J/ψ and ψ' productions in nucleus-nucleus collisions at the CERN-SPS

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NA50 Collaboration

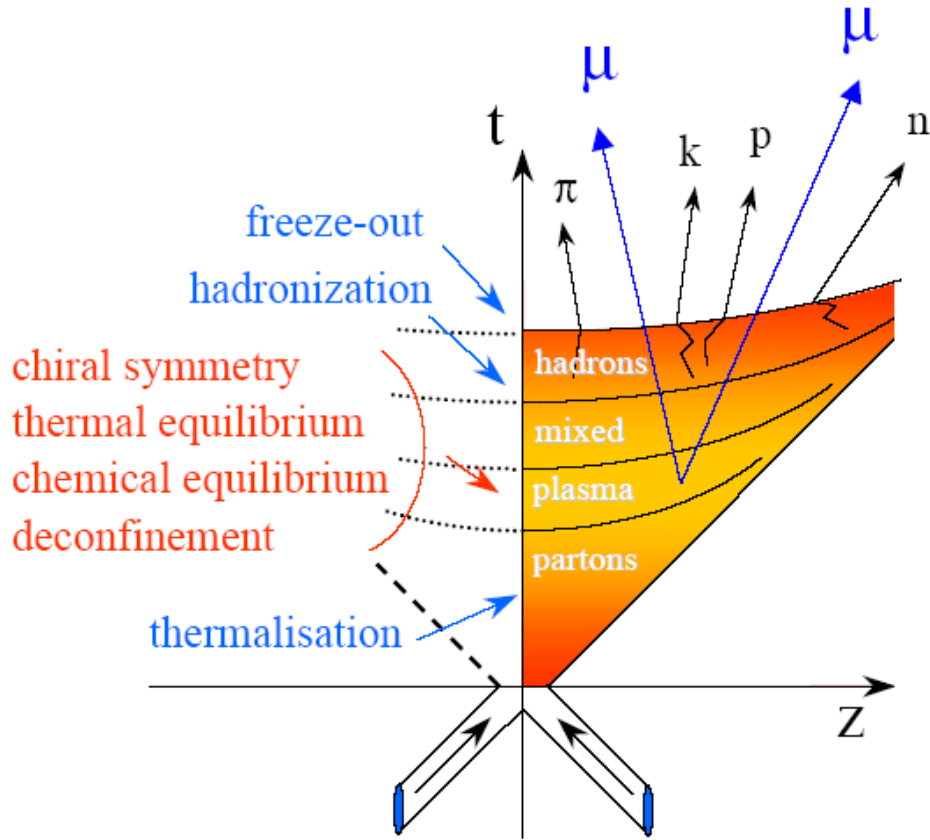**Outline**

- **Introduction**

- **NA50 experiment overview**

- **Analysis procedure**

- **Results in Pb-Pb collisions**

- **Results in lighter systems and comparisons**

- **Conclusions**

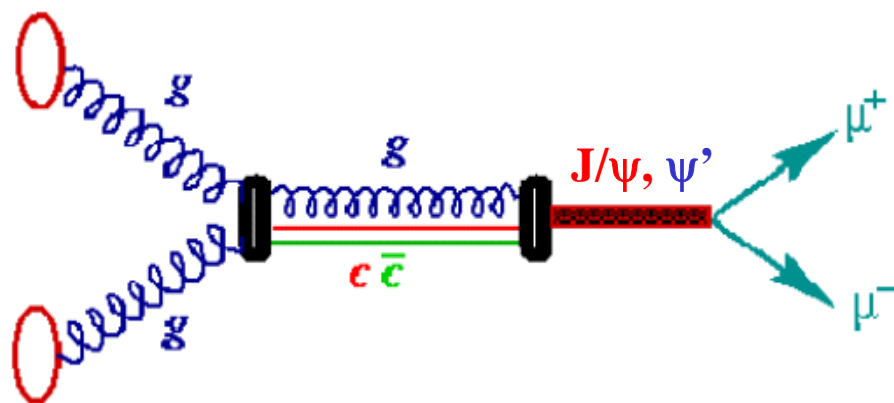# Phenomenology of the Heavy Ion Collisions

Evolution of interacting matter

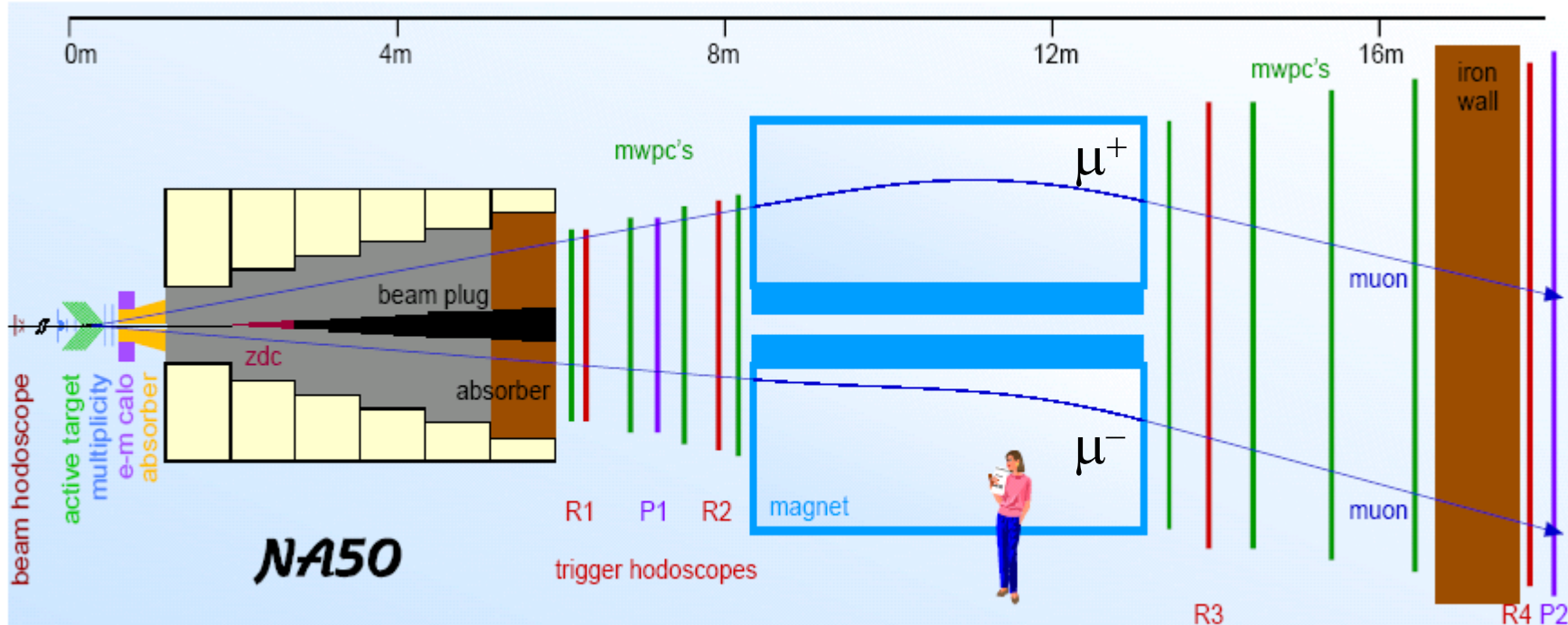- **Pre-equilibrium partonic system**

- **Quark Gluon Plasma**

- **Hadronization and freeze-out**

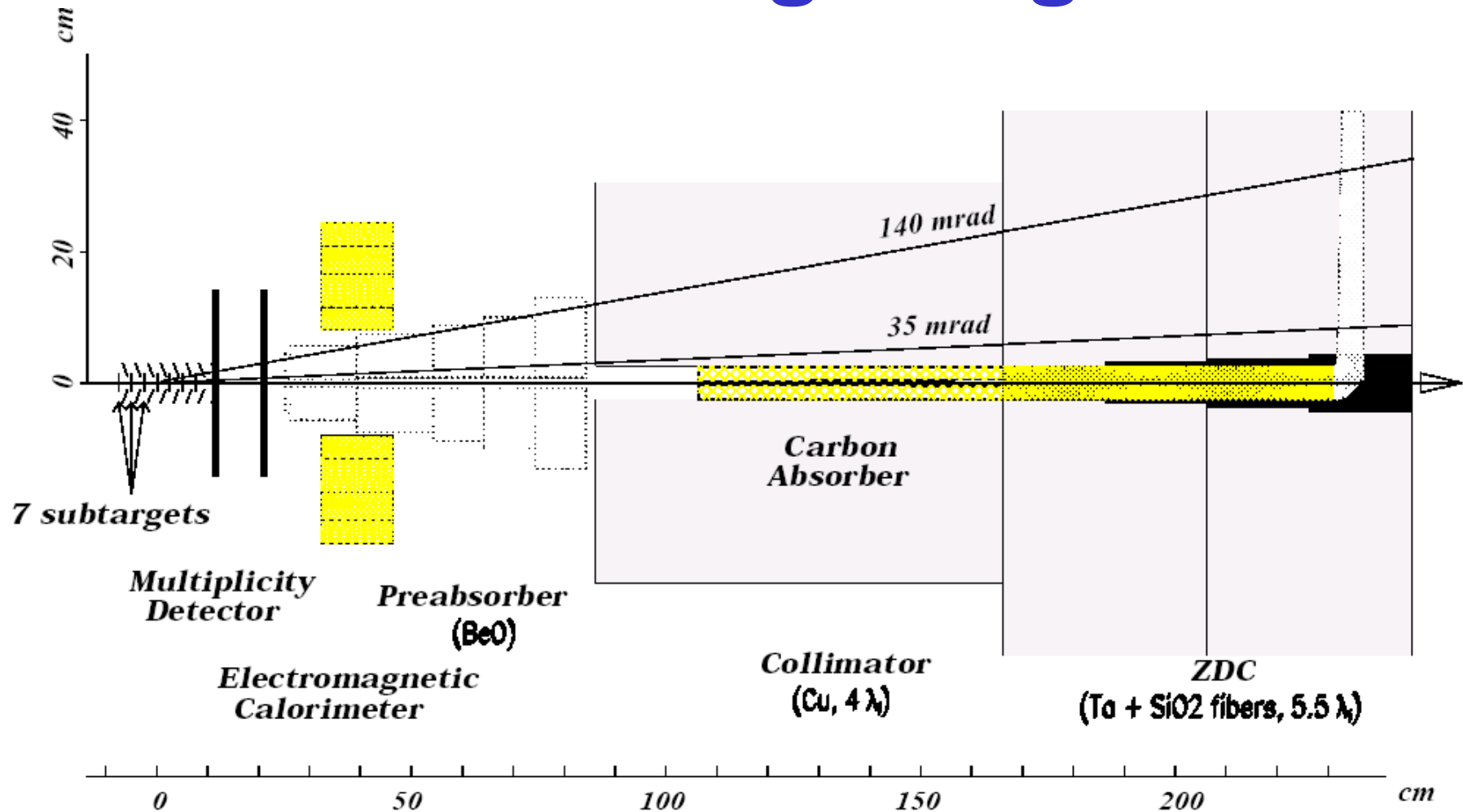**J/ψ** suppression by **Debye colour screening** is a strong signature of **QGP**

The NA50 Experiment

Kinematical Domain: $2.92 \leq y_{lab} < 3.92$, $\quad |cos\theta_{CS}| < 0.5$

Acceptances

J/ψ	$12.42 \pm 0.02 \pm 0.17$ %
ψ'	$14.77 \pm 0.03 \pm 0.26$ %
DY$_{2.9\text{-}4.5}$	$13.79 \pm 0.05 - 0.16$ %

The NA50 target region

Acceptance: $1.9 \leq \eta_{lab} \leq 4.2$ for the Multiplicity Detector

$1.1 \leq \eta_{lab} \leq 2.3$ for the Electromagnetic Calorimeter

$\eta_{lab} \geq 6.3$ for the Zero Degree Calorimeter

Data samples review

NA50 uses proton and lead beams colliding on fixed targets.

The spectrometer is almost the same used in the previous **NA38** experiment (study of p-A, O-Cu, O-U and S-U systems)

Data samples in Pb-Pb collisions

| data sample	total target thickness	number of sub-targets	beam intensity (ions/burst)	number of J/ψ	number of ψ'
1995	17% λ_I	7 (in air)	3×10^7	50000	
1996	30% λ_I	7 (in air)	5×10^7	190000	
1998	7% λ_I	1 (in air)	5.5×10^7	49000	380
2000	9.5% λ_I	1 (in vacuum)	7×10^7	129000	905

Data selection

• **Upstream interactions in the beam hodoscope are rejected by dedicated detectors**

• **Interaction pileup is rejected**

• **In-target interactions are identified using the Multiplicity Detector:**

  ✓ **No Pb-air contamination in peripheral interactions**
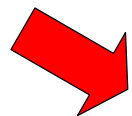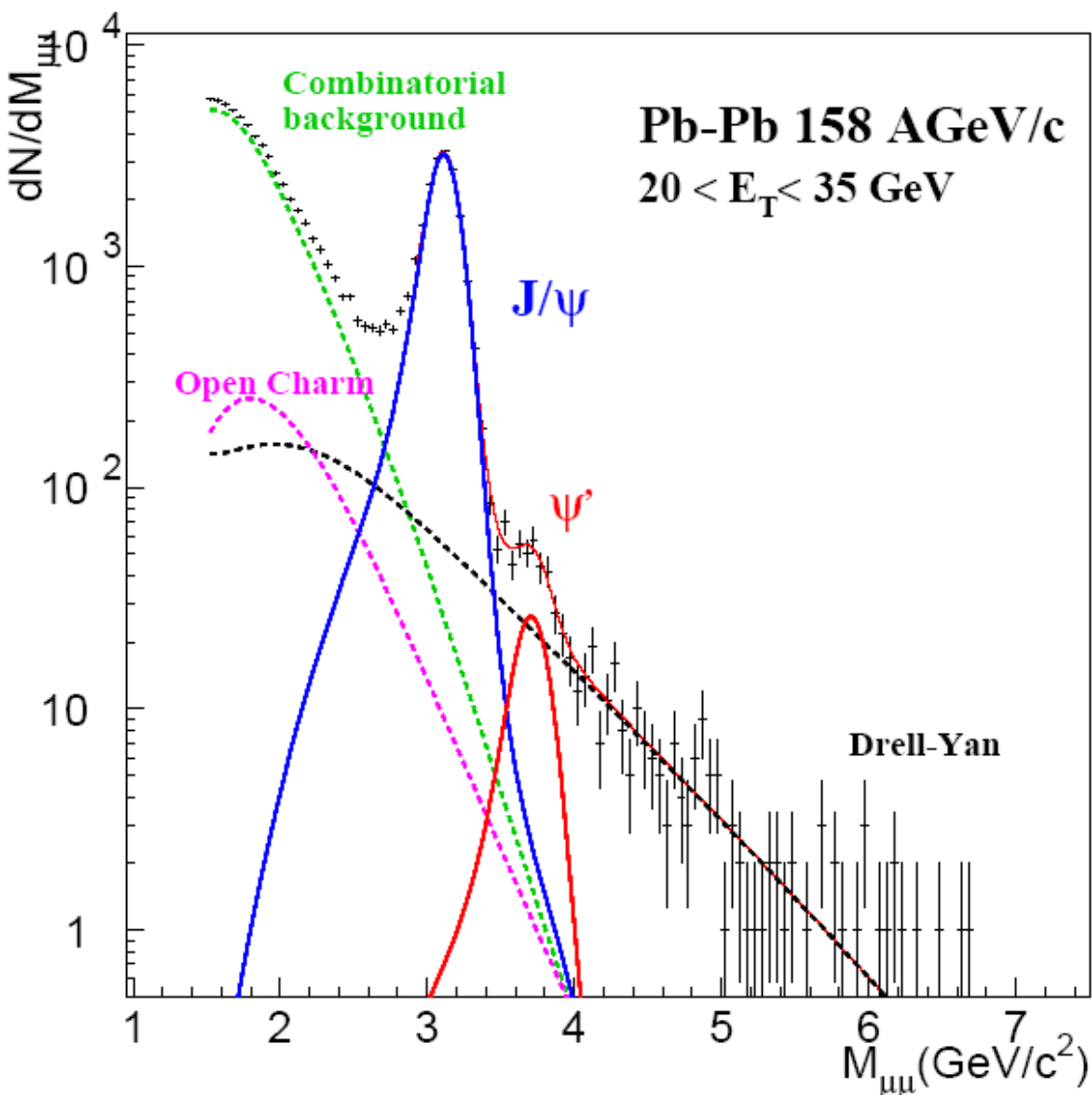
  ➡ **Re-analysis of Pb-Pb 1998 data**

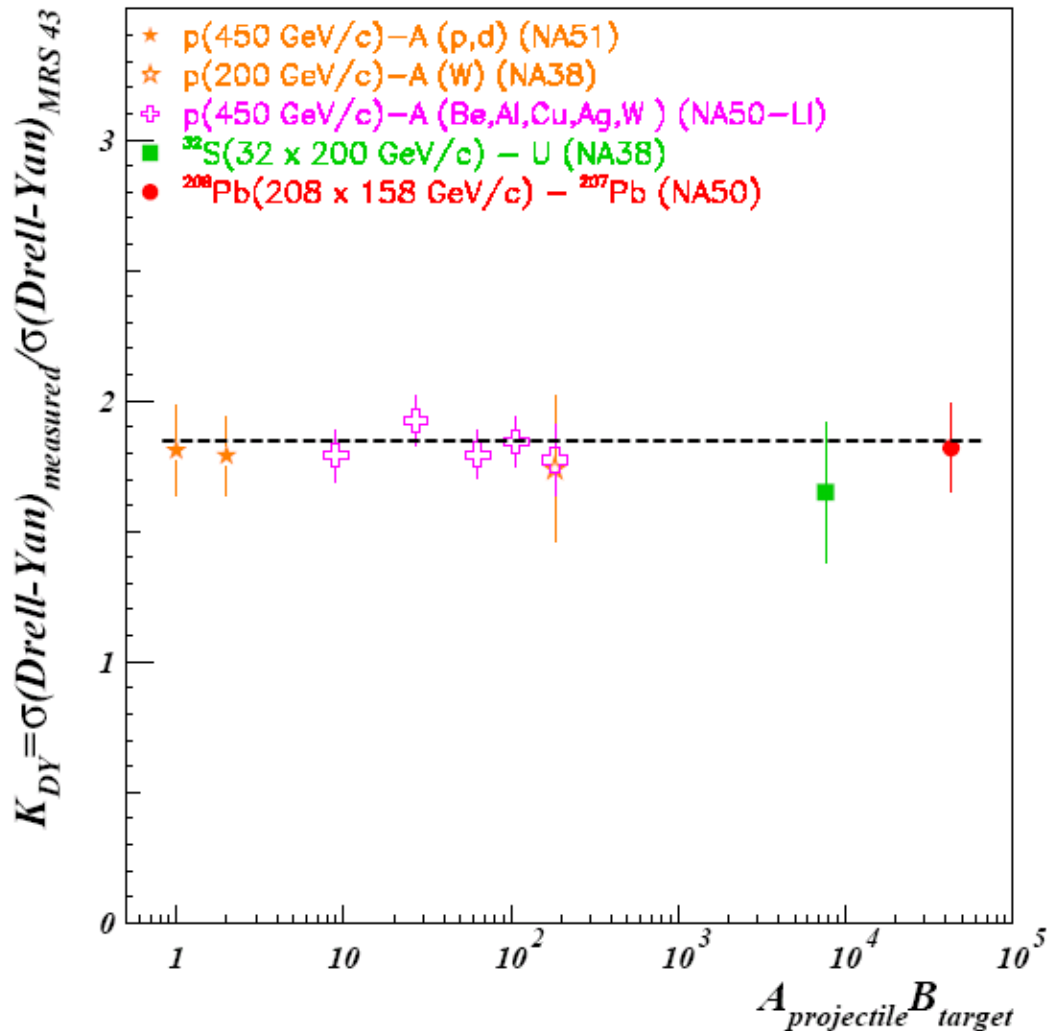 ✓ **Efficient primary vertex in-target identification**
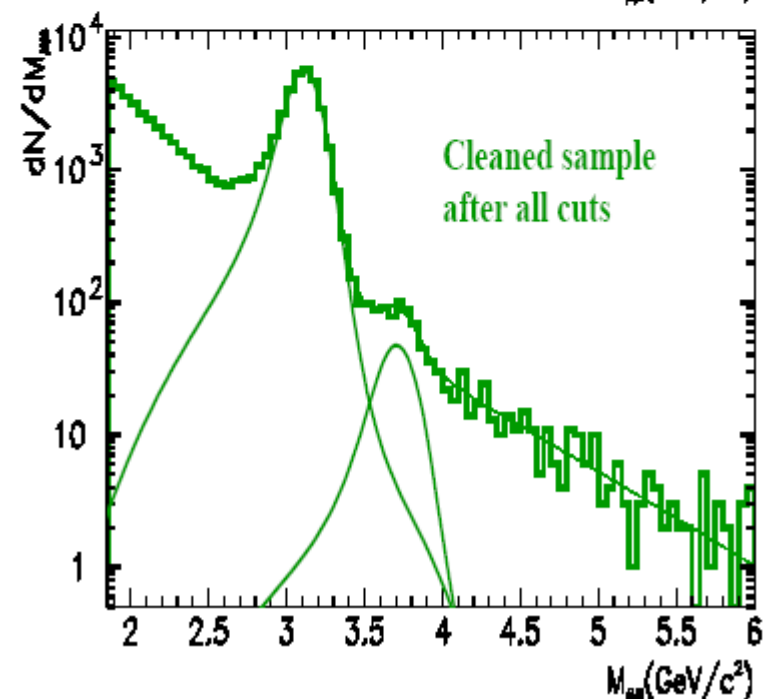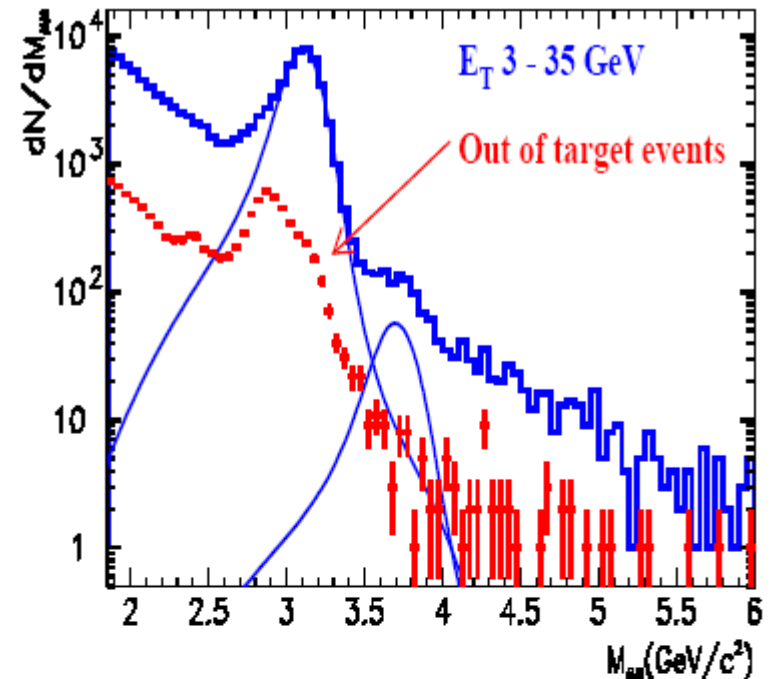
The analysis method

$$\frac{dN^{+-}}{dM} = A_{J/\psi}\frac{dN_{J/\psi}}{dM} + A_{\psi'}\frac{dN_{\psi'}}{dM} + A_{DY}\frac{dN_{DY}}{dM} + A_{D\bar{D}}\frac{dN_{D\bar{D}}}{dM} + \frac{dN_{BG}}{dM}$$

- $J/\psi, \psi', DY$ and $D\bar{D}$ shapes are generated by Monte Carlo and reconstructed as real data

- J/ψ and ψ' mass resolutions are $\sim$100 MeV

- **Combinatorial background**, mostly from pion and kaon decays, is extracted from measured like-sign pairs

Reference for charmonia production

Drell-Yan

p(450 GeV/c)−A (p,d) (NA51)
p(200 GeV/c)−A (W) (NA38)
p(450 GeV/c)−A (Be,Al,Cu,Ag,W) (NA50−LI)
^{32}S(32 × 200 GeV/c) − U (NA38)
^{208}Pb(208 × 158 GeV/c) − ^{207}Pb (NA50)

Advantages:

• σ**(DY)** is proportional to the number of nucleon-nucleon collisions from **p-p** up to **Pb-Pb** (in the NA50 phase space, at least)

• **Same selection criteria**

• **Same eventual biases and inefficiencies**

$\rightarrow$ **Good normalization for**
J/ψ **and** ψ'

Drawback: relatively poor statistics

The J/ψ suppression

Results on $B_{\mu^+\mu^-}\sigma(J/\psi)/\sigma(DY_{2.9-4.5})$ as a function of E_T for **Pb–Pb 2000** data
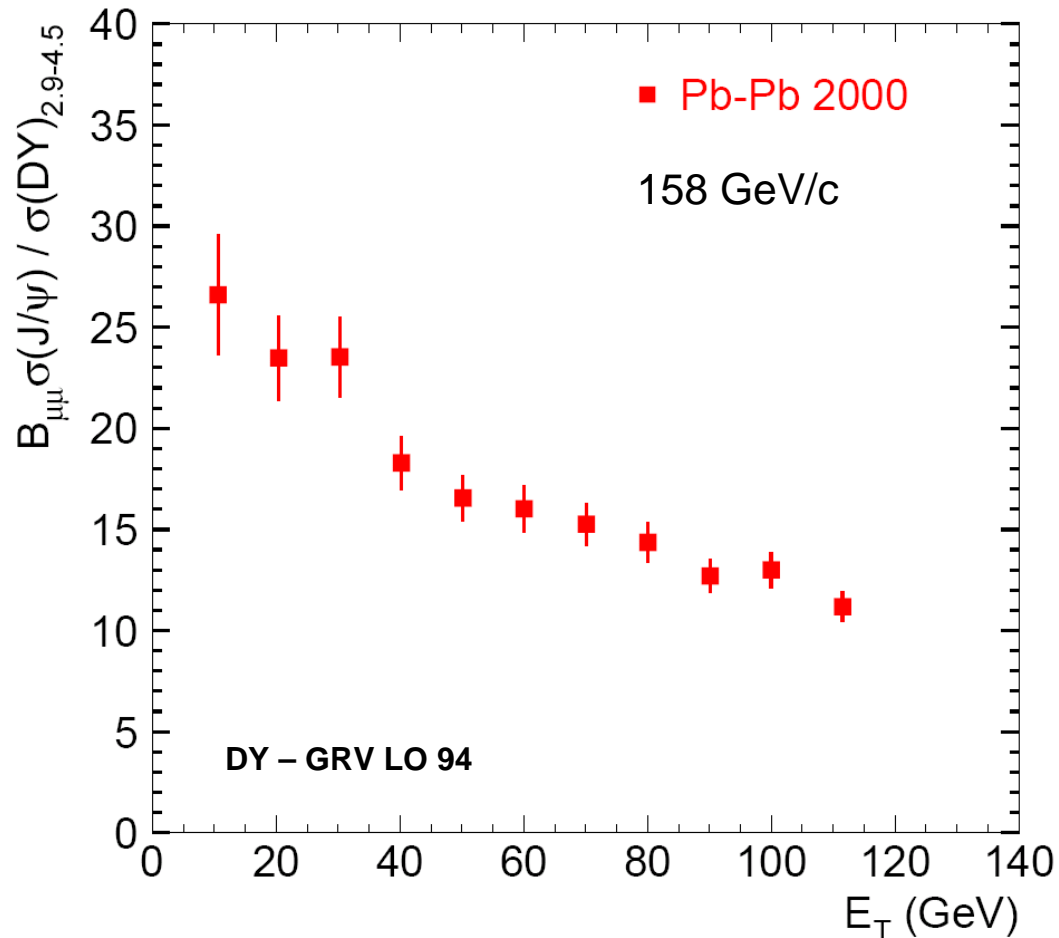
- **The ratio of cross-sections decreases from peripheral to central collisions by a factor of ~2.5**
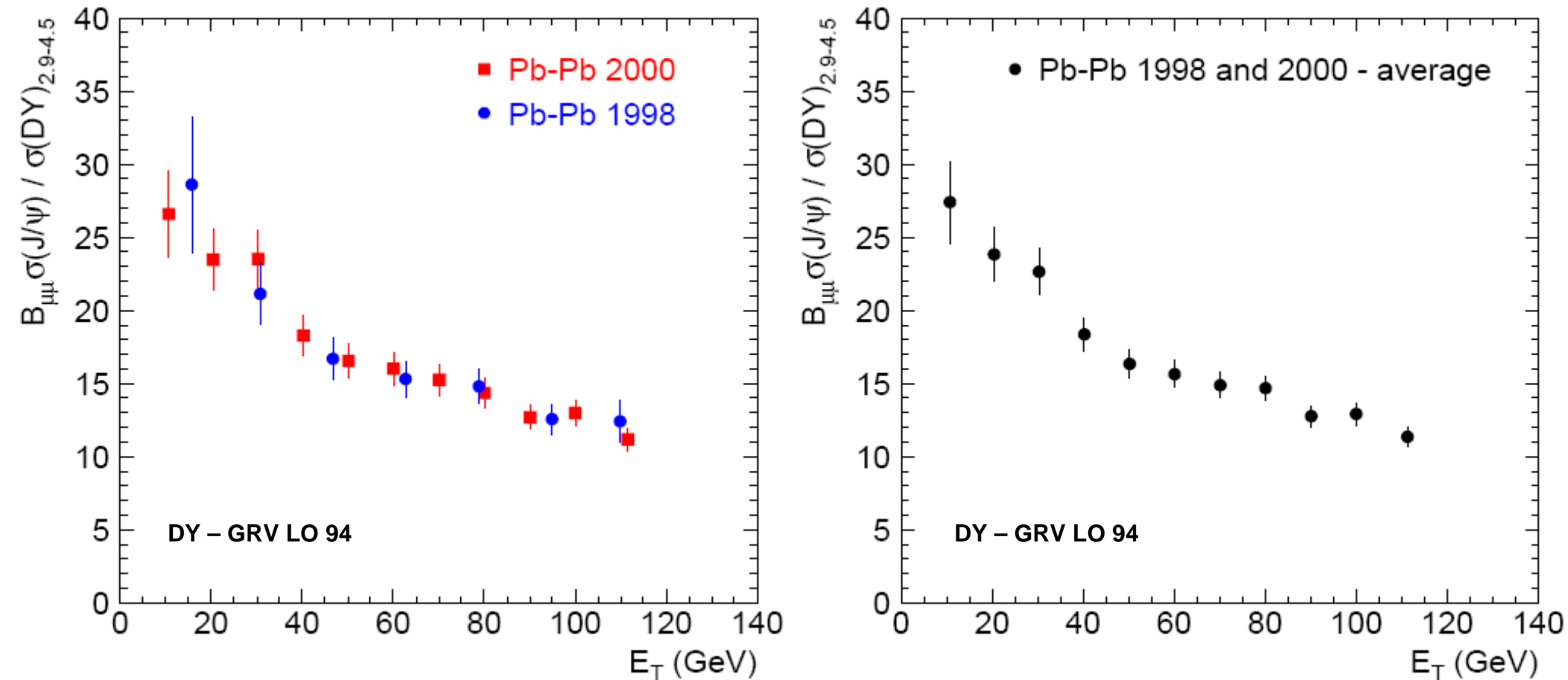
- **No saturation is seen for the most central reactions**

✓ **Statistical errors varying between 9% and 7%**

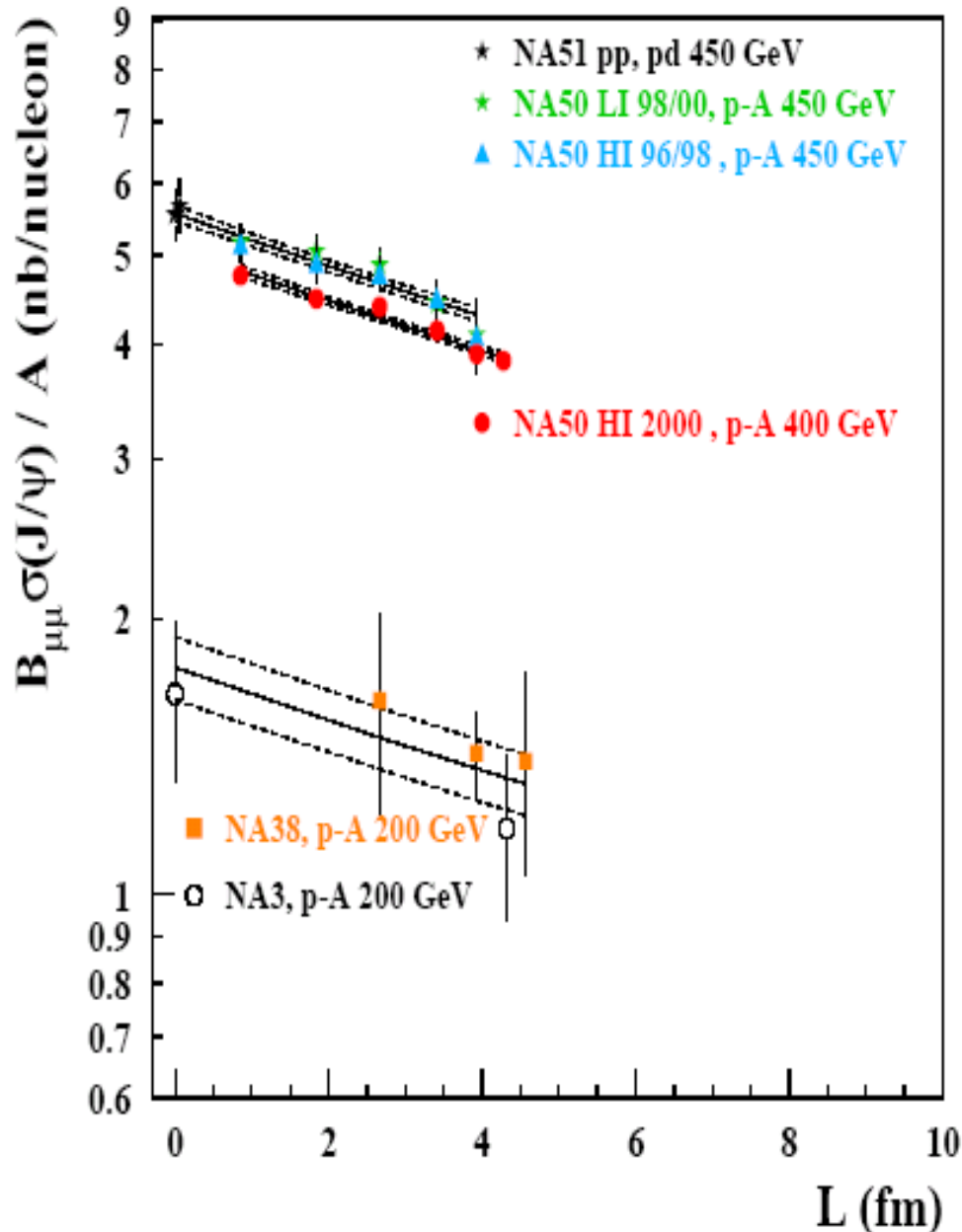✓ **The overall systematic error stands between -1.4% and +3.8%**

The J/ψ suppression

Results on $B_{\mu^+\mu^-}\sigma(J/\psi)/\sigma(DY_{2.9-4.5})$ **as a function of** E_T **for Pb–Pb 2000 and 1998 data**

- **Very good compatibility between the results from the two samples**

- **Systematics under control** ⟶ **average** ⟶ **better accuracy**

The normal nuclear absorption

Determine absorption reference at 158 GeV from p-A

Legend in figure:
- ★ NA51 pp, pd 450 GeV
- ★ NA50 LI 98/00, p-A 450 GeV
- ▲ NA50 HI 96/98 , p-A 450 GeV
- ● NA50 HI 2000 , p-A 400 GeV
- ■ NA38, p-A 200 GeV
- ○ NA3, p-A 200 GeV

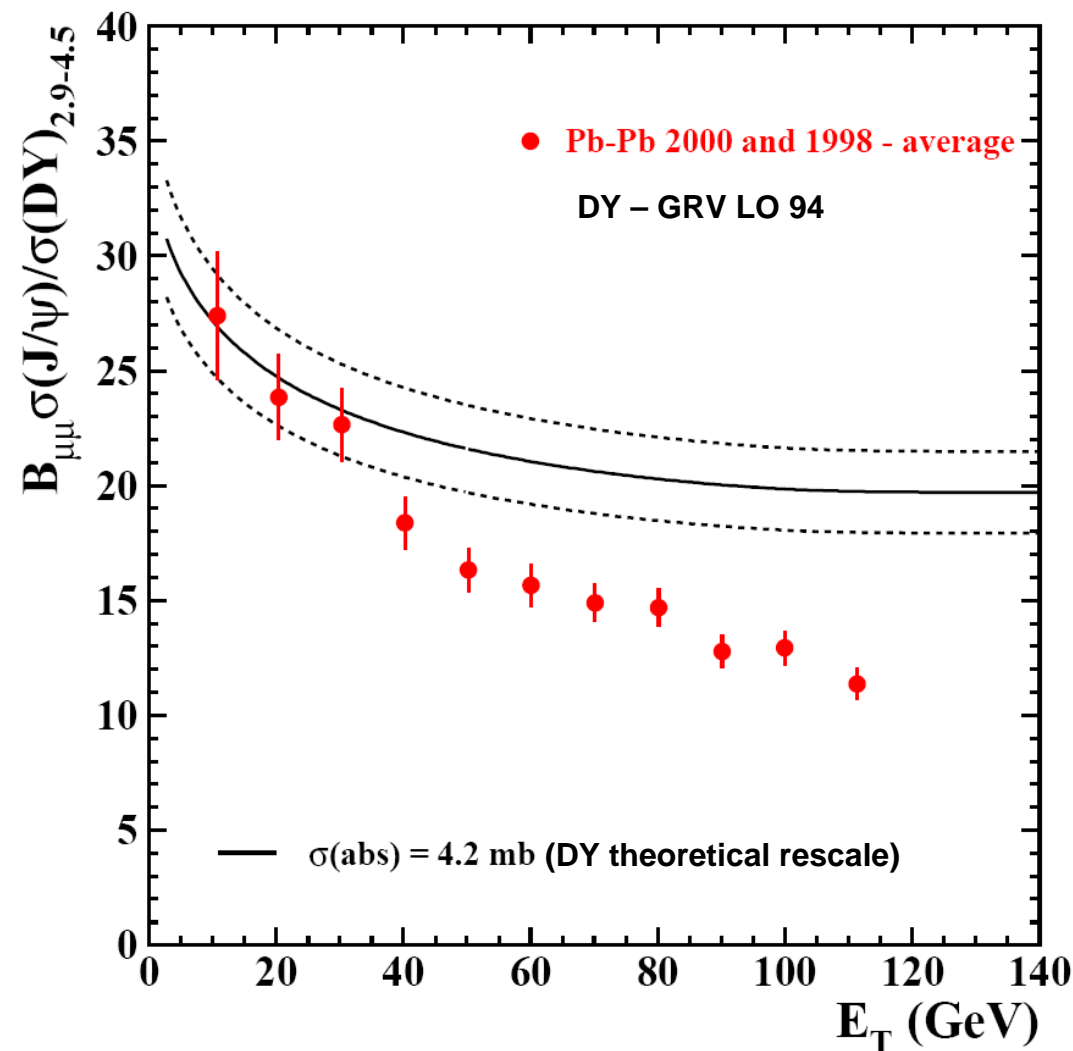Axes: $B_{\mu\mu}\,\sigma(J/\psi) / A$ (nb/nucleon) vs L (fm)

Data from:

➢ **NA50** p-A at 400/450 GeV

➢ NA51 p-p and p-d at 450 GeV

➢ All available 200 GeV data (NA38) + p-p and p-Pt (NA3)

• Absolute J/ψ cross sections

• Independent fits are fully compatible

• Simultaneous fit leads to σ_{abs} = 4.1 ± 0.4 mb and rescaling factor from 450 to 200 GeV

• Theoretical rescale from 200 to 158 GeV
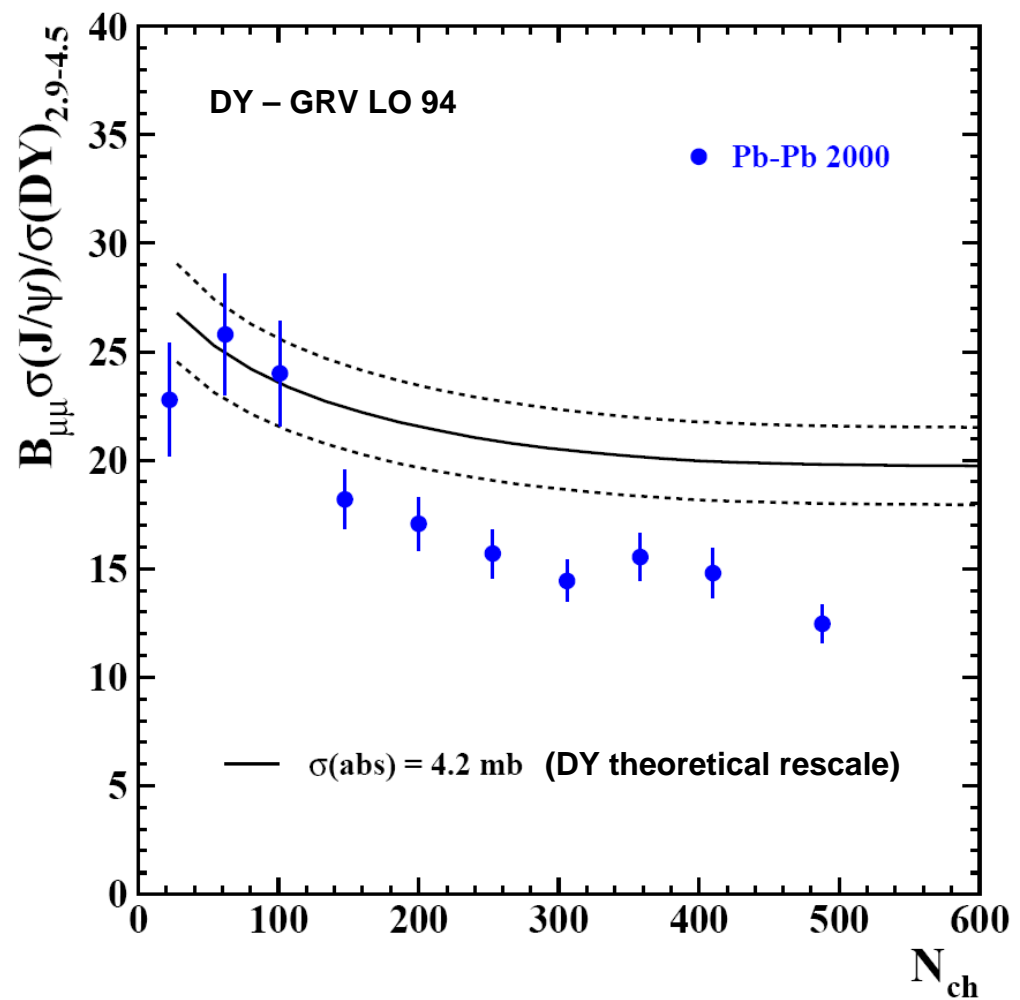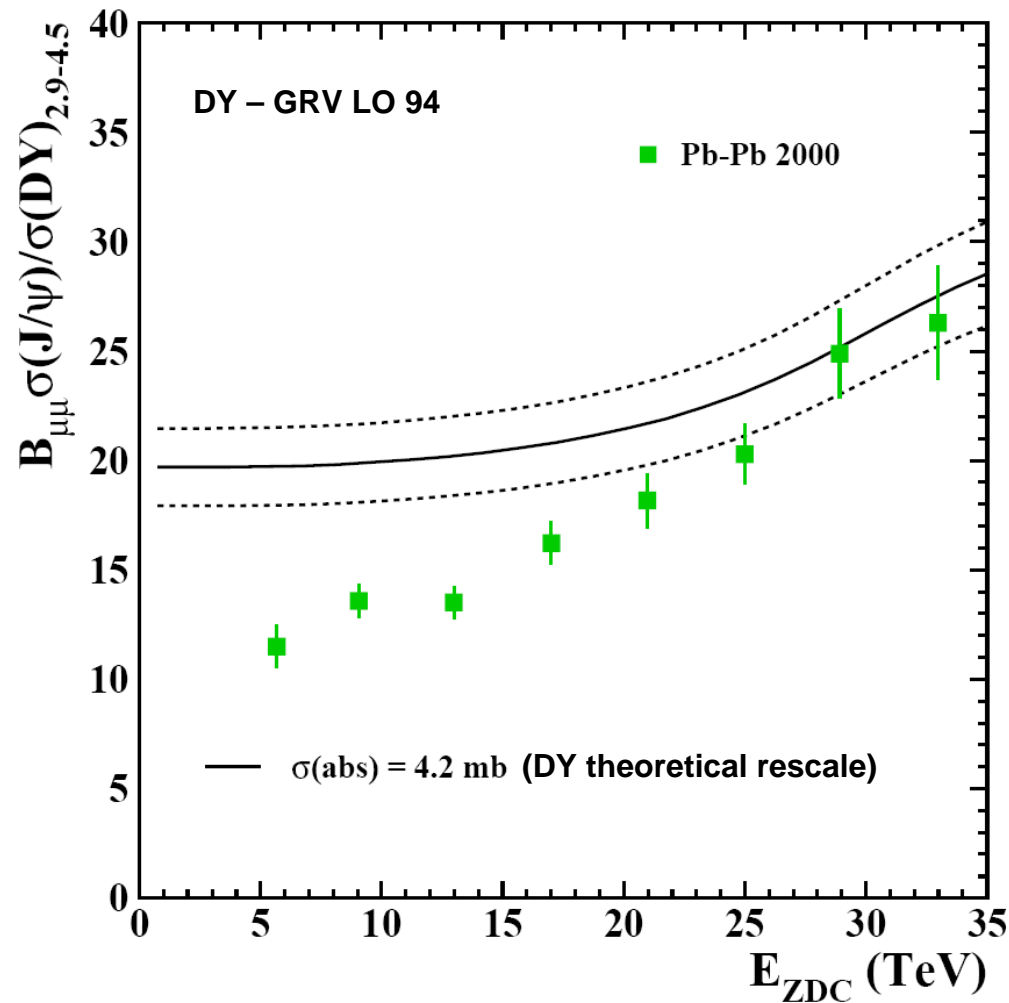
J/ψ/DY in Pb-Pb with p-A reference as a function of E_T

The ratio σ(J/ψ)/σ(DY):

• Behaves "as p-A" for peripheral collisions

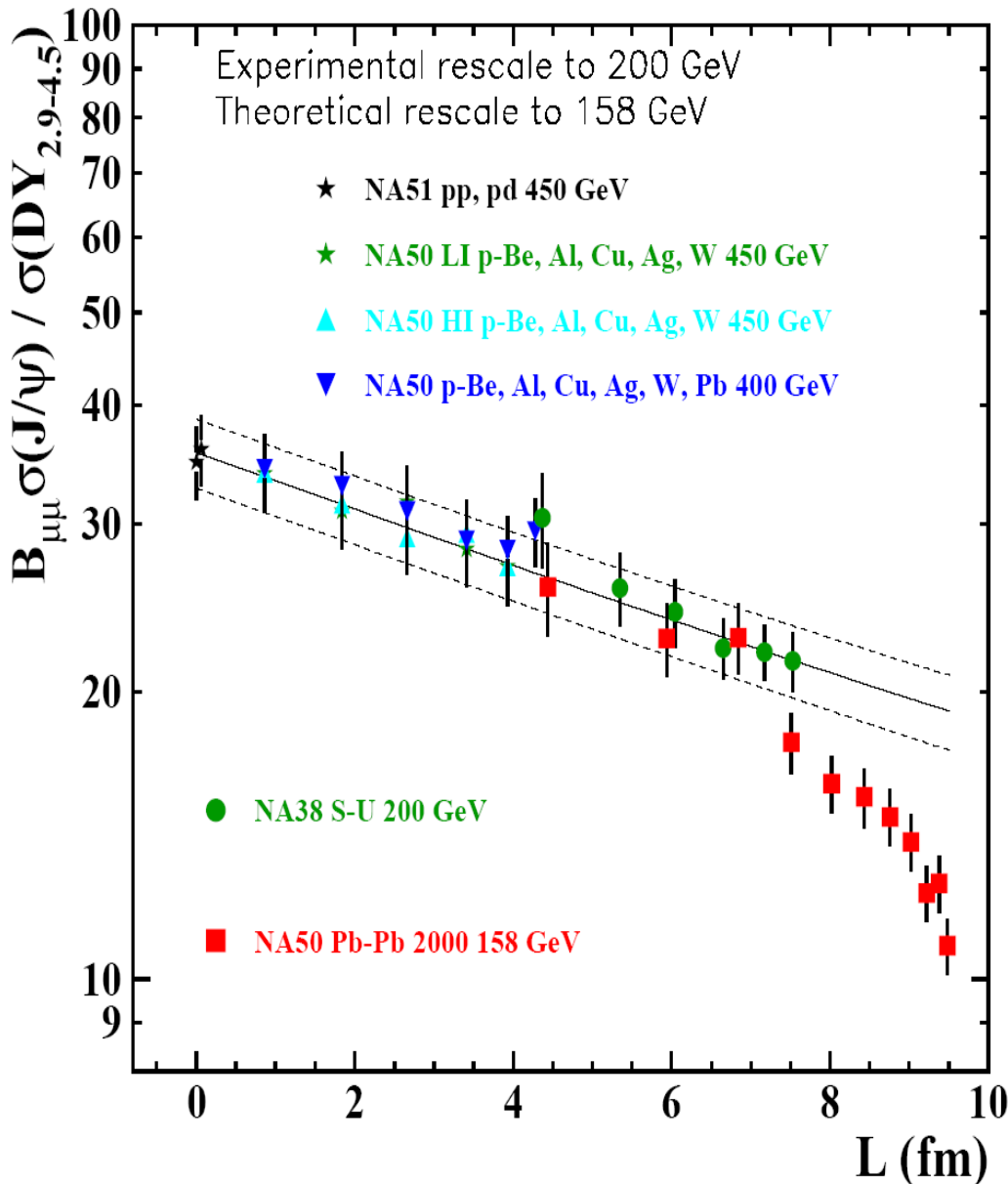• Departs from the normal absorption at $E_T \approx 35$ GeV

• Becomes more and more abnormal for more and more central collisions

J/ψ/DY as a function of forward energy and charged multiplicity

3 independent estimators, E$_T$, E$_{ZDC}$ and N$_{ch}$, confirm the same anomalous J/ψ suppression pattern

J/ψ/DY from p-p to Pb-Pb systems as a function of *L*

J/ψ suffers:

➢ **Normal suppression in S-U and peripheral Pb-Pb**

➢ **Anomalous suppression in central Pb-Pb**

The ψ' study

Pb-Pb 158 AGeV/c Peripheral Collisions


Pb-Pb 158 AGeV/c Central Collisions

Challenging due to:

- small dimuon cross section
- large suppression
- several dimuon sources overlap

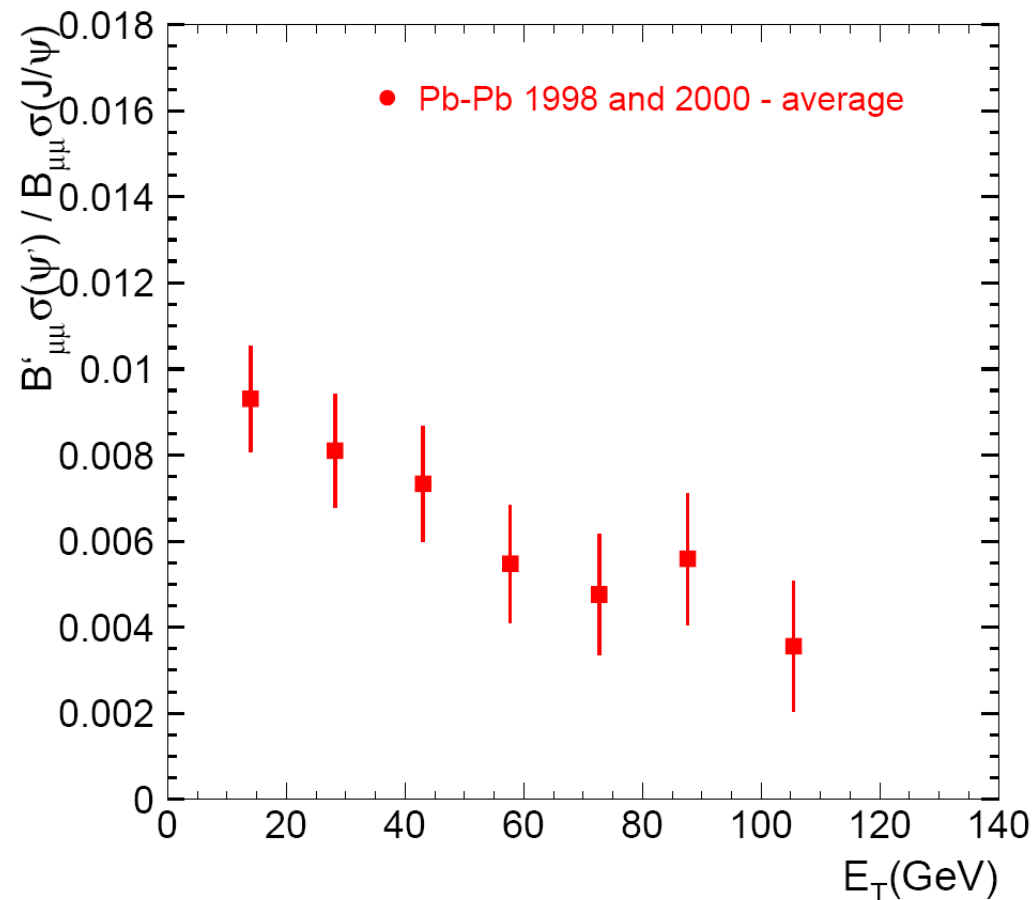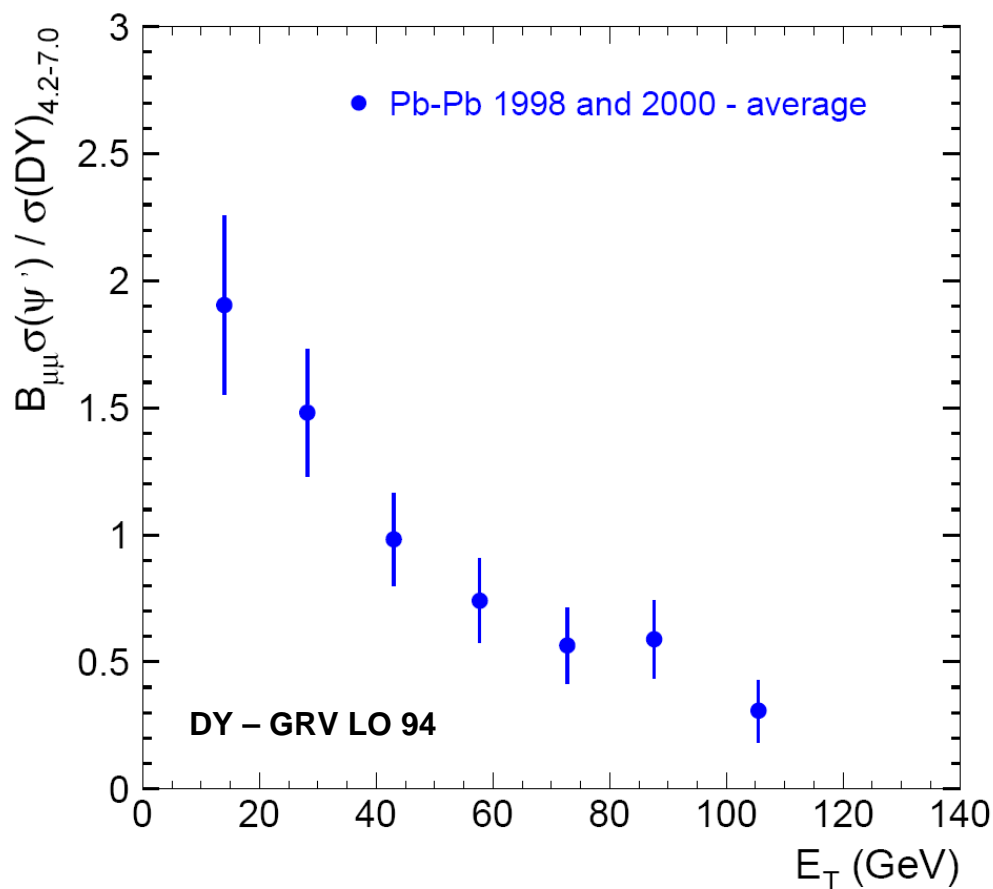◇ Structure functions chosen to simulate Drell-Yan induce up to 7% difference in ψ' normalizations

◇ Combinatorial Background is accurately measured from like-sign sample in each centrality region

◇ The uncertainty due to Open Charm semi-leptonic decays is $<1.5\%$
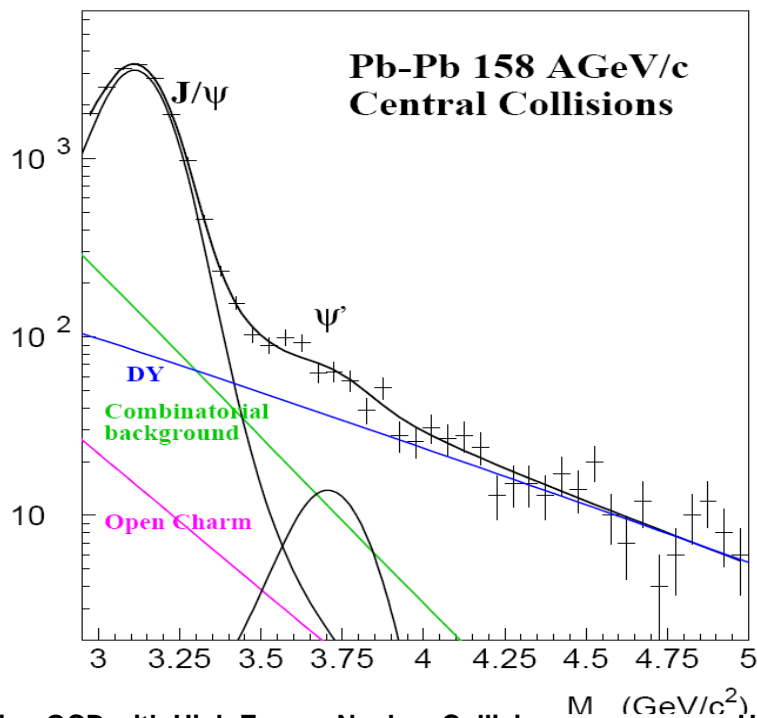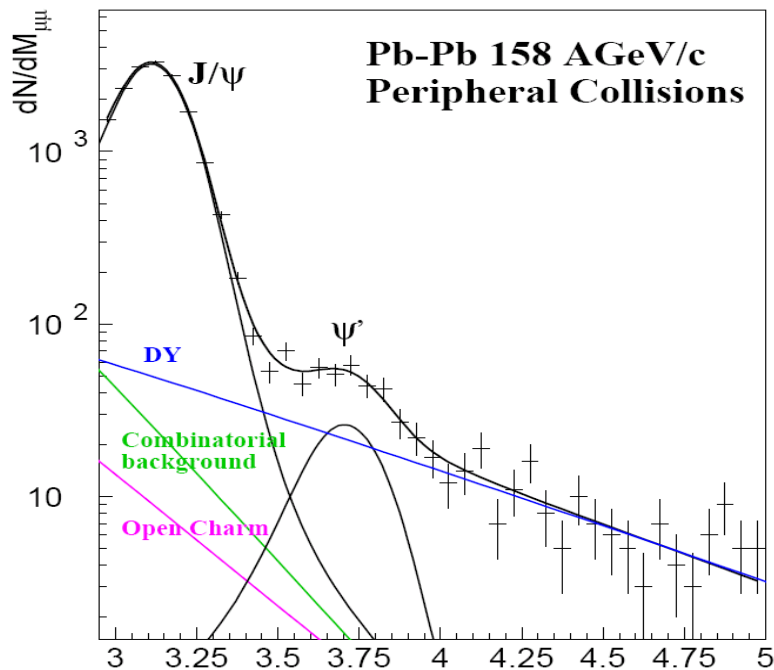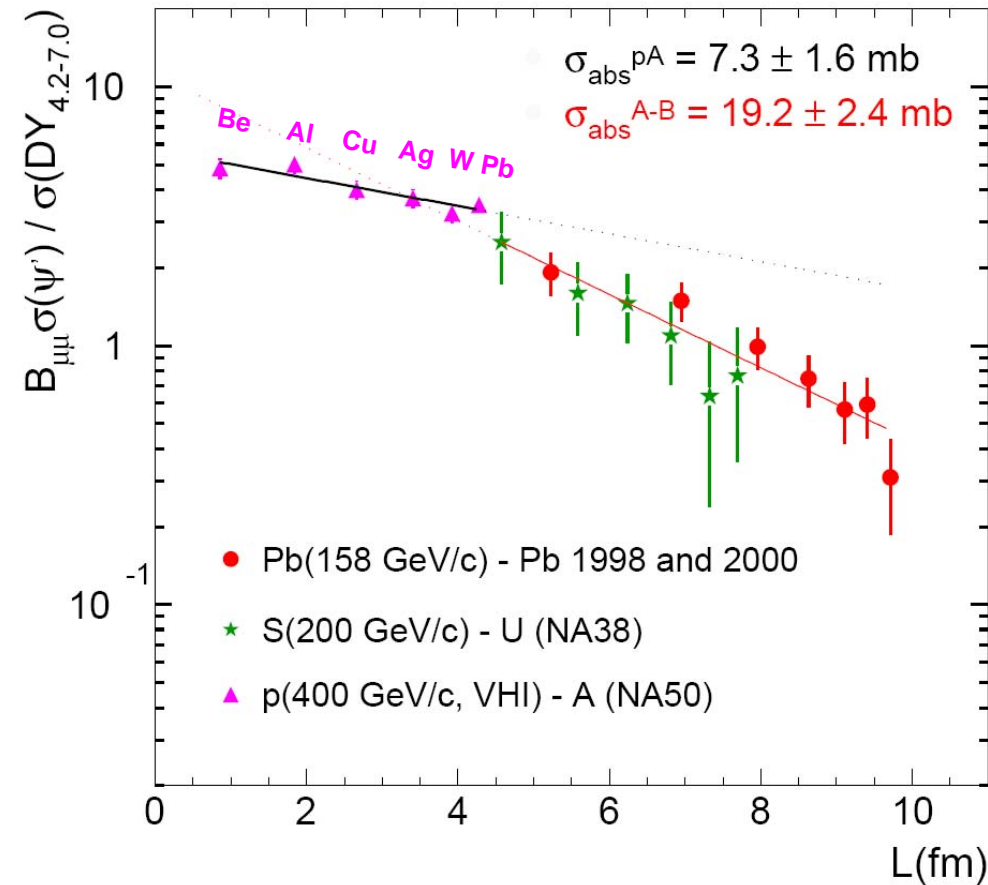
The ψ' suppression

$B_{\mu^+\mu^-}\sigma(\psi')/\sigma(DY_{4.2-7.0})$ and $B'_{\mu^+\mu^-}\sigma(\psi')/B_{\mu^+\mu^-}\sigma(J/\psi)$ as a function of E_T – Average between Pb-Pb 2000 and 1998

- ψ' is increasingly suppressed with respect to Drell-Yan

- The ratio of the two charmonium states decreases with centrality by a factor of 2.5 between peripheral and central collisions

ψ'/DY in p-A, S-U and Pb-Pb systems as a function of L

$$\sigma_0 e^{-\langle\rho L\rangle\sigma_{abs}}$$

Using a exponential parametrization:

One obtains in p-A collisions for ψ'

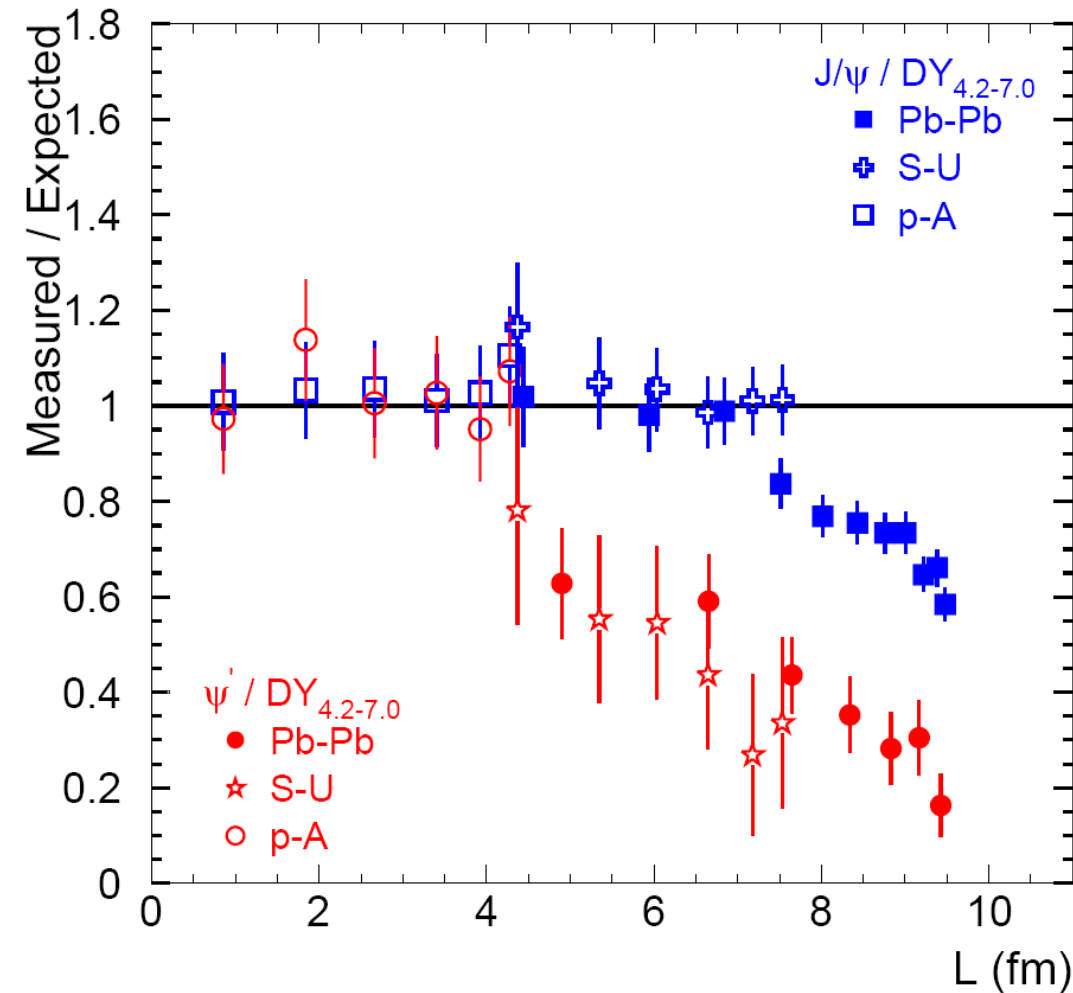$$\sigma_{abs}^{p-A} = 7.3 \pm 1.6 \text{ mb}$$

and

$$\sigma_{abs}^{A-B} = 19.2 \pm 2.4 \text{ mb}$$

for S-U e Pb –Pb collisions fitted simultaneously

- **Different behaviours between p-A and A-B collisions**

- **Strong suppression of** ψ' **between peripheral and central A-B interactions**

- **Same** ψ' **suppression in S-U e Pb-Pb collisions as a function of centrality**

J/ψ and ψ' – measured over expected

Expected: absorption model (full Glauber calculation) with

$$\sigma_{abs}^{J/\psi} = 4.2 \pm 0.4 \text{ mb}$$

$$\sigma_{abs}^{\psi'} = 7.6 \pm 1.2 \text{ mb}$$

In A-B collisions, the ψ' departs from the nuclear absorption curve for less central reactions w.r.t. J/ψ

Conclusions – J/ψ

1. σ**(DY) is proportional to the number of nucleon-nucleon collisions from p-p up to Pb-Pb**

2. **The measurement of J/ψ production in p-A collisions at 450, 400 and 200 GeV provides reliable predictions of nuclear absorption cross section, $\sigma_{abs}^{J/\psi}$ (p-A), at 158 GeV**

3. **For S-U and peripheral Pb-Pb collisions, the ratio σ(J/ψ)/ σ(DY) follows the normal nuclear absorption (like p-A)**

4. **For Pb-Pb central collisions, J/ψ production departs from this normal behaviour. It exhibits an abnormal suppression, which increases with increasing centrality**

Conclusions - ψ'

1. ψ' is strongly suppressed relatively to Drell-Yan as a function of E_T by a factor of 7 between peripheral and central collisions

2. A steady decrease of the ratio between the two charmonium states as a function of E_T is observed, reaching a factor of 2.5

3. The ψ' suppression pattern is the same in S-U and Pb-Pb collisions, and not compatible with the one exhibited in p-A reactions

   A comparison between ψ' and J/ψ suppressions, normalized to the suppression expected, shows that the ψ' anomalous suppression sets in earlier than for J/ψ