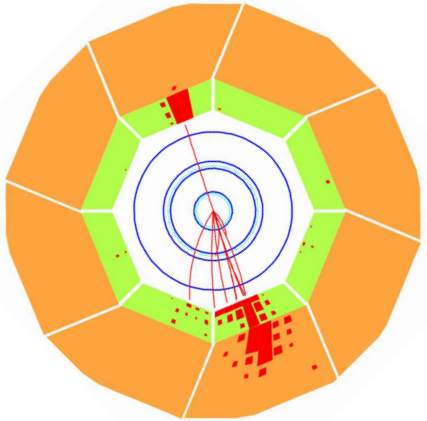
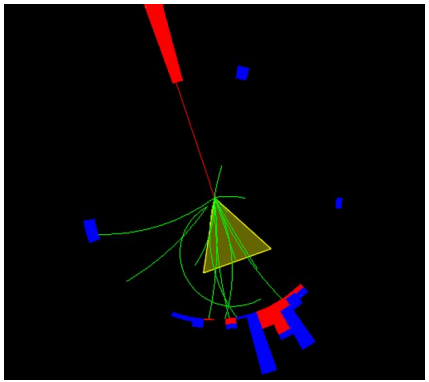
Jets in DIS
Present & Future

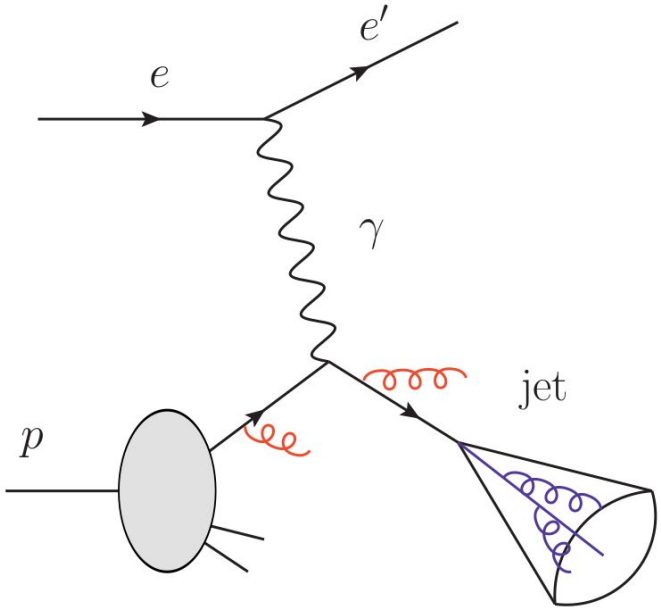


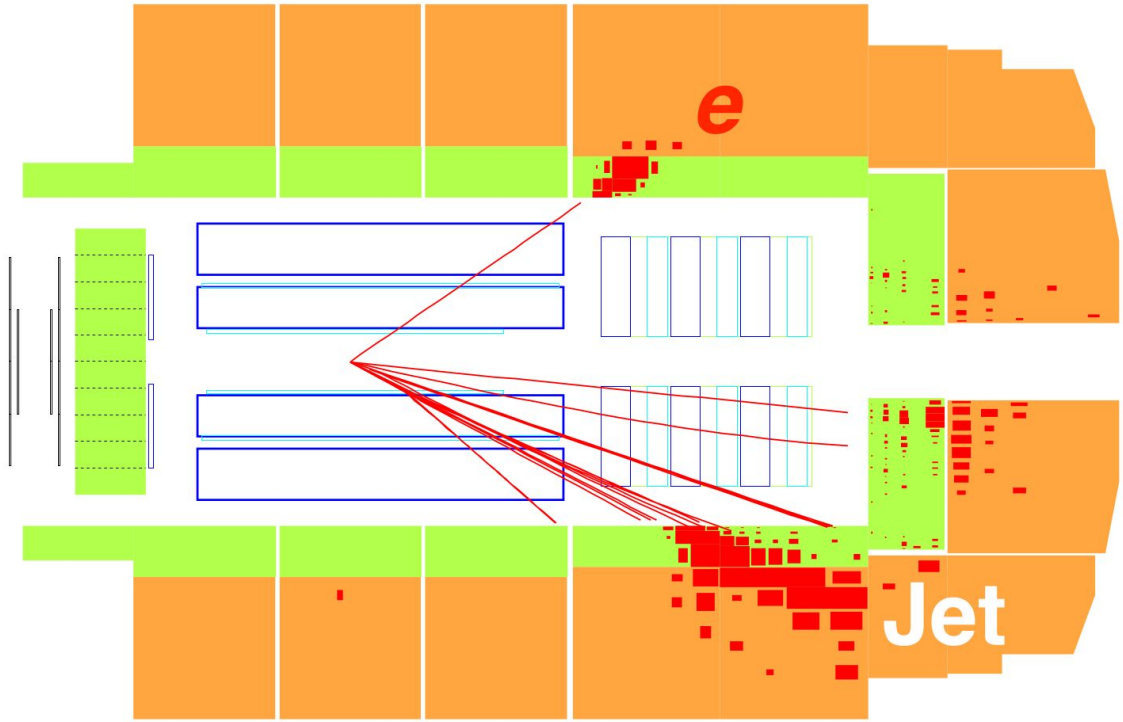


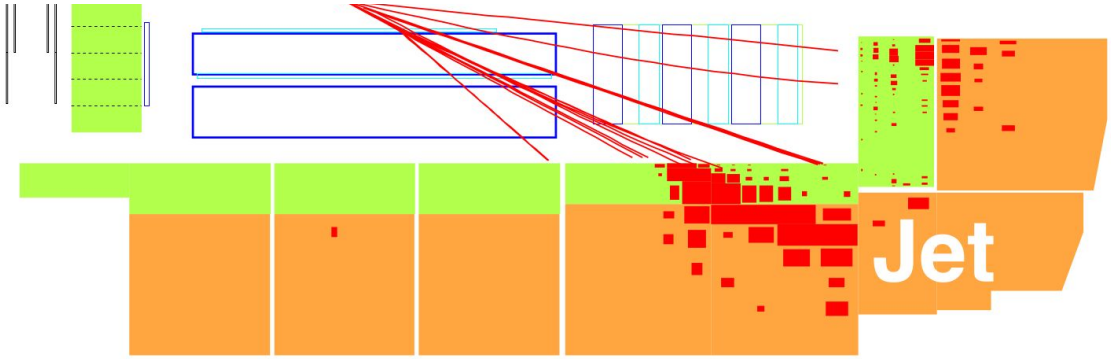
Miguel Arratia

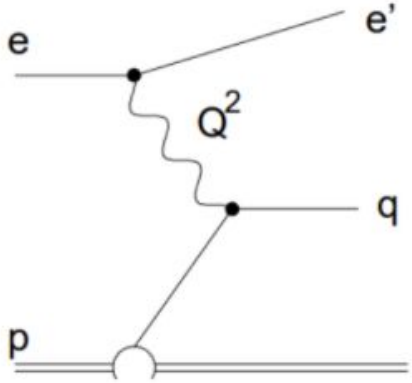
UC RIVERSIDE

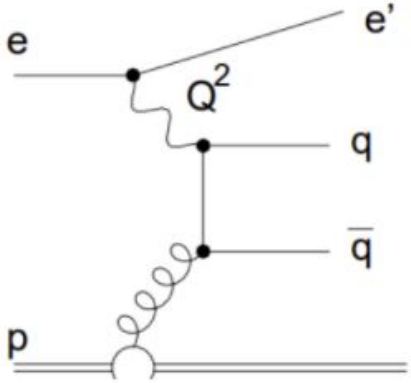
CTEQ Fall Meeting, Nov 21th, 2024

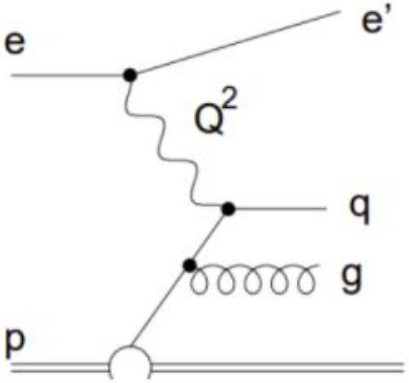

e
e′
γ
jet
p

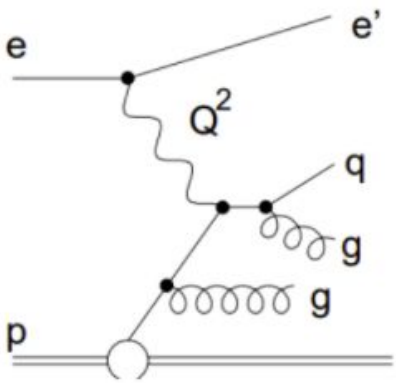

e
Jet


Jet


e
e'
Q2
q
p


e
e'
Q2
q
q̄
p

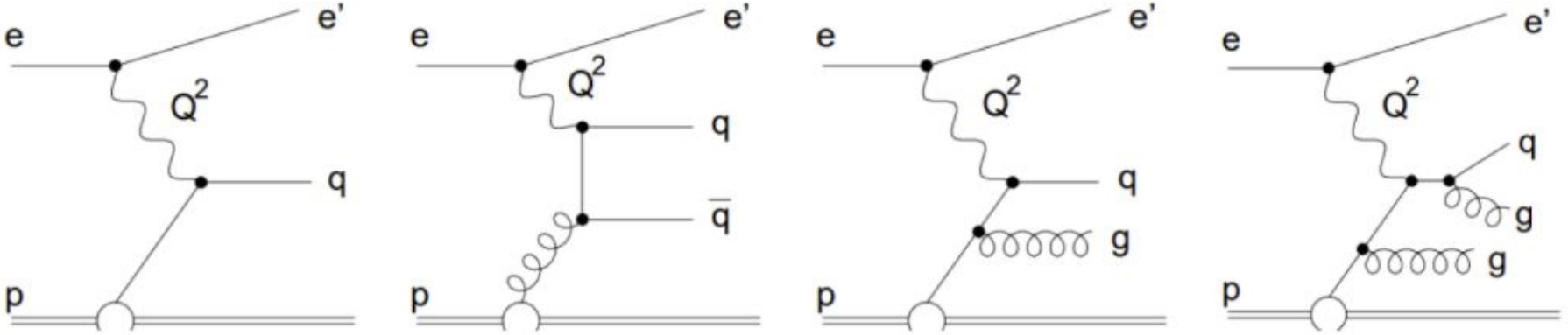

e
e'
Q2
q
g
p


e
e'
Q2
q
g
g
p

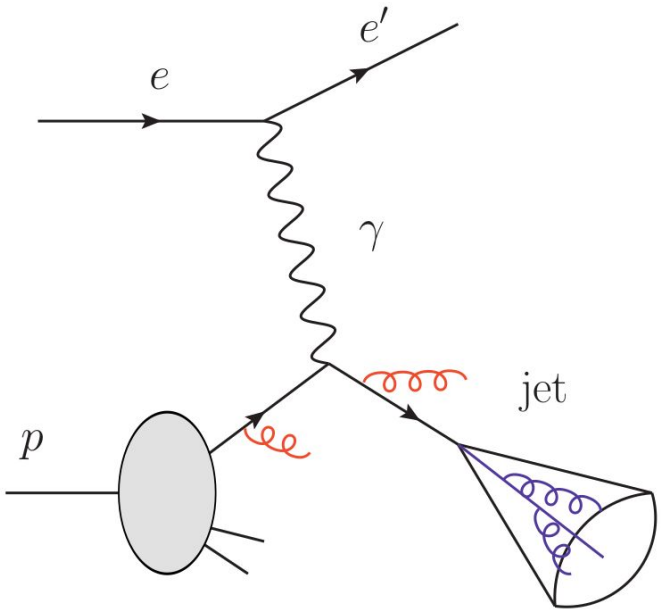
For most of HERA jets studies:

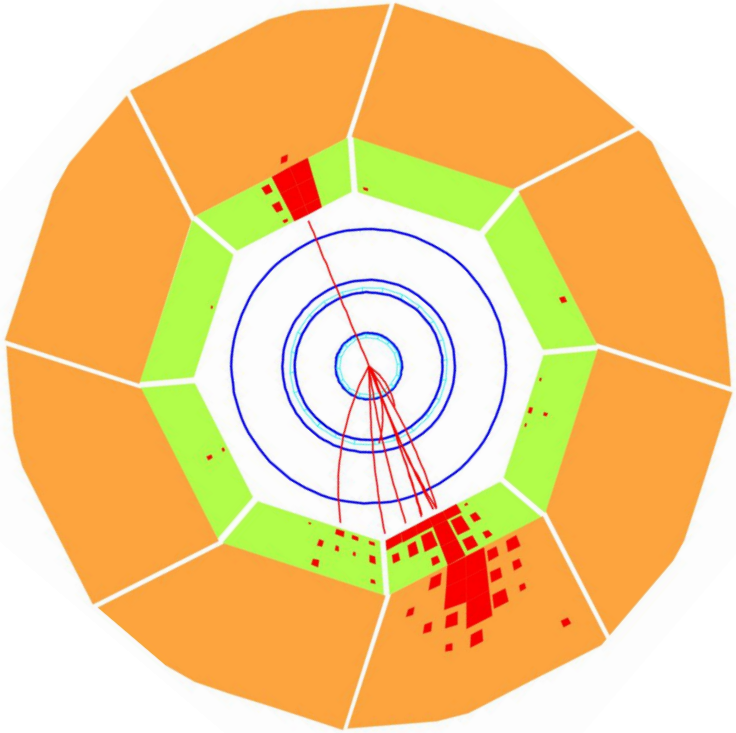
~ 0 p_T in Breit frame
Background

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



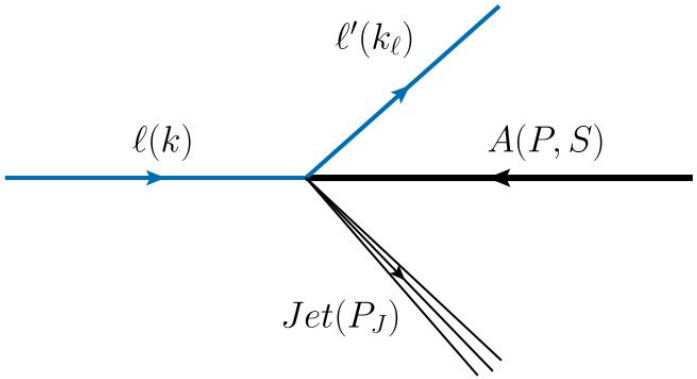
Common wisdom from 90s to 2020s:
"Naive quark-parton model background"





With EIC in horizon, new ideas emerged changing paradigms

Liu et al. PRL. 122, (2019)192003, Gutierrez et al. PRL. 121 (2019), 162001

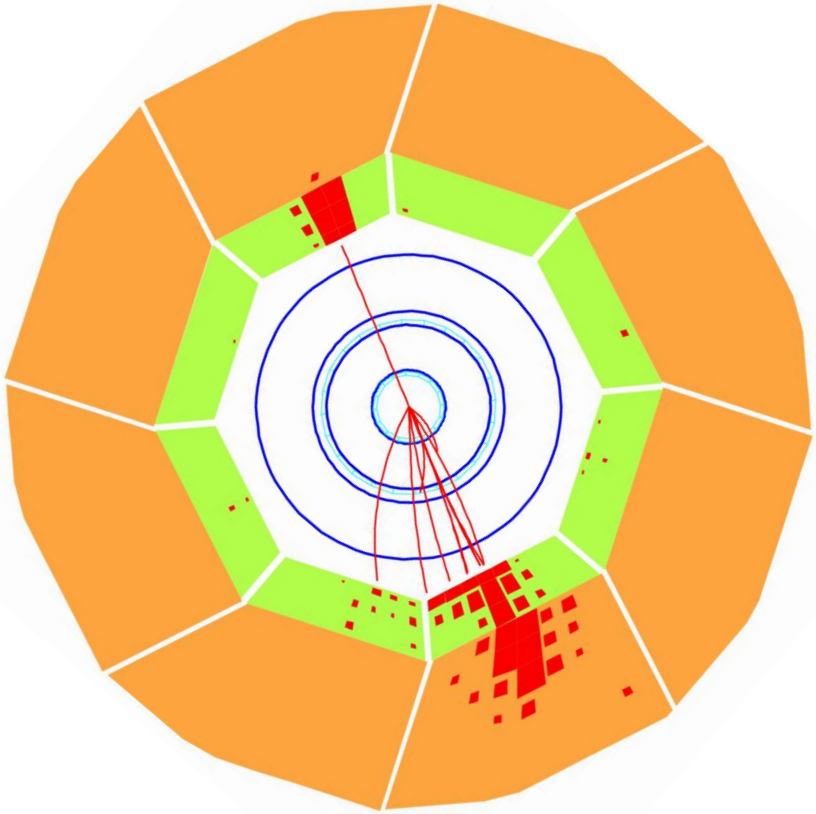


"The advantage of the lepton-jet correlation as compared to the standard SIDIS processes is that it ***does not involve TMD fragmentation functions.***"

$$q_T = |\vec{k}_{l\perp} + \vec{p}^{\,j}_{\perp}|$$

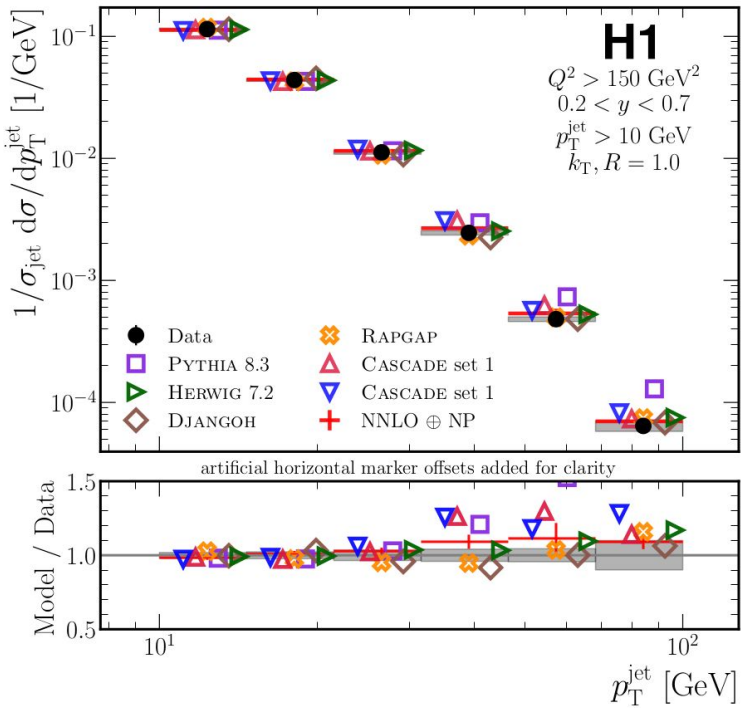
$$\frac{d^5\sigma(\ell p \to \ell' J)}{dy_\ell d^2k_{\ell\perp} d^2q_\perp} = \sigma_0 \int d^2k_\perp d^2\lambda_\perp x f_q(x, k_\perp, \zeta_c, \mu_F) \times H_{\mathrm{TMD}}(Q, \mu_F) S_J(\lambda_\perp, \mu_F) \times \delta^{(2)}(q_\perp - k_\perp - \lambda_\perp).$$

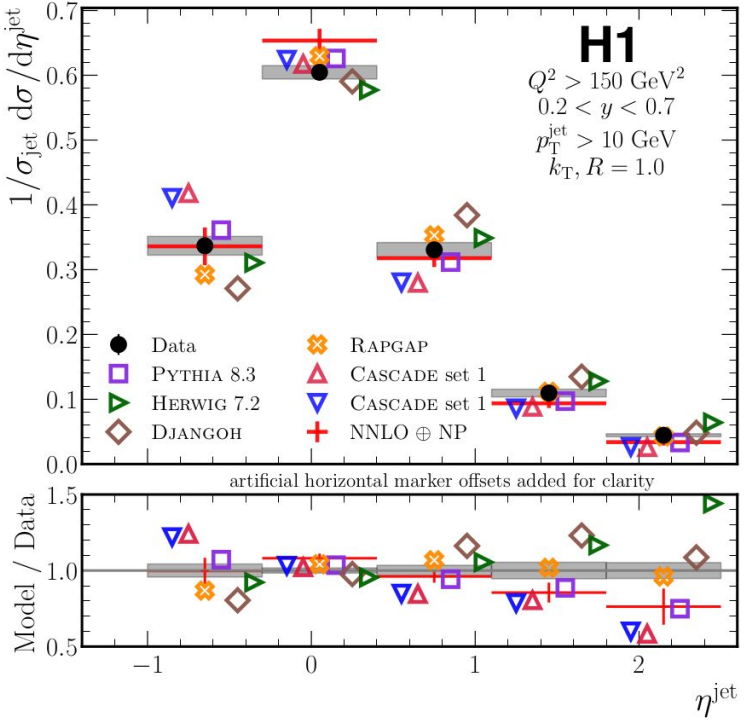
“Crazy idea”: measure it with HERA data!



Measurement of inclusive jet spectra in DIS

H1 Collaboration, PRL 128 (2022) 13, 132002

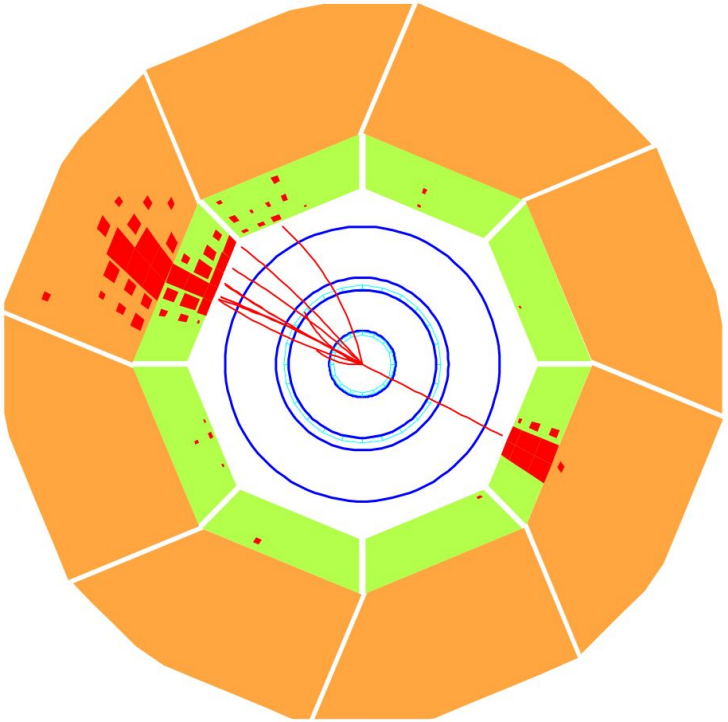


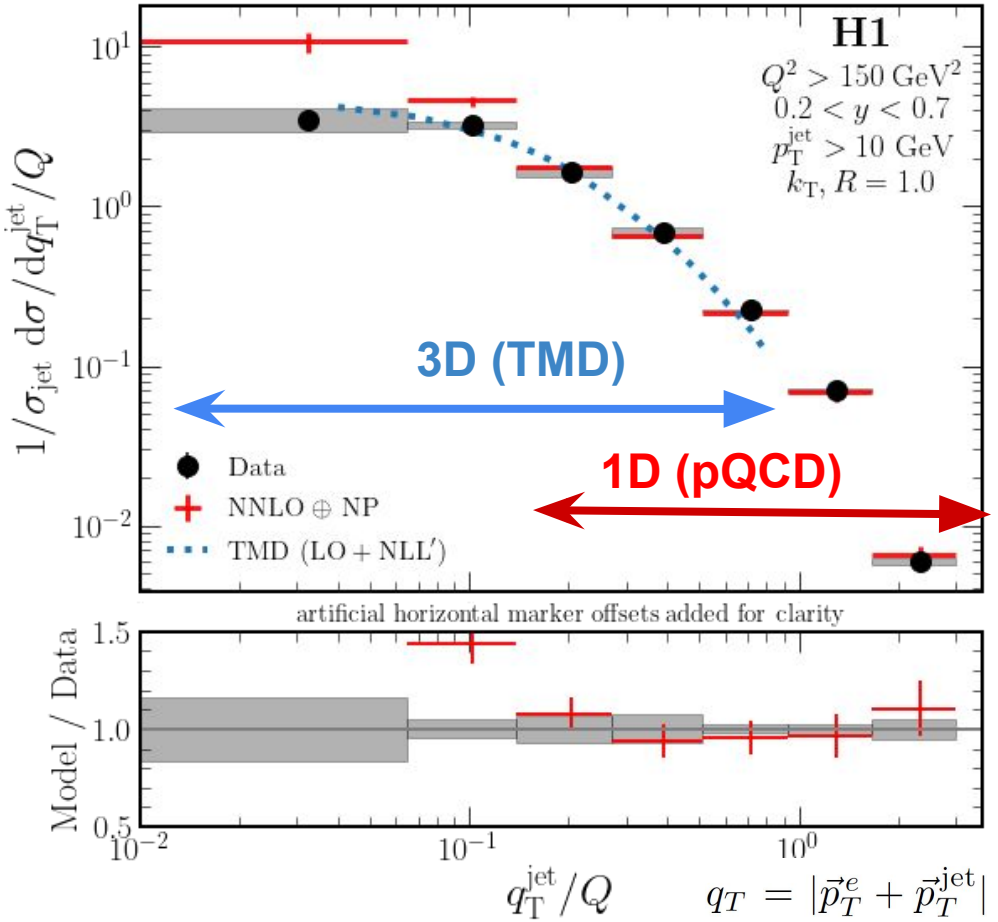


Precise & accurate data test modern MC generators in DIS and NNLO calculations.
Excellent reference for EIC

Lepton-jet correlation

H1 Collaboration, PRL 128 (2022) 13, 132002



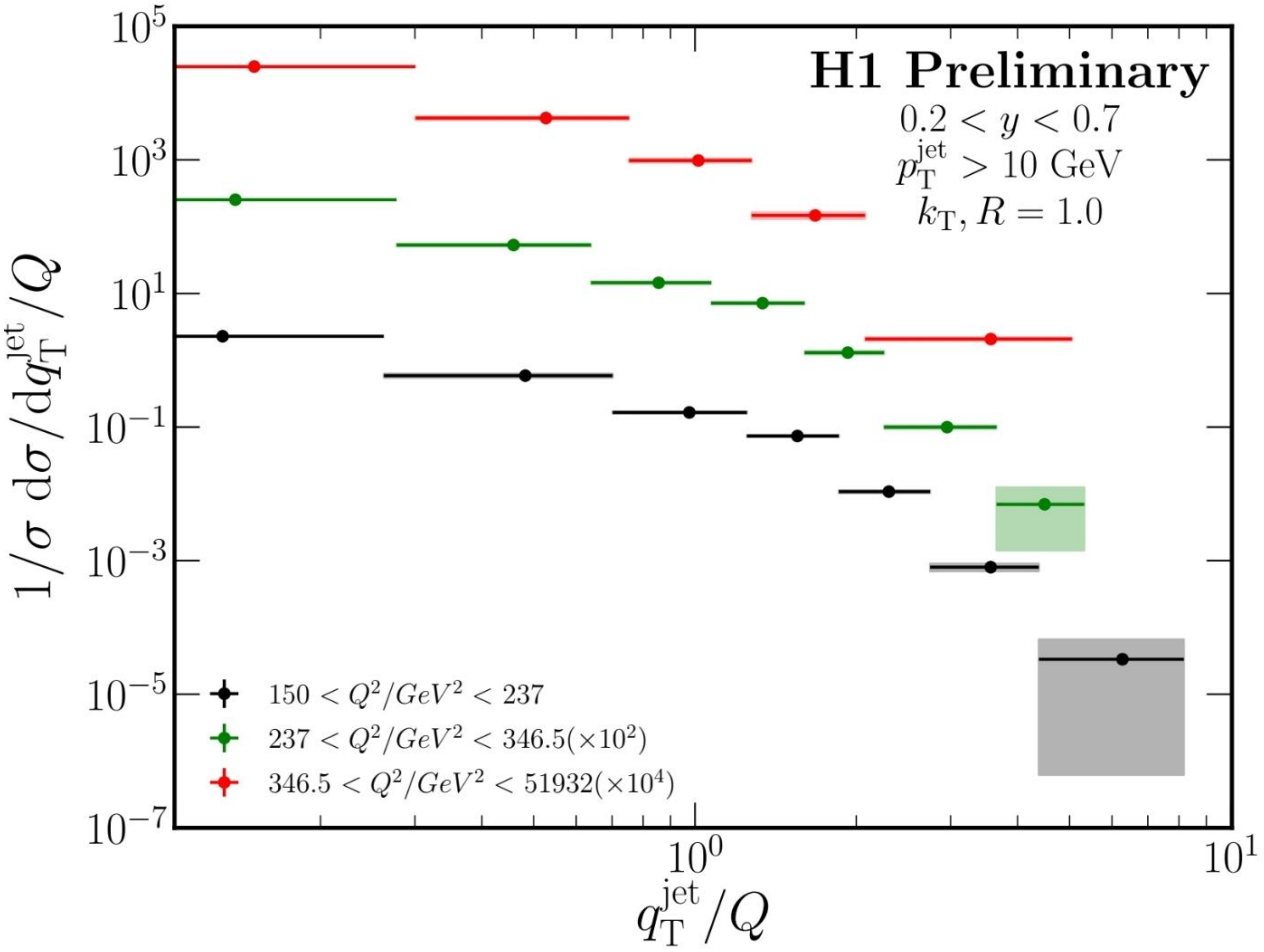


Textbook example of “matching” between collinear pQCD and TMD frameworks

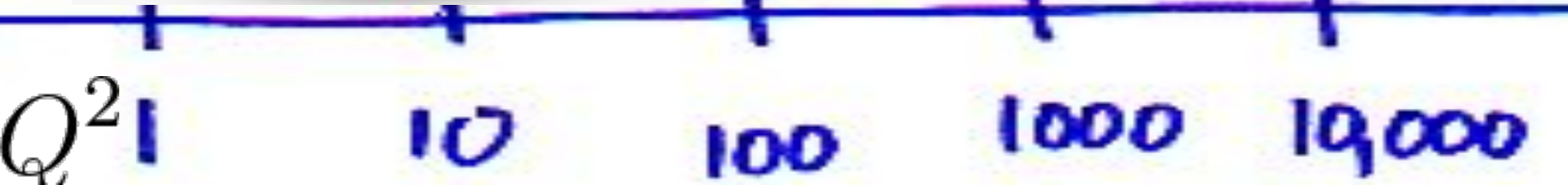
First time seen!

Q2 evolution of lepton-jet correlation

H1 Collaboration,
Coming Soon to arXiv



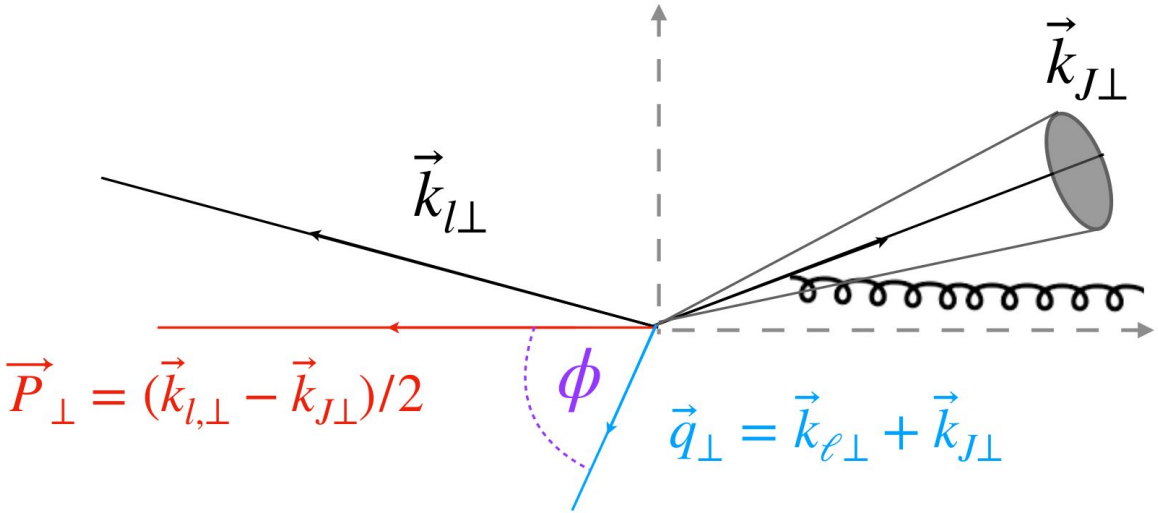
TMD evolution: Endgame

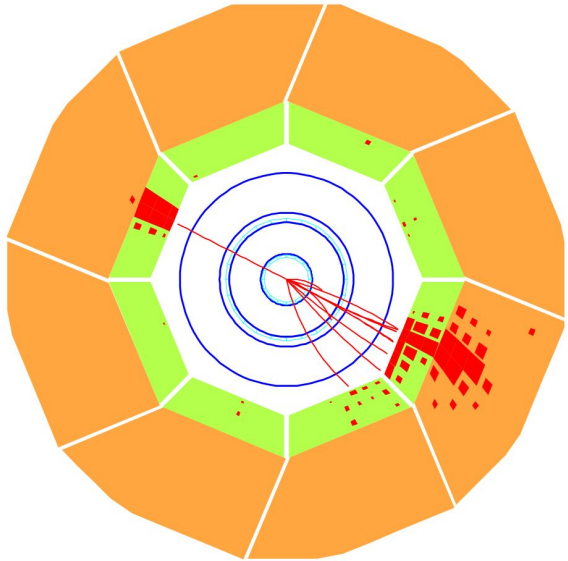


Lepton-jet azimuthal modulations

This type of observables was proposed to probe proton structure (TMD, GPDs), but found to be sensitive to gluon radiation

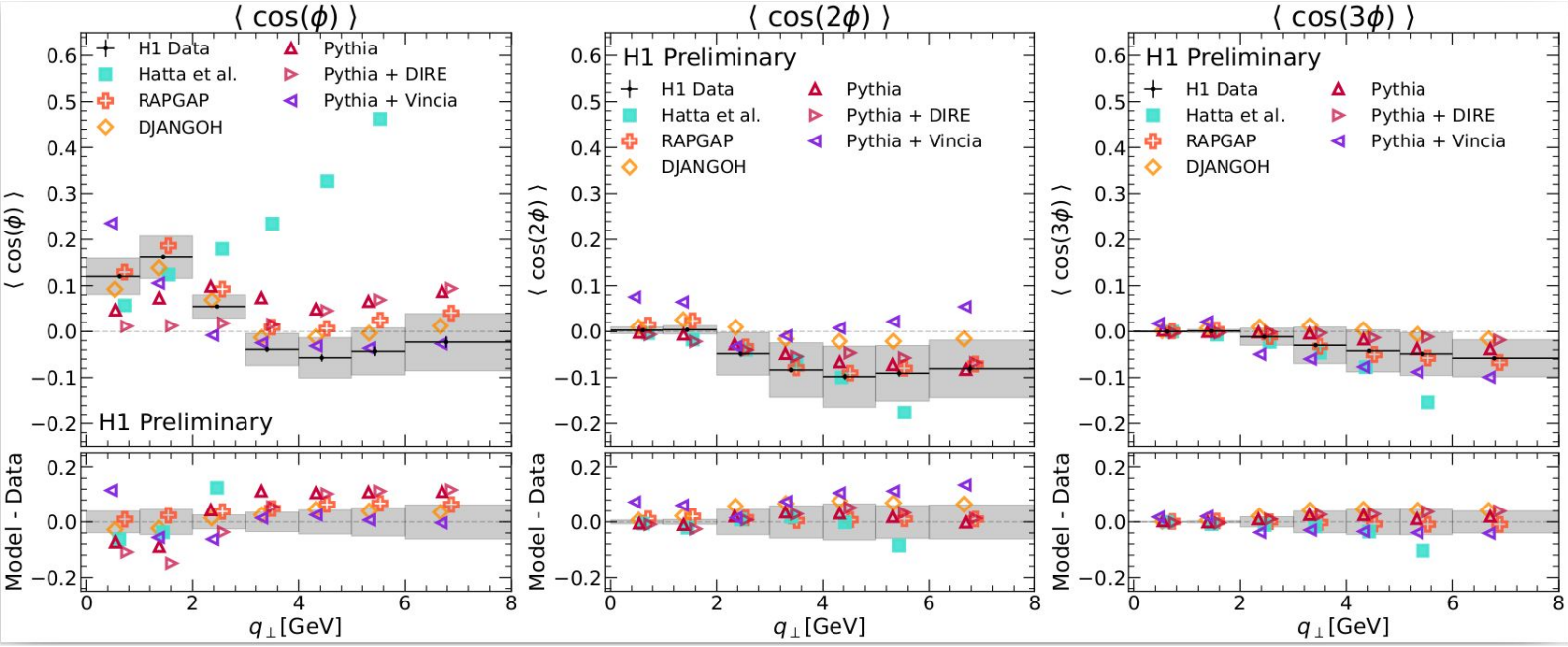
Hatta et al. PRL. 116 (2016) 20, 202301; PRD, 054037 (2021);
Tong et al. PRL. 130 (2023), PRD 109 (2024) 5, 054004





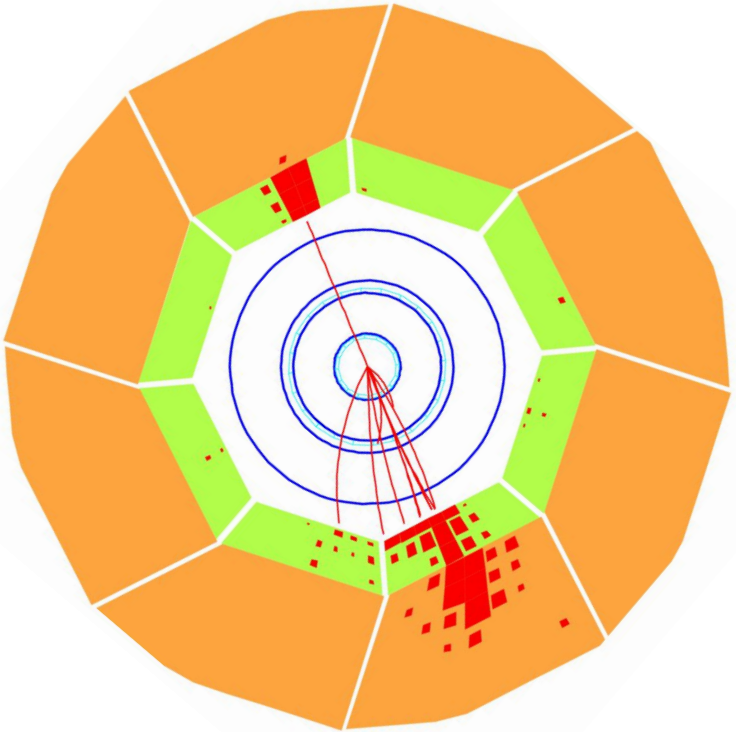
Lepton-Jet Azimuthal Modulations in DIS

H1collaboration, to appear in arXiv before DIS2025

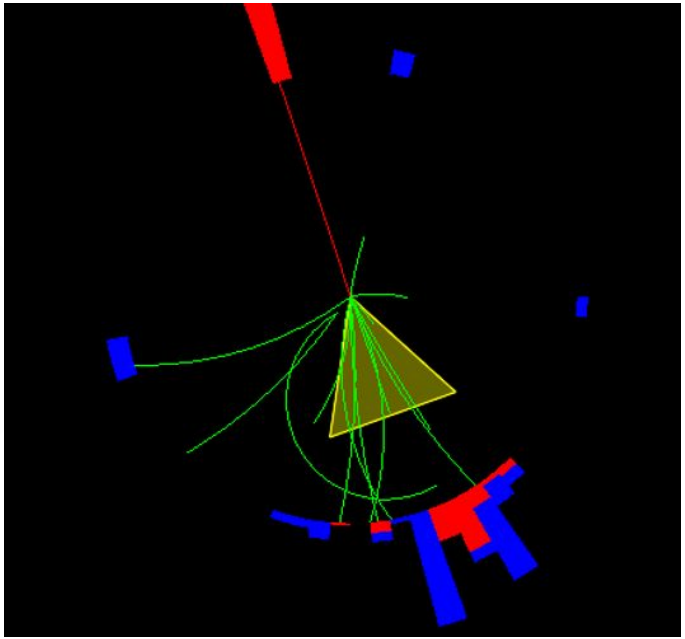


Confirms expected dominance of first Fourier coefficient at low qT, tests analytical calculations and modern MC generators and DIS parton showers

H1@HERA

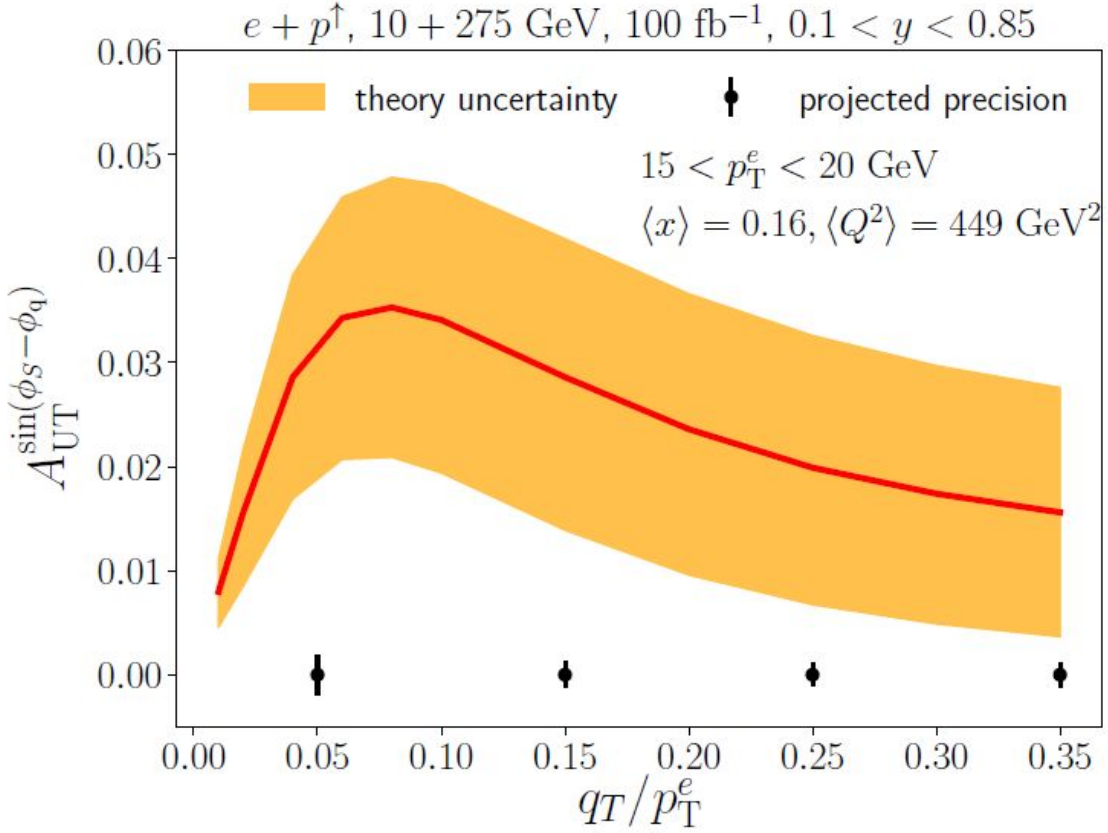


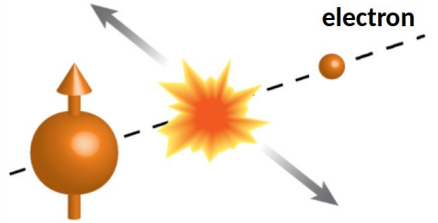
EIC



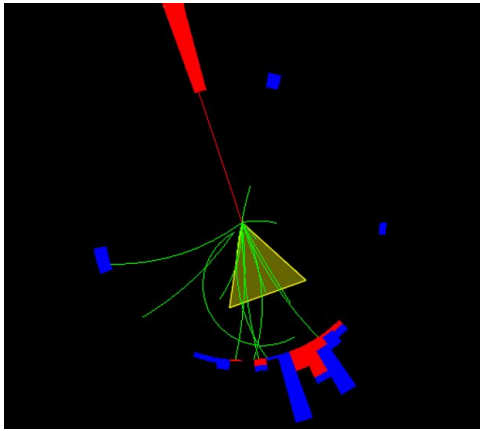
Projection for Lepton-jet Sivers asymmetry

Arratia et al. PRD 102 (2020) 7, 074015





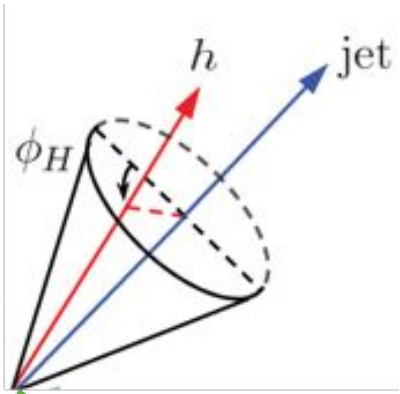
Transversely-polarized proton



$$q_T = |\vec{p}_T^{\,e} + \vec{p}_T^{\,\mathrm{jet}}|$$

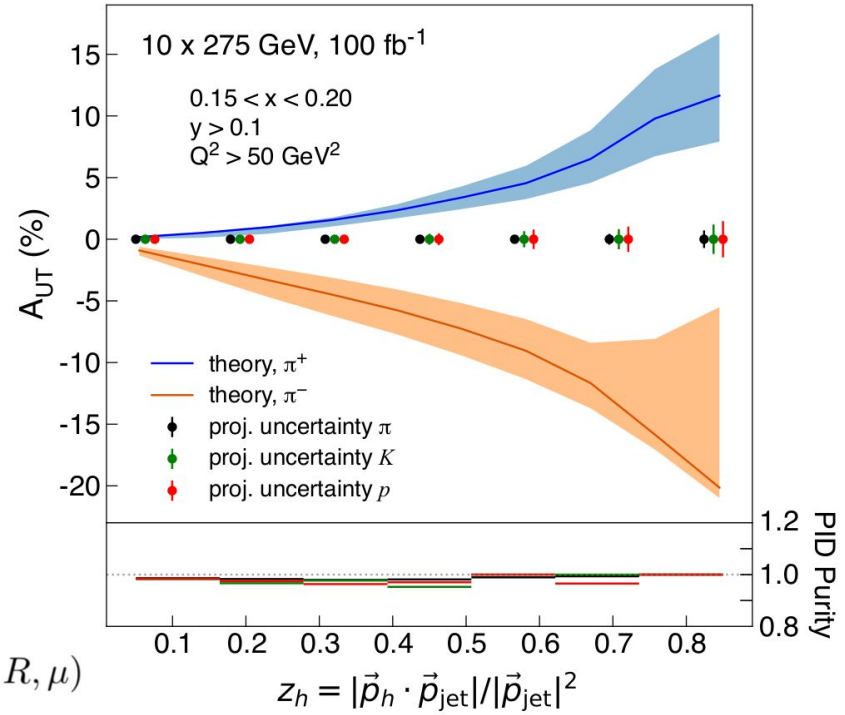
“Hadron-in-jet” spin-asymmetry measurements in DIS

Arratia et al. PRD 102 (2020) 7, 074015



$$F_{UU}^{h} = \sigma_0 \, H_q(Q,\mu) \sum_q e_q^2 \, \mathcal{G}_q^h(z_h, \vec{j}_T, p_T^{\text{jet}} R, \mu)$$

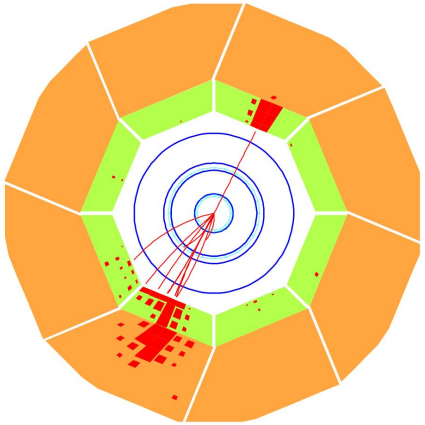
$$\times \int \frac{\mathrm{d}^2 \vec{b}_T}{(2\pi)^2} \, e^{i\vec{q}_T \cdot \vec{b}_T} \, f_q^{\text{TMD}}(x, \vec{b}_T, \mu) \, S_q(\vec{b}_T, y_{\text{jet}}, R, \mu)$$

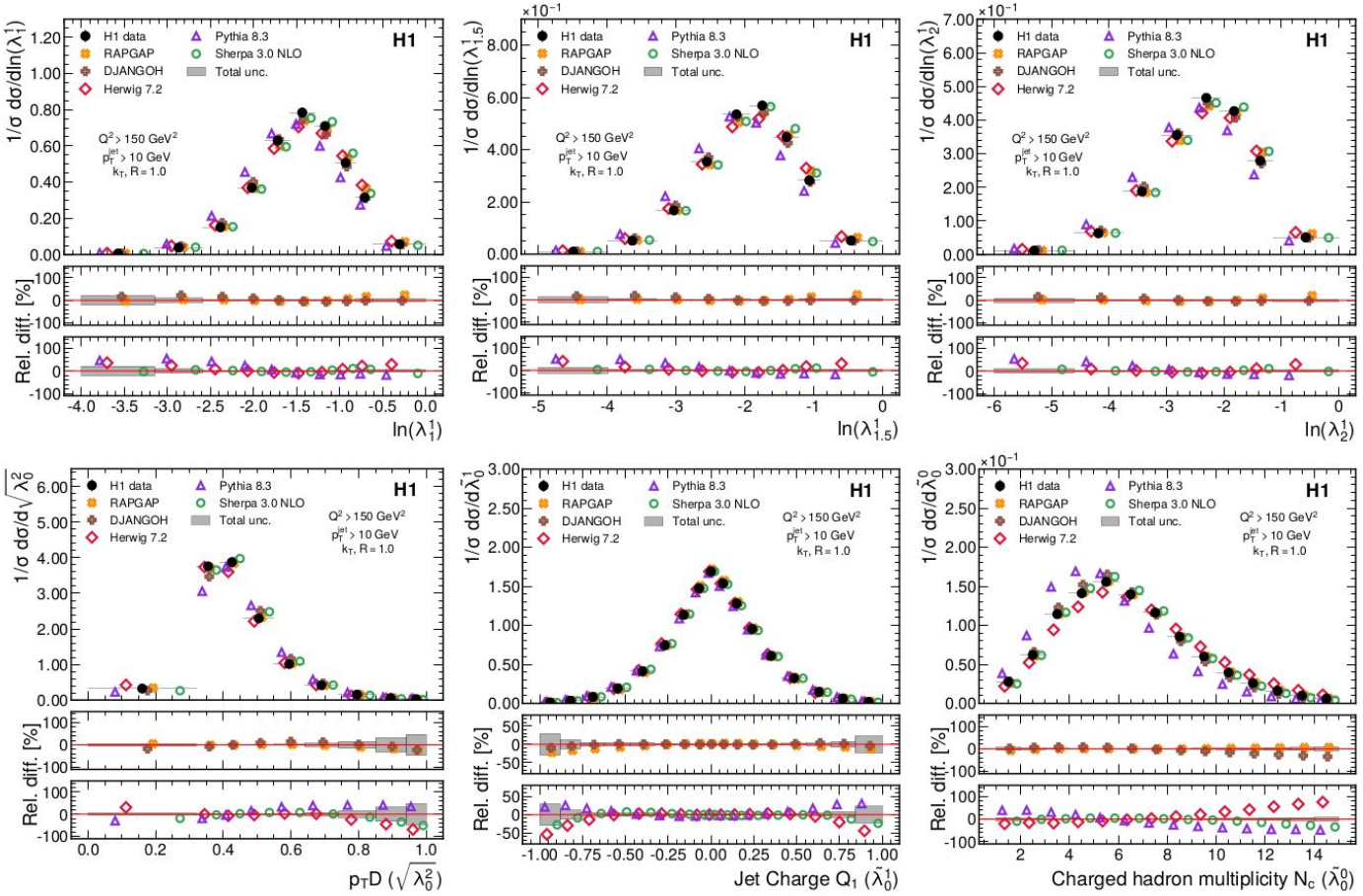


Simultaneous measurement of electron, hadron and jet lead to better control of TMDs

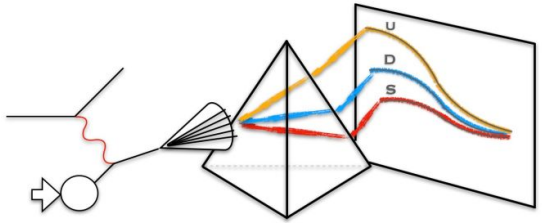
Jet substructure in DIS

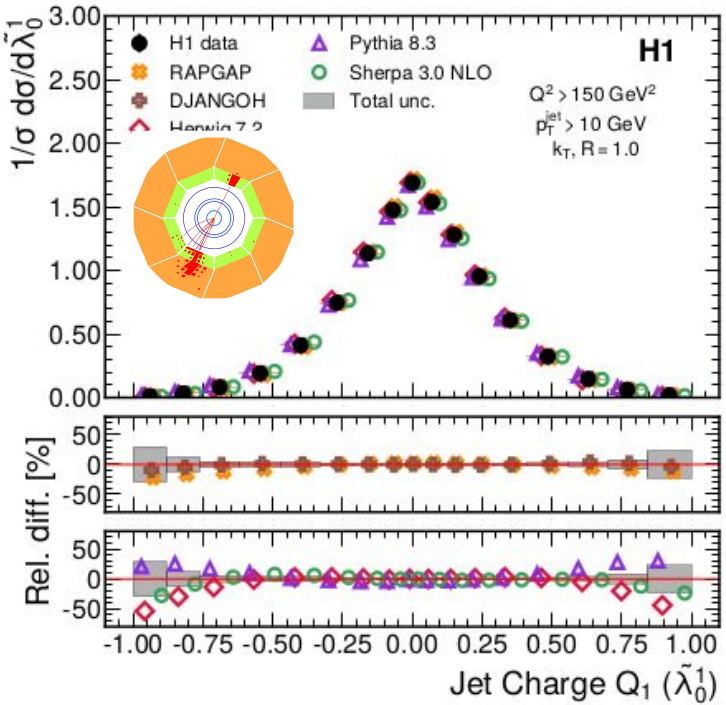
H1 Collaboration, *Phys.Lett.B* 844 (2023) 138101



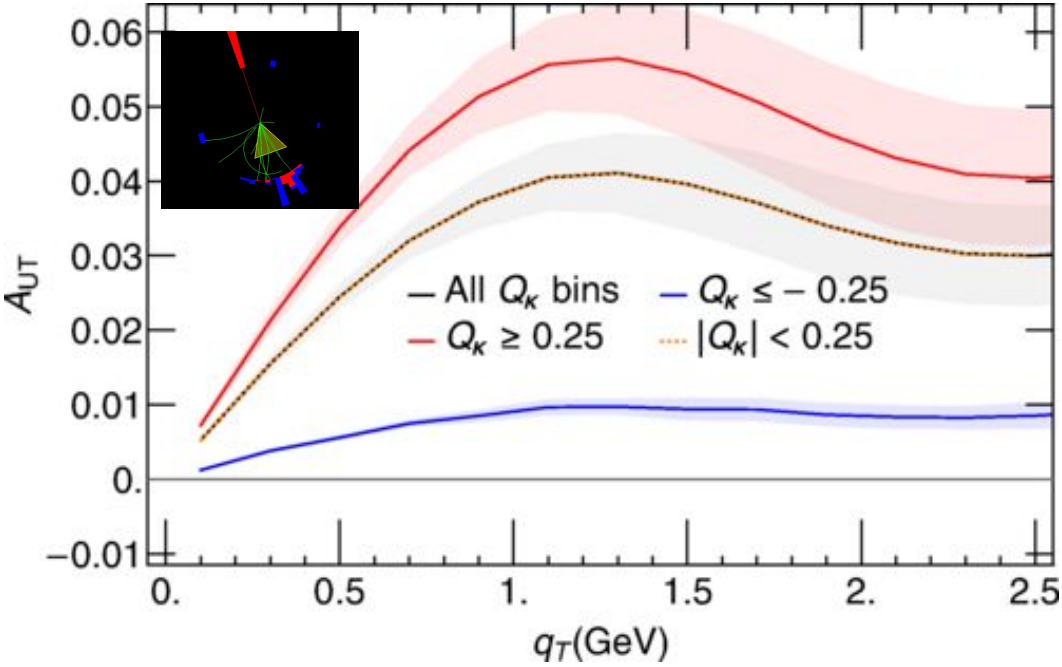


Highlight: Jet charge, “a flavour prism”



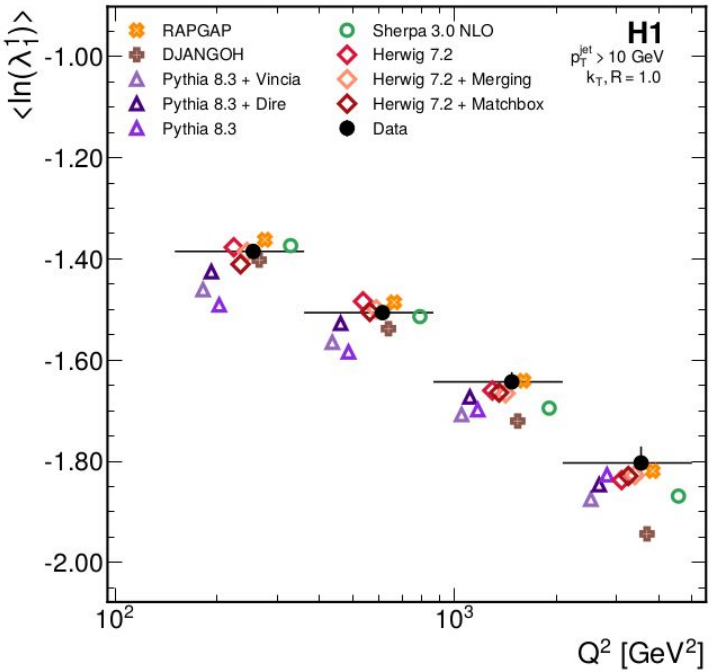


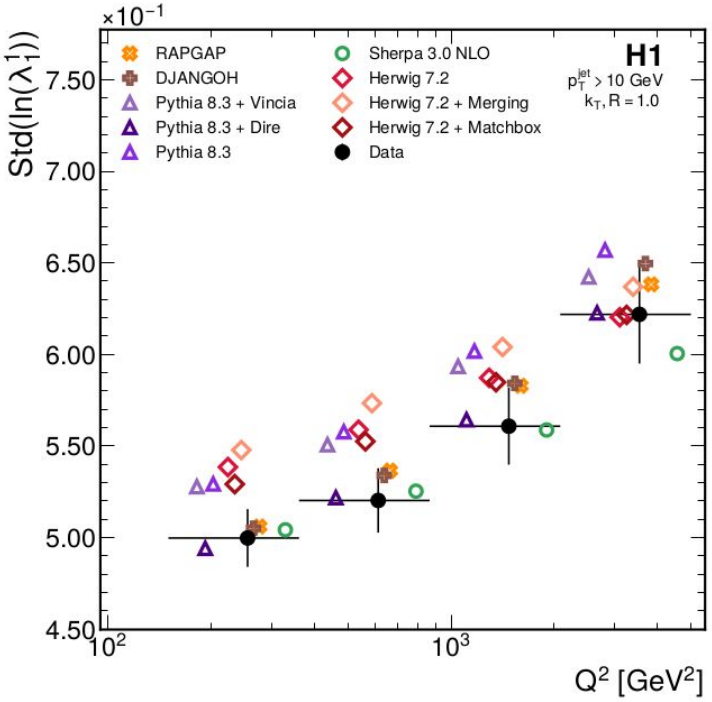
Kang et al. PRL 125, 242003



Q2 evolution of moments of jet substructure in DIS

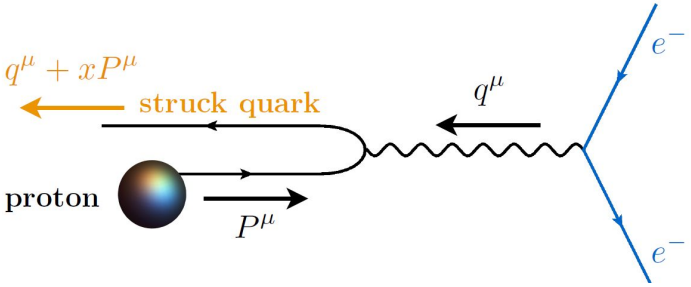
H1 Collaboration, *Phys.Lett.B* 844 (2023) 138101

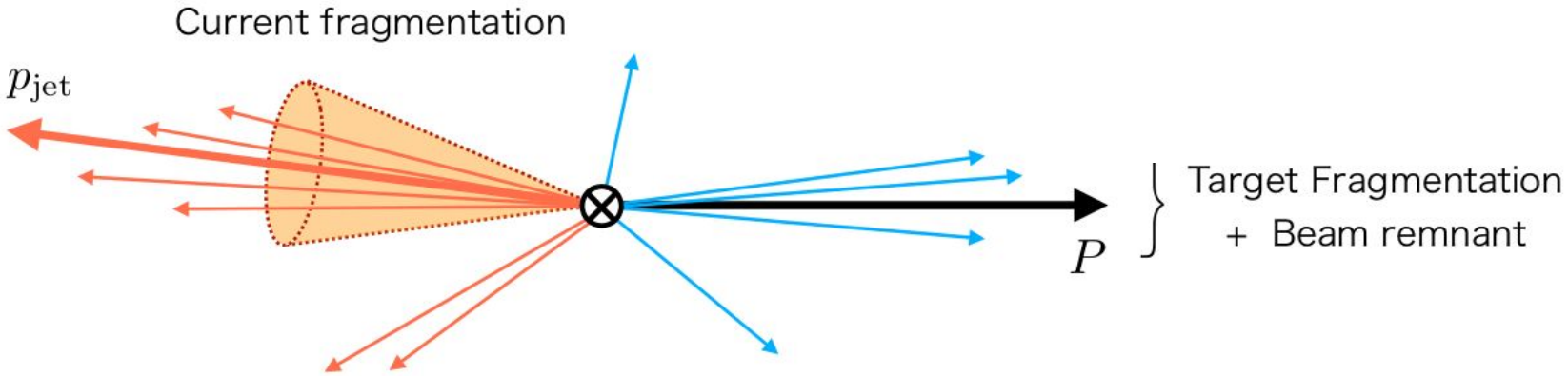




Rigorous test of modern MC generators and parton showers in DIS.
Excellent testing ground for EIC.

Rethinking jets in electron scattering.
How to do clustering in the SIDIS frame?





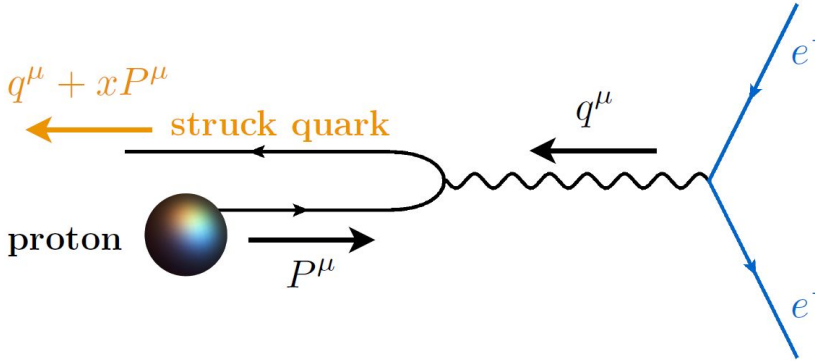
It is not possible to cluster struck-quark jet that goes to y= -∞ with kT family

Centauro Algorithm

M. Arratia et al. PRD 104, 034005 (2021)

$$d_{ij} = \left[(\Delta\bar{\eta}_{ij})^2 + \bar{\eta}_i \bar{\eta}_j (1 - \cos(\Delta\phi_{ij})) \right] / R^2$$

$$\bar{\eta}_i = \frac{p_{\mathrm{T},i}}{n_\mu \cdot p_i}, n_\mu = (1,0,0,1) \quad d_{i,B} = 1$$



- First asymmetric clustering metric ever
- Can cluster struck-quark jet (unlike anti-KT)
- Longitudinally invariant and avoids clustering beam-remnant (like anti-kT)

Recent competition in from arXiv:2408.03129
P. Caucal, E. Iancu, A.Mueller, and F. Yuan.

$$d_{ij} = \frac{M_{ij}^2}{(z_i z_j)^p Q^2 R^2}, \quad d_{iB} = 1,$$

Centauro metric and event shapes in DIS

Chu et al. JHEP 06 (2022) 111
Knobbe et al. JHEP 09 (2023) 194

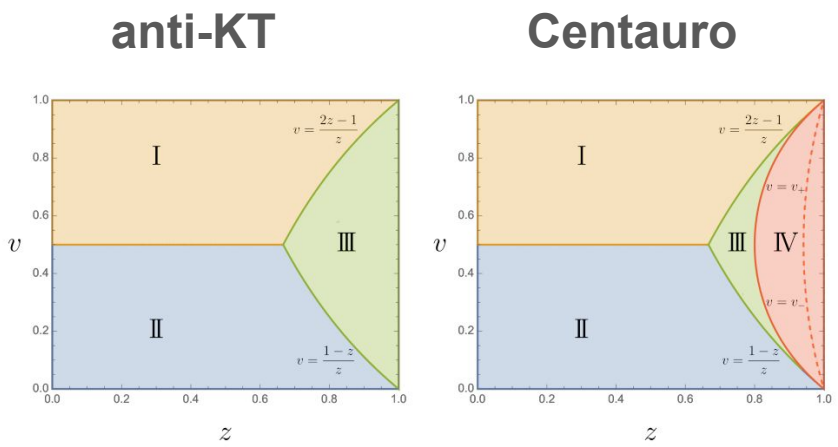
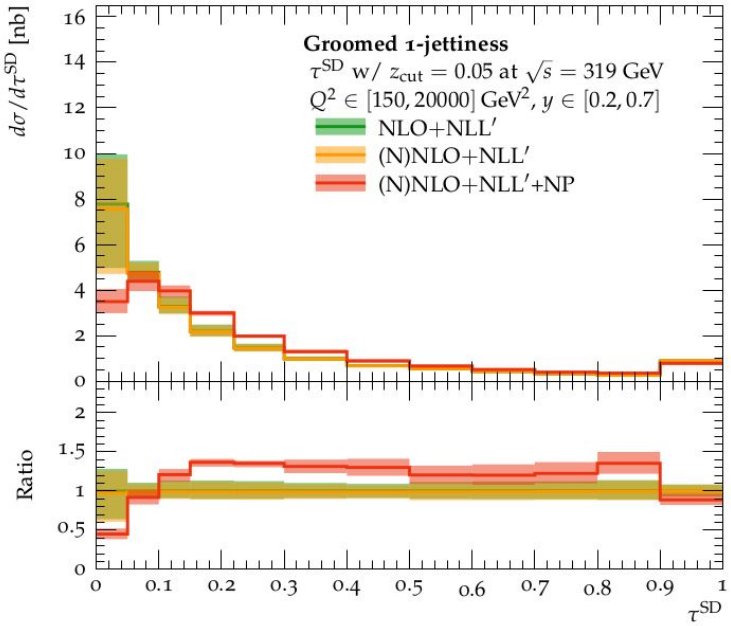
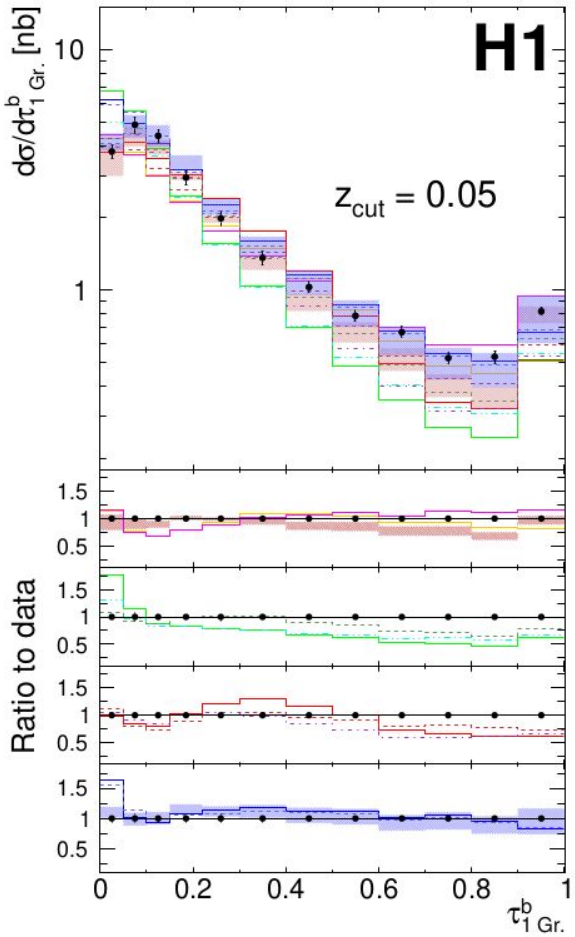


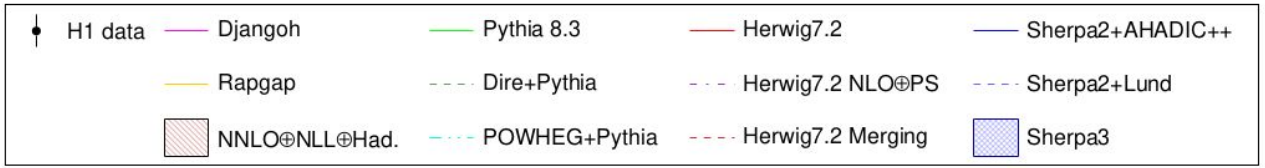
Figure 1. Two-body phase space for 1-jettiness, $\tau^{\mathrm{jt,kt}}$ with jettiness/anti-k_T axis (left) and τ^{ct} with Centauro axis (right). 1-jettiness takes the same expression in first three regions while the fourth region is only for τ^{ct}. The bound of fourth region for jet radius $R = 1$ and 2 is shown in red dashed and red solid, respectively.



Groomed Event shape in DIS using Centauro Metric

H1 Collaboration, Eur.Phys.J.C 84 (2024) 7

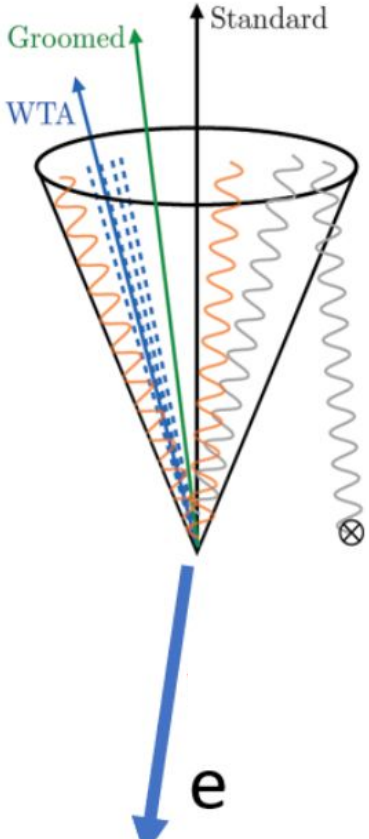


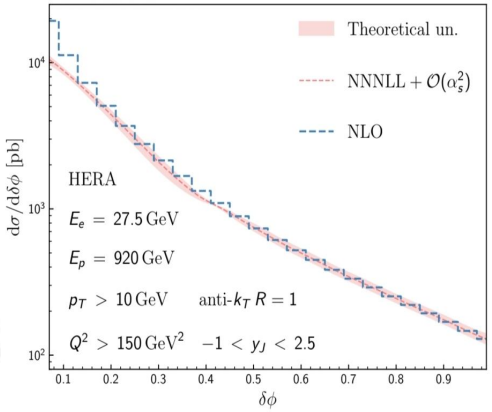


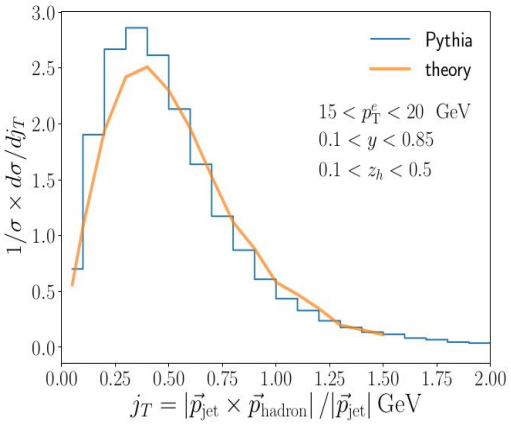
Calculation using Centauro metric

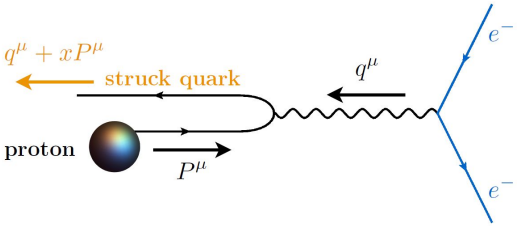
Coming Soon (DIS2025)

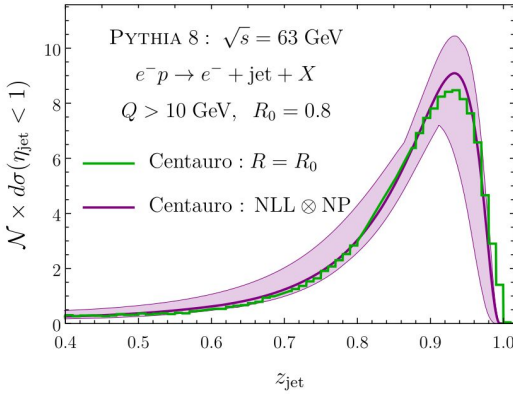
Lepton-jet with recoil-free axis (winner-take all), Centauro jets, jet EEC, and more!



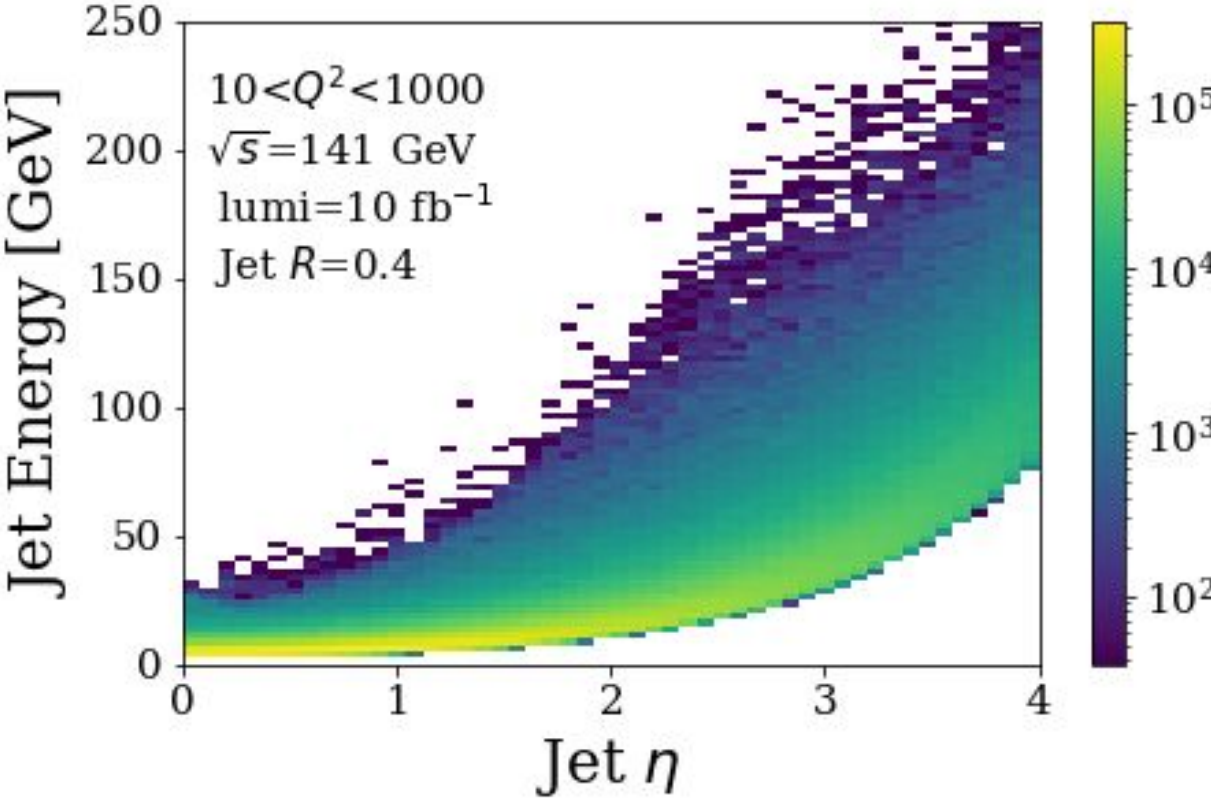


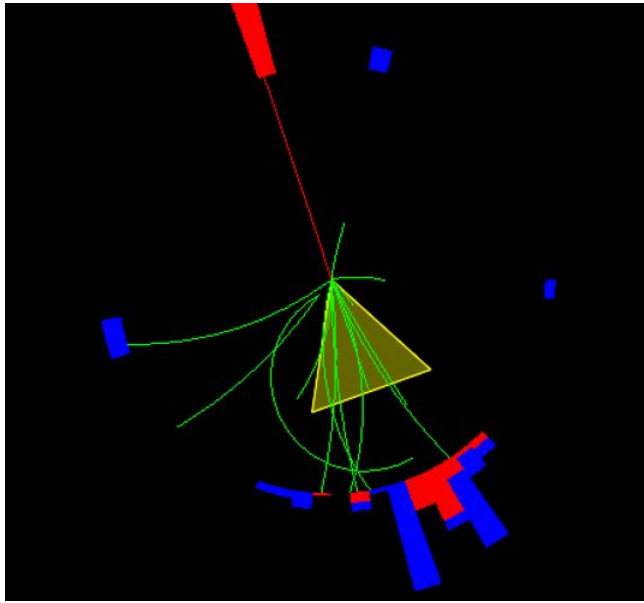






Jet spectra @ EIC

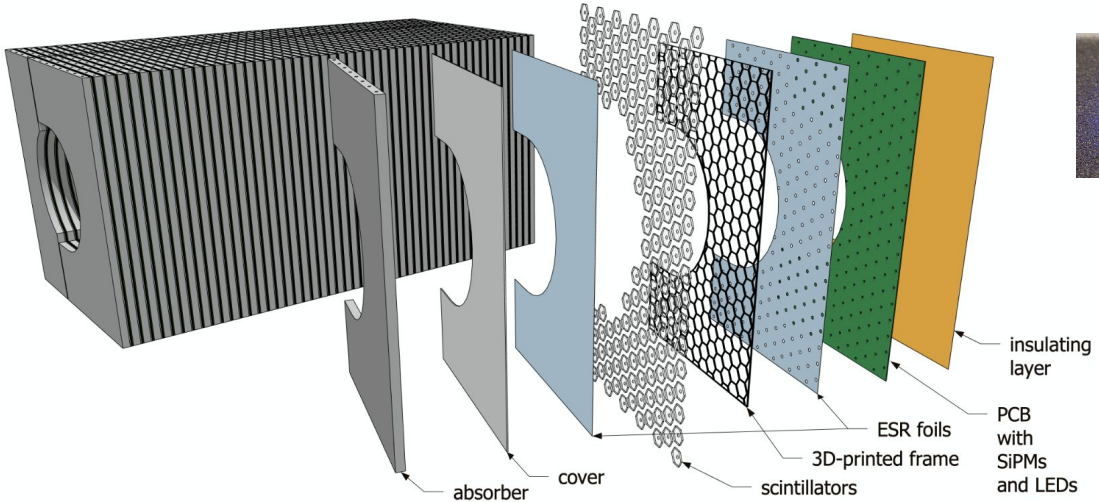


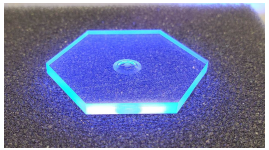


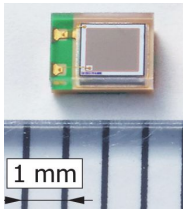
Measuring the highest-energy jets at EIC

High-granularity design for forward jets

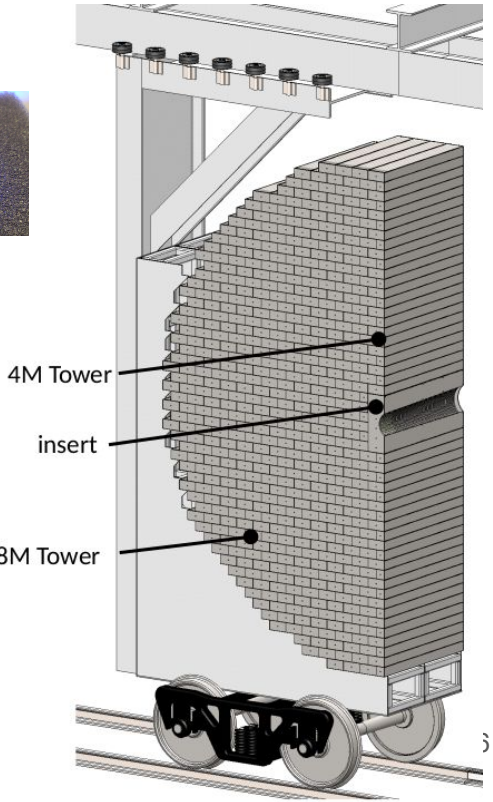
M. Arratia et al. NIMA 1047 (2023) 167866; JINST 18 (2013) P05045; Instruments 2023, 7(4), 43; NIMA 1060 (2024) 169044







Insert is at the heart of forward HCAL **3<η<4**

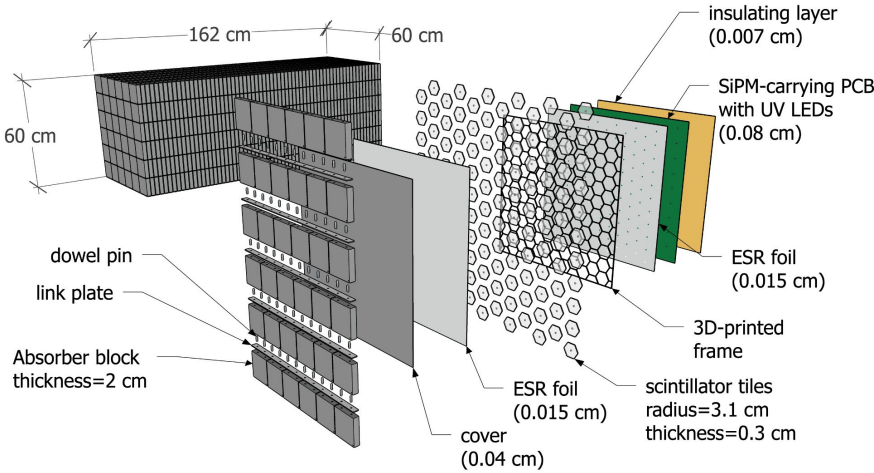


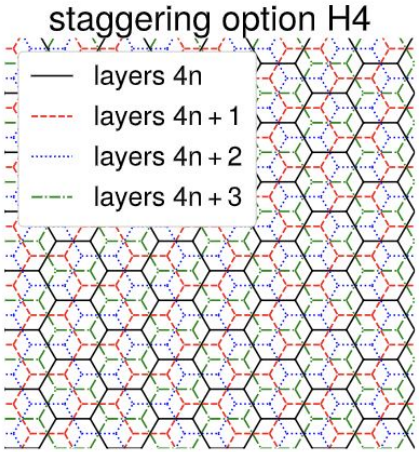
Calorimeter Insert was first EIC detector designed using SiPM-on-tile technology

Now used in many subdetectors, including all of HCAL endcaps

Zero Degree Calorimeter

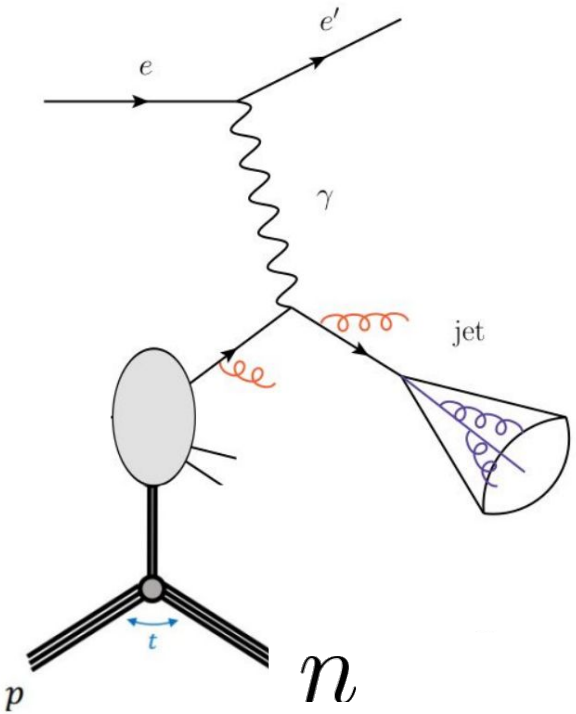
S.Paul & M. Arratia NIMA 1060 (2024) 169044
Milton et al. arXiv:2406.12877

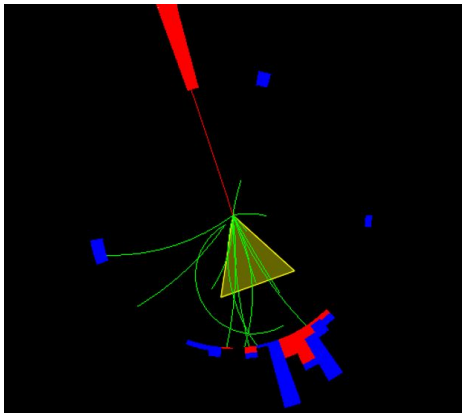




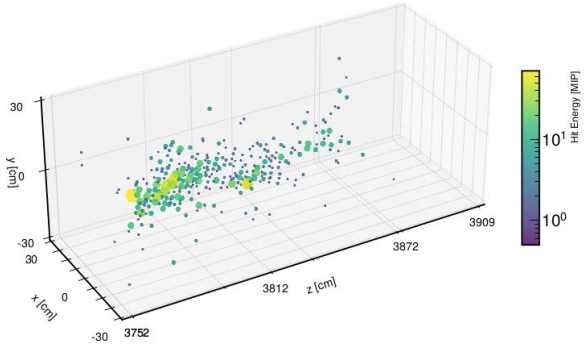
ZDC

Jets in DIS off a Pion target





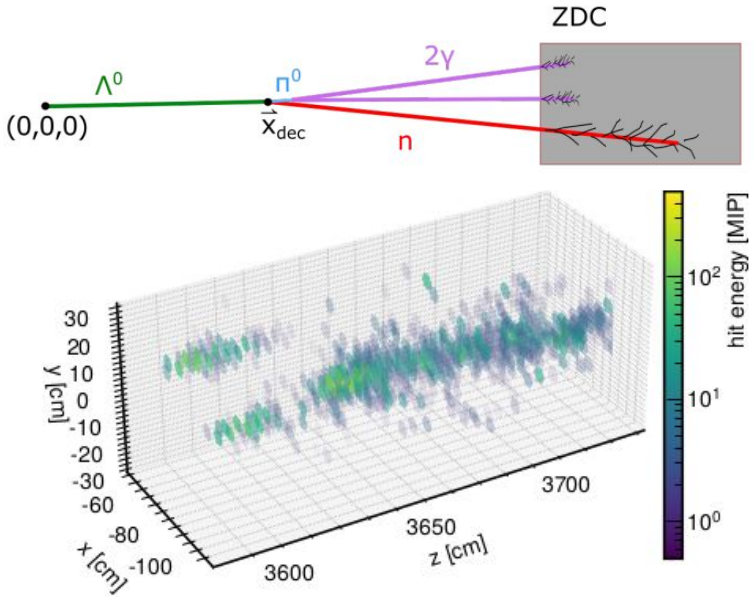
Main detector view

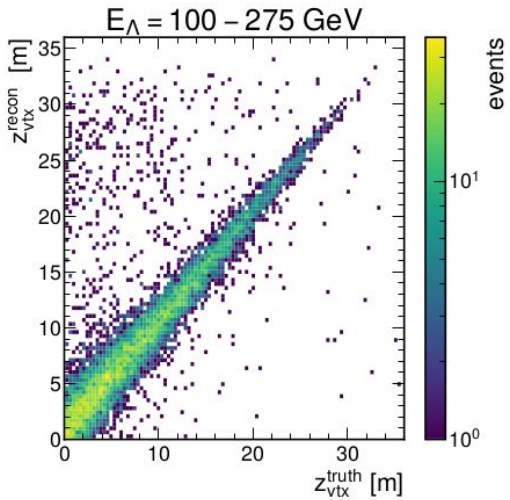


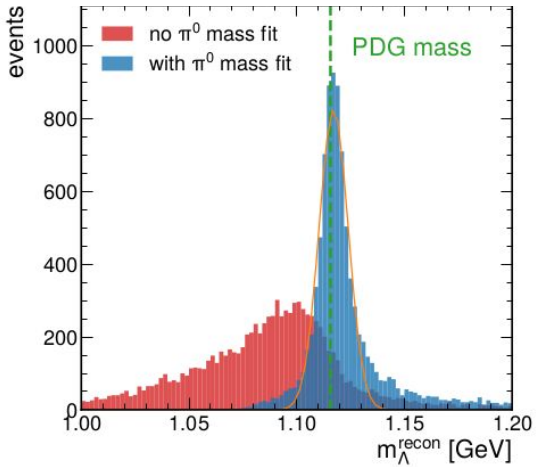
ZDC view

Lambda reconstruction with ZDC

Milton et al. to appear in arXiv:2411:XXXX



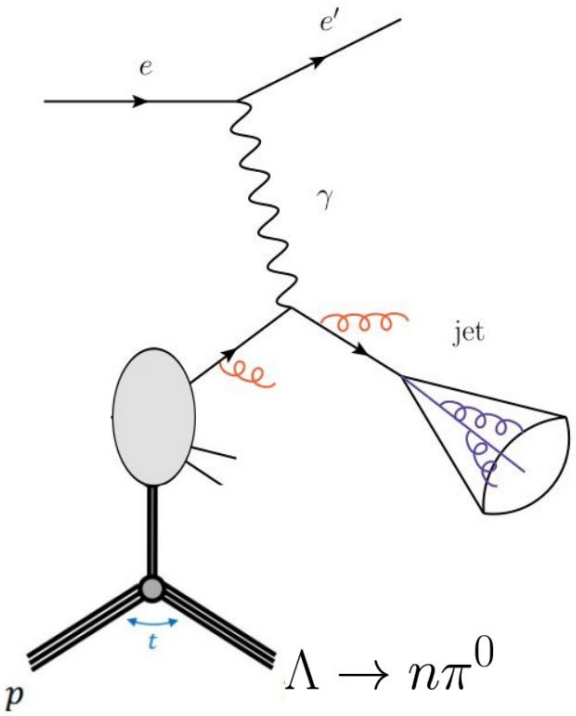


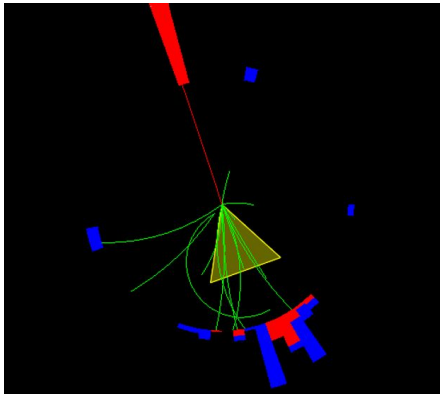


First-time that this channel has been simulated.

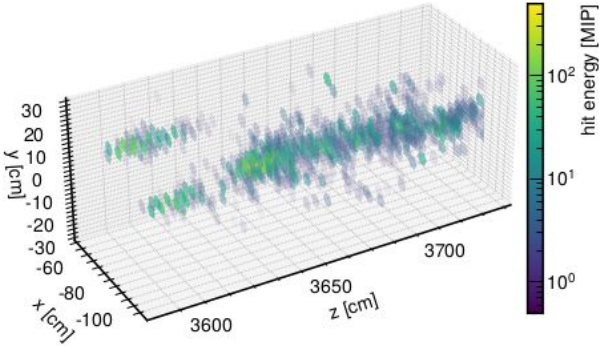
Allows access to high-energy Lambdas, not measurable otherwise in charged-channel

Jets in DIS off a Kaon target





Main detector view

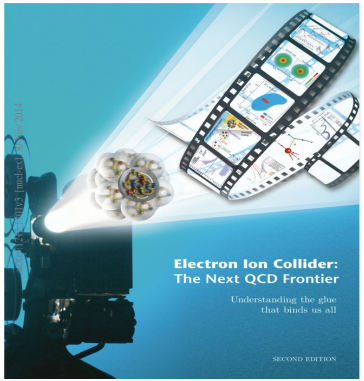


ZDC view

Jets in DIS

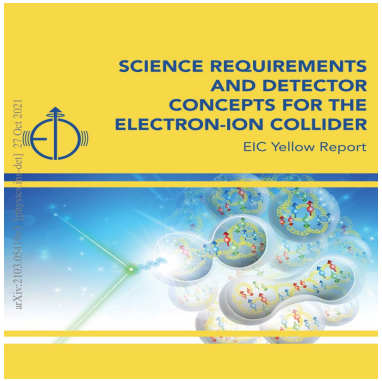
Past

Almost no jet studies



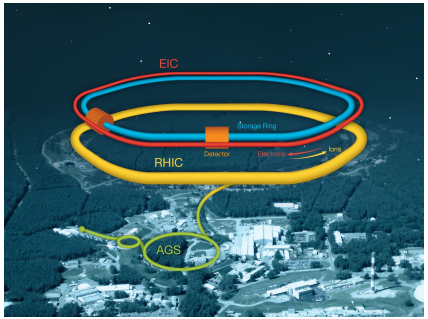
Present

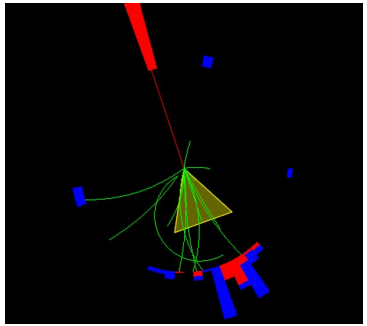
Lots of jets studies

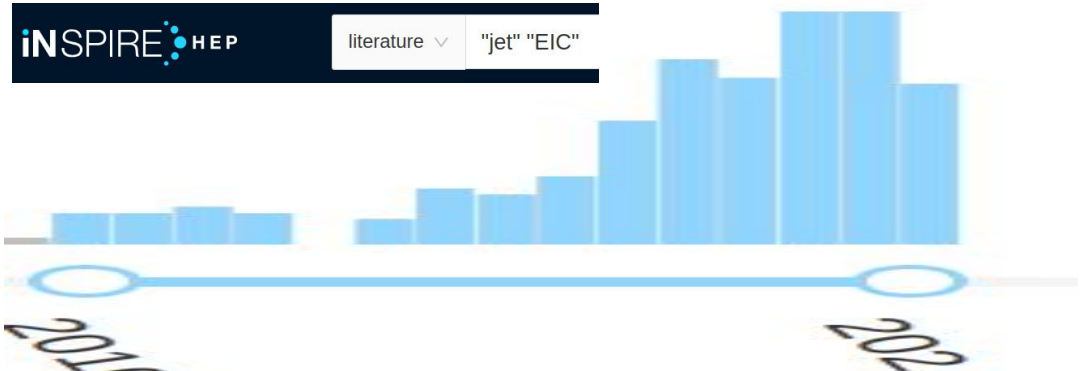


Future:

I'd bet that ~half papers (and discoveries!) will involve jets & related topics like event shapes, correlators, etc.







A glimpse into the jet future

https://youtu.be/XhOxi-YLW1E?si=lqrpG14WoI_sDl5V

https://photos.app.goo.gl/J1cSDc1ogw9C7t1v5