GEP Analysis: High-level Overview

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GEP analysis meeting
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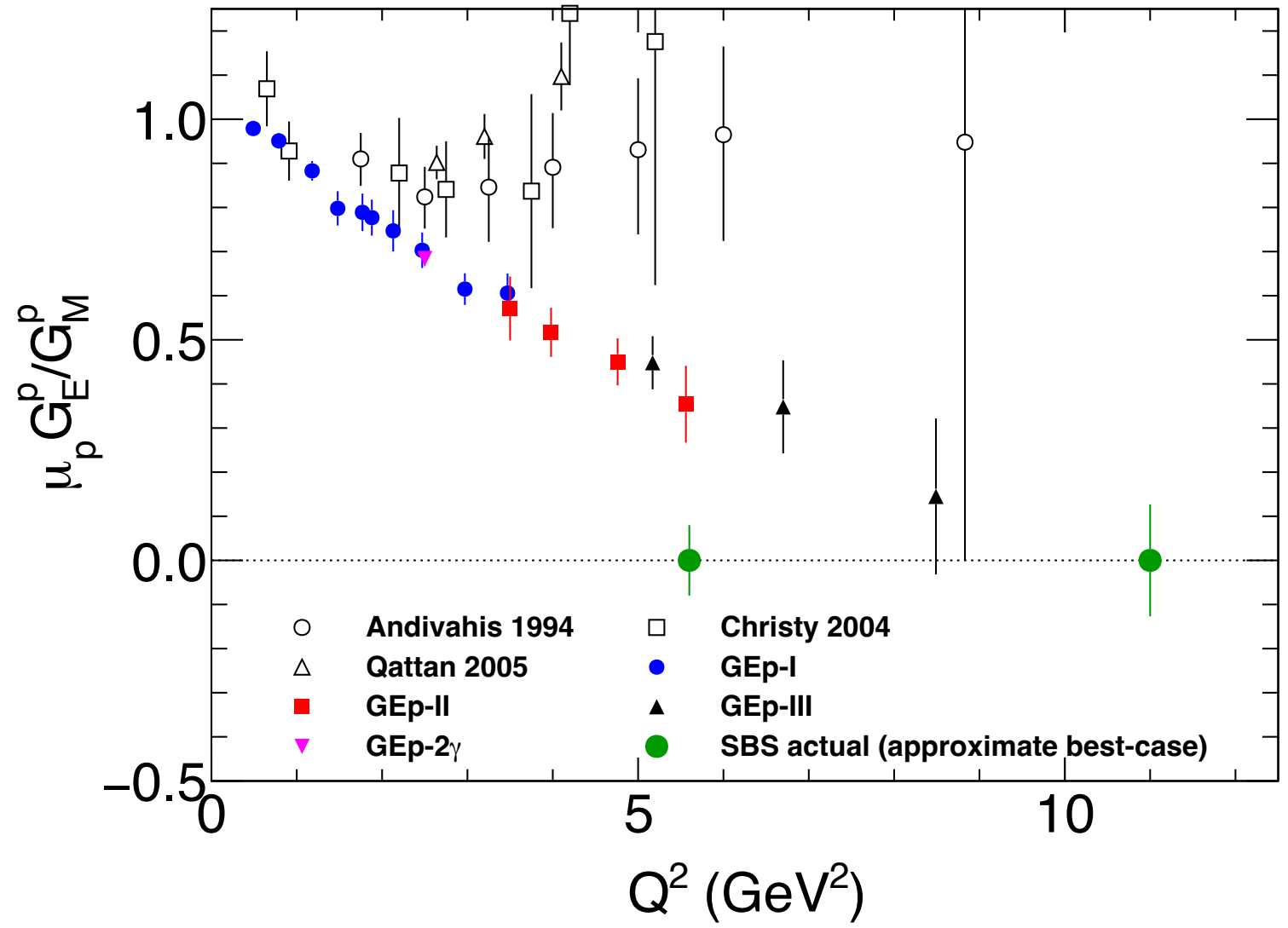
Summary of data collected and best-case scenario for physics result

- $Q^2 = 5.6\ GeV^2$: 3.7 C
- $Q^2 = 11\ GeV^2$: 94.2 C
- Note: these estimates are based on the "GEp5 Run Sheet" and may be slight underestimates.
- I made the figure at right just before last week's meeting.
- The two projected points from the SBS GEP experiment as executed represent somewhat optimistic *best-case* scenarios based on the accumulated charge at each Q^2 assuming overall trigger/detection/reconstruction efficiency of 70% (and does not account for radiative losses).
- Reality will fall short of this projection, perhaps significantly.



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Overview of GEP analysis methodology/strategy

- There are three major analysis tasks for this type of experiment:
  1. Event reconstruction (most difficult for this experiment)
  2. Elastic event selection and background estimation
  3. Extraction of polarization transfer observables
     a) Reconstruction of secondary scattering parameters
     b) Selection of useful secondary scattering events for polarimetry
     c) Calculation of proton spin transport coefficients
     d) Analyzing power calibration
     e) Maximum-likelihood extraction of polarization transfer components and FF ratio
     f) Measurement and ”subtraction” of background asymmetries
  4. Evaluation of systematic uncertainties
- Most of the analysis work will be in the calibration and optimization of event reconstruction.
- In this analysis, unlike in previous experiments of this type, tasks 1, 2, and 3a,b are intricately and inextricably intertwined.

Essential reading for thesis students and others analyzing data

https://sbs.jlab.org/wiki/index.php/GEP_Analysis_Page#Essential_papers_on_JLab_GEP_polarization_transfer_measurements

Useful documents/links

- Original proposal
- PAC47 (Jeopardy) proposal
- PAC52 proposal for "GEP+": PDF
- Past GEp from polarization transfer papers and thesis - Please update any missing ones.
- Elastic Electromagnetic Form Factors review articles and book chapters - Please update any missing ones.

Essential papers on JLab GEP polarization transfer measurements

GEP-1:

- Jones *et al*, PRL 2000
- Punjabi *et al*, PRC 2005

GEP-2:

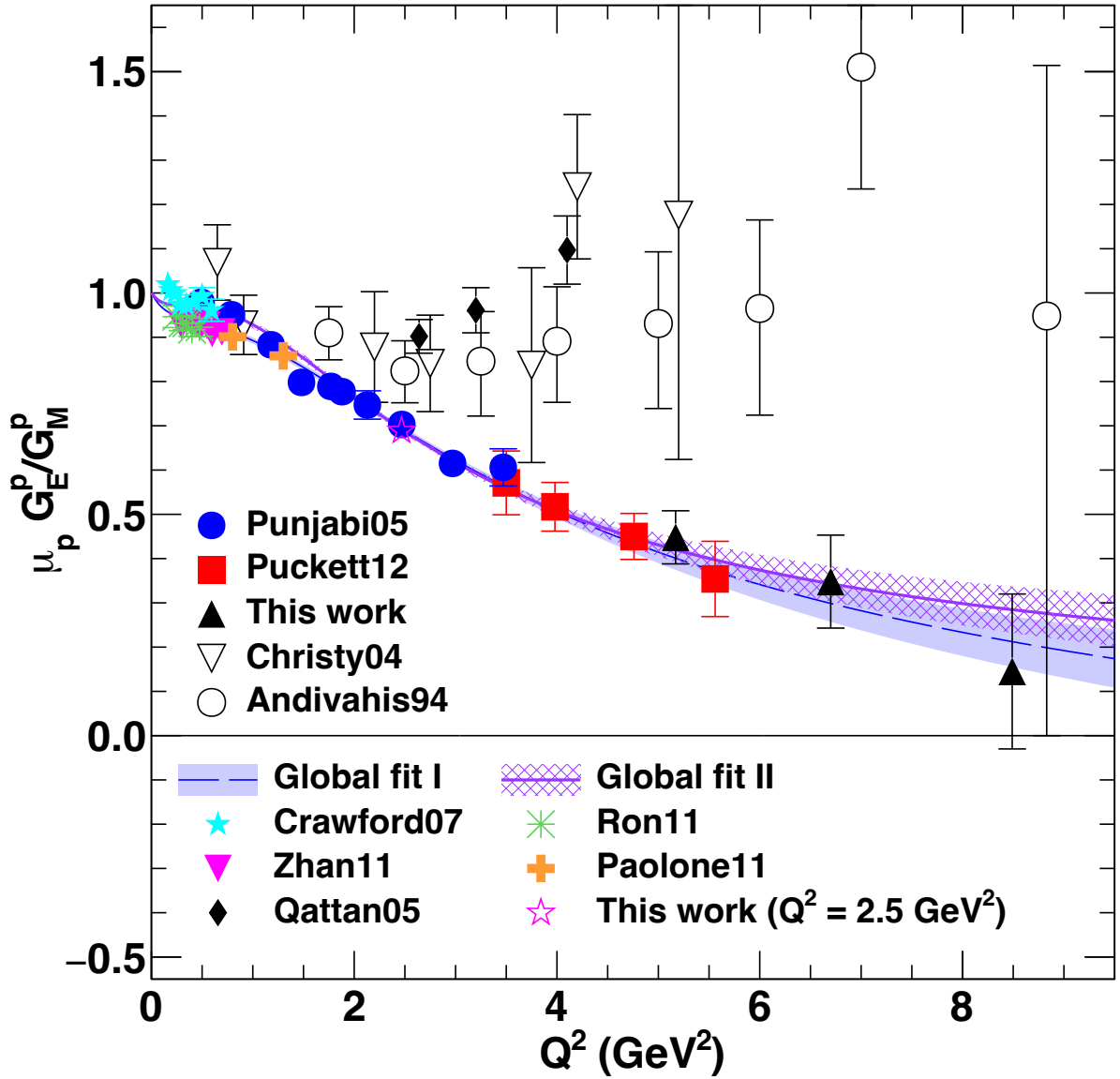
- Gayou *et al*, PRL 2002
- Puckett *et al*, PRC 2012

GEP-3/GEp-2gamma:

- Puckett *et al*, PRL 2010
- Meziane *et al*, PRL 2011
- Puckett *et al*, PRC 2017
  - (see also: Puckett *et al*, NIM 2018)

Other GEp/GMp polarization transfer (mostly low-Q^2):

- Ron *et al*, PRL 2007 and PRC 2011
- Paolone *et al*, PRL 2010
- Zhan *et al*, PLB 2011



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Event reconstruction

- Most challenging part of analysis for this experiment
- Proceeds from raw data decoding to high-energy clustering in ECAL/CDET and HCAL to track reconstruction in SBS polarimeter GEMs
- Elastic kinematic constraints are ”baked-in” within the trigger itself and throughout each step of reconstruction:
  - In this experiment, there is an acute danger of biasing our reconstruction algorithms so much that they either “hallucinate” good events that don’t exist or shift false tracks and other non-elastic events into our “good” elastic *ep* sample, that tend to dilute and/or bias the resulting physics asymmetry → we always need to keep this in mind as we refine the existing event reconstruction algorithms and weigh the efficiency/purity tradeoffs in our various cuts and parameters
- Integrating CDET into the reconstruction—straightforward in principle but not yet accomplished in practice
  - CDET data should help reduce inelastic physics background and help shrink the “region of interest” for track finding in the front GEMs.

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Elastic event selection

- Relies on ~mrad angular resolution of ECAL/HCAL/SBS
- ECAL angular resolution exists only in combination with the SBS vertex resolution of ~few-mm
- ECAL+CDET provide vertical angle resolution of ~1-few mrad. However, the long (~30-cm) target plus momentum dispersion plus vertex ambiguity limit the resolution with which the proton trajectory can be predicted based on electron arm information alone.
- Variables for elastic event selection (see https://github.com/JeffersonLab/SBS-offline/blob/master/SBSGEPHeepCoinModule.cxx):
  - Proton angle-momentum correlation ("dpp")
  - Electron-proton polar-angle correlation ("etheta-eth_pth" or "ptheta-pth_eth")
  - Electron-proton azimuthal-angle correlation ("ephi-pphi-π" or "acoplanarity")
  - ECAL(+CDET)+HCAL coincidence timing ("dt_ADC")
  - Electron energy-angle correlation or "missing" energy or "E over p" ("ecalo/eprime_eth-1" and other combinations thereof).
- Many other variables or combinations of variables based on two-body kinematic correlations can be used for elastic event selection (e.g., $\Delta x, \Delta y$, "missing energy/momentum", "acoplanarity", "inelasticity", etc.) but the list above exhausts all *independent* possibilities based on quantities directly measured by the detectors on an event-by-event basis.
- Different ways of constructing exclusivity cut variables lead to different resolutions and correlations between/among variables, and different distributions of background events (real-coincidence inelastic, accidentals, false tracks, etc).
- Best practice is to only apply a "minimal" set of independent cuts and **avoid "too tight" and/or "redundant" cuts, especially on strongly-correlated variables—in this kind of analysis, cuts can introduce bias in the polarization observables due to event-by-event errors, biases in the calculation of proton spin rotation matrices, scattering angles in the polarimeter, etc.**

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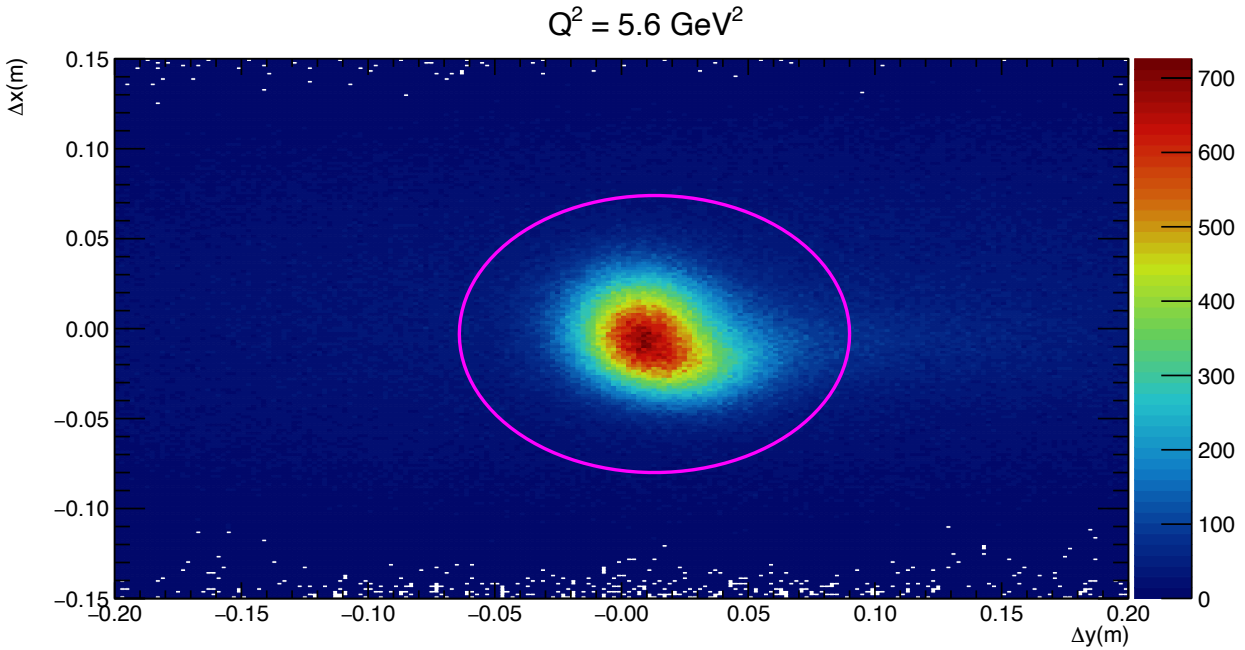
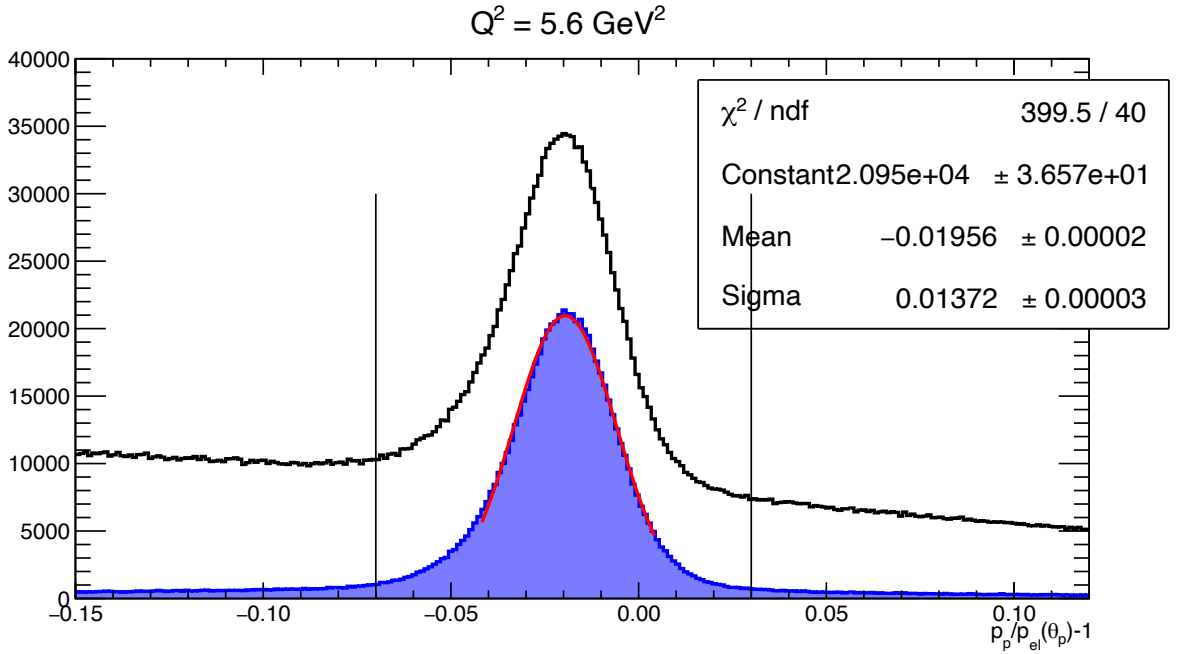
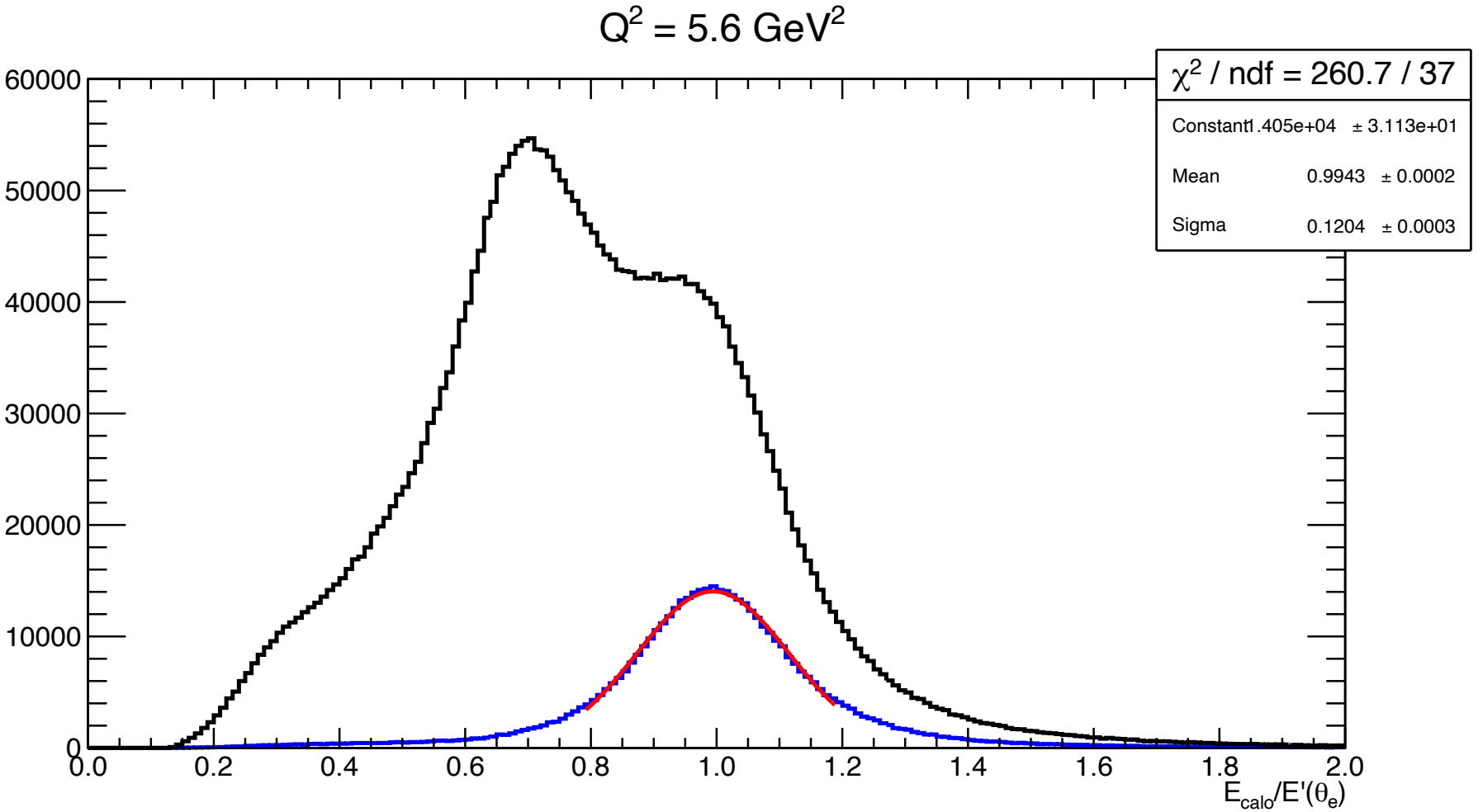
Elastic Event Selection, I: Kin. 1 dx vs dy and "dpp"





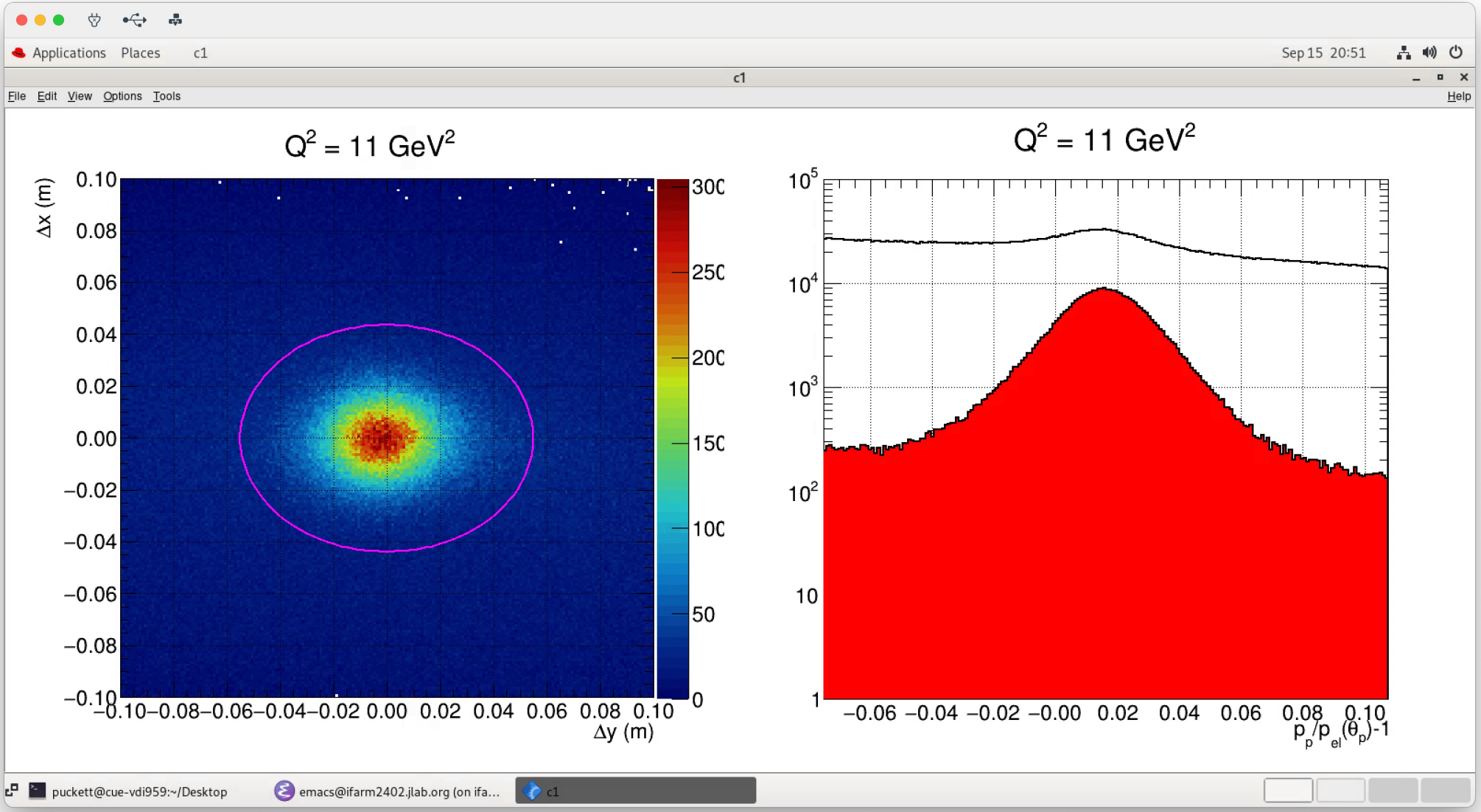
- Left: $(\Delta y, \Delta x)$ at ECAL ("angles-only" method): pink ellipse represents loose cut to select elastic peak
- Right: $\frac{p_p}{p_{el}(\theta_p)} - 1$: proton angle-momentum correlation cut; before (black) and after (blue) cuts on other exclusivity cut variables

Elastic event selection, II: Kin. 1 E/p



- $\frac{\sigma_E}{E} \approx 12\%$ in initial calibration of Kin. 1 data (expected ~5-6%). Discrepancy not yet fully understood

Elastic event selection, III: Kin. 3 dx vs dy and “dpp”



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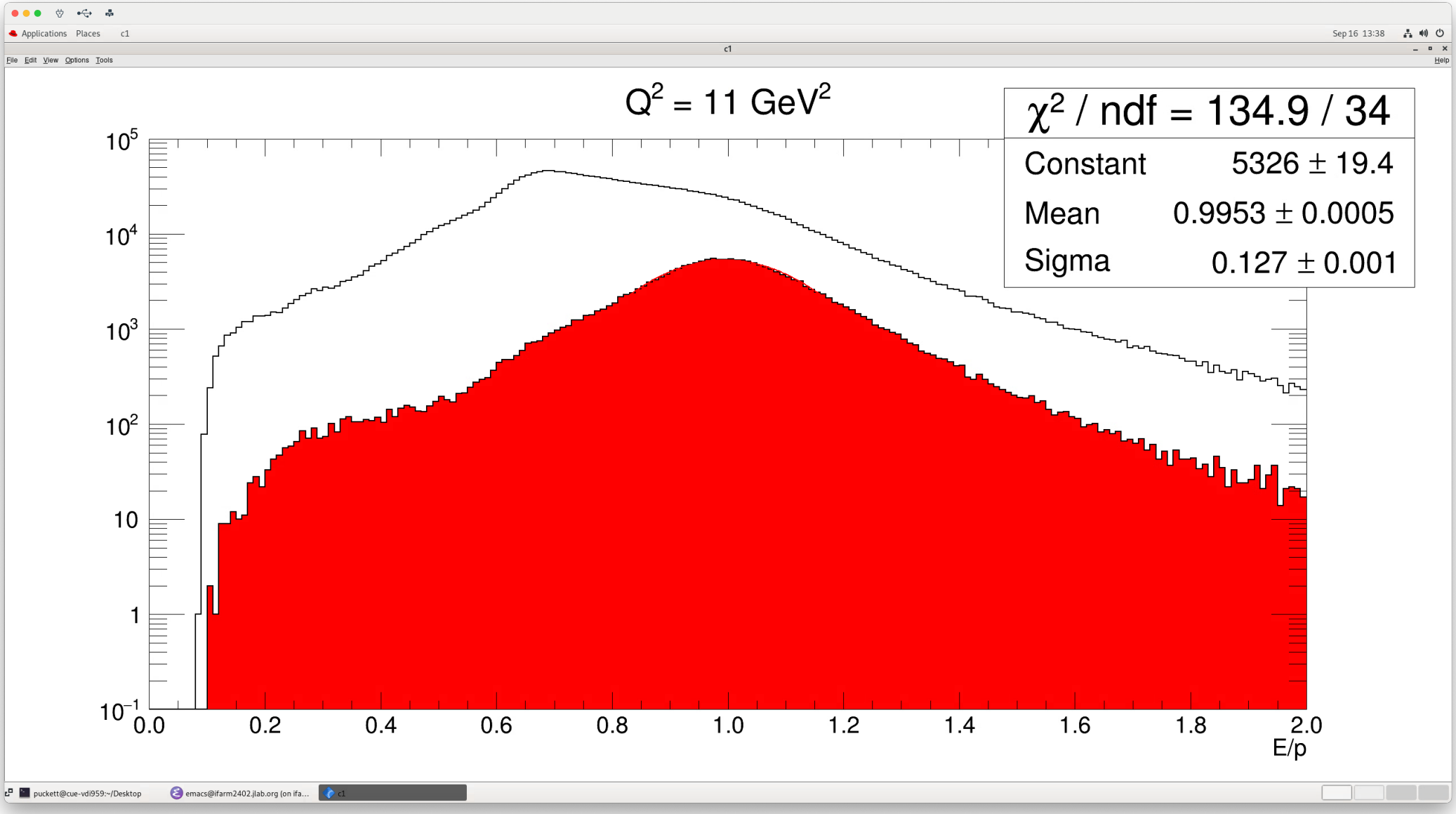
Elastic Event Selection: Kin. 3 E/p



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Polarimeter Reconstruction

- There are four basic quantities describing the secondary scattering:
  - Polar and azimuthal scattering angles θ, φ
  - Distance of closest approach and z –coordinate of point of closest approach between front and back tracks: s_{close}, z_{close}
- In either the "front-to-back" or "back-to-front" tracking algorithms, the region of interest calculation for the back and front trackers, respectively, enforces loose constraints on the closest-approach distance and scattering angle
- FPP tracks are required to point to the "highest-energy" cluster in HCAL.
- Calculations are done "online" in https://github.com/JeffersonLab/SBS-offline/blob/7d7feeab74fad6b3d9e8f6391029bd2d946a782f/SBSGEMPolarimeterTracker.cxx#L854
- Formulas for these quantities are derived/described in, e.g., https://inspirehep.net/literature/1386858

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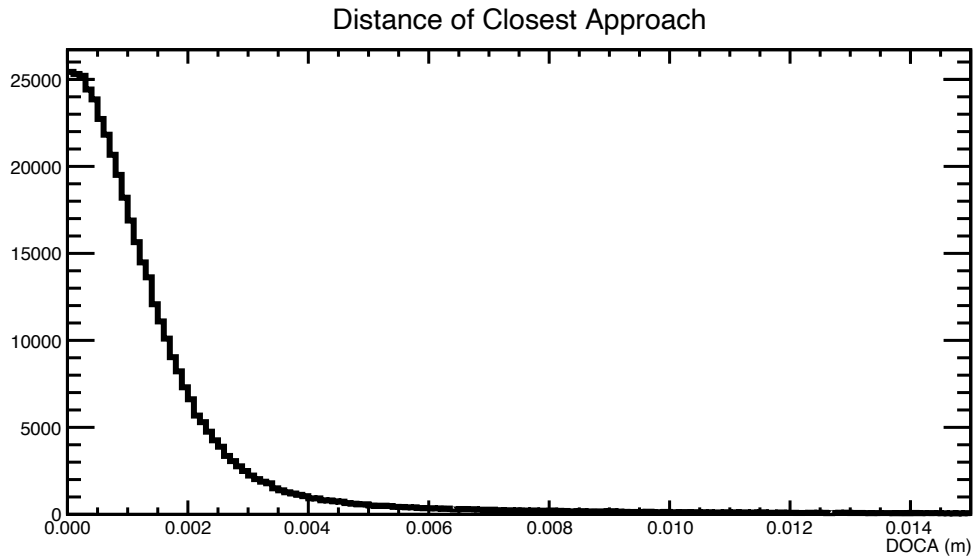
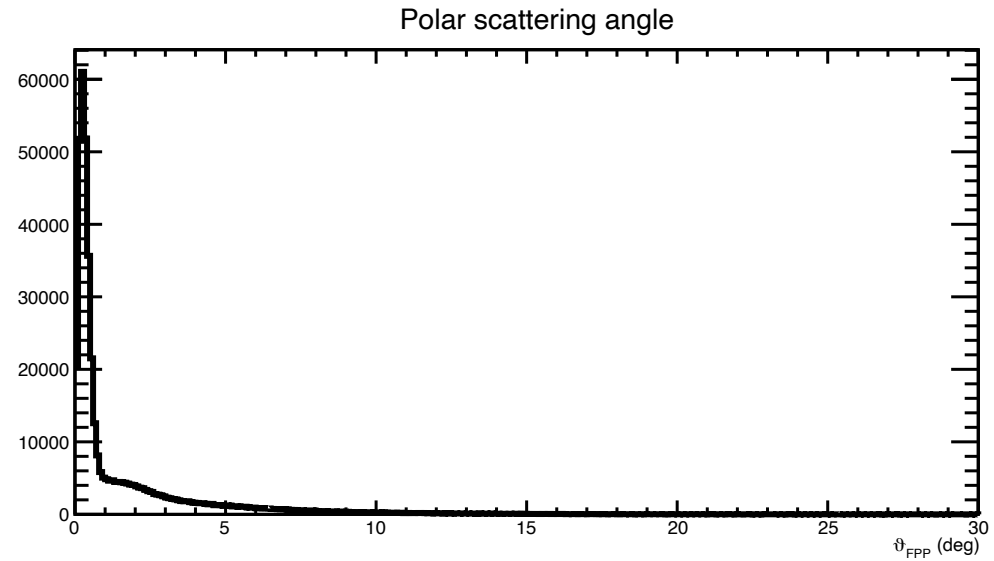
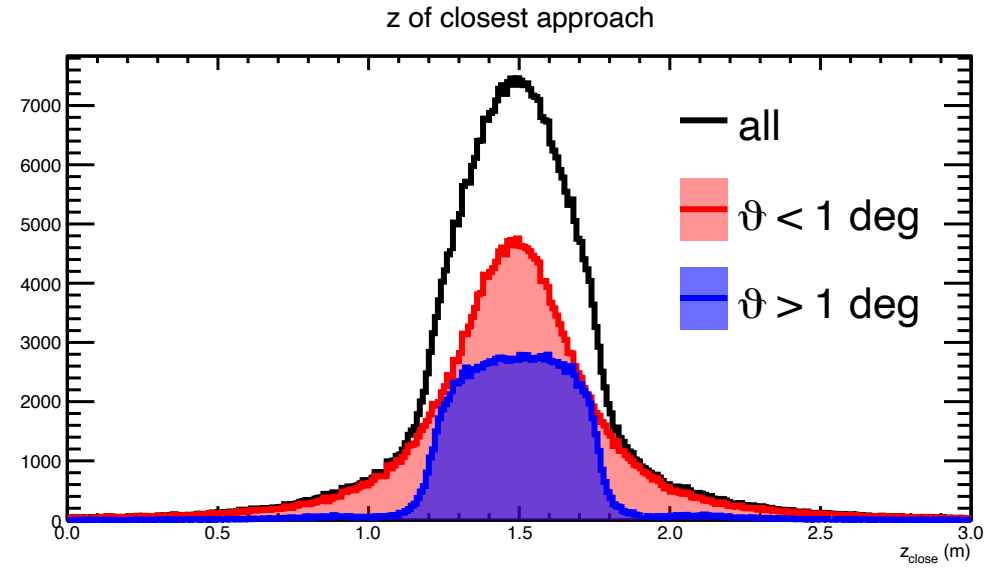
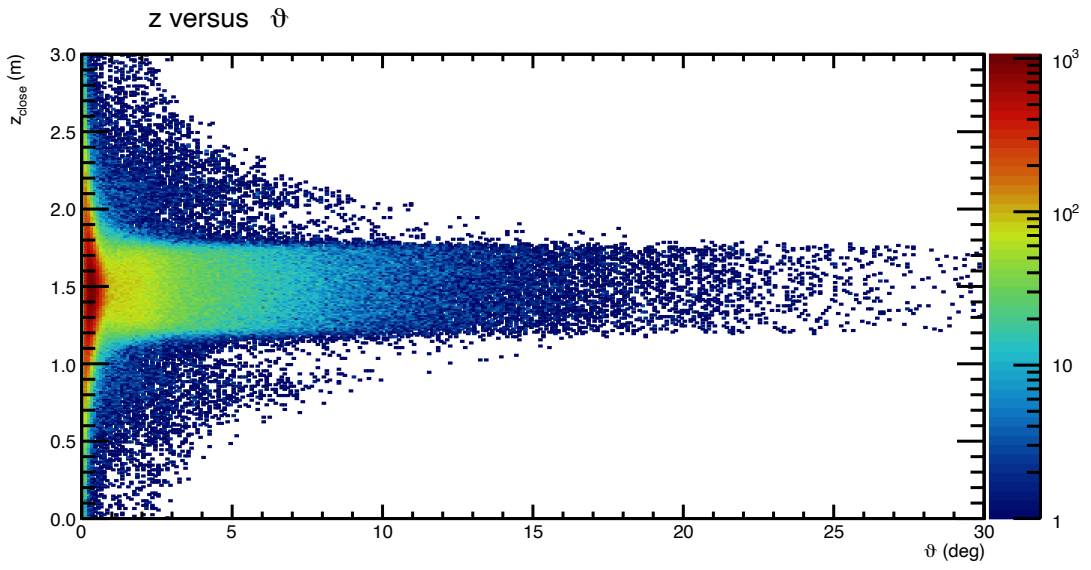
FPP Scattering Angle and Closest Approach Reconstruction, Kin 1

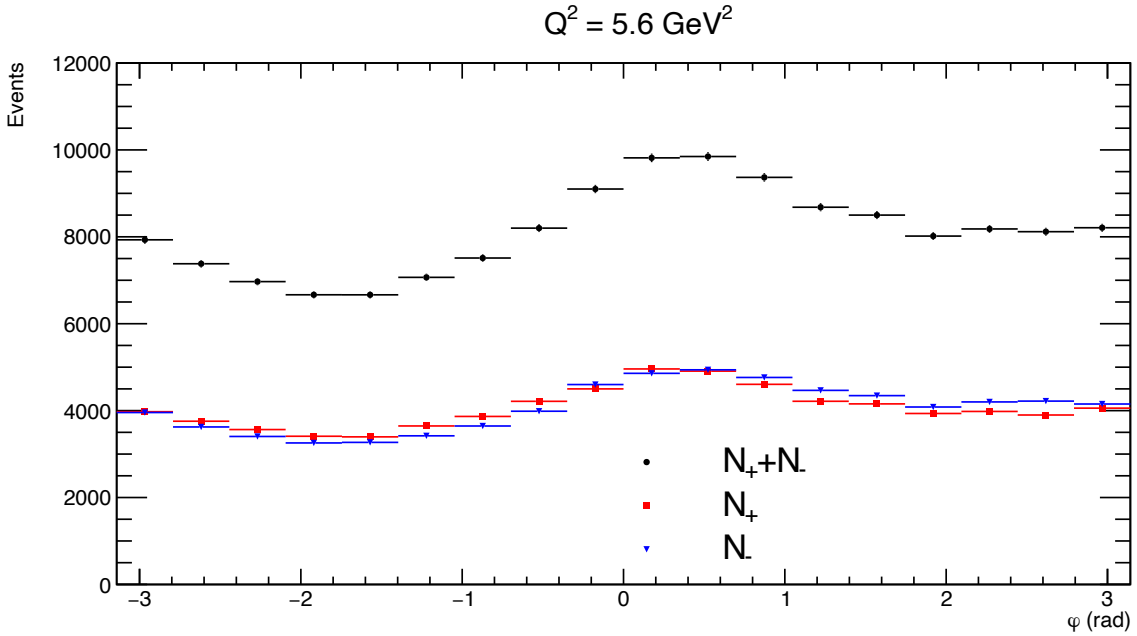


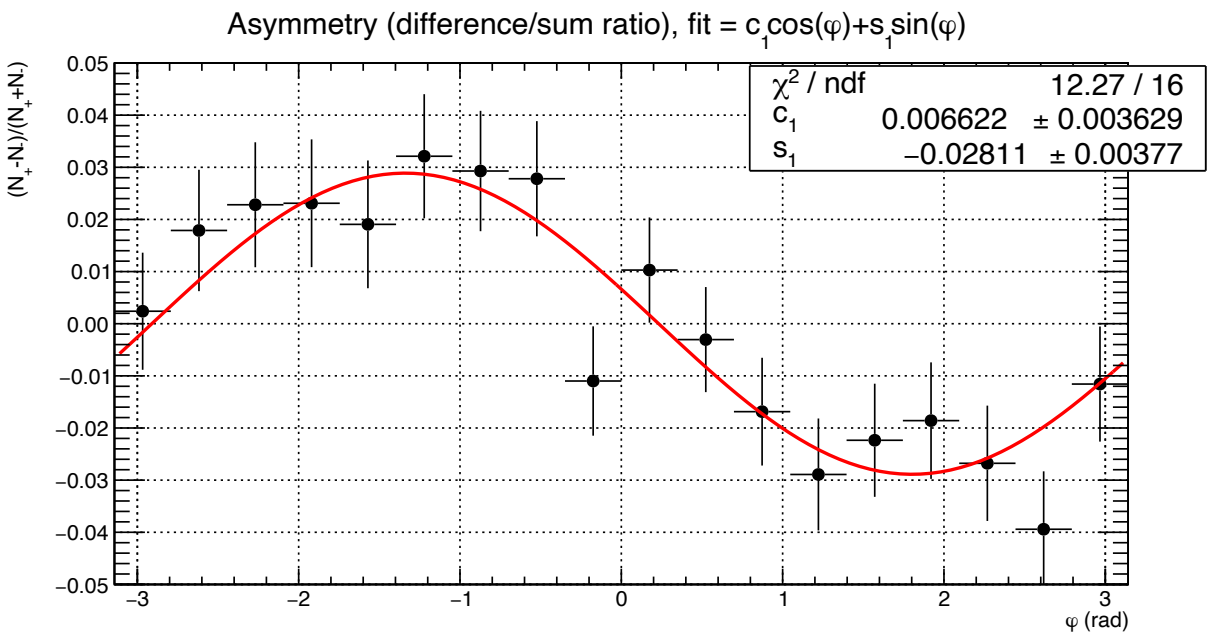






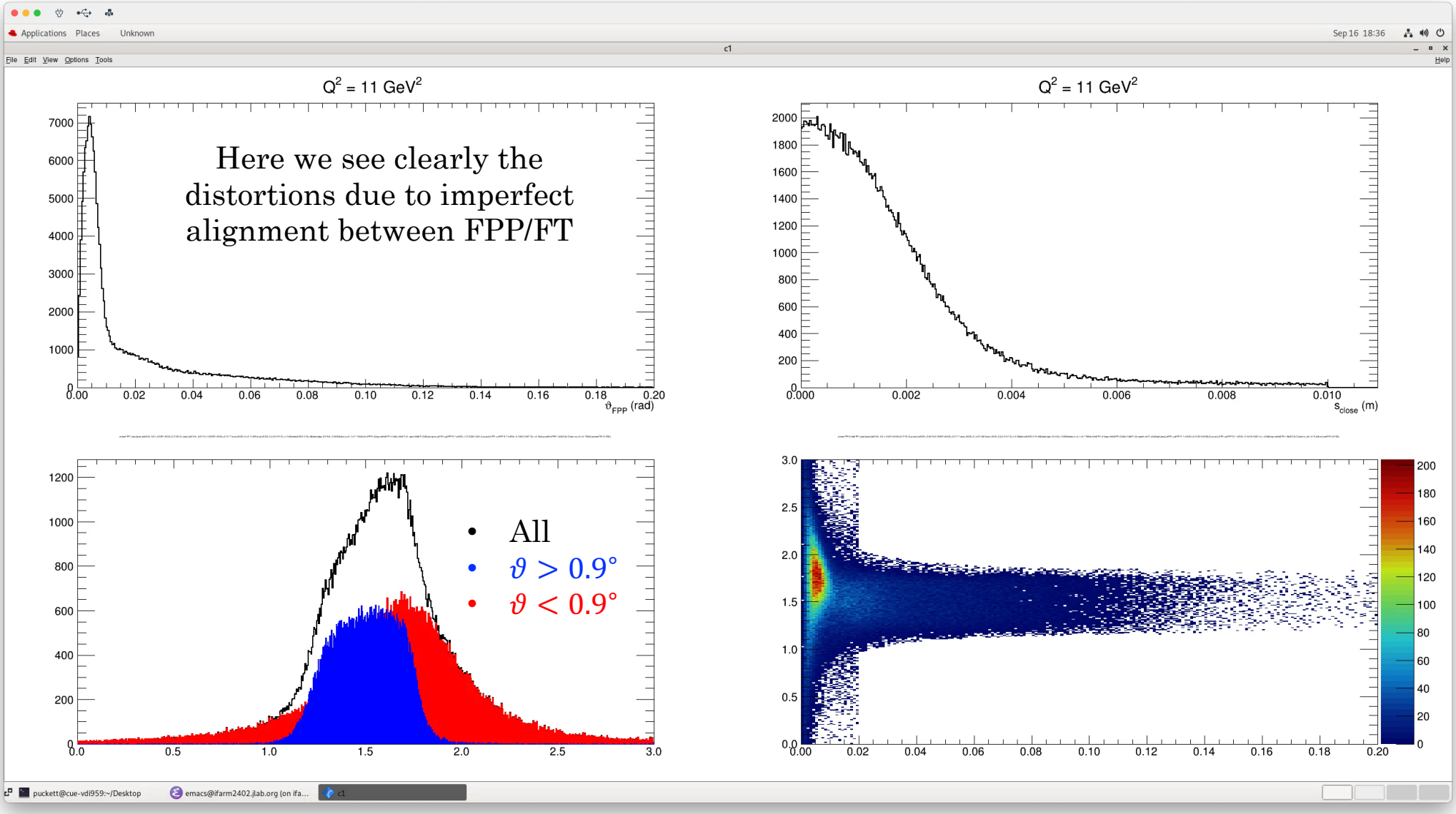
FPP Kin. 1 azimuthal distribution and asymmetry





- Left: FPP azimuthal angle distribution passing all exclusivity and other cuts; for helicity sum and individual helicity states—large instrumental asymmetry due to nonuniform acceptance/efficiency
- Right: Helicity asymmetry: difference/sum ratio and cancellation of false asymmetry
- Asymmetry amplitude and relative sign/magnitude of sine and cosine asymmetries are consistent with expectations, with low statistical significance
- No evidence (yet) for analyzing power increase due to HCAL energy sensitivity

FPP Scattering Angle and closest-approach reconstruction, Kin. 3



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More GEP analysis resources

- https://sbs.jlab.org/wiki/index.php?title=GEP_Analysis_Page (main wiki page with meeting agendas)
- https://docs.google.com/spreadsheets/d/1Kun7n5QeULwzmT70JepQyYntRJRAlOe8gPjcCGNfYQI/edit?gid=0#gid=0 (tracking GEP analysis tasks)
- Online "Run sheet": https://docs.google.com/spreadsheets/d/1G49e26ZHH8fNhpvK2XlgGtei94XF0viT3iykOviHT98/edit?gid=43955465#gid=43955465