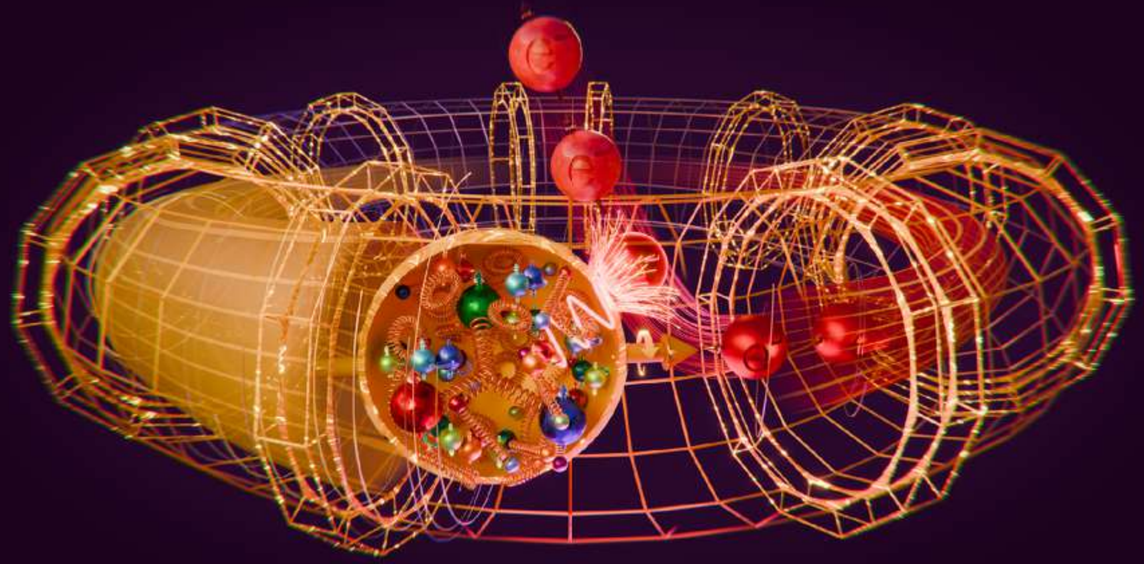
Unveiling the True Mechanism of Forward Neutron Production



Daria Trotsenko
Harvard University

HARVARD UNIVERSITY

T-2 group

July 28th 2026 T Lightning Talk, LANL

Los Alamos NATIONAL LABORATORY

U-NAPR-26-23527

A little about me



- PhD student in particle physics @ Harvard in Prof. Matt Schwartz's group

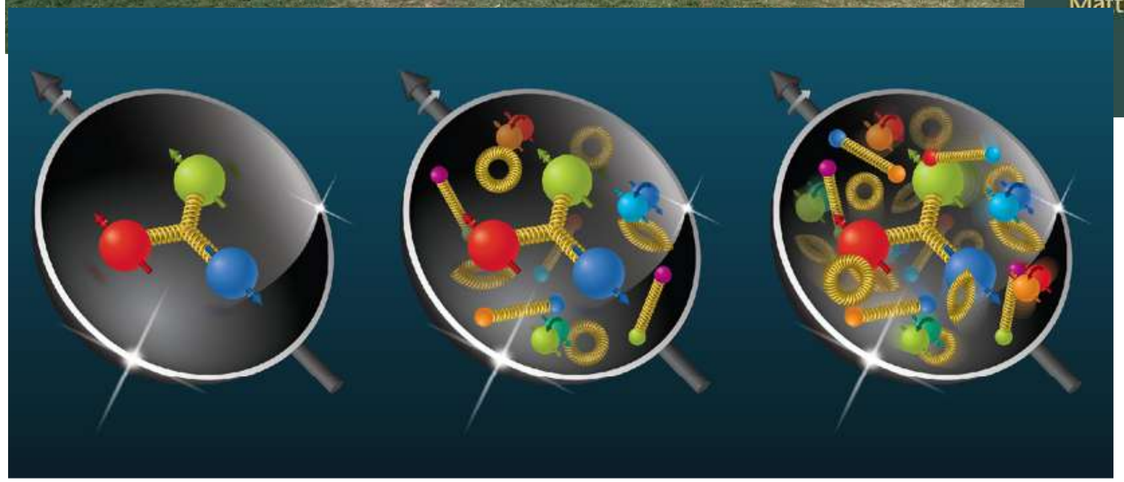
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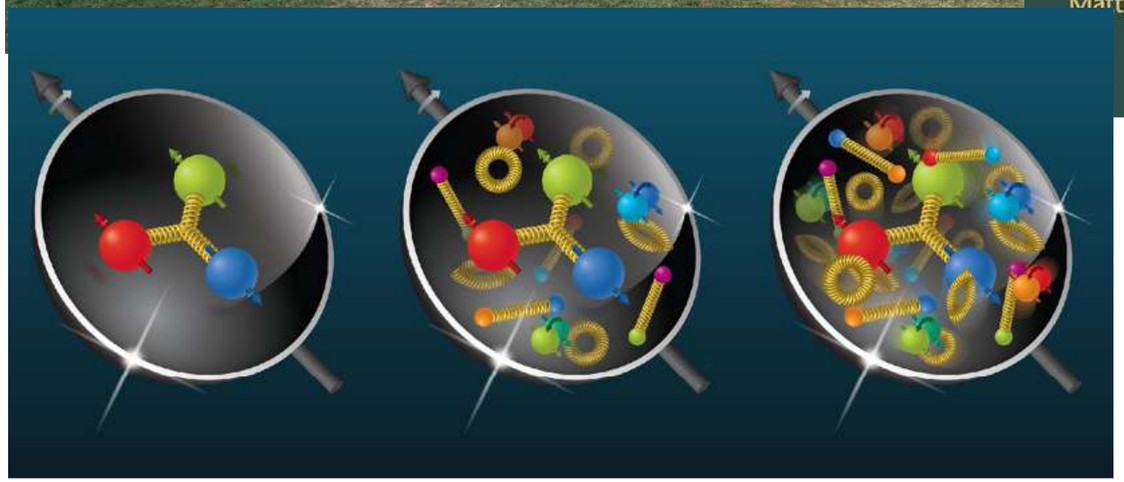




- PhD student in particle physics @ Harvard in Prof. Matt Schwartz's group
- QCD and effective field theory

A little about me





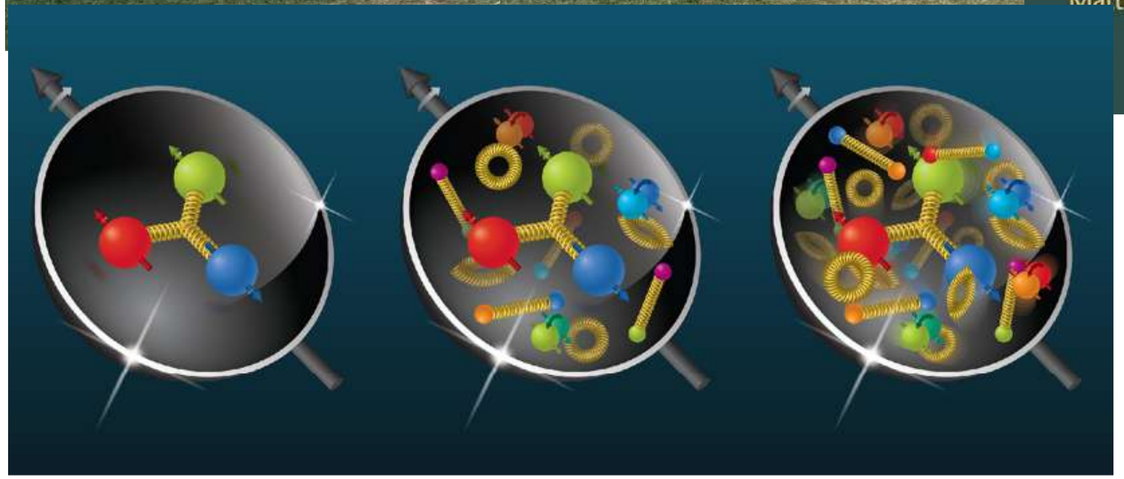


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- QCD and effective field theory
- MSc from the University of Amsterdam

A little about me



- PhD student in particle physics @ Harvard in Prof. Matt Schwartz's group
- QCD and effective field theory
- MSc from the University of Amsterdam
- My hobby: taking photos of fat Boston squirrels!

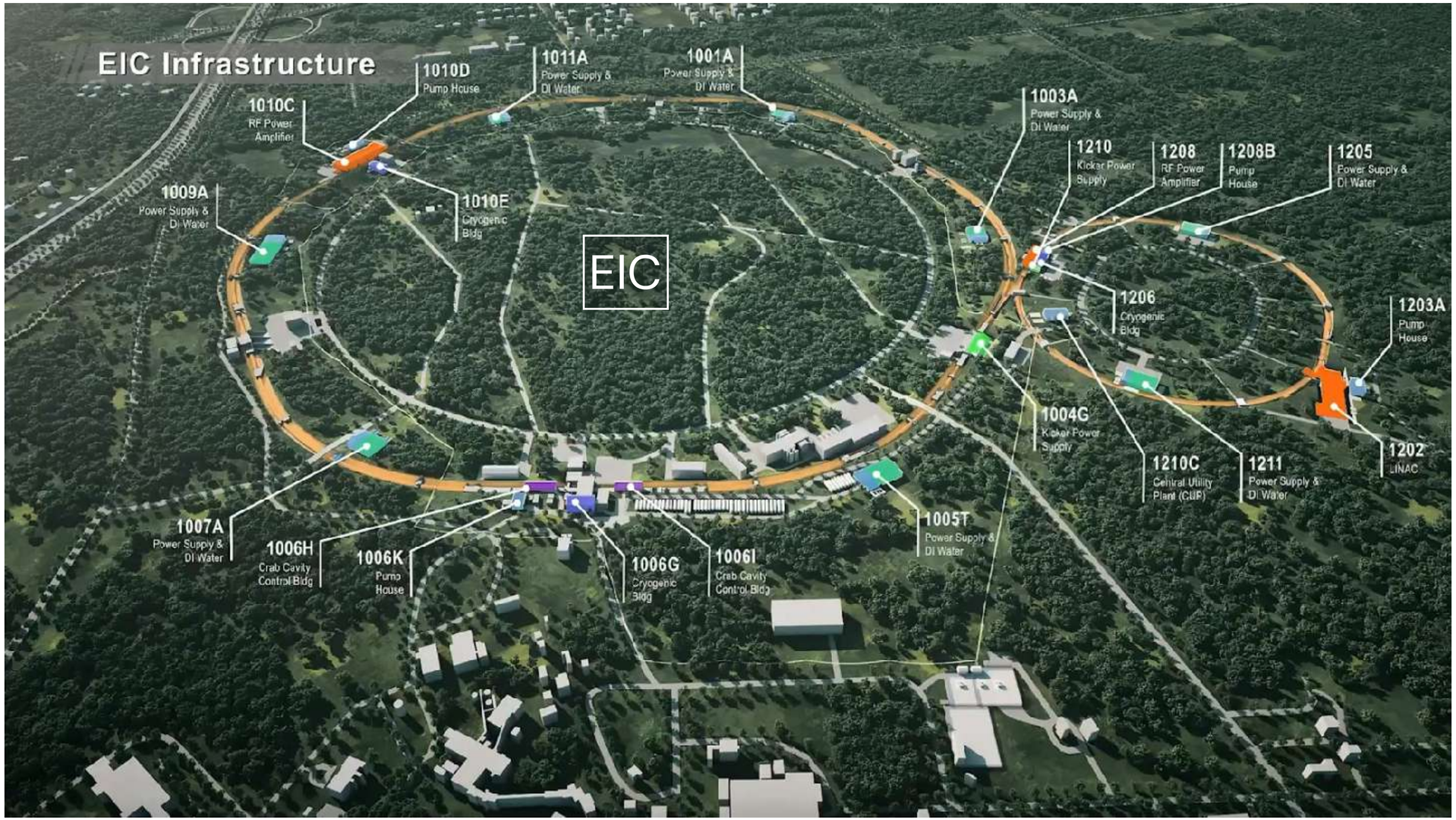






Electron–Ion Collider at Brookhaven National Laboratory

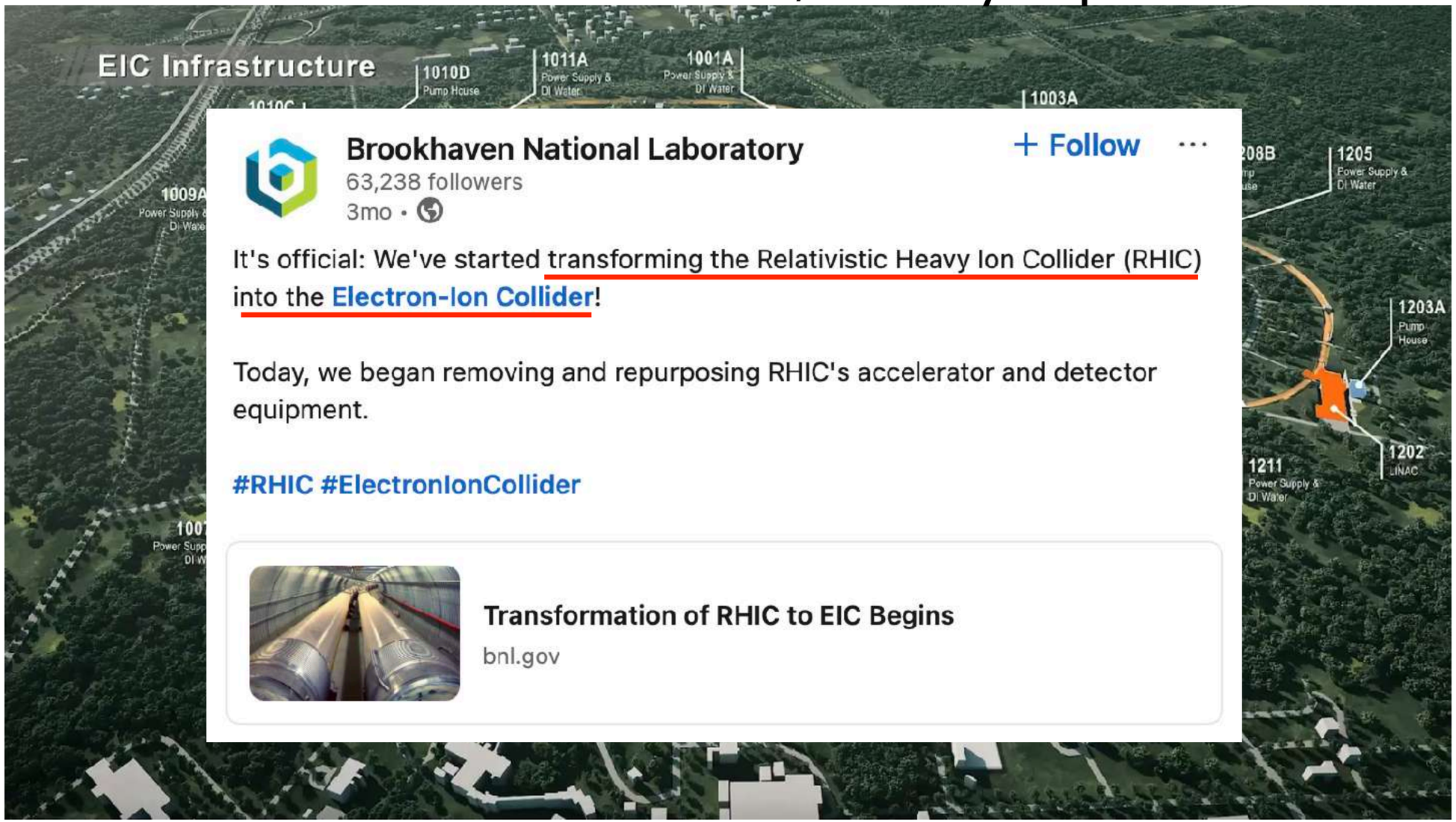
- $3 billion instrument



(Figures: BNL, EIC)

Electron-Ion Collider at Brookhaven National Laboratory

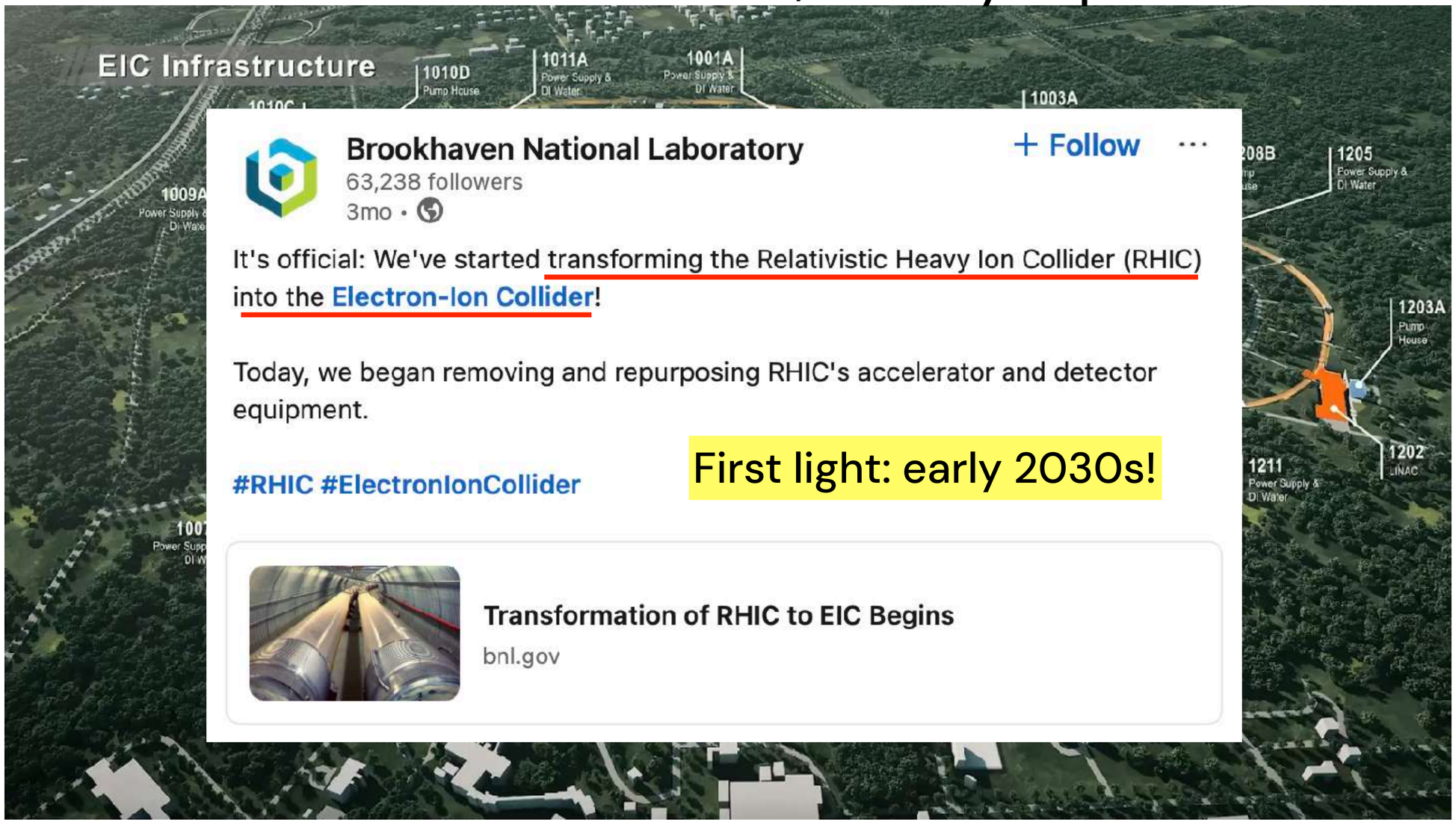
- $3 billion instrument , already in process!



(Figures: BNL, EIC)

Electron-Ion Collider at Brookhaven National Laboratory

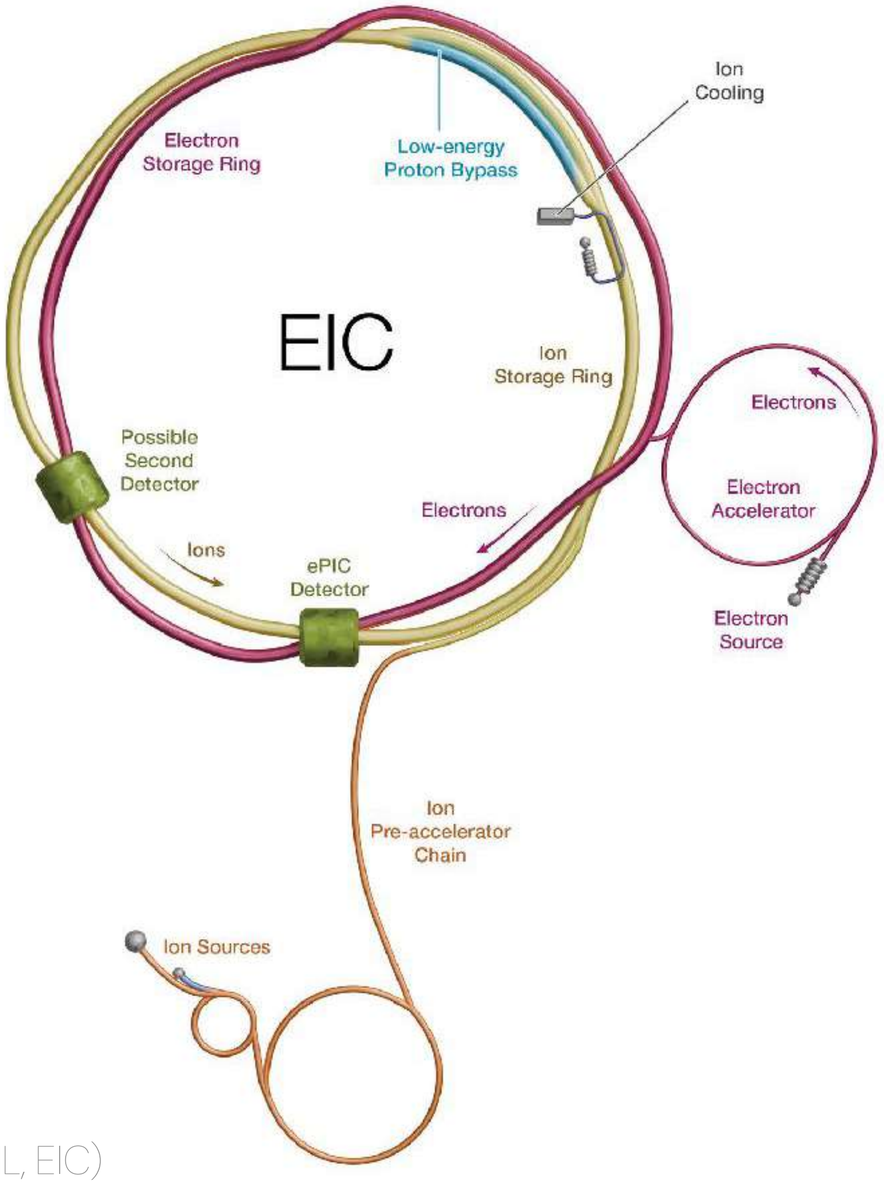
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(Figures: BNL, EIC)

Electron–Ion Collider at Brookhaven

Collisions of $e + p,\ e + A$

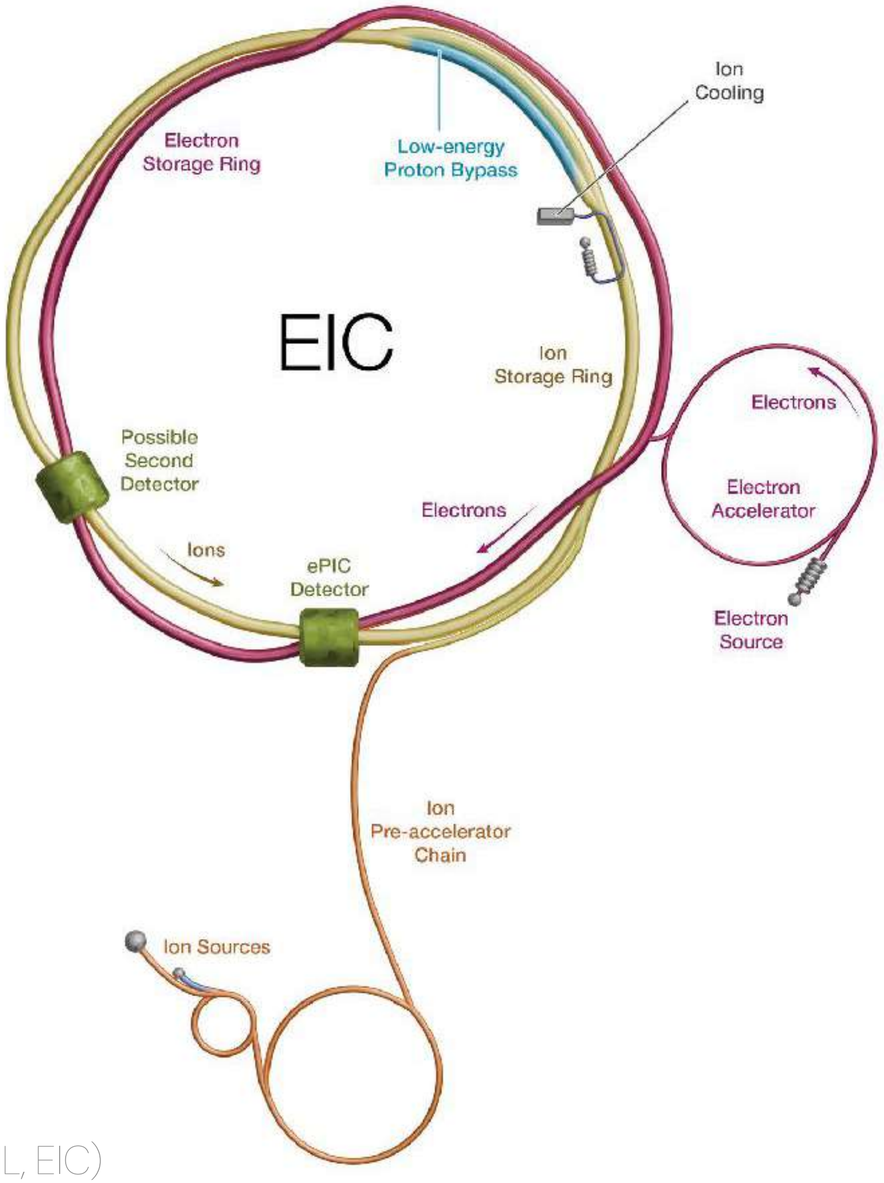


- **Only collider of its kind** when running

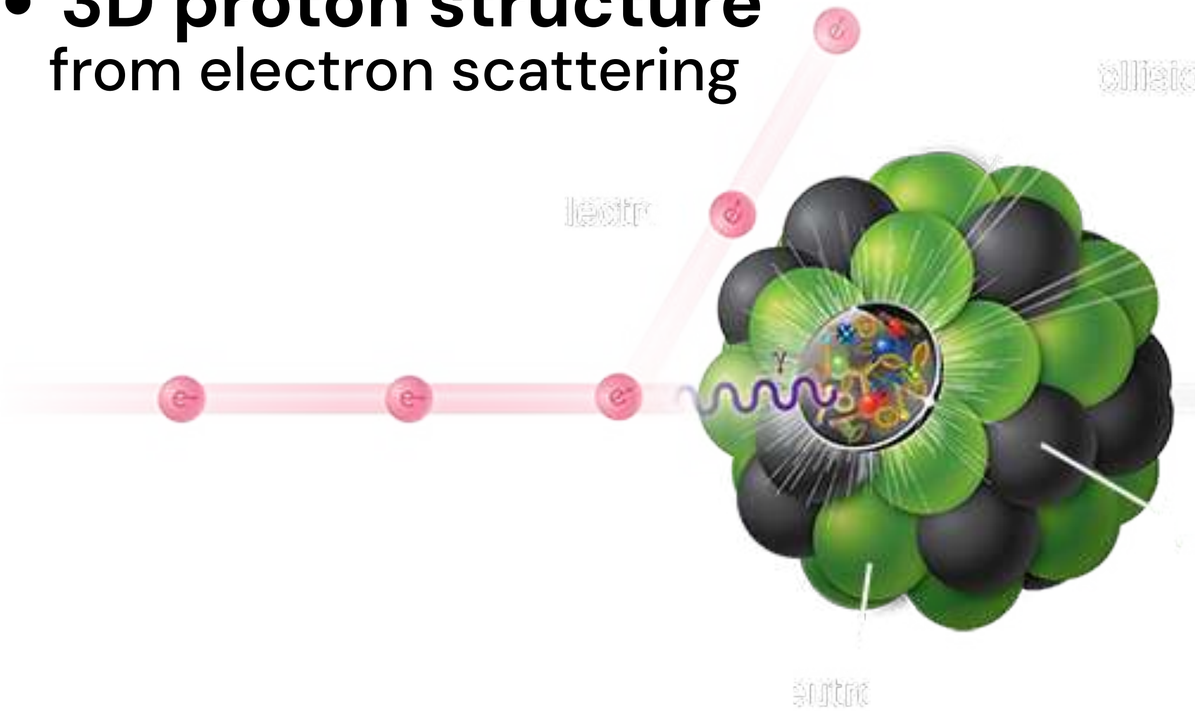
(Figures: BNL, EIC)

Electron–Ion Collider at Brookhaven

Collisions of $e + p,\ e + A$



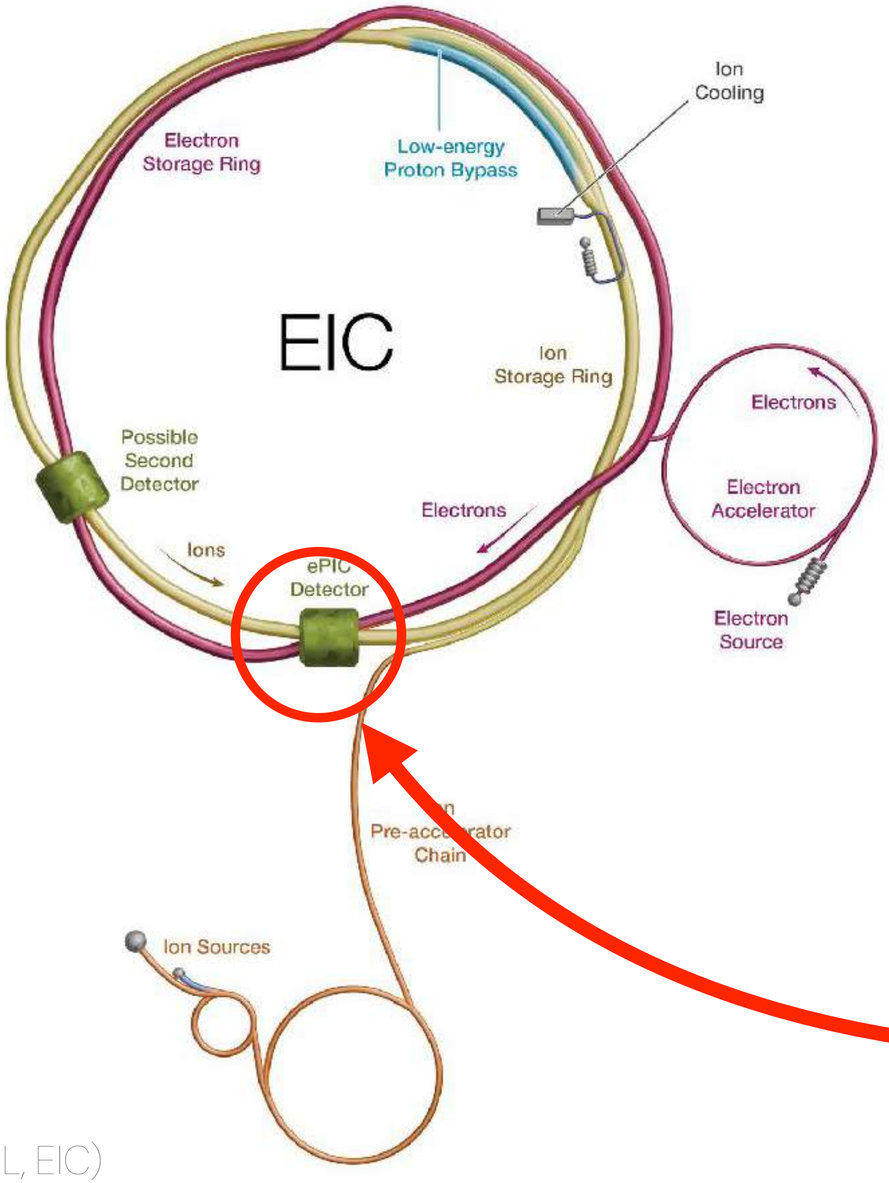
- **Only collider of its kind**
  when running
- **3D proton structure**
  from electron scattering



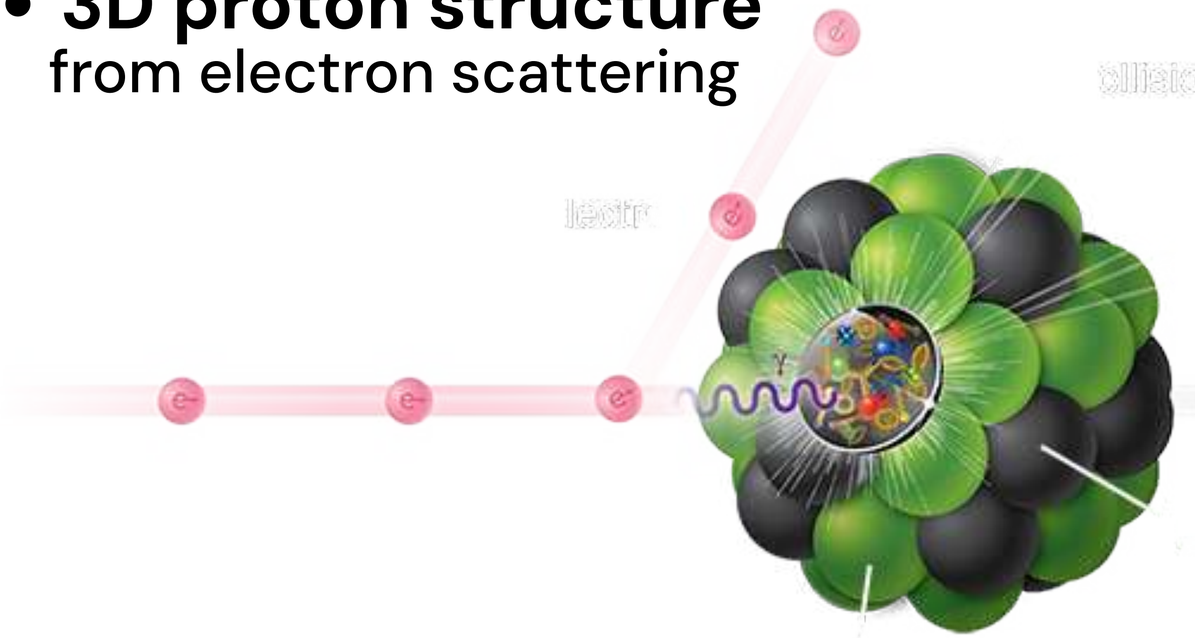
(Figures: BNL, EIC)

Electron–Ion Collider at Brookhaven

Collisions of $e + p,\ e + A$



- **Only collider of its kind** when running
- **3D proton structure** from electron scattering

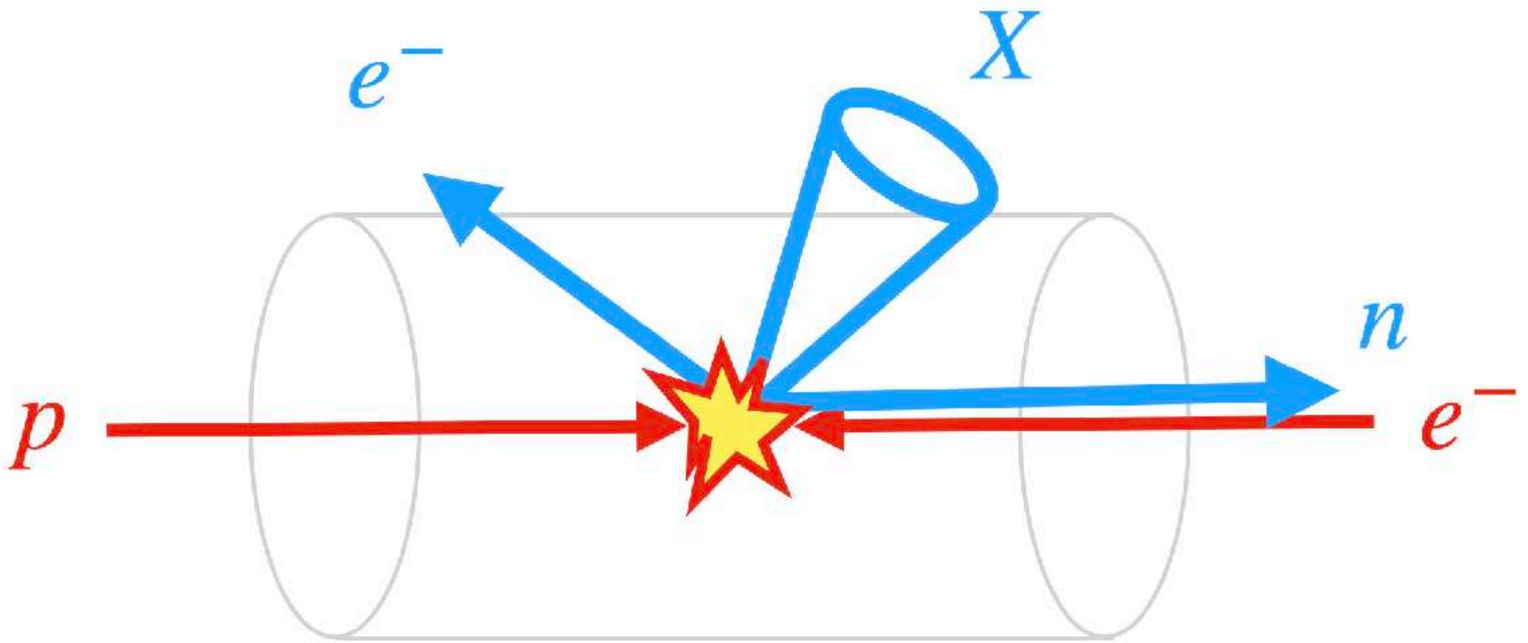


- **Powerful Zero-Degree Calorimeter** in the ePIC experiment

(Figures: BNL, EIC)

Forward neutrons at ePIC

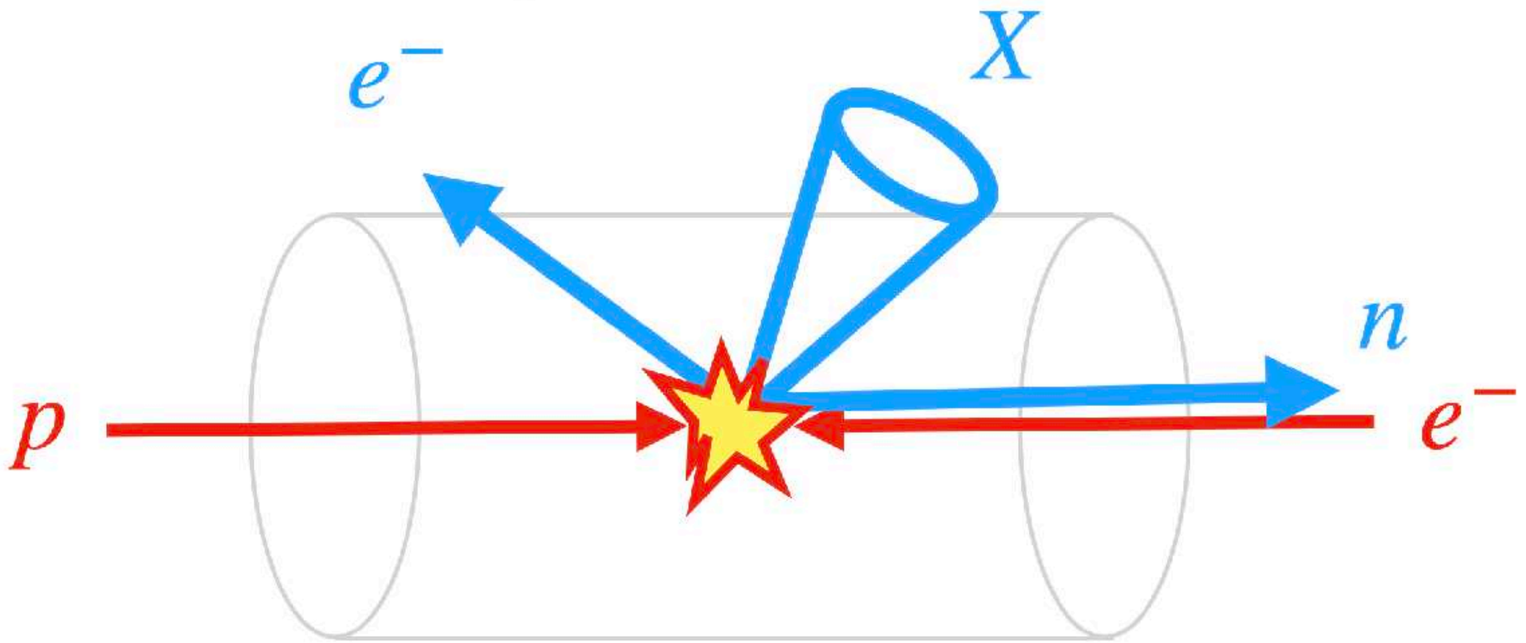
$$ep \rightarrow eXn$$



“Sullivan process”

Forward neutrons at ePIC

$$ep \rightarrow eXn$$



"Sullivan process"

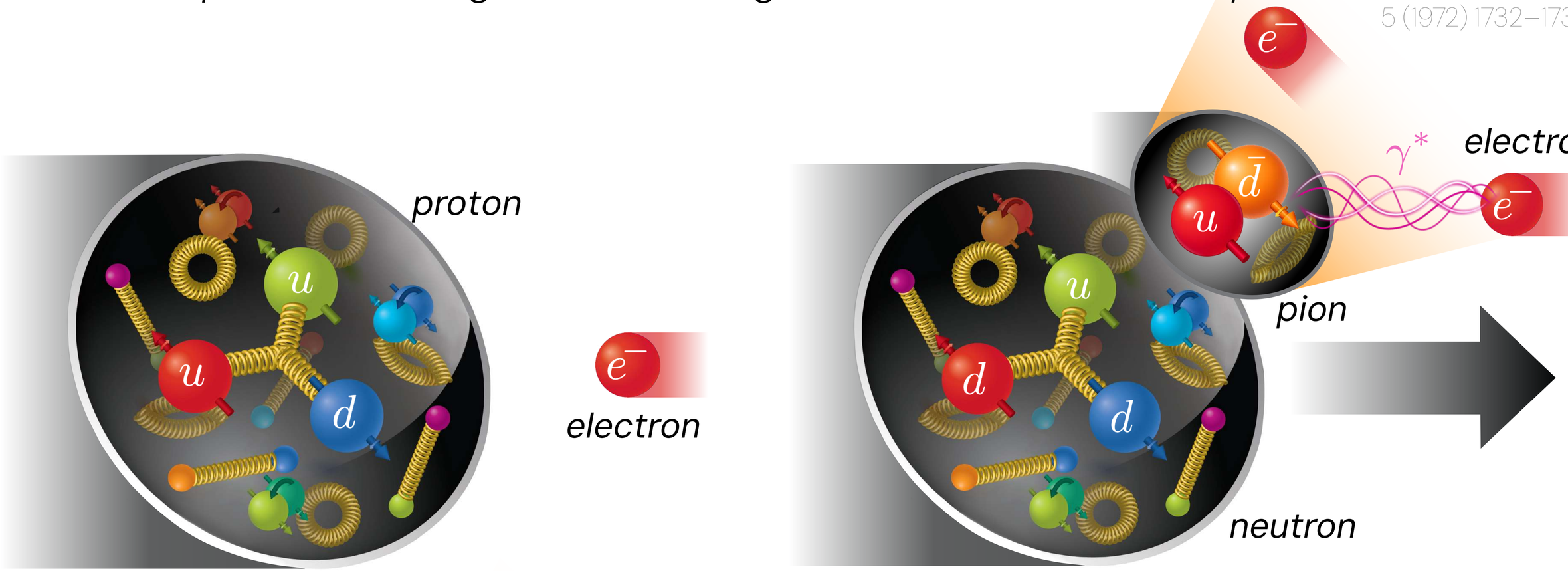
- ~2–8% of the ep events at HERA had forward neutrons
- up to ~20%* of the ep events at EIC

*extrapolation from HERA (H1 Collaboration, 1001.0532) (Y. Yamazaki, "Neutron angular distribution and dose in ZDC")

The Sullivan process: history

$ep \to eXn$

Proposed in 1971 right after learning of inner structure of the proton (Sullivan, Phys. Rev. D 5 (1972) 1732–1737)



Idea:
only one pion exchanged

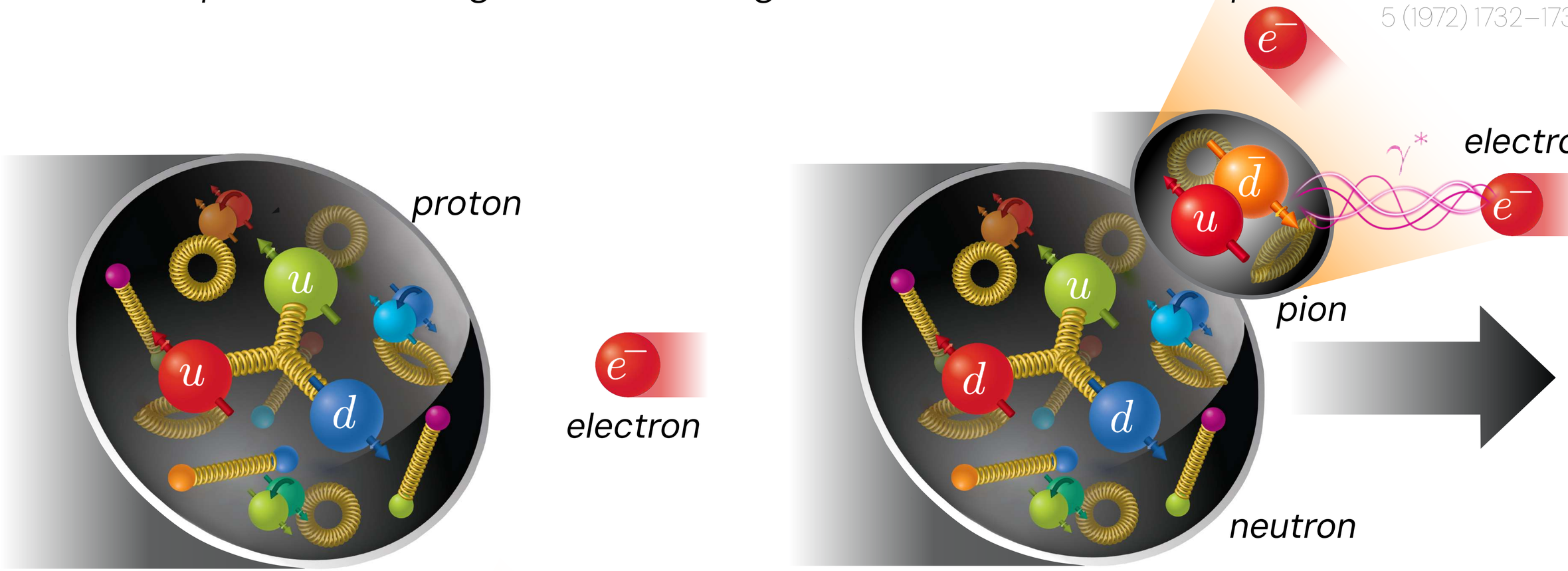
Claim:
able to access the internal gluon structure of the pion

(Figure: BNL)

The Sullivan process: history

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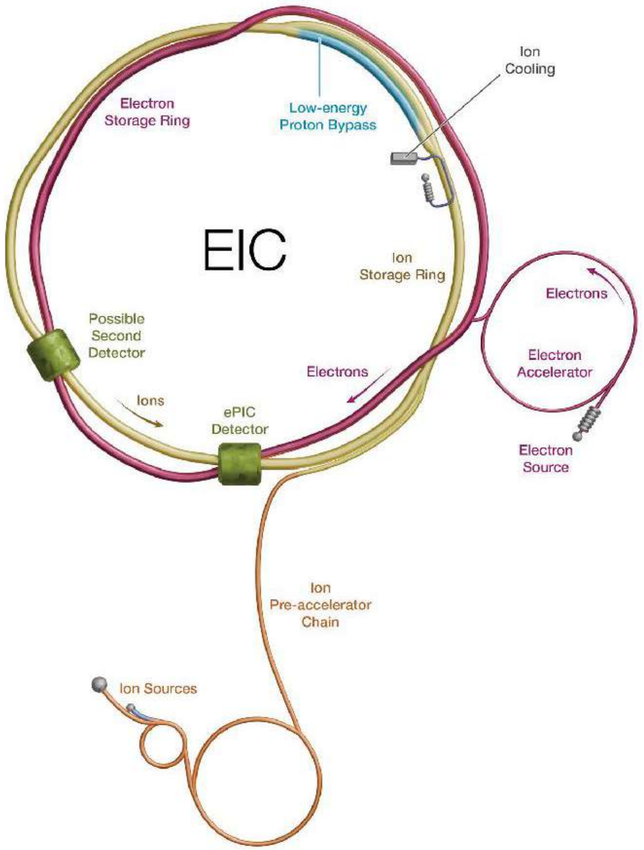
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Experiments disagree!

(Figure: BNL)

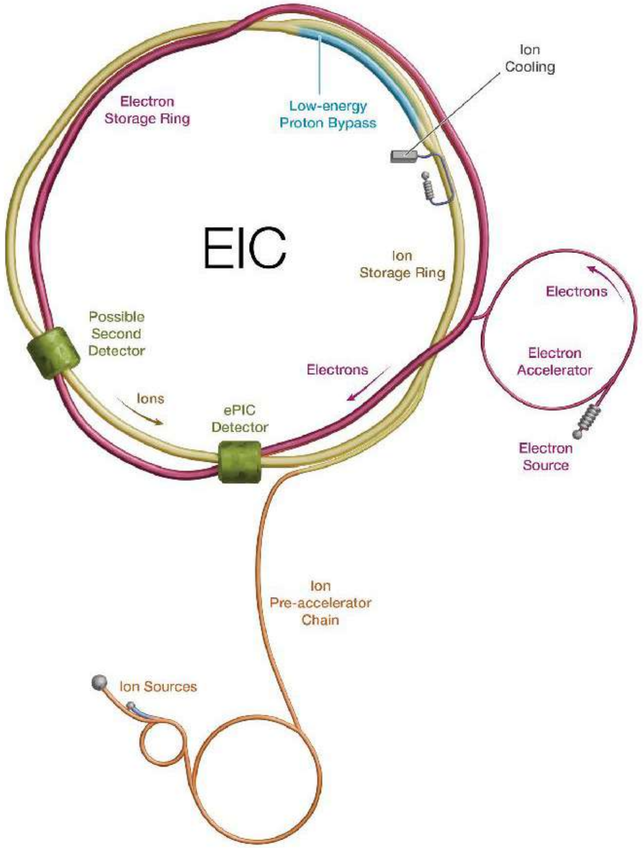
Quick math

$3 billion dollar collider



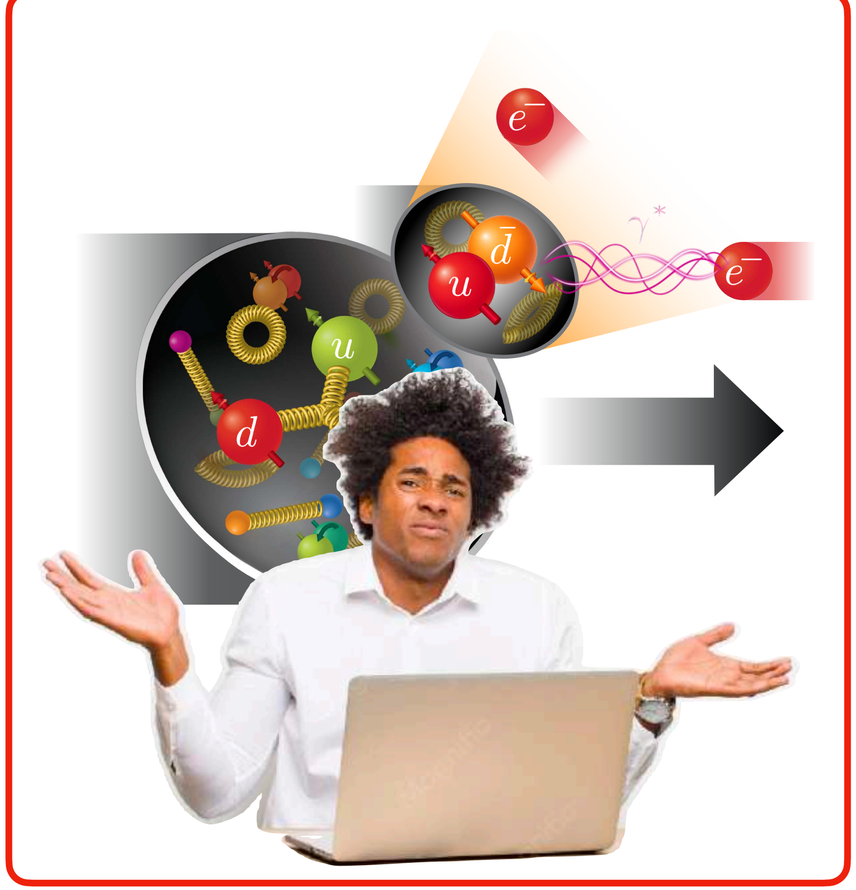
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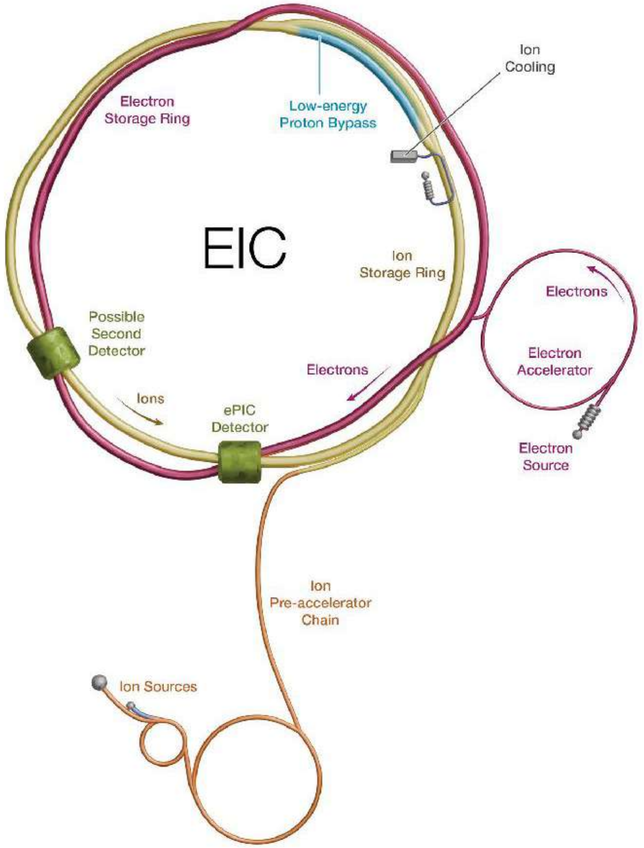
+

20% of the data not correctly explained theoretically



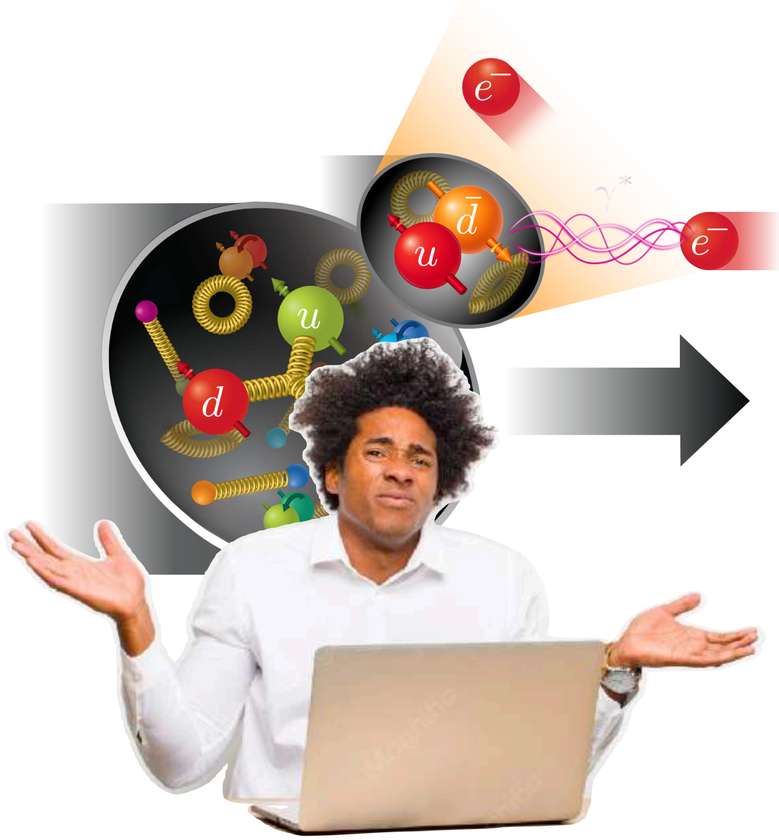
Quick math

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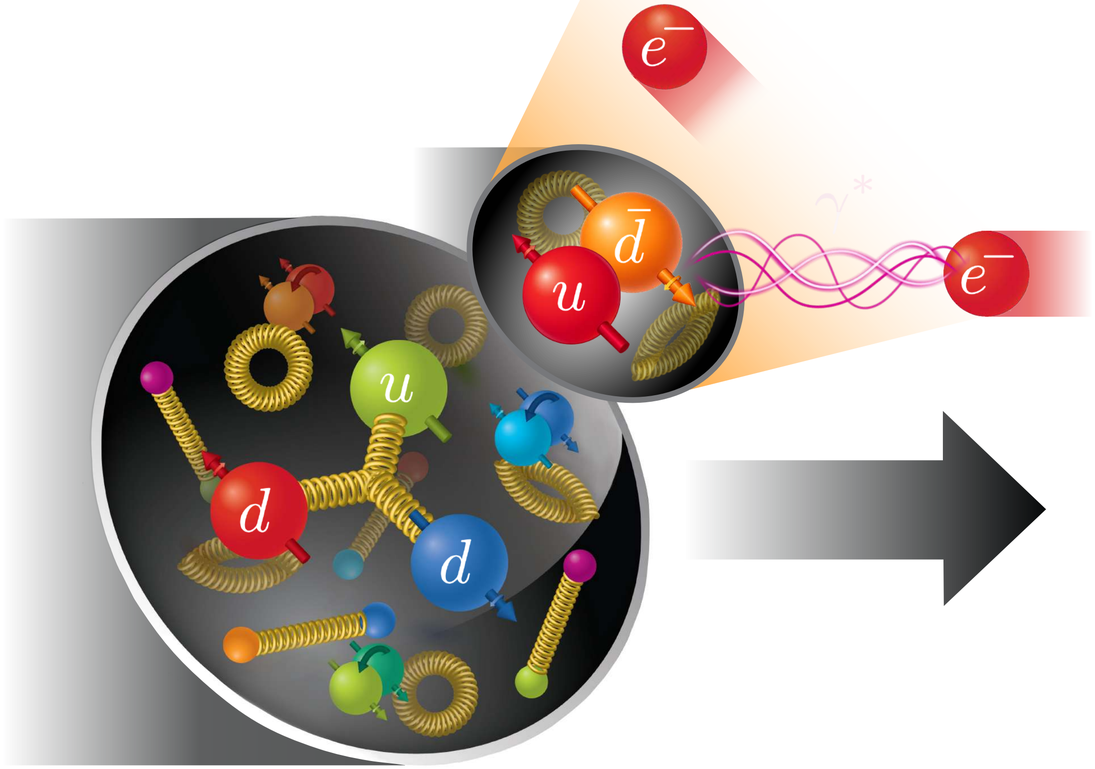


=

$600 million wasted!

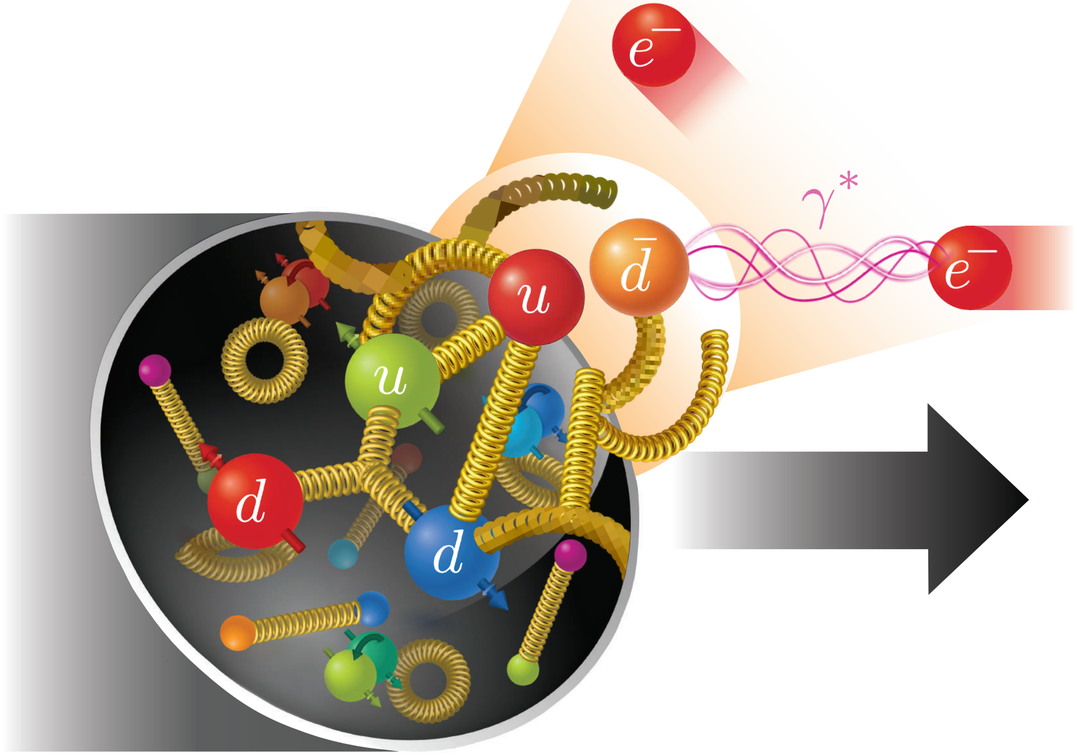


The Sullivan process: reality



Experimentalists' dream

- Mediated by a pion
- Can access pion's inner structure
- But models don't fit data



Theorists' reality

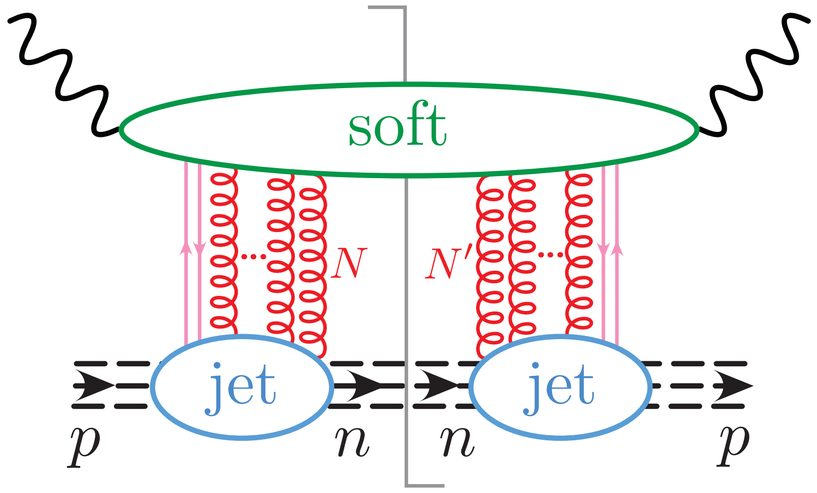
- Widely separated momentum scales
- SCET gives a systematic description
- Two quarks + infinite gluons → **not a pion**

First principles formula for Sullivan process

$$F_i^D = S_{iNN'} \otimes_\perp (J_N \times J_{N'})$$

$$J_N^{R^N} = \frac{1}{\bar{n}\cdot p}\langle p|\Big\{\mathcal{O}_n(0,\tau_{u\perp})\bar{\mathcal{O}}_n(0,\tau_{\bar{d}\perp})\prod_{i=1}^{N-1}\mathcal{O}_n^{A_i}(0,\tau_{i\perp})\hat{\mathcal{O}}_n^{A_N}(0)\Big\}P_N^{R^N}|n\rangle$$

$$S_{iNN'}^{R^N R^{N'}} = \left(\frac{Q}{n\cdot q}\right)^2 \mathcal{P}'_{i\,\mu\nu}\int[d\tilde{y}][d\tilde{y}']đ^{\,d}z e^{iz\cdot q}\sum\!\!\!\!\!\!\int_{X_s}\langle 0|\bar{T}J_s^\mu(z)\Big\{\bar{\mathcal{O}}_n^s(\tilde{y},-\tau_{u\perp})\mathcal{O}_n^s(\tilde{y},-\tau_{\bar{d}\perp})\prod_{i=1}^{N}\mathcal{O}_s^{A_i}(\tilde{y},\tau_{i\perp})\Big\}P_N^{R_A^N}|X_s\rangle$$
$$\times\langle X_s|P_{N'}^{R_{A'}^{N'}}TJ_s^\nu(0)\Big\{\bar{\mathcal{O}}_n^s(\tilde{y}',-\tau_{u\perp})\mathcal{O}_n^s(\tilde{y}',-\tau'_{\bar{d}\perp})\prod_{j=1}^{\infty}\mathcal{O}_s^{A'_i}(\tilde{y}',-\tau'_{i\perp})\Big\}|0\rangle$$



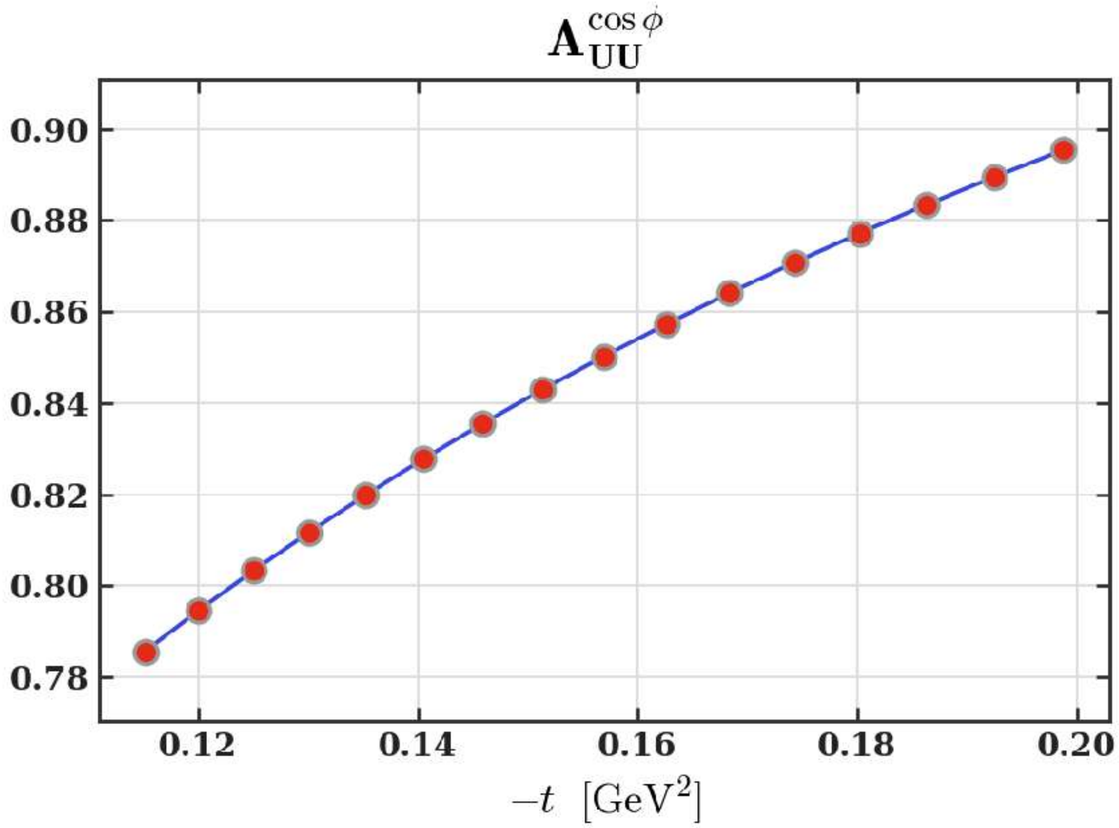
$$\iint_{(N,\,N')}^{\perp\, u\bar{d}} \equiv \frac{(-i)^N i^{N'}}{N!\,N'!}\int\frac{đ^{\,d'}\tau_{u\perp}}{\not{\tau}_{u\perp}}\frac{đ^{\,d'}\tau_{\bar{d}\perp}}{\not{\tau}_{\bar{d}\perp}}\prod_{i=1}^{N}\frac{đ^{d'}\tau_{i\perp}}{\vec{\tau}_{i\perp}^{\,2}}\,\delta^{\,d'}\Big(\tau_{u\perp}+\tau_{\bar{d}\perp}+\sum_i\tau_{i\perp}+\tau_\perp\Big)$$
$$\times\int\frac{đ^{\,d'}\tau'_{u\perp}}{\not{\tau}'_{u\perp}}\frac{đ^{\,d'}\tau'_{\bar{d}\perp}}{\not{\tau}'_{\bar{d}\perp}}\prod_{j=1}^{N'}\frac{đ^{d'}\tau'_{j\perp}}{\vec{\tau}_{j\perp}^{\,\prime 2}}\,\delta^{\,d'}\Big(\tau'_{u\perp}+\tau'_{\bar{d}\perp}+\sum_j\tau'_{j\perp}-\tau_\perp\Big)$$

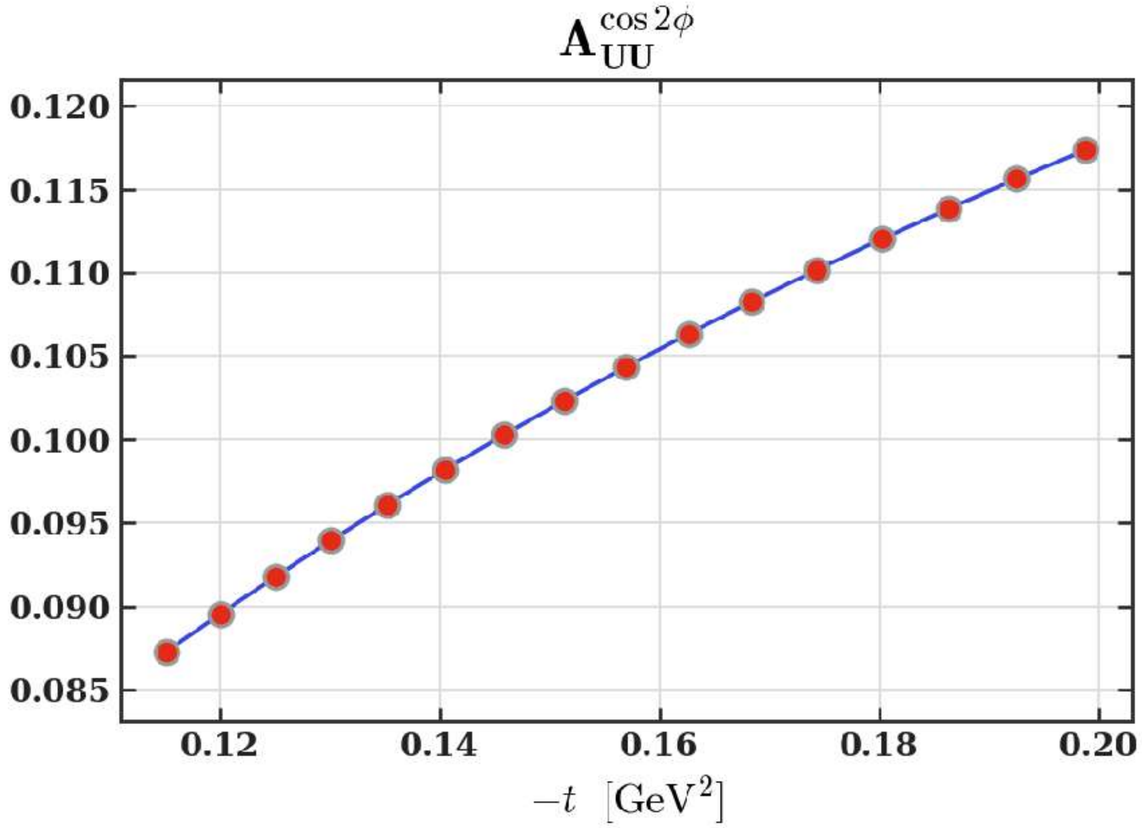
Unpolarized azimuthal modulations

Tell us whether unpolarized events prefer one direction in the azimuth.

Simplified pion model: $A_{UU}^{\cos\phi} = A_{UU}^{\cos 2\phi} = 0$

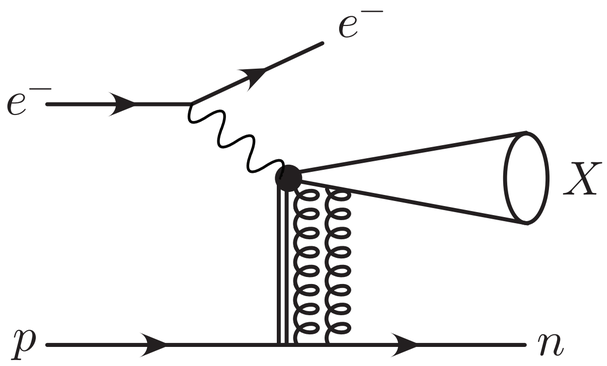
Illustrative EFT result (assuming spin-blind jet-side interactions)**:**

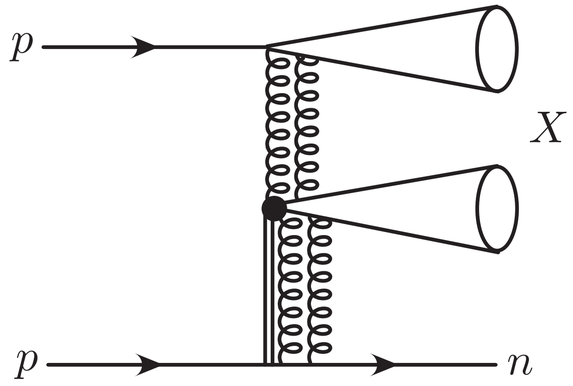


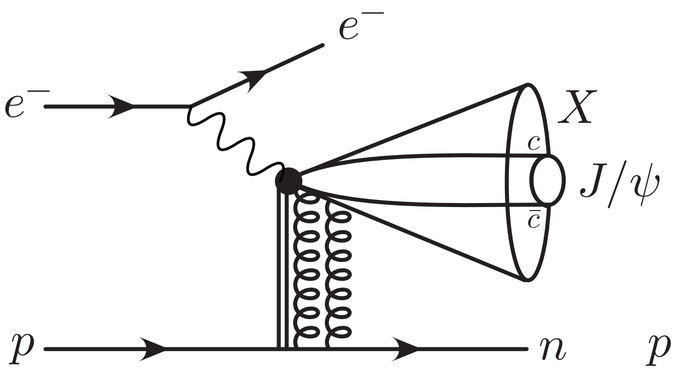


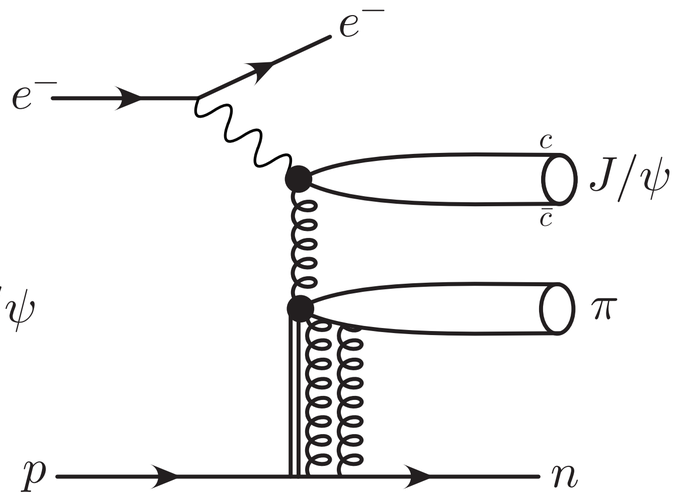
Extensions

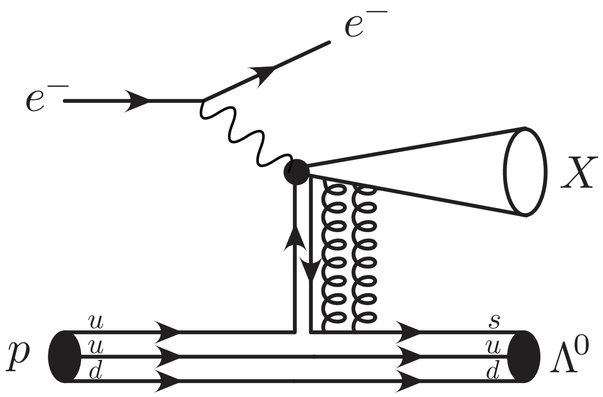
Easily extendable to other processes!



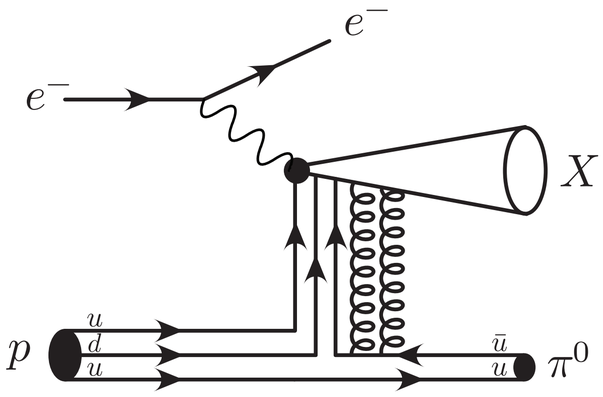




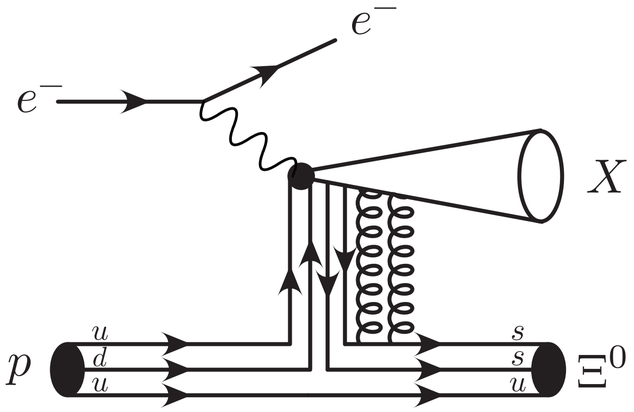




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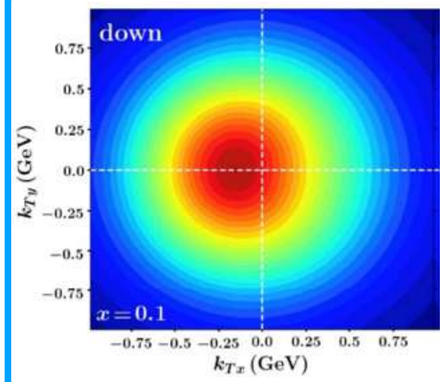


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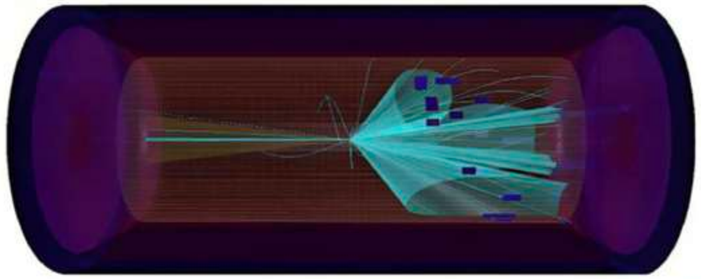
Broader impacts

hadron structure



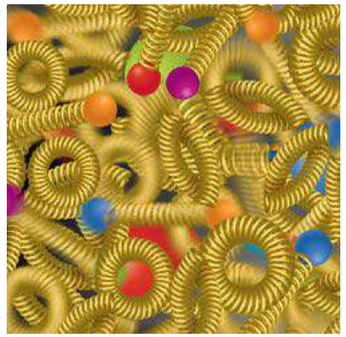
probe the proton-to-neutron transition

forward physics



inform EIC design and scientific goals

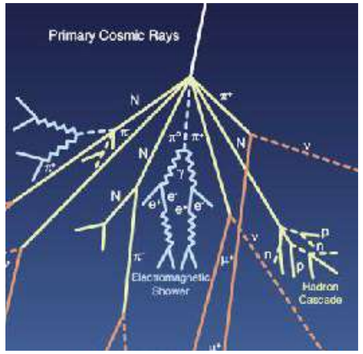
saturation



test nonlinear small-x dynamics

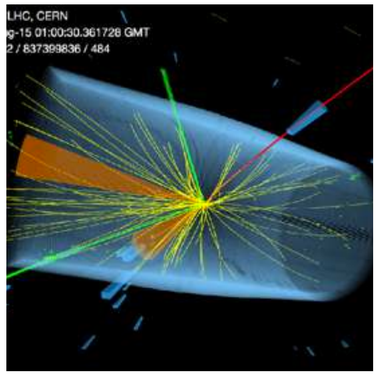
a major target for EIC!

cosmic rays



constrain hadronic MC modeling

new physics



gaps make our processes clean probes for new physics

Acknowledgements



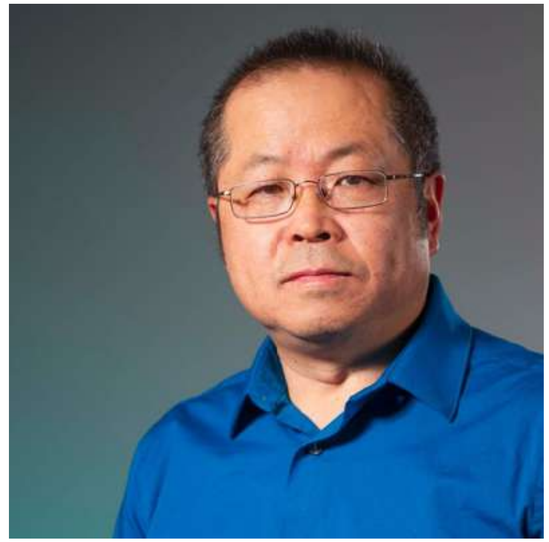
Stella Schindler



Christopher Lee



Duff Neill



Ming Liu

HARVARD UNIVERSITY

Los Alamos NATIONAL LABORATORY

LANL'S LDRD Program