Hybrid method for the reconstruction of neutral mesons in the tracking system and the ECAL

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Photon registration in MPD

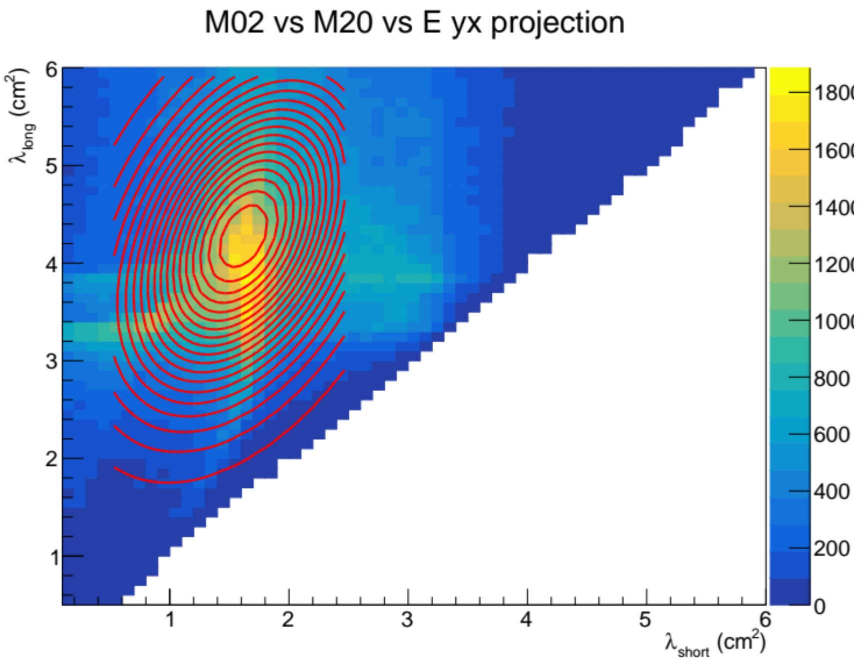
- ECAL
  - (+) High efficiency
  - (-) Low purity especially at low p_T
  - (-) Modest energy and position resolution at low p_T
- V0 reconstruction
  - (+) High purity
  - (+) Good momentum resolution at low p_T
  - (-) Small conversion probability =>small eff.
  - (-) p_T < 300-400 MeV/c not accessible

Completely independent appraoches with very different systematic uncertainties. Excellent possibility to cross-check results: 3 independent measurements at once.

ECAL: photon identification criteria

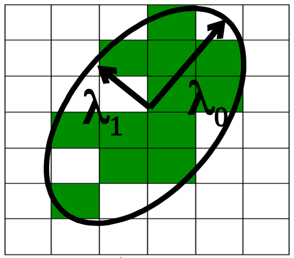
- Multiplicity
- Shower shape
  - 2D dispersion cut
  - χ^2 cut
  - Ratio cut
- Neutrality
- Time of flight

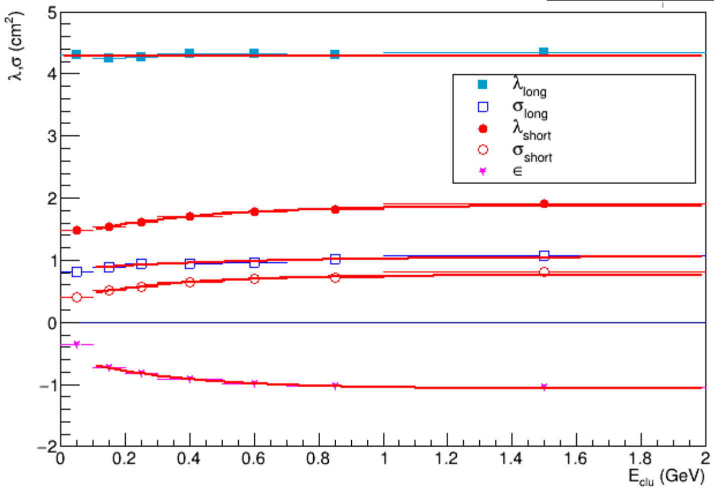
2D dispersion cut



$$D^{ij} = \frac{\sum_k w_k (x_k^i - \bar{x}^i)(x_k^j - \bar{x}^j)}{\sum_k w_k}$$

$$\lambda_{1,2} = \frac{1}{2}(D_{xx} + D_{zz}) \pm \sqrt{(D_{xx} - D_{zz})^2/4 + D_{xz}^2}$$





Fit distribution for photons with

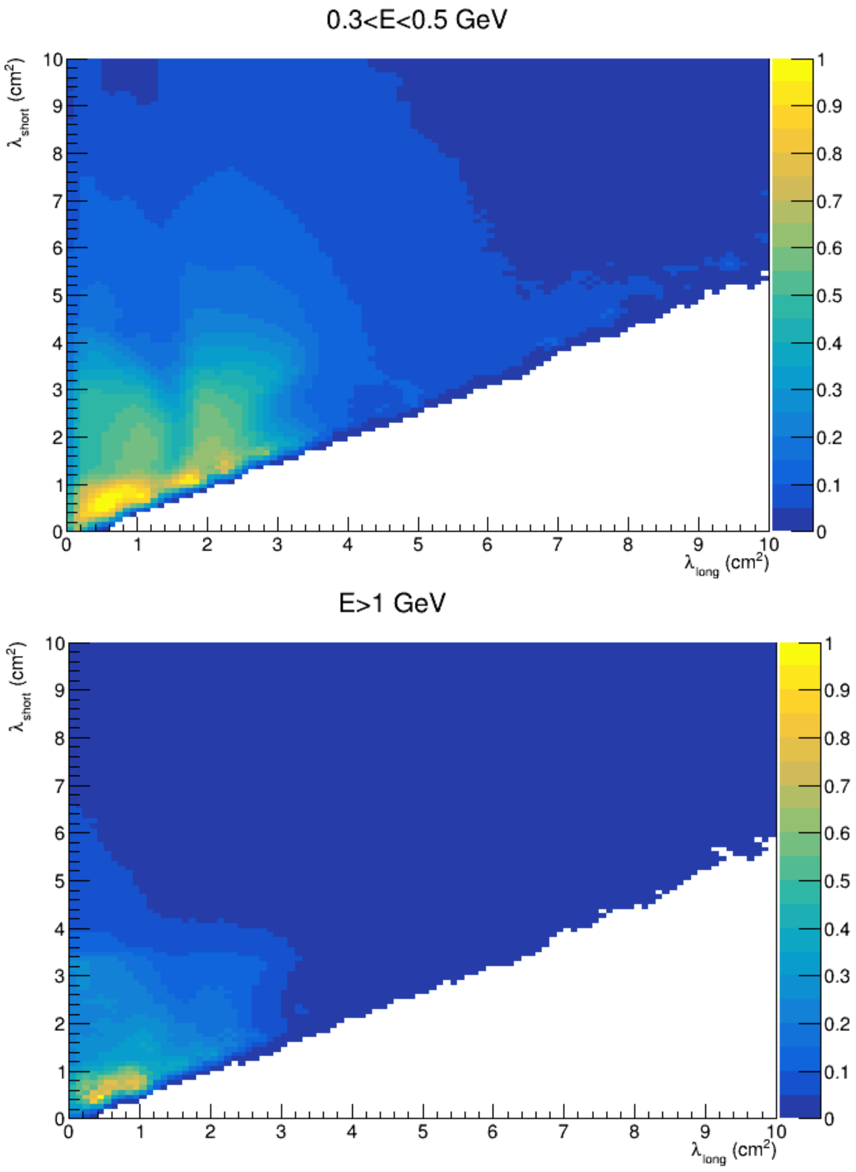
$$\exp\left(-\frac{(\lambda_{long} - \lambda_{long}^{mean})^2}{2\,\sigma_{long}^2} - \frac{(\lambda_{short} - \lambda_{short}^{mean})^2}{2\,\sigma_{short}^2} - c\,\frac{(\lambda_{long} - \lambda_{long}^{mean})(\lambda_{short} - \lambda_{short}^{mean})}{2\,\sigma_{long}\,\sigma_{short}}\right)$$

```
float EvalLambdaCut(float l1,float l2,float E){
  float longM = 4.28333 ;
  float shortM= 1.88168-5.06456e-01*exp(-E/3.83640e-01) ;
  float longS = 1.05616-2.12212e-01*exp(-E/5.46530e-01) ;
  float shortS= 7.58640e-01-3.97720e-01*exp(-E/3.18150e-01) ;
  float c = -1.0+5.42460e-01*exp(-E/3.22982e-01) ;
  return sqrt((l1-longM)*(l1-longM)/(longS*longS*2.)
            +(l2-shortM)*(l2-shortM)/(shortS*shortS*2.)
            +c*(l1-longM)*(l2-shortM)/(longS*shortS*2.));
}
```

Ratio cut

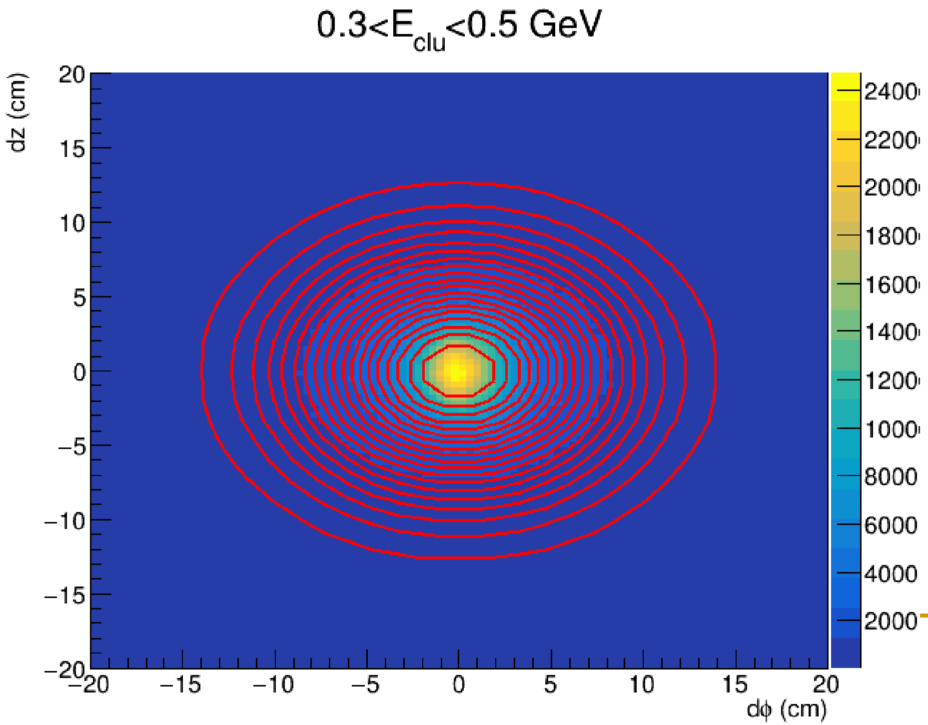
- Make ratio of (λ_{short},λ_{long}) distribution of photon and of contamination
- Find a region in (λ_{short},λ_{long}) plane where photon/contamination ratio is maximal
- Return ratio photons/contamination R normalized to 1 at maximum (0..1)
- Accept particle if R>threshold

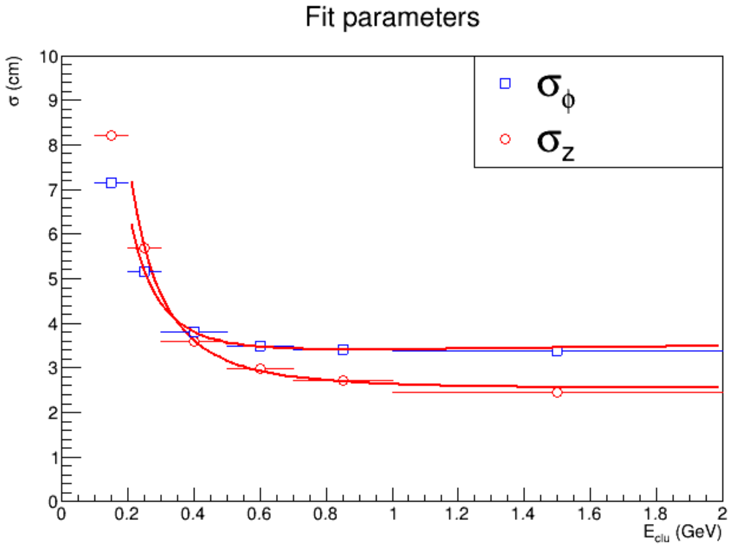
Pro: better discriminating power
Contra: depends also on description of calorimeter response to hadrons
Still under development



Neutrality cut

- Calculate distance to closest track
- Fit distance for pion tracks:

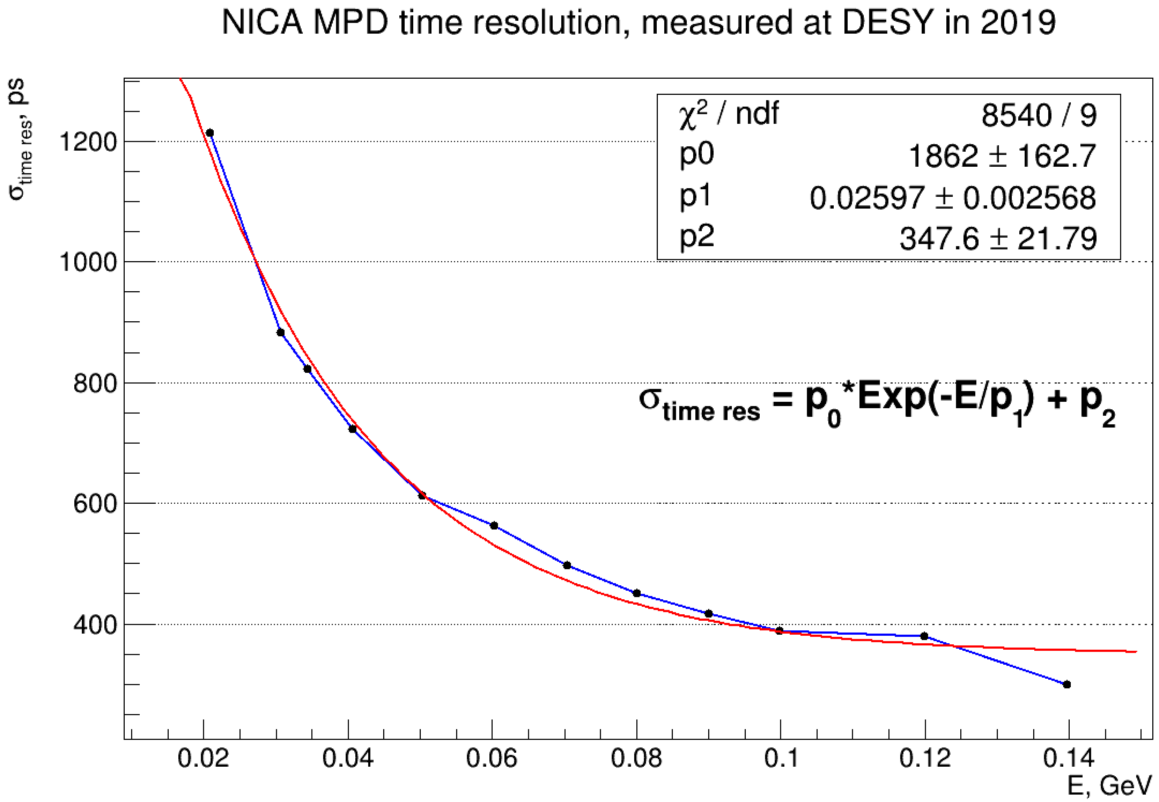




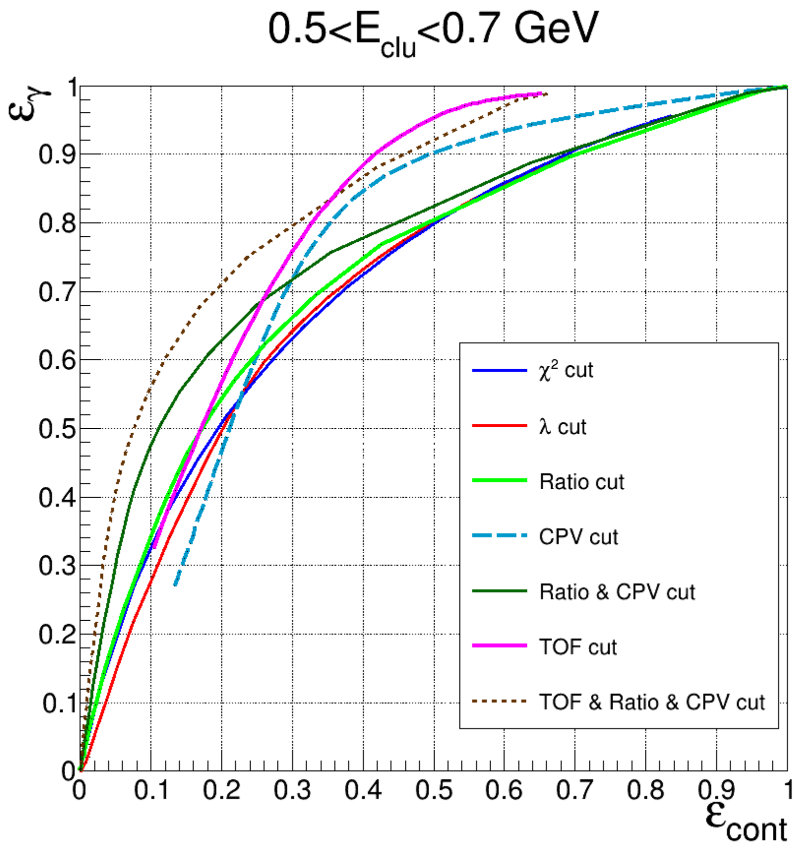

```
float EvalDistCPV(float dphi, float dz, float E){
  //returns distance in sigma
  float sigmaPhi = 3.66601-4.63964e-01/E+2.08779e-01/E/E ;
  float sigmaZ   = 2.58409-1.87502e-01/E+2.40143e-01/E/E ;
  dphi=dphi/sigmaPhi ;
  dz=dz/sigmaZ ;
  return sqrt(dphi*dphi + dz*dz) ;
}
```

Time cut

- Parameterize time resolution (thanks to Andrey Semenov)
- Smear arrival time
- Calculate dt = arrival time – expected photon arrival time.
- Cut: |dt|< 2 ns



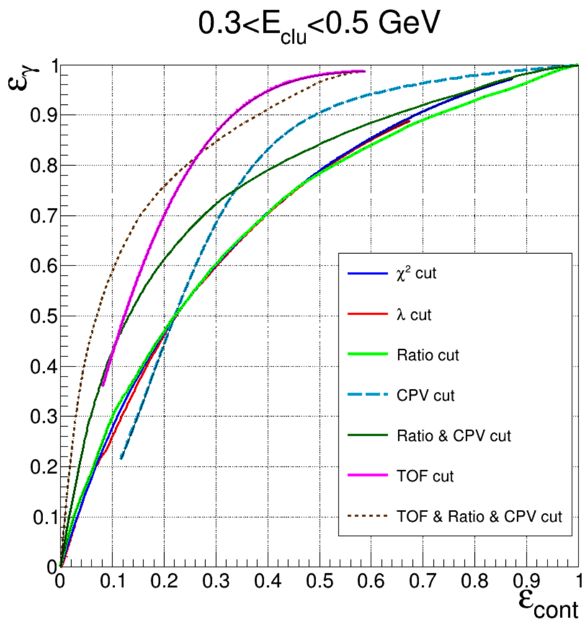
Receiver Operating Characteristic (ROC)

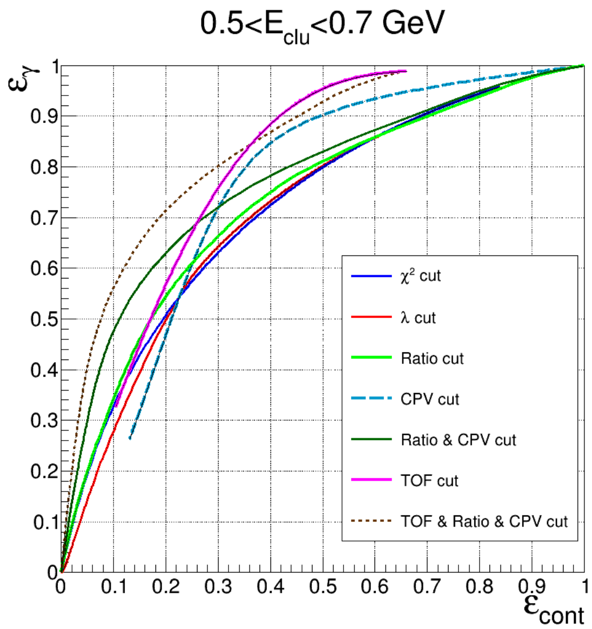


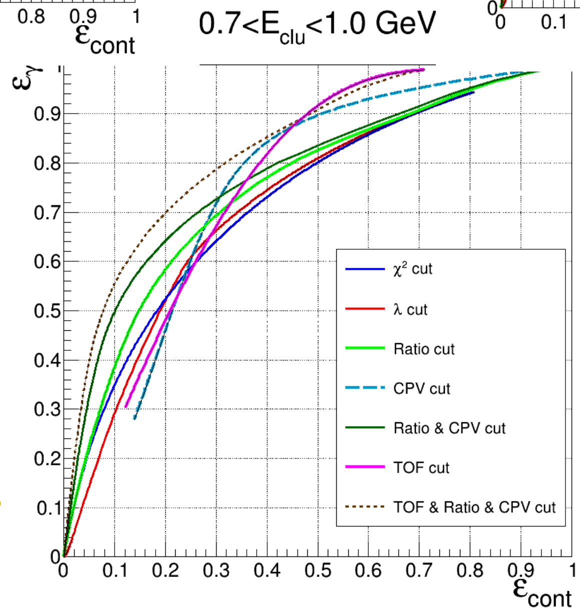
Quality of cuts:
Probability to pass cut for a photon vs probability to pass cut for a contamination (electrons, pions, protons etc.). NB!This is not contamination of photon spectrum!

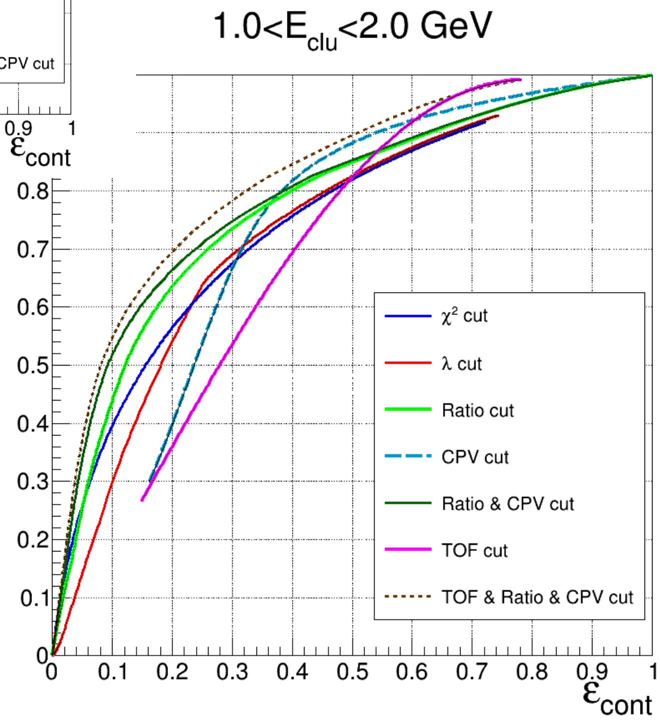
χ^2 and (λ_{short},λ_{long}) cuts show similar results
"Ratio" shows slightly better performance
CPV and TOF cuts show better performance at low E

ROC: Other energies





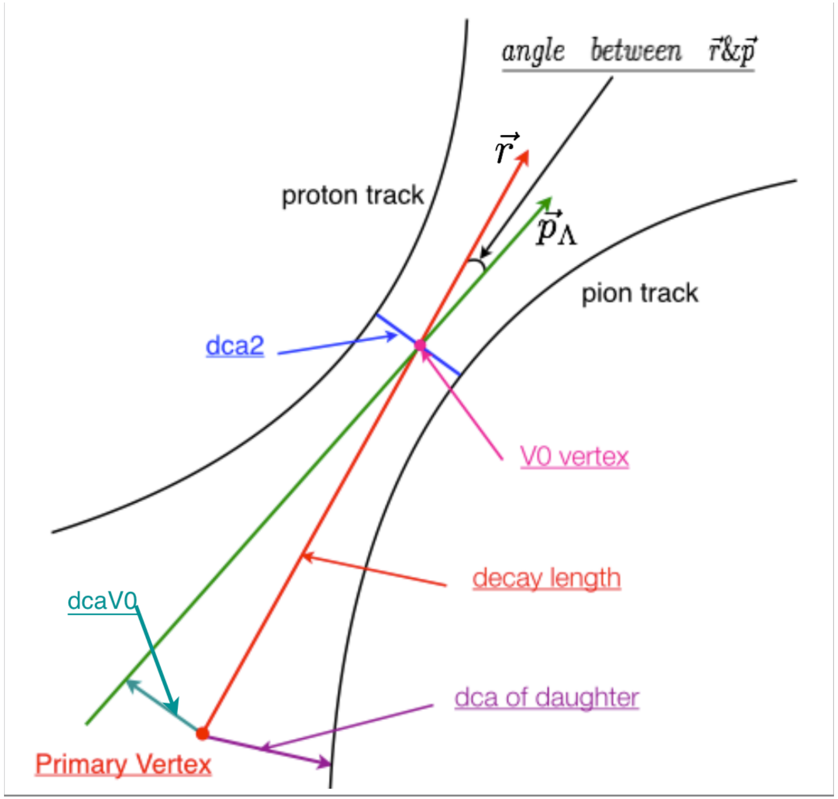




Converted photon reconstruction

Definition of variables for V0 selection

- Tracks with opposite charges
- Conversion radius
- χ^2 of Kalman fit of track pair
- m_{e+e-}
- α = angle between $\bar{r}$ & $\bar{p}$
- Daughter tracks DCA
- Asymmetry
- Ψ-cut (pair orientation w.r.t. B)



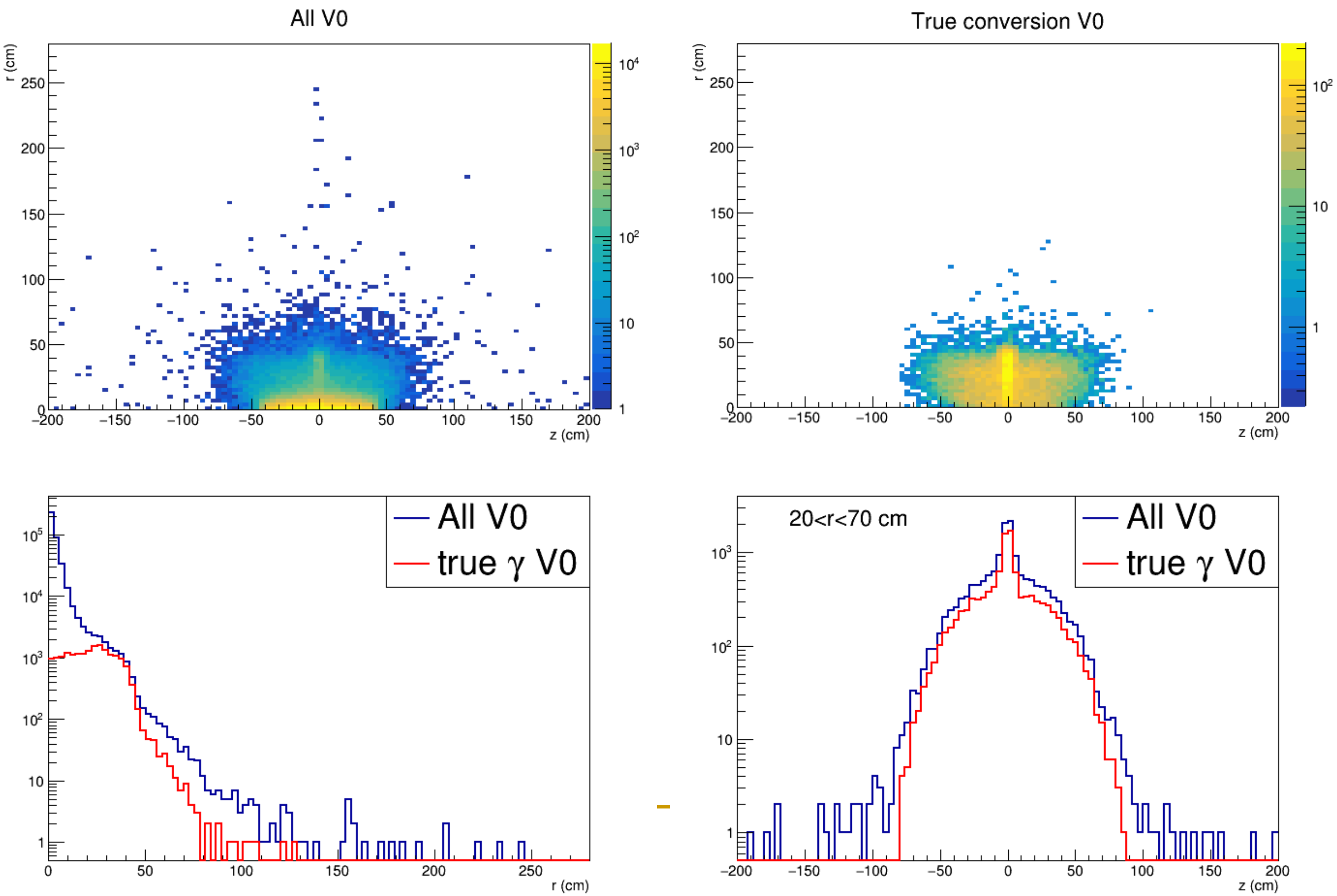
Plot from STAR collaboration

Material budget or conversion map

- Cut on minimal conversion radius effective

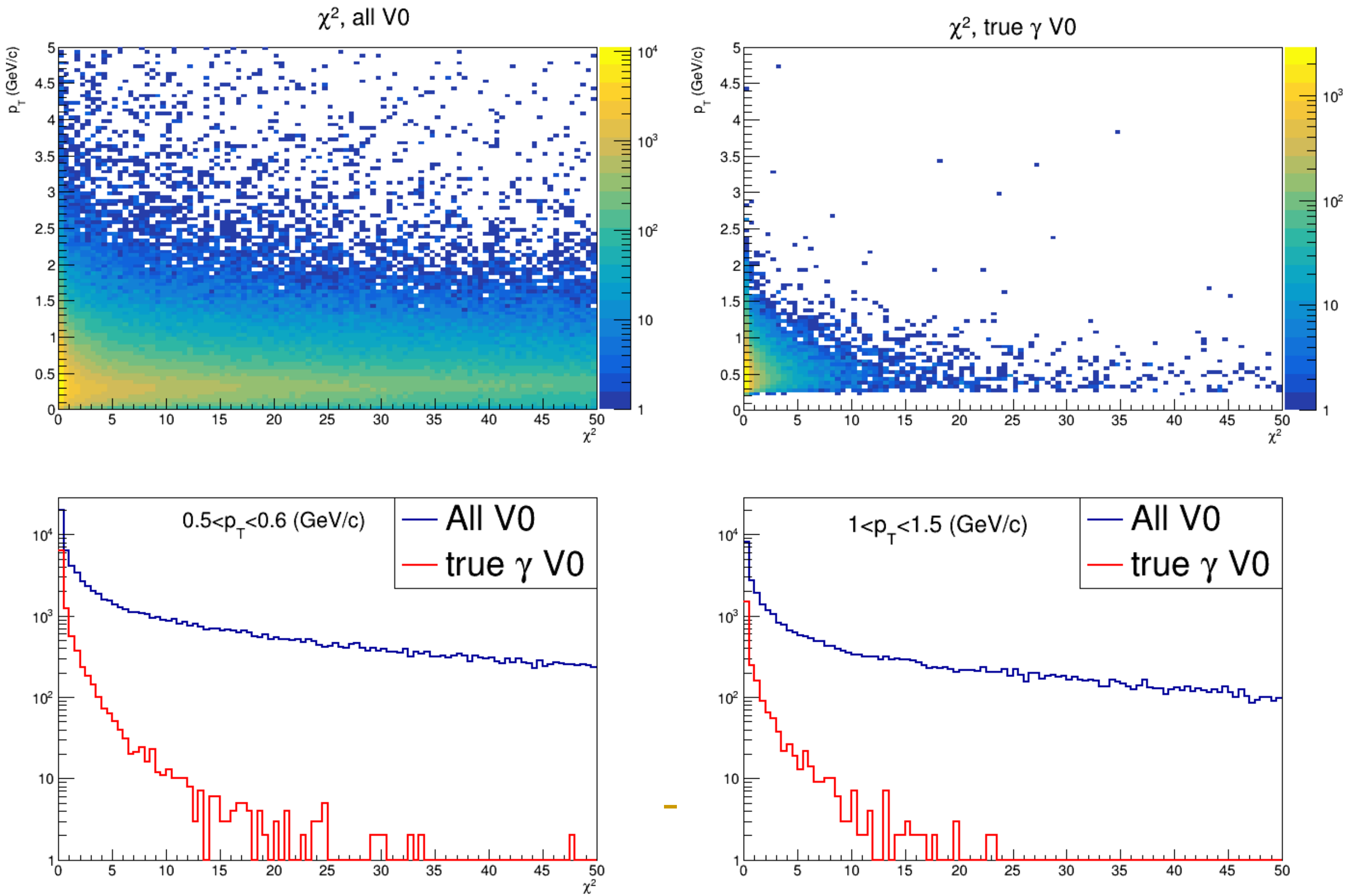
  20<r<100 cm (remove combinatorics and Dalitz decays)
- Cut on

  |z| < 100 cm possibly useful



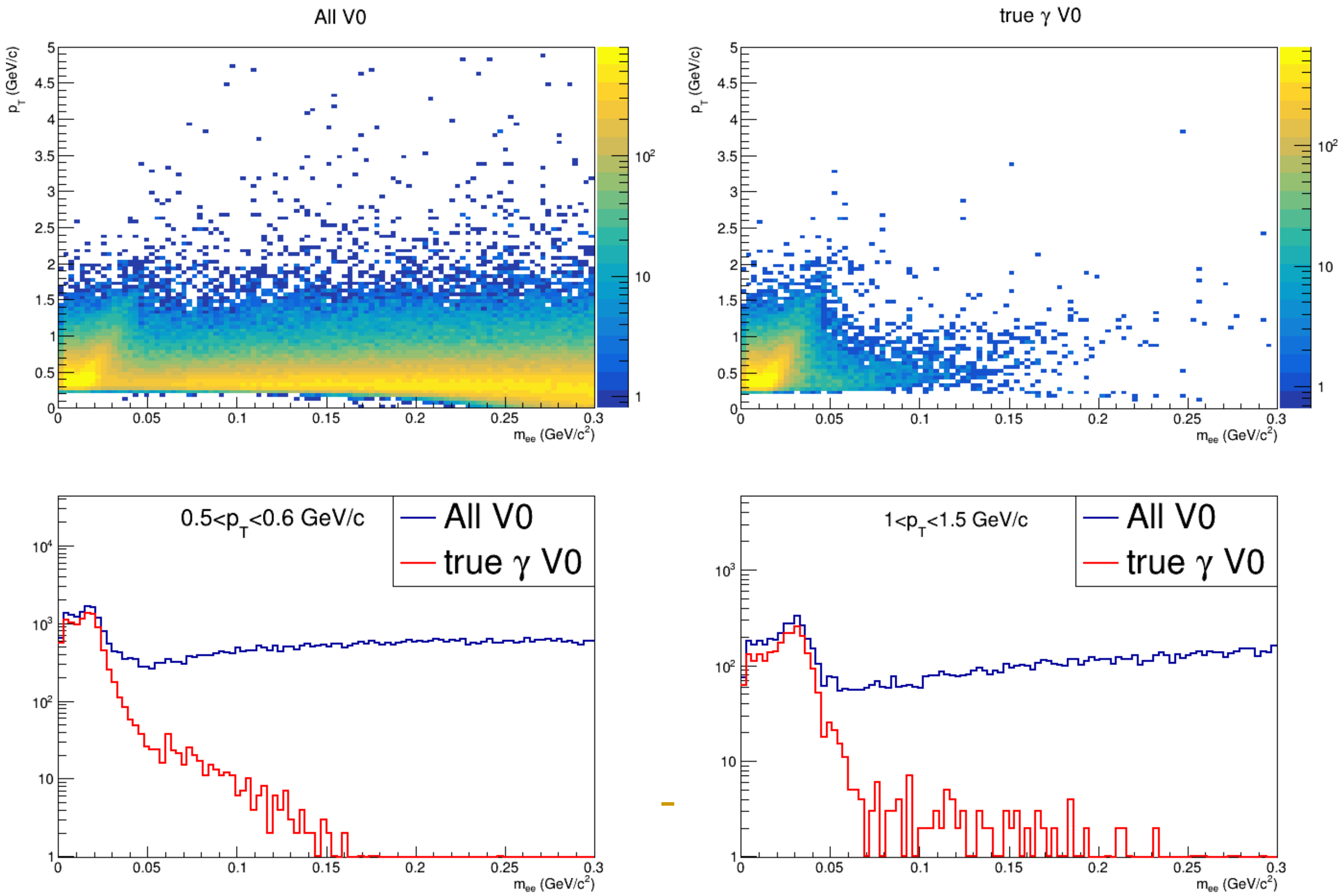
Kalman fit χ^2

- Distribution for true pairs is narrower. Try χ^2<Cut



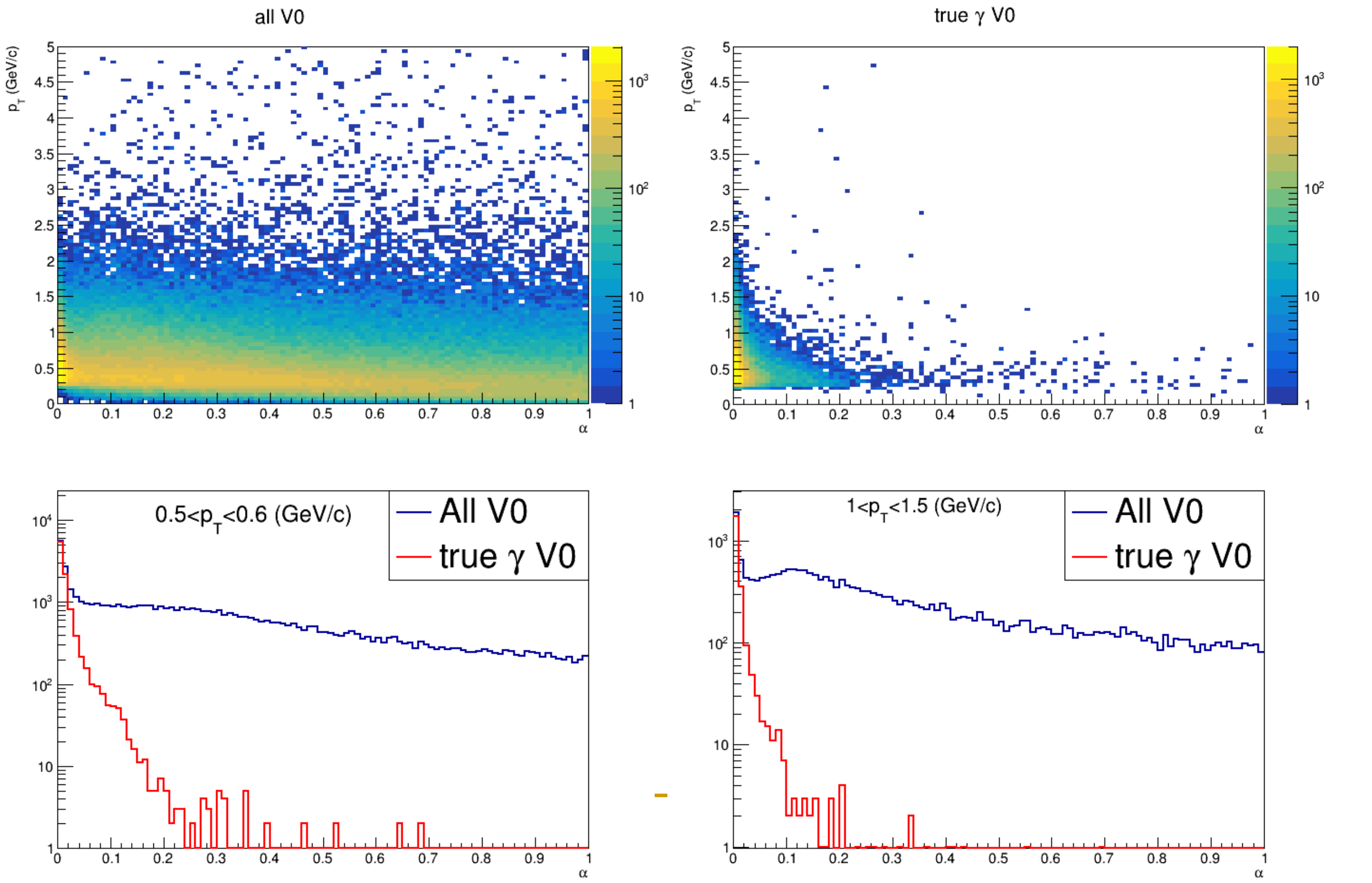
e+e- invariant mass

- One of the most effective cuts, use m<cut



Alpha angle

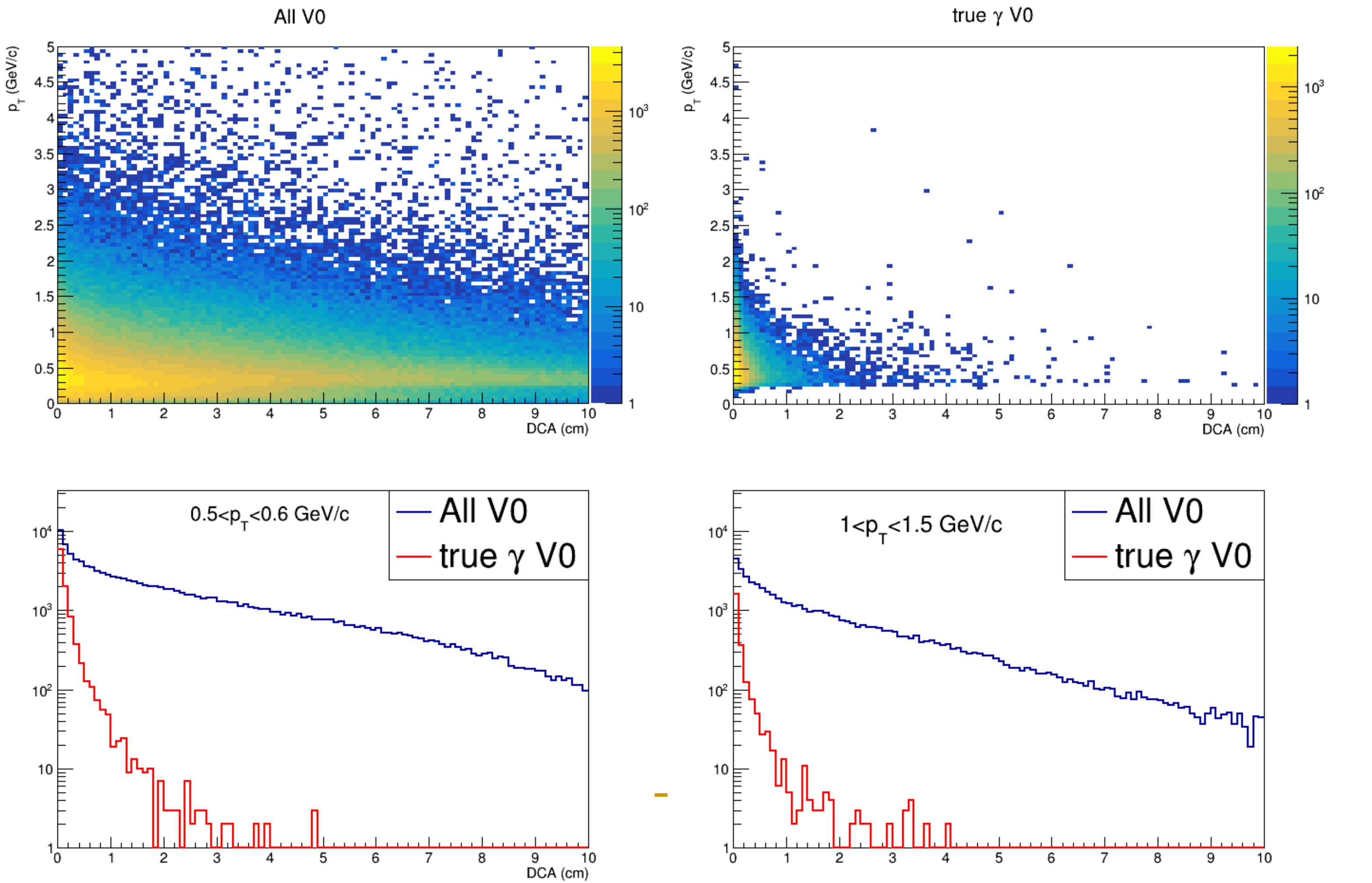
- The most effective cut, use α<cut



Daughter DCA

- Reduce combinatorial background, use (p_T-independent)

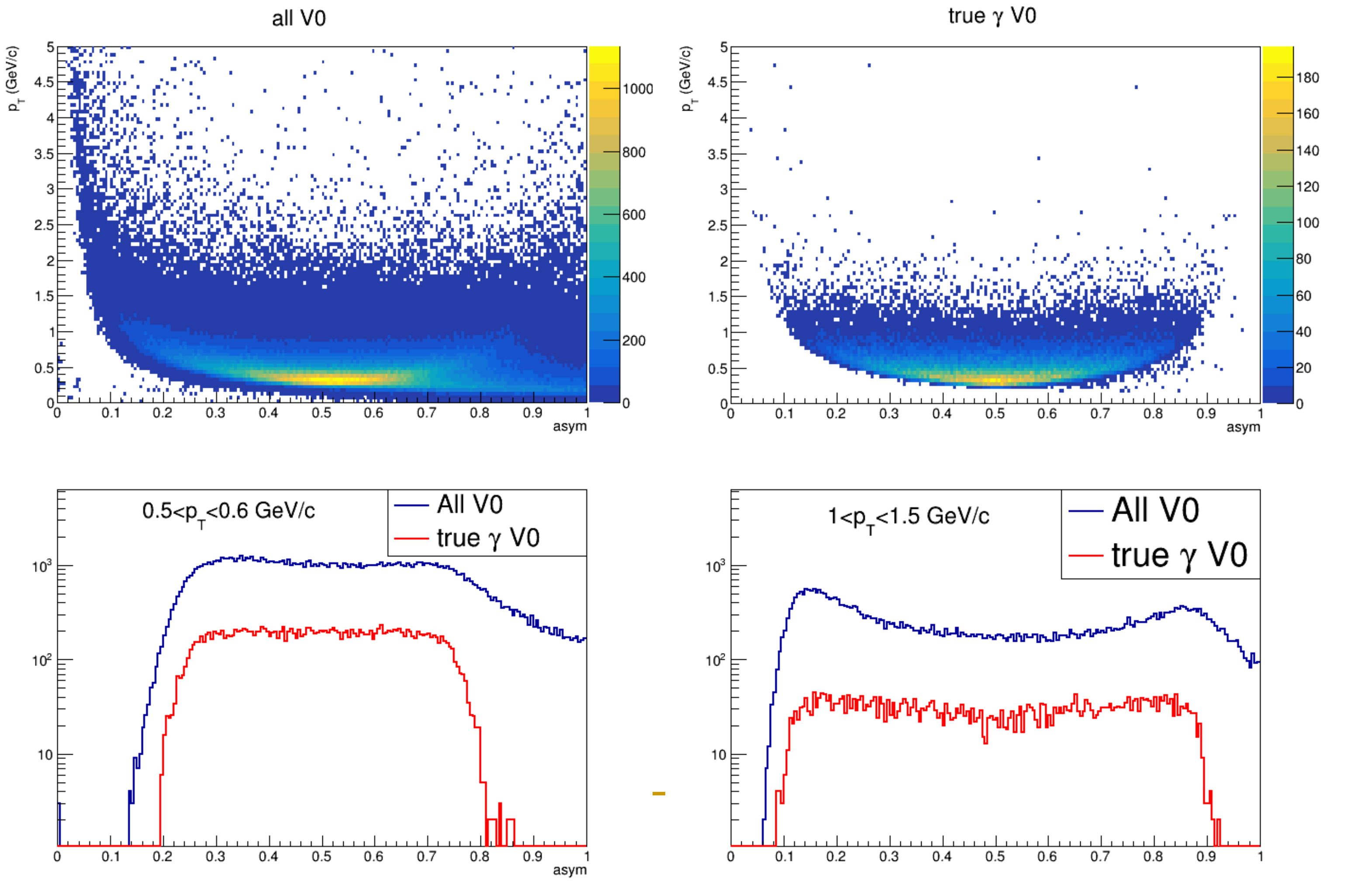
  dca <cut



Asymmetry cut

- Almost useless cut, use

  cut<asym<1-cut



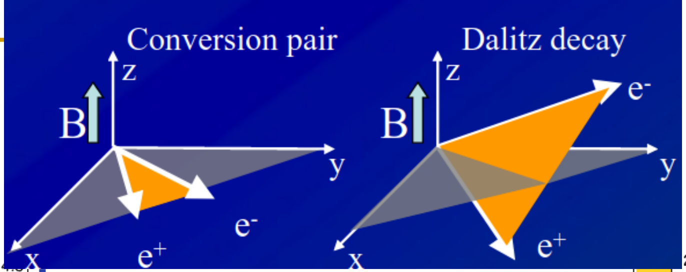
ψ cut

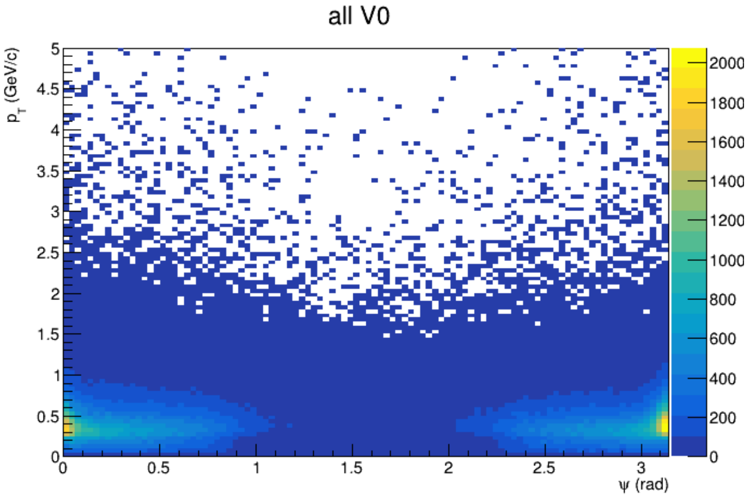
- Pair orientation wrt B-field,

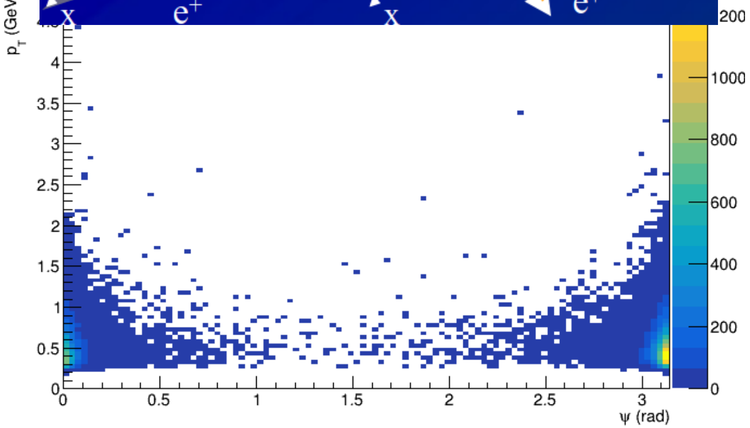
  use

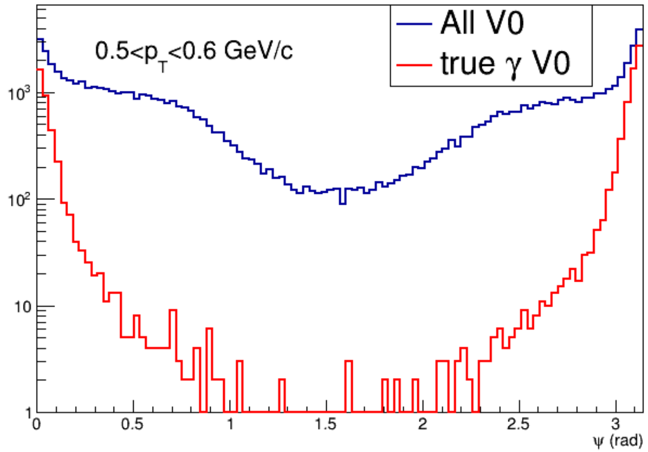
  ψ<cut ||

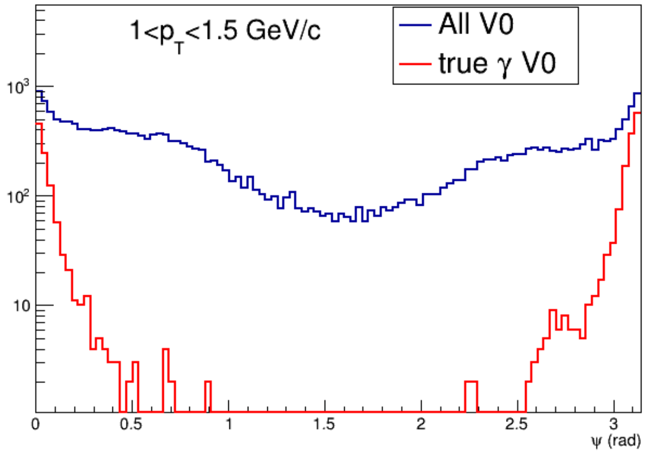
  π-cut <ψ







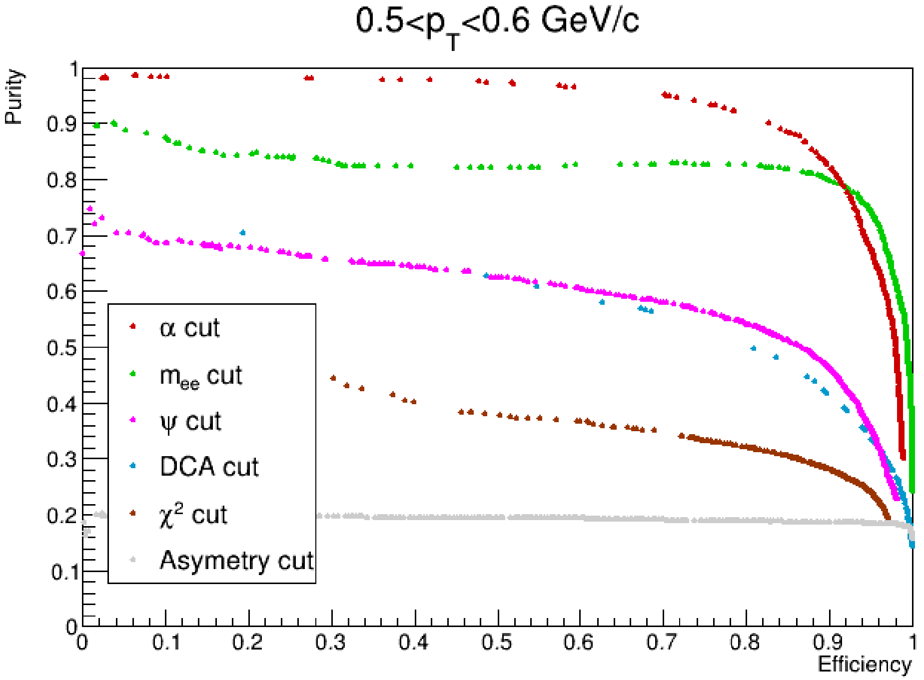


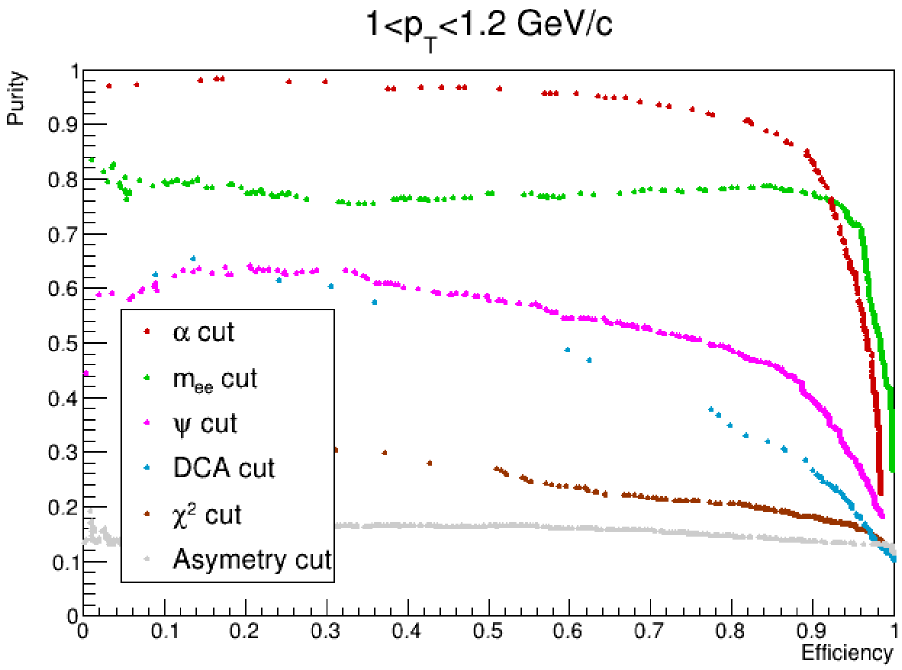


Cut optimization

- 6-7 cuts to be optimized
- Cuts are strongly correlated: optimization of one cut will influence another, e.g. one cut may contradict another and reduce efficiency without improving purity
- Simultaneous optimization
  - For each cut define possible variation range and scale to have $cut_i=f(x)$, $x=0..1$
  - Scan MC data fill tree with V0 parameters
  - Generate random sets $(x_1,...x_n)$ and for each set calculate pair (Efficiency,Purity)

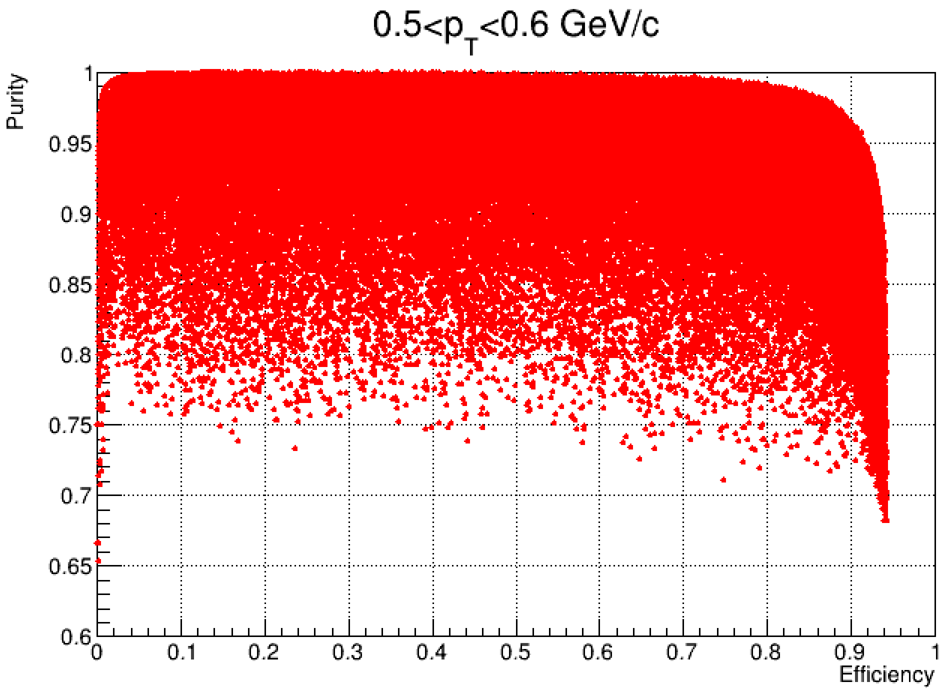
ROC for individual cuts

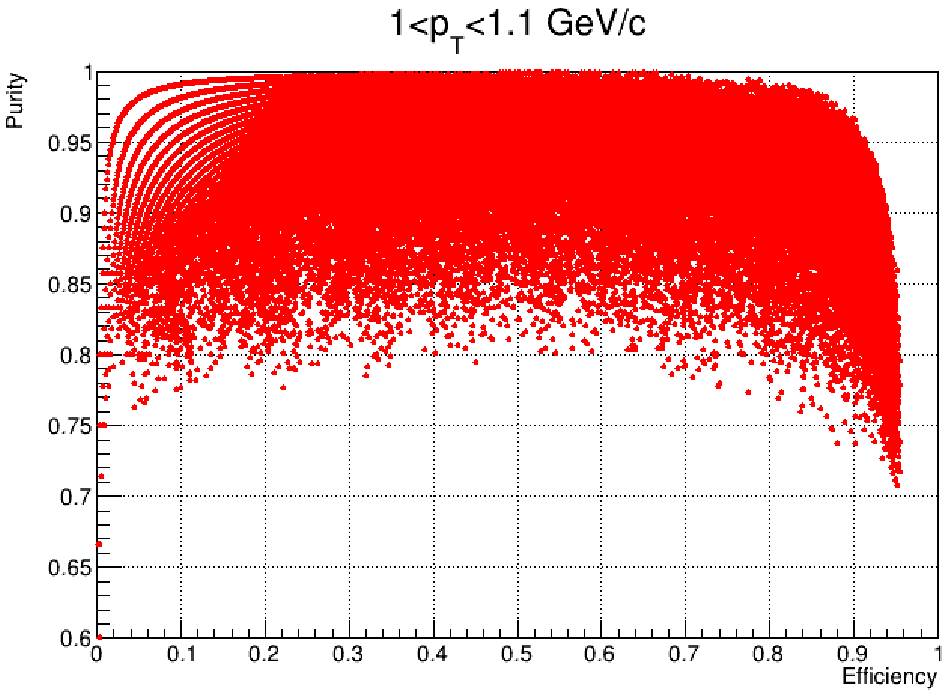




Most effective is α-cut, and cut on m_{ee}. Asymmetry cut has no resolving power

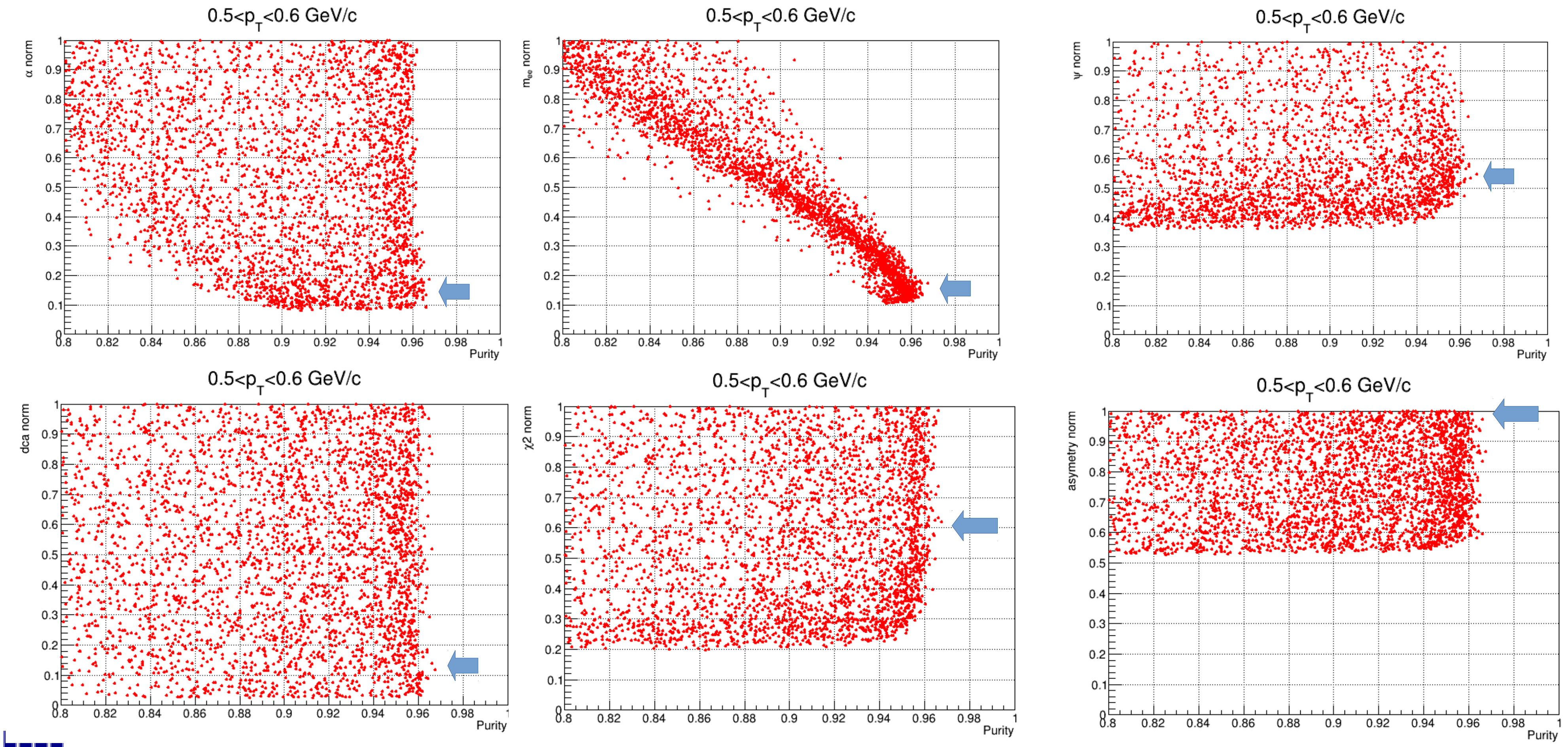
ROC: combined cuts





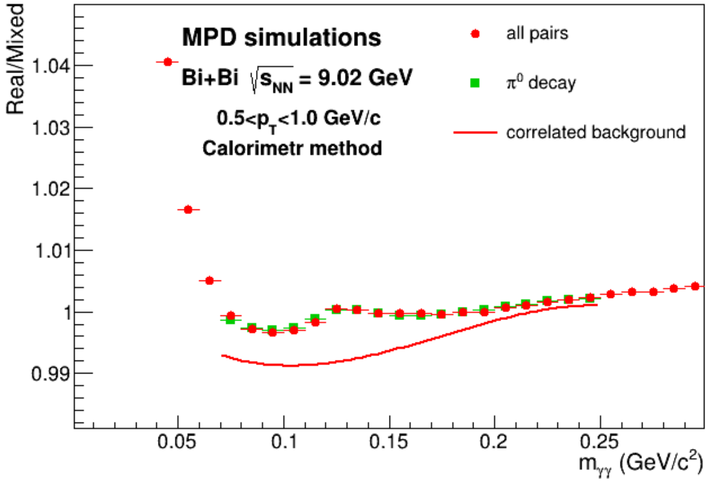
Not optimal combination of cuts can reduce purity for a fixed eff by ~20%.
Find combinations, providing maximal purity for a fixed efficiency

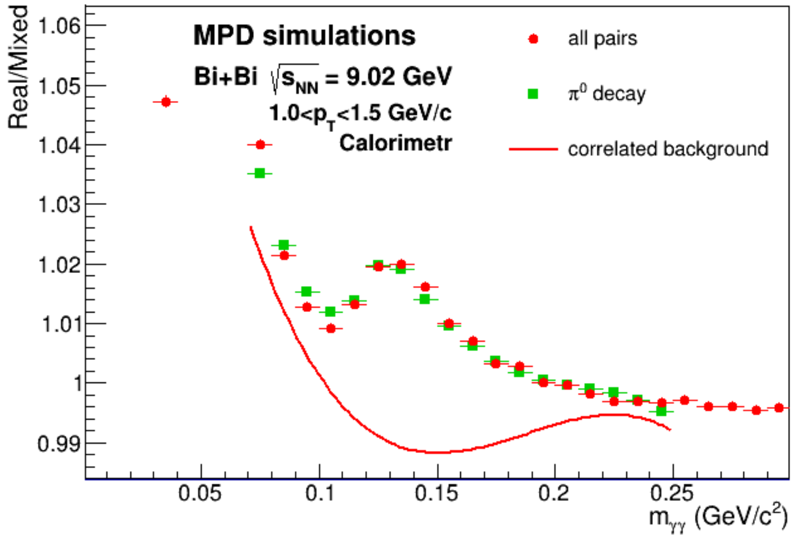
Cut optimization for efficiency=0.9



Test with neutral pion peak

Pion peaks: two photons in ECAL



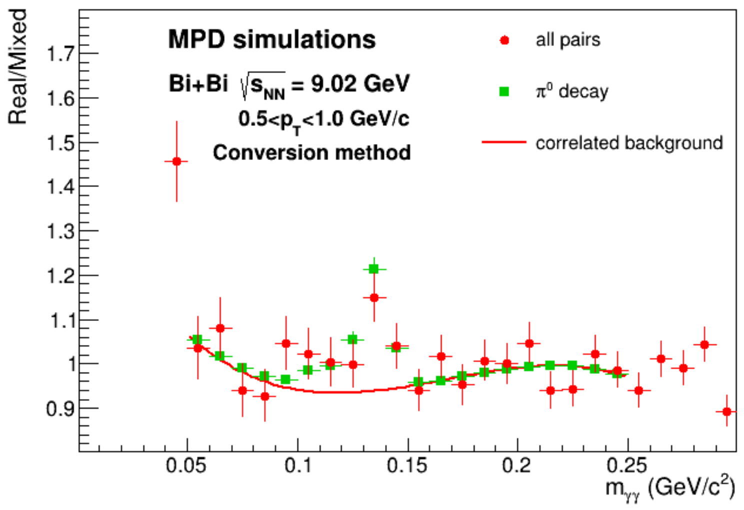


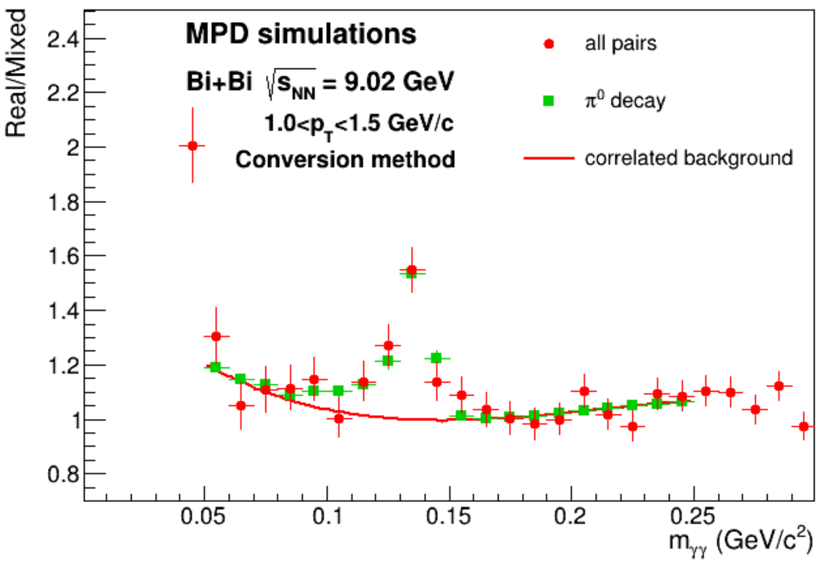
Correlated background calculated so that being added with π^0 pairs reproduce measured Re/Mi ratio

Signal/Background ratio is small, but statistics is sufficient to extract π^0 spectrum

Shape of the combinatorial background can be improved if use finer centrality and reaction plane binning

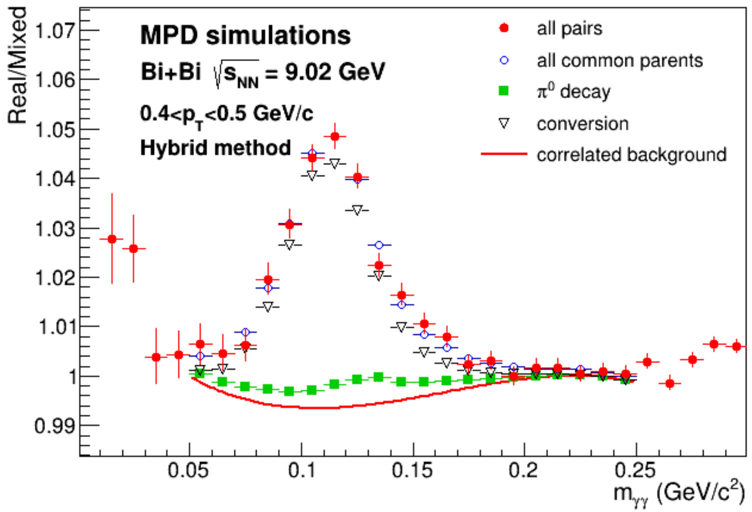
Pion peak: two converted photons

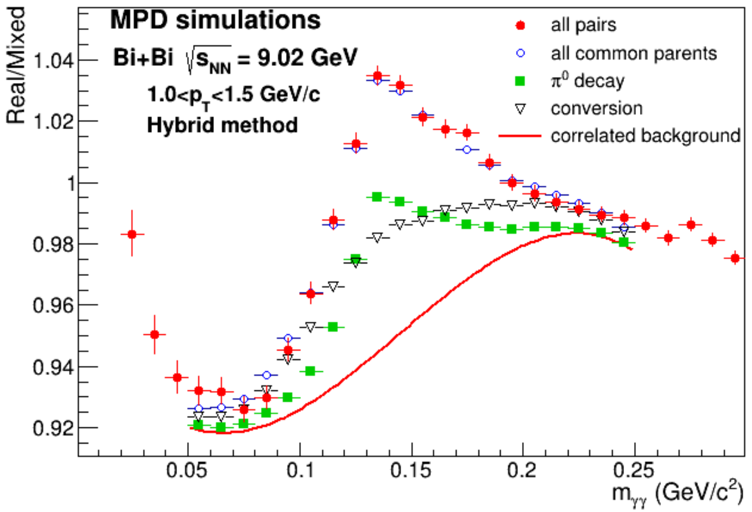


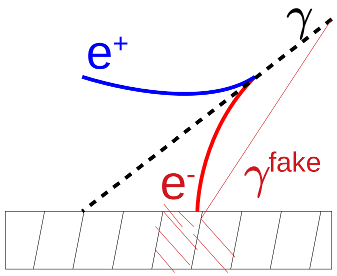


Clear pion peaks, excellent S/Bg ratio.
But very low efficiency.

π⁰ peak: hybrid approach





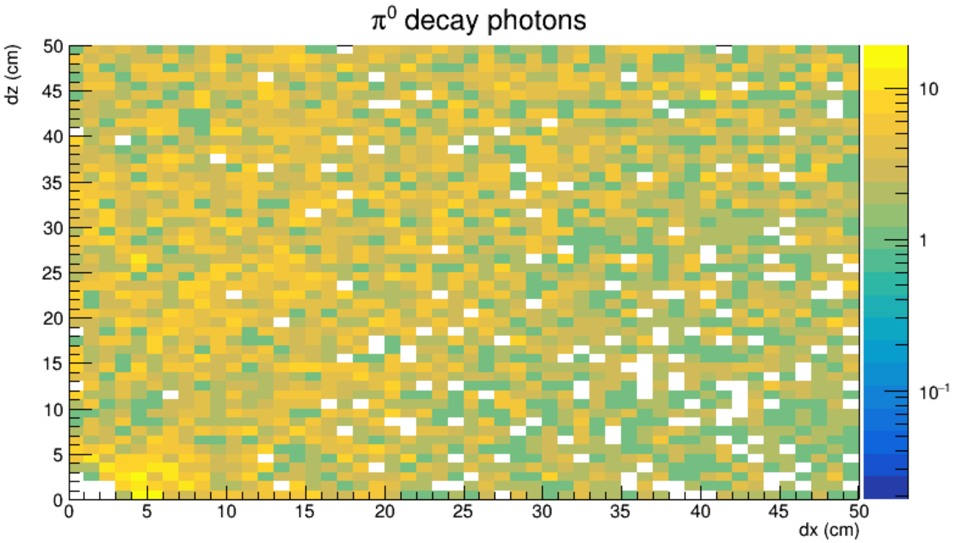


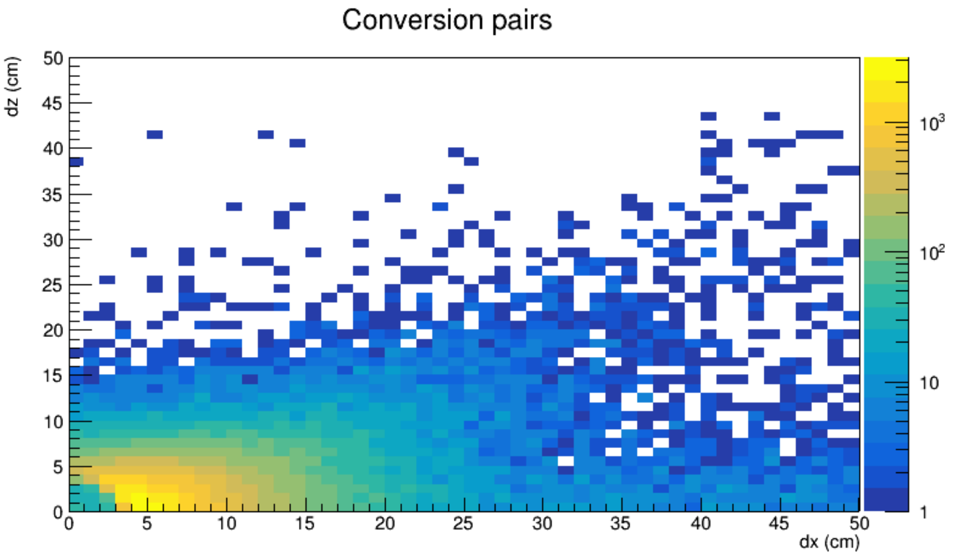
Hybrid approach: combining converted photon with one reconstructed in calorimeter.

Large background correlations between reconstructed V0 photon and daughter electron/positron cluster in calorimeter! Unfortunate combination of B-field and material budget put contamination peak close to pion one

Reducing same tracks contamination

Estimate distance between cluster and V0 tracks extrapolated to EMC



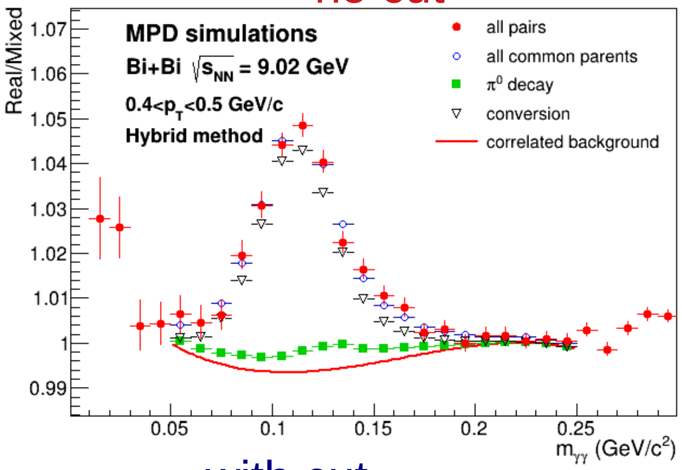


Clusters from different daughter photons uniformly distributed in dx,dz plane.
Clusters from same tracks have narrow distribution along z (B-field) and wider perpendicular to B

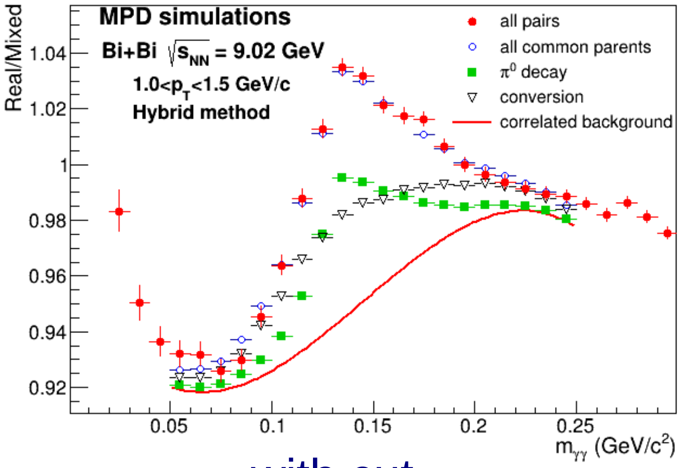
Remove clusters pairs if $r^2 = \left(\frac{dz}{5\,cm}\right)^2 + \left(\frac{dx}{18\,cm}\right)^2 < 1$

π^0 peak: hybrid corrected

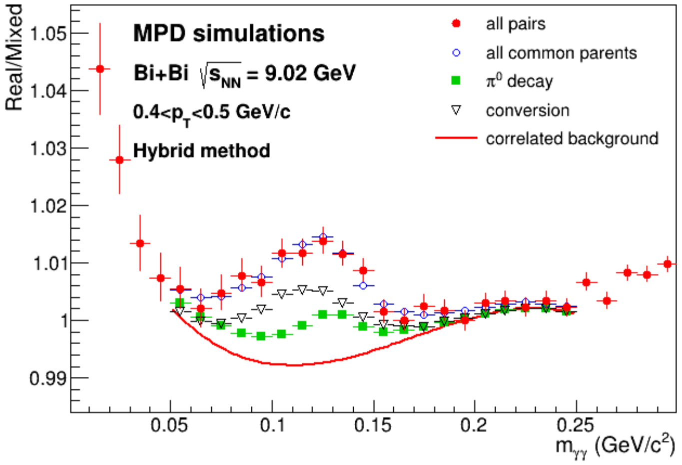
no cut



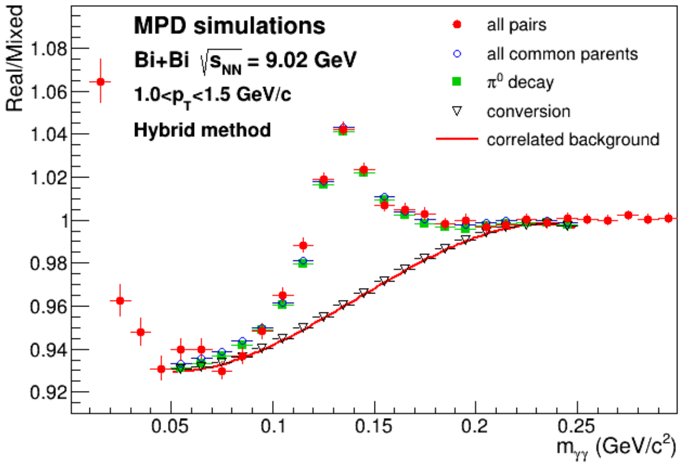
no cut



with cut

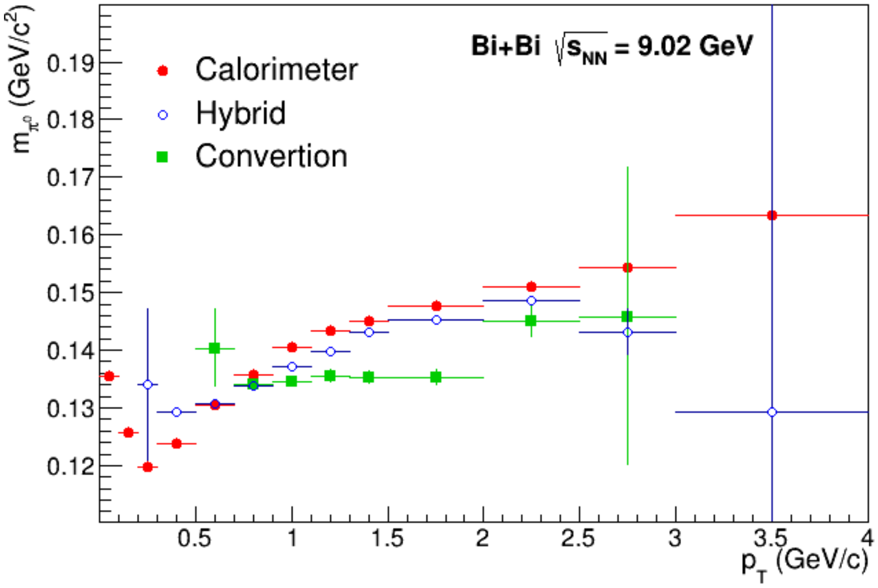


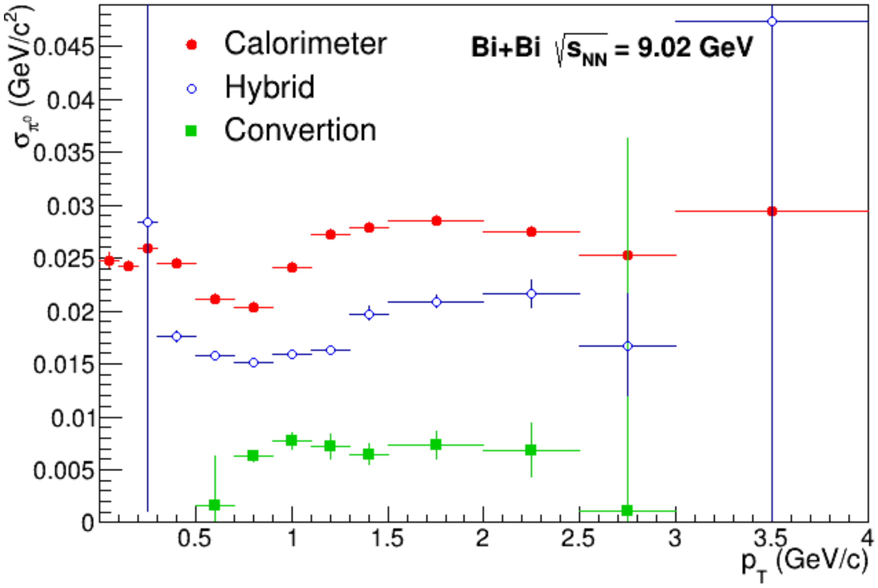
with cut



Cut reduces contamination by factor ~5, probably, more strict cut necessary for low p_T

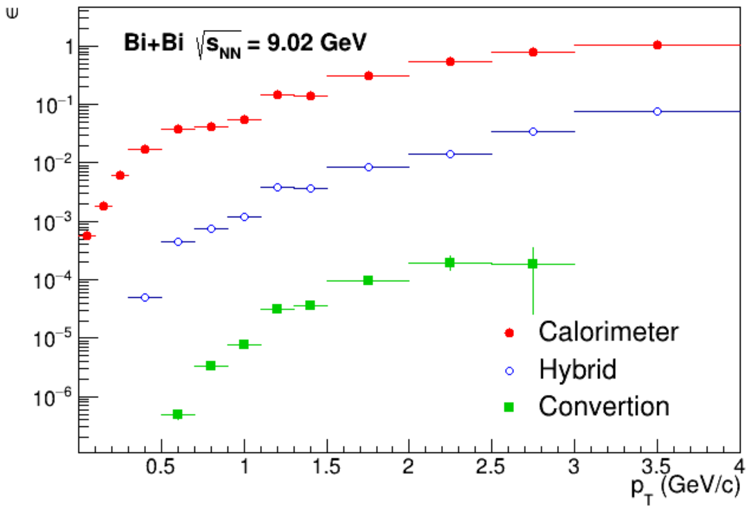
Peak parameters

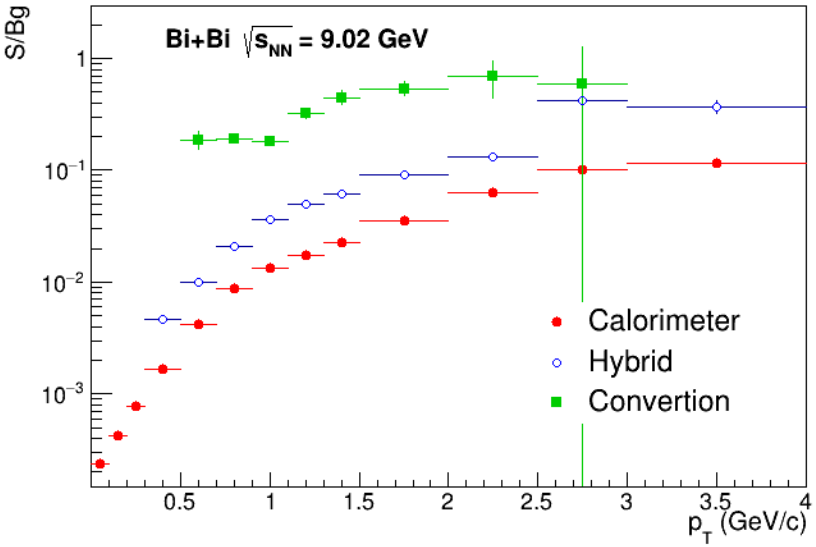


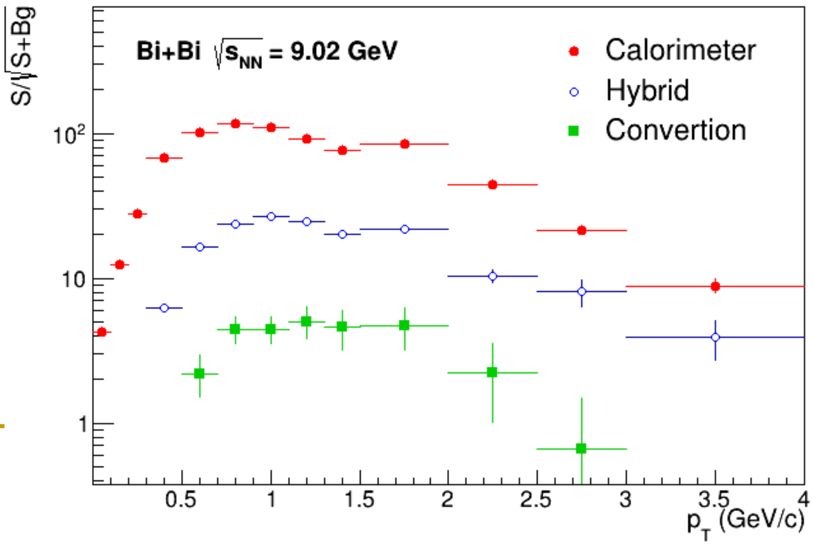


Conversion approach shows best width and stable peak position,
Calorimeter - peak position shifts with increase of energy, width is larger
Hybrid – average of two approaches.

Efficiency, significance…







Conversion demonstrates best S/Bg ratio but worst efficiency.
Expected significance is better for calorimeter approach

Conclusions

- Photon reconstruction in ECAL and with conversion technique was tested
- Identification criteria were optimized for both techniques
- Expected significance is largest for calorimeter approach and smallest for conversion
- It is important to measure photon and neutral meson spectra with 3 methods simultaneously for cross-check and reducing systematic uncertainties

Code implementation

- Cluster and V0 selection implemented in class
  - physics/photons/MpdConvPi0.*
- Set of cuts for photon selection in calorimeter and V0 is in the class
  - physics/photons/MpdPhotonAnalysisParams
- To be added to repository