An experiment to measure χ_c suppression at the CERN SPS

CHIC: Charm in Heavy Ion Collisions

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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

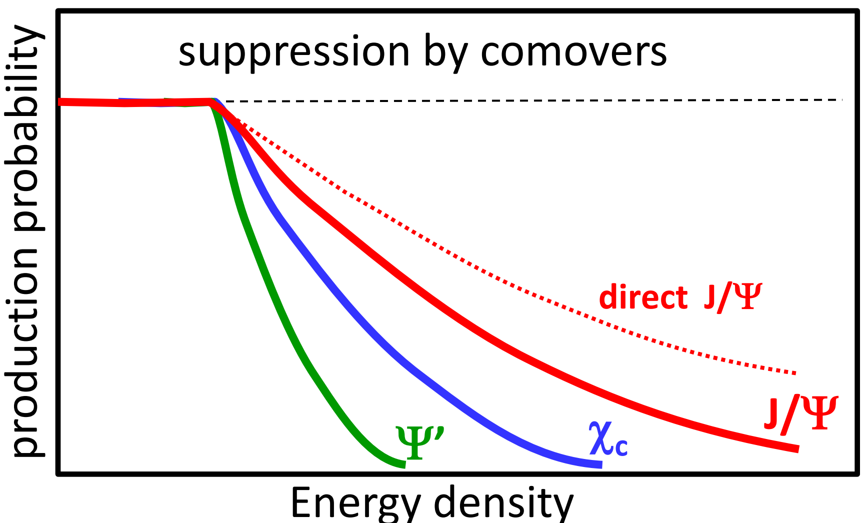
  - Because of feed-downs and different T_d, **sequential suppression** should show up.
- **Experimentally**
  - J/Ψ production in A+A collisions is (has been) studied at :
    - SPS (√s~17 GeV) : NA38, NA50, NA60 experiments
    - RHIC (√s~200 GeV) : PHENIX, STAR experiments
    - LHC (√s~2.76 TeV) : ALICE, CMS experiments
  - **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)

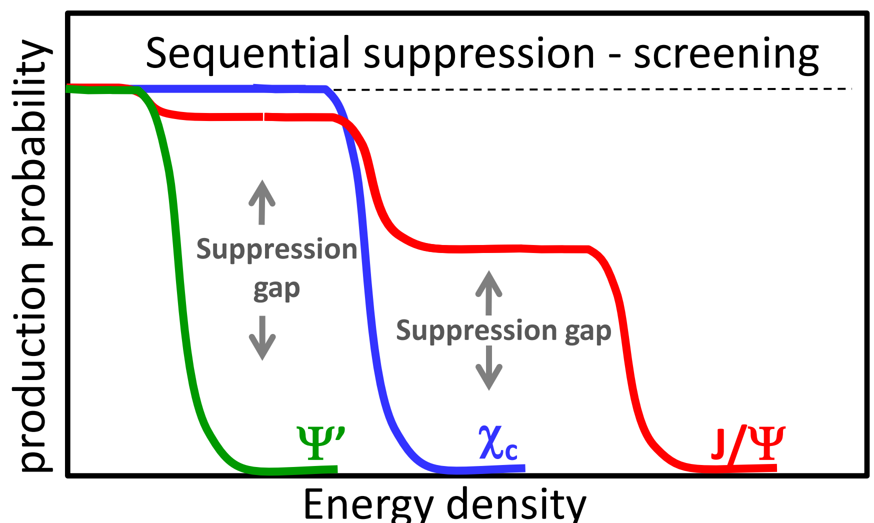
Testing color screening

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 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 :* $S_{\Psi'} > S_{\chi} > S_{J/\Psi}$





Charmonia in A+A Sequential suppression

- **Anomalous suppression at SPS**

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

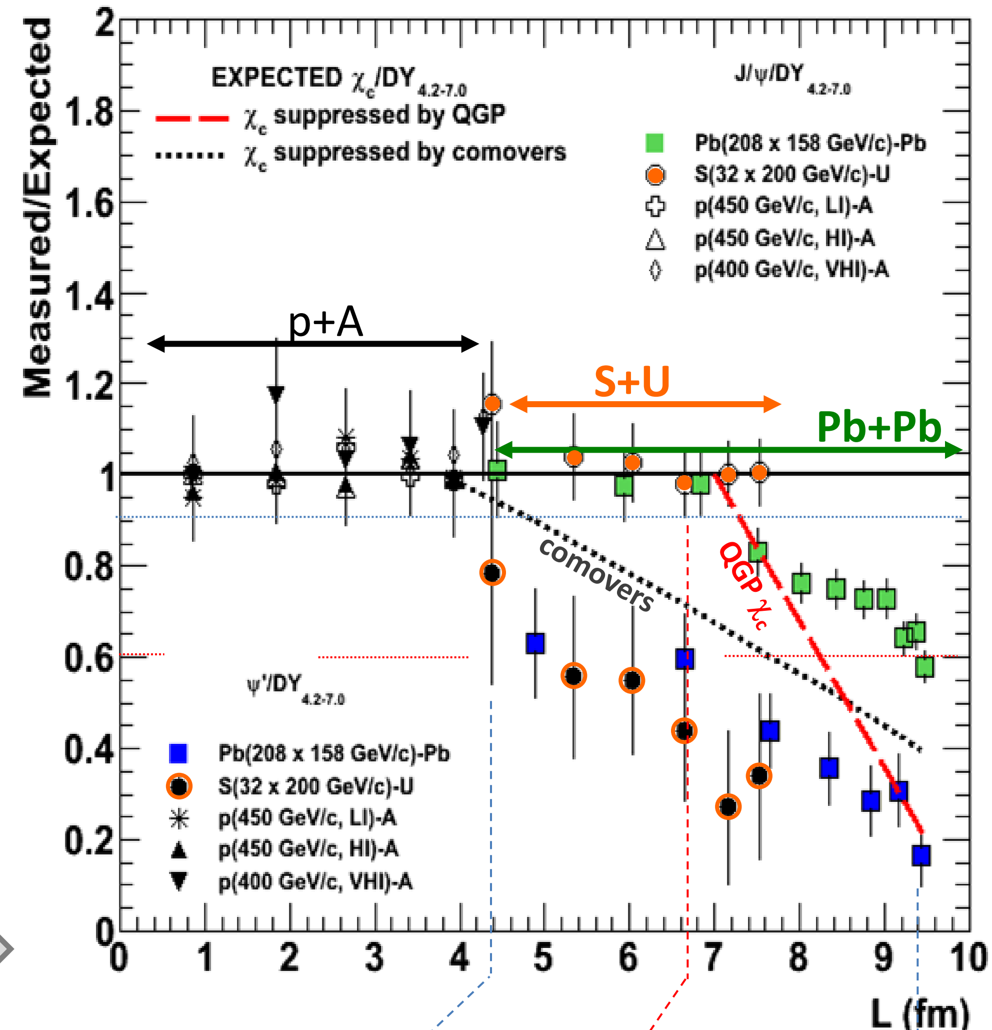
sequential suppression (QGP) ?
or
comovers (no QGP) ?

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

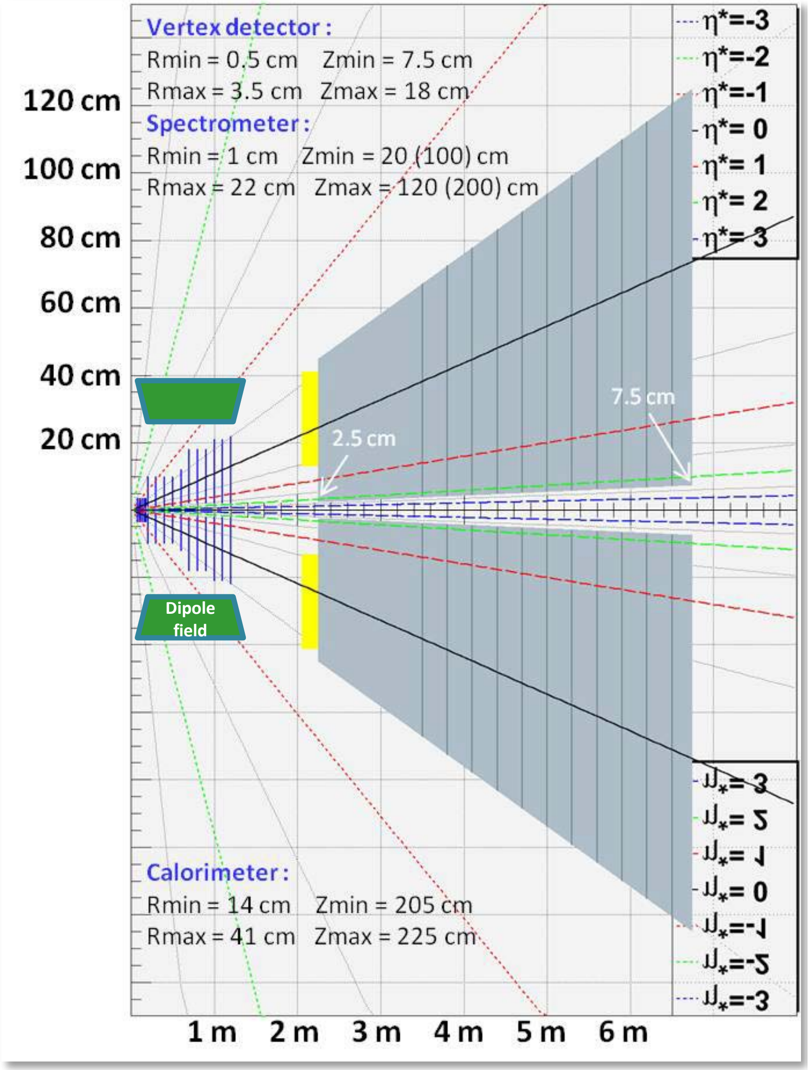
Measuring J/Ψ, Ψ' and χ_c suppression patterns will give the answer



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

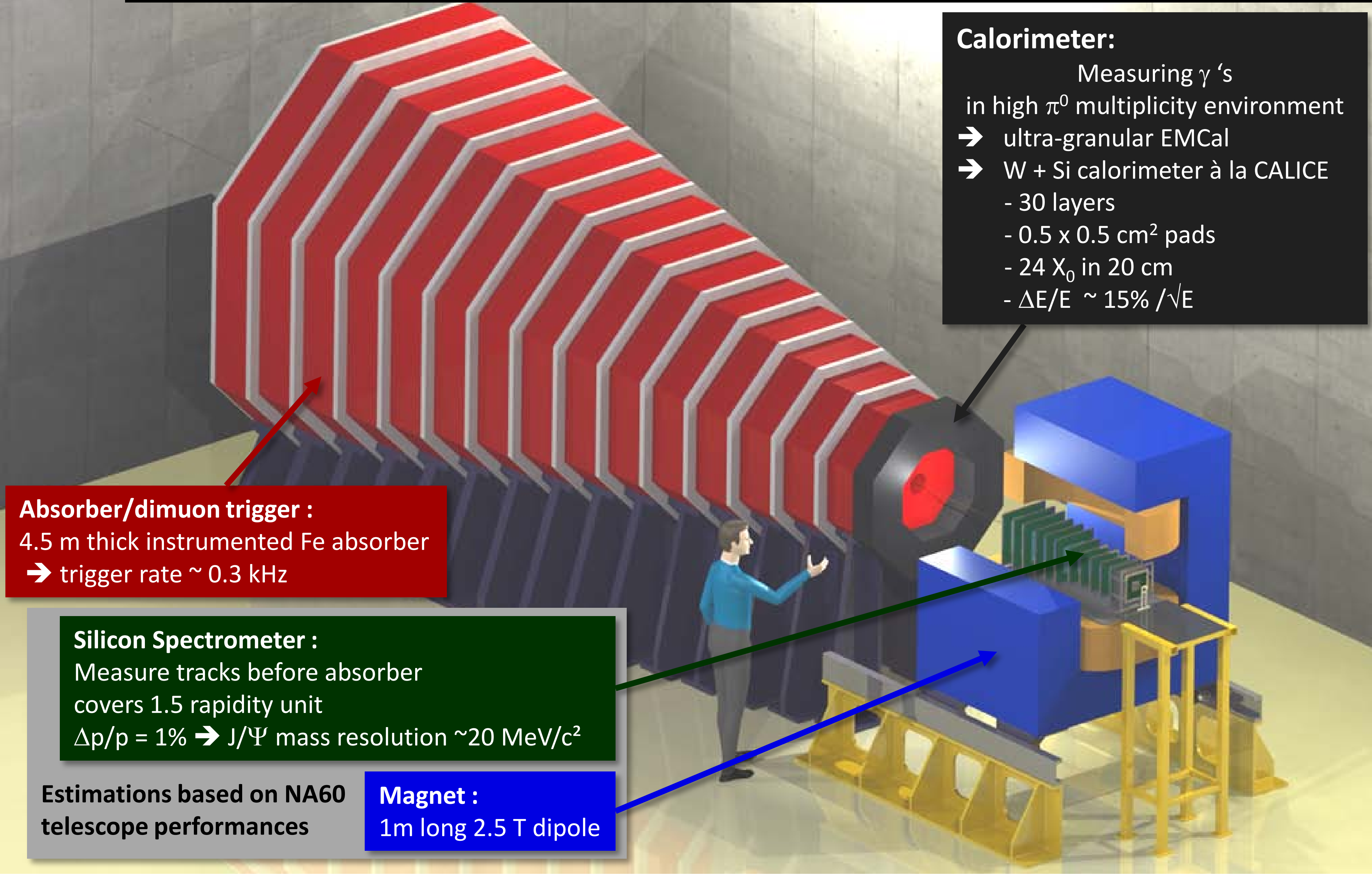
Measuring χ_c at SPS

- **Operate a new experiment 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



Apparatus

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
- $\Delta E/E$ ~ 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/Ψ mass resolution ~20 MeV/c^2

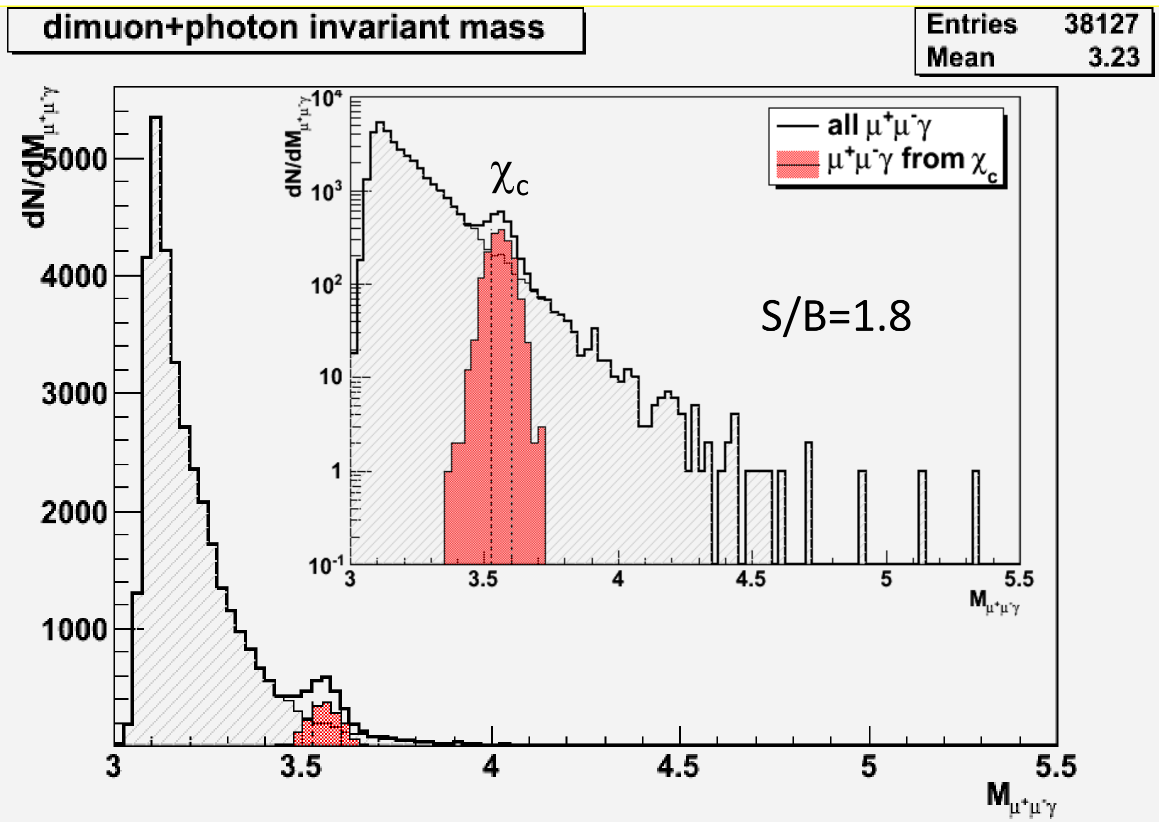
Estimations based on NA60 telescope performances

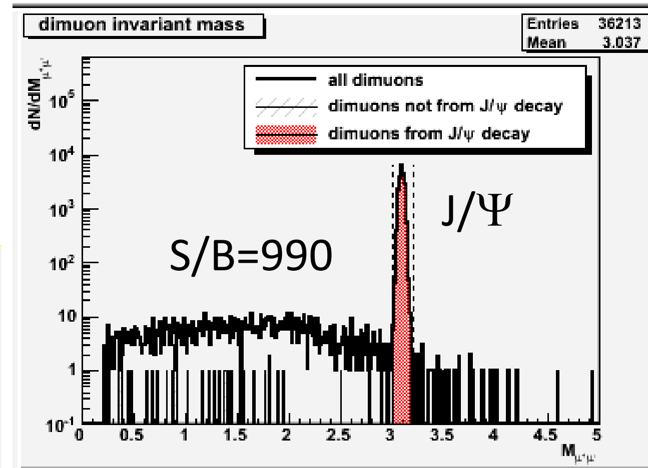
Magnet :

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 one month Pb+Pb run**
  - ~ 200 000 inclusive $J/\Psi \rightarrow \mu^+\mu^-$ expected
  - 2 extreme scenarios:
    - If χ_c suppressed as J/Ψ: $\frac{\chi_c \text{ yield}}{J/\Psi \text{ yield}} \sim 4\%$

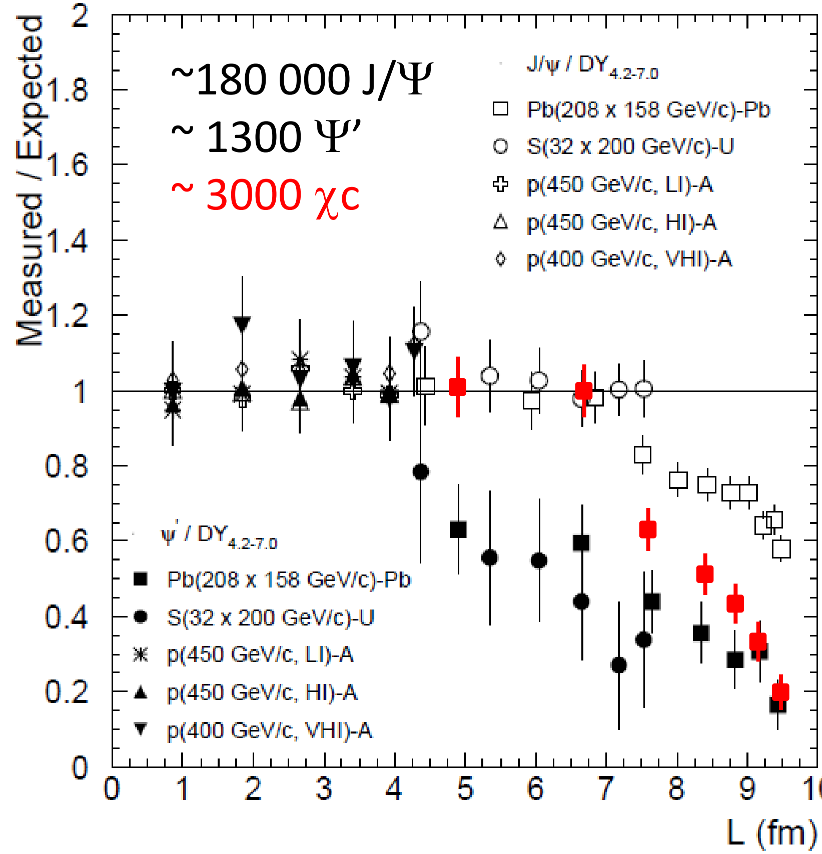
$$\to \left(\begin{matrix}\text{most periph.}\\ \chi_c \text{ yield}\end{matrix}\right) = 16942 \times 4\% = 677$$

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

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

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**



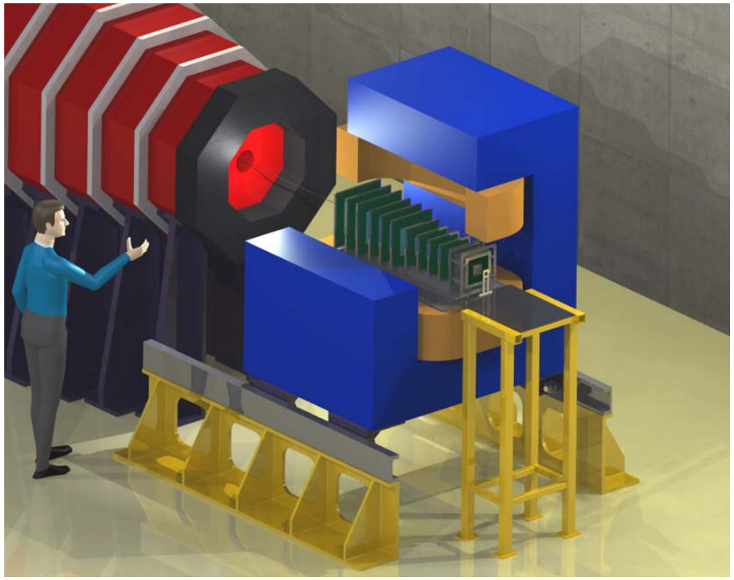
p+A program investigate Cold Nuclear Matter

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

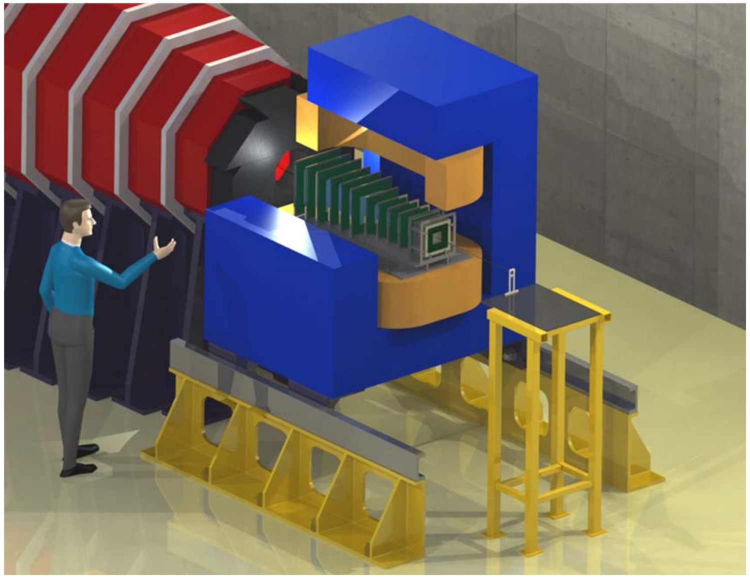
- **Must control (understand) :**
  - charmonium absorption by cold nuclear matter ➔ A dependence
  - Shadowing/anti-shadowing (x_2 scaling)
  - Energy loss (saturation)… (x_F scaling)

  } ➔ **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 : $y_{CMS} \in [0.5 ; 2]$

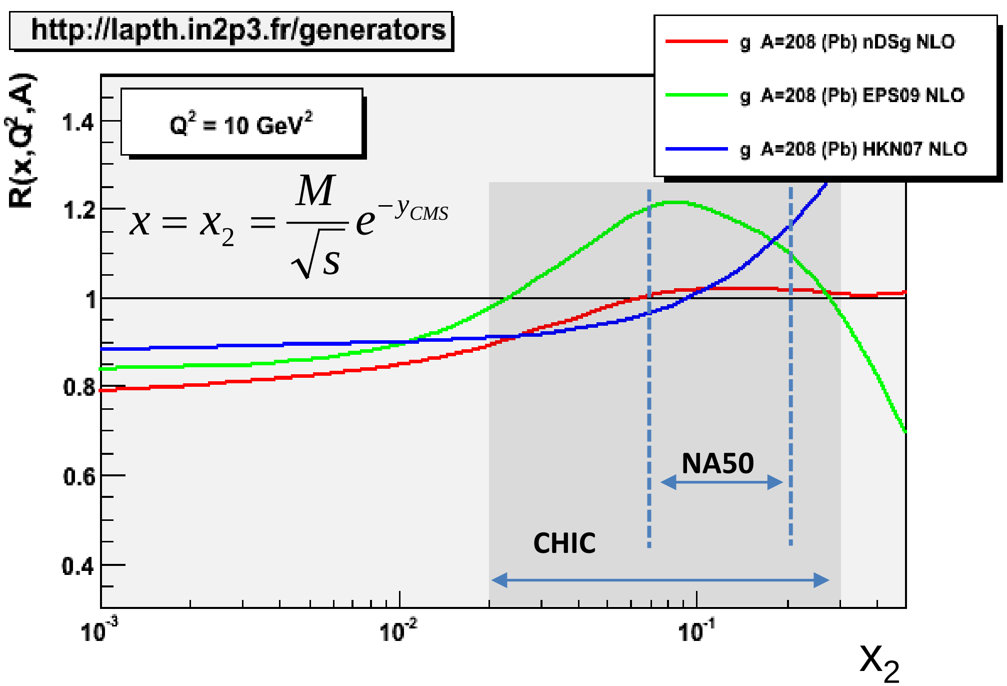


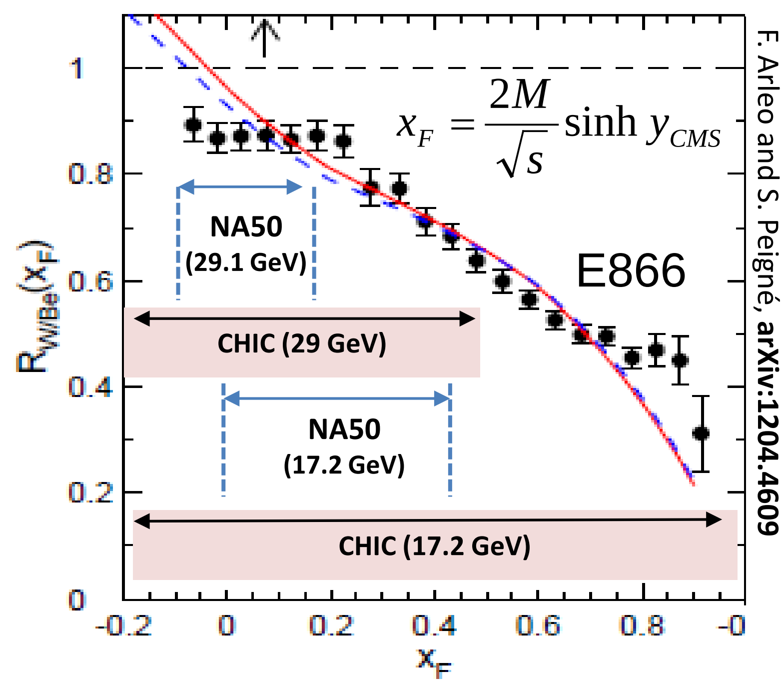
p+A program investigate Cold Nuclear Matter

A thorough p+A program requires

- **J/Ψ, Ψ', χ_c with several targets** (NA50: p+Be, p+Al, p+Cu, p+Ag, p+W, p+Pb)
- **J/Ψ, Ψ', χ_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]





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

New upsilon results

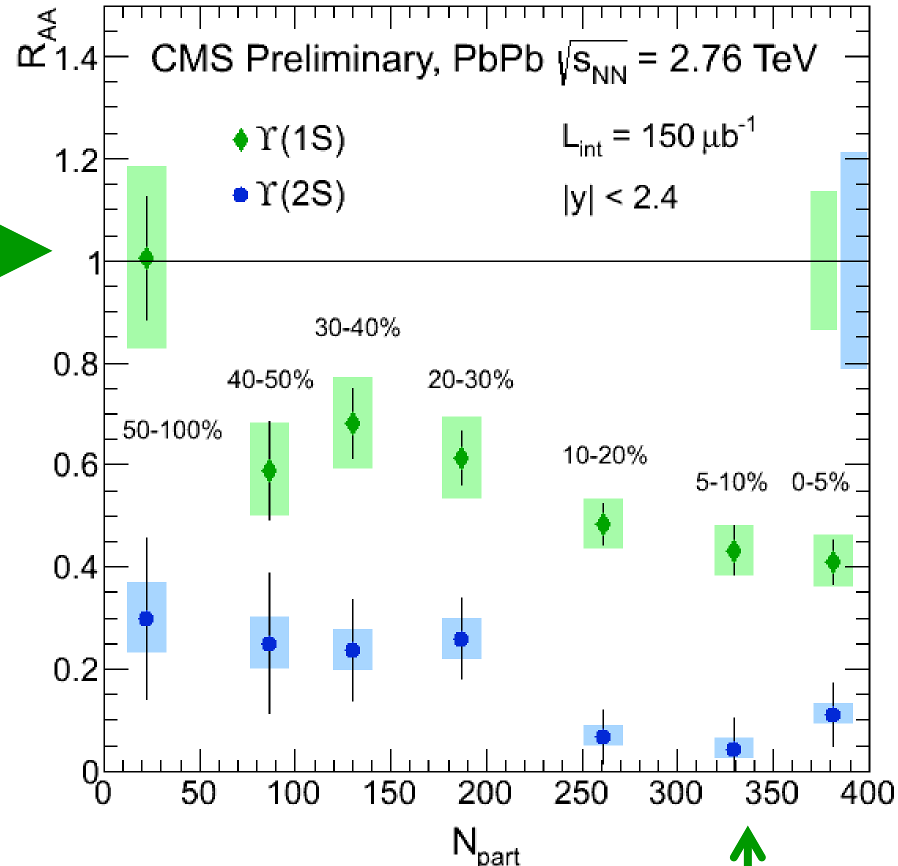
Beautiful results from CMS

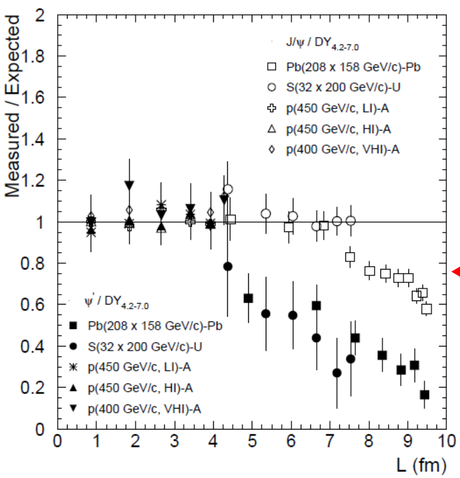
(Camelia Mironov, HP2012)

◉ Suppression pattern as expected in the sequential melting scenario

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

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



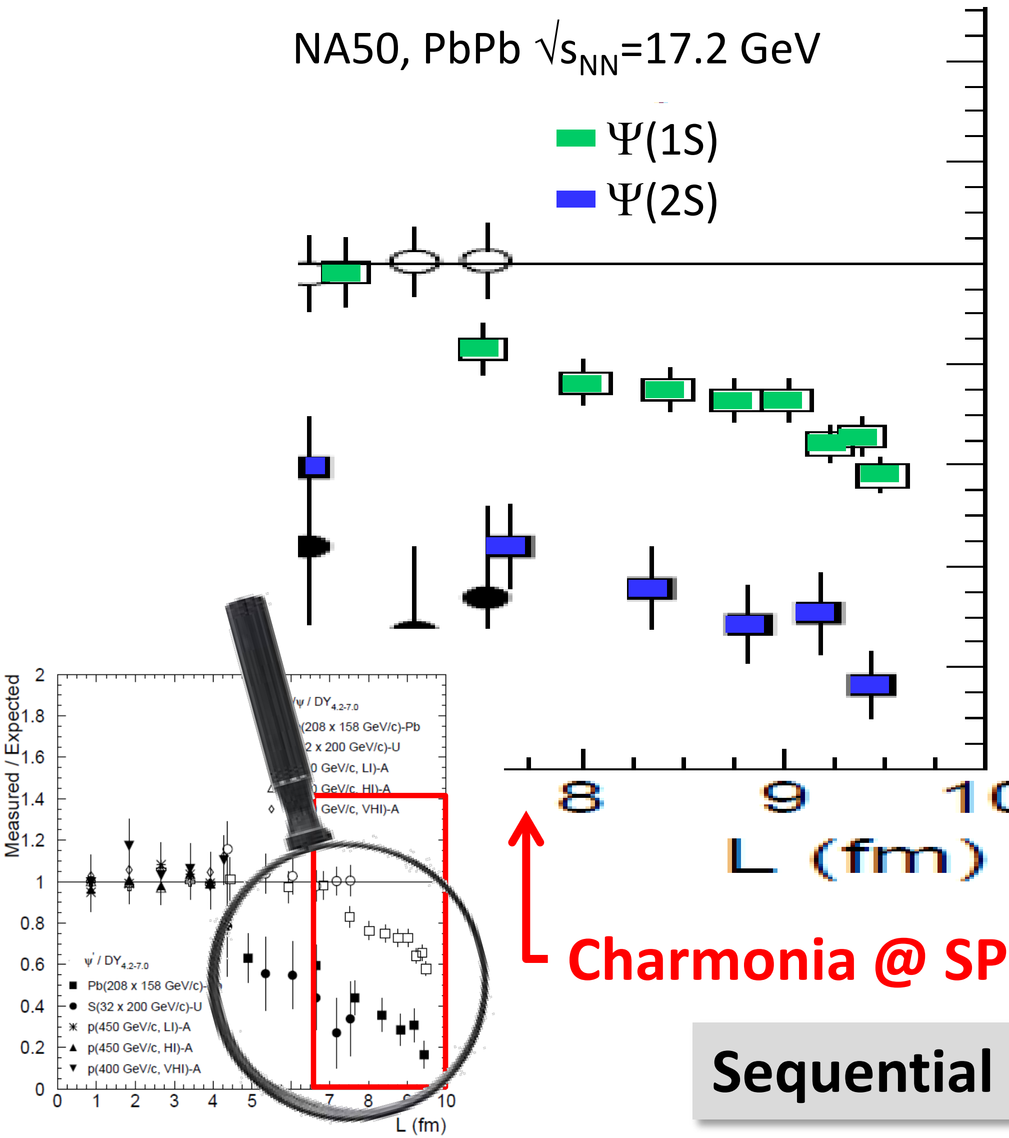


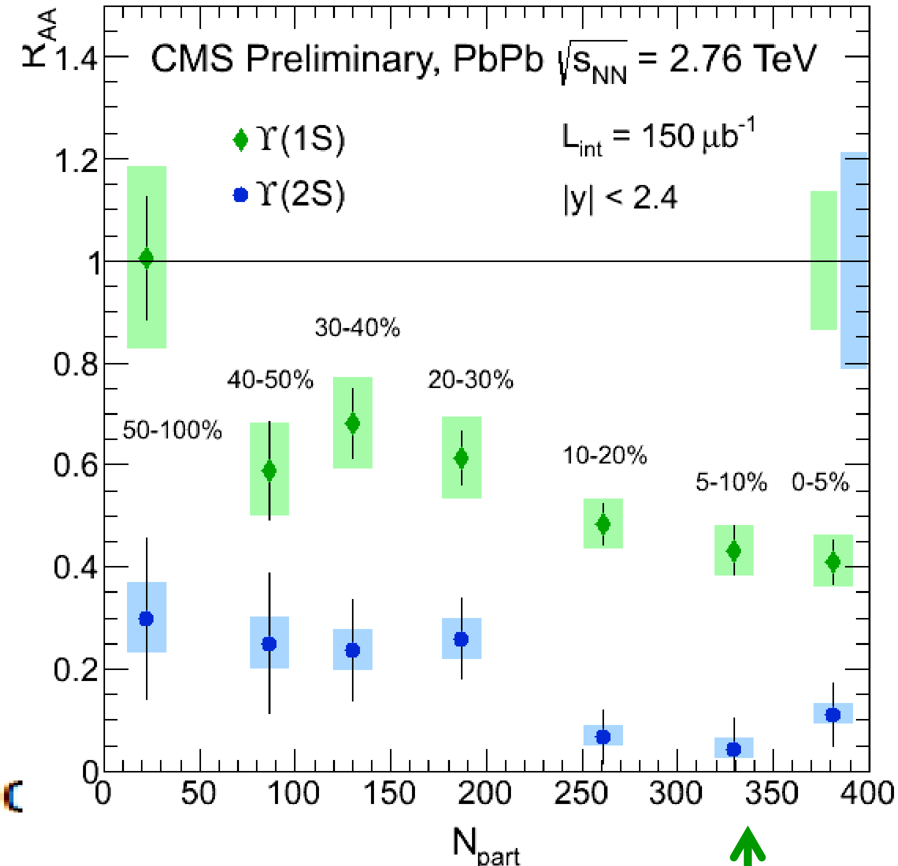
Charmonia @ SPS

bottomonia @ LHC

Sequential suppression ?

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





Charmonia @ SPS

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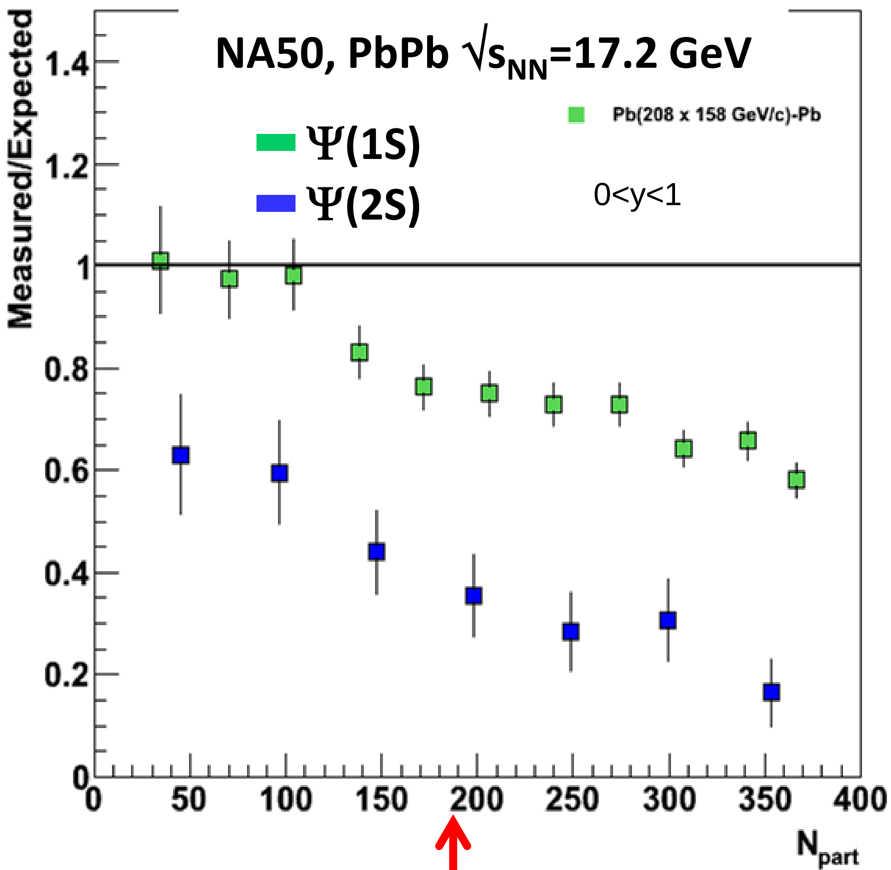
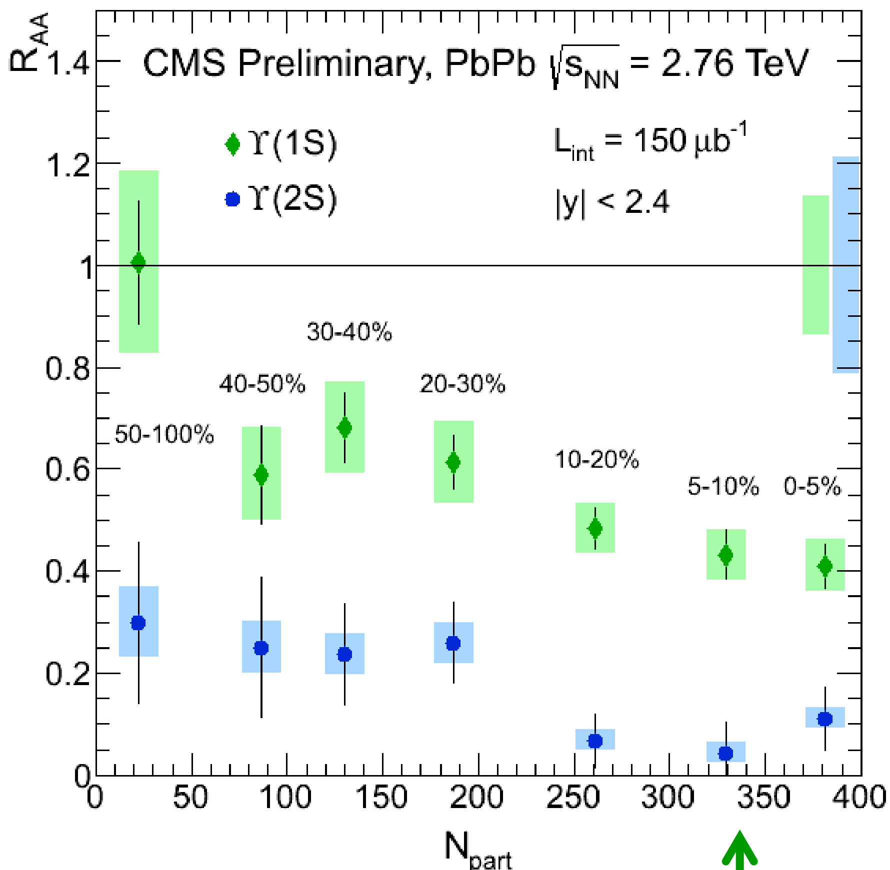
Sequential suppression ?

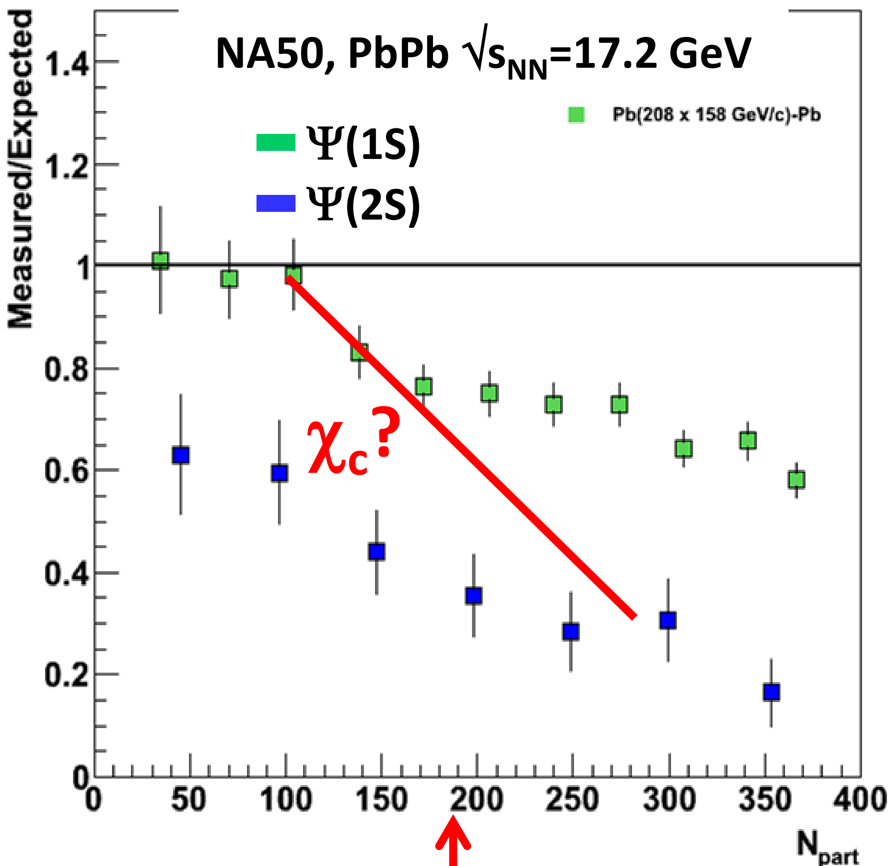


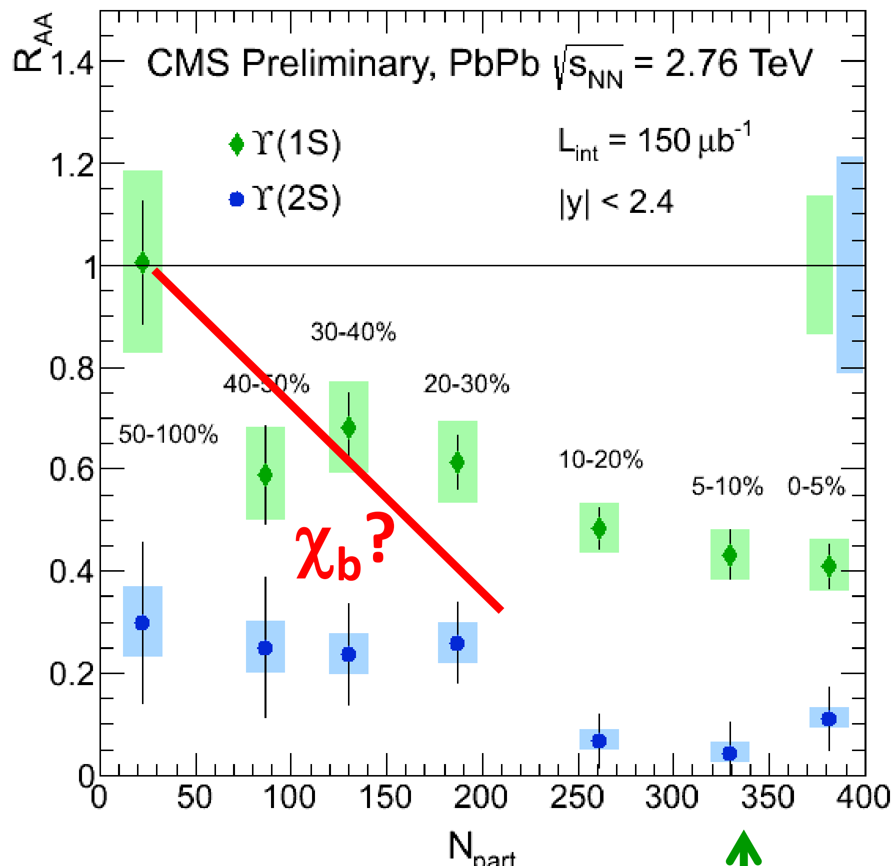


Charmonia @ SPS **bottomonia @ LHC**

On the same axis

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





Charmonia @ SPS

bottomonia @ LHC

Let's measure χ_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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