Cold nuclear matter effects in Drell-Yan process and J/ψ production at NA58

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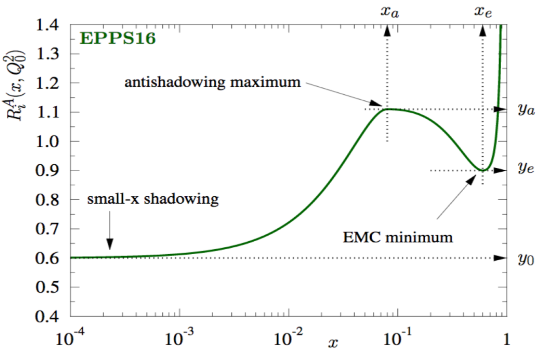
Introduction

- Suppression of heavy quarkonia is one of the most distinctive signatures of QGP in heavy-ion collisions.
- Suppression can also takes place in hadron-nucleus(hA) collisions due to cold nuclear matter(CNM) effects.
- hA collisions are important to disentangle the effects of QGP from CNM to interpret AA collisions.
- Quarkonia and Drell-Yan cross-sections in small systems like hadron-hadron(hh) and hA collisions are crucial tool for studying CNM effects.
- Measurements are done from fixed target to collider experiments (SPS, $\sqrt{s} \approx 20$ GeV to LHC, $\sqrt{s} = 8.16$ TeV)
- CNM effects are studied at COMPASS via Drell-Yan and J/ψ production at $\sqrt{s} =$ 18.9 GeV.

Physics motivation

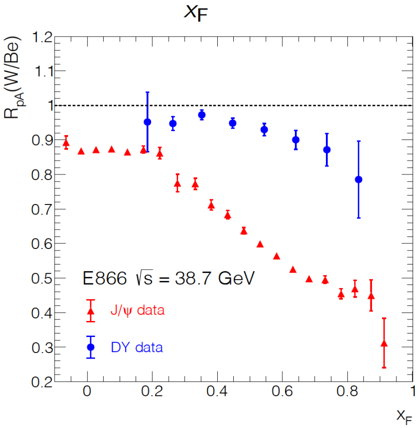
The cold nuclear effects in hA collisions characterized by nuclear modification factor:
$R_{hA}(x_F) = \frac{1}{A}\frac{\mathrm{d}\sigma_{\mathrm{hA}}/\mathrm{dx_F}}{\mathrm{d}\sigma_{\mathrm{hp}}/\mathrm{dx_F}}$ (= 1 for no nuclear effects)

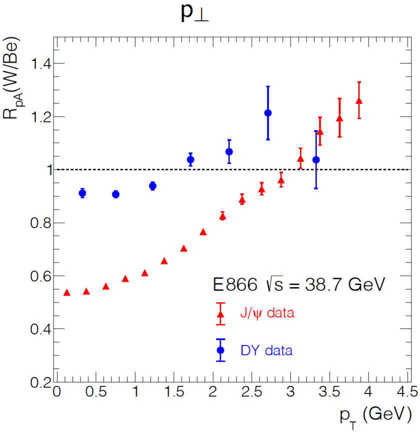
- Nuclear modification factor depends on nPDF, $f_j^{p/A} \neq f_j^p$
- nPDF depends on x, distinguishes among Nuclear Shadowing, Anti-Shadowing, EMC effects
- Parton Energy loss



Observations from previous fixed target experiments

- J/ψ is more suppressed than DY as a function of x_F and $p_\perp$
- Different CNM effects for J/ψ and DY [PRL 84 (2000) 3256]

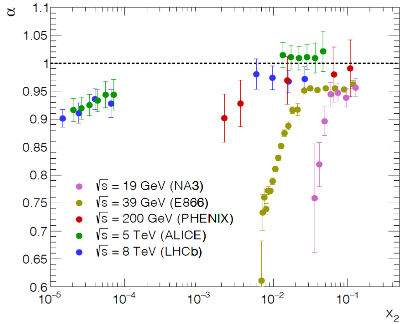




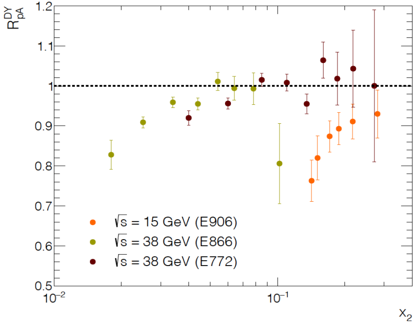
Observations from previous experiments

- No scaling as a function of x_2 [Arleo, Naim, Platchkov, JHEP01(2019)129]
- J/ψ suppression depends on $\sqrt{s}$

J/ψ data



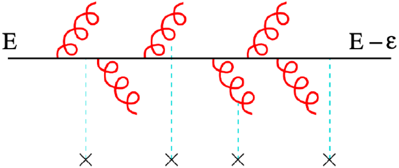
DY data



- Coherent energy loss regime explains alone E866 J/ψ data at $\sqrt{s} = 38.7$ GeV. [Arleo, Peign´e, JHEP03(2013)122]
- Energy loss model explains the strong suppression at large x_F for DY. [Arleo, Naim, Platchkov, JHEP01(2019)129]

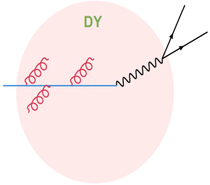
Parton energy loss effects

A high energy parton travelling in a medium can radiate gluons induced by the elastic scatterings with the constituents of the medium



Parton energy loss effects in different hard processes:

- Drell-Yan process: $hA \to \ell^+\ell^- + X$
  - Initial state radiation
- Hadron production: $hA \to q/g(\to h') + X$
  - Initial state radiation
  - Final state radiation
  - Interference of both



Parton energy loss regimes

- Landau Pomeranchuk Migdal or the LPM effect (small formation time $t_f \leq L$)

$$\langle \epsilon \rangle_{LPM} \propto \alpha_s \hat{q} L^2$$

  - Drell-Yan process: $hA \rightarrow \ell^+ \ell^- + X$
- Full coherent parton energy loss effect (large formation time $t_f \gg L$)

$$\langle \epsilon \rangle_{coherent} \propto \sqrt{\hat{q} L}/M.E \gg \langle \epsilon \rangle_{LPM}$$

  - Quarkonium production: $hA \rightarrow [Q\hat{Q}(g)]_8 + X$

Transport coefficient : The scattering properties of the medium, depends on x_F and $p_\perp$ distribution

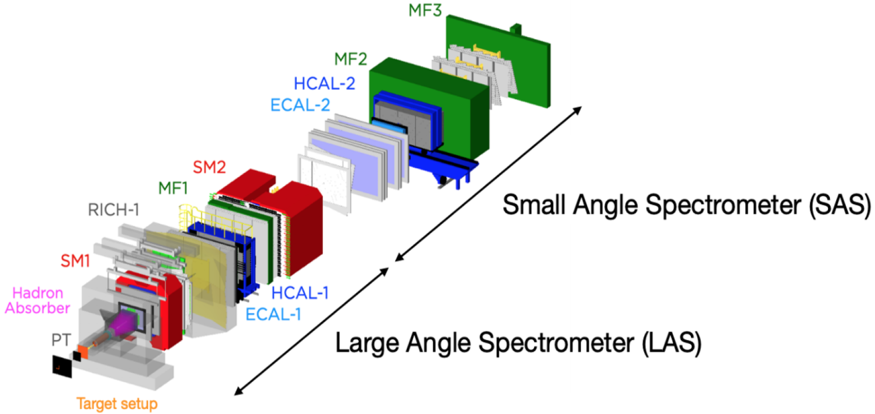
$$\hat{q} = \frac{4\pi^2 \alpha_s C_R}{N_c^2 - 1} \rho \times xG(x, Q^2), \hat{q} \equiv \frac{\mu^2}{\lambda} = \frac{\mathrm{d}\Delta \mathrm{p}_\perp^2}{\mathrm{dL}}$$

Single $\hat{q}$ to study both energy loss effects and $p_\perp$ broadening.
These nuclear effects are worth investigating with COMPASS DY data.

COMPASS experimental set up

Beam

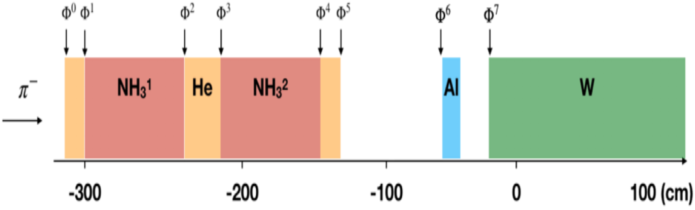
- π^- beam at 190 GeV
- $I_{beam} \approx 7 \times 10^7 hadrons.s^{-1}$



Target setup and data sample

Nuclear targets

1. Ammonia (NH_3) 2. Aluminium (Al^{27}) 3. Tungsten (W^{184})



- "Light" nuclei - Mixed between ammonia and helium
- "Intermediate nuclei" - Aluminium 7cm length target
- "Heavy nuclei" - Tungsten first 10 cm used

Data from 2018 have been analyzed

Observable

The double differential cross section of J/ψ and DY production is given by

$$\frac{\mathrm{d}^2\sigma^{\pi^- \mathrm{A}}}{\mathrm{d}\mathrm{x_F}\mathrm{d}\mathrm{p}_\perp} = \frac{\mathrm{N}^{\mu^+\mu^-}_{\mathrm{events}}(\mathrm{x_F}, \mathrm{p}_\perp)}{\epsilon^{tot}.\mathrm{BR}.\Delta\mathrm{x_F}.\Delta\mathrm{p}_\perp.\mathcal{L}}$$

with

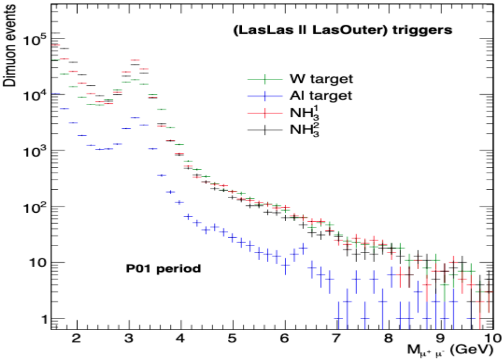
$$\mathcal{L} = \alpha^i \Phi^0 \times L^i_{eff} \times \rho^i \times \frac{\mathcal{N}_A}{M^i}$$

$$R_{\pi^- A}(A/B) = \frac{\mathrm{N_A}(\mathrm{x_F}, \mathrm{p}_\perp)}{\epsilon_A.\alpha^A.L^A_{eff}.\rho^A} / \frac{\mathrm{N_B}(\mathrm{x_F}, \mathrm{p}_\perp)}{\epsilon^B.\alpha^B.L^B_{eff}.\rho^B}$$

- Observable independent of Φ^0 absolute initial flux.
- The ratio of cross-section of tungsten and aluminium is calculated to estimate the $R_{\pi^- A}(x_F, p_\perp)$

Invariant mass of dimuon

- $\sim 4X10^5$ dimuon events in Al target
- $\sim 2.3X10^6$ dimuon events in W target



- Invariant dimuon mass spectra is shown for one period(out of 9) of data.
- The normalization of each dimuon mass distribution depends on the target.
- Resolution of J/ψ peak varies around M $\sim$ 3 GeV depending on target.

J/ψ signal extraction: "Cocktail Method" from MC

- In order to reproduce the dimuon invariant mass spectrum, the contributions OC, DY, J/ψ, $\psi(2S)$ are fitted to the RD dimuon mass spectrum: "cocktail method"
- The normalisation of CB is fixed to 1 because this contribution is calculated from the RD

Fit function for M $>$ 2 GeV

$$f(M)_{fit} = \alpha_0 f(M)_{MC}^{DY} + \alpha_1 f(M)_{fit}^{J/\psi} + \alpha_2 f(M)_{MC}^{\psi(2S)} + \alpha_3 f(M)_{MC}^{OC} + \alpha_4 f(M)_{RD}^{CB}$$

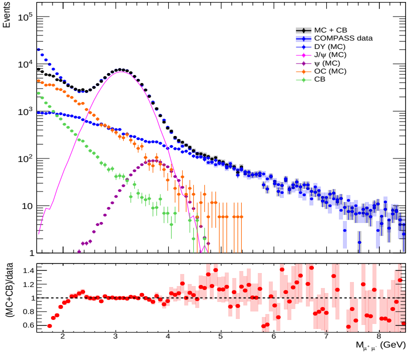
α_0 α_1 α_2 and α_3 are free parameters, and α_4 is fixed to 1.
In order to take into account the underestimated resolution of J/ψ signal in MC,

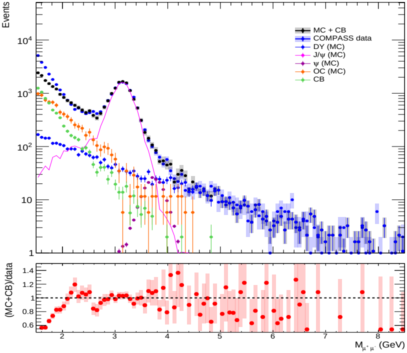
$$f(M)_{fit}^{J/\psi} = f(M)_{MC}^{J/\psi} \times \mathcal{N} e^{-\frac{(M-\mu)^2}{2\sigma^2}}$$

where σ, μ and $\mathcal{N}$ are free parameters.

J/ψ signal extraction: "Cocktail Method" from MC

Integrated dimuon mass fit for all $0 < x_F < 0.9$ and $0 < p_T < 4$ (GeV)



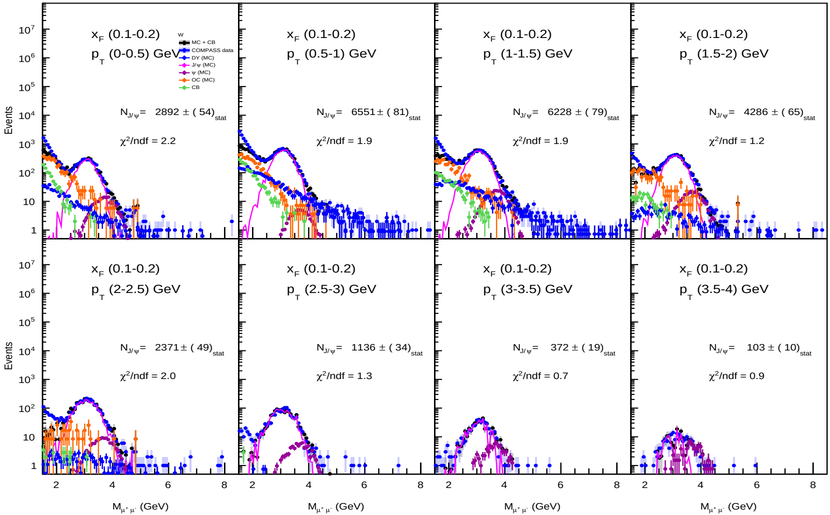


$N^{J/\psi} = 76701 \pm 277$
$\chi^2/ndf = 2.9$ (W Target)

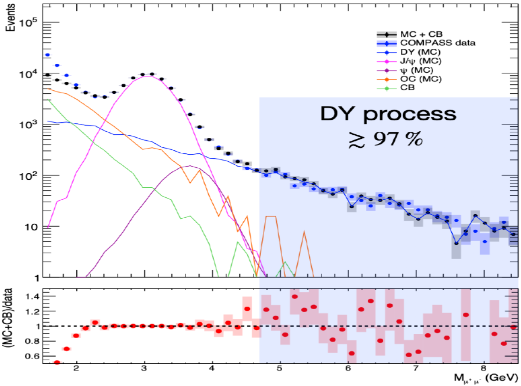
$N^{J/\psi} = 11913 \pm 109$
$\chi^2/ndf = 2.6$ (Al Target)

J/ψ extraction as a function of x_F and p (W target)

Example of signal extraction of J/ψ in $0.1 < x_F < 0.2$ for P01 period in W target.



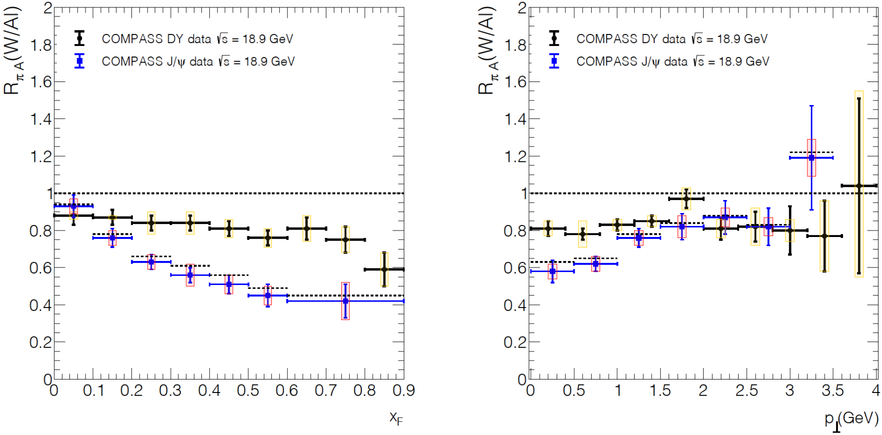
Drell-Yan analysis



- Suitable at the high mass region M $\in$ (4.7,8.5) GeV, DY purity 97%
- The J/ψ and DY events are corrected by the geometrical acceptance, trigger, detector efficiency etc.
- Correction due to migration of events from W to Al target is also taken in to account.

Preliminary results at COMPASS

[C-J. Naim, PhD. Thesis (2020)]



- J/ψ more suppressed than DY
- DY suppression 20% at $x_F \sim 0.9$
- Strong suppression at large x_F indicates energy loss effects.

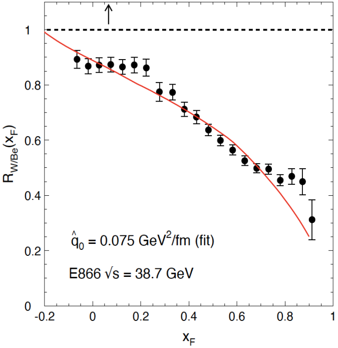
Outlook

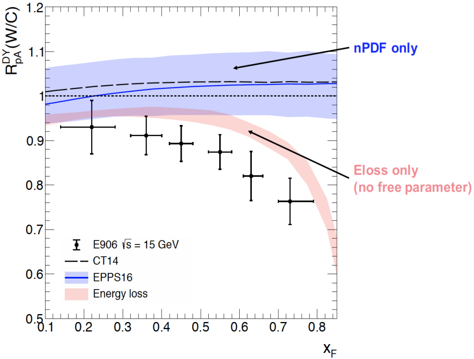
- Preliminary results of nuclear dependence of J/ψ data have been calculated for W and Al targets.
- Preliminary results for nuclear dependence of DY are also available.
- Nuclear target dependence is observed.
- Cross-check of these preliminary results is going on.
- To finalise the results with newly reconstructed data and fine tune MC.
- To investigate these effects in NH_3 target as well.

Thank You for your attention.

Extras

Theoretical model model comparison of data





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