Charmonia Experimental Studies

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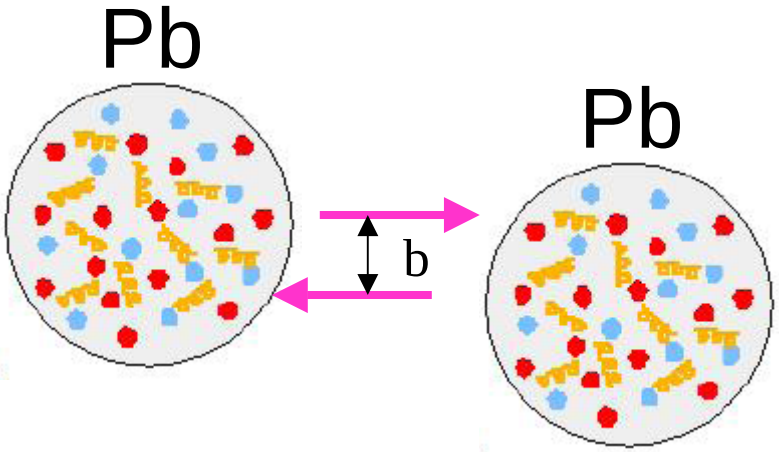
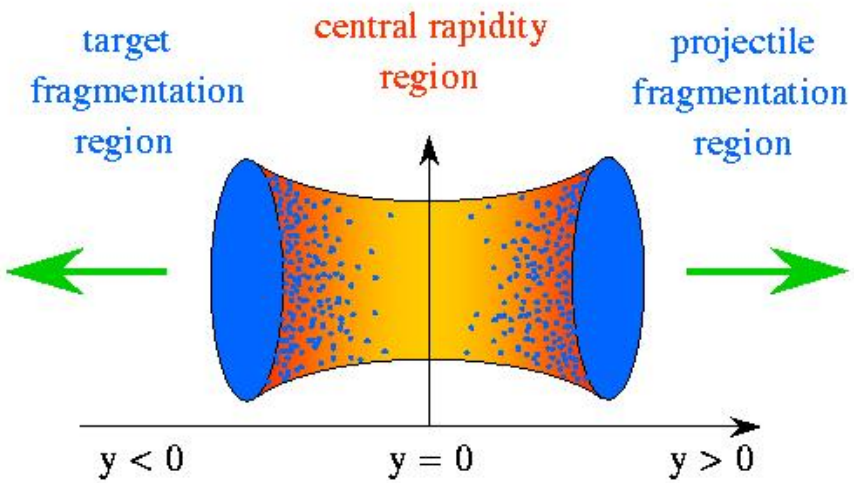
NA50 Collaboration

Outline

- **Motivation**
- **NA50 experiment overview**
- **The J/ψ and ψ' studies**

Phenomenology of Heavy Ion Collisions





relativistic heavy colliding nuclei generate new state of matter, the

Quark Gluon Plasma

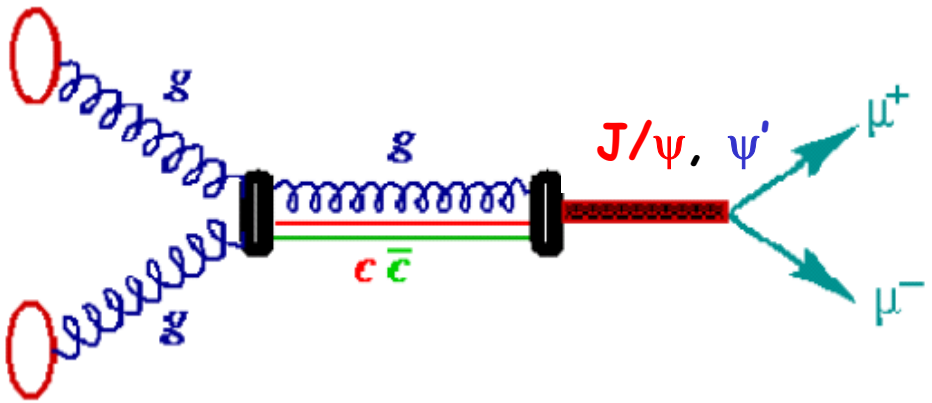
looking for signatures:

CERN - SPS BNL - RHIC CERN - LHC

increasing energy density

Looking for Signatures

at CERN - SPS a set of experiments search for the charmonia suppression by Debye colour screening (Matsui and Satz prediction in 1986)



NA38: p-A at 200 and 450 GeV, O-Cu, O-U and S-U at 200 GeV

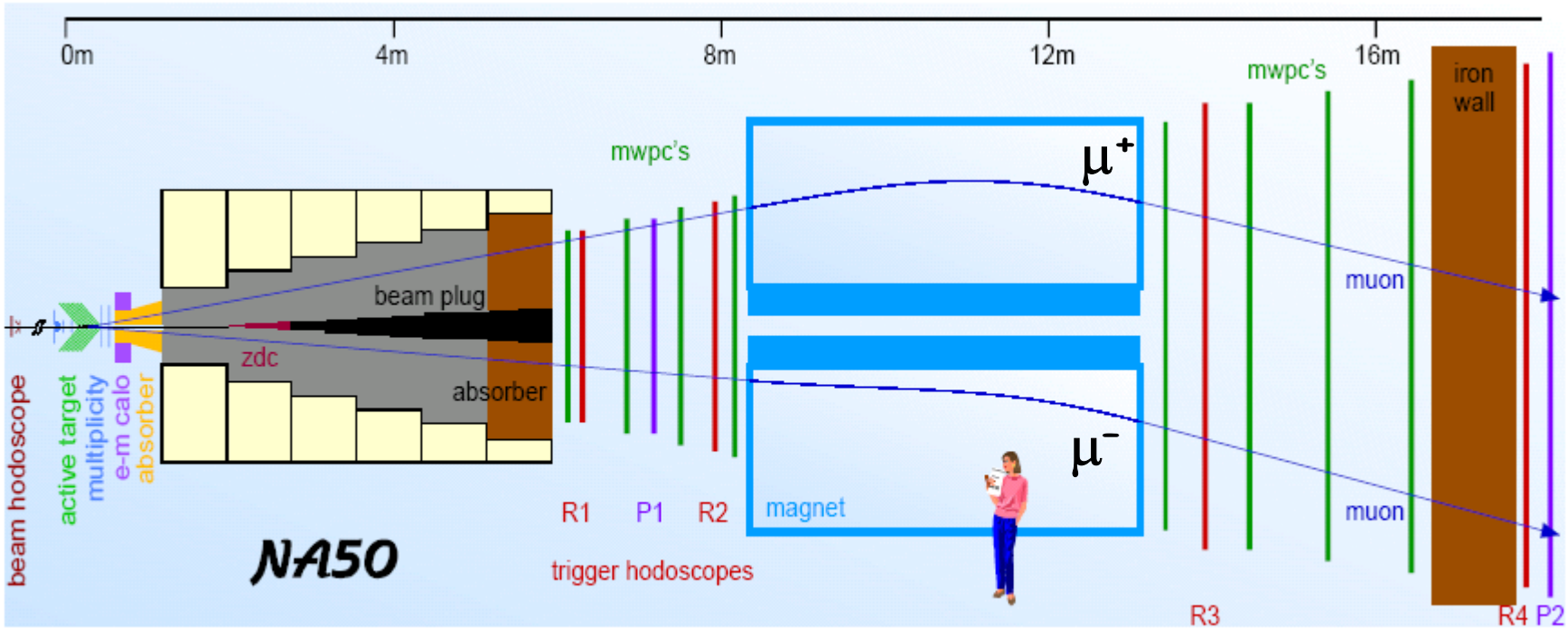
NA50: p-A at 400 and 450 GeV, Pb-Pb at 158 GeV

NA60: p-A at 400 and 158 GeV, In-In at 158 GeV

a major feature - high statistical sample

study of charmonia production as a function of the impact parameter

The NA50 Experiment

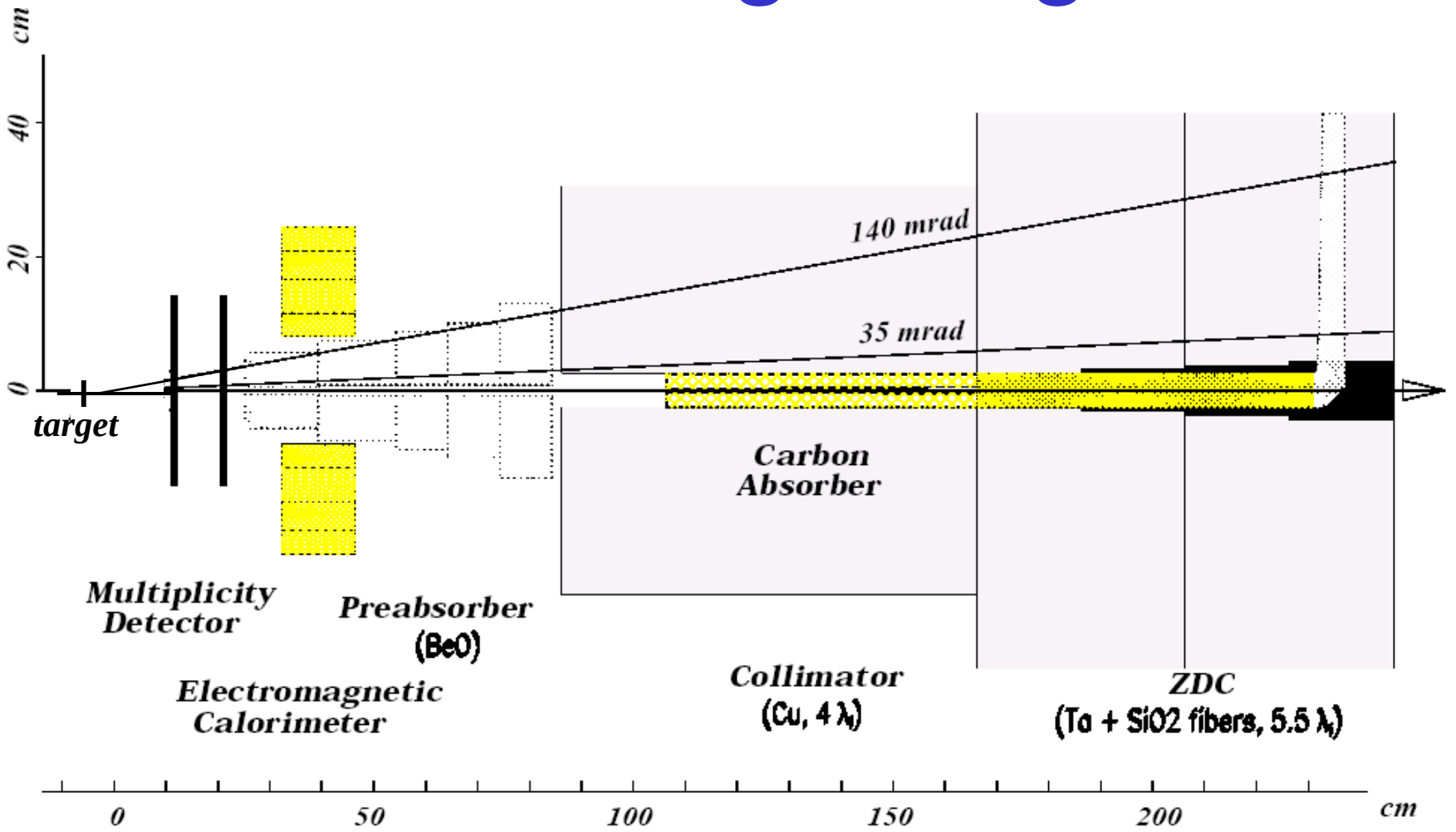


Kinematical Domain: $2.92 \leq y_{lab} < 3.92, \quad |\, cos\theta_{CS} \,| < 0.5$

Acceptances

J/ψ	12.4 ± 0.2%
ψ'	14.8 ± 0.3 %
$DY_{2.9-4.5}$	13.8 ± 0.2 %

The NA50 Target Region



Acceptance: $1.9 \leq \eta_{lab} \leq 4.2$ for the Multiplicity Detector

$1.1 \leq \eta_{lab} \leq 2.3$ for the Electromagnetic Calorimeter

$\eta_{lab} \geq 6.3$ for the Zero Degree Calorimeter

Data Samples Review

NA50 uses proton and lead beams colliding on fixed targets.

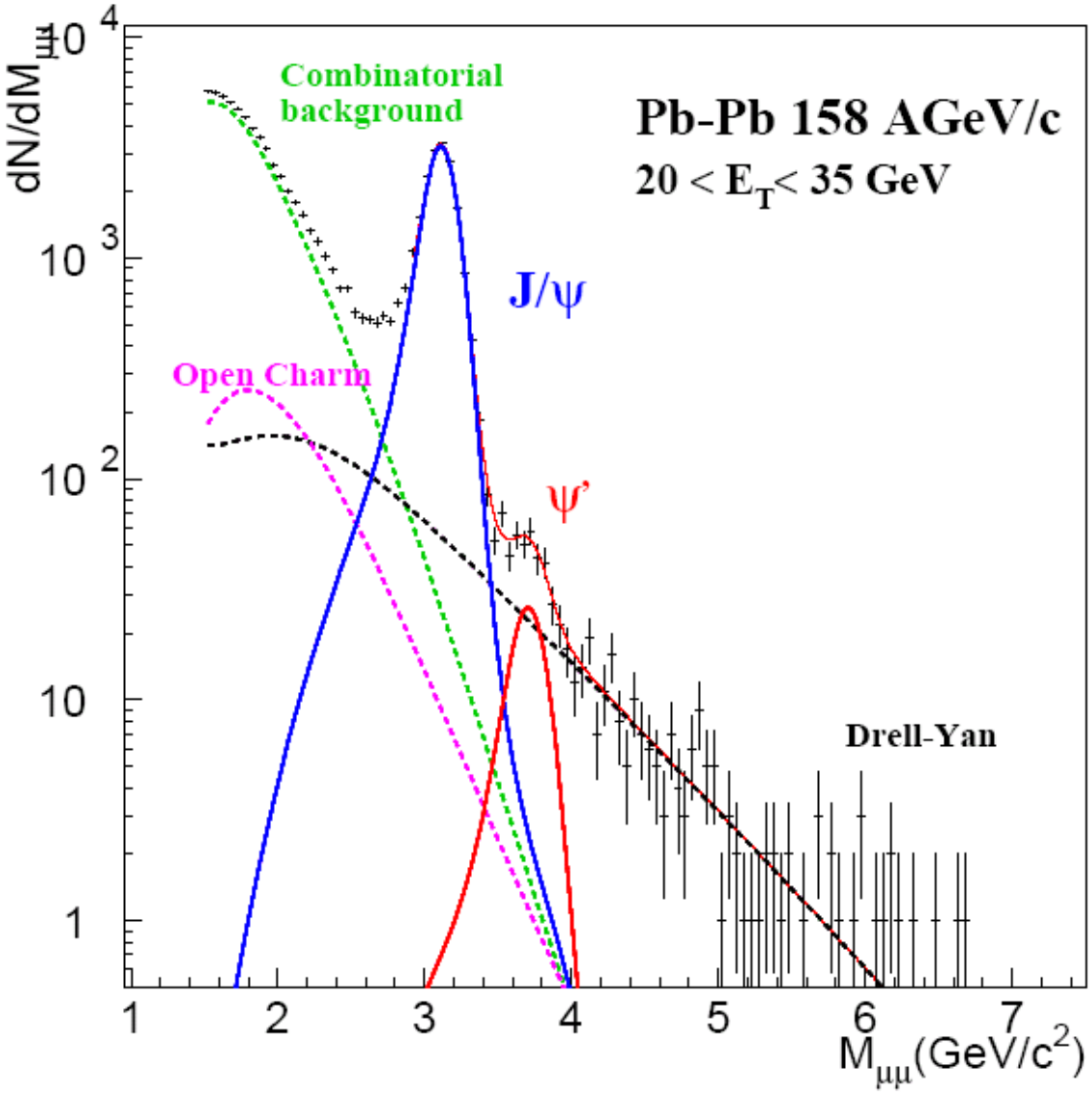
The spectrometer is almost the same used in the previous NA38 experiment (study of p-A, O-Cu, O-U and S-U systems)

Data samples in Pb-Pb collisions

data sample	total target thickness	number of sub-targets	beam intensity (ions/burst)	number of J/ψ	number of ψ'
1995	17% λ_I	7 (in air)	3×10^7	50000	
1996	30% λ_I	7 (in air)	5×10^7	190000	
1998	7% λ_I	1 (in air)	5.5×10^7	49000	380
2000	9.5% λ_I	1 (in vacuum)	7×10^7	129000	905

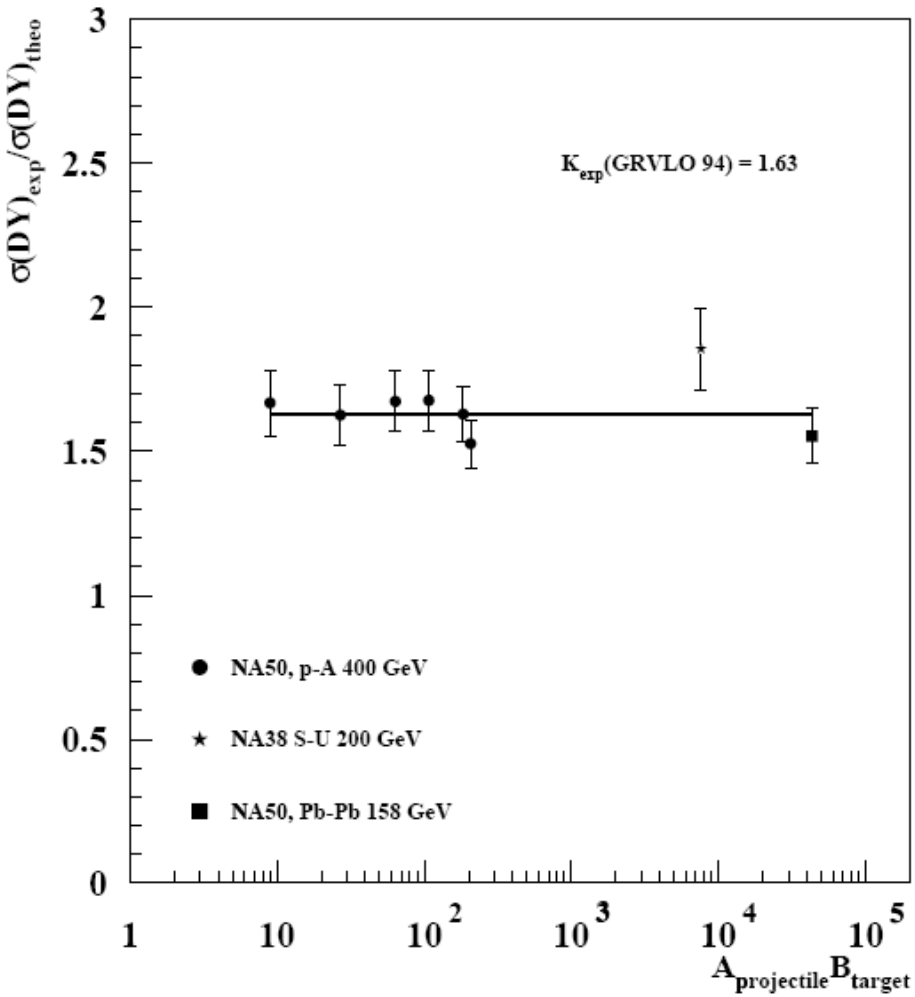
The Opposite Sign Dimuon Mass Spectrum

$$\frac{dN^{+-}}{dM} = A_{J/\psi}\frac{dN_{J/\psi}}{dM} + A_{\psi'}\frac{dN_{\psi'}}{dM} + A_{DY}\frac{dN_{DY}}{dM} + A_{D\bar{D}}\frac{dN_{D\bar{D}}}{dM} + \frac{dN_{BG}}{dM}$$



Reference for Charmonia Production

Drell-Yan



advantages:

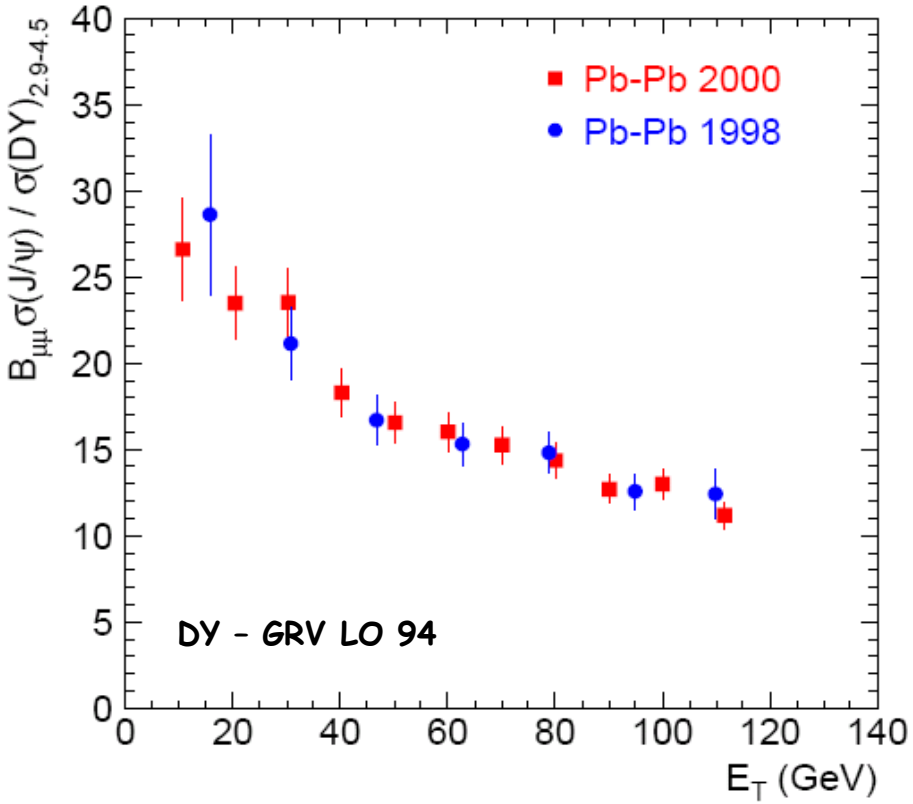
- σ(DY) is proportional to the number of nucleon-nucleon collisions from p-p up to Pb-Pb (in the NA50 phase space, at least)
- same selection criteria

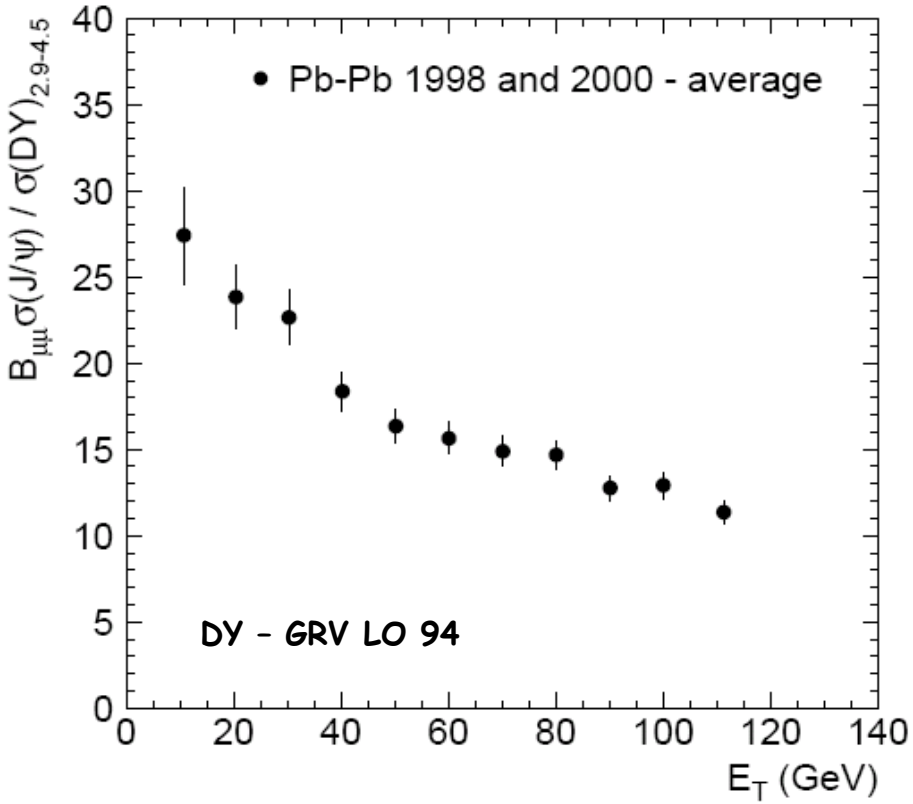
→ Good normalization for J/ψ and ψ'

drawback: relatively poor statistics

The J/ψ Suppression

Results on $B_{\mu^+\mu^-}\sigma(J/\psi)/\sigma(DY_{2.9-4.5})$ as a function of E_T for Pb–Pb 2000 and 1998 data





- The ratio of cross-sections decreases from peripheral to central collisions by a factor of ~2.5
- No saturation is seen for the most central reactions

The Normal Nuclear Absorption

Aim: baseline for J/ψ production in Pb-Pb collisions at 158 GeV → data from lighter systems needed

Constraints: no available 158 GeV p-A data

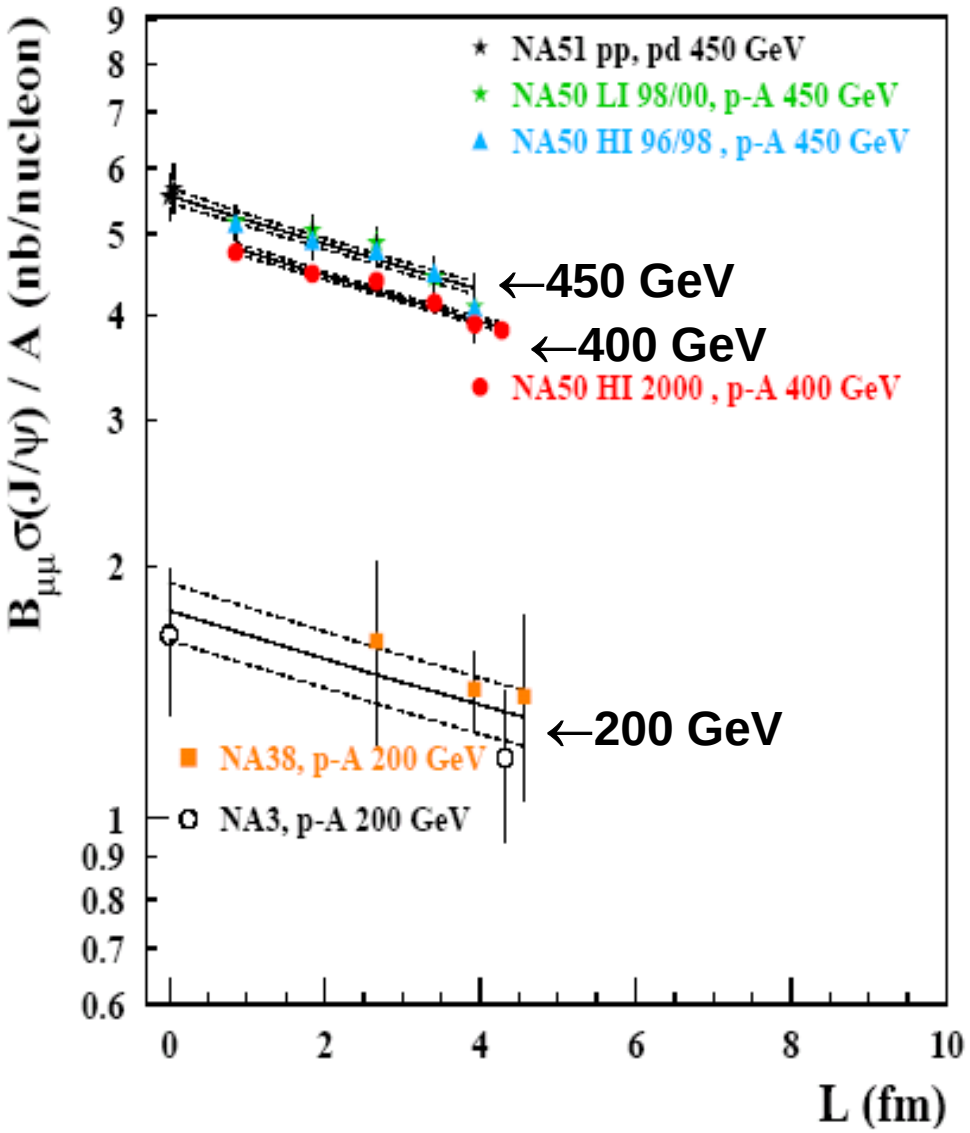
⇒ use absolute J/ψ cross sections at 200, 400 and 450 GeV p-A data to obtain experimental rescaling factor to 200 GeV

⇒ Drell-Yan rescaled to 200 GeV using GRVLO94 calculations

⇒ determine level of (J/ψ)/DY at 158 GeV using phenomenological fit ("Schuler" parametrization) to available data on J/ψ cross sections and theoretical Drell-Yan

⇒ take into account neutron halo effect, which affects centrality dependence of absorption curve

J/ψ cross sections in p-A at 450, 400 and 200 GeV

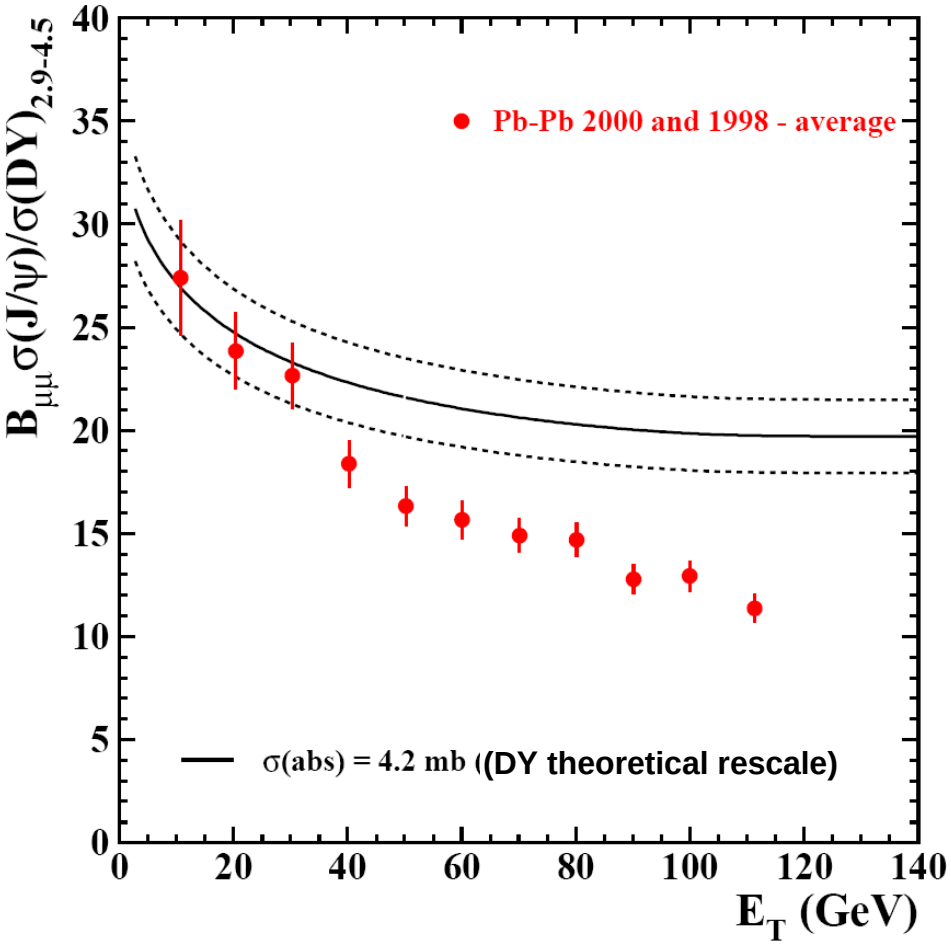


Data from:

- **NA50 p-A at 400/450 GeV**
- **NA51 p-p and p-d at 450 GeV**
- **All available 200 GeV data (NA38) + p-p and p-Pt (NA3)**

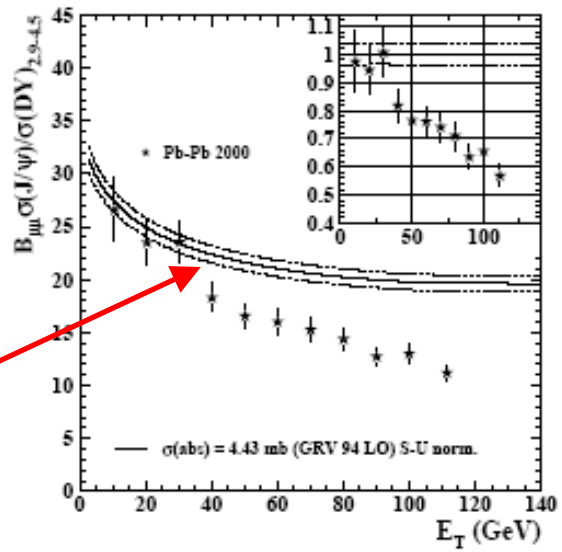
- **Absolute J/ψ cross sections**
- **Independent fits are fully compatible**
- **Simultaneous fit leads to $\sigma_{abs} = 4.5 \pm 0.4$ mb and rescaling factor from 450 to 200 GeV**
- **Theoretical rescale from 200 to 158 GeV**

J/ψ/DY in Pb-Pb with p-A Reference as a Function of E_T



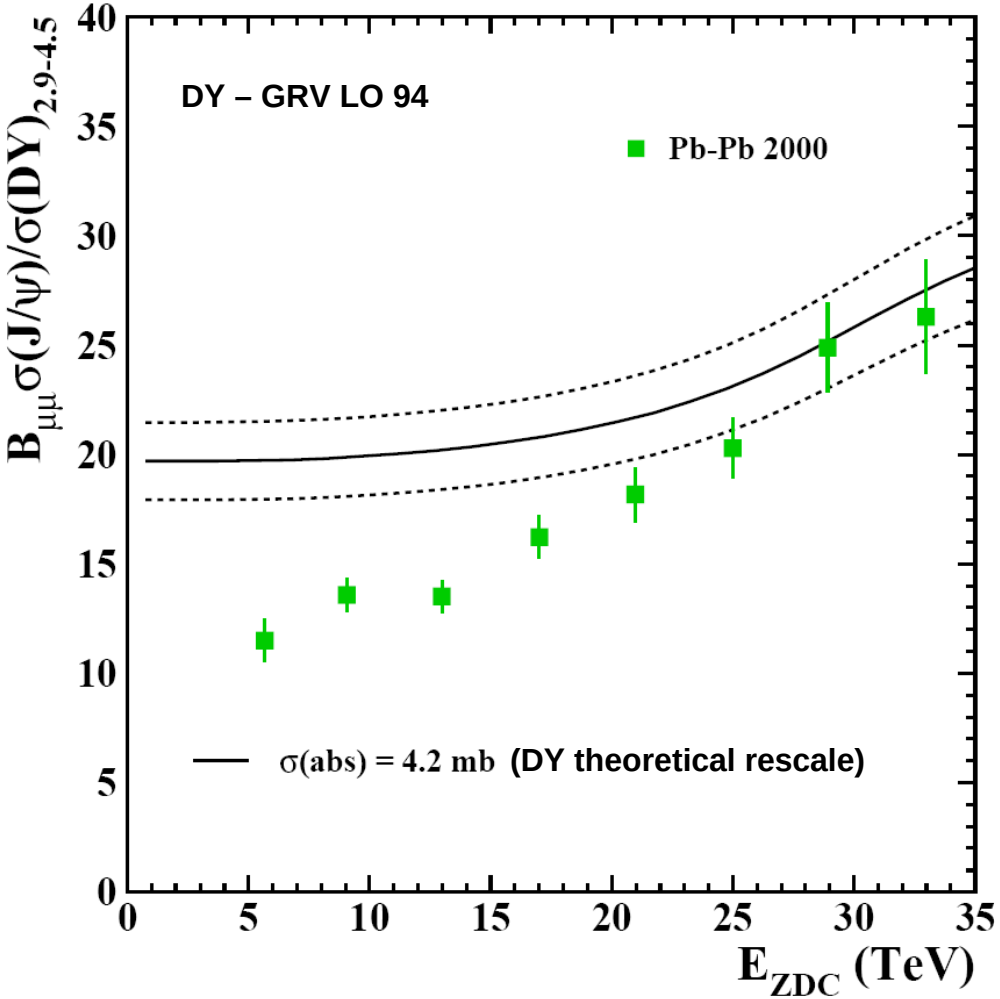
The ratio $\sigma(J/\psi)/\sigma(DY)$:

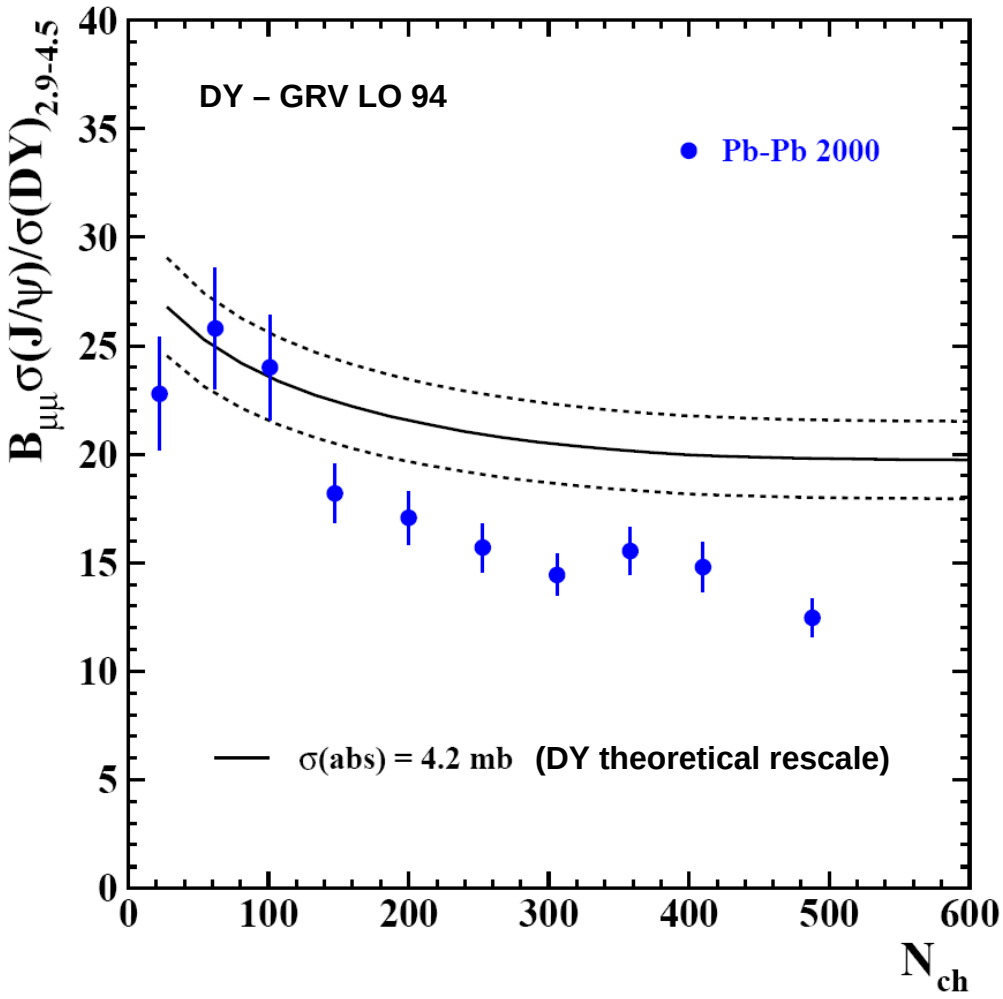
- Behaves "as p-A" for peripheral collisions
- Departs from the normal absorption at $E_T \approx 35$ GeV
- Becomes more and more abnormal for more and more central collisions



Previous absorption curve using also S-U data: smaller error but assumes that S-U is normal

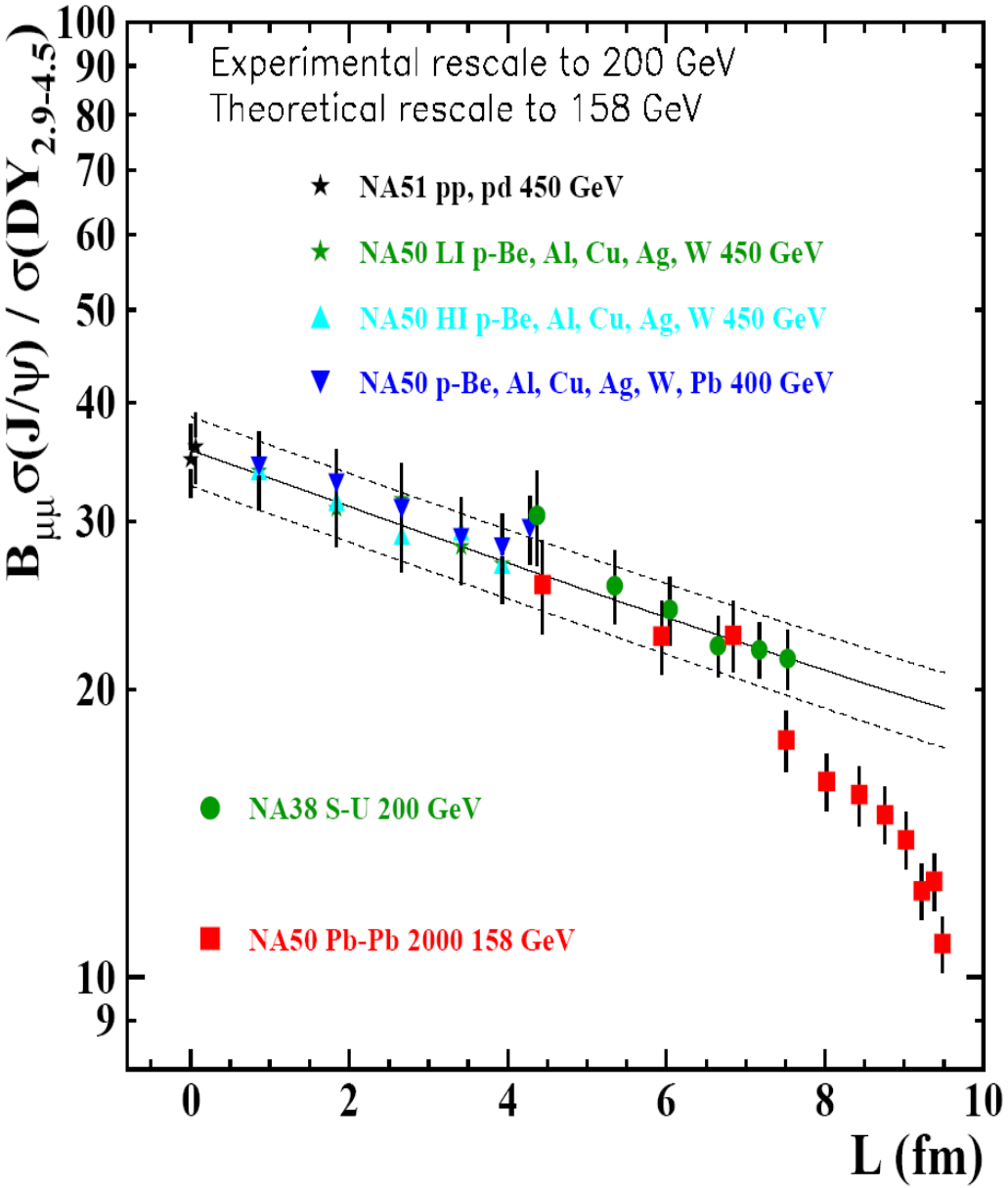
J/ψ/DY as a Function of Forward Energy and Charged Multiplicity





3 independent estimators, E_T, E_{ZDC} and N_{ch}, confirm the same anomalous J/ψ suppression pattern

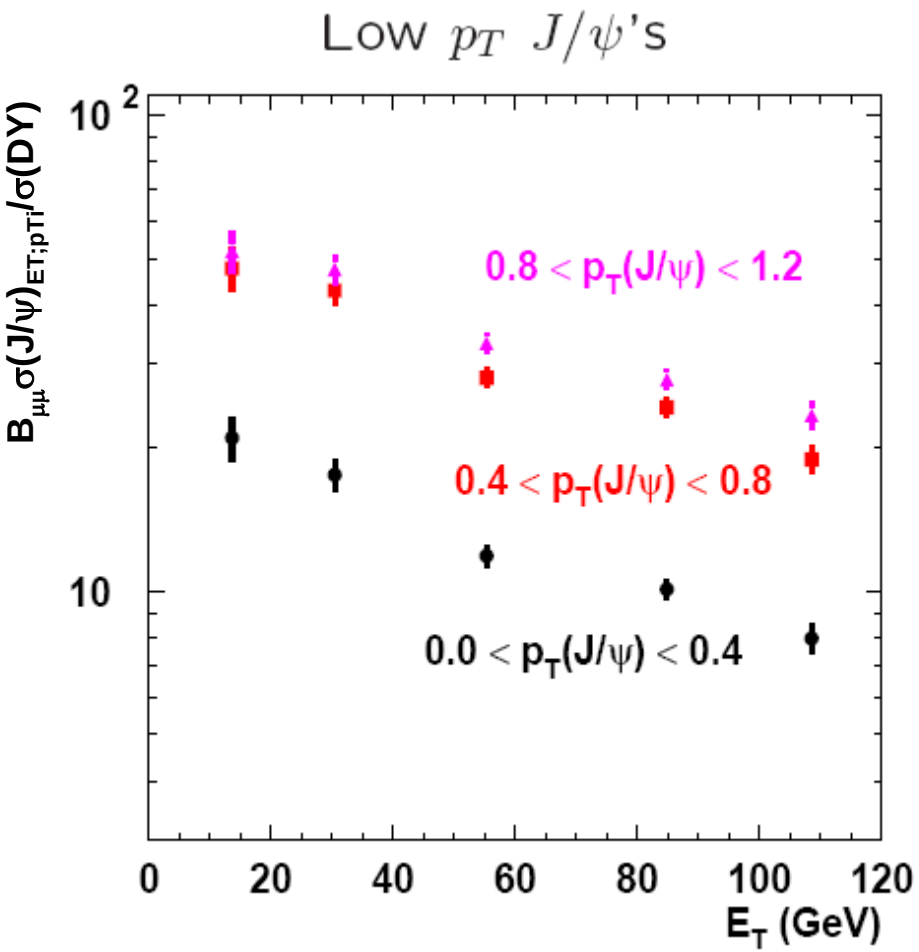
J/ψ/DY from p-p to Pb-Pb Systems as a Function of L

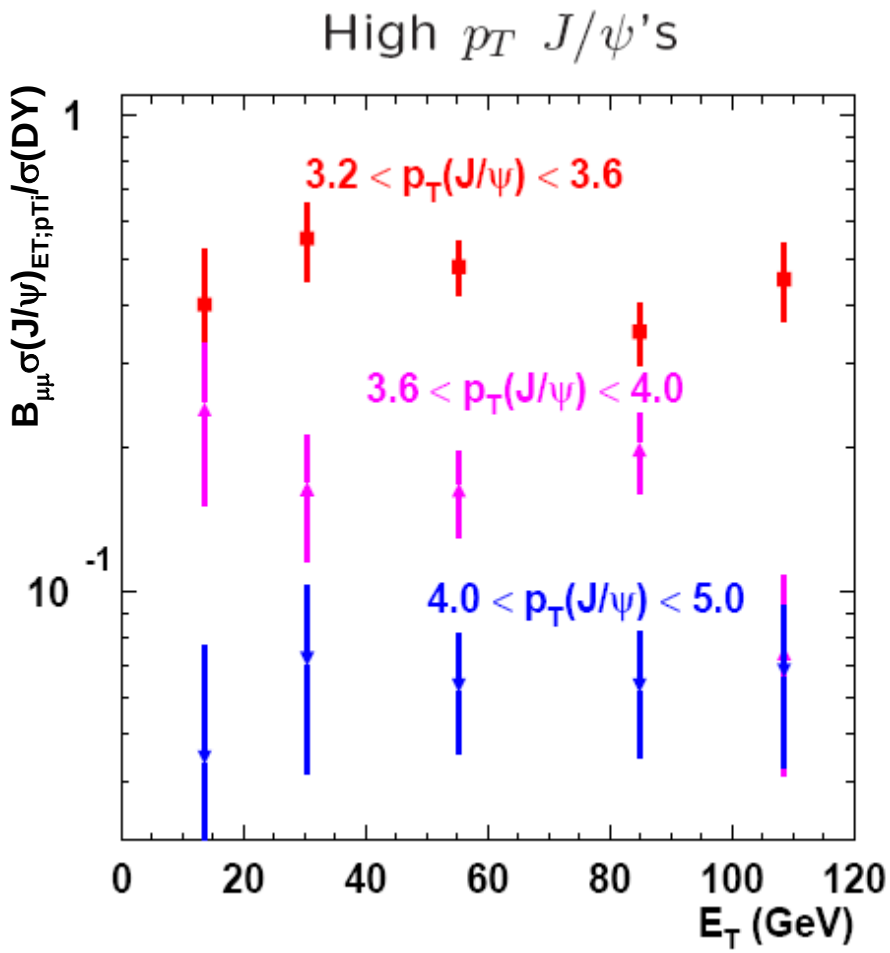


J/ψ Suffers:

- Normal Suppression in S-U and Peripheral Pb-Pb
- Anomalous Suppression in Central Pb-Pb

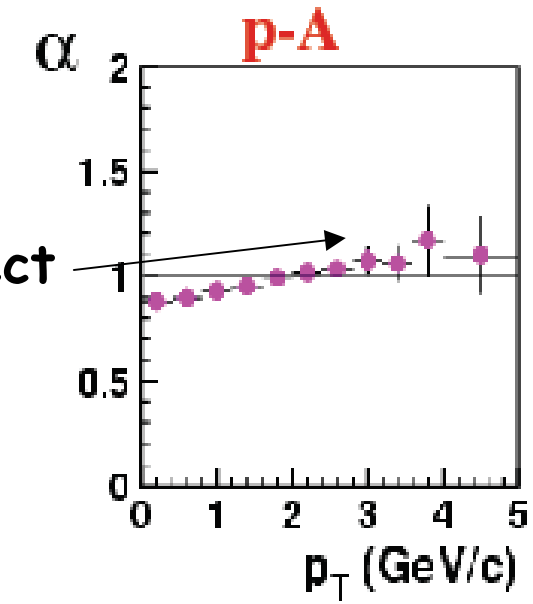
J/ψ Suppression vs Centrality in P_T Bins



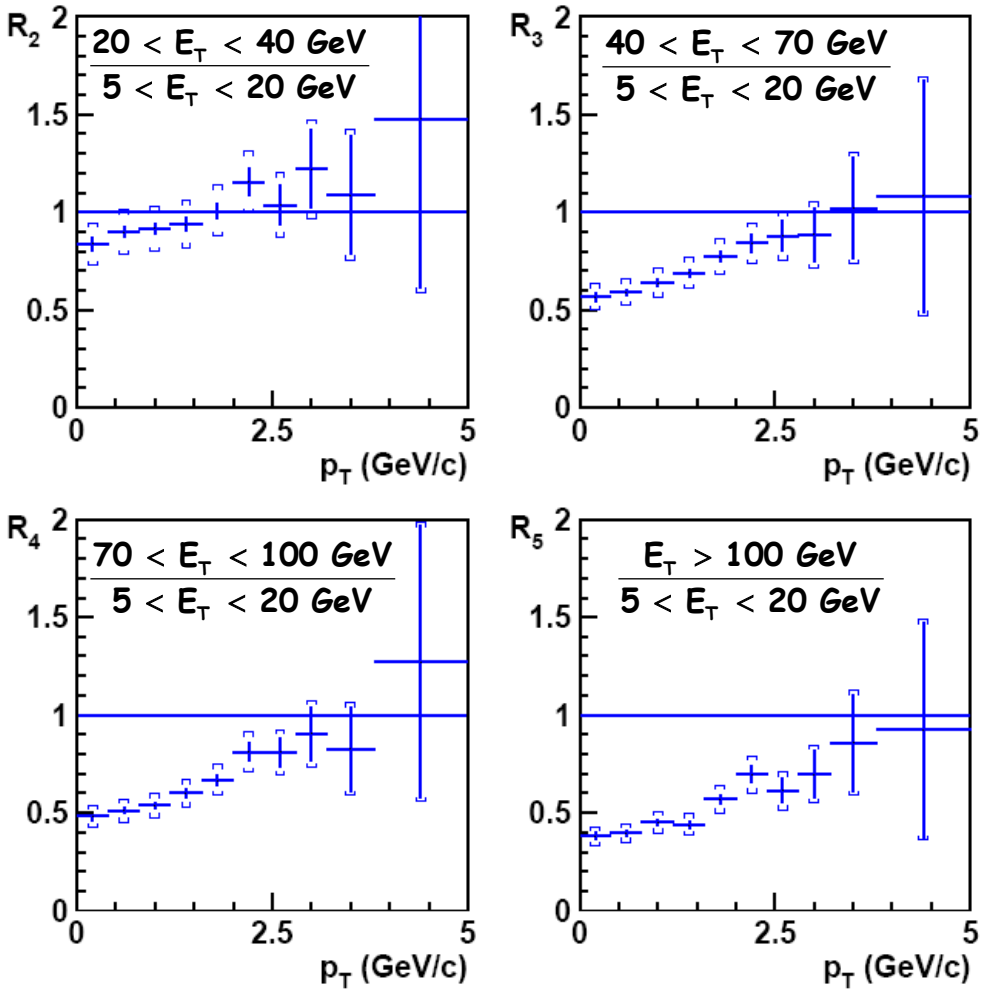


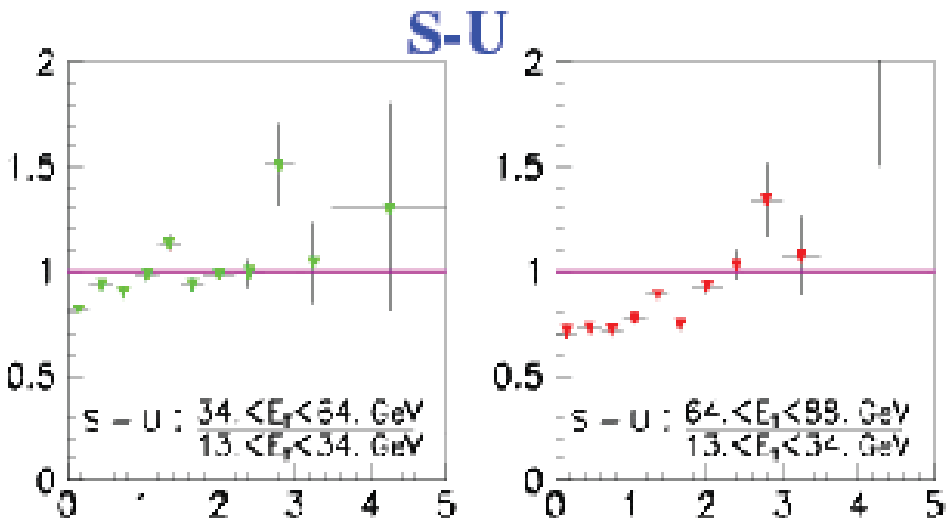
Clear centrality dependence for low p_T

Ratio "R_{cp}" as a Function of P_T



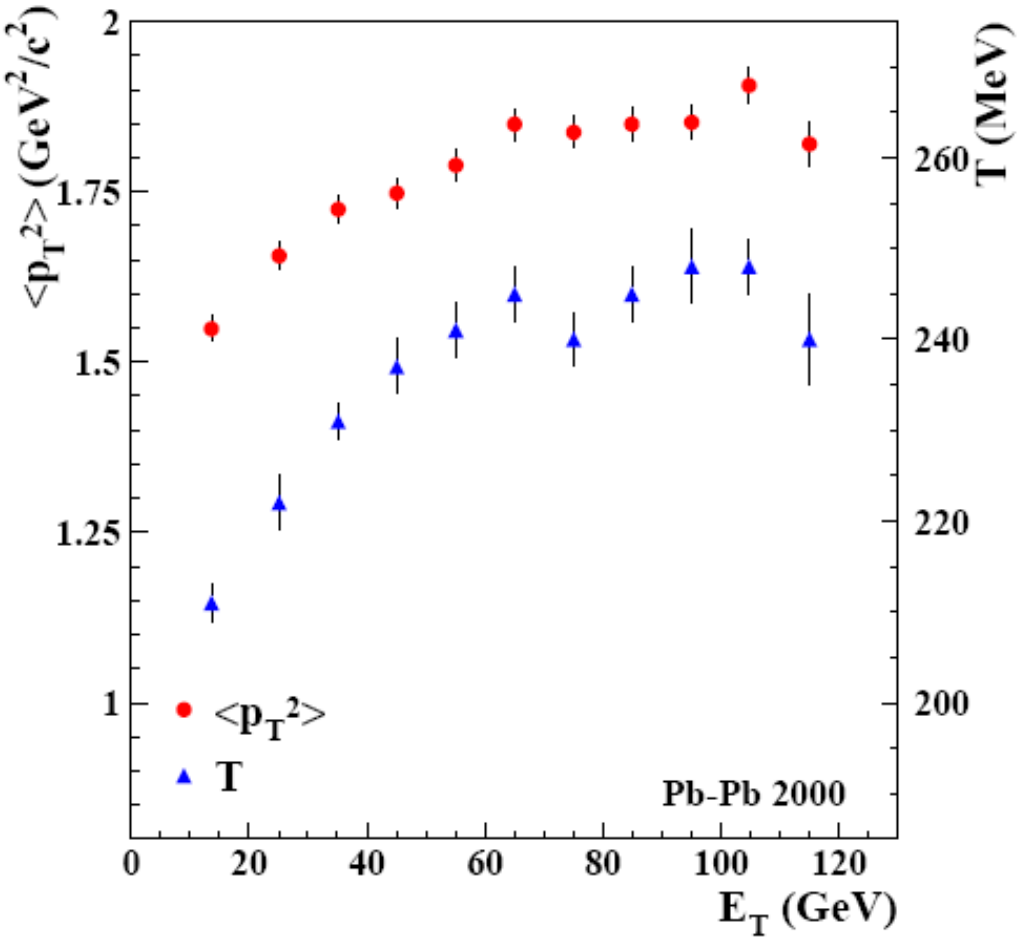
$$R^i_{CP}(p_T) = \frac{N^i_\psi(p_T)}{N^i_{DY}} \Big/ \frac{N^1_\psi(p_T)}{N^1_{DY}}$$





- J/ψ is mainly suppressed at low p_T
- For Pb-Pb central events J/ψ is suppressed over the whole p_T range

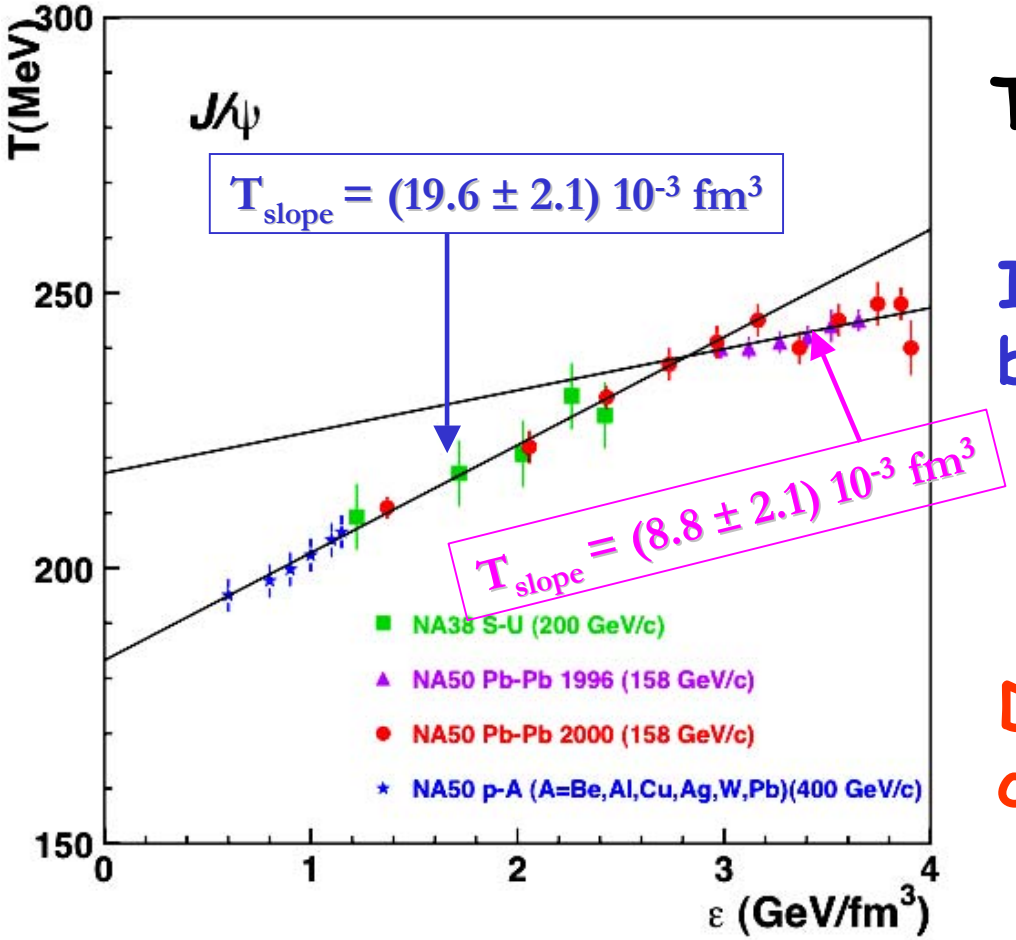
J/ψ $\langle p_T^2 \rangle$ and T as a Function E_T for Pb-Pb collisions



Both $\langle p_T^2 \rangle$ and T increase as E_T increases followed by a saturation for central events

$T_{J/\psi}$ as a Function of the Energy Density, ε

p-A and S-U results rescaled to 158 GeV



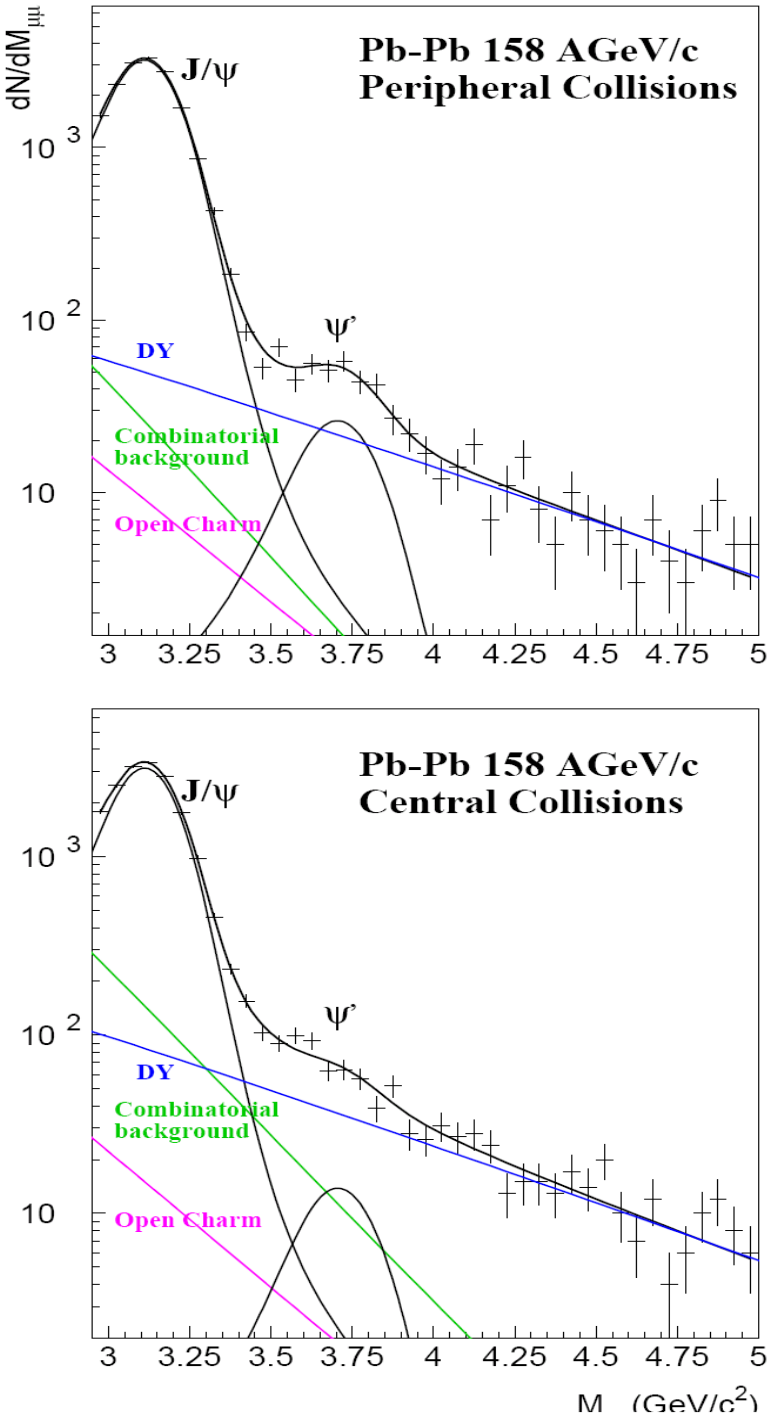
$$T_{J/\psi}(\varepsilon) = T_{(\varepsilon=0)} + \varepsilon T_{slope}$$

Initial values independent on beam energy:

$T_{(\varepsilon=0)}$=180 ± 4 MeV

Different T_{slope} for Pb-Pb central collisions

The ψ' Study



Challenging due to:

- small dimuon cross section
- large suppression
- several dimuon sources overlap

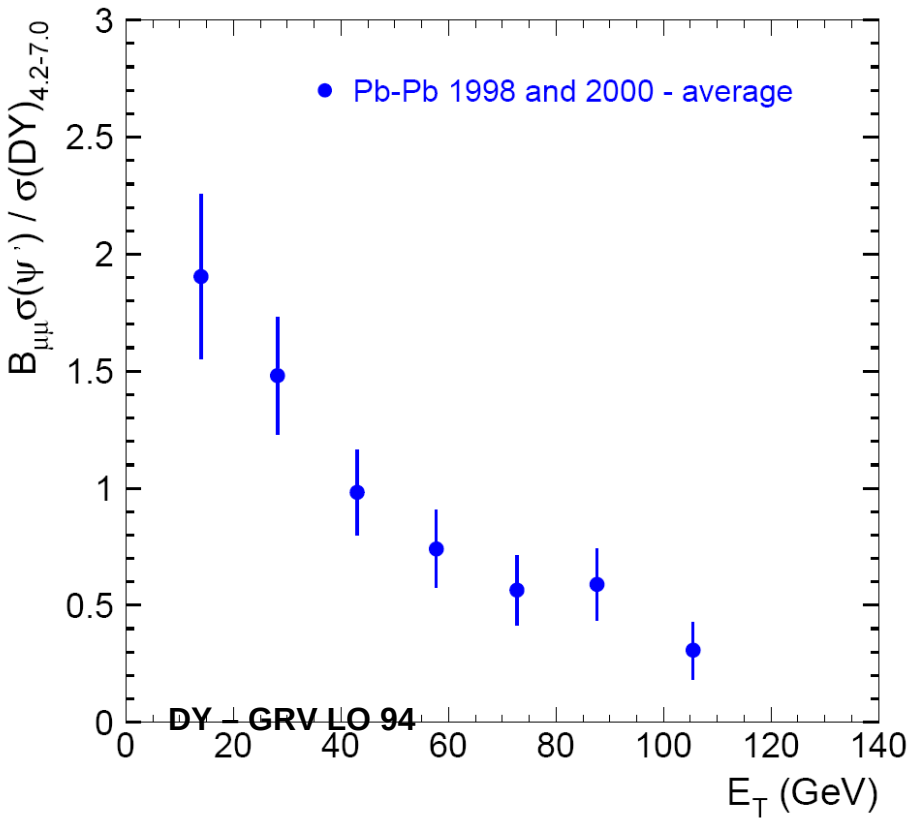
◇ Structure functions chosen to simulate Drell-Yan induce up to 7% difference in ψ' normalizations

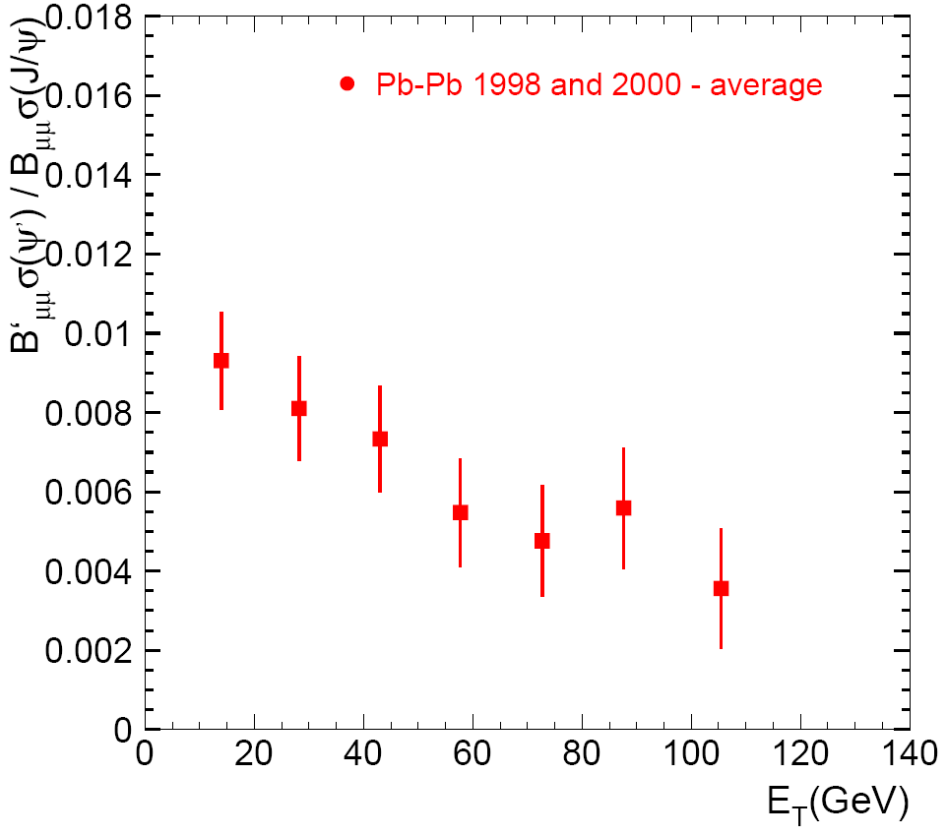
◇ Combinatorial Background is accurately measured from like-sign sample in each centrality region

◇ The uncertainty due to Open Charm semi-leptonic decays is $<1.5\%$

The ψ' Suppression

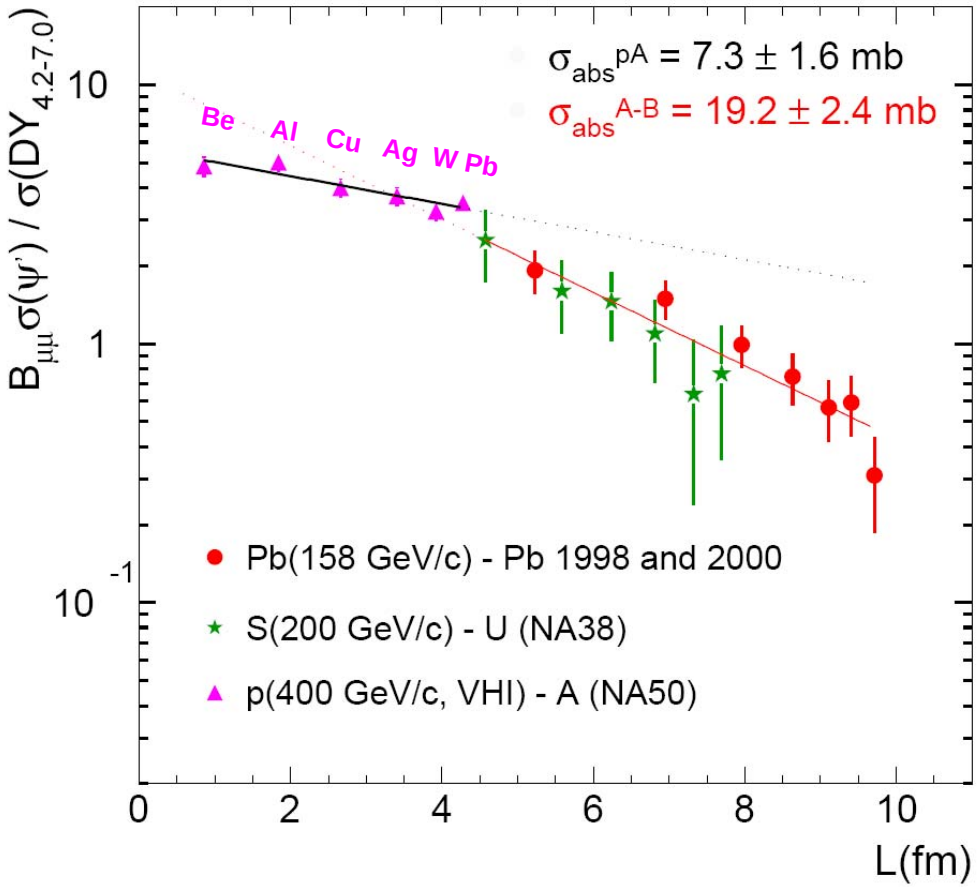
$B_{\mu^+\mu^-}\sigma(\psi')/\sigma(DY_{4.2-7.0})$ and $B'_{\mu^+\mu^-}\sigma(\psi')/B_{\mu^+\mu^-}\sigma(J/\psi)$ as a function of E_T – Average between Pb-Pb 2000 and 1998





- ψ' is increasingly suppressed with respect to Drell-Yan
- The ratio of the two charmonium states decreases with centrality by a factor of 2.5 between peripheral and central collisions

ψ'/DY in p-A, S-U and Pb-Pb Systems as a Function of L



Using a exponential parametrization:

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

One obtains in p-A collisions for ψ'

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

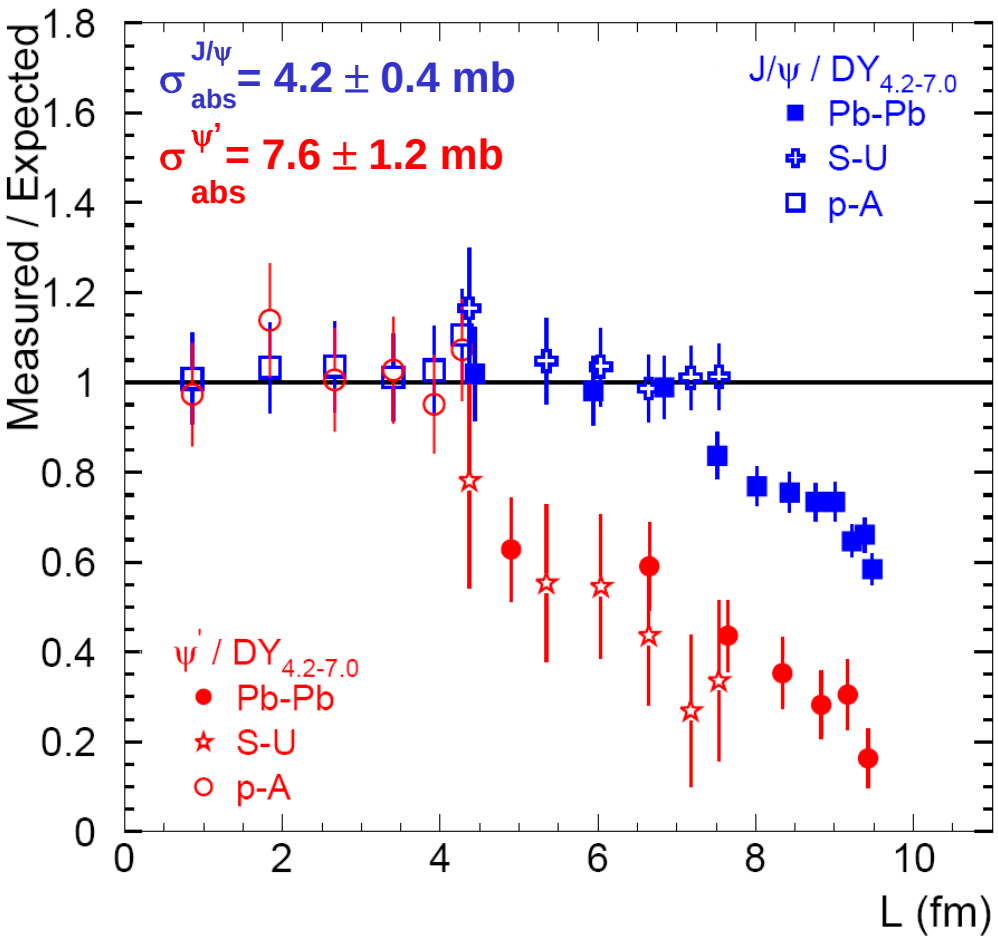
and

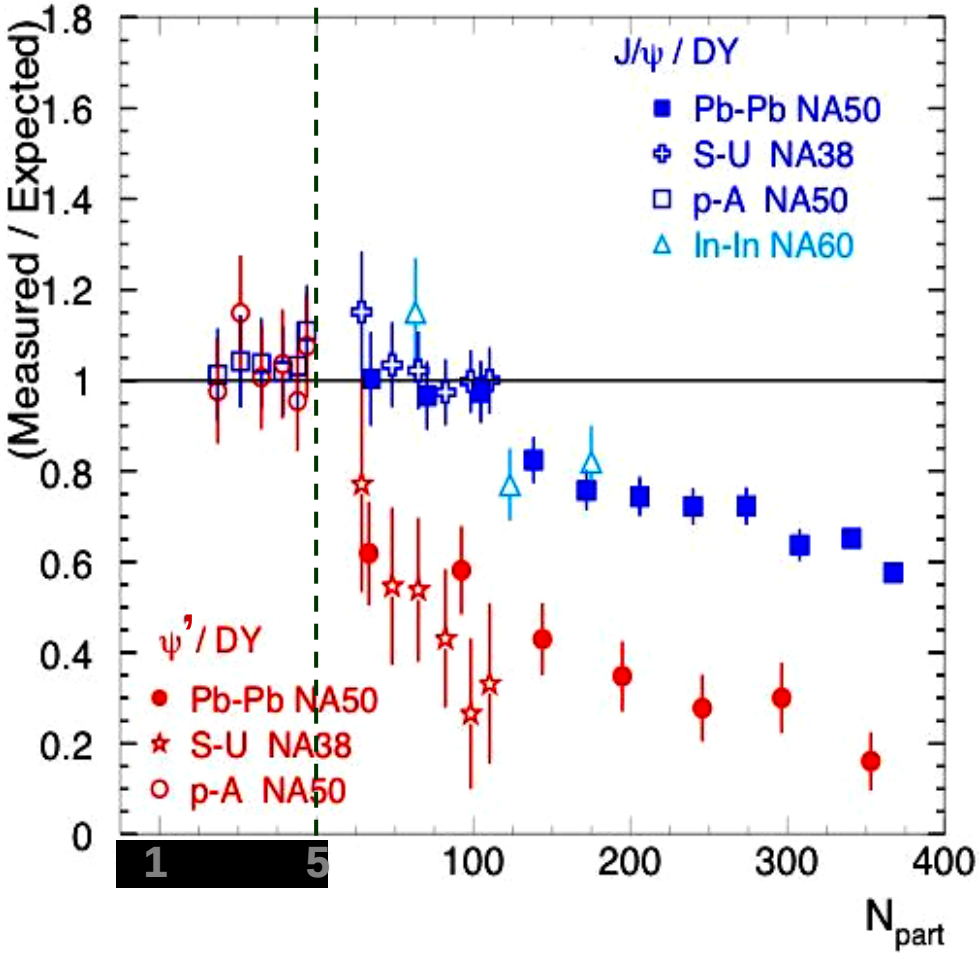
$$\sigma_{abs}^{A\text{-}B} = 19.2 \pm 2.4 \text{ mb}$$

for S-U e Pb –Pb collisions fitted simultaneously

- **Different behaviours between p-A and A-B collisions**
- **Strong suppression of ψ' between peripheral and central A-B interactions**
- **Same ψ' suppression in S-U e Pb-Pb collisions as a function of centrality**

J/ψ and ψ' – Measured Over Expected





- Expected: absorption model (full Glauber calculation)
- In A-B collisions, the ψ' departs from the nuclear absorption curve for less central reactions w.r.t. J/ψ

Conclusions

1. For S-U and peripheral Pb-Pb collisions, the ratio $\sigma(J/\psi)/\sigma(DY)$ follows the normal nuclear absorption (like p-A)
2. For Pb-Pb central collisions, J/ψ production departs from this normal behaviour. It exhibits an abnormal suppression, which increases with increasing centrality
3. the J/ψ suppression is concentrated at low p_T, but "R_{CP}" < 1 over the whole p_T range for Pb-Pb high centrality collisions;
4. The ψ' suppression pattern is the same in S-U and Pb-Pb collisions, and not compatible with the one exhibited in p-A reactions
5. A comparison between ψ' and J/ψ suppressions, normalized to the suppression expected, shows that the ψ' anomalous suppression sets in earlier than for J/ψ