

Updates on π -N TDA measurement feasibility at $\bar{\text{P}}\text{ANDA}$ with $\bar{p}p \rightarrow \pi^0 J/\psi \rightarrow \pi^0 e^+ e^-$

GDR PH-QCD

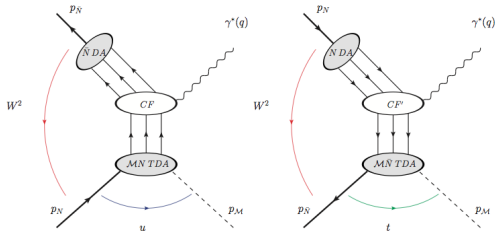
Ermias ATOMSSA

Institut de Physique Nucléaire d'Orsay

December 16, 2014

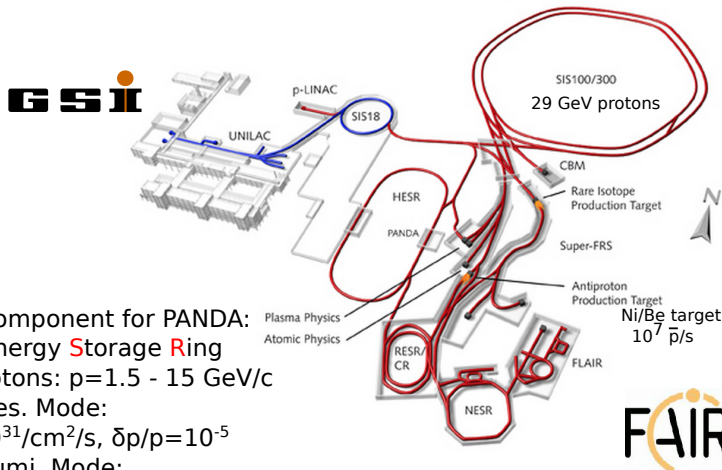
Nucleon-to-meson TDAs through $\bar{p}p \rightarrow \pi^0 J/\psi \rightarrow \pi^0 e^+ e^-$

J-P. Lansberg et. al. Phys. Rev. D 75 (2007) 074004



- Occur in collinear factorization of $\bar{p}p \rightarrow \pi^0 \gamma^* \rightarrow \pi^0 e^+ e^-$ and $\bar{p}p \rightarrow \pi^0 J/\psi \rightarrow \pi^0 e^+ e^-$
- π -N TDAs : parametrizations of hadronic matrix elements as a function of momentum fractions (x_i), skewness (ξ) and momentum transfer squared ($\Delta^2 = t/u$)
- Universality: non dependence on W^2 and q is one proposed signature of factorization
- **Feasibility of measurements to constrain π -N TDAs through $\bar{p}p \rightarrow \pi^0 J/\psi \rightarrow \pi^0 e^+ e^-$**
 - Complimentary to $\bar{p}p \rightarrow \pi^0 \gamma^* \rightarrow \pi^0 e^+ e^-$ study (hep-ex/1409.0865)

$\bar{P}$ ANDA at the FAIR accelerator complex



Main component for PANDA:

High **E**nergy **S**torage **R**ing

Antiprotons: $p=1.5 - 15$ GeV/c

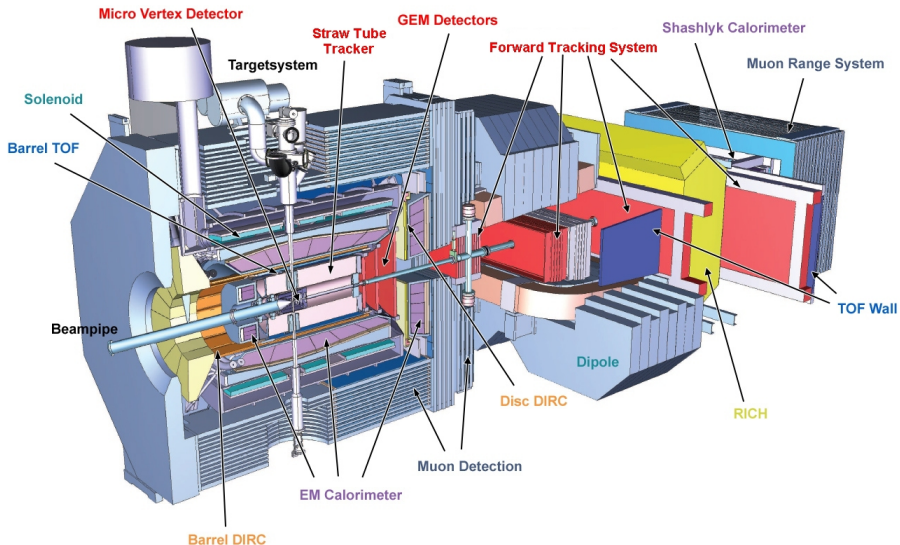
High Res. Mode:

$$L=10^{31}/\text{cm}^2/\text{s}, \delta p/p=10^{-5}$$

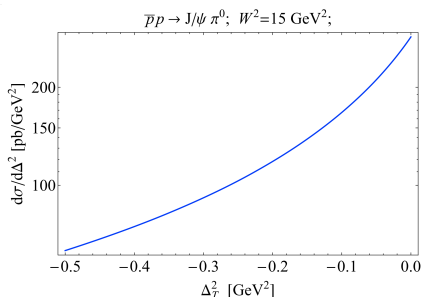
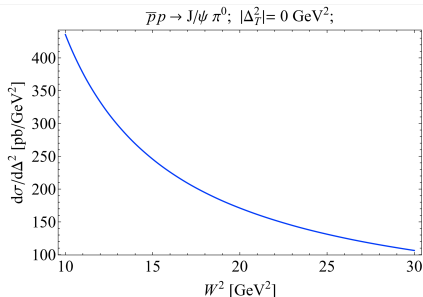
High Lumi. Mode:

$$L=2 \times 10^{32}/\text{cm}^2/\text{s}, \delta p/p=10^{-4}$$

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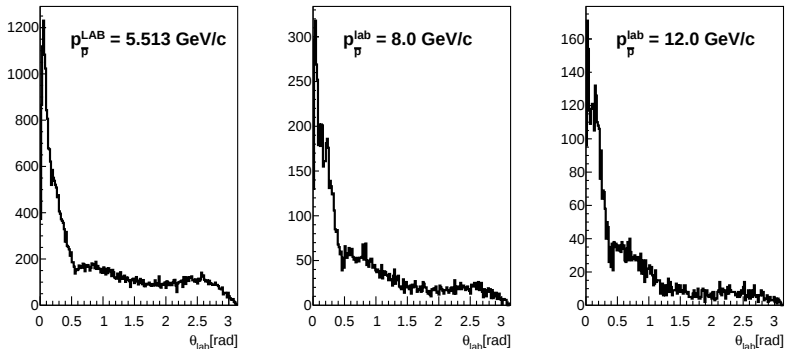


Event generation for $\bar{p}p \rightarrow \pi^0 J/\psi \rightarrow \pi^0 e^+ e^-$



- Based on TDA formalism prediction in B. Pire et. al. Phys. Lett. B 724 (2013) 99197
 - Reproduces existing data from Fermi Lab at $p_{\bar{p}} = 5.513 \text{ GeV}/c$
- Two validity ranges
 - Small $|t| \ll Q^2$, forward going π^0 (wrt. $\bar{p}$), $\Delta^2 = t$
 - Small $|u| \ll Q^2$, backward going π^0 (wrt. $\bar{p}$), $\Delta^2 = u$
- Highly peaked at forward and backward angles
- Number of simulated events (assuming 2 fb^{-1})
 - From integrated rates within the validity range
 - 28k at $p_{\bar{p}} = 5.513 \text{ GeV}/c$, 24k at $p_{\bar{p}} = 8 \text{ GeV}/c$, and 15k at $p_{\bar{p}} = 12 \text{ GeV}/c$
 - Very slow decay as a function of $p_{\bar{p}}$

Event generation for $\bar{p}p \rightarrow \pi^0\pi^+\pi^-$

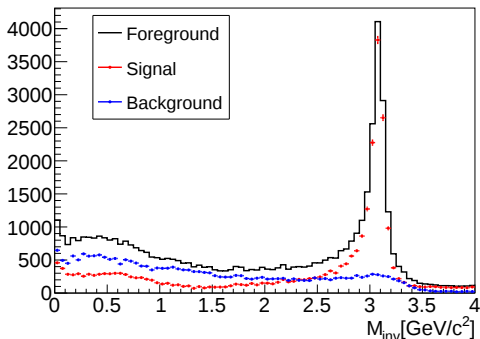


- Most dominant background by ≈ 2 orders of magnitude
- Dual Parton Model (DPM) used as event generator for spectra
 - A. Capella *et. al*, Phys. Rep. 236, p225329, 1994
- Cross sections were set to intra(extra)polaion of closest available data points
 - V. Flaminio *et. al*, CERN-HERA 84-01, 1984
 - 0.2 mb ($p_{\bar{p}}=5.513 \text{ GeV/c}$), 0.05 mb ($p_{\bar{p}}=8 \text{ GeV/c}$) and 0.001 mb ($=12 \text{ GeV/c}$)
 - Decay rate much faster than $\bar{p}p \rightarrow \pi^0 J/\psi \rightarrow \pi^0 e^+ e^-$ (comes at a cost of signal efficiency)
- Number of events estimated to survive EID cuts on charged pion were passed to full GEANT simulation (π^0 's are analyzed in the full GEANT MC)

Analysis steps

- Full GEANT montecarlo + standard PANDA reconstruction
- Properly normalized signal and background rates for $p\bar{p}=5.513$ GeV/c at 2 fb^{-1}
- Kinematic region: $0.44 < |t| < 0.63$ or $0.44 < |u| < 0.63$ in both signal and background

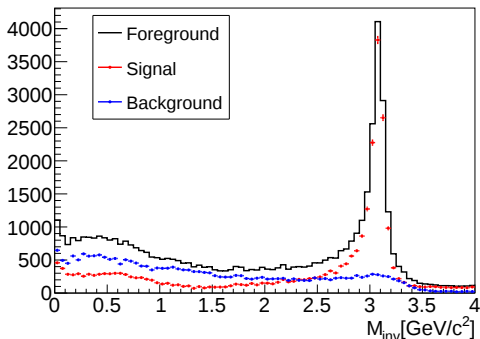
- All charged tracks
- Require EID (Only signal)
- Require $N_{e^+e^-} = 1$
(Truth match for BG)
- Require $N_{\pi^0} > 0$
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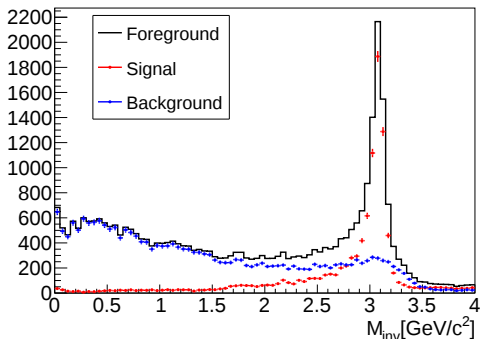
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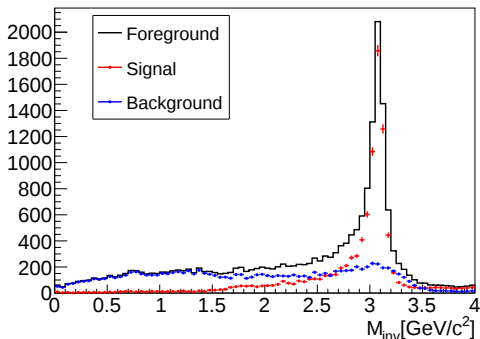
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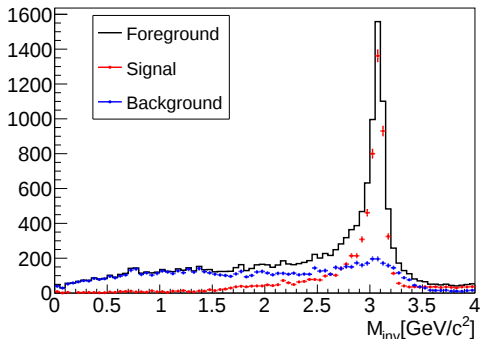
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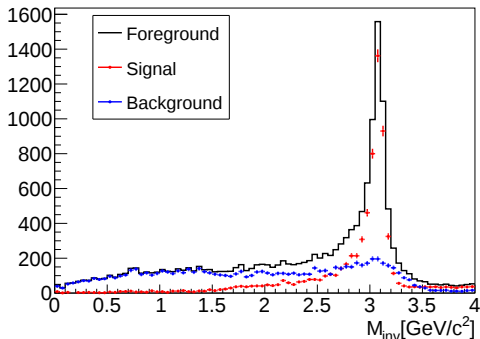
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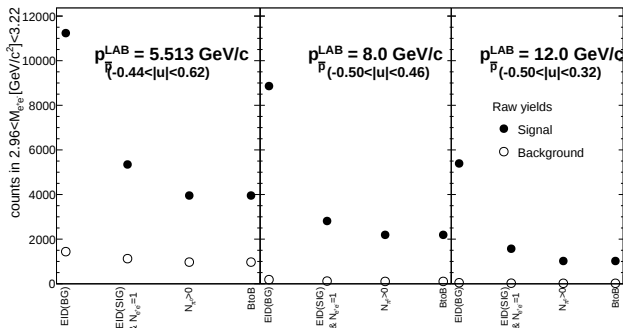
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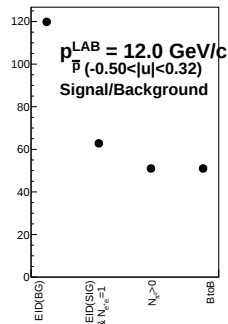
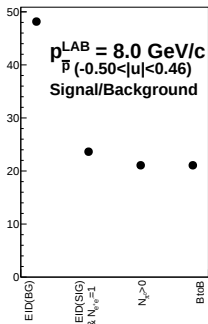
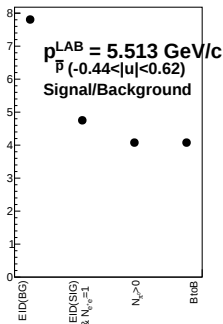


Yield and S/B ratio vs. beam energy



- Yield counts in $2.96 < M_{e^+e^-} [\text{GeV}/c^2] < 3.22$
- Background cross sections already highly suppressed wrt. to signal at higher beam energies
- Most severe efficiency loss comes from EID step
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Other sources of background

- Multi pion events
 - Low probability of being reconstructed as $\pi^+\pi^-\pi^0$
 - Can further be suppressed by missing mass cut
- $\bar{p}p \rightarrow \pi^0\gamma^* \rightarrow \pi^0e^+e^-$
 - Can not be reduced with PID or kinematic cuts
 - x-section under the J/ψ mass peak (2σ) $\approx 0.048 \text{ pb}^{-1}$
 - Rate $\approx < 1\%$ of signal
- J/ψ decay to $\pi^+\pi^-$
 - Very low BR (1.5×10^{-4}), in addition to suppression by EID
 - Not really a background if it could be reconstructed

Summary and outlook

- Test of π -N TDA feasibility in $\bar{\text{P}}\text{ANDA}$ through $\bar{p}p \rightarrow \pi^0 J/\psi \rightarrow \pi^0 e^+ e^-$
 - Full MC used as much as possible
 - Beam energy dependence explored
 - Both forward and backward validity regions
 - Full analysis chain
- Findings
 - Feasible at all beam energies considered
 - $S/B \approx 4$ at $5.513 \text{ GeV}/c^2$, ≈ 20 at $8 \text{ GeV}/c^2$ and ≈ 50 at $12 \text{ GeV}/c^2$,
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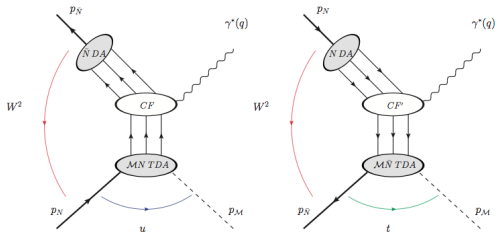
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Nucleon-to-meson TDAs

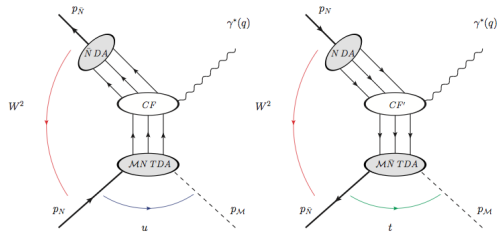
J-P. Lansberg et. al. Phys. Rev. D 75 (2007) 074004



- Occur in collinear factorization of $\bar{p}p \rightarrow \pi^0 \gamma^* \rightarrow \pi^0 e^+ e^-$ and $\bar{p}p \rightarrow \pi^0 J/\psi \rightarrow \pi^0 e^+ e^-$
- Valid only for large values of $s = (p_N + p_{\bar{N}})^2 = W^2$
 - Backward kinematics (small $|u|$), π^0 in direction of nucleon (probes π -N TDAs)
 - Forward kinematics (small $|t|$), π^0 in direction of anti-nucleon (probes π - $\bar{N}$ TDAs)
- CF: Hard sub-process amplitude

Nucleon-to-meson TDAs

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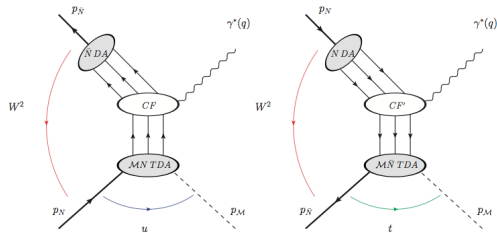
- π -N TDA : Fourier transform of non-diagonal (baryon-to-meson transition) matrix elements of non local three (anti-)quark operators on the light cone:

$$\langle \pi^0(p_\pi) | \varepsilon_{c_1 c_2 c_3} u_\rho^{c_1}(\lambda_1 n) u_\tau^{c_2}(\lambda_2 n) u_\xi^{c_3}(\lambda_3 n) | N^p(p_N, S_N) \rangle$$

parameterized as a function of momentum fractions (x_i), skewness (ξ) and momentum transfer squared ($\Delta^2 = t/u$ in fwd/bwd kinematics resp.) **independent of W^2 and q**

Nucleon-to-meson TDAs

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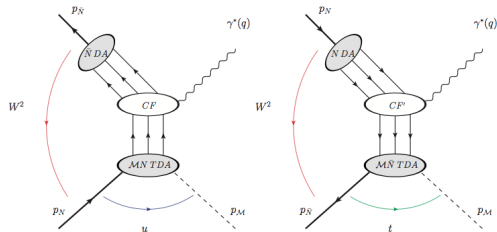


- DAs: Diagonal matrix elements of non local three (anti-)quark operators on the light cone

$$\langle 0 | \varepsilon_{c_1 c_2 c_3} u_{\rho}^{c_1}(\lambda_1 n) u_{\tau}^{c_2}(\lambda_2 n) u_{\xi}^{c_3}(\lambda_3 n) | N^P(p_N, S_N) \rangle$$

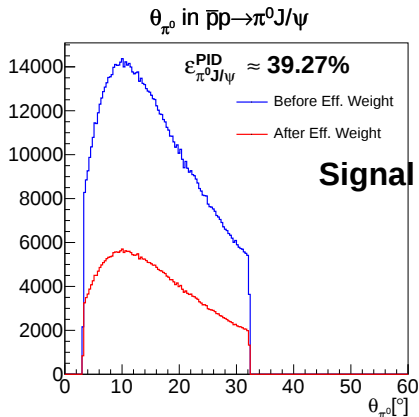
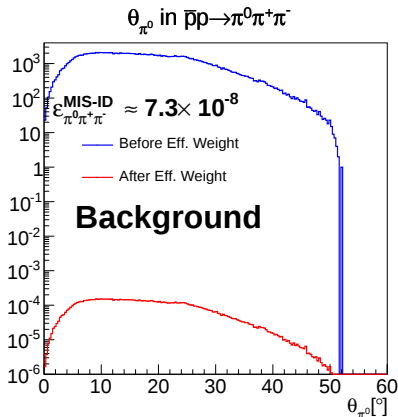
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- Feasibility study completed by M. Carmen Mora Espí (submitted to EPJA)
- Forward and backward kinematic regions, at $s=5 \text{ GeV}^2$ and $s=10 \text{ GeV}^2$
- Expected signal event rate for 2 fb^{-1} is 3350 (@ $s=5 \text{ GeV}^2$) and 465 (@ $s=10 \text{ GeV}^2$)
- S/B is assumed $\sigma(\bar{p}p \rightarrow \pi^0 \gamma^* \rightarrow \pi^0 e^+ e^-) / \sigma(\bar{p}p \rightarrow \pi^0 \pi^+ \pi^-) \approx 10^{-6}$
- Cross-section measurements are readily feasible under this assumption

Reminder from previous presentation



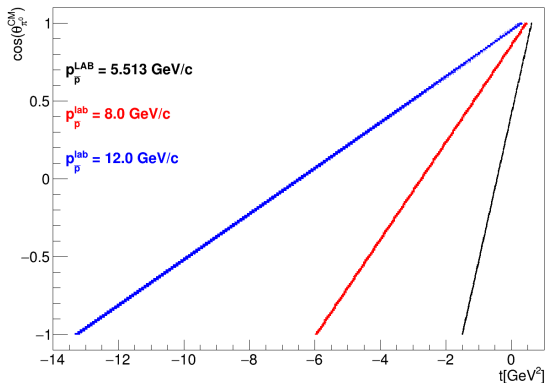
- Estimated counts rates based on parametrized efficiencies on generator output

- $\mathcal{C}_{SIG} = \mathcal{R}_{SIG}^{tot} \cdot \epsilon_M^{SIG} \cdot \epsilon_{\pi^0 \pi^+ \pi^-}^{MIS-ID} \approx 1.3 \times 10^4 \times 0.64 \times 0.39 = 3.3 \times 10^3$
- $\mathcal{C}_{BG} = \mathcal{R}_{BG}^{tot} \cdot \epsilon_t \cdot \epsilon_M^{SIG} \cdot \epsilon_{\pi^0 J/\psi}^{PID} \approx 4.0 \times 10^{11} \times 0.05 \times 7.3 \times 10^{-8} = 1.5 \times 10^3$
- S/B: about $\mathcal{C}_{SIG}/\mathcal{C}_{BG} \approx 2.3$

Improvements from last presentation

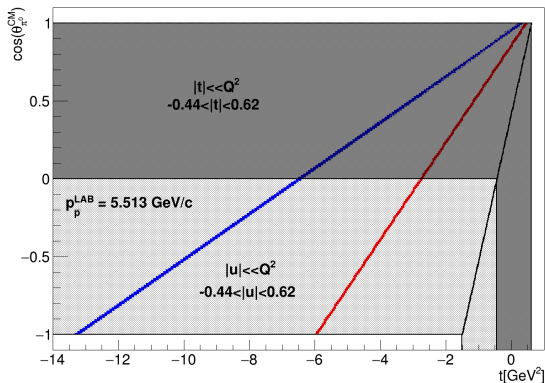
- Signal generation
 - Both small u and t approximations included
 - Three different energies ($p_{\bar{p}} = 5.513, 8$ and 12 GeV/c)
- Full MC (GEANT+PandaROOT reconstruction) used whenever possible
 - Every step except e^+e^- EID efficiency for $\bar{p}p \rightarrow \pi^0 J/\psi \rightarrow \pi^0 e^+e^-$ analysis
 - Every step except $\pi^+\pi^-$ mis-id rate for $\bar{p}p \rightarrow \pi^0 \pi^+\pi^-$ analysis
- Full analysis chain
 - EID and exclusivity cuts
 - Handling $\gamma - \gamma$ combinatoric background
 - Background subtraction

Validity domain at different energies



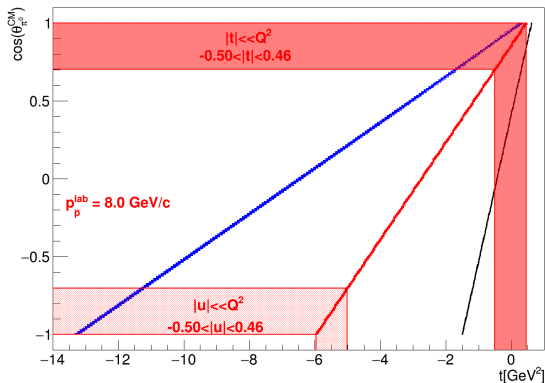
- Phase space coverage strongly dependent on energy
- Low beam energies (eg. $p_p^{lab} = 5.513 \text{ GeV/c}$): all available phase space is within validity range (Small $|t|$ for $0 < \cos \theta_{\pi^0}^{CM} < 1$, small $|u|$ for $-1 < \cos \theta_{\pi^0}^{CM} < 0$)
- Higher beam energies: decay products too forward/backward $\Rightarrow$ poor efficiency
- Number of events simulated normalized to integrated cross section over validity range

Validity domain at different energies



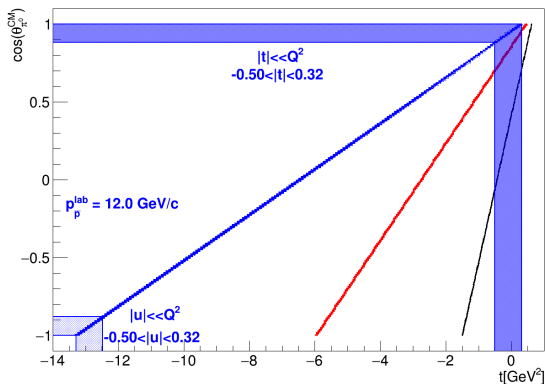
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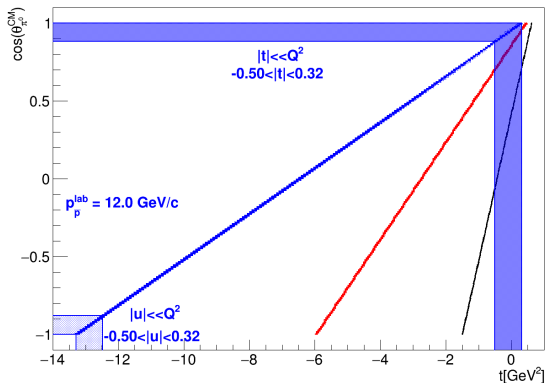
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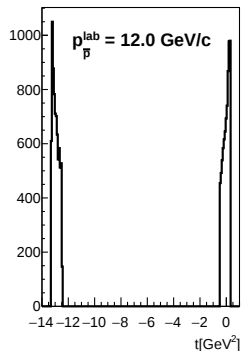
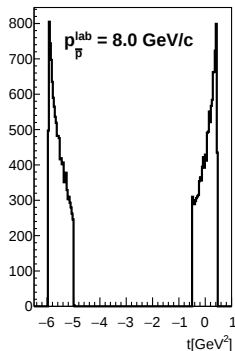
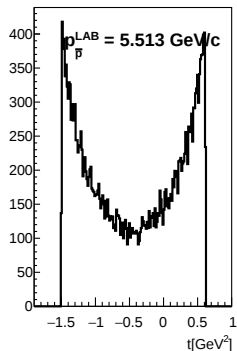
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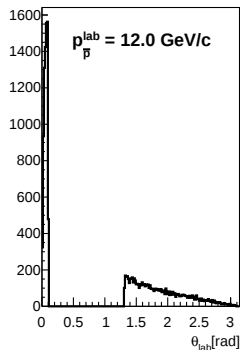
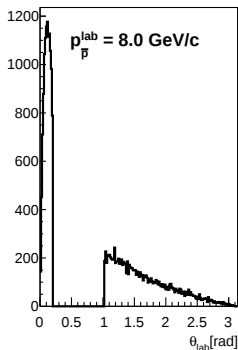
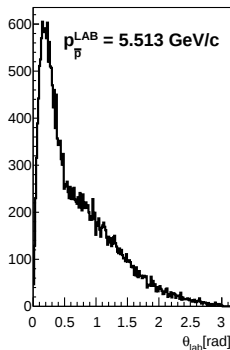
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Generated distributions for signal simulation



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- Integrated rates with assumed luminosity of 2 fb^{-1}
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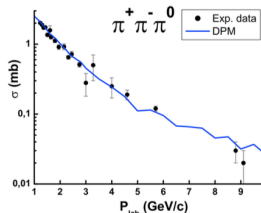


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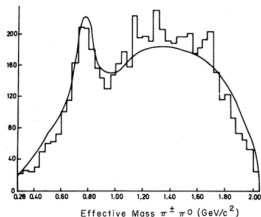
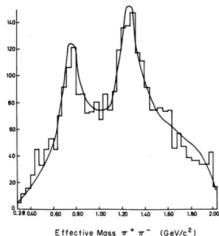
$$\bar{p}p \rightarrow \pi^0 \pi^+ \pi^-$$

- Main background $\pi^0 \pi^+ \pi^-$ similar event topology and kinematically very close to signal
- Cross section relatively well known

A. Galoyan, AIP Conf.Proc.796:79-82,2005

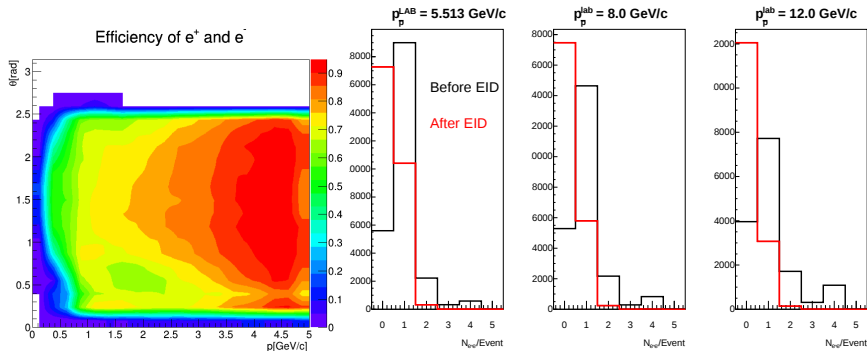


Phys. Rev. D 7, 577 (1974)



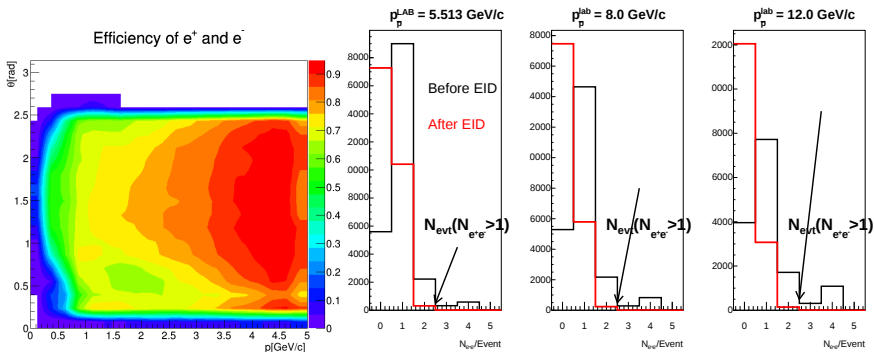
- Data from CERN-HERA 84-01, 1984 and references therein
- Interpolated x-sect at $p_{\bar{p}} = 5.51$ GeV/c of $\sigma = 0.2 \pm 0.05$ mb used for BG rate estimations
- DPM reproduces both cross-sections and invariant mass distributions of data

Electron Identification



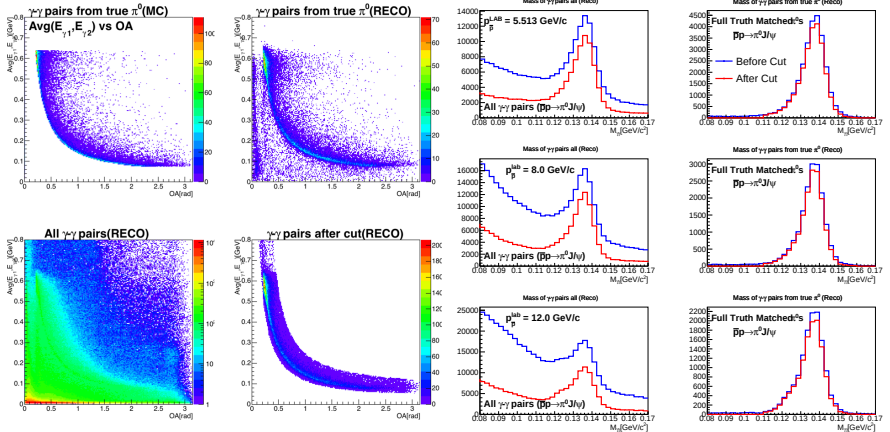
- Signal: Accept e^+e^- with a probability set to their efficiency (function of **true** p and θ)
- Background: Number of events already takes into account EID: accept all tracks
- EID efficiency drops significantly at higher energies
- After EID, require only one candidate e^+e^- in event
 - For $\bar{p}p \rightarrow \pi^0\pi^+\pi^-$ this condition is not applied to avoid double counting
 - Instead, best MC truth matching pair is accepted as the only pair in the event

Electron Identification



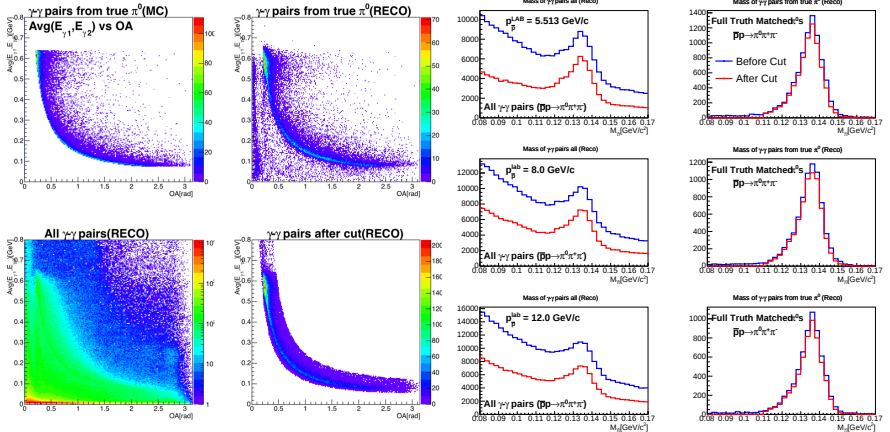
- Signal: Accept e^+e^- with a probability set to their efficiency (function of **true** p and θ)
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π^0 selection



- Significant combinatoric background from neutral candidates
- Distinct signal opening angle - energy correlation from combinatoric background
- Sufficient to reduce background with minimal cost on true π^0 's
- In addition a mass cut of $0.1 < M_{\gamma-\gamma} < 0.165$ is applied before subsequent steps

π^0 selection

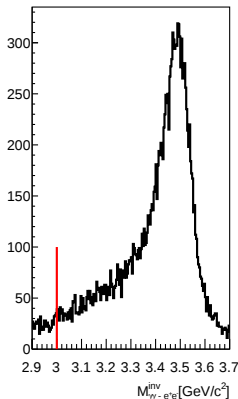


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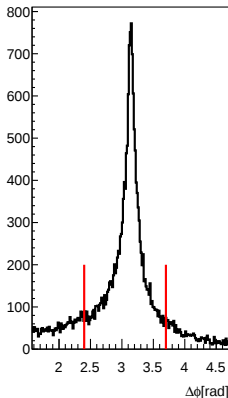
Exclusivity and kinematic cuts

- At this point, there is one e^+e^- pair and any number of $\gamma\gamma$ pairs in event
- The most back to back $\gamma\gamma$ pair is picked
- Potentially an additional cut on $\Delta\phi$ and $\Delta\theta$ could be applied, but is not useful against $\bar{p}p \rightarrow \pi^0\pi^+\pi^-$ (not applied here)

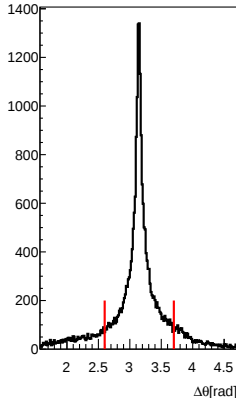
$\theta_{\pi^+} + \theta_{e^-}$ vs. $M_{\pi^+\pi^-}^{inv}$ (from true $J/\psi \rightarrow \pi^0$ (Reco))



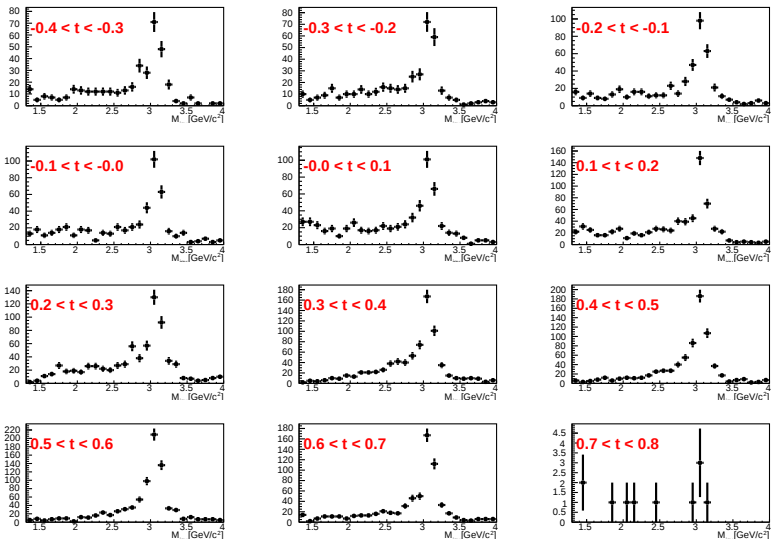
$\theta_{\pi^+} + \theta_{e^-}$ vs. $\phi_{\pi^+} - \phi_{\pi^-}$ (from true $J/\psi \rightarrow \pi^0$ (Reco))



$\theta_{\pi^+} + \theta_{e^-}$ vs. $\phi_{\pi^+} - \phi_{\pi^-}$ (from true $J/\psi \rightarrow \pi^0$ (Reco))

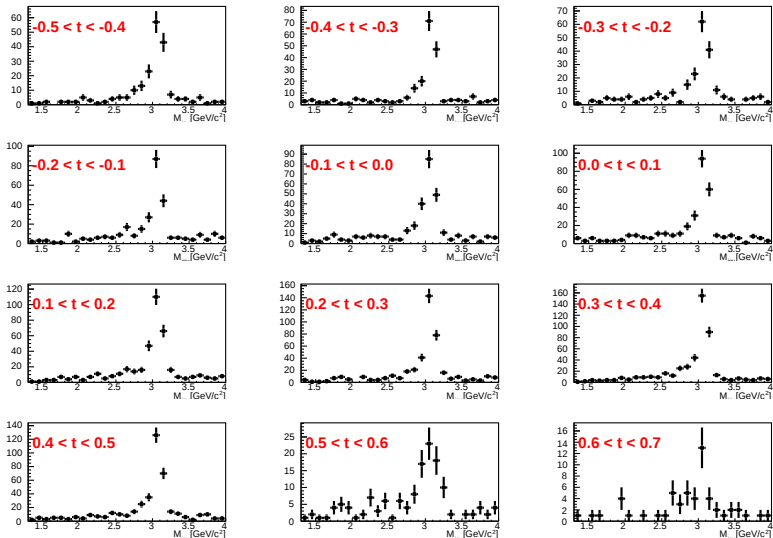


Differential mass plots at $p_{\bar{p}} = 5.513 \text{ GeV}/c$



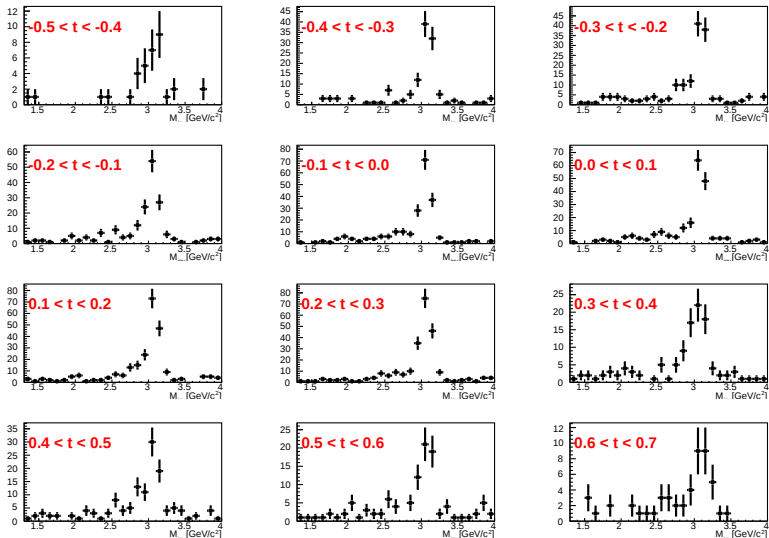
- Non negligible background that can be subtracted

Differential mass plots at $p_{\bar{p}} = 8.0 \text{ GeV}/c$



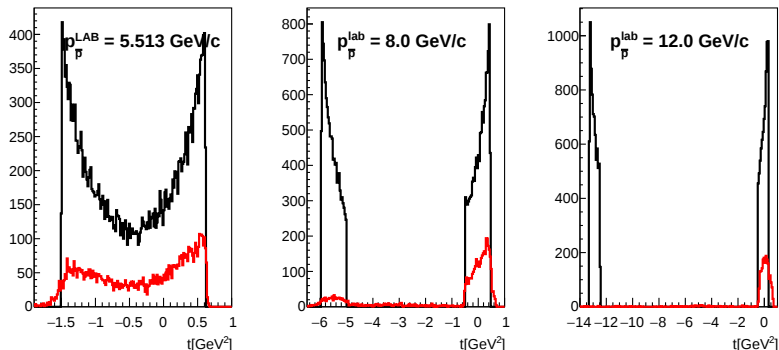
- Background is less of an issue at higher beam energies

Differential mass plots at $p_{\bar{p}} = 12.0 \text{ GeV}/c$



- Background is less of an issue at higher beam energies

t dependence of efficiency



- Reasonable efficiency at lowest beam energy
- Very small to no efficiency for the small $|u|$ validity range at higher beam energies
- NB: cutoffs in t distribution are **NOT** an experimental limitation, but rather imposed by the validity range of the TDA formalism used for event generation