Backward-Angle (u-channel) Pysics Workshop

September 22, 2020

Studying TDAs with $\bar{p}p \rightarrow e^+e^-\pi^0$ at the PANDA Experiment

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Stefan Diehl

for the PANDA collaboration

Justus Liebig University Giessen

University of Connecticut

Outline

- The PANDA Experiment at FAIR
- Study of TDAs with the reaction $\bar{p}p \longrightarrow e^+e^-\pi^0$

Experimental access to Transition Distribution Amplitudes with the $\bar{\text{P}}$ANDA experiment at FAIR

The $\bar{\text{P}}$ANDA Collaboration

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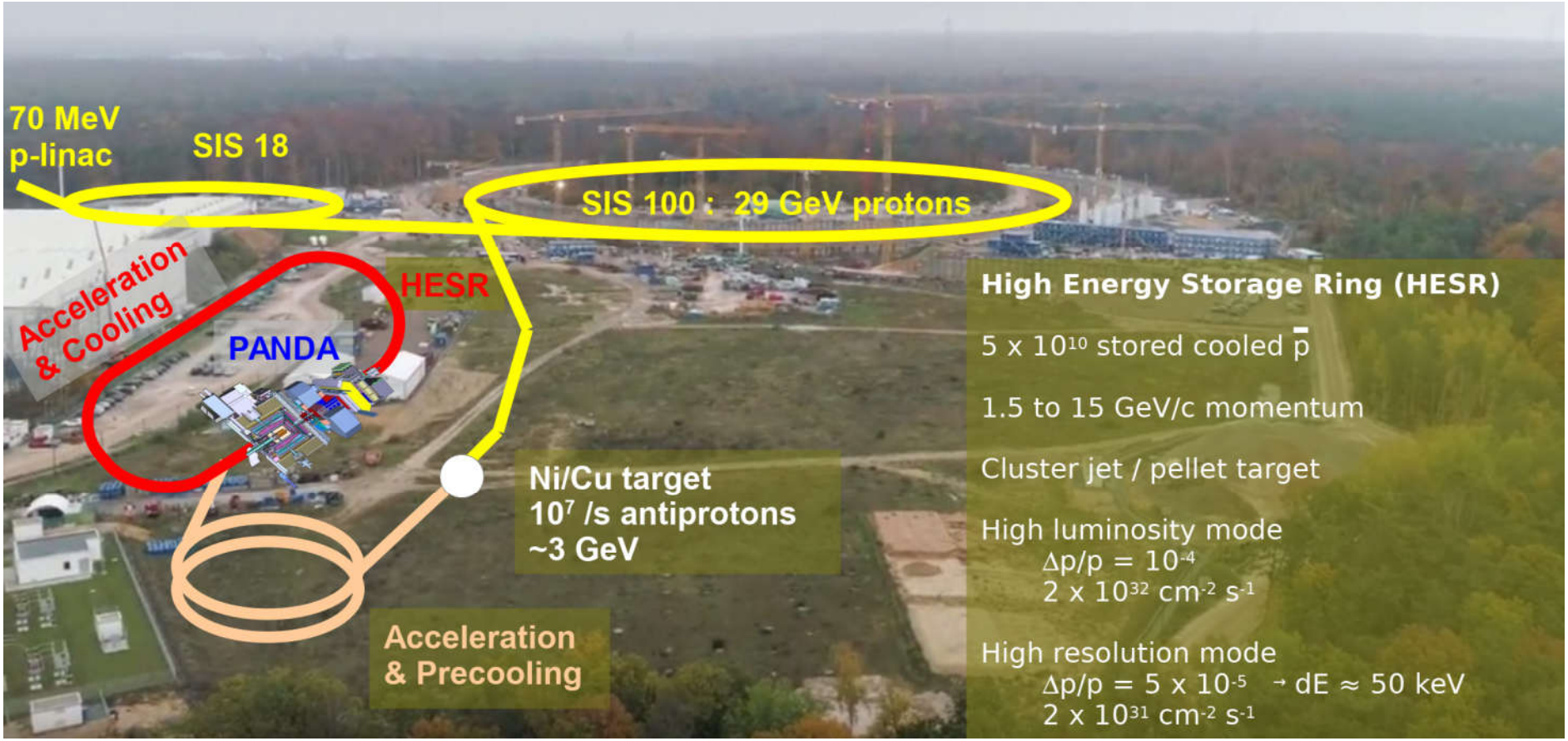
- Study of TDAs with the reaction $\bar{p}p \rightarrow J/\psi\pi^0$

Feasibility study for the measurement of πN TDAs at $\bar{\text{P}}$ANDA in $\bar{p}p \rightarrow J/\psi\pi^0$

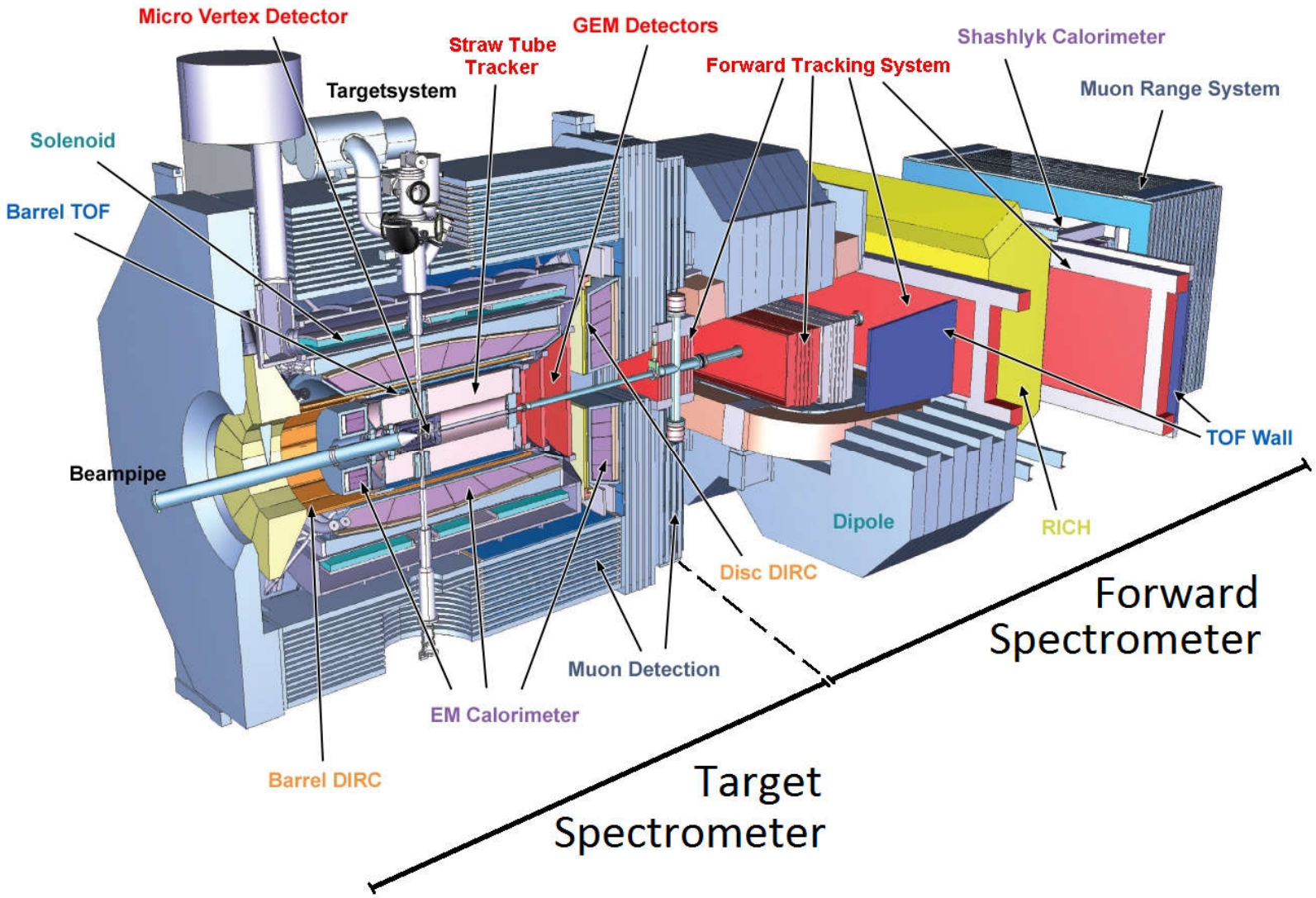
The $\bar{\text{P}}$ANDA Collaboration

Phys. Rev. D 95, 032003 (2017)

The PANDA Experiment at FAIR



The PANDA Experiment at FAIR

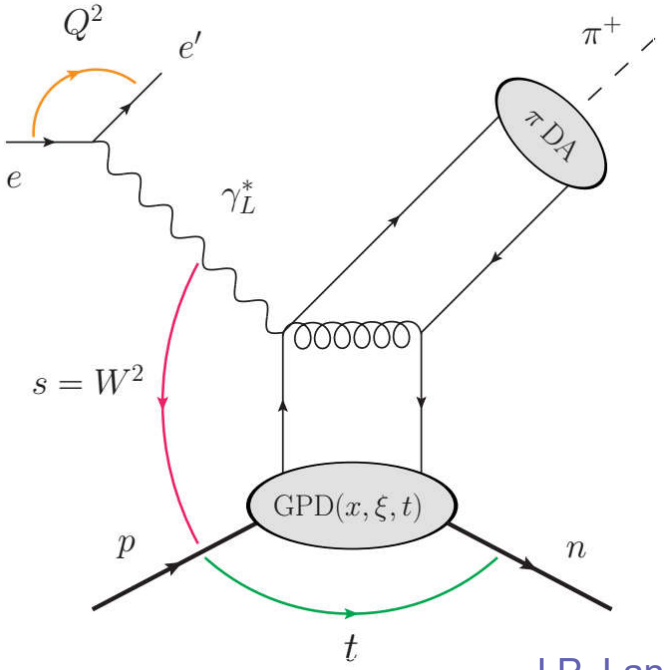


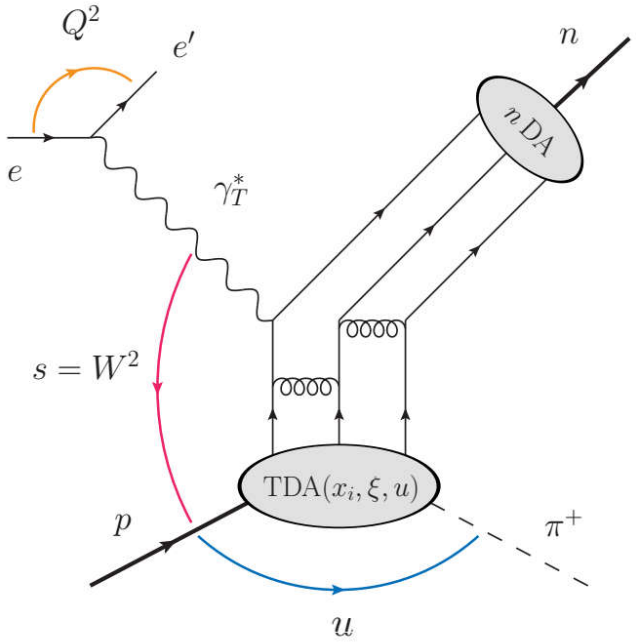
TDAs: From electron scattering to proton-antiproton annihilation

J. Collins, L. Frankfurt, M. Strikman '97 — colinear factorization theorem — L. Frankfurt, M. V. Polyakov, M. Strikman et al.'02

GPD based description
large Q^2 and s, x_B fixed
small t channel contribution
➔ **π in forward region**

TDA based description
large Q^2 and s, x_B fixed
small u channel contribution
➔ **π in backward region**





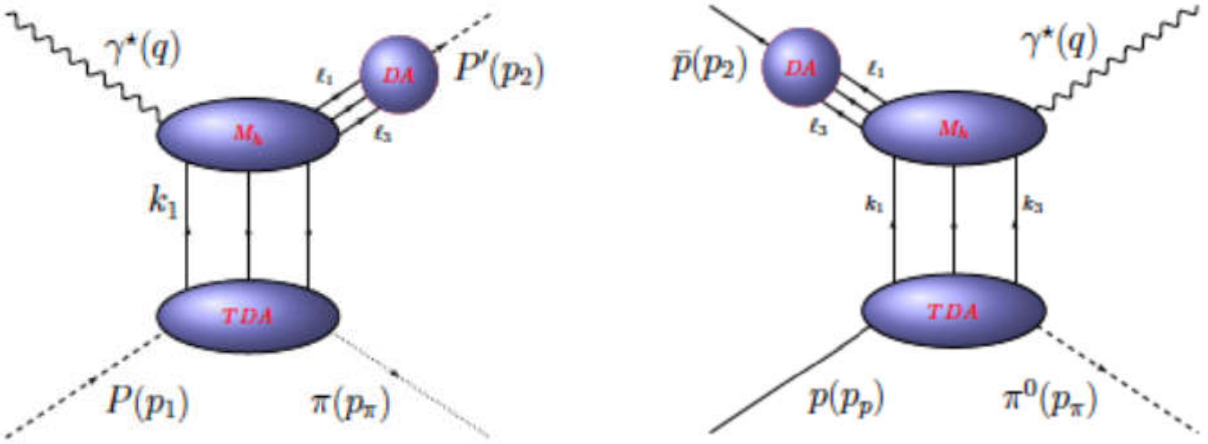
J.P. Lansberg, B. Pire, K. Semenov and L. Szymanowski (2012)

TDAs: From electron scattering to proton-antiproton annihilation

TDAs also occur in factorized description of:

$$\bar{N} + N \to \gamma^*(q) + \pi \to \ell^+ + \ell^- + \pi$$

$$\bar{N} + N \to J/\psi + \pi \to \ell^+ + \ell^- + \pi$$



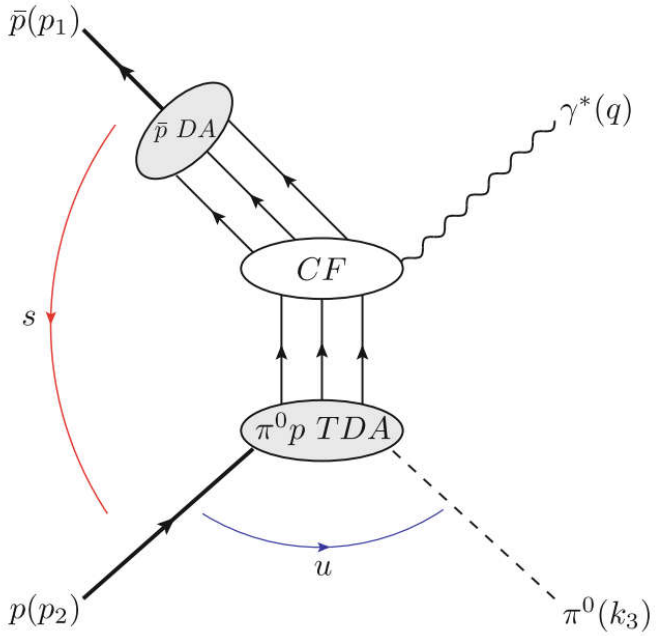
crossing symmetry

J.P. Lansberg et al. (2012), B. Pire, L. Szymanowski, K. Semenov-Tian-Shansky (2013)

Factorisation in the annihilation process

$$\bar{p}p \to \gamma^* \pi^0$$

Two possibilities for factorization in the annihilation process

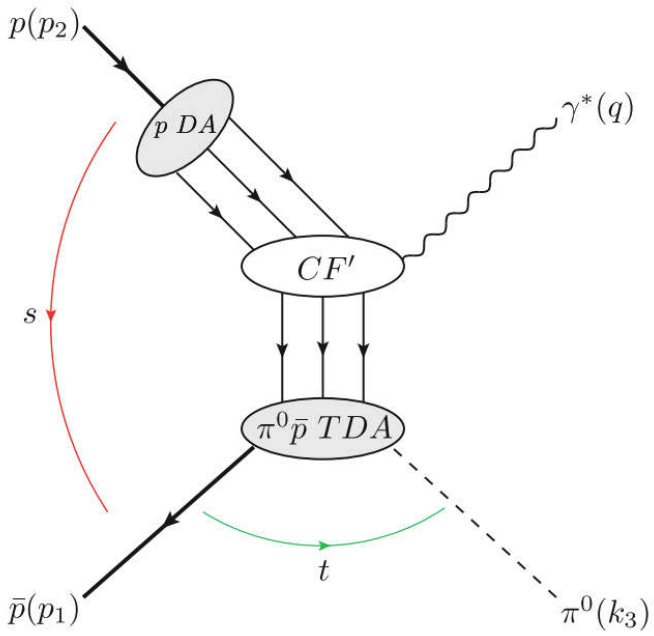


near backward regime

$s = (p_1+p_2)^2$, q^2 - large

$|t| = |(k_3 - p_1)^2| \sim 0)$

➔ **Pion in backward ($\bar{p}$) direction**



near forward regime

$s = (p_1+p_2)^2$, q^2 - large

$|u| = |(k_3-p_2)^2| \sim 0$

➔ **Pion in forward (p) direction**

Expected characteristics from the TDA model

Experimental checks for the onset of the collinear factorization regime for hard exclusive reactions:

→ Dominance of the specific polarization of the virtual photon

→ Characteristic scaling behaviour of the cross section in $1/q^2$.

→ Universality of the corresponding non-perturbative quantities

$$\bar{p}p \rightarrow \gamma^* \pi^0 -> e^+ e^- \pi^0$$

➔ transverse polarization of the virtual photon dominantes

$$\left.\frac{\mathrm{d}\sigma}{\mathrm{d}t\ \mathrm{d}q^2\ \mathrm{d}\cos\theta_\ell^*}\right|_{\text{Leading twist}} = \frac{K}{s-4M^2}\frac{1}{(q^2)^5}(1+\cos^2\theta_\ell^*)$$

TDA measurements with PANDA ($\gamma^* \pi^0$)

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First feasability study for: $\bar{p}p \rightarrow \gamma^* \pi^0 -> e^+ e^- \pi^0$

Two different momenta of the antiproton beam were investigated:

i) $s = 5\ \mathrm{GeV}^2 \quad \rightarrow \quad 3.0 < q^2 < 4.3\ \mathrm{GeV}^2, \quad |\cos\theta_{\pi^0}| > 0.5$

ii) $s = 10\ \mathrm{GeV}^2 \quad \rightarrow \quad 5 < q^2 < 9\ \mathrm{GeV}^2, \quad |\cos\theta_{\pi^0}| > 0.5$

Estimated beam time: ½ year at the design luminosity of $1.5 \cdot 10^{32}$ $cm^{-2}s^{-1}$

⇒ Luminosity= 2 fb^{-1}

TDA measurements with PANDA ($\gamma^* \pi^0$)

Different background processes have been investigated

Most dominant background expected from $\bar{p}p \longrightarrow \pi^+\pi^-\pi^0$

$$\sigma(\pi^+\pi^-\pi^0)/\sigma(e^+e^-\pi^0) \sim 10^6$$

Background suppression:

$s = 5\ \mathrm{GeV}^2$: $5 \cdot 10^7$ at low q^2 $(1 \cdot 10^7$ at high $q^2)$

$s = 10\ \mathrm{GeV}^2$: $1 \cdot 10^8$ at low q^2 $(6 \cdot 10^6$ at high $q^2)$

➔Background can be well suppressed by the PANDA PID in all cases

➔ Signal reconstruction efficiency is in the order of 40 %

TDA measurements with PANDA (γ* π⁰)

$$\bar{p}p \rightarrow \gamma^{*}\pi^{0}$$

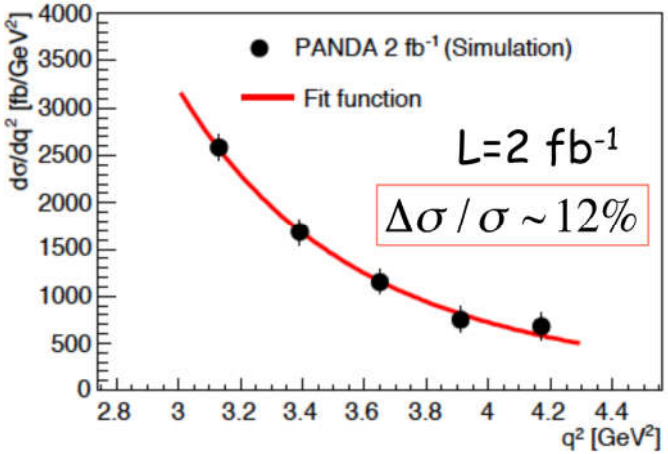
$$\frac{d\sigma}{dq^2} \sim \frac{1}{(q^2)^5}$$

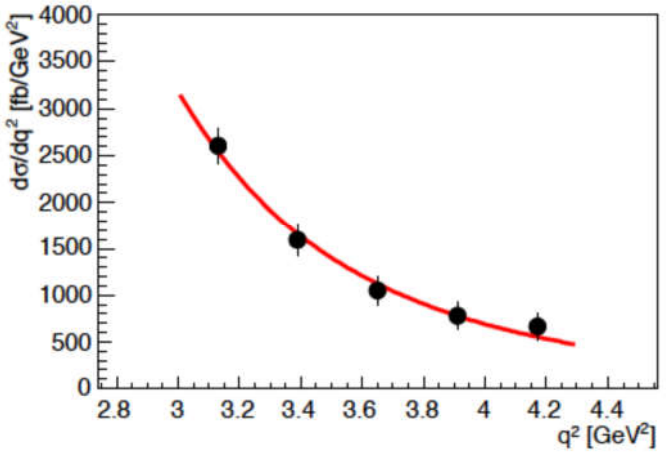
➔ q² scaling of the cross section is a test for the QCD factorisation

π⁰ in forward direction

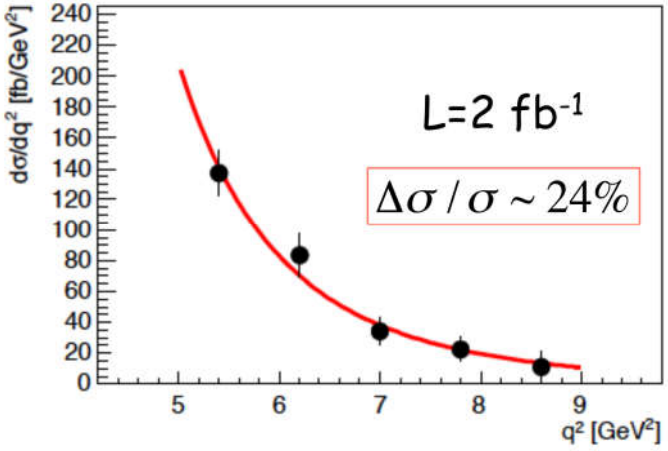
π⁰ in backward direction

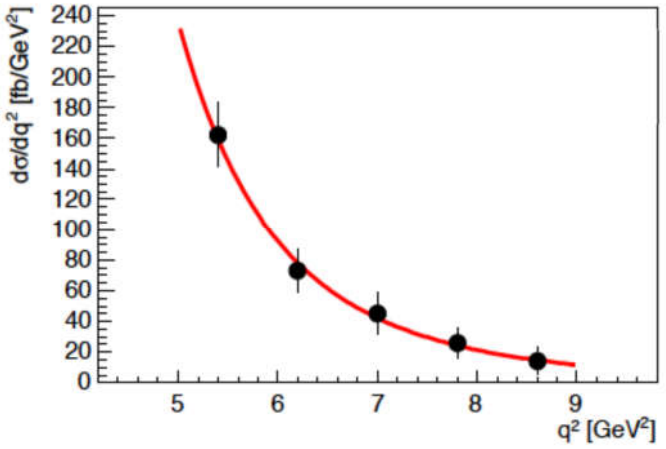
s = 5 GeV²





s = 10 GeV²





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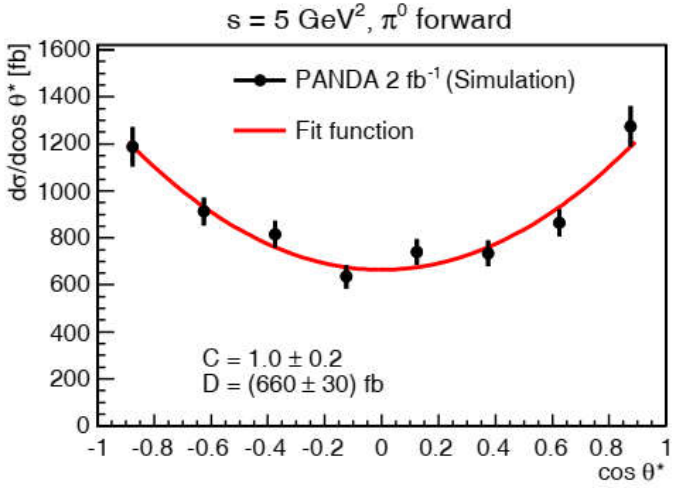
TDA measurements with PANDA (γ* π⁰)

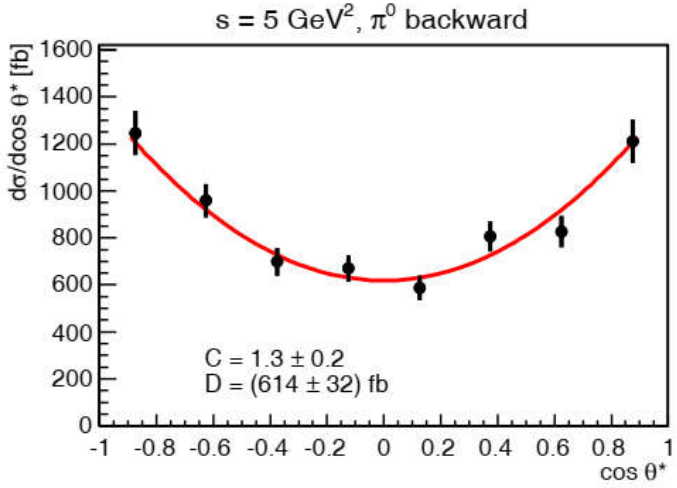
$\bar{p}p \rightarrow \gamma^* \pi^0$

$\frac{d\sigma}{dq^2} \sim + \cos^2 \theta_\ell^*)$

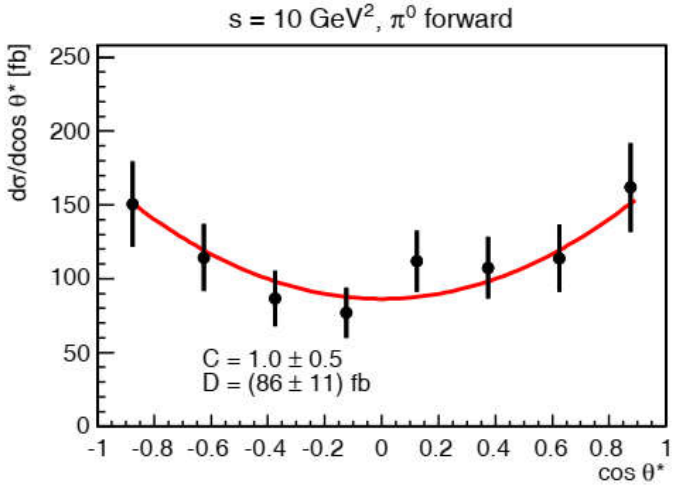
➔ Test of the dominance of the transverse polarisation of the virtual photons

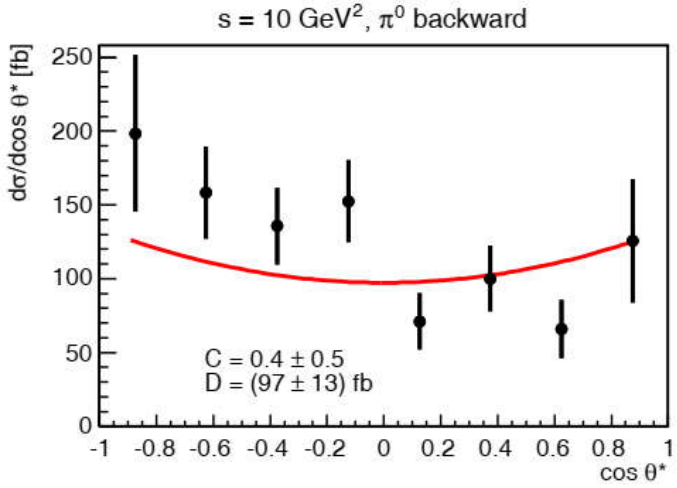
s = 5 GeV²





s = 10 GeV²





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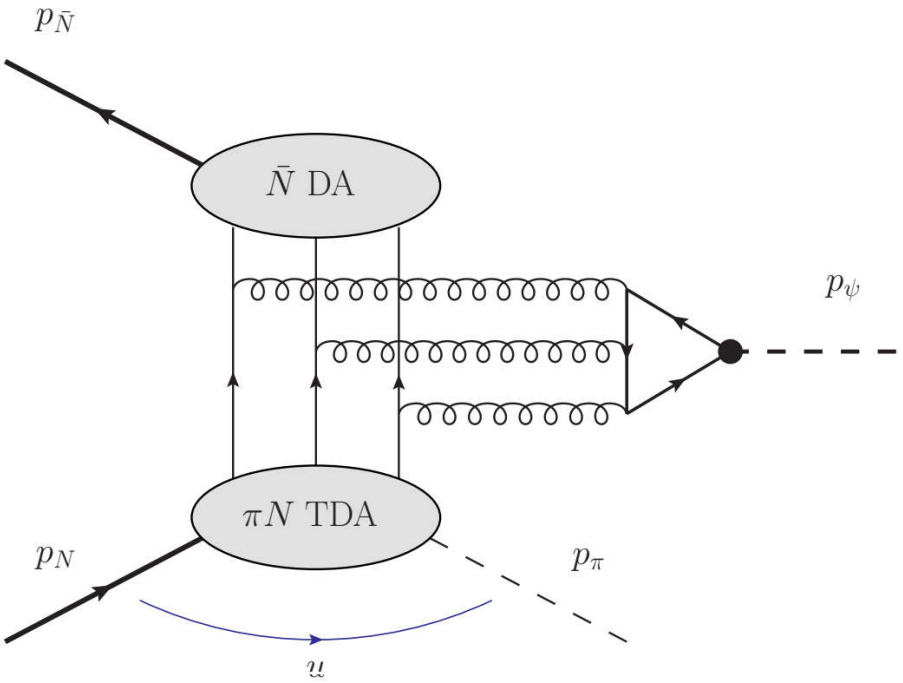
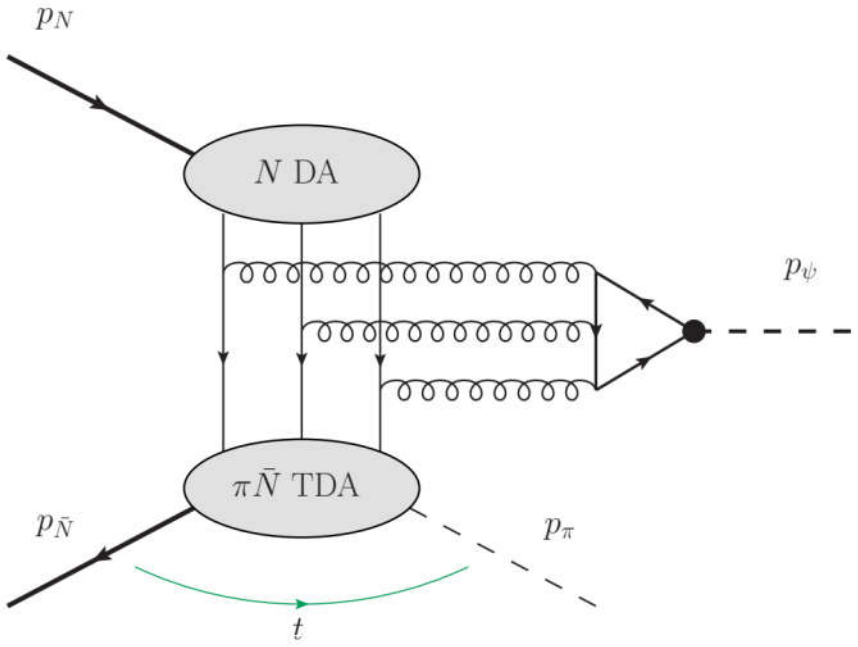
TDA measurements with PANDA (J/ψ π^0)

Feasability study for: $\bar{p}p \rightarrow J/\psi\pi^0 -> e^+e^-\pi^0$



near backward regime



near forward regime

B. Pire et al., Phys. Lett. B. 724 99-107 (2013)

TDA measurements with PANDA (J/ψ π^0)

- **A TDA model based event generator has been used**

π^0 distributions at the 3 studied beam energies:

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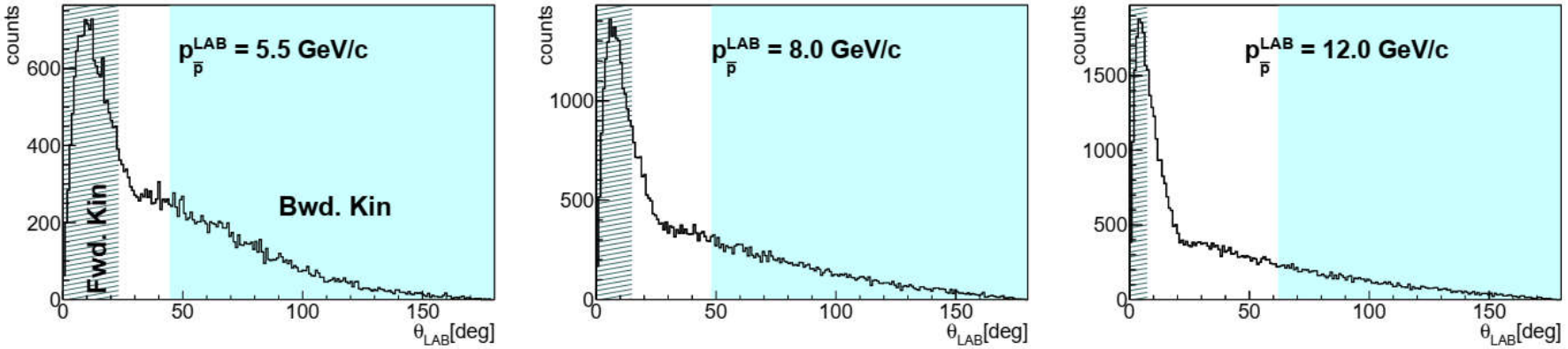
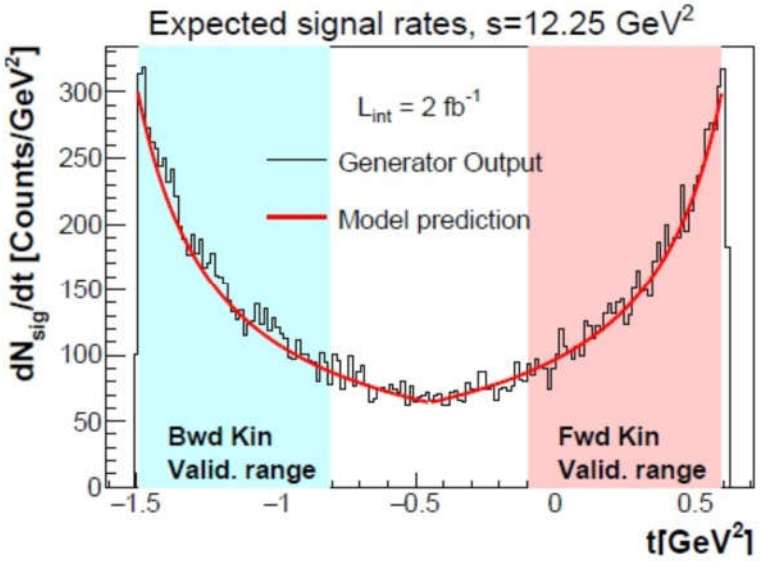




C invariance
„perfect symmetry“

➔ High signal cross section

➔ Large q² fixed to $Q^2 = M_{J/\psi}^2 = 9.6 GeV^2$

→ Factorization theorem is likely reached

➔ Complementary measurement for $\bar{p}p \rightarrow \gamma^* \pi^0$

→ Test of universality of TDAs

TDA measurements with PANDA (J/ψ π^0)

Different background processes have been investigated

A. Three Pion Production $\bar{p}p \to \pi^+\pi^-\pi^0$ (B/S~10^5 - 10^6)

B. Multi-pion Final States ($N_\pi \geq 4$) $\pi^0\pi^0\pi^+\pi^-$, $\pi^0\pi^+\pi^-\pi^+\pi^-\ \pi^0$ (B/S~3-15)

C. $\bar{p}p \to J/\psi\pi^0\pi^0$ **with** $J/\psi \to e^+e^-$

D. Di-electron Continuum: $\bar{p}p \to \gamma^*\pi^0 \to e^+e^-\pi^0$

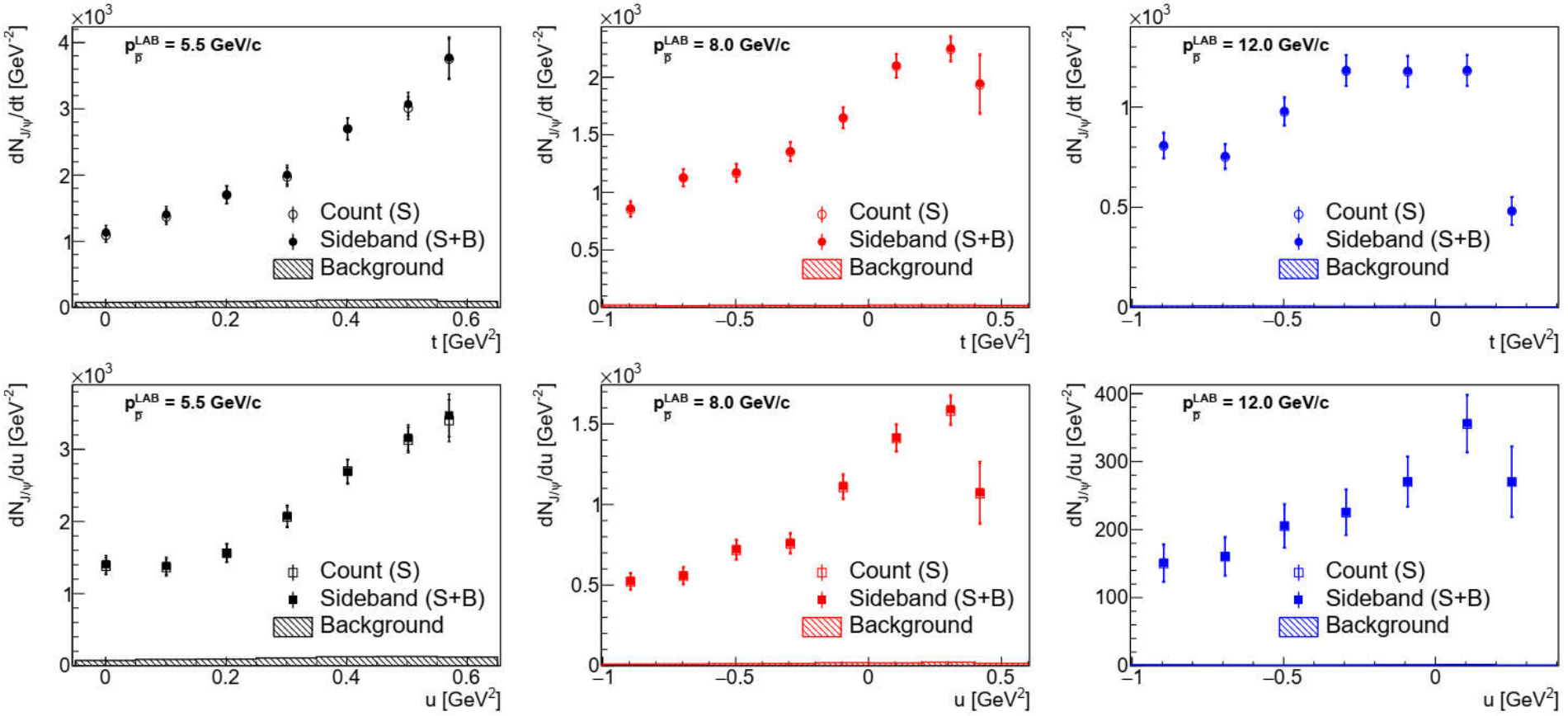
E. Hadronic Decays of J/ψ

➔ After a simple event selection,
the dominant background is contributed by $J/\psi\pi^0\pi^0$

➔ Several backgrond rejection and subtraction methods
have been developed and investigated

TDA measurements with PANDA (J/ψ π^0)

Signal and background contribution of fully reconstructed events after all cuts:



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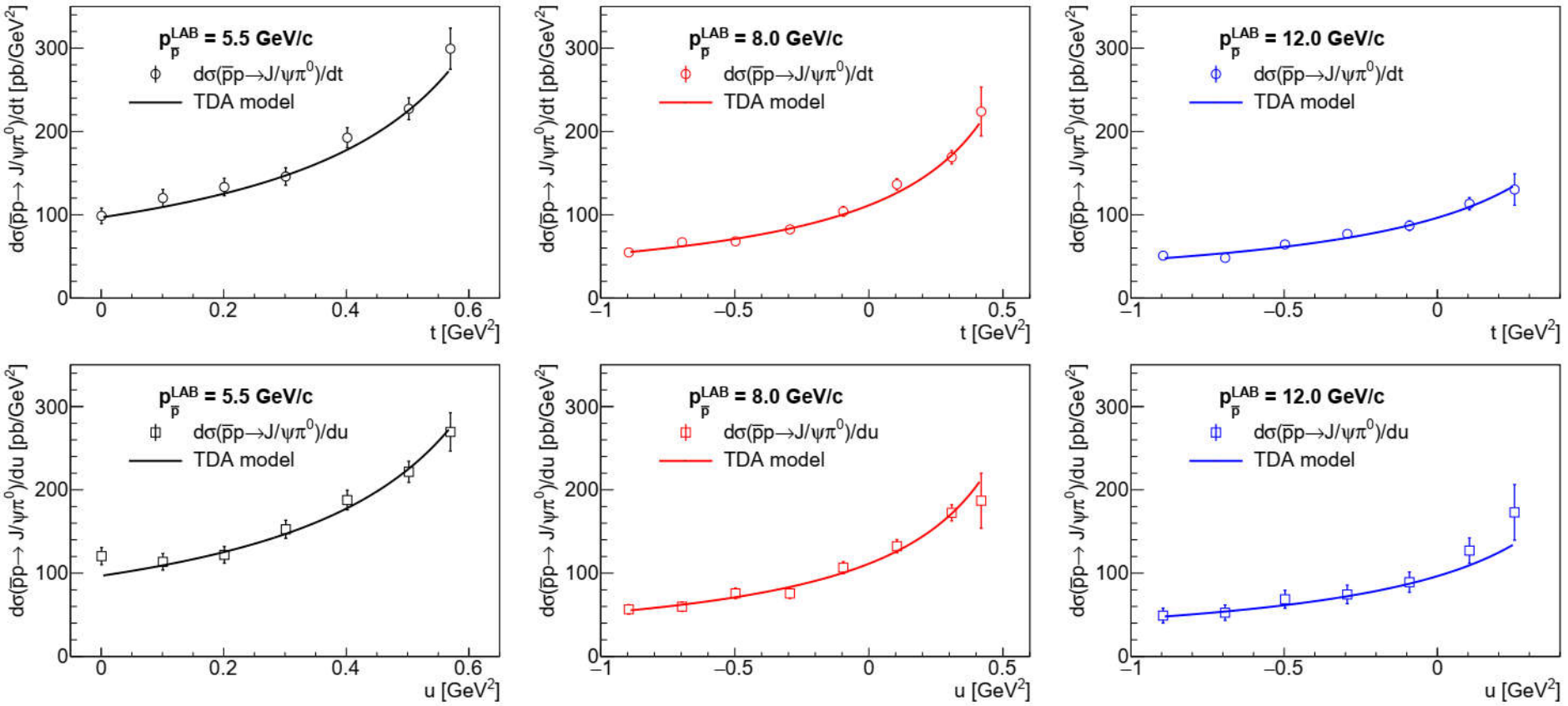
TDA measurements with PANDA (J/ψ π^0)

- Cross sections extracted from the fully efficiency corrected yields
- 2 fb^{-1} integrated luminosity



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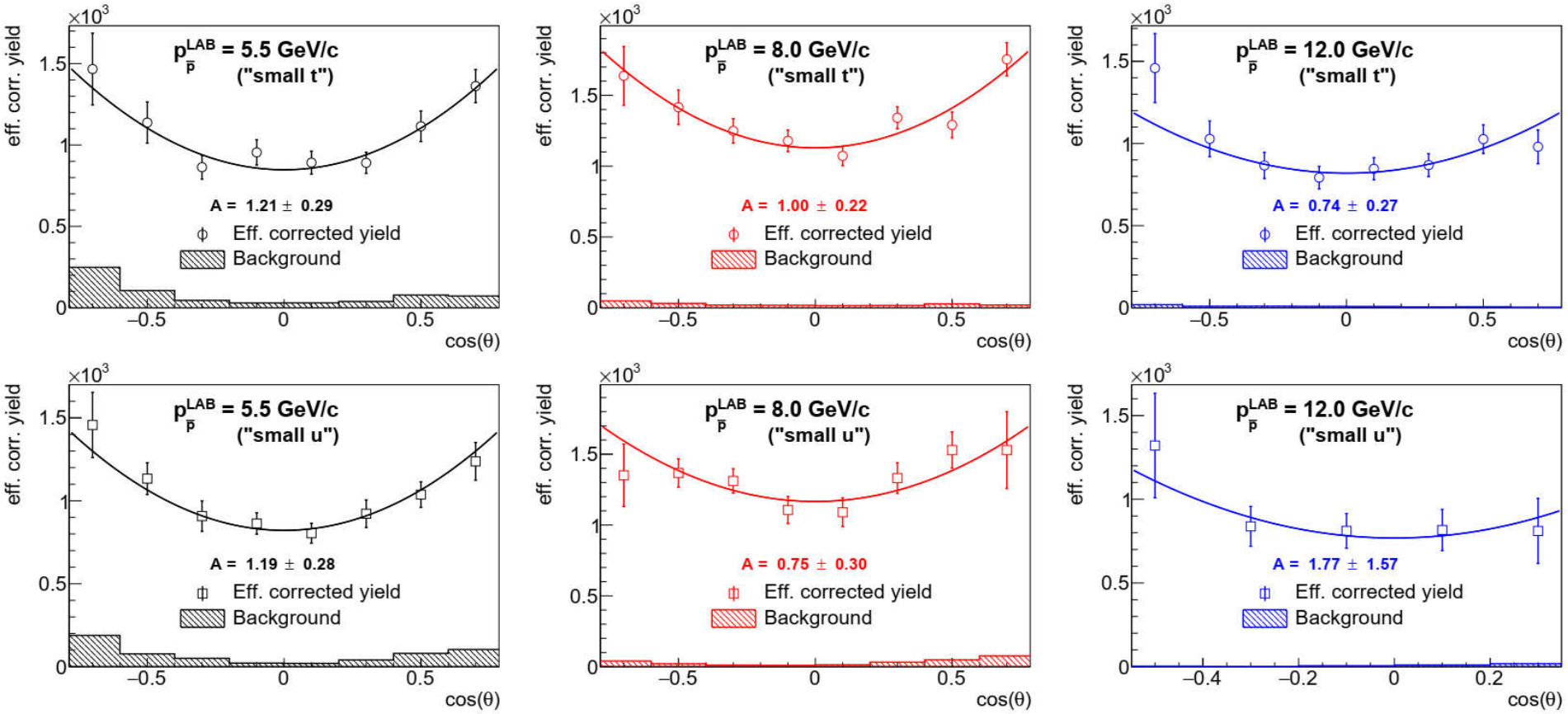
TDA measurements with PANDA (J/ψ π⁰)

$$\frac{d\sigma}{d\theta^{e^+}_{J/\psi}} \sim 1+\cos^2(\theta^{e^+}_{J/\psi})$$

Fit function: $B \times (1 + A\cos^2\theta^{e^+}_{J/\psi})$



L=2 fb^{-1} ➔ $\Delta\sigma(t,u)/\sigma(t,u) \sim 5\% - 10\%$

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Summary and Outlook

- PANDA is well suited to verify basic characteristics of the TDA modell with a high precision within a relatively short period of beam time
- The feasability has been studied in detail for two channels
- PANDA will enable the extraction of TDAs with high precision
- TDAs can be measured by electron scattering (JLAB) and anti-proton proton annihilation (PANDA)

  ➔ A comparison of different channels and reactions can provide a proof for the assumed universality of TDAs

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