

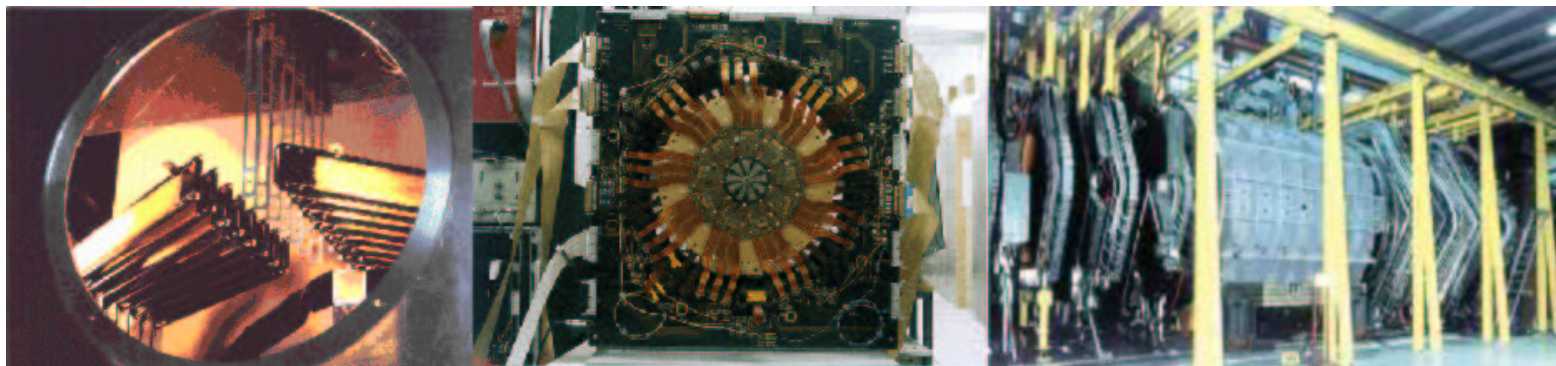
## Final results on charmonia suppression in Pb-Pb collisions

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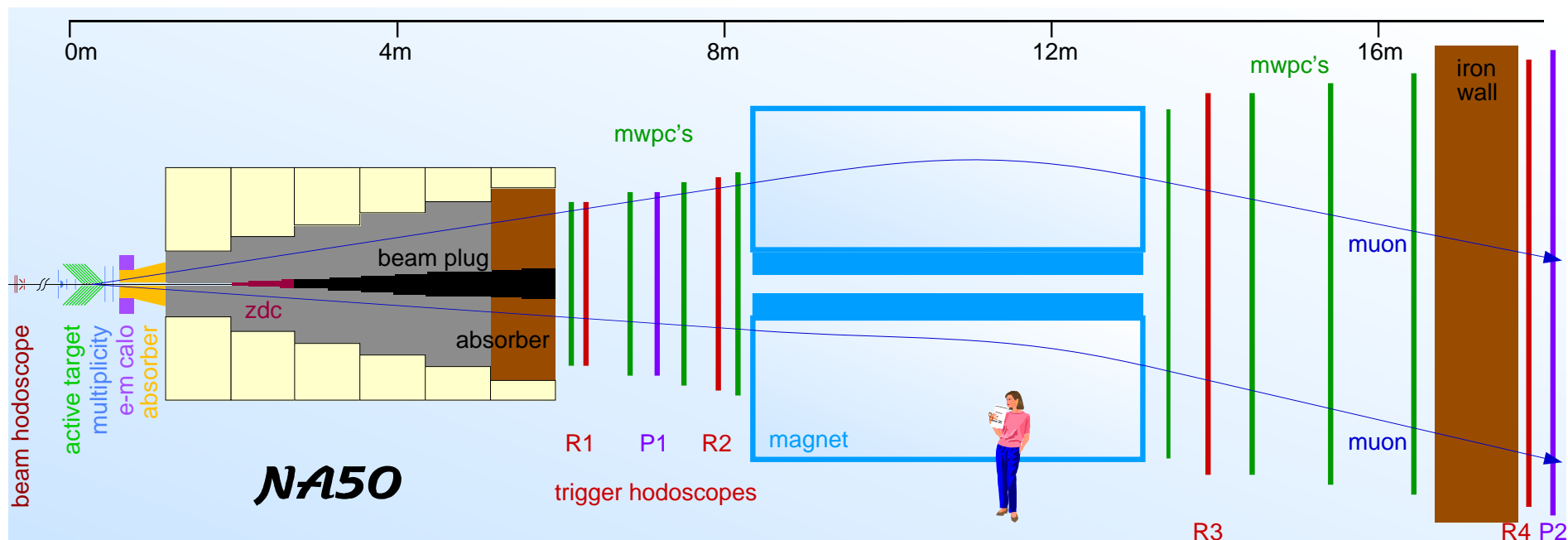
on behalf of the NA50 Collaboration

### Outline:

- The NA50 experiment
- The data samples
- $J/\psi/DY$  vs centrality ( $E_T$ , L)
- The normal nuclear absorption
- Other centrality estimators
- $\psi'$  absorption
- Conclusions



## The experimental setup



Kinematical domain:

$$2.92 \leq Y^{lab} < 3.92$$

$$|\cos \theta| < 0.5$$

Trigger on **dimuons**.

Setup optimized for  **$J/\psi$**  detection.

Acceptances (Pb-Pb at 158 GeV):

$$J/\psi: 12.42 \pm 0.02 \pm 0.17 \%$$

$$DY_{2.9-4.5}: 13.79 \pm 0.05 \pm 0.16 \%$$

$$\psi': 14.77 \pm 0.03 \pm 0.26 \%$$

## The data samples

NA50 took data with protons at 400 and 450 GeV/c, and with Pb ions at 158 A GeV/c.

### Pb-Pb collisions data samples

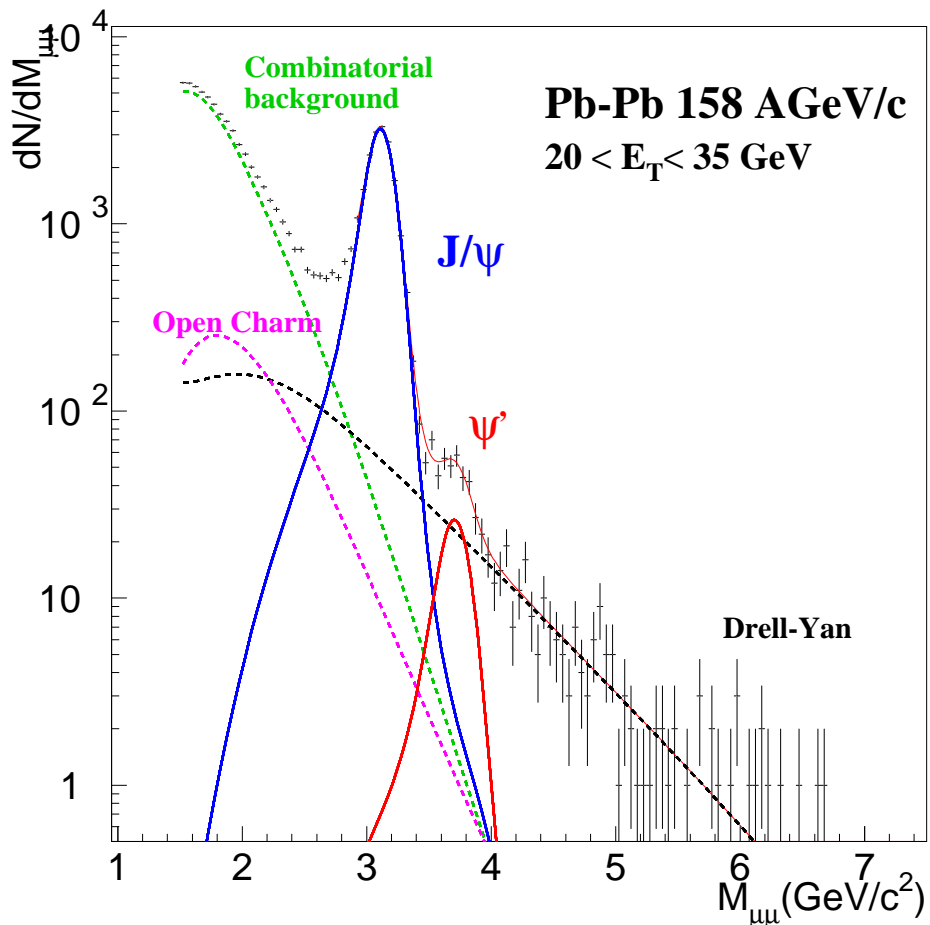
year	sub-targets	target thickness	beam intensity (ions/burst)	$J/\psi$	$\psi'$
1995	7 (in air)	17 % $\lambda_I$	$3 \times 10^7$	50000	—
1996	7 (in air)	30 % $\lambda_I$	$5 \times 10^7$	190000	—
<b>1998</b>	<b>1 (in air)</b>	<b>7 % <math>\lambda_I</math></b>	<b><math>5.5 \times 10^7</math></b>	<b>49000</b>	<b>380</b>
<b>2000</b>	<b>1 (in vacuum)</b>	<b>10 % <math>\lambda_I</math></b>	<b><math>7 \times 10^7</math></b>	<b>129000</b>	<b>905</b>

**1998:** only 1 thin sub-target  $\longrightarrow$  avoid re-interactions that could simulate single collisions with high centrality  $\longrightarrow$  **Confirm behaviour for high centrality collisions.**

**2000:** 1 thin sub-target in vacuum  $\longrightarrow$  avoid Pb-Air interactions  $\longrightarrow$  **Confirm behaviour for peripheral collisions.**

**The use of MD information, available in 1998 and 2000, for the recognition of interactions allows to efficiently identify very peripheral collisions ( $E_T > 3$  GeV).**

## The method of analysis

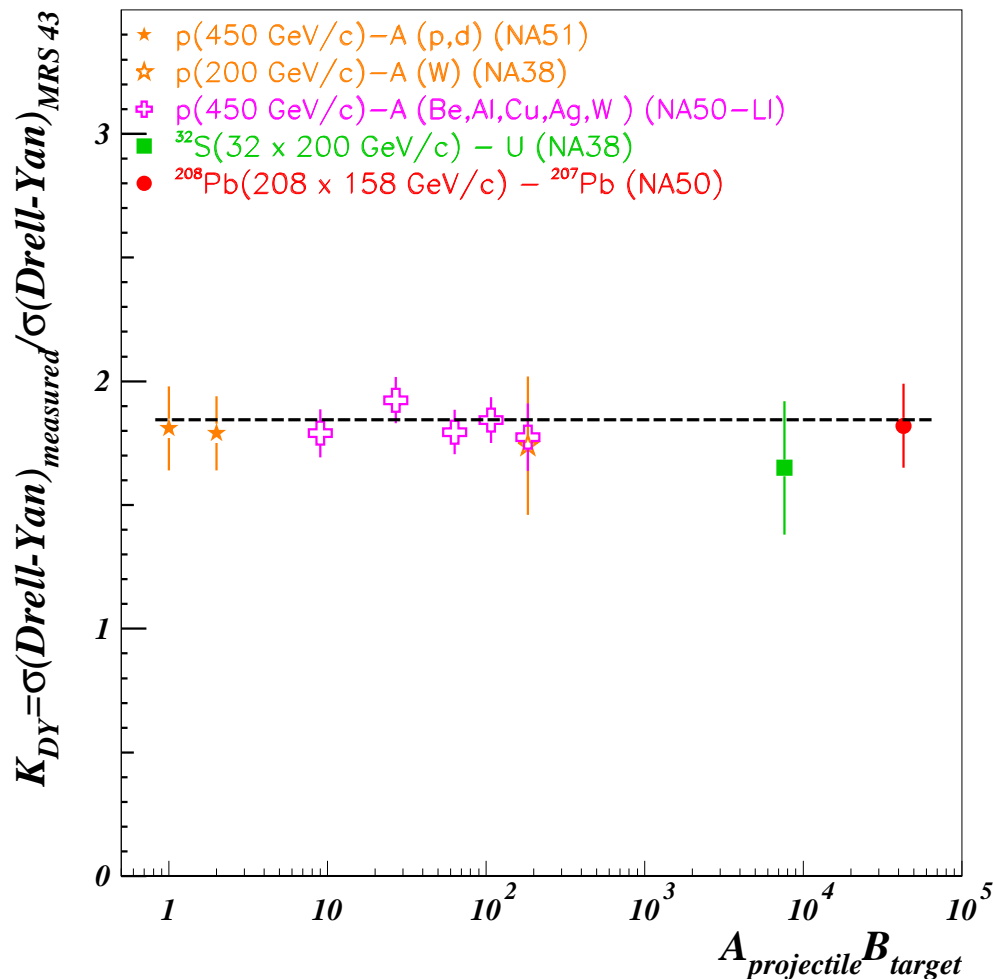


- Fit the dimuon mass spectra, for each centrality region.
- Combinatorial background (mostly from  $\pi$  and  $K$  decays) is taken from the measured like-sign dimuon distributions.
- Functional forms of  $J/\psi$ ,  $\psi'$ ,  $D\bar{D}$  and DY from Monte-Carlo generation + NA50 spectrometer simulation.
- DY shape generated using PYTHIA with GRV 94 LO set of PDFs.

$$\frac{dN^{+-}}{dM} = \mathcal{N}_{J/\psi} \frac{dN_{J/\psi}}{dM} + \mathcal{N}_{\psi'} \frac{dN_{\psi'}}{dM} + \mathcal{N}_{DY} \frac{dN_{DY}}{dM} + \mathcal{N}_{D\bar{D}} \frac{dN_{D\bar{D}}}{dM} + \mathcal{N}_{Bkg} \frac{dN_{Bkg}}{dM}$$

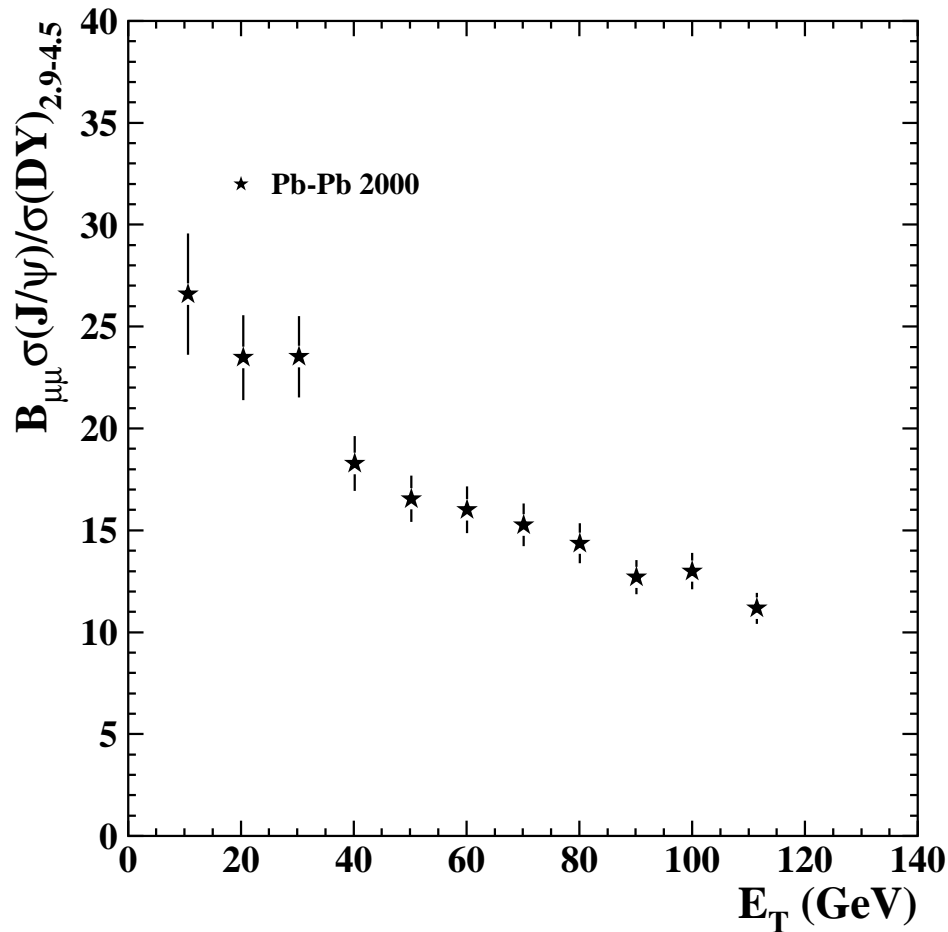
## Drell-Yan as reference process

DY is used as normalization to study  $J/\psi$  and  $\psi'$  production.



- ☺ DY is a well-known process, proportional to the number of NN collisions from p-p up to Pb-Pb.
- ☺ DY selection criteria identical to charmonia.
- ☺ Cancellation of most systematical errors when using DY as normalization for charmonia production.
- ☹ But: low statistics.

## $J/\psi/DY_{2.9-4.5}$ vs centrality



- The study is done using 3 independent centrality estimators
  - ◆ **ECal** integrates the flux of neutral transverse energy released in the range  $1.1 \leq \eta < 2.3 - E_T$
  - ◆ **MD** detects charged particles in the range  $1.9 \leq \eta < 4.2 - N_{ch}$
  - ◆ **ZDC** detects the forward energy carried by the beam spectator nucleons in the range  $\eta > 6.3 - E_{ZDC}$
- After a multi-step mass fit, the evaluated  $J/\psi$  and DY contributions are corrected by the individual acceptances obtained from Monte-Carlo.

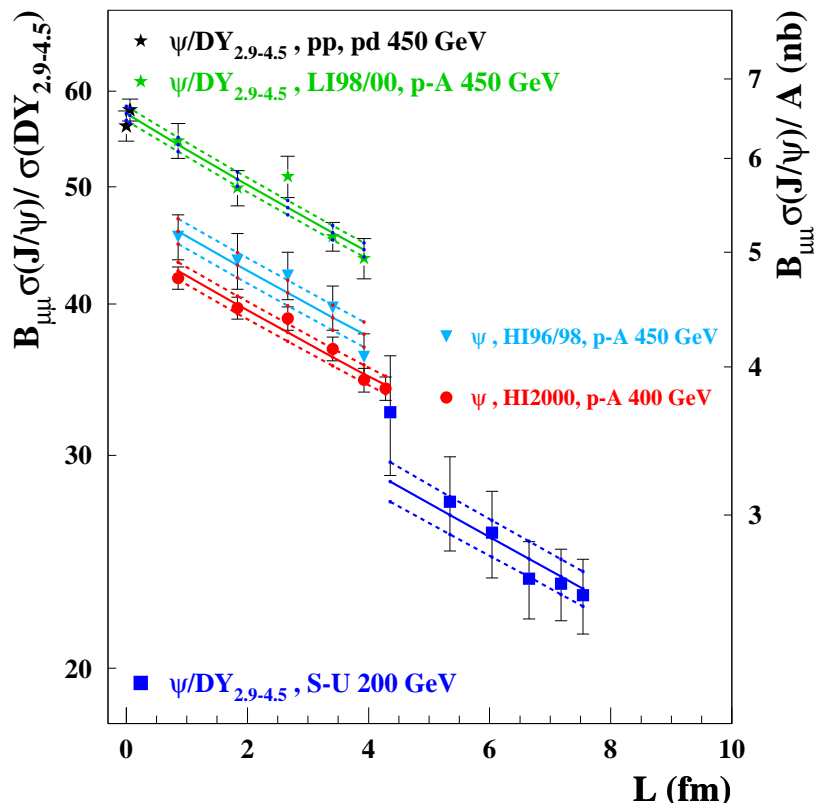
## $J/\psi$ normal nuclear absorption (I)

Already in **p-A** collisions there is absorption of the  $J/\psi$  in the medium. We need to evaluate this **normal absorption**, in order to compare it with our results in **Pb-Pb** collisions at 158 GeV.

Since we don't have p-A data at 158 GeV,

what we used to do was:

- Use the high NA50 p-A data at 400 and 450 GeV/c, together with NA51 data, and NA38 S-U data at 200 GeV/nucleon, to extract  $J/\psi/DY$ .
- Check that the data sets at these different energies have compatible  $\sigma_{abs}$ , within errors.
- Since they do, fit them simultaneously, to extract  $\sigma_{abs}^{J/\psi}$  and the rescaling factor to go from 450 to 200 GeV. From the Glauber fit one gets:  $\sigma_{abs} = 4.18 \pm 0.35$  mb.
- Use this  $\sigma_{abs}$  to compute the normal absorption curve, and rescale it from 200 to 158 GeV, to compare with Pb-Pb data.



## $J/\psi$ normal nuclear absorption (II)

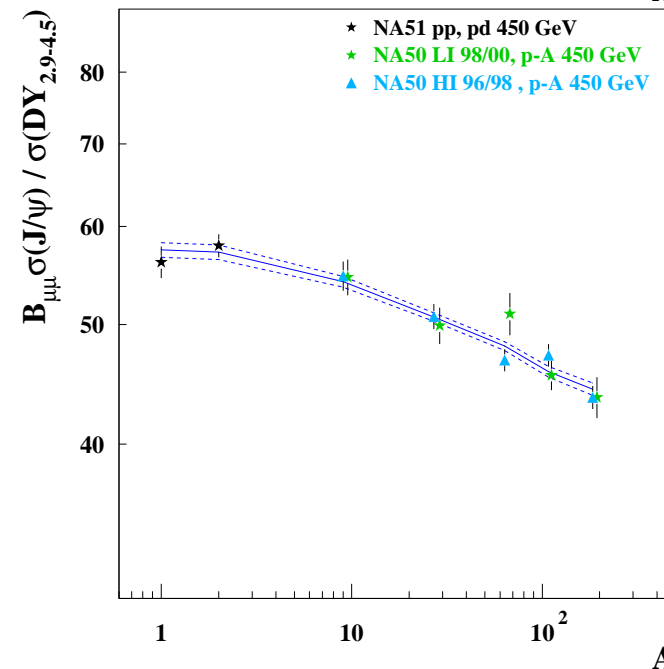
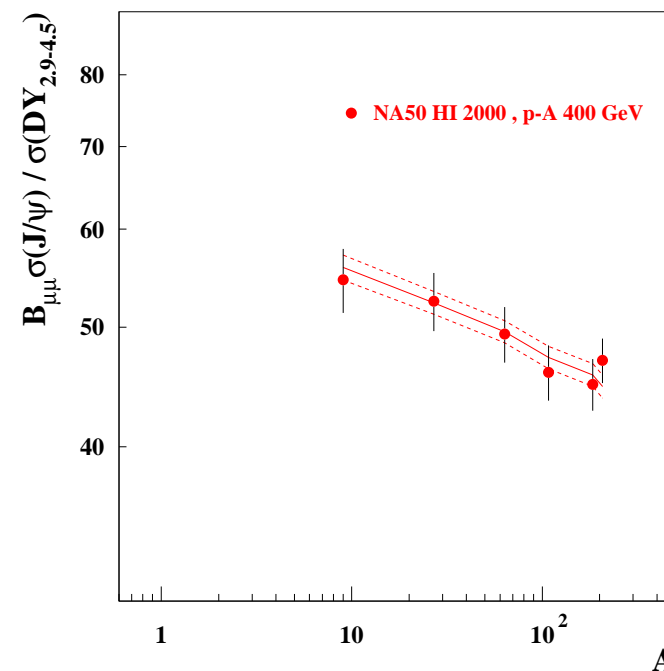
Are there still any doubts about the robustness of the normal absorption curve?

We can do **even better**:

NEW

- Use the high statistics NA50 p-A data at 400 and 450 GeV/c, together with NA51 data, to extract the  $J/\psi$  cross-section as a function of the target mass number  $A$ .
- From the Glauber fit to all set of data points, one gets:

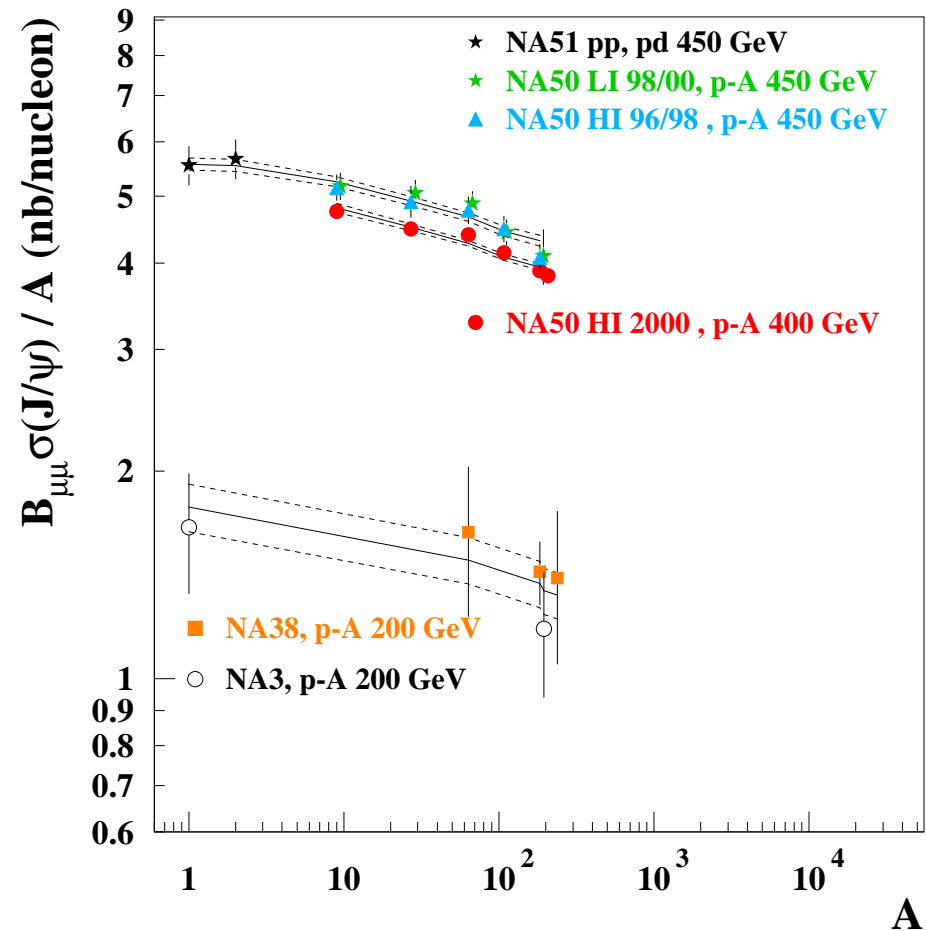
$$\sigma_{abs} = 4.18 \pm 0.35 \text{ mb}$$



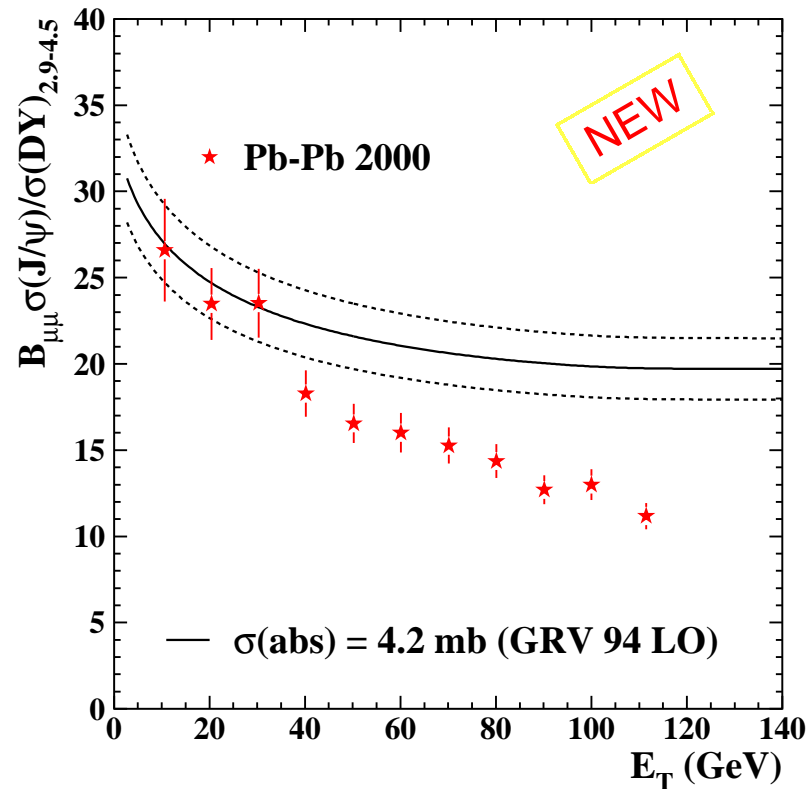
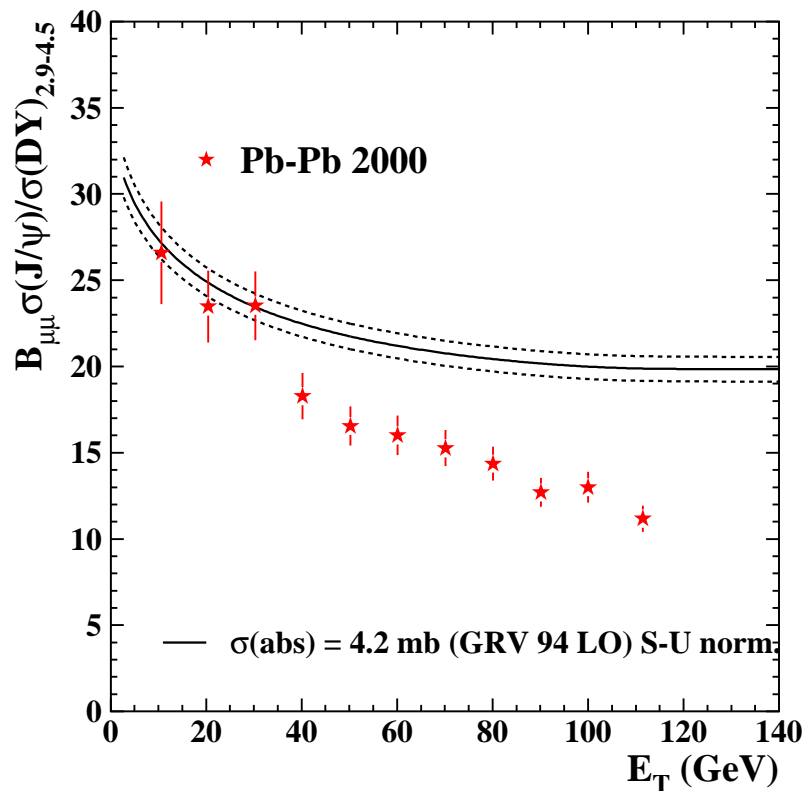
## $J/\psi$ normal nuclear absorption (III)

NEW

- Besides the  $\sigma_{abs}$  value, one also needs the normalization of the absorption curve at 158 GeV/c.
- The rescaling factor to bring the  $J/\psi$  from 450 GeV/c to 200 GeV is done from the simultaneous fit of NA51, NA50, NA38 and NA3 p-A data.
- The small rescaling factor to bring the  $J/\psi$  from 200 GeV/c to 158 GeV/c is done using the Schuler parameterization.
- The rescaling factor for Drell-Yan is obtained theoretically.



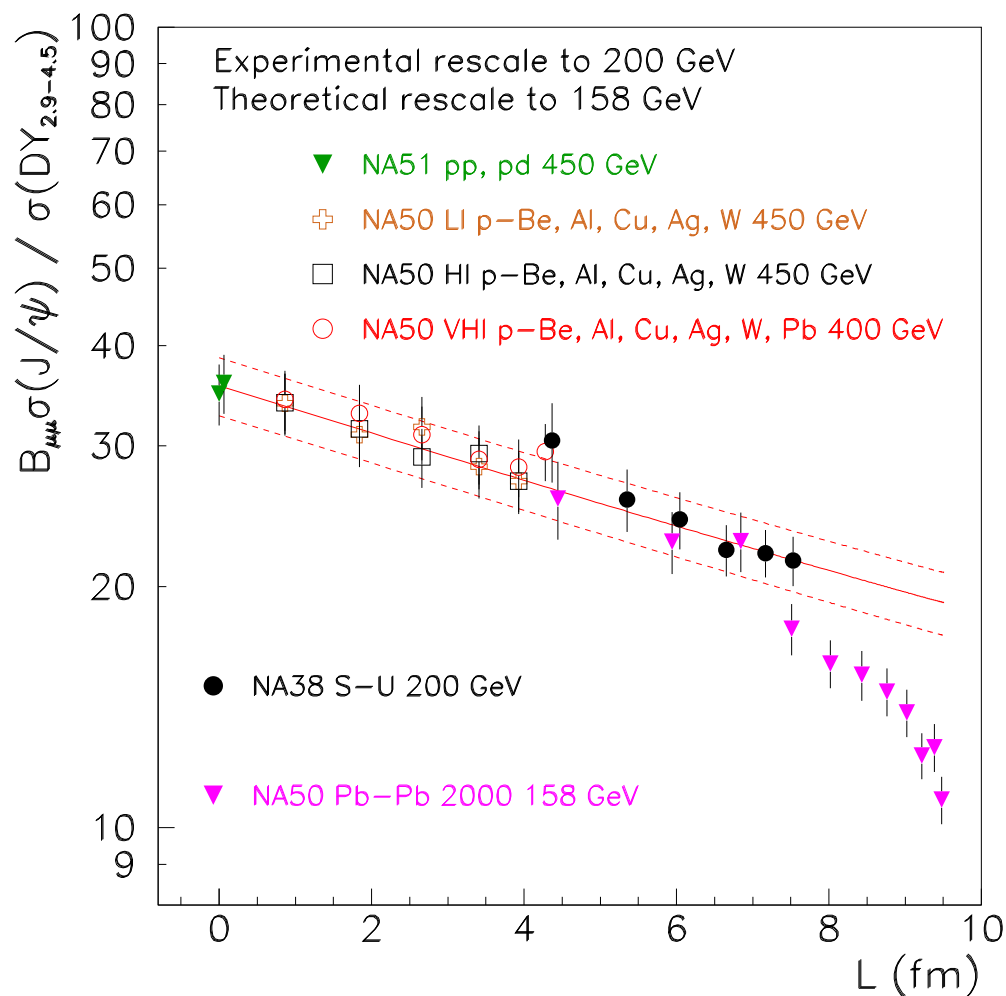
# $J/\psi/DY$ : Pb-Pb results and the normal absorption curve



The normal nuclear absorption curve does not change from one method to the other, only the systematic error bands differ!

This shows that S-U is fully compatible with the normal p-A behaviour.

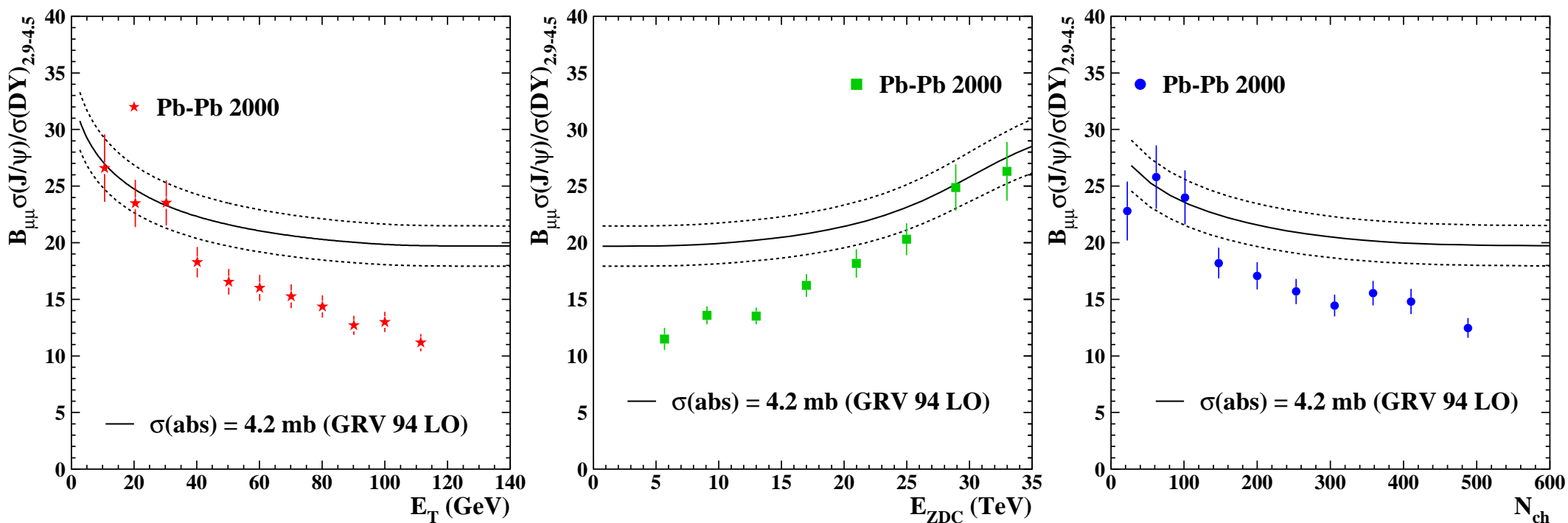
## $J/\psi/DY$ : from p-p to Pb-Pb



- L is the mean path length traversed by the  $c\bar{c}$  pair in the nuclear matter.
- L is evaluated using one of the available centrality estimators, through a Glauber calculation.
- For S-U collisions,  $J/\psi/DY$  suppression follows the normal absorption curve.
- For Pb-Pb collisions, there is a clear departure from the normal absorption curve from mid-centralities on.

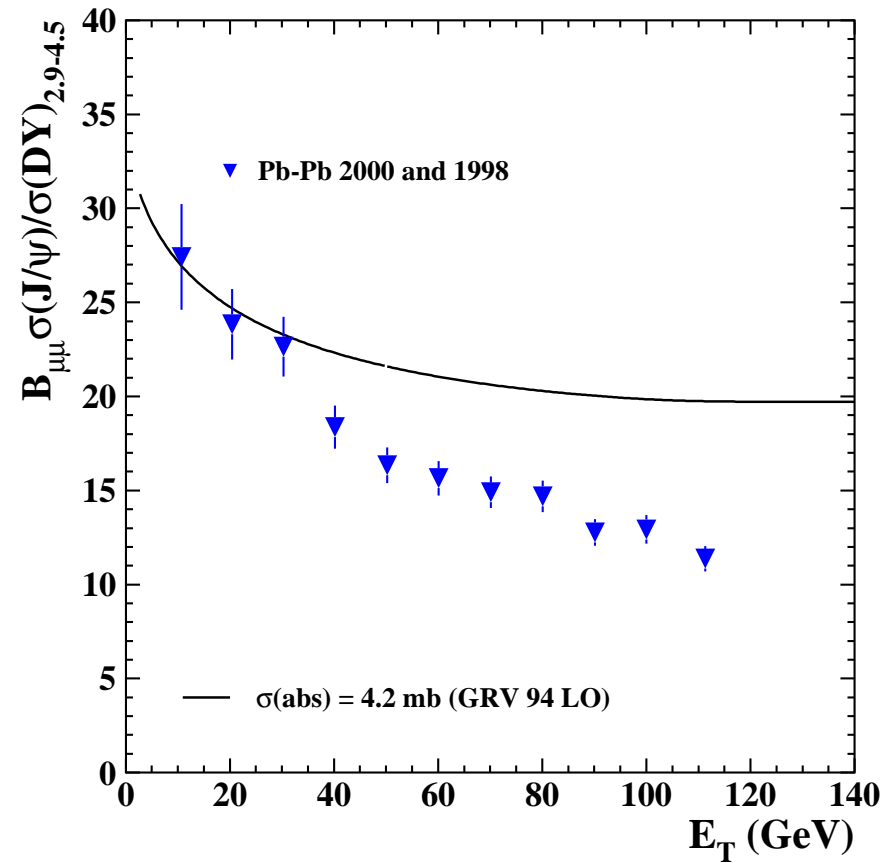
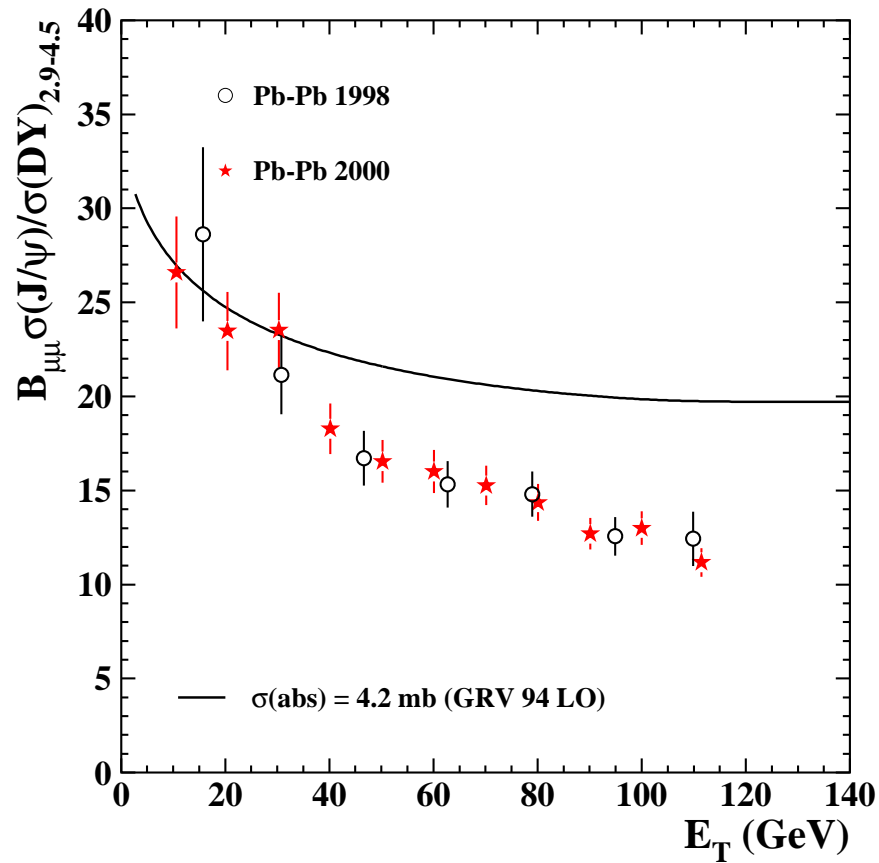
## $J/\psi/DY$ vs $E_T$ , $E_{ZDC}$ or $N_{ch}$

3 independent analyses of  $J/\psi/DY_{2.9-4.5}$  are compared with the extrapolated normal nuclear absorption curve.



There is **compatibility** with the normal absorption curve for **peripheral collisions**, a **departure** from this curve starting at **mid-centralities**, and a **non-saturation** for **high centrality** collisions.

## $J/\psi/DY$ final averaged results



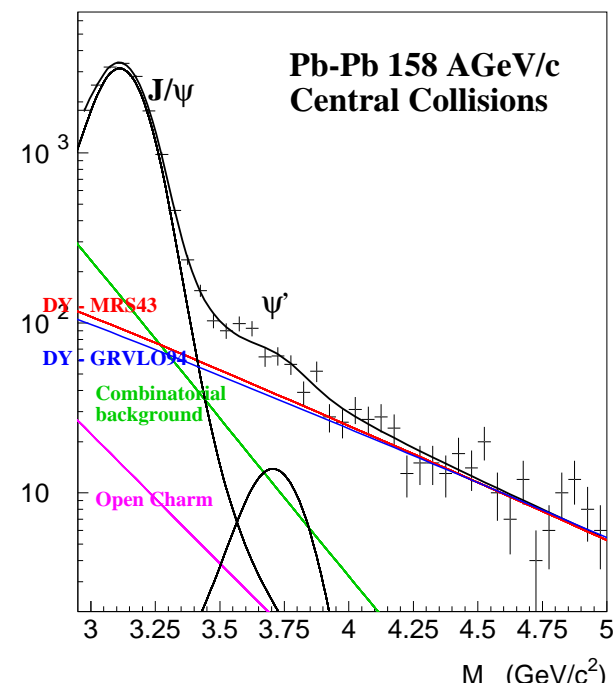
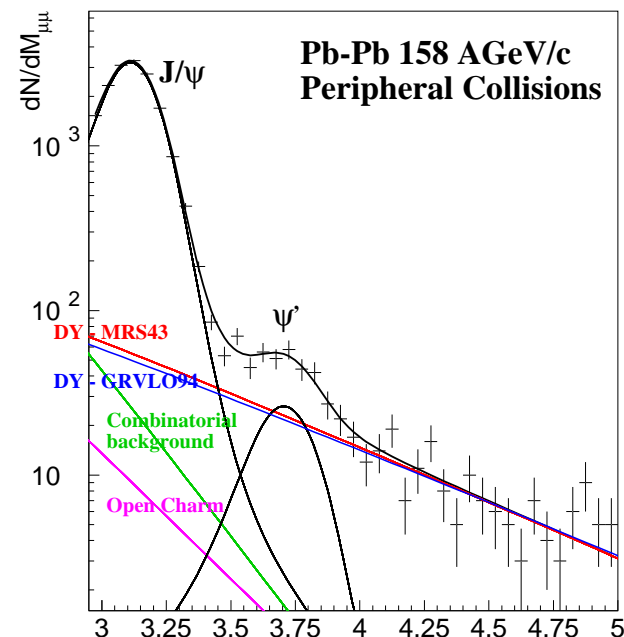
- Very good compatibility between the 2 data sets.
- Averaged result (for better precision) confirms the abnormal suppression pattern.

## $\psi'$ suppression

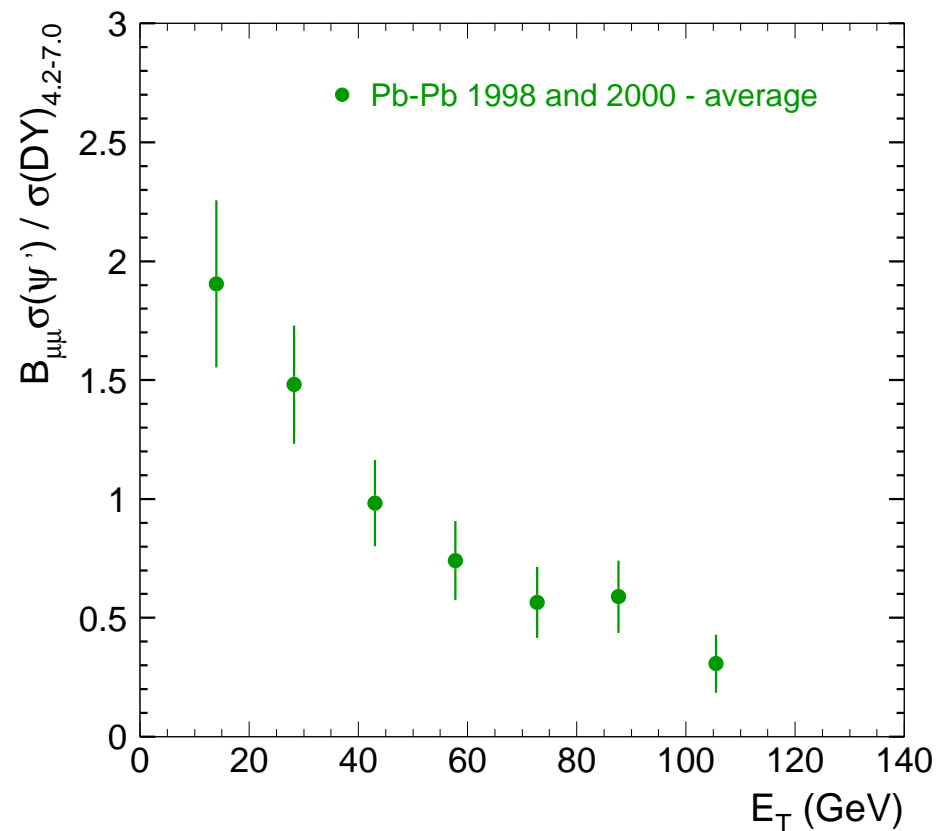
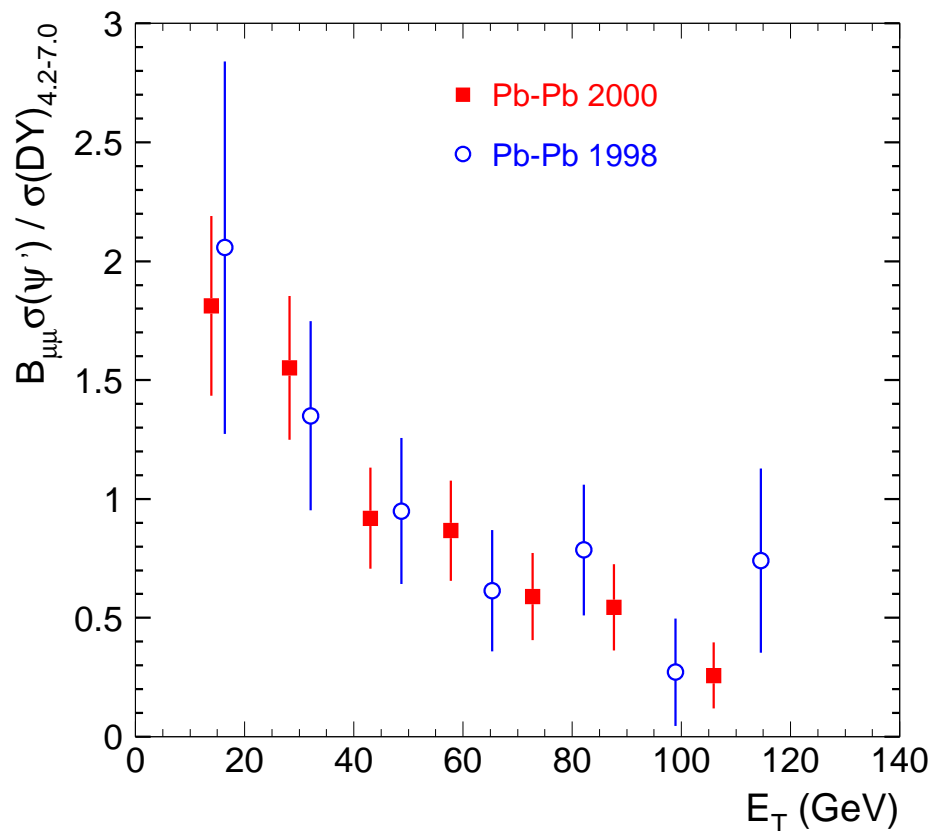
$\psi'$  is a less bound charmonium state ( $E_{binding}(\psi') = 50 \text{ MeV}$ ) than the  $J/\psi$  ( $E_{binding}(J/\psi) = 640 \text{ MeV}$ ).

The analysis method used is similar. But:

- ☹ large suppression
- ☹ small dimuon cross-section
- ☹ superposition of  $\neq$  physics contributions
- ☹ PDFs chosen to get Drell-Yan shape induce up to 7% difference in  $\psi'$  normalization
- ☺ Uncertainty from open charm decays is less than 1.5%

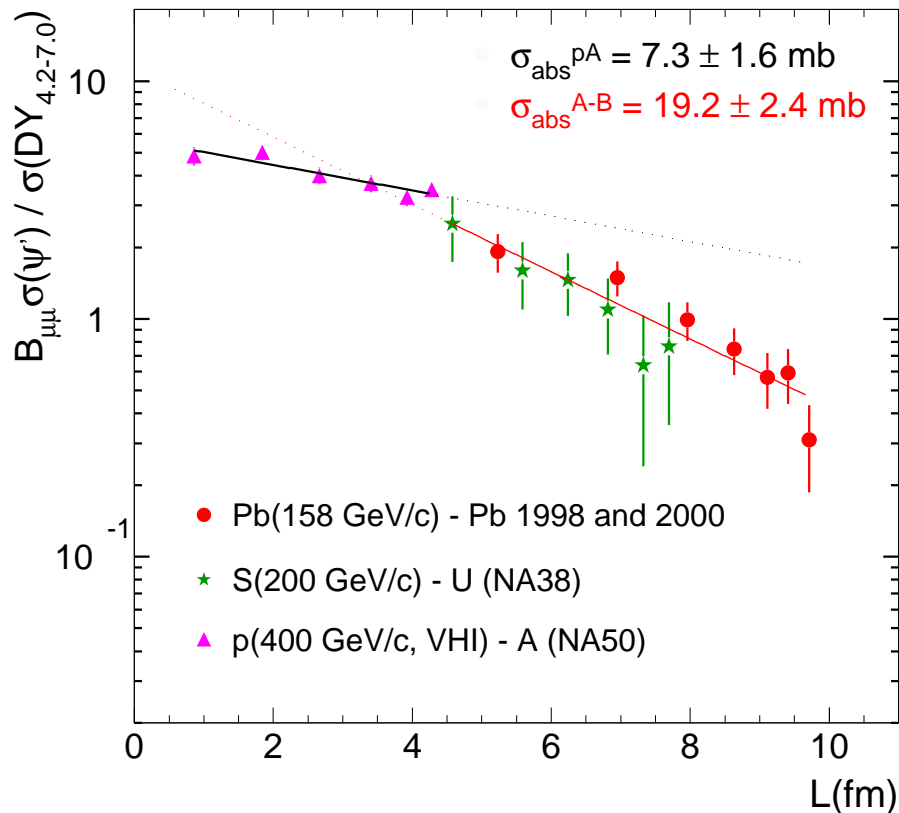


## $\psi'/DY$ vs $E_T$



- Good compatibility between data sets – averaged result for better accuracy.
- $\psi'$  is **increasingly suppressed** with respect to DY as a function of centrality.

## $\psi'/DY$ vs L



Using an exponential parameterization for  $\psi'$ :

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

- From the fit to **p-A** data

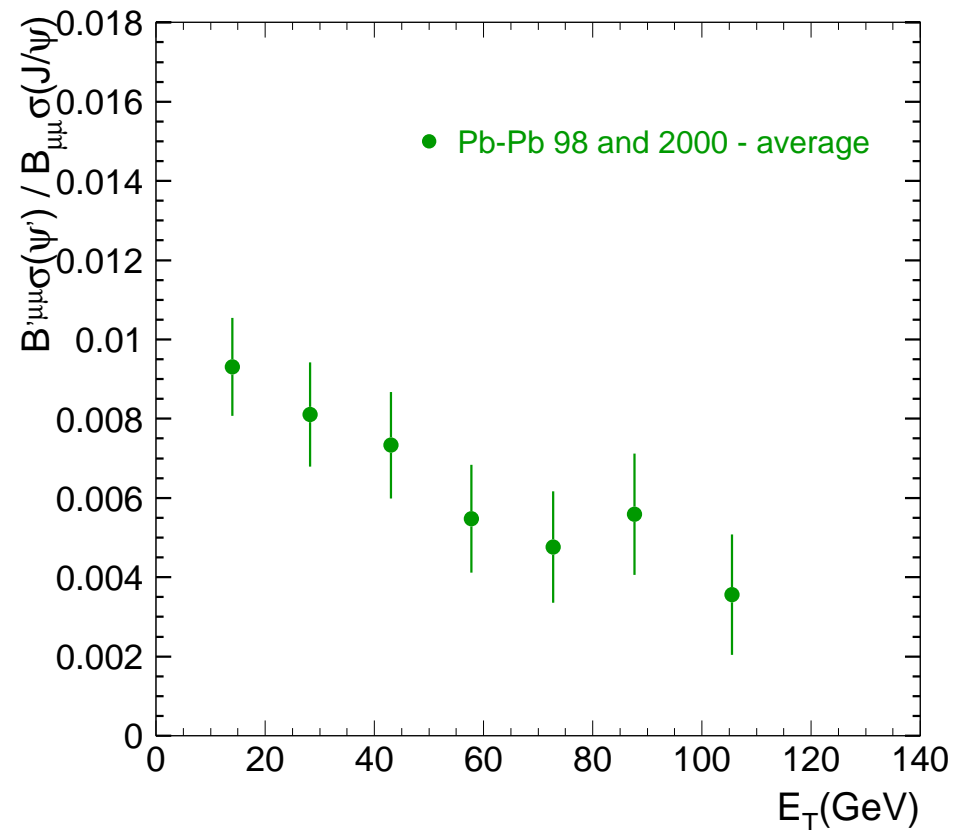
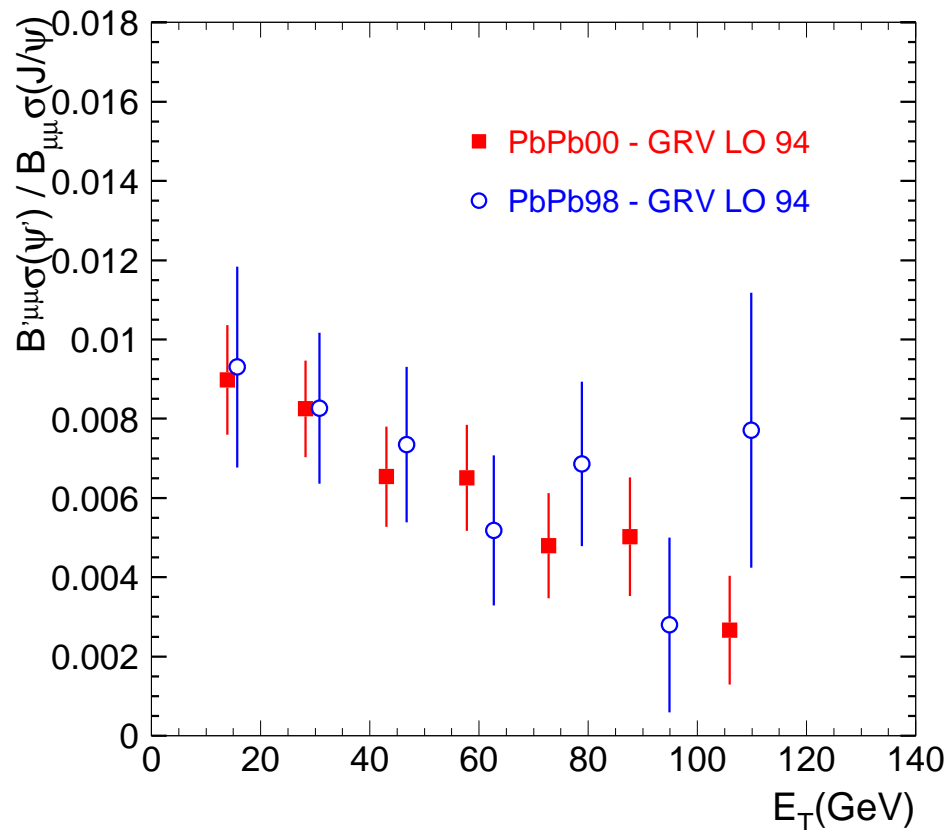
$$\sigma_{abs}^{p-A} = 7.3 \pm 1.6 \text{ mb}$$

- From the fit to **S-U** and **Pb-Pb** data

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

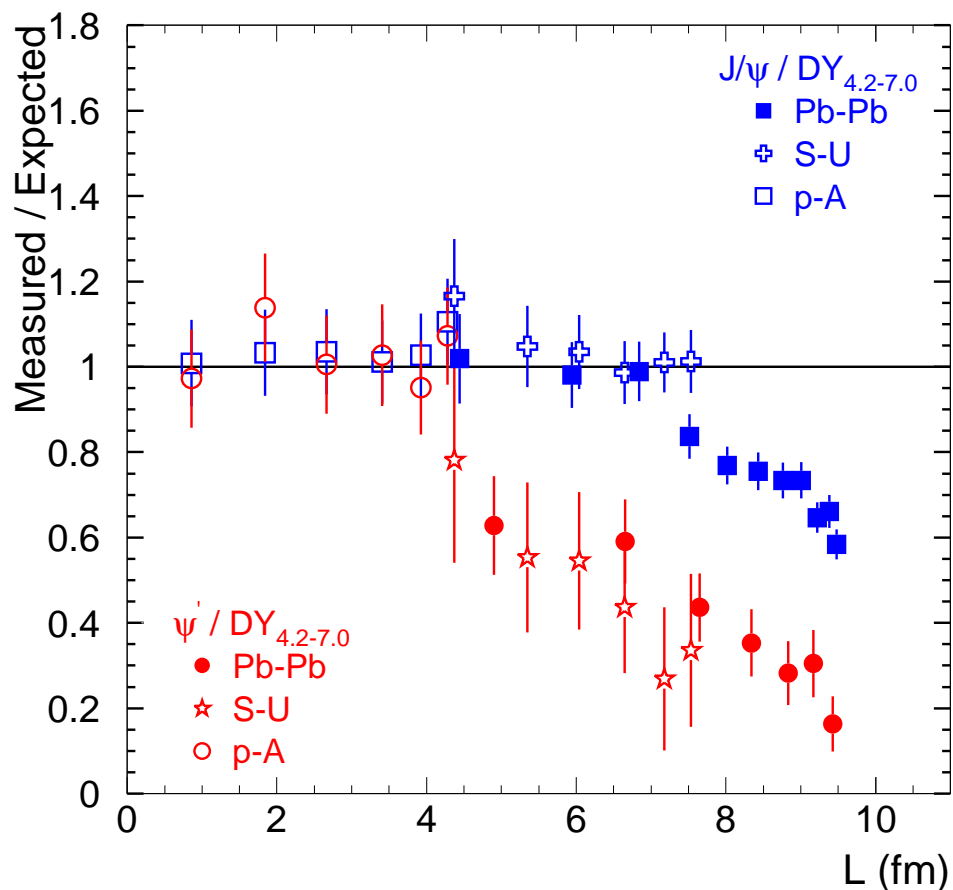
- $\psi'$  has a different behaviour in **p-A** and **A-B** collisions.
- In **A-B** collisions,  $\psi'$  suppression increases with centrality.

## $\psi'/J/\psi$ vs $E_T$



- Good compatibility between data sets – averaged result for better accuracy.
- $\psi'$  is more suppressed than the  $J/\psi$ . The ratio of the 2 charmonia states decreases by a factor 2.5 from peripheral to central collisions.

## $J/\psi$ and $\psi'$ : Measured/Expected



- Expected: normal nuclear absorption, from a full Glauber calculation with

$$\sigma_{abs}^{J/\psi} = 4.18 \pm 0.35 \text{ mb}$$

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

- In A-B collisions the  $\psi'$  departs from the normal absorption curve “earlier” in centrality than the  $J/\psi$ .

## Conclusions

- From the measurement of  $J/\psi$  production in **p-A** collisions at 450, 400 and 200 GeV/c we obtain a reliable prediction of the **normal nuclear absorption**  $\sigma_{abs}^{J/\psi}$  at 158 GeV/c.
- The ratio  $\sigma(J/\psi)/\sigma(DY)$  obtained in **S-U** and **peripheral Pb-Pb** collisions follows the normal nuclear absorption curve.
- $J/\psi$  production for **Pb-Pb central collisions** at 158 GeV/c per nucleon shows an **anomalous suppression** as compared to the behaviour in p-A systems, which increases with the centrality of the collisions.
- $\psi'$  is **strongly suppressed** relatively to **Drell-Yan**, as a function of centrality. A **steady decrease** of the ratio  $\sigma(\psi')/\sigma(J/\psi)$  with centrality is also observed.
- The  $\psi'$  suppression pattern is the same in **S-U** and **Pb-Pb** collisions, and is not compatible with the one observed in **p-A** collisions.
- Comparing the ratio of **measured** and **expected suppressions** of the 2 charmonium states, one observes that the  $\psi'$  anomalous suppression sets in **earlier** than the  $J/\psi$  one.