BNL LDRD Detector-II Weekly Meeting

Update on Muon ID Study at ePIC

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What’s New

- Estimate FTOF performance on muons comparing to pions
  - $1/\beta$ vs momentum
  - Time Of Fight (TOF) for muon and pion
- Estimate background from DIS sample
  - ep 18 on 275 GeV with Q^2_{min} = 1
  - Event selection with 3 tracks (3 charged particles in a detector)
  - Exclude scattered electron using true PID
  - Calculate invariant mass of two leftover particles
  - Apply PID table/true PID to cut protons and kaons
  - Look at calorimeter response to see if MIP-like events
  - Use ML (Work In Progress)

Approach

- Estimate FTOF performance on muons comparing to pions
  - $1/\beta$ vs momentum
  - Time Of Fight (TOF) for muon and pion

FTOF Performance at ePIC

- Barrel Region
  - e/pi up to 0.5 GeV/c
  - pi/K up to 1.9 GeV/c
  - K/p up to 3.1 GeV/c
- Endcap Region
  - e/pi up to 0.8 GeV/c
  - pi/K up to 2.7 GeV/c
  - K/p up to 4.6 GeV/c

Oskar Hartbrich (Oak Ridge)

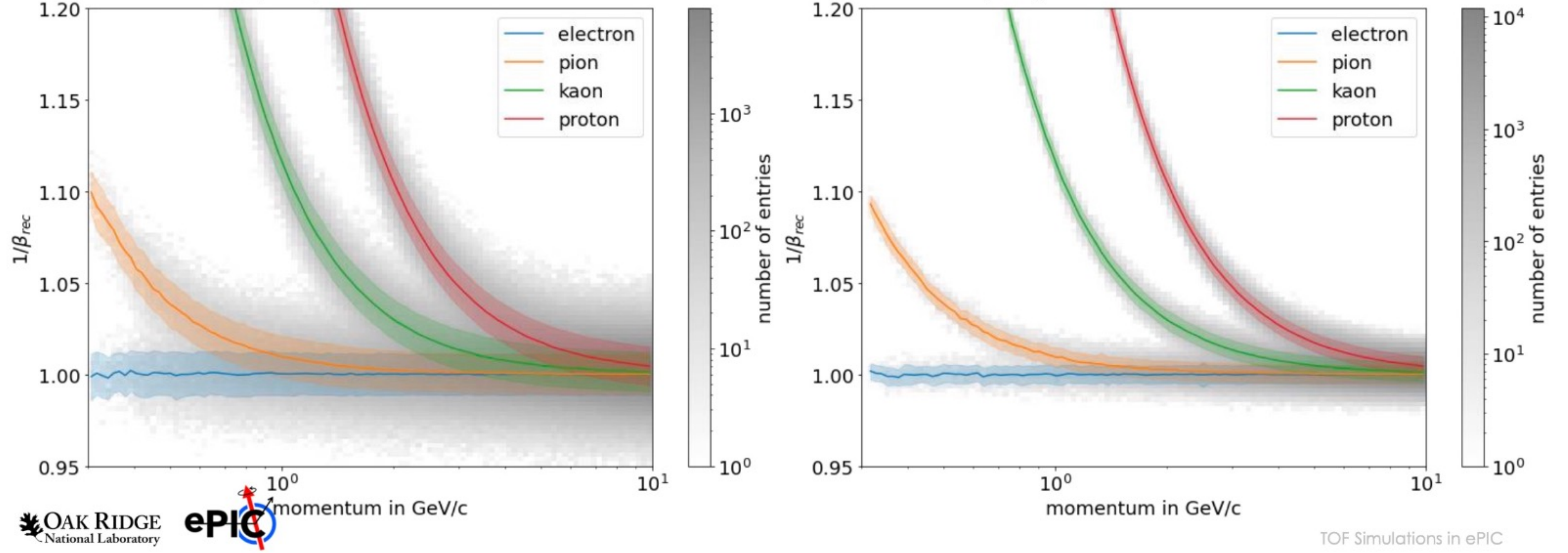
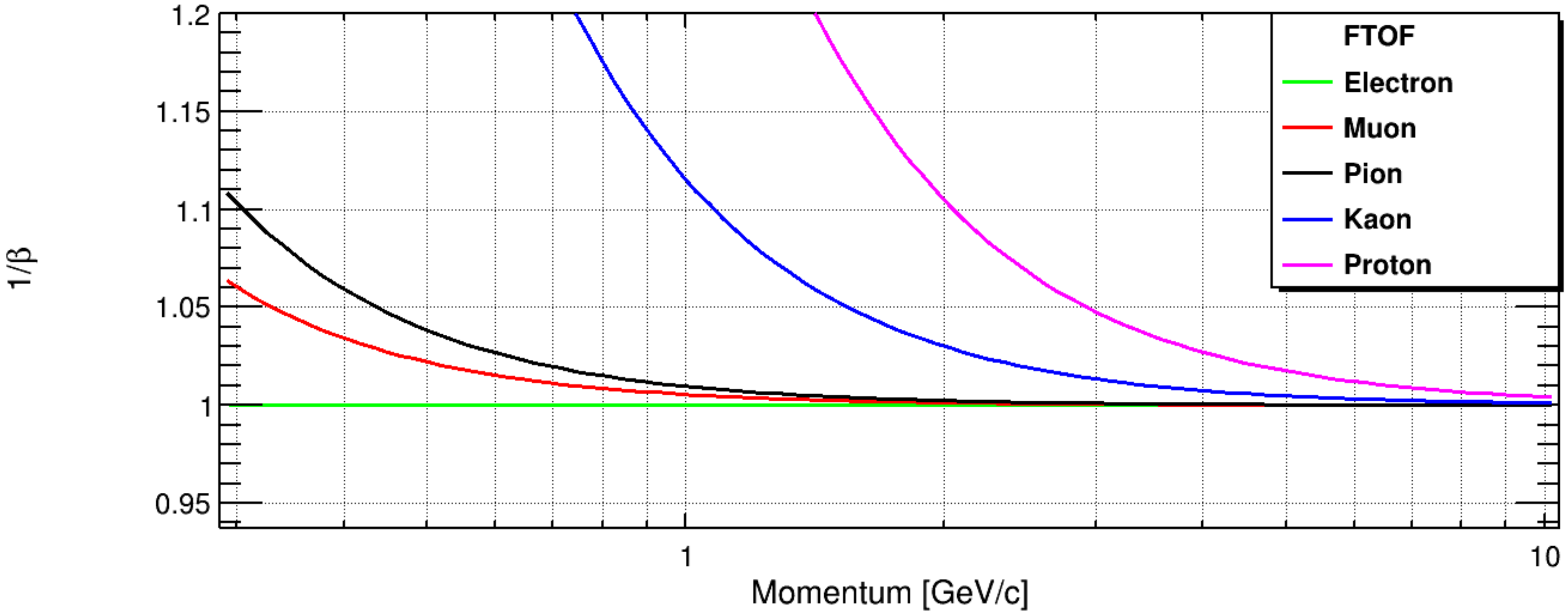


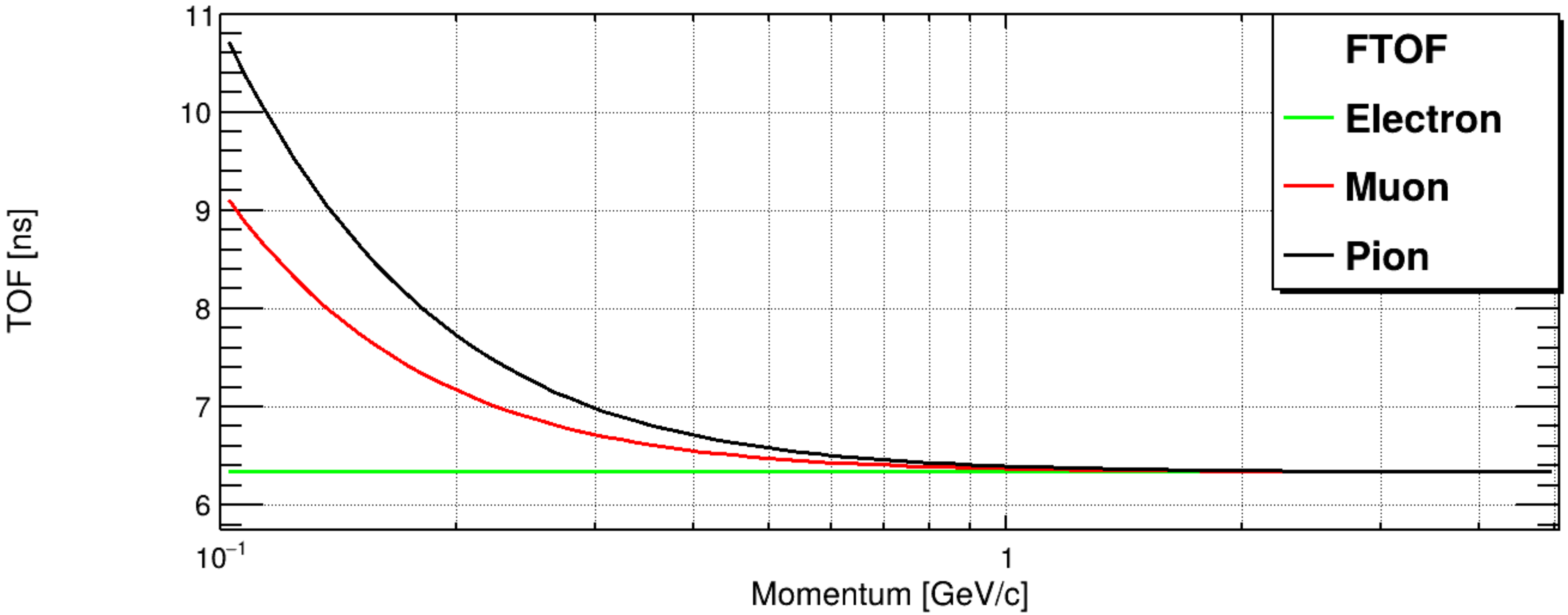
Figure 8.64: simulation of $1/\beta$ as a function of particle momentum for BTOF and FTOF performance.

Taken from EIC PDR v.1 (Figure 8.64 on page 123)

FTOF Performance – 1/β vs Momentum



FTOF Performance – Time of Flight

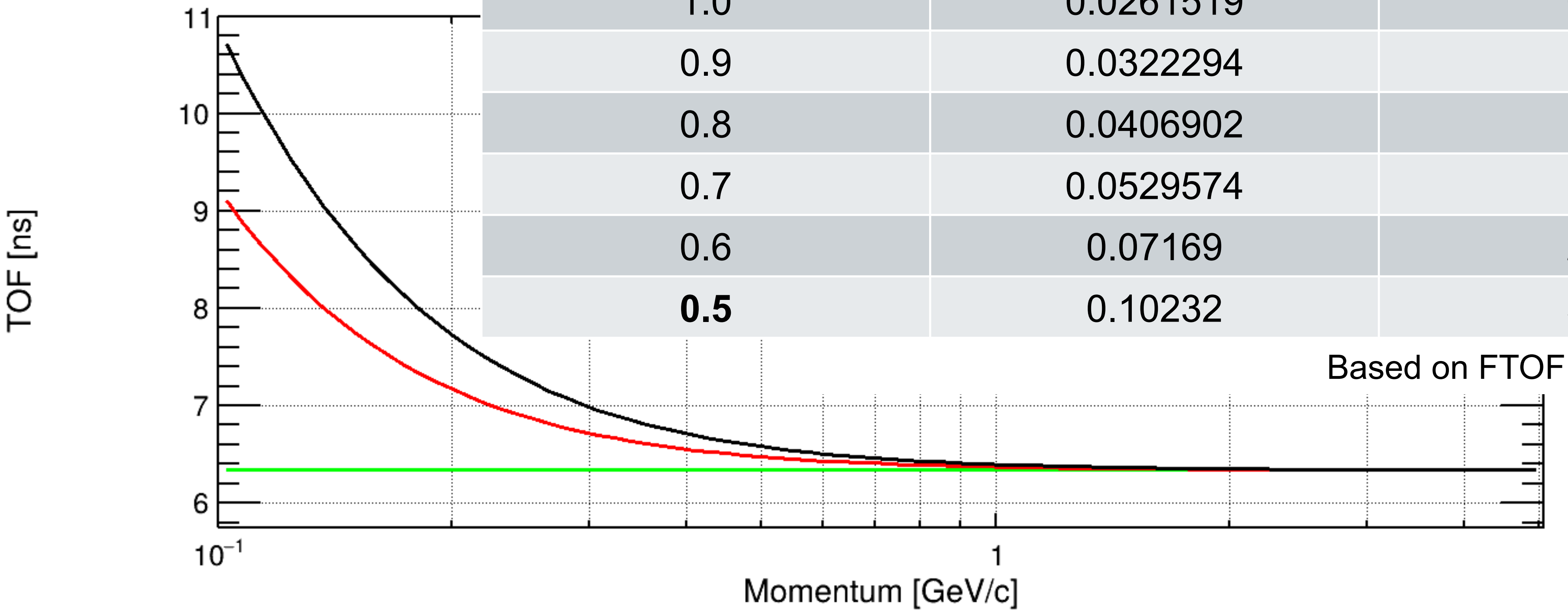


Assumed distance (straight from IP to FTOF plane; z_{min} = 185 cm and r_{max} = 60 cm)

FTOF Performance – Time of Flight

Momentum [GeV/c]	Difference in TOF [ns]	Estimated σ Level
1.0	0.0261519	0.87
0.9	0.0322294	1.07
0.8	0.0406902	1.36
0.7	0.0529574	1.77
0.6	0.07169	2.39
0.5	0.10232	**3.41**

Based on FTOF resolution 30 ps



Assumed distance (straight from IP to FTOF plane; z_{min} = 185 cm and r_{max} = 60 cm)

PID Summary for Muon ID

dRICH n = 1.026	Difference in Cherenkov Angle [mrad]	Estimated σ Level
p = 1.5 GeV	8.69475	17.4σ
p = 2.0 GeV	4.73642	9.5σ
p = 2.5 GeV	2.98872	6σ
p = 3.0 GeV	2.05997	4.1σ
p = 3.5 GeV	1.50669	**3σ**
FTOF d = IP to FTOF plane	**Difference in TOF [ns]**	**Estimated σ Level**
p = 1.0 GeV/c	0.0261519	0.87σ
p = 0.8 GeV/c	0.0406902	1.36σ
p = 0.7 GeV/c	0.0529574	1.77σ
p = 0.6 GeV/c	0.07169	2.39σ
p = 0.5 GeV/c	0.10232	**3.41σ**

Upper limit (3σ separation)

- dRICH
  - μ/π up to 3.5 GeV/c
- FTOF
  - μ/π up to 0.5 GeV/c

<u>dRICH could be helpful for low momentum (below 3.5 GeV/c)</u>

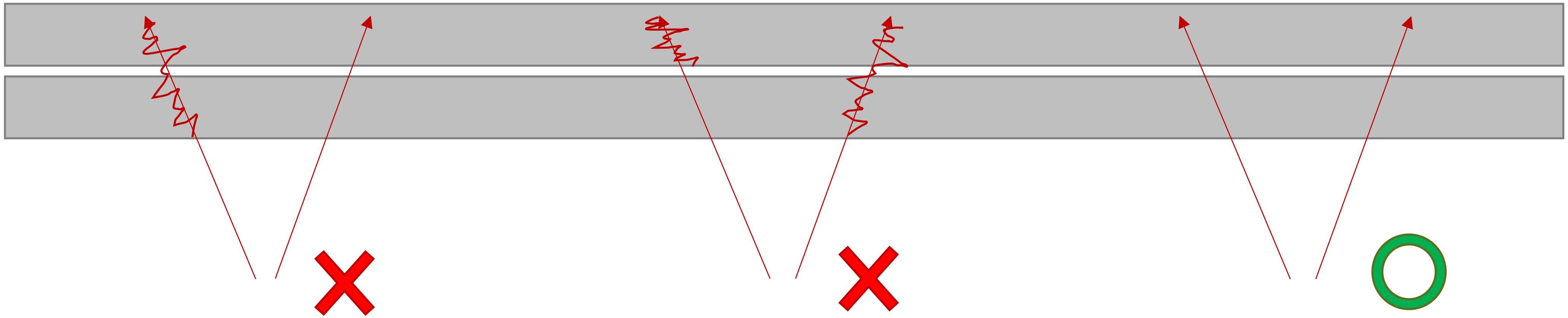
Need to think about

- Good enough momentum resolution at very low momentum
- How many low momentum muons/pions can travel beyond PID and reach up to forward calorimeter

Approach

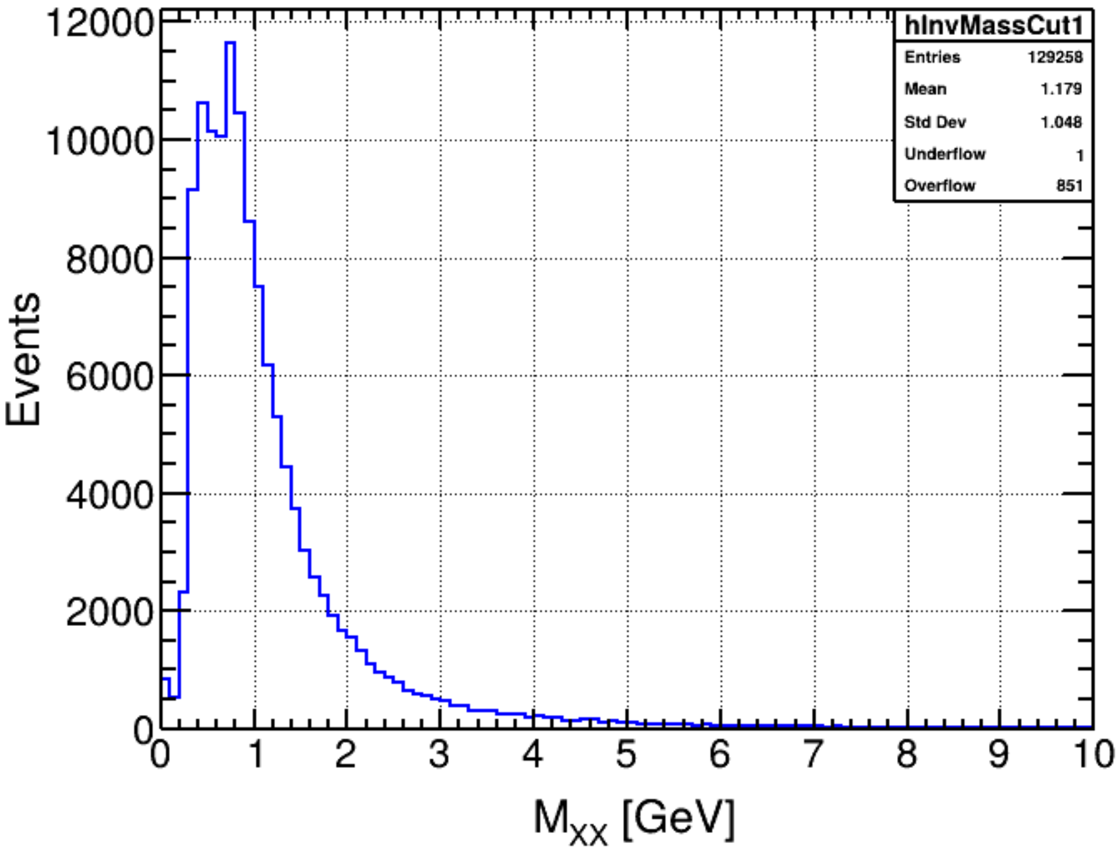
- Estimate background from DIS sample
  - ep 18 on 275 GeV with $Q^2_{min} = 1$
  - Event selection with recon 3 tracks (3 charged particles in a detector)
  - Exclude scattered electron using true PID
  - Calculate invariant mass of two leftover particles
  - Apply PID table/true PID to cut protons and kaons
  - Look at calorimeter response to see if MIP-like events

Not scaled



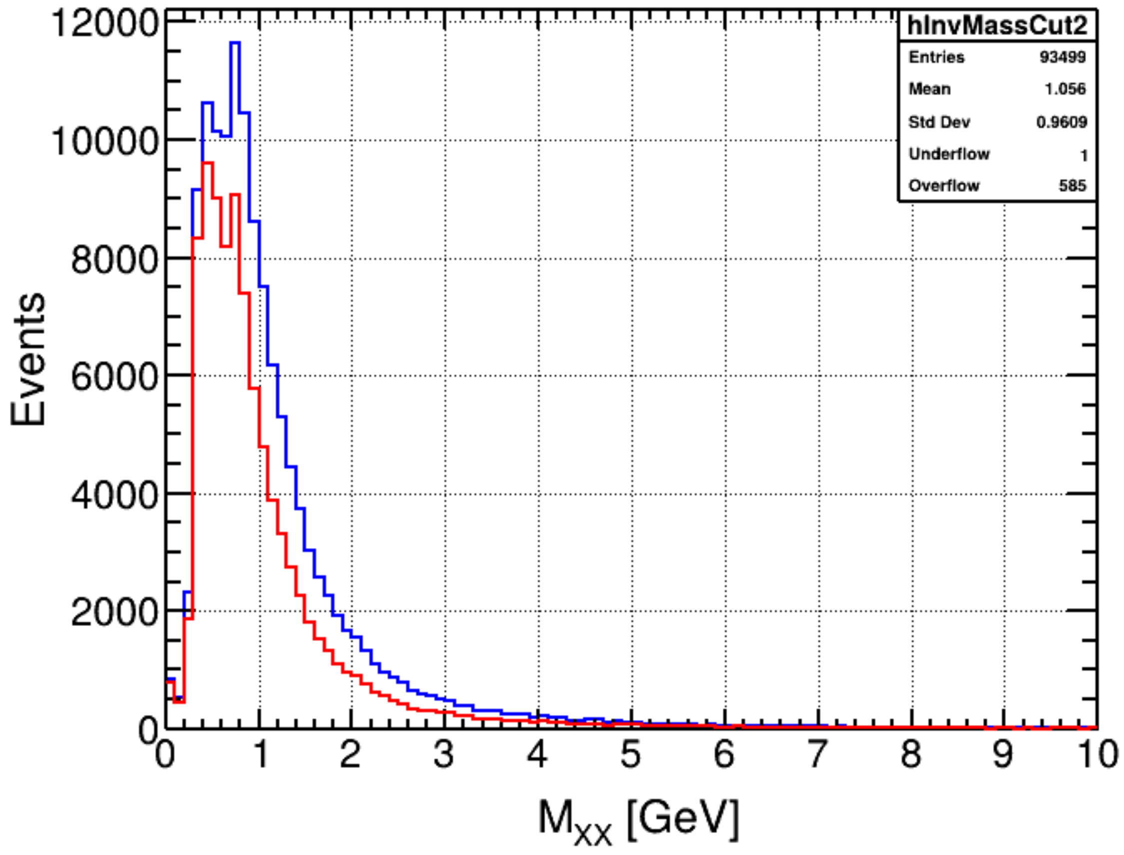
DIS Event Background

- Only 3 recon tracks within an event
- Exclude scattered e by true ID
- Calculate M_{XX} using remaining 2 tracks



DIS Event Background

- Only 3 recon tracks within an event
- Exclude scattered e by true ID
- Calculate M_{XX} using remaining 2 tracks
- Exclude p and $K^{\pm}$ by true ID
  - Next step will be using PID look-up table



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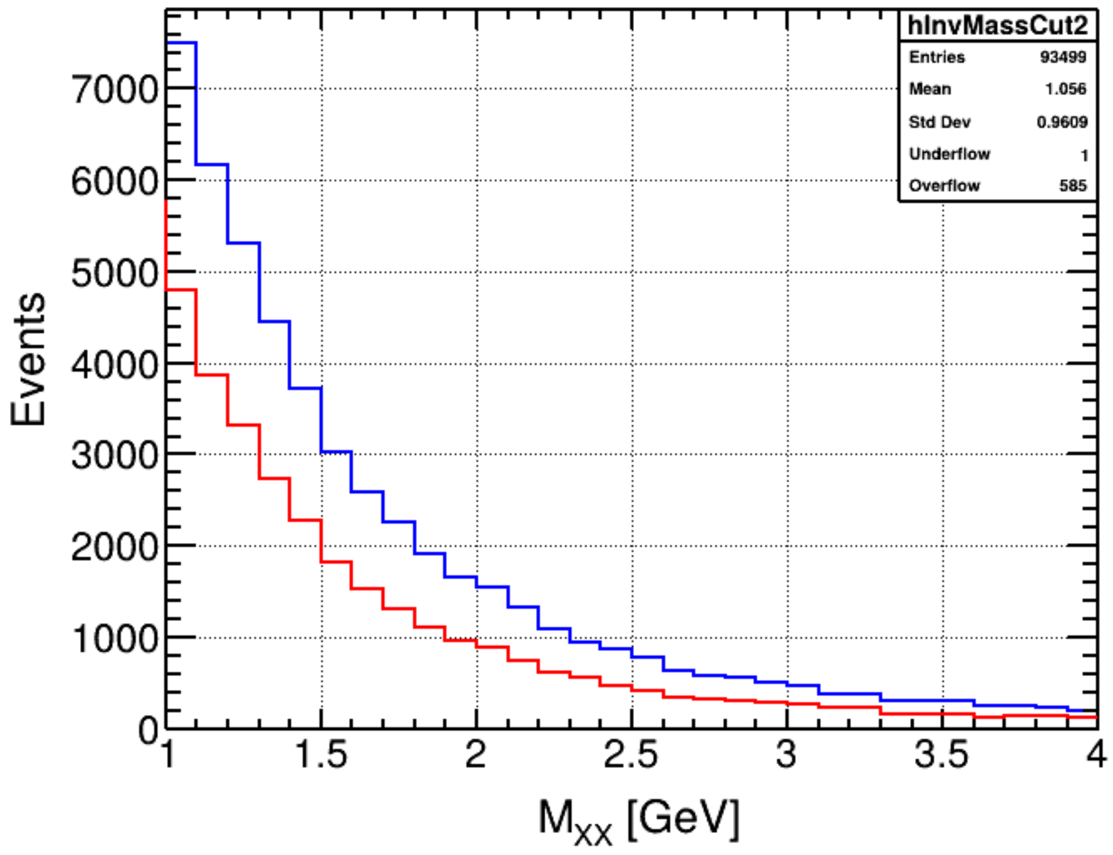
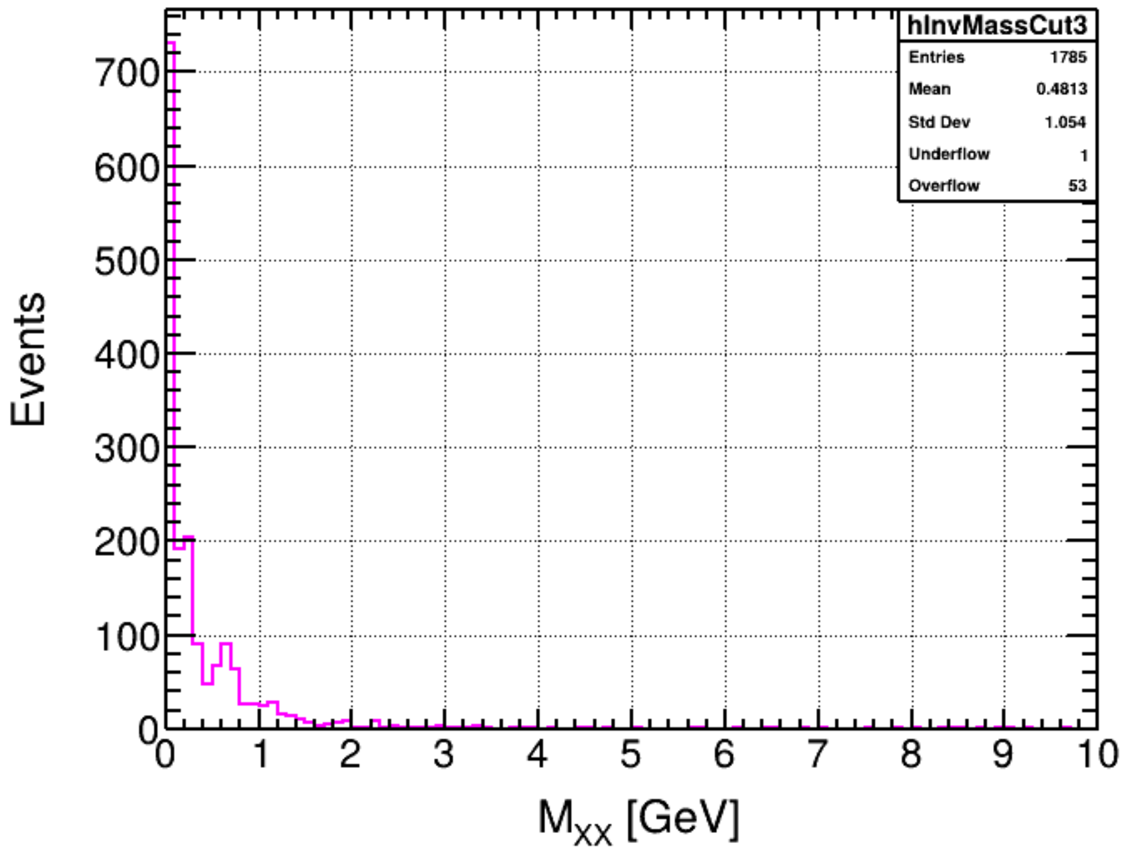


DIS Event with All Cuts

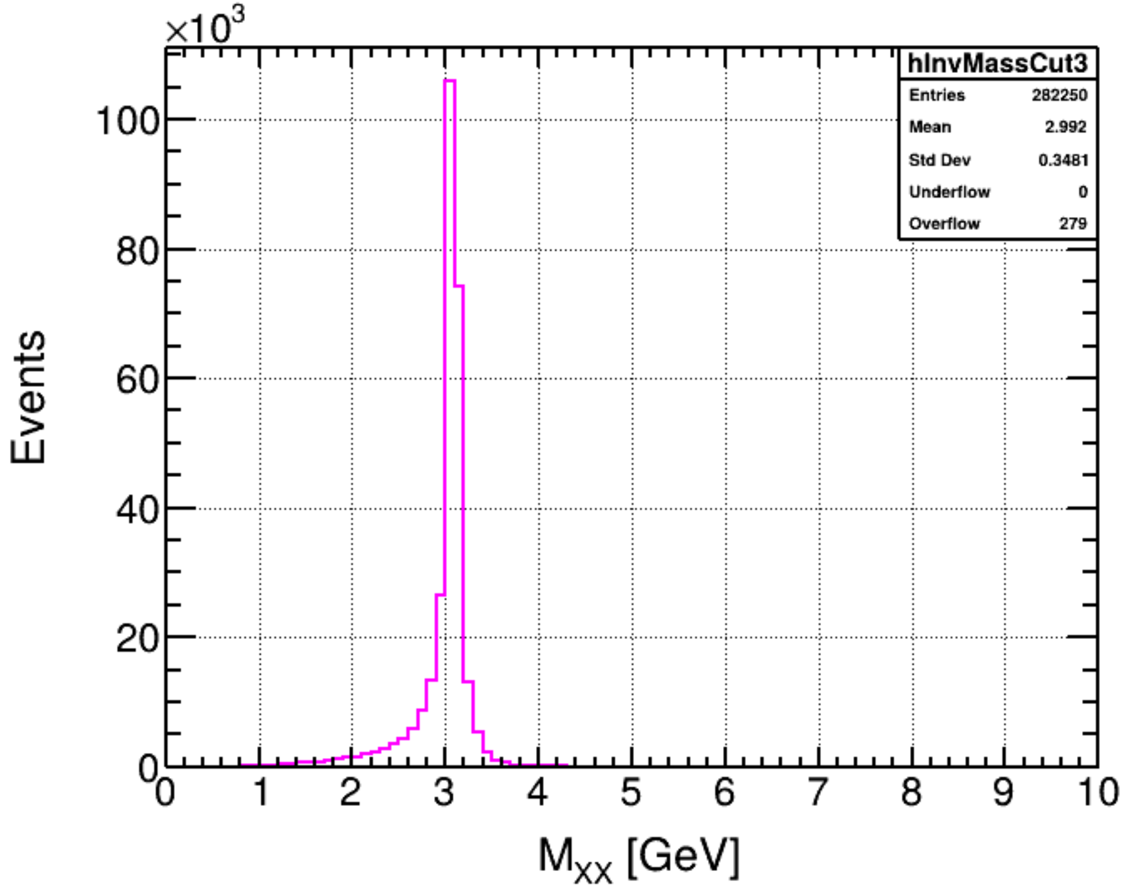
- Only 3 recon tracks within an event
- Exclude scattered e by true ID
- Exclude p, $K^{\pm}$, and $\pi^{\pm}$ by true ID
- Calculate M_{XX} using remaining 2 tracks
  - Mostly electron/positron pairs, muons, etc

Unfortunately, there are no J/ψ in this sample.



DIS Event Real Signal with J/ψ

- Only 3 recon tracks within an event
- Exclude scattered e by true ID
- Exclude p, $K^{\pm}$, and $\pi^{\pm}$ by true ID
- Calculate M_{XX} using remaining 2 tracks



DIS Event Background

- Only 3 recon tracks within an event
- Exclude scattered e by true ID
- Calculate M_{XX} using remaining 2 tracks
- Exclude p and $K^{\pm}$ by true ID
- Check calorimeter response

Looking at calorimeter clusters,
- Each reconstructed hit have no true PID, but each calorimeter cluster have true PID
- Each Cluster have # of hits, energy, and position in (x,y,z)

Not trivial, A bit complicated than what I expected:
- Multiple calorimeter clusters assigned to same true particle
- Calorimeter cluster selection: Match tracker info and calorimeter cluster by (η, ϕ)

In ML, I used sum of reconstructed hits in # of hits and energy for Ecal and Hcal layer, not cluster level.

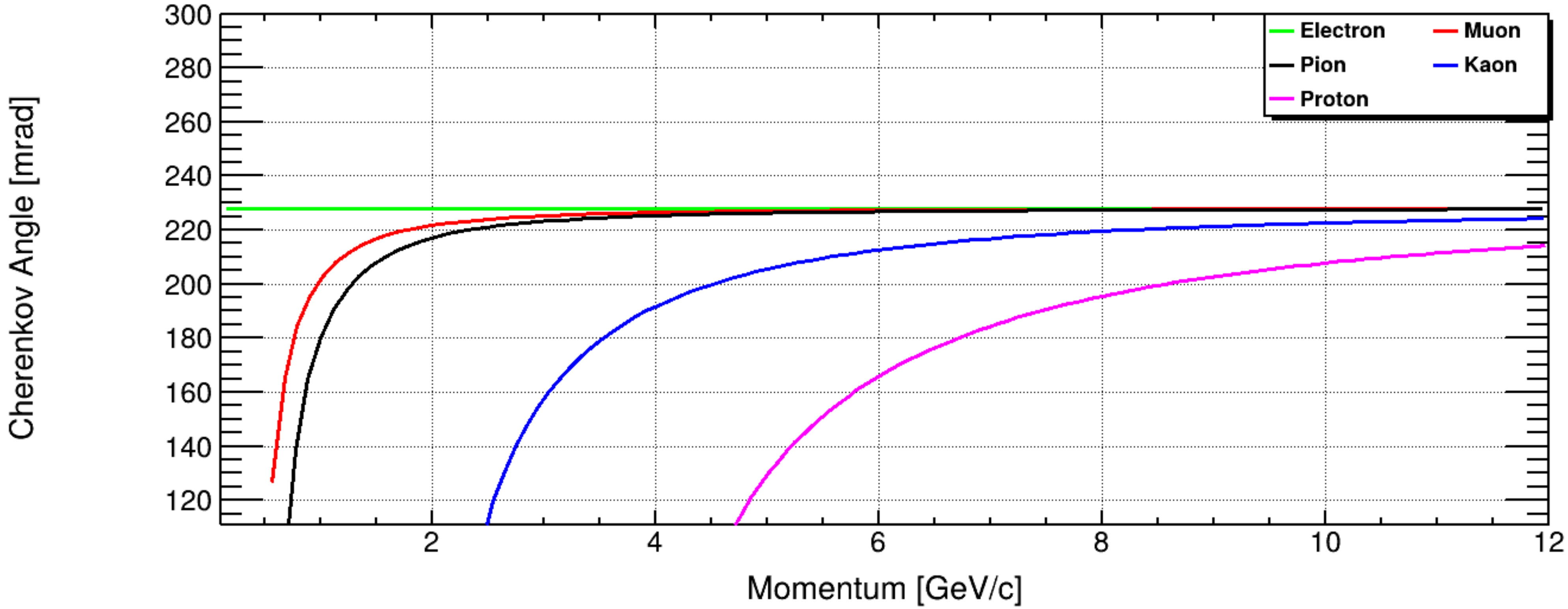
To-Do List

- ❑ Use ML on ep DIS events for muon ID
  - ❑ Divide into three rapidity regions (backward/central/forward)
    - ❑ (Signal) Muon with $f(\theta, p)$
    - ❑ (Background) Pion with $f(\theta, p)$
    - ❑ Calorimeter level? Reconstructed hit level?
    - ❑ Track and Calorimeter cluster matching
- ❑ Include PID information?

Backup Slides

Estimate PID Performance

Based on $\theta^2 \sim 2(n-1) - \frac{m^2}{p^2}$ where n = 1.026 (dRICH)



According to Chandra Chatterjee, n = 1.026 (baseline 1.019)
Aerogel single photon resolution at n = 1.026 is ~ 2.4 mrad
Ring (track-level) resolution ~ 0.5 mrad
Given we can detect 15 photons

Estimate PID Performance

▼ Muon and pion separation in Cherenkov Angle

	n = 1.015	n = 1.026	n = 1.040
p = 1.5 GeV	12.1446 [mrad]	8.69475 [mrad]	6.83120 [mrad]
p = 2.0 GeV	6.42687 [mrad]	4.73642 [mrad]	3.76644 [mrad]
p = 2.5 GeV	4.00843 [mrad]	2.98872 [mrad]	2.38896 [mrad]
p = 3.0 GeV	2.74643 [mrad]	2.05997 [mrad]	1.65104 [mrad]
p = 3.5 GeV	2.00184 [mrad]	1.50669 [mrad]	1.20952 [mrad]

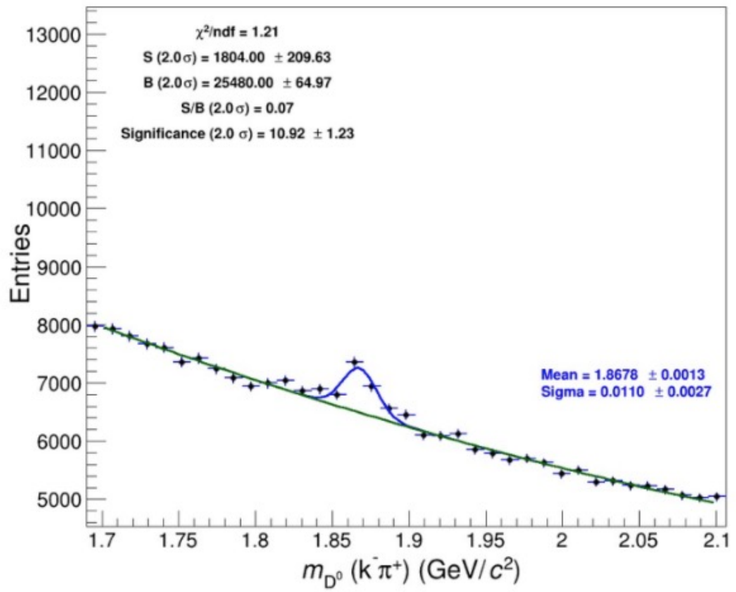
- In ePIC baseline aerogel refraction index ~ 1.019
- However, n = 1.026 performs better because of optical quality of material improvement (CLAS12 n = 1.019)
- Aerogel single photon resolution for 1.026 ~ 2.4 mrad (where for 1.019 ~ 3 mrad)
- With aerogel 1.026 we gain ~ 50 % more photons compared to 1.019
- Regarding ring (track-level) resolution, it depends on thickness optimization of aerogel (4 cm and 6 cm were studied). Resolution 0.5 mrad and given we can detect 15 photons

From Jets/HF Early Science Plans by Rongrong Ma at Jan 2025 ePIC collaboration meeting, Shyam Kumar (INFN, Bari) and Connie Yang (UT Austin) developing ML to optimize topological cuts for D^0 reconstruction

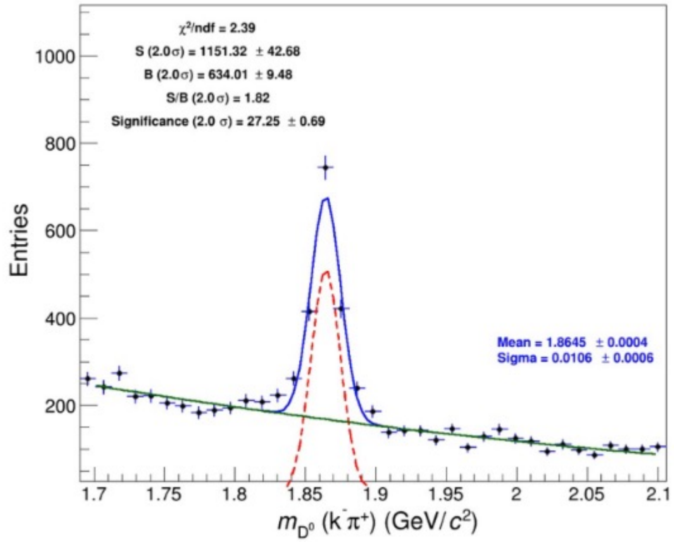
Recent progress: Machine learning

By Shyam Kumar (INFN)

No BDT cut



BDT > 0.8



- For 5 fb^{-1} which corresponds to 6.5M ep collisions at 10x100 with $Q^2 > 100$ GeV^2, we expect significance ~ 30 in total with current study

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