An experimental overview of jet physics with the ECCE detector at the EIC

Forward QCD: open questions and future directions
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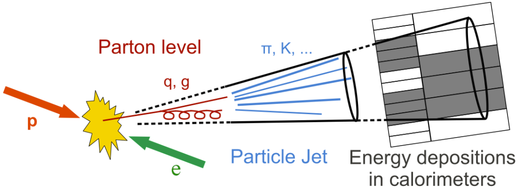
Motivation and Basics for Jets

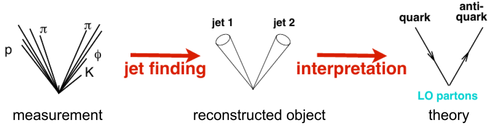
Jet advantages:

- Superior **proxies for parton kinematics** compared to single particles
- Minimize hadronization uncertainties
- **Jet substructure** gives access to a wide variety of physics at the EIC
  $\rightarrow$ e.g. fragmentation/hadronization + interplay

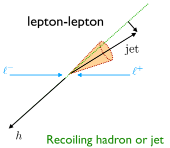
Jet ingredients:

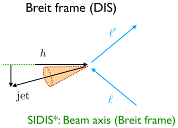
- **Jet finding algorithm** (centauro, (anti)-k_T, ...)
  $\rightarrow$ choice depends on physics
- Reconstructed charged particle tracks and energy deposits in calorimeters
  $\rightarrow$ good energy and angular resolution critical
- **Underlying event (UE) subtraction** necessary
  $\rightarrow$ various approaches: toward/transverse/away, transverse-cone, ...
  $\rightarrow$ very small underlying event at EIC (small effect from ISR/FSR on UE)



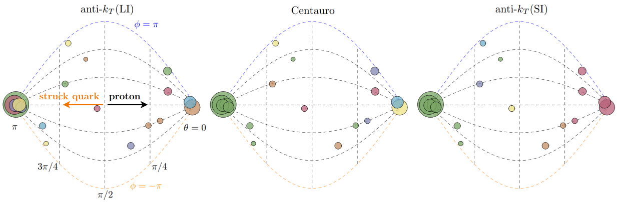


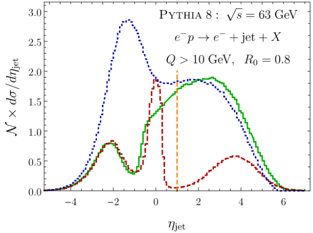
Ingredients: Jet Finders - Centauro

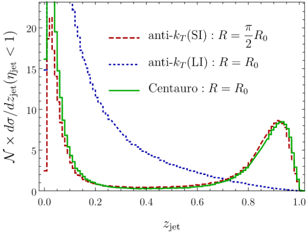




- k_{T}**-type algorithms** perform clustering in $y - \phi$ plane
  $\rightarrow$ longitudinally invariant algorithm
  $\rightarrow$ **can not form a jet around beam axis (**$y = \inf$**)**
- **Centauro algorithm** clusters in Breit frame
  $\rightarrow$ designed to be **invariant along** z **axis and spherically invariant in backward hemisphere**
  $\rightarrow$ optimized to study energetic jets with low p_{T} in DIS
  $\rightarrow$ provides relevant input for jet spectra, substruture, quark TMDs, spin physics, and cold-nuclear matter effects at the EIC
  $\rightarrow$ allows to see leading struck quark and its fragments



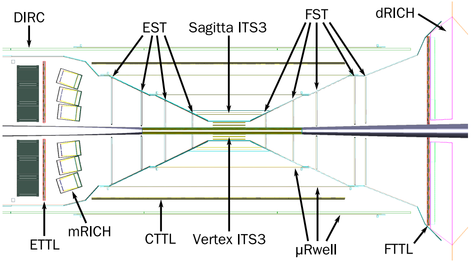




Ingredients: ECCE tracking and PID

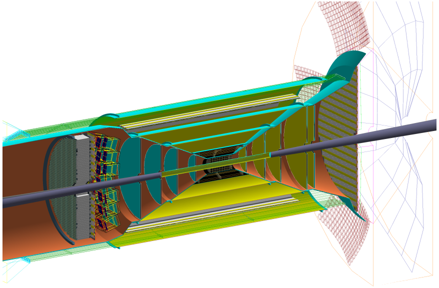
Tracker Design:

- ITS-3 type **MAPS technology** in barrel (3 vertex, 2 sagitta layers) and for forward/backward disks
  → very low material budget (EST, BST, FST)
- μ**RWELL technology** in barrel (3 layers)
- **AC-LGAD tracking/timing layers** in barrel and forward/backward (ETTL, CTTL, FTTL)
- **AI optimized design**

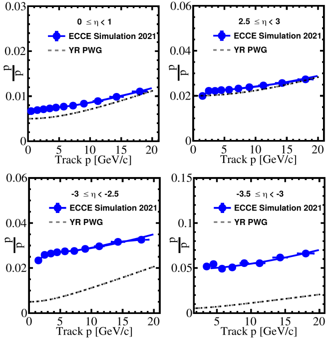


PID Detectors:

- π/K separation with:
  → AC-LGAD timing layers in barrel and forward/backward
  → mRICH (backward), dRICH (forward)
  → DIRC (barrel)
- e/π with calorimeters using shower shape and E/p

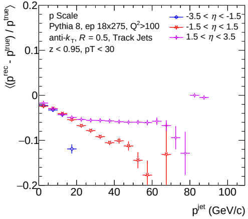


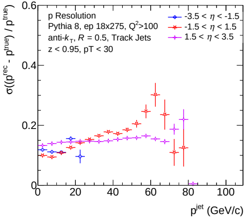
Ingredients: ECCE tracking and PID - 2

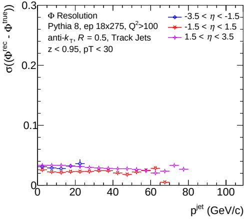


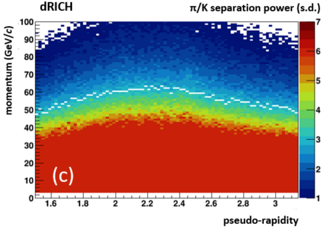
Tracking and charged jet performance:

- Combined tracking with all layers using Kalman filter
- **High momentum resolution in barrel and forward**
  $\rightarrow$ in backward region physics requirements are met by including EM calorimeter
- Charged jet reconstruction with great performance
  $\rightarrow$ JES can be improved with calibrations (+ calorimeters)
  $\rightarrow$ good angular resolution for correlating jet with scattered electron





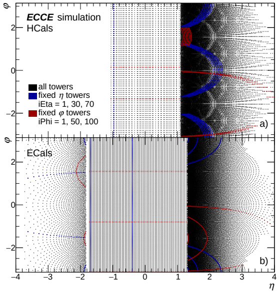


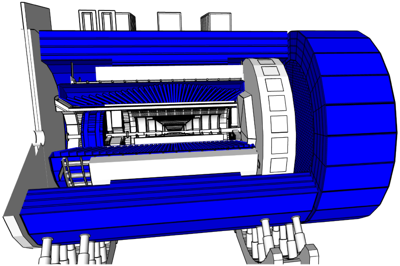


Ingredients: ECCE calorimetry

Calorimeter Design:

- **EM calorimeters**:
  - → Barrel ECal (BEMC) - SciGlass (4×4cm towers)
  - → e-going ECal (EEMC) - PWO crystals (2×2cm towers)
  - → h-going ECal (FEMC) - Pb-Sci Shashlik
- **Hadronic calorimeters**:
  - → Barrel HCals (i/oHCAL) - Fe-Sci ($\Delta\eta \times \Delta\varphi \approx 0.1 \times 0.1$)
  - → h-going HCal (LFHCAL) - Fe/W-sampling (5×5cm towers)
- Near-full η coverage from -3.5 to 3.5
- **Modern approaches** for better performance
  - → sub-Molière towers
  - → longitudinal separation
  - → SiPM readout





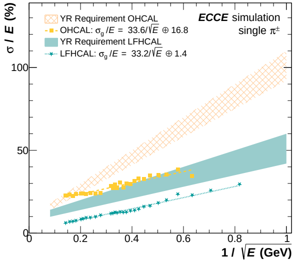
Ingredients: ECCE calorimetry - 2

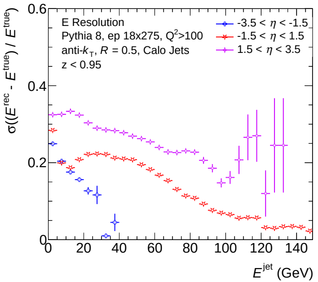
Calorimeter Performance:

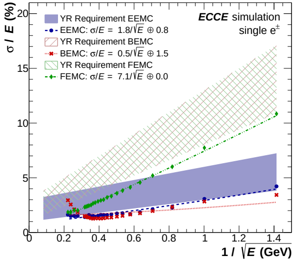
- **Excellent energy resolutions** for all calorimeters based on Geant4 full detector simulations
  $\rightarrow$ exceeding requirements by EIC WGs
- PID via E/p with up to 50k rejection factor
  $\rightarrow$ excellent for flavor tagging

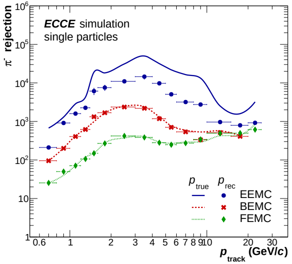
Calorimeter Jets:

- Jet reco. using EM and hadronic clusters
- Reconstruction possible in all η regions
- **Calo-only jet energy resolution below 0.35**
- JES not shown due to incomplete calibrations



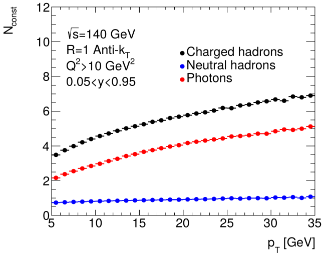


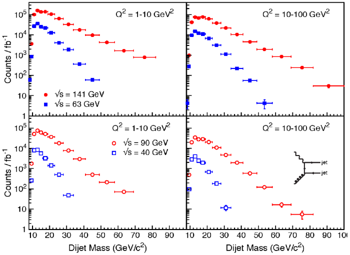


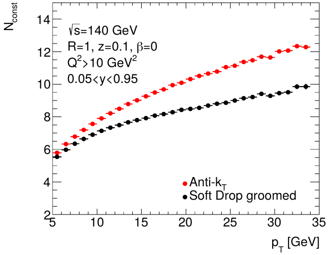


Jets at the EIC - Characteristics

- **Jets at EIC contain few particles**
  → require clean events with moderate underlying event
  → typical low p_T requires precision tracking to reduce JES uncertainties
- Low center-of-mass energy leads to **lower jet yields and limited p_T reach**
  → **high luminosity needed** to accumulate sufficient statistics
  → high reco. efficiency necessary
  → high di-jet masses only possible with high $\sqrt{s}$
- **Flavor tagging** via identification of the highest p_T hadron in the jet
- Jet substructure (Grooming, Trimming, Soft-Drop,...)
  → jets at EIC likely to already satisfy grooming criteria (unlike at LHC)
  → **groomed jets have 0–2 constituents removed** on average







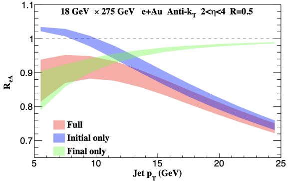
EIC physics involving jets

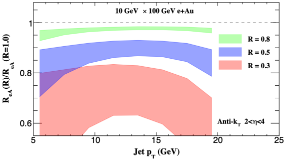
- Spin and mass of the Proton
- 3D nucleon/nucleus tomography
- Saturation (new form of gluon matter)
- Hadronization and quarks+gluons in the nucleus
- Jets at NNLO
- Jet substructure - low p_{T} but clean environment
- TMDs + spin, back-to-back correlations
- Energy loss in e–p and e–A
  $\rightarrow$ measurement of leading jets momentum fraction
- Determination of higher twist operators (PRD84 (2011))
- Measure properties of the nuclear medium with event shapes (PRD88 (2013))
- Measurement of the strong coupling constant through DIS event shapes (arXiv:1601.01499)

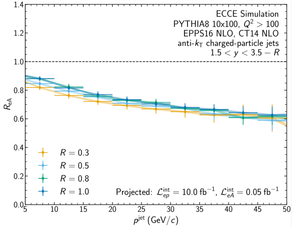
Rich physics program at the EIC!

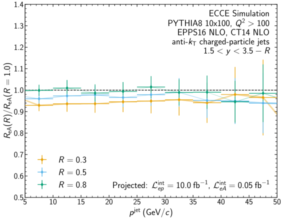
Example Physics: Jet R_{eA}

- Measurement to **disentangle initial and final state effects due to nuclear matter**
- Nuclear modification factor: $R_{\mathrm{eA}} = \frac{\alpha\sigma_{\mathrm{eA}}}{\sigma_{\mathrm{ep}}}$, $\sigma = \frac{\mathrm{d}^2\sigma}{\mathrm{d}y\mathrm{d}p^{\mathrm{jet}}}$
- Modifications expected to be largest in forward direction
  $\rightarrow$ probing of **anti-shadowing and EMC regions** of nPDFs at large x
- Clear **suppression** in full ECCE Geant4 simulation of pythia 10 $\times$ 100 GeV events
  $\rightarrow$ only small detector effects to be corrected via unfolding
- R_{eA} **double ratios** approximately flat vs p^{jet}
  $\rightarrow$ **probing of final-state effects** (initial-state cancels)
  $\rightarrow$ projected uncertainties point at non-sensitivity for $< 10\%$ effects









Summary

- **Rich jet physics program at the EIC!**
- Jet reconstruction with ECCE detector in interesting kinematic regions
  $\rightarrow$ tracking and calorimetry with high resolution
  $\rightarrow$ novel jet finders used for desired physics
  $\rightarrow$ particle flow for full jets yet to be studied with ECCE
- First look at jets from full detector simulations
  $\rightarrow$ jet R_{eA} with visible modification

Join the EIC Detector 1 jet efforts!

Backup

Example Physics: Spin of the Proton

- Exploration of the gluon contribution to the proton spin (ΔG) via longitudinal double spin asymmetry (A_{LL}) at leading order
- Requires tagging of photon-gluon fusion (PGF) events
- Properties of PGF events:
  → production of back-to-back particles with large p transverse to the photon-proton interaction axis
  → background from resolved and QCD compton processes
- parton and photon momentum fraction (x_γ, x_p) used for discrimination of backgrounds

$$x_\gamma = \frac{1}{2E_e y}(m_{\mathrm{T},1} \cdot \mathrm{e}^{-Y_1} + m_{\mathrm{T},2} \cdot \mathrm{e}^{-Y_2})$$

$$x_p = \frac{1}{2E_p}(m_{\mathrm{T},1} \cdot \mathrm{e}^{Y_1} + m_{\mathrm{T},2} \cdot \mathrm{e}^{Y_2})$$

- Further discrimination via Q^2 cut to remove DIS contributions and by requiring $x_\gamma \approx 1$
- Asymmetry A_{LL} as average of weights containing parton level asymmetry, PDF of the virtual γ and of the proton
- Asymmetry for each subprocess increases up to 20%
  → opposite signs mean that total asymmetry will be smaller
  → improvement of isolation of gluon contribution requires reduction of QCDC events