Mitglied der Helmholtz-Gemeinschaft

JÜLICH
FORSCHUNGSZENTRUM

Antiproton - nucleus collisions with PANDA

Feb 25, 2011 | Albrecht Gillitzer

IKP, Forschungszentrum Jülich & Jülich Center for Hadron Physics

In-Medium Effects in Hadronic and Partonic Systems, Obergurgl, Feb 21-25, 2011

Outline

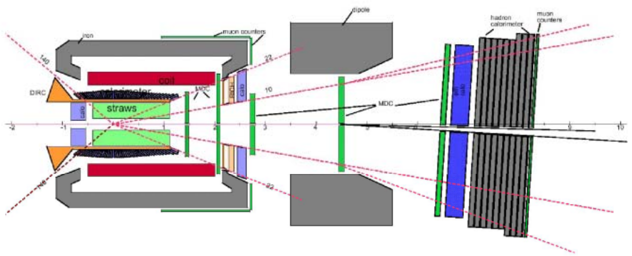
- Ideas for a $\bar{p}$A physics* program with PANDA
- Kinematical and instrumental aspects
- J/ψ absorption in nuclear matter
- Non-charmed hadrons in nuclear matter
- $\bar{p}$-induced hard processes in nuclei
- Possible roads to slow D mesons in nuclei
- Summary

*excl. hypernuclear physics

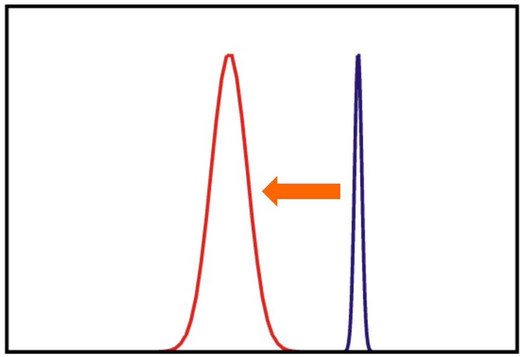
The "early" picture

- Motivation to study hadron properties in the nuclear medium

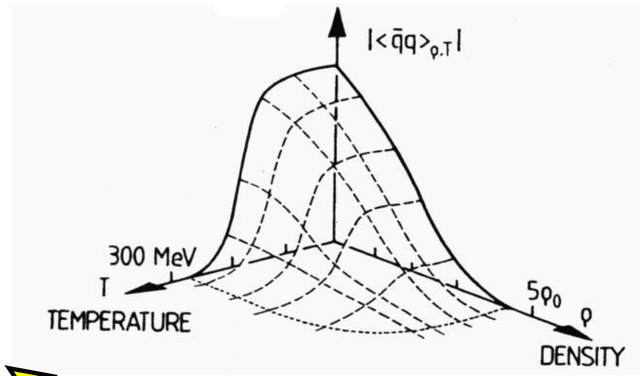
Experiment



Mass shift



quark condensate



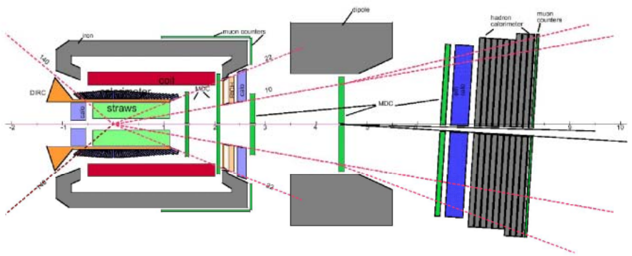
partial restoration of chiral symmetry

Fundamental property of QCD !

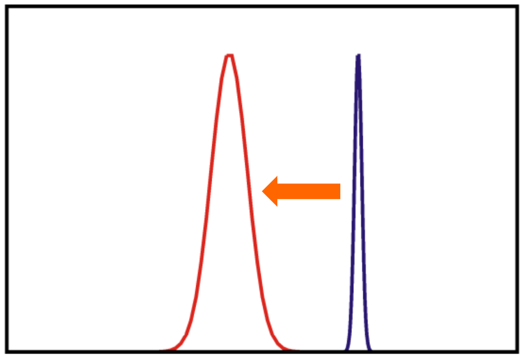
The "early" picture

- Motivation to study hadron properties in the nuclear medium

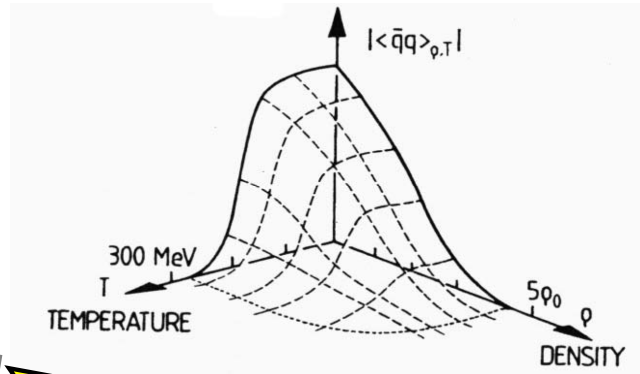
Experiment



Mass shift



quark condensate



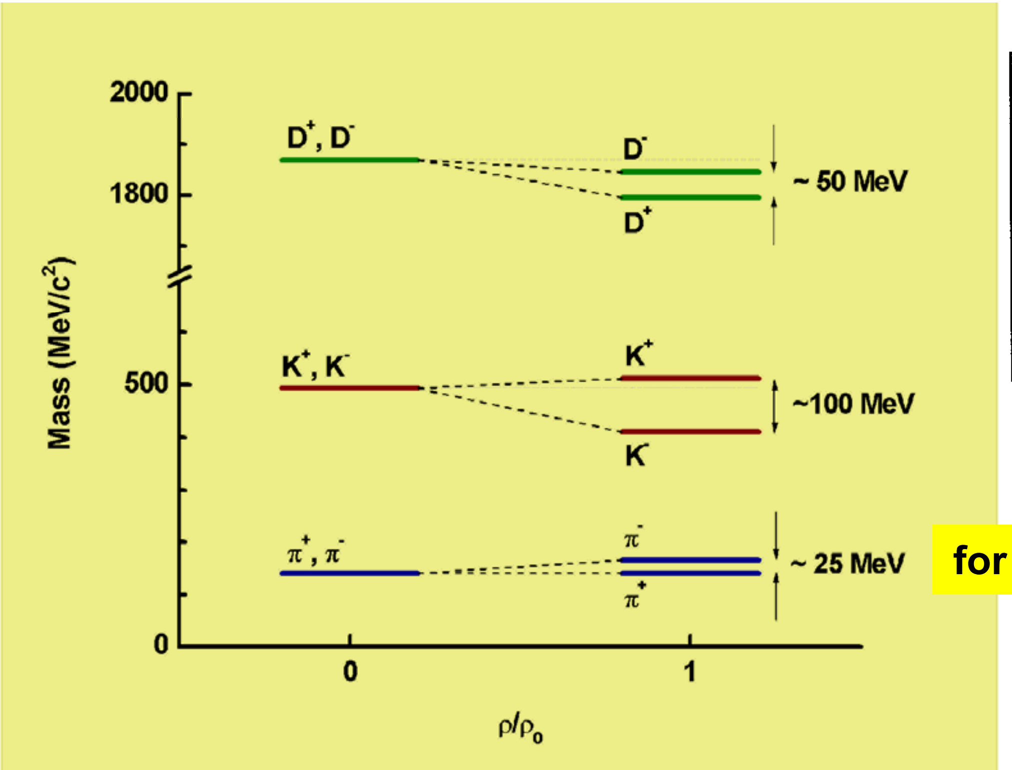
partial restoration of chiral symmetry

Nature is more complicated, but medium effects are still interesting !

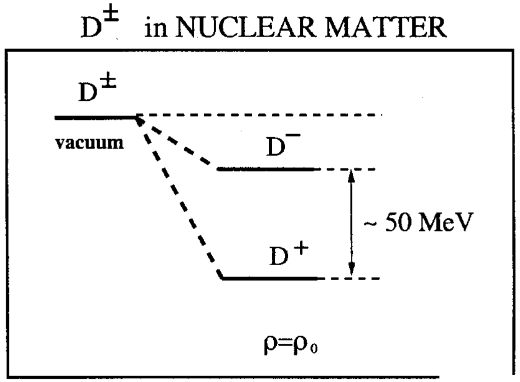
Fundamental property of QCD !

Medium modification of D mesons I

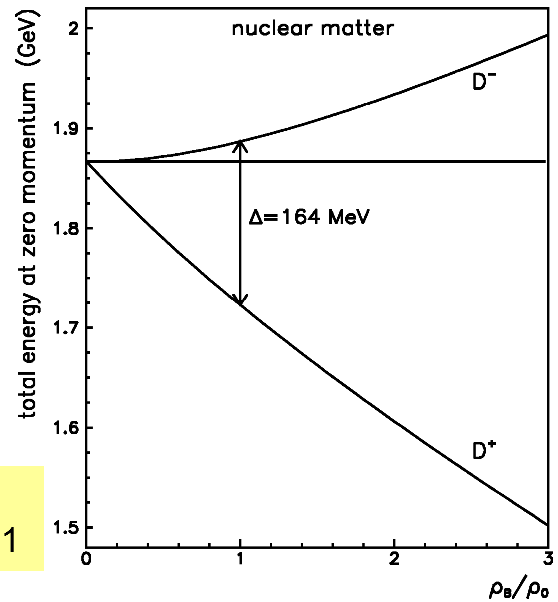
- idea: extend in-medium studies to the charm sector



for N > Z



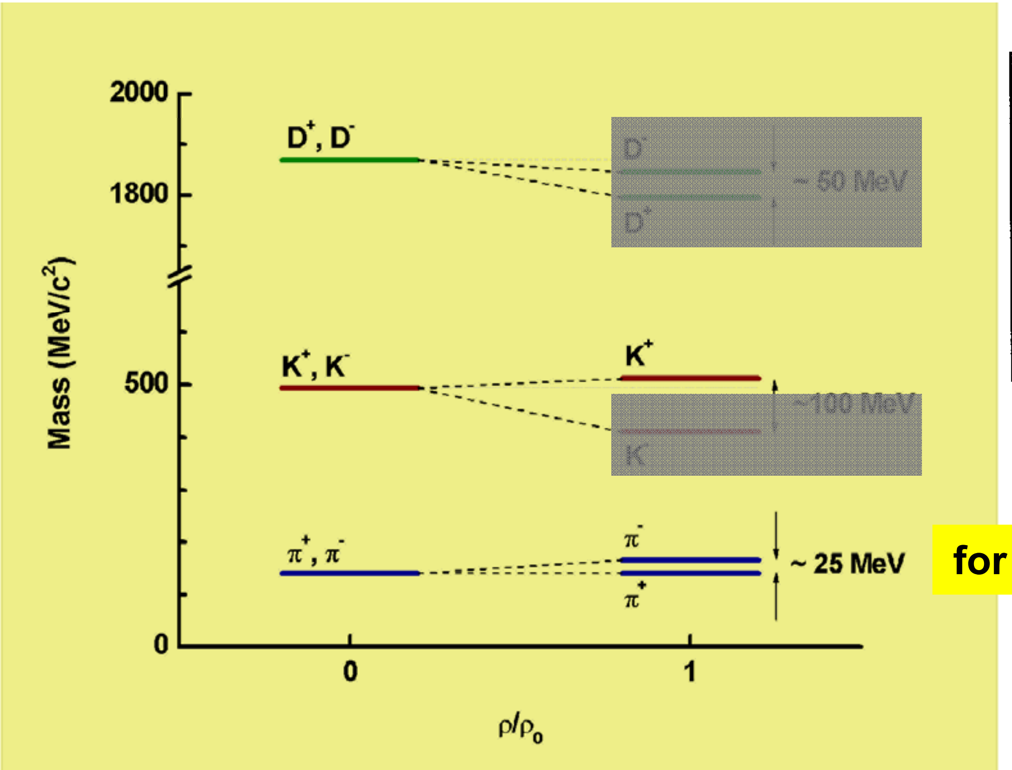
W. Weise,
Proc. Hirschegg 2001



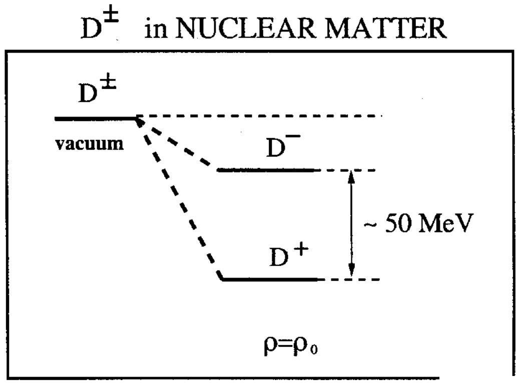
A. Sibirtsev *et al.*,
EPJA 6 (1999) 351

Medium modification of D mesons I

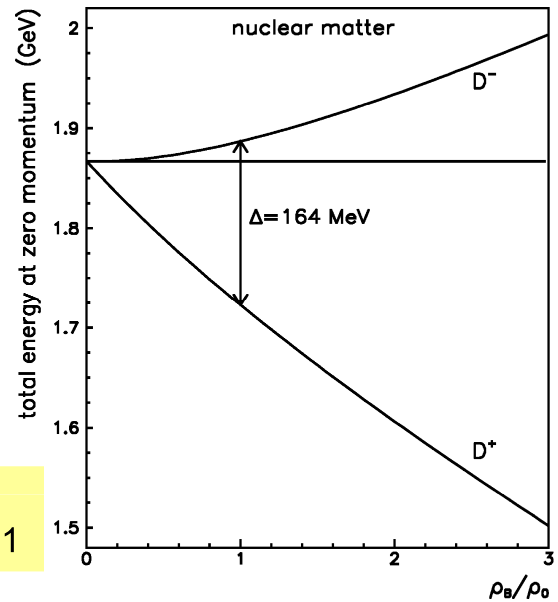
- idea: extend in-medium studies to the charm sector



for N > Z



W. Weise,
Proc. Hirschegg 2001



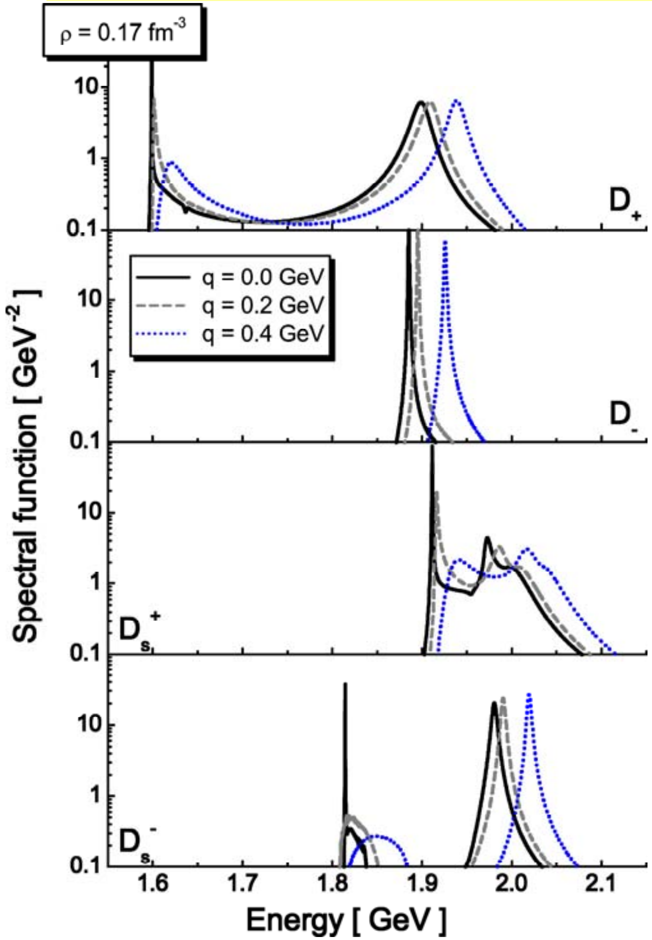
A. Sibirtsev *et al.*,
EPJA 6 (1999) 351

$\overline{K}$ potential: still controversial
D potential: large uncertainties
$\overline{K}$, D will have large width

Medium modification of D mesons II

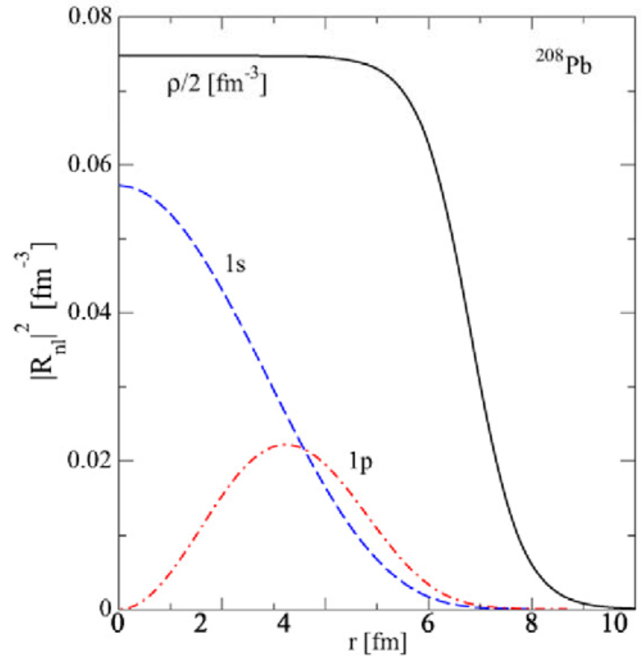
- more recent theory work …

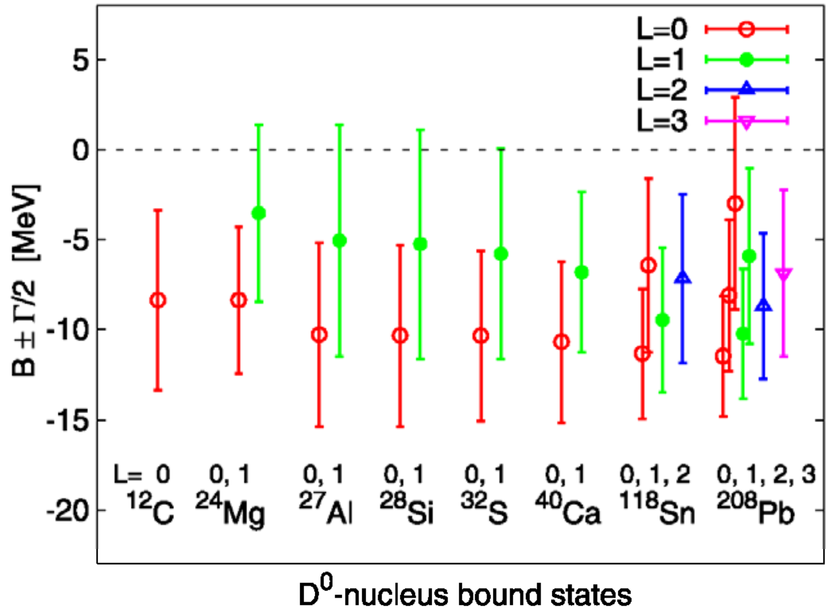
M.F.M. Lutz, C.L. Korpa, PLB 633 (2006) 43



bound nuclear D^0 ($c\bar{u}$) states:

C. Garcia-Recio *et al.*, PLB 690 (2010) 369



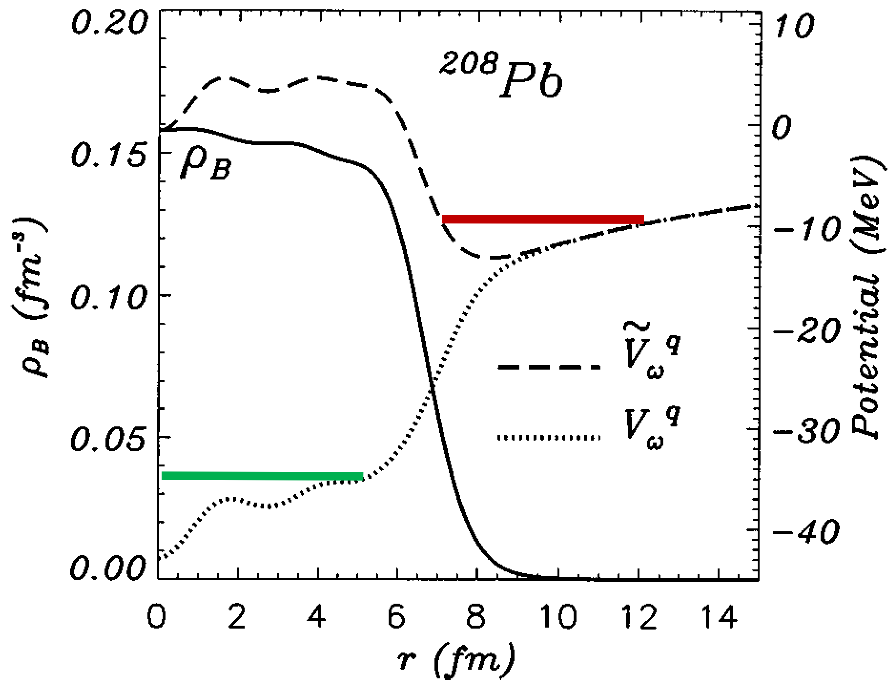


see also T. Mizutani, A. Ramos, PRC 74 (2006) 065201

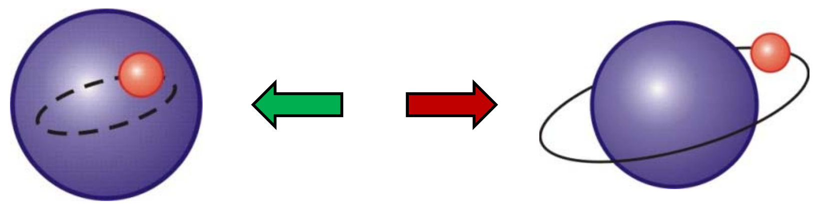
Bound D^- states?

- assisted by Coulomb potential
- Pb nucleus: $V_C(0)$ = -25 MeV
- even bound with repulsive D^- potential
- only weak decay → narrow !
- new family of anti-charmed hypernuclei
- further theoretical studies welcome

L. Tolos *et al*., PRC 77 (2008) 015207
ΔM = 15 … 20 MeV



K. Tsushima *et al*., PRC 59 (1999) 2824



Medium modification of charmonium I

	Quantum numbers	QCD 2nd Stark eff.	Potential model	QCD sum rules	Effects of DD loop
η_c	0^{-+}	**−8 MeV** [1]		**−5 MeV** [4]	
J/ψ	1^{--}	**−8 MeV** [1]	**-10 MeV** [3]	**−7 MeV** [4]	**+3 MeV** [5]
$\chi_{c0,1,2}$	$0,1,2^{++}$	**-40 MeV** [2]		**-60 MeV** [2]	
$\psi(3686)$	1^{--}	**-100 MeV** [2]			**-30 MeV** [5]
$\psi(3770)$	1^{--}	**-140 MeV** [2]			**+15 MeV** [5]

→ strong binding for higher states?

[1] Peskin, NPB 156 (1979) 365, Luke *et al*., PLB 288 (1992) 355

[2] S.H. Lee, nucl-th/0310080

[3] Brodsky *et al*., PRL 64 (1990) 1011

[4] Klingl, Kim, Lee, Morath, Weise, PRL 82 (1999) 3396

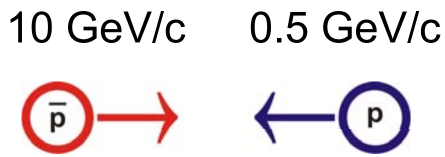
[5] Lee, Ko, PRC 67 (2003) 038202

$\Delta M_{J/\psi}$ = -16…-24 MeV

G. Krein *et al*., arXiv:1007.2220

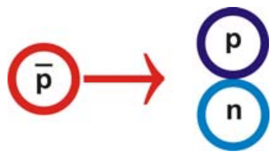
Kinematics in $\bar{p}$A collisions

- $\bar{p}$N annihilation in nuclear target: charmed mesons are produced at high momentum in the nuclear rest frame!
- holds for D mesons and charmonium states
- e.g. $\bar{p}p \rightarrow D^+D^-$ at threshold: $p_{\bar{p}} = 6.44$ GeV/c
- Fermi momentum not sufficient:



$p_D > 0.72$ GeV/c

- $\bar{p}NN \rightarrow \bar{D}\Lambda_c$ may help more:



$p_D > 0.23$ GeV/c

- → no direct road to slow charmed hadrons in nuclear matter

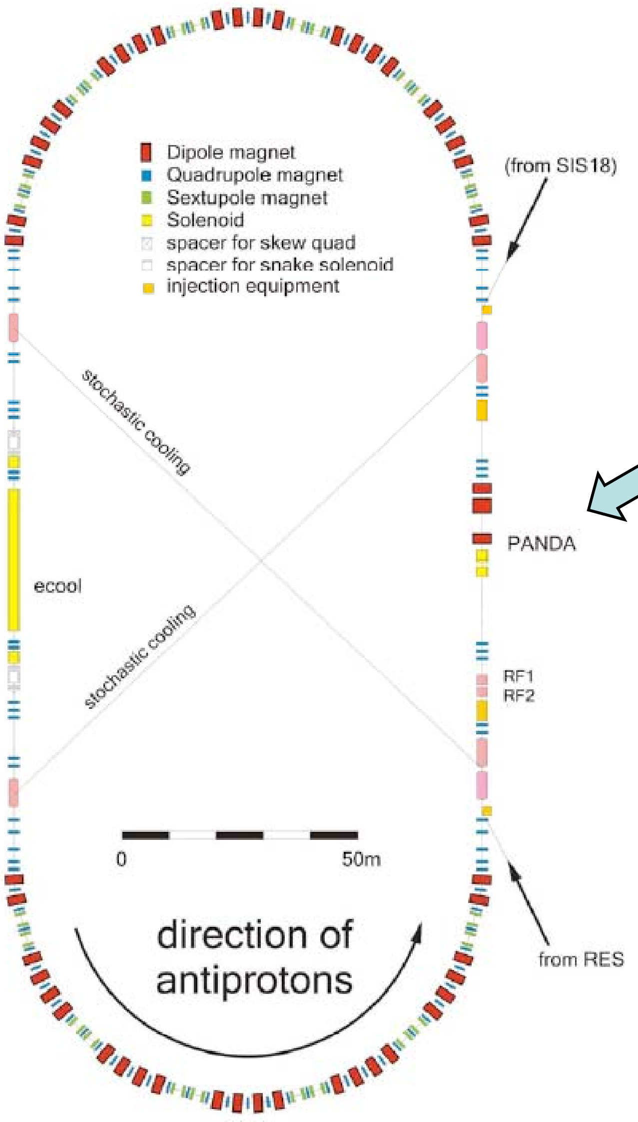
Options for PANDA

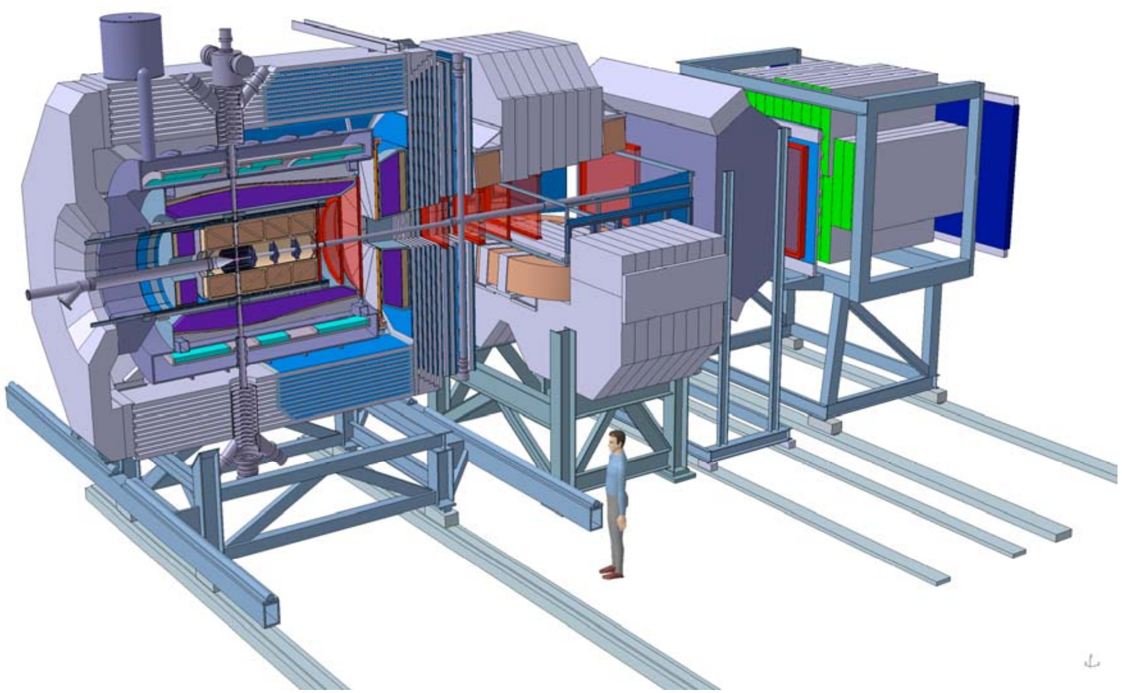
can we still do something interesting?

Y E S, we can !

- use the nucleus as a laboratory for hadron-nucleon interactions
- access to hadron-nucleon cross section / imaginary nuclear potential in attenuation measurements
- access to real part of nuclear potential in cases where slow hadrons can be produced (?)
- study of hard reactions inside the nuclear environment

HESR and PANDA



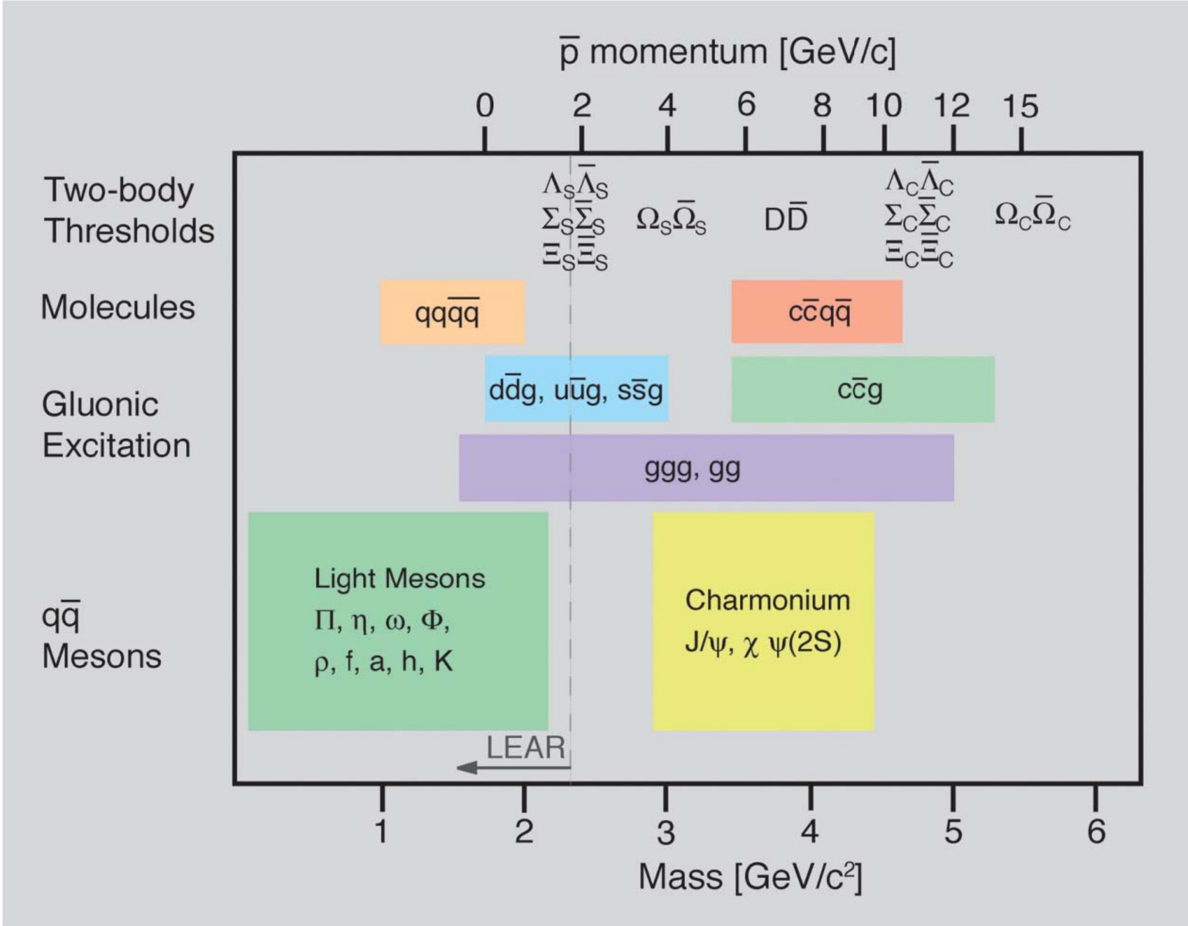


- $\bar{p}$ momentum: 1.5 … 15 GeV/c
- L_{max} ~ 10^{32} $cm^{-2}s^{-1}$ (R ~ 10^7/s)
- ~4π acceptance for charged and neutrals
- p, K, π, $e^{\pm}$, $\mu^{\pm}$, γ identification
- displaced vertex detection

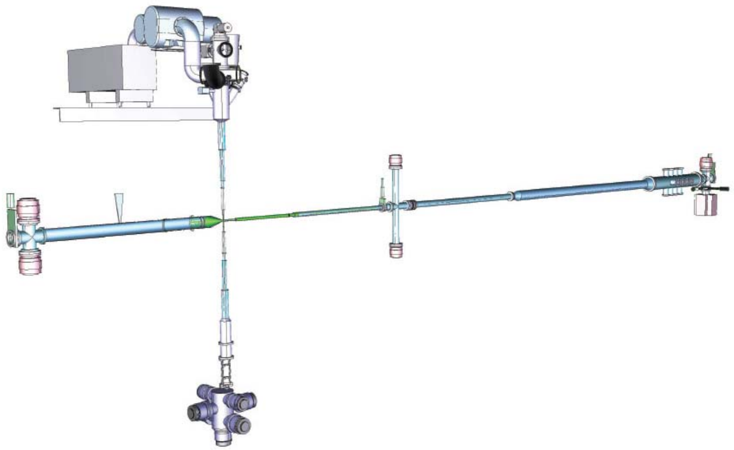
Physics reach

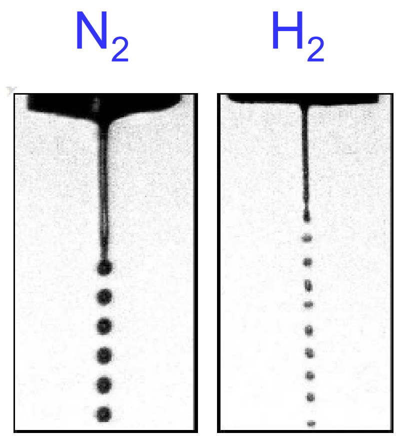
key issues of the program:

- study of charmonium or charmonium-like states
- search states with gluonic excitations
- kinematic limit:
  $\sqrt{s}$ = 5.5 GeV ~ $\Omega_c\bar{\Omega}_c$

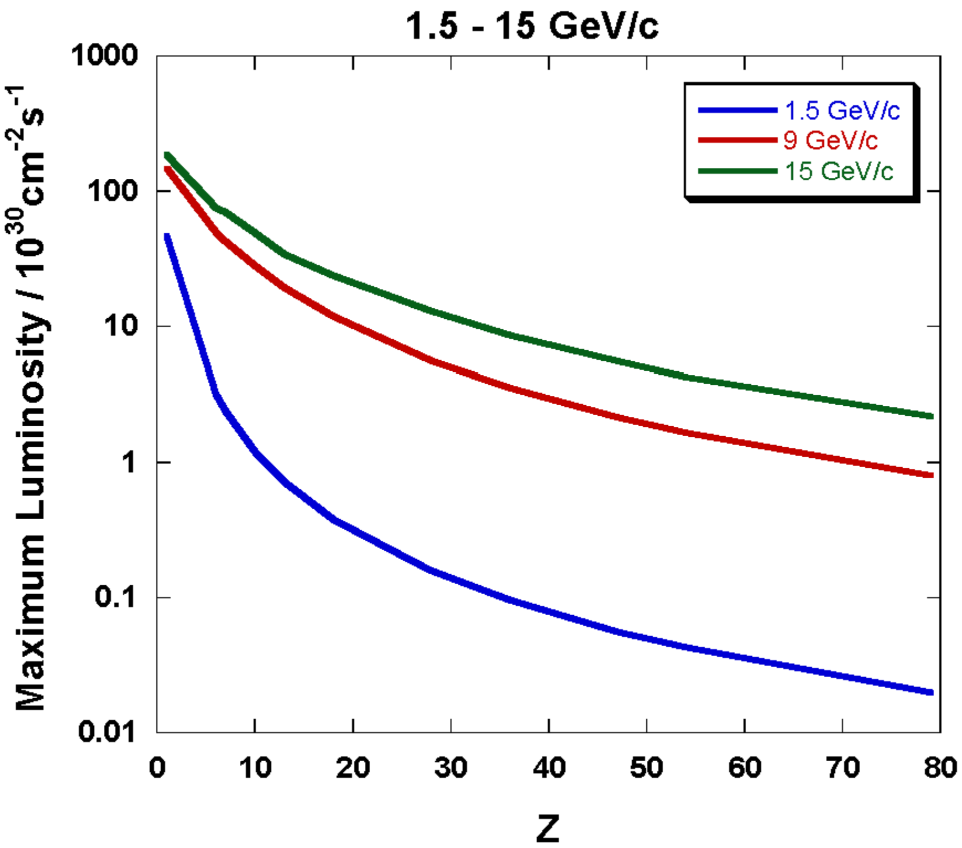


$\bar{p}$-nucleus collisions





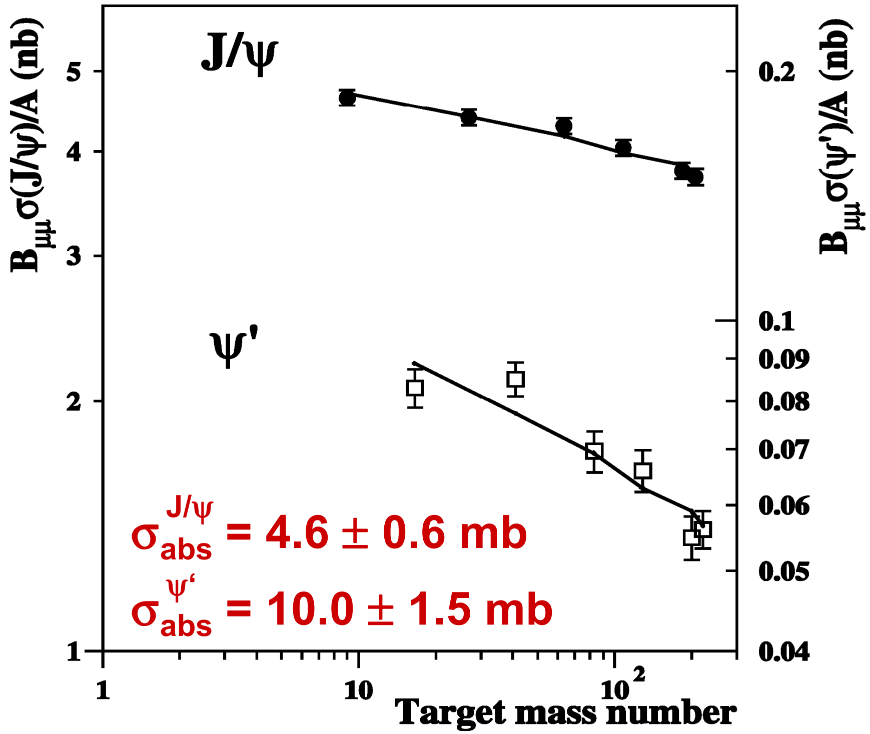
- targets: pellet, cluster jet, solid
- pellet & cluster jet work for: D_2, N_2, Ne, Ar, Kr, Xe
- L_{max} decreases with Z
- Au target: lose ~factor 10^3 at 1.5 GeV/c, ~10^2 at 15 GeV/c
- luminosity determination for $\bar{p}p$ doesn't work for $\bar{p}A$



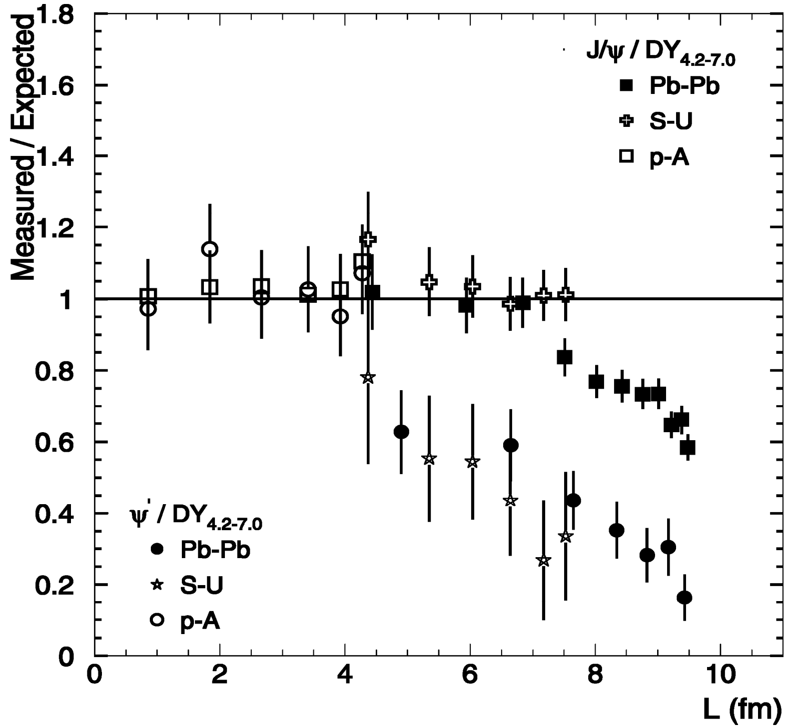
J/ψ and ψ' absorption in nuclei

J/ψ as indicator for QGP formation in relativistic nucleus-nucleus collisions:

NA50: 400 GeV/c p + A → J/ψ(ψ') + X



NA50: A + A' → J/ψ(ψ') + X



G. Borges, JPG 30 (2004) S1351, B. Alessandro *et al.*, EPJC 33 (2004) 31; EPJC 48 (2006) 329

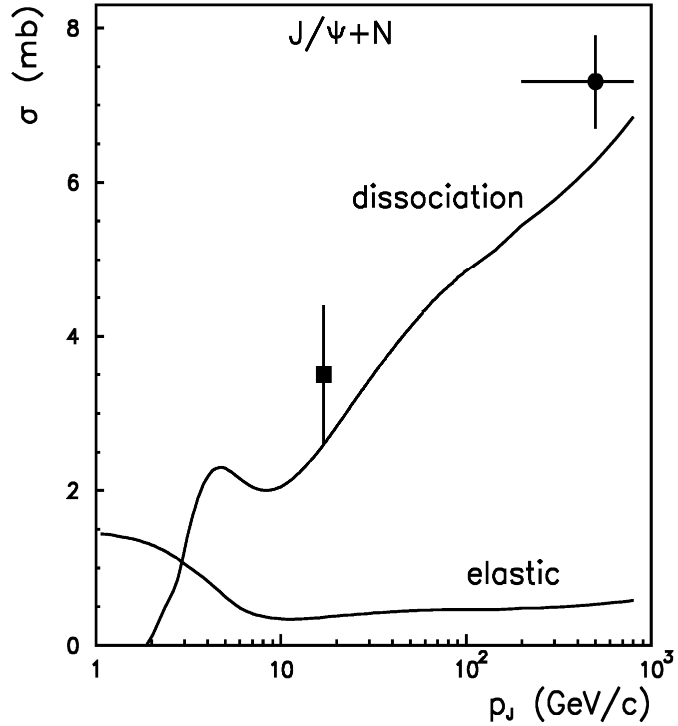
PHENIX: $\sigma_{diss}^{J/\psi}$ ~ 3 mb; other analyses: $\sigma_{diss}^{J/\psi}$ = 1…7 mb

energy dependence uncertain

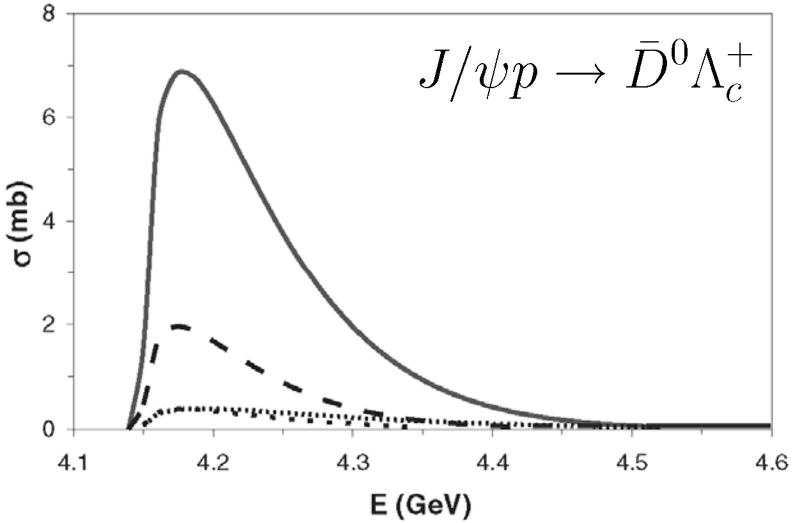
J/ψ absorption in nuclei

- model calculations show large variation of J/ψN cross section dependent on choice of parameters
- different predictions with meson-exchange and quark-interchange model

A. Sibirtsev *et al.*, PRC 63 (2001) 044906



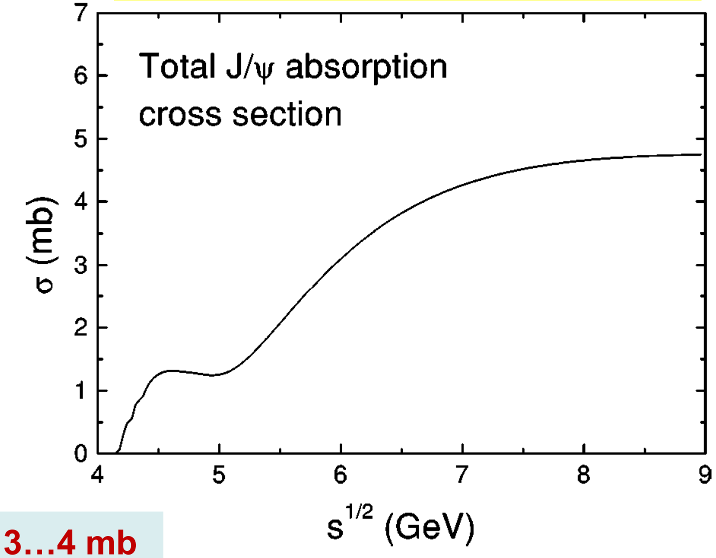
J.P. Hilbert *et al.*, PRC 75 (2007) 064907



see also:

Y. Oh *et al.*,
PRC 75 (2007) 064903

W. Liu *et al.*, PRC 65 (2002) 015203



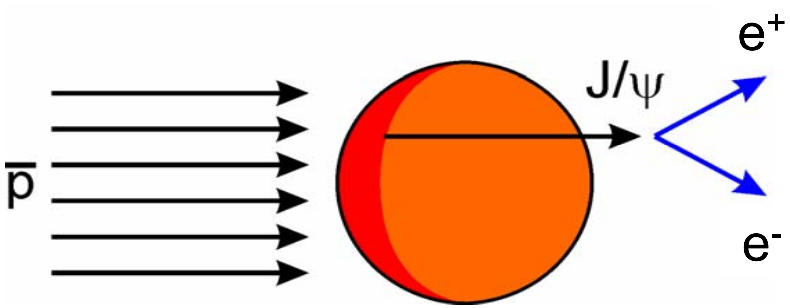
See also L. Gerland, L. Frankfurt, M. Strikman, PLB 619 (2005) 95: GVDM, $\sigma_{J/\psi N}$ ~ 3…4 mb

J/ψ N dissociation cross section with $\bar{p}$

well-defined production 'on-resonance'

$\bar{p} + A \rightarrow J/\psi + X \rightarrow e^+e^- + X$

$\bar{p} + A \rightarrow J/\psi + X \rightarrow \mu^+\mu^- + X$

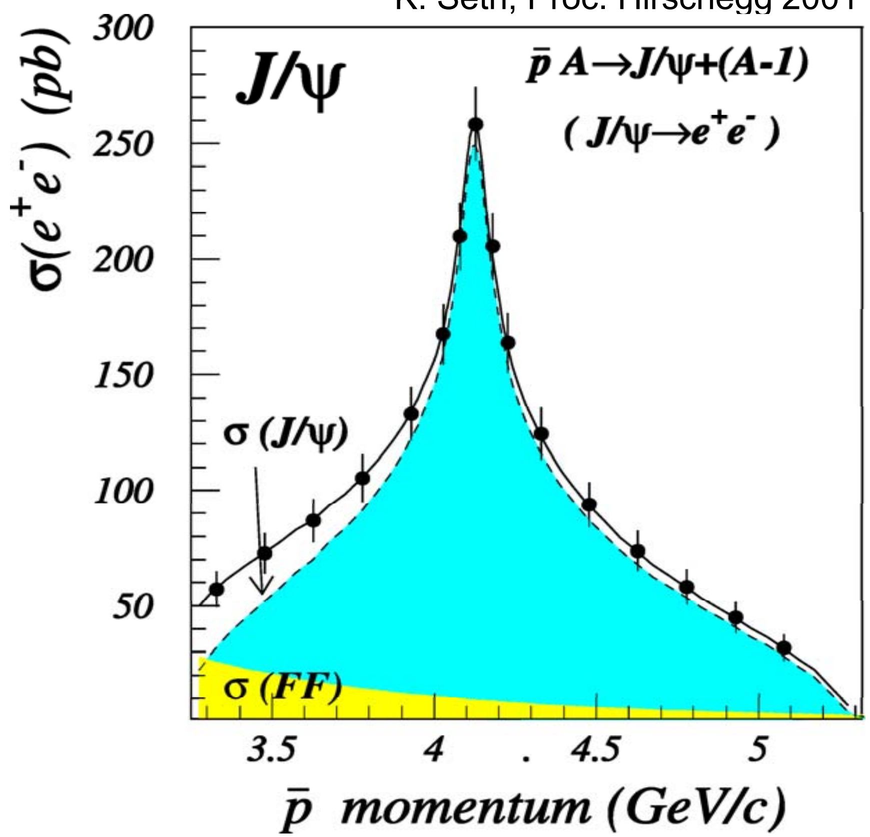


$$P_{\text{surv}} = e^{-\sigma\rho \text{d}l}$$

measure cross section as function of A and $p_{\bar{p}}$

deduce J/ψN dissociation cross section at *lower, well-defined* J/ψ momentum

K. Seth, Proc. Hirschegg 2001



See also S.J. Brodsky, A.H. Müller, PLB 206 (1988) 685,
G.R. Farrar, L.L. Frankfurt, M.I. Strikman, NPB 345 (1990) 125

note: $\sigma_{\bar{p}A \rightarrow J/\psi X} \ll \sigma_{\bar{p}p \rightarrow J/\psi}$

need to detect S/B = 10^{-10} !

J/ψ N dissociation cross section with PANDA

- "on-resonance" → $p_{\bar{p}} = 4.05$ GeV/c, $\sqrt{s}_{J/\psi N} = 4.48$ GeV
- rate of $J/\psi \to e^+e^- / \mu^+\mu^-$: ~ $20/d \times L/10^{30}\ cm^{-2}s^{-1} \times f_{esc} \times f_{instr}$
- no J/ψ background due to feeding from ψ'
- only few open channels $J/\psi N \to \bar{D}^{(*)}Y_c^{(*)}$, $\eta_c N$, $\chi_c N$
- $J/\psi N \to D\bar{D}N$ only with Fermi momentum $-p_z > 0.23$ GeV/c
- exclusive measurements of $J/\psi n$ final states with $\bar{p}d$
- systematic study of inclusive 'resonant' J/ψ production with D_2, N_2, Ne, Ar, Kr, Xe, Au (?) targets

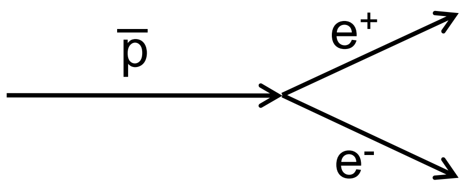
Simulation studies for PANDA

- First detailed simulation studies done — P. Bühler, SMI Vienna
- Signal:
  - use $\bar{p}A \to J/\psi X$ event generator — A. Sibirtsev
  - 80 k 4.05 GeV/c $\bar{p} + {}^{40}Ca \to J/\psi + X \to e^+e^- + X$
  - 80 k 4.05 GeV/c $\bar{p} + {}^{40}Ca \to J/\psi + X \to \mu^+\mu^- + X$
- Background:
  - 26.4 M UrQMD 4.05 GeV/c $\bar{p} + {}^{40}Ca$ generic background
  - 30 M 4.05 GeV/c $\bar{p}$ + ‘p‘ $\to \pi^+ \pi^-$; ‘p‘ with Fermi momentum

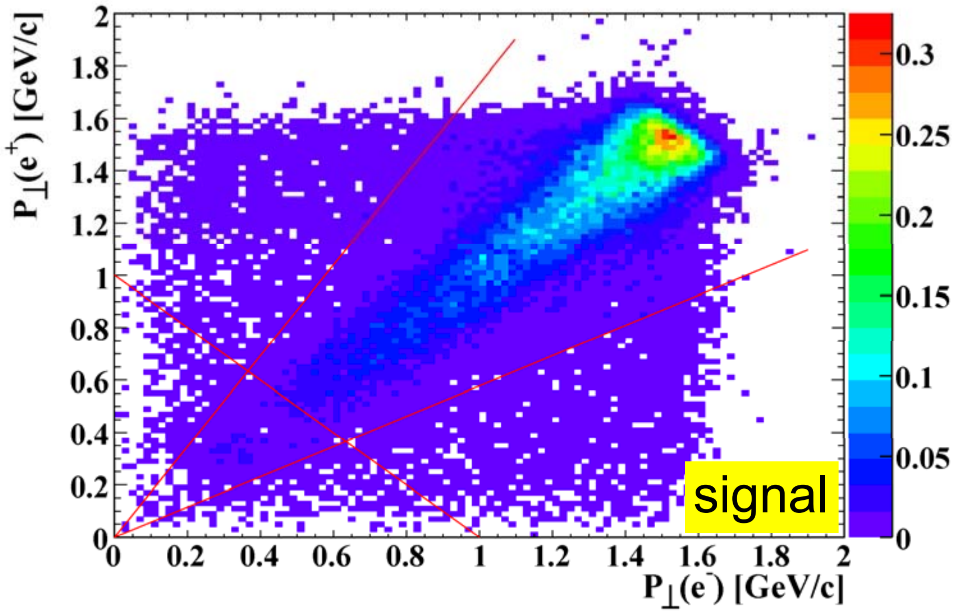
Simulation studies for PANDA

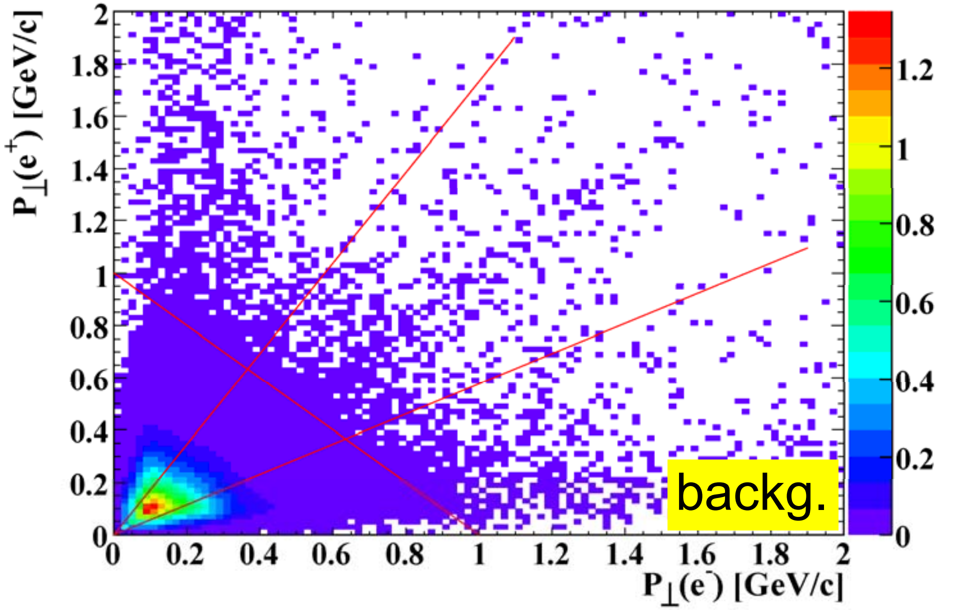
e^+e^- identification → background reduction not sufficient

→ exploit topology of signal events:



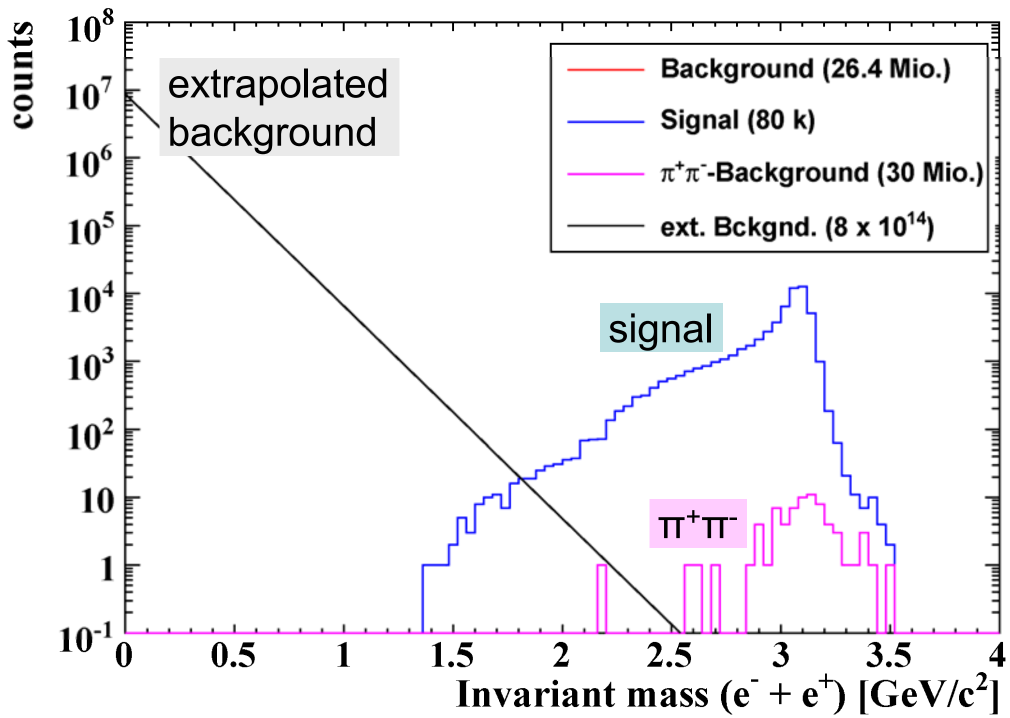
- track origin at primary vertex
- $p_z(e^+) + p_z(e^-) \sim p_z(\bar{p})$
- $p_x(e^+) + p_x(e^-) \sim 0$
- $p_y(e^+) + p_y(e^-) \sim 0$





Simulation result

- reconstruction efficiency: $\varepsilon_{signal} = 0.73$
- background suppression for UrQMD generic: no event out of 26.4 M!
  $f_{bg} < 3.8 \cdot 10^{-8} \rightarrow S/B > 5 \cdot 10^{-3}$
- background suppression for $\pi^+\pi^-$: $2.4 \cdot 10^{-6} \rightarrow S/B \sim 10$



generic background needs to be extrapolated based on assumptions:

- integral background = 1 event
- background shape independent of cuts
- scale background sample up to $8 \cdot 10^{14}$ events = $10^{10} \times$ signal

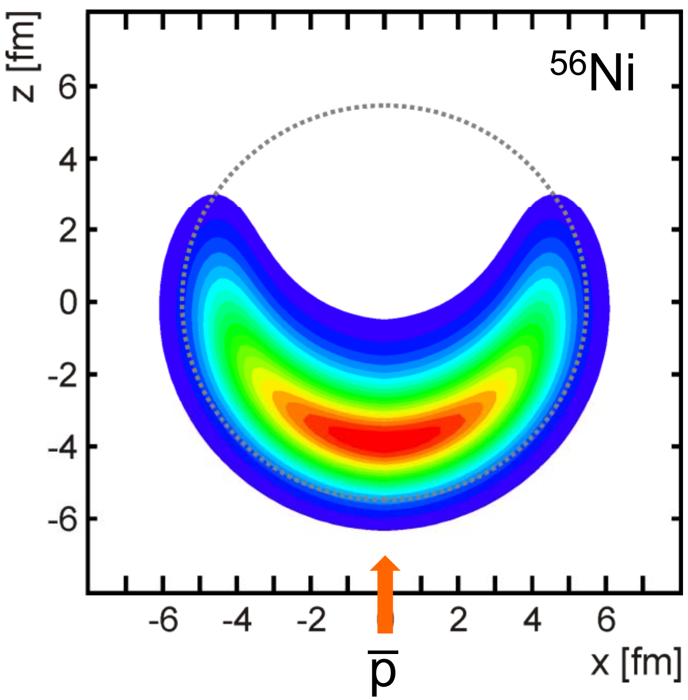
J/ψ N dissociation cross section from A dependence

- 1st step: use simple geometric MC model: $\bar{p}$ absorption, Fermi momentum, J/ψ absorption

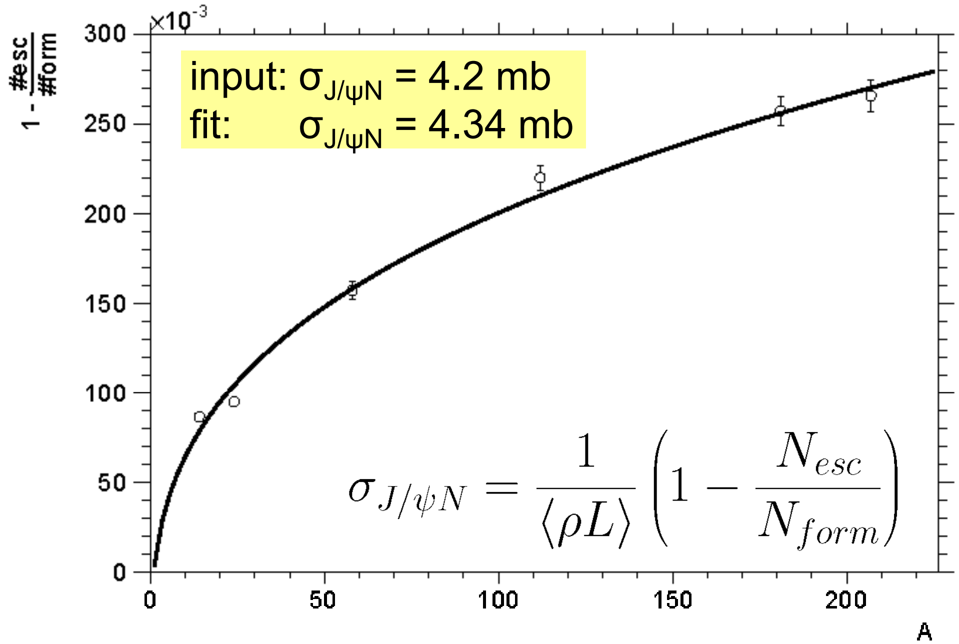
P. Bühler, SMI Vienna

- next step: use transport code, e.g. GiBUU

distribution of J/ψ formation



$\sigma_{J/\psi N}$ extracted from A-dependence



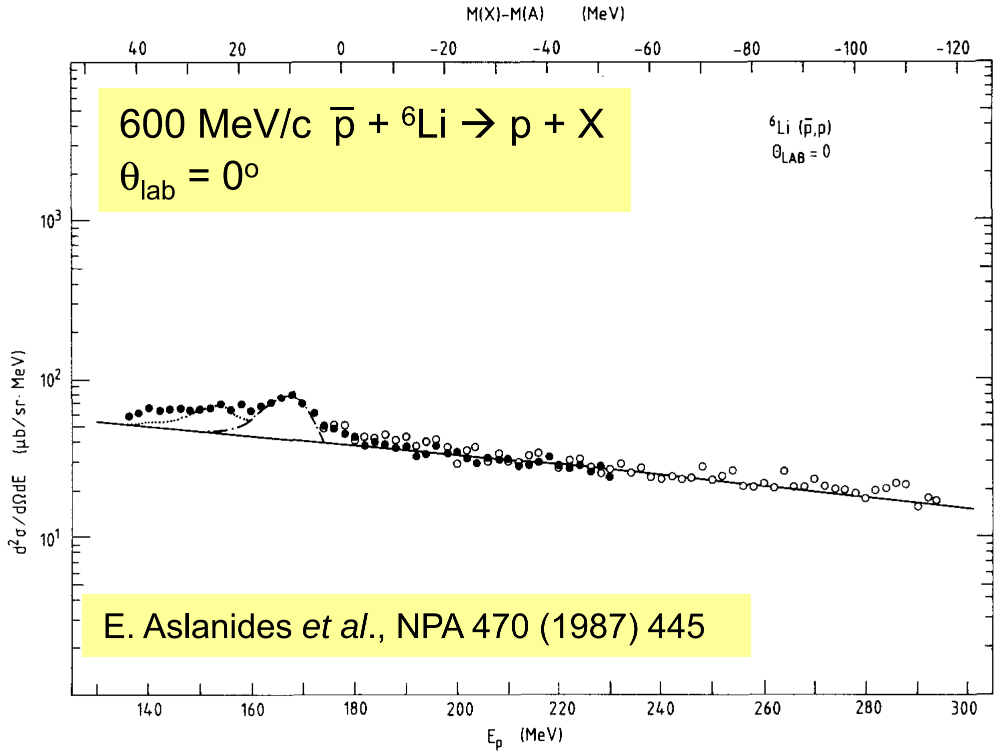
$$\sigma_{J/\psi N} = \frac{1}{\langle \rho L \rangle} \left(1 - \frac{N_{esc}}{N_{form}}\right)$$

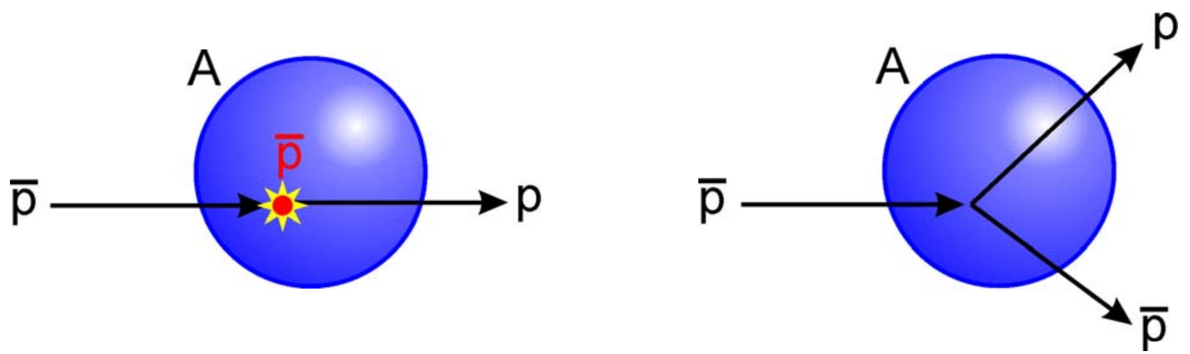
Nuclear potential for non-charmed hadrons?

- charmed hadrons much too fast to feel nuclear potential
- access to nuclear potential for light (u,d,s) hadrons?
- methods:
  - reconstruct mass shift from in-medium decay
  - reconstruct excitation energy of residual system from missing mass measurement (~recoil-free kinematics)
  - transverse momentum distributions
- possible for $\bar{p}$, $\bar{\Lambda}$, ϕ, $\bar{K}$, $\bar{K}^*$, η'

Antiprotons

- low energy measurements don't have sensitivity to Re $U_{\bar{p}}$
- models predict deep potential with cold nuclear compression
  I.N. Mishustin *et al.*, PRC 71 (2005) 035201,
  A.B. Larionov *et al.*, PRC 78 (2008) 014604
- repeat p knock-out experiment at high energy with PANDA





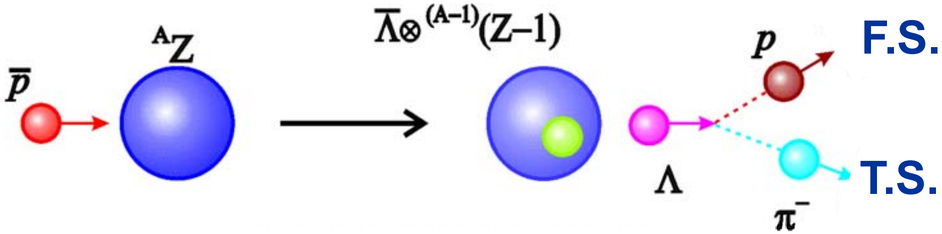
$M_{(A-1)\bar{p}}$ from MM_p

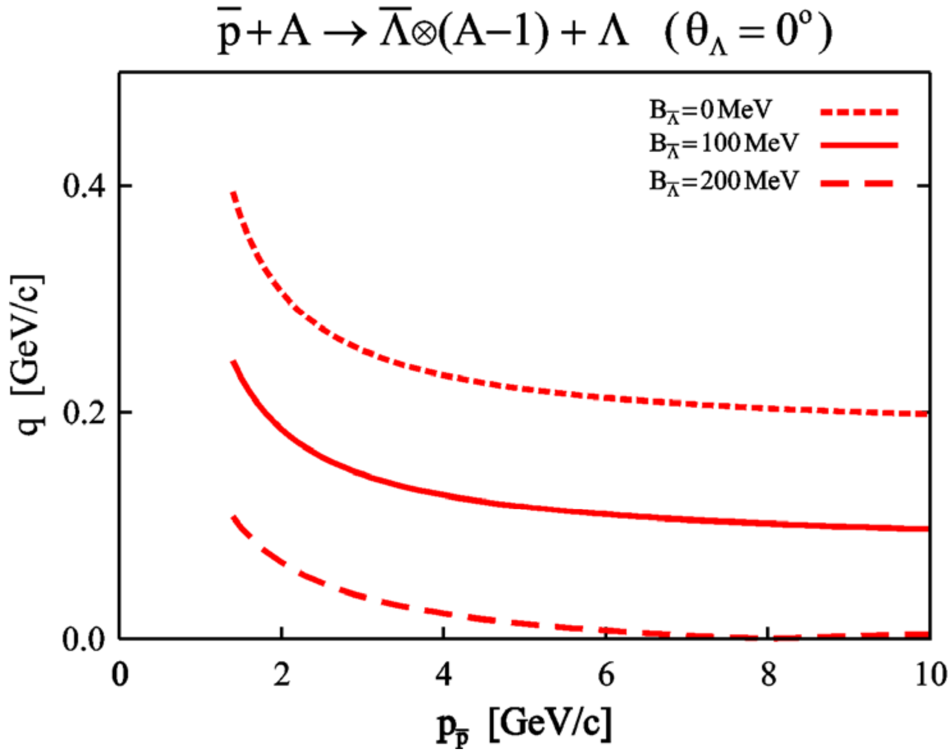
$M_{(A-1)}$ from $MM_{\bar{p}p}$

Anti-Lambda's

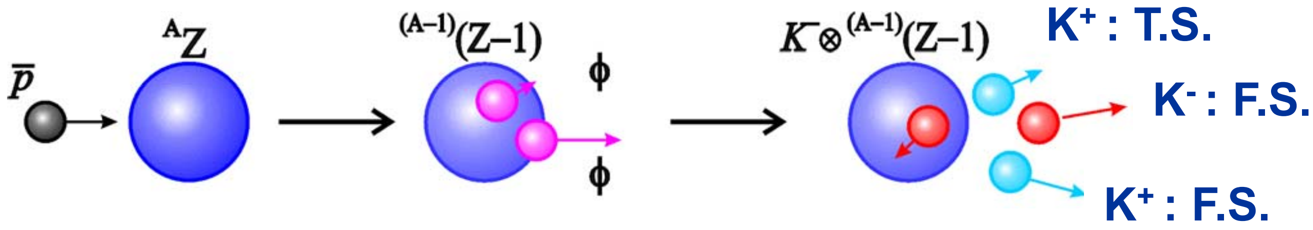
- nuclear potential non known
- use $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ at $\theta_\Lambda \sim 0^o$ with nuclear proton
- small momentum transfer
- $d\sigma/d\Omega_{\bar{p}p\rightarrow\bar{\Lambda}\Lambda}(\theta_\Lambda \sim 0^o) = 2\ \mu b/sr$ at p = 1.77 GeV/c
  P.D. Barnes *et al*. (LEAR-PS185), PRC 54 (1996) 2831

  $\sigma \sim \mu b$: large signal rate
- alternative proposal: measure Λ and $\bar{\Lambda}$ p_t distributions in coincidence
  J. Pochodzalla, PLB 669 (2008)306





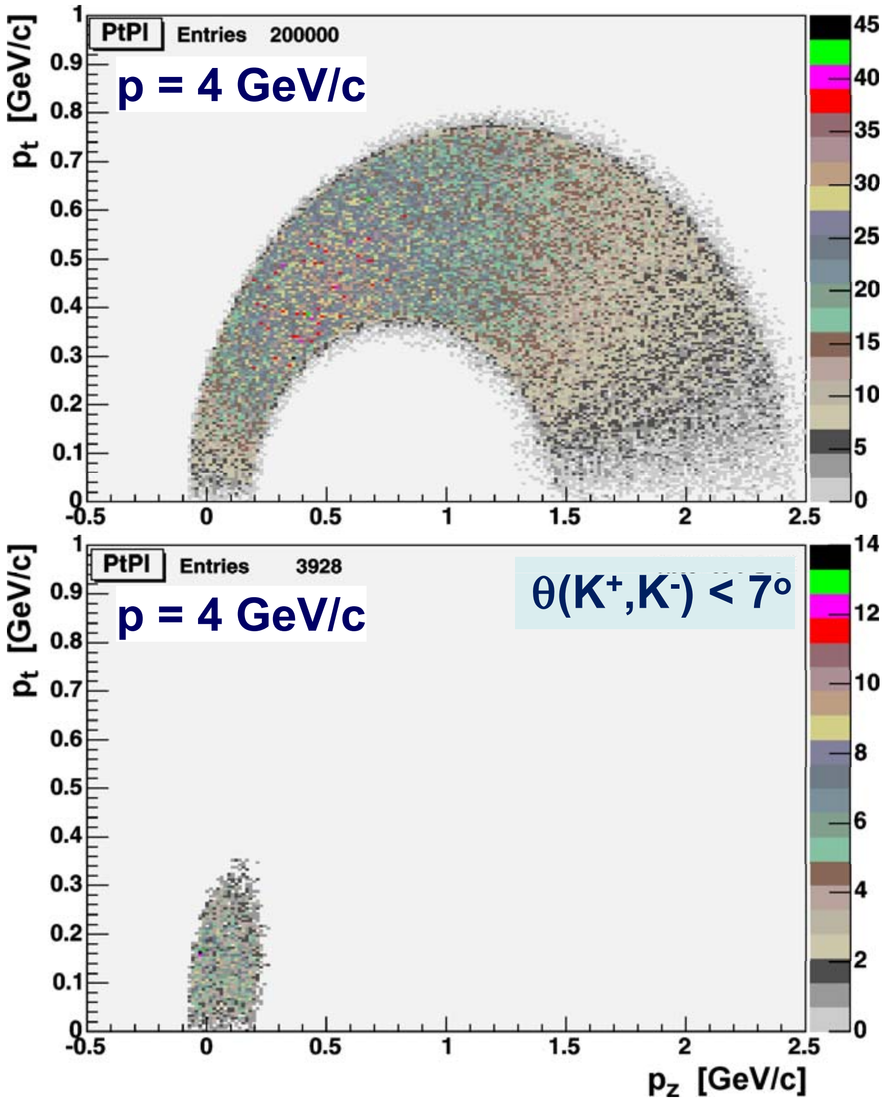
Anti-Kaons



- nuclear potential of $\overline{K}$ still controversially discussed
- use $\overline{p}p \rightarrow \phi\phi$ at $\theta = 0^o$ to produce slow K^- in nuclei
- $\sigma_{\overline{p}p\rightarrow\phi\phi} \approx 4\ \mu b$ at $p = 1.4$ GeV/c

  JETSET: PLB 345 (1995) 325

- K^- captured in attractive potential
- measure ϕK^+ missing mass
- problem: detect and identify slow K^+

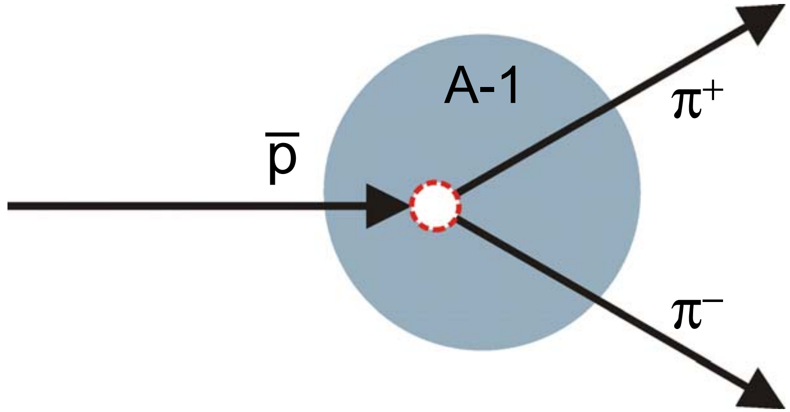


New ideas: Color Transparency (CT)

- initiated by B. Pire, M. Strikman and others
- small size color-neutral objects have reduced cross section
- analogous effect in QED
- conditions to observe CT:
  - large momentum transfer Q^2
    → transverse size $d \sim 1/\sqrt{Q^2} \ll$ hadron size
  - high momentum of produced hadrons
    → $l_{coh} \sim 0.6\ \text{fm} \times p\ [\text{GeV/c}] > d_{NN}$
- CT established at high energies
- CT at intermediate energies in $(e,e'\pi^+)$ at JLAB

B. Clasie *et al.*,
PRL 99 (2007) 242502

CT at PANDA: $\bar{p}\, A \to \pi^+ \pi^- (A\text{-}1)$



- exclusive: need missing mass resolution $\delta M \ll m_\pi$ (~ few 10 MeV)
- $\sigma_{tot}(\bar{p}p \to \pi^+\pi^-)$ ~ few μb
  R ~ few 10/s at L = 10^{31} $cm^{-2}s^{-1}$
- e.g. p = 15 GeV/c, $\theta_{cm} = 90^o$:
  pion transverse and longitudinal momenta:
  p_l = 7.5 GeV/c, p_t = 0.93 GeV/c larger than in JLab experiment
  t = -14.1 GeV^2
  $\theta_\pi^{(lab)} = 7^o$, Lorentz boost $\gamma_\pi = 54$
- many other reactions should and can be studied: $\bar{p}p \rightarrow \rho\pi, \bar{K}K, \phi\phi, \bar{p}p, \bar{\Lambda}\Lambda, \bar{\Sigma}\Sigma$

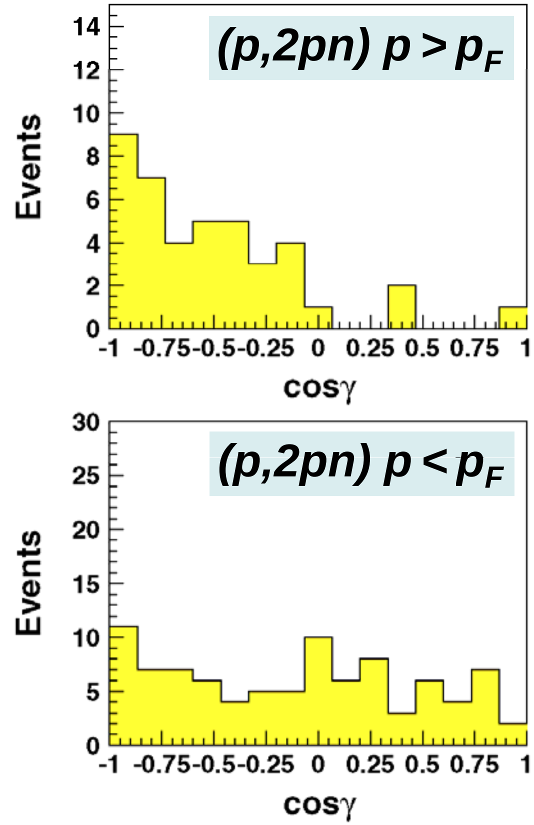
measure transparency ratio:

$$T = \frac{d\sigma_A}{A\, d\sigma_p}$$

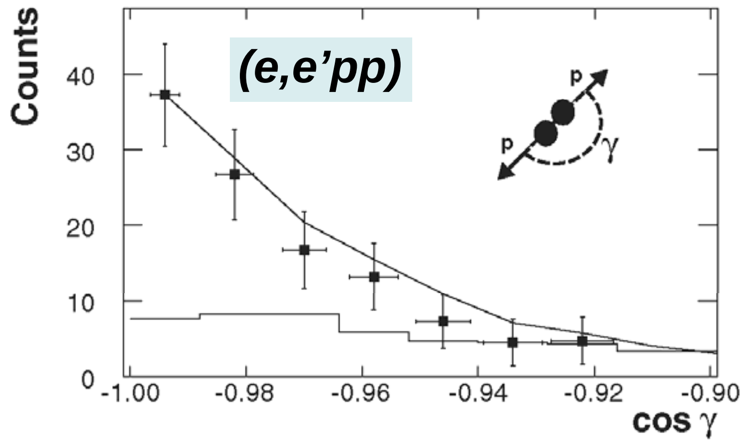
Study of Short Range Correlations

- understanding of high momentum components / high density behavior of nuclear matter
- high momentum nucleons are paired
- recent observation at BNL and JLAB
- most nucleons with $p > p_F$ are paired
- most pairs are pn
- pp pairs are rare but particularly interesting since directly related to high density matter in neutron stars
- PANDA can observe both pp and pn correlations

A. Tang *et al.*, PRL 90 (2003) 042301



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



Outlook: slow D/$\bar{D}$ mesons in nuclei

- $m_D \sim 2m_N$ → D can be stopped in the nucleus if its momentum is transferred to a NN pair

min $p_D \sim 0$ GeV/c

- "3rd generation" experiment at PANDA: combine D meson production with knock-out of correlated NN pair
- very low cross section expected
- excitation energy of the residual D-mesic nuclear system needs to be reconstructed from complicated final state

Outlook: slow D/$\bar{\text{D}}$ mesons in nuclei (2)

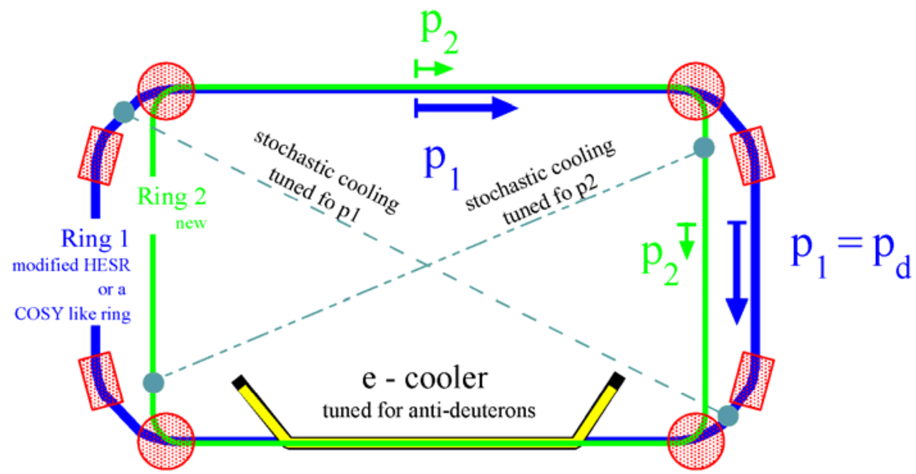
- consider $\bar{d}d$ annihilation: how likely is $6\bar{q}$-6q annihilation into $c\bar{c}$?
- $\bar{d}$ observed in e^+e^- annihilation at CLEO D.M. Asner *et al.*, PRD 75 (2007) 012009 and at Belle S. Künze *et al.*, DPG 2010, HK 36.11
- d form factor measured in e^- scattering up to $Q^2 = 4$ GeV^2

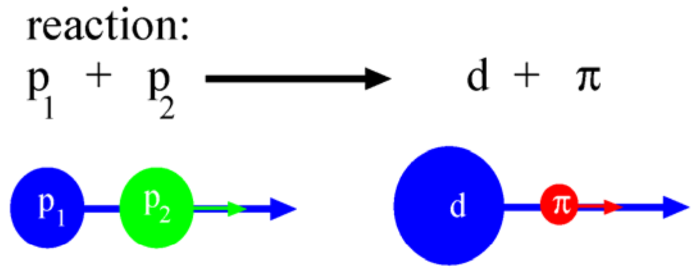
$$(1 + Q^2/m_p^2)\, F_d(Q^2) \approx 4 \cdot 10^{-2}\, F_{1p}^2\,(Q^2/4)$$

R.G. Arnold *et al.*, PRL 35 (1975) 776

- concept for $\bar{d}$ breeding in $\bar{p}\,\bar{p} \rightarrow \bar{d}\,\pi^-$ using double-ring collider with momentum matching exists:

  ~20000 $\bar{d}$/day estimated

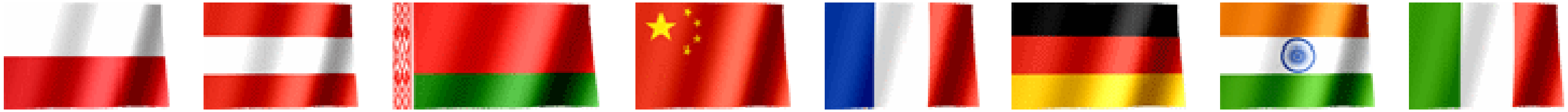


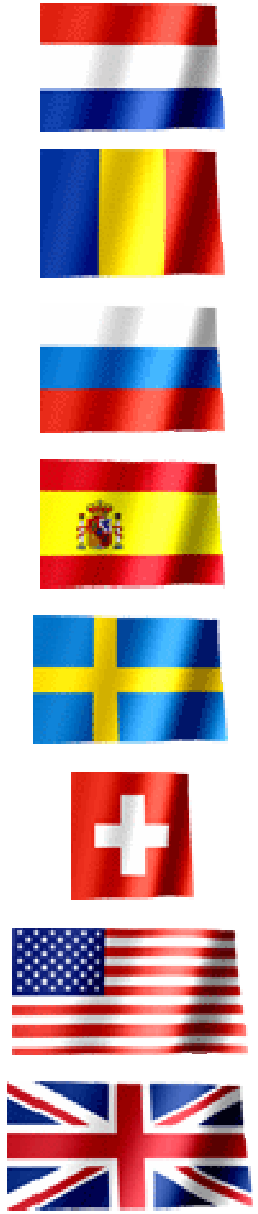


D. Möhl *et al.*, NIM 202 (1982) 427,
K. Kilian *et al.*, FAIR-LoI (2004)

Summary

- With its universal design PANDA allows to address many different physics questions in anitiproton-nucleus collisions.
- As a first step to study the interaction of charmed hadrons with nucleons we are planning the measurement of the A dependence of resonant J/ψ formation.
- Hadrons with light quarks ($\bar{p}$, $\bar{\Lambda}$, ϕ, $\bar{K}$) can be studied at rest or low momentum in the nuclear environment in recoil-free reactions.
- The study of hard exclusive reactions inside nuclei gives access to phenomena like color transparency or short range correlations.
- The observation of D meson mass shifts, D-mesic nuclear states or anti-charmed nuclei requires complicated reaction schemes.





About 420 physicists from 53 institutions in 16 countries

U Basel
IHEP Beijing
U Bochum
IIT Bombay
U Bonn
IFIN-HH Bucharest
U & INFN Brescia
U & INFN Catania
JU Cracow
TU Cracow
IFJ PAN Cracow
GSI Darmstadt
TU Dresden
JINR Dubna
(LIT,LPP,VBLHE)
U Edinburgh
U Erlangen
NWU Evanston

U & INFN Ferrara
U Frankfurt
LNF-INFN Frascati
U & INFN Genova
U Glasgow
U Gießen
KVI Groningen
IKP Jülich I + II
U Katowice
IMP Lanzhou
U Lund
U Mainz
U Minsk
ITEP Moscow
MPEI Moscow
TU München
U Münster
BINP Novosibirsk

IPN Orsay
U & INFN Pavia
IHEP Protvino
PNPI Gatchina
U of Silesia
U Stockholm
KTH Stockholm
U & INFN Torino
Politecnico di Torino
U Piemonte Orientale, Torino
U & INFN Trieste
U Tübingen
TSL Uppsala
U Uppsala
U Valencia
SMI Vienna
SINS Warsaw
TU Warsaw

About 420 physicists from 53 institutions in 16 countries

U Basel
IHEP Beijing
U Bochum
IIT Bombay
U Bonn
IFIN-HH Bucha
U & INFN Bres
U & INFN Cata
JU Cracow
TU Cracow
IFJ PAN Craco
GSI Darmstadt
TU Dresden
JINR Dubna
(LIT,LPP,VBLHE)
U Edinburgh
U Erlangen
NWU Evanston

U & INFN Ferrara
U Frankfurt
LNF-INFN Frascati
U Minsk
ITEP Moscow
MPEI Moscow
TU München
U Münster
BINP Novosibirsk

IPN Orsay
U & INFN Pavia
IHEP Protvino
TSL Uppsala
U Uppsala
U Valencia
SMI Vienna
SINS Warsaw
TU Warsaw

Large collaboration - however:

The antiproton-nucleus physics group is small …

New members are welcome !