Jets for 3D imaging

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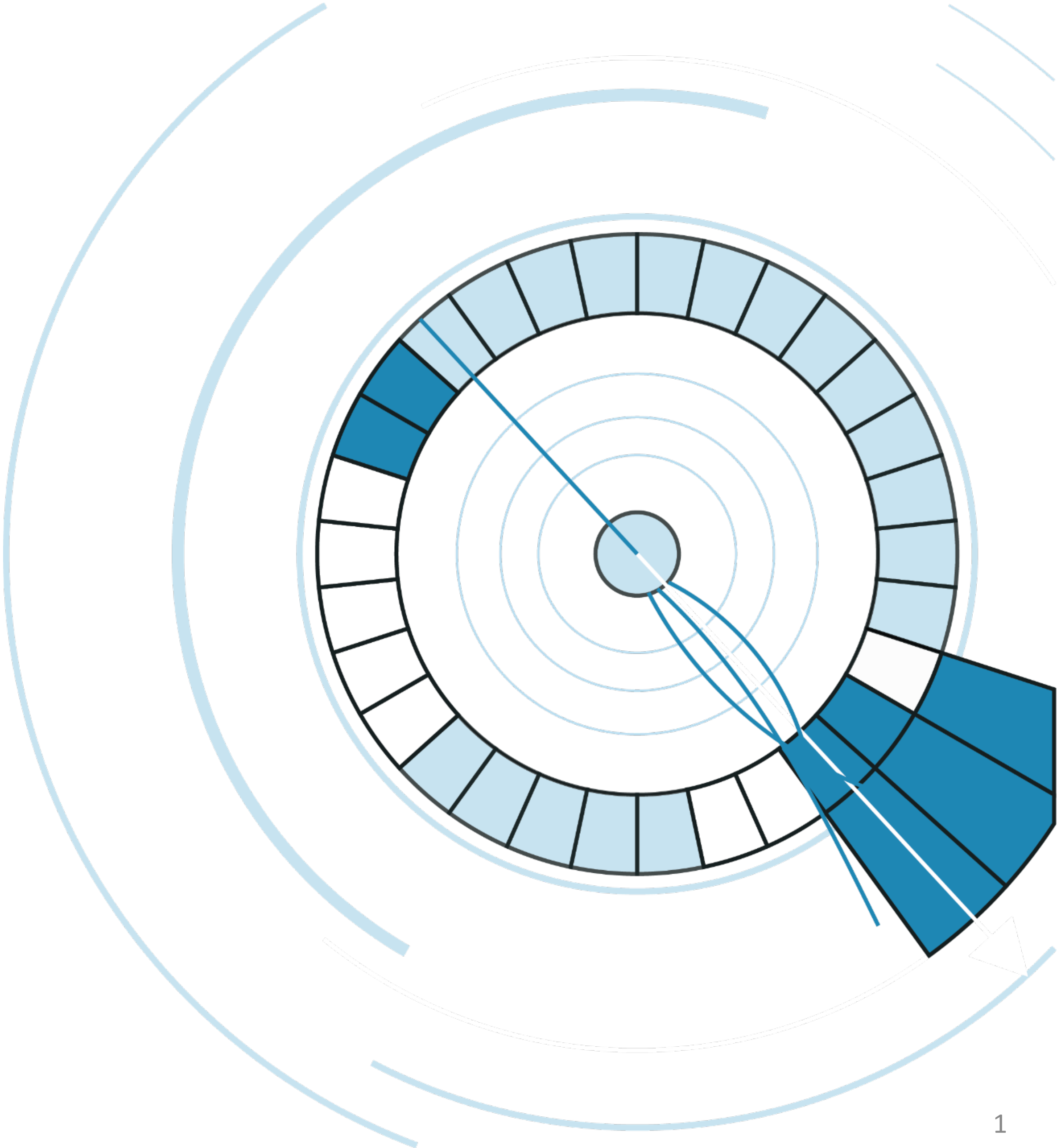
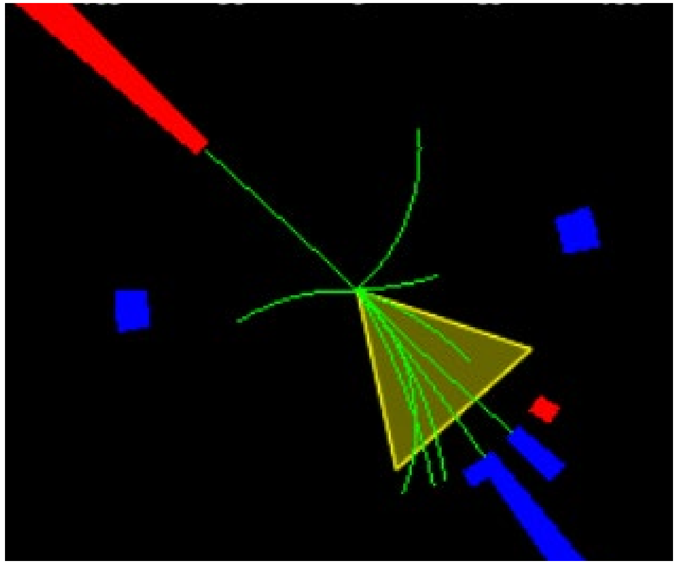
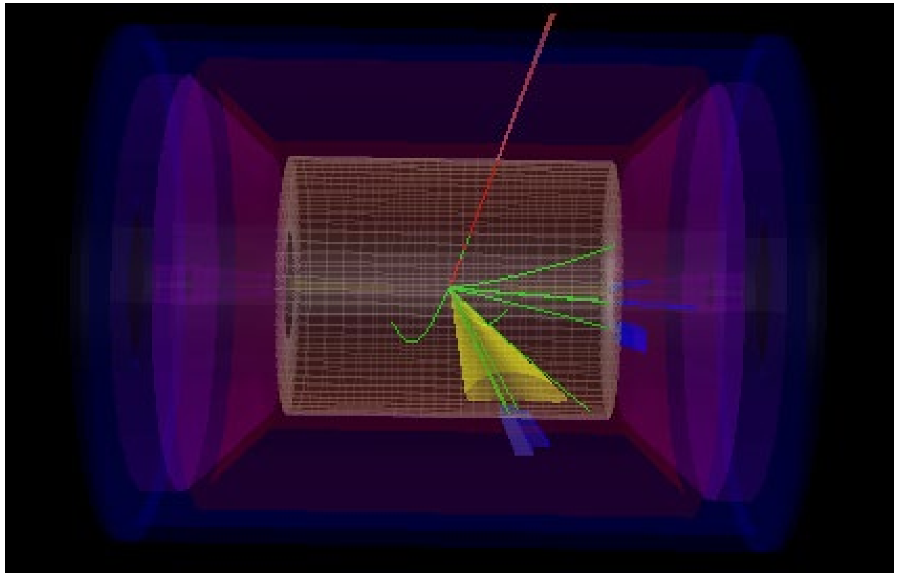
UNIVERSITY OF CALIFORNIA
UC RIVERSIDE

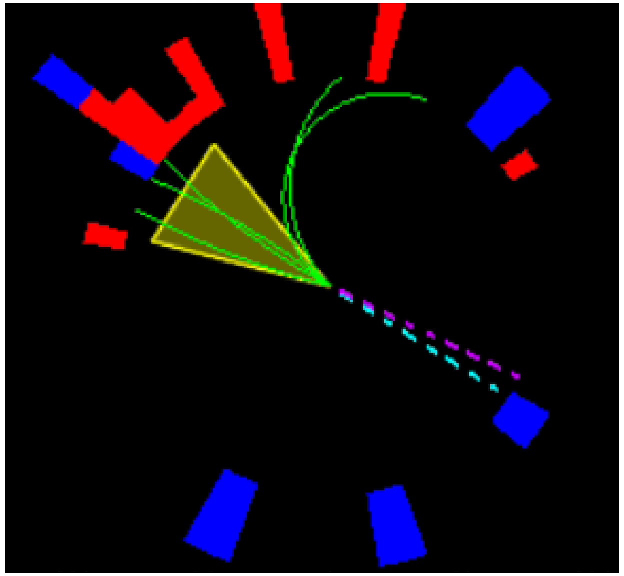
SIDIS YR group, May 18th 2020



EIC, a jet factory, will make the first jets in polarized DIS



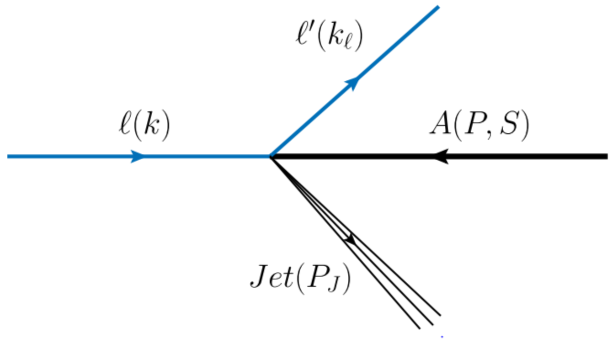


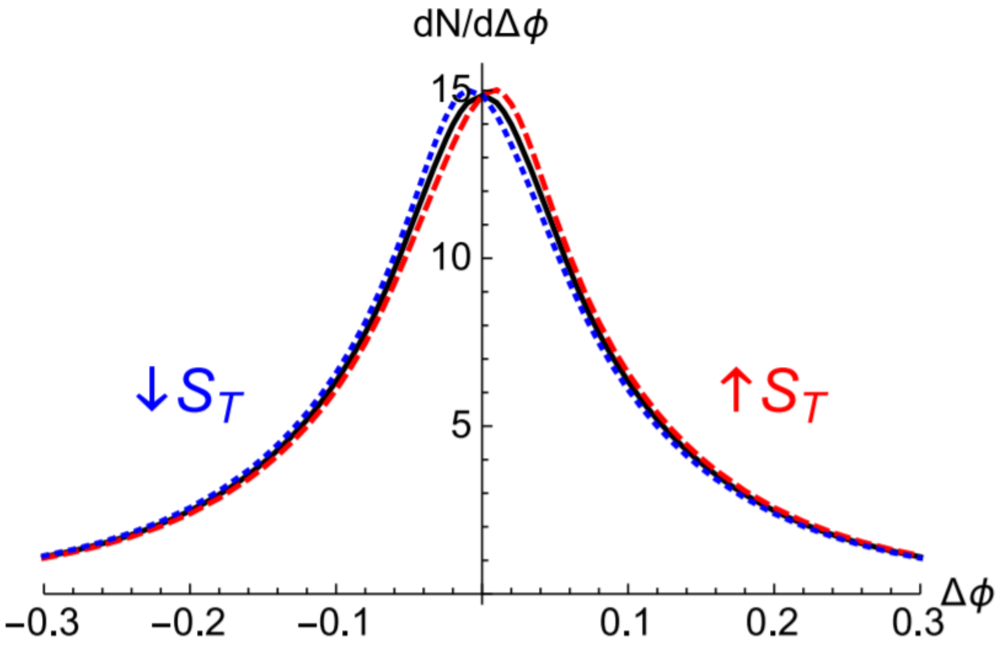


- DIS jets: a new tool for 3D imaging to address key EIC goals.
- Potential for unique jet program, unlike any previous collider or fixed-target experiment

Quark Sivers effect with Jets

Liu, Ringer, Vogelsang, Yuan, PRL 122 192003 (2019)

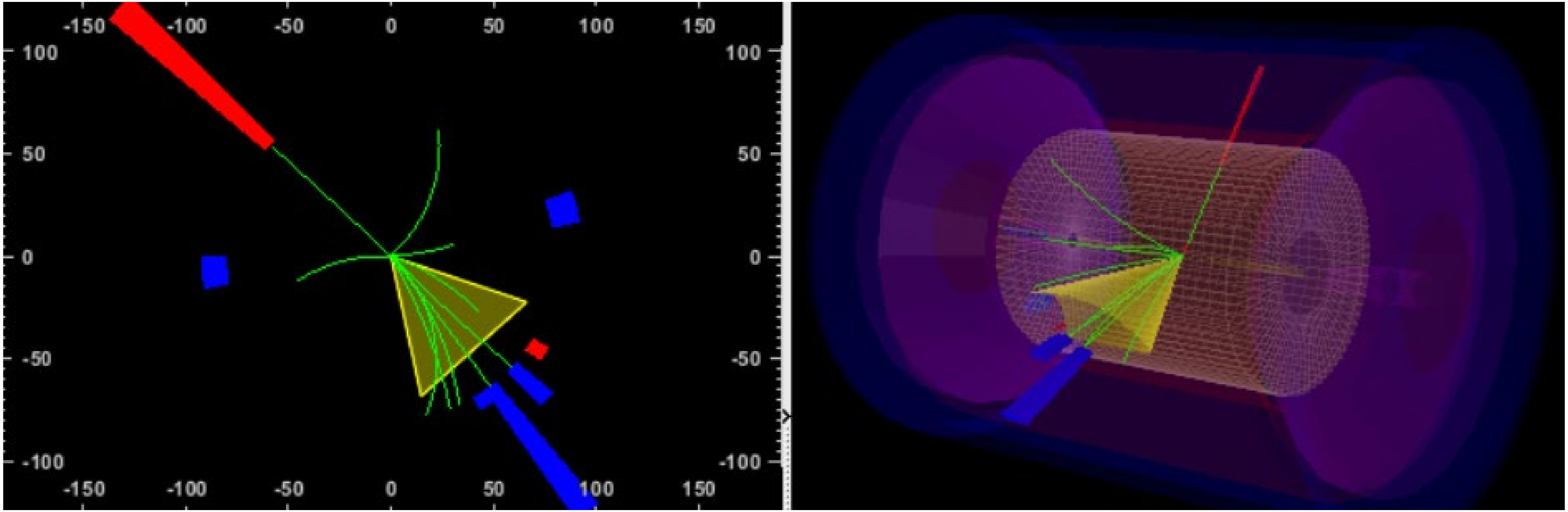




$$\frac{d^5\sigma(\ell p \to \ell' J)}{dy_\ell d^2k_{\ell\perp} d^2q_\perp} = \sigma_0 \int d^2k_\perp d^2\lambda_\perp x f_q(x, k_\perp, \zeta_c, \mu_F) \times H_{\rm TMD}(Q, \mu_F) S_J(\lambda_\perp, \mu_F)\, \delta^{(2)}(q_\perp - k_\perp - \lambda_\perp) \ .$$

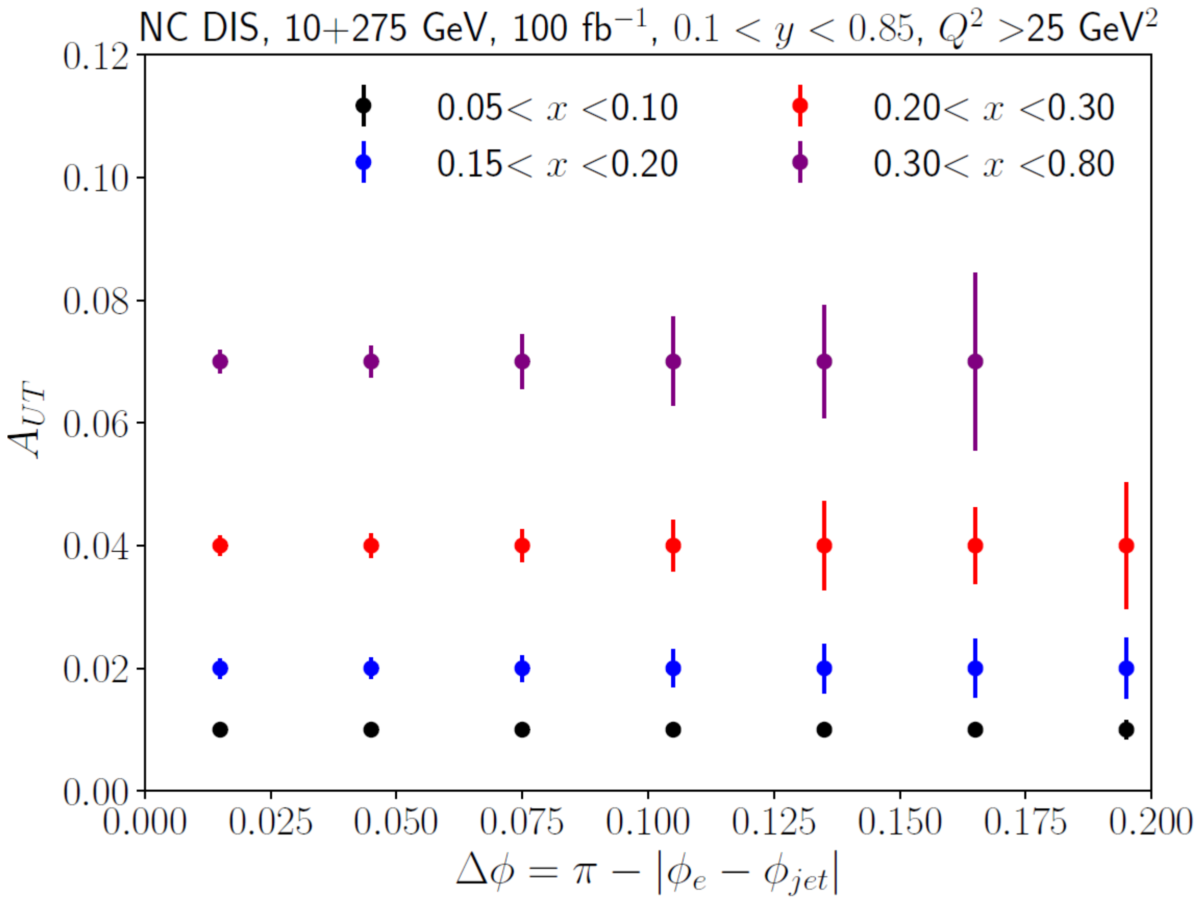
"The advantage of the lepton-jet correlation as compared to the standard SIDIS processes is that it does not involve TMD fragmentation functions."

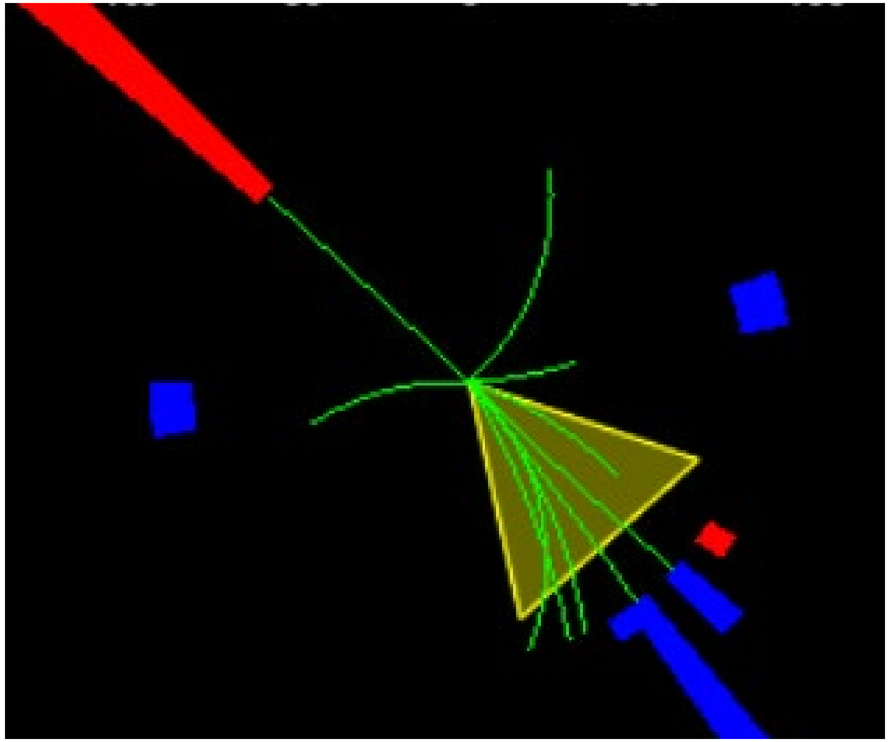
Electron-jet channel at the EIC



Delphes fast simulation of an EIC detector and Pythia8 neutral-current DIS event

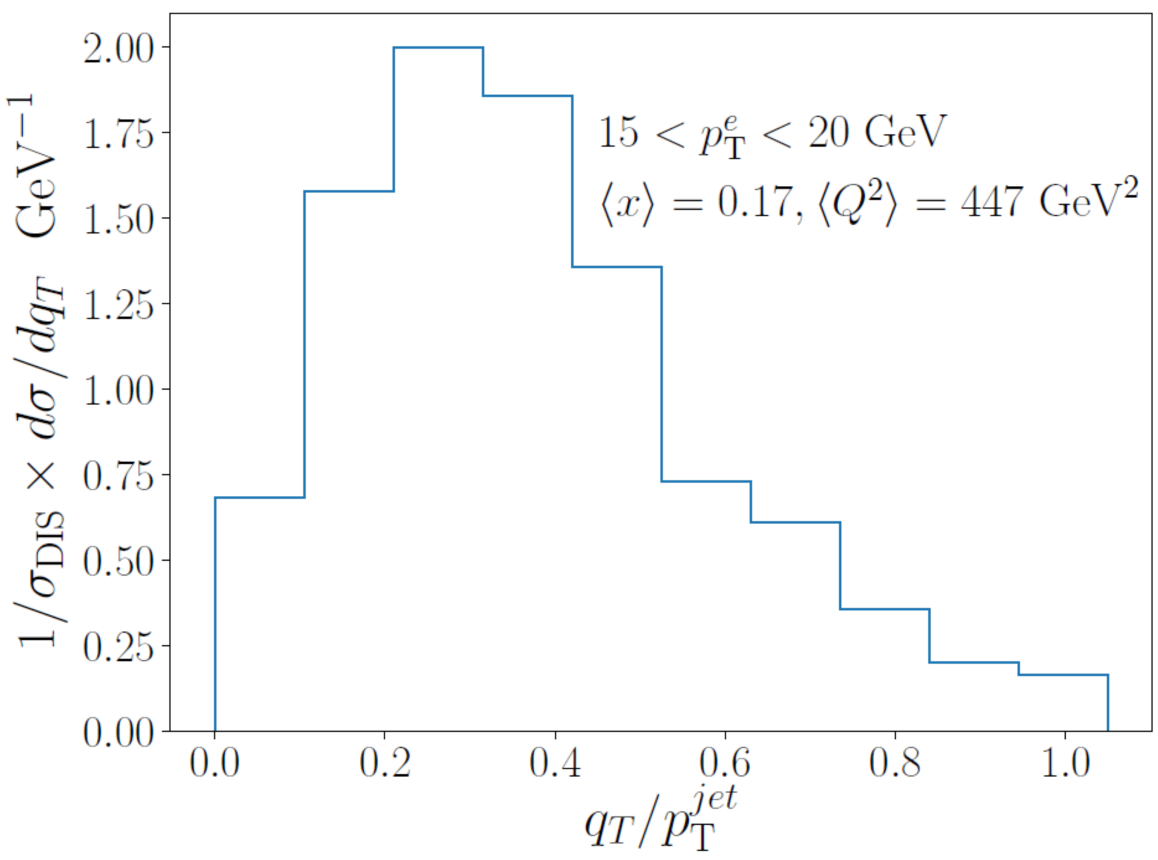
Quark Sivers effect with electron-jet correlations

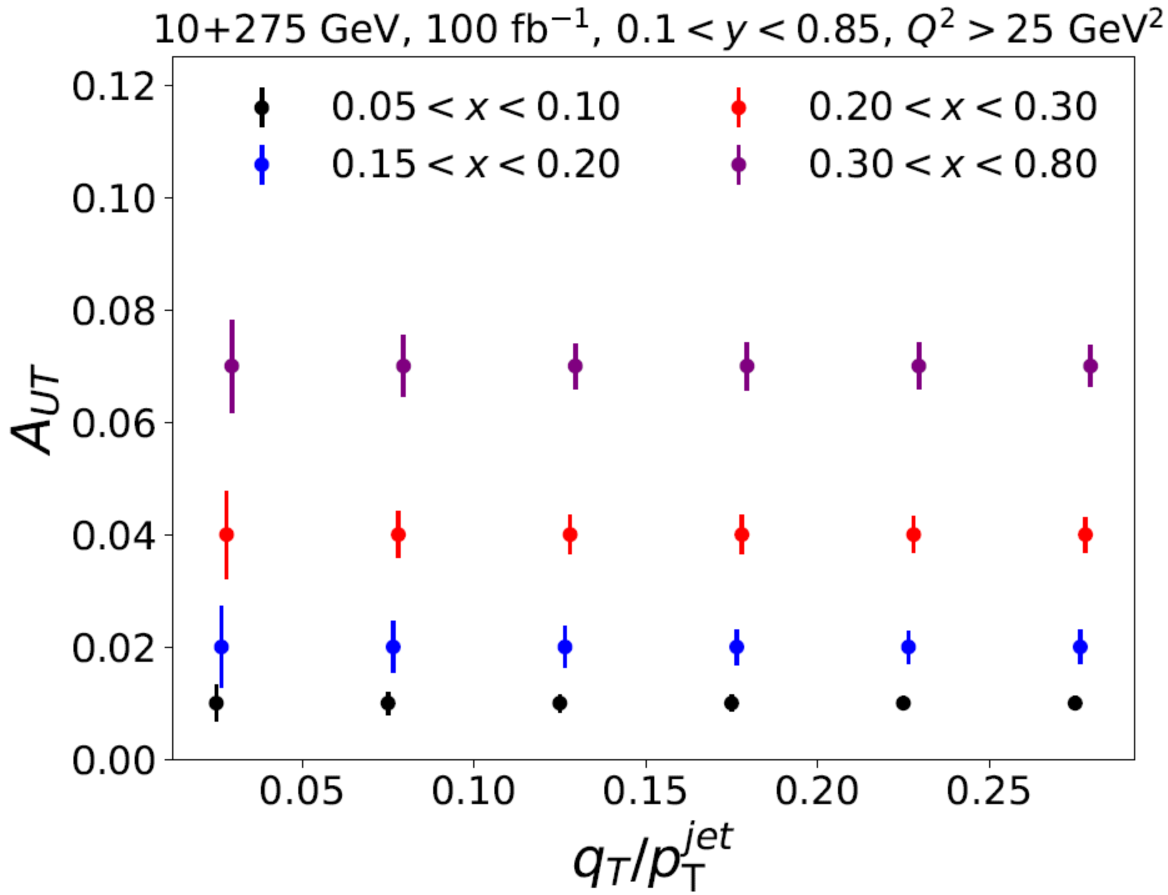




70% polarization, 50% overall efficiency.

Vox Populi, Vox Dei = qT plots:





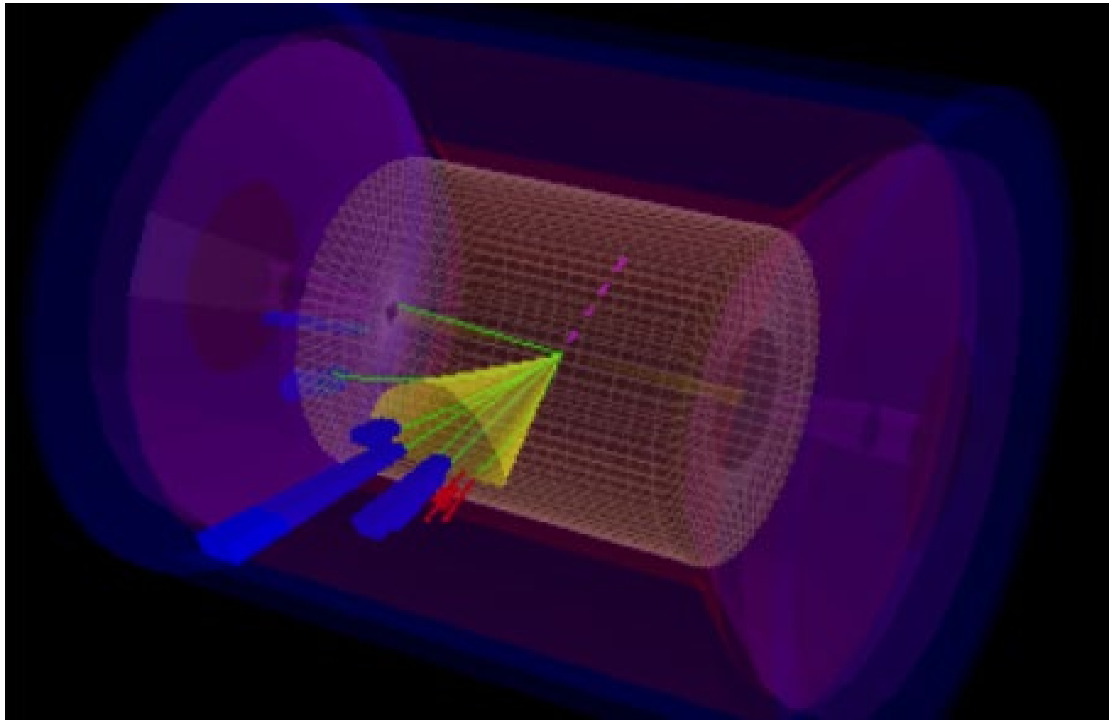
EIC detector in Delphes

https://github.com/miguelignacio/delphes_EIC/blob/master/delphes_card_EIC.tcl

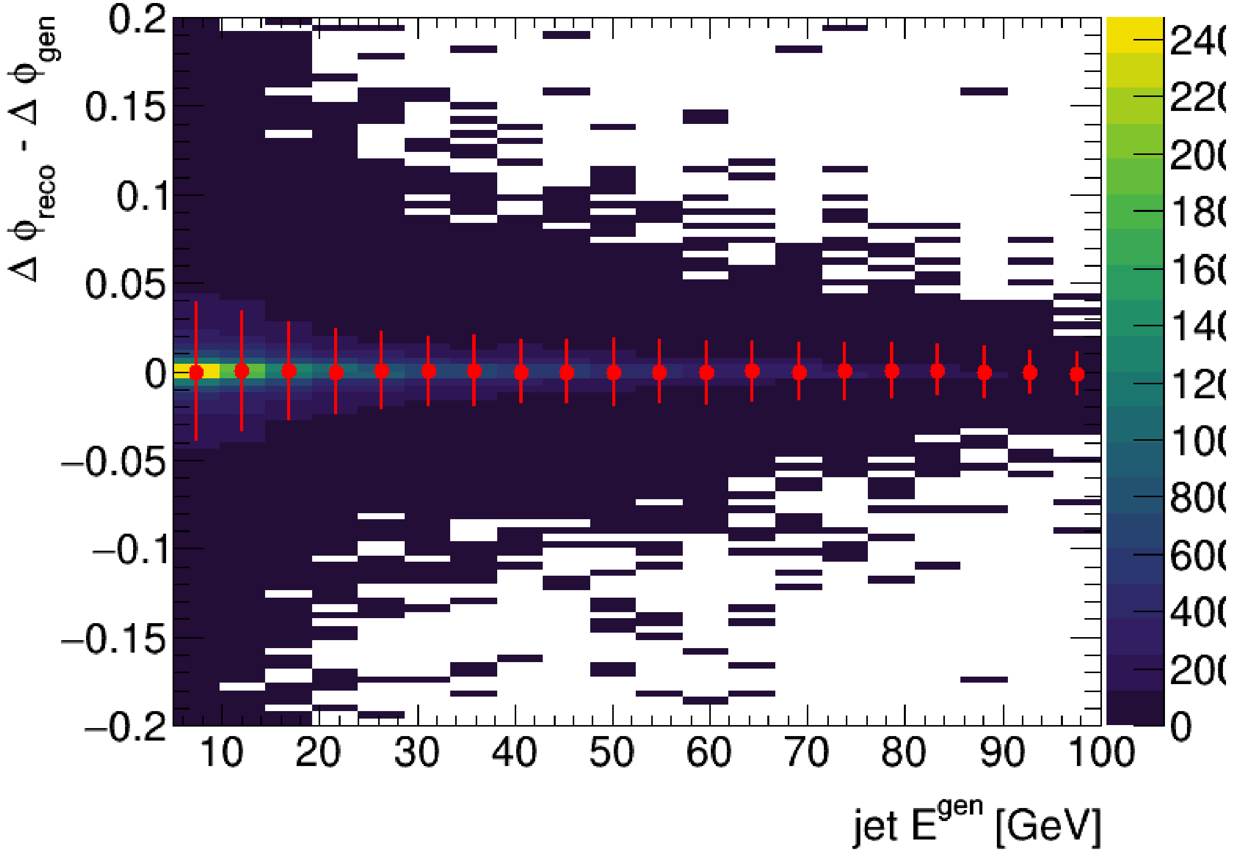
Tracking resolution, EMCAL resolution and HCAL resolution as in EIC detector handbook.

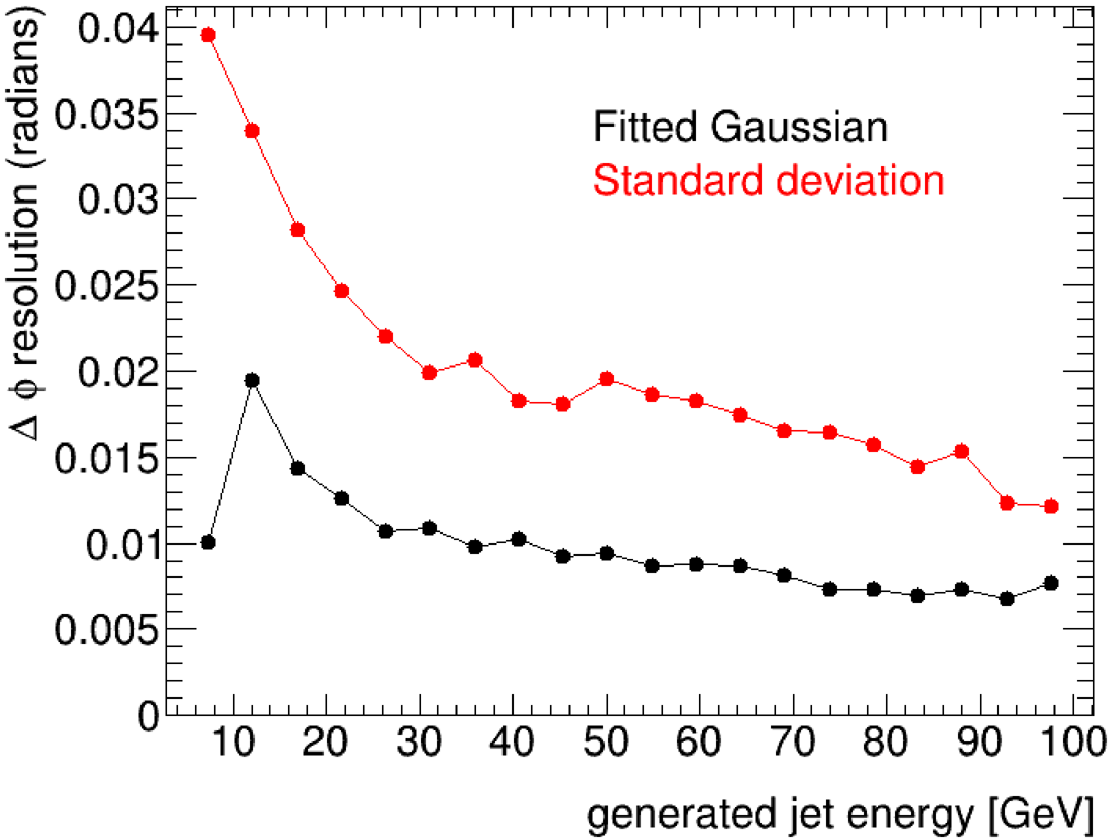
In addition:

- B=1.5 T, R=0.80 m, L = 1 m
- EMCAL granularity (dphi x deta):
  0.02 x 0.02 for |eta|<3.5
- HCAL granularity (dphi x deta):
  0.1 x 0.1 for |eta|<1.0
  0.025 x 0.025 for 1.0 |eta|<4.0
  (10x10 cm2 at 3.6 m)
- HCAL resolution:
  100%/sqrt(E) + 10% in barrel (0.0—1.0)
  50%/sqrt(E) + 10% in encap (1.0—4.0)
- Tracking threshold 100 MeV pT;
  EMCAL threshold of 200 MeV; (noise ~ 30 MeV per tower)
  HCAL threshold of 500 MeV; (noise ~100 MeV per tower)
- No PID yet, but it can be included (LHCb is in Delphes).
  Need parametrization of efficiency and mis-identification matrix



Electron-jet opening angle resolution

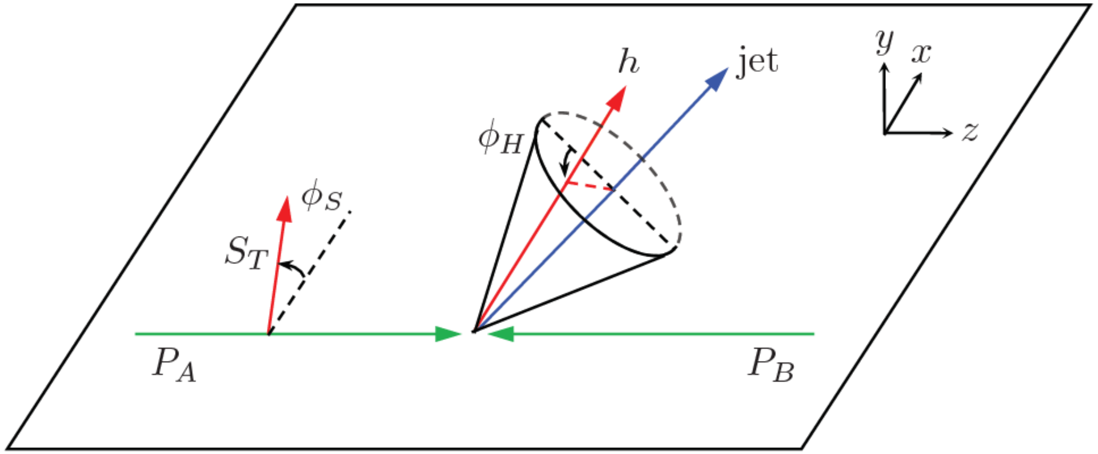




Driven by jet energy resolution,
much smaller than “intrinsic width”

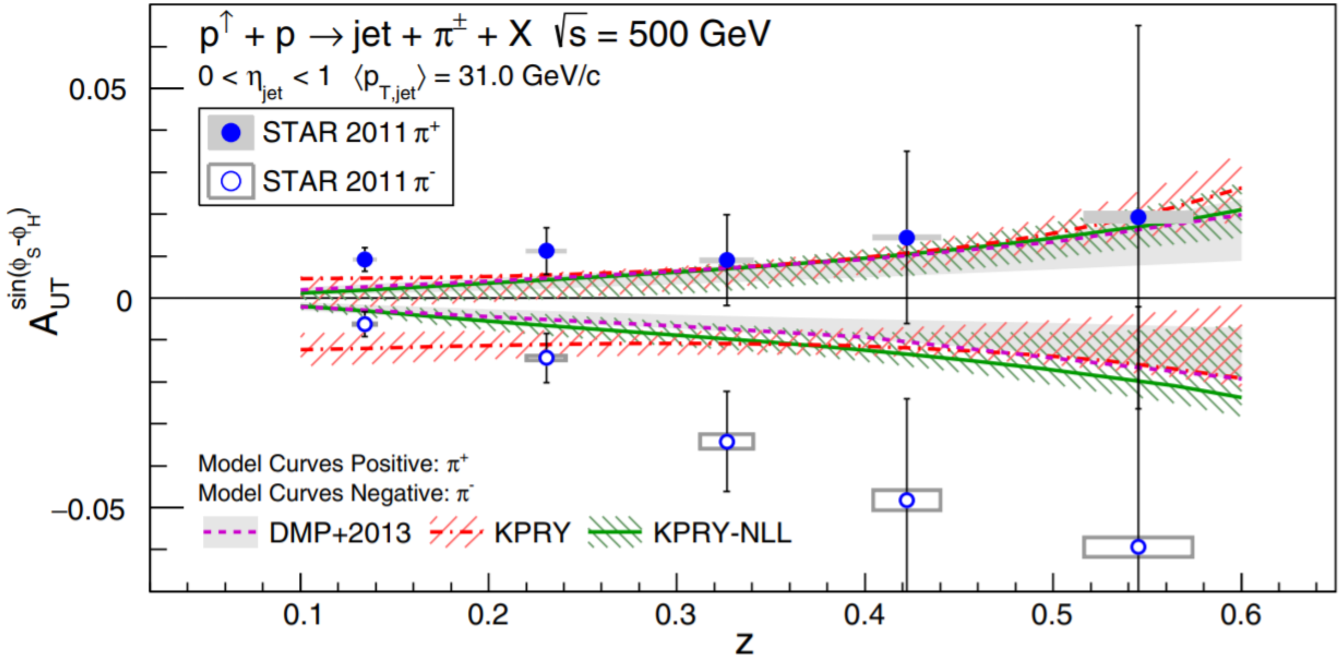
Transversity with jets

distribution of transversely polarized quarks inside a transversely polarized nucleon



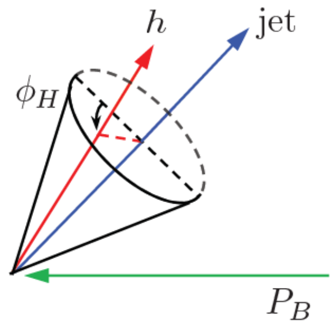
"Collins azimuthal asymmetries of hadron production inside jets", Phys. Lett. B 774, 635 (2017), Kang et al., and several other references.

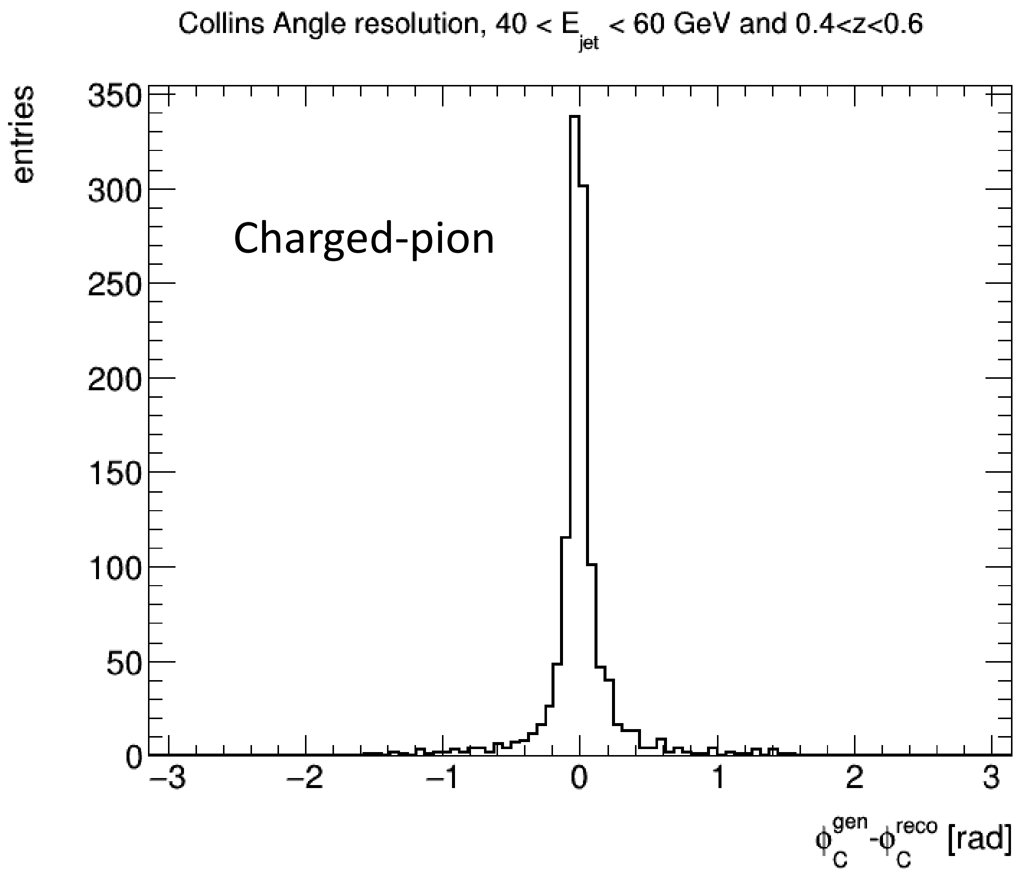
STAR Collaboration, Phys. Rev. D 97, 032004 (2018)

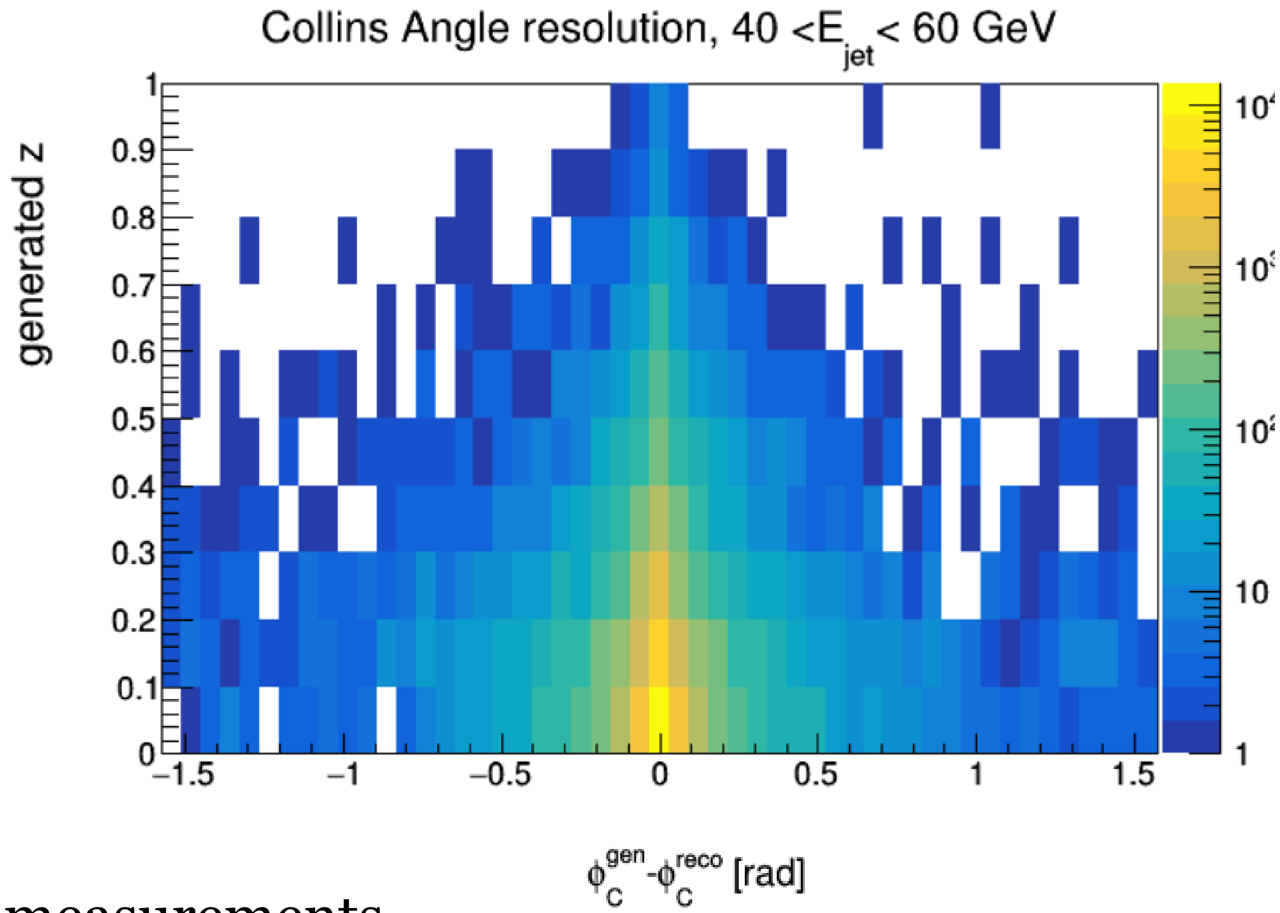


- Jet axis measurement crucial to factorize initial and final state TMD effects.
- **At EIC, qT of e-jet balance controls kT ; jT of hadron wtr jet axis controls fragmentation pT.**
- At EIC, tests of TMD evolution & universality.

Collins Angle resolution

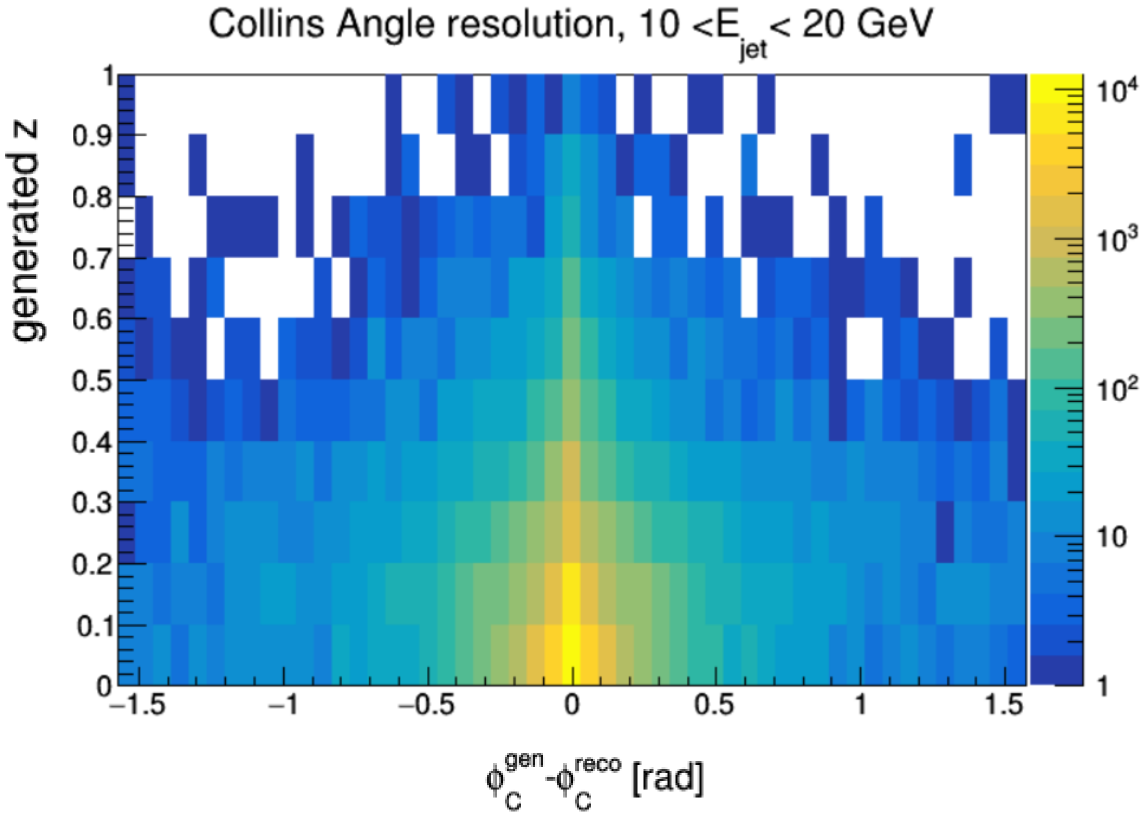


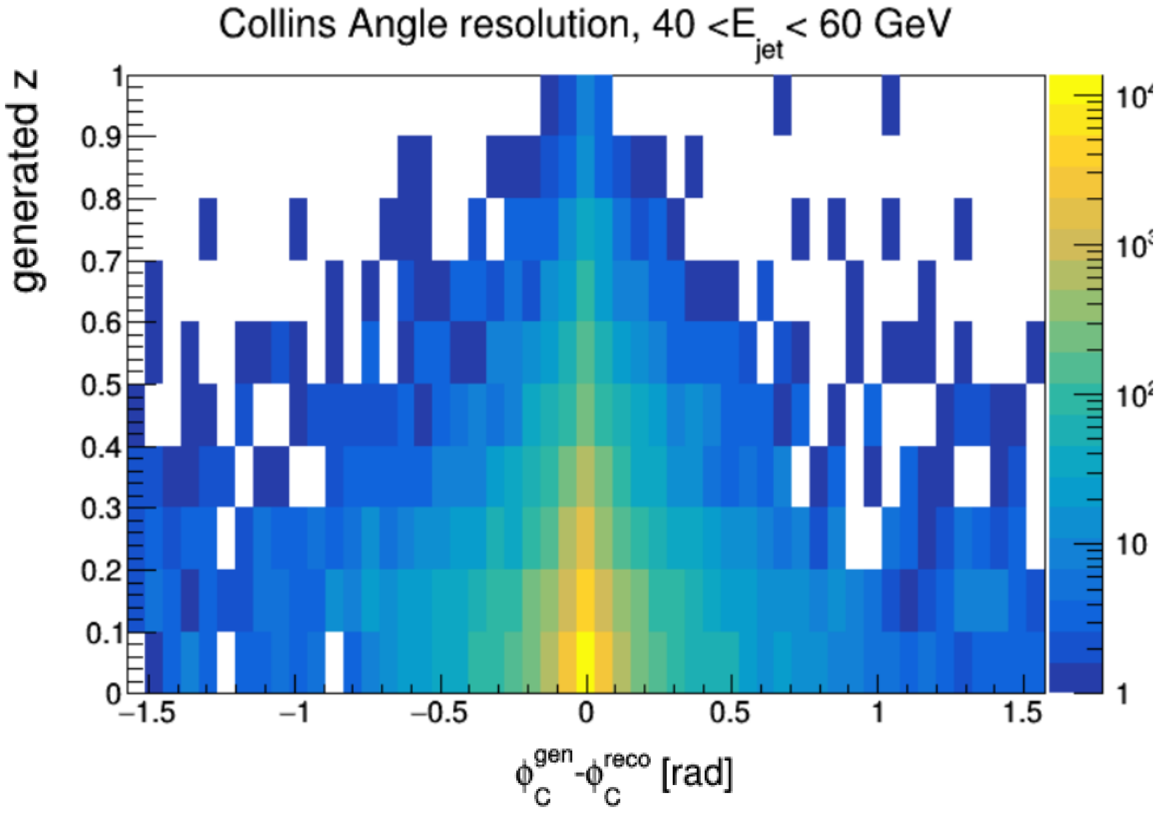




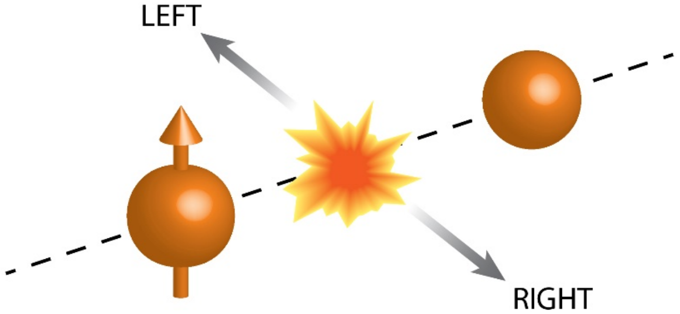
- Compares favorably to STAR measurements
- Calculation on how this propagates to “asymmetry dilution” ongoing

Jet-energy dependence of Collins Angle resolution

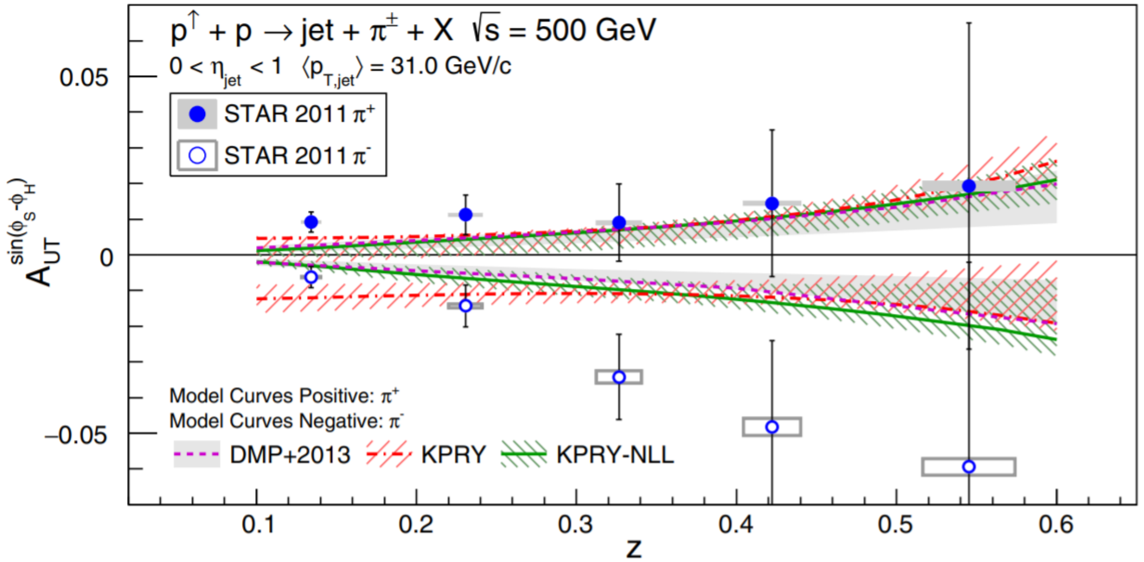




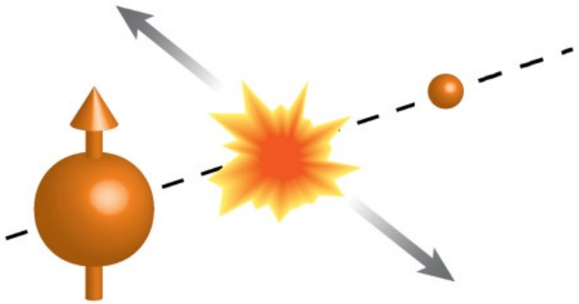
- There is an interplay between energy resolution for jet (improves with energy) and momentum resolution for hadron (degrades)



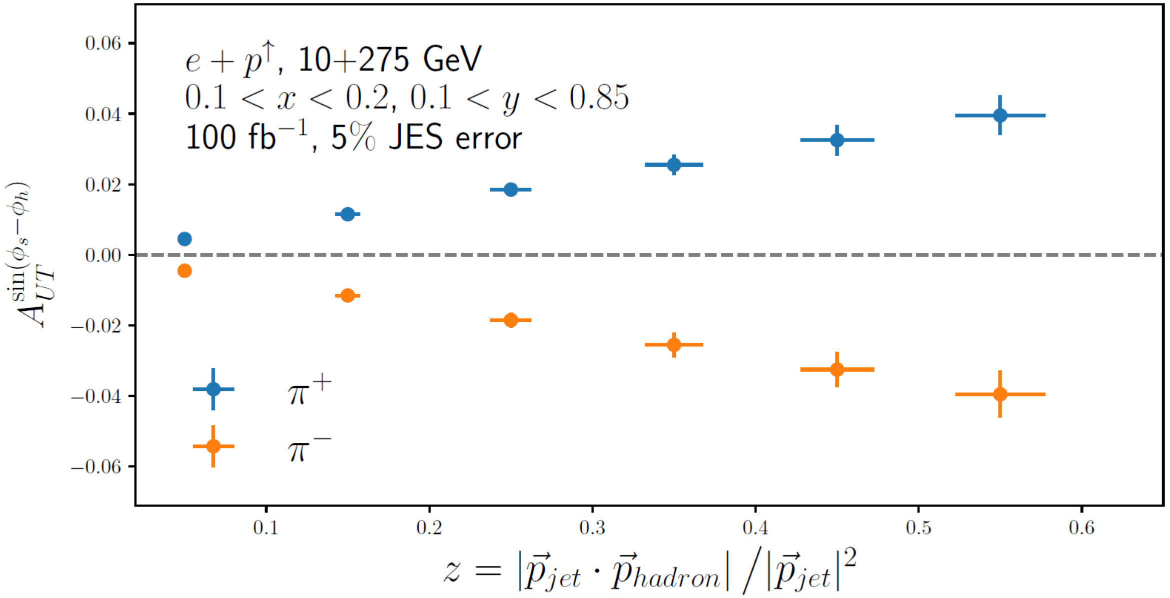
pp at RHIC



Phys. Lett. B 774, 635 (2017)



ep at EIC



This would be a nice YR money plot...

Lambda-in-jet....

arXiv:2005.02398 (cross-list from hep-ph) [pdf, other]

Polarized jet fragmentation functions

Zhong-Bo Kang, Kyle Lee, Fanyi Zhao

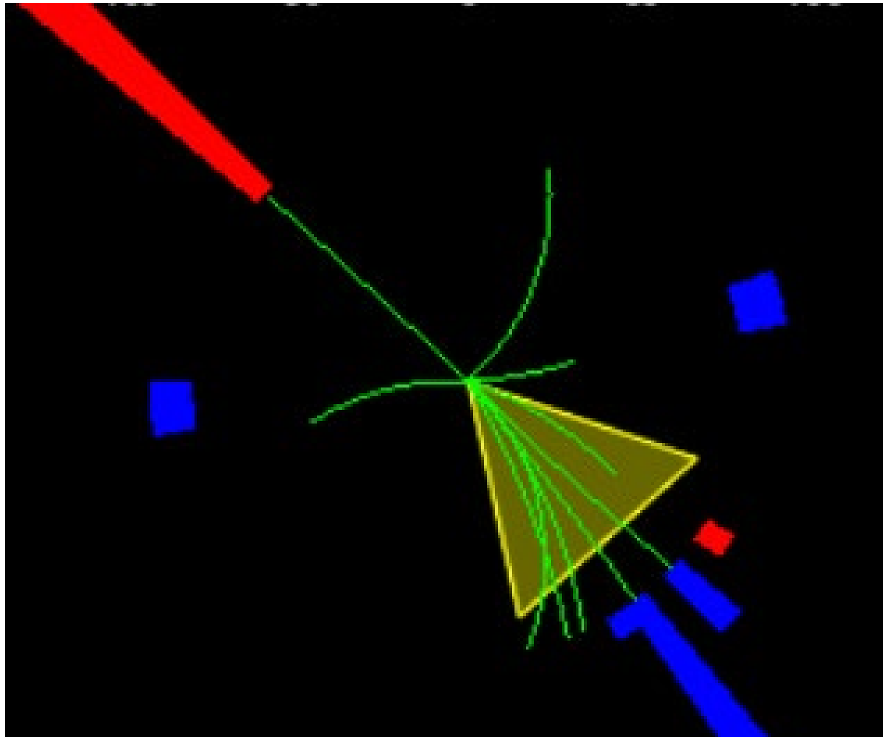
Comments: 14 pages, 5 figures

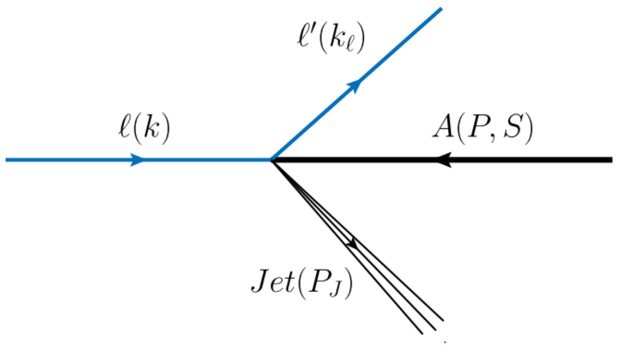
Subjects: **High Energy Physics - Phenomenology (hep-ph)**; High Energy Physics - Experiment (hep-ex); Nuclear Experiment (nucl-ex); Nuclear Theory (nuc

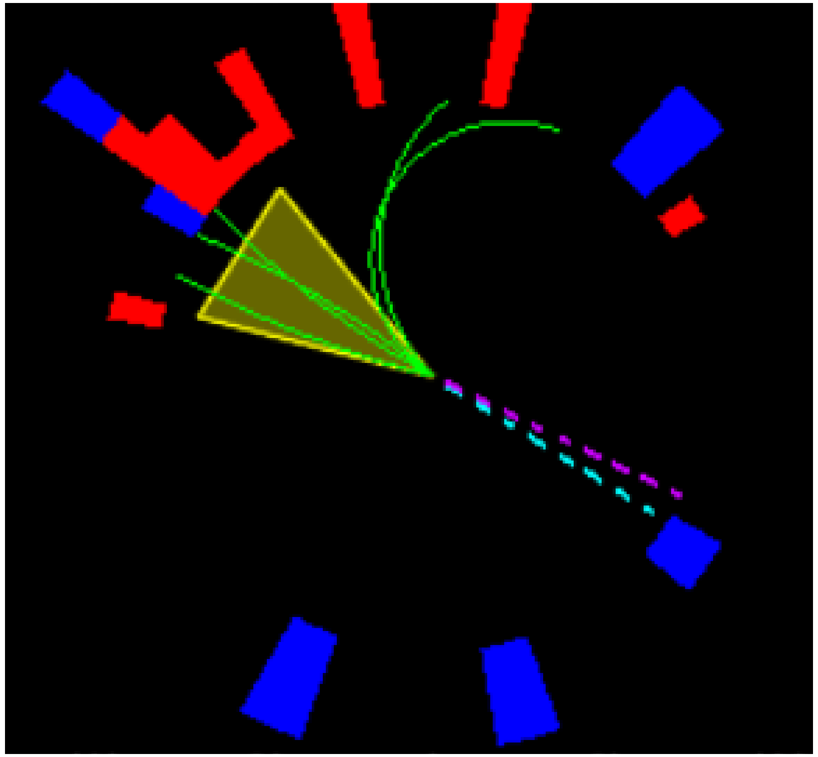
We develop the theoretical framework needed to study the distribution of hadrons with general polarization inside jets, with and without transve in this paper, referred to as "polarized jet fragmentation functions", opens up new opportunities to study both collinear and transverse moment framework, we study longitudinally polarized collinear Λ and transversely polarized TMD Λ production inside jets in both pp and ep collisions. fragmentation functions with sizeable asymmetries predicted, in particular, at the future Electron-Ion Collider.

"We expect our work will open new and exciting opportunities in the direction of studying spin-dependent hadron structures using ***hadrons inside jets****."*

My crazy idea: replace electron with neutrino!







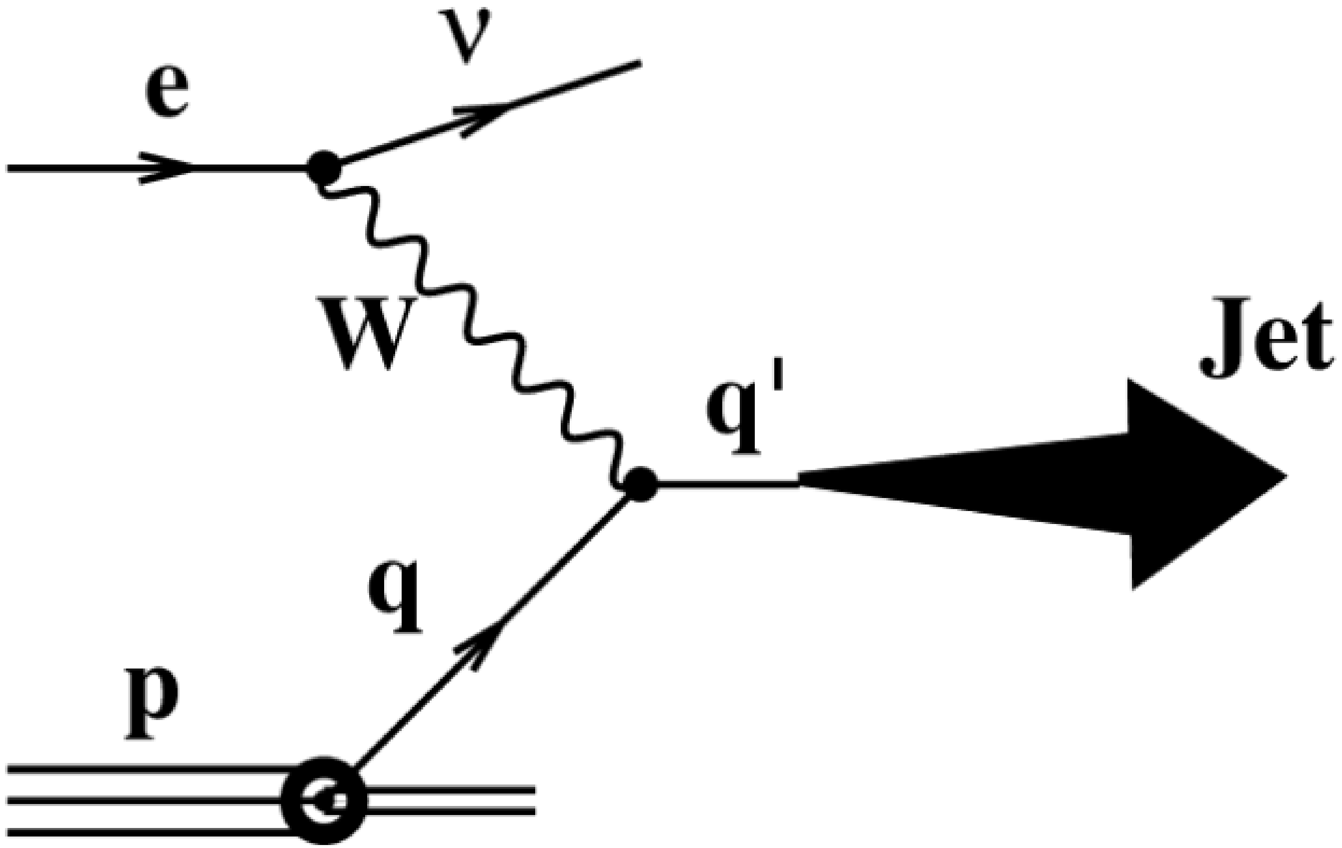
Novel channel for quark Sivers and quark transversity

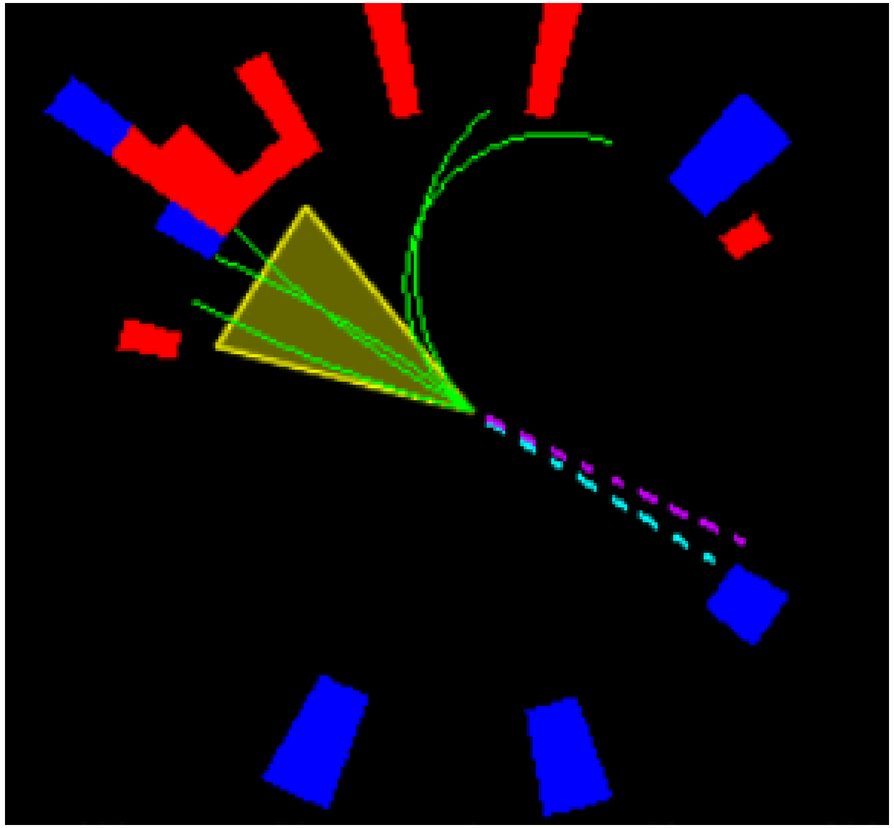
Same as left, but with flavor sensitivity. u-quarks for electron, d-quark for positron

Clean flavor selectivity

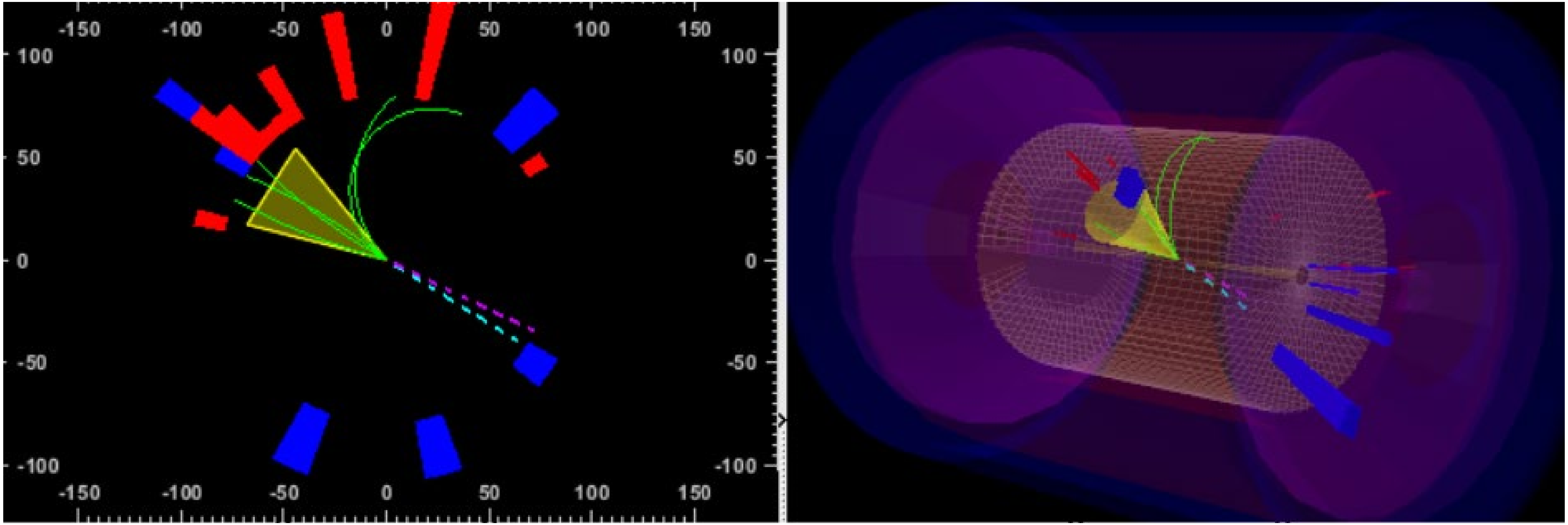
u-quarks for electron, d-quark for positron

strange from charm-jets



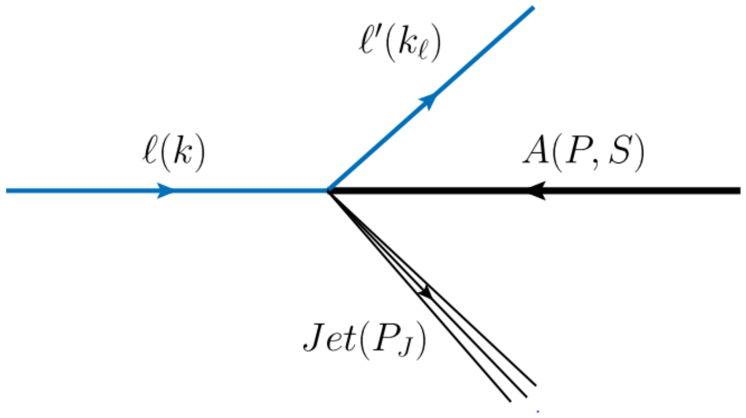


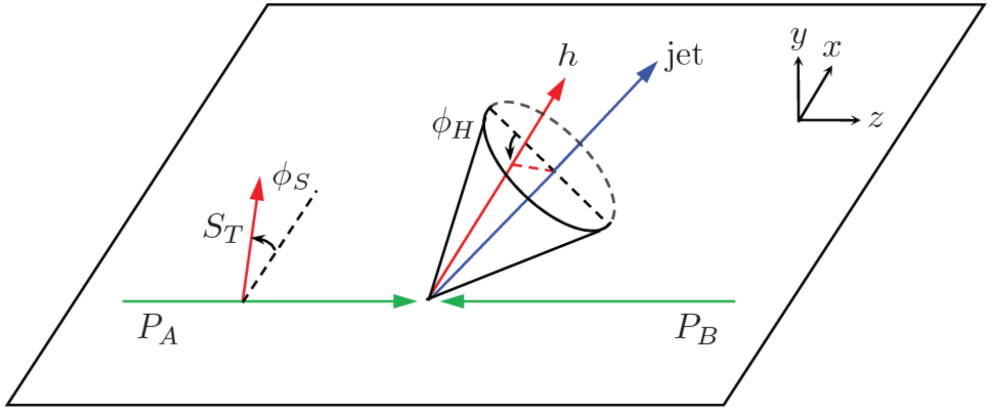
Charged-current DIS at the EIC

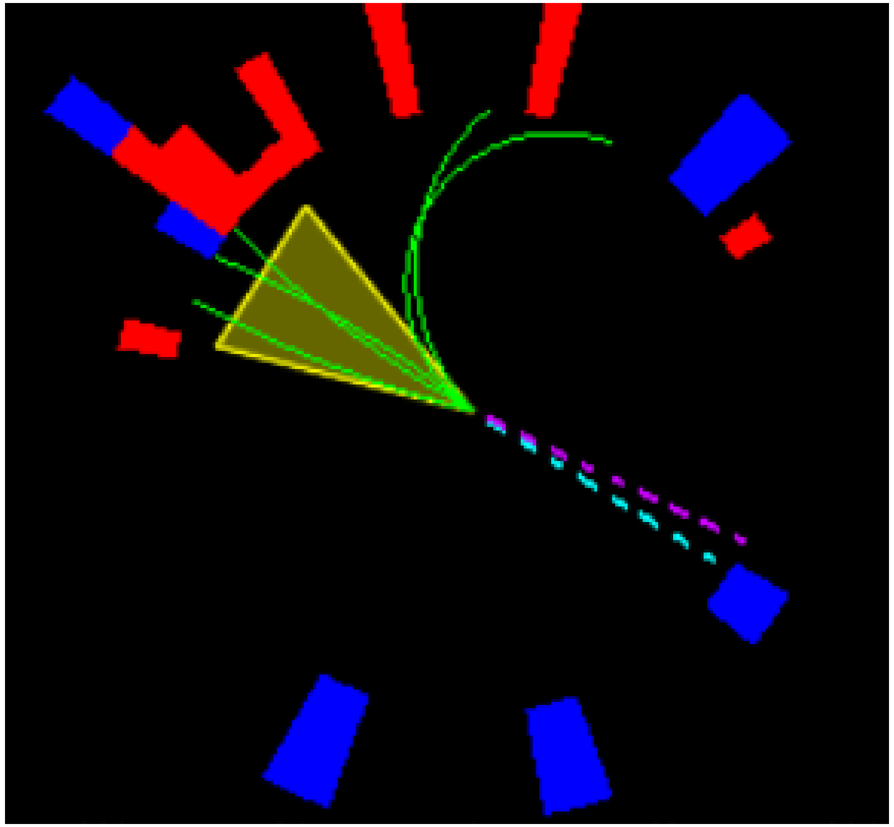


Delphes fast simulation of an EIC detector and Pythia8 charged-current DIS event

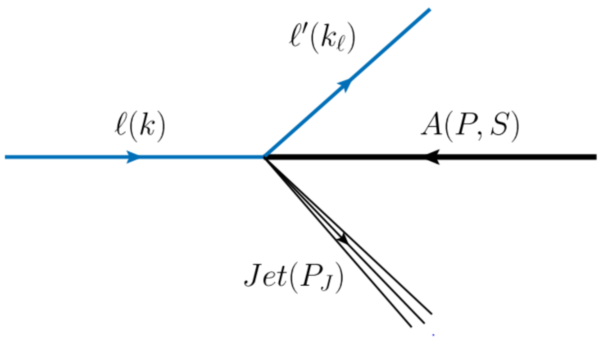
Boosting to Breit-frame is not an option!
The jet way is the only way to do TMD CC DIS

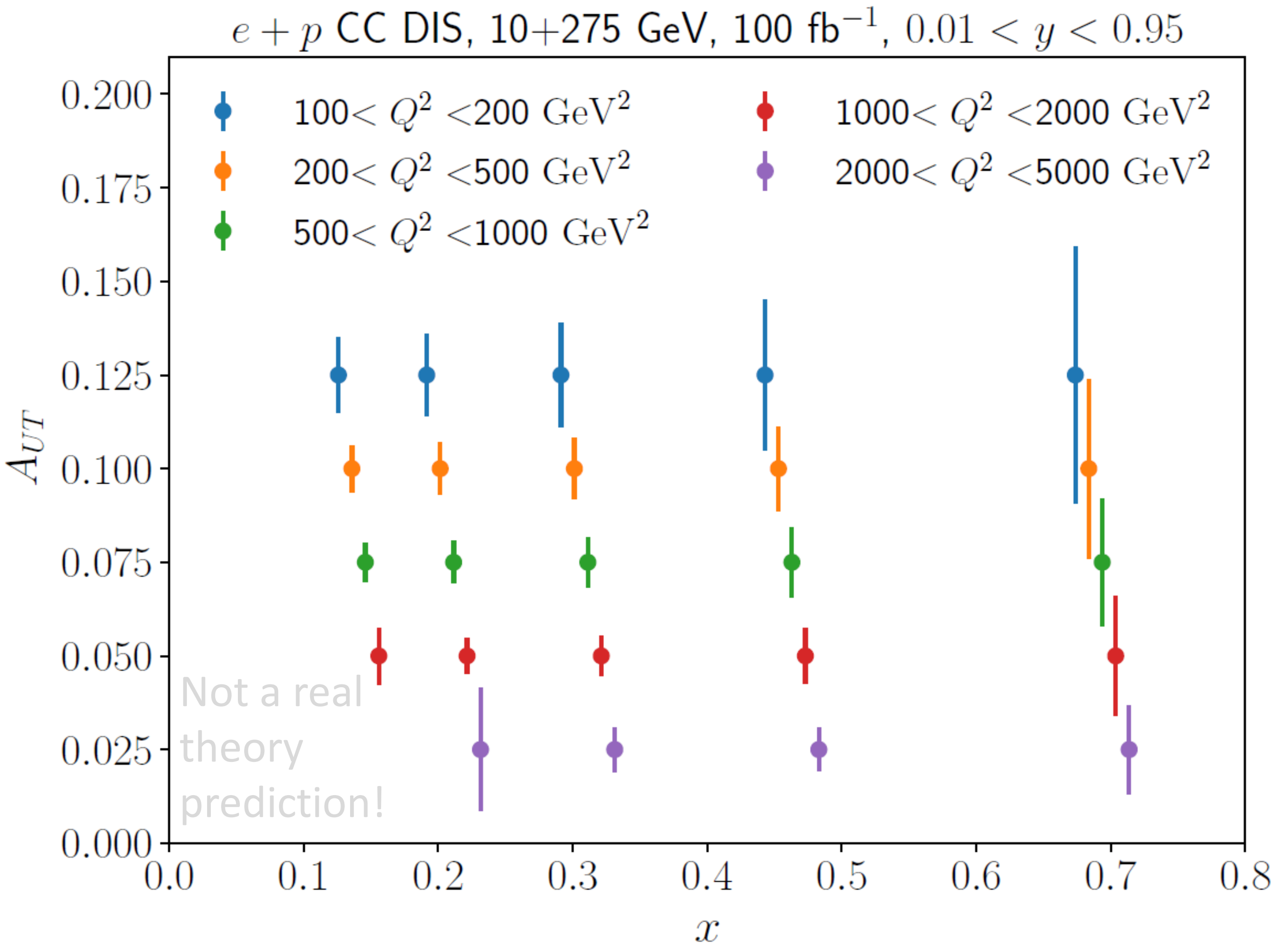


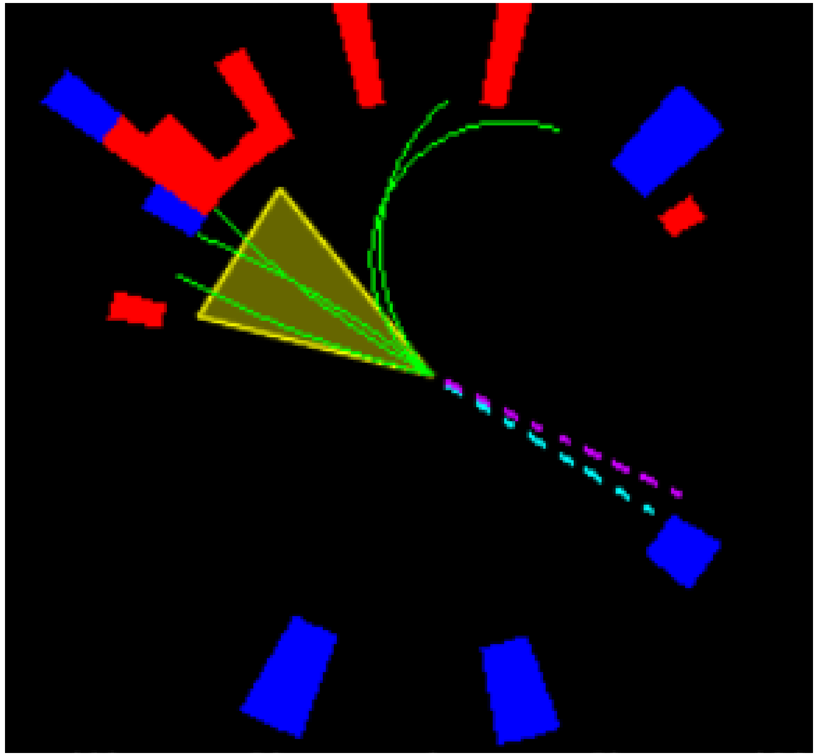




u-quark Sivers with neutrino-jet correlations

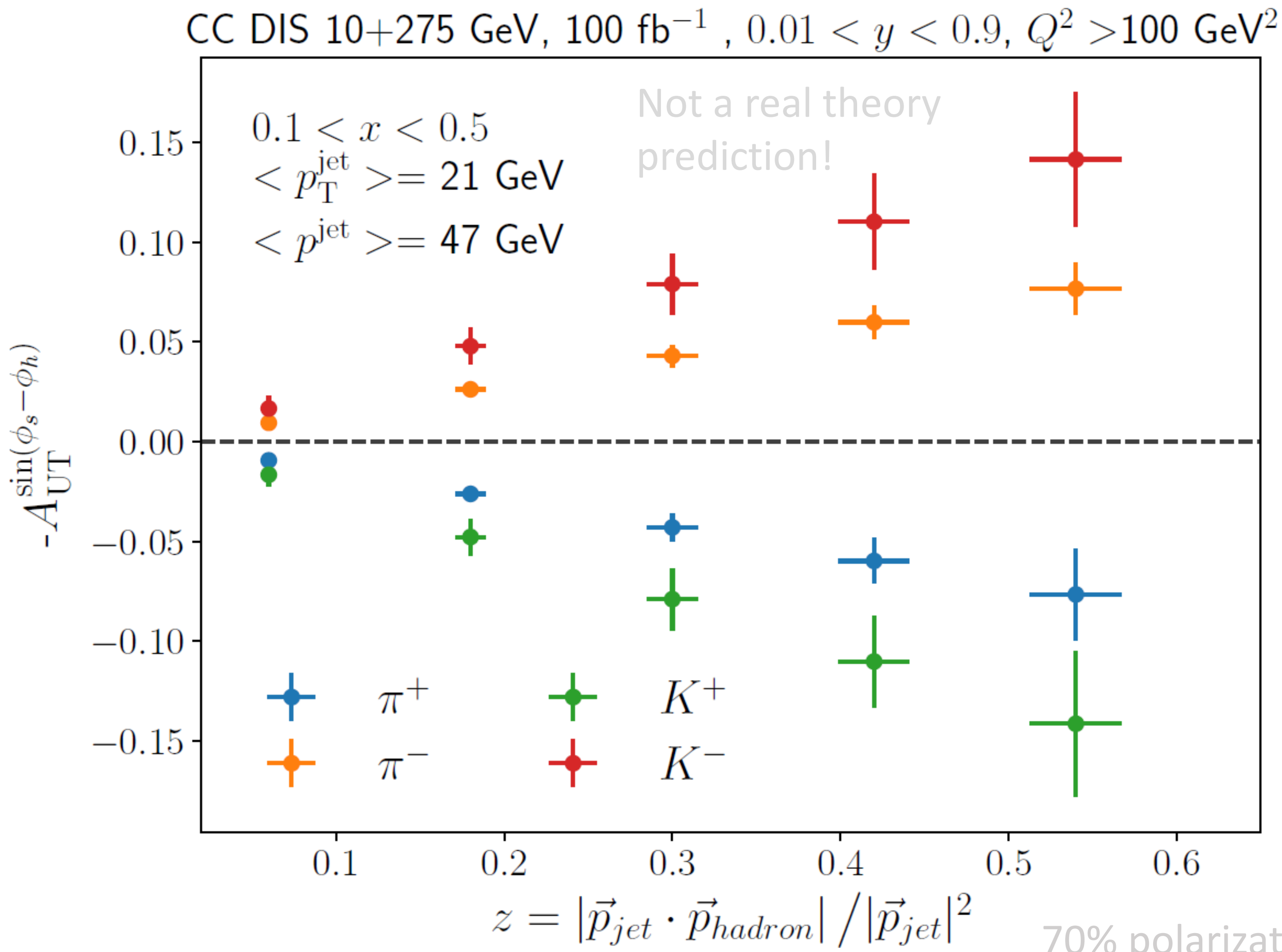


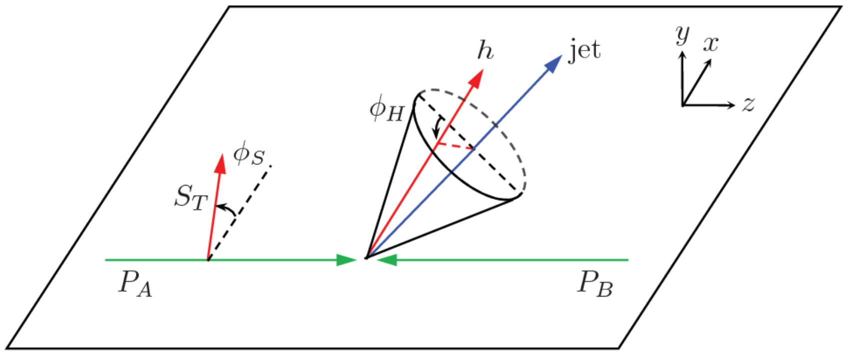




70% polarization, 50% overall efficiency.

u-quark Transversity in charged-current DIS



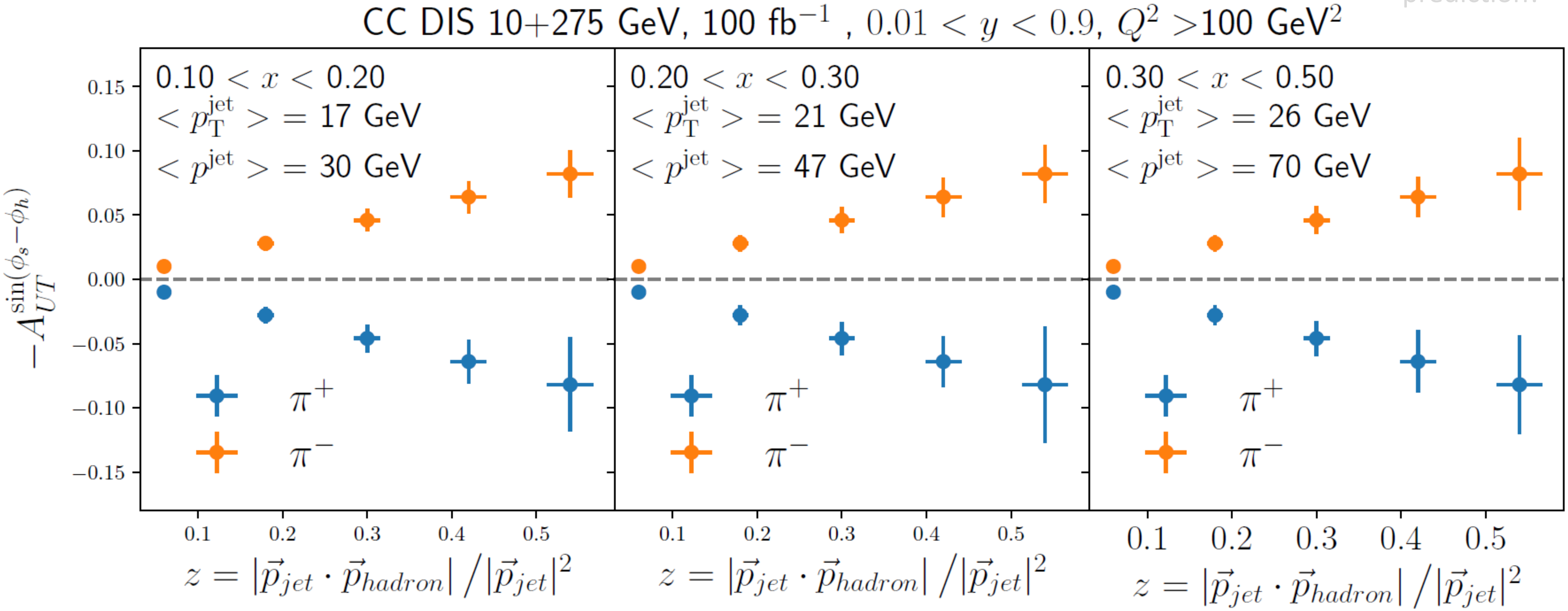


- Decent statistics, specially for pions.
- Flavor specific
  (u-quark for electrons;
  d-quark for positrons)
- Non-cancellation of u/d transversity will lead to larger asymmetries.

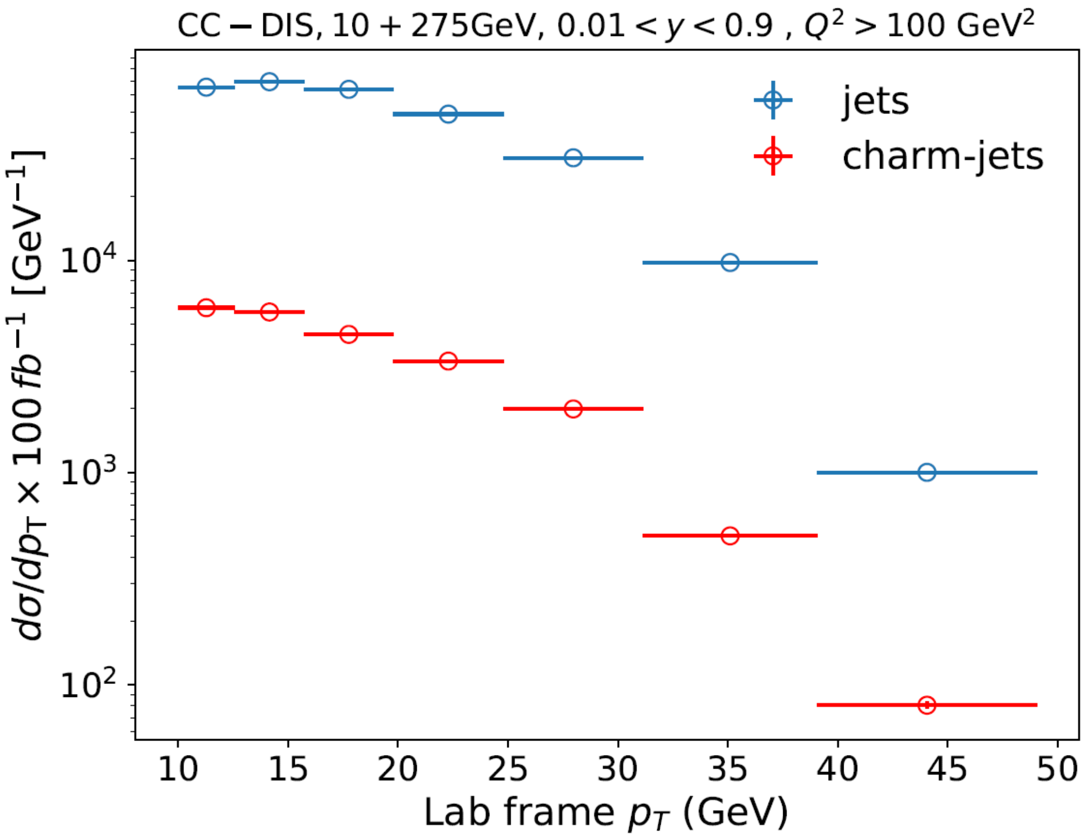
70% polarization, 50% overall efficiency.

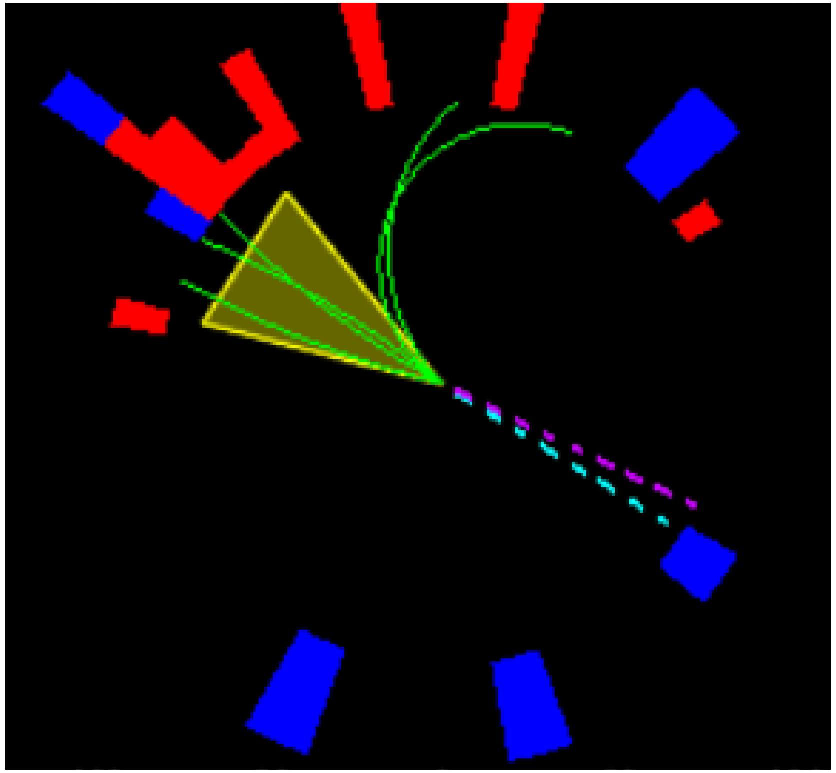
u-quark Transversity

Not a real theory prediction!



Tag charm-jets to cleanly access **strange quark**

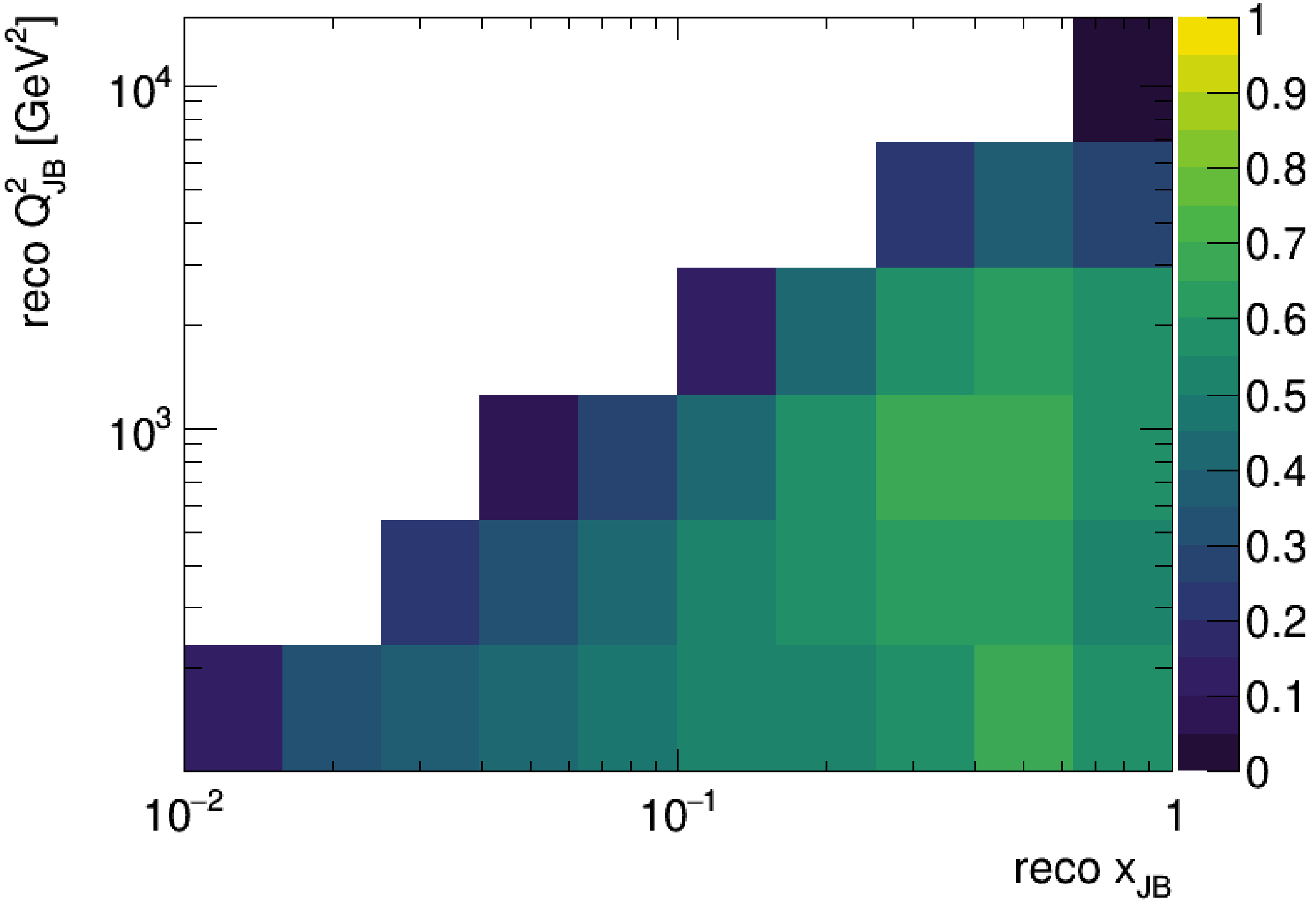




- ZEUS data JHEP 05 (2019) 201 of ~0.3 fb-1 yielded a proof of concept, but with very large errors
- EIC trackers will dwarfed the HERA ones, plus much higher lumi makes this promising for both collinear and TMD physics

Jacquet-Blondel Purity

$$\text{purity} = (N_{gen} - N_{out})/(N_{gen} - N_{out} + N_{in})$$

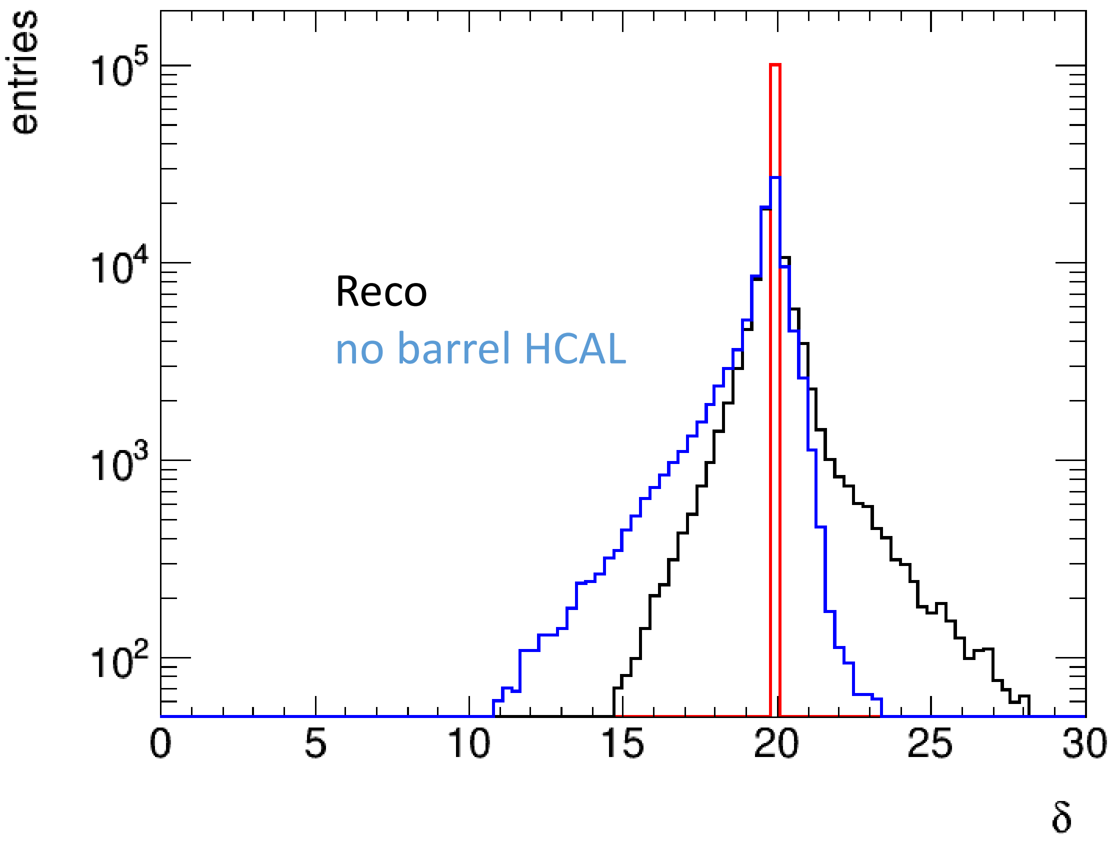


- Reasonable purity reached at high-x and high Q2. (similar conclusion reached in Aschenauer et al. Phys. Rev. D 88, 114025 (2013))
- This is one figure of merit, but one should not forget to consider non-Gaussian tails in response…

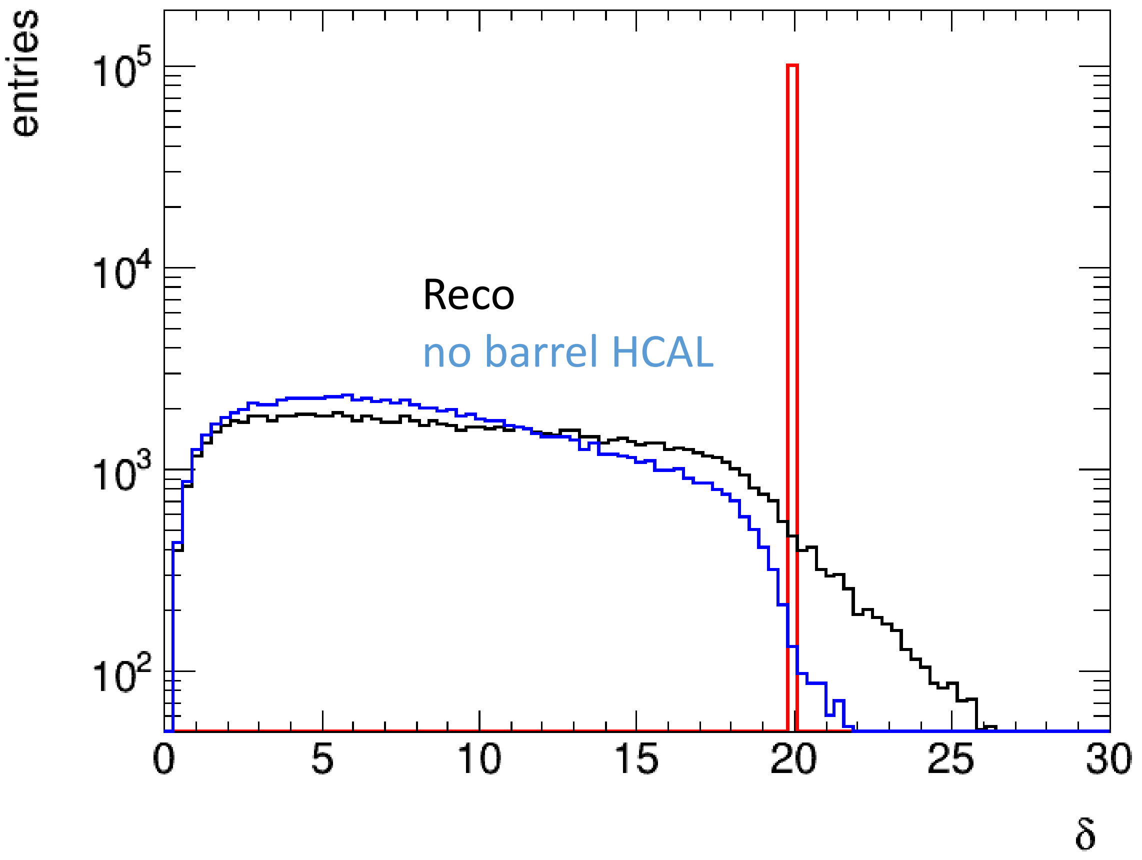
Background rejection to NC DIS:

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

NC DIS

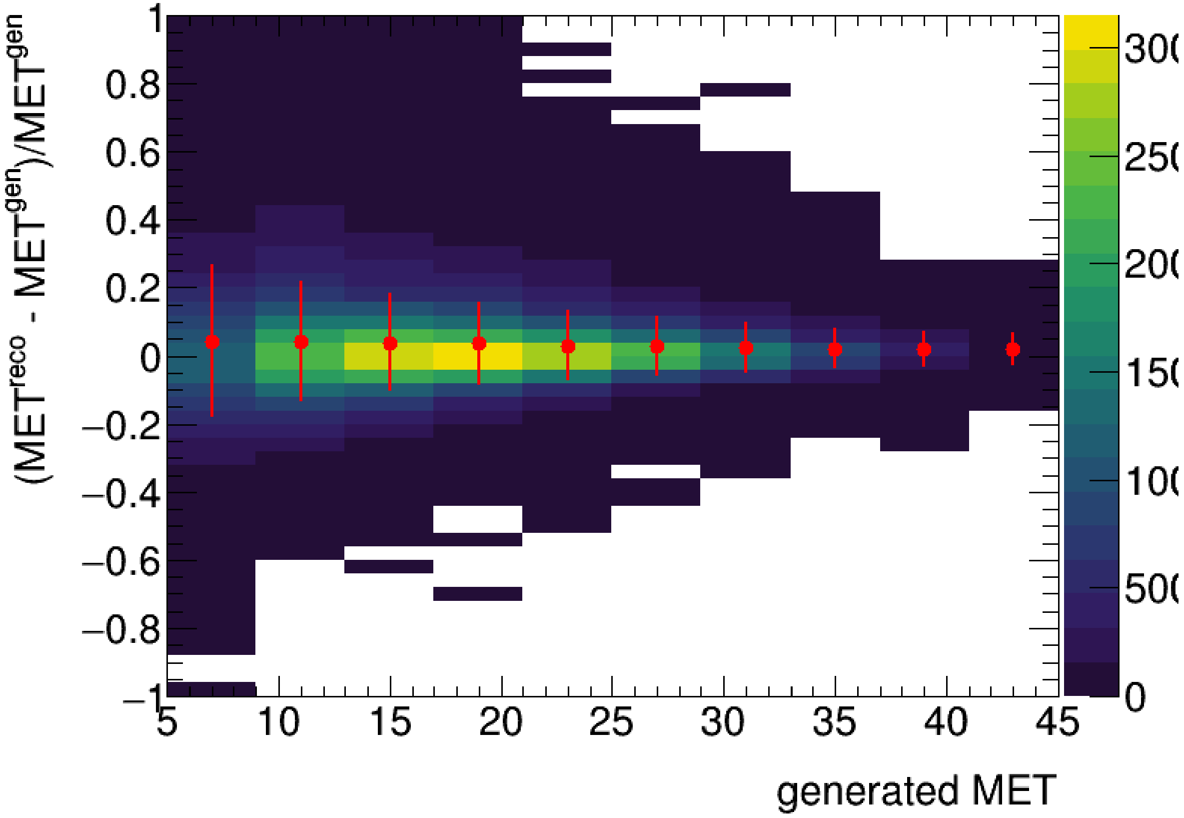


CC DIS

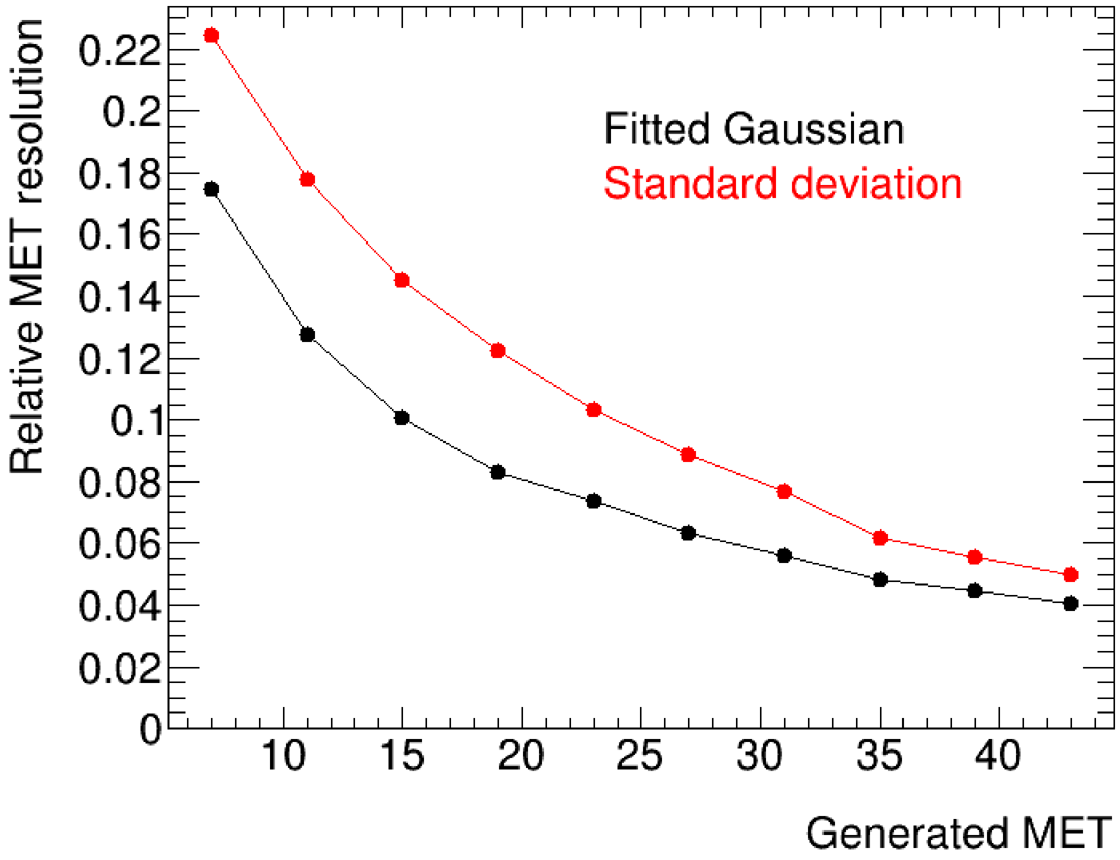


- If one misses track of electron but measures cluster (or viceversa), delta-cut useful to veto NC DIS.

Neutrino pT

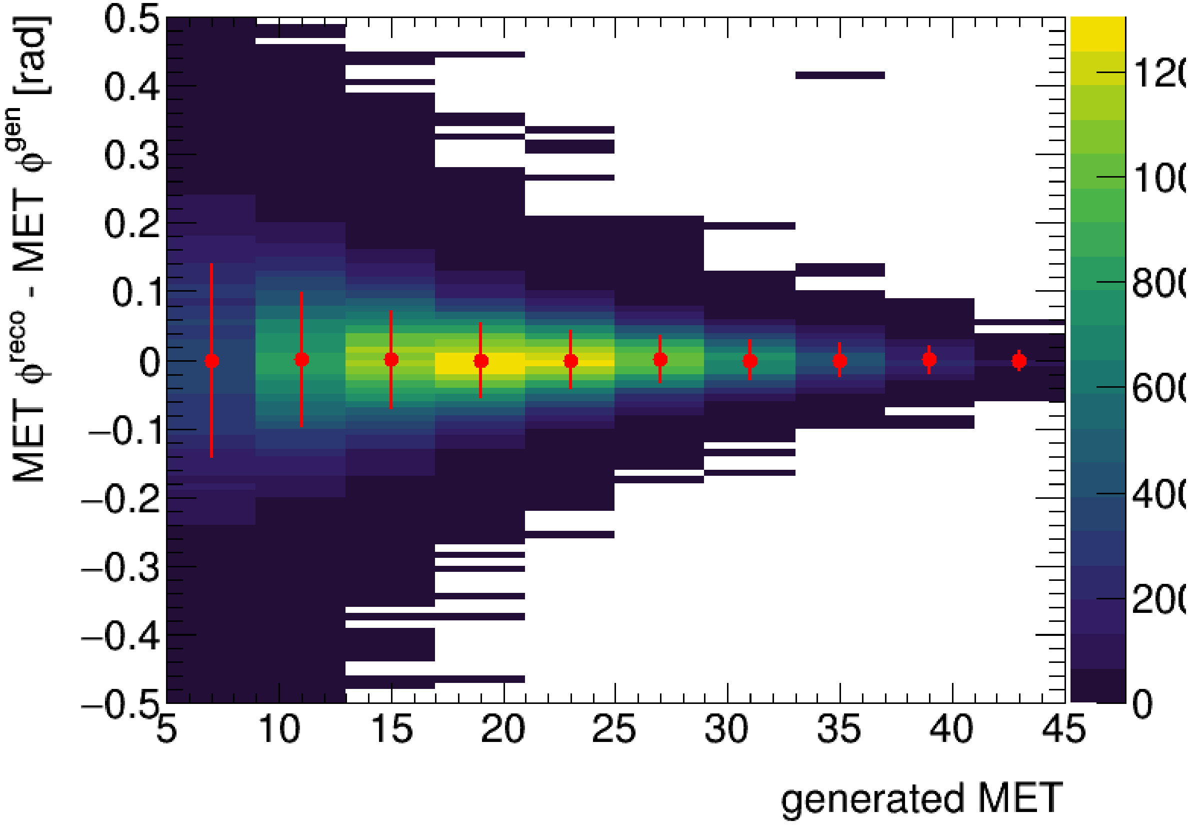


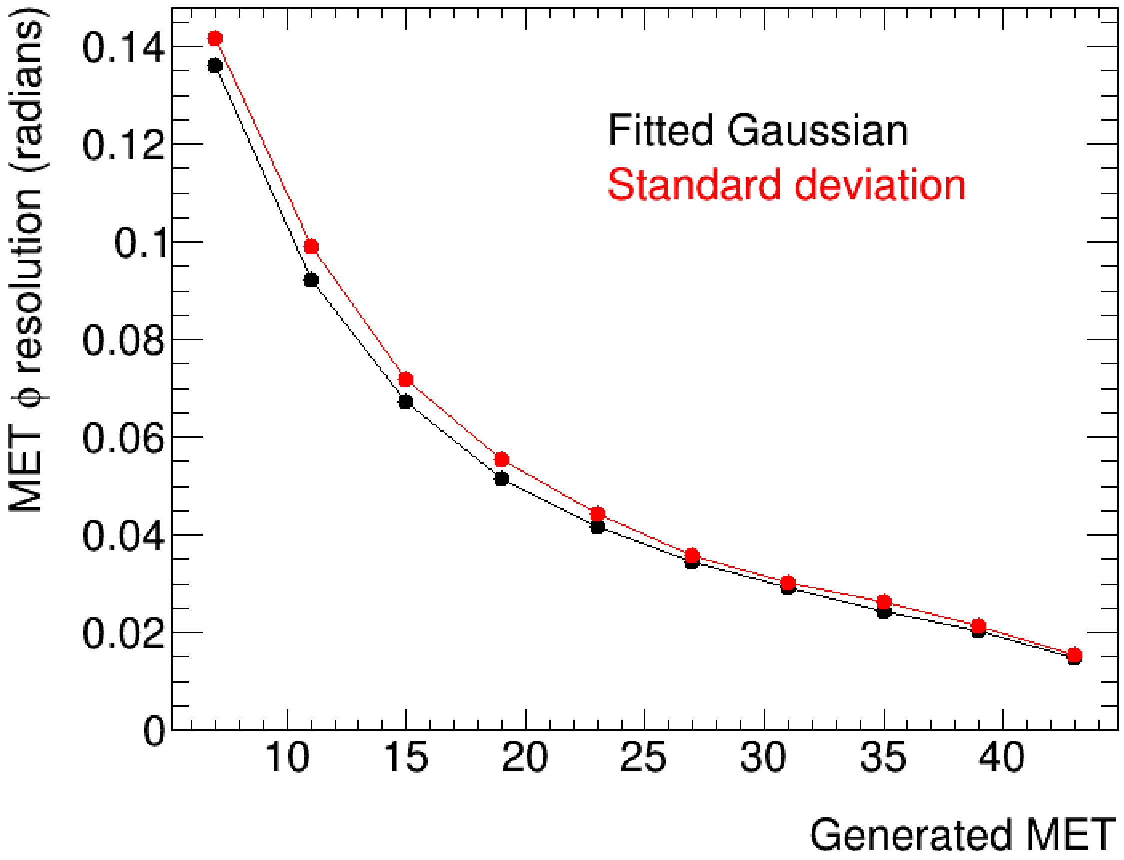
$(MET^{reco} - MET^{gen})/MET^{gen}$
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
5
10
15
20
25
30
35
40
45
generated MET
0
50(
10(
15(
20(
25(
30(



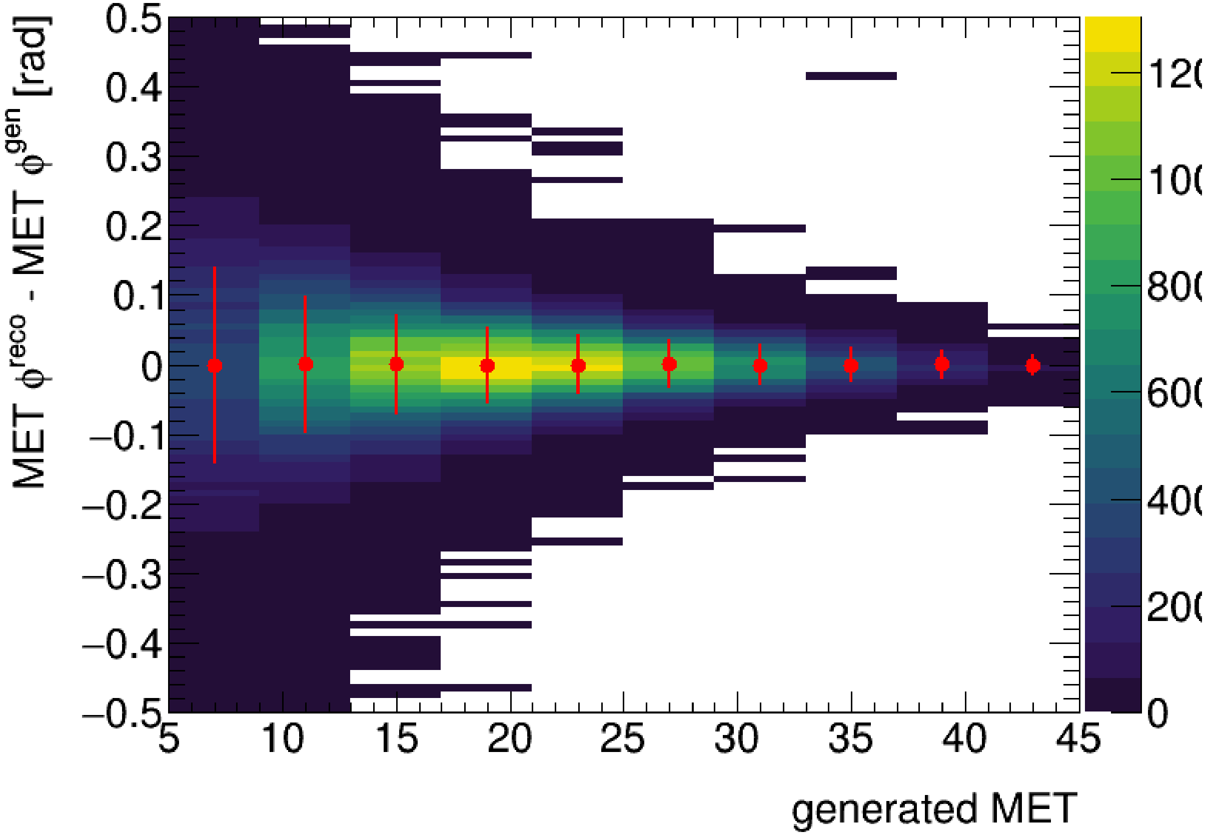
Relative MET resolution
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
10
15
20
25
30
35
40
Generated MET
Fitted Gaussian
Standard deviation

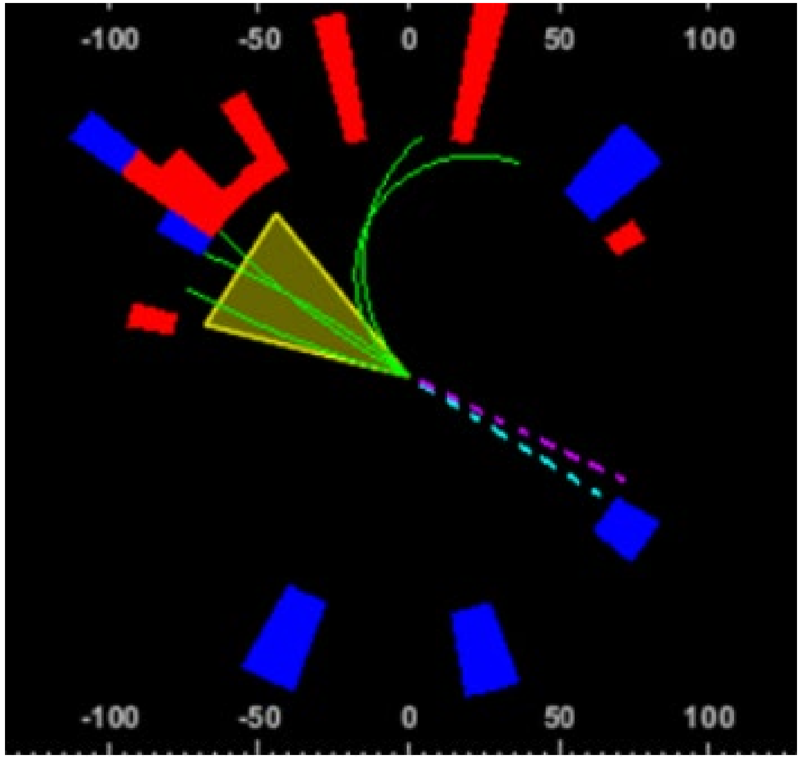
Neutrino azimuthal angle





Resolution for Neutrino-jet opening angle

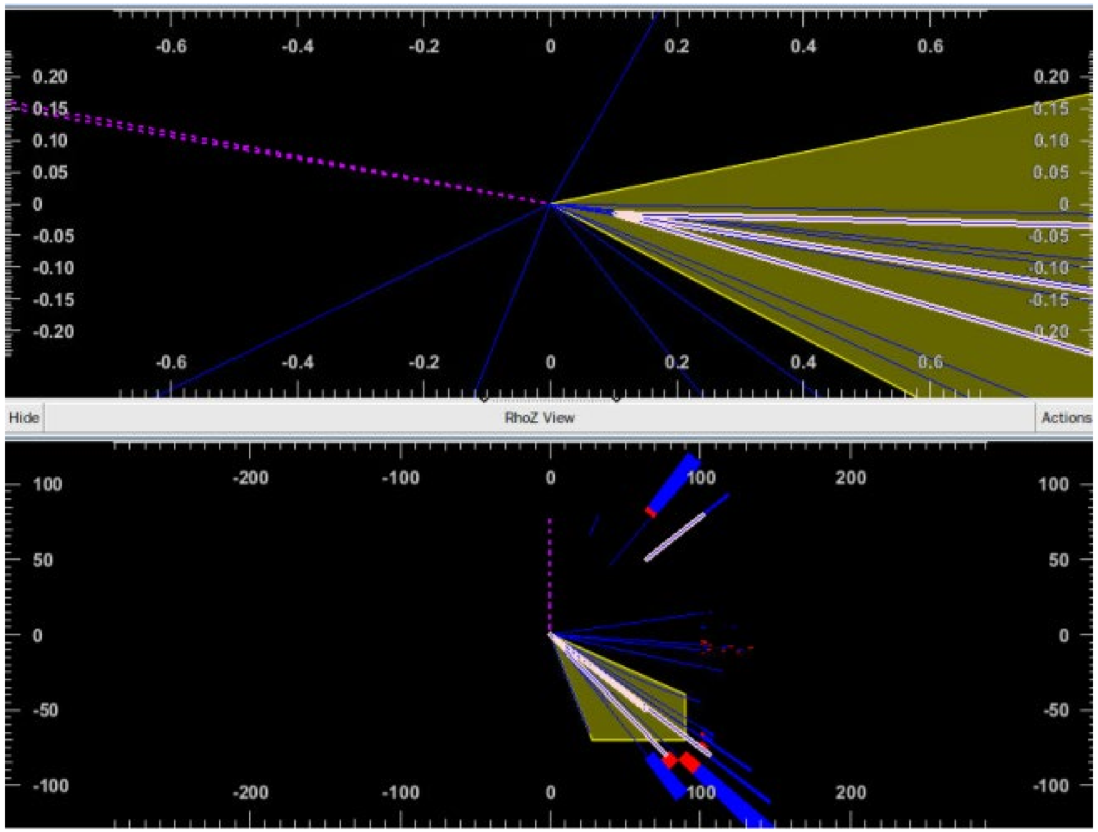


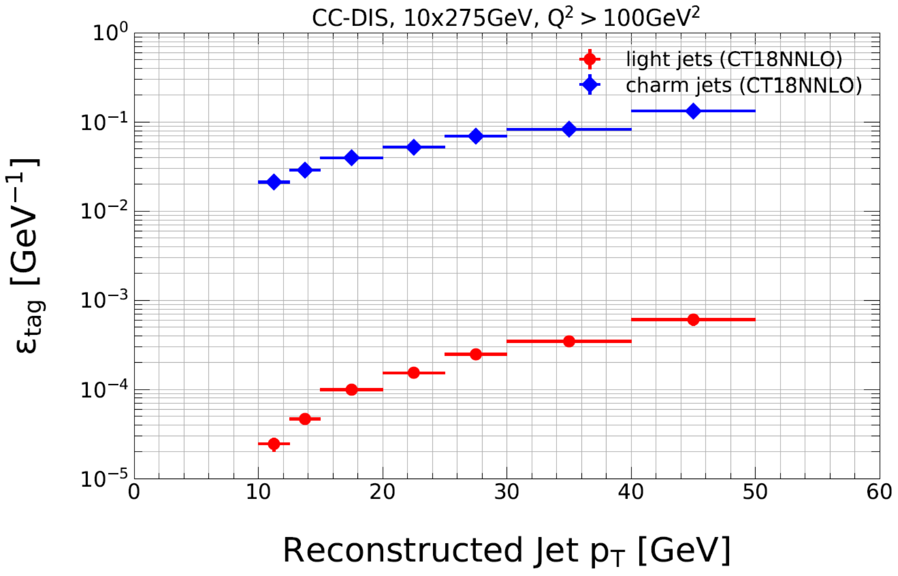


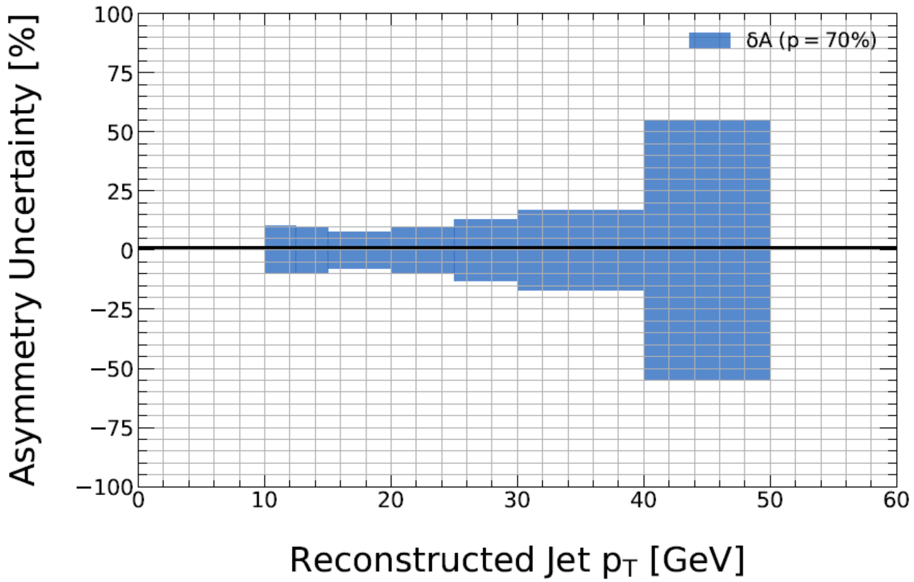
Feasibility studies still ongoing but looking promising!
(comparable RMS to dijet at RHIC Phys. Rev. Lett. **99**, 142003)

Charm-jets: the portal to strange PDF, helicity, transversity

(just a teaser, see S. Sekula's talk at Pavia for more details)







Plots by Display by S. Sekula

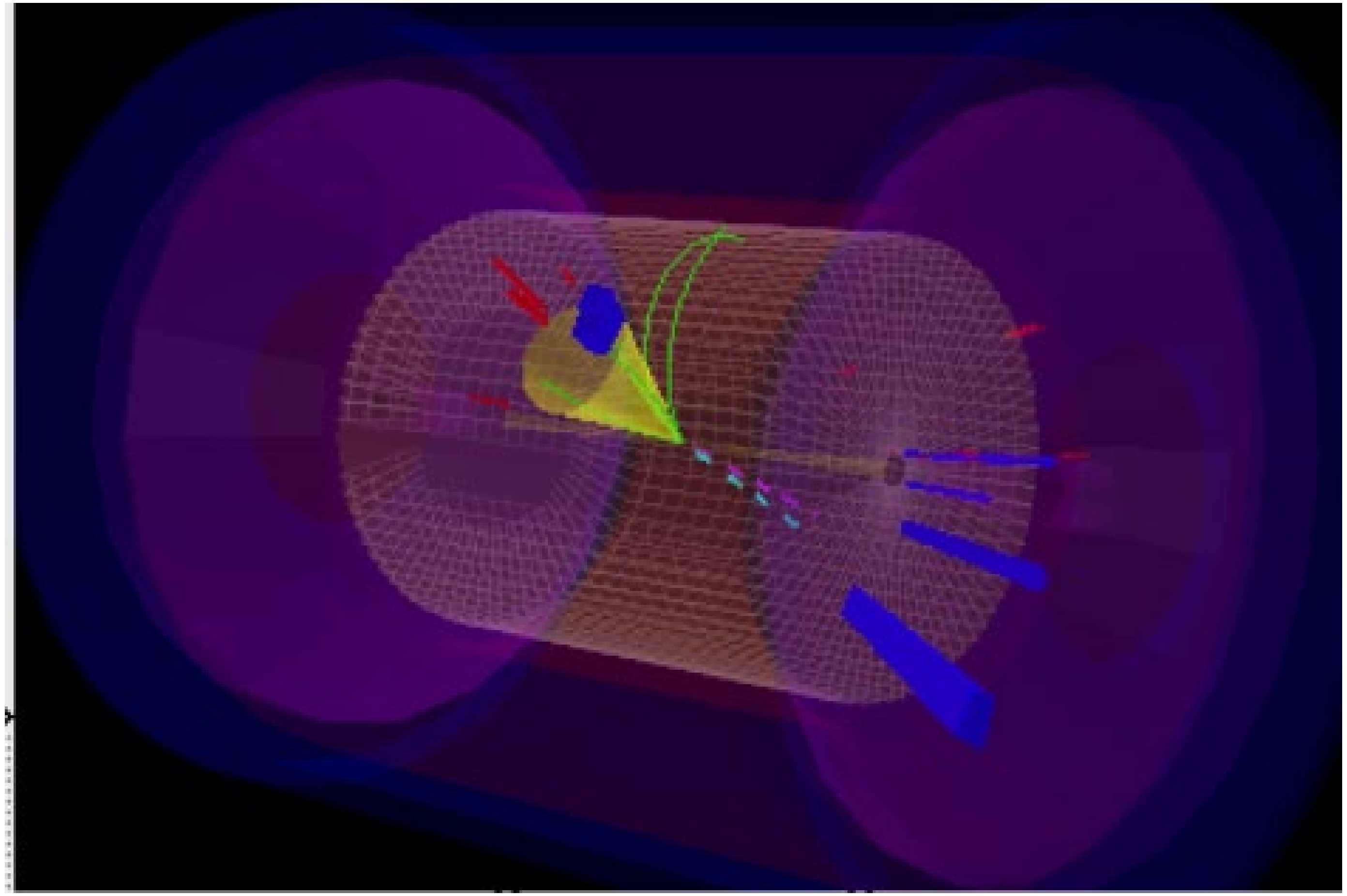
Requirements of "Jets for 3D imaging" program (under construction)

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 18, 2020, Miguel Arratia

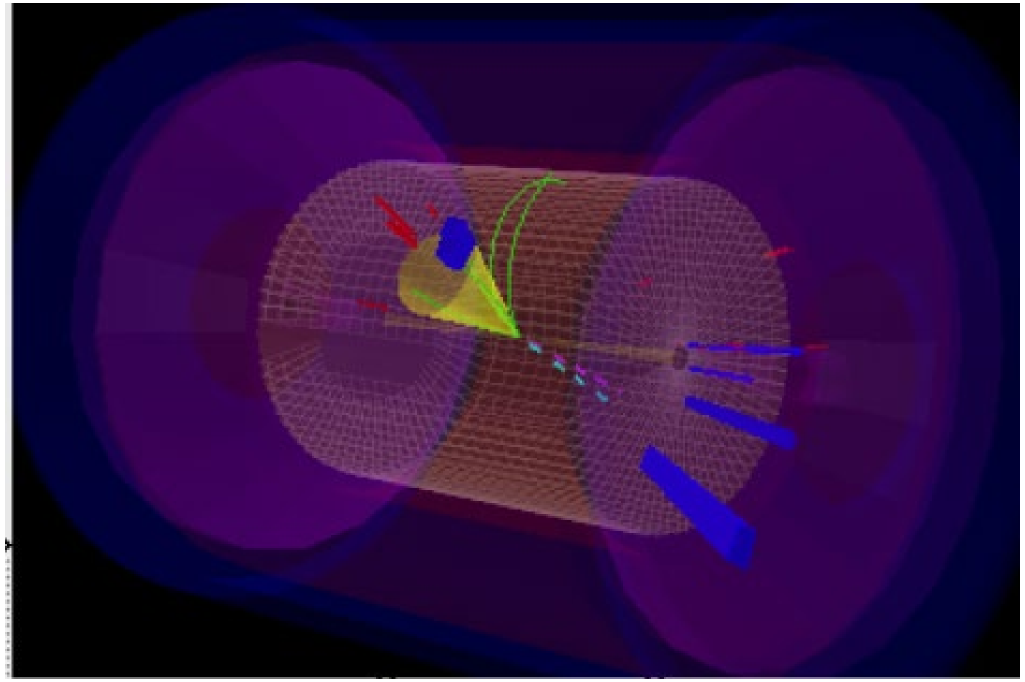
Channel	Observable	Goal	Physics-driven requirement	Category	numbers
e-jet (NC) 100 fb^{-1}	$d\sigma$, $A_{UT}(\Delta\phi)$	k_T-dependence of quark Sivers	$\Delta\phi$ res. << intrinsic width $R = 1.0 \rightarrow$ had. corr. $O(1)\%$ particle-flow reco	Jet res. Acceptance Granularity	jet $dE/E < 15\%$ 2π, $\|\eta\| < 3.5$ 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	$dp/p < 5\%$ at 50 GeV $\eta < 3.5$ and 40 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, $\|\eta\| < 3.5$ 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%) DCA = 20 μm, $\approx$ 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	—	—

*Not listed here: dijets for gluon Sivers, diffractive jets for Wigner, and others.

What do we need?
A hermetic detector



“a hermetic detector (also called a 4π detector) is a particle detector designed to observe ***all possible decay products*** *of an interaction between subatomic particles in a collider by* ***covering as large an area*** *around the interaction point as possible and incorporating multiple types of sub-detectors”* ***Source:*** **Wikipedia**



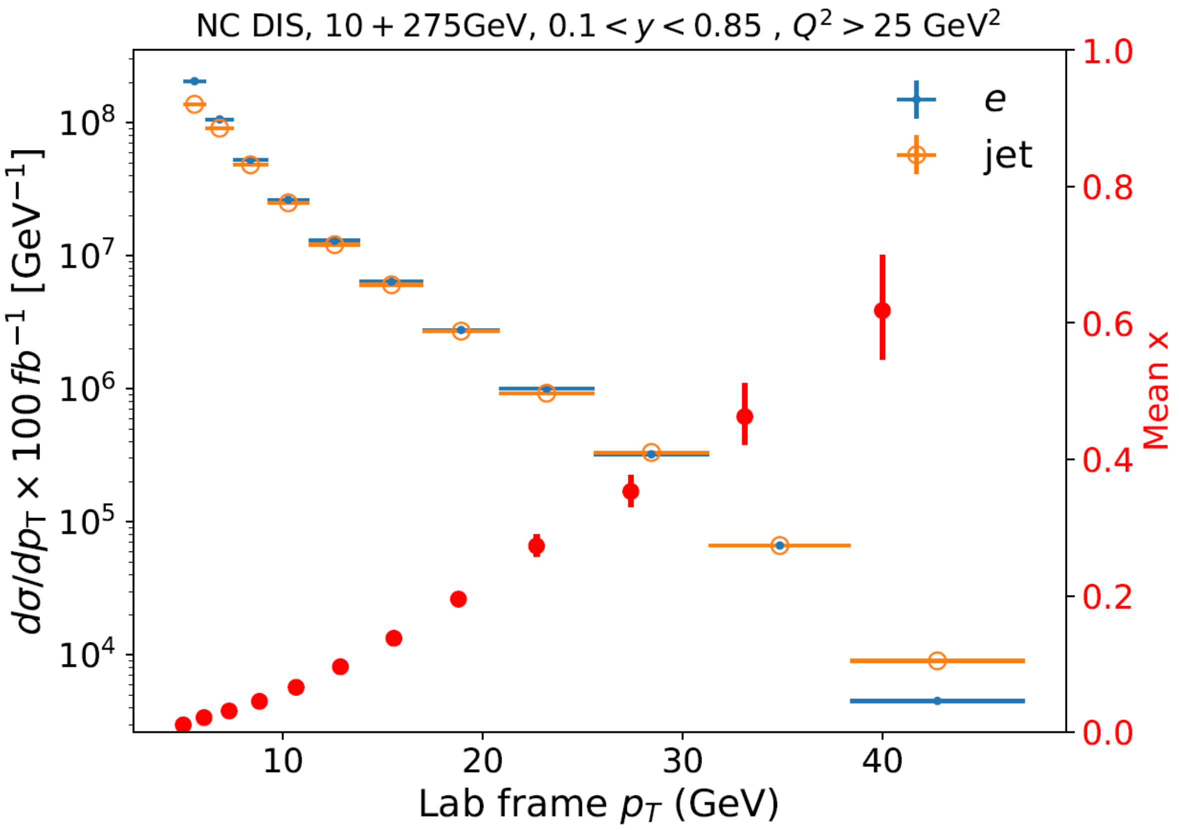
Summary

- Sivers and Collins measurements with electron-jet channel look promising.
- TMD CC DIS enabled with recent jet-physics developments
- Sivers in CC DIS seems possible.
- Collins in CC DIS looks promising.
- Strange in CC DIS looks promising.

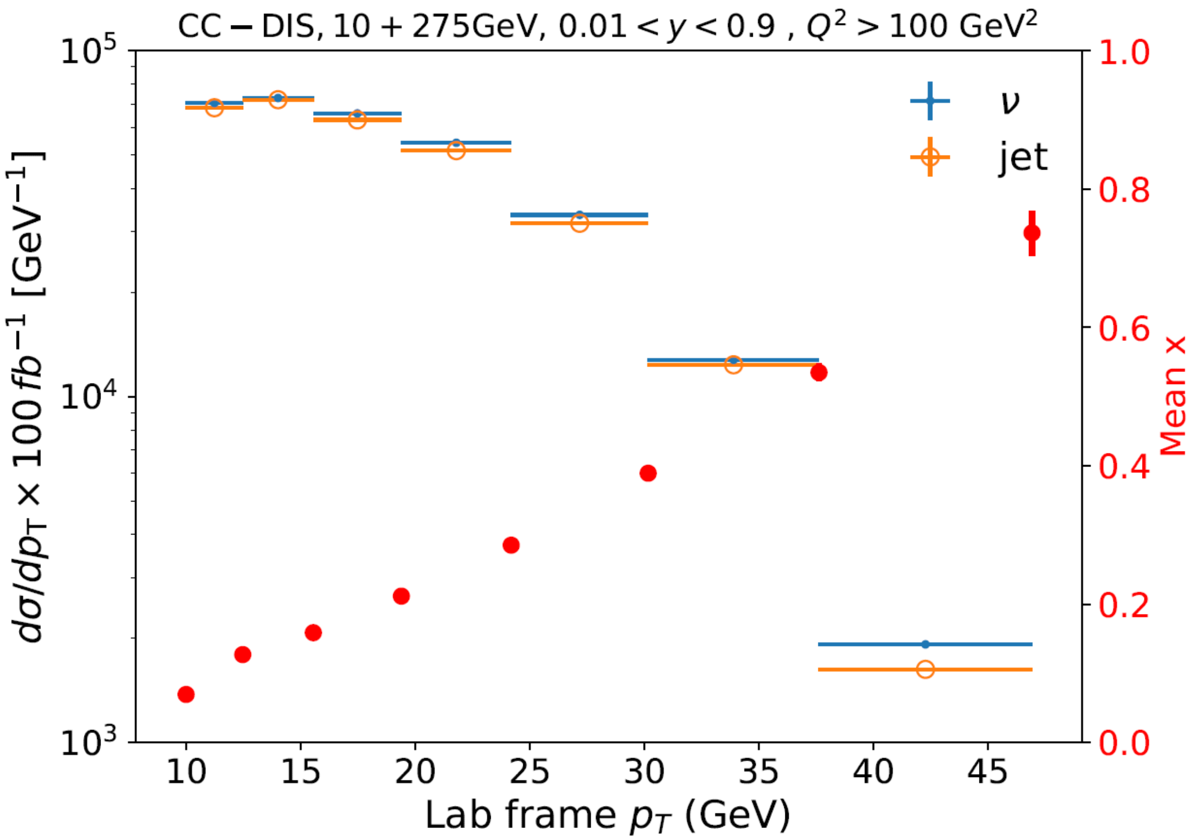
Backup

Jet cross-section (anti-kT, R=1.0)

Neutral-current events



Charged-current events



- **Contributions beyond LO are very small (<10%), so Pythia8 (LO) provides an excellent approximation for both NC and CC DIS**

Collins angle resolution at STAR

J. Kevin Adkins, STAR Thesis 2019
https://arxiv.org/abs/1907.11233

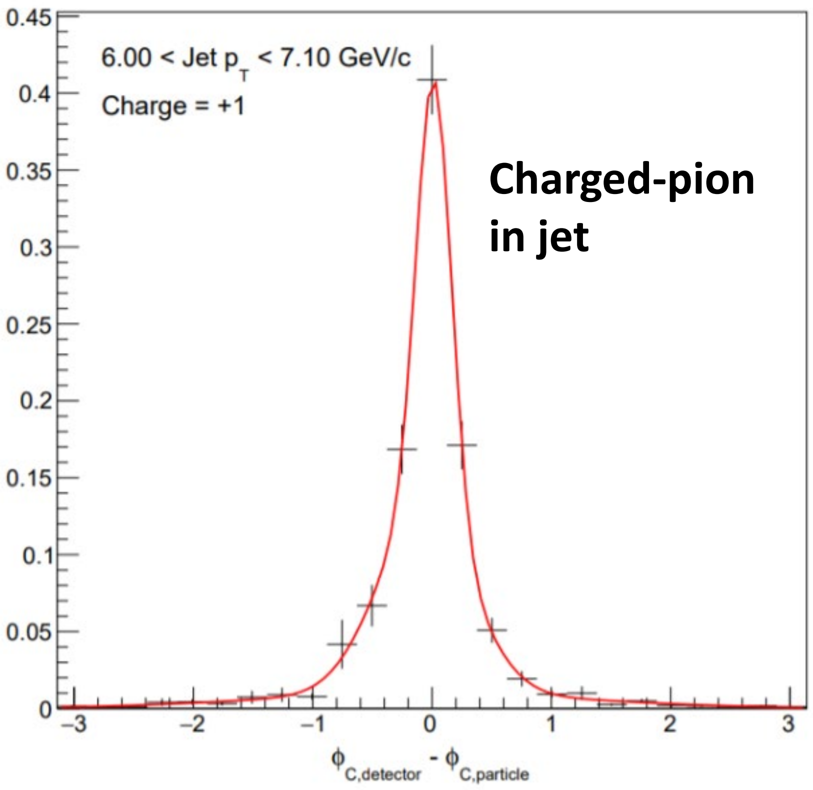


Figure 6.12: ϕ_C **Resolution Example Fit** - A triple Gaussian fit to the spread in detector minus particle level ϕ_C values.

Yuxi Pan, STAR Thesis, 2015