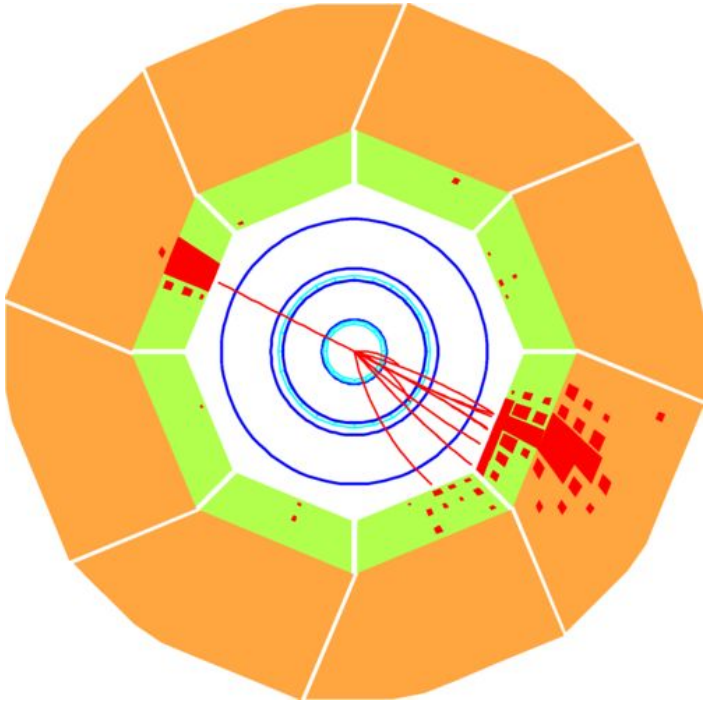
Jet and heavy flavour at the EIC

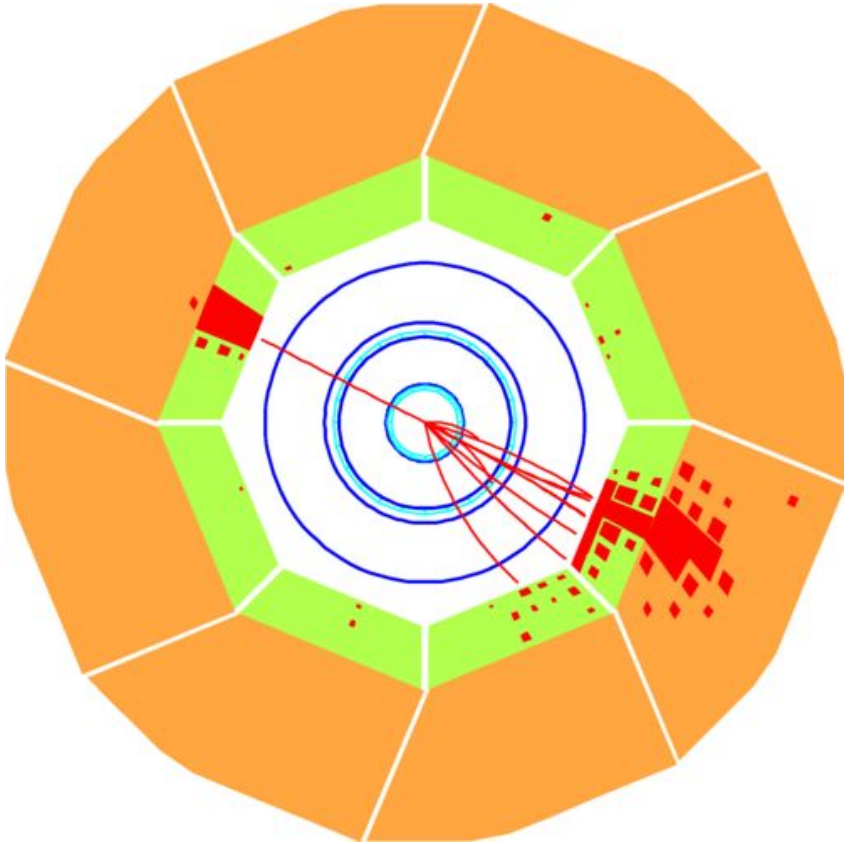
CFNS EIC Summer School 2022

Miguel Arratia

UC RIVERSIDE



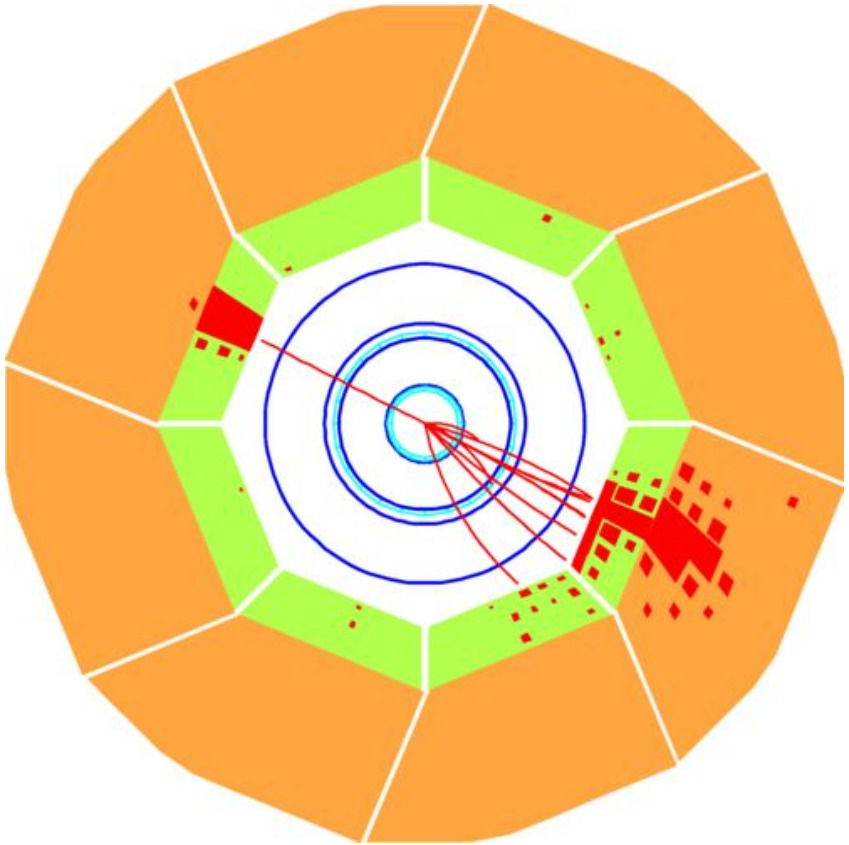
Summary of previous lecture



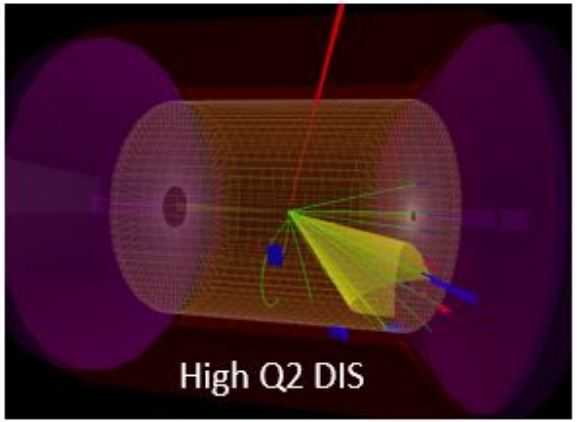
What is a jet?
Output of a jet algo

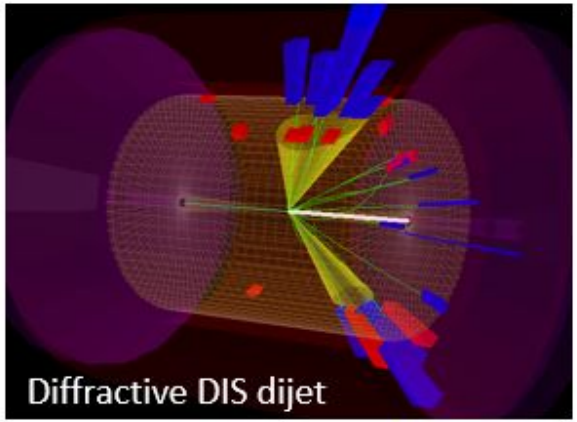
Why are jets useful?
Proxies to partons & their substructure encodes rich & useful info

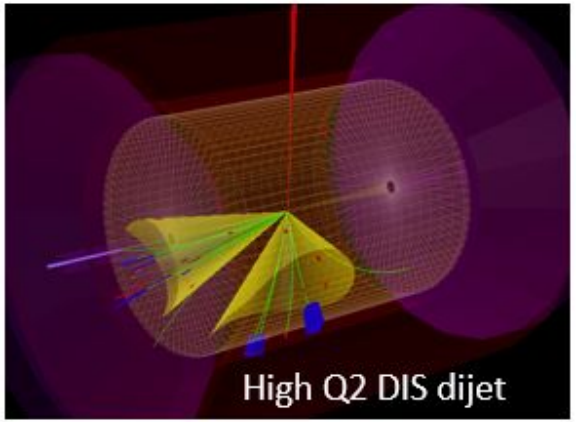
Why jets at the EIC?

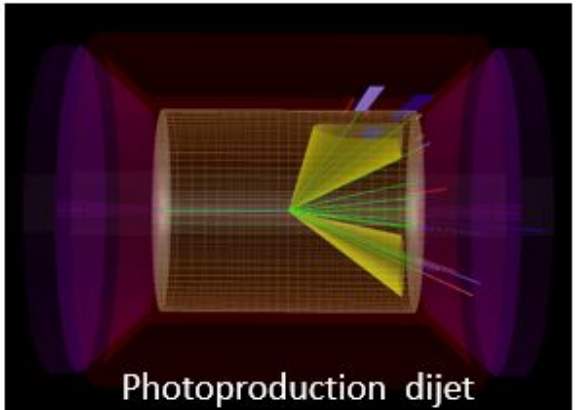


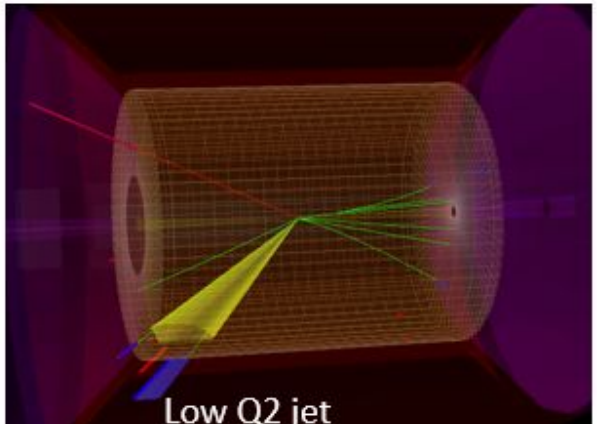
The EIC, a jet factory, will make the first jets in nuclear DIS and proton-polarized DIS

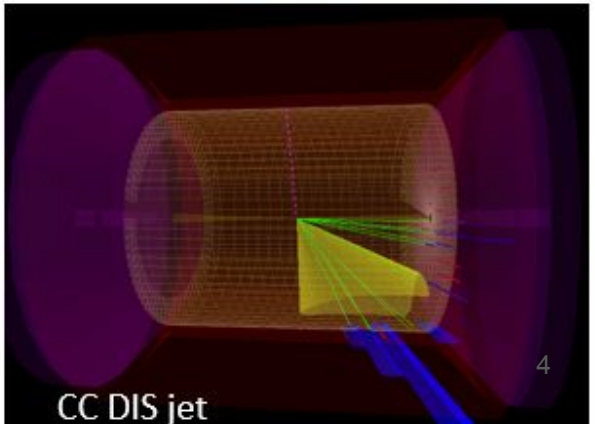






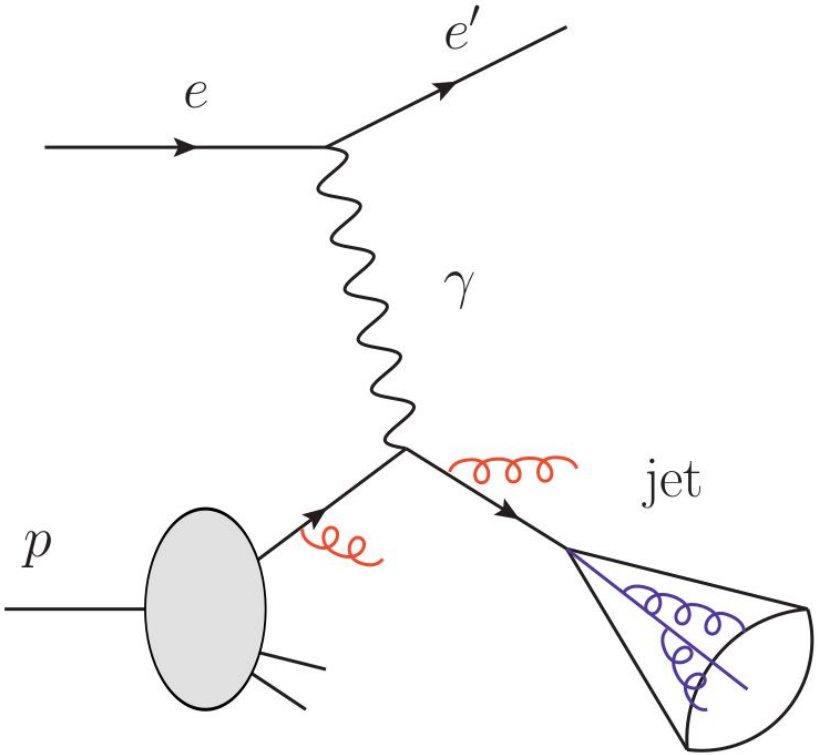


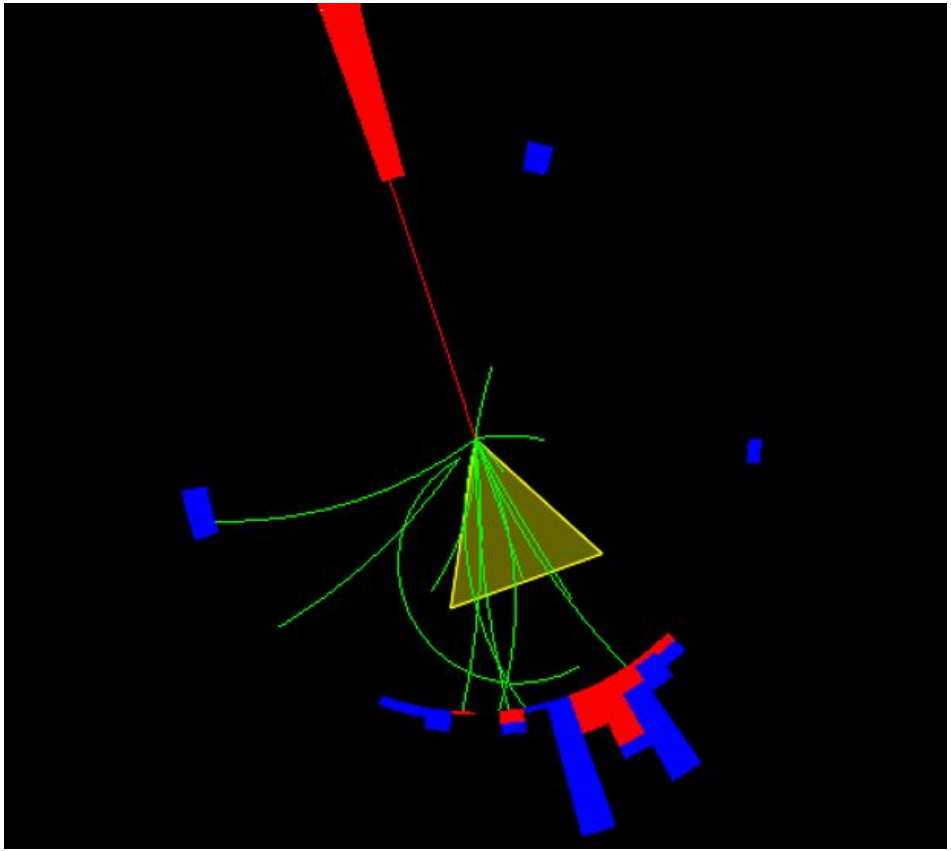




Back-to-back topology

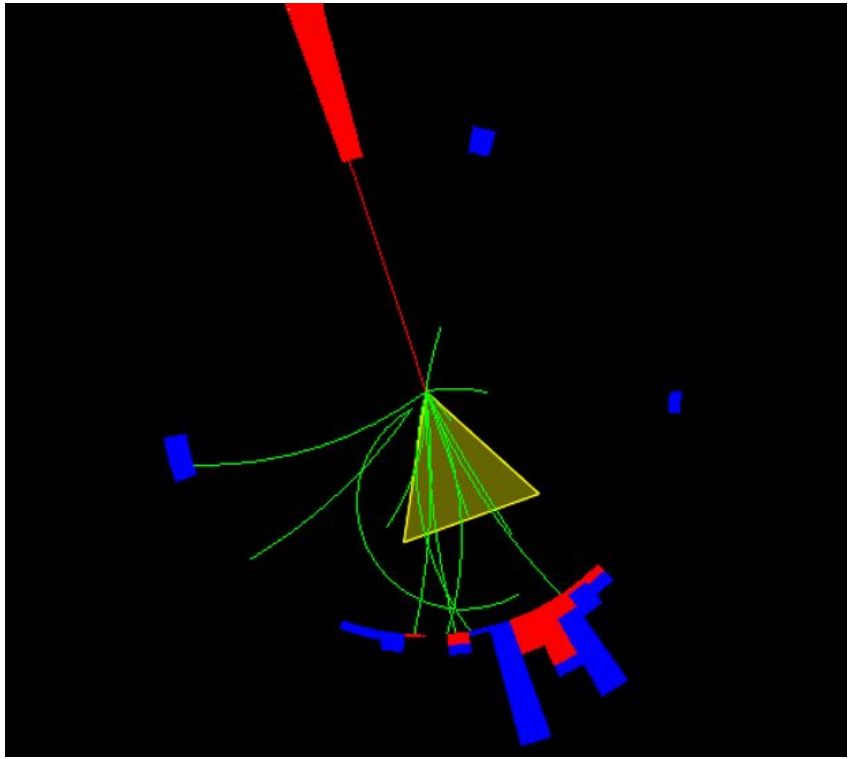
$$\gamma^* q \to q$$





A new channel to probe for quark transverse-momentum distributions (TMDs) and evolution

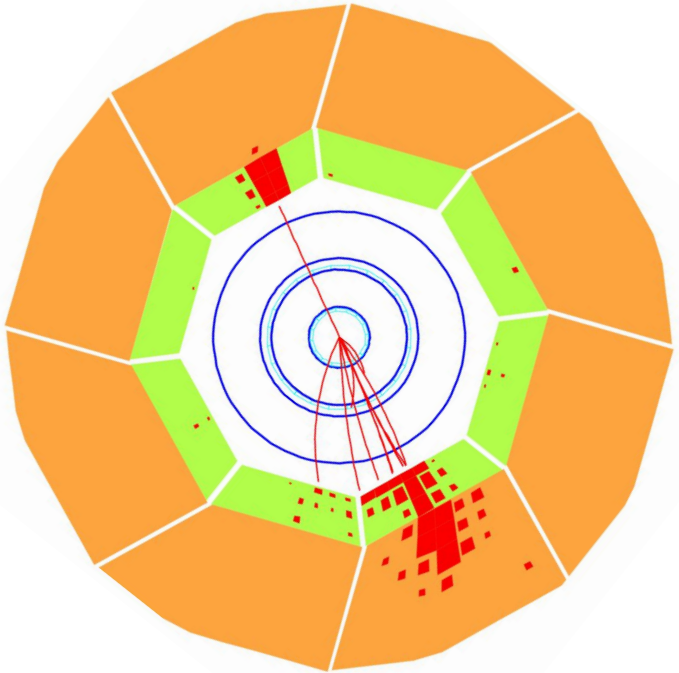
Liu et al. PRL. 122, 192003, Gutierrez et al. PRL. 121, 162001



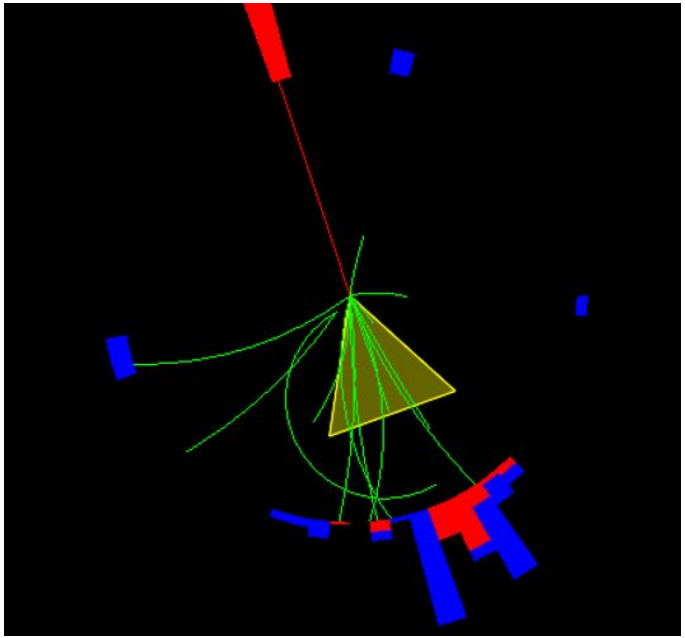
$$\gamma^* q \rightarrow q$$

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

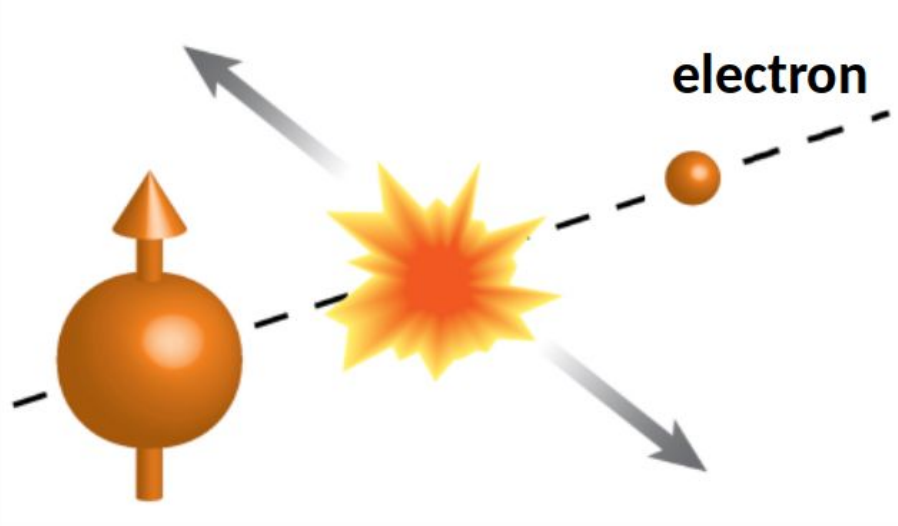
H1@HERA



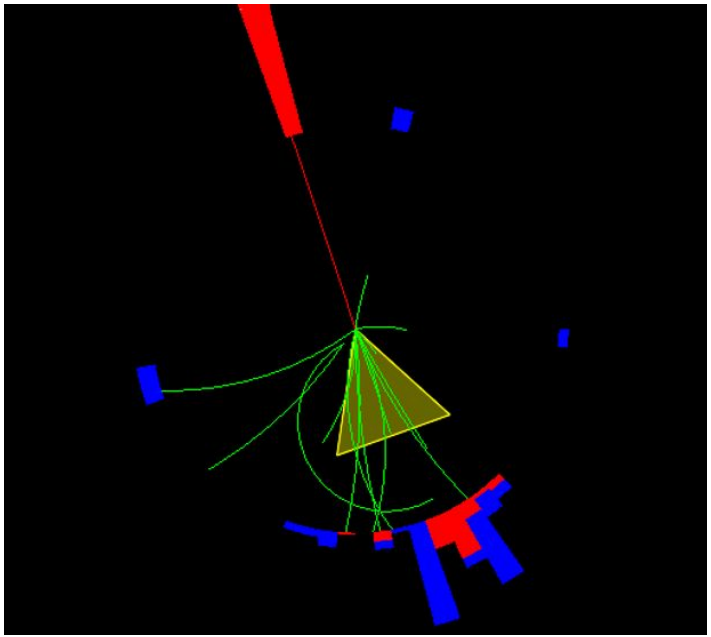
EIC



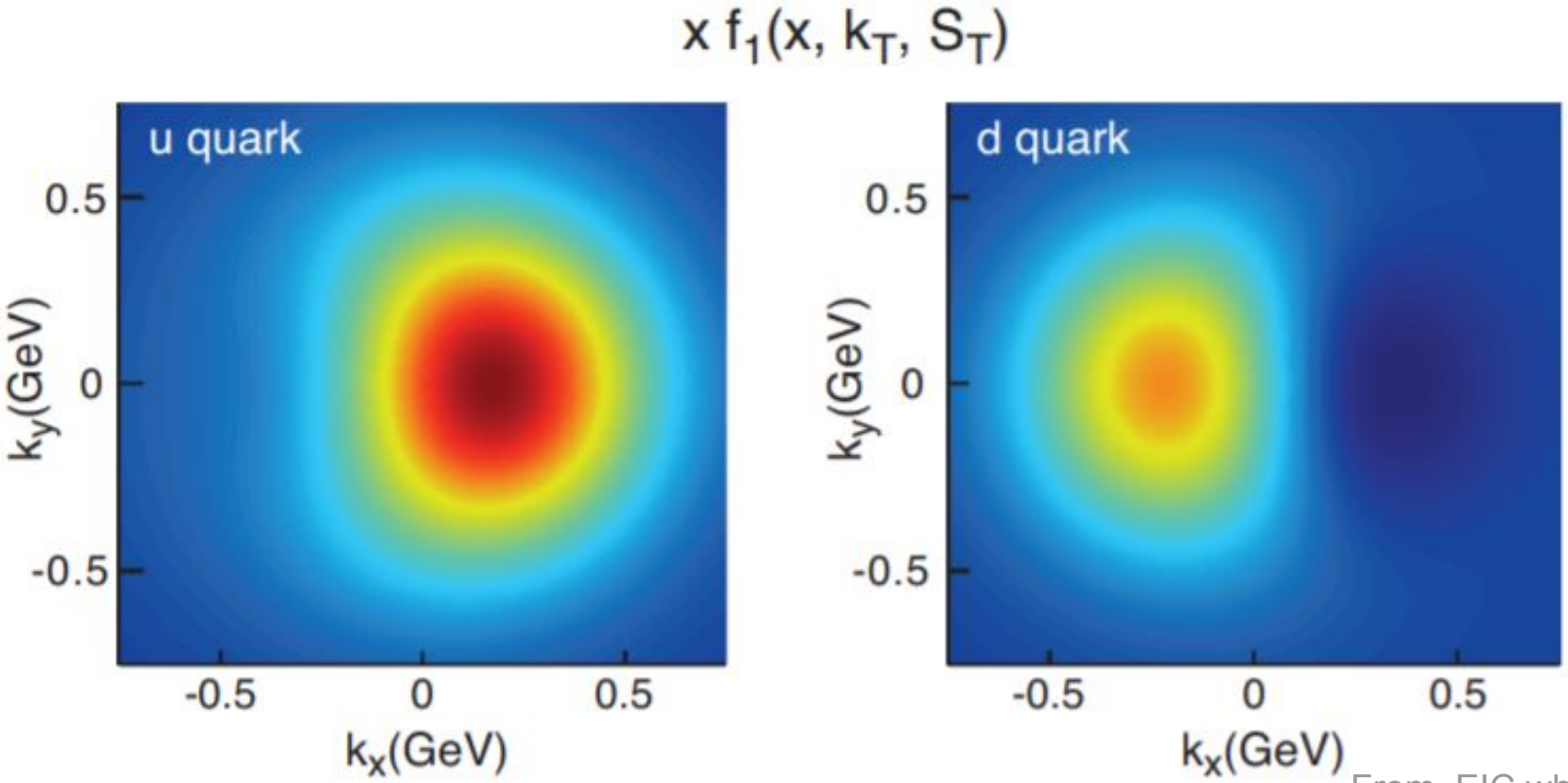
Spin-orbit correlations lead to azimuthal asymmetries



Transversely-polarized proton

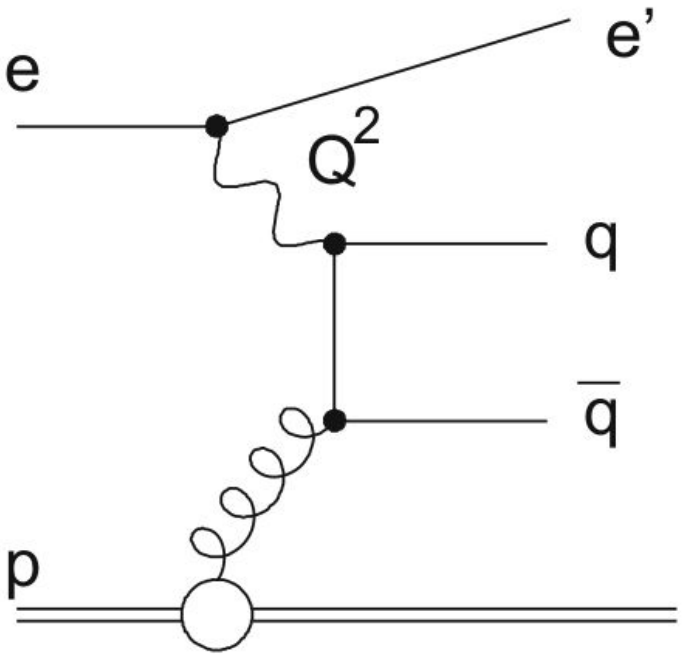


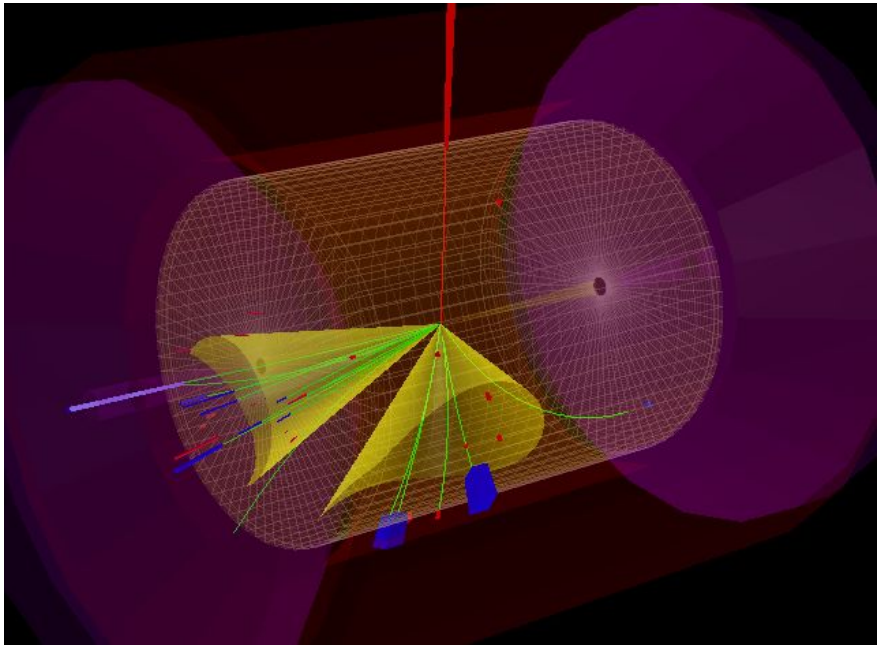
The asymmetry strength reflects a correlation between proton spin and quark momentum, “Sivers function”



From EIC white paper

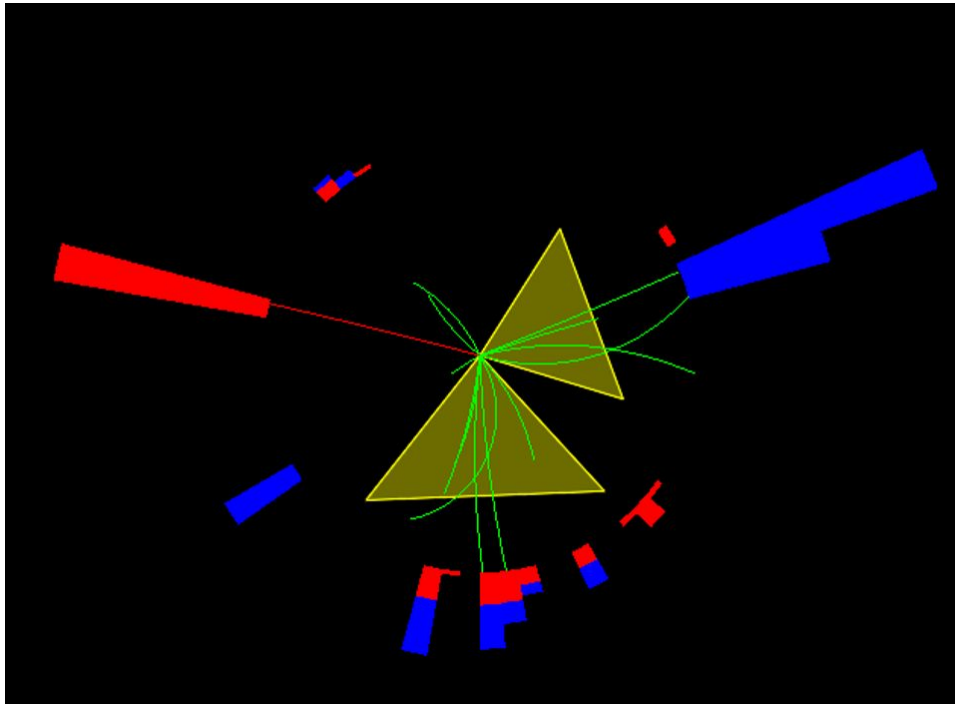
Dijet events probe the gluon TMD distributions

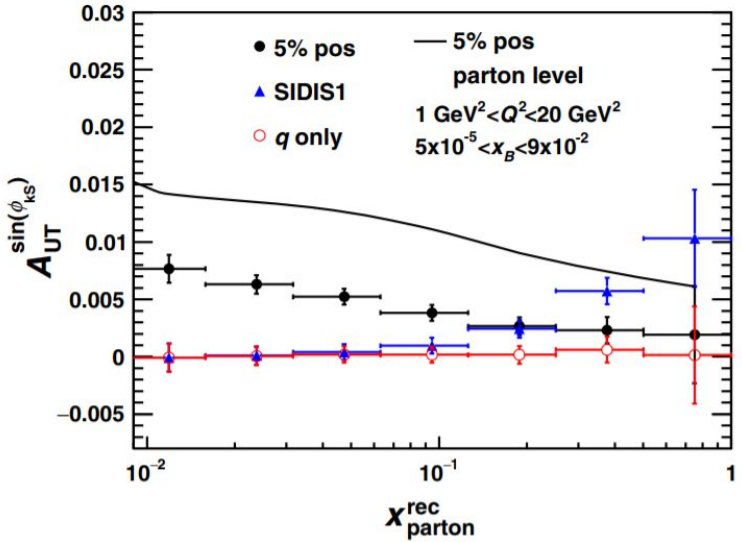




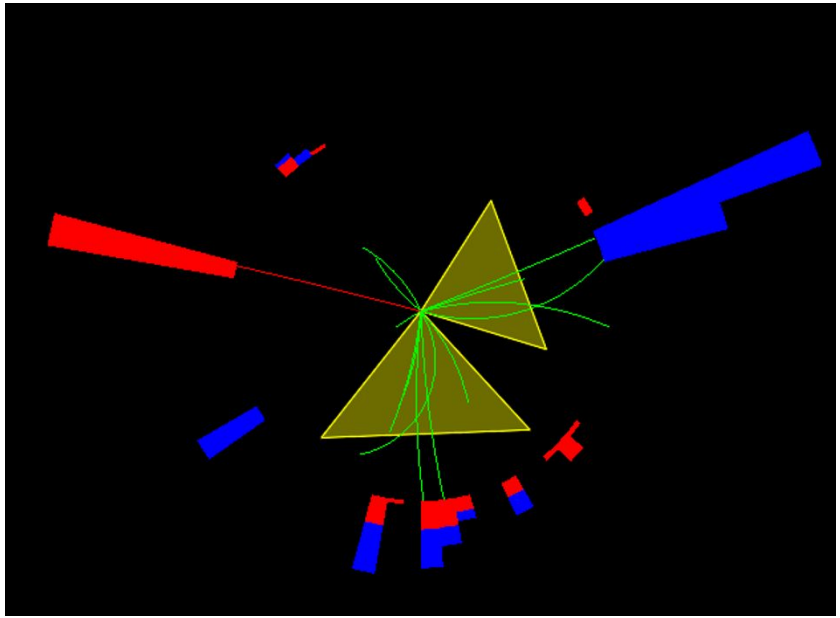
“Di-jet channel is the most promising way to constrain the magnitude of the Gluon Sivers function”

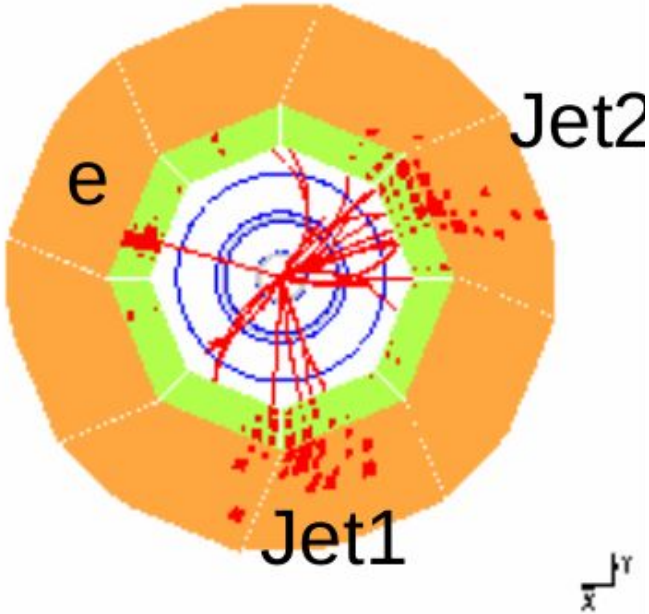
L. Zheng et al. Phys. Rev. D 98, 034011 (2018)



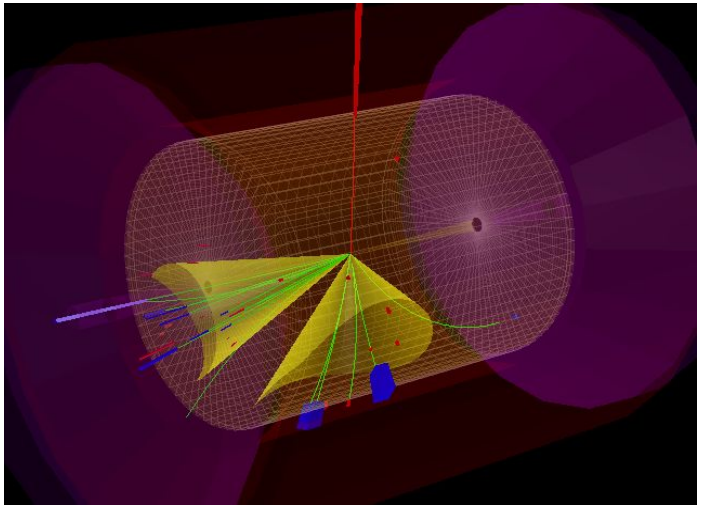


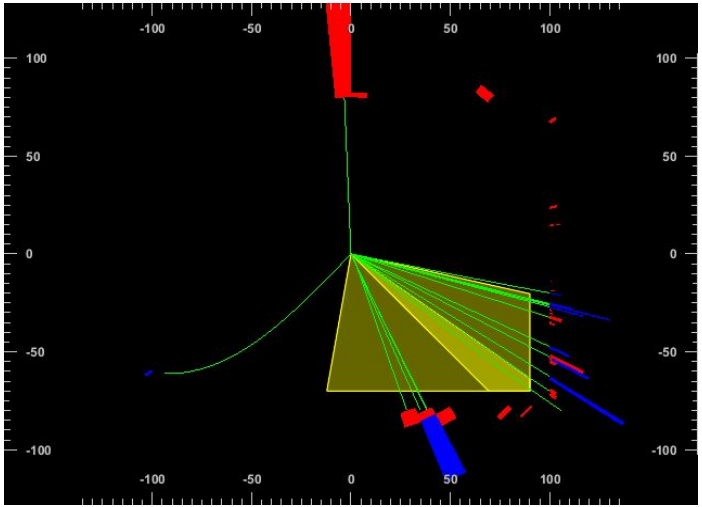
Gluon TMDs, low-x reach

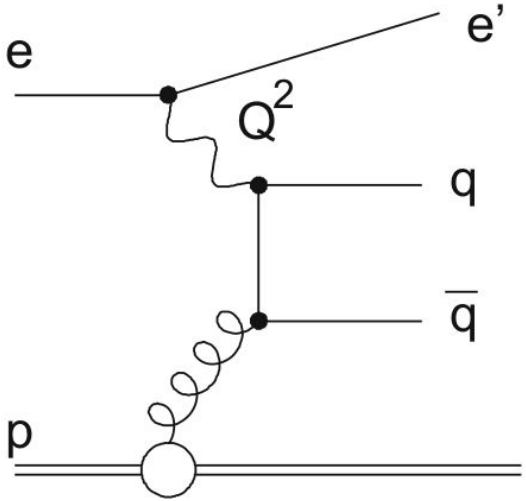


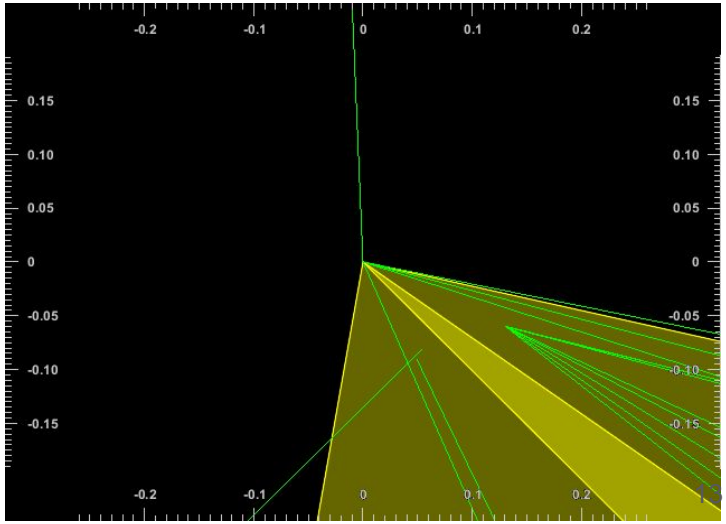


Double charm jet events

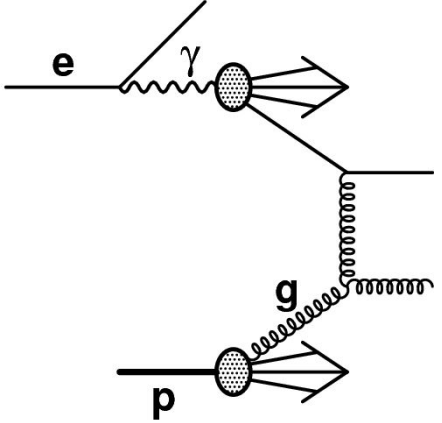


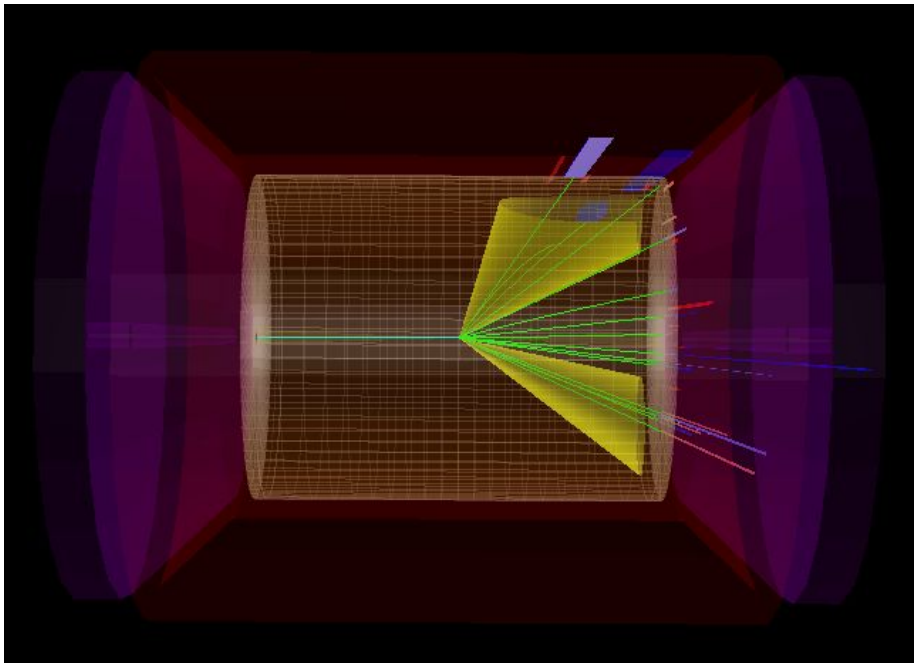


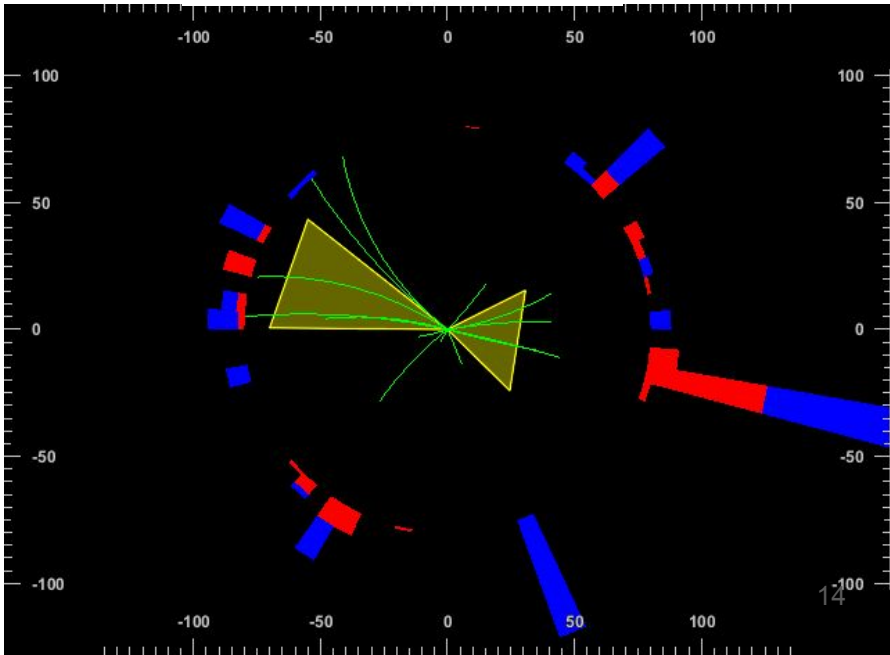




Dijets in photoproduction can probe the photon TMD structure





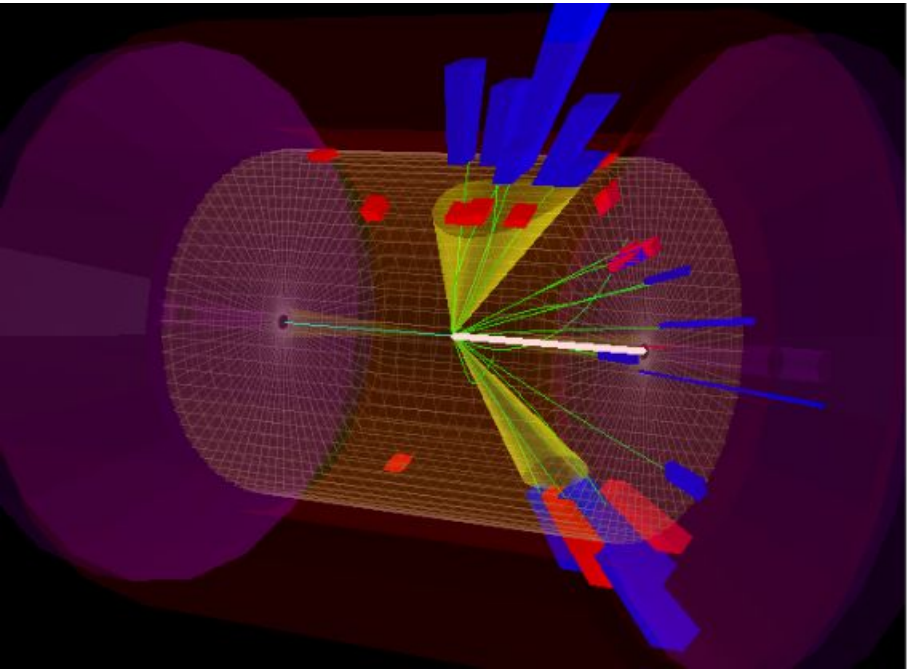


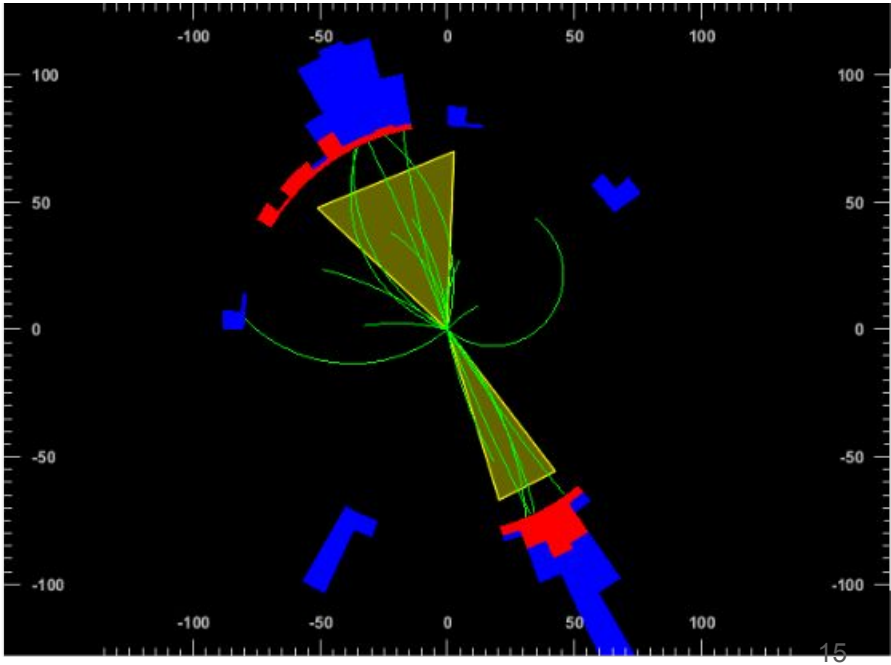
Diffractive jets azimuthal asymmetries probe Wigner function

(Hatta et al. PRL. 116, 202301 (2016))

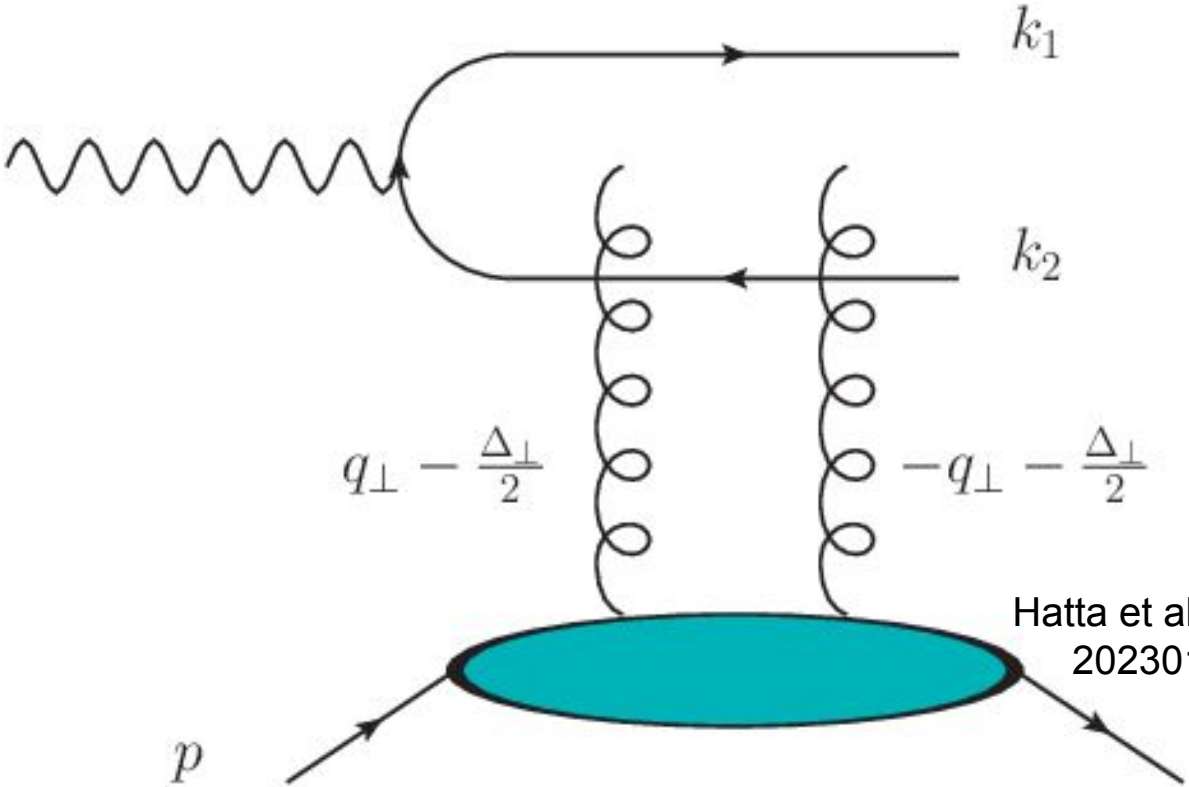
The “holy grail” of 3D imaging studies

$$W(x,p) = \int \psi^*(x-\eta/2)\psi(x+\eta/2)e^{ip\eta}d\eta \ ,$$





Diffractive dijets



Hatta et al. PRL. 116, 202301 (2016)

Probing the Small- x Gluon Tomography in Correlated Hard Diffractive Dijet Production in Deep Inelastic Scattering

Yoshitaka Hatta (Tsukuba U., GSPAS), Bo-Wen Xiao (Columbia U.), Feng Yuan (LBNL, NSD)

Jan 7, 2016

6 pages

Published in: *Phys.Rev.Lett.* 116 (2016) 20, 202301

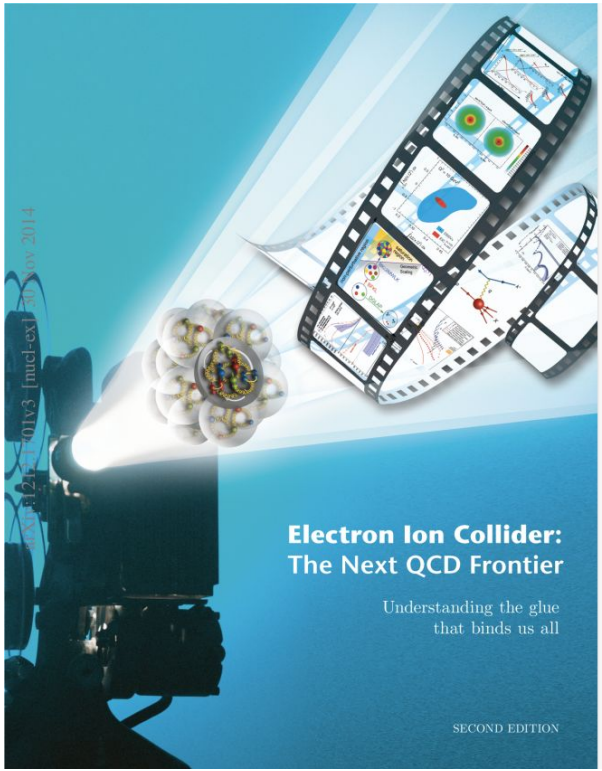
Published: May 20, 2016

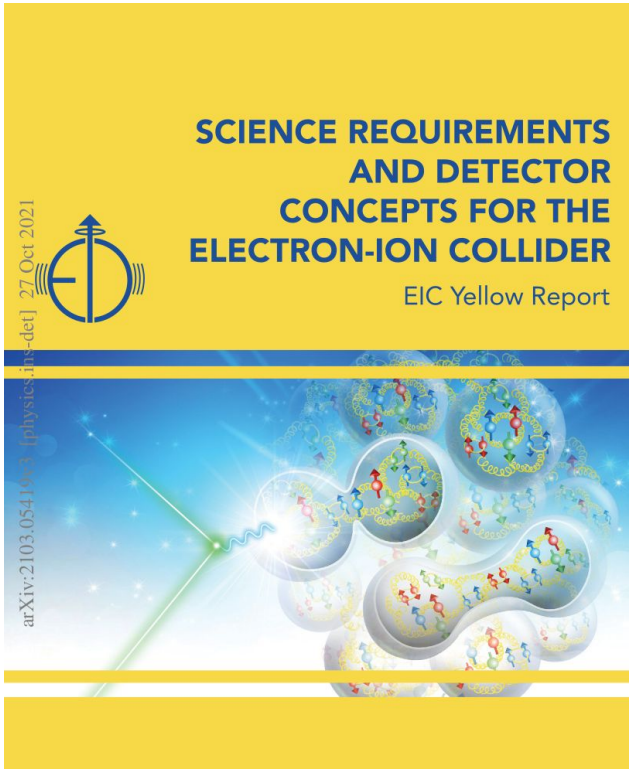
e-Print: 1601.01585 [hep-ph]

DOI: 10.1103/PhysRevLett.116.202301

Report number: YITP-16-1

Two important EIC documents separated by about a decade

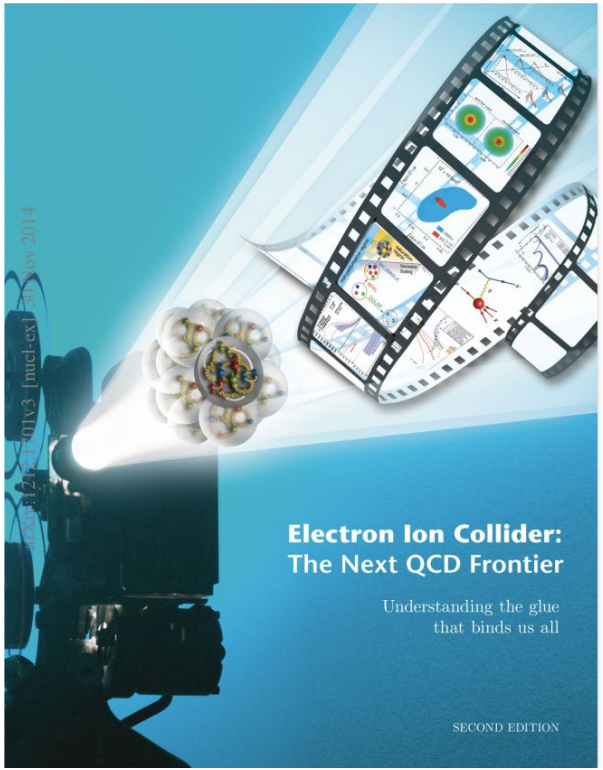




This one has not much about jets (~2010)

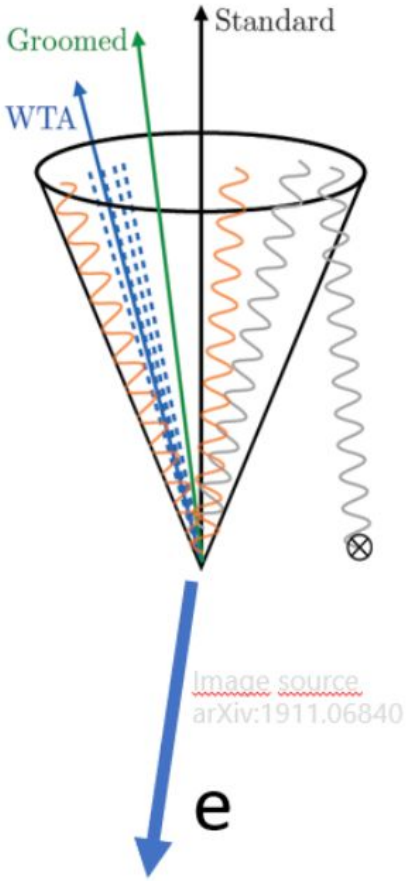
This one has a lot more (~2022)

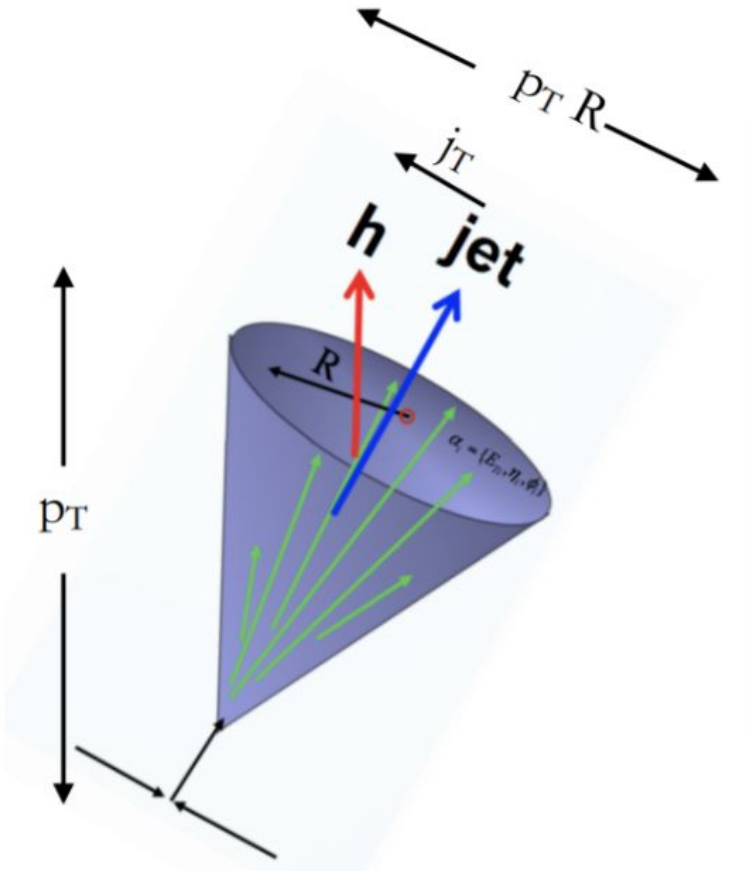
“Although there is no known way to measure Wigner distributions for quarks and gluons…”

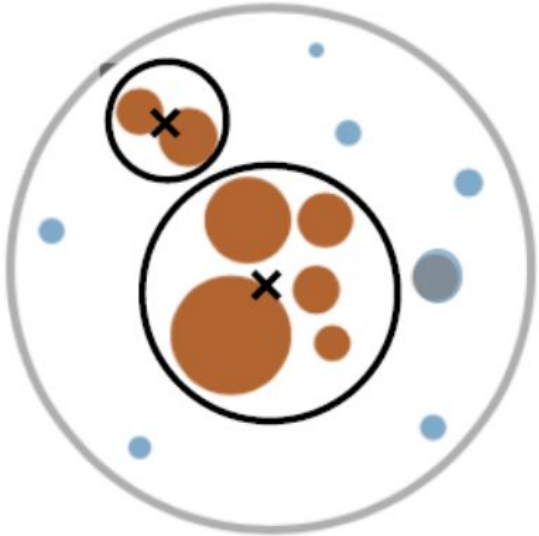


Beware the field moves fast!

Jets have rich substructure, which encodes rich dynamics







“Hadron in jet” measurements in DIS involve many variables and angles…This is the generalization of “SIDIS”

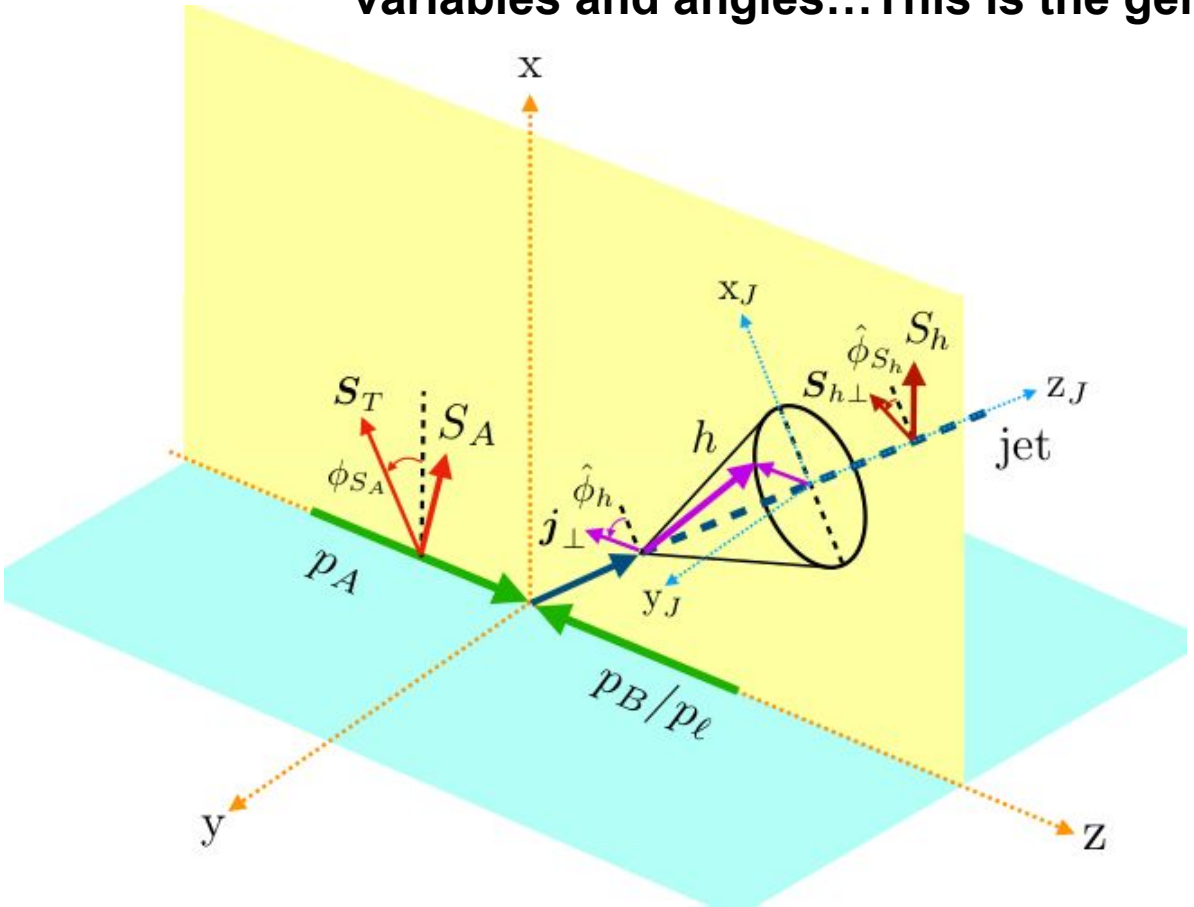
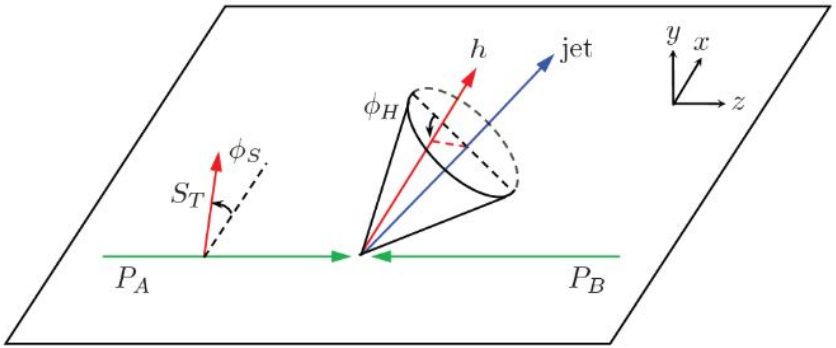


Figure by Z. Kang

Transversity with jets

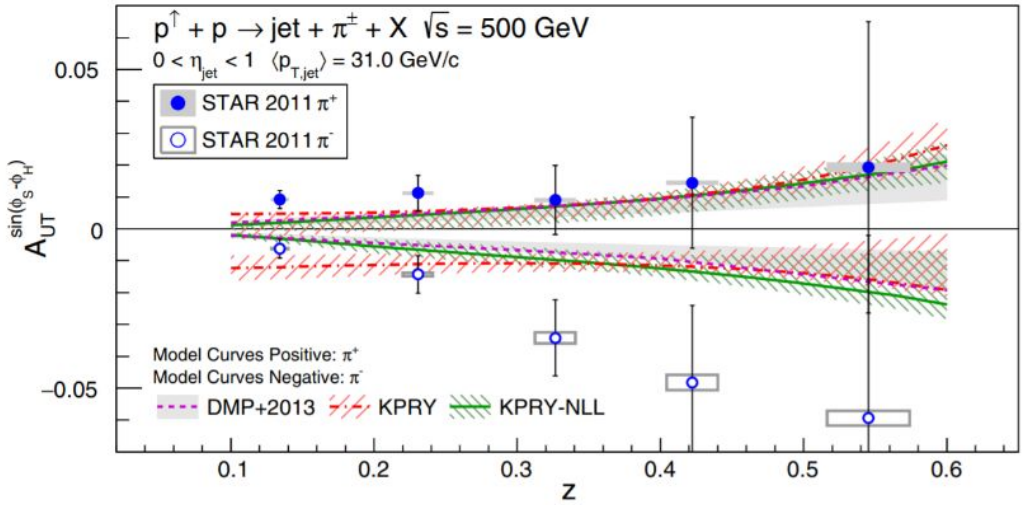
distribution of transversely polarized quarks inside a transversely polarized nucleon

This is measured with “Hadron-in-jet” azimuthal asymmetries:

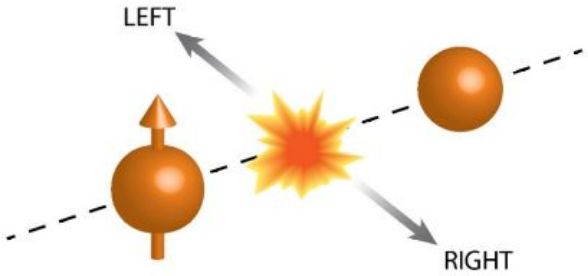


Phys. Lett. B 774, 635 (2017), Kang et al.
Phys.Rev.D77:074019 (2008) Yuan.

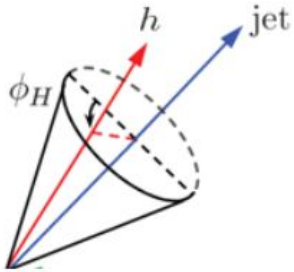
Measured at the RHIC proton-collider
STAR Collaboration, Phys. Rev. D 97, 032004 (2018)

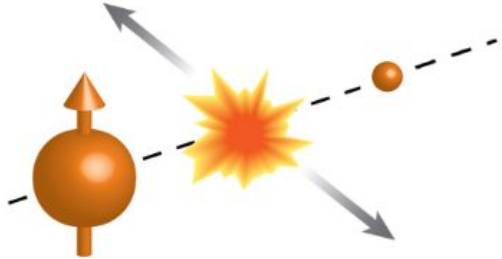


Complementarity

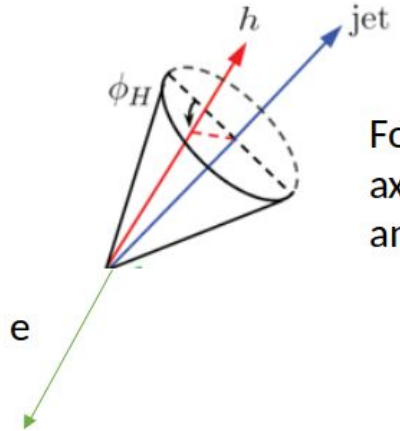


pp at RHIC

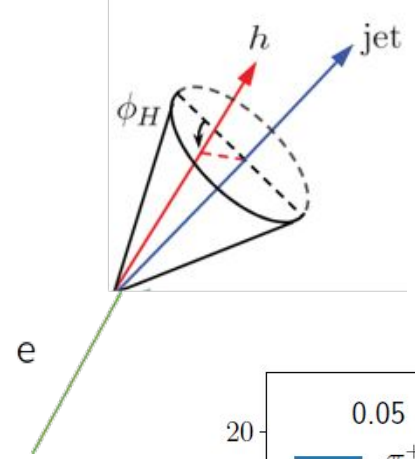




ep at EIC

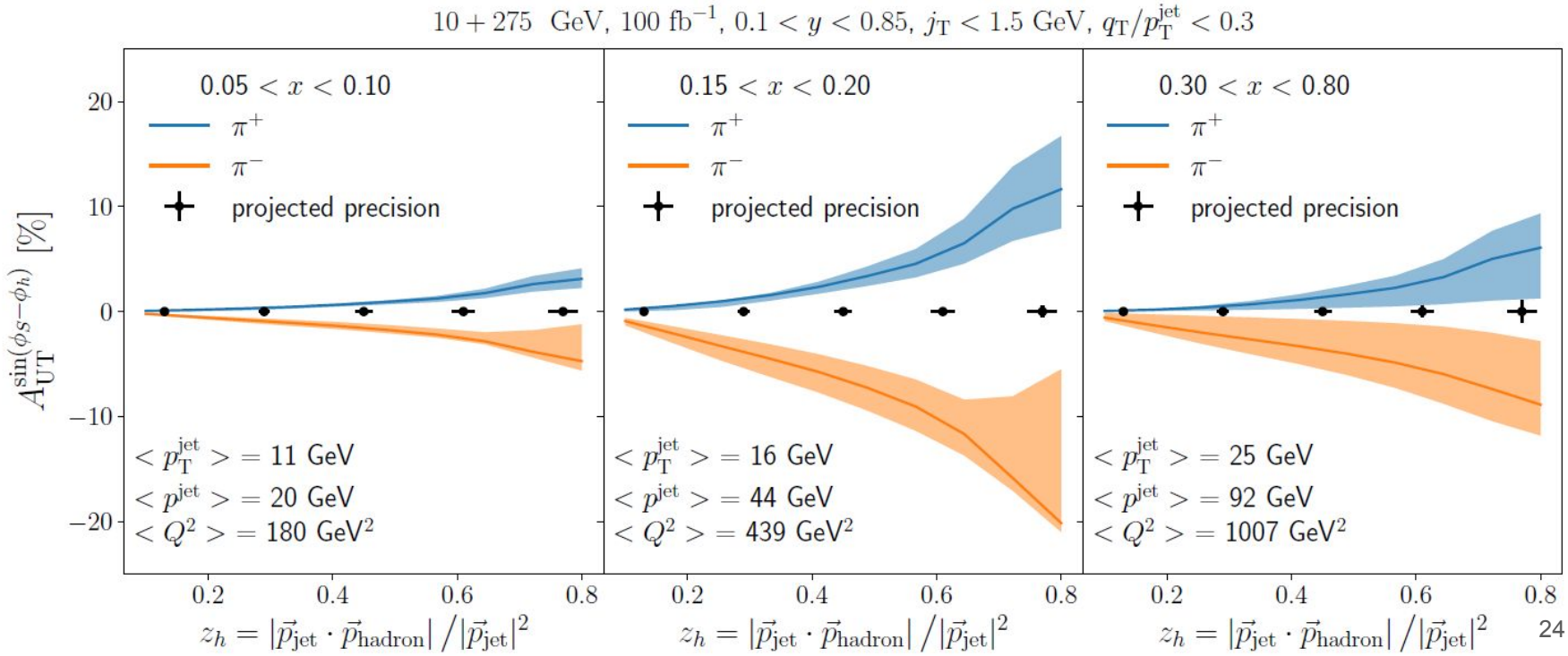


For DIS we will have 2 axes (virtual photon and jet).

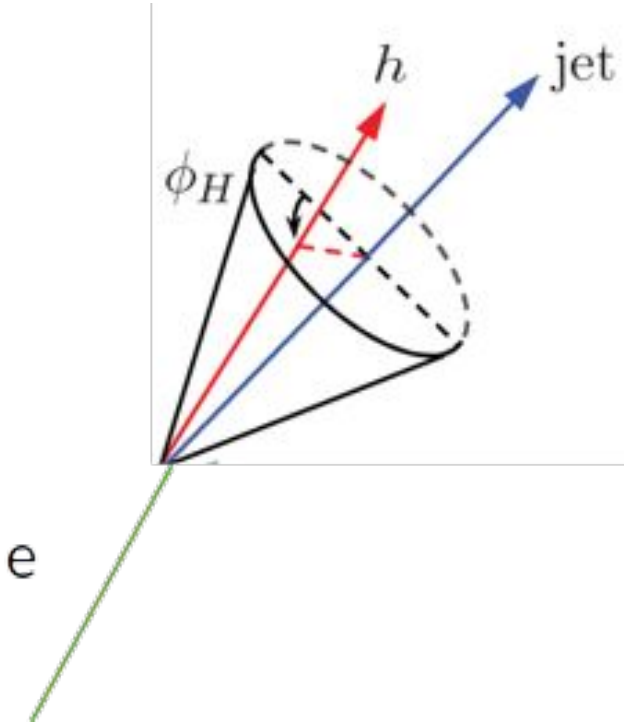


Hadron-in-jet Collins asymmetry at EIC

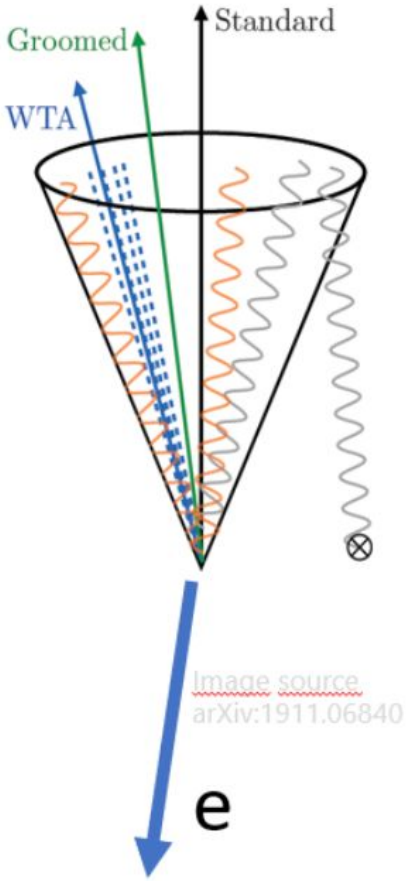
PRD 102, 074015 (2020)

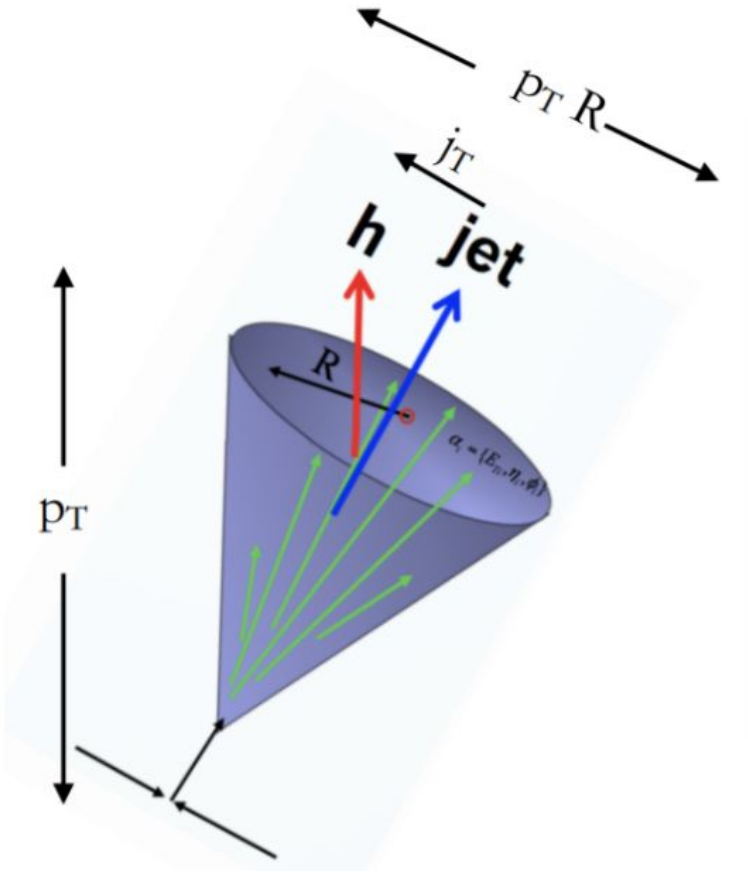


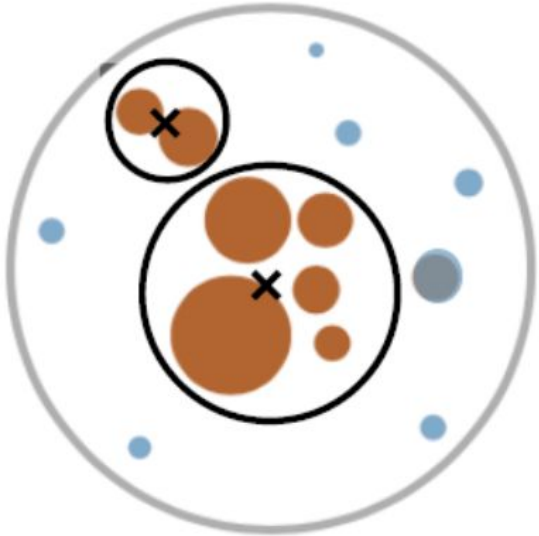
These measurements are perhaps the simplest example Of jet substructure possible…much more is yet to come



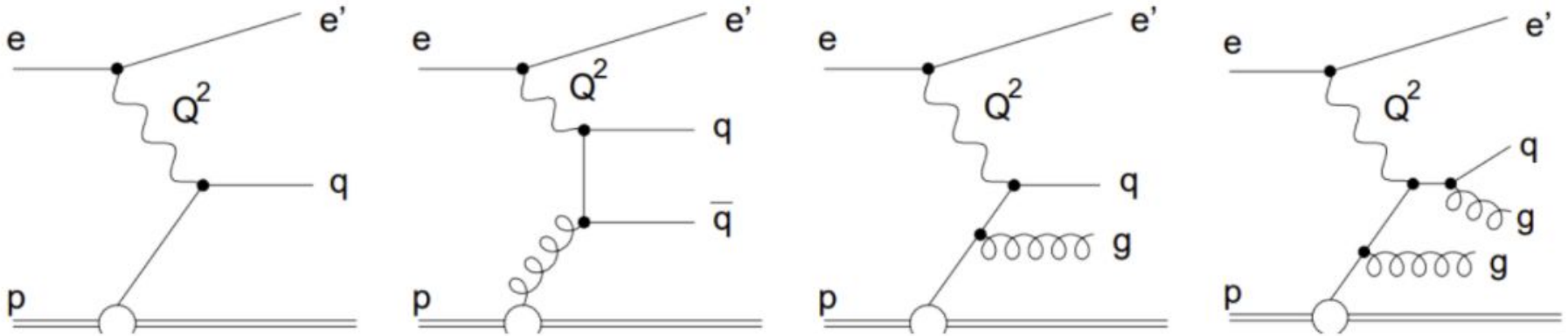
Jets have rich substructure, which encodes rich dynamics







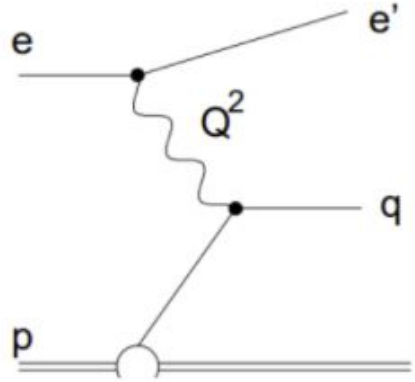
Jet production in DIS

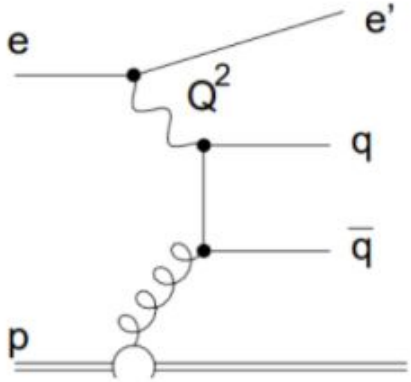


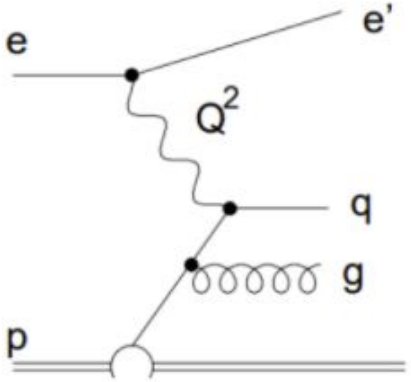
For most HERA studies:

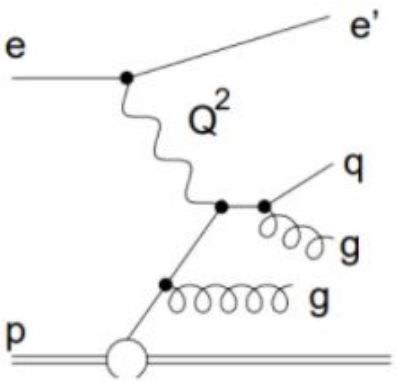
~ 0 p_T in Breit frame
Background

High p_T in Breit frame
Signal (gluon PDFs, alpha_s)





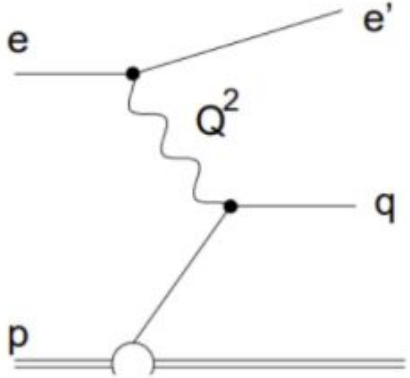


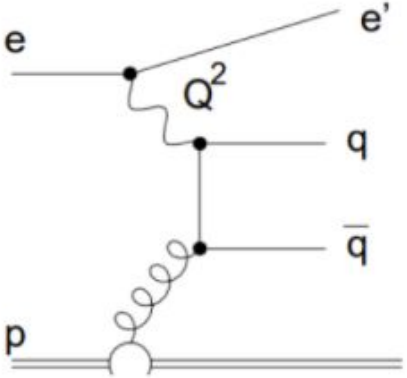


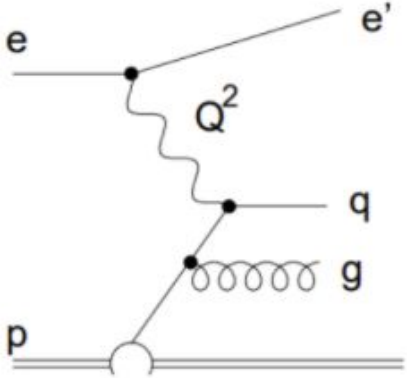
At the EIC, we expect:

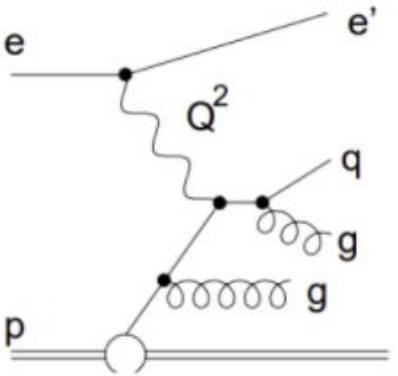
~ 0 p_T in Breit frame
Signal: quark TMDs

High p_T in Breit frame
Signal: gluon TMDs

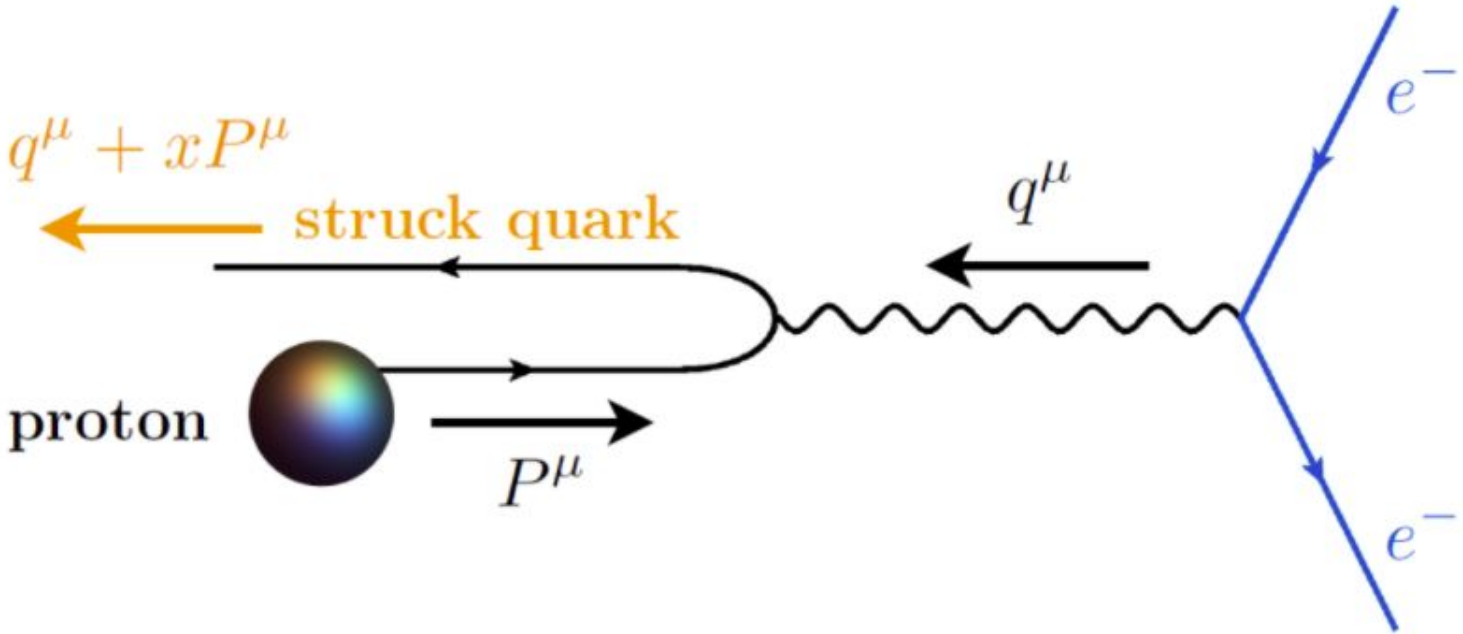








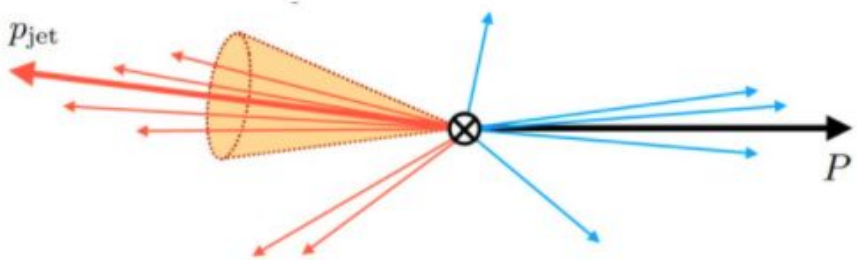
How do we study this jet configuration?

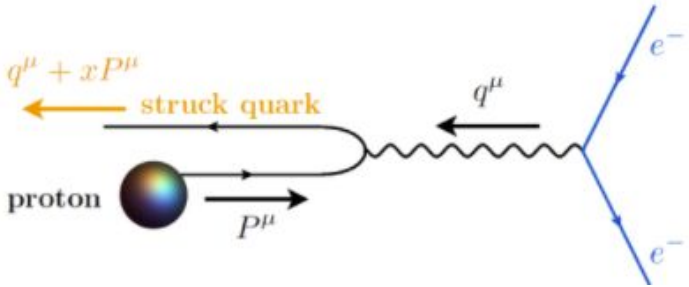


Standard jet algorithms used at HERA (and pp collisions), yield **pathological** results for Born kinematics

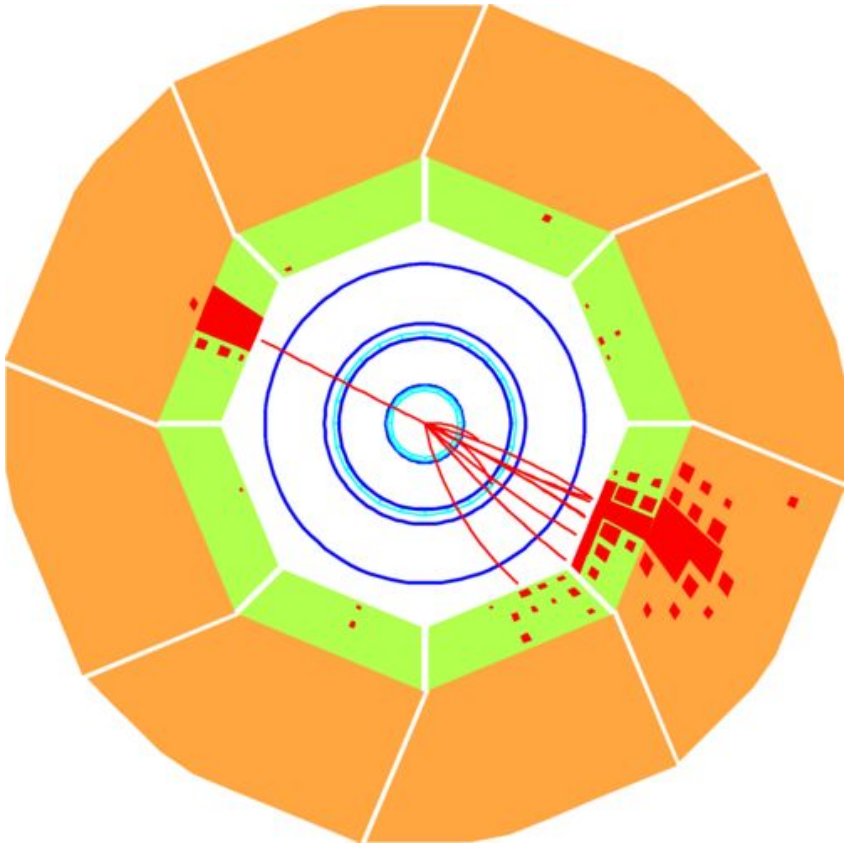
$$d_{ij} = \min(p_{Ti}^{2p}, p_{Tj}^{2p})\Delta R_{ij}^2/R^2$$

$$\Delta R_{ij} = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$$





How will we measure Jet at EIC?



Some key aspects in jet performance

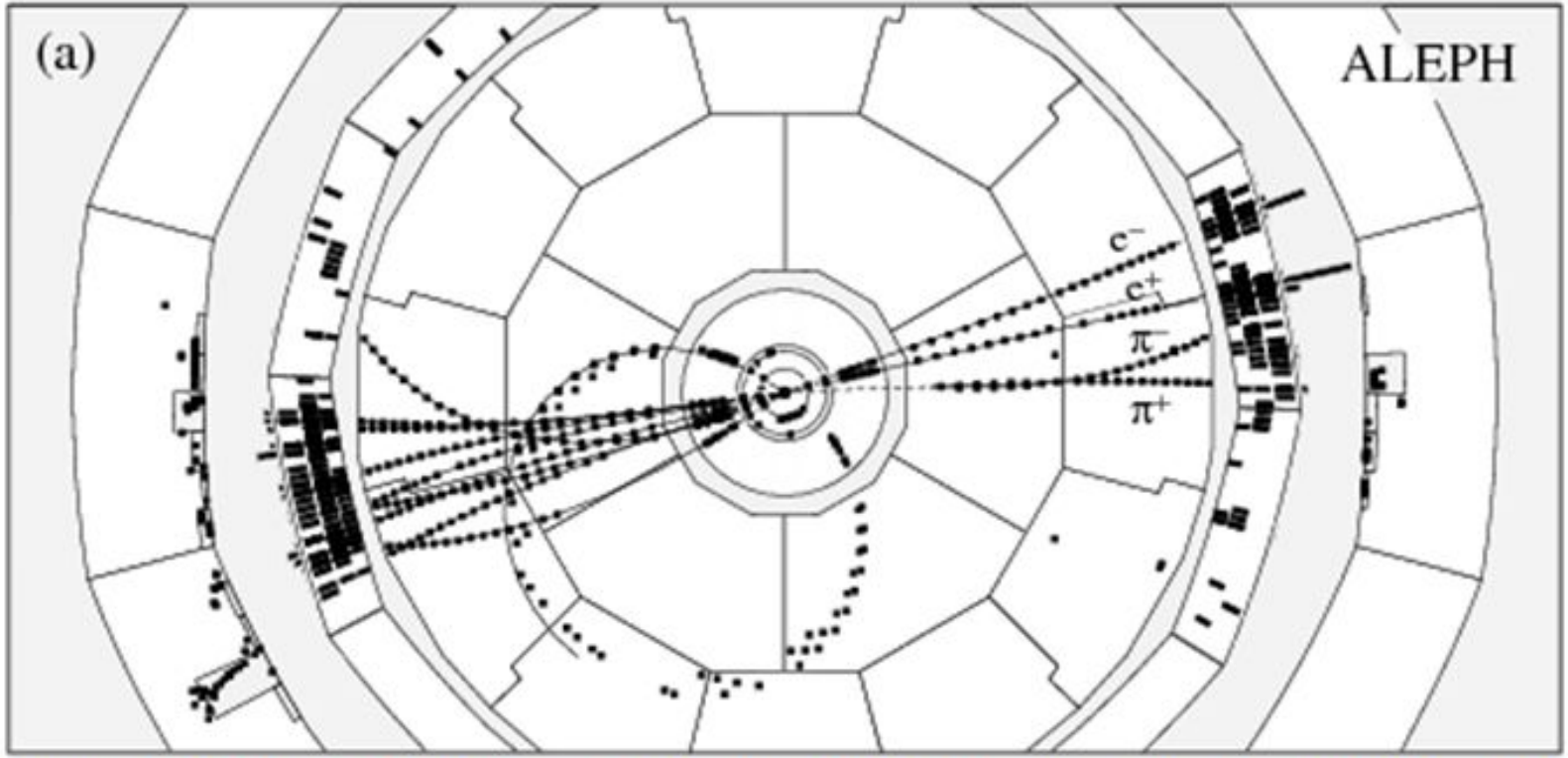
“On average 50% of the momentum of a 50 GeV jet is carried by particles with a momentum less than 5% of the jet’s momentum”

Some key aspects in jet performance

“On average about 60% of a jet’s momentum is carried by charged hadrons, photons account for about 25% of the total jet momentum and the remaining 15% can be attributed to long-lived neutral hadrons”

Rev. Mod. Phys. 91, 45003 (2019)

Energy-flow is not precisely new…



(Used by ALEPH@LEP, CDF@Tevatron, H1@HERA, CMS@LHC, and is planned at sPHENIX@RHIC …)

10

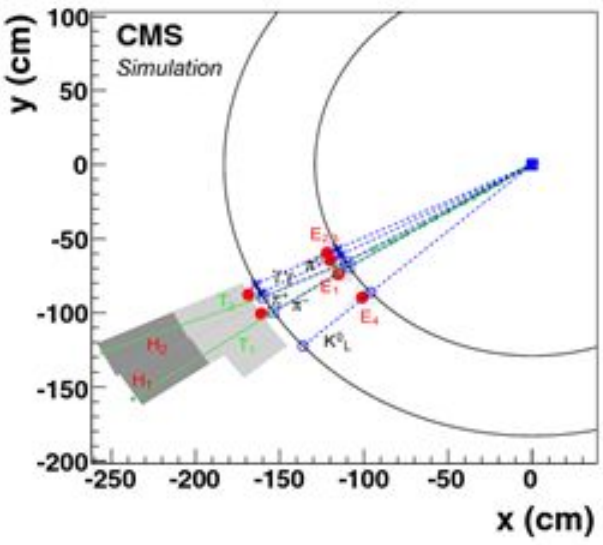
"Energy-flow" method

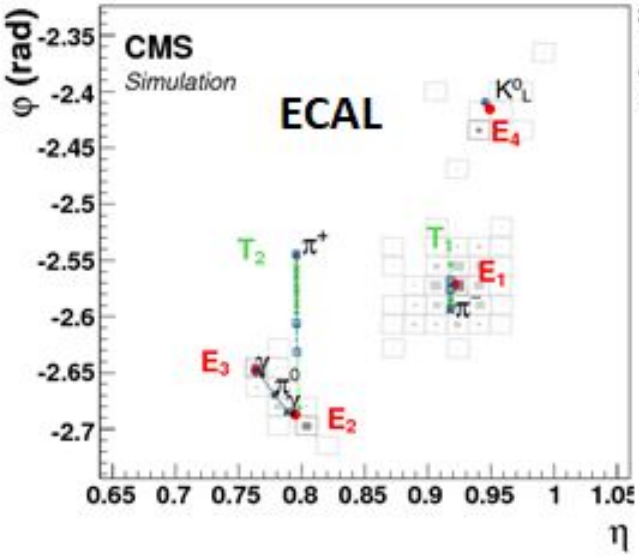
(1) charged tracks and identified leptons contributions are taken from their tracking measurement
(2) γ and π^0 from the electromagnetic calorimetry
(3) neutral hadron from both calorimeter measurement
(4) the last component being the residual from charged hadrons or γ which should be kept at the lowest level

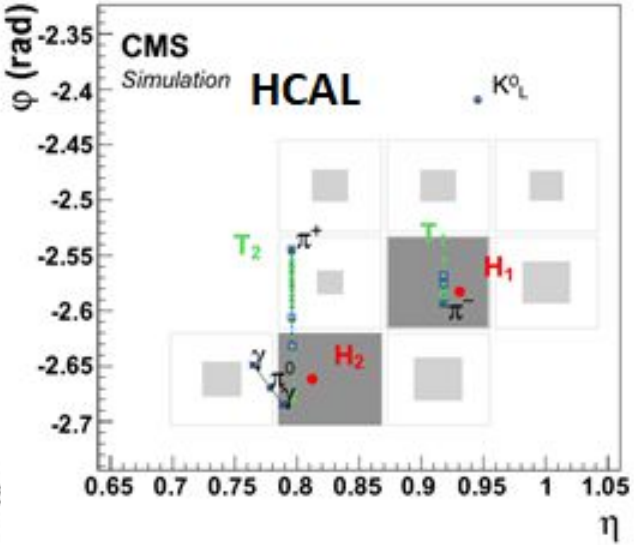
http://hal.in2p3.fr/in2p3-00012827/document

Energy flow in practice

CMS Collaboration *JINST* 12 (2017) P10003

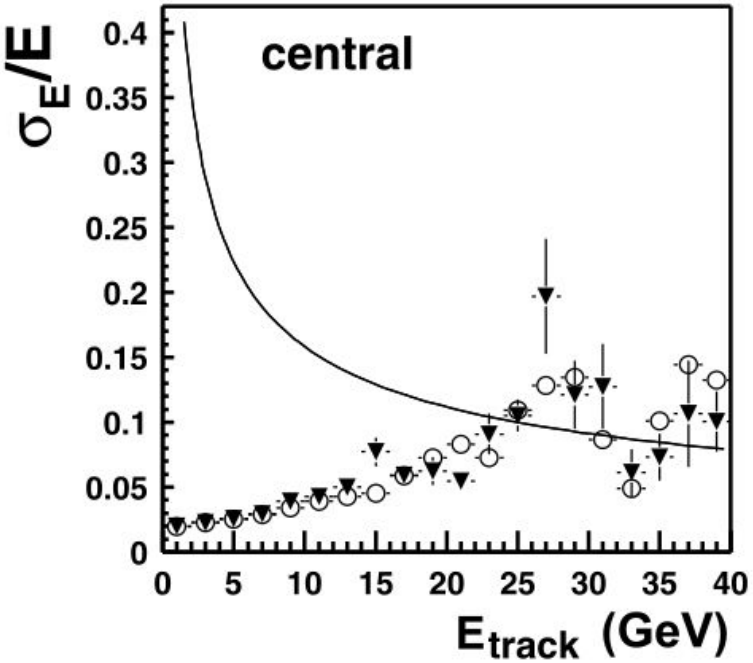






Granularity of calorimeters key, "confusion" drives the resolution

Energy flow at H1@HERA



▼ tracks data

○ tracks MC

— LAr expectation

Fig. from “An energy flow algorithm for Hadronic Reconstruction in OO: Hadroo2”

Tracker will be much better than at HERA. Yet, tracker alone is not enough.

Jet performance at the LHC

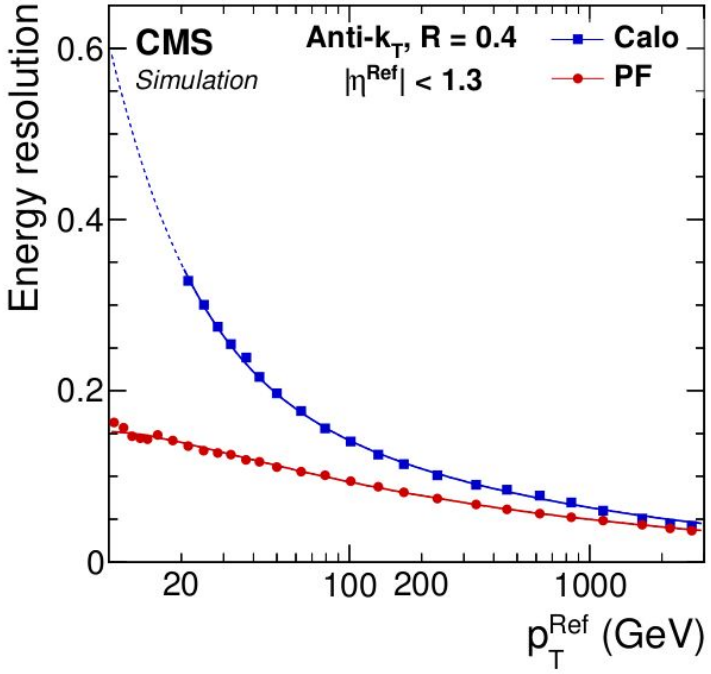
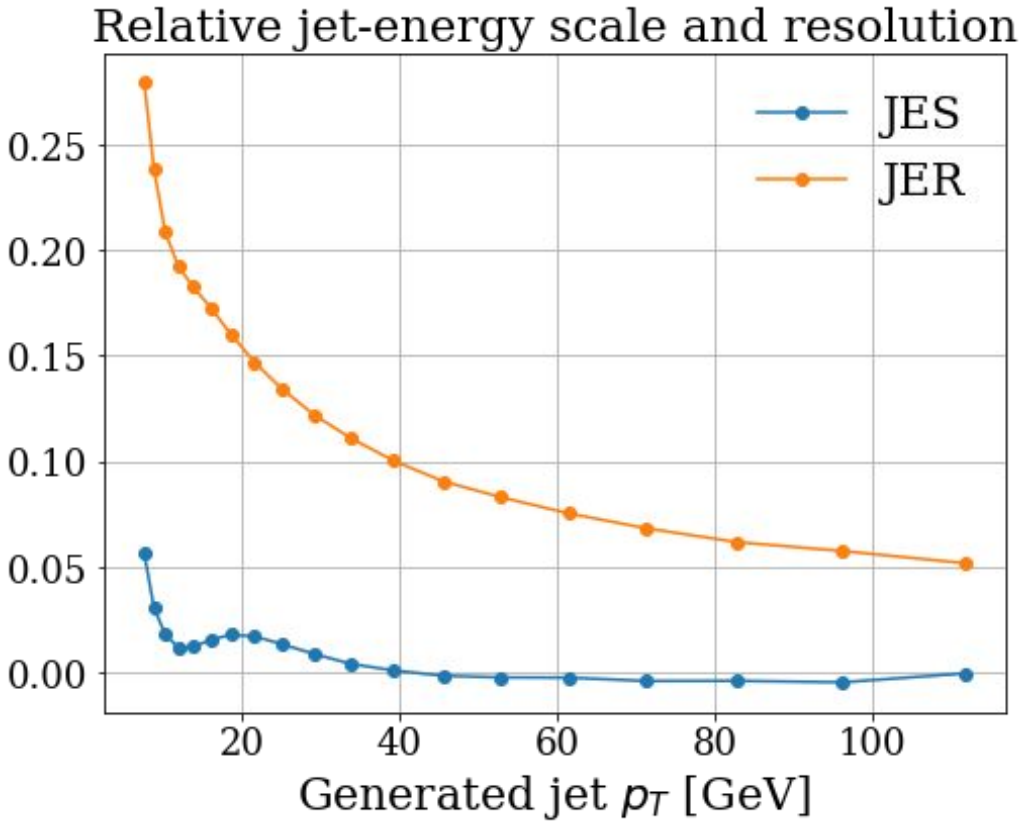


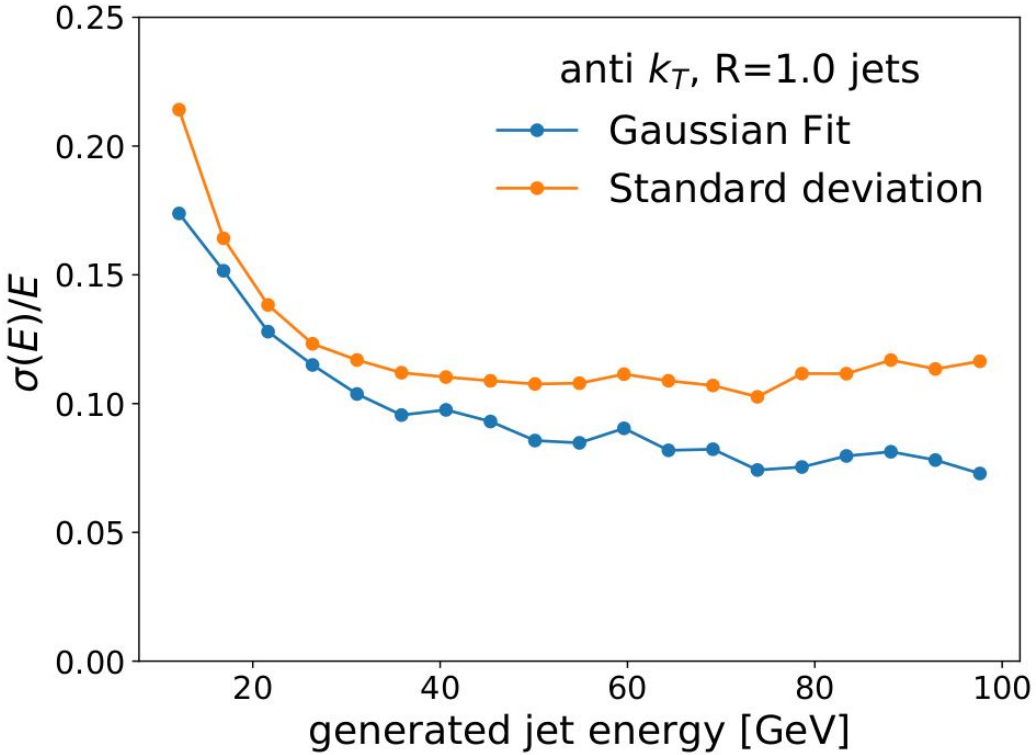
Figure 3: Jet energy resolution for particle flow (red, lower line) and calorimeter-only (blue, upper line) jets in the barrel region in CMS simulation, with no pile-up, as a function of the p_T of the reference jet. Taken from [53].

H1 energy-flow performance



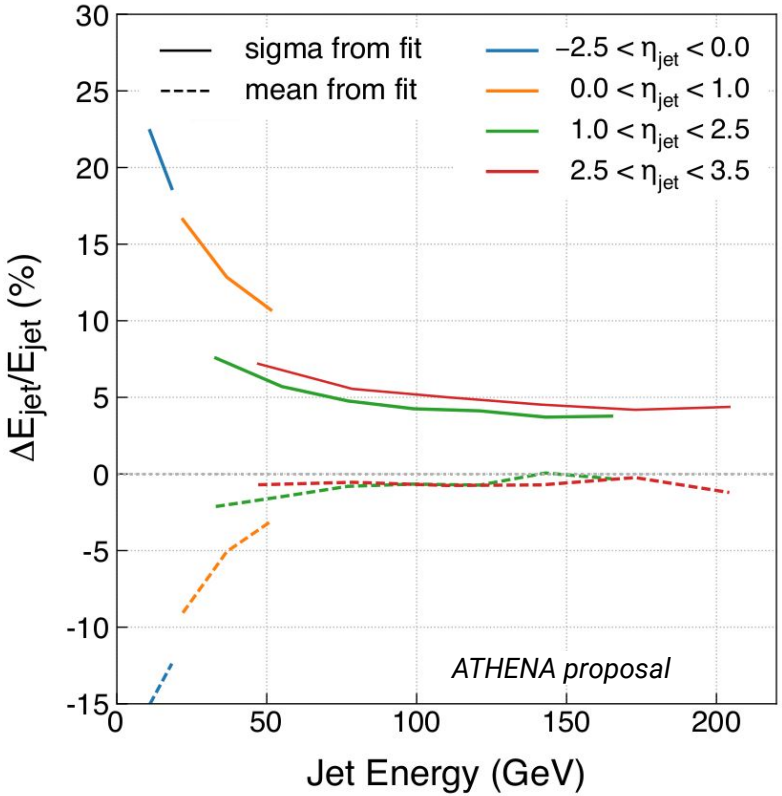
Expected jet performance at the EIC

(with energy-flow algorithm)

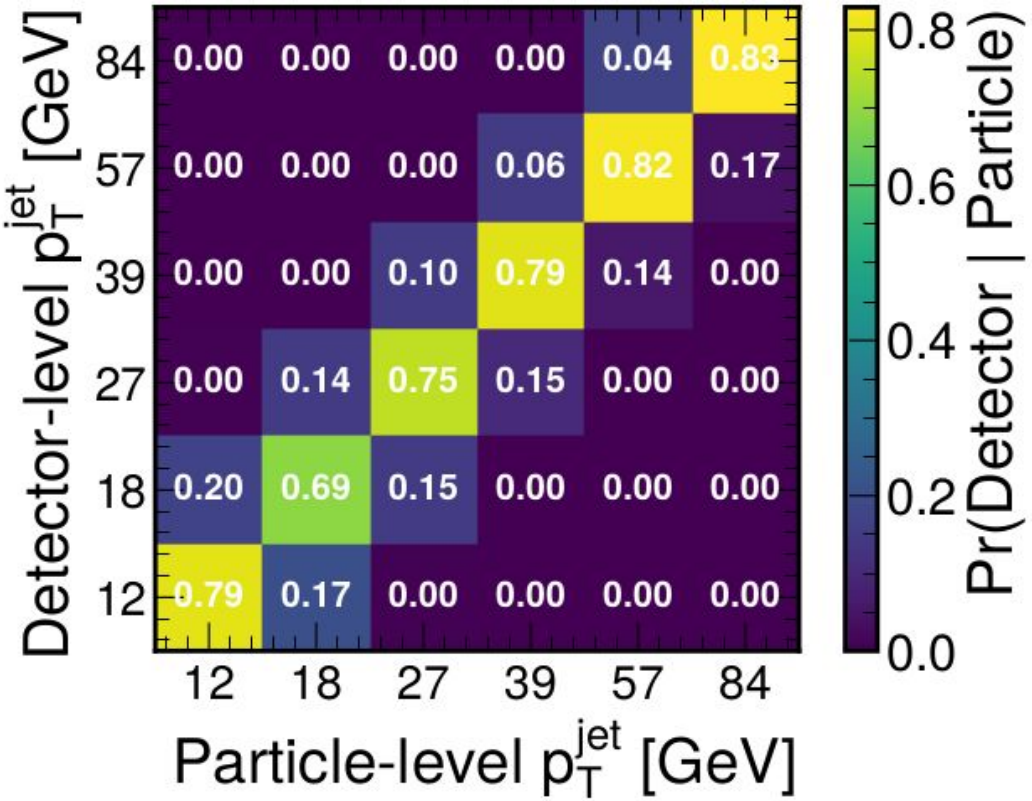


Phys.Rev.D 102 (2020) 7, 074015

Expected jet performance at the EIC vs angle



Unfolding: the art of regularized matrix inversion



SVD approach to data unfolding

#1

Andreas Hocker (Orsay, LAL), Vakhtang Kartvelishvili (Manchester U.) (Aug, 1995)

Published in: *Nucl.Instrum.Meth.A* 372 (1996) 469-481 • e-Print: hep-ph/9509307 [hep-ph]

pdf DOI cite 610 citations

A Multidimensional unfolding method based on Bayes' theorem

G. D'Agostini (Rome U. and INFN, Rome)

Jun, 1994

20 pages

Published in: *Nucl.Instrum.Meth.A* 362 (1995) 487-498

DOI: 10.1016/0168-9002(95)00274-X

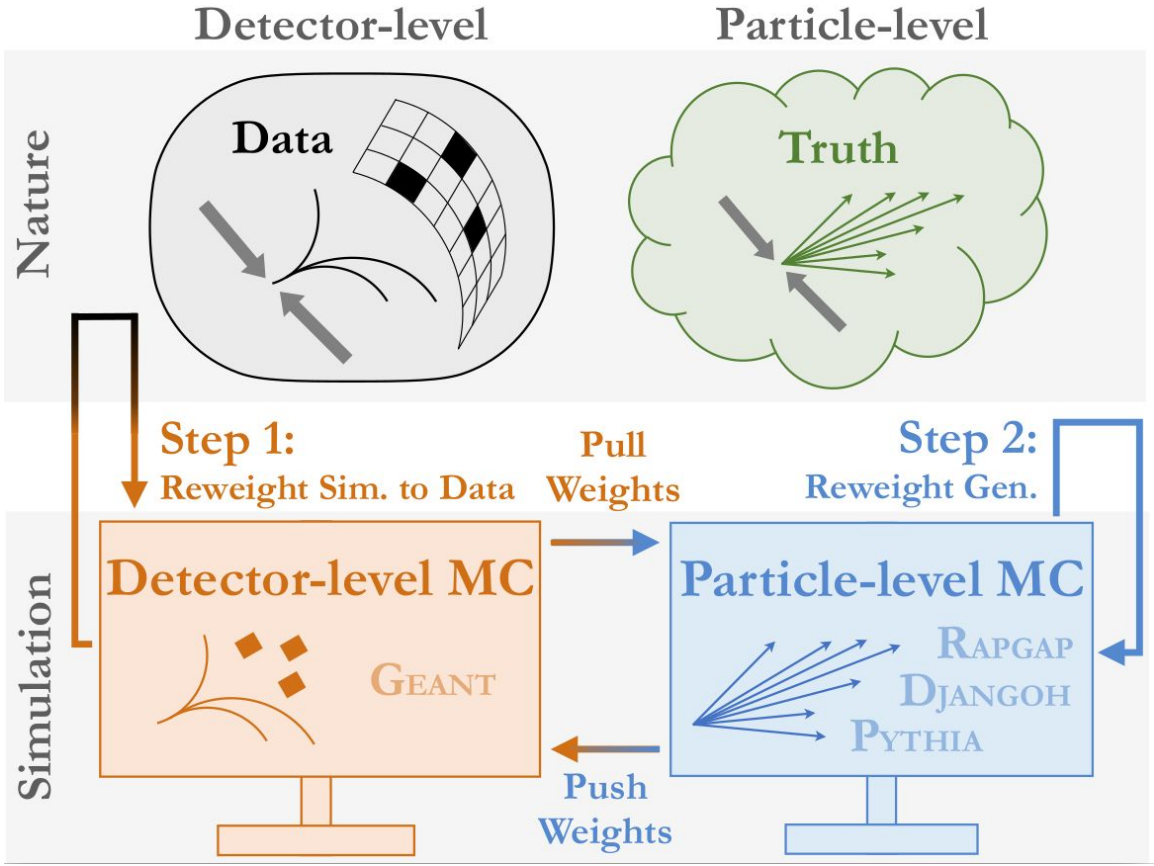
Report number: DESY-94-099

View in: KEK scanned document

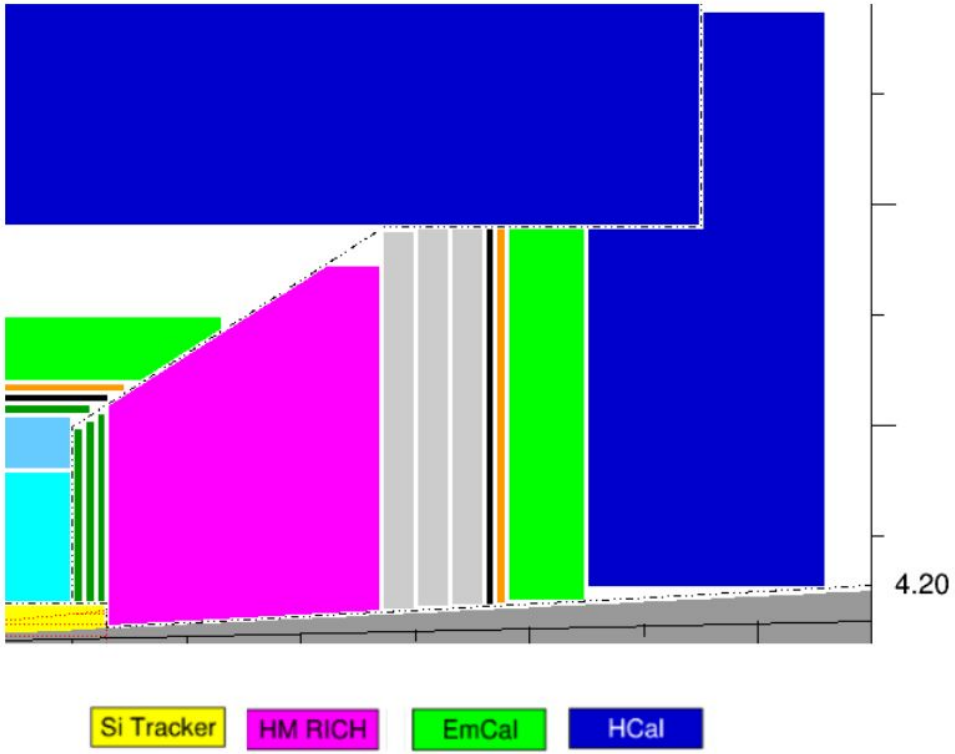
pdf cite 1,367 citations

Unfolding with Omnifold (via machine-learning).

Andreassen et al. PRL **124**, 182001 (2020)



Potential for unprecedented jet measurements



Combined with EIC high luminosity and polarization, this combination will enable unique **jet substructure measurements**

Why jets at the EIC?

New, powerful tool for all pillars of EIC science

How will we measure jets at EIC?

Optimal combination of tracks, calorimeters, and PID detectors. AI-assisted reconstruction & unfolding