Feasibility of exploration of pion-nucleon TDAs trough $\bar{p}p \to \pi^0 J/\psi \to \pi^0 e^+ e^-$ in the di-electron channel with $\bar{\text{P}}$ANDA

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

Ermias ATOMSSA

Institut de Physique Nucléaire d'Orsay

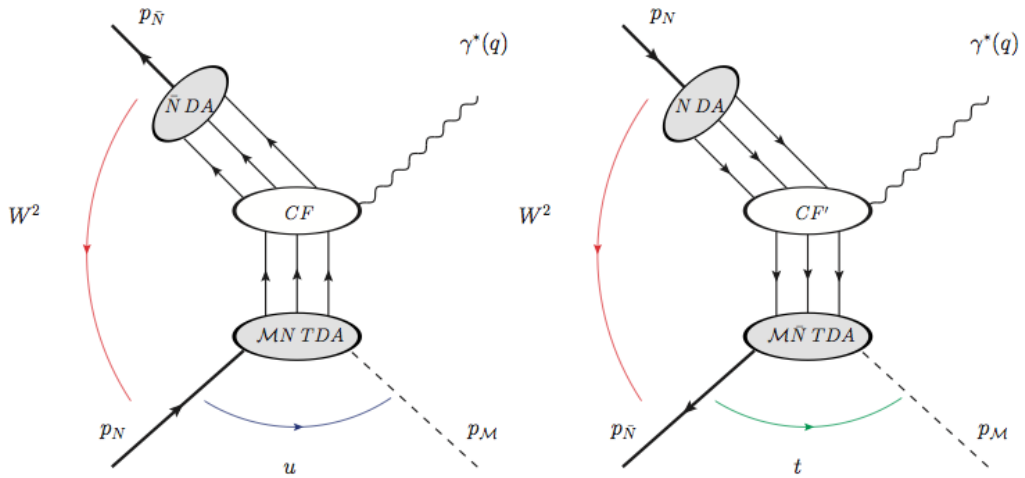
September 9, 2014

Outline

- Transition Distribution Amplitudes
- Event Generation (Signal and Background)
- Efficiency and rejection estimation
- Effective signal to background

Nucleon-to-meson TDAs

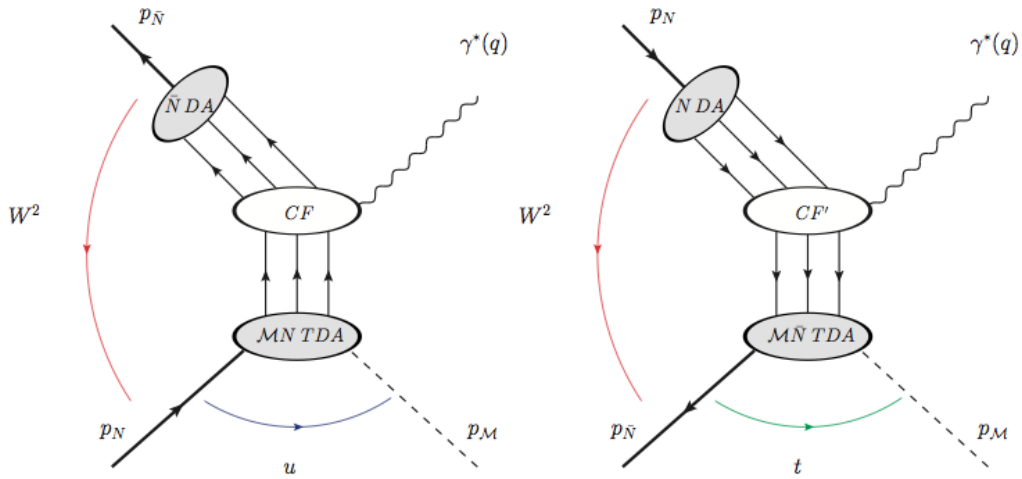
J-P. Lansberg et. al. Phys. Rev. D 75 (2007) 074004



- Occur in collinear factorization of $\bar{p}p \to \pi^0\gamma^* \to \pi^0 e^+e^-$ and $\bar{p}p \to \pi^0 J/\psi \to \pi^0 e^+e^-$
- 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

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



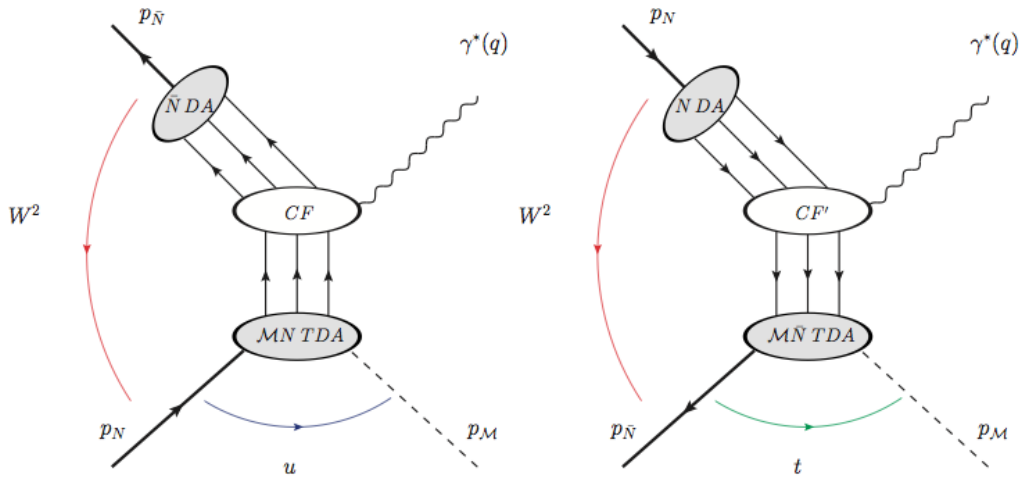
- π-N TDA : Fourier transform of non-diagonal (baryon-to-meson transition) matrix elements of non local three (anti-)quark operators on the light cone:

$$< \pi^0(p_\pi)|\varepsilon_{c_1c_2c_3}\, u_\rho^{c_1}(\lambda_1 n) u_\tau^{c_2}(\lambda_2 n) u_\xi^{c_3}(\lambda_3 n)|N^p(p_N, S_N) >$$

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

Nucleon-to-meson TDAs

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

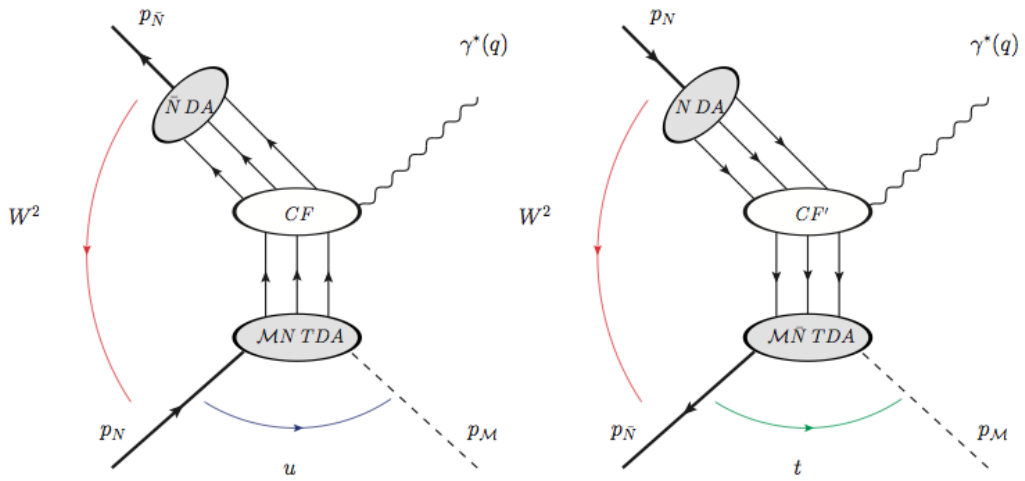


- DAs: Diagonal matrix elements of non local three (anti-)quark operators on the light cone

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

Nucleon-to-meson TDAs

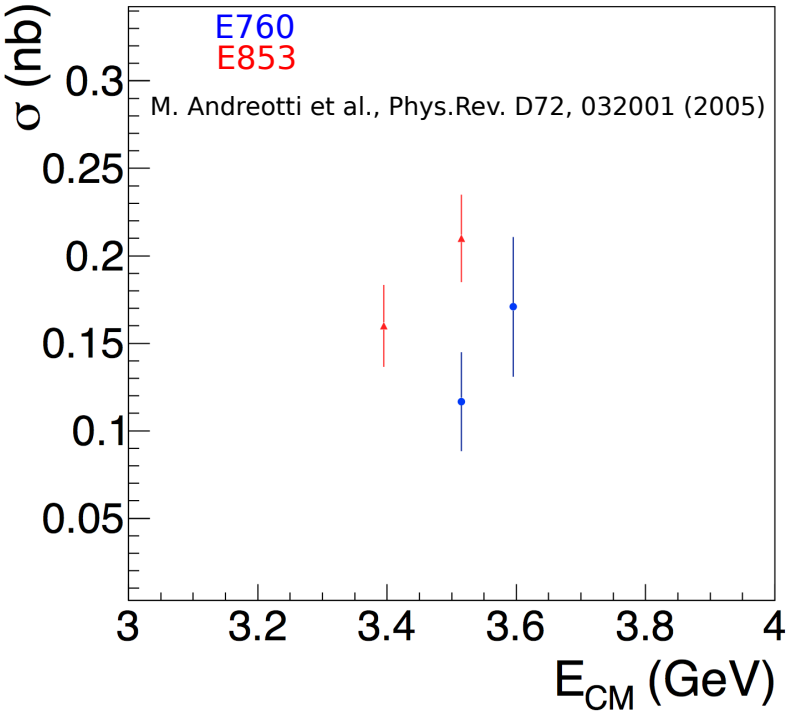
J-P. Lansberg et. al. Phys. Rev. D 75 (2007) 074004

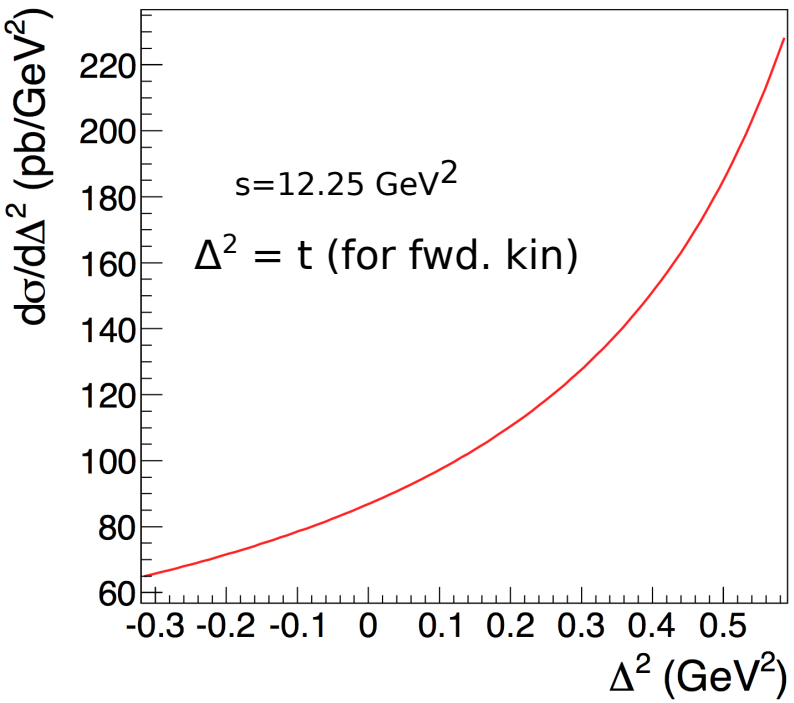


- Feasibility study completed by M. Carmen Mora Espí (submitted to EPJA)
- Forward and backward kinematic regions, at s=5 GeV^2 and s=10 GeV^2
- Expected signal event rate for 2 fb^{-1} is 3350 (@ s=5 GeV^2) and 465 (@ s=10 GeV^2)
- S/B is assumed $\sigma(\bar{p}p \to \pi^0\gamma^* \to \pi^0 e^+e^-)/\sigma(\bar{p}p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

π-N TDAs in $\bar{p}p \to \pi^0 J/\psi \to \pi^0 e^+ e^-$

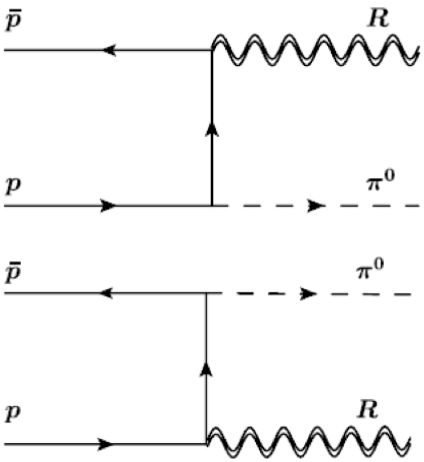
- Higher signal cross section and large q^2 $(= M^2_{J/\psi})$ -B. Pire et. al. Physics Letters B 724 (2013) 99107
- Reduces uncertainty on DAs by using $J/\psi \to p\bar{p}$ partial decay width data

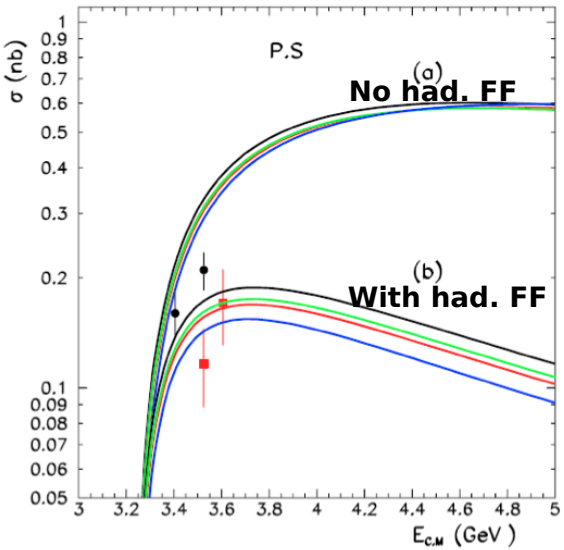


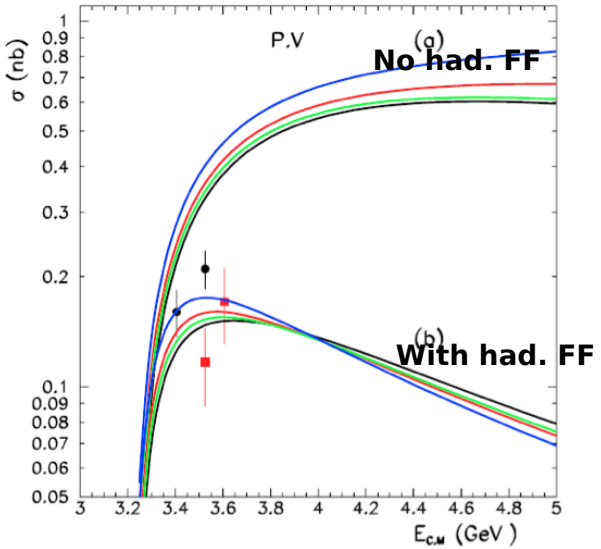


- X-sect. predictions reproduce existing data from Fermilab at $\sqrt{s} = 3.5$ GeV (M_{h_c})
- Test of universality of TDAs by comparing to $\bar{p}p \to \pi^0 \gamma^* \to \pi^0 e^+ e^-$ at different q^2

Alternative models $\bar{p}p \to \pi^0 J/\psi \to \pi^0 e^+ e^-$

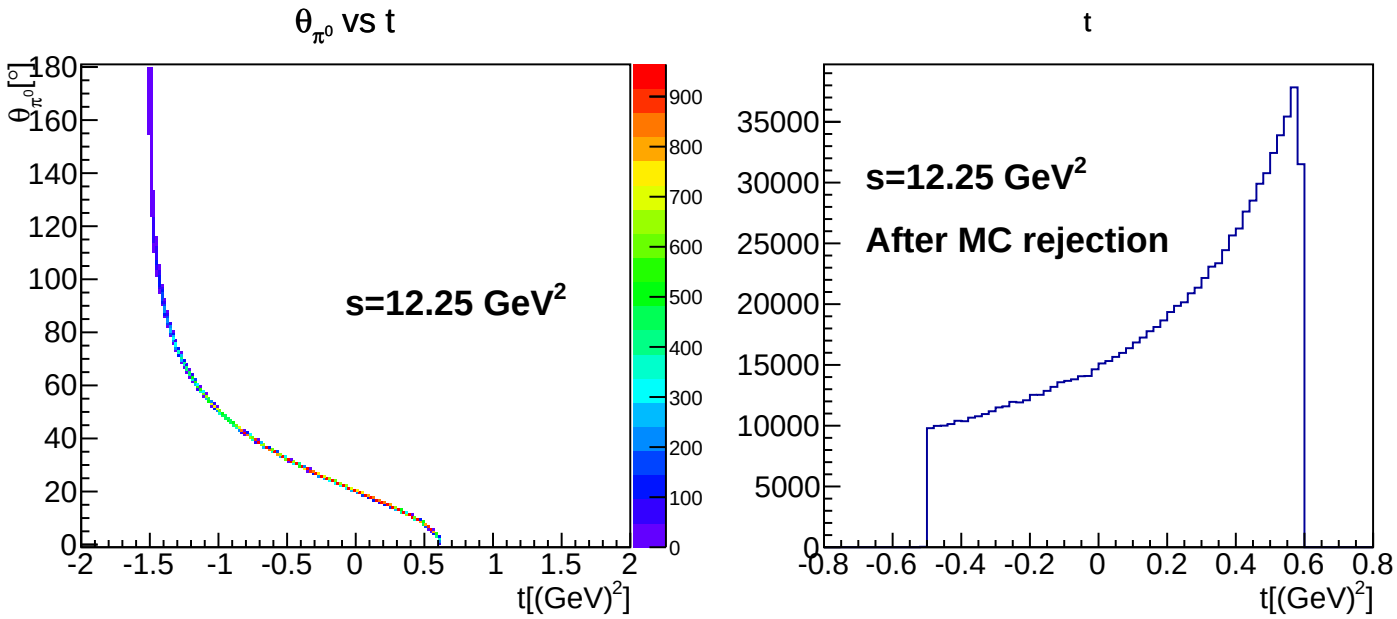






- Alternative calculation based on effective Lagrangian approach
  (J. Van de Wiele, S. Ong Eur.Phys.J. C73, 2640 (2013))
- Different colors $\Longrightarrow$ different parameters of $\bar{p}pJ/\psi$ Lagrangian
- Good description of Fermilab data with both PS and PV πNN coupling
- However a dipole hadronic form factor at the πNN vertex to take into account the offshell nature of the exchanged nucleon is required to reproduce the data

Event generation and rate estimates for $\bar{p}p \to \pi^0 J/\psi \to \pi^0 e^+ e^-$



- New event generator based on TDA model for $\bar{p}p \to \pi^0 J/\psi \to \pi^0 e^+ e^-$ reaction (collaboration K. Semenov/B. Ma)
- $s = 12.25$ GeV^2 picked to correspond to Fermilab data points

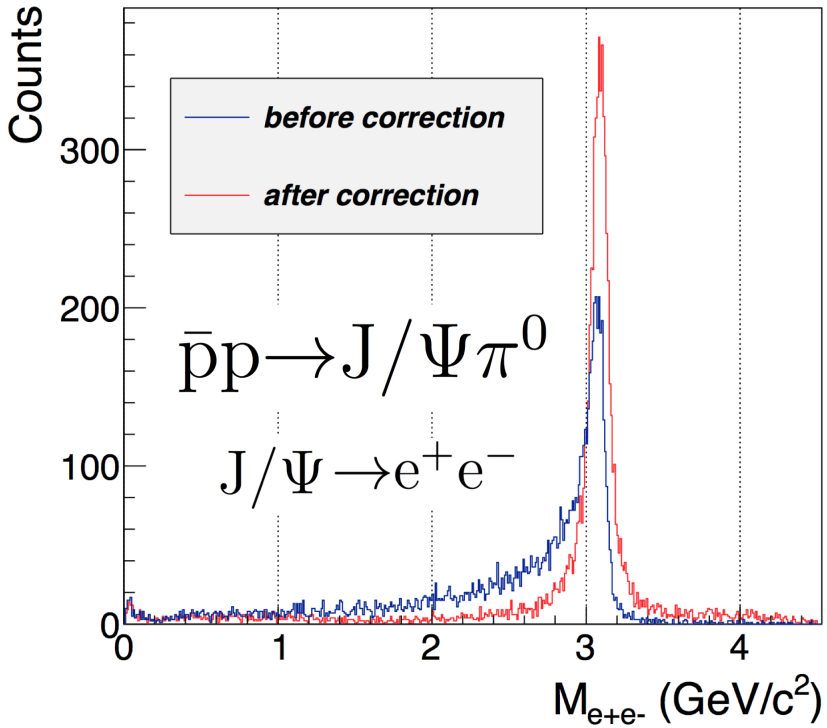
Expected signal rate in forward kinematics for s=12.25 GeV^2 for 2 fb^{-1} with 100% Acc·ε:

$$\mathcal{R}_{SIG}^{tot} = \mathcal{L}_{int}\sigma \mathrm{BR} = 2fb^{-1} \cdot 105\mathrm{pb} \cdot 5.94\% \approx 13\mathrm{k}$$

J/ψ reconstruction in $\bar{\text{P}}$ANDA

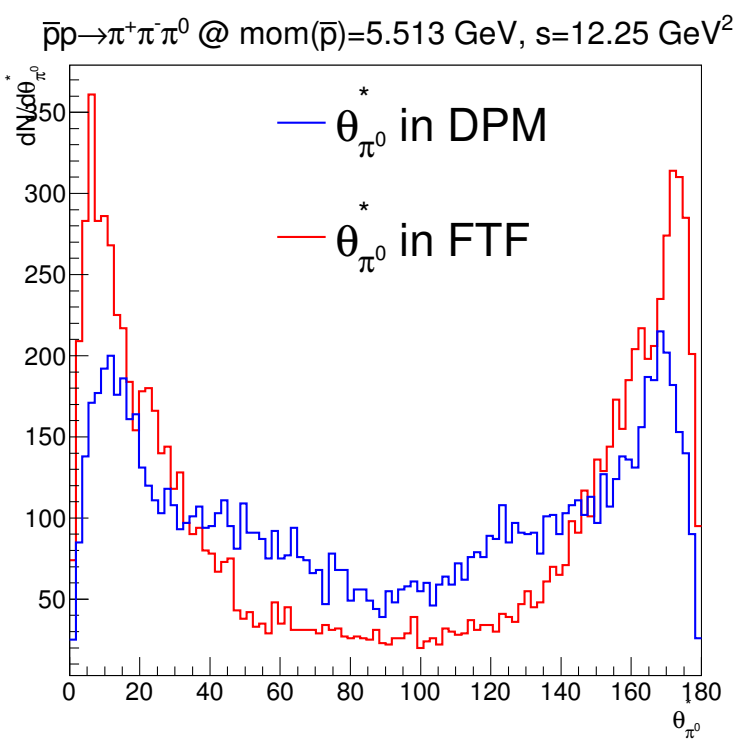
- For optimal S/B, it is crucial to have best possible J/ψ mass resolution
- In PandaROOT momentum resolution of electrons can be improved by correcting for Bremsstrahlung energy loss (Thesis Work by B. Ma to be defended on 23/09/2014)
- Allows to improve mass cut efficiency on e^+e^- from J/ψ by 70%
- A mass cut of $2.96 < M_{inv} < 3.22$ has an efficiency of $\varepsilon_M^{SIG} = 64\%$ for signal events

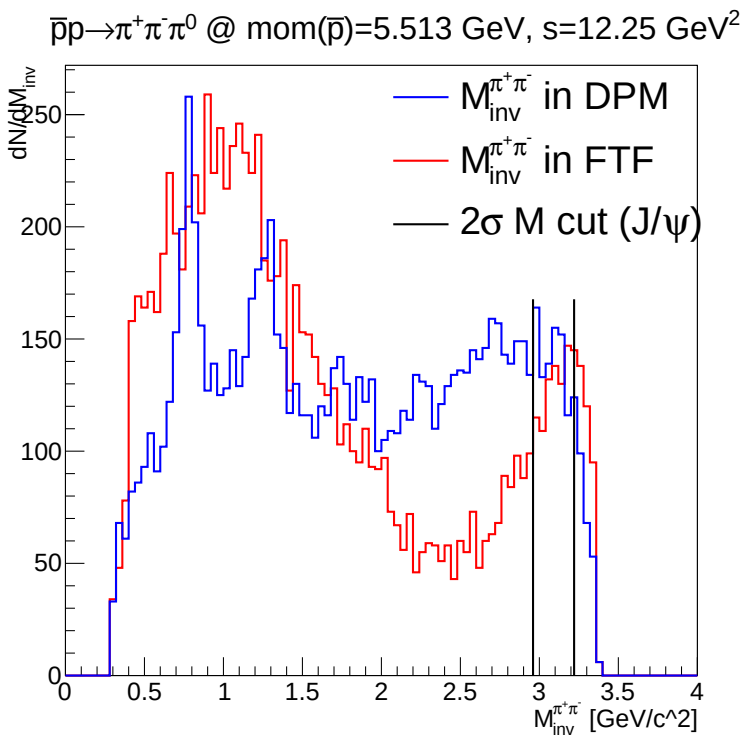
$$\Longrightarrow \mathcal{R}_{SIG} \cdot \varepsilon_M^{SIG} = 8.3\text{k events}$$



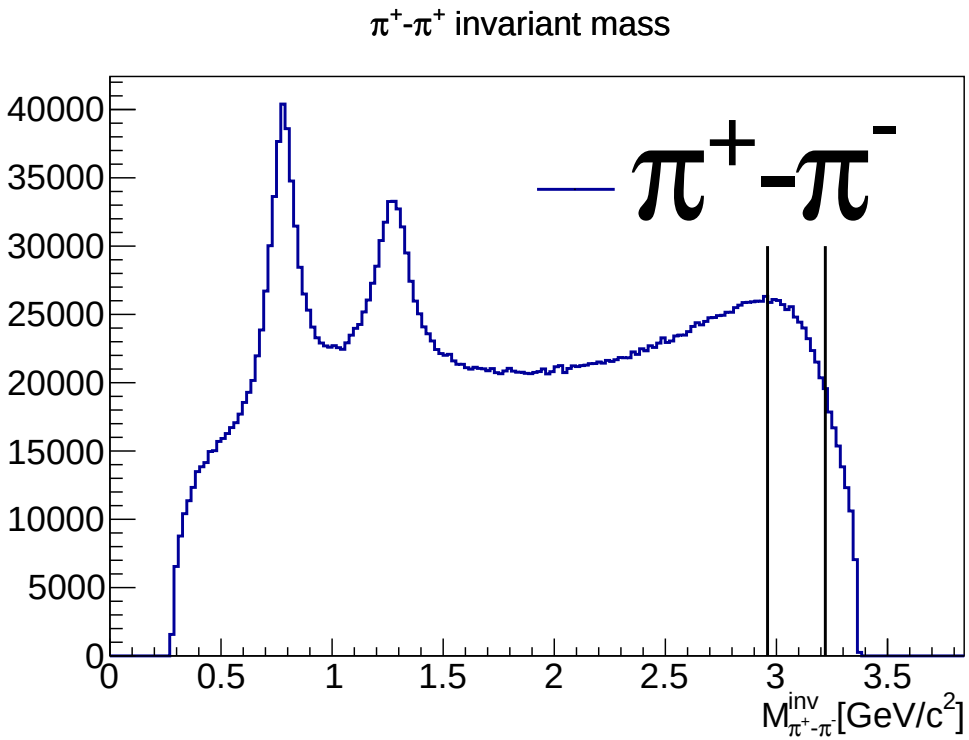
Background

- Main background $\pi^0\pi^+\pi^-$ similar event topology and kinematically very close to signal
- Cross section relatively well known (cf. slide 11)
- Rate estimation restricted to $-0.5 < t[\mathrm{GeV}^2] < 0.6$, $2.96 < M_{inv}[\mathrm{GeV}/c^2] < 3.22$
- Rejection from J/ψ mass cut is ≈90%, compatible between FTF and DPM



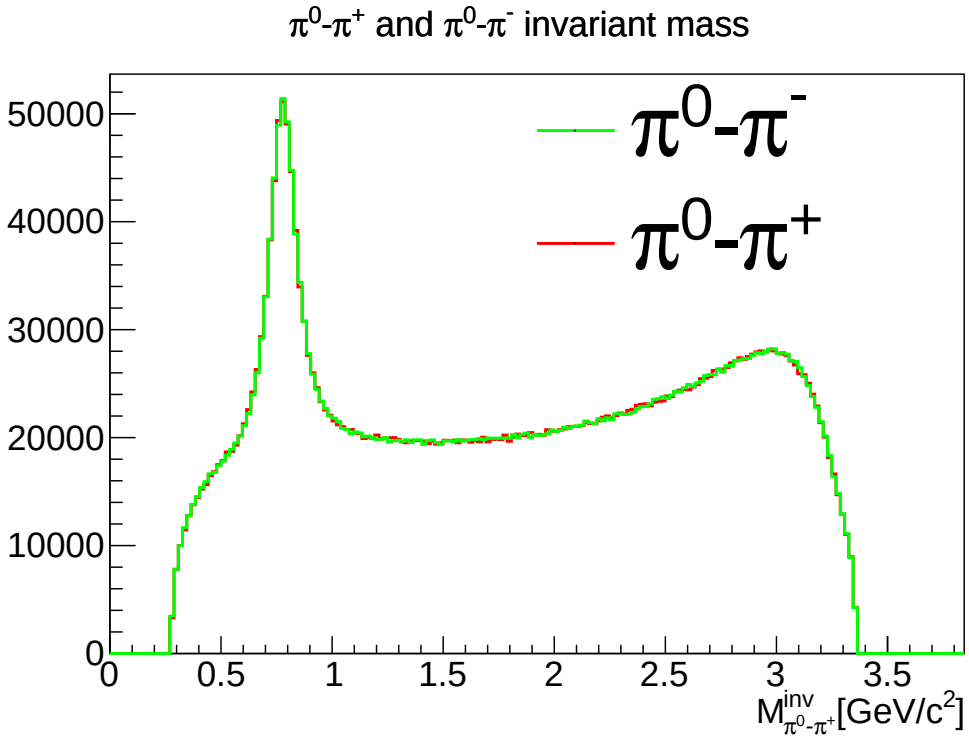


π^0 $\pi^+\pi^-$ Background distributions from DPM



- ρ and f_0 resonances peaks in $\pi^+\pi^-$
- Contribute outside the J/ψ mass selection window $2.96 < M_{inv} < 3.22$

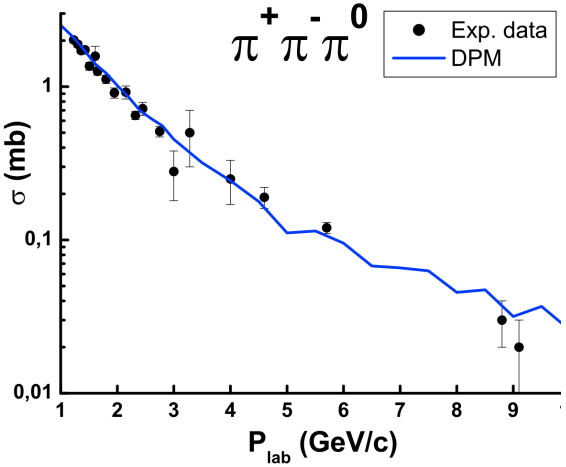
$\pi^0\ \pi^+\pi^-$ Background distributions from DPM



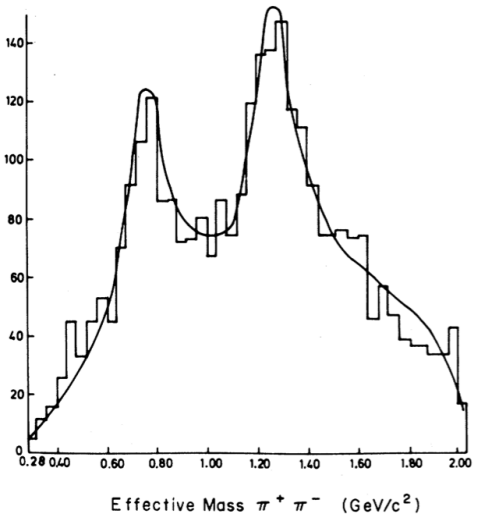
- ρ and f_0 resonances peaks in $\pi^+\pi^-$
- Contribute outside the J/ψ mass selection window $2.96 < M_{inv} < 3.22$
- $\rho^+ and \rho^-$ resonance peaks in $\pi^0\pi^+$ and $\pi^0\pi^-$ respectively
- Provide a means to empirically control background contamination

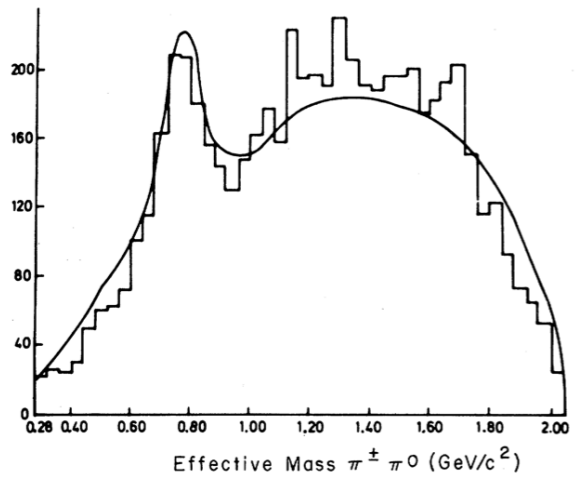
Existing data on $\pi^0\pi^+\pi^-$

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
- DPM reproduces both cross-sections and invariant mass distributions of data
- Closest data points to s=12.25 GeV/c^2:
  - $\sigma(p_{\bar{p}} = 4.6 \text{ GeV/c}) = 0.19 \pm 0.03$ mb (Everett et al. Nucl. Phys. B. 73, 448)
  - $\sigma(p_{\bar{p}} = 5.7 \text{ GeV/c}) = 0.12 \pm 0.01$ mb (Braun et al., Nucl. Phys. B 95, 481)
- Interpolated x-sect at $p_{\bar{p}} = 5.51$ GeV/c of σ =0.2±0.05 mb used for BG rate estimations

Background rate estimates

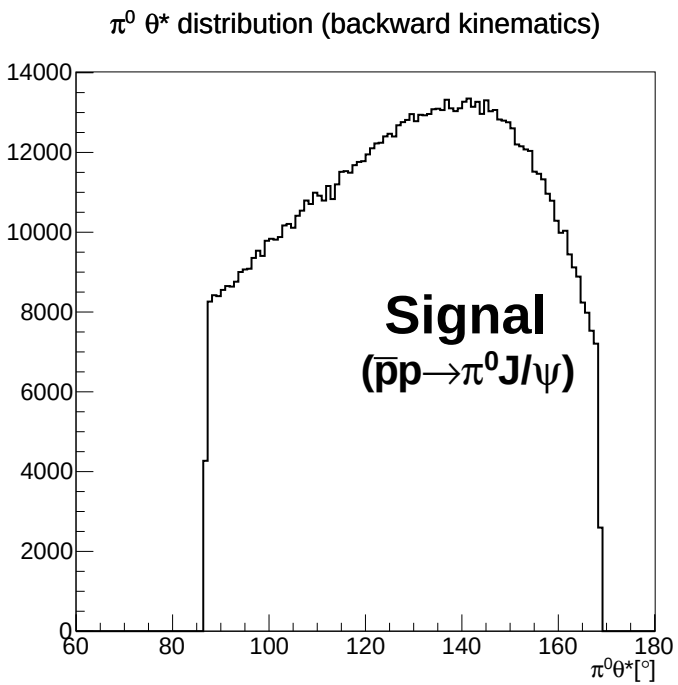
- Total rate of $\bar{p}p \rightarrow \pi^0\pi^+\pi^-$ for 2 fb^{-1} integrated luminosity

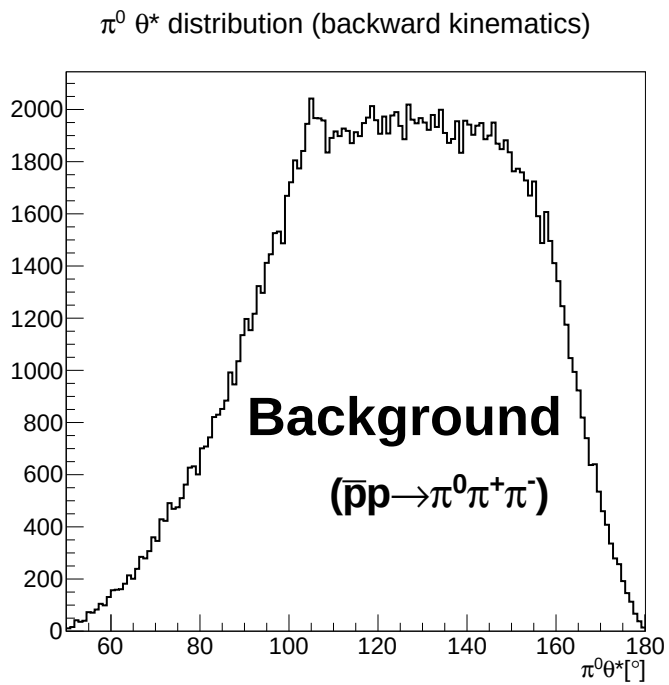
$$\mathcal{R}^{BG}_{tot} = \mathcal{L}_{int}\sigma = 2fb^{-1} \cdot \ 0.2 \pm 0.05mb \ \approx \ (4 \pm 0.1) \times 10^{11}$$

- Reduction by 95% for forward π^0 emission after J/ψ mass cut ($\varepsilon_t \cdot \varepsilon^{BG}_M \approx 5\%$)
- Expected background rate that has to be dealt with PID and kinematic fits:

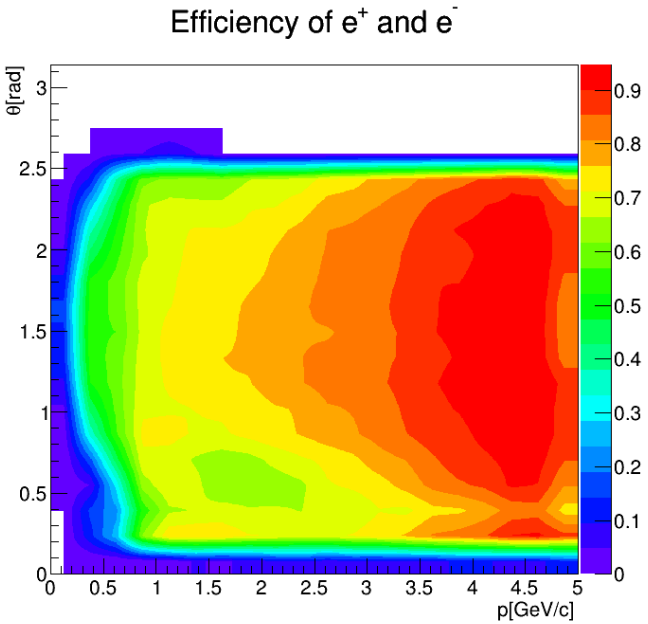
$$\mathcal{R} = \mathcal{R}^{BG}_{tot} \cdot \varepsilon_t \cdot \varepsilon^{BG}_M = (4 \pm 0.1 \times 10^{11}) \cdot 5\% \ \approx \ (2 \pm 0.05) \times 10^{10}$$

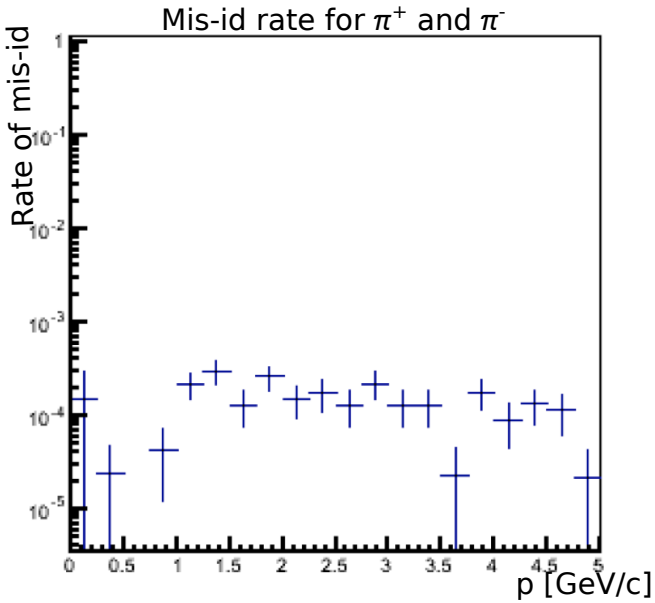
  which gives S/B ratio before PID of $\approx 8.2\times10^3/2\times10^{10} \approx 4.1\times10^{-7}$
- PID will therefore be critical for this measurement





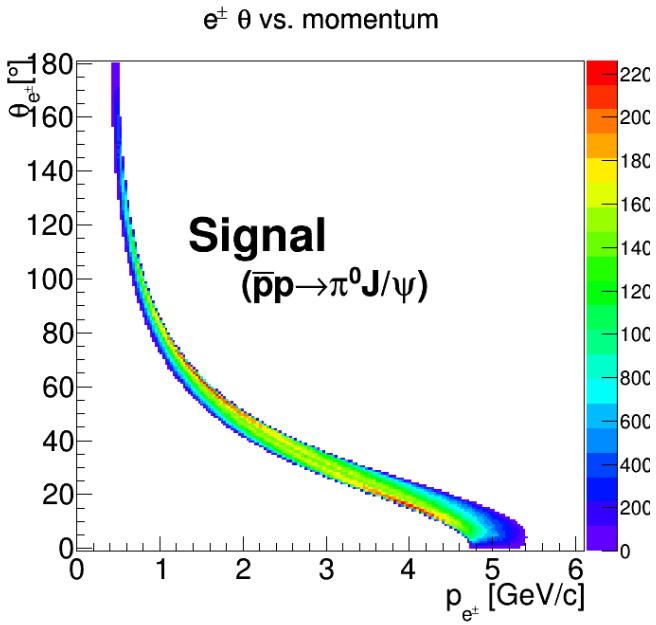
PID efficiency for electrons and charged pions

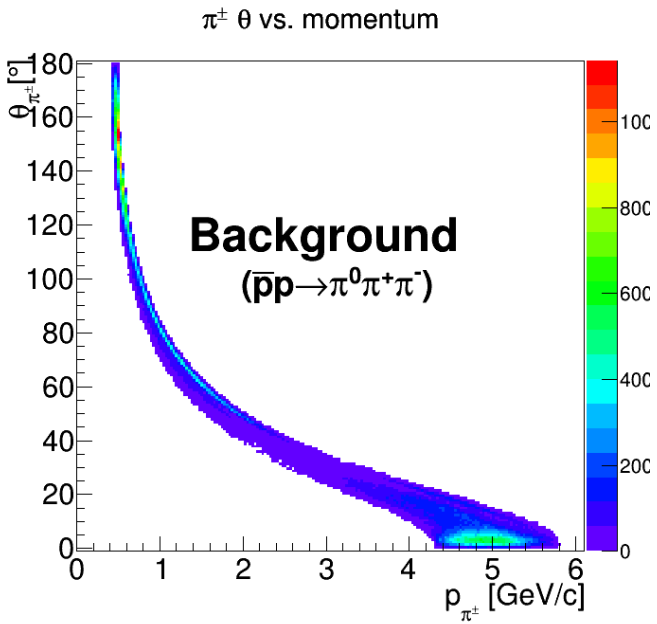




- Effect of PID cuts studied using parametrized efficiency and rejection
- The parametrization was based on a Bayesian classifier constructed by R. Kunne using response to electrons and pions in a full MC (using EMC, STT, DIRC and DISC)
- Efficiency of $e^{\pm}$ and mis-id rate of $\pi^{\pm}$ were calculated as a function of (θ,p) and p respectively by requiring a combined probability of 99.9% of being an electron
- For each track from the simulation, a weight proportional to the corresponding efficiency was applied

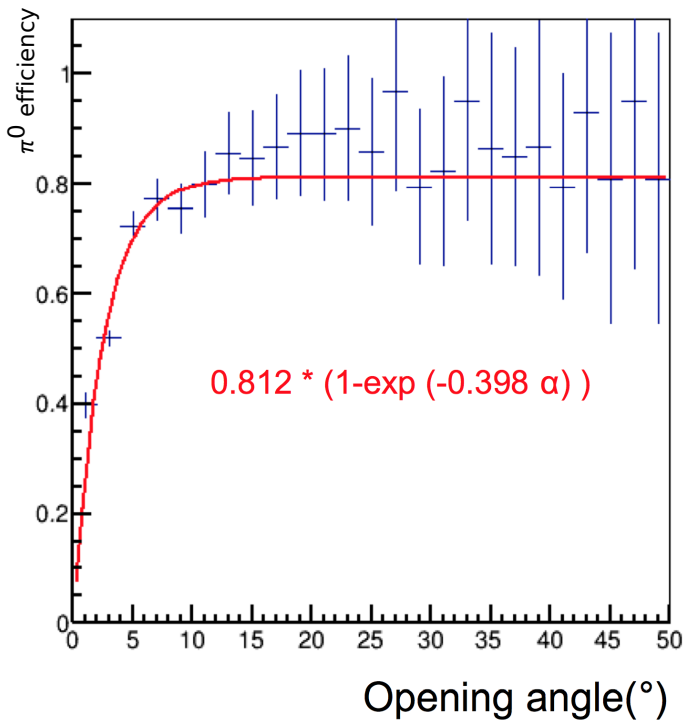
PID efficiency for electrons and charged pions





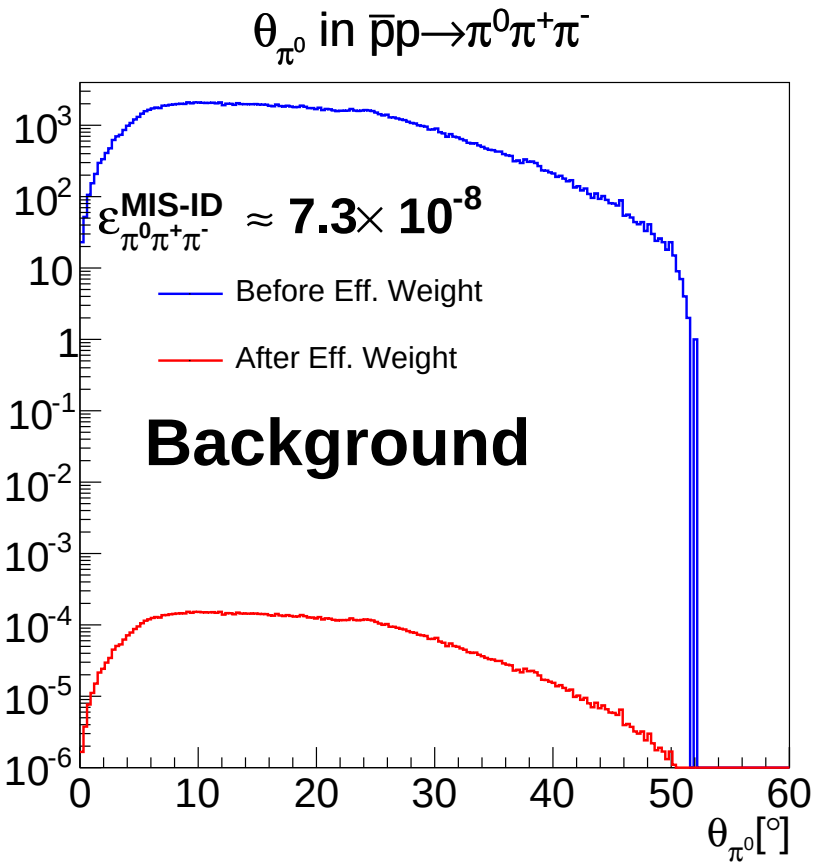
- Effect of PID cuts studied using parametrized efficiency and rejection
- The parametrization was based on a Bayesian classifier constructed by R. Kunne using response to electrons and pions in a full MC (using EMC, STT, DIRC and DISC)
- Efficiency of $e^{\pm}$ and mis-id rate of $\pi^{\pm}$ were calculated as a function of (θ,p) and p respectively by requiring a combined probability of 99.9% of being an electron
- For each track from the simulation, a weight proportional to the corresponding efficiency was applied
- Low efficiency for $e^{\pm}$ below $\approx$0.5 GeV doesn't affect efficiency for signal

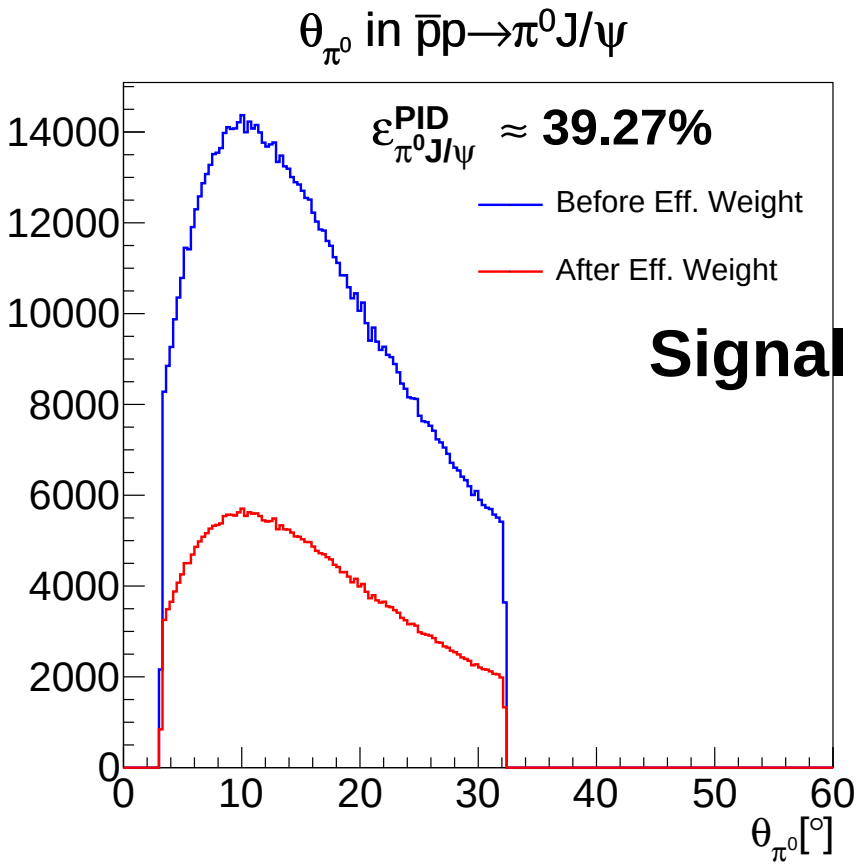
PID Efficiency for π^0



- cf. Presentation by R. Kunne Apr. 28 '04 @ analysis meeting
- Most of the efficiency variation ultimately comes from opening angle
- Minimum opening angle of $\approx 12^\circ$ ensures most of the signal lies in the plateau region of the efficiency (not affected by drop of efficiency at low opening angles)

Efficiency estimate of $\bar{p}p \rightarrow \pi^0 J/\psi \rightarrow \pi^0 e^+ e^-$ and $\bar{p}p \rightarrow \pi^0 \pi^+ \pi^-$





Effective Signal/Background

- Estimated S/B counts ratio based on ingredients presented above
  - Signal counts ($\mathcal{C}_{SIG}$)

$$\mathcal{C}_{SIG} = \mathcal{R}^{tot}_{SIG} \cdot \varepsilon^{SIG}_{M} \cdot \varepsilon^{MIS-ID}_{\pi^0\pi^+\pi^-} \approx 1.3 \times 10^4 \times 0.64 \times 0.39 = 3.3 \times 10^3$$

  - Background counts ($\mathcal{C}_{BG}$):

$$\mathcal{C}_{BG} = \mathcal{R}^{tot}_{BG} \cdot \varepsilon_t \cdot \varepsilon^{SIG}_{M} \cdot \varepsilon^{PID}_{\pi^0 J/\psi} \approx 4.0 \times 10^{11} \times 0.05 \times 7.3 \times 10^{-8} = 1.5 \times 10^3$$

- S/B will therefore come out to about $\mathcal{C}_{SIG}/\mathcal{C}_{BG} \approx 2.3$
- Further improvement should be possible with kinematic fits
- Background rejection at the percent level probably out of reach

  $\Longrightarrow$ precise measurement and subtraction of $\pi^0\pi^+\pi^-$ background needed.

Summary

- TDAs are universal non perturbative hadronic matrix elements that appear in factorized calculations of amplitudes that carry information about the structure of hadrons through correlations between constituents
- In P̄ANDA , TDAs can be accessed through $\bar{p}p \to \pi^0\gamma^* \to \pi^0 e^+e^-$ or $\bar{p}p \to \pi^0 J/\psi \to \pi^0 e^+e^-$ (the later of which is more favorable due to higher S/B under the J/ψ peak)
- Good significance requires high performance PID, in particular $\pi^\pm$ rejection will be critical
- Rough estimation for forward kinematics based on parameterized efficiencies and rejections
  - S/B ratio of 2.3 before kinematic fit
  - Total count of events will be about 3.3k for 2 fb^{-1}
  - Needs some refinement, but orders of magnitude are realistic
- Background rejection at the percent level probably out of reach