Radiative correction studies with the Bremsstrahlung correction method in PANDA

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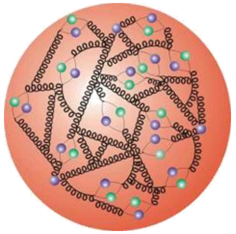
Outline

- Nucleon form factors by $\bar{p}p \rightarrow e^{+}e^{-}$.
- Two problems in analysis:
  - Bremsstrahlung photons in the detector's material:
  - Radiation from the vertex.
  - Effect of the Bremsstrahlung correction method on the radiative correction.
- Method for the radiative correction.
- Conclusions

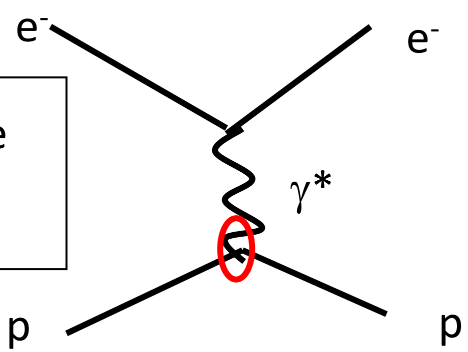
Nucleon form factors

- The nucleon electromagnetic internal structure is characterized by two form-factors : $G_E(q^2)$ (electric), $G_M(q^2)$ (magnetic)



Space-like

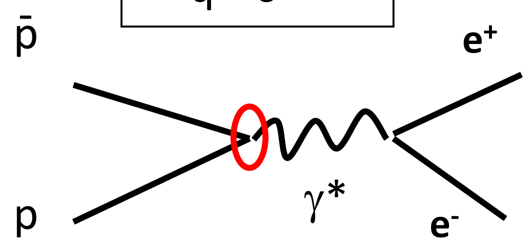
$q^2 < 0$



Form factors are real

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

Time-Like
$q^2>0$



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

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

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

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

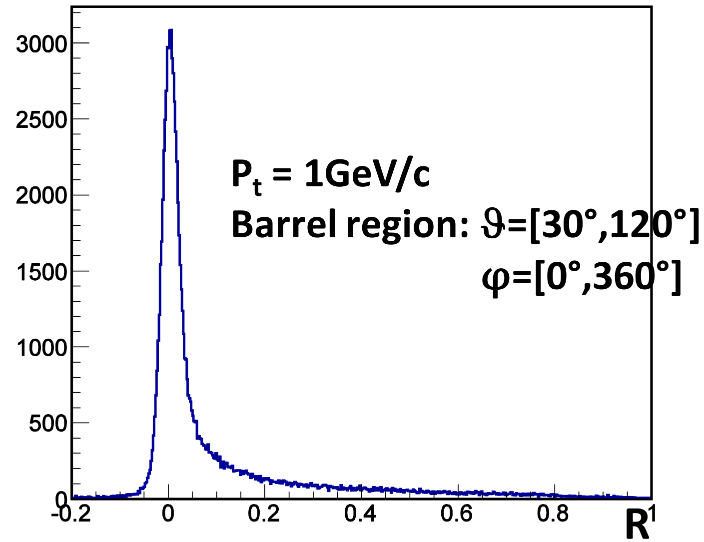
Problems in the analysis of $\bar{p}p \rightarrow e^+e^-$

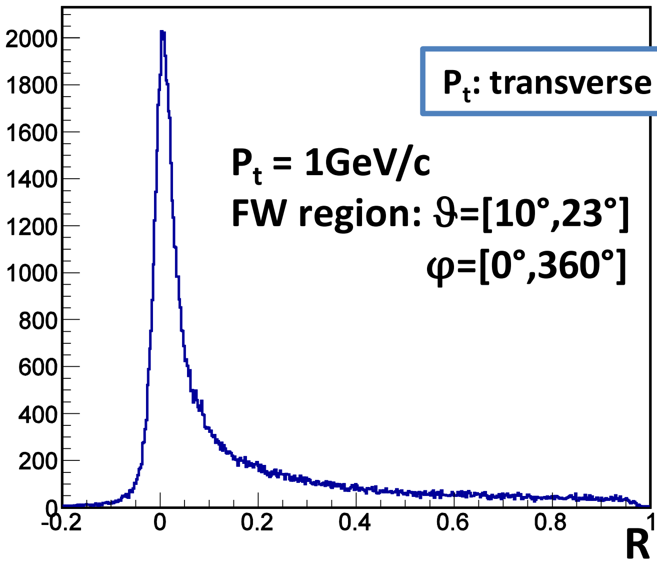
- Radiation at the vertex ($\bar{p}p \rightarrow e^+e^-\gamma$): changes the distributions of the cross section, correction can be calculated, but depends on maximum E_γ in the selected events.
- High energy Bremsstrahlung photons emitted by e+/e- traversing detector material: bad electron momentum resolution.
- Background rejection ($\pi^+\pi^-$, $\pi^+\pi^-\pi^0$, $e^+e^-\pi^0$): Very strict PID and kinematic cuts .
  - Strong dependence on electron resolution.
  - Will affect efficiency and radiative correction.

Bremsstrahlung photons in the detectors

Electron momentum resolution

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





P_t: transverse momentum

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

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

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Electron Bremsstrahlung correction method

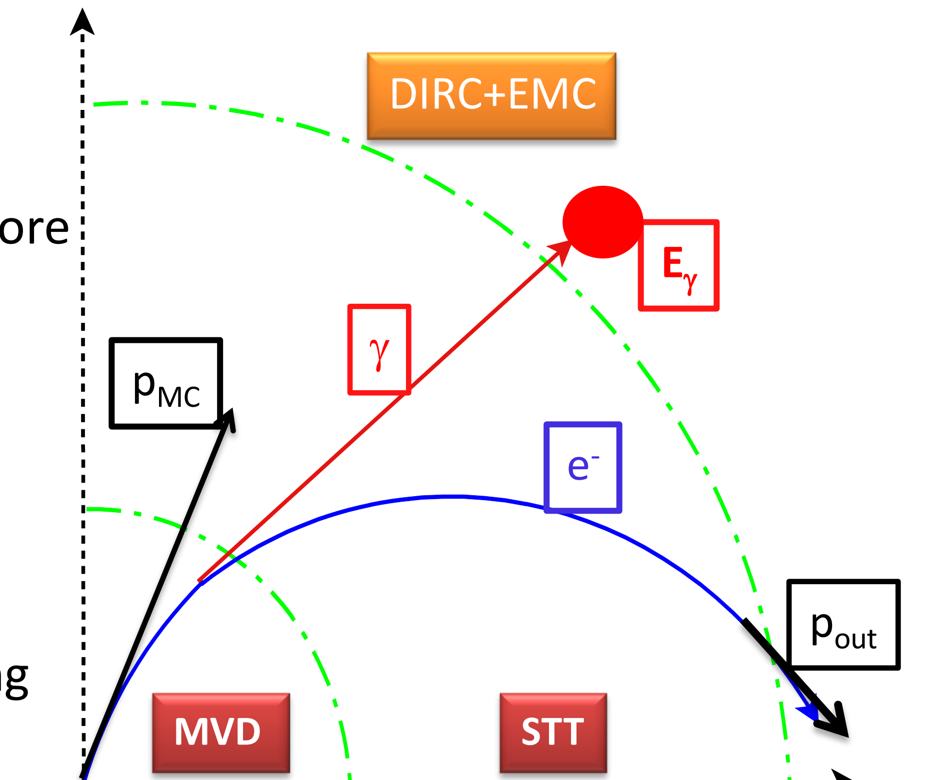
- Handle the problem event by event and use the γ energy from EMC

- The 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^-)

- Searching the associated Bremsstrahlung γs in the EMC.(ΣE_γ)

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

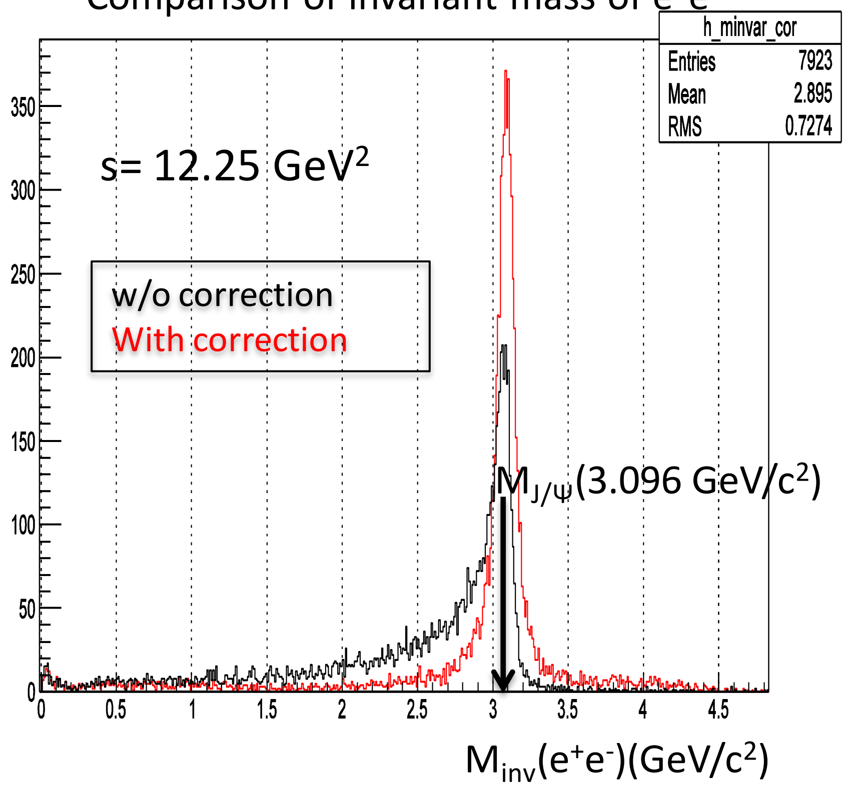


- Most γ emitted close to target (MVD)
- The track is mostly defined by STT hits (MVD 4 to 6 points, STT 24 to 26 points)
- $P_{rec} \approx P_{out}$

Test for electromagnetic channels

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

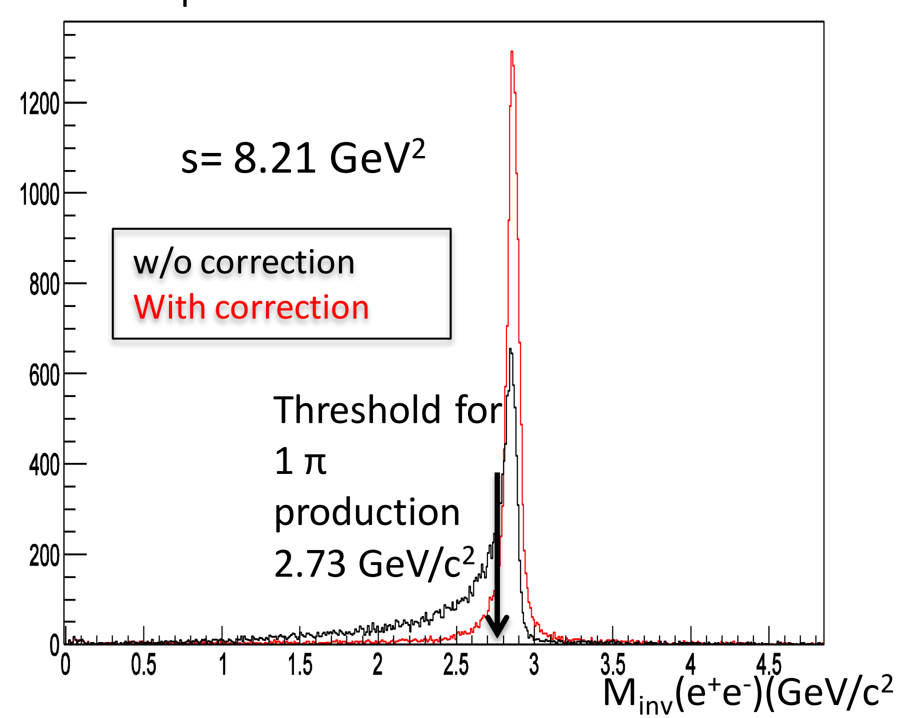
Comparison of invariant mass of e^+e^-



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

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

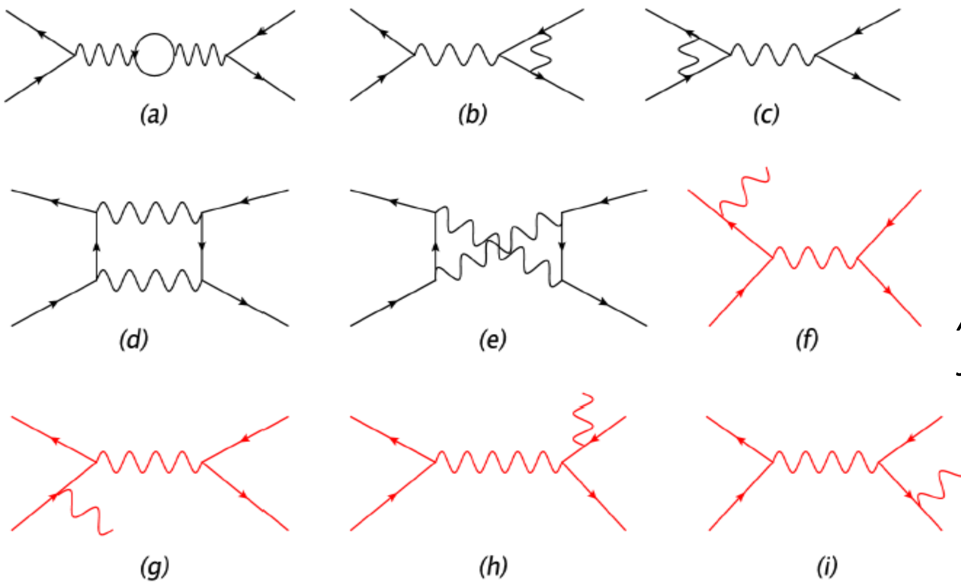
Comparison of invariant mass of e^+e^-



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

Radiation from the vertex

Radiative corrections for $\bar{p}p \rightarrow e^+e^-$



Virtual photon contributions

Real photon contributions

A.I.Ahmadov et al Phys.Rev.D82 094016(2010)

J.Van de Wiele et S Ong, Eur.Phys.J. A49 (2013) 18

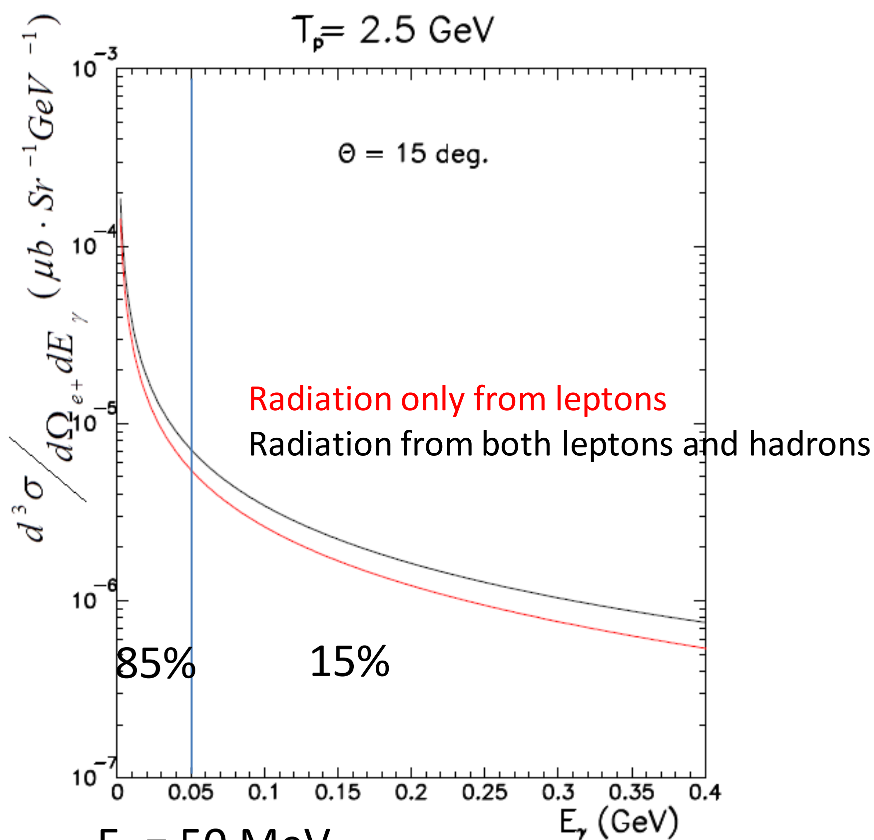
Relation between real cross section and Born cross section:

$$\left(\frac{d\sigma}{d\cos\theta}\right)_R = \left(\frac{d\sigma}{d\cos\theta}\right)_B \left(1+\delta^{soft}(\omega)\right) + \int_{\omega}^{E_\gamma^{max}} \frac{d^5\sigma}{dE_\gamma\, d\Omega_\gamma\, d\Omega_{e^+}} dE_\gamma\, d\Omega_\gamma$$

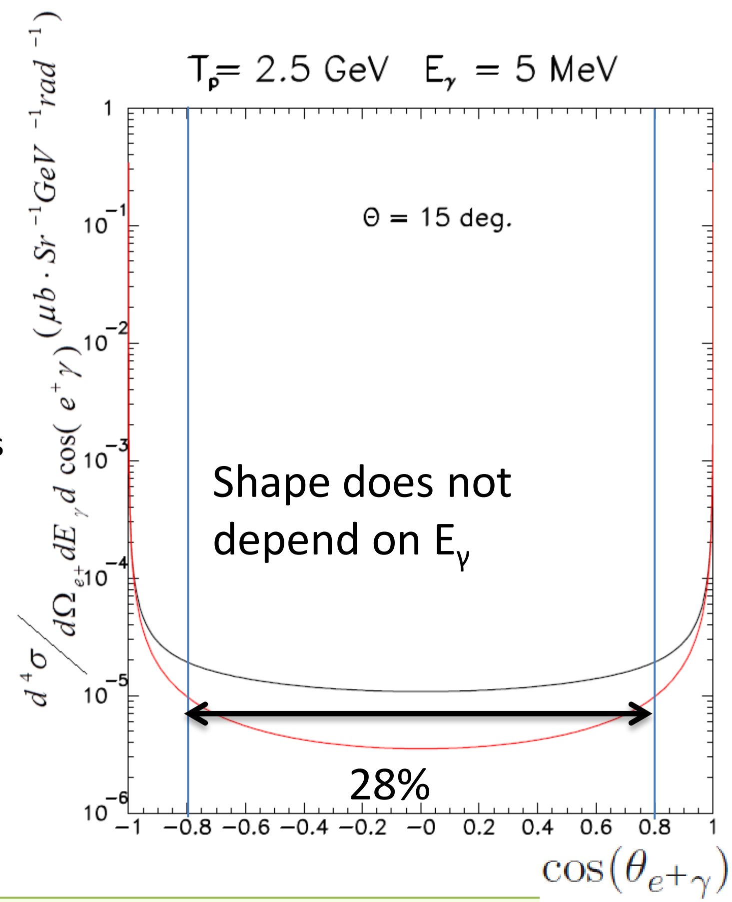
soft photon correction　　　hard photon correction

E_γ and $\cos(\theta_{e+\gamma})$ distribution

$\bar{p}p \rightarrow e^+e^-\gamma$



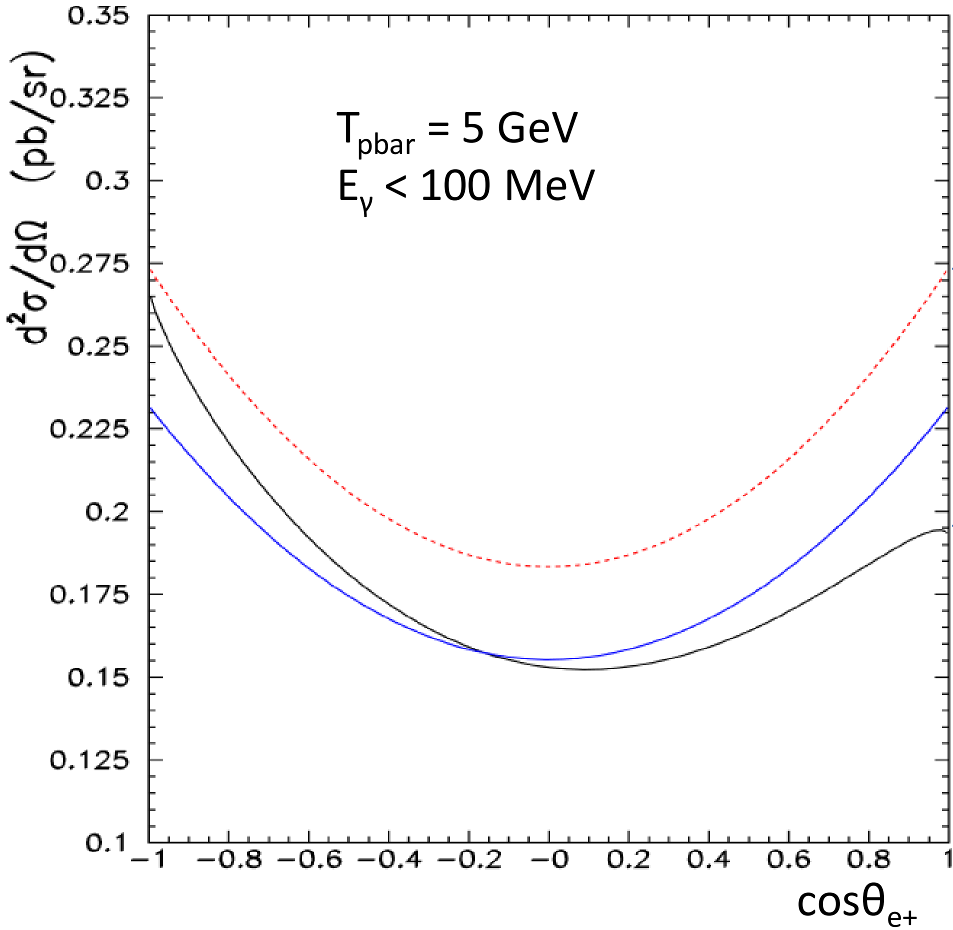
E_γ = 50 MeV



Photon energy and opening angle distributions very peaked, contributions of high energy photons or non collinear photons are small but not negligible

Angular distribution

$\bar{p}p \rightarrow e^+e^-\gamma$



Born cross section

No radiation from hadrons

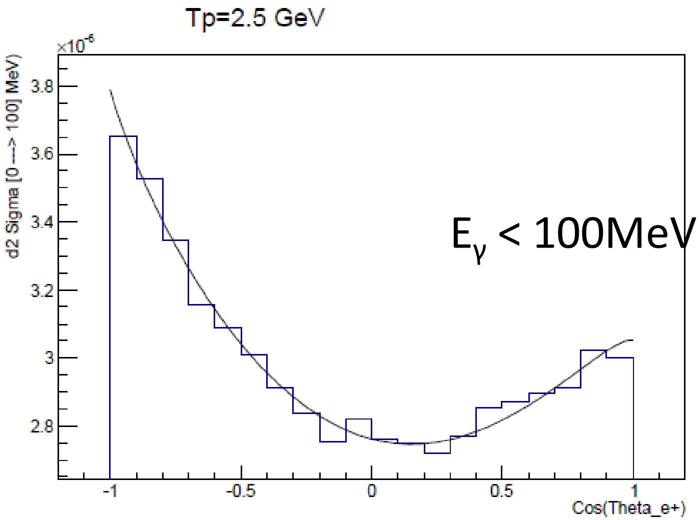
With radiation from both leptons and hadrons

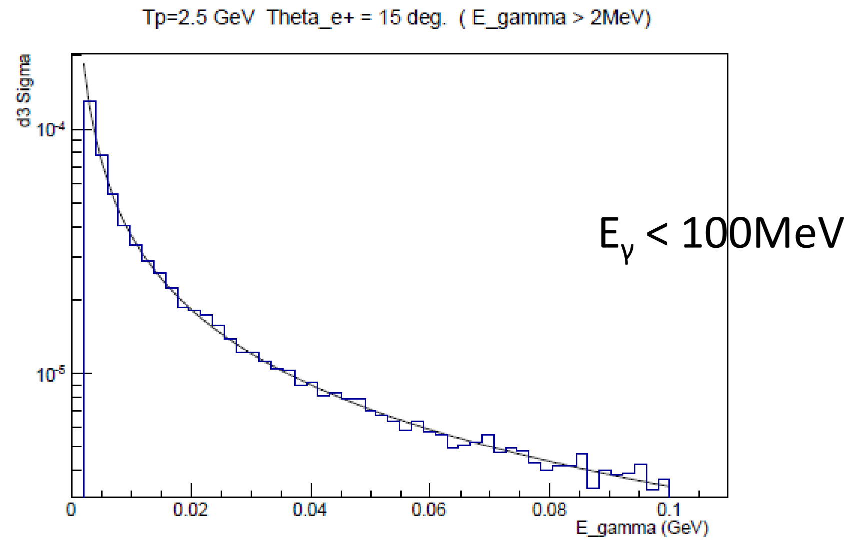
40% but depends on E_γ cut

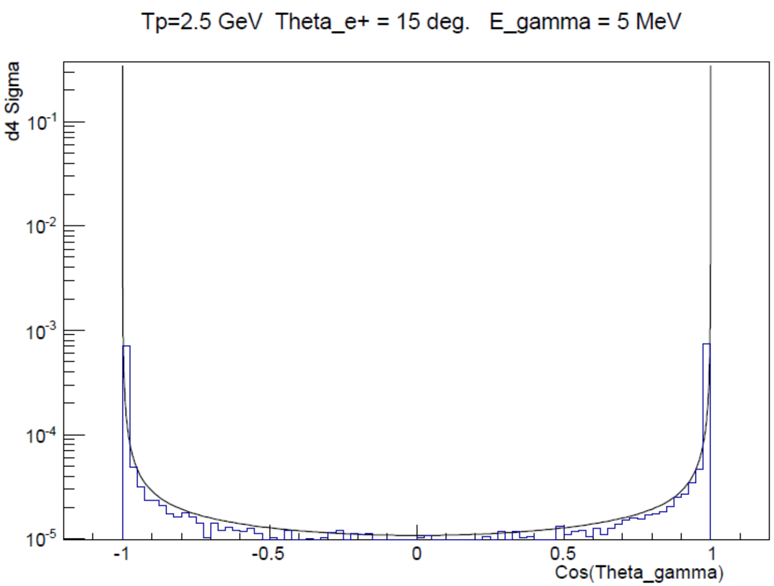
Asymmetry in the angular distribution due to interference between radiation from hadrons and from leptons

Generator

Generated spectra and Model







Model by: J.Van de Wiele et S.Ong, Eur.Phys.J. A49 (2013) 18

Effect of the Bremsstrahlung correction method for the radiatve correction

Simulation steps

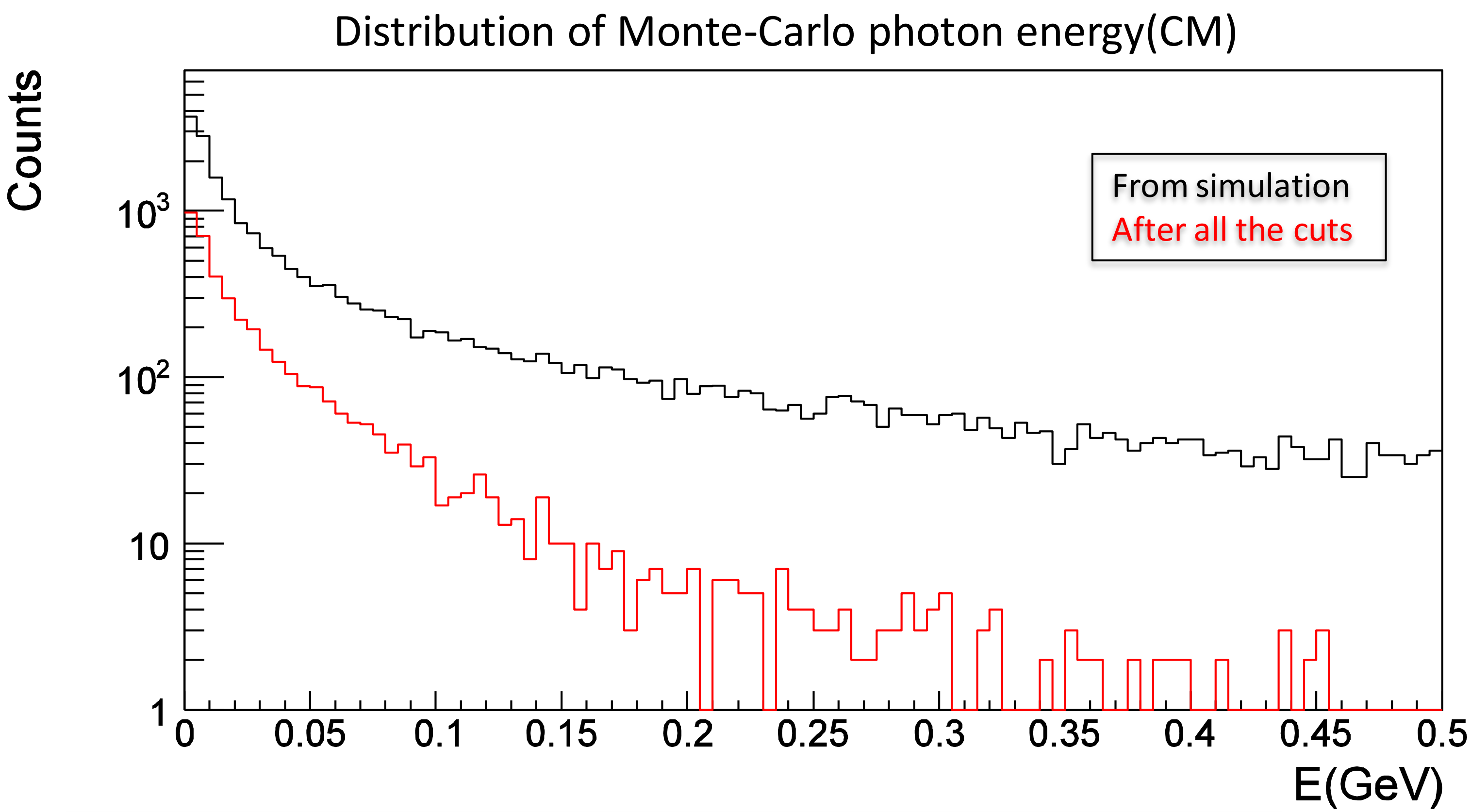
- Two reactions
  - $\bar{p}p \rightarrow e^+e^-\gamma$
  - $\bar{p}p \rightarrow e^+e^-$
- 20000 events for each reaction
- T_{pbar} = 2.5GeV, θ_{e+}^{CM} = 40˚, E_γ < 500MeV
- Compare the result with and w/o using the Bremsstrahlung correction method

Analysis cuts:

Total e^+/e^- PID	> 90%
PID from each detectors	>5%
Nb. of fired crystals in the EMC	>5
$(\theta^+ + \theta^-)[CM]$	[178°-182°]
$\|\phi^+ - \phi^-\|$	[178°-182°]
Invariant mass	> 2.72GeV

$M_{e+e-} > \sqrt{s} - M_{\pi 0}$

Energy of photon from vertex

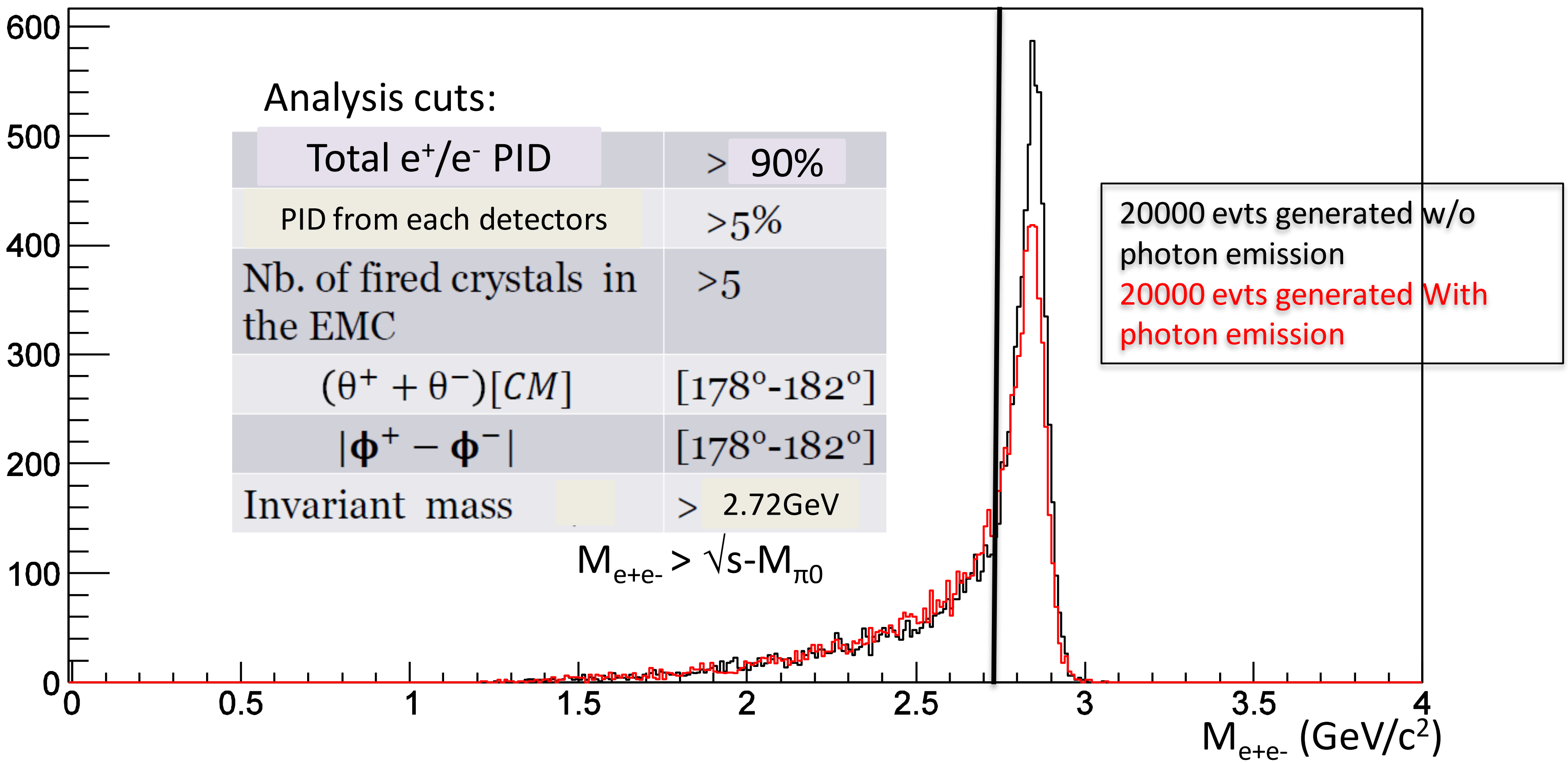


analysis cuts-> smooth cut on the energy of the vertex photon

Effect of photon emission from the vertex

T = 2.5GeV, θ_{e+}^{CM} = 40˚, E_γ < 500MeV

$\bar{p}p \rightarrow e^+e^-\gamma$ and $\bar{p}p \rightarrow e^+e^-$



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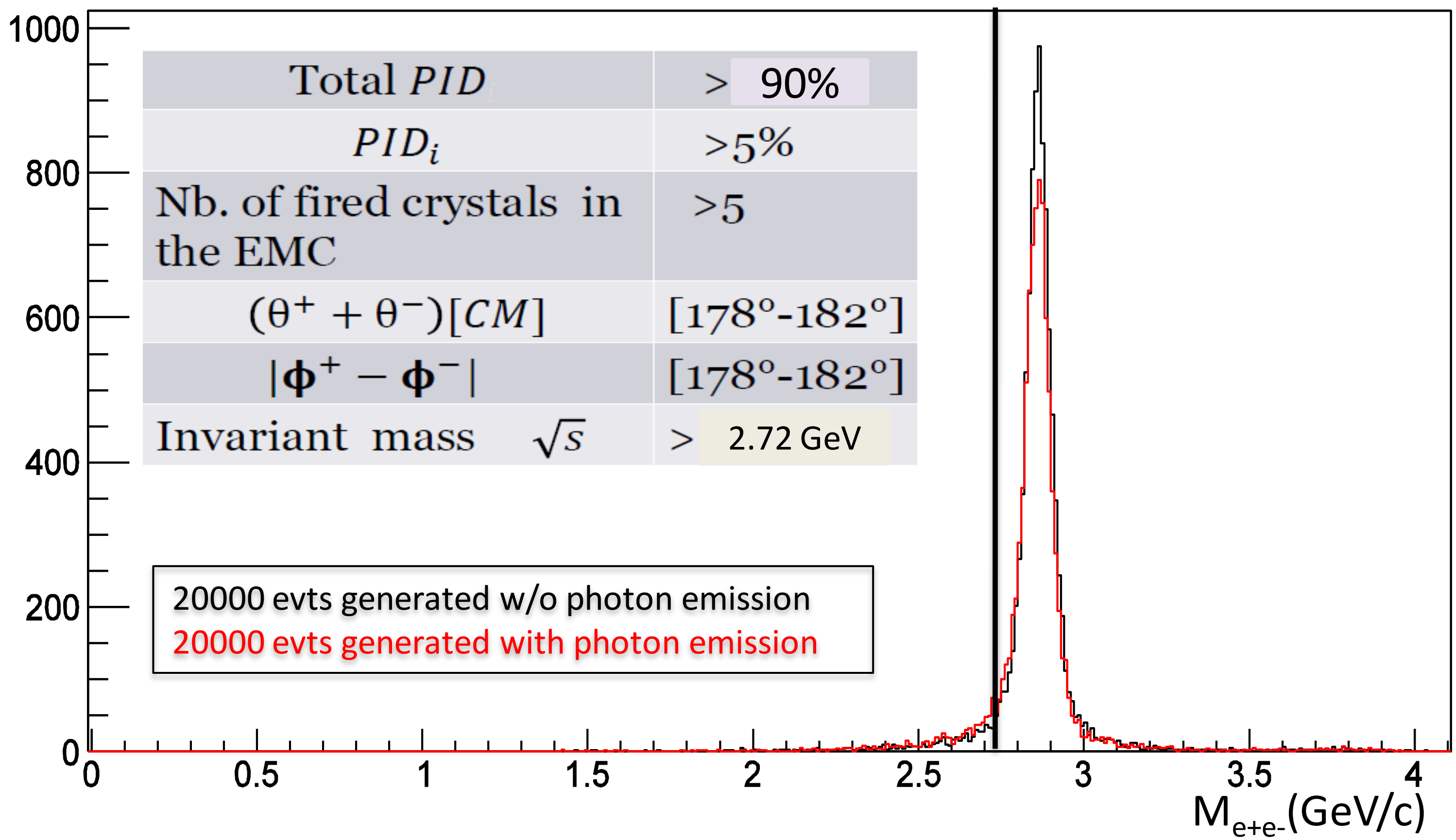
Nb. of fired crystals in the EMC	>5
$(\theta^+ + \theta^-)[CM]$	[178°-182°]
$\lvert\phi^+ - \phi^-\rvert$	[178°-182°]
Invariant mass	> 2.72GeV

With photon emission at the vertex, efficiency is lower by a factor 0.83
Much larger efficiency loss by Bremsstrahlung in the detectors (~40% evts in the tails)

Effect of photon emission from the vertex after using the Bremsstrahlung correction method

$\bar{p}p \rightarrow e^+e^-\gamma$ and $\bar{p}p \rightarrow e^+e^-$



Total PID	> 90%
PID_i	>5%
Nb. of fired crystals in the EMC	>5
$(\theta^+ + \theta^-)[CM]$	[178°-182°]
$\lvert\phi^+ - \phi^-\rvert$	[178°-182°]
Invariant mass $\sqrt{s}$	> 2.72 GeV

Gain of efficiency with the Bremsstrahlung correction method.
The loss of efficiency due to photon emission at vertex is slightly lower (0.1 instead of 0.17)

Method for radiative corrections

Principle of the method

- Signal events include radiation from the vertex.

- Correction of the data (E_{max}=300MeV): with an efficiency correction deduced from PANDARoot simulations taking into account emission of the photons up to E_{max} and analysis cuts.

$$\left(\frac{dN}{d\cos\theta}\right)_R (p\bar{p}\to e^+e^-\gamma) = \left(\frac{dN}{d\cos\theta}\right)_{cuts} \Big/ \varepsilon(\theta)$$

- Calculate the remaining radiative correction δ to retrieve the Born distribution using the model (event generator).

$$\left(\frac{dN}{d\cos\theta}\right)_B (p\bar{p}\to e^+e^-) = \left(\frac{dN}{d\cos\theta}\right)_R (p\bar{p}\to e^+e^-\gamma) \Big/ (1+\delta)$$

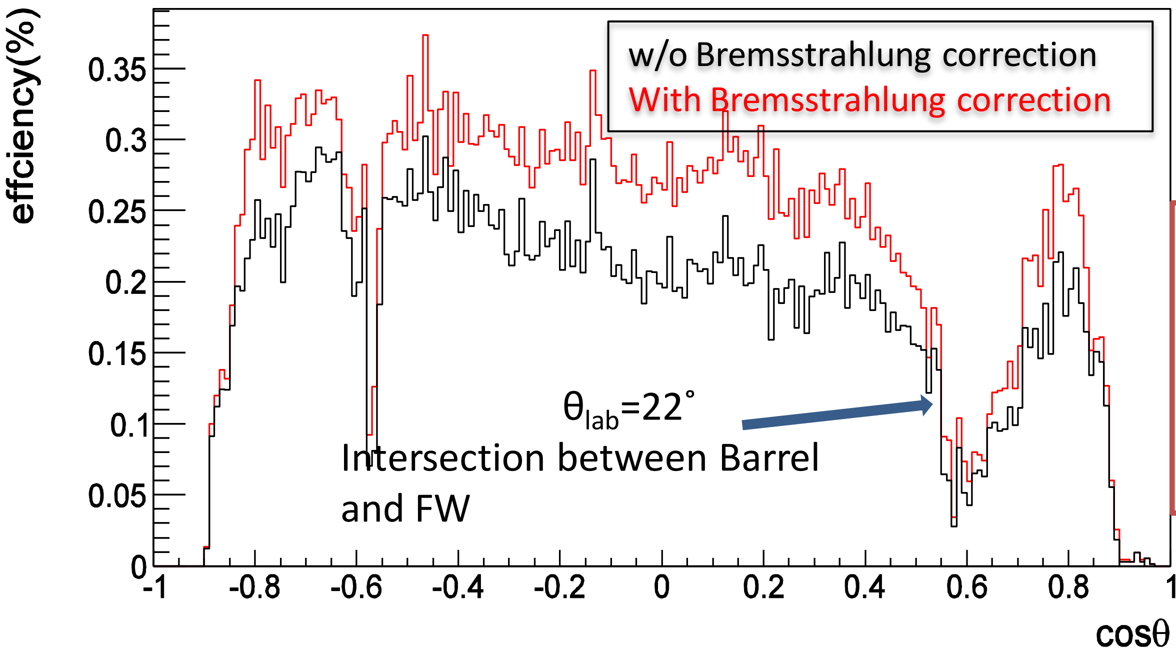
- Fit the Born distribution by the angular distribution function of G_E and G_M.

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

Calculation of the efficiency

10^5 events , E_γ<300MeV
G_E, G_M: fitted to BABAR data ($R=|G_E|/|G_M|$~1)

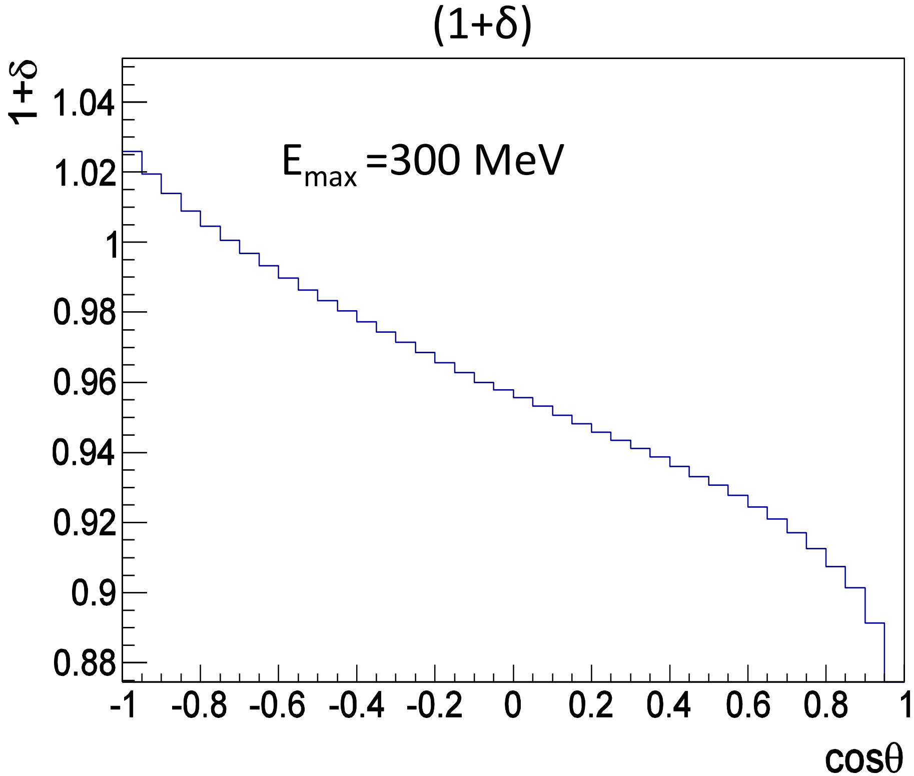
$\varepsilon(\text{cuts}, E_{max}, \theta)=N_{selected}(\theta)/N_{MC}(\theta)$

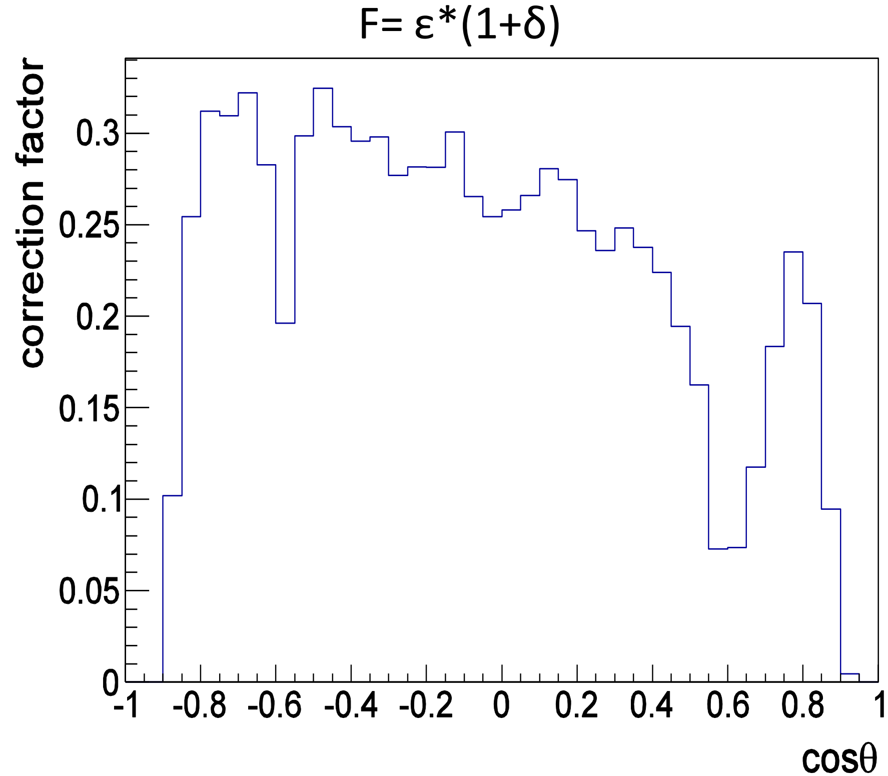


Combined effects of vertex photon emission up to E_γ = 300 MeV (10%) and reconstruction efficiency and analysis cuts (90%).

With using the Bremsstrahlung correction method, efficiency increases by a factor 1.3.

radiative and global correction factor

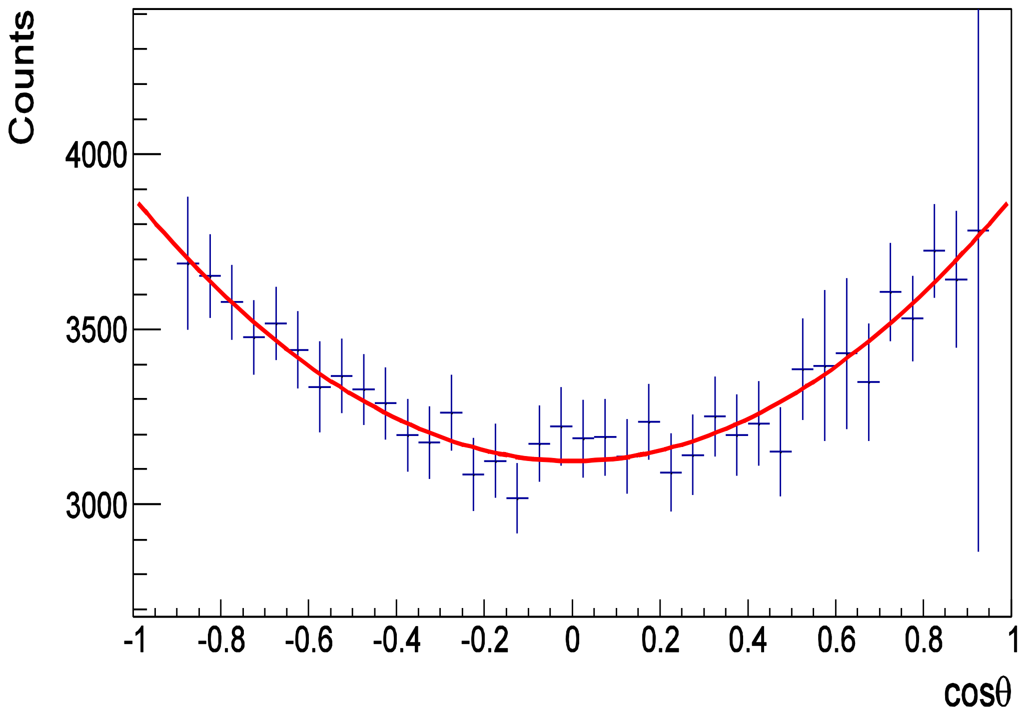




$$\left(\frac{d\sigma}{d\cos\theta}\right)_R = \left(\frac{d\sigma}{d\cos\theta}\right)_B (1+\delta)$$

$$\left(\frac{d\sigma}{d\cos\theta}\right)_{Born} = \frac{\left(\frac{d\sigma}{d\cos\theta}\right)_{exp}}{F}$$

Check of the method

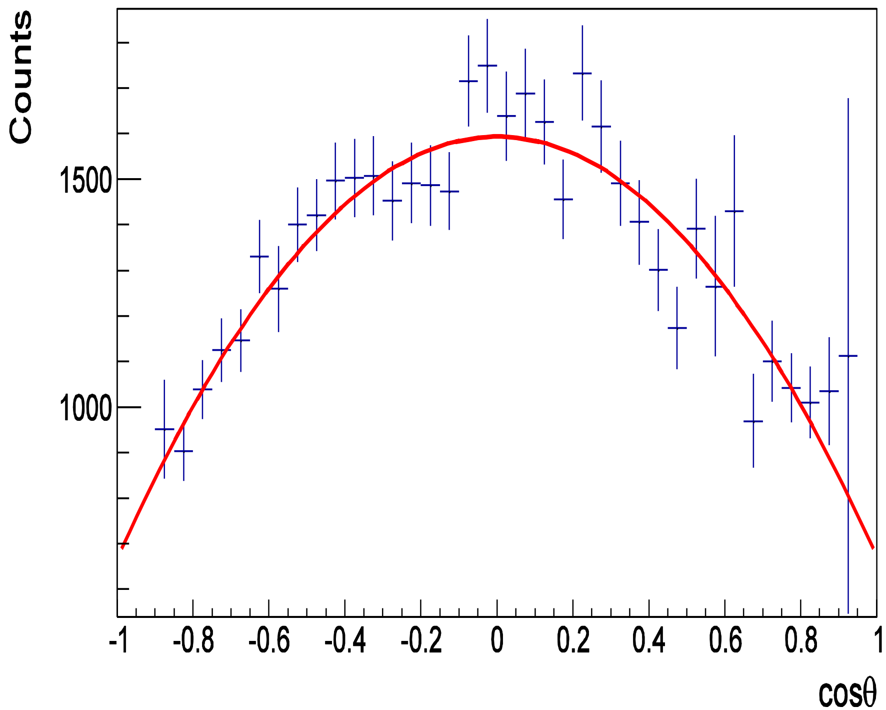


10^5 events, E_γ<300MeV
G_E, G_M: fitted to BABAR data

Born distribution deduced from correction of the simulation events
Fitting function

Consistency check of the method.
The value of R parameter from the fitting function: 1.19

Test of the method over other FFs model



$5*10^4$ event , E_{γ}<300MeV
The FFs model: R=3

Born distribution deduced from correction of the simulation events
Fitting function

The value of R parameter from the fitting function: 2.95
The Born distribution can be retrieved.
To be checked with higher statistic.

Conclusions

- Time-Like proton form factors study by $\bar{p}p \rightarrow e^+e^-$.
- With the Bremsstrahlung correction method, the global efficiency of signal selection is strongly increased.
- With applying the correction factor which combines the radiative correction and the detection efficiency, the Born cross section can be well retrieved.
- To do list:
  - More statistic is needed to check the method.
  - Stability with respect to analysis cuts.
  - Errors on G_E and G_M extraction.

THANK YOU FOR YOUR ATTENTION!

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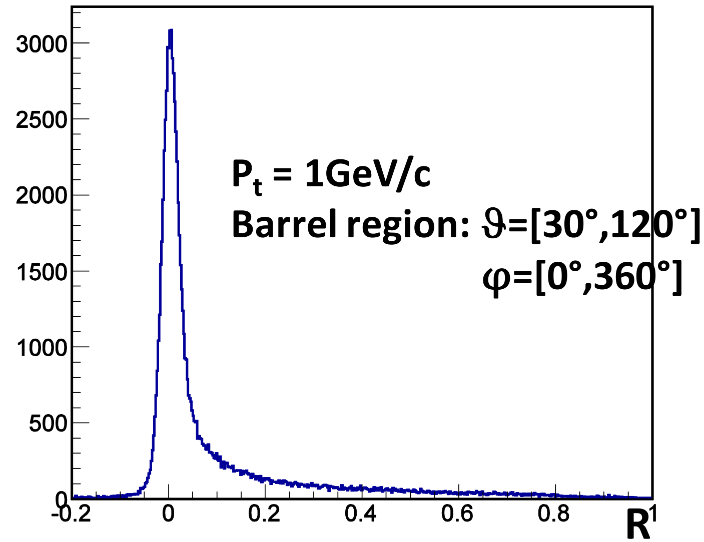
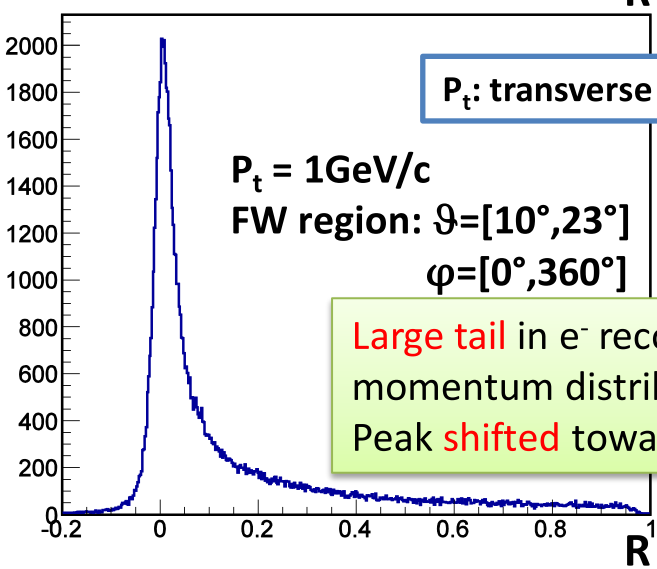
Backup slides

Electron momentum resolution

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





P_t: transverse momentum

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

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
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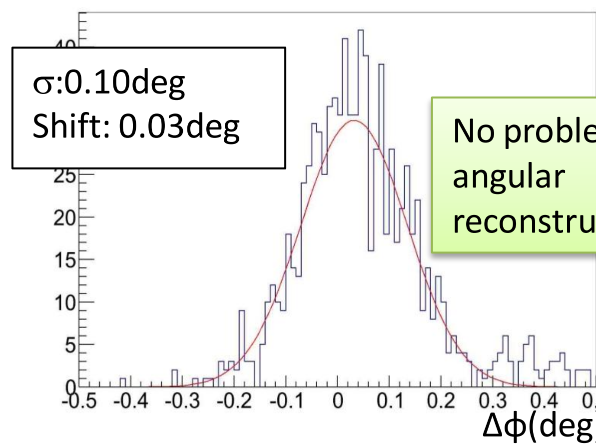
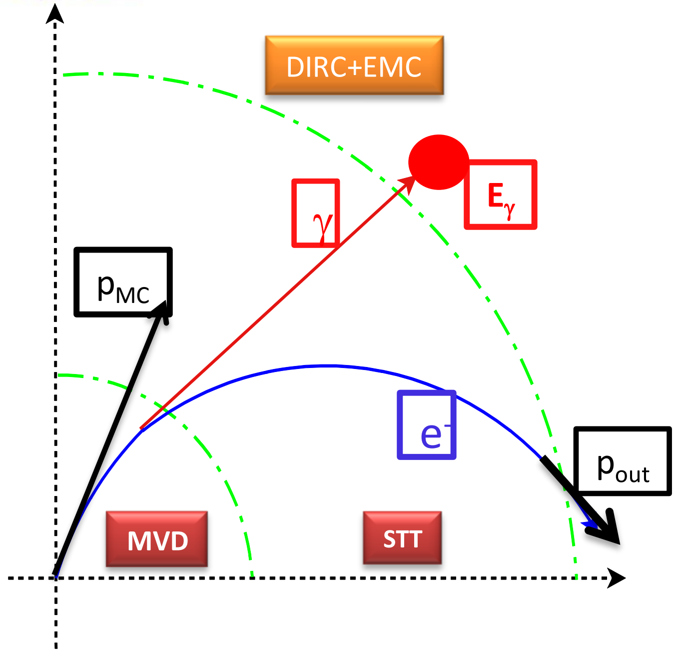
Needs to be improved

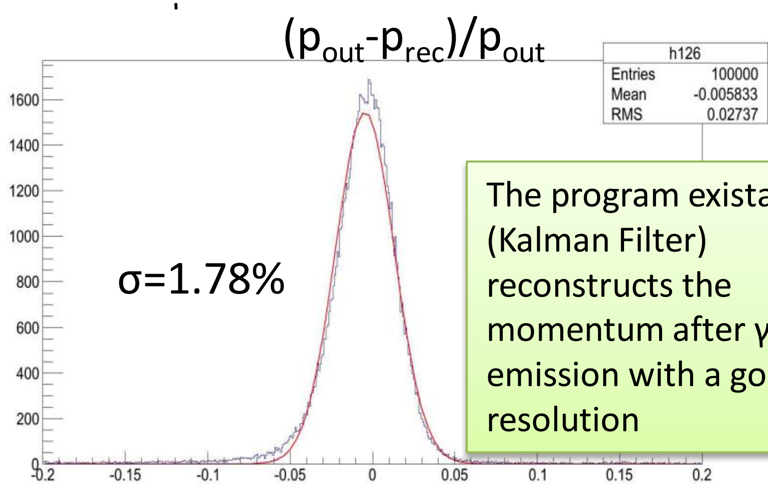
Electron angular resolution



No problem for angular reconstruction

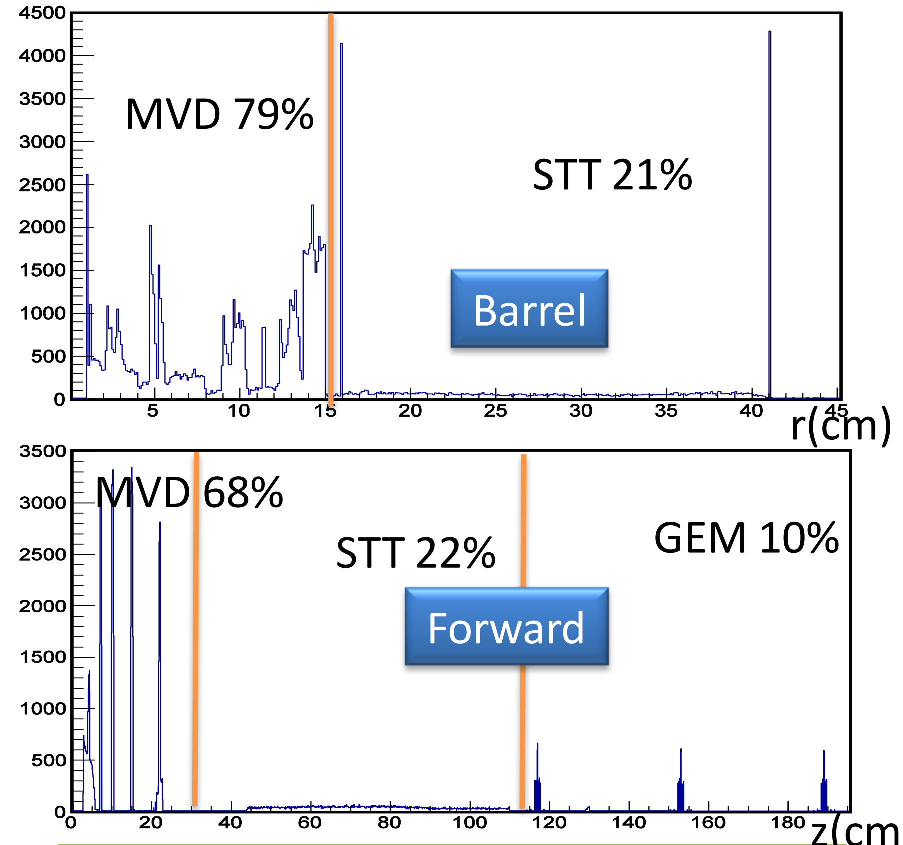
e^- momentum reconstruction with γ emission





The program existant (Kalman Filter) reconstructs the momentum after γ emission with a good resolution

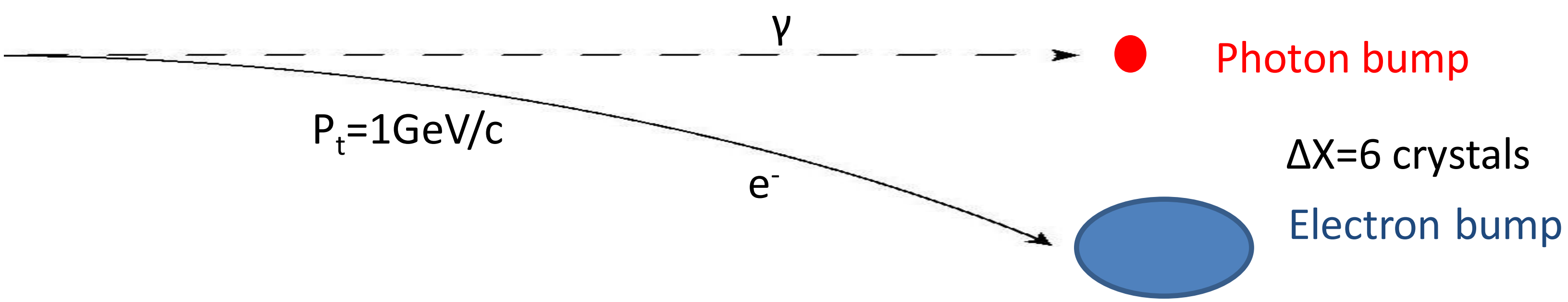
The position of gamma emission



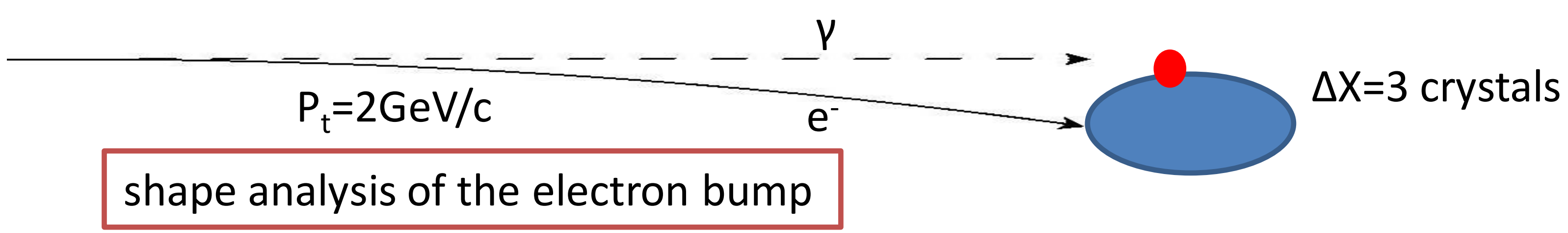
- Most γ emitted close to target(MVD)
- The track is mostly defined by STT hits
  (MVD 4 to 6 points, STT 24 to 26 points)
- $P_{rec} \approx P_{out}$

Looking for the Bremsstrahlung γ in EMC

- Case one: the clusters or bumps of e^- and γ can be well distinguished.



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



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

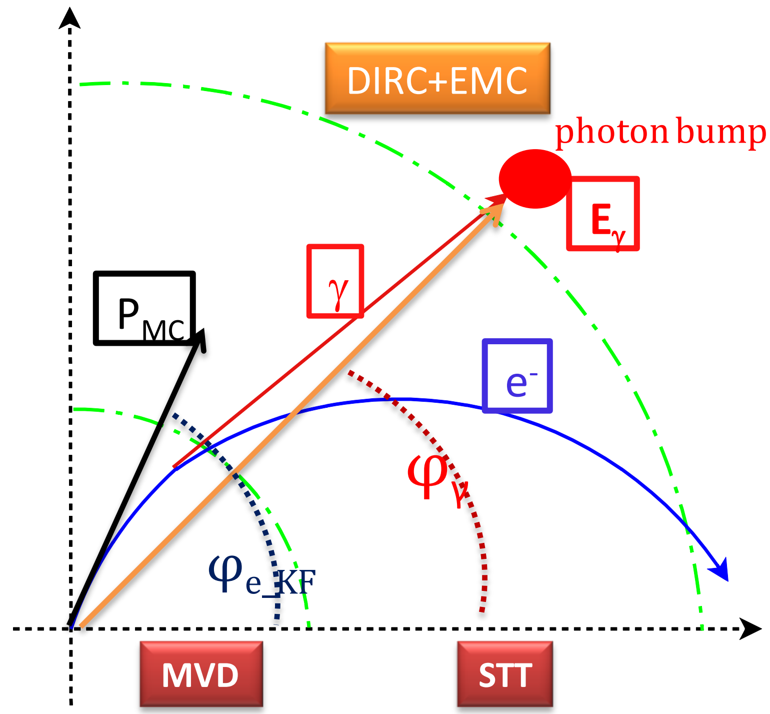
Bremsstrahlung γ selection algorithm for separated e^-/γ bumps

→ Look for a photon bump in EMC:
(a neutral candidate)

→ Selection of photons emitted before DIRC :
Using $\Delta\theta$ and $\Delta\varphi$:

$$\Delta\theta = \theta_\gamma - \theta_{e\_rec}$$
$$\Delta\varphi = \varphi_\gamma - \varphi_{e\_rec}$$

γ bump (for θ_γ, φ_γ) — tracking (for θ_{e_rec}, φ_{e_rec})

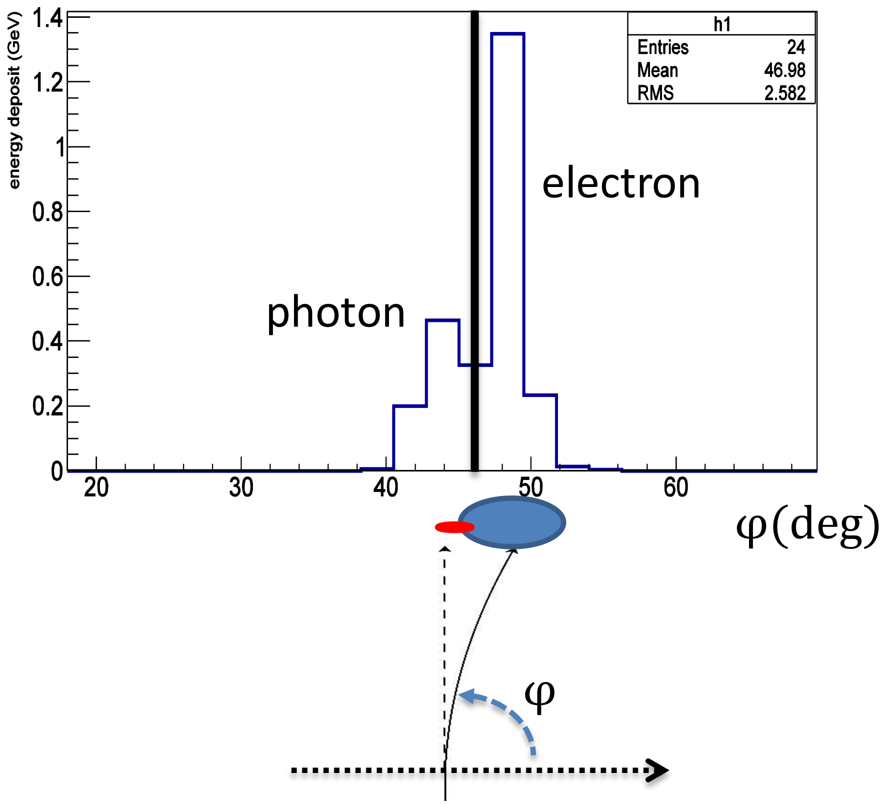


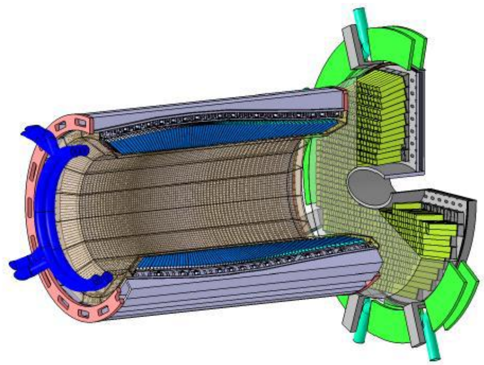
Cuts : $|\Delta\theta| < 2°$
$-1° < \Delta\varphi < 2\arcsin(0.12/P_t)$. barrel
$-1° < \Delta\varphi < (1.2/P_t)\tan\theta$. forward

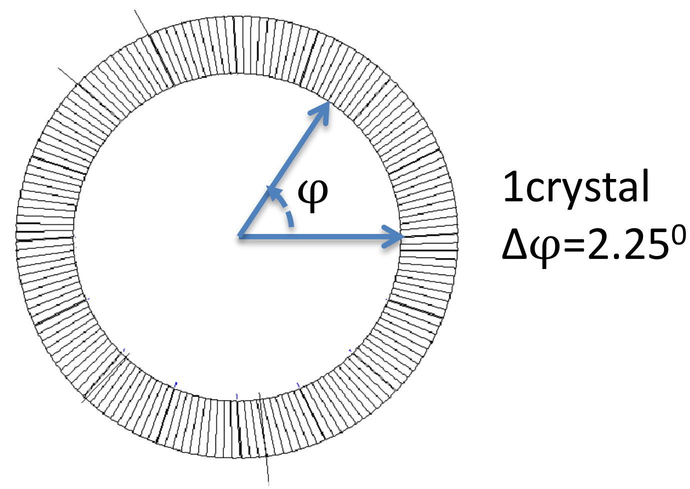
Maximum e^- deviation angle

γ selection algorithm for merged e^-/γ bumps

- Sum of energy deposits in crystals at a given φ.





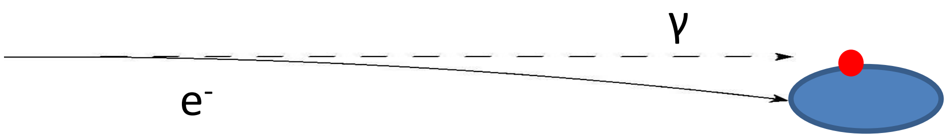


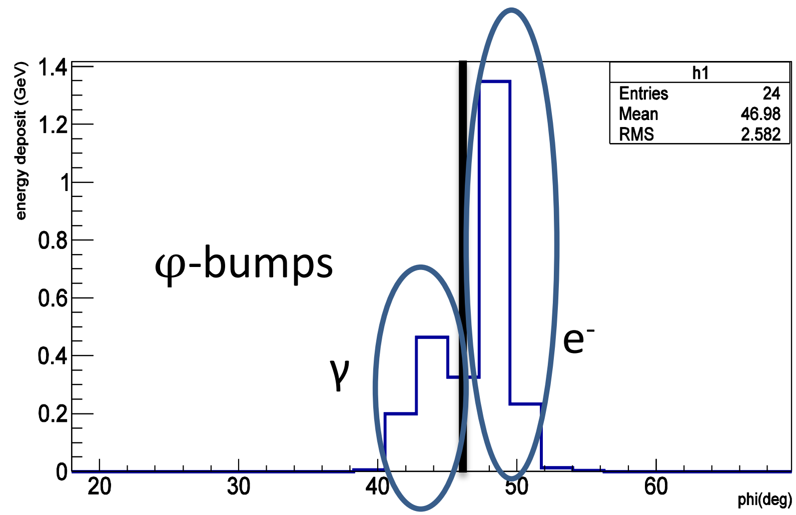
γ selection algorithm for merged e^-/γ bumps

Looking for a φ-bump:

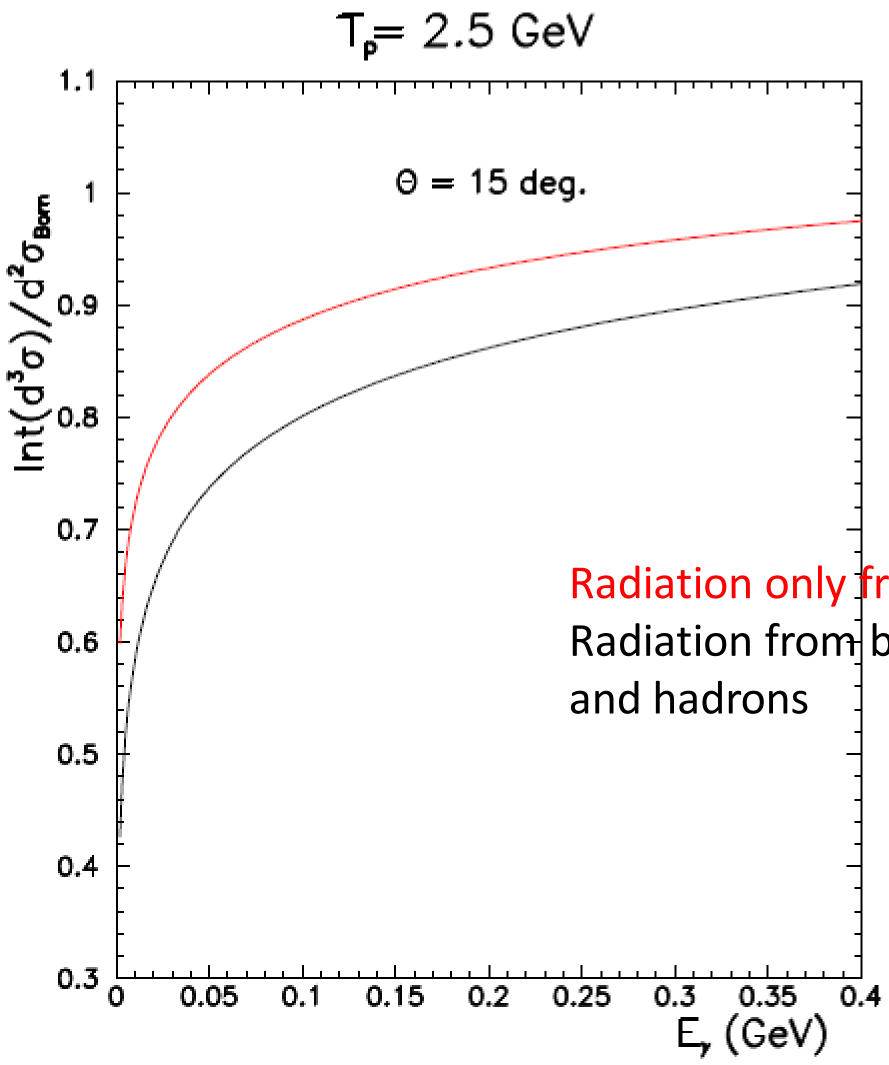
- Scan the bins of the energy deposit spectrum three by three, each bin i receives a code depending on N_{i-1}, N_i, N_{i+1}.
- φ-bumps are defined between two valleys (code =-2).
- The φ-bump at the right edge is considered as e^-. The other φ-bumps are considered as photons.
- The split electron φ-bumps are also considered.
- $p_{corr} = p_{rec} + \sum E_{\gamma(i)}$

code	cases
1	Rise
-1	Drop
0	Peak
-2	Valley





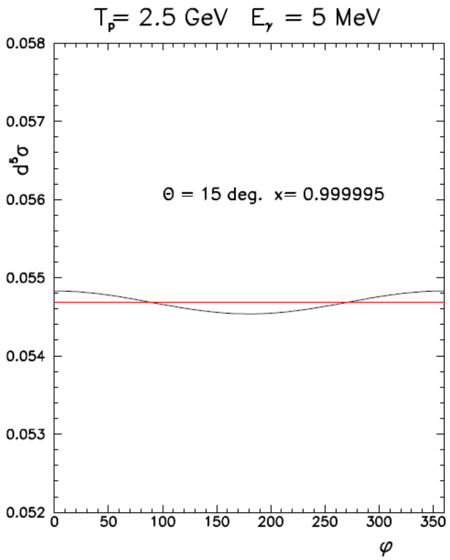
Integrated cross section

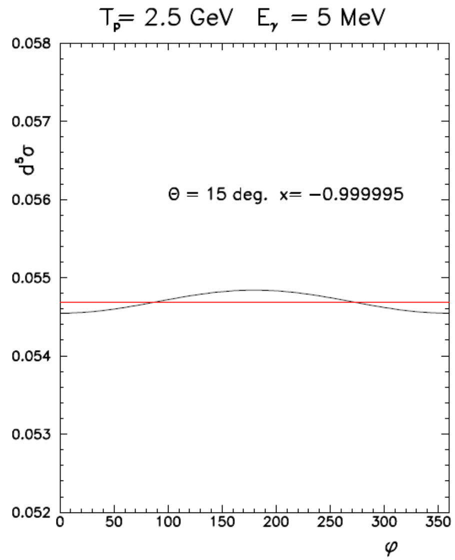


Radiation only from leptons

Radiation from both leptons and hadrons

ϕ distribution





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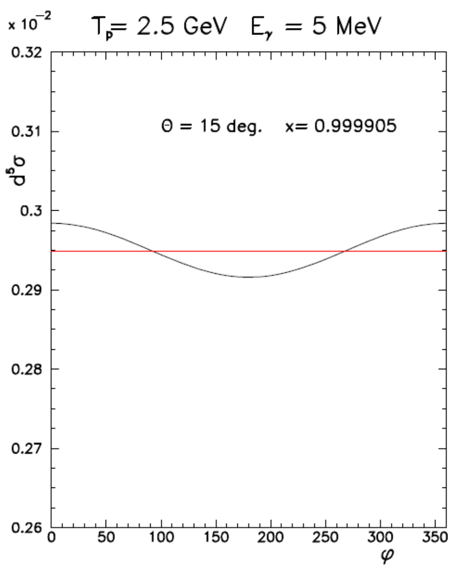
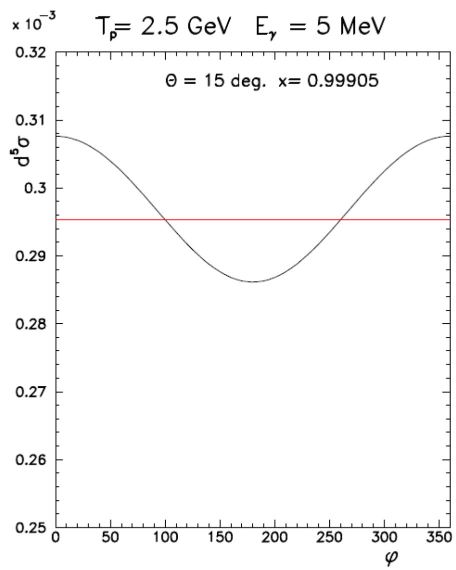
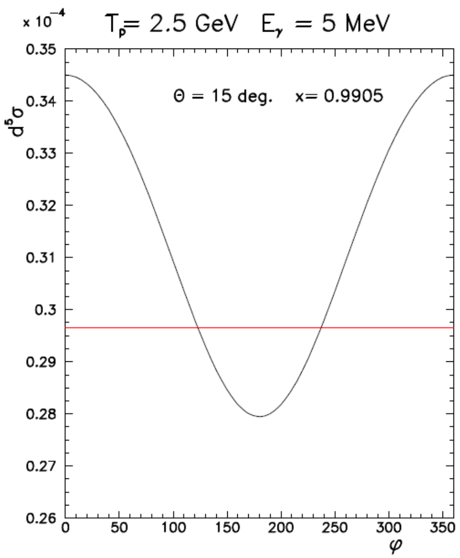
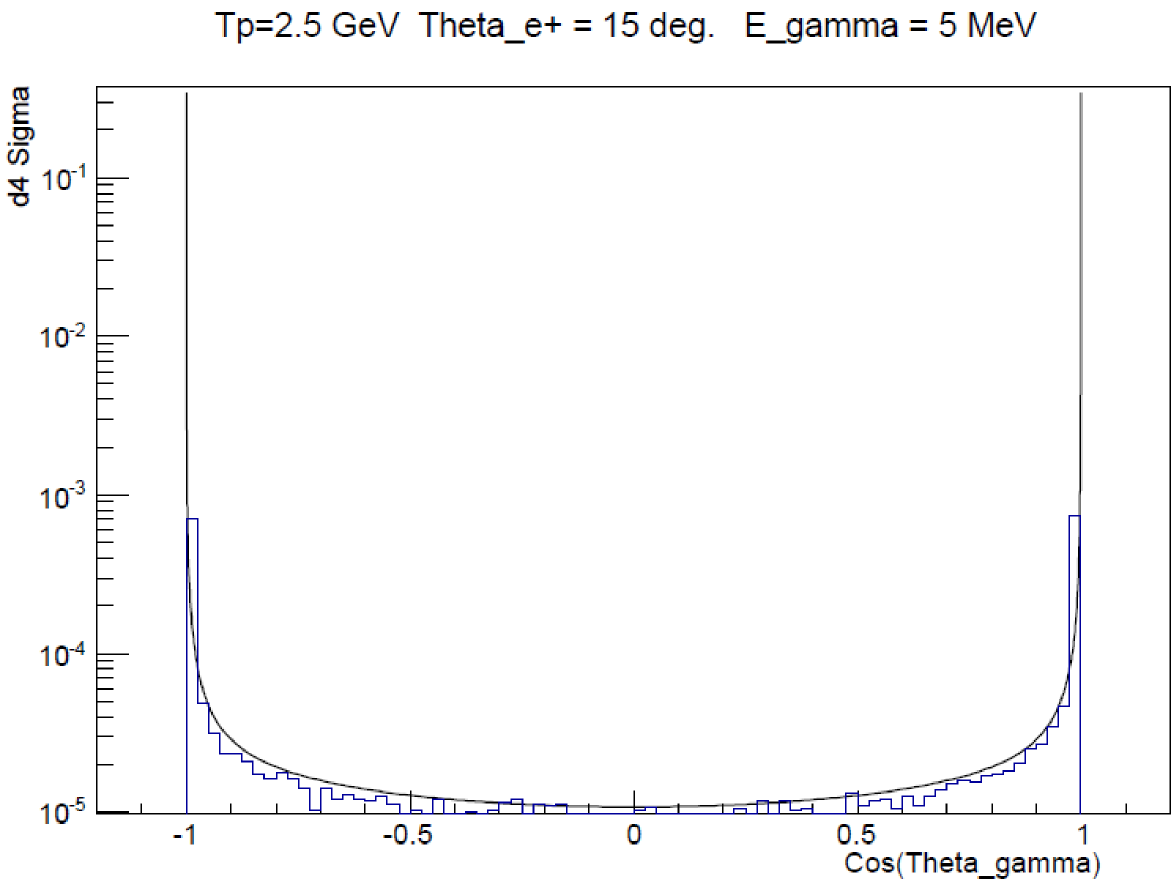


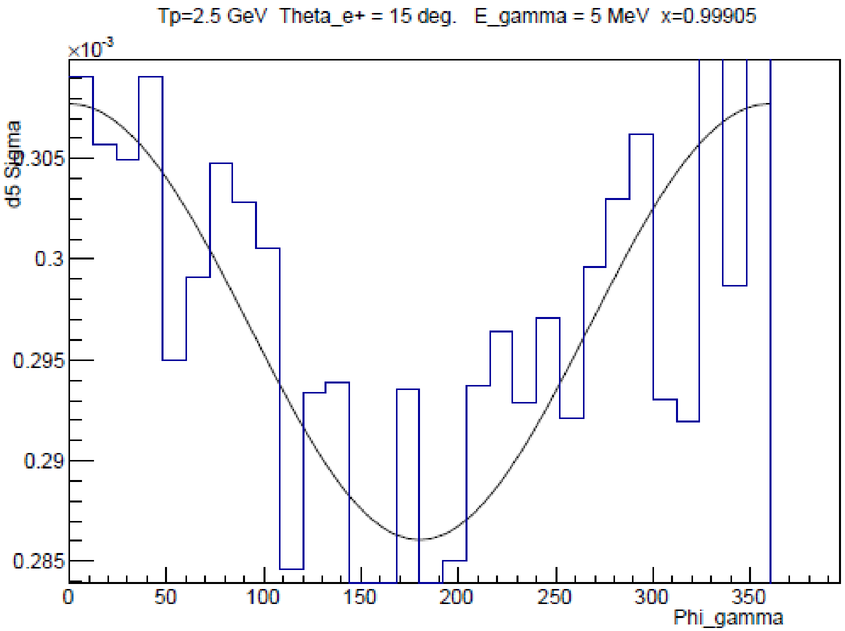


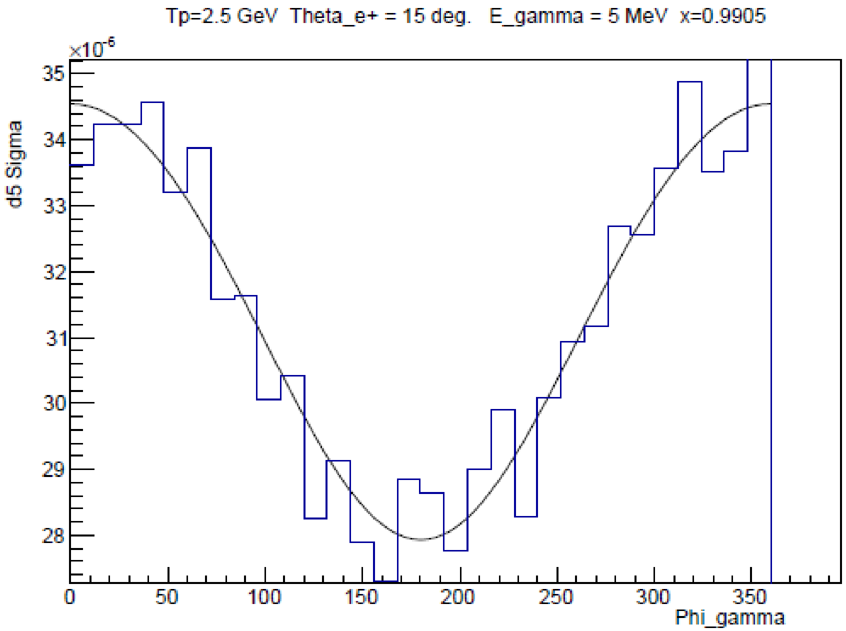


cos($\theta_{e+\gamma}$) distribution after generator



ϕ distribution after generator





Correction factor

- Angular distribution of the efficiency ε after the cuts.
  - Simulation of 10^5 event with Jacque's generator and E_γ<300MeV. (N_{mc})
  - The FFs model: fitting of the Babar's data.
  - Using PID and Kinematic cut to select the signal. ($N_{selected}$)
  - $\varepsilon = N_{selected}/N_{mc}$
- Angular distribution of rapport between the Born cross section and the real cross section(1+δ)
  - Obtained from the model $\left(\frac{d\sigma}{d\cos\theta}\right)_R = \left(\frac{d\sigma}{d\cos\theta}\right)_B (1+\delta)$
- Correction factor F=ε*(1+δ).
- The Born differential cross section can be given by

$$\left(\frac{d\sigma}{d\cos\theta}\right)_{Born} = \frac{\left(\frac{d\sigma}{d\cos\theta}\right)_{exp}}{F}$$