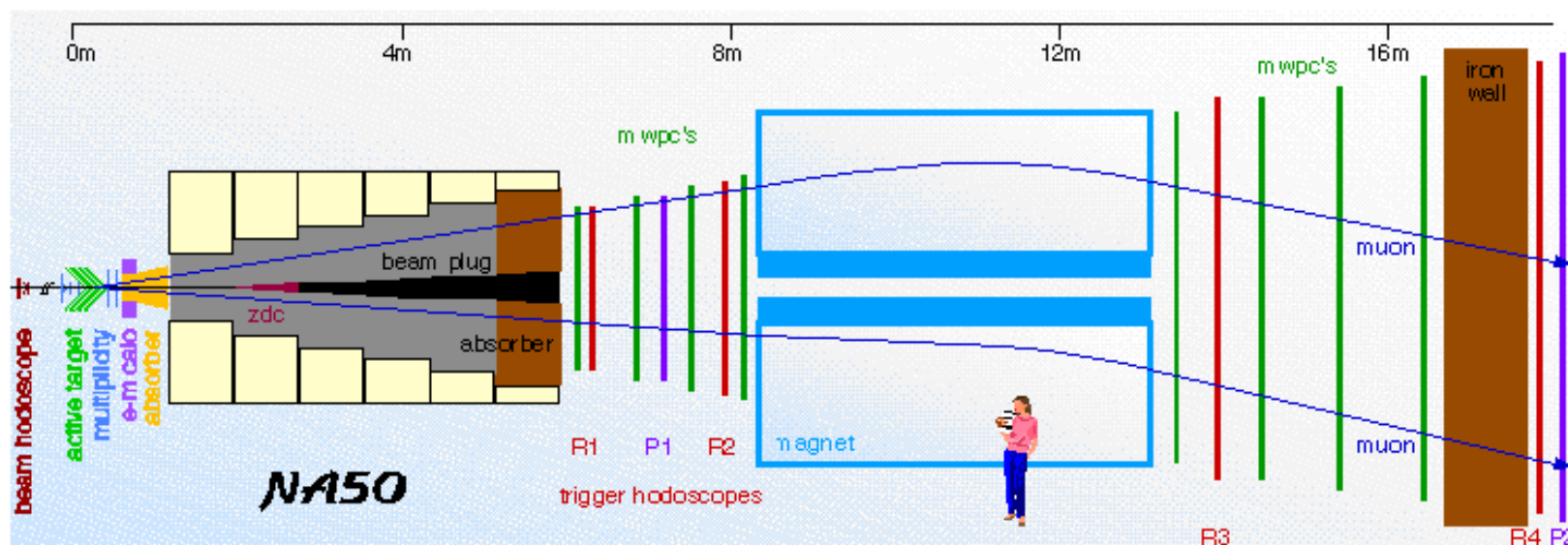


# Quarkonium production and suppression in Pb-Pb and p-A collisions at SPS energies

## NA50 Collaboration



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Quark Matter 2005, Budapest, Aug. 4-9, 2005

# Outline of the talk

- Results on charmonium production and suppression
    - **new reference** for  $J/\psi$  normal nuclear absorption:
      - \* **using** high statistics **p-A** data at 450, 400 and 200 GeV
      - \* **excluding S-U** data at 200 GeV
    - **$J/\psi$  anomalous suppression** in Pb-Pb collisions at 158 GeV/nucleon and comparison with lighter systems
    - **$\psi'$  absorption** from p-A to Pb-Pb
  - $p_T$  dependence of  $J/\psi$  suppression
  - $J/\psi$  transverse momentum distributions
- }  $\Rightarrow$  poster 210 N. Topilskaya
- $\Upsilon$  production in p-A  $\Rightarrow$  parallel talk 5b/1 Sat. 16:00 P. Cortese
  - Conclusions

# Charmonium physics in NA50

- **Charmonium suppression** by QGP color screening: Matsui+Satz 1986
- Measurements by NA38 with **p-A**, **O-U** and **S-U** collisions (1986-1992):
  - observed suppression of  $J/\psi$  finally understood as due to absorption in ordinary nuclear matter
- New measurements by **NA50** with **p-A** and **Pb-Pb** collisions:
  - Discovery of **anomalous  $J/\psi$  suppression** in central Pb-Pb collisions (1995-1996 data)
  - Last two Pb-Pb data samples collected under improved conditions
    - ⇒ **final results**:
    - \* **single thin target** (1998) ⇒ no reinteractions in targets
    - \* **vacuum** around target (2000) ⇒ no Pb-air interactions

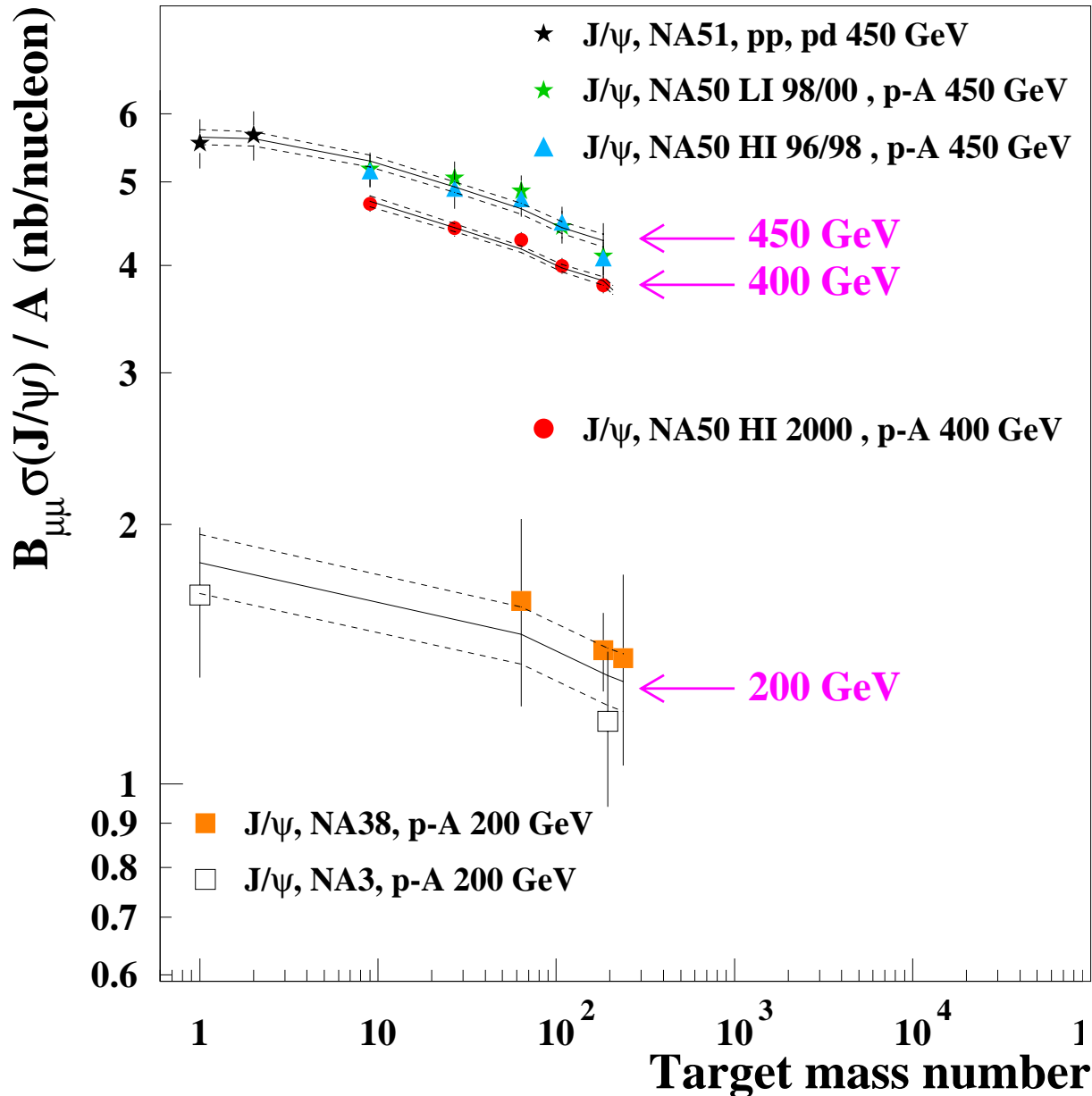
## Developments since Q.M. 2004

- Charmonium analysis (ratios of  $J/\psi$  and  $\psi'$  to Drell-Yan) in Pb-Pb:
  - **Same PDF's** (GRV 94 LO) used for Drell-Yan **in all analyses**
- Reference curve for normal nuclear absorption:  
**no available** 158 GeV p-A data  $\Rightarrow$  use higher energy p-A & rescale:
  - **Determine**  $\sigma_{abs}^{J/\psi}$  **from** a coherently analyzed set of  $(J/\psi)/DY$  **p-A** data at **450** and **400** GeV  $\Rightarrow$  **shape of absorption curve**
  - **Determine level of**  $(J/\psi)/DY$  **at 158 GeV** without using S-U data but only  $J/\psi$  cross-sections from 450, 400 and 200 GeV p-A data, plus calculation for Drell-Yan  $\Rightarrow$  **normalization of absorption curve**
  - Take into account the **neutron halo**  
(different spatial distributions of neutrons and protons in nuclei)  
 $\Rightarrow$  affects **centrality dependence** of absorption curve

Final NA50 results on  $(J/\psi)/DY$  in Pb-Pb: Eur. Phys. J. C 39 (2005) 335;

Reference for neutron halo: Phys. Rev. Lett. 87 (2001) 082501.

# $J/\psi$ cross-sections in p-A at 450, 400 and 200 GeV



- Glauber fit to  $B_{\mu\mu} \sigma(J/\psi)$

$$\Rightarrow \sigma_{abs}^{J/\psi} = 4.48 \pm 0.42 \text{ mb}$$

$$N_{200}/N_{450} = 0.320 \pm 0.025$$

$$N_{200}/N_{400} = 0.357 \pm 0.027$$

normalizations  $N_{450}$ ,  $N_{400}$  and  $N_{200}$  include both energy and kinematical domain changes

- $(J/\psi)/DY$  ratios (available only at 450, 400 GeV)

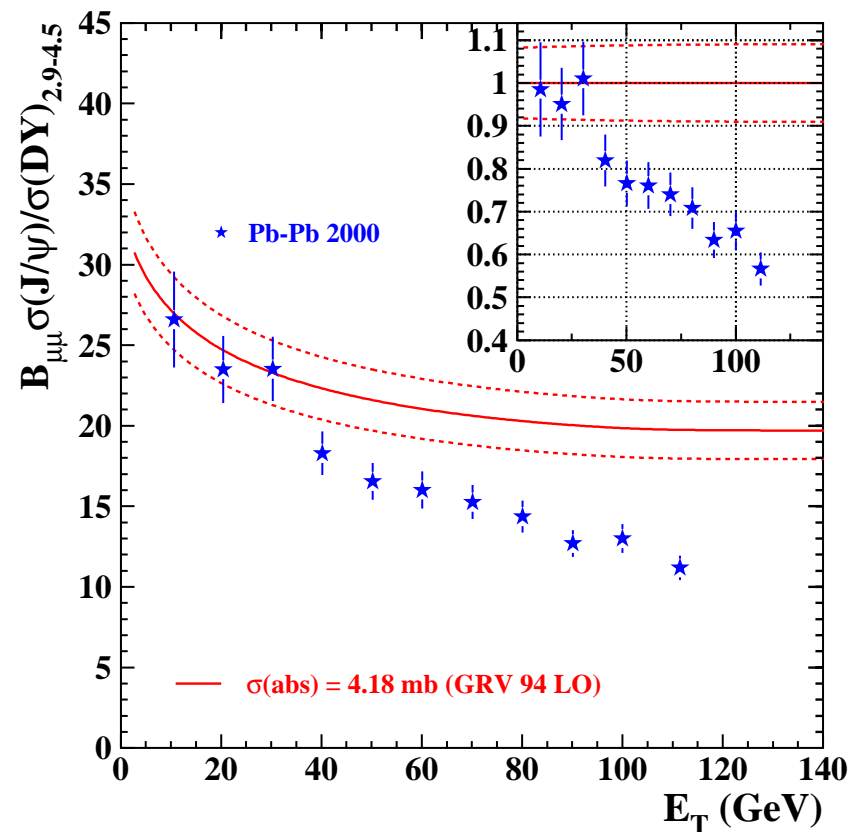
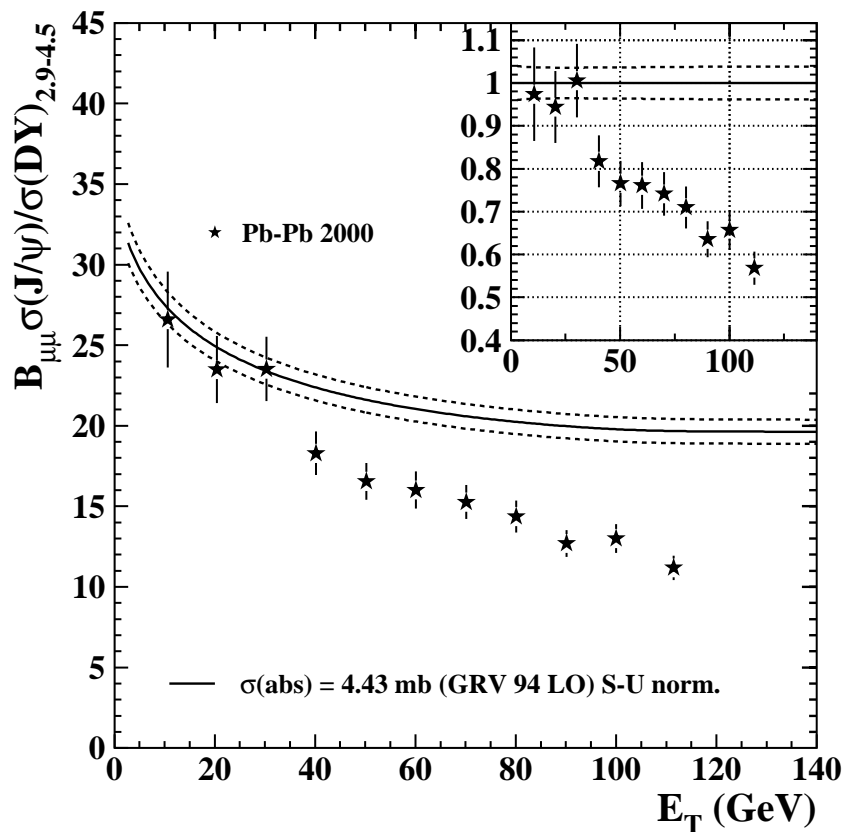
$$\Rightarrow \sigma_{abs}^{J/\psi} = 4.18 \pm 0.35 \text{ mb}$$

Fair agreement between both determinations

# The absorption curve for $(J/\psi)/DY$ in Pb-Pb

- Start from  $(J/\psi)/DY$  **normalization at 450 GeV** (1.4% error)
- **Rescale to 200 GeV** using:
  - ◇ *measured* absolute  $J/\psi$  cross-sections (7.8% error, including syst.)
  - ◇ LO *calculation* for Drell-Yan (2.5% error)
- **Rescale to 158 GeV** using:
  - ◇ *fit "à la Schuler"* to measured  $J/\psi$  cross-sections (1.5% error)
  - ◇ LO *calculation* for Drell-Yan (negligible error)
- **Glauber calculation** (including neutron halo) plus experimental smearing to calculate absorption curve vs. observables  $E_T$ ,  $E_{ZDC}$ ,  $N_{ch}$
- **Remarks:**
  1. **Main assumption is:**  
 $J/\psi$  **normal nuclear absorption cross-section is the same** at 158 GeV and in 450, 400 and 200 GeV p-A collisions
  2. Absorption curve **determination completely independent of S-U** (used previously to fix normalization of normal nuclear absorption curve at 200 GeV and reduce its error)

# $(J/\psi)/DY$ vs. $E_T$ in Pb-Pb (2000 data)

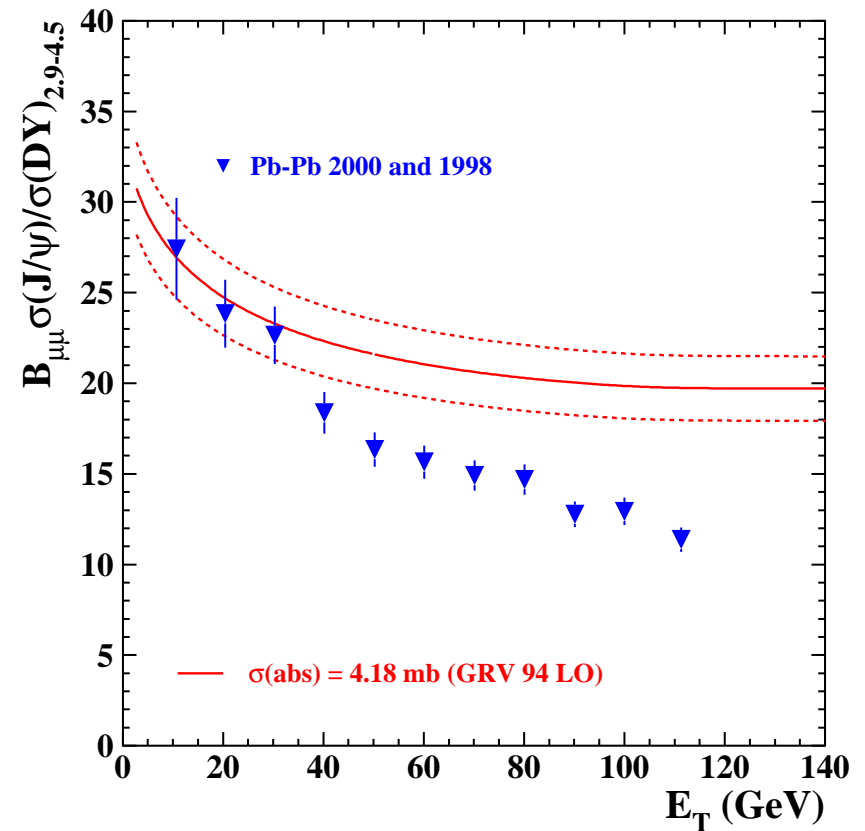
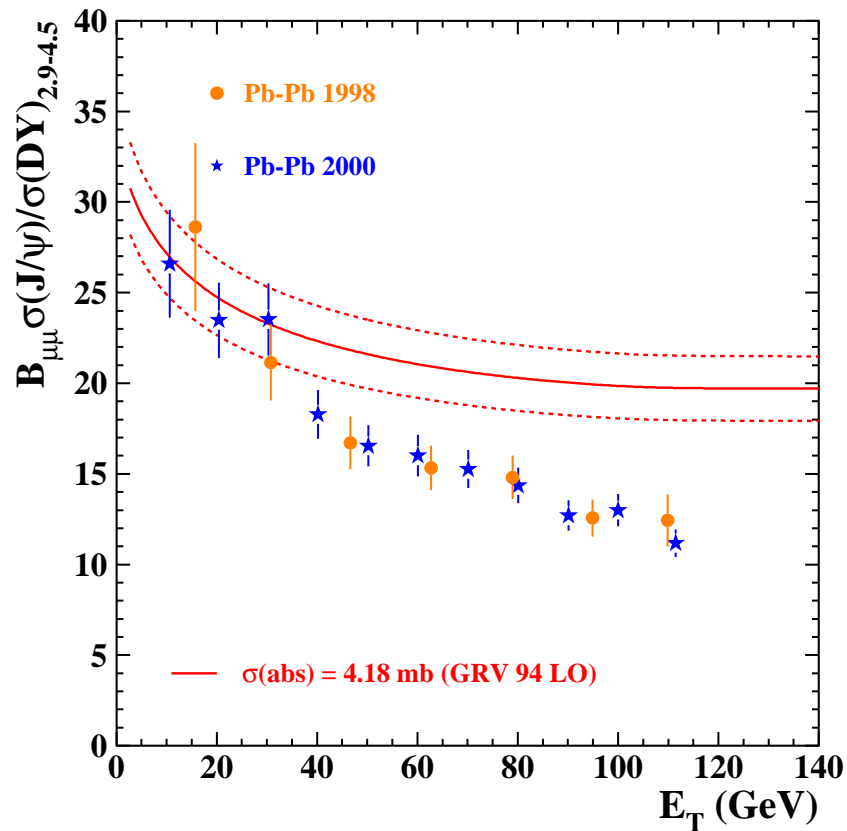


Previous procedure using also S-U data for absorption curve normalization: small error BUT assumes S-U is normal

New procedure with absorption curve from p-A data only: larger error BUT free from assumptions on S-U

**The absorption curve itself is almost the same with both procedures**

# Anomalous $J/\psi$ suppression vs. $E_T$ in Pb-Pb



Pb-Pb 1998 and 2000 data ...

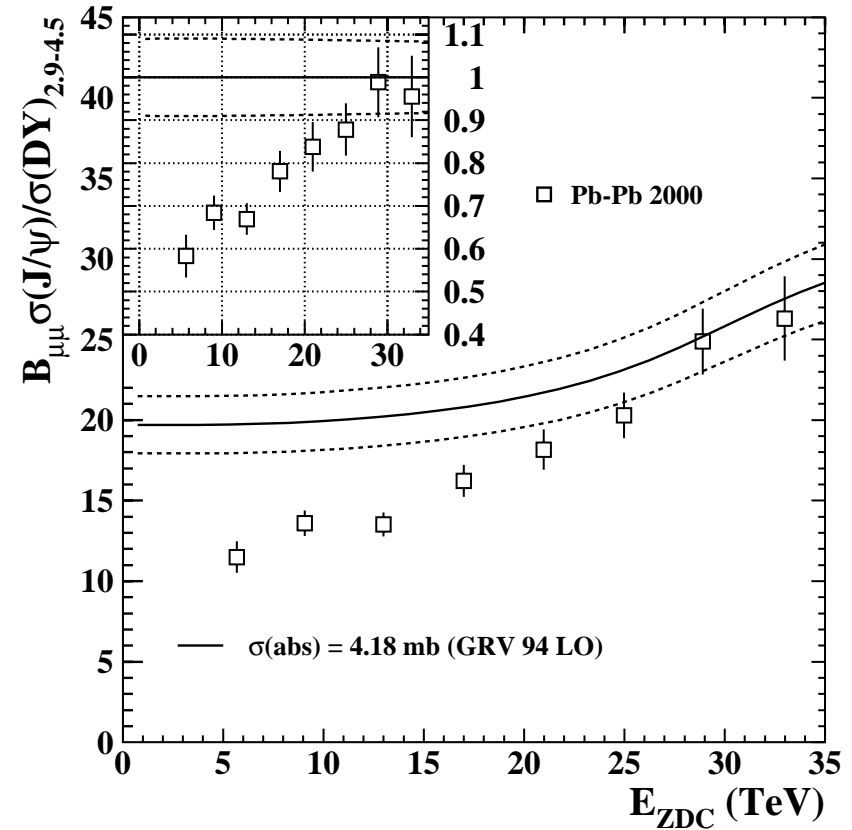
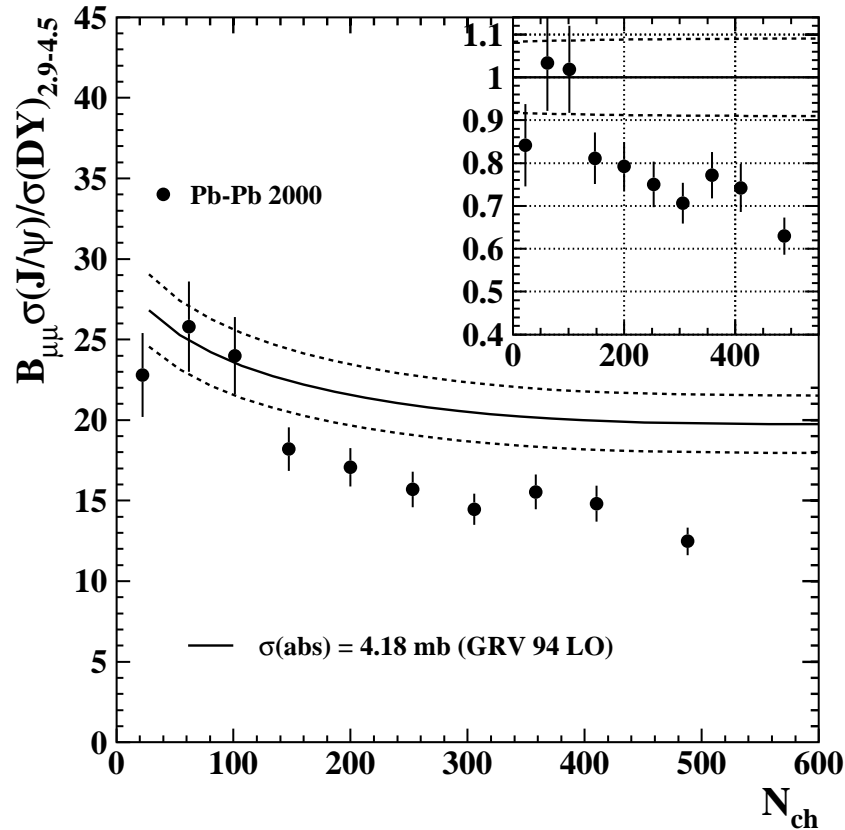
... and averaged result

Pb-Pb (1998 + 2000 data):

⇒ **departure from normal nuclear absorption at mid-centrality**

⇒ **suppression increases with centrality**

# Anomalous $J/\psi$ suppression vs. $N_{ch}$ , $E_{ZDC}$

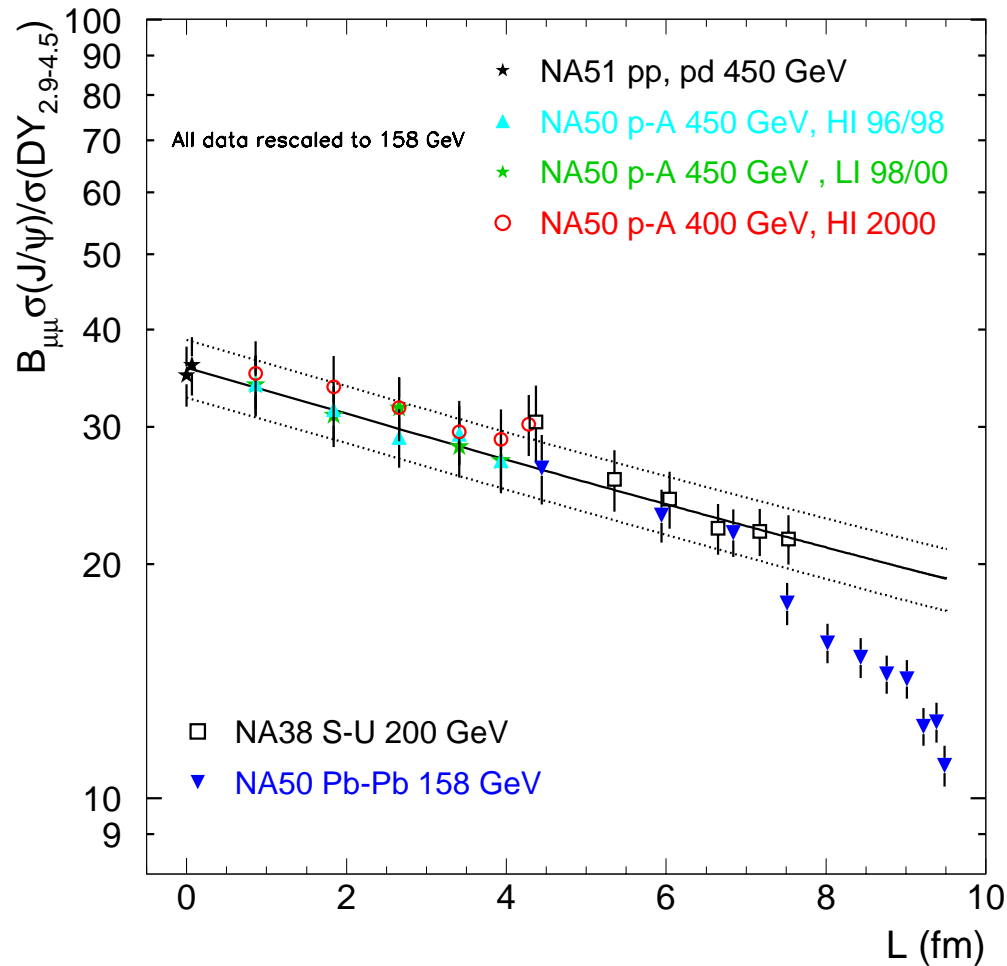


Independent analysis vs.  $N_{ch}$  . . .

. . . and vs. forward energy  $E_{ZDC}$

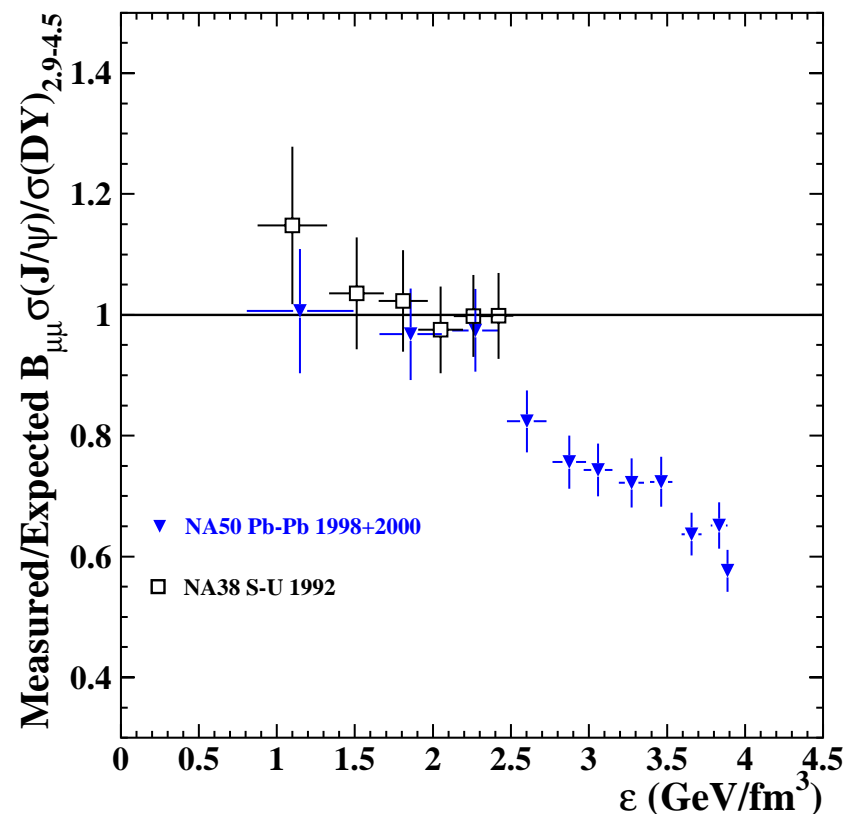
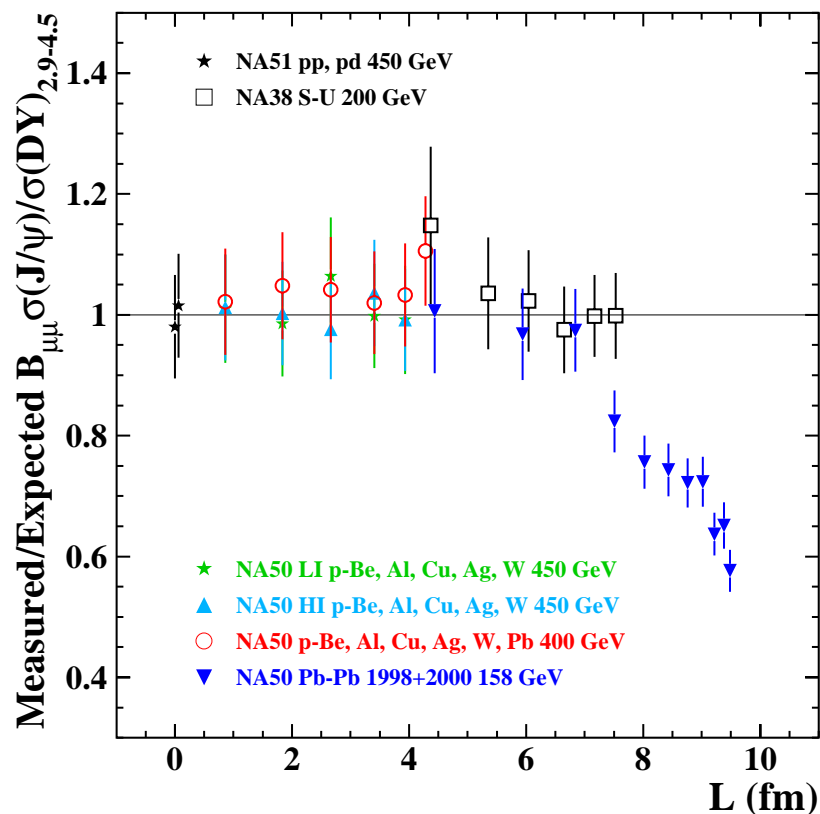
⇒ similar suppression pattern as previously shown vs.  $E_T$

# $(J/\psi)/DY$ : p-A, S-U and Pb-Pb collisions



- **Average path  $L$  in nuclear matter:** appropriate to visualize nuclear absorption in different systems
- **Absorption curve from p-A data only**  
 $\Rightarrow$  allows new conclusion
- **Peripheral Pb-Pb data points but ALSO all of S-U data points compatible with normal nuclear absorption**

# $(J/\psi)/DY$ : Measured/Expected in A-B collisions



From results of previous slide but here in terms of  
**”measured/normally expected”**

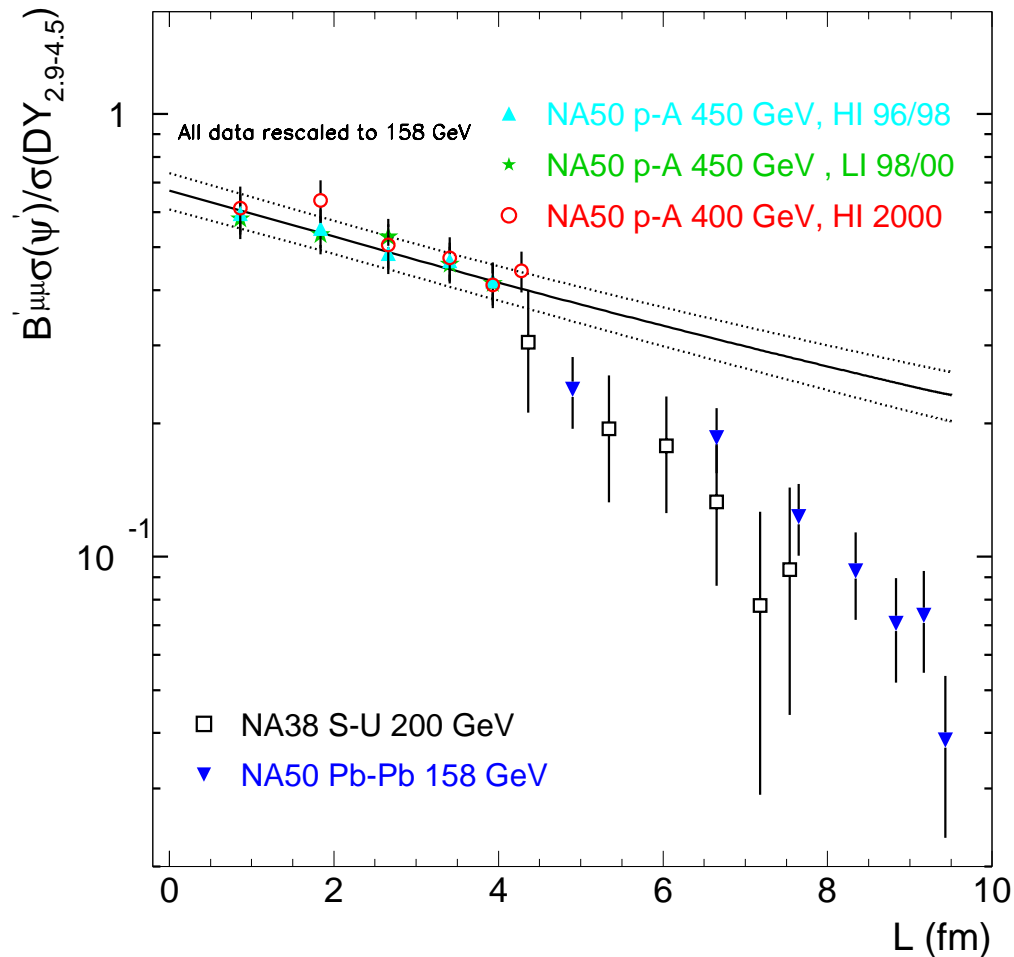
as a function of:

**average path  $L$**

and

**energy density  $\epsilon$**

# $\psi'/DY$ : p-A, S-U and Pb-Pb collisions



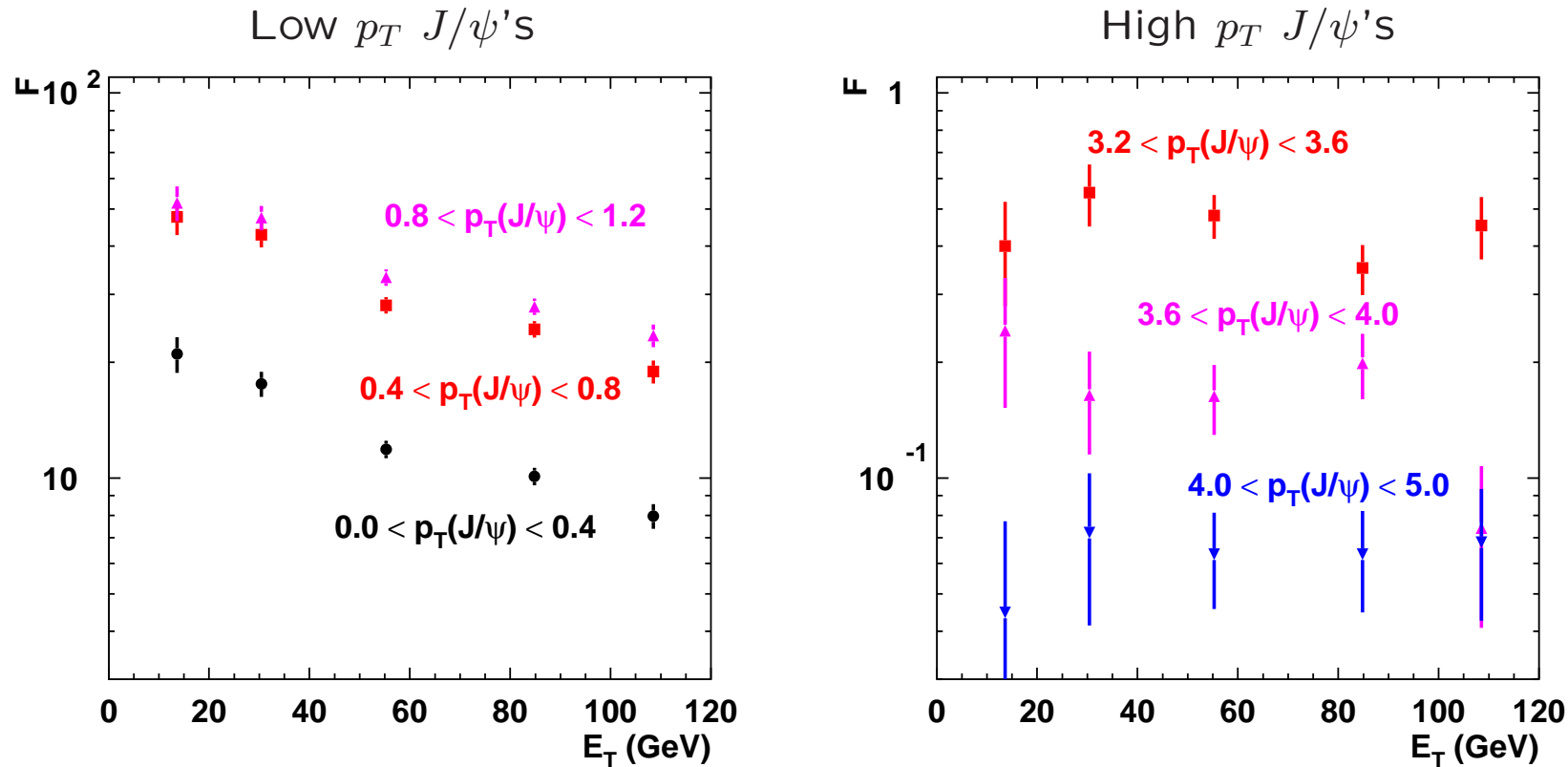
- Glauber fit to p-A  $\psi'/DY$   
 $\Rightarrow \sigma_{abs,pA}^{\psi'} = 7.6 \pm 1.1 \text{ mb}$

- **Already in S-U**  
 $\psi'/DY$  deviates from p-A behaviour, showing **larger absorption**

- **Pb-Pb and S-U show very similar  $\psi'$  absorption larger than observed in p-A**

# $J/\psi$ suppression vs. centrality in $p_T$ bins

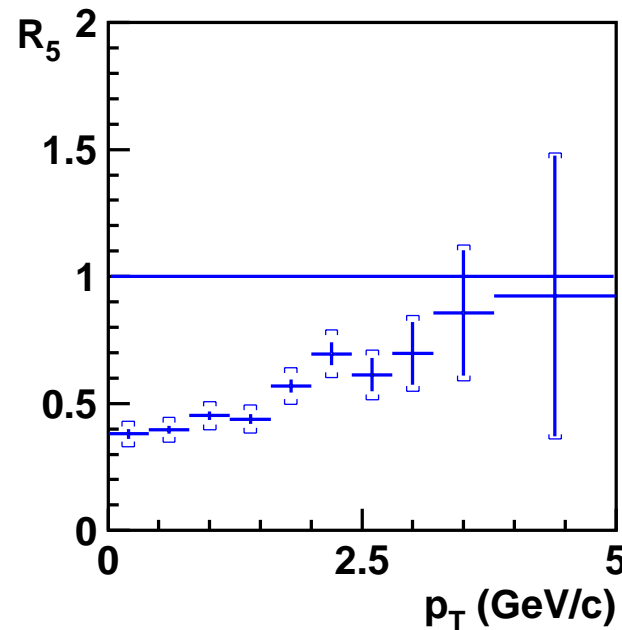
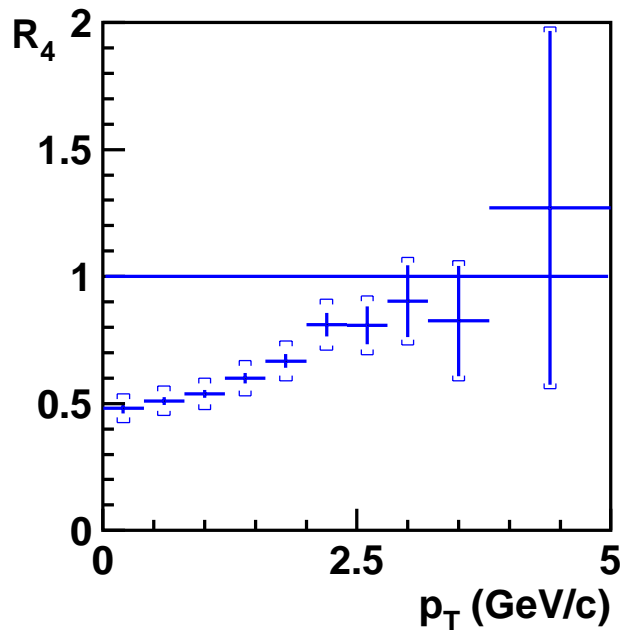
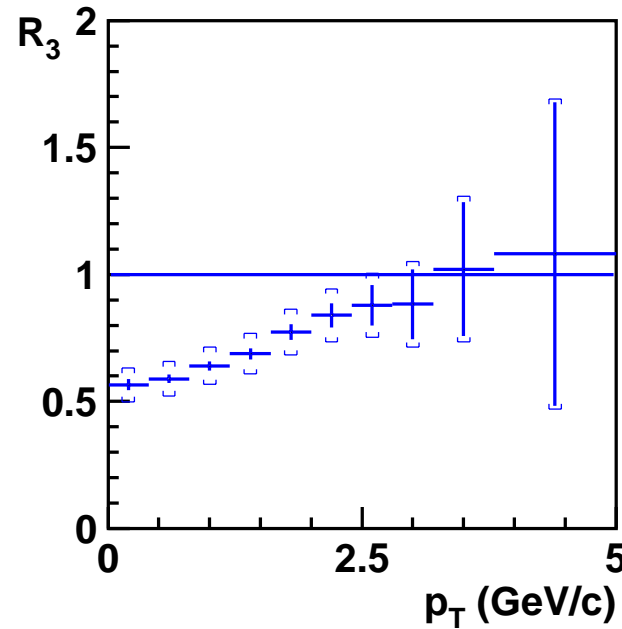
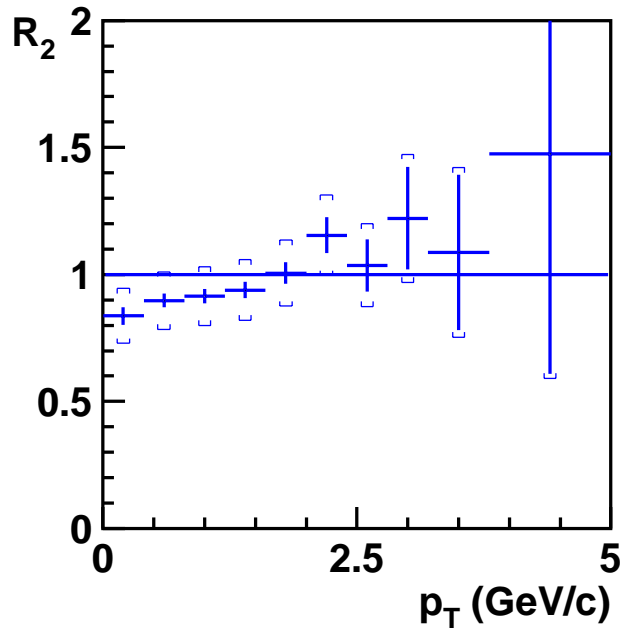
$$F(E_T; p_{Ti}) = N_\psi(E_T; p_{Ti}) / N_{DY}(E_T)$$



$F(E_T; p_{Ti})$  is the ratio  $(J/\psi)/DY$  limited to  $J/\psi$ 's in a given  $p_T$  bin

$\Rightarrow$  **Anomalous  $J/\psi$  suppression is concentrated at low  $p_T$**

# $J/\psi$ central to peripheral ratio “ $R_{CP}$ ” vs. $p_T$



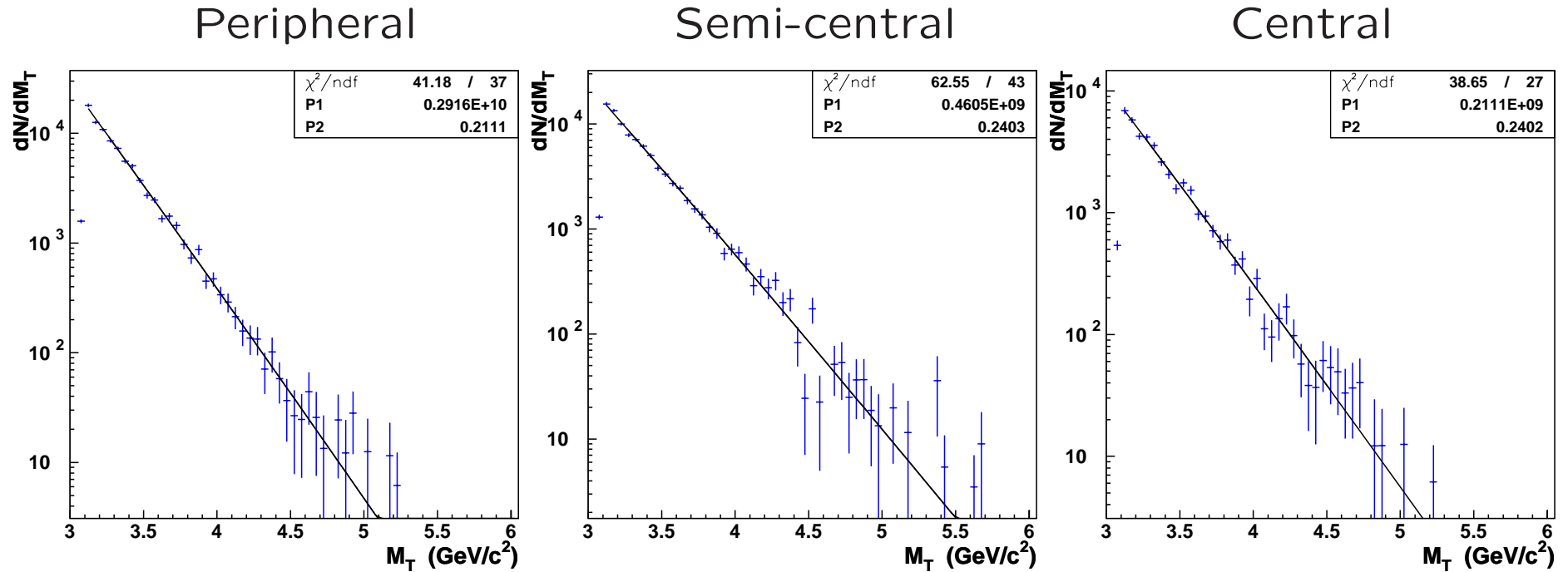
The ratios  $R_{CP}^i(p_T)$  are defined as:

$$\frac{N_{\psi,i}(p_T)}{N_{DY,i}} / \frac{N_{\psi,1}(p_T)}{N_{DY,1}}$$

with  $N_{DY,i}$  prop. to  $N_{coll}^i$

- Central to peripheral ratio  $R_{CP}^i$  for centrality bins  $i = 2, 5$  where  $i = 1$  is the most peripheral bin
- $J/\psi$  suppression is mainly at low  $p_T$
- For  $p_T > 3.5$  GeV/c centrality dependence of  $J/\psi$  suppression is weak

# $J/\psi$ transverse mass distributions in Pb-Pb



$$T = 211 \pm 2 \text{ MeV}$$

$$\langle p_T^2 \rangle = 1.55 \pm 0.02 \text{ GeV}^2$$

$$240 \pm 3 \text{ MeV}$$

$$1.84 \pm 0.02 \text{ GeV}^2$$

$$240 \pm 5 \text{ MeV}$$

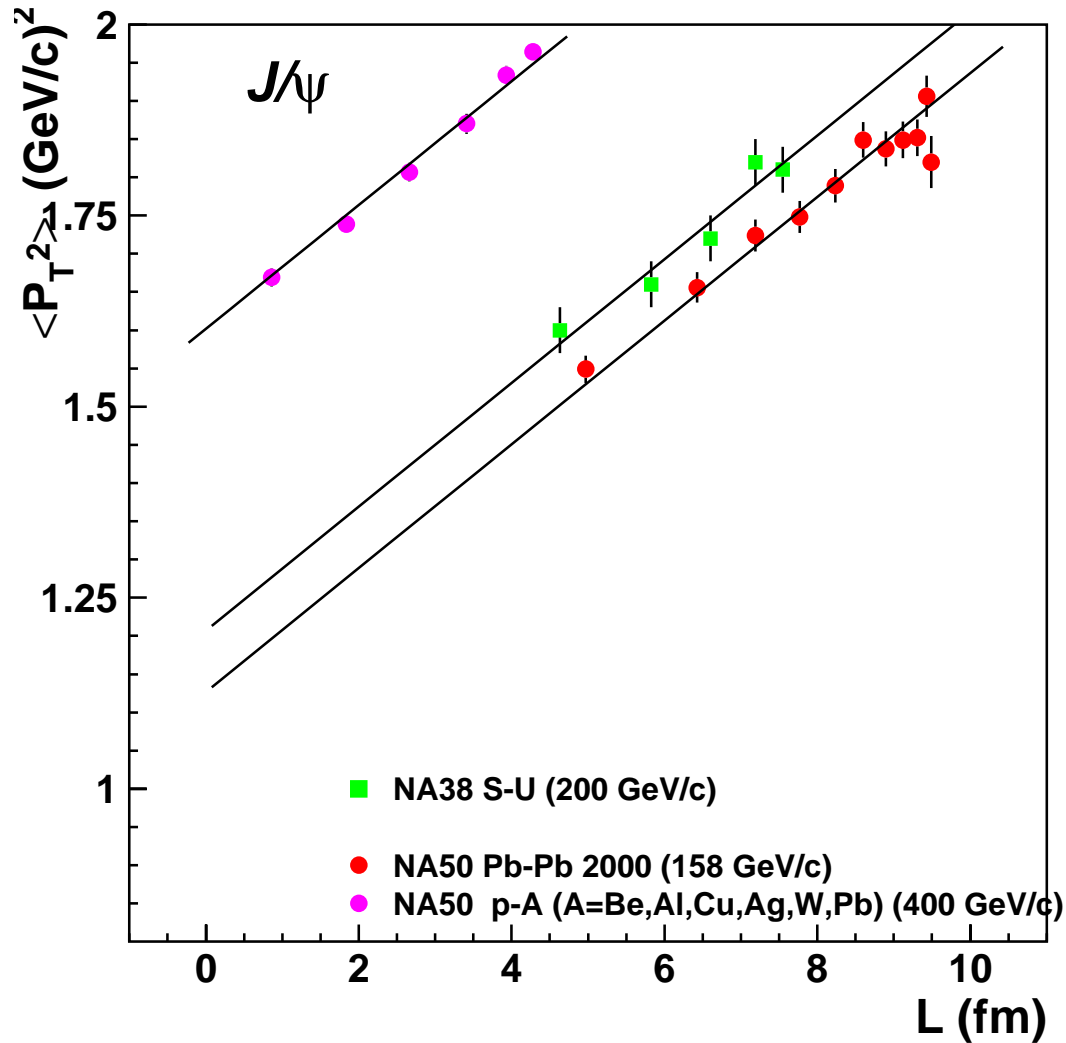
$$1.82 \pm 0.03 \text{ GeV}^2$$

Fit transverse mass distributions  $dN/dM_T$  in each centrality bin with thermal model:  $M_T^2 K_1(M_T/T)$

Extract effective **temperature**  $T$  from fit

note that  $T$  and  $\langle p_T^2 \rangle$  are linearly correlated

# $J/\psi$ 's $\langle p_T^2 \rangle$ from p-A to Pb-Pb



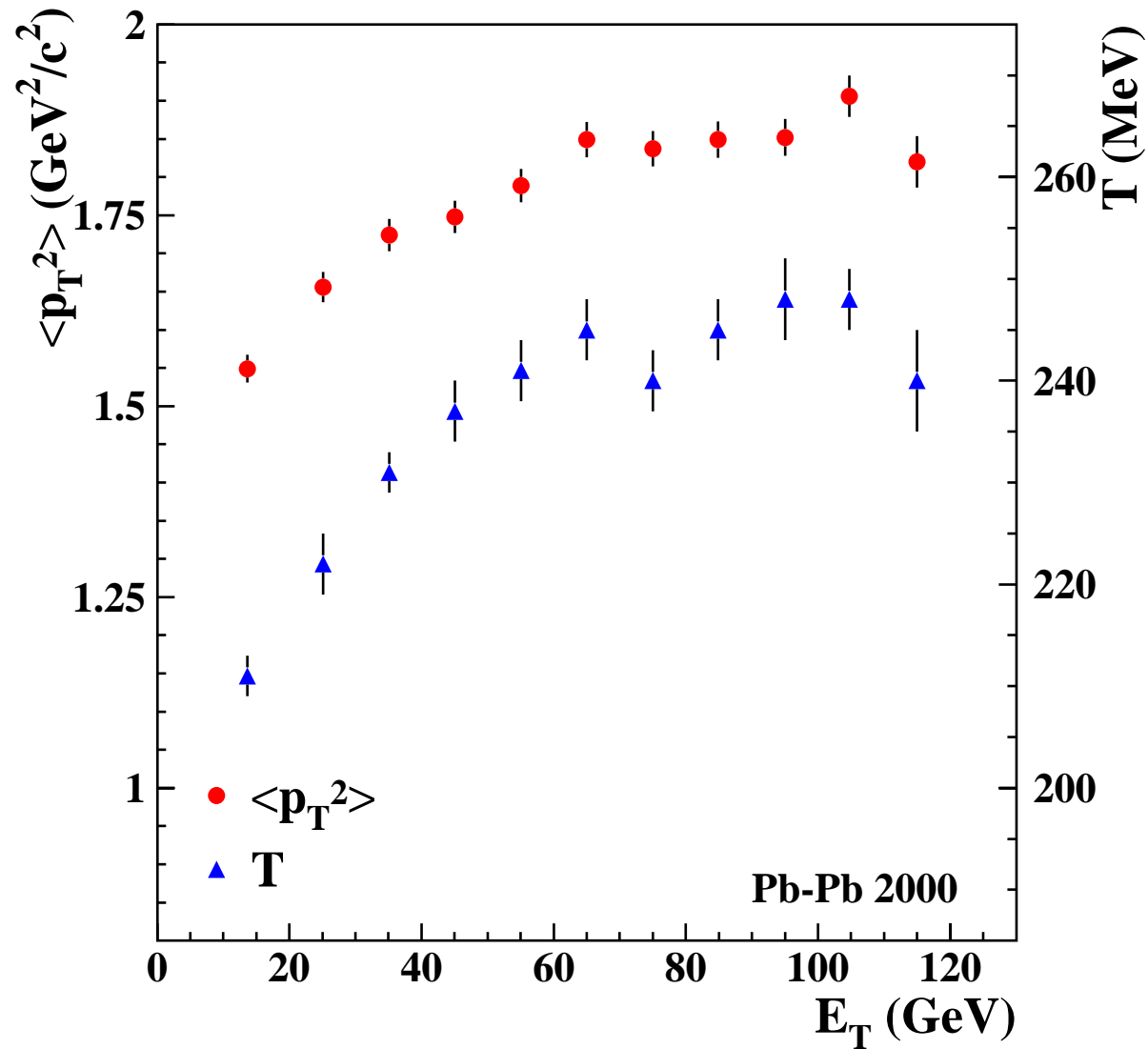
- All systems show that both  $\langle p_T^2 \rangle$  and  $T$  are **linearly increasing** with average path  $L$
- Attributed to multiple scattering of initial partons (gluons)
- Phenomenological description with the expression:

$$\langle p_T^2 \rangle (L) = \langle p_T^2 \rangle_{pp} + \alpha_{gN} L$$

with an energy dependent

$$\langle p_T^2 \rangle_{pp} \text{ and a common slope: } \alpha_{gN} = 0.081 \pm 0.002 \text{ GeV}^2/c^2/\text{fm}$$

# $\langle p_T^2 \rangle$ and $T$ of surviving $J/\psi$ 's vs. centrality

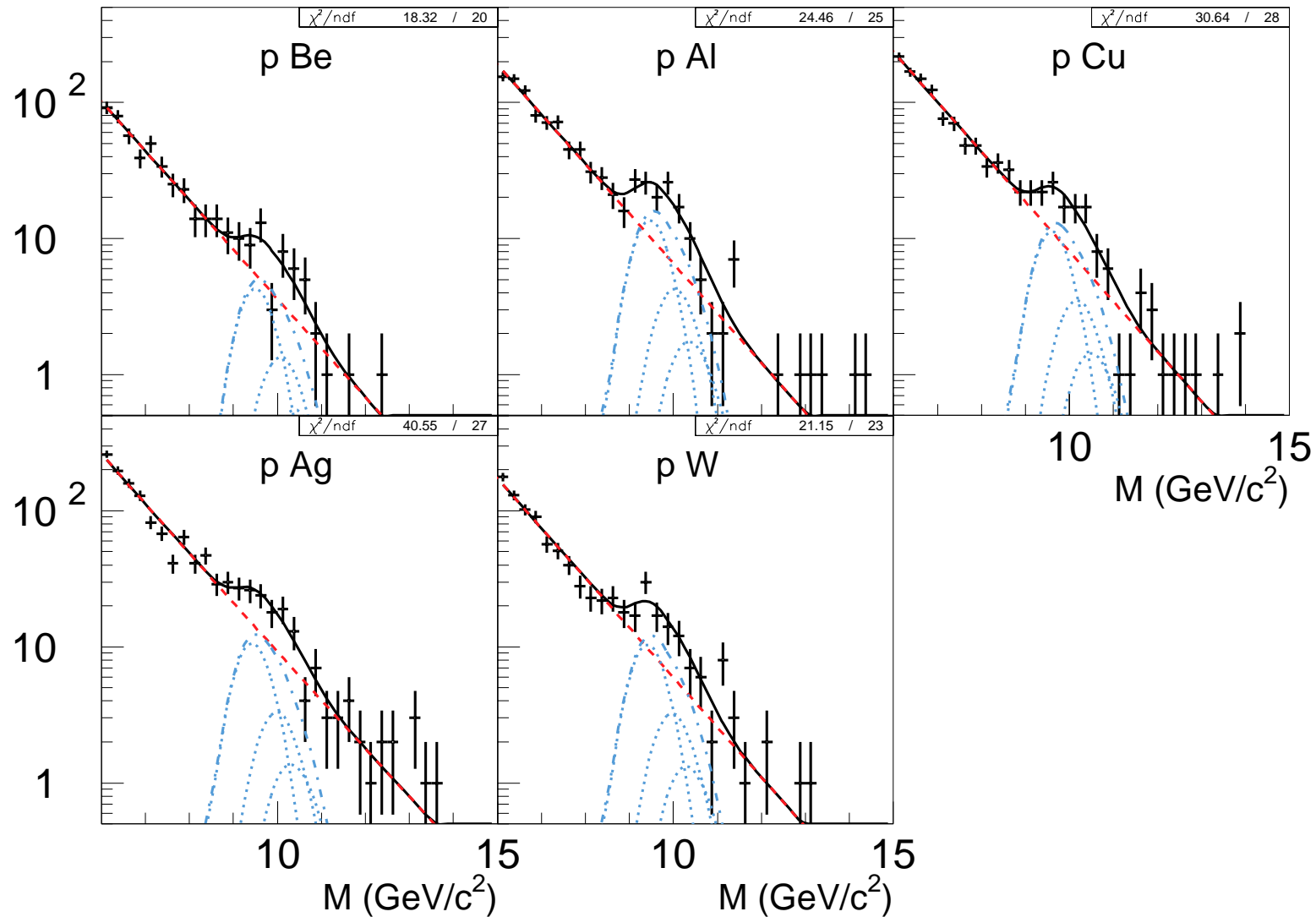


- More detailed examination of  $\langle p_T^2 \rangle$  and  $T$  in Pb-Pb vs. centrality (here vs. measured  $E_T$ )



- **Saturation of:**  
 $\langle p_T^2 \rangle$  vs.  $E_T$   
is observed for central Pb-Pb collisions
- **Same behaviour for:**  
 $T$  vs.  $E_T$

# $\Upsilon$ production in p-A collisions



Nuclear dependence of Drell-Yan and  $\Upsilon$  production at  $\sqrt{s} = 29.1$  GeV  
see **P. Cortese's talk at parallel session ...**

## Conclusions on charmonia

- Charmonium production and suppression:

with **normal** nuclear absorption

**derived from p-A collisions only**

we find in Pb-Pb collisions at 158 GeV/nucleon:

–  $(J/\psi)/DY$ :

- ◇ **Anomalous suppression** in semicentral and **central** collisions
- ◇ **Peripheral Pb-Pb BUT ALSO ALL OF S-U** production in **agreement with normal** nuclear absorption
- ◇ **Anomalous suppression** of  $J/\psi$  mostly **at low  $J/\psi$   $p_T$**

–  $\psi'/DY$ :

- ◇ **same suppression pattern in S-U and in Pb-Pb, very different from** normal absorption in **p-A collisions**

- $J/\psi$  transverse momentum distributions:

- ◇ **saturation of  $\langle p_T^2 \rangle$  and temperature  $T$  for central Pb-Pb collisions**

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