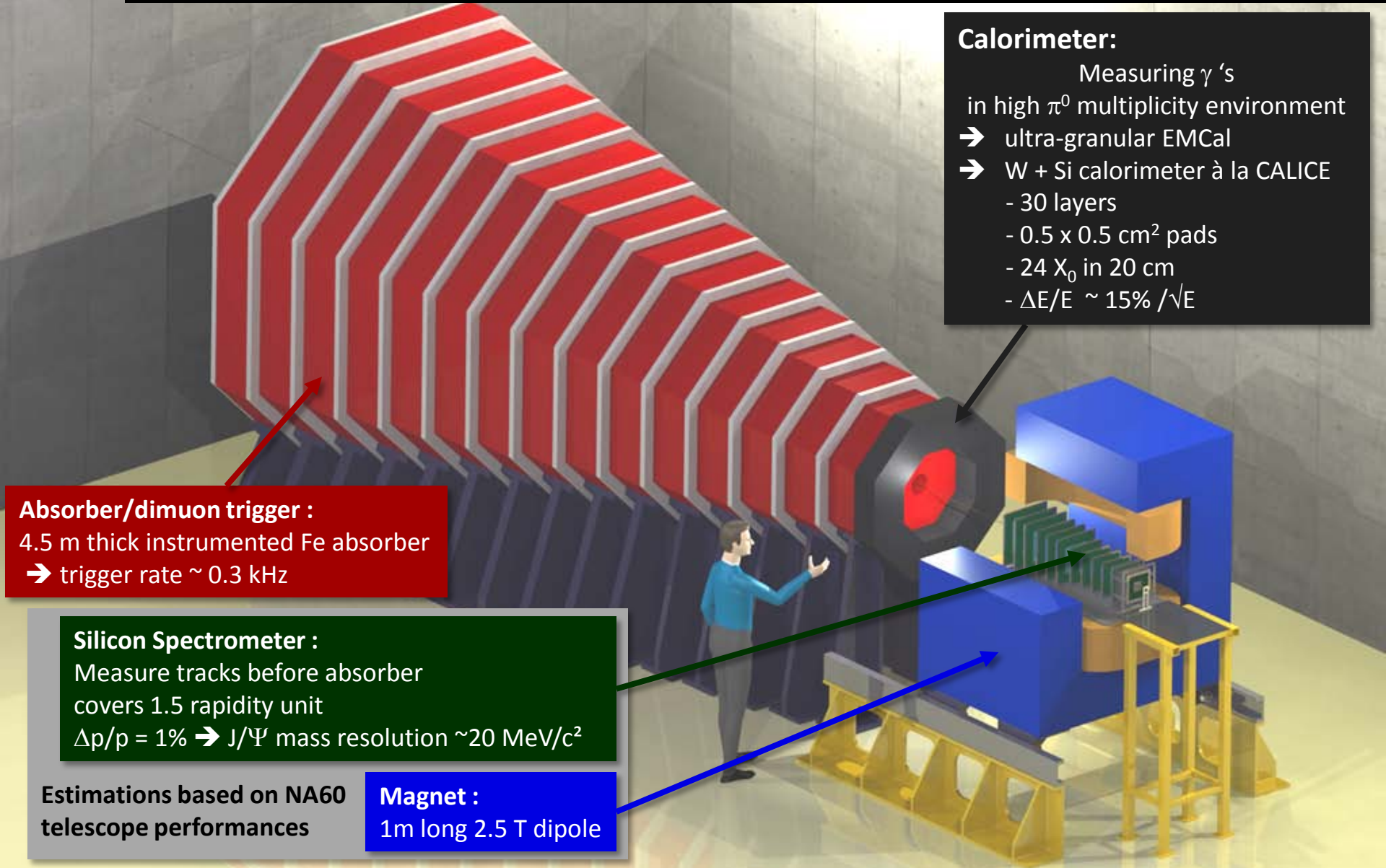
→ need of a larger feed-down fraction

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



- 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 γ in high π^0 multiplicity environment
 3. **Absorber/trigger**
 - » Absorb π/K
 - » Minimize fake triggers from π/K decays





Calorimeter:
 Measuring γ 's
 in high π^0 multiplicity environment
 → ultra-granular EMCal
 → W + Si calorimeter à la CALICE
 - 30 layers
 - 0.5×0.5 cm² 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

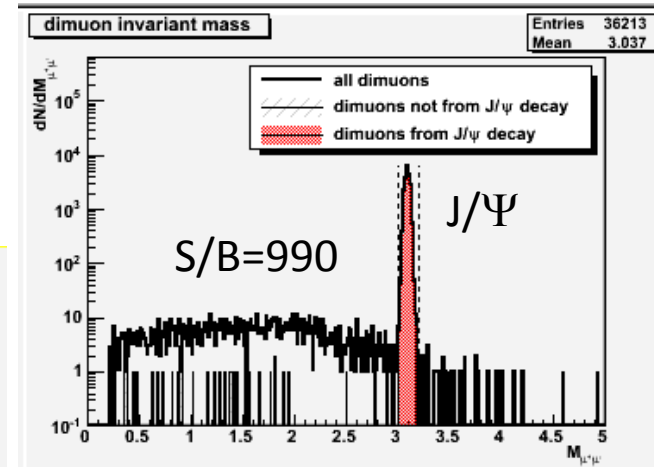
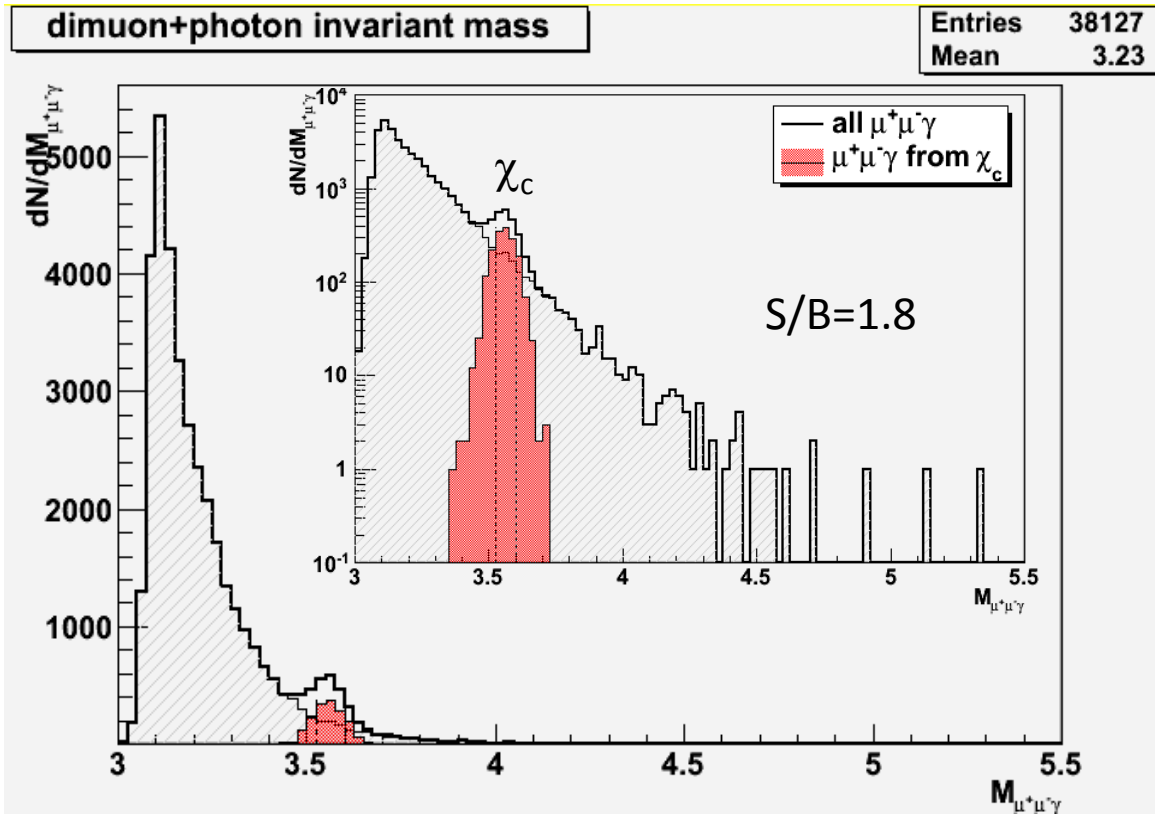
Silicon Spectrometer :
 Measure tracks before absorber
 covers 1.5 rapidity unit
 $\Delta p/p = 1\% \rightarrow J/\Psi$ mass resolution ~ 20 MeV/c²

Estimations based on NA60
 telescope performances

Magnet :
 1m long 2.5 T dipole

- Typical mass plots (5 days data taking w/ a 10% λ_1 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/ c^2
- 1700 χ_c
 → **acc x eff = 2.8 %**
 mass resolution ~ 45 MeV/ c^2

- Typical one month Pb+Pb run

- ~ 200 000 inclusive $J/\Psi \rightarrow \mu^+\mu^-$ expected

- 2 extreme scenarios:

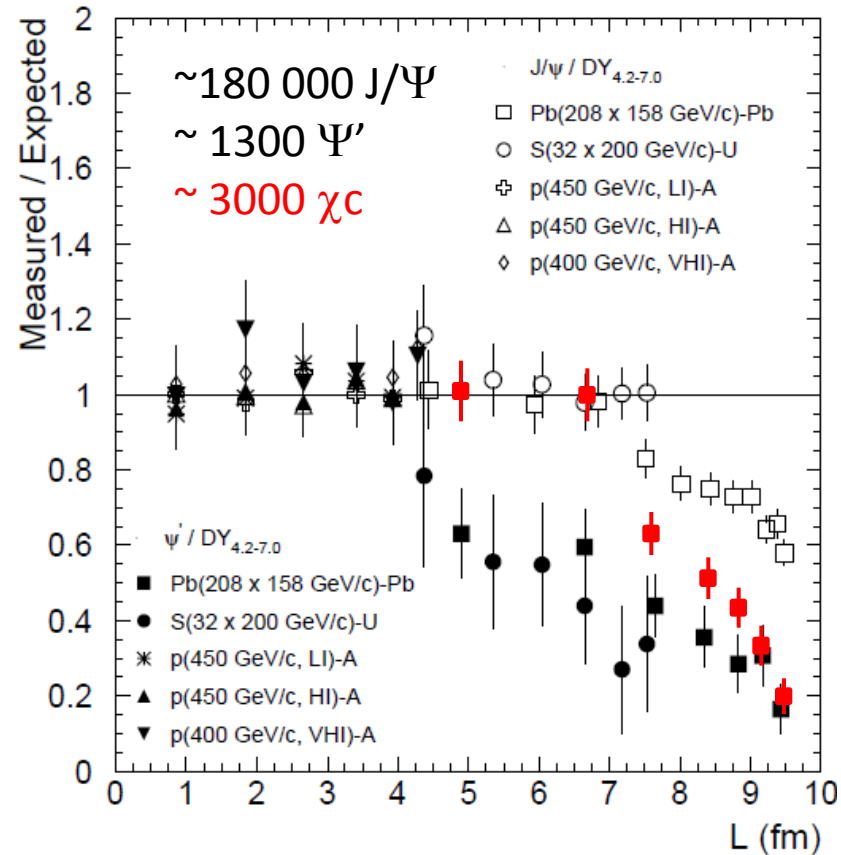
- If χ_c suppressed as J/Ψ $\frac{\chi_c \text{ yield}}{J/\Psi \text{ yield}} \sim 4\%$

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

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

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

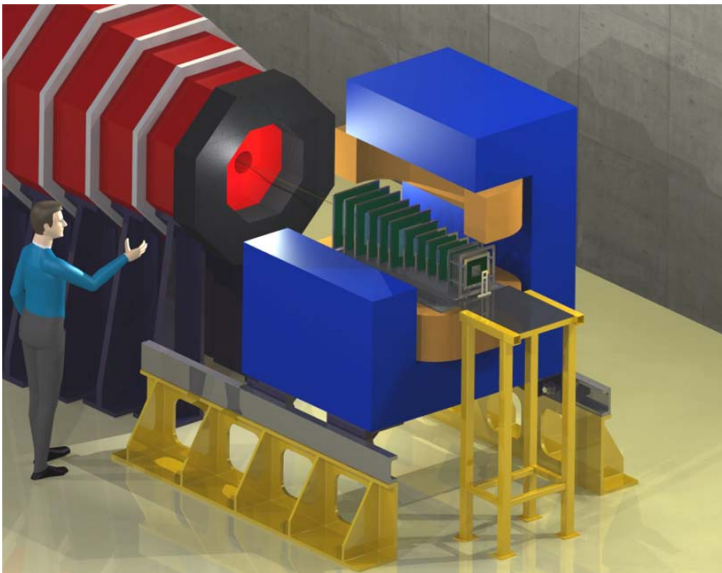
E_T range (GeV)	ψ'	J/ψ	χ_c as Ψ'	χ_c as J/Ψ
3–20	186 ± 25	16942 ± 146	406	677
20–35	243 ± 31	25229 ± 181	530	1010
35–50	227 ± 35	27276 ± 192	495	1091
50–65	193 ± 36	27681 ± 196	421	1107
65–80	154 ± 36	27315 ± 200	336	1093
80–95	159 ± 37	25111 ± 193	647	1004
95–150	110 ± 40	28570 ± 209	240	1143
			3075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



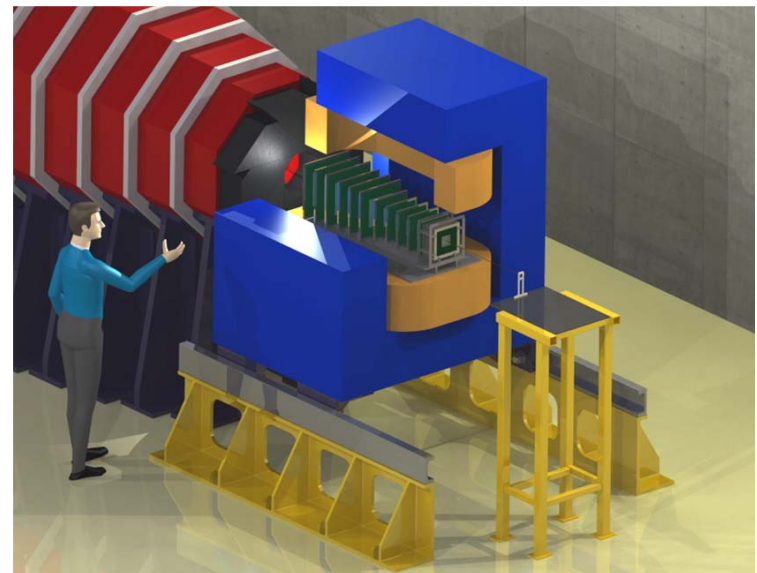
A thorough p+A program is mandatory as reference for hot nuclear matter effects

- **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 $y_{\text{CMS}} \in [-0.5 ; 2]$**

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



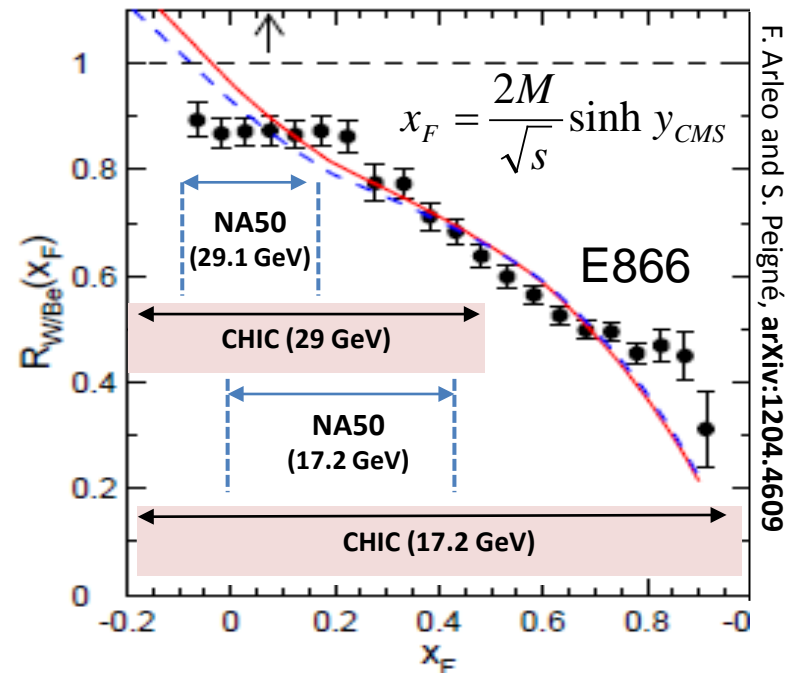
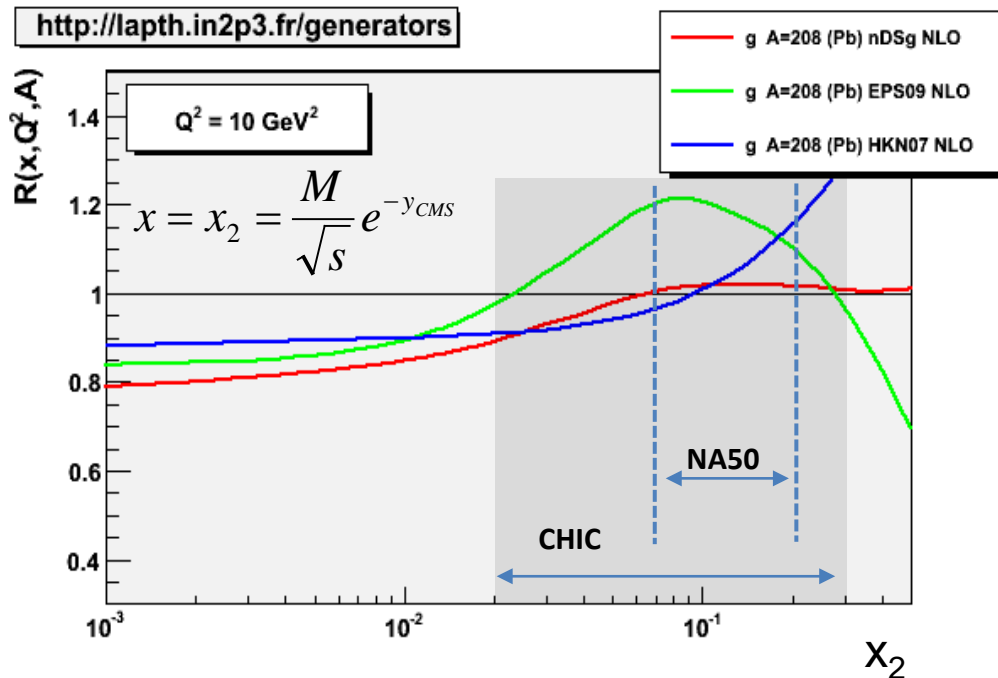
Forward-rapidity : $y_{\text{CMS}} \in [0.5 ; 2]$



A thorough p+A program requires

- $J/\Psi, \Psi', \chi_c$ with several targets (NA50: p+Be, p+Al, p+Cu, p+Ag, p+W, p+Pb)
- $J/\Psi, \Psi', \chi_c$ 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]



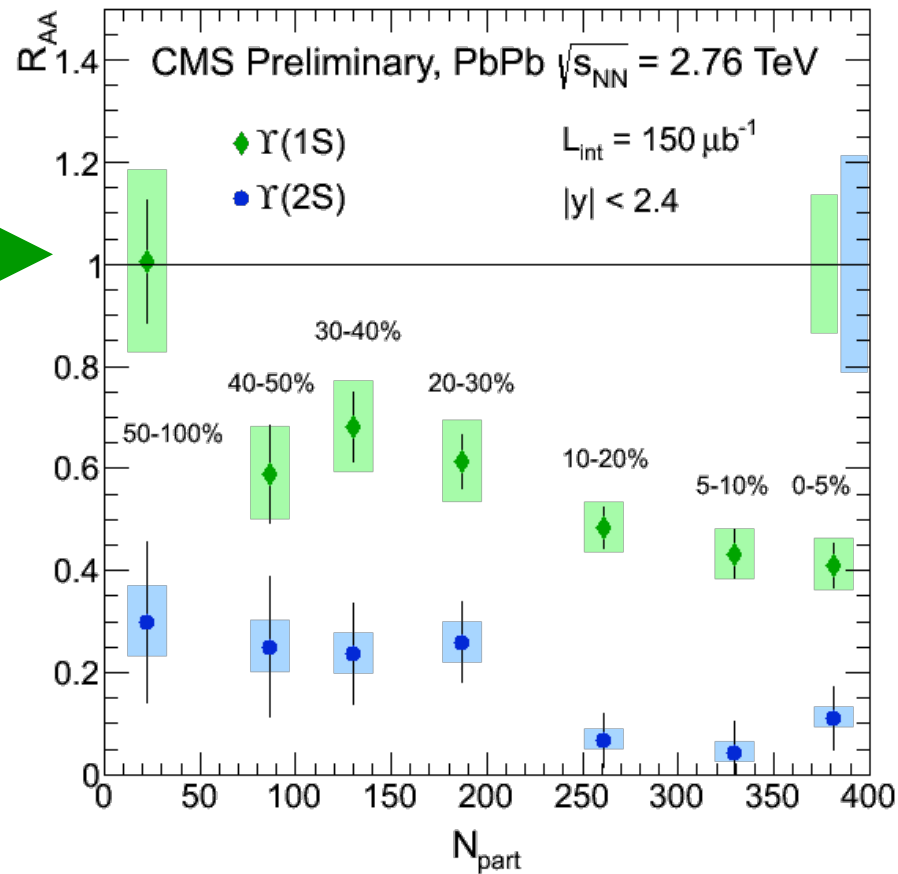
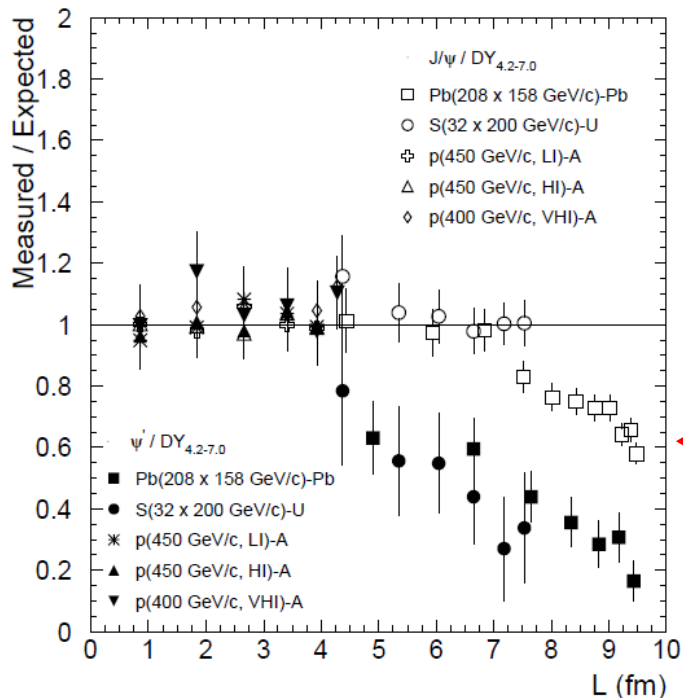
Conclusion

- Measuring together J/Ψ , Ψ' and 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.
- **Understanding sequential suppression at SPS is crucial to fully understand RHIC and LHC results.**

Results from CMS

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

PRL 109, 222301 (2012)

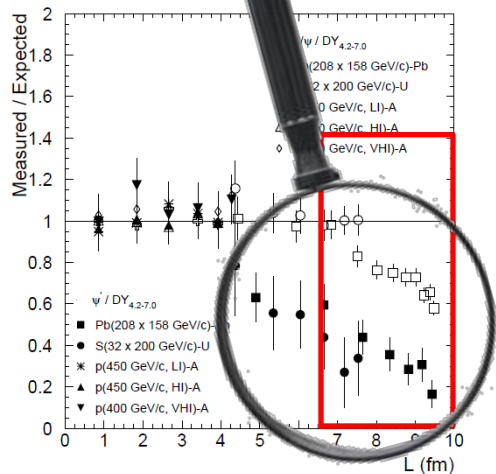
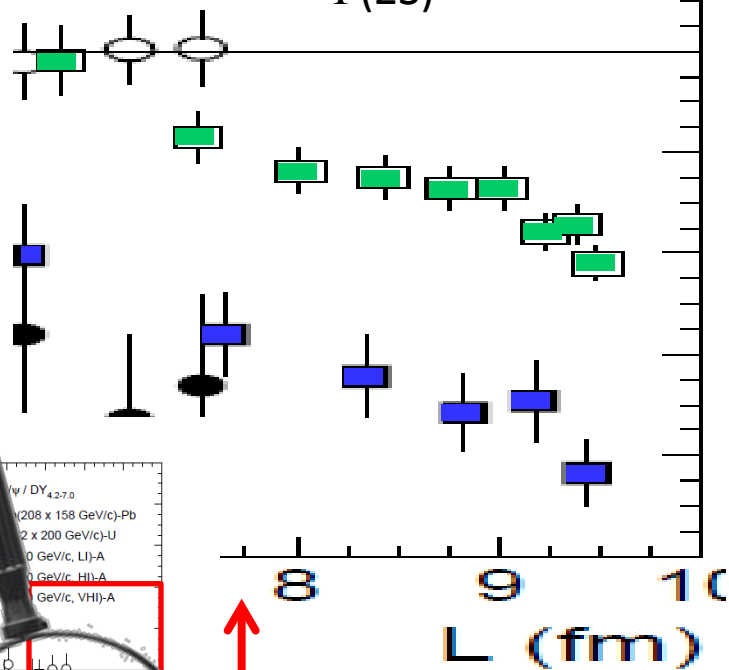


Charmonia @ SPS

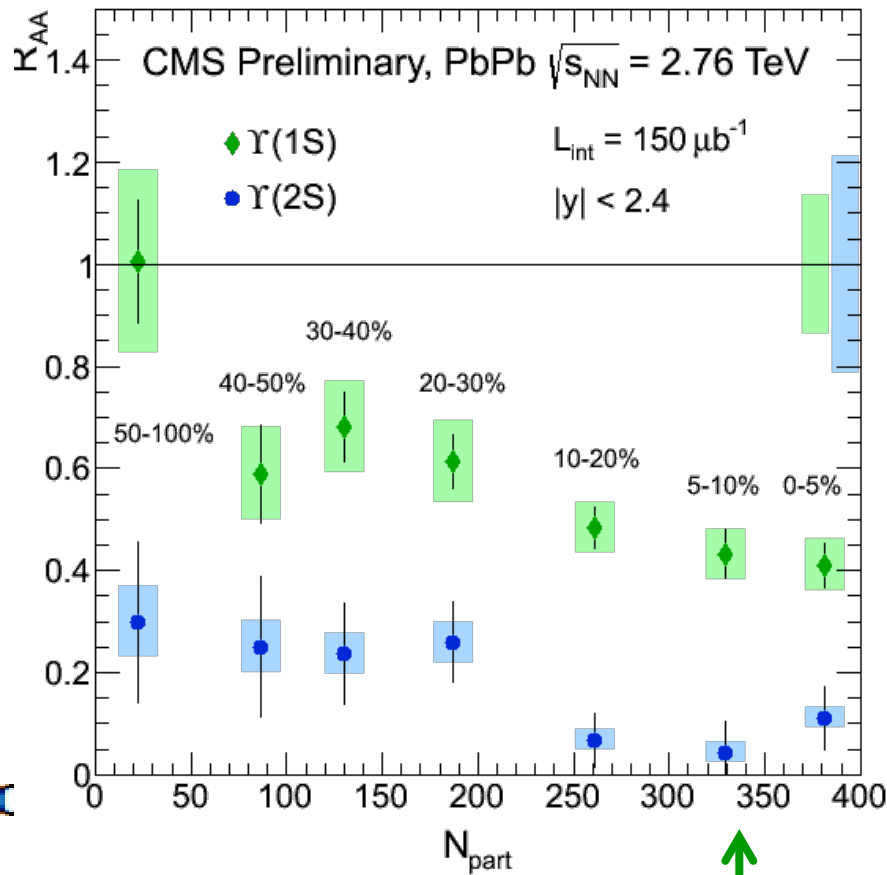
bottomonia @ LHC

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

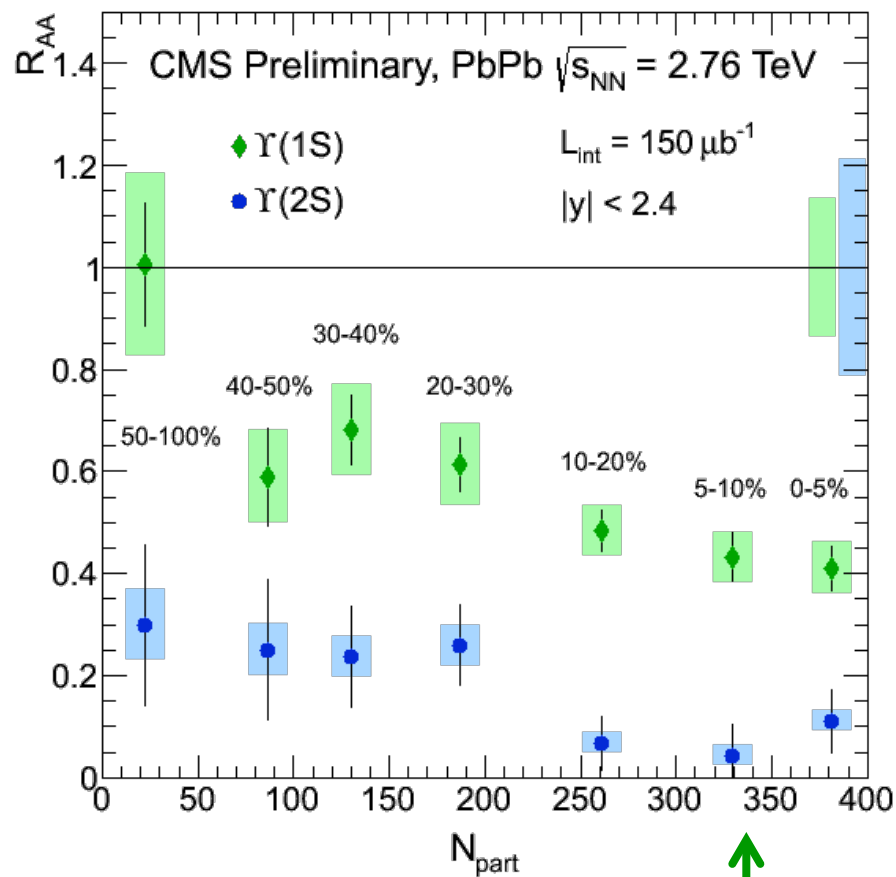
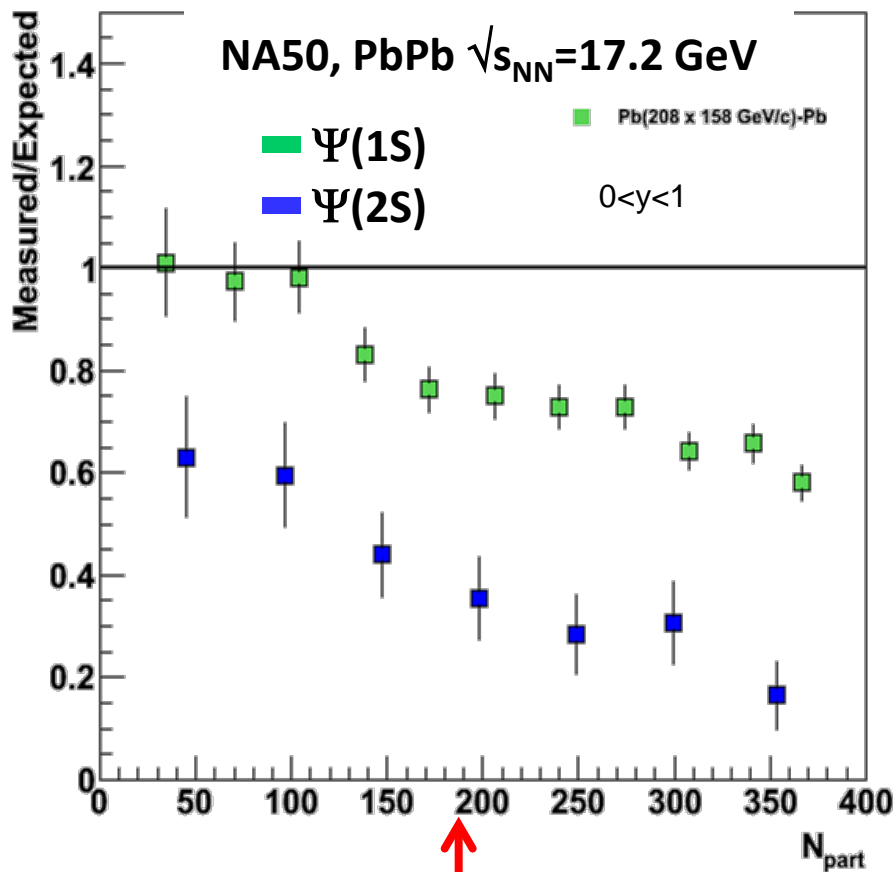
■ Ψ(1S)
■ Ψ(2S)



Charmonia @ SPS



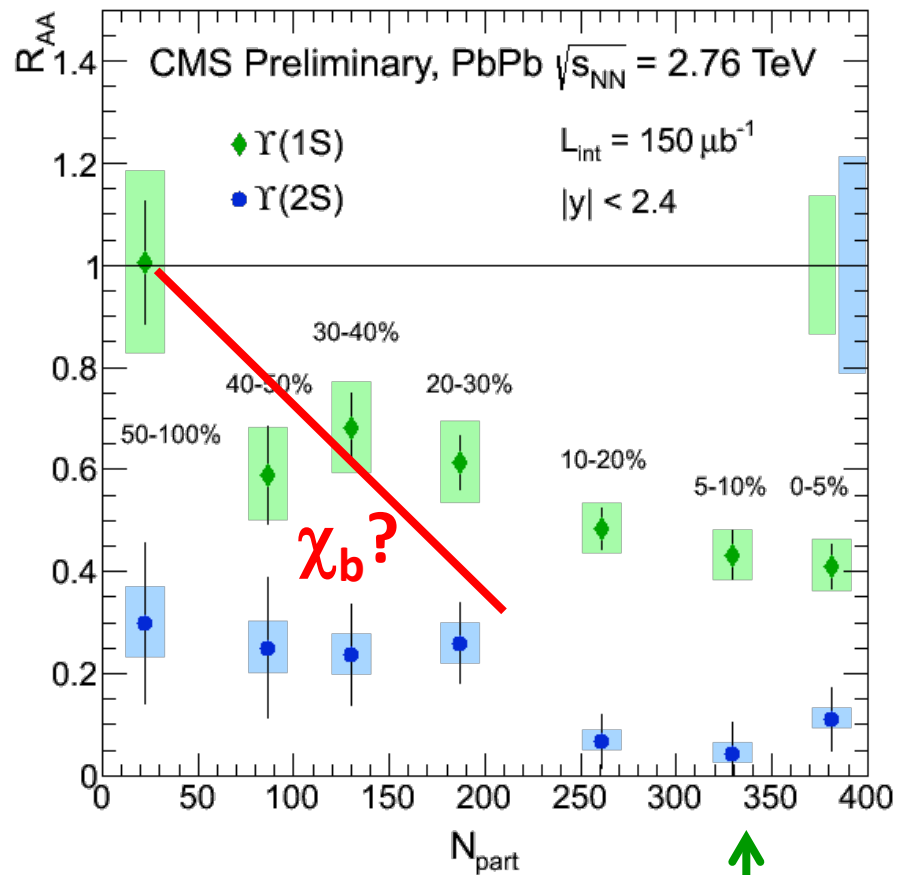
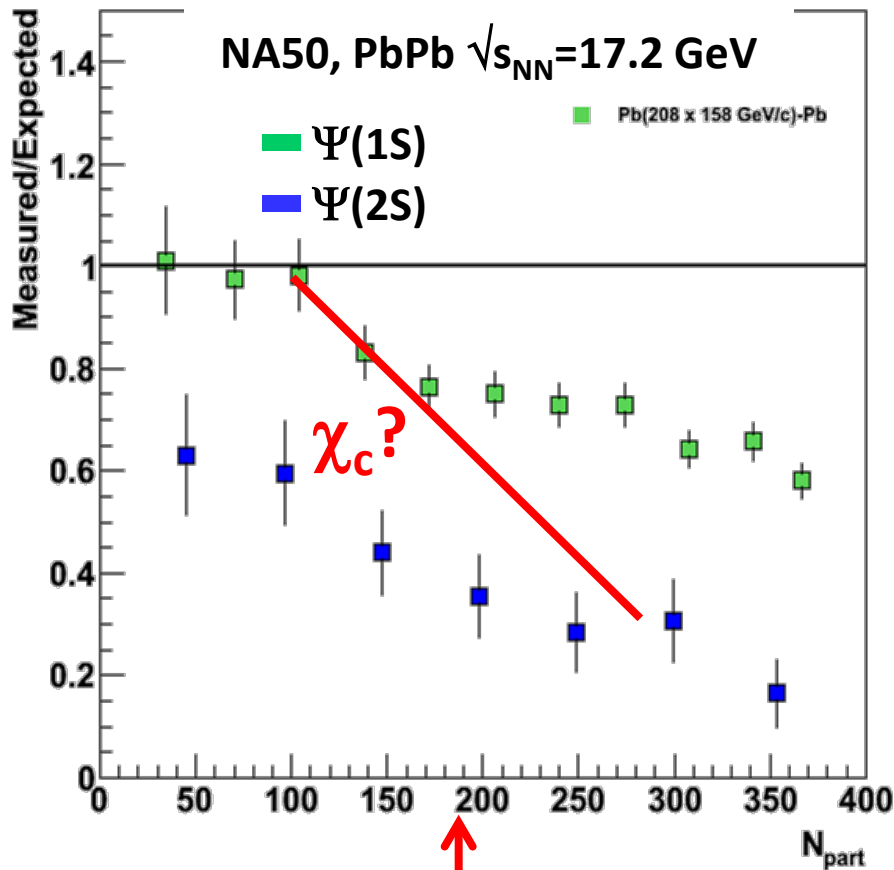
bottomonia @ LHC



↑ Charmonia @ SPS

↑ bottomonia @ LHC

On the same axis



↑ Charmonia @ SPS

↑ bottomonia @ LHC

Let's measure χ_c at SPS !

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.**”

Expression of interest

- Submitted to SPSC (october 2012) – under review

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](#)