# New results on J/$\psi$ and $\psi\prime$ nuclear absorption in p-A and S-U collisions at the CERN/SPS


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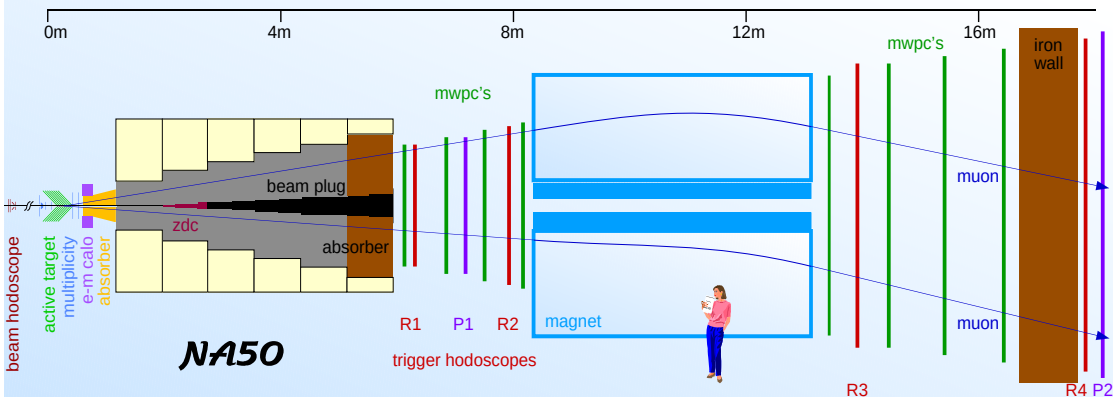
**for the**

**NA50 Collaboration**

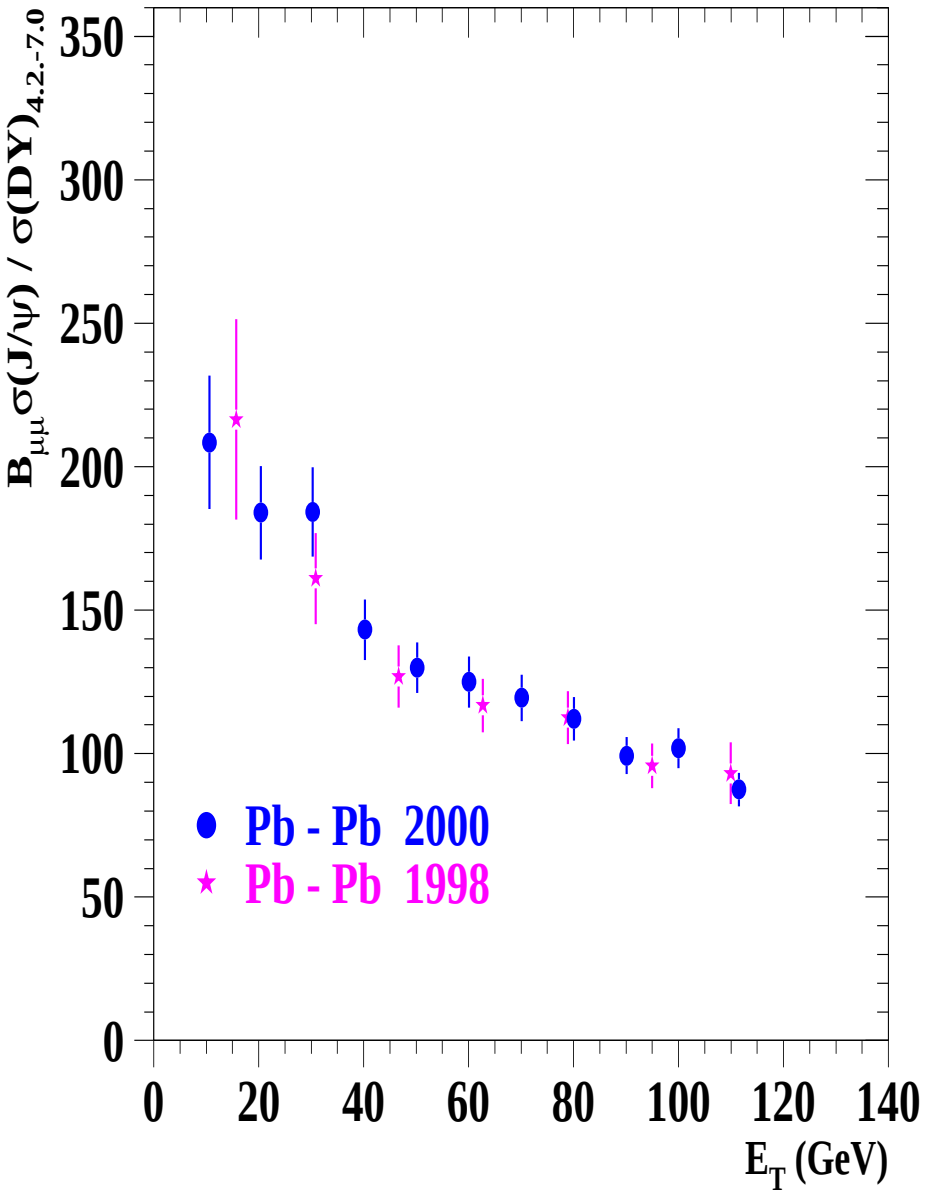




# Outline

- **Motivation: Why collect proton data?**
- **State of the art (QM2002)**
- **The experimental apparatus**
- **Analysis method**
- **J/$\psi$, $\psi$' and DY cross-sections at 400 GeV**
- **Comparison with previous p-A and light ion results**
- **Conclusions**

# Motivation: Why collect proton data?




- **NA50 studies J/$\psi$ production in Pb-Pb collisions**

  **In order to distinguish between**

  **J/$\psi$ absorption in nuclear matter &**

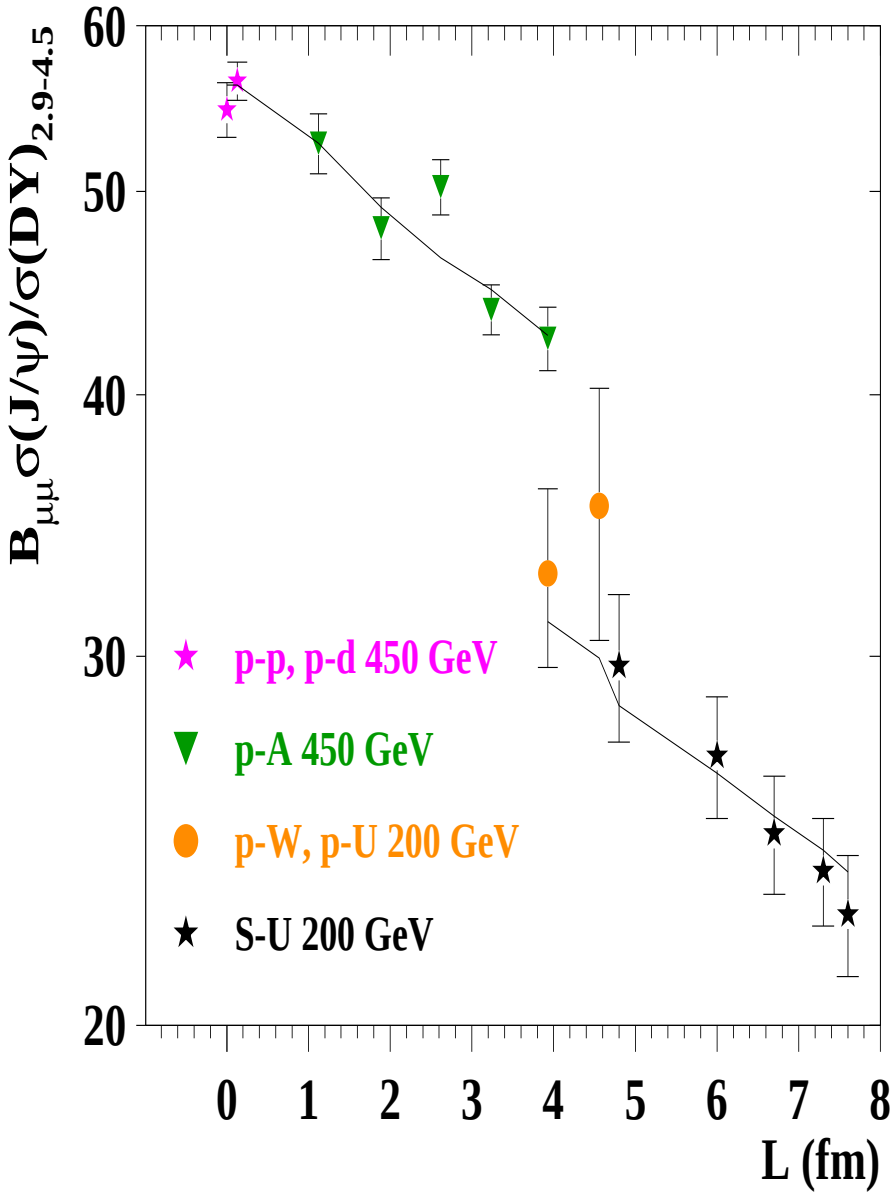
  **any J/$\psi$ abnormal suppression**

  **it is necessary to do a systematic study with several systems where it is assumed that only normal absorption plays a role.**

- **A good baseline is needed**

  **$\hookrightarrow$ Such a baseline can be provided by proton-nucleus data.**

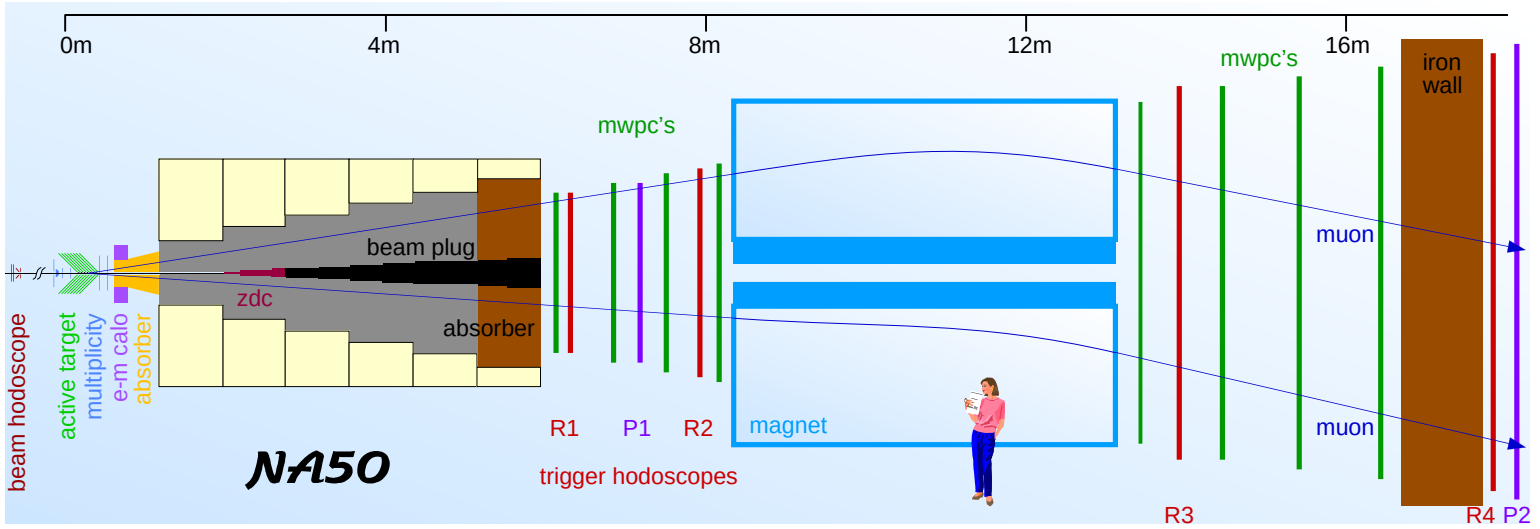
# The state of the art (QM2002)




- **Data are plotted as a function of the average distance traveled by the $c\bar{c}$ pair through nuclear matter.**
- **A Simultaneous Glauber fit is performed using $\frac{\psi}{DY_{2.9-4.5}}$ results from**
  - ↪ **p-p, p-d at 450 GeV**
  - ↪ **p-A 98/00 at 450 GeV**
  - ↪ **p-U, p-W at 200 GeV**
  - ↪ **S-U at 200 GeV**
- **The line joins together the results of the best Glauber fit which leads to**

$$\hookrightarrow \sigma^{\psi}_{\text{abs}} = 4.4 \pm 0.5 \text{ mb}$$
$$(\chi^2/dof = 1.0)$$

# The experimental setup




$J/\psi$ **is detected via its decay into muon pairs** $J/\psi \to \mu^+\mu^-$

- **Dimuon detection in:**

$$2.92 < y_{\rm Lab} < 3.92 \quad |\cos\theta_{\rm CS}| < 0.5$$

- **Proton beams at 450 or 400 GeV energy**

  $\hookrightarrow$ **3 independent detectors to measure the number of incident protons**

- **Several fixed targets: Be, Al, Cu, Ag, W, Pb**

- **Typical acceptances:**

$\hookrightarrow$ $\mathcal{A}^{J/\psi}$ **= 13.8** $\%$**,** $\mathcal{A}^{\rm DY}_{2.9-4.5}$ **= 14.5**$\%$**,** $\mathcal{A}^{\psi'}$ **= 16.3**$\%$

# NA50 p-A runs

| Data sample | Energy (GeV) | target thicknesses | targets | beam intensity (protons/s) | $N^{J/\psi}$ ($\times 10^3$) |
|---|---|---|---|---|---|
| 1996-1998 | 450 | 26-39% $\lambda_I$ | Be,Al,Cu,Ag,W | (4 - 13) $\times 10^8$ | 350 : 800 |
| 1998-2000 | 450 | 26-39% $\lambda_I$ | Be,Al,Cu,Ag,W | (0.8 - 2.5) $\times 10^8$ | 80 : 180 |
| 2000 | 400 | 26-39% $\lambda_I$ | Be,Al,Cu,Ag,W,Pb | (9 - 13) $\times 10^8$ | 38 : 68 |

- Absolute cross-sections from data collected in different years are affected by different systematic effects giving additional problems to the study of the **charmonia absorption using several target nuclei**

- To **minimize** such systematics, the last NA50 p-A run was taken
  - $\hookrightarrow$ On a **very short period of time** at high intensity
  - $\hookrightarrow$ **Using 6 targets** on a run by run **rotating regime**

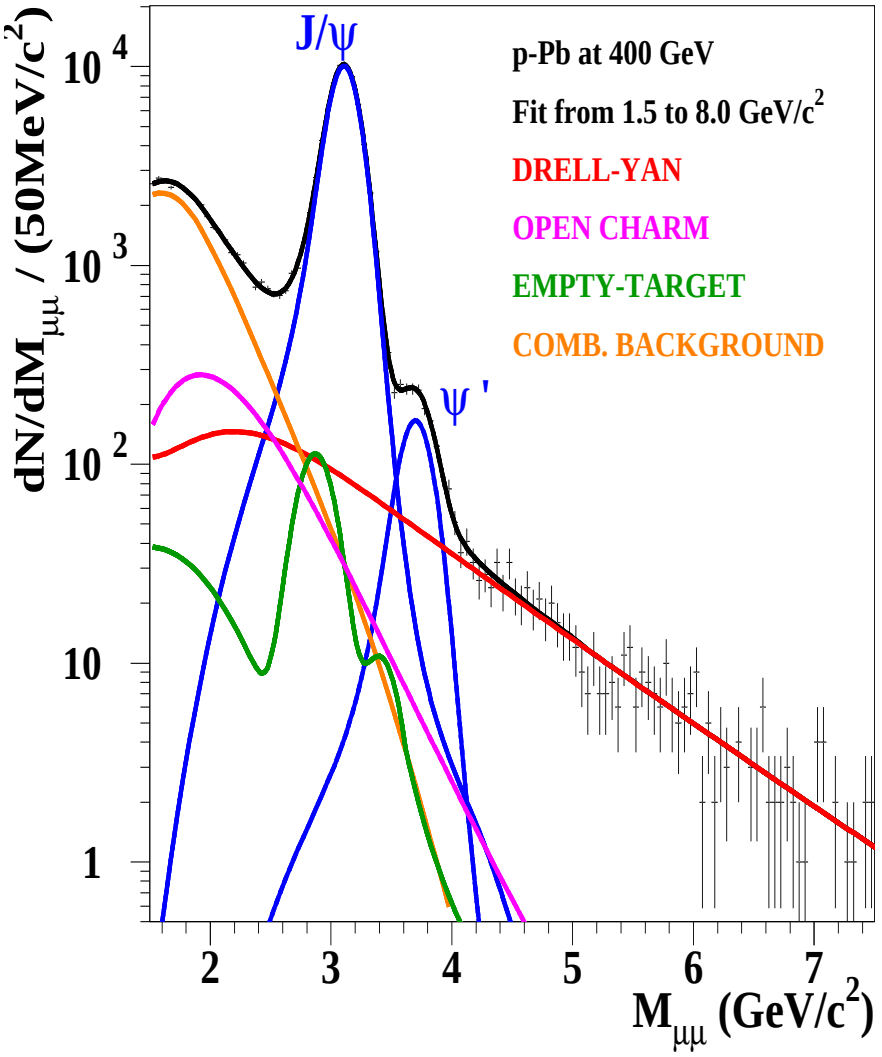
$\Downarrow$

The goal of the **last 2000 NA50 p-A run** was to precisely measure the

**J/$\psi$ absorption cross-section**

# Analysis method

$$\frac{dN}{dM_{\mu\mu}} = N_{J/\psi}\frac{dN_{J/\psi}}{dM} + N_{\psi\prime}\frac{dN_{\psi\prime}}{dM} + N_{DY}\frac{dN_{DY}}{dM} + N_{D\bar{D}}\frac{dN_{D\bar{D}}}{dM} + \frac{dN_{Bkg}}{dM} + \frac{dN_{Empty}}{dM}$$



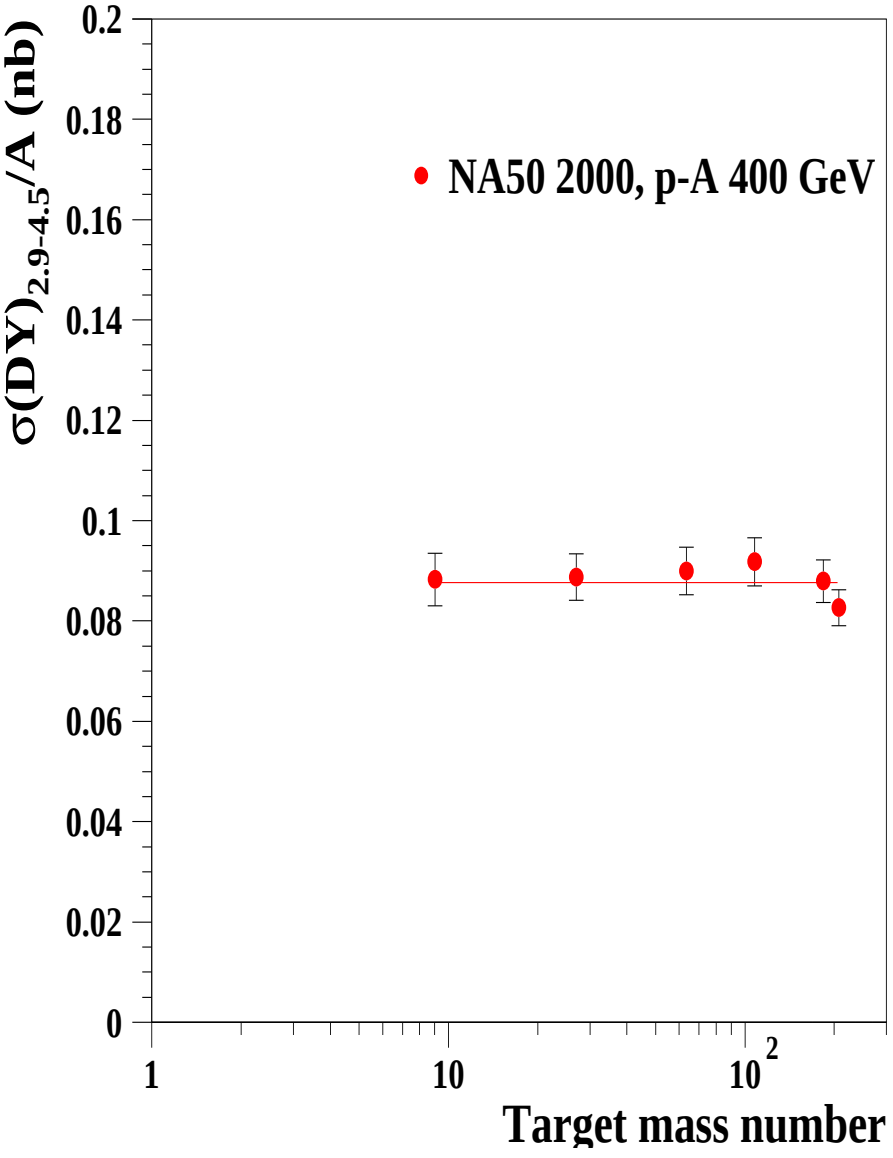

- **Opposite sign mass spectrum ingredients**
  - ↪ **JI$\psi$** $\rightarrow$ $\mu^+\mu^-$
  - ↪ $\psi\prime$ $\rightarrow$ $\mu^+\mu^-$
  - ↪ **Drell-Yan** ($q\bar{q} \rightarrow \mu^+\mu^-$)
  - ↪ **Simultaneous semi-leptonic decays of open charm mesons**
  - ↪ **Combinatorial background**

$$N^{+-}_{\mathrm{Bkg}} = 2R\sqrt{N^{++}N^{--}}$$

- **MC is treated as real data**
  - ↪ **Acceptances and line shapes are determined via Monte Carlo and spectrometer simulation**

# DY cross-sections at 400 GeV

$$\sigma^{\mathrm{DY}}_{\mathrm{p-A}} = \sigma^{\mathrm{DY}}_{0} \times A^{\alpha}$$




- $\alpha^{\mathrm{DY}}$ **is expected to be 1 since DY production is proportional to the number of nucleon - nucleon collisions**
- **The fit to our data leads to**

$$\alpha^{\mathrm{DY}} = 0.986 \pm 0.018 \pm 0.008$$
$$(\chi^2/dof = 0.6)$$

**in nice agreement with the expectation.**

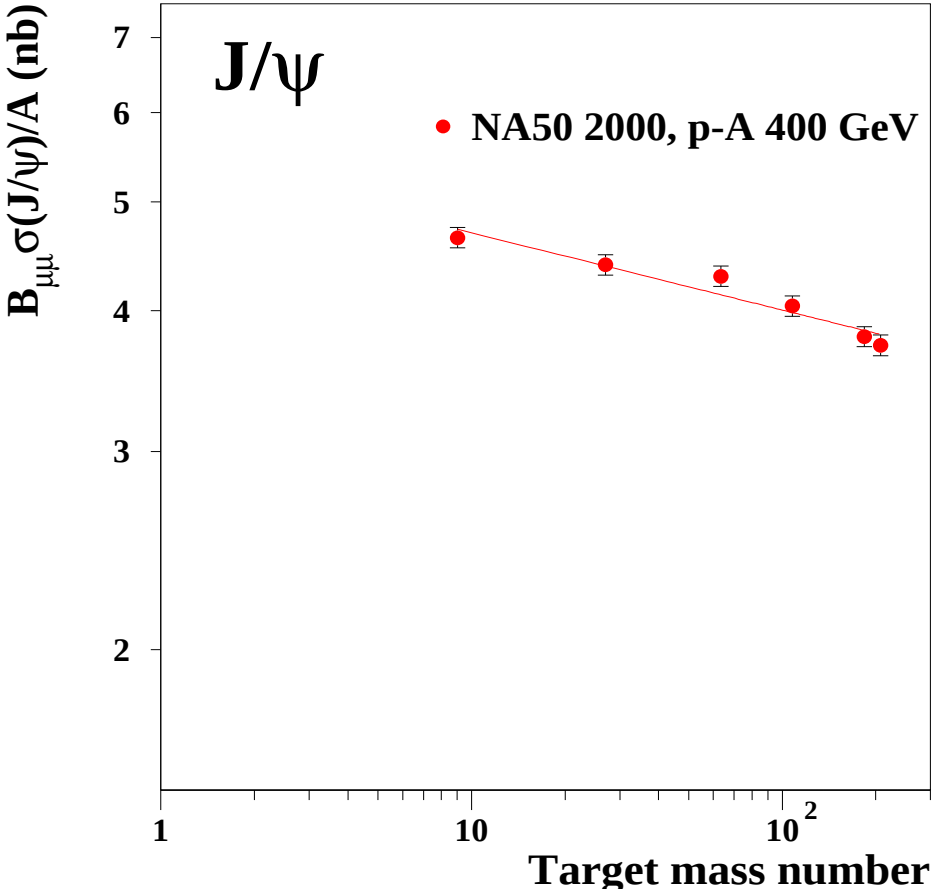
- **Nuclear effects (shadowing) are negligible in the explored phase space**

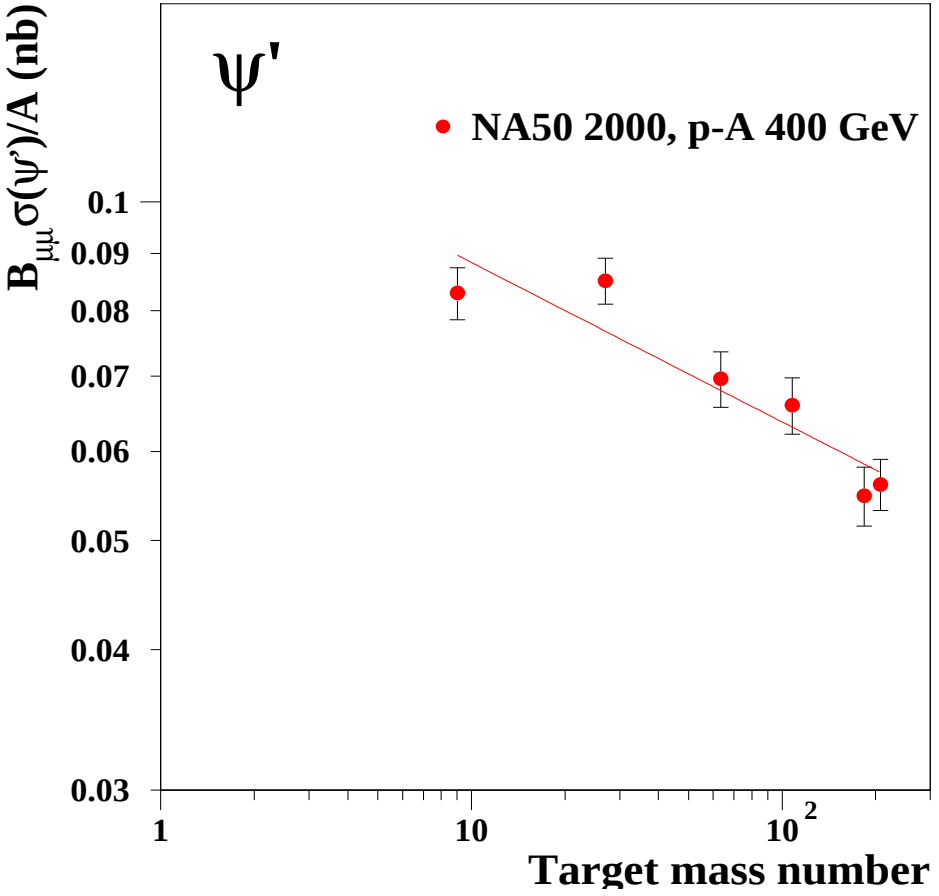
# J/ψ and ψ' absorption in nuclear matter

$$\sigma_{\mathrm{p-A}}^{J/\psi,\psi\prime} = \sigma_0^{J/\psi,\psi\prime} \times A^{\alpha}$$

$$\alpha^{J/\psi} = 0.931 \pm 0.002 \pm 0.007 \quad (\chi^2/dof = 1.4)$$

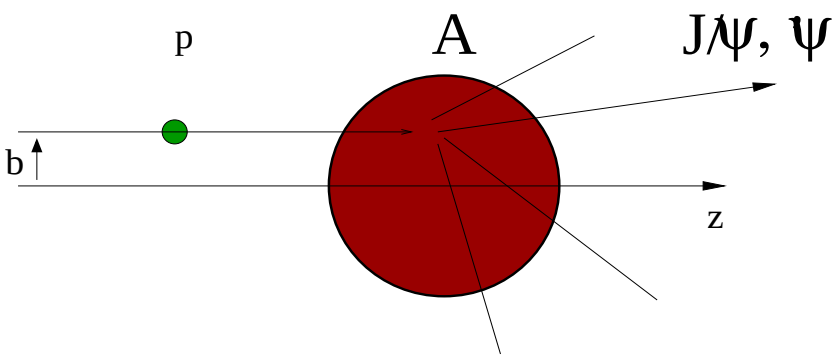
$$\alpha^{\psi\prime} = 0.858 \pm 0.017 \pm 0.008 \quad (\chi^2/dof = 2.2)$$




★ **Data show a larger ψ′ absorption as compared to J/ψ**

# The Glauber model




↪ **Charmonia production follows the hard process cross-section**

$$\sigma_{\mathrm{p-A}} = A\,\sigma_{\mathrm{NN}}$$

↪ **After production, charmonia states can interact with the surrounding nuclear matter with a given cross-section** $(\sigma_{\mathrm{abs}})$**.**

- **Taking into account both processes**

  ↪ **production of the charmonium state,**

  ↪ **Possible absorption on it's way through nuclear matter, we get:**

$$\frac{\sigma_{\mathrm{p-A}}}{A} = \sigma_0 \frac{1}{(A-1)\sigma_{abs}} \times \int d^2b\; e^{-(A-1)T_A(\vec{b})\;\sigma_{abs}}$$

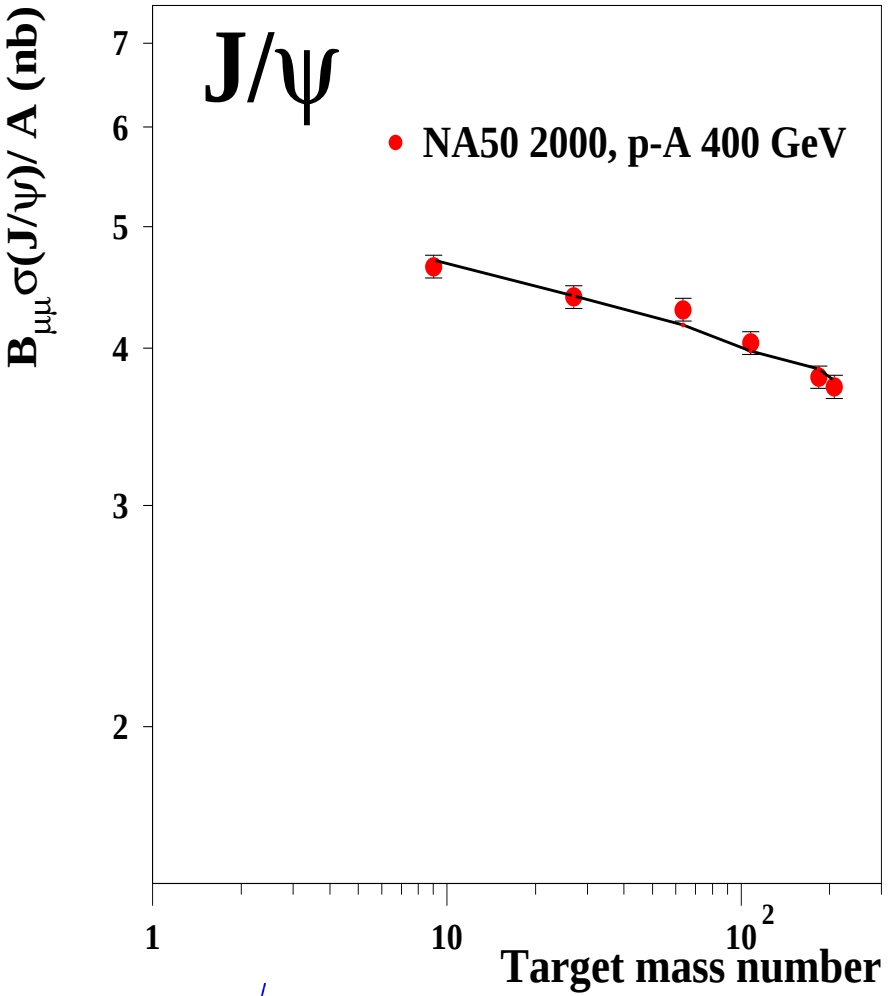
$T_A(\vec{b})$**: Nuclear thickness function**

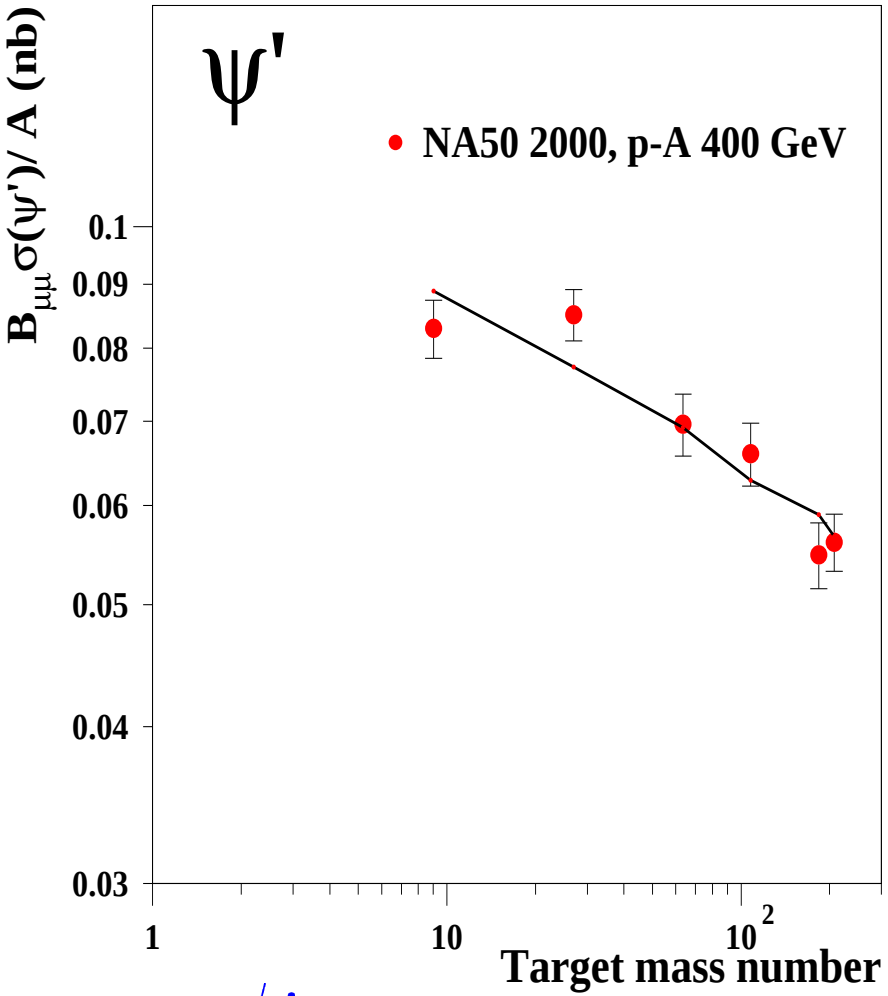
- **Charmonia experimental cross-sections can be fitted using this Glauber model with 2 free parameters:**

$$\hookrightarrow \sigma_0,\ \sigma_{\mathrm{abs}}$$

# $\sigma_{\rm abs}$ results with Glauber model

- J/$\psi$ and $\psi$' results




$$\sigma^{\psi}_{\rm abs} = 4.2 \pm 0.5\ {\rm mb} \quad (\chi^2/dof = 0.9)$$

$$\sigma^{\psi\prime}_{\rm abs} = 9.6 \pm 1.6\ {\rm mb} \quad (\chi^2/dof = 2.0)$$

# Comparison: All NA50 p-A data

- **3 NA50 p-A data samples:**
  - ↪ 96/98 data, High Intensity, 450 GeV [1]
  - ↪ 98/00 data, Low Intensity, 450 GeV (average of analyses [1,2])
  - ↪ 2000 data, 400 GeV
- **Values from the different p-A samples**

**Individual $\sigma_{\mathrm{abs,\ p-A}}$ Glauber fits**

| Data | $\sqrt{s}$ (GeV) | $\sigma^{\psi}_{\mathrm{abs}}$ (mb) | $\chi^2$/dof | $\sigma^{\psi\prime}_{\mathrm{abs}}$ (mb) | $\chi^2$/dof |
|---|---|---|---|---|---|
| 1996-1998 (HI) | 29.1 | $4.8 \pm 1.0$ | 0.8 | $8.0 \pm 1.4$ | 1.2 |
| 1998-2000 (LI) | 29.1 | $4.7 \pm 1.0\ (*)$ | 1.0 | $6.0 \pm 1.9$ | 0.6 |
| 2000 (VHI) | 27.4 | $4.2 \pm 0.5$ | 0.9 | $9.6 \pm 1.6$ | 2.0 |

- **All results are compatible ↪ Perform simultaneous fit**

**(*) Estimated from** $\frac{B_{\mu\mu}\sigma(\psi)}{\sigma(DY_{2.9-4.5})}$


[1] Euro Phys J C, in print.
[2] B. Alessandro et al. (NA50 Collaboration), Phys. Lett. B553 (2003) 167.

# Simultaneous fit

- **Method to estimate $J/\psi$ absorption**

  ↪ **Use the best estimate of each individual analysis ($\frac{\psi}{DY}$ or $\psi$)**

  ↪ **Fit all samples with a common $\sigma_{abs}$**

  ↪ **Leave normalizations as free parameters to take into account the different energies and kinematical conditions.**

- **Method to estimate $\psi\prime$ absorption**

  ↪ **Use the best estimate of each individual analysis ($\frac{\psi\prime}{\psi}$)**

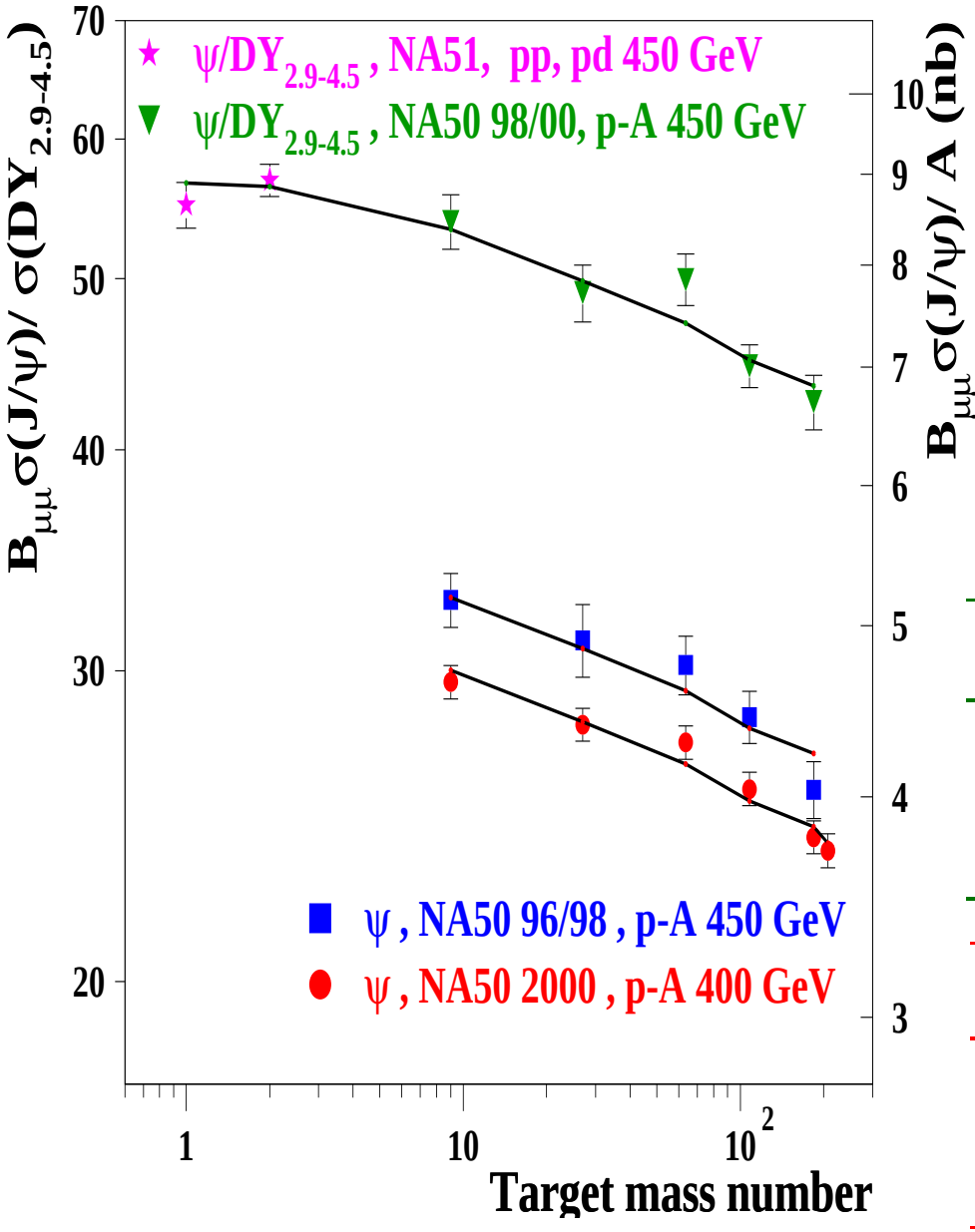
  ↪ **Fit all samples with a common $\sigma_{abs}$**

  ↪ **Assume that there is no $\frac{\psi\prime}{\psi}$ energy dependence.**

- **For the last NA50 p-A data set**

  ↪ **Luminosity systematic errors have been neglected since they affect all targets in essentially the same way (no effect on $\sigma_{abs}$ measurement).**

# $\sigma^{\psi}_{abs}$ simultaneous fit in p-A data




- **Perform a simultaneous Glauber fit**

  **with** $\frac{B_{\mu\mu}\sigma(\psi)}{\sigma(DY_{2.9-4.5})}$ **results from :**

  $\hookrightarrow$ **p-p, p-d at 450 GeV**

  $\hookrightarrow$ **p-A 98/00 at 450 GeV**

  **and** $\frac{B_{\mu\mu}\sigma(\psi)}{A}$ **results from:**

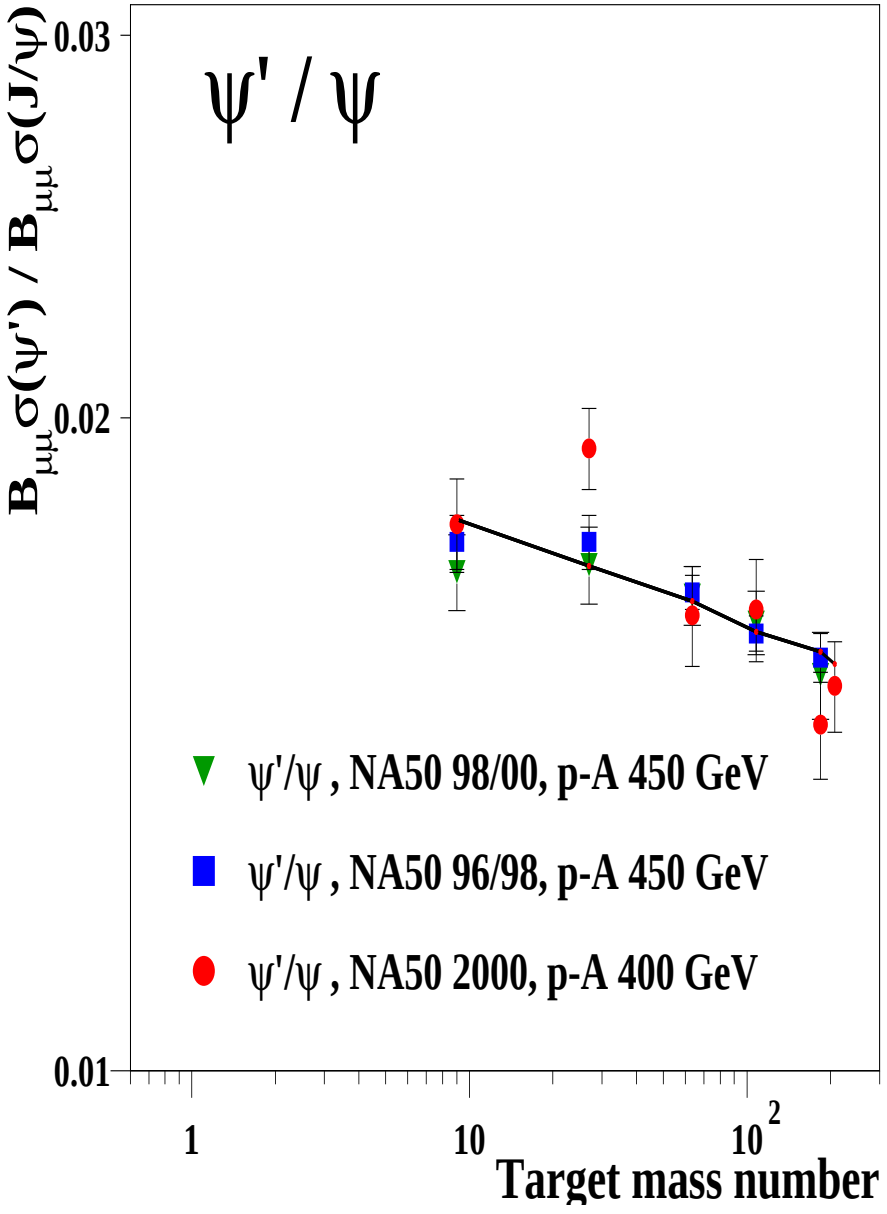
  $\hookrightarrow$ **p-A 96/98 at 450 GeV**

  $\hookrightarrow$ **p-A 2000 at 400 GeV**

| Glauber fit | $\sigma^{\psi}_{abs}$ (mb) | $\chi^2$/dof |
|---|---|---|
| Without p-p, p-d | $4.4 \pm 0.4$ | 0.8 |
| With p-p, p-d | $4.3 \pm 0.3$ | 0.7 |

| $A^{\alpha}$ fit | $\alpha^{\psi}$ | $\chi^2$/dof |
|---|---|---|
| Without p-p, p-d | $0.929 \pm 0.006$ | 1.1 |
| With p-p, p-d | $0.941 \pm 0.004$ | 1.7 |

# $\sigma^{\psi\prime}_{\rm abs}$ simultaneous fit in p-A data




- **Performing a simultaneous Glauber fit using $\frac{\psi\prime}{\psi}$ results from:**

  ↪ **p-A 98/00 at 450 GeV**

  ↪ **p-A 96/98 at 450 GeV**

  ↪ **p-A 2000 at 400 GeV**

**and assuming a J/$\psi$ absorption**

$$\sigma^{\psi}_{abs} = 4.4 \pm 0.4\ \mathrm{mb}$$

**we get**

| Glauber fit | $\sigma^{\psi\prime}_{\rm abs}$ (mb) | $\chi^2$/dof |
|---|---|---|
| | 7.9 ± 0.6 | 1.0 |

$$\sigma^{\psi\prime}_{\rm abs} - \sigma^{\psi}_{\rm abs} = 3.5 \pm 0.7\ \mathrm{mb}$$

# $\sigma^{\psi}_{\rm abs}$ from NA38 S-U published data

- **NA38 has measured $\frac{B_{\mu\mu}\sigma(\psi)}{\sigma(DY_{2.9-4.5})}$ at 200 GeV as a function of $E_T$.**

  ↪ **The full Glauber model taking into account the centrality of the collision can be used to obtain the J/$\psi$ absorption in light ions collisions.**

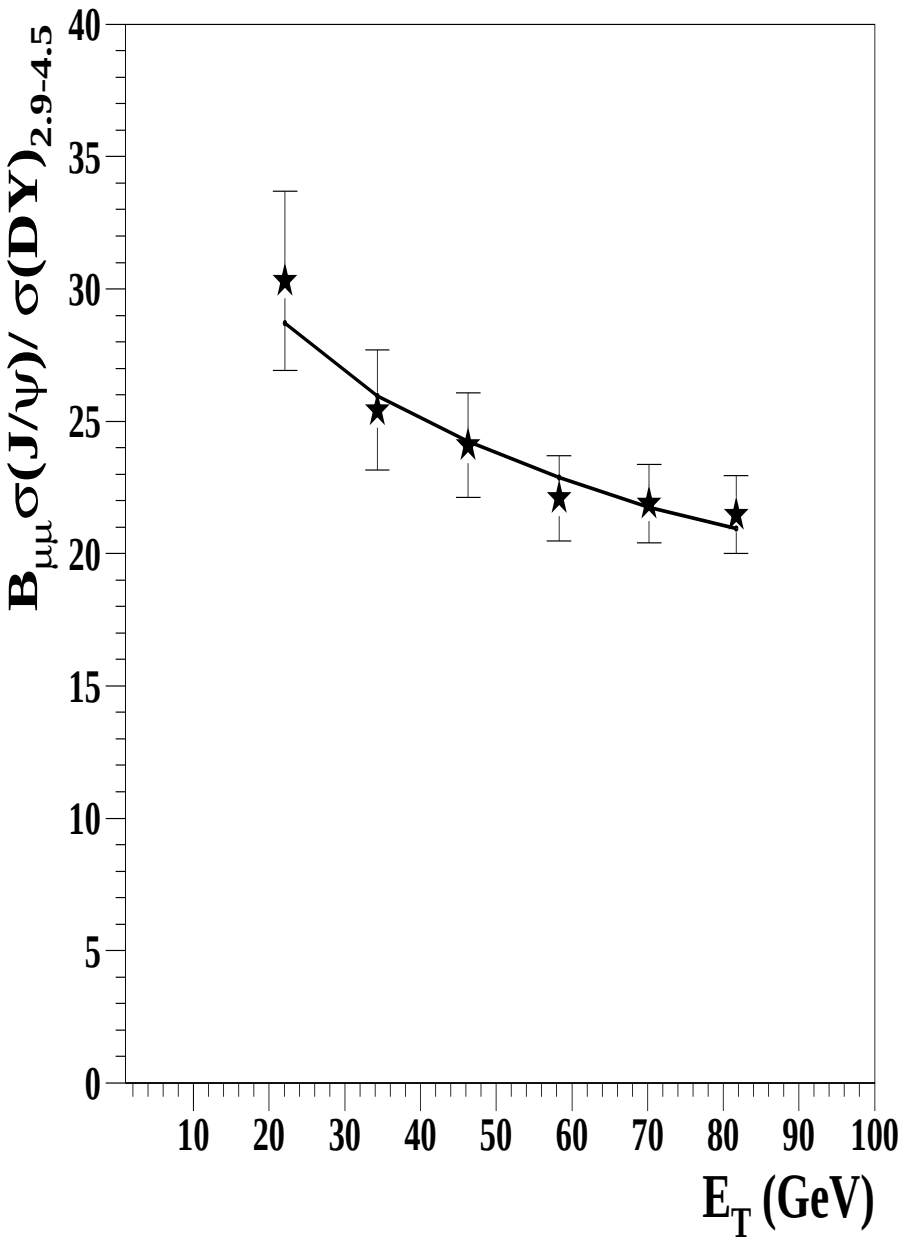
  ↪ **Published results show**

$$\sigma^{\psi}_{\rm abs}(S-U) = 7.1 \pm 3.0 \ {\rm mb}$$

- **NA38 S-U data are now reanalysed using the best of our present knowledge.**

  ↪ **Same methods and procedures as used in Pb-Pb analyses**

# S-U reanalysis results




- **Reanalysis conditions:**
  - ↪ **6 different bins**
  - ↪ **MRS A (low $Q^2$) set of PDF**
  - ↪ **Same analysis procedure as used in NA50 PbPb data.**

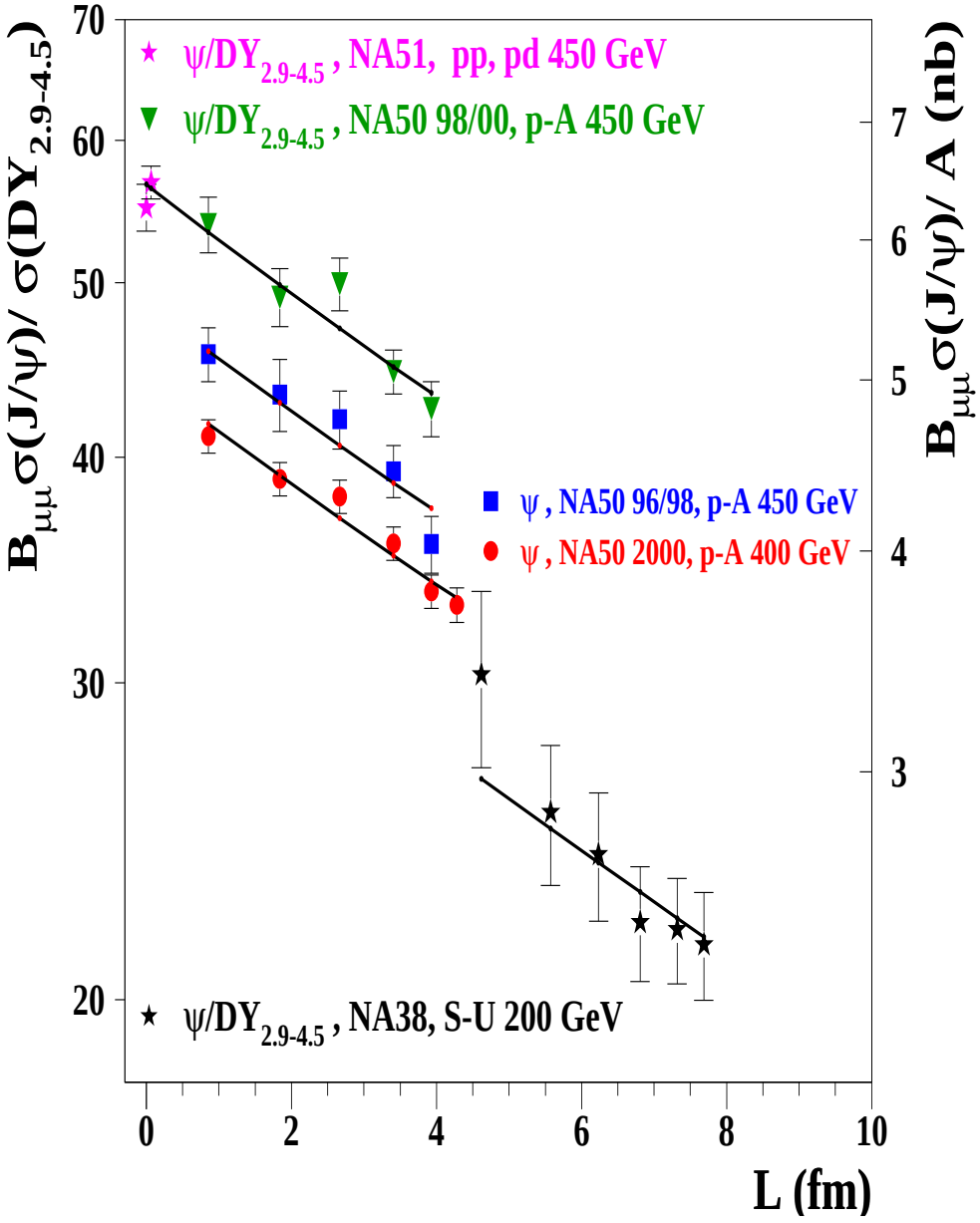
- **New absorption cross-section extracted from S-U collisions:**

$$\sigma^{\psi}_{\rm abs} = 7.2 \pm 3.2\ {\rm mb}$$

- **Error bar is due to the :**
  - ↪ **Small Drell-Yan statistics**
  - ↪ **Large correlation between normalization and $\sigma^{\psi}_{\rm abs}$**

| $\sigma^{\psi}_{\rm abs}$ **(p-A)** | $\sigma^{\psi}_{\rm abs}$ **(S-U)** |
|---|---|
| **$4.3 \pm 0.3$ mb** | **$7.2 \pm 3.2$ mb** |

# Simultaneous Glauber fit with p-A and S-U



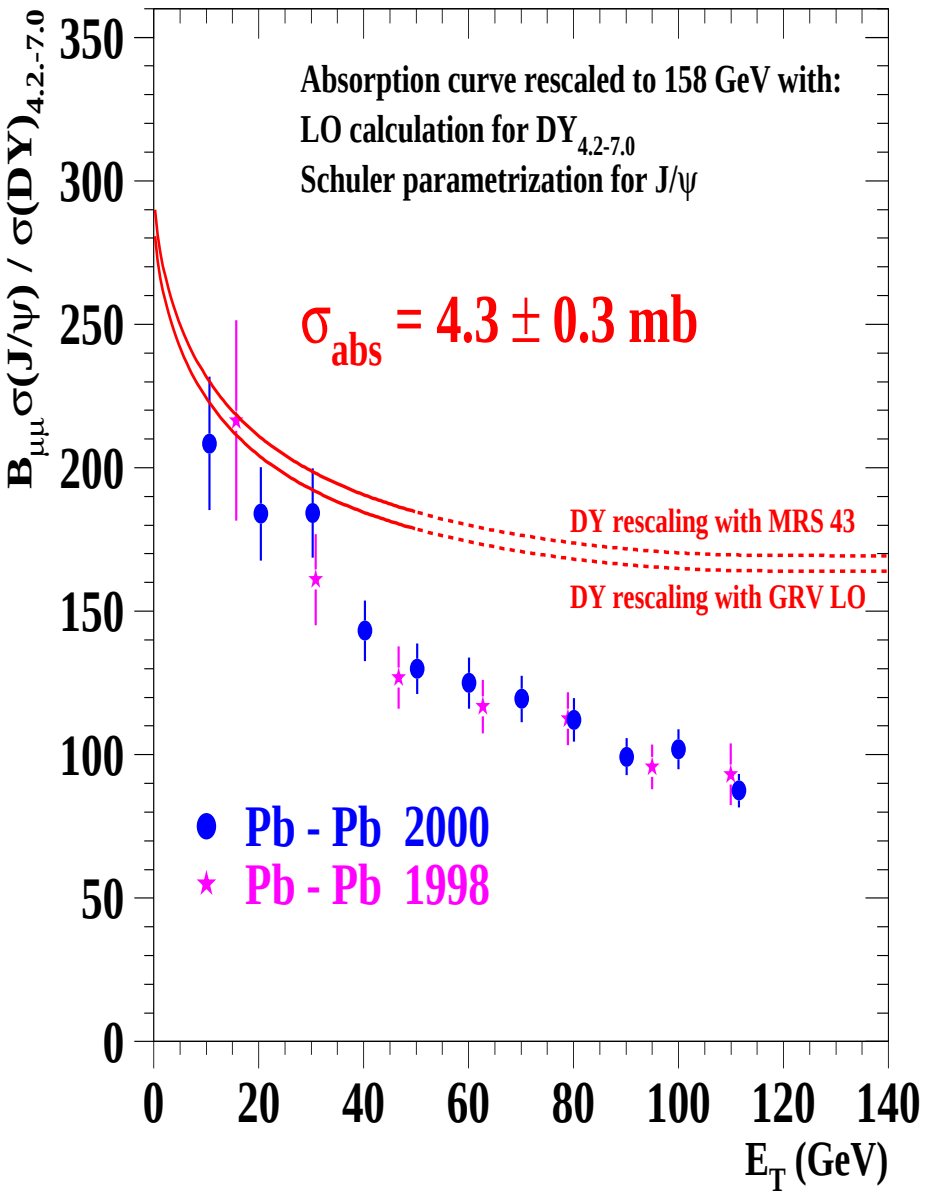

- **Perform a simultaneous Glauber fit with** $\frac{B_{\mu\mu}\sigma(\psi)}{\sigma(DY_{2.9-4.5})}$ **results from :**
  - ↪ **p-p, p-d at 450 GeV**
  - ↪ **p-A 98/00 at 450 GeV**
  - ↪ **S-U at 200 GeV**

  **and** $\frac{B_{\mu\mu}\sigma(\psi)}{A}$ **results from:**
  - ↪ **p-A 96/98 at 450 GeV**
  - ↪ **p-A 2000 at 400 GeV**

- **New estimate of J/$\psi$ absorption:**

$$\sigma^{\psi}_{abs} = 4.3 \pm 0.3 \text{ mb}$$
$$(\chi^2/dof = 0.6)$$

# Comparison with Pb-Pb results




- **An absorption curve can be drawn as a function of $E_T$:**

  ↪ **Using the Glauber model, the measured $\sigma^{\psi}_{\rm abs}$ and accounting for the different NA38 and NA50 calorimeter resolutions we can calculate the expected nuclear absorption for Pb-Pb collisions as a function of $E_T$.**

  ↪ **The curve normalization is estimated from the S-U data rescaled to the Pb-Pb kinematical conditions.**

  ↪ **The 2 curves represent the uncertainty on the absorption curve due to the $DY_{4.2-7.0}$ rescale from 200 to 158 GeV.**

# Conclusions

- **Results from a new NA50 p-A data set, at 400 GeV incident energy, are now available**
  - ↪ **Systematics are minimized with rotating targets.**
  - ↪ **Data taking aimed for $\sigma^{\psi}_{\rm abs}$ measurement.**
- **Global $\sigma^{\psi}_{\rm abs}$ and $\sigma^{\psi\prime}_{\rm abs}$ are obtained by means of a simultaneous fit using the best estimates of each NA50 p-A analyses**

| Global fit | $\sigma^{\psi}_{\rm abs}$ (mb) | $\sigma^{\psi\prime}_{\rm abs}$ (mb) | $\sigma^{\psi\prime}_{\rm abs}$ - $\sigma^{\psi}_{\rm abs}$ (mb) |
|---|---|---|---|
| | $4.3 \pm 0.3$ | $7.9 \pm 0.6$ | $3.5 \pm 0.7$ |

- **Old NA38 S-U data were reanalysed and from it we obtain an absorption cross-section of $\sigma^{\psi}_{\rm abs} = 7.2 \pm 3.2\ mb$.**
- **From a simultaneous fit including all NA50 p-A results and NA38 S-U reanalysis results we obtain $\sigma^{\psi}_{\rm abs} = 4.3 \pm 0.3\ mb$.**

**Good precision in the J/$\psi$ absorption cross-section measurement.**

# NA50 Collaboration Institutions

- Università del Piemonte Orientale, Alessandria and INFN-Torino, Italy
- LAPP, CNRS-IN2P3, Annecy-le-Vieux, France
- LPC, Univ. Blaise Pascal and CNRS-IN2P3, Aubière, France
- IFA, Bucharest, Romania
- Università di Cagliari/INFN, Cagliari, Italy
- CERN, Geneva, Switzerland
- LIP, Lisbon, Portugal
- INR, Moscow, Russia
- IPN, Univ. de Paris-Sud and CNRS-IN2P3, Orsay, France
- Laboratoire Leprince-Ringuet, Ecole Polytechnique and CNRS-IN2P3, Palaiseau, France
- Università di Torino/INFN, Torino, Italy
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- YerPhI, Yerevan, Armenia