TOF-PID WG Status Report

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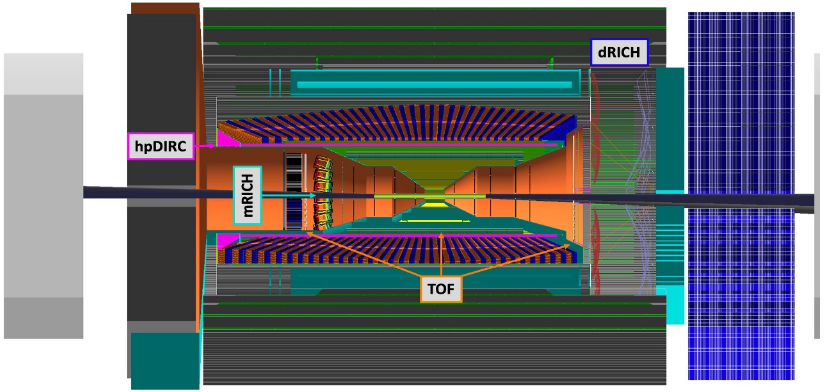
on behalf of the Detector-1 TOF-PID WG

Electron-Ion Collider User Group Meeting - 2022

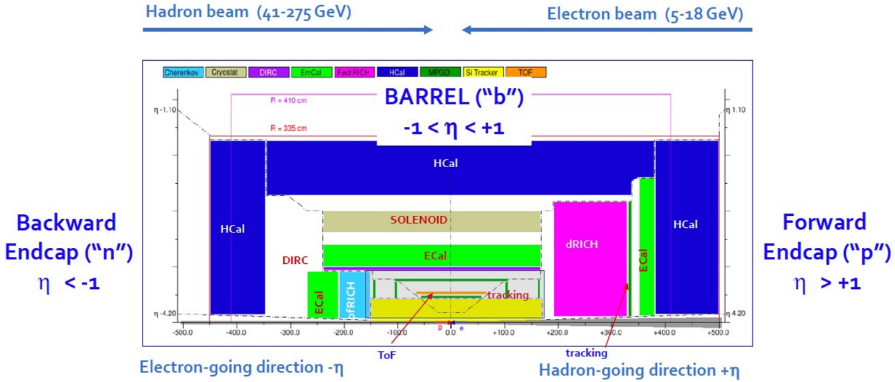
CFNS, Stony Brook University, July 26 - 29, 2022

EIC Detector-1 TOF (tracking) Design

ECCE design (reference design for detector 1)
- B=1.4T
- 4π TOF coverage



ATHENA design
- B=3T
- barrel TOF only (endcaps as upgrades)



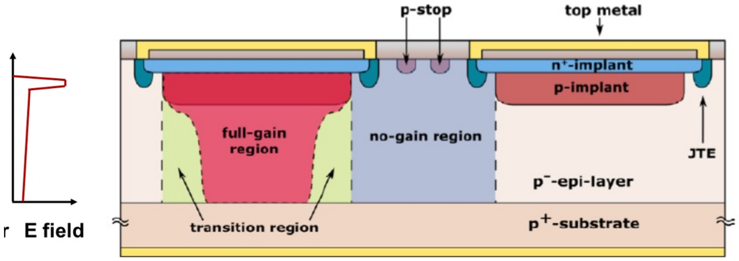
Both are based on the AC-coupled low gain avalanche diodes (LGADs)

Main charges to the **TOF-PID WG**:
- Identify and understand non-trivial design differences.
- Optimize toward the final conceptual and technical design.

In parallel, targeted R&D carried out within the **LGADs consortium** and **eRD112**

Low Gain Avalanche Diodes (LGADs)

DC-LGADs

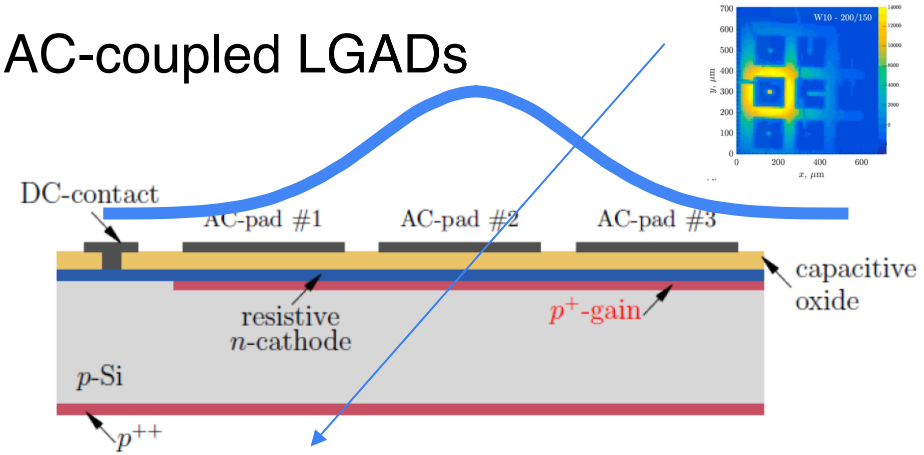


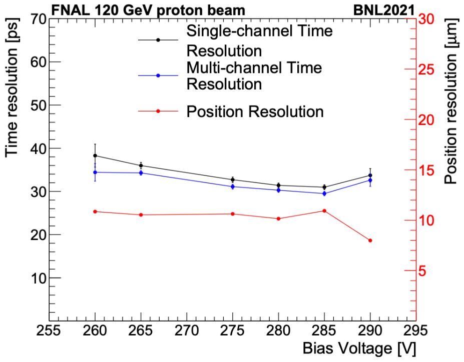
silicon sensor with fast timing

Used by CMS and ATLAS upgrades

- Time resolution: ~30 ps
- Position resolution: ~375 μm

AC-coupled LGADs





R. Heller et. al., arXiv:2201.07772

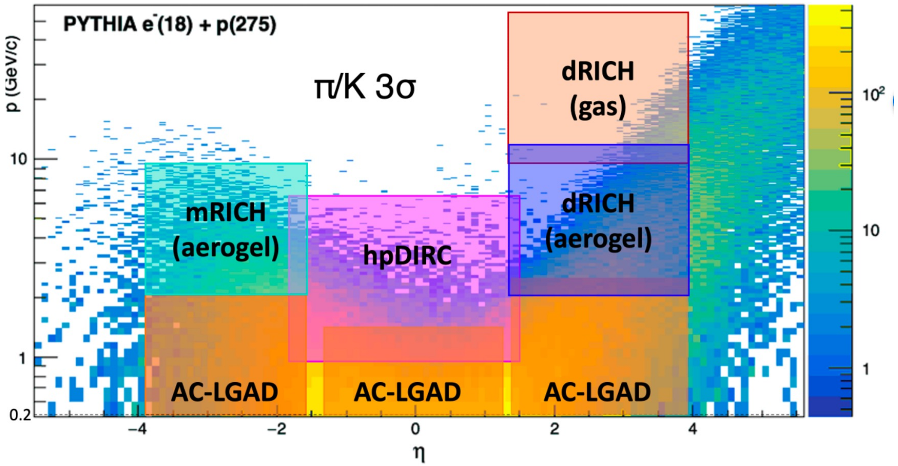
Excellent position resolution by charge sharing

Aim to be applied at EIC for the first time!

EIC Detector-1 TOF (tracking) Design

General design goals:

- A 4π-coverage TOF for full (e/π/K/p) ID at low-to-intermediate *p* range.
- Serve as a tracking layer with high spatial resolution.
- Provide a high angular resolution of tracks at the entry plane of Cherenkov PID systems.



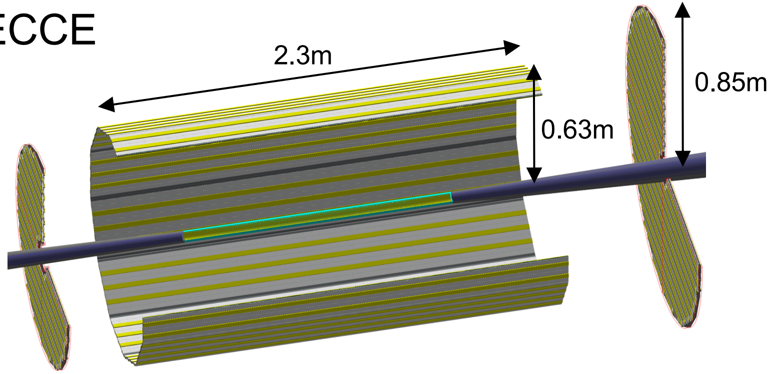
imaging mode (full PID) for RICH considered

Forward ($1.5<\eta<3.5$)	$0.15 < p < 2.5$ GeV
Central ($\|\eta\|<1.4$)	$0.15 < p_T, p < 1.5$ GeV
Backward ($-3.7<\eta<-1.74$)	$0.15 < p < 2$ GeV

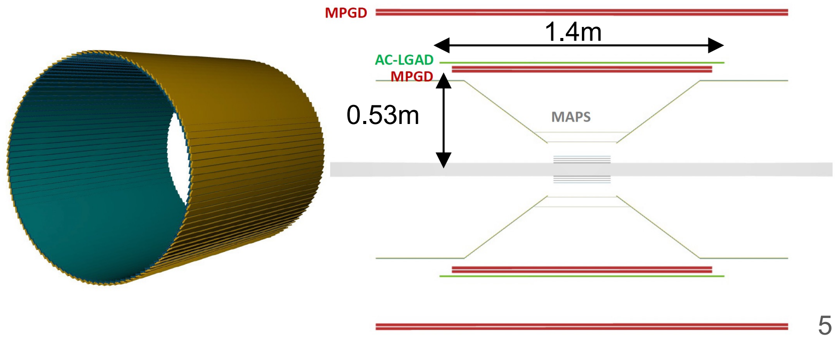
ECCE vs. ATHENA TOF (tracking) Design

Key Specification	ECCE	ATHENA
Time resolution (ps)	25	25
Pixel size (mm^2)	0.5x**3**	0.5x**10**
Material budget (X/X_0)	**8%**	**1%**
Barrel area (m^2)	**10.1**	**5**
Forward area (m^2)	**2.3**	**N/A**
Backward area (m^2)	**1.3**	**N/A**

ECCE



ATHENA



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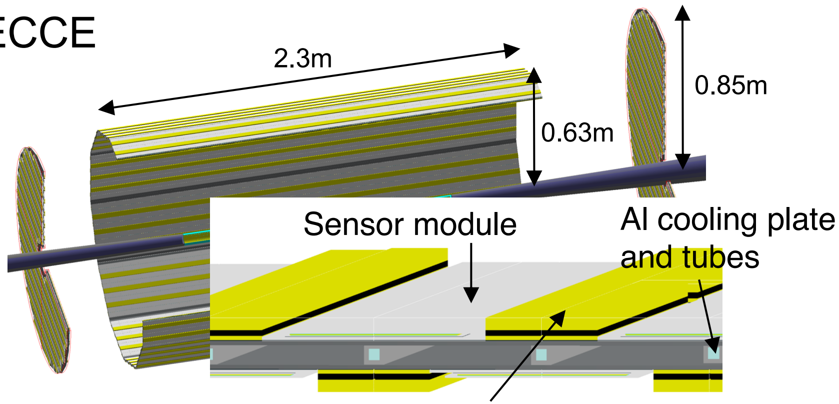
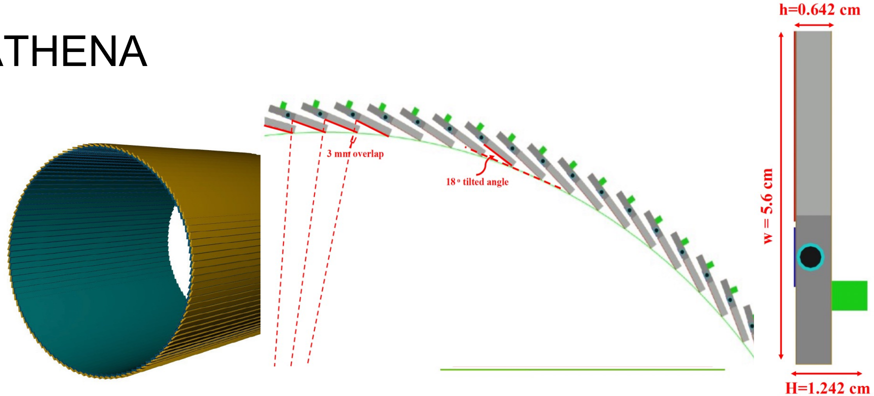
ECCE



"CMS" design

ATHENA



"STAR" design

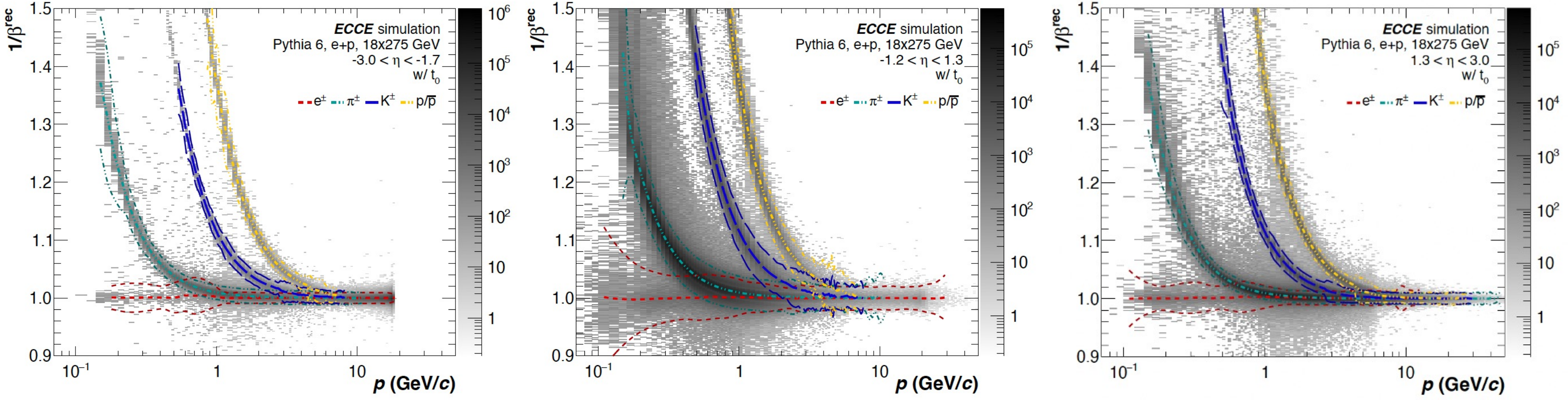
Toward the final conceptual design

Specific charges and tasks identified:

- Finalize **requirements on the time and position resolution** based on physics requirements and performance (engage with physics, tracking, Cherenkov-PID WG): optimal and minimal scenarios
- Study and determine maximal **material budget allowed** without impacting the energy resolution of scattered electrons (engage with calorimeter WG).
- Investigate the pros and cons of **pixel vs strip sensor options** to arrive at the optimal design (engage with far forward WG to seek for a common solution if possible)
  - O(mm) vs O(cm) in length
  - Bump bonding vs wire bonding
- Study and determine maximal **material budget allowed** without impacting the tracking performance (engage with tracking WG)
- Investigate the requirements/constraints on the **cooling and mechanical support**
- Investigate the requirements/constraints on the **service distribution, DAQ and detector integration** (engage with DAQ, integration WG)
- Consider **upgrade and staging options**
- Investigate feasible **fallback options** to reduce the risk

TOF-PID performance in the reference design

Backward Barrel Forward



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

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

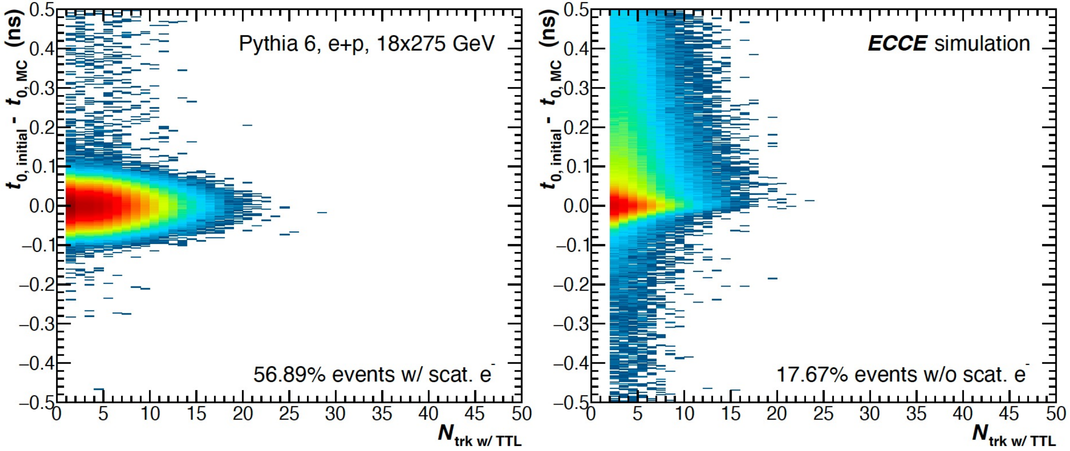
- σ_t~25 ps for single hits (optimal scenario)
- start time (t_0) determined by scattered *e*- and/or fitted with all detected hadrons

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

More studies being finalized to determine the "minimal" scenario (30, 40, 50 ps etc.)

Start time (t_0) (self)determination

Initial t_0 determination



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

a) scattered electron found

- Scattered electron found if: $p_{e^-} > 3$ GeV/c, $\eta < 0.5$ in calo/ cherenkov detector acceptance
- Assuming calo & cherenkov detectors together can identify electron w/o losses

$\Rightarrow$ initial t_0 determined based on scattered electron

(importance of 4π coverage)

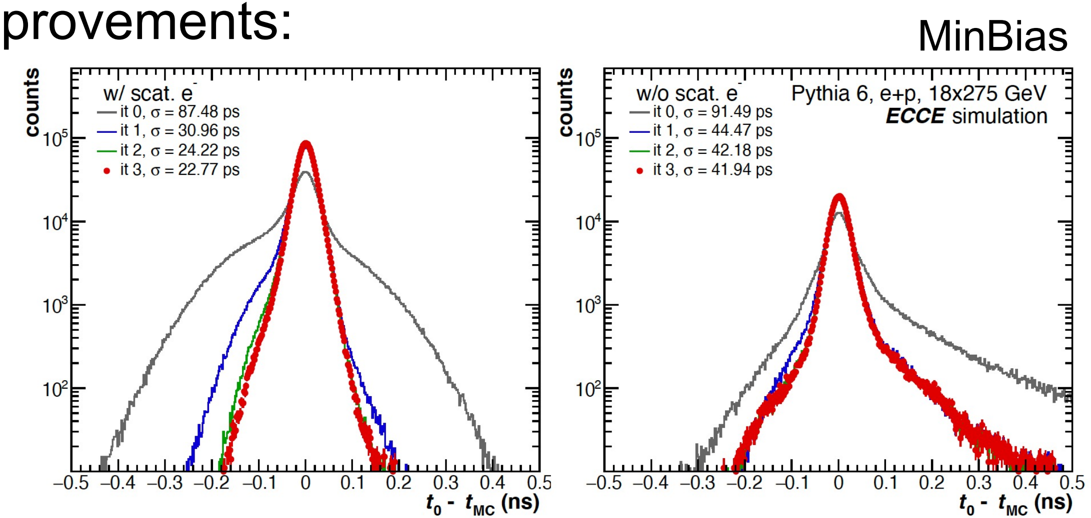
b) scattered not electron found

- Assume all particles in event charged pions
- All orgininate from common vertex
- Needs at least 2 tracks with TTL hits

$\Rightarrow$ initial t_0 determined based pion assumption

Start time (t_0) (self)determination

Iterative improvements:



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

- Common procedure after intial t_0 determination
- For all particles the velocity estimate is based on $t_{part,rec} - t_{0,it-1}$
- In iterations $1/\beta$ is calculated and compared to expectation value for π,K,p and e
  $\rightarrow$ assumed to be corresponding particle if within 1% of expectation value & $p < 6$ GeV/c
  $\rightarrow$ $p > 15$ GeV/c pion mass assumed, except for scattered electron candidates
- Latest after 4 iterations no significant change observed any more

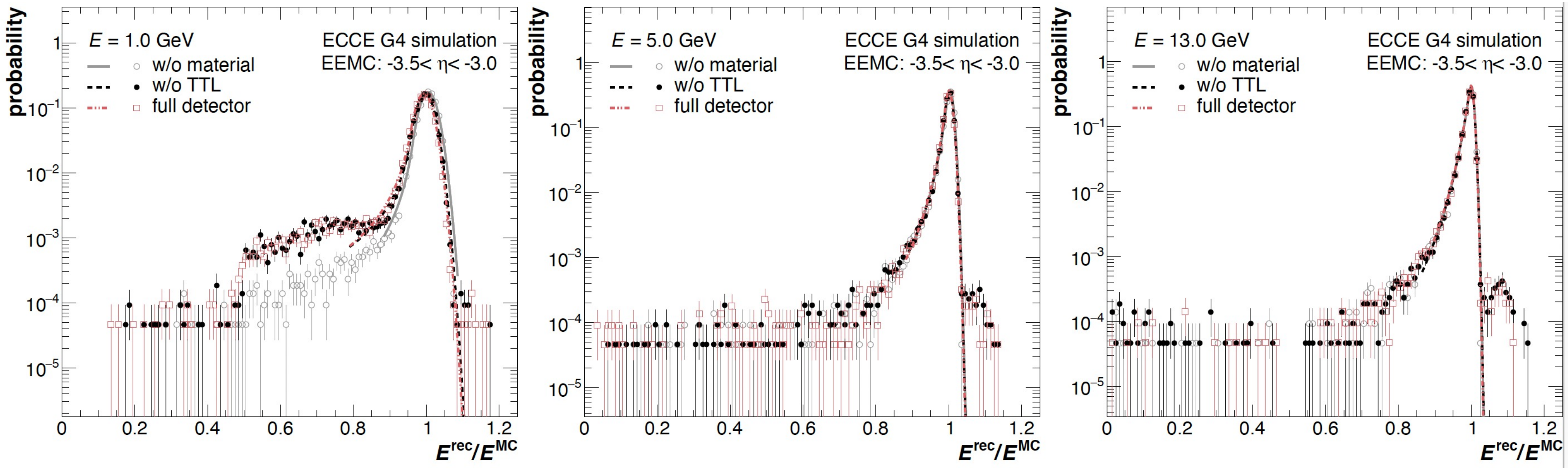
Also complemented by t_0 from the beam profile: ~30 ps (A. Kiselev)

TOF impacts on EMCAL

In the backward region, TOF is situated right in front of the EMCAL

TTL= timing-tracking layer (X/X_0~8%)

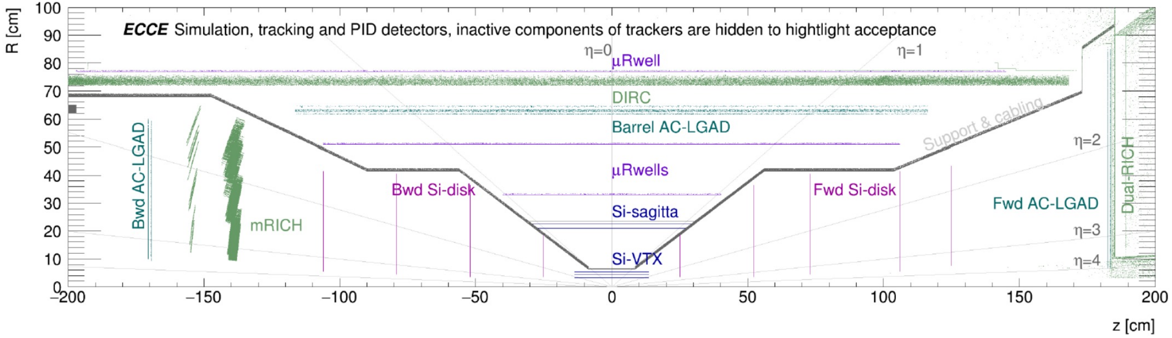
F. Bock (ORNL)



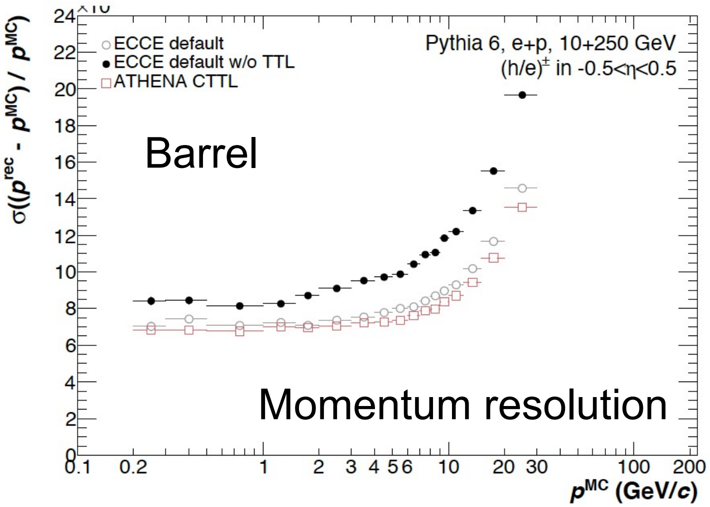
- Negligible (or no) impact of TOF to the electron energy resolution
- For high energy electrons (>5GeV), little impact from all inner materials

TOF impacts on tracking

LGADs TOF layer is an integral part of the tracking system



How TOF position resolution and material budgets will impact the tracking performance?



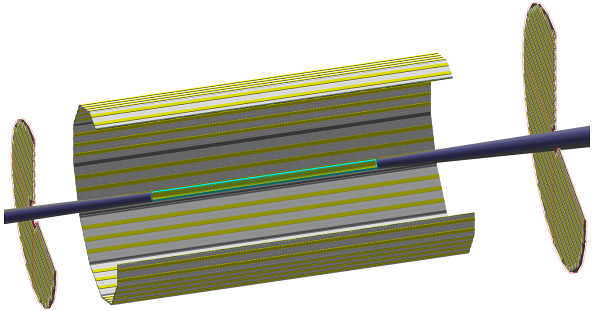
N. Schmidt (ORNL)

Tracking performance isn't very sensitive to TOF material budget (X/X_0 ~ 8% vs. 2%)

Studies for forward/backward regions with more material scenarios (e.g., X/X_0~16%) and various position resolutions ongoing

Service, Integration, DAQ

T. Ljubicic (BNL)
(pre-Strawman)



#		Jun 2022 (this talk)	Jun+ 2022
1	count of Barrel Readout Modules (fibers)	160	
2	count of Endcap L Readout Modules (fibers)	30	
3	count of Endcap R Readout Modules (fibers)	50	
4	**strip size**	500 µm x 1cm	
5	particles in TOF per event (collision)	~50	
6	collision rate	500 kHz	
7	random noise per strip	1 kHz	

Assumptions:

- Segmented into long "stave" of 5cm wide
- Each "stave" is readout by 1 Readout Board ("RDO") with 1 fiber to DAQ
- 1 copper cable each for BV and LV

Preliminary findings/thoughts:

- A few hundreds of fibers and cables expected
- Signal data rate: ~ 300 MB/s for 2.8M channels (~1 MB/s per fiber)
- Noise data rate: ~ 11 GB/s for 2.8M channels (~50 MB/s per fiber)

} Not much even for 10M channels

No showstopper expected for DAQ, # of service channels (and thus integration)

More studies ongoing and planned

To converge on the desired pixel granularity and time resolution:

- Track momentum resolution in forward/backward regions.
- Track angular resolution evaluated at projection planes in front of Cherenkov detectors: requirement of <0.5 mrad
- In the scenario of very long strip, precision of projected hit position on the strip
- Dependence of PID coverage on the time resolution

Seek engineering opinions (ORNL) on the mechanical structure and cooling design.

Iterate with other subdetector WG, physics WG, GD/I WG to consolidate the design.

The TOF-PID WG is making steady progress in addressing charge items and is on track to converge on the final design by the expected timeline.

Strong interests in TOF(tracking) system

22 institutes expressed interests in AC-LGADs based TOF and tracking systems

Conveners are in the process of reaching out to all institutes to discuss their specific interests and integrate them into the ongoing and future WG activities.

Please feel free to reach out to us anytime!

Brookhaven National Laboratory
IIT Madras
Indian Institute of Science Education and Research, Berhampur
Iowa State University
Massachusetts Institute of Technology (MIT)
National Central University
National Cheng Kung University
National Institute of Science Education and Research (NISER)
Oak Ridge National Laboratory
Ramakrishna Mission Residential College (Autonomous)
Rice University
South China Normal University
University of California, Santa Cruz
University of Illinois Chicago
University of Science and Technology of China
CEA-Saclay
Goa University
Los Alamos National Laboratory
MNIT Jaipur
National Taiwan University
RIKEN Nishina Center
University and INFN Bari

Backups

TOF PID Detector Working Group

A few relevant pointers

- Mailing list: eic-projdet-tofpid-l@lists.bnl.gov
    - Subscription information: https://lists.bnl.gov/mailman/listinfo/eic-projdet-tofpid-l
- Indico page (TOF PID): https://indico.bnl.gov/category/414/
- Wiki page: https://wiki.bnl.gov/eic-project-detector/index.php/TOFPID (linked to indico)
- Zoom: https://riceuniversity.zoom.us/j/91367321111?pwd=ZGRGZEN1dXg1aFBlSVdnMWsyaFE1UT09 (linked to indico)

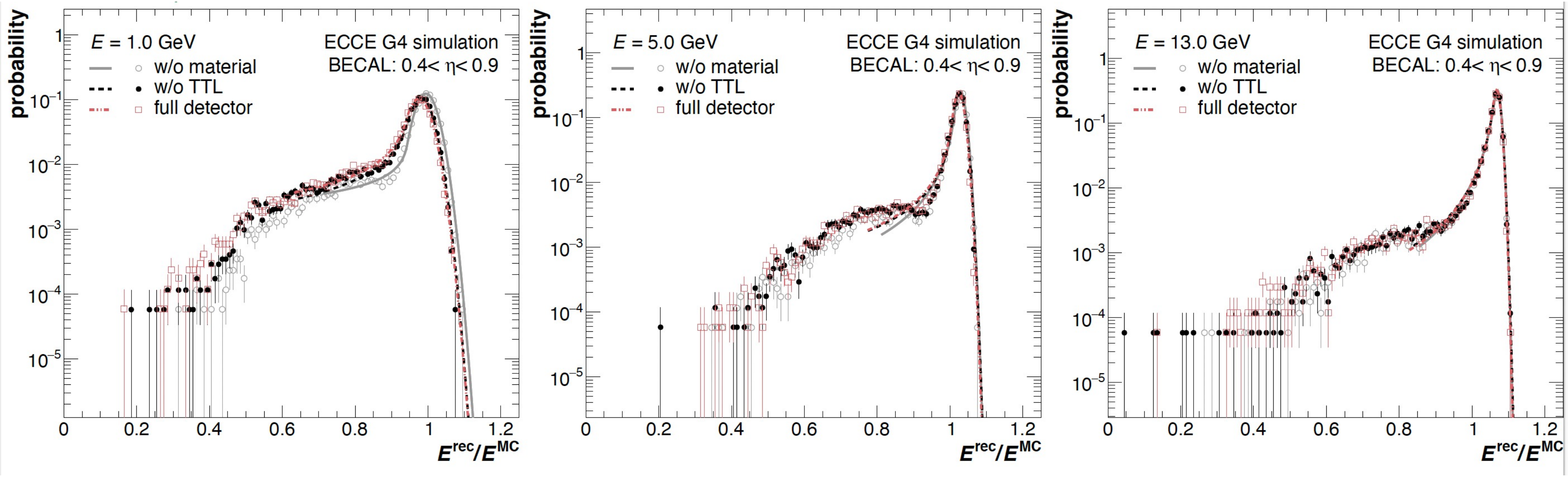
Default meeting time: 11:30am (EDT), Monday

Conveners contact info:

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

TOF impacts on EMCAL

Barrel EMCAL



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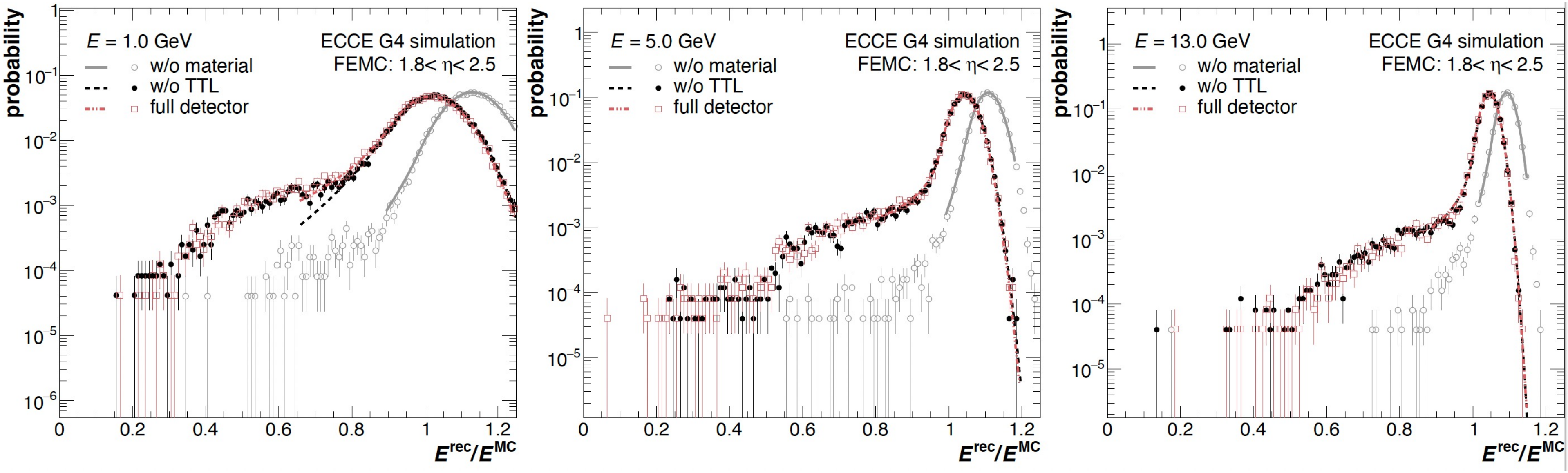
TOF impacts on EMCAL

Forward EMCAL



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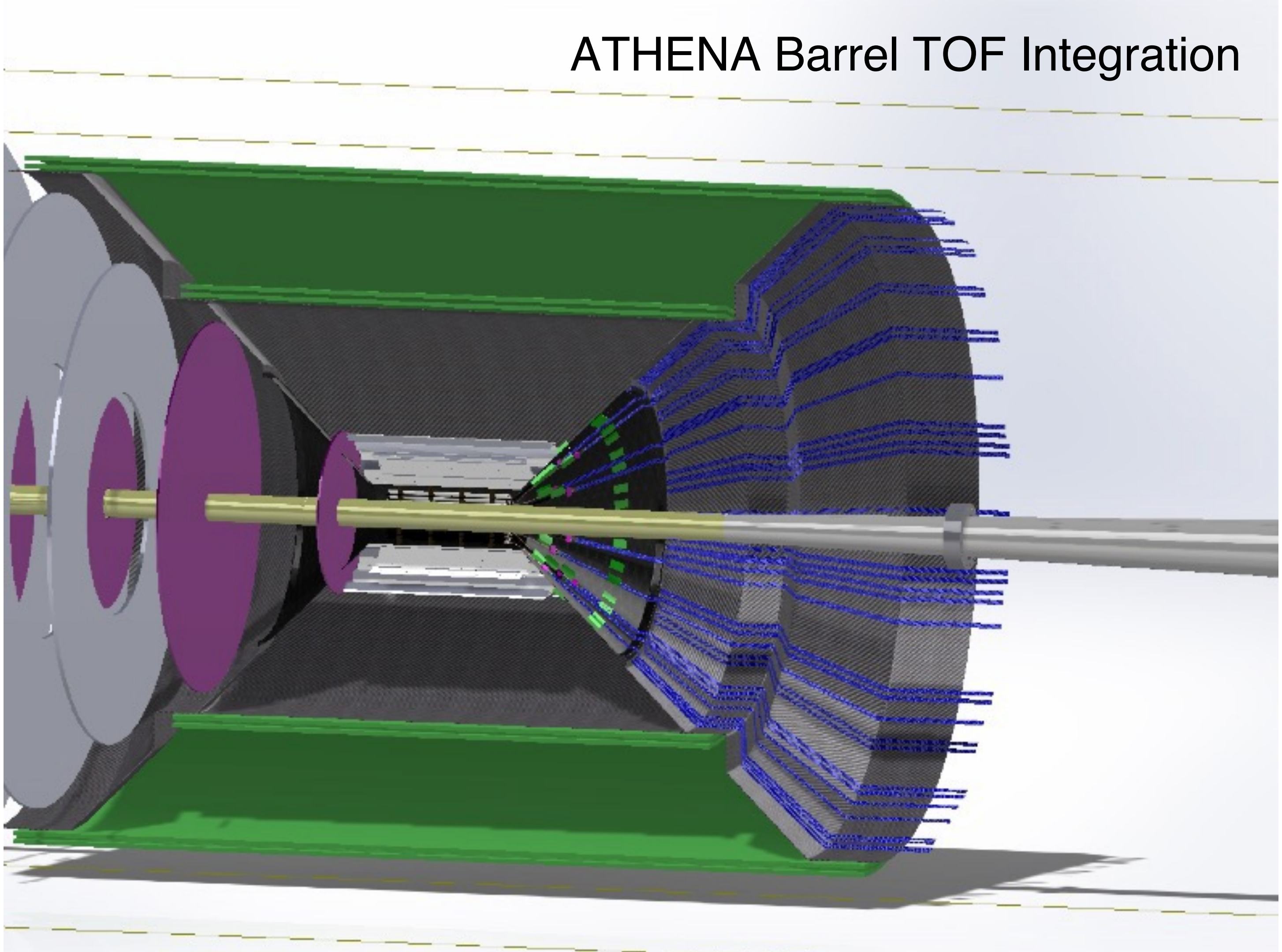
Timeline – What is Coming

❑ CD-0 approval	December 19, 2019
❑ Community-wide Yellow Report effort	Dec. 2019 – Feb. 2021
❑ CD-1 review (includes CDR)	January 26-29, 2021
❑ Call for Collaboration Proposals for Detectors	March 6, 2021
❑ CD-1 approval	June 29, 2021
❑ DOE/OPA Status Review	October 19-21, 2021

❑ Status Update to Federal Project Director	June 28-30, 2022, @BNL
❑ Cost and Schedule Event(s)	May-June 2022
❑ Technical Subsystem Reviews	January – December 2022
❑ OPA Status Review	January 2023
❑ Preliminary Design Complete & Review	May 2023
❑ Final Design/Maturity Readiness for CD-3A Items	May 2023
❑ CD-2/3A review (expectation), requires pre-TDR	~October 2023
❑ CD-2/3A (expectation)	~January 2024
❑ CD-3 review (expectation)	~January 2025
❑ CD-3 (expectation), requires TDR	~April 2025

ATHENA Barrel TOF Integration



ECCE TOF (tracking) Design

Schematics of dimensions and locations