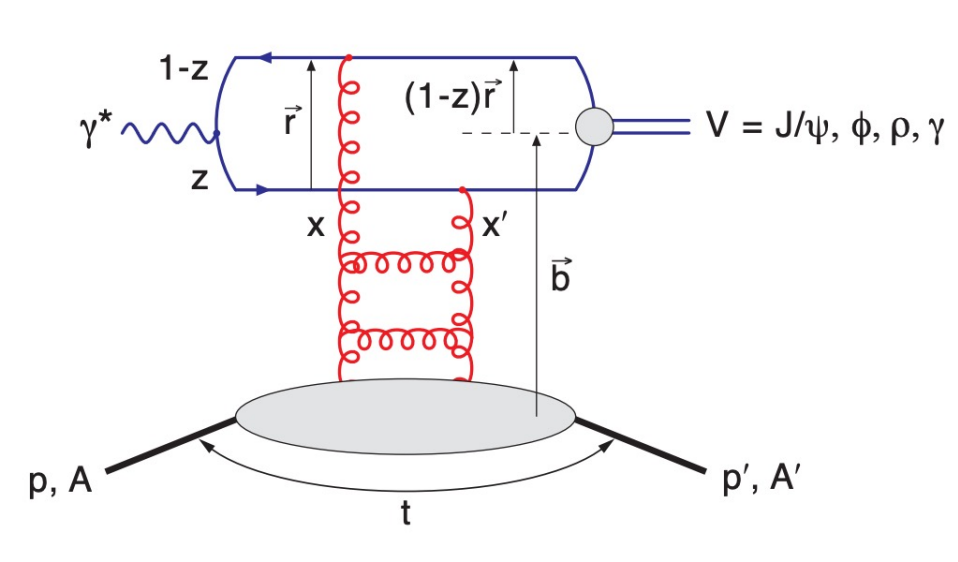
Measuring the spatial gluons distribution in nuclei with ePIC at the EIC



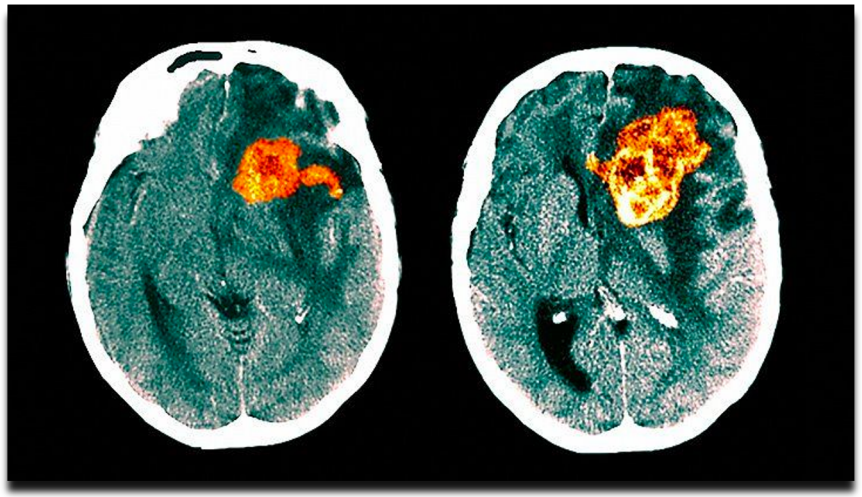
Kong Tu (BNL)
for the ePIC Collaboration

Seeing is believing - the power of *imaging*

38 billion km (~10^{12}m)

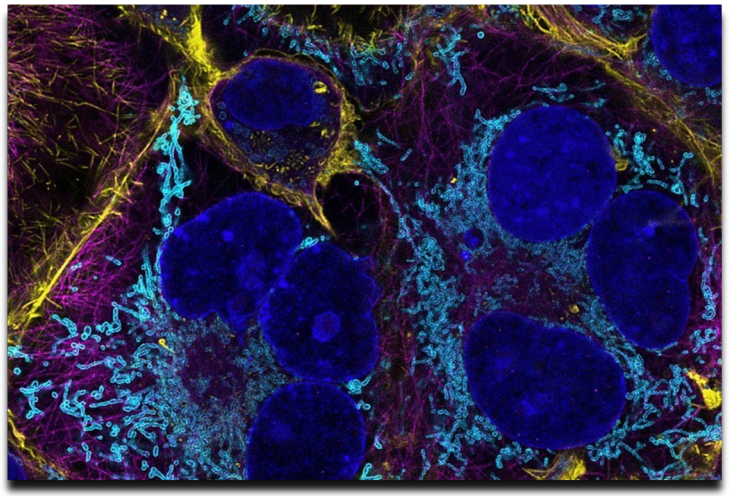
First-ever image of a black hole - *Event Horizon Telescope*

a few centimeter (~10^{-2} m)



CT scan sequence of a patient with a *glioblastoma*.

10-100 nanometer (~10^{-9} m)

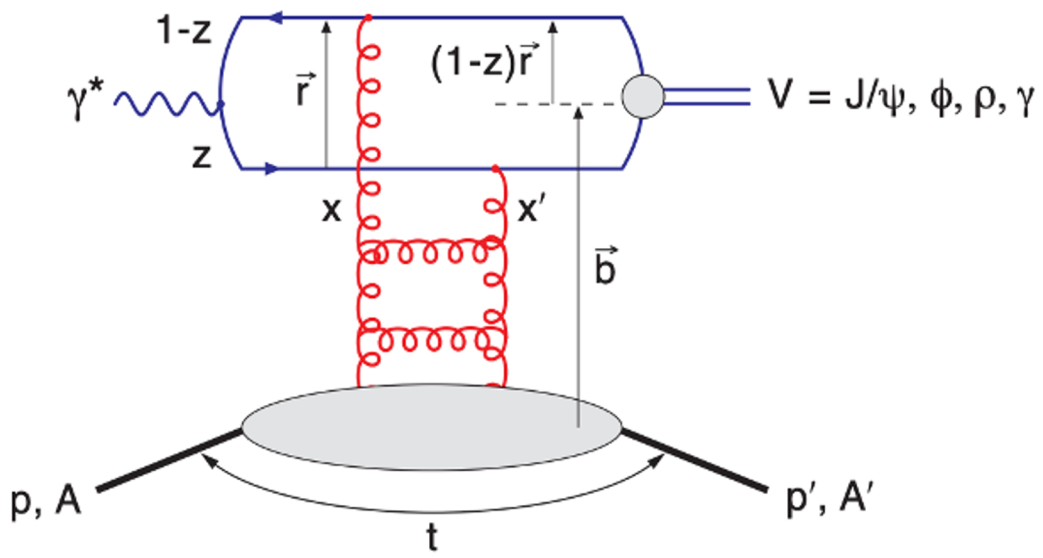


3D images of myelin - the insulation coating our nerve fibres

Astronomical scale → microscopic scale

Imaging: one of the most convincing scientific methods to understand our nature!

Exclusive and diffractive vector meson production



At NLO, things may look differently [arXiv:2203.11613]

Momentum (t) and position (b) are conjugate variable, and can be related by Fourier Transform:

$$F(b) = \frac{1}{2\pi}\int_0^\infty \mathrm{d}\Delta\Delta J_0(\Delta b)\sqrt{\frac{\mathrm{d}\sigma_{\mathrm{coherent}}}{\mathrm{d}t}(\Delta)\Big|_{\mathrm{mod}}}$$

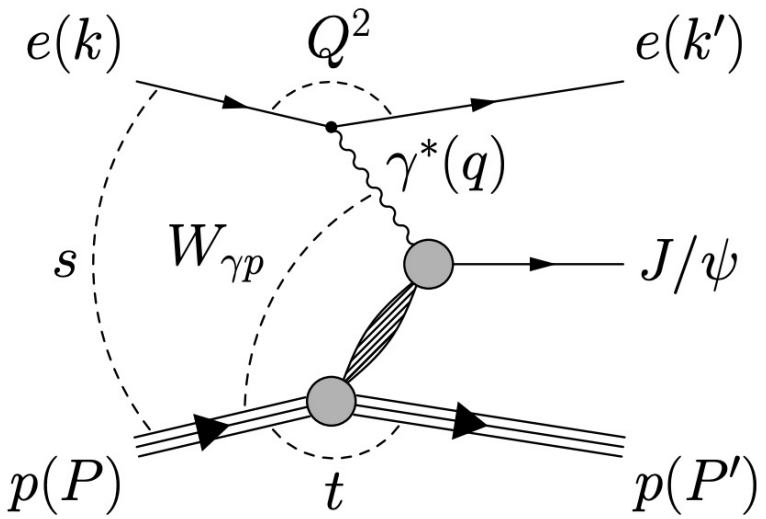
$$\Delta = \sqrt{-t}$$

A sensitive probe to the gluon density, spatial distributions, and their fluctuations.

Reconstruction method of $-t$

- Method Exact (E): $-t = -(\boldsymbol{p}_e - \boldsymbol{p}_{e'} - \boldsymbol{p}_{VM})^2 = -(\boldsymbol{p}_{A'} - \boldsymbol{p}_A)^2$
- Method Approximate (A) (UPCs) $-t = (p_{T,e'} + p_{T,VM})^2$
- Improved Method E: Method L $-t = -(\boldsymbol{p}_{A',corr} - \boldsymbol{p}_A)^2,$

where $\boldsymbol{p}_{A',corr}$ is constrained by exclusive reaction.



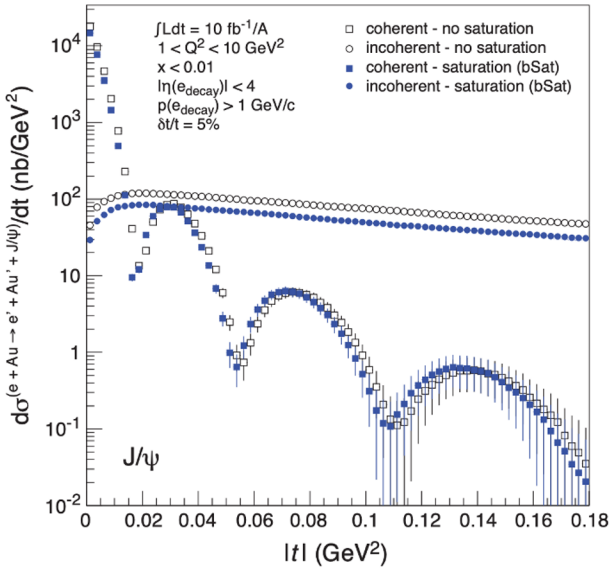
Best method concluded from the EIC Yellow Report – **Method L**

- Insensitive to beam effects, e.g., angular divergence and momentum spread.
- More precise than Method A for electroproduction

Diffractive VM timeline

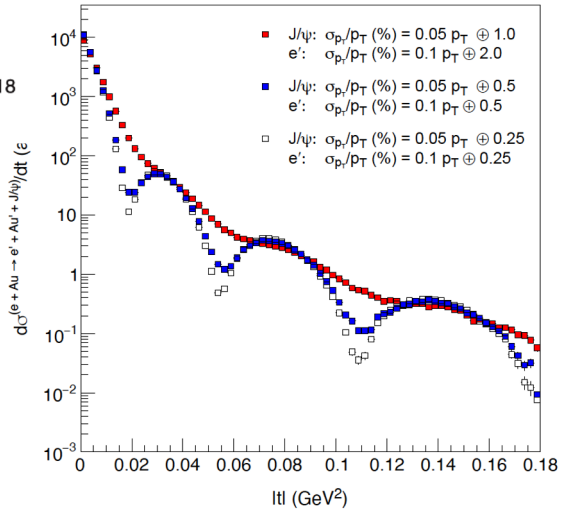
intense debate; some were caused by software differences

2012 — 2019 — 2021 — 2022 — Time

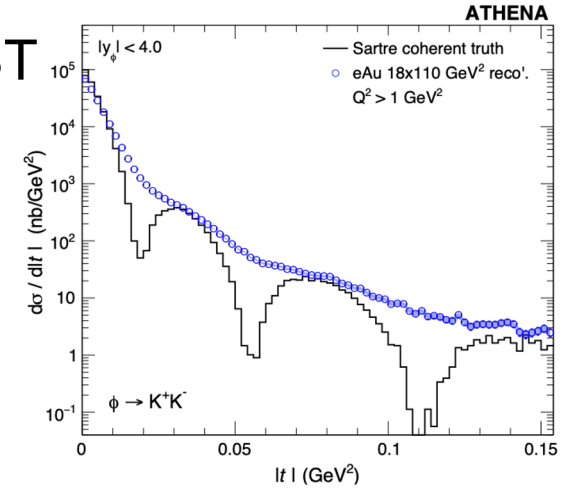


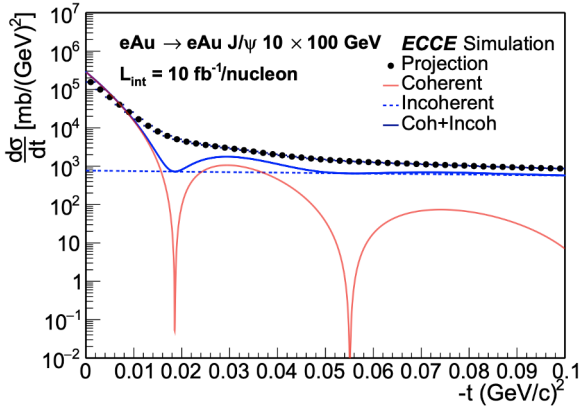
EIC White paper

EIC Yellow Report

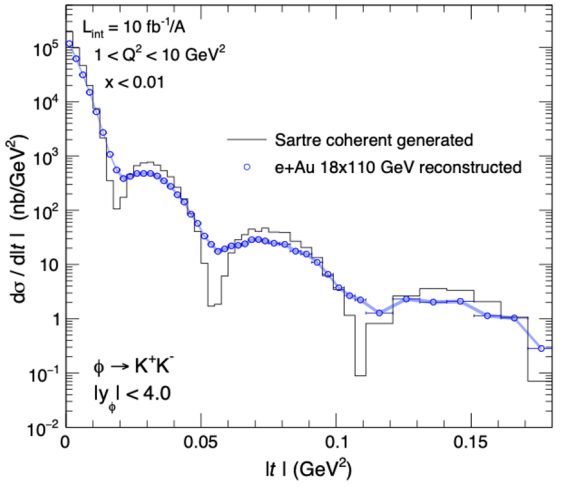


ATHENA 3T (DD4HEP)





ECCE 1.5T (Fun4all)



ATHENA 3T + 1% E reso. EMCal (DELPHES)

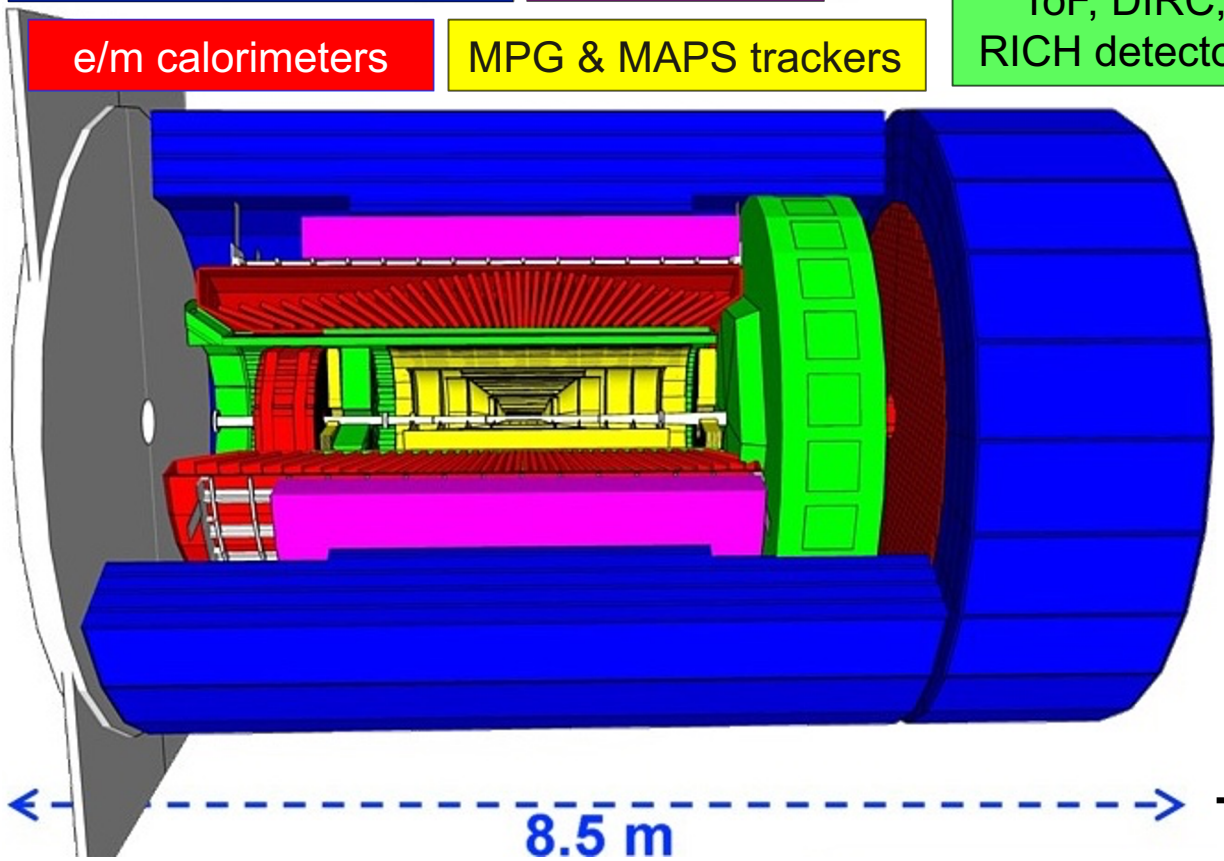
Shown last DIS

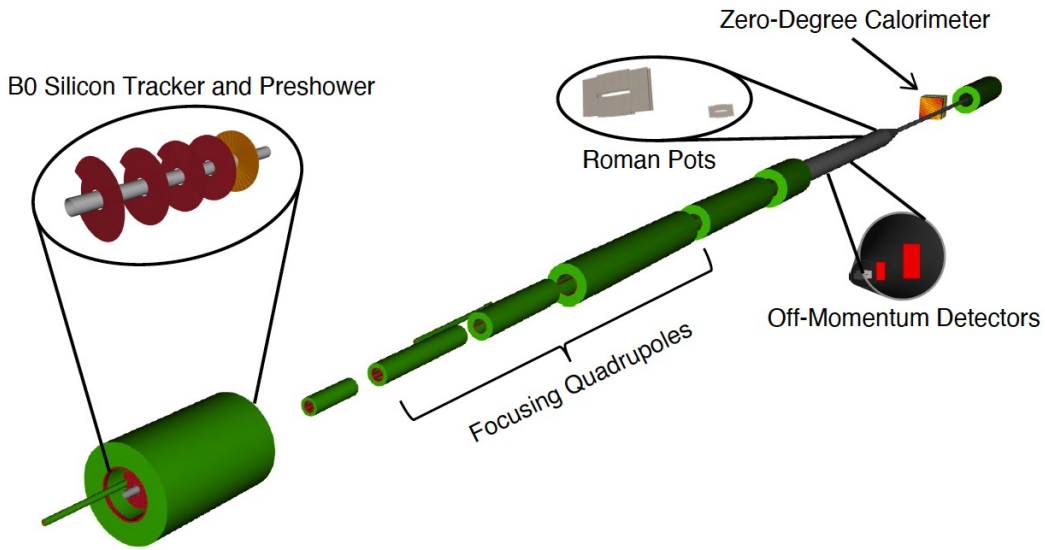
ePIC experiment at the EIC

hadronic calorimeters | solenoid coils | e/m calorimeters | MPG & MAPS trackers | ToF, DIRC, RICH detectors | Far-forward detectors

See. A. Jentsch's talk (Mar 28, 2023, 5:50 PM)

1.7 T solenoid magnet



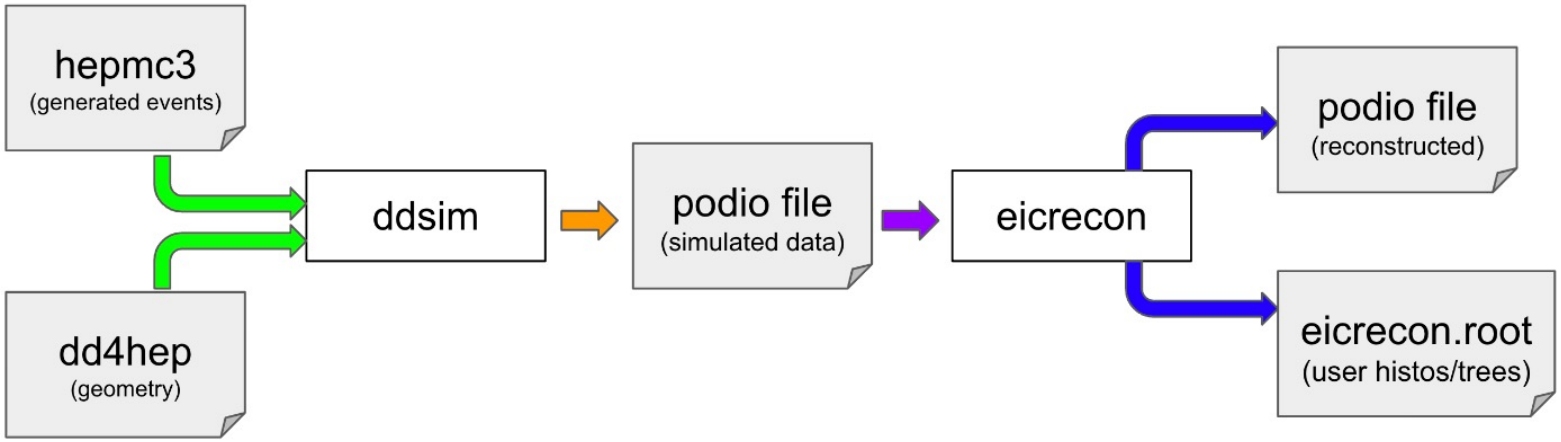


8.5 m

38 m to ZDC

Modern software and simulation

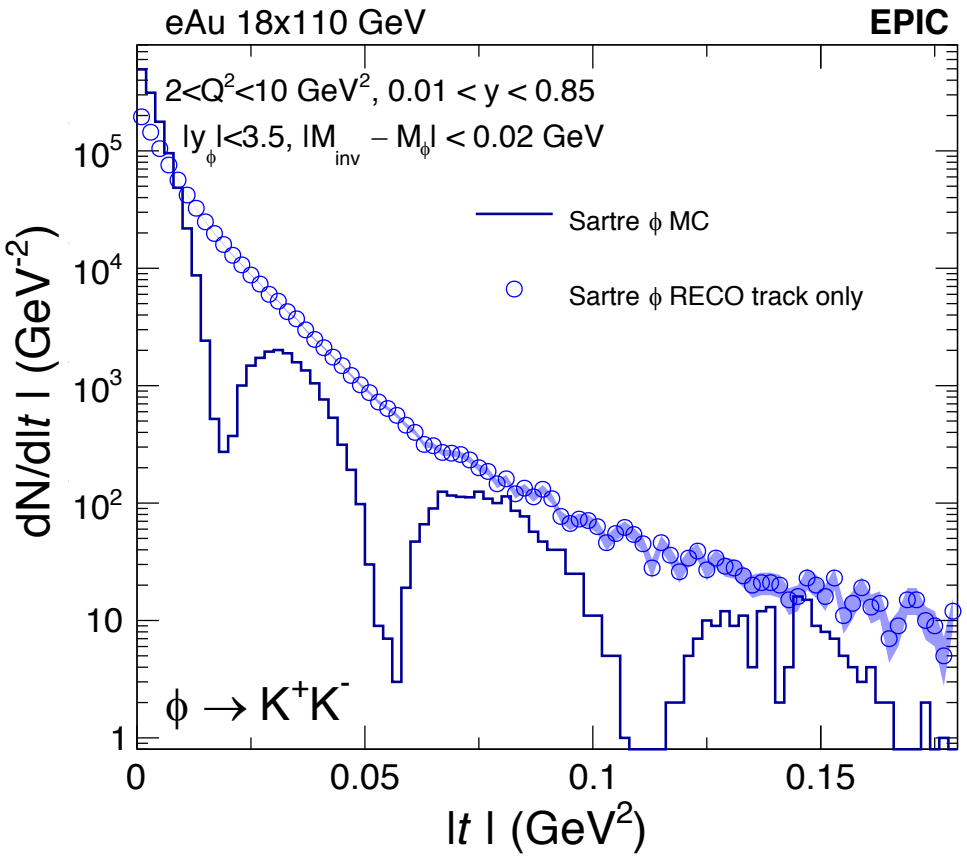
- dd4hep detector geometry description (see EPIC detector, https://github.com/eic/epic)
- ddsim for simulation/digitization
- edm4eic data structure defined with podio and edm4hep (https://github.com/eic/EDM4eic)
- EICrecon reconstruction framework based on JANA (https://github.com/eic/EICrecon)
- Reconstructed output → Ready for physics!



(We are constantly recruiting for software enthusiasts☺)

Results I

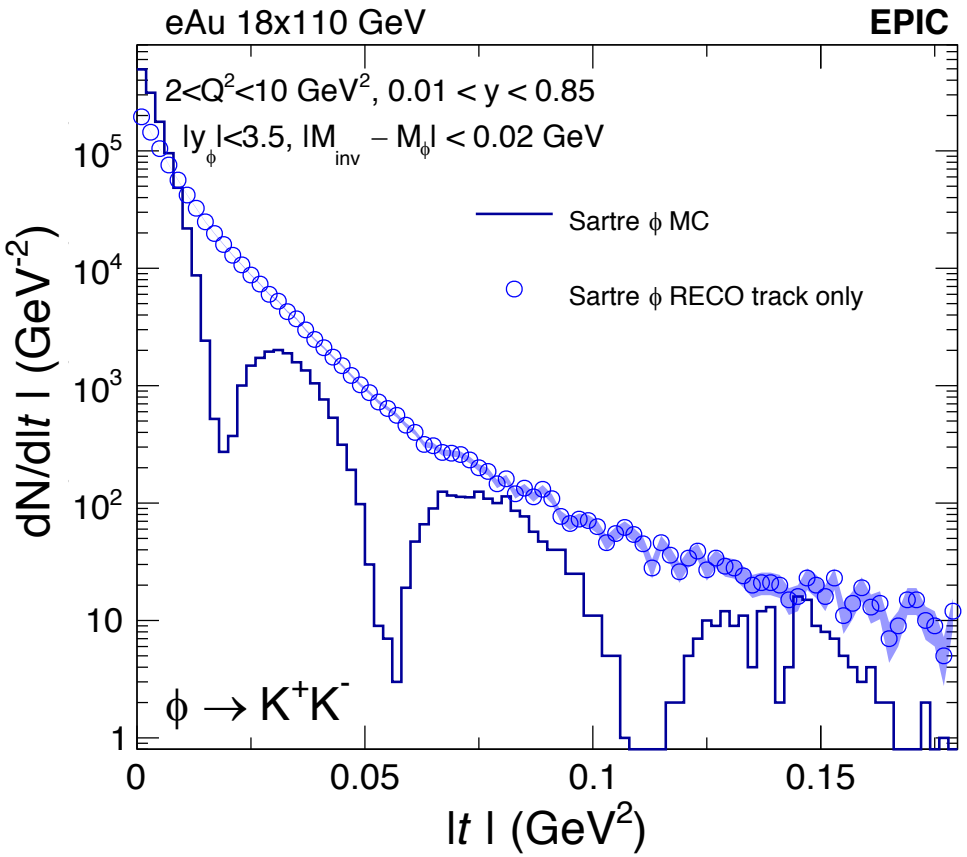
Legend details:
- Track only: e', φ→KK, all from tracking

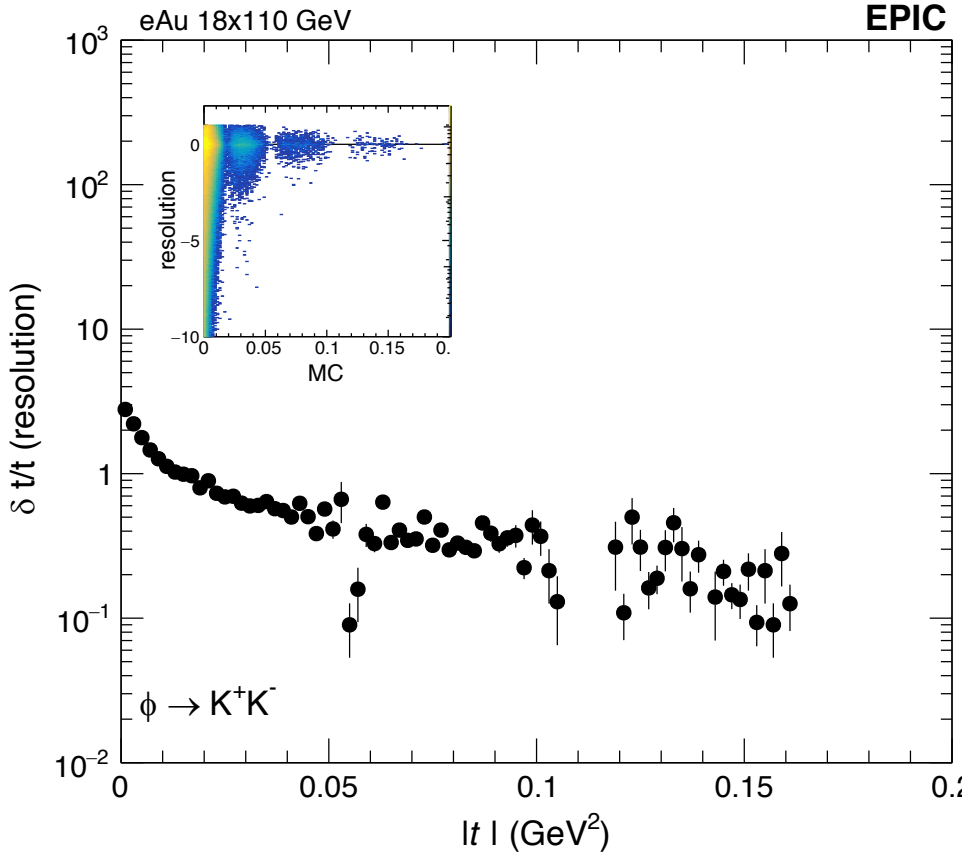


Results I

Legend details:
- Track only: e', φ→KK, all from tracking

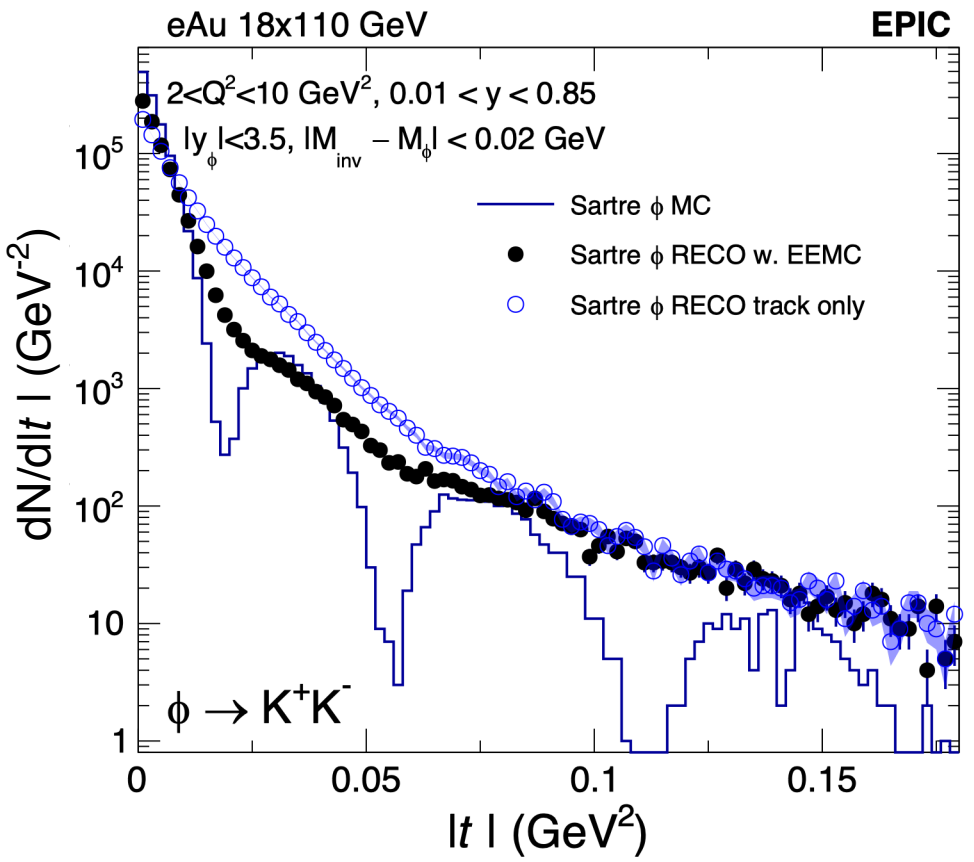
p (p_T) resolution of the scattered electron in this region ~ 4%





Tracking p resolution directly impact the $|t|$ resolution; even 3T field cannot do it, let alone 1.7T

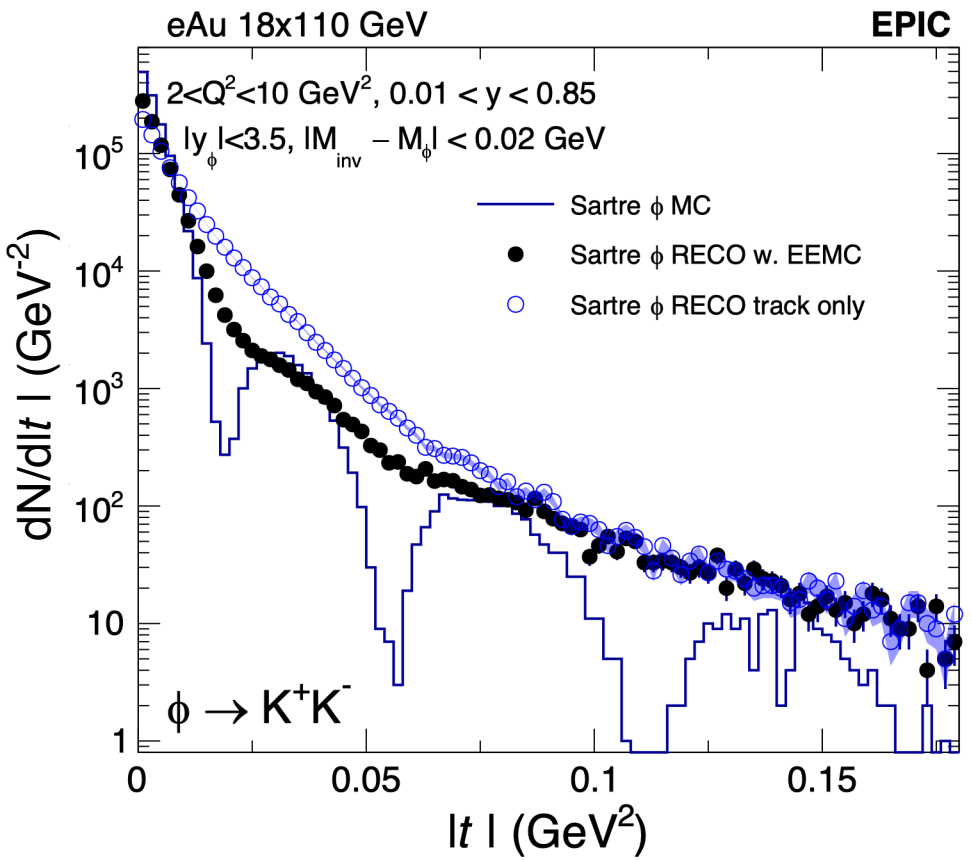
Results II



Legend details:

- w. EEMC: electron energy from EEMC, electron mass (PDG), angle (eta,phi) from tracking; φ→KK from tracking.
- Track only: e', φ→KK, all from tracking

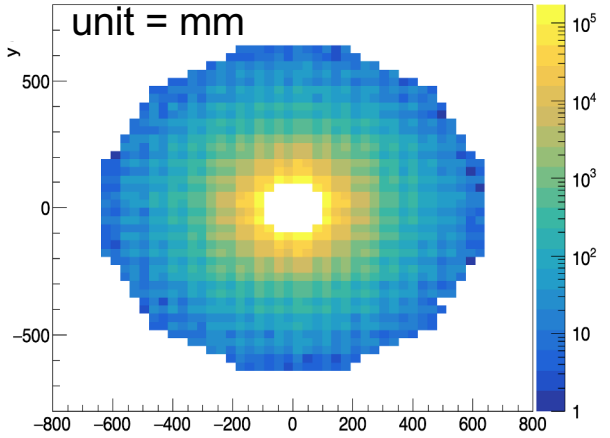
Results II

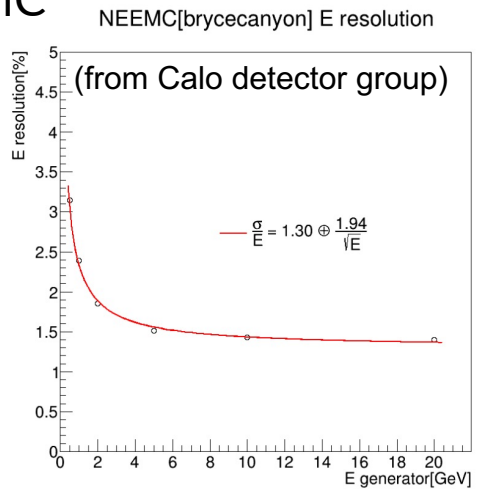


Legend details:

- w. EEMC: electron energy from EEMC, electron mass (PDG), angle (eta,phi) from tracking; φ→KK from tracking.
- Track only: e', φ→KK, all from tracking

1. Electron energy from EEMC





20x20mm crystal

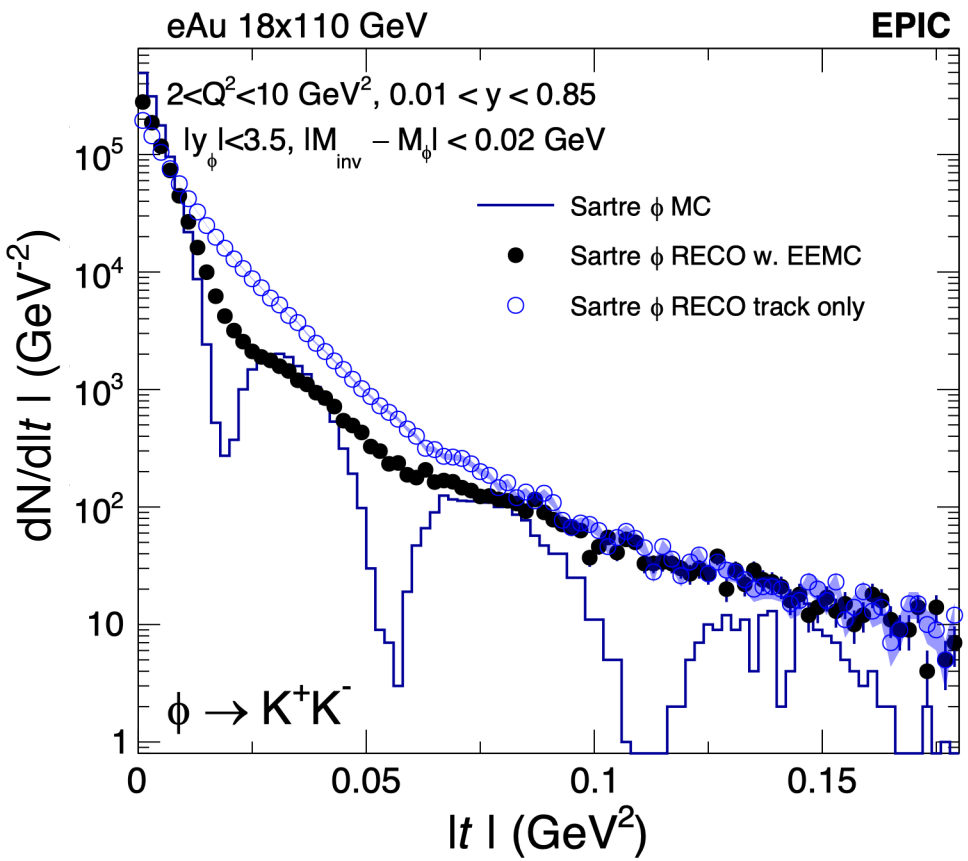
~ 1.5% energy resolution

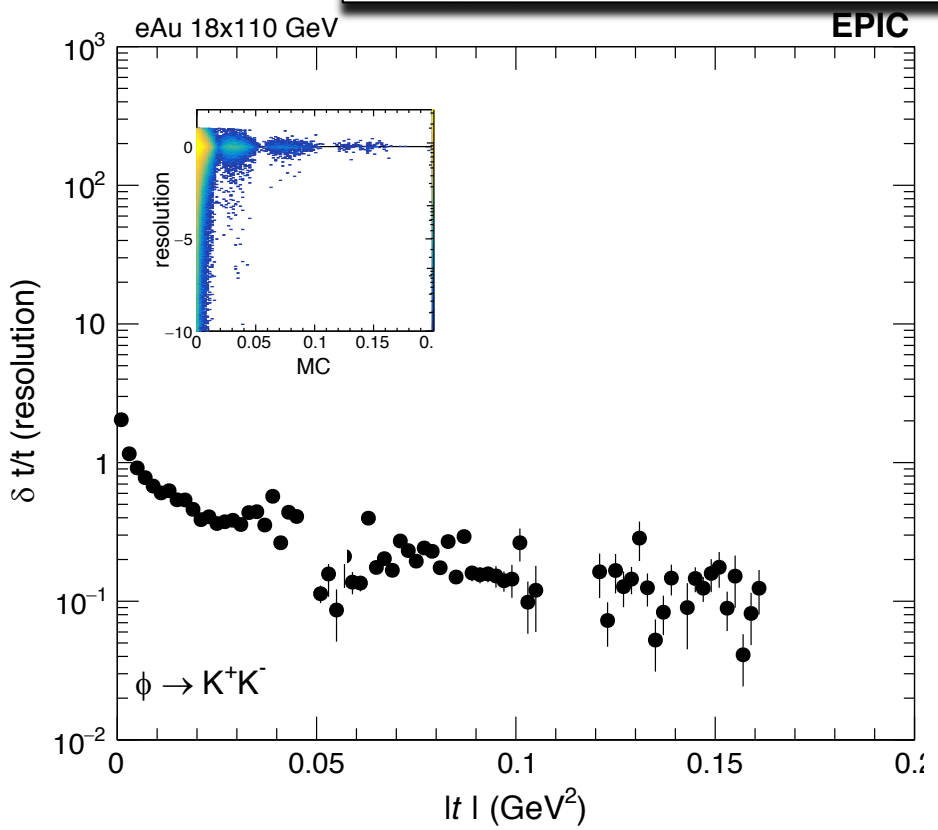
2. Assume electron mass (PDG)

3. Angle (position) from tracking
(better resolution than from cluster position)

Results II

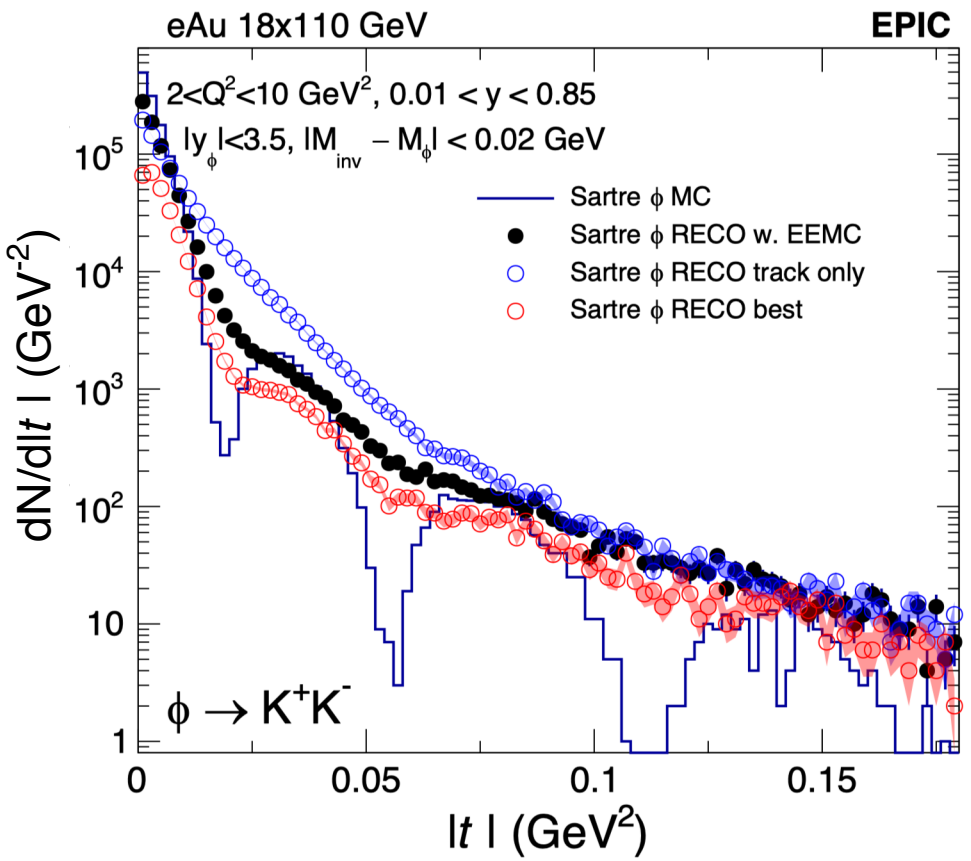
Legend details:
- w. EEMC: electron energy from EEMC, electron mass (PDG), angle (eta,phi) from tracking; φ→KK from tracking.
- Track only: e', φ→KK, all from tracking





Some huge improvements have been seen with the EEMC

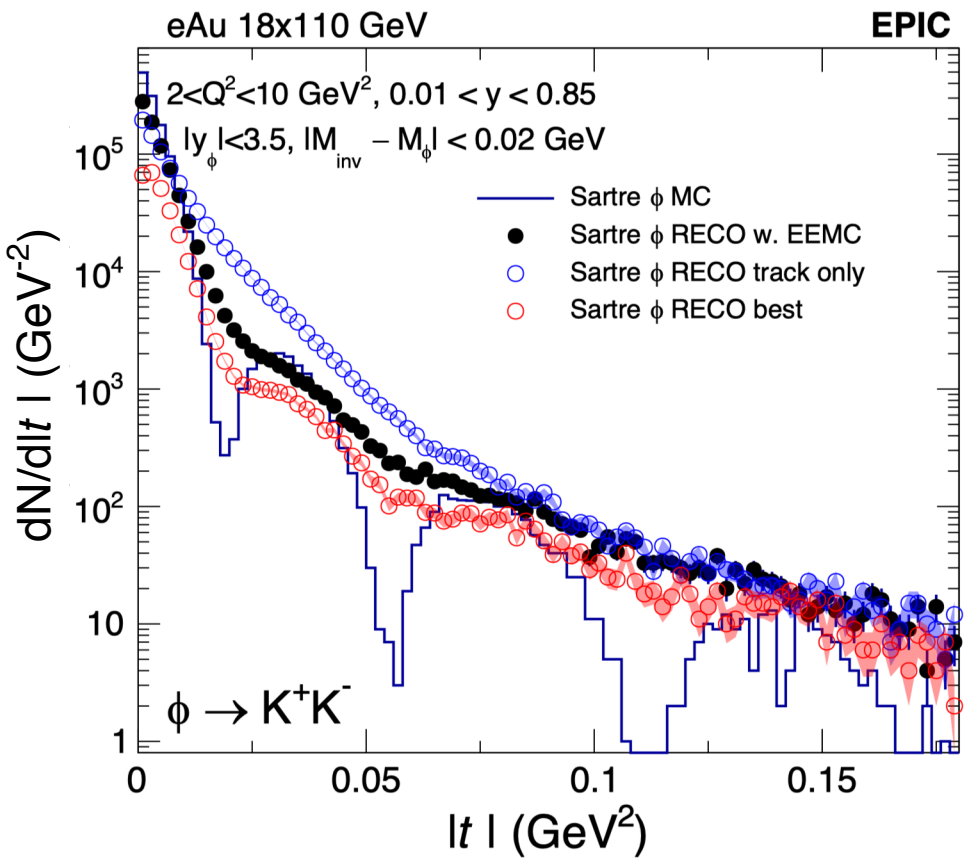
Results III



Legend details:

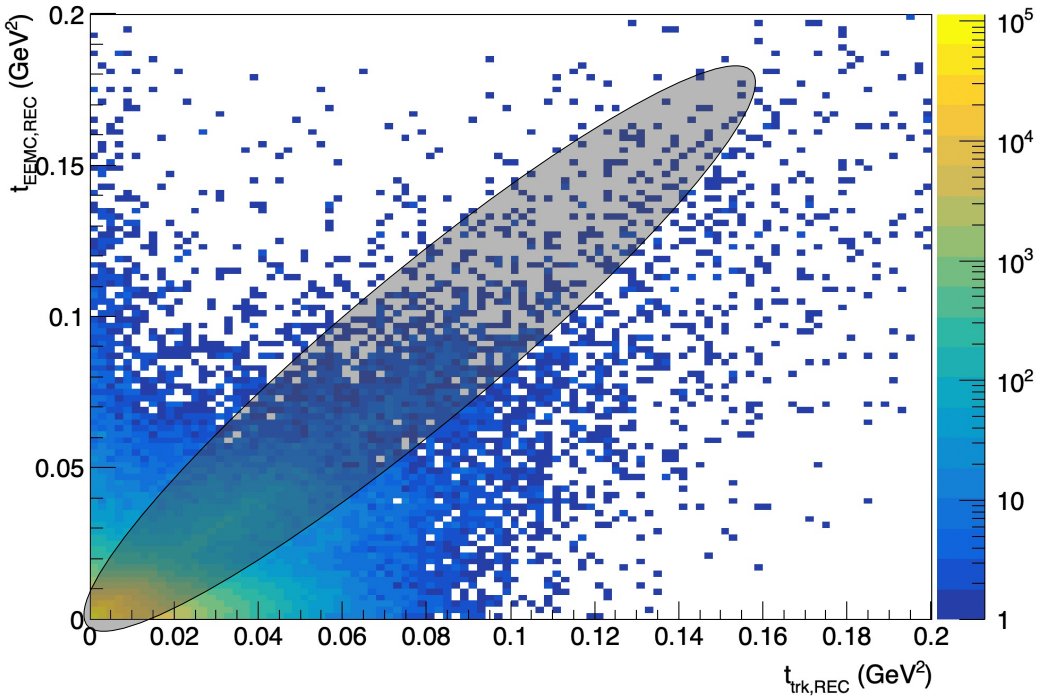
- w. EEMC: electron energy from EEMC, electron mass (PDG), angle (eta,phi) from tracking; φ→KK from tracking.
- Track only: e', φ→KK, all from tracking
- Best: average of the above 2 E-by-E.

Results III



Legend details:

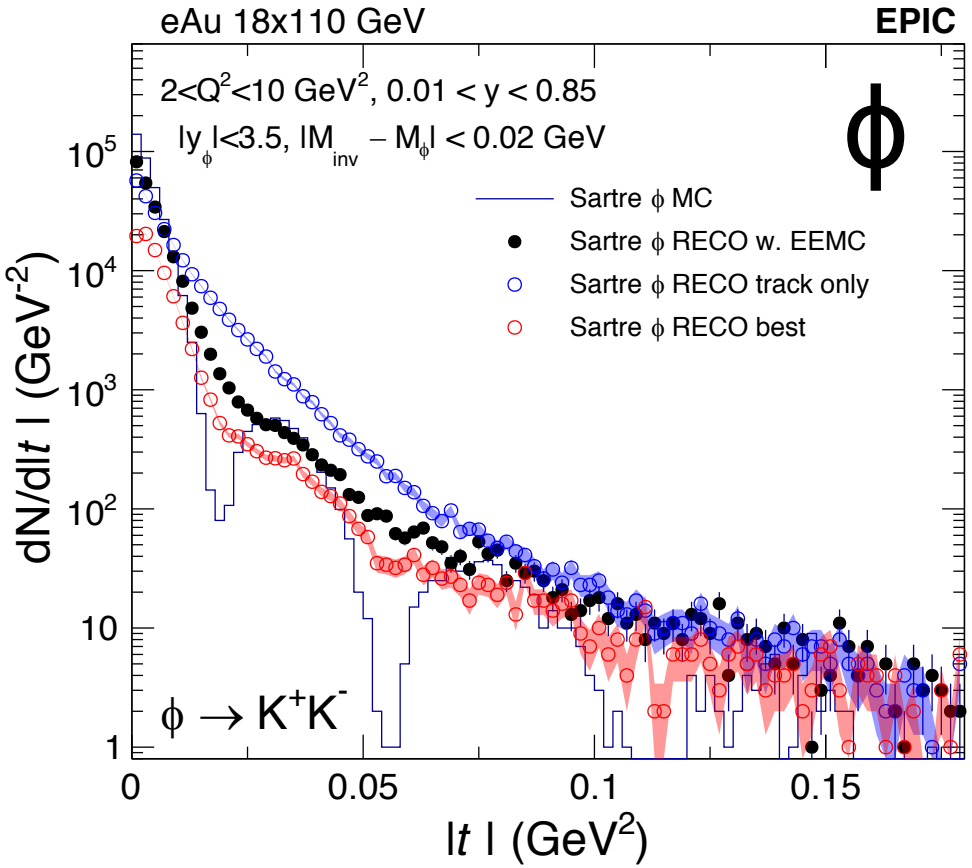
- w. EEMC: electron energy from EEMC, electron mass (PDG), angle (eta,phi) from tracking; φ→KK from tracking.
- Track only: e', φ→KK, all from tracking
- Best: average of the above 2 E-by-E.

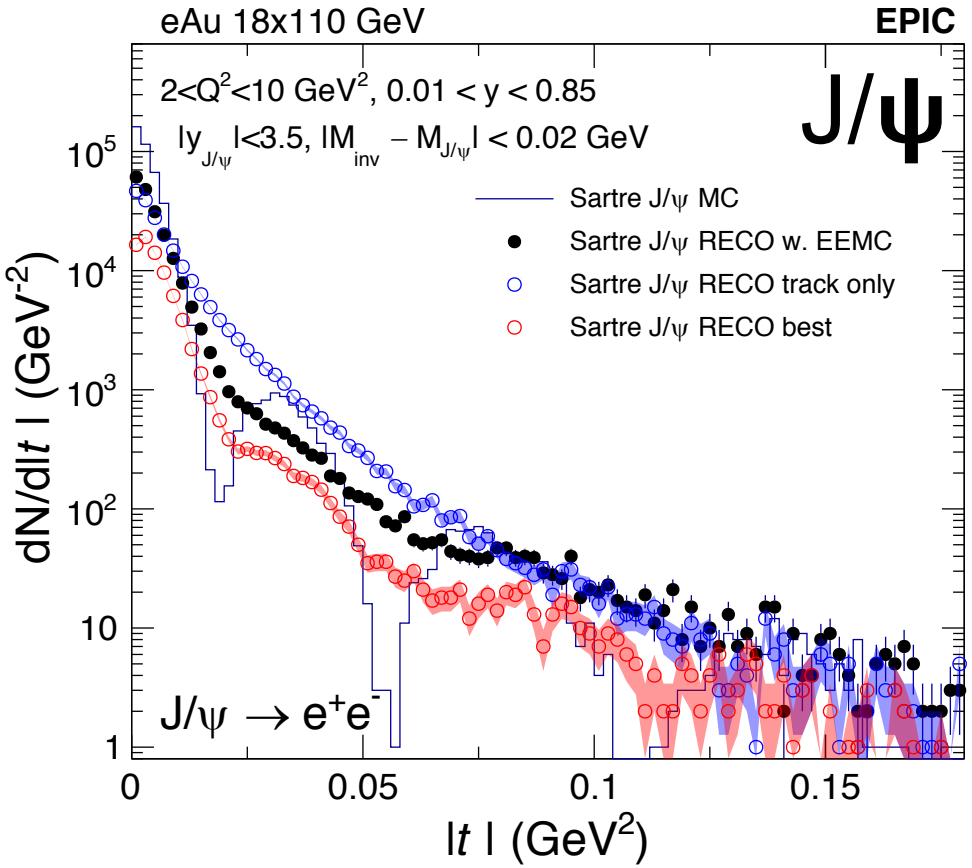


Improvements from *algorithm*:

- The two methods can be used together to further improve the |*t*| resolution.

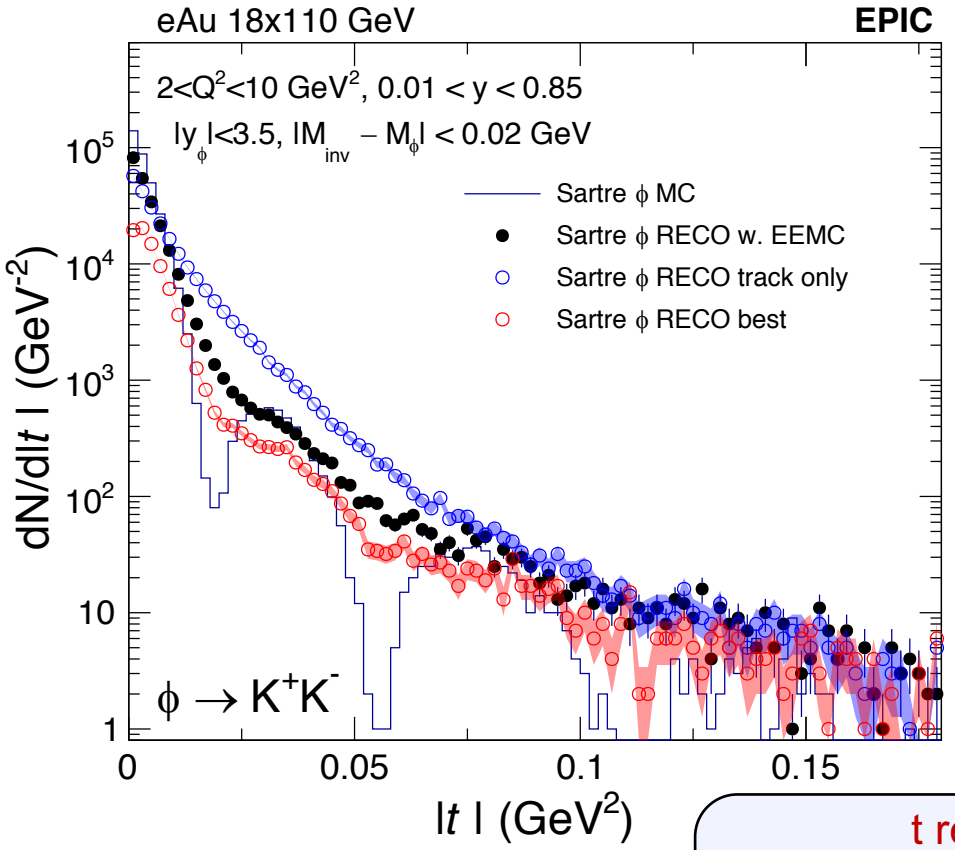
ϕ vs J/ψ

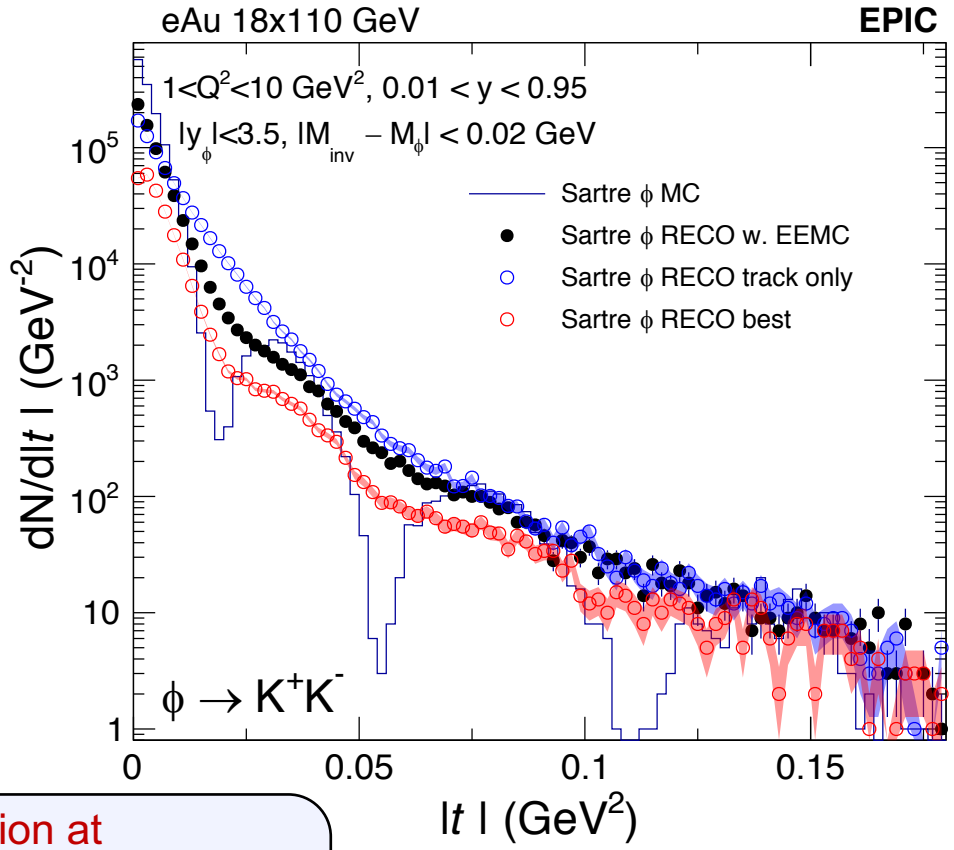




Similar performance for ϕ and J/ψ particle. Bottle neck is scattered electron

$Q^2 > 2$ vs $Q^2 > 1$ GeV^2

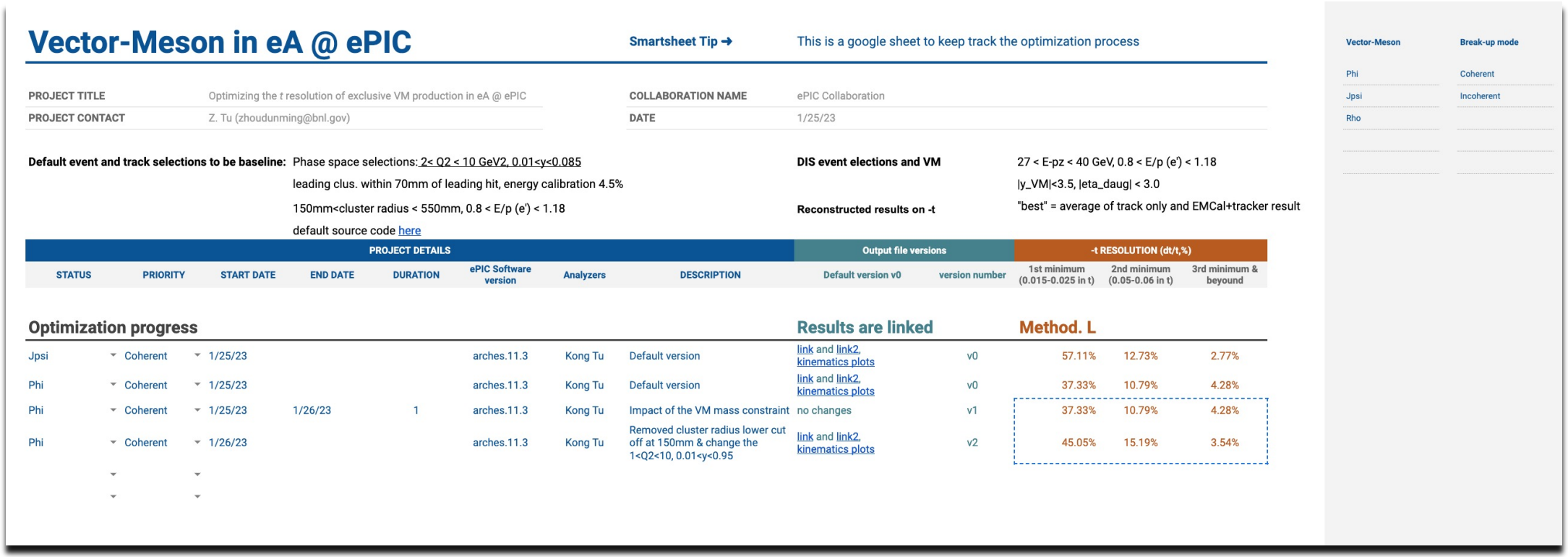




t resolution at

	1st dip	2nd dip	3rd dip
$Q^2 > 2$	37.33%	10.79%	4.28%
$Q^2 > 1$	45.05%	15.19%	3.54%

Process of optimization



Vector-Meson in eA @ ePIC

Smartsheet Tip → This is a google sheet to keep track the optimization process

PROJECT TITLE	Optimizing the *t* resolution of exclusive VM production in eA @ ePIC	COLLABORATION NAME	ePIC Collaboration
PROJECT CONTACT	Z. Tu (zhoudunming@bnl.gov)	DATE	1/25/23

Default event and track selections to be baseline: Phase space selections: 2< Q2 < 10 GeV2, 0.01<y<0.085
leading clus. within 70mm of leading hit, energy calibration 4.5%
150mm<cluster radius < 550mm, 0.8 < E/p (e') < 1.18
default source code here

DIS event elections and VM 27 < E-pz < 40 GeV, 0.8 < E/p (e') < 1.18
|y_VM|<3.5, |eta_daug| < 3.0

Reconstructed results on -t "best" = average of track only and EMCal+tracker result

PROJECT DETAILS								Output file versions		-t RESOLUTION (dt/t,%)		
STATUS	PRIORITY	START DATE	END DATE	DURATION	ePIC Software version	Analyzers	DESCRIPTION	Default version v0	version number	1st minimum (0.015-0.025 in t)	2nd minimum (0.05-0.06 in t)	3rd minimum & beyound
Optimization progress								**Results are linked**		**Method. L**		
Jpsi	Coherent	1/25/23			arches.11.3	Kong Tu	Default version	link and link2, kinematics plots	v0	57.11%	12.73%	2.77%
Phi	Coherent	1/25/23			arches.11.3	Kong Tu	Default version	link and link2, kinematics plots	v0	37.33%	10.79%	4.28%
Phi	Coherent	1/25/23	1/26/23	1	arches.11.3	Kong Tu	Impact of the VM mass constraint	no changes	v1	37.33%	10.79%	4.28%
Phi	Coherent	1/26/23			arches.11.3	Kong Tu	Removed cluster radius lower cut off at 150mm & change the 1<Q2<10, 0.01<y<0.95	link and link2, kinematics plots	v2	45.05%	15.19%	3.54%

Vector-Meson	Break-up mode
Phi	Coherent
Jpsi	Incoherent
Rho	

Include **incoherent background** will be the next step in ePIC simulation for exclusive VM
(progress: nuclear PDG code was just accepted in ePIC software.)

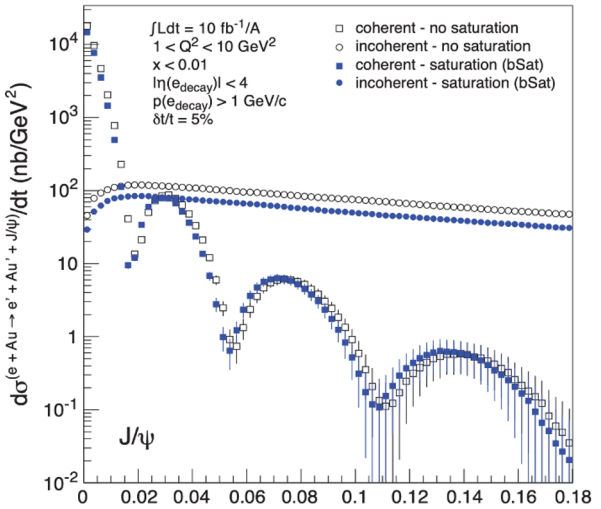
Summary - a dream came true

- Diffractive Vector-Meson is a powerful experimental tool to study the nucleon and nuclear structure, e.g., **gluon spatial distributions**.

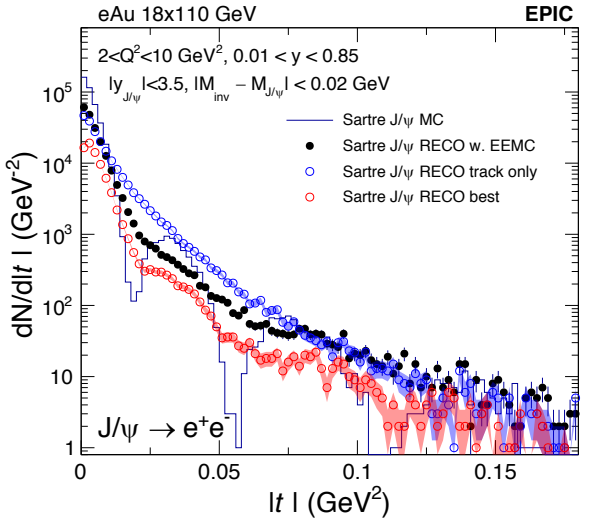
- From 2022 DIS to 2023 DIS:
  - **We achieved:** First full **ePIC simulation** in an unified and modern software framework.
  - **Next in ePIC:** Incoherent background, where the nucleus breaks up. Veto on far-forward particles.

- Will be further optimizing the algorithm and detector performance – full speed towards the TDR.

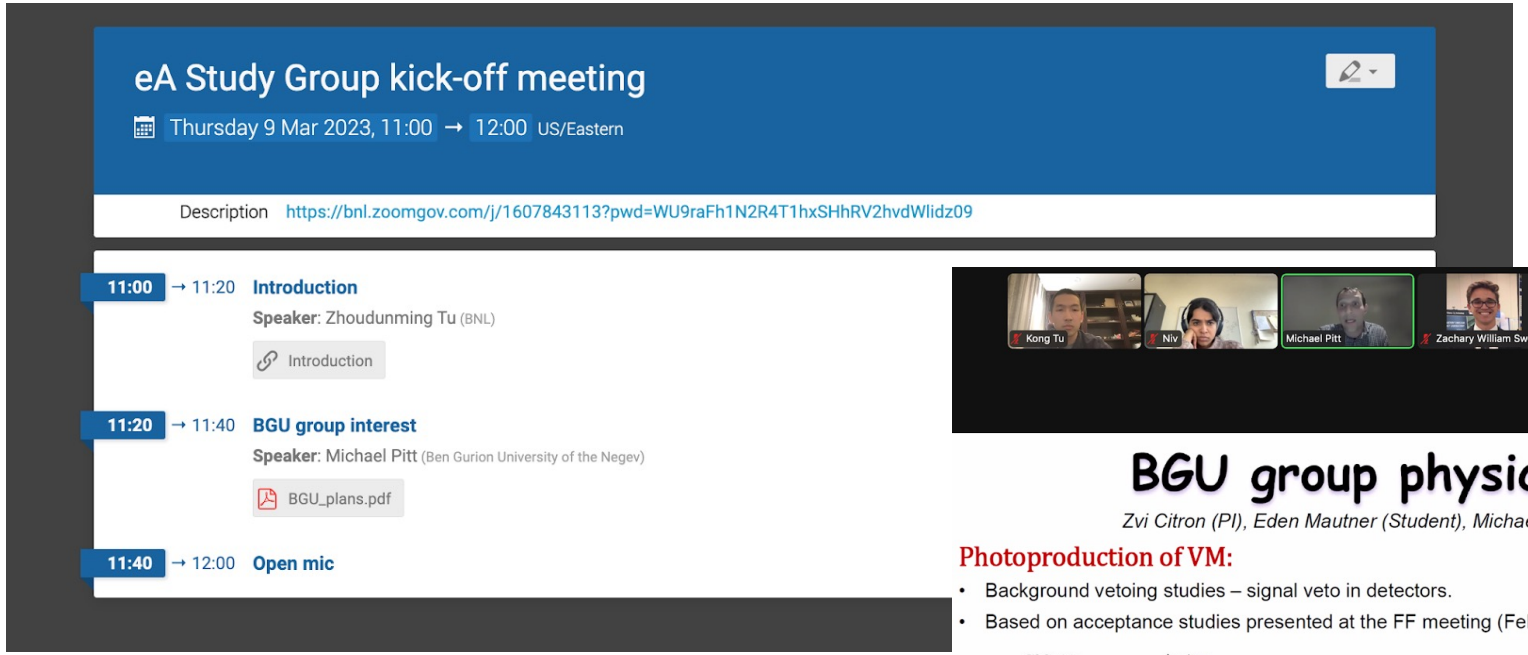
2012

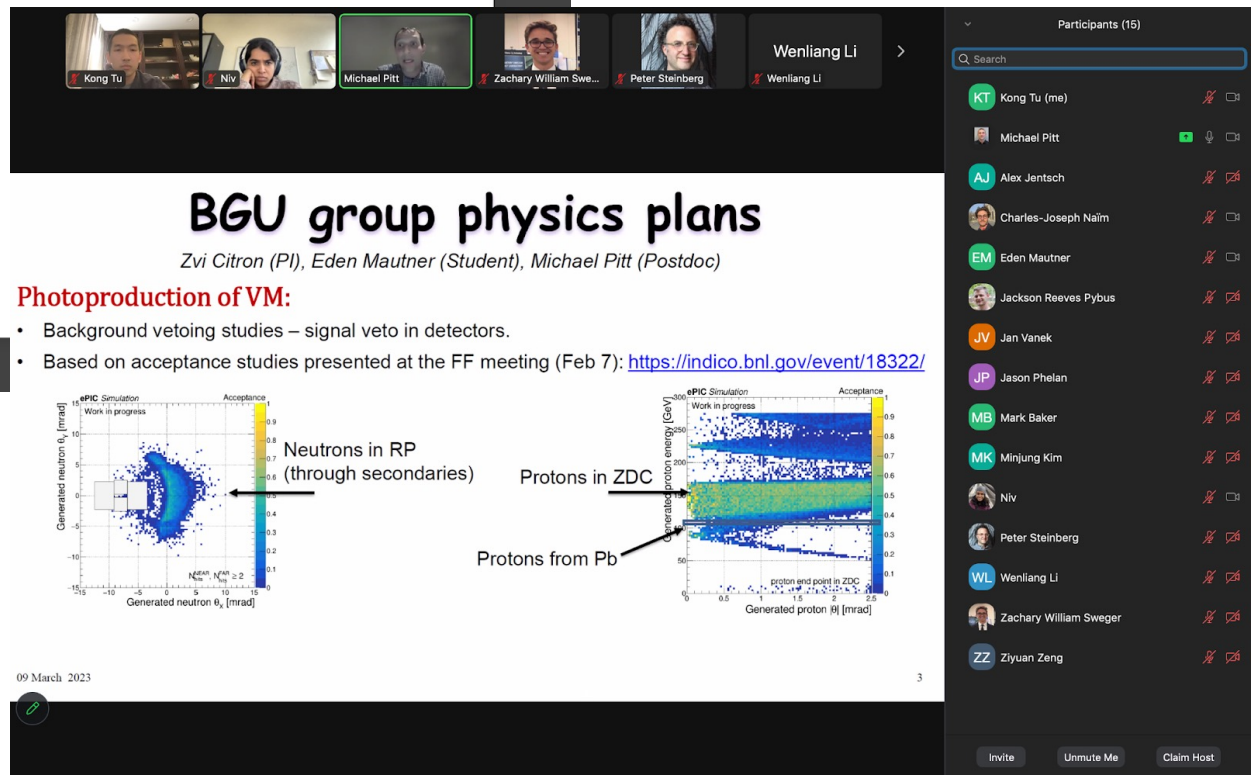


2023



eA Study Group

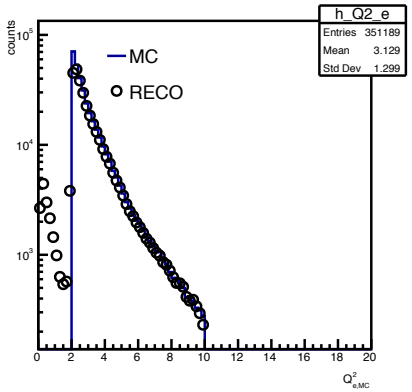


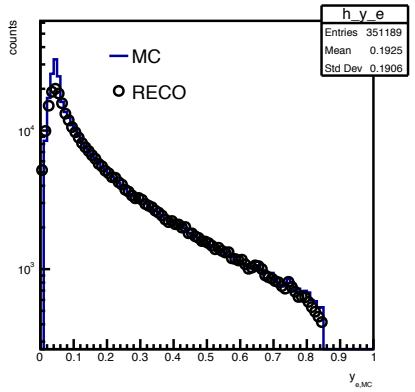


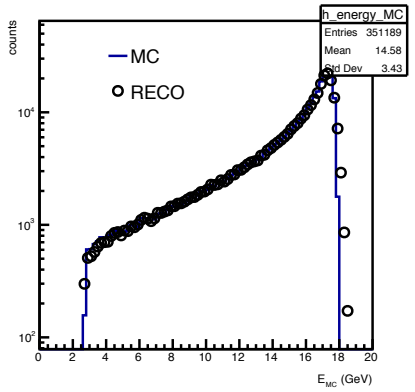
https://indico.bnl.gov/event/18684/

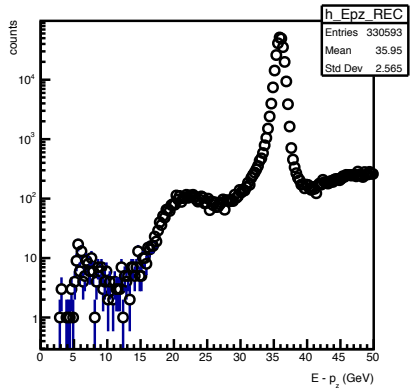
Backup

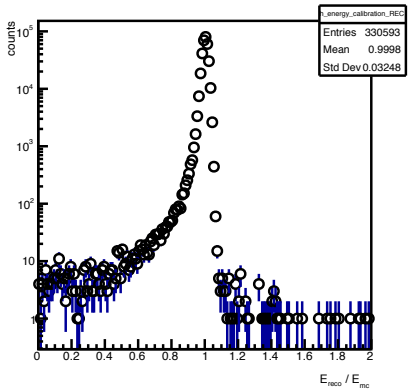
DIS control $Q^2 > 2$ GeV^2

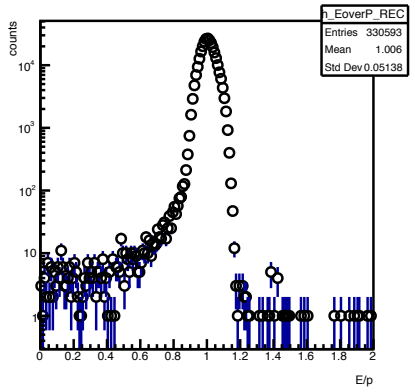


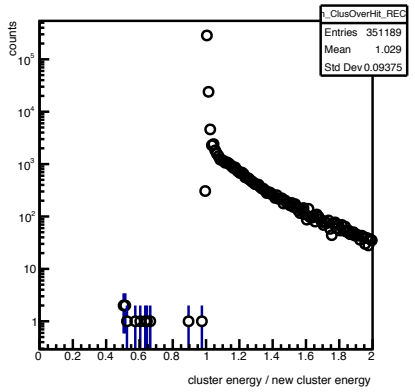


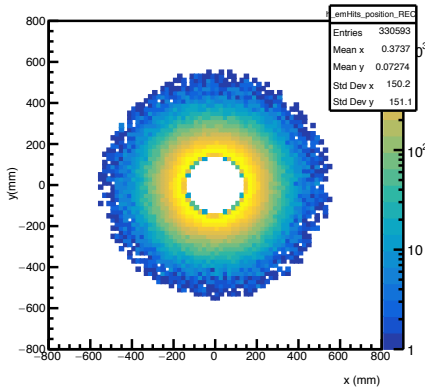












DIS control $Q^2 > 1$ GeV^2