Future opportunities for exploring collectivity using extra small systems

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Snowmass EF07 meeting:
High Density QCD in
Small Collision Systems

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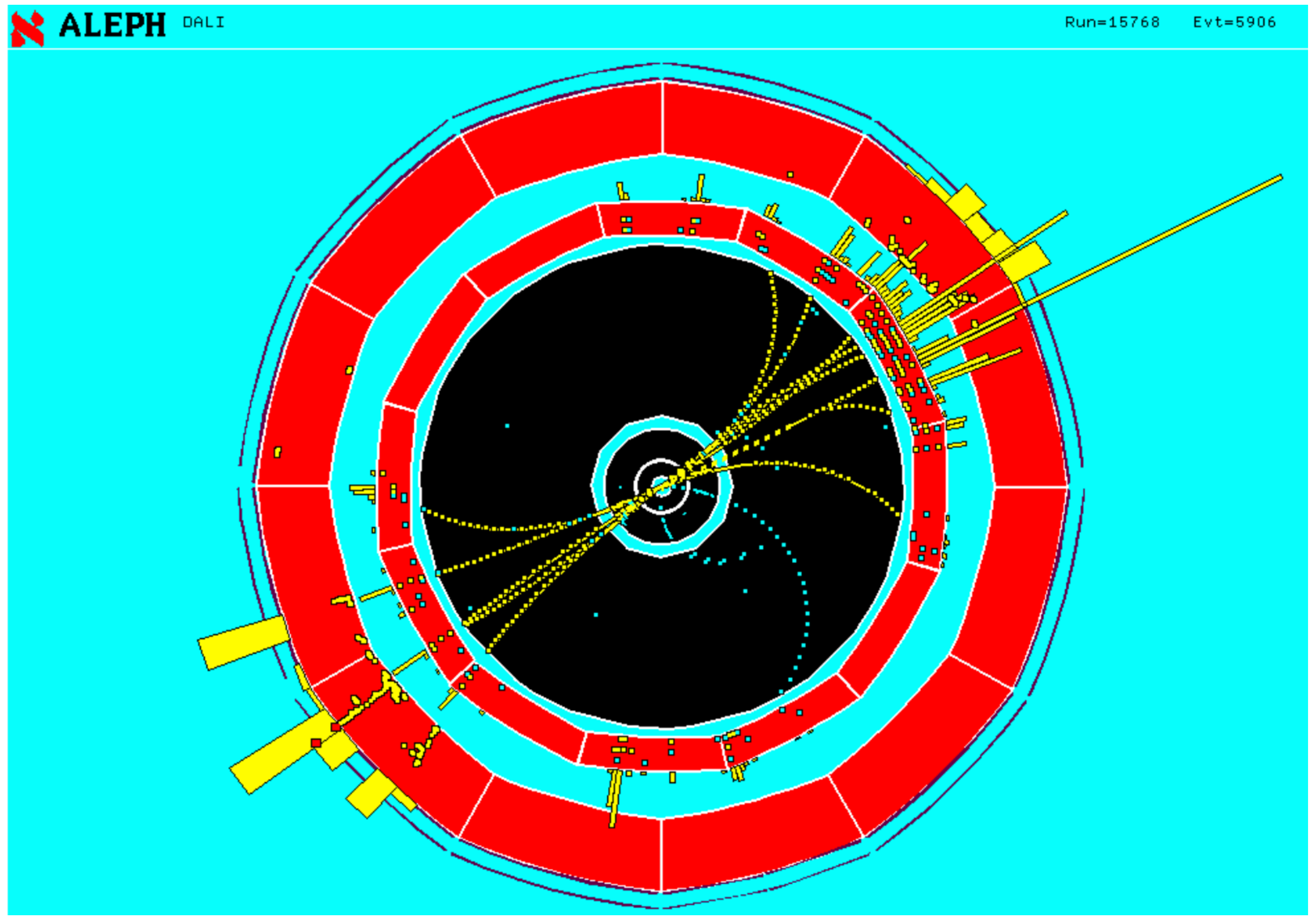
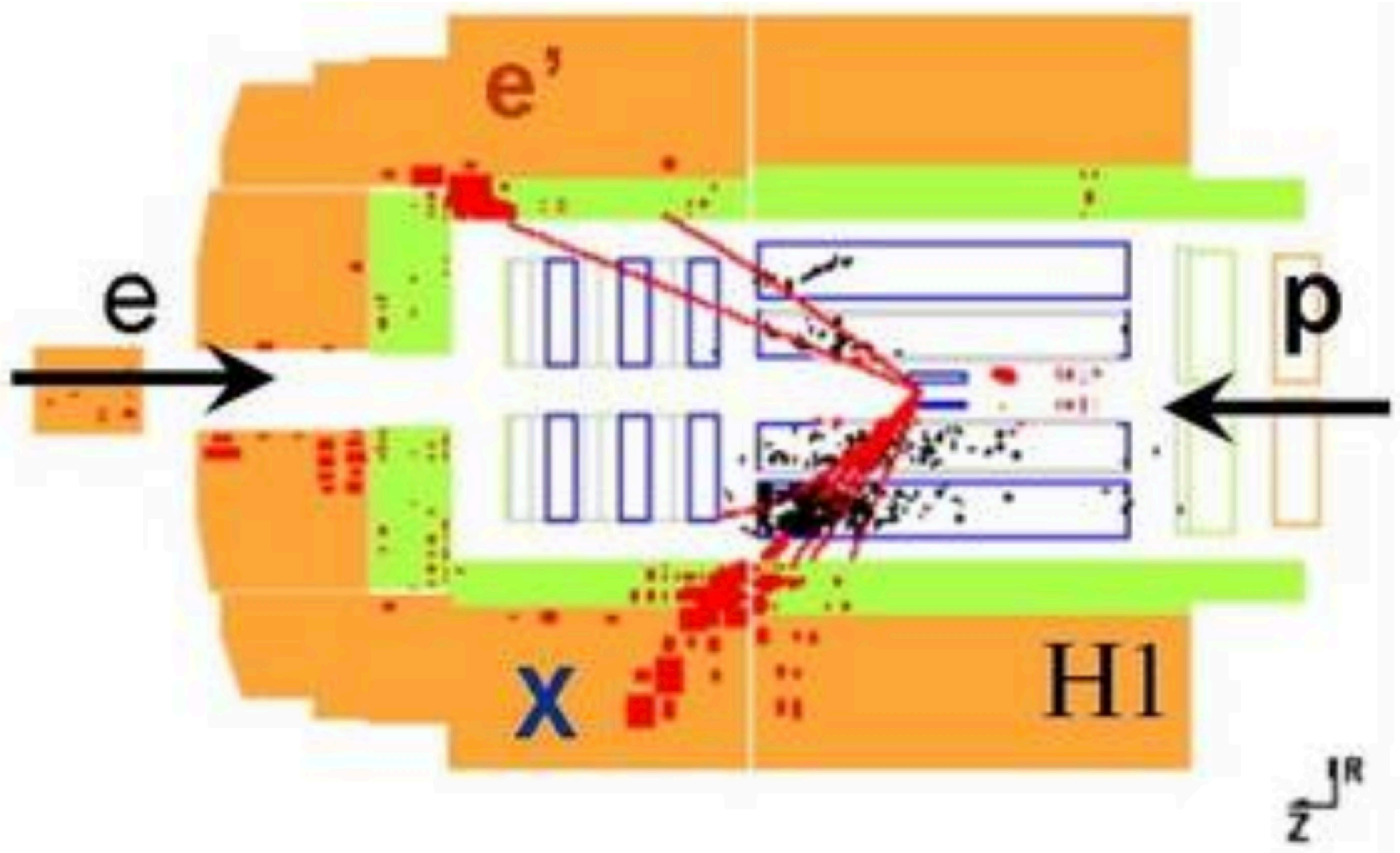
What is ‘extra small?’

- The ‘size’ of a system is not well-defined by the colliding particles
- Typically we refer to pp/pA collisions as ‘small’ (relative to AA)
- A ‘extra small’ system: at least one colliding particles is not a nucleon or nucleus

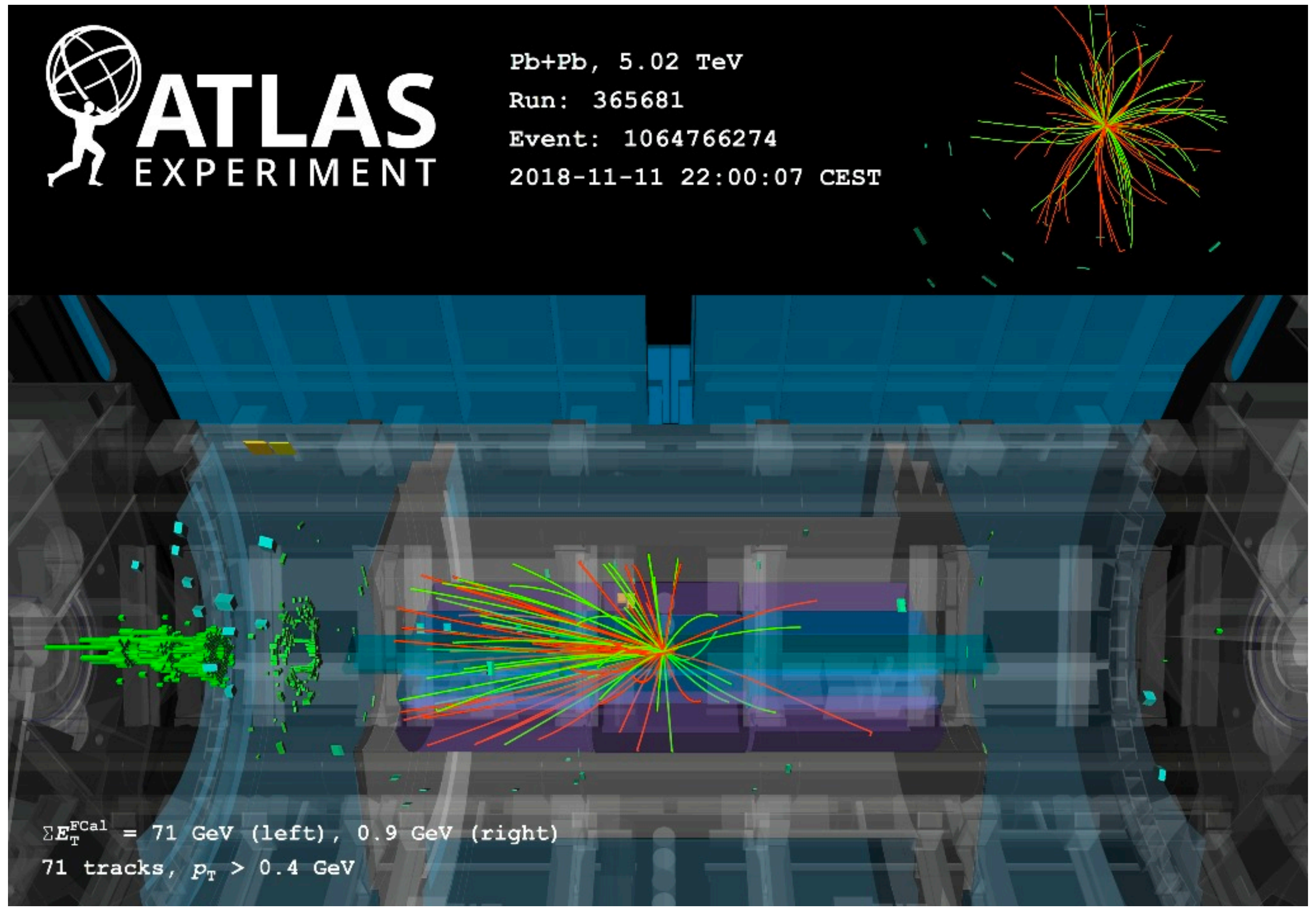
e^+e^-



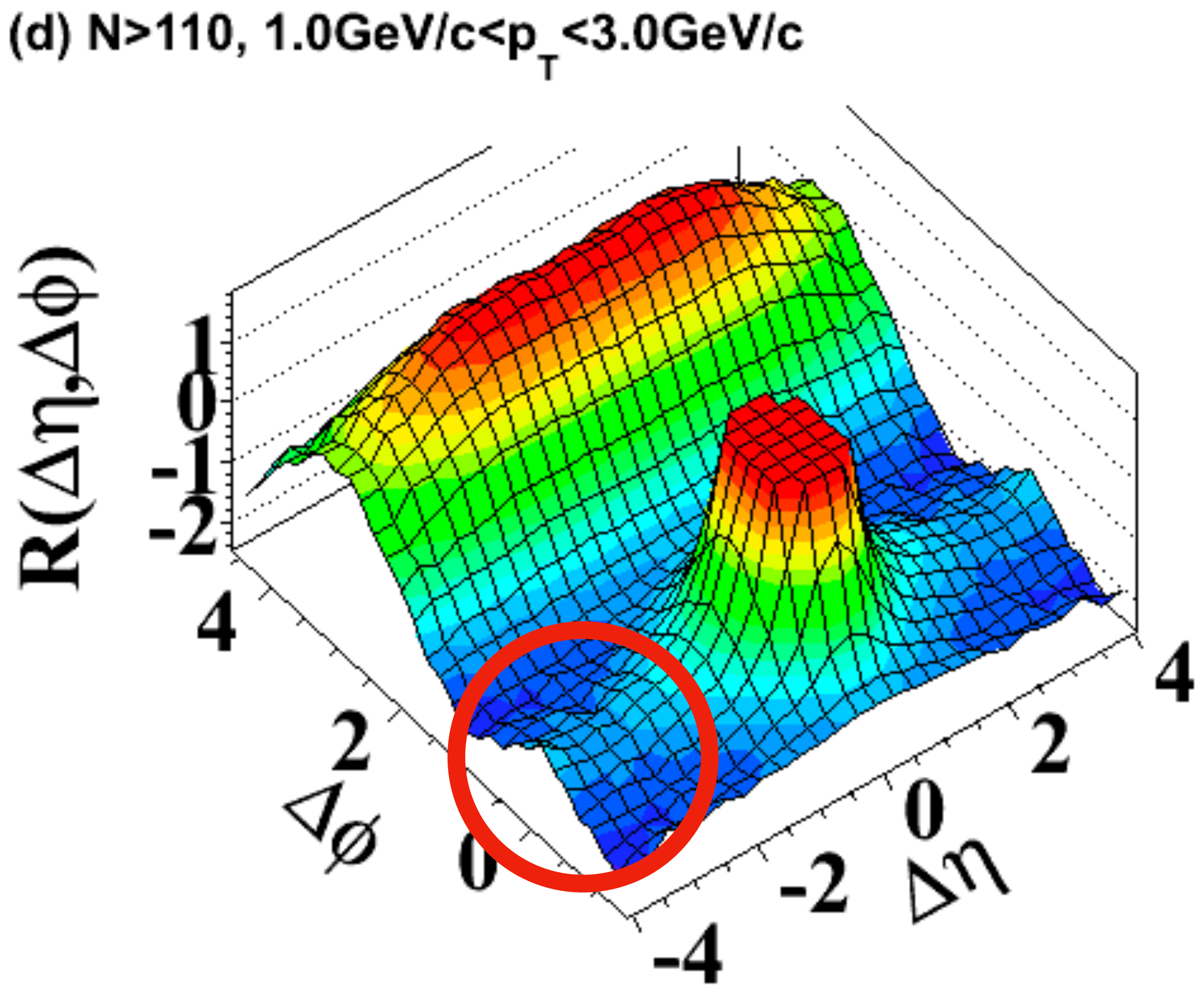
ep

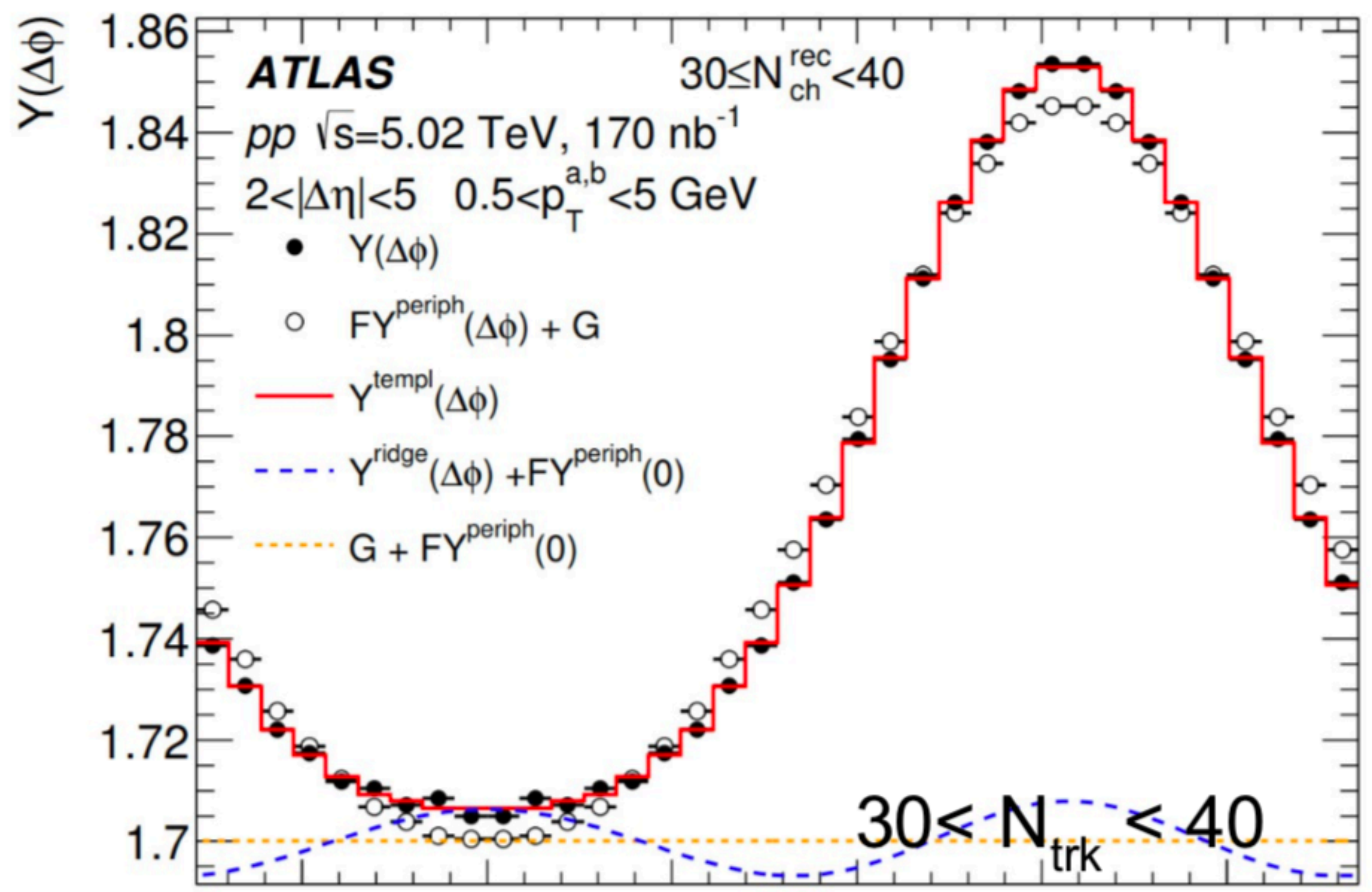


γA and γp

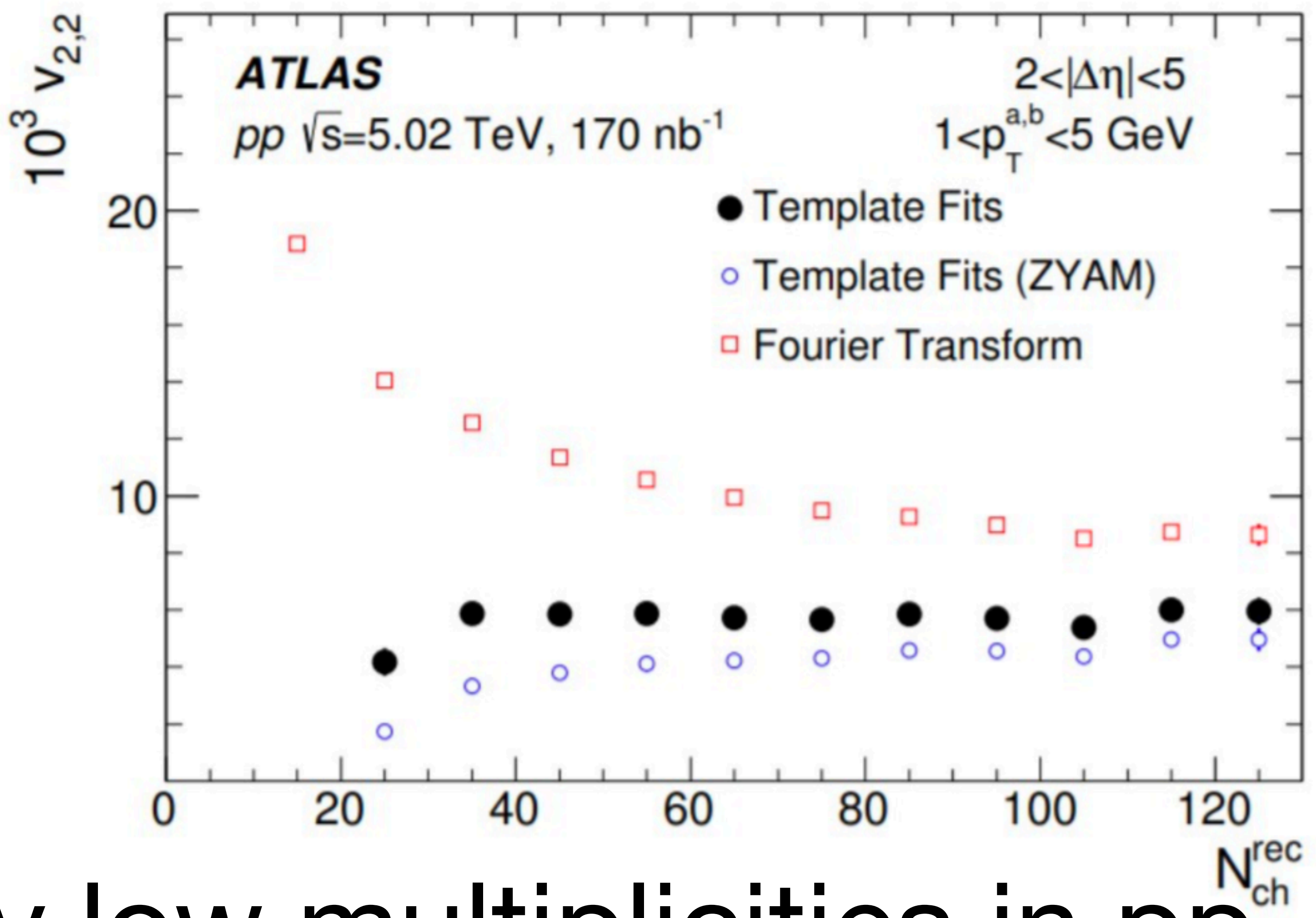


Why go smaller than pp?



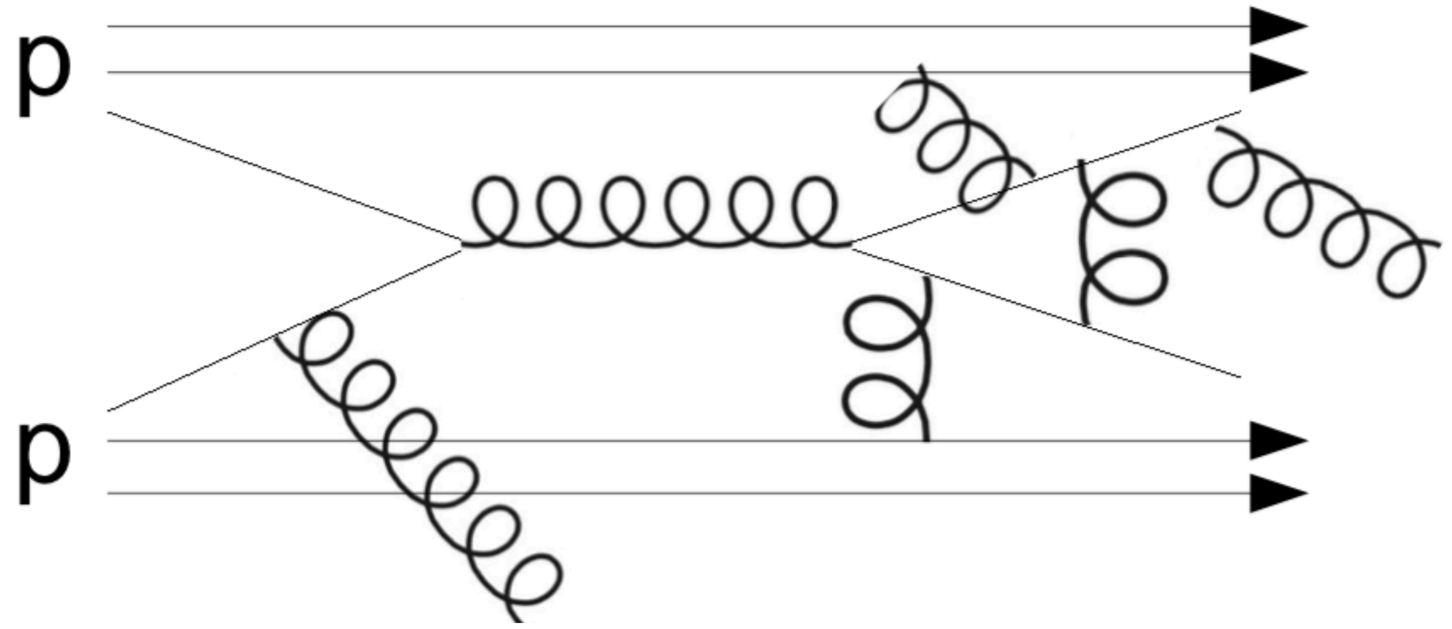


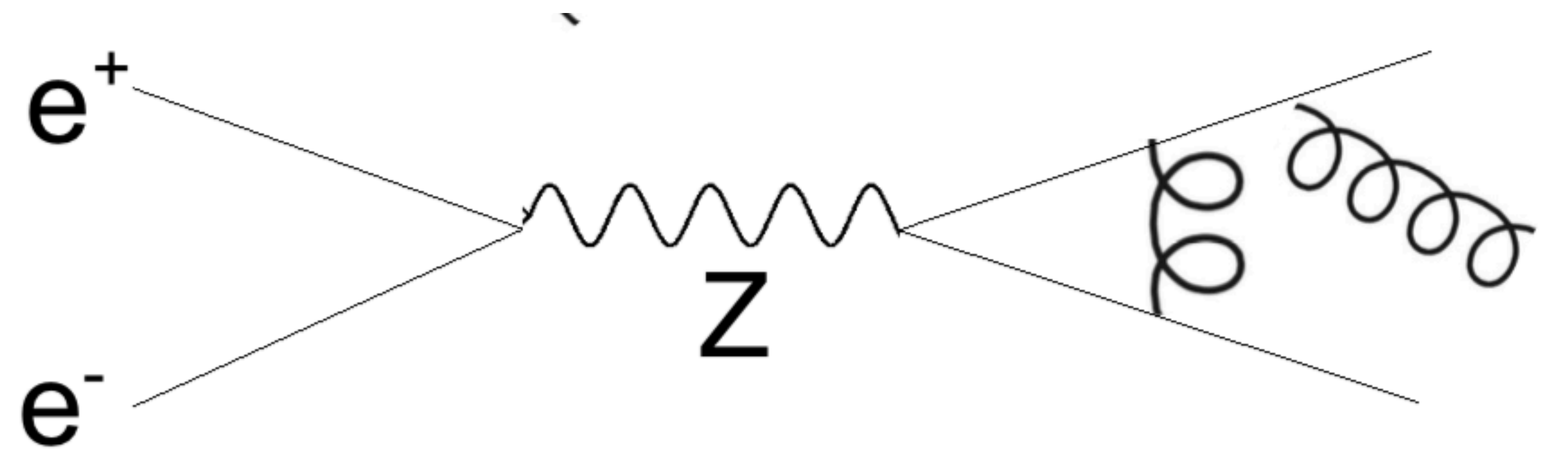
Phys. Rev. C 96 (2017) 024908



- Near side ridge and v_2 signals have been found at fairly low multiplicities in pp

- How do we isolate effects if signal is present in our ‘reference’ measurements?
- Can examine specific aspects of QCD using other systems

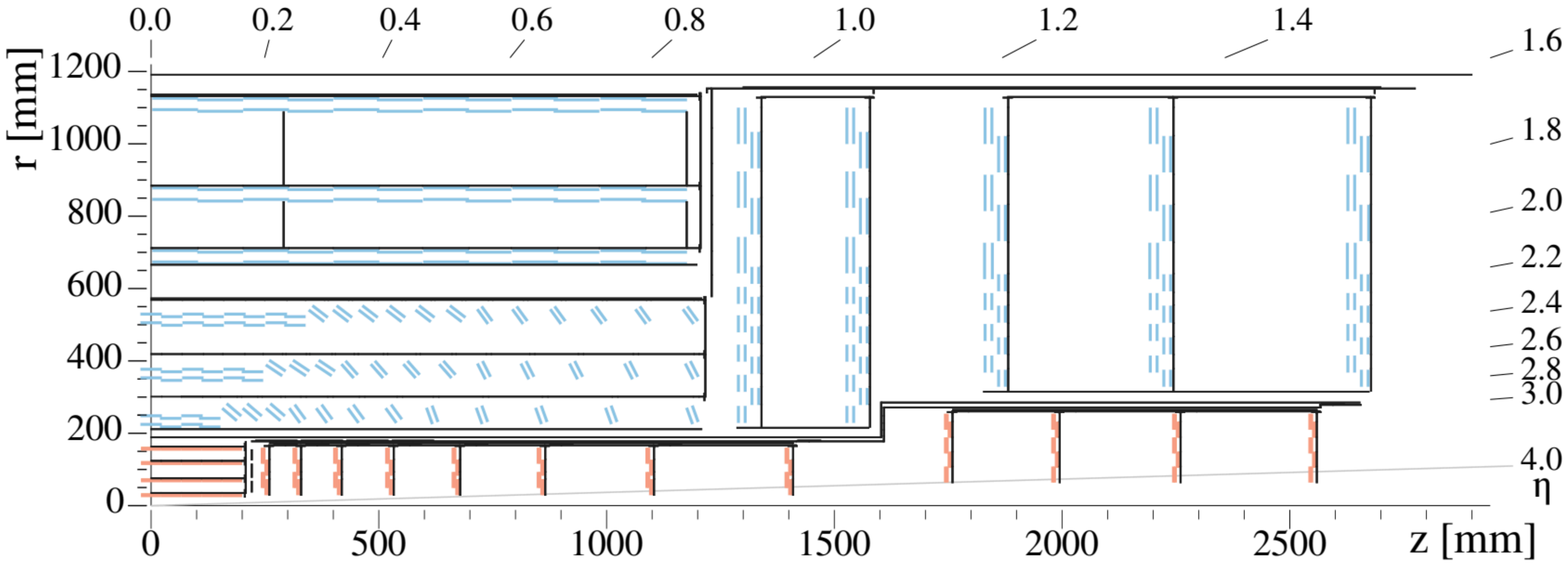




What detectors are needed?

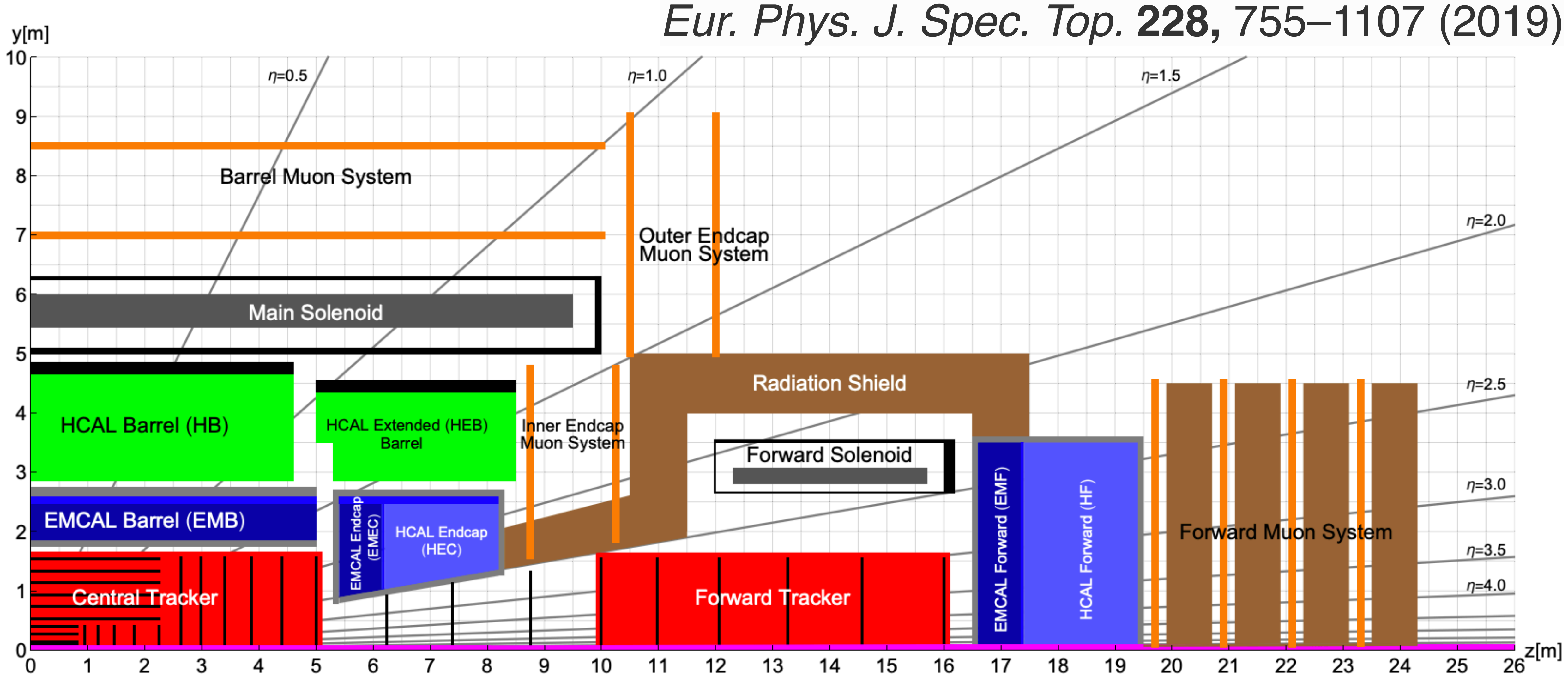
- Precise reconstruction of charged particle kinematics and multiplicities
- **Large η coverage and forward tracking** for boosted collision systems (ep, γA)
  - More accurate multiplicity measurements
  - More statistics for multiparticle analyses
  - Larger η gaps

CMS-TDR-014



HL-LHC
CMS Phase 2 Tracker
$|\eta|$<4

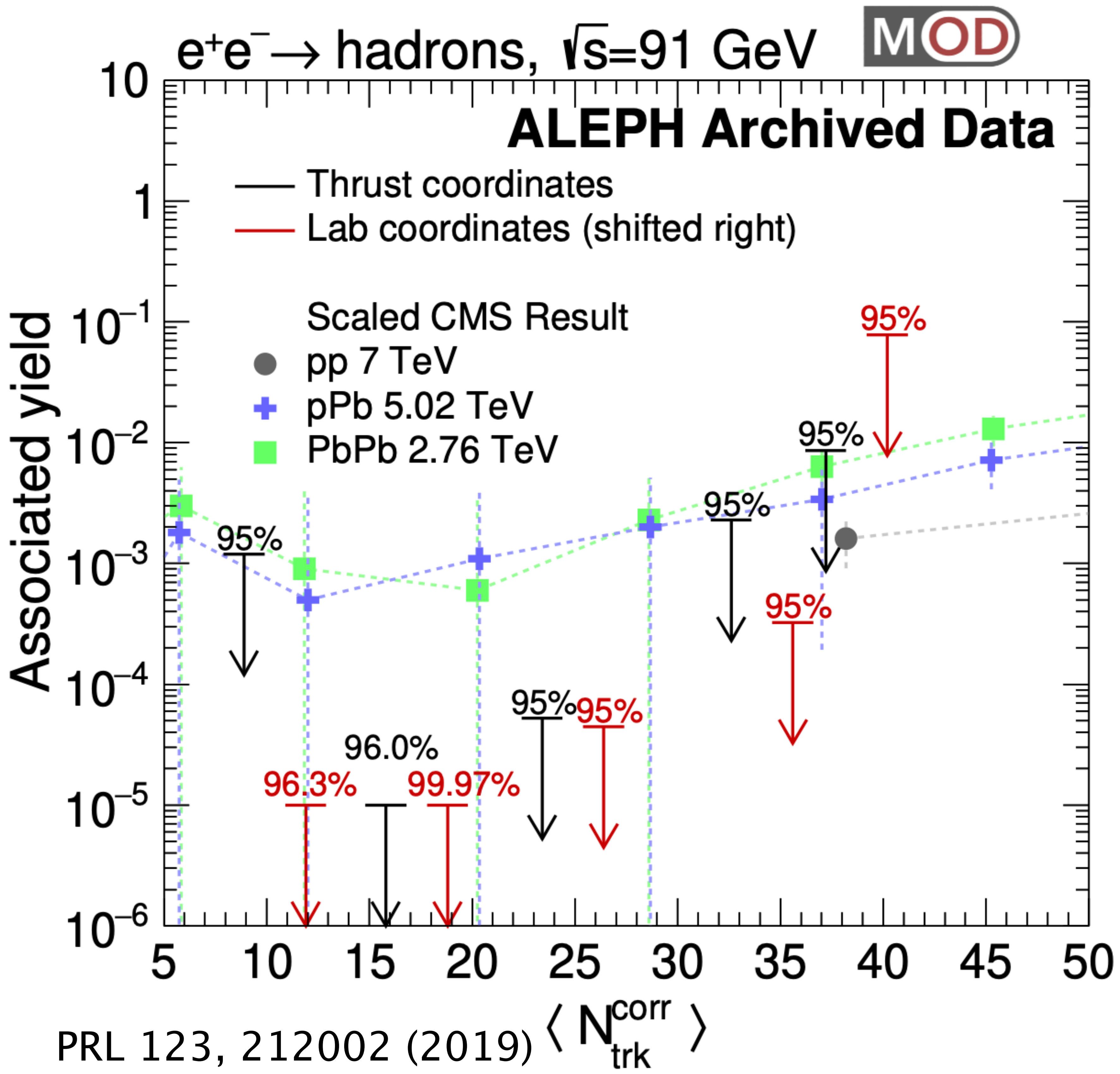
Eur. Phys. J. Spec. Top. **228,** 755–1107 (2019)



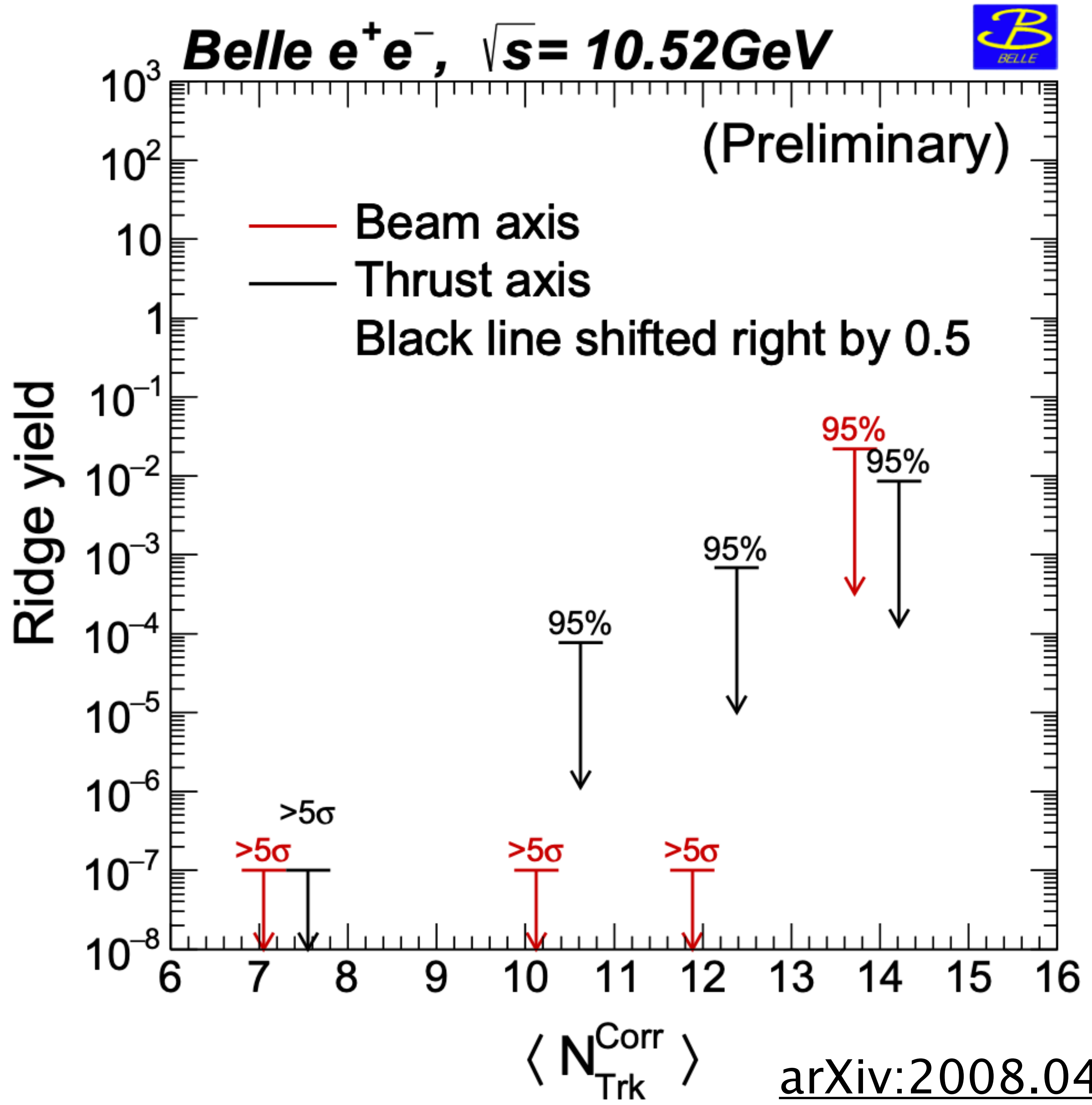
FCC-hh
Reference Detector
$|\eta|$<6

Existing e+e- measurements

- Will we see collectivity in e+e- if the energy density is high enough?
  - Would imply it is not an initial state effect?
  - Existing data from ALEPH and Belle see no sign of a ridge
- Multiplicity reach is limited by lumi (ALEPH) or energy (Belle)



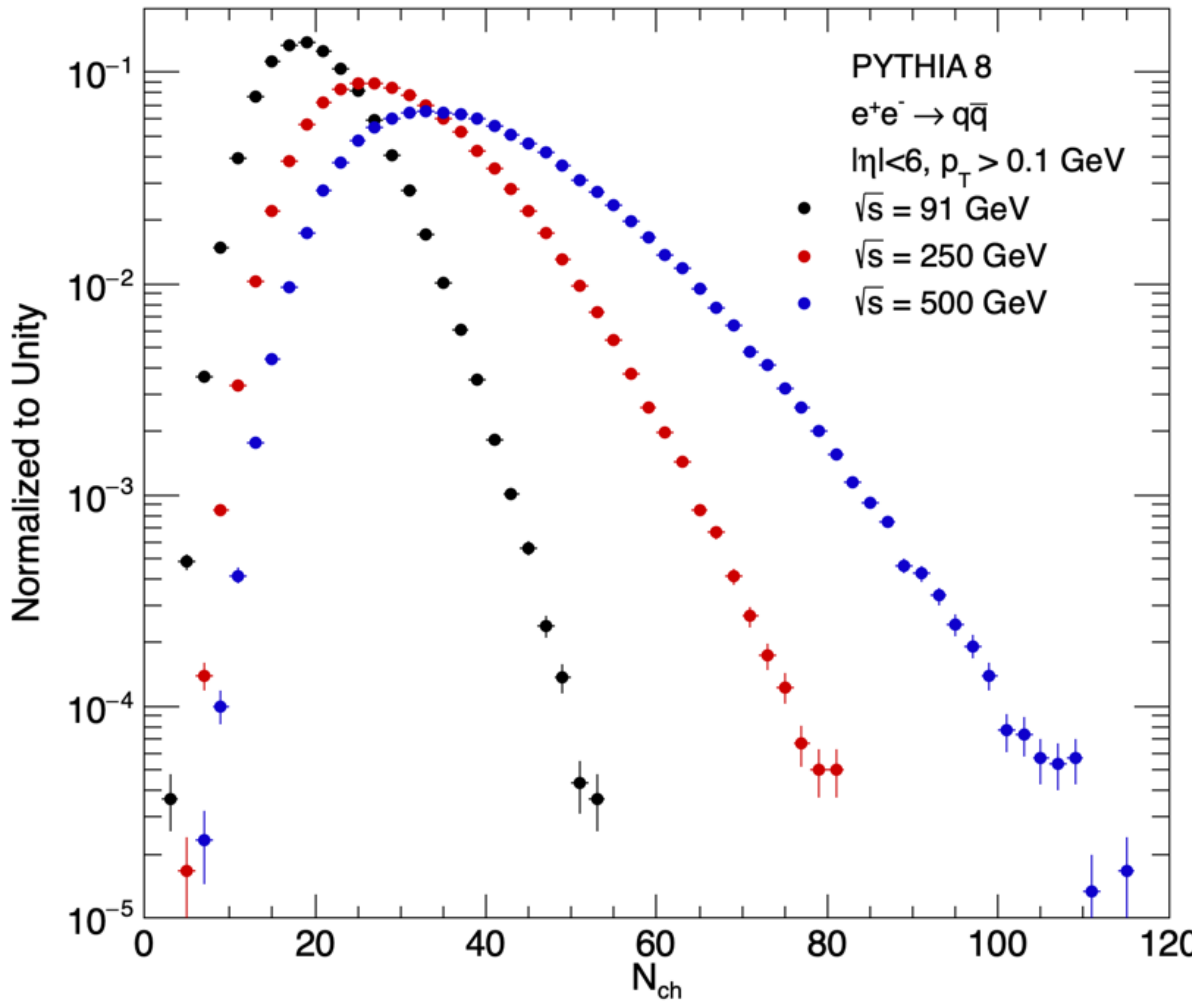
PRL 123, 212002 (2019)



arXiv:2008.04187

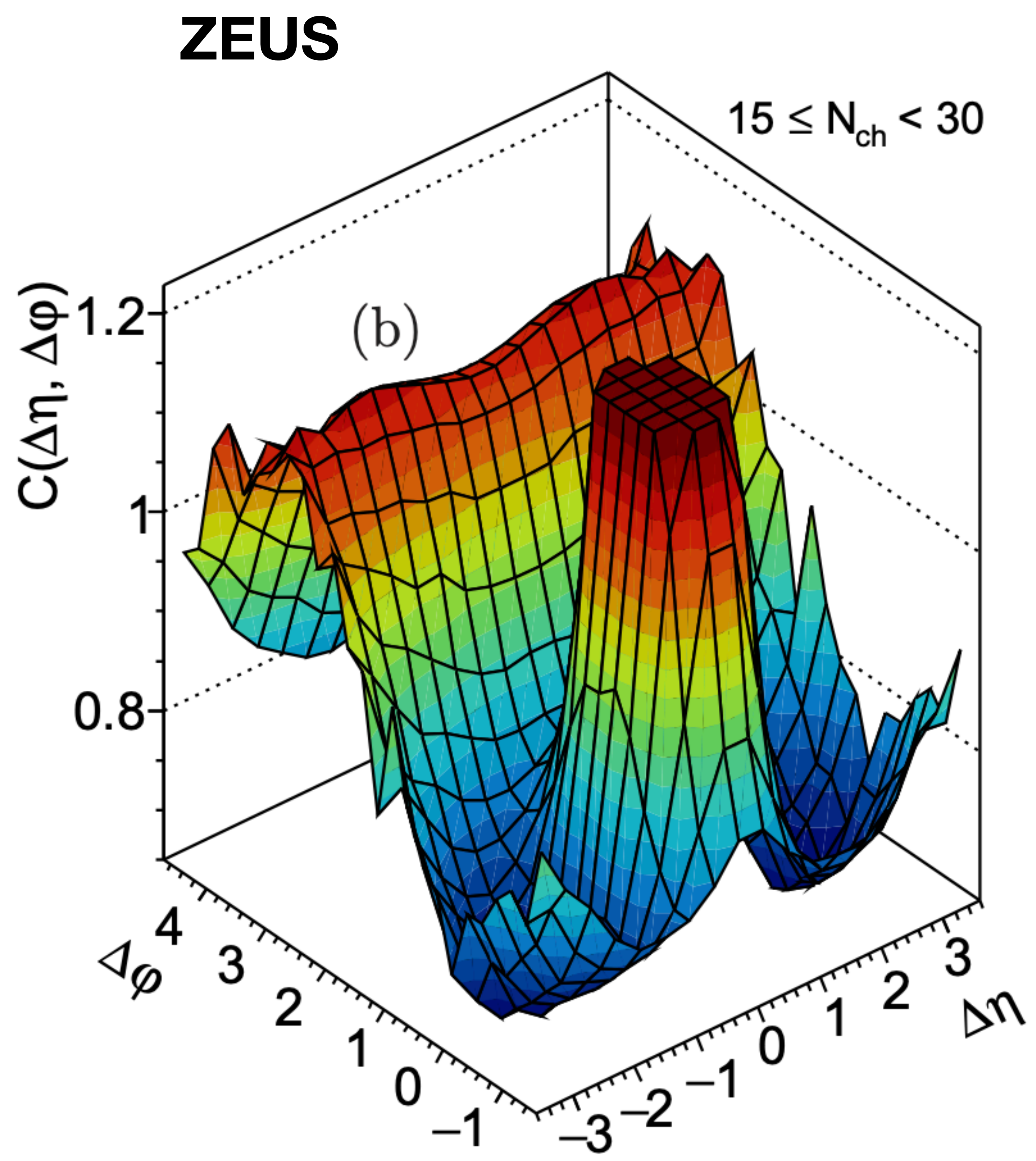
Future e+e- multiplicities

- Various proposals ILC/CLIC/FCC-ee could solve both these issues
- Multiplicity reach can extend 1.5-2x from energy increase alone
- Much greater inst. luminosity for more differential studies
  - FCC-ee: 3000x that of LEP 2
  - Multiparticle correlations, detailed PID studies, isolation of soft components

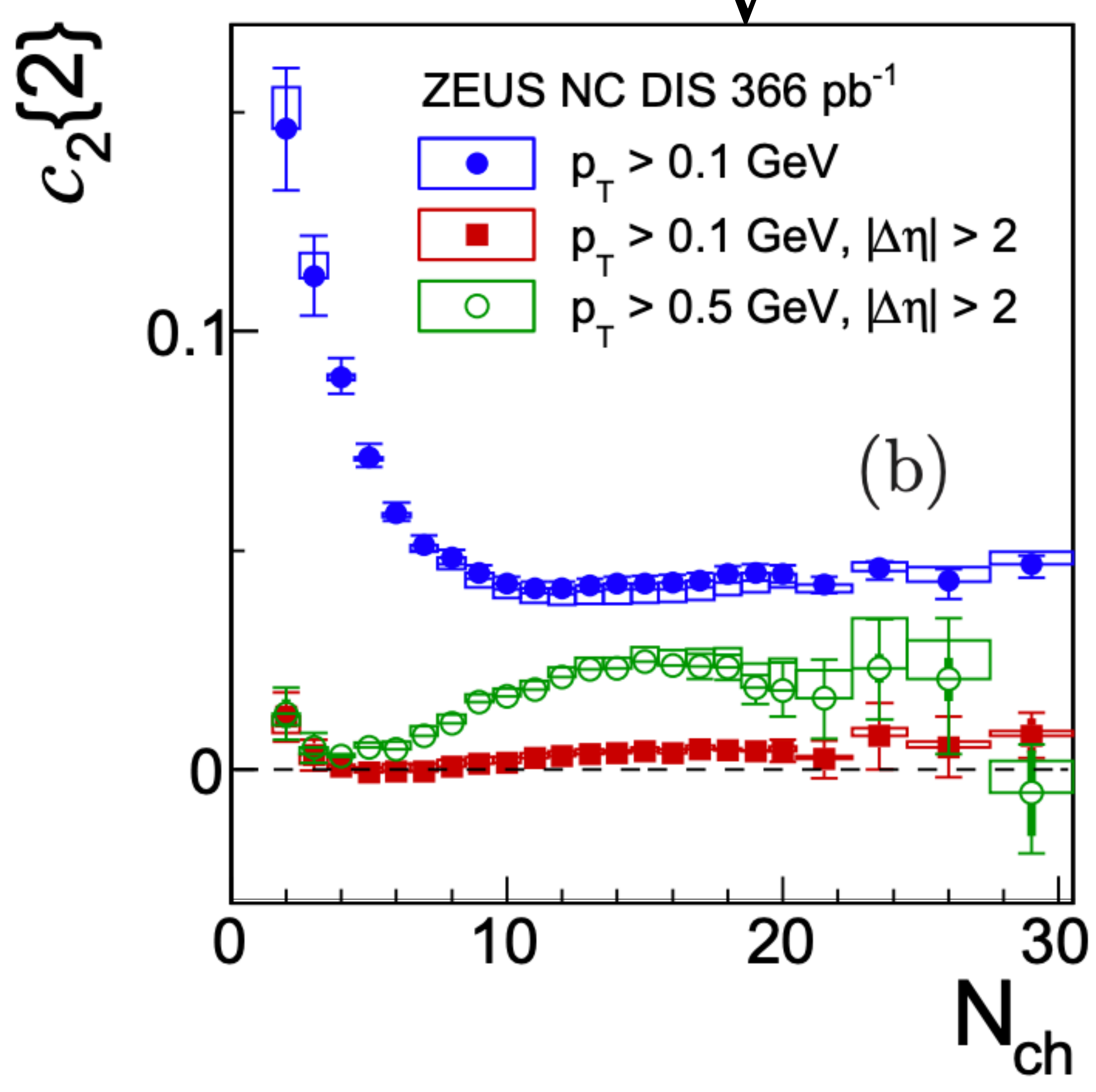


Existing ep measurements

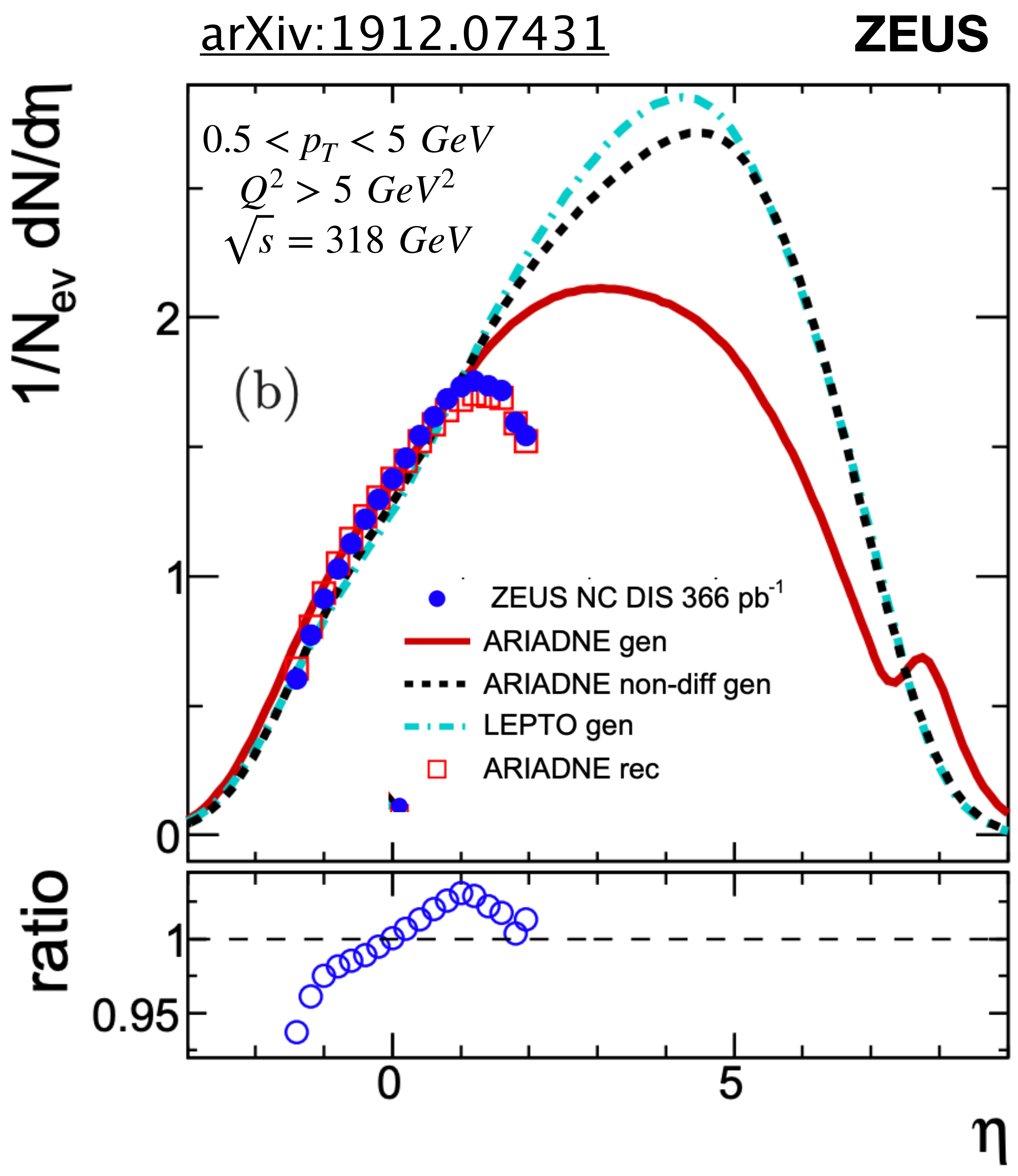
- Measured by ZEUS in HERA DIS data
- No evidence for collectivity; behavior can be explained by jet-like behavior
- Multiplicities measured up to 30
  - Most of the multiplicity out of acceptance



$c_2\{2\} = \sqrt{v_2}$

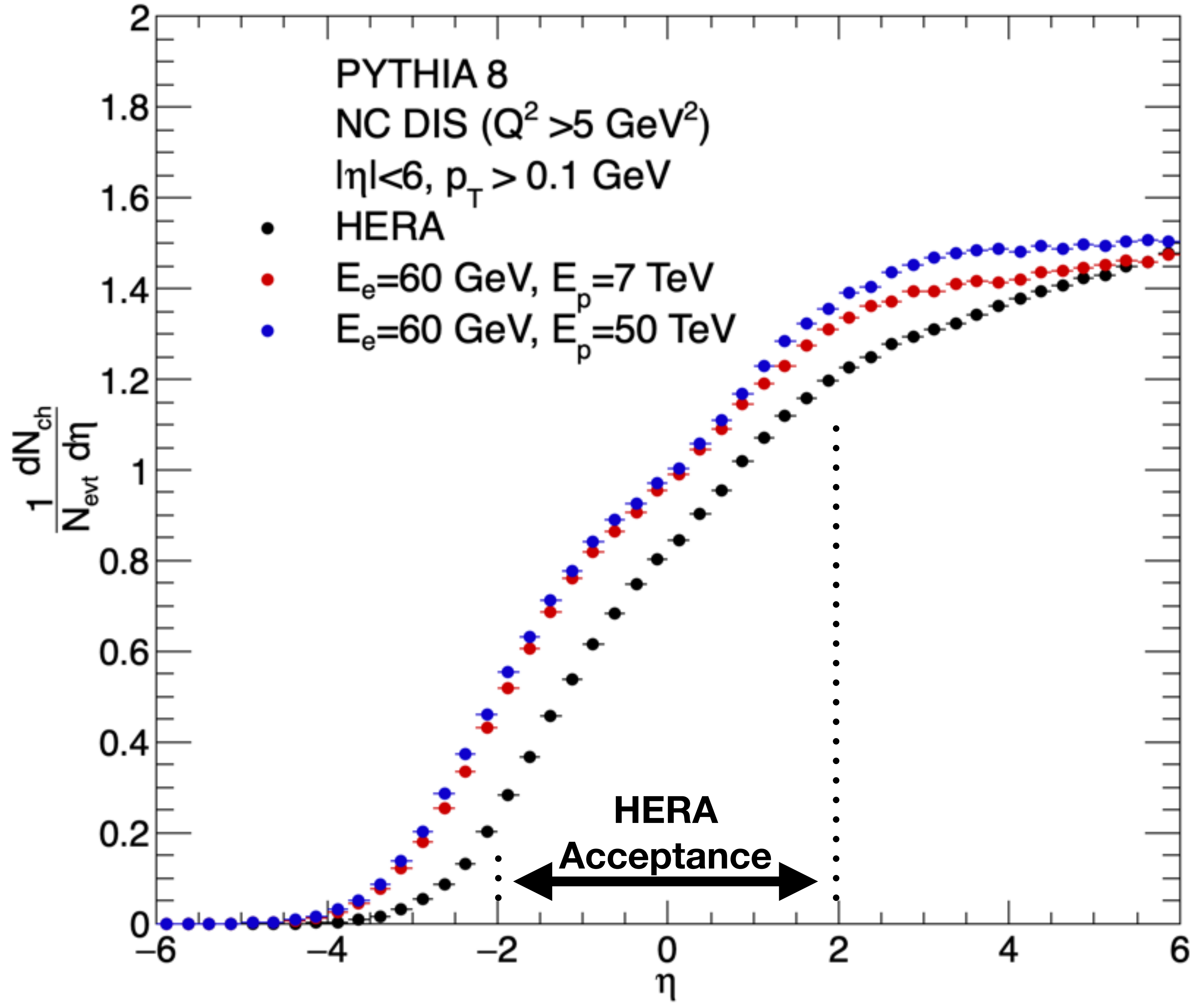


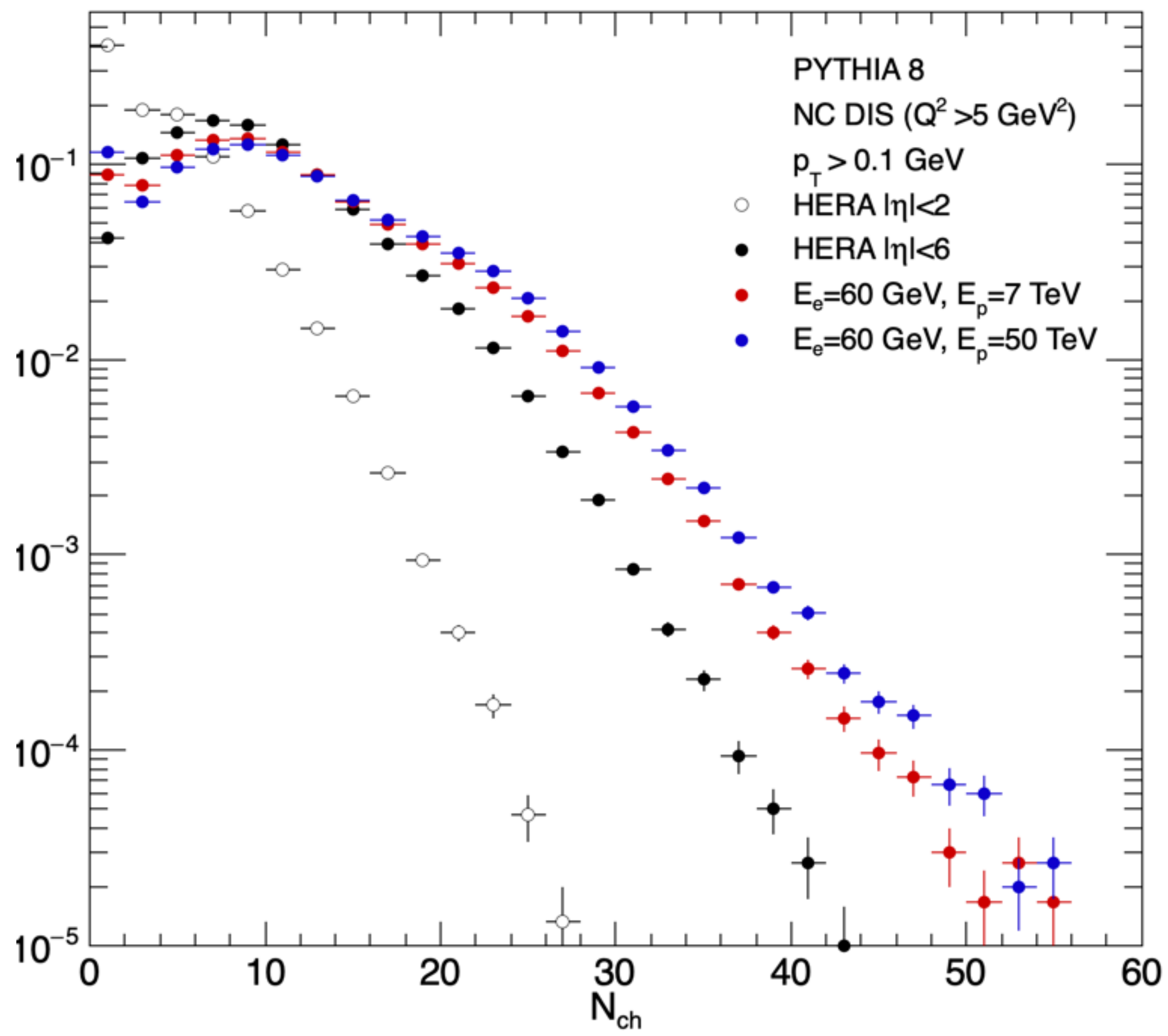
arXiv:1912.07431



Future ep DIS multiplicities

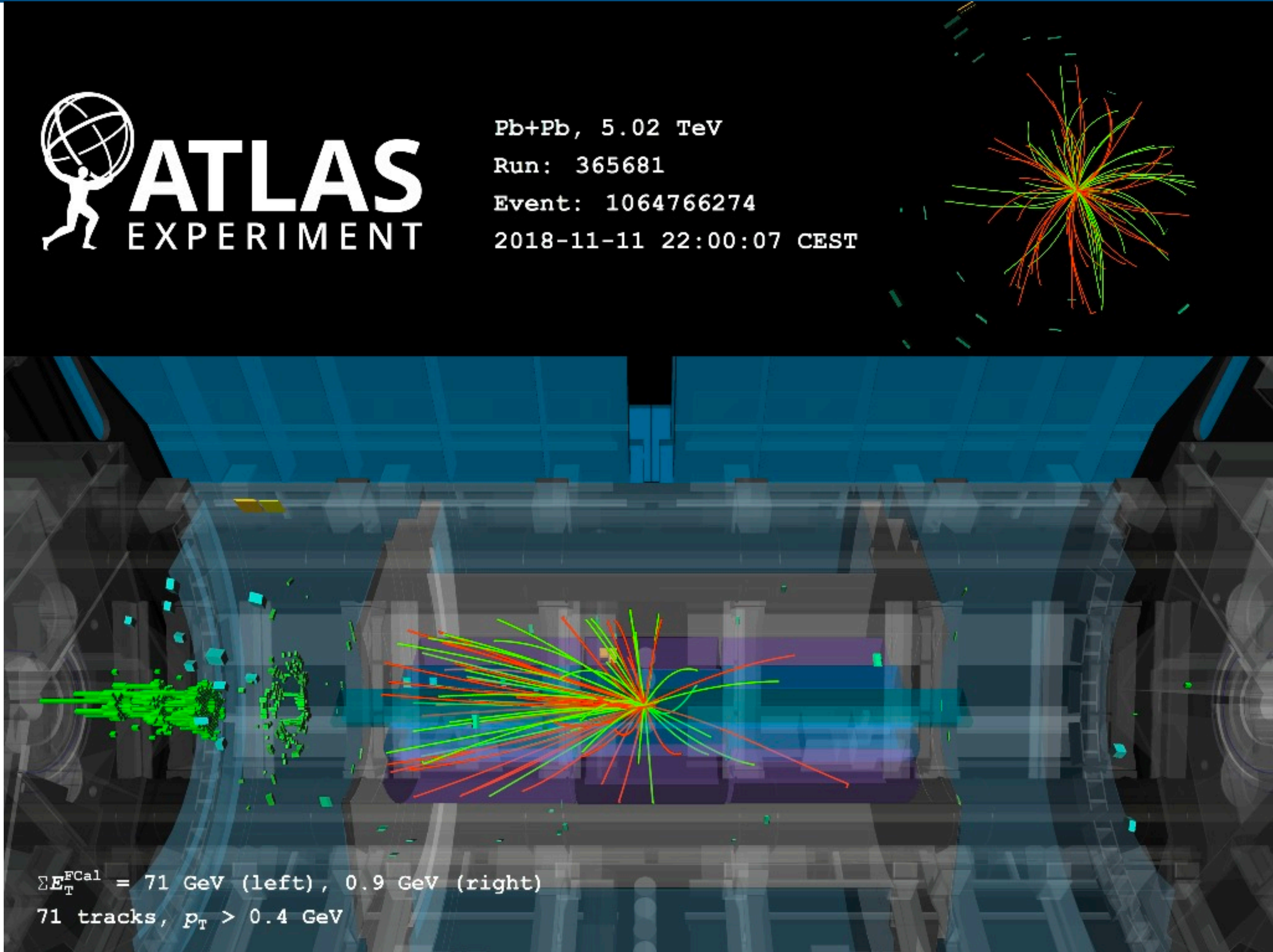
- Potential realizations via LHeC or FCC-eh with 60 GeV electrons
- Marginal increase in multiplicities from beam energy
- Forward acceptance key for capturing large fraction of total multiplicity
  - Potential to reach multiplicities similar to where collectivity is seen in pp





γA collisions

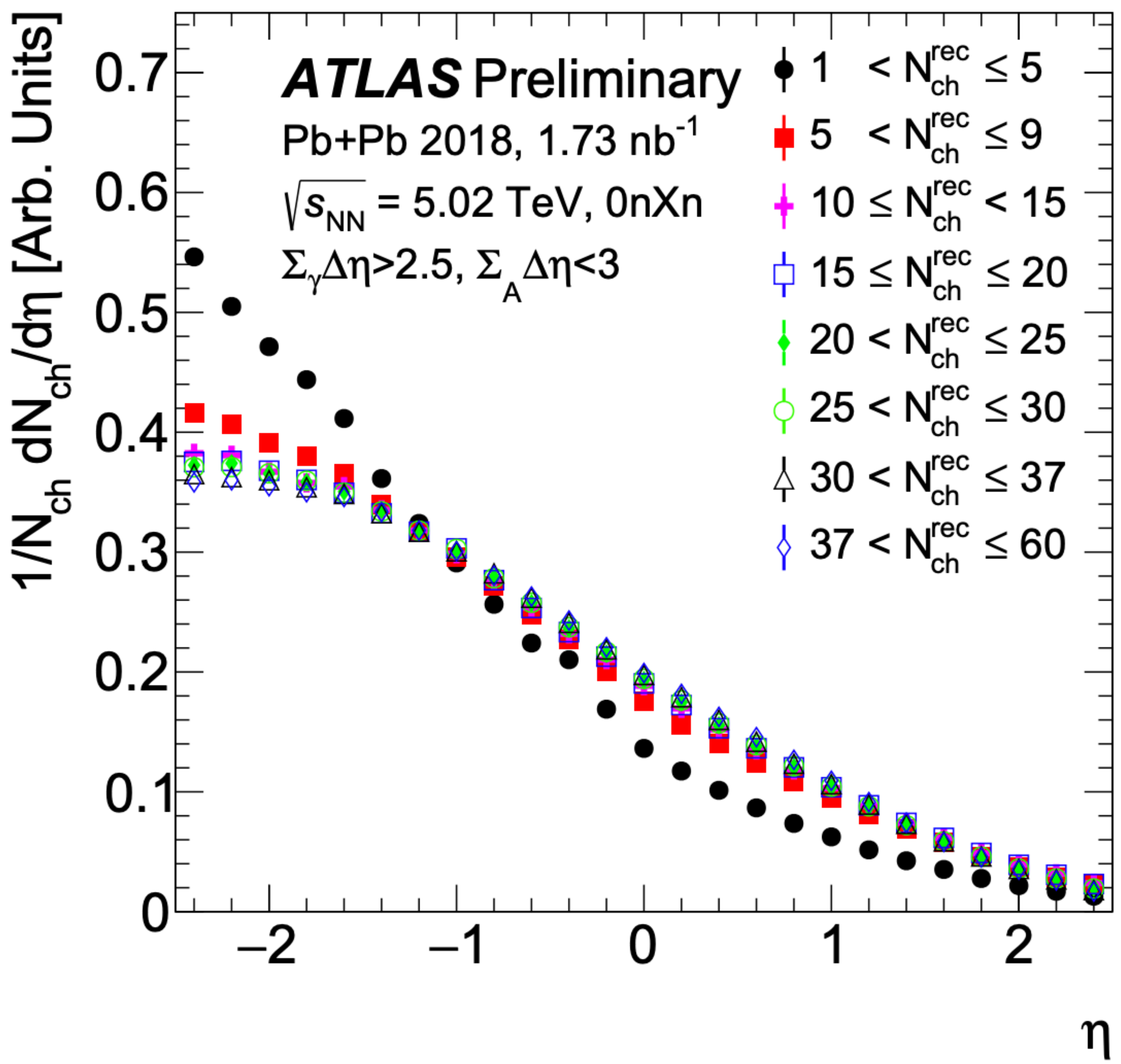
- Strong EM fields around ions can be treated as photon flux
- Results is one-sided collisions
- Enhanced by Z^2
- Photon energy and boost of the system cannot be directly controlled

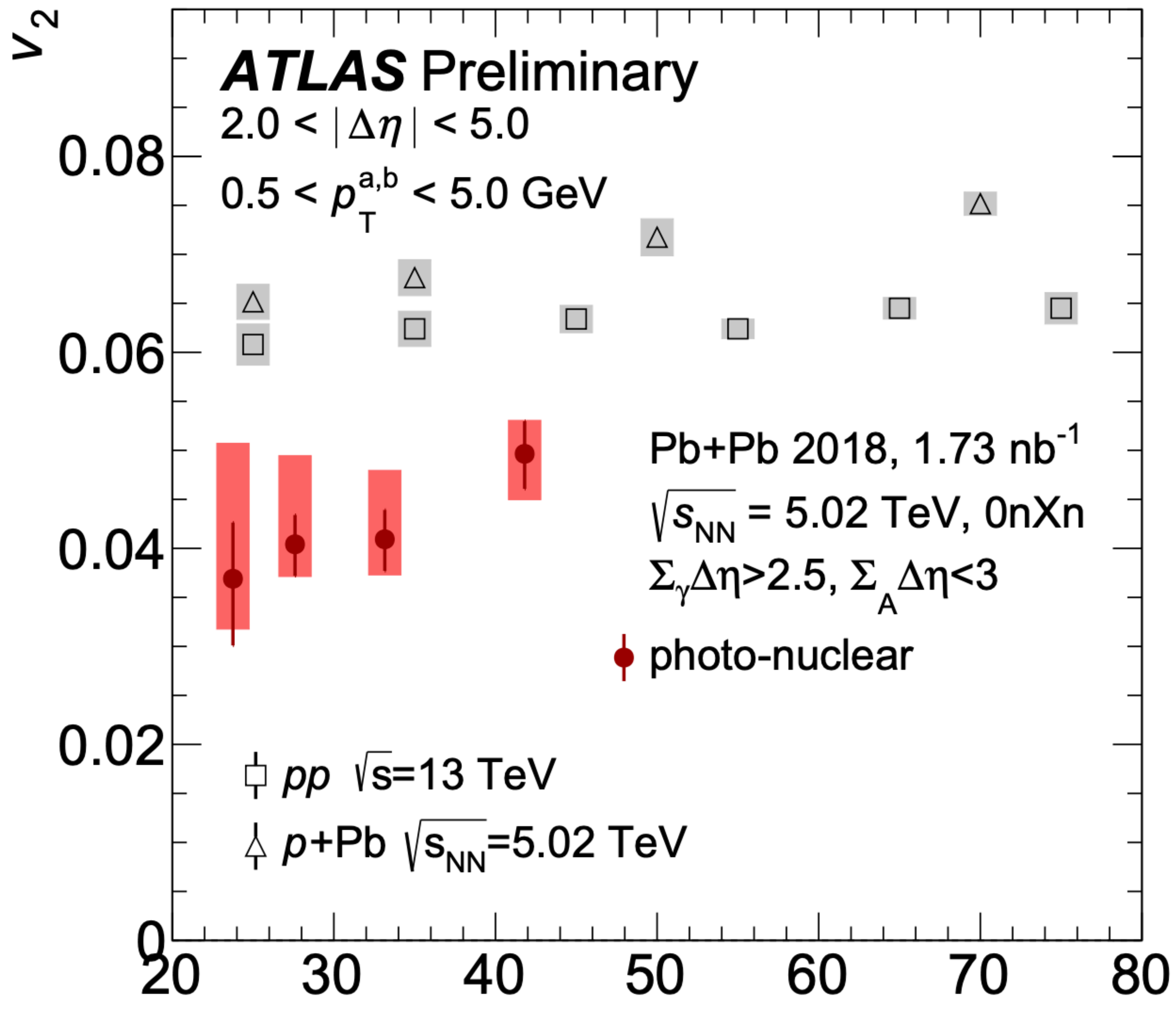


Existing γA measurements

- Nonzero v_2 signal seen in γA collisions

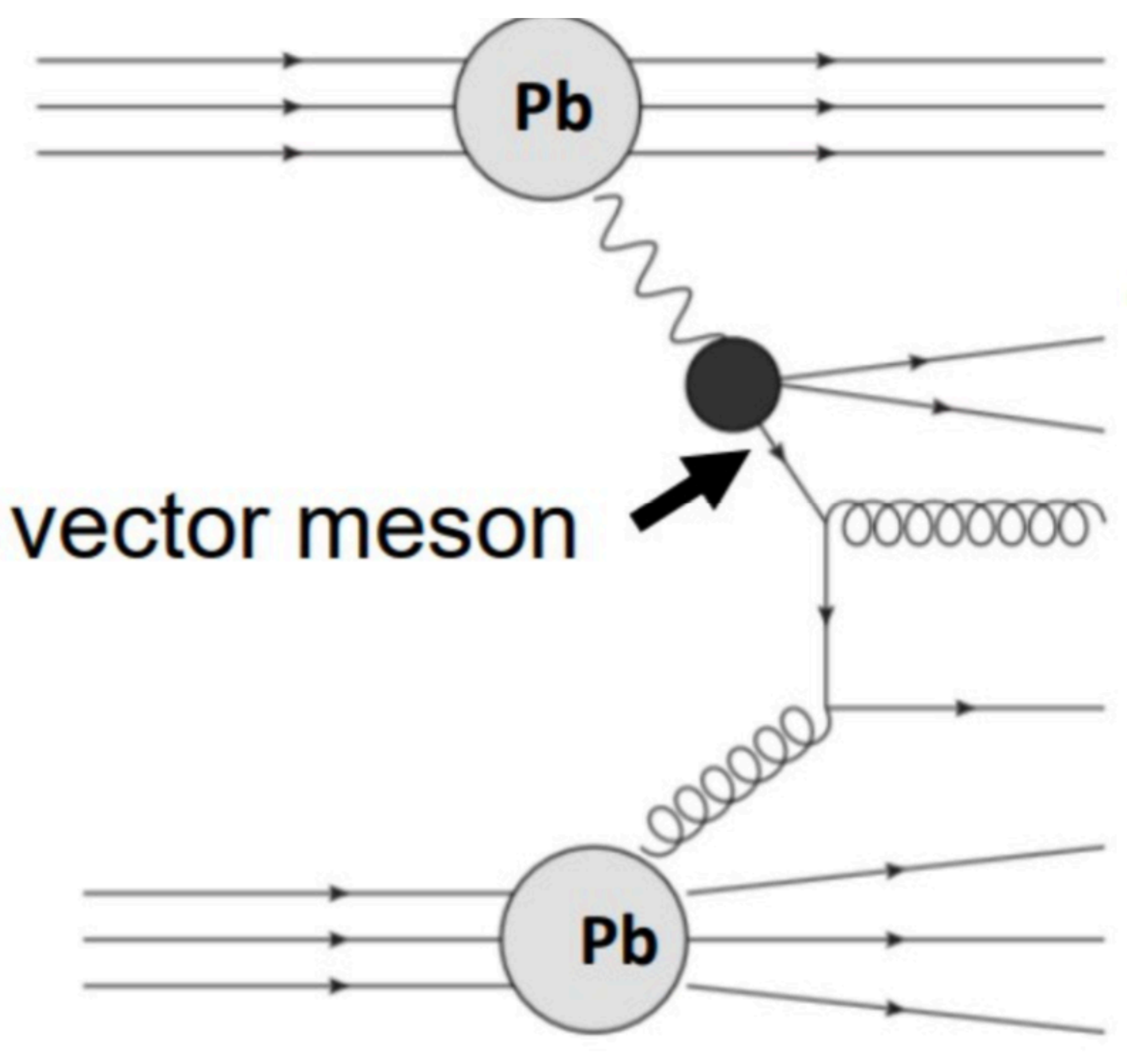
- Up to ~50 charged particles
- Particle density peaking at edge of detector





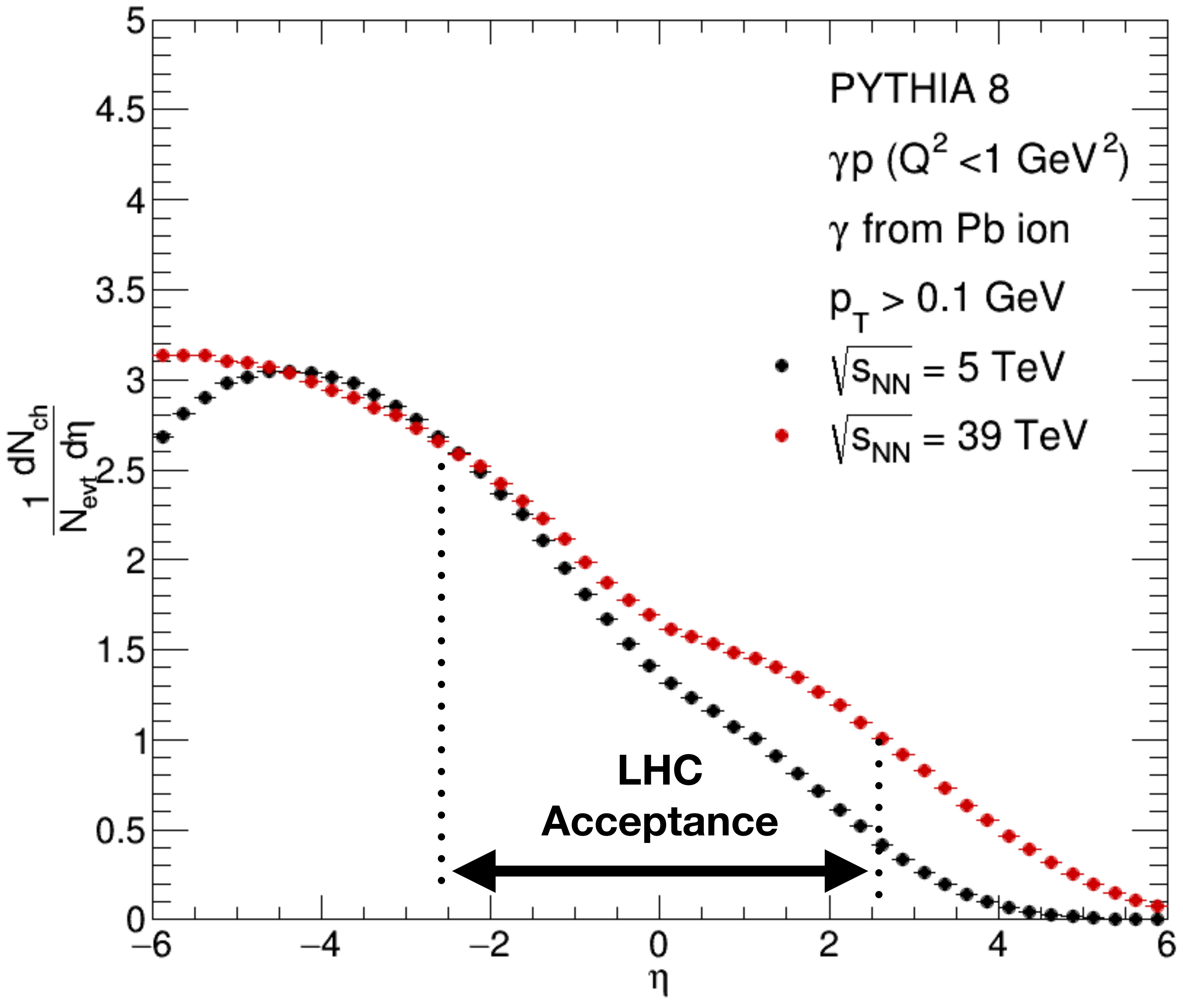
ATLAS-CONF-2019-022

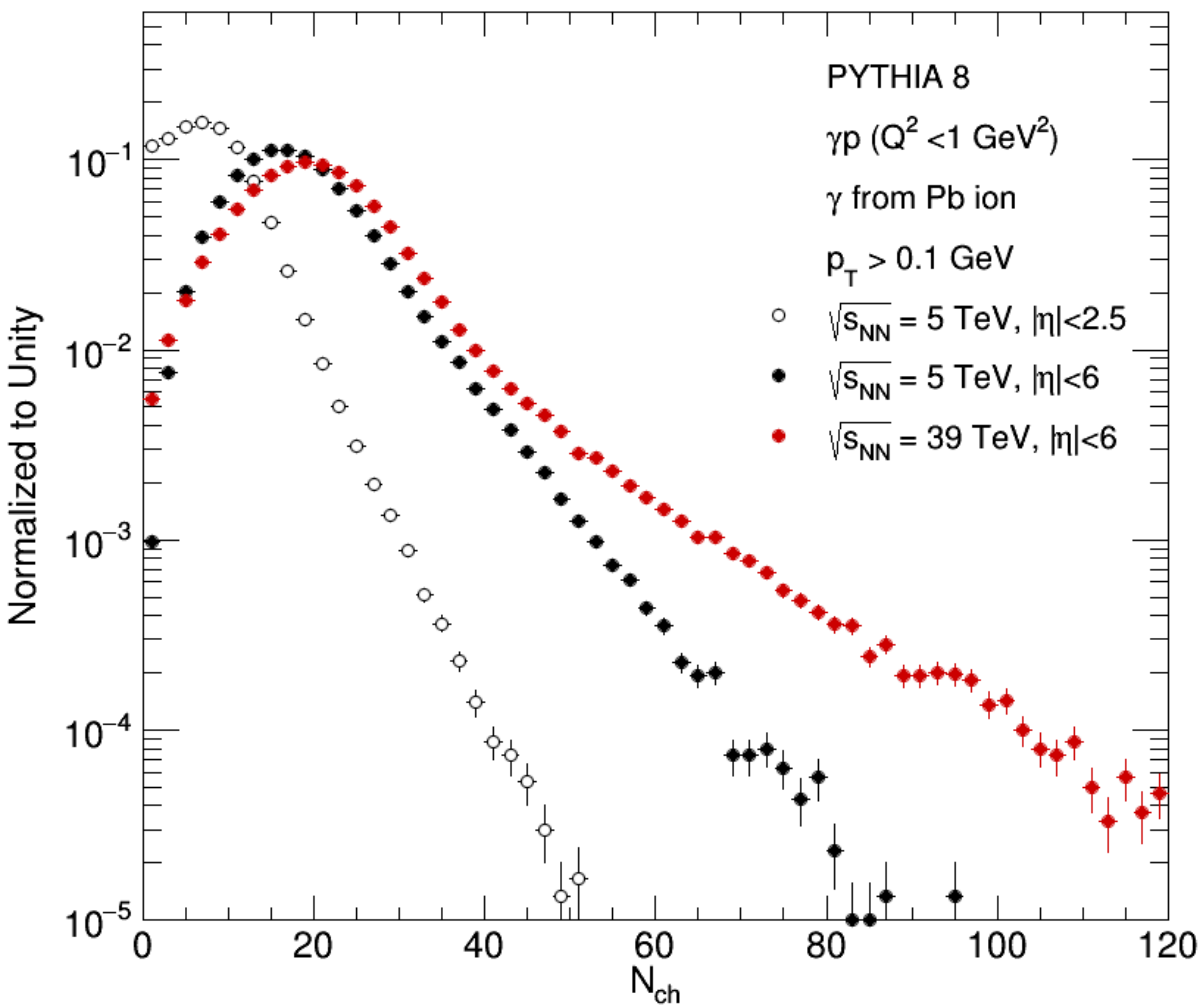
Can be thought of as a ρA or ωA collision (vector meson dominance)



Future γA measurements

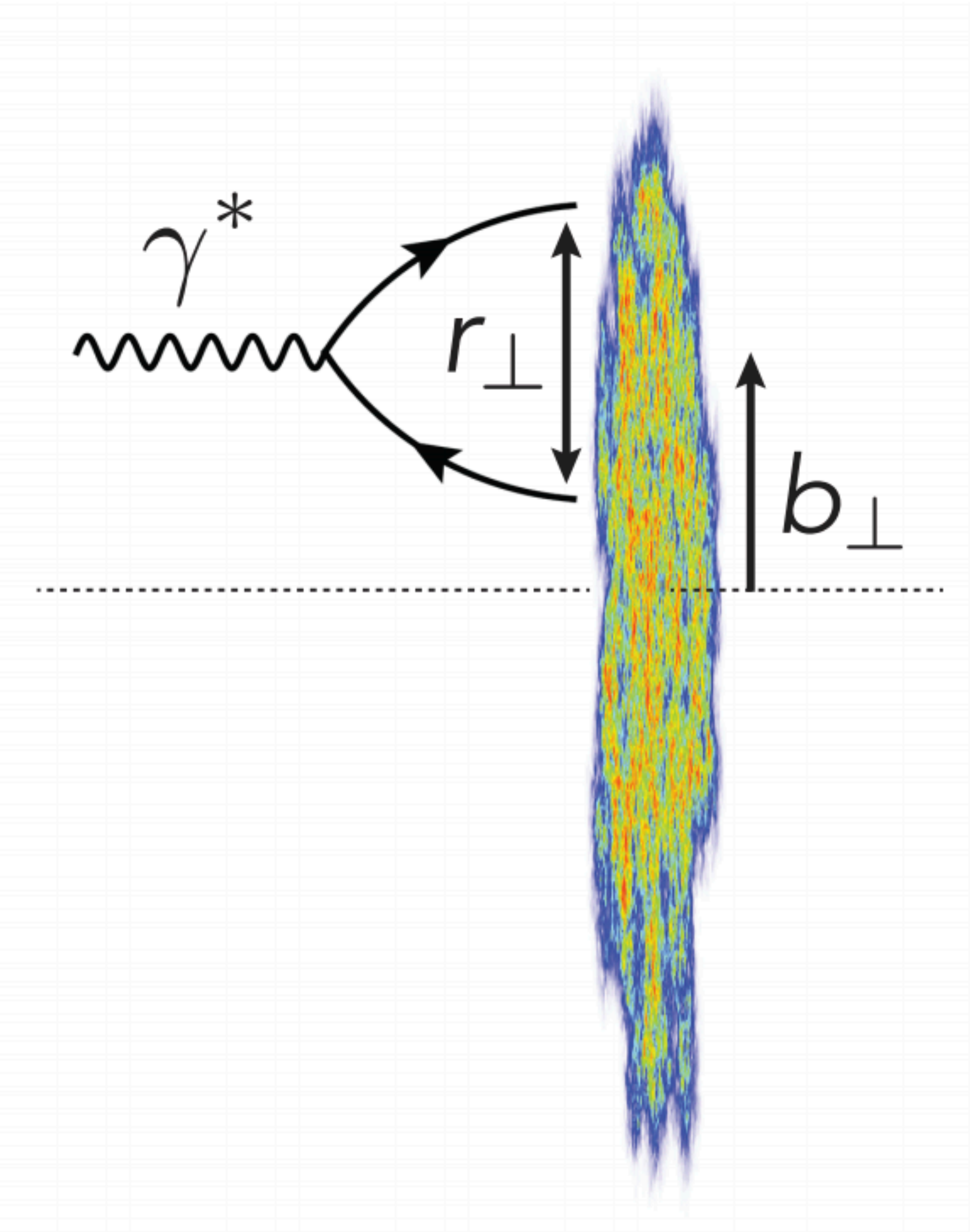
- Use Pythia to generate photon flux around a Pb ion
  - Simulate γp collisions (not full ion) at LHC and FCC-hh energy
- Forward tracking improvements will greatly improve multiplicity reach
- Continue to explore with LHC data in Run 3/4
  - More differential measurements with increased luminosity





Synergies with the EIC program

- The Electron-Ion Collider program is designed to probe gluon saturation (CGC)
- Results could be available before a next-gen collider is built
- Potential to apply what we learn at higher energies
  - Do we find consistent results when looking at higher energy ep or γA?



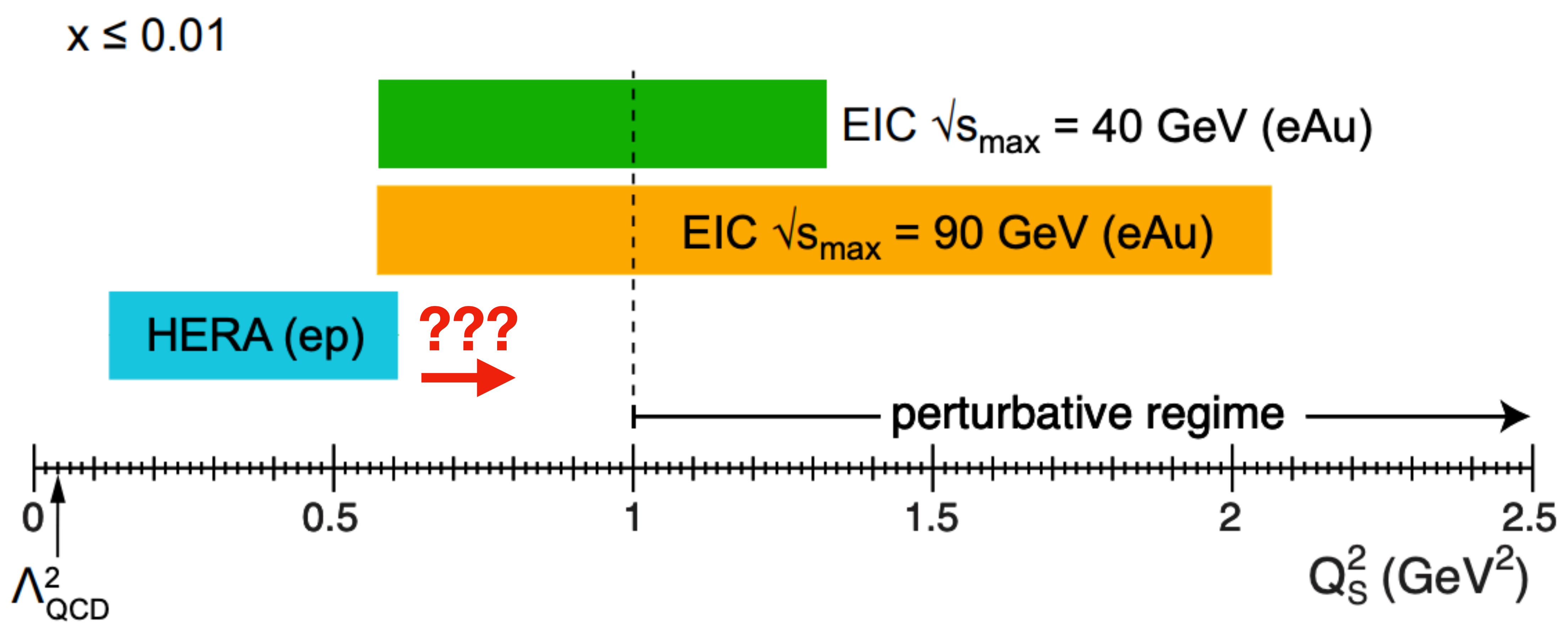
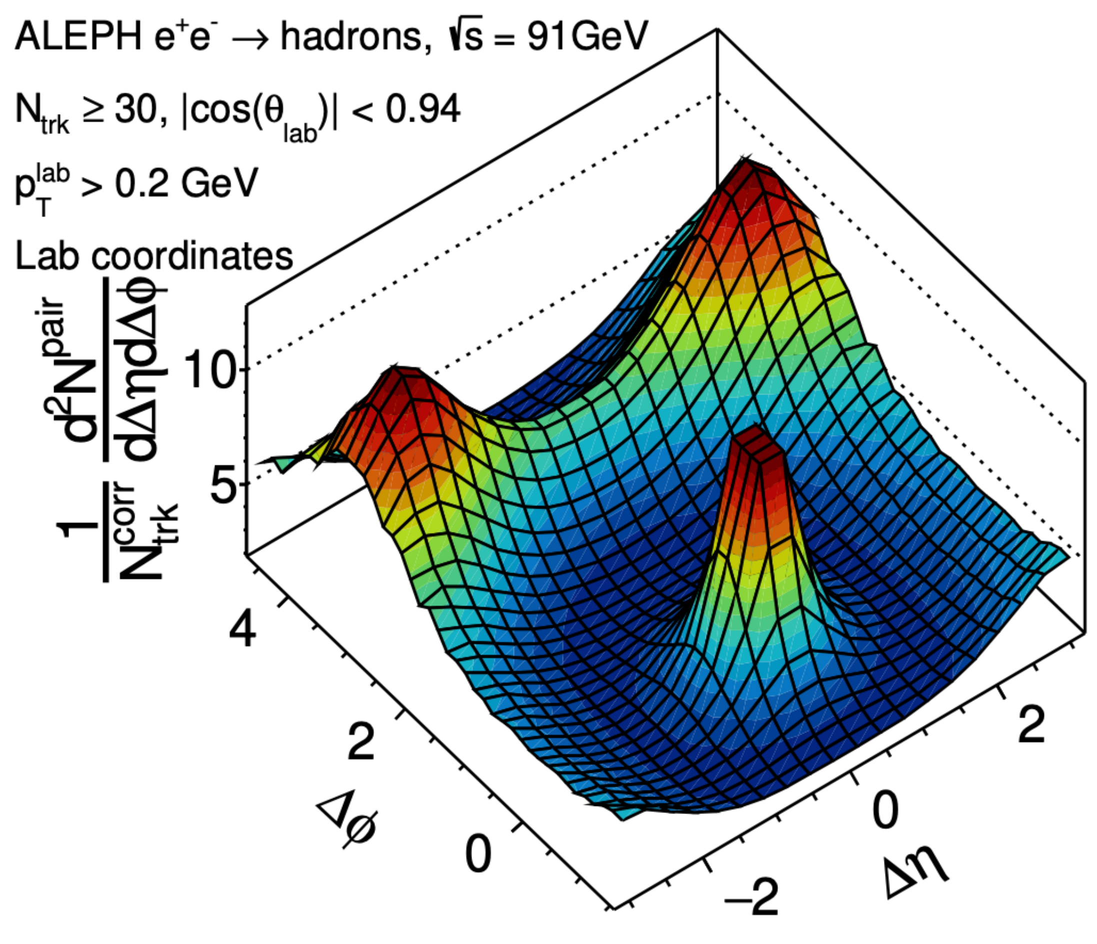


Figure 6: Accessible values of the saturation scale Q_s^2 at an EIC in e+A collisions assuming two different maximal center-of-mass energies. The reach in Q_s^2 for e+p collisions at HERA is shown for comparison.

arXiv:1708.01527

Conclusions

- ‘Extra’ small systems are references to collective phenomena we observe in small systems
- LHC Run 3 and 4 can still provide interesting info regarding γA collisions
- Future colliders will allow access to higher energy densities and multiplicities
- Larger η coverage and forward tracking benefit asymmetric collision measurements
- Potential synergies exist with knowledge to be gained with the EIC



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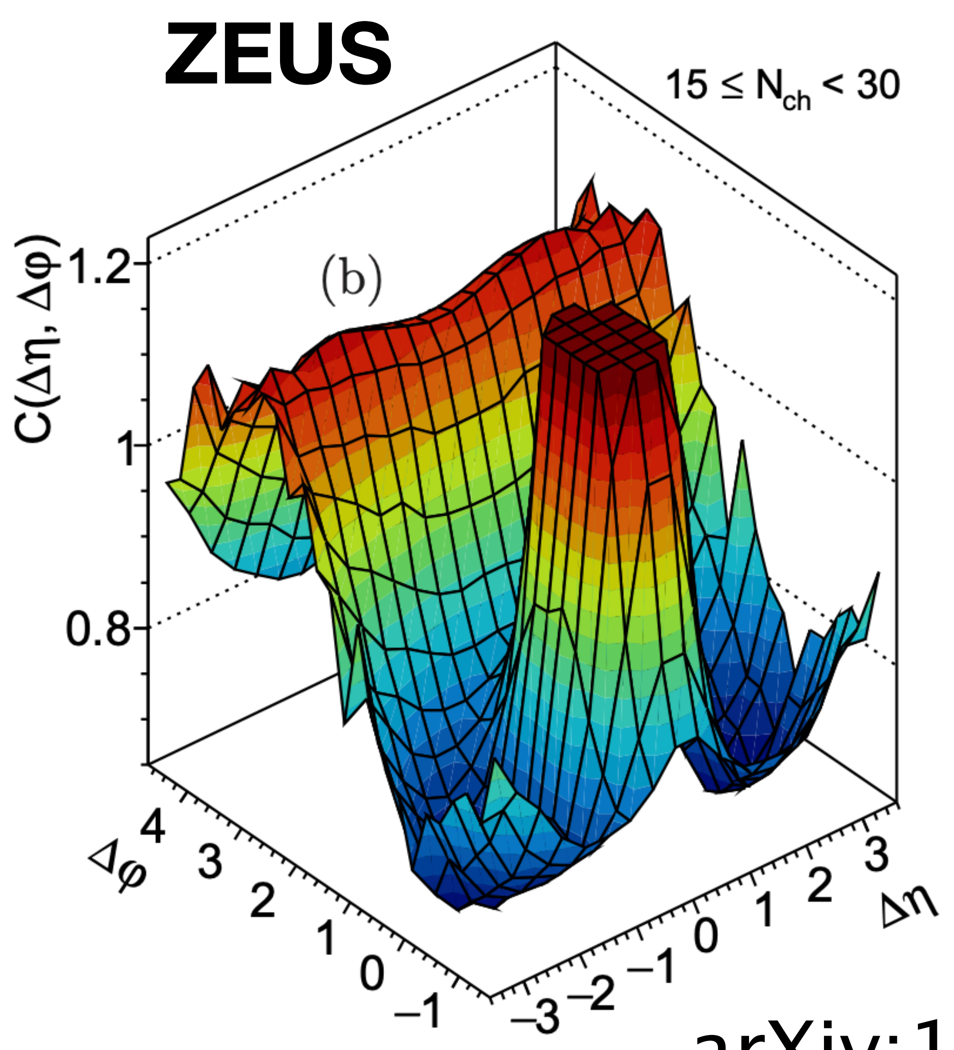

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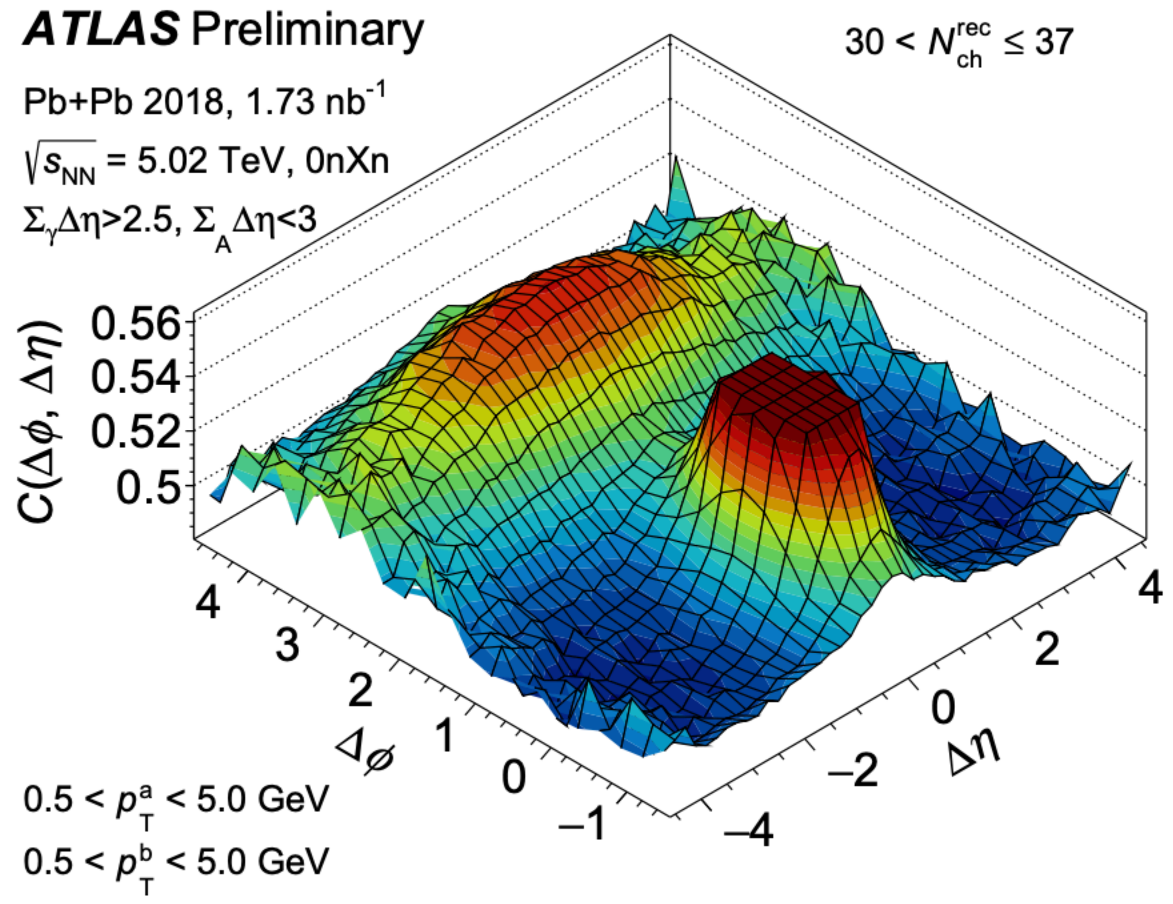

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Thank you!