Report from LAPPD workshop

Alexander Kiselev (BNL)

ATHENA PID Working Group meeting

April 4, 2022

LAPPD Workshop

Monday 21 Mar 2022, 08:00 → 12:00 America/New_York

Description Organizers: Silvia Dalla Torre (INFN), Alexander Kiselev (BNL), Deb Sankar Bhattacharya (INFN), Junqi Xie (ANL)

Hosted by CFNS: https://stonybrook.zoom.us/j/98025752609?pwd=WTlicTlwTmxkNE9wODlOZEx2NU1sUT09

Argonne NATIONAL LABORATORY

Brookhaven National Laboratory

INFN

Center for Frontiers in Nuclear Science

Agenda

Indico: https://indico.bnl.gov/event/15059/ (recording available)

75+ participants

Incom Inc.

- **8:00 AM** → 8:10 AM **Introduction**
  Speaker: Silvia Dalla Torre (INFN, Trieste)
- **8:10 AM** → 8:30 AM **LAPPD overview**
  Speaker: Shawn Shin (Incom Inc.)
  LAPPD Overview_S...
- **8:30 AM** → 8:40 AM **LAPPD Photocathode Development**
  Speaker: Alexey Lyashenko (Incom Inc.)
- **8:40 AM** → 8:55 AM **HRPPD Development**
  Speaker: Michael Foley (Incom Inc.)
  2022-03-21 Foley H...
- **8:55 AM** → 9:15 AM **LAPPD R&D effort at INFN Bologna**
  Speaker: Vincenzo Vagnoni (INFN Bologna)
- **9:15 AM** → 9:30 AM **LAPPD R&D effort at BNL**
  Speaker: Alexander Kiselev (BNL)
- **9:30 AM** → 9:50 AM **LAPPD R&D effort at IJS Ljubljana**
  Speaker: Rok Pestotnik (IJS)

Nalu Scientific

- **9:50 AM** → 10:00 AM **A short break**
- **10:00 AM** → 10:20 AM **LAPPD R&D effort at Argonne**
  Speaker: Junqi Xie (ANL)
- **10:20 AM** → 10:35 AM **Cherenkov and scintillation separation in water-based liquid scintillator**
  Speaker: Ed Callaghan (UC Berkeley)
- **10:35 AM** → 10:50 AM **LAPPDs in ANNIE: from test bench to a full experiment**
  Speaker: Matthew Wetstein (Iowa State University)
- **10:50 AM** → 11:15 AM **LAPPD Readout Plane - Modelling and Optimization**
  Speaker: Luca Macchiarulo (Nalu Scientific)
  Nalu-Incom-HFAD-S...
- **11:15 AM** → 11:30 AM **Digitizer ASIC options for LAPPD applications**
  Speaker: Isar Mostafanezhad (Nalu Scientific)
- ! **11:30 AM** → 12:00 PM **Discussion, ad hoc contributions, future plans, closing remarks**

Actually, ran till ~1:20pm

Introduction

- the LAPPD question is pending since too long
- sharing knowledge, analyze together within a community as wide as possible as a way to overcome the pending question

→ Understand if LAPPDs are adequate, reliable, mature for use in particle/nuclear experiment
  → Time properties in detail?
  → Adequate for single photon detection ?

The organizers from EIC community, fully open to a larger Community in view of common interests

ABOUT SINGLE PHOTON DETECTORS

Time resolution (σ)

- PMTs, MAPMTs >/~ 0.3 ns
- MCP-PMT <100 ps
- SiPM <100 ps
- MWPCs >/~ 20 - 400 ns
  - FE dependent, ballistic deficit implications (*)
- MPGDs ~ 7-10 ns (INTRINSIC)

(*) COMPASS – Gassiplex 400 ns, ballistic def. 50%
APV25 20ns, ballistic def. 25%

Effective QE range

- Vacuum-based devices & SiPMs
  λ > 300, 250, 200 nm
- Gaseous devices (CsI):
  λ < 205 nm
- On-going studies with H-ND
  λ < 200 nm, still preliminary stage

Operation in magnetic field

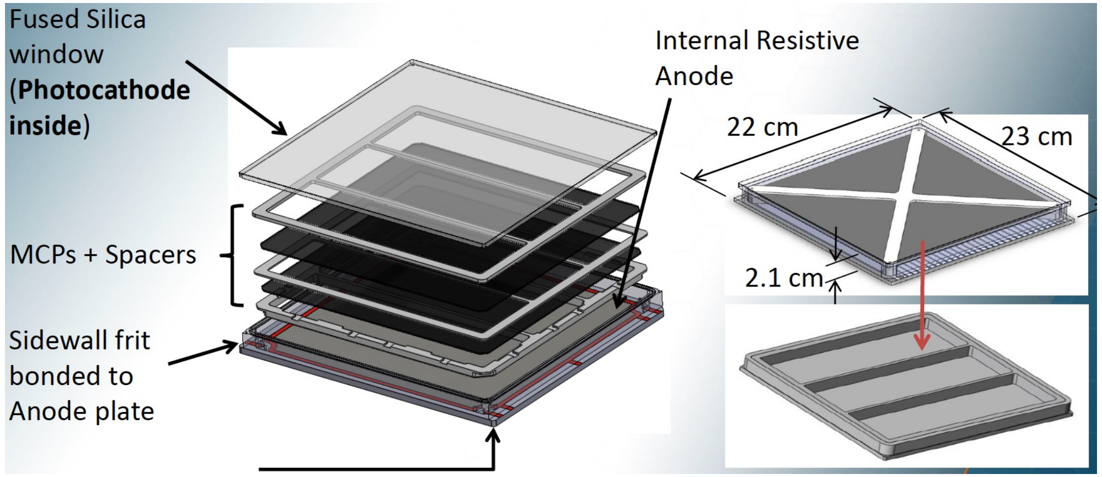
- PMTs, MAPMTs, HPMTs NO
- MCP-PMT ~YES
- MWPCs, MPGDs YES
- SiPM YES

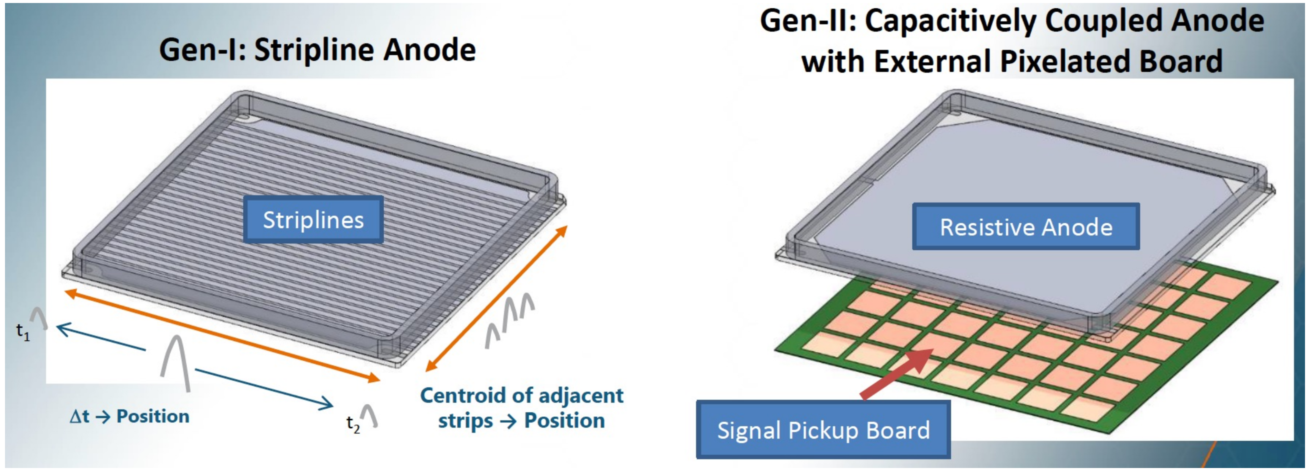
COSTS

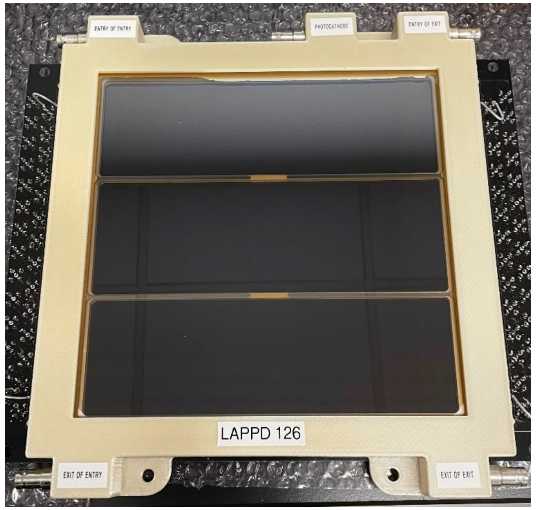
- Gaseous (*) - $ (0.2-0.4 M / m^2)
- MAPMTs - $$ (0.5-1 M / m^2)
- SiPM - $$ (0.8-1 M / m^2)
- MCP-PMT - $$$ (???)
  - LAPPD - $$ (0.8-1 M / m^2)

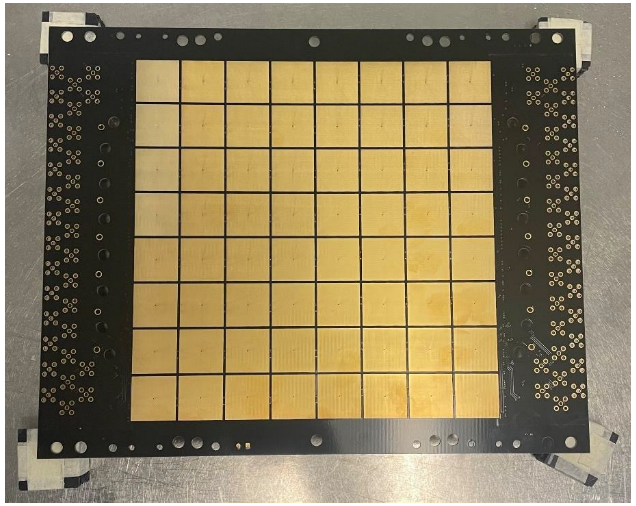
(*) UV: gas system, mirrors more DEMANDING → expensive

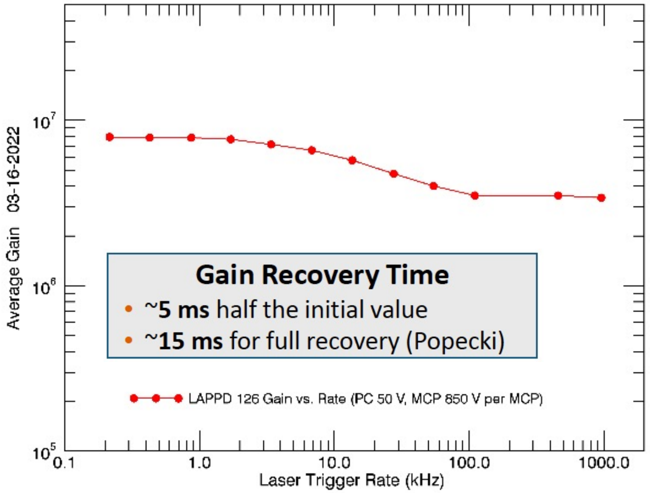
Incom Inc. (overview)

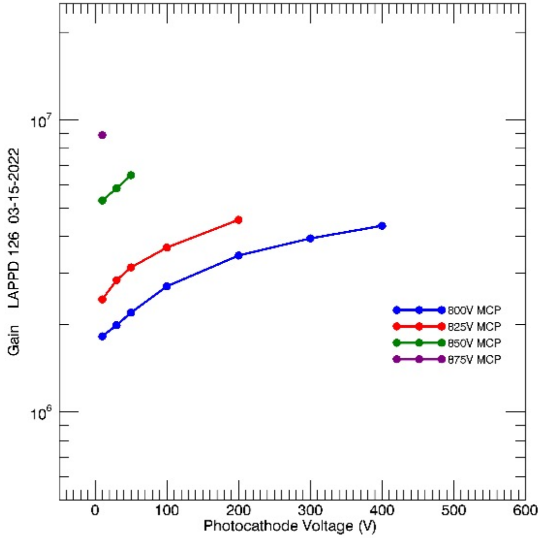












Gain recovery time is an issue!

Incom Inc. (overview)

Features

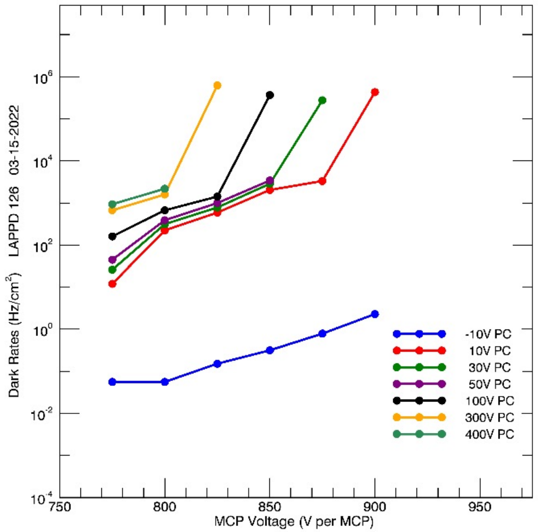
- **10 μm/20 μm** MCPs
- Glass/Ceramic
- New internal support design → **373 cm²** (97% active area)
- Gen-II → flexible **pickup pattern modification**

Performance

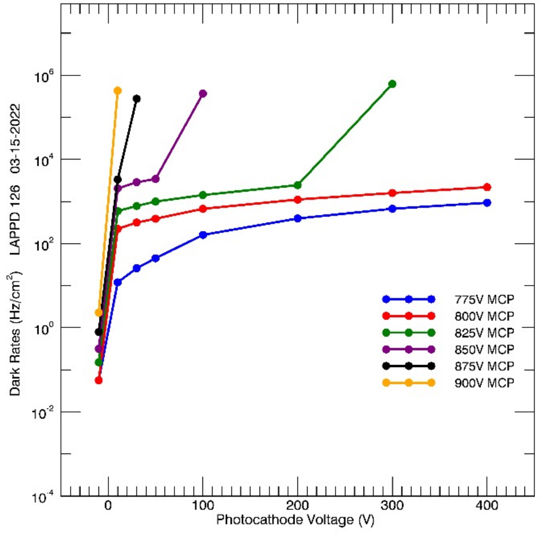
- **High QE** (Blue-sensitive) + High uniformity
- **~1E7** Gain
- Low Dark Rates
- **~30 ps** SPE, **~15 ps** MPE
- ***O*(mm)** position resolution

Availability

- Gen I Direct readout & Gen II Capacitively Coupled readout are available today.
- High Rate Picosecond Photodetector (**HRPPD** 10 cm)

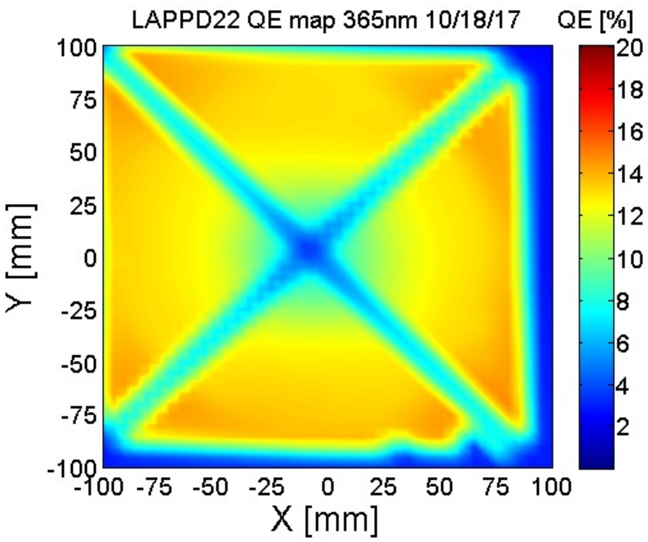


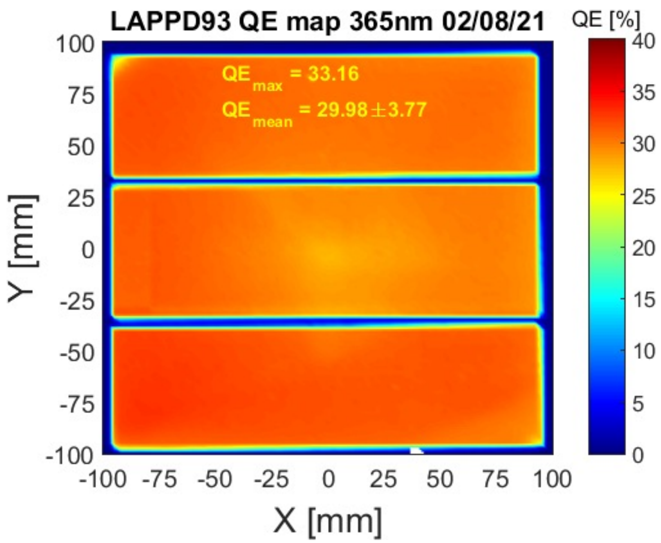
Gain ~$6\cdot10^6$, Dark rates ~1 kHz/cm²
@ 850V/MCP, 30V PC



Shawn Shin

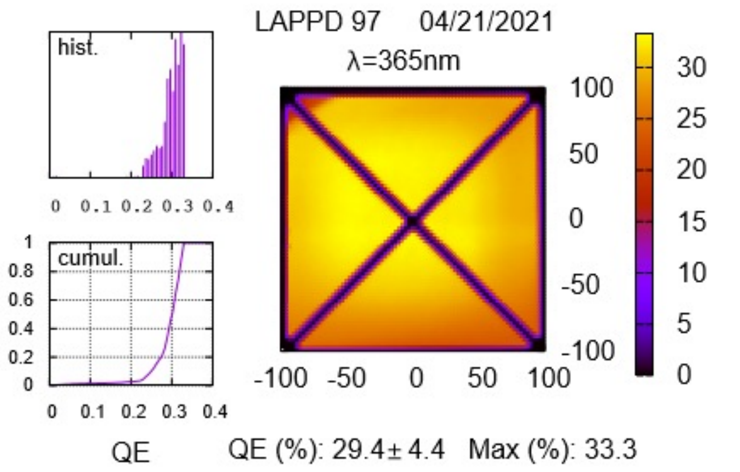
Incom Inc. (photocathodes)

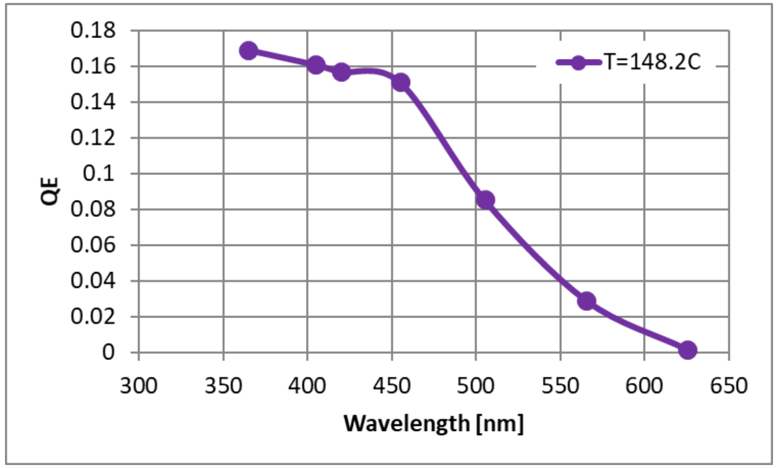




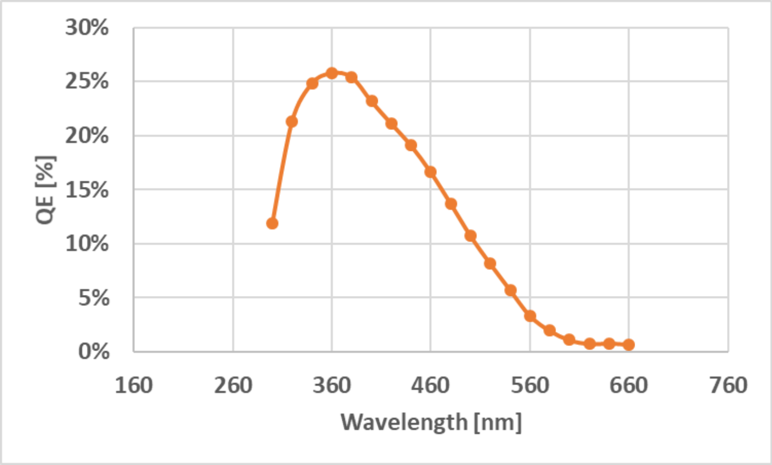
Progress with Na_2KSb photocathodes

Na$_2$KSb photocathode in *ceramic* package

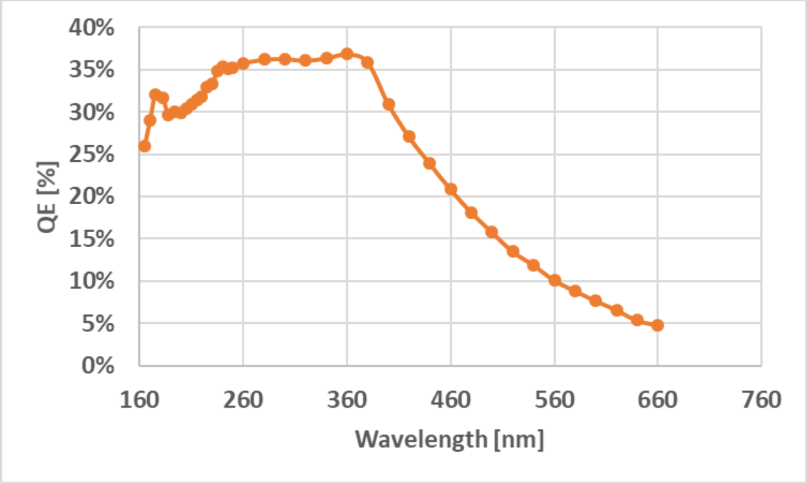




RbKSb



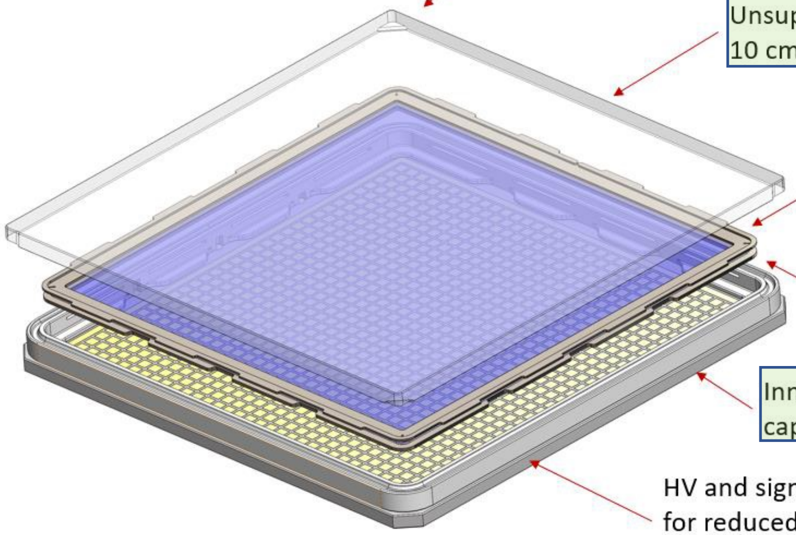
CsKSb



LAPPD with UV-graded fused silica window

Alexey Lyashenko

Incom Inc. (HRPPD)



Fused Silica, B33, or MgF_2 (115 nm cutoff) window

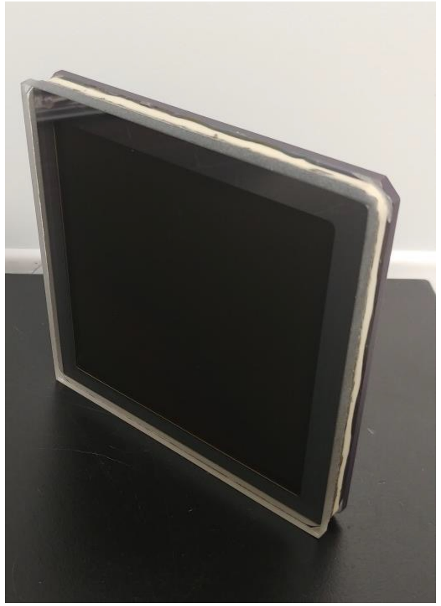
Unsupported window with no obstruction
10 cm × 10 cm field of view

Reduced gap spacing and small pore MCPs (10 µm) for fast timing and B-field tolerance

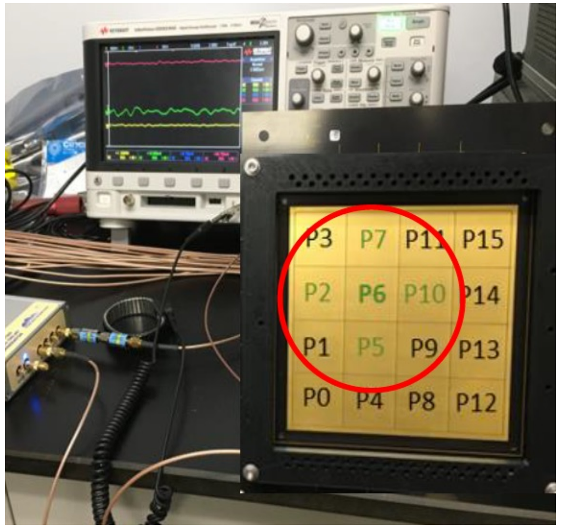
MCP stack clamped in sidewall for better control of forces and assembly simplification

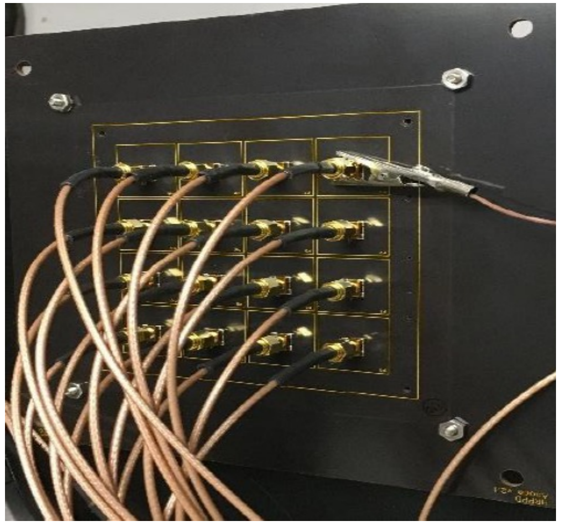
Innovative anode for direct or capacitive coupling readout

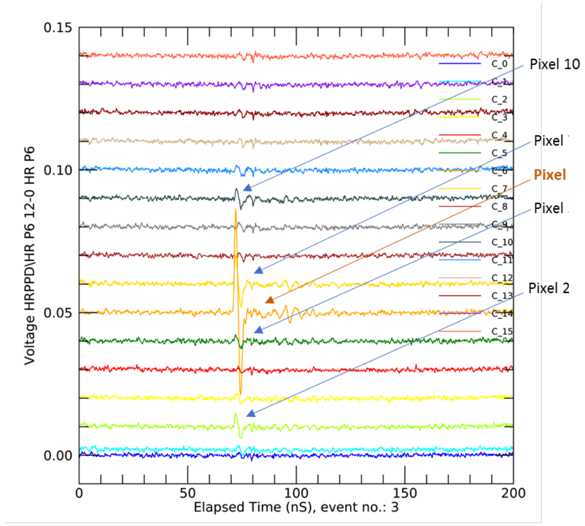
HV and signal connections on bottom and for reduced deadspace 0.35” [8.89 mm] to improve tiling



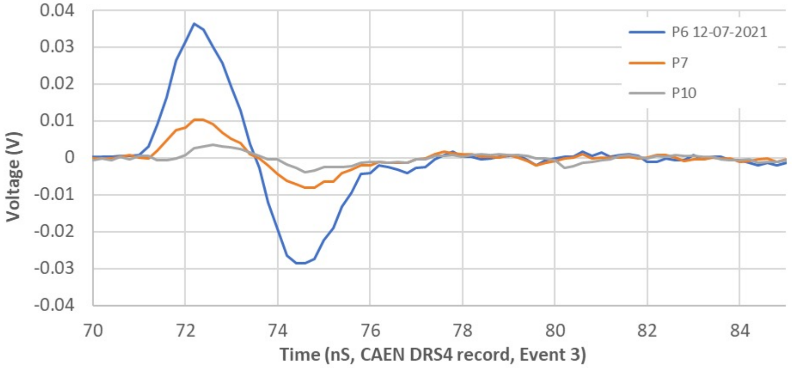
First sealed Gen I HRPPD







pulse by DRS4 ch HR P6 Event 3 12-7-2021.png



Michael Foley

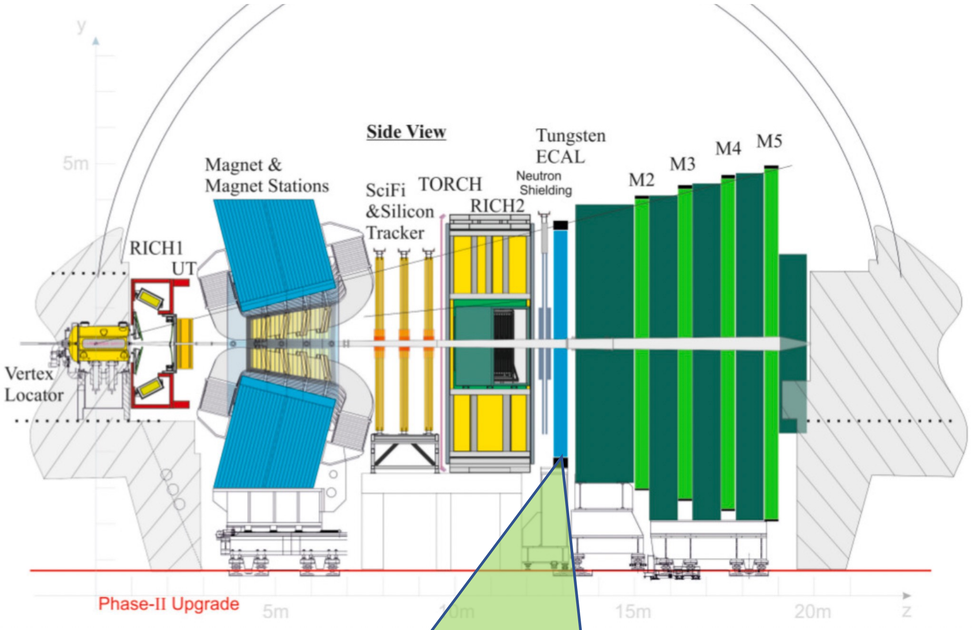
Incom Inc. (HRPPD)

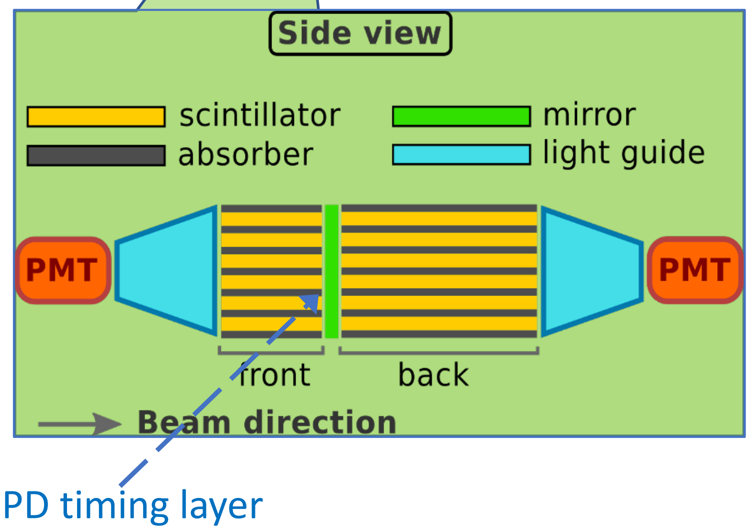
- **March – May ’22** **(end of 1st year)**
  - **Verify new ceramic components:** metallize sidewalls, fuse lower tile assemblies, apply resistive anode layer.
  - Fabricate trials with leftover **Phase I components in parallel.**
    - Process both capacitively coupled devices and co-fired versions. Several co-fired anodes in house.
  - **The target for the first sealed working HRPPDs (capacitively coupled) is May ’22.**
    - **Once Incom tested**, these will be made available to the **EIC consortium**, namely **Brookhaven** to start.
  - Incom’s glass manufacturing team processing 10 µm pore glass capillary array material for **HRPPD MCPs**.
    - Proper handling and novel processing are key for **high quality and yield** of the thin (**600 µm**) GCAs.
- **Year 2 (May ‘22 to May ’23)**
  - Fabrication of ceramic **capacitively coupled** HRPPD will continue (1 to 2 starts/month).
  - **Co-fired** direct readout fabrication is a 2nd priority. (design modifications are anticipated).
    - Measurement & Testing for 1024 direct readout pads will be a challenge.
  - **Magnetic Field tests** (possibly earlier): Start with Baseline LAPPD, then HRPPD.
  - **All glass version** components are ordered: parallel path for success (**if needed**).
- Currently in discussions with OEM on sealing tank design, pricing and lead time.
  - **50+ weeks lead time and higher costs** are anticipated plus time for installation/commissioning at Incom.

INFN Bologna

LHCb e/m calorimeter upgrade

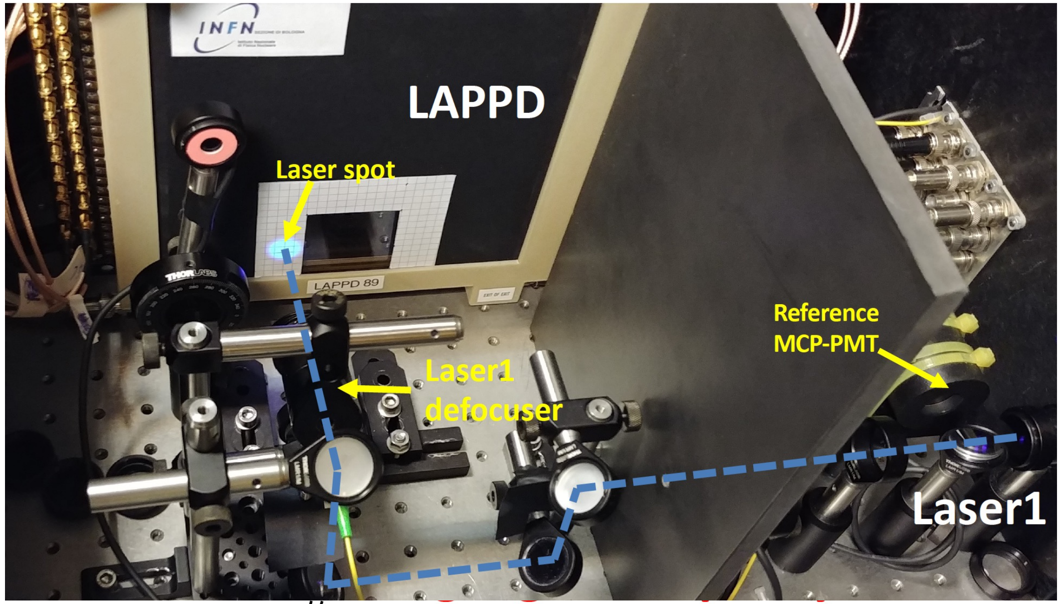
- Three LAPPDs have been tested
  - Gen-I and Gen-II with 20 μm pore size
  - Gen-I with 10 μm pore size
- Which tests
  - Measurements with picosecond lasers in Bologna
  - Measurements with 1-6 GeV electrons at DESY
  - Measurements with 20-100 GeV electrons at CERN SPS

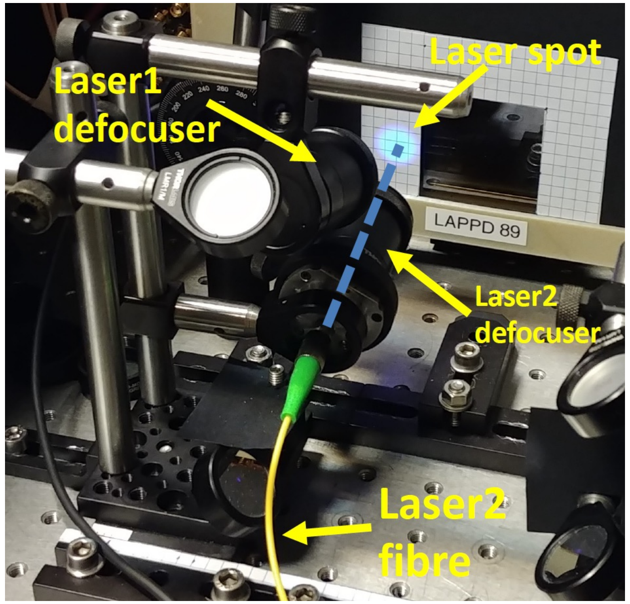


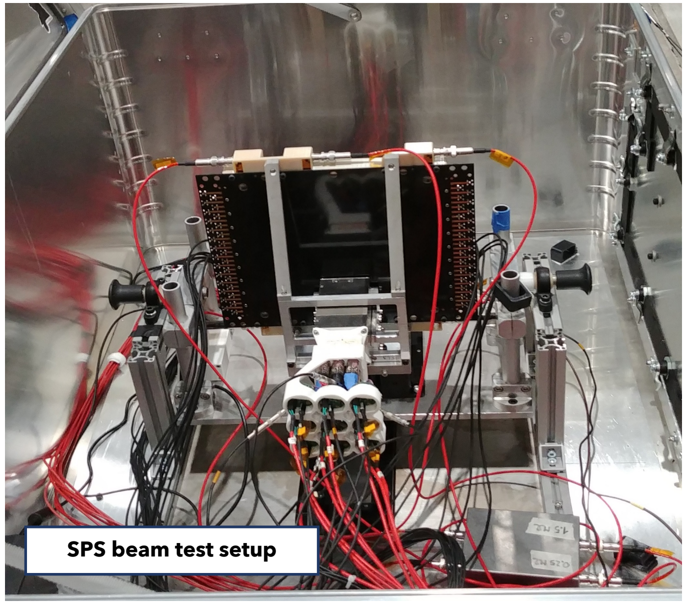


- We want to mimic particle flux expected at LHCb in the laboratory
  - Each charged particle entering the LAPPD is assumed to produce order of one cascade-initiating electron with the PC inhibited (to first order this is probably not far from reality, but needs further understanding)

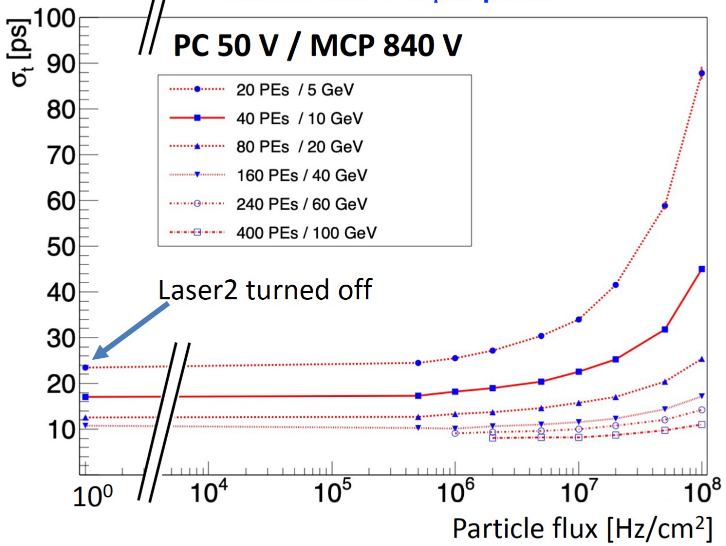
INFN Bologna



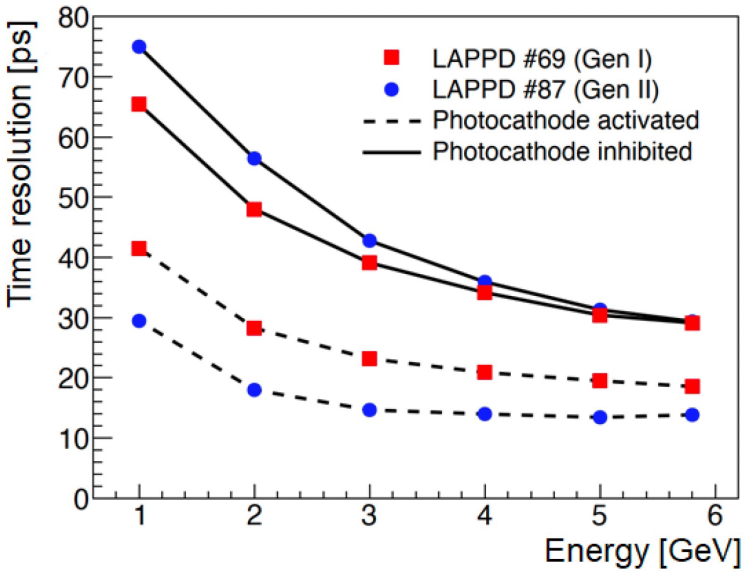




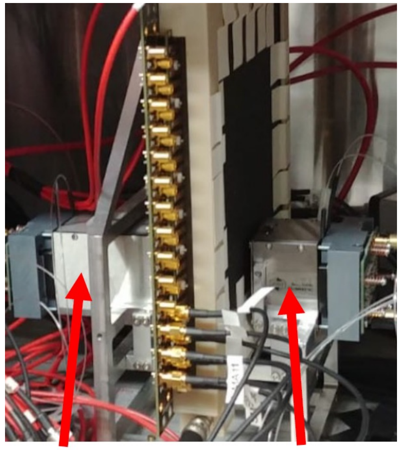
LAPPD Gen-I 10 μm pores



Test stand data



DESY beam test



SPACAL back

SPACAL front

Vincenzo Vagnoni

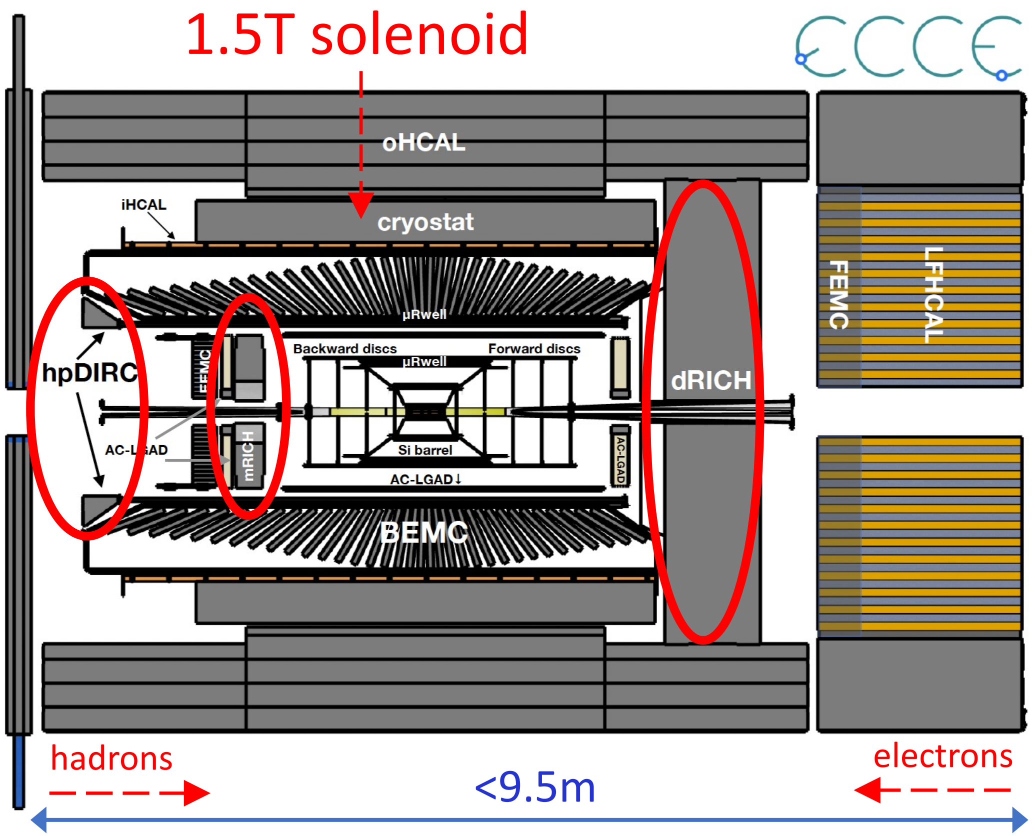
Brookhaven (few words for EIC)

EIC: Electron-Ion Collider @ Brookhaven Lab

EIC physics detector proposal selection	Concluded few weeks ago
DOE CD-3 (Approve start of construction)	End of FY24
ECCE PID subsystems ready for installation	End of FY28

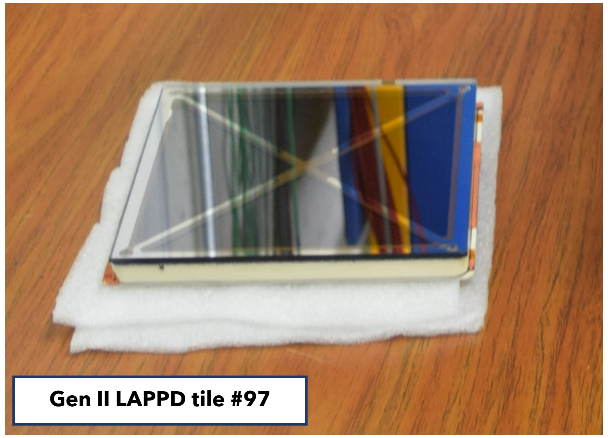
- LAPPDs are supposed to
  - be more cost-efficient than MCP-PMTs
  - provide better timing and have (much) smaller dark noise rate than SiPMs

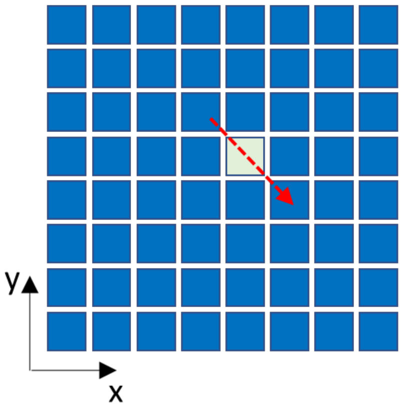
Barrel DIRC likely requires “Gen I” MCP-PMT type

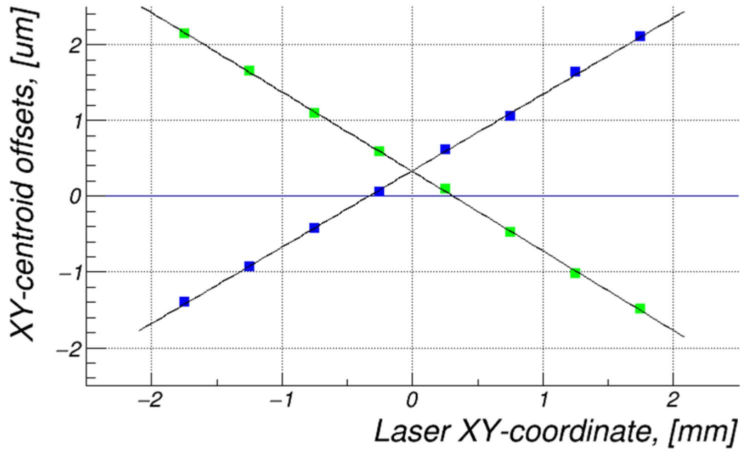


	Default option	Single photon time resolution	Spatial resolution equivalent	Sensor area
E-endcap mRICH	SiPMs	best possible	~3mm pixels	64 ~10x10 cm^2 spots
Barrel DIRC	MCP-PMTs	<100 ps	~3mm pixels	~0.65 m^2 total
H-endcap dRICH	SiPMs	~100 ps	~3mm pixels	~3.10 m^2 total

Brookhaven

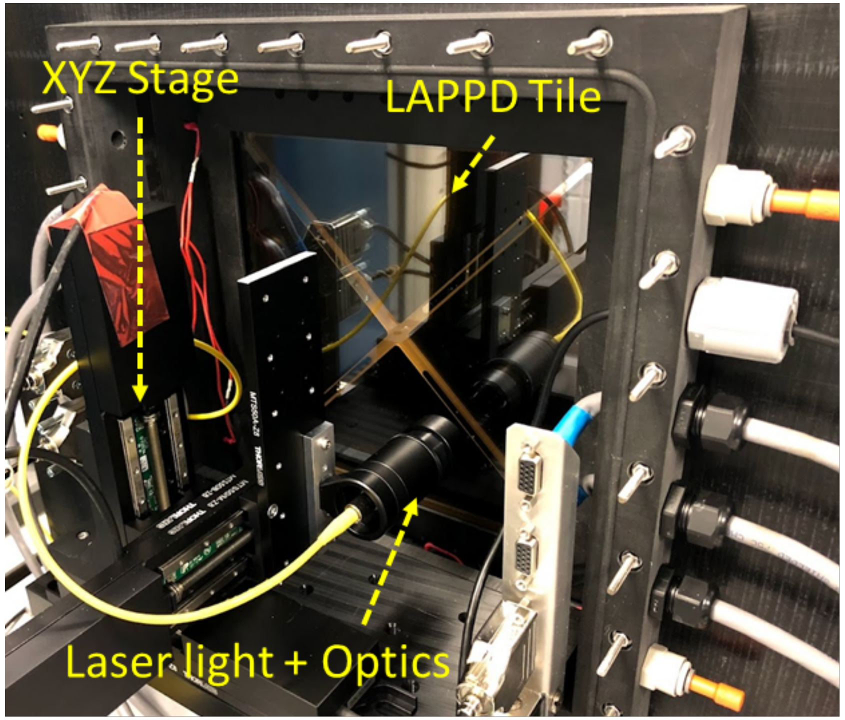




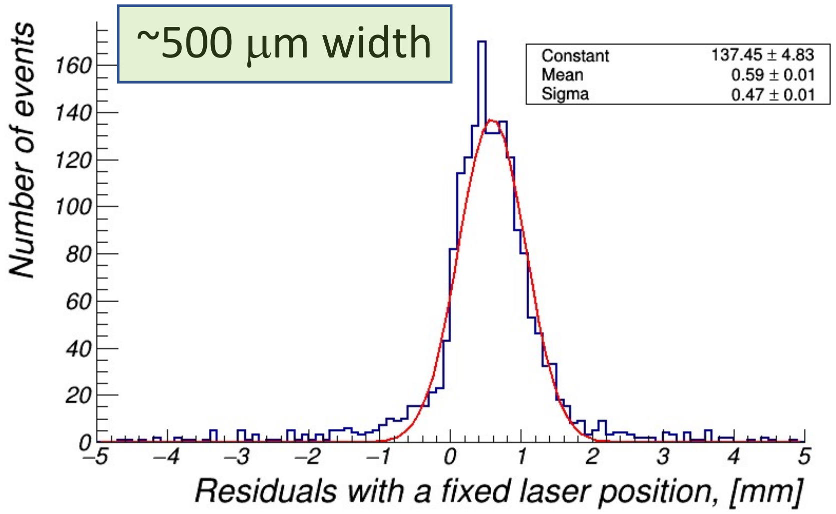


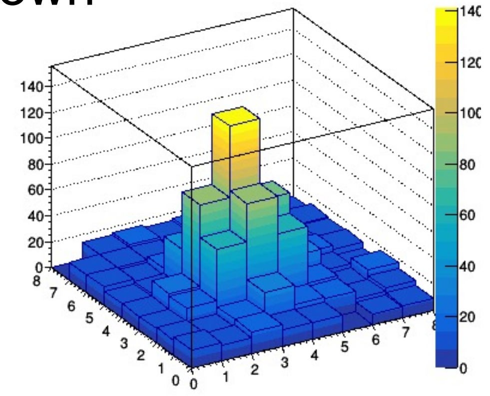
- Spatial resolution and linearity study in a "Single-photon" mode
  - ~10 mV signals

Test stand setup



- 8x8 field with 3mm pixels, connected to a pair of V1742s
- Linearity scan along diagonal direction shown

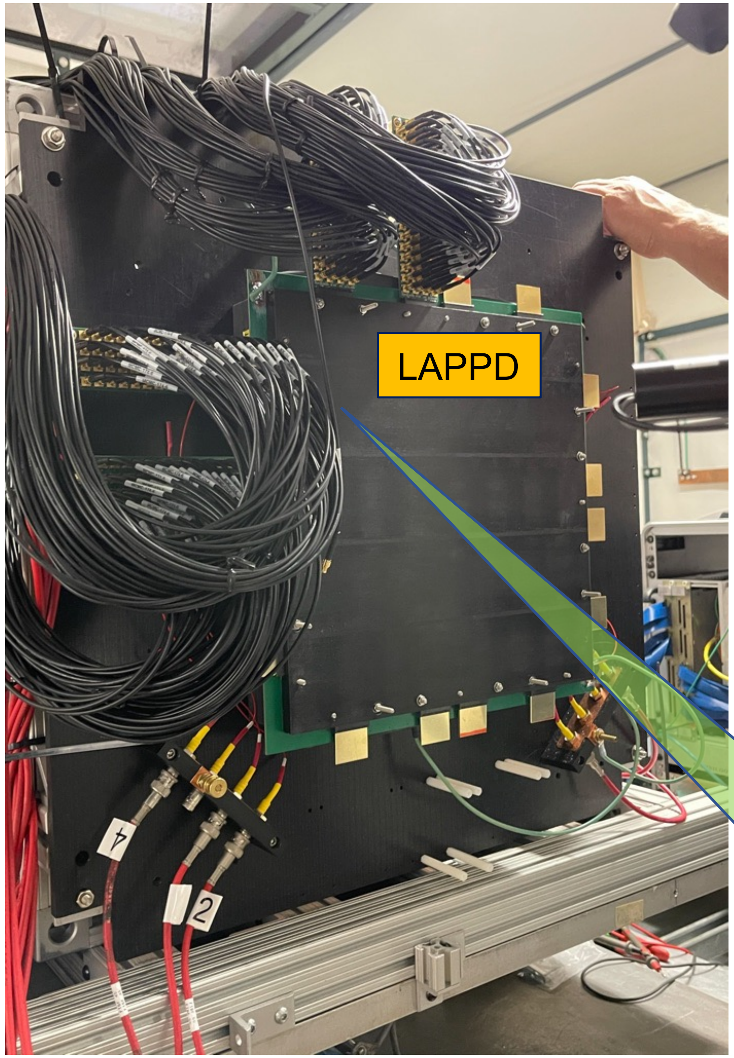




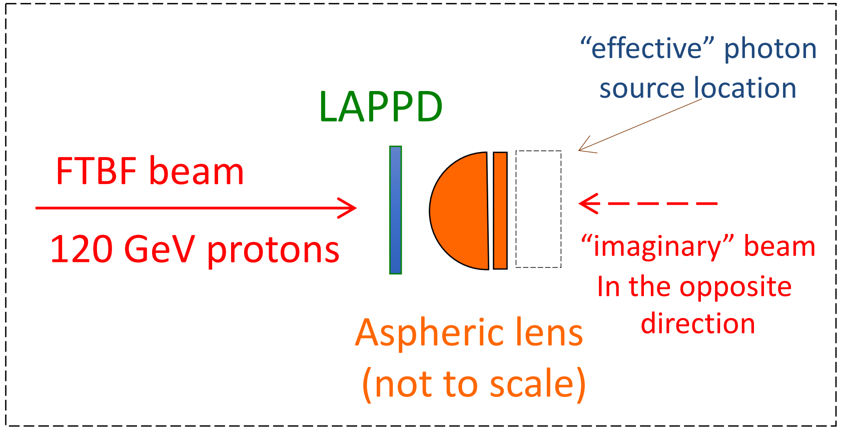
Typical single photon cluster has RMS ~ 3.5 mm

AK

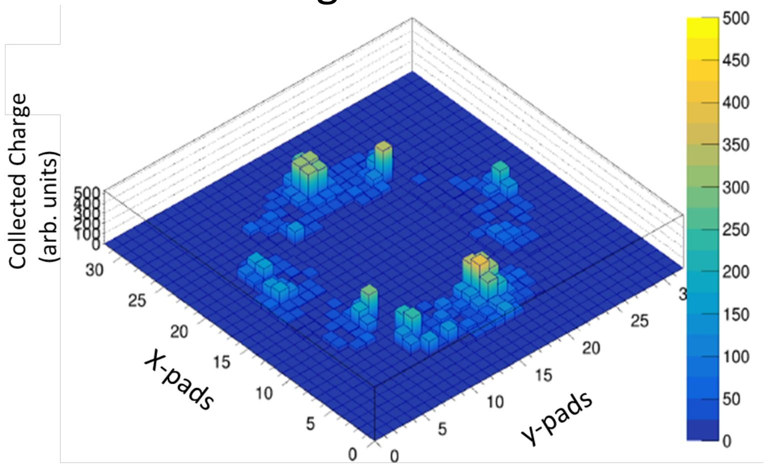
Brookhaven, Incom Inc., ANL, GSU, SBU & other groups



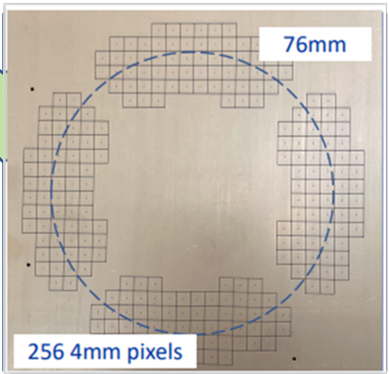
June 2021 beam test schematic view

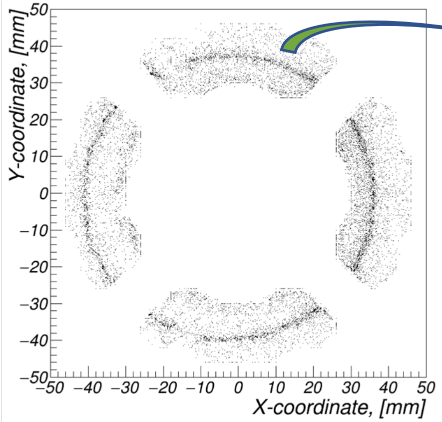


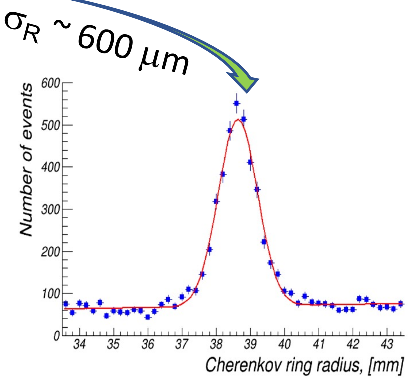
Single event

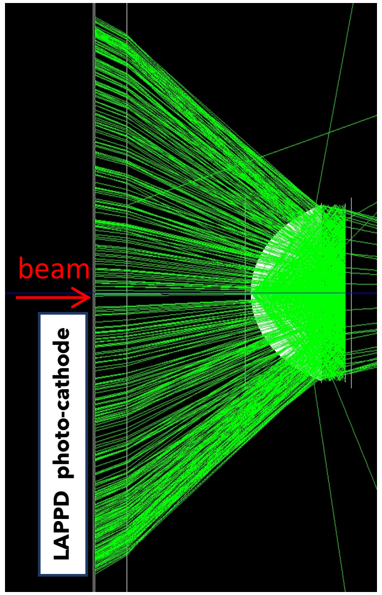


Pixel pattern & accumulated *single photon* XY-coordinates









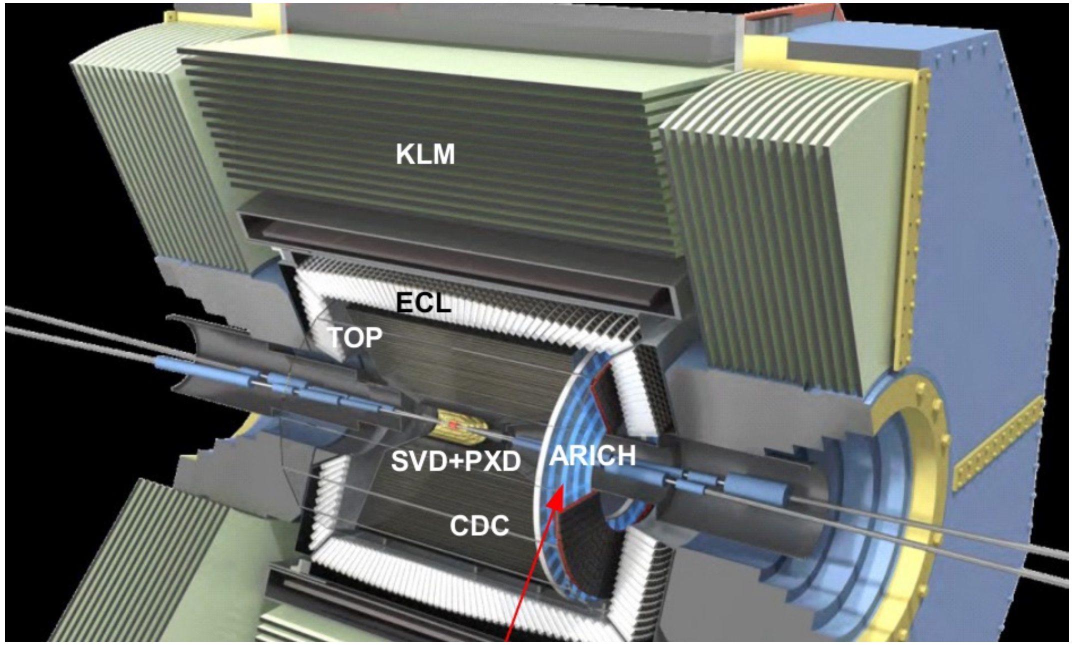
Radiator setup

Next beam test campaign @ Fermilab: June 2022

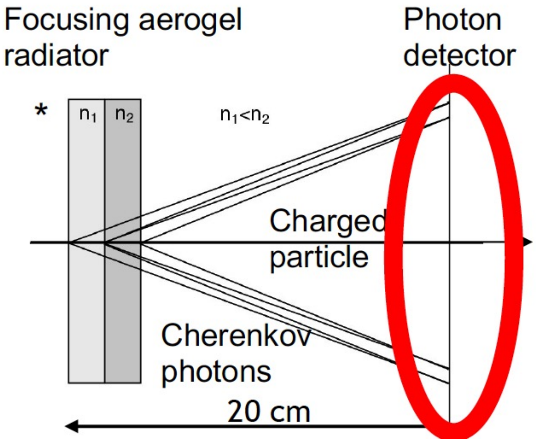
AK

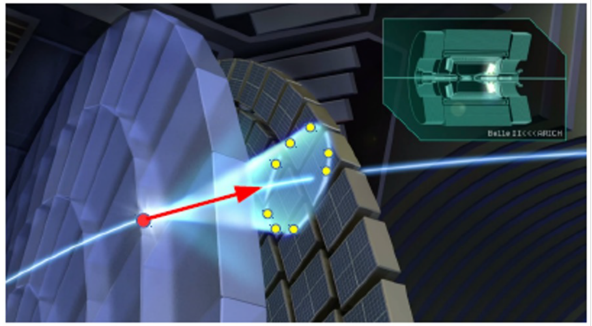
IJS Ljubljana

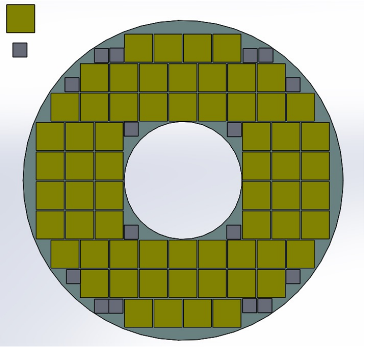
- 2 possible applications, both requiring pixelated readout – Gen II LAPPD:
  - LHCb RICH
  - Belle II Aerogel RICH



- Belle II Upgrade: 5x increase in Luminosity
  - To be published in The Belle II Detector Upgrade Program, Snowmass whitepaper
- Currently 420 Hybrid Avalanche Photo Detectors detect single photons from aeorgel radiator
- HAPD - gradual reduction of performance due to irradiation
- Possible replacement of photon detectors in long term upgrade (203x)
  - Candidates: SiPM and LAPPS
- Possible Layout with LAPPDs
  - 10 um Gen II devices
  - 20x20cm2 and 10x10cm2 sensors
  - If possible:
    Triangular geometries to cover larger area





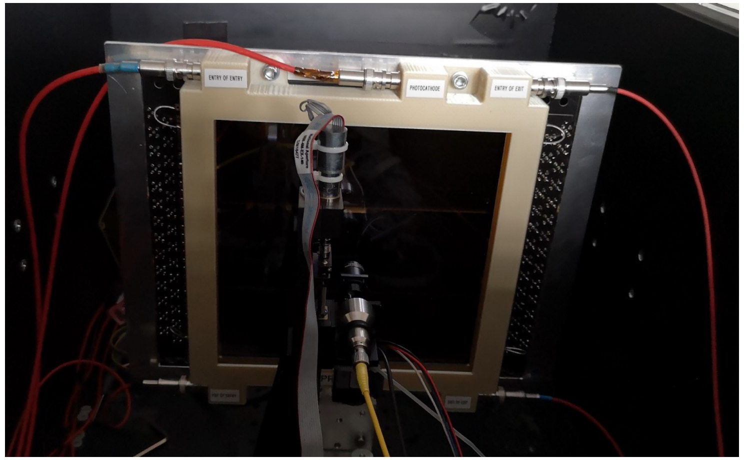


Belle II

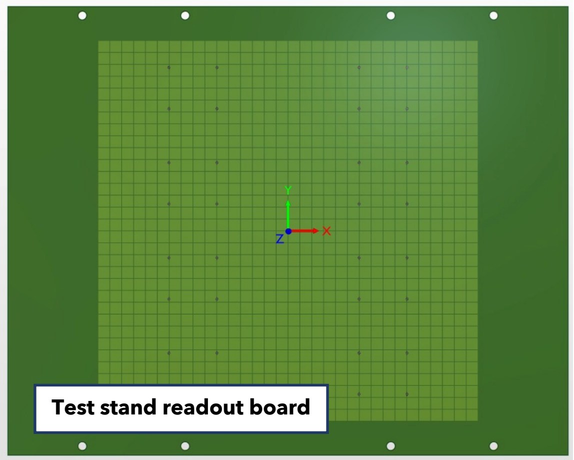
IJS Ljubljana

- Upg2b 2033-2035 new photosensors – SiPM baseline, LAPPD also candidate
  - HL-LHC / L= 10^{34} $cm^{-2}s^{-1}$ = x50 present Lumi
  - Number of Primary Vertices/collision =38
  - Occupancies in RICH1 in most occupied regions with 3x3 mm^2 channels> 130%
  - Increase of granularity / measurement of pulse height needed

LHCb



Application	ARICH @ Belle II	RICH @ LHCb
Sensor size	5 mm	1 - 3 mm - low and high occupancy region
Single photon sensitivity	required	required
Low DCR	+	+
Peak PDE	Blue	Green
SPTR (ps)	100 or less	100
Operating T(°C)	Preferably -20 .. 20	-100 (Gas vessel @ 20 °C)
Magnetic field	1.5 T perpendicular	residual fields up to 2.5 mT
Area to cover	4.5 m2	1m2/9m2
Fluence n_{eq}/cm^2	**10^{12}**	**$3x10^{13}$**
Trigger rate	30 kHz	40 MHz
Phot. incident angl. [°]	0-30	0-10
Start	203x	203x



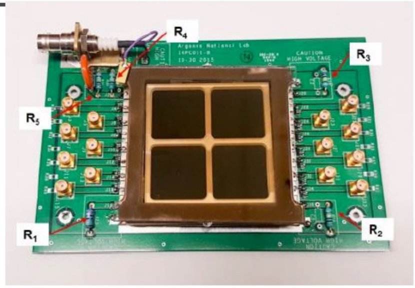
6mm pixels

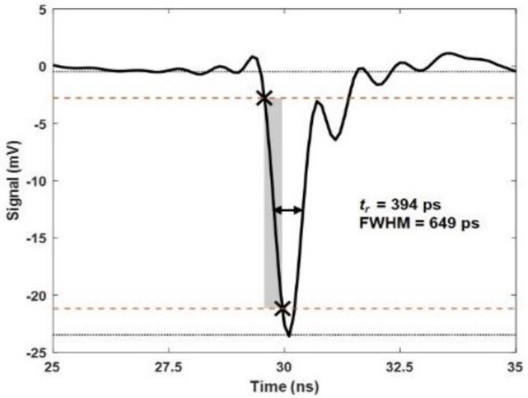
Argonne

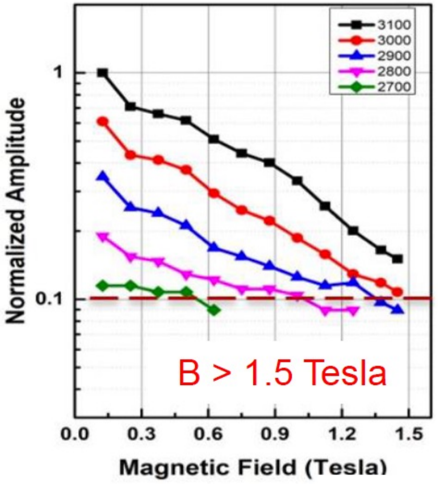
DETAILED PARAMETERS AND PERFORMANCE OF ARGONNE MCP-PMT

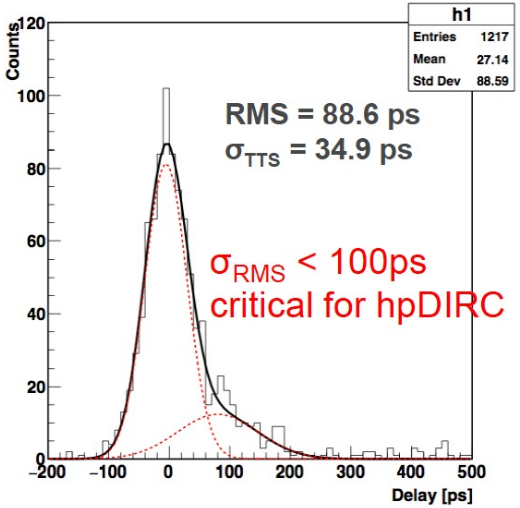
ANL **low-cost** MCP-PMT with 10 μm pore size MCPs and reduced spacing

MCP	Pore size	10 μm
	Length to diameter ratio (L/d)	60:1
	Thickness	0.6 mm
	Open area ratio	70 %
	Bias angle	13º
Detector geometry	Window thickness	2.75 mm
	Spacing 1	2.25 mm
	Spacing 2	0.7 mm
	Spacing 3	1.1 mm
	Shims	0.3 mm
	Tile base thickness	2.75 mm
MCP-PMT stack	Internal stack height	**5.55 mm**
	Total stack height	11.05 mm
Gain Characteristic	Gain	2.0×10^7
Time Characteristic	Rise time	**394 ps**
	TTS RMS time resolution	88.6 ps
	TTS resolution	35 ps
Magnetic Field	Magnetic field tolerance	**Over 1.5 T**









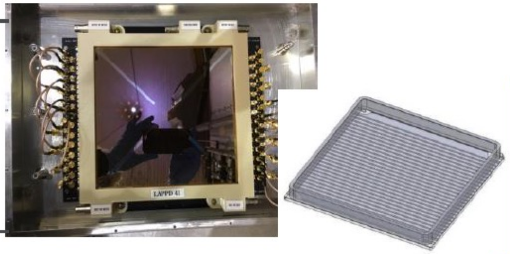
J. Xie et al 2020 JINST 15 C04038

5

TEST OF GEN-I STRIPLINE LAPPD AT JLAB

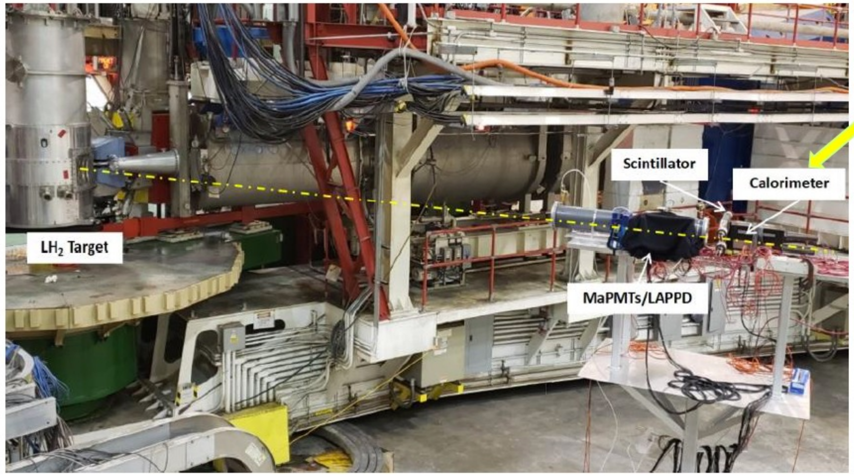
Received Gen-I LAPPD

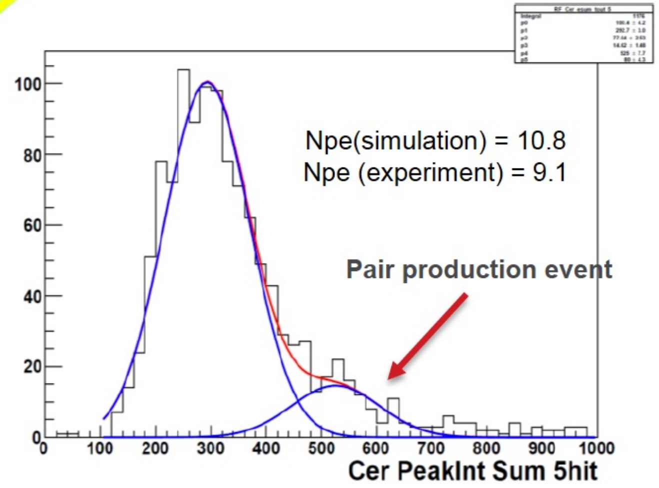
Window material	Fused silica
Readout anode	**Inside stripline**
Quantum Efficiency	**Mean: 7.3%, Maximum: 11%**
Gain	5.4×10^6 with MCPs @ 975V
Time resolution	56 ps



Experimental high rate background environment

Detector package:
Cherenkov tank (CO_2 at 1 atm)
scintillator planes
calorimeter blocks
Photosensors: LAPPD or 2x2 MaPMTs





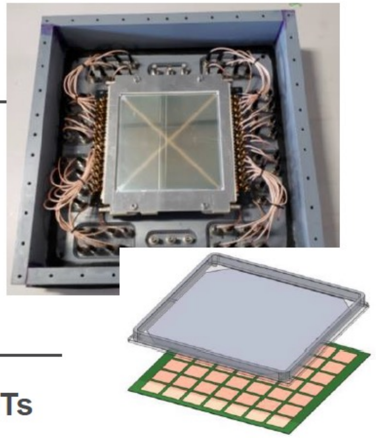
Ref: *C. Peng et al., arXiv:2011.11769*

- **The first JLab Hall C test shows that the LAPPD might work in the Hall C harsh environment to separate Cherenkov events.**
- **Needs high QE, pixelated LAPPDs for follow up testing.**

TEST OF GEN-II PIXEL LAPPD AT JLAB

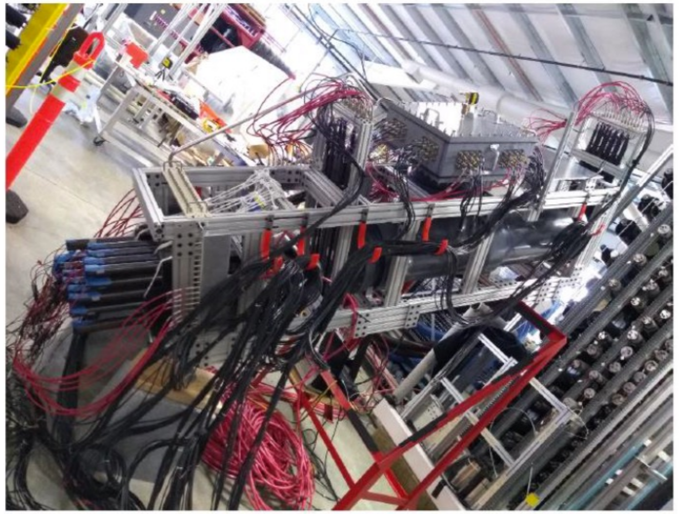
Received Gen-II LAPPD

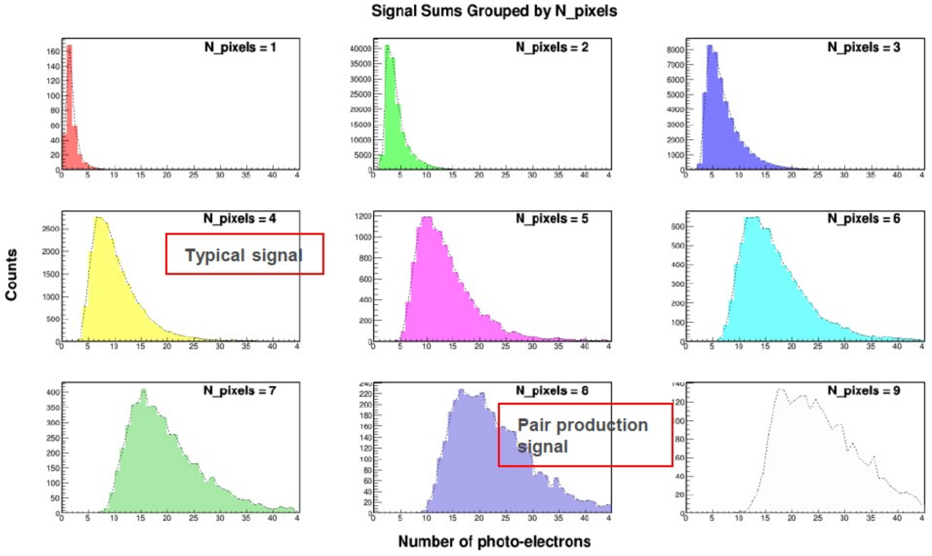
Window material	B33 glass (with wavelength shifter coating)
Readout anode	**Capacitive coupled 25mm x 25mm pixel**
Quantum Efficiency	**Mean: 15%, Maximum: 17%**
Gain	9.5×10^6 with MCPs @ 875V
Time resolution	79 ps



Coated with wavelength shifter at Temple Univ.

Similar detector setup but larger volume, accommodate 4x4 MaPMTs





- **The 2nd JLab Hall C confirms that the LAPPD works at high rate environment.**
- **With pixelized readout, utilizing geometrical information of pixels could improve the separation.**

LAPPDs in neutrino experiments

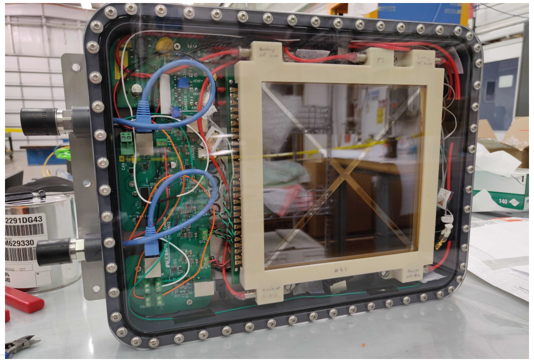
LAPPDs in ANNIE

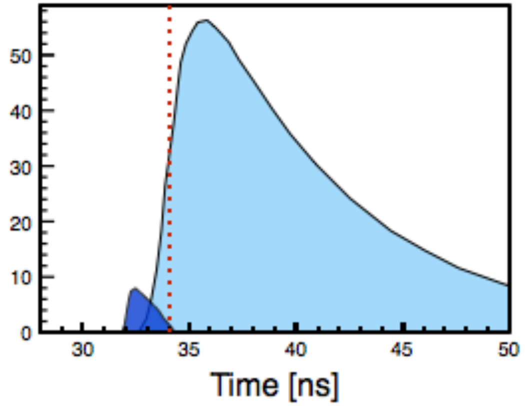
From Test Bench to Full Experiment

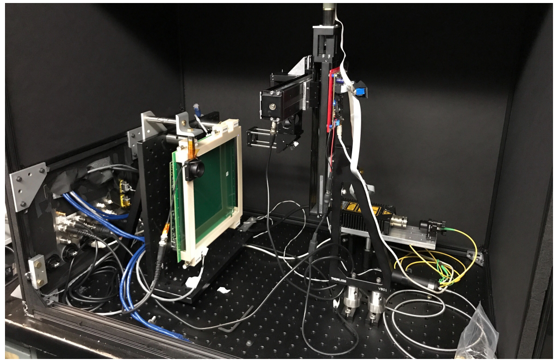
Amanda Weinstein(ISU) and Matt Wetstein (ISU)

on behalf of the ANNIE collaboration

March 21, 2022







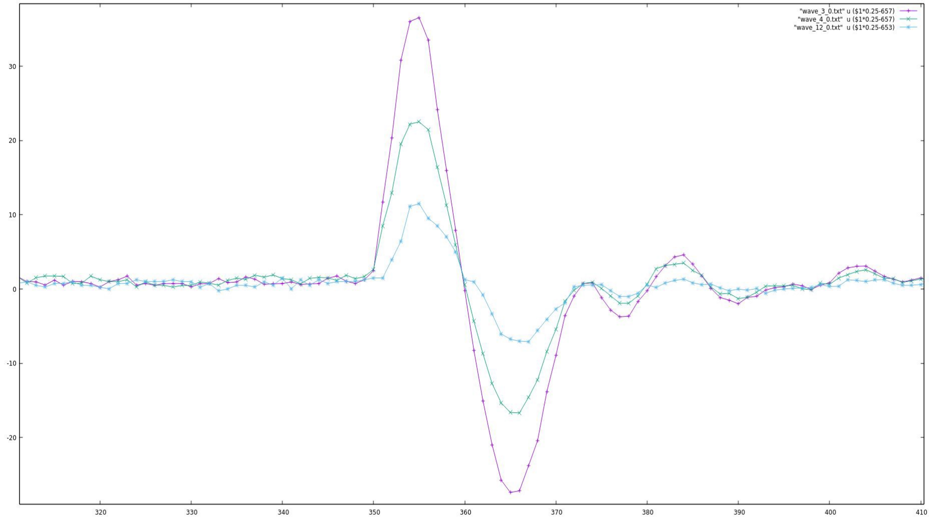
Was also a talk by Ed Callaghan

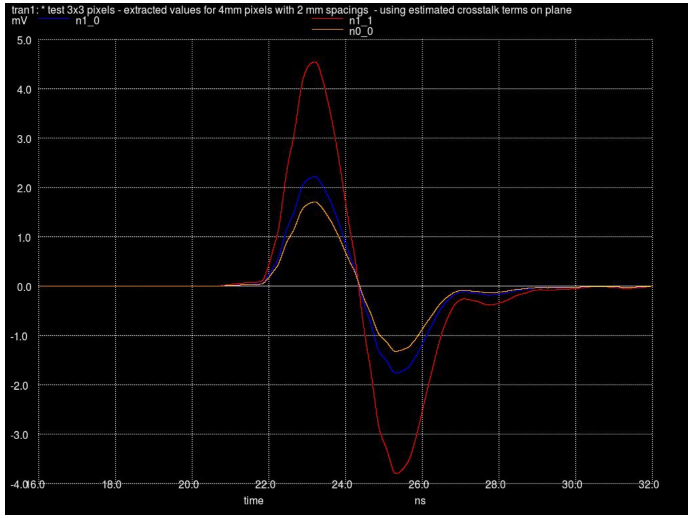
Nalu Scientific: Gen II LAPPD modeling

<u>Modeling</u>:
- Model properties
- Induced charge integration
- Readout plane board coupling
- Readout coupling

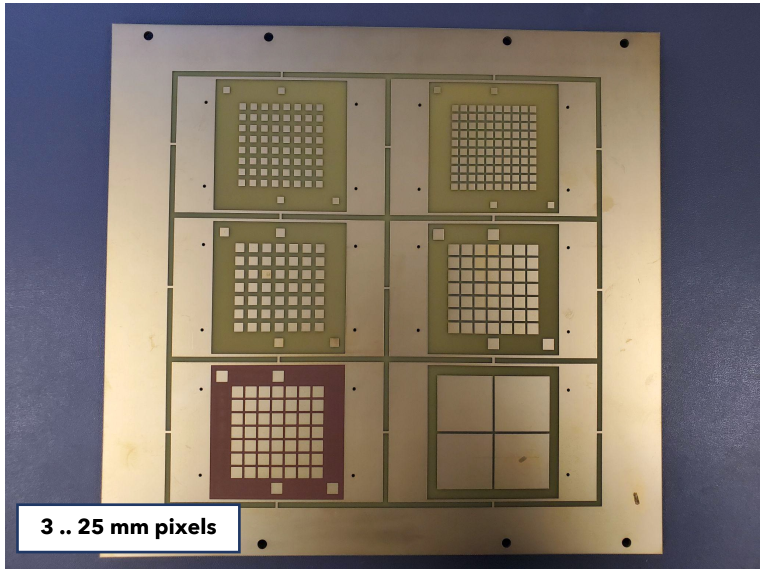
<u>Validation boards</u>:
- Design and geometry choices
- Measurements and Data Analysis

<u>Comparisons with models</u>:
- Qualitative consistence
- Modeling successes and failures



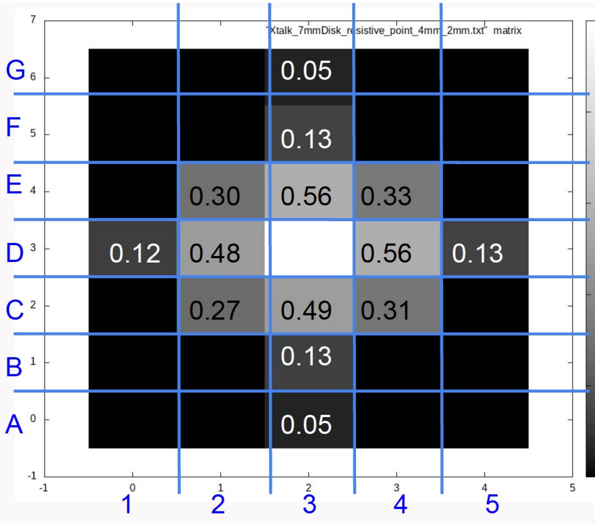


LAPPD test readout board



Cross-talk modeling and measurements

- **Example plot (right) shows 4mm x 4mm, 2mm gap; input at center (D3)**
  - **4mm x 4mm, 2mm gap crosstalk <u>greater</u> than 5mm x 5mm, 1mm gap**
    - **contrary to expectations but very small difference**
  - **Further ground crosstalk generally <u>greater</u> than closer ground**
    - **As predicted by model**



Luca Macchiarulo

Nalu Scientific: ASIC development

Fast Growing Startup in Honolulu, Hawai'i
- Located at the Manoa Innovation Center near U. of Hawaii
- 18 staff members-diverse background
- Access to advanced design tools
- Rapid prototyping and testing lab

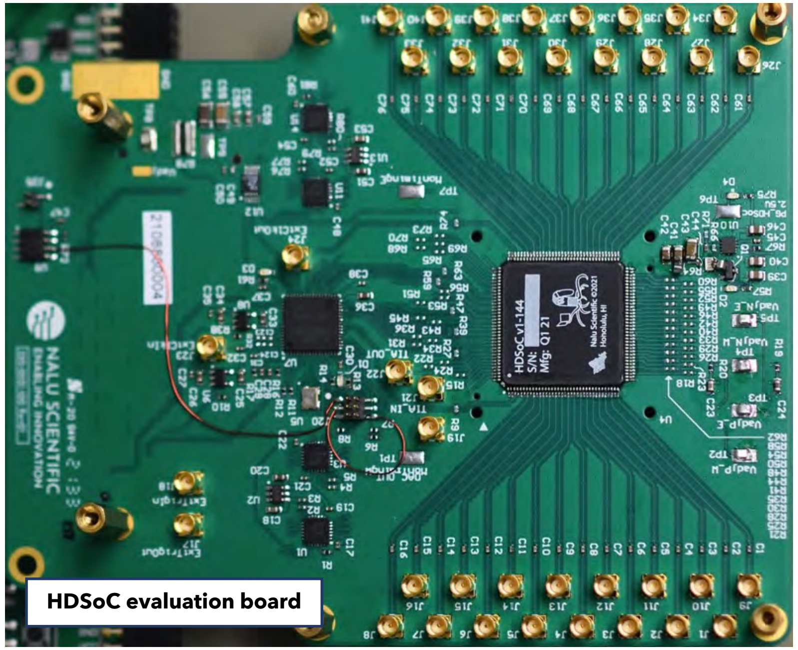
Technical Expertise

IC design:	Analog + digital System-on-Chip (SoC)
Hardware design:	Complex multi-layer PCBs
Firmware design:	FPGAs, CPUs
Software design:	GUI, analysis, documentation

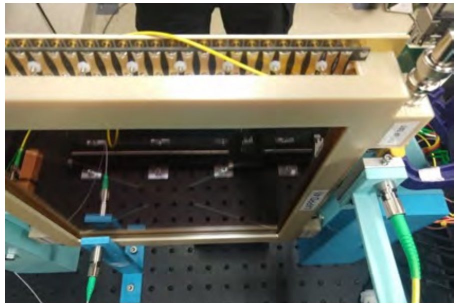
Scientific Expertise - NP/HEP subject matter experts
- Physicists (3x) - Recent hire: Kevin Flood
- Electronics for large scientific instruments

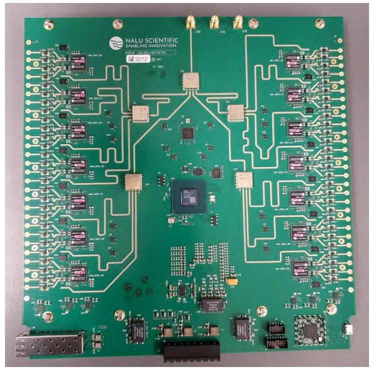
Project	Sampling Frequency (GHz)	Input BW (GHz)	Buffer Length (Samples)	Number of Channels	Timing Resolution (ps)	Available Date
ASoC	3-5	0.8	16k	4	35	Rev 3 avail
HDSoC	1-3	0.6	2k	64	80-120	Rev 1 avail
AARDVARC	8-14	2.5	32k	4	4	Rev 3 avail
AODS	1-2	1	8k	1-4	100-200	Rev 2 avail
UDC	10	1.8	2048	16	5-10	Rev 1 avail
STRAWZ	5	2	2k	64	10	TBD
HPSoC	8-10	2	2k	64	4	Dec'23

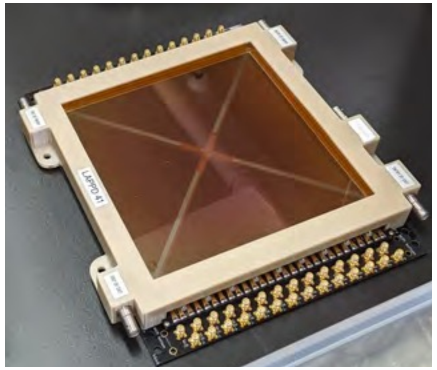
- **ASoC**: Analog to digital converter System-on-Chip
- **HDSoC**: SiPM specialized readout chip with bias and control
- **AARDVARC**: Variable rate readout chip for fast timing and low deadtime
- **AODS:** Low density digitizer with High Dynamic Range (HDR) option
- **STRAWZ:** Streaming Autonomous Waveform-digitizer with Zero-suppression
- **HPSoC:** High Pitch digitizer SoC: AC-LGADs specific readout



HDSoC evaluation board







HiPER readout board (14x AARDVARC chips)

Summary and outlook

- Workshop attracted quite some attention
- Several interesting presentations, accompanied by questions & discussions

- Plans for the future:
  - Establish means of communication (at the very least, a mailing list)
  - Have such workshops on a regular basis, 3-4 times a year
  - Next workshop in summer 2022: design standards (LAPPD, electronics, software), etc