A forward/backward spectrometer for detector 2

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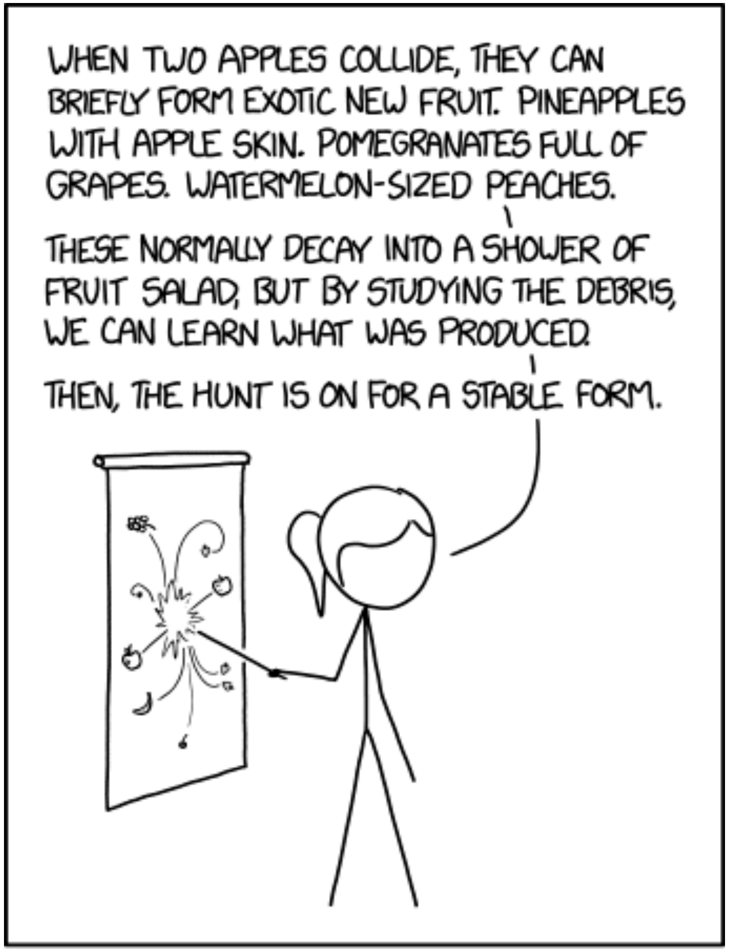
- Forward and backward physics
- Differentiating from ePIC
- LHCb as an example
- Thoughts on a detector design
- Conclusions

Be consistent re. forward and backward



HOW NEW TYPES OF FRUIT ARE DEVELOPED

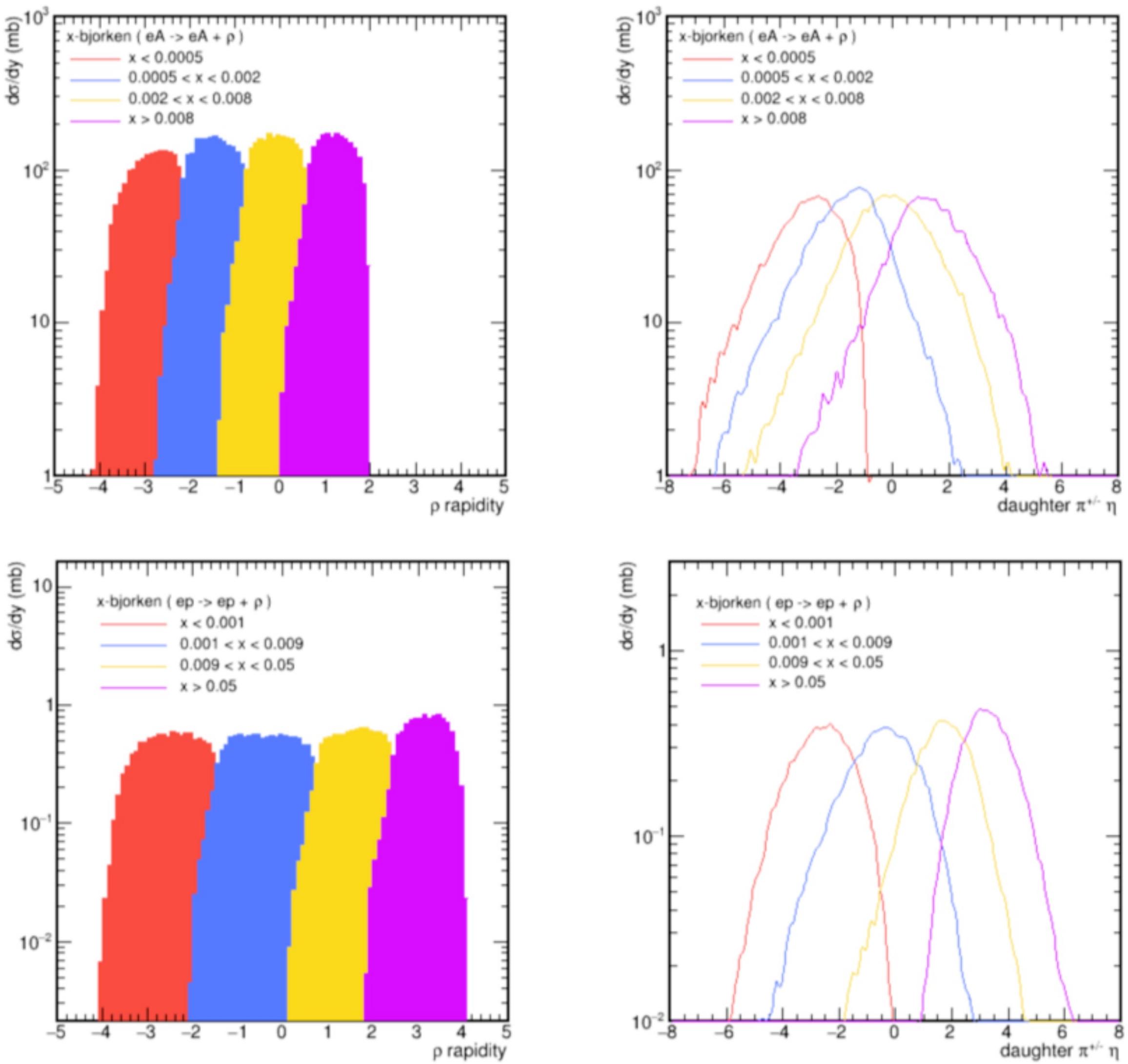
https://xkcd.com/1949/

Bjorken-x and rapidity

- In exclusive production, there are simple relations between:
  - photon energy (k)
  - final-state mass (M_f)
  - rapidity(y)
- $y = \ln(M_f/2k) = -\ln(Mf/2x\gamma mp)$
- High-photon energy (near kinematic limit) -> large rapidity
  - Without forward-enough instrumentation, we miss the highest-energy reactions that probe the lowest x values
- Near threshold production -> large negative rapidity
  - Conversely, without adequate backward-enough instrumentation, we miss near-threshold reactions, including important tests like Υ production
- A second detector should concentrate on these regions. ePIC will cover mid-rapidity well.

The ρ^0

- $10^{-4} < x < 1$ corresponds to $-4 < y < 4$
- Coverage up to rapidity $|y|$ requires coverage to $|\eta| > |y|+1$



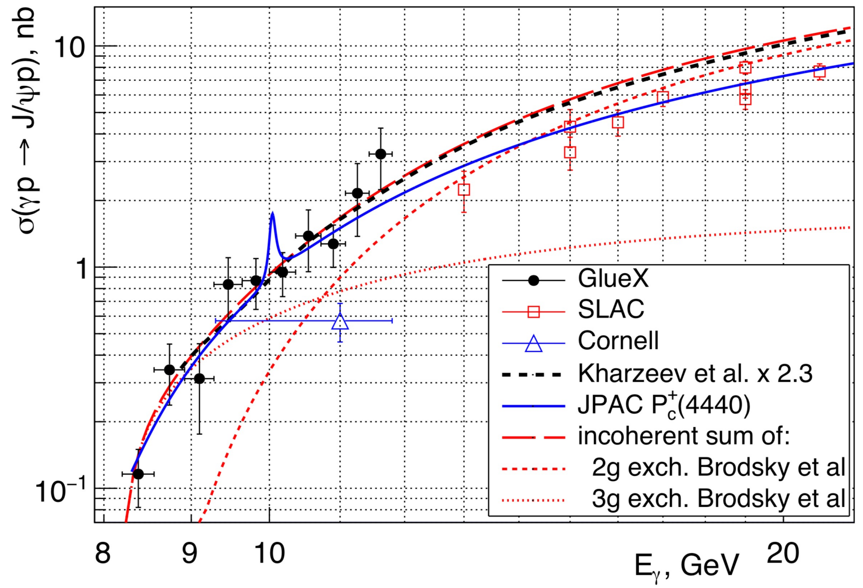
eAu
18 GeV * 100 GeV

ep
18 GeV * 275 GeV

J. Arrington *et al.*,
arXiv:2102.08337

Near threshold quarkonium production

- Near-threshold quarkonium production is sensitive to new mechanisms (i. e. 3-gluon exchange)
  - GlueX data favors a mix gluon exchange for J/ψ
- Sensitive to near-threshold
  - $P_C^+(4440)$ == J/ψ p
    - Pentaquark candidate

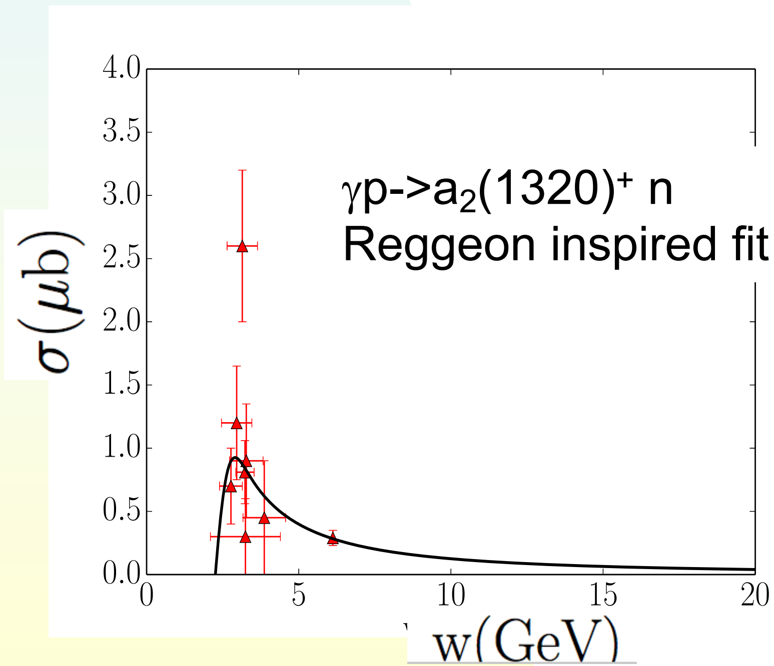


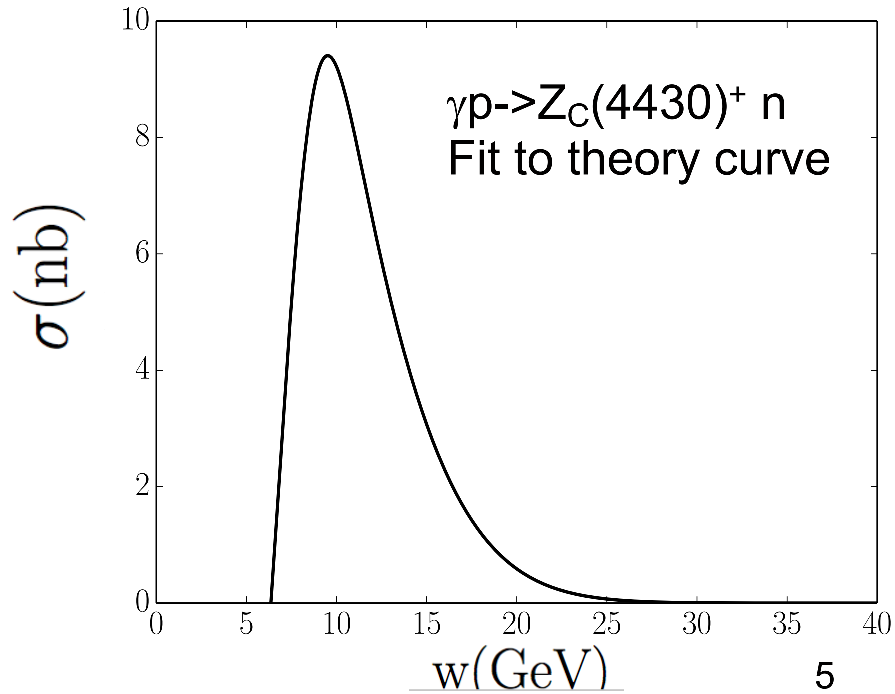
- EIC will study ψ', Υ states and probe the Q^2 dependence of multiple resonances
- For nuclei, near-threshold or sub-threshold production is sensitive to short-range nuclear correlations.
- Requires good acceptance in the ion-going direction

GlueX Collaboration, PRL **123**, 072001 (2019)

Reggeon exchange and forward production

- Examples: the $a_2^+(1320)$ standard candle and the exotic $Z_c^+(4430)$
- Use data/calculations of $\sigma(\gamma p\text{->}X+n)$ as input to eSTARlight to predict $d\sigma/dy$ for the same process in EIC collisions/
  - Use the same Q^2 scaling as the ρ (for the a_2) and J/y (for the Z_c)

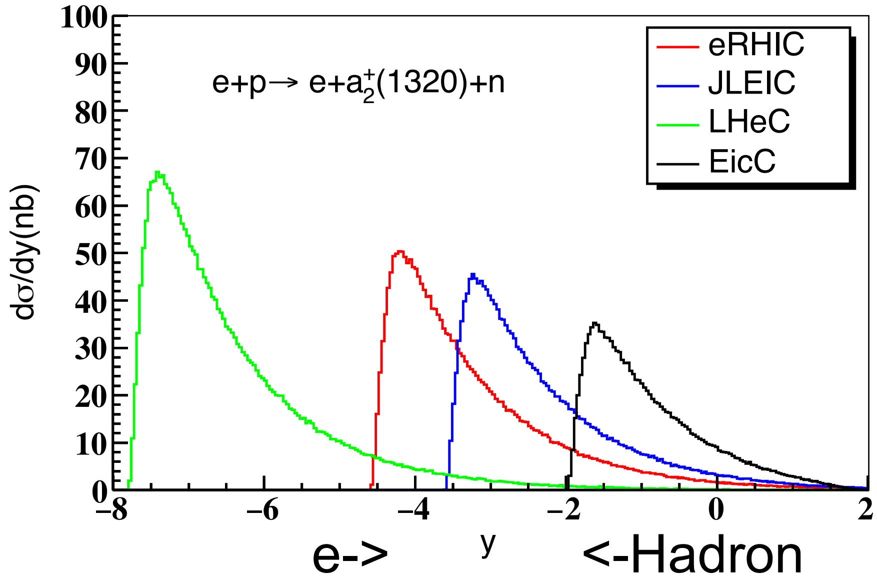


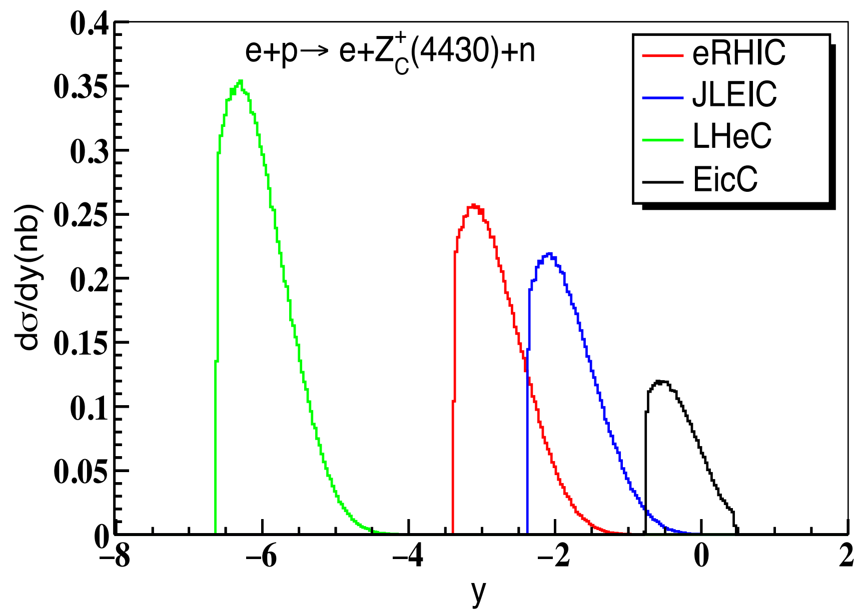


PRD(93)074016 & PRC(83)065203

$a_2^+(1320)$ and $Z_c^+(4430)$ production in ep collisions at the EICs

- The $a_2^+(1320)$ is mainly at negative rapidity
  - σ ~80 nb at eRHIC
    - Copiously produced
- The $Z_c^+(4430)$ is heavier, and so somewhat more centrally produced.
  - σ is 0.26 nb at eRHIC
- Both require good ion-going acceptance to be observable
- Both might be easier to observe at lower beam energies

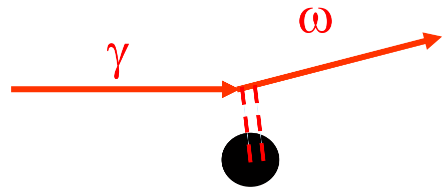




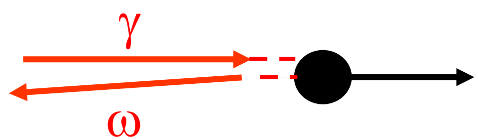
SK and Ya-Ping Xie, PRC **100**, 024620 (2019)

Backward meson production

- Data from fixed-target experiments (including JLab), show that photoproduction can also occur in the backward production
  - Model via a baryon exchange trajectory



- Normally, photoproduction is maximal when t (momentum transfer from target) is small
  - $d\sigma/dt \sim \exp(-Bt)$
    - B~ hbar/target size



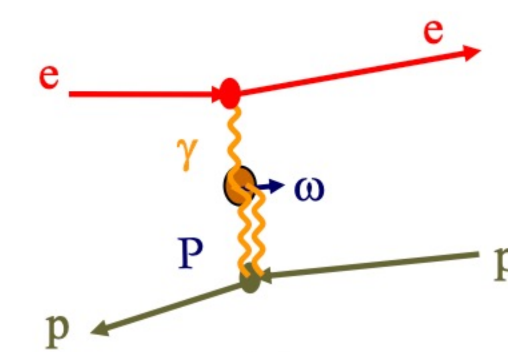
- In baryon exchange, in the CM frame, the meson scatters backward 180 degrees causing the baryon to recoil
  - In CM frame, baryon and photon/meson trade momentum
  - Mandelstam u is small, but t is large ($t>Q^2$)
- How does an intact baryon recoil at high energies? Similar to baryon stopping in RHI collisions

Backward ρ/ω production

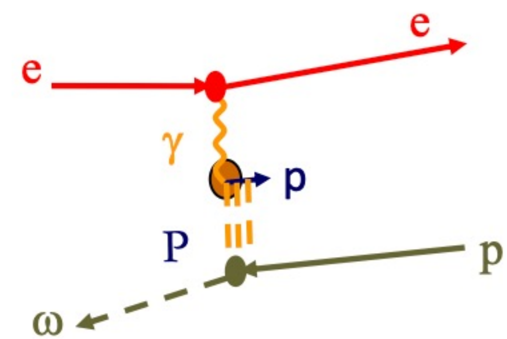
- Two examples of experimental interest
  - One decays to $\pi^+\pi^-$, the other to $\pi^0\gamma$)
- Production extrapolated from fixed-target data using a Regge model
  - Faster dropoff with W than forward production

$$\left.\frac{d\sigma}{du}\right|_{u=0} = A\left(\frac{k}{1\ \mathrm{GeV}}\right)^{-\eta} = A\left(\frac{W^2 - m_p^2}{2m_p(1\ \mathrm{GeV})}\right)^{-\eta}$$

$$\frac{d\sigma(s,u)}{du} = \left|A(u)s^{\alpha(u)-1} + B(u)e^{i\phi(u)}s^{-n/2}\right|^2.$$



(a)

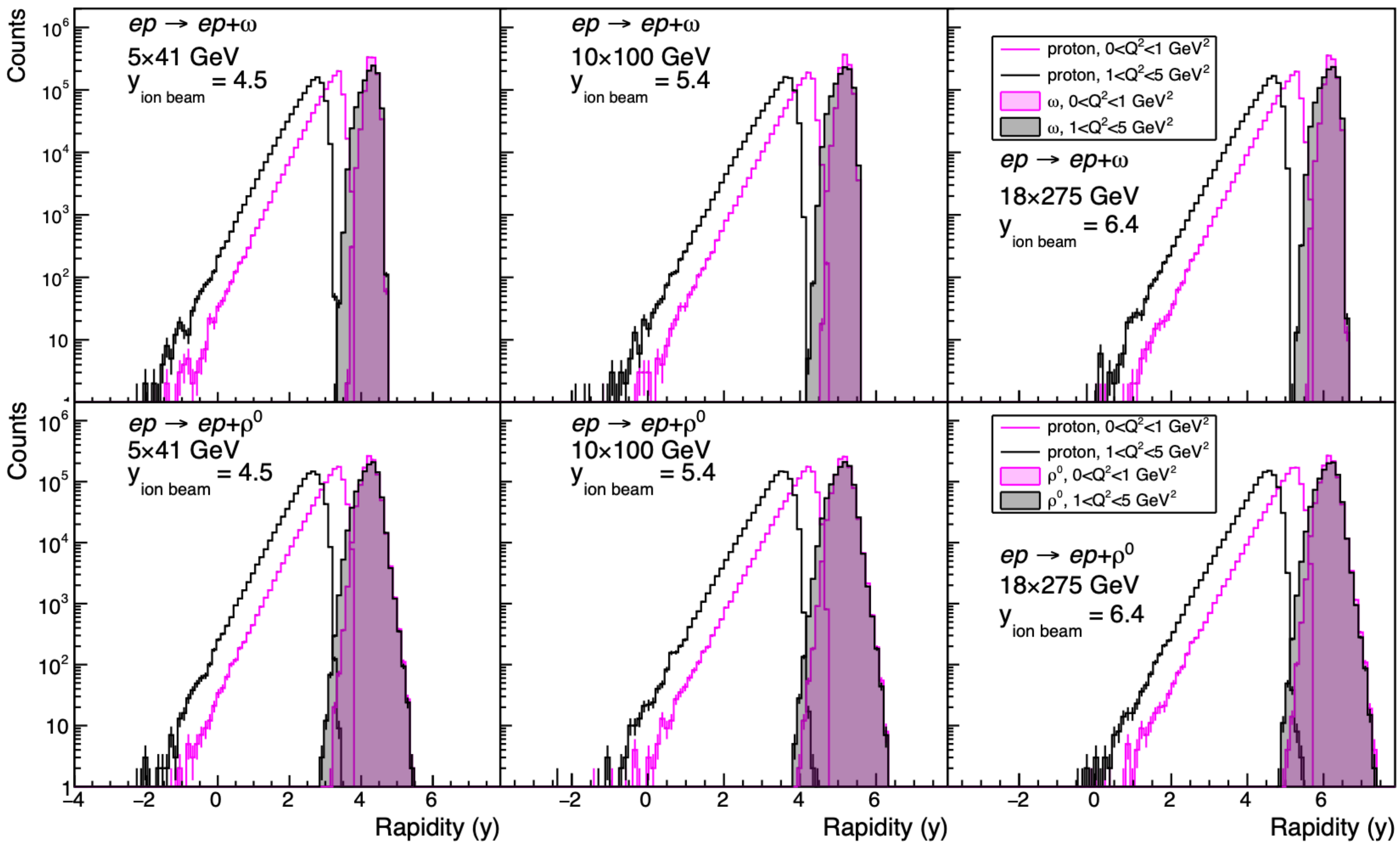


- Rates are order 0.1-1% of their forward production counterparts

D. Cebra et al. (SK), Phys. Rev. C **106**, 015204 (2022)

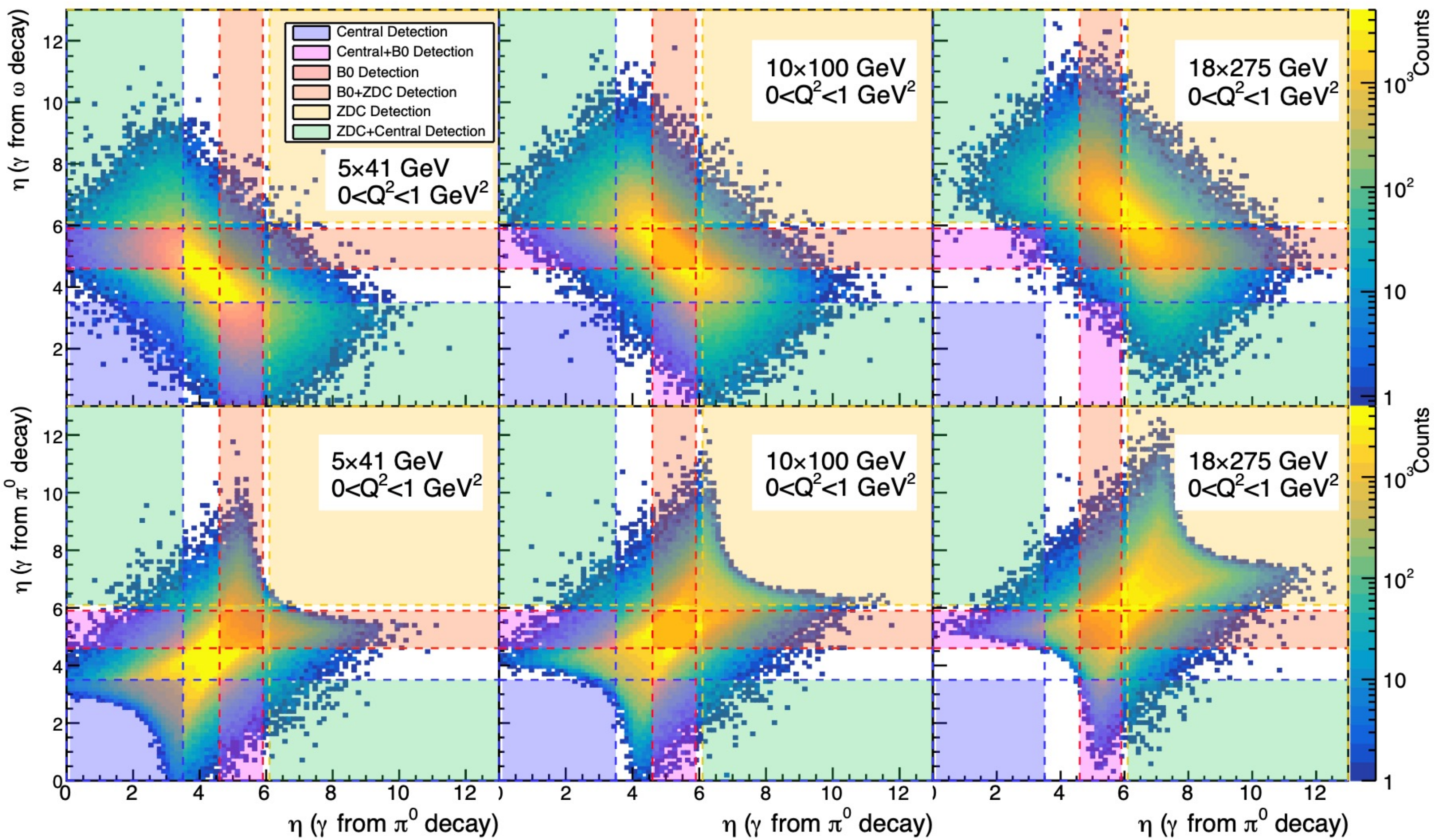
Final state rapidity

The final state mesons are in the far forward region



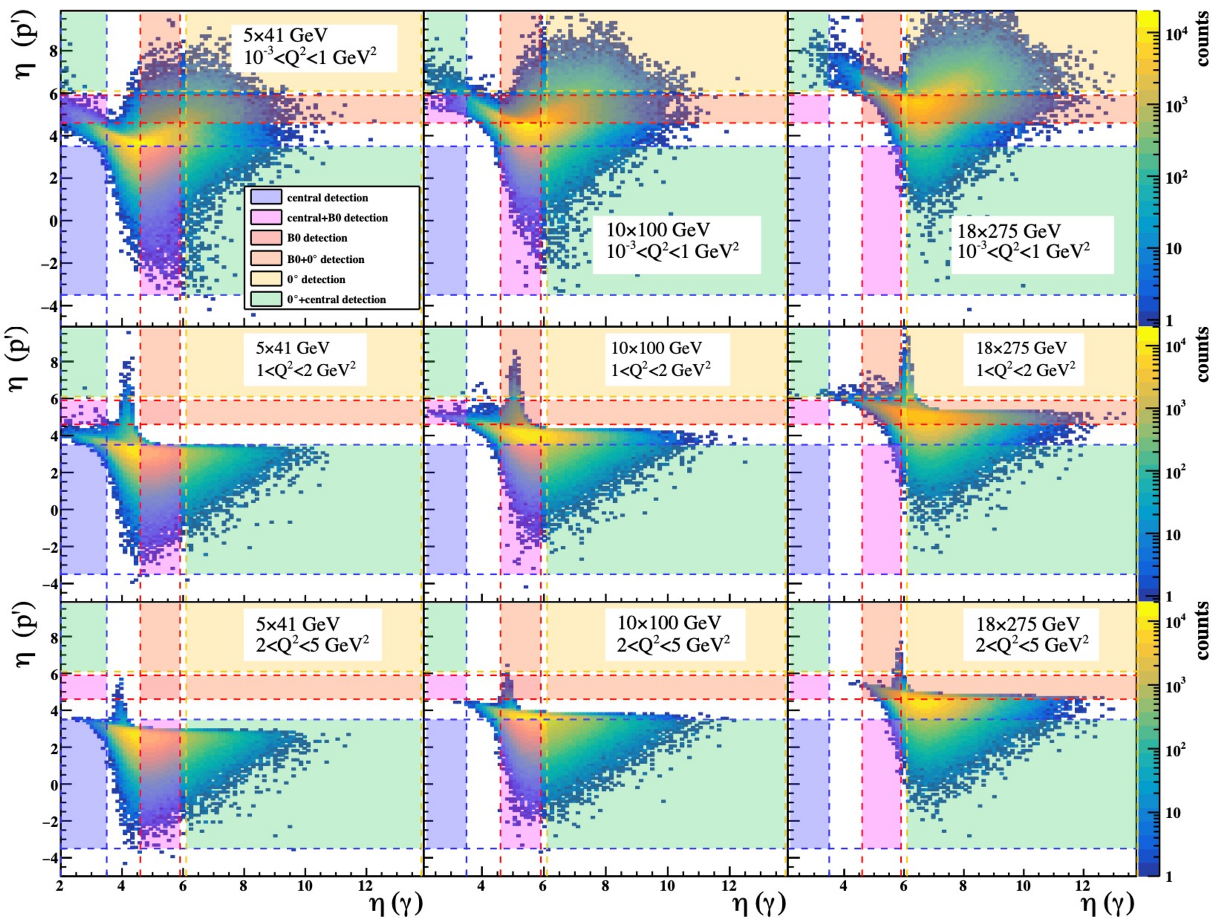
Pseudorapidity of the daughter particles

ePIC is not optimal for studying this physics



Backward π^0/Virtual Compton Scattering (VCS)

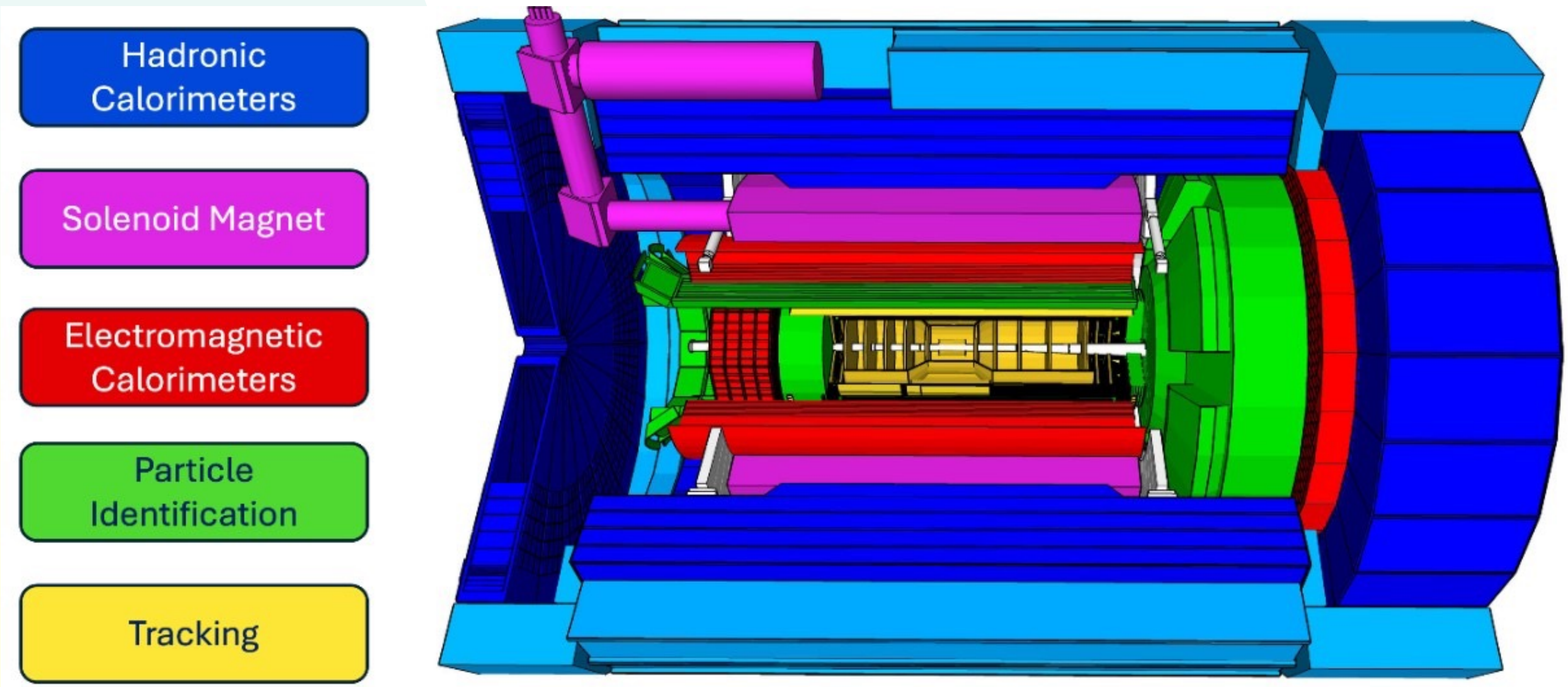
- Also modelled with Regge trajectories
- π^0 rejection is a major challenge for VCS
  - Requires well-segmented calorimetry



Z. Sweger et al. (SK),
Phys. Rev. C **108**, 055205 (2023)

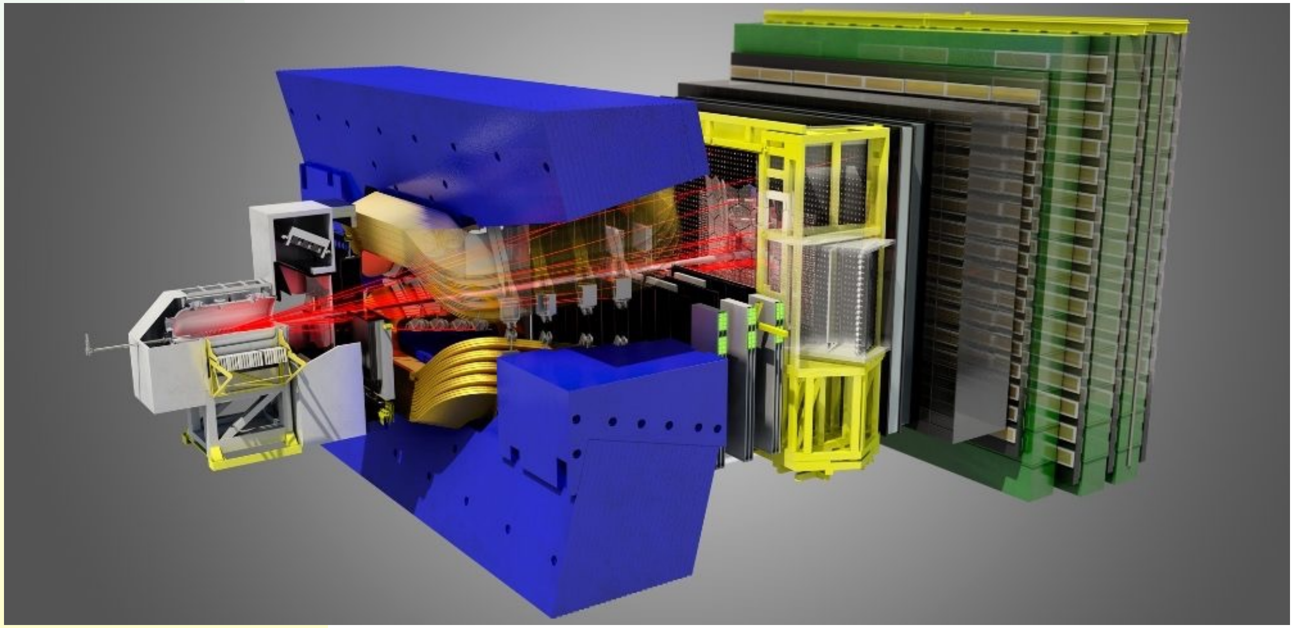
ePIC

- Excellent mid-rapidity coverage
  - $-3.5 < \eta < 3.5$, but resolution drops at large $|\eta|$
- B0 magnet provides some coverage $4.6 < \eta < 5.9$
- ZDC covers ~~ η>6.1 (not azim. Symmetric) + Roman Pots…
- Holes at large $|\eta|$. A second detector might compromise at midrapidity to cover the large $|\eta|$ region



Forward spectrometers at colliders

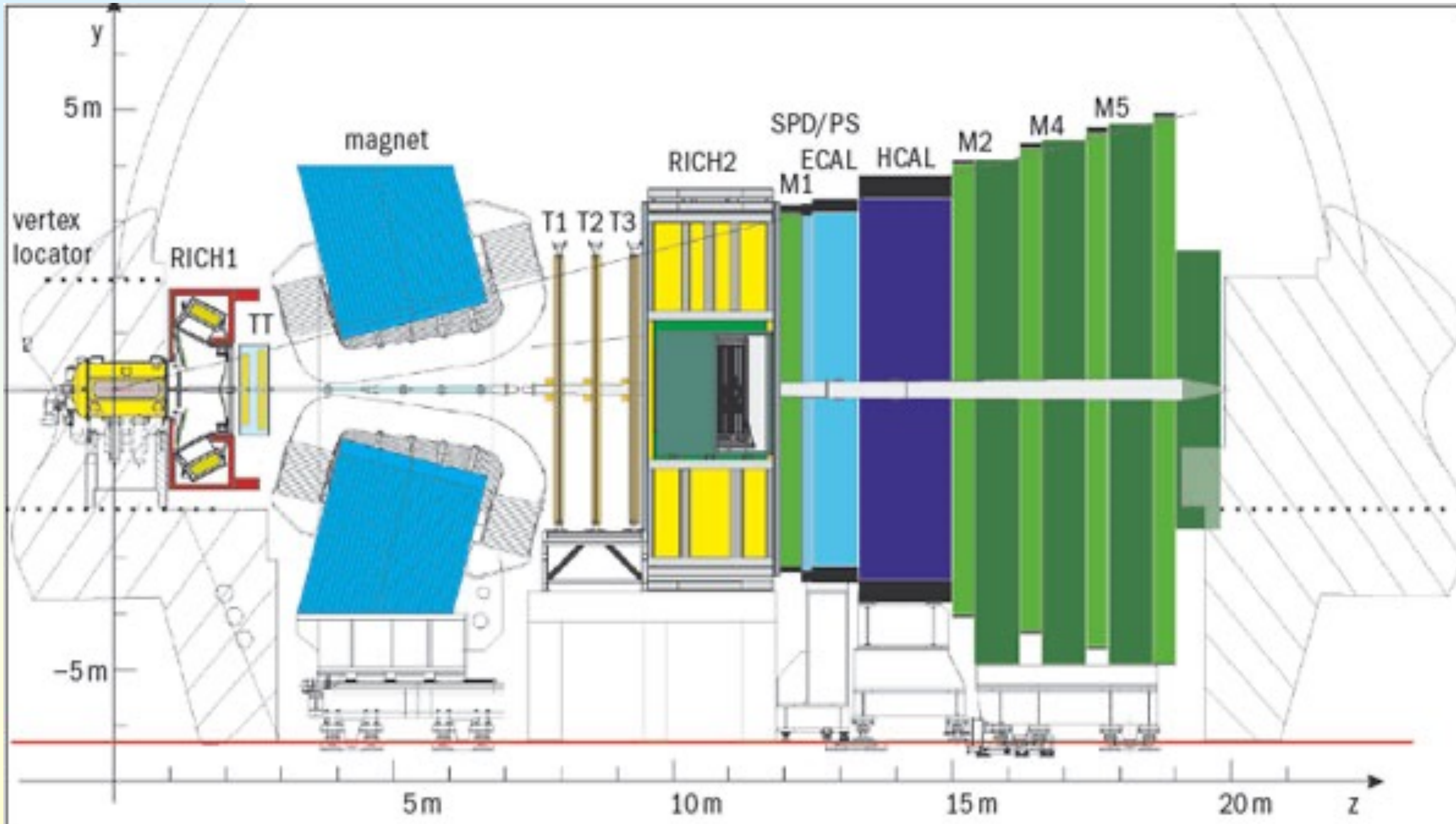
- BTeV at the Tevatron (proposed)
- HERA-b (did not run for long)
- LHCb
  - Very successful at b-physics, CP violation, low-x physics (due to its large rapidity), ultra-peripheral collisions & other physics.
- Forward hardware is simpler than collider geometry; main challenge is very high rates



LHC-b instrumentation

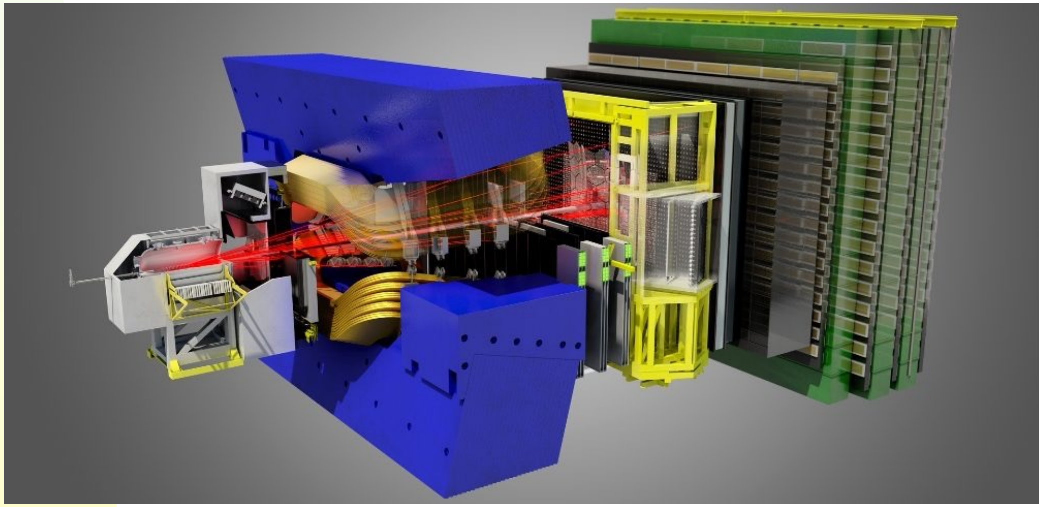
Spectrometer with vertexing, charged particle tracking, electromagnetic and Hadronic calorimetry, RICH for PID and a muon system

2 T (max.) warm dipole magnet!



What could an EIC forward/backward detector look like?

- Forward and backward spectrometers similar to LHCb, but optimized for lower momentum particles
  - Smaller magnet, less lever arm required
  - Lower rate requirements
  - Retain full acceptance coverage
- Excellent PID for electrons
  - RICH + TRD?



A central detector(?)

- Compromises would be needed in the central region
- Either a lower solenoidal magnetic field, or no field.
- High efficiency particle detection over the full solid angle
  - Limited (or no) momentum resolution
    - Possibly calorimetry only

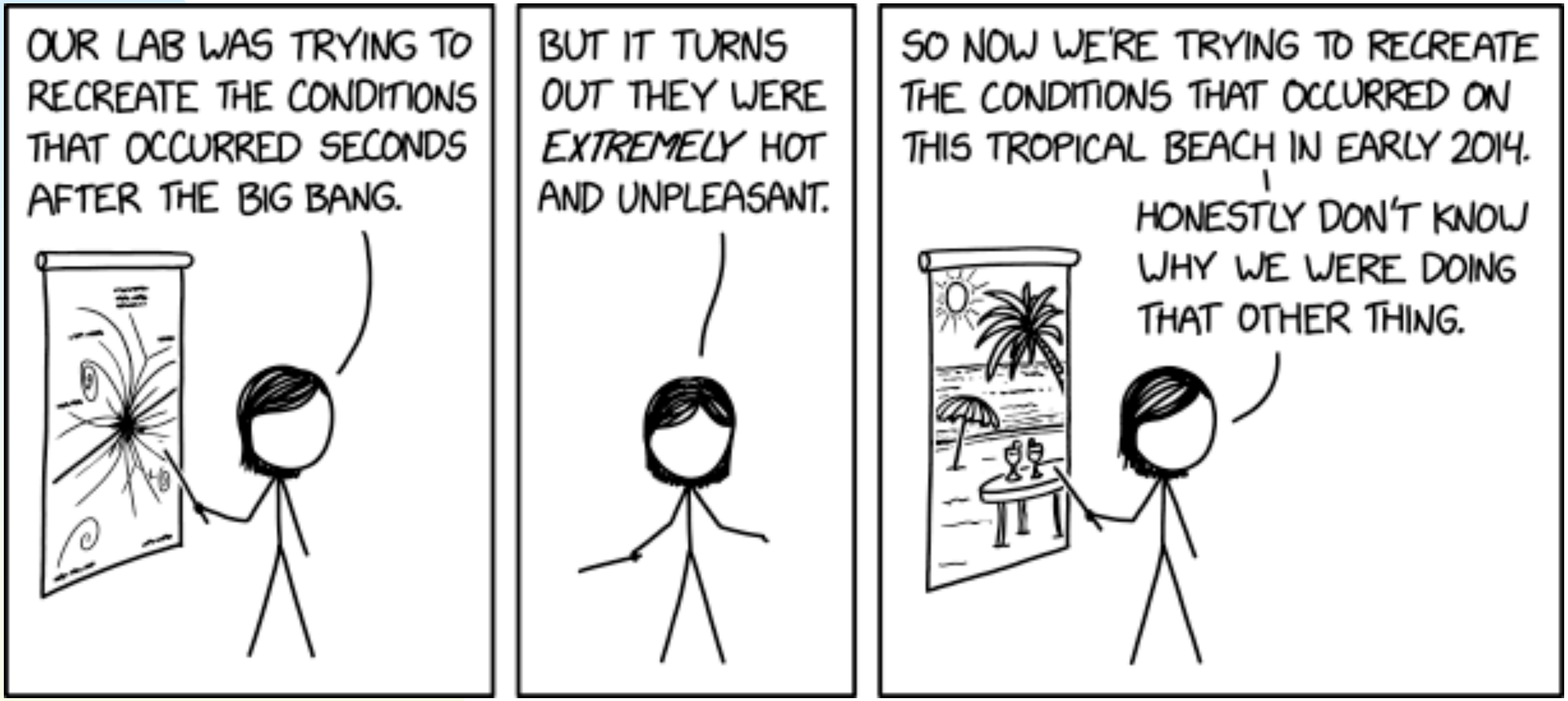
The far-forward region –meshing with the EIC

- Possible tension between accelerator needs (magnet placement, etc.) and the desire for full coverage.
- The EIC magnetic lattice will need adjustment to account for the dipole fields of the detector magnets.
  - Co-design?
  - Dipoles with horizontal fields?
- The far-forward region will require a dedicated design that preserves full coverage while taking advantage of the magnetic fields

Conclusions

- For exclusive interactions, the Bjorken-x of the struck parton maps into rapidity. For many final states, the daughter pseudorapidity is within ± 1 unit from the final state rapidity
- Some of the most interesting physics is at the lowest accessible Bjorken-x, or near threshold, at large x.
  - Large positive and negative rapidity
- A detector optimized to study large |rapidity| events would nicely complement ePIC.
  - This ties in well with the IP-8 optics, which allow for improved tracking of nuclear fragments.
- This detector could consist of forward and backward spectrometers that look like smaller versions of LHCb, with dipole magnets and a forward-backward geometry.

Questions?

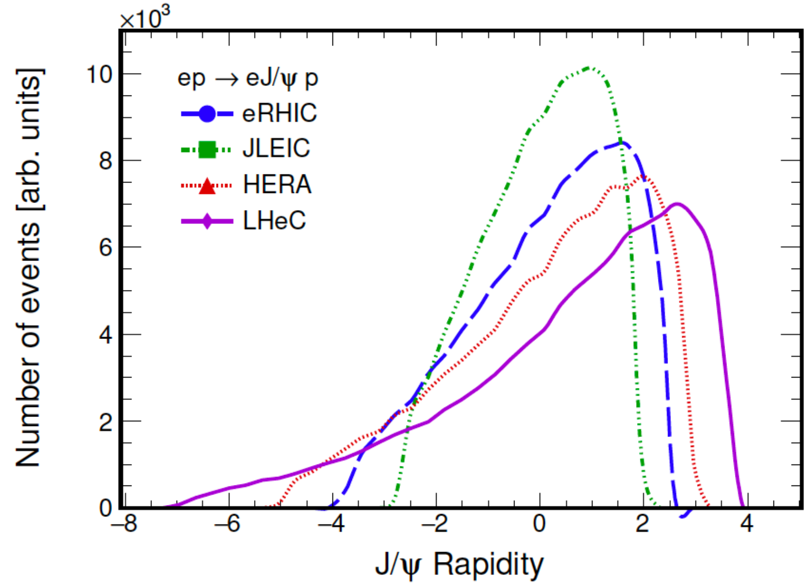


https://xkcd.com/2511/

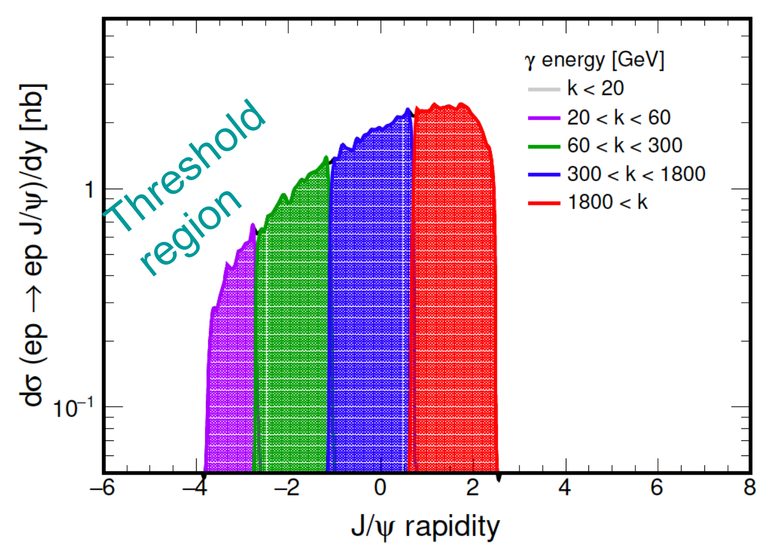
backup.

EIC photoproduction kinematics

- Maps photon energy onto rapidity
- $k = \frac{M}{2}\exp(y)$
- y=ln(2k/M)
- Reggeon activity strongest at low photon energies
  - Requires good acceptance in the hadron-going direction
- Highest photon energies correspond to electron-going direction
  - Need good e-going acceptance



e-> <-Hadron



SK & M. Lomnitz, Phys. Rev. **C99**, 015203 (2019)