Improvements to Bremsstrahlung energy loss correction for electron momentum reconstruction

P̄ANDA Collaboration Meeting

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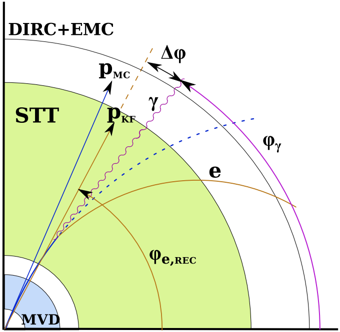
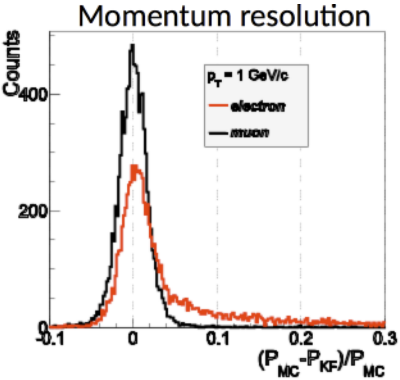
March 17, 2015

Effect of Bremsstrahlung radiation

- Photon emission by electrons before exiting the tracking system
- Some or all of the tracking points are created after the track loses momentum
- Leads to mis-reconstruction of the momentum that shows as a tail in resolution distributions and invariant mass spectra

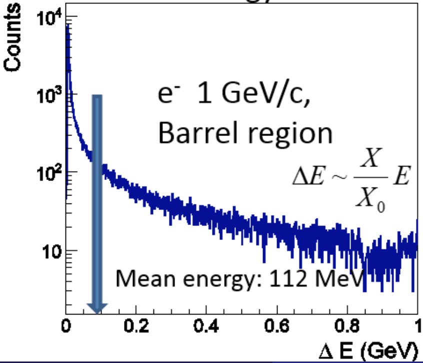


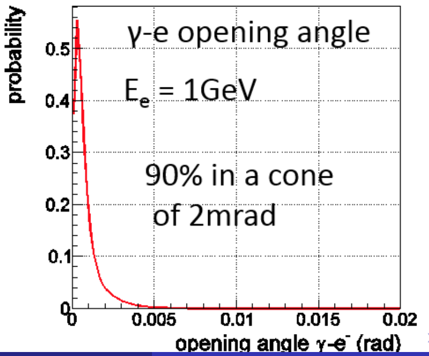


General approach

- Thesis work by Binsong Ma, 23 Sept 2014, Université Paris Sud
- Energy distribution highly non Gaussian: Can not be corrected easily with Kalman Filter
- Search for clusters in the EMC generated by the Bremsstrahlung photons associated with each track and add the total energy to the track's momentum
- Relies on the observation that
  - 90% of Bremsstrahlung photons are emitted within a cone of 2 mrad
  - The angular separation of the reconstructed electron momentum and photon cluster position is a reliable predictor of the radius at which the photon was emitted

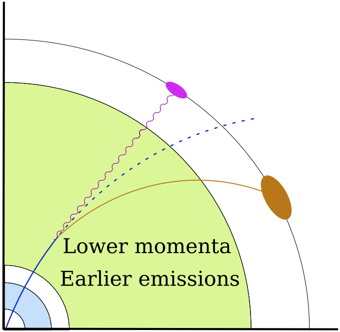
Electron energy loss:

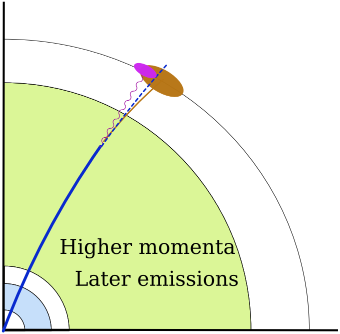




Cluster merging

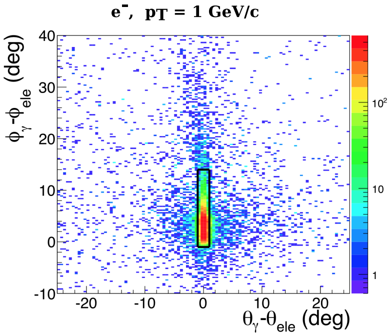
- Depending on the momentum and point of emission, Bremsstrahlung photon clusters can be reconstructed separately from or merged with that of the electron
- Higher momentum tracks and late emission of photons tend to result in merging, whereas lower momenta and early emission result in separate clusters
- The method has to handle both cases for every track





Separate bumps

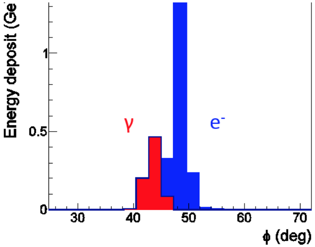
- Dominant at low momentum and late emission
- Search for bumps in the EMC with $E_{bump} > 1\% E_{track}$
- Apply angular selection on $\Delta\phi = \pm(\phi_{bump} - \phi_{e\mp})$ and $\Delta\theta = \pm(\theta_{bump} - \theta_{e\mp})$
  - $\Delta\theta$: $|\Delta\theta| < 2°$ (no bending assumed in theta)
  - $\Delta\phi$ (Barrel): $-1° < \Delta\phi < 2\arcsin((0.3 \cdot B \cdot R^{ext}_{TRK})/p^{rec}_T)$
  - $\Delta\phi$ (Forward): $-1° < \Delta\phi < (0.3 \cdot B \cdot Z_{STT+MVD+GEM} \cdot \tan\theta_{rec})/P^{rec}_T$
- Corrected momentum: $p_{COR} = p_{KF} + E^{TOT}_{\gamma,sep}$, where $E^{TOT}_{\gamma,sep} = \sum E^{Brem\ cut}_{\gamma,sep.\ bumps}$



Photons emitted before exit from tracking system

Merged bumps

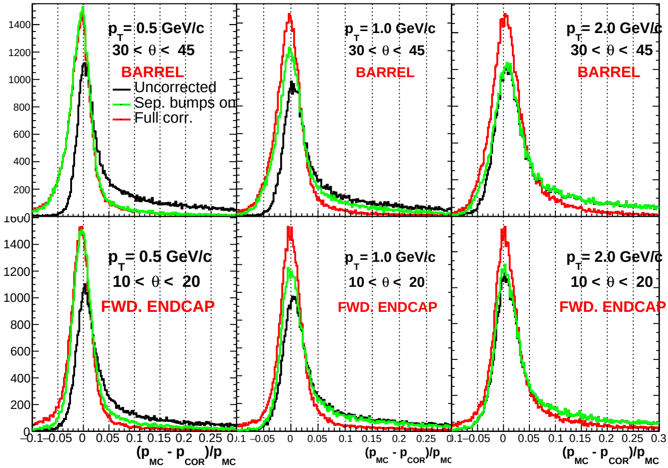
Distribution of energy deposits in crystals versus ϕ.



- Project the energy deposits in the cluster associated to the electron in ϕ direction
- Split the phi projection along local minima into "ϕ-bumps"
- The right (left) most ϕ-bump with sufficient energy is considered as originating from the e^+ (e^-) and the total energy of the phi bumps to the left (right) is added to the momentum of the track depending on charge

$$p_{COR} = p_{KF} + E^{TOT}_{\gamma,sep} + E^{TOT}_{\gamma,mrg}, \text{ where } E^{TOT}_{\gamma,mrg} = \sum E_{\phi-bumps}$$

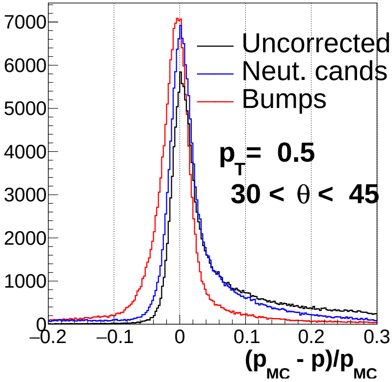
Performance of the method



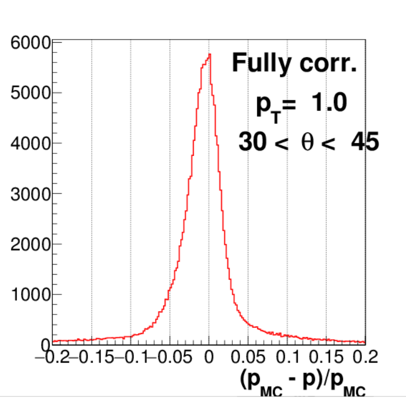
- Significantly improved resolution at all angles (L:Barrel, R:FWD) and momenta
- Correction with separated only and both separated and merged photons
- Contribution from merged increases with momentum

Neutral candidates vs. bumps

- Initial code used neutral candidates for separated bump correction to avoid adding bumps already associated with the electron
- Results in a dependence on track-cluster association criteria
  - Issue first noticed in recent PANDAroot releases ($\approx$ scrut14 and above)
  - Possibly due to bumps being assigned to secondary electrons/fake tracks?
- All bumps used now with a condition that EmcIndex(bump) $\neq$ EmcIndex(track)



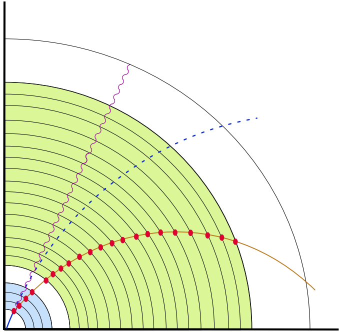
Over-correction

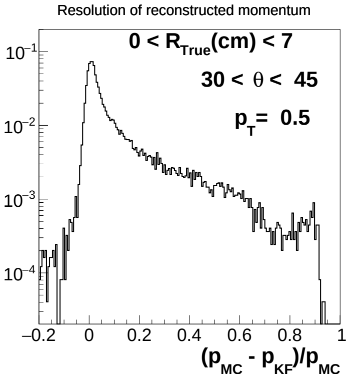


- Visible asymmetry of corrected resolution, too much energy is being added back
- For tracks that emit late, the momentum reconstruction is mostly based on “good” hits
- Adding the full energy of the photon for such tracks over-corrects momentum

Emission radius dependence of resolution degradation

- Photons emitted in later half of tracking system do not affect the reconstructed momentum as much as photons emitted early
- Reconstructed momentum resolution improves with increasing MC radius (R_{True}) of emission (ie. fraction of tracking points before emission)





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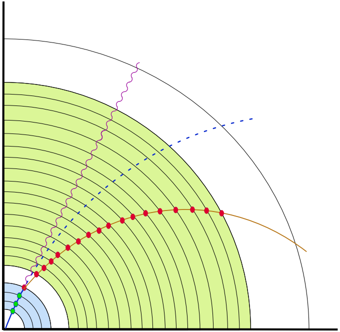

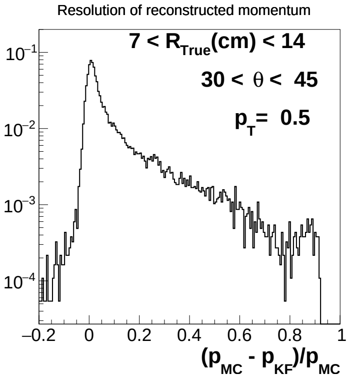

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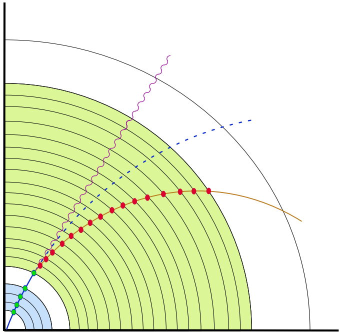

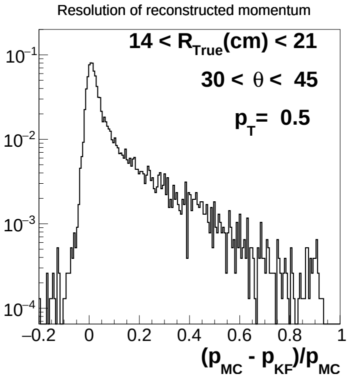

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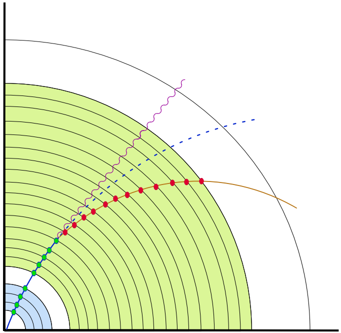

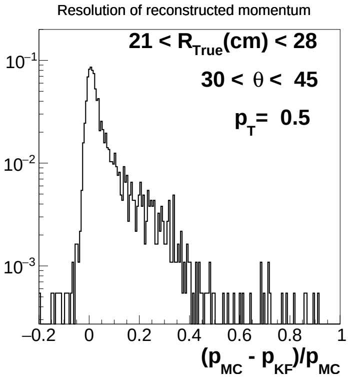

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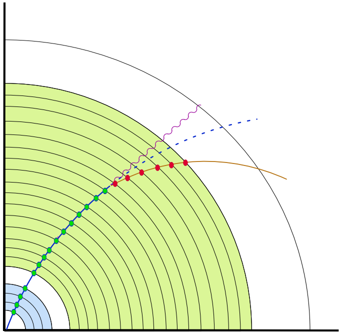

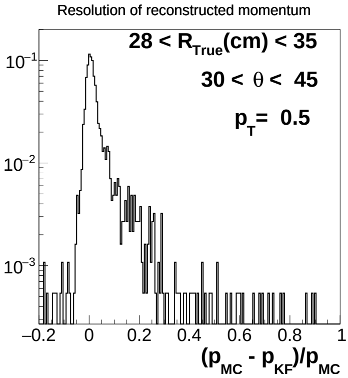

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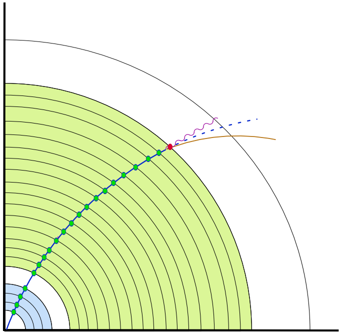
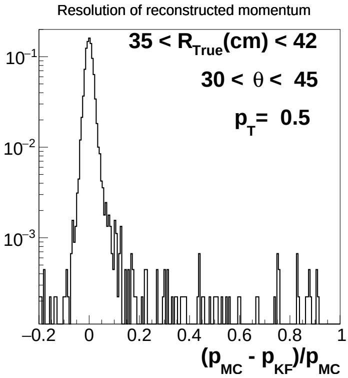
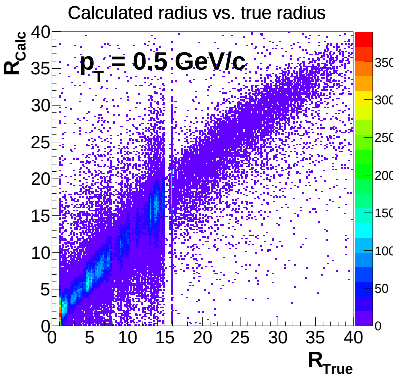
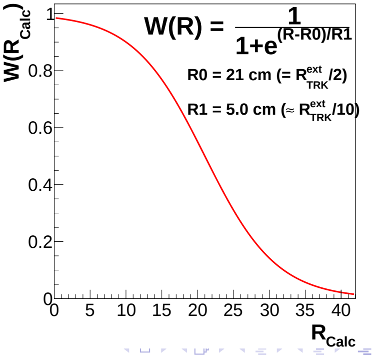




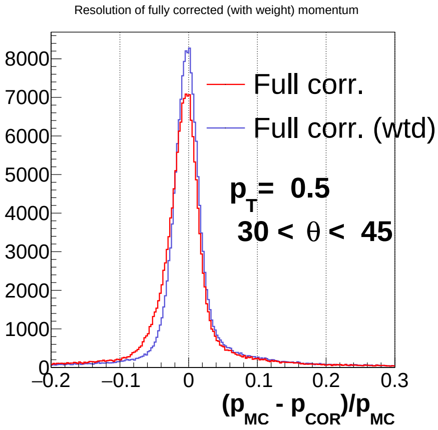
Emission radius weighted correction

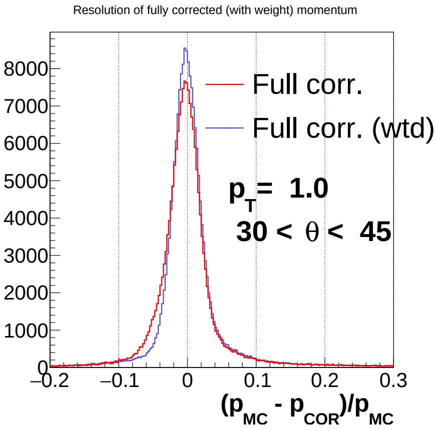
- Solution: Add a smaller fraction of the energy for photons emitted later:
$$E^{TOT}_{\gamma,sep} = \sum W(R) \times E^{Brem\ cut}_{\gamma,sep.\ bumps}$$
- Constraints on weight function: $W(0) = 1$ and $W(R^{ext}_{TRK}) = 0$.
- Estimator of R based on the relation between R_{True},$\Delta\phi$, p_T: $R_{Calc} = K \times \frac{2p_T \sin(\Delta\phi/2)}{0.3B}$
- Correlation plot: Events with single Bremsstrahlung photon ($R_{emission} < R_{TRK}$) and single identified separate bump (cut on $\Delta\phi$, $\Delta\theta$), MC matching required
- Weight: Fermi function with inflection point at the middle of tracking system





Results with weighted correction (Barrel Region)

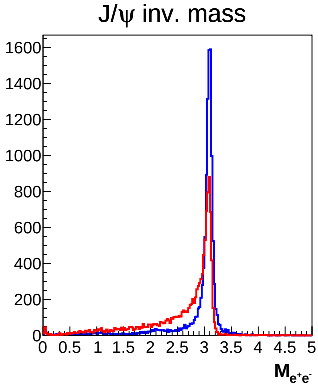


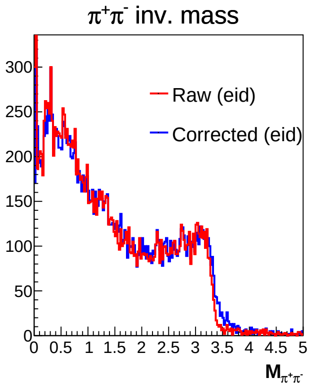


- Weighting fixes over-correction at all momenta and angles (more plots in backup)
- The same function is used everywhere
- Particularly useful for low momentum tracks where search window can be wide

Full event simulation

- Presence of other particles that generate hits in the EMC can bias the correction
- Potential issue especially at low momenta, where $\Delta\phi$ search window is large
- To test the stability in presence of other particles: $\pi^0 J/\psi$ and $\pi^0\pi^+\pi^-$
- Significantly improved J/ψ mass resolution with minimal effect on $\pi^+\pi^-$ spectrum
  - Modifications (discussed on PANDAroot forum, msg:17933) to the track-cluster matching algorithms were used
  - Reason: A failed association can result in adding the energy of the electron's cluster back to the momentum
- Allows for much tighter mass cut while improving efficiency





Implementation in PANDAroot (1/3)

- ϕ-bumps are created for all clusters and stored separately in PndEmcPhiBumpSpiltter.cxx (called from XYZ..). No change required in "official" simulation macros for this step
- Corrected momentum calculated for all reconstructed tracks and stored separately in a TCA by PndPidBremCorrector.cxx. Add the following to pid_complete.C:

```
// after all the Pid modules...
PndPidBremCorrector *bremCorr = new PndPidBremCorrector();
fRun->AddTask(bremCorr);
...
```

- In analysis macro, request RhoCandidate objects to be filled with corrected momenta by adding "Brem" to the selection string

```
PndAnalysis* theAnalysis = new PndAnalysis();
RhoCandList eplus;
while (theAnalysis->GetEvent() && i++<nevts) {
  ...
  theAnalysis->FillList(eplus,  "BremElectronVeryTightMinus");
  ...
}
...
```

Implementation in PANDAroot (2/3)

- Alternatively, working directly with charged candidates

```
// MyTask.h:
TClonesArray* fBremCorr;
...
// MyTask.cxx
#include "PndPidBremCorrected4Mom.h"
// in MyTask::Init() method
fBremCorr =
   dynamic_cast<TClonesArray *> (ioman->GetObject("BremCorrected4Mom"));
...
// in MyTask::Exec() method
for (int j=0; j<fChargedCandList.GetLength(); ++j) {
  int trk_id = fChargedCandList[j]->GetTrackNumber();
  PndPidBremCorrected4Mom *bremCorr =
       (PndPidBremCorrected4Mom*) fBremCorr->At(trk_id);
  TVector3 mom_corrected = bremCorr->GetMomentum());
  double energy_corrected = bremCorr->GetEnergy());
  ...
}
...
```

Implementation in PANDAroot (3/3)

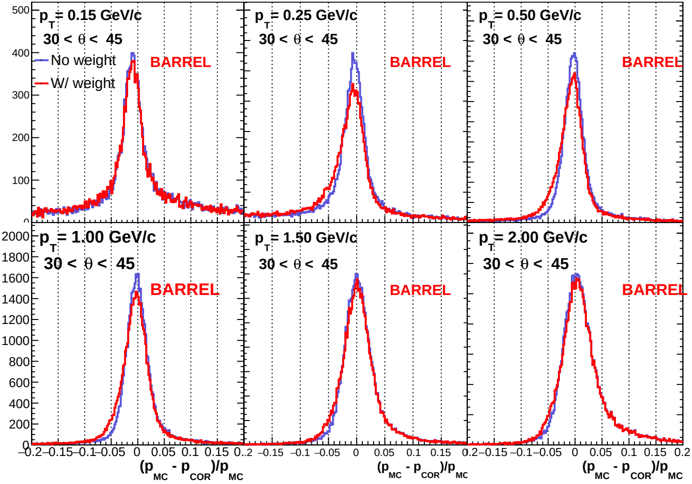
- Does not affect any analysis that doesn't request it explicitly (separate storage)
- PID consideration:
  - All PID probabilities are still calculated with uncorrected momentum
  - Not advisable to use corrected momenta as input for PID algorithms at this point unless PID probabilities are recomputed
  - Potential to use the corrected momentum as additional input to PID algorithms
- Will be available soon in trunk release (pending approval)
- In the meantime all the relevant source files can be found here: https://github.com/atomssa/brempatch

Conclusion

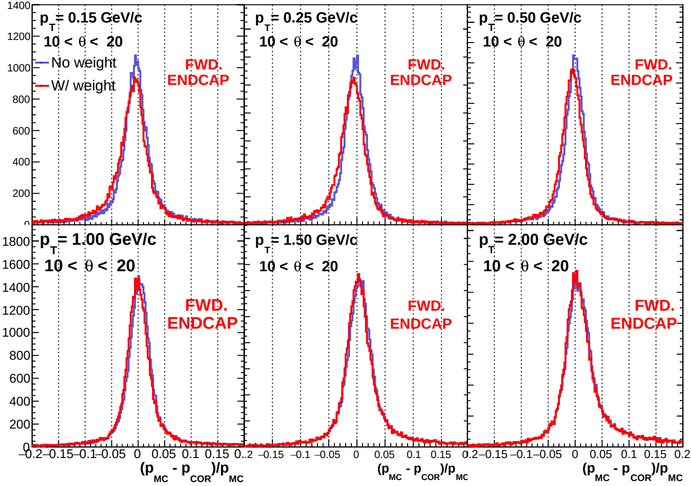
- Bremsstrahlung correction method for electrons fully debugged and implemented in PANDAroot with some improvements
- Offers improved spectra for signals with electrons in the exit channel and improved mass cut efficiency for resonances
- Simple usage instructions for simulations are provided

Backup

Performance with varying momentum (Barrel Region)



Performance with varying energy (FWD Region)



Performance with varying angles (Barrel Region)