University of Massachusetts Amherst

MENP

Charged Pion Polarizability in Hall D

Jefferson Lab

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HUGS 2024 Student Seminar

Overview

- Theory Background for χPT
- Polarizability
- Hall D CPP Experiment Setup
- Analyzing Muon Tracks
- Developing π/μ neural net

Chiral Lagrangian

- Chiral Perturbation Theory (χPT) acts as an effective field theory for low energy QCD in the regime where the strong coupling does not allow perturbation techniques

- In this regime we desire a theory that explains Hadron interactions

- $$\mathscr{L}_2 = \frac{F_\pi^2}{4} Tr(\partial_\mu U \partial^\mu U^\dagger) + \frac{m_\pi^2}{4} F_\pi^2 \, Tr(U + U^\dagger)$$

Pion Field

$$U = \exp\left(\sum \lambda_i \phi_i / F_\pi\right)$$

$$F_\pi = 93MeV$$

Higher than Tree Level

- Going above tree level (one loop and beyond) brings about issues in the forms of divergences.
- Weinberg posited that these divergences can be absorbed in to phenomenological constants, much like QED.
- This gave rise to the Gasser-Leutwyler Lagrangian

Gasser-Leutwyler

$$\begin{aligned}
\mathcal{L}_4 &= \sum_{i=1}^{10} L_i \mathcal{O}_i = L_1 \left[\mathrm{tr}(D_\mu U D^\mu U^\dagger)\right]^2 + L_2 \mathrm{tr}(D_\mu U D_\nu U^\dagger) \cdot \mathrm{tr}(D^\mu U D^\nu U^\dagger) \\
&+ L_3 \mathrm{tr}(D_\mu U D^\mu U^\dagger D_\nu U D^\nu U^\dagger) + L_4 \mathrm{tr}(D_\mu U D^\mu U^\dagger) \mathrm{tr}(\chi U^\dagger + U \chi^\dagger) \\
&+ L_5 \mathrm{tr}\left(D_\mu U D^\mu U^\dagger \left(\chi U^\dagger + U \chi^\dagger\right)\right) + L_6 \left[\mathrm{tr}\left(\chi U^\dagger + U \chi^\dagger\right)\right]^2 \\
&+ L_7 \left[\mathrm{tr}\left(\chi^\dagger U - U \chi^\dagger\right)\right]^2 + L_8 \mathrm{tr}\left(\chi U^\dagger \chi U^\dagger + U \chi^\dagger U \chi^\dagger\right) \\
&+ i L_9 \mathrm{tr}\left(F^L_{\mu\nu} D^\mu U D^\nu U^\dagger + F^R_{\mu\nu} D^\mu U^\dagger D^\nu U\right) + L_{10} \mathrm{tr}\left(F^L_{\mu\nu} U F^{R\mu\nu} U^\dagger\right)
\end{aligned}$$

$$D_\mu U = \partial_\mu U + \{A_\mu, U\} + [V_\mu, U]$$

$$F^{L,R}_{\mu\nu} = \partial_\mu F^{L,R}_\nu - \partial_\nu F^{L,R}_\mu - i[F^{L,R}_\mu, F^{L,R}_\nu],\ F^{L,R}_\mu = V_\mu \pm A_u$$

$$L_i^r = L_i - \frac{\gamma_i}{32\pi^2}\left[-\frac{2}{\epsilon} - \ln(4\pi) + \gamma - 1\right]$$

Bare value

Gasser-Leutwyler Lagrangian

- The values of the L_i^r coefficients were found through experiment.
- At the one-loop level, this theory is perfectly valid for our low energy levels (hadronic interactions)
- For higher order corrections the $\mathscr{L}_6$ Lagrangian can be used to absorb higher divergences.

$$
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\end{aligned}
$$

$$
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$$

Coefficient	Value	Origin
L_1^r	0.65 ± 0.28	$\pi\pi$ scattering
L_2^r	1.89 ± 0.26	and
L_3^r	-3.06 ± 0.92	$K_{\ell 4}$ decay
L_5^r	2.3 ± 0.2	F_K/F_π
L_9^r	7.1 ± 0.3	π charge radius
L_{10}^r	-5.6 ± 0.3	$\pi \to e\nu\gamma$

Predicted Quantities

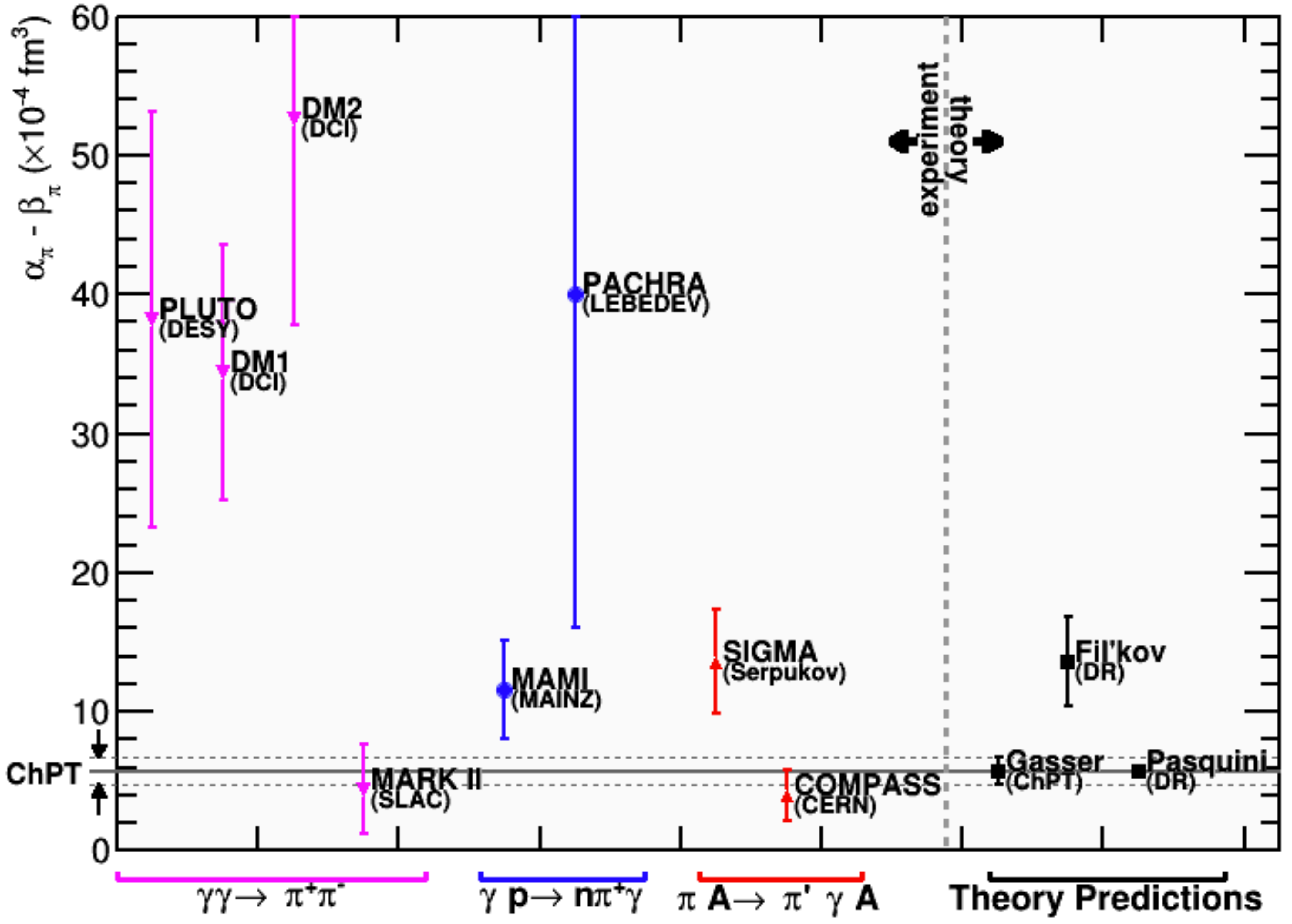
Charged Pion Polarizability

$$\alpha_\pi = -\beta_\pi = \frac{4\alpha}{m_\pi F_\pi^2}(L_9^r - L_{10}^r)$$

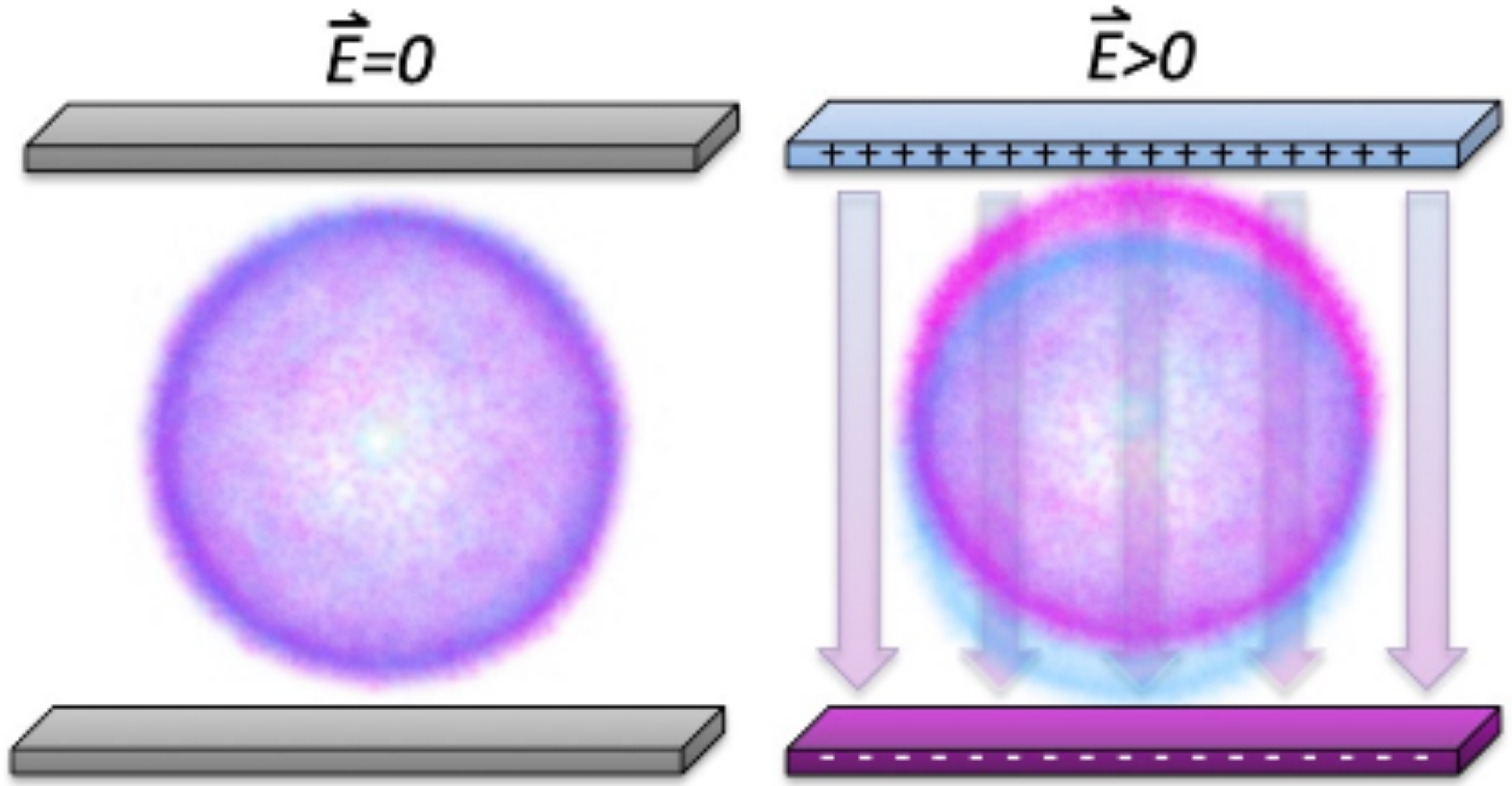
$$L_{QCD}(p^4) = L^{chiral\ even} + L^{chiral\ odd}$$

- The Lagrangian, or more importantly the constants gave rise to predictions of different quantities

- One from the Chiral-even terms of the Lagrangian give Charged Pion Polarizability. Which there has been some agreement with experiment



What is Polarizability?



Hadron surrounded by Pion Cloud

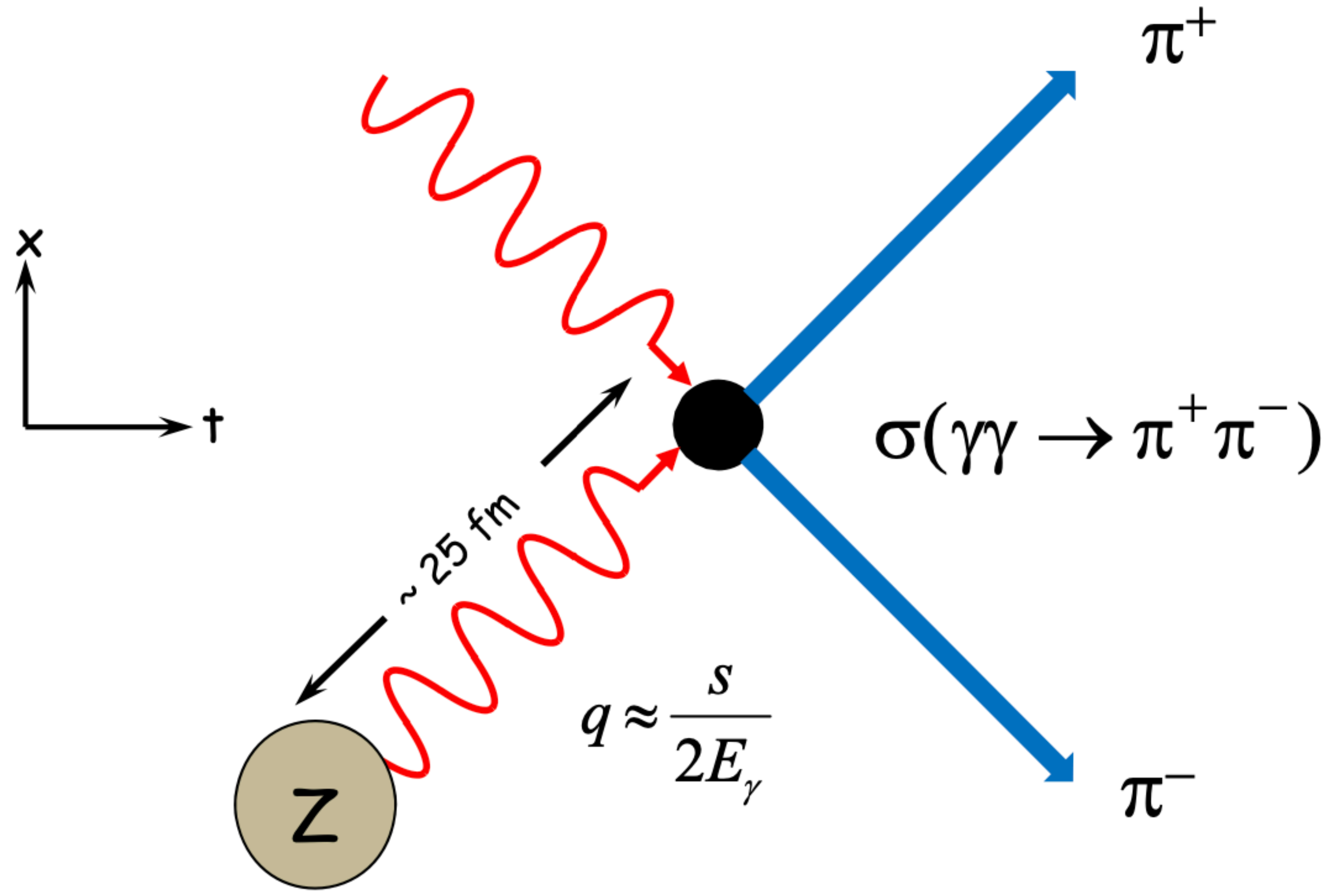
Hadron surrounded by displaced Pion Cloud

$$\vec{p} = -\alpha\vec{E}$$
$$\vec{\mu} = \beta\vec{H}$$

Electric Polarizability $= \alpha \approx 10^{-4} \times$ **Volume**

Magnetic Polarizability $= \beta \approx 10^{-4} \times$ **Volume**

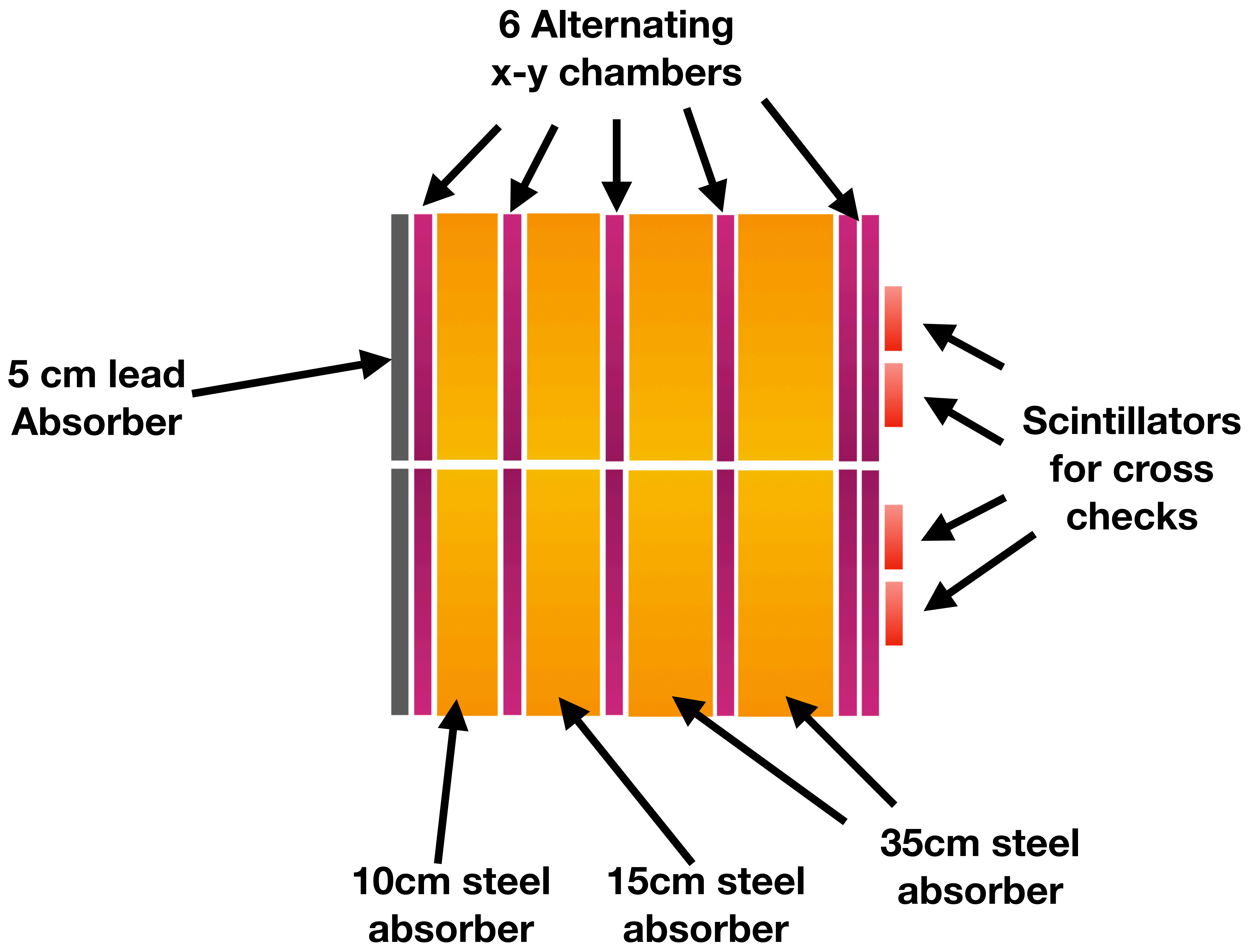
$$\frac{d^2\sigma_{primakoff}}{d\Omega dM} = \frac{2\alpha Z^2}{\pi^2}\frac{E_\gamma^4\beta^2}{M}\frac{sin^2\theta}{Q^4}\left|F(Q^2)\right|^2\left(1 + P_\gamma \cos\varphi_{\pi\pi}\right)\sigma(\gamma\gamma \to \pi\pi)$$



Hall D Target and Detector CPP Run

Muon Detector

- 8 Chambers built at UMASS, 6 used in CPP
- Each MWPC has 144 channels (sense wires)
- 90% Ar + 10% CO_2 gas mixture
- Ran at 1780V
- 4 Scintillators (CTOF) placed downstream of final chamber

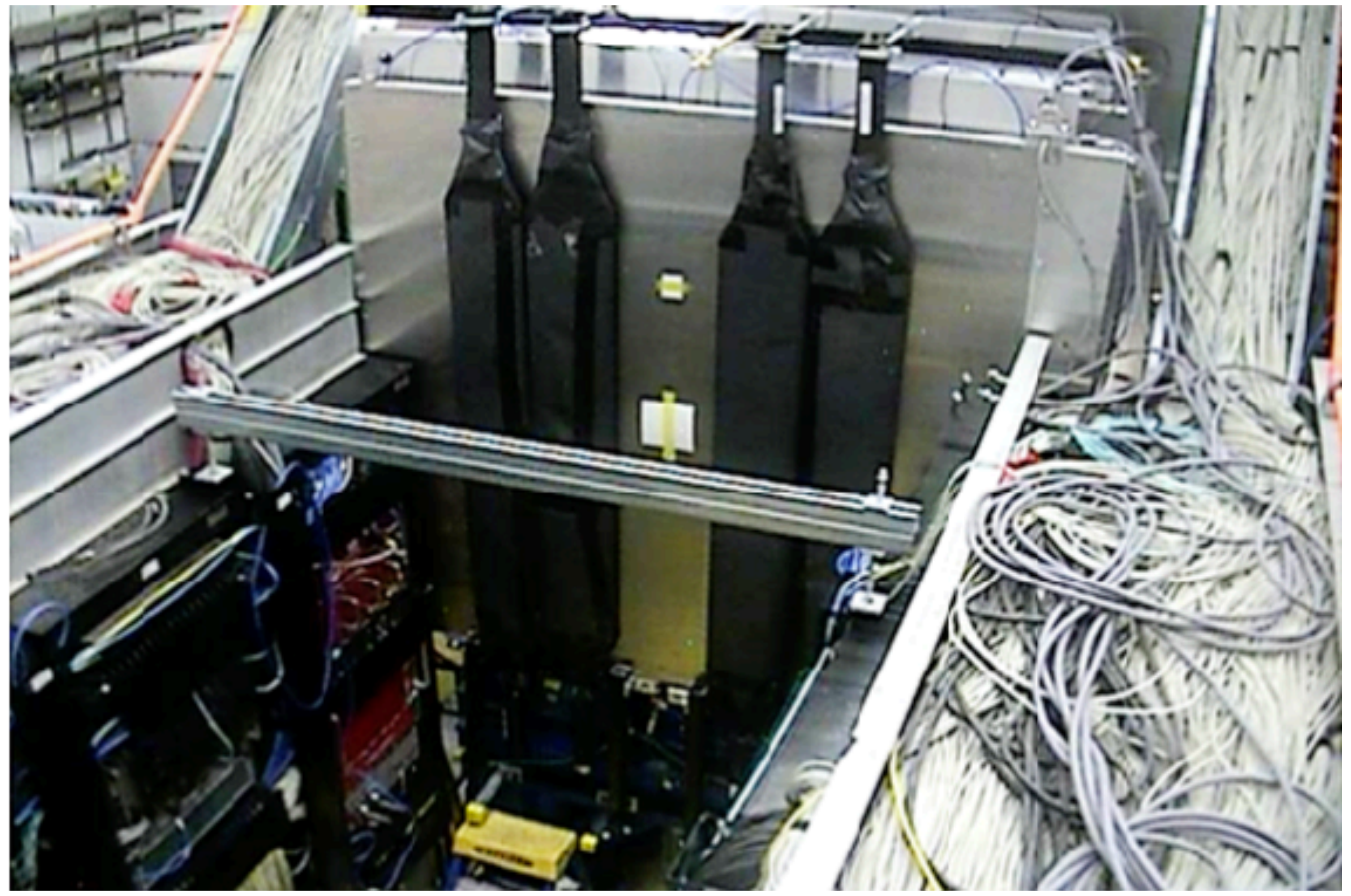


Muon Detector

Wire Chambers

Chambers installed with Iron Absorbers

CTOF Installed behind muon chambers



$\mu^+\mu^-$ Pairs Candidates

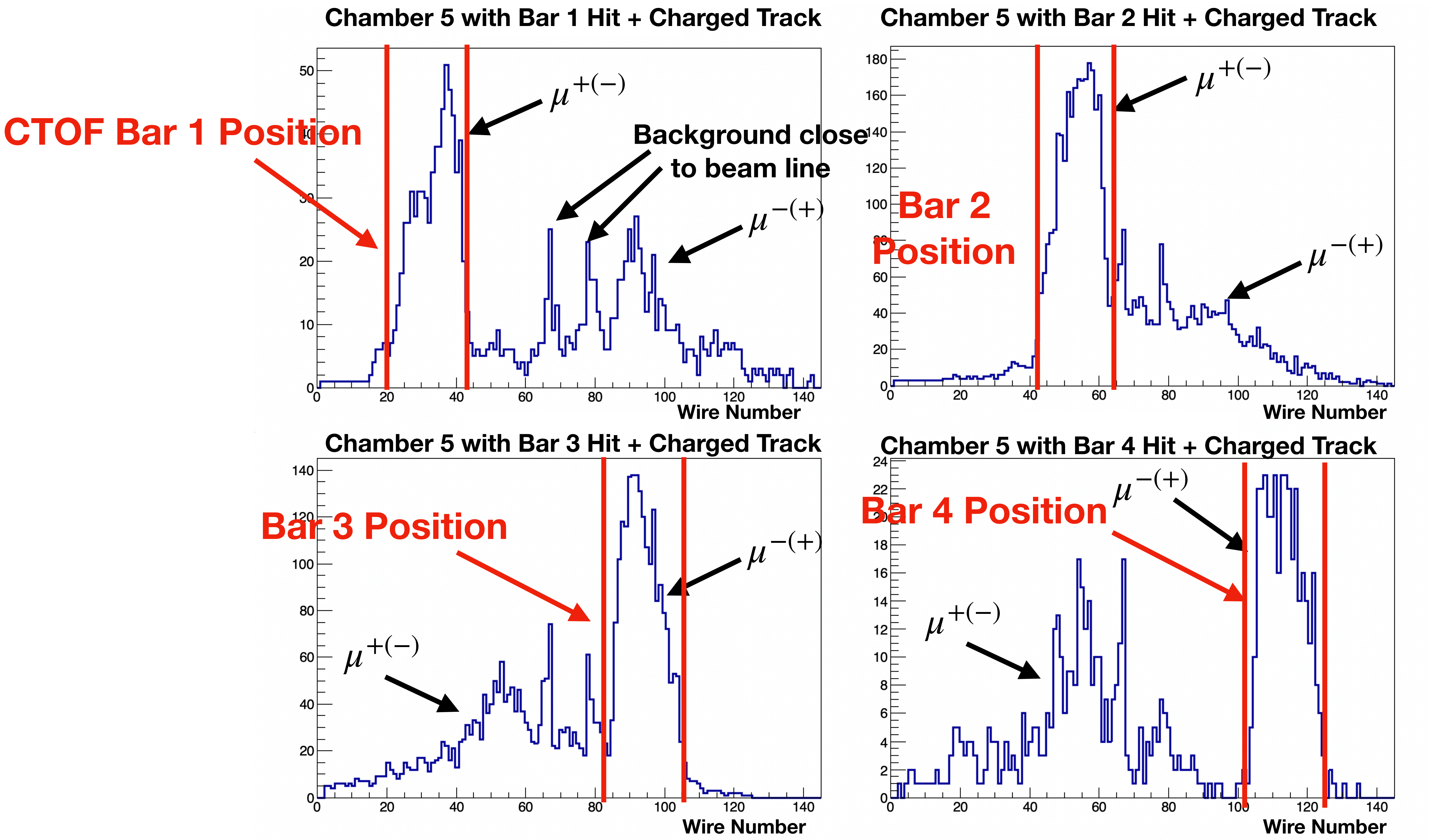
CTOF

- Pulse Height Cuts
- 2D Pulse Height Band Cuts
- TOF Trigger only
- Hits are calibrated through CTOFHit_factory

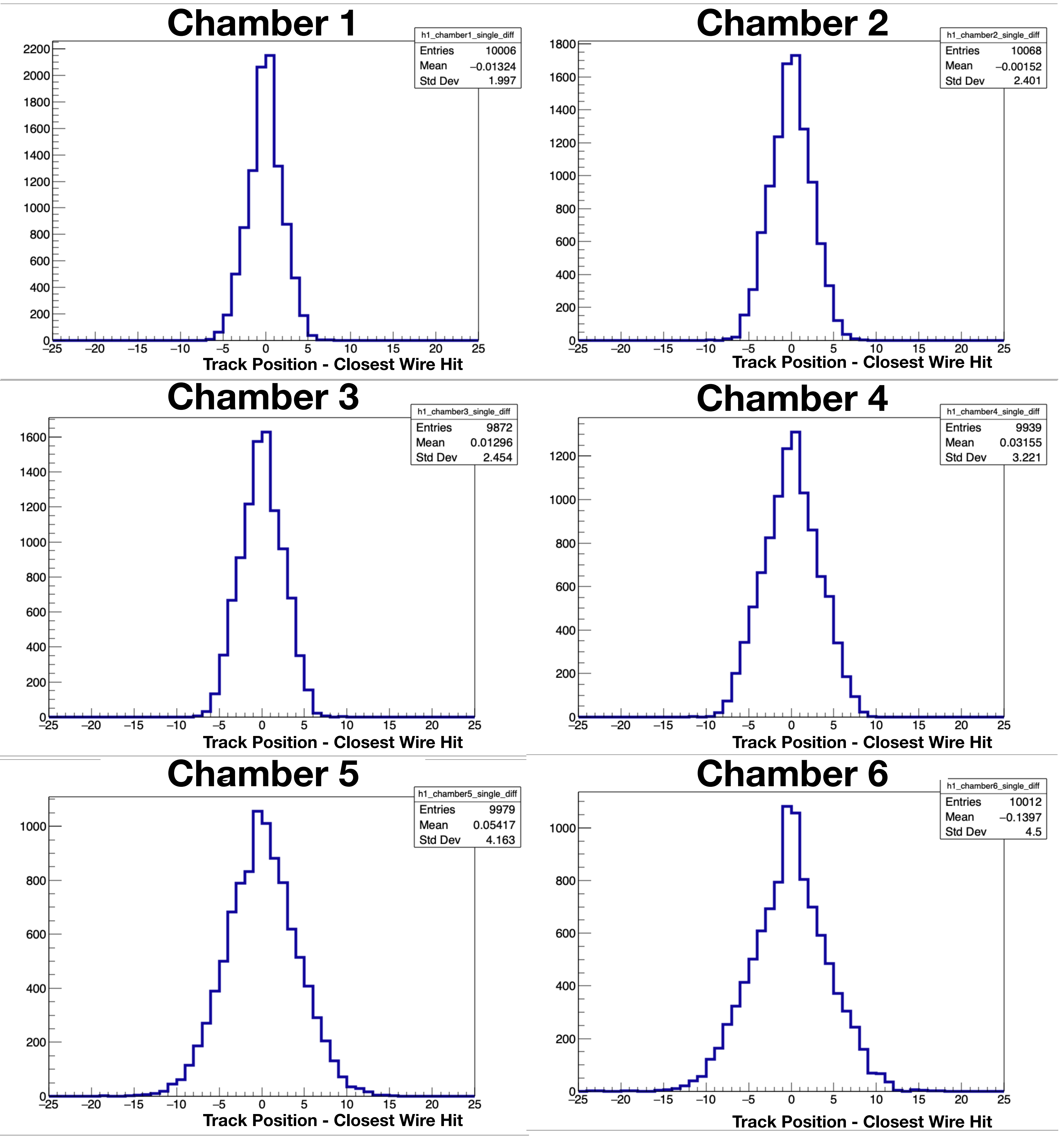
Charged Track

- At least 1 charged track pointing to a paddle with a good hit in CTOF
- Charged Track matched to hit in TOF
- No minimum momentum requirement on track

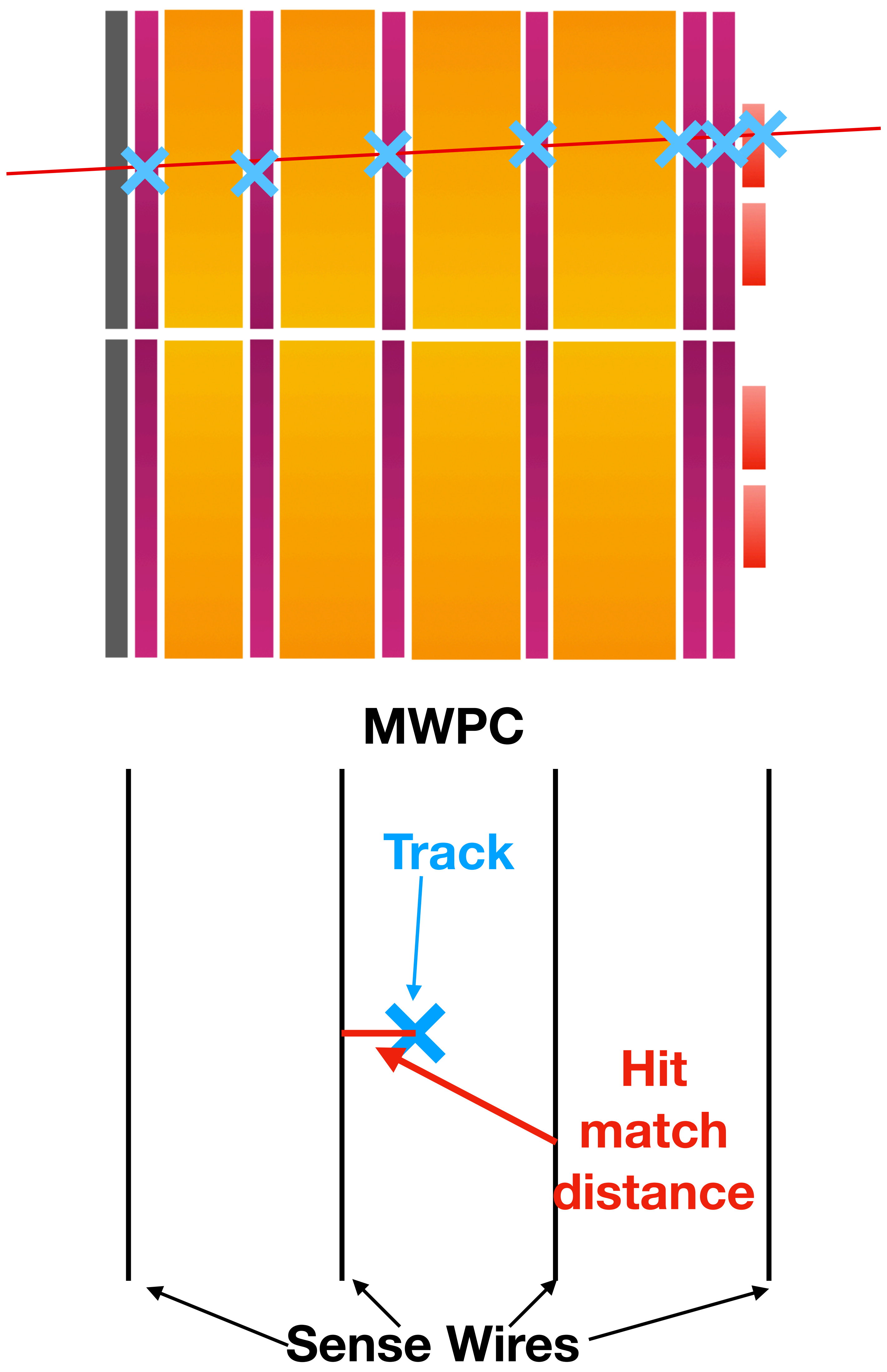
All Hits in Chamber 5 (vertical wires) that Satisfy Analysis Requirements



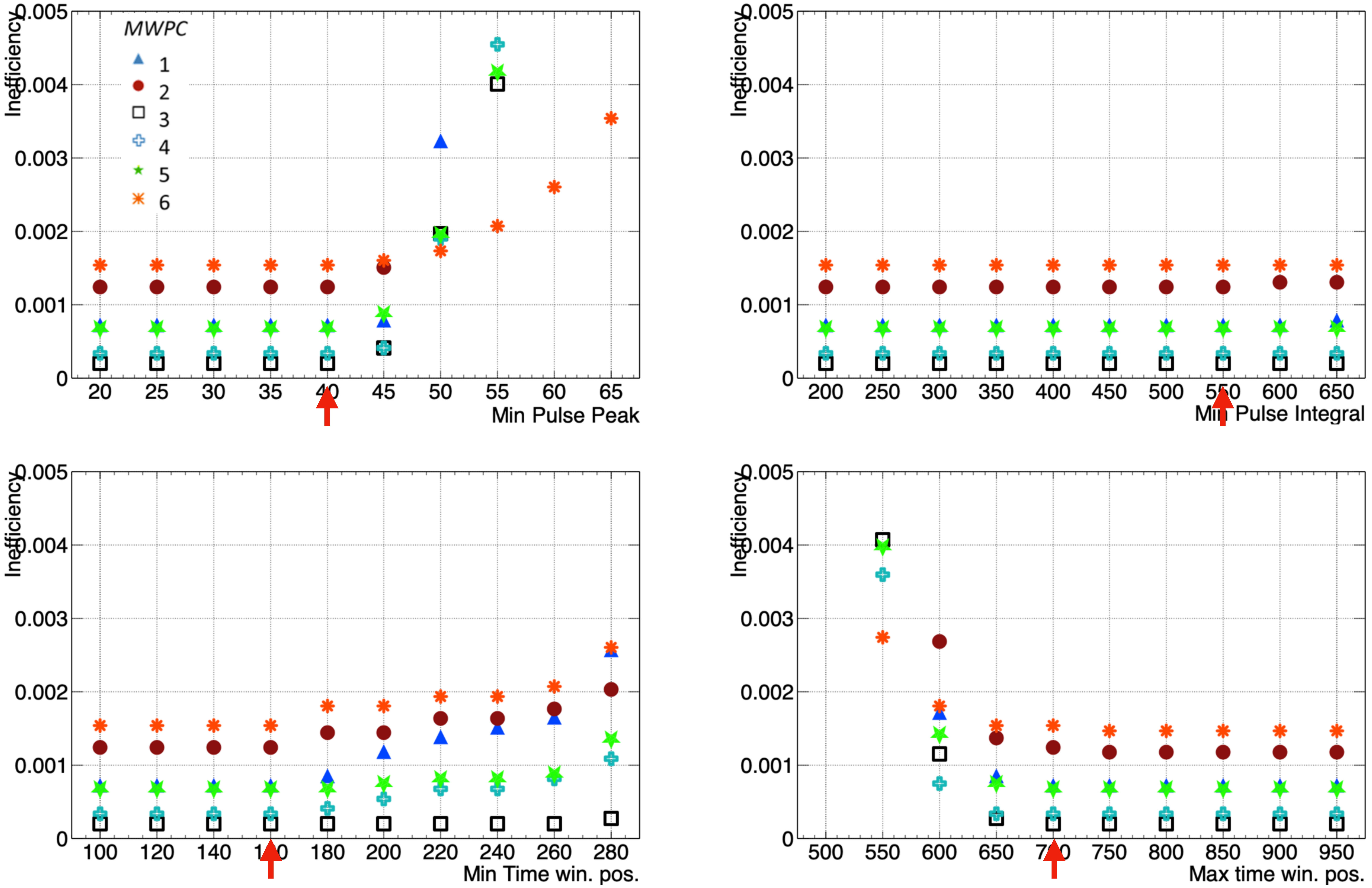
MWPC Track Matching Resolution



- Charged tracks from the FDCs are extrapolated to each MWPC layer.
- The track is matched to hits in 5 chambers (a hit and track position required to be within 2σ, σ from Ilya)
- Then the distance from the projected track to the closest chamber hit is plotted



Inefficiency Plots for MWPCs



- Testing FMWPC digi-hit cuts for each chamber
- Value for cut chosen at tightest cut with lowest inefficiency.
- All chambers with selected cuts (red arrows) shown with efficiency above 99.8%
- Chamber efficiency tests in the EEL showed chamber efficiency of 99.7%

Modifications to CPP/NPP REST files for neural nets

DCPPEpEm_factory (μ/π and e/π neural net inferences for CPP) has been modified to work on REST files

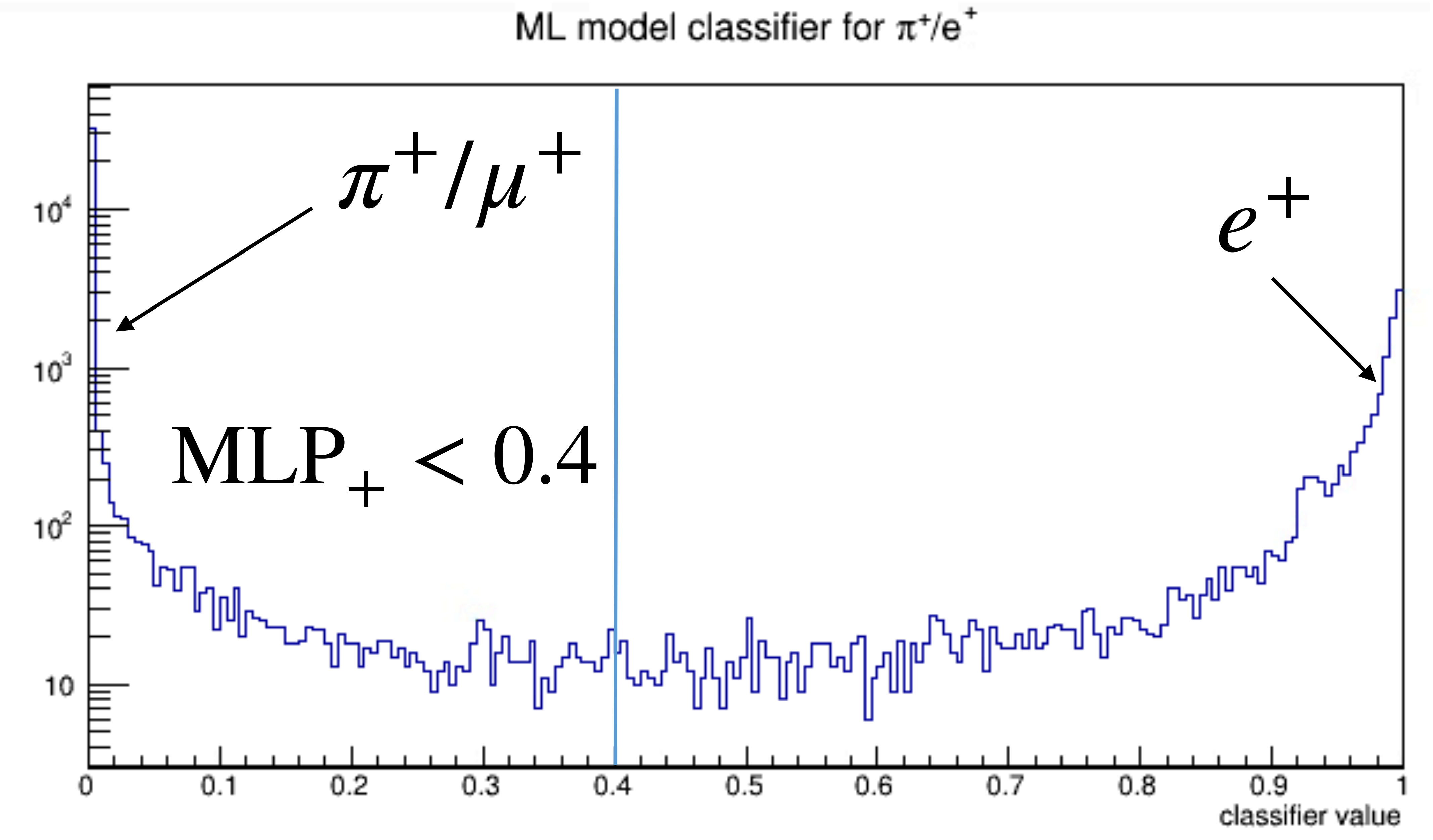
https://github.com/JeffersonLab/halld_recon/tree/AddFmwpcMatches

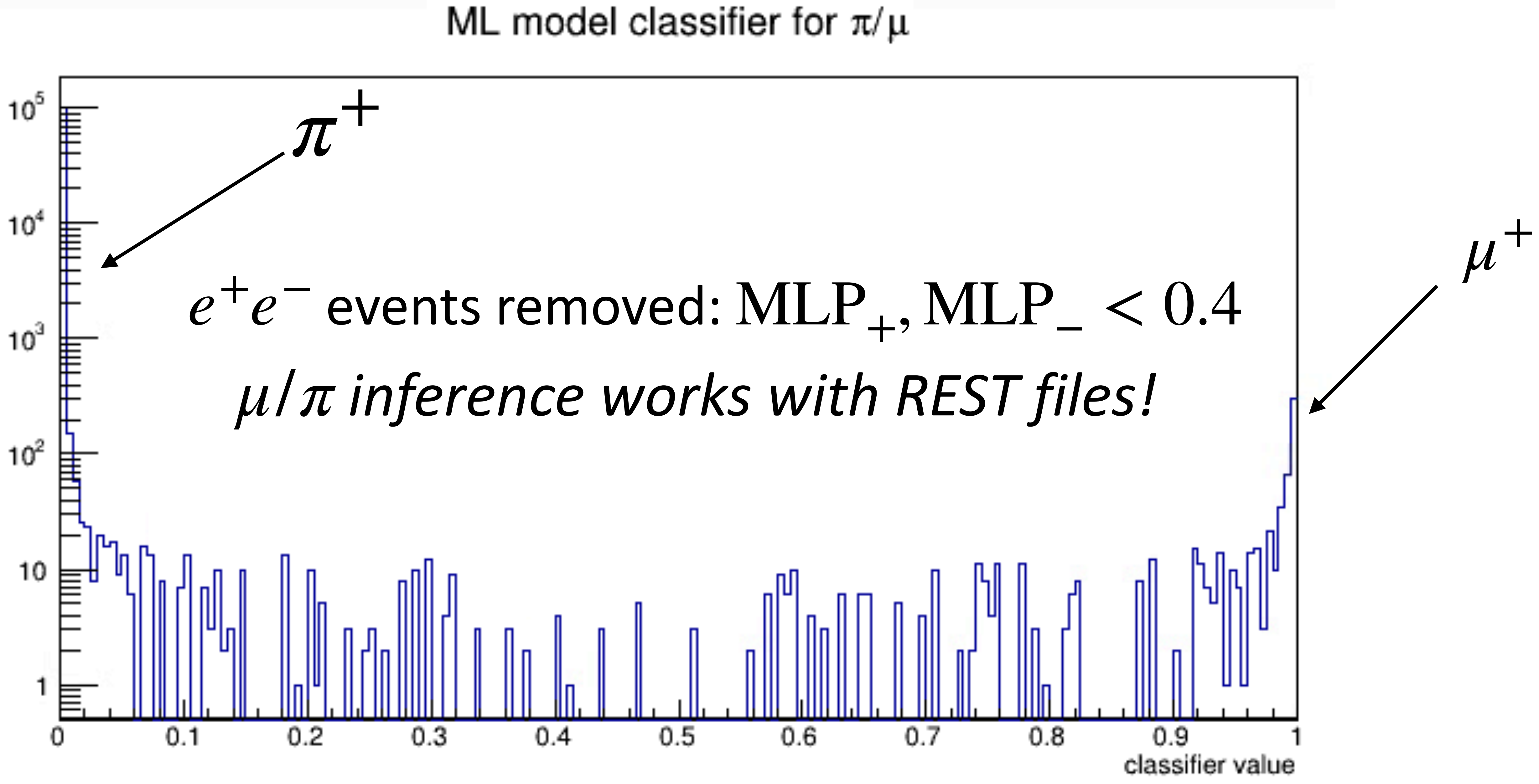
All FMWPC quantities needed for the CPP μ/π neural net have been added to the REST file structure for CPP/NPP run period by default.

Additional FCAL quantities *required* by μ/π neural net can be added optionally to REST: PPID:ADD_FCAL_DATA_FOR_CPP 1

MLP Response refers to the model giving a "score" to the particle whether it is closed to signal or background. We place a cut on the response for the seperation.

Test on 1 evio file converted to REST:





Summary and Plans

- High purity muon skims: /lustre19/expphy/cache/halld/home/alfab/muon_skims_ver3_apr5/ (through CTOF analysis)
- CTOF calibrations complete, BCAL position fixed energy calibrations in progress.
- FCAL calibrations updated, energy linearity function updated
- π/μ neural net refining and testing for real data
- The muon skims will be used to test neural net response for muons
- $\pi^+\pi^-$ with invariant mass near ρ^0 peak to test response for pions

Questions

Works Cited

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- Miskimen, R. et al “Measuring the Charged Pion Polarizability in the $\gamma\gamma \rightarrow \pi+\pi-$ Reaction." Jefferson Lab PAC40 Proposal.