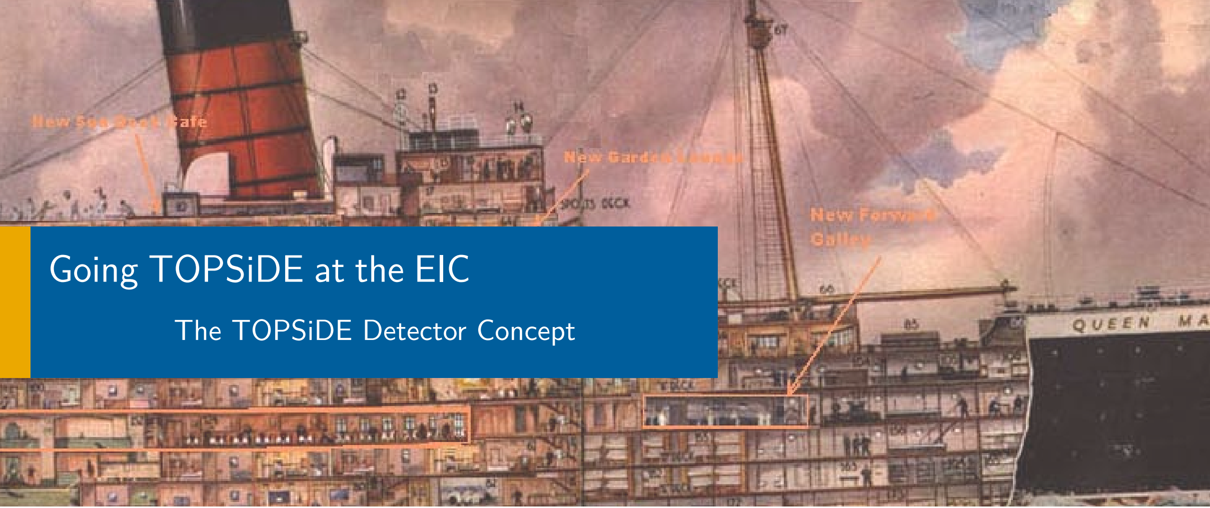


Going TOPSiDE at the EIC

The TOPSiDE Detector Concept

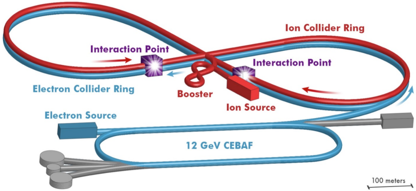
Whitney R. Armstrong
Argonne National Laboratory

June 18, 2018
JLab UGM 2018

Argonne NATIONAL LABORATORY

Overview and Introduction

1. The detector concept
   - What is TOPSiDE and what is it not?
   - Why does TOPSiDE have to offer?
2. Where we are going?
3. Collaborate and build science case



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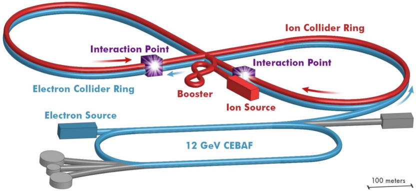

The EIC physics program demands a machine with **high luminosity and polarization**.

Why multiple interaction points?

EIC will be unique facility worldwide

Two IP can verify discoveries

Cross check and combine results

Complementary systematics (especially TOPSiDE)

Detectors for the EIC

Requirements for interaction region detector

- **100% acceptance** for all particles produced (acceptance $\times$ luminosity)
- Momentum/energy resolutions to meet the needs of **all physics**
- **Full Particle Identification** (PID) for all particles

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Detector needs from the processes defining hadron tomography program:
(see M. Diehl's talk next)

DVCS: Exclusivity, background free γ detection

DVMP: Exclusivity, full PID

SIDIS: Hadron PID ($K - \pi - p$ separation)

Tagging: 100% acceptance, extreme forward detection

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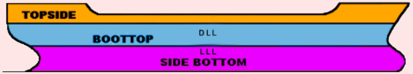
In other words, the detector output should closely resemble MC generated simulation input, i.e., a list particles and their momenta

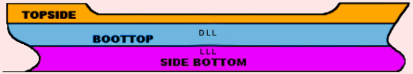
What is TOPSiDE?



Topside: "The upper part of a ship's side, above the waterline."

Although the TOPSIDE is one of the most visible parts, it isn't anywhere near the entirety of the ship!

What is TOPSiDE?



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TOPSiDE: Timing Optimized PID Silicon Detector for the EIC

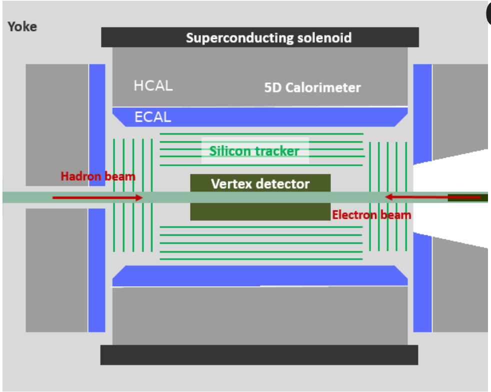
5D Detector Concept → Measure {E, x, y, z, t}

The basic ideas behind TOPSiDE:

- Simple design: **ultra-fast Si trackers** (UFSD) and highly granular **imaging calorimeters**
- **Full PID** over entire central and backward regions ($-5 < \eta < 3$)
- Covers a **well defined central region** where no extra PID detectors are needed
- Focused efforts for dedicated PID detectors in forward region where it is needed

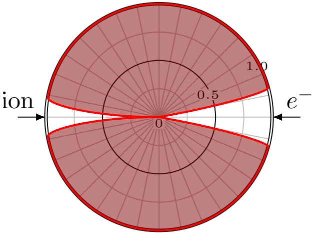
TOPSiDE: **T**iming **O**ptimized **P**ID **Si**licon **D**etector for the **E**IC

5D Detector Concept $\rightarrow$ Measure {E, x, y, z, t}



Central detector region: $(-3 < \eta < 3)$

- Symmetric design with close to 4π coverage
  $\rightarrow$ **Ensure exclusivity**



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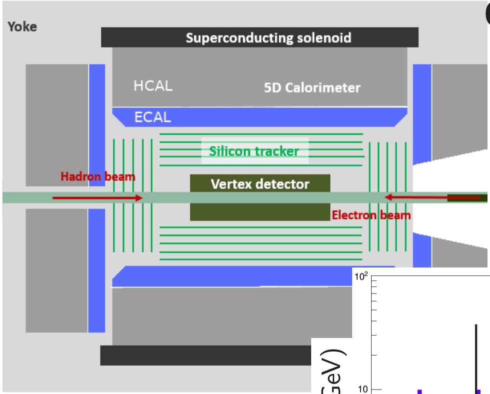
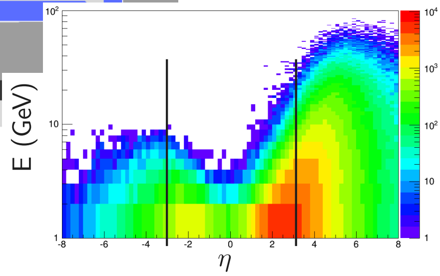
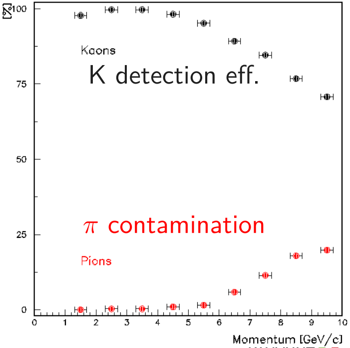


Central detector region: $(-3 < \eta < 3)$

- Symmetric design with close to 4π coverage
  → **Ensure exclusivity**
- Ultra-fast Si detectors for TOF $\pi - K - p$ separation
  → Provides PID necessary for **SIDIS**





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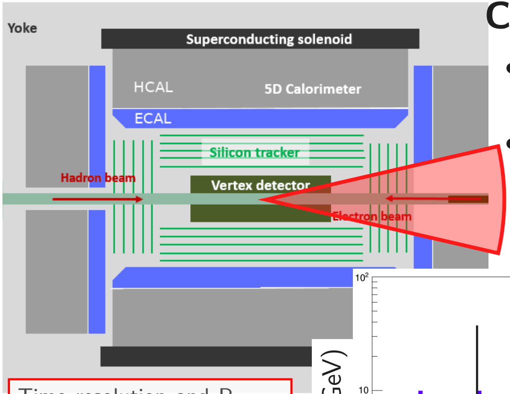

Time resolution and P_{max} define the minimum angle of central detector

Central detector region: $(-3 < \eta < 3)$

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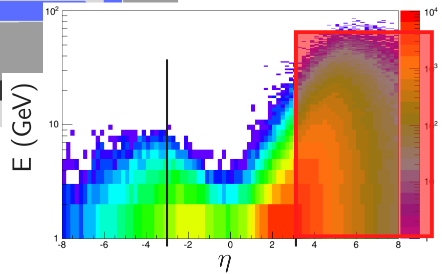

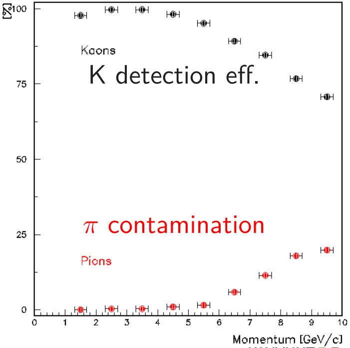

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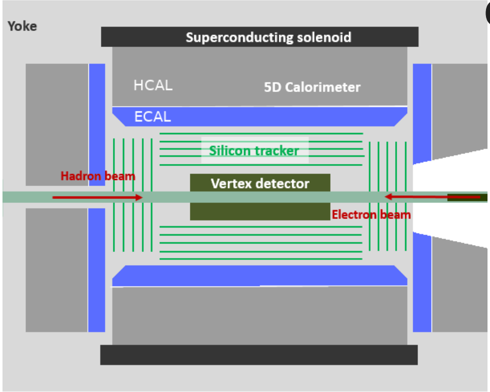

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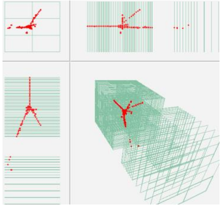
  → **Ensure exclusivity**
- Ultra-fast Si detectors for TOF $\pi - K - p$ separation
  → Provides PID necessary for **SIDIS**
- Imaging calorimeters and particle flow algorithms
  → PID of hadrons/neutrals and background rejection important for **DVCS and DVMP**



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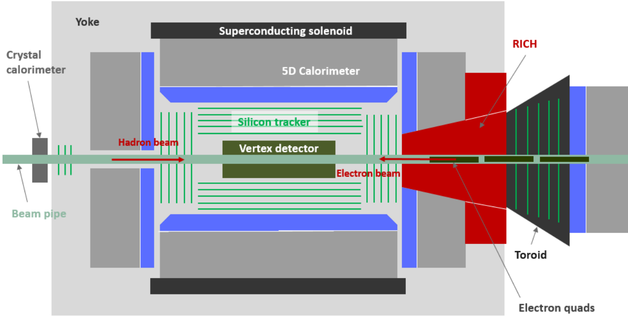
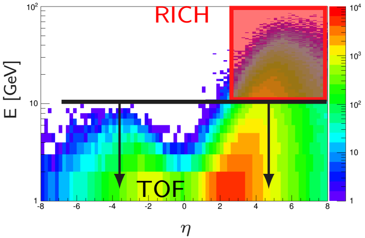


Forward Detectors $(3 < \eta < 5)$

- For $\theta < 10°$, UFSD TOF and gaseous RICH PID $\rightarrow (\pi - K - p)$ separation for **SIDIS**



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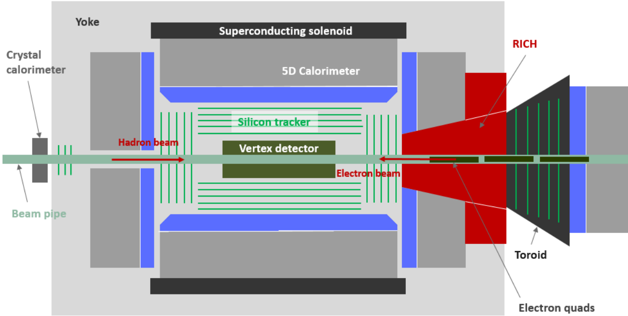

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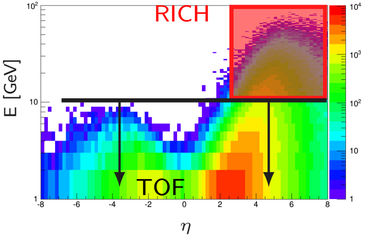
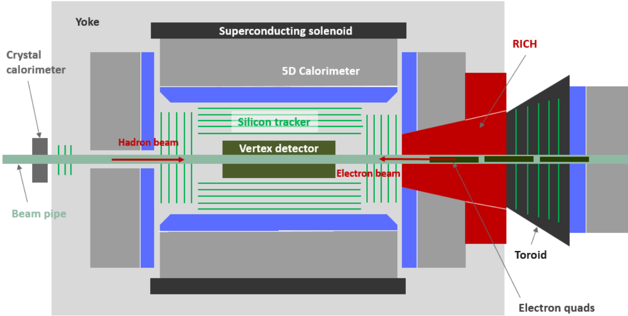
- For $\theta < 10°$, UFSD TOF and gaseous RICH PID → $(\pi - K - p)$ separation for **SIDIS**
- Dipole or toroid for momentum measurement → Momentum resolution for **SIDIS and DVMP**



TOPSiDE: Timing Optimized PID Silicon Detector for the EIC

5D Detector Concept $\rightarrow$ **Measure** $\{$**E, x, y, z, t**$\}$



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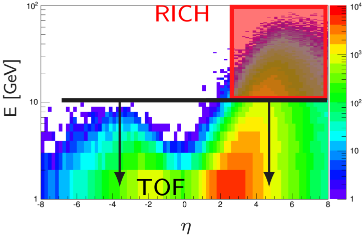
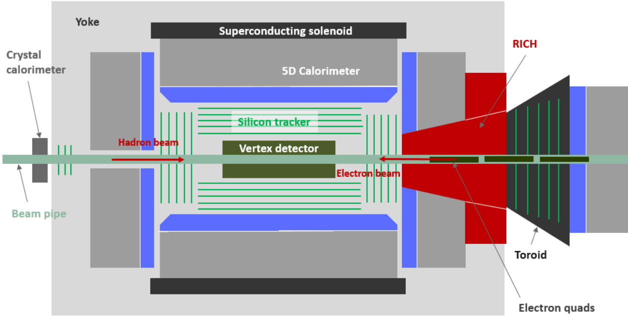
- UFSD TOF for full PID (no RICH needed) $\rightarrow$ Provides PID needed for **SIDIS**



TOPSiDE: Timing Optimized PID Silicon Detector for the EIC

5D Detector Concept → Measure {E, x, y, z, t}



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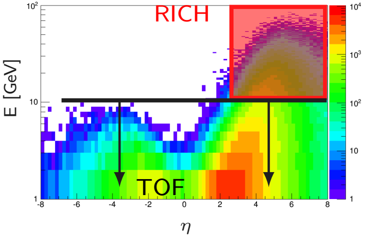


Backward Detectors $(-5 < \eta < -3)$

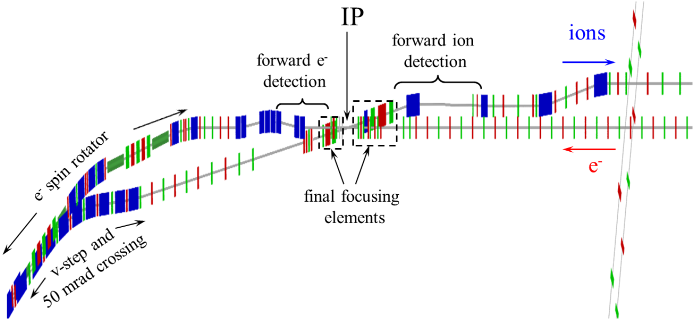
- UFSD TOF for full PID (no RICH needed) → Provides PID needed for **SIDIS**
- Crystal calorimeter for optimal energy resolution → **Exclusivity for DVCS/DVMP**

Far-Forward and Far-Backward Regions

$\theta < 1^\circ$

Finally, 100% acceptance requires far forward/backward detectors

Equally important to the science as the central/forward detectors



See JLEIC talks of V. Morozov and Y. Furletova

Far-Forward and Far-Backward Regions

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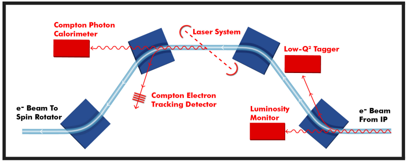
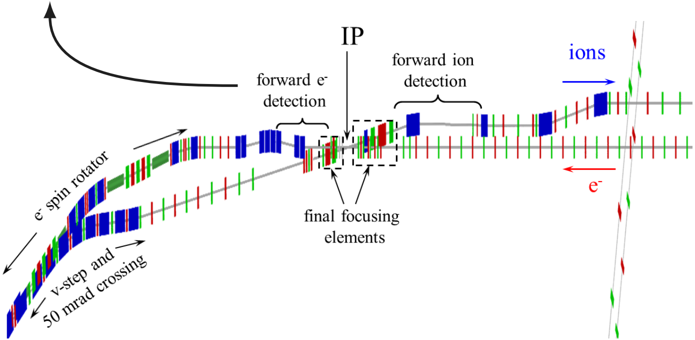


Addresses key items for EIC: polarization and luminosity

- Compton Polarimeter
- Luminosity monitor
- Low-Q^2 tagger



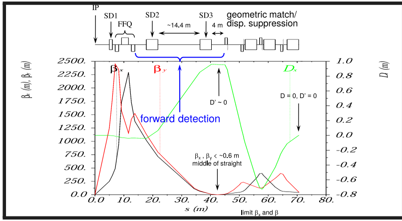
See JLEIC talks of V. Morozov and Y. Furletova

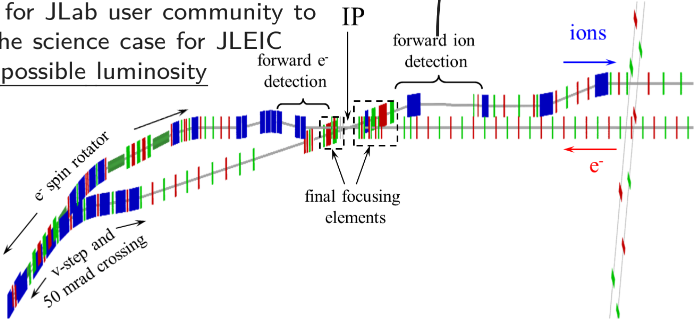
Far-Forward and Far-Backward Regions

$\theta < 1^\circ$

Far-forward ion spectrometer

- Needed for spectator **tagging** and coherent processes on nuclei
- Not yet included in full TOPSiDE simulation $\rightarrow$ implementation highly site specific (JLab/BNL)
- Opportunity for JLab user community to strengthen the science case for JLEIC and highest possible luminosity





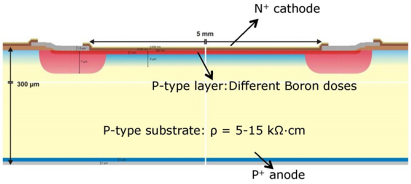
See JLEIC talks of V. Morozov and Y. Furletova

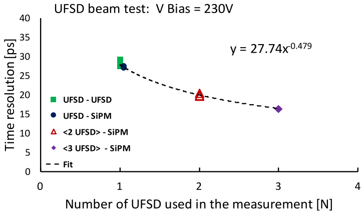
Ultra-fast Silicon Detectors

10 ps timing resolution needed for the TOPSiDE 5D Concept

- Implement in tracker and calorimeter for Particle ID ($\pi - K - p$ separation)

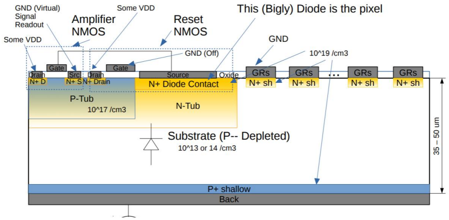
Low-Gain Avalanche Diodes (LGAD)





Cartiglia, NIM A850 (2017) 83-88

HV-CMOS



K.-W. Shin - in progress

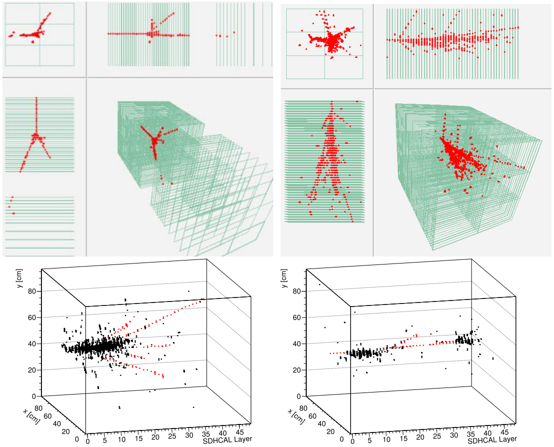
- LGAD currently state-of-the-art (best time resolution)
- HVCMOS is promising, possibly cheaper, and monolithic design easier
- HBT SiGe technology is also promising (similar character to CMOS but faster and lower power)

Imaging Calorimetry

Advantages

- Particle ID
  - Electrons, muons, hadrons → (almost) trivial
  - Muon system redundant
- Software compensation
  - Typical calorimeters have e/h ≠ 1
  - Weighting of individual sub-showers possible
  - significant improvement in $\sigma_{E_{had}}$
  - Use longitudinal shower information to compensate for leakage → improve $\sigma_{E_{had}}$
  - Measure momentum of charged particles exiting calorimeter
- Gain monitoring
  - Reconstruct track segments within hadronic showers
  - Utilize MIP signal to monitor gain
  - Assess local radiation damage
- Separate underlying events and background
  - Background can be identified and subtracted
- Application of Particle Flow Algorithms (PFAs)
  - Use PFAs to reconstruct the energy of hadronic jets

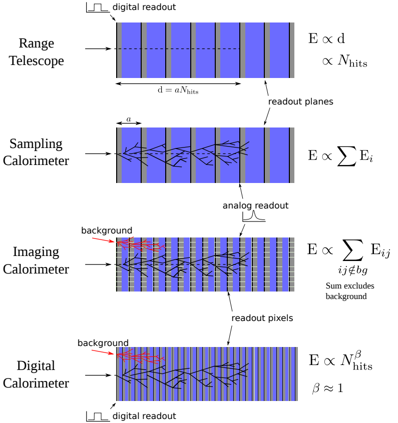
Digital HCAL (DHCAL) - CALICE collab.



SDHCAL - CALICE, JINST 11 (2016) no.04, P04001

See Calorimetry for the Future, J.Repond, *LHeC and FCC-eh Workshop*

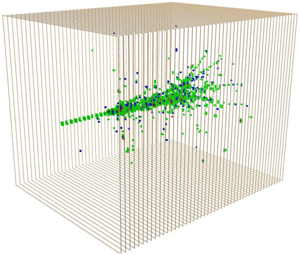
Imaging, Digital, and semi-Digital Hadronic Calorimeters

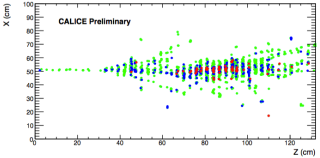


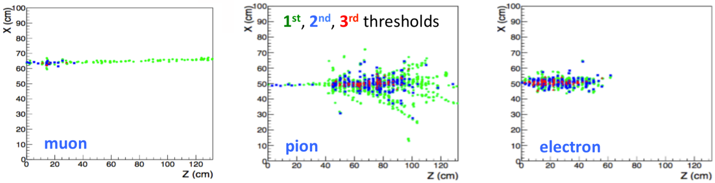
Semi-Digital (2 bits):

$E \propto \sum(\alpha N_1 + \beta N_2 + \gamma N_3)$

where $\alpha \sim \beta/2 \sim \gamma/3$

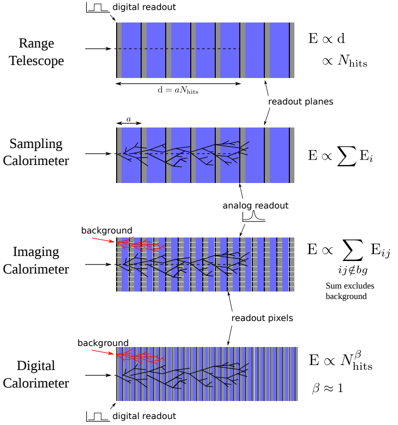






From D. Boumediene (LPC)-CEPC WS 2018, Roma III

Imaging, Digital, and semi-Digital Hadronic Calorimeters



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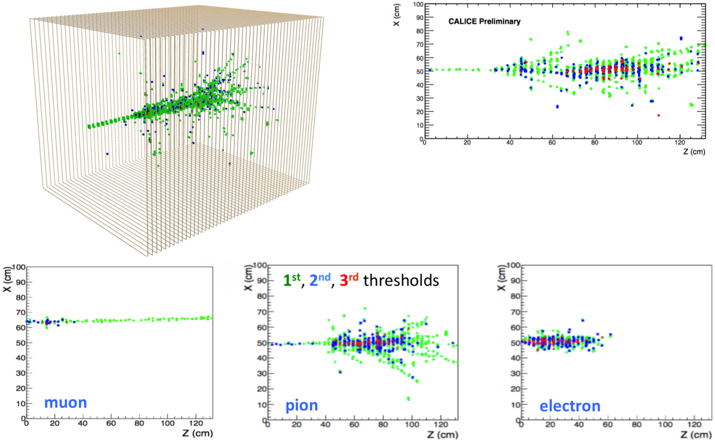
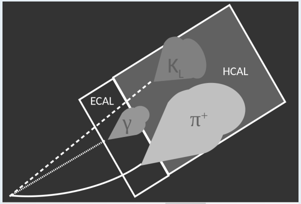


From D. Boumediene (LPC)-CEPC WS 2018, Roma III

This technology is the future of calorimetry

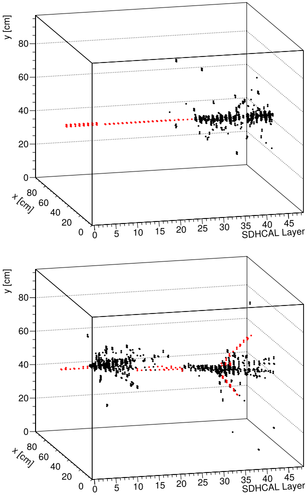
Imaging Calorimetry and Particle Flow Algorithms

"Particle flow" algorithms (PFA) use **all detector information** to reconstruct event



- "Particle flow" always provides the best reconstruction.
- Higher granularity → less confusion
- Track segments connect adjacent showers associated with same primary particle
- New "Particle Flow" algorithms and methods possible with fine segmentation and excellent time resolution
- PFA output is a list of particles

Semi-Digital HCAL



SDHCAL - CALICE, JINST 11 (2016) no.04, P04001

DIS 5 GeV on 60 GeV

Partic…
11 (e…
321 (…
-211 (…
-211 (…
211 (…
111 (…

Proton DVCS 5 GeV on 60 GeV

Particle ID	P_x	P_y	P_z
11 (e^-)	xxxxx	xxxxx	xxxxx
2212 (p)	xxxxx	xxxxx	xxxxx
22 (γ)	xxxxx	xxxxx	xxxxx

Simulation and Reconstruction Software from Argonne

Software for the next decade and beyond

- Identified software with emphasis on **long-term maintainability**
- Targeting **exascale computing** resources (ALCF's THETA and the coming AURORA)
- **Parallelism at every level**: from thread level down to vectorized CPU instructions.
- Heavy use of containers (D.Blyth, containerization expert, is doing interesting things with workflow)
- Plan to migrate to next generation collaboration platform (HepSim 2.0)

A lot of momentum behind Argonne software

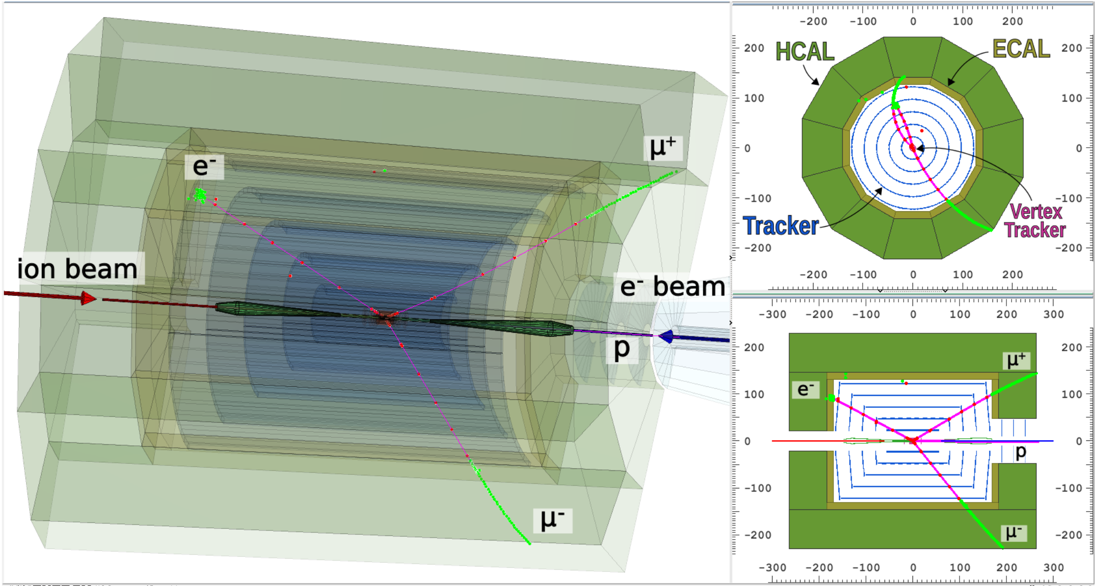
Full tool-chain is **ready now**

→ Event generation, GEANT4, digitization, reconstruction, event display, analysis

Key software in tool-kit

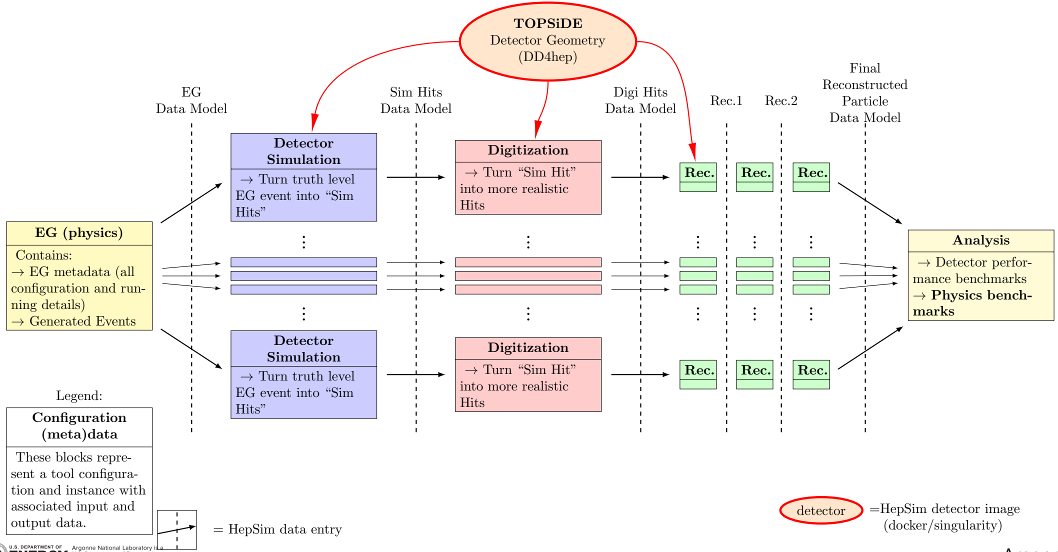
- `DD4hep` - detector description
- `proio` - data model tool
- `PandoraPFA` - particle flow
- `HepSim` - data management
- and many more

TOPSiDE: Event display



Simulation and reconstruction workflow

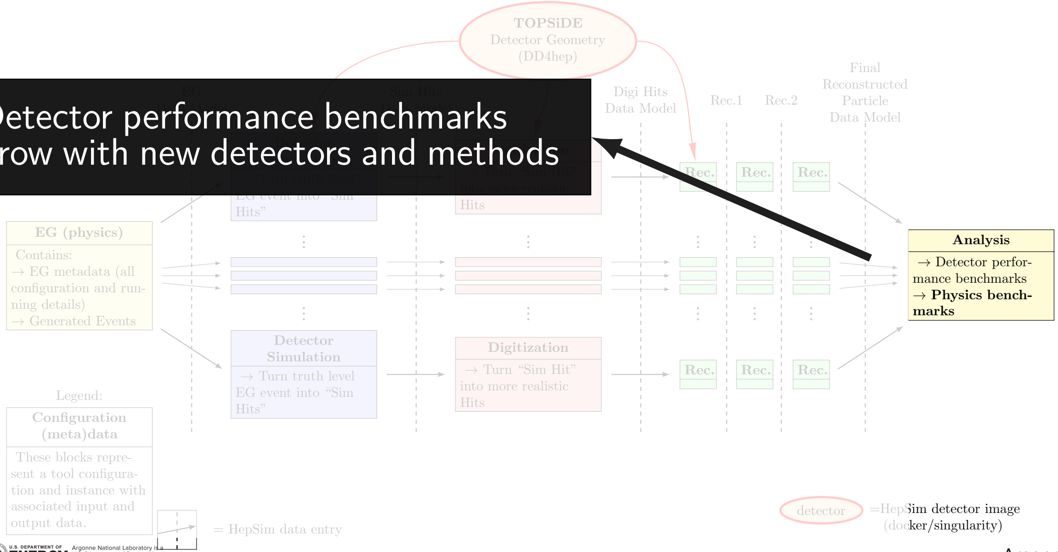
Basic tasks and data management



Simulation and reconstruction workflow

Basic tasks and data management

Detector performance benchmarks grow with new detectors and methods



Simulation and reconstruction workflow

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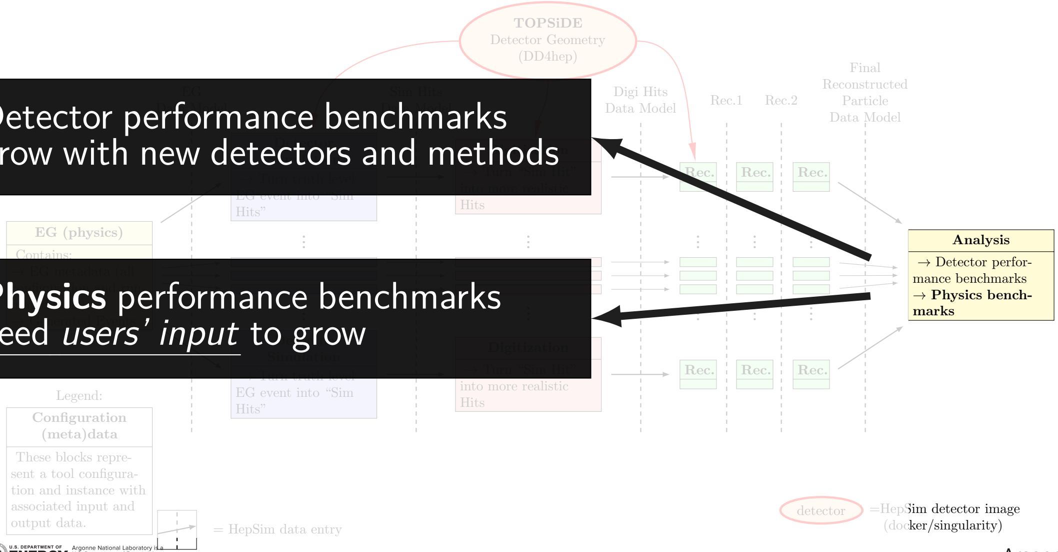
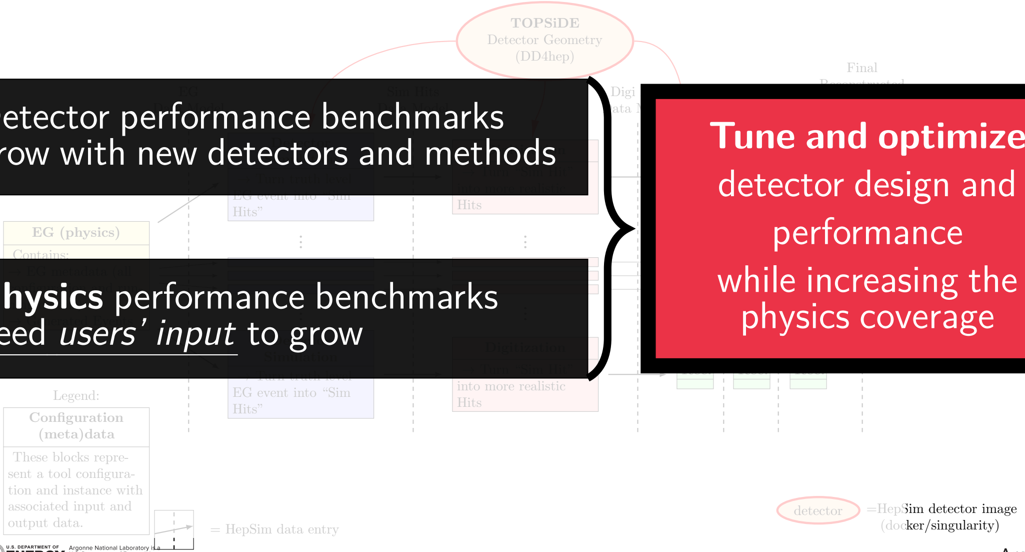


Detector performance benchmarks grow with new detectors and methods

Physics performance benchmarks need *users' input* to grow

Simulation and reconstruction workflow

Basic tasks and data management



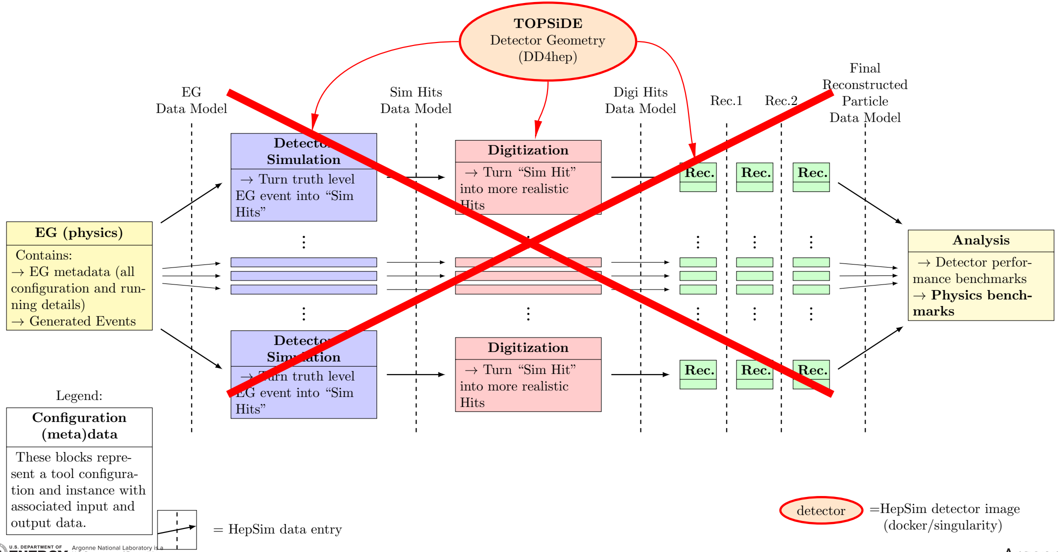
Detector performance benchmarks grow with new detectors and methods

Physics performance benchmarks need *users' input* to grow

Tune and optimize
detector design and performance
while increasing the physics coverage

An invitation to the JLab User Group

Get involved with a first look at your **physics** with TOPSiDE



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MC generated events → **Fully reconstructed list of particles**

EG (physics)
Contains: → EG metadata (all configuration and running details) → Generated Events

Analysis
→ Detector performance benchmarks → **Physics benchmarks**

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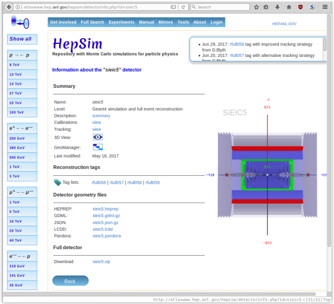

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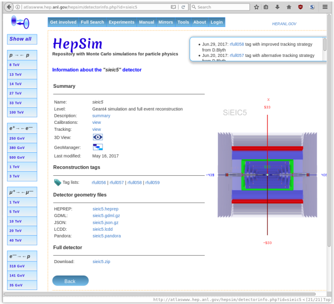

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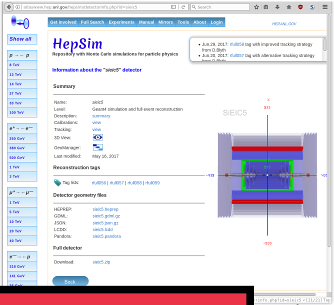

nov)

Great jumping-off point for getting involved

Getting involved

The JLab user community's input is critical for building the best science case

Start looking at your physics!

1. We will simulate your MC events
2. Output will be fully reconstruction four momenta
3. Analyze the reconstructed data for **Physics Performance** $\rightarrow$ benchmark
4. Optimize (machine, detectors, reconstruction algorithms, new ideas)
5. Repeat to **build the best physics case possible**

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We will take just about any EG format!

Now is the time to get going!

From 12 GeV to EIC

(see the talks)

Summary

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- The **TOPSiDE** concept is a **simple and modern design**, and uniquely addresses the detector needs of the motivating physics for the EIC

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The scientific creativity of the JLab User Community is critically important to fully develop the scientific program of the EIC

- Get involved in any way possible (JLEIC, TOPSiDE, BNL, etc.) to build the best science case **now** to get the best machine in the future

Thank you!

The TOPSiDE Team

José Repond, David Blyth, Whitney Armstrong, Jessica Metcalfe, Kyung-Wook (Taylor) Shin, Sergei Chekanov, Mohammad Hattawy, Adam Freese, Sereres Johnston, Junqi Xie, Sylvester Joosten

Backup