Jets and Heavy Flavor Detector Requirements Summary

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CUA YR Meeting

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Outline

- Summary of / response to questions from DWGs

- Detector requirements
  - Track momentum resolution
  - Vertex resolution
  - PID
  - ECal
  - HCal

- Continuing work

Response to DWG Questions

- Documenting studies
  - All Jet and Heavy flavor requirements are documented on our wiki page: https://wiki.bnl.gov/eicug/index.php/Yellow_Report_Physics_Jets-HF

- Monte Carlo Validation / Jet definition / Jet multiplicities
  - pythiaeRHIC (Pythia 6) implements a HERMES tune and reproduces HERA jet cross sections and jet profiles (arxiv:1705.08831, arxiv:1910.11460)
  - The group did not impose a single choice of jet definition, although most analyses used the anti-kT algorithm with a variety of radii from 0.3 to 1.0
  - Jet yields for various settings can be found in the following for example in arxiv:1912.05931 and arxiv:1911.00657

- Physics impact of not reaching requested performance
  - Some of this addressed in PID and Hadron Calorimetry slides – further breakdowns into x-Q2 bins can likely be made

- Can loss of phase space be compensated
  - Loosing PID or calorimeter coverage (for example) will cut into available phase space, this can be somewhat compensated by varying com energy but there will be regions which are lost
  - Need better understanding of tradeoffs and impacts on other physics programs and likely more differential studies to determine if the losses are acceptable

Response to DWG Questions

- Detection strategy – detector correlations and boundary conditions
  - Some limited correlation between detectors is implicit in the particle flow implementation in Delphes, but for the most part, robust correlations are not taken into account

- Physics program optimization and subsystem integration
  - Believe some code is already up on github, can document what code goes with which analysis on our wiki page
  - Strongly encourage DWG members to collaborate with relevant analyzers to ensure output is reliable

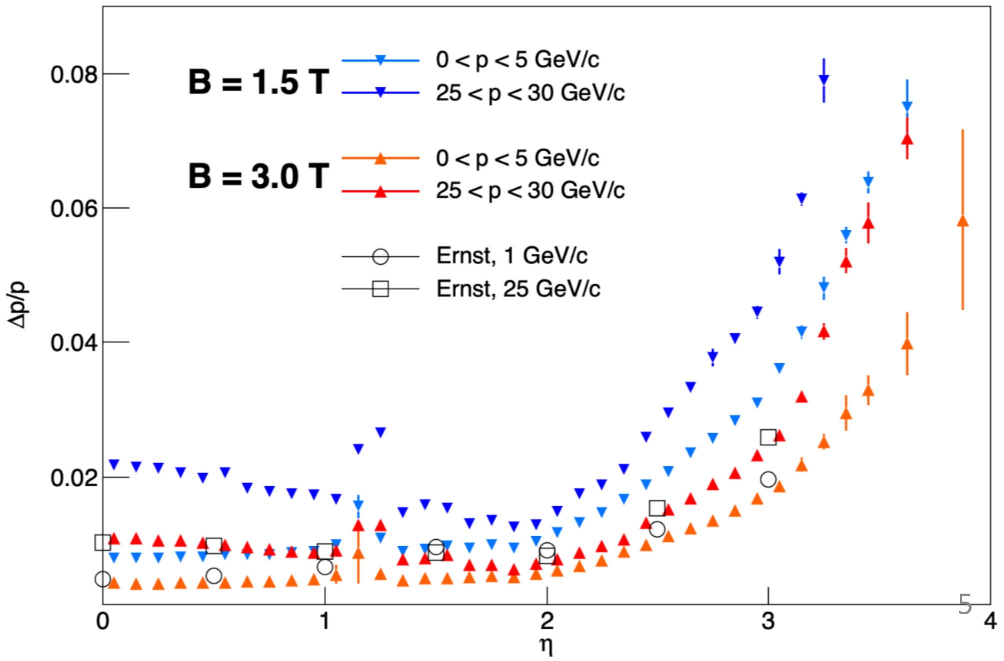
Tracking: Momentum Resolution

Track Momentum Resolution

Eta Range	Default Resolution (σP/P)%	Requested (σP/P)%
-3.5 < η < -2.5	0.1%*P + 0.5%	Same
-2.5 < η < -2.0	0.1%*P + 0.5%	Same
-2.0 < η < -1.0	0.05%*P + 0.5%	Same
-1.0 < η < 1.0	0.05%*P + 0.5%	Same
1.0 < η < 2.5	0.05%*P + 1.0%	Same
2.5 < η < 3.5	0.1%*P + 2.0%	Same

- In addition to momentum resolution and minimum p_T, it would be good to have some input on potential track efficiencies
- We also worry that in the highest eta bin, the resolution formula overestimates the achievable resolution for high momentum (~20-25+ GeV) tracks

- We also request a field for minimum track transverse momentum be included (several analyses assumed values between 100 and 250 MeV)
- This will be relevant for substructure / global event shape measurements as well as decays from HF mesons
- The soft pion from D* decays is a driver here

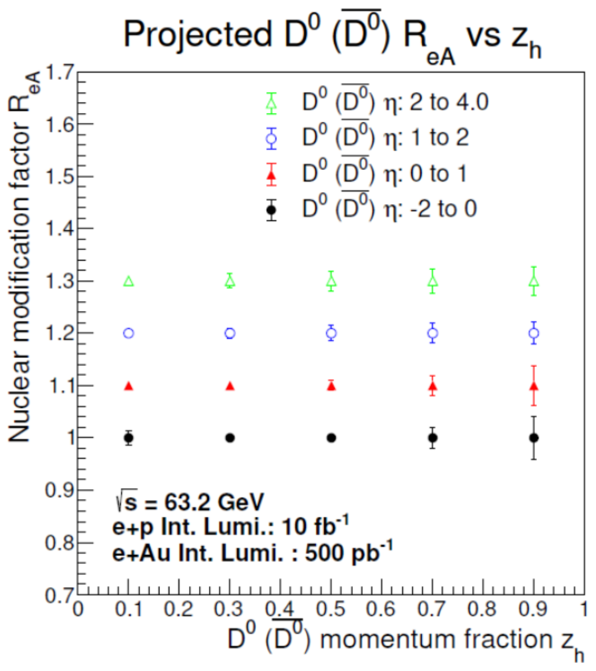


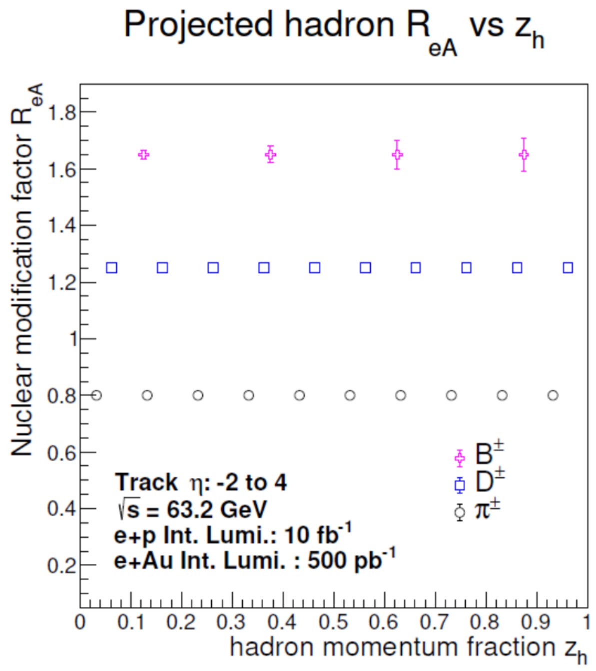
Tracking: Vertex Resolution

Vertex Resolution

Eta Range	Default Resolution	Requested Resolution
$-3.5 < \eta < -3.0$		N/A
$-3.0 < \eta < -2.5$	TBD	$\sigma_{xy} = 30/p_T + 40\ \mu m$
$-2.5 < \eta < -1.0$		$\sigma_{xy} = 30/p_T + 20\ \mu m$
$-1.0 < \eta < 1.0$	σ_{xyz}~20μm, $\sigma_{xy} \sim \sigma_z \sim 20\mu m/p_T + 5\mu m$	Same
$1.0 < \eta < 2.5$		$\sigma_{xy} = 30/p_T + 20\ \mu m$
$2.5 < \eta < 3.0$	TBD	$\sigma_{xy} = 30/p_T + 40\ \mu m$
$3.0 < \eta < 3.5$		$\sigma_{xy} = 30/p_T + 60\ \mu m$

- Vertex resolution driven by need to reconstruct charmonium and bottomonium states
- Resolutions listed above enable the high statistics measurements of ReA shown to the right for D and B mesons over a wide pseudorapidity range
- Enhancing (degrading) resolutions will improve (decrease) signal significance and decrease (increase) integrated luminosity needed to reach a given precision



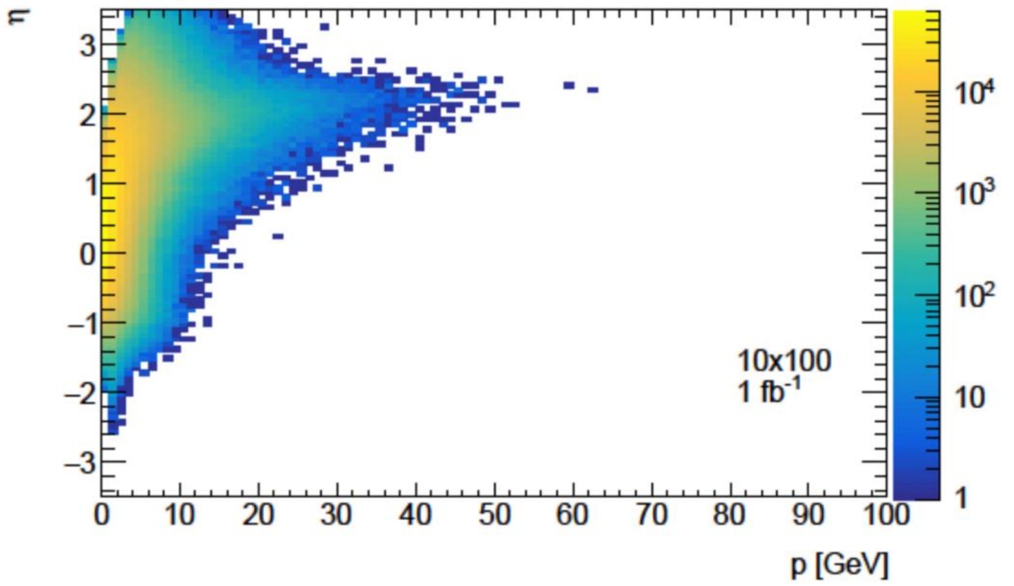


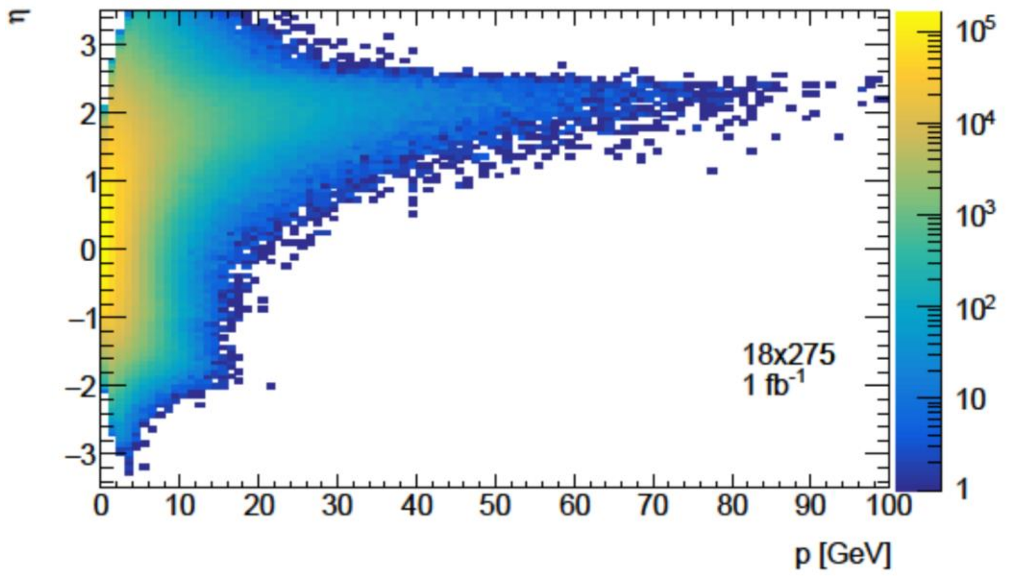
PID

PID Momentum Coverage

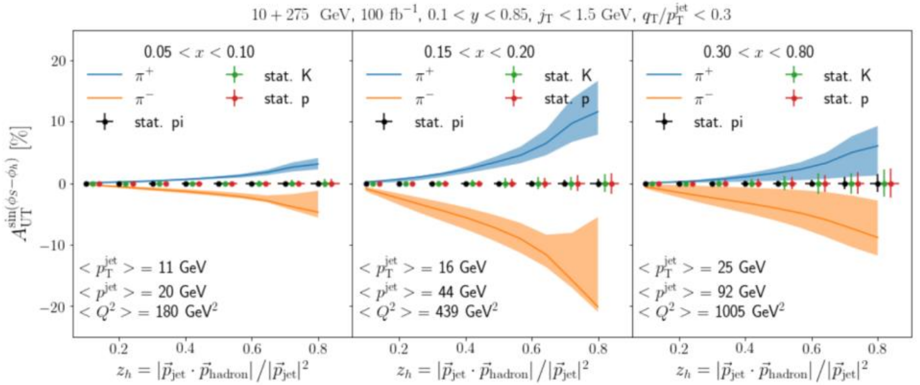
<table>
<tr><th>Eta Range</th><th>Default Momentum Coverage</th><th>Requested Momentum Coverage</th></tr>
<tr><td>$-3.5 < \eta < -1.0$</td><td>≤ 7 GeV</td><td>Same</td></tr>
<tr><td>$-1.0 < \eta < 0.0$</td><td rowspan="3">≤ 5 GeV</td><td rowspan="2">≤ 10 GeV</td></tr>
<tr><td>$0.0 < \eta < 0.5$</td></tr>
<tr><td>$0.5 < \eta < 1.0$</td><td>≤ 15 GeV</td></tr>
<tr><td>$1.0 < \eta < 1.5$</td><td rowspan="2">≤ 8 GeV</td><td>≤ 30 GeV</td></tr>
<tr><td>$1.5 < \eta < 2.0$</td><td rowspan="2">≤ 50 GeV</td></tr>
<tr><td>$2.0 < \eta < 2.5$</td><td rowspan="2">≤ 20 GeV</td></tr>
<tr><td>$2.5 < \eta < 3.0$</td><td>≤ 30 GeV</td></tr>
<tr><td>$3.0 < \eta < 3.5$</td><td>≤ 45 GeV</td><td>Can tolerate ≤ ~20 GeV</td></tr>
</table>

- PID requirements driven by unpolarized and polarized (Collins asymmetry) hadron-in-jet fragmentation measurements at mid to high z
- Figures to the right show charged particle momentum for different pseudorapidity – inform the eta ranges and momentum requirements above
- Very demanding expansion of PID capabilities – important for complementarity discussions

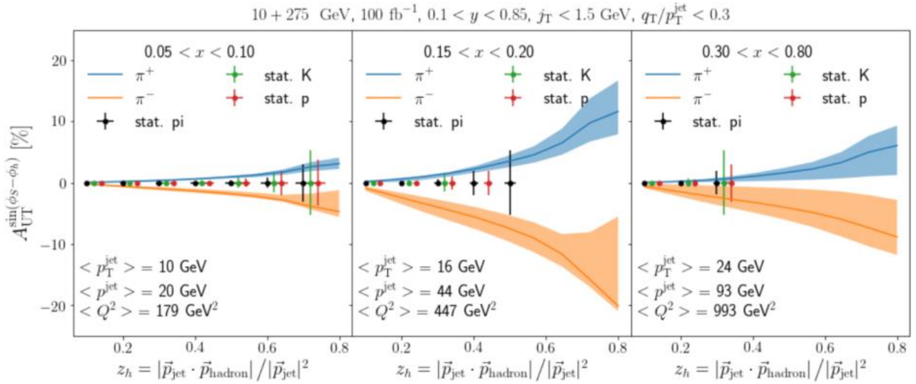




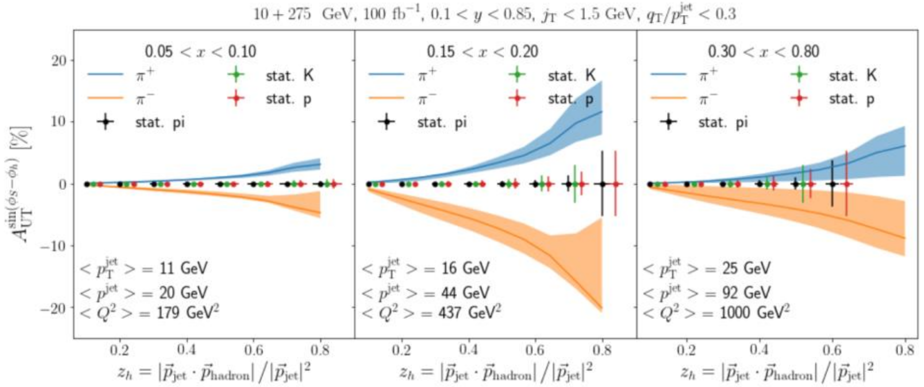
PID



Perfect

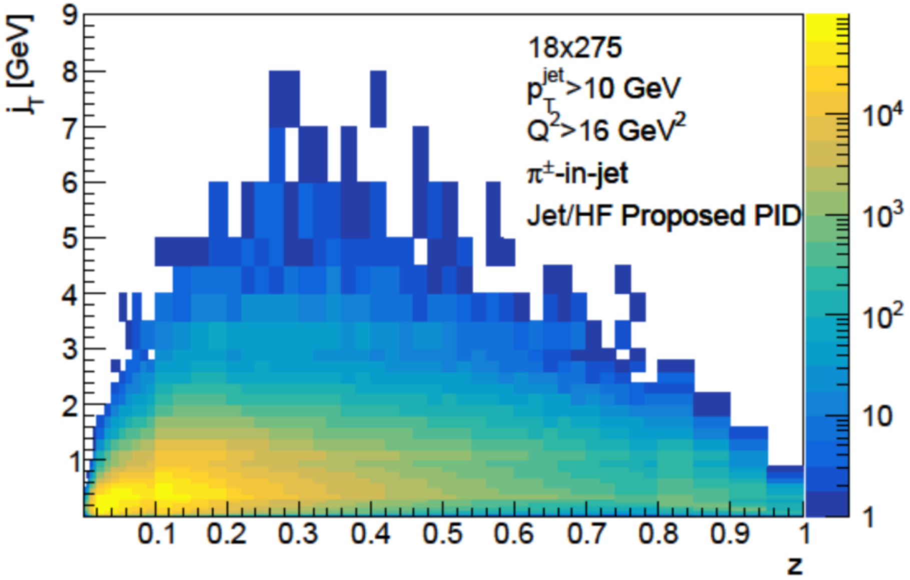


Default

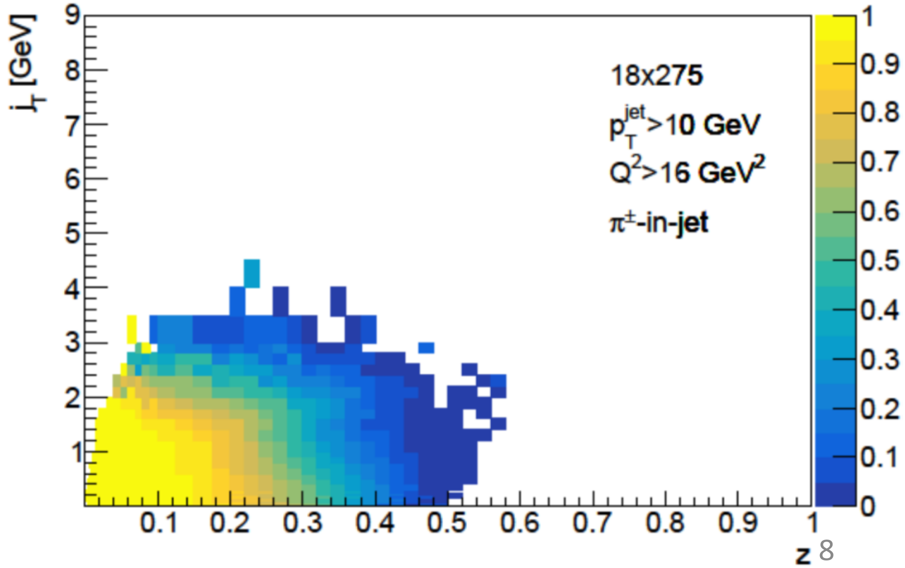


Requested

Requested Coverage: j_T Vs z



Default / Requested Ratio



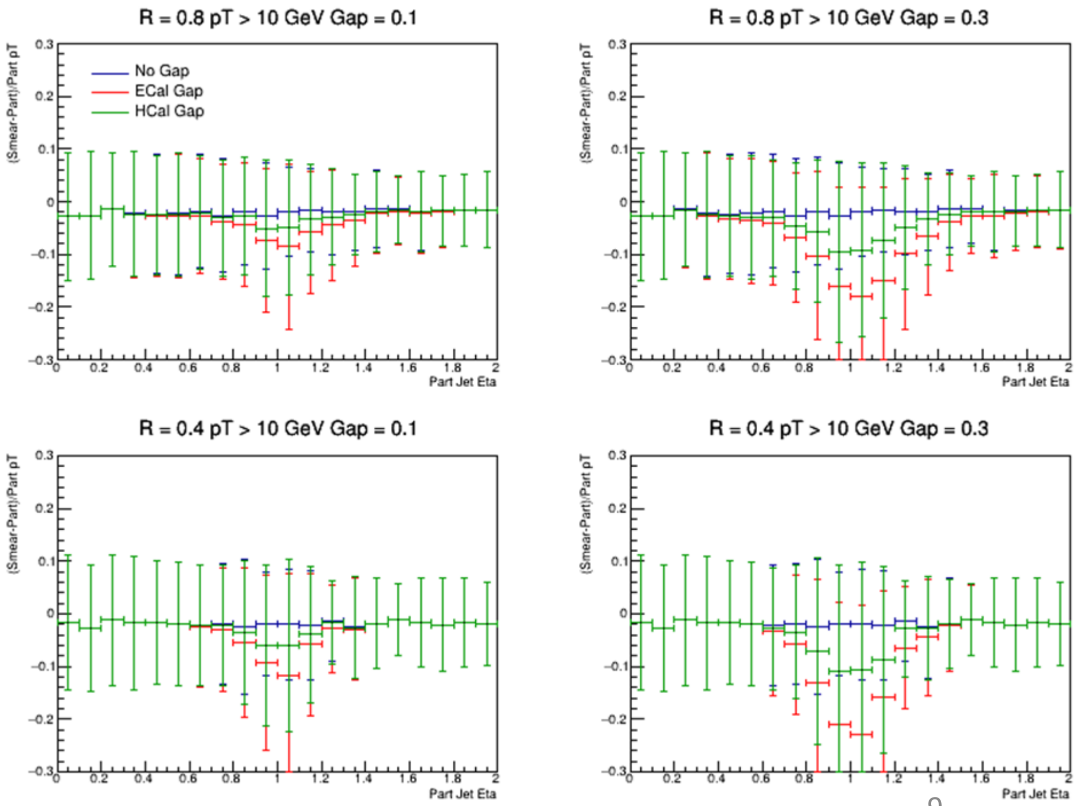
Calorimetry: Electromagnetic

EMCal Energy Resolution

Eta Range	Default Resolution (σE/E)	Requested (σE/E)
$-4.5 < \eta < -2.5$	2%/√E	Same (1-3% constant term acceptable)
$-2.5 < \eta < -2.0$	2%/√E	Same (1-3% constant term acceptable)
$-2.0 < \eta < -1.5$	7%/√E	Same (1-3% constant term acceptable)
$-1.5 < \eta < -1.0$	7%/√E	Same (1-3% constant term acceptable)
$-1.0 < \eta < 4.5$	10-12%/√E	Same (1-3% constant term acceptable)

- Default ECal energy resolutions were found to be sufficient for our needs – even with the addition of realistic constant terms of 1 to 3%
- As with tracker, would like guidance on minimum cluster energy
- Would also like estimate on achievable cluster position resolution and separation
- ~~Can the ECal actually extend to eta of 4.5?~~

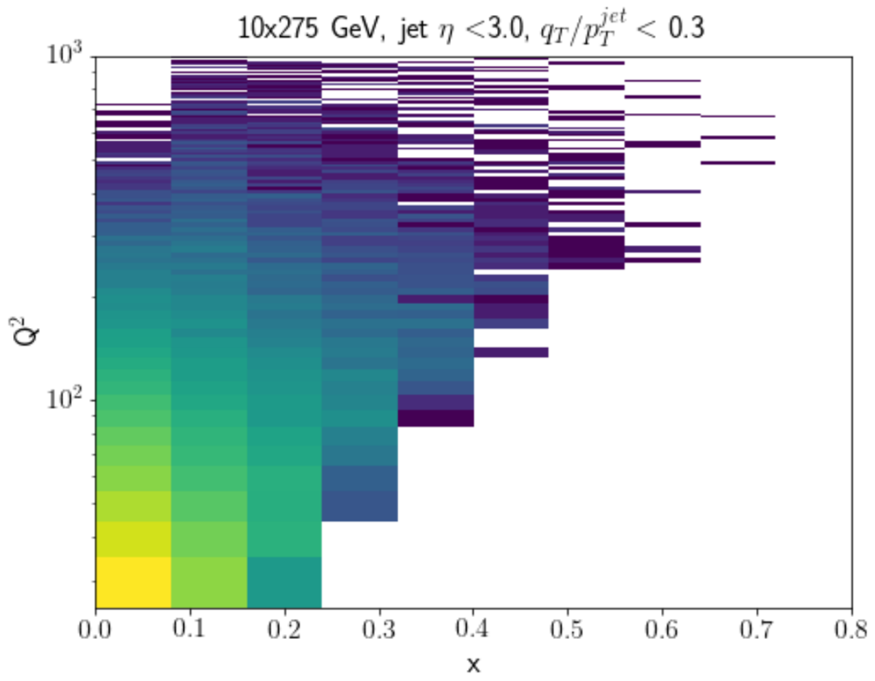
- Also looked at the effect of a service gap (eta = 0.1 or 0.3) on jet reconstruction
- Advocate for the most complete coverage possible

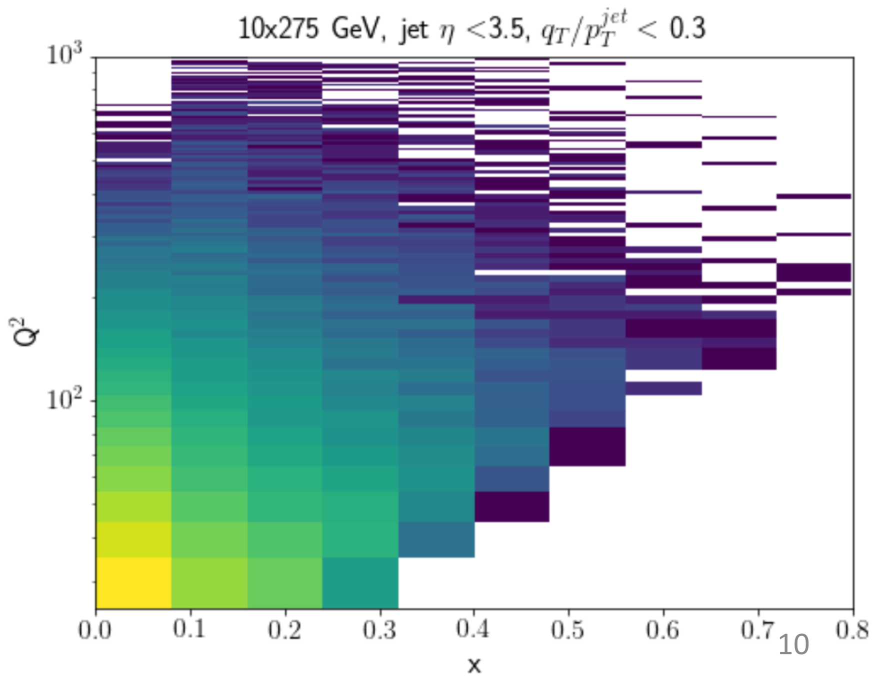


Calorimetry: Hadronic

HCal Energy Resolution

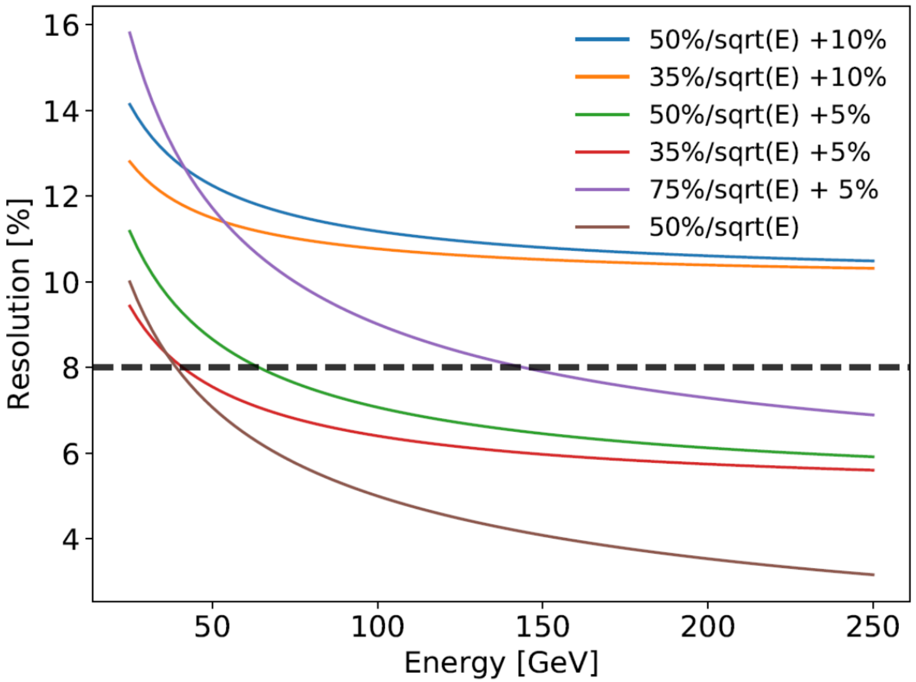
Eta Range	Default Resolution (σE/E)	Requested (σE/E)
$-3.5 < \eta < -1.0$	50%/√E	Same (~10% constant term is acceptable)
$-1.0 < \eta < 1.0$	N/A	85%/√E + 10%
$1.0 < \eta < 3.0$	50%/√E	50%/√E + 10%
$3.0 < \eta < 3.5$		50%/√E + 5%
$3.5 < \eta < 4.0$	N/A	





- Barrel HCal requested for missing transverse energy measurements in CC events (also for Jaquet-Blondel), measurement of neutral hadrons
- 100%/√E sufficient for missing energy, but seen that better resolution needed for accurate jet reconstruction toward smaller eta values
- Request coverage extension up to eta = 4 to gain access to higher x values – constant term of 5% for eta > 3 (constant term dominates at these energies) keeps jet energy resolutions at required levels for measurements such as lepton-jet Sivers
- More study of position resolution / potential cluster separation needed as being able to select jets with no neutral hadron shows possibility of greatly improving jet energy resolution, especially at low eta / p_T / x

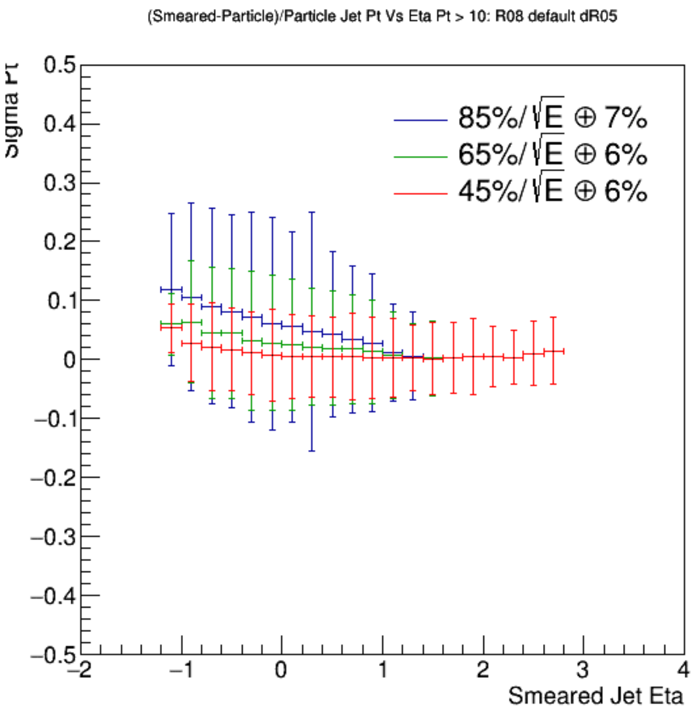
Calorimetry: Hadronic

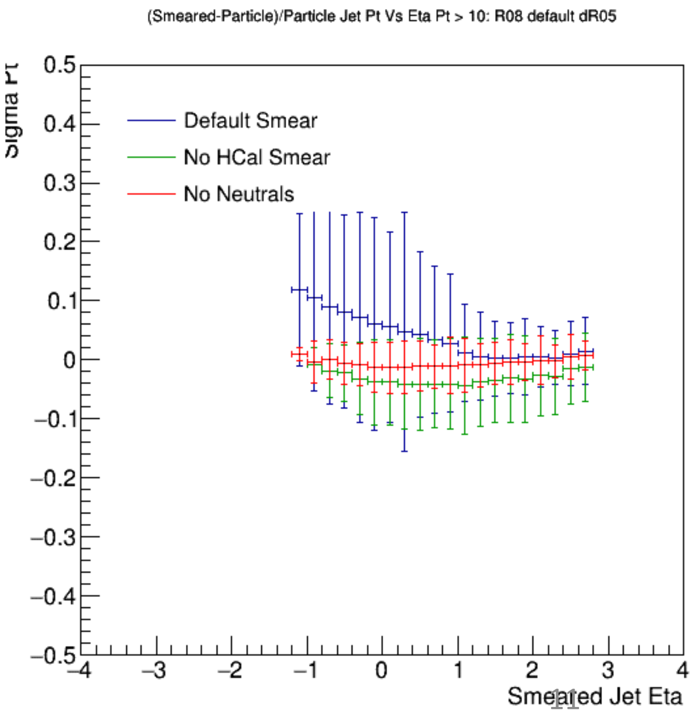


- Improving resolution of barrel HCal can reduce bias in jet energy scale at low eta caused by poorly reconstructed neutral hadrons as seen in left plot below

- Using HCal as a 'neutral hadron veto' can substantially improve jet energy resolution and reduce scale bias as seen in the right plot below

- Plot of different HCal stochastic and constant term combinations shows that constant term dominates at large energy (high eta)





Ongoing Work

Work continues for many of our analyses to look at, for example, different energy ranges or detector configurations as well as to produce realistic statistical projections. We do not anticipate that any ongoing studies will change our detector requirements.

- Open HF studies from LANL group
  - Explore different beam energy combinations (~end of September)
  - HF jet reconstruction taking into account implemented detector performance (~November)

- HF studies from LBNL group
  - Incorporate detector performance to get statistical projections on F2 Charm, etc (~October)
  - Get D-Dbar projections for gluon Sivers and linearly polarized gluon TMD measurements (~October)
  - Λ_c/D^0 projections for hadronization / CNM studies (~November)

- Displaced tracks as a tag of heavy quark states (~October)
  - Explore effects of larger beam pipe
  - Utility in extractions of F2 Charm

- Heavy flavor jet substructure
  - Explore effects of different PID ranges on S/B

Ongoing Work

- Stony Brook jet substructure studies (~November)
  - Study momentum-charge correlations of identified (sub)leading particles as well as neutral particles
  - Explore effects of different PID coverages
  - Jets in eA collisions using the BeAGLE MC

- Jet fragmentation studies
  - Run over increased statistics (different Q2 ranges)
  - Incorporate newest detector parameterizations

- Jet angularity studies
  - Look at different energies and Q2 ranges (~October)

In addition to the topics above, which are being explore via simulation, there are a large number of theoretical presentations that can be studied further beyond the YR