Electron-Ion Collisions in the JETSCAPE Framework

Eric Kolbusz
Wayne State University
on behalf of the JETSCAPE Collaboration

HP2026 Satellite Workshop on Jets and Heavy Flavor Physics,
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June 28, 2026

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JETSCAPE

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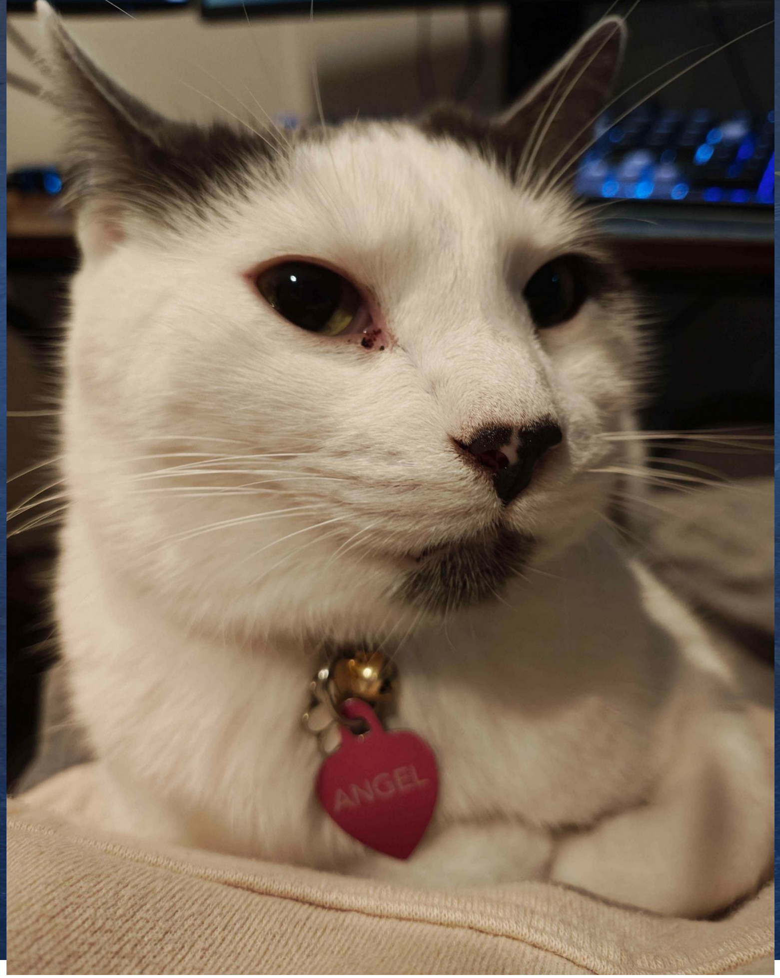

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JETSCAPE

Motivation

HERA | EIC

2007 | You are here | 2036?

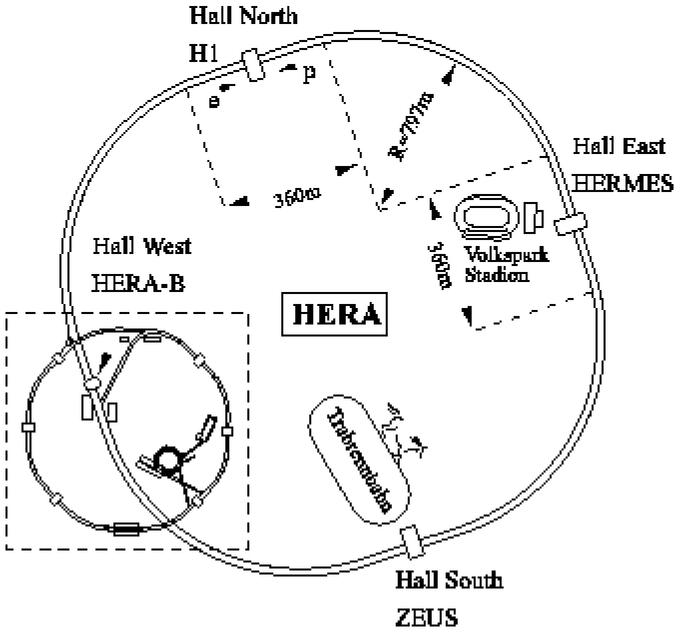

Image: DESY

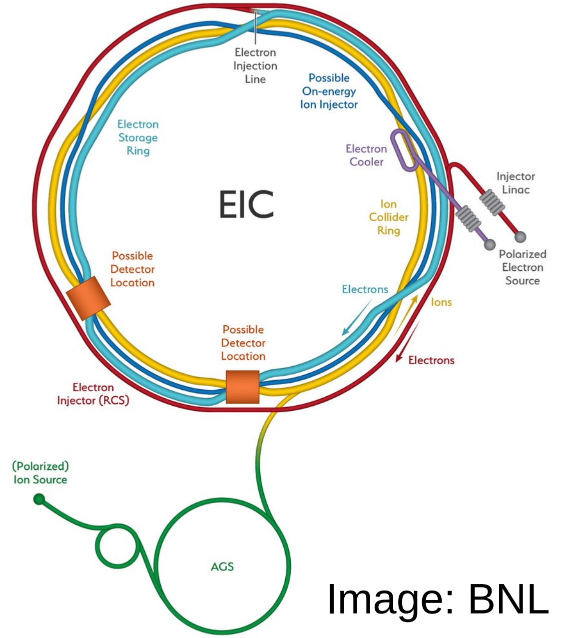

Image: BNL

Motivation

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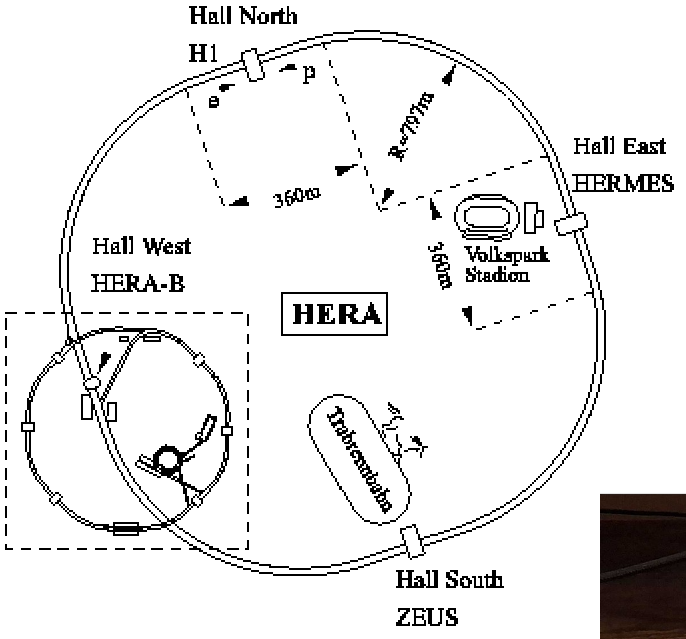

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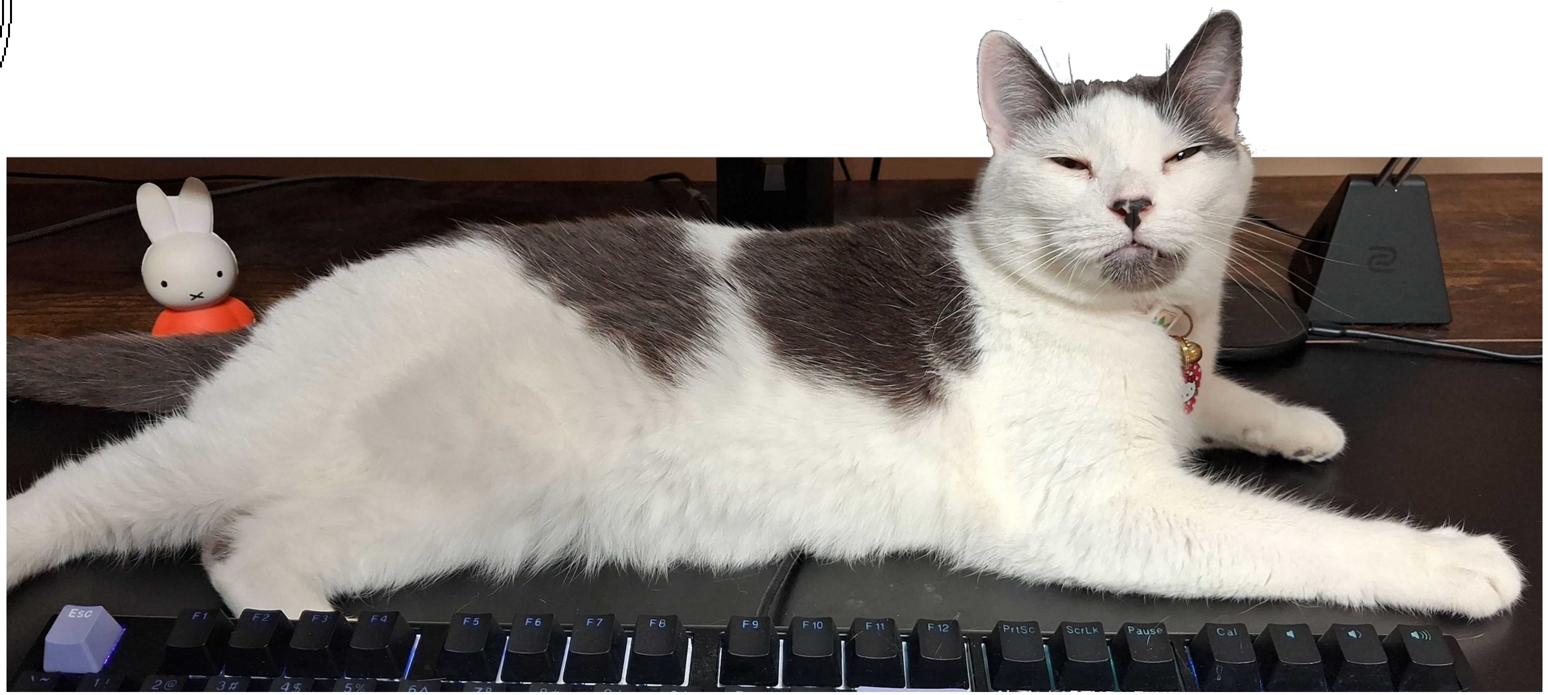


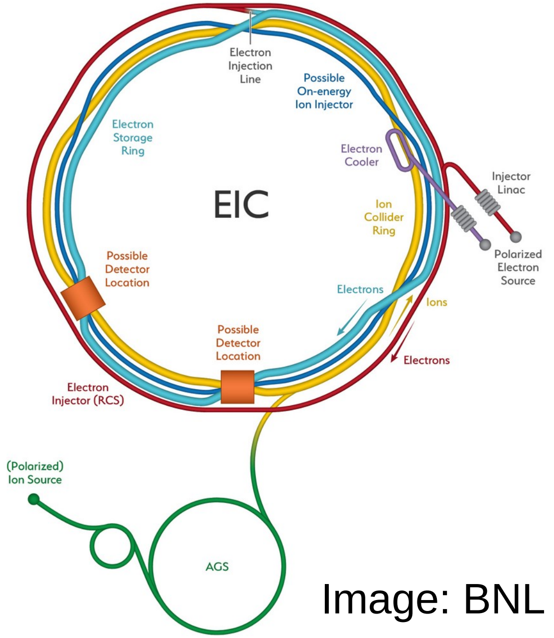
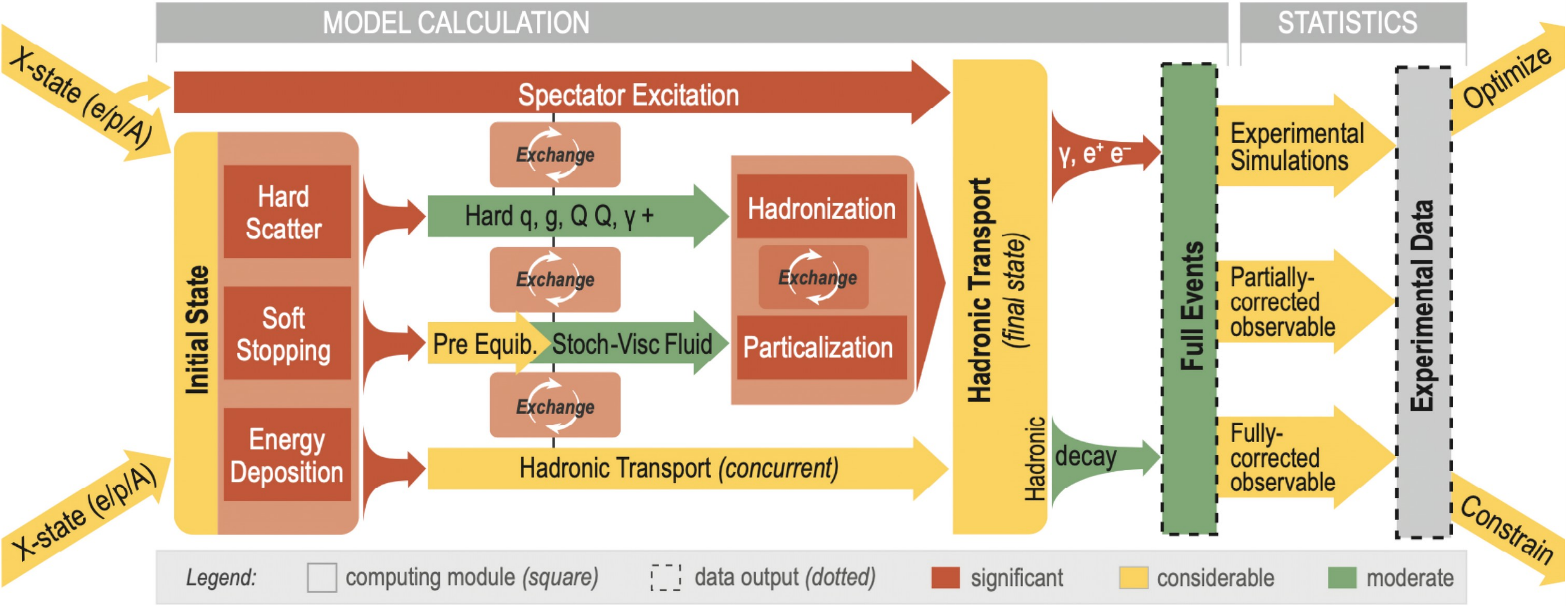


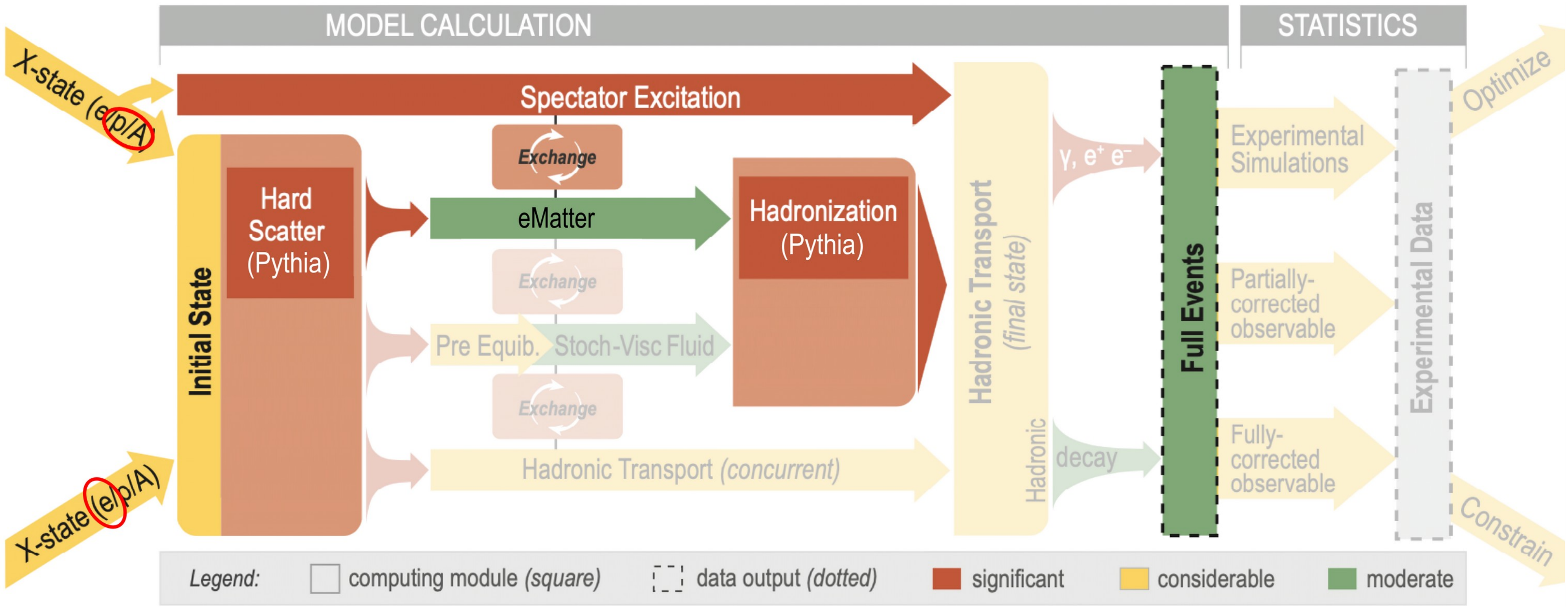
Image: BNL

The X-SCAPE Framework



- Modular event generation framework
- Supports p-p, p-A, A-A, e-p, and now e-A

The X-SCAPE Framework

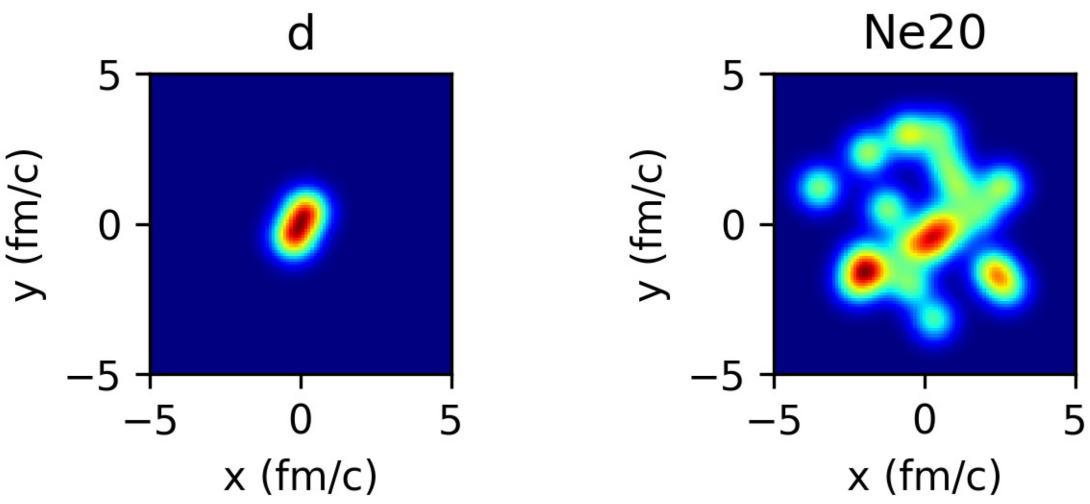


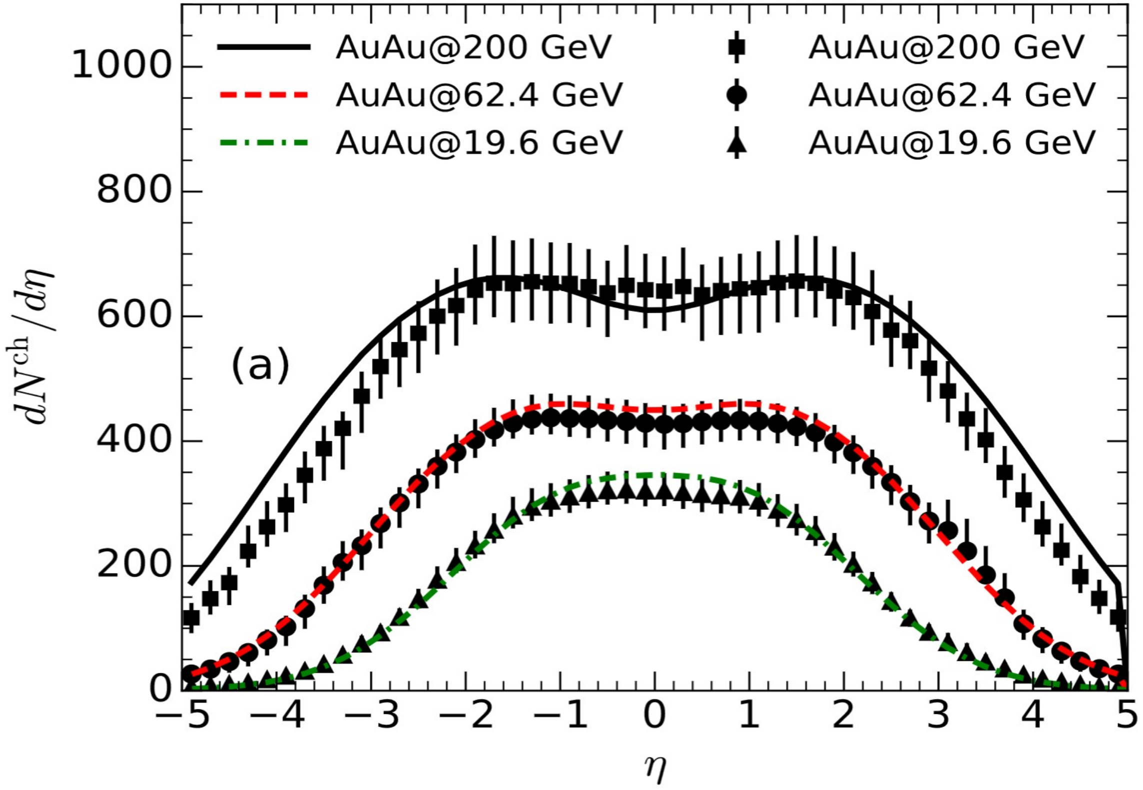
- Modular event generation framework
- Supports p-p, p-A, A-A, e-p, and now e-A

The 3D Glauber Model

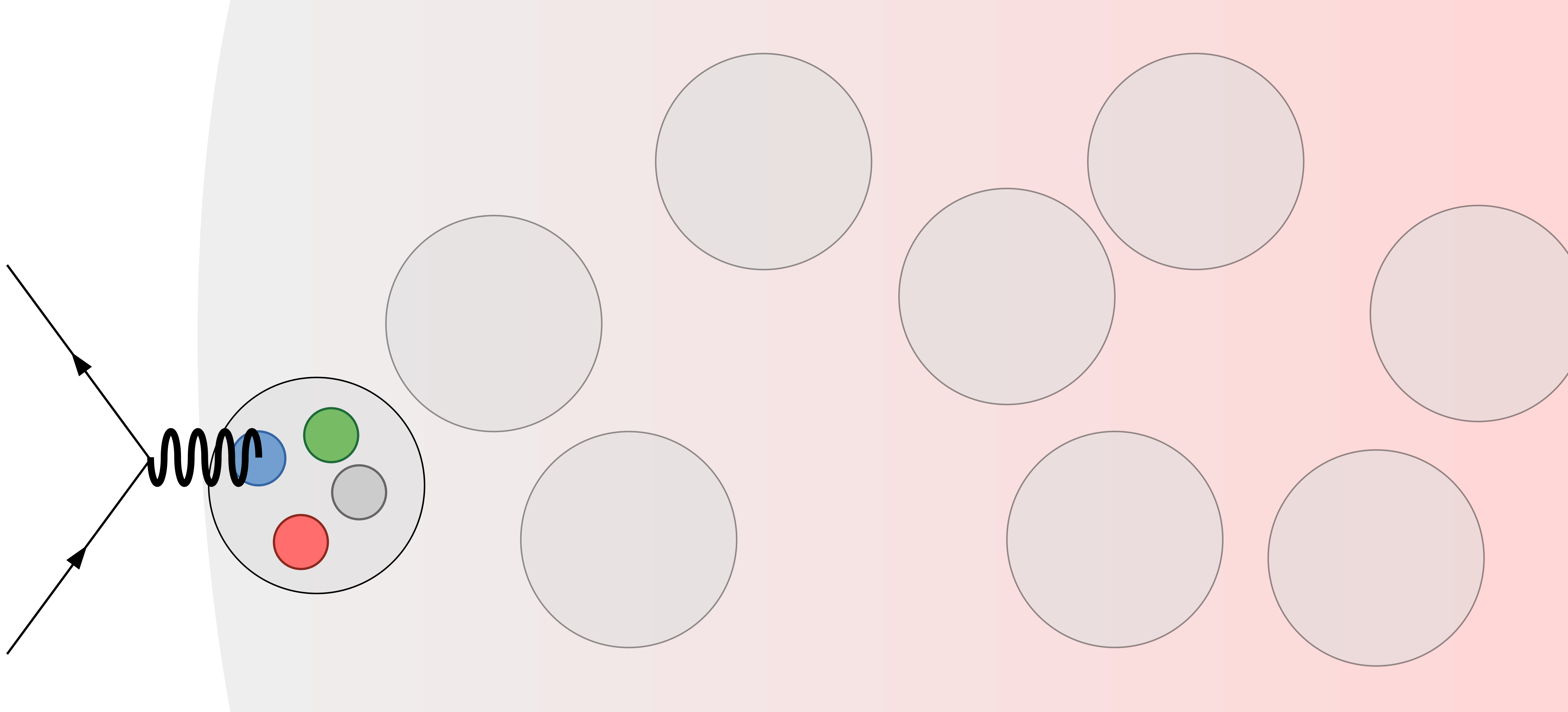
Shen and Schenke, Phys. Rev. C 97, 024907 (2018)

- Nucleons modeled as hotspots in nucleus
- Positions sampled using Woods-Saxon
- Deformation parameters for non-spherical nuclei
- Heavily tested in a variety of settings

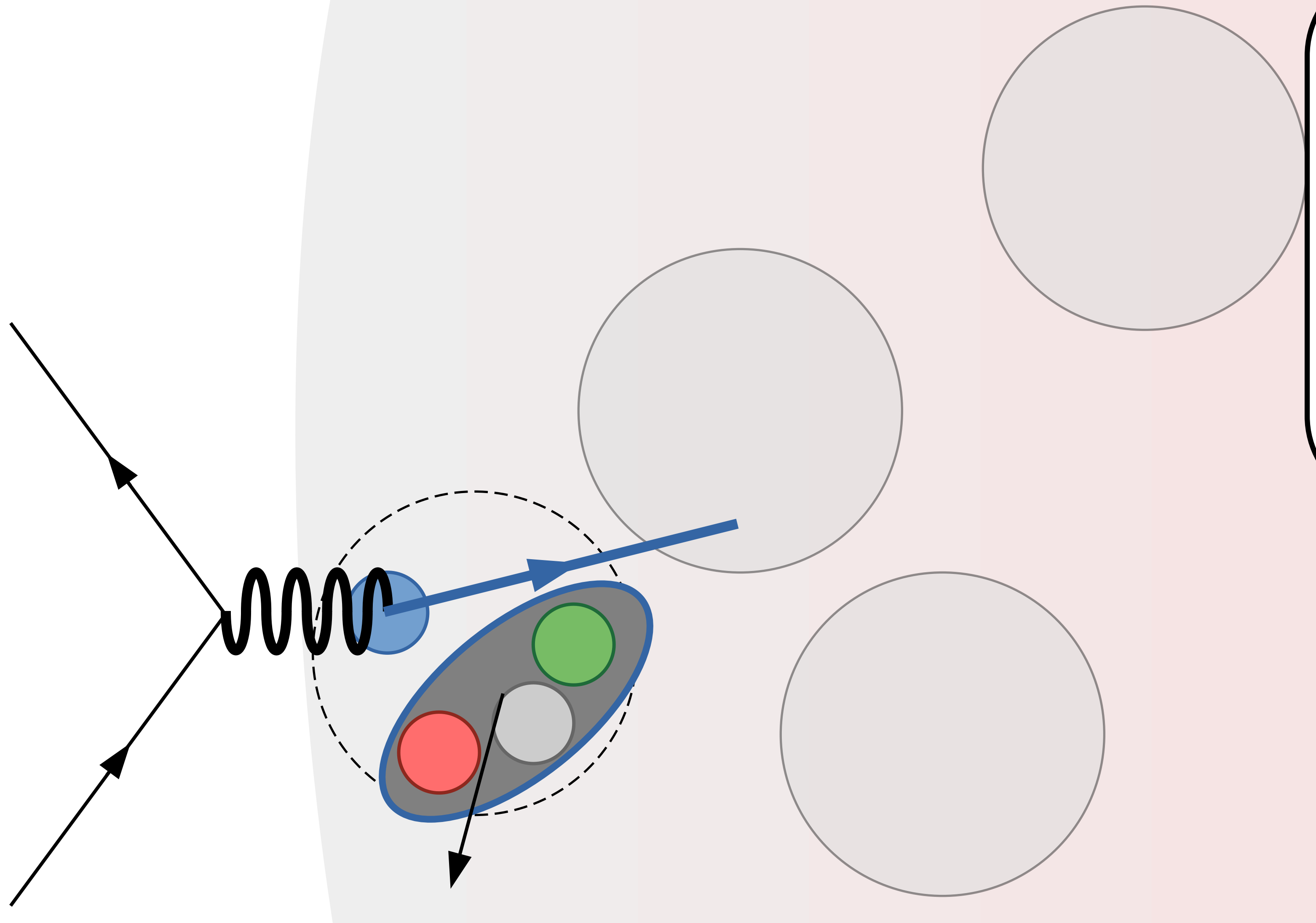




Generating e-A Events



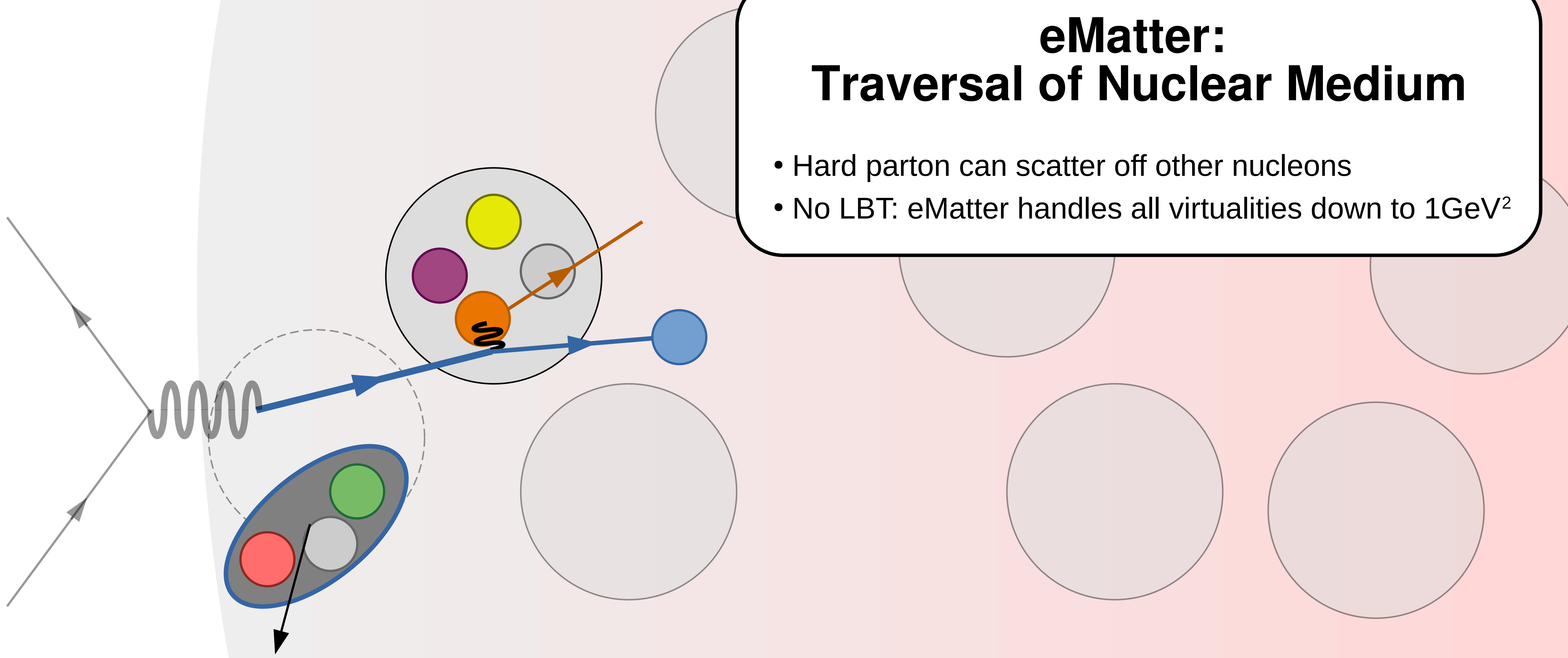
Generating e-A Events



eAGun: Initial Hard Scattering

- Incident nucleon randomly sampled
- Wounded nucleon leaves behind remnant
- Hard parton, remnant taken from Pythia e-p with no ISR, FSR

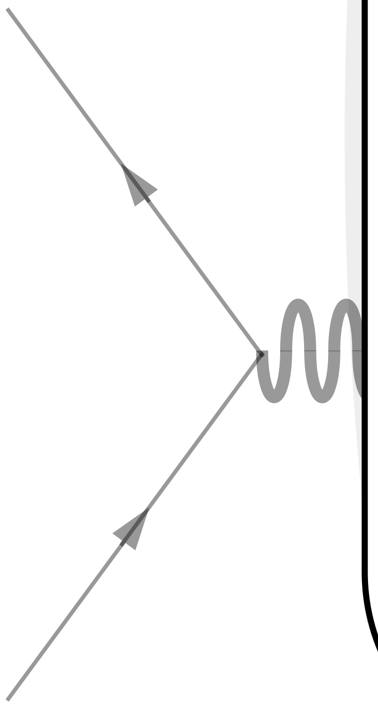
Generating e-A Events



eMatter: Traversal of Nuclear Medium

- Hard parton can scatter off other nucleons
- No LBT: eMatter handles all virtualities down to $1\mathrm{GeV}^2$

Generating e-A Events



LBT: He et al., Phys. Rev. C 91, 054908 (2015)
Cao et al., Phys. Rev. C 94, 014909 (2016)

$$\langle\langle X\rangle\rangle = \frac{\gamma_2}{16E_1(2\pi)^4}\int dE_2 d\theta_2 d\theta_4 d\phi_4 \; X f_2(E_2,T) S_2(s,t,u)\,|\mathcal{M}_{12\to34}|^2 \frac{E_2E_4\sin\theta_2\sin\theta_4}{E_1-|\vec{p}_1|\cos\theta_4+E_2-E_2\cos\theta_{24}}$$

eMatter:

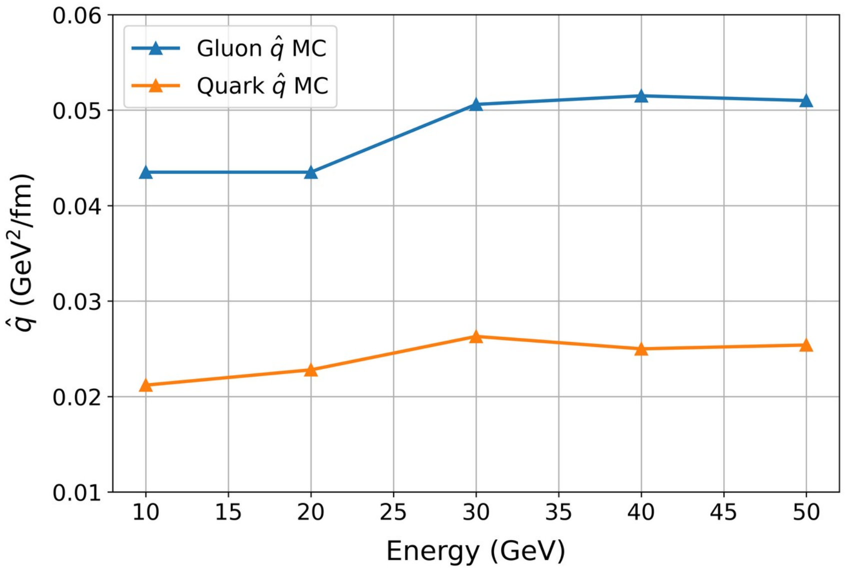
$$\langle\langle X\rangle\rangle = \frac{\gamma_2}{16E_1(2\pi)^4}\int dE_2 d\theta_2 d\theta_4 d\phi_4 \; X f_2(\vec{p}) S_2(s,t,u)\,|\mathcal{M}_{12\to34}|^2 \frac{E_2E_4\sin\theta_2\sin\theta_4}{E_1-|\vec{p}_1|\cos\theta_4+E_2-E_2\cos\theta_{24}}$$

$$f(\vec{p}) \sim \exp\left(-\frac{|\vec{p}|^2}{\sigma^2}\right), \sigma^2 = 0.8\,\mathrm{GeV}^2$$

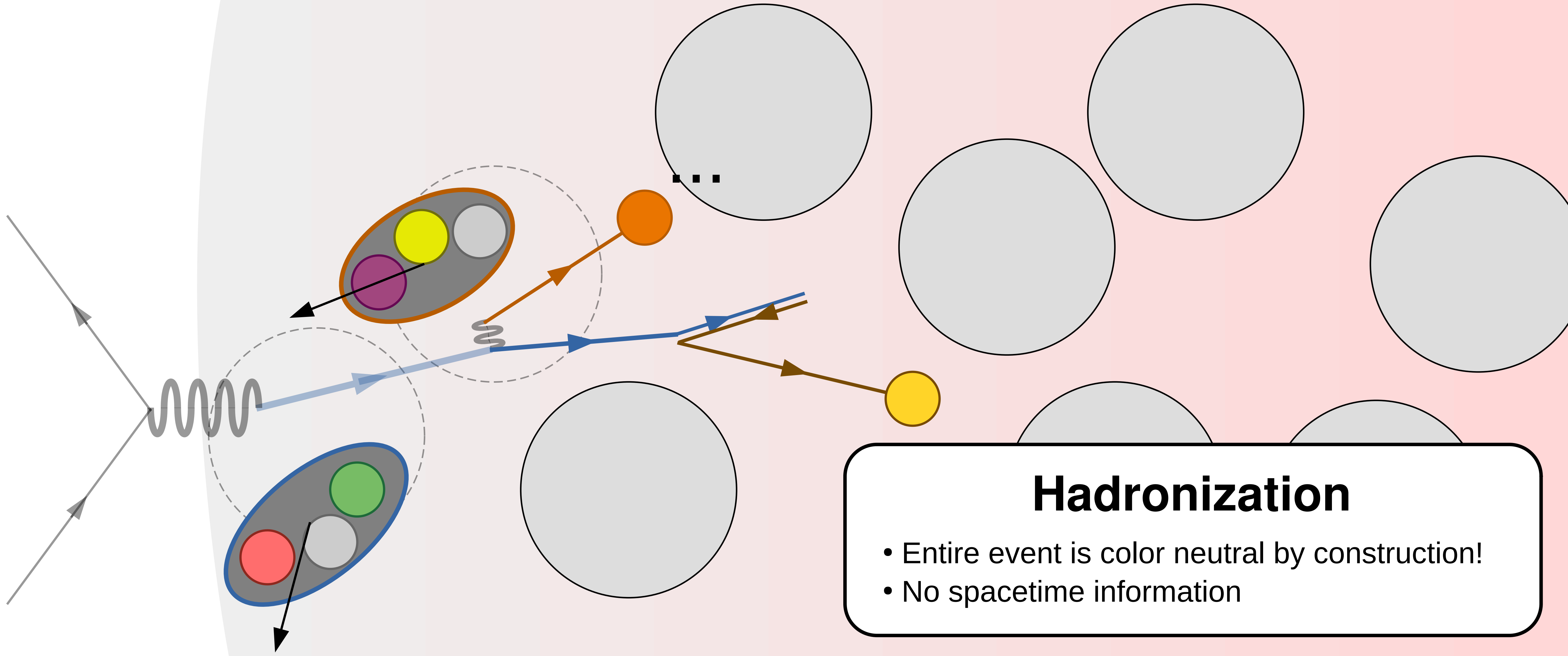
Not tuned, just a certain choice

$$\Gamma_{12\to34} = \langle\langle 1\rangle\rangle$$

$$\hat{q} = \langle\langle(\vec{p}_3 - \hat{p}_1\cdot\vec{p}_3)^2\rangle\rangle$$



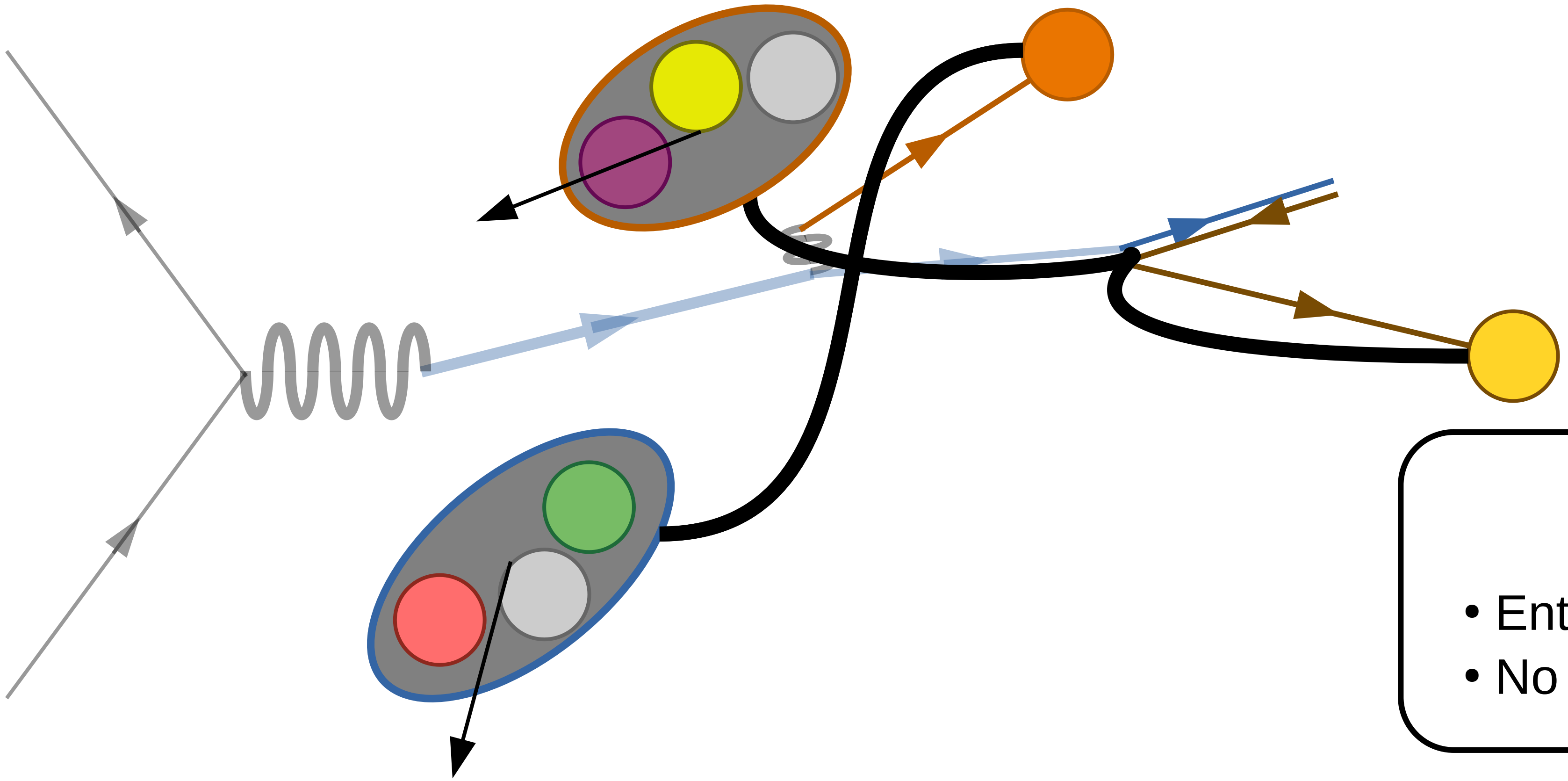
Generating e-A Events



Hadronization

- Entire event is color neutral by construction!
- No spacetime information

Generating e-A Events



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- Entire event is color neutral by construction!
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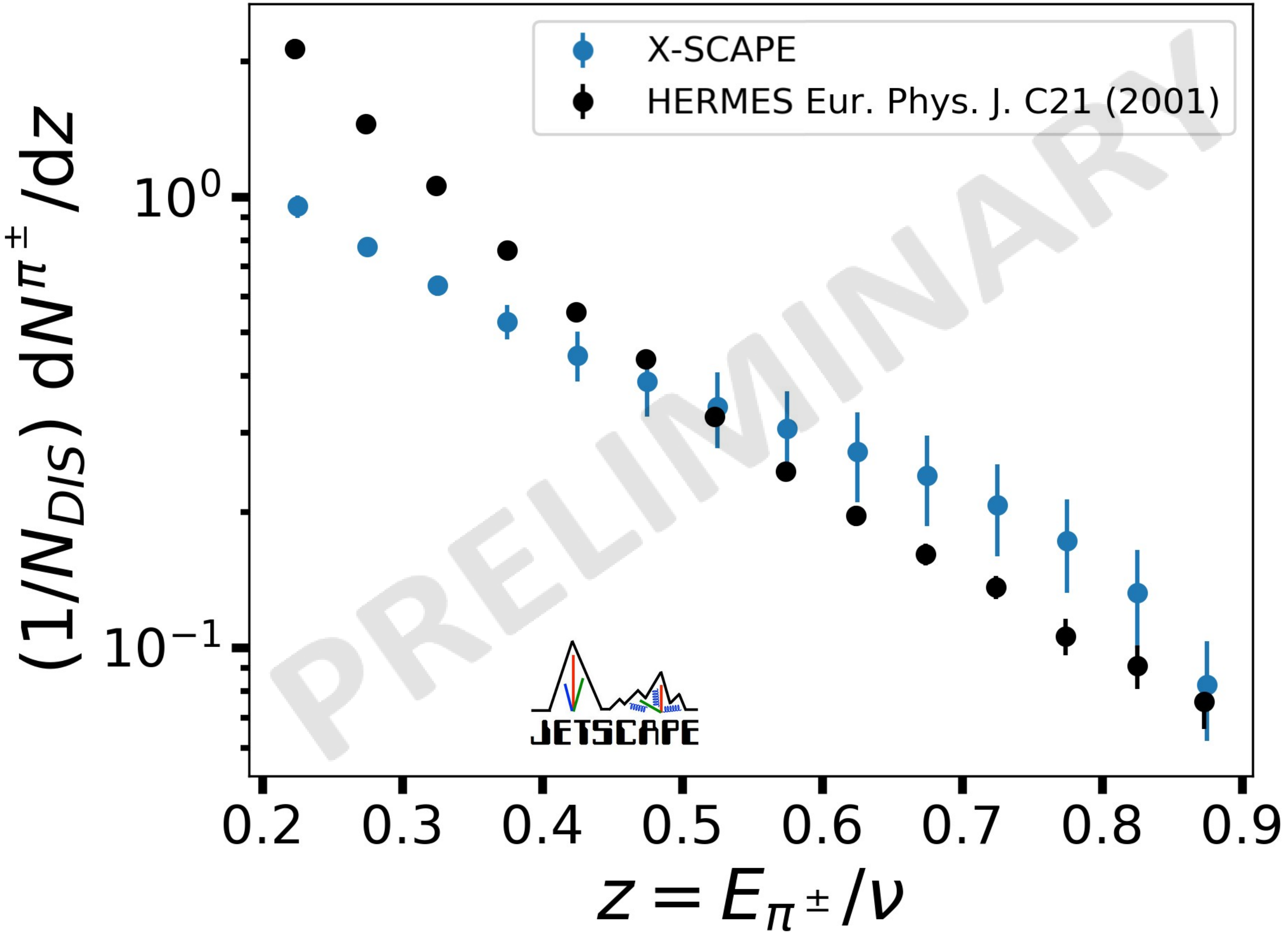
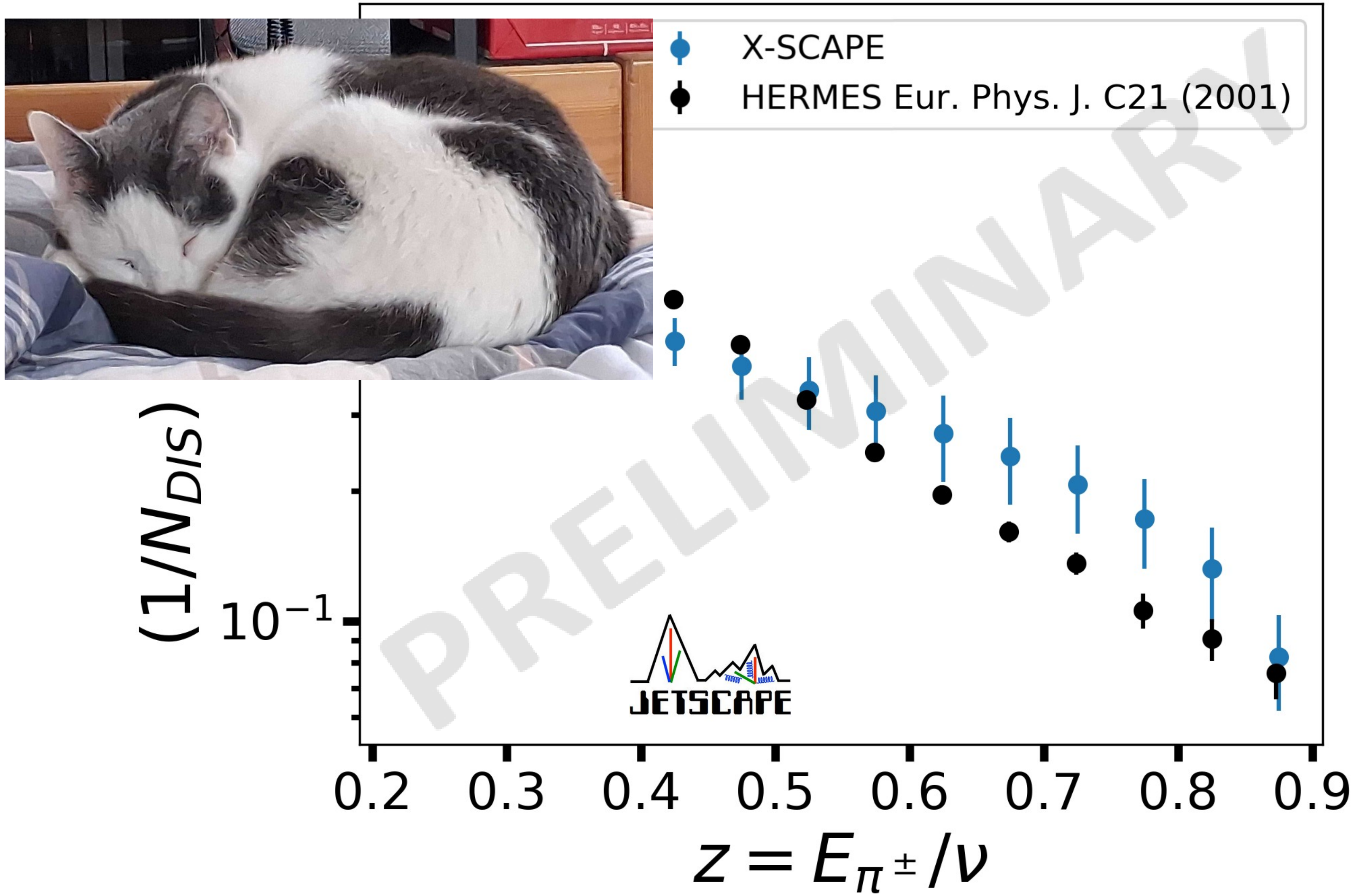
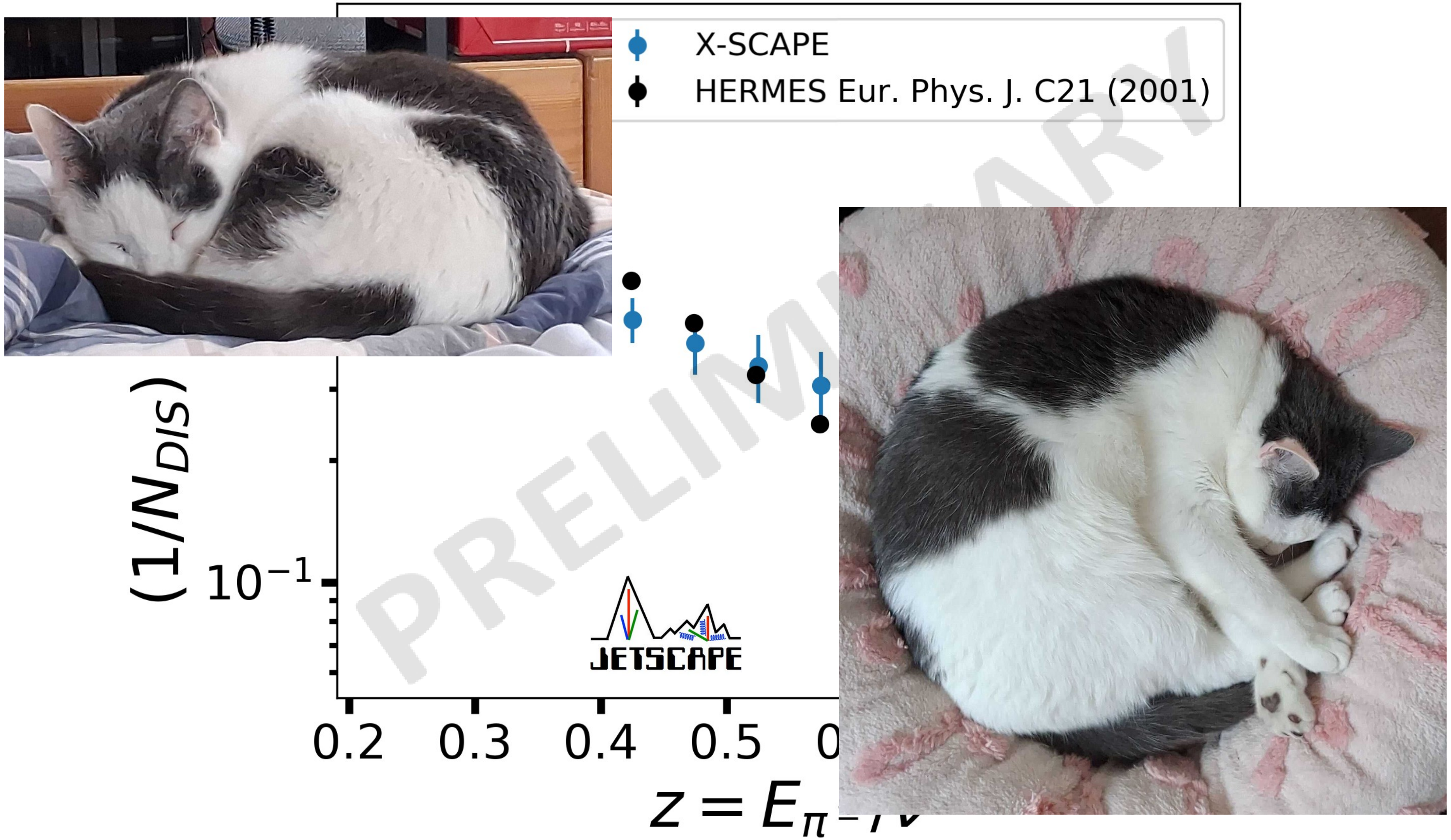
Results – e-d π± Production



Results – e-d π± Production



Results – e-d $\pi^{\pm}$ Production

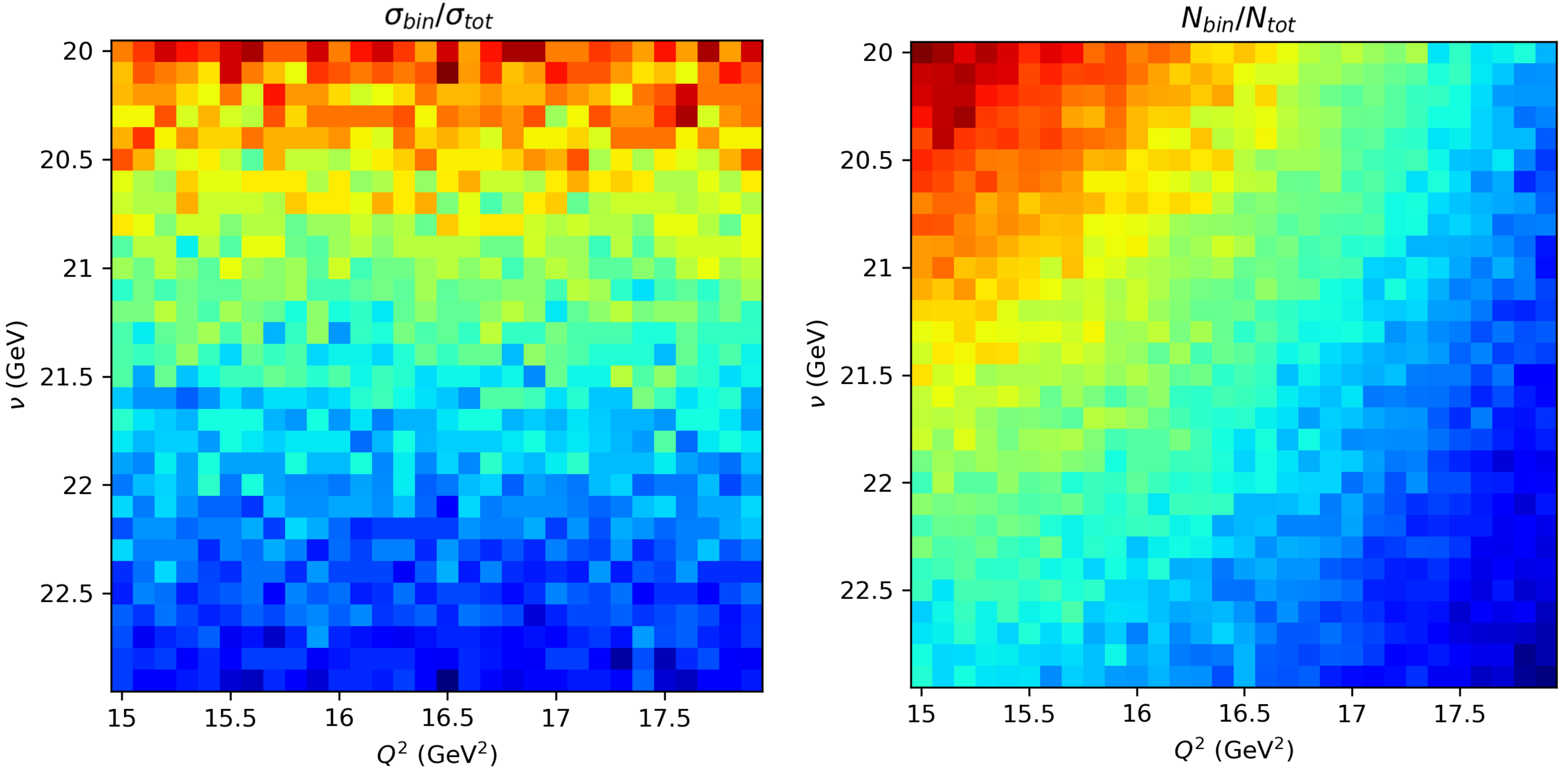


Accurate Sampling

- Pythia has a preference for low ν, Q^2

  ➡ bin the 2D parameter space in units of 1GeV, 1GeV²

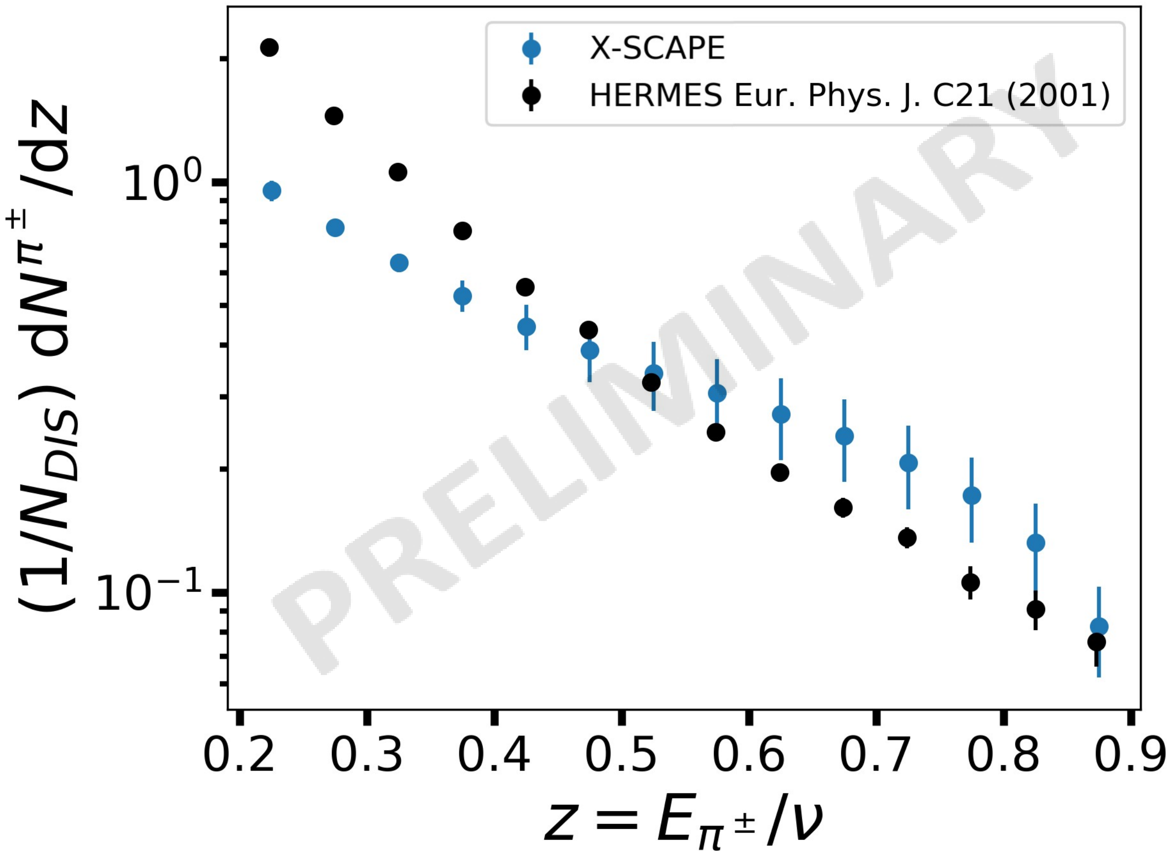
$$Y = \frac{\sum_{\text{bins}} \sigma_i Y_i}{\sum_{\text{bins}} \sigma_i}$$



- Assume equal acceptance
- Perturbative simulation:

$$\sum \sigma_i < \sigma_{tot}$$

Results – e-d π± Production



HERMES:

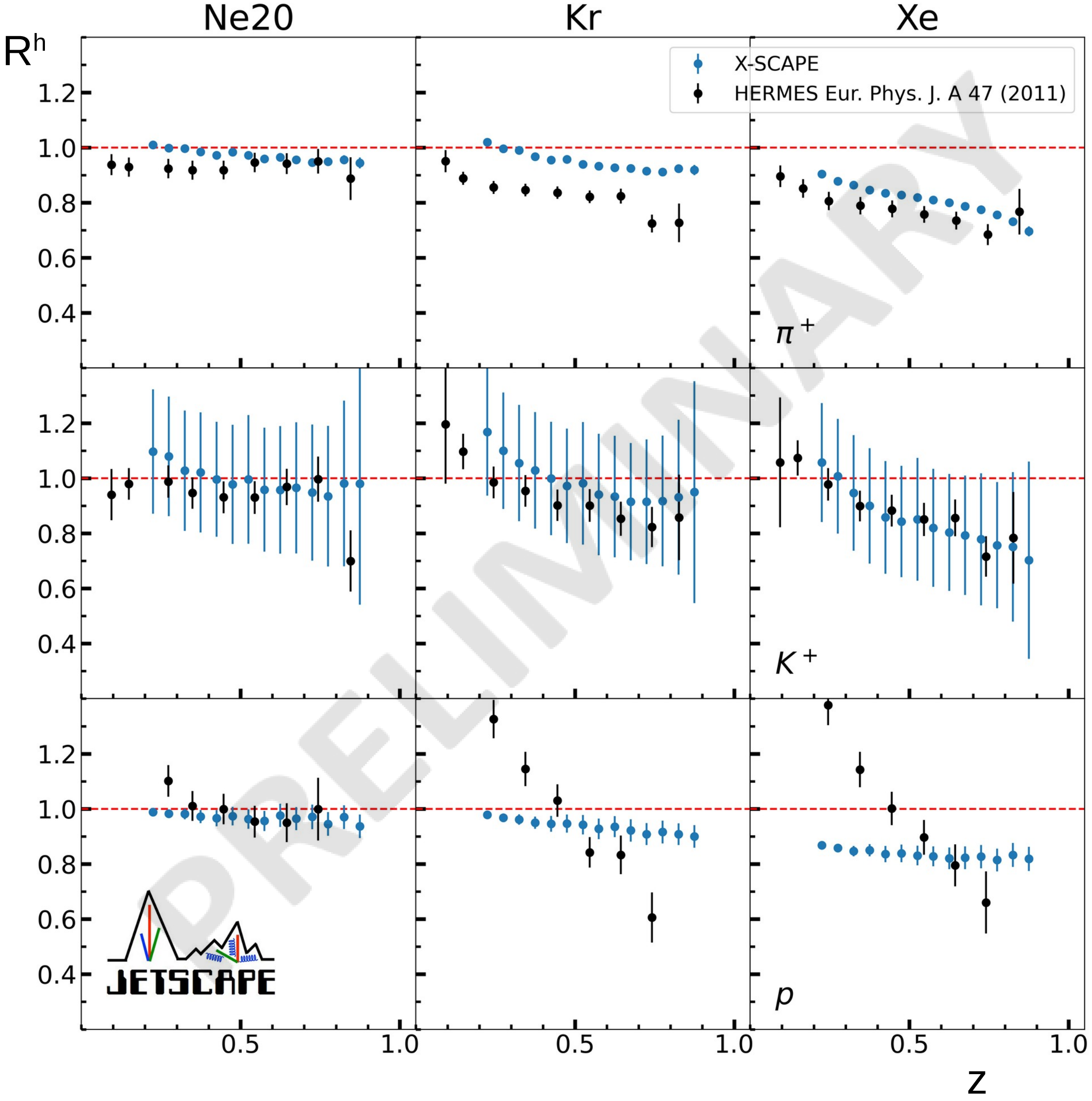
$$\langle E_{beam}\rangle = 27.5\,\mathrm{GeV}$$
$$\nu < 0.85\,\langle E_{beam}\rangle$$
$$1\,\mathrm{GeV}^2 < Q^2$$
$$\langle \nu \rangle = 16.1\,\mathrm{GeV}$$
$$\langle Q^2 \rangle = 2.5\,\mathrm{GeV}^2$$

X-SCAPE:

$$E_{beam} = 27.5\,\mathrm{GeV}$$
$$4\,\mathrm{GeV} < \nu < 0.85 E_{beam}$$
$$\nu < \frac{Q^2}{1\,\mathrm{GeV}} < 2\nu$$
$$\langle \nu \rangle = 8.4\,\mathrm{GeV}$$
$$\langle Q^2 \rangle = 9.8\,\mathrm{GeV}$$

<u>Does not include nonperturbative physics</u>

Results – Nuclear Effects



$$R_A^h(\nu, Q^2, z, p_t^2) = \frac{\left(\dfrac{N^h(\nu, Q^2, z, p_t^2)}{N^e(\nu, Q^2)}\right)_A}{\left(\dfrac{N^h(\nu, Q^2, z, p_t^2)}{N^e(\nu, Q^2)}\right)_D}$$

HERMES:

$$17\,\mathrm{GeV} < \nu < 23\,\mathrm{GeV}$$

$$1\,\mathrm{GeV}^2 < Q^2$$

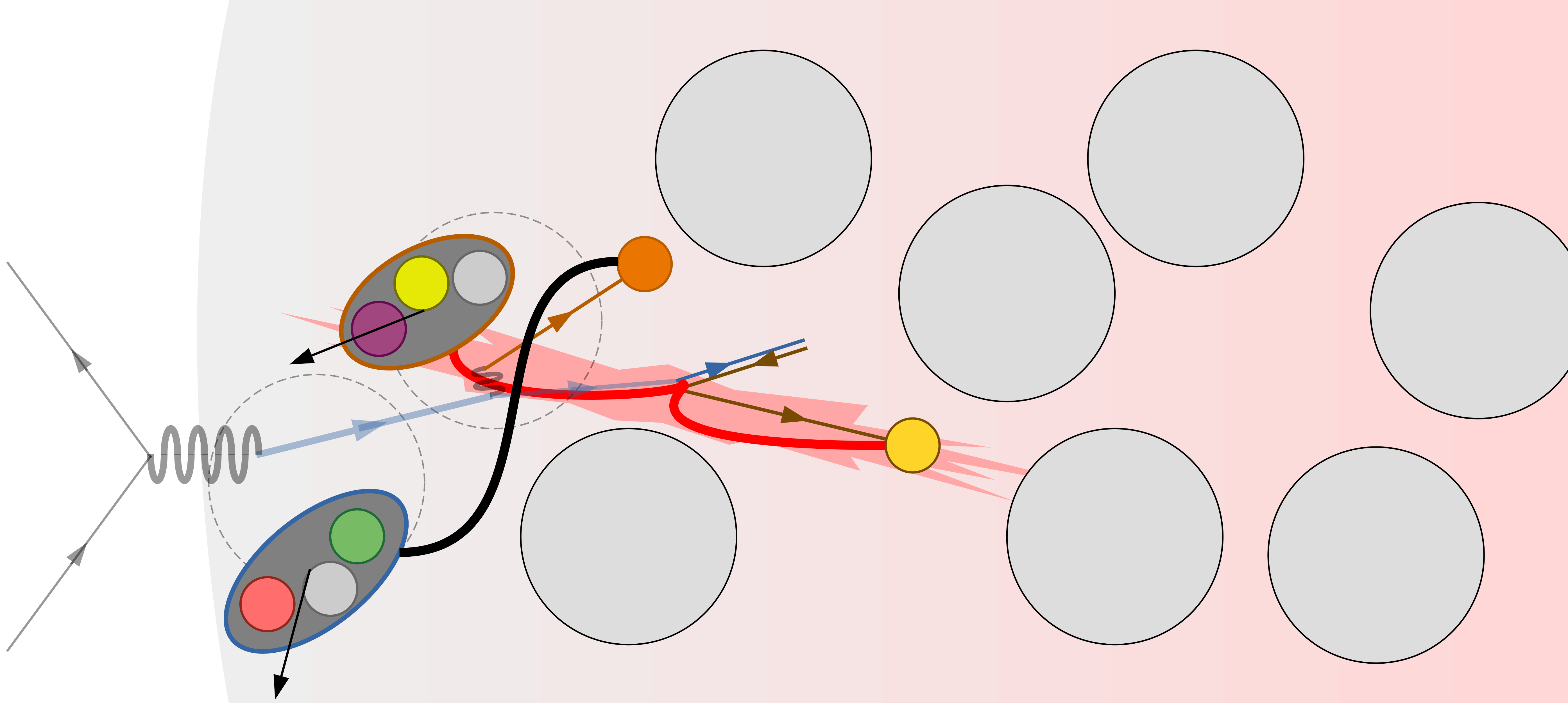
X-SCAPE:

$$17\,\mathrm{GeV} < \nu < 23\,\mathrm{GeV}$$

$$\nu < \frac{Q^2}{1\,\mathrm{GeV}} < 2\nu$$

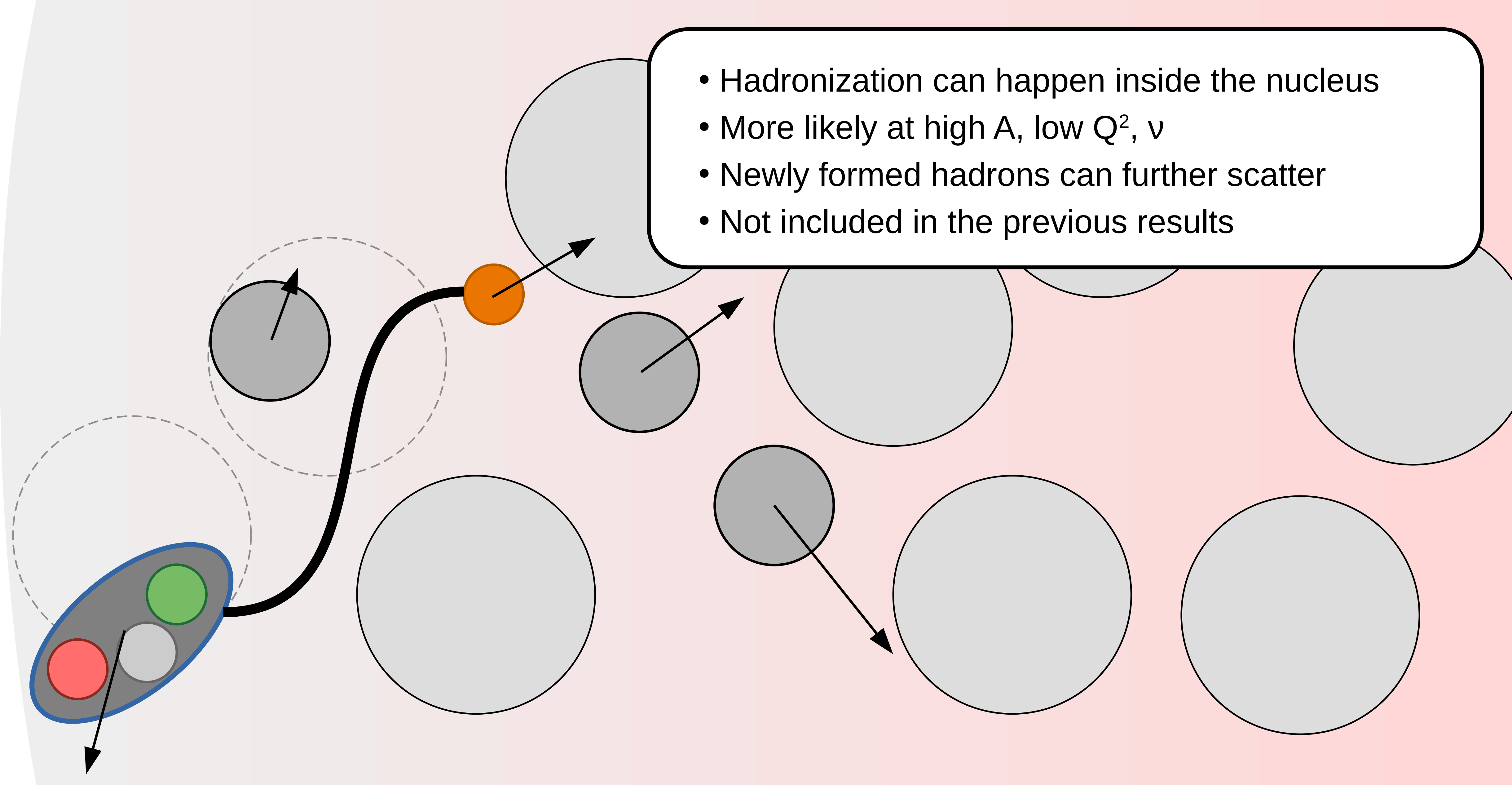
<u>All hadrons produced via fragmentation</u>

Next Steps – In-Nucleus Hadronization

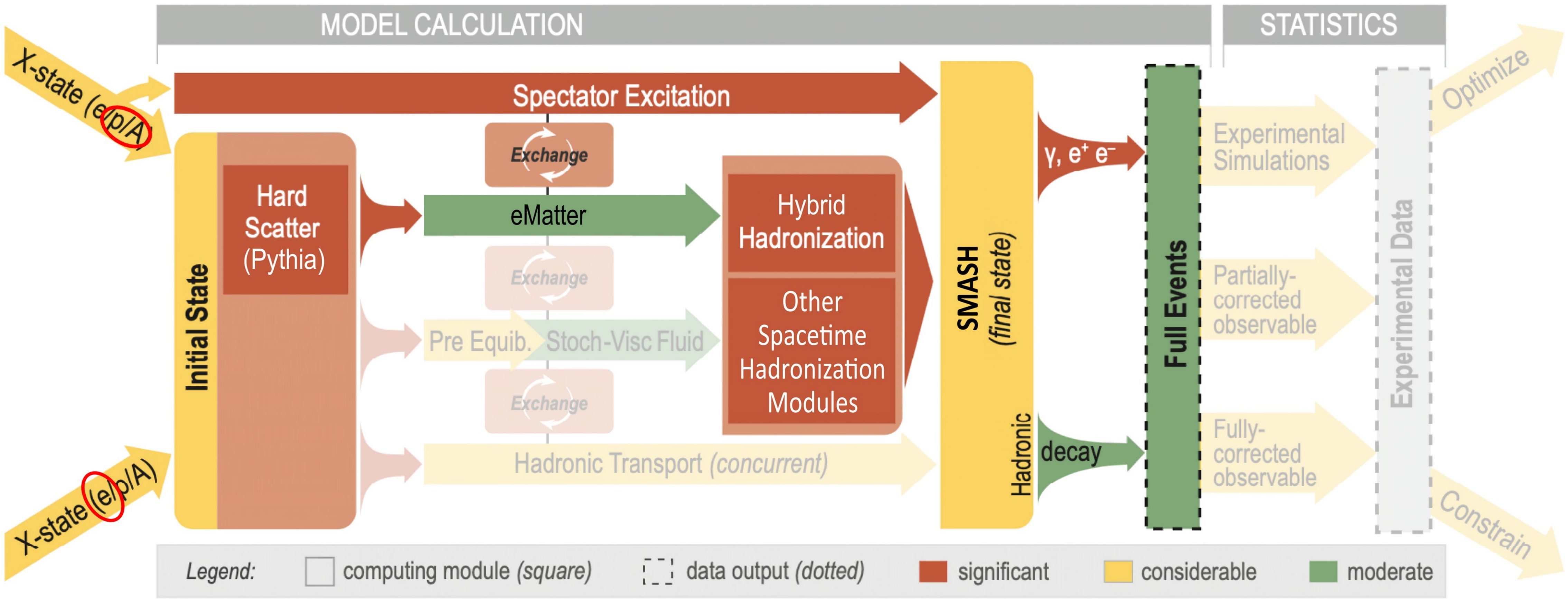


Next Steps – In-Nucleus Hadronization

- Hadronization can happen inside the nucleus
- More likely at high A, low Q^2, ν
- Newly formed hadrons can further scatter
- Not included in the previous results



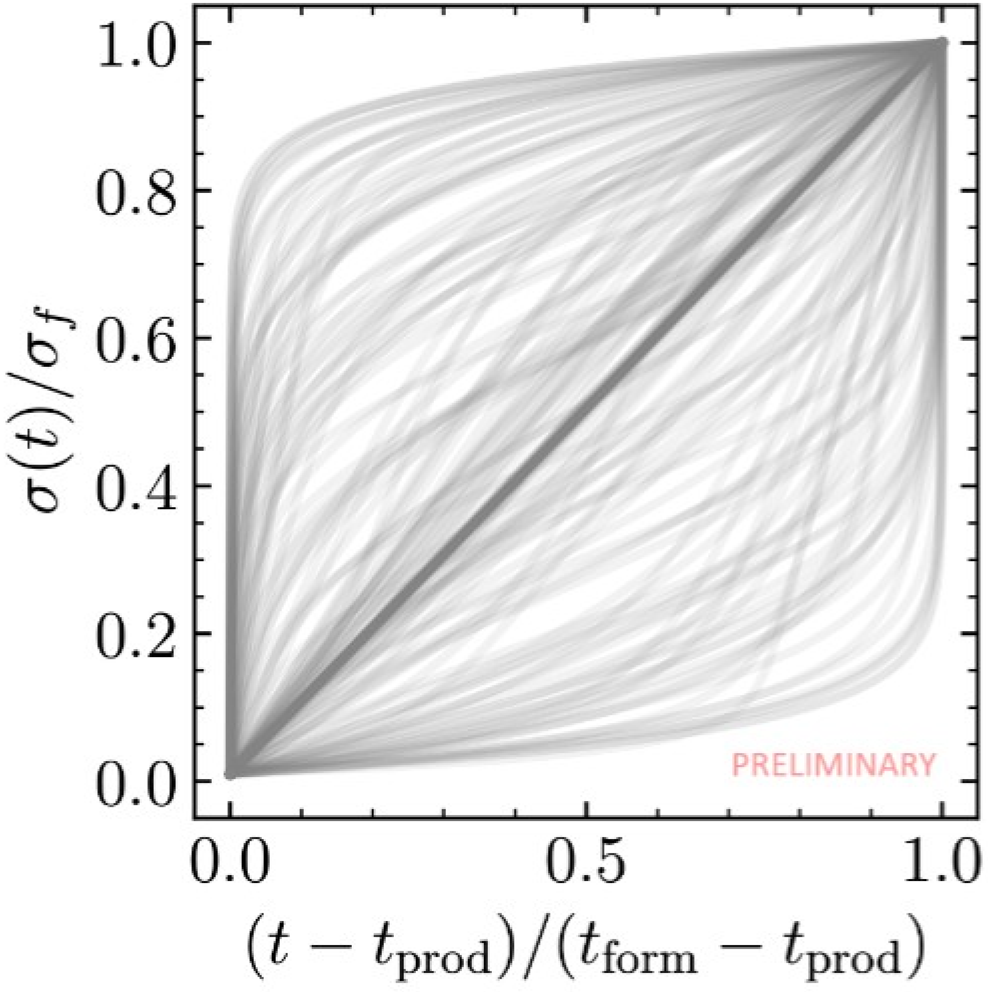
Next Steps – In-Nucleus Hadronization



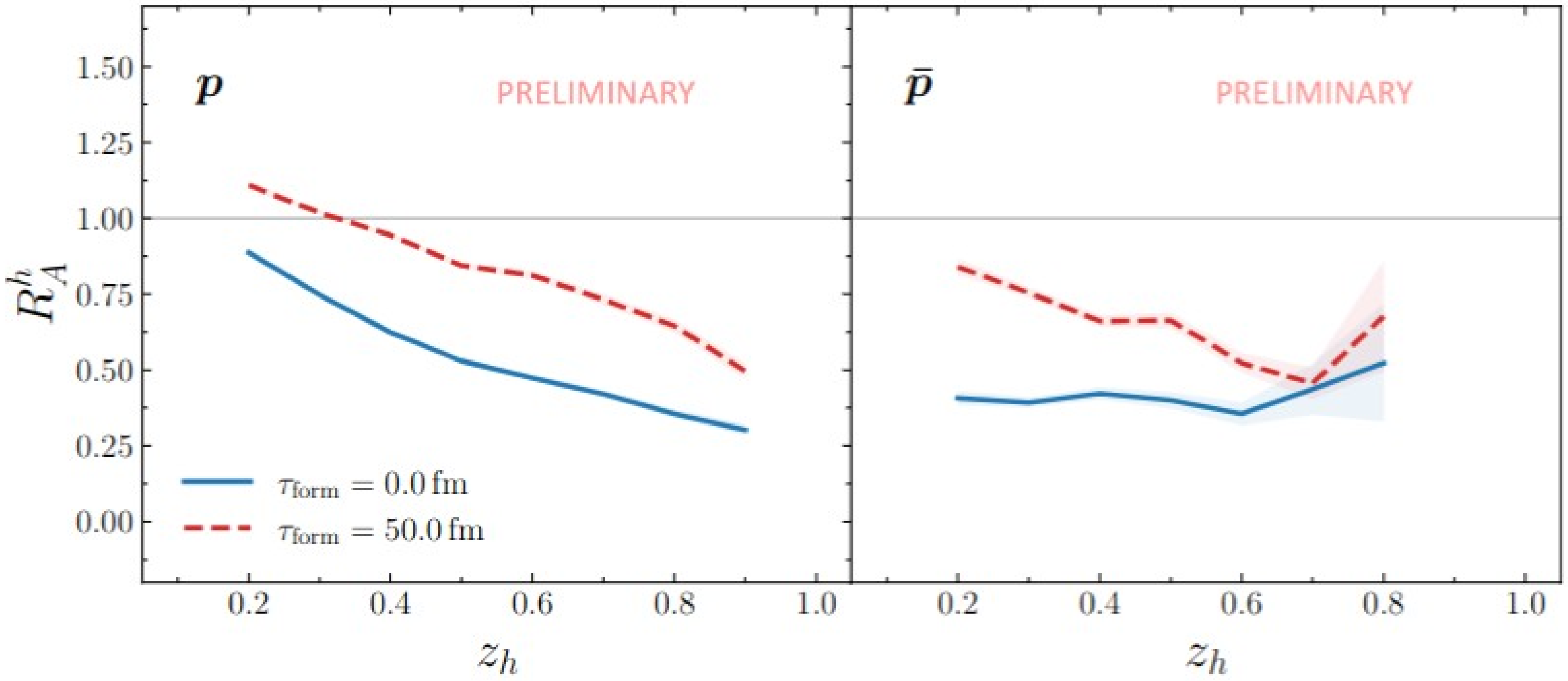
- New in-medium hadronization module
  - SMASH for hadronic transport

Related Work from HP2026

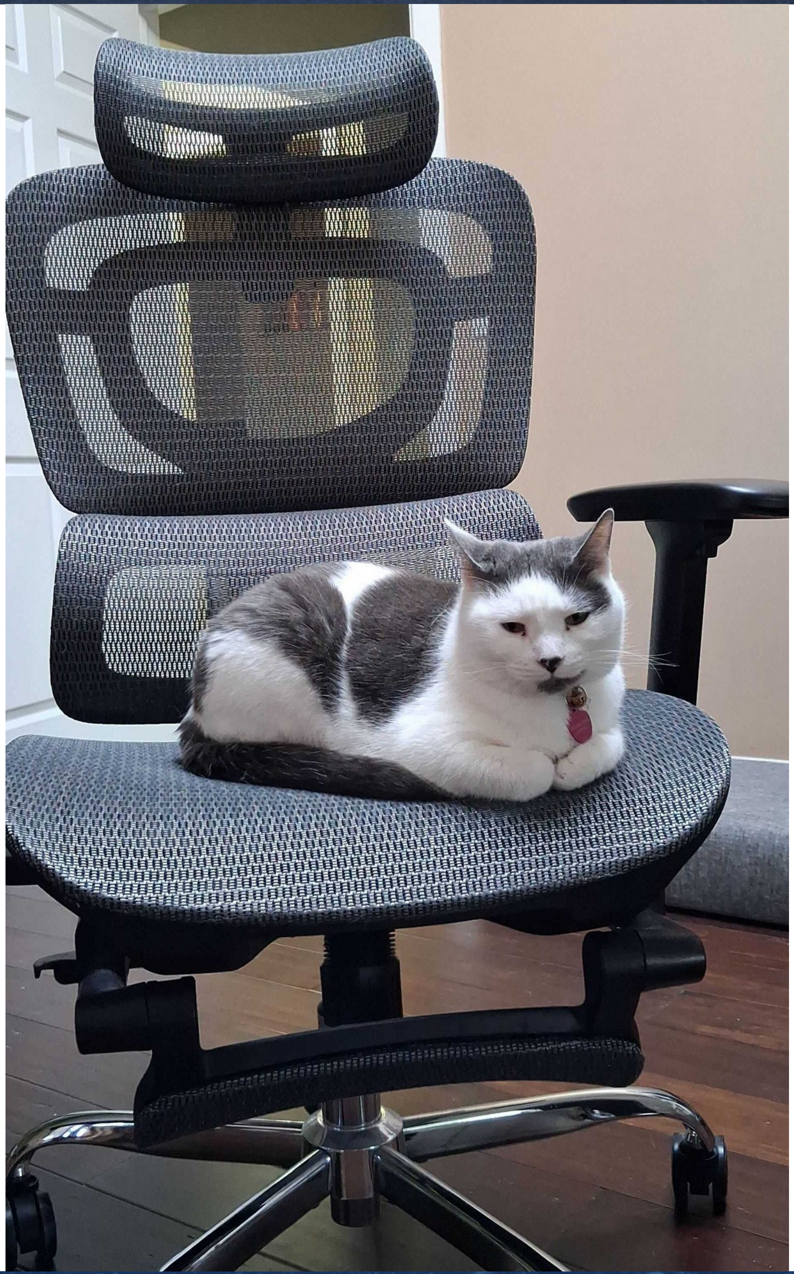
Jordi Salinas San Martín, HP2026 Poster Session

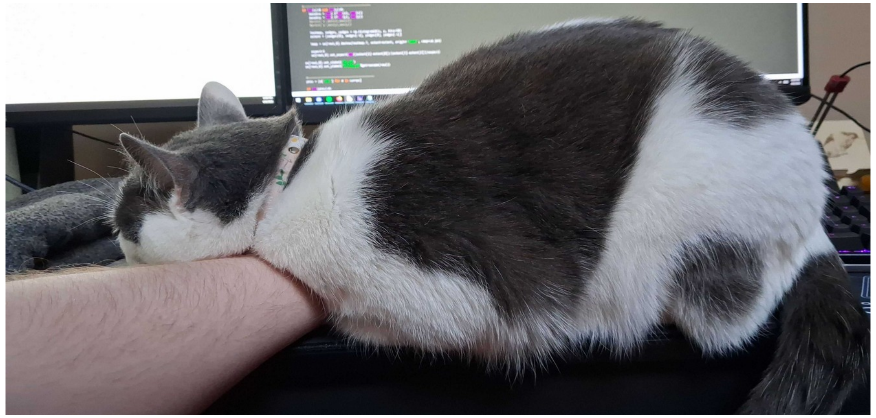


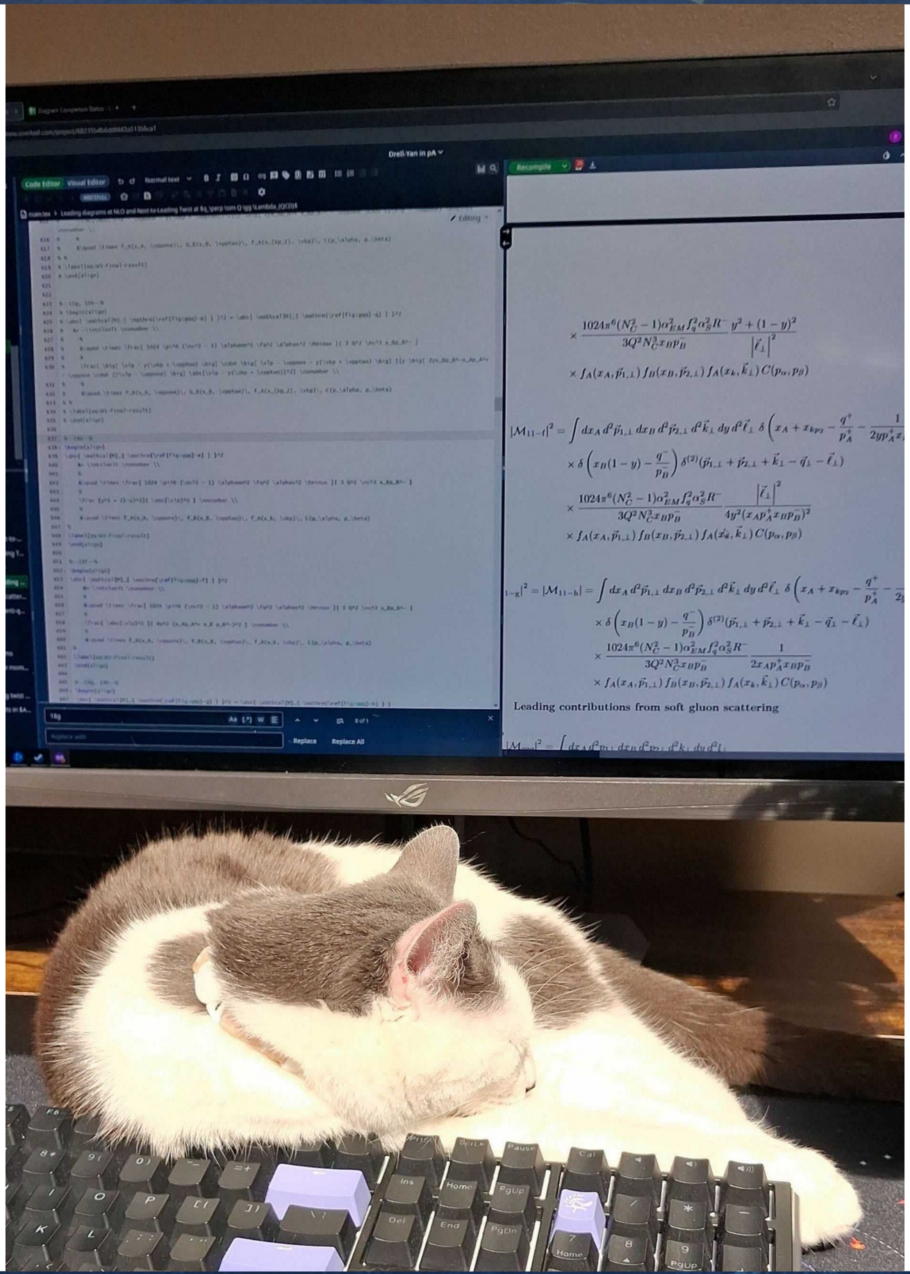
In-medium hadronization in eHIJING



Next Steps – In-Nucleus Hadronization







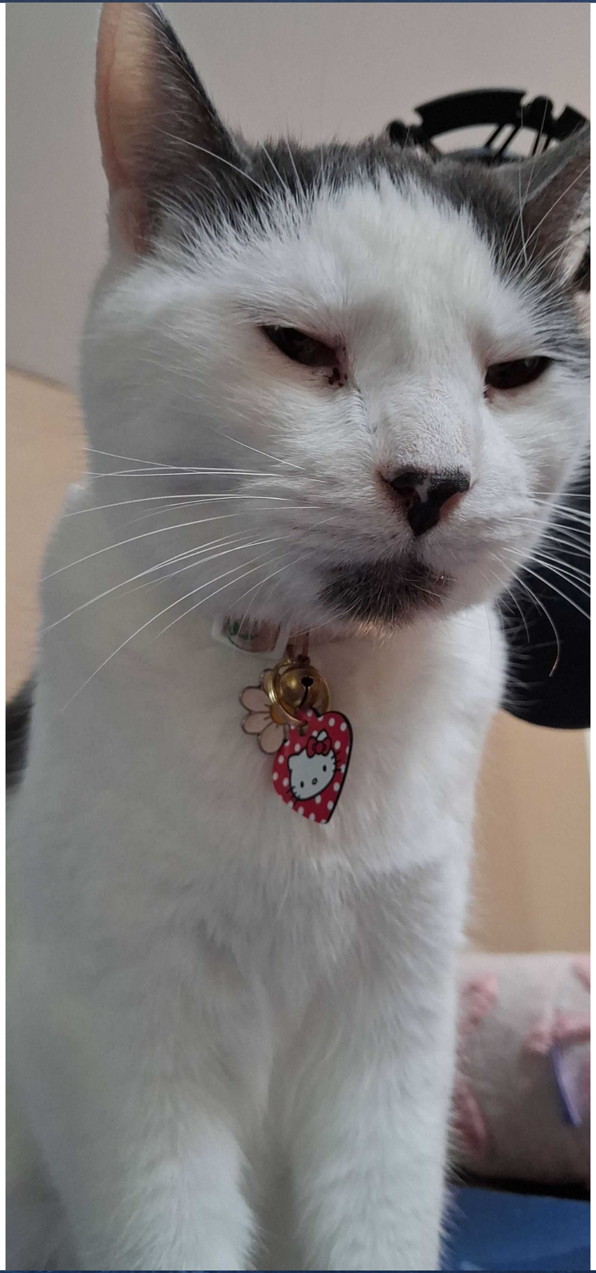
Summary

- First implementation of e-A in X-SCAPE
- Encouraging first results – no parameters fit ($\sigma^2 = 0.8\text{GeV}^2$)

Still to come:

- Spacetime picture of hadronization
- Boosting the target nucleus
- Include ISR

Backup



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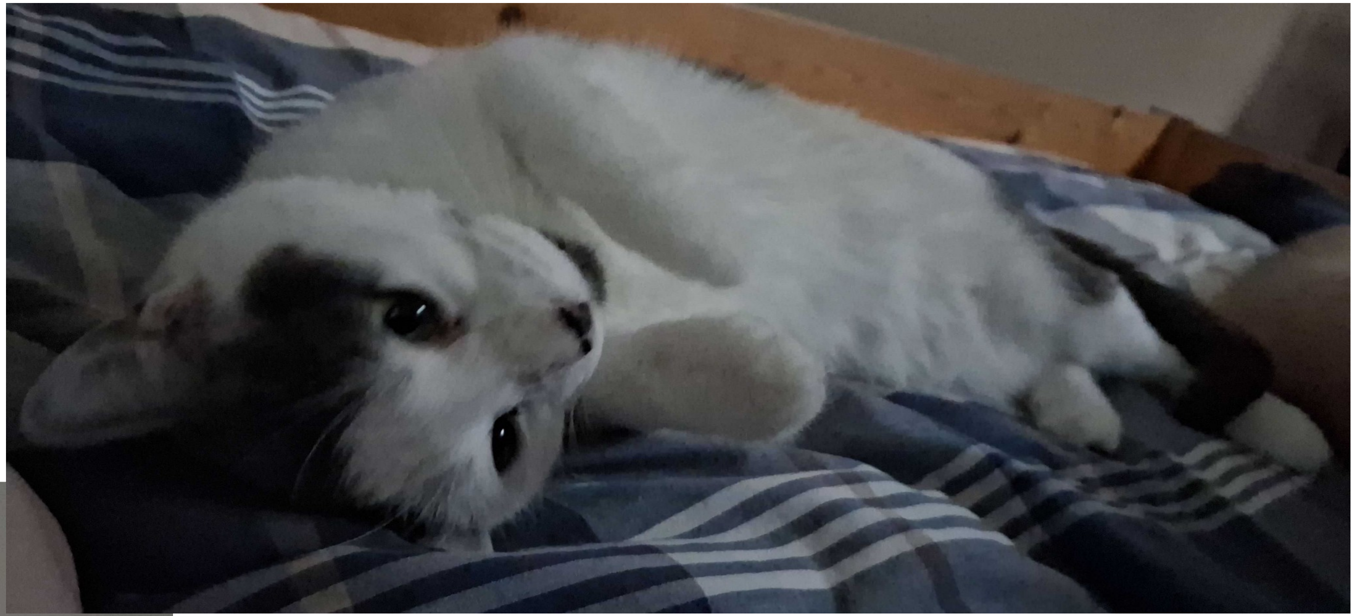
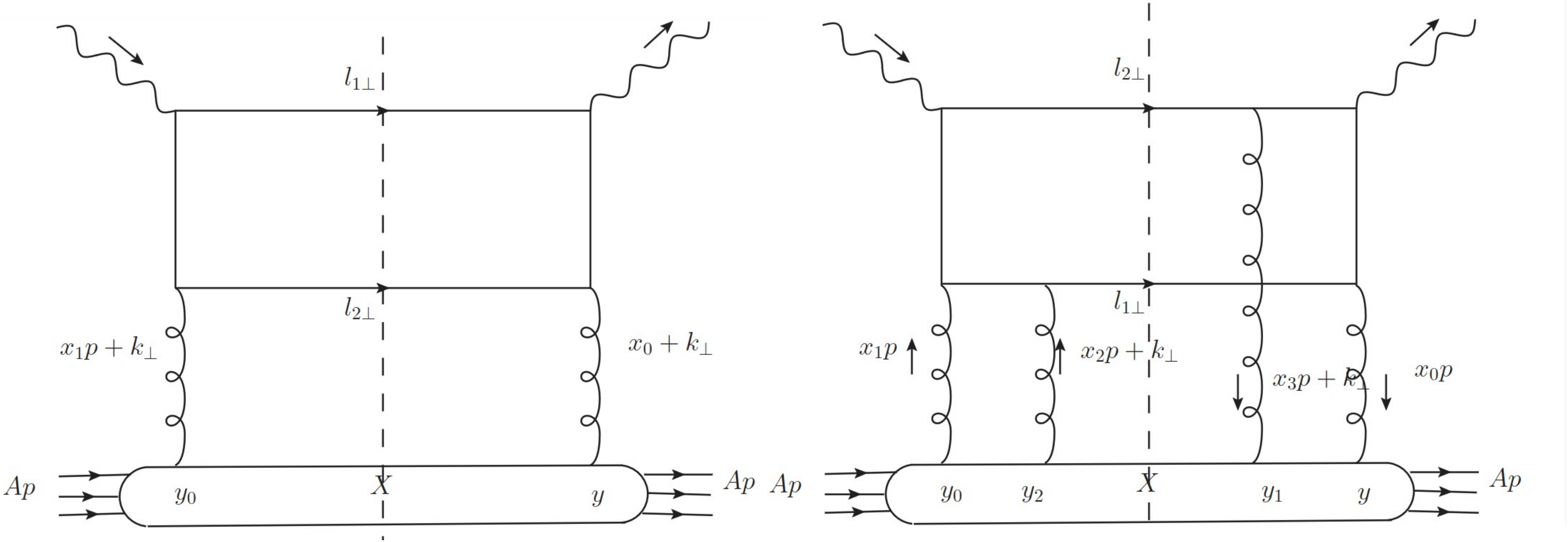


More Related Work from HP2026

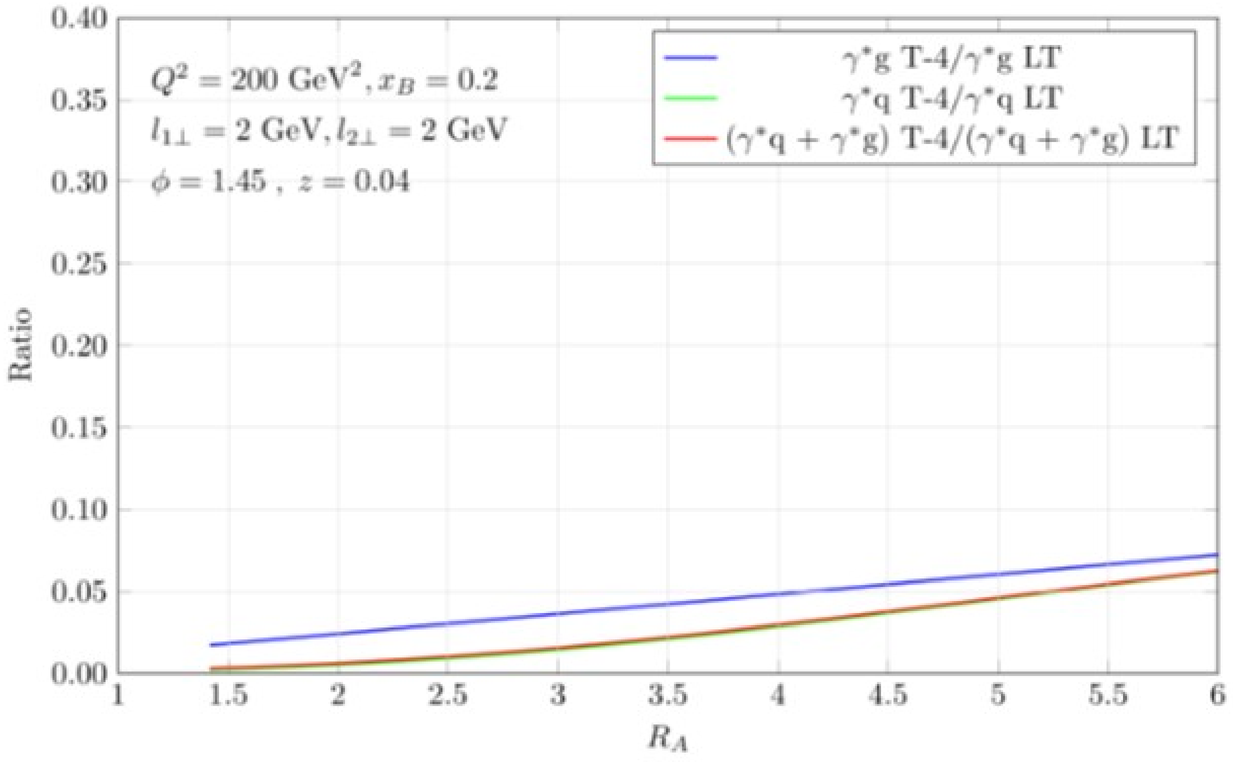
Photon-gluon fusion at intermediate x



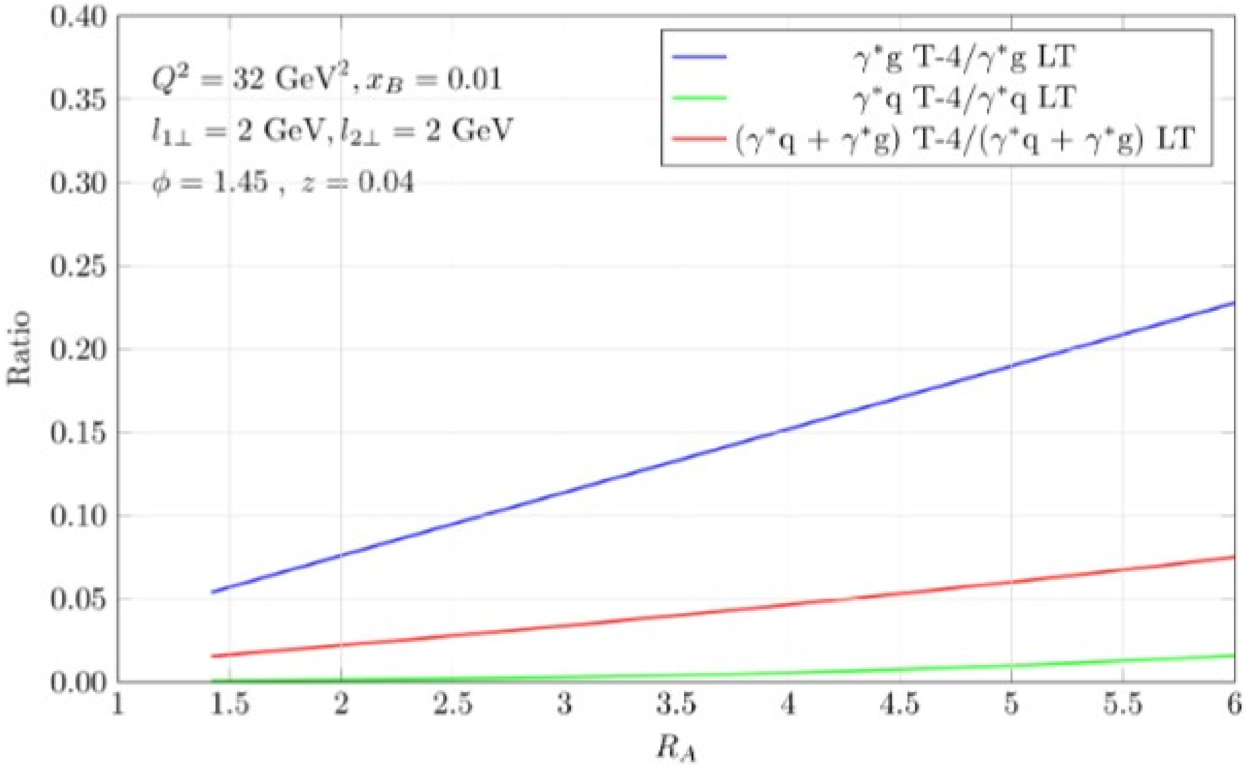
More Related Work from HP2026

Yu Fu, HP2026 Poster Session

Photon-gluon fusion at intermediate x



$x = 0.2$



$x = 0.01$