Final results on charmonia suppression in Pb-Pb collisions

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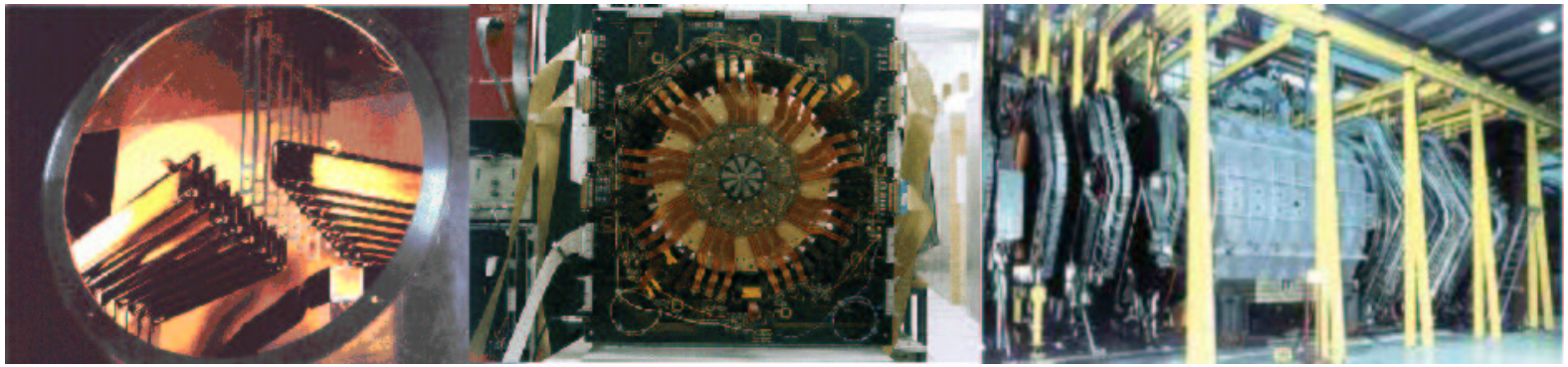
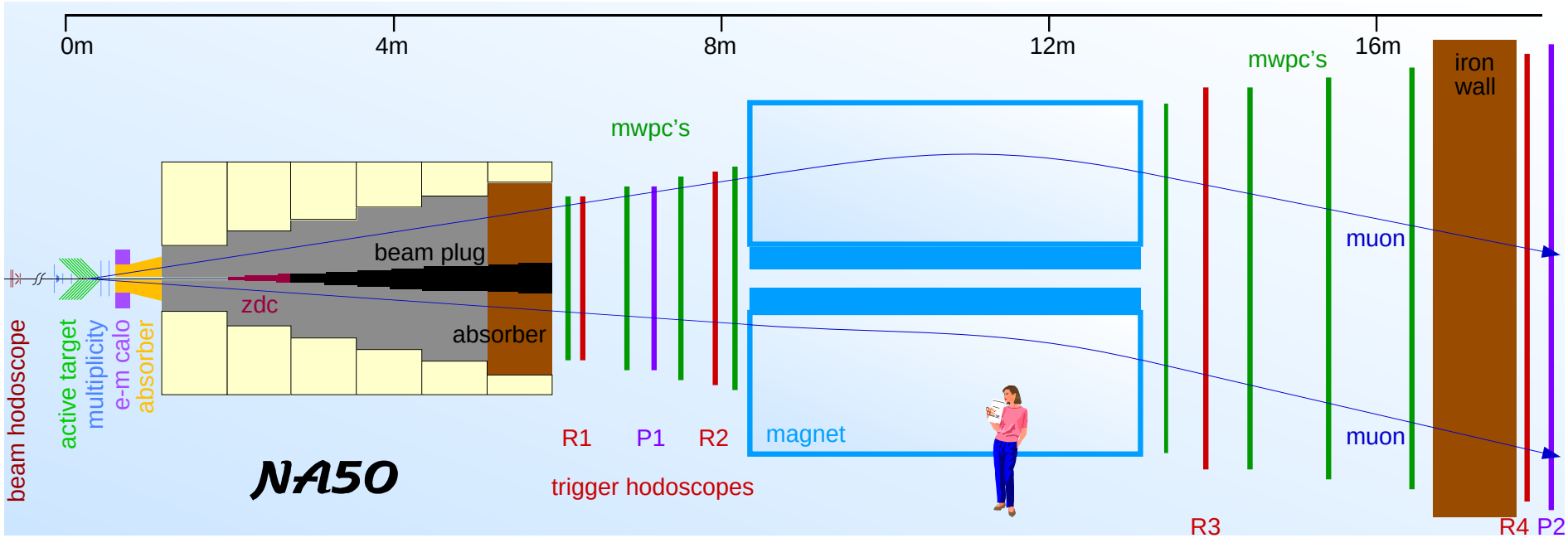
on behalf of the NA50 Collaboration

Outline:

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



The experimental setup



Kinematical domain:

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

$|\cos\theta| < 0.5$

Acceptances (Pb-Pb at 158 GeV):

J/ψ: $12.42 \pm 0.02 \pm 0.17$ %

$\mathrm{DY}_{2.9-4.5}$: $13.79 \pm 0.05 \pm 0.16$ %

ψ': $14.77 \pm 0.03 \pm 0.26$ %

Trigger on dimuons.

Setup optimized for J/ψ detection.

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

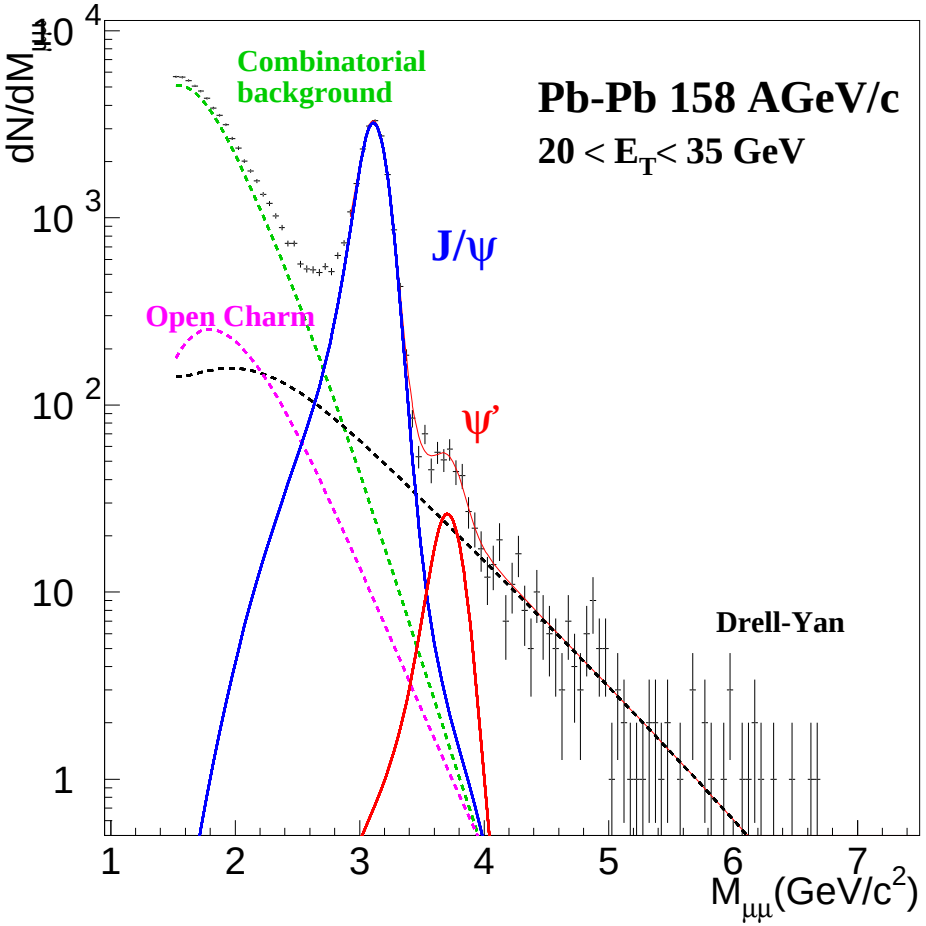
year	sub-targets	target thickness	beam intensity (ions/burst)	J/ψ	ψ'
1995	7 (in air)	17 % λ_I	3×10^7	50000	—
1996	7 (in air)	30 % λ_I	5×10^7	190000	—
1998	**1 (in air)**	**7 % λ_I**	**5.5×10^7**	**49000**	**380**
2000	**1 (in vacuum)**	**10 % λ_I**	**7×10^7**	**129000**	**905**

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

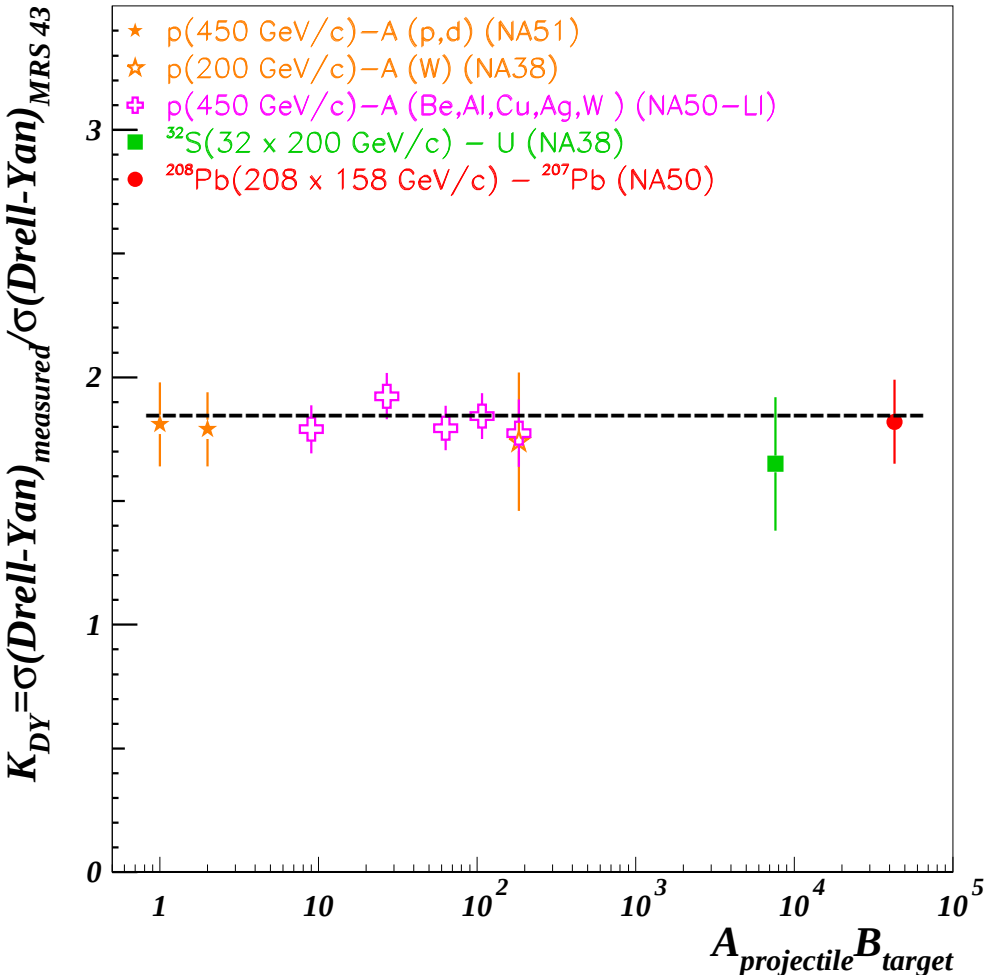


- Fit the dimuon mass spectra, for each centrality region.
- Combinatorial background (mostly from π and K decays) is taken from the measured like-sign dimuon distributions.
- Functional forms of J/ψ, ψ', $D\bar{D}$ and DY from Monte-Carlo generation + NA50 spectrometer simulation.
- DY shape generated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

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

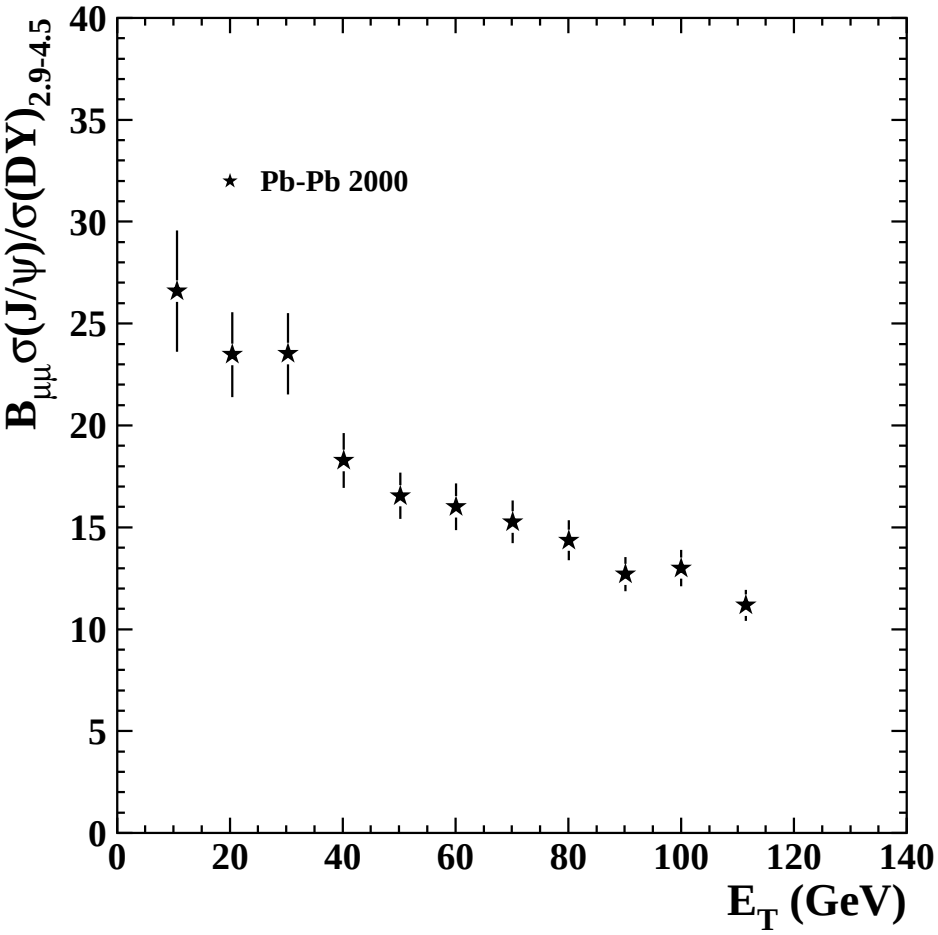
Drell-Yan as reference process

DY is used as normalization to study J/ψ and ψ' 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/ψ/DY$_{2.9-4.5}$ vs centrality

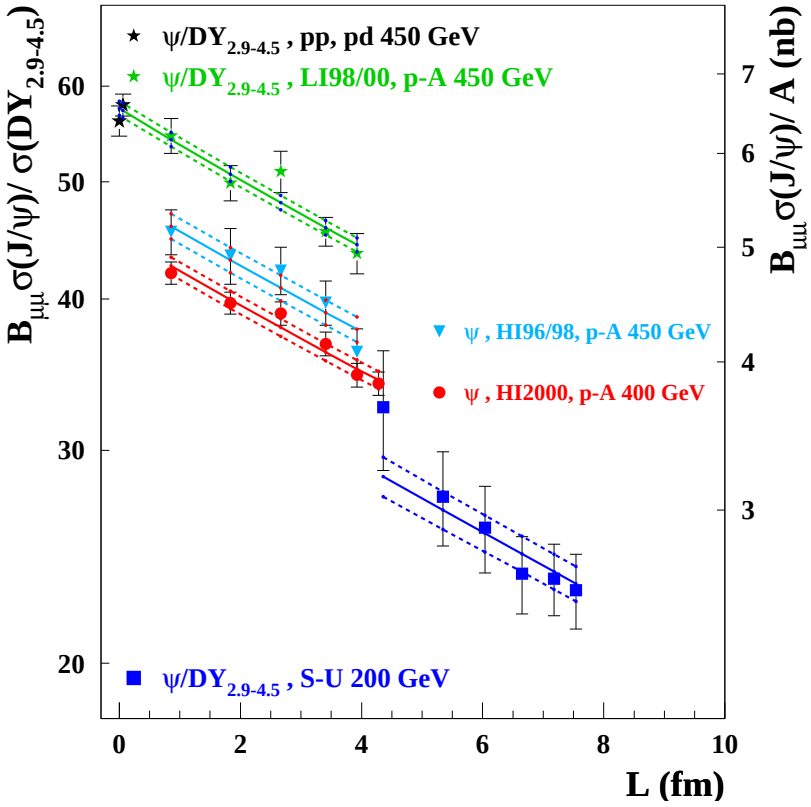


- The study is done using 3 independent centrality estimators
  - **ECal** integrates the flux of neutral transverse energy released in the range $1.1 \leq \eta < 2.3$ – $\mathbf{E}_T$
  - **MD** detects charged particles in the range $1.9 \leq \eta < 4.2$ – $\mathbf{N}_{ch}$
  - **ZDC** detects the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

J/ψ normal nuclear absorption (I)

Already in **p-A** collisions there is absorption of the J/ψ 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/ψ/DY.
- Check that the data sets at these different energies have compatible σ_{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 σ_{abs} to compute the normal absorption curve, and rescale it from 200 to 158 GeV, to compare with Pb-Pb data.

J/ψ normal nuclear absorption (II)

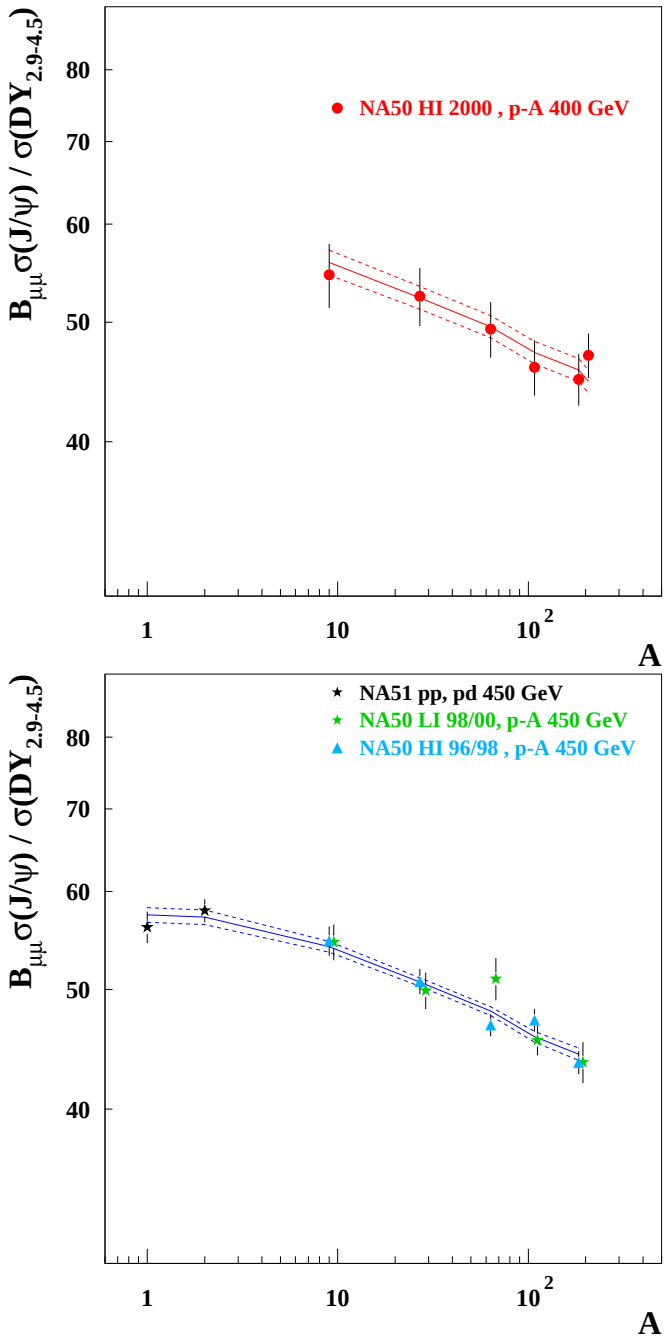
Are there still any doubts about the robustness of the normal absorption curve?

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/ψ cross-section as a function of the target mass number A.
- From the Glauber fit to all set of data points, one gets:

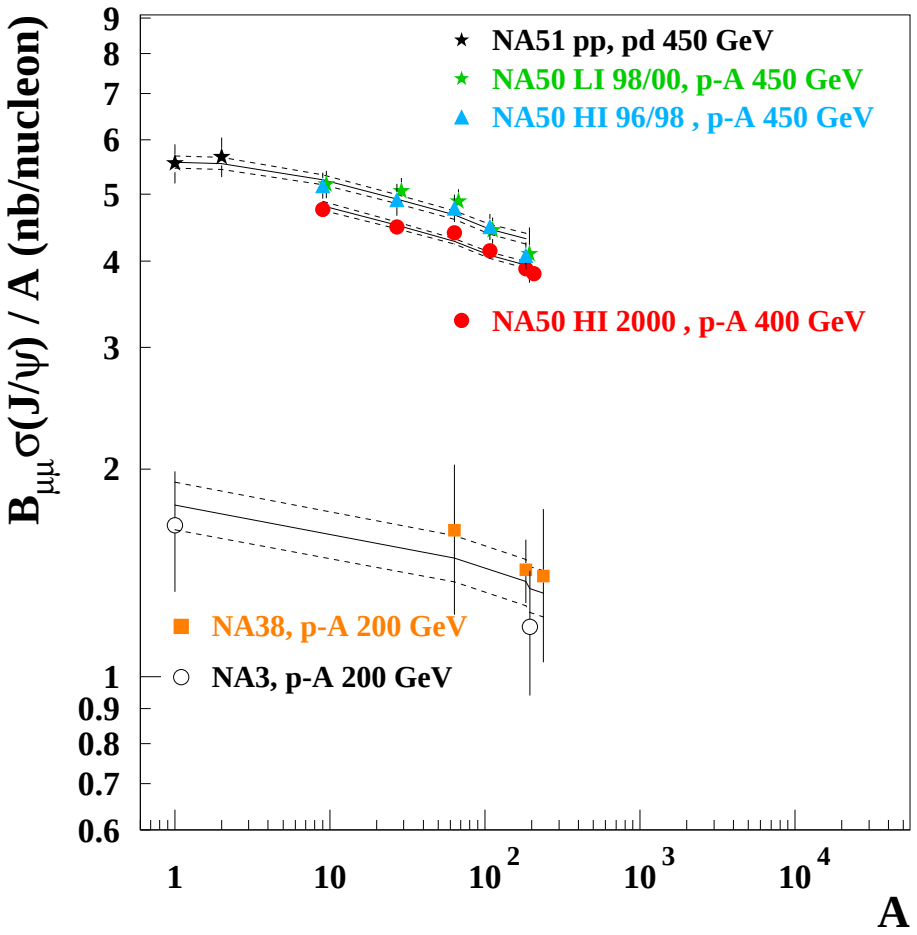
$$\sigma_{abs} = 4.18 \pm 0.35 \ mb$$



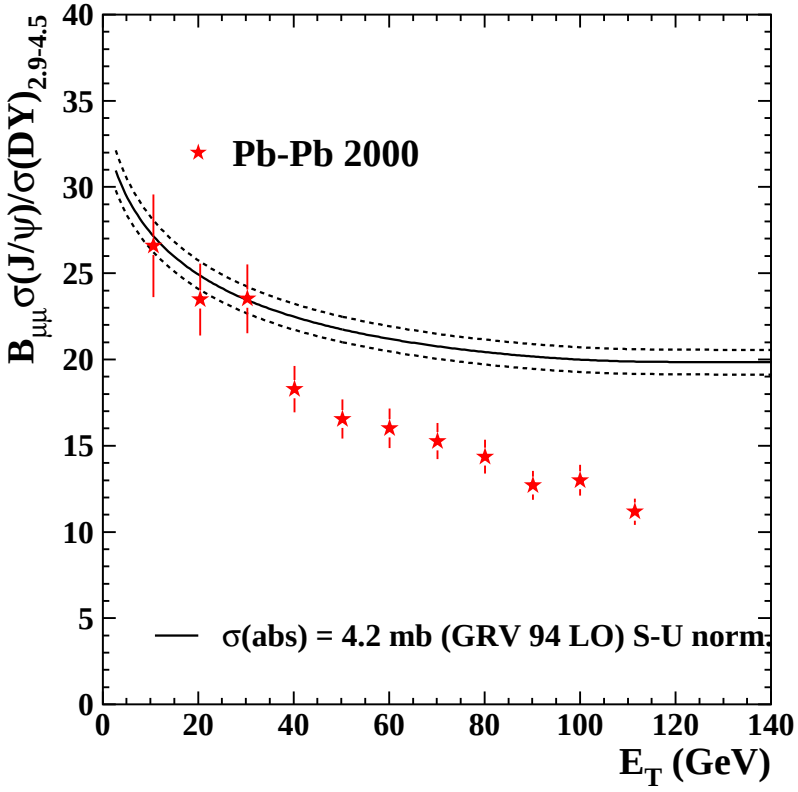
J/ψ normal nuclear absorption (III)

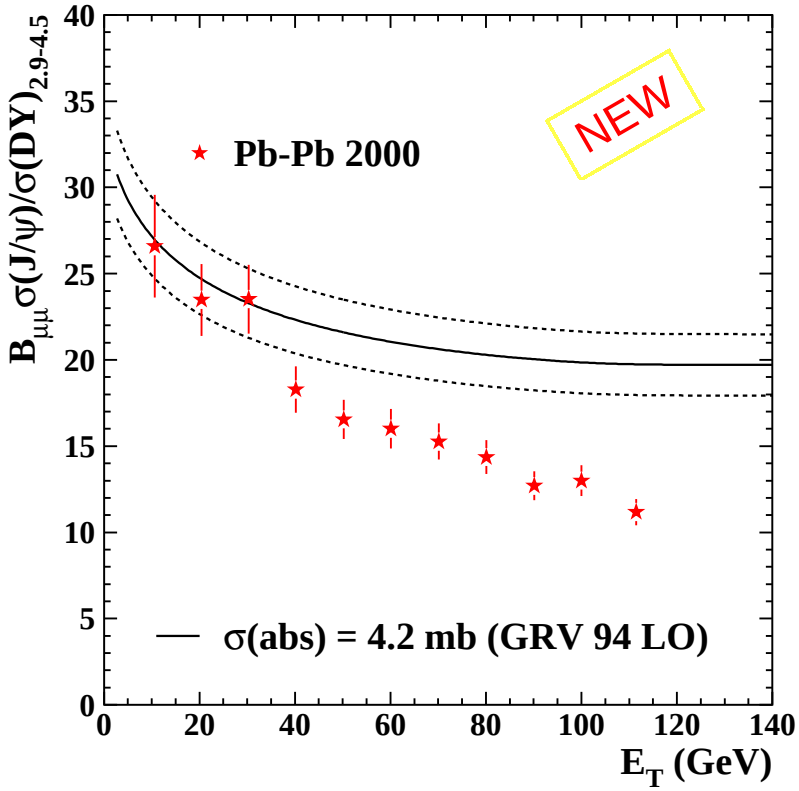
NEW

- Besides the σ_{abs} value, one also needs the normalization of the absorption curve at 158 GeV/c.
- The rescaling factor to bring the J/ψ 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/ψ from 200 GeV/c to 158 GeV/c is done using the Schuler parameterization.
- The rescaling factor for Drell-Yan is obtained theoretically.



J/ψ/DY: Pb-Pb results and the normal absorption curve

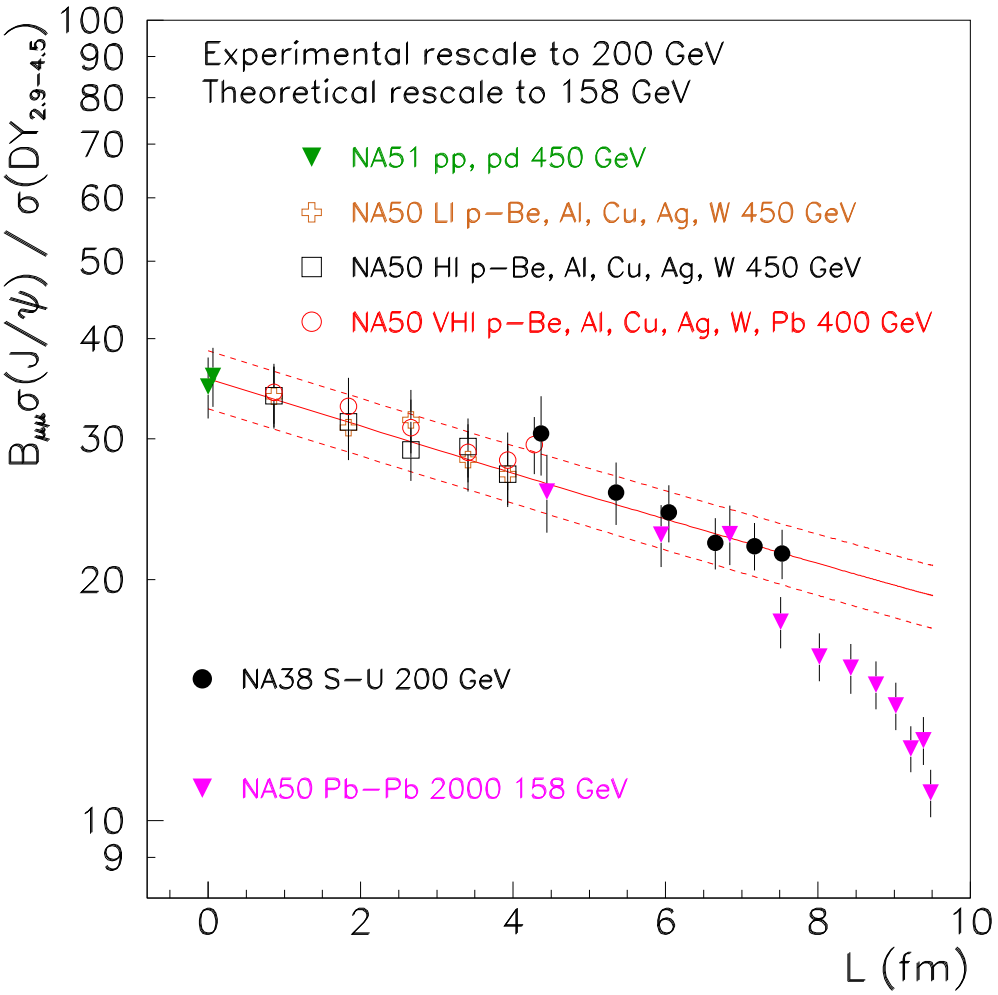




The normal nuclear absorption curve does not change from one method to the other, only the systematic error bands differ!

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

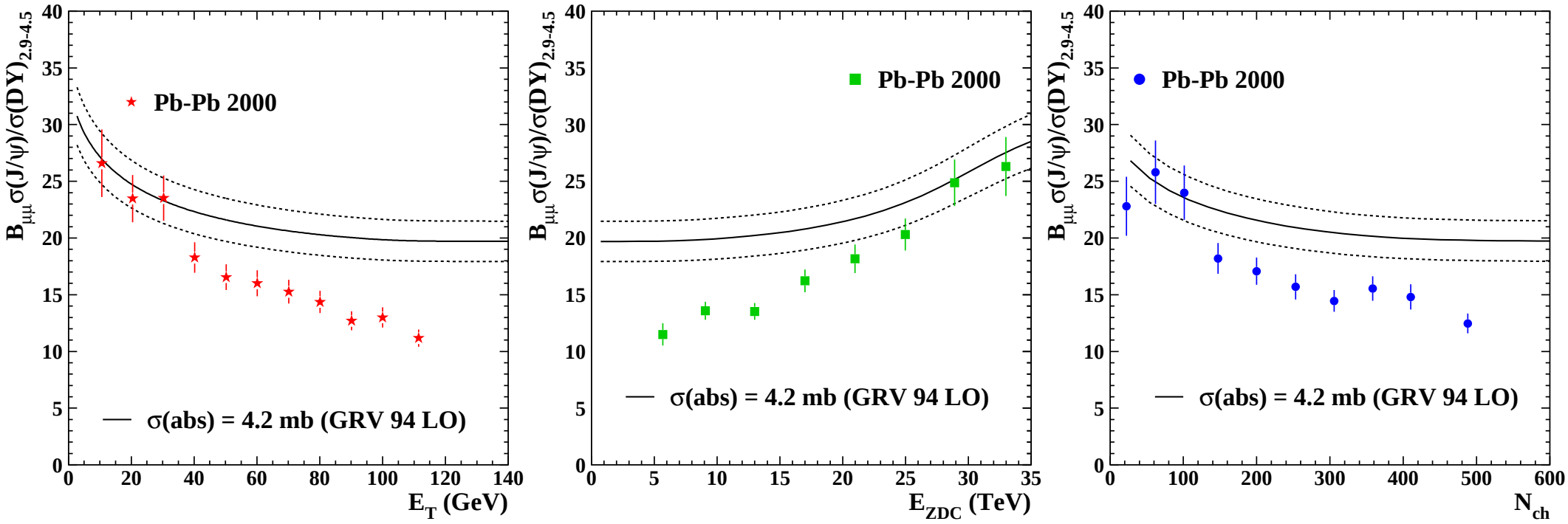
J/ψ/DY: from p-p to Pb-Pb



- 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/ψ/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.

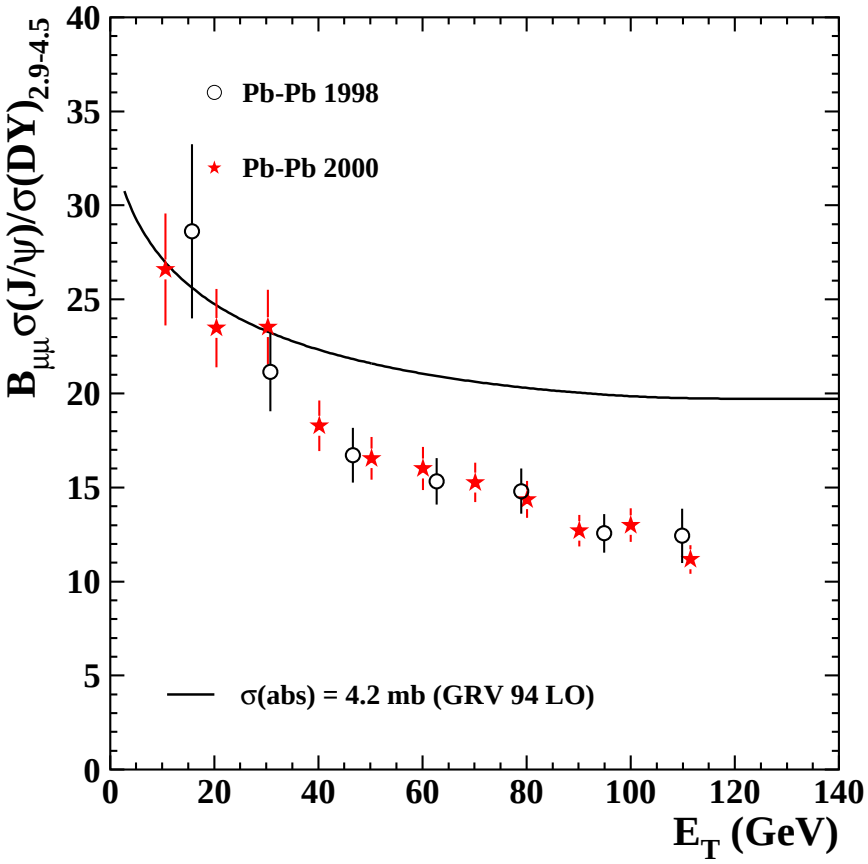
J/ψ/DY vs E_T, E_{ZDC} or N_{ch}

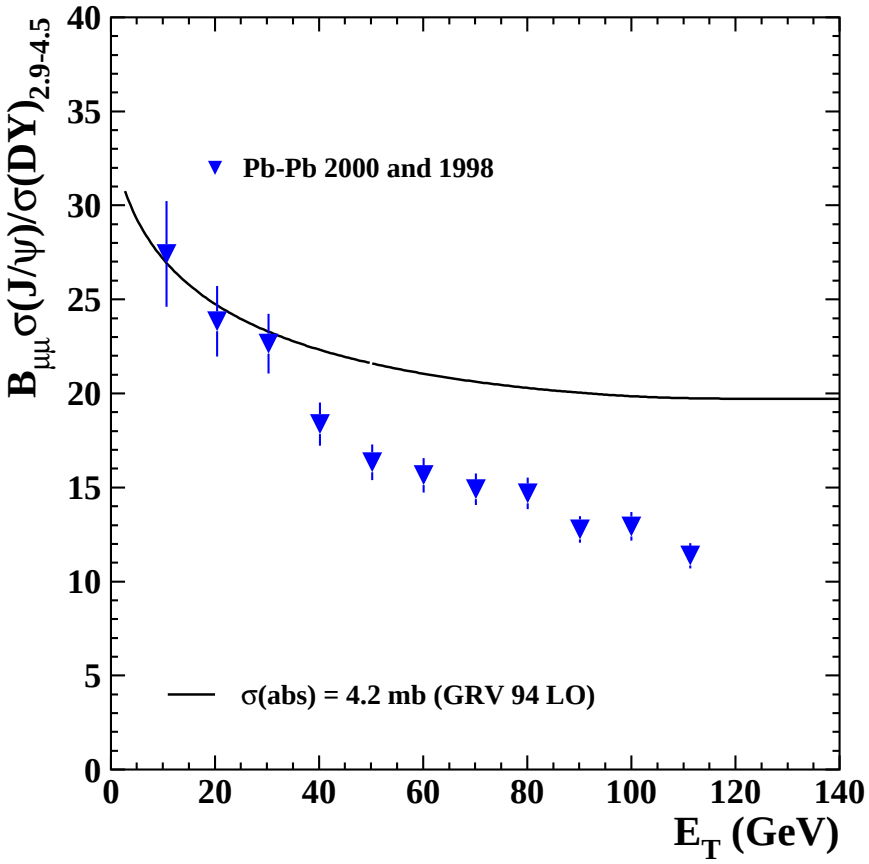
3 independent analyses of **J/ψ/DY**$_{2.9-4.5}$ are compared with the extrapolated normal nuclear absorption curve.



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/ψ/DY final averaged results





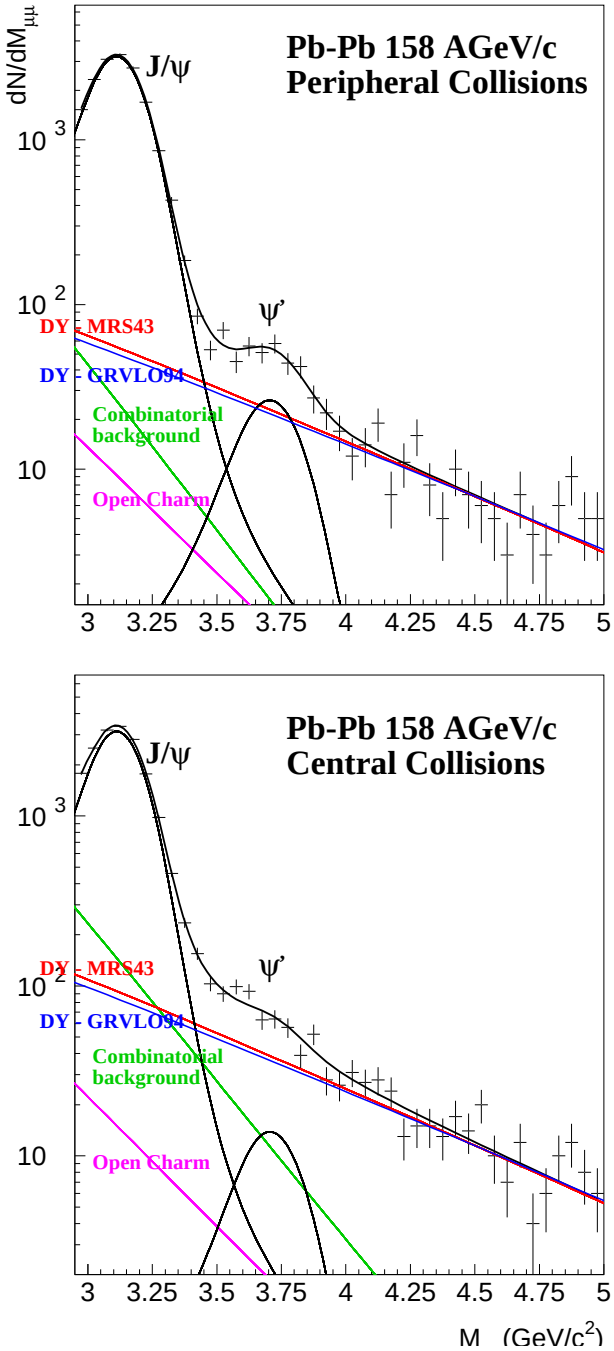
- Very good compatibility between the 2 data sets.
- Averaged result (for better precision) confirms the abnormal suppression pattern.

ψ' suppression

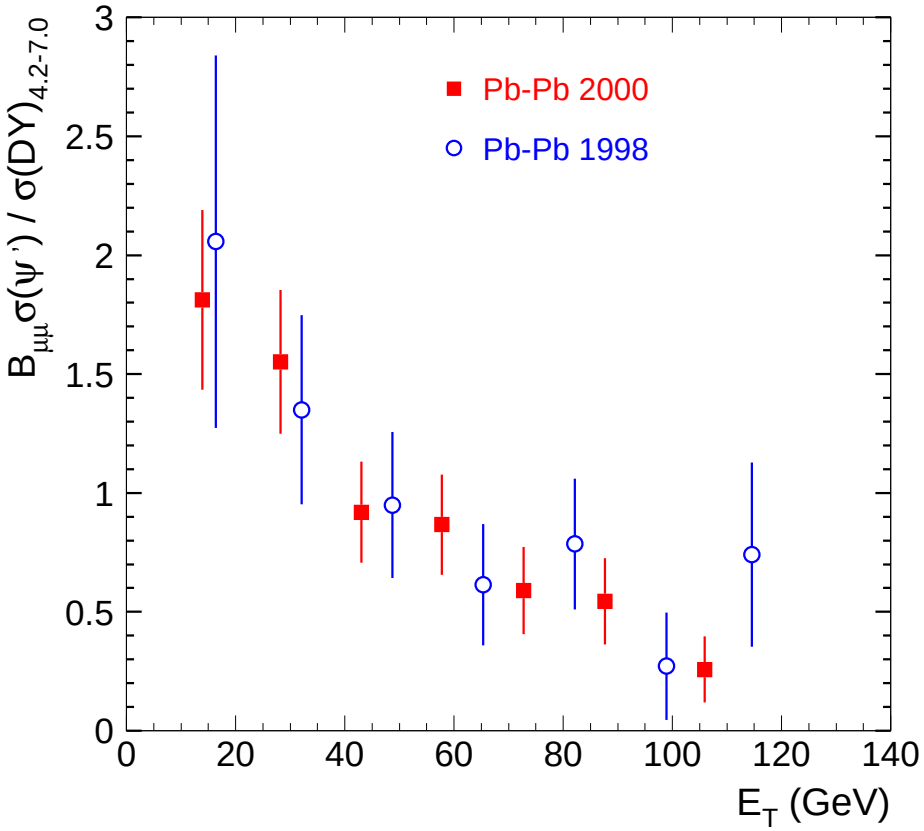
ψ' is a less bound charmonium state ($E_{binding}(\psi')$ = 50 MeV) than the **J/ψ** ($E_{binding}(J/\psi)$ = 640 MeV).

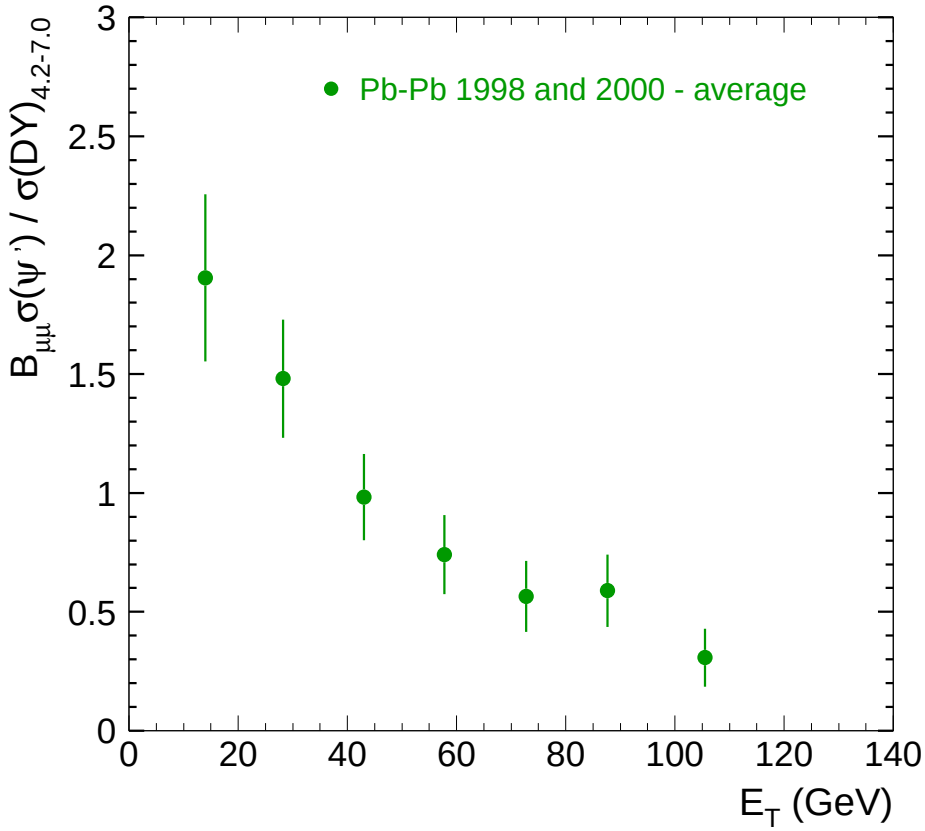
The analysis method used is similar. But:

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



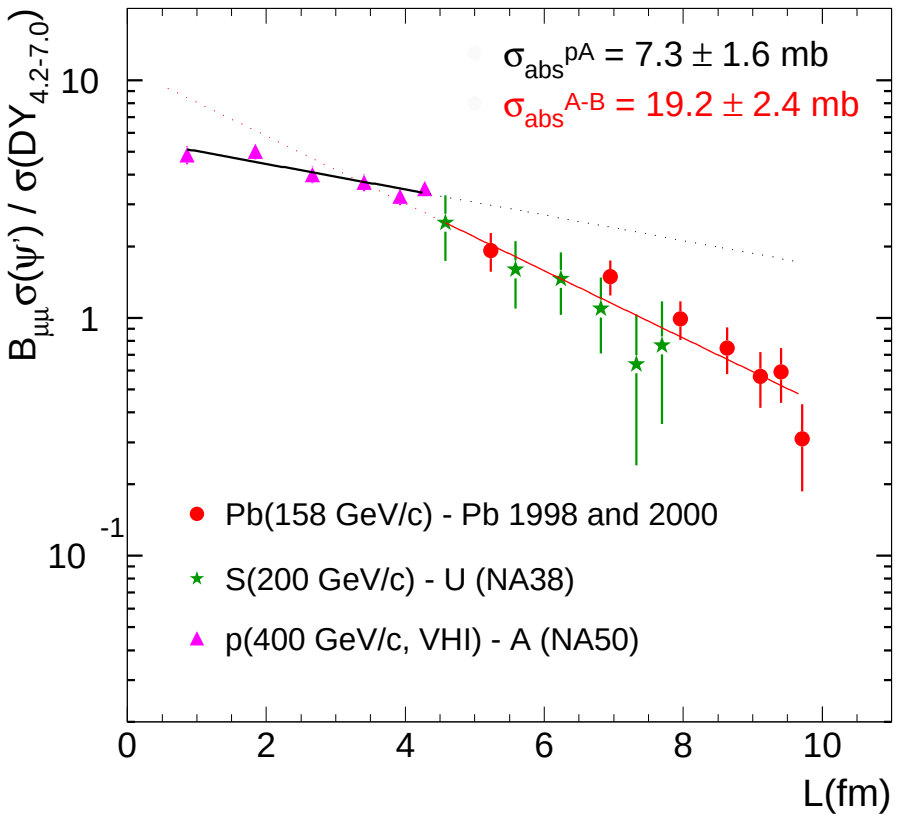
ψ'/DY vs E_T





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

ψ'/DY vs L



Using an exponential parameterization for ψ':

$$\sigma_0 \, e^{-<\rho L>\sigma_{abs}}$$

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

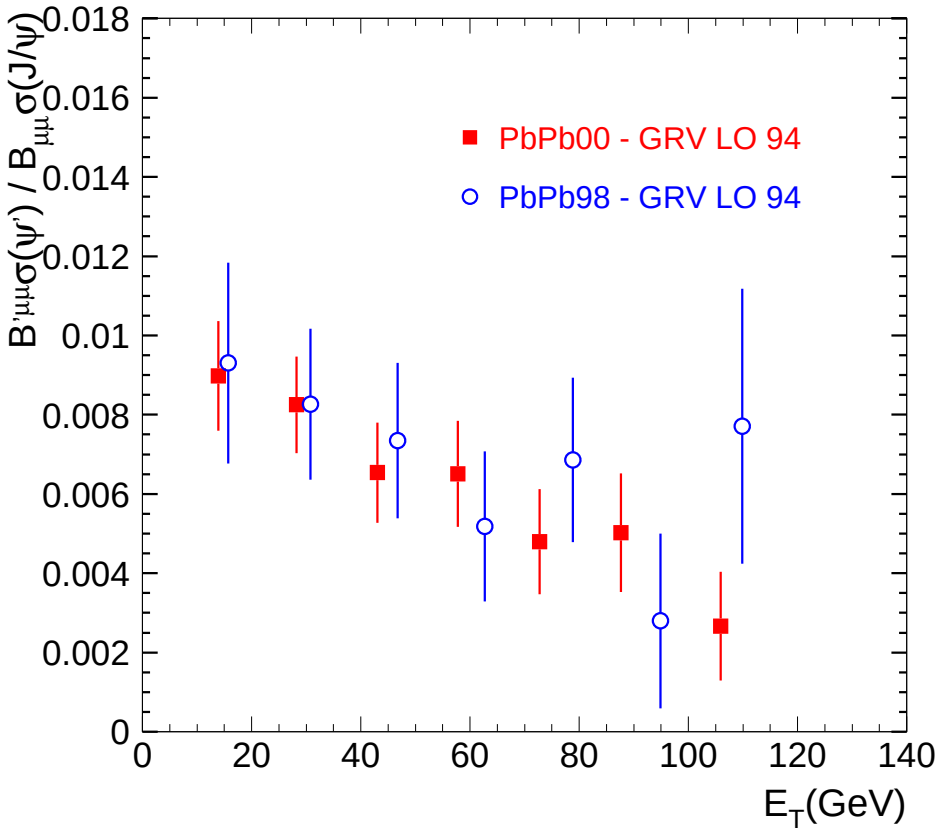
$$\sigma_{abs}^{p-A} = 7.3 \pm 1.6 \ mb$$

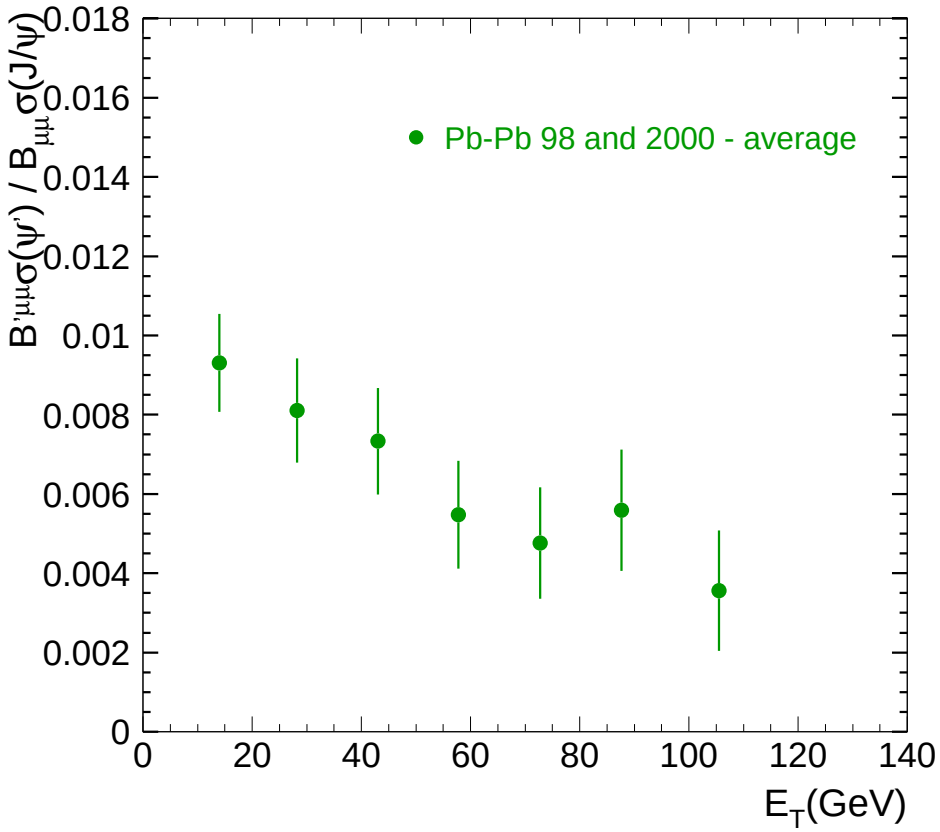
- From the fit to **S-U** and **Pb-Pb** data

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

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

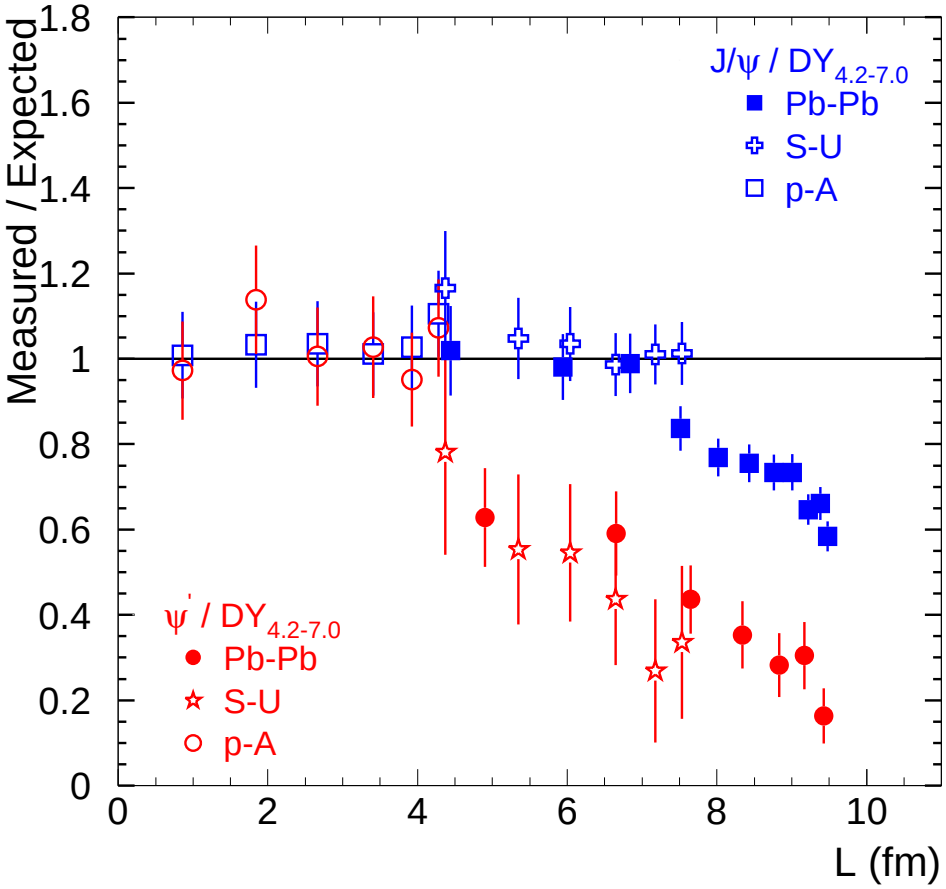
ψ'/J/ψ vs E_T





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

J/ψ and ψ': Measured/Expected



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

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

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

- In A-B collisions the ψ' departs from the normal absorption curve "earlier" in centrality than the J/ψ.

Conclusions

- From the measurement of **J/ψ** 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/ψ** 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.
- **ψ'** 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 **ψ'** 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 **ψ'** anomalous suppression sets in **earlier** than the **J/ψ** one.