An experiment to measure χ_c suppression at the CERN SPS

CHIC: Charm in Heavy Ion Collisions

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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

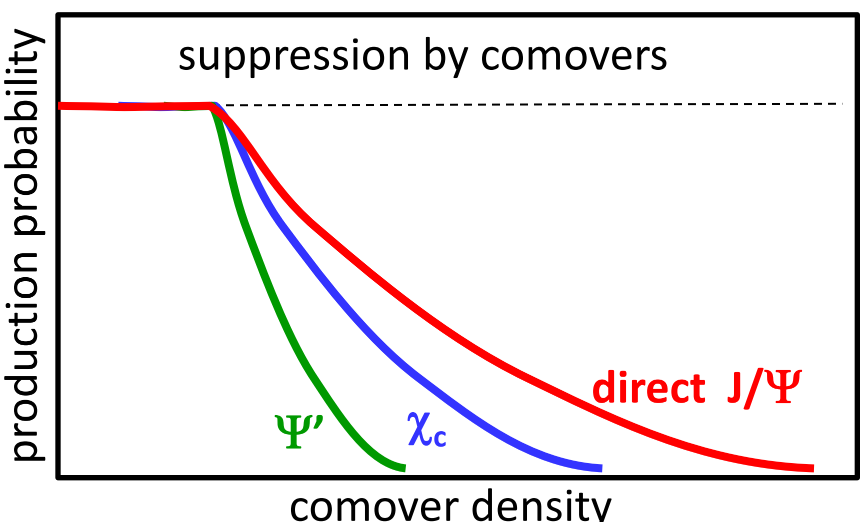
  - Because of feed-downs and different T_d, **sequential suppression** should show up.
- **Experimentally**
  - J/Ψ production in A+A collisions is (has been) studied at :
    - SPS (√s~17 GeV) : NA38, NA50, NA60 experiments
    - RHIC (√s~200 GeV) : PHENIX, STAR experiments
    - LHC (√s~2.76 TeV) :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

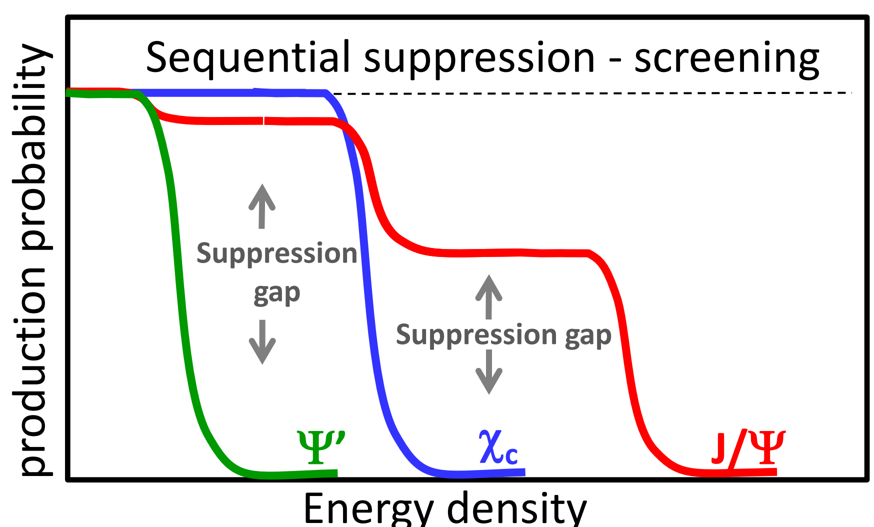
Testing color screening

Testing sequential suppression with charmonia :

1. must be in a regime where recombination is negligible ➔ **SPS energies**
2. must measure the suppression pattern of **two 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**

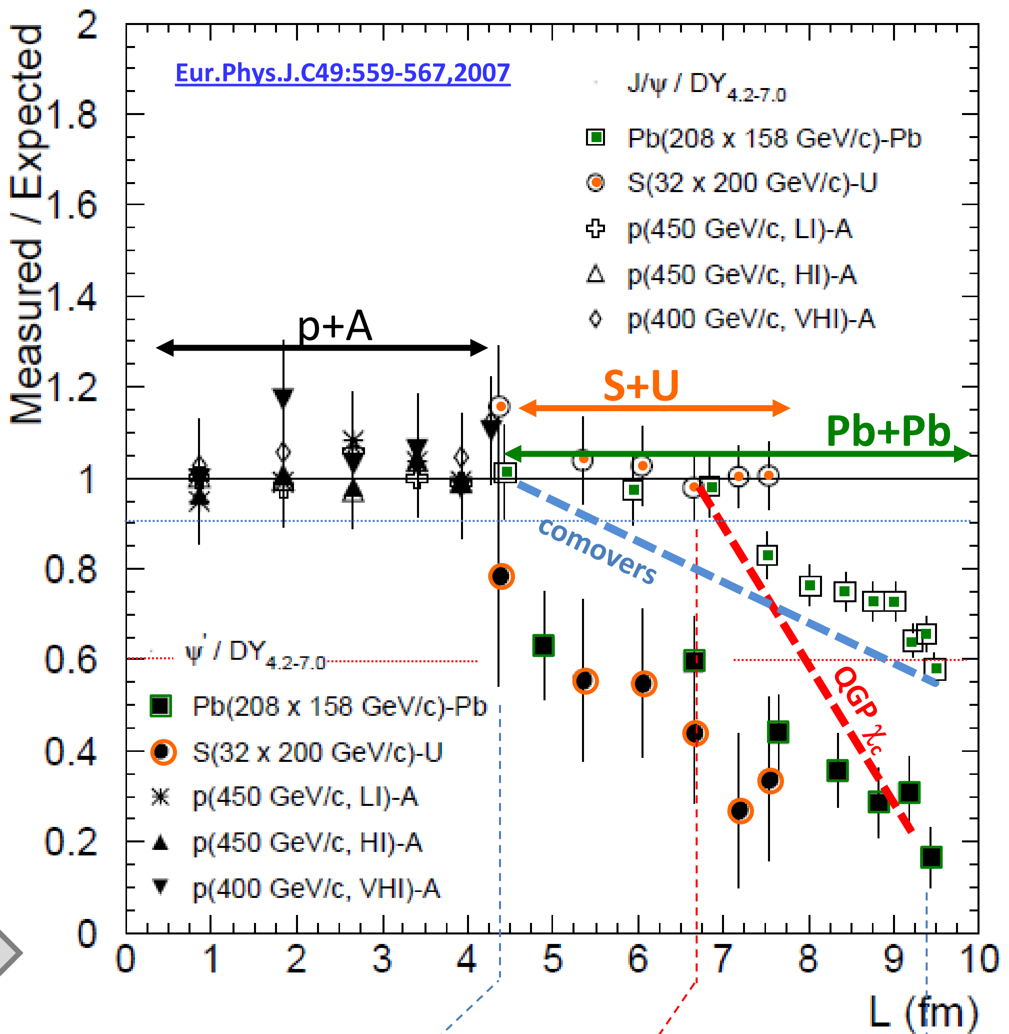
sequential suppression (QGP) ?
or
comovers (no QGP) ?

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

Charmonia in A+A

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 450 GeV/c proton beam
  - Detector features :
    1. **Vertex + Spectrometer**

       » Measure tracks before absorber for very good mass resolution

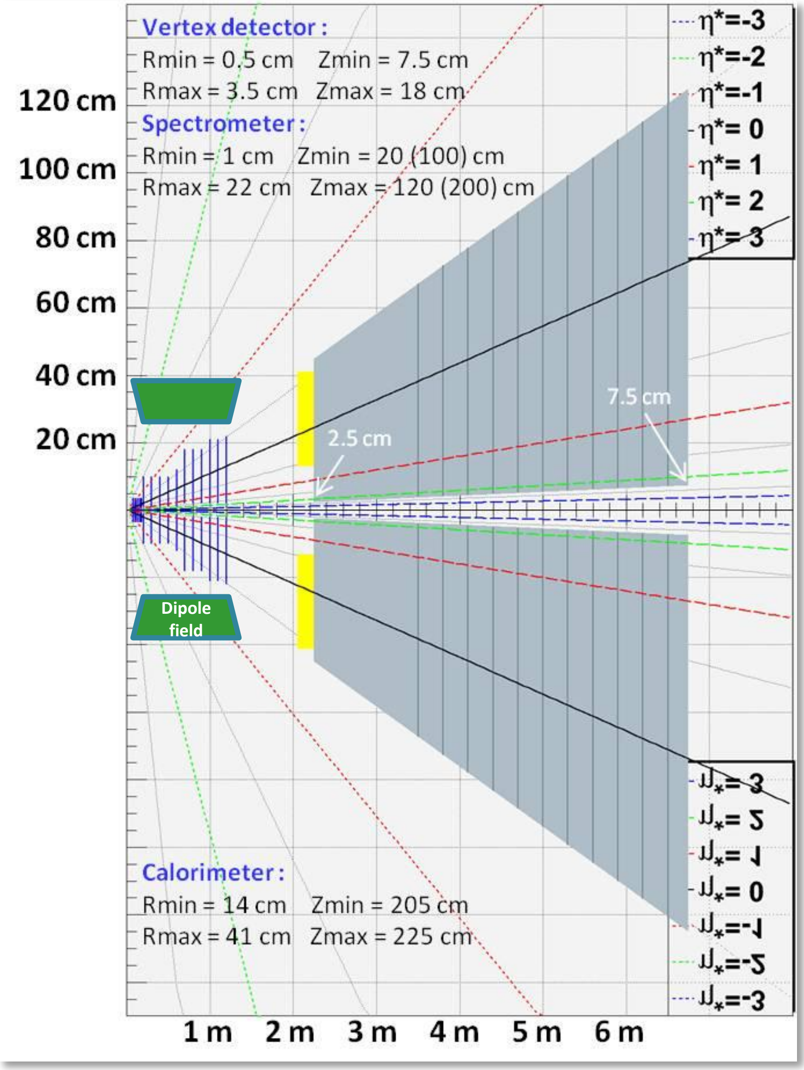
    2. **Calorimeter**

       » Measure low energy γ in high π^0 multiplicity environment

    3. **Absorber/trigger**

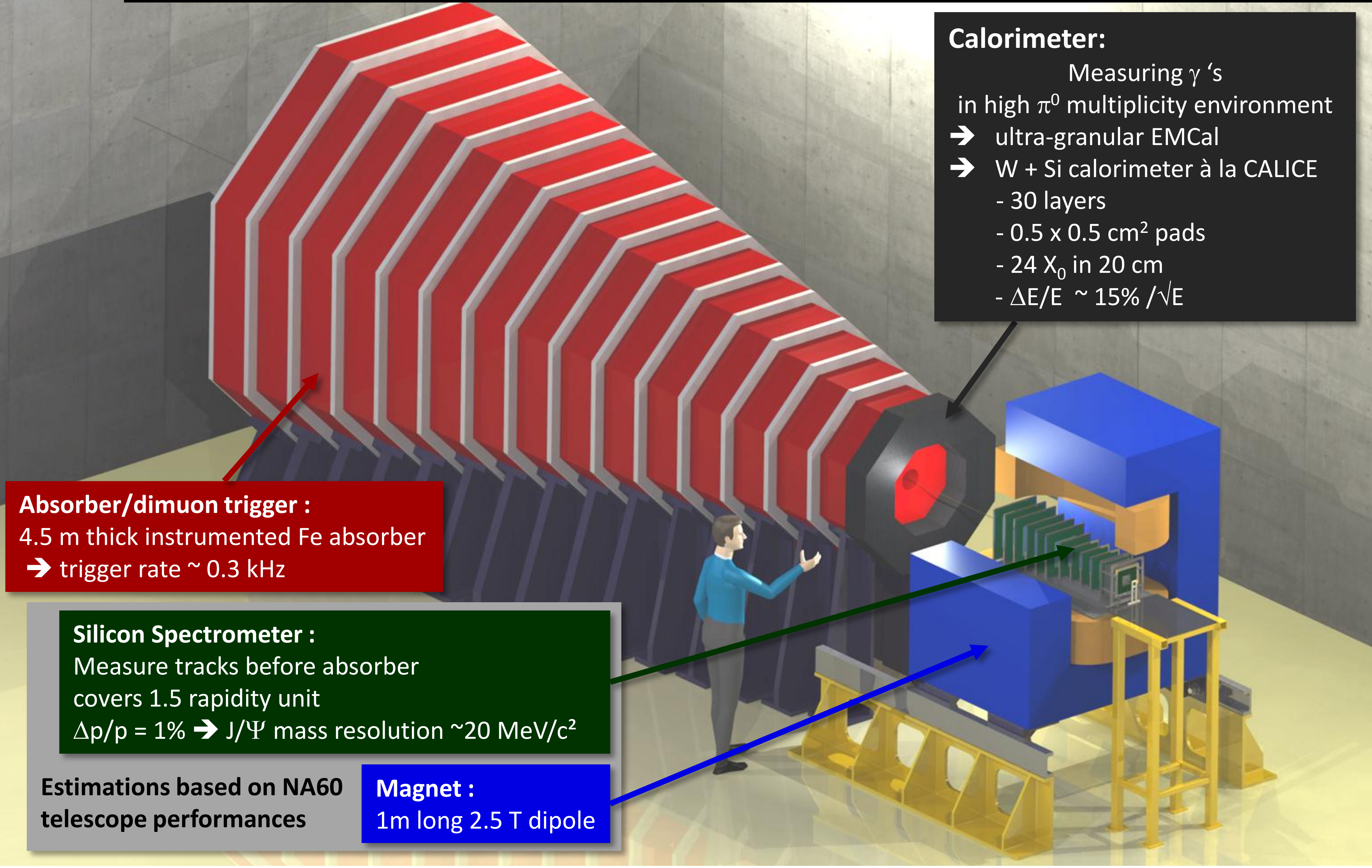
       » Absorb π/K

       » Minimize fake triggers from π/K decays



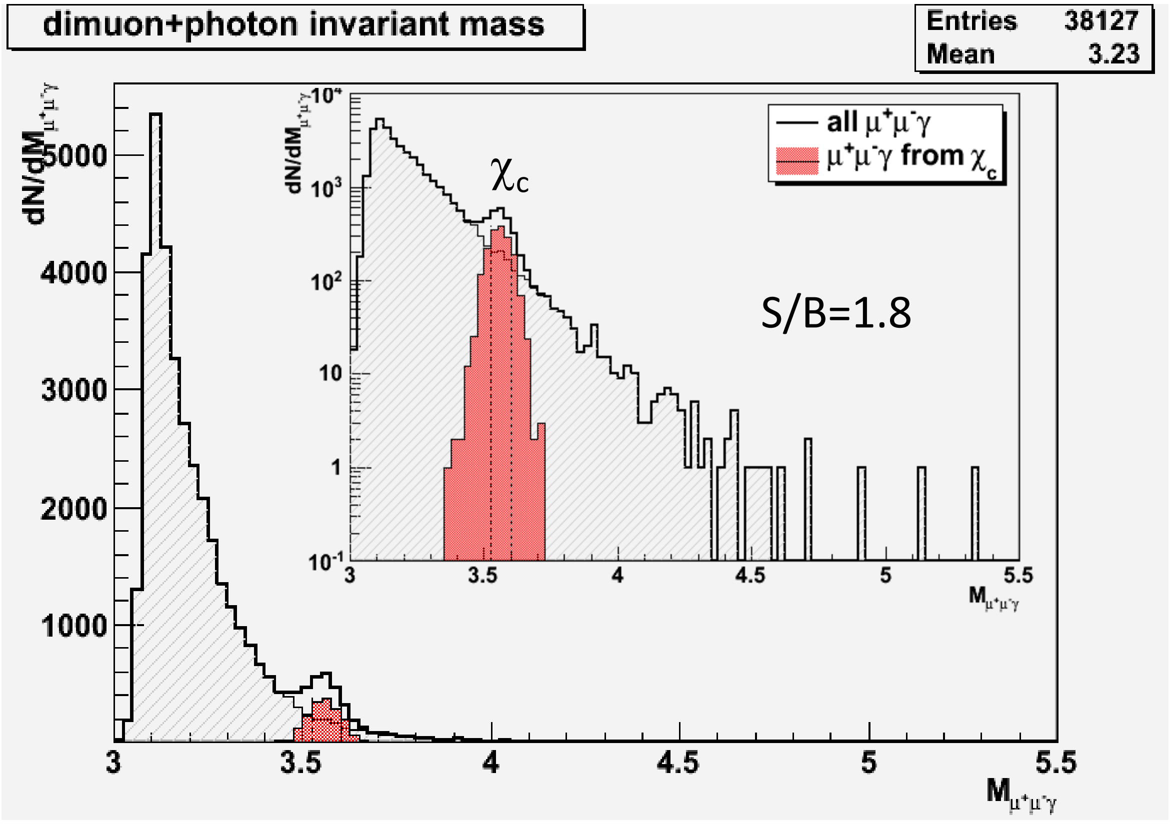
Apparatus

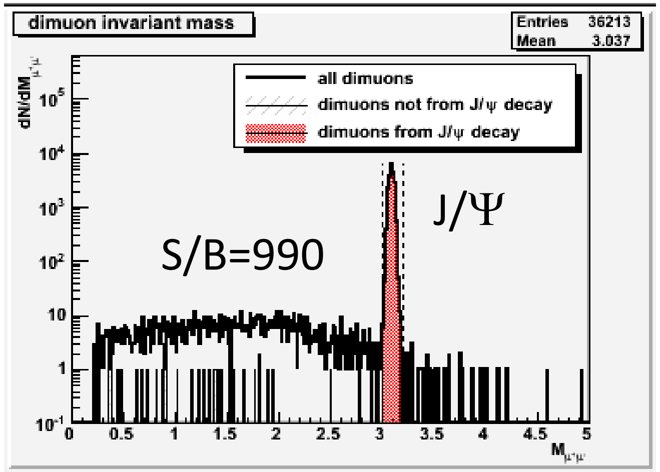
Main purpose : measure $\chi_c \rightarrow J/\Psi+\gamma$ in Pb+Pb collisions at $\sqrt{s}$ = 17.2 GeV



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

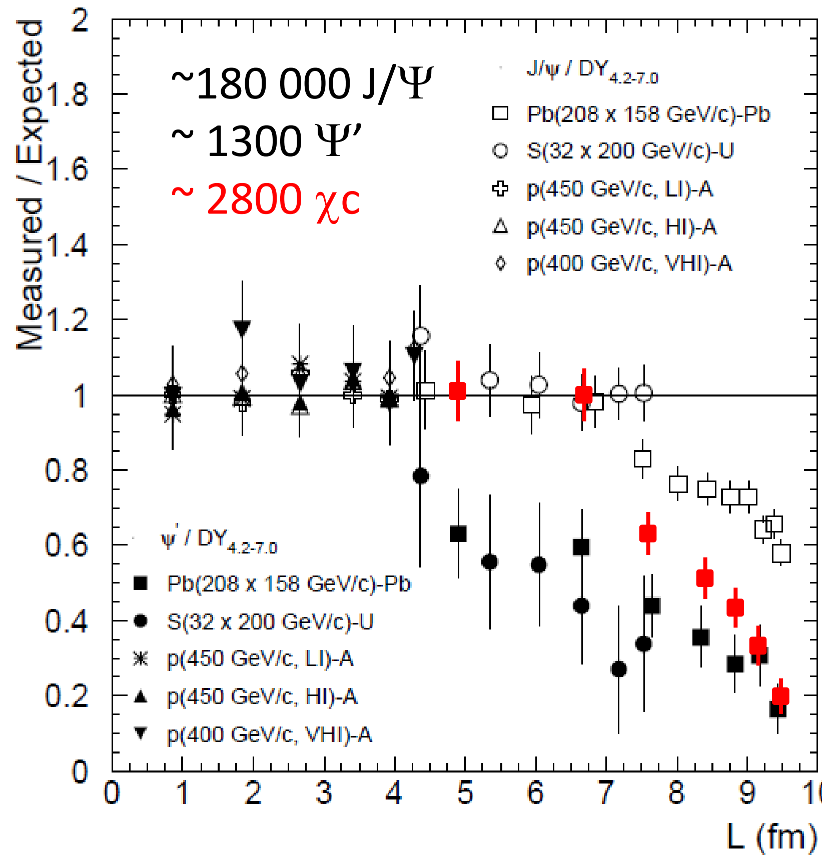
Statistics

- **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 $\quad \frac{\chi_c \text{ yield}}{J/\Psi \text{ yield}} \sim 4\%$

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

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

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



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
			2775	**7125**

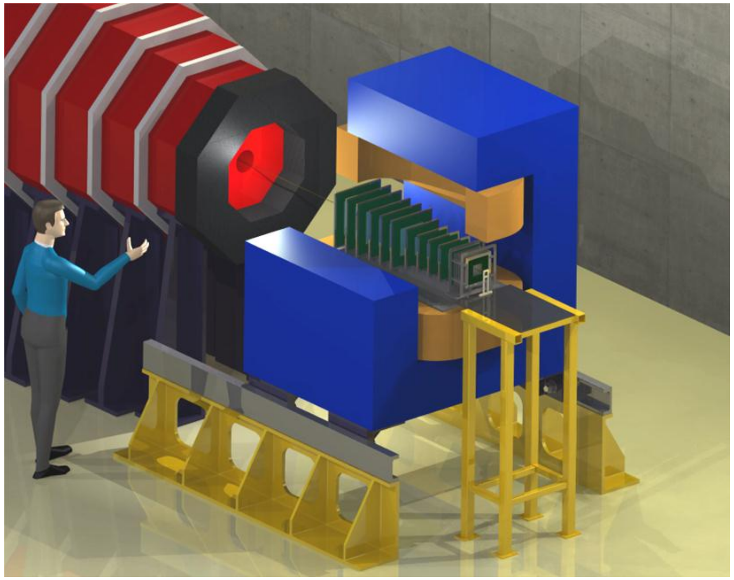
p+A program investigate Cold Nuclear Matter

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

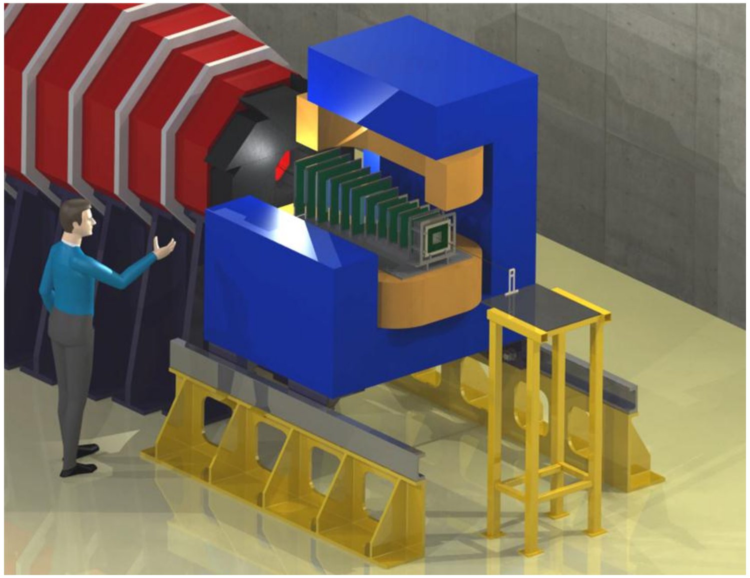
- **Must control (understand) :**
  - charmonium absorption by cold nuclear matter ➔ A dependence
  - Shadowing/anti-shadowing (x_2 scaling)
  - Energy loss (saturation)… (x_F scaling)

  ➔ **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 : $y_{CMS} \in [0.5 ; 2]$

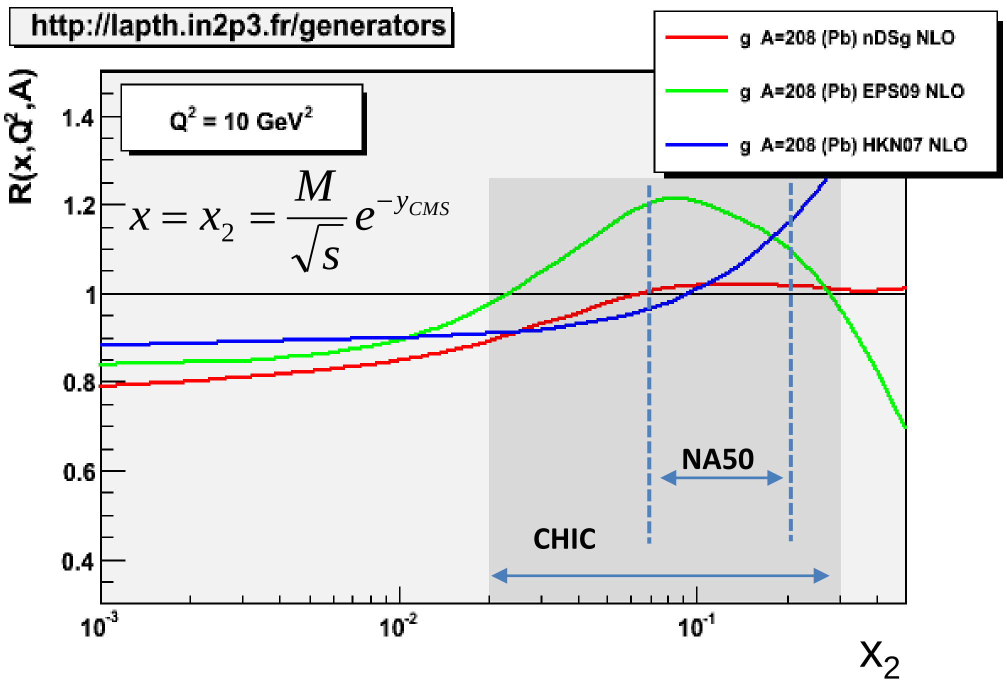


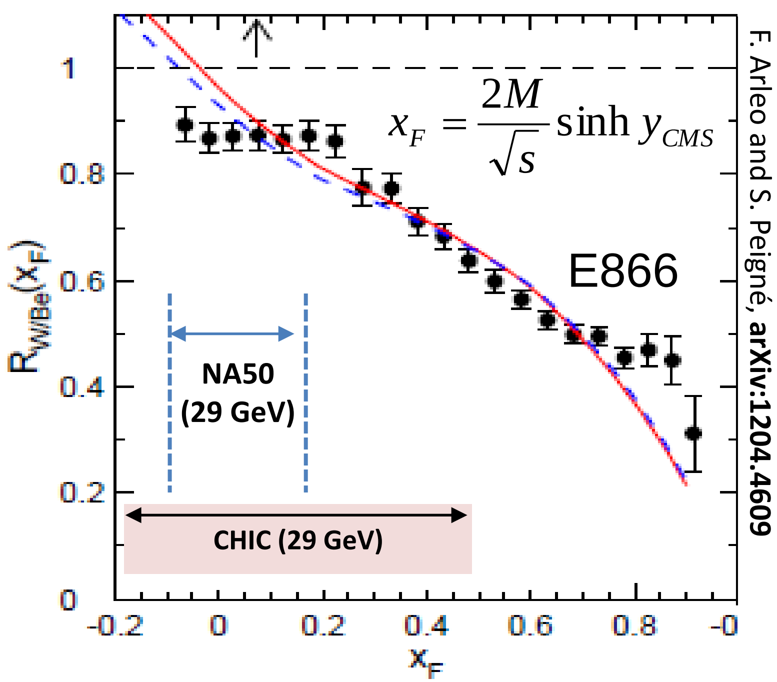
p+A program investigate Cold Nuclear Matter

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;0.43]
	CHIC	[-0.5;2]	[0.02;0.30]	[-0.2;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]	[-0.2;0.5]





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 use of ultra-granular calorimetry gives access to photon measurement in high multiplicity environment ➔ first measurement of χ_c in A+A collisions.**
- **Understanding sequential suppression at SPS is crucial to fully understand RHIC and LHC results.**

New upsilon results

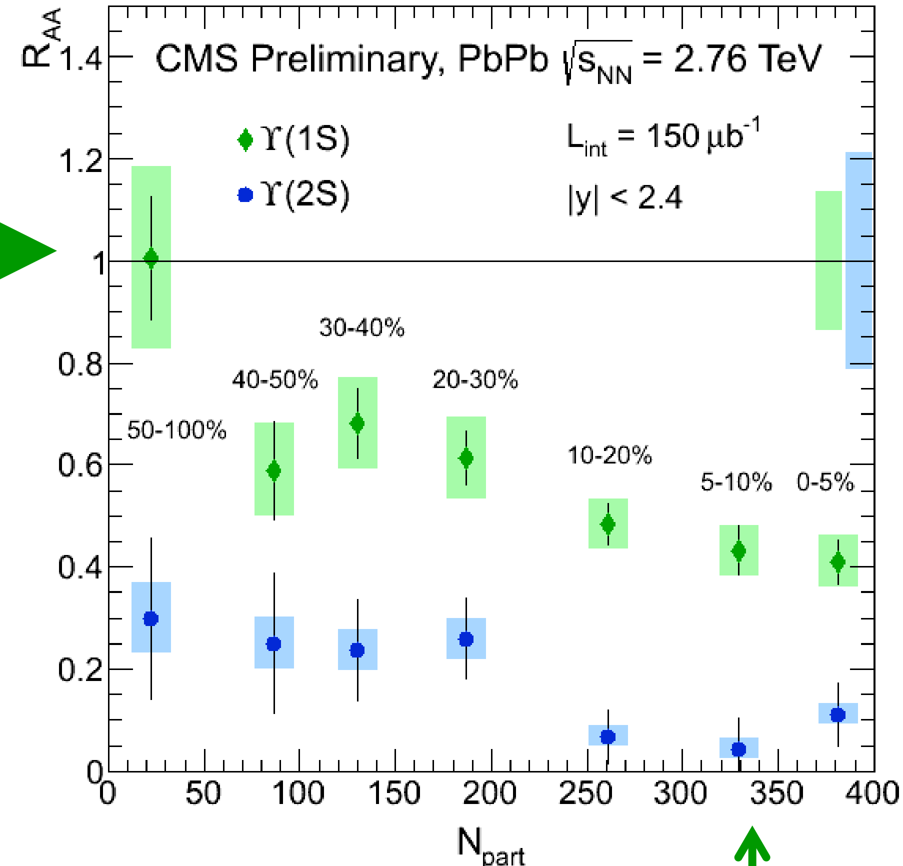
Beautiful results from CMS

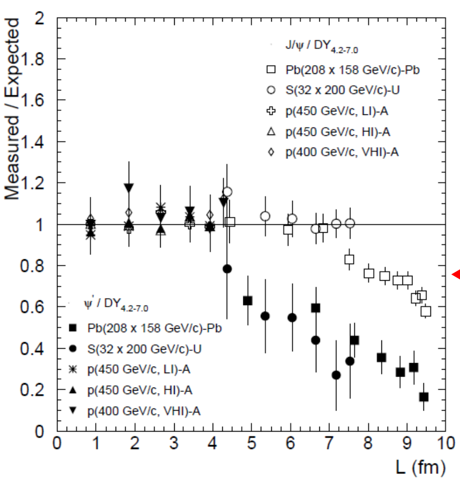
(Camelia Mironov, HP2012)

◉ Suppression pattern as expected in the sequential melting scenario

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

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



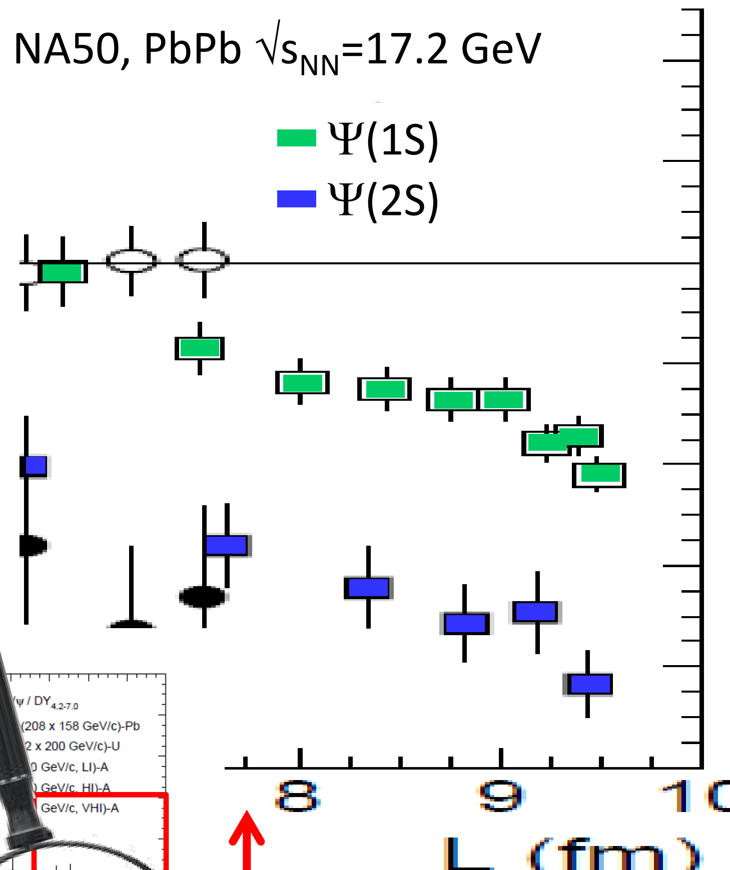


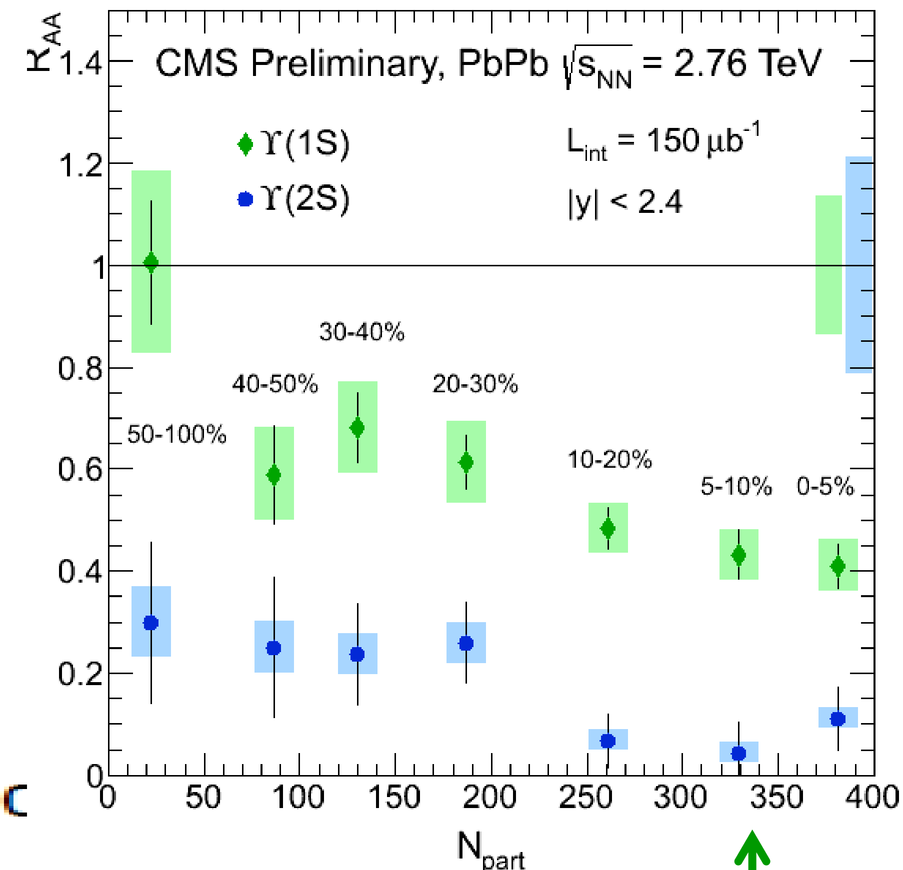
Charmonia @ SPS

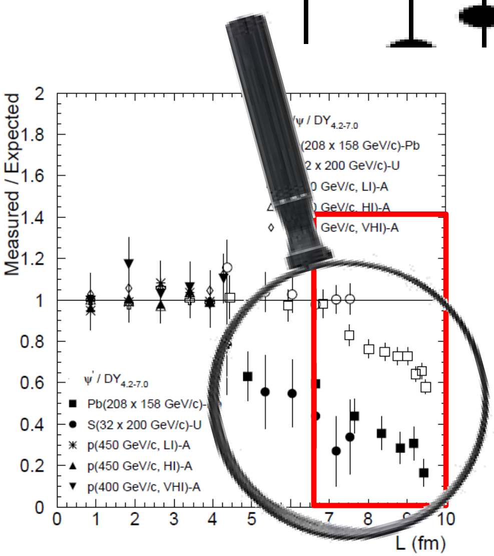
bottomonia @ LHC

Sequential suppression ?

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







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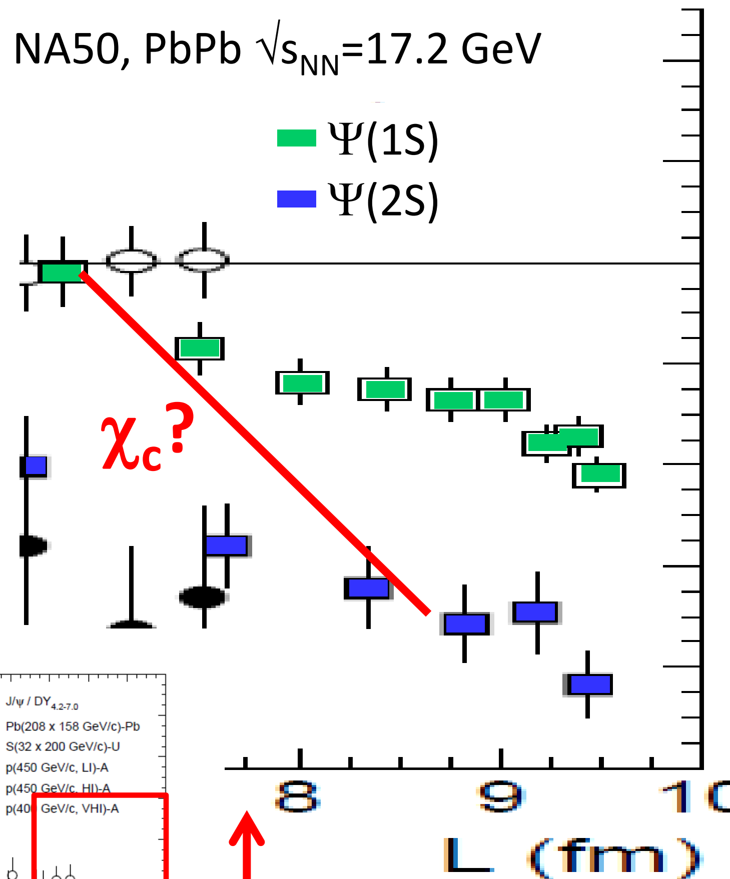
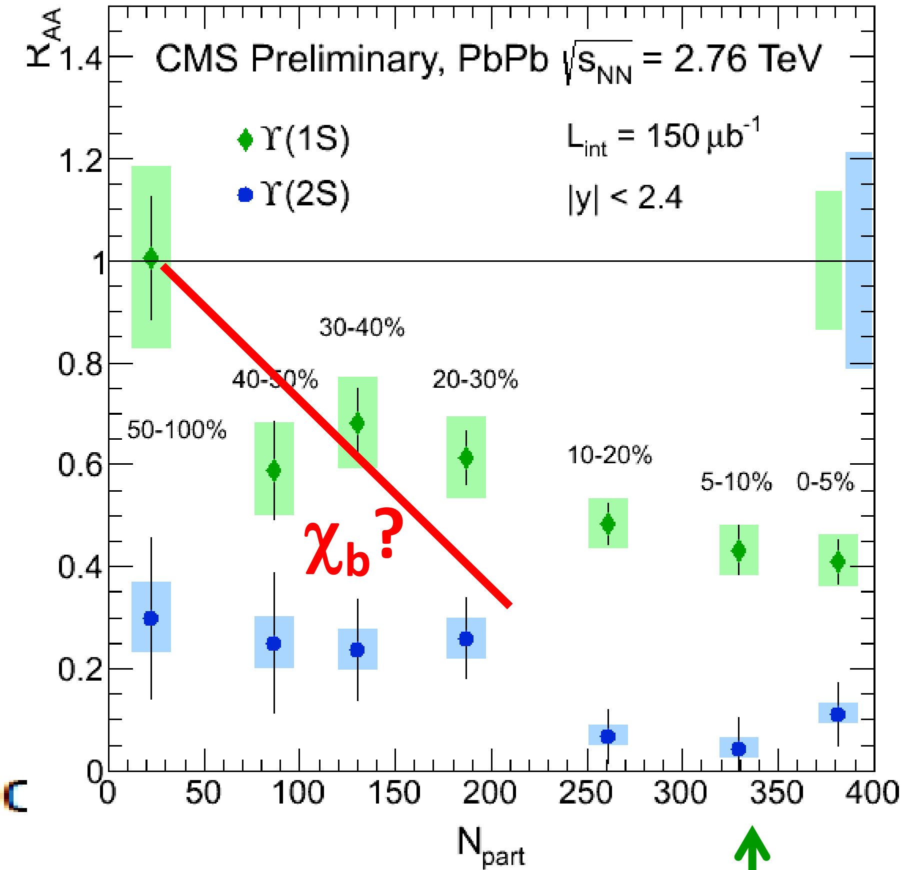
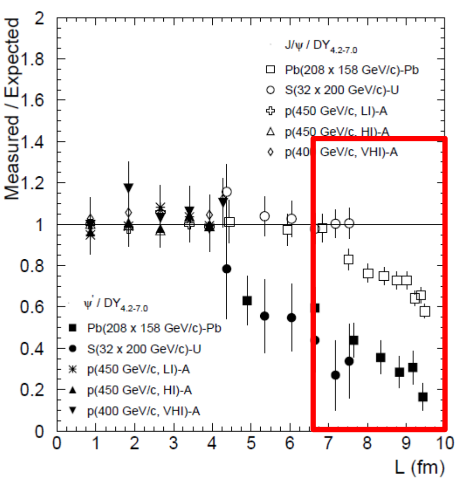
Sequential suppression ?

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







Charmonia @ SPS **bottomonia @ LHC**

Let's measure χ_c at SPS !