ZDC at ePIC detector

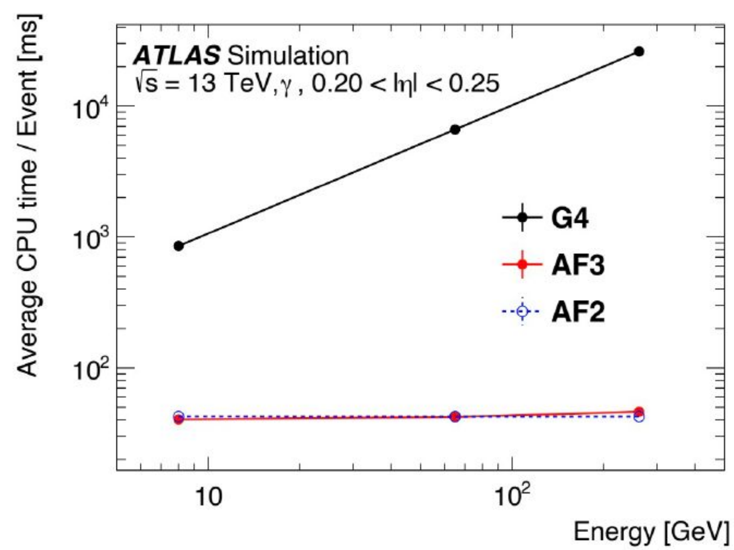
Yun-Ju Lu
Academia Sinica

6th Nov, 2024
AS ZDC discussion

ATLFast3

2109.02551v2

- FastCaloSim: Parametric simulations of the calorimeter response simulate the energy of a particle shower
  - FastCaloSim V2: All EM & hadronic showers with low(<4 GeV) and high(>512 GeV) energies
  - FastCaloGAN : Medium-energy hadrons because of their ability to model correlated fluctuations (Generative Adversarial Networks)
  - Secondary particles punch through to the muon spectrometer is parameterized and those particles are simulated with Geant4
  - Each cell belongs to a longitudinal sampling layer of the calorimeter
    - Barrel : A cuboid in η, ϕ, and r
    - Endcap : A cuboid in η, ϕ, and z
    - Forward: A cuboid in x, y, and z

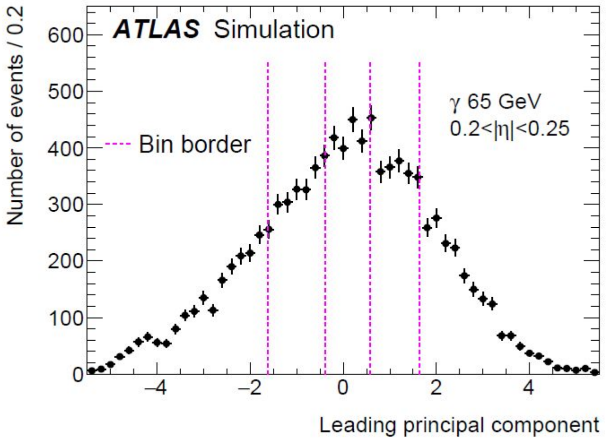


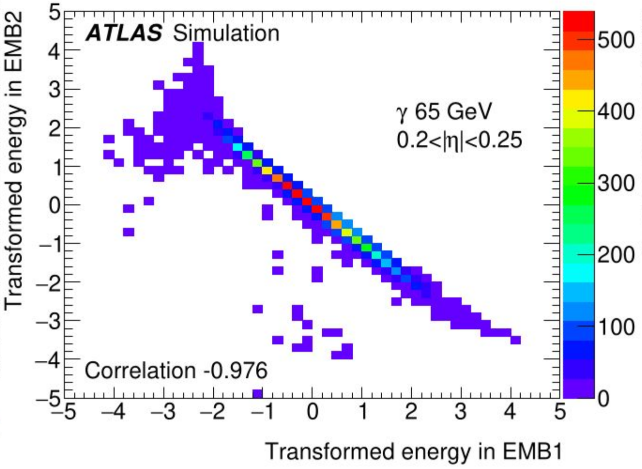
GEANT4 dataset

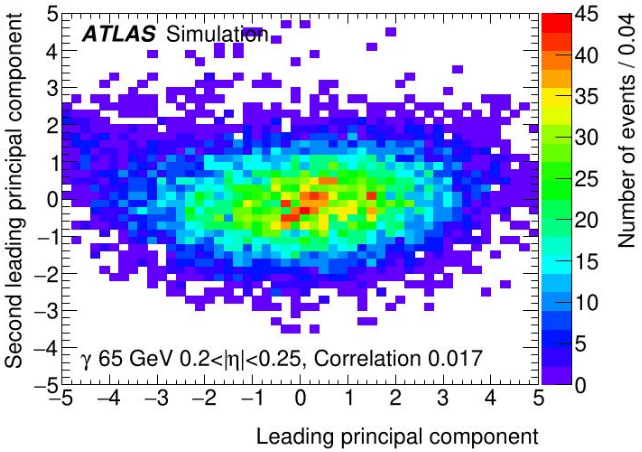
- Photons (γ) and electrons ($e^{\pm}$) are used to parameterize electromagnetic showers, and positively and negatively charged pions ($\pi^{\pm}$) are used to parameterize hadronic showers.
- The calorimeter parameterization is obtained for 100 uniform η slices to provide coverage up to $|\eta| = 5$.
- 16 MeV , 32 MeV, 64 MeV … to 4.2 TeV
- Voxel: the spatial energy deposits in each layer
  - FastCaloSim V2 : Smaller than cell dimension
  - FastCaloGAN : Optimized for an accurate training of the GANs
  - Hit location. Extrapolation of particle enter and pass through the calorimeter

FastCaloSim V2

- Longitudinal shower development
  - Energy fraction deposits in each calorimeter layer
  - Cumulative distribution function to transfer set of energy into Gaussian
  - Decorrelate set of energy deposit usings Principal Component Analysis (PCA)
    - Principal components : uncorrelated variables
  - Define PCA bins using leading/subleading principal components(variance)
  - Classify event into PCA bins
  - 2nd PCA step
    - Energy fraction in each PCA bin
    - Generate uncorrelated and approximately Gaussian distributions in PCA bins

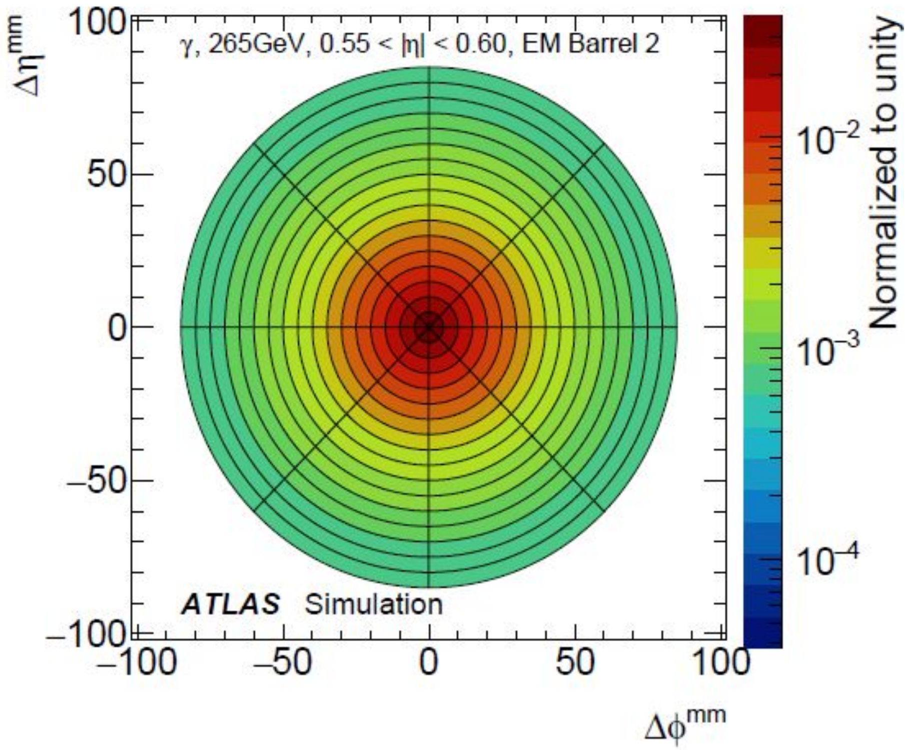






FastCaloSim V2

- Lateral shower shape
  - Characterized using lateral energy distribution of GEANT4 hits in each calorimeter layer and PCA bin
  - Parameterized in voxels
  - 2D histograms with optimized binning used to preserve the lateral distribution
  - Store the PDF for simulation New in FastCaloSim V2



Using average shower shape vs using PDF has significant impact in jet clustering

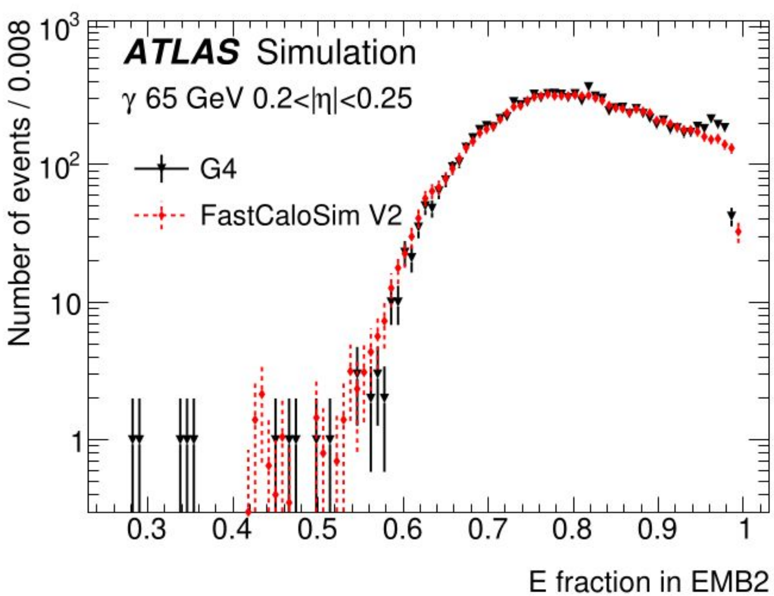
Important to account for the case when the particle hit the calorimeter with angle

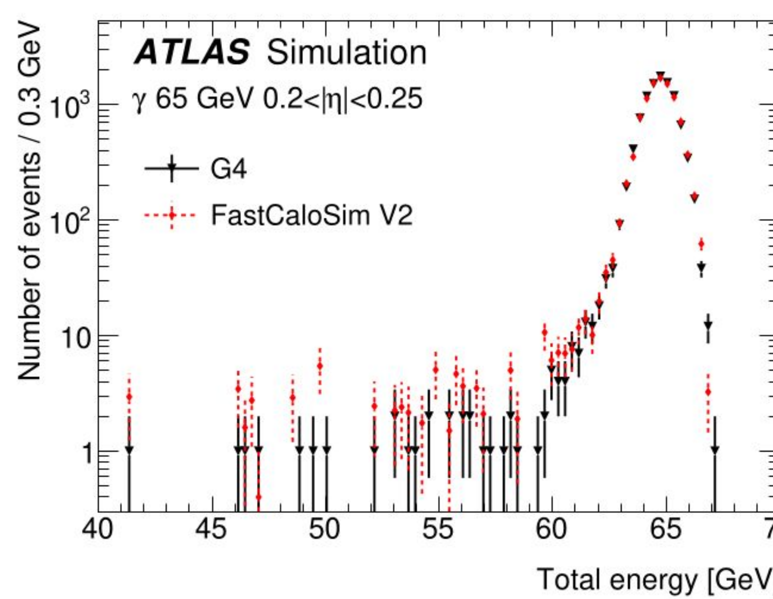
FastCaloSim V2

- Simulate hits
- Inputs: 1st and 2nd PCA matrix, PDF for shower shape
  - Random number : PCA bin probability
  - Inverse 2nd PCA to get energy fraction
  - Mapping back to energy fraction and deposit using error fruition and inverse cumulative distribution of the first PCA

$$\sigma_E/E = a/\sqrt{E/\mathrm{GeV}} \oplus c$$

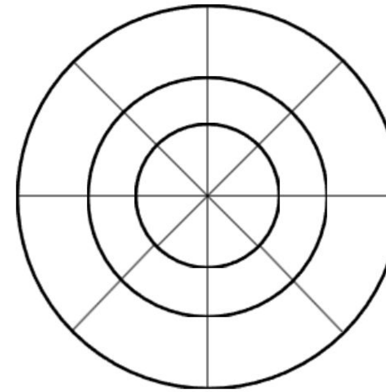
- N_{hit} e, γ : From the energy deposited in each layer and the intrinsic resolution(detec)
- N_{hit} Hadrons : same as above with additional pion sample to determine a

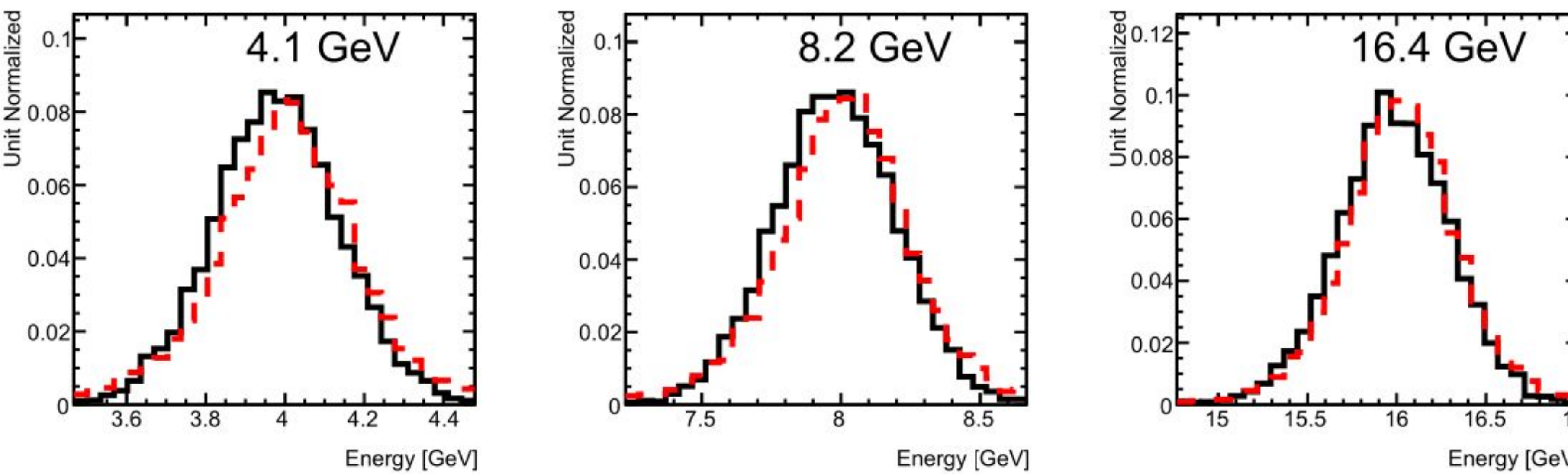




FastCaloGAN

- 300 GANs : one for each particle type and η slice
- Voxels: dR and dϕ
- Simulate longitudinal and lateral shower shower in 1 step

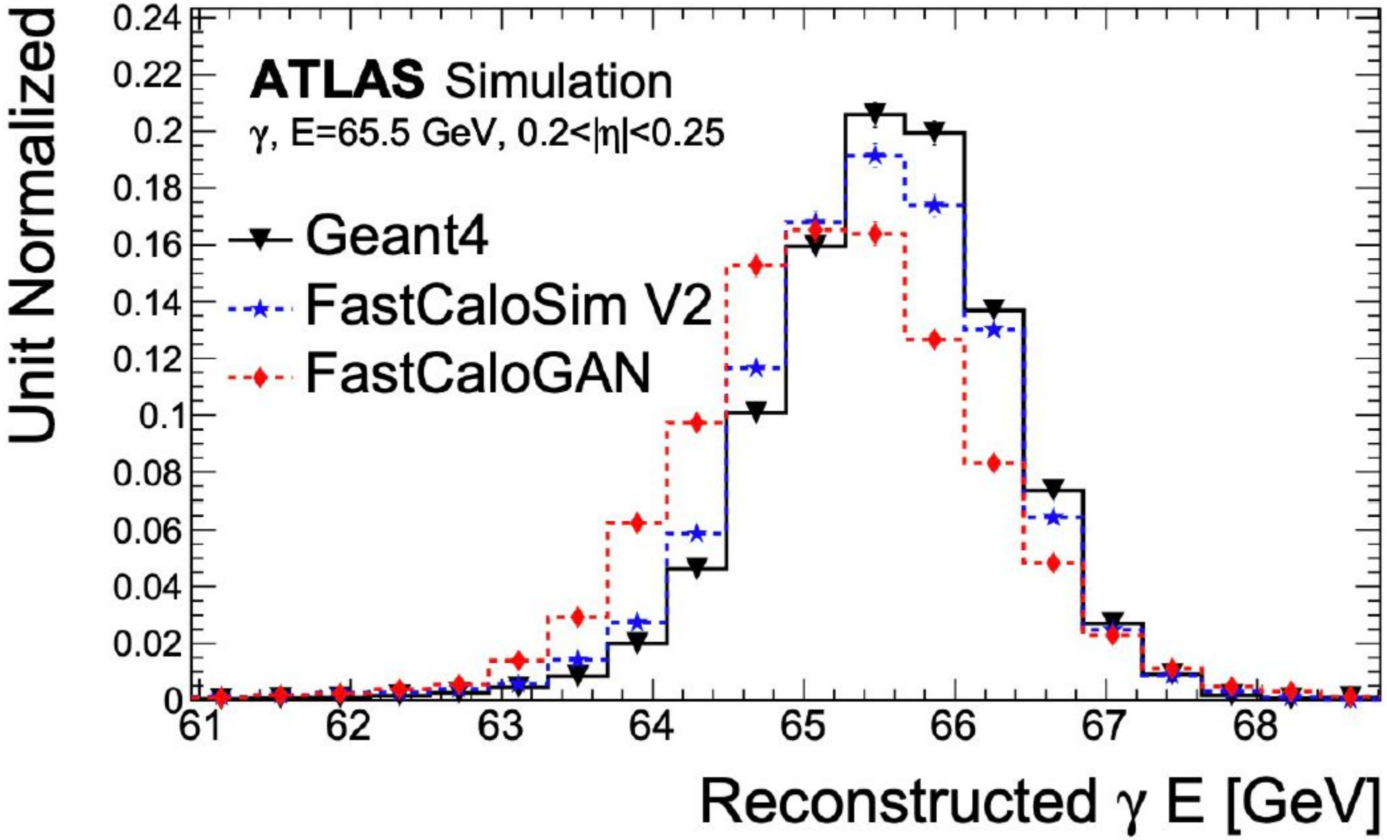




Performance

Electrons and photons

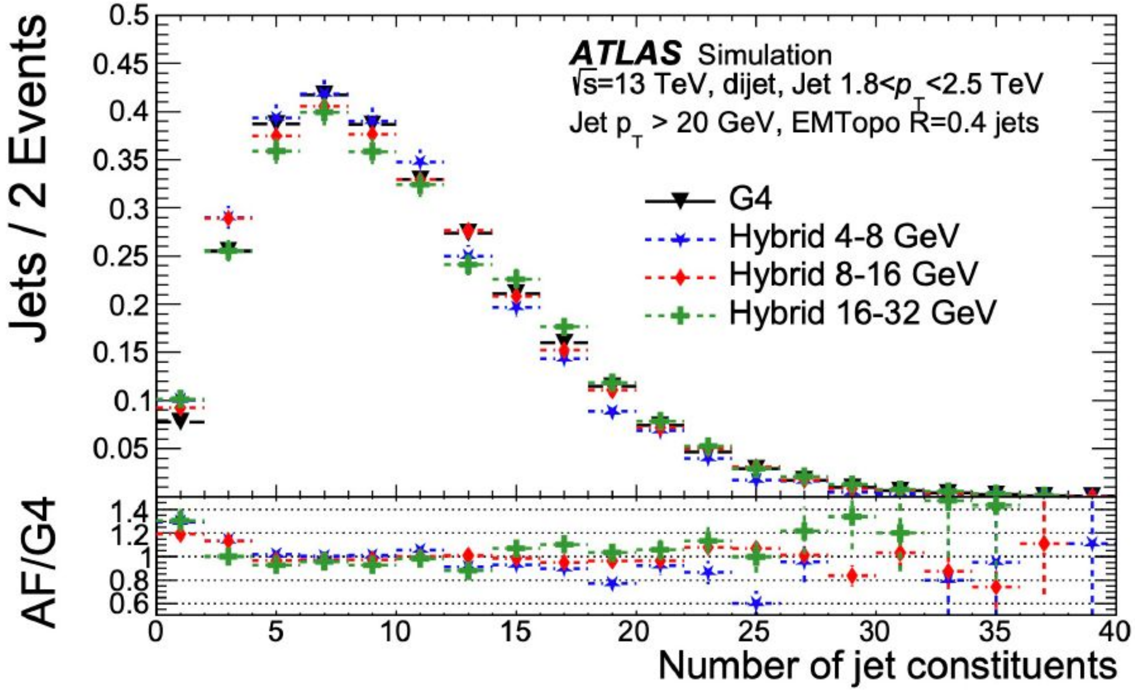
- FCSv2 shows better total energy performance
- FCSv2 is used to simulate all photons and electrons



Performance

Medium energy hadrons

- FastCaloGAN shows better jet constituent modelling for medium energy hadrons.
- Transition threshold of 8-16GeV is chosen.

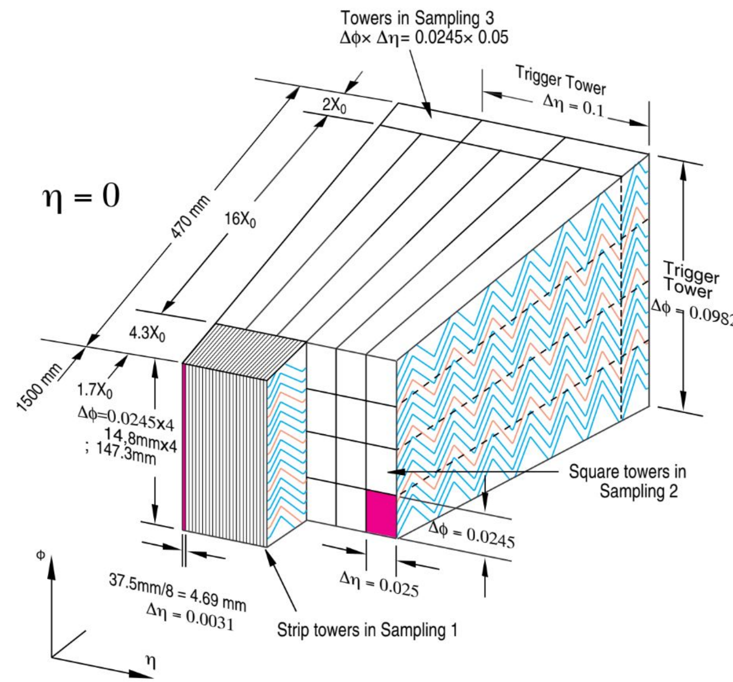


Ideas and to do

- Standard PCA method sims to handle electron and photo better than GAN
  - GAN is limited by energy resolution and scale not corrected in training input
  - Trade off between number of voxels and ML training time
- ZDC fast sim
  - Can start to generate electron, photon, and pion samples in various energy
  - It may be worthwhile to setup a standard analytical/numerical reference method
  - Defining voxels is general in all methods
    - Start with large voxel in XYZ for ZDC ?

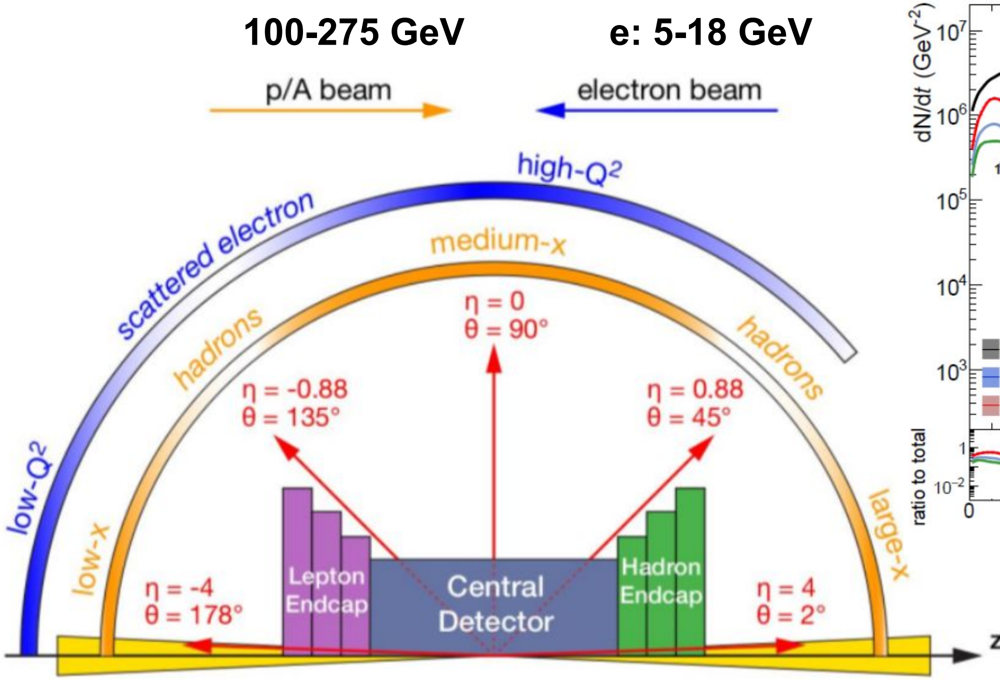
Back up

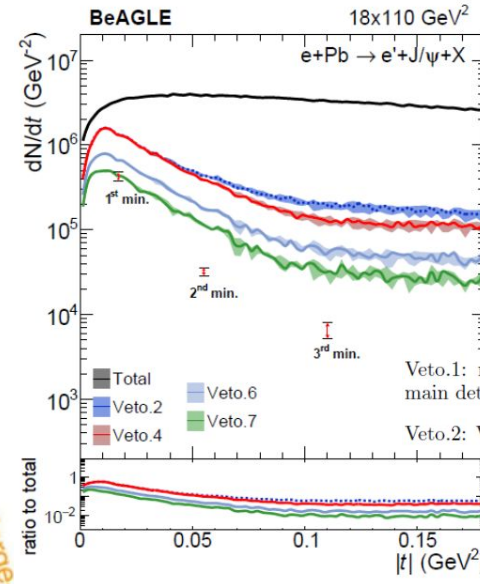
An additional thin LAr Presampler covering |η| < 1.8 corrects for energy loss in material upstream of the calorimeters.



Calorimeter	Layers	Module Name	η-coverage	Sampling Layer
Electromagnetic calorimeters	4	Electromagnetic Barrel (EMB)	$\|\eta\| < 1.5$	PreSamplerB, EMB1, EMB2, EMB3
	4	Electromagnetic Endcap (EMEC)	$1.5 < \|\eta\| < 1.8$	PreSamplerE
			$1.5 < \|\eta\| < 3.2$	EME1, EME2
			$1.5 < \|\eta\| < 2.5$	EME3
Hadronic calorimeters	4	Hadronic Endcap (HEC)	$1.5 < \|\eta\| < 3.2$	HEC0, HEC1, HEC2, HEC3
	3	Tile Barrel (TileBar)	$\|\eta\| < 1.0$	TileBar0, TileBar1, TileBar2
	3	Tile Extended Barrel (TileExt)	$0.8 < \|\eta\| < 1.7$	TileExt0, TileExt1, TileExt2
	3	Tile Gap (TileGap)	$1.0 < \|\eta\| < 1.6$	TileGap1, TileGap2, TileGap3
Forward calorimeter	3	FCal	$3.1 < \|\eta\| < 4.9$	FCal0, FCal1, FCal2
Transition regions	-	between barrel and endcap	$\|\eta\| \approx 1.45$	-
	-	between outer and inner wheel of endcap	$\|\eta\| = 2.5$	-
	-	between endcap and FCal	$\|\eta\| \approx 3.2$	-

ZDC at ePIC detector

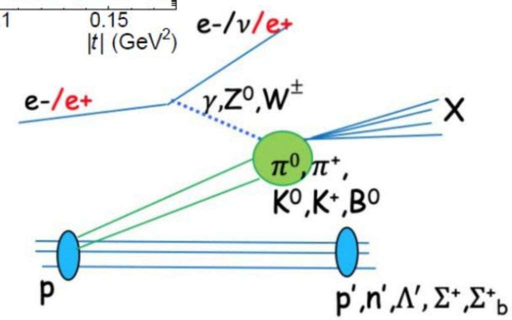




Rejection of the Incoherent vector meson production: Veto neutrons and photons

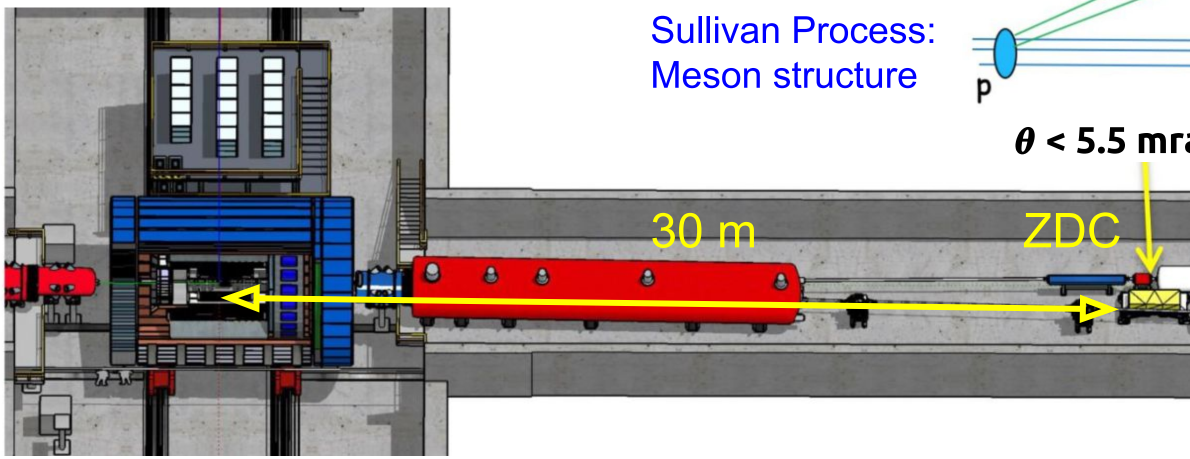
Veto.1: no activity other than e^- and J/ψ in the main detector ($|\eta| < 4.0$ and $p_T > 100$ MeV/c) ;

Veto.2: Veto.1 and no neutron in ZDC;



Sullivan Process: Meson structure

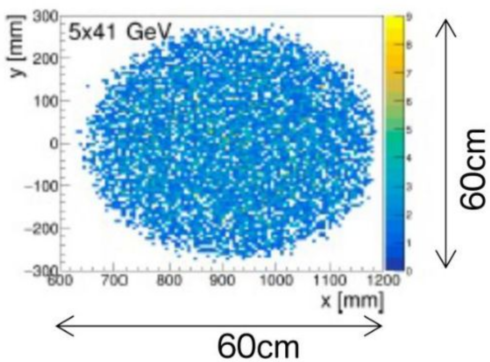
θ < 5.5 mrad (η > 6)

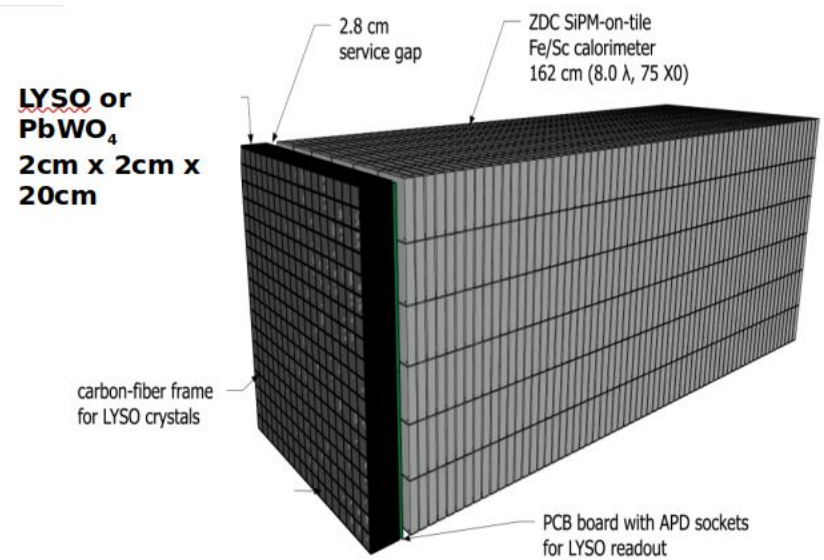


ZDC at ePIC detector

- EM section – 20 cm long LYSO or PbWO4 crystals
- Hadronic section : FE/SC+SiPM
- Under developments

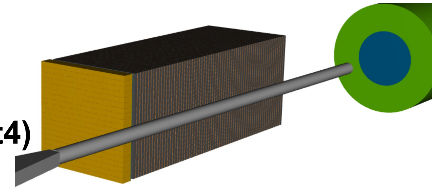
Neutrons from e+p→ e'+X+n





	Energy Range	Energy Resolution	Position Resolution	
Neutron	~275GeV	$50\%/\sqrt{E}$	$3mrad/\sqrt{E}$	Meson structure
Photon	100MeV~1G eV	20~30%		Veto photons
	20~40GeV	$35\%/\sqrt{E}$	0.5~1mm	Meson structure

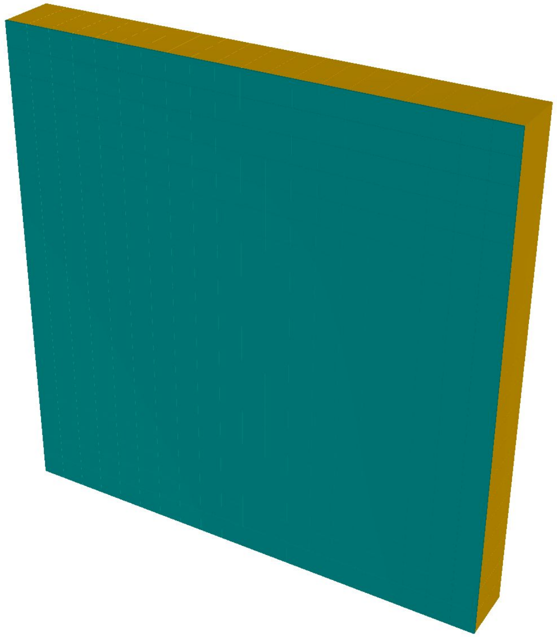
Particle gun test (detector geo)



`ddsim` : part of the DD4hep (relies on ROOT geometry package, and the Geant4)

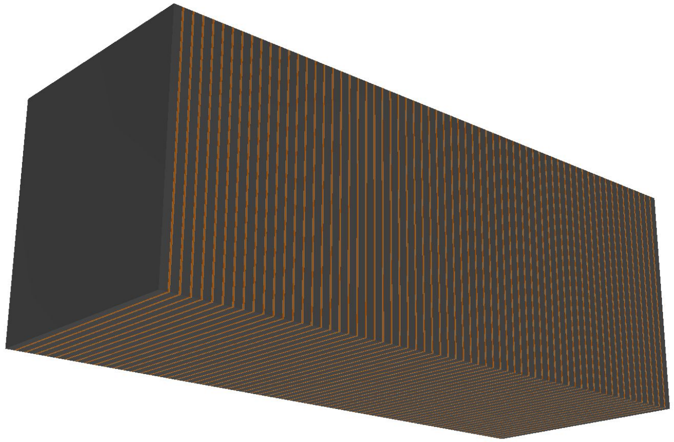
```
<constant name="ZDC_width"          value="60.0 * cm"/>
<constant name="ZDC_r_pos"          value="3550.0 * cm"/>
<constant name="ZDC_y_pos"          value="0.0 * cm"/>
<constant name="ZDC_Crystal_r_pos"          value="ZDC_r_pos + 5.9 *cm +19.2*cm"/>
<constant name="ZDC_Crystal_z_pos"          value="ZDC_Crystal_r_pos * cos(ionCrossingAngle)"/>
<constant name="ZDC_Crystal_x_pos"          value="ZDC_Crystal_r_pos * sin(ionCrossingAngle)"/>
<constant name="ZDC_Crystal_y_pos"          value="ZDC_y_pos"/>
<constant name="ZDC_Crystal_rotateX_angle"  value="0"/>
<constant name="ZDC_Crystal_rotateY_angle"  value="ionCrossingAngle"/>
<constant name="ZDC_Crystal_rotateZ_angle"  value="0"/>
<constant name="ZDC_Crystal_width"          value="ZDC_width"/>


<constant name="ZDC_Crystal_cell_width"     value="3.*cm"/>
<constant name="ZDC_Crystal_cell_length"    value="7.*cm"/>
<constant name="ZDC_Crystal_frame_thickness"  value="0.3*mm"/>
<constant name="ZDC_Crystal_active_x"       value="ZDC_width"/>
<constant name="ZDC_Crystal_active_y"       value="ZDC_width"/>
<constant name="ZDC_Crystal_nx"             value="ZDC_Crystal_active_x/ZDC_Crystal_cell_width"/>
<constant name="ZDC_Crystal_ny"             value="ZDC_Crystal_active_y/ZDC_Crystal_cell_width"/>
<constant name="ZDC_Crystal_APD_socket_z"   value="2.5*mm"/>
<constant name="ZDC_Crystal_space"          value="2.8*cm"/>
```



```
  #### Material Thicknesses
</documentation>
<constant name="HcalFarForwardZDC_SiPMonTile_AirThickness"                value="0.02*cm"/>
<constant name="HcalFarForwardZDC_SiPMonTile_AbsorberThickness"           value="2*cm"/>
<constant name="HcalFarForwardZDC_SiPMonTile_ScintillatorCoverThickness"  value="0.04*cm"/>
<constant name="HcalFarForwardZDC_SiPMonTile_PolystyreneThickness"        value="0.30*cm"/>
<constant name="HcalFarForwardZDC_SiPMonTile_PCBThickness"                value="0.08*cm"/>
<constant name="HcalFarForwardZDC_SiPMonTile_ESRFoilThickness"            value="0.015*cm"/>

<documentation>
  - ZDC N Layers and computed Thickness
```



64 layer   `Detector Geometry from epic main branch`

ZDC acceptance (Yellow report)

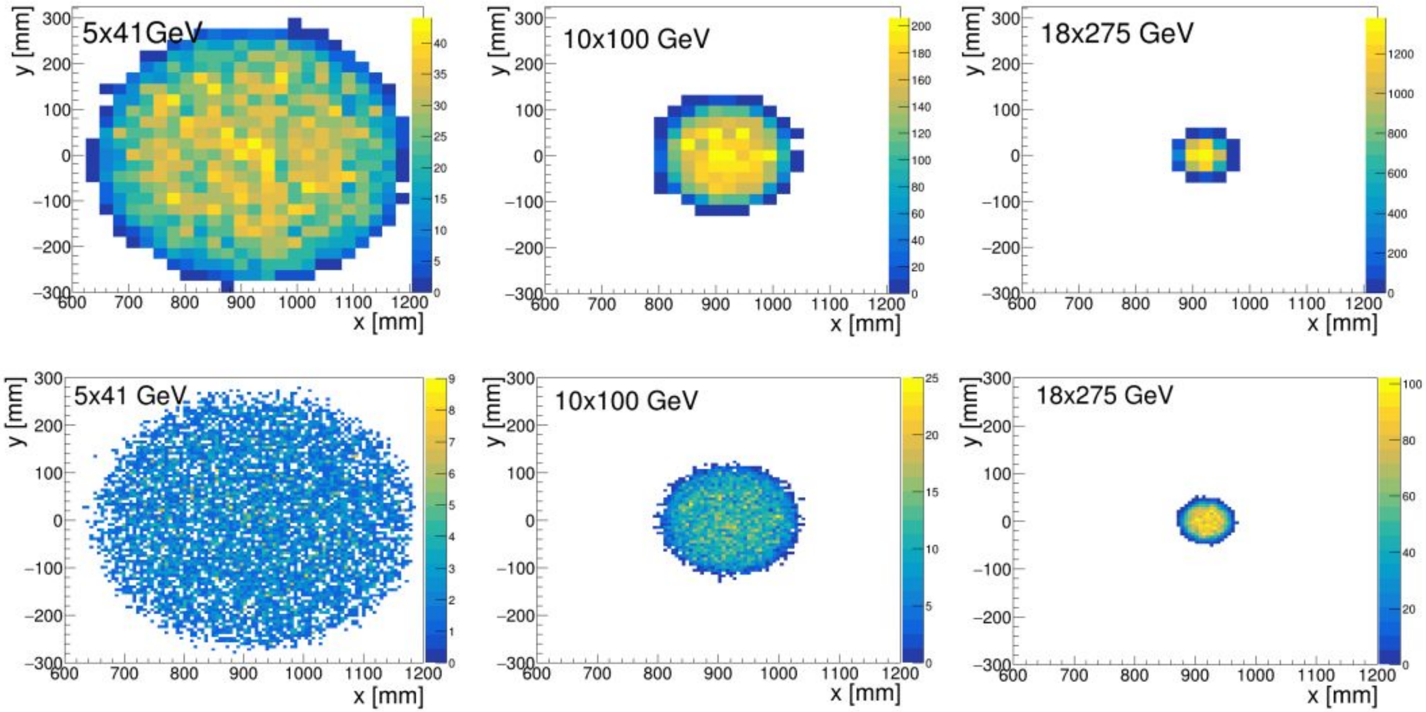
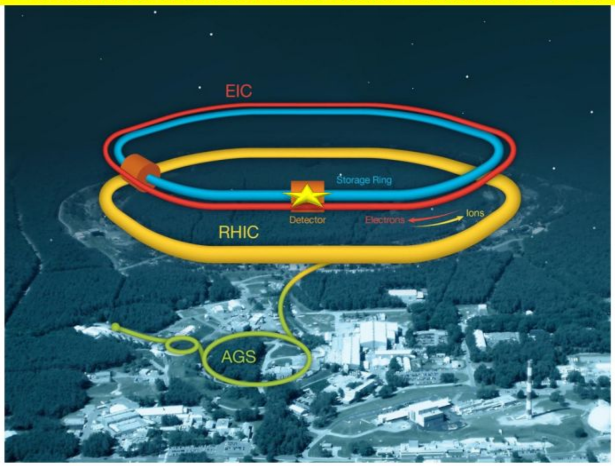


Figure 8.104: Sullivan process $e + p \to e' + X + n$: acceptance plot for neutrons in 60×60 cm^2 ZDC, with a low spatial resolution of 3 cm (upper panels) and with a high spatial resolution of 0.6 cm (lower panels), for different beam energy settings, from left to right 5 GeV on 41 GeV, 10 GeV on 100 GeV, and 18 GeV on 275 GeV, all with a luminosity of 100 fb^{-1}. The acceptance plot for 5 GeV on 100 GeV would be similar as shown for 10 GeV on 100 GeV. The lower proton (ion) energies set the requirement for the size of the ZDC, whereas the higher proton (ion) energies drive the spatial resolution requirement.

ePIC: the Detector and Collaboration

2nd detector at IP8: see Pawel Nadel-Turonski's talk today



EIC Critical Decision Plan

CD-0/Site Selection	December 2019 ✓
CD-1	June 2021 ✓
CD-3A	Early 2024
CD-3B	**October 2024**
CD-2/3	**April 2025**
early CD-4	October 2032
CD-4	**October 2034**

2020: detector conceptual design in yellow report

2021: call for detector proposal (ATHENA, CORE, ECCE)

2022: ECCE as the reference design → ATHENA+ECCE → project detector

2022.7: detector 1 collaboration formed, name voted: **ePIC**

2023: charter ratified and leadership elected. Technology selections.

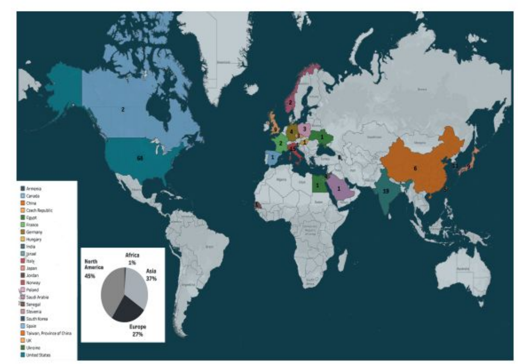
2024: working towards TDR…

https://wiki.bnl.gov/EPIC/index.php
https://www.bnl.gov/eic/epic.php

Collaboration meetings:

2023.7 @ Warsaw
2024.1 @ ANL
2024.7 @ Lehigh U.
2025.1 @ TBD

170+ institutions, 24 countries



ePIC Detector Overview @ DIS2024 3

https://lpsc-indico.in2p3.fr/event/3268/contributions/7417/attachments/5398/8122/epic_DIS2024_ShujieLi.pdf

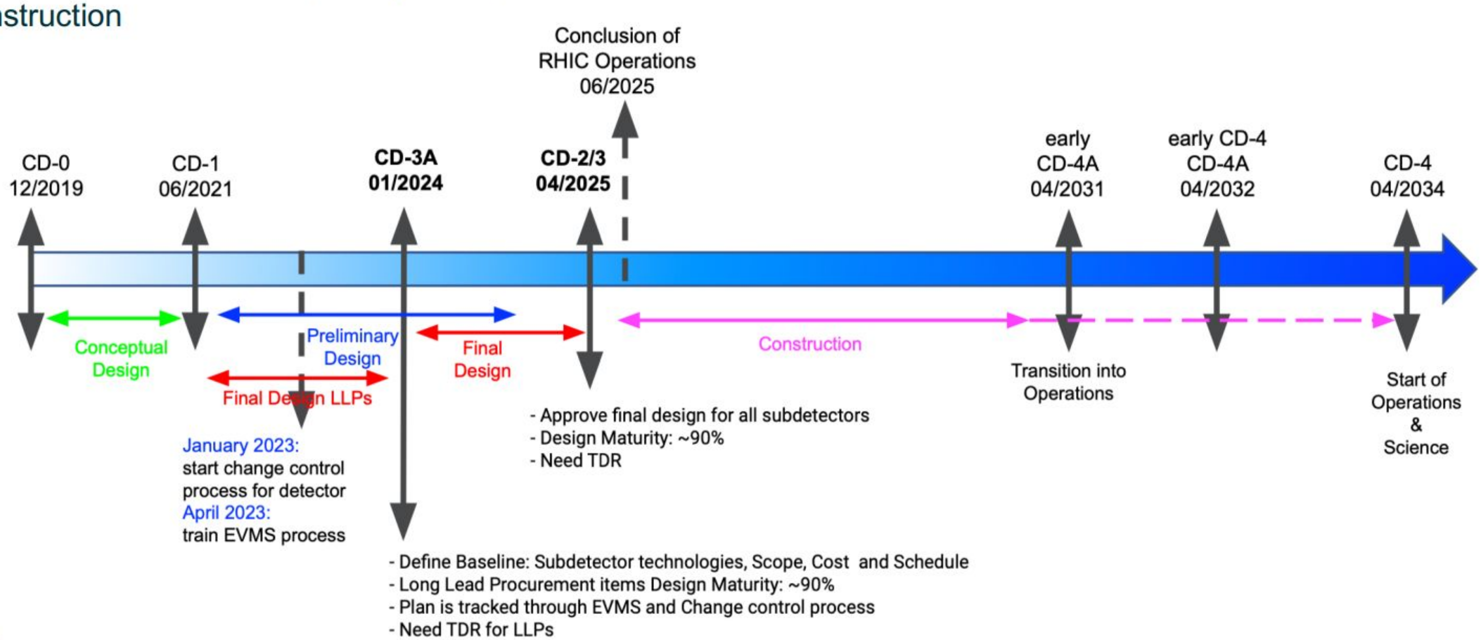
ATLAS EXPERIMENT

Current Status: towards CD-2

- Generic EIC-related detector R&D
- Beam test
- Readout and database
- Integration
- Simulation with full material, background ,and reconstruction

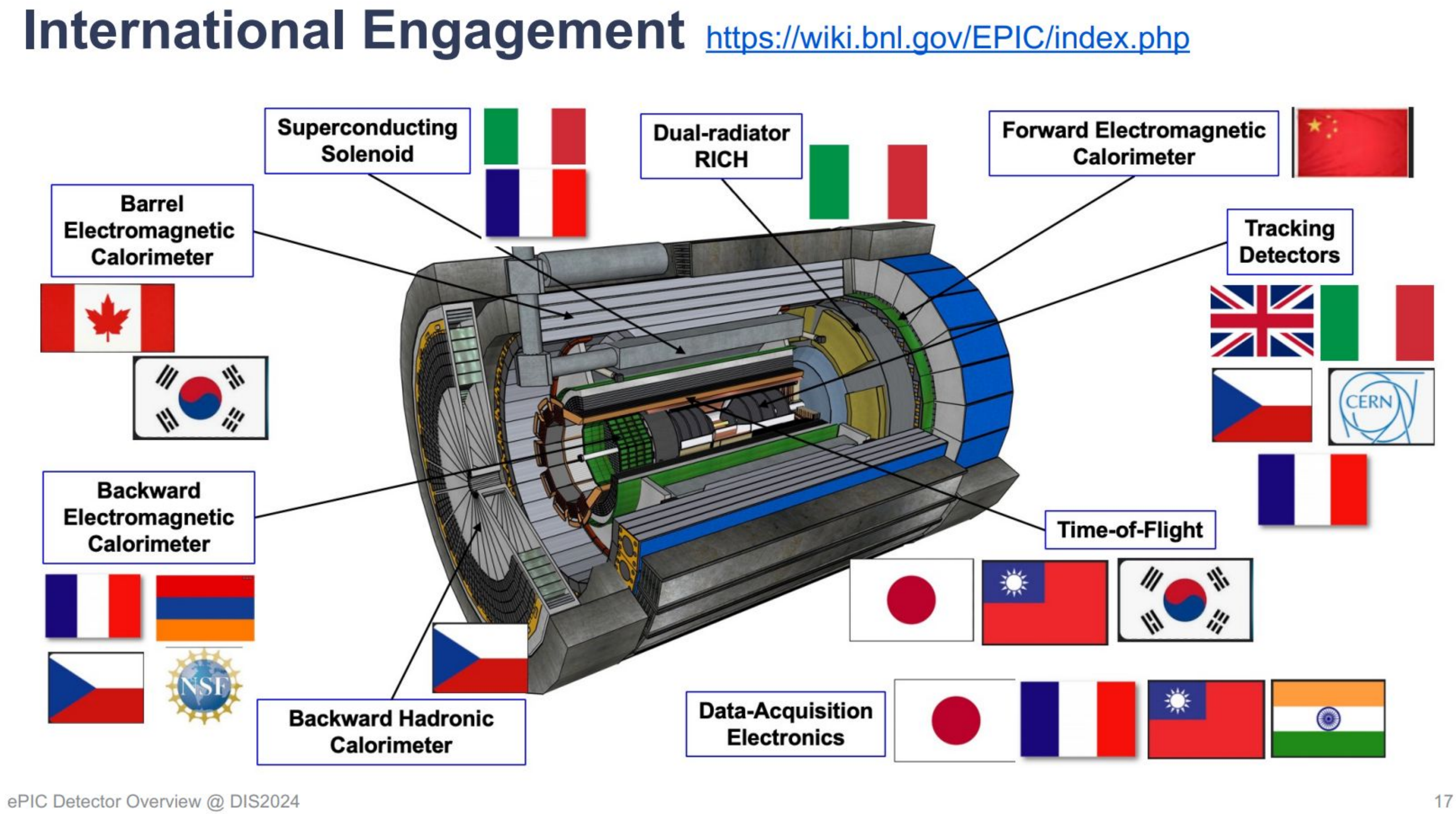
➔ Subsystem internal review (time, cost, performance)

➔ Prepare for Technical Design Report:



ePIC Dete

16


International Engagement https://wiki.bnl.gov/EPIC/index.php
Superconducting Solenoid
Dual-radiator RICH
Forward Electromagnetic Calorimeter
Barrel Electromagnetic Calorimeter
Tracking Detectors
CERN
Backward Electromagnetic Calorimeter
Time-of-Flight
NSF
Backward Hadronic Calorimeter
Data-Acquisition Electronics
ePIC Detector Overview @ DIS2024
17