Mitglied der Helmholtz-Gemeinschaft

Antiproton Nucleus Collisions

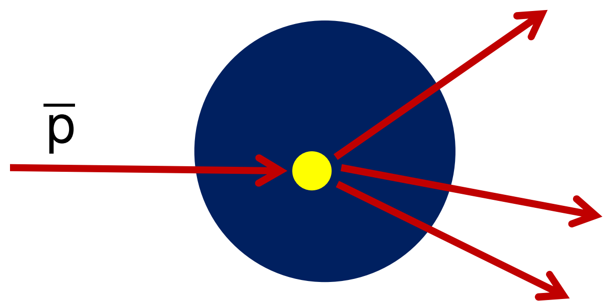
Dec 2, 2015 | Albrecht Gillitzer, IKP Forschungszentrum Jülich

PANDA LV Collaboration Meeting, Vienna, Nov 30 – Dec 4, 2015

Why to Study $\bar{p}$A Collisions at $\overline{\text{P}}$ANDA ?

- Sensitivity to nuclear potential of produced hadrons at low momentum

- Resonant formation of $c\bar{c}$ states with all fermion-antifermion quantum numbers



- Access to a large number of 2-body states in $\bar{p}$N ‚annihilation‘

- $\bar{p}$ momentum range up to 15 GeV/c → access to large momentum transfer reactions

- Large detector acceptance, tracking and PID capability → allows studying large variety of final states

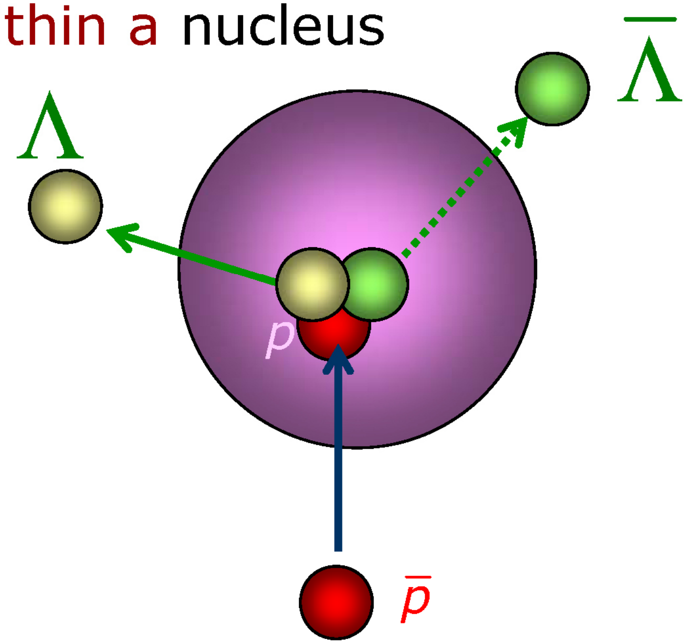
Topics in $\bar{p}$A Collisions

- Nuclear potential of hadrons (antibaryons, $\bar{K}$, …)
- Charmonium nucleon interaction
- Color transparency
- Short range nucleon correlations
- Non-nucleonic components (d, heavier nuclei)

Can we measure the potential for $\bar{Y}$?

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

- antiprotons are optimal for the production of mass without large momenta
- consider $p+\bar{p} \rightarrow Y+\bar{Y}$ close to threshold within a nucleus
- Λ and $\bar{\Lambda}$ that leave the nucleus will have different asymptotic momenta depending on the respective potential



- experimental complications
  - Avoid annihilation
  - Fermi motion of struck proton
  - Non-isotropic production
  - Density distribution $U(\rho)$
  - Exclusiveness
  - Momentum dependence of potential

need to look at average *transverse* momentum close to threshold of *coincident $Y\bar{Y}$* pairs

J. Pochodzalla, PLB 669 (2008)306

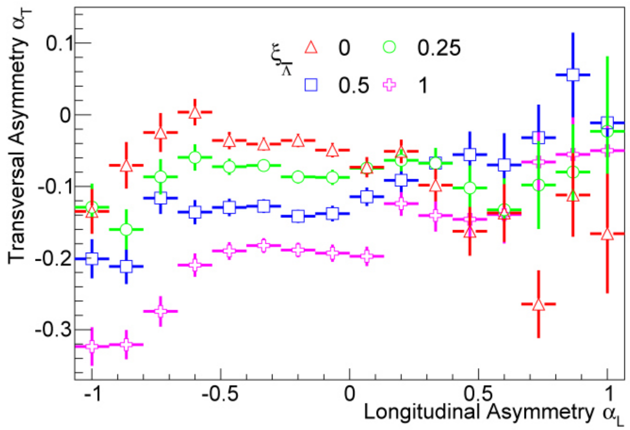
Study of $\bar{\Lambda}$ Potential with GiBUU

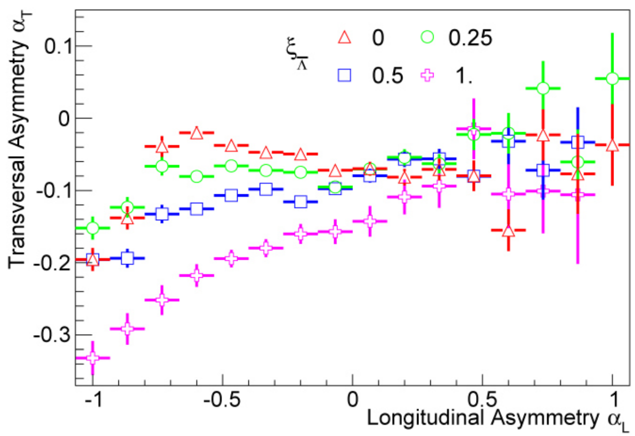
- $\bar{p}\ ^{20}Ne \rightarrow \bar{\Lambda}\Lambda + X$ (E_{kin} = 0.85, 1 GeV)
- ~8000 $\bar{\Lambda}\Lambda$ each
- G parity transformation: $U_{\bar{\Lambda}} \cong -450$ MeV
- $\xi = 0 \ldots 1$ scaling factor

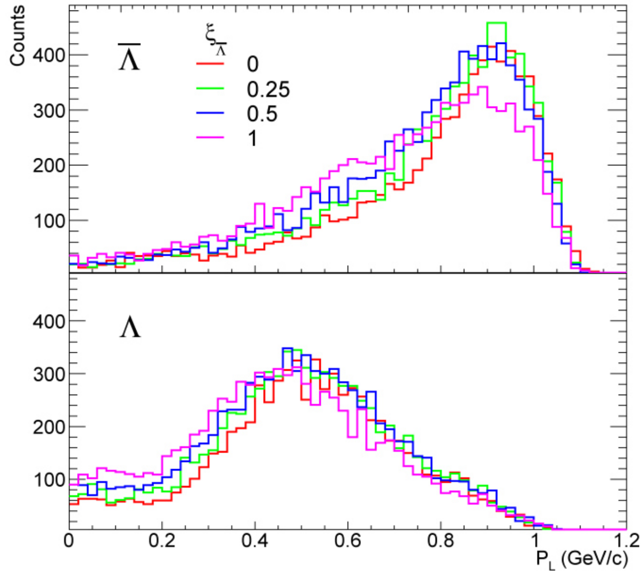
$$\alpha_T = \frac{p_T(\Lambda)-p_T(\bar{\Lambda})}{p_T(\Lambda)+p_T(\bar{\Lambda})}$$

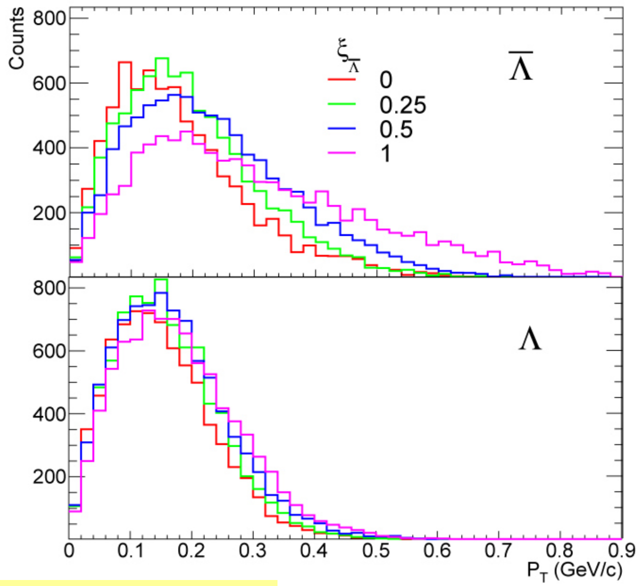
$$\alpha_L = \frac{p_L(\Lambda)-p_L(\bar{\Lambda})}{p_L(\Lambda)+p_L(\bar{\Lambda})}$$

- plot α_T vs. α_L









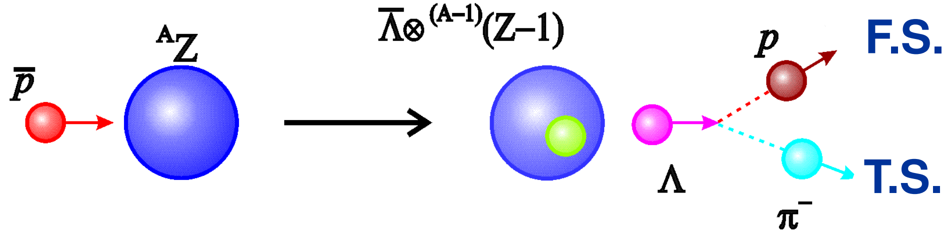
A. Sanchez Lorente *et al.*, PLB 749 (2015) 421

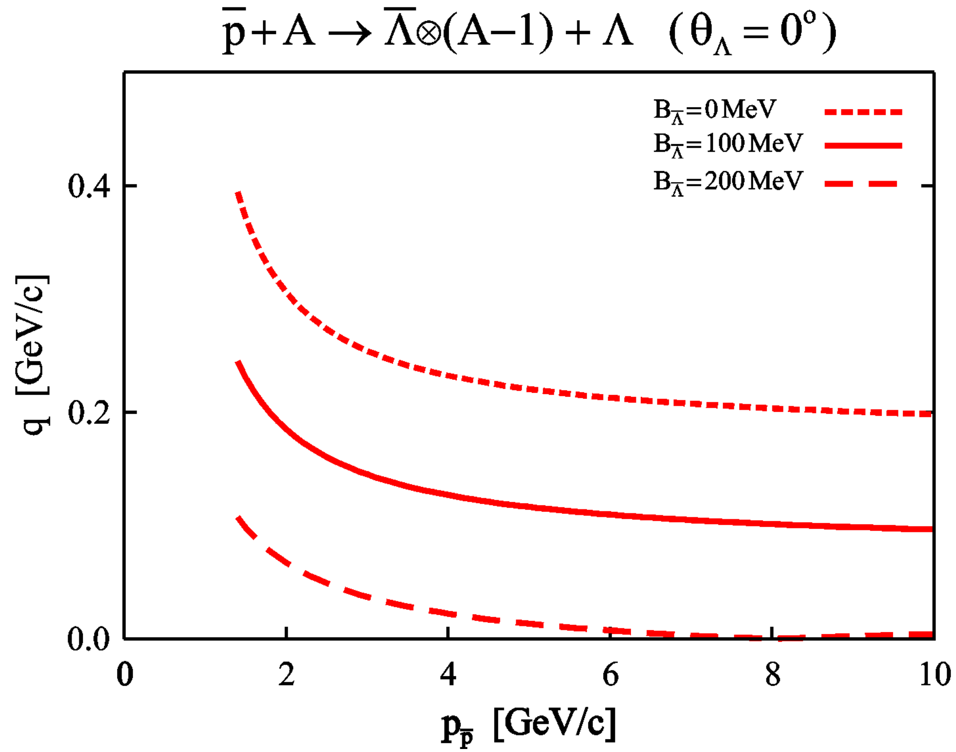
$\bar{\Lambda}$ Nuclear Potential from Recoilfree Reaction

- use $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ at $\theta_{\Lambda} \sim 0^{o}$ with nuclear proton
- detect $p\pi^{-}$ in Forward Spec.
- small momentum transfer
- $\left(\frac{d\sigma}{d\Omega}\right)_{\bar{p}p \rightarrow \bar{\Lambda}\Lambda,\, \theta_{\Lambda} \sim 0^{o}} \cong 2\, \mu b/sr$ at p = 1.77 GeV/c

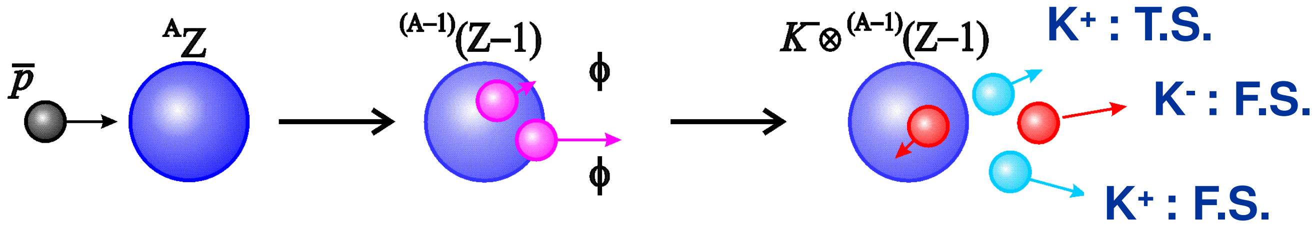
P.D. Barnes *et al*. (LEAR-PS185), PRC 54 (1996) 2831

- residual system: $\bar{\Lambda}N \rightarrow \bar{K} + n\pi$



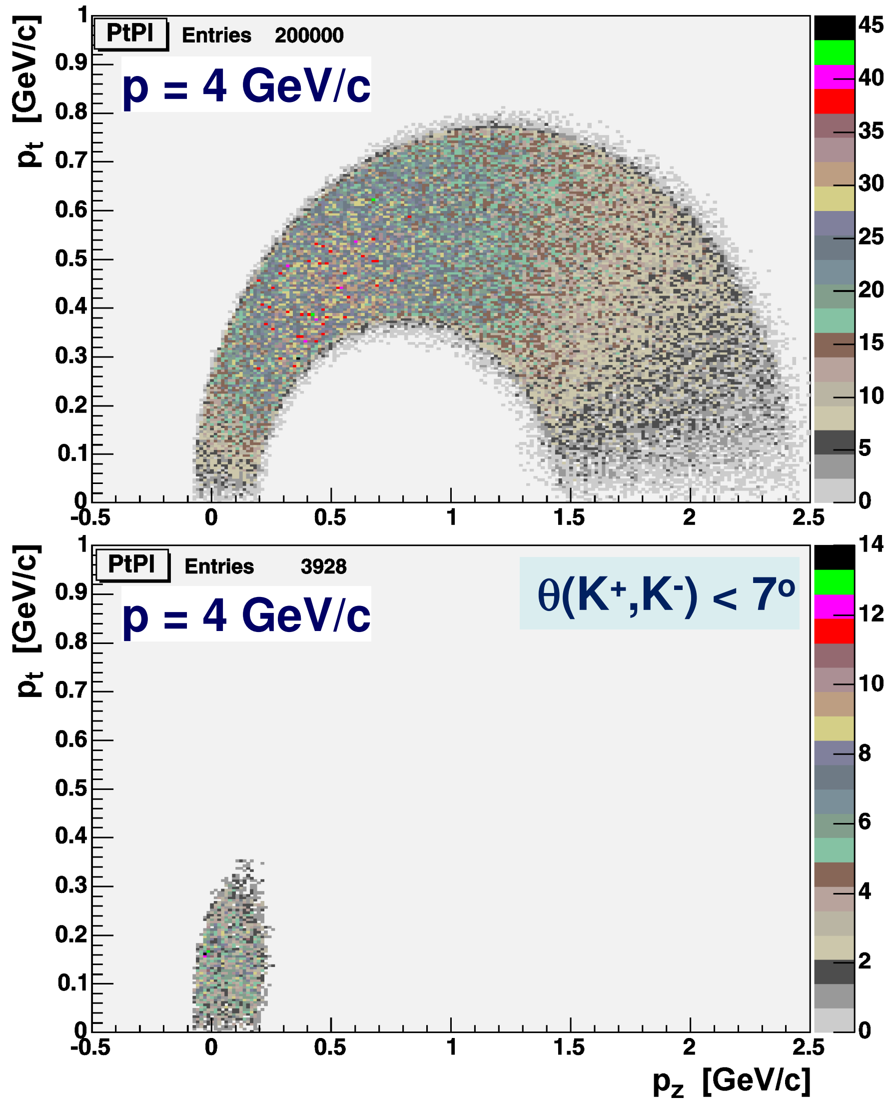


Anti-Kaons

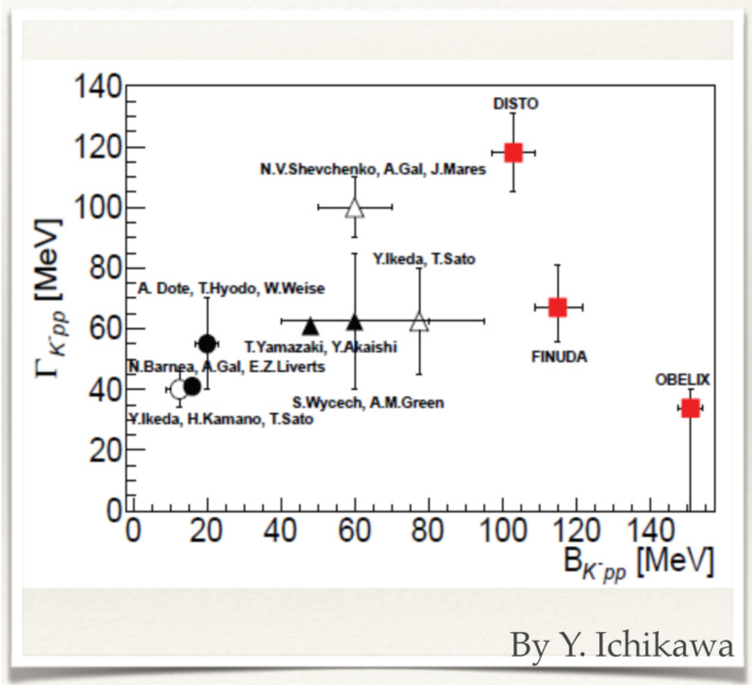


- nuclear potential of $\overline{K}$ still controversially discussed
- use $\bar{p}p \rightarrow \phi\phi$ at $\theta = 0^{o}$ to produce slow K^{-} in nuclei
- $\sigma_{\bar{p}p\rightarrow\phi\phi} \approx 4\ \mu b$ at $p = 1.4$ GeV/c

  JETSET: PLB 345 (1995) 325
- K^{-} captured in attractive potential
- measure ϕK^{+} missing mass
- challenge: detect and identify slow K^{+}



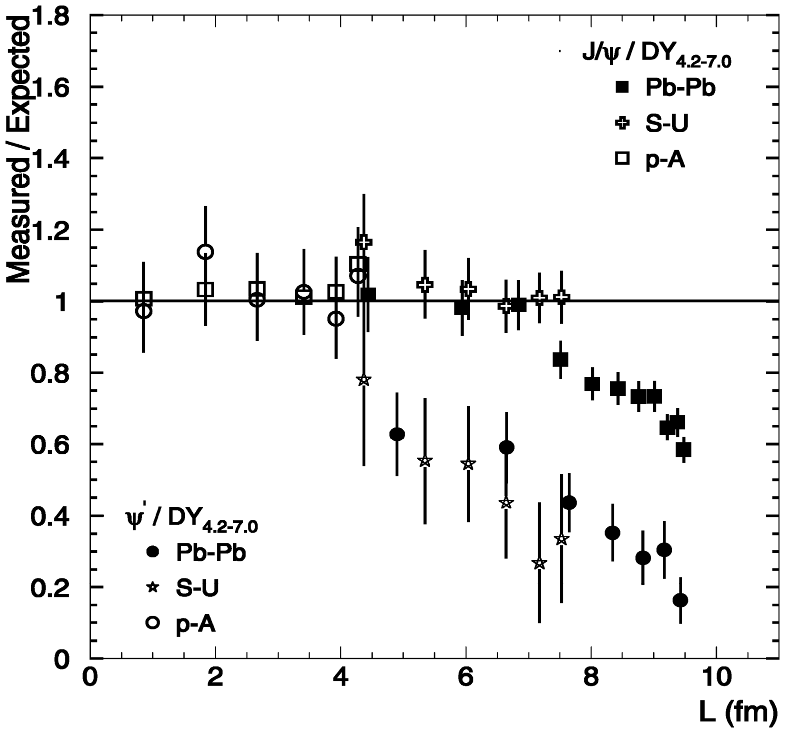
Bound $\bar{K}$NN System?



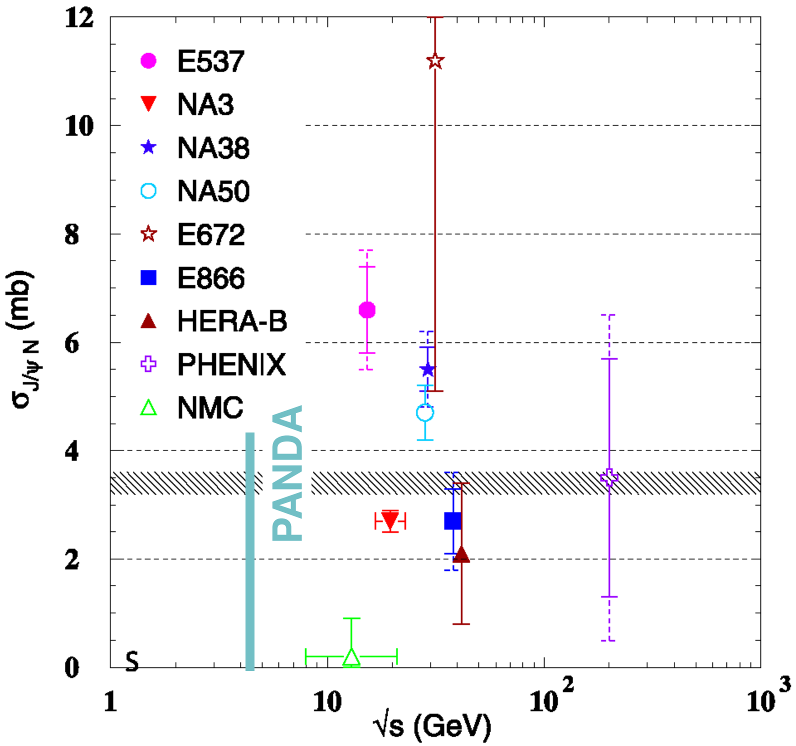
- theoretical contraversy
- experimental claims (FINUDA, DISTO)
- other studies performed or planned: HADES, FOPI, COSY-TOF, AMADEUS, J-PARC E15, E27
- PANDA: use elementary process $\bar{p}p \rightarrow \bar{\Lambda}\Lambda(1405)$ on nuclear proton (any nucleus A)
- for $\bar{K}NN$: use $\bar{p}d \rightarrow \bar{\Lambda}\,[\bar{K}NN]^0$
- detectable decays: $[\bar{K}NN]^0 \rightarrow \Lambda p\pi^-, \Sigma^0 p\pi^-$

J/ψ Nucleon Interaction – an Old Problem

NA50: A + A‘ → J/ψ(ψ‘) + X



B. Alessandro *et al.*, EPJC 39 (2005) 335

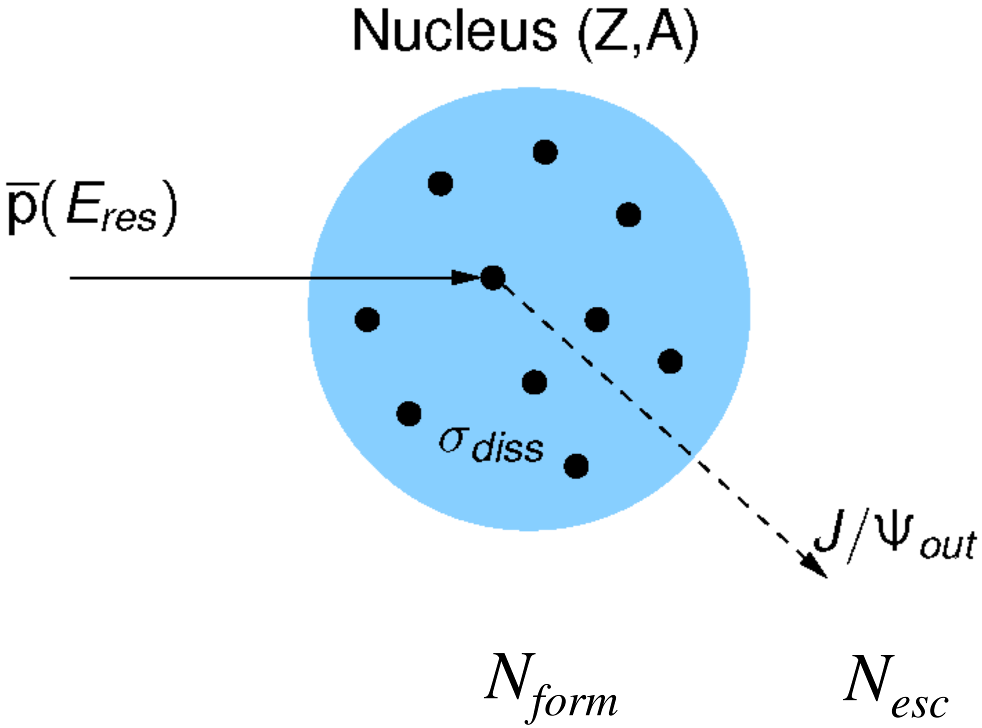


F. Arleo, EPJC 55 (2008) 449

→ evidence for QGP ?

- PANDA: $\sqrt{s}_{J/\psi N}$ = 4.5 GeV

J/ψ N Dissociation Cross Section with p̄A



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

- **S.J. Brodsky, A.H. Müller, PLB 206 (1988) 685**
- G.R. Farrar et al., NPB 345 (1990) 125
- K. Seth, 629 (1998) 358

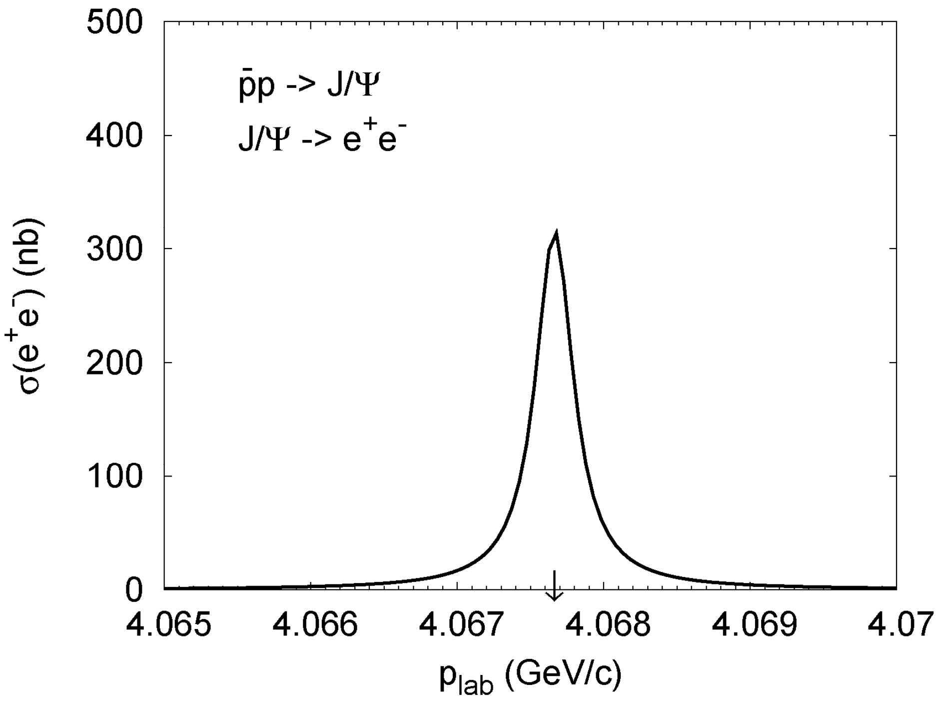
- well-defined conditions: exclusive resonant J/ψ formation on target proton at rest at 4.05 GeV/c
- no ambiguities due to feed-down, co-movers, …
- antiproton mean free path sufficiently known

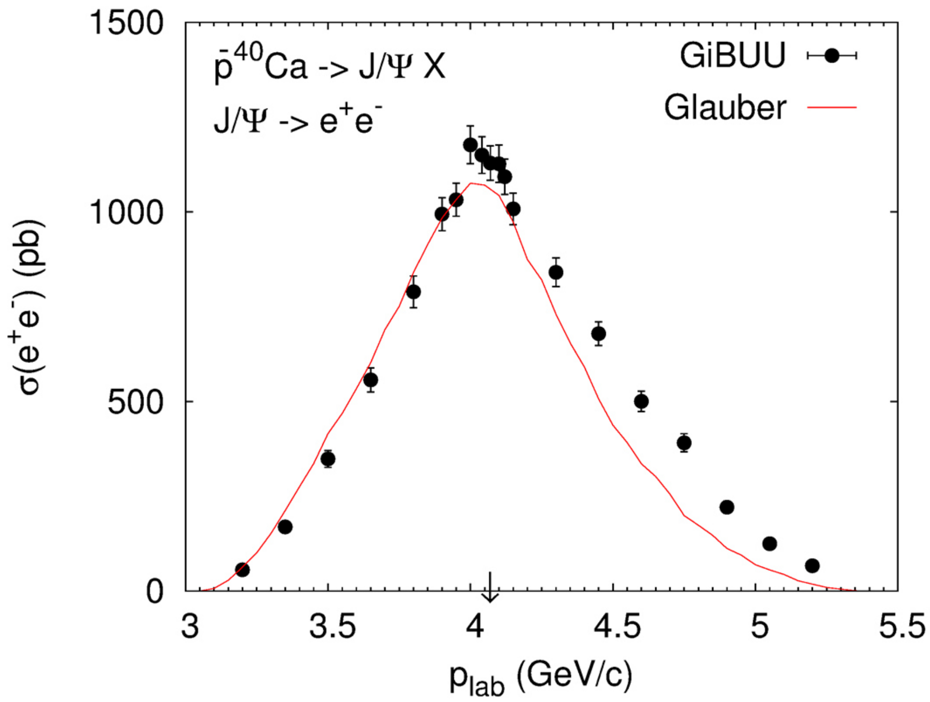
→ **PANDA is unique !**

$\bar{p}$ A → J/ψ X in GiBUU & Glauber Model

- resonant J/ψ formation implemented in GiBUU
- first results in comparison to Glauber model:
  - nuclear absorption effect visible ($\sigma_{J/\psi N}$ from A. Sibirtsev)
  - side-feeding not important

Alexei Larionov *et al.*, PRC 87 (2013) 054608





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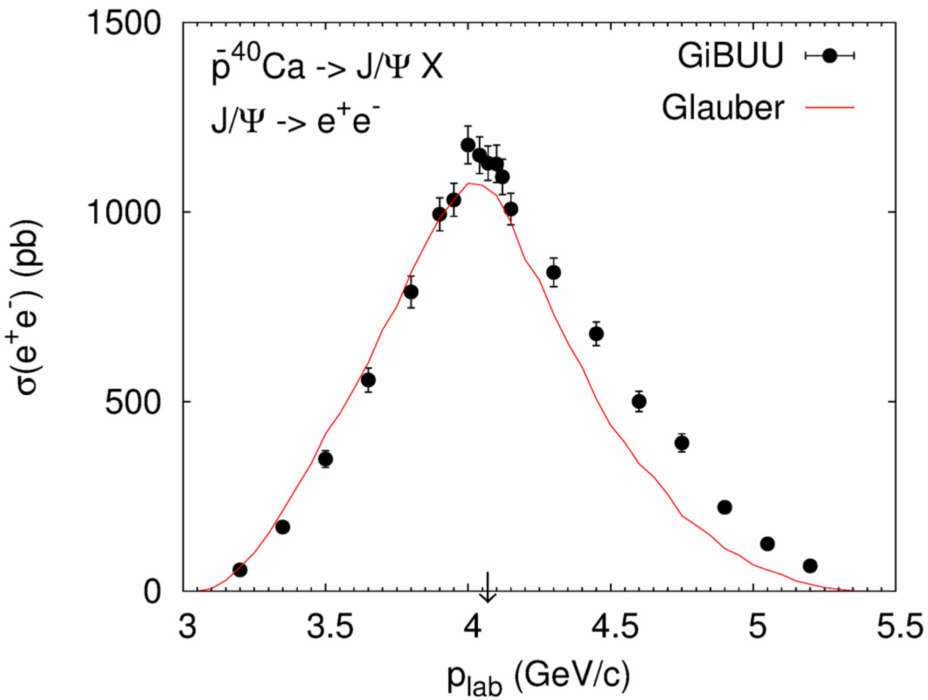
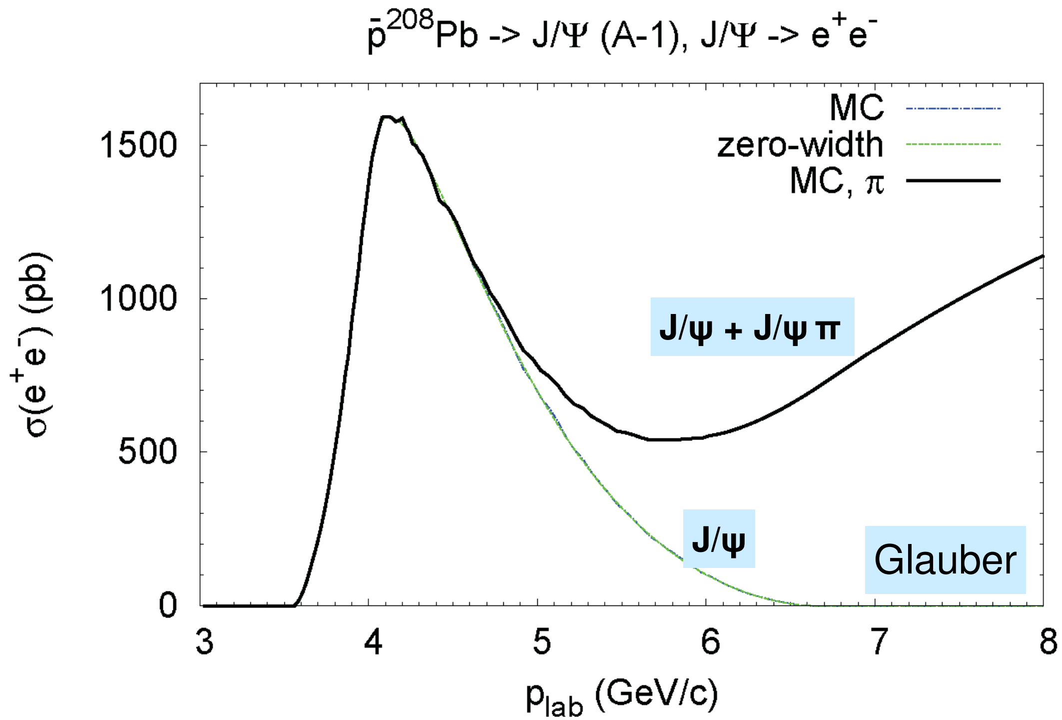


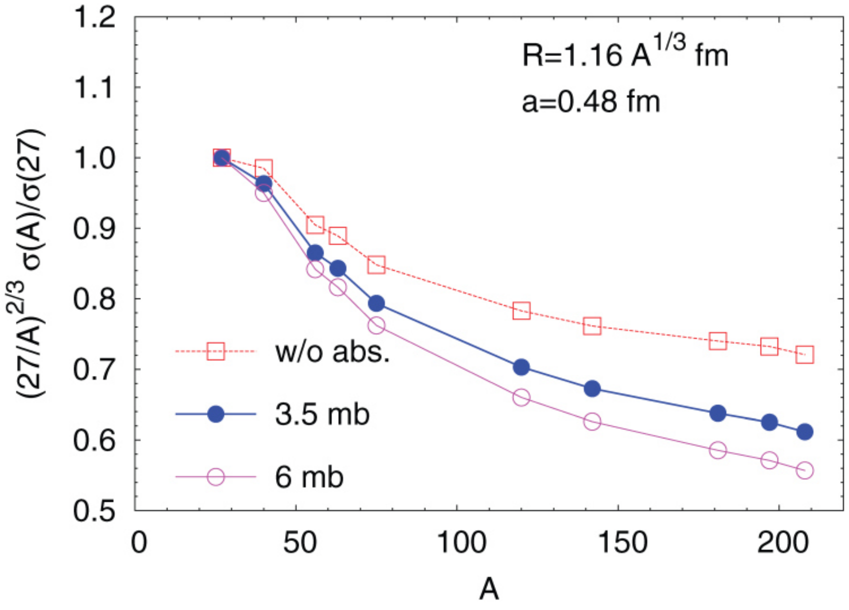


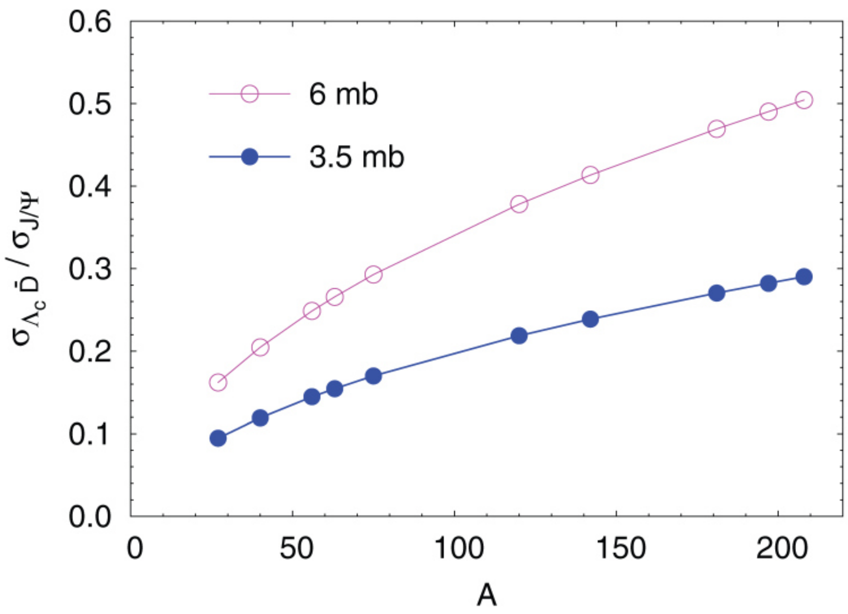
A. Larionov *et al.*, PRC 87 (2013) 054608

How to Deduce σ(J/ψN)

- Measure A dependence of J/ψ yield
- Measure D^+, D^0 yield in addition
- Exclusive measurement with d target: use Pontecorvo reaction:
  $\bar{p}d \rightarrow \bar{\Lambda}_c^+ D^0$ at $\sqrt{s} = M_{J/\psi}$
  $(\sigma \sim 20\, pb)$

A. Larionov, priv. comm. (2014)

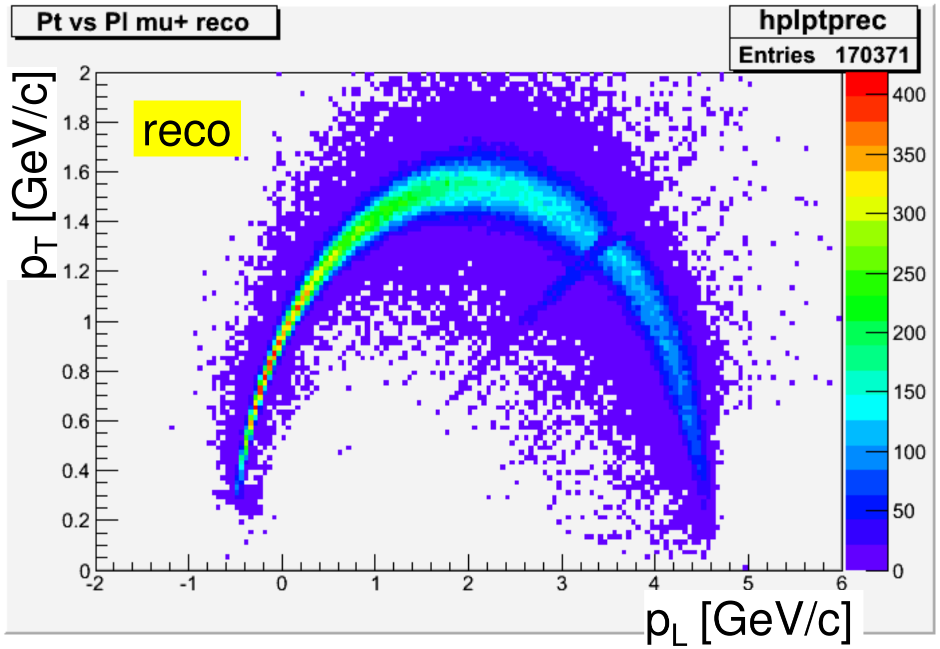




A. Larionov *et al.*, PRC 87 (2013) 054608

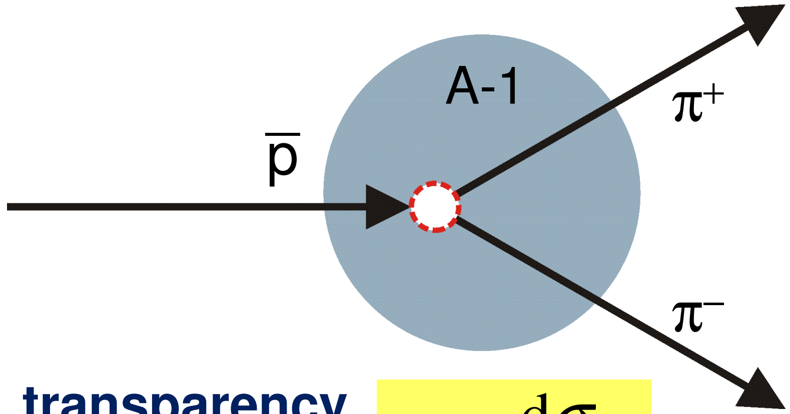
Nuclear J/ψ Absorption in PANDA: Status

- Signal and background studies with old framework for Physics Performance Report (Paul Bühler)
- GiBUU Event Generator for J/ψ (A. Larionov), interface to PandaRoot
- GiBUU 4.05 GeV/c $\overline{p}$ + ^{40}Ca: ~2×10^5 J/ψ, ~2×10^4 $\overline{D}\Lambda_c^+$
- PandaRoot simulation and analysis of J/ψ → e^+e^-, $\mu^+\mu^-$



Color Transparency at PANDA

- small-size color-neutral objects have reduced cross section → should be seen at large momentum transfer

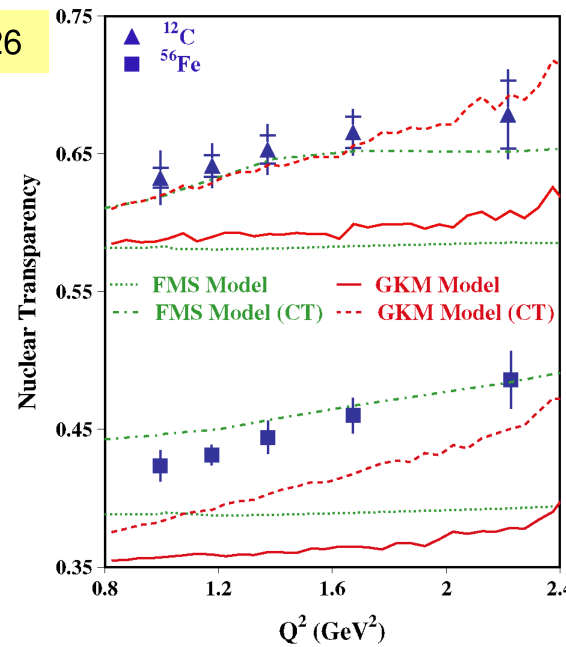


- CT established at high energies, evidence at intermediate energies:
  JLAB: $(e,e'\pi^+)$ — B. Clasie *et al.*, PRL 99 (2007) 242502
  and $\gamma^* A \rightarrow \rho^0 X$ — L. El Fassi *et al.*, [CLAS] PLB 712 (2012) 326

transparency ratio:

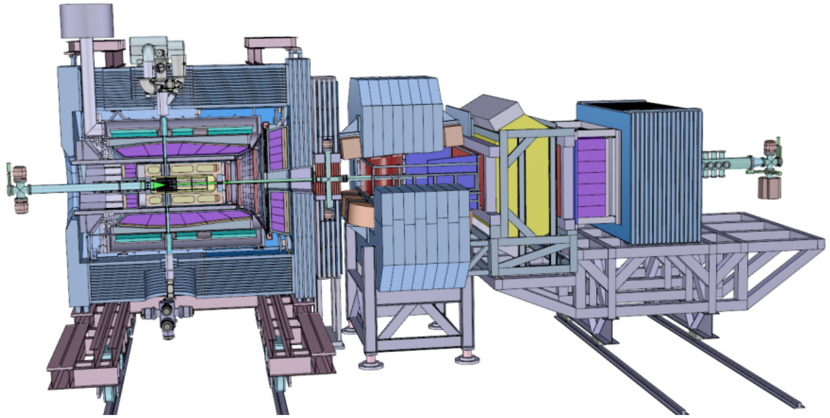
$$T = \frac{d\sigma_A}{A\,d\sigma_p}$$

- proposal: study CT with $\bar{p}$ at PANDA in two-body reactions, e.g. in $\pi^+\pi^-$ annihilation (B. Pire, M. Strikman, …)



- CT conditions should be achieved at momenta above 6 GeV/c

Color Transparency at PANDA II

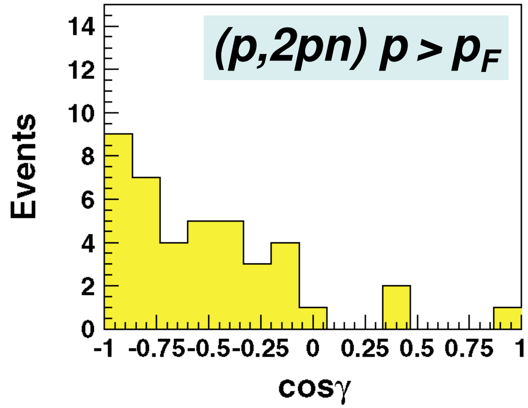


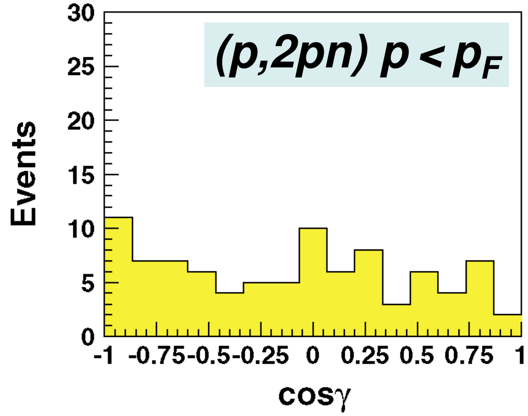
- comparably large rates in $\bar{p}$ induced reactions
- access to various 2-body final states in $\bar{p}p$ and $\bar{p}n$: $\pi^+\pi^-$, $\pi^0\pi^0$, $\pi^0\pi^-$, $\rho^+\rho^-$, $\rho^0\rho^0$, $\rho^0\rho^-$, $\eta\eta$, $\eta\eta'$, $\eta'\eta'$, $\phi\phi$, K^+K^-, K_sK^-, $p\bar{p}$, $\Delta^{++}\bar{\Delta}^{--}$, $\Delta^+\bar{\Delta}^-$, $\Delta^0\bar{\Delta}^0$, $\Delta^+\bar{\Delta}^{--}$, $\Delta^0\bar{\Delta}^-$
- sufficient acceptance for complex final states
- p_{max} = 15 GeV/c → $|t_{max}| \sim 14$ GeV^2
- momentum resolution $\delta p/p \sim 1\%$ & veto condition on further particles should suppress high excitation energies of residual nuclei (to be proven quantitatively …)

Short Range Correlations in Nuclei

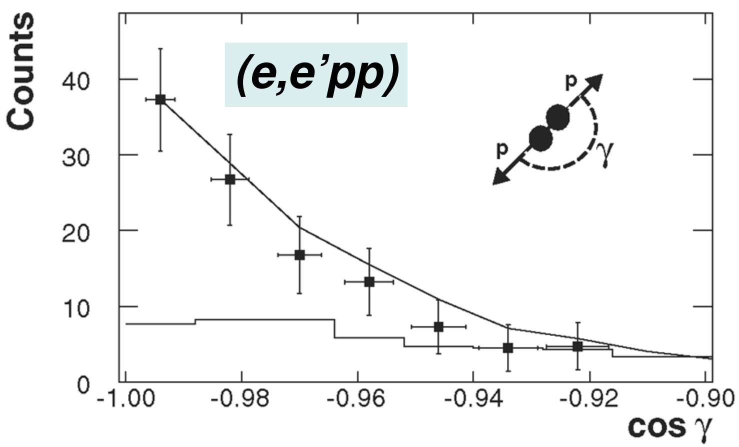
- understanding of high momentum components / high density behavior of nuclear matter
- high momentum nucleons are paired
- recent observation at BNL and JLAB
- most nucleons with $p > p_F$ are paired
- most pairs are pn
- pp pairs are rare but particularly interesting since directly related to high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

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

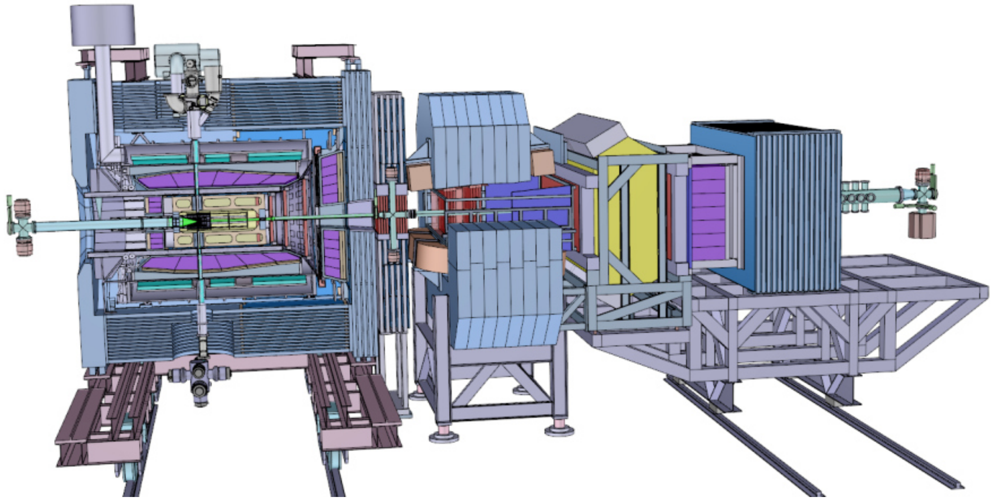




R. Shneor *et al.*, PRL 99 (2007) 072501



SRC at PANDA



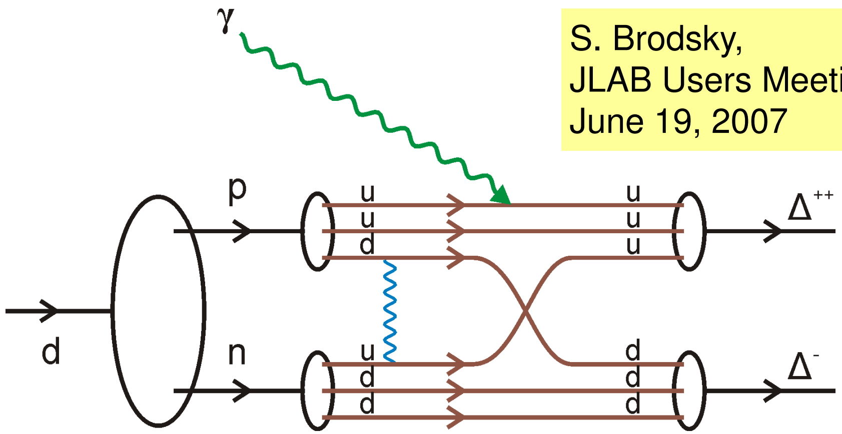
- large cross sections
- large acceptance
- complementarity to *p* and e^- induced reactions
- SRC can be probed both in nucleon knock-out *and* in annihilation-like 2-body reactions
- *pn* pairs can be identified without neutron detection, e.g. in a $(\bar{p},\pi^-\pi^0 p)$ reaction
- method can be extended to non-nucleonic components

Non-Nucleonic Component in the Deuteron

- ‚Hidden colors‘ of the deuteron
- ΔΔ component should be enhanced at short distances
- Experimental limit $G_{\Delta\Delta} < 0.4\%$

D. Allasia *et al.*, PLB 174 (1986) 450

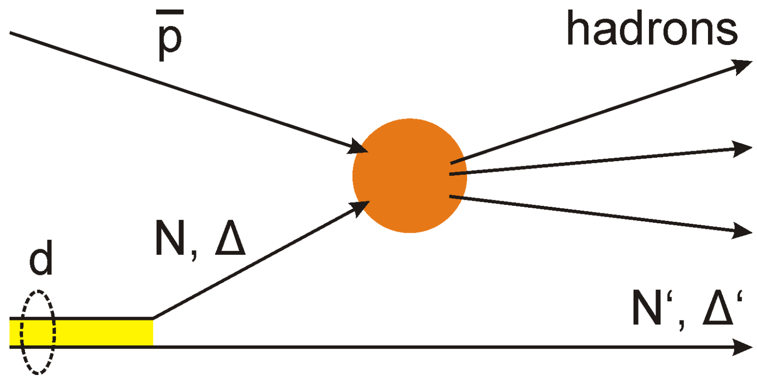
S. Brodsky, JLAB Users Meeting June 19, 2007



JLAB LOI 11-103

C. Granados, M. Sargsian, PRC 83 (2011) 054606

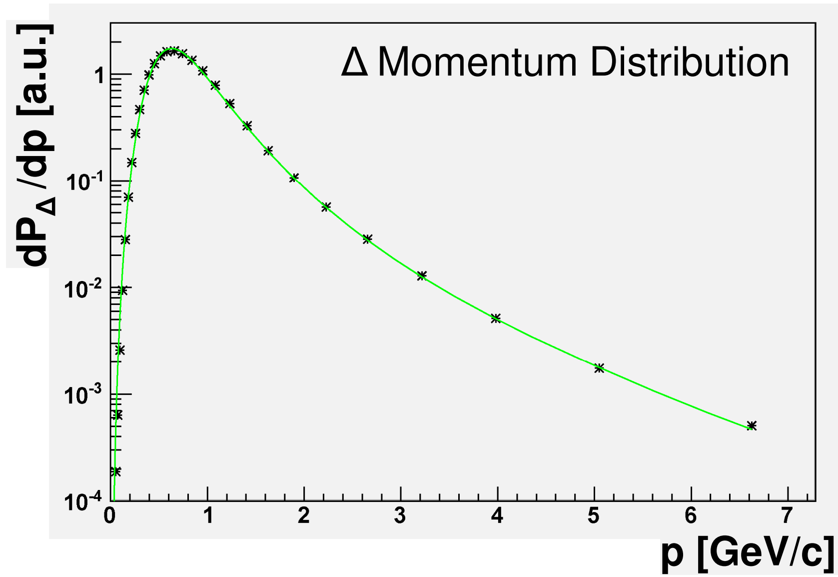
- Alternative to photo-disintegration: high momentum $\bar{p}$d collisions
- Kinematical separation of the $\bar{p}\Delta$ and the recoiling Δ
- Reaction: $\bar{p}d_{\Delta^{++}\Delta^{-}} \rightarrow (p\pi^+)(\pi^-\pi^-)$

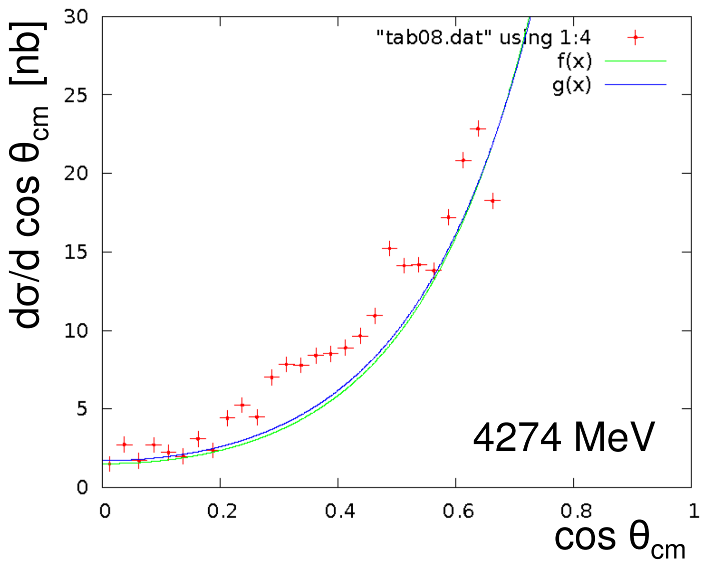


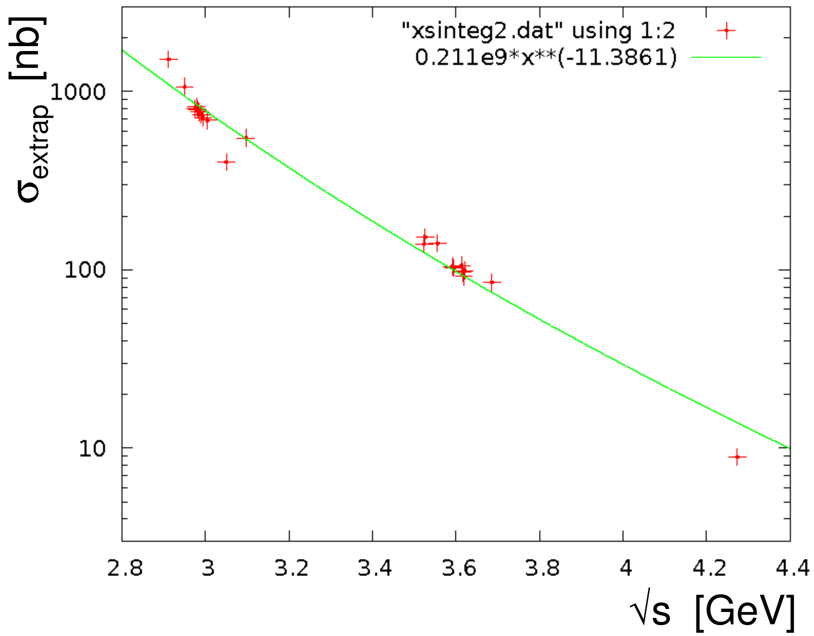
ΔΔ in the Deuteron: A Simple Model

- d Δ wave function by J. Haidenbauer
- $\sigma_{\text{tot}}(\sqrt{s})$ and $\mathrm{d}\sigma/\mathrm{d}t$ parametrized according to Fermilab E 760 data on $\bar{p}p \to \pi^0\pi^0$ ($\sqrt{s}$~2.9 … 4.3 GeV)
- $\sigma_{\text{tot}} \propto s^{-5.7}$
- $\frac{\mathrm{d}\sigma}{\mathrm{d}z}(z) = A \cdot \left(e^{\beta z} + e^{-\beta z}\right),$

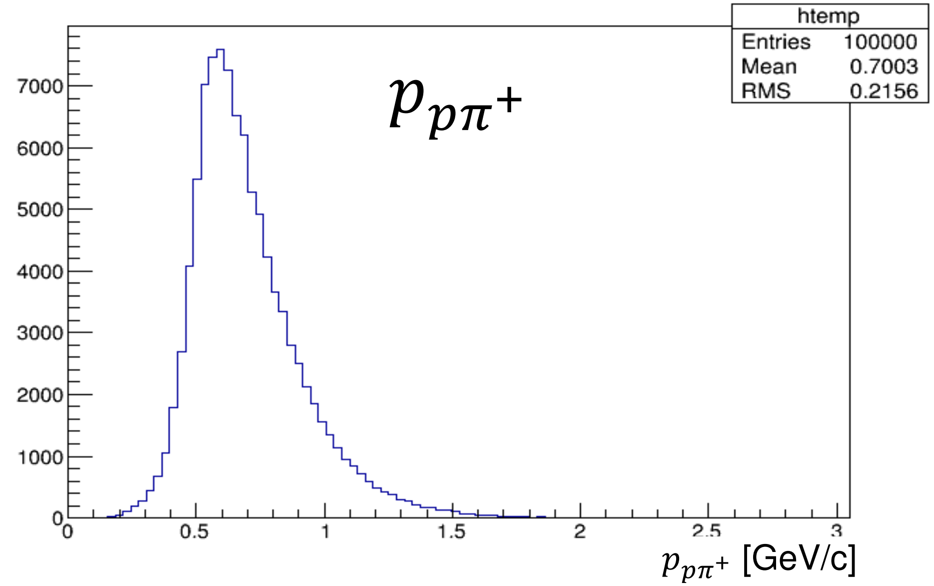
  $z = \cos\theta_{\text{cm}}$

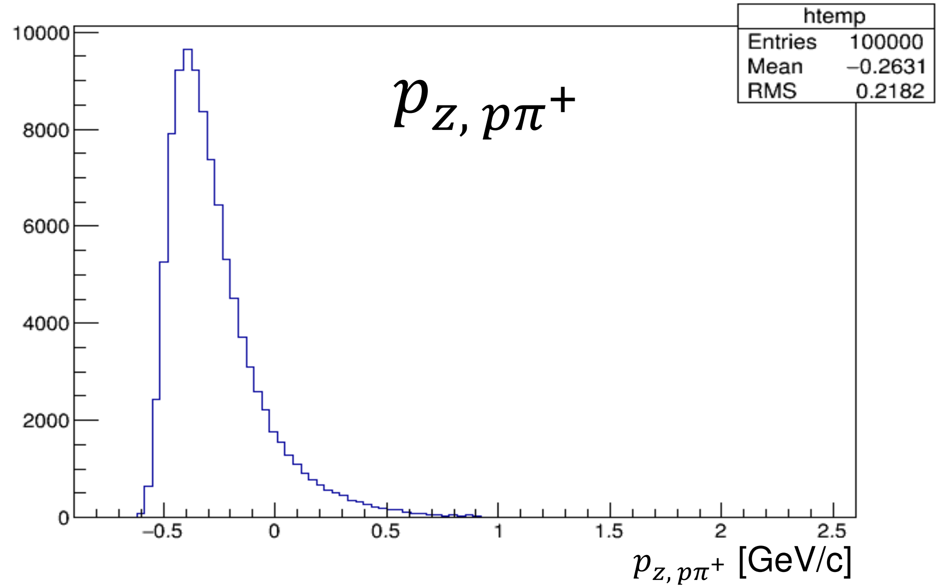


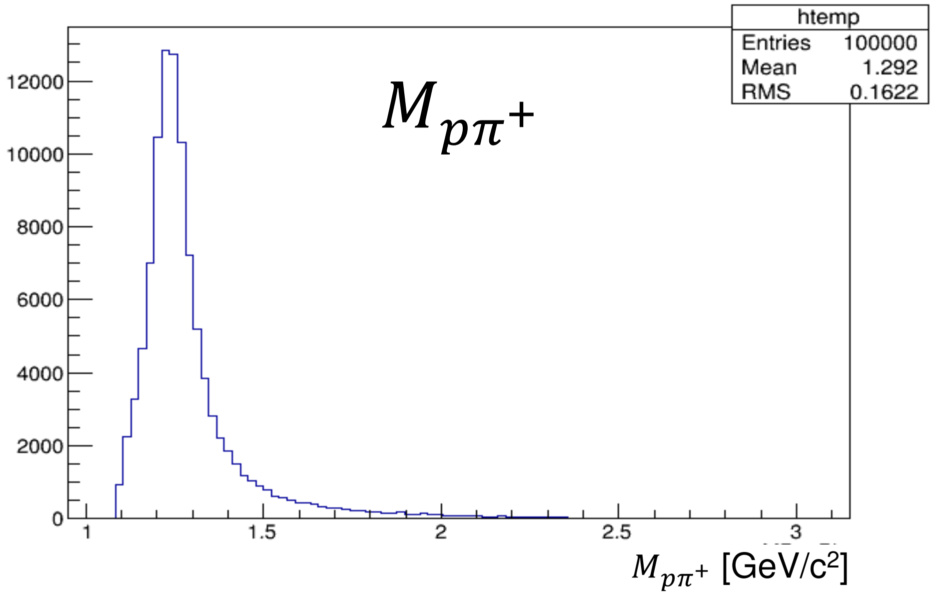




EvtGen: Generated Events







- $\bar{p}$ momentum = 8.0 GeV/c
- negative mean P_z of Δ^{++} due to energy dependence of cross section

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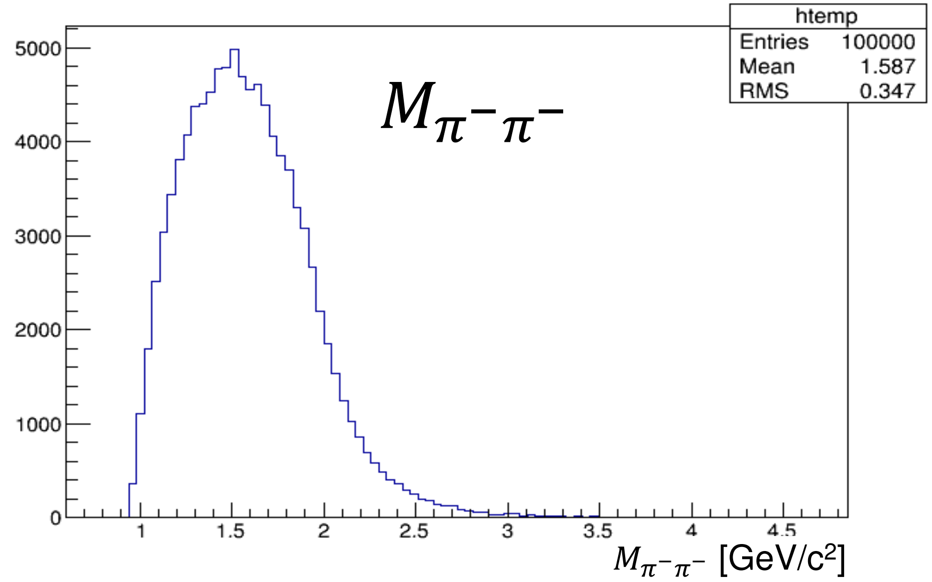

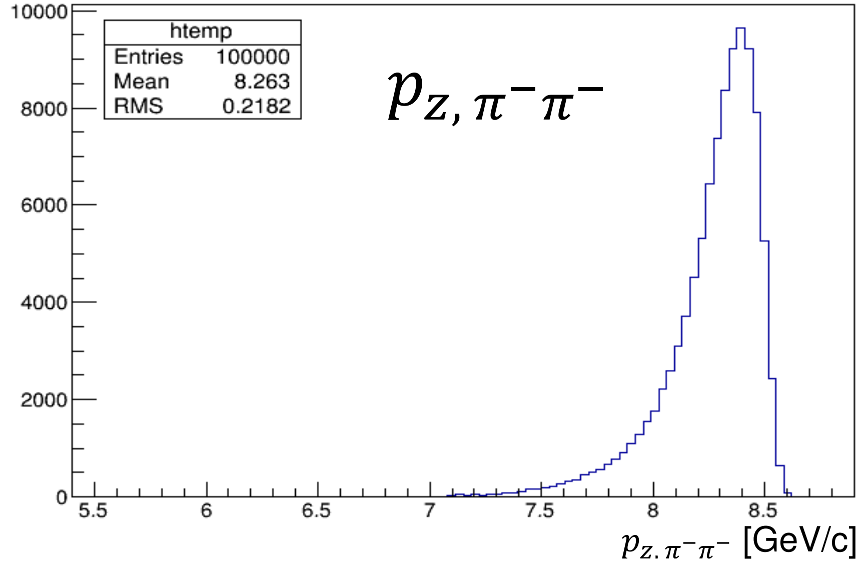

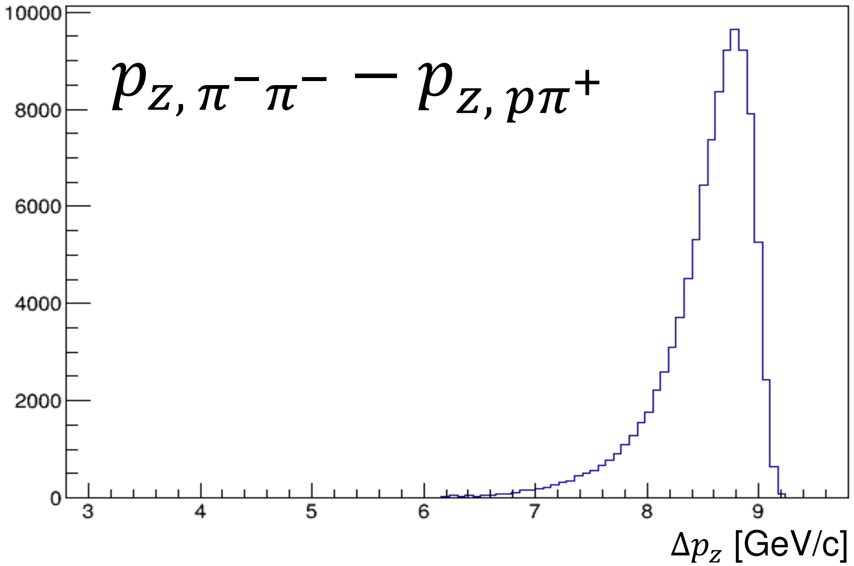

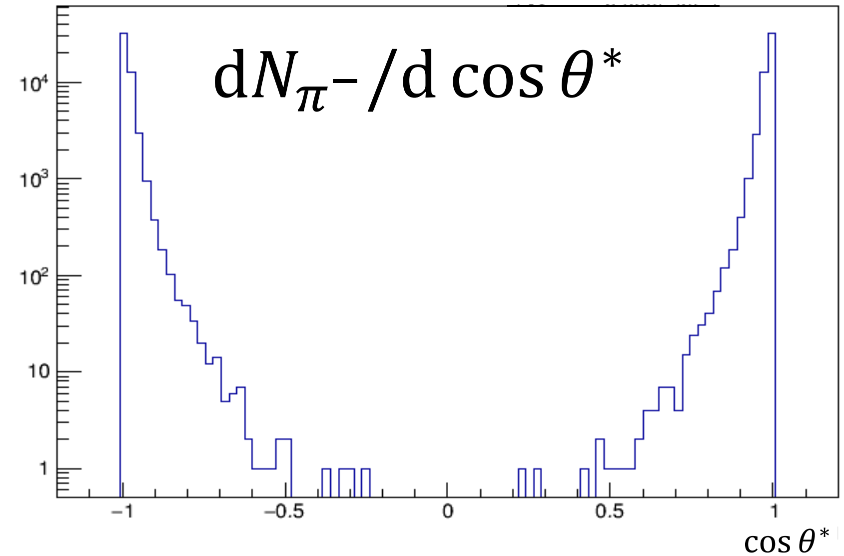

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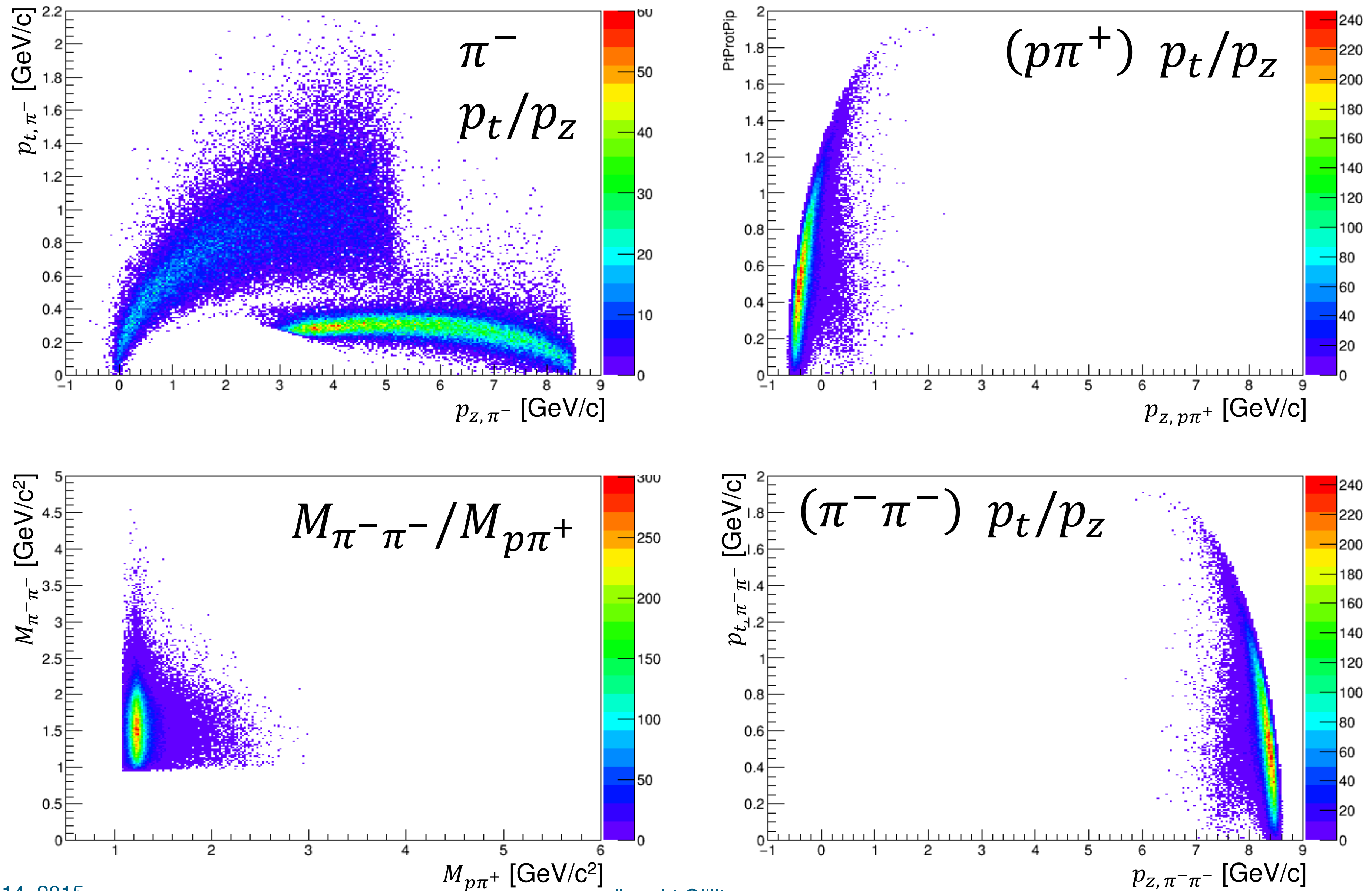

Which Signal and Background Rates to Expect?

- signal rate estimate: $R_{\mathrm{sig}} \cong 1/s$ (produced) with:
  - $\sigma_{\bar{p}\Delta^- \to \pi^- \pi^-}(\sqrt{s} = 2\ \mathrm{GeV}) \cong 100\mu\mathrm{b} \cong 0.001 \cdot \sigma_{\mathrm{tot}}$
  - $\sigma_{\bar{p}\Delta^- \to \pi^- \pi^-}(\sqrt{s} = 1.5\ \mathrm{GeV}) \cong 2.7\mathrm{mb} \cong 0.027 \cdot \sigma_{\mathrm{tot}}$
  - $f(\Delta^{++}\Delta^-) = 10^{-3}$, $R_{\mathrm{tot}} = 10^6/s \leftrightarrow L = 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- background rate estimate: $R_{bg} \cong 500/s$ with:
  - $\sigma_{\bar{p}n \to \pi^+ \pi^- \pi^-}(\sqrt{s} = 4\ \mathrm{GeV}) \cong 50\mu\mathrm{b}$
- so far only quasi-free background studied:
- 0 out of 250000 background events survive with appropriate cuts

Recent & Present Simulation & Analysis Studies

- *J*/ψ absorption in nuclei: A.G., suspended
  generator, background studies
- $\bar{\Lambda}$ potential: Alicia Sanchez, ongoing
- ΔΔ component in deuteron: A.G., ongoing
  analysis note in preparation
- generators: Alexei Larionov (various)
  Vladimir Uzhinsky (FTF)

Comment to the SG Report

"Although many ideas have been developed, the PBA group is the weakest among all physics groups in PANDA concerning manpower and the expertise for extraction of observables. Both have to be considerably strengthened to be successful by any means.

It is unclear which detectors are needed, since we lack reasonable MC studies, but good results may already be achieved with only tracking capabilities.

Therefore it is of utmost importance to perform MC studies and to develop sophisticated analysis tools to validate the feasibility and sensitivity of the unique measurements."

⇒ If the Collaboration thinks that this physics is interesting and competitive then it should significantly increase the level of participation in this field!

Summary

- $\bar{p}A$ collisions at PANDA offer worldwide unique opportunities
- access to
  - properties of hadrons inside the nuclear environment
  - the properties of the nuclear medium itself
  - the time scale of hard reactions
- *present situation very unsatisfactory and disappointing*
- ***significant increase of participation in simulation & analysis required!***