Jets at the Electron-Ion Collider

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Brookhaven National Laboratory

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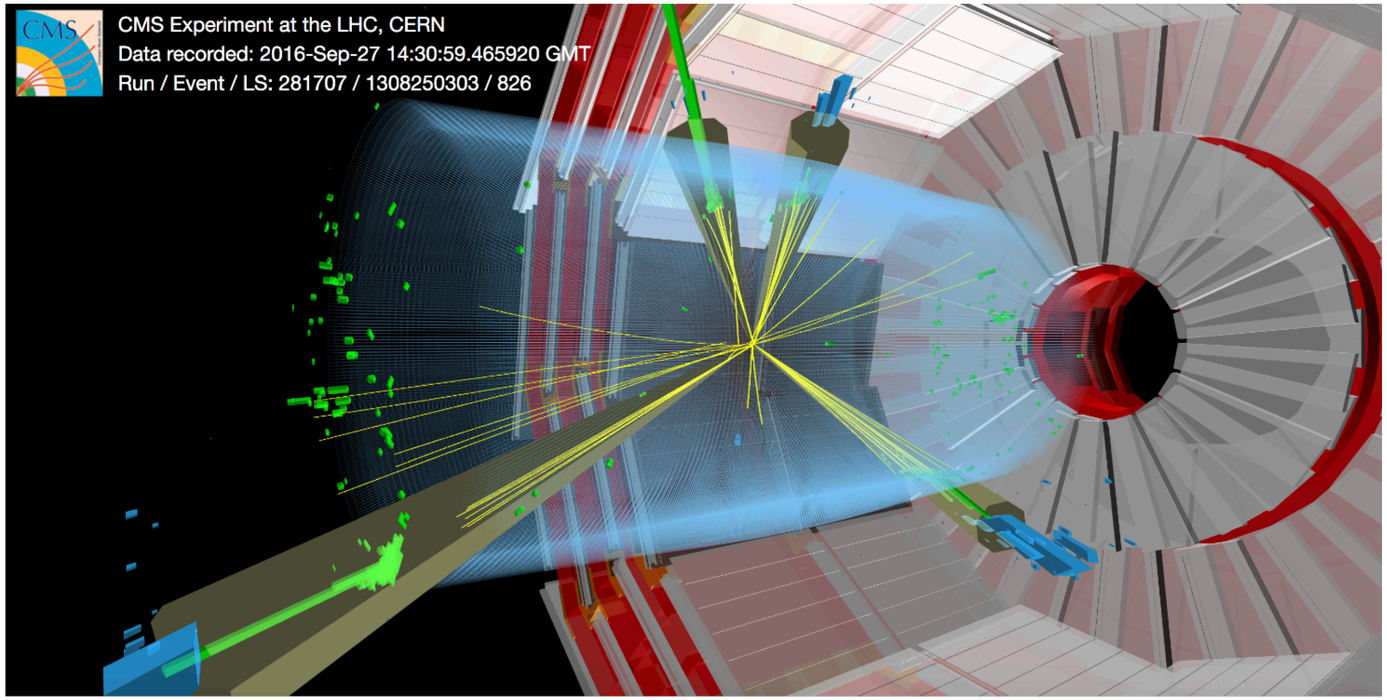
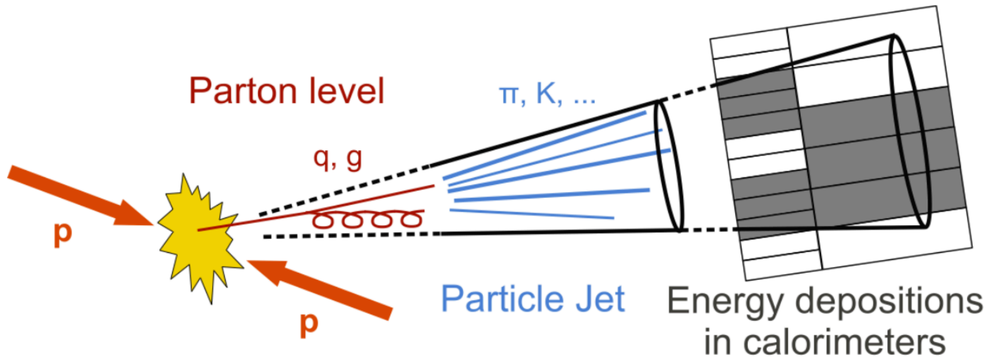
STATE UNIVERSITY OF NEW YORK

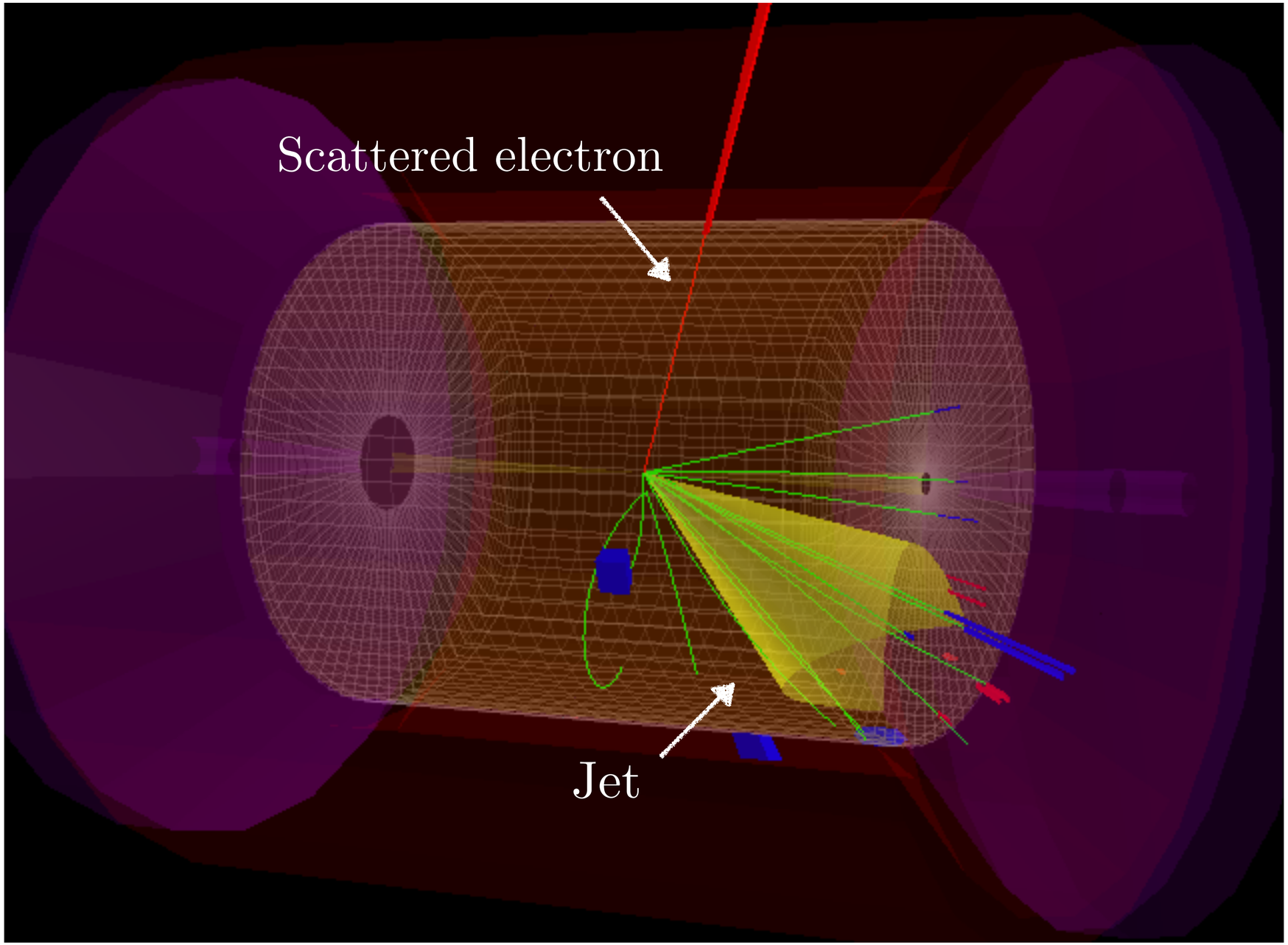
Jets at collider experiments

- Collimated sprays of particles
- Most direct access to high-energy quarks and gluons

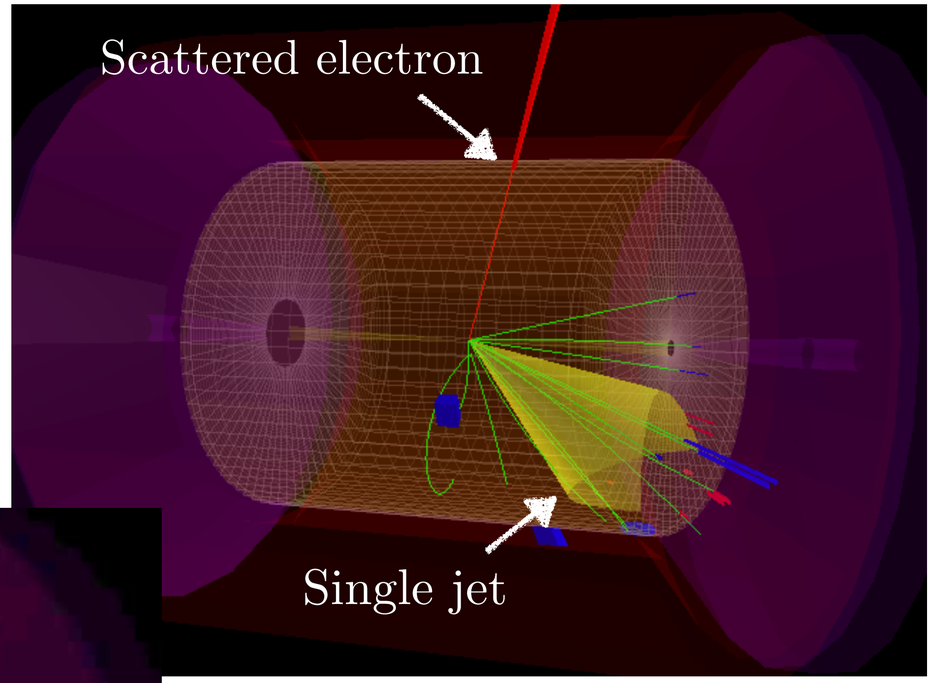


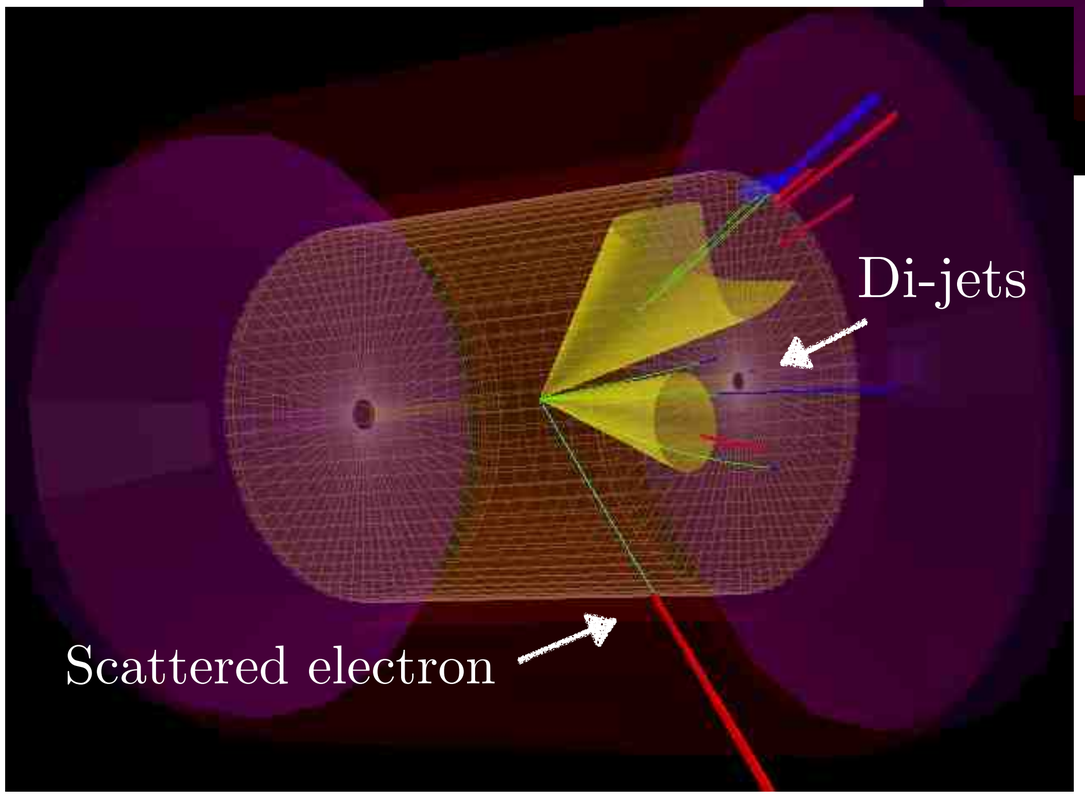


Laboratory frame



Laboratory frame



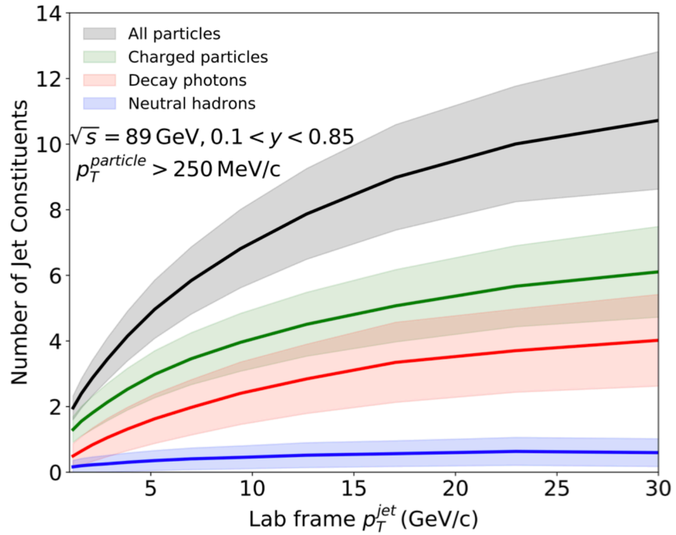


- Cf. proton-proton: jets vs. Z+jet
- Different quark/gluon fractions

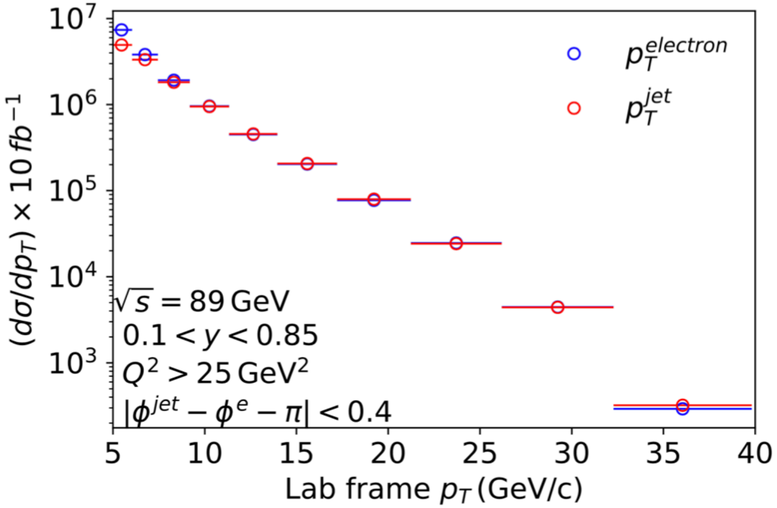
Nature of jets at the EIC

Particle #

Quark-like

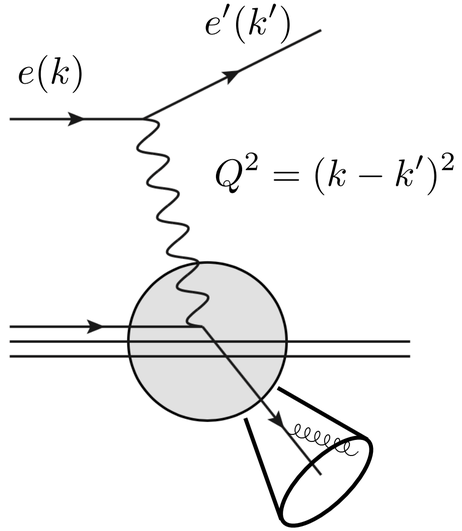


Transverse momentum



Two "natural" hard scales

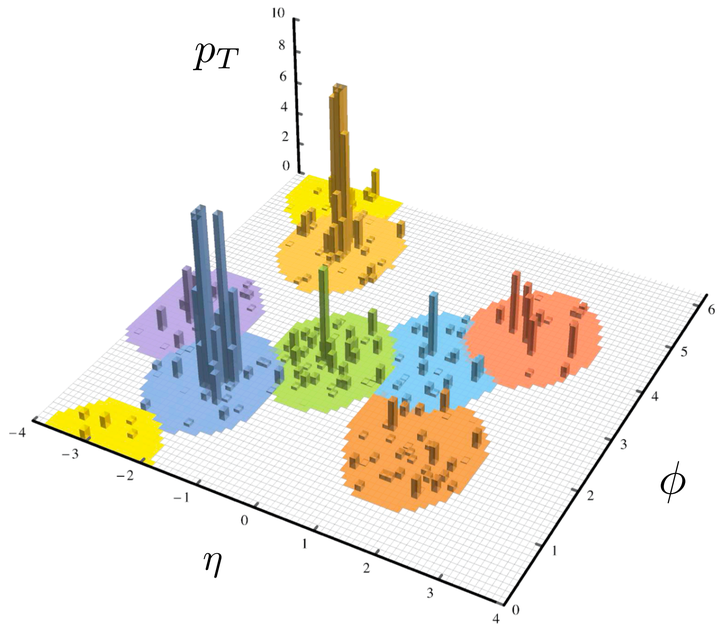
- Jet transverse momentum p_T
- Photon virtuality Q^2

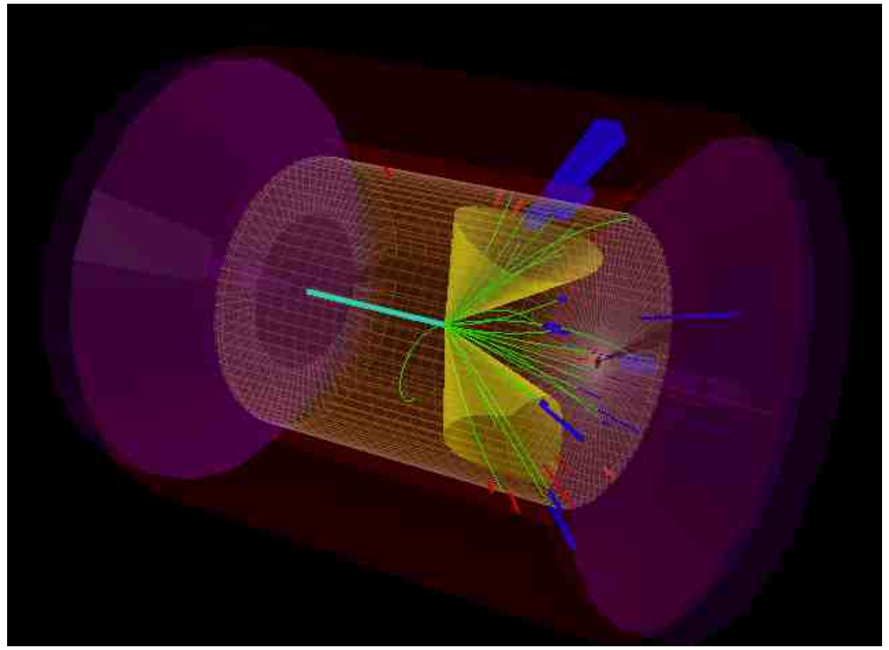


Arratia, Jacak, FR, Song `19
see also Aschenauer et al.

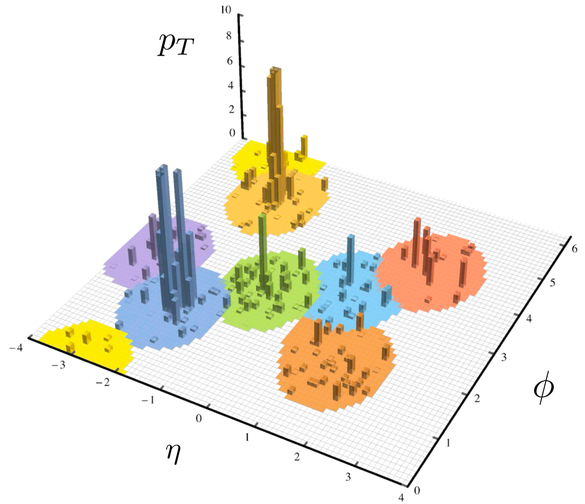
EIC jet physics

- Relevant for hadron structure, cold nuclear matter effects, etc.
- Clean EIC environment
- Jet substructure & correlations
- Versatile jet reconstruction algorithms & frame dependence
- New physics searches





Jet algoritms



k_T type algorithms

Rapidity/azimuth and transverse momentum

$$d_{ij} = \min\left(p_{Ti}^{2p}, p_{Tj}^{2p}\right)(\Delta\eta + \Delta\phi^2)^2/R^2, \quad d_{iB} = p_{Ti}^{2p}$$

Spherically symmetric

Angles and energies

$$d_{ij} = \min\left(E_i^{2p}, E_j^{2p}\right)\theta_{ij}^2/R^2, \quad d_{iB} = E_i^{2p}$$

e^+e^- or Breit frame

ep or pp in the lab frame - clusters the beam remnants into a jet

Jets - Frame & algorithm dependence

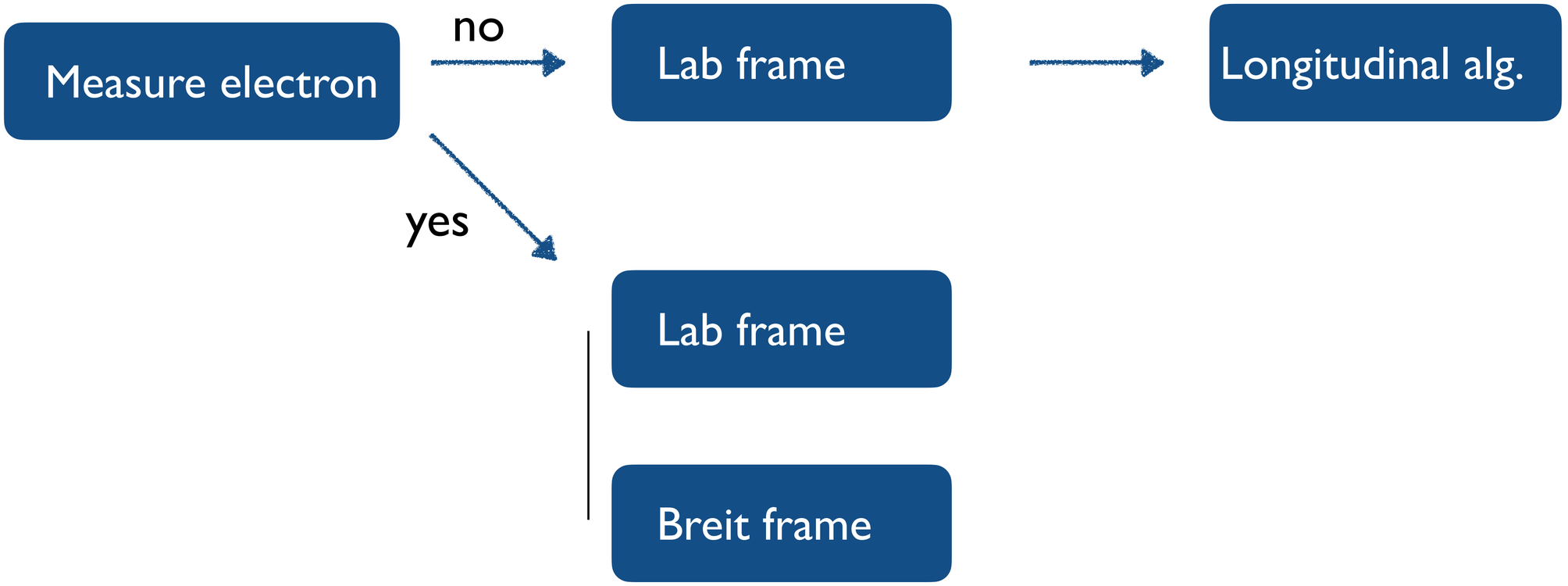
Measure electron → (no) → Lab frame → Longitudinal alg. $\frac{\mathrm{d}\sigma}{\mathrm{d}p_T \mathrm{d}\eta}$

Vogelsang et al., Boughezal, Petriello et al.

Q^2 small or large

see also asymmetric Centauro algorithm Makris et al.

Jets - Frame & algorithm dependence



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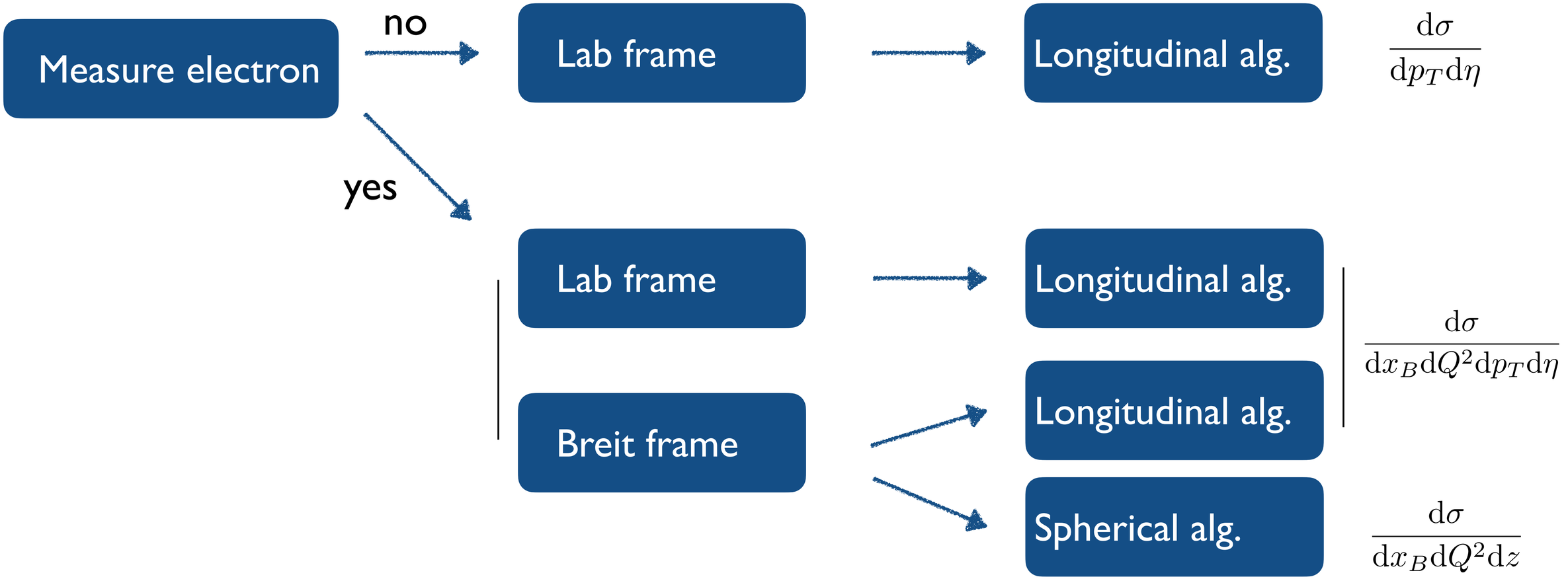


Q^2 small or large

see also asymmetric Centauro algorithm Makris et al.

Algorithm dependence

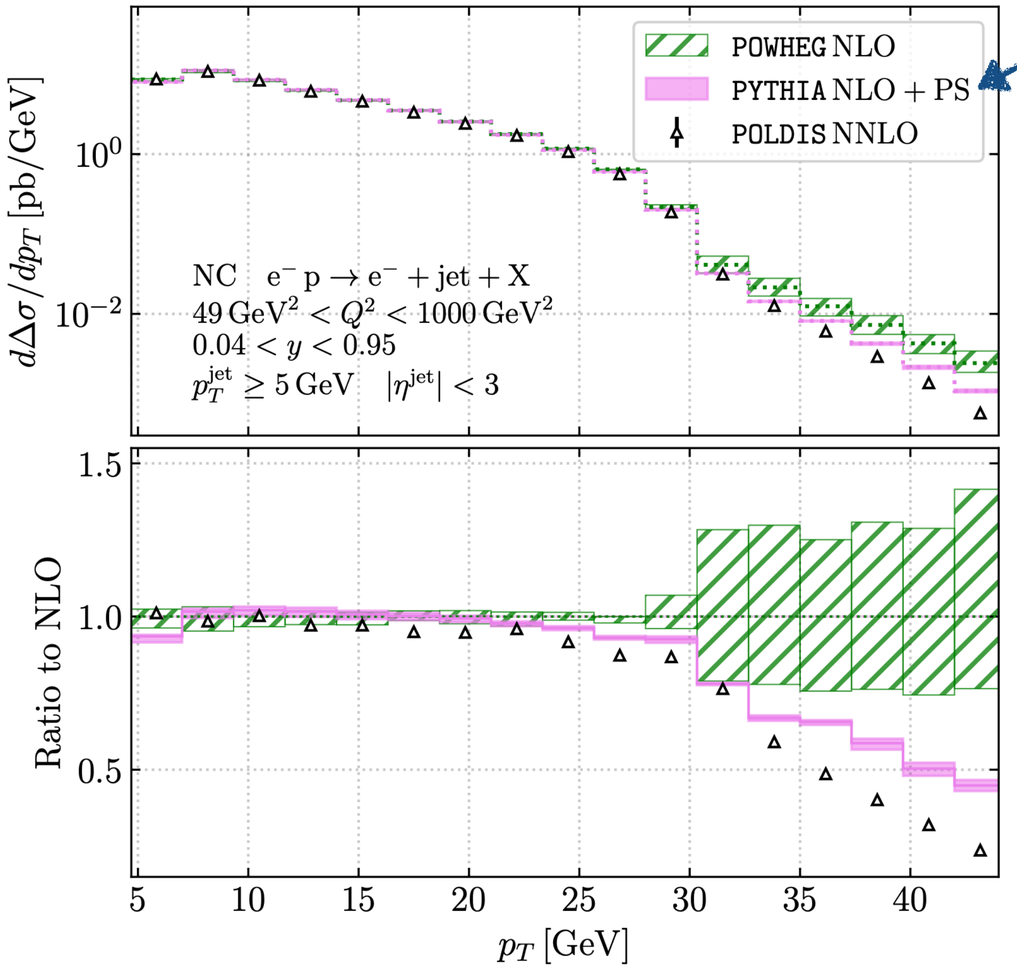
de Florian, Borsa `22
Borsa, Jager `24

Lab frame

Longitudinally invariant algorithm (p_{Ti}, d_{ij})

- NLO matched to parton shower
- Unpolarized and long. polarized
- POWHEG BOX implementation

$$e^-(k_e) + p(k_p) \to \ell(k') + \text{jet}(p_{\text{jet}}) + X$$



Pythia

Significant effects for pol. cross section

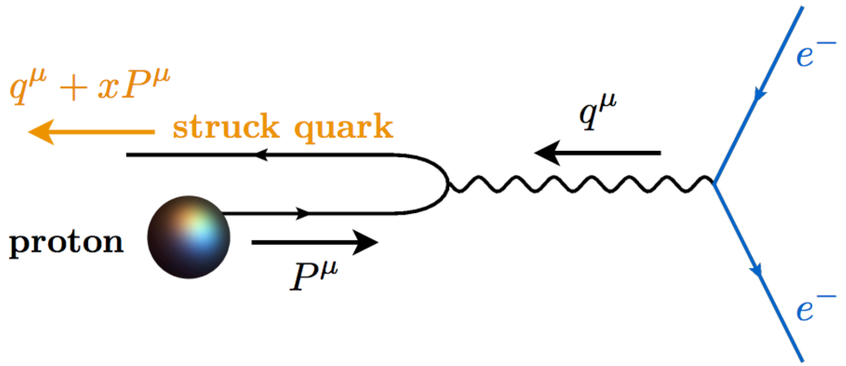
Algorithm dependence

Breit frame

Spherically invariant algorithm (E_i, θ_{ij})

See Arratia, Makris, Neill, FR, Sato `20
Caucal, Iancu, Mueller, Yuan `24

$$\frac{\mathrm{d}\sigma^{\mathrm{SI}}}{\mathrm{d}x_B \mathrm{d}Q^2 \mathrm{d}z} \sim \sum_{ab} f_a \otimes H_{ab} \otimes J_b$$



- Collinear jet function, resummation of $\ln R$
- Particularly useful for jet substructure
- Quark-jets dominate
- A few percent of gluon jets at NLO

Algorithm dependence

Breit frame

Spherically invariant algorithm (E_i, θ_{ij})

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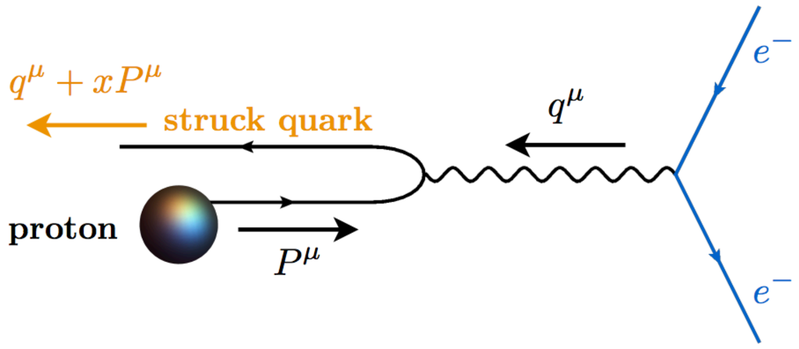
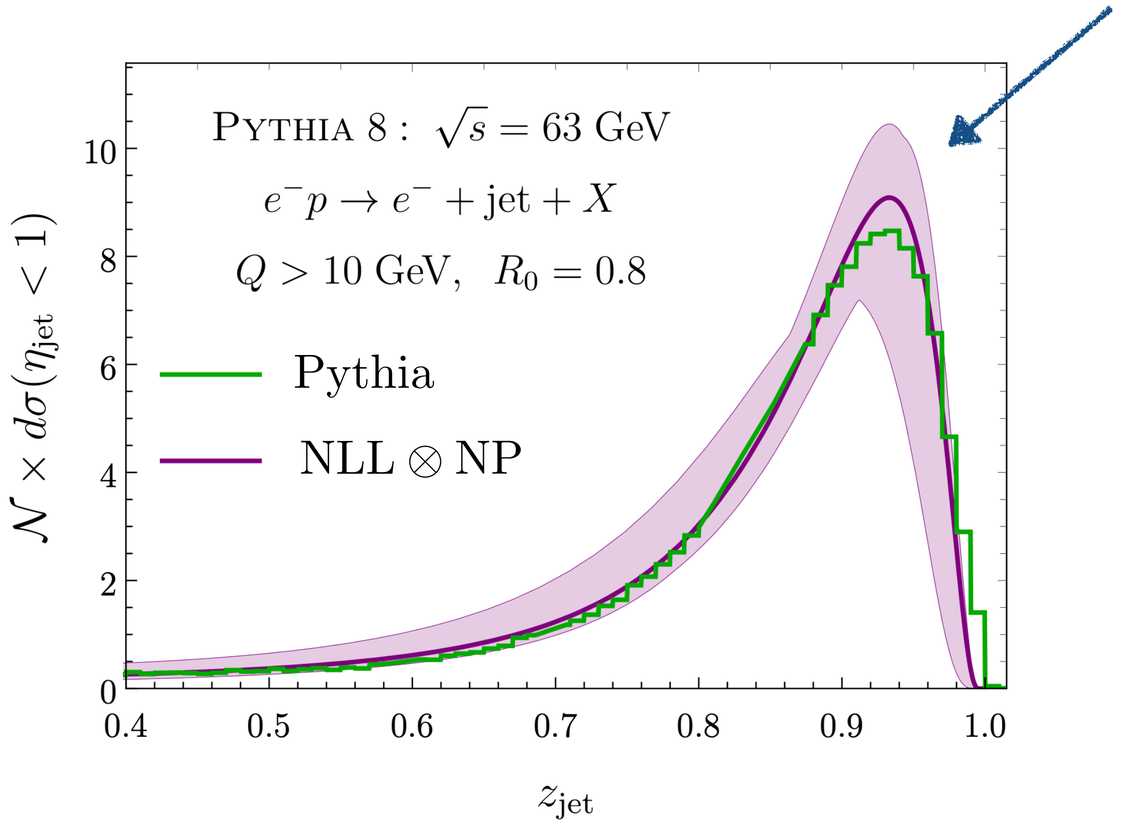
$$\frac{\mathrm{d}\sigma^{\mathrm{SI}}}{\mathrm{d}x_B \mathrm{d}Q^2 \mathrm{d}z} \sim \sum_{ab} f_a \otimes H_{ab} \otimes J_b$$

Requires threshold resummation





- Unpolarized measurement at HERA?

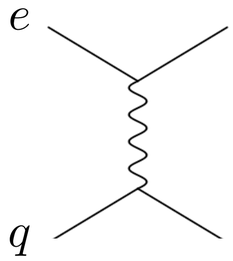
Algorithm dependence

Breit frame

Spherically invariant algorithm (E_i, θ_{ij})

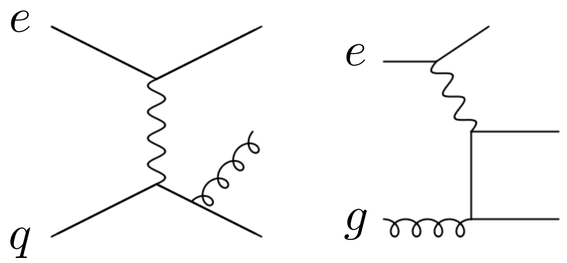
$$\frac{\mathrm{d}\sigma^{\mathrm{SI}}}{\mathrm{d}x_B \mathrm{d}Q^2 \mathrm{d}z} \sim \sum_{ab} f_a \otimes H_{ab} \otimes J_b$$

Leading order



Longitudinally invariant algorithm $(p_{Ti}, \Delta\eta + \Delta\phi)$

$$\frac{\mathrm{d}\sigma^{\mathrm{LI}}}{\mathrm{d}x_B \mathrm{d}Q^2 \mathrm{d}p_T \mathrm{d}\eta} \sim \sum_{ab} f_a \otimes \tilde{H}_{ab} \otimes J_b$$

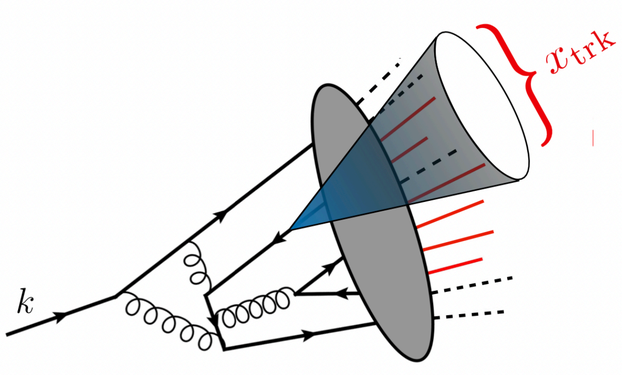


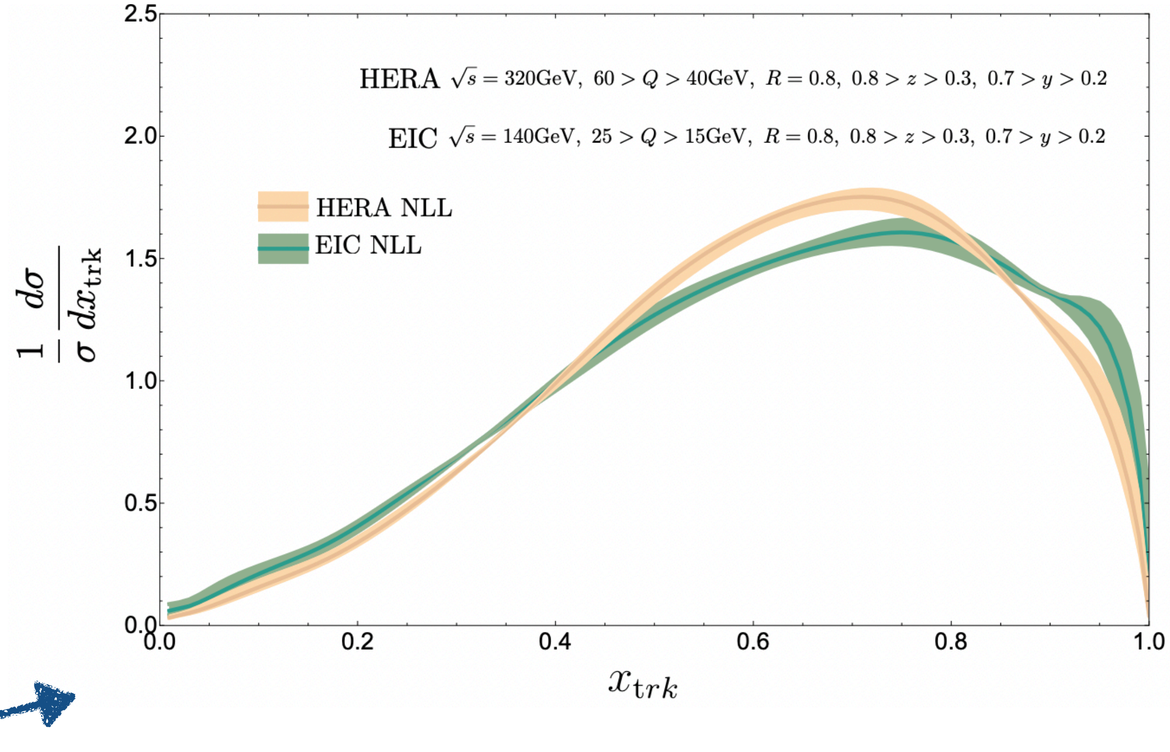
- Expect significant fraction of gluon jets
- Add jet substructure

Jet substructure

Krohn, Schwartz, Lin, Waalewijn `12
Lee, Moult, FR, Waalewijn `23

- Charged particle momentum fraction of the jet
- EIC can constrain flavor dependence of track functions

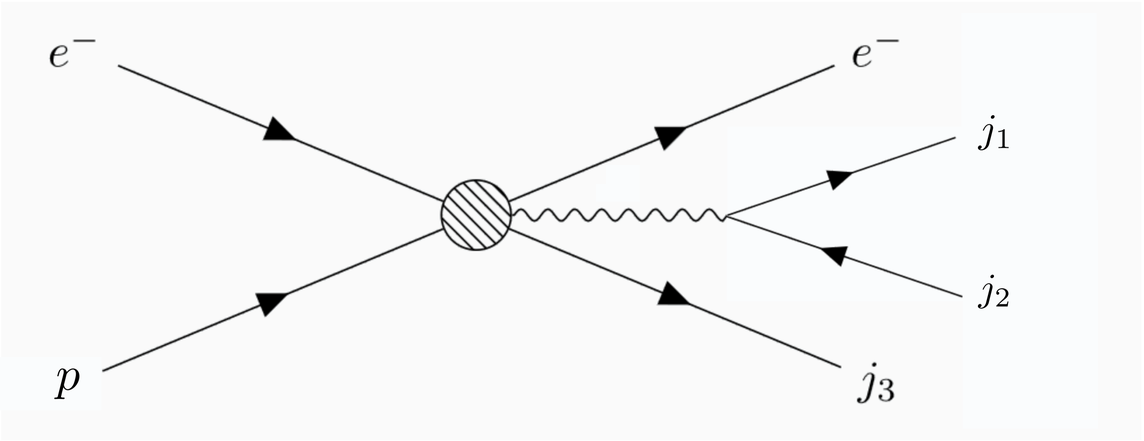




Small QCD scale uncertainty

New physics searches with jets

- Consider an exemplary BSM signal
- B-L model, Z'_{B-L} from gauged $U(1)_{B-L}$
- Constraints in the low-mass region within reach of the EIC
- Electron + 3 jet signal (hadronic decay)

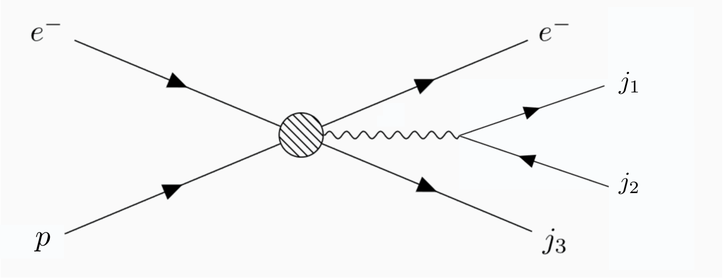


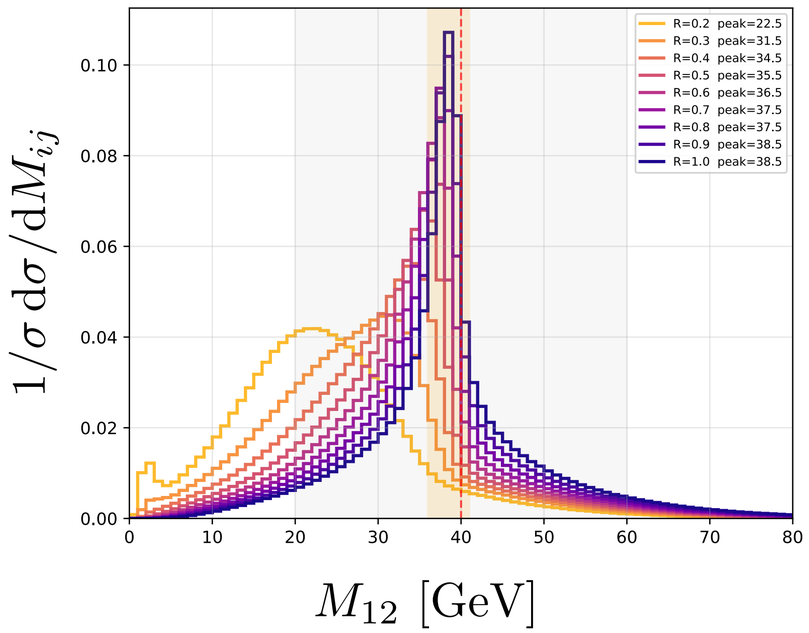
$$\mathcal{L}_{\text{int}} = g_{B-L} Z'_\mu J^\mu_{B-L} \quad \text{with} \quad J^\mu_{B-L} = \sum_f Q^f_{B-L} \bar{f} \gamma^\mu f$$

Athanasakos, Grieninger, Liu, Mangan, FR, Szafron - in preparation

New physics searches with jets

- B-L model, Z'_{B-L} from gauged $U(1)_{B-L}$
- Signal cross section for $m_{Z'} = 40$ GeV





← Different jet radii R

← Only large-R jets align $M_{12} \sim m_{Z'}$

Athanasakos, Grieninger, Liu, Mangan, FR, Szafron - in preparation

New physics searches with jets

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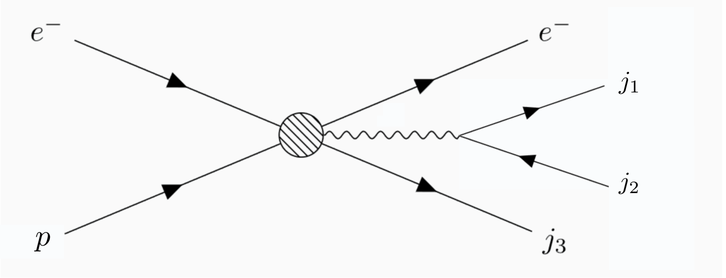
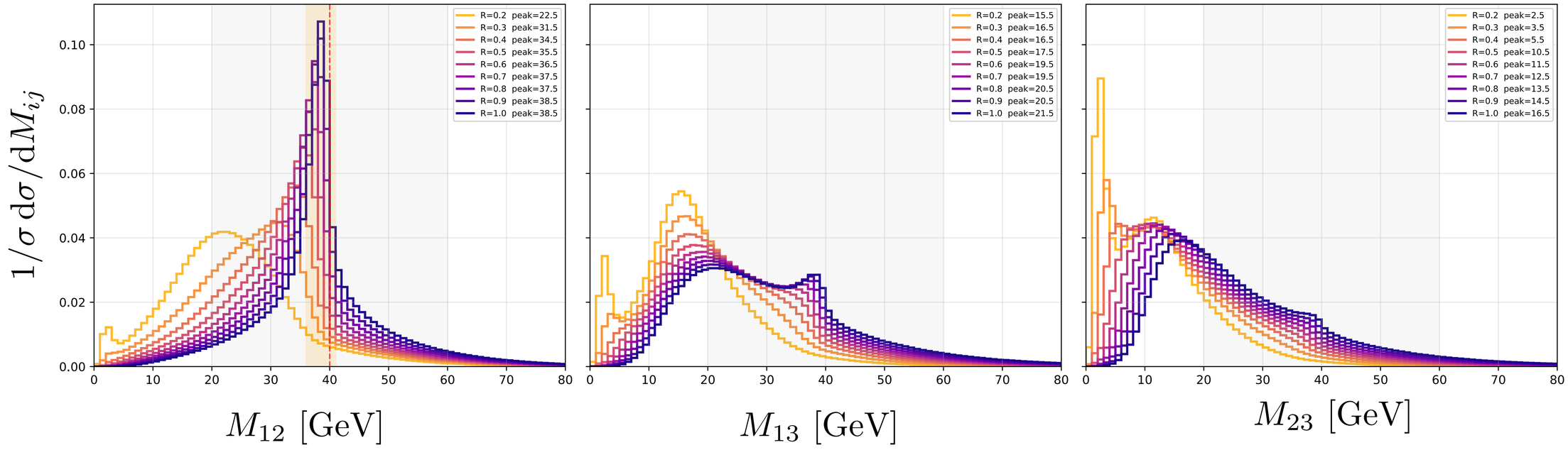




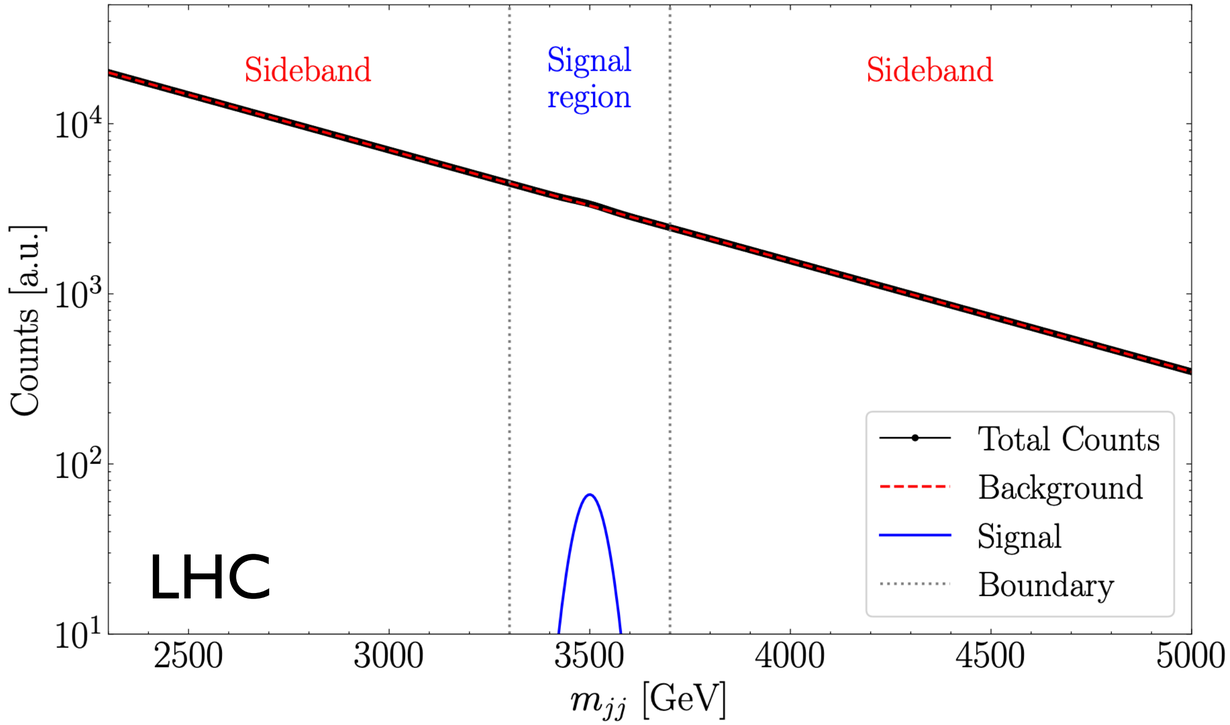
→ Use full event information!

Athanasakos, Grieninger, Liu, Mangan, FR, Szafron - in preparation

New physics searches with jets

- Signal + background
- Use full event information
- Train classifier on data vs. signal-free background events
- Use conditional generative model trained on sideband regions

See e.g. Nachman, Mikuni, Thaler, Plehn et al.



→ Enhance signal sensitivity

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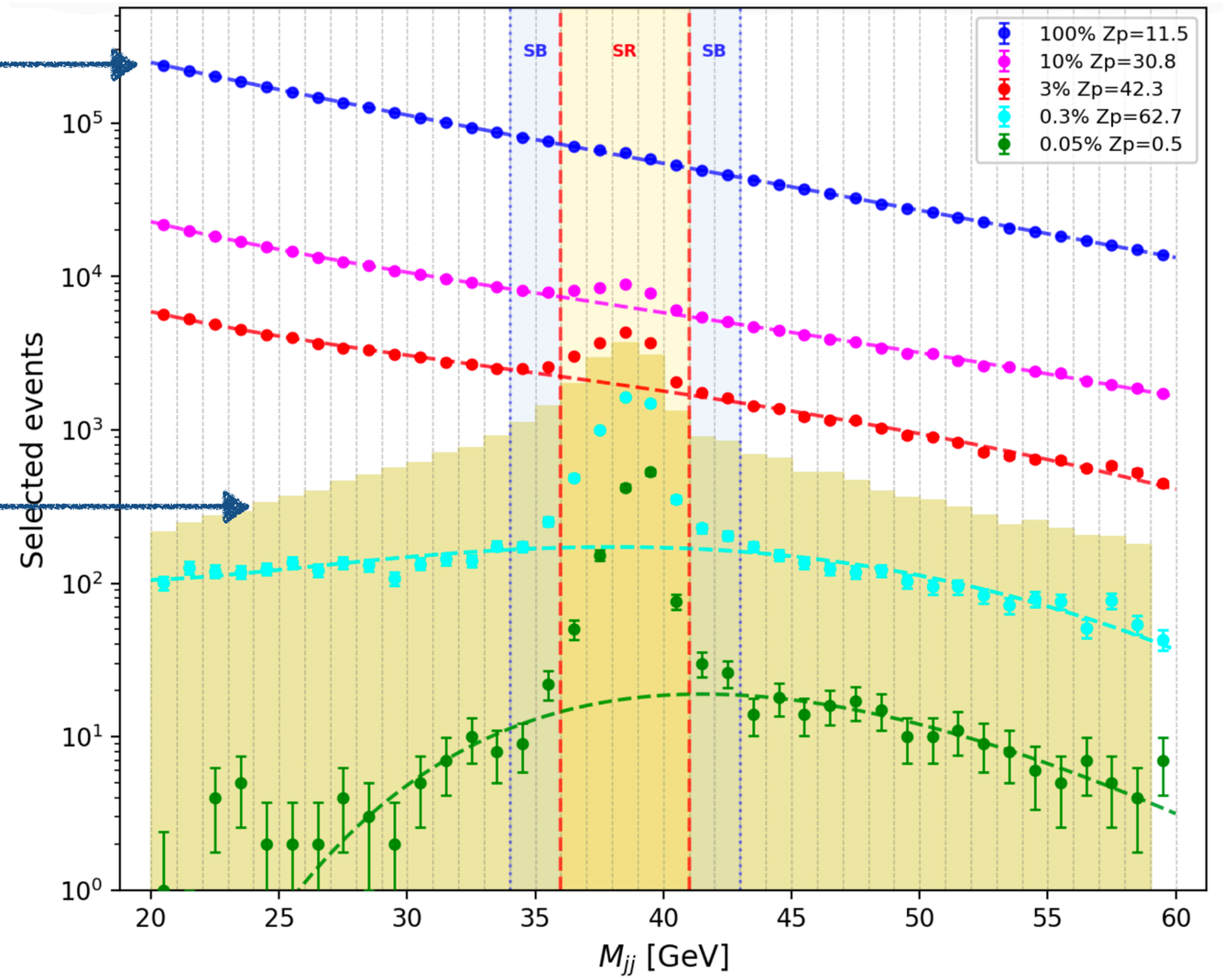
New physics searches with jets

Signal + background

Signal



$S/B = 0.04$

Preliminary

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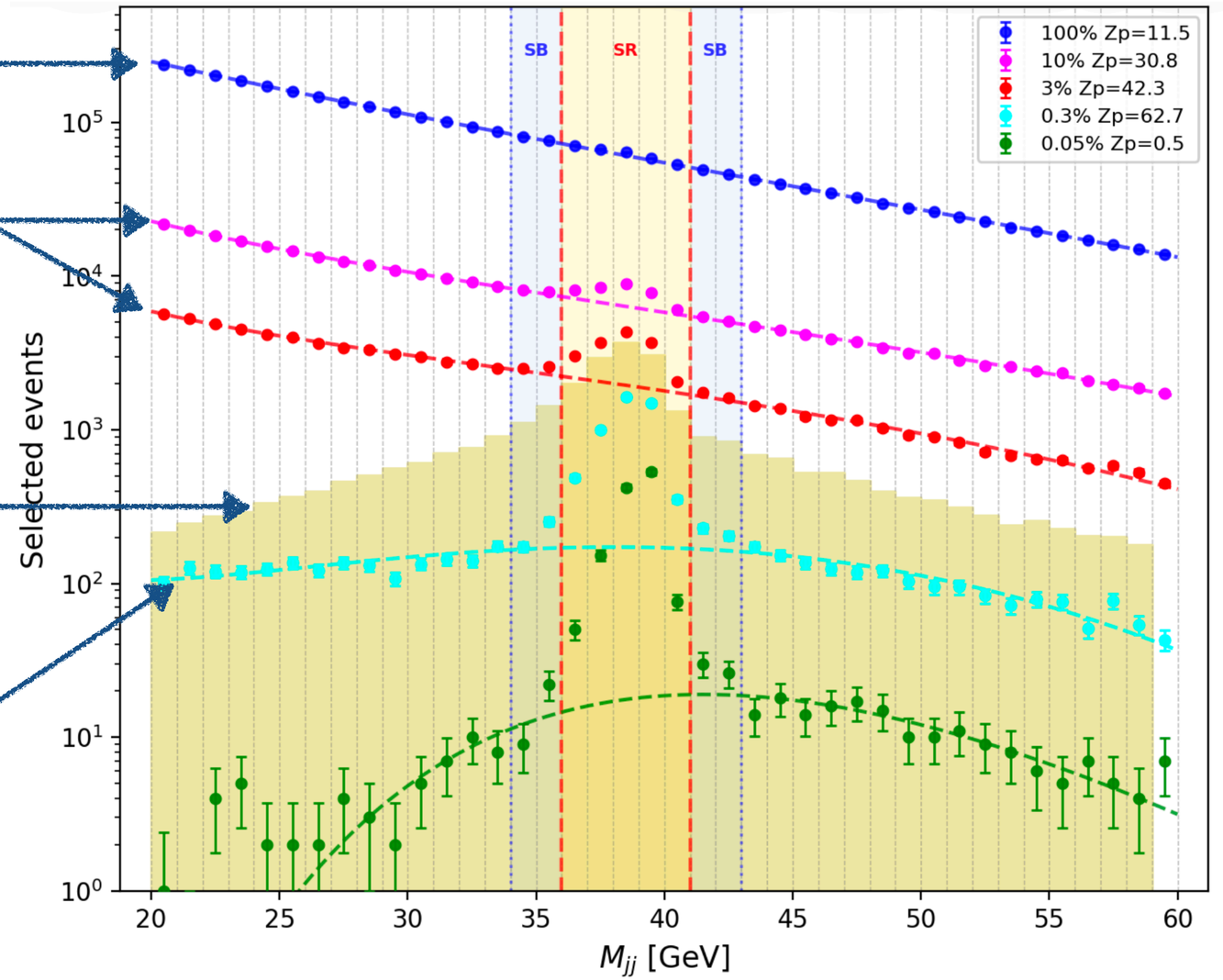
New physics searches with jets

Signal + background

Additional cut on classifier output

Signal

Dashed: Fits excluding the signal region



$S/B = 0.04$

Preliminary

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Summary

- Jets will be versatile tools at the EIC
- Algorithm and frame dependence
- Clean environment at the EIC
- More quantitative studies of hadron structure, TMDs, CNM, etc.
- Enable new physics searches