Open charm and charmonium production in p-A collisions at the CERN SPS

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- Introduction
- Charmonium suppression in p-A (and A-A) collisions
- Preliminary results on the A-dependence of the open charm yield
- Conclusions
Charmonia suppression: pA, AA

- Study of charmonium production/suppression in pA/AA collisions

THE hard probe at SPS energy

AA collisions

Color screening and charmonium suppression
> 20 year long history

pA collisions

Production models (CSM, NRQCD, CEM, ....)
Reference for understanding dissociation in a hot medium
Initial/final state nuclear effects (shadowing, dissociation, ...)

Open charm shares the same initial state effects that influence J/ψ production → its study can be useful to separate initial/final effects
The NA60 experiment

NA60, the third generation experiment studying dimuon production at the CERN SPS

- **2.5 T dipole magnet**
- **Vertex tracker**
- **Match in coordinate and momentum space**
- **Muon trigger and tracking**
- **NA10/38/50 spectrometer**
- **Hadron absorber**
- **Iron wall**

Data samples

- **In-In** collisions at 158 GeV/nucleon
- **p-A** collisions at 158 and 400 GeV
  - 9 nuclear targets, Al-U-W-Cu-In-Be1-Be2-Be3-Pb
    (mixed A-order to limit possible z-dependent systematics)
p-A data analysis

- Not enough DY statistics to extract $B_{\mu\mu} \sigma_{J/\psi}/\sigma_{DY}$ target by target
- Estimate of nuclear effects through relative cross sections:

$$\frac{\sigma_{A}^{J/\psi}/A}{\sigma_{Be}^{J/\psi}/A_{Be}} = \frac{N_{A}^{J/\psi}/A}{N_{Be}^{J/\psi}/A_{Be}} \times \frac{N_{inc}^{A} \times N_{A}^{targ} \times A_{A} \times \varepsilon_{A}}{N_{inc}^{Be} \times N_{Be}^{targ} \times A_{Be} \times \varepsilon_{Be}}$$

- Beam luminosity factors $N_{i}^{inc}$ cancel out (apart from a small beam attenuation factor) → no systematic errors
- Acceptance and reconstruction efficiencies do not completely cancel out (targets see the vertex spectrometer under a (slightly) different angle)
- Kinematic window is restricted, to reduce $y$-related systematics
  - $J/\psi \rightarrow 0.28 < y_{cm} < 0.78$ at 158GeV and $-0.17 < y_{cm} < 0.33$ at 400GeV
  - Open charm $\rightarrow -0.45 < y_{cm} < 0.55$ at 400 GeV
  (larger $y$ window for open charm, $y$-acceptance is less target-dependent)
Systematic errors on relative cross sections

- The sources of systematic errors investigated are connected with:
  - Uncertainty on target thicknesses (1.5%)
  - Uncertainty on the $J/\psi$ rapidity distribution (1.5%)
  - Uncertainty in the reconstruction efficiency calculation (3%)

- We only quote the fraction of the total systematic error which is not common to all the points (i.e. the one which affects the evaluation of $\sigma_{J/\psi}^{\text{abs}}$)

- Systematic uncertainties are at a minimum in the center of the spectrometer rapidity acceptance and raise towards the edges.
Nuclear dependence of $J/\psi$ production

Using the Glauber model, we get

$$\sigma_{\text{abs}} \frac{J/\psi}{A_0} \left(400 \text{ GeV}\right) = 4.3 \pm 0.8 \text{ (stat)} \pm 0.6 \text{ (syst)} \text{ mb}$$

$$\sigma_{\text{abs}} \frac{J/\psi}{A_0} \left(158 \text{ GeV}\right) = 7.6 \pm 0.7 \text{ (stat)} \pm 0.6 \text{ (syst)} \text{ mb}$$

Using $\sigma_{J/\psi} = \sigma_0 \cdot A^\alpha$, we get

$$\alpha \left(400 \text{ GeV}\right) = 0.927 \pm 0.013 \text{ (stat)} \pm 0.009 \text{ (syst)}$$

$$\alpha \left(158 \text{ GeV}\right) = 0.882 \pm 0.009 \text{ (stat)} \pm 0.008 \text{ (syst)}$$

(effective values, shadowing not corrected for)
Comparisons with other experiment: $x_F$

- Results on $\alpha$ vs $x_F$ from HERA-B, NA50, E866, NA3 (removed $\alpha$ bias from use of p-p)

- In the region close to $x_F = 0$, stronger deviation of $\alpha$ from 1 when decreasing $\sqrt{s}$

- NA60
  - 400 GeV: very good agreement with NA50
  - 158 GeV: smaller $\alpha$
  - Disagreement with NA3 200 GeV results
Studying nuclear effects vs $x_2$

The $x_2$ acceptance of the NA60 spectrometer is $\sim$ energy independent.

- Shadowing effects (2$\rightarrow$1 approach) scale with $x_2$.
- If parton shadowing and final state absorption were the only two relevant mechanisms
  $\Rightarrow$ $\alpha$ should not depend on $\sqrt{s}$ at fixed $x_2$.

$x_2$ is strongly correlated with $\sqrt{s_{\psi-N}}$ $\Rightarrow$ expect same absorption at fixed $x_2$. 
Clearly effects different from shadowing and final state absorption are present

\[ \Delta \alpha = \alpha(400) - \alpha(158) \]

NA60 can measure within the same experiment → common systematics cancel → reduced systematics on \( \Delta \alpha \)
Reference for AA data

- CNM effects, evaluated in pA, can be extrapolated to AA, assuming a scaling with the L variable and taking into account that:

  $\sigma_{\text{abs}}$ shows a dependence on energy/kinematics in AA collisions, shadowing affects both projectile and target

  reference obtained from 158 GeV pA data (same energy/kinematics as the AA data)

  proj. and target antishadowing taken into account in the reference determination

The current reference is based on:

- slope determined only from pA@158GeV
  $\sigma_{\text{abs}}^{J/\psi} (158 \text{ GeV}) = 7.6 \pm 0.7 \pm 0.6 \text{ mb}$

- normalization to $\sigma_{J/\psi}^{pp}$ determined from pA@158 GeV (J/\psi/DY point) and (to reduce the overall error) SU@200GeV

SU has been included in the fit, since it has a slope similar to pA at 158 GeV

advantage: small error on normalization (3%)
drawback: hypothesis that SU is “normal”
New result: $\psi$ cross section in pA

- $\psi$ production cross sections for pA data

- Systematic error on (absolute) luminosity estimation quite high
  - Relative luminosity estimate between 158 and 400 GeV much better known ($\sim$2-3% systematic error)
  - Normalize NA60 400 GeV cross section ratios to NA50 results

- 158 GeV cross sections constrained by the relative normalization
New reference using $J/\psi$ cross sections

- Alternative approach for the normalization of the pA reference curve based on the pA $J/\psi$ absolute cross section
- To fully profit from this approach, a measurement of the absolute $J/\psi$ cross section in In-In would be needed. For the moment...
  - $J/\psi$/DY values are obtained rescaling the DY cross section measured at 450 GeV by NA50 (not enough statistics at 158 GeV)
  - Main advantage: no assumption on SU, since it is not used anymore in the fit

No practical consequence on anomalous $J/\Psi$ suppression

difference with previous CNM reference $\sim 1\%$ well within errors
Using the previously defined reference:

Central Pb-Pb:
→ still anomalously suppressed

In-In:
→ almost no anomalous suppression

B. Alessandro et al., EPJC39 (2005) 335
Open charm production in \( p-A \) collisions

- Open charm shares initial state effects with charmonium → a measurement of open charm in \( p-A \) collisions may help in understanding \( J/\psi \) suppression

- Recent results from SELEX and E866 suggest rather strong nuclear effects on open charm

A. Blanco et al. (SELEX), EPJC64(2009) 637
M. Leitch (E866), workshop on “Heavy Quarkonia Production in Heavy-Ion Collisions”, ECT* 2009
Open charm dimuons in p-A: NA60

- NA50 tried to evaluate DD production studying the IMR in pA
  - Large background levels ($S/B \sim 0.05$ at $m_{\mu\mu} = 1.5$ GeV/c$^2$)
- NA60 is much better placed, thanks to the muon matching
  - $S/B$ is $\sim 60$ times more favourable

NA50 had to impose a constant DD/DY vs A (i.e. $\alpha_{DD} = \alpha_{DY} \sim 1$)

M.C. Abreu et al., EPJC14(2000) 443
Low background in the IMR (matching)

Good resolution on the longitudinal position of the vertex in the IMR → good target assignment

Cross target contamination (0.5-9%) has been corrected for
Fit to the mass spectra

- Not possible to **directly measure** the D decay length in p-A

- Simultaneous semi-muonic decays of DD pairs are the **dominant source** in the invariant mass region $m < m_{J/\psi}$

- High-mass DY statistics is low
  - Drell-Yan cannot be directly constrained by the fit
- Use the ratios $\psi/DY$ from NA50 (EPJC 48 (2006) 329) to fix DY
- Background evaluated with **event mixing** technique, remaining muon pairs come from open-charm decay
Open charm signal(s) in the mass spectra

- Low background, small Drell-Yan contribution
- Open charm is the dominant source of dimuons in the IMR
Nuclear dependence of open charm

\[ \chi^2/\text{ndf} = 0.4 \text{(stat.)}, 0.2 \text{ (tot.)} \]

\[ \alpha_{DD} (400 \text{ GeV}) = 0.948 \pm 0.022 \text{ (stat)} \pm 0.018 \text{ (syst)} \]

- Systematic include uncertainties on: target thickness, reconstruction efficiencies, fit inputs (\(\psi/DY\) measured by NA50), background subtraction. They include also the effect of applying different fitting approaches and quality cuts.
Influence of shadowing

• To properly compare $J/\psi$ with open-charm one has to take into account possible differences in shadowing effects due to the different $x_2$ coverage.

Calculate the expected $\alpha$ (pure shadowing) for $J/\psi$ and $D\bar{D}$ pairs decaying into muons in the NA60 acceptance at 400 GeV.
Nuclear dependence, J/ψ vs open charm

- Shadowing effects quite similar for J/ψ and open-charm
- Shadowing is not the origin of the measured $\alpha < 1$ for open-charm
  - Anti-shadowing region
- Experimentally we observe similar $\alpha$ for J/ψ and open-charm
Outlook: open charm at 158 GeV

- Possible presence of a strong nuclear dependence → to be further investigated
- Open-charm signal lower than at 400 GeV, need careful check of systematics
  - DY subtraction
    - constrained by NA50 measurement at 158 GeV (EPJC 49 (2007) 559)
    - direct fit on data
    - Background subtraction
Conclusions

• NA60 performed detailed studies of charmonium suppression in p-A collisions at 158 and 400 GeV

  • Nuclear effects stronger when decreasing $\sqrt{s}$

  • Lack of $x_2$ scaling for $J/\psi$ nuclear dependence is confirmed $\rightarrow$ shadowing + nuclear absorption scenario is ruled out

  • Absolute $J/\psi$ cross section at 158 GeV has been estimated

• Measurement of nuclear dependence of open-charm production at 400 GeV

  • Contrary to the expectation from shadowing an open-charm suppression is observed (1.7 $\sigma$ effect)

  • $\alpha$ values similar for open-charm and $J/\psi$