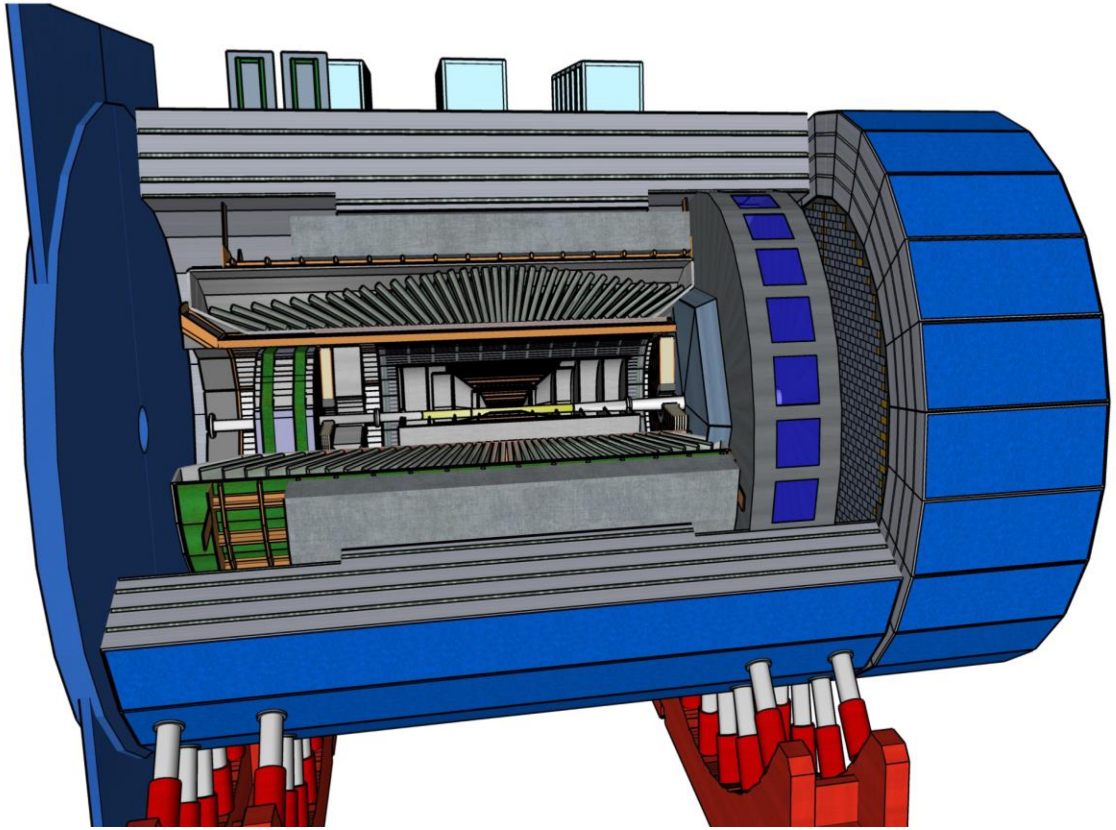
ECCE

EIC Comprehensive Chromodynamics Experiment



Muon detection and quarkonium reconstruction at the EIC with ECCE

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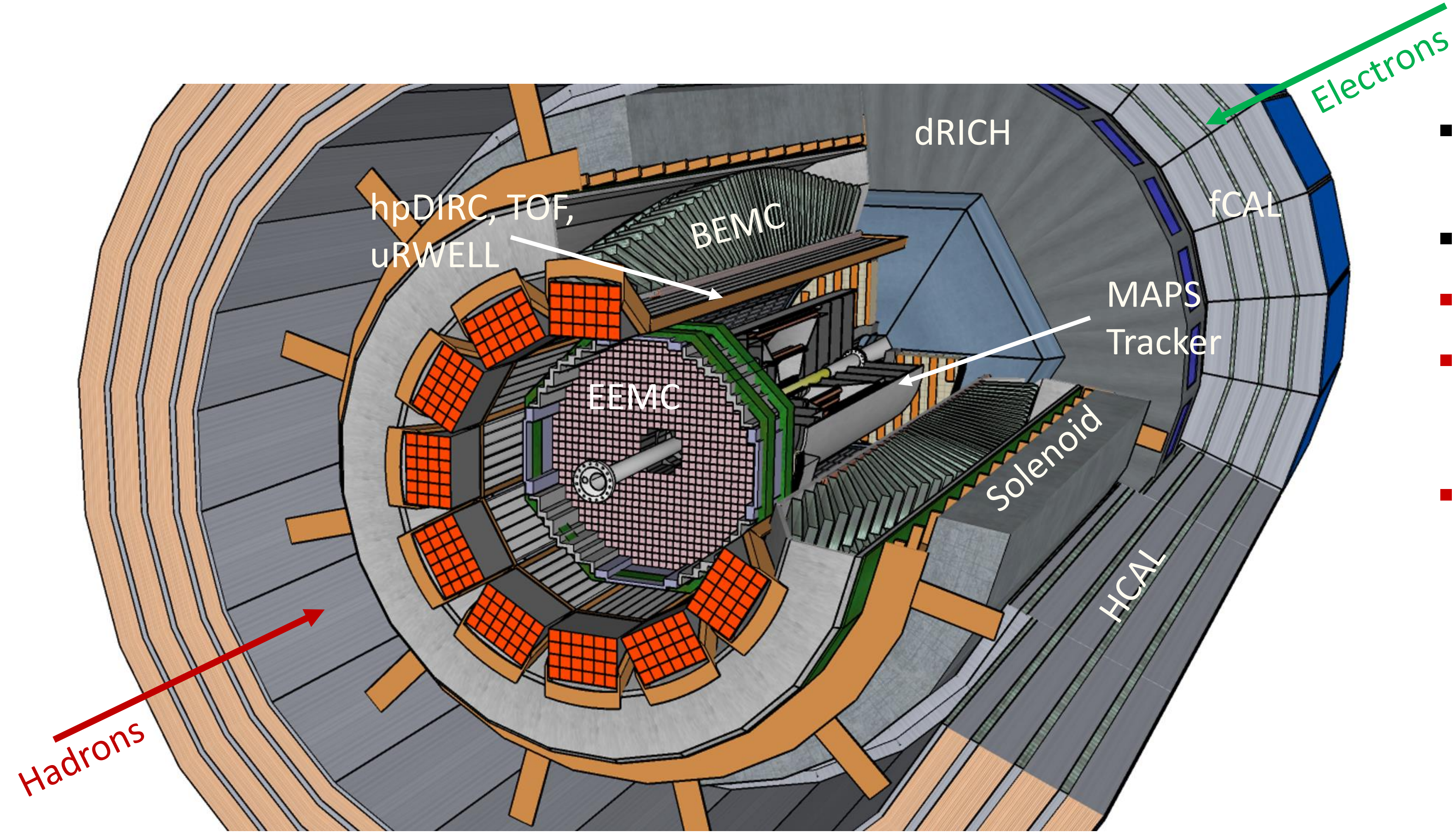
The ECCE detector



- Reuse of the 1.4 T BaBar solenoid and sPHENIX barrel HCAL
- Limited number of technologies
- Tracking: hybrid Si tracker
- PID: hpDIRC + dRICH + mRICH + TOF (AC-LGADs)
- Calorimetry: homogeneous ECAL (back+barrel) + scintillating Pb (ECAL) + steel/W (HCAL) in forward endcap.

No HCAL in back-endcap

Far-forward and far-backward detectors very similar and all 3 EIC detector proposals

ECCE studies involving quarkonium

- XYZ spectroscopy
- Hard exclusive J/Ψ production
- Diffractive J/Ψ production in eA
- (J/Ψ production at threshold)

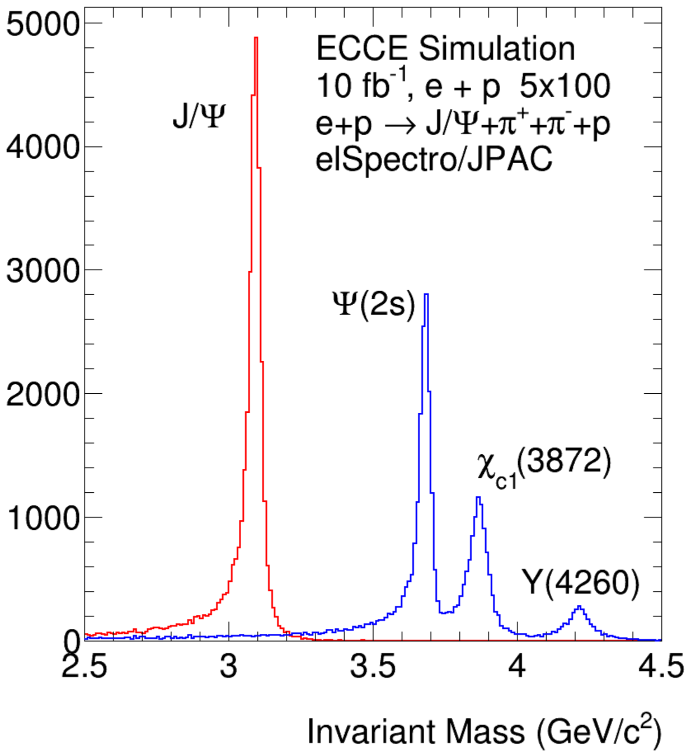
XYZ spectroscopy

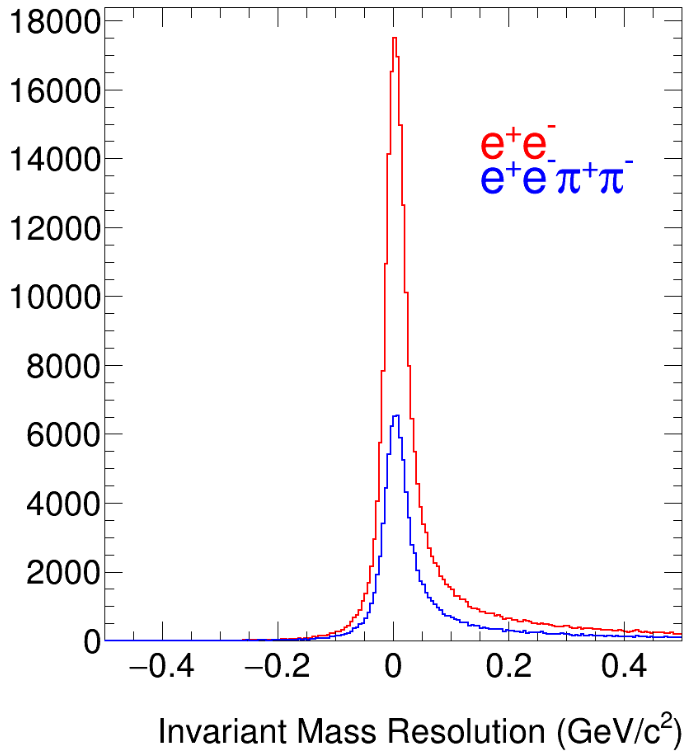
- Photoproduction of "XYZ" meson states probes underlying dynamics and allow determining their quantum number
- Detection of *low energy pions* is crucial while providing *good invariant mass resolution* :

  1.4T field is optimal for spectroscopy

Reconstructed invariant mass for 3 simulated states:
$\chi_{c1}(3872)$, $\Upsilon(4260)$ and $\Psi(2s)$

30 MeV resolution achieved with ECCE

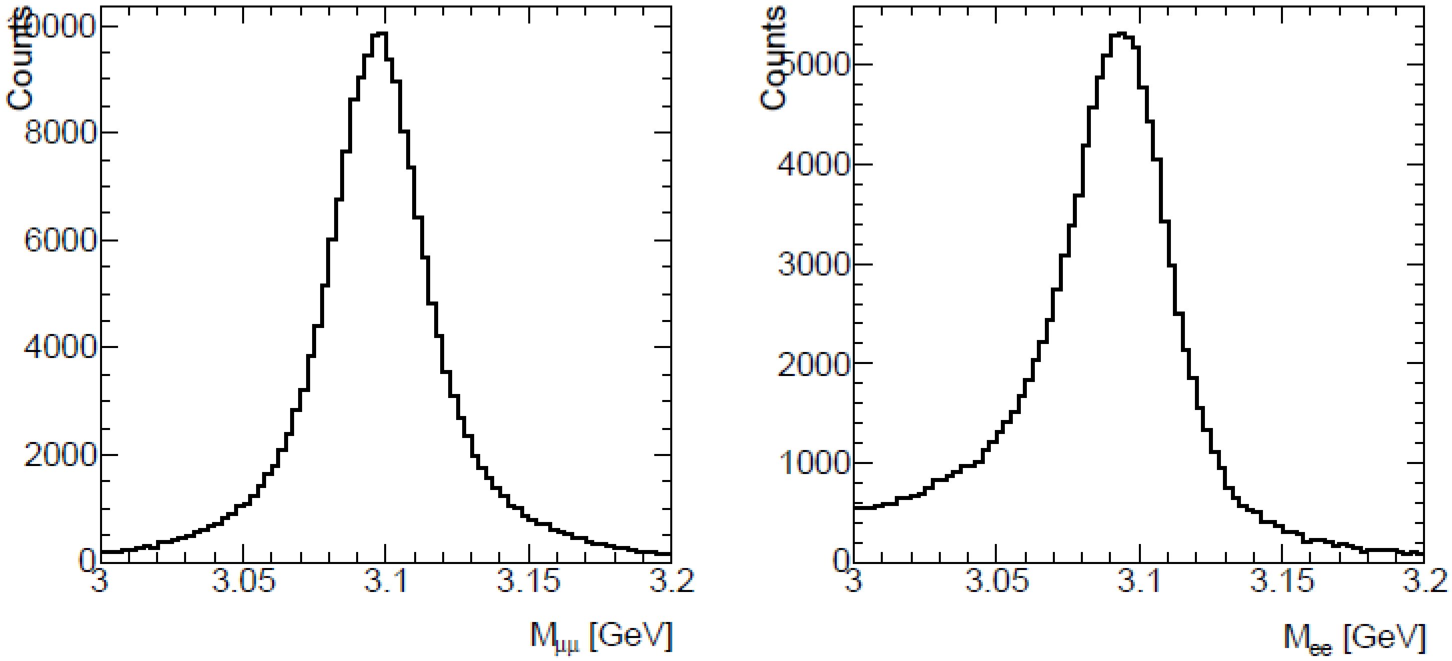




Low-Q^2 tagger (far-backwards region) is crucial for this measurement

Diffractive J/Ψ in eA

Reconstructed J/Ψ mass with muons and electrons

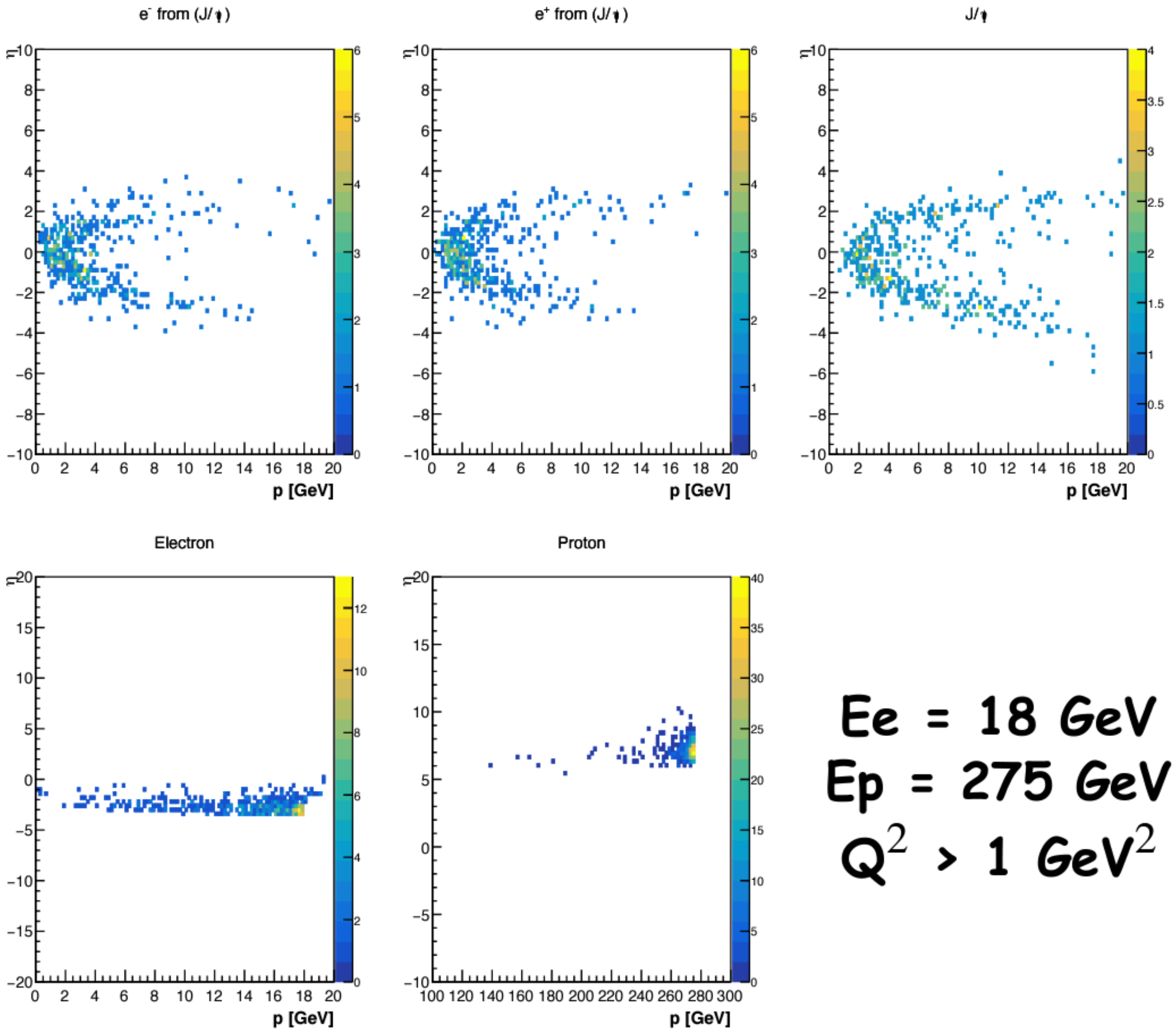


Similar resolution (<30 MeV) achieved, with a low radiative tail in the case of electrons

Hard exclusive J/Ψ production

Kinematics:

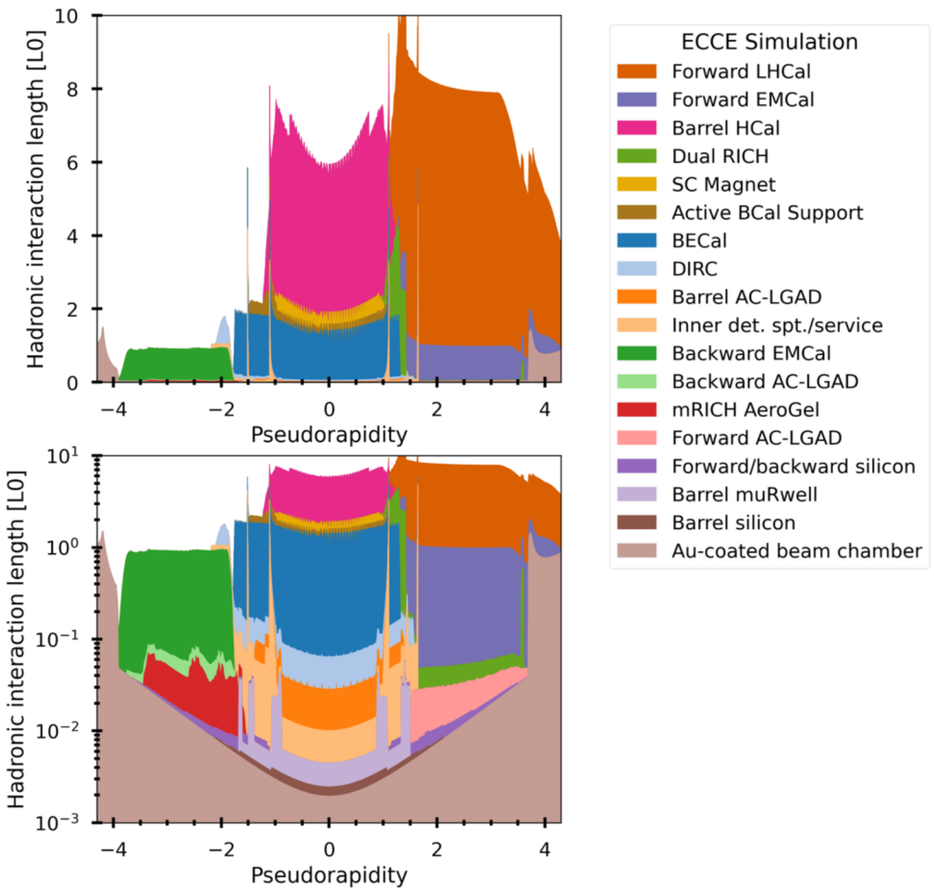
Also good separation of DIS electron and J/Ψ electron



Ee = 18 GeV
Ep = 275 GeV
$Q^2 > 1\ GeV^2$

ECCE approaches to muon-ID

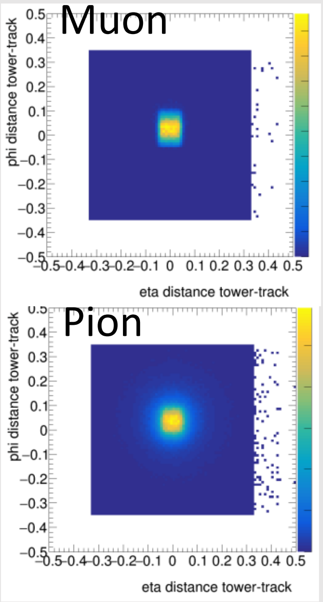
- ECCE has complete EMCal + HCal coverages in the central and forward calorimeter stacks
  - Total hadron interaction length:
    6-7 λ_0 for central and 7-8 λ_0 for forward
    Pion punch through probability: 10^{-2} to 10^{-3} level
  - Pion rejection quantified with full detector simulation, reconstruction, and AI-based classifier in following slides
- In the backward direction, the current YR physics program does not justify a hadronic calorimeter
  - ECCE has 8-16 inch field return steel which can be used as pion absorber followed by a muon chamber as upgrade. Total thickness 3-5 λ_0 , pion punch through prob.: 10^{-1} to 10^{-2}
  - Example is a muon detector behind field return door, similar to approach of STAR Muon Telescope Detector and strong experience in ECCE.

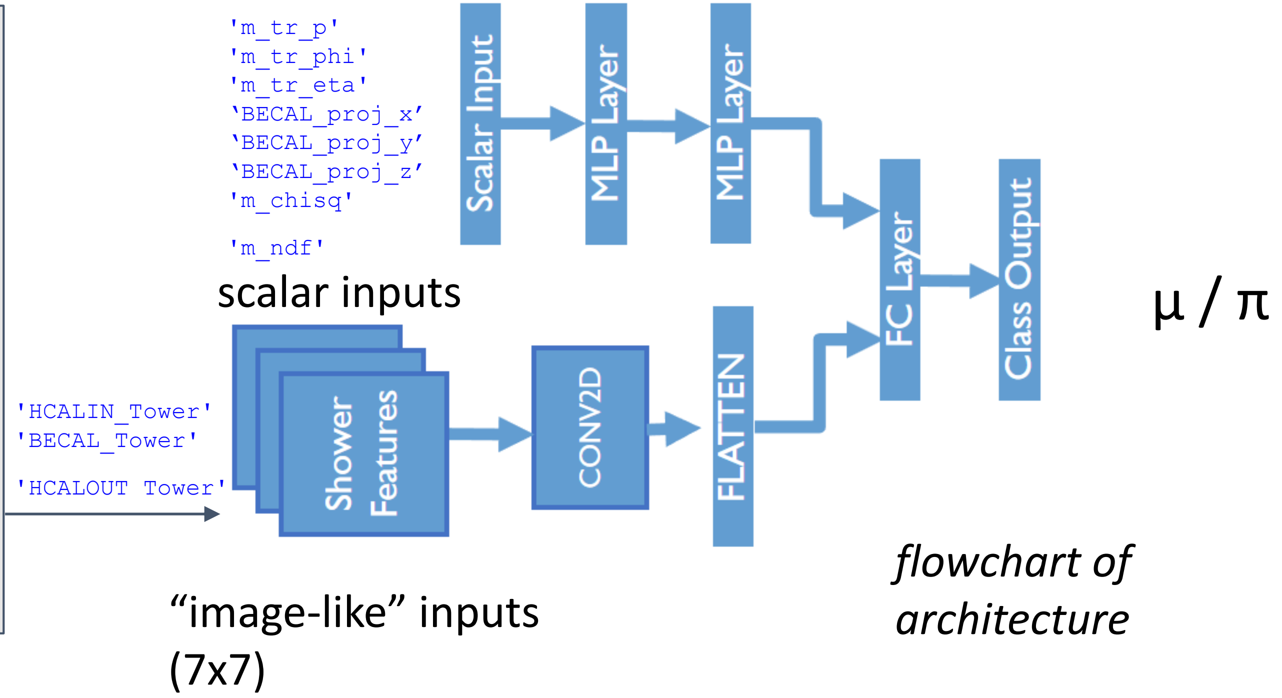


ECCE simulation and AI algorithm design

- Based on full detector simulation and reconstruction.
- AI-based muon-pion classifier based on reconstructed track parameters and tower-by-tower energy deposition images near the track projection at each layer
- Developed a custom architecture that combines convolutional neural network and a deep neural network to analyse simultaneously image-like inputs and scalar features, respectively.

Positively charged Muon and Pion showers imaged on Central HCal towers, stacked over 200k showers with track projection in the center. Shower size and fluctuation are used in the AI discriminator via “image-like” input nodes

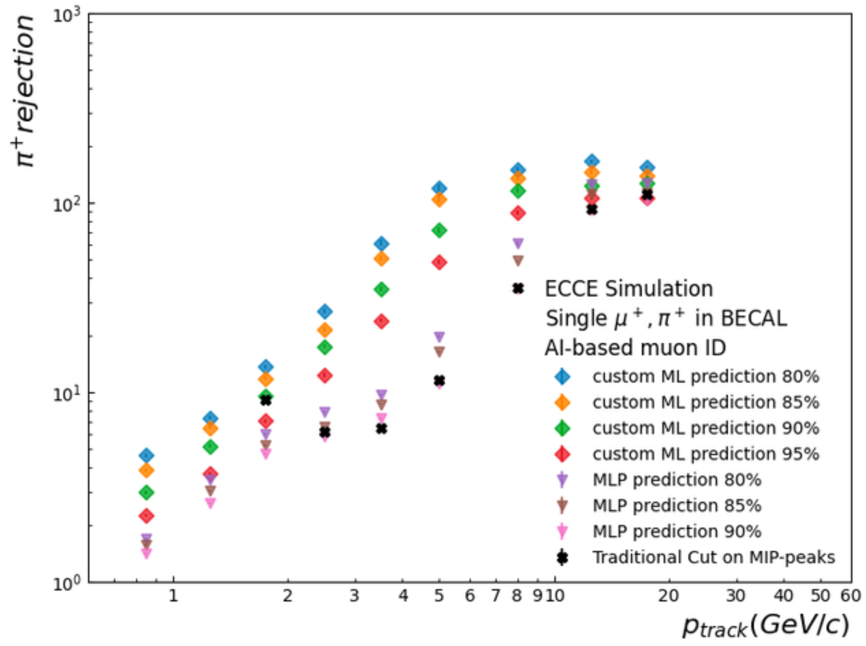


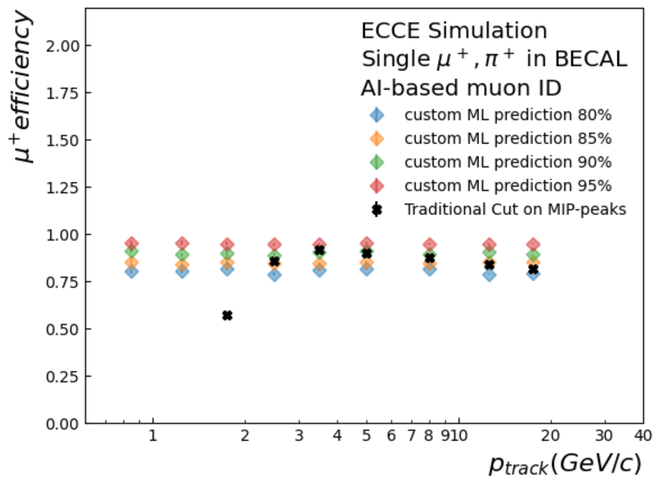


flowchart of architecture

Details on ML muon-pion classifier

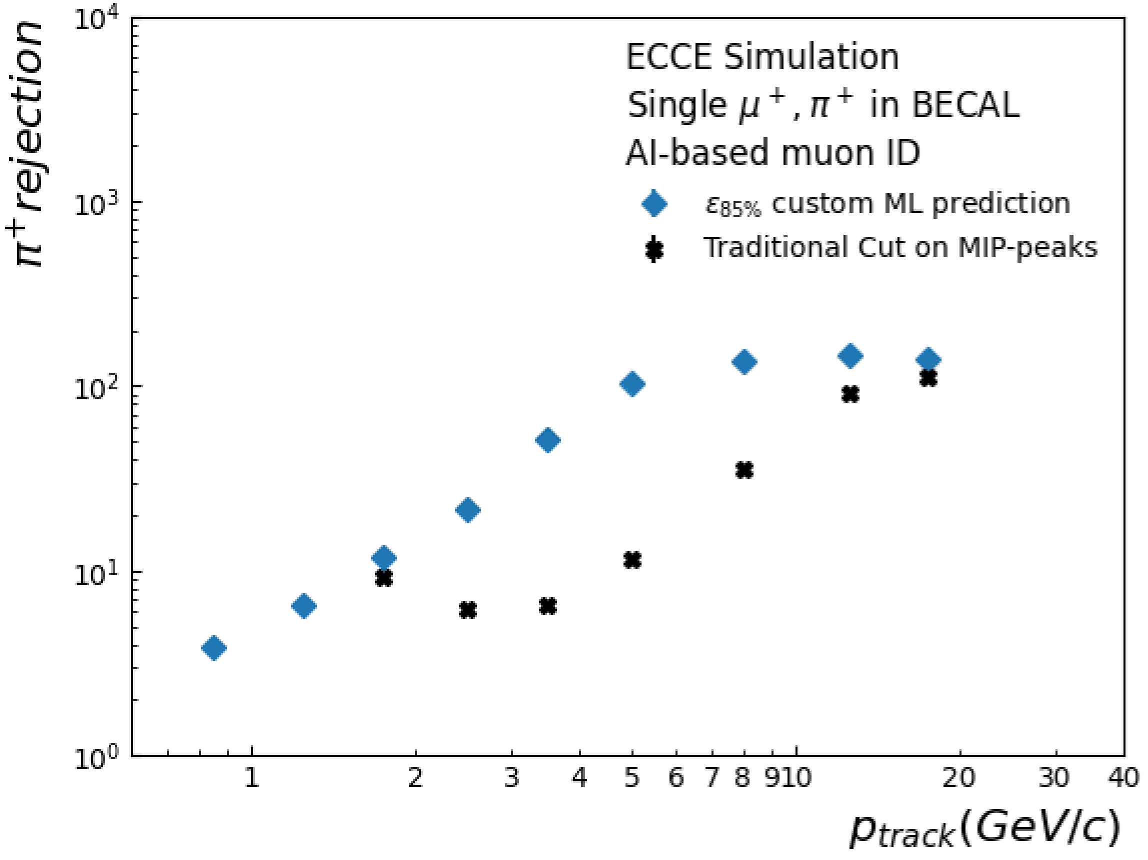
- The ECCE AI WG developed a custom architecture that combines convolutional neural network and a deep neural network to analyse simultaneously image-like inputs and scalar features, respectively.
- Different classifiers been explored and benchmarked against the custom architecture we developed.
- Room for further optimization of the hyper-parameters of the custom architecture.
- As shown in the plot simpler models such as Multi-Layer-Perceptron (MLP) performs better than traditional selection, but are outperformed by our custom architecture.
- This is currently being further validated by additional studies with ensemble methods such as XGBoost

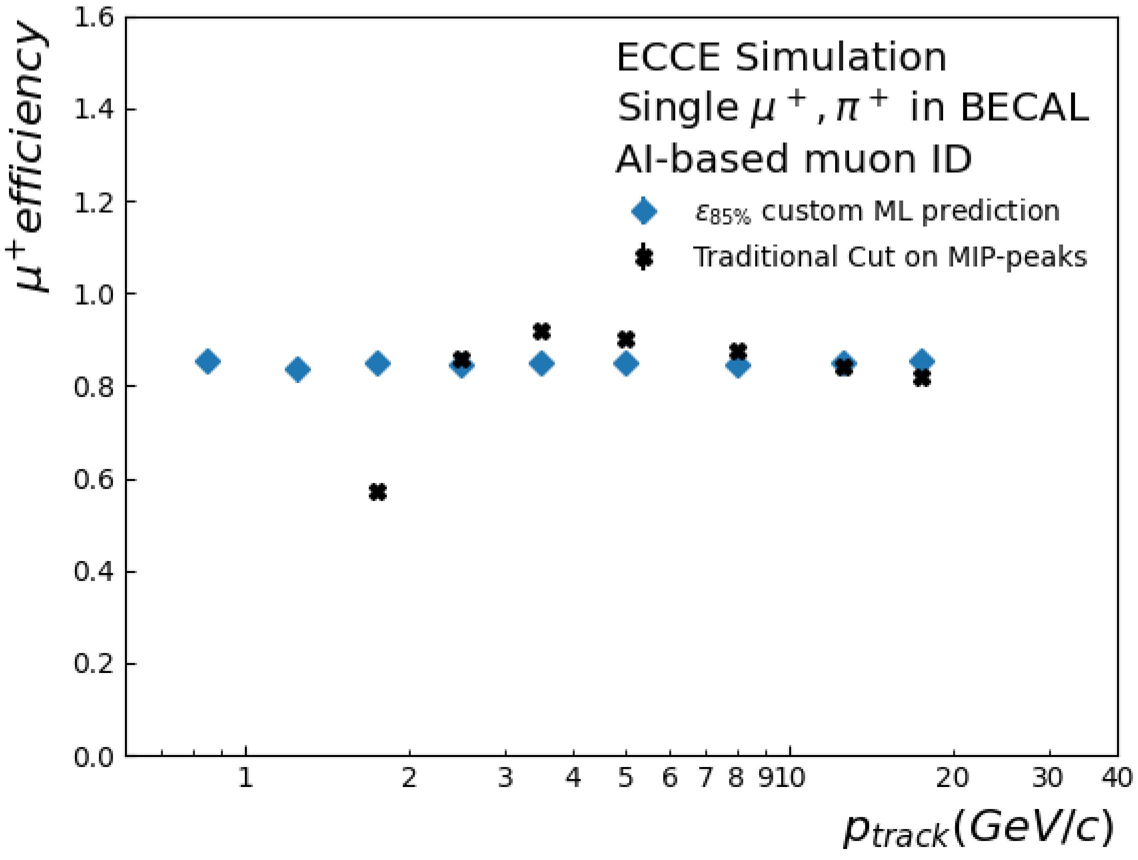




Pion rejection/muon efficiency - central

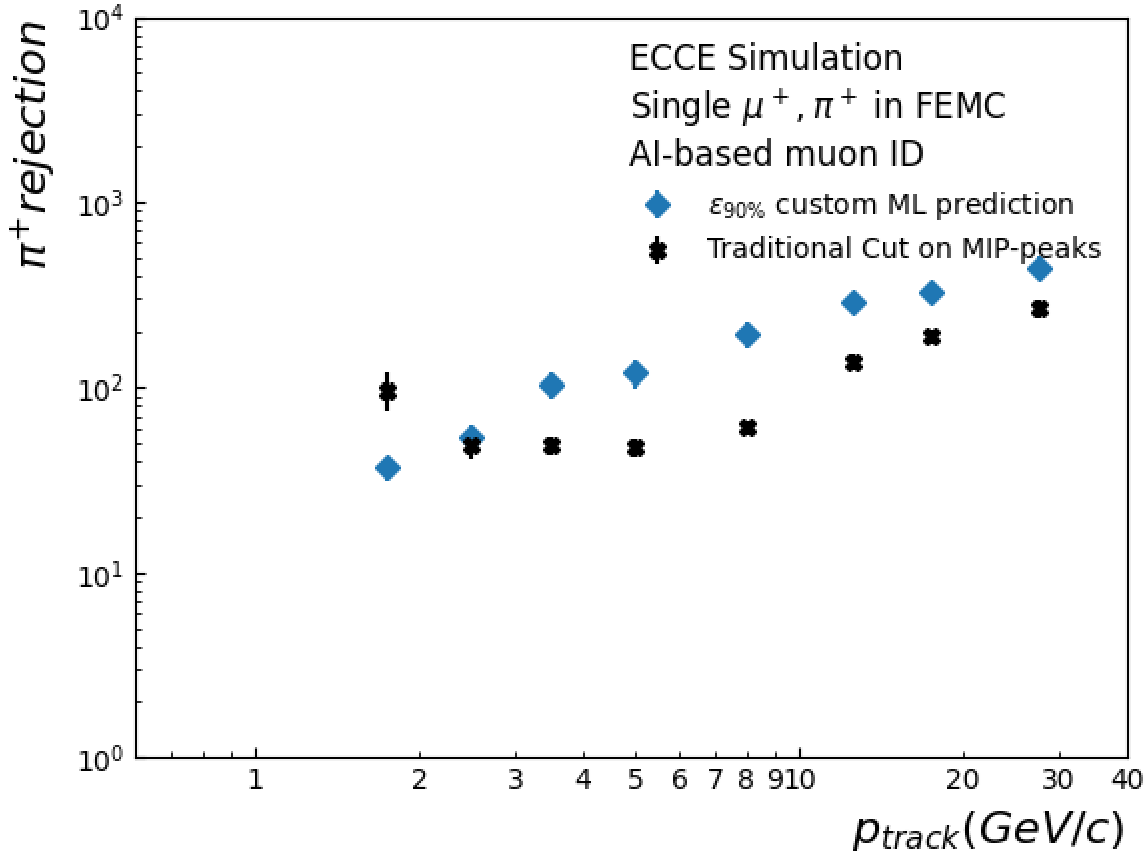
- Utilizing central track, barrel EMCal, EMCal active support and barrel HCal
- Pion rejection starting at 10^{-1} at low p and saturate above 100:1 above a few GeV/c

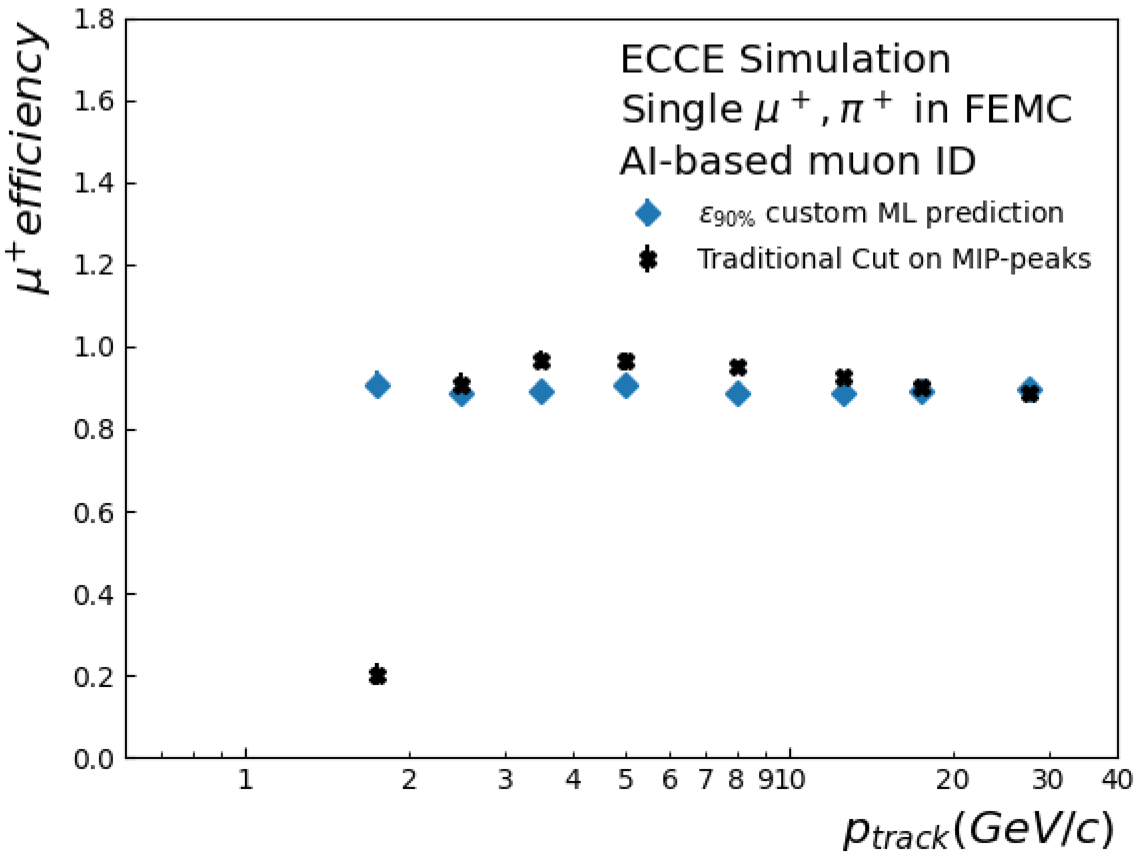




Pion rejection/muon efficiency - forward

- Utilizing tracking, forward EMCal, and six layers of forward HCal
- Pion rejection starting at few 10s:1 at low p and increase to a few 100:1 above a few GeV/c



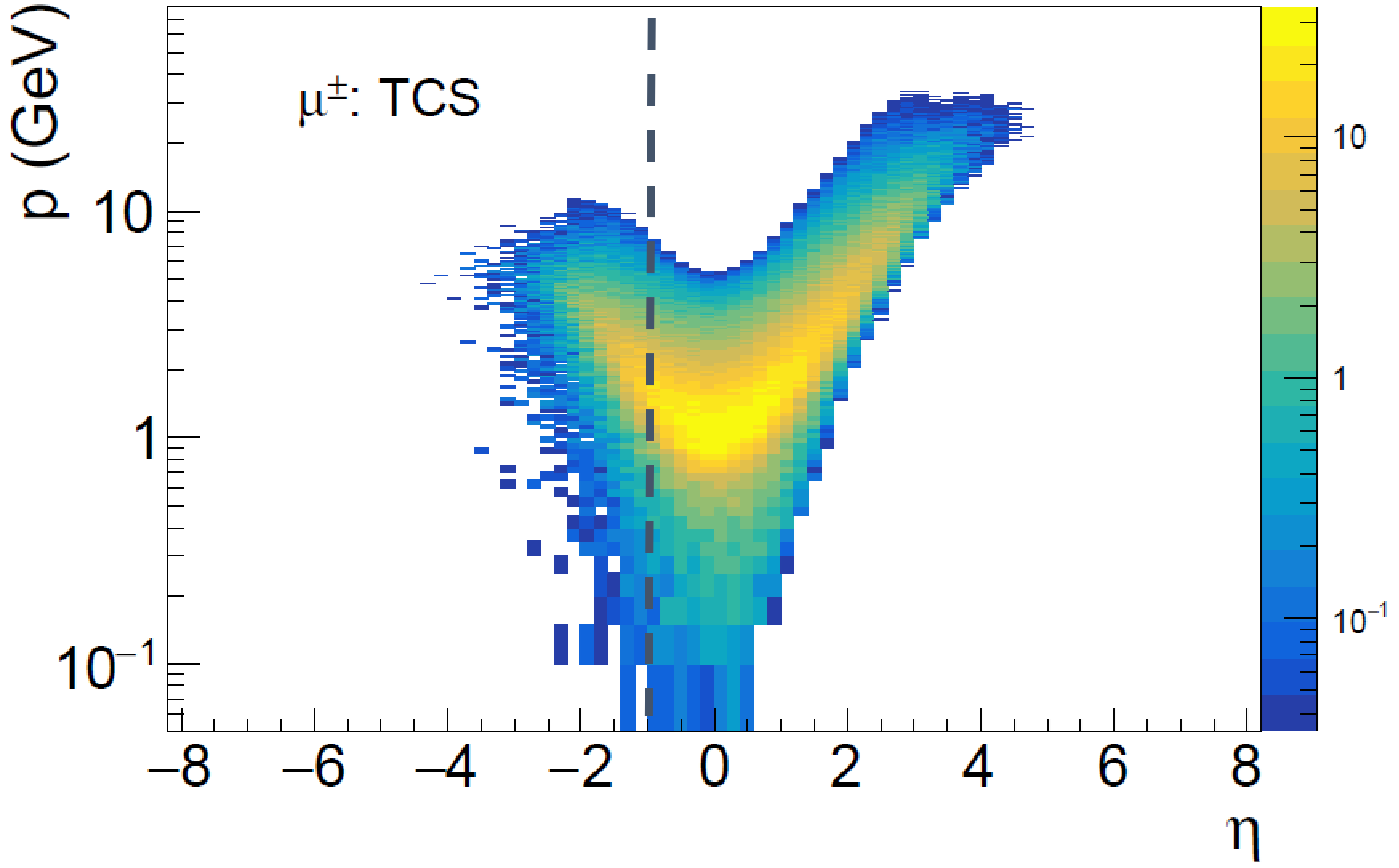


TCS muon-ID coverage

η<-1: potential muon chamber upgrade

η>-1: ECCE muon ID coverage with EMCal + HCal

- ECCE cover majority of the TCS phase space with EMCal + HCal based muon ID
- Boosted ID performance with deep learning expertise in ECCE.
- Pion-pair rejection at 10^2 to 10^5 level (square of single track rejection)
- Potential muon chamber upgrade to complete the cover for η<1



Conclusions

- ECCE can reconstruct J/Ψ with good resolution (in both electron and muon channels)
- ECCE performs muon PID using a combination of EM and Hadron calorimetry.
    - Pion-pair rejection is at 10^2 to 10^5 level.
- Works well to suppress pions at $\eta>-1$.
- Muon chamber upgrade for the backward endcap will enable muon PID for $\eta<-1$.