Charmonia suppression in p-A collisions at 450 GeV/c; new results from NA50

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for the NA50 collaboration

QM2001 Quark Matter 2001

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- Analysis
- Results on cross sections: $\sigma_{J/\psi}$, $\sigma_{\psi'}$, σ_{DY}
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The NA50 collaboration

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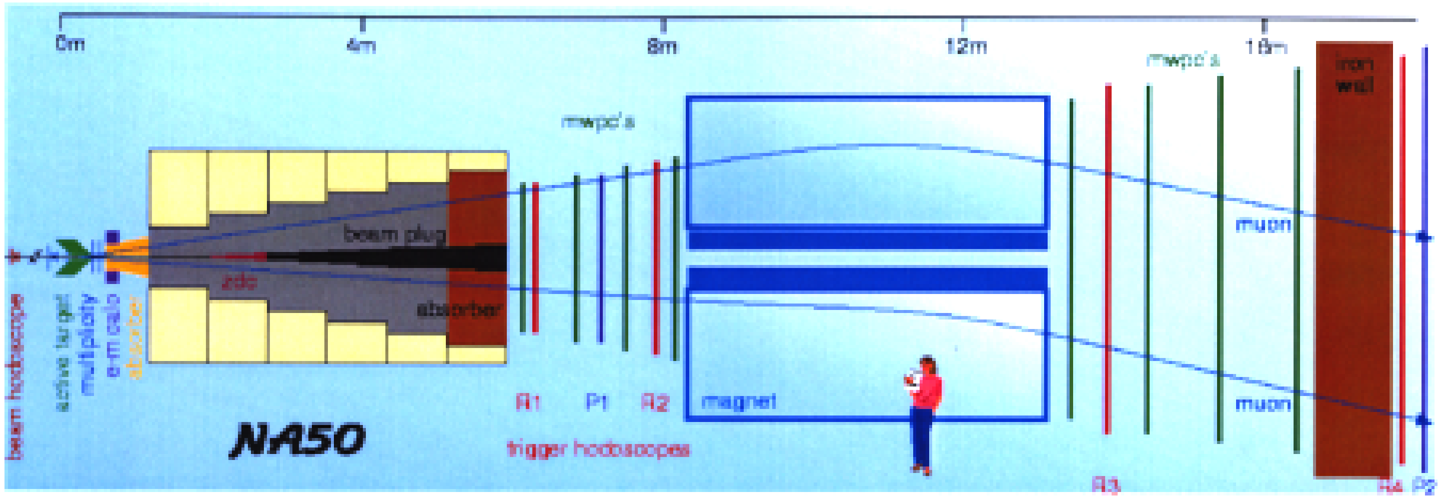
Physics motivation

- Study of the different absorption mechanisms of charmonia in p-A and A-A
- p-A: nuclear absorption
- A-A: nuclear absorption+hadronic comovers+color screening
- Picture complicated by:
    - Charmonium formation time arguments
    - Feeding of low-lying states from e.m. decays ψ', $\chi \rightarrow J/\psi$

- Need accurate data over large phase space regions as input to theory
- Obtain complementary information with respect to E866. In NA50:
    - E_p=450 GeV
    - 5 nuclear targets
    - Phase space window restricted ($-0.1 < x_F < 0.1$)
    - Large acceptance at $x_F \sim 0$ (~15% for J/ψ)
    - $10 < \gamma_{J/\psi} < 30$ for NA50, while $\gamma_{J/\psi} \sim 14$ for E866

NA50: experimental apparatus



- Muon spectrometer: air-gap toroidal magnet with <B>=2.1 Tm
- Phase space coverage: $3<y_{lab}<4$, $m_T \geq 1.3$ GeV/c^2, $|\cos\theta_{CS}|<0.5$
- Limited acceptance window in x_F: $-0.1< x_F<0.1$ @ 450 GeV
- Good p_T coverage with constant acceptance up to 4 GeV/c

Data taking conditions

- SPS primary proton beam at 450 GeV/c

- Intensity at NA50: ~$2\cdot10^8$ p/s (2.36 s spill)
  - Avoid event pileup in the spectrometer (could spoil reconstruction efficiency)
  - Low trigger rate (~20 Hz)
    - Live time ~ 100%

- Targets: Be, Al, Cu, Ag, W with thickness ranging from 24 $g\cdot cm^{-2}$ (Be) to 96 $g\cdot cm^{-2}$ (W)

- Sign of magnetic field in the spectrometer periodically changed

Data reduction: reconstruction

- Dimuon reconstruction
  - Requires two tracks in the air sectors of the toroidal magnet fully reconstructed in the MWPC
  - Trigger condition checked offline
  - Quality cuts on tracks
    - Target cut (→ see next slide)
    - Image cut → ensures that muons have the same acceptance independently from their charge

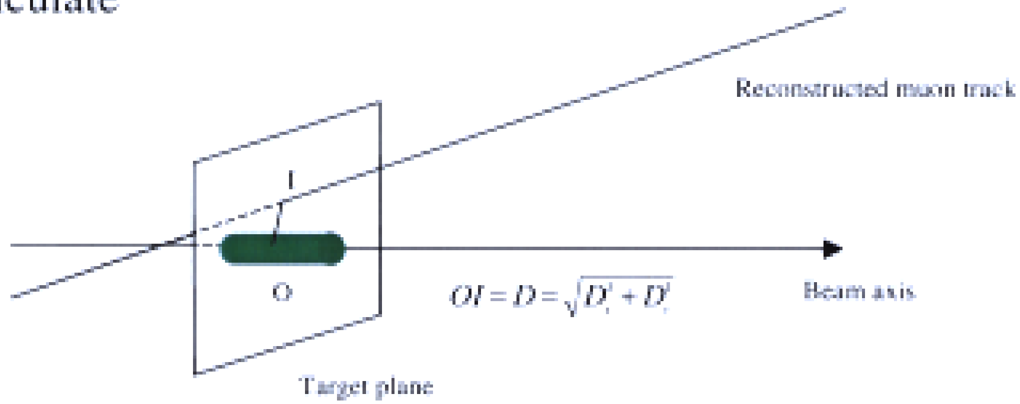
- Typical reconstruction rate ~35 %

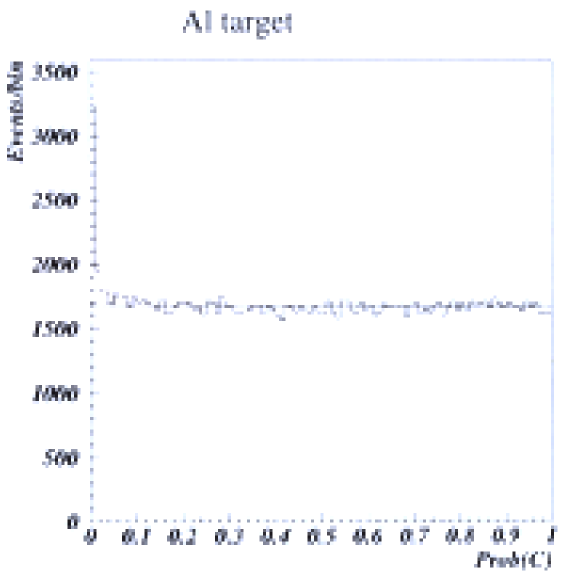
Target cut

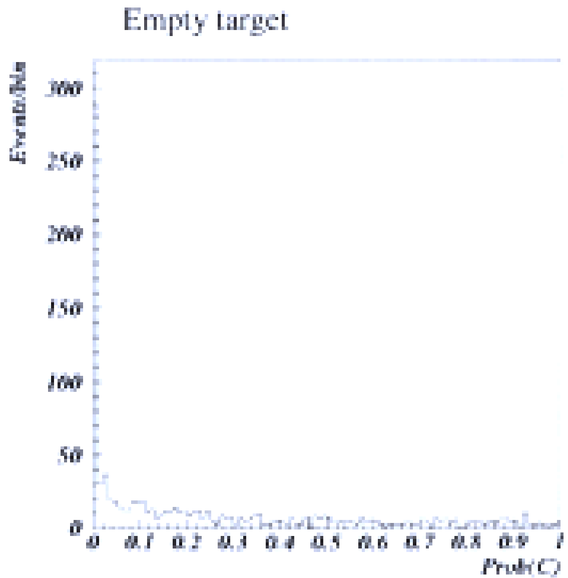
Consider for each track the quantities D_x, D_y (distance of the track from the beam axis at the target plane) and calculate

$$C = \left(\frac{p_x(D_x - \mu_x)}{\sigma_x}\right)^2 + \left(\frac{p_y(D_y - \mu_y)}{\sigma_y}\right)^2$$

$$\mathrm{Prob}(C) = \int_C^{\infty} f(\chi^2)\,d\chi^2$$







- Selecting events with Prob(C)>0.01 rejects most non-target background
- Stability of the results vs cut value has been tested

Data reduction: stability criteria and kinematical cuts

- Check distribution of :
  - Azimuthal asymmetries in the distribution of reconstructed tracks
    - Discard run periods (at 2.5 σ level) with anomalous percentage of tracks in a given sextant of the spectrometer (temporary hardware problems)
  - Distribution of reconstructed quantities ($M_{J/\psi}$, $\sigma_{J/\psi}$)
    - Discard run periods (at 2.5 σ level) with abnormal values: may indicate problems in the field delivered by the toroidal magnet
- Kinematical selection (to eliminate acceptance edges):
  - $-0.6<y_{CM}<0.4$, $-0.5<\cos\theta_{CS}<0.5$

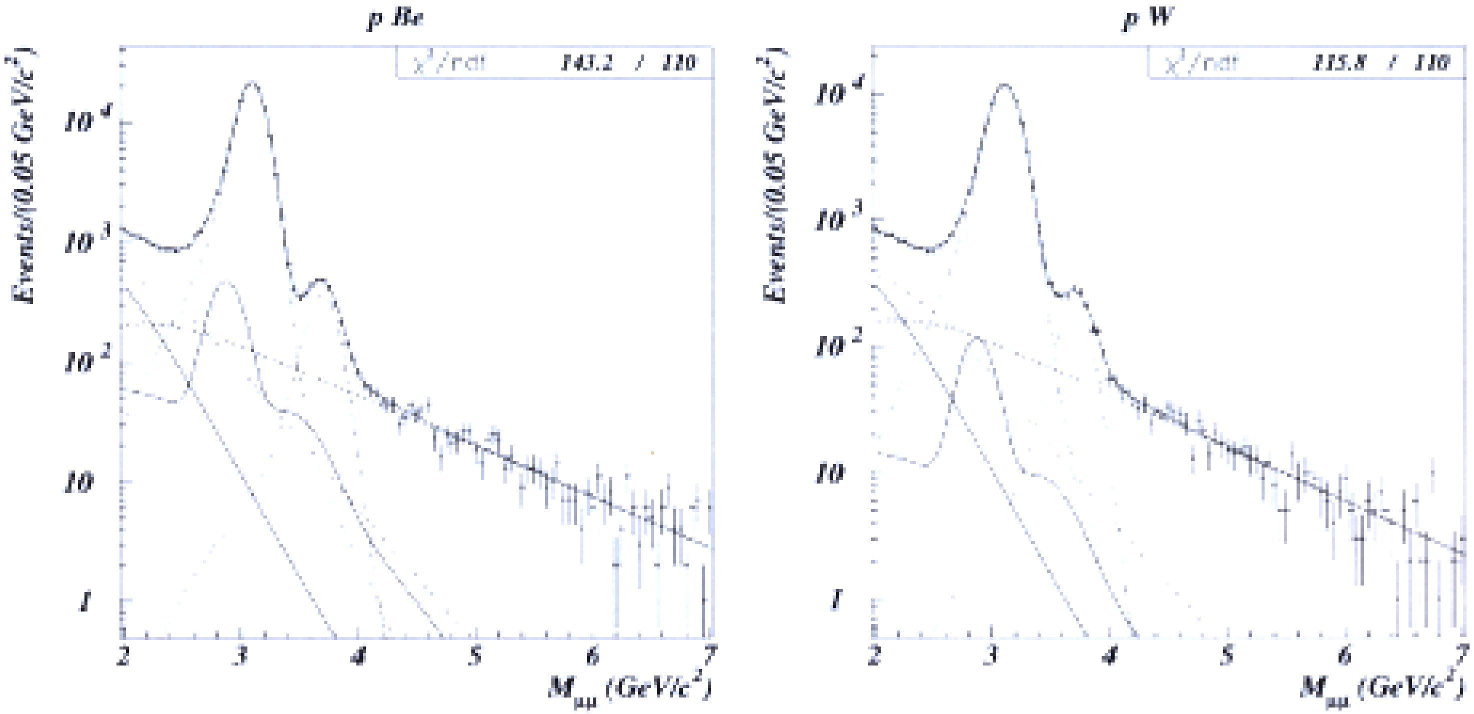
Fit of the mass spectra: method

- Fit the measured opposite sign invariant mass spectra according to:

$$\frac{dN^{+-}}{dM} = n^{DY}\frac{dN^{DY}}{dM} + n^{J/\psi}\frac{dN^{J/\psi}}{dM} + n^{\psi'}\frac{dN^{\psi'}}{dM} + n^{D\bar{D}}\frac{dN^{D\bar{D}}}{dM} + R\frac{dN^{bck}}{dM}$$

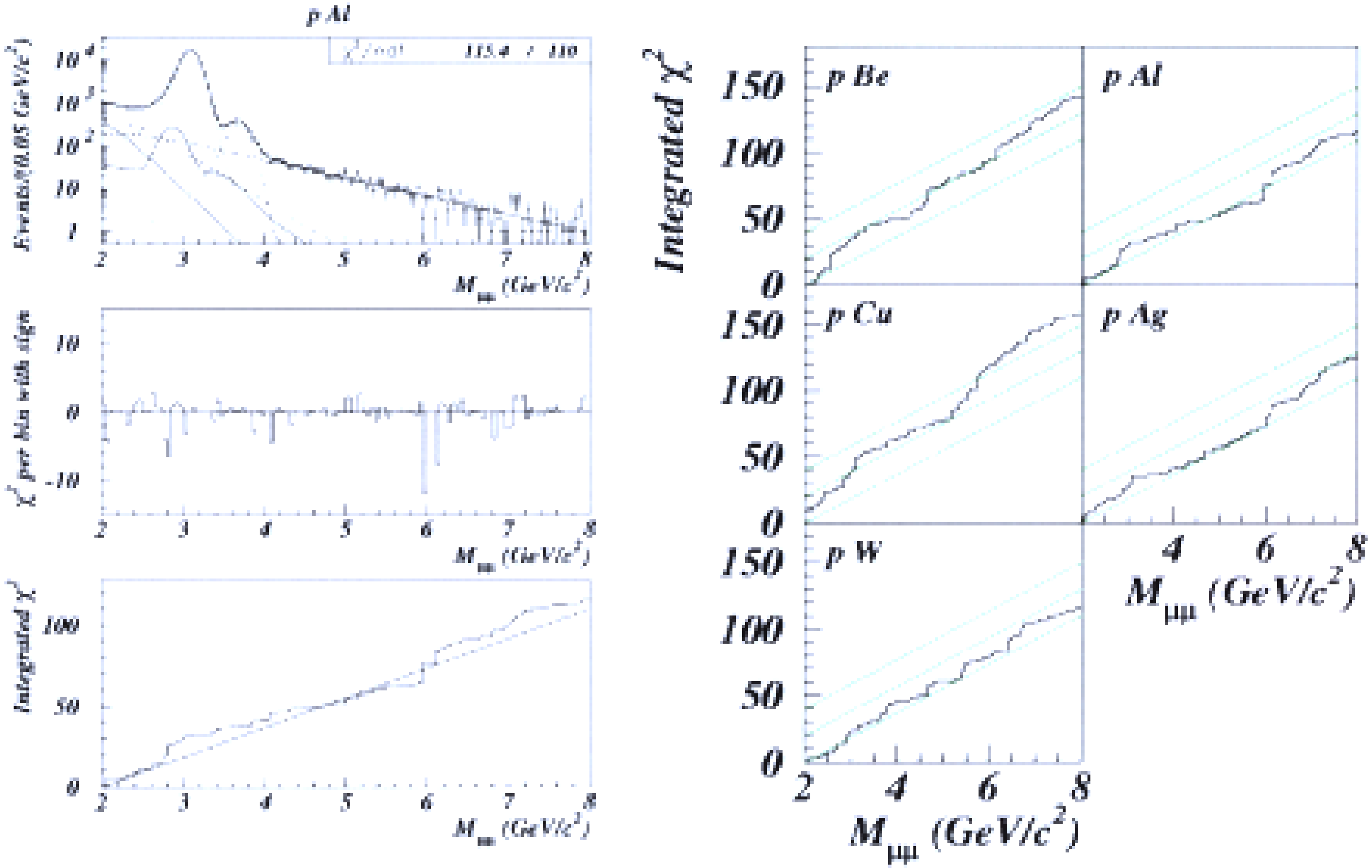
- dN^i/dM determined by Monte-Carlo simulation
- Background shape from like-sign dimuon distributions
- R factors (charge correlation effects) calculated with a simulation based on VENUS 4.12.
    - range from 1.09 (Ag) to 1.14 (W), depend on beam intensity
- n^i are free parameters in the fit

Fit to mass spectra: results



- Satisfactory description of all the mass spectra
- Empty target contribution, normalized to incident flux, included at the fit level
- Fit the invariant mass region $M_{\mu\mu}>2$ GeV/c^2 → check stability of the results
- Two procedures
    - Global fit
    - Fix high mass DY ($M_{\mu\mu}>5$ GeV/c^2)

A closer look to invariant mass fits



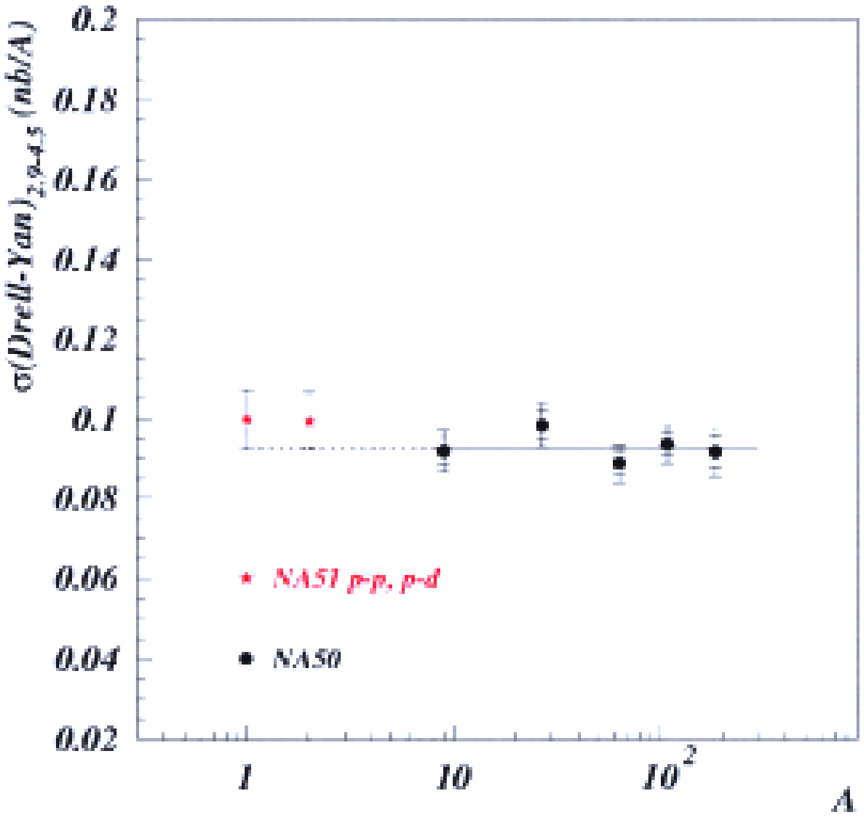
- Good quality of the fit all along the mass range
- Crucial region between J/ψ and ψ' well reproduced

Cross sections calculation

- Luminosity determination: 3 independent argon counters
  - Calibrated at low intensity
  - Linearity checked up to at least 10^{10} p/s
- Efficiency calculation:
  - Reconstruction efficiency (MWPCs) $\varepsilon_{rec}>0.97$ for all data sets
  - Trigger efficiency (special runs with dedicated hardware) ranges from $\varepsilon_{trig}= 0.86$ to $\varepsilon_{trig}= 0.90$
- Acceptances: $A_{J/\psi}=15.0\%$, $A_{\psi'}=17.3\%$, $A_{DY}=14.8\%$ ($2.9<M_{\mu\mu}<4.5$ GeV/c^2)

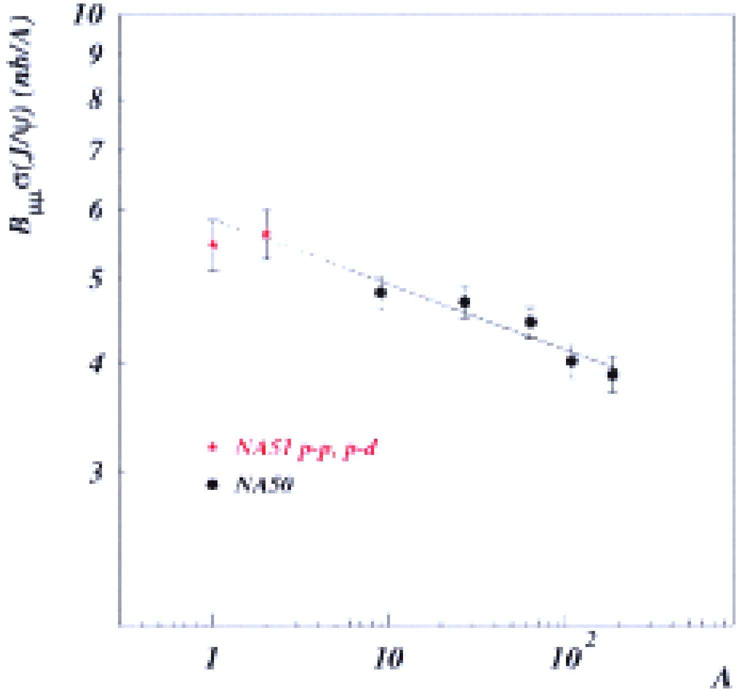
- Systematic errors:
  - $\varepsilon_{rec}\sim 1\%$
  - $\varepsilon_{trig}\sim 2\%$
  - Luminosity:
    - ~3% (relative, oscillations between the argon counters response
    - ~4% (absolute calibration, not include in plots and fits used in determining
    - nuclear absorption)
  - Residual (short range fluctuations of trigger efficiency): ~1.5÷3%, depending on target

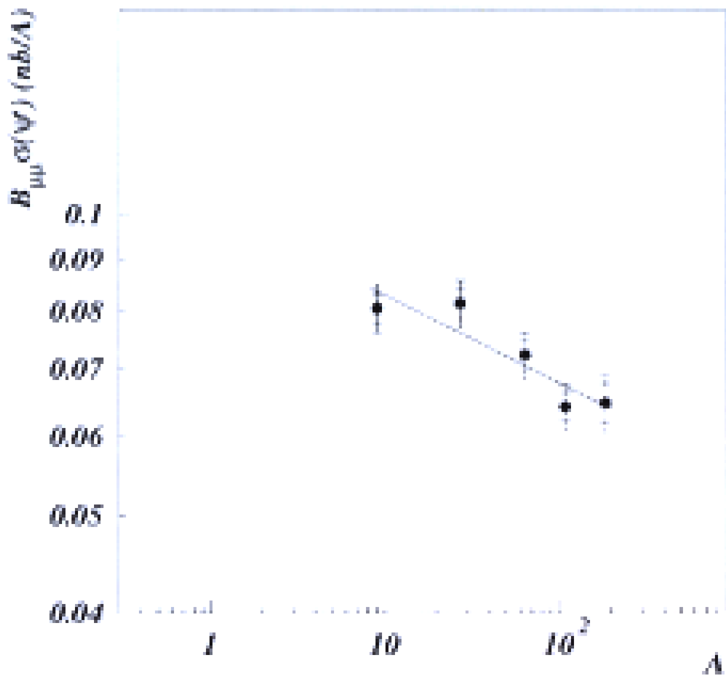
DY cross section



- In the mass range $2.9 < M_{\mu\mu} < 4.5$ GeV/c^2:
- α_{DY}=0.994±0.016 (stat) χ^2/dof=1.4
- α_{DY}=0.992±0.019 (syst) χ^2/dof=1.0
- α_{DY}=0.993±0.025 (syst+stat) χ^2/dof=0.6
- σ_{DY}=0.093 ±0.02 nb/nucleon (syst+stat)
- Nuclear effects (shadowing) negligible in the explored phase space range
- Confirms theory predictions (K. Eskola et al., hep-ph/0009251)
- Drell-Yan can be safely used as a reference process for the study of charmonia production in our kinematical window
- Isospin effects in Drell-Yan production taken into account (MRS A-low Q^2 set of p.d.f.)

Charmonia cross sections





- $\alpha_{J/\psi}$=0.925±0.002 (stat) χ^2/dof→∞
- $\alpha_{J/\psi}$=0.925±0.018 (syst+stat) χ^2/dof=0.75

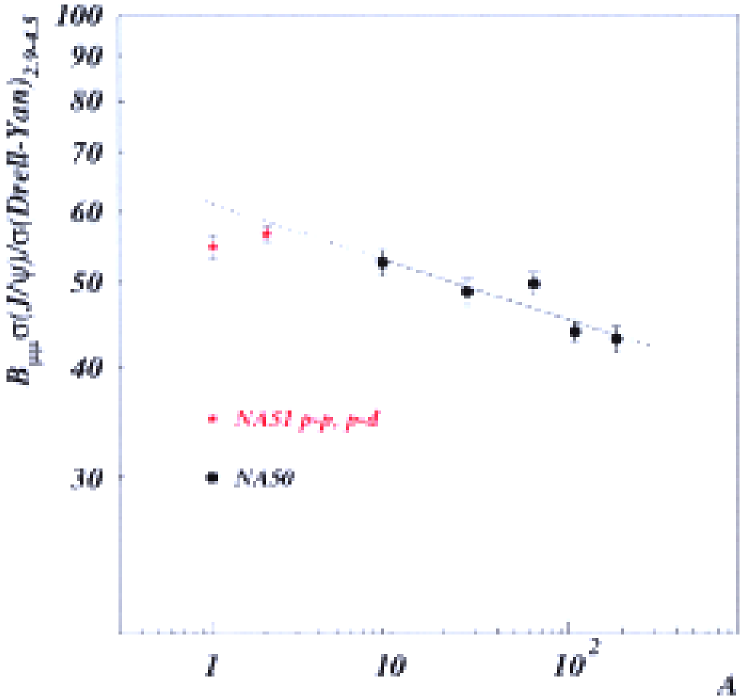
- $\alpha_{\psi'}$=0.913±0.015 (stat) χ^2/dof=2.5
- $\alpha_{\psi'}$=0.912±0.018 (syst) χ^2/dof=1.7
- $\alpha_{\psi'}$=0.913±0.024 (syst+stat) χ^2/dof=1.0

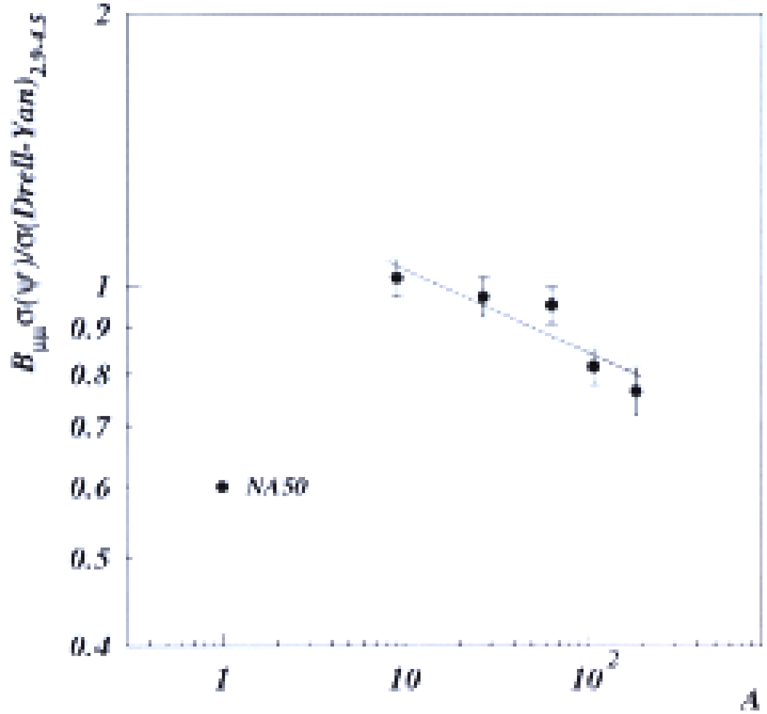
- $\sigma_{J/\psi}$=5.8 ±0.4 nb/nucleon(syst+stat)
- $\sigma_{\psi'}$=0.10 ±0.01 nb/nucleon(syst+stat)

Cross section ratios

- Study the ratios $\sigma_{J/\psi}/\sigma_{DY}$, $\sigma_{\psi'}/\sigma_{DY}$, $\sigma_{\psi'}/\sigma_{J/\psi}$
- Advantages
  - Cancel systematic errors connected with evaluation of:
    - Detection efficiencies
    - Luminosities
  - Reduce considerably systematic errors connected with evaluation of acceptances
- Drawbacks
  - Increase statistical errors on J/ψ measurement due to relatively small number of ψ' and Drell-Yan events

$\sigma_{J/\psi}/\sigma_{DY}$, $\sigma_{\psi'}/\sigma_{DY}$



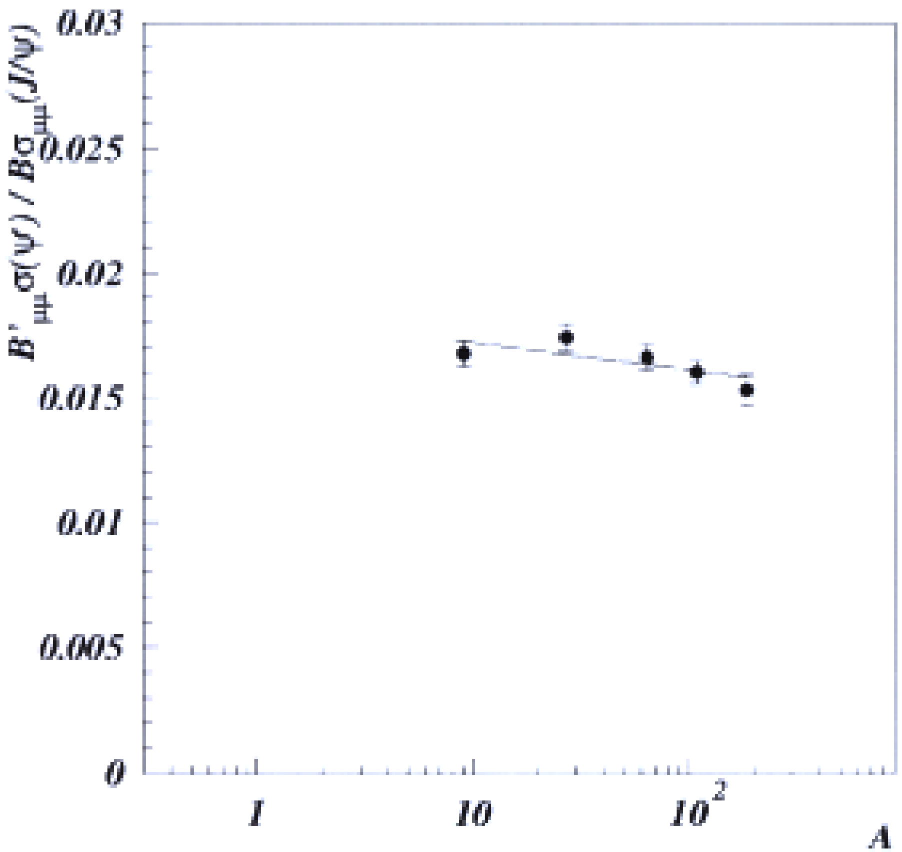


- $\alpha_{(J/\psi)/DY}=0.934\pm0.014$ $\chi^2/dof=1.7$ (all points)
- $\alpha_{(J/\psi)/DY}=0.932\pm0.014$ $\chi^2/dof=0.9$ (excluding pCu)

- $\alpha_{\psi'/DY}=0.909\pm0.020$ $\chi^2/dof=1.4$ (all points)
- $\alpha_{\psi'/DY}=0.903\pm0.021$ $\chi^2/dof=0.4$ (excluding pCu)

- Data indicate a slightly larger nuclear absorption effect for ψ'

$\sigma_{\psi'}/\sigma_{J/\psi}$

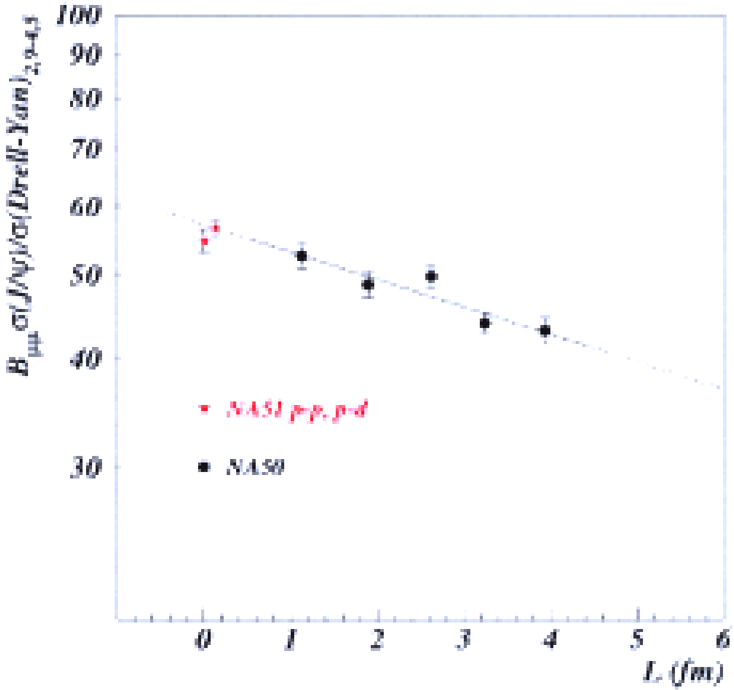


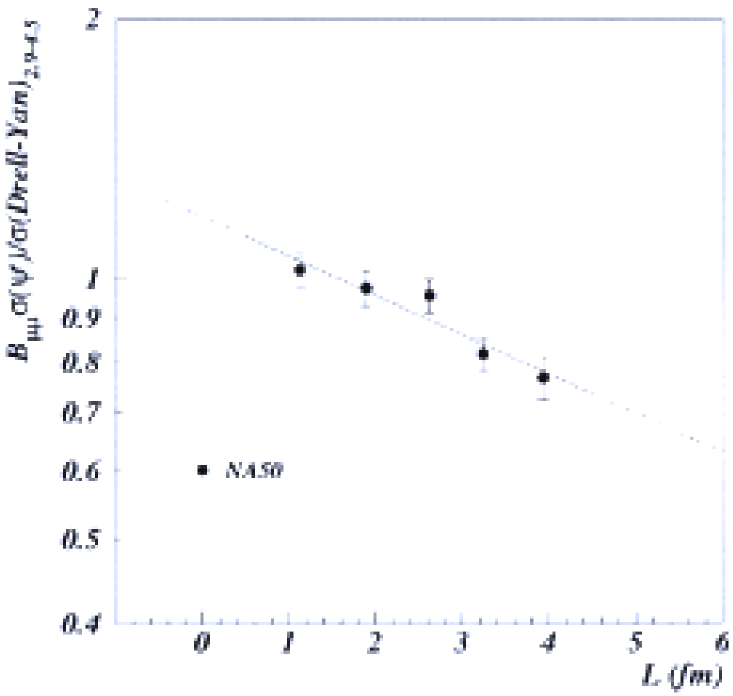
$\Delta\alpha=\alpha_{J/\psi}-\alpha_{\psi'}=0.029\pm0.014(stat)\pm0.003(syst)$
$(\chi^2/dof=1.1)$

Imposing $\Delta\alpha=0$
$B_{\psi'\rightarrow\mu\mu}\sigma_{\psi'}/B_{J/\psi\rightarrow\mu\mu}\sigma_{J/\psi}=0.0164\pm0.0002$
$(\chi^2/dof=1.8)$

Effective $\sigma_{J/\psi\text{-}N}$ and $\sigma_{\psi'\text{-}N}$ cross sections

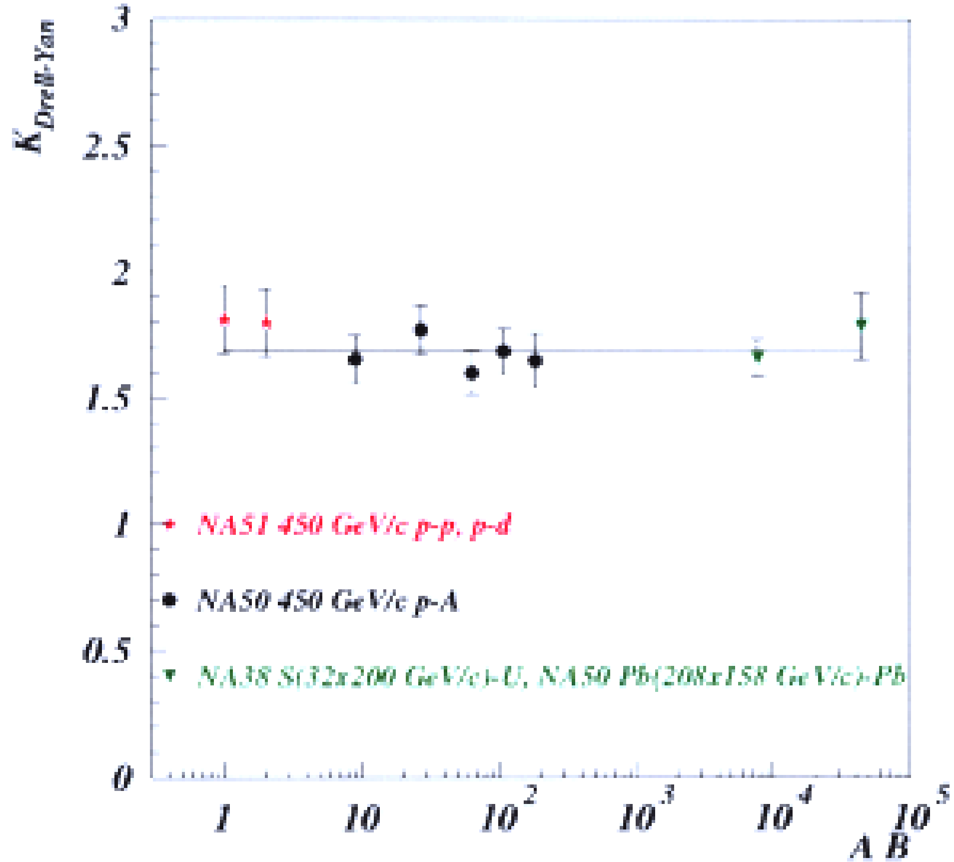
- Plot $\sigma_{J/\psi}$ and $\sigma_{\psi'}$ as a function of L, the mean thickness of nuclear matter seen by the produced ccbar pair
- Fit with a simple exponential: $\sigma_{J/\psi(\psi')} = A \cdot e^{-\rho_0 \sigma_{J/\psi(\psi')\text{-}N} L}$ with ρ_0=0.17 fm^{-3}





- Estimate $\sigma_{\psi'\text{-}N} - \sigma_{J/\psi\text{-}N}$=1.9 ±1.6 mb

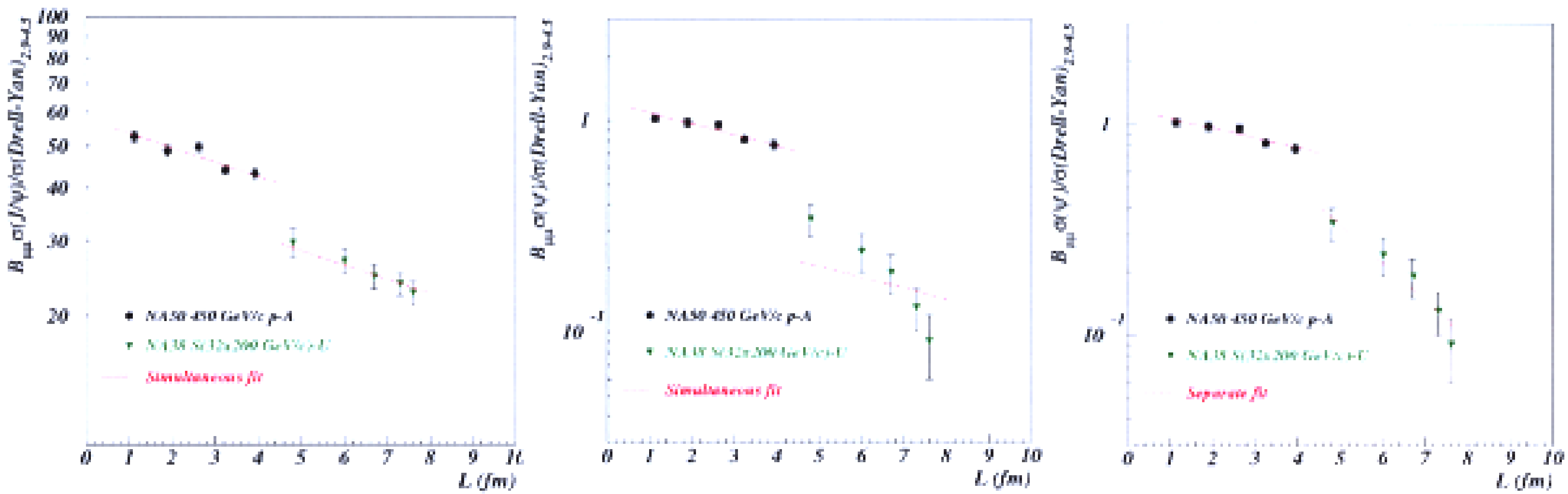
Comparison with nucleus-nucleus: DY K-factors



K_{DY}=1.69±0.03

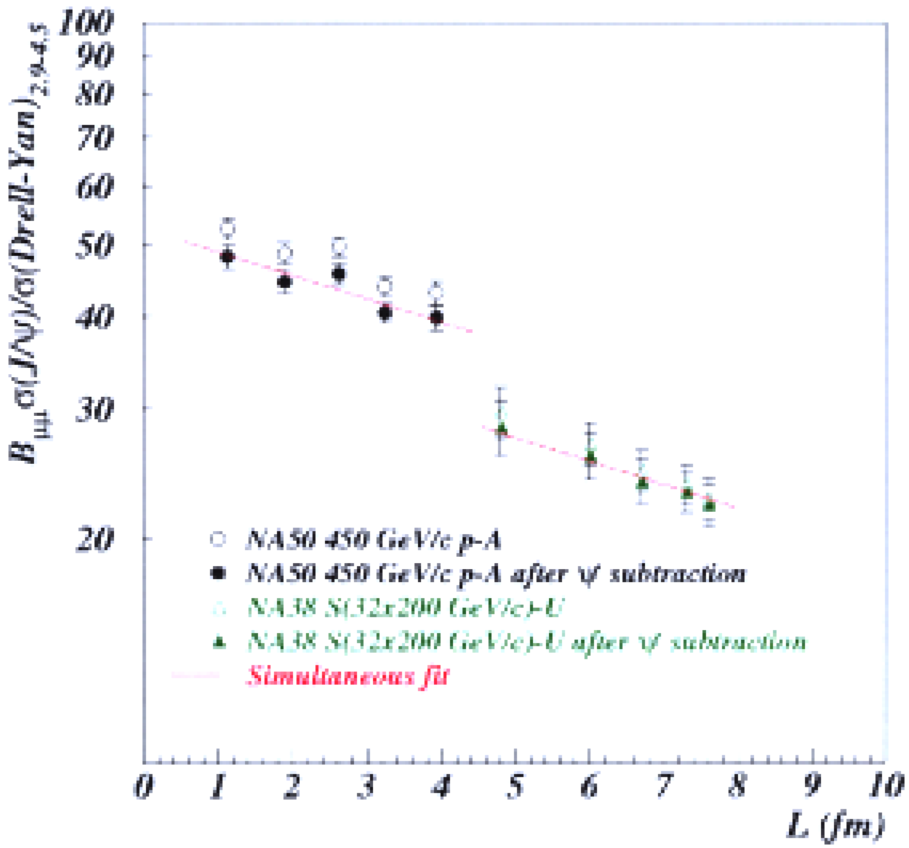
- DY K-factor constant from p-p to Pb-Pb (χ^2/n.d.f.=0.48)
- DY can be safely used as a reference for J/ψ suppression studies in nucleus-nucleus collisions

Comparison with nucleus-nucleus: $\sigma_{J/\psi}/\sigma_{DY}$, $\sigma_{\psi'}/\sigma_{DY}$ vs L



- $\sigma_{J/\psi}/\sigma_{DY}$ slopes are compatible in pA and S-U collisions: simultaneous fit gives χ^2/dof=0.7
- Separate exponential fit gives $\sigma_{J/\psi\text{-}N}^{SU}$ - $\sigma_{J/\psi\text{-}N}^{pA}$ =1.4 ±2.1 mb
- $\sigma_{\psi'}/\sigma_{DY}$ slopes are clearly not compatible in pA and S-U collisions: χ^2/dof=2.0
- Two slopes are needed to satisfactorily fit the data

Comparison with nucleus-nucleus: remove ψ' contribution in J/ψ spectra



- Using measured ψ'/DY ratios and known branching ratios $\psi' \to \mu\mu$, $\psi' \to J/\psi$, remove ψ' contribution from J/ψ spectra

- Gives better fit quality: now χ^2/dof=0.5
- Separate exponential fit gives now $\sigma_{J/\psi\text{-}N}^{SU} - \sigma_{J/\psi\text{-}N}^{pA} = 0.9 \pm 2.2$ mb

Conclusions

- Cross sections, and ratios of cross sections for charmonia production in pA collisions have been measured by NA50 at 450 GeV, in the rapidity region $-0.4<y_{CM}<0.6$

- Drell-Yan scales with the number of N-N collisions: $\alpha_{DY}=0.993\pm0.025$
- Use ratio of cross sections to obtain nuclear dependence of charmonia production through the parameter α: $\sigma_{J/\psi(\psi')}/\sigma_{DY} \propto A^{\alpha-1}$
- $\alpha_{J/\psi}=0.934\pm0.014$, $\alpha_{\psi'}=0.909\pm0.020$
- Study of absolute charmonia cross sections (larger systematic errors) gives compatible results

- Comparison with nucleus-nucleus:
    - Drell-Yan K-factors constant from p-p to Pb-Pb
    - $\sigma_{J/\psi}/\sigma_{DY}$ vs L slopes are compatible between p-A and S-U
    - Description of $\sigma_{\psi'}/\sigma_{DY}$ vs L needs two different slopes in p-A and S-U
    - Remove ψ' contribution from J/ψ spectra: better compatibility between p-A and S-U

- Forthcoming NA50 high statistics data (5 times the present sample) soon available: study of α vs p_T, x_F and γ