A new method to improve the electron momentum reconstruction in PANDA

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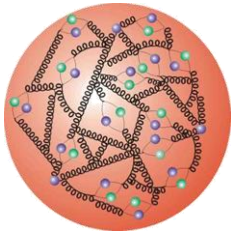
Outline

- Introduction
  - Physics motivations for nucleon structure studies with PANDA
  - PANDA detectors and the tracking system
- Electron momentum reconstruction
  - The problem with Bremsstrahlung
  - A new method to correct its effect
  - Results and applications
    - ✓ Form factors study ($\bar{p}p \rightarrow e^+e^-$)
    - ✓ Transition Distribution Amplitudes ($\bar{p}p \rightarrow J/\Psi\pi^0$)
- Conclusions

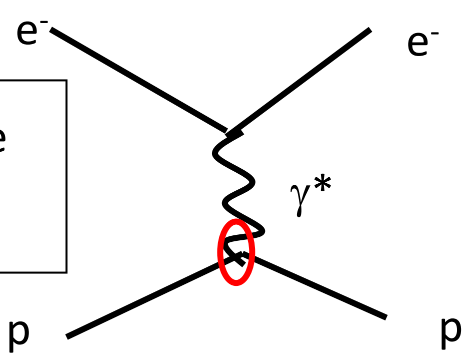
Nucleon form factors

- The nucleon electromagnetic internal structure is characterized by two form-factors : $G_E(q^2)$ (electric), $G_M(q^2)$ (magnetic)
- q^2 is the four-momentum squared transferred at the γ^*-hadron vertex = squared mass of the virtual photon $q^2=M_\gamma^2$



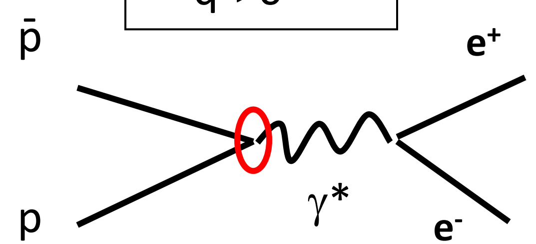
Space-like

$q^2 < 0$



$G_M(0) = \mu_p$
$G_E(0) = 1$

Time-Like
$q^2>0$



Form factors are real

Form factors are complex for $q^2 > 4m_\pi^2$

Time-Like Form Factor measurement with PANDA

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Cross-sections: $\bar{p}p \rightarrow e^+e^-$

$$\boxed{\sigma_{tot} \sim |G_{eff}|^2 = \frac{2\tau |G_M|^2 + |G_E|^2}{2\tau + 1}}$$

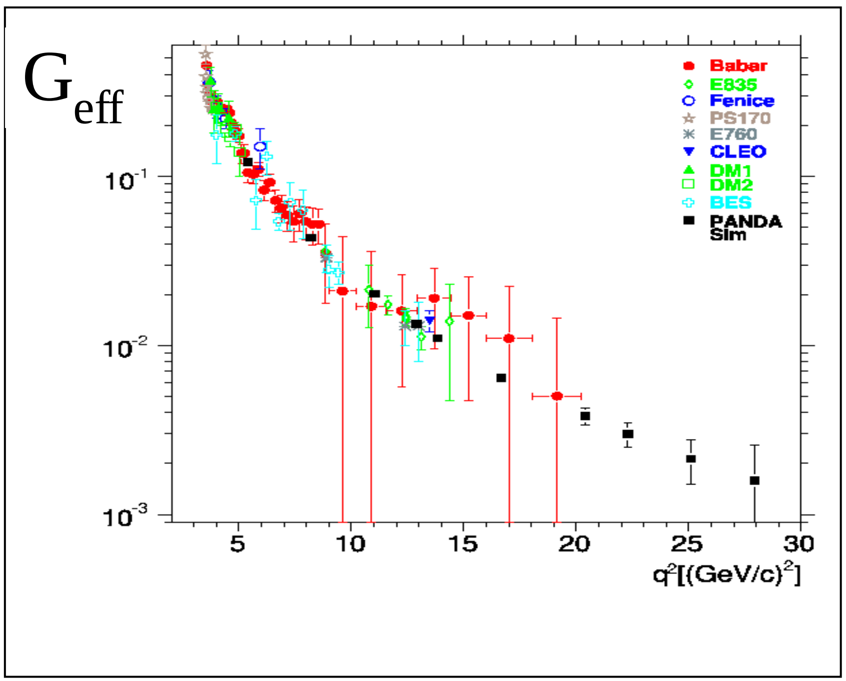
$$\tau = \frac{q^2}{4M_p^2}$$

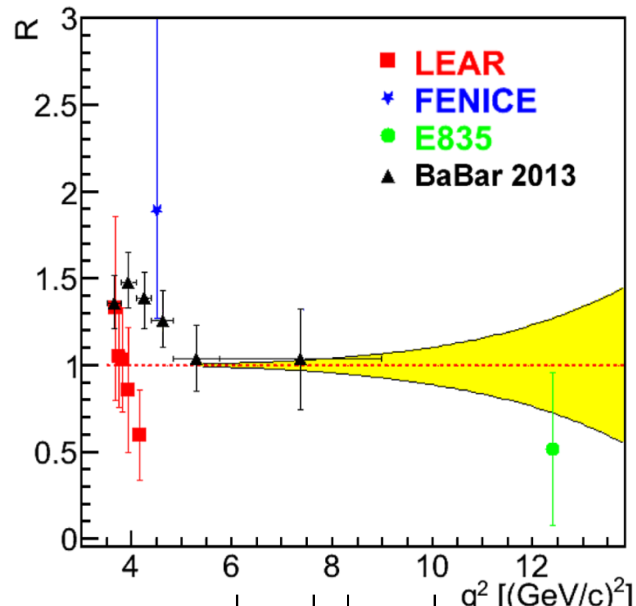
angular distributions: $\bar{p}p \rightarrow e^+e^-$

$$\boxed{\frac{d\sigma}{d(\cos\theta_{CM})} \sim \left[\tau |G_M^{TL}|^2 (1+\cos^2\theta_{CM}) + |G_E^{TL}|^2 \sin^2\theta_{CM}\right]}$$

A.Zichichi et al., Nuovo Cimento 24 (1962) 170
Egle Tomasi-Gustafsson et al., EPJA24 (2005) 419

Estimates for an integrated luminosity of 2fb^{-1}





$$R = |G_E| / |G_M|$$

Sudol et al. EPJA 44 (2010) 373

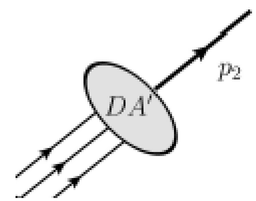
Distribution Amplitude and Transition Distribution Amplitude

- *A way to probe the proton wave function:*

$$\underbrace{qqq}_{\text{Described by DA}} + \underbrace{qqq\pi + qqq\rho + qqq\eta}_{\text{TDA}} \;\ldots\ldots$$

- *Hadronic matrix elements of 3 quark operators on the light cone*
  - Distribution Amplitude (DA) :

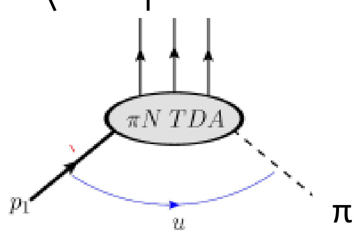
$$\left\langle 0 \left| \varepsilon^{ijk} u_\alpha^i(z_1 n) u_\beta^j(z_2 n) d_\gamma^k(z_3 n) \right| p \right\rangle$$



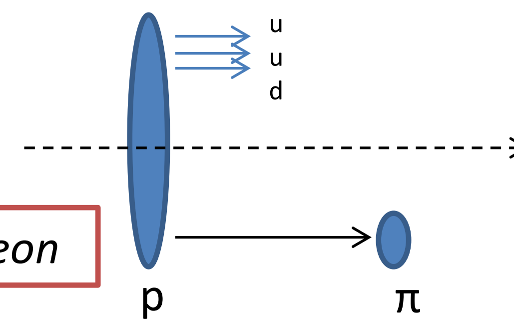
Related to FFs at large q^2

  - Transition Distribution Amplitude (TDA) :

πN case: $\left\langle \pi^0 \left| \varepsilon^{ijk} u_\alpha^i(z_1 n) u_\beta^j(z_2 n) d_\gamma^k(z_3 n) \right| p, s_p \right\rangle$



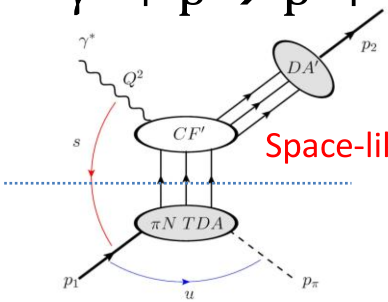
Quantifies the pion cloud in nucleon



Access to TDA in different reactions

- Factorized description:

• $\gamma^* + p \rightarrow p' + \pi^0$



Space-like

Hard scale amplitude (large|q²|)

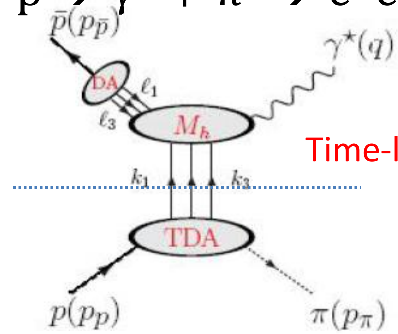
Non perturbative matrix elements

L. L.Frankfurt et al, Phys.Rev. D60 (1999) 014010

Backward π electroproduction

On-going analysis at Jlab

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

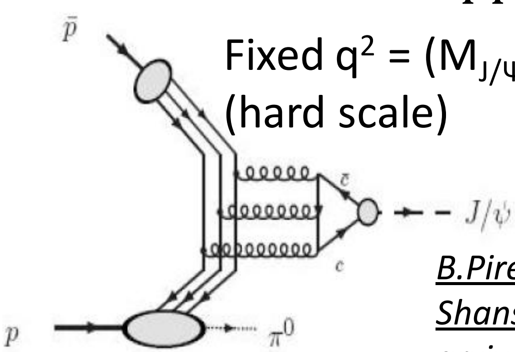


Time-like

J.P.Lansberg et al. , Phys Rev D 76 111502(R) (2007)

Feasibility study with PANDA by Maria Carmen Mora Espi,
Helmholtz Institut-Mainz. (PHD 2013)

- New calculation for $\bar{p}p \rightarrow J/\Psi\pi^0 \rightarrow e^+e^-\pi^0$ reaction



Fixed $q^2 = (M_{J/\psi})^2 = 9.59\,\text{GeV}^2$ (hard scale)

B.Pire, K.Semenov-Tian-Shansky, L.Szymanowski, arxiv: 1304.6298v2

Validity of the factorization:

$|u| << q^2$ backward pion emission ($p\pi$ TDA)

$|t| << q^2$ forward pion emission ($\bar{p}\pi$ TDA)

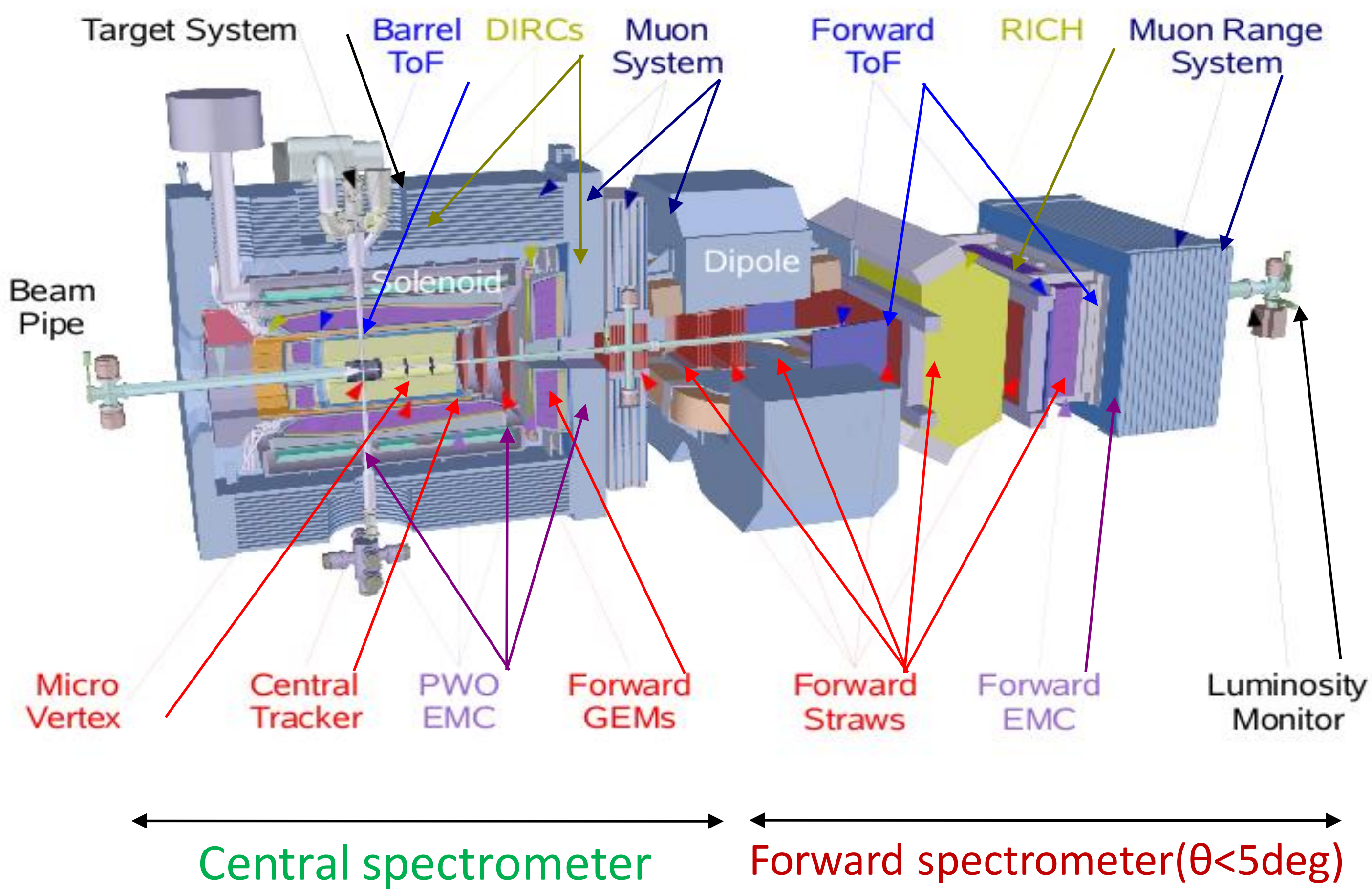
Challenge of nucleon structure studies in $\bar{p}p$ reactions

- Exclusive electromagnetic channels
  - $\bar{p}p \rightarrow e^+e^-$
  - $\bar{p}p \rightarrow e^+e^-\pi^0$
  - $\bar{p}p \rightarrow J/\Psi\pi^0$, … …
- Huge hadronic background

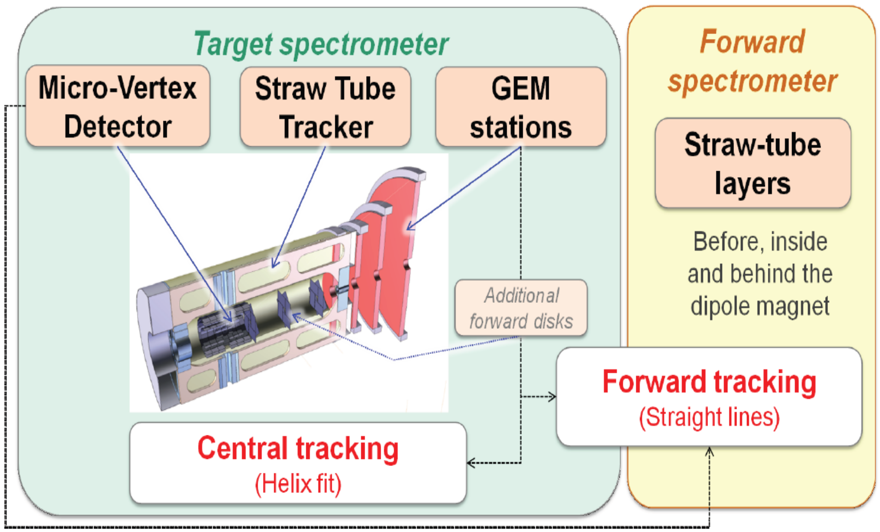
  (e.g. $\sigma(\bar{p}p \rightarrow \pi^+\pi^-)/\sigma(\bar{p}p \rightarrow e^+e^-) \sim 10^6$)
- Need excellent detector performance
  - Particle Identification
  - Momentum resolution (kinematical constraints)

P̄ANDA experiment

Antiproton ANnihilation at DArmstadt



Tracking system and algorithm



Pattern recognition → Prefit → Kalman fit → Extrapolation

- **Pattern recognition**: Form tracks from associated hits
- **Prefit**: Evaluation of the track parameters with a preliminary fit (Helix fit)
- **Kalman fit**: Improvement of track parameters by correcting for energy losses
- **Extrapolation**: Extrapolation of the parameters to the plane where they need to be known

TDR for the PANDA STT, arXiv:1205.5441

Kalman Fit

GenFit: $$k_i = \frac{\frac{m_i}{\sigma_m^2} + \frac{x_i}{\sigma_{th}^2}}{\frac{1}{\sigma_m^2} + \frac{1}{\sigma_{th}^2}}$$

GEANE: Calculates x_i and σ_{th} using multi-scattering, ionisation

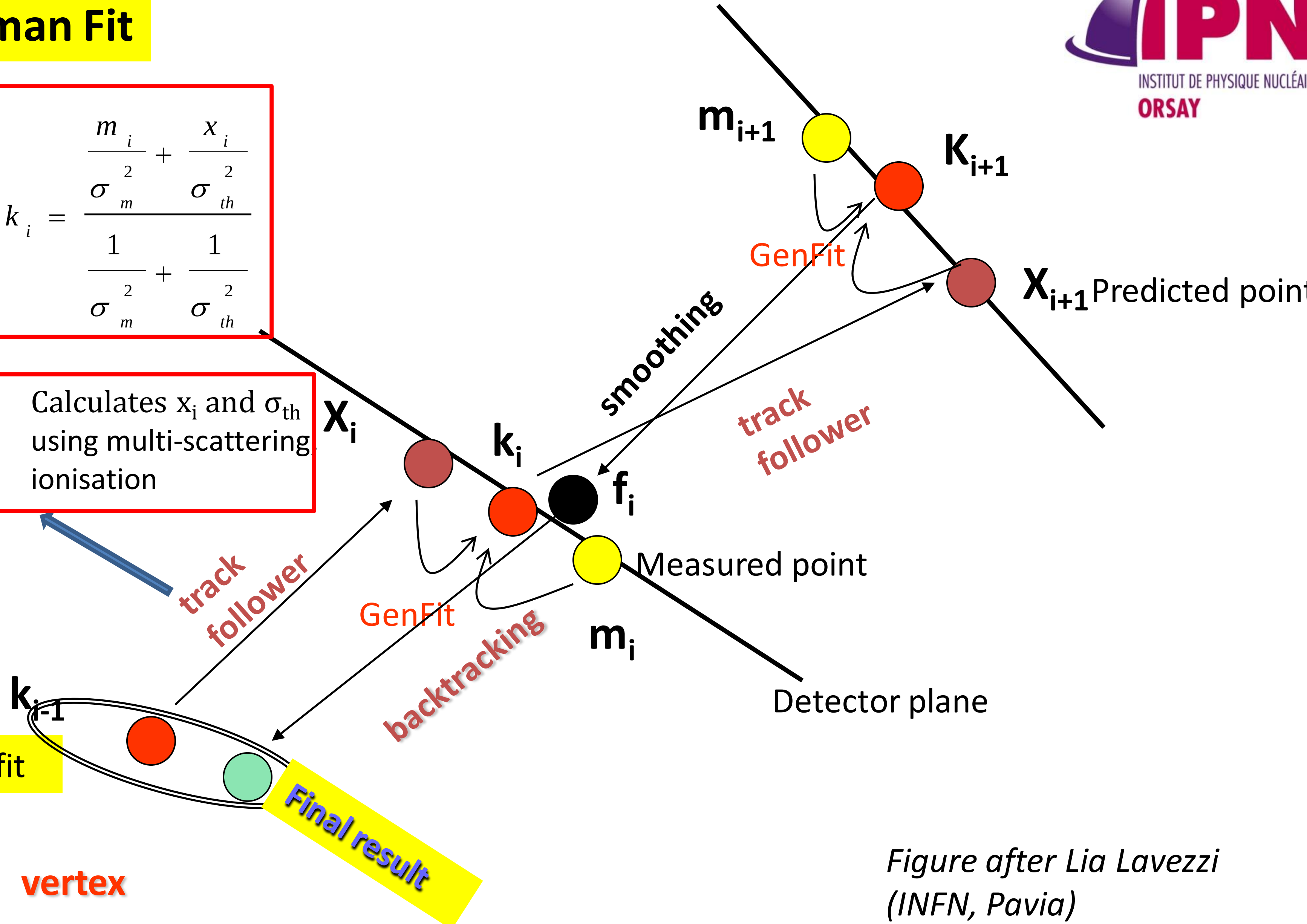
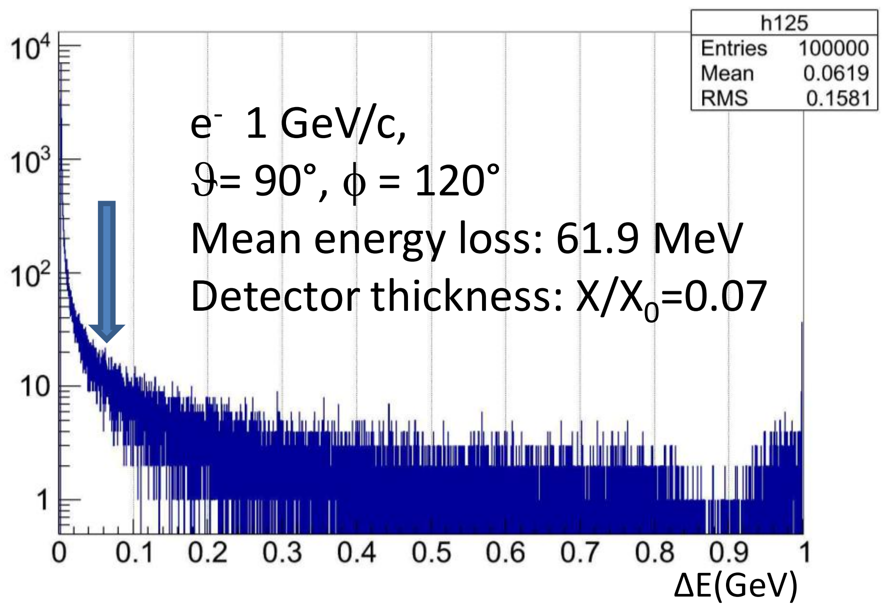


Figure after Lia Lavezzi (INFN, Pavia)

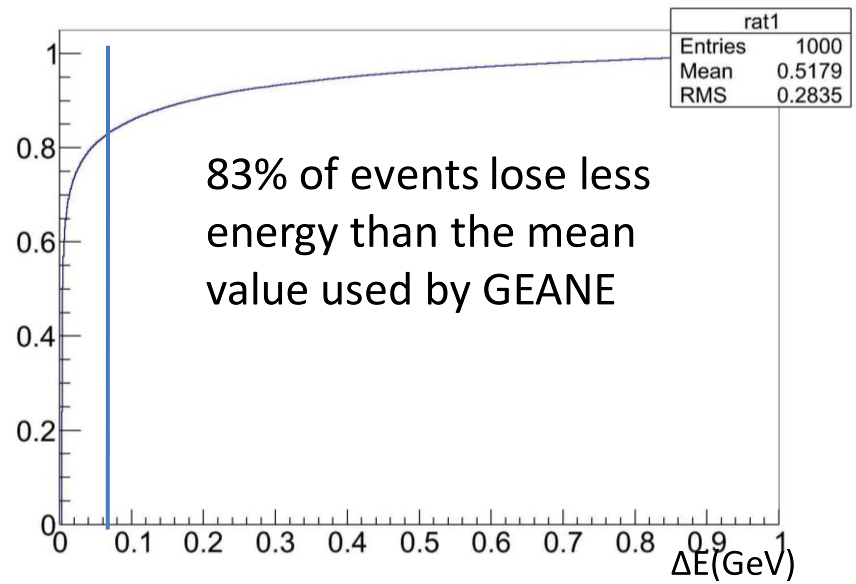
Problem of e^+/e^- reconstruction with Kalman Fit

- Track follower of Kalman Filter(KF): GEANE
- GEANE calculates the mean electron energy loss and the rms, but Bremsstrahlung is highly non-gaussian!

Electron energy loss in tracking system



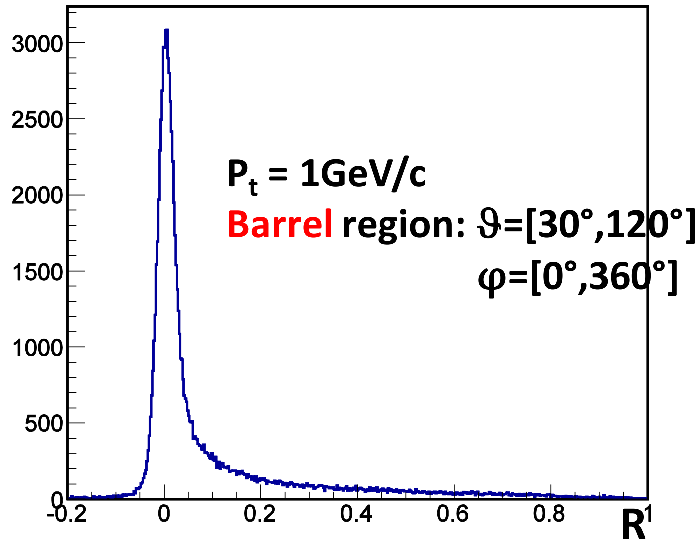
Proportion of events with energy loss below ΔE



So, KF can not handle the problem correctly

Electron momentum resolution after Kalman Fit

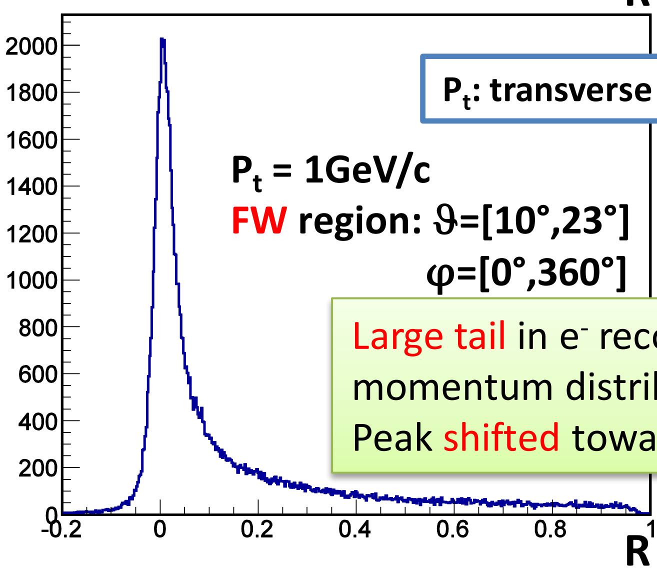
$R = (P_{MC}-P_{rec})/P_{MC}$



P_t(GeV/c)	σ(%) from Gaussian fit	Evts inside 2σ(%)
0.5 Barrel	1.5	55.6
1 Barrel	1.8	58.9
2 Barrel	2.4	61.0
0.5 FW	1.9	46.6
1 FW	2.1	46.3
2 FW	2.4	45.6

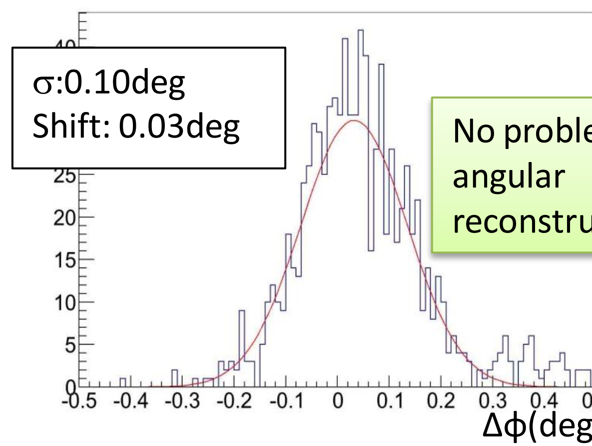
Needs to be improved

P_t: transverse momentum



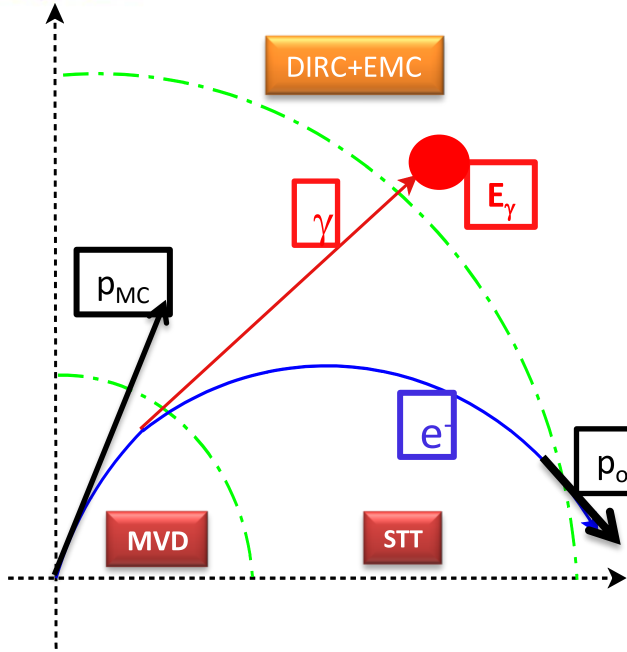
Large tail in e^- reconstructed momentum distribution,
Peak shifted towards positive values.

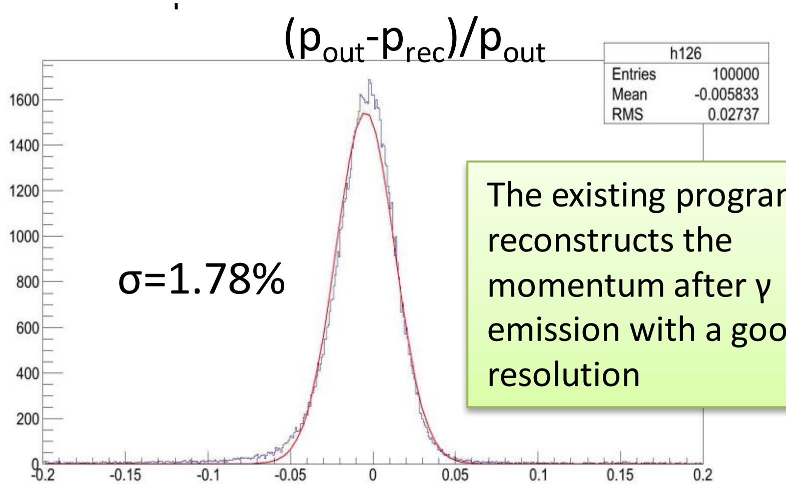
Electron angular resolution



No problem for angular reconstruction

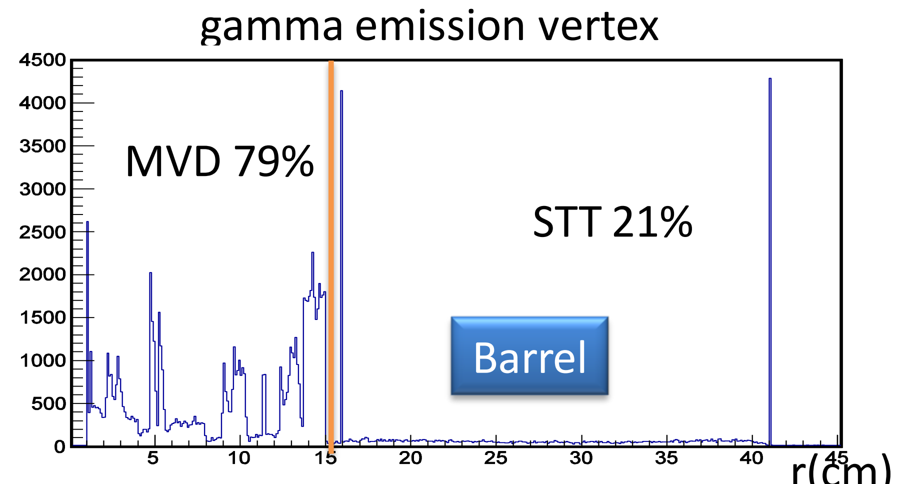
e^- momentum reconstruction with γ emission

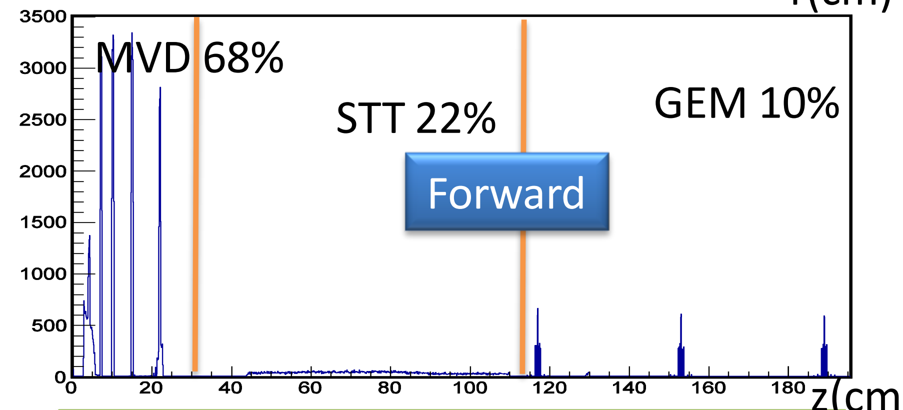




The existing program reconstructs the momentum after γ emission with a good resolution

-p_{rec}:Reconstructed momentum by tracking





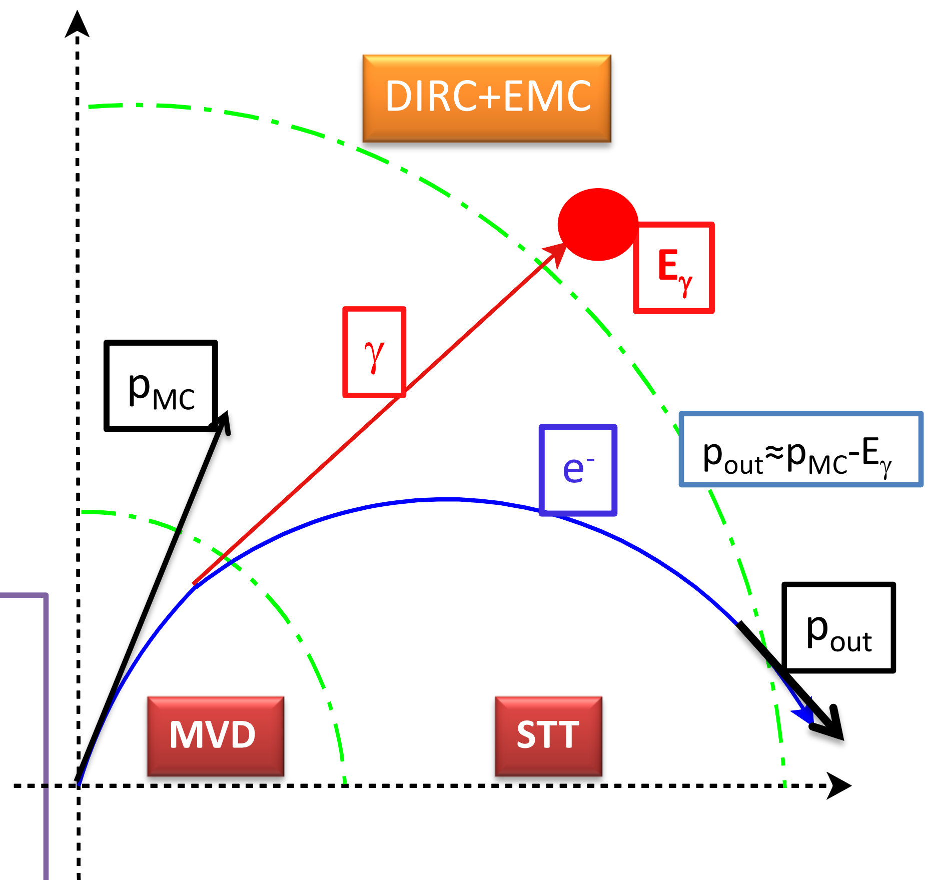
- Most γ emitted close to target(MVD)
- The track is mostly defined by STT and GEM hits. (MVD: only 4 to 6 points).
- $P_{rec} \approx P_{out}$

My proposal: use the γ energy from EMC

Justification:

- Reconstructed momentum $p_{rec} \approx p_{out}$ (momentum of the electron before the DIRC)

- If a γ is emitted before the DIRC: $p_{out} \approx p_{MC} - E_{\gamma}$ (γ is emitted in the same direction as e^-)



In practice:

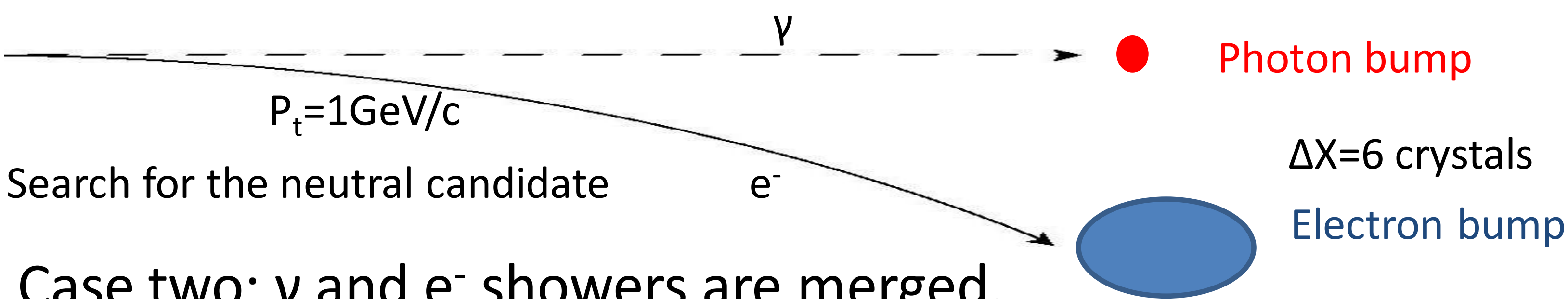
- Handle the problem event by event

- Search for the associated Bremsstrahlung γs in the EMC.(ΣE_{γ})

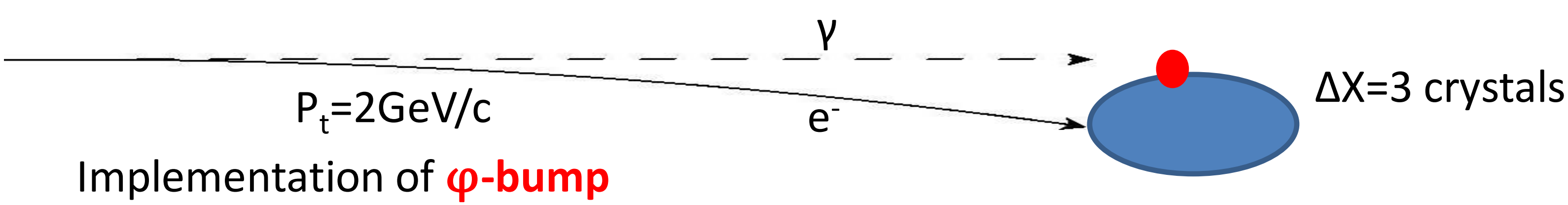
- Calculate: $\mathbf{p_{corr} = p_{rec} + \Sigma E_{\gamma(i)}}$

Electron Bremsstrahlung correction method

- Case one: the showers of e^- and γ can be well distinguished.

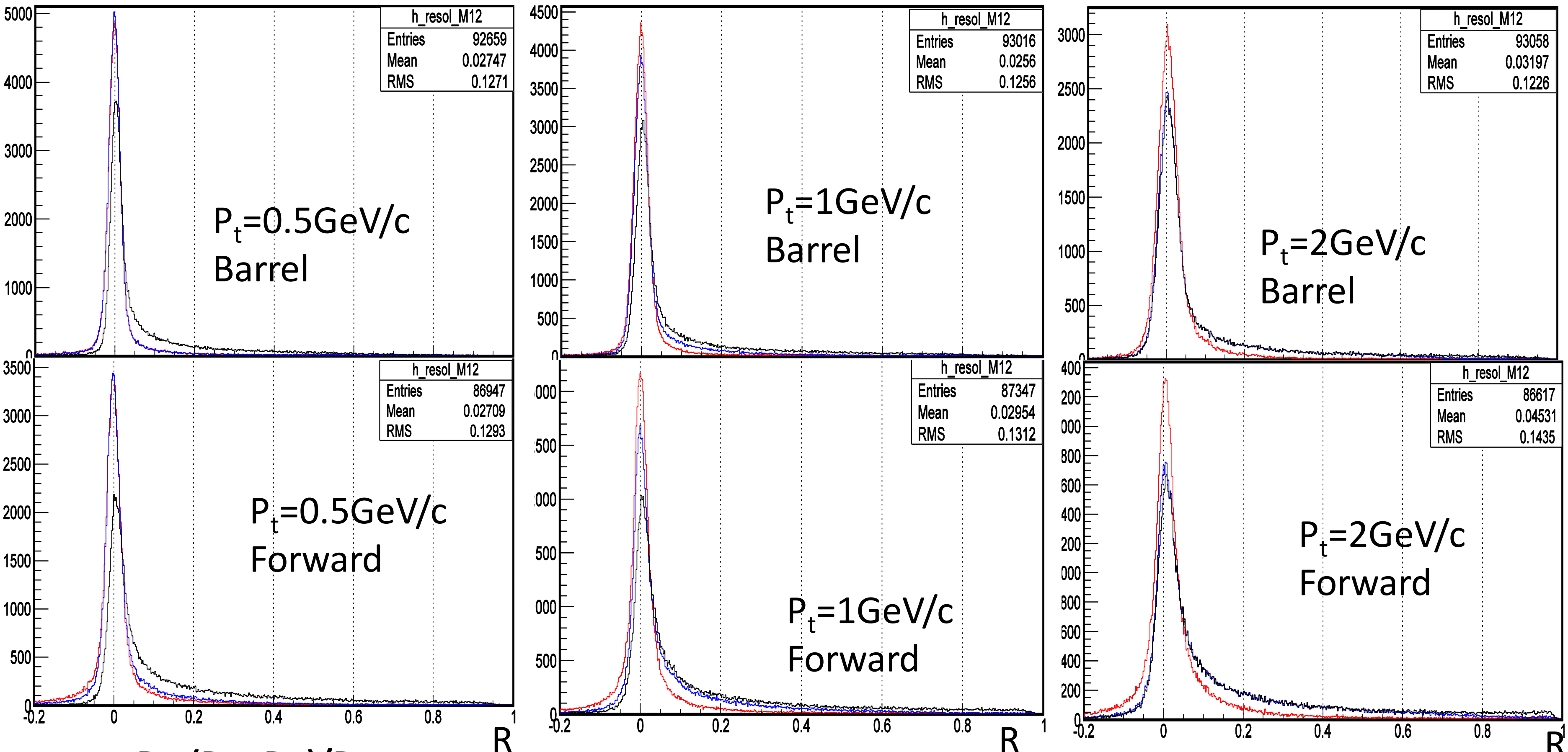


- Case two: γ and e^- showers are merged.



- For an electron event both cases are considered in parallel.

Preliminary result of Bremsstrahlung correction method for single e⁻ tracks



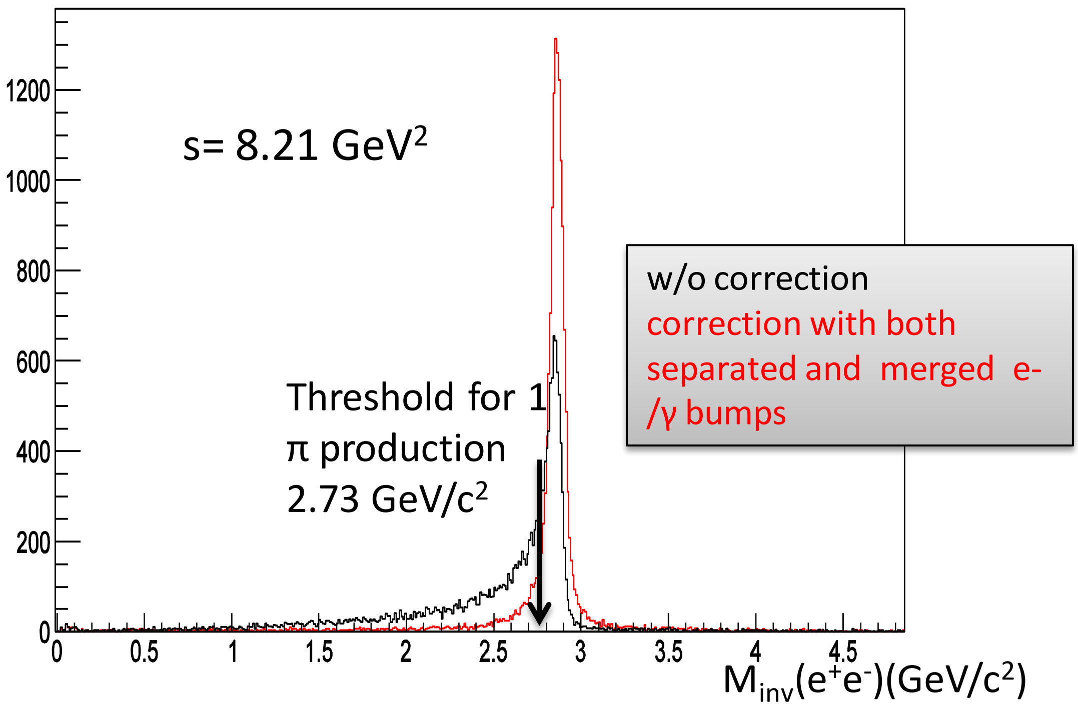
$R = (P_{MC} - P_{KF})/P_{MC}$

w/o correction
correction with only separated e-/γ bumps
correction with both separated and merged e-/γ bumps

- Reduction of the shift.
- Increase of number of electrons inside two sigma: 60% → 79% for Barrel (about 85% for ideal case) and 46% → 65% for FW (about 80% for ideal case).

Application for nucleon form factors studies in $\bar{p}p \to e^+e^-$ (no radiation include)

Invariant mass of e^+e^- before cuts



Selection of $\bar{p}p \to e^+e^-$ channel

- PID
- Angular correlations
- Cut on $M_{inv}(e^+e^-) \sim \sqrt{s}$

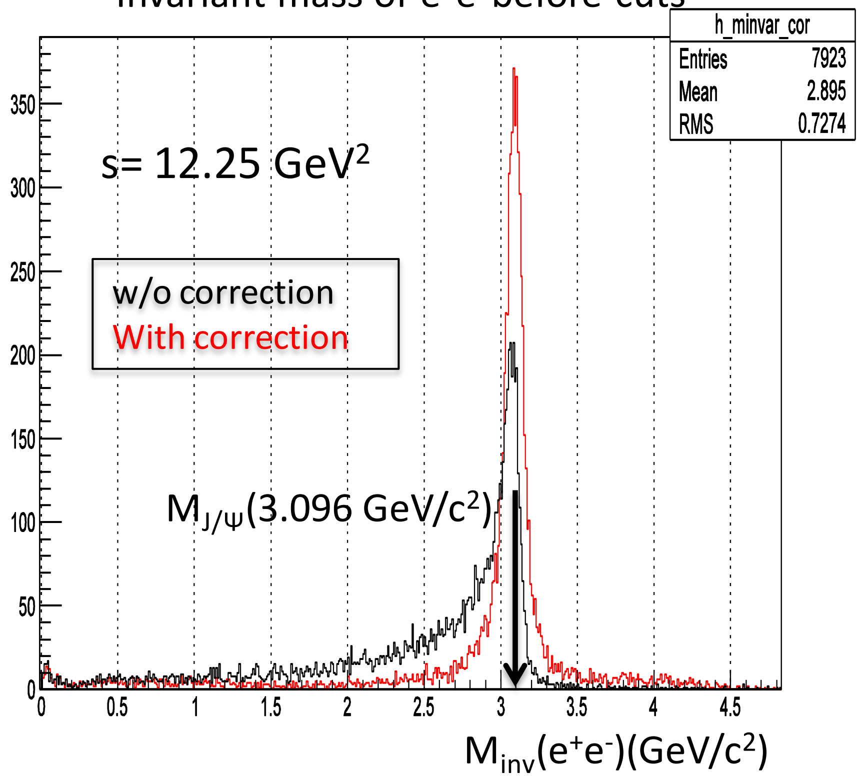
Main backgrounds:

- $\bar{p}p \to \pi^+\pi^-, \pi^+\pi^-\pi^0$
- $\bar{p}p \to e^+e^-\pi^0$

Improvement of number of events inside the cut : 51%→87%

Application for TDAs studies in $\bar{p}p \rightarrow J/\Psi\pi^0 \rightarrow e^+e^-\pi^0$

Invariant mass of e^+e^- before cuts



Selection of $\bar{p}p \rightarrow J/\Psi\pi^0 \rightarrow e^+e^-\pi^0$ channel:

- PID($e^+e^-2\gamma$)
- π^0 reconstruction: $M_{inv}(2\gamma) \sim M_{\pi^\circ}$
- Cut for $M_{inv}(e^+e^-) \sim M_{J/\Psi}$
- Kinematical constraints

Main backgrounds:

- $\bar{p}p \rightarrow \pi^+\pi^-\pi^0, \pi^+\pi^-\pi^0\pi^0$
- $\bar{p}p \rightarrow J/\Psi\pi^0\pi^0$
- Non resonant $\bar{p}p \rightarrow e^+e^-\pi^0$

Improvement of number of events inside 2σ: 38.4%→61.0%

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Conclusions

- Studies of the nucleon structure with PANDA. (FFs, TDAs, … …) need an optimized electron momentum reconstruction.
- A new method based on the Bremsstrahlung photon detection is proposed.
- Promising results are obtained:
  - ✓ Improvement of electron momentum resolution.
  - ✓ Increase of signal selection efficiency for electromagnetic channels
- Influence on radiative corrections needs to be studied.

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THANK YOU!

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