Feasibility Studies for Nucleon Structure Measurements with $\bar{\text{P}}$ANDA

Meson 2014

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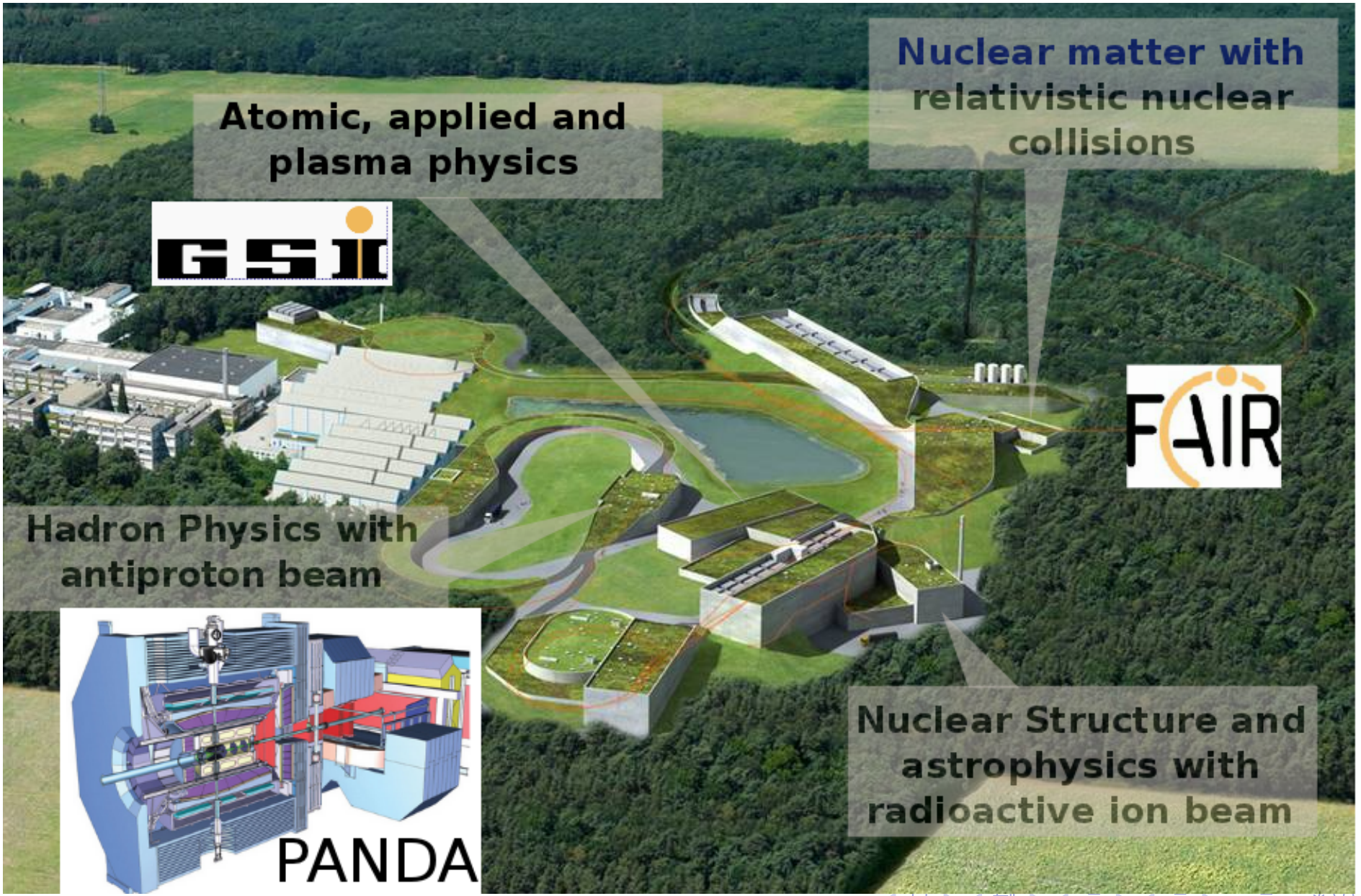
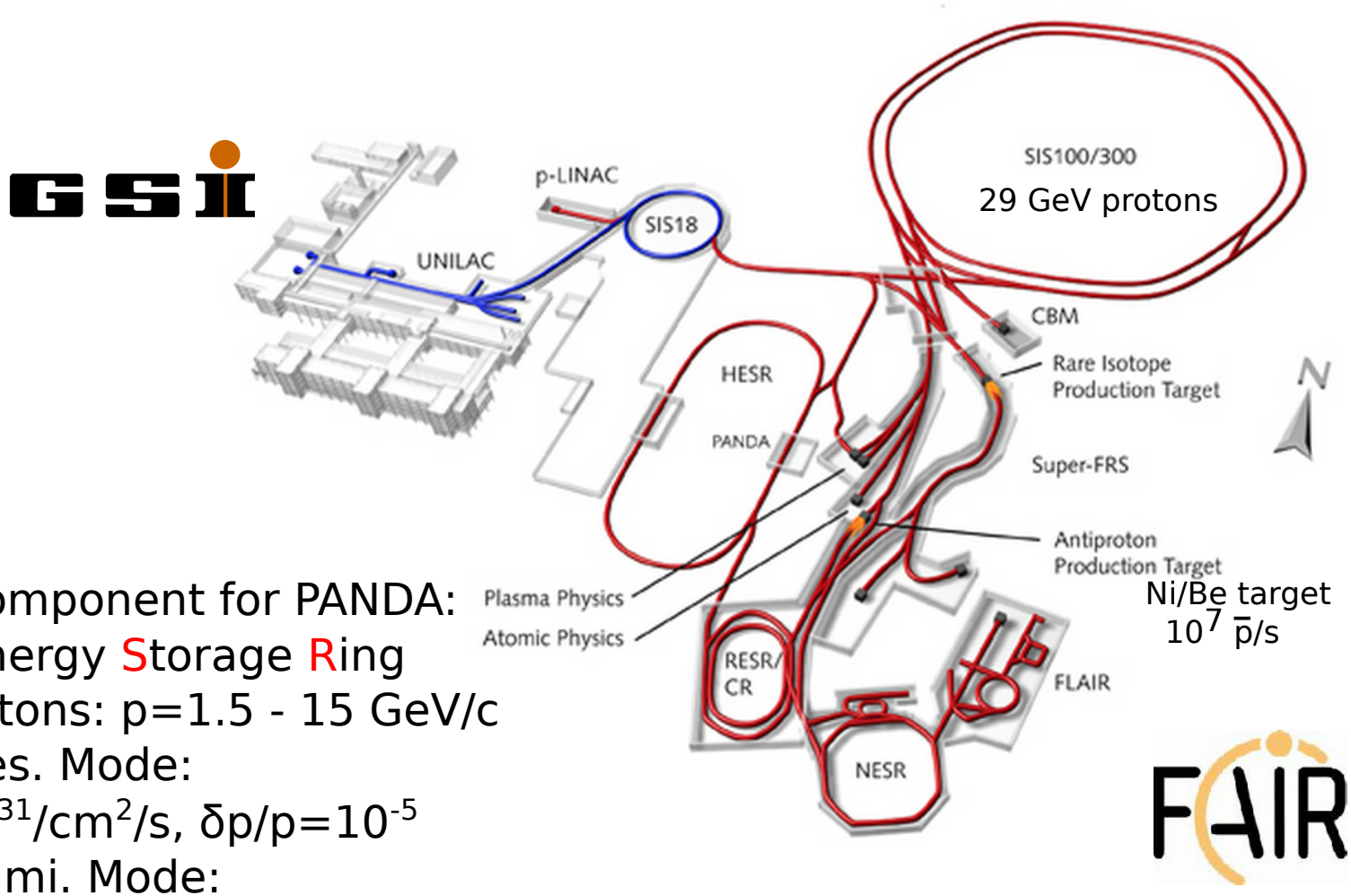
Outline

- $\bar{\text{P}}$ANDA experimental setup
- $\bar{\text{P}}$ANDA physics program overview
- Nucleon structure: Form Factors and TDAs
- Feasibility studies of nucleon structure measurements

FAIR: Facility for Antiproton and Ion Research



The FAIR Accelerator Complex

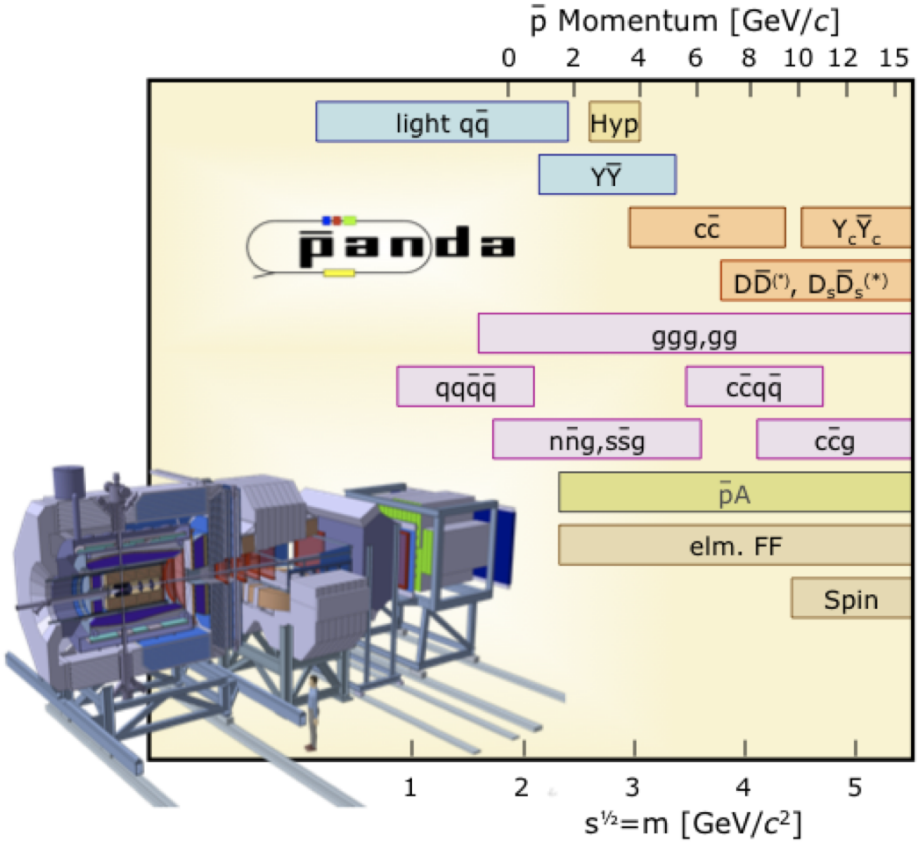


Main component for PANDA:
High Energy Storage Ring
Antiprotons: p=1.5 - 15 GeV/c
High Res. Mode:
$L=10^{31}/cm^2/s$, $\delta p/p=10^{-5}$
High Lumi. Mode:
$L=2x10^{32}/cm^2/s$, $\delta p/p=10^{-4}$

Overview of $\bar{\text{P}}$ANDA physics program

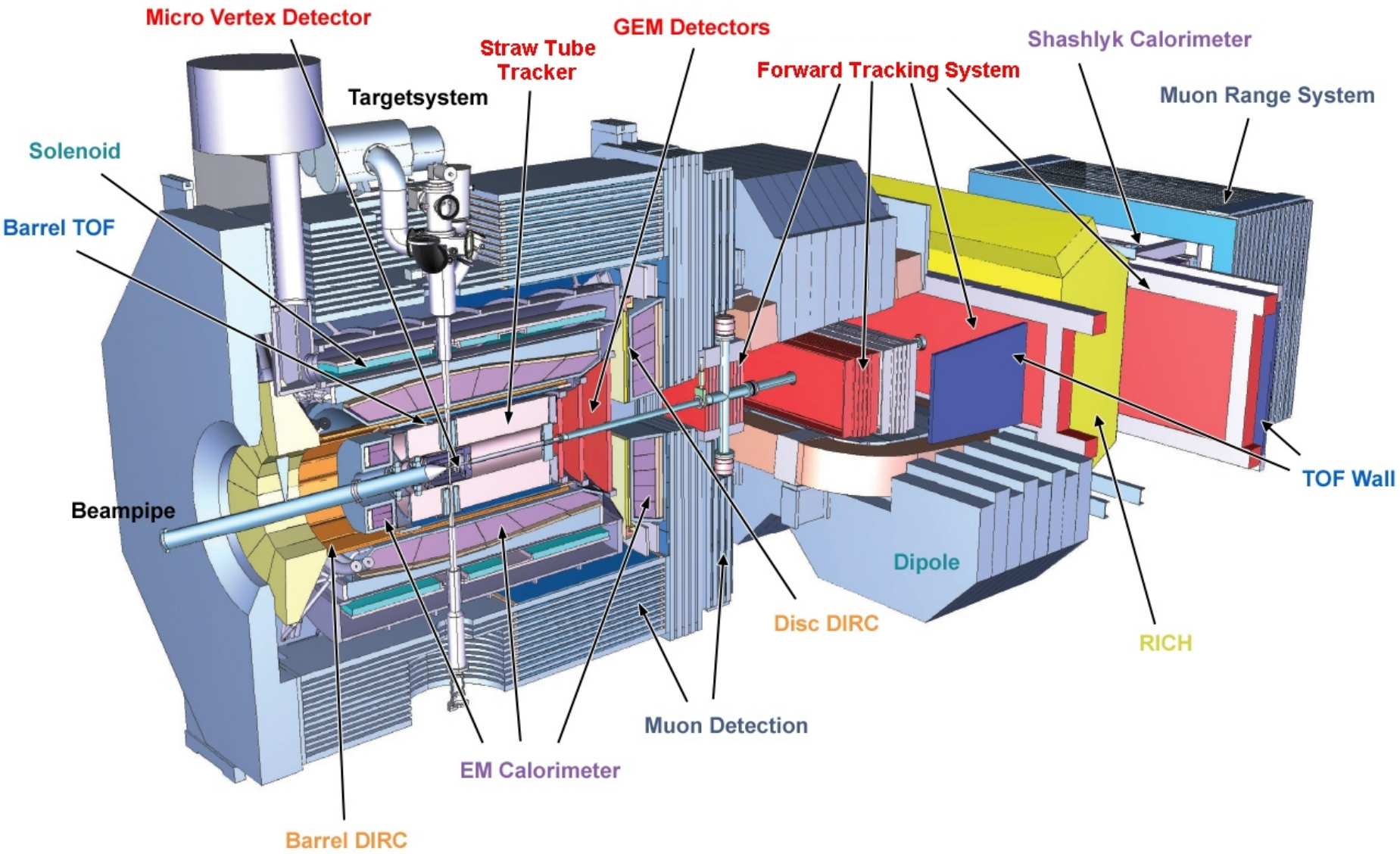
$\bar{\text{P}}$ANDA : Anti-Proton ANnihilation at DArmstadt

- Meson Spectroscopy
  D mesons, charmonia
- Search for exotic QCD states
  Glueballs, tetraquarks, hybrids, molecules
- Single and double hypernuclei
- Hadrons in nuclear matter
- Nucleon structure using EM probes

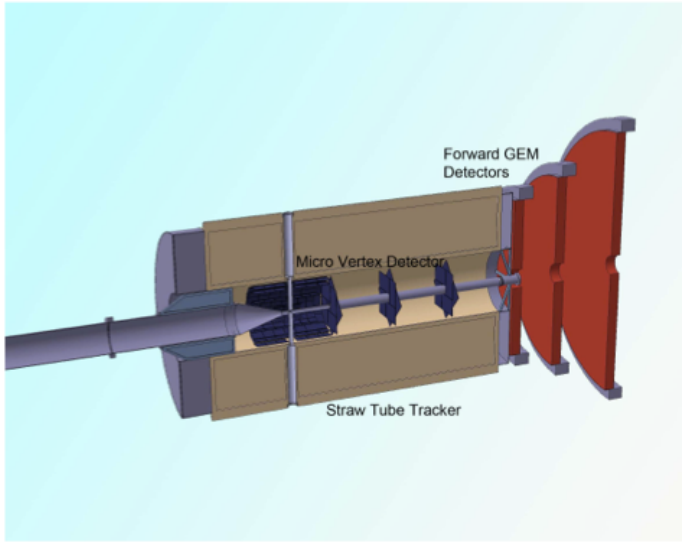


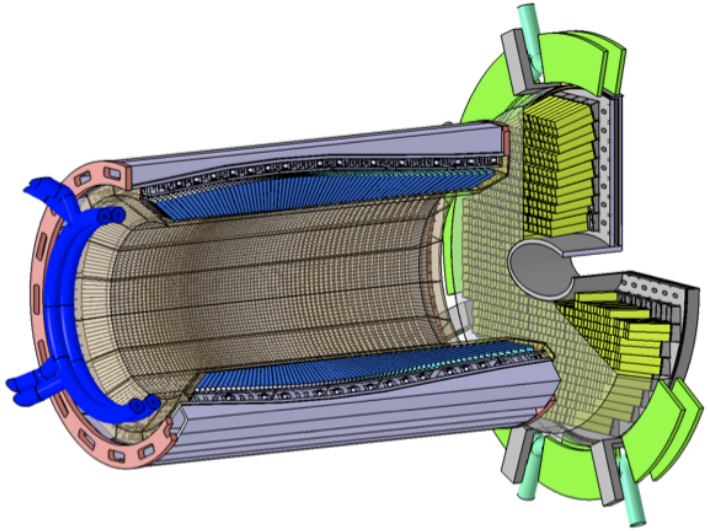
Physics Performance Report - arXiv:0903.3905

$\bar{\text{P}}$ANDA detector



Tracking and PID for Nucleon Structure Physics

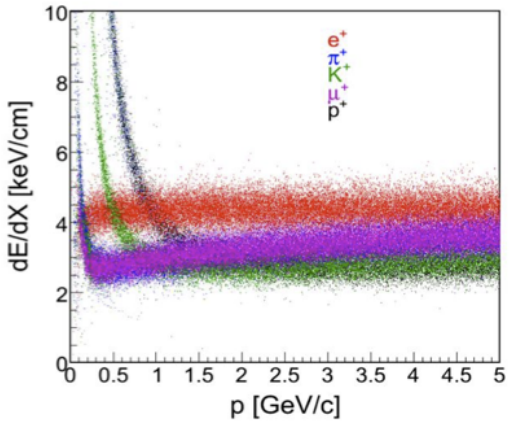




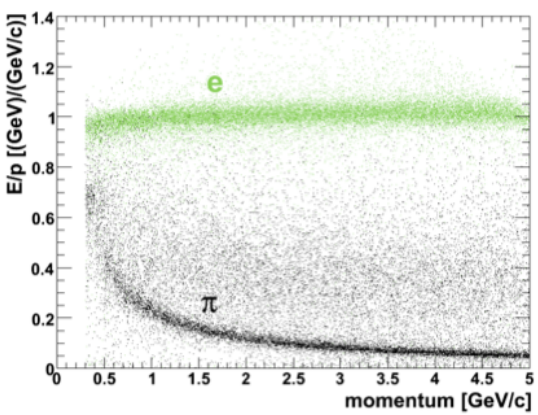
Large coverage (2π, $5^\circ < \theta < 145^\circ$)
Silicon MVD and Straw Tube and GEM tracker
dE/dx for PiD from STTs

PbWO crystal EMCal, APDs (barrel) VPT (forward)
Operation at -25°C for optimal photon production
Wide dynamic range: $\gtrsim$ 3 MeV
Excellent resolution: $\sigma(E)/E \approx 1\% \oplus 2\%/\sqrt{E(GeV)}$

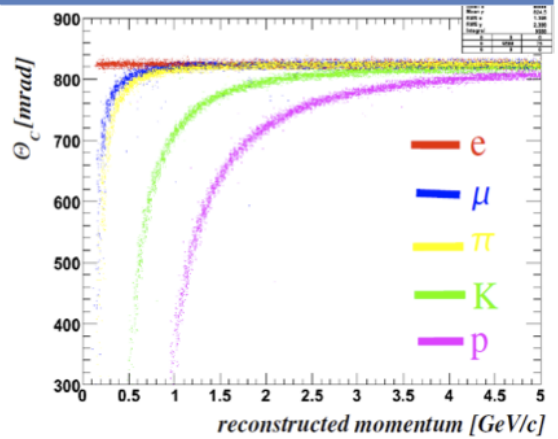
Straw Tube Tracker



ElectroMagneticCalorimeter



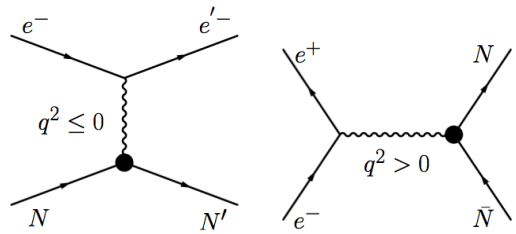
DIRC(Cerenkov)



Form Factors

Parametrizations of hadronic current in the matrix element for:

- Elastic scattering of a lepton off a nucleon ($l^{\pm}N \rightarrow l^{\pm}N$):
  Spacelike (SL) real analytic functions of $q^2 < 0$
  Well constrained to high values of $-q^2 \approx 30\ GeV^2$
- Annihilation reaction of l^+l^- or $N\bar{N}$ pairs ($N\bar{N} \leftrightarrow e^+e^-$):
  Timelike (TL) complex analytic functions of $q^2 > 4m_p^2$
  Scarce data for TL FF (especially at high q^2)



Extraction in the TL region:

Cross section of $\bar{p}p \rightarrow e^+e^-$

$$\sigma_{tot} = \frac{\pi\alpha^2}{6M_p^2}\frac{(2\tau+1)\,|G_{eff}|^2}{\tau\sqrt{\tau\,(\tau-1)}}$$

$$G_{eff}^2 = \frac{2\tau|G_M|^2 + |G_E|^2}{2\tau+1}, \quad and\ \tau = \frac{q^2}{4M_p^2}$$

Angular distribution $\bar{p}p \rightarrow e^+e^-$

$$\frac{d\sigma}{d\cos\theta_{CM}} = \frac{\pi\alpha^2}{8M_p^2\tau\sqrt{\tau\,(\tau-1)}} \times$$

$$\left[\tau|G_M|^2\left(1+\cos^2\theta_{CM}\right) + |G_E|^2\sin^2\theta_{CM}\right]$$

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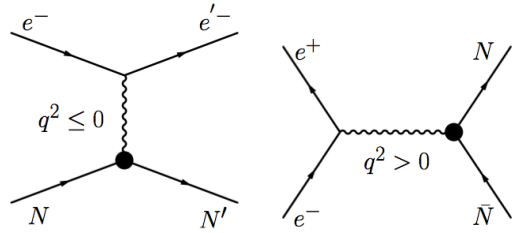
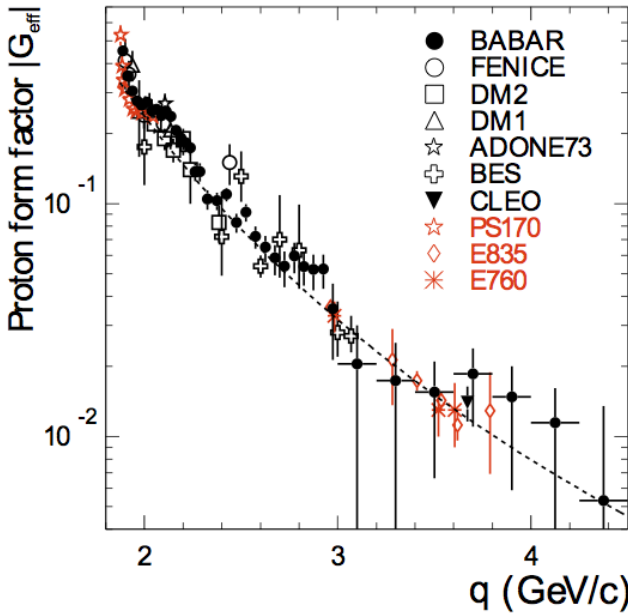
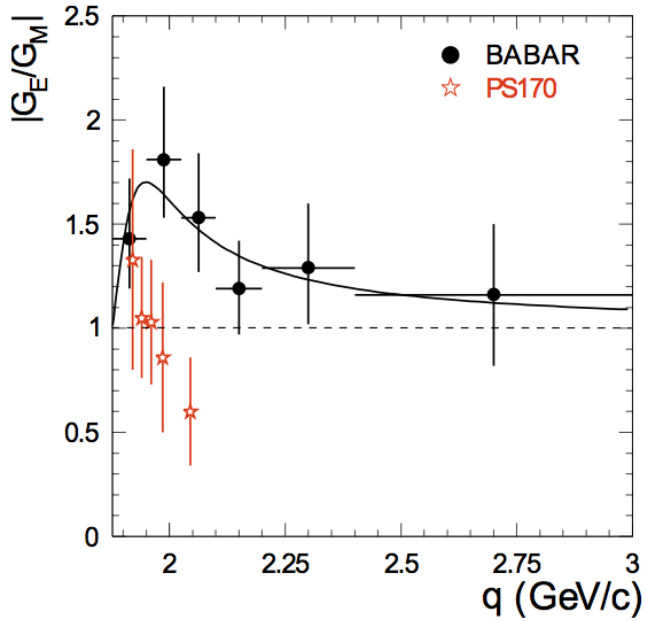


TL FFs existing data (Phys Rev D87 (2013) 092005)

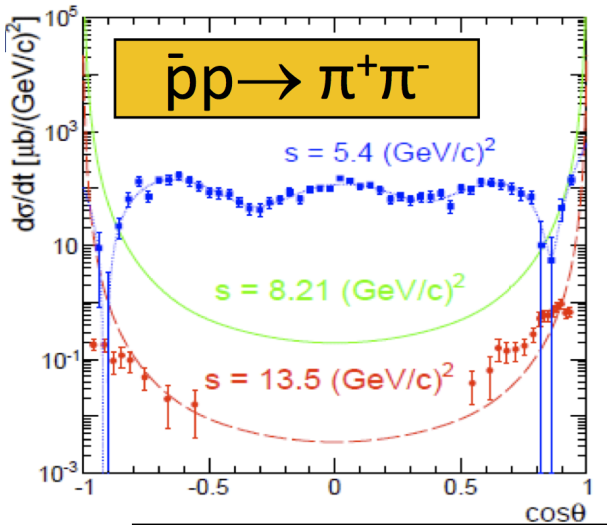
- $|G_{eff}|$ large uncertainties above $q^2 \approx 16\ GeV^2$
- Large uncertainties in $|G_M/G_E|$
- No data on relative phase



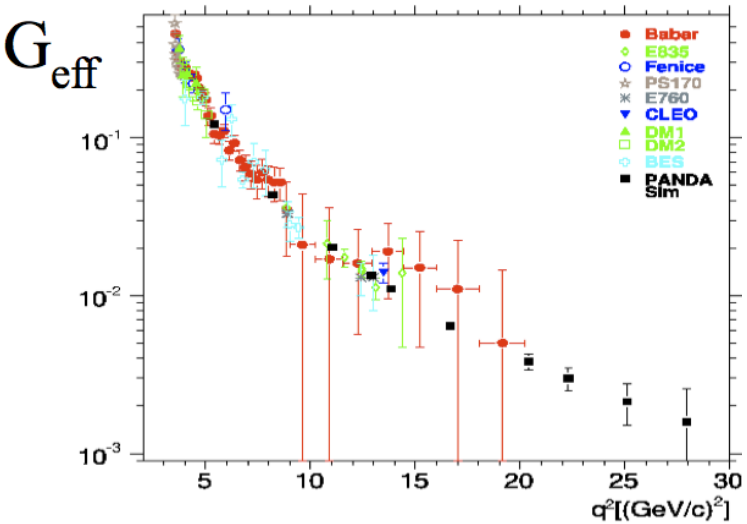


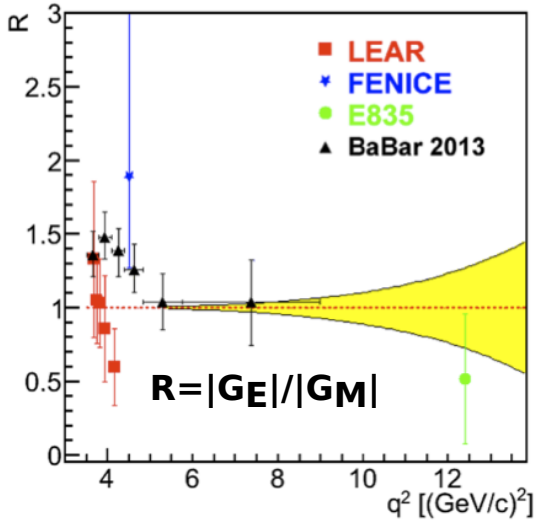
Feasibility of Timelike FF Measurements

- Full MC of Main background sources:
  $\bar{p}p \to \pi^+\pi^-$ $\sigma \approx 10^6 \times \bar{p}p \to e^+e^-$
  Param. by Ong and Van de Wiele (EPJA46 (2010) 291)
  $\bar{p}p \to \pi^0\pi^0$ followed by π^0 Dalitz: Relatively easy to reject using kinematical constraints
- Requirement on background rejection: $< 0.1\%$
- Full $\bar{P}$ANDA PiD with kinematical cuts:
  Rejection of 10^9 on background
  Efficiency for signal above 20% (average 40%)



M. Sudol et al. EPJA44 (2010) 373

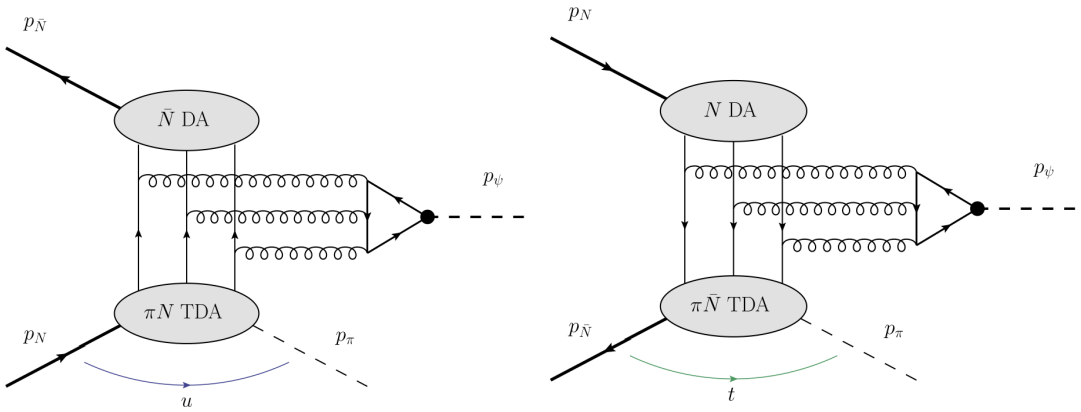




Significant improvement with 4 months @ $2x10^{32}/cm^2/s$

Transition Distribution Amplitudes

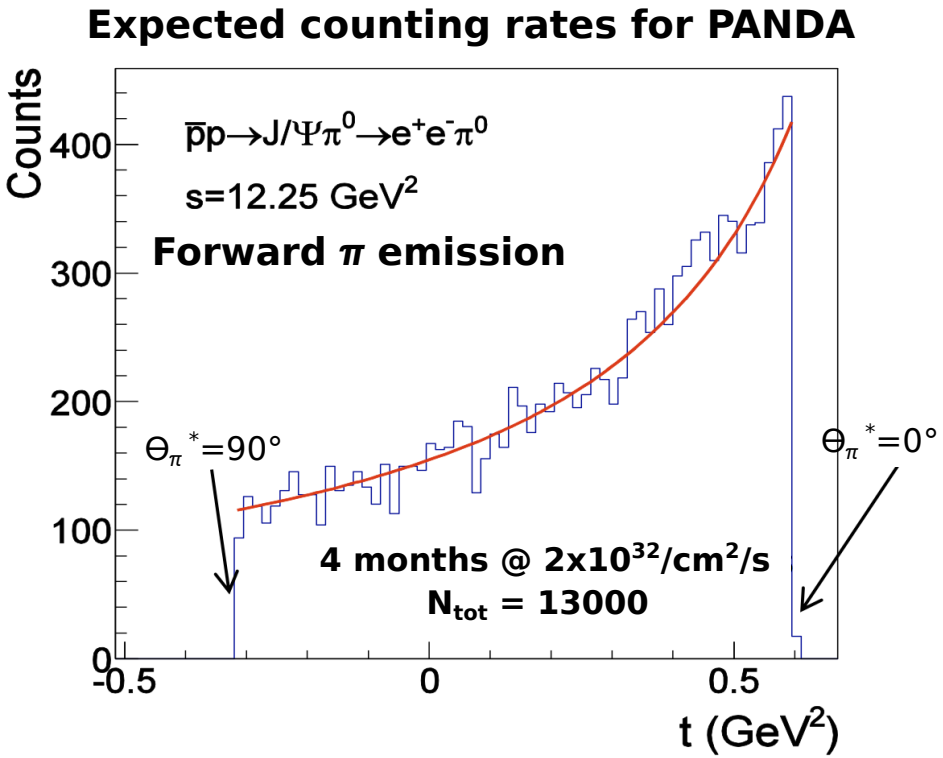
Universal non perturbative objects that appear in the factorized calculation of cross sections of some exclusive processes (Eg: $\bar{p}p \to J/\psi\pi^0$, $\bar{p}p \to e^+e^-\pi^0$ and $\gamma^* N \to \pi N$)

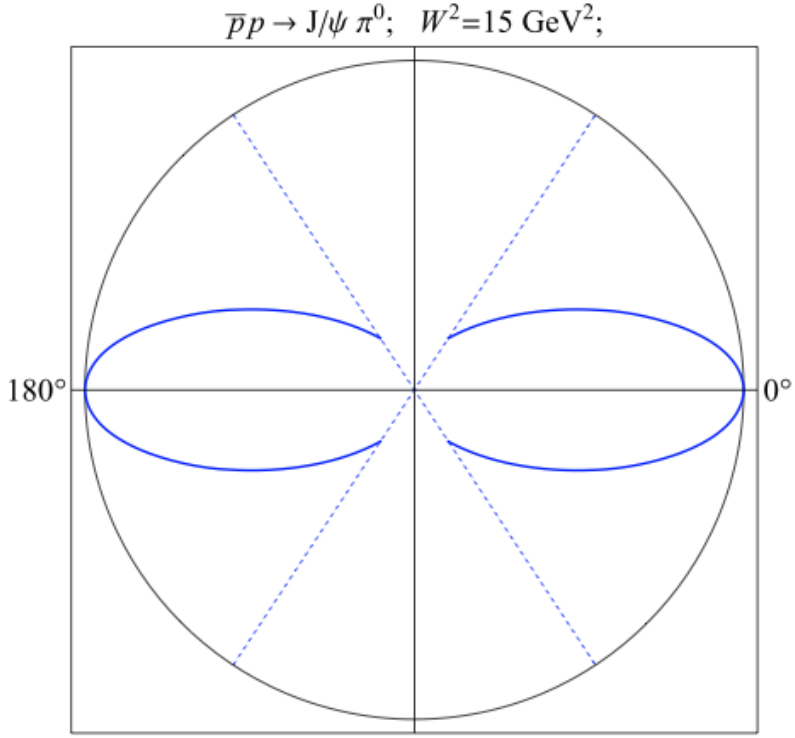


- Short distance dominated part computed within pQCD
  - Validity requires large scale (usually taken as virtuality of lepton pair emission)
- Universal non-perturbative components: TDA and DA
  - TDA: Probe the mesonic content of nucleon wave functions
- Factorization description valid in two kinematical regimes
  - Near forward kinematics $t = (p_\pi - p_{\bar{N}})^2 \approx 0$ for $\pi\bar{N}$ TDA
  - Near backward kinematics $u = (p_\pi - p_N)^2 \approx 0$ for πN TDA
- Test universality of TDAs that occur also in $\gamma^* N \to \pi N$ and $N\bar{N} \to l^+l^-\pi$ reactions

Feasibility of $\bar{p}p \to J/\psi\pi^0$ in $\bar{\text{P}}$ANDA (Signal)

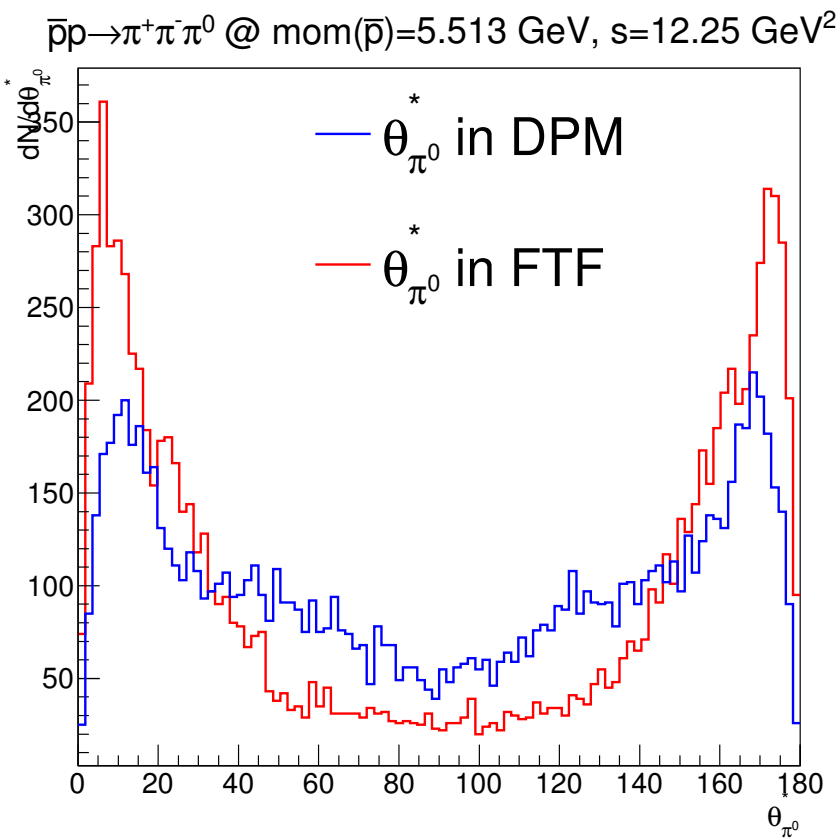
- Background in charmonium spectroscopy studies ($c\bar{c}$ resonances that decay into $J/\psi\pi$)
- Cross section calculation from Pire *et.al* (Phys. Lett. B. 724 99-107): $\sigma \approx$ 2x100 pb
- Cross section peaked around $\theta^*_{\pi^0} = 0°$ for $\bar{p}\pi$ TDA and at $\theta^*_{\pi^0} = 180°$ for $p\pi$ TDA
- Compared to e^+e^-: Pros: mass cut for background rejection, Cons: fixed Q^2

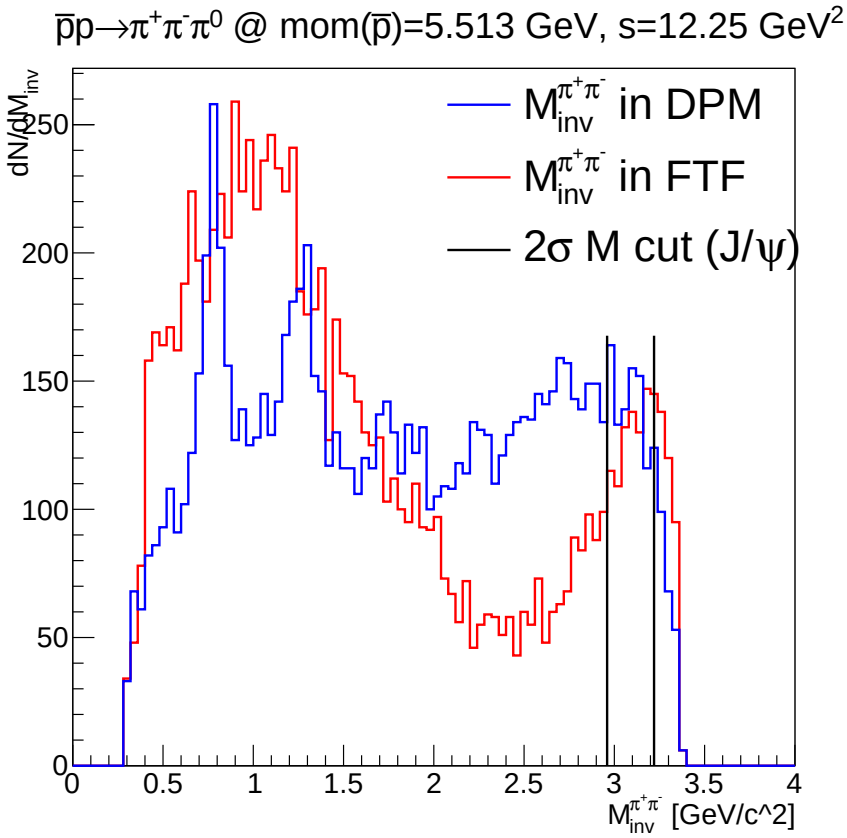




Feasibility of $\bar{p}p \to J/\psi\pi^0$ in PANDA (Backgrou

- Main background: $\pi^+\pi^-\pi^0$ $\sigma \approx 400$ μb
- Two string fragmentation models DPM and FTF give similar π^0 CM polar angle distribution peaked near $\theta^*_{\pi^0} = 0°$ and $\theta^*_{\pi^0} = 180°$ like signal (simulations by A. Galoyan)
- $\pi^+\pi^-$ invariant mass distribution, with substantial difference between models
  - High precision measurement by PANDA will help discriminate between models
  - 2σ mass cut for J/ψ rejects ≈90% of $\pi^+\pi^-\pi^0$ background (before PID)
  - Better momentum resolution $\implies$ better rejection

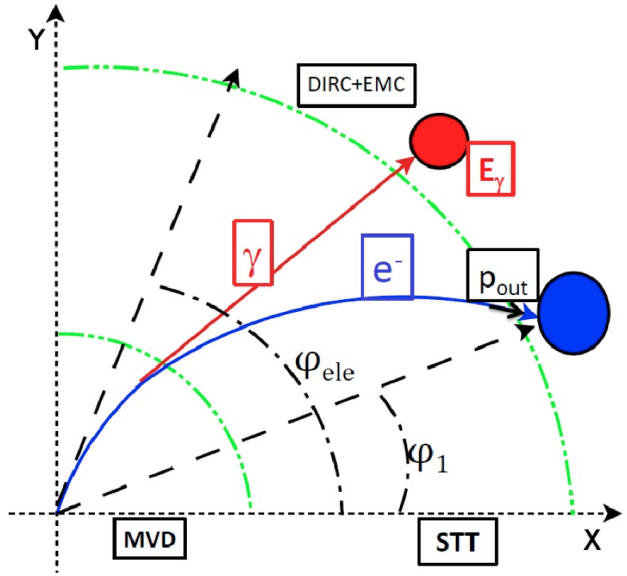


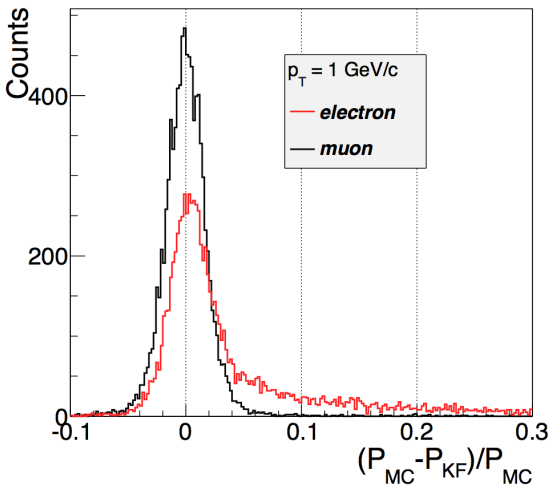


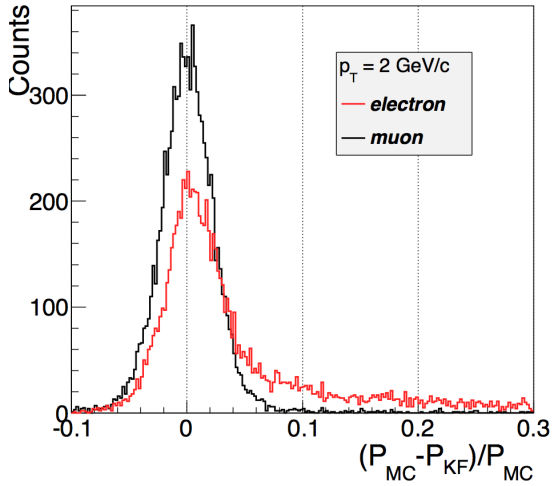
Electron momentum reconstruction in $\bar{P}$ANDA

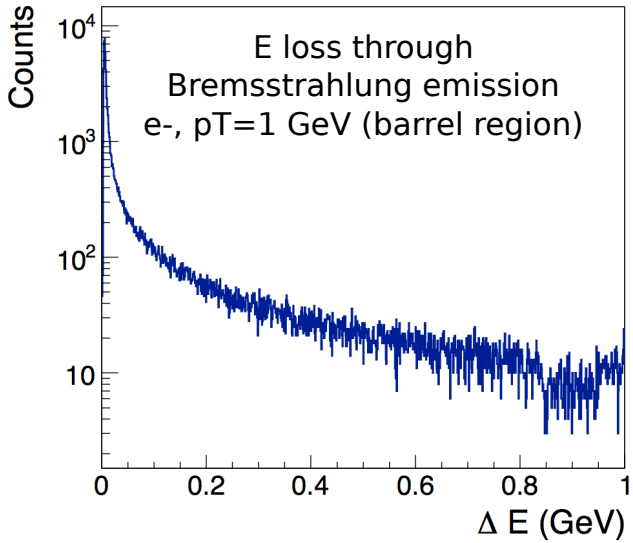
Resolution loss due to Bremsstrahlung

- Tracking points: MVD (4 to 6) and STT (up to 24)
- 80% of X/X_0 inside tracking system from MVD
- Significant Bremsstrahlung photon emission
  (Almost collinear with photon direction)
- Helix prefit used as input for Kalman filter
- Kalman filter assumes Gaussian errors
  $\Longrightarrow$ External radiation not taken into account



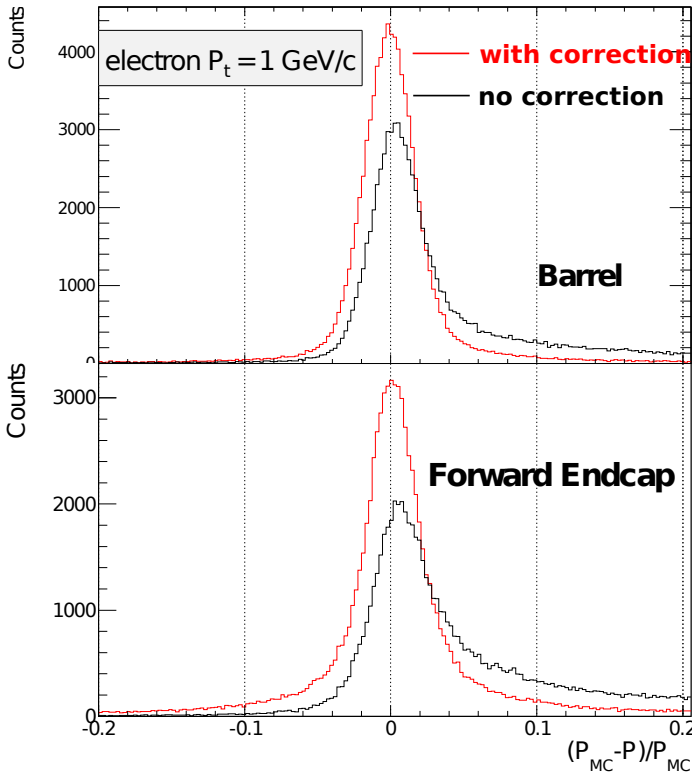


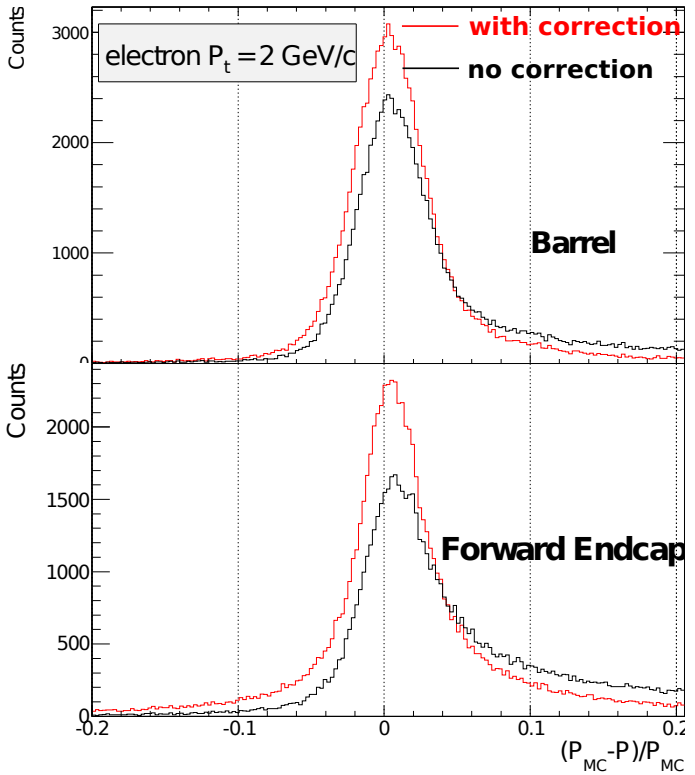




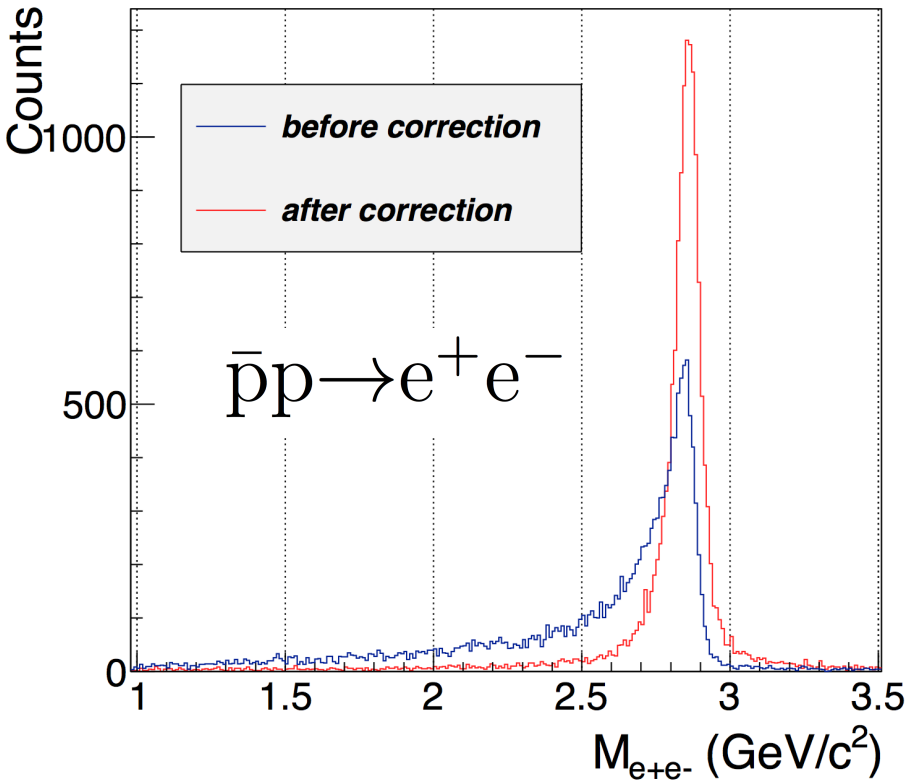
Event by event correction of Bremsstrahlung

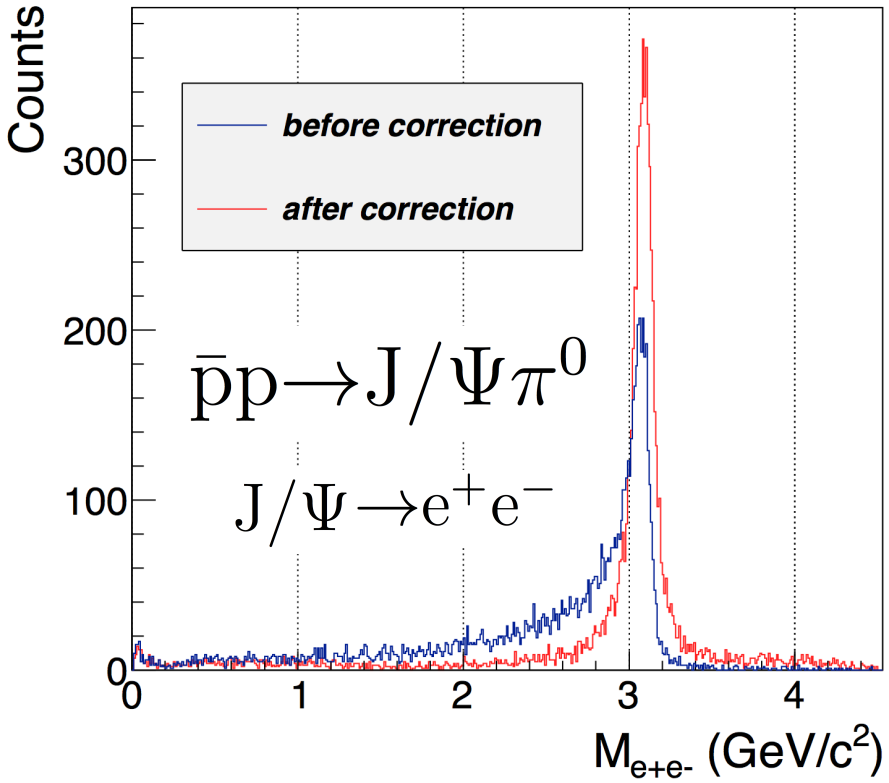
- Exploit spatial correlation between γ_{Brem} and e^+/e^- clusters
- Combined with low threshold EMCal, possible to
  - Find Bremsstrahlung photon candidates track by track
  - Correct each track's momentum by adding back total energy from all γ_{Brem}
- Approach works: clear improvement in electron momentum resolution





Improvement on nucleon structure observables





60% gain in efficiency with 2σ cut for $\bar{p}p \to J/\psi\pi^0$

70% gain in efficiency with minimum mass cut of $\sqrt{s} - m_{\pi^0}$ for $\bar{p}p \to e^+e^-$

Summary

- $\bar{\text{P}}$ANDA will open exciting opportunities for hadronic physics
- Form factor measurements in the TL region over an extended range of q^2
- Excellent test bed for the universality TDAs
- Correcting momentum reconstruction for Bremsstrahlung yields quantitaive improvements