Studying Hadrons in Matter with PANDA

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on behalf of
PANDA collaboration

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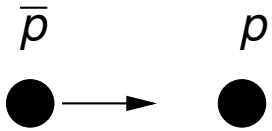
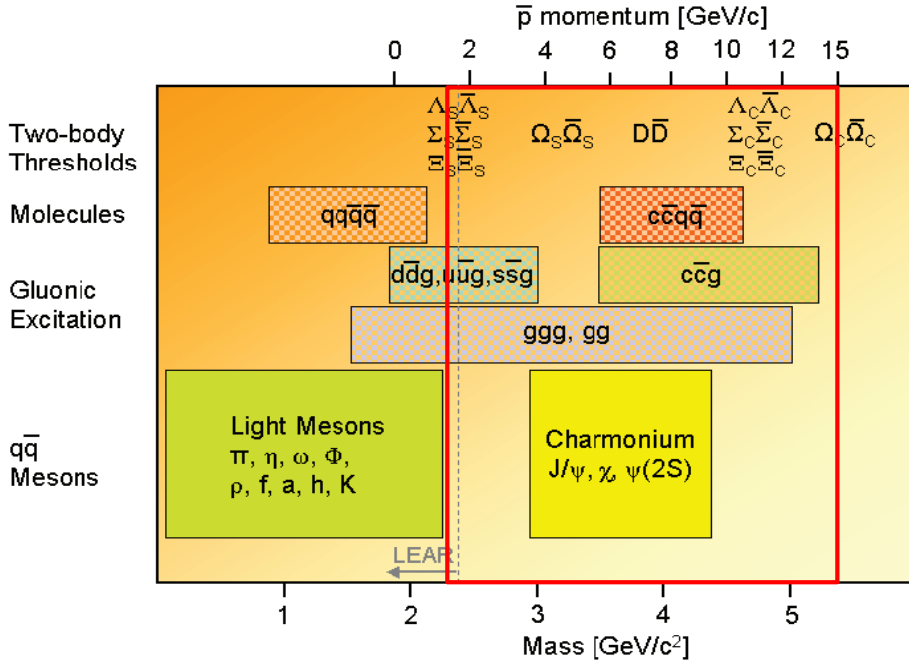
PANDA experimental program





Hadron spectroscopy

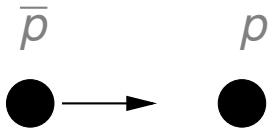
- Charmonium spectroscopy
- D meson spectroscopy
- Baryon meson spectroscopy
- Gluonic excitations

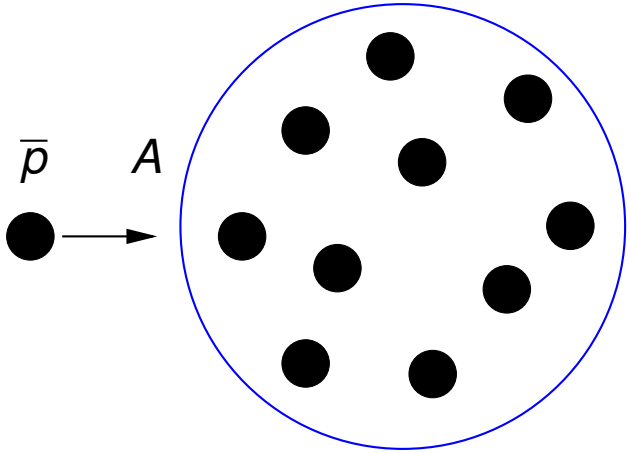
Nucleon Structure

- Generalized Parton distributions
- Time-like form factor of Proton

Hypernuclei

PANDA experimental program





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Hypernuclei

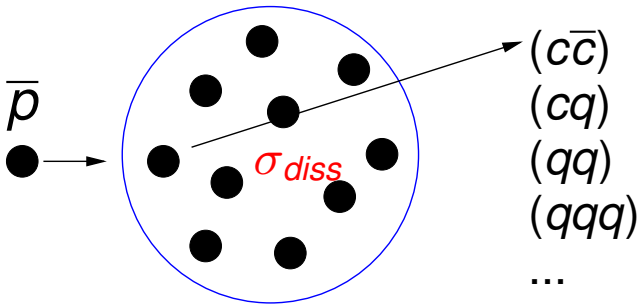
Hadrons in Matter

- In-medium modifications
- $c\overline{c}$ absorption
- Nucleon short range correlations
- Color transparency
- ...

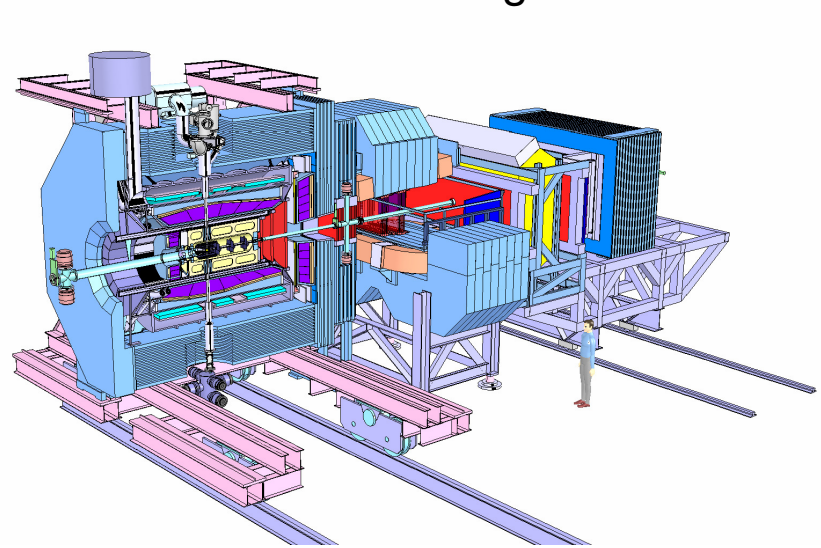
First $\overline{p}A$ program at $E_{cm} \approx m_{c\overline{c}}$

Experimental situation

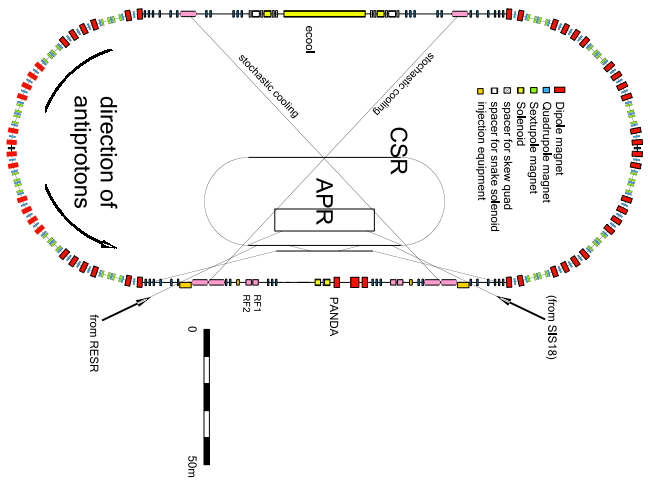
$\rho \neq 0,\ P_N = P_{Fermi}$

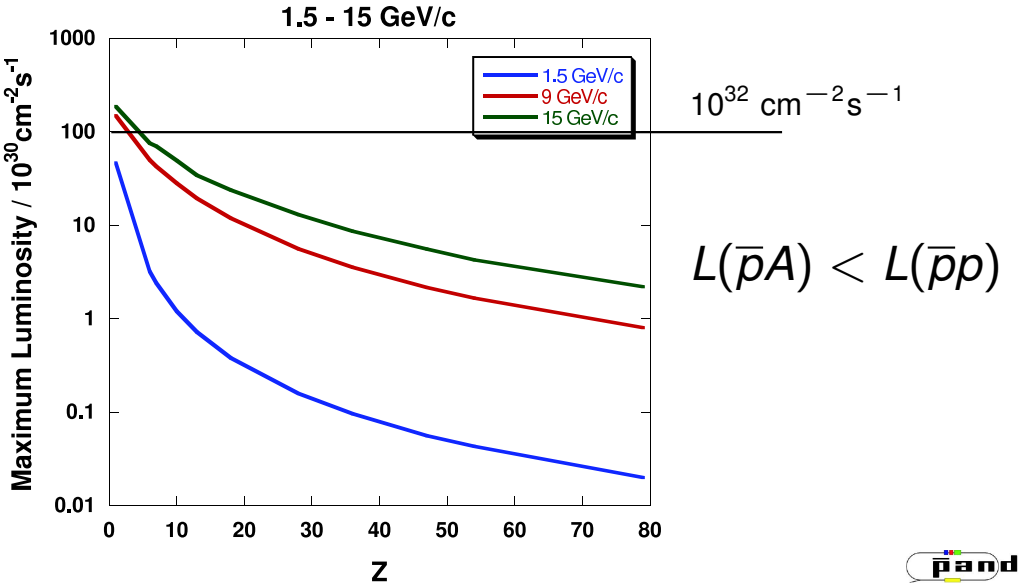


PANDA: $\approx 4\pi$ coverage



HESR: $1.5 < P_{\overline{p}} < 15\ GeV/c$

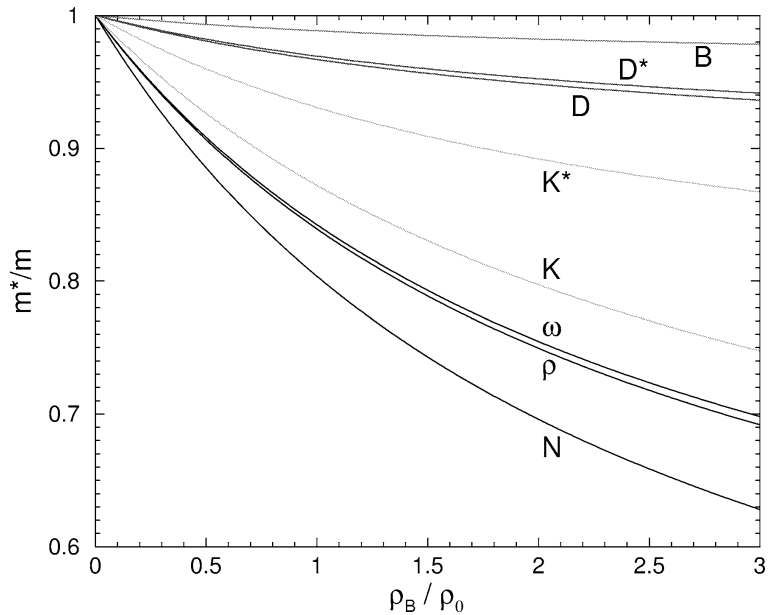




$L(\overline{p}A) < L(\overline{p}p)$

In-medium modifications

- Partial restoration of chiral symmetry in nuclear medium
- Effect of finite matter density on hadron properties: change of mass and width, absorption
- Subject of large interest (ongoing attempts!), mainly in the light quark sector (e.g. Metag, PPNP **55** (2005) 35)
- Extension of these studies to charmed hadrons



Tsushima & Khanna, Prog. Theor. Phys. Suppl **149** (2003) 160

In-medium modifications

- mass shifts

	Mass shift @ $\rho \approx \rho_0$ [MeV]	Refs.	Γ [MeV]
η_c	-5	[1], [5]	30
J/Ψ	-4 - -24	[2], [3], [4], [5]	0.09
$\chi_{c_{0,1,2}}$	-40	[5]	<10
$\Psi(3686)$	-100	[3], [5]	0.3
$\Psi(3770)$	-100	[3], [5]	30
D-mesons	-50	[2]	< 1
$\overline{\Lambda}_c$, $\overline{\Sigma}_c$	-40	[6]	< 3

[1] Klingl et al., PRL **82** (1999) 3396

[2] Hayashigaki, PLB **487** (2000) 96

[3] Lee & Ko, PRC **67** (2003) 038202

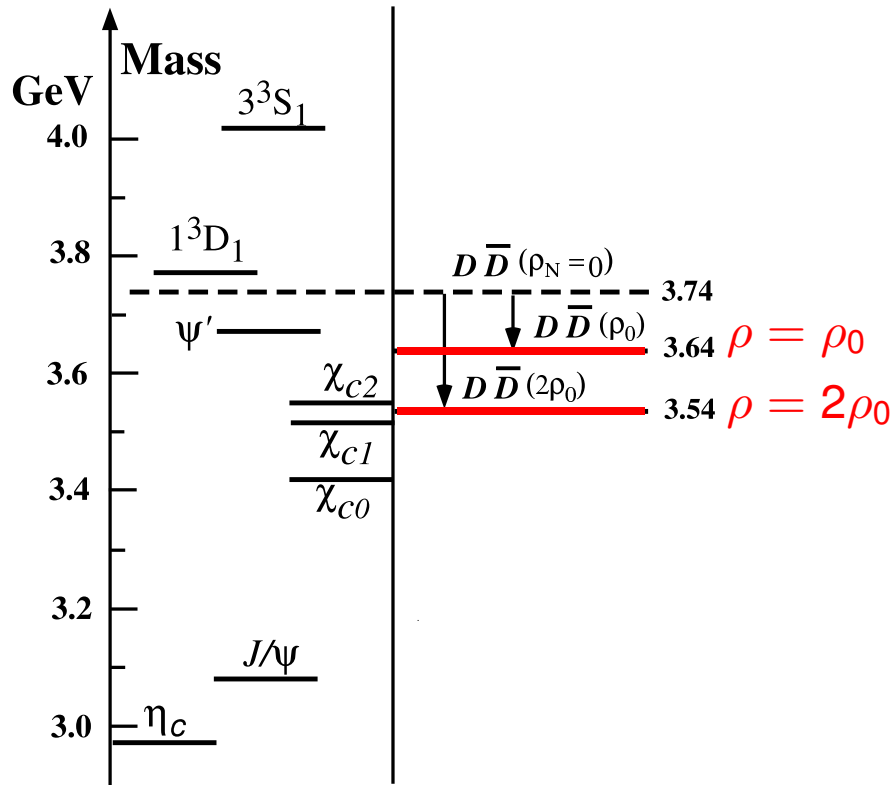
[4] Krein et al., PLB **697** 136

[5] Lee, AIP Proc. Conf. **717** (2004) 780

[6] Tolos et al., PRC **77** (2008) 015207

In-medium modifications

- Relative change of masses $\Rightarrow$ level crossings
- Broadening of Ψ' and χ_{c_2}



Hayashigaki, PLB **487** (2000) 96

see also Sibirtsev, EPJA **18** (2002) 475

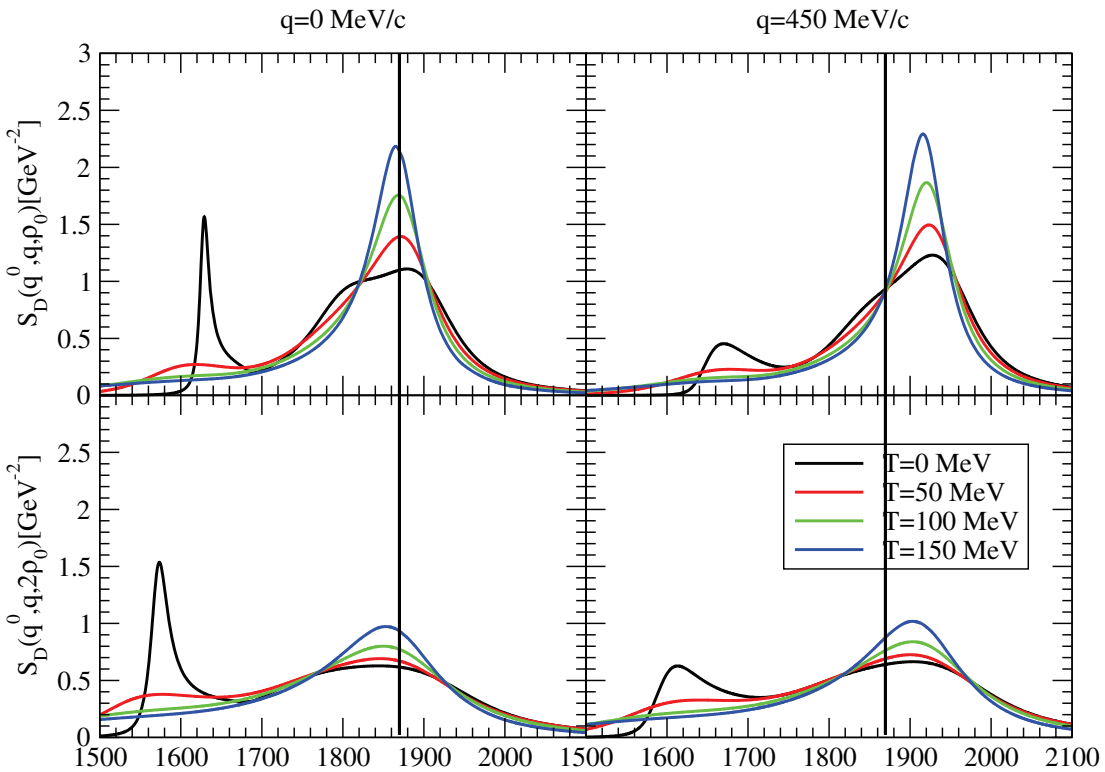
In-medium modifications

- Recent coupled-channel calculations reveal more complicated picture

D-meson

$\rho = \rho_0$

$\rho = 2\rho_0$



Tolos et al., PRC **77** (2008) 015207

see also Lutz & Korpa, PLB **633** (2006) 43

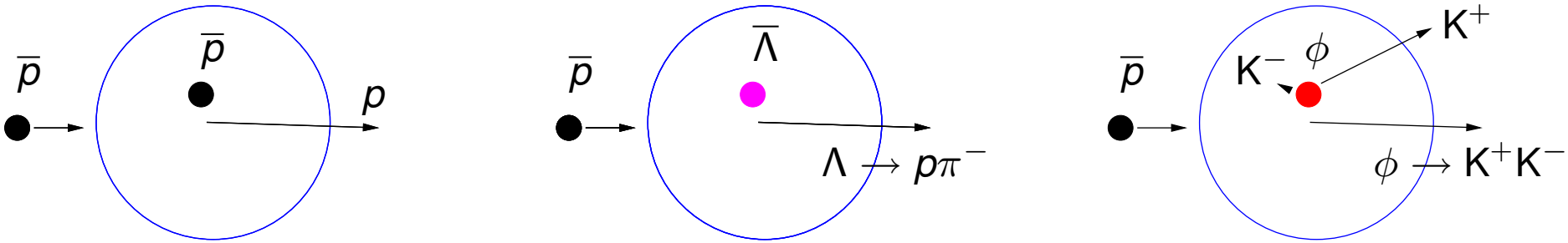
In-medium modifications

1. Measurement of line shapes
2. Measurement of transparency ratios
3. Measurement of excitation functions

- How to 'place' charmed hadron at rest in the center of a nucleus?
  - Penetration depth of anti-proton is a few *fm* ($\sigma_{\bar{p}p}^{tot} \approx 60\ mb, \rho \approx 0.16 fm^{-3}$)
  - in $\bar{p}N$ annihilation, charmed mesons are produced at relatively high momentum in nuclear rest frame
  - In $\bar{p}A \rightarrow D^+D^-$, $p_D > 0.7\ GeV/c$
  - Many hadrons leave nucleus before they decay
  - Selecting $\bar{p}NN$ reduces minimum P_D but also reduces cross section significantly
- Much easier with light hadrons ...

In-medium modifications

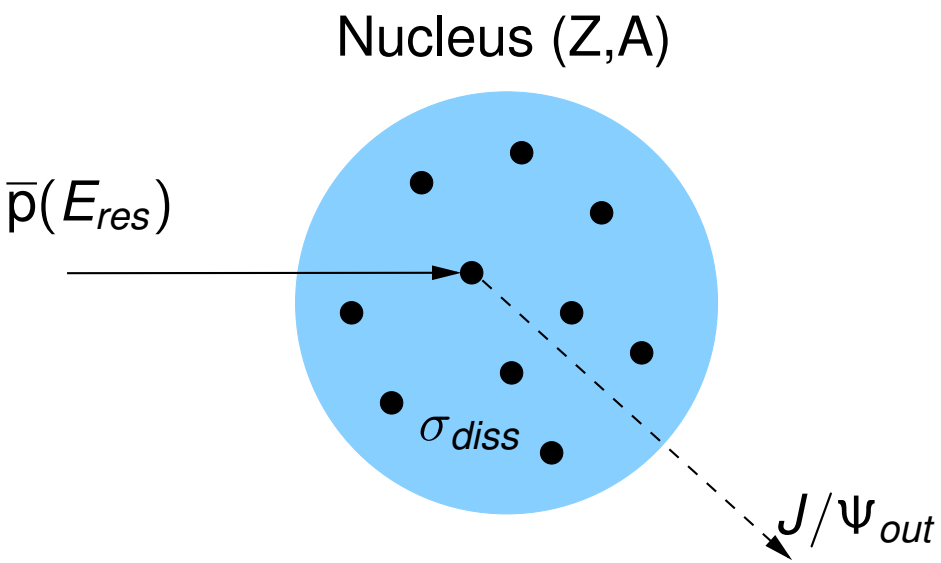
Light anti-hadrons



- recoil-free reactions
- select fast hadron at $\Theta \approx 0^\circ \Rightarrow$ anti-hadron approx. at rest
- reasonably large cross sections ($\mu b/sr$)
- missing mass analysis $\Rightarrow$

investigation of nuclear potentials

Measurement of J/Ψ - Nucleon inelastic cross section



- Brodsky & Mueller, PLB **206** (1988) 685,
  Farrar et al., NPB **345** (1990) 125,
  Seth, NPA **629** (1998) 358

- Exclusive formation of J/Ψ
- Avoid effects from large momenta, feed down, co-movers as in *pA* production

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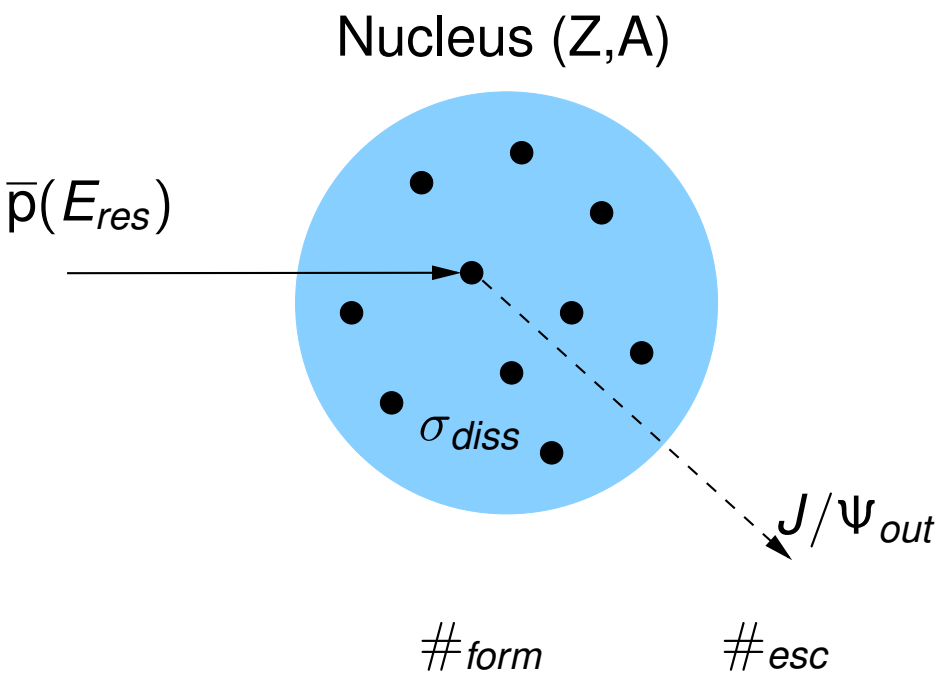

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- Exclusive formation of J/Ψ
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$$\#_{esc} = \#_{form} \cdot (1 - \sigma_{diss} \cdot \langle \rho L \rangle)$$

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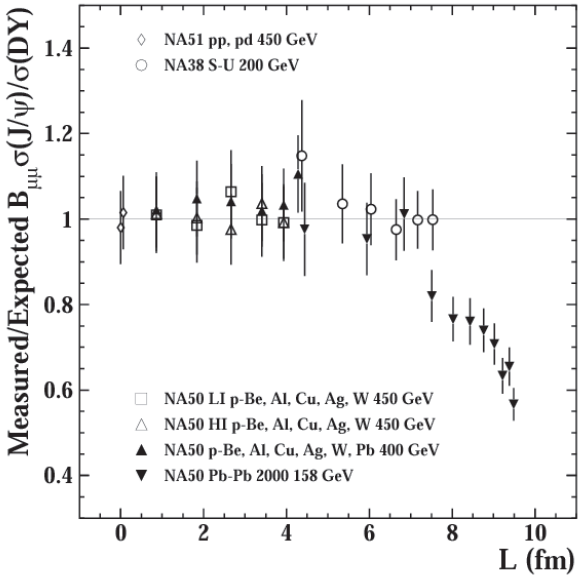
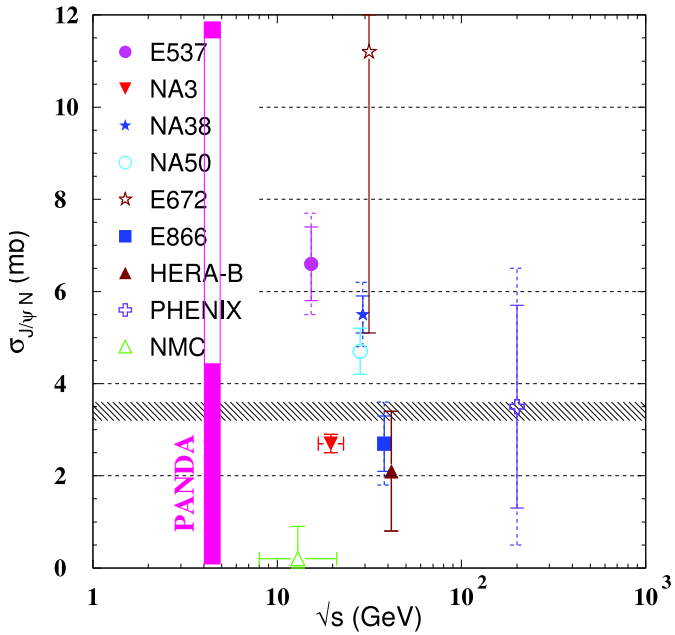


NA50 collaboration, EPJC **39** (2005) 335

- Needed for interpretation of J/Ψ-production in HI

- Values deduced mainly from *pA* and *lA*
- PANDA can contribute at $\sqrt{s} \approx 4.5\ GeV/c$



Arleo, EPJC **55** (2008) 449

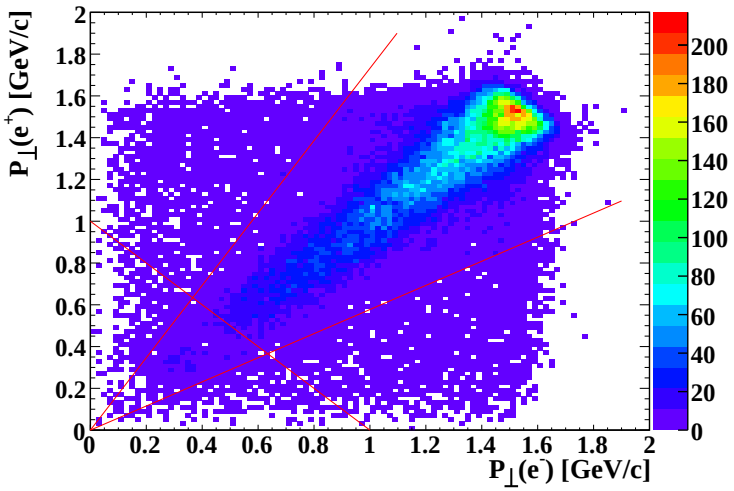
Measurement of J/Ψ - Nucleon inelastic cross section

- $\overline{p} + A \rightarrow J/\Psi \rightarrow l^+ l^-$
- cross sections in the order of 100 *pb*
- total cross section in the order of 1 *b*
- $\Rightarrow$ need background suppression of $> 10^{10}$
- Combination of cuts allows to efficiently suppress background ($< 10^{-10}$)

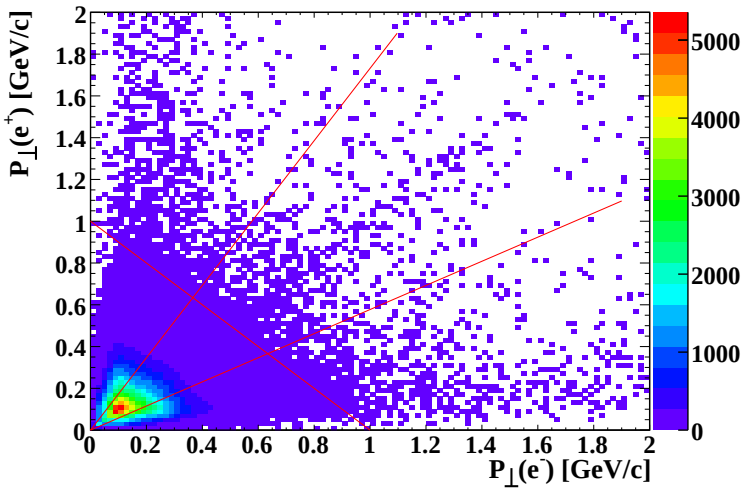
PANDA Physics Performance Report, arXiv:0903.3905

e.g. $\underline{P}_\perp(e^+)$ versus $\underline{P}_\perp(e^-)$

signal

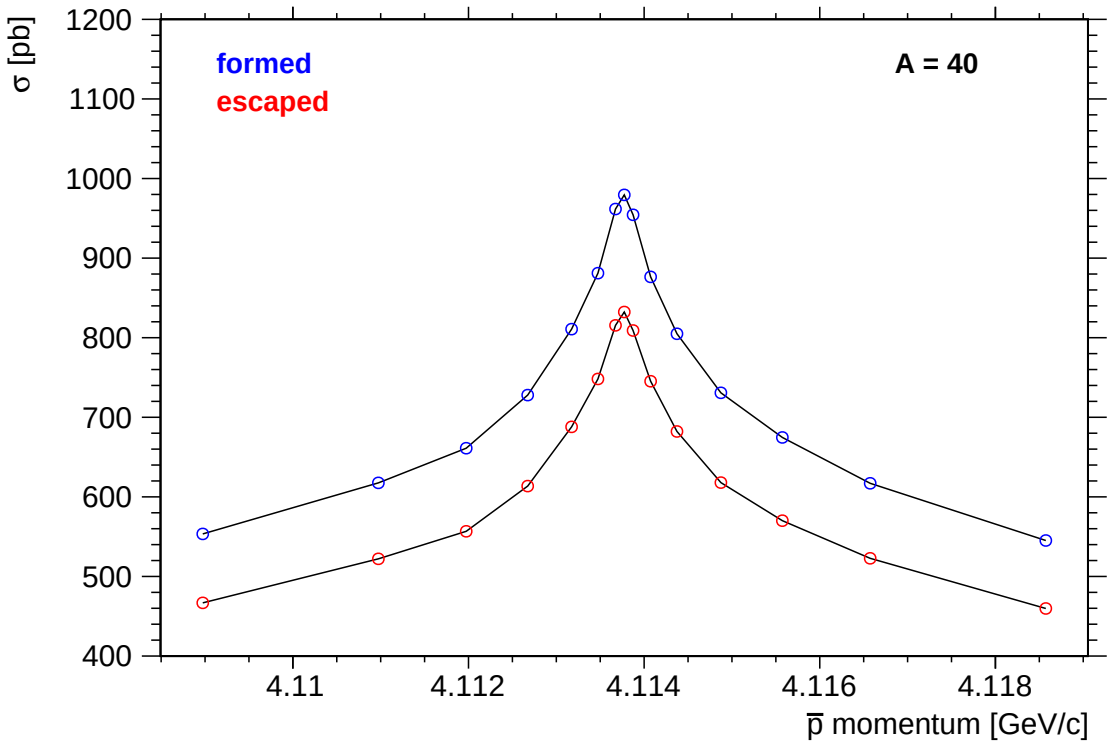


background



Measurement of J/Ψ - Nucleon inelastic cross section

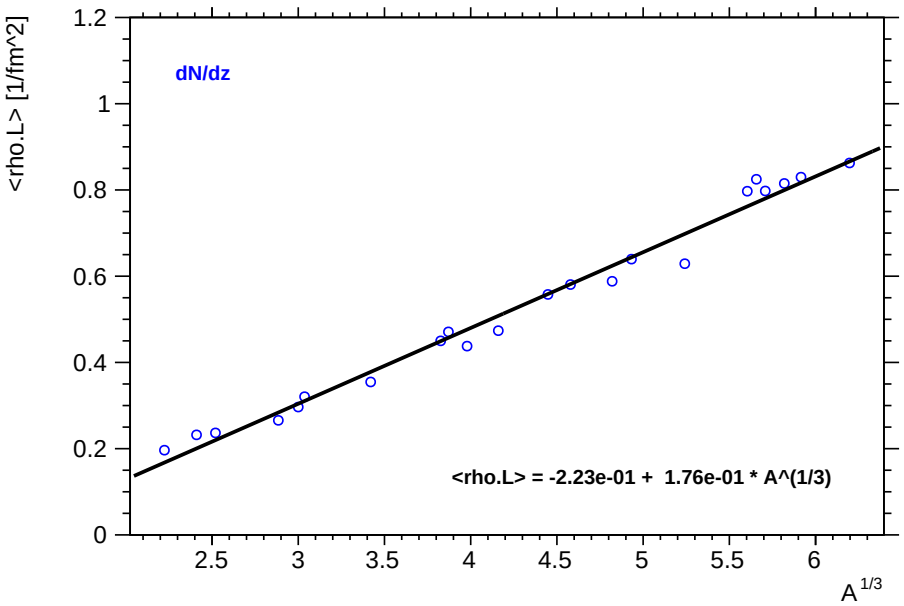
- $\sigma_{form}(\bar{p}A) \propto \int_0^{P_F} BW(\sqrt{s})\, d\sqrt{s}$, average over all formations
- Model of nucleus needed
- Deduced from MC simulations using Glauber type model
- Cross section for detection: $\sigma_{det_{peak}} \approx 600\ pb$
- With $L = 10^{31}\ \mathrm{cm}^{-2}\mathrm{s}^{-1} \Rightarrow < 500\ \frac{J/\Psi}{d}$

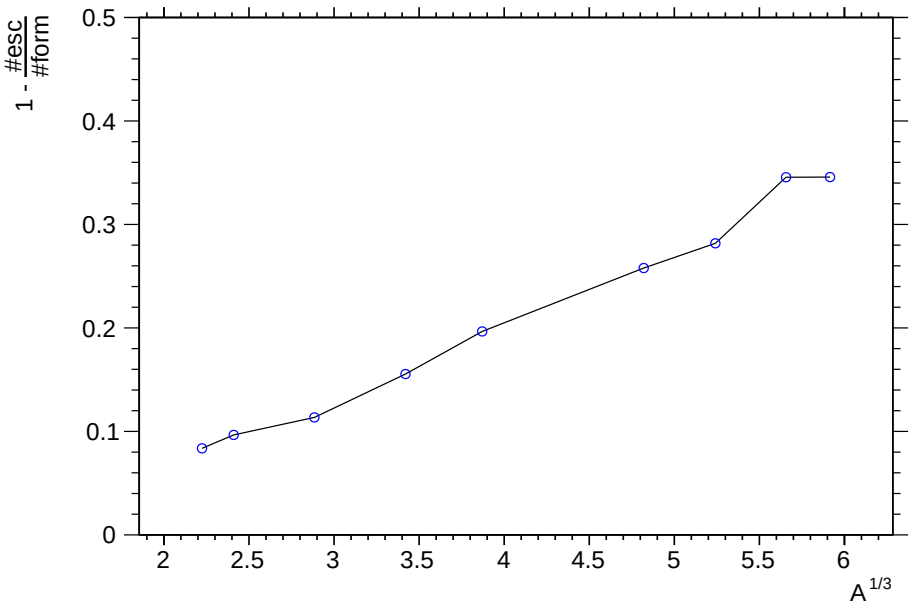


Measurement of J/Ψ - Nucleon inelastic cross section

- As function of A - check consistency, reduce errors

$$\sigma_{diss} \cdot \langle \rho L \rangle (A) \quad = \quad \left[1 - \frac{\#esc}{\#form} \right] (A)$$





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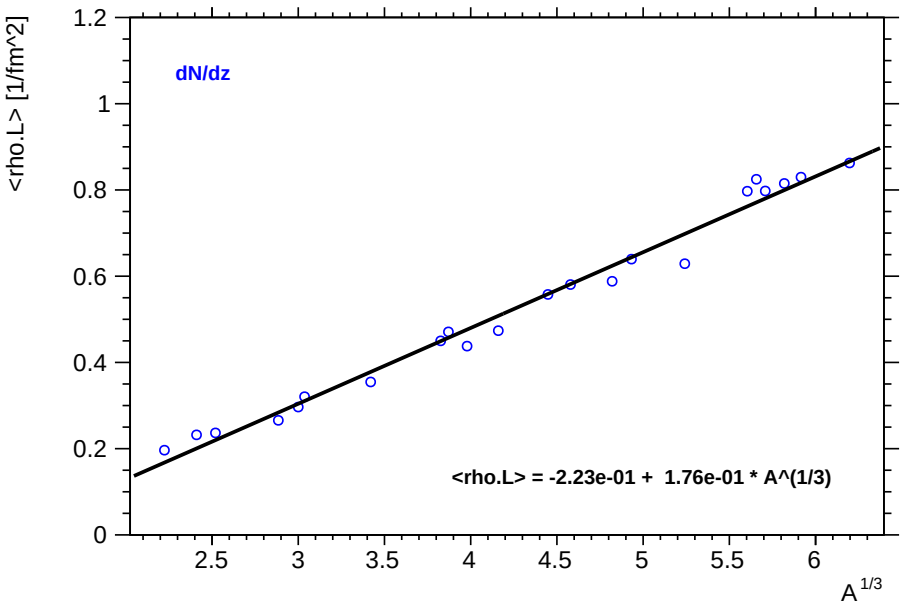
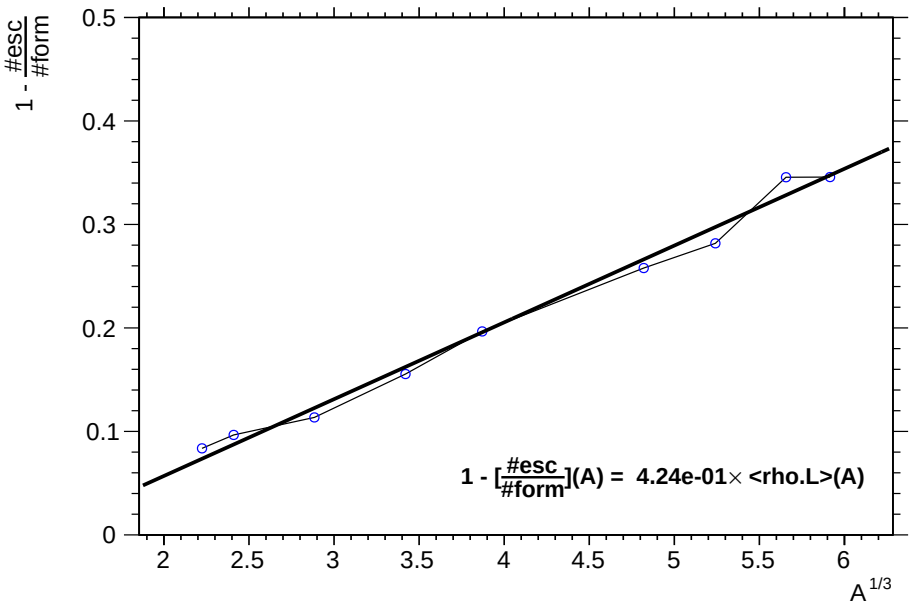
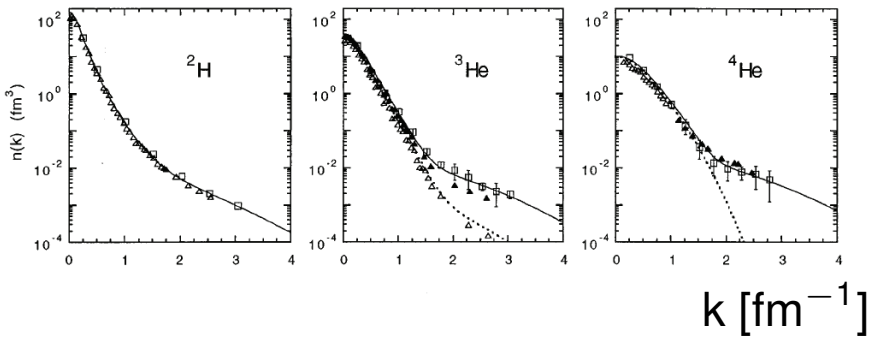




$$\Rightarrow \sigma_{diss} = 4.2 \text{ mb}$$

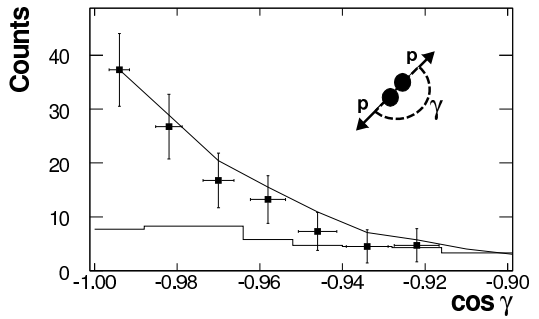
Short range Nucleon-Nucleon correlations

- Investigation of nature of high momentum nucleons
- Governed by short range properties of NN interaction



Ciofi degli Atti & Simula, PRC **53** (1996) 1689

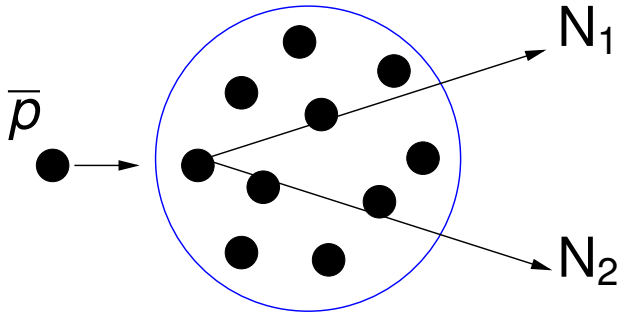
- Most nucleons with $P > P_F$ are paired
- Most of them are pn - fewer pp



$^{12}C(e, e'pp)$

Shneor et al., PRL **99** (2007) 072501

- Hard exclusive reactions with PANDA to study short range NN interaction properties



Conclusions

- PANDA offers potential to address various physics questions in antiproton-nucleus reactions
- Study of in-medium effects can be extended to the charm sector
- Measurement of J/Ψ formation on a series of nuclear targets to study J/Ψ-nucleon interaction has high priority
- Light hadrons can be 'placed' with low momentum in nuclear environment
- Study of hard exclusive reactions inside nucleus gives access to phenomena like color transparency or short range correlations