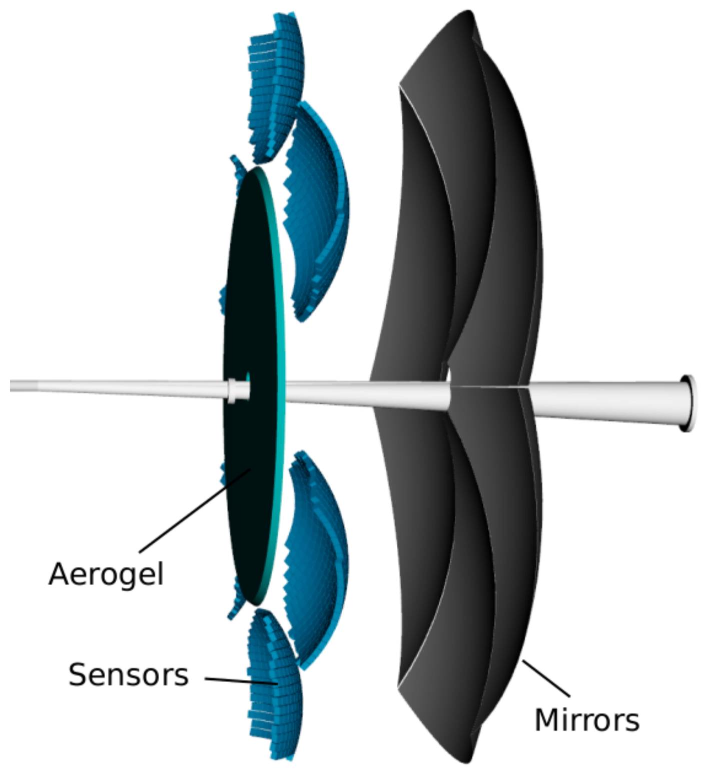
PID Systems:
TDR efforts and Progress

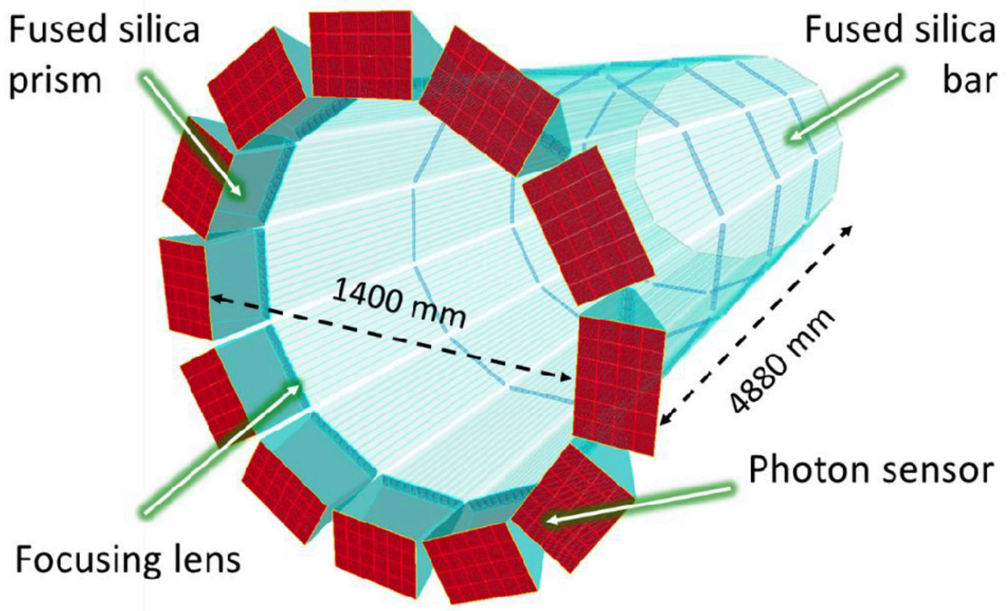
Thomas Ullrich on behalf of the PID DSCs

TIC Meeting

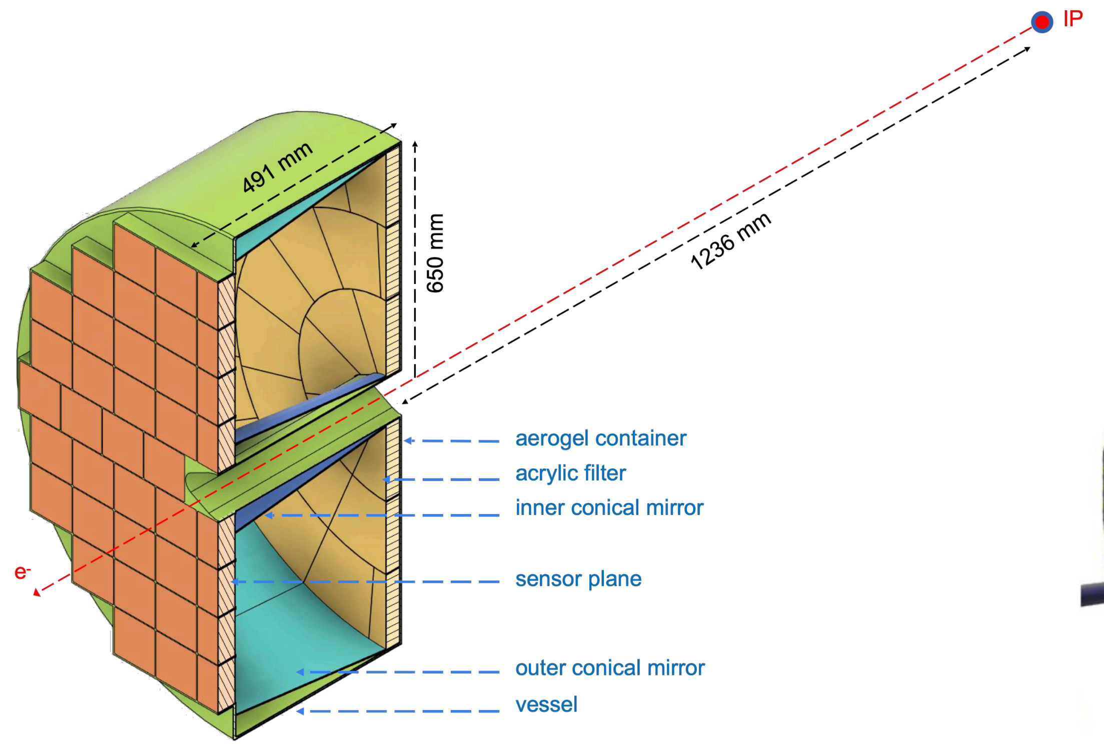
June 10, 2024



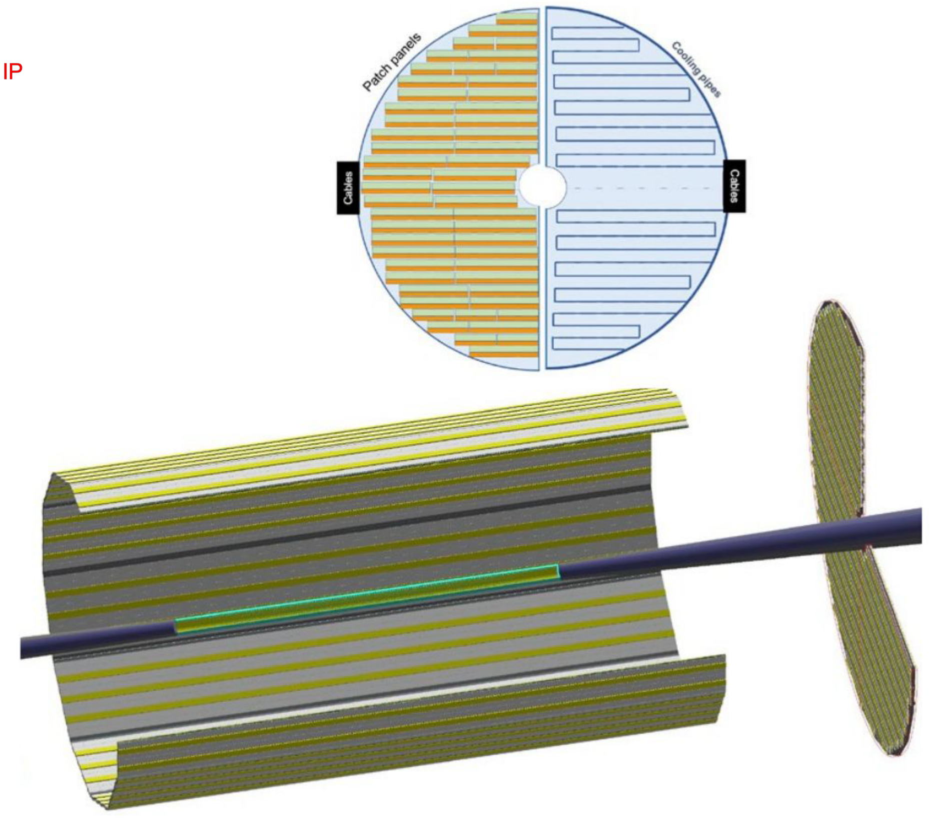
dRICH



hpDIRC



pfRICH



ToF

Brookhaven National Laboratory

Upfront - Plans for Lehigh Meeting

- PID DSCs prefer parallel type of meeting
- Focus on Cherenkov based detectors since ToF has separate all day meeting
- Details will vary according to DSCs

PID Working Group at Lehigh Collaboration Meeting (Breaks to be added)

R&D	Personnel	Title	Duration (incl. discussion)	Time Start	Time End
Welcome			5m	9:00	9:05
pfRICH	TBD	Mechanics, frame, mirrors, aerogel	25m	9:05	9:30
pfRICH	TBD	HRPPD, Electronics	25m	9:30	9:55
pfRICH	TBD	Software, Sims, TRD Status	25m	9:55	10:20
dRICH	TBD	Mechanics, frame, mirrors, aerogel, gas	25m	10:20	10:45
dRICH	TBD	SiPM, Electronics	25m	10:45	11:10
dRICH	TBD	Software, Sims, TRD Status	25m	11:10	11:35
hpDIRC	TBD	Mechanics, frame, bars, exp vol	25m	11:35	12:00
hpDIRC	TBD	MCP-PMTs (HRPPD), Electronics	25m	12:00	12:25
hpDIRC	TBD	Software, Sims, TRD Status	25m	12:25	12:50
ToF	TBD	Update	25m	12:50	13:15
Common Software	Umberto	Belle-II and other modes + Discussion	30m	13:15	13:45
Adjourn			0m	13:45	13:45

Breaks to be added

Possibly move to common reco mtg. or hybrid solution

pf*RICH*

TDR Preparation

Existing pfRICH CDR:

1 Introduction 5
1.1 The need for a PID detector in the backward region 6
1.2 The case for time-of-flight in the backward region 8
1.3 Overview of the proximity focusing RICH 8

2 pfRICH Design and Integration 11
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5 Physics Performance 46
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7.3 HRPPDs 55
7.3.1 Institutional responsibilities 55
7.3.2 R&D plan for FY23 55
7.3.3 Preview of remaining R&D in FY24 55
7.4 ASICs and front end electronics 56

- The material from the existing pfRICH CDR has been mapped into the agreed-upon Pre-TDR structure
- Resulting document resides on a private overleaf (pro account) that the pfRICH team will be able to edit freely

Pre-TDR Structure:

FOR EACH SUBSYSTEM

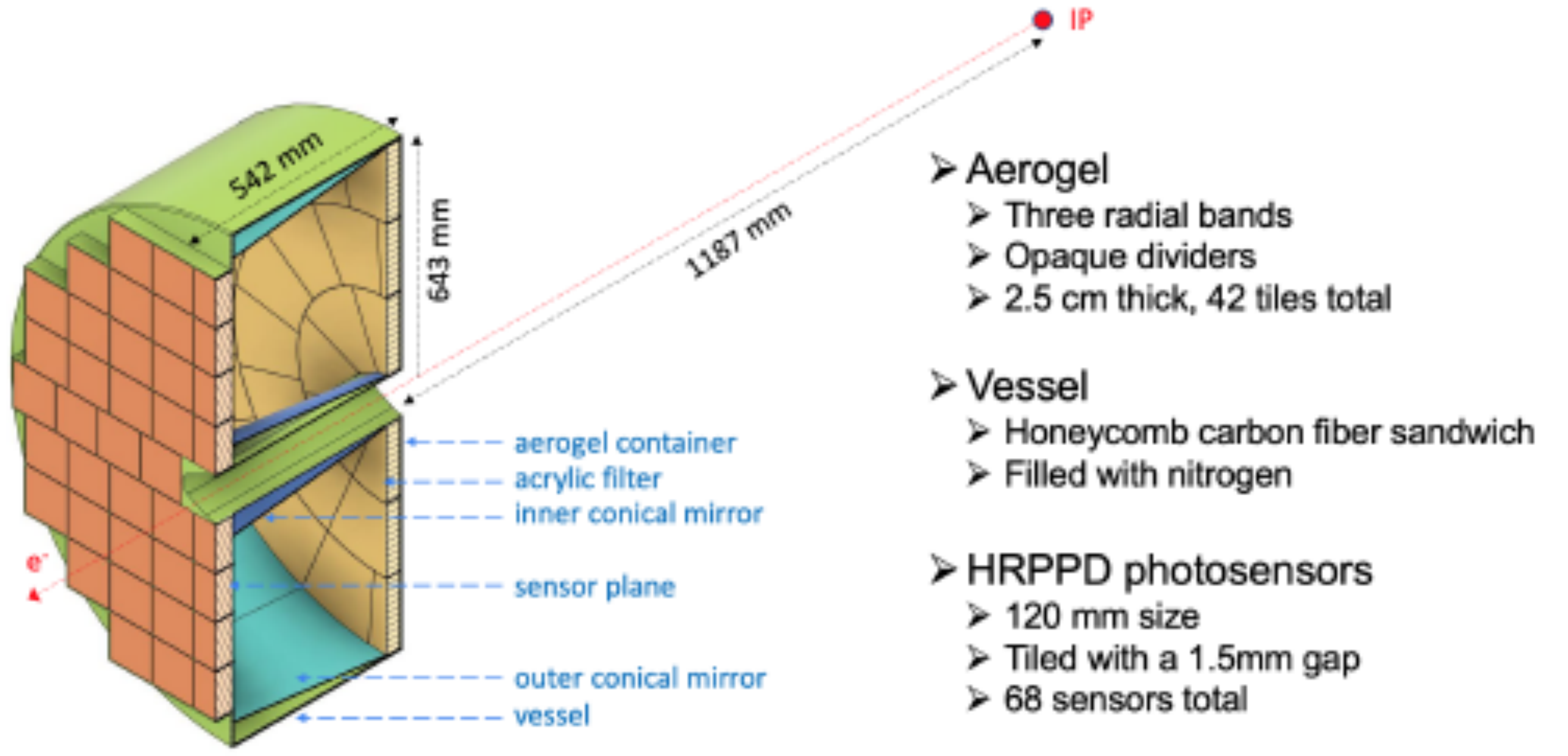
- Requirements
  - From **physics**
  - **Radiation hardness**
  - Expected **data rates**
- Justification
  - Device **concept and justification** for the technological choice
  - **Description**
    - General device description
    - Sensors
    - FEE (for rates with reference to a global table in electronics/DAQ section)
    - Other components (f.i.: radiators in calorimetry and in Cherenkov devices, ...)
  - **Performance** from available input (lab studies, test beam, prototyping, simulation studies)
- Implementation
  - **Services** (cooling, gas system, sensor power supply, FEE power supply, ...)
  - Subdetector **mechanics and integration**
  - **Calibration, alignment and monitoring** strategy and tools
  - **Status and remaining design effort**
    - R&D up to here (and missing, if any); E&D status and outlook
    - Other work needed for design completion
    - Status of maturity (with reference to next slide)
  - **ES&H** (Environmental, Safety & Health) aspects and **QA** (Quality Assessment) planning
  - **Construction planning**
  - **Collaborators** (=Institutions) and their role, resources and workforce
  - **Risks and mitigation strategy**

Next Steps

1. Identify editor(s) responsible for each section (this will partially map from the CDR, but need to confirm and find people for new sections)
2. Identify Pre-TDR sections that do not have CDR antecedents and develop necessary material. Also identify sections with existing material which may need substantial new simulation or beam/bench tests
3. Edit/update existing material
4. Evaluate the need for appendices and iterate

Critical Figures

- pfRICH has a pretty good idea of needed plots/figures from the CDR but may need to modify somewhat based on space and/or new insights
  - Some Examples:
  - Detector Diagram
  - Aerogel Properties and HRPPD QE Curve used in simu
  - Ring reconstruction and track level Cherenkov angle res
  - N-sigma separation vs momentum
  - Electron-pion and pion-kaon physics performance



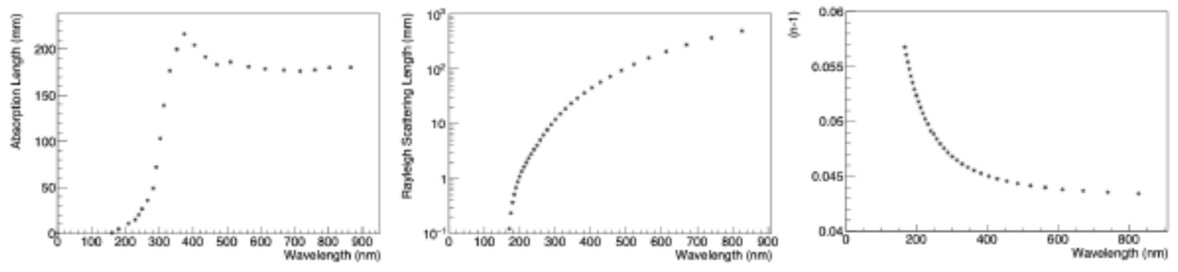


Figure 4.2: Belle II aerogel#1 (n = 1.045) optical properties used in the GEANT simulations.

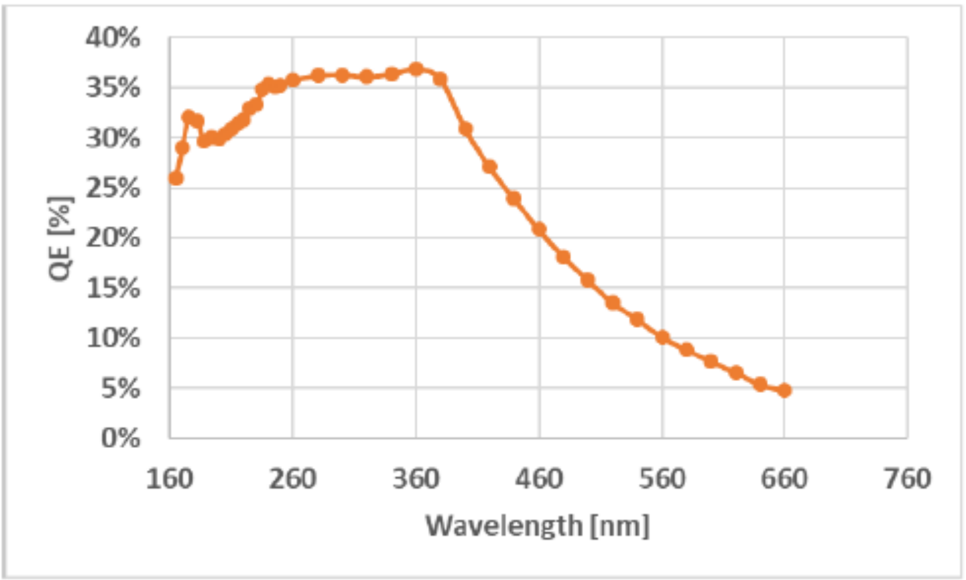
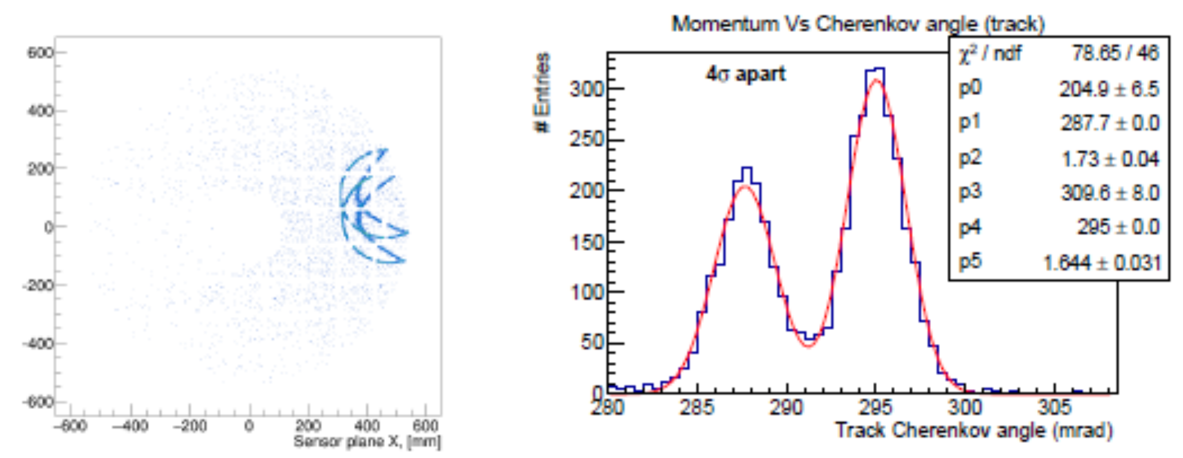


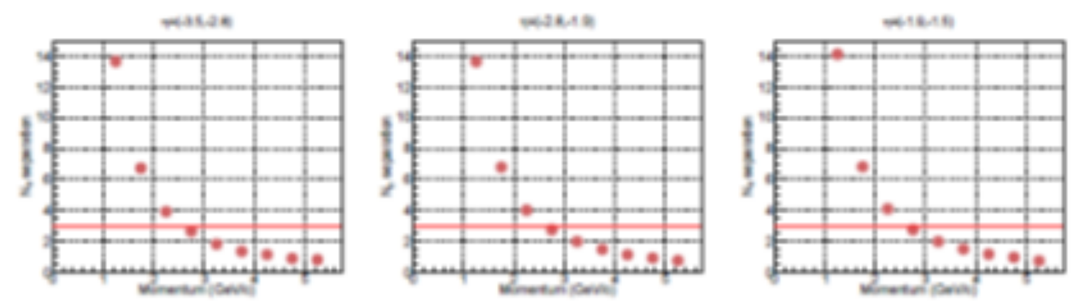
Figure 4.3: LAPPD tile #126 QE spectrum.



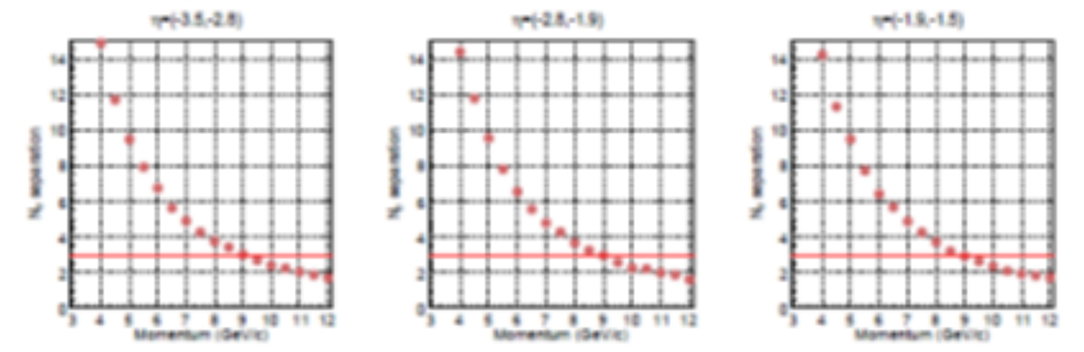
(a) Overlapping rings of pion and kaons (b) Separation of pion and kaons at 7.25 GeV/c

Figure 4.9: Separation of pion and kaon particles with overlapping rings

Figure 4.11: N_σ separation



(a) N_σ separation between the electron an pion hypotheses as a function of momentum for different bins of pseudo-rapidity.



(b) N_σ separation between the pion and kaon hypotheses as a function of momentum for different bins of pseudo-rapidity.

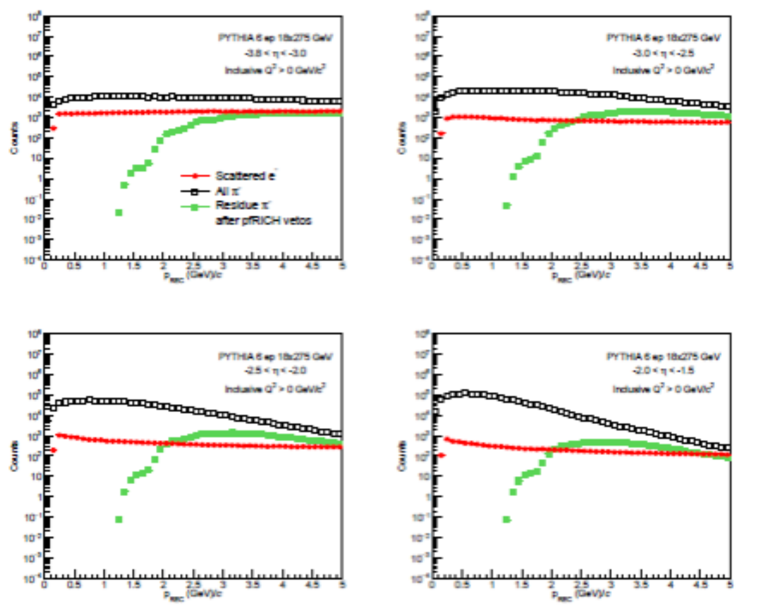
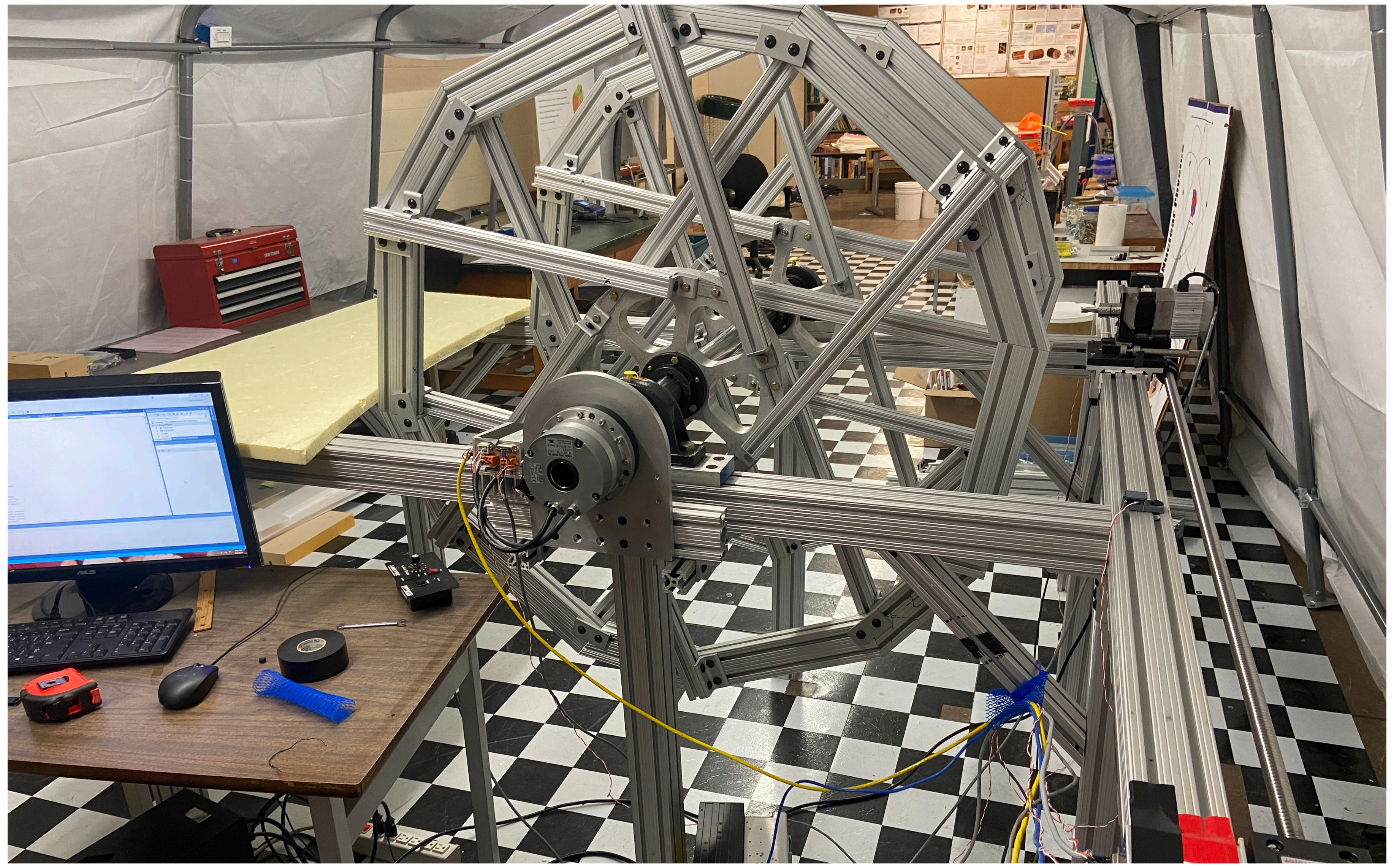


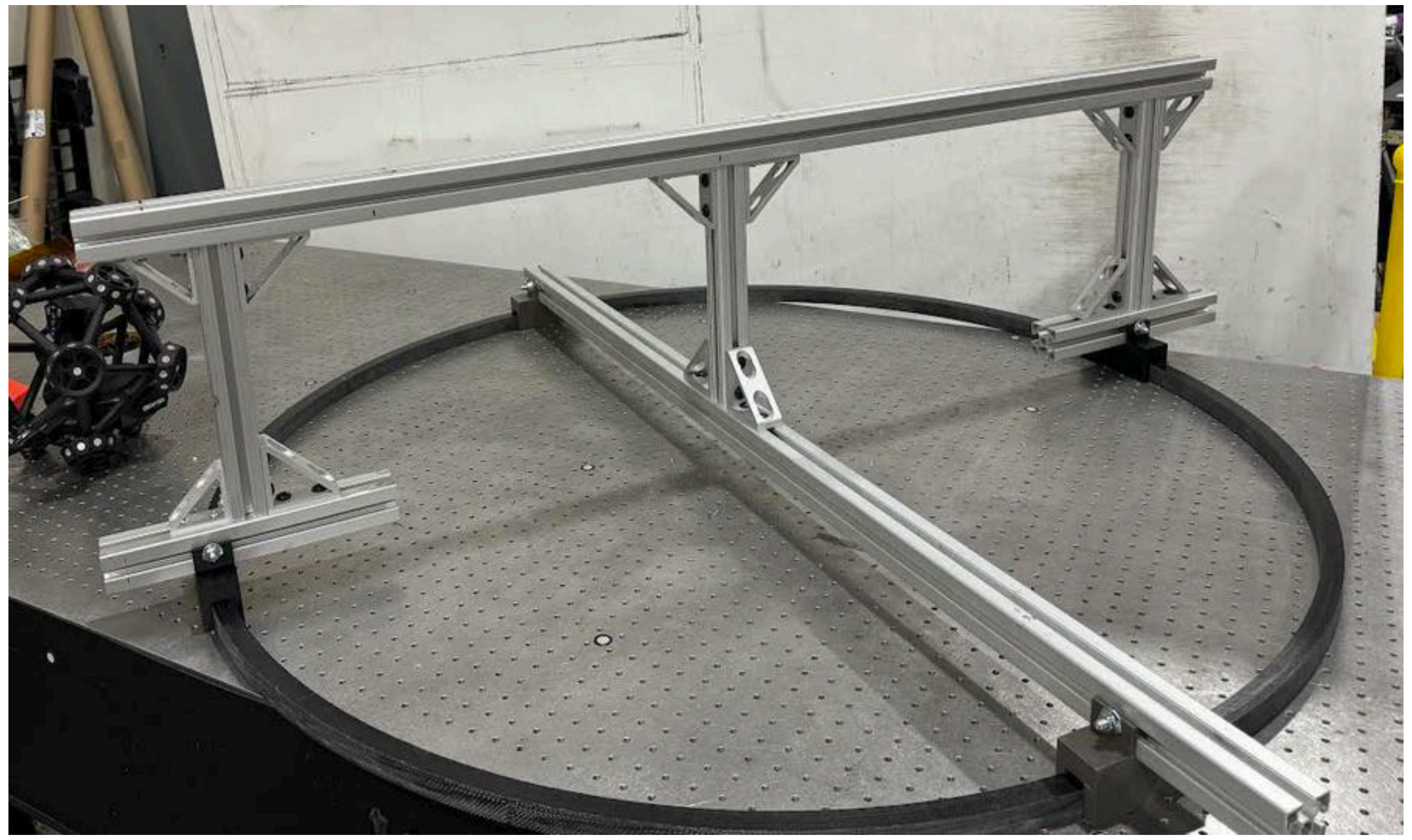
Figure 5.1: Scattered electron momentum distributions in PYTHIA 6 e+p collisions at 18×275 GeV compared to π^- before (open black squares) and after (green full squares) pfRICH veto in four η bins, covering full pfRICH η acceptance.

Vessel

- Good progress on all fronts
- Vessel should be ready in August



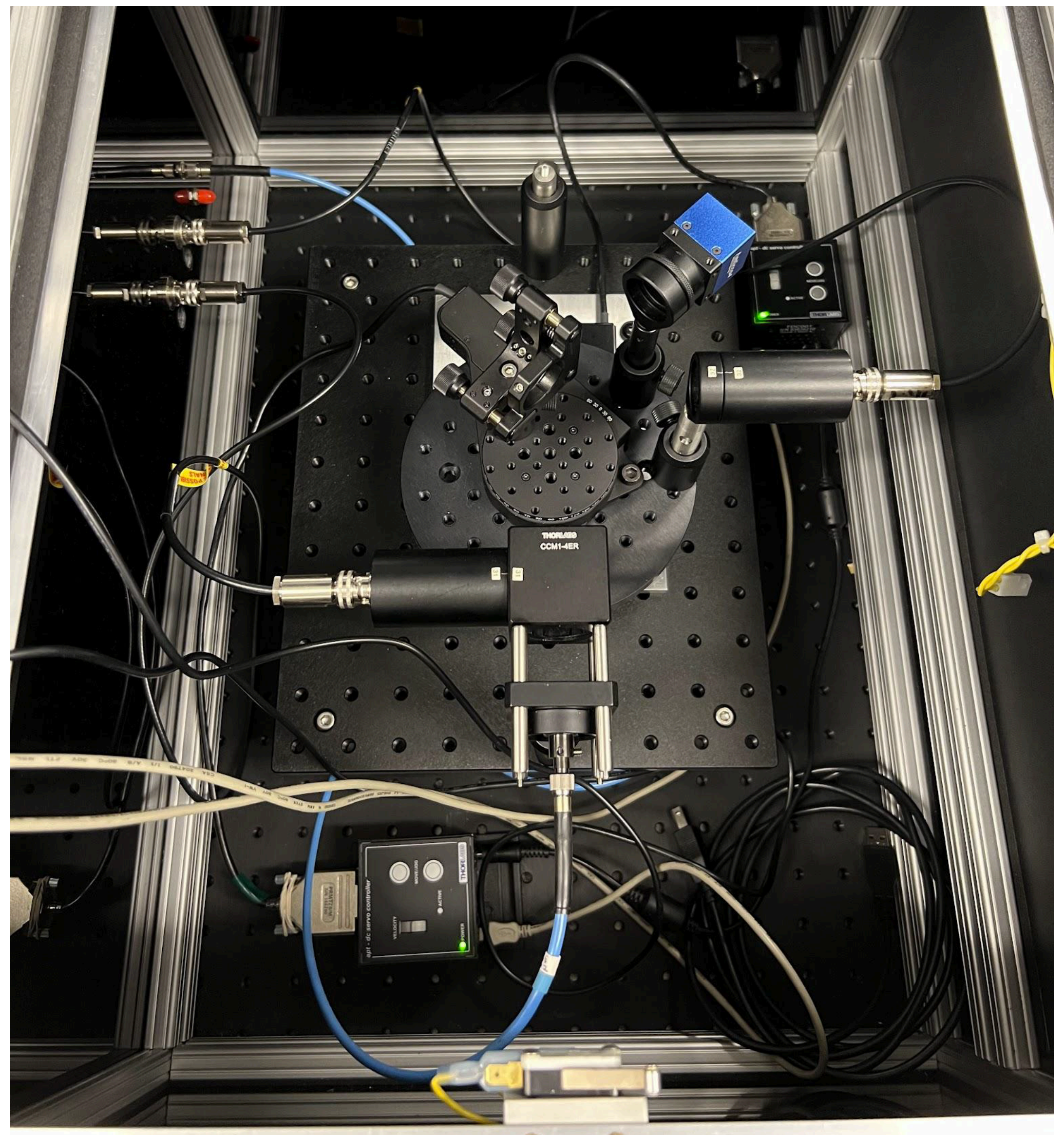
Mandrel & foam blocks (Stony Brook)



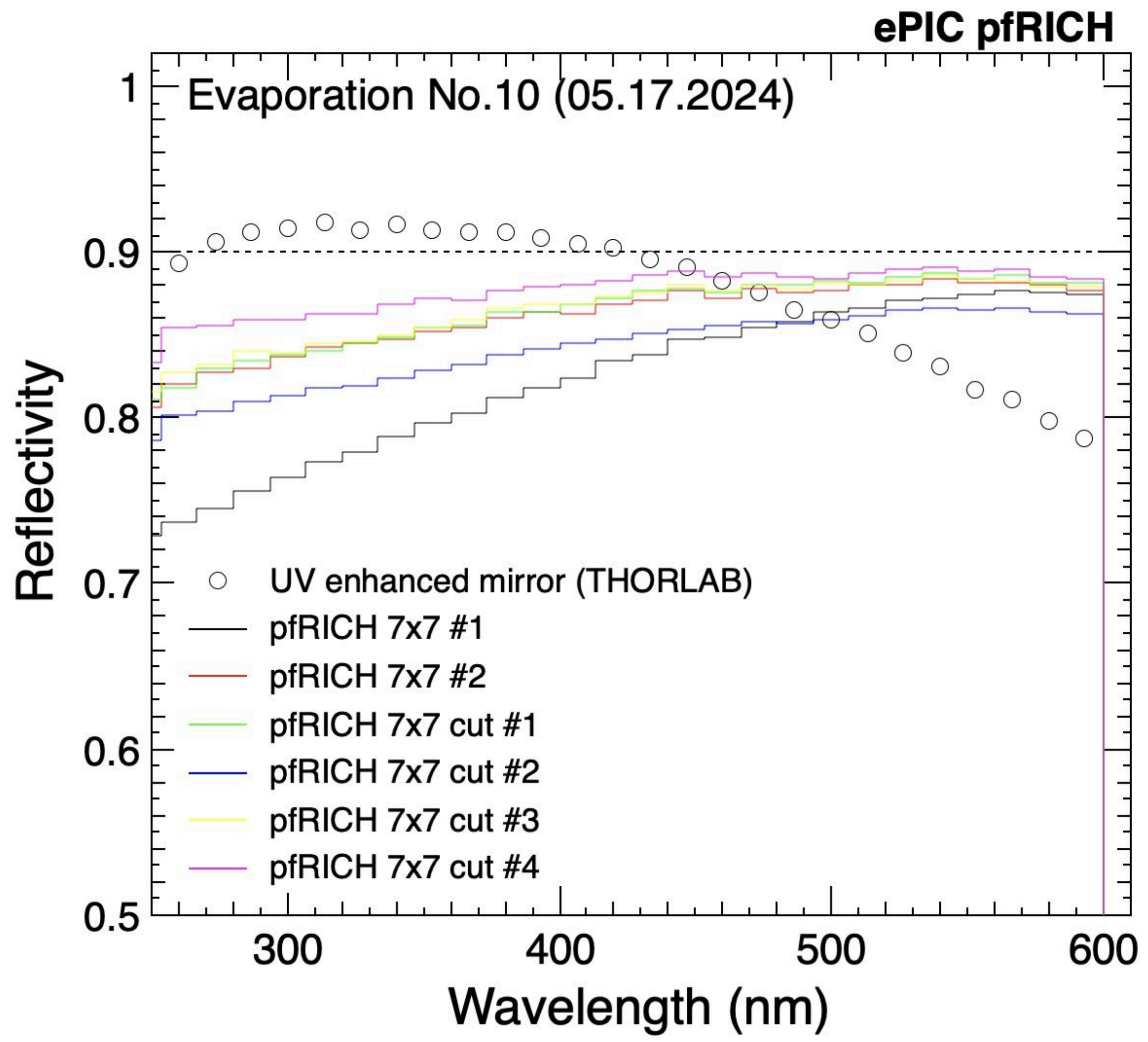
End ring construction (Purdue)

Mirrors

Evaporator (Stony Brook)

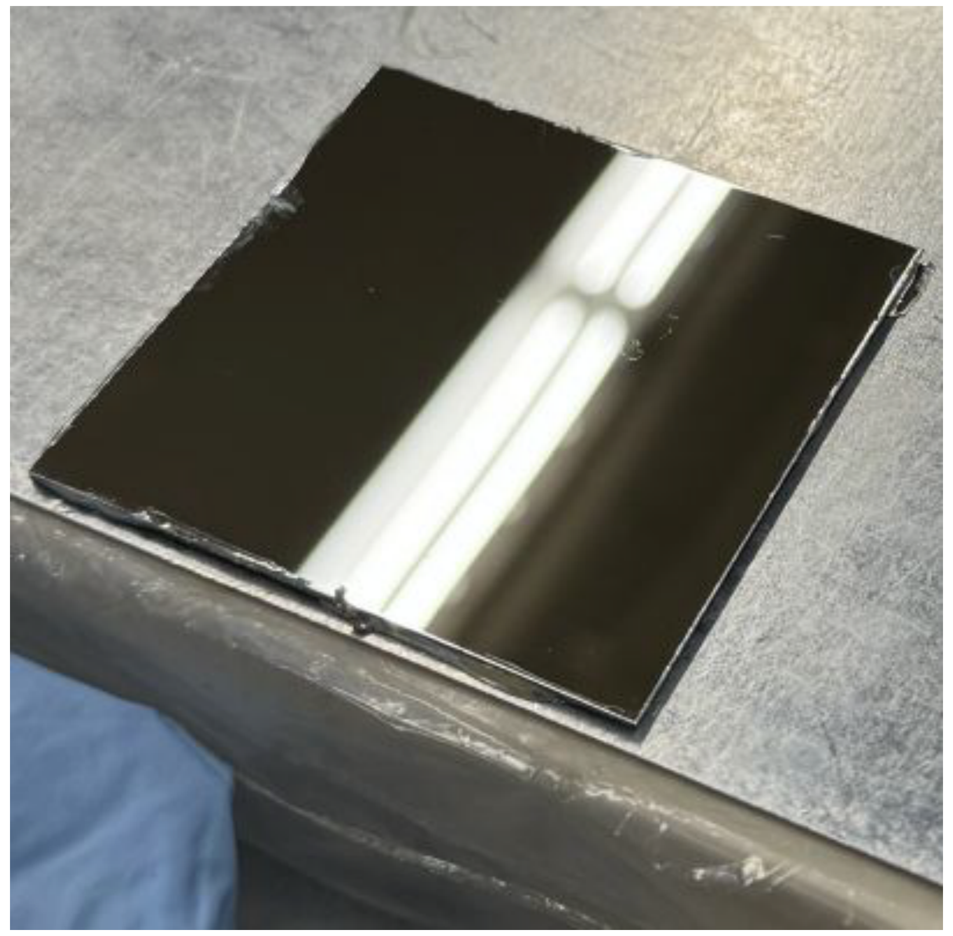


Mirror test stand (BNL)



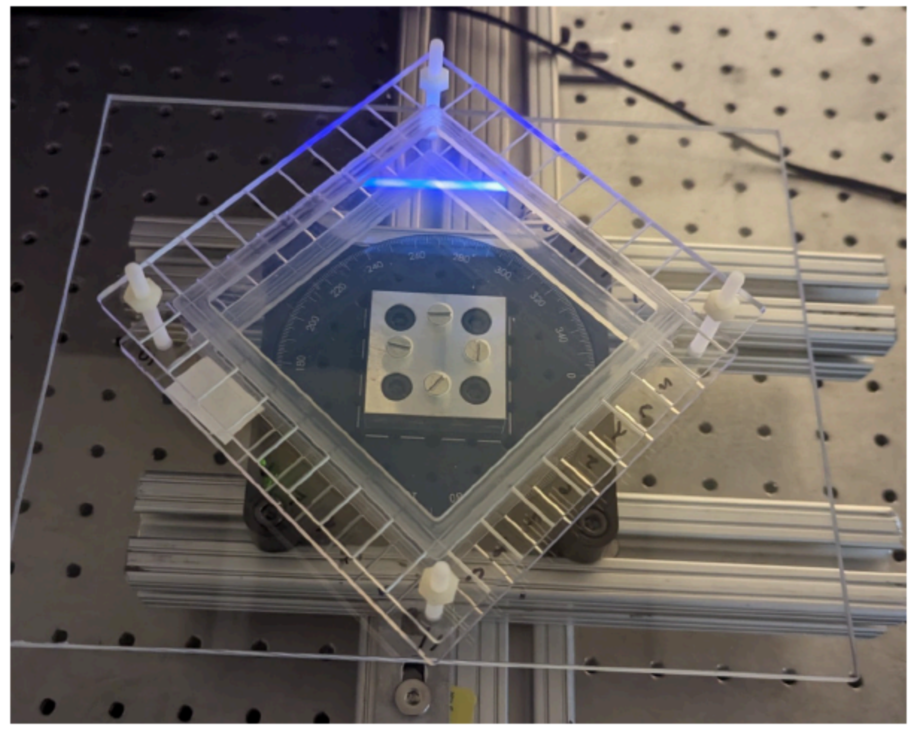
Reflectivity measurements

- Stony Brook evaporator refurbishment is in progress
- Ten coating exercises so far; getting close to required reflectivity
- Mirror reflectivity measurement tests stand at BNL commissioned
- Lexan co-bonding trials at Purdue are ongoing
- Conical mirror design is pretty much finished



Mirror sample

Aerogel

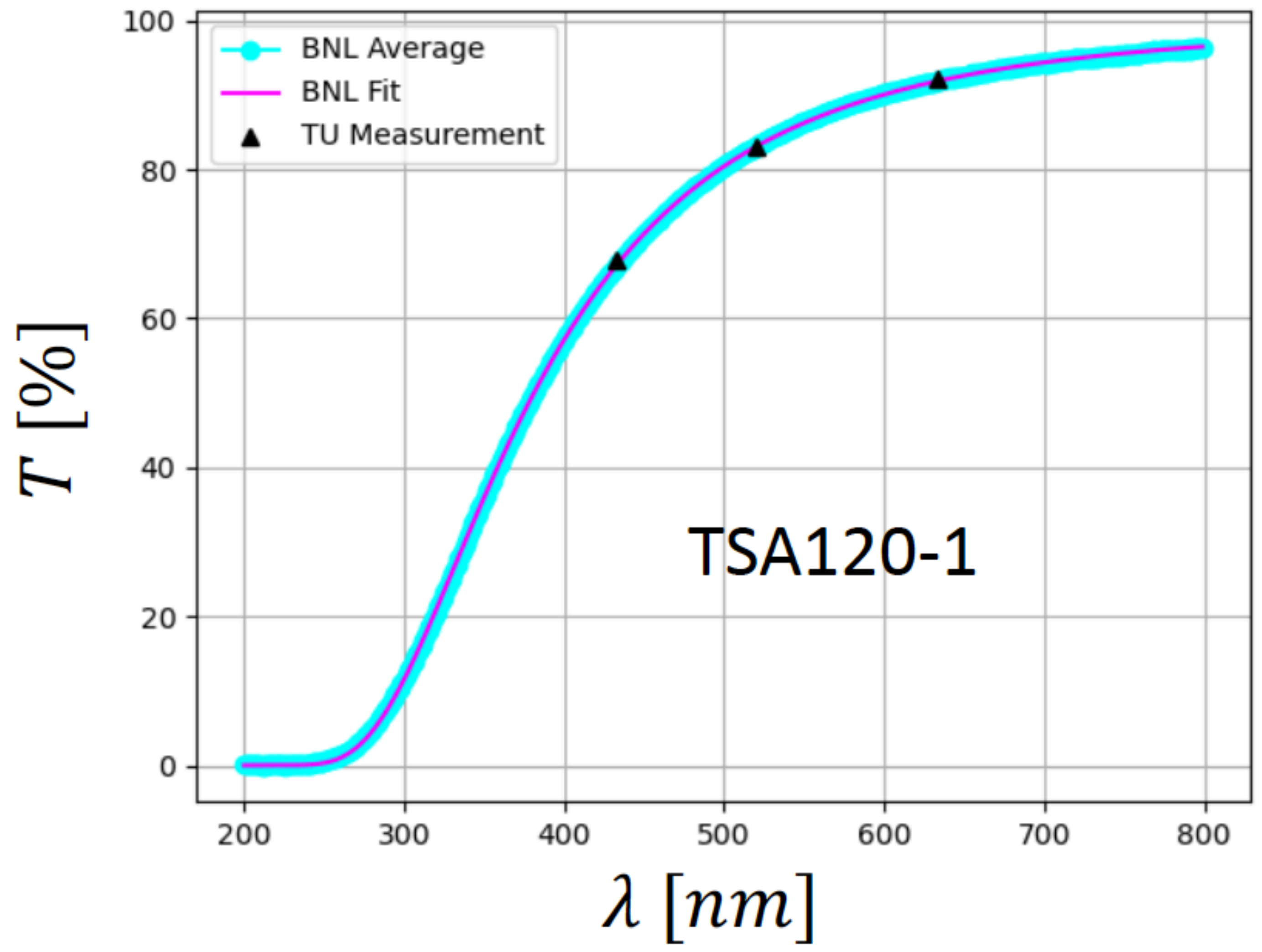


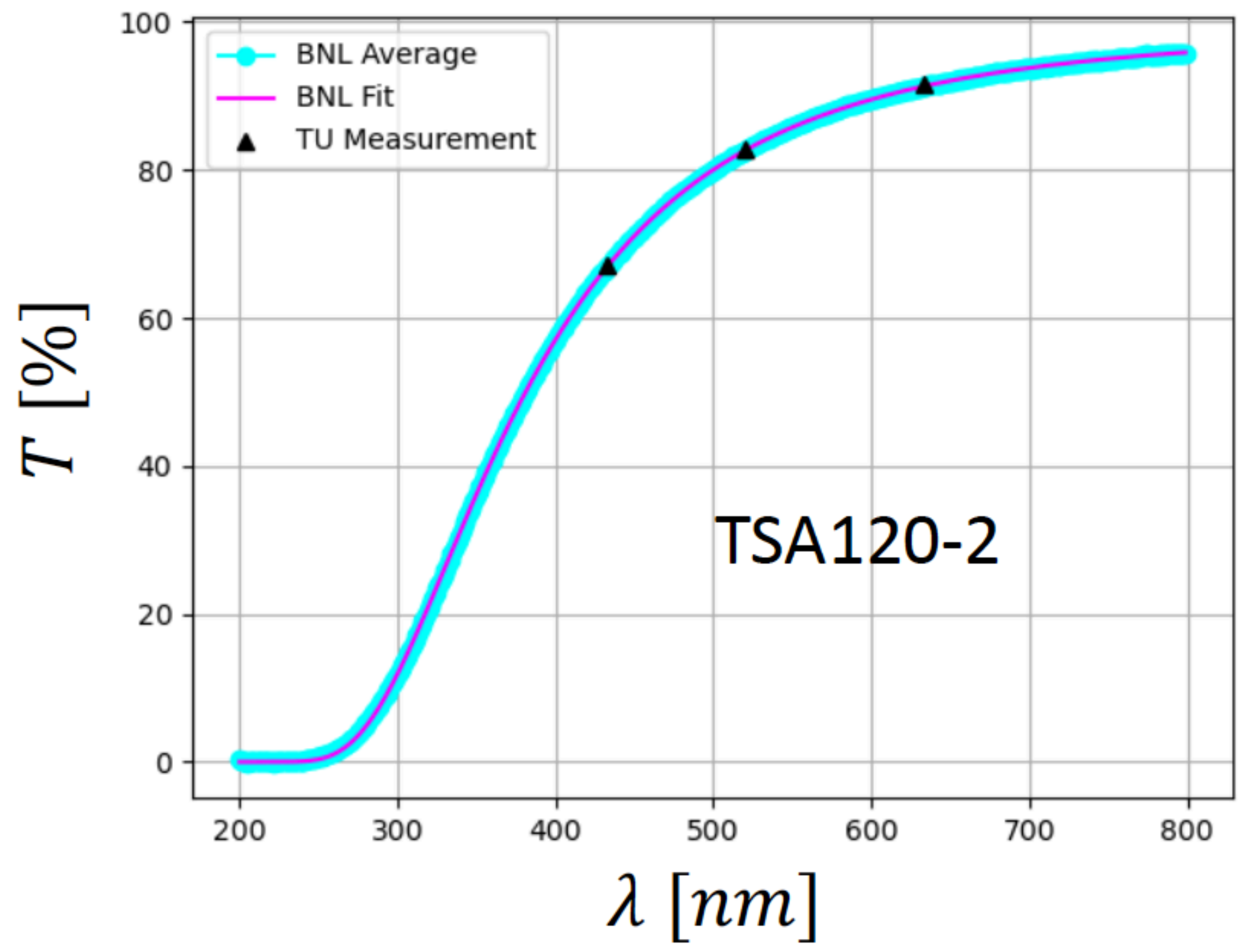
Comparison of TU (average of four corners) and Aerogel Factory index of refraction measurements

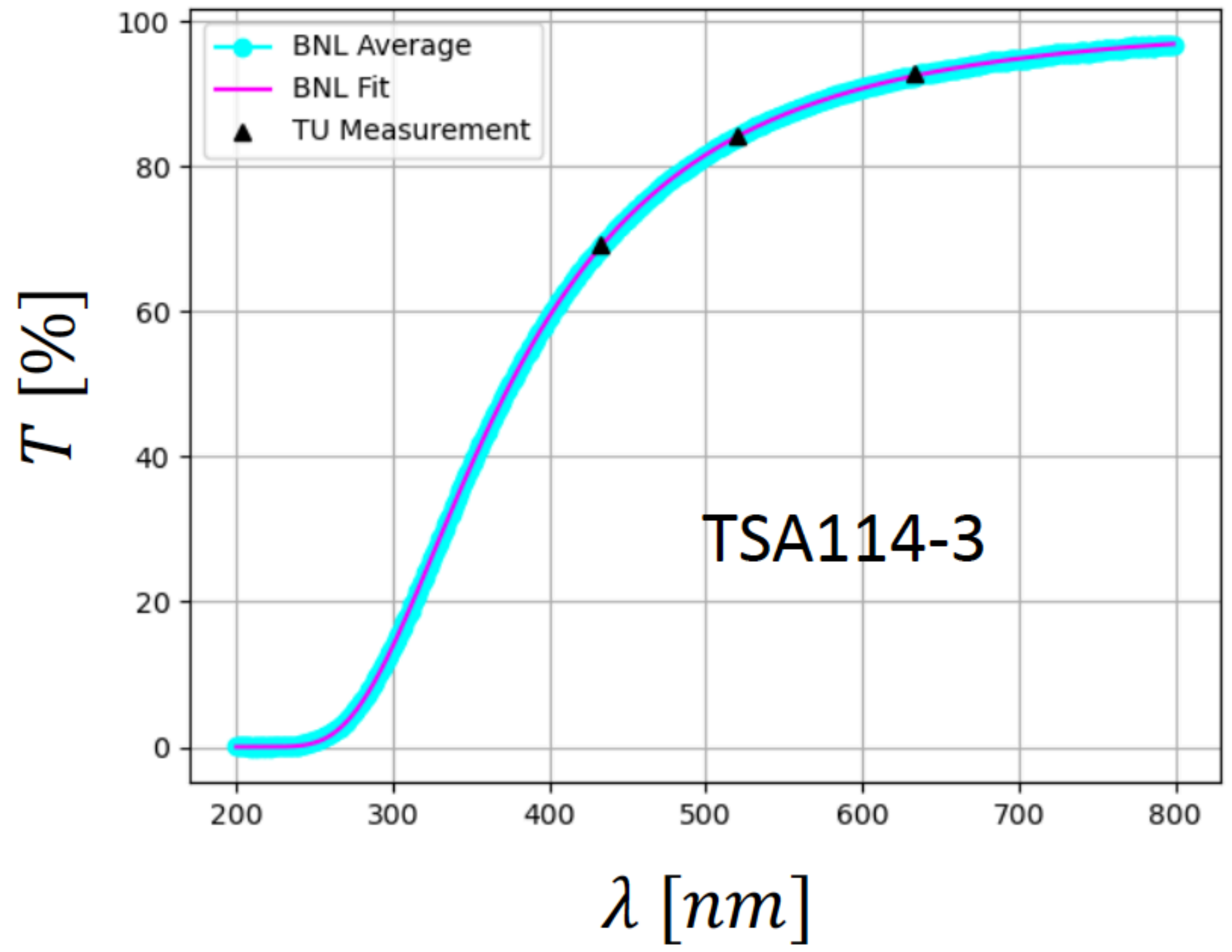
Tile	TU ($\lambda = 403\ nm$)	AF ($\lambda = 405\ nm$)	(TU-AF)/AF [%]
TSA88-1	1.0398 +/- 0.0007	1.0390	0.077
TSA120-1	1.0413 +/- 0.0011	1.0404	0.087
TSA120-2	1.0401 +/- 0.0025	1.0401	0.000
TSA114-3	1.0383 +/- 0.0026	1.0377	0.062

- Consistency within ~1% between Aerogel Factory, Temple & Brookhaven

Refractive index measurement comparison (Temple)







Transmittance measurement comparison (Temple / Brookhaven)

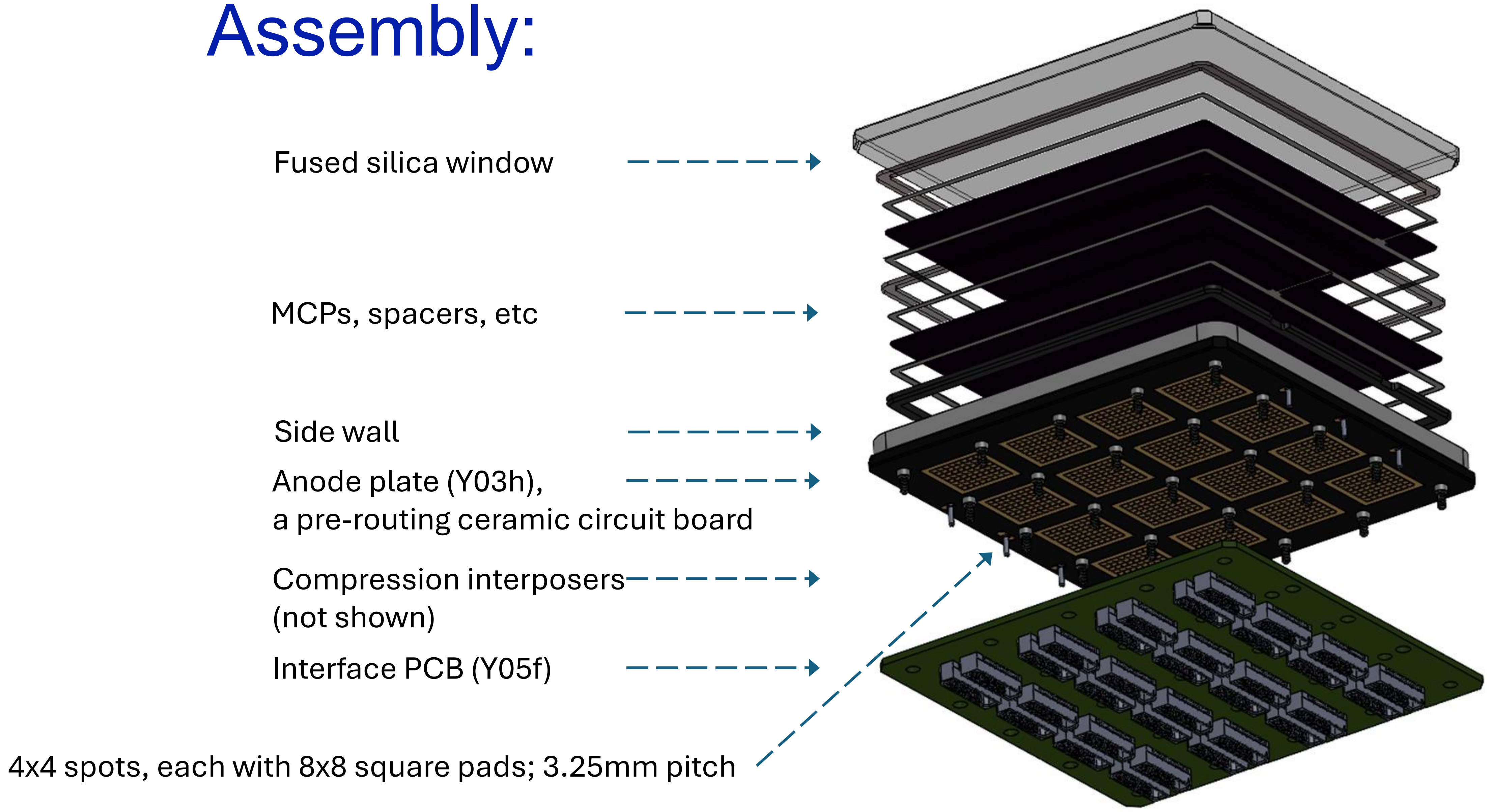
HRPPDs

Remaining 2 EIC specific HRPPDs send to JLab

First HRPPDs now at BNL being tested

Started regular meetings with eRD110 & INCOM (Wed 10am)

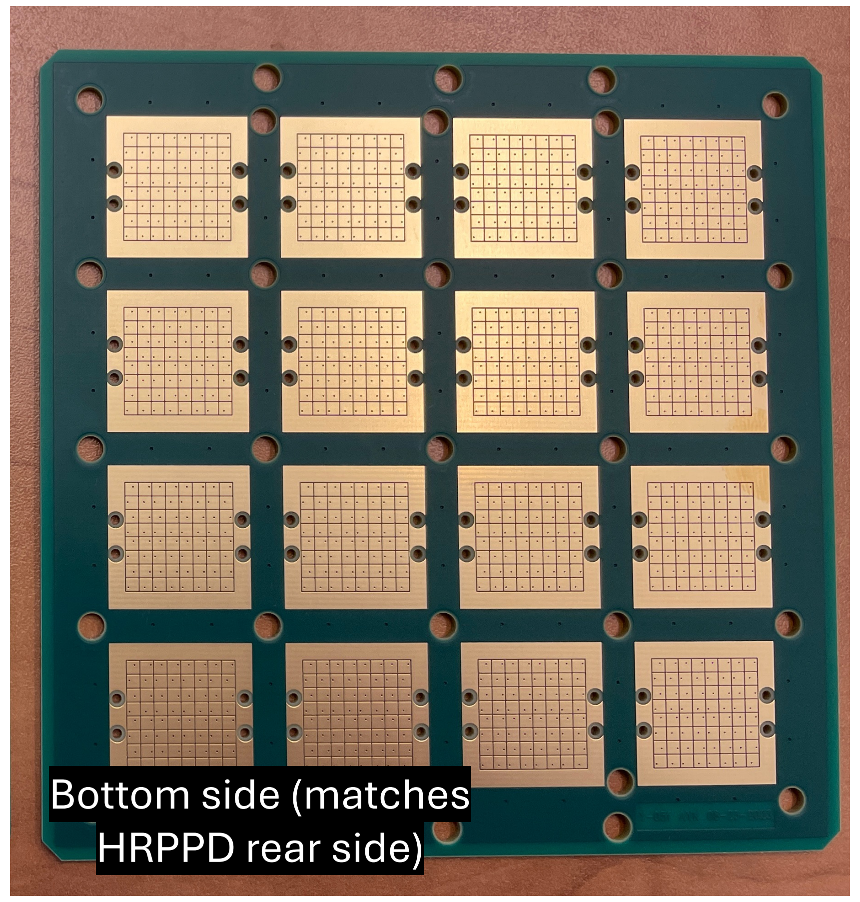
Assembly:



Charge path:

inner side anode pads
➟ anode plane stackup
➟ outer pads
➟ compression interposers
➟ interface PCB
➟ MMCX adapter PCB
➟ pigtail RG-316 (?) cables
➟ 6” RG-174 cables
➟ V1742 digitizer

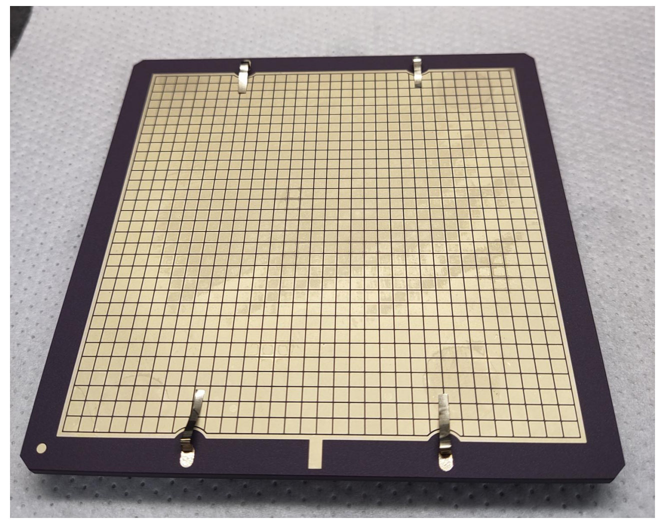
Passive interface PCB:

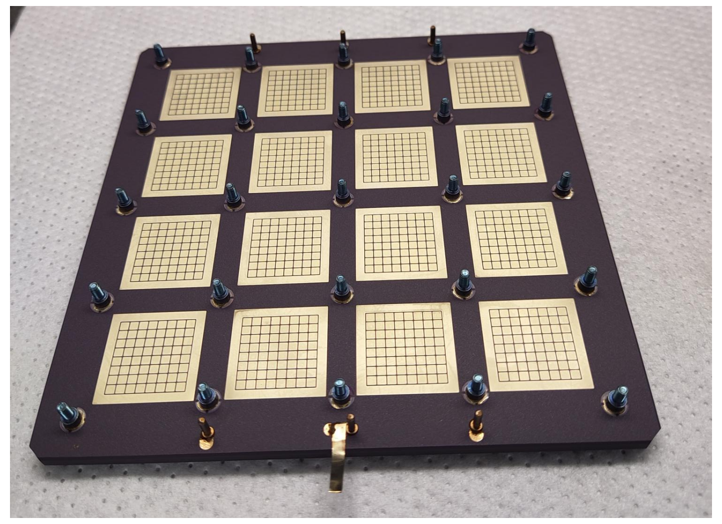

Bottom side (matches HRPPD rear side)

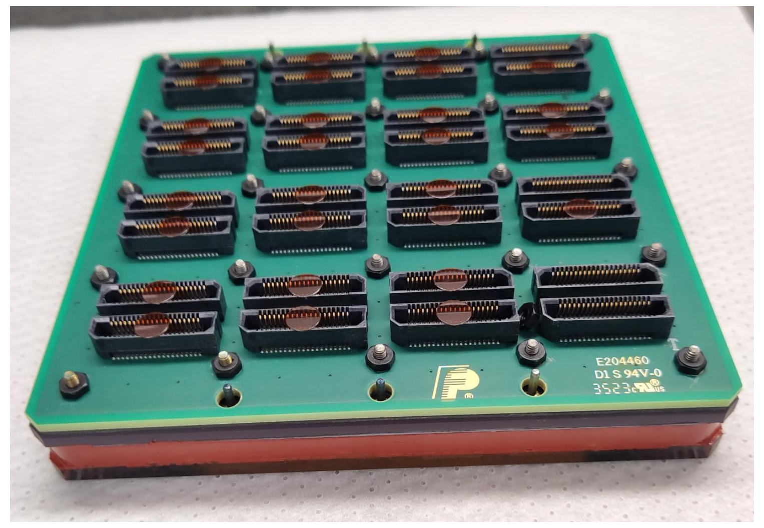

Top side (32x Samtec ERF8 connectors)

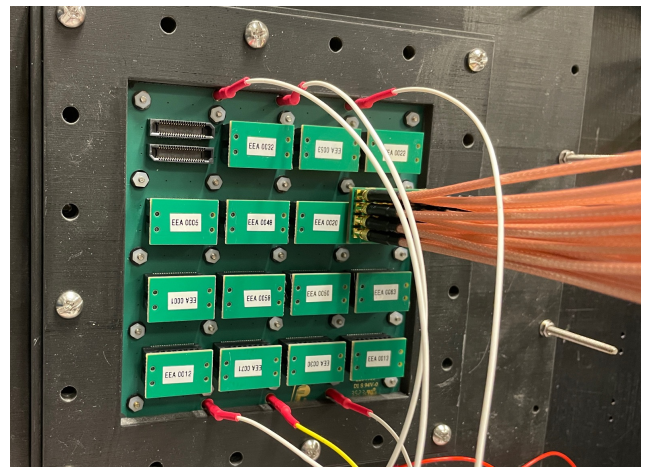
- A simple 119mm x 119mm two-layer board with Samtec ERF8 connectors

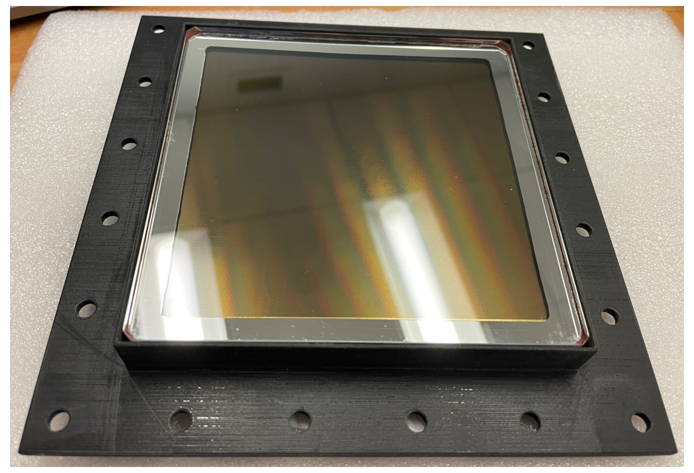
Gallery:

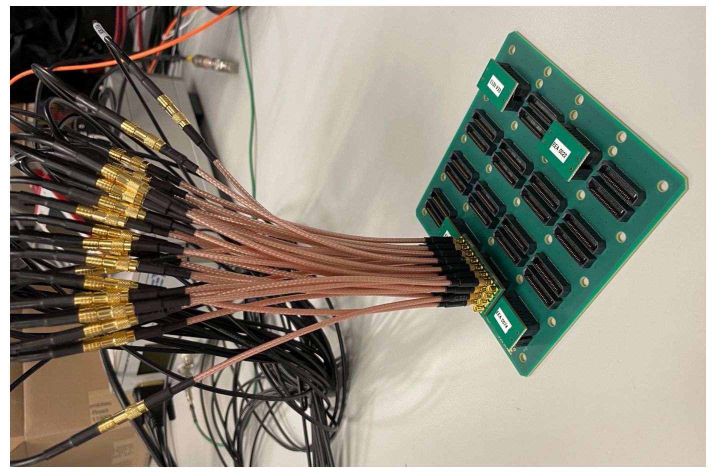

Anode plate vacuum side


Anode plate air side


With Y05f board mounted


With MMCX interface

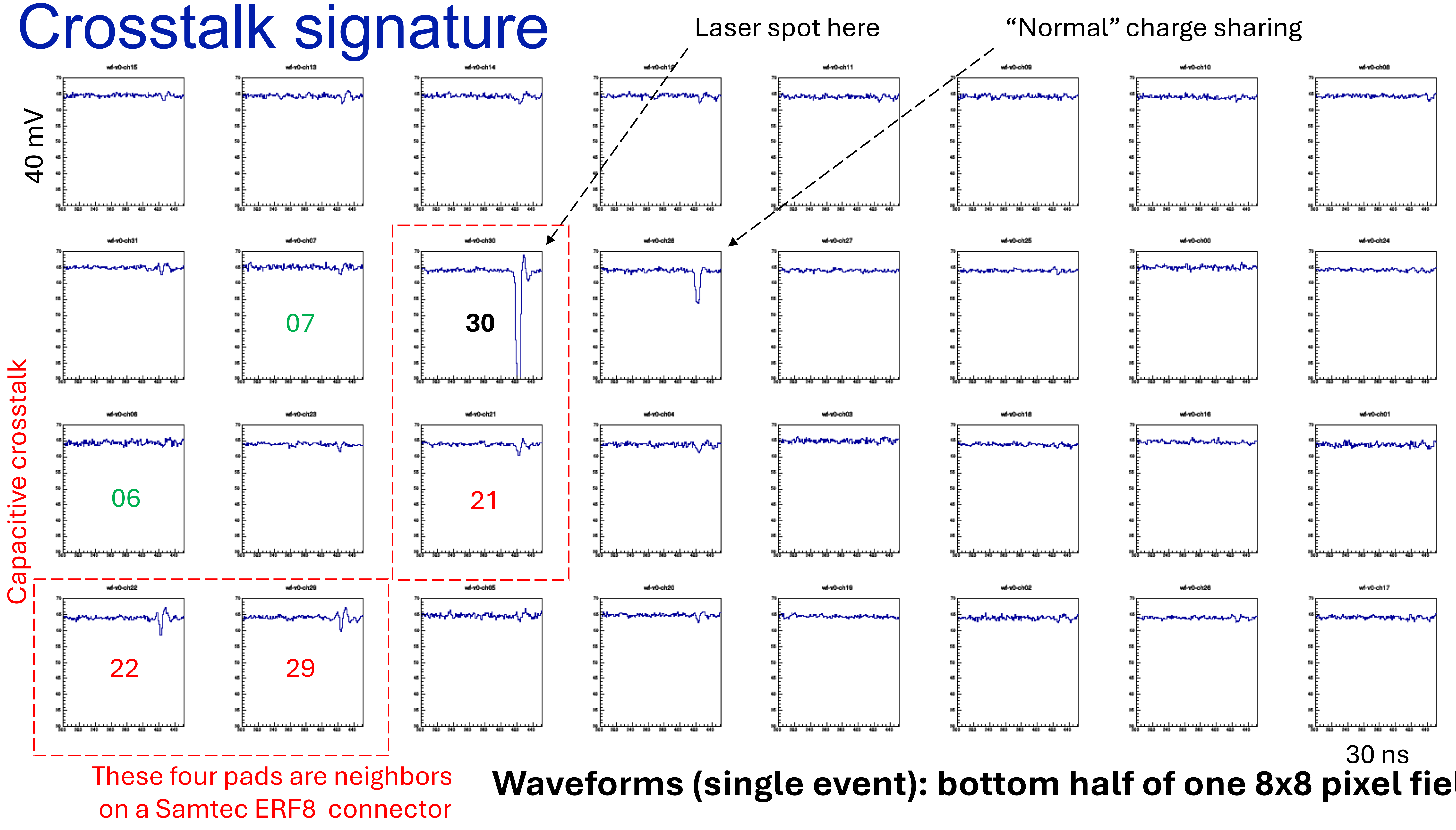

Fused silica window


MMCX -> MCX pigtail cables

Crosstalk

- Observe crosstalk in HRPPDs
- Most likely not related to HRPPD itself but to current backplane
- Good enough for single photon but not for high occupancies studies

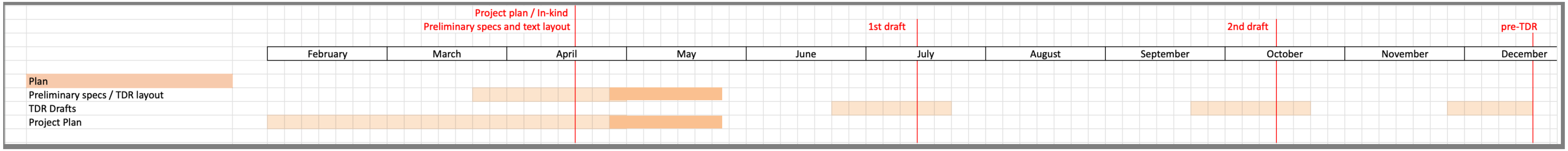
Crosstalk signature



Waveforms (single event): bottom half of one 8x8 pixel field

d*RICH*

TDR Effort (2024)



April: Preliminary specs & text layout Project plan / in-kind preview

July: 1st draft

October: 2nd draft

December: Pre-TDR

Assumptions: Pre-TDR (CD2) required at the end of the year
Scheme driven by manpower/lead time: remains the same for a TDR (CD3)
Extra-time needed for real-scale mechanics & RDO demonstrators

Si-PM Technical Specs

Parameters	Value	Notes (all parameters at the recommended operating voltage and T = 25 C, unless specified)
Device type	SiPM array	
Number of channels	64	8 x 8 matrix
Active Area	3 x 3 mm^2	active area of one channel, total active area is 64 x 3 x 3 mm^2
Device Area	< 28 x 28 mm^2	device area should be small such as to have > 75% fraction of active area over device total area
Pixel Size	40 - 80 um	pitch of the microcell SPAD
Package Type	surface mount	
Operating voltage	< 64 V	
Peak Sensitivity	400 - 450 nm	
PDE	> 35%	at peak sensitivity wavelength
Gain	> 1.5 10^6	
DCR	< 1.5 MHz	
Temperature coefficient of Vop	< 60 mV / C	
Direct crosstalk probability	< 10%	
Terminal capacity	< 600 pF	
Packing granularity		
Vop variation within a tray	< 300 mV	Vop variation between channels in one device
Recharge Time	< 100 ns	ctau recharge time constant
Fill Factor	> 70%	
Protective Layer	silicone resin (n = 1.5 - 1.6)	radiation resistant, heat resistant (up to T = 180 C)
DCR at low temperature	< 10 kHz	at T = -30 C
DCR increase with radiation damage	< 1 MHz / 10^9 neq	at T = -30 C, after a radiation damage corresponding to 10^9 1-MeV neutron equivalent / cm^2 (neq)
Residual DCR after annealing	< 25 kHz / 10^9 neq	at T = -30 C, after a radiation damage of 10^9 neq and a 150 hours annealing cycle at T = 150 C
Single photon time resolution	< 200 ps FWHM	corresponding to < 85 ps RMS

SiPM LLP Review Sep 2023

Baseline sensor

64 (8x8) channel SiPM array

3x3mm2/channel

very important parameters to ensure detector performance over the years

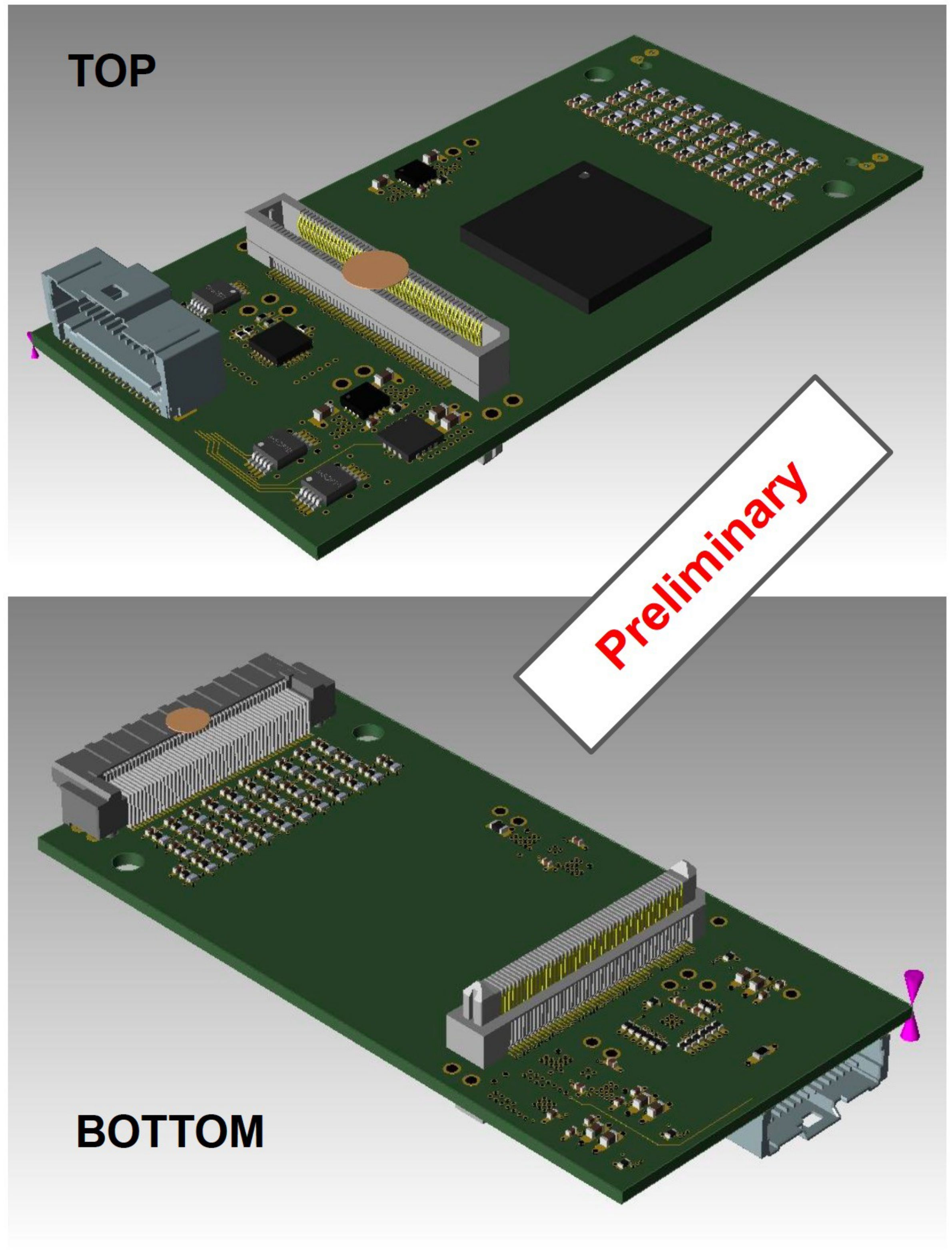
we will evaluate as part of QA, testing sensor samples in received batches

Preliminary Specs: ALCOR FEB & RDO & Mirror

ALCOR FEB:

Preliminary selection of connectors and components:

- **Linear Regulators** (2.5 V DVDD_IO, 1.2 V DVDD, 1.2 V AVDD): *Analog Devices ADP1752ACPZ-2.5-R7, ADP1761ACPZ-R7*
- **Current monitors** (before regulators): *Microchip Technology MIC2040-1YMM-TR*
- **I2C to Parallel-Port Expander** (read/control regulators and current monitors): *Texas Instruments PCF8575RGER*
- **RC High Pass Filter** (AC-coupling between SiPMs and ALCOR)
- **Annealing circuit**: to be included

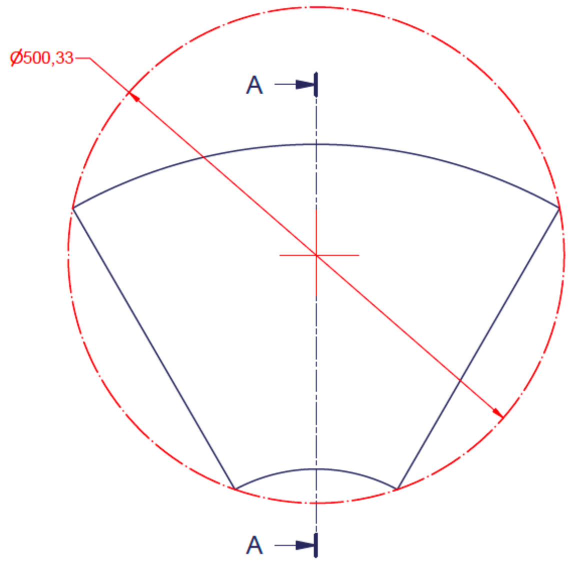


RDO:

Component function	QTY	Baseline option	V	Comments
Main FPGA	1	Xilinx AU15P-SBVB484	0.85, 0.9, 1.2, 1.8 , 2.5	Artix Ultrascale+ Overview
Scrubber FPGA	1	Microchip MPF050T-FCSG325	1.0 1.2 1.8	Polarfire overview
QSPI Flash	1	MT25QU01	1.7 - 2.0 V	package W9 6x8 mm Datasheet
VTRX+	1	CERN	1.2V, 2.5V	https://edms.cern.ch/ui/file/2149674/1/VTRxPlusApplicationNote.pdf
SIPMbus connector	2	Samtec ERF5-020-05.0-L-DV-TR	N/A	
ALCORbus connector	2	Samtec ERF5-050-05.0-L-DV-K-TR	N/A	
ADC for NTC (4 = 1 per FEB)	2	Texas Instruments ADS1219-4	2,3-5.5 V	3x3 mm (WQFN package) Datasheet
IO expander (I2C)	2	Microchip MCP23017	1.8-5.5 V	likely needed: we save 32 I/O on FPGA 6x6 mm 16 I/O https://ww1.microchip.com/downloads/aemDocuments/documents/APID/ProductDocuments/DataSheets/MCP23017-Data-Sheet-DS20001952.pdf
LDO	2	LTM4709	VDH VDL	6x12 mm Datasheet link, Demo board link
Temperature sensors	2	TMP116NAIDRVT or TMP119	2.5	Close to LDO and VTRX https://docs.rs-online.com/2b49/A700000009837783.pdf https://www.ti.com/lit/ds/symlink/tmp119.pdf?ts=1711373203560&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FTMP119
Step-Up Charge Pump	1	LTC3203	VDH	ededDH VBIAS a LDO Datasheet
uC to read current monitor	1	ATtiny416	VDH	Datasheet
Clock multiplier/ jitter cleaner	1	SkyWorks SI5326	1.8 or 2.5 V	6x6 mm, 2 input - 2 output Family Datasheet and Si5326 Datasheet
3OT Crystal for Si5236	1		N/A	3.2 x 2.5 mm SkyWorks guidance
Crystal oscillator	1			A 98.5 MHz crystal or "similar"

Mirror:

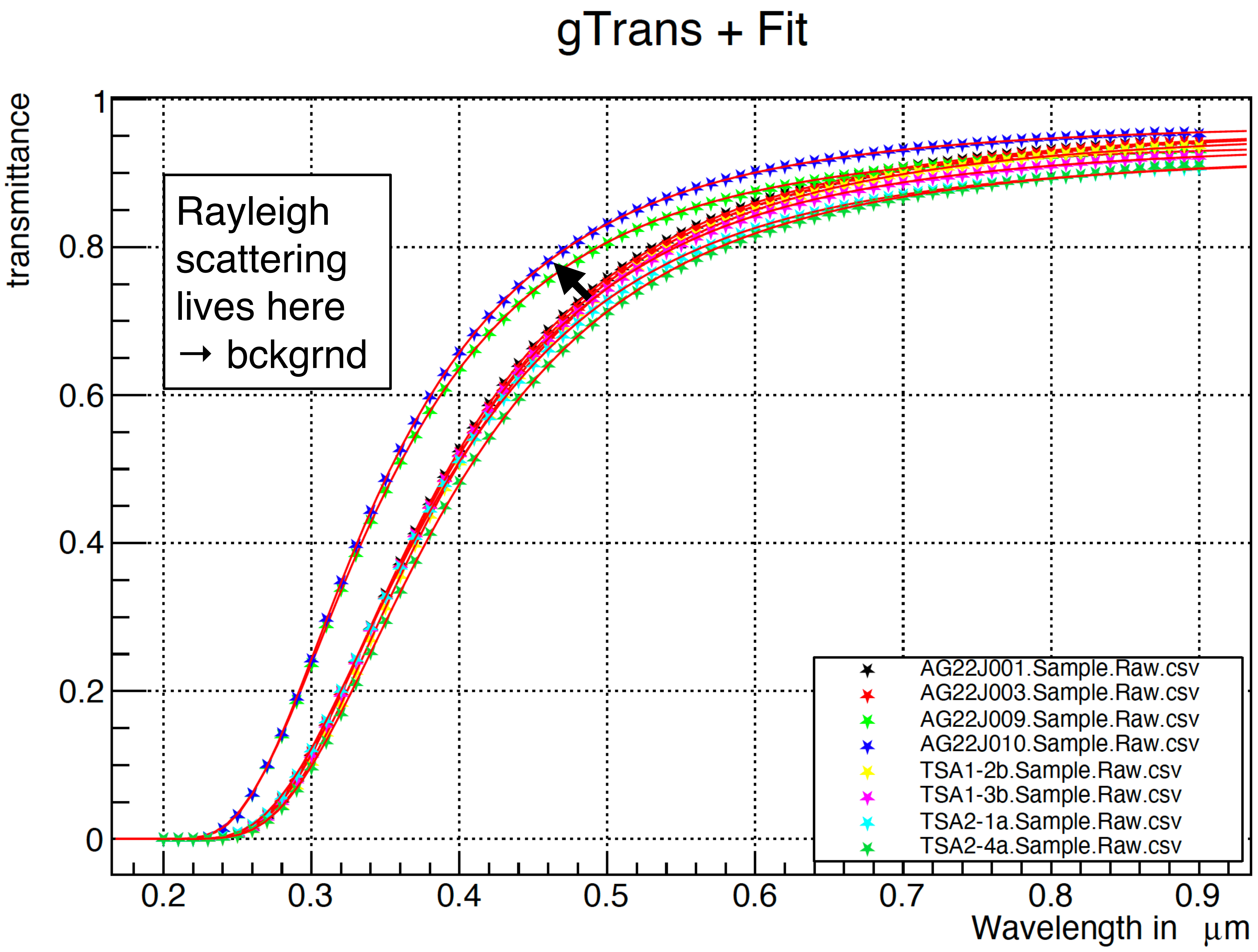
- Radius within 1% of nominal RoC value (the nominal RoC values is defined by the customer before production in the range 2000 mm +/- 10%),
- Roughness < 2 nm,
- Pointlike image spot size D0 < 2.5 mm,
- Compatibility with fluorocarbon gases (C_2F_6),
- Compatibility with SiO_2 reflecting coating.



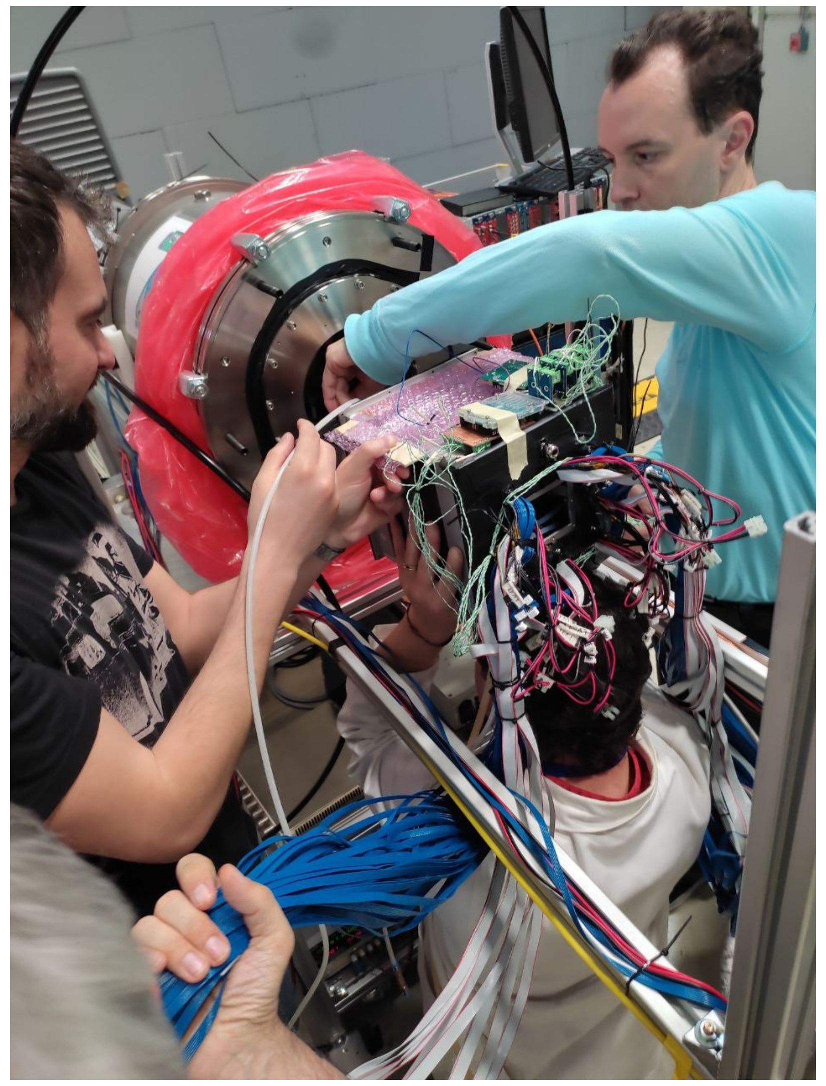
Preliminary Specs: Aerogel

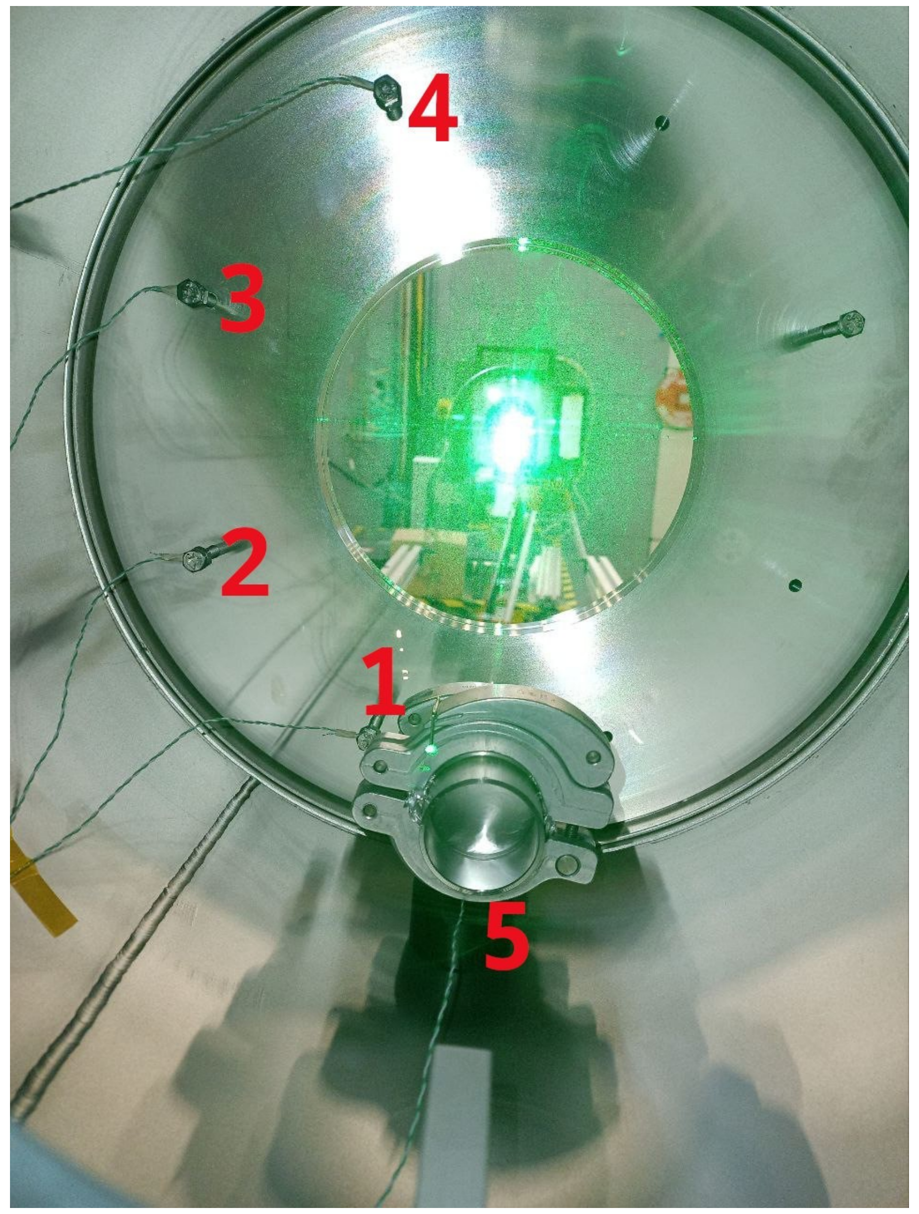
Optimization ongoing in the refractive index rage 1.02-1.03

New samples received from Aerogel Factory

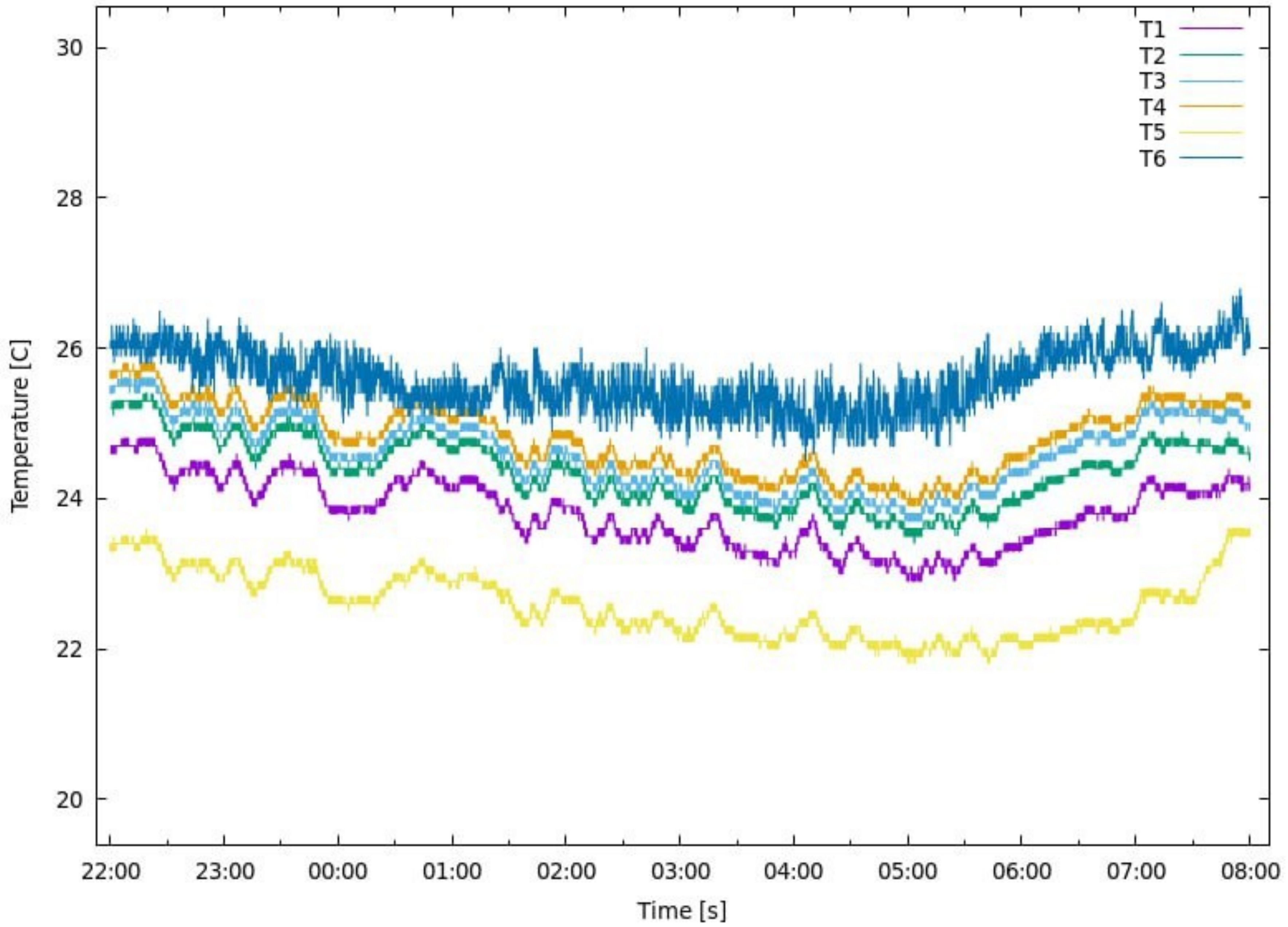


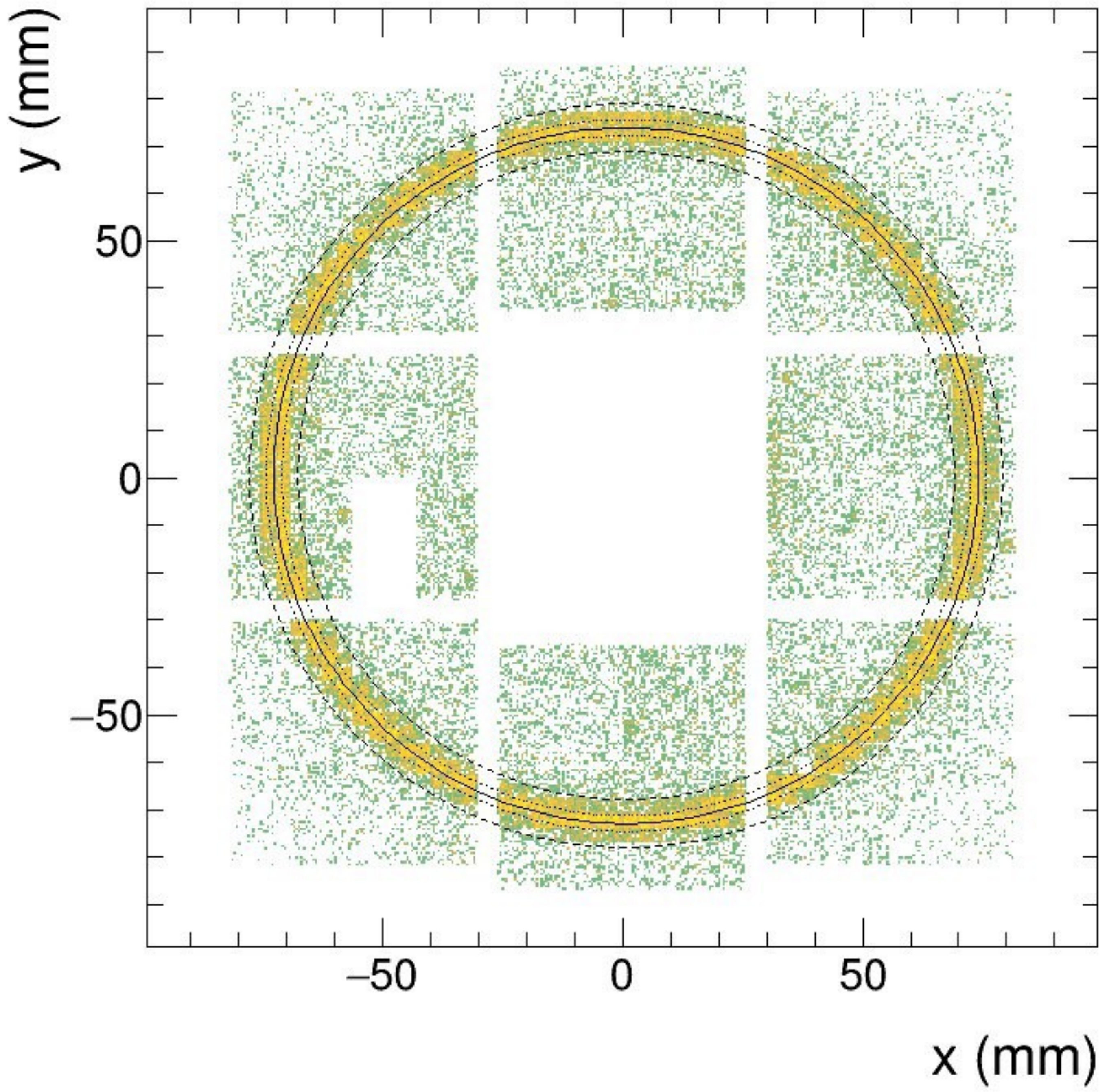
Prototype Test Beam at CERN





Temperature:





Aerogel Imaging:

$X_0 = 0.72 \pm 0.01$ mm

$Y_0 = 0.50 \pm 0.01$ mm

$R = 73.42 \pm 0.01$ mm

$\sigma_R = 1.68 \pm 0.01$ mm

$N_{sig} = 20.12 \pm 0.09$

$N_{bkg} = 12.55 \pm 0.10$

hp*DIRC*

hpDIRC Annual Workshop in Jefferson Lab

- May 16th – 22nd (https://indico.bnl.gov/event/23332/)
- 11 participants in person, 7 participants online (some only for specific sessions)
- All sessions had focus on TDR readiness and overall hpDIRC/ePIC schedule
- Designated TDR sessions used to identify remaining studies, required figures, and write detailed plan
- Several days before and after the meeting were used to work on hpDIRC project planning, schedule, and updating P6 plan

Day	Date	Morning	Afternoon
Thursday	May 16	MCP-PMTs	Sensors SiPMs / TDR
Friday	May 17	Test Besam NIM paper	BaBar bar boxes / eRD103
Saturday	May 18	Simulation Studies	CRT / PicoSec / eRD103
Sunday	May 19	ePIC Simulation	TDR
Monday	May 20	Simulation Studies	BaBar bar boxes / eRD103
Tuesday	May 21	Mechanical Design	TDR
Wednesday	May 22	TDR	BaBar bar boxes / Project Planning

TDR Section Outline Prepared

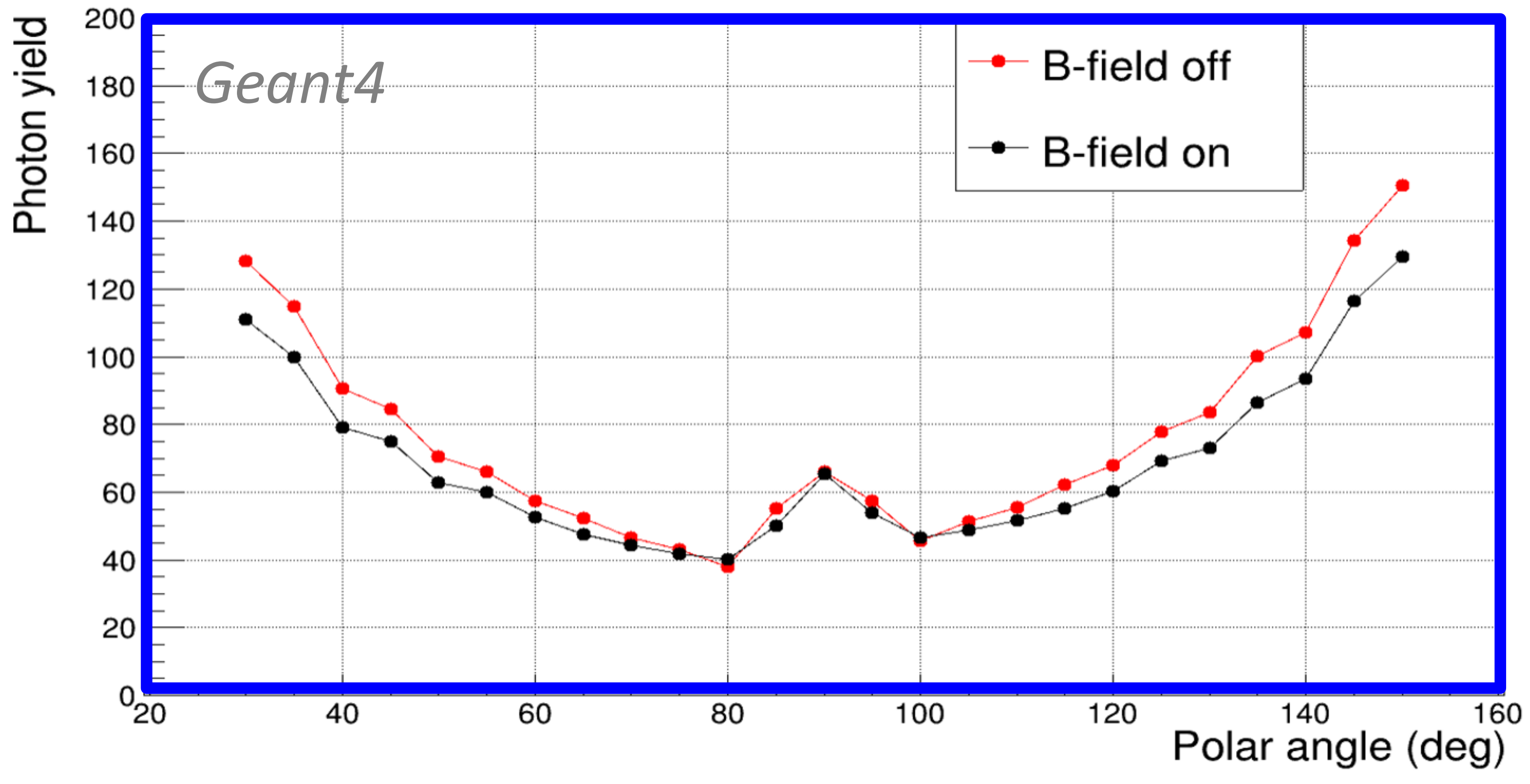
- Relevant needed figures identified
- Some needed figures will be referenced (B field, radiation map, etc.), might include them in paper with ZOOM to hpDIRC region
- Detailed breakdown of needed content – ready to write!
- Remaining questions/studies identified and assigned
- Performance plots will be updated for final geometry and are easy to adjust to uniformly agreed representation and style with other systems

Section	Subsecion	Content
Requirements/Motivation		
	Performance	
	Integration	
System Description		
	Concept	hpDIRC unique aspects
	Design	description of components, how the required performance (KPP) will be achieved
	Performance	description of simulation and reconstruction method, CERN validation
	Calibration	alignment - survey marks, experimental data for calibration
Implementation		
	Mechanical	Design and integration, Assembly of modules, Installation
	Services	nitrogen, cooling, voltage, controls and monitoring, laser calibration
	Other activities needed	
	QA	CRT (Full module), Readout (Sensors + Front-end Electronics), Bars/Mirrors (Laser Lab in JLab), Prisms (?), Lenses (ODU setup)
	Timeline, workforce, work packages	
	ES&H	
	Risk mitigation	Readout electronics, Sensor (Whatever is not tested)

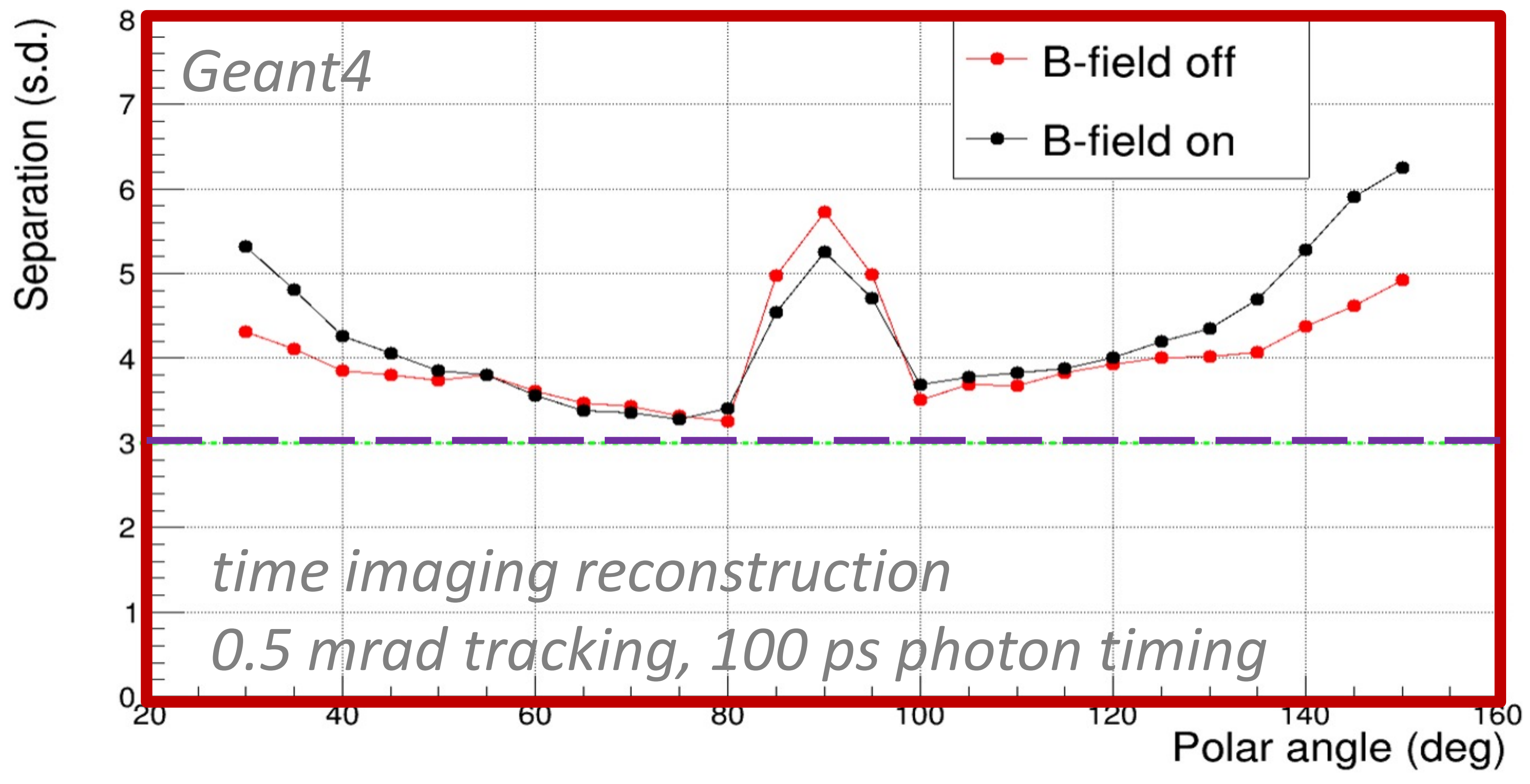
Performance Studies

- Updates to hpDIRC reconstruction previously done have no impact on performance, small impact on acceptance
- Studies of hpDIRC performance were done with test beam validated simulation
  - Realistic ePIC magnetic field map was used
  - Studies with Pythia physics events were done
  - Multiple tracks per event in single bar showed very small impact on performance
  - Most studies assumed 0.5 mrad angular tracking resolution but software ready to import and include detailed parametrization of tracking

Photon yield per particle



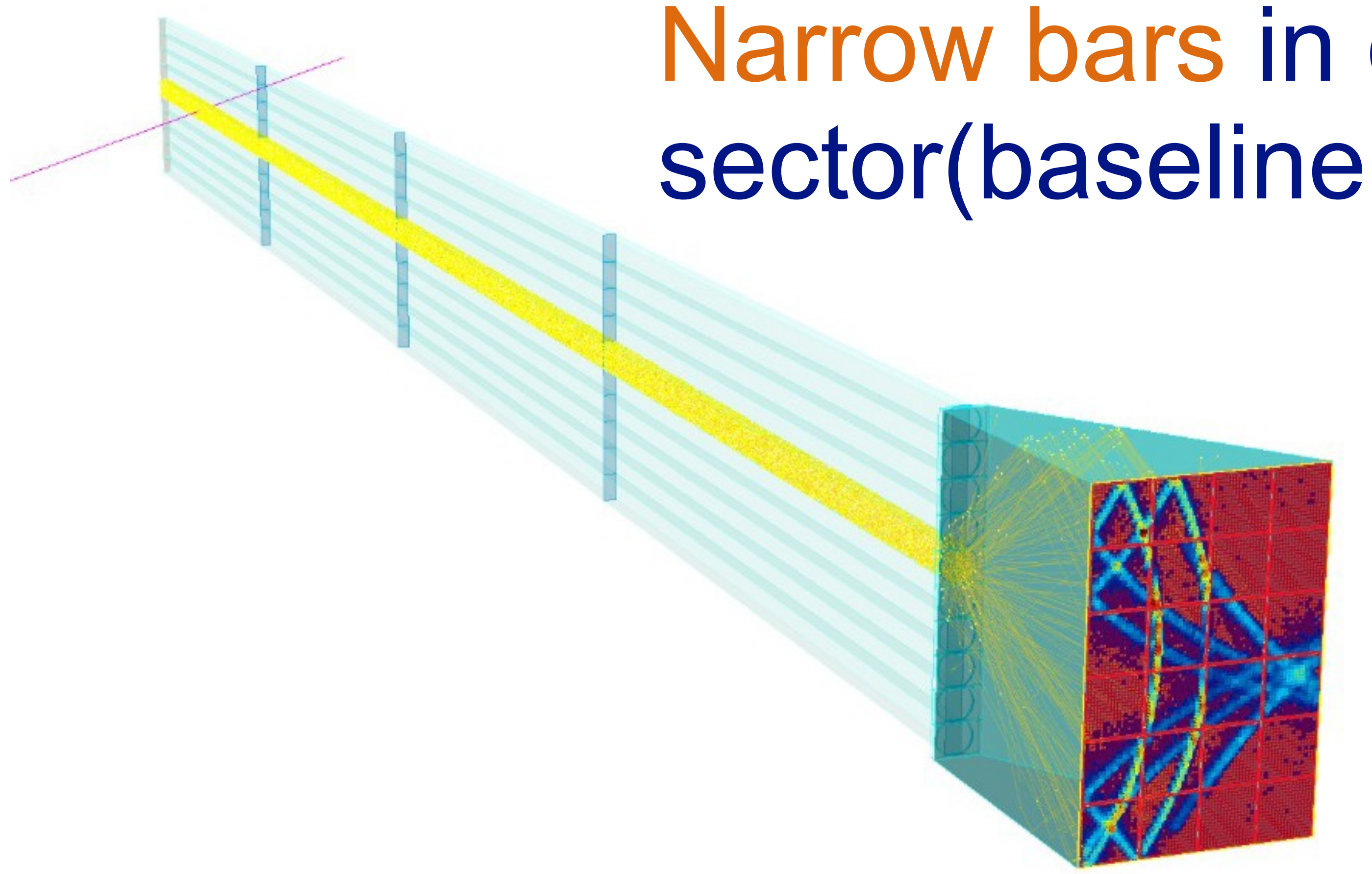
π/K separation power at 6 GeV/c



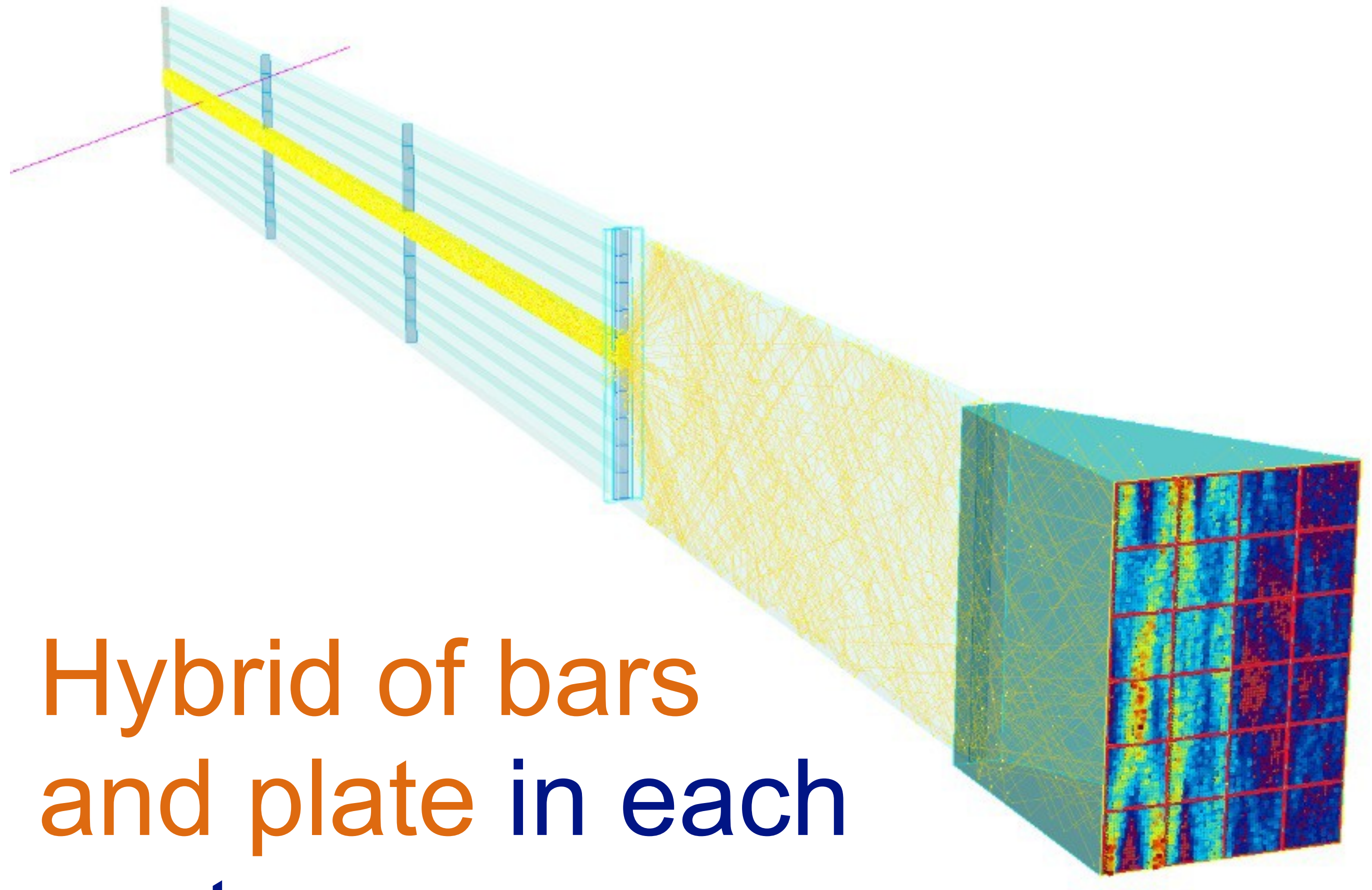
TDR Preparations: Remaining Questions/Studies

- Possibility of reusing BaBar DIRC bars
  - late fall (currently still in boxes)
- Decision on plate vs narrow bars for lightguide section
  - late summer/early fall
- Optimal bar width in case new are needed
  - late summer/early fall
- ”Split-Prism” expansion volume option as part of cost/risk mitigation
  - late summer/early fall
- Potential software-based multiple scattering mitigation
  - late summer/early fall

Geant4 visualization of the two light-guide options



Narrow bars in each sector(baseline)

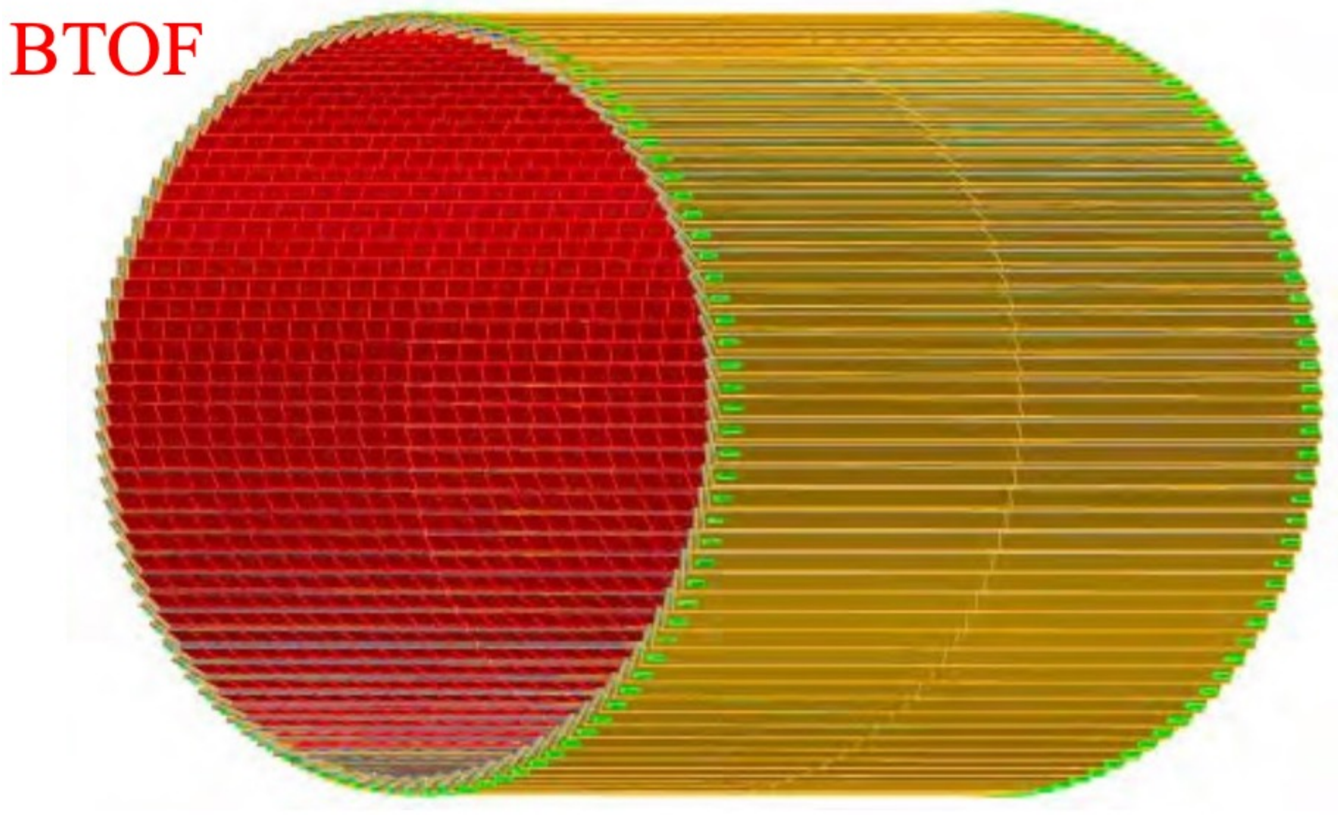


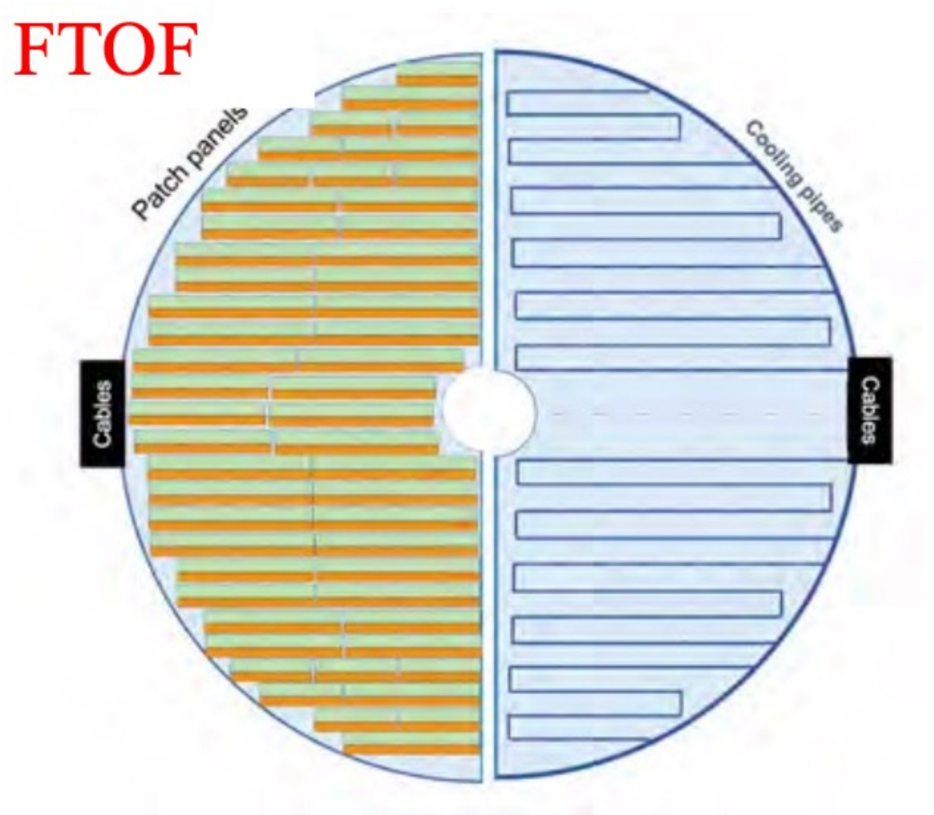
Hybrid of bars and plate in each sector

ToF

ToF - Key Elements for TDR

Detector configurations and Key requirements

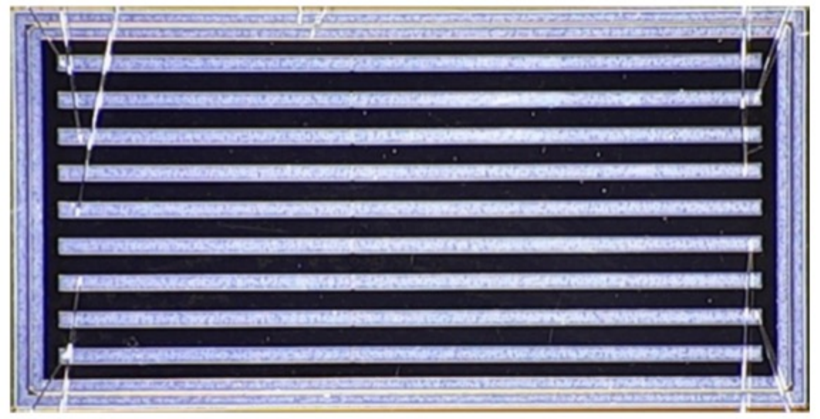


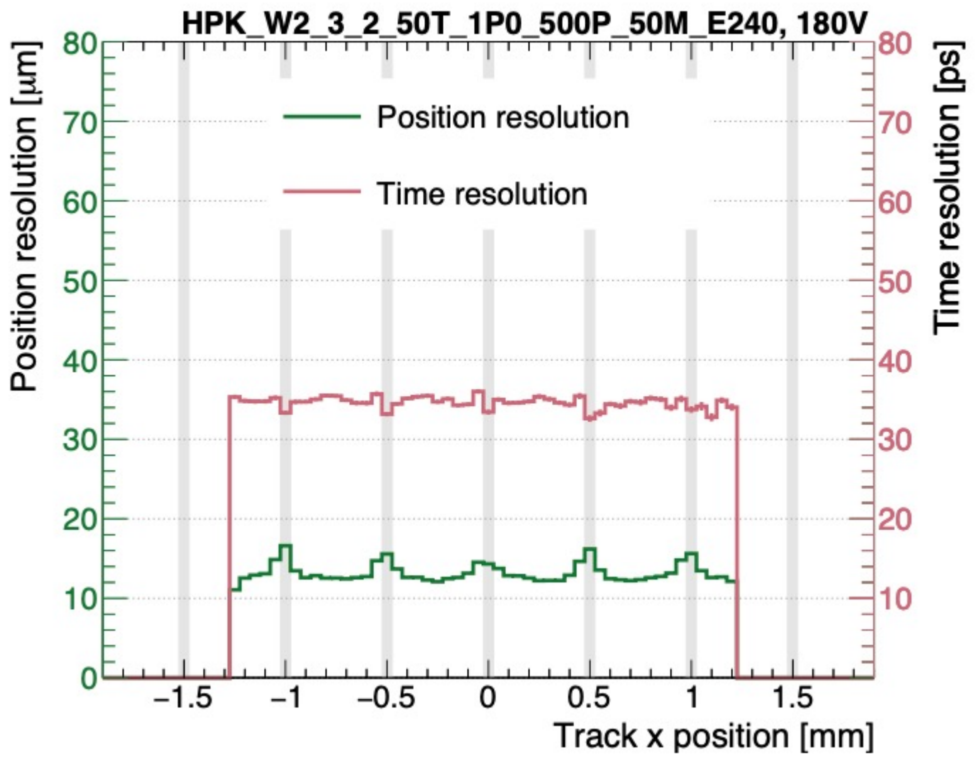


	Area (m^2)	Channel size (mm^2)	# of Channels	Timing Resolution	Spatial resolution	Material budget
Barrel TOF	10	0.5*10	2.4M	35 ps	30 μm in $r \cdot \varphi$	0.01 X_0
Forward TOF	1.4	0.5*0.5	5.6M	25 ps	30 μm in x and y	0.05 X_0
B0 tracker	0.07	0.5*0.5	0.28M	30 ps	20 μm in x and y	0.05 X_0
RPs/OMD	0.14/0.08	0.5*0.5	0.56M/0.32M	30 ps	140 μm in x and y	no strict req.
Lumi Tracker						

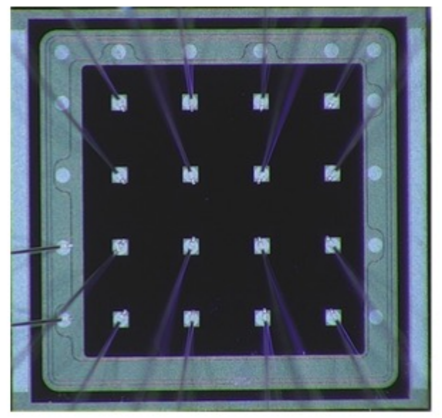
Position and timing resolutions

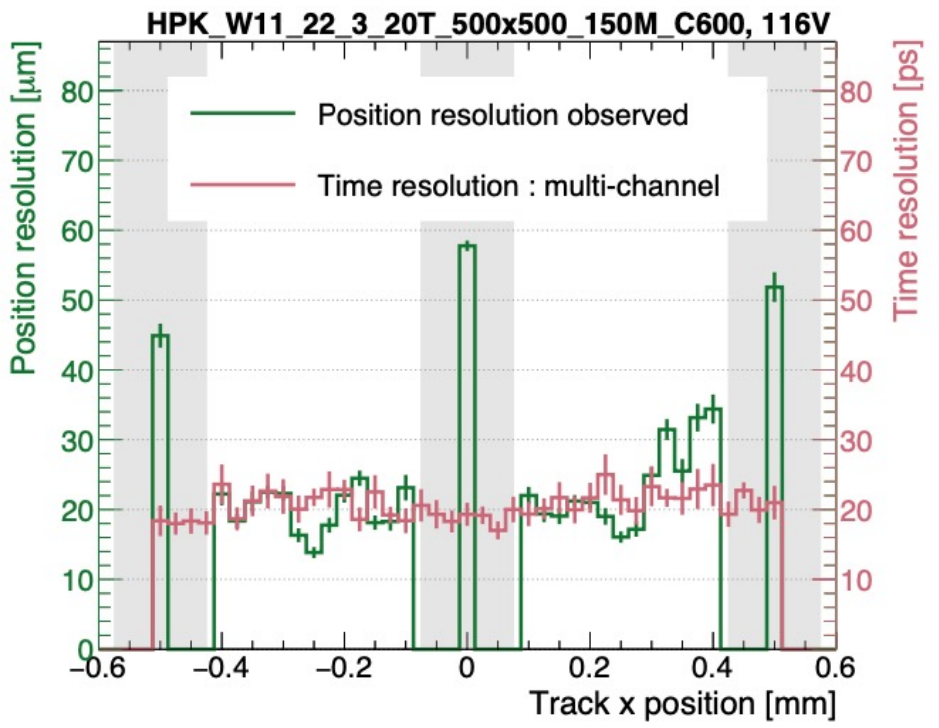
HPK Strip Sensor (4.5x10 mm²)





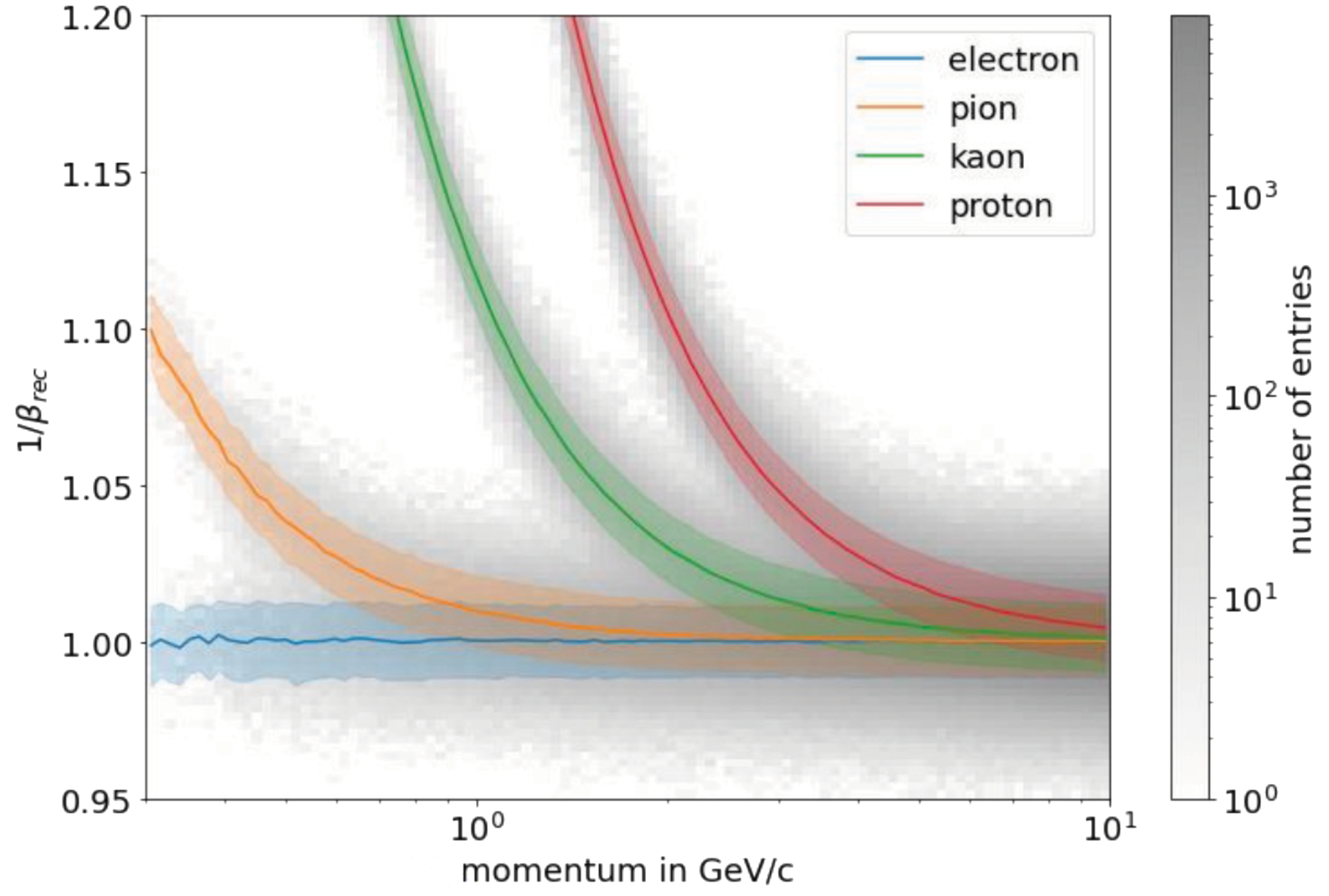
HPK Pixel Sensor (2x2 mm²)

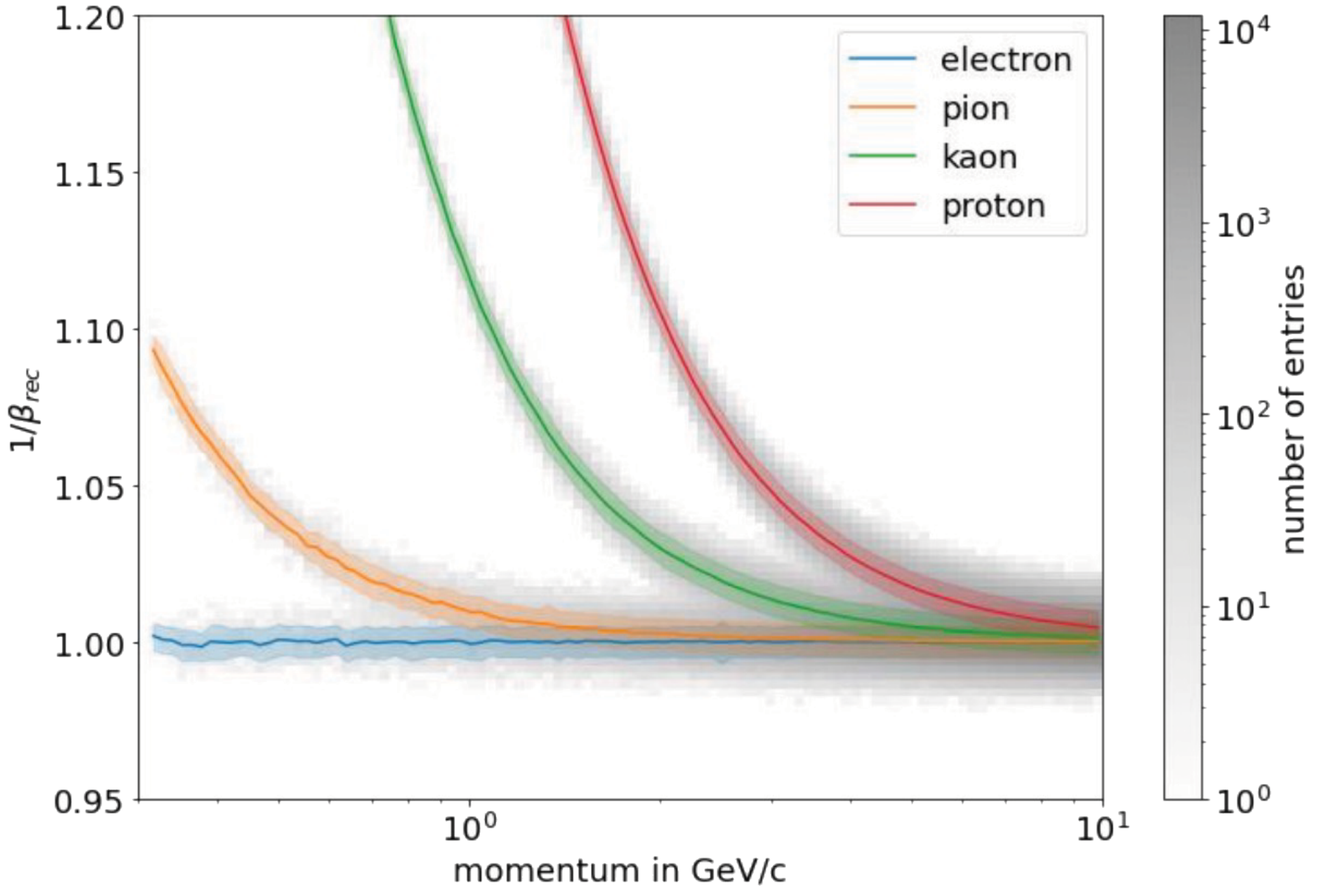




ToF - Key Plots on ToF Performance

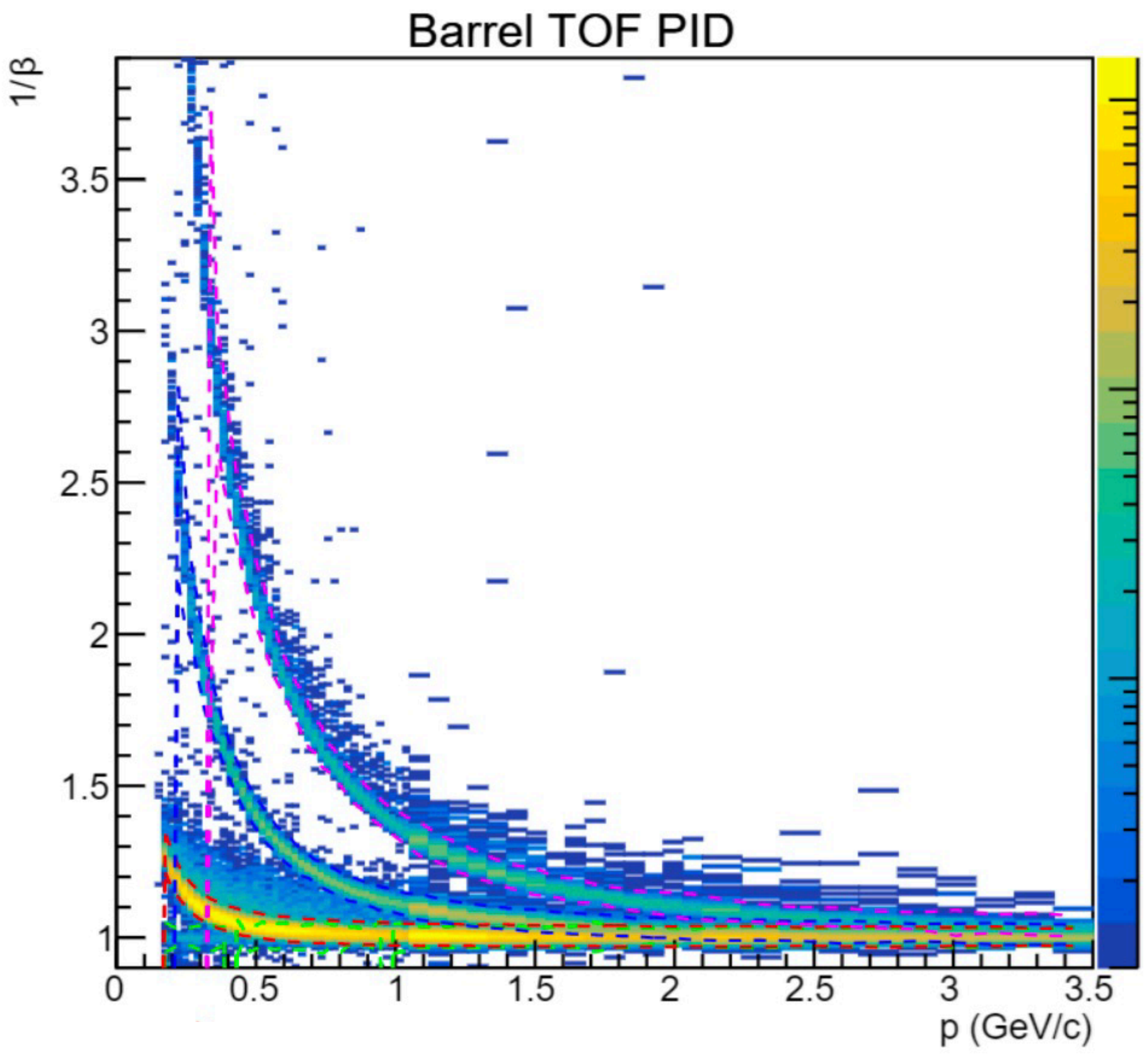
- Barrel Region
  - e/π up to 0.5 GeV/c
  - π/K up to 1.9 GeV/c
  - K/p up to 3.1 GeV/c
- Endcap Region
  - e/π up to 0.8 GeV/c
  - π/K up to 2.7 GeV/c
  - K/p up to 4.6 GeV/c



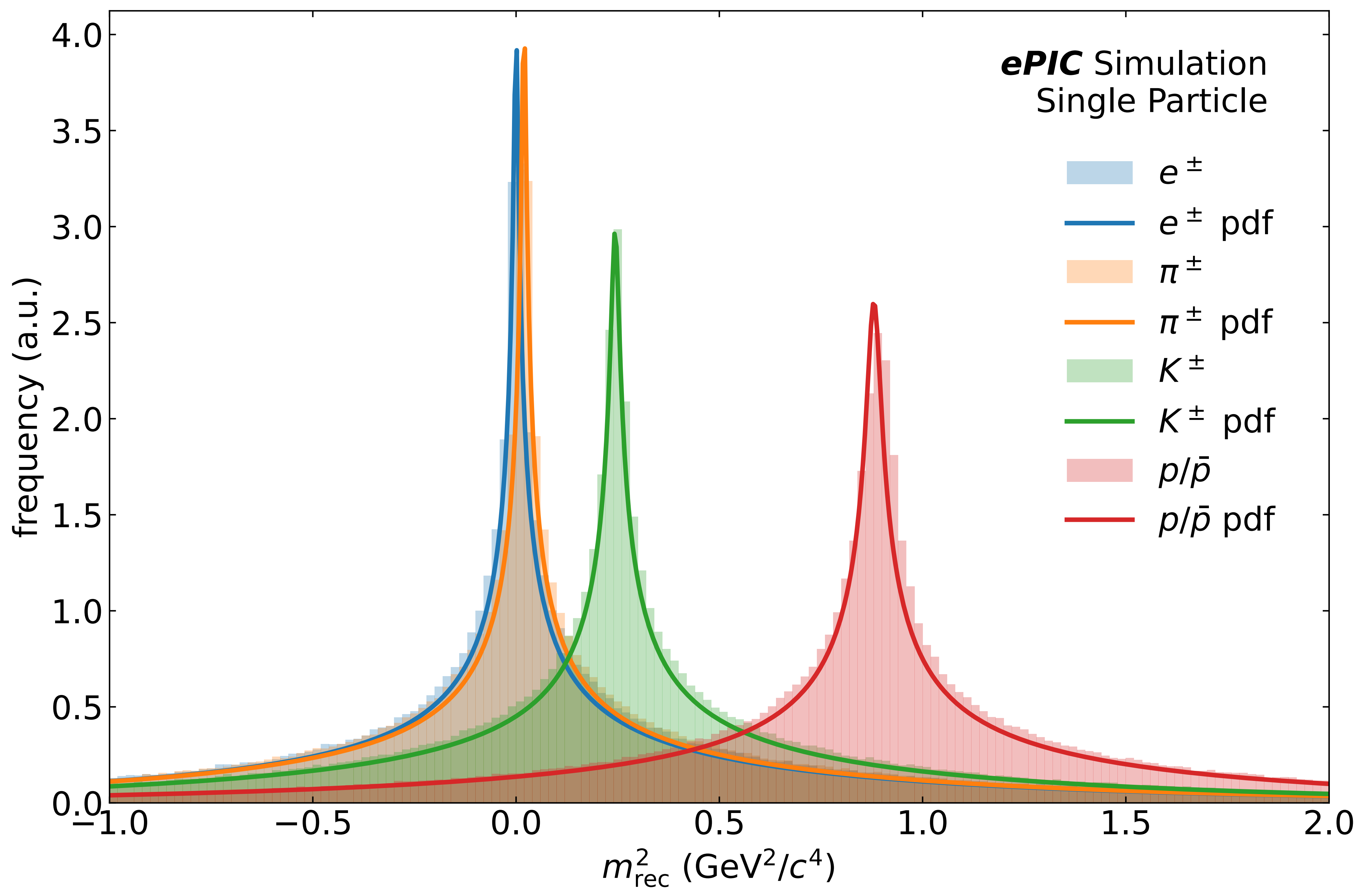


ToF - PYTHIA DIS Simulations

- PYTHIA DIS event without beam background

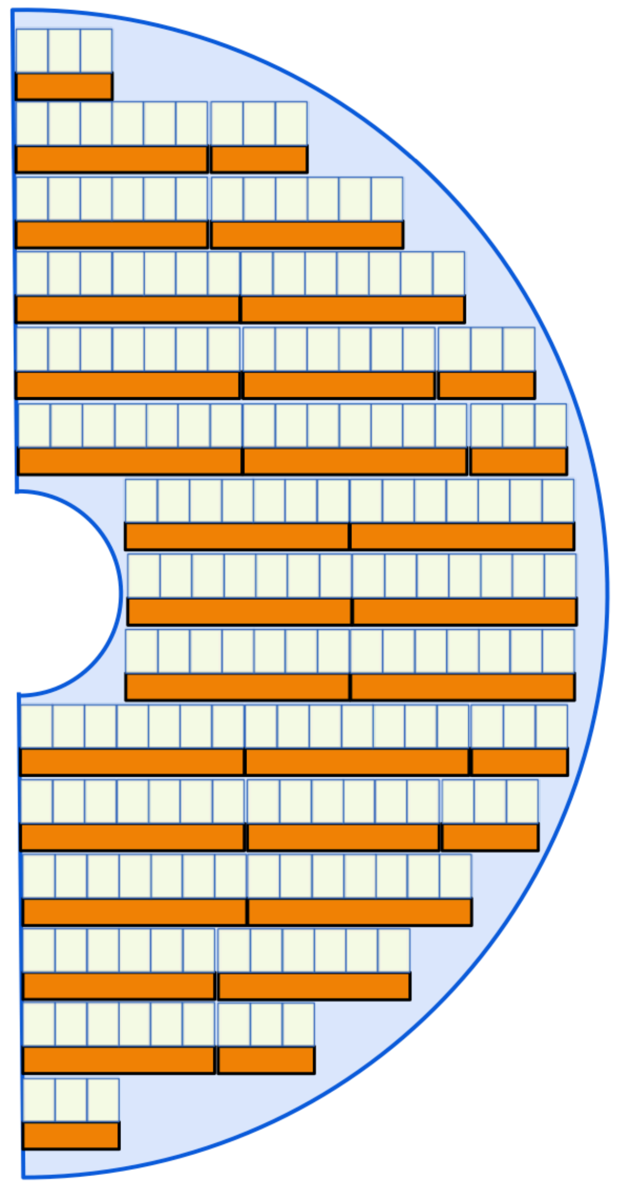


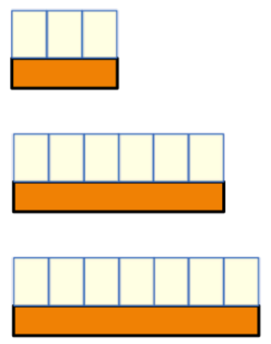
- PYTHIA DIS event with beam background and full reconstruction
- to be done



New Since Last Report

Updates with detector geometry material

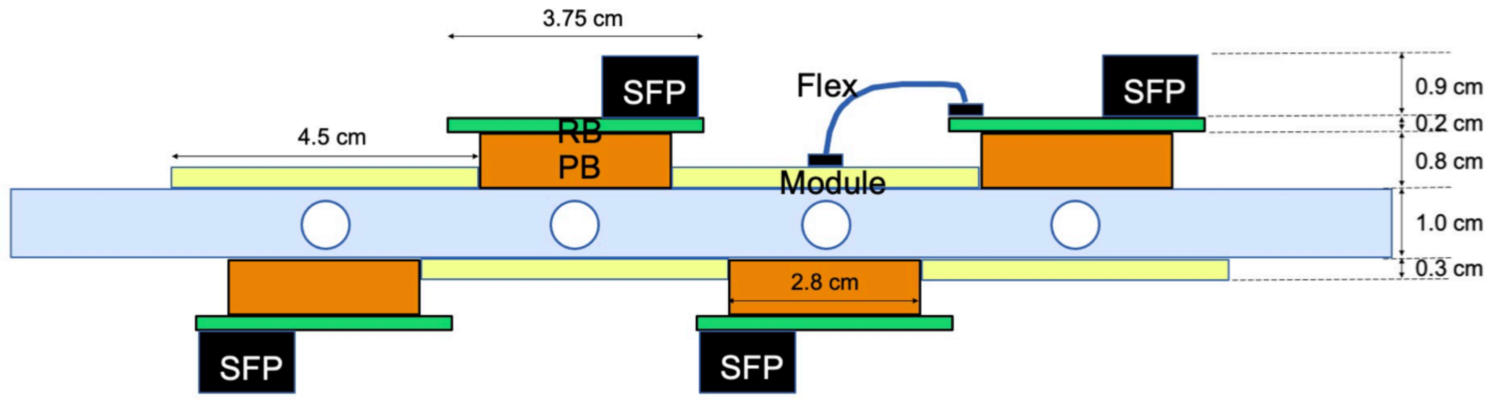




4 EICROCs per module

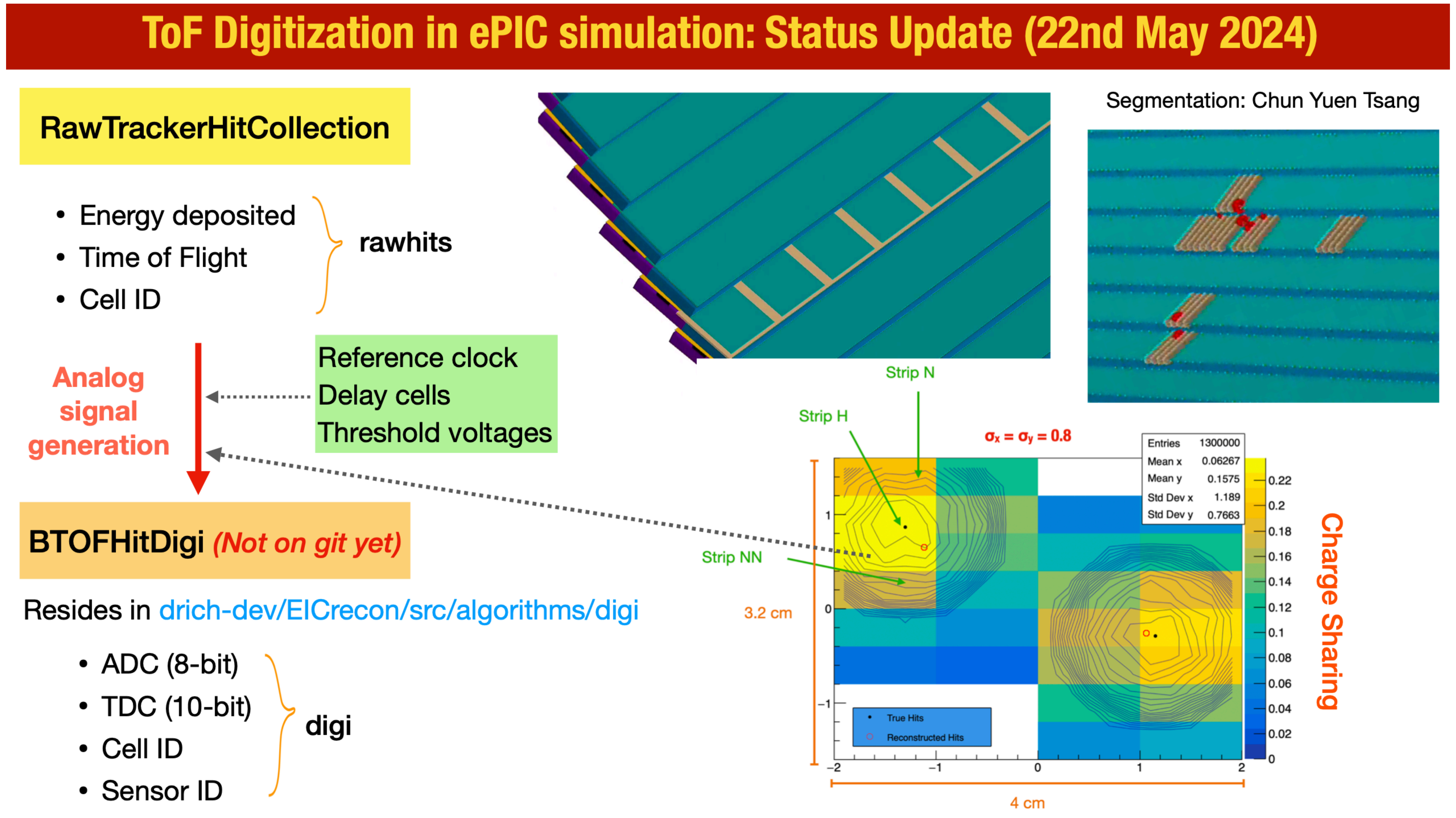
Total number of modules: **736**
Total number of service hybrids: **128**

Envelope in z is now **8cm**



Some confusion about available space settled

Simulation progress: toward more realistic background simulation



At the End …

Comments and Observations

- All LUT for PID in EICRecon
- Reasonable progress in implementing things in EICrecon
- Need for improved information exchange between engineering and DSCs
  - Request/Question on shortening hpDIRC bars by 8 cm on dRICH side ?!
  - Irrelevant for performance but lose vital overlap with dRICH
  - Requires sims for evaluation of impact
  - Unclear if just an option or necessity - need o clarify
- PID groups will have to have a close look at current acceptance (gaps, overlap, etc)
- PID groups are all progressing towards TDR
  - Manpower still on the short side
  - Last round of R&D (proposals due July 1)
    - dRICH - eRD102
    - hpDIRC - eRD103
    - pfRICH/photosensors - eRD110
    - ToF/AC-LGAD - eRD112
    - ASICs/FEE - eRD109