

# NA50 Experiment

## Status Report

SPSC, May 13, 2003

- Analysis progress report
  1. Charmonium studies - p-A and Pb-Pb (year 2000)
  2. Low mass resonances - 1996 data
  3. Fission of Pb projectile at 40 and 158 AGeV
- On-going activities
  1. Final results on  $J/\psi$  suppression and  $p_T$
  2. Analysis of latest p-A data sample (systematics)
  3. Low mass resonances - 1998 and 2000 data
  4. Flow

L. Ramello for the NA50 Collaboration

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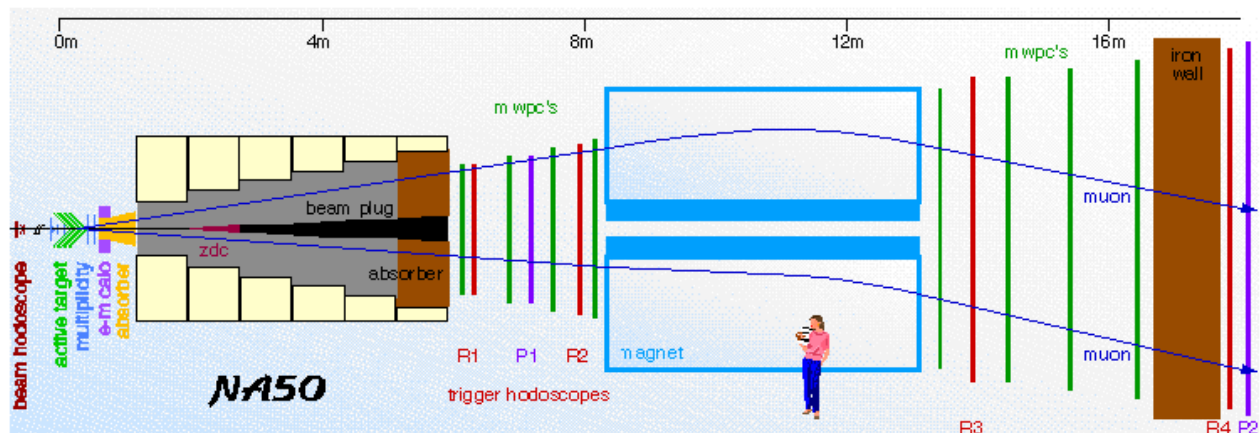
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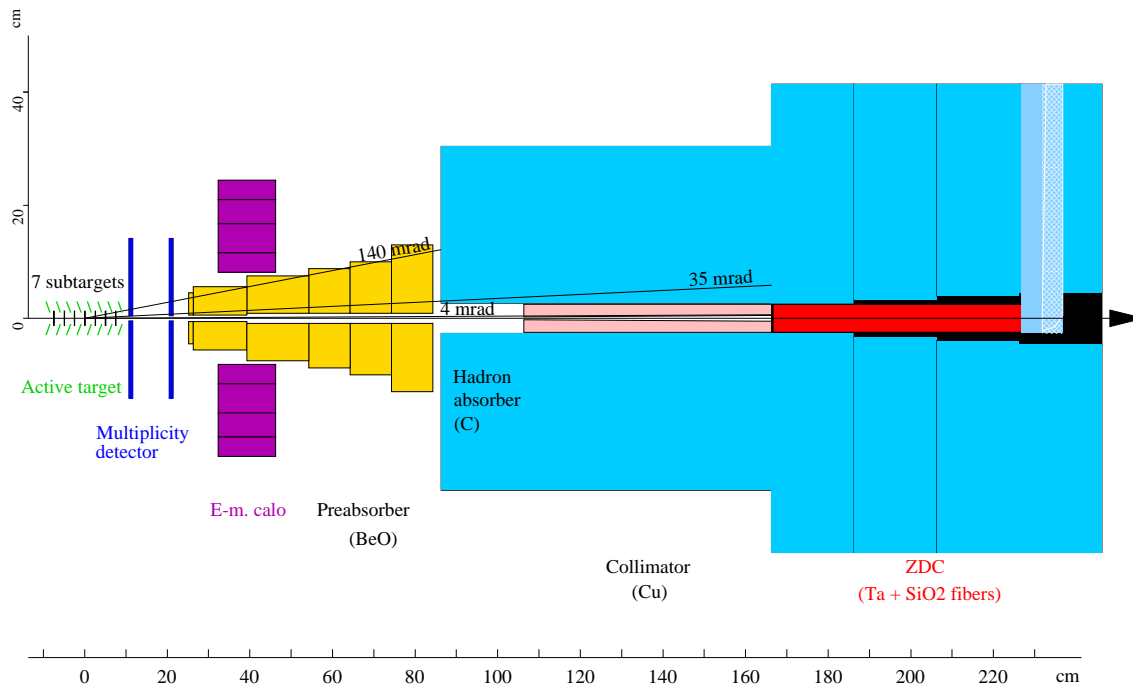
# Summary of NA50 Pb-Pb runs

Year	1995	1996	1998	1999	2000
Target thickness ( $L/\lambda_I$ )	17%	30%	7%	7%	9.3%
No. of sub-targets	7	7	1	1	1
Target in:	air	air	air	<b>vacuum</b>	<b>vacuum</b>
$E_{beam}/nucleon$ (GeV)	158	158	158	<b>40</b>	<b>158</b>
Beam intensity / 5 sec.	$3 \times 10^7$	$5 \times 10^7$	$5.5 \times 10^7$	$1 \times 10^6$	$7 \times 10^7$
No. of days (eff.)	24	28	42	–	<b>33</b>
No. of $J/\psi$	50000	190000	90000	–	<b>110000</b>

- **1999 run: study of charged multiplicity, flow, fission**  
(no dimuon physics)
- **2000 run: optimized conditions for charmonium studies in Pb-Pb** (one subtarget under vacuum, interaction identification based on multiplicity detector)



# The NA50 target region



- Multiplicity Detector ( $1.9 < \eta < 4.2$ )
- E.M. Calorimeter ( $1.1 < \eta < 2.3$ )
- Zero Degree Calorimeter ( $\eta > 6.3$ )

# Charmonium studies - outline

- **Analysis of two high precision p-A data samples:** Low Intensity and High Intensity, LI and HI, collected by NA50 (1996-2000) to determine baseline for  $J/\psi$  (and  $\psi'$ ) absorption in ordinary hadronic matter
- **Analysis of the very last Pb-Pb data sample collected during the fall of year 2000**

After an intense analysis effort, the Collaboration was able to present the first **preliminary results on  $J/\psi$  suppression** (based on year 2000 Pb-Pb data and on the LI p-A data) at the Quark Matter 2002 conference:

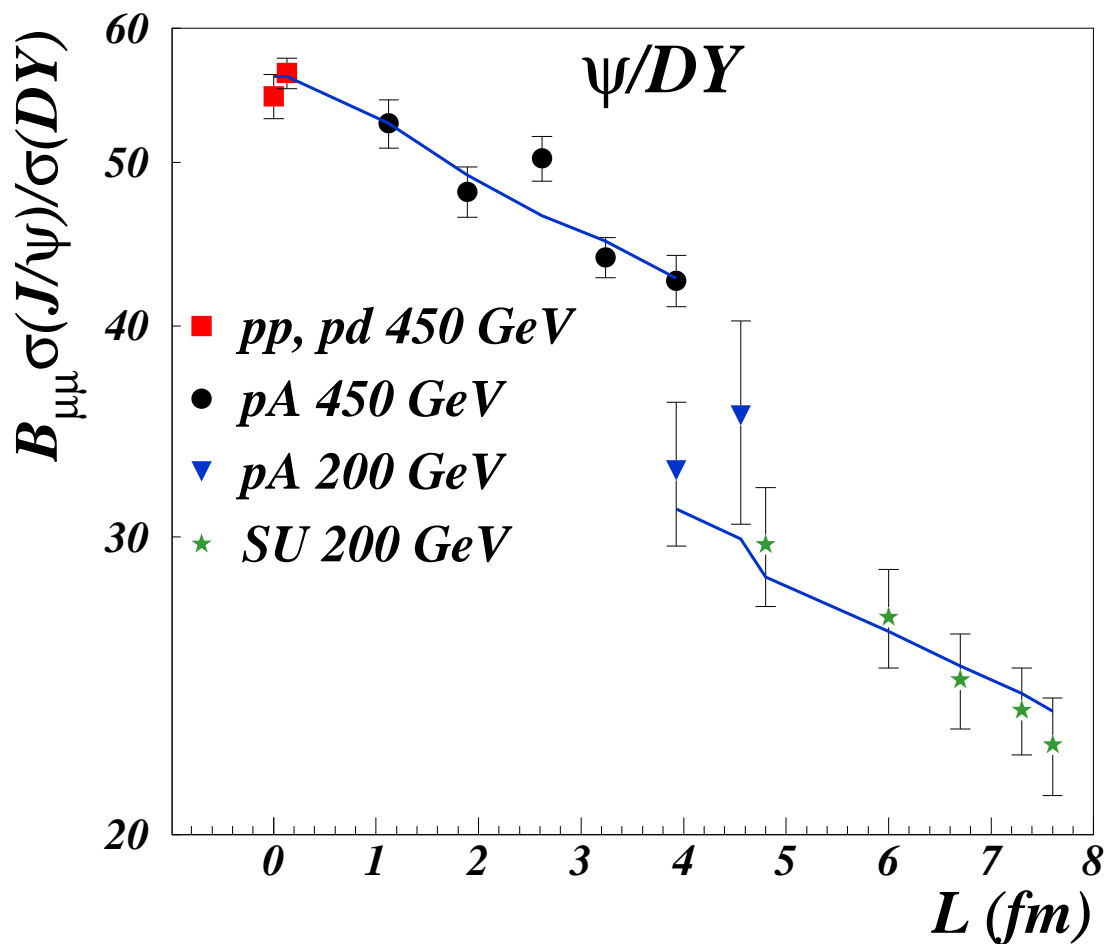
- 1. Results on leptonic probes from NA50**
- 2. Charmonia absorption in p-A collisions at the CERN SPS: results and implications on Pb-Pb interactions**
- 3. Transverse momentum distributions of  $J/\psi$  produced in Pb-Pb and p-A interactions at the CERN SPS**

QM 2002 proceedings are published in *Nucl. Phys. A 715 (2003)*. Furthermore, proton-nucleus results for the LI and HI samples have been finalized:

- Charmonia and Drell-Yan production in proton-nucleus collisions at the CERN SPS, *Phys. Lett. B 553 (2003) 167*
- Charmonium production and absorption in p-A interactions at 450 GeV, *being submitted to Phys. Lett. B*

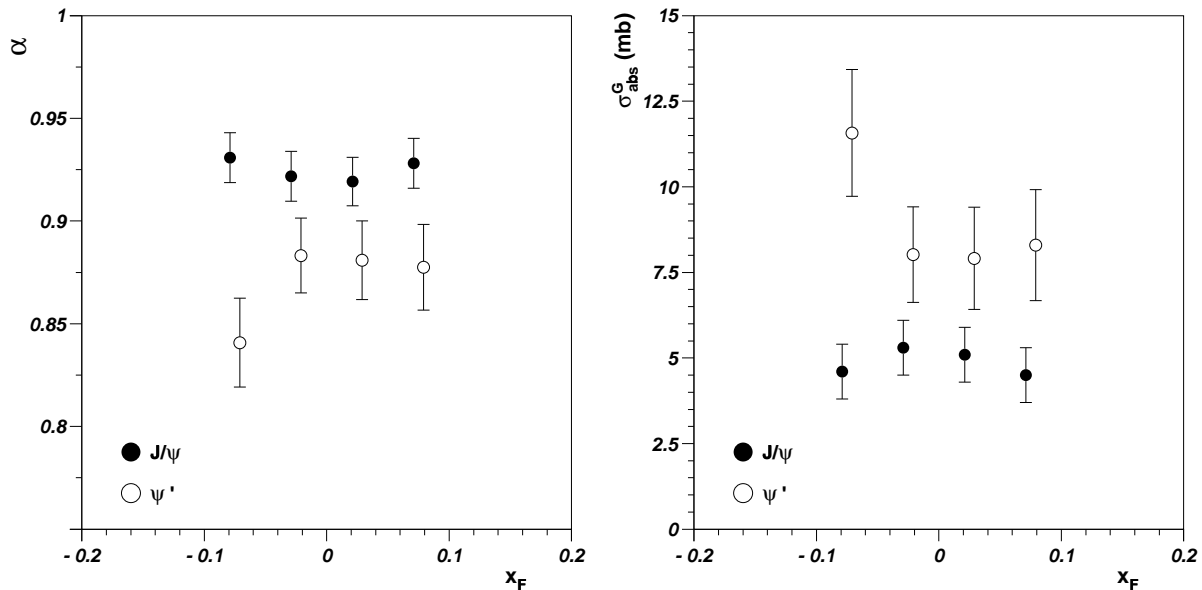
# The NA50 proton-nucleus data

- Refine the baseline for  $J/\psi$  absorption in ordinary hadronic matter, using Drell-Yan as the reference process
- Include high statistics measurement of p-p, p-d (NA51) and proton-nucleus (NA50) at 450 GeV, plus NA38 p-A and S-U measurements in a different kinematical domain at 200 GeV



Lines represent a Glauber fit with a common value for the  $J/\psi$  absorption cross-section, independent from colliding system and kinematical conditions:  $\sigma_{abs} = 4.4 \pm 0.5 \text{ mb}$  ( $4.3 \pm 0.5 \text{ mb}$  if p-A 200 GeV points are excluded or if feed-down from  $\psi'$  decays is corrected for)

## More detailed study of $J/\psi$ and $\psi'$



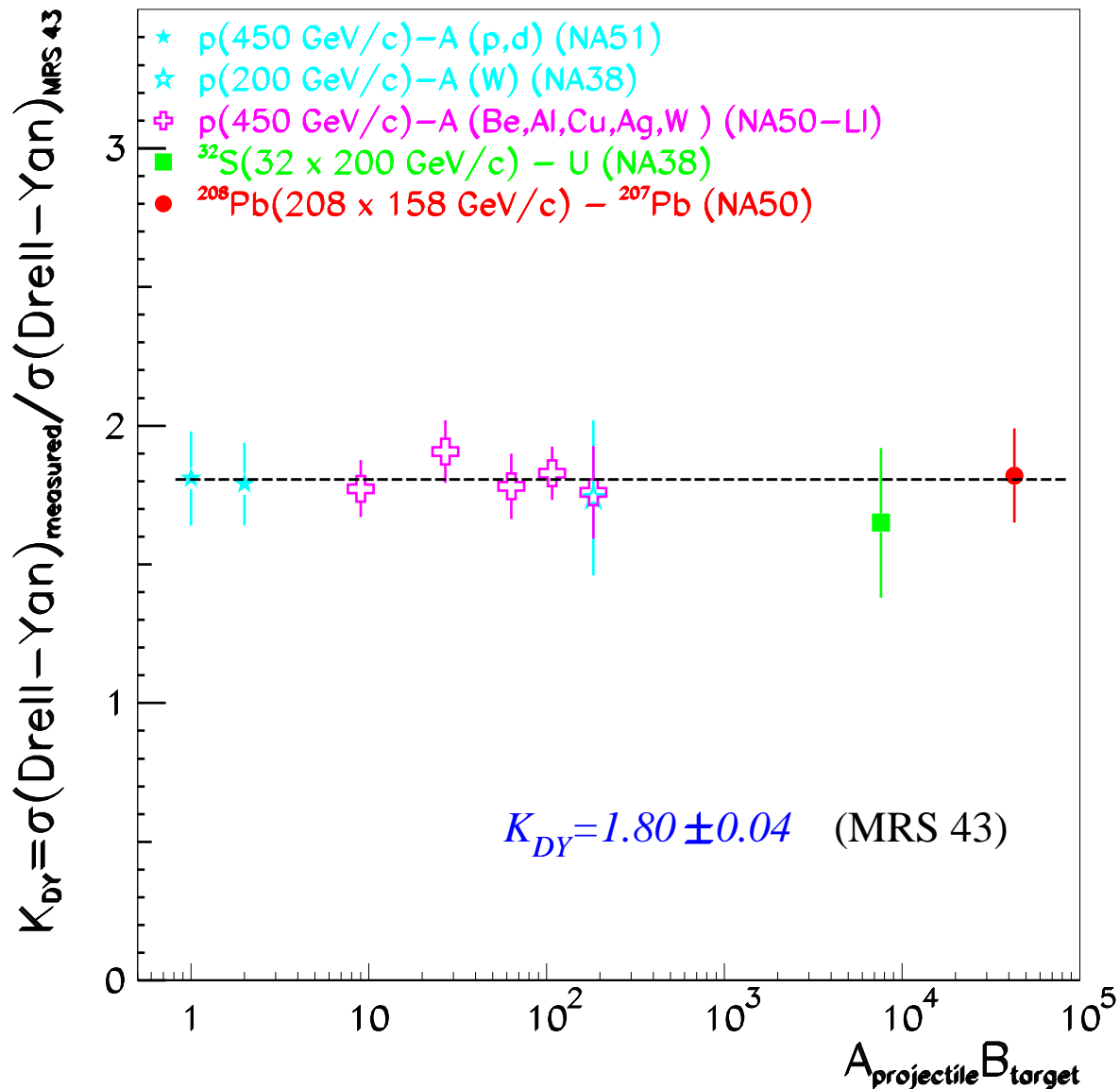
- High Intensity and Low Intensity NA50 p-A data taken together give more detailed information about  $J/\psi$  and  $\psi'$  absorption:
- For both resonances, our data at 450 GeV indicate a stronger absorption with respect to 800 GeV data

$-0.1 < x_F < 0.1$	NA50	E866
$\alpha(J/\psi)$	$0.924 \pm 0.012$	0.95
$\alpha(\psi')$	$0.881 \pm 0.014$	0.93

- There is some hint of a stronger absorption of the  $\psi'$  in the backward hemisphere

# The Drell-Yan reference

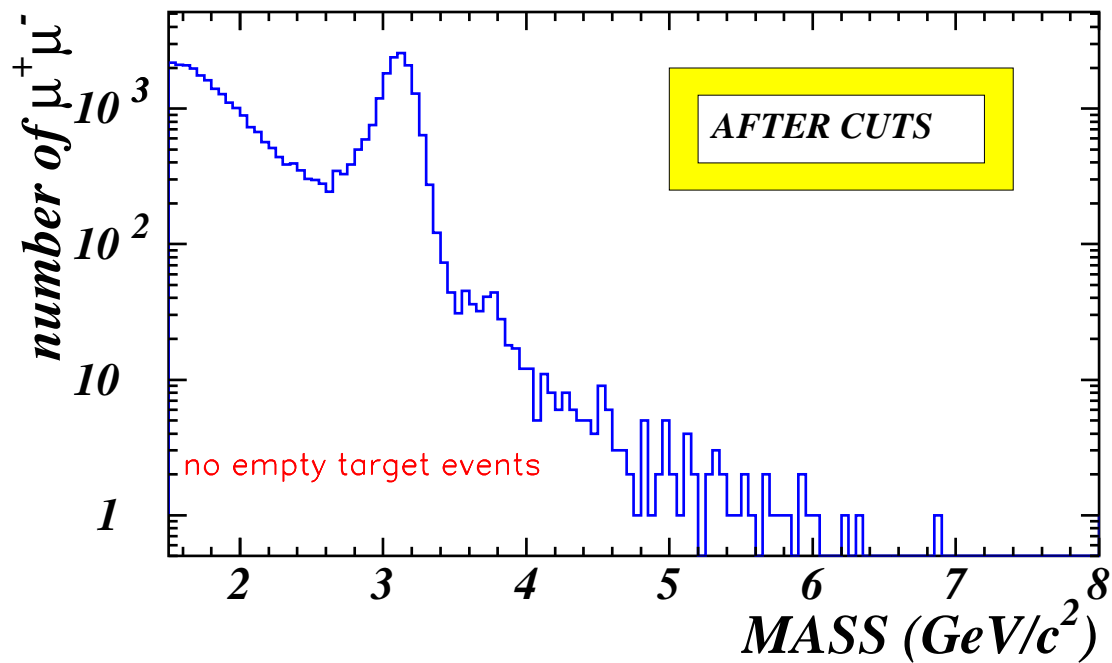
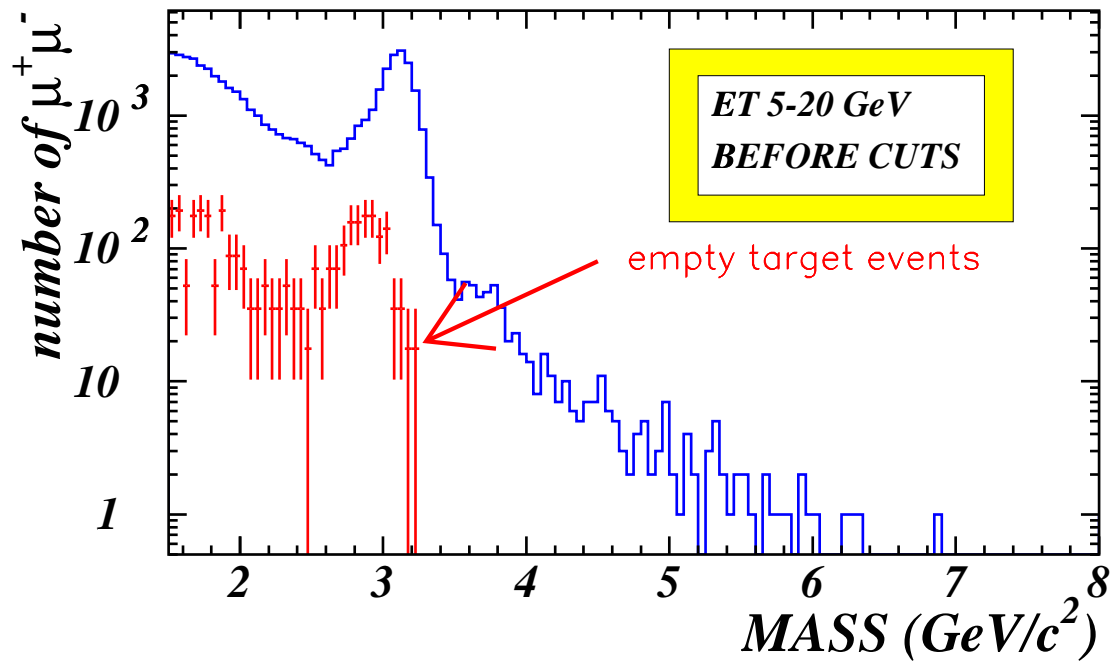
The ratio of measured (NA51, NA38 and NA50 experiments) to computed Drell-Yan cross-section (with the MRS 43 parametrization of parton distribution functions):



indicates that the **Drell-Yan yield is proportional to the number of nucleon-nucleon collisions**, from pp to Pb-Pb



# Pb-Pb 2000 run: clean conditions

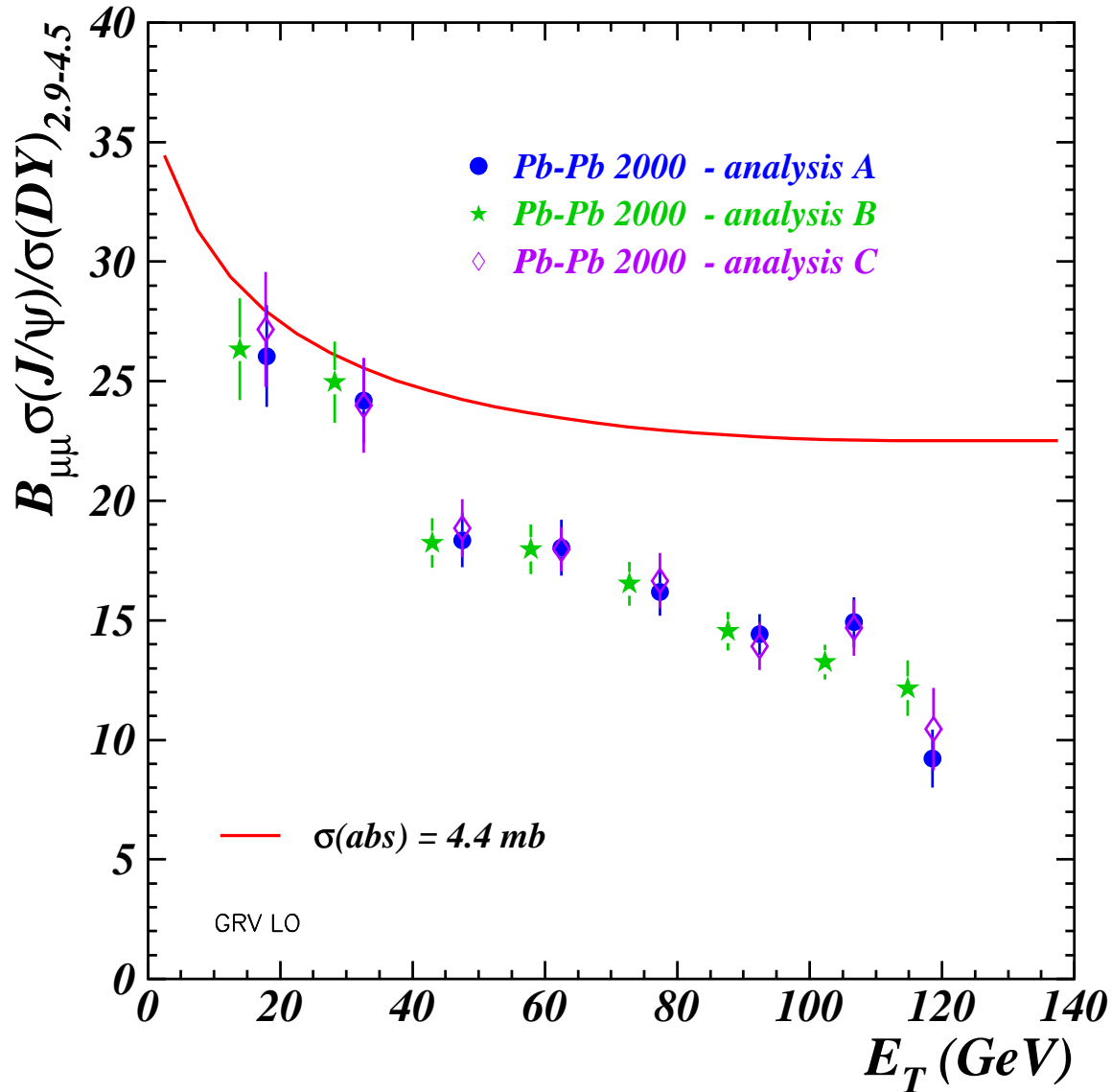


low  $E_T$ : contamination at  $M < M_{J/\psi}$  removed by target cuts (higher  $E_T$ : no contamination even before cuts)

# The standard analysis method

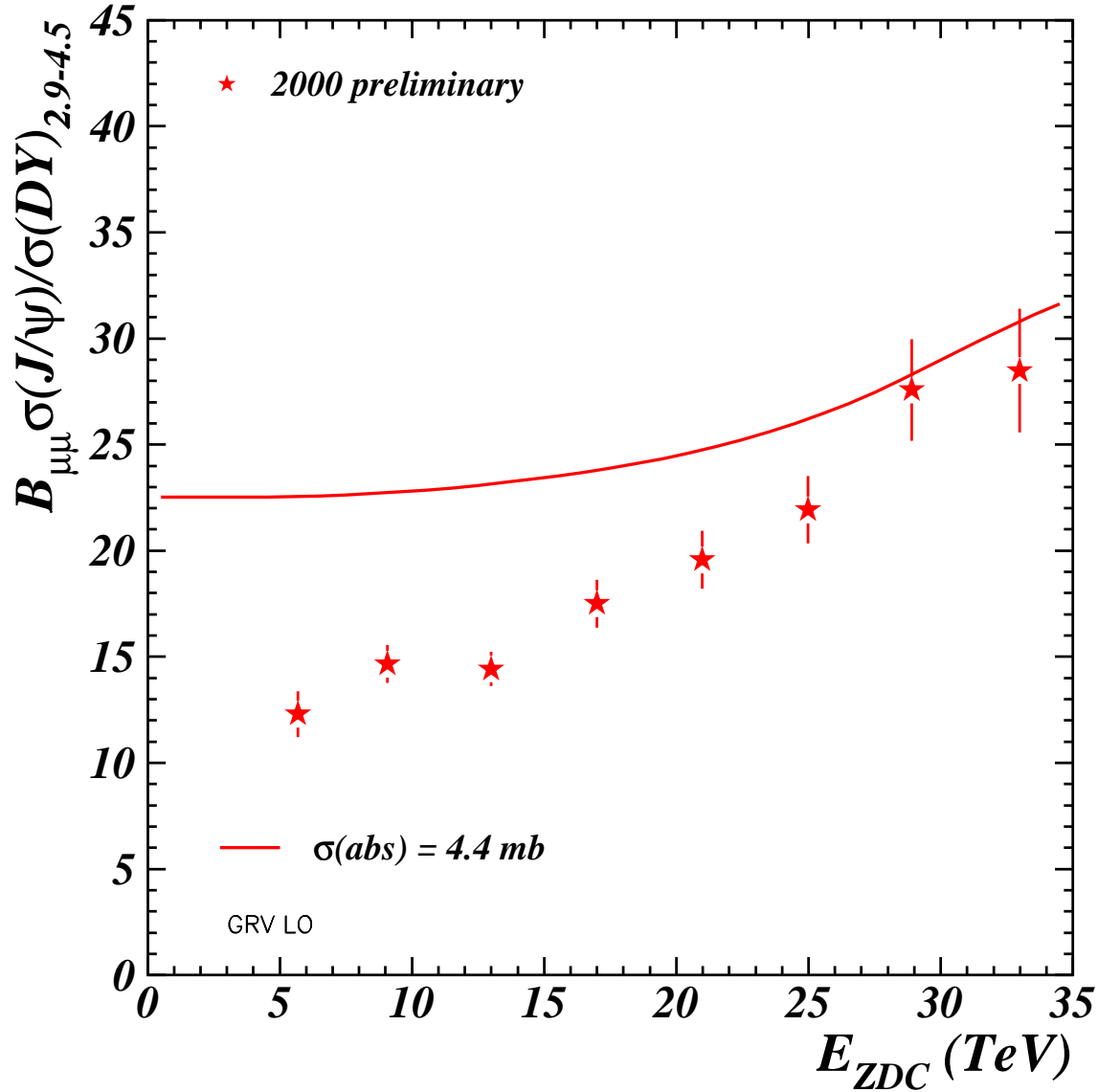
- Fit to  $\mu^+\mu^+$ ,  $\mu^-\mu^-$  mass spectra to determine combinatorial background in the  $\mu^+\mu^-$  sample from  $\pi$  and  $K$  decays
- Fit to  $\mu^+\mu^-$  mass spectra with four signal contributions:  $J/\psi$ ,  $\psi'$ , Drell-Yan and Open Charm (simultaneous  $D\bar{D}$  muonic decays)
- Extract  $J/\psi$  and Drell-Yan yields
- Advantages:
  - ratio of dimuon processes
    - ⇒ efficiencies cancel out (same trigger)
  - absolute normalization
    - ⇒ straightforward comparison to normal absorption curve
- Price to pay:
  - low statistics for high mass Drell-Yan

# $(J/\psi)/DY$ vs. $E_T$ in year 2000



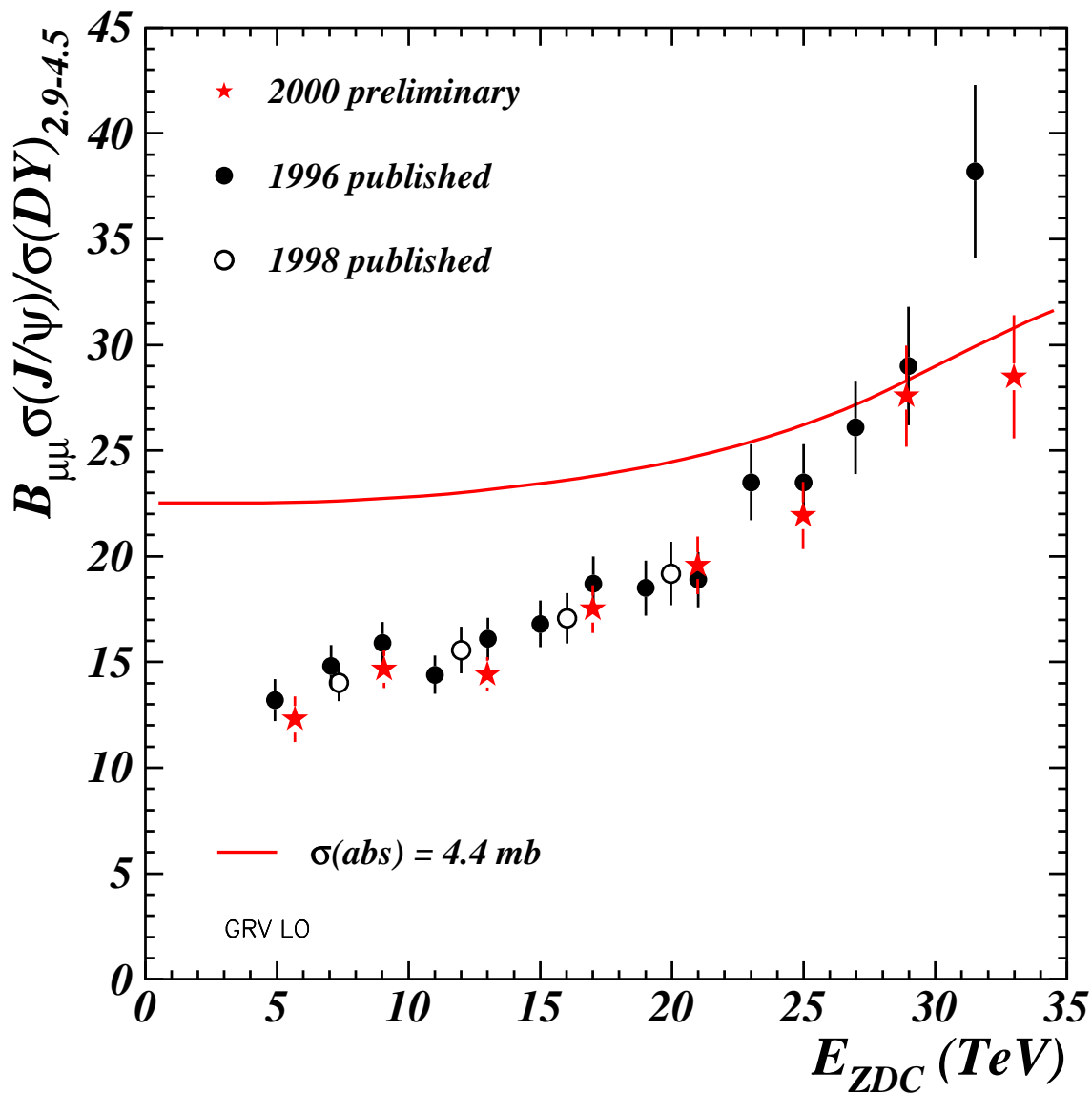
- $J/\psi$  production in peripheral Pb-Pb collisions follows normal nuclear absorption pattern deduced from p-A and S-U collisions
- no saturation seen in the data at high  $E_T$

# $(J/\psi)/DY$ vs. $E_{ZDC}$



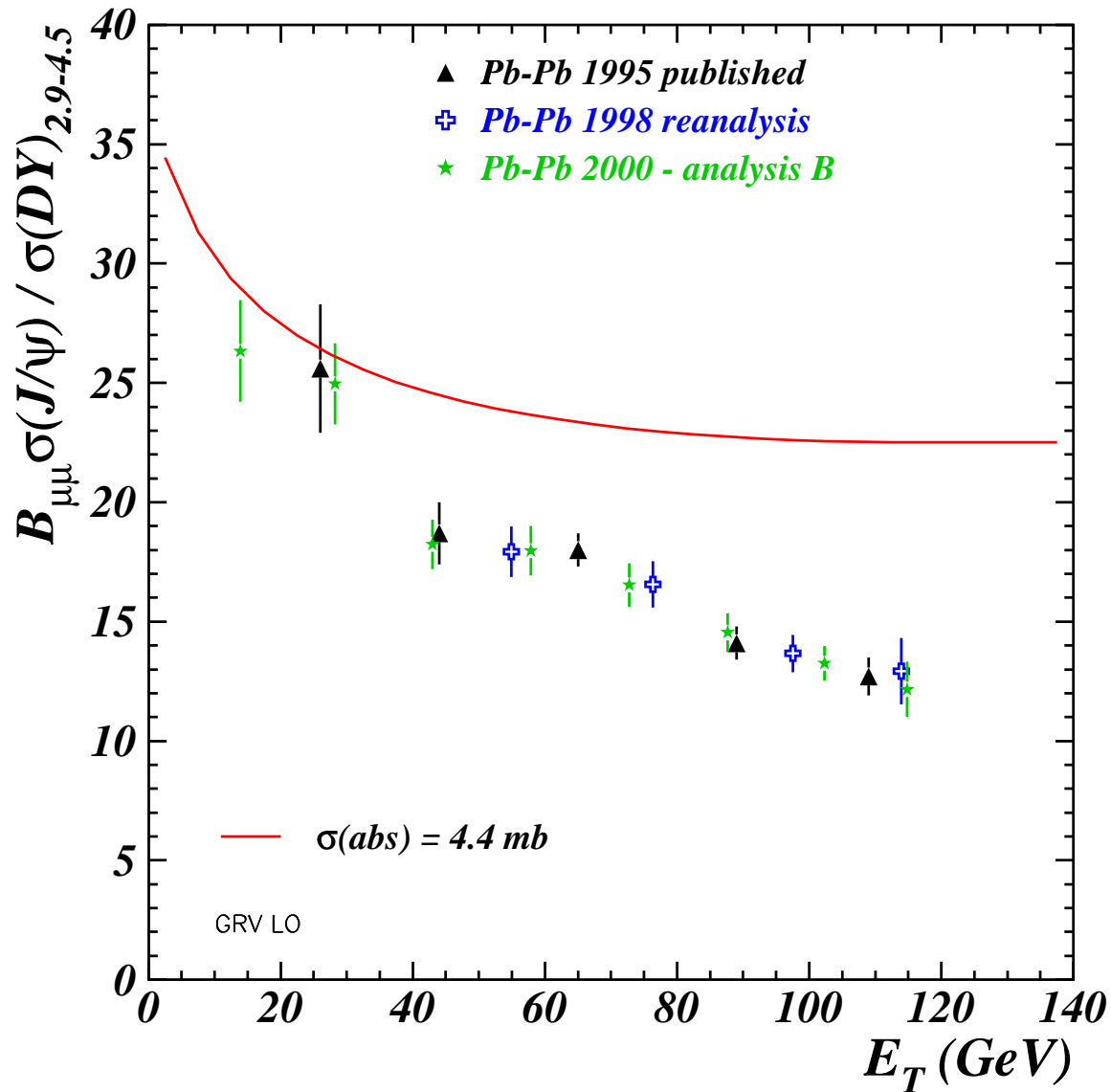
Using forward energy as centrality estimator,  $J/\psi$  production in peripheral Pb-Pb collisions again follows the normal nuclear absorption deduced from p-A and S-U collisions

## 2000 and previous results vs. $E_{ZDC}$



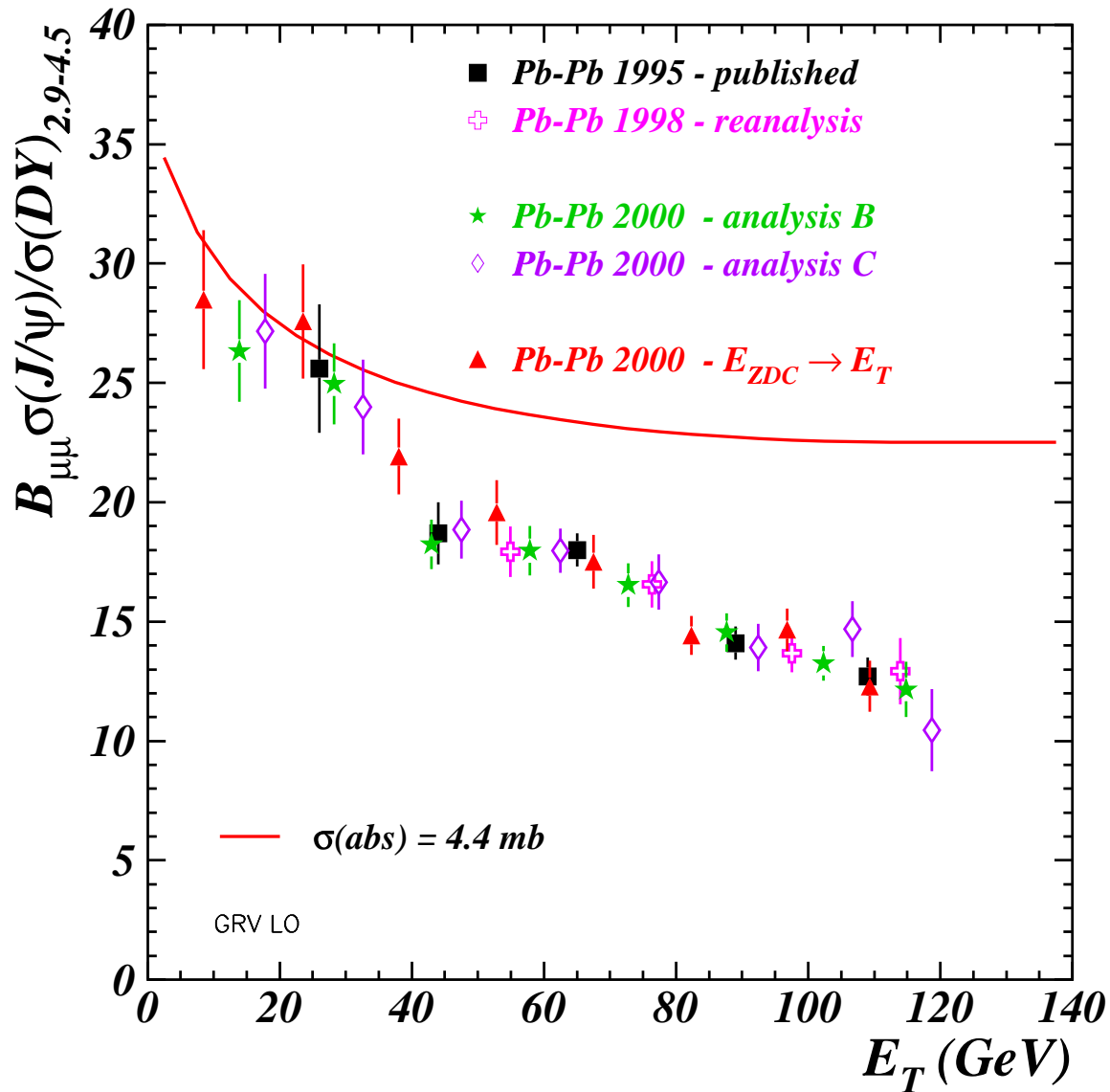
Except for the 1996 most peripheral collisions (probably contaminated by Pb-air interactions in the past), good agreement with published analyses

## 2000 and previous results vs. $E_T$



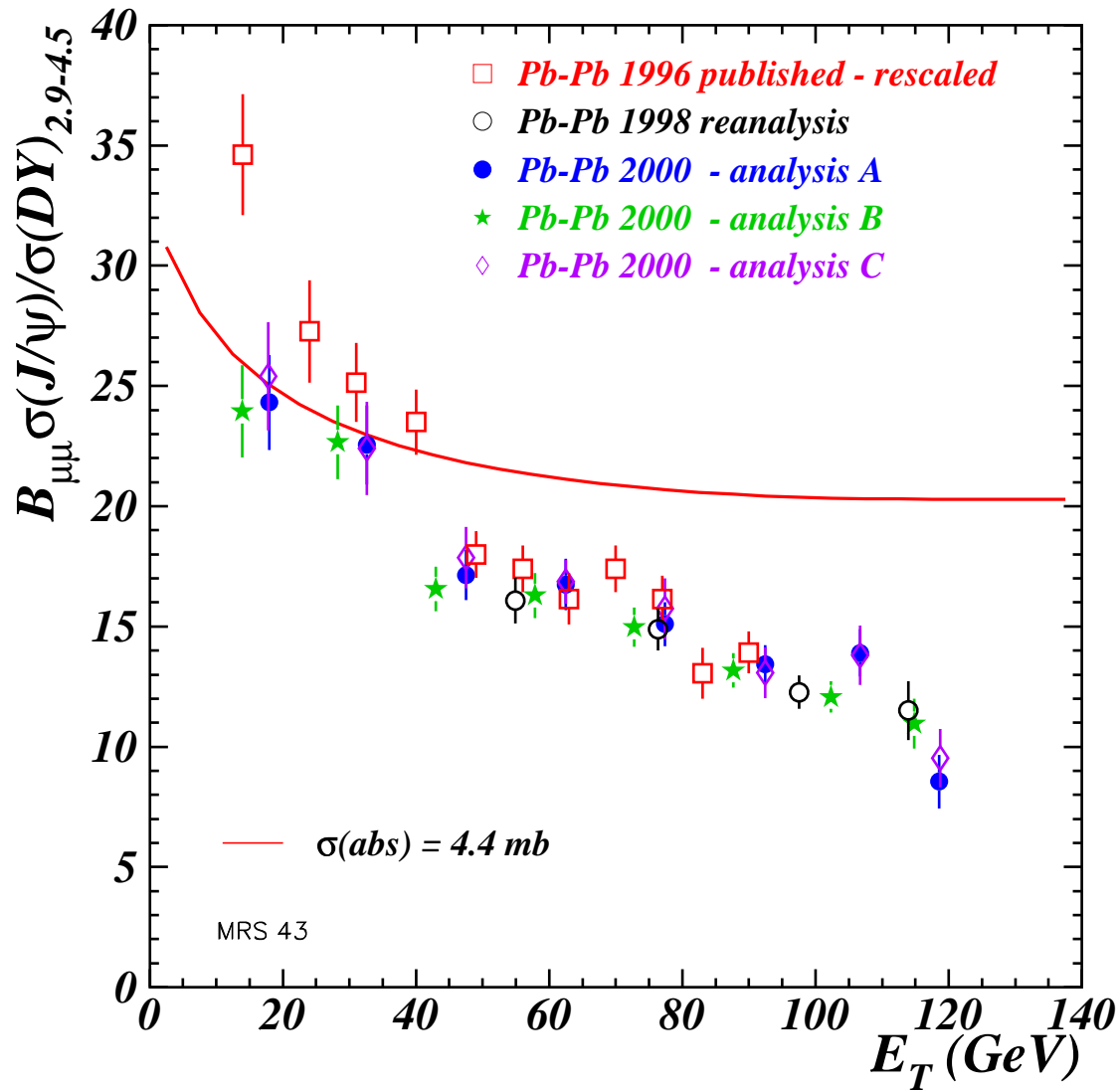
- (i) peripheral interactions agree with the normal absorption curve
- (ii) there is a departure at  $E_T \simeq 40$  GeV
- (iii) there is no saturation at high  $E_T$

# $E_T$ and $E_{ZDC}$ analyses



within the different resolutions vs. centrality of the two calorimeters, the  $E_{ZDC}$  analysis translated into  $E_T$  shows good consistency with the  $E_T$  analyses

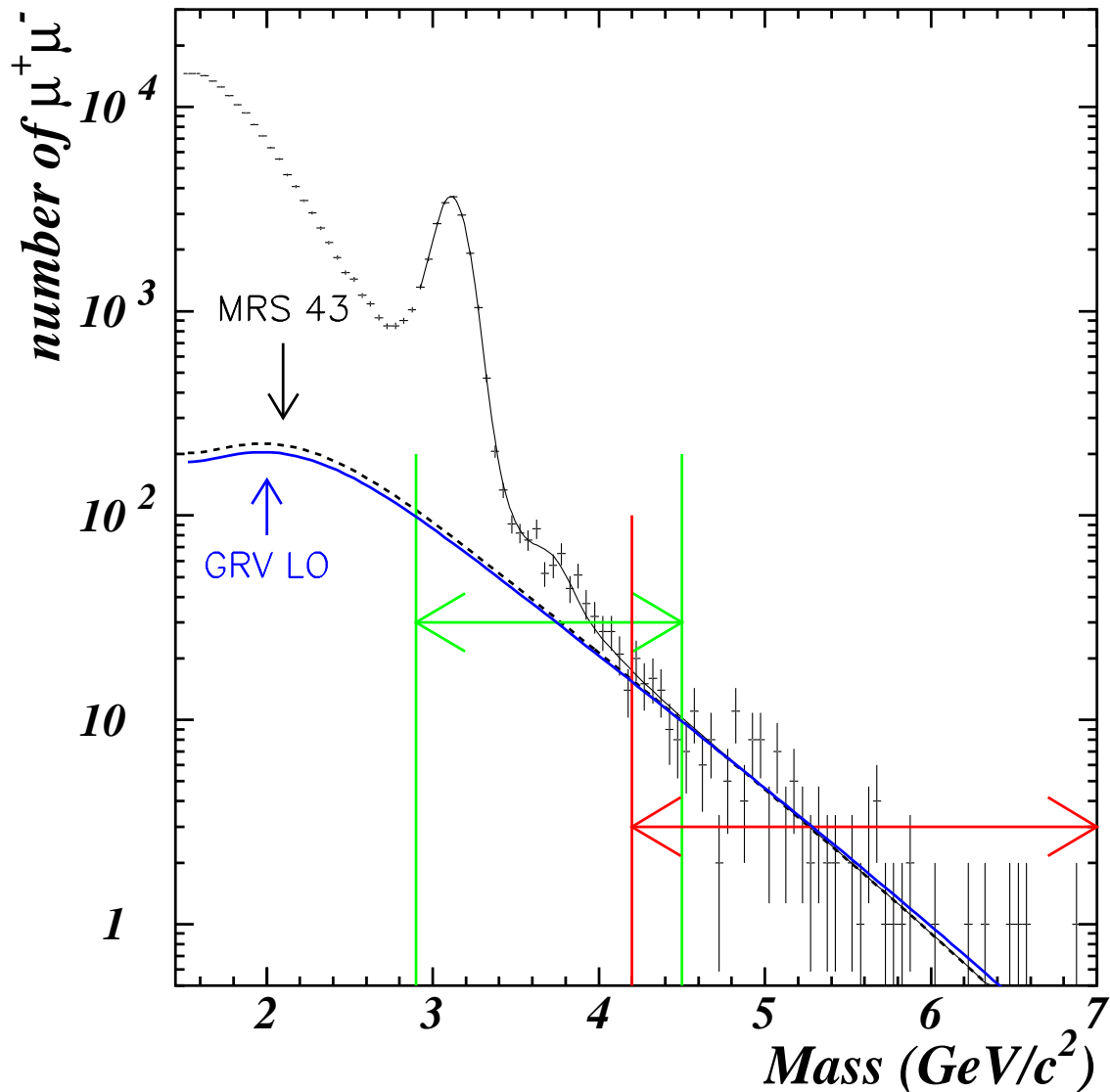
## 2000 results vs. $E_T$ - MRS 43



- Same pattern vs.  $E_T$  as in the GRV LO analysis, but slightly different absolute value of  $B_{\mu\mu} \sigma(J/\psi) / \sigma(DY)_{2.9-4.5}$
- The 2000 results agree reasonably well with published analyses when all of them use the MRS 43 PDFs

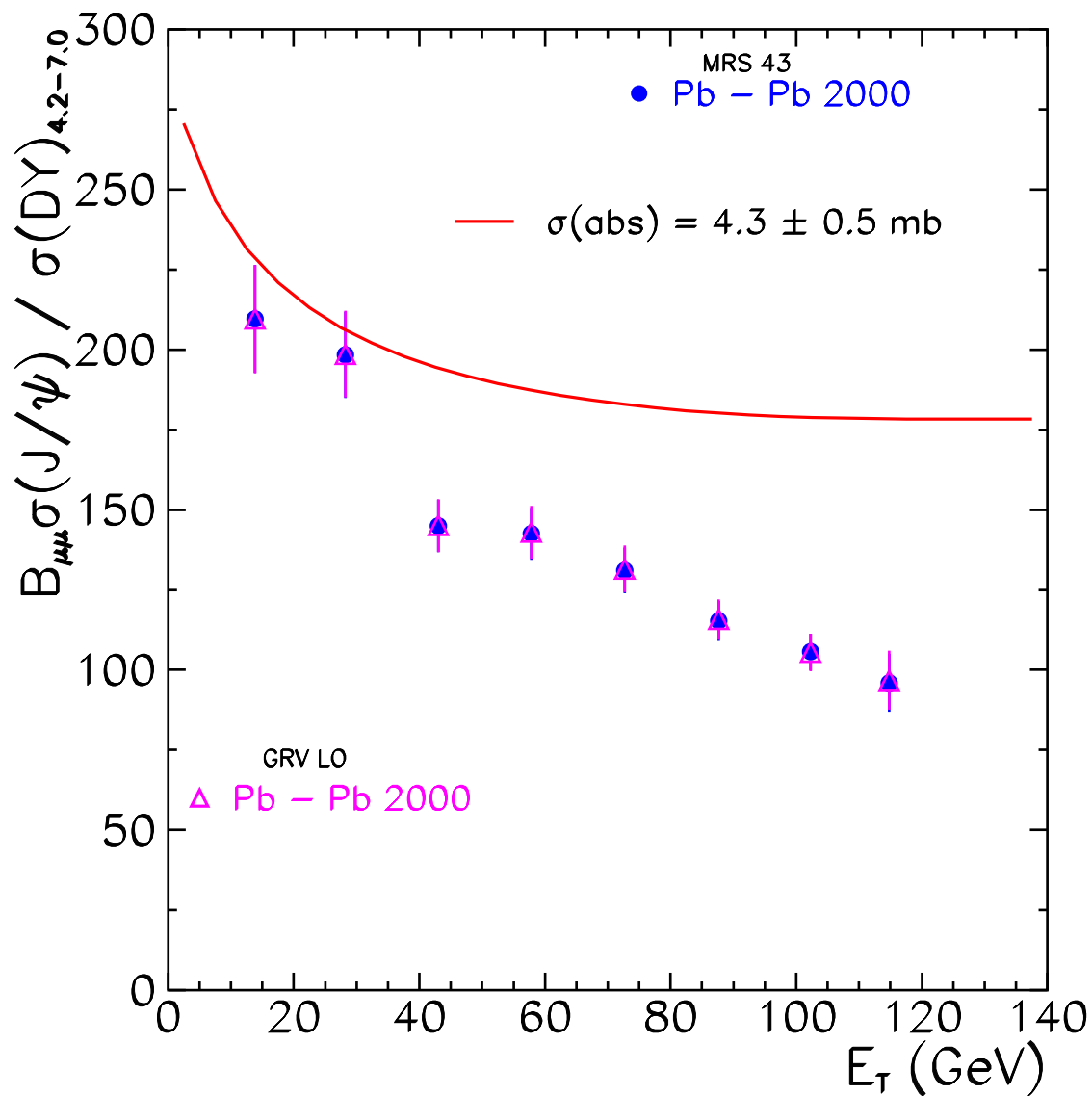


# New reference: DY(4.2-7.0)



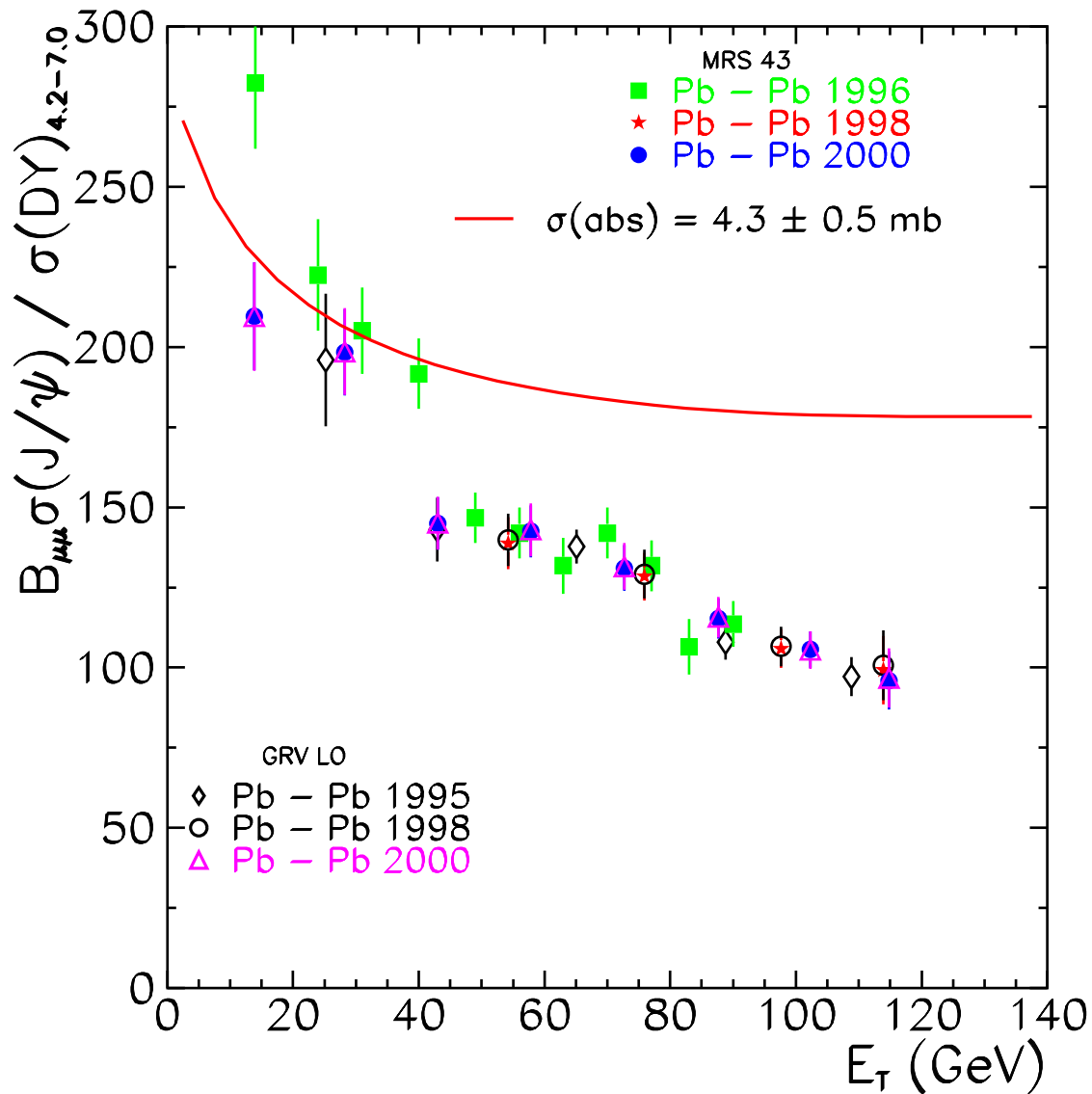
- $\sigma_{DY}(2.9 - 4.5)$  depends on extrapolation of  $dN_{DY}/dM$  from mass region where DY is the only contribution
- different parton distributions lead to different results
- using  $\sigma_{DY}(4.2 - 7.0) \Leftrightarrow$  unique result

## 2000 results: $(J/\psi)/DY(4.2 - 7.0)$



with this presentation our results do not depend any more on the chosen set of parton distribution functions

# Pb-Pb results: $(J/\psi)/DY(4.2 - 7.0)$

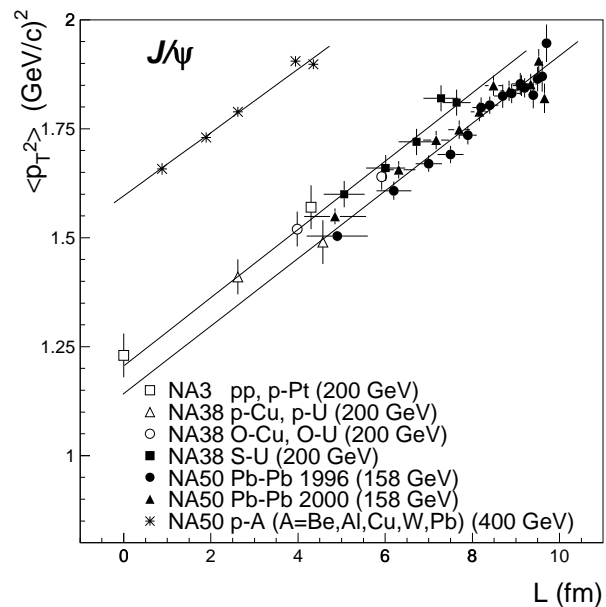
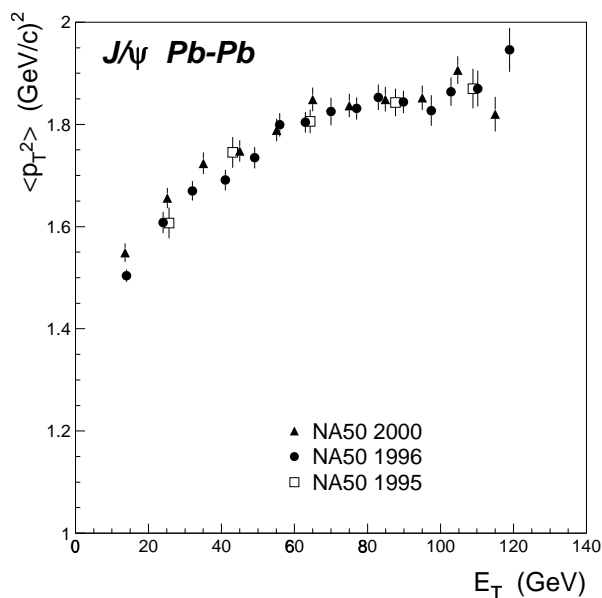


comparison with previous years shows reasonable agreement (except for most peripheral point in 1996)

## $J/\psi$ Transverse momentum

- Pb-Pb: fast increase with centrality of  $J/\psi$ 's  $\langle p_T^2 \rangle$ , followed by flattening for central collisions
- Data of many colliding systems well described by  $\langle p_T^2 \rangle = \langle p_T^2 \rangle_{pp} + a_{gN}L$ , with  $\sqrt{s}$ -dependent  $\langle p_T^2 \rangle_{pp}$  and:  

$$a_{gN} = 0.077 \pm 0.002 \text{ (GeV/c)}^2 \text{ fm}^{-1}$$

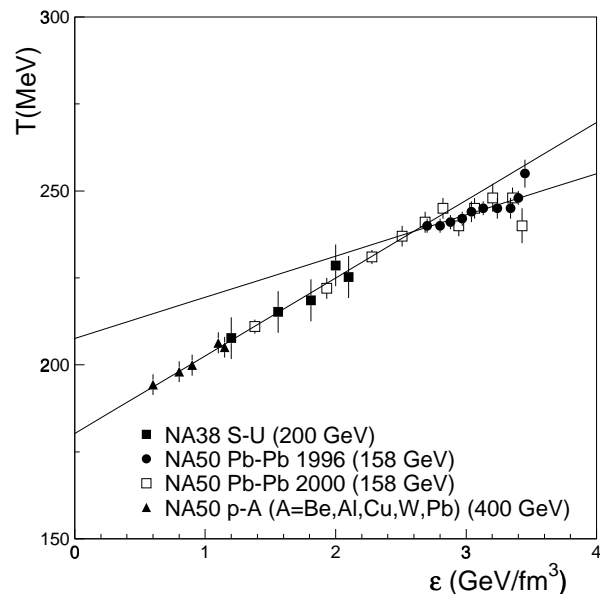
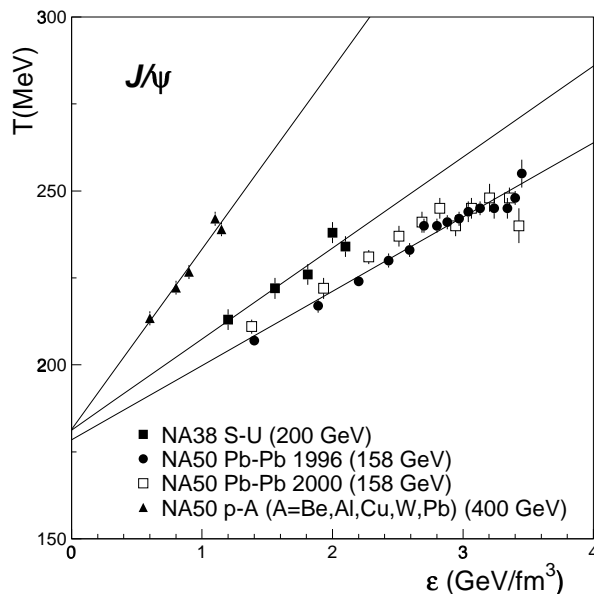


## $J/\psi$ Transverse momentum (cont.)

- A linear dependence of the fitted temperature  $T$  on the energy density  $\epsilon$  is found for three different  $\sqrt{s}$  values, with:

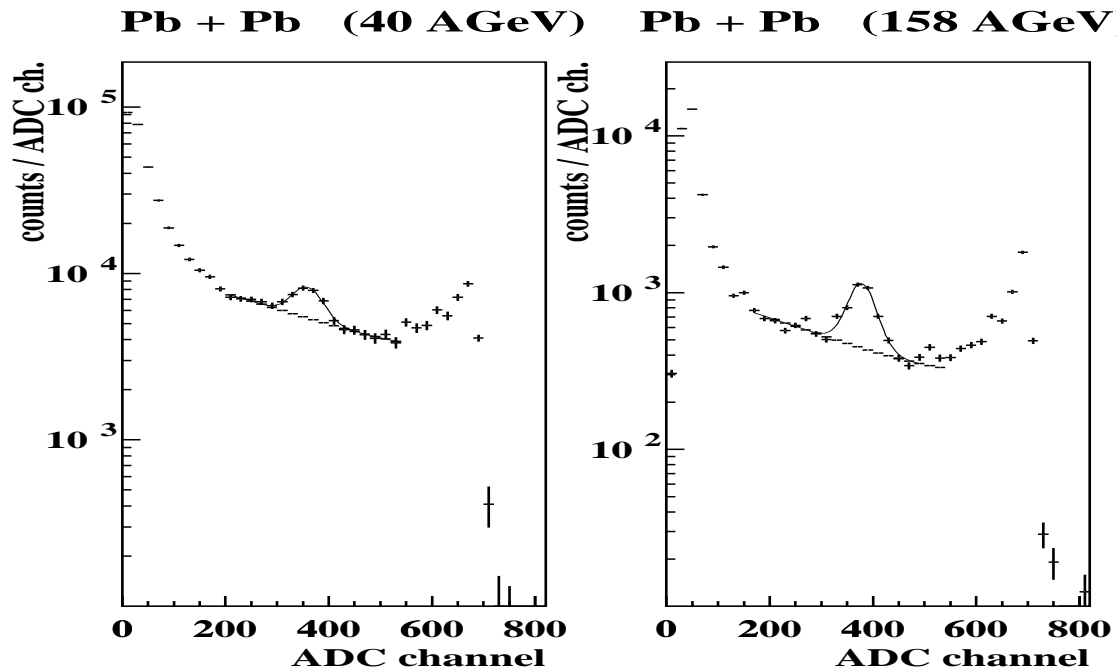
$$T(\epsilon = 0) = 179 \pm 2 \text{ MeV}$$

- After rescaling to the same  $\sqrt{s}$ , all points fall on same straight line, except for a change of slope in the most central Pb-Pb data

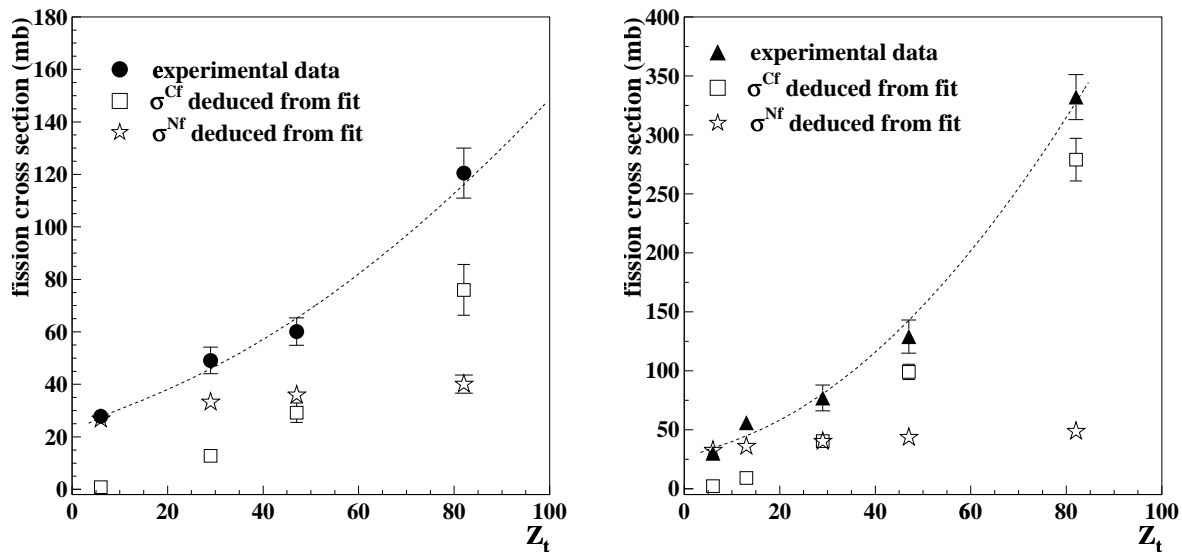


# Fission of Pb projectile (1999-2000 data)

- Fragment detector (quartz blade) in front of ZDC measures  $\Sigma Z_i^2 \Rightarrow$  binary fission of Pb is detected

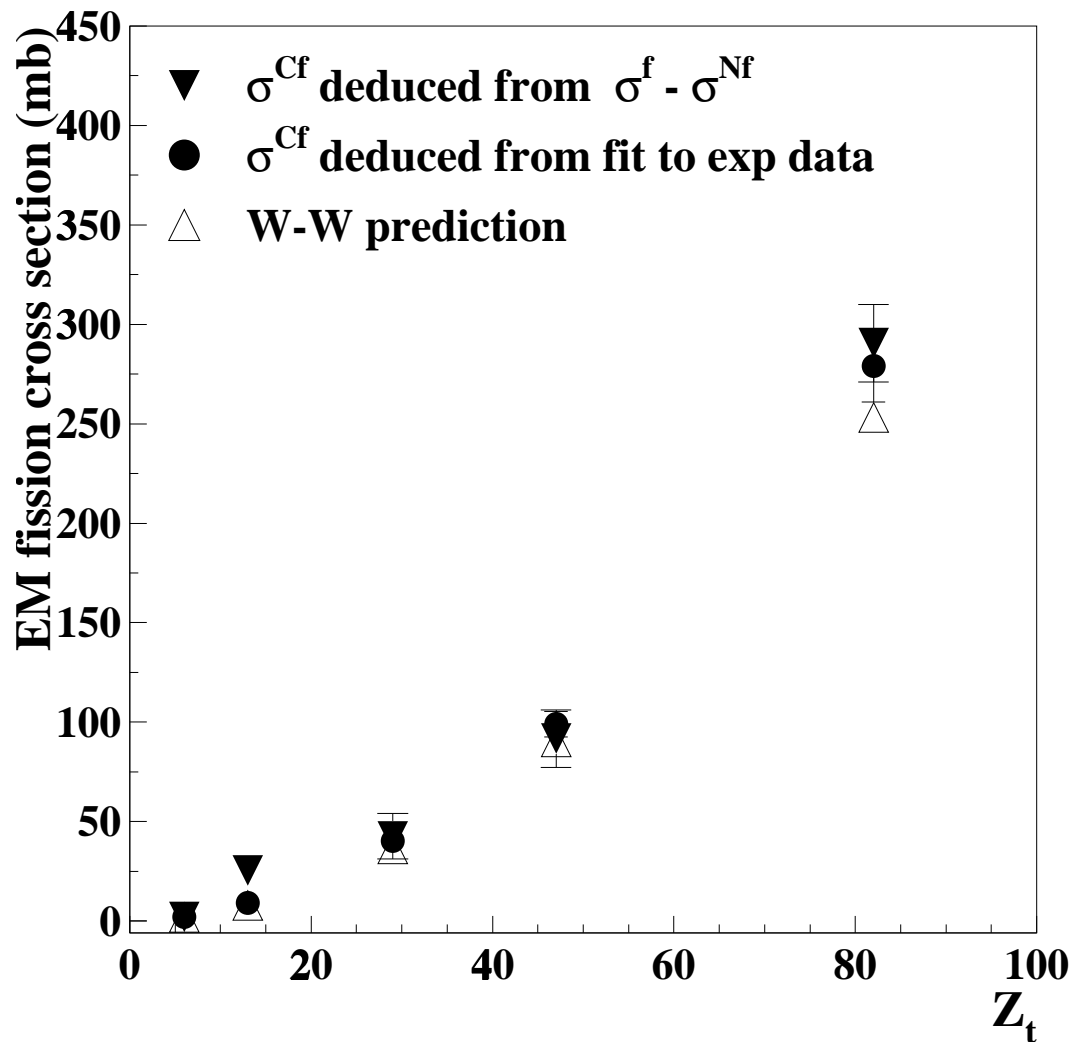


- Systematics with C, Al, Cu, Ag, Pb at 40 and 158 A GeV/c allows us to disentangle Coulomb and Nuclear fission



## Fission of Pb projectile (cont.)

- Electromagnetic contribution to fission cross-section compares well with Weizsäcker-Williams calculations at both energies (except on the Pb target at 40 A GeV), the figure shows the cross-sections at 158 A GeV
- Experimental check of WW calculations for Pb is useful to validate LHC Pb beam lifetime estimates

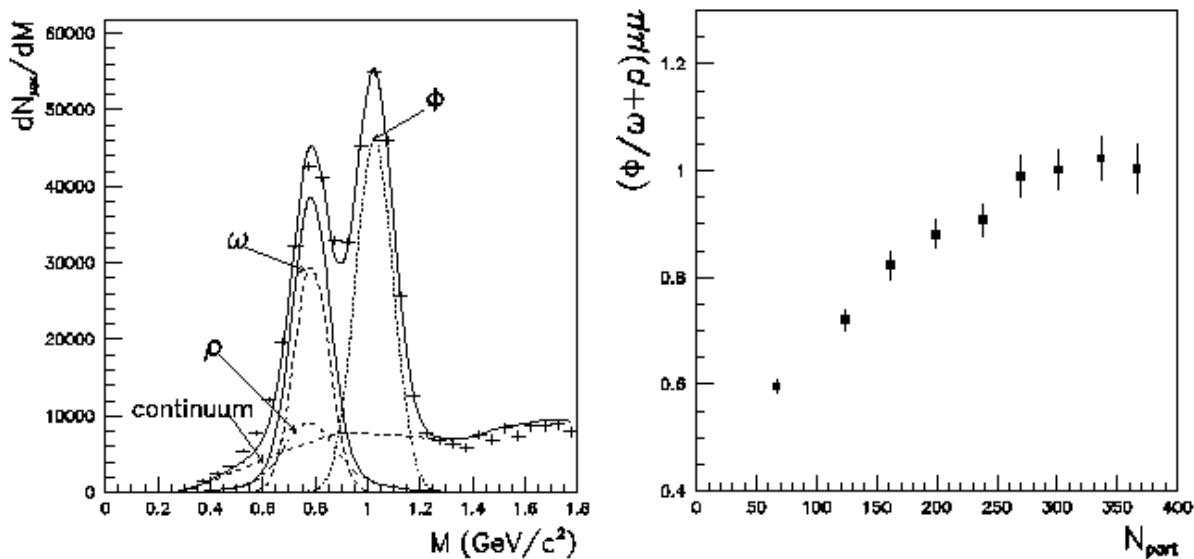


Fission paper is being submitted to Phys. Rev. C

# Low mass resonances - 1996 data

- Measure  $\phi$  and  $(\rho + \omega)$  yields in Pb-Pb with NA50 setup:
  - limited acceptance (high magnetic field, optimized for  $J/\psi$  mass region),  $M_T > 1.5 \text{ GeV}/c^2$
  - limited mass resolution ( $\sigma \approx 70 \text{ MeV}/c^2$ ), no separation between  $\omega$  and  $\rho$

Data collected in 1996 (7 subtargets, air in target region)  $\Rightarrow$  published in *Phys. Lett. B 555 (2003) 147*

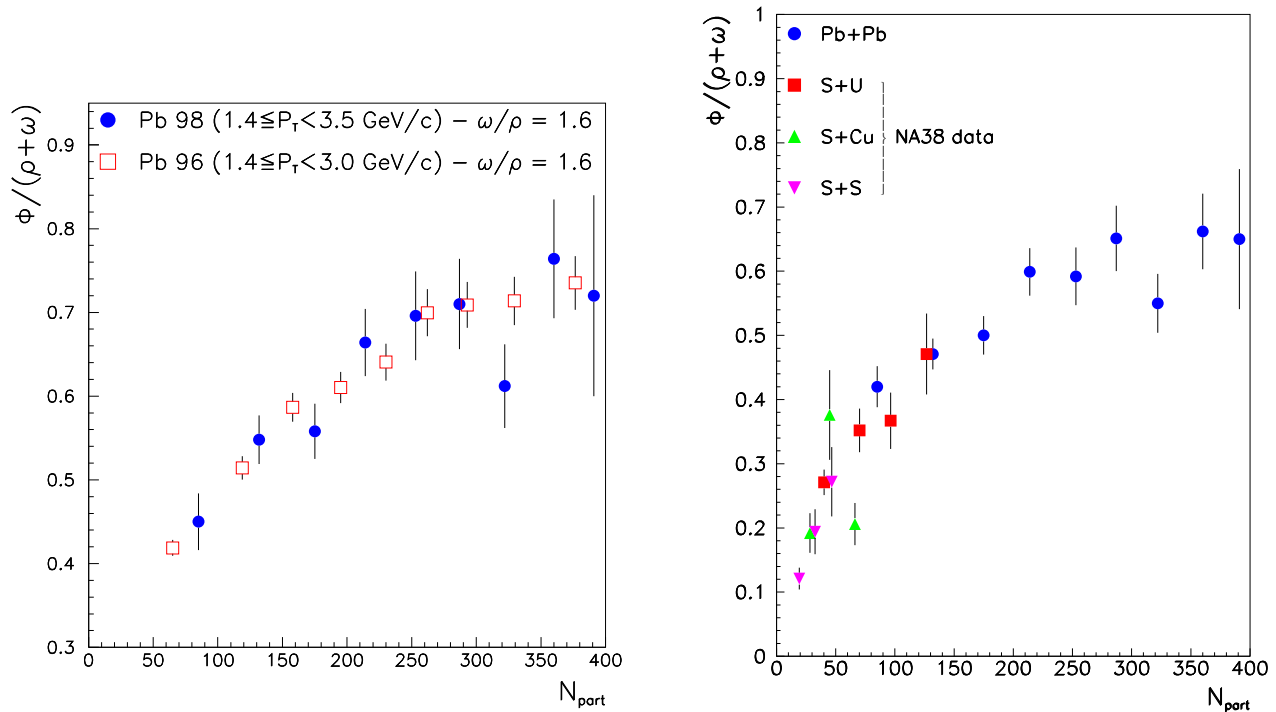


**The  $\phi/(\rho+\omega)$  ratio increases 70% when going from most peripheral to most central Pb-Pb collisions, and flattens for  $N_{\text{part}} > 250$**

The increase is due to an enhancement of the  $\phi$  production, while the  $(\rho + \omega)$  yield per participant stays constant



# Low mass resonances - other samples

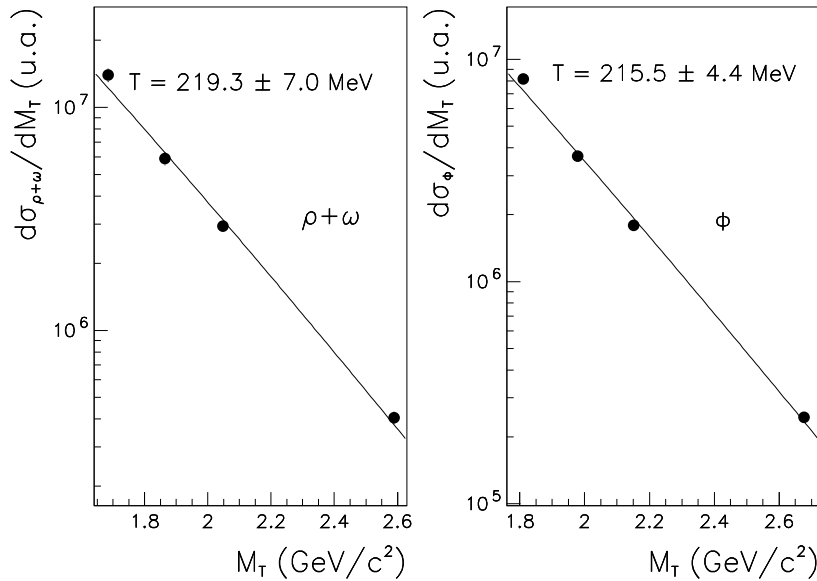


- The analysis of the 1998 data sample with improved setup (1 subtarget instead of 7) shows excellent agreement with the published 1996 data
- Comparison with lighter systems (NA38 experiment) shows a steady increase of the  $\phi/(\rho + \omega)$  ratio when going from S-S to Pb-Pb

# Effective temperatures

- Effective temperatures are obtained from the differential  $M_T$  spectra assuming a Boltzmann thermal distribution:

$$d\sigma/dM_T \propto M_T^n \exp(-M_T/T)$$



- Temperatures from 1996 and 1998 data samples are quite consistent and similar between  $\rho + \omega$  and  $\phi$  (furthermore, they do not depend on centrality):

T (MeV)	$\rho + \omega$	$\phi$
1996 ( $n = 1$ )	$224 \pm 10$	$228 \pm 10$
1998 ( $n = 3/2$ )	$219.3 \pm 7.0$	$215.5 \pm 4.4$

- The  $\phi$  effective temperature is below the line

$$T = T(f.o.) + \frac{1}{2} M v_T^2$$

valid for non-strange and single-strange hadrons, possibly indicating earlier decoupling from the hadron gas (as observed by WA97 for  $\Omega + \bar{\Omega}$ )

## Low mass resonances - 2000

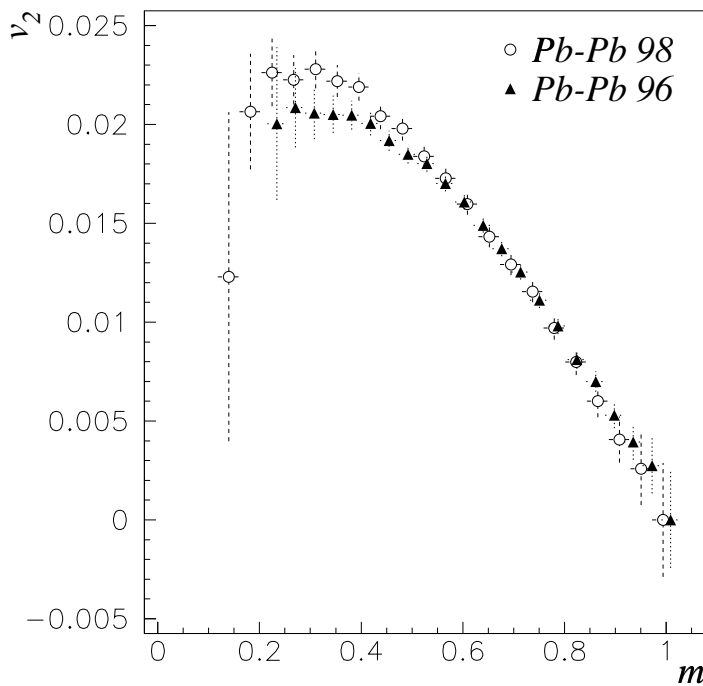
- Goal: check systematics in measurement of  $\phi$  and  $(\rho + \omega)$  yields in Pb-Pb with improved NA50 setup
- Data were collected in 2000 with 1 subtarget under vacuum
- This sample should give improved results for peripheral collisions

Analysis of the 2000 data sample is progressing (preliminary results were presented at the Strange Quark Matter 2003 conference)

There is also progress in comparing our results with those of NA49, in terms of  $\phi$  enhancement, temperatures and absolute yields (taking into account the different  $M_T$  domains and decay channels of the two experiments)

# Flow

- Elliptic flow studied with Electromagnetic Calorimeter (60° azimuthal segmentation): preliminary results presented at Quark Matter 1999, *Nucl. Phys. A 661 (1999) 345c* and at the IXth Int. Workshop on Multiparticle Production, *Nucl. Phys. B (Proc. Suppl.) 92 (2001) 55-61*; a paper on the flow with E.M. Calorimeter being finalized (Pb-Pb and lighter systems)



$v_2$ : coefficient of elliptic flow

$m$  : centrality variable ( $E_T/E_T^{max}$ )

- Flow study with Multiplicity Detector (10° azimuthal segmentation): analysis under way (Pb-Pb 1998 and 2000 data samples)

# Summary of NA50 Publications

- Published since previous Status Report:

1. The silicon multiplicity detector for the NA50 experiment at CERN

*Nucl. Instr. Meth. Phys. Res. A 493 (2002) 30*

2. Charmonia and Drell-Yan production in proton-nucleus collisions at the CERN SPS

*Phys. Lett. B 553 (2003) 167*

3.  $\phi$  production in Pb-Pb collisions at 158 GeV/c per nucleon incident momentum

*Phys. Lett. B 555 (2003) 147*

- (being) submitted:

1. Fission cross-sections of Pb projectiles at 40 and 158 A GeV

2. Proton-nucleus High Intensity data:  $J/\psi$ ,  $\psi'$  and Drell-Yan cross-sections

3. Flow studied from Azimuthal Anisotropy of Transverse Energy

# Summary of ongoing analysis work

1. Finalize results on  $J/\psi$  and  $\psi'$  suppression (year 2000 Pb-Pb data)
2. Complete analysis of  $p_T$  distributions (year 2000 Pb-Pb data and p-A data)
3. Complete analysis of  $J/\psi$  and  $\psi'$  for the year 2000 Very High Intensity p-A data sample (aimed at reducing systematic errors on cross-sections)
4. Complete low mass resonance study for year 2000 data sample
5. Complete the flow analysis with the charged multiplicity detector

# Conclusion and Outlook

- The NA50 proton-nucleus data samples (1996-2000) have been almost fully analyzed, one paper was published and a second one is being submitted
- Analysis of the year 2000 Pb-Pb data is well advanced, preliminary results on  $J/\psi$  suppression and  $p_T$  distributions have been presented at Quark Matter 2002
- Other physics subjects, like low mass resonances and flow, are being actively studied
- Work is going on to finalize these analyses and to submit final papers for publication