

The normal J/ψ nuclear absorption



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NA50 Collaboration

Outline

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- Data analyses
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 - 450 GeV, 400 GeV, 200 GeV
- Comparison with ion $B_{\mu\mu} \sigma(J/\psi)/AB$ results
 - 200 GeV O-Cu, O-U, S-U and 158 GeV Pb-Pb
- Comparison with ion $B_{\mu\mu} \sigma(J/\psi) / \sigma(DY)_{2.9-4.5}$ results
 - 200 GeV S-U and 158 GeV Pb-Pb
- Conclusions



Motivation

- NA50 studies J/ψ production in Pb-Pb collisions at 158 GeV.
- A very well grounded baseline, describing the normal J/ψ nuclear absorption, has to be established.
 - ▶ Study J/ψ production measured in proton collisions with several A targets.
- Extrapolate the expected J/ψ normal nuclear behaviour (as deduced from p-A collisions) to heavier systems.



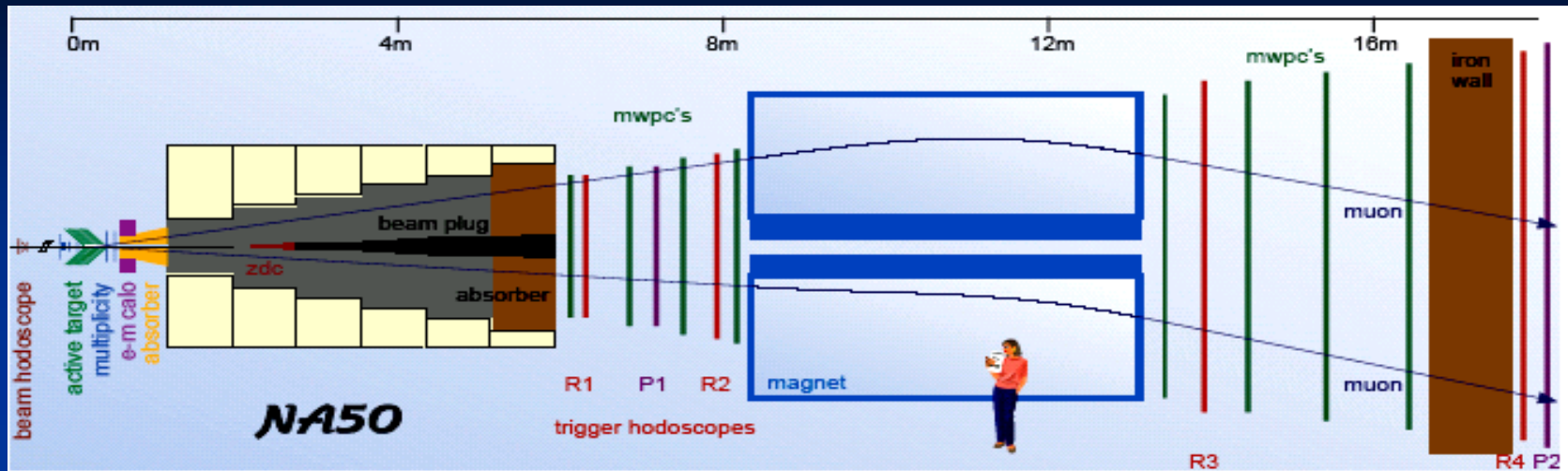
Available p-A data sets

- Several experiments have measured J/ψ production, in proton-nucleus collisions, at different energies and kinematical domains:
 - **NA50 experiment**
 - p-A (A = Be, Al, Cu, Ag, W) at 450 GeV
 - p-A (A = Be, Al, Cu, Ag, W, Pb) at 400 GeV
 - **NA51 experiment**
 - pp, pd at 450 GeV
 - **NA38 experiment**
 - p-A (A = C, Al, Cu, W) at 450 GeV
 - p-A (A = Cu, W, U) and A-B (O-Cu, O-U, S-U) at 200 GeV
 - **NA3 experiment**
 - pp, pPt at 200 GeV

Same Spectrometer



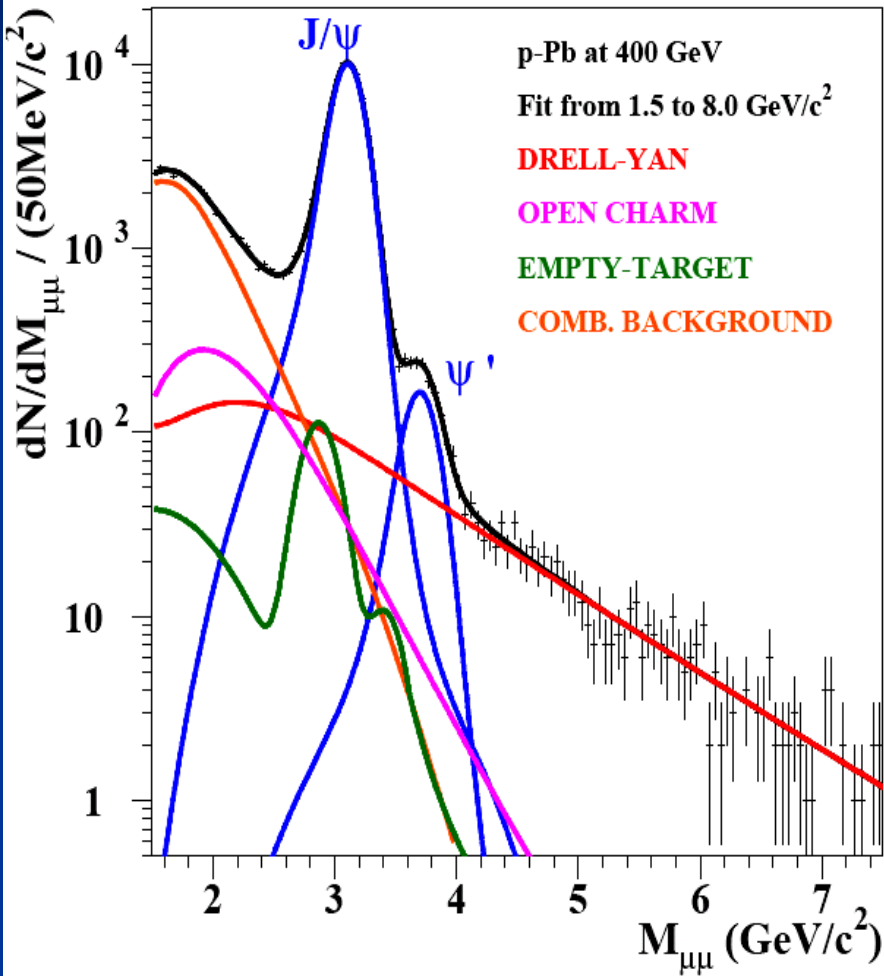
Experimental setups



	E_{lab} (GeV)	Data	$Y_{\mu\mu}^*$	$ \text{Cos}(\theta_{\text{CS}}) $	Absorber
NA50	450	p-A	-0.50 : 0.50	< 0.5	C, Fe
NA50	400	p-A	-0.45 : 0.55	< 0.5	C, Fe
NA50	158	Pb-Pb	0.00 : 1.00	< 0.5	C, Fe
NA51	450	pp, pd	-0.40 : 0.60	< 0.5	C, Fe
NA38	450	p-A	-0.40 : 0.60	< 0.5	C
NA38	200	p-A	0.00 : 1.00	< 0.5	C
NA38	200	A-B	0.00 : 1.00	< 0.5	C

Data analyses

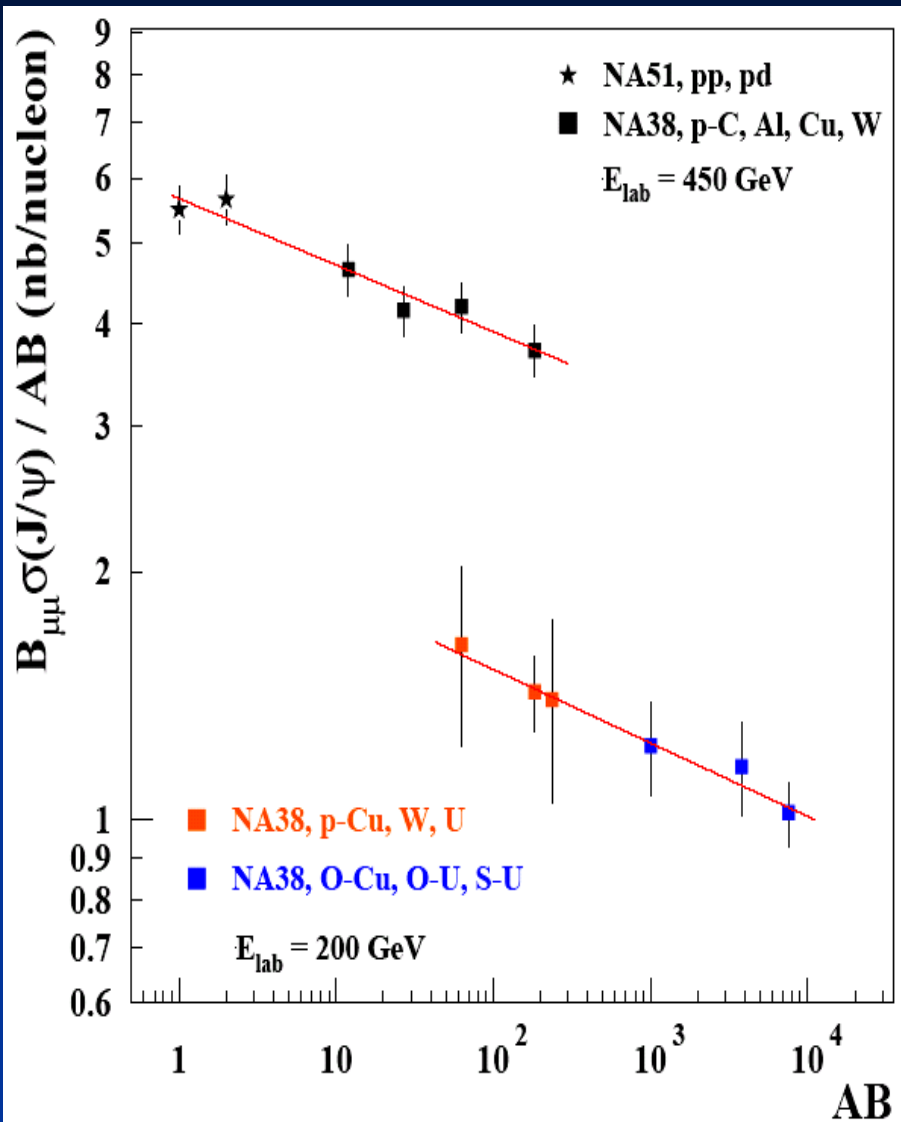
$$N_{J/\psi} \frac{dN_{J/\psi}}{dM} + N_{\psi'} \frac{dN_{\psi'}}{dM} + N_{DY} \frac{dN_{DY}}{dM} + N_{D\bar{D}} \frac{dN_{D\bar{D}}}{dM} + \frac{dN_{Bkg}}{dM} + \frac{dN_{Empty}}{dM}$$



- NA50, NA51 and NA38 analyses are performed with identical methods.
- The experimental dimuon opposite-sign mass spectrum is analysed through a fit including several ingredients:
 - $J/\psi \rightarrow \mu^+\mu^-$
 - $\psi' \rightarrow \mu^+\mu^-$
 - Drell-Yan process
 - Correlated semileptonic decays of open charm mesons.
 - Combinatorial background



NA51 and NA38 joint α fit

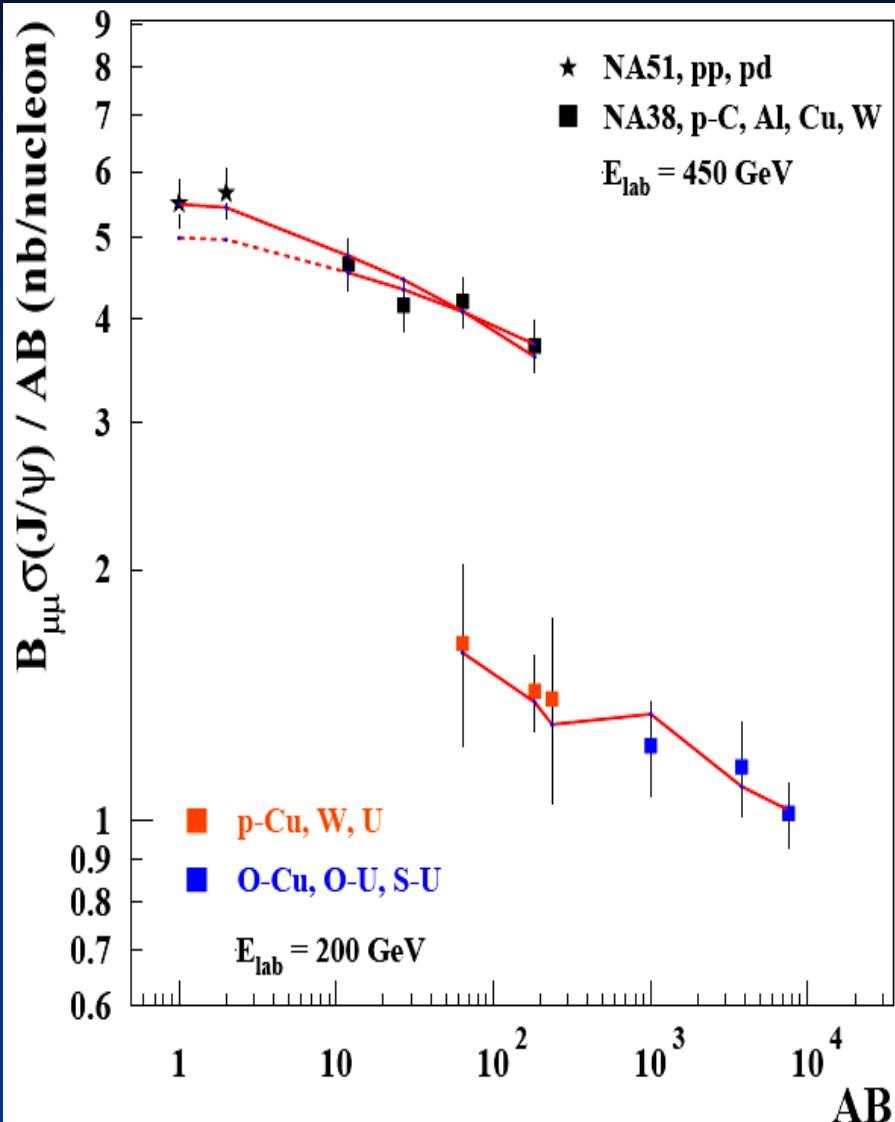


- NA38 has measured J/ψ production in several systems at 450 GeV and 200 GeV.
- NA38 results are compiled in PLB 466 (1999) 408 and analysed together with NA51 450 GeV pp, pd results.
- J/ψ nuclear dependence was parametrized as $\sigma(J/\psi) = \sigma_0 A^\alpha$

P_{lab}	N_0 (nb)	$\alpha_{J/\psi}$
450 GeV	5.7 ± 0.3	0.919 ± 0.015
200 GeV	2.3 ± 0.6	0.911 ± 0.034



NA51 and NA38 joint Glauber fit



- A **Glauber Model** was used to describe J/ψ nuclear dependence production

E_{lab}	N_0 (nb)	σ_{abs} (mb)
450 GeV	5.5 ± 0.2	7.1 ± 1.6
200 GeV	2.2 ± 0.5	7.8 ± 3.5

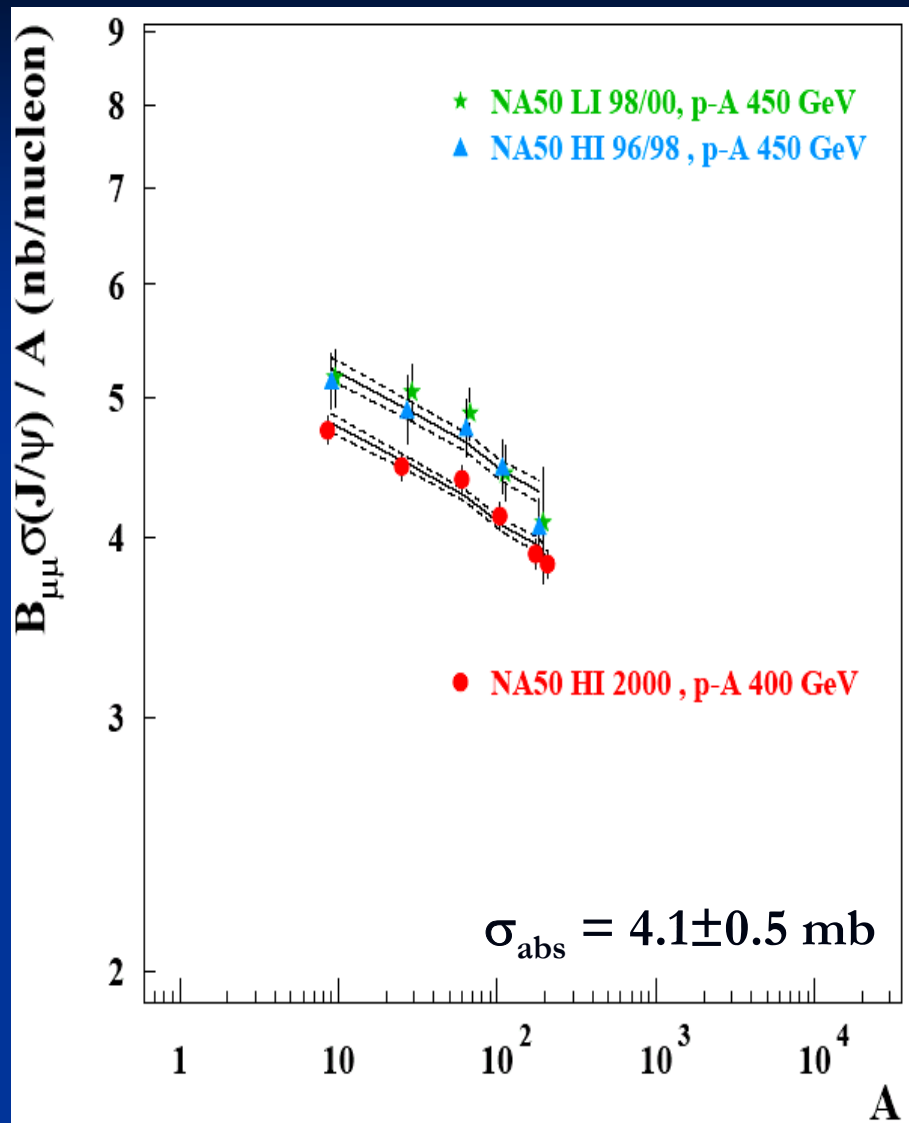
- If NA51 results are excluded from the Glauber fit, we obtain:

E_{lab}	N_0 (nb)	σ_{abs} (mb)
450 GeV	5.0 ± 0.5	4.8 ± 2.6
200 GeV	2.2 ± 0.5	7.8 ± 3.5

- ▶ Possible normalization problem between NA51 and NA38 450 GeV p-A results?



NA50 Glauber fit results



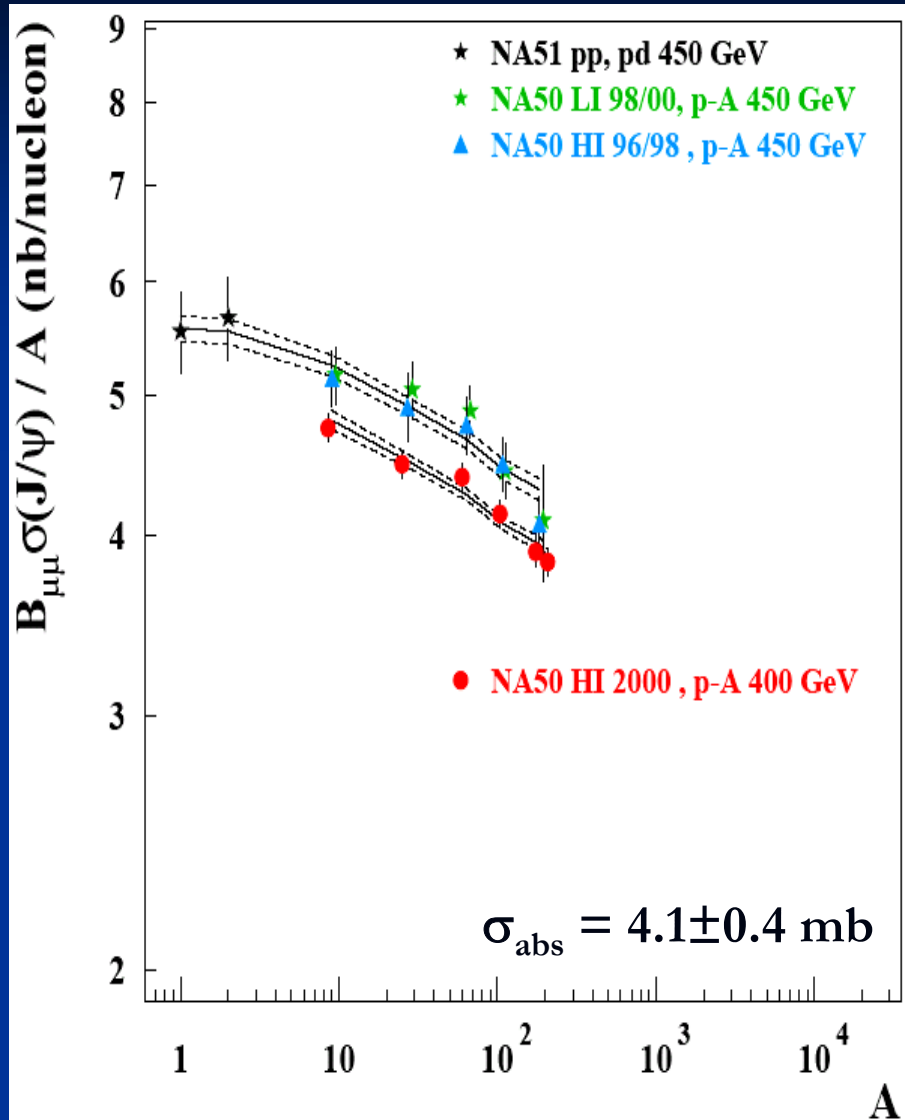
- NA50 has 3 different p-A data collections, at 2 different energies and using several targets (A=Be,Al,Cu,Ag,W,Pb)

Set	E_{lab}	N_0 (nb)	σ_{abs} (mb)
HI 96/98	450 GeV	5.6 ± 0.3	4.4 ± 1.2
LI 98/00	450 GeV	5.6 ± 0.3	4.0 ± 1.4
HI 2000	400 GeV	5.1 ± 0.1	4.0 ± 0.5

- Results from different data sets are compatible
- Perform a simultaneous Glauber fit

E_{lab}	N_0 (nb)	σ_{abs} (mb)
450 GeV	5.6 ± 0.1	4.1 ± 0.5
400 GeV	5.1 ± 0.1	

NA51 and NA50 joint Glauber fit



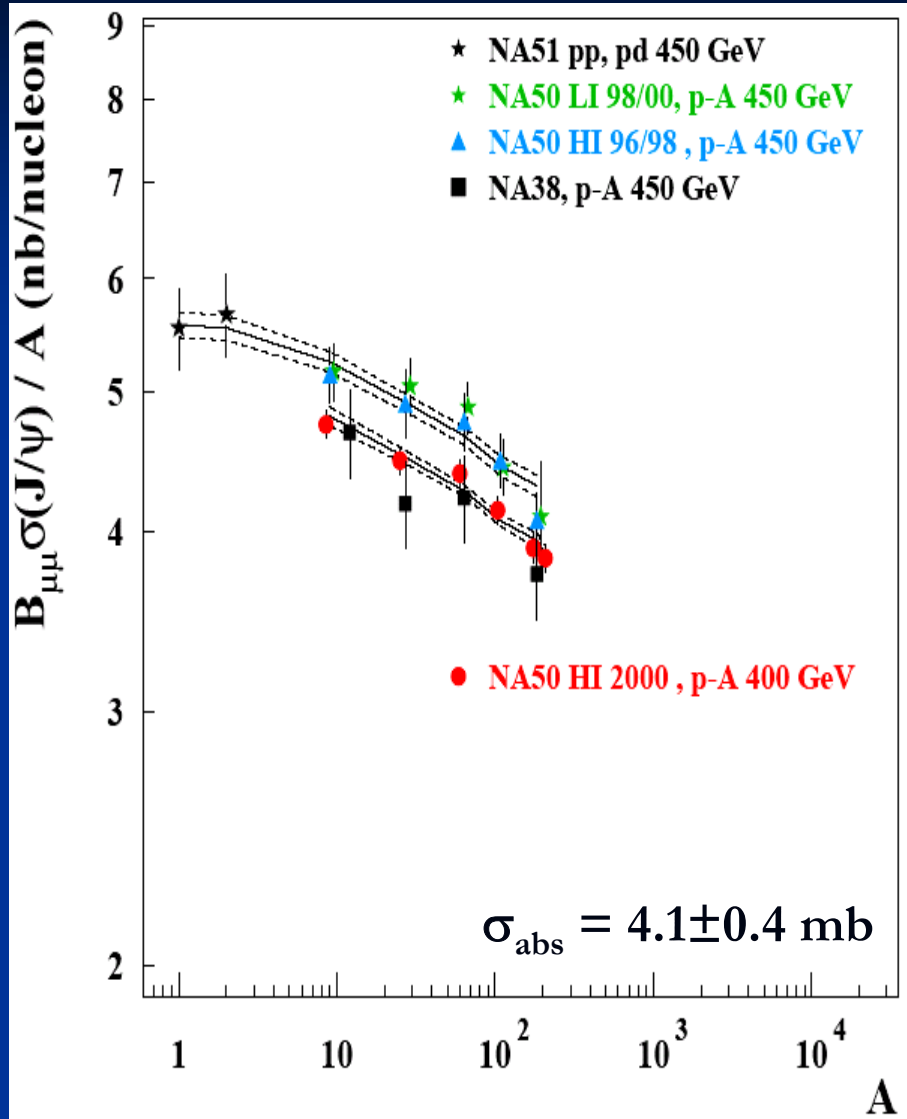
- Glauber fit results including NA51 data

P_{lab}	N_0 (nb)	σ_{abs} (mb)
450 GeV	5.6 ± 0.1	4.1 ± 0.4
400 GeV	5.1 ± 0.1	

- NA51 results are consistent with the extrapolated Glauber behaviour from the NA50 450 GeV p-A results.
- No apparent problem in normalization between NA51 and NA50 450 GeV p-A results.



NA51, NA50 and NA38 Glauber fit

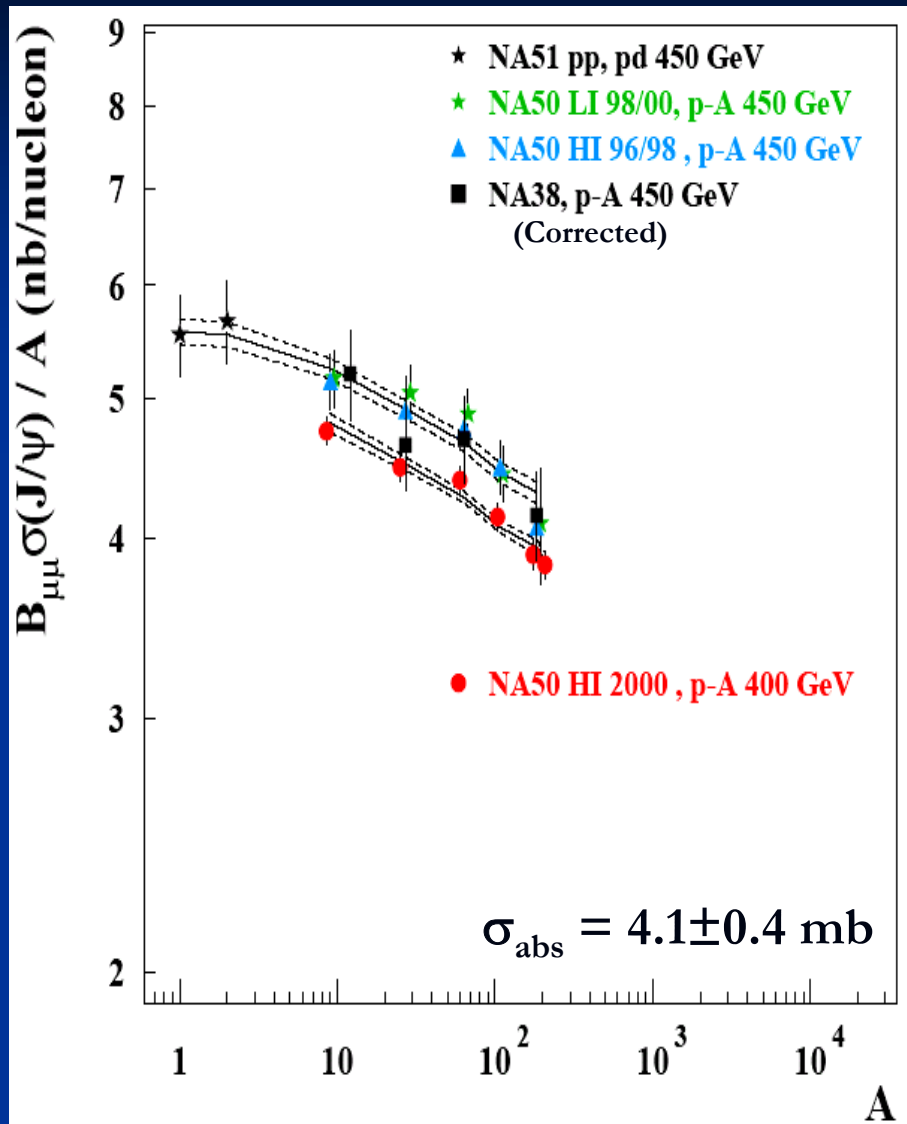


- NA50 and NA38 p-A 450 GeV results are not in agreement regarding normalization.

- ▶ Possible systematic problem on NA38 cross-section measurements when compared to NA50.

Set	E_{lab}	N_0 (nb)	σ_{abs} (mb)
NA50	450 GeV	5.6 ± 0.1	4.1 ± 0.4
NA50	400 GeV	5.1 ± 0.1	
NA38	450 GeV	4.9 ± 0.2	

NA51, NA50 and NA38 Glauber fit



- We revisited the NA38 studies.
 - A problem was found in the NA38 450 GeV p-A reconstruction.
 - This problem does not affect the NA38 p-A 200 GeV results (at much lower intensity beam).
 - An overall $\sim 11\%$ correction has to be applied to the NA38 450 GeV p-A results.

Set	P_{lab}	N_0 (nb)	σ_{abs} (mb)
NA50	450 GeV	5.6 ± 0.1	4.1 ± 0.4
NA50	400 GeV	5.1 ± 0.1	
NA38 (corrected)	450 GeV	5.5 ± 0.2	

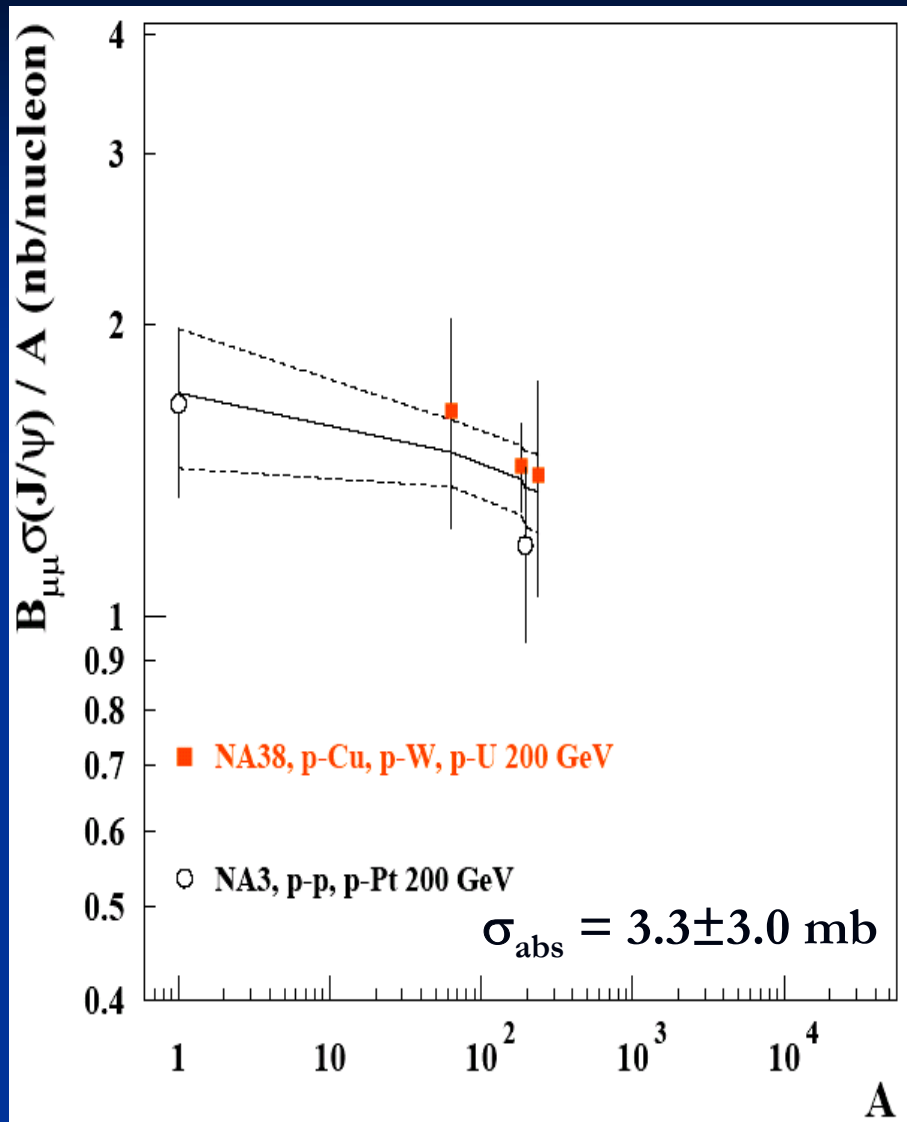


NA50 and NA38 comparisons

- The fact that NA50 450 GeV p-A results are now compatible with NA38 450 GeV p-A results (within 2-3%) indicate that:
 - The systematic differences between the two experiments are small and under control;
 - NA50 data at 450/400 GeV can be safely compared with NA38 data at 200 GeV, in terms of slopes and normalizations.



NA38 and NA3 200 GeV Glauber fit



- The 200 GeV NA38 p-A results are not sufficient to extract σ_{abs} .
- NA3 has measured J/ψ production in pp and pPt collisions at 200 GeV. The inclusion of these data in the Glauber fit will constrain the σ_{abs} determination.

E_{lab}	N_0 (nb)	σ_{abs} (mb)
200 GeV	1.7 ± 0.3	3.3 ± 3.0

Comparison of σ_{abs} results

- Glauber fit results to the 450/400 GeV p-A data:

E_{lab}	N_0 (nb)	σ_{abs} (mb)
450 GeV	5.6 ± 0.1	4.1 ± 0.4
400 GeV	5.1 ± 0.1	

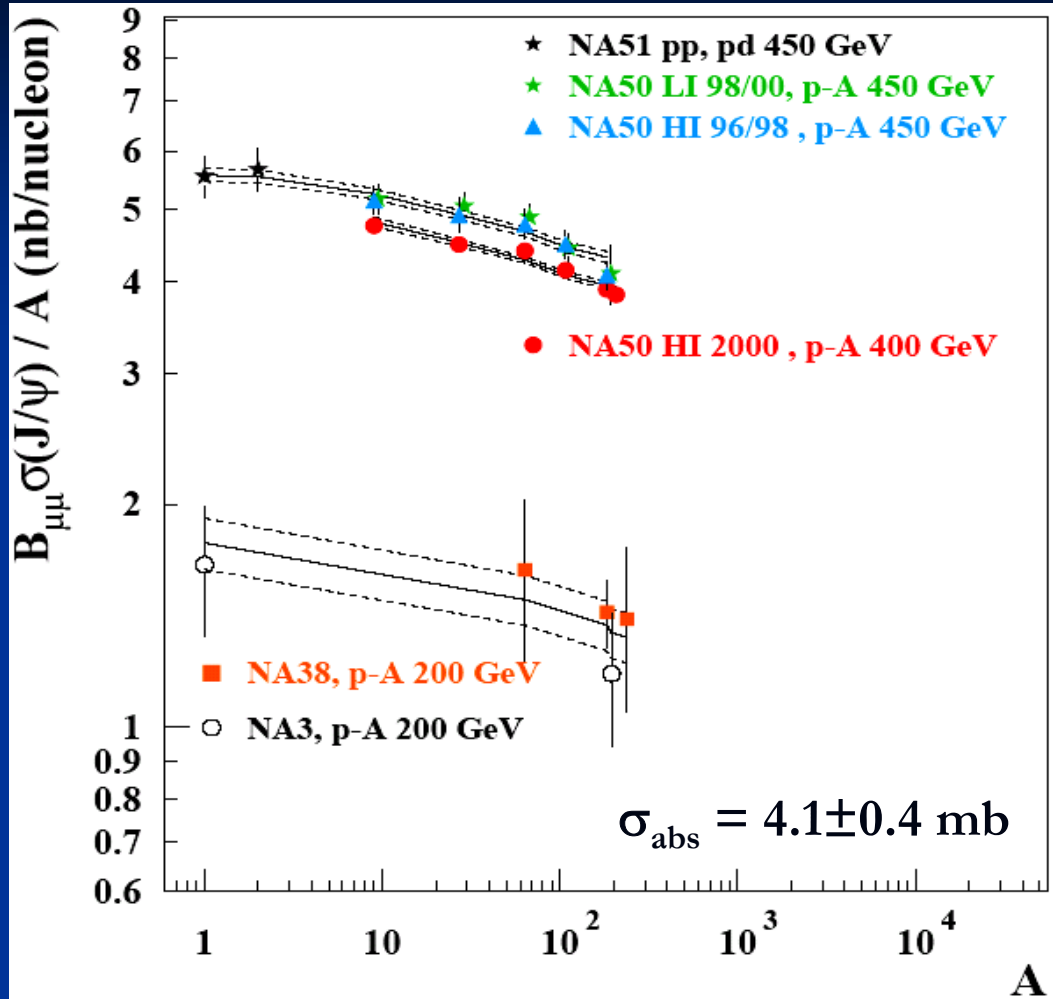
- Glauber fit results to the 200 GeV p-A data

E_{lab}	N_0 (nb)	σ_{abs} (mb)
200 GeV	1.7 ± 0.3	3.3 ± 3.0

- σ_{abs} is determined with bad accuracy at 200 GeV. However, these data are important since they establish the normalization at lower energies.
- σ_{abs} results for the different energies are compatible
 - ▶ Assume σ_{abs} is constant between 450, 400 and 200 GeV.



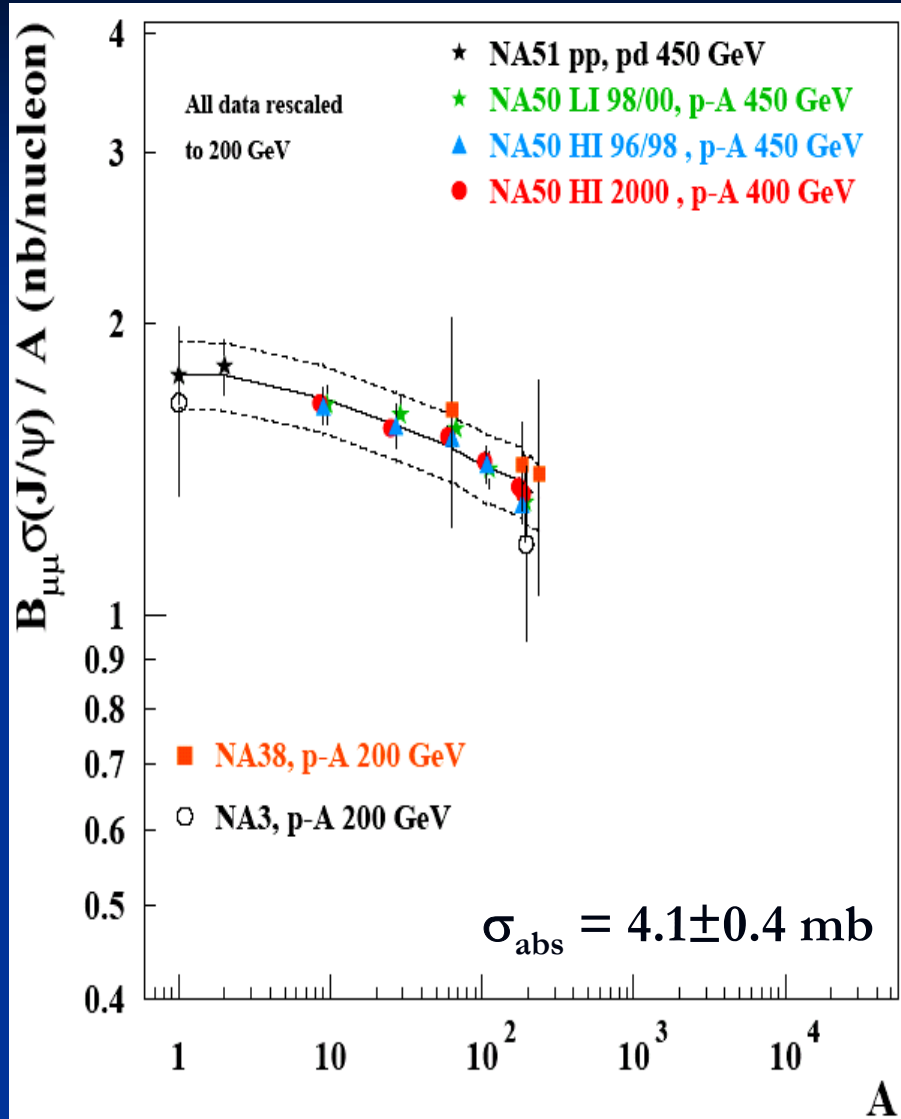
Final σ_{abs} results



- Final results are obtained from a simultaneous Glauber fit performed for the 450/400/200 GeV p-A data

N_0^{200} (nb)	N_0^{400} (nb)	N_0^{450} (nb)	N_0^{200}/N_0^{400}	N_0^{200}/N_0^{450}	σ_{abs} (mb)
1.8 ± 0.1	5.1 ± 0.1	5.6 ± 0.1	0.348 ± 0.027	0.319 ± 0.025	4.1 ± 0.4

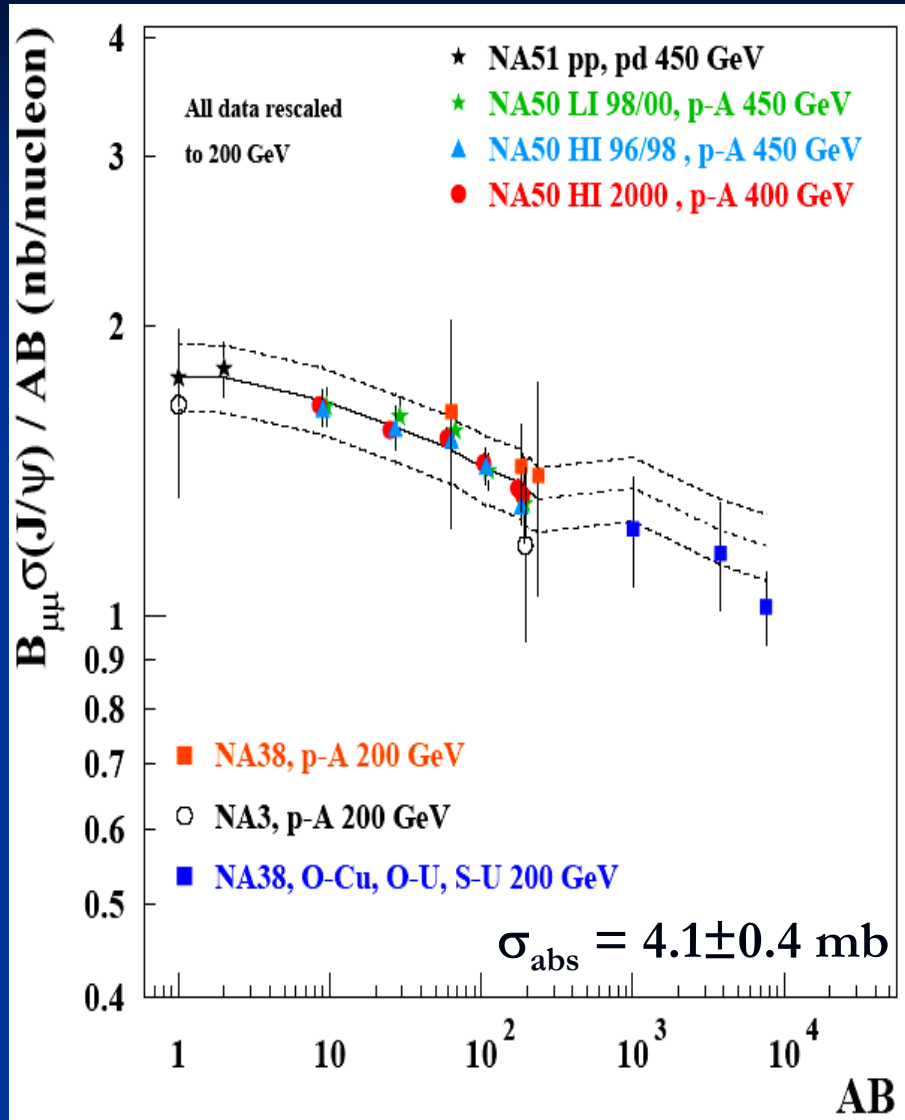
Experimental rescaling to 200 GeV



- The ratios N_0^{200}/N_0^{450} and N_0^{200}/N_0^{400} are used to scale down J/ψ absolute cross-sections from higher energies to 200 GeV.
- The rescale systematic error (7.8%) is not included in the data error bars.



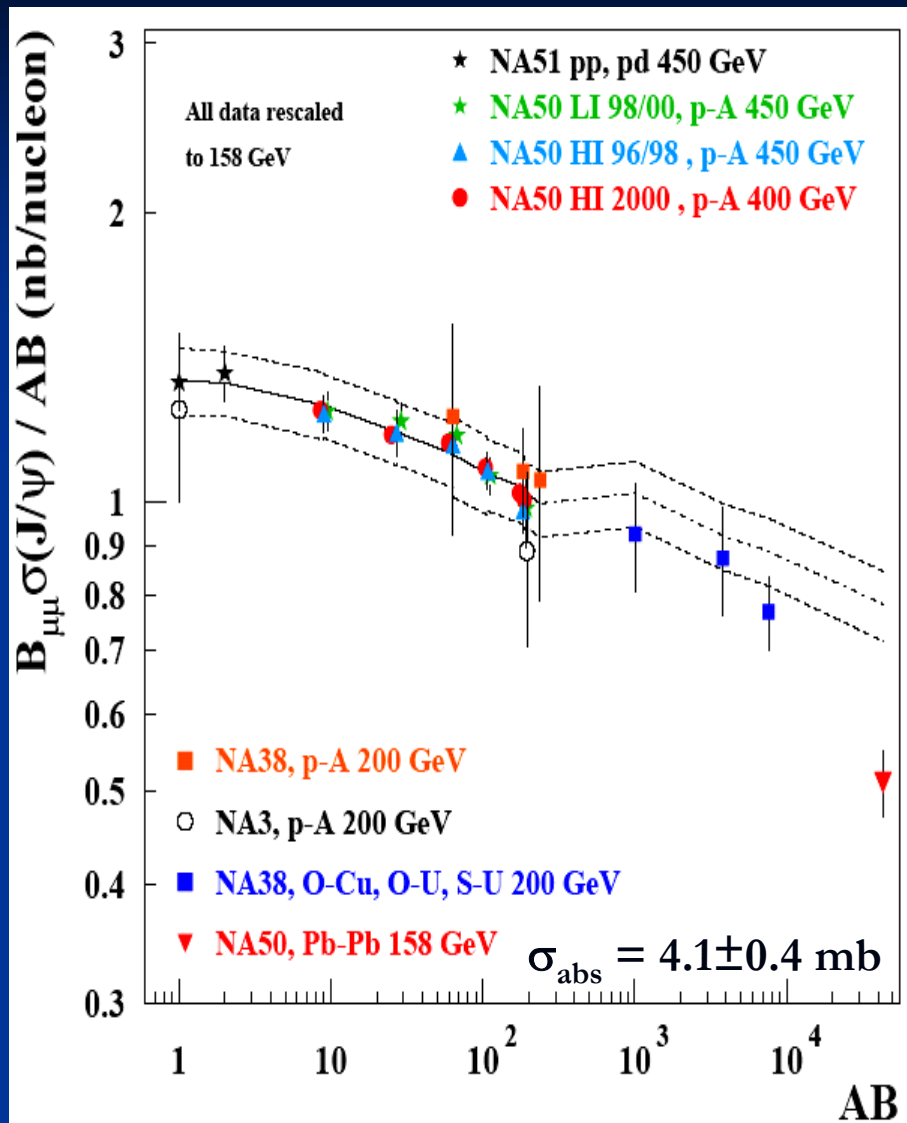
Comparison with NA38 light ion data



- The A-B data from NA38 are not included in the Glauber fits.
- They are just plotted and compared with the corresponding Glauber estimation deduced from **p-A data**.



Comparison with NA50 Pb-Pb results



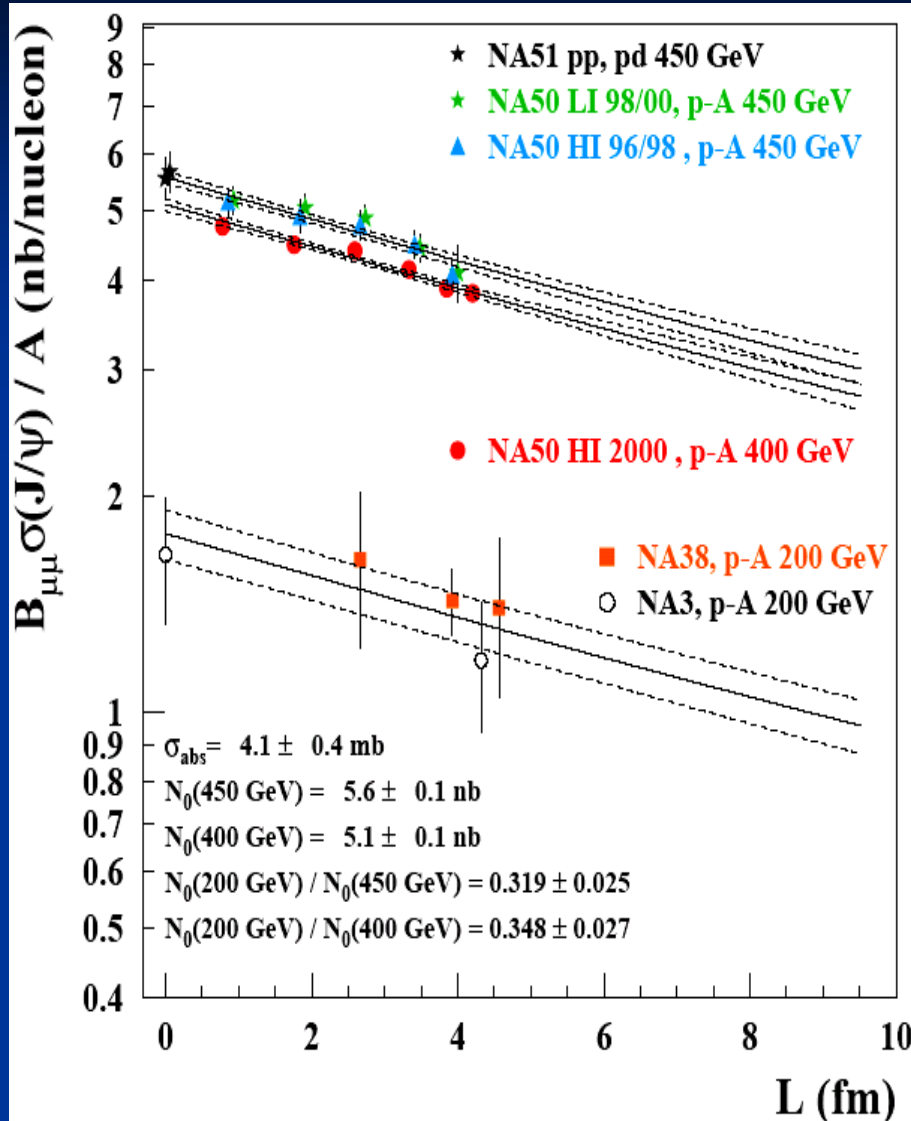
- NA50 has also measured Pb-Pb J/ψ absolute cross-section at 158 GeV.

- The “Schuler parametrization” (in energy and x_F) is used to scale down all data from the 200 GeV kinematical domain to the 158 GeV kinematical domain.

- The Pb-Pb J/ψ production result is compared with the extrapolated Glauber behaviour deduced from p-A data with no assumptions at all regarding A-B results.



ψ absorption curve as a function of L



- The same absorption curve, with $\sigma_{abs} = 4.1 \pm 0.4 \text{ mb}$, is drawn as a function of L, the average path length of J/ ψ in nuclear matter, for the 3 different energies:

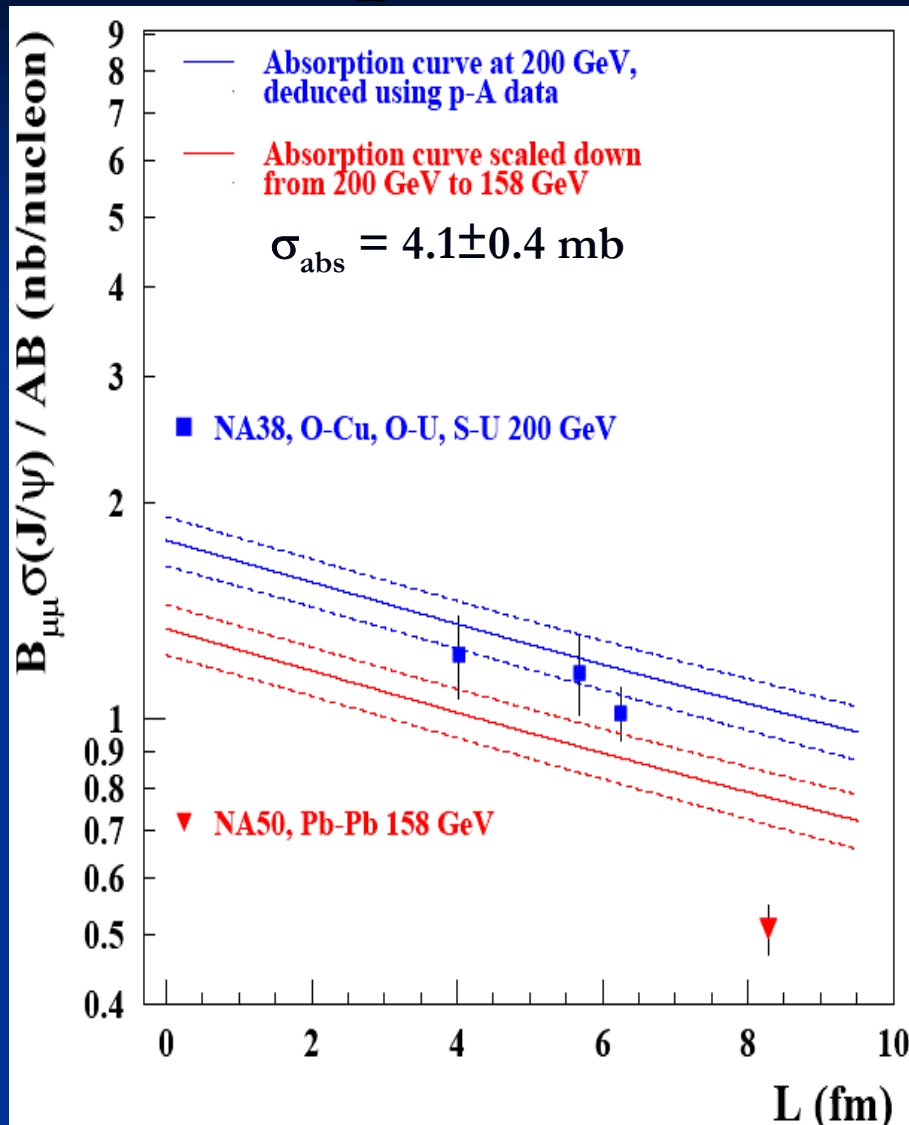
- 450 GeV

- 400 GeV

- 200 GeV



ψ absorption curve as a function of L (2)

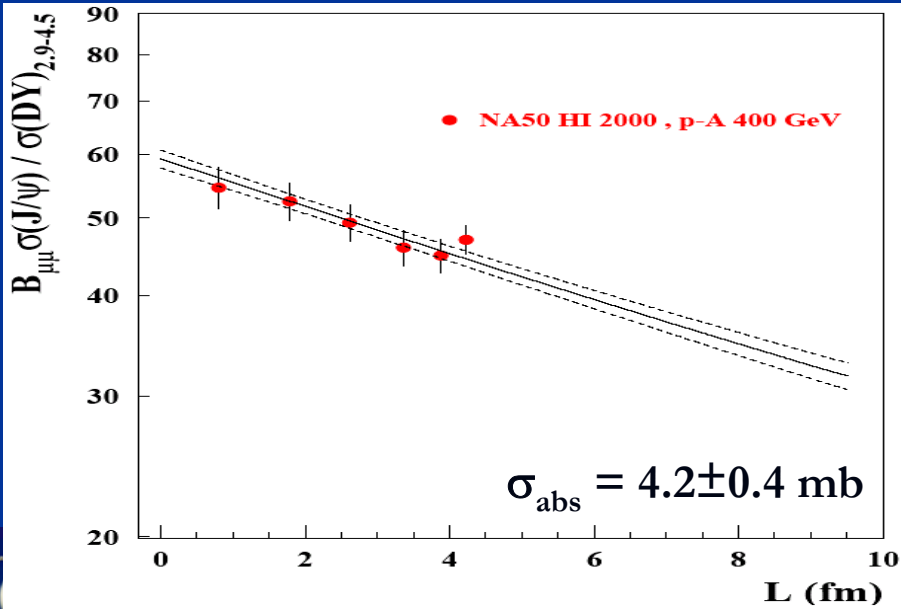
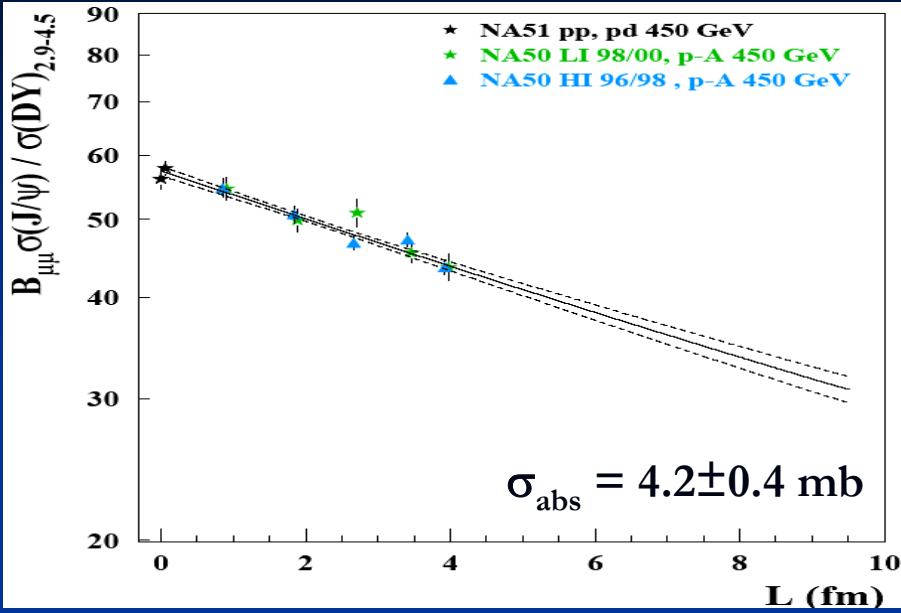


- The absorption curve is directly compared with NA38 $B_{\mu\mu} \sigma(\psi) / AB$ results at 200 GeV.

- The absorption curve has to be scaled down to the NA50 158 GeV kinematical domain for a direct comparison with Pb-Pb $B_{\mu\mu} \sigma(\psi) / AB$ results.



p-A $B_{\mu\mu} \sigma(\psi) / \sigma(DY)_{2.9-4.5} \sigma_{abs}$ result

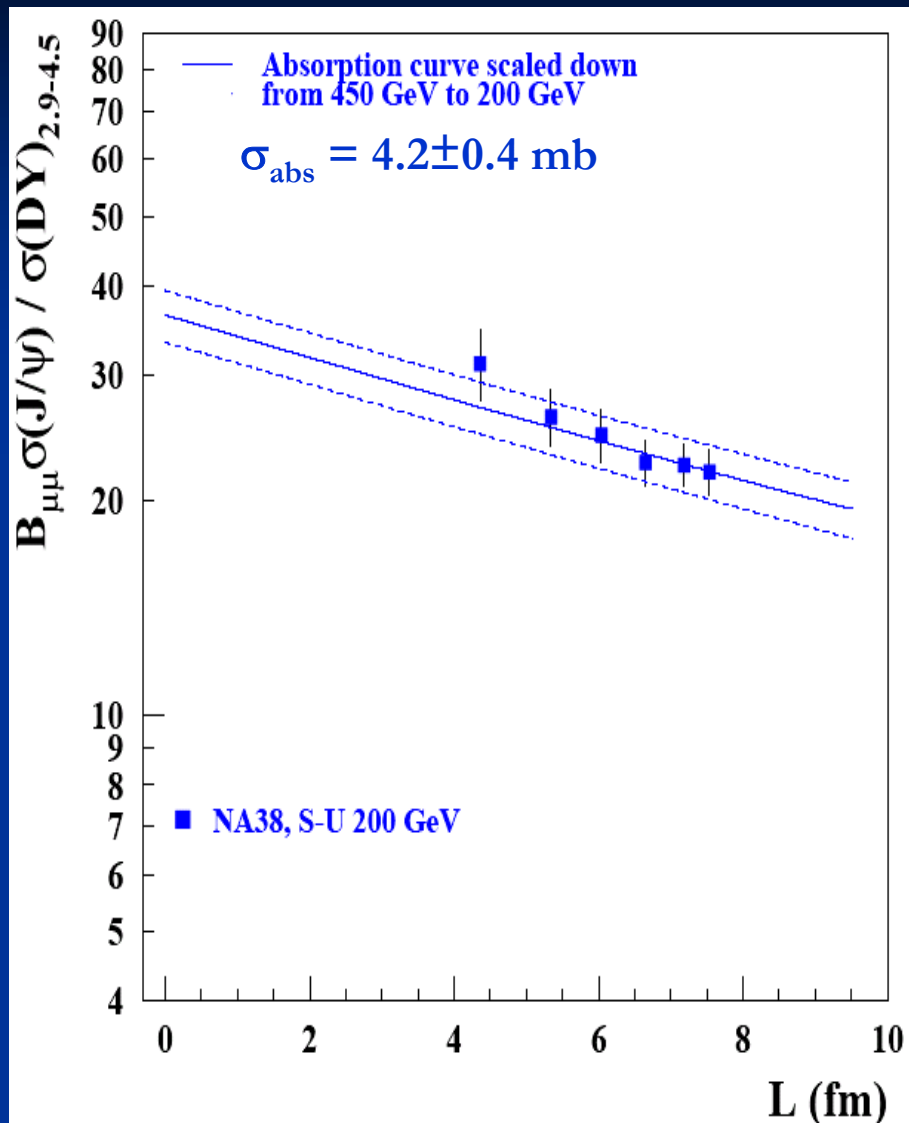


- $B_{\mu\mu} \sigma(\psi) / \sigma(DY)_{2.9-4.5}$ results in p-A collisions are extracted from NA51 and NA50 data. A Glauber fit is performed using these measurements:

P_{lab}	N_0 (Ψ/DY)	σ_{abs} (mb)
450 GeV	57.5 ± 0.8	4.2 ± 0.4
400 GeV	59.3 ± 1.5	

- This σ_{abs} value is in good agreement with the one obtained from $B_{\mu\mu} \sigma(\psi) / AB$ results ($\sigma_{abs} = 4.1 \pm 0.4 \text{ mb}$).

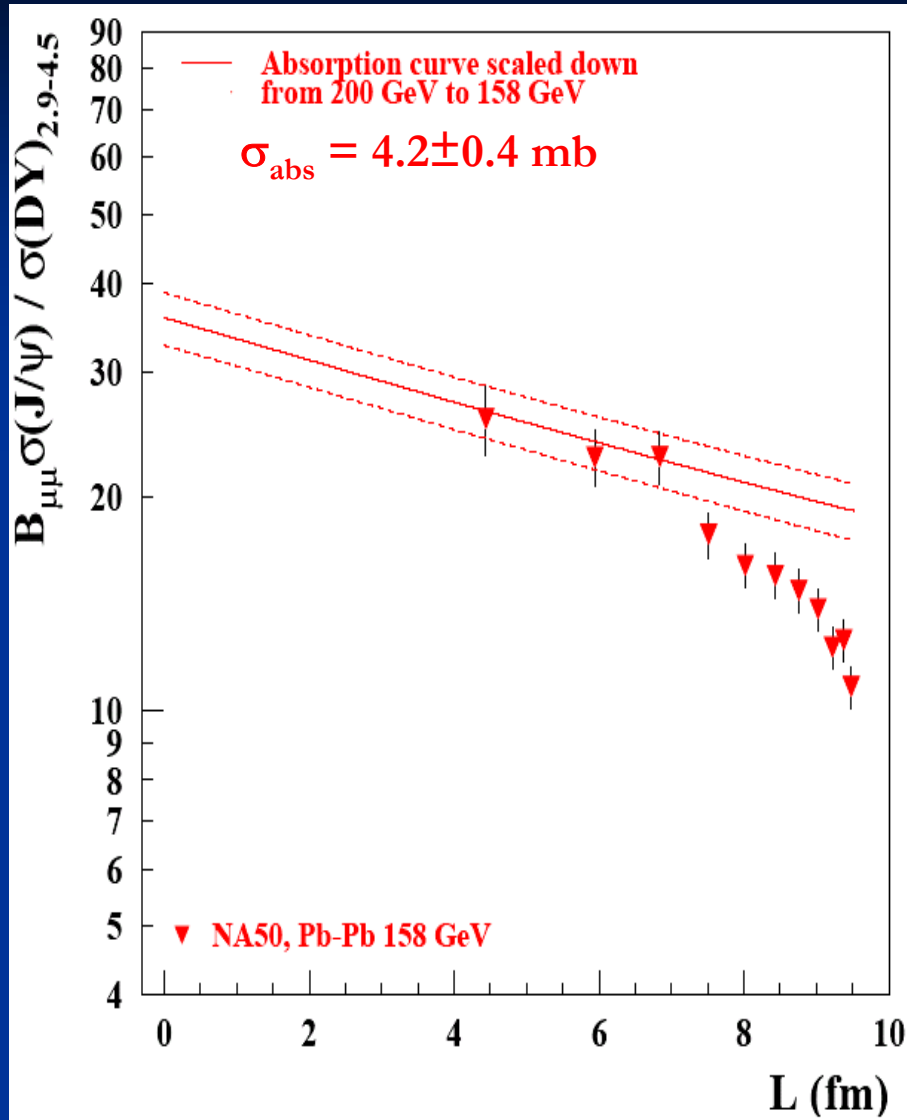
ψ /DY absorption curve as a function of L



- The ψ /DY absorption curve is **scaled down to 200 GeV** using the J/ψ experimental rescales measured in p-A data and a LO DY calculation.
- S-U $B_{\mu\mu} \sigma(\psi) / \sigma(DY)_{2.9-4.5}$ results at 200 GeV are compared with the absorption curve.



ψ /DY absorption curve as a function of L (2)



- $B_{\mu\mu} \sigma(\psi) / \sigma(DY)_{2.9-4.5}$
Pb-Pb results are compared with an absorption curve **scaled down from 200 GeV to 158 GeV using Schuler energy/ x_F dependence** and a LO DY calculation.



Summary and Conclusions

- J/ψ production was deeply studied using the **available p-A data** at different energies (450, 400 and 200 GeV) from several experiments (NA51, NA50, NA38 and NA3).
- From the J/ψ absolute cross-section used in this study, we have obtained
 - $\sigma_{\text{abs}}(450, 400 \text{ GeV}) = 4.1 \pm 0.4 \text{ mb}$
 - $\sigma_{\text{abs}}(200 \text{ GeV}) = 3.3 \pm 3.0 \text{ mb}$

allowing us to assume that σ_{abs} may be the same within the energy range and kinematical domains of the different experiments.



Summary and Conclusions (2)

- Results from a simultaneous fit to p-A data at the different energies and kinematical domains, give $\sigma_{\text{abs}} = 4.1 \pm 0.4 \text{ mb}$ and allow to scale down absolute cross-section from higher energies to 200 GeV.
- We observe that the J/ ψ NA38 O-Cu, O-U and S-U results lie on top of the absorption curve deduced from p-A data.
- Pb-Pb results are systematically below the absorption curve, either in:
 - $B_{\mu\mu} \sigma(\psi) / \text{AB}$ measurements
 - $B_{\mu\mu} \sigma(\psi) / \sigma(\text{DY})_{2.9-4.5}$ measurements



More details in analysis method

- The opposite sign mass spectrum is analysed in a multistep fit procedure:
 - $1.5 \leq M_{\mu\mu} < 8.0 \text{ GeV}/c^2 \rightarrow 1^{\text{st}} \text{ approach. Obtain good initial values.}$
 - $1.5 \leq M_{\mu\mu} < 2.3 \text{ GeV}/c^2 \rightarrow \text{Get } R_{\text{BKG}}$
 - $2.7 \leq M_{\mu\mu} < 4.1 \text{ GeV}/c^2 \rightarrow \text{Precise definition of the resonance shapes}$
 - $1.5 \leq M_{\mu\mu} < 8.0 \text{ GeV}/c^2 \rightarrow \text{Get } N_{\psi}, N_{\psi'}, N_{\text{DY}}, N_{\text{DD}} \text{ contributions}$
- Acceptances and physical shapes of the different contributions are obtained via MC and spectrometer simulation.
- Background shape is obtained from the like sign mass spectra coming from π^{\pm}, K^{\pm} uncorrelated decays
$$N^{\pm} = 2 R_{\text{BKG}} (N^{++} N^{--})^{1/2}$$
- An empty target contribution is included taking into account dimuons produced upstream and downstream from the target.



Systematics between NA38 and NA3 ?

- The systematics between NA3 and NA38 data at 200 GeV may exist.
- We have increased NA3 data by a factor 1.21 corresponding to the ratio

$$(\sigma_{pW}/A_W)|_{NA38} / (\sigma_{pPt}/A_{Pt})|_{NA3}$$

- The simultaneous Glauber calculation was performed as before. We have obtained:

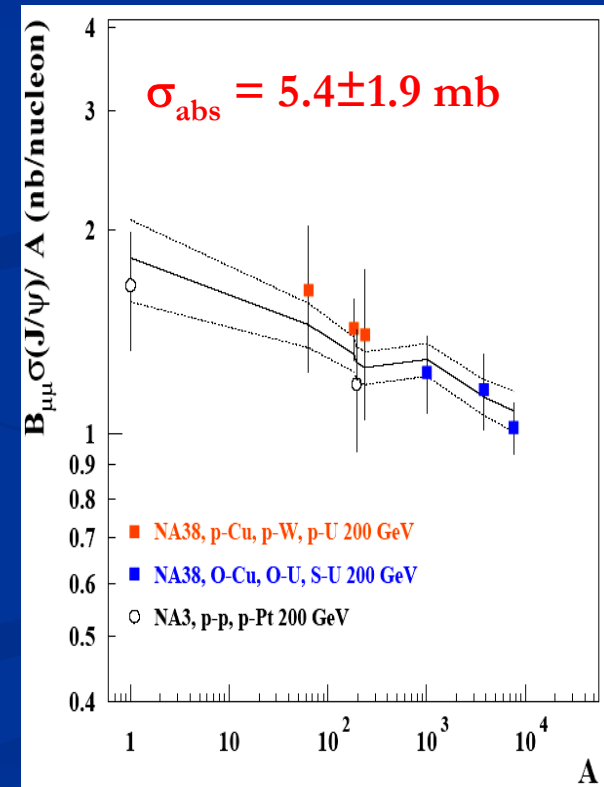
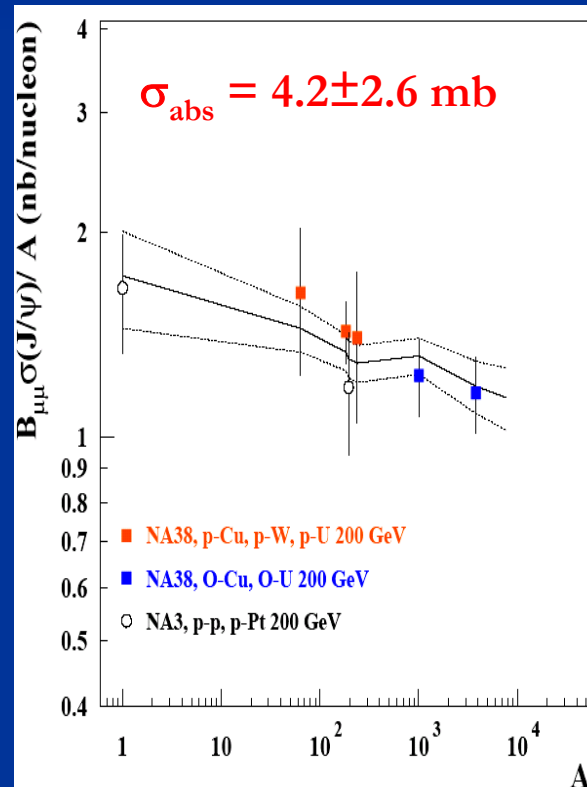
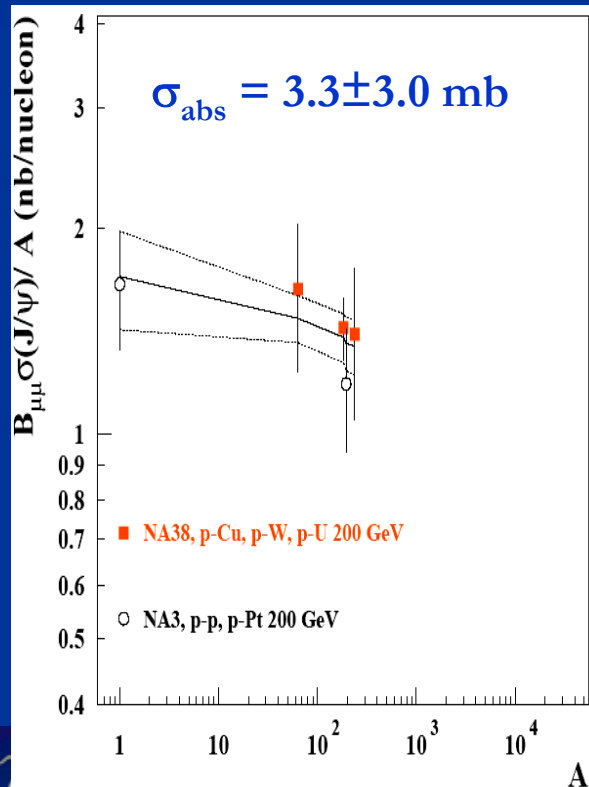
E_{lab}	N_0 (nb)	σ_{abs} (mb)
200 GeV	1.7 ± 0.3	3.3 ± 3.0
200 GeV	2.0 ± 0.4	5.4 ± 3.4



200 GeV A-B Glauber fit results

- Include A-B results in the Glauber fits at 200 GeV

E_{lab}	p-A	O-Cu,U	S-U	N_0 (nb)	σ_{abs} (mb)
200 GeV	✓			1.7 ± 0.3	3.3 ± 3.0
200 GeV	✓	✓		1.7 ± 0.3	4.2 ± 2.6
200 GeV	✓	✓	✓	1.8 ± 0.3	5.4 ± 1.9



From NA3 to NA38 kinematical domain

- NA3 has measured J/ψ production in pp, pPt collisions. Results are obtained to $x_F > 0$ and reported in Z. Phys. C20 (1983) 101.

	$\sigma_{\pi-A}$ (nb/nuc)	$\sigma_{p-A} / \sigma_{\pi-A}$	σ_{p-A} (nb/nuc)
H ₂	6.3±0.8	0.58±0.07	3.654±0.640
Pt	4.92±0.77	0.53±0.05	2.608±0.477

- Rescale to NA38 kinematical domain:

- Divide by a factor 2 (assuming an uniform $|\cos(\theta_{CS})|$ distribution)
- Multiply by 0.907 ± 0.084 to rescale to NA38 x_F domain at 200 GeV.

- $d\sigma/dx_F \sim (1 - |x_F|)^d$

	σ_{p-A} (nb/nuc)
H ₂	1.657±0.328
Pt	1.182±0.242



“Schuler parametrization” and R.Vogt calculations

■ NA51/NA50/NA38/NA3 experimental rescale

$$\sigma_0(450 \text{ GeV}, -0.5 < Y_{\mu\mu} < 0.5) / \sigma_0(200 \text{ GeV}, 0.0 < Y_{\mu\mu} < 1.0) =$$

$$0.319 \pm 0.025$$

■ Comparison with other J/ψ production descriptions

E_{lab}	x_F	Schuler (E, x_F)	R. Vogt (E, x_F)
450 GeV → 200 GeV	[-0.11 : 0.11[→ [0.00 : 0.38[$(0.460 \pm 0.009) * (0.866 \pm 0.139) =$ 0.398 ± 0.064	$0.394 * 0.947 = 0.373$
200 GeV → 158 GeV	[0.00: 0.38[→ [0.00: 0.42[$(0.738 \pm 0.006) * (1.020 \pm 0.013) =$ 0.753 ± 0.011	$0.724 * 1.026 = 0.743$

■ R.Vogt calculation from

- Int. J. Mod. Phys. E12 (2003) 211
- hep-ph/0311048

■ Schuler parametrizations

- $d\sigma/dx_F \sim (1 - |x_F|)^d$ with $d = [13.5 \pm 4.5] / (1 + ([44.9 \pm 21.9]/s^{1/2}))$
- $\sigma \sim (1 - M/s^{1/2})^n$ with $n = 12.7 \pm 0.3$

