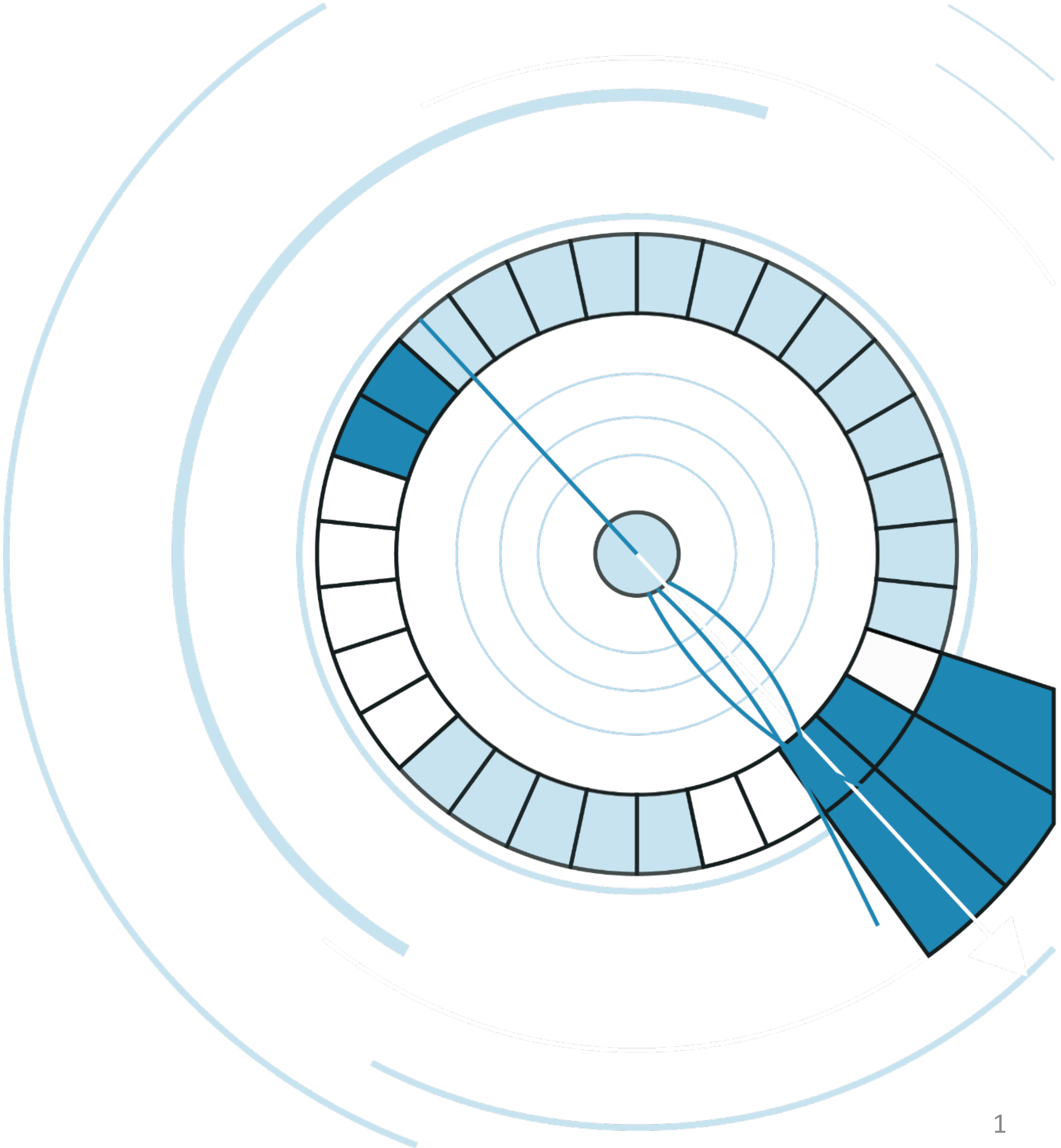
Jets for 3D imaging

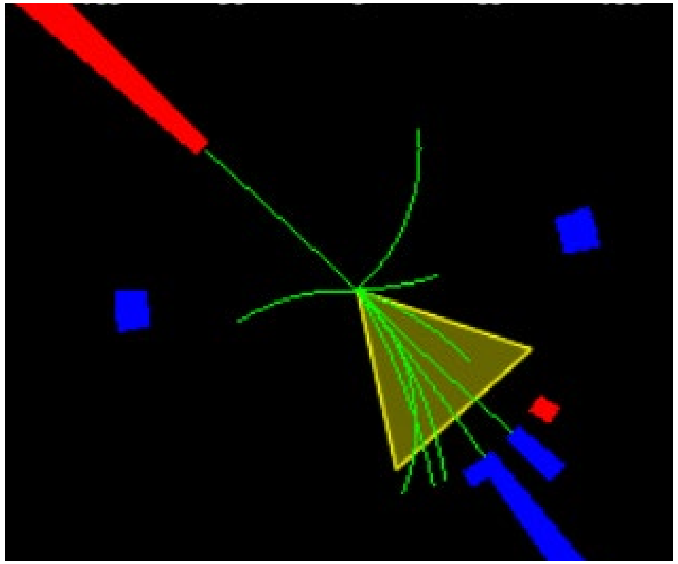
Miguel Arratia

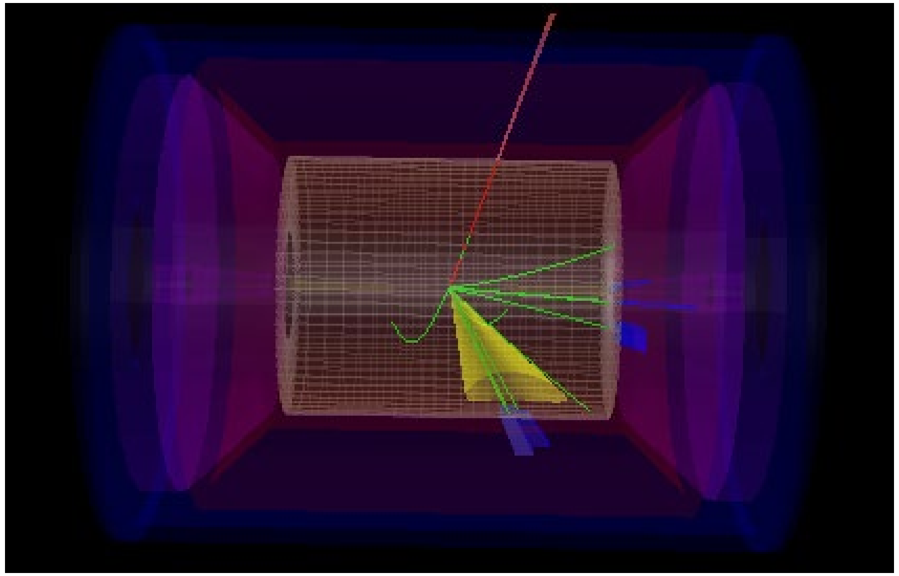
UC Riverside — University of California

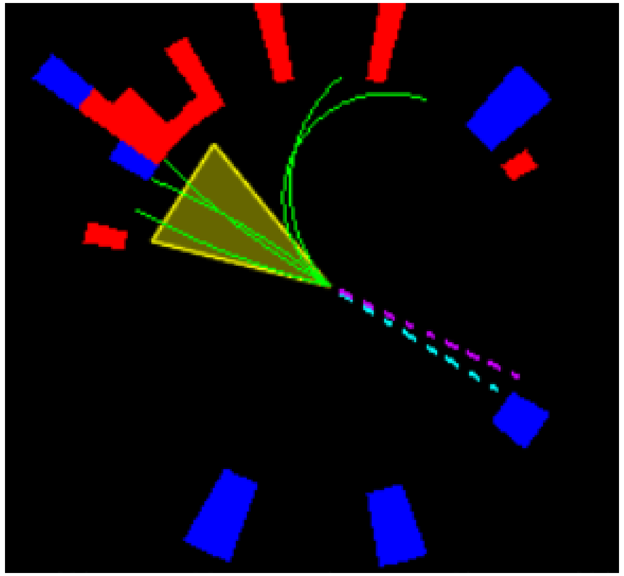


Pavia EIC YR Meeting, May 21th 2020

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



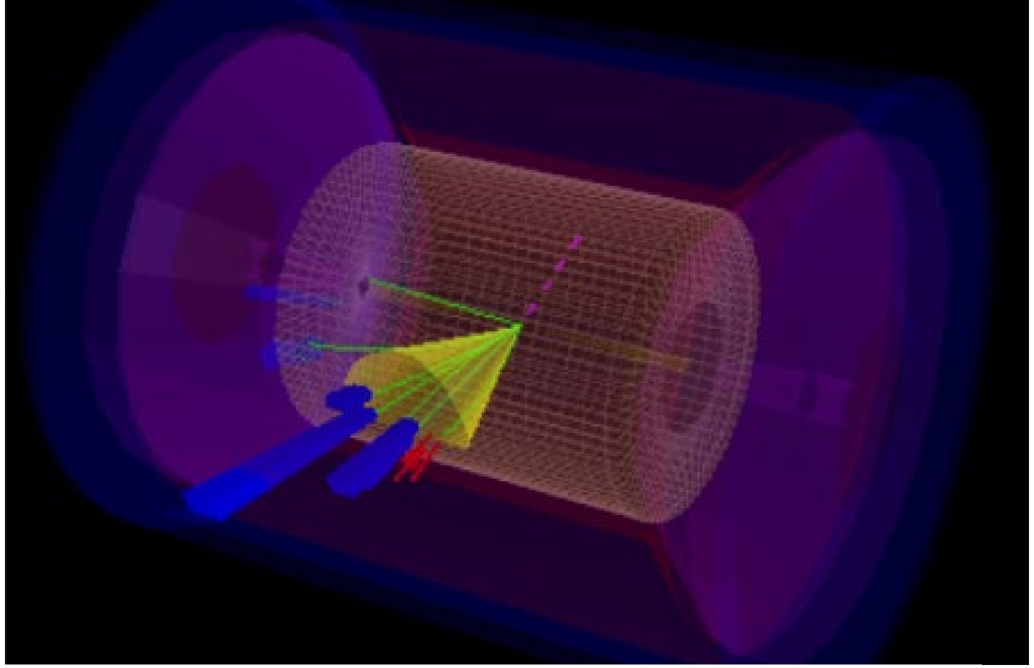




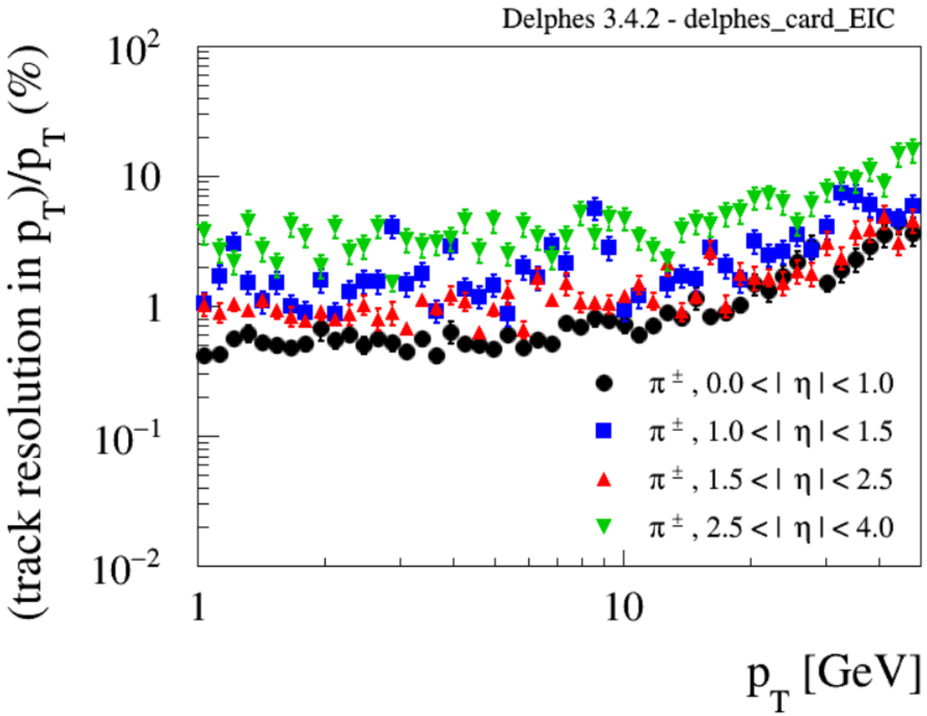
- DIS jets: a new tool for 3D imaging.
- Potential for unique jet program, unlike any previous collider or fixed-target experiment

EIC detector in Delphes

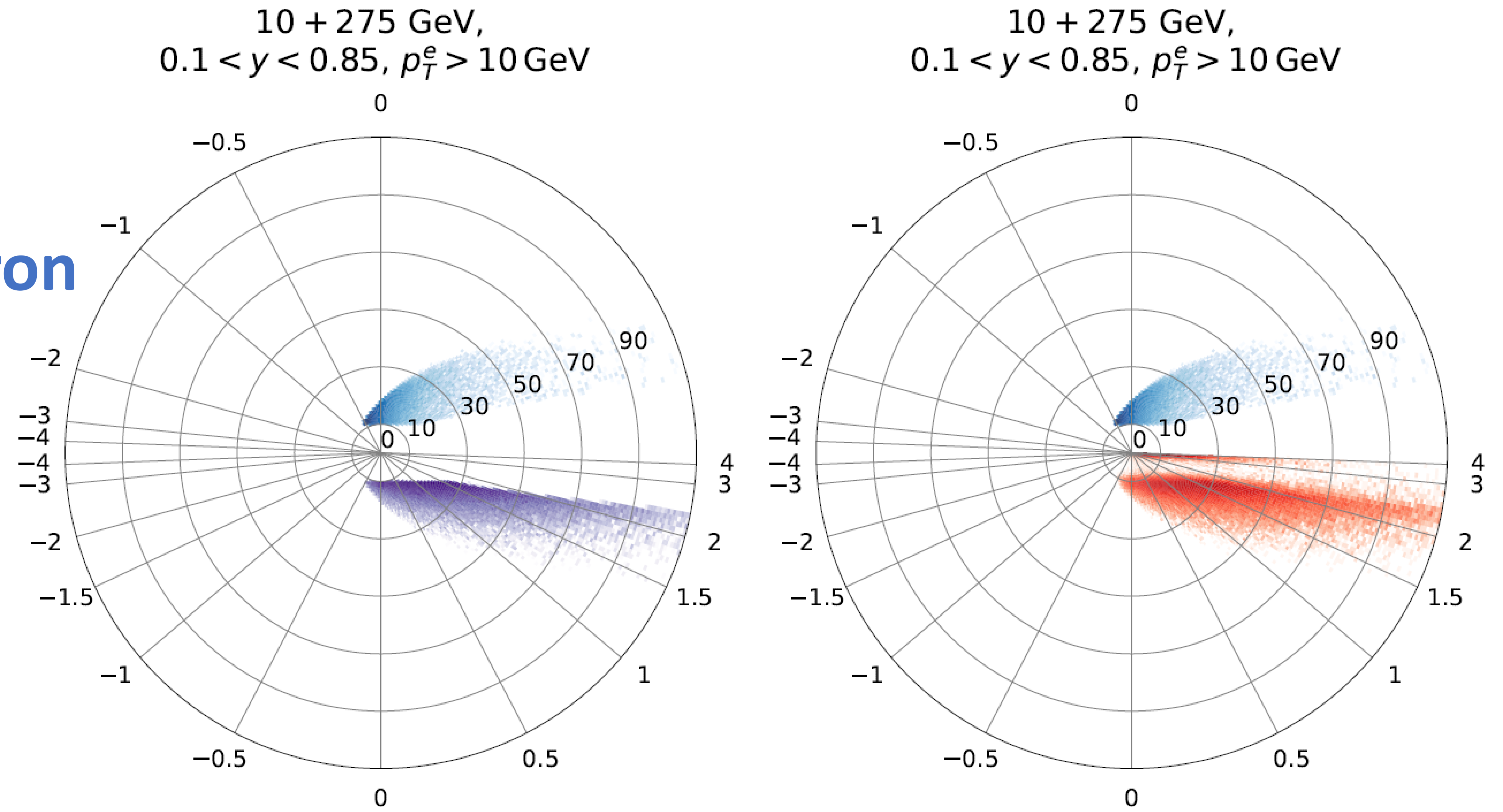
https://cp3.irmp.ucl.ac.be/projects/delphes



- DELPHES card of EIC detector as in handbook is in: https://github.com/miguelignacio/delphes_EIC/blob/master/delphes_card_EIC.tcl
- Using is fast and <u>painless</u>: ./DelphesPythia8 eicdetector.tcl out.out , then python analysis.py out.root.
- Particle-flow jet/MET, granularity, B-field, secondary vertices, charm-tagging, and much more.
- Automatic validation scripts (dozens like the one in right)
- ~10 years of testing and debugging by HEP, hundreds of active users, standard in "CERN Yellow reports"
- There is a growing EIC Delphes community, you can join us here https://join.slack.com/share/zt-ebq4da5z-UILcXLKKD3G8byJ~phqMow



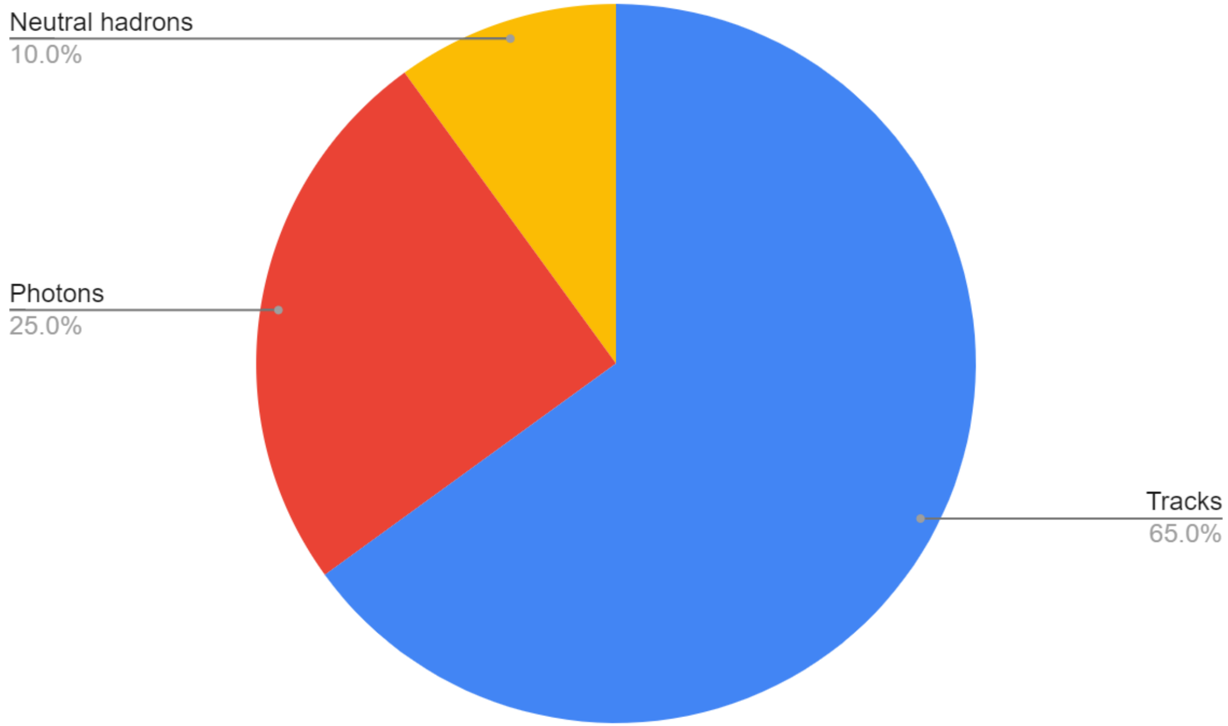
electron



Struck quark

Jet R=1.0

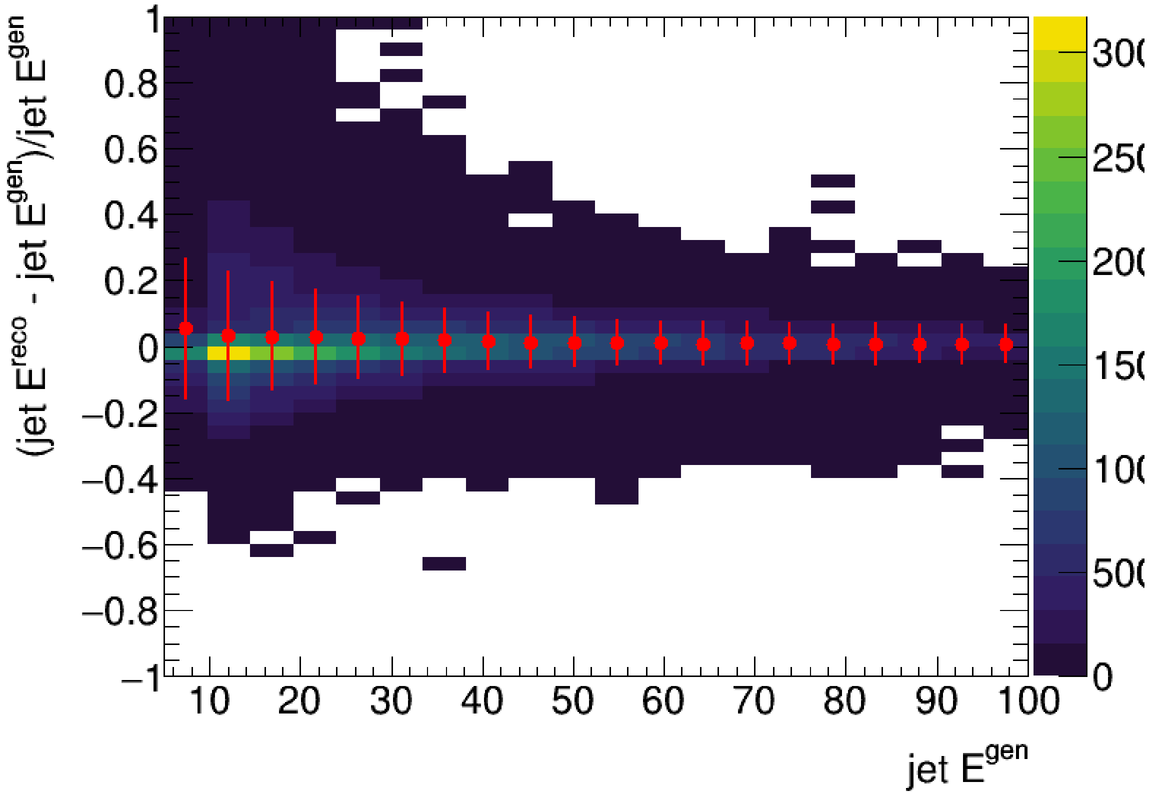
Jet energy budget

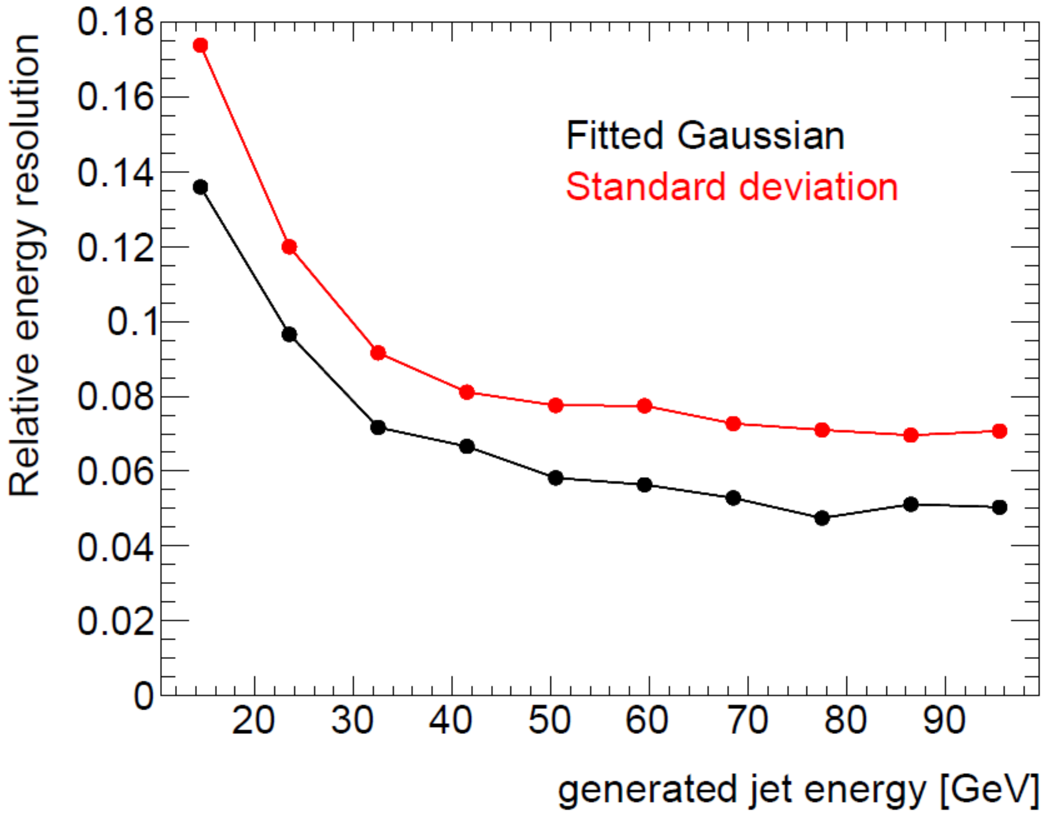


- For accurate jet and MET measurements, we need to be able to capture everything.
- Combined ECAL&HCAL resolution is key, tracking negligible.
- Tracking and calorimeter thresholds also important.

Jet-energy resolution

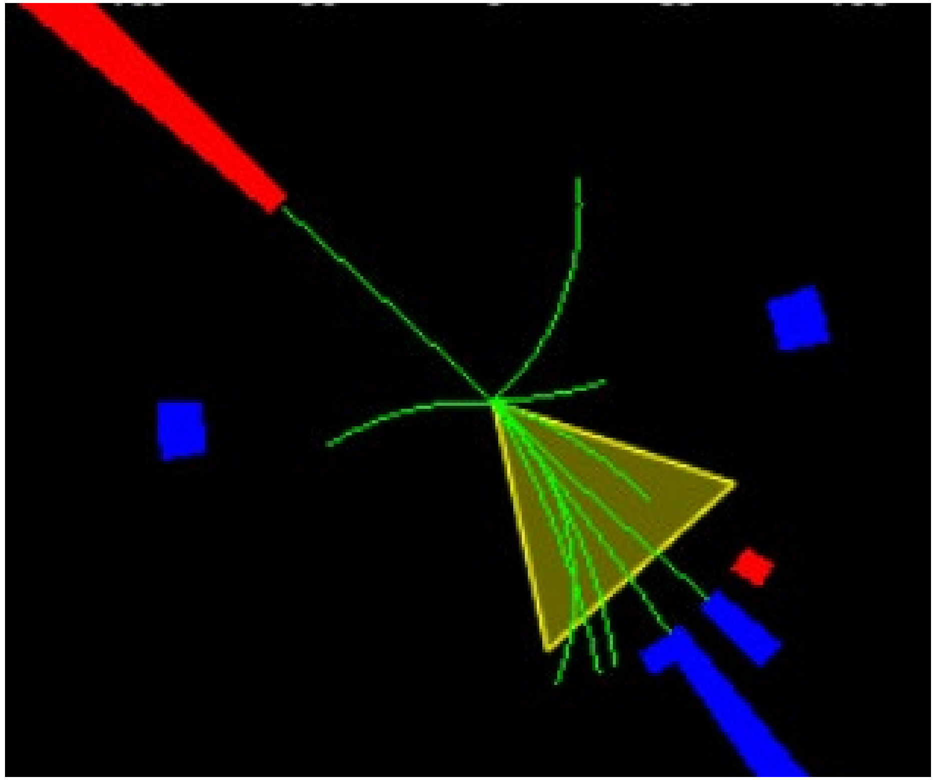
(particle-flow, R=1.0)



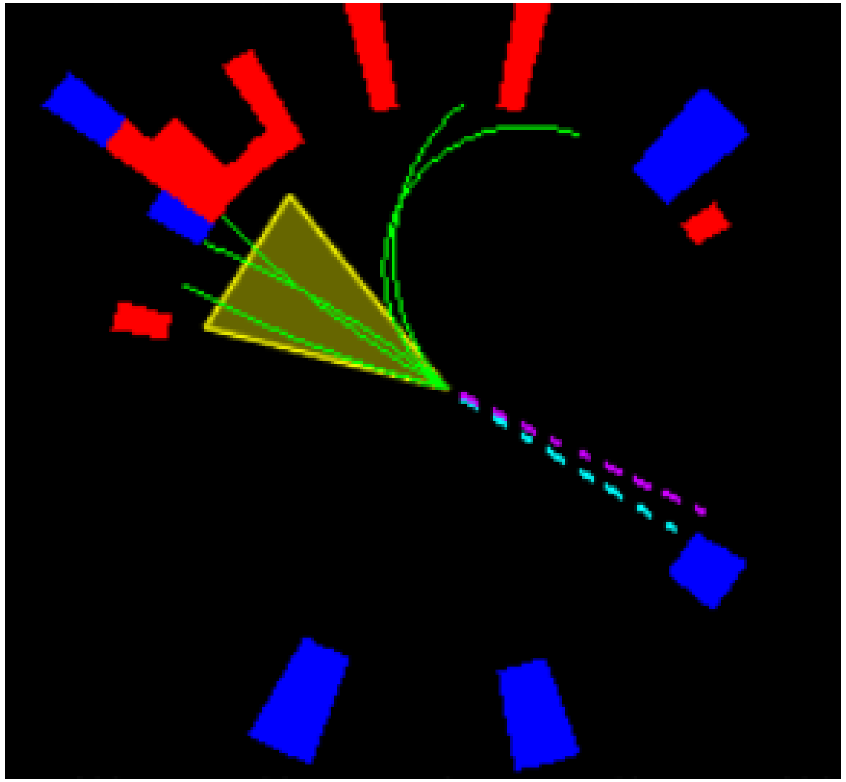


Goal is to measure accurately the azimuthal angle between lepton and jet

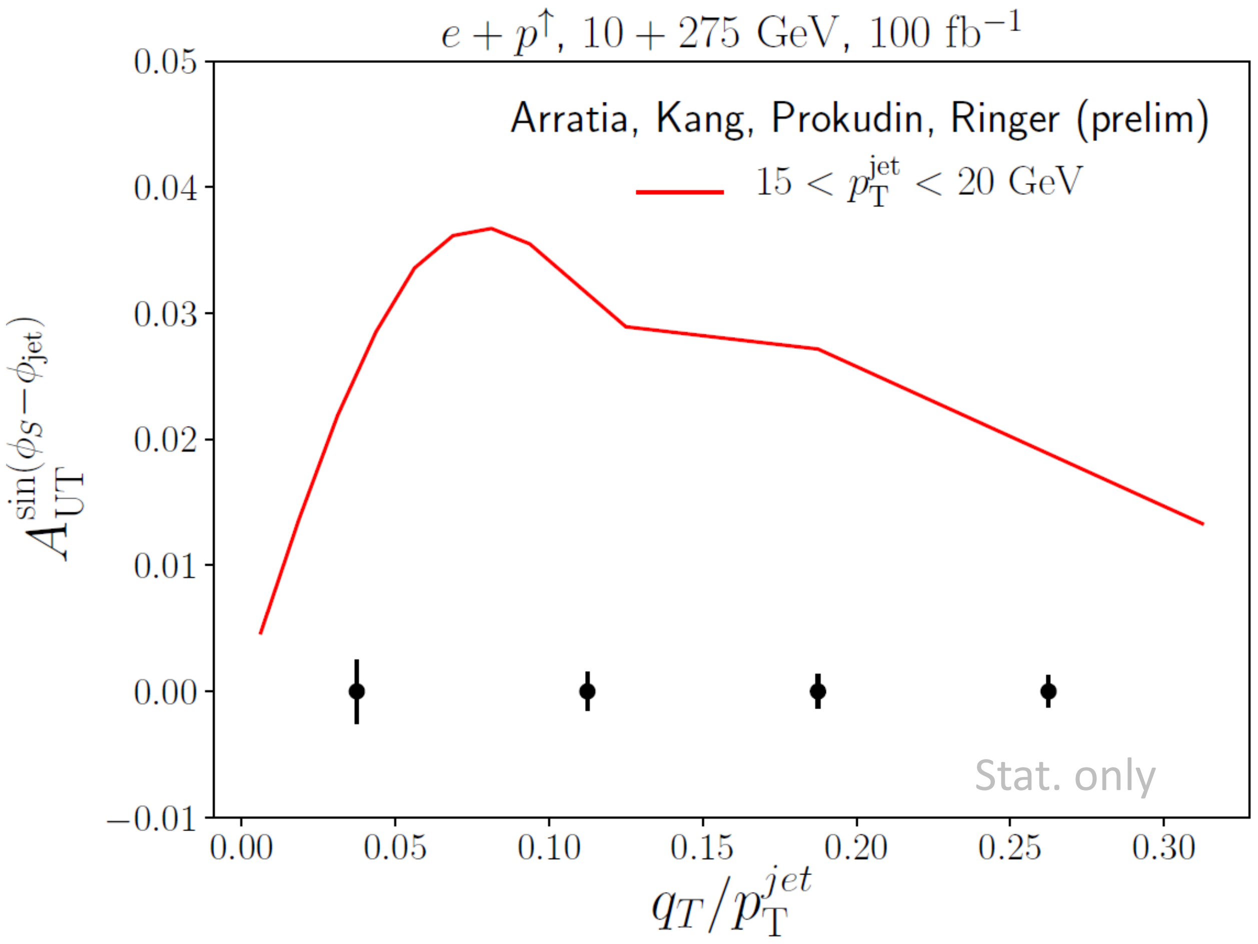
Electron-jet

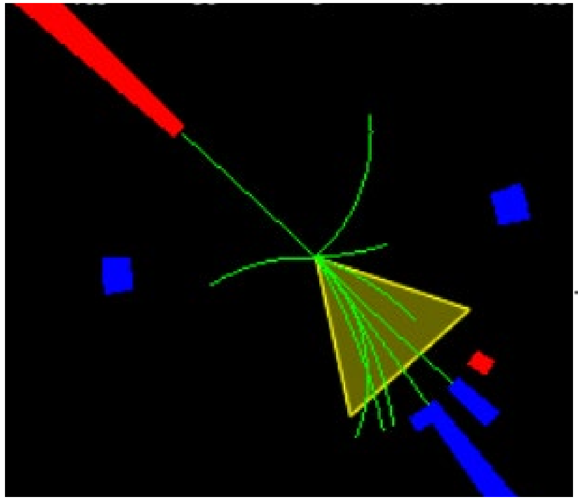


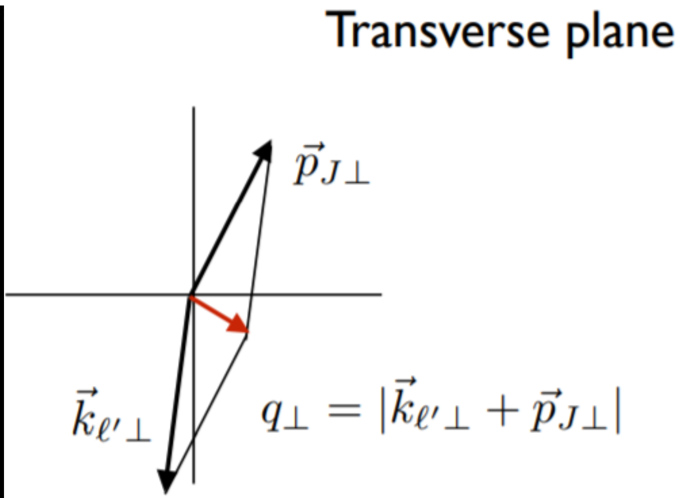
Neutrino-jet



Electron-jet Sivers asymmetry prediction (new!)





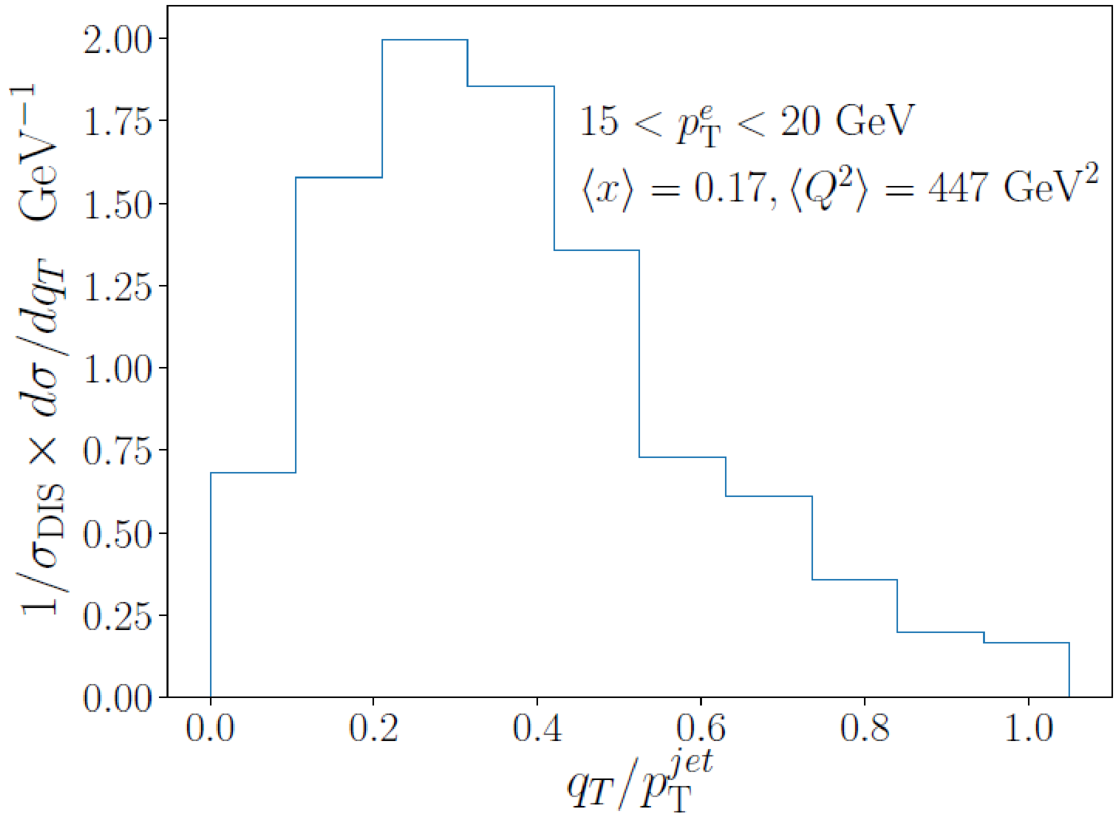


$$\frac{d\sigma}{dy_e\, d^2\vec{p}_T^{\,e}\, d^2\vec{q}_T} = \sigma_0\, H_q(Q,\mu) \sum_q e_q^2\, J_q(p_T^{\rm jet} R, \mu)$$

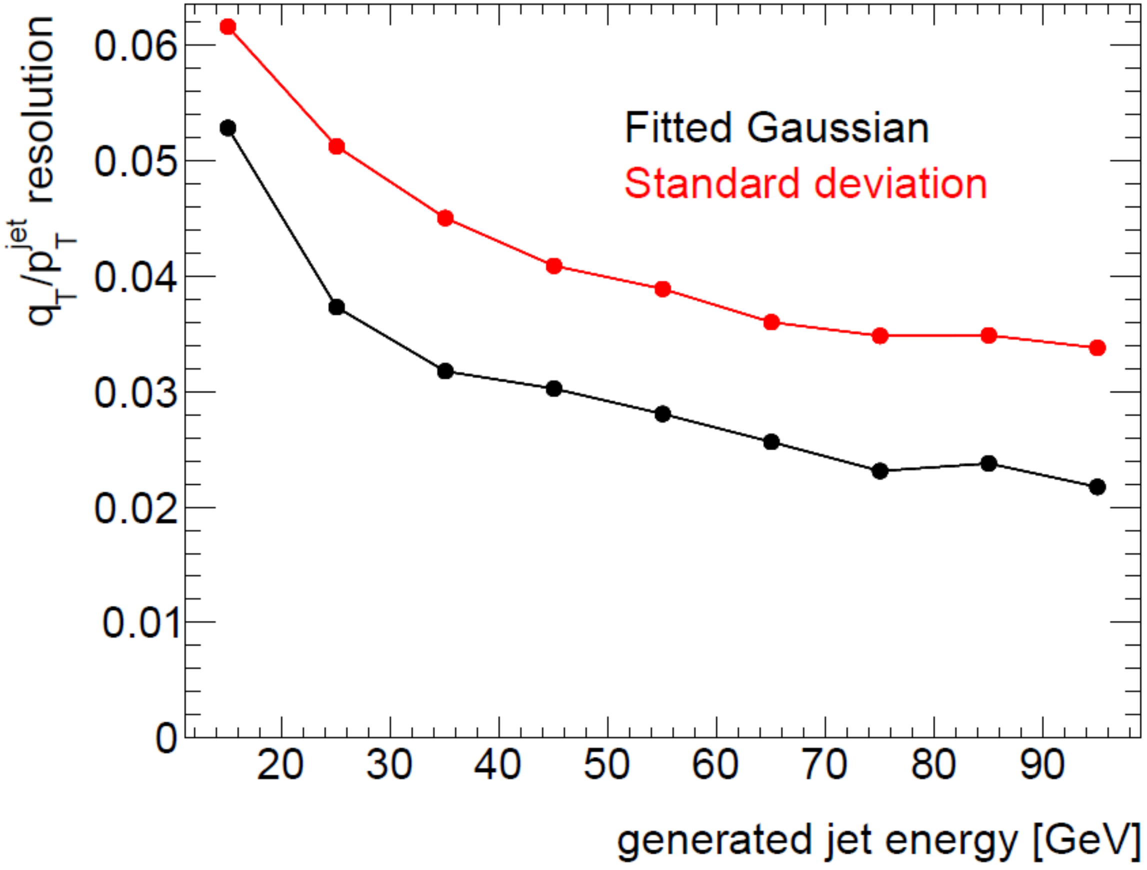
$$\times \int \frac{d^2\vec{b}_T}{(2\pi)^2}\, e^{i\vec{q}_T\cdot\vec{b}_T}\, f_q(x, \vec{b}_T, \mu)\, S_q(\vec{b}_T, y_{\rm jet}, R, \mu)\,.$$

Similar formalism than, PRL 122 192003 (2019), and arXiv:1812.07549 , different parametrizations

“Intrinsic width”

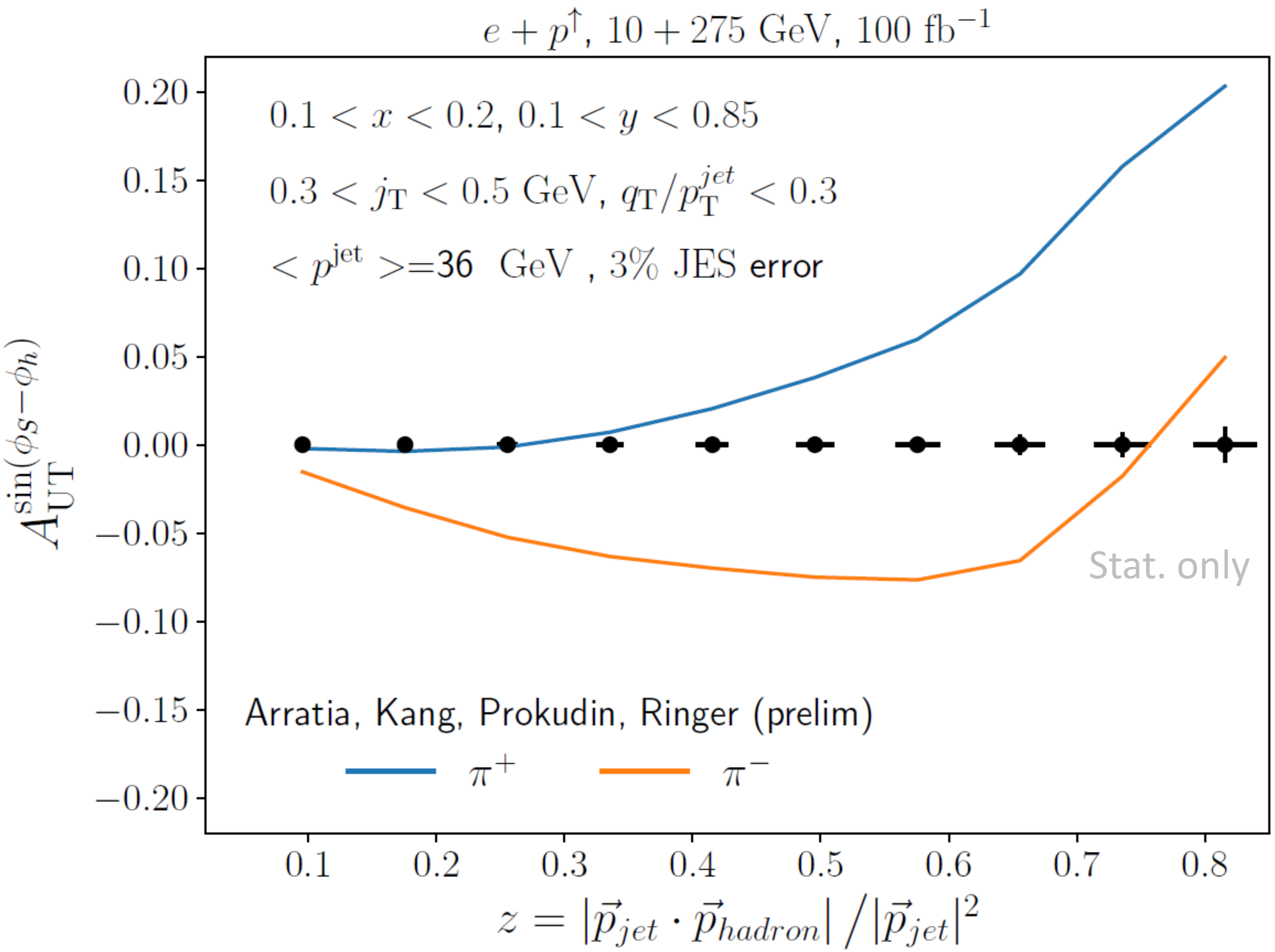


Detector resolution



Impact of smearing on asymmetries is under evaluation

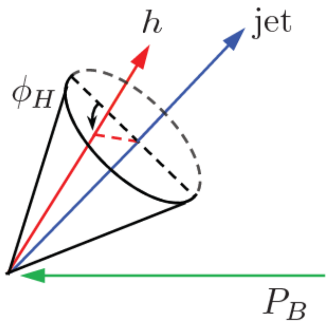
Hadron-in-jet theory prediction (new!)

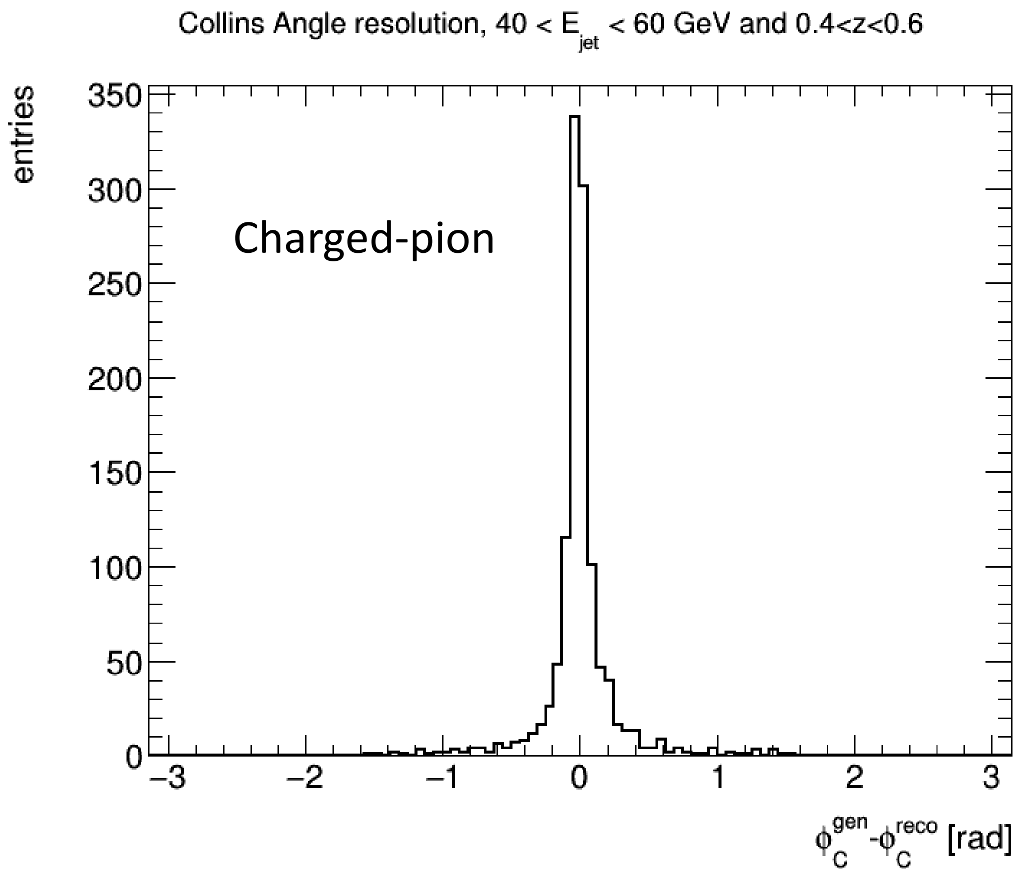


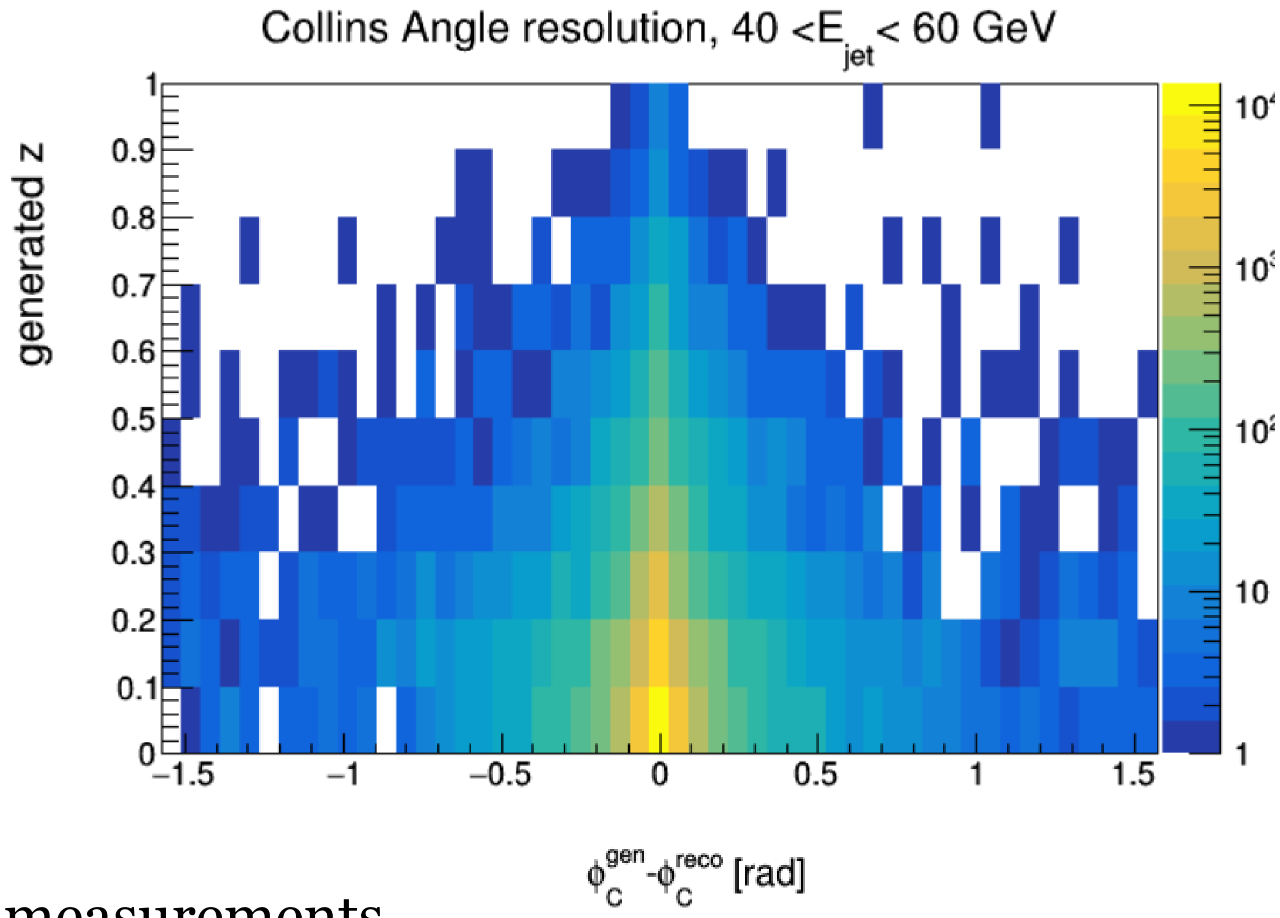
- By measuring both photon axis and jet axis we control separately TMD PDF (qT) and TMD FF (jT, z).
- Goal is multi-differential quark-transversity study.

$$\frac{d\sigma}{dy_e\, d^2\vec{p}_T^{\,e}\, d^2\vec{q}_T\, dz_h\, d^2\vec{j}_T^{\,h}} =$$
$$\times\, \sigma_0\, H_q(Q,\mu) \sum_q e_q^2\, \mathcal{G}_q(z_h, \vec{j}_T, p_T^{\rm jet} R, \mu)$$
$$\times \int \frac{d^2\vec{b}_T}{(2\pi)^2}\, e^{i\vec{q}_T\cdot\vec{b}_T}\, f_q(x, \vec{b}_T, \mu)\, S_q(\vec{b}_T, y_{\rm jet}, R, \mu)$$

Collins Angle resolution

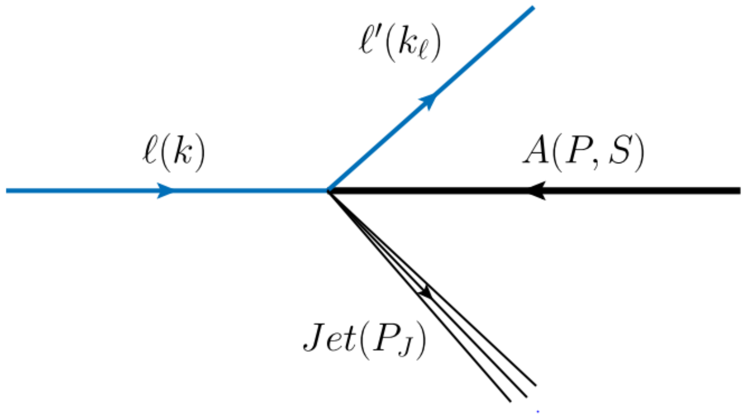


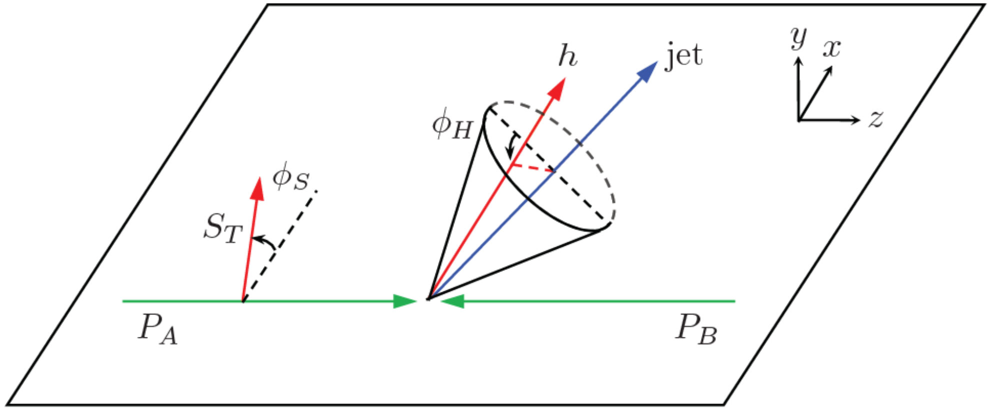


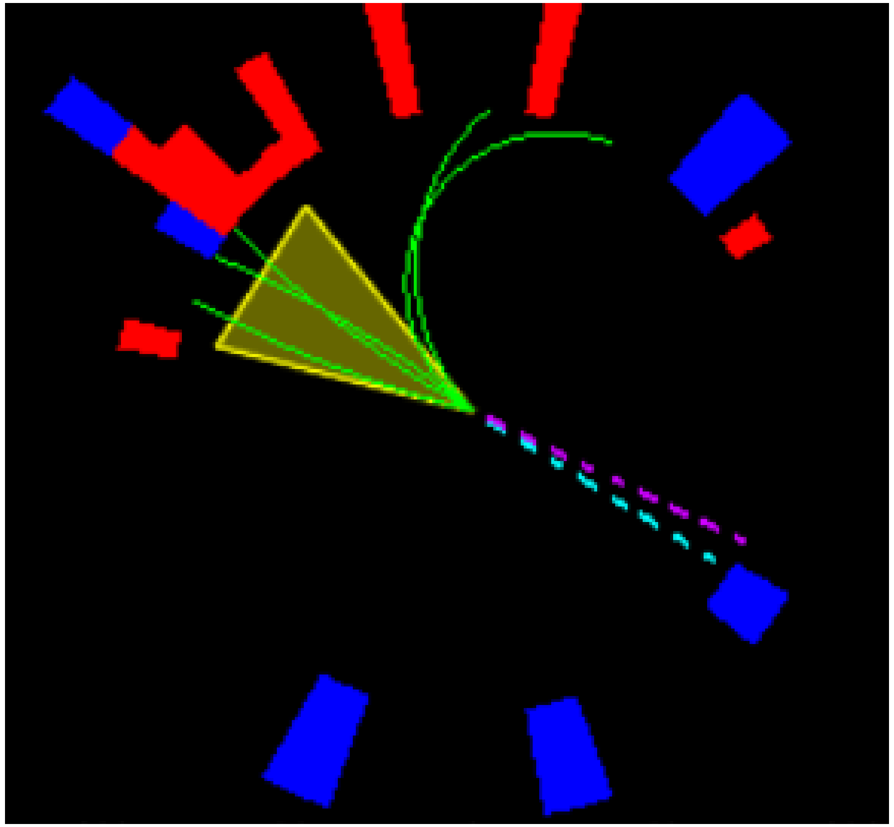


- Compares favorably to STAR measurements
- Calculation on how this propagates to "asymmetry dilution" ongoing

Boosting to Breit-frame is not an option!
The jet way bypasses the need of boost



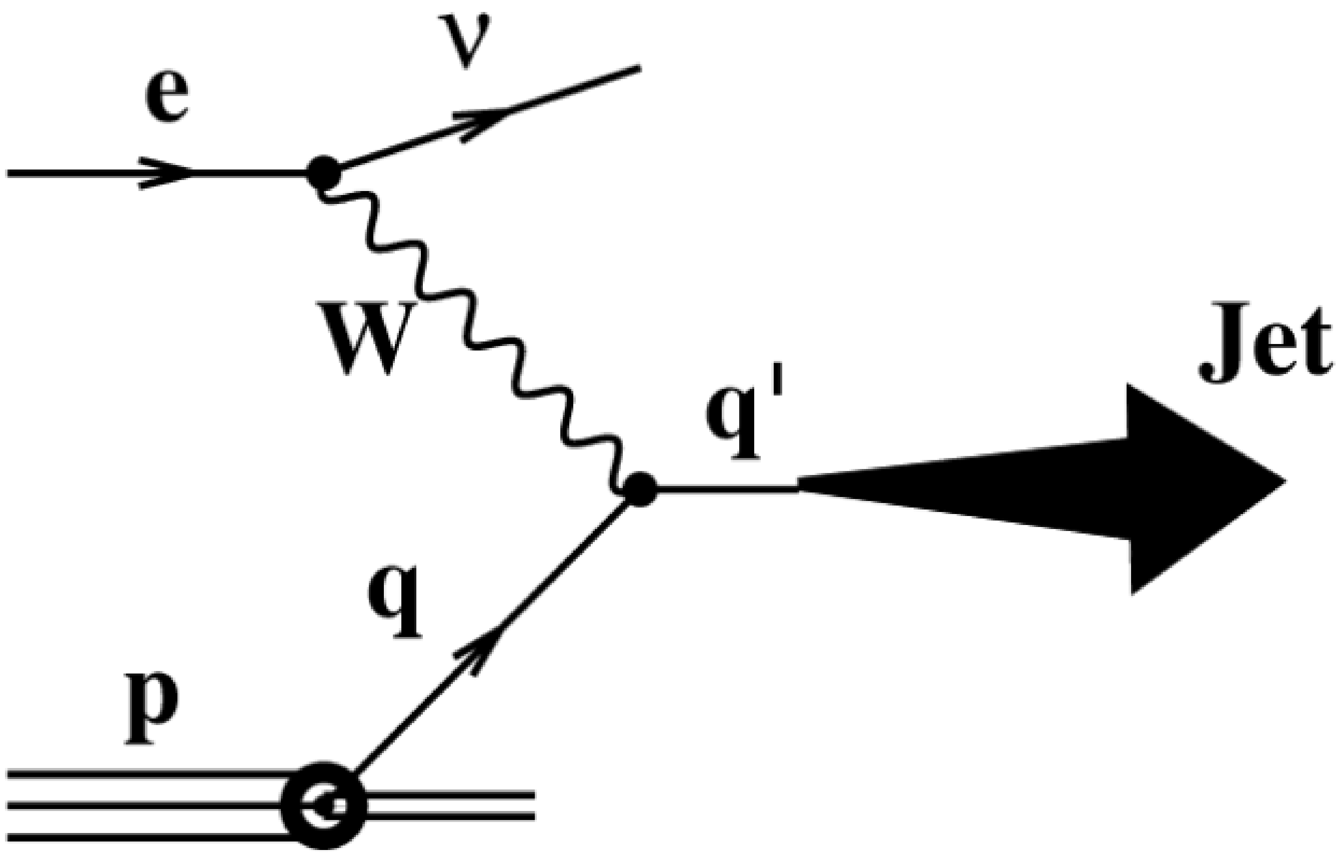


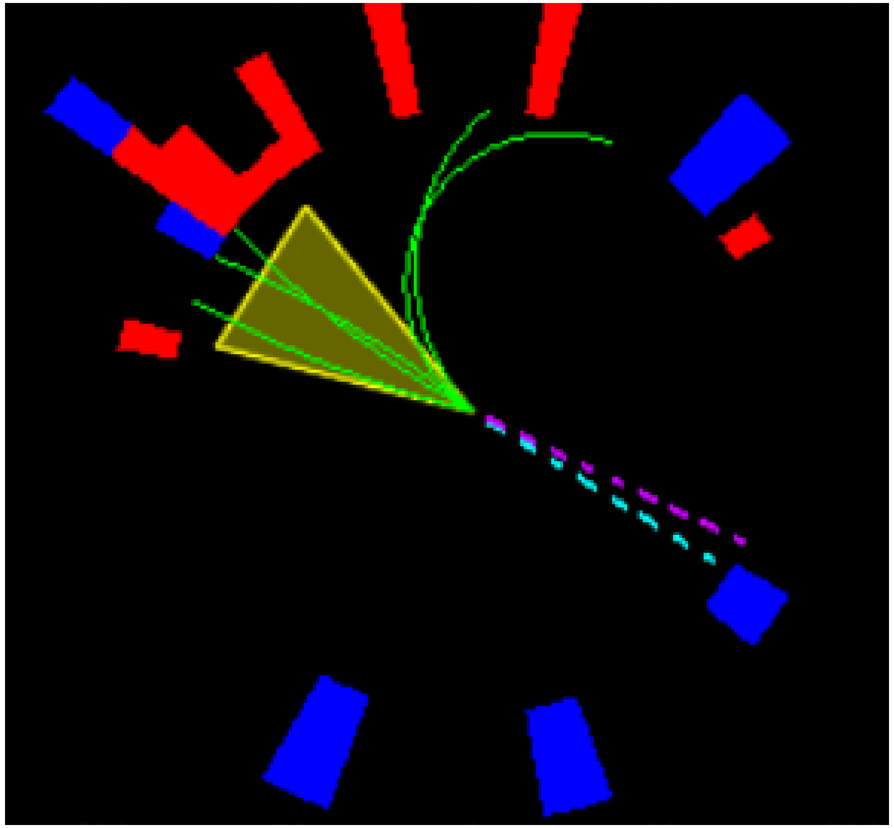


Clean flavor selectivity

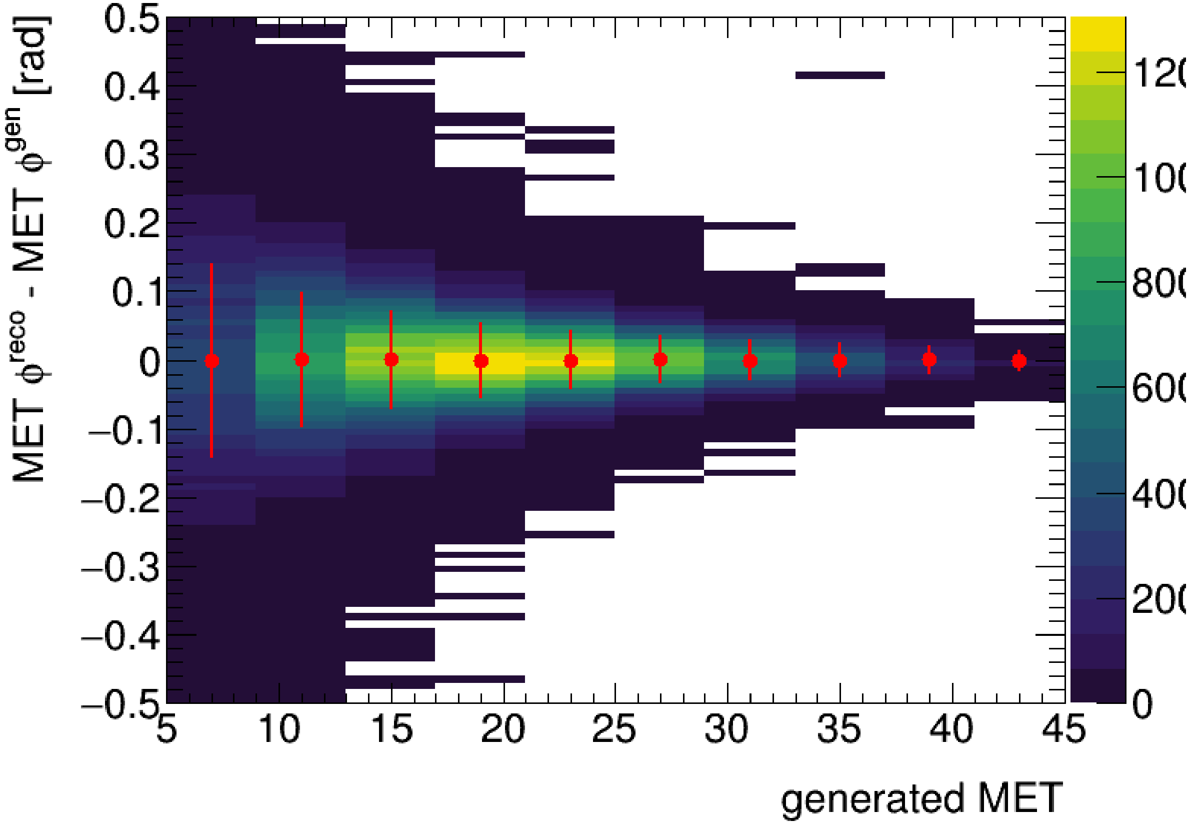
u-quarks for electron, d-quark for positron

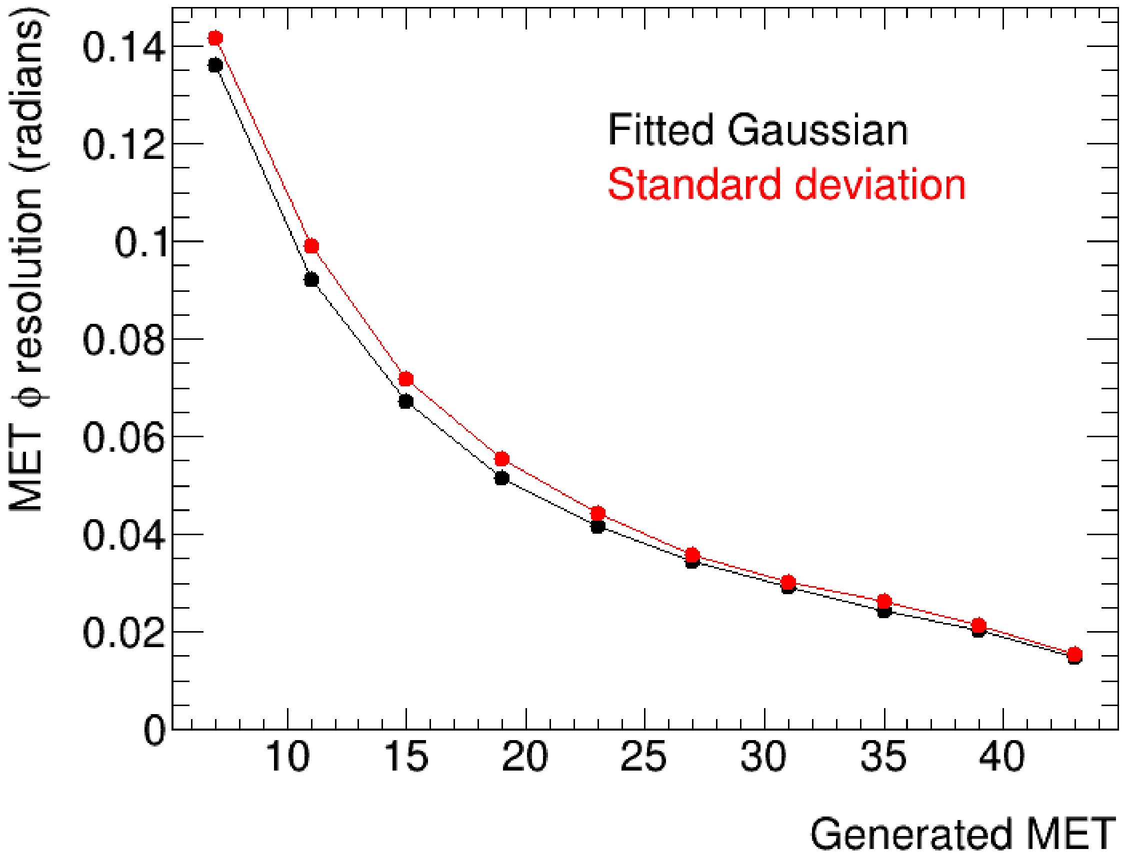
strange from charm-jets



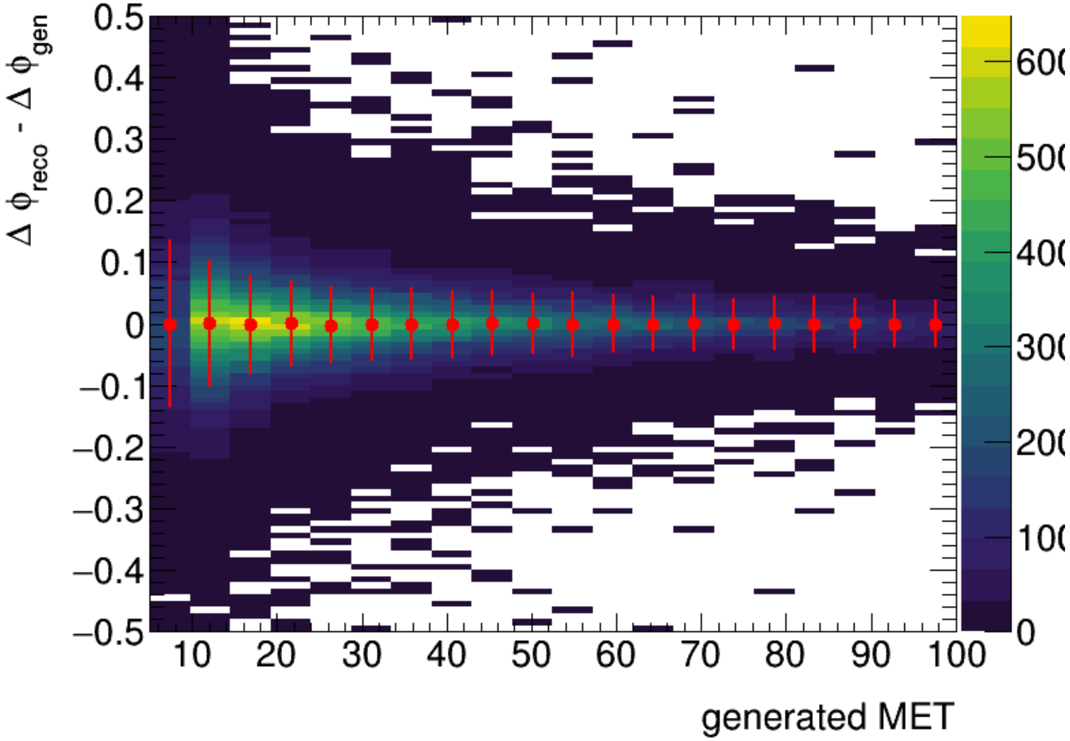


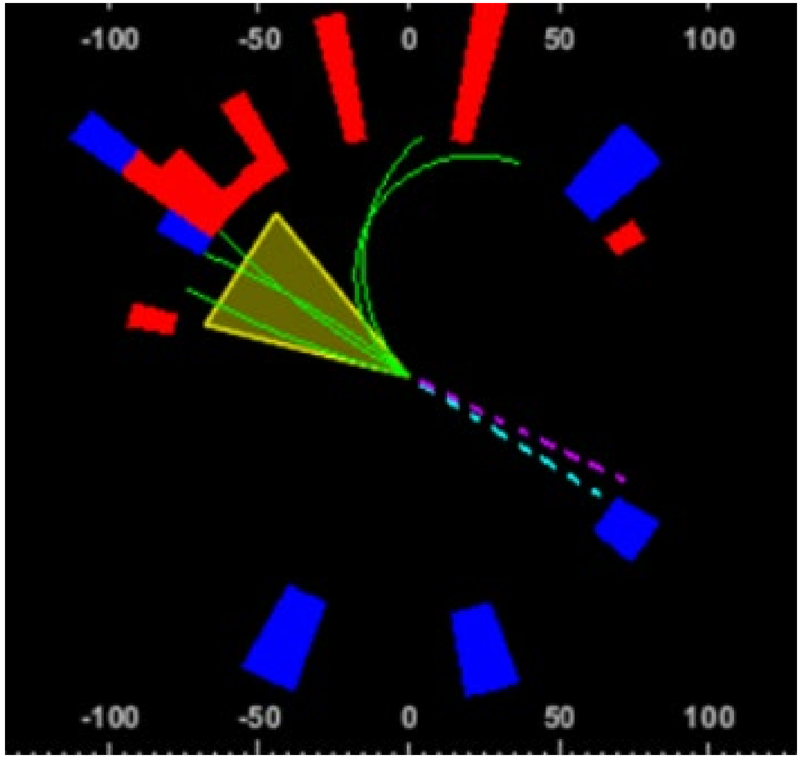
Neutrino azimuthal angle





Resolution for Neutrino-jet opening angle





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

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 21, 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	ECAL&HCAL $dE/E < 60\%/\sqrt{E}$ 2π, $-1.0 < \eta < 3.5$ 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	$dp/p < 3\%$ at 50 GeV, up to $\eta = 3.0$ up to $-1.0 < \eta < 3.5$ 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, $\|\eta\| < 3.5$ 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 $> 10\%$ ($<0.05\%$) $\sigma(DCA) = 20\ \mu$m, up to $\|\eta\| = 3$ $\approx 100\%$ 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	—	—

*Not listed here: dijets for gluon Sivers, diffractive jets for Wigner, and others that will also be central for jets for 3D imaging

Summary

- Kinematic mappings and statistical projection done (since Temple)
- Fast simulations done for jet-based Sivers and Collins measurements in NC and CC DIS
- Key requirements identified.
- New theory predictions.

Fast simulation with Delphes3

DELPHES 3, A modular framework for fast simulation of a generic collider experiment
DELPHES 3 Collaboration (J. de Favereau *et al.*). Jul 24, 2013. 26 pp.
Published in **JHEP 1402 (2014) 057**
DOI: 10.1007/JHEP02(2014)057
e-Print: **arXiv:1307.6346 [hep-ex]** | PDF

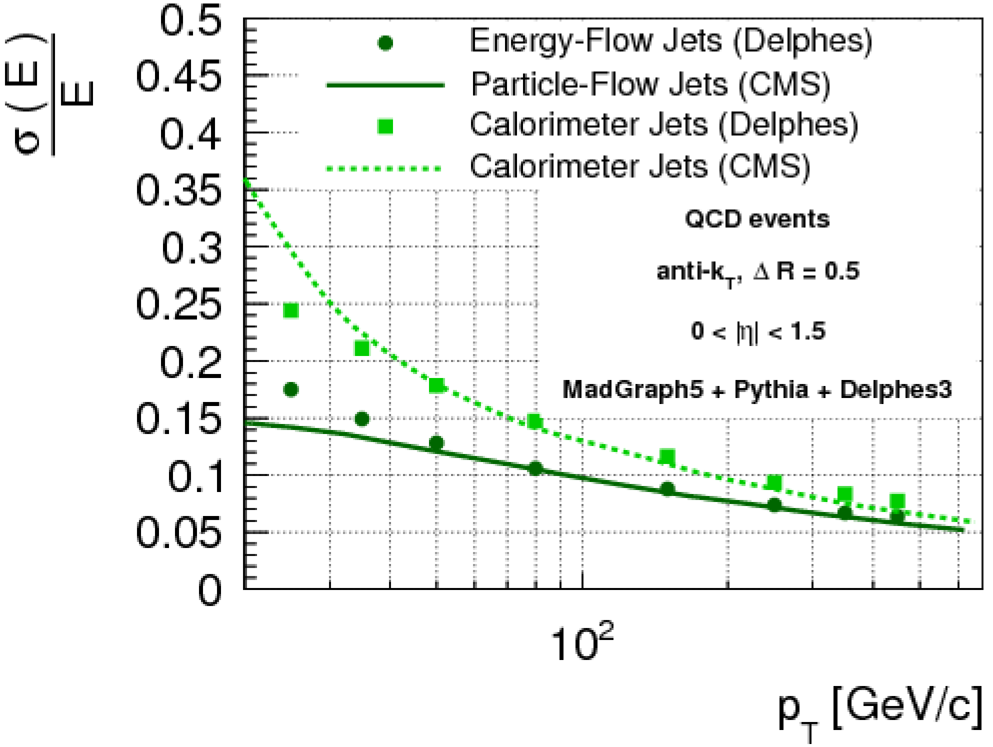
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service; Link to Article from SCOAP3

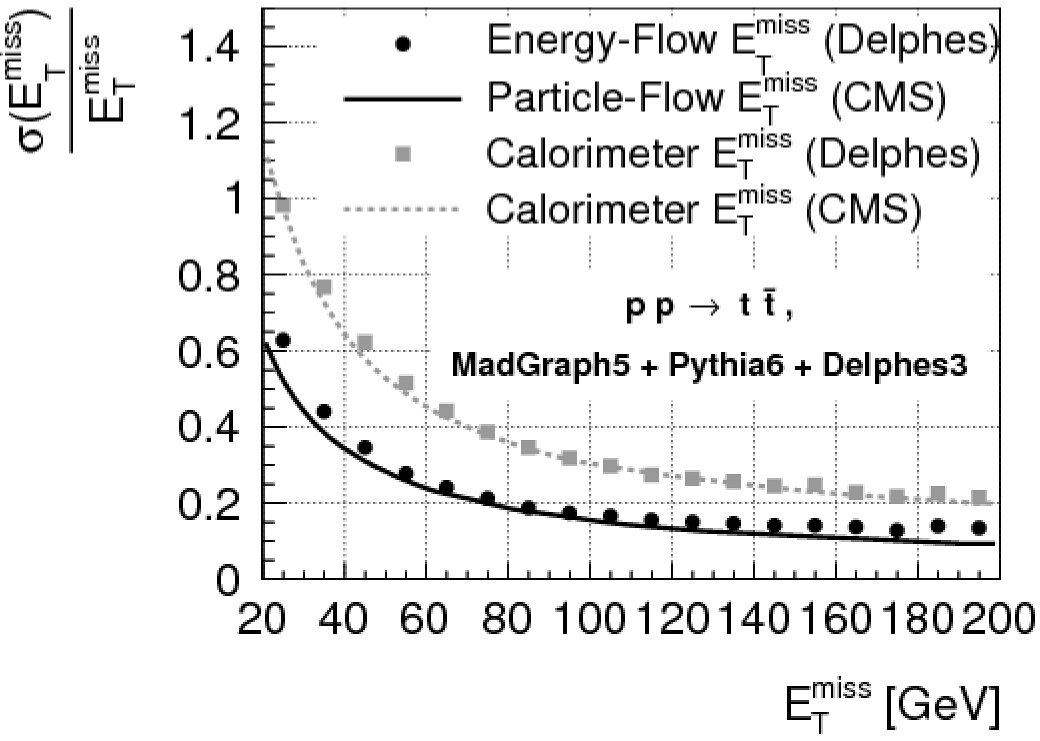
Detailed record - Cited by 1518 records 1000+

Citations include:
"Higgs Physics at the HL-LHC and HE-LHC" - Cepeda, M. et al. **CERN Yellow Rep.Monogr. 7 (2019)**
"Physics at a 100 TeV pp Collider: Standard Model Processes" - Mangano, M.L. et al**. CERN Yellow Rep. (2017)**
"FCC Physics Opportunities : Future Circular Collider Conceptual Design Report Volume 1" Eur.Phys.J. C79 (2019) no.6, 474
"The Compact Linear Collider (CLIC) - 2018 Summary Report" **CERN Yellow Rep.Monogr. 1802 (2018) 1-98**
Also several studies for ILC, CEPC…etc.

- It is based on parametrized tracking and calorimeter resolutions.
- Pythia8-Delphes3 can be run simultaneously. Accepts HEPMC and other formats as well
- It includes bending in magnetic field, granularity of calorimeters (not longitudinal segmentation though). PID efficiency/fake-rate, Jet reconstruction, particle flow, missing-energy, b-tagging, tau-tagging etc.

Jet/Met performance in Delphes vs CMS

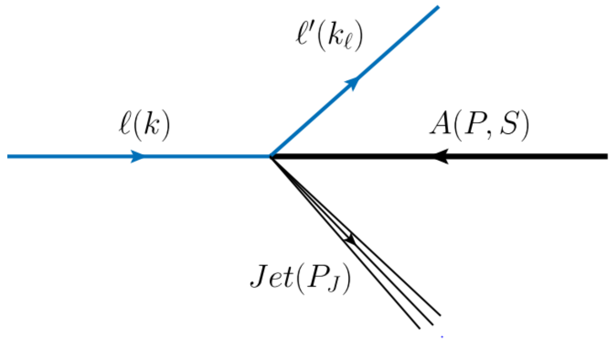


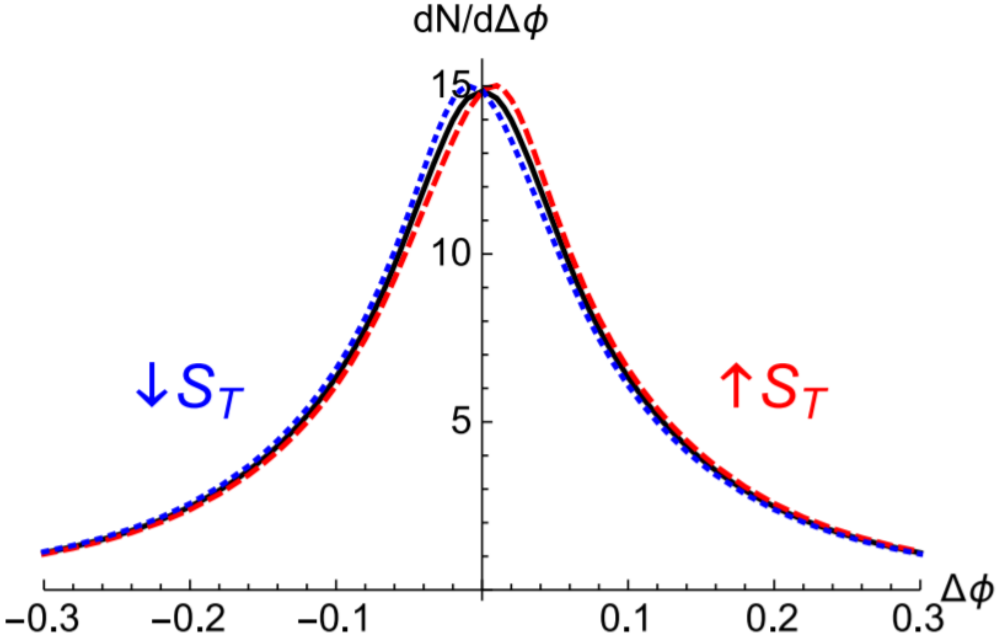


This is **not** by construction, it emerges from tracking and calorimetry resolution and granularity, as well as implementation of “particle flow”

Quark Sivers effect with Jets

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



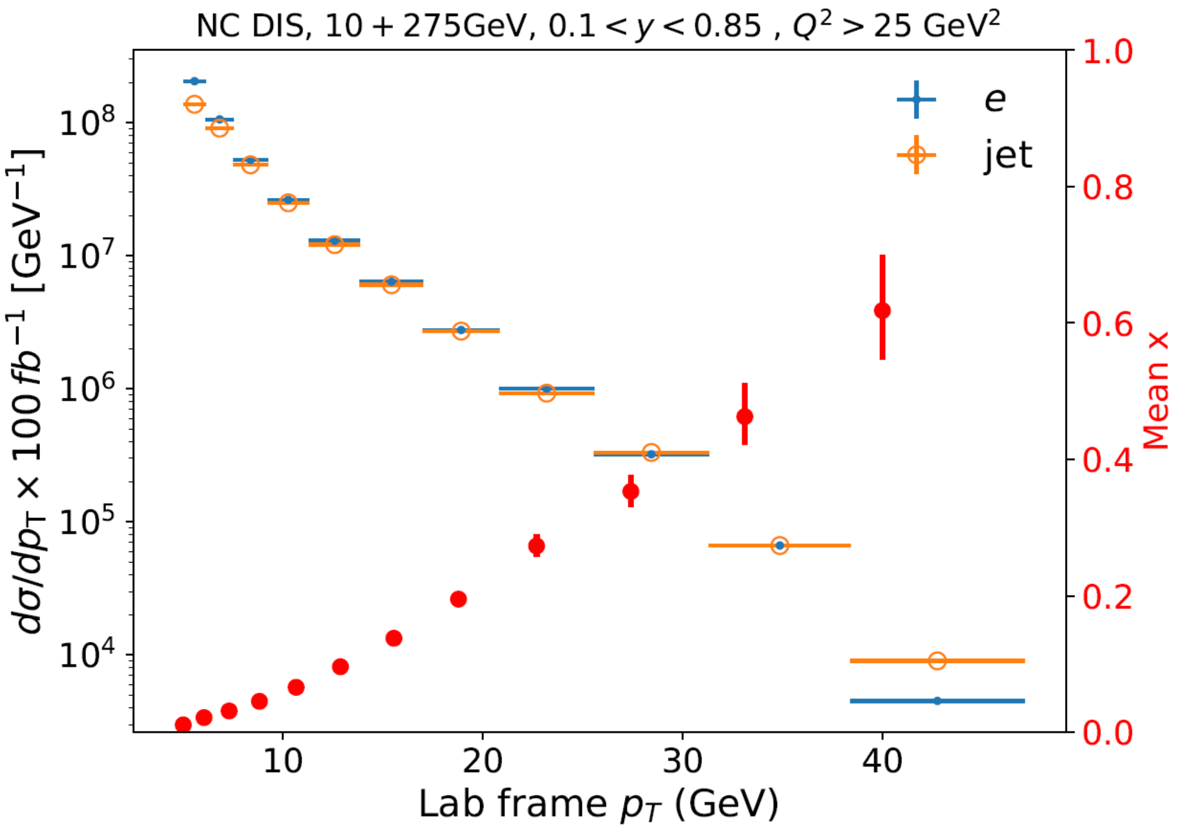


$$\frac{d^5\sigma(\ell p \to \ell' J)}{dy_\ell d^2 k_{\ell\perp} d^2 q_\perp} = \sigma_0 \int d^2k_\perp d^2\lambda_\perp x f_q(x, k_\perp, \zeta_c, \mu_F) \times H_{\rm TMD}(Q, \mu_F) S_J(\lambda_\perp, \mu_F)\, \delta^{(2)}(q_\perp - k_\perp - \lambda_\perp) \ .$$

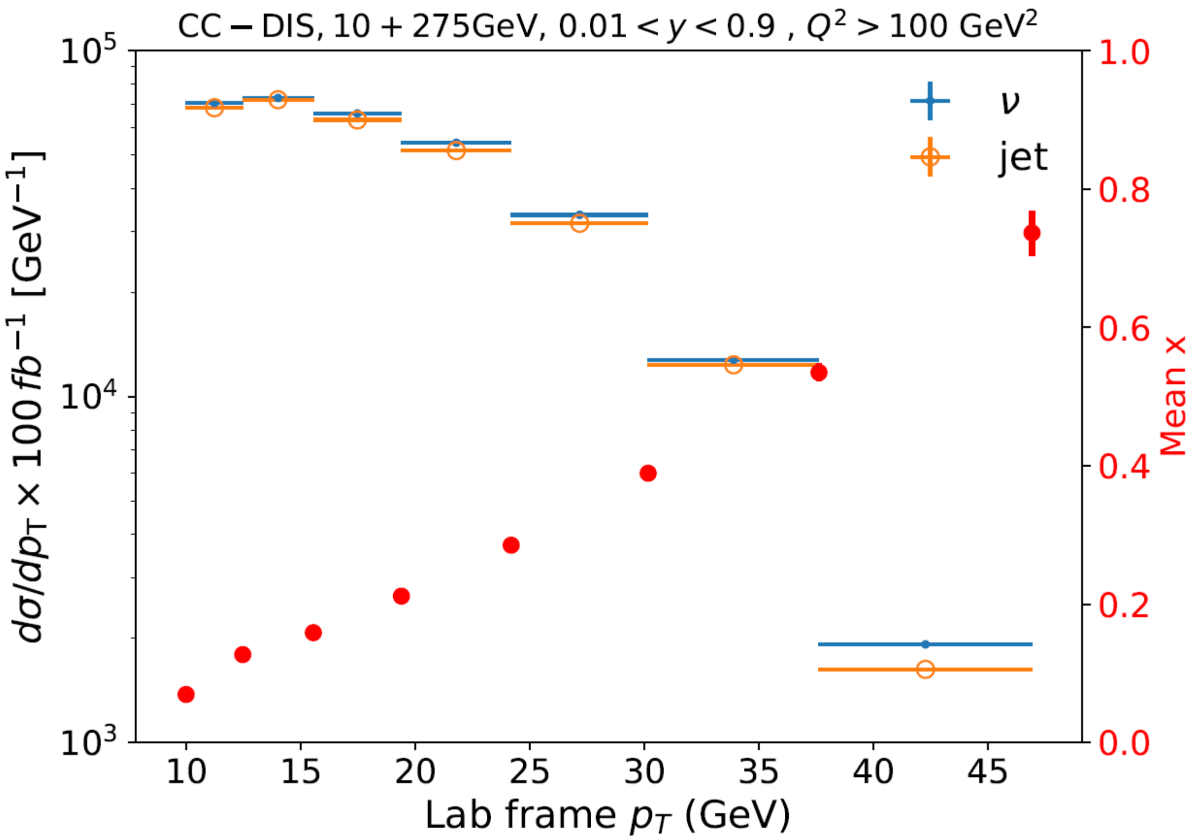
"The advantage of the lepton-jet correlation as compared to the standard SIDIS processes is that it does not involve TMD fragmentation functions."

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

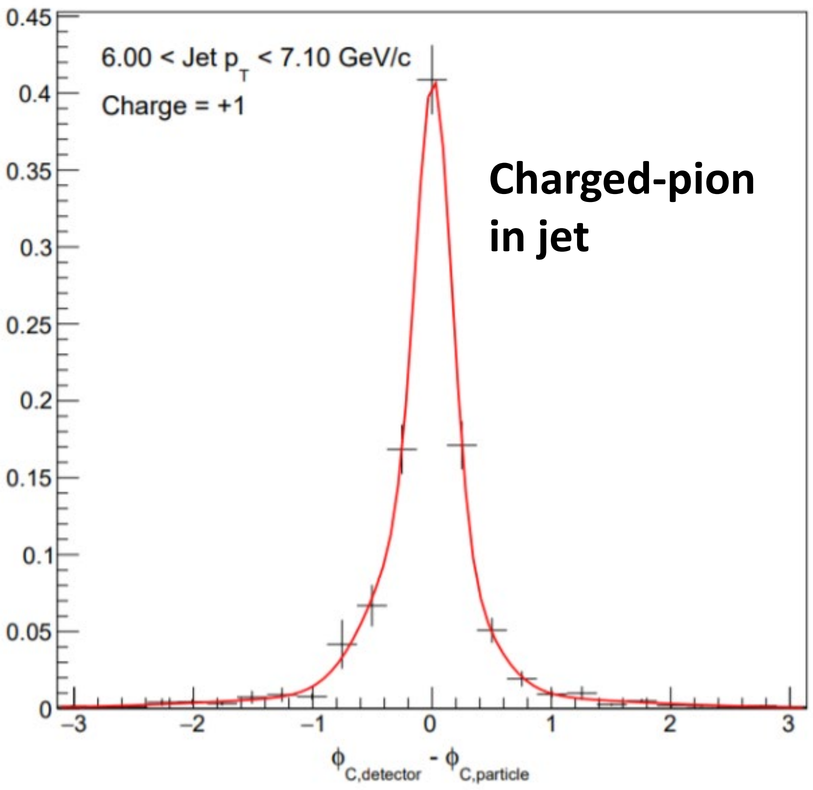
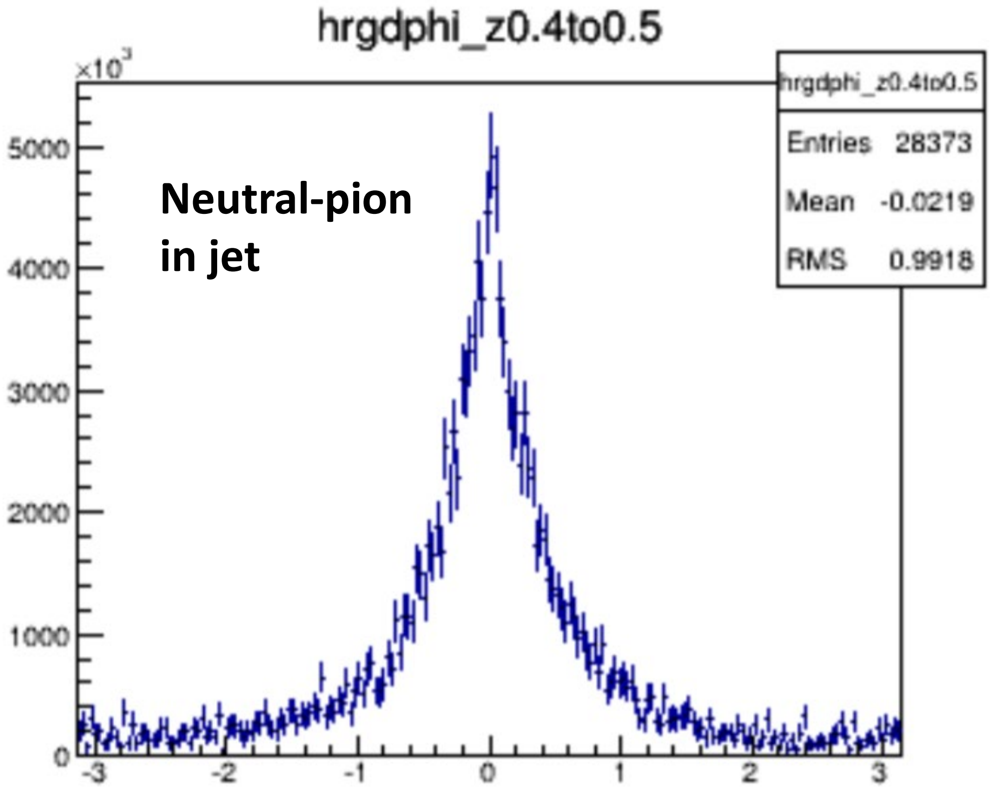
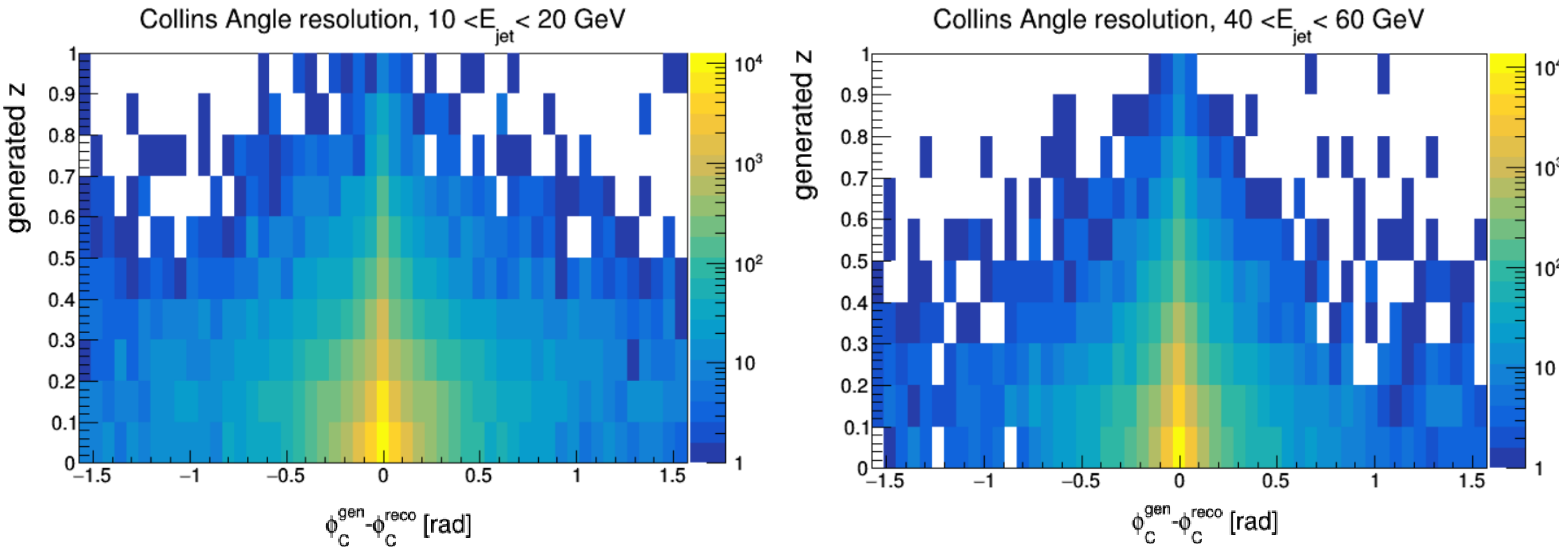


Figure 6.12: ϕ_C **Resolution Example Fit** - A triple Gaussian fit to the spread in detector minus particle level ϕ_C values.

Yuxi Pan, STAR Thesis, 2015



Jet-energy dependence of Collins Angle resolution

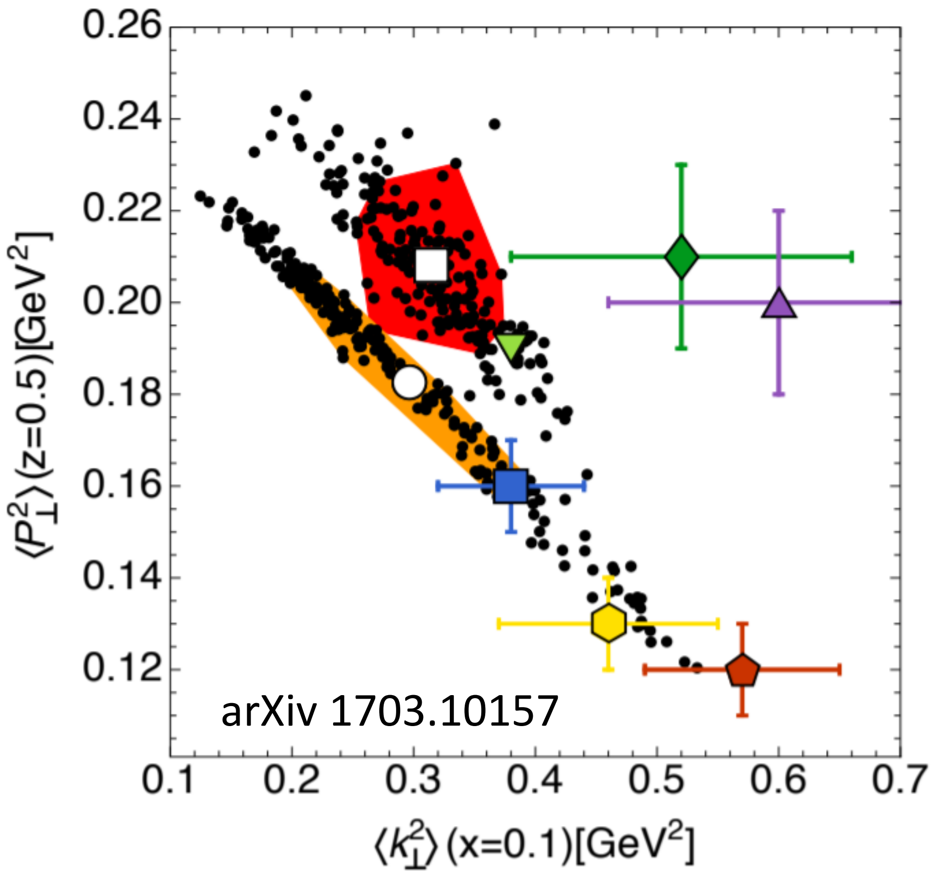


- There is an interplay between energy resolution for jet (improves with energy) and momentum resolution for hadron (degrades)

Jets break convolution that creates correlations

$$\int d^2\boldsymbol{k}_\perp\, d^2\boldsymbol{P}_\perp\, f_1^a(x,\boldsymbol{k}_\perp^2;Q^2)\, D_1^{a\to h}(z,\boldsymbol{P}_\perp^2;Q^2)\, \delta^{(2)}(z\boldsymbol{k}_\perp - \boldsymbol{P}_{hT} + \boldsymbol{P}_\perp)$$

TMD FF

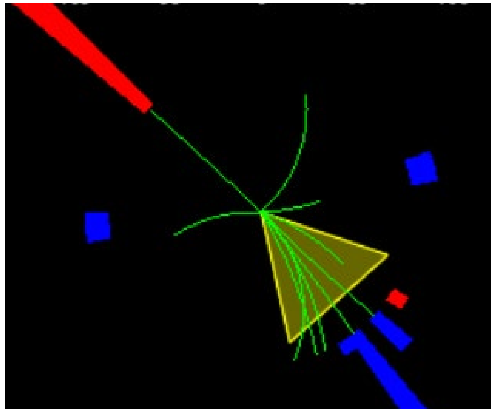


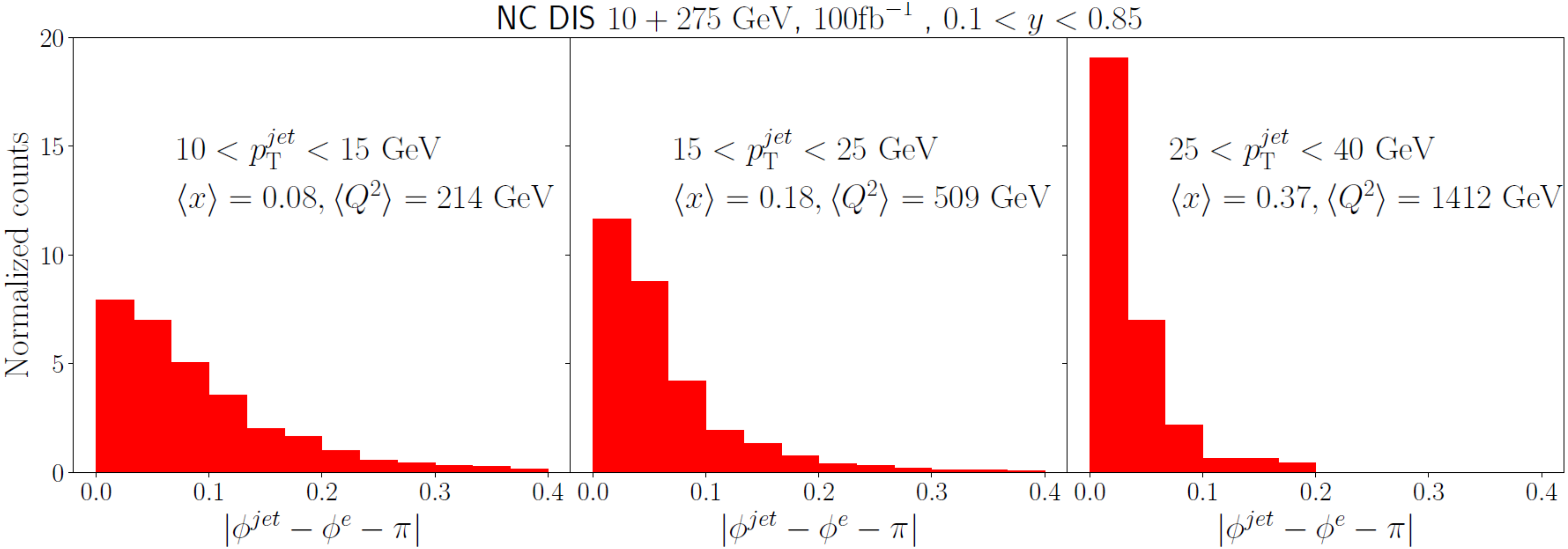
TMD PDF

Jets would also help us avoid:

- Ad-hoc Gaussians
- x/z factorization,
- Flavour assumptions, etc

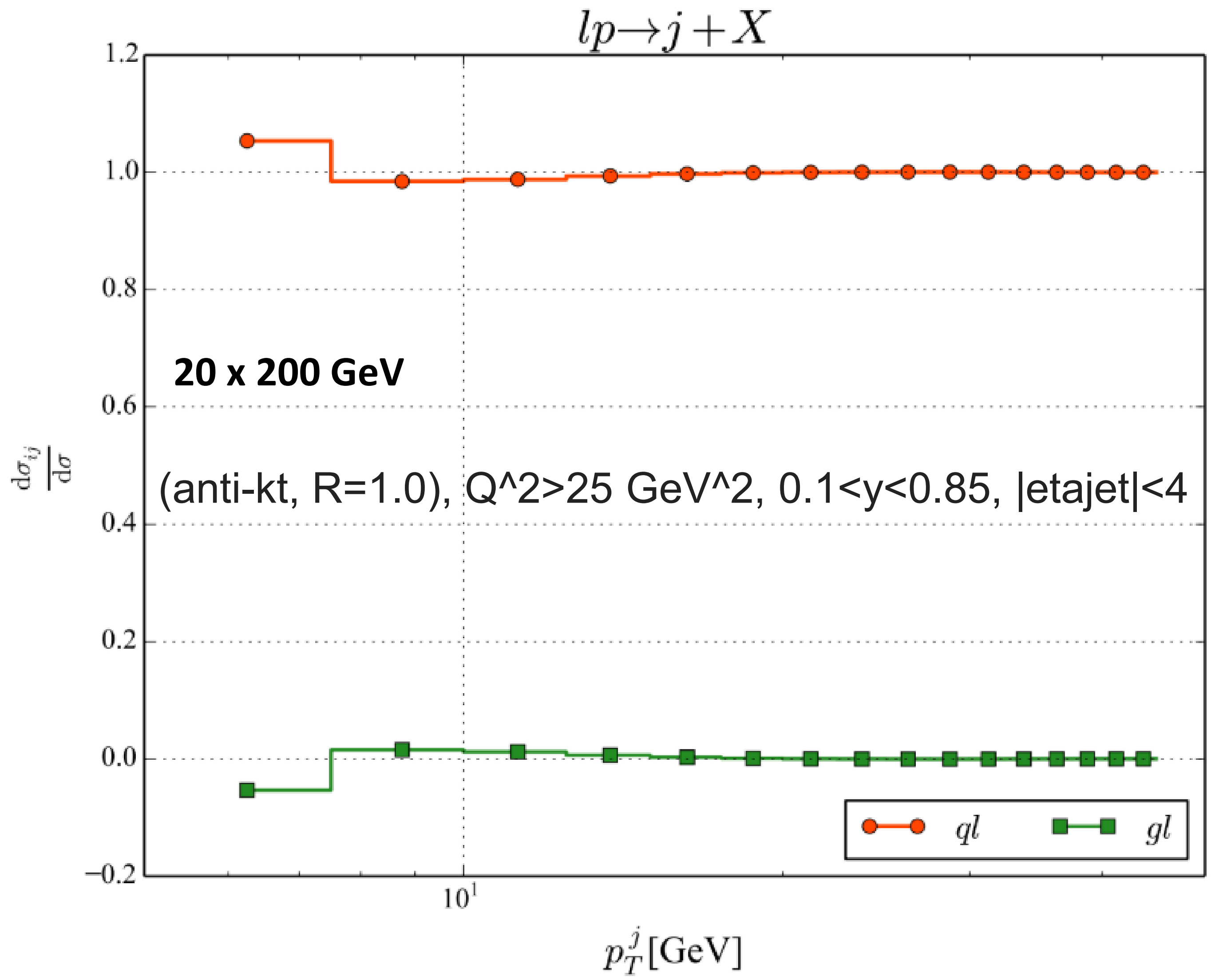
Electron-jet correlation

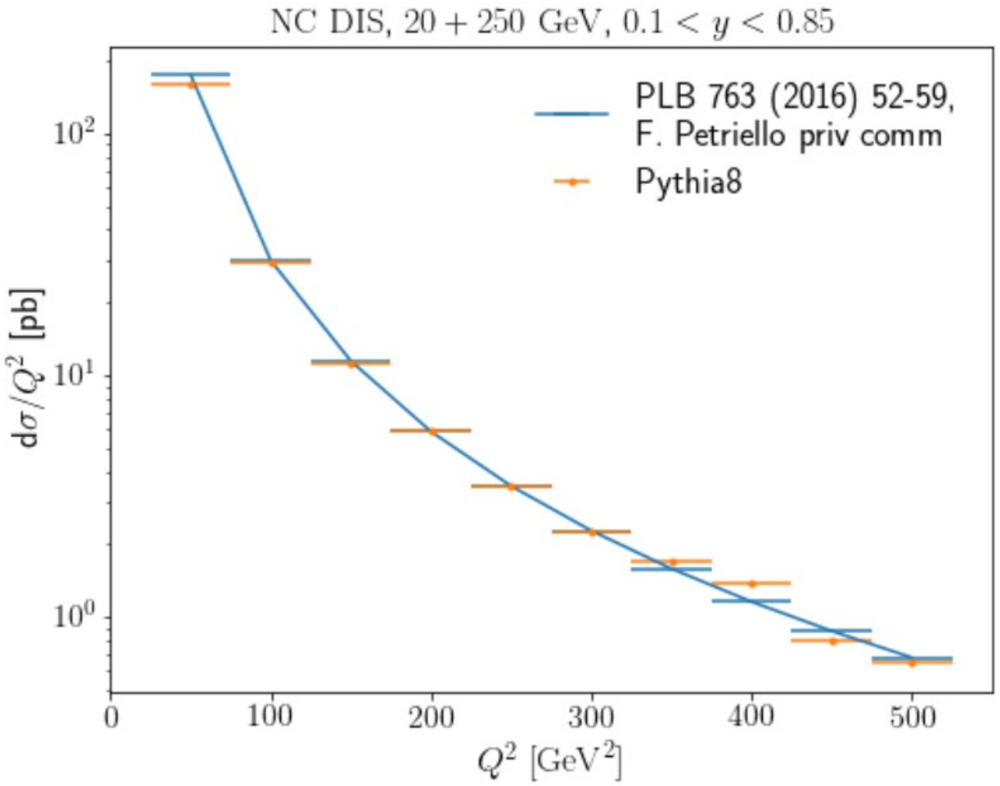




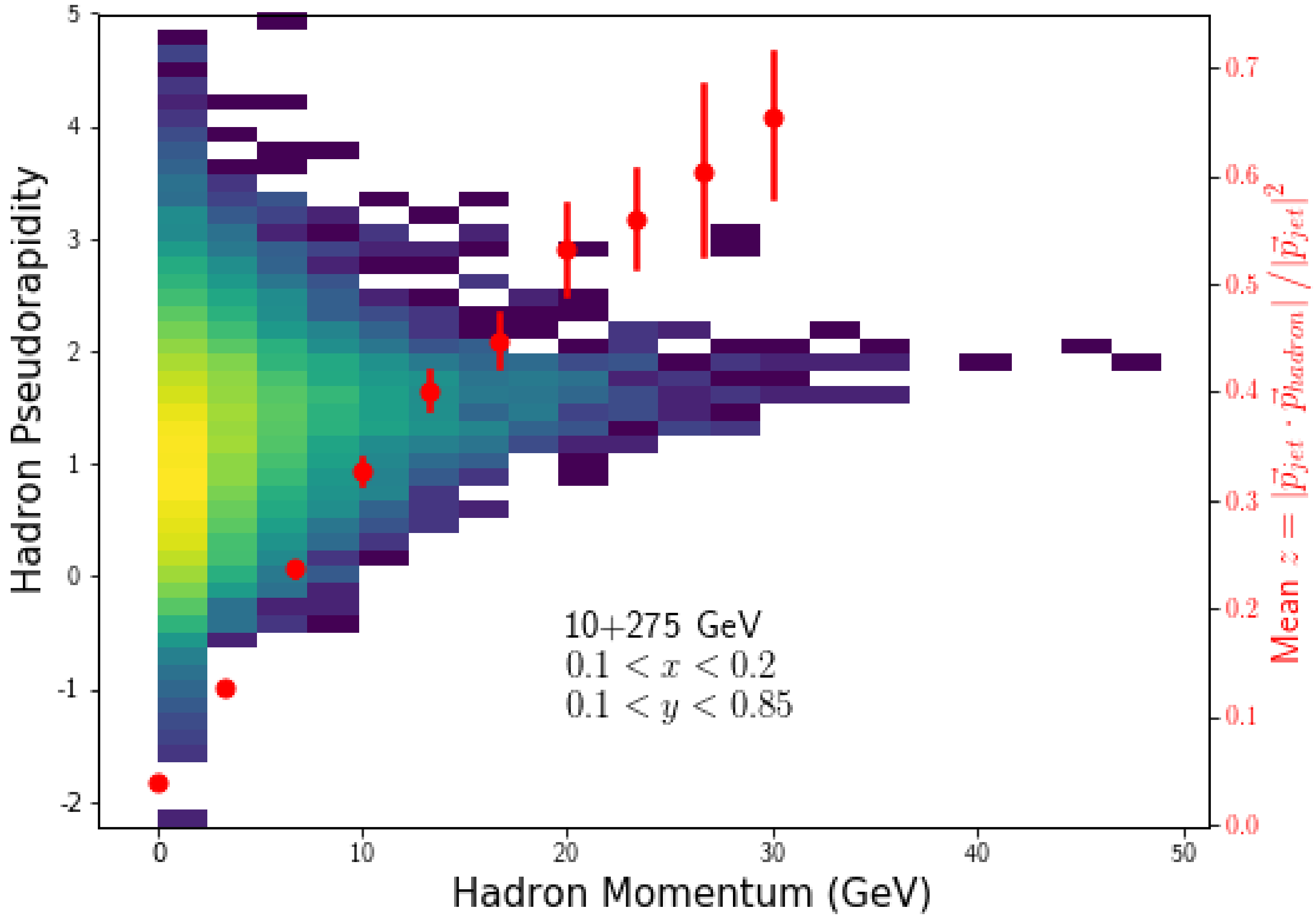
- Strong kinematic dependence on the width, but in general widths <0.1 rads.

Partonic channel, (NNLO calculation by F. Petriello)





PID requirements:



- Charged pions separation from Kaons and protons up to ~30 GeV