The decay $\bar{p}p \to \pi^0\pi^0\eta \to 6\gamma$

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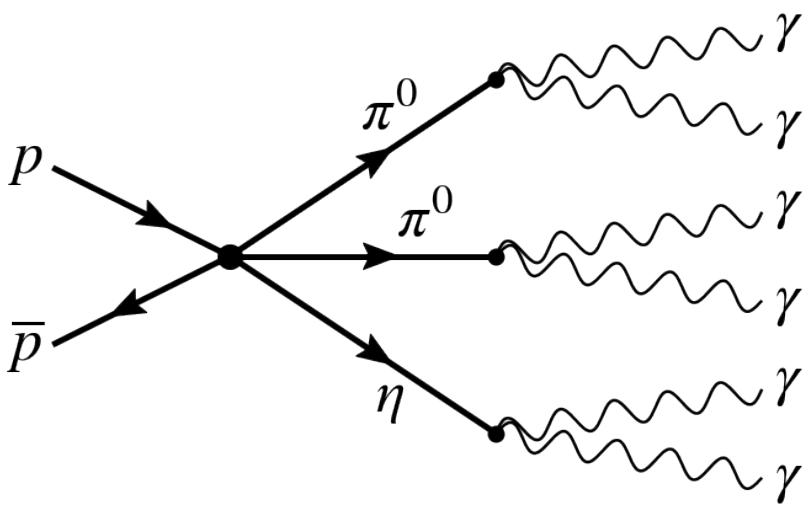
Why a kinematic fit ?

- Improve resolution of reconstructed quantities (1)
- $\chi^2 = (\alpha_{\text{fit}} - \alpha_{\text{reco}})\mathsf{V}^{-1}_{\alpha_{\text{reco}}}(\alpha_{\text{fit}} - \alpha_{\text{reco}}) + 2\lambda^{\mathsf{T}}(\mathsf{d} + \mathsf{D}\delta\alpha_{\text{reco}})$ (2)
- Parameter vector α contains all relevant reconstructed quantities
- Standard least-squares fit $\Rightarrow$ inversion of very large matrices $\mathsf{V}_{\alpha_{\text{reco}}}$
  $\rightarrow$ Use Kalman Filter approach (3)
- Can use DecayTreeFitter to fit complete decay tree in one go
- Later apply this to the reaction $\bar{\text{p}}\text{p} \rightarrow \pi^0\pi^0\eta \rightarrow 6\gamma$



Outline

Decay Tree Fitter

Previous behavior

- Originally developed by W. Hulsbergen for BaBar and later adapted for PandaRoot by Ralf Kliemt (3)(4)
- Primary vertex fit hardcoded into the routine
- However: Requires ≥ 2 charged final state particles
  $\rightarrow$ DecayTreeFitter is not applicable for uncharged reactions
- Solution: Add option to disable primary vertex fit
- Derivatives for final state photons are missing
- Very short lived particles are not treated properly

Changes to the usage

- New optional argument "perform_vertex_fit" turns of prim. vertex fit
  $\rightarrow$ Default value is set to perform prim. vertex fit
- Added missing derivatives for final state photons
  $\rightarrow$ Important for charged reactions with involved photons
- Short lived particles, such as π^0 and η are now treated as intended
- Apart from bugfixes code can be used exactly as before
- Documentation on changes can be found in respective folder

FTF background generator

Issues with the current behavior

- Adjusted for PANDA by A. Galoyan and V. Uzhinsky, based on Geant4 (5)
- Currently treated inconsistently, when paired with Geant3 and Geant4
- Geant3 for transport $\Rightarrow$ uses supplied seed for random generator
- Geant4 $\Rightarrow$ Seed given to PndFtfDirect is overwritten by Geant4
  $\rightarrow$ Problematic due to issue introduced in Fairsoft Apr22 and Nov22
- Since Root 6.24: gRandom$\rightarrow$GetSeed() no longer returns seed for random generator

  $\Rightarrow$ Geant4 always runs same initialization for random generator!
  $\Rightarrow$ Always the same starting point, when paired with Geant4

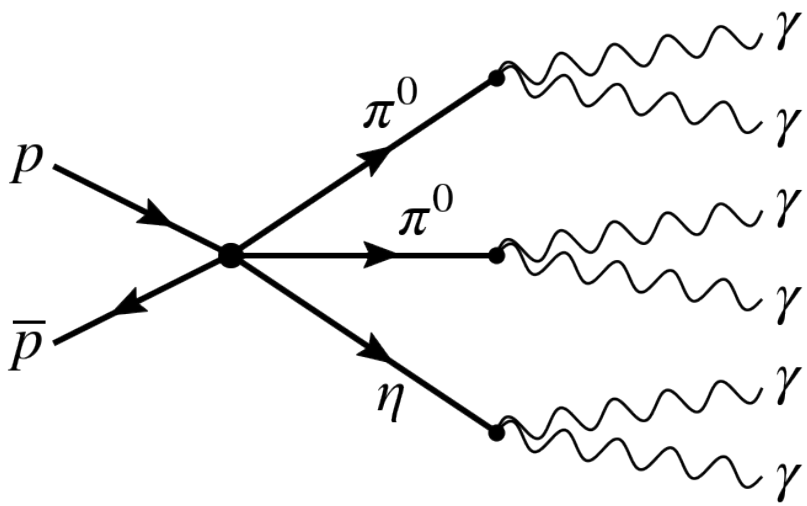
Solutions for these problems

Problems:	Solutions:
Incompatibilities in Fairsoft Apr22 and Nov22	Have to wait for Fairsoft team to adjust this
gRandom→GetSeed() does not return random seed	gRandom→TRandom::GetSeed() can be used instead
Geant3 and Geant4 are treated differently	moved setting the random seed to the setup stage
Need to specify seed, instead of automatically using gRandom	Added new constructor, which reads seed from gRandom

Results for $\bar{p}p \to \pi^0\pi^0\eta \to 6\gamma$

Details on the simulation

- Simulated 50000 events using EvtGen (beam momentum: 1.94GeV)
- Generic phase space model PHSP without resonances
- Applied 200 / 300 MeV wide cuts on π^0 / η
- Furthermore 0.8 / 1 GeV wide cuts on $\bar{p}p$ momentum / energy
- Require mass constraints on π^0, η
- Require overall 4-momentum conservation
- Overall 34 parameters and 41 constraints



PandaRoot code for $\bar{p}p \rightarrow \pi^0\pi^0\eta \rightarrow 6\gamma$

```
const Double_t m_p = 0.938; //GeV
const Double_t p_Mom = 1.94; //GeV
TLorentzVector pbarp{0,0,p_Mom,TMath::Sqrt(p_Mom*p_Mom+m_p*m_p)+m_p};

double res = 1e-4 * p_Mom;
RhoError pbarp_cov(4);
pbarp_cov[0][0] = 1e-6 * 1e-6;
pbarp_cov[1][1] = 1e-6 * 1e-6;
pbarp_cov[2][2] = res * res;
pbarp_cov[3][3] = res * res * p_Mom * p_Mom / (p_Mom * p_Mom + m_p * m_p);

RhoLorentzVectorErr pbarp_mom{pbarp, pbarp_cov};
```

set 4-momentum for beam

```
[...]
```

```
etas.Combine(photons, photons, pdb->GetParticle("eta"));
pi0s.Combine(photons, photons, pdb->GetParticle("pi0"));
etapi0pi0.Combine(pi0s, pi0s, etas, pdb->GetParticle("pbarpSystem"));
```

specify decay tree

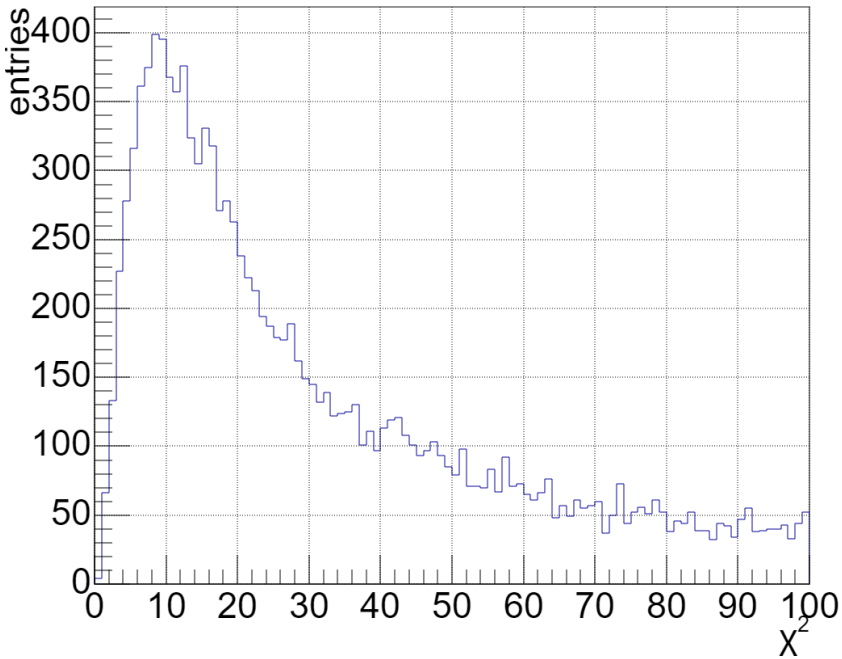
```
[...]
```

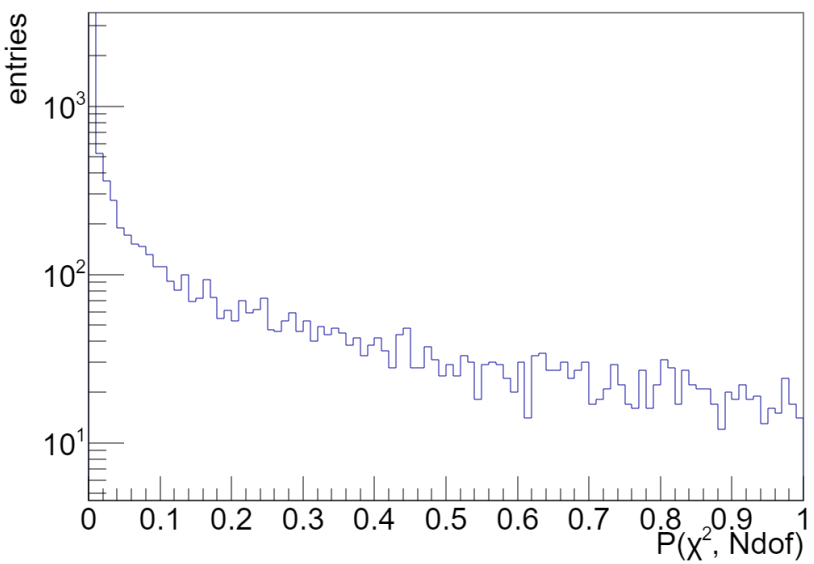
```
for (Int_t j = 0; j < etapi0pi0.GetLength(); ++j) {
  RhoDecayTreeFitter fittree(etapi0pi0[j], pbarp_mom, false);
  fittree.setMassConstraint(etapi0pi0[j]->Daughter(0));
  fittree.setMassConstraint(etapi0pi0[j]->Daughter(1));
  fittree.setMassConstraint(etapi0pi0[j]->Daughter(2));
  fittree.Fit();

  chi2_m = fittree.GetChi2(); // get chi^2 of the fit
  prob_m = fittree.GetProb(); // access probability of the fit
}
```

turn off fit of primary vertex

perform fit of full decay tree

χ^2 and P(χ^2, N_{dof}) for signal channel $\pi^0\pi^0\eta$

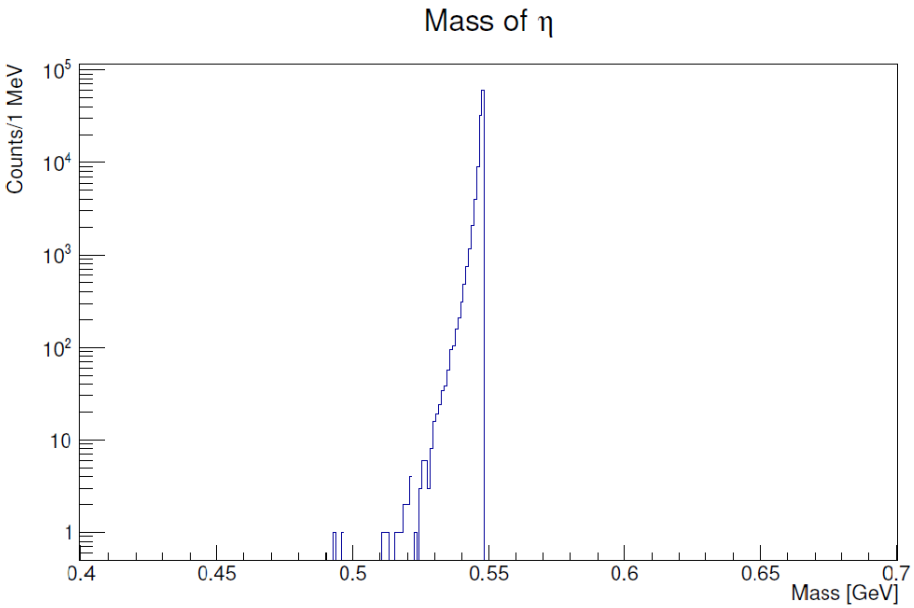




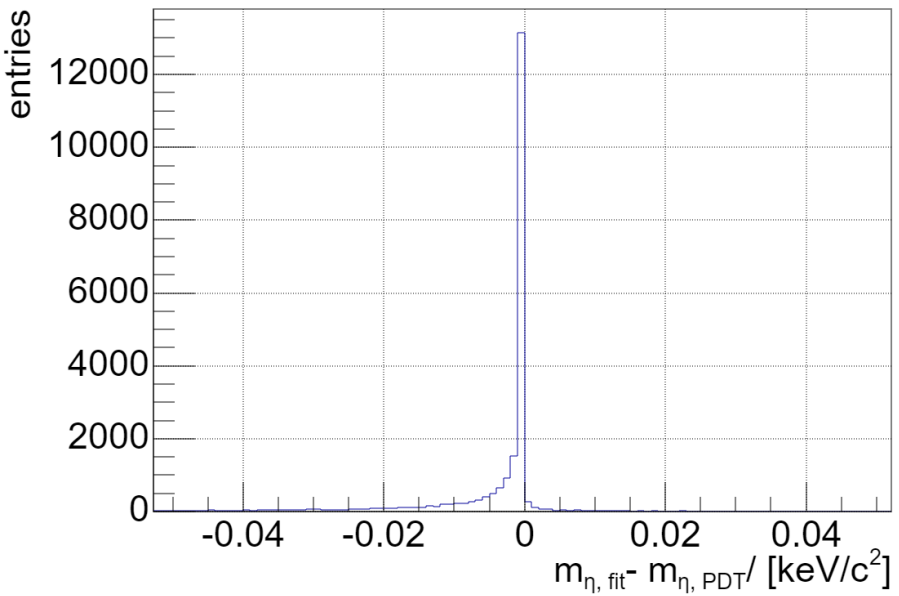
- Distributions contain combination with best χ^2 for each event
- Distributions are similar to those obtained for charged decay channels
- P(χ^2, N_{dof})-distribution clearly suggests underestimated errors

Improved fullfillment of constraints

$\bar{p}p \to \Xi^- \bar{\Xi}^+ \eta$ (6)

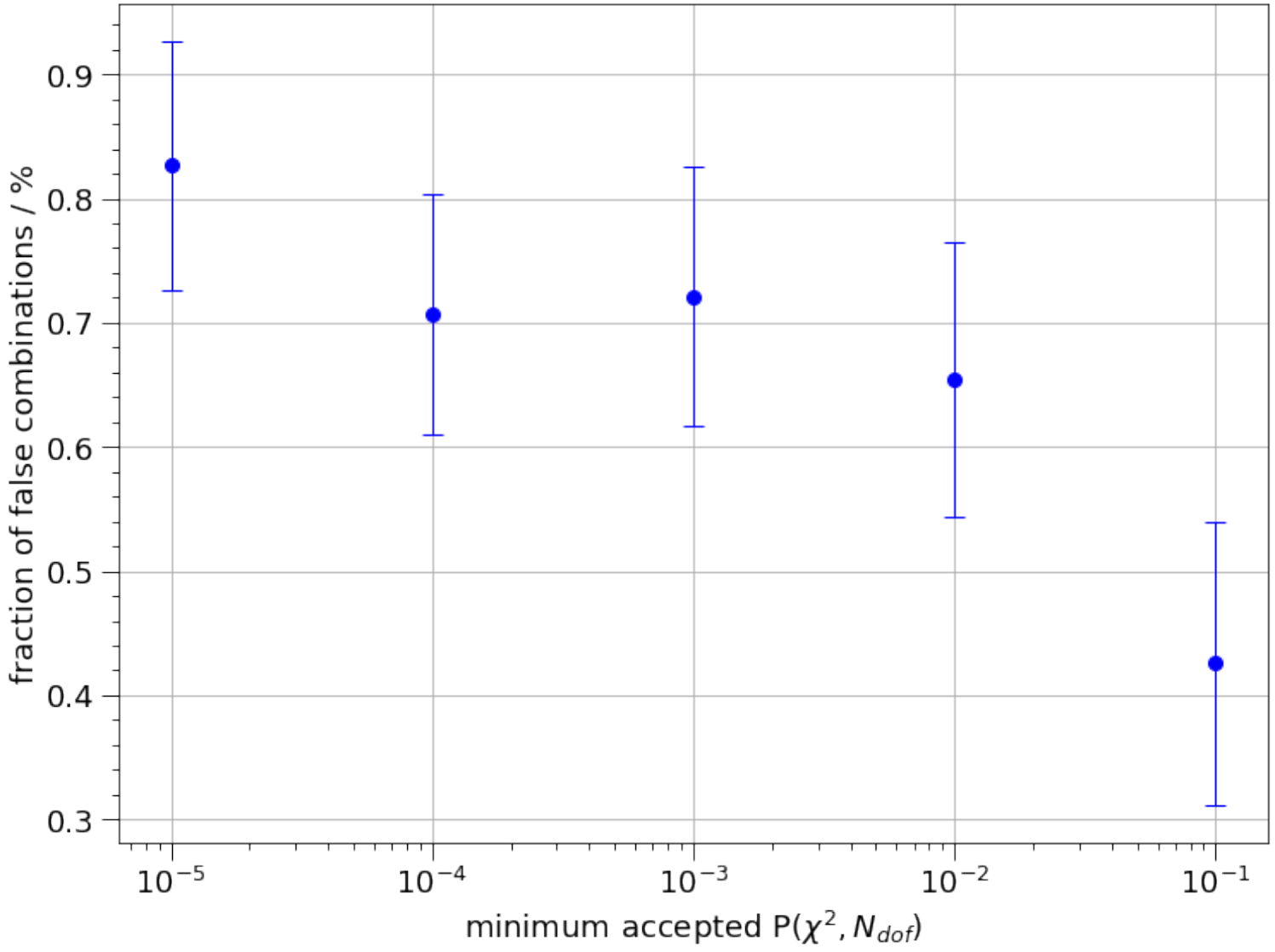


$\bar{p}p \to \pi^0 \pi^0 \eta$

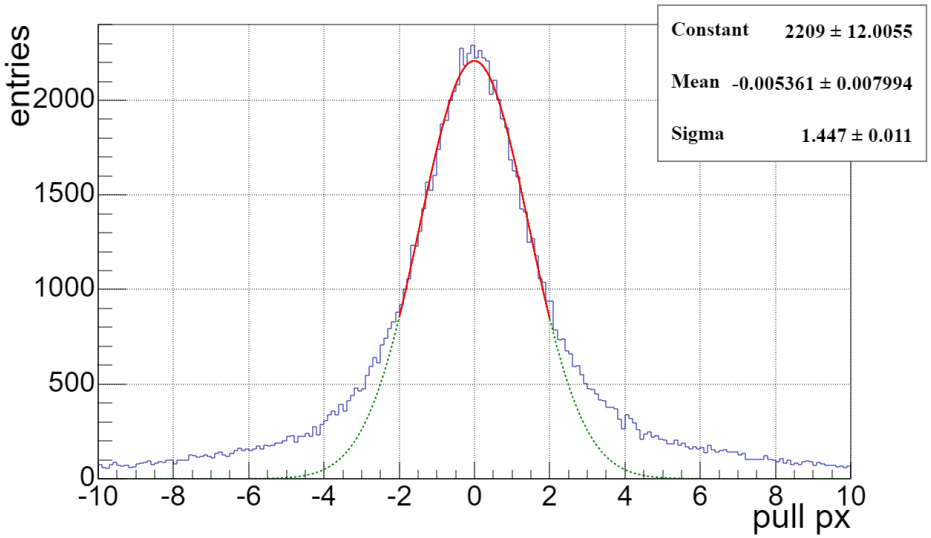


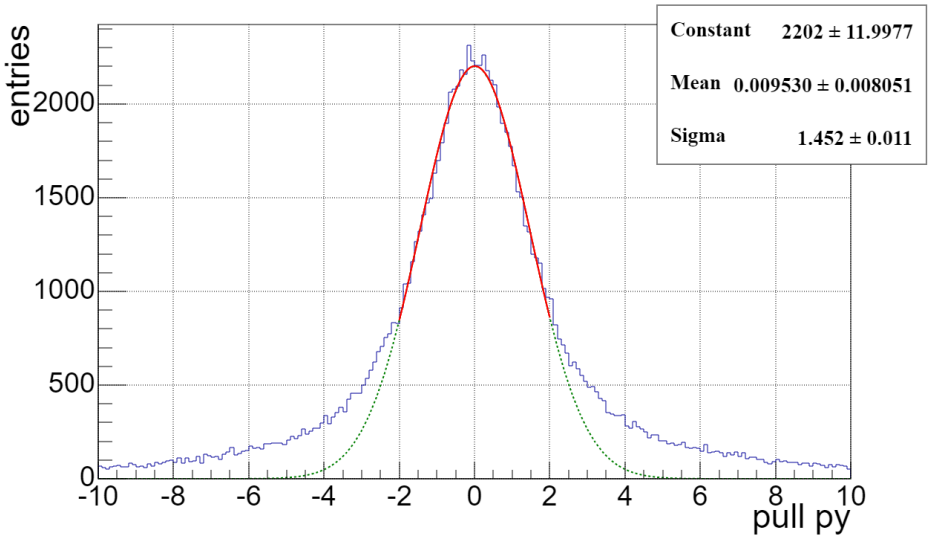
- Comparable, despite different reactions
- Previous issues likely due to missing derivatives
- All 6 other constraints fullfilled equally well

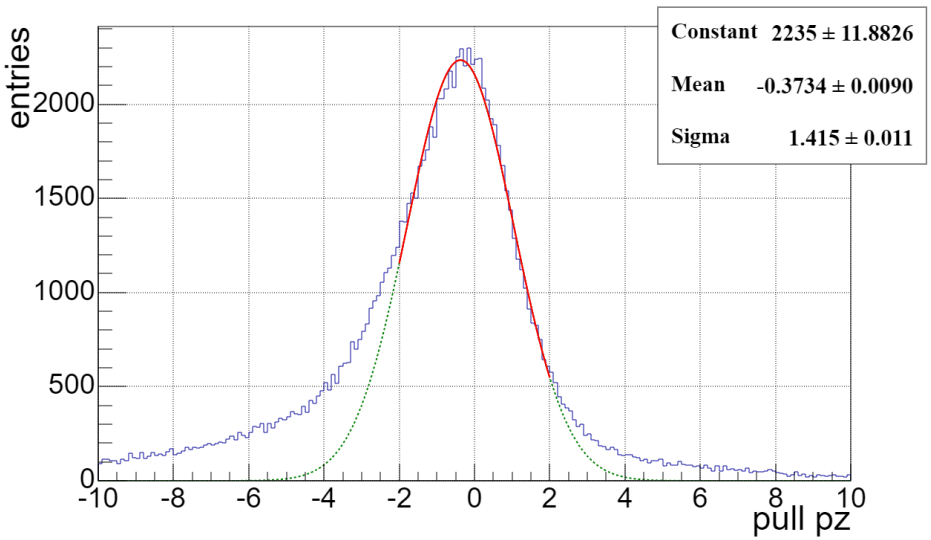
Purity after various probability cuts



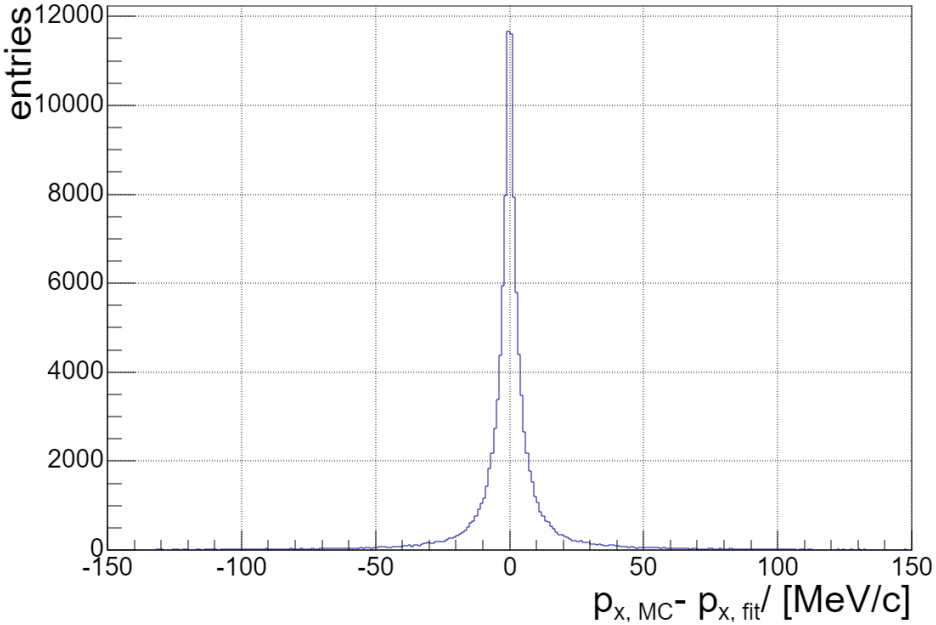
Pull distributions

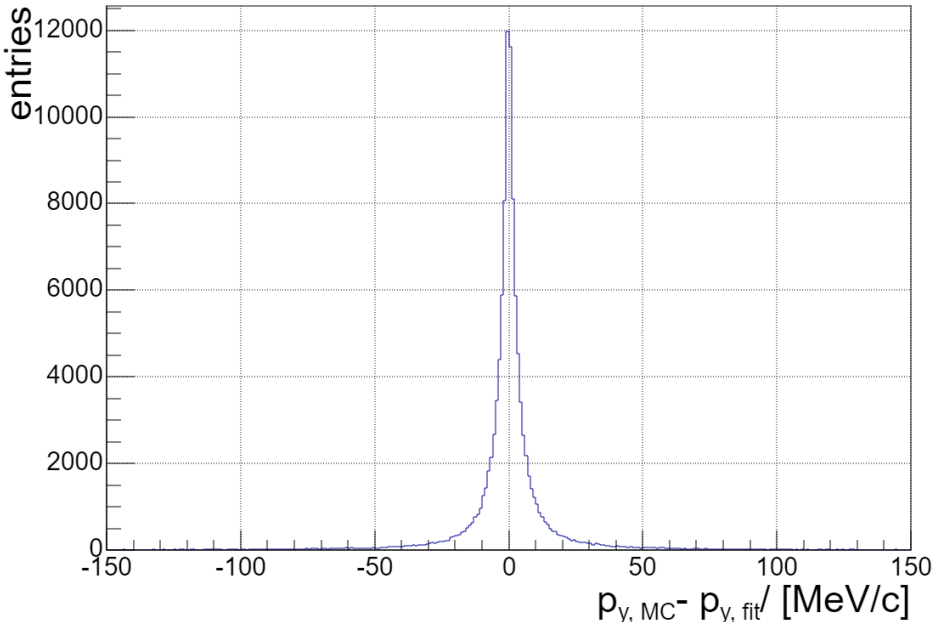


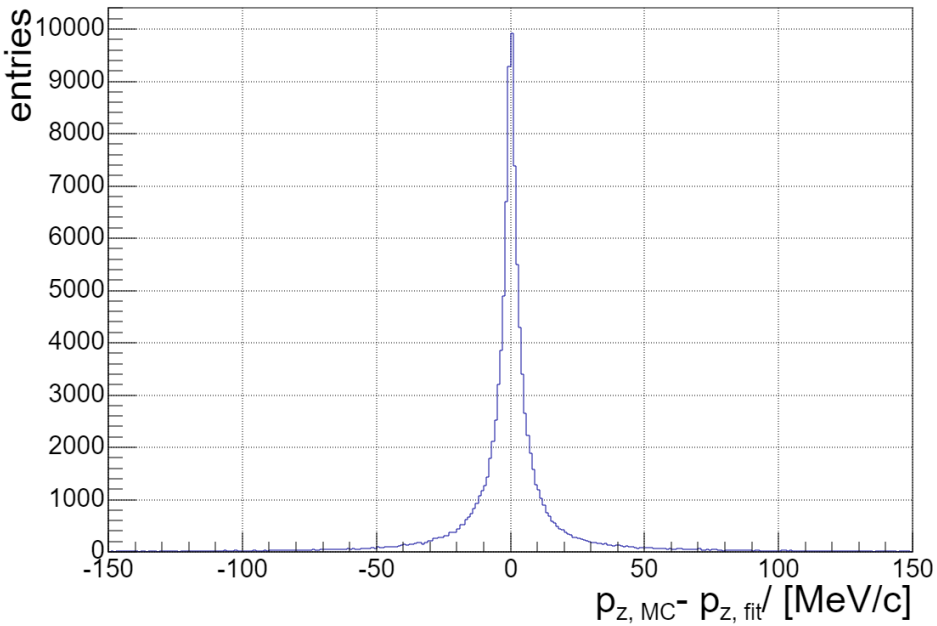


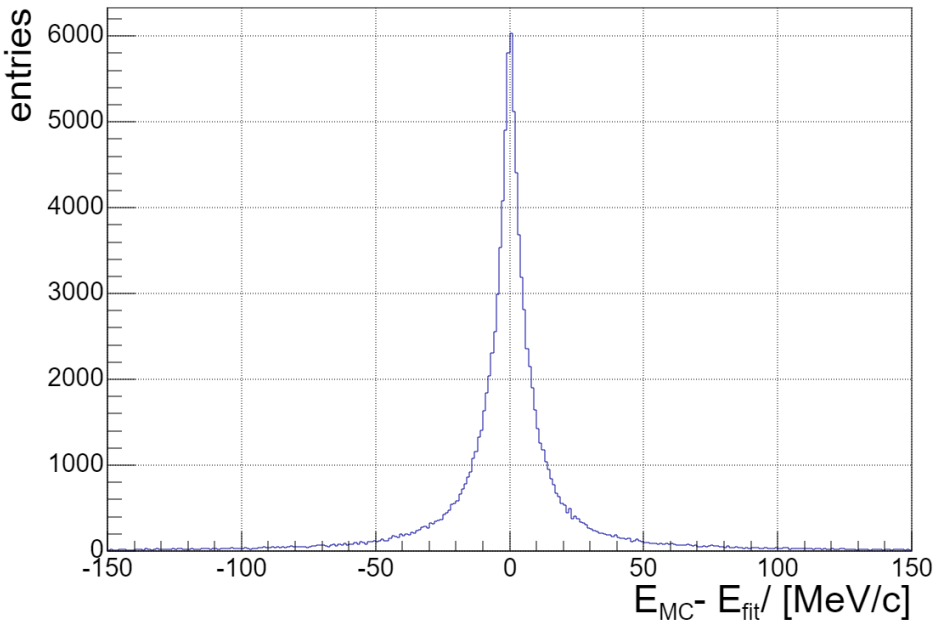


Corrections made by fit



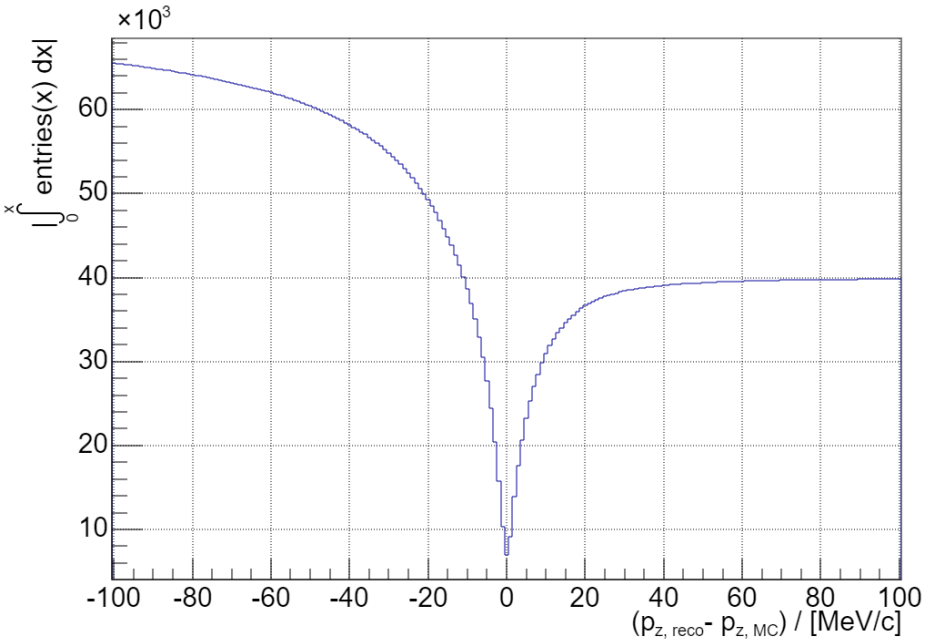




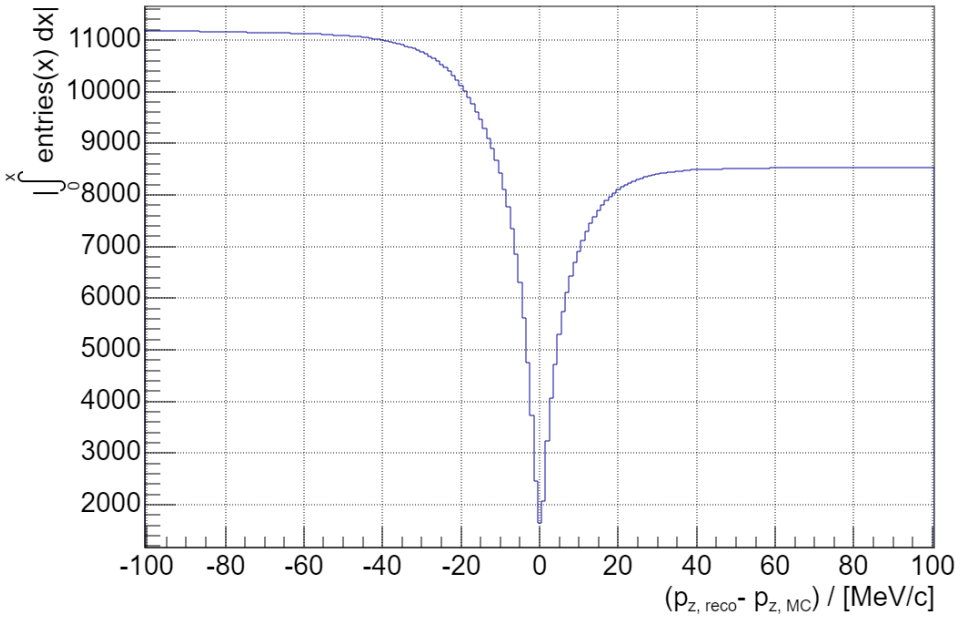


Integrated Distributions

no $P(\chi^2, N_{dof})$ cuts:



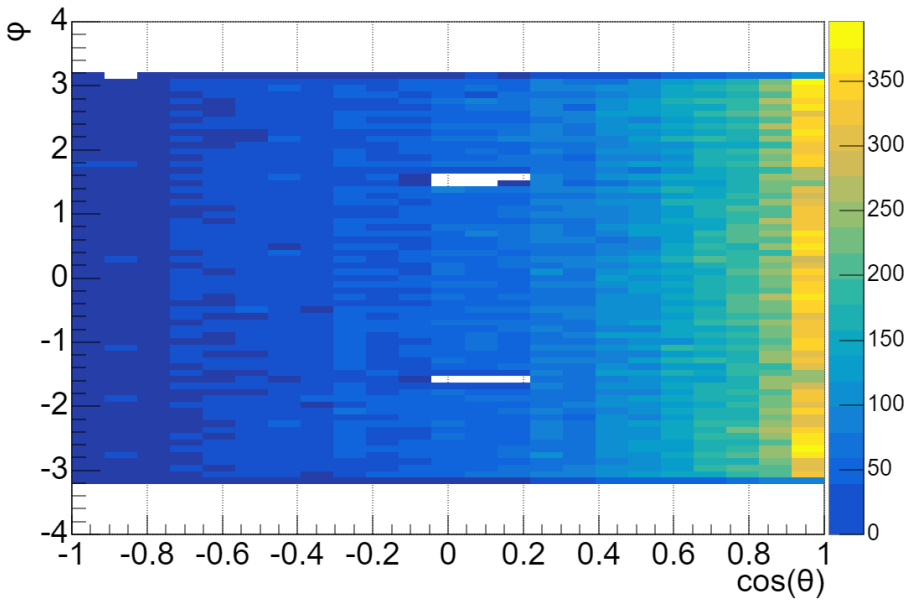
$P(\chi^2, N_{dof}) \geq 0.1$



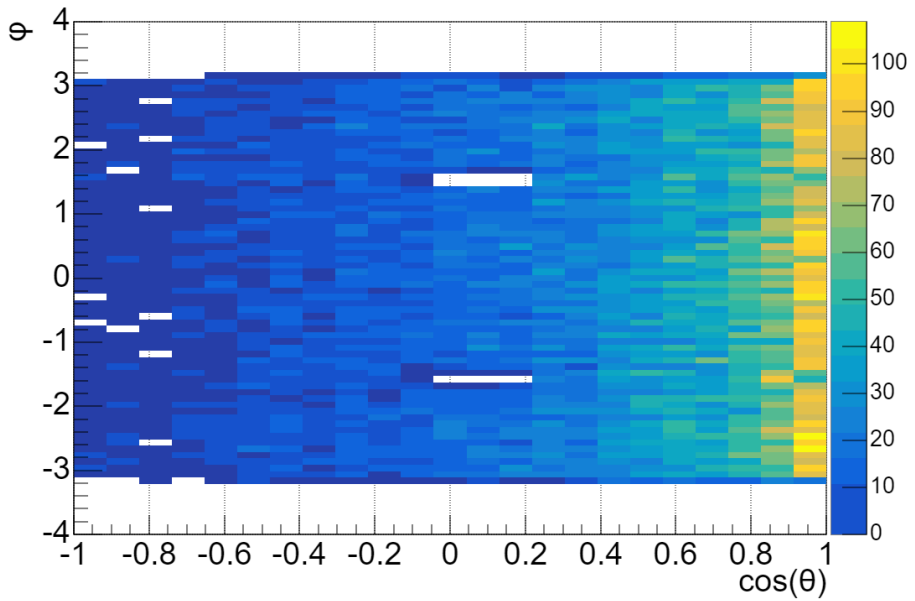
- Strong asymmetry towards too small values in reconstruction
- Likely arises from energy leakage
- Cut disproportionately removes values reconstructed to too small values

Reconstructed angular distribution

no $P(\chi^2, N_{dof})$ cuts:



$P(\chi^2, N_{dof}) \geq 0.1$



- Above angles for the 6 photons are given in the Lab-frame
- No particular angular region especially affected by cut
  $\Rightarrow$ Good indication that cuts behave as intended

Summary and Outlook

Summary

1. Adjusted DecayTreeFitter to be applicable for fully neutral reactions
2. Fixed several bugs/oversights for our DecayTreeFitter
3. Improved interface to PndFtfDirect to behave as intended
4. Promising results for examined channel
   - DecayTreeFitter fullfills constraints to good precision
   - Obtain high purity of best reconstructed combinations
   - DecayTreeFitter adjustments correct for bias in reconstruction

Outlook

- Generate background using the FTF and DPM generators
- Perform background studies to better understand and improve event selection
- Include $\pi^0\pi^0$-/ and $\pi^0\eta$-resonances
- Right now no option to include primary vertex via free parameters
- Apply the DecayTreeFitter to other neutral reactions
- Test if mass constraints for uncharged particles work for charged reactions now

Thank you for your attention!
Any questions ?

Sources I

(1) FrankMeier, "Kinematic Vertex Fit", Cern TWiki, https://twiki.cern.ch/twiki/bin/view/CMSPublic/SWGuideKinematicVertexFit (last visited: 03.06.2023)

(2) Paul Avery, "Kinematic fitting algorithms and lessons learned from KWFIT", Comput. Phys. Commun 140 (2001): 135.

(3) Wouter D. Hulsbergen, "Decay Chain Fitting with a Kalman Filter", Published in: Nucl.Instrum.Meth.A 552 (2005) 566-575

(4) Ralf Kliemt, "A Decay Tree Fitter for PANDA", Computing Session at CM LV., Computing Session at CM LV., Dec. 2015, https://indico.gsi.de/event/4305/contributions/19762/attachments/14603/18544/2015-12-Treefit.pdf (last visited: 09.06.2023)

Sources II

(5) V. V. UZHINSKY, "The Fritiof (FTF) model in GEANT4", In: Proceedings, International Conference on Calorimetry for the High Energy Frontier (CHEF 2013): Paris, France. 2013. S. 260-264.

(6) Kevin Luckas, "Simulation and Reconstruction of the Reaction $\bar{p}p \rightarrow \Xi^{-}\overline{\Xi}^{+}\eta$ for the PANDA Experiment", master thesis, University of Bonn, 2019