Jets and Heavy Flavor physics working subgroup

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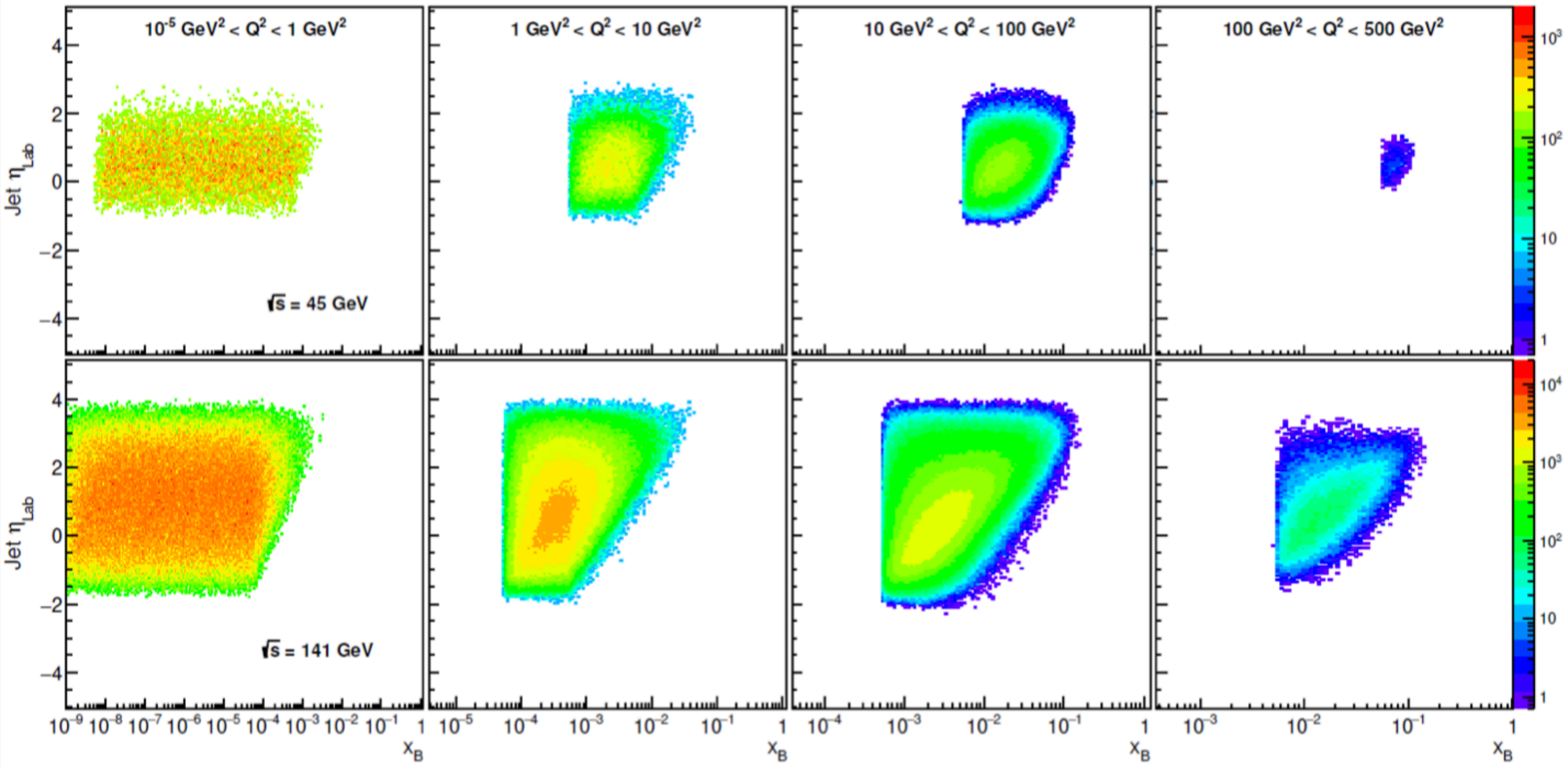
Of course, what follows is the work by many;
Brian, Matt, Miguel, Sooraj, Xuan, Yue Shi, and others

Physics measurement	Channel
Longitudinal spin structure	Inclusive jet and dijet measurements
Sivers asymmetry, special focus on gluons	Jet, lepton-jet and di-jet measurements
Electroweak structure functions, charged currents	Jets, flavor separated jets, Longitudinally polarized reactions ep, parity violating asymmetries
TMDs, nuclear broadening, energy loss	D-jets and photon/lepton tagged jets, ep, eA
Longitudinal and transverse (TMD) fragmentation, shapes and splitting functions	Inclusive jet measurements -> hadrons in jets, energy flow, angularities
Energy loss and hadronization	Heavy mesons cross sections in comparison to light mesons in ep, eA
Charm and beauty content of nucleons and nuclei	Heavy flavor-tagged jets, ep, eA
Flavor and mass dependence of parton showers	Heavy flavor-tagged jet substructure, ep, eA, quarkonia in jets
Extraction of fundamental parameters, hadronization constants, α_s	Global event shapes, thrust, angularities, N-jettiness

Jets

Jet Kinematics

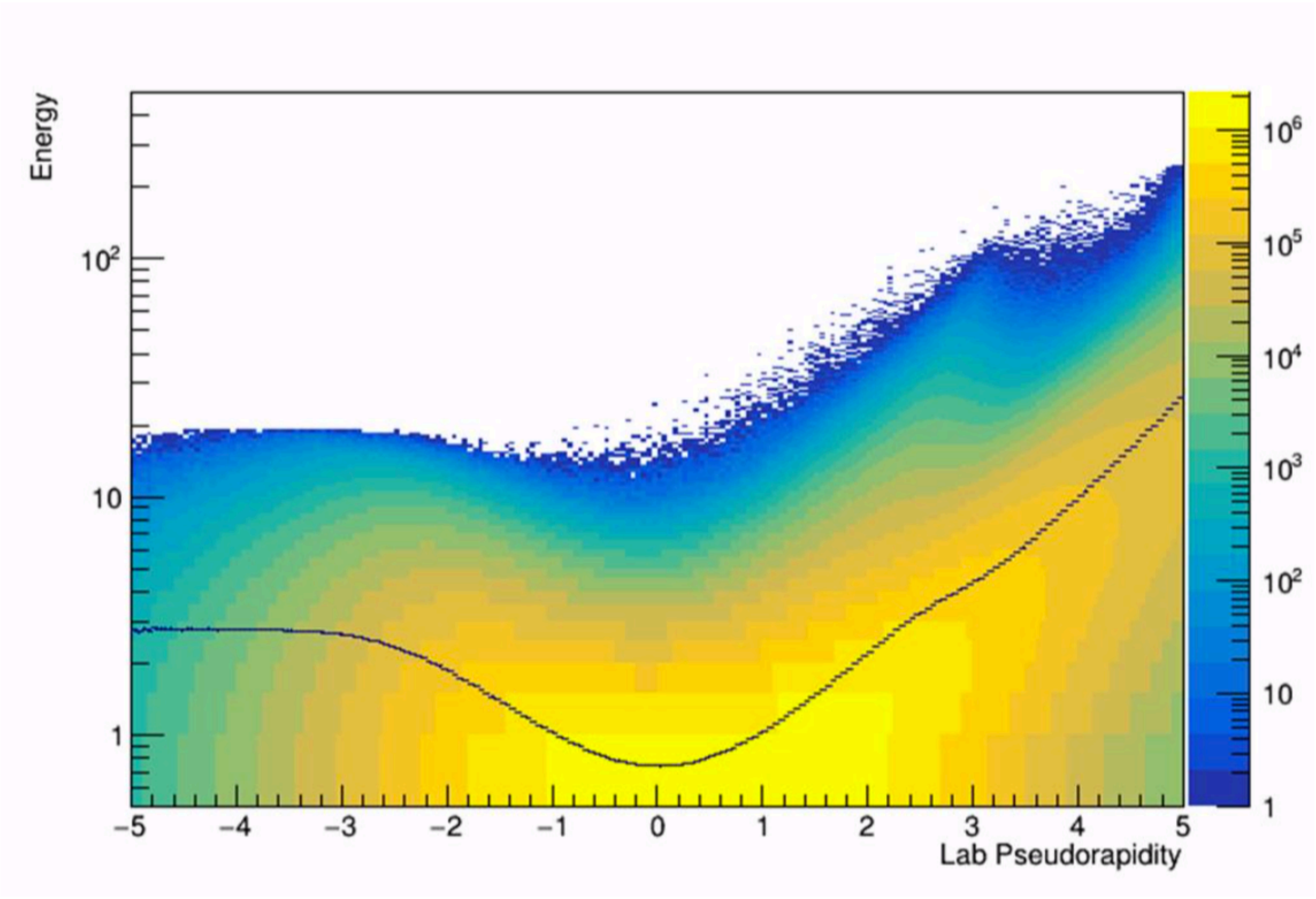


- Jet production extends quite far forward (proton going direction), especially at higher energies – forward tracking and calorimetry will be as important as mid-rapidity

arXiv:1911.00657

Jets

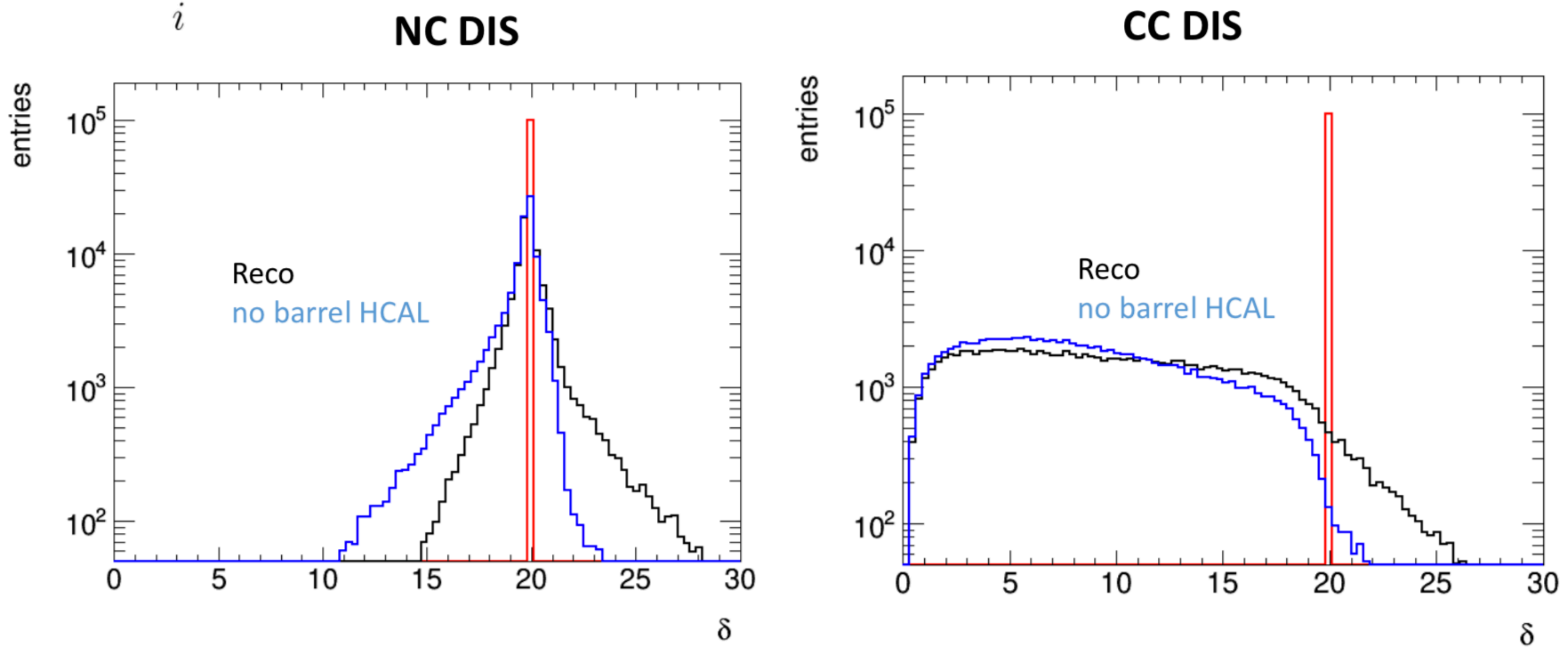
Particle Energy Vs η



Jets - studies are extending to charged-current processes

Background rejection

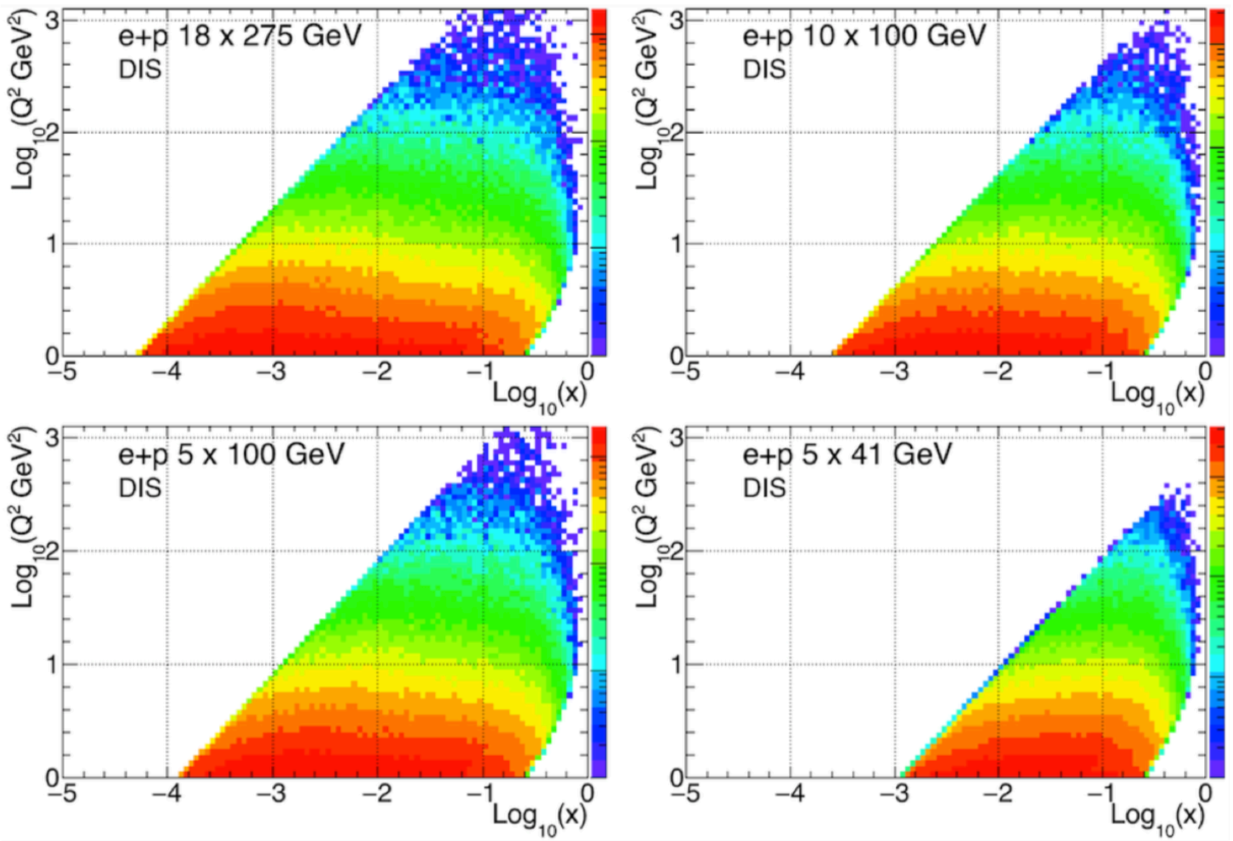
$$\delta = \sum_i E_i(1 - \cos\theta_i)$$

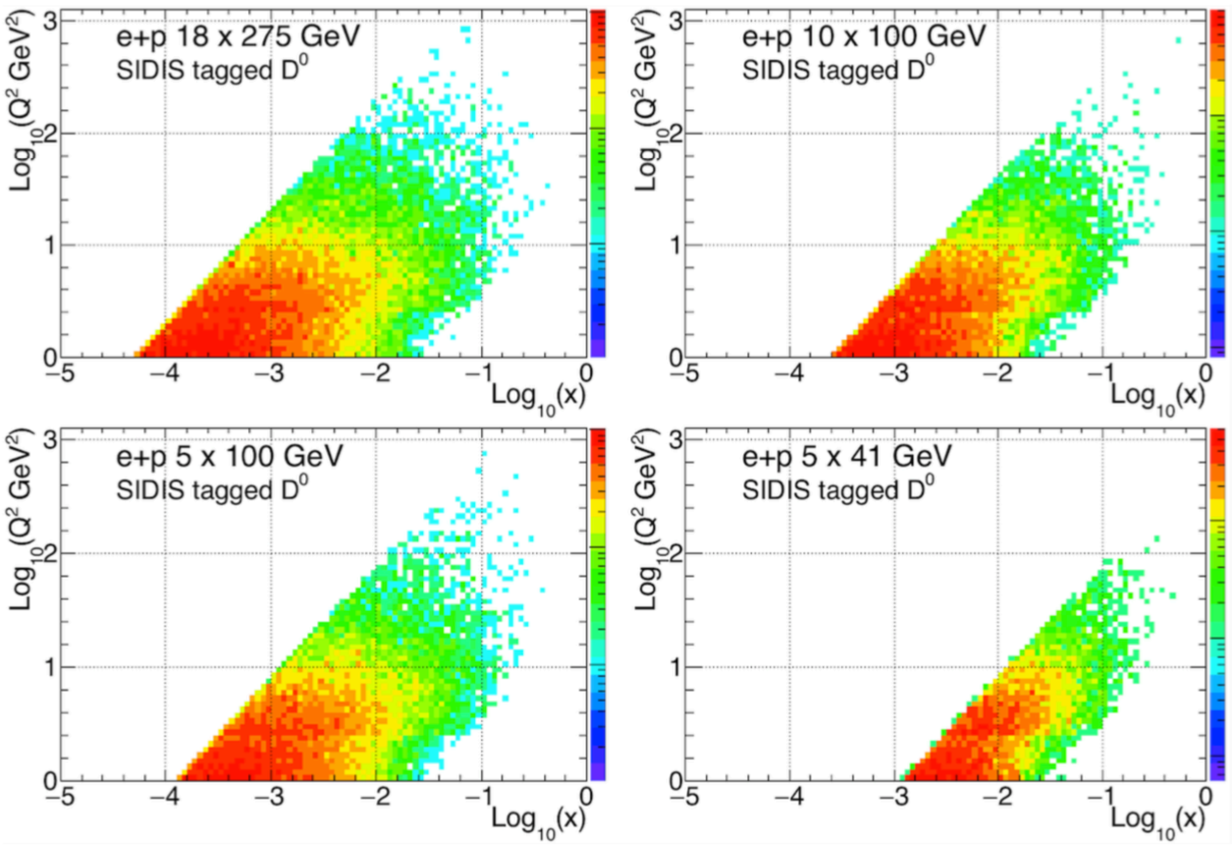


- If one misses track of electron but measures cluster (or viceversa), delta-cut useful to veto NC DIS. Ongoing studies to quantify impact in cross-section

Heavy Quarks

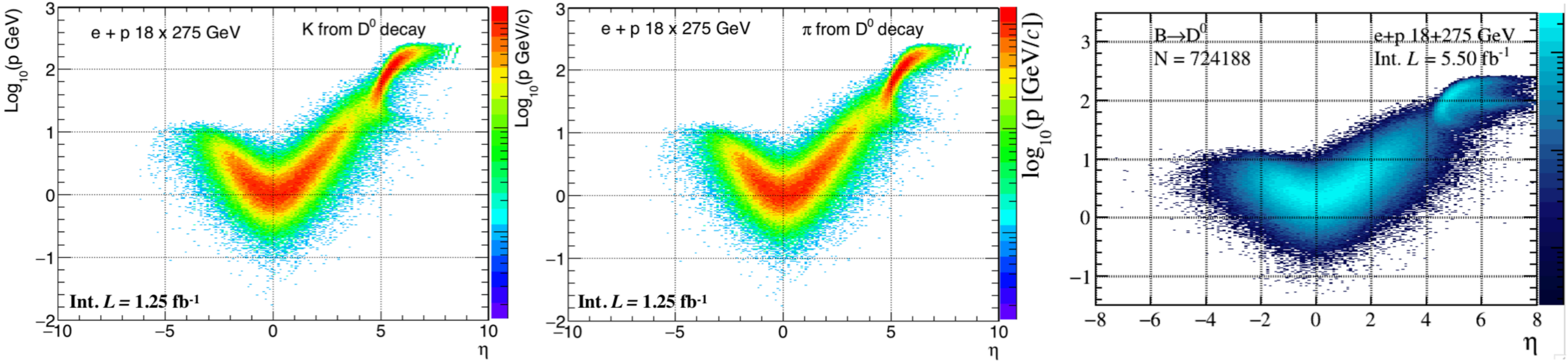
$\log(Q^2)$ vs. $\log(x)$





- **Energies for electron + proton collision program**

Heavy-Flavor Decay Distributions

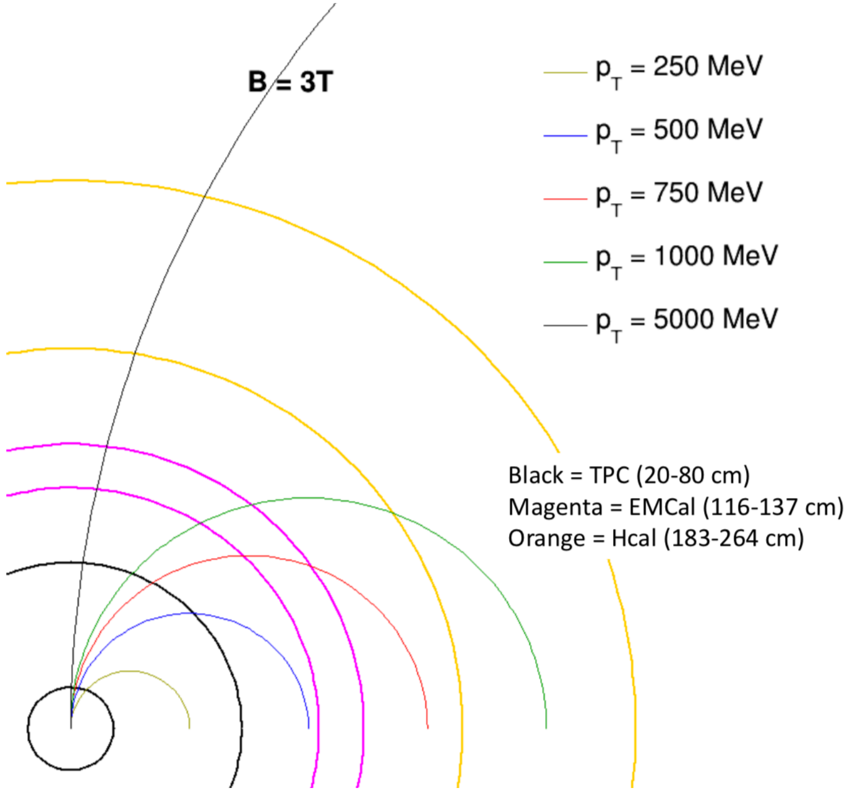


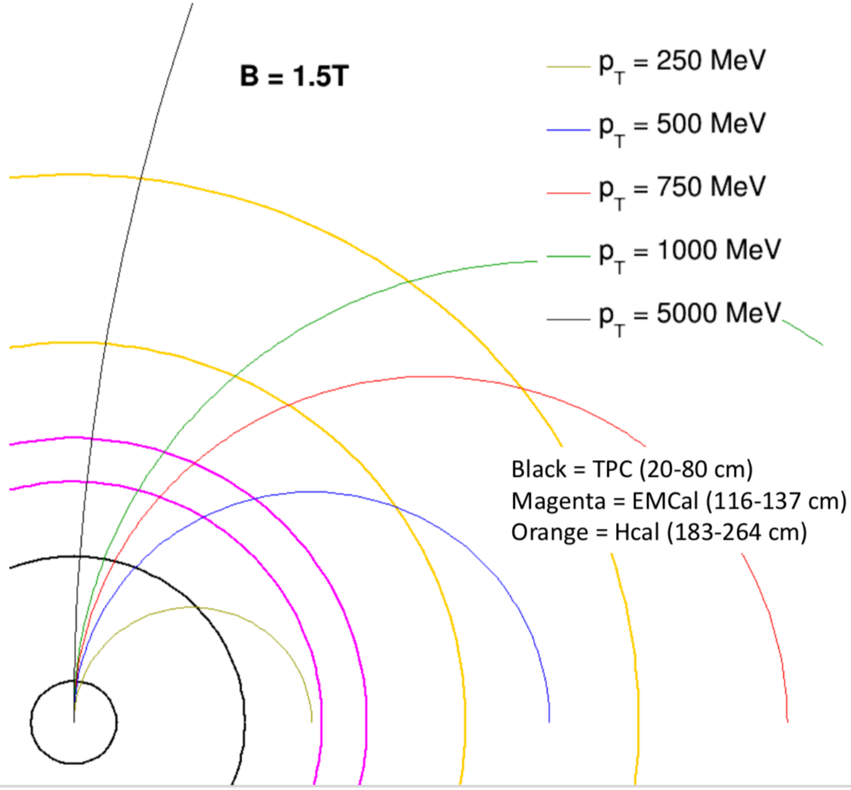
- Charm and bottom decay products within |η|<3
- Similar distributions for other charm hadron decays and $B\rightarrow D^+$/Lepton decays

Which physics processes have contradictory requirements not possible to consolidate in one detector

JHQ has trade-offs in low-momentum (transverse w.r.t. beam-lines) acceptance and forward momentum measurement; this holds for both jets and (very) soft daughters from heavy-quark decays.

Most of the current fast-simulation studies use the physics-detector table. They will need to be extended to include pT thresholds and acceptance-dependent resolutions. Until this is done, it is hard to confirm or refute if these needs can be sufficiently met with one general purpose detector concept.





What physics processes need a dedicated detector / cannot be fulfilled by a general- purpose detector

Fast simulation studies have not identified such processes thus far.

Is the large rapidity acceptance (|etal 3-4) critical for your physics? Any problems if the focusing quadrupoles would be inside the detector volume

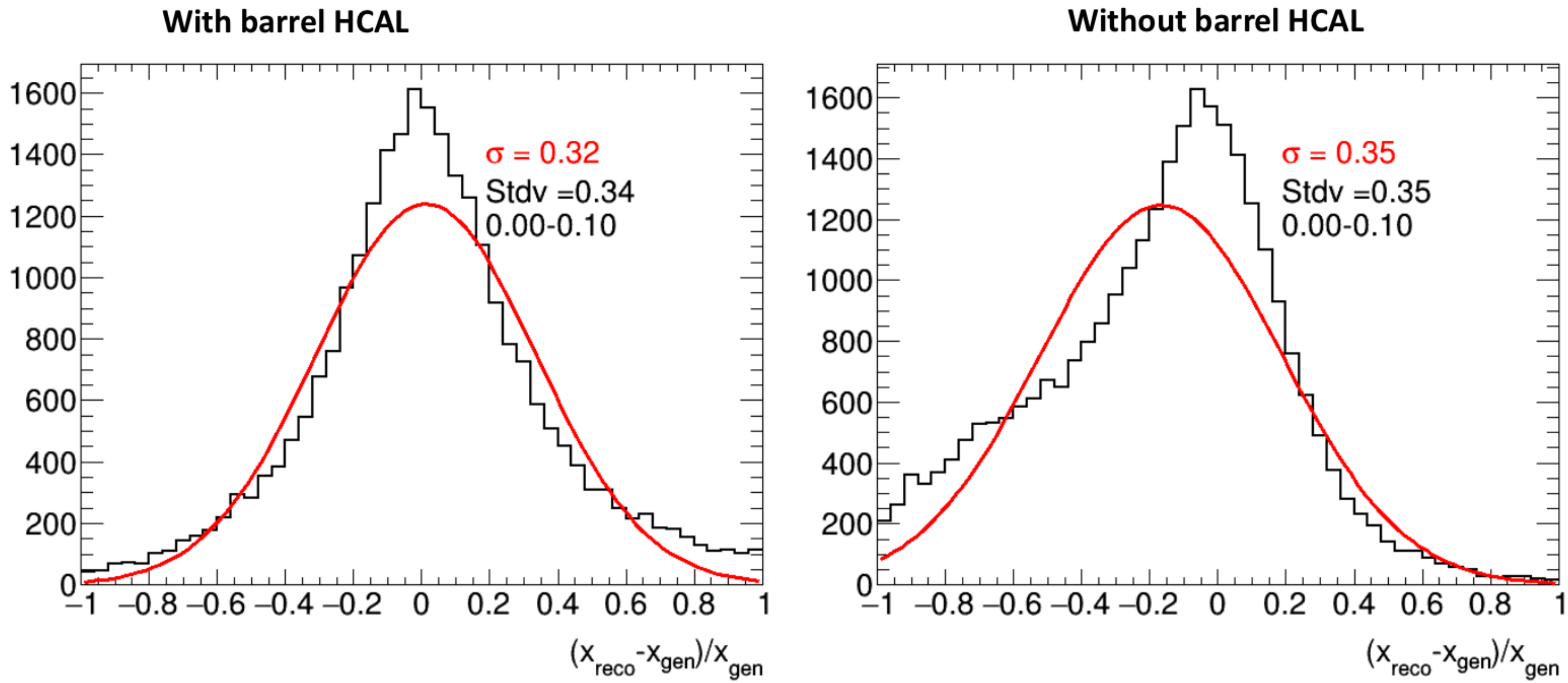
It is important.

Can you briefly summarize your planned physics program in terms of processes of interest and (where applicable) basic kinematic ranges in (x,Q2) or other relevant variables.

A birds-eye view was given on previous slides.

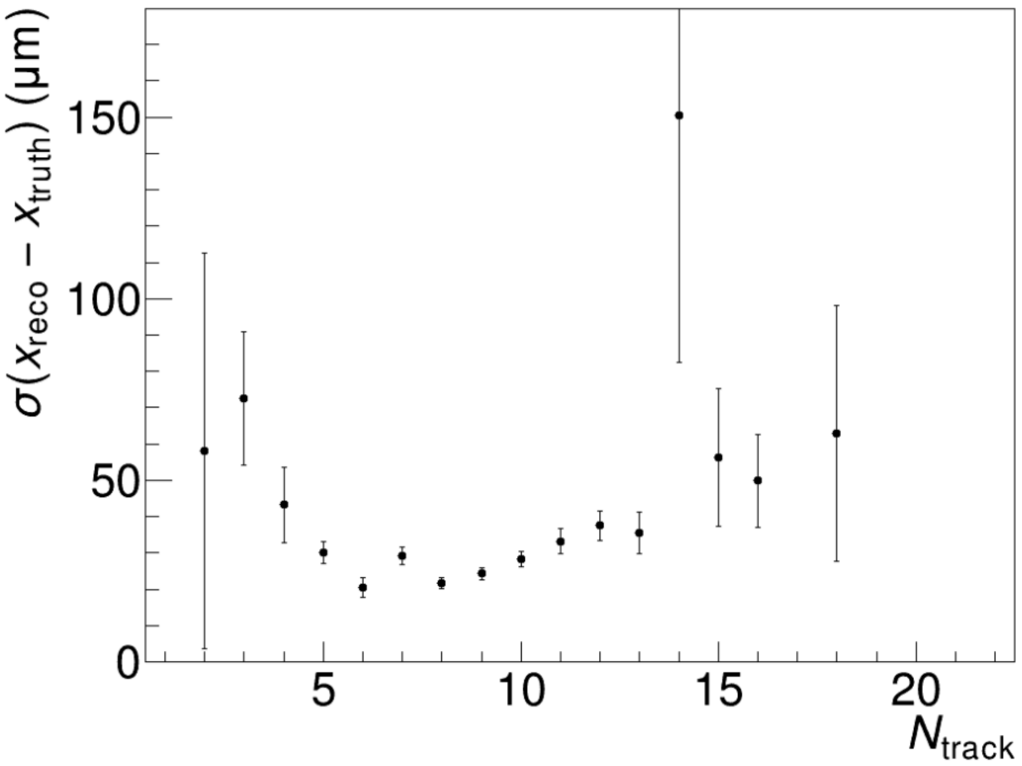
Which basic detector-level measurements (eg track pT/eta, scattered electron, forward neutron/ proton observables, overall HFS, displaced vertices, dE/dx ...) are most essential to realise your physics aims? Can you already say what sort of measurement (acceptance) ranges and resolutions / performance you need?

Fast simulation studies have so far mostly adopted the handbook table and show workable results, with several important qualifiers. E.g. tails in jet reconstruction. From Miguel's studies of CC DIS:



Which basic detector-level measurements (eg track pT/eta, scattered electron, forward neutron/ proton observables, overall HFS, displaced vertices, dE/dx ...) are most essential to realise your physics aims? Can you already say what sort of measurement (acceptance) ranges and resolutions / performance you need?

Fast simulation studies have so far mostly adopted the handbook table and show workable results, with several important qualifiers.   E.g. vertexing. Fast simulation studies are starting to go beyond adopting a single DCA number. Beamline constraints, as discussed by Ferdinand Willeke during the Pavia accelerator Q&A, have not yet been propagated. Some of the WG members are involved in GEANT-based simulations within the tracking WG.



EICroot based,

Standalone RAVE vertex reconstruction (GENFIT tracks),

10um pixels

Old beam-pipe diameter

Which basic detector-level measurements (eg track pT/eta, scattered electron, forward neutron/ proton observables, overall HFS, displaced vertices, dE/dx ...) are most essential to realise your physics aims? Can you already say what sort of measurement (acceptance) ranges and resolutions / performance you need?

Fast simulation studies have so far mostly adopted the handbook table and show workable results, with several important qualifiers. Ideal PID has been assumed in most/all JHQ work thus far.

Which basic detector-level measurements (eg track pT/eta, scattered electron, forward neutron/ proton observables, overall HFS, displaced vertices, dE/dx ...) are most essential to realise your physics aims? Can you already say what sort of measurement (acceptance) ranges and resolutions / performance you need?

Fast Simulation Setup

η	Nomenclature			Tracking: Resolution	Tracking: Allowed X/X_0	Tracking: Si-Vertex	Electrons: Resolution σ_E/E	Electrons: PID	$\pi/K/p$: p-Range (GeV/c)	$\pi/K/p$: Separation
-6.9 to -5.8	↓ p/A	Auxiliary Detectors	low-Q2 tagger	$\sigma\theta/\theta < 1.5\%$; $10^{-6} < Q^2 < 10^{-2}$ GeV^2						
...										
-4.5 to -4.0			Instrumentation to separate charged particles from photons				$2\%/\sqrt{E}$			
-4.0 to -3.5										
-3.5 to -3.0		Central Detector	Backward Detector	$\sigma_p/p \sim 0.1\% \oplus 0.5\%$	~5% or less X	TBD		π suppression up to 1:10^4	≤ 7 GeV/c	≥ 3 σ
-3.0 to -2.5										
-2.5 to -2.0				σ_p/p $0.1\% \oplus 0.5\%$			$2\%/\sqrt{E}$			
-2.0 to -1.5				σ_p/p $0.05\% \oplus 0.5\%$			$7\%/\sqrt{E}$			
-1.5 to -1.0							$7\%/\sqrt{E}$			
-1.0 to -0.5			Barrel	$\sigma_p/p \sim 0.05\% \times p + 0.5\%$		$\sigma_{xyz} \sim 20$ μm, $d_0(z) \sim d_0(r\Phi) \sim 20/p_T$GeV μm + 5 μm	$(10\text{-}12)\%/\sqrt{E}$		≤ 5 GeV/c	
-0.5 to 0.0										
0.0 to 0.5										
0.5 to 1.0										
1.0 to 1.5			Forward Detectors	$\sigma_p/p \sim 0.05\% \times p + 1.0\%$		TBD			≤ 8 GeV/c	
1.5 to 2.0										
2.0 to 2.5									≤ 20 GeV/c	
2.5 to 3.0				$\sigma_p/p \sim 0.1\% \times p + 2.0\%$						
3.0 to 3.5									≤ 45 GeV/c	
3.5 to 4.0	↑ e	Auxiliary Detectors	Instrumentation to separate charged particles from photons							
4.0 to 4.5										
...			Neutron Detection							
> 6.2			Proton Spectrometer	$\sigma_{intrinsic}(\lvert t \rvert)/\lvert t \rvert < 1\%$; Acceptance: $0.2 < p_T < 1.2$ GeV/c						

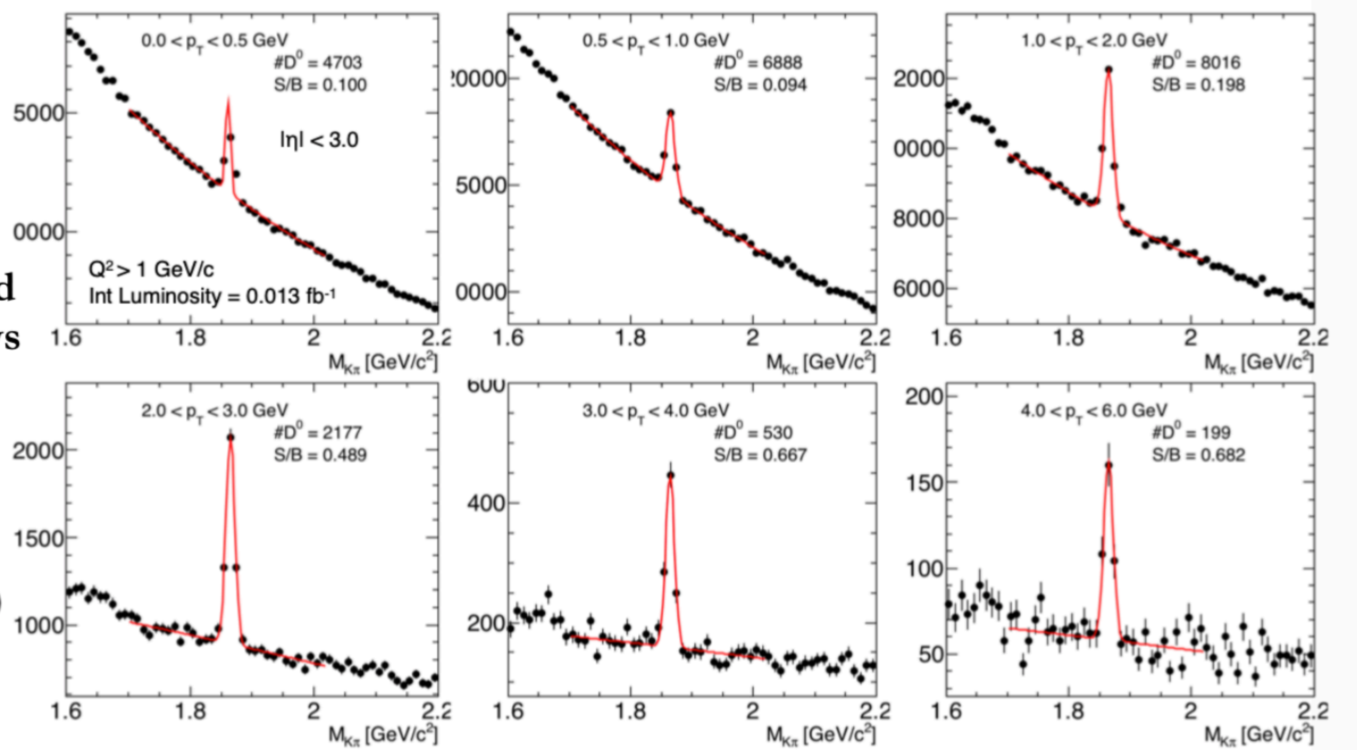
https://physdiv.jlab.org/DetectorMatrix/

- Charm and bottom reconstruction studied using fast simulation smearing of PYTHIA 6.4 output
- Momentum and pointing resolutions taken from detector matrix page as baseline (focusing on central detector $|\eta|<3$)
- Working assumptions: Perfect tracking and PID, and central transverse pointing resolution extends to $|\eta|<3$

Which basic detector-level measurements (eg track pT/eta, scattered electron, forward neutron/ proton observables, overall HFS, displaced vertices, dE/dx ...) are most essential to realise your physics aims? Can you already say what sort of measurement (acceptance) ranges and resolutions / performance you need?

D^0 Reconstruction

- All $K\pi$ pairs taken from PYTHIA output (no vertex requirement)
- Background from combinatorial and partially reconstructed charm decays
- Good S/B compared to hadron-hadron collisions
  - p+p (1/100 @ √s= 200 GeV)
  - A+A (1/10000 @ √s$_{NN}$= 200 GeV)



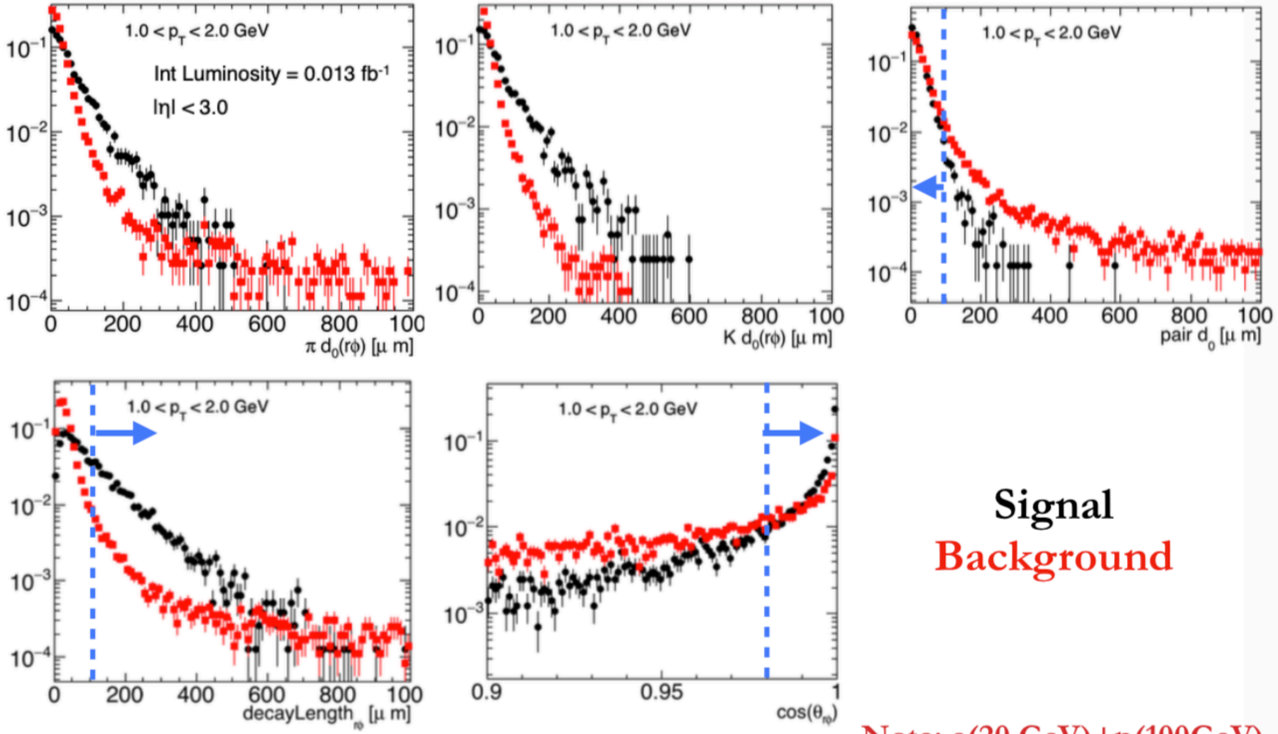
Note: e(20 GeV)+p(100GeV)

Which basic detector-level measurements (eg track pT/eta, scattered electron, forward neutron/ proton observables, overall HFS, displaced vertices, dE/dx ...) are most essential to realise your physics aims? Can you already say what sort of measurement (acceptance) ranges and resolutions / performance you need?

D^0 Topological Variables

- Only transverse impact parameters (d_0) looked at
- Possibility to add longitudinal dimension for additional improvement
- Using a rφ vertex resolution of 20 μm
  - "By-eye" cuts chosen:
    - $\cos(\theta_{r\varphi}) > 0.98$
    - dL > 40 μm
    - pair d_0 < 150 μm
  - No optimization or p_T dependence

D^0 p_T range of 1-2 GeV/c for example



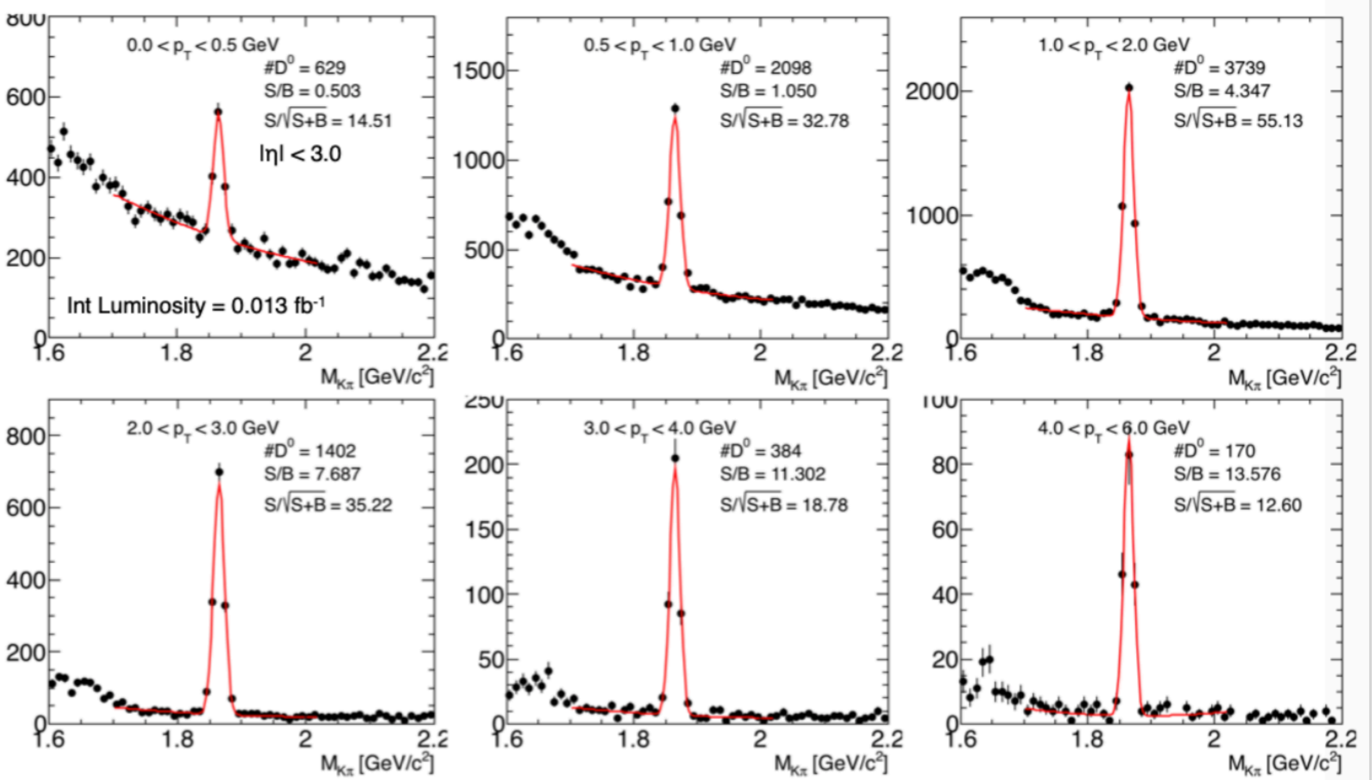
Signal
Background

Note: e(20 GeV)+p(100GeV)

Which basic detector-level measurements (eg track pT/eta, scattered electron, forward neutron/ proton observables, overall HFS, displaced vertices, dE/dx …) are most essential to realise your physics aims? Can you already say what sort of measurement (acceptance) ranges and resolutions / performance you need?

D^0 Reconstruction w/ Vertexing

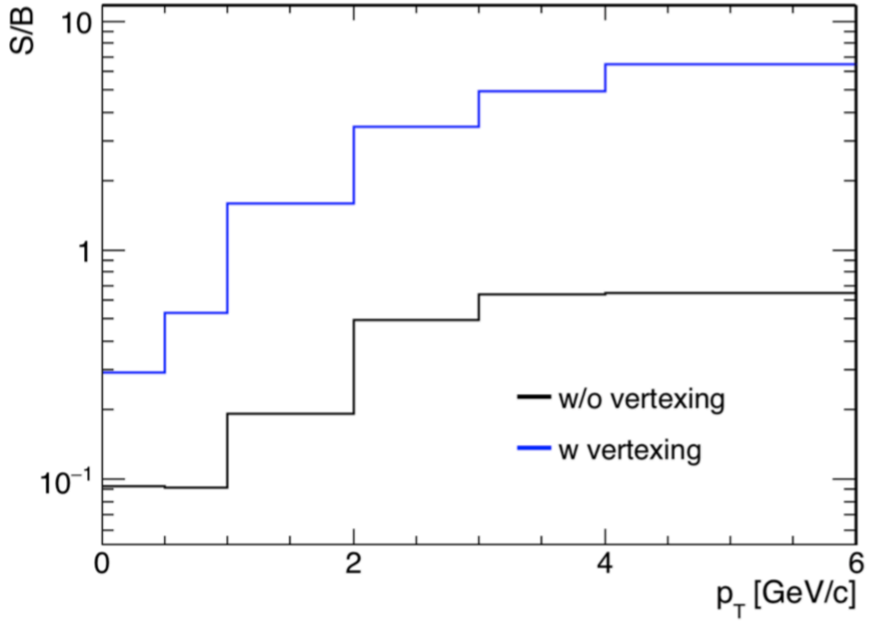
- Significant reduction of background and improvement of signal significance
- Room for additional improvement with optimization and incorporating longitudinal dimension on topological variables

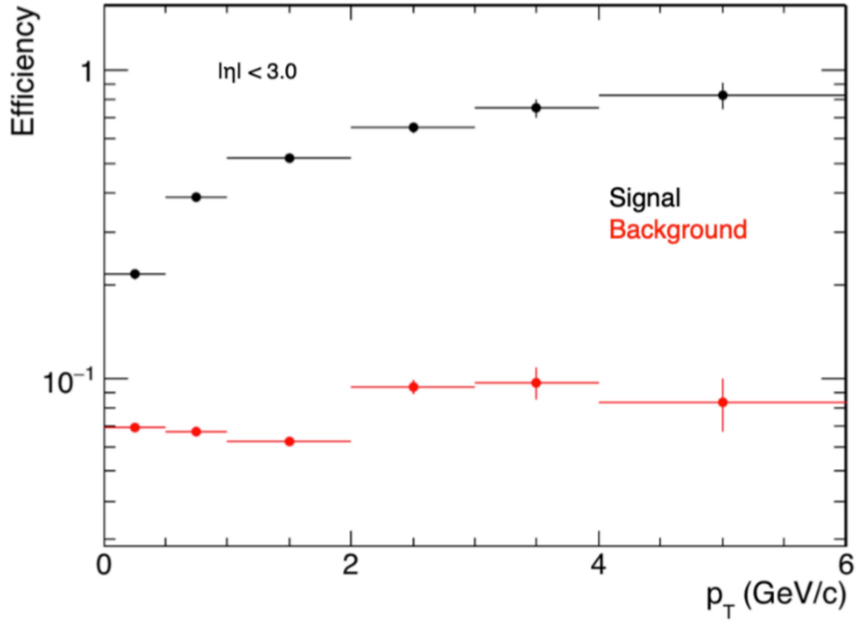


Note: e(20 GeV)+p(100GeV)

Which basic detector-level measurements (eg track pT/eta, scattered electron, forward neutron/proton observables, overall HFS, displaced vertices, dE/dx ...) are most essential to realise your physics aims? Can you already say what sort of measurement (acceptance) ranges and resolutions / performance you need?

D^0 S/B and Efficiency





- **Reiterating nice improvement of D^0 S/B with vertexing**
  - Factor of 10(2) for high(low) p_T
- **Modest signal efficiency with "by-eye" cuts**

Which basic detector-level measurements (eg track pT/eta, scattered electron, forward neutron/proton observables, overall HFS, displaced vertices, dE/dx ...) are most essential to realise your physics aims? Can you already say what sort of measurement (acceptance) ranges and resolutions / performance you need?

Table 1: Channels listed are increasingly demanding. For every row consider all requirements above as well. The (x, Q^2) dependence of the observables is omitted for brevity. Date: May 20, 2020, Miguel Arratia

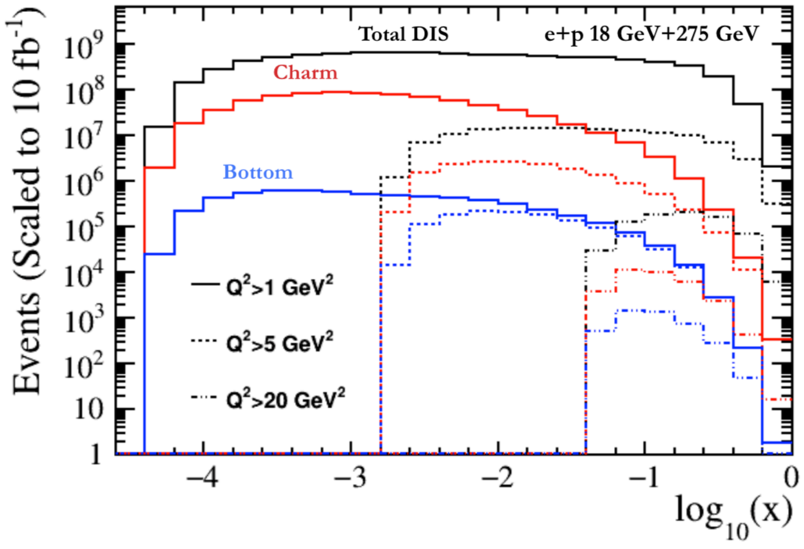
Channel	Observable	Goal	Physics-driven requirement	Category	numbers
e-jet (NC) 100 fb^{-1}	$d\sigma$, $A_{UT}(\Delta\phi)$	k_T-dependence of quark Sivers	$\Delta\phi$ res. << intrinsic width $\sigma(\Delta\phi) < 0.02$ rad $R = 1.0 \rightarrow$ had. corr. $O(1)\%$ particle-flow reco	Jet res. Acceptance Granularity	jet $dE/E < 20\%/\sqrt{E}$ $\rightarrow$ ECAL&HCAL $dE/E < 60\%/\sqrt{E}$ 2π, $\lvert\eta\rvert < 3.5$ HCAL and ECAL endcap $\Delta\phi \times \Delta\eta \leq 0.025 \times 0.025$
h-in-jet (NC) 100 fb^{-1}	$d\sigma$, $A_{UT}(z_h, j_T)$	q-transversity	dp/p at high $z <$ jet dE/E	Tracker PID	$dp/p < 3\%$ at 50 GeV, up to $\eta = 3.0$ up to $\eta < 3.5$ and 50 GeV
ν-jet (CC) 100 fb^{-1}	$d\sigma$, A_{UT}	u Sivers	$\Delta\phi$ << 0.3 rad Bkg. rej. to phot and NC >70% survival prob. for 5 bins per-decade in x, Q^2	E_T^{miss} res. Acceptance Jet/E_T^{miss} res.	$dE_T^{miss}/E_T^{miss} < 15\%$ 2π, $\lvert\eta\rvert < 3.5$ HCAL and ECAL E>100 MeV thres. ECAL E>400 MeV thres. HCAL $p_T > 100$ MeV tracker $dx/x < 20\%$, $dE_T^{miss}/E_T^{miss} < 15\%$
h-in-jet (CC) 100 fb^{-1}	$d\sigma$, $A_{UT}(z_h, j_T)$	u-transversity	—	—	—
c-jet (CC) 100 fb^{-1}	$d\sigma$, A_{LL}	s PDF& helicity	charm-tagging	Tracker PID	c-jet tag at $> 10\%$ (<0.05%) $\sigma(DCA) = 20$ μm, up to $\lvert\eta\rvert = 3$ $\approx$ 100% eff. TBD
h-in-c-jet (CC) 100 fb^{-1}	$d\sigma$, $A_{UT}(z_h, j_T)$	s-transversity	—	—	—
c-jet (e^+ CC) 100 fb^{-1}	$d\sigma$, A_{LL}	$s/\bar{s}$ asymmetry	positrons	—	—

For charged particles, how important is low momentum acceptance versus high momentum resolution (this informs the optimal choice of magnetic field). What is the sensitivity to the magnitude of the magnetic field.

Touched on in earlier slides. Refined fast-simulation studies will require consideration of threshold effects and tracker configuration (e.g. 2 vs. 3 vertexing layers will make a difference).

How important is integrated luminosity? For the anticipated integrated luminosities, will your observable be systematic or statistics-limited? If you expect to be systematically limited, which systematic source (or sources) are the most important?

Bottom Production Rate

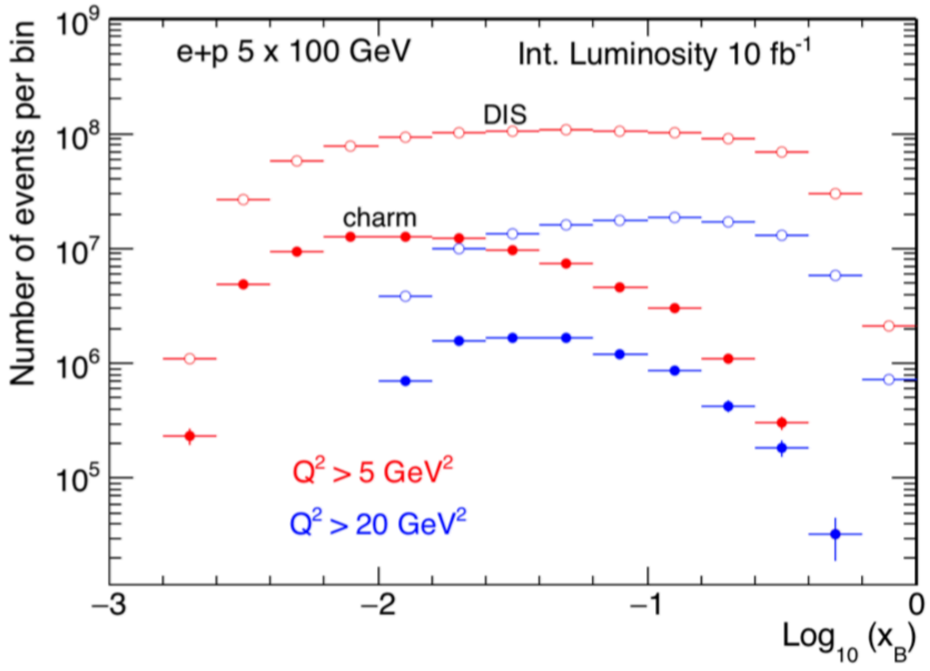


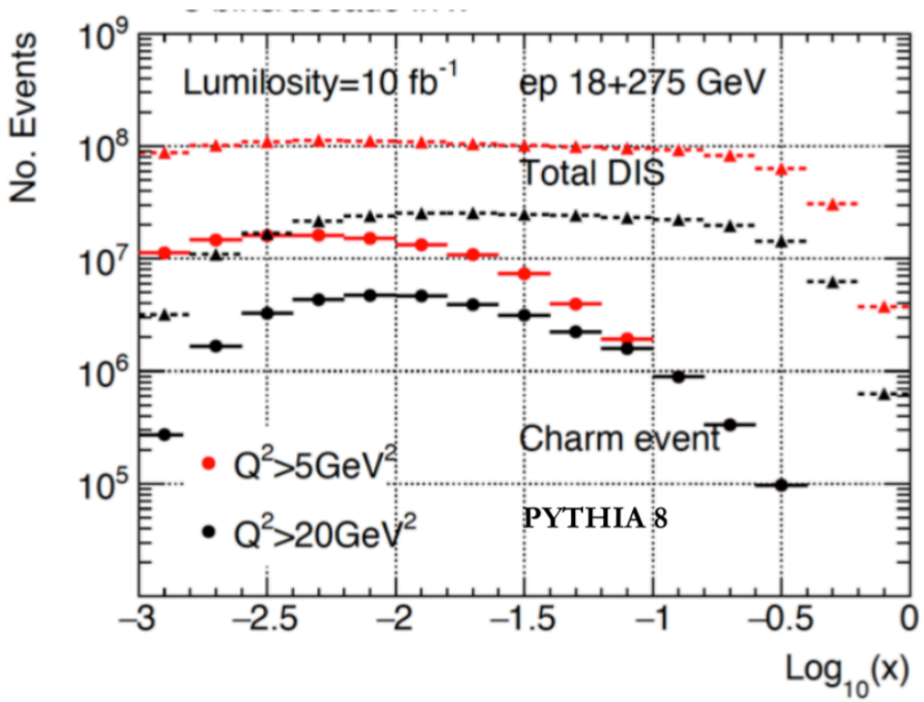
- Bottom cross-section roughly 10% of charm for $Q^2 > 5$ GeV^2

What beam energies are ideal for your physics aims (quantify if possible)?

A measurement of F2-charm reaching small(-ish) x with a reasonable Q2 lever-arm will require high center-of-mass. The converse, high-x, favors (measurement wise) smaller sqrt(s).

Charm Production Rate





- Total charm cross-section w.r.t. total DIS comparable between PYTHIA 6 and 8
- Note different collisional energies
- Similar to previous studies in arXiv:1608.08686 + arXiv:1610.08536

How important is polarisation to your physics programme (quantify if possible, in terms of polarisation level and systematic precision requirements)? If applicable, discuss lepton and hadron polarization separately.

Required e.g. for jet A_{LL} (double-spin asymmetries do not really distinguish electron from hadron). Otherwise, too early for us to discuss in depth.

How important is the Interaction Region design for your physics observable and do you have criteria that might impact the design? For example, would you be impacted by reduced forward acceptance for neutrons, protons, photons?

No detailed studies to identify or back up specific jet and heavy-quark needs.

What is the sensitivity of your physics to the lower y-cut and the depolarization factor

Inclusive jet A_{LL} would not depend (directly) on depolarization in the scattering of the electron, or a y-cut (high or low).