TOF PID Working Group Report

Constantin Loizides (ORNL), Franck Geurts (Rice), Wei Li (Rice), Zhenyu Ye (UIC)

TOF-PID Detector Working Group

- Mailing list: eic-projdet-tofpid-l@lists.bnl.gov
  - Subscription information: https://lists.bnl.gov/mailman/listinfo/eic-projdet-tofpid-l
- Indico page: https://indico.bnl.gov/category/414
- Wiki page and task list: https://wiki.bnl.gov/eic-project-detector/index.php/TOFPID
- Meeting time: Monday 11:30am ET

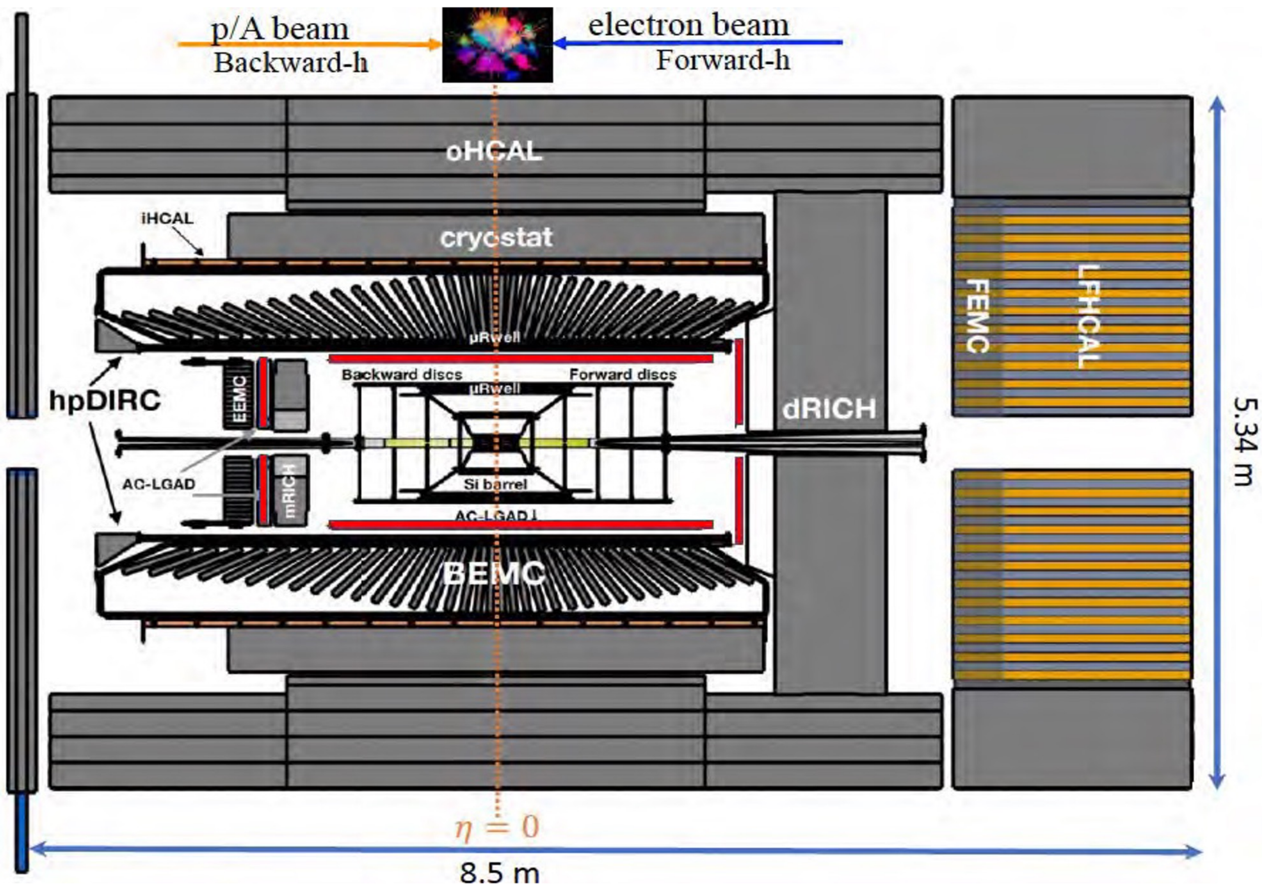
- Conveners:
  - Constantin Loizides (ORNL) constantin.loizides@cern.ch
  - Frank Geurts (Rice) geurts@rice.edu
  - Wei Li (Rice) wl33@rice.edu
  - Zhenyu Ye (UIC) yezhenyu@uic.edu

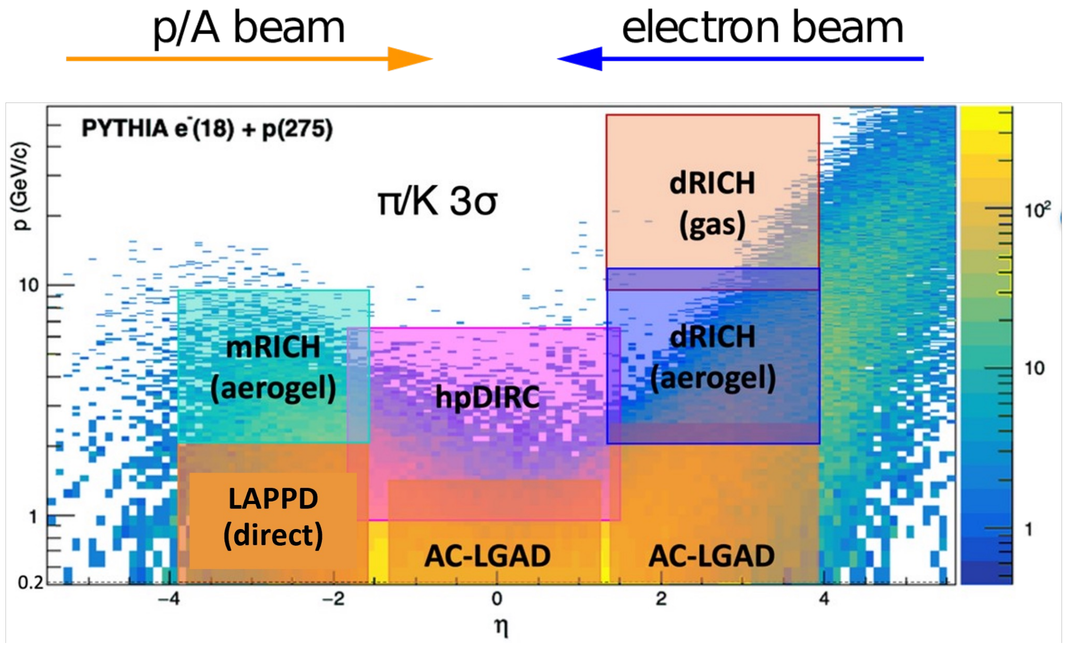
Liaisons:

- DAQ: Tonko Ljubicic (BNL) tonko@bnl.gov
- Simulation: Nicolas Schmidt (ORNL) nicolas.schmidt@cern.ch

- eRD112/LGAD Consortium:
  - Mailing list: https://mailman.rice.edu/mailman/listinfo/lgads-eic
  - Indico page: https://indico.bnl.gov/category/323/
  - Meeting time: Wednesday 11:30am ET

AC-LGAD TOF Overview





majority of particles are low momentum (<2 GeV/c)

	PID coverage (π/K)
Forward (1.5<η<3.5)	$0.15 < p < 2.5$ GeV/c
Barrel (|η|<1.4)	$0.15 < p_T < 1.5$ GeV/c

Baseline design:

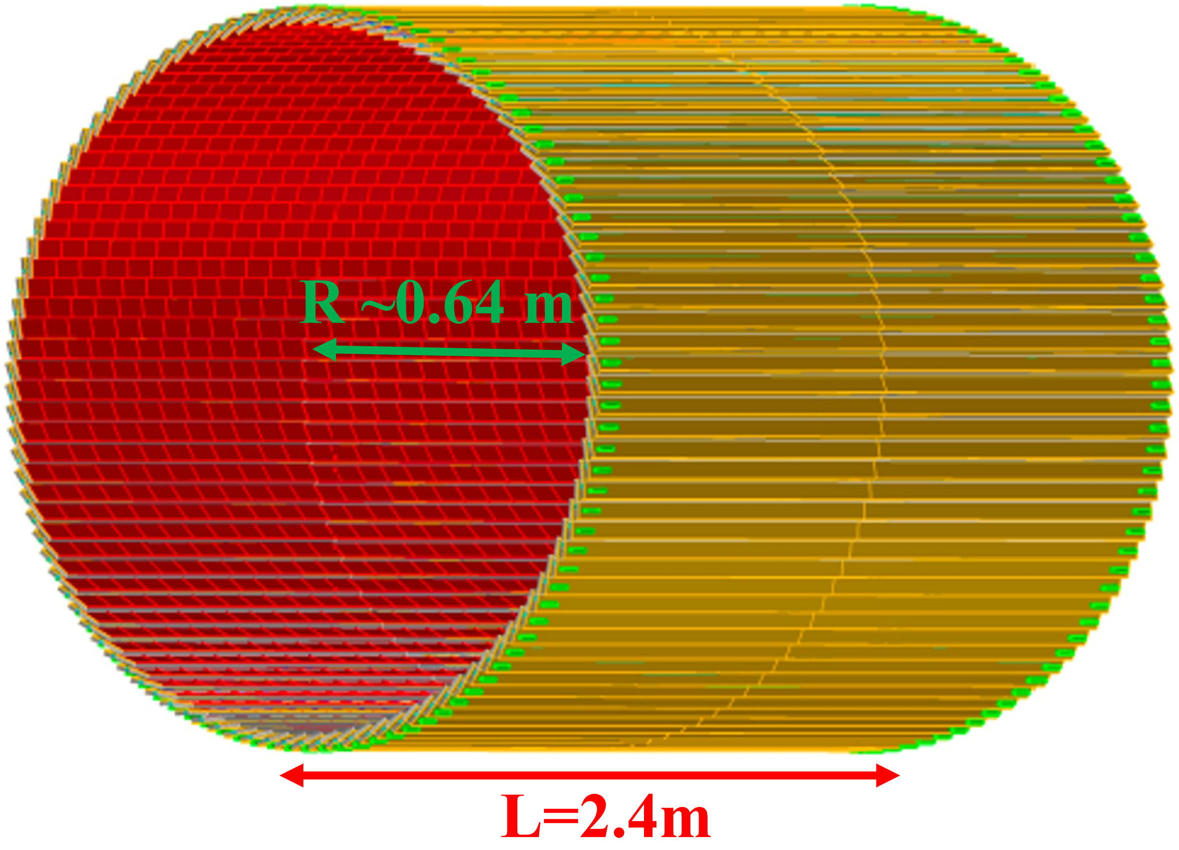
- 500 μm x 1 cm strip, ~1% X_0 for barrel
- 500 x 500 μm^2 pixel, 8% X_0 for forward
- 25 ps single hit time resolution
- ~30 μm spatial resolution

- Barrel TOF: improve momentum resolution when single hit is missing in Si layers
- Forward TOF: expect positive impact on momentum and angular resolution when included in tracking

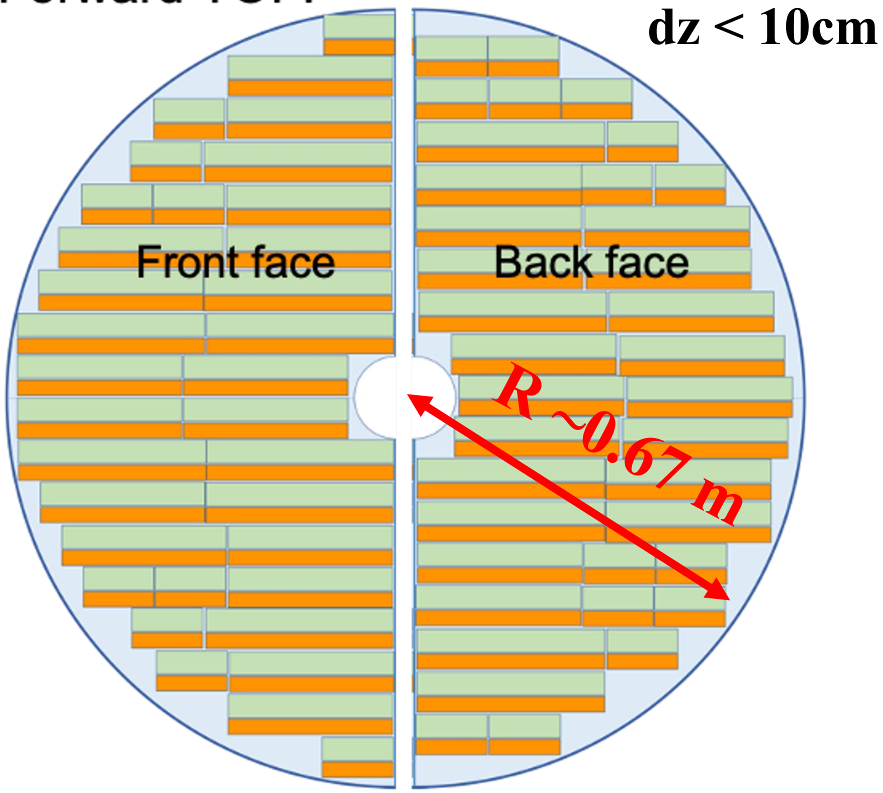
TOF Layout

More details: https://indico.bnl.gov/event/16765/
https://indico.bnl.gov/event/17336/

Barrel TOF:



Forward TOF:



- 288 staves, each with 32 strip sensors wire-bonded to 64 frontend ASICs on low mass Kapton flex and CF support
- Power consumption: ~4 kW for 500µm x 1cm strips (2.4 kW for ASIC, 1.0 kW for DC-DC, 0.6 kW for sensor+cable+RB)

- 212 modules, each with 24 to 96 bump-bonded pixel sensor + ASIC assemblies on Al disk
- Power consumption: 13 kW for 500x500 μm^2 pixels (6 kW for 800 x 800 μm^2)

On-going Work

Simulation [1]

- Geometry, digitization, reconstruction
- Timing resolution
- Spatial resolution (granularity)
- Material budget

R&D [2]

- Sensor: BNL/HPK
- ASIC: EICROC, FCFD, UCSC/SCIPP
- ASIC/Sensor integration
- Low-density mechanical structure
- Low-mass service hybrid

Project Engineering and Design [3]

- Mechanical engineering
  - Mechanical structure and cooling
- Electric engineering (via DAQ group)
  - Prototype readout board, cables
  - Precision clock distribution

Simulation: Oskar Hartbrich (ORNL)
Sensor R&D: Gabriele Giacomini (BNL)
ASIC R&D: Dominique Marchand (IJCLab)

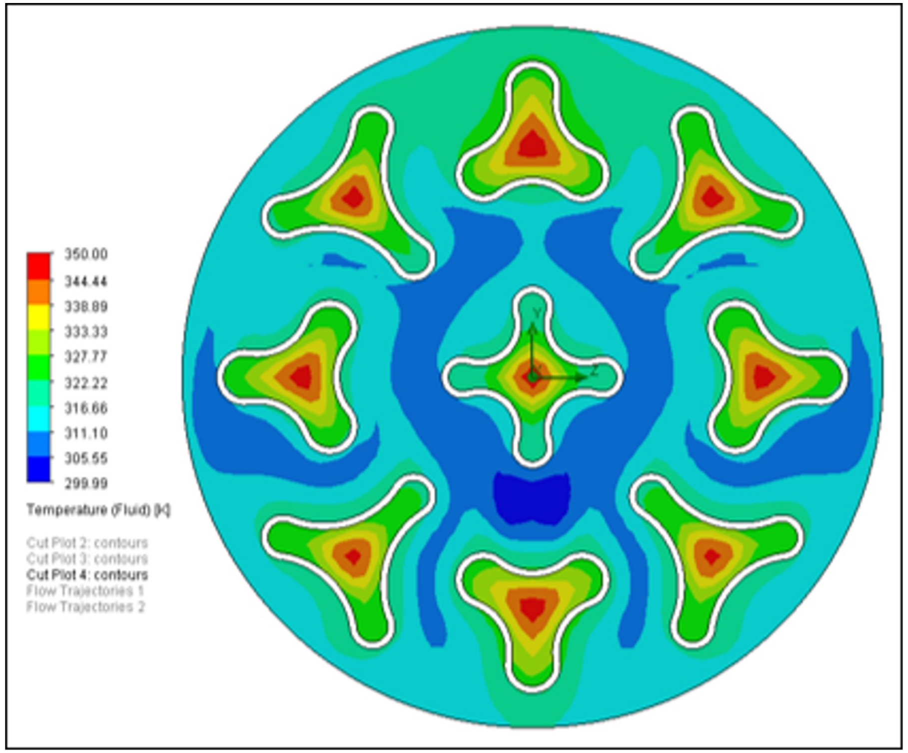
[1] https://wiki.bnl.gov/EPIC/index.php?title=TOFPID
[2] https://wiki.bnl.gov/conferences/index.php/ProjectRandDFY23
[3] https://www.overleaf.com/read/vftxyvjtjrvp

Mechanical Structure and Cooling

Need realistic engineering design for AC-LGAD systems for CD2/3a

- Minimal material budget, appropriate cooling system for stable operation, heat load impact on nearby sub-detectors
- Requested R&D resources in eRD112 and PED request

- Purdue/NCKU: lightweight support and Barrel mechanical design
  - Studies based on CF composites/PEEK
  - Extensive experience with lightweight composite tracking detector supports from CMS tracking upgrade projects
- ORNL: TOF Endcap mechanical design
  - Integrated water cooling system
  - Wealth of experience from similar projects
- Engineers have experience with FEA, Solidworks and ANSYS Comp. Fluid. Dyn.



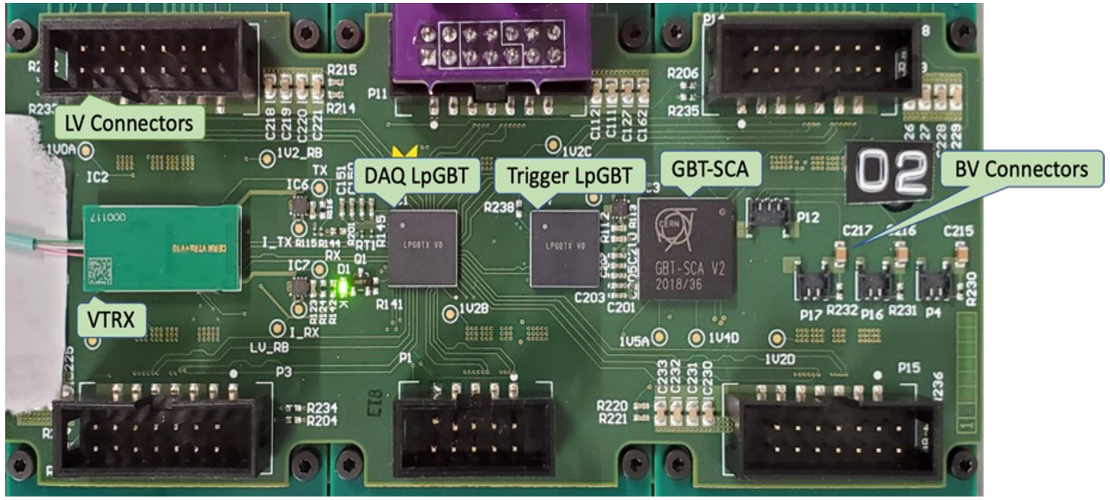
On-detector Electronics Development

Approved R&D proposal (eRD109) includes readout electronics work from ORNL. Further PED request by BNL, Rice and other institutions through DAQ group is anticipated

- ORNL: Readout R&D for barrel implementation
  - Targeting kapton flex design for minimal material budget
  - Integration into barrel mechanics

- BNL:
  - Readout board reference prototype
  - Precision clock distribution

- Rice: Readout board implementation for TOF endcap, power board
  - Based on CMS-ETL service hybrids



TOF Electronics Development

- To develop a Readout Board (RDO) prototype in conjunction with the DAQ WG
  RDO: optical-electrical interface board with many parts common to all detectors
  - FPGA based: Xilinx Artix Ultrascale+ device set as possible target (with an associated PROM)
  - clock-cleaner devices e.g. the Si5xxx family
  - common optical interface modules (SFP+)
  - common firmware (very important!) for all ePIC detectors
  - common data & clock distribution protocols for all ePIC detectors
- TOF is using the same DAQ-approved RDO prototypes for this step
  - The chosen Xilinx ZCU102 Development kit (purchase underway) can directly interface (via FMC connectors) to the already existing TOF ASIC “EICROC” daughtercard
  - Firmware development is in progress at BNL (Prashanth, Prithwish, Tonko)
- TOF RDO provide low jitter clocks to ASICs as well control and data interfaces
  - Clock jitter requirement for TOF(like) systems is the most stringent of all: **5 ps jitter**
  - however, the CERN-developed clock recovery scheme claims this has been achieved
    - see the “CERN High Precision Timing Project”
  - and the first step is to understand, replicate and measure its performance under ePIC conditions
- DAQ WG formed an “RDO & timing subgroup” where TOF (Tonko) is actively involved

Summary and Outlook

- Geometry implementation in ePIC software simulation done. (Re-)starting PID + tracking performance analyses to optimize the design

We reviewed the situation and your proposal carefully and decided to postpone any funding decision until the specification for forward- and barrel-ToF AC-LGADs as well as Roman Pots are clearly defined. This will allow us to make a more informed decision. We expect that the specs will be known by the end of December and submitted in a report to us. Concerning the requirements and specifications, the following questions should be answered as a minimum for both the barrel and forward ToF systems and if applicable to the Roman Pots

Q1. What is the occupancy of the system and how does this impact the pixelization of the systems?
Q2. What material budget is tolerable based on the performance of the detectors sitting behind ToF systems?
Q3. To what momentum can one separate π, K, p and e at the 3-sigma level for real DIS events?
Q4. How are the services impacted by the final pixelization of both systems?
Q5. What requirements does the TOF system has on other systems, i.e. tracking, DAQ, electronics?

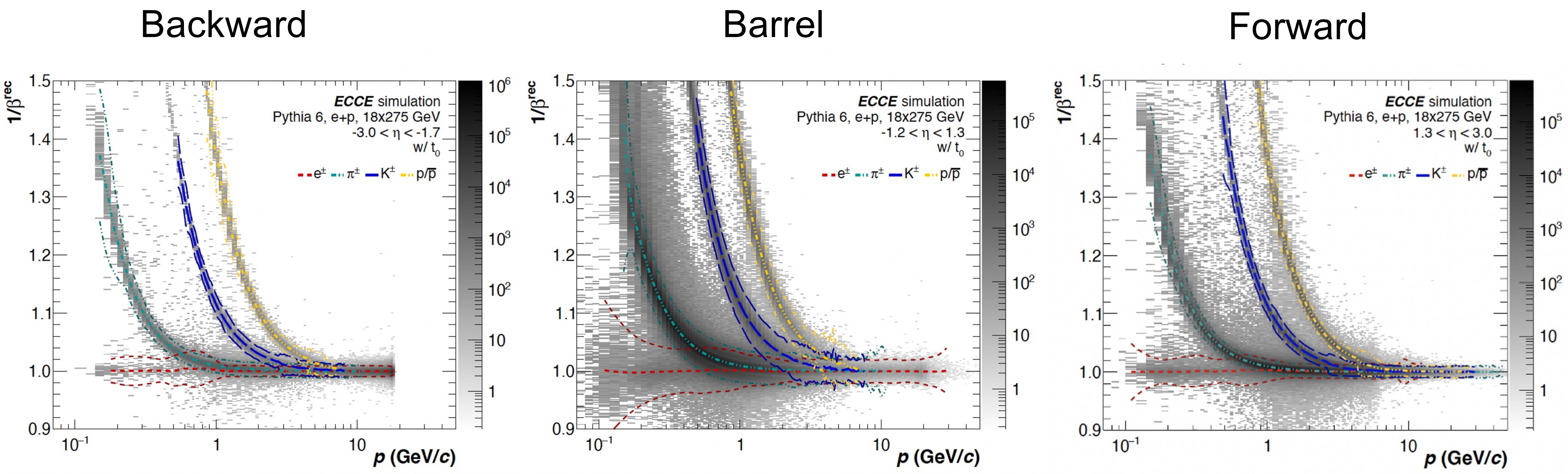
- Work on technical design towards CD2/3a with funding requests submitted to project: eRD109, eRD112, PED while engaging new institutions and external resources
  - R&D on sensor, ASIC, sensor/ASIC integration, lightweight support and electronics
  - PED on mechanical and electrical engineering support
  - Involving multiple institutes with wide range of experience

Members and Institutions

- **Brookhaven National Laboratory (USA)**: E. C. Aschenauer, G. Giacomini, P. Shanmuganathan, P. Tribedy, A. Tricoli, T. Ljubicic, Z. Xu
- **Fermi National Accelerator Laboratory (USA)**: A. Apresyan, R. Heller, C. Madrid, C. Pena, S. Xie, T. Zimmerman
- **Los Alamos National Laboratory (USA)**: X. Li
- **Oak Ridge National Laboratory (USA)**: F. Bock, M. Benoit, O. Hartbrich, C. Loizides, K. F. Read, N. Schmidt
- **Ohio State University (USA)**: D. Brandenburg
- **Purdue University (USA)**: A. Jung, M. Liu
- **Rice University (USA)**: F. Geurts, W. Li
- **University of California, Santa Cruz (USA)**: M. Gignac, S. Mazza, J. Ott, A. Seiden, S.H. Sadrozinski, B. Schumm
- **University of Illinois at Chicago (USA)**: O. Evdokimov, J. Gupta, S. Nanda, N. Raha, Z. Ye
- **South China Normal University (China)**: S. Yang
- **University of Science and Technology of China (China)**: Y.-F. Zhang
- **IJCLAB/OMEGA/CEA-Irfu (France)**: B.Y Ky, D. Marchand, C. Munoz Camacho, E. Rauly, L. Serin, A.-S. Torrento, P.-K. Wang, P. Dinaucourt, N. Seguin-Moreau, C. de La Taille, M. Morenas, F. Bouyjou
- **National Institute of Science Education and Research (India):** B. Mohanty, P. Palni, G. Tambave
- **Hiroshima University (Japan):** K. Shigaki, S. Yano
- **Nara Women's University (Japan):** T. Hachiya
- **RIKEN (Japan):** Y. Akiba, Y. Goto, I. Nakagawa
- **National Cheng Kung University/Academia Sinica (Taiwan)**: W.-C. Chang, P.-J. Lin, Y. Yang
- **National Taiwan University (Taiwan)**: R.-S. Lu

Backup

Studies prior to ePIC



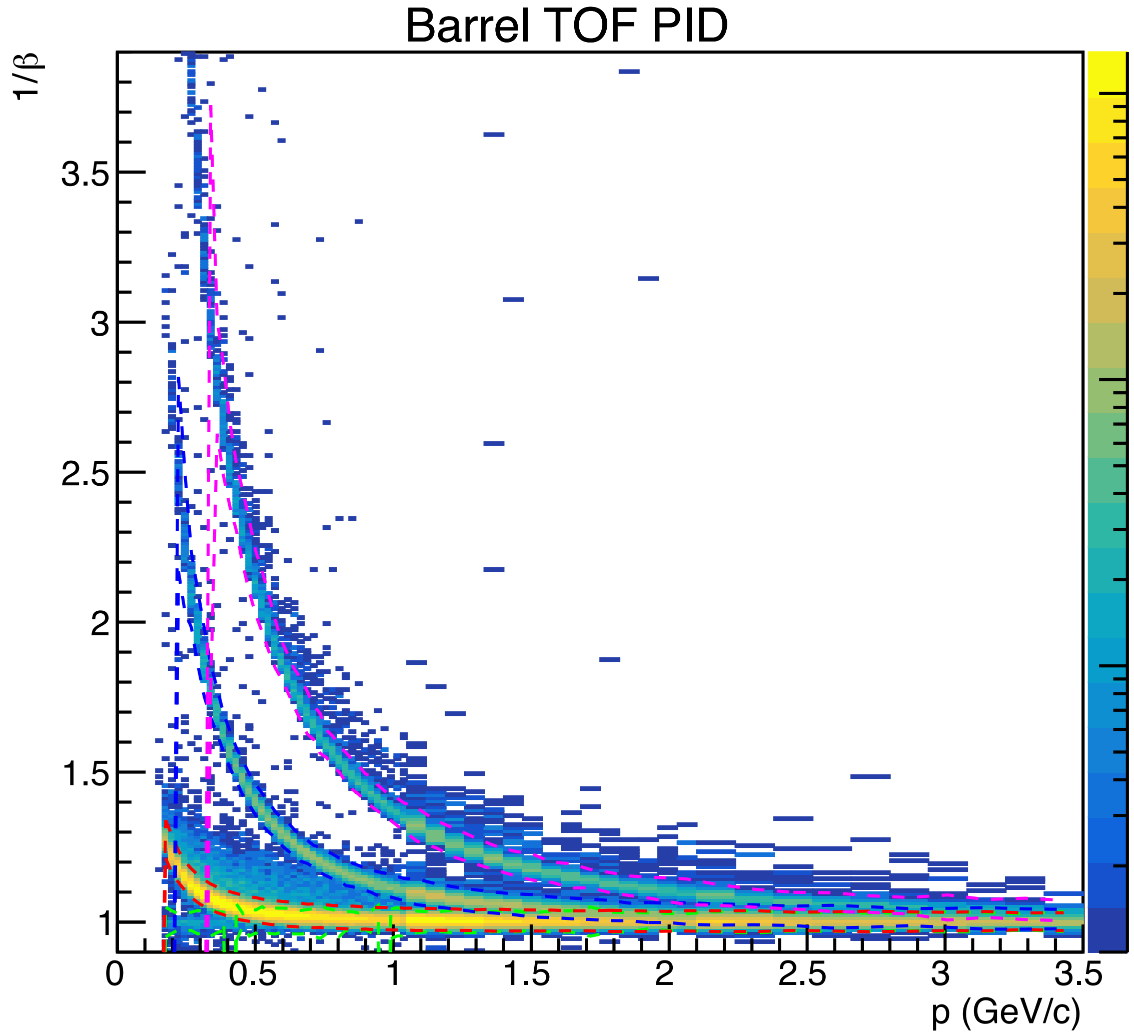
$1/\beta = (t - t_0)/L$

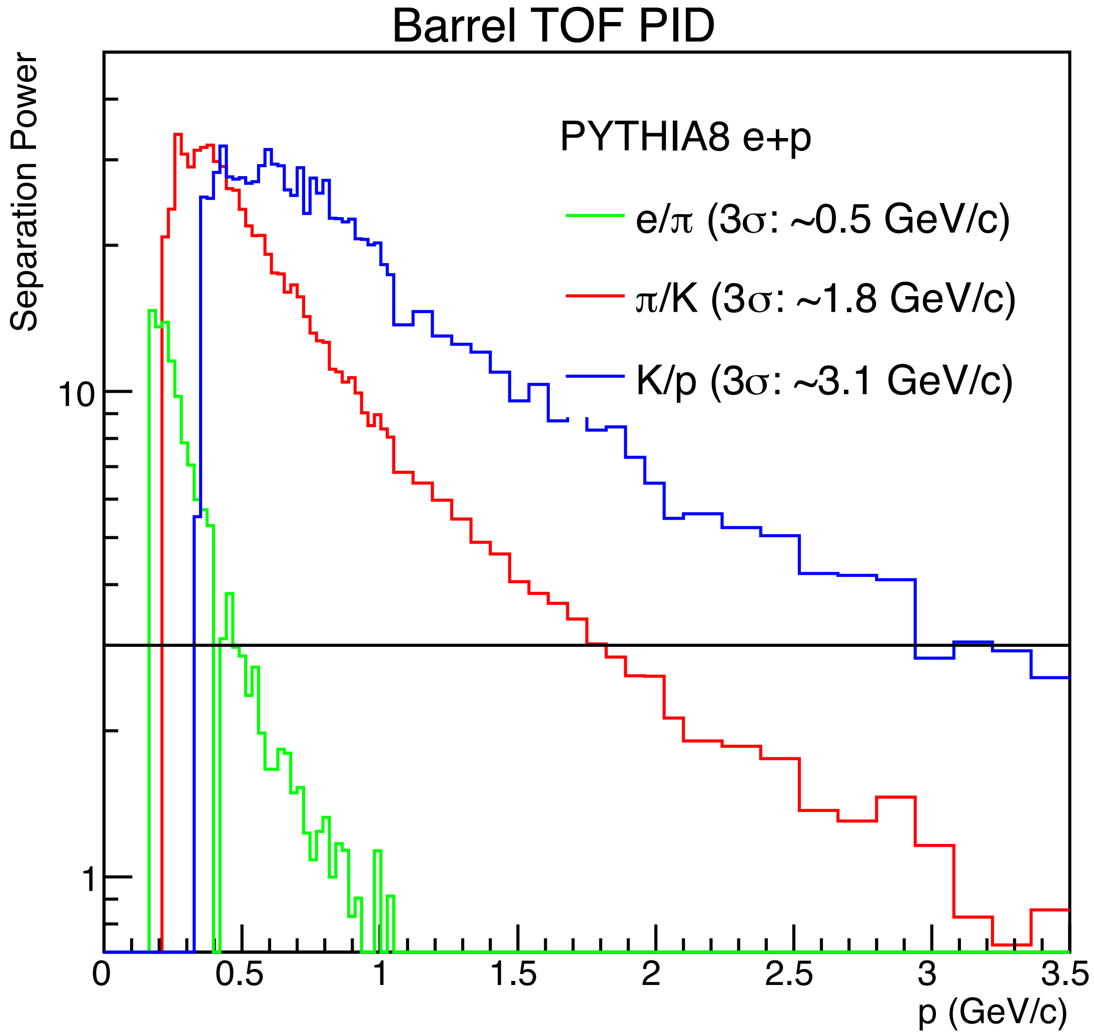
F. Bock (ORNL)
S. Yang (SCNU)

- σ_t~25 ps for single hits (optimal scenario)
- start time (t_0) determined by scattered *e-* and/or fitted with all detected hadrons

Full PID of π, K, p, and even *e-* (p<0.5 GeV) down to ~0.15 GeV

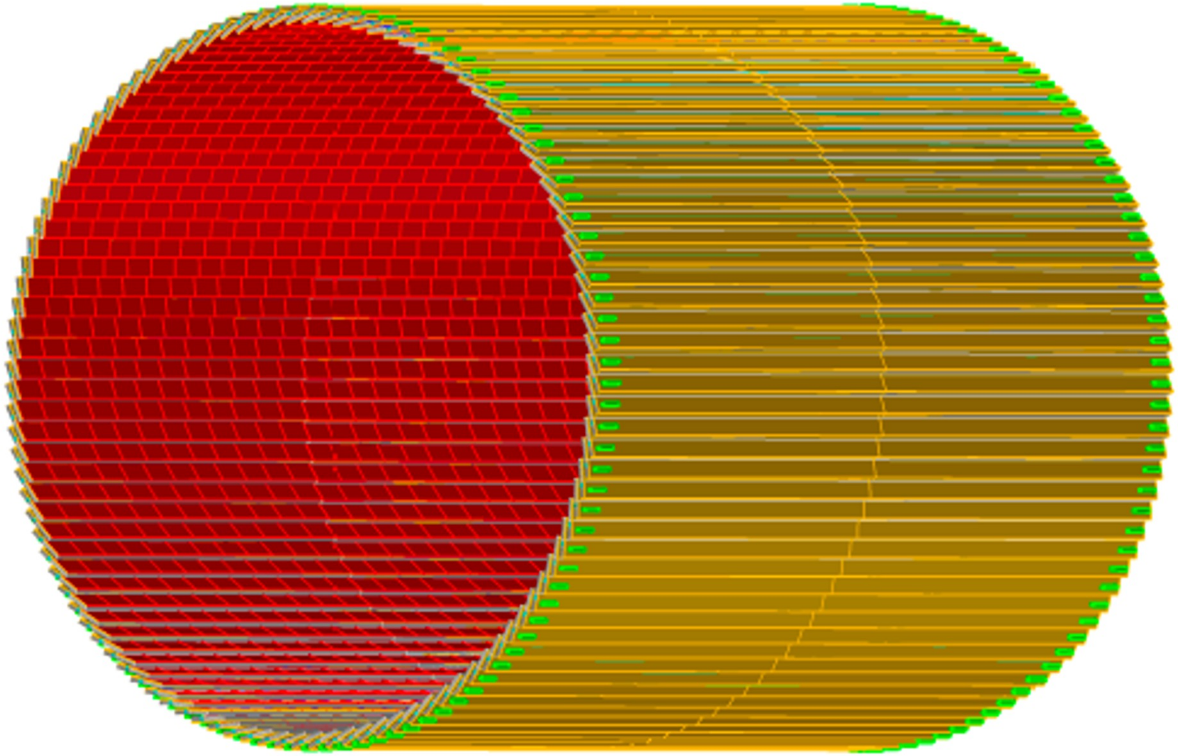
Barrel TOF PID Performance

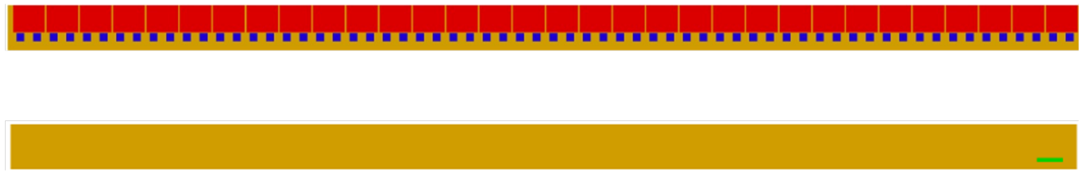




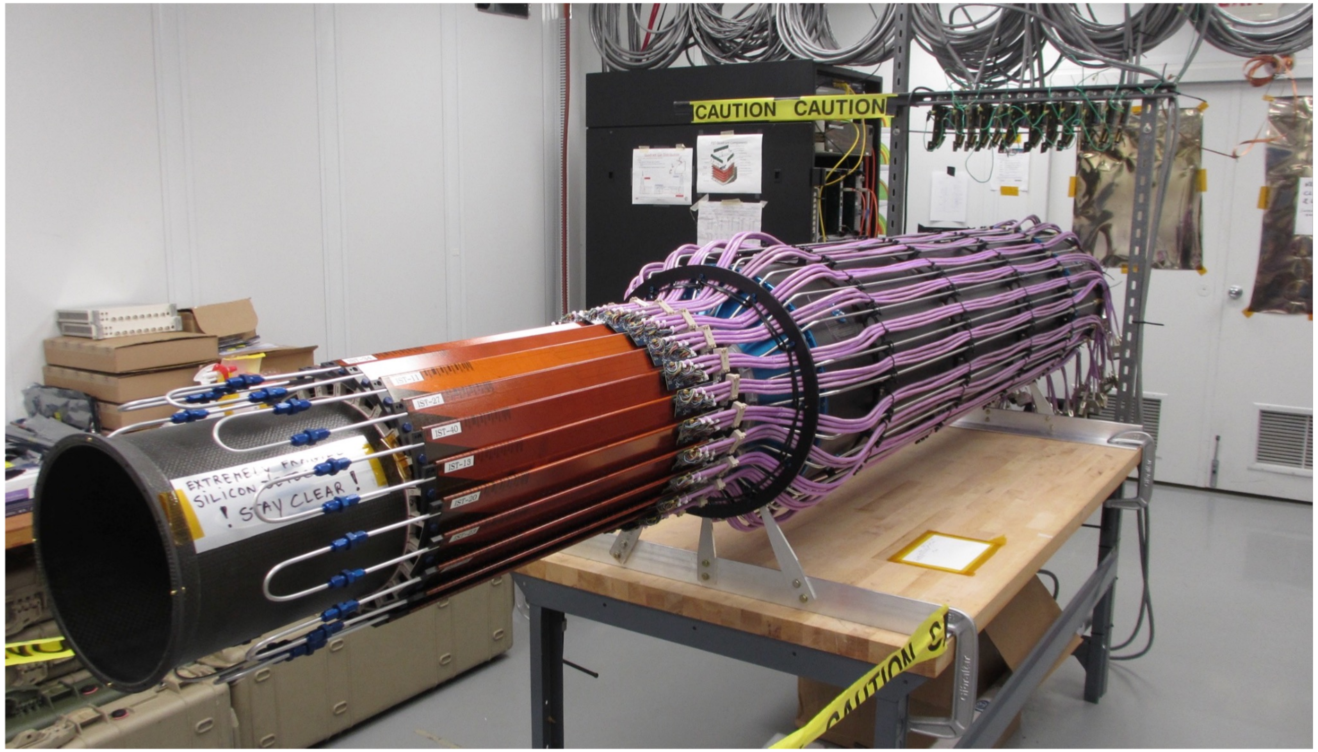
Barrel TOF Layout and Integration

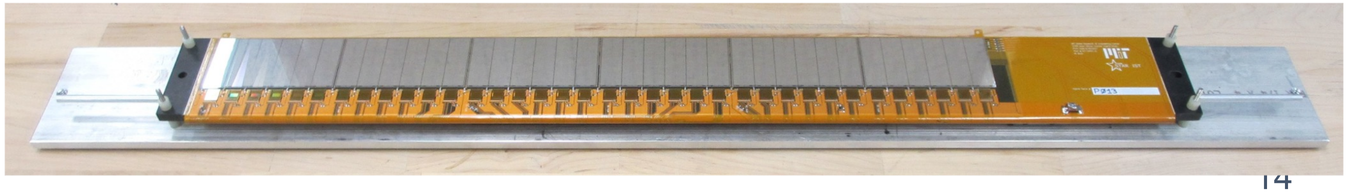
Barrel TOF CAD Drawing





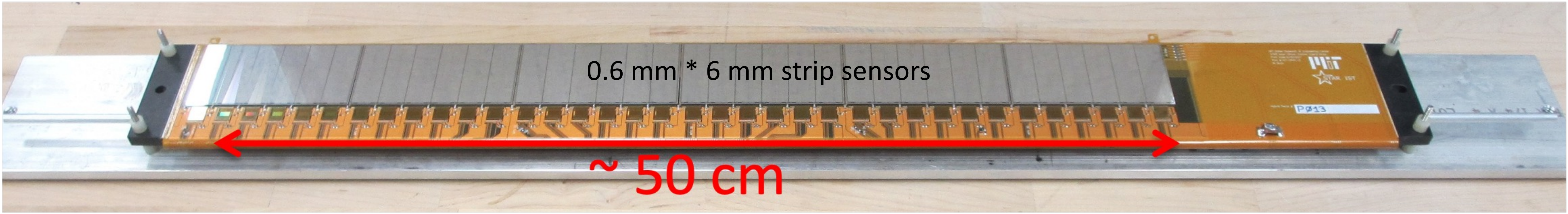
STAR Intermediate Silicon Tracker

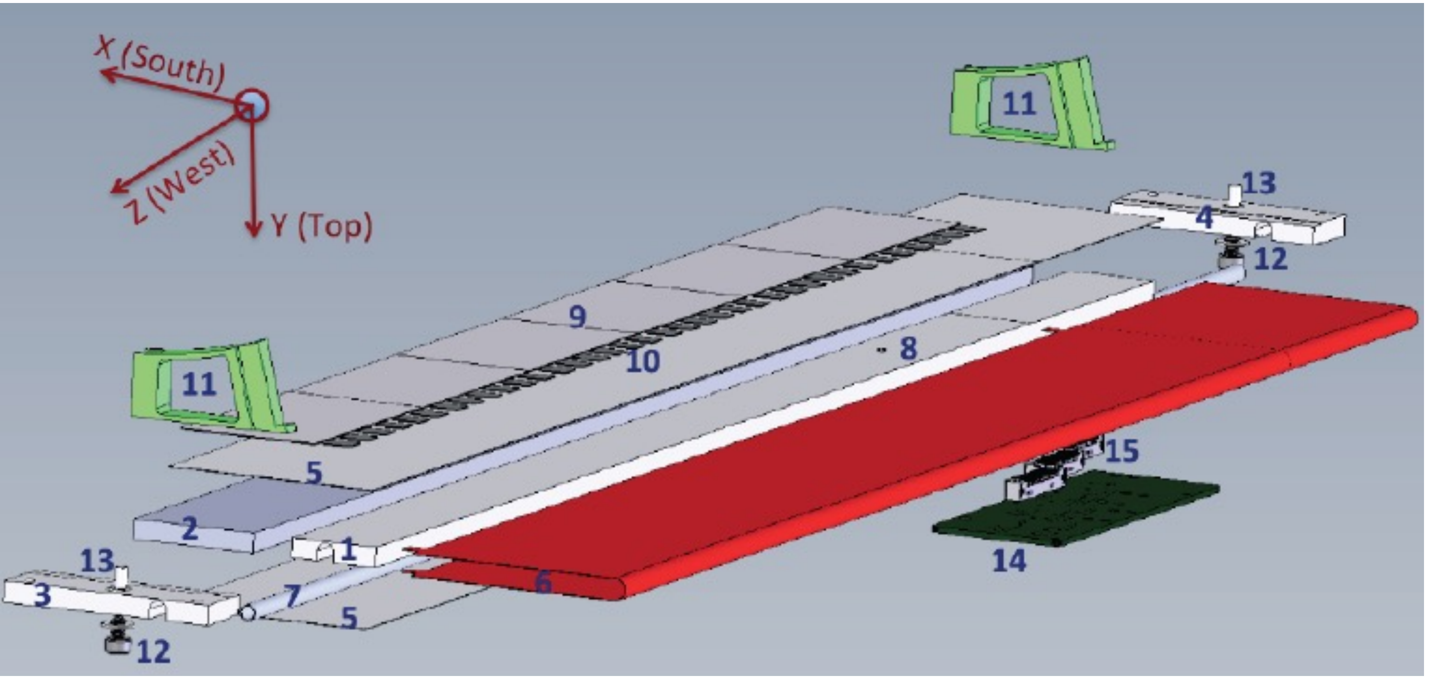




AC-LGAD Barrel TOF Detector for EIC – STAR IST

AC-LGAD Barrel TOF Detector for EIC – STAR IST

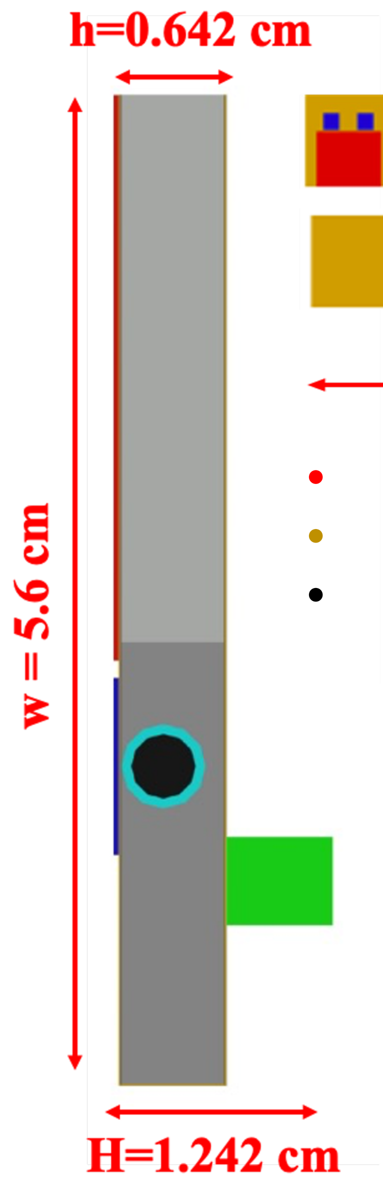


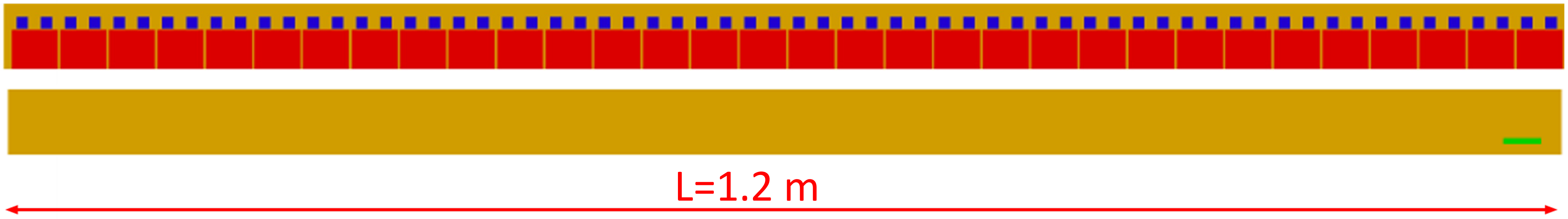


1) carbon foam 2) carbon honeycomb 3) west carbon end-cap 4) east Al end-cap 5) carbon fiber skins 6) Kapton hybrid 7) Al cooling tube with cooling liquid inside 8) thermal sensor 9) silicon sensors 10) APV chips 11) support blocks 12) screws with washers 13) spacers 14) transition board 15) readout connectors.

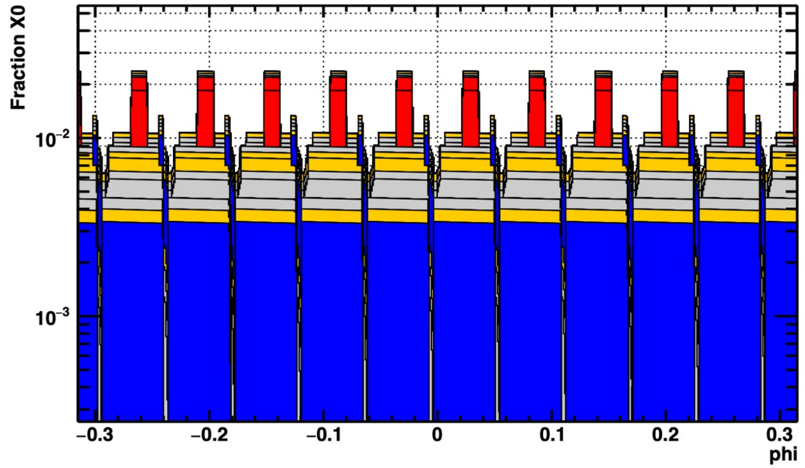
Material budget <1% X_0

Barrel TOF Layout and Integration





- **32 AC-LGAD sensors**, each 3.2*4 cm^2 read out by **2 ASICs**
- **Low mass flexible Kapton PCB** distributes power and I/O signals from a low mass connector(s) at the edge
- **Liquid coolant** in **Al cooling tube** takes away heat from the ASICs



288 modules, each powered and read out by 1 service board with

1 LV+HV cable, 1 fiber to DAQ, 1 liquid cooling line

Total weight: ~70 kG

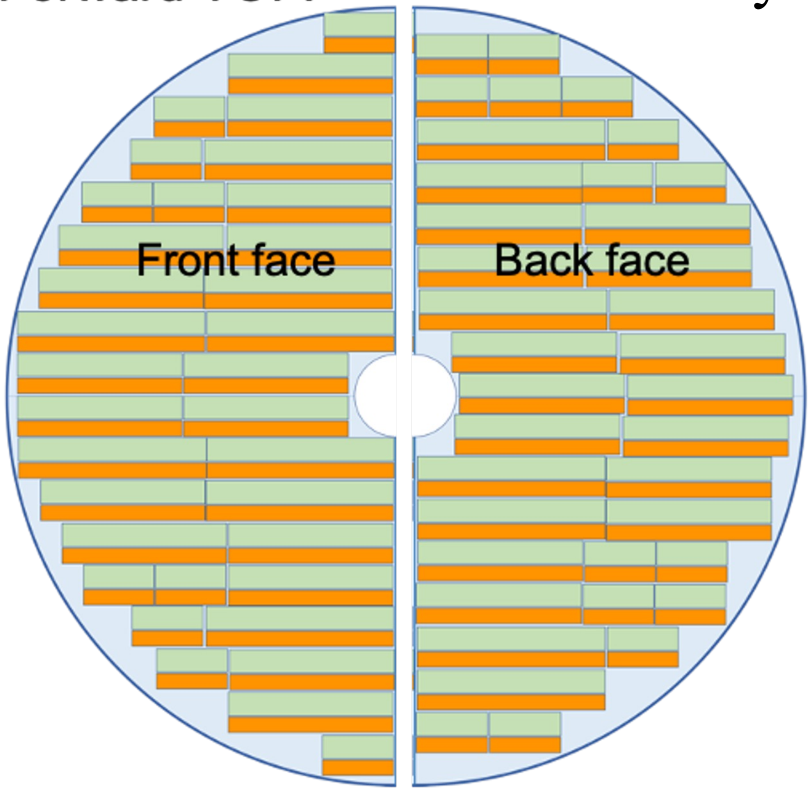
Total power consumption: ~4 kW (2.4kW for ASIC, 1.0kW for DC-DC, 0.6kW for sensors+cables+RB)

https://indico.bnl.gov/event/17336/

Forward TOF Layout

More details: https://indico.bnl.gov/event/17336/

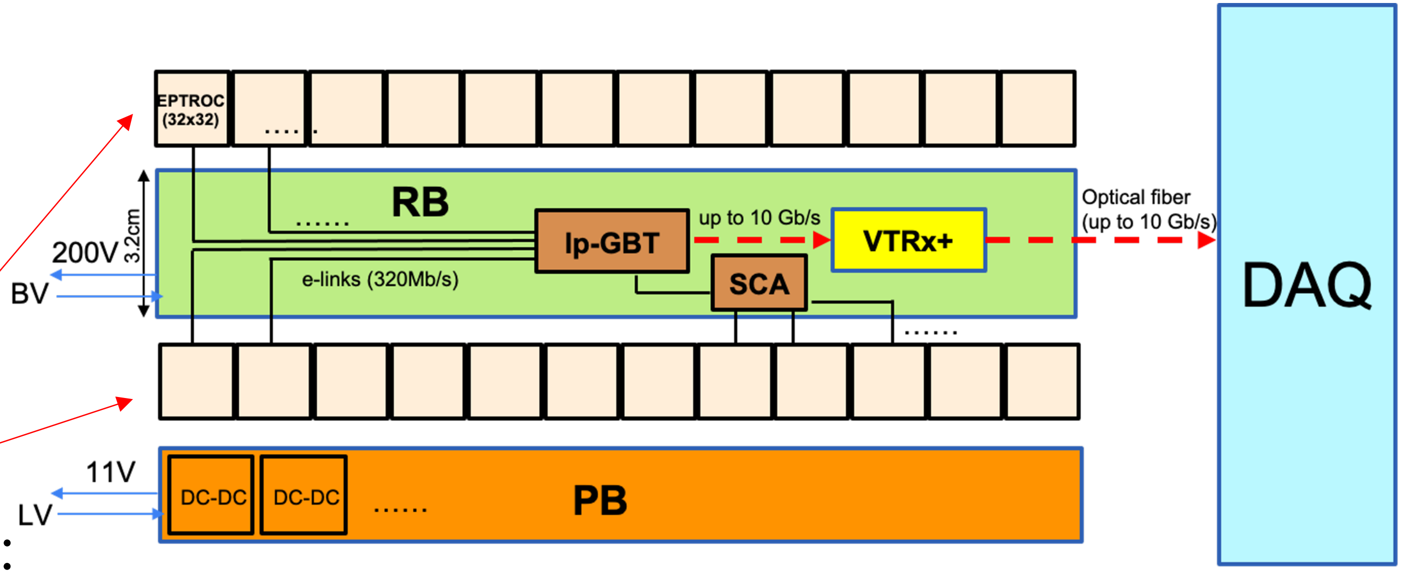
Forward TOF: Strawman layout



"Clam shells" or DEEs:

- Convenient for installation/maintenance
- Each is patched by TOF modules (one or more types) on both faces

Detector module with readout and power boards

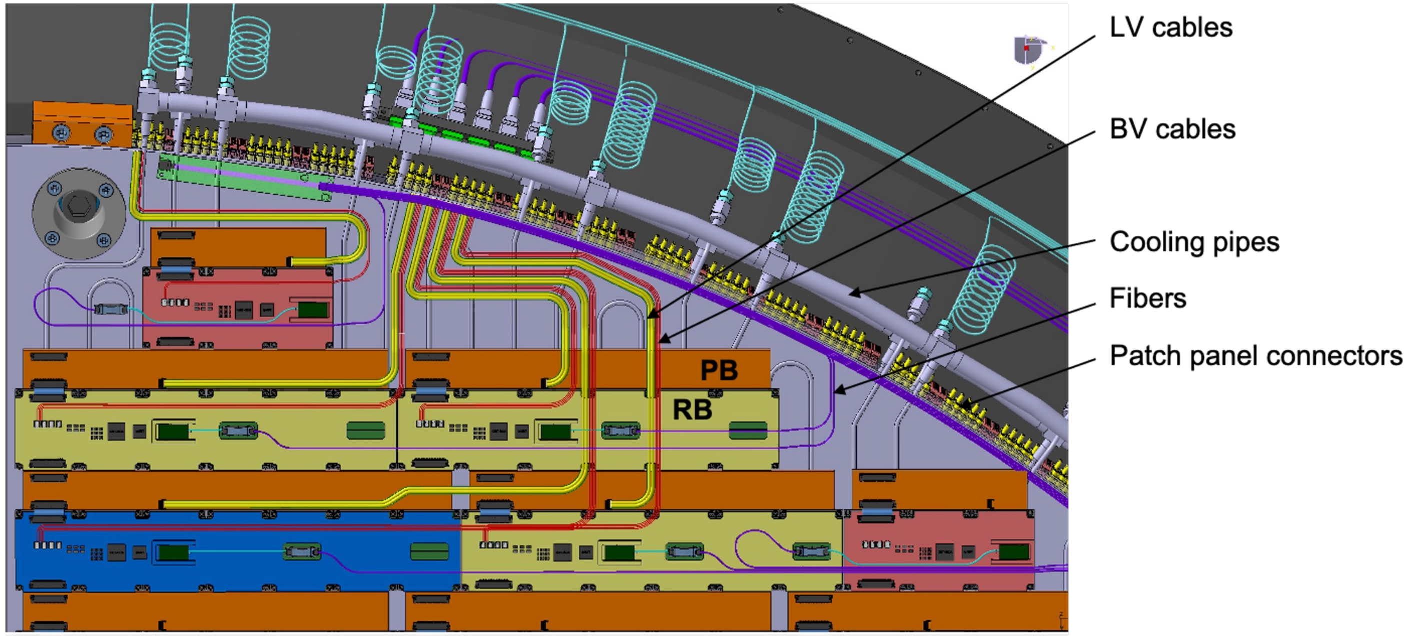


(Baseline) bump-bonded Sensor+ASICs:
32x32 pixels with pitch of 0.5x0.5 mm^2

Forward TOF Integration

More details: https://indico.bnl.gov/event/17336/

Service routing, similar to the CMS design



<10cm in z thickness

Services (baseline)	Forward
Sensors/ASICs	8704
LV cables	424
HV cables	424
Fibers	212

Power Consumption	Forward
500x500 micron^2 (baseline)	13kW
800x800 micron^2 (possible alternative)	6kW

Planned/proposed R&Ds to optimize baseline design to minimize power consumption and develop effective cooling scheme

Some References

- Barrel TOF Layout: Zhenyu Ye
- Endcap TOF Layout: Wei Li
- TOF Reconstruction: Dmitry Romanov
- TOF in Tracking: Nicolas Schmidt