Backward Hadronic Calorimeter for ePIC

A detector for diffractive physics at the EIC

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The Ohio State University

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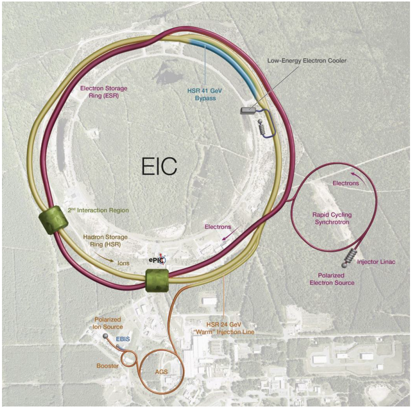
The Ohio State University

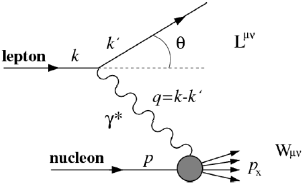
Outline

Electron Ion Collider (EIC)

- To be built at Brookhaven National Laboratory
  - Modify RHIC
  - Add electron ring
  - More info here: `https://www.bnl.gov/eic/`
- Collisions of polarized (except A):
  - $e + p$ $5 \times 41 - 18 \times 275\ \mathrm{GeV}$
  - $e + A$ $5 \times 41 - 18 \times 110\ \mathrm{GeV}$
  - Wide spectrum of ion species $A = d, U$...
- High luminosity $10^{33} - 10^{34}\ \mathrm{cm}^{-1}\mathrm{s}^{-1}$ ($100 - 1000\times$ HERA)
- High polarization $\sim 70\%$
- Large coverage in x (longitudinal momentum frac. of p) and Q^2 (resolution)
- First data expected in early 2030s
- Physics questions:
  - Study spin and mass origin of the proton/nuclei
  - Imaging of nucleon and nuclei (TMDs and GPDs, diffractive processes)
  - Gluon saturation
  - Nuclear modifications and flow
  - QCD in unexplored kinematics
  - EW, BSM physics and more...



Deep inelastic scattering (DIS)

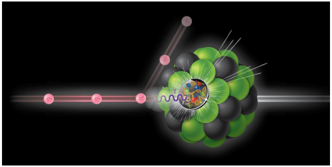


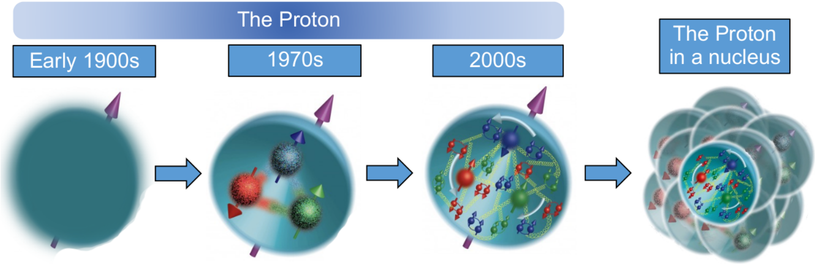
$$Q^2 = -q^2 = -(k - k')^2$$

$$W^2 = (q + P)^2$$

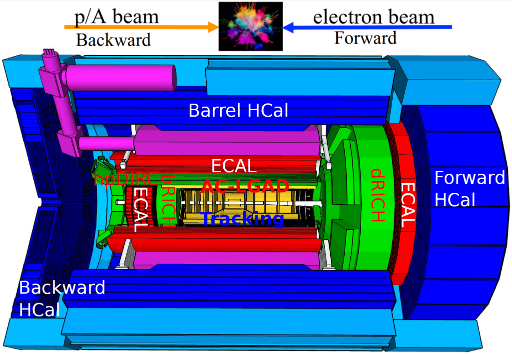
$$y = \frac{q \cdot P}{k \cdot P}$$

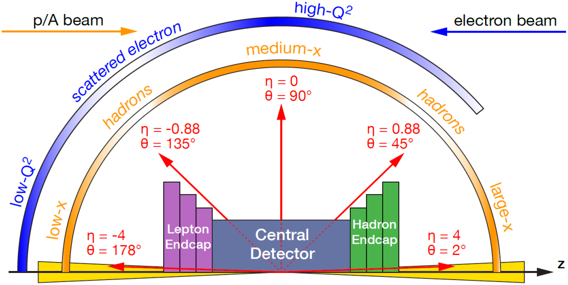
Bjorken scaling variable $$x = \frac{Q^2}{2p \cdot q}$$





ePIC detector (Electron-Proton Ion Collider Experiment)



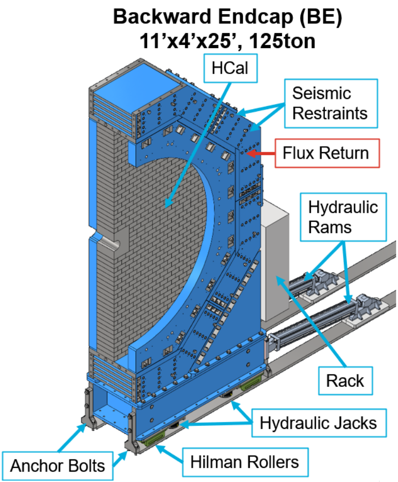


- First detector to be built at the EIC
- Webpage:
- `https://www.epic-eic.org/`
- Large acceptance $-4.2 < \eta < 4.2$, $1.7\ \mathrm{T}$ solenoidal field

- **nHCal - Negative Hadronic Calorimeter**, a tail catcher
- Started as part of Mobility Project at CTU in Prague - few months in BNL
- Detector Subsystem Leader (DSL)
  - L. Kosarzewski
- Participating institutions: OSU, CTU in Prague, UIUC, help from BNL
- Members of H1 at HERA recognized that the lack of a backward HCAL hurt several important physics measurements, especially low-x related studies. SPACAL was part of first upgrade.
  - [NIM A386 (1997) 397-408]
  - [DESY 08-053]

Acceptance

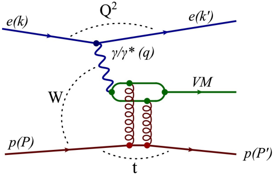
$-4.16 < \eta < -1.16$



The Ohio State University · ČVUT České vysoké učení technické v Praze · Brookhaven National Laboratory · University of New Hampshire · University of Illinois Urbana-Champaign

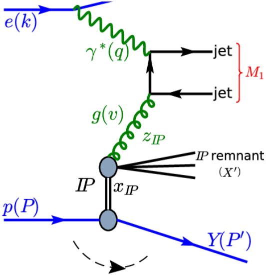
Motivation for nHCal

Diffractive vector meson production



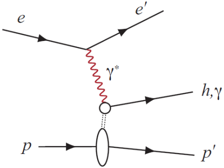
- VM: $J/\psi, \phi...$
- $J/\psi \to \mu\mu$
- Crucial for EIC: [Nuclear Physics A 1026 (2022) 122447] [BNL-98815-2012-JA; JLAB-PHY-12-1652]
- $\phi \to KK \to \mu\mu$
- $\phi \to K_L^0 K_S^0$
- Muon ID helps discriminating against scattered beam electron

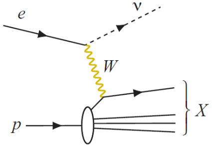
Diffractive dijet production



- [Phys. Rev. D 107, 094038]
- [Phys. Rev. D 101, 072003 (2020)]
- Access to very low x
- Identify jets with neutral component
- Measure low energy neutrons
- Improve resolution by identifying charged only jets

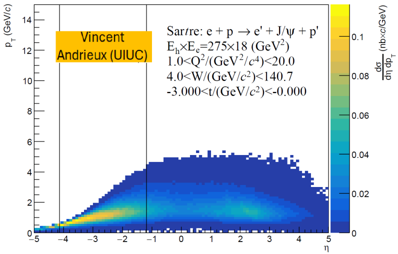
Hermeticity/scattered electron ID

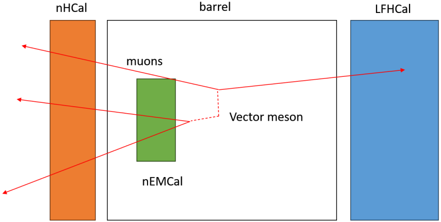




- Need hermetic coverage to make sure no extra particles for exclusive process
- Determine event kinematics via hadronic final state at low-x
  - photoproduction
  - charged current interactions

Sartre simulation of diffractive $J/\psi \to \mu^+\mu^-$ production

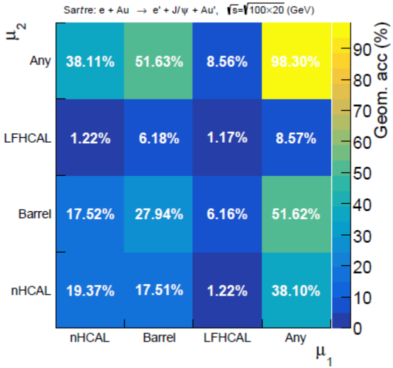


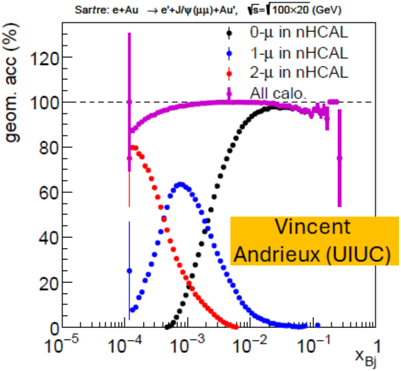


- Backward acceptance needed to access full available diffractive cross section
- Most J/ψ produced in backward direction

- Increases acceptance and gives access to different topologies and kinematics:
  - nHCal & nHCal
  - nHCal & barrel HCal
  - nHCal & LFHCAL

Sartre simulation of diffractive $J/\psi \to \mu^+\mu^-$ photoproduction





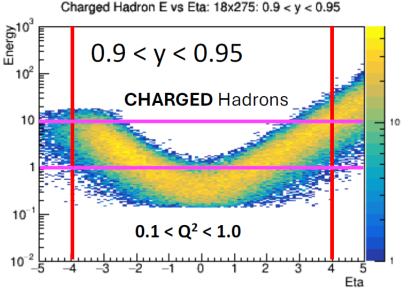
- Fraction of events with muons in acceptance of each detector
- nHCal+any: 38% of J/ψ produce muons in acceptance of nHCal and any other hadronic calorimeter
  - Missing nHCal means loss of large fraction of J/ψ

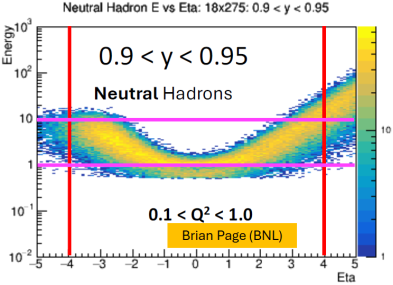
- nHCal required to access $x < 10^{-3}$
- No ambiguity with scattered electron when using dimuon channel

Acceptance

"The importance of jet probes was reflected in the EIC Yellow Report where they touched on nearly every major physics topic" [Nuclear Physics A 1026 (2022) 122447]

PYTHIA simulation, diffractive events (not all are jets) [Phys. Rev. D 101, 072003 (2020)]

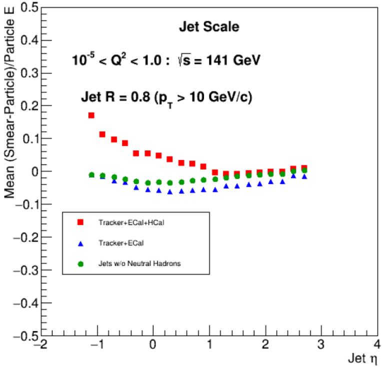


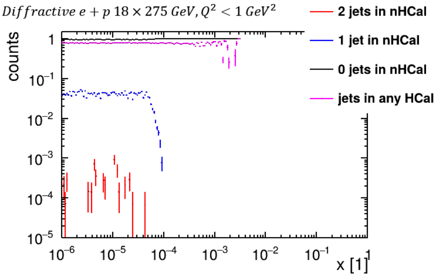


- Low-x and high-y events produce activity both in backward and forward direction
- Need good neutron detection efficiency and position resolution to distinguish neutral and charged clusters in a jet
  - Typical neutron kinematics: $< E >= 1.38\,\mathrm{GeV}$, $< p >= 2.12\,\mathrm{GeV/c}$, $E_{low} = 0\,\mathrm{GeV}$, $p_{low} = 0\,\mathrm{GeV/c}$
  - Reach as low as possible

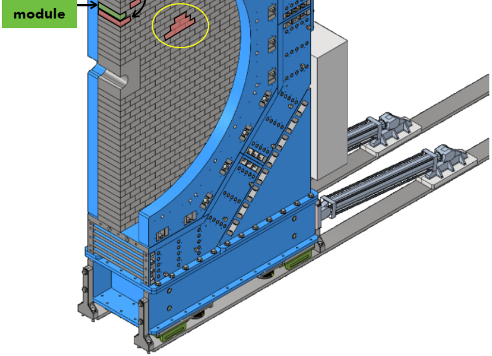
Diffractive dijet measurement

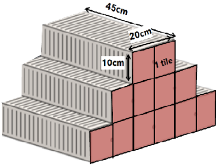
PYTHIA simulation, diffractive events (not all are jets)



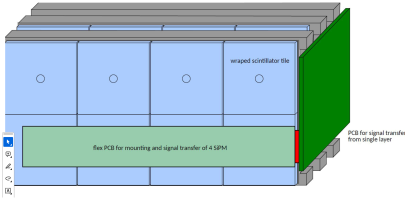


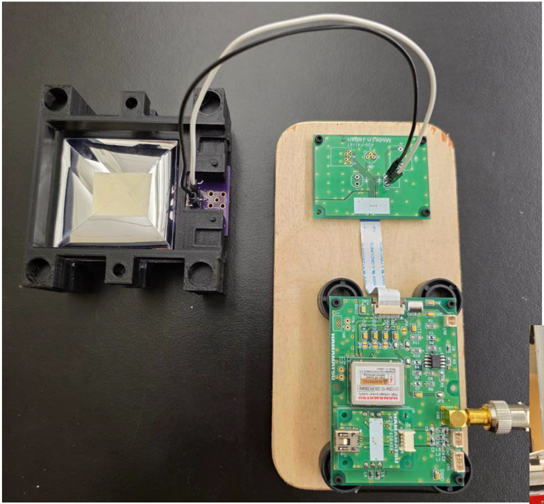
- Distinguishing charged only and jets with neutrals improves jet energy resolution
- Diffractive dijets offer an even lower reach in $x < 10^{-4}$





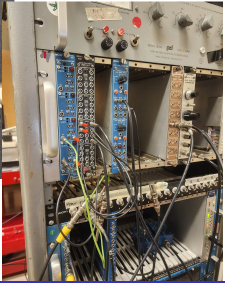
- Tail catcher sampling calorimeter
- Similar design to Forward Hadronic Calorimeter (LFHCAL)
- Initial design to be optimized:
  - 10 layers $\approx 2.4\lambda_0$
  - 4 cm non-magnetic steel
  - 4 mm plastic scintillator tiles
- SiPMs used for light collection
- SiPM placed on tile inspired by CALICE
  - [JINST 18 P11018]
  - First ever test in collider mode [Nucl. Instrum. Meth. A, 1047:167866, 2023]
  - Tile size TBD: 5 cm $\times$ 5 cm or 10 cm $\times$ 10 cm





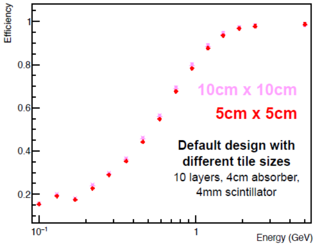
Yevheniia Khyzhniak
Maria Stefaniak (OSU)

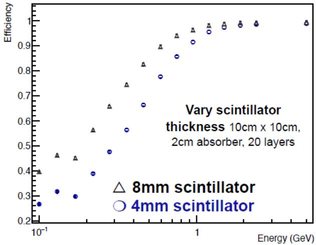
- Tile tests using cosmic ray muons in progress
  - Light yield, MIP response, efficiency
- Uniformity tests with a sealed source and translation table
- Test setup:
  - 3D printed tile frame
  - SiPM on the test board (purple)
  - Hamamatsu MPPC evaluation circuit C12332-02
    - Configure via USB with PC/Laptop
    - Analog SMA output to DAQ
  - DAQ system with NIM modules and CAMAC

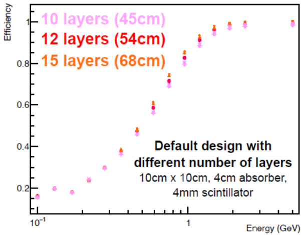


Neutron detection efficiency

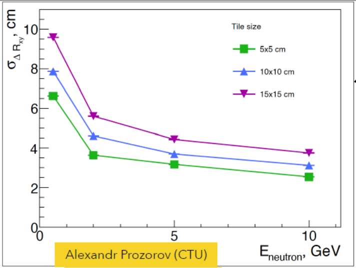
- Investigated different geometry configurations
- Tile size has a small impact
- Increasing the number of layers improves efficiency
    - 5% increase going from 10 → 15 layers
- Scintillator thickness vs. absorber
    - 20% increase when changing from $4\ \mathrm{mm} \rightarrow 8\ \mathrm{mm}$
- Work in progress

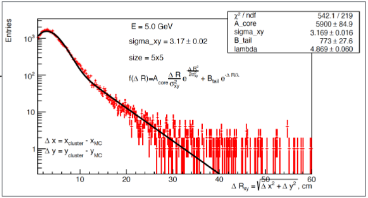






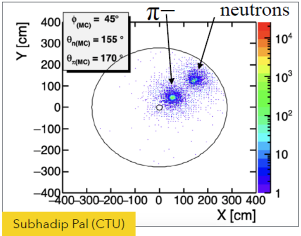
Sam Corey (OSU)

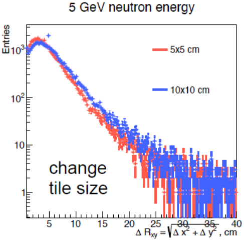


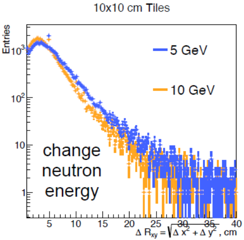


$$\Delta R_{xy} = \sqrt{\Delta x^2 + \Delta y^2}$$

$$\Delta x = x_{cluster} - x_{MC}$$
$$\Delta y = y_{cluster} - y_{MC}$$







- Varied tile size for default design (in progress)
- Used single neutrons and reconstructed clusters to estimate position resolution
- Tile size has a very small impact on the resolution
  - Hadronic showers are much larger than tile size
- Also investigated 2-particle position resolution
  - neutrons and pions can be separated down to ~ 30 cm

Conclusions

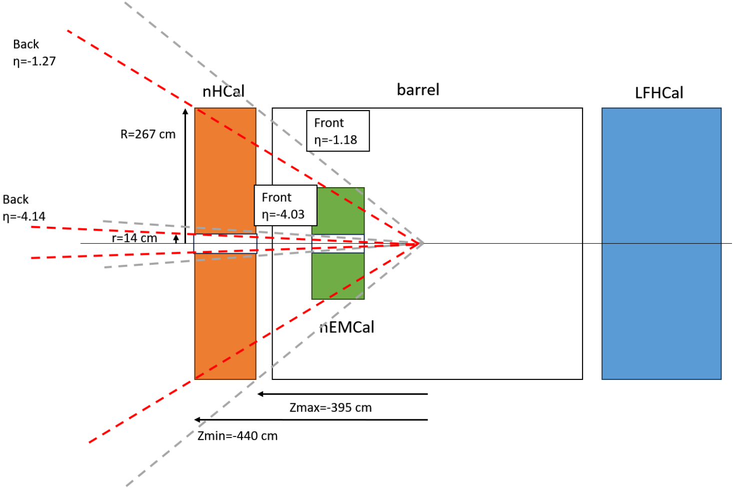
- nHCal for ePIC is a crucial detector for diffractive physics
- Covers low-x kinematics, which is the frontier for proton and nuclear structure and one of the goals of EIC construction
- Enables measurements of $VM \rightarrow \mu^+\mu^-$
  - Avoids ambiguity with scattered electron
- Measures neutral component of jets to identify charged only jets

New opportunities for groups to join the effort!

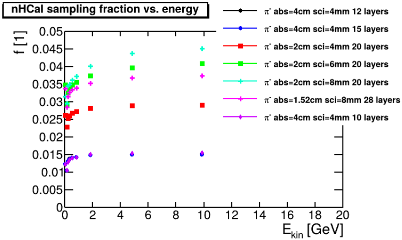
- Lots of tasks and experience for students and postdocs
  - Simulations, testing, hardware work, reconstruction, machine learning
- Perfect for small groups
- Very easy to start!

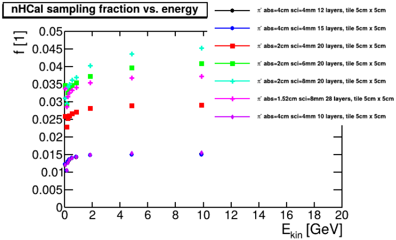
BACKUP

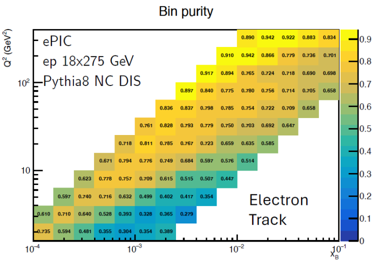
Acceptance check



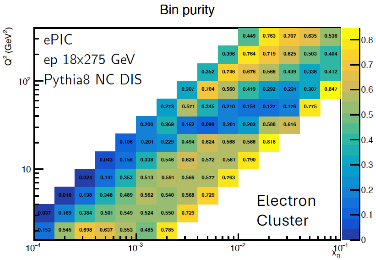
- Front geometry limit: $-4.03 < \eta < -1.18$
- Back geometry limit: $-4.14 < \eta < -1.27$
- Clusters: $-3.95 < \eta < -1.25$
- MC particles showering in nHCal(with hits): $-4.16 < \eta < -1.16$


nHCal sampling fraction vs. energy
π- abs=4cm sci=4mm 12 layers
π- abs=4cm sci=4mm 15 layers
π- abs=2cm sci=4mm 20 layers
π- abs=2cm sci=6mm 20 layers
π- abs=2cm sci=8mm 20 layers
π- abs=1.52cm sci=8mm 28 layers
π- abs=4cm sci=4mm 10 layers
f [1]
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
2
4
6
8
10
12
14
16
18
20
E_kin [GeV]


nHCal sampling fraction vs. energy
π- abs=4cm sci=4mm 12 layers, tile 5cm x 5cm
π- abs=4cm sci=4mm 15 layers, tile 5cm x 5cm
π- abs=2cm sci=4mm 20 layers, tile 5cm x 5cm
π- abs=2cm sci=6mm 20 layers, tile 5cm x 5cm
π- abs=2cm sci=8mm 20 layers, tile 5cm x 5cm
π- abs=1.52cm sci=8mm 28 layers, tile 5cm x 5cm
π- abs=4cm sci=4mm 10 layers, tile 5cm x 5cm
f [1]
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
2
4
6
8
10
12
14
16
18
20
E_kin [GeV]



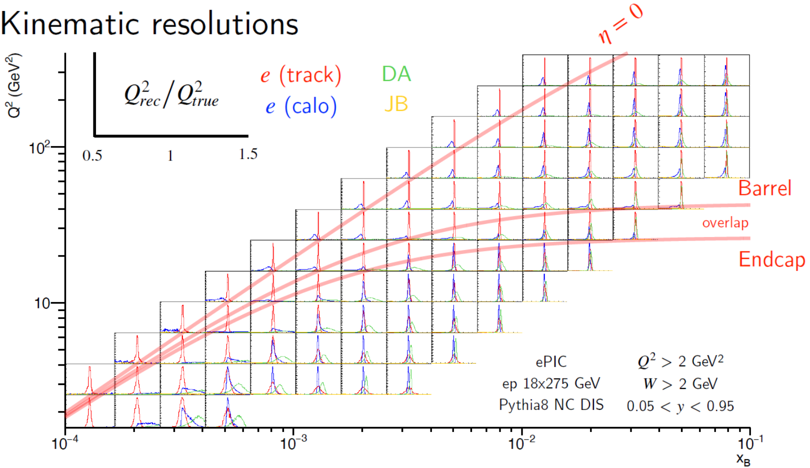
$$P = \frac{N_{gen+rec}}{N_{rec}}$$



$$P = \frac{N_{gen+rec}}{N_{rec}}$$

Tyler Kutz

Kinematic resolutions



Tyler Kutz