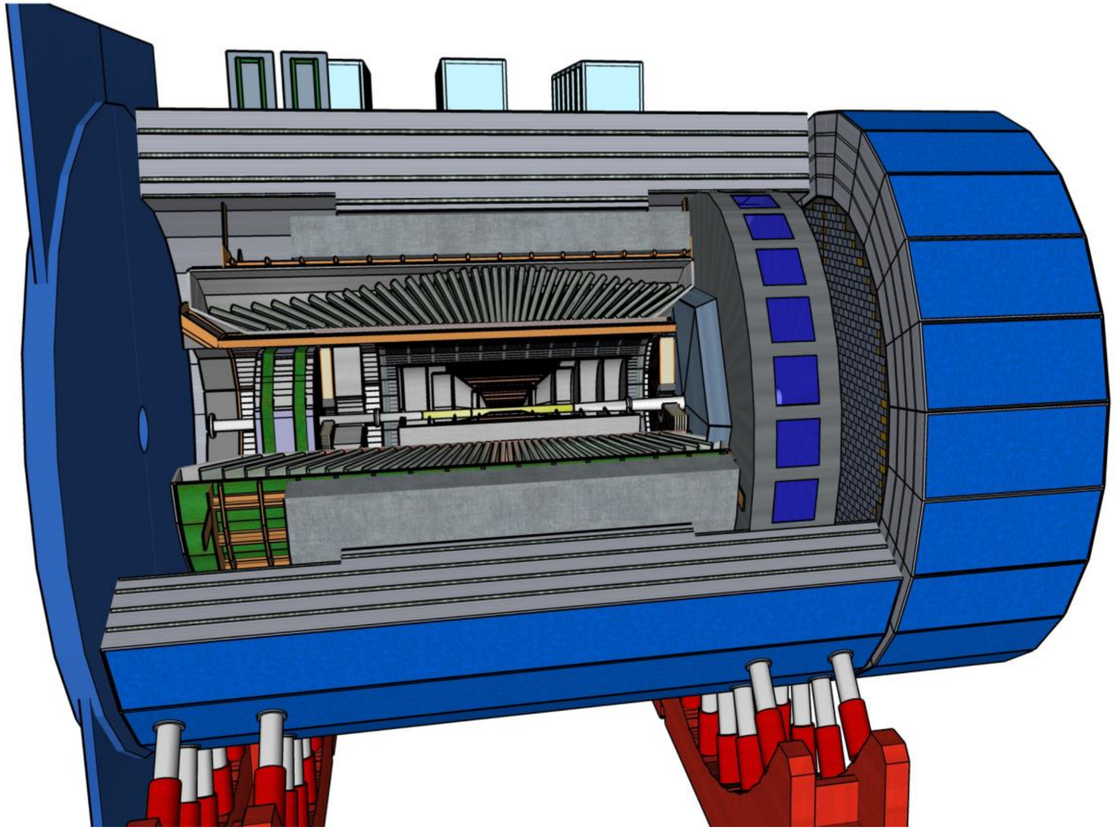
EIC Comprehensive Chromodynamics Experiment



ECCE Physics Overview

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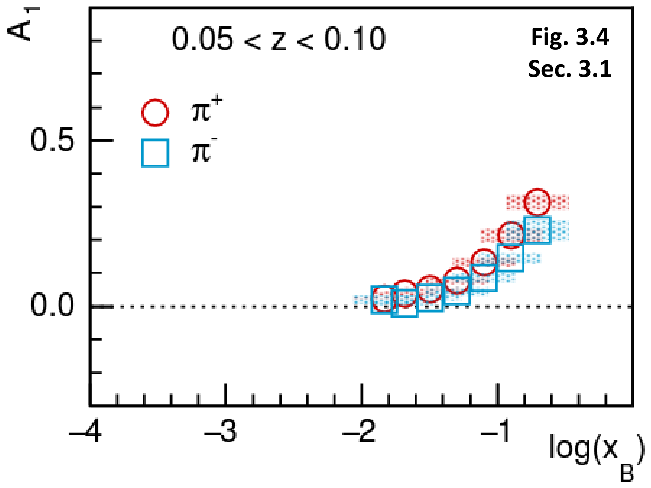
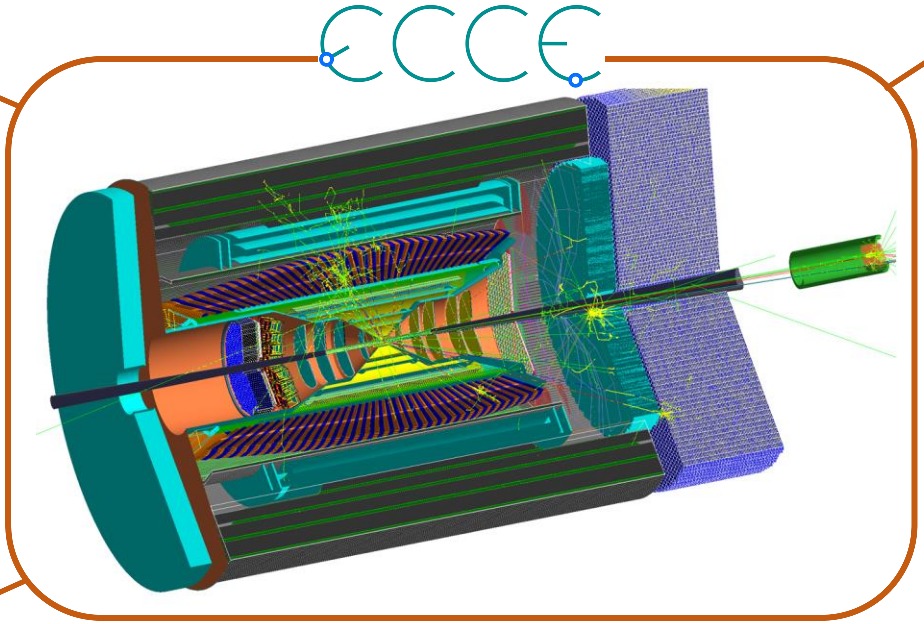
Key science questions that the EIC will address

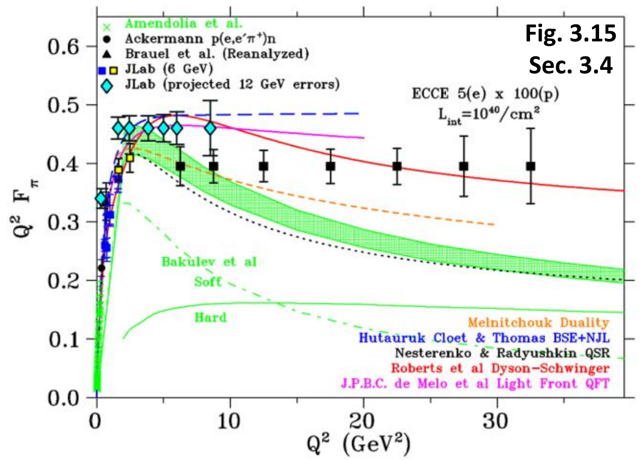
Origin of spin



- How does the spin-1/2 of the nucleon arise from the spin of quarks, gluons and their orbital angular momenta?

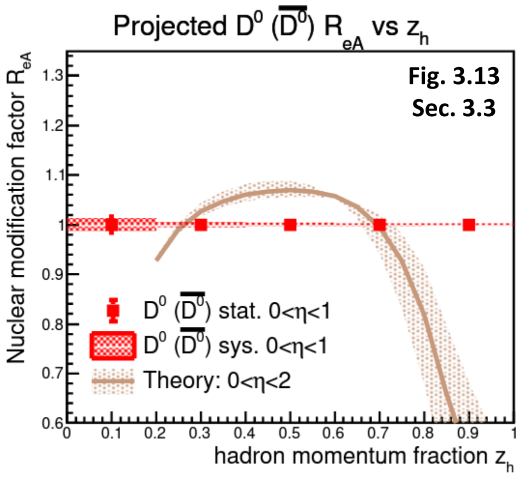


Origin of mass



- How do massless gluons make up for most of the nucleon mass?

Gluons in nuclei



- Does gluon density saturate at high energy giving rise to a new regime of matter?

- ➢ ECCE was **designed to address all these questions**
- ➢ Detailed analyses based on full Geant4 simulations demonstrate that **ECCE can deliver on the science outlined in the EIC White Paper and the NAS report**
- ➢ All studies are documented in dedicated analysis notes: https://www.ecce-eic.org/ecce-internal-notes (pwd: ECCEprop)

Origin of nucleon spin: physics requirements

Physics measurements:

- Inclusive Deep Inelastic Scattering (DIS) measurements
  - Double spin asymmetry $A_1(x)$

  Good scattered electron identification and resolution

  High resolution homogeneous ECALs in both backwards endcap and barrel

  Good momentum resolution with hybrid AI-optimized tracker

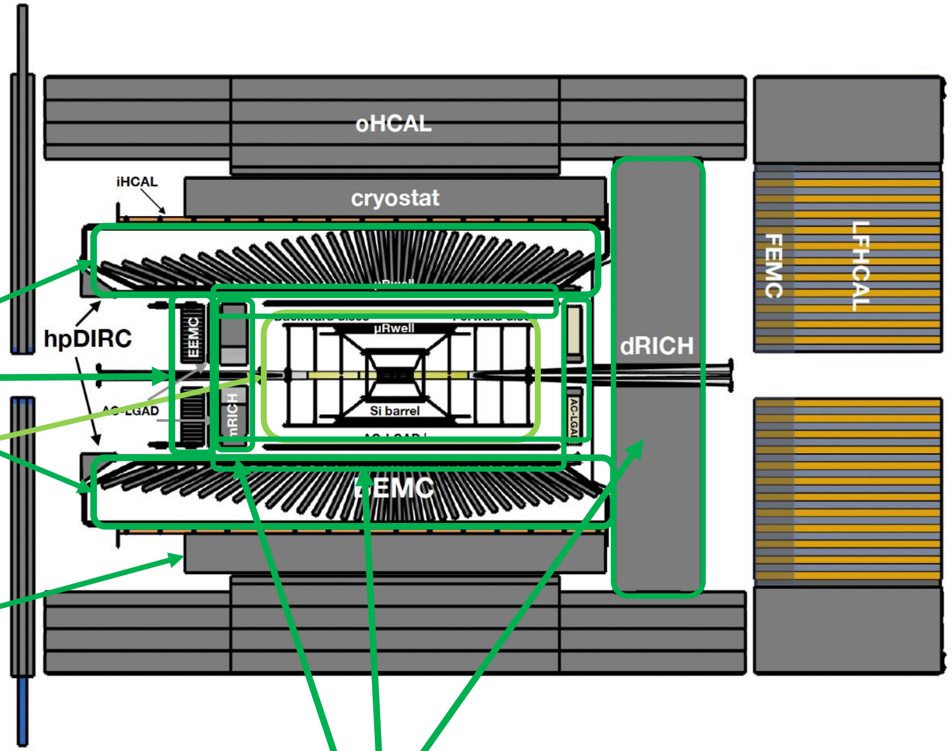
- Semi-inclusive DIS measurements
  - Collins & Sivers asymmetries

  Low p_T acceptance down to 100 MeV for π

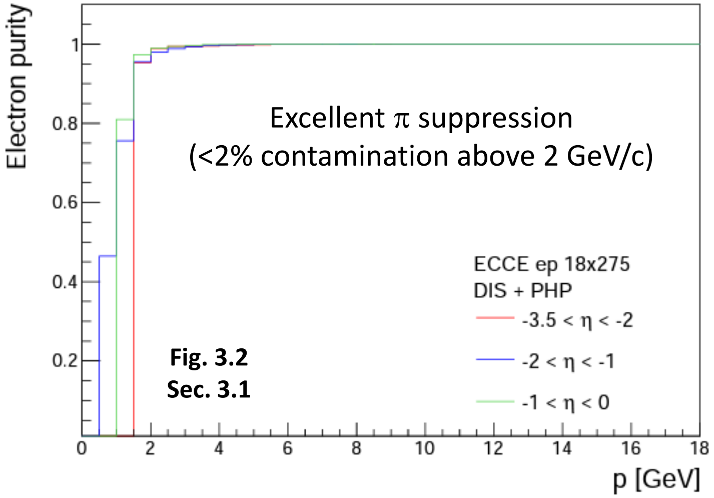
  1.4T field

  3σ h-PID up to 8 GeV/c (backward) & up to 6 GeV/c (central) & up to 50 GeV/c (forward)

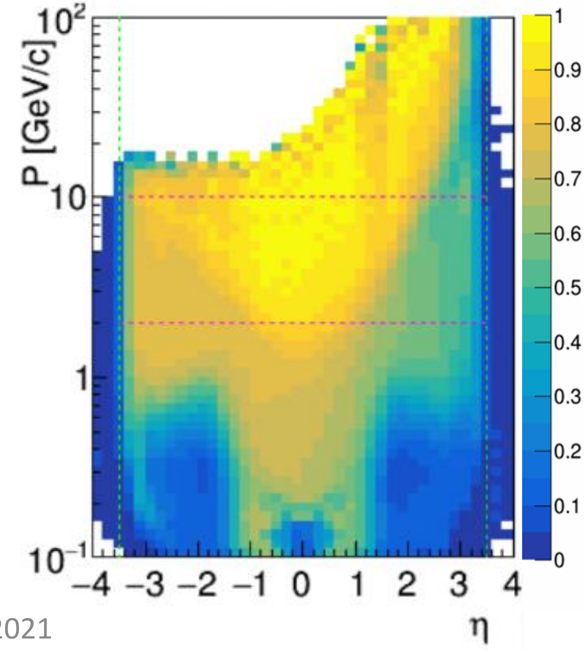
  High performance Cherekov PID systems for large momenta complemented by TOF systems for low-p PID



Origin of nucleon spin: physics performance



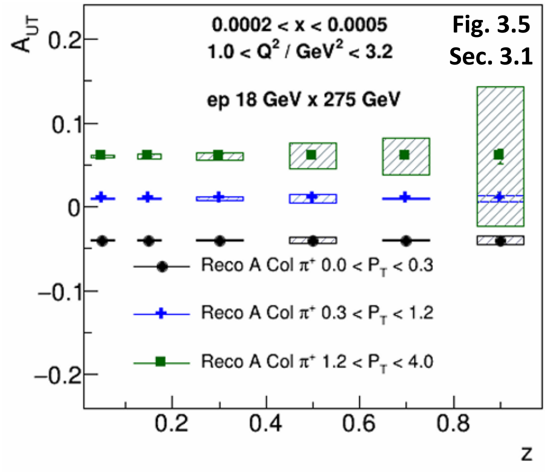
Hermeticity -3.5<η<3.5 and low momenta π acceptance

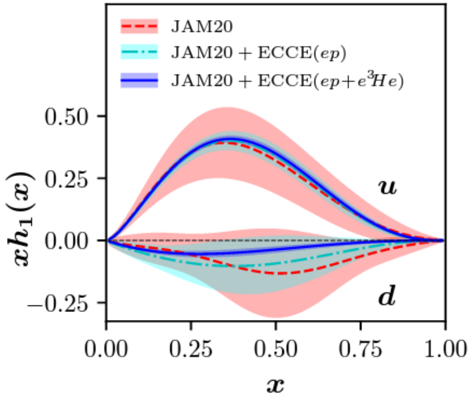


Full Geant4 simulation

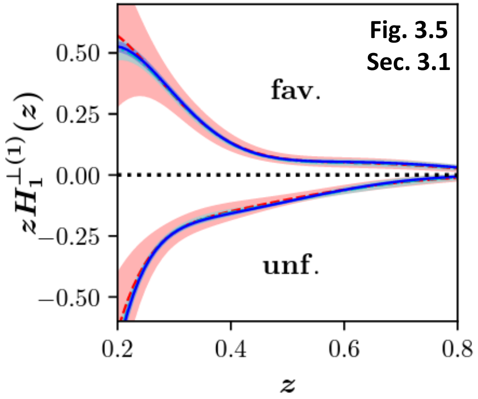
Systematic uncertainties: difference between reconstructed & truth kinematics

Transverse spin asymmetry as a function of hadron momentum z



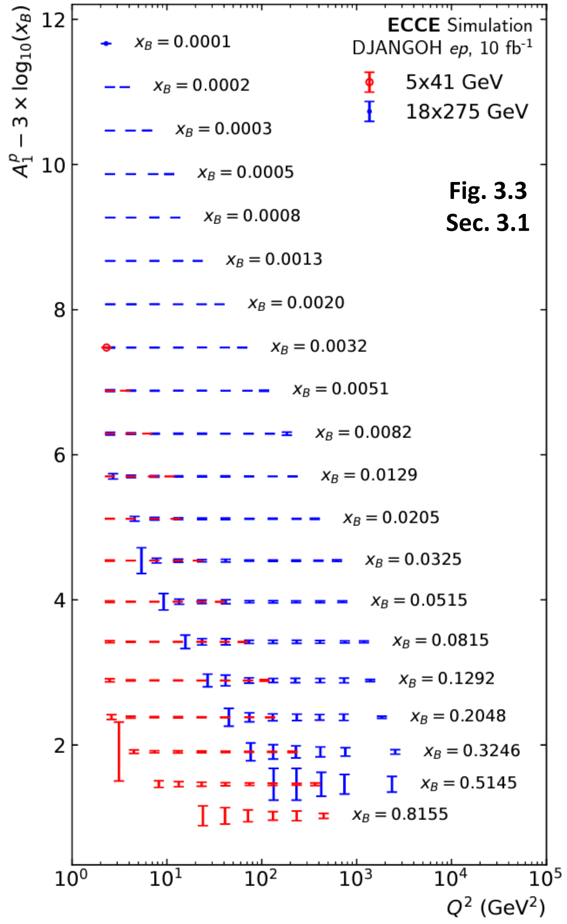


Impact on u and d transversity distributions



Impact on favored & disfavored Collins fragmentation functions

Inclusive double spin asymmetry $A_1(x)$



Accuracy compatible with projections in the YR

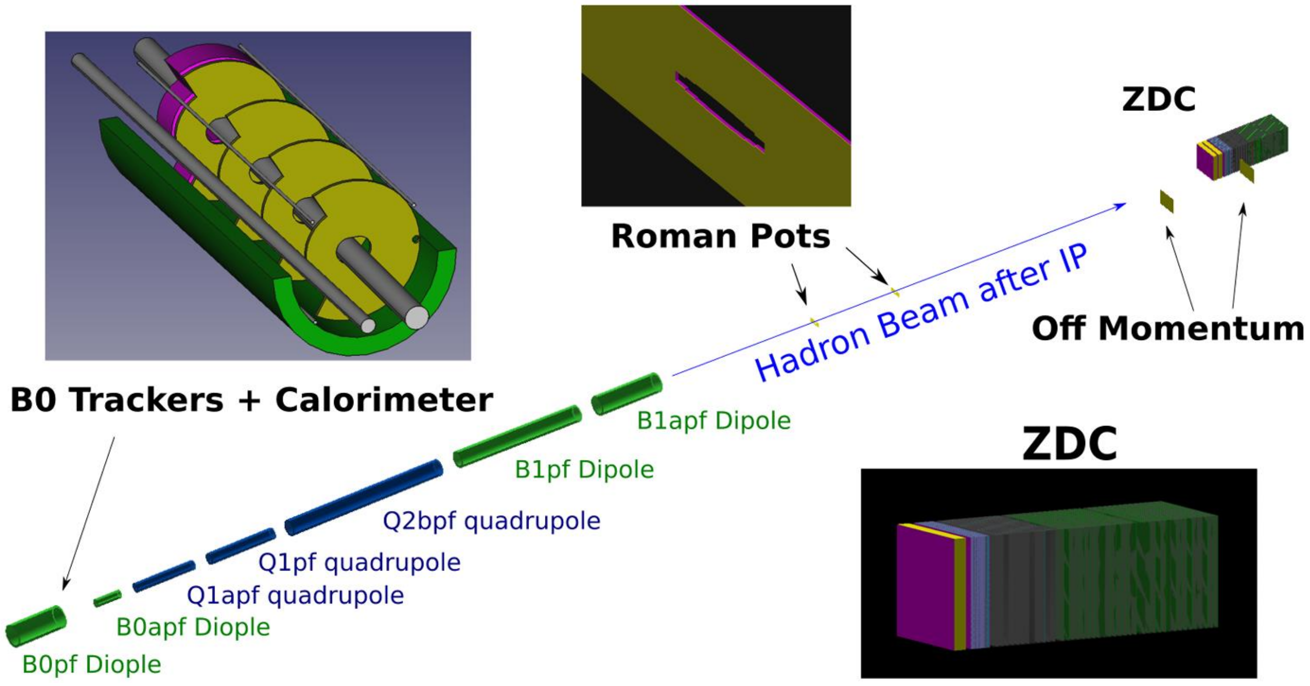
Origin of the mass: requirements

Physics measurements:

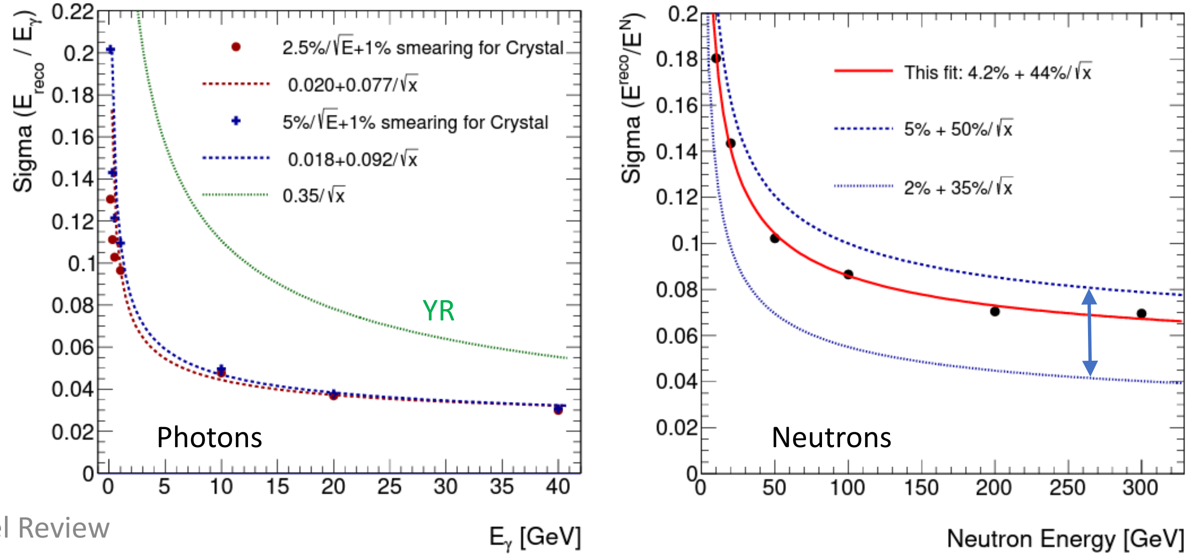
- ➢ Exclusive reactions with very forward particle detection/tagging

- High acceptance down to very small p_T
- Excellent p_T resolution
- Precise timing (correction crab cavity rotation)

- ➢ High precision tracking and timing (AC-LGADs) in all B0, Roman Pots & Off-Momentum detectors
- ➢ Zero-Degree Calorimeter (ZDC) design as developed during the YR
- ➢ Lead-tungsten calorimeter in B0 magnet to measure physics beyond the WP & NAS report (eg. u-channel DVCS)



ZDC energy resolution (full sim)



Origin of mass: physics performance (1)

3D imaging of quarks and gluons

- Full simulation of several exclusive channels (DVCS, exclusive J/ψ…)
- Beam effects (cross-angle & beam divergence) included
- Large and continuous coverage in $-t$ ($\sim p_T^2$) up to very small values of p_T

Exclusive J/ ψ production

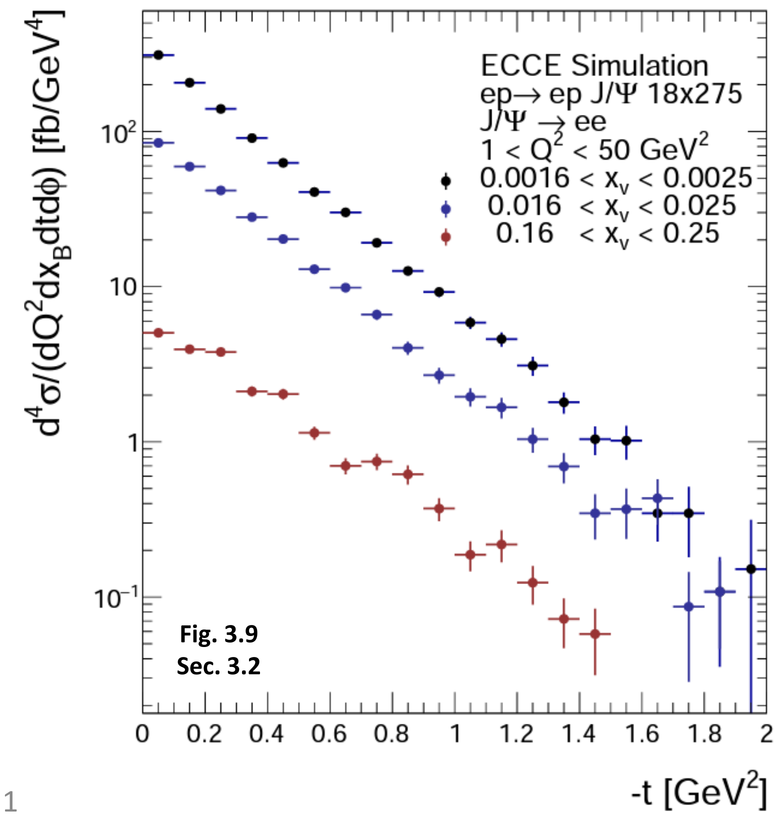


Fig. 3.9
Sec. 3.2

ECCE can deliver the physics outlined in the WP and NAS report

t-dependence of DVCS cross section

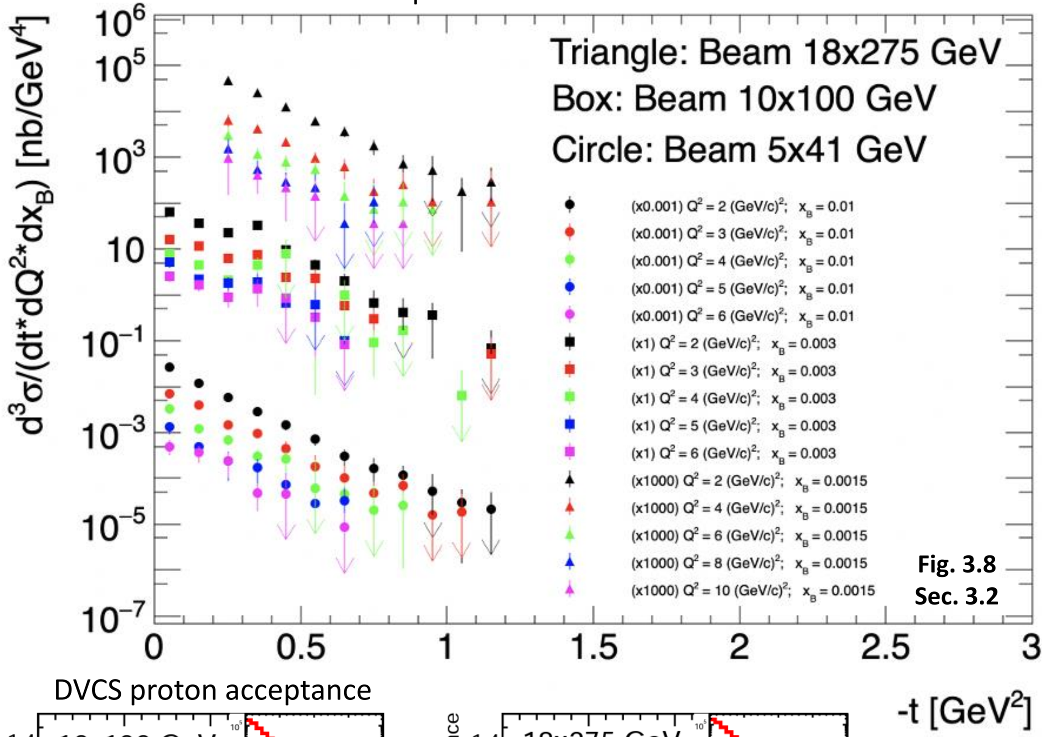


Fig. 3.8
Sec. 3.2

DVCS proton acceptance

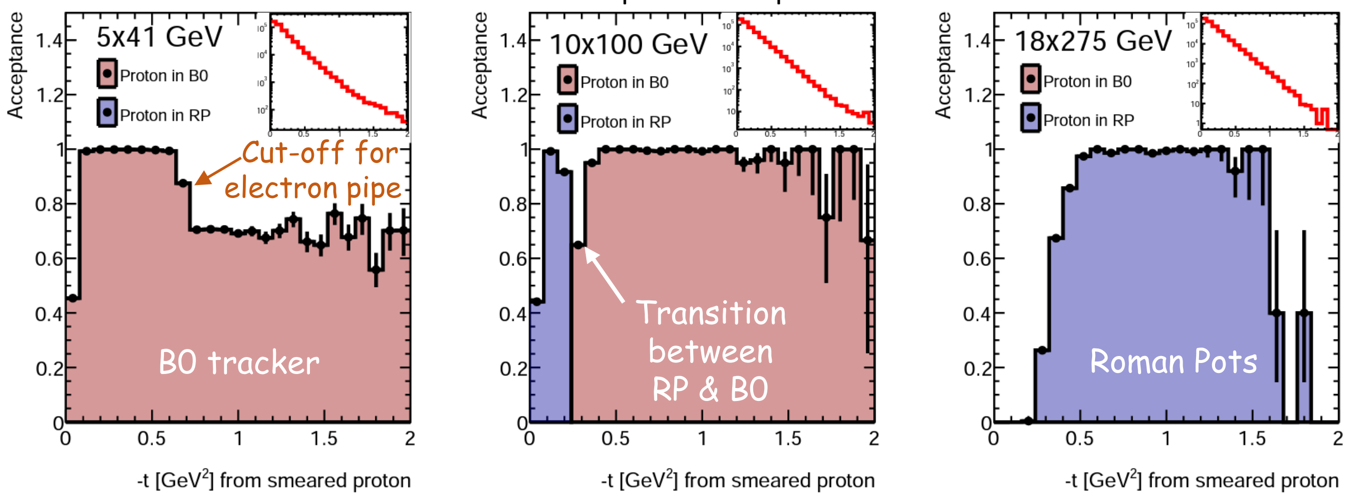
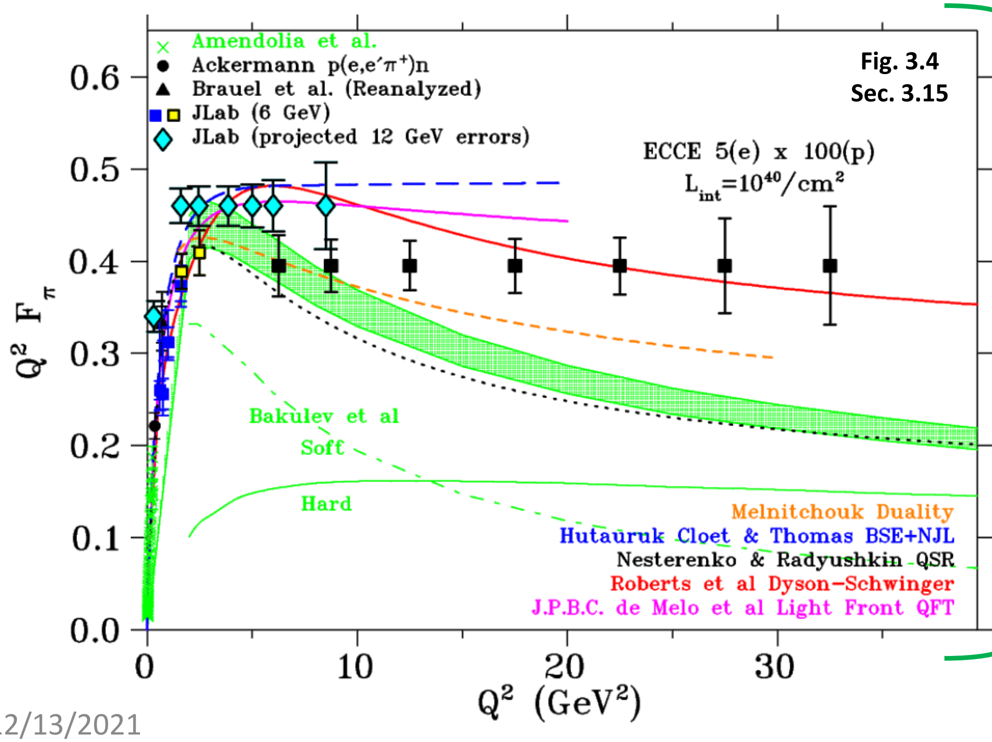


Fig. 3.7
Sec. 3.2

Origin of mass: physics performance (2)

- Threshold J/Ψ production as a function of Q^2 is sensitive to the trace anomaly contribution to the proton mass
- Meson structure measurements (structure function & form factor) probe the hadron mass generation through chiral symmetry breaking

Pion form factor: measurements up 30 GeV²



Far-forward detectors are key for reconstructing mesons at very forward η

Tracking capabilities of ECCE enable J/Ψ over wide range in *t* and Q²

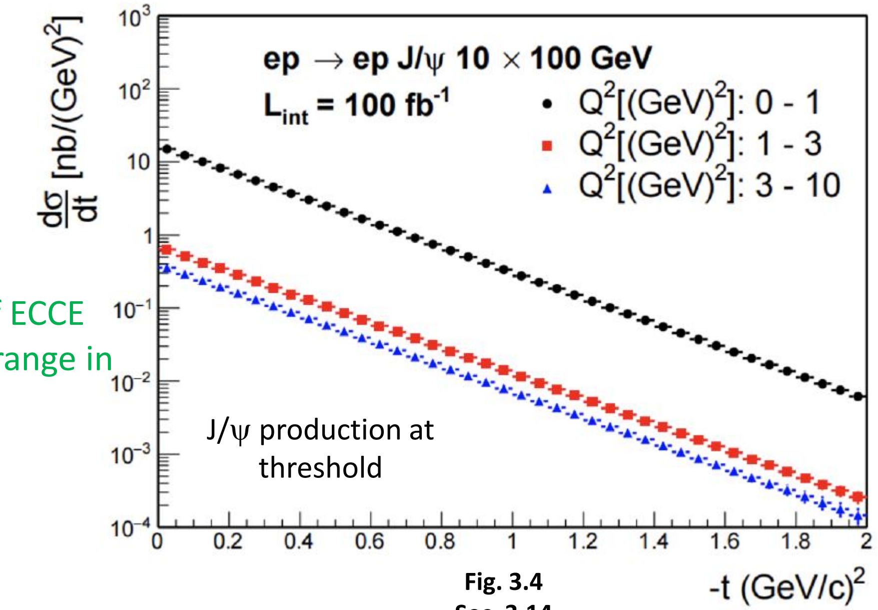
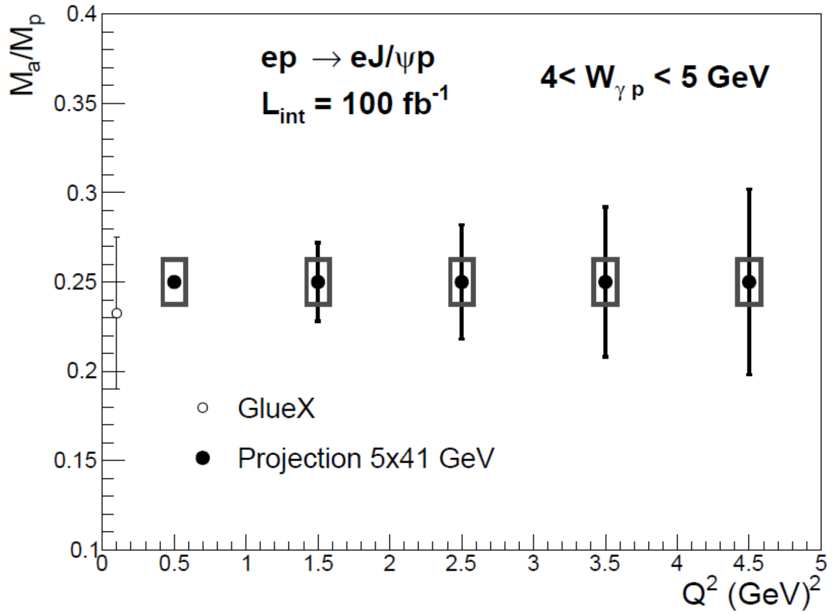


Fig. 3.4
Sec. 3.14



Gluons in nuclei: physics requirements

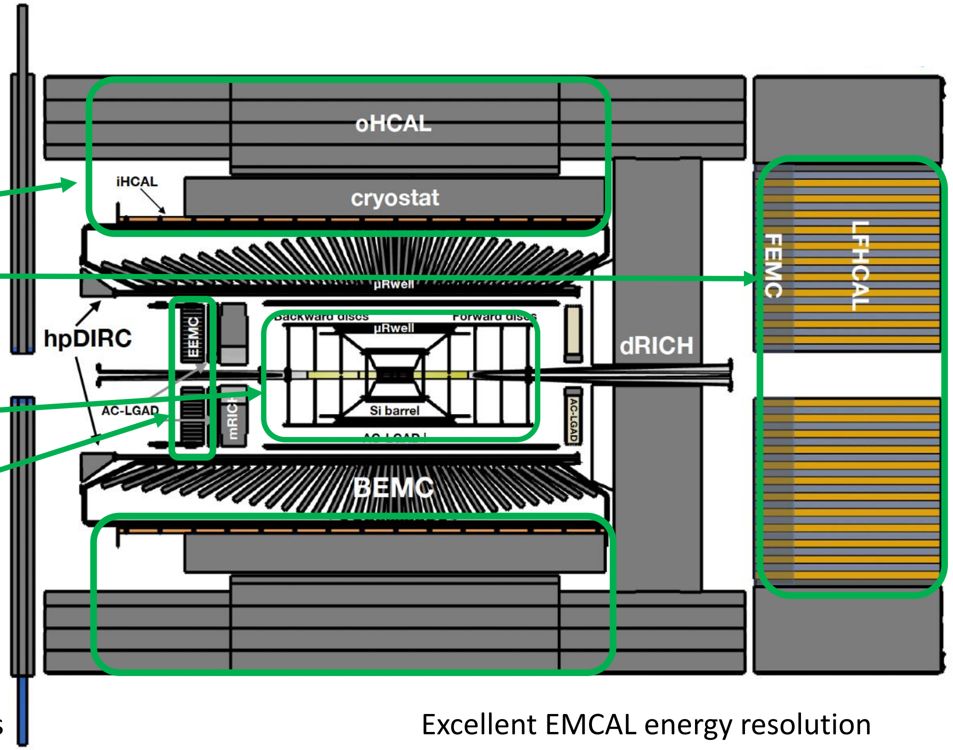
Physics measurements:

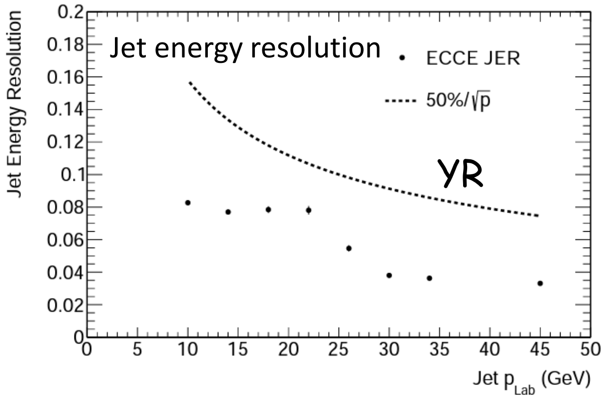
- Dijets measurements
  - Good hadron calorimetry

    1.4T, thin magnet (<0.5λ/λ_I) good HCALs (oHCAL reuse)
- SIDIS heavy flavor production
  - Good vertex resolution for open heavy flavor reconstruction

    AI-optimized hybrid Si tracker
- Diffractive processes off nuclei
  - Excellent backwards EMCal

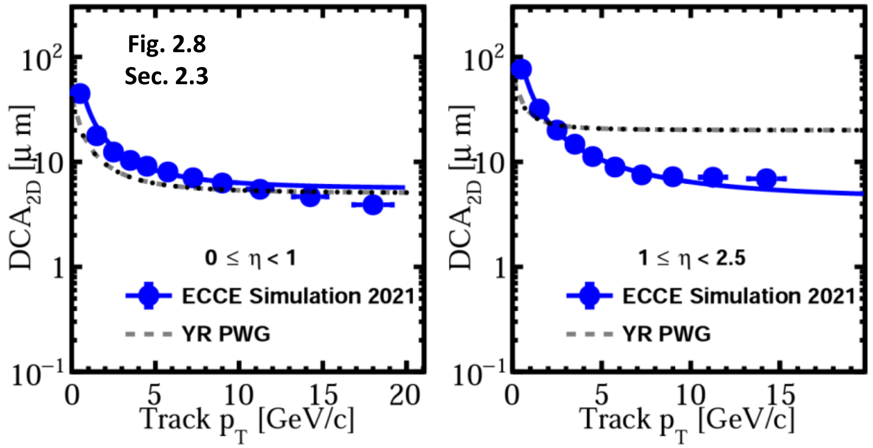
    Choice of full $PbWO_4$ crystal calorimeter



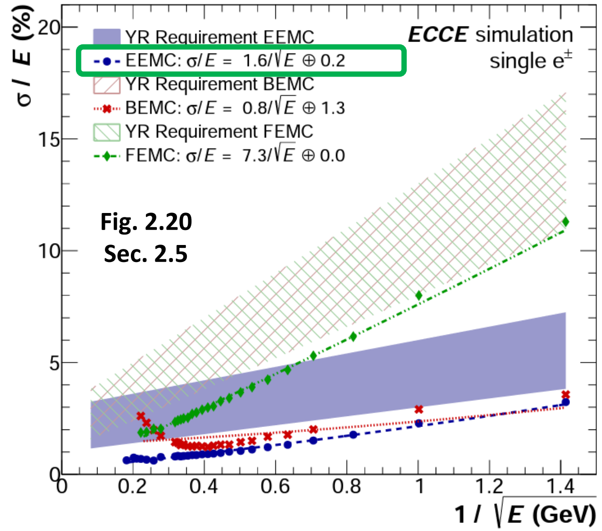


Reconstruction for track+cluster jets exceeds YR requirements

Distance of closest approach within YR requirements



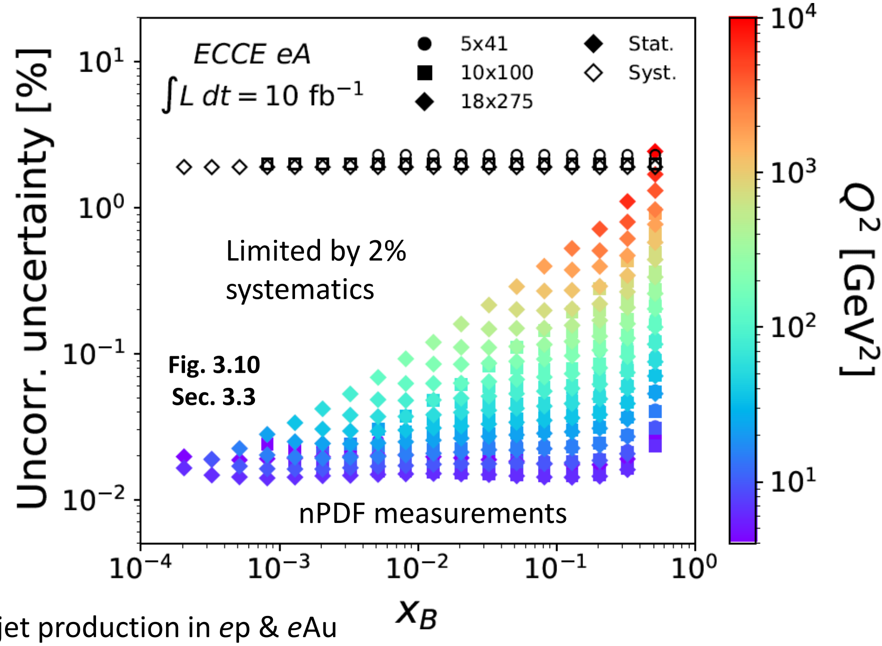
Excellent EMCAL energy resolution



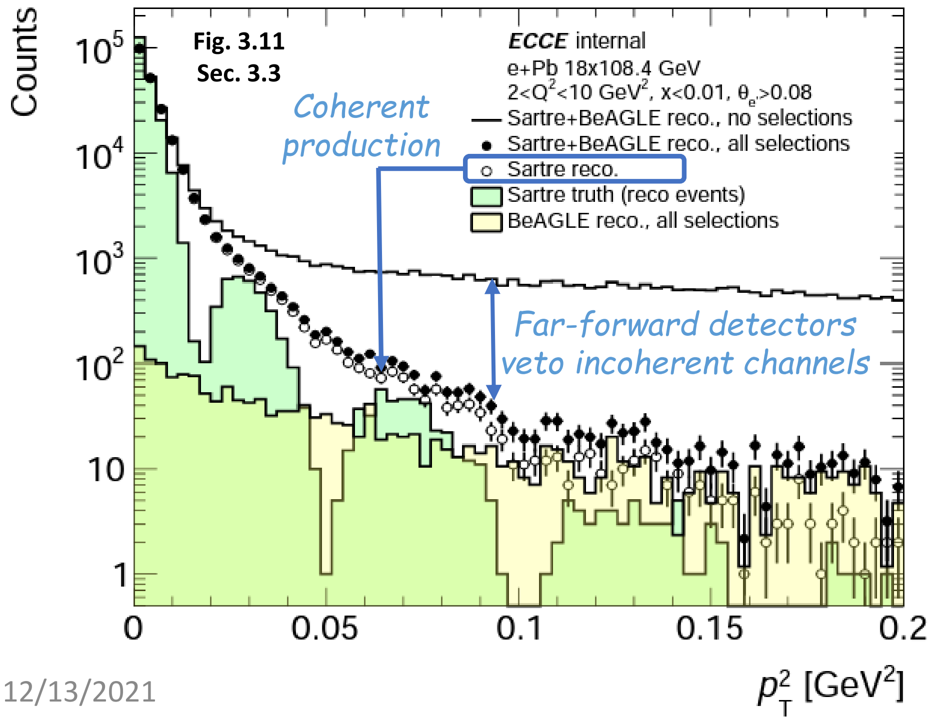
Gluons in nuclei: physics performance (1)

Gluon saturation

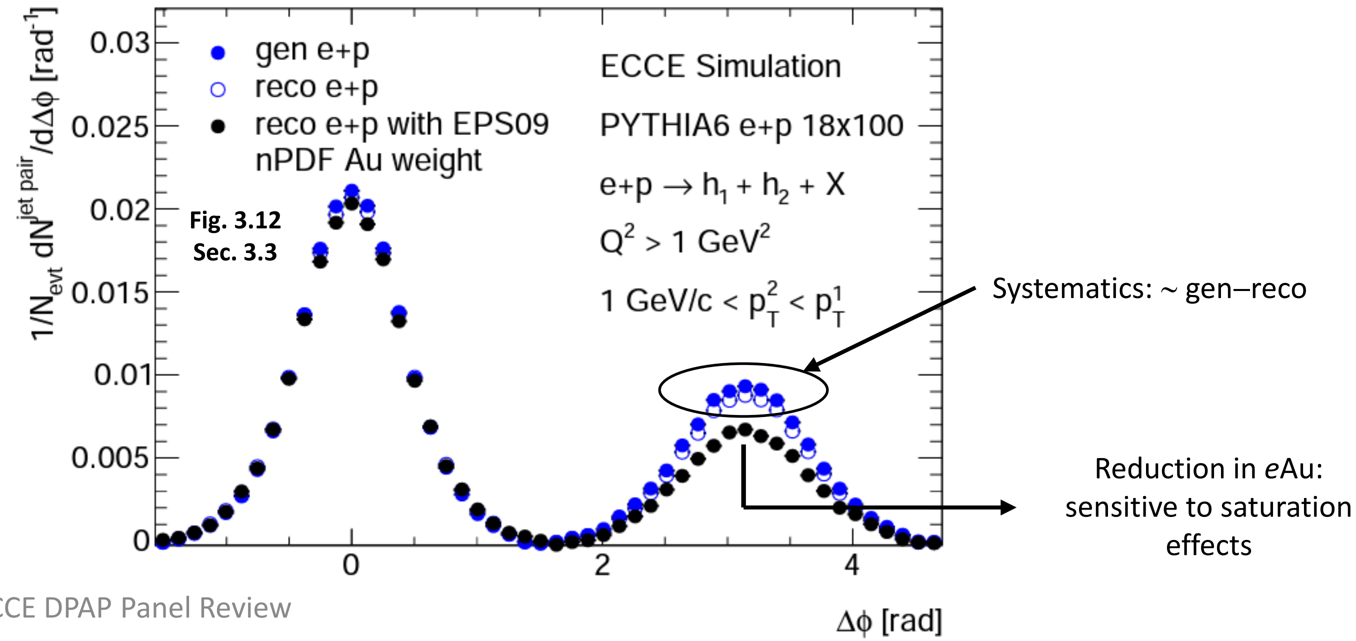
- Early nPDF measurements will probe gluon saturation regime (by comparing to DGLAP evolution and by using different nuclei)
- High resolution backward EMCAL allows to distinguish change in slope in diffractive production
- Jet reconstruction sensitive to saturation effects in *eg.* dihadron correlations



Diffractive J/ψ production off Pb



Dihadron correlation from dijet production in *ep* & *eAu*

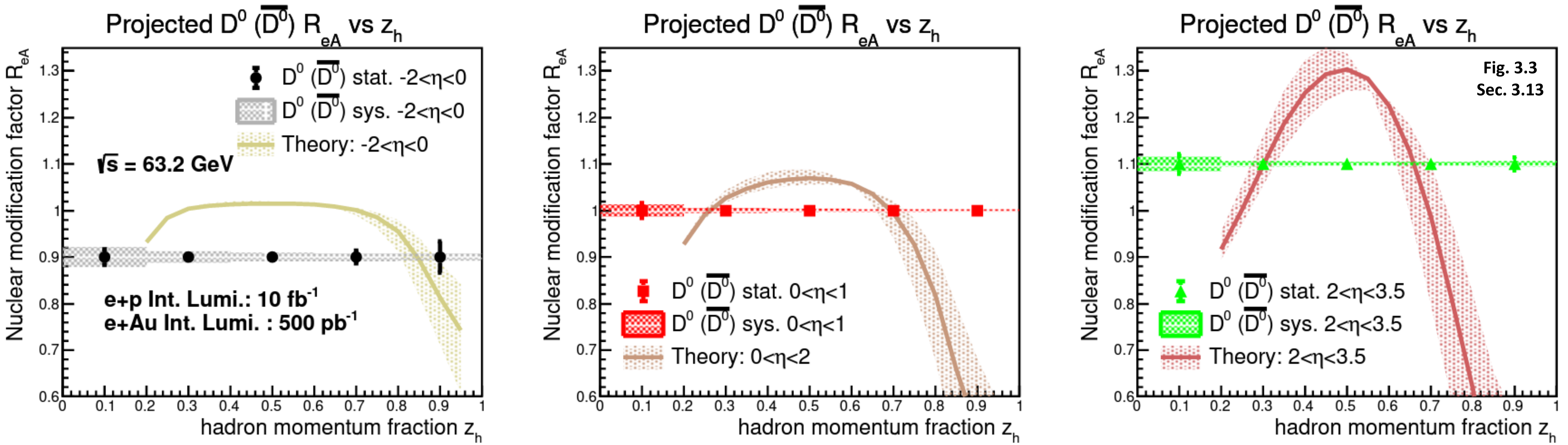


Gluons in nuclei: physics performance (2)

Nuclear matter and hadronization

- SIDIS in eA is an excellent process to understand hadronization
- Heavy flavor (HF) production provides a clean probe of gluon dynamics in nucleons and nuclei
- Comparison of HF production in *ep* & *eA* (R_{eA}) probes the hadronization process in vacuum and in a cold nuclear medium

Nuclear modification factor in *ep* vs *eAu* for D^0 ($\overline{D}^0$) as a function of z_h



- ✓ Tracking reconstruction of ECCE provides the necessary discriminating power between different model predictions of hadronization
- ✓ Acceptance for low momentum pions thanks to the 1.4T field significantly increases statistical uncertainties

Science beyond the NAS report (1)

Precision electroweak and BSM physics

- The ECCE consortium is interested in parity-violating (**PV**) asymmetries and charged lepton flavor violating (**CLFV**) processes to search for physics BSM
- Using the DIS reconstruction capabilities and 100 fb^{-1} integrated luminosity, ECCE will set stringent limits in BSM physics

PVDIS asymmetries: Expected limits on 2 sets of Wilson coefficients associated with BSM degrees of freedom in the SMEFT

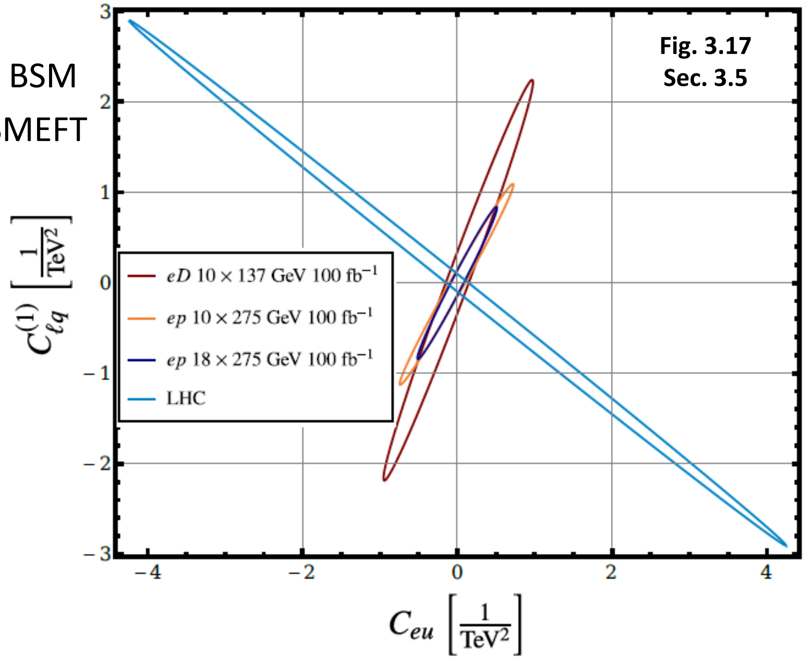
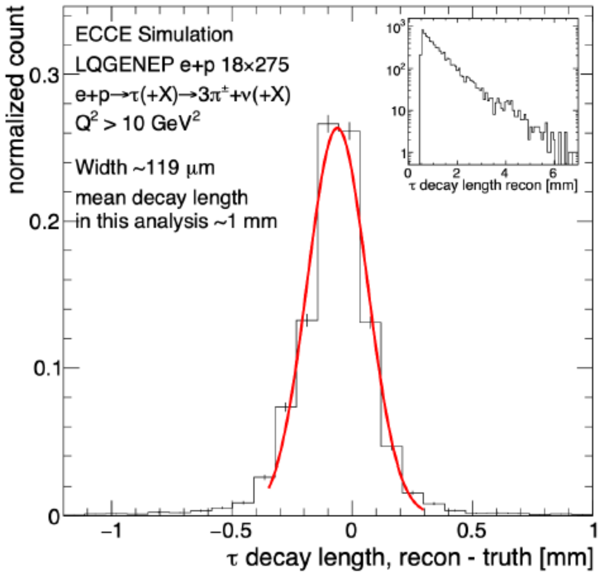


Fig. 3.17
Sec. 3.5

Leptoquarks

Resolution in t decay length: 119 mm



Limits on contact interaction terms based on ep→τX cross section

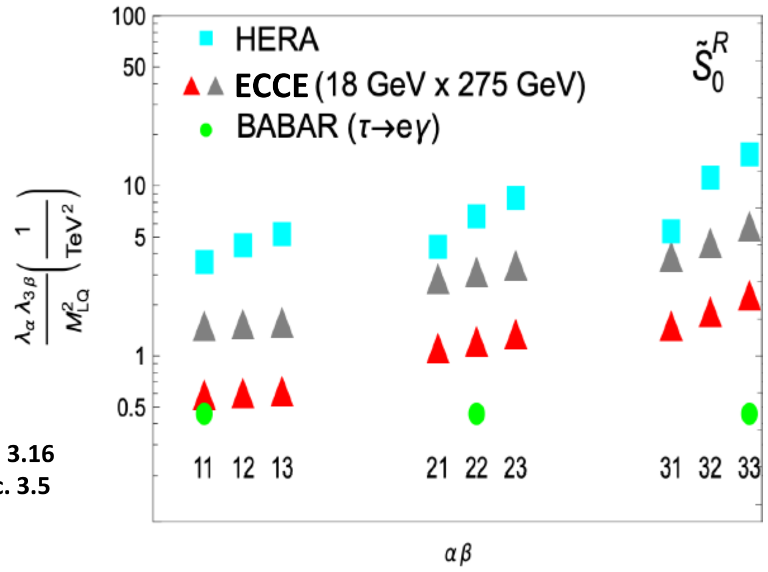


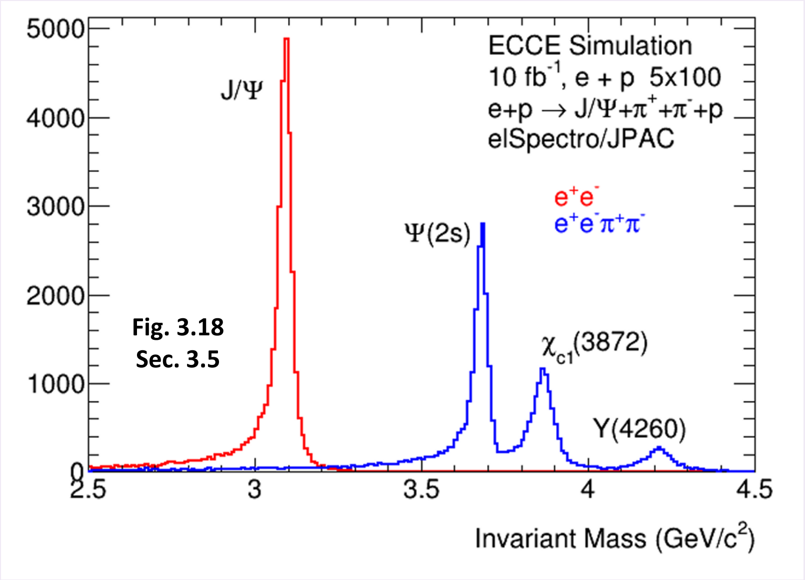
Fig. 3.16
Sec. 3.5

Science beyond the NAS report (2)

XYZ Spectroscopy

- Photoproduction of "XYZ" meson states probes underlying dynamics and allow determining their quantum number
- Detection of *low energy pions* is crucial while providing *good invariant mass resolution* :

  1.4T field is optimal for spectroscopy



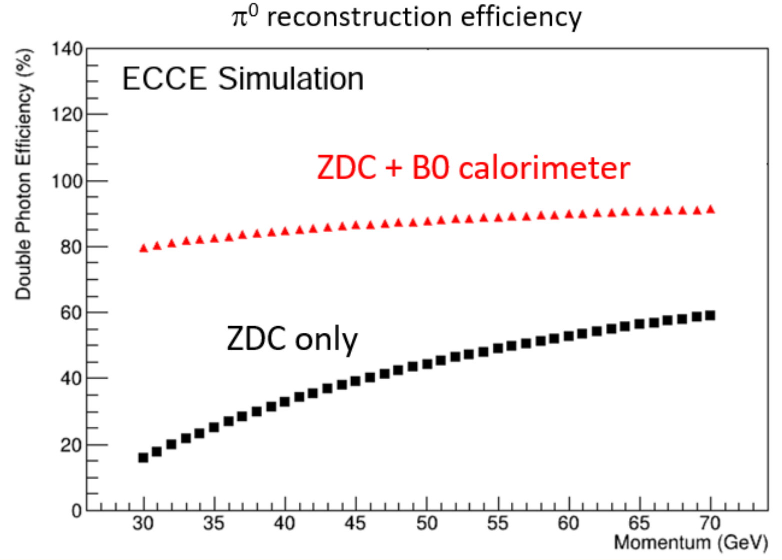
- Reconstructed invariant mass for 3 simulated states:

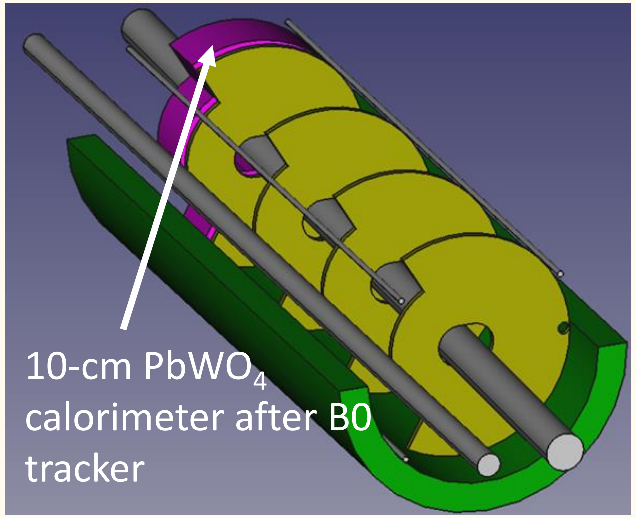
  χ_{c1}(3872), Υ(4260) and Ψ(2s)
- 30 MeV resolution achieved with ECCE

Low-Q^2 tagger (far-backwards region) is crucial for this measurement

u-channel DVCS

- Access to nucleon *Transition Distribution Amplitudes* (TDA): light-cone matrix elements complementary to GPDs
- Bethe-Heitler is suppressed in the *u*-channel, but π^0 background suppression is needed via an EMCal at very forward rapidity (B0 magnet)





Conclusion

- ECCE design was driven by the different physics measurements required to address the full set of EIC science
  - Each subsystem technology was chosen to address specific physics requirements

- ECCE can deliver on *all* these physics measurements and we have demonstrated this through full Geant4 simulations
  - ECCE meets (or exceeds) the detector requirements outlined in the Yellow Report
  - ECCE can address all of the physics topics listed in the EIC White Paper and the NAS report
  - ECCE physics performance is compatible with projections from the Yellow Report exercise

- ECCE can also address several exciting physics topics beyond the WP and the NAS report

- All studies thoroughly documented in 15 physics analysis notes (+10 detector notes):

  https://www.ecce-eic.org/ecce-internal-notes (pwd: ECCEprop)