Kinematic Fitting of CLAS12

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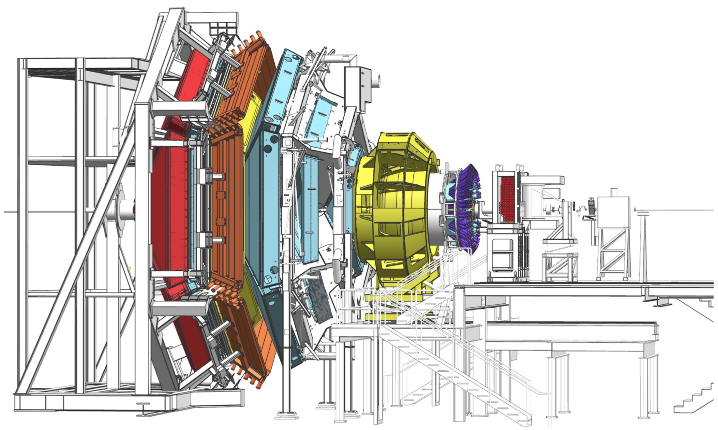

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Kinematic Fitting - Intro

- Mathematical technique that improves measurements, such as momentum, and helps discriminate between signal and background
- By utilizing constraints (invariant mass, missing mass, etc.) in context of conservation of momentum and energy
- Constraints implemented through minimization of χ^2 via Lagrange multiplier technique, with knowledge of resolutions and correlations, covariance

$$\eta = \mathbf{y} + \epsilon$$

Measured value: true value + error

$$c_k(\mathbf{y}) = 0$$

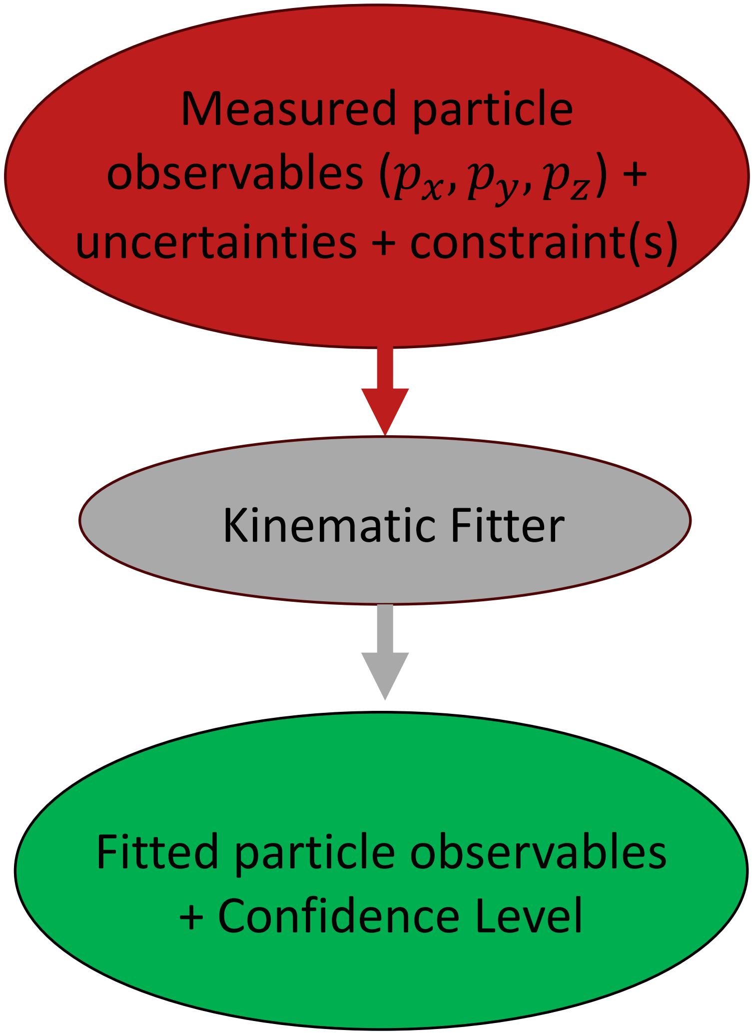
Fitted value must satisfy constraints

$$c_k(\mathbf{y}_n + \delta) = c_k(\mathbf{y}_n) + \sum_i \frac{dc_k}{dy_i}\delta_i$$

$$\mathcal{L} = \delta^T C_\eta^{-1}\delta + 2\mu^T(B\delta + c)$$

$$\delta = -C_\eta B^T C_B \mathbf{c}$$

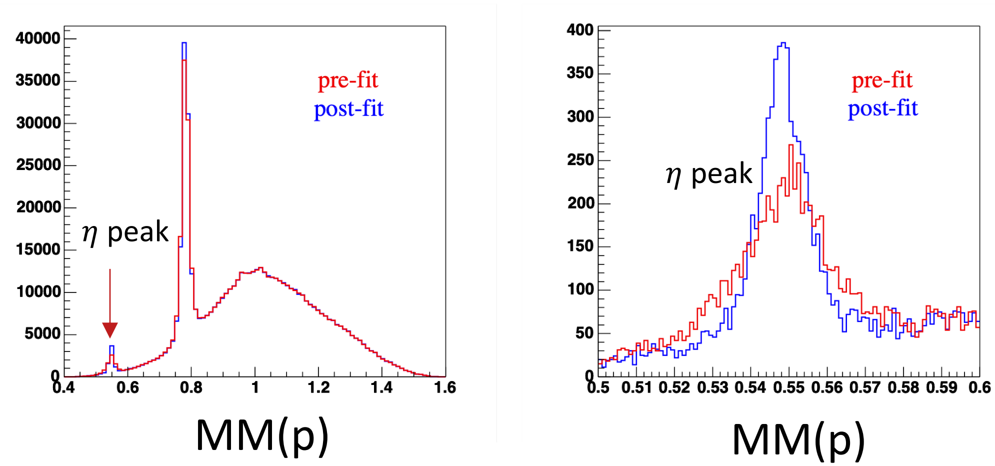
Kinematic Fitting - Intro



- Example (CLAS photoproduction):

$$\gamma p \rightarrow p\pi^+\pi^-\pi^0$$

  - Missing π^0
  - Missing mass constraint (1-C fit)



Plots/Example from CLAS-NOTE 2003-017, M. Williams

Goals of this Project

- Support for kinematic fitting of all 4-momentum constraints relevant for CLAS12 physics analyses
- DST HIPO input → HIPO output (with new, kinematic-fitted particle banks)
- Runnable by analyzers and easily configurable at runtime for different constraints/reactions
- Ultimately, include in standard CLAS12 workflows
    - Run groups just define the desired reactions, á la trains

Our Starting Point

- Surveyed available software, chose to start with a minimal C++ kinematic fitter written by by F. Cao for the CLAS eg6 experiment

- Extended it to support most common constraints for CLAS12, 1-C, 2-C, etc, and added some diagnostics

- Only standard C++ library and ROOT dependencies

```
auto kin = new KinFitter({KinParticle(target), KinParticle(beam)}, kin_parts_sme);
kin->Add_InvMass_Constraint(constraint_idx, invmass);
kin->Add_MissingMass_Constraint(constraint_idx, missmass);
kin->DoFitting(100);
```

Where the magic happens

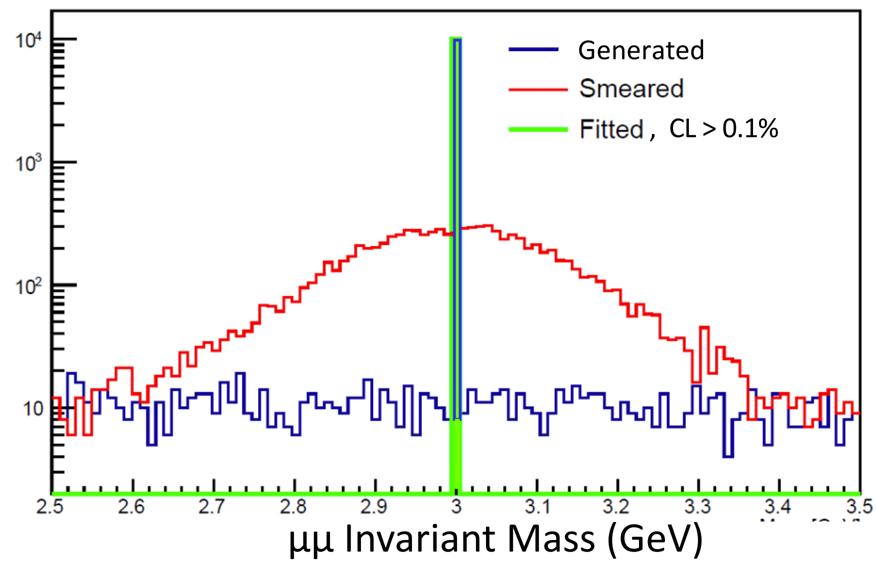
Provide list of constrained particles

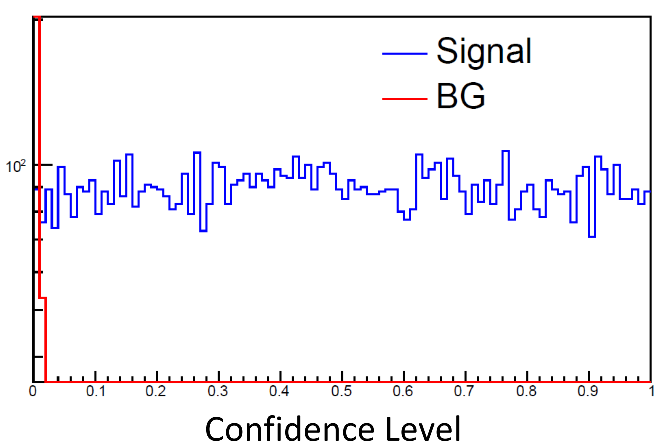
Constraint Example: 4-C Fit

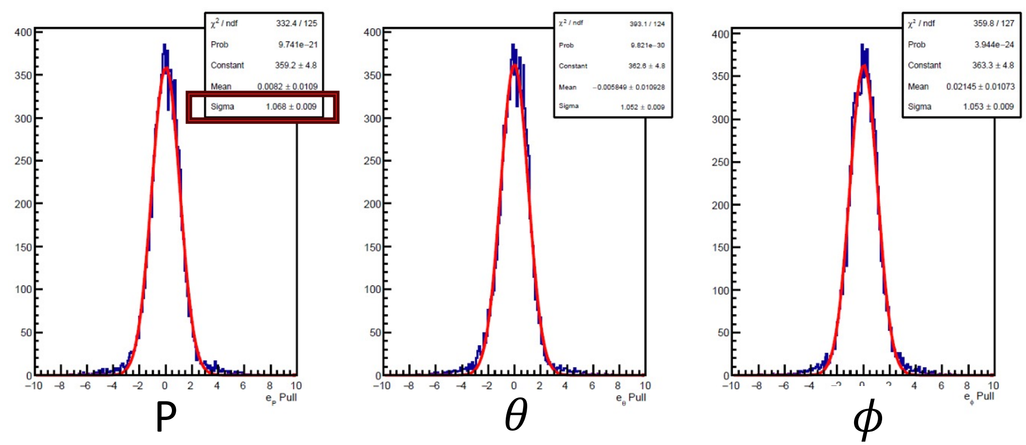
```
double data[4][_nvars] = {
    {sin(theta) * cos(phi),  p * cos(theta) * cos(phi), -p * sin(theta) * sin(phi)},
    {sin(theta) * sin(phi),  p * cos(theta) * sin(phi),  p * sin(theta) * cos(phi)},
    {cos(theta),            -p * sin(theta),             0},
    {p / E,                  0,                          0}
};

TMatrixD dfdx(_nconstraints, _nvars, *data);
```

First Fitting Test: Toy Monte Carlo

- Simple generators
  - Signal: "J/ψ" (0 width)→μμ
  - Background: γ*→μμ
- Simple, uncorrelated, gaussian smearing in p/θ/ϕ
- 1-C fit to J/ψ invariant mass





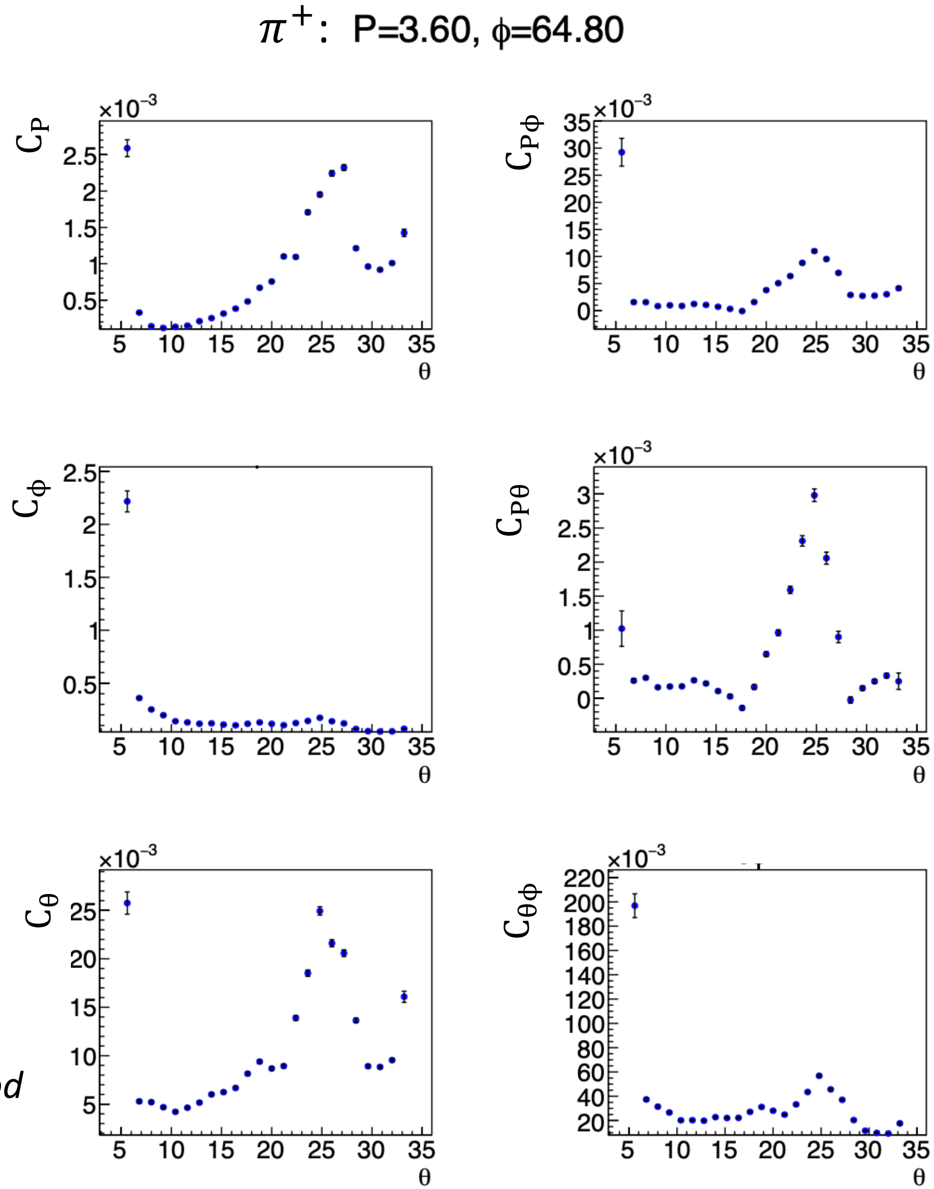


Normalized Pulls

Issue: Modeling the DC Covariance Matrix

- Not available so far from tracking, but an accurate covariance matrix is essential for kinematic fitting
  - Almost every reaction for kinematic fitting needs DC, so decided to verify we can model it first

- We chose to measure it empirically using full GEMC simulations
  - Chose a binned and interpolated approach due to kinematic dependencies
  - Binned in P, θ, and ϕ, currently ignoring z



Ongoing tracking improvements may provide a good covariance matrix in the future, Tongtong's talk

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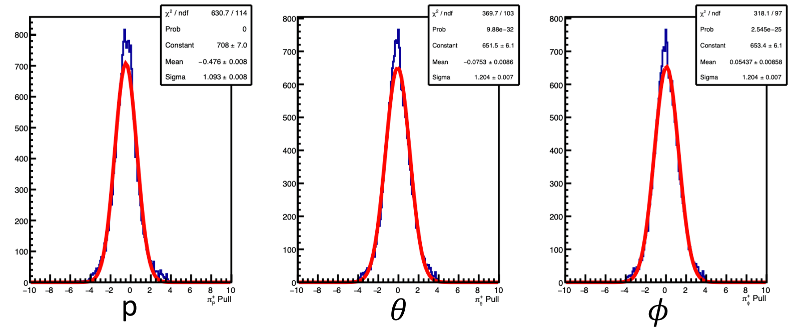
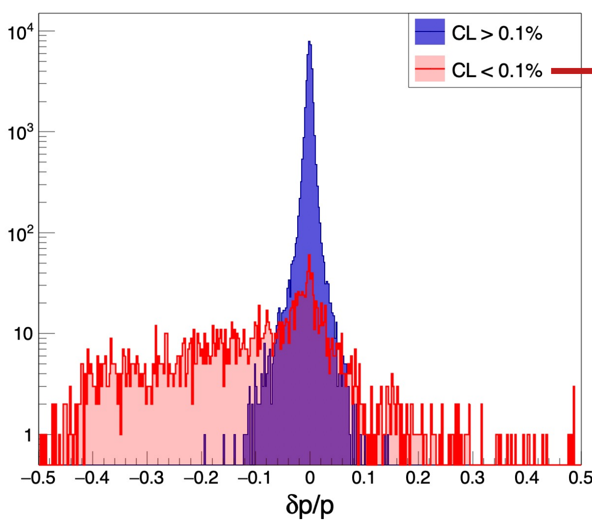
Latest Fitting Test: Full Phasepace, GEMC, Tracking

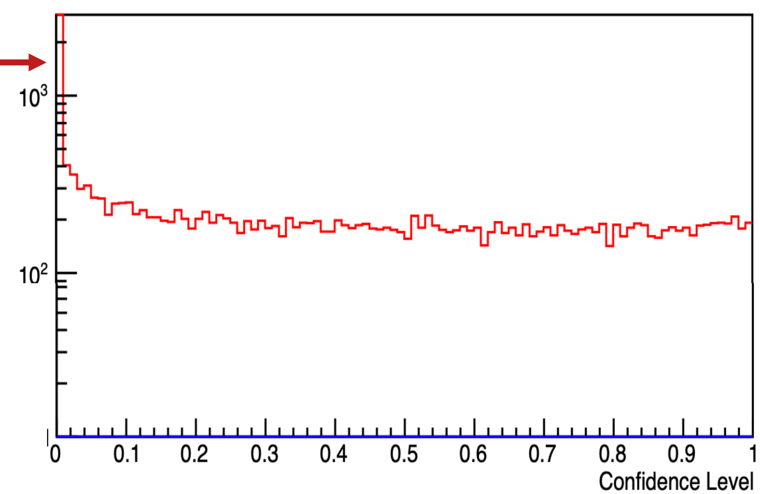
- Generate $ep \rightarrow e'p\rho \rightarrow e'p\pi^+\pi^-$
  - 0 width ρ, chosen to provide large phase-space test
  - over full detector acceptance
  - with 11 GeV beam
- Kinematic fit with 1-C invariant mass constraint, $m_{\pi\pi} = 0.775$ GeV
- Tracking resolutions have ~% contribution from very long, non-gaussian tails
  - **Requires robust method to remove outliers to avoid corrupting the core covariance**
  - So far, no correlation with any kinematics or tracking parameters has been found, just a concentration at very small confidence levels for events with such tracks



Normalized Pulls

- Some optimization still due, evidenced by pulls and slight tilt in confidence level
  - e.g., binning, momentum corrections
  - but already pretty close





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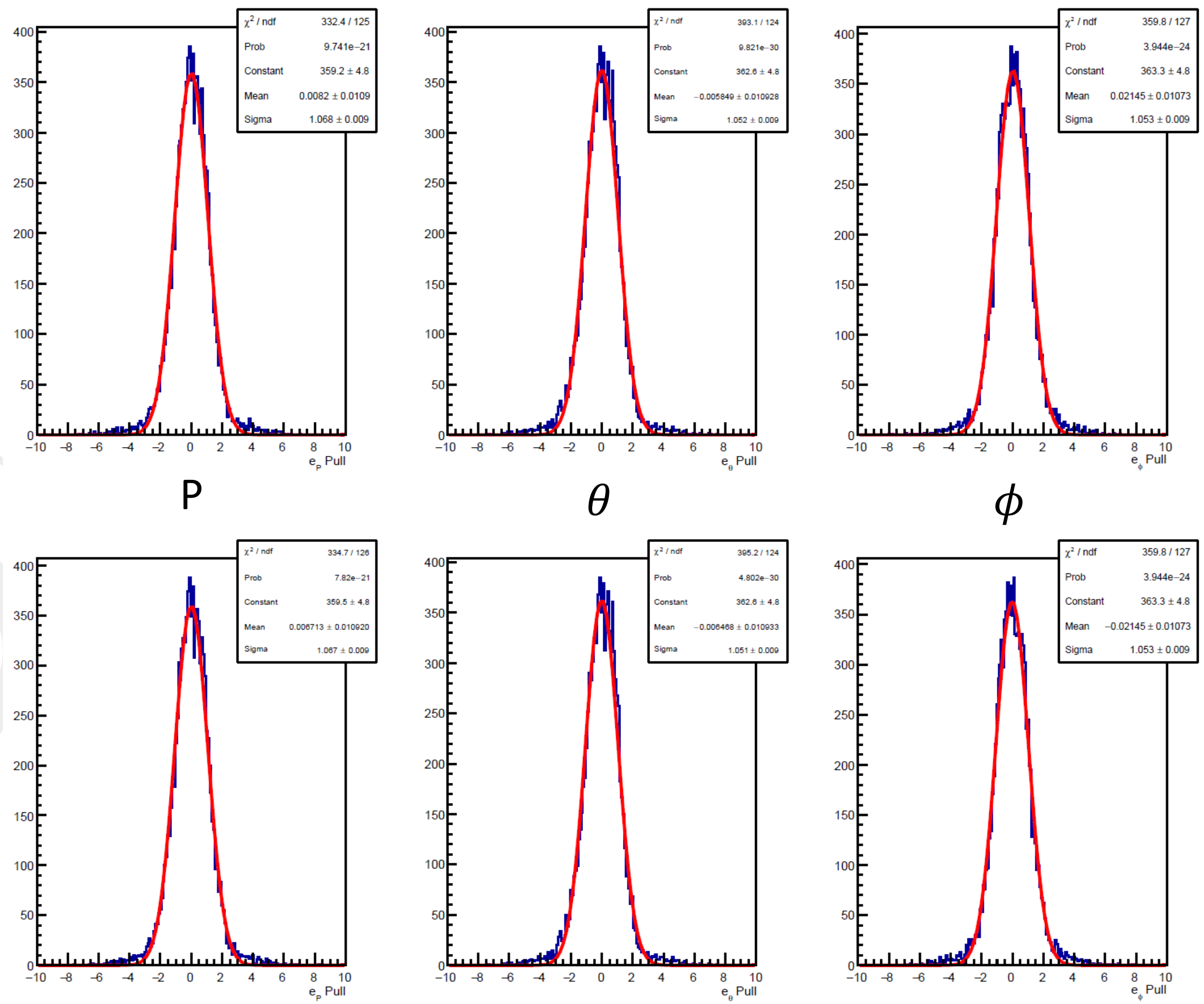
Summary & Outlook

- Current Status
  - Adopted and modified a CLAS kinematic fitter for use with CLAS12
    - Successfully tested with simplest case, toy MC
  - Demonstrated that we can effectively model DC covariance matrix with GEMC
    - Promising results with simulation (GEMC, CLAS12 reconstruction)
- Short-term
  - Finalize DC covariance matrix extraction
  - Calculate DC covariances for additional particles, e/K/p
- Intermediate (~3 months)
  - Test CVT covariance matrix provided by tracking
  - Extract covariance for other FD and FT detectors/particles
    - Electron – FT energy
    - Photons – ECAL energy , FT energy
    - Neutrons – ECAL timing, CND timing
  - Contributions from others (service work) very welcome
- Long-term (~6 months)
  - Extend to real data
    - Requires more momentum corrections and likely manipulation of covariances
  - User friendly, robust code for covariance matrix extraction
    - As detector performance and reconstruction software evolve, this will need to be redone
  - Output HIPO file with fitted results included

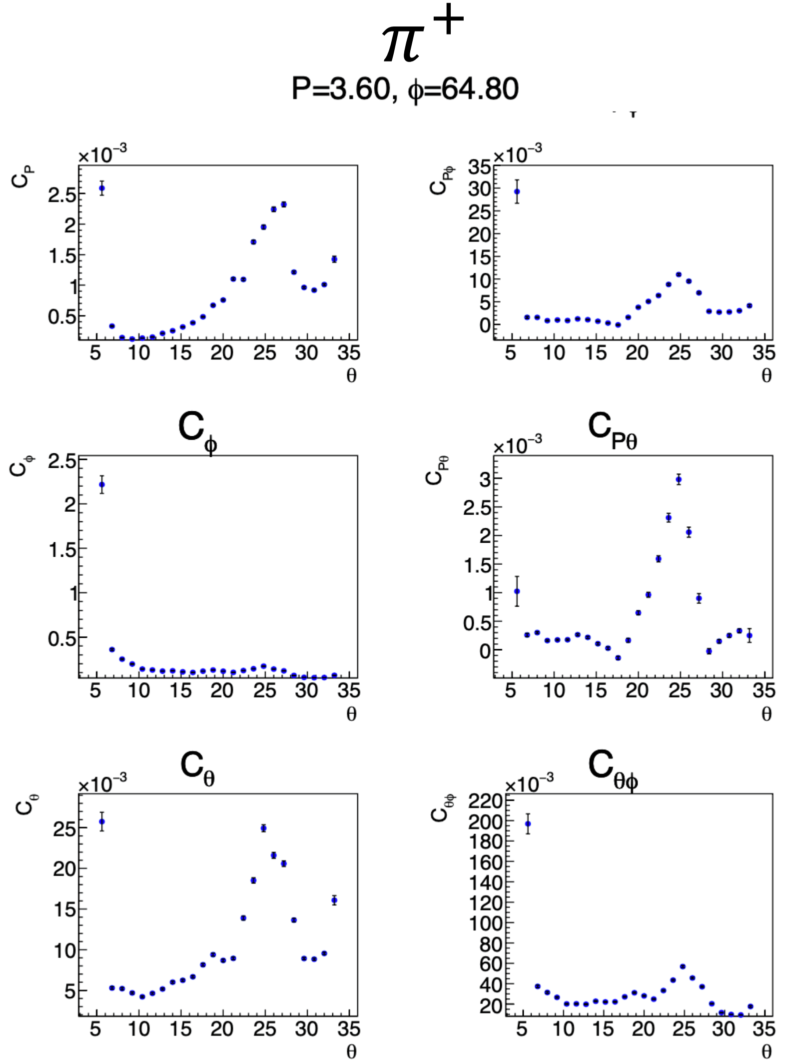
Backup Slides

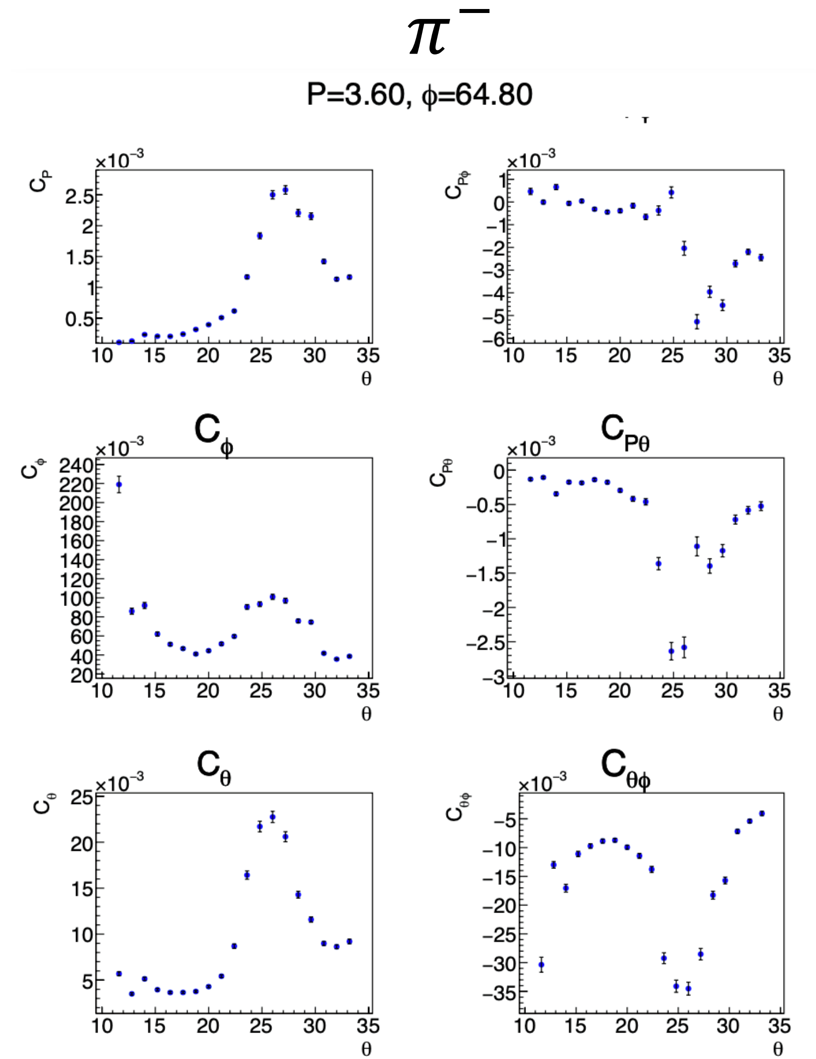
Toy MC

Normalized Pulls



DC Covariance Matrix





Invariant Mass Constraint Test