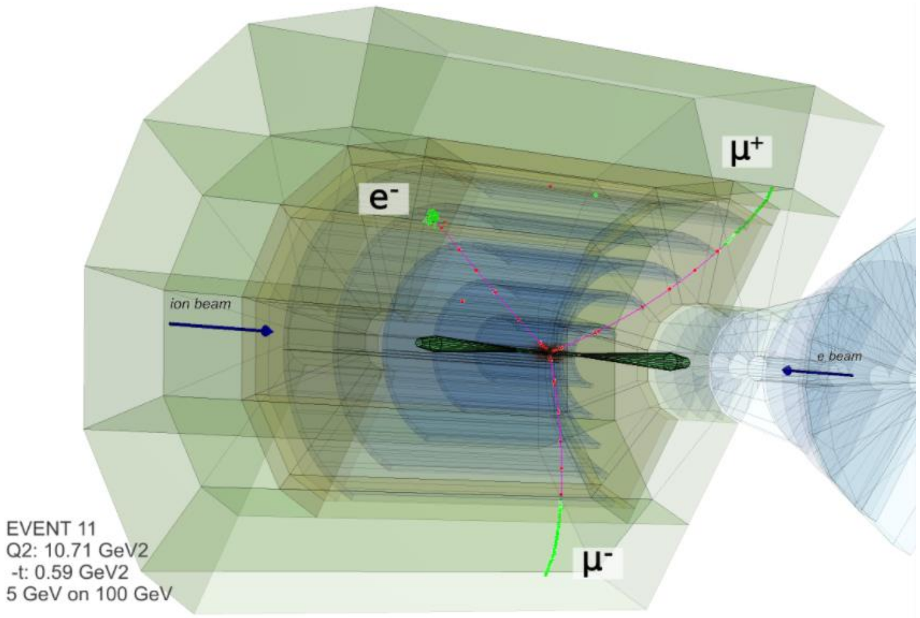
TOPSiDE – Concept of an EIC Detector



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Argonne National Laboratory

DIS 2018
Kobe, Japan
April 16 – 20, 2018

Electron-Ion Collider EIC

Polarized ep, eA collider

√s = 35 – 180 GeV
Luminosity = 10^{34} cm^{-2}s^{-1}

Two possible sites

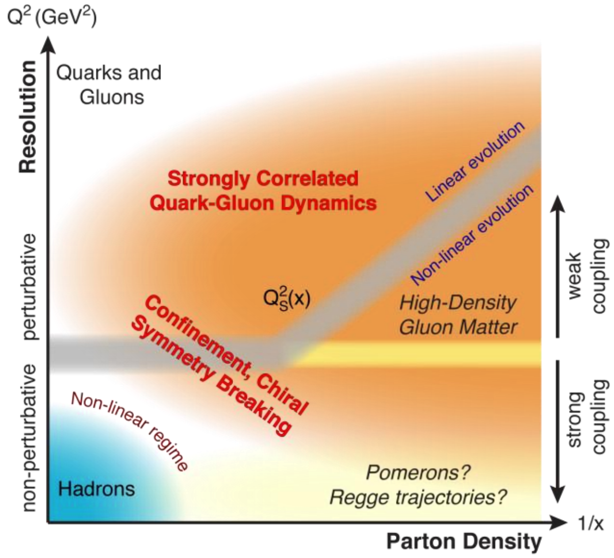
Brookhaven → eRHIC
Jefferson lab → JLEIC

Scientific goals

Study of perturbative & non-perturbative QCD
Tomography (including transverse dimension) of the nucleon, nuclei
Understanding the nucleon spin
Discovery of gluon saturation…

Construction to start in 2025

Nuclear physics community optimistic about its realization
CD0 expected in FY2019 (making it a project)



- **To achieve the EIC physics goals we need**

100% acceptance for all particles produced (<u>acceptance is luminosity!</u>)
Excellent momentum/energy resolution
PID for all particles

→ This requires full integration of the central, forward detectors and the beamline

- **Particle list at MC hadron level**

Particle ID	P_x	P_y	P_z
11 (e^-)	-0.743	-0.636	-4.842
321 (K^+)	0.125	0.798	6.618
-211 (π^-)	0.232	0.008	3.776
-211 (π^-)	0.151	-0.007	4.421
211 (π^+)	0.046	0.410	2.995
111 (π^0)	-0.093	0.048	1.498
2112 (p)	0.115	-0.337	31.029
211 (π^+)	0.258	0.145	6.336
310 (K_S^0)	0.385	-0.408	3.226

DIS event

E_e = 5 GeV
E_p = 60 GeV

- **Detector output**

We want a detector which provides the same type of information

TOPSiDE – 5D Concept

Timing **O**ptimized **P**ID **Si**licon **D**etector for the **E**IC

Salient features

Symmetric design of the central detector (-3 < η < 3)
- Unlike the HERA detectors (ZEUS and H1)
- Electrons, photons and hadrons go everywhere

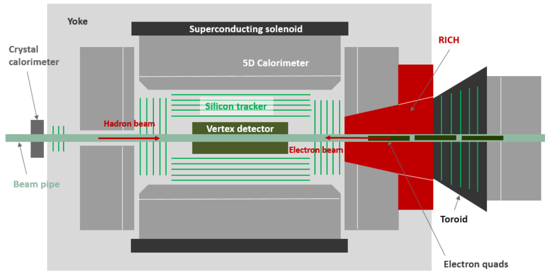
Silicon tracking
- Vertex, outer, and forward/backward trackers

Imaging calorimetry with very fine granularity
- Silicon ECAL and (gaseous or scintillator) HCAL
- Close to 4π coverage

Ultra-fast silicon
- 10 ps time resolution for Time-of-Flight (PID)

Superconducting solenoid
- 2.5 – 3 Tesla
- Outside the barrel calorimeters

Measure E, x, y, z, t



TOPSiDE – 5D Concept

Timing **O**ptimized **P**ID **Si**licon **D**etector for the **E**IC

Salient features

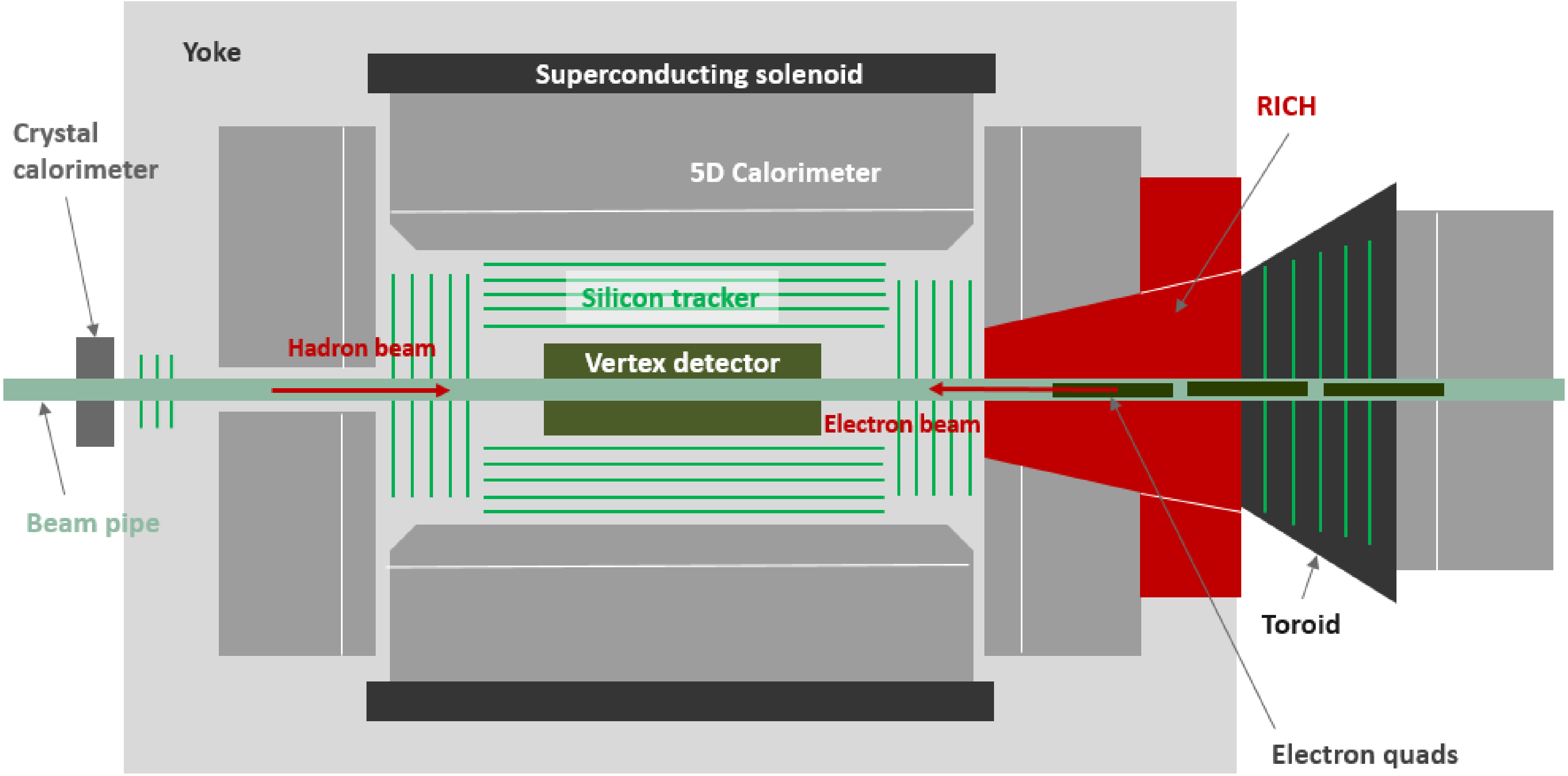
Forward (hadron) direction (3 < eta < 5)
Gaseous RICH for momenta between 10 and 50 GeV/c (within a cone of $<10^0$)
Dipole or toroid for momentum measurement
Ultra-fast silicon for tracking and TOF (PID for momenta up to 10 GeV/c)

Backward (electron) direction (-3 > eta > -5)
Crystal calorimeter for optimal energy resolution
Luminosity, polarization, low-Q^2 tagging

No additional
Preshower, TOF, TRD, Cerenkov, muon chambers ← Not needed

in front of the calorimeter

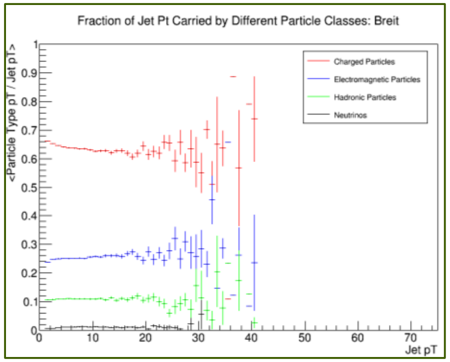
TOPSiDE – 5D Concept



Area of silicon ~1,400 m^2 or \$14M @ \$1/cm^2

(Compare: CMS HGCAL upgrade ~ 600 m^2)

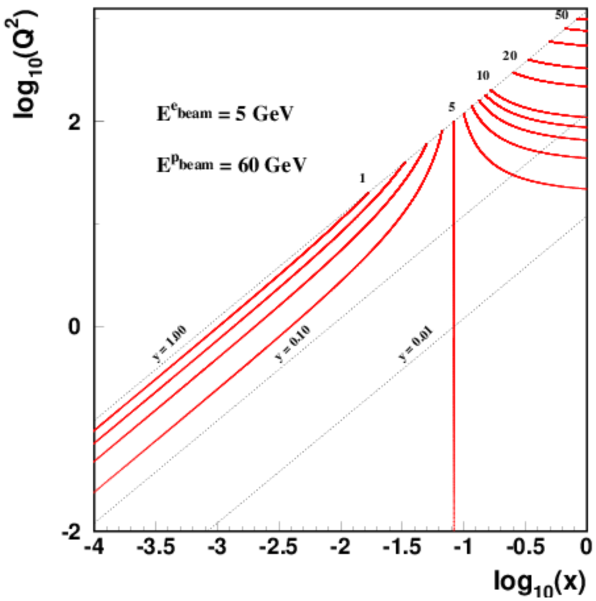
TOPSiDE – 5D Concept



The case for a hermetic (4π) hadron calorimeter

The EIC is a precision machine (at the 1% level)
$E_{neutral}$ is small in average, but there are large fluctuations
Electron ID is needed in the barrel region and is helped by a hadron calorimeter
Background rejection requires hermeticity (detection of all particles)
Kinematic reconstruction needs all hadrons
⟶ In particular for charged current events (no electron)
⟶ At medium/large x or low y (where the electron method fails ⟶ double angle)

$$\frac{\delta x}{x} = \frac{1}{y}\frac{\delta E_e}{E_e} = \frac{1}{1-y}\frac{\delta E_q}{E_q}$$

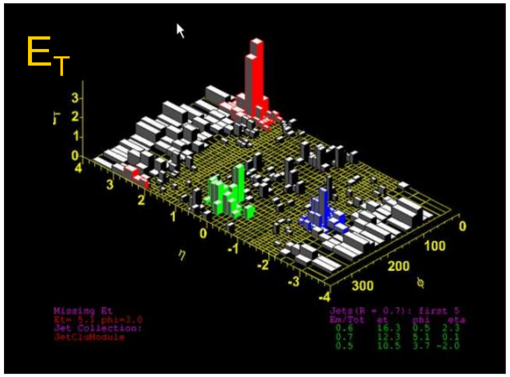


Special features/challenges of TOPSiDE

- Imaging calorimetry
- Ultra-fast silicon
- Tilted tracking sensors

} ⟶ next slides

Imaging Calorimetry



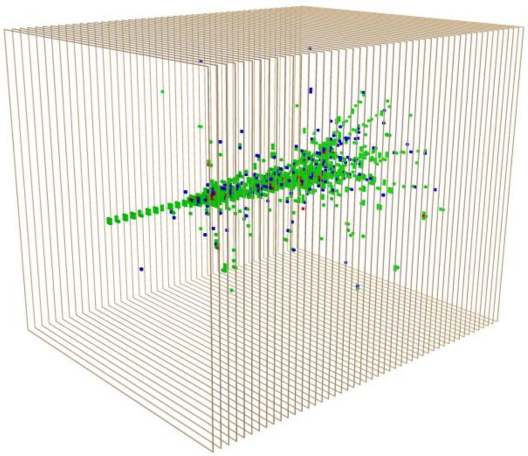
Replace

Tower structure with very fine granularity (lateral and longitudinally)
Few 1,000 channels → few 10,000,000 channels
Option to reduce resolution on single channels to low-bit depth

Technologies developed in past decade

Silicon sensors with 1 x 1 cm^2, 0.5 x 0.5 cm^2 and 0.16 cm^2 pixels
Scintillator strips (4.5 x 0.5 cm^2) or scintillator pads (3 x 3 cm^2)
Resistive Plate Chambers with 1 x 1 cm^2 pads
Micromegas and GEMs with 1 x 1 cm^2 pads

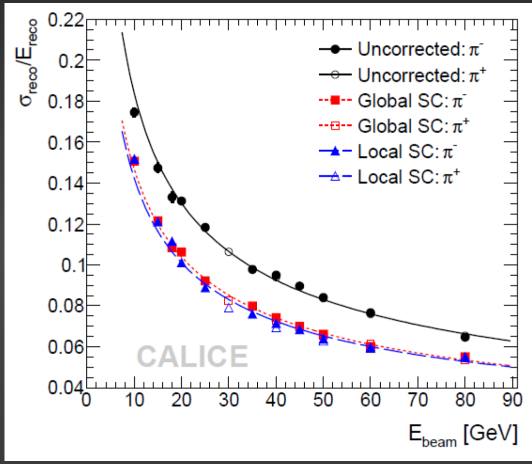
These technologies have been (mostly) validated

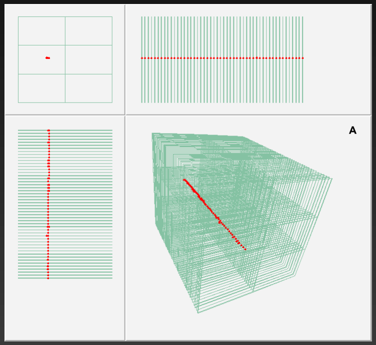


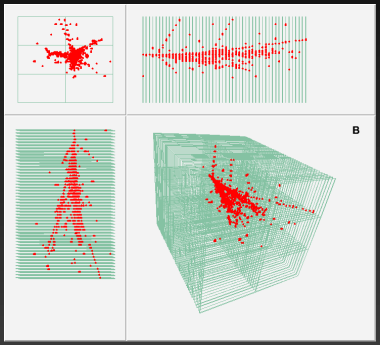
Advantages of Imaging Calorimetry I

Particle ID

Electrons, muons, hadrons ⟶ (almost) trivial
Muon system redundant





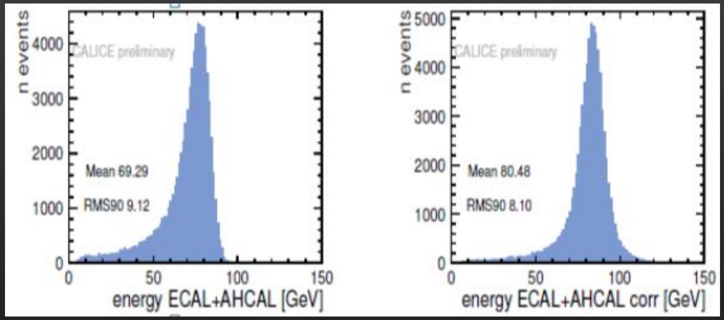


Software compensation

Typical calorimeters have e/h ≠ 1
Weighting of individual sub-showers possible
⟶ significant improvement in σ_E^{had}

Leakage corrections

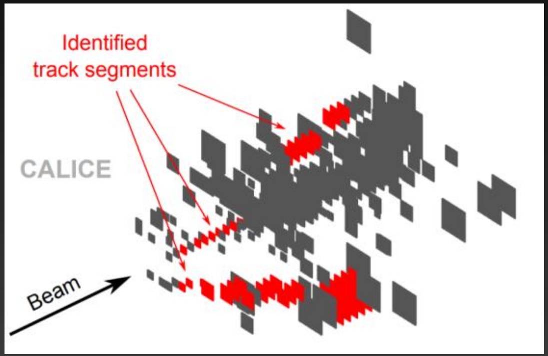
Use longitudinal shower information to compensate for leakage
⟶ significant improvement in σ_E^{had}
Measure momentum of charged particles exiting calorimeter

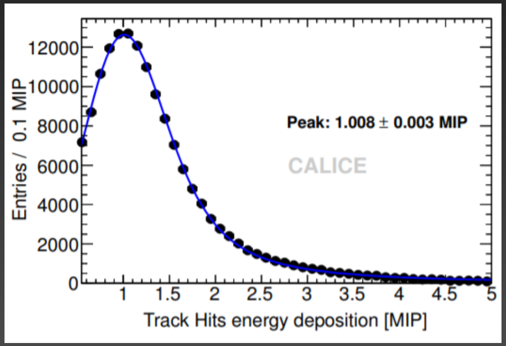


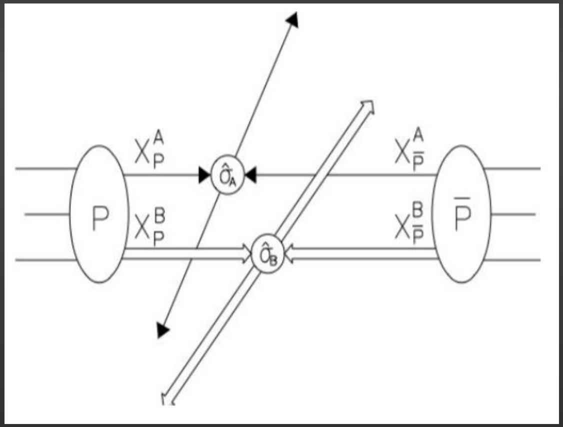
Advantages of Imaging Calorimetry II

Gain monitoring

Reconstruct track segments within hadronic showers
Utilize MIP signal to monitor gain
Assess local radiation damage







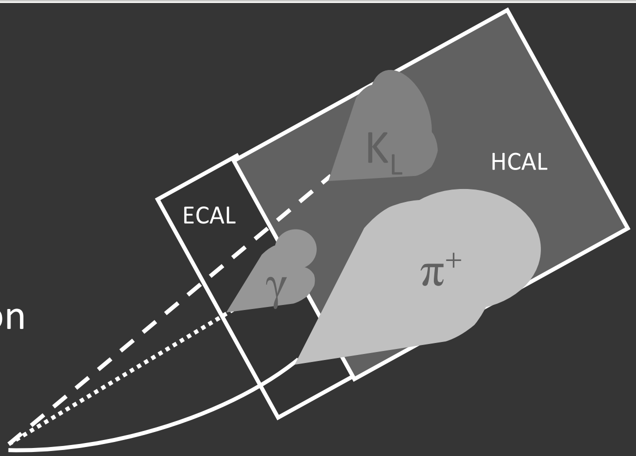
Identify underlying events

Multiparton interactions generate background of low energy particles
This background can be identified and subtracted (LHC)

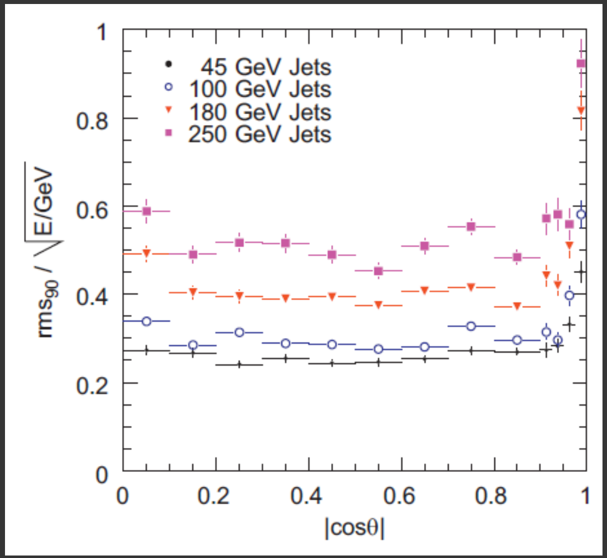
Application of Particle Flow Algorithms (PFAs)

Use PFAs to reconstruct the energy of hadronic jets

Particle Flow Algorithms



Attempt to measure the energy/momentum of each particle in a hadronic jet with the detector subsystem providing the best resolution



PANDORA PFA based on ILD detector concept

Particles in jets	Fraction of energy	Measured with	Resolution [σ^2]
Charged	65 %	Tracker	Negligible
Photons	25 %	ECAL with 15%/√E	$0.07^2\ E_{jet}$
Neutral Hadrons	10 %	ECAL + HCAL with 50%/√E	$0.16^2\ E_{jet}$
Confusion	If goal is to achieve a resolution of 30%/√E →		**≤ $0.24^2\ E_{jet}$**

18%/√E

Factor ~2 better jet energy resolution than previously achieved

EIC environment: particularly suited for PFAs, due to low particle multiplicity and low momenta

ULTRA - FAST SILICON

Needed for 5D Concept

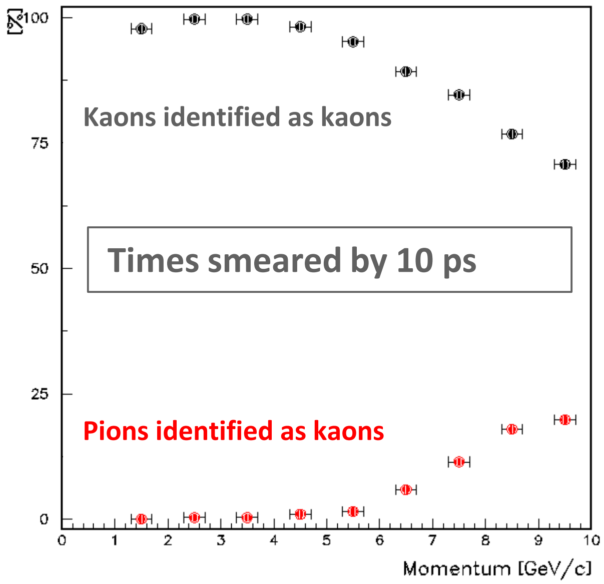
Implement in calorimeter and tracker for Particle ID
(π – K – p separation)
Resolution of 10 ps → separation up to ~ 7 GeV/c

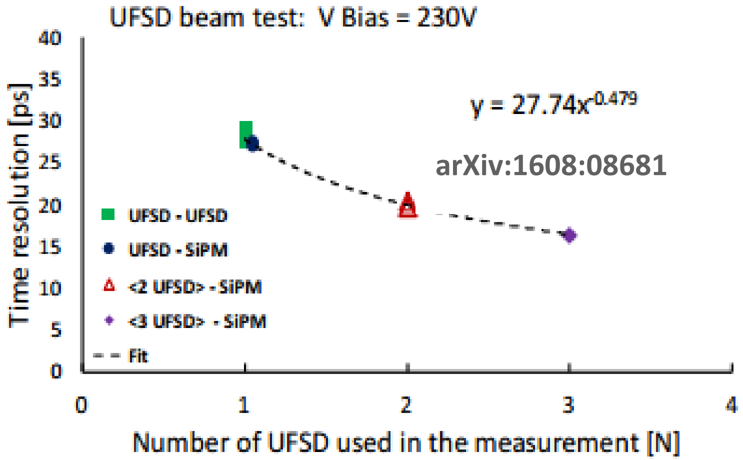
Current status

Being developed based on the LGAD technology
Best timing resolution about 27 ps

Future

Further improvements ongoing
→ Several groups worldwide





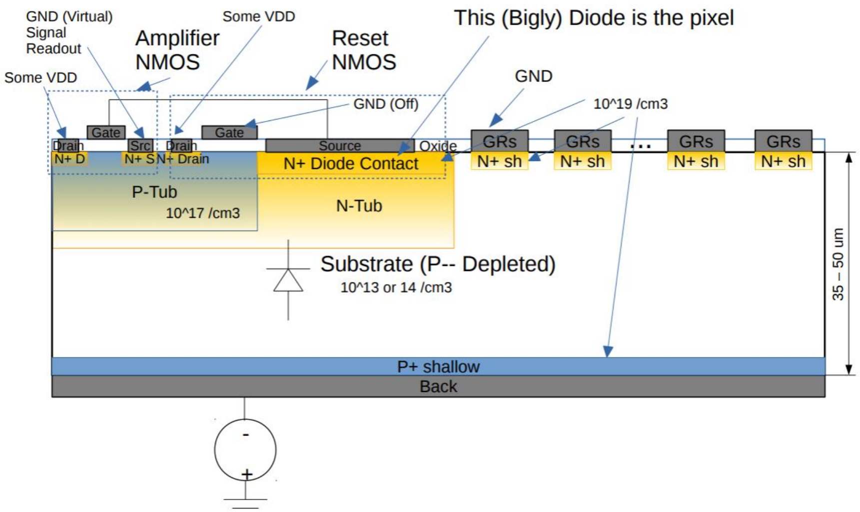
Argonne Silicon Development

Testing

Assembly of test bench for silicon sensors started
→ Acquired necessary tools: fast scope, HV, LV supplies, sources, clean space…
Opening for a new postdoc
→ Testing of sensors to start in 1 – 2 months
Participation in testing of sensors (ATLAS upgrade)in Fermilab test beam

Simulation

Simulation of HVCMOS sensors started
Goal is to improve the timing resolution
→ Implementation of additional amplification layer



Time distribution system

Timing jitter of < 10 ps required
Looking into RF technologies

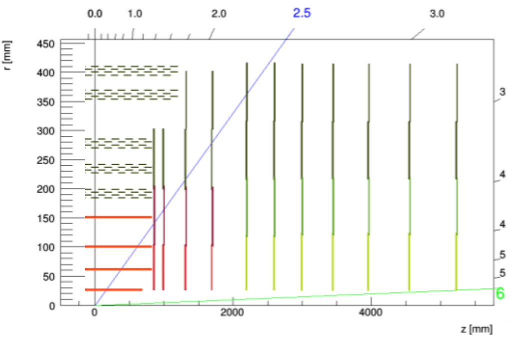
Collaboration with

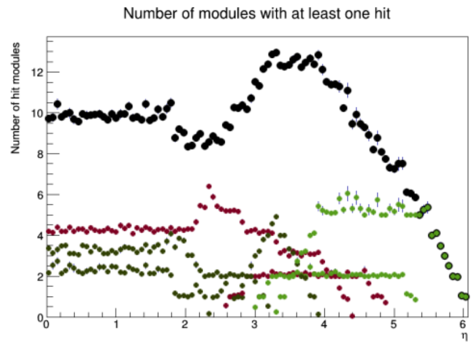
Argonne HEP (ATLAS), Geneva, Santa Cruz, Fermilab, (Kansas)…

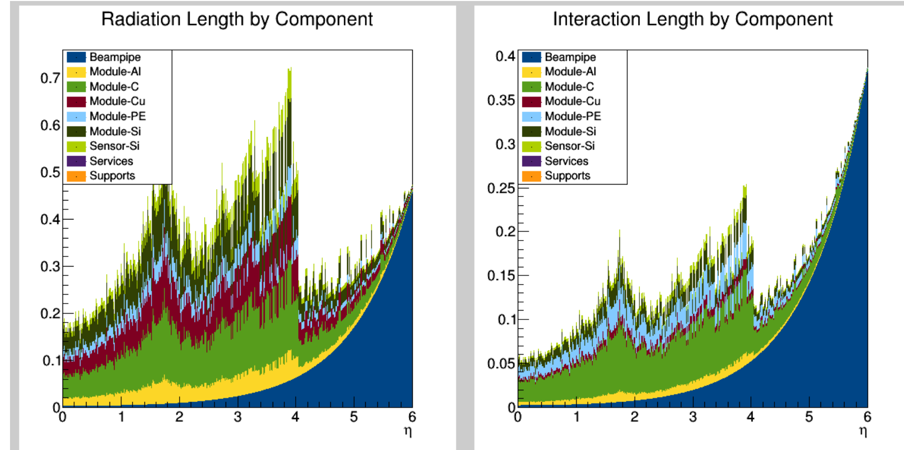
Silicon Tracker: Considering tilted sensors

Taken from Peter Kostka and Alessandro Polini (LHeC studies)

Non Tilted Sensor Planes

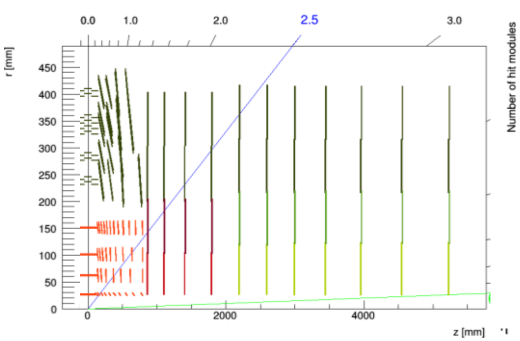


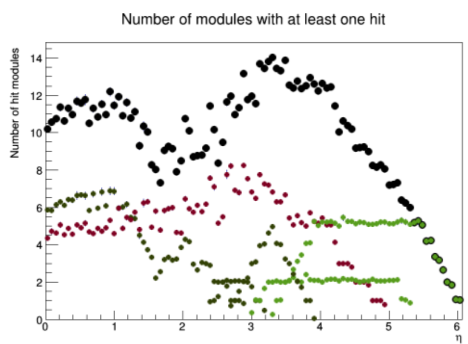


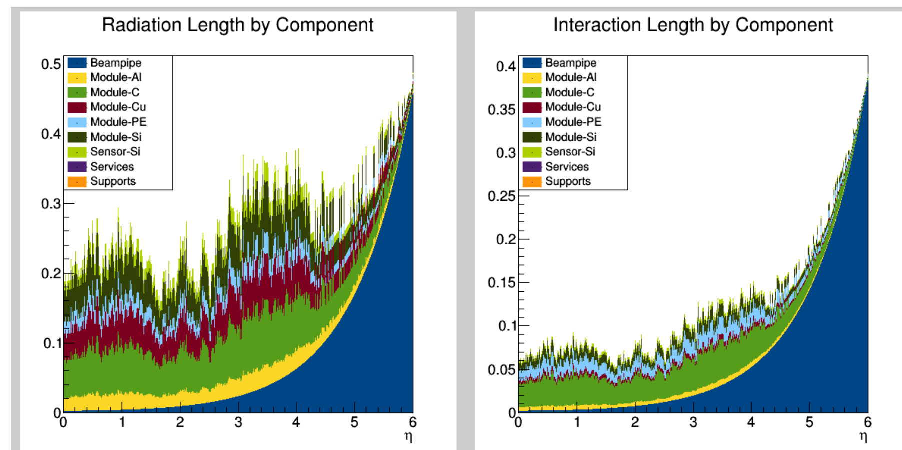


Tilted Sensor Planes

More hits, 25% less material (in X_0)





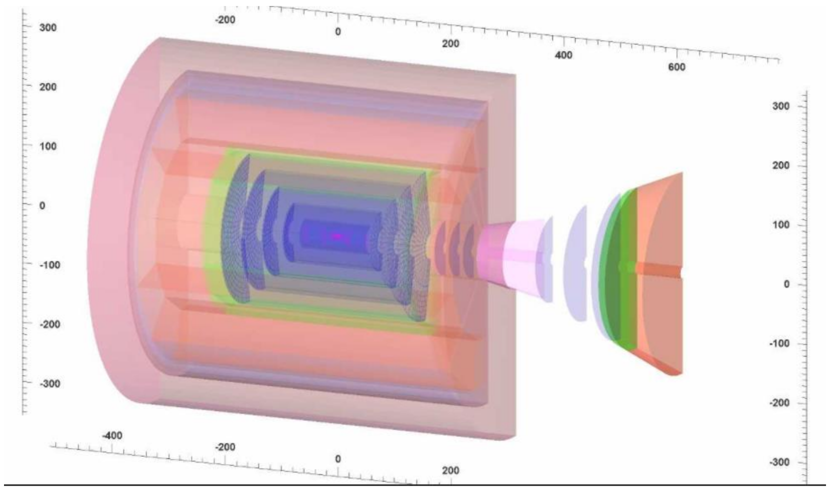


To be implemented in TOPSiDE simulation

TOPSiDE in Simulation

Starting point

SiD detector concept developed by ILC community



TOPSiDE

Some initial modifications from SiD

Longer barrel, lower B-field, shallower calorimeters

No performance tuning yet
(detector optimized for $|\eta| < 3.0$)

Simulation

Entire chain available
→ Event generation, GEANT4, digitization, reconstruction, event display, analysis

Introduced DD4Hep
→ One geometry file for simulation, digitization, reconstruction, analysis

Ongoing replacement of parts difficult to maintain/develop
→ digitization, tracking → generic tracking

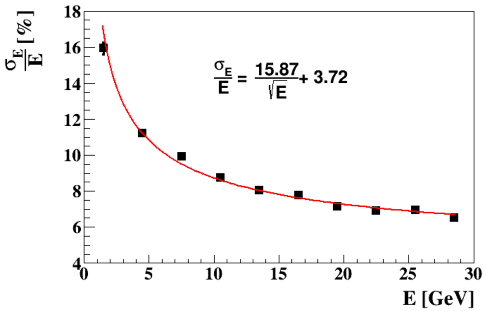
Changes to geometry → Development of workflow for ‘rapid detector iteration’

Simulation Studies

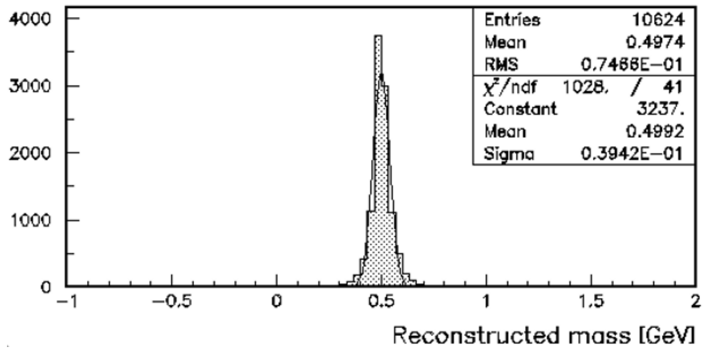
Single Particle Resolutions

Generated photons with 1 – 30 GeV
Spread over most of solid angle

Photon energy resolution



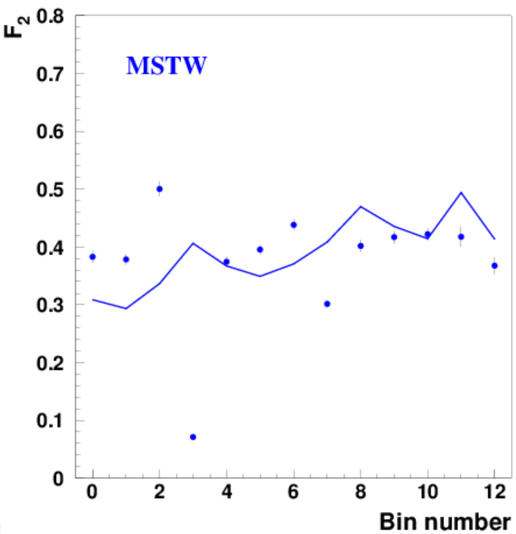
TOF PID using silicon with 10 ps resolution



Determination of TOF Requirement

Using timing information in tracker and ECAL
For each track fit time versus path length

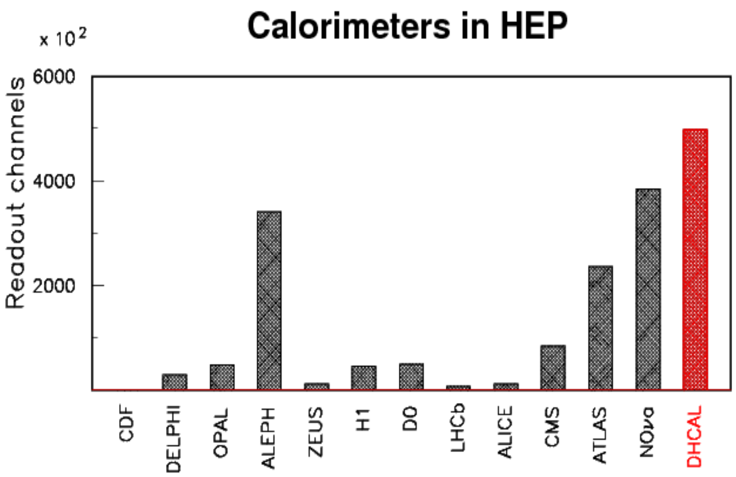
Comparison of true and reconstructed F_2



Reconstruction of the F_2 Structure Function

Use MSTW PDF to generate DIS events
Use CTEQ PDF to correct for acceptance
(problem with CTEQ phase space)
Validation of entire simulation tool chain

Number of channels



This is only a prototype

ECAL

Silicon pixels with an area of 0.25 cm^2
Total area about 1,400 m^2

⟶ 51M channels
⟶ Resolution per pixel ~14-bit

HCAL

Scintillator pads with an area of 3 x 3 cm^2 with 14-bit/pad resolution or
RPCs with 1 x 1 cm^2 readout pads with 1-bit/pad resolution
Total area about m^2

⟶ 3M (Scintillator) -> 26M (RPC) channels

Tracker/RICH

⟶ <1M channels

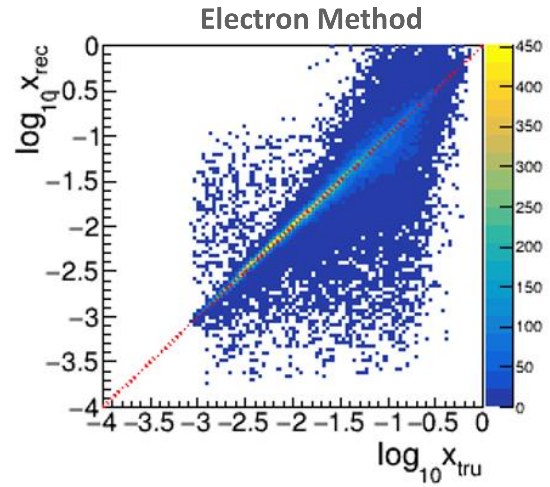
Total

Of the order of 55 – 80 M channels

Conclusions

TOPSiDE

Based on silicon
Features ultra-fast silicon, imaging calorimetry → 5D concept
Completely hermetic



Advantages of TOPSiDE

Simplicity of design (limited number of subsystems)
Based on silicon, which is robust (no gas, high voltages, stable operation, radiation hardness)
Excellent kinematic reconstruction
Excellent background rejection (hermeticity)
Minimal 'dead' material in front of calorimeters
No additional TOF, TRD, Cerenkov, muon system
Provides list of particles, similar to MC

Next steps

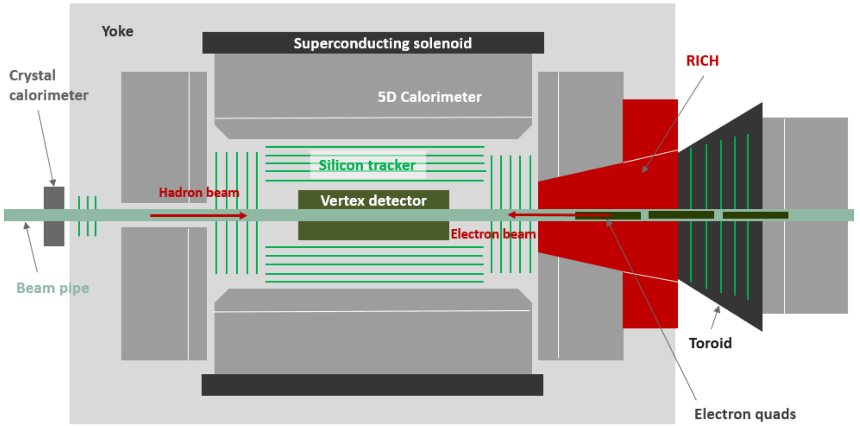
Complete revamping of simulation chain
Implement TOF PID
Tune ECAL sampling structure
Develop Ultra-Fast Silicon Detectors

Backup Slides

TOPSiDE: A detector concept for the EIC

Goal

Measurement and identification of all particles emerging from collisions individually



TOPSiDE concept

4π , multipurpose, hermetic detector
Based mostly on silicon (tracker, calorimeter)
Finely segmented calorimeter ⟶ Particle flow
Use of ultra-fast silicon (in tracker, calorimeter) for TOF
Large solenoid outside barrel calorimeter
RICH in hadron direction for particle ID (10 – 50 GeV/c)
Toroid/dipole in forward direction for momentum measurement

No additional TOF, Cerenkov detectors, transition radiation detectors, muon chambers
⟶ not needed