Backward Hadronic Calorimeter status

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The Ohio State University

ePIC TIC meeting 28.10.2024

THE OHIO STATE UNIVERSITY

Outline

- A lot of progress since collaboration meetings
- Clearly defined motivation
- Engineering design selected to be a shorter version of LFHCAL modules
- Small but growing DSC: OSU, CTU in Prague, UIUC, help from BNL

Main webpage

https://wiki.bnl.gov/EPIC/index.php?title=Backward_Hcal

Weekly meetings page (many updates!)

https://indico.bnl.gov/category/549/

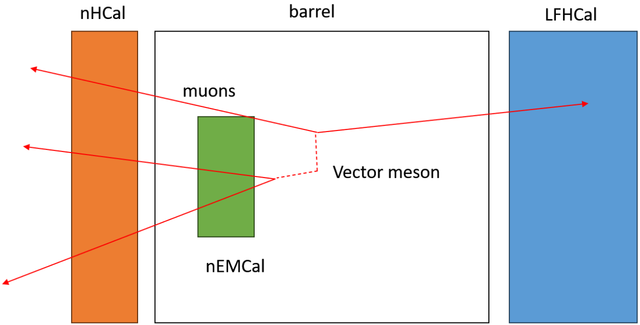
The Ohio State University ČVUT České vysoké učení technické v Praze Brookhaven National Laboratory University of New Hampshire University of Illinois Urbana-Champaign

Motivation for nHCal

- Members of H1 recognize that the lack of a backward HCAL hurt several important physics measurements, especially low-x related studies.
  - [NIM A386 (1997) 397-408]
  - [DESY 08-053]

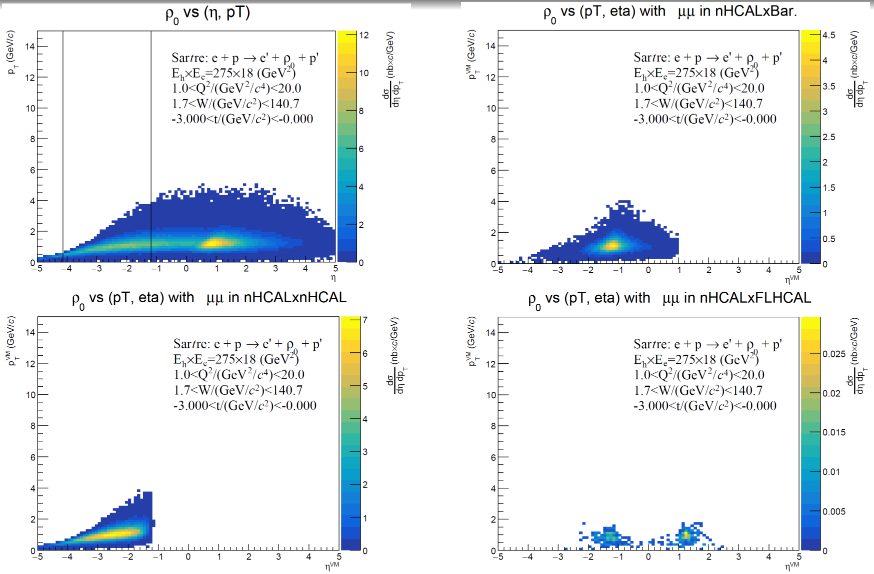
1. Measure vector meson production in dimuon channel
   1. Crucial physics topic according to Yellow Report and EIC White Paper
      - Promised to be delivered by ePIC
      - [Nuclear Physics A 1026 (2022) 122447]
      - [BNL-98815-2012-JA; JLAB-PHY-12-1652]
   2. Access to low-pT VM's
   3. Increase acceptance
   4. Double statistics
   5. Muons not affected by bremsstrahlung
   6. Measure all VMs via dimuon final states (eg. $\phi \to KK \to \mu\mu$)
2. Measure diffractive dijets
3. Distinguish charged jets from those including neutrals
4. Improve scattered electron ID
5. Veto for dRICH

Vector meson reconstruction in dimuon channel



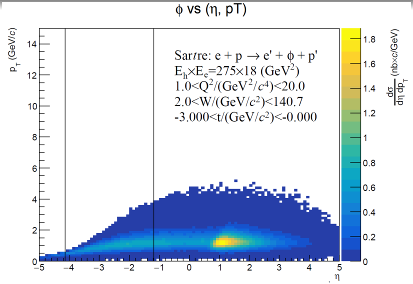
- Important for high y or low-p_T vector mesons - depends on kinematics
- Increases acceptance
- Need projected MIP tracks and MIP signals in backward HCal and EMCal
  - μ/π distinction important, position resolution...
- Simulations done by UIUC with event generators:
  - Simulated exclusive, diffractive $\rho_0, \phi, J/\psi, \rightarrow \mu\mu$ production in DIS regime with Sartre
  - Skipped PYTHIA8 for now, because of limitations of hard diffraction implementation
  - For ρ_0 and ϕ KK or even $\pi\pi$ decays may be more relevant than $\mu\mu$ due to low branching ratio
  - Performance estimates underway with full ePIC simulation (needed for TDR)

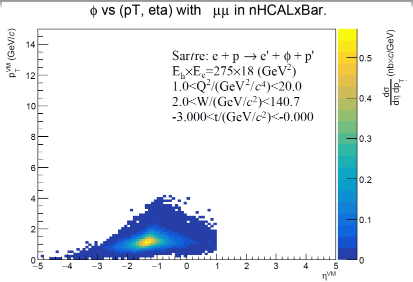
ρ_0 distributions with Sartre

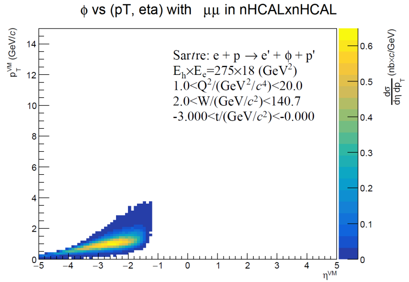


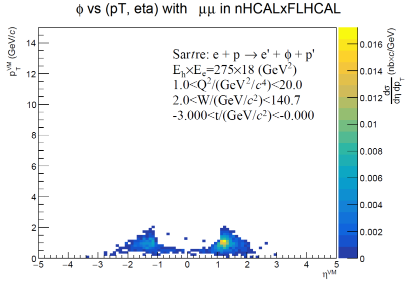
Vincent Andrieux, UIUC

- Branching ratio $\rho_0 \to \mu\mu$ not included
- nHCal can extend the rapidity range, better access to low-x physics





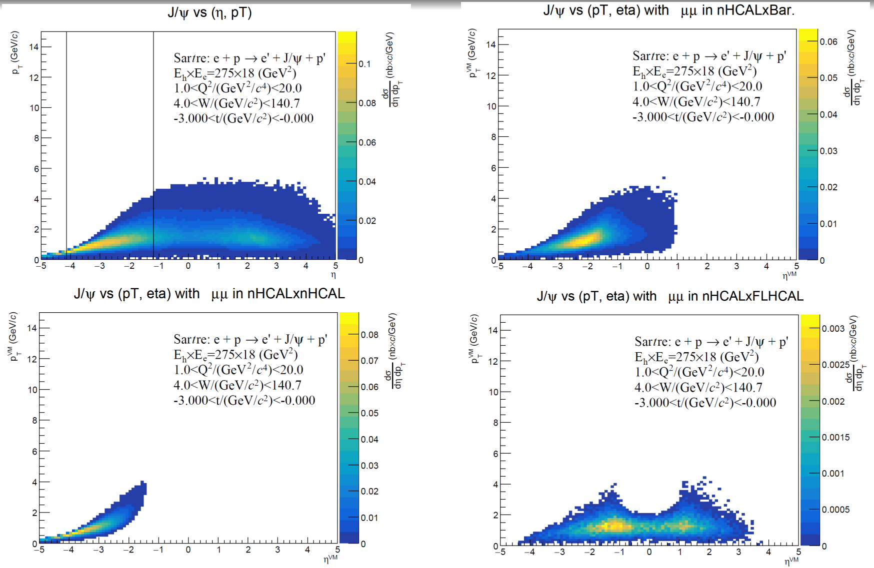




Vincent Andrieux, UIUC

- Branching ratio $\phi \to \mu\mu$ not included
- nHCal can extend the rapidity range, better access to low-x physics

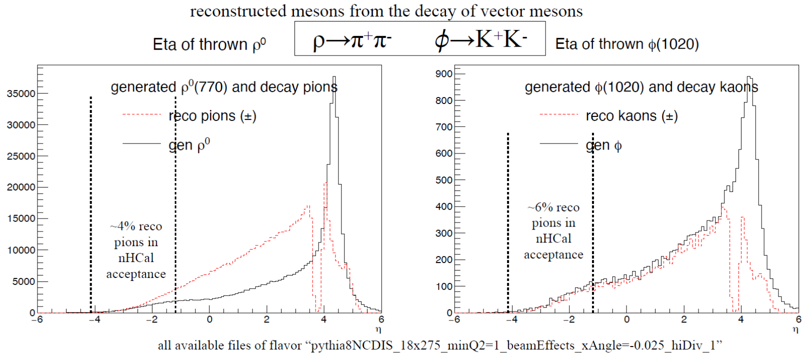
J/ψ distributions with Sartre



Vincent Andrieux, UIUC

- Branching ratio $J/\psi \to \mu\mu$ not included
- nHCal is important for J/ψ study, what about Υ?

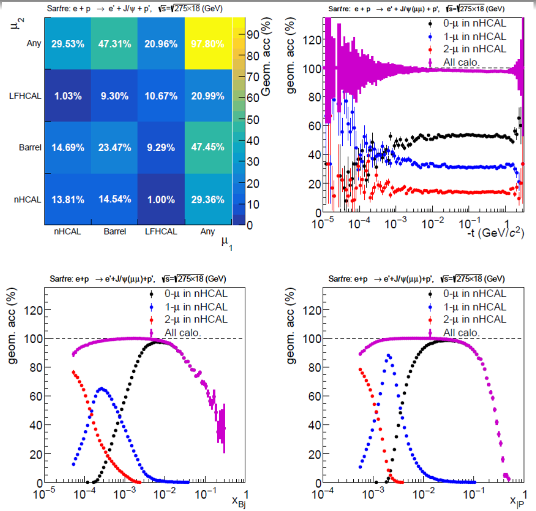
pythia8NCDIS_18x275_minQ2=1 large sample



Caroline Riedl, UIUC

- $\sim 4-6\%$ of mesons from VM decay in nHCal acceptance
- centrally generated PYTHIA8 with full simulation of the ePIC detector and tracks reconstructed
- studied decays: $\rho_0(770) \rightarrow \pi^+\pi^-$, $\phi(1020) \rightarrow K^+K^-$

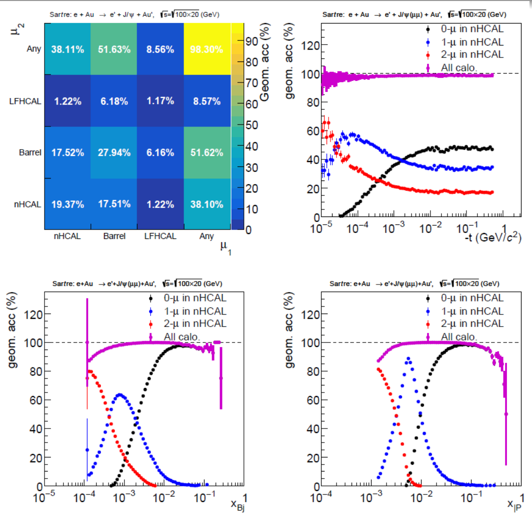
$J/\psi \to \mu\mu$, $e + p$, $18 \times 275\mathrm{GeV}$



Vincent Andrieux, UIUC

- nHCal crucial to measurements below $x = 10^{-3}$
- Other detectors limited to $x = 10^{-3}$
- Necessary for one of the physics topics in EIC YR and promised by ePIC

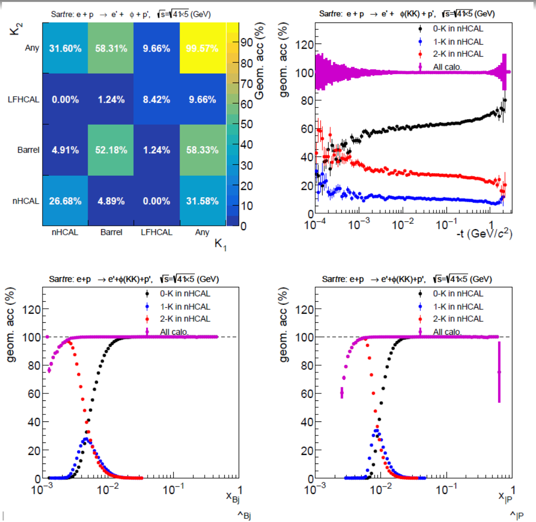
$J/\psi \rightarrow \mu\mu$, $e + A$, 20×100GeV



Vincent Andrieux, UIUC

- nHCal crucial to measurements below $x = 10^{-2}$ in $e + A$
- Other detectors limited to $x = 10^{-2}$ in $e + A$
- Necessary for one of the physics topics in EIC YR and promised by ePIC

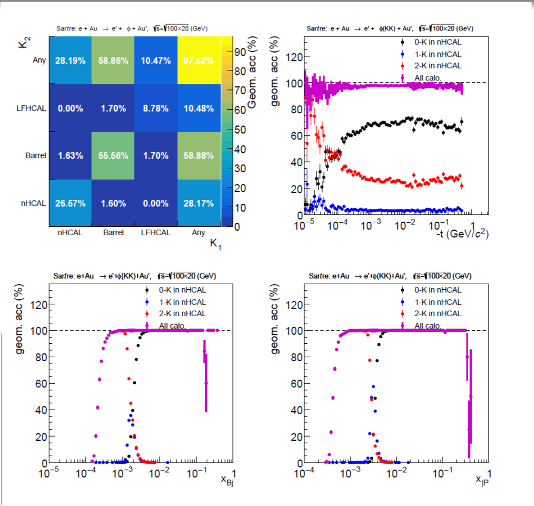
$\phi \to \mu\mu$, $e + p$, $5 \times 41\text{GeV}$



Vincent Andrieux, UIUC

- nHCal crucial to measurements below $x = 10^{-2}$
- Other detectors limited to $x = 10^{-2}$
- Necessary for one of the physics topics in EIC YR and promised by ePIC

$\phi \to KK$, $e + A$, $20 \times 100\text{GeV}$



Vincent Andrieux, UIUC

- nHCal crucial to measurements below $x = 10^{-2}$ in $e + A$
- Other detectors limited to $x = 10^{-2}$ in $e + A$
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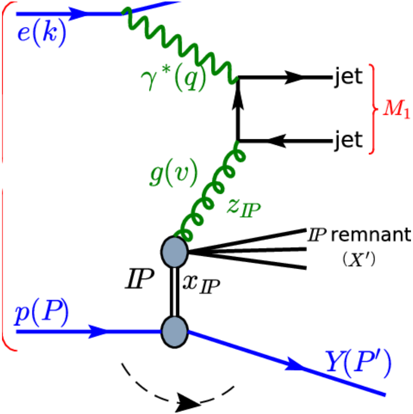
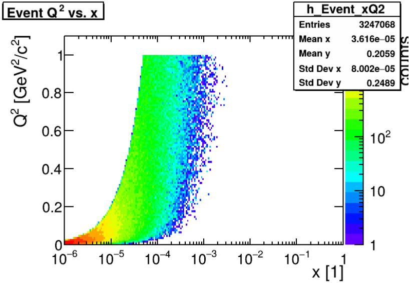
Diffractive dijets with nHCal

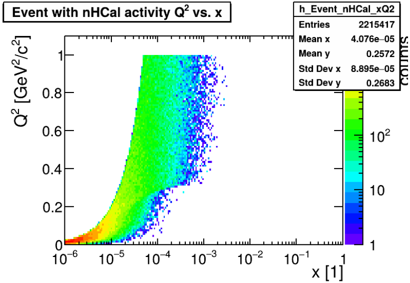


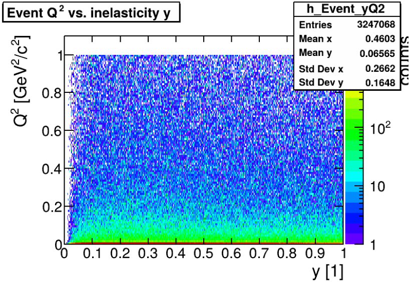
[Phys. Rev. D 107, 094038]

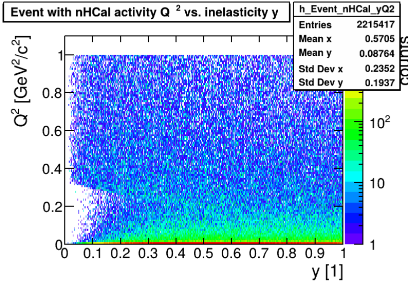
All events



With activity in nHCal



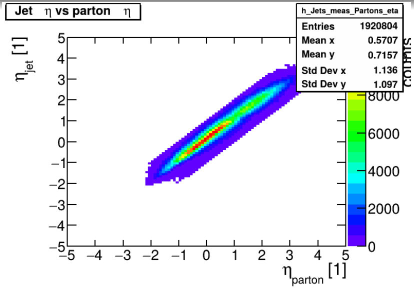


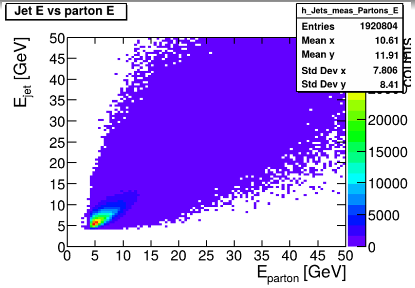


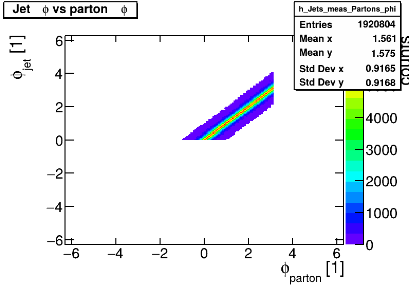
- $\sim$ 63% events with activity in nHCal
- nHCal crucial for low-x measurements coverage

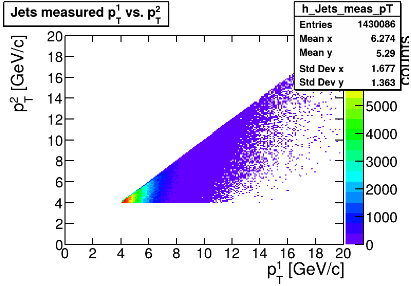
Jet clustering

- Final state particles in pure PYTHIA - full ePIC simulation study underway
- Beam particles excluded!
- Clustered charged particles in trackers ($-3.61 < \eta < 3.44$) and neutrals in HCals to obtaine "measured" jets
- Anti-k_T algorithm seems to work well, IR and collinear safe
  -
  - $d_{ij} = \min(\frac{1}{p_{Ti}^2}, \frac{1}{p_{Tj}^2}) \frac{\Delta R_{ij}^2}{R^2}$
  - $d_{iB} = \frac{1}{p_{Ti}^2}$
- $R = 1$
- Jet $p_T > 4\,\mathrm{GeV}$
- Sorted jets vs. p_T

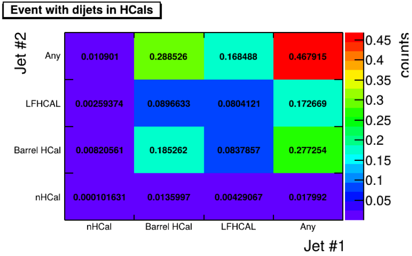


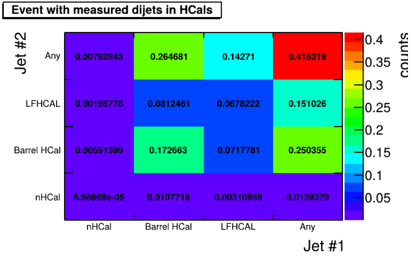




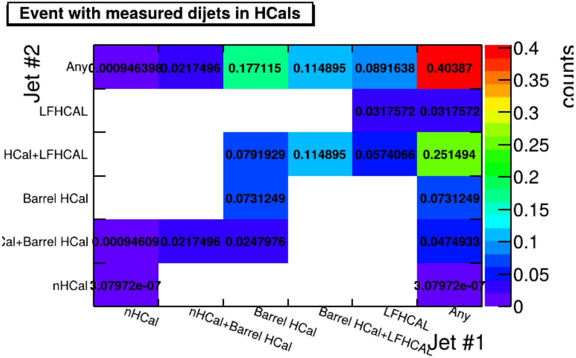


- Jets seem to reconstruct partons well
- Reconstructed quantities correlated with the parton

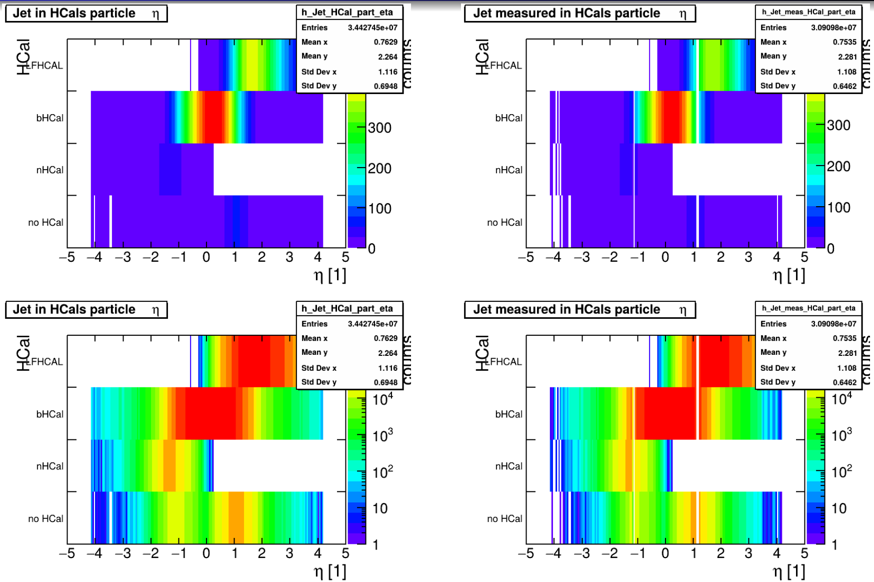




- Fractions of events with jets in HCals
- Relative to events with 2 partons in ePIC acceptance
- All particles (left) and "measured" in trackers+HCals (right)
- 1.8 and 1.4 percent of all and measured jets with 1 jet in nHCal
    - But selects specific kinematics!

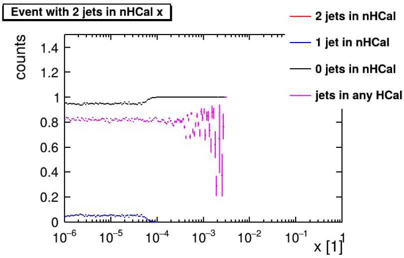


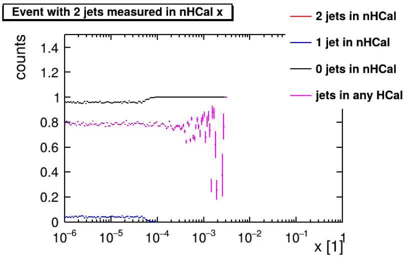
- Fractions of events fully contained/particles shared in HCals
- Relative to events with 2 partons in ePIC acceptance
- 4.8 of jets share particles between nHCal and Barrel
  - Need nHCal to fully reconstruct those

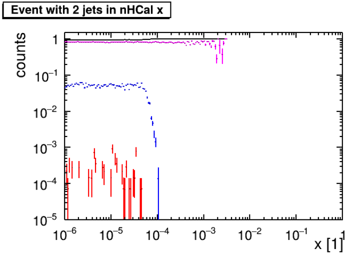


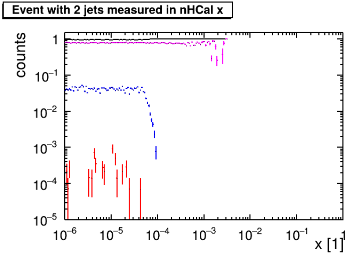
- η distributions for constituents of jets in HCals
- Illustrates sharing of particles between HCals

Acceptance x



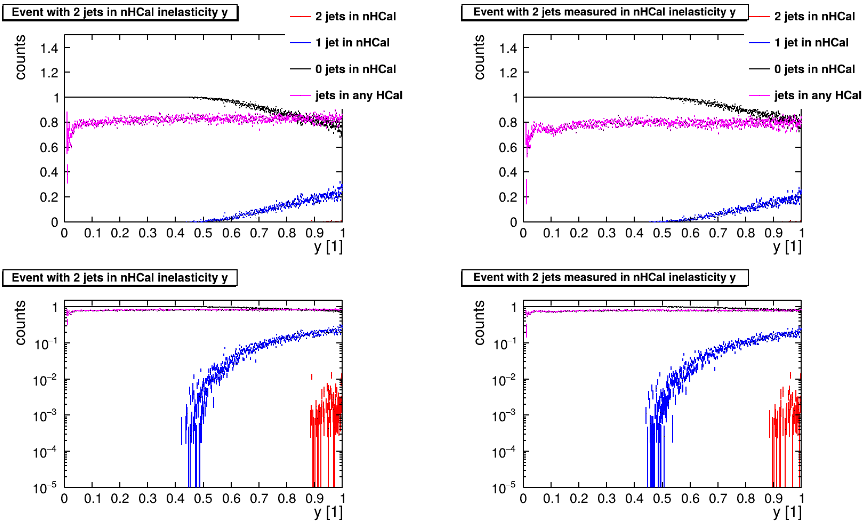






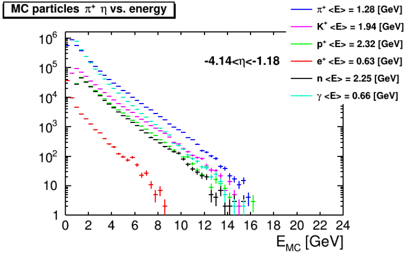
- Fractions of events with jets in HCals
- nHCal selects events with high y (inelasticity) and low $x \sim 10^{-4}$

Acceptance y

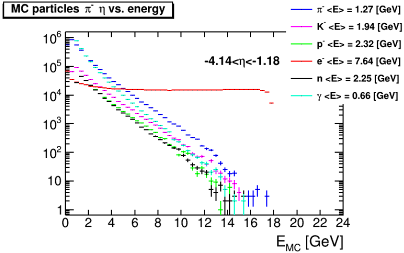


- Fractions of events with jets in HCals
- nHCal selects events with high y (inelasticity) and low x

positive charge



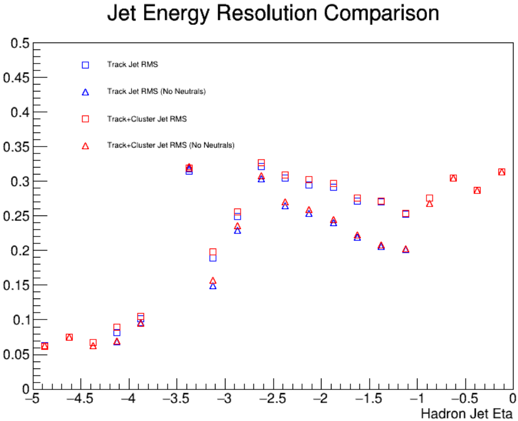
negative charge



- Total energy distributions vs. η
  - Average neutron energy similar to inclusive events
- Kinetic energy is measured in nHCal

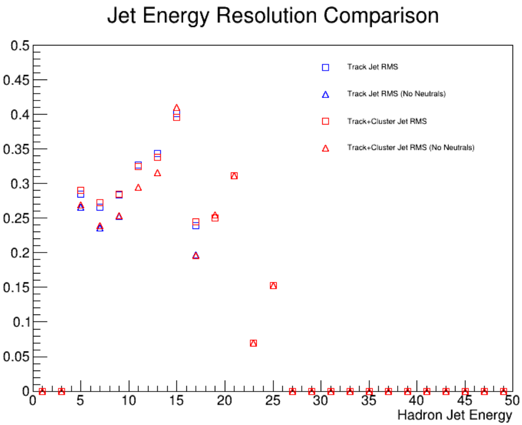
Jets with neutrals

Brian Page, BNL



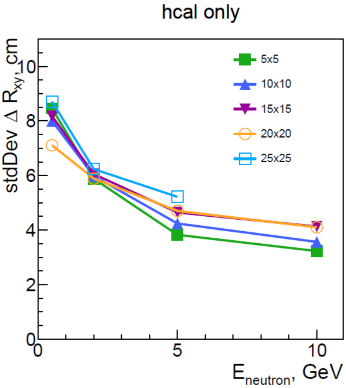
- Idea: use nHCal to separate charged only jets and those with neutrals
- WARNING: affected by the wide clustering bug, so may improve
- RMS of the full distribution of jet $(E_{reco} - E_{generated})/E_{generated}$ vs. η_{jet}
- Isolating neutral $(20 - 25\%$ of all jets) and charged jets already improves the resolution by $\sim 20\%$
- Unavoidable deterioration of resolution when adding clusters
  - Tracking offers better resolution in this kinematic range
  - However hadron measurements still needed for neutrals!

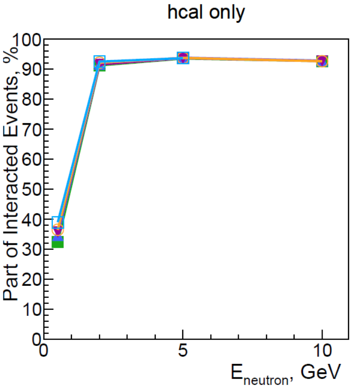
Brian Page, BNL



- WARNING: affected by the wide clustering bug, so may improve
- RMS of the full distribution of jet $(E_{reco} - E_{generated})/E_{generated}$ vs. $E_{generated}$
- Mostly smooth dependence, increases with energy

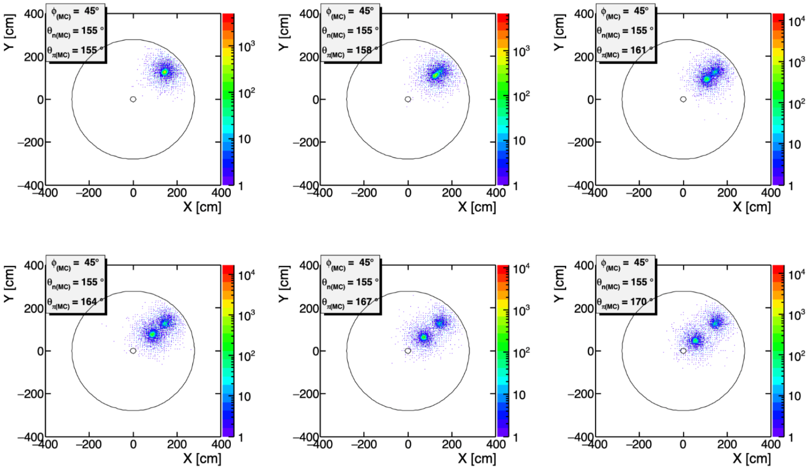
Alexandr Prozorov, CTU





- Shoot single neutrons and compare ideal projections to RECO clusters
- Vary energy and tile size to obtain scaling
- Even large tiles up to 25 cm seem to be OK
- Need track projections and cluster matching in realistic DIS events - next steps

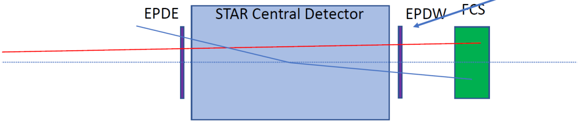
Increasing separation →

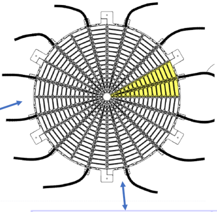


Subhadip Pal, CTU

- n and π clusters are well separated down to $30 - 40\text{cm} \approx 2\lambda_0$
- Detailed checks at closer distance in progress
- Pion clusters steal energy from overlapping neutron showers
- At low energy pions shower much more than neutrons

- RHIC is a living beast, you never know what it will throw at you !
- Run24 beam background is quite high due to multiple reasons
- Machine attempts to reduce background yielded modest improvements
- And at the end it is up to experiments to find efficient solutions to clean it up!





fcsJP2*EPDveto
fcsJPA1*EPDveto
fcsJPA0*EPDveto
fcsJPBC1*EPDveto
fcsJPBC0*EPDveto
fcsJPDE1*EPDveto
fcsJPDE0*EPDveto
fcsDiJP*EPDveto
fcsDiJPAsy*EPDveto

- Upstream background polluted some FCS trigger by ~ 30% in Run24.
- EPD has enough resolution to apply timing veto cut to clean it up

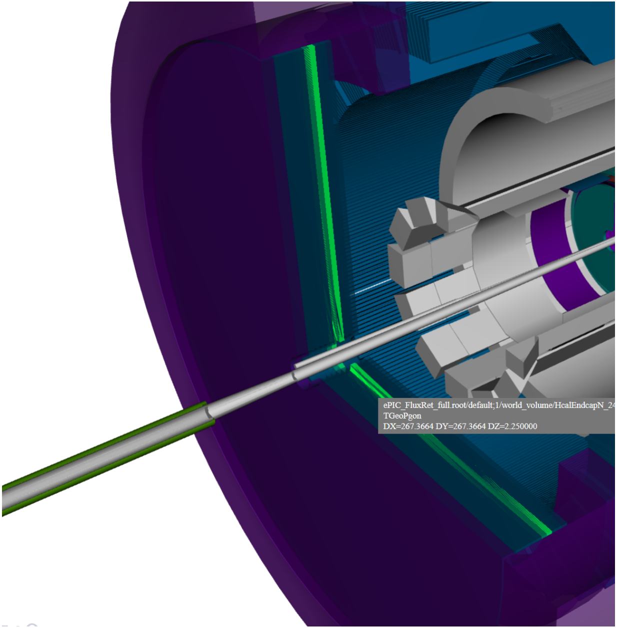
- In ePIC. nHCal will help to shield dRICH from such events.
- \+ Timing information from both nHCla and forward HCal similar to EPDE/EPDW

Questions is will it be good to have something similar to EPD/BBC in ePIC? It is much simpler detectors than calorimeters. May be re-used (EPD) from STAR and sPHENIX? Space?

See Oleg's presentation:
`https://indico.bnl.gov/event/20727/contributions/94377/`

- We are working on realistic studies, but they require:
  - realistic background, full material budget, multiple detector reconstruction, timing info, etc.
- Potential to reject 30% or more background is worthwhile to investigate

Design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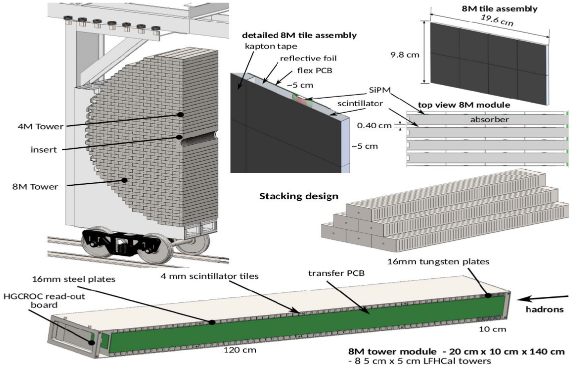
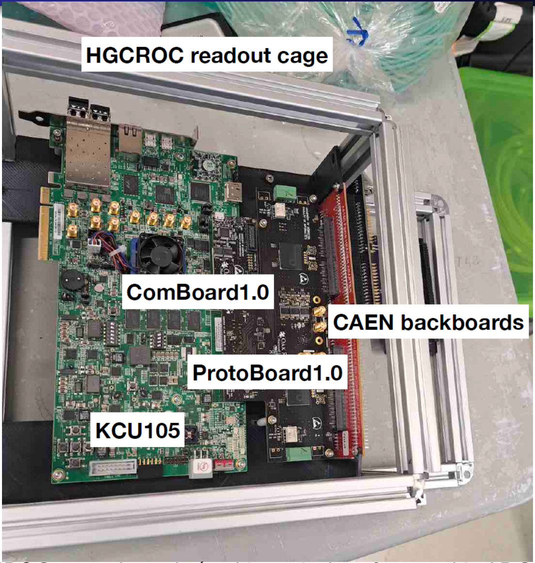
TGeoPgon
DX=267.3664 DY=267.3664 DZ=2.250000

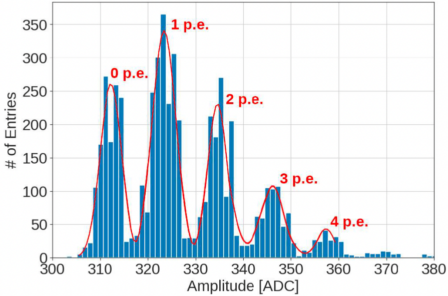


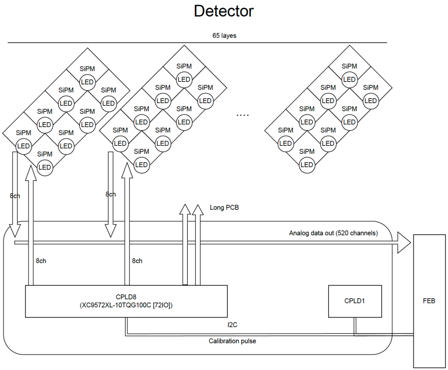
- Sampling calorimeter with 10 alternating layers, $2.4\lambda^0$ (red):
  - non-magnetic steel 4 cm
  - plastic scintillator 4 mm - to be adjusted
- Light collection by SiPM:
  - Candidate (to verify): S14160-1315PS https://www.hamamatsu.com/eu/en/product/optical-sensors/mppc/mppc_mppc-array/S14160-1315PS.html
- Electronics to follow solutions of other calorimetry systems HGCROCv3
- FEEs placed in front of nHCal
- Use similar module structure as LFHCAL: $20\ \mathrm{cm} \times 10\ \mathrm{cm} \times 45\ \mathrm{cm}$
- This determines max size of tiles: $10\ \mathrm{cm} \times 10\ \mathrm{cm}$ (can use smaller close to the beam)
  - Determined during meeting with project engineers: https://indico.bnl.gov/event/25021/



- FEE: HGCROCv3 78 channels (15 bit equivalent from 10 bit ADC and 12 bit TOT via TDC)
  - Design by Norbert Novitzky (LFHCAL group, ORNL) - needs just connection topology and number of channels
- 2352 channels per layer (independent readout gives total of 10×2352)

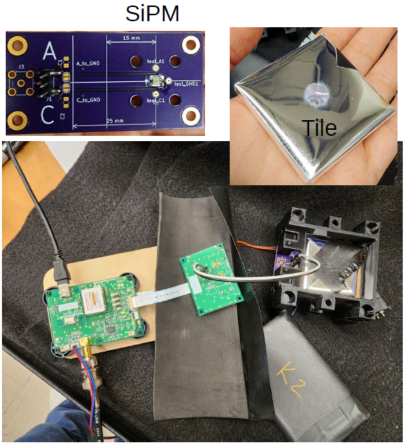
- **2mm²:**

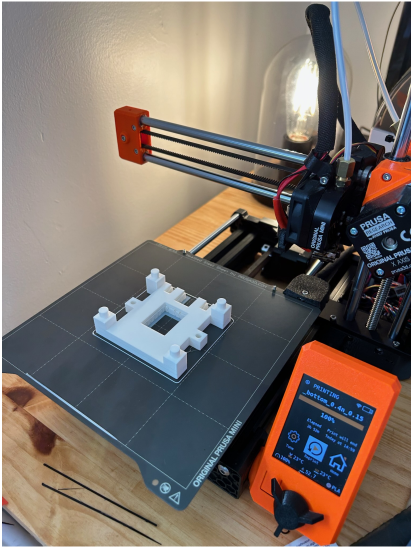




- 1 LED per channel operated via I^2C
- Use single photon spectra to calibrate the response
- Can simulate any pattern: realistic showers etc.
- Check for cross-talk and light leakage
- Design by Norbert Novitzky (LFHCAL group, ORNL) - need channel topology

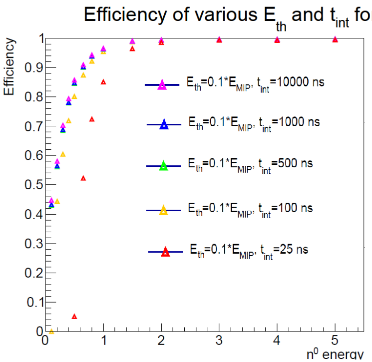
Yevheniia Khyzhniak, OSU



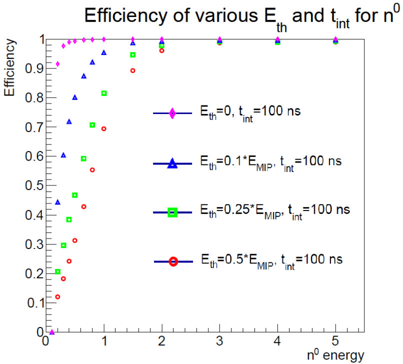


- Ongoing tests of tiles
- Received equipment and help from ORNL group, thanks!
- Plan to order more tiles for testing - in contact with Oleg Eyser

Integration time dependence



Threshold dependence



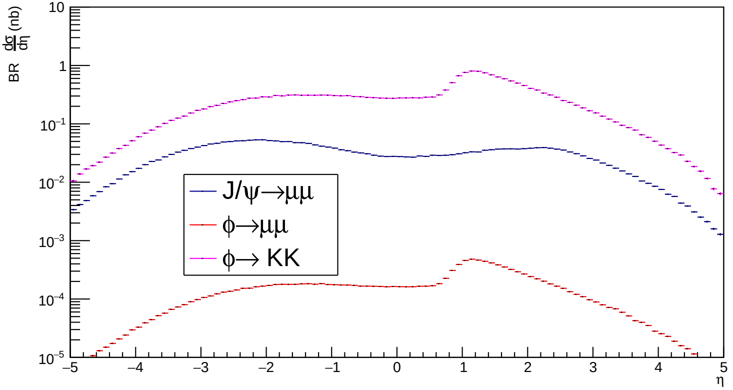
Sam Corey, OSU

- Efficiency of requiring a hit with a sum of hit contributions energy integrated up to t_{int} and passing a threshold E_{th}, $t_0 = 0$
- Checked with simulation only - no digitization
- E_{MIP} is 0.75 MeV per layer
- E_{th} has the biggest impact
- 100 ns is good enough, but lower energy neutrons may need longer times
- 60% efficiency for $E = 300$ MeV neutrons $E_{th} = 0.1 \times E_{MIP} = 75$ keV and 100 ns

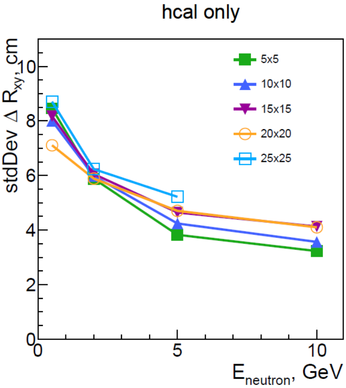
Conclusions

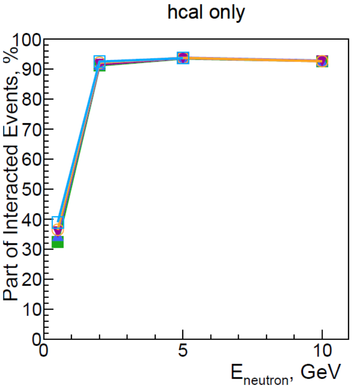
- Backward HCAL is crucial for delivering promised Physics
- Many low-x physics topics through diffractive events (VMs, dijets, etc.) require nHCAL and/or greatly benefit over other channels
- Other benefits are being actively studied (scattered electron ID, dRICH veto, etc.)
- H1 collaboration recognizes that lack of a backward HCAL limited physics output on key topics
- Physics requirements are being used to determine the baseline design requirements for the nHCAL
  - Max size of tile: $10\ \mathrm{cm} \times 10\ \mathrm{cm}$ (can use smaller close to the beam)
- Last steps: full ePIC simulation of the studied processes

BACKUP


BR dσ/dη (nb)
10
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
–5
–4
–3
–2
–1
0
1
2
3
4
5
η
J/ψ→μμ
ϕ→μμ
ϕ→ KK

Alexandr Prozorov, CTU



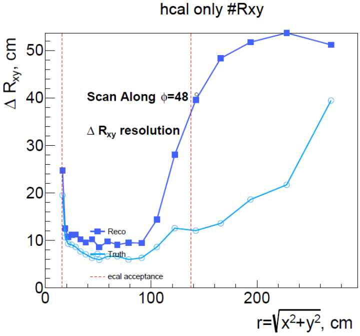


- Shoot single neutrons and compare ideal projections to RECO clusters
- Vary energy and tile size to obtain scaling
- Even large tiles up to 25 cm seem to be OK
- Need track projections and cluster matching in realistic DIS events - next steps

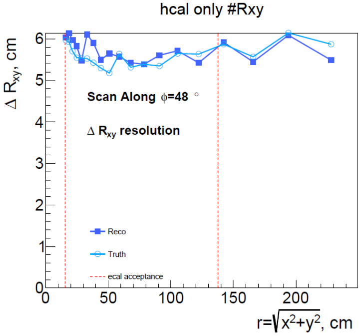
Position resolution full ePIC vs. nHCal only

Alexandr Prozorov, CTU

Exploiting ϕ symmetry (see details), make a scan along single ϕ angle



full epic

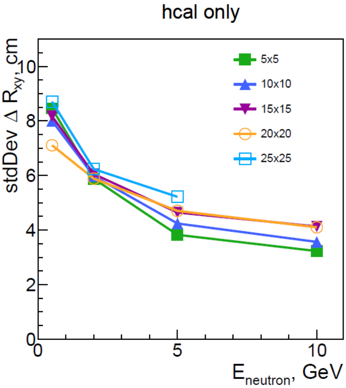


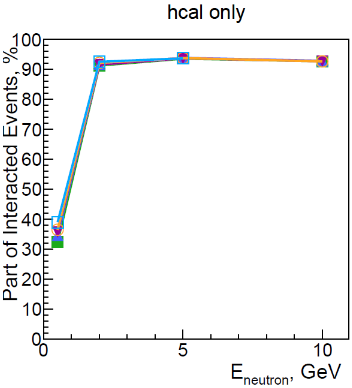
hcal only

- Barrel materials in front deteriorate the position resolution due to scattering

Single particle position resolution study

Alexandr Prozorov, CTU





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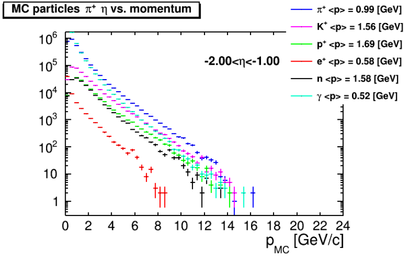
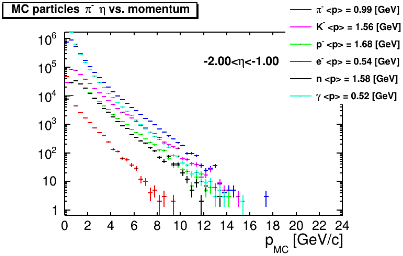
positive charge

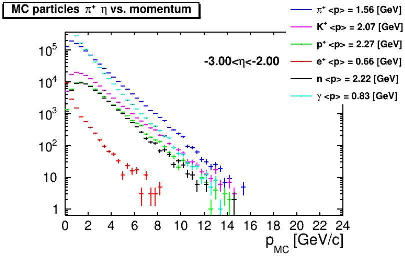


negative charge

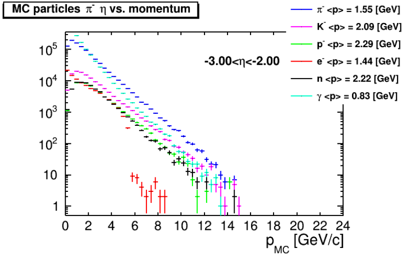


- Total energy distributions vs. η

positive charge



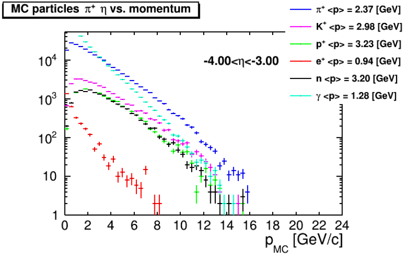
negative charge



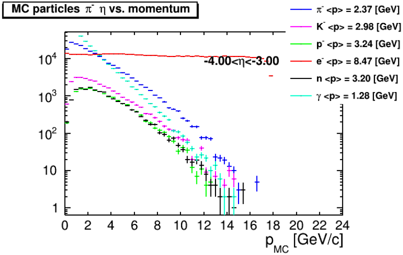
- Total energy distributions vs. η

Particle distributions in nHCal

positive charge

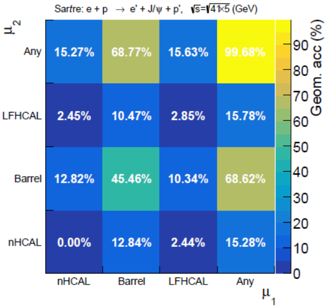


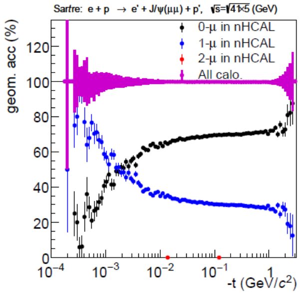
negative charge

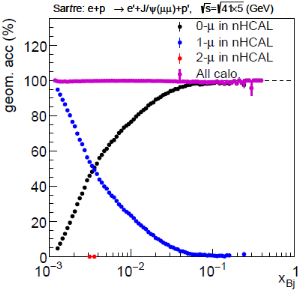


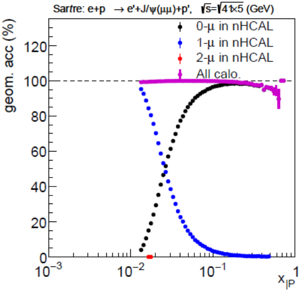
- Total energy distributions vs. η

$J/\psi \to \mu\mu$, e + p, 5 × 41GeV









Vincent Andrieux - UIUC

Diffractive dijet - simulation setup

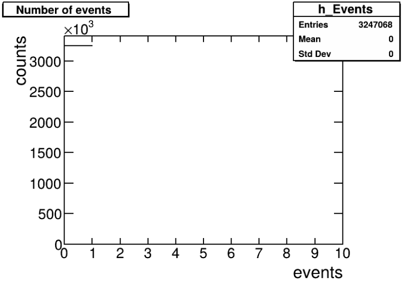
- Simulation setup for diffractive dijets
- PYTHIA version 8.311 simulation from EIC container:
  - $18 \times 275\ \mathrm{GeV}$ $e + p$ collisions, $0 < Q^2 < 1\ \mathrm{GeV}^2$
  - $6M$ events
- Run at Ohio Supercomputing Center (OSC) to use local computing resources

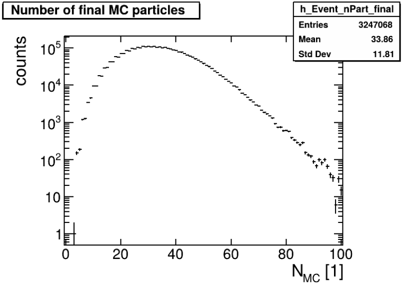
Listing: Simulation settings

```
pythia8->ReadString("Beams:frameType=2");
pythia8->ReadString("Beams:idA=2212");
pythia8->ReadString("Beams:idB=11");
pythia8->ReadString("275.");
pythia8->ReadString("18.");
  //according to main342 for H1 dijets
pythia8->ReadString("PDF:lepton2gamma = on"); // Allow for photon-from lepton
pythia8->ReadString("Photon:ProcessType = 0"); // Allow all photon processes
pythia8->ReadString("Photon:Q2max = 1."); // Maximal Q2
pythia8->ReadString("HardQCD:all = on"); // All dijet MEs
pythia8->ReadString("PhotonParton:all = on"); // All dijet MEs with photons
pythia8->ReadString("PhaseSpace:pThatMin = 4."); // Minimal pT cut
pythia8->ReadString("MultipartonInteractions:pT0Ref = 3."); // Tuned ep value

// Setup of diffractive framework.
pythia8->ReadString("Diffraction:doHard = on");
pythia8->ReadString("Diffraction:sampleType = 1"); // 'PDF' sample
pythia8->ReadString("Diffraction:hardDiffSide = 2"); // Diff. on photon side
pythia8->ReadString("SigmaDiffractive:PomFlux = 7"); // H1 Fit B LO
pythia8->ReadString("PDF:PomSet = 6"); // H1 Fit B LO
```

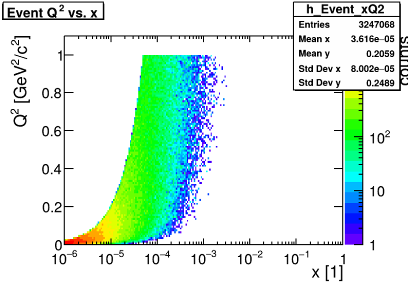
Events



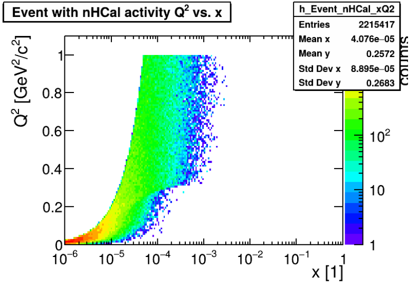


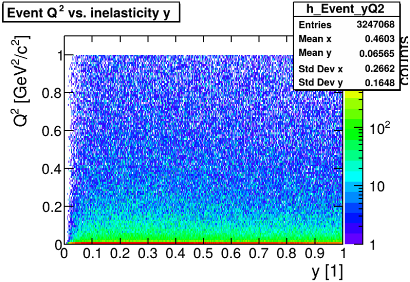
- First look at diffractive dijet events
- 33 final state particles on average
- Small amount of energy contained in diffractive dijets, rest mostly going forward

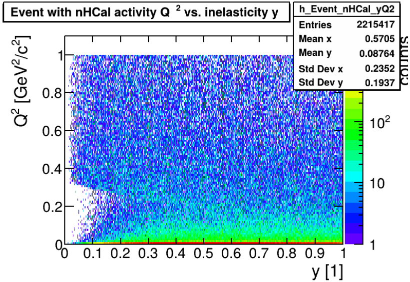
All events



With activity in nHCal

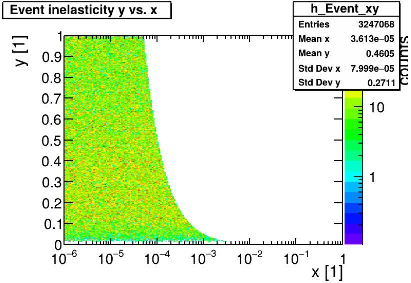




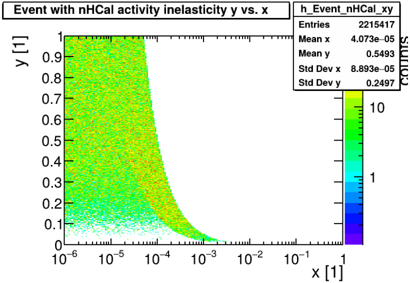


- $\sim$ 63% events with activity in nHCal
- nHCal crucial for low-x measurements coverage

All events

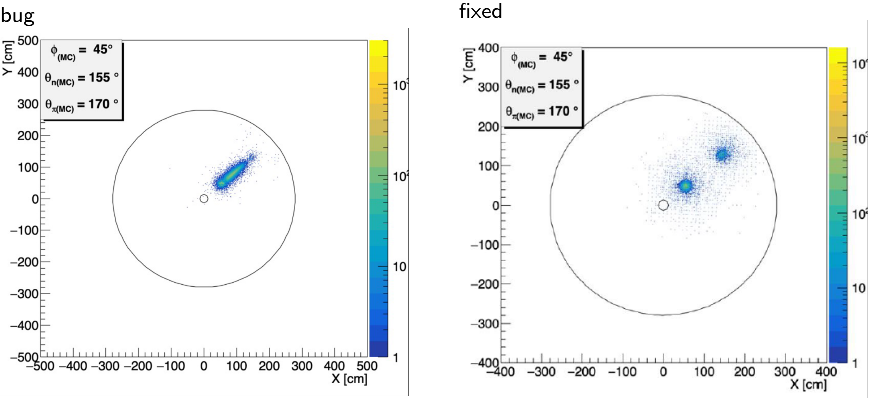


With activity in nHCal



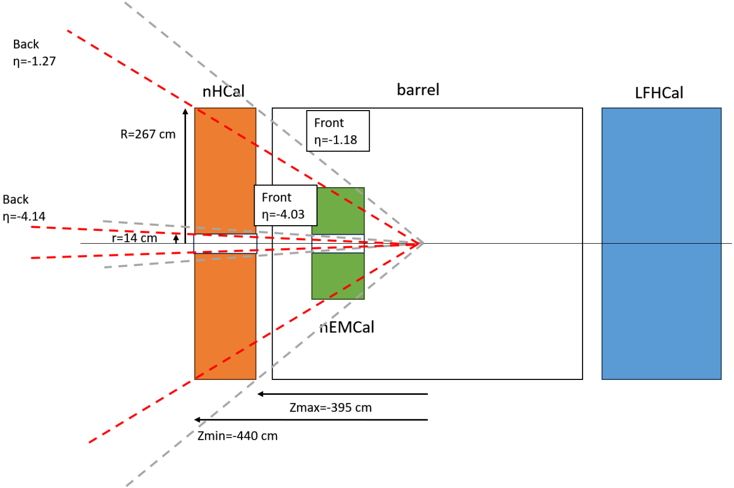
- $\sim 63\%$ events with activity in nHCal
- nHCal crucial for low-x measurements coverage

Hit merger bug



- Used 10× larger reco hit positions
- Caused clusters to be merged over 10× larger distance
- Fixed with help of Wouter `https://github.com/eic/EICrecon/pull/1598`
- Prevented us from getting reasonable results for 2-particle studies
- Affects also LFHCAL
- Possibly affected neutral jet study - results can improve!

Acceptance check



- Front geometry limit: $-4.03 < \eta < -1.18$
- Back geometry limit: $-4.14 < \eta < -1.27$
- Clusters: $-3.95 < \eta < -1.25$
- MC particles showering in nHCal(with hits): $-4.16 < \eta < -1.16$