LAPPD R&D effort at IJS Ljubljana

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Motivation

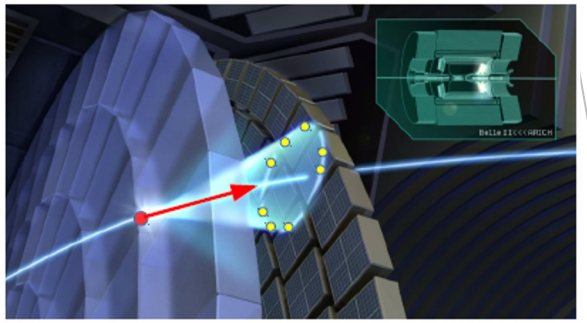
Use of LAPPDs for light detection in new generation of PID detectors

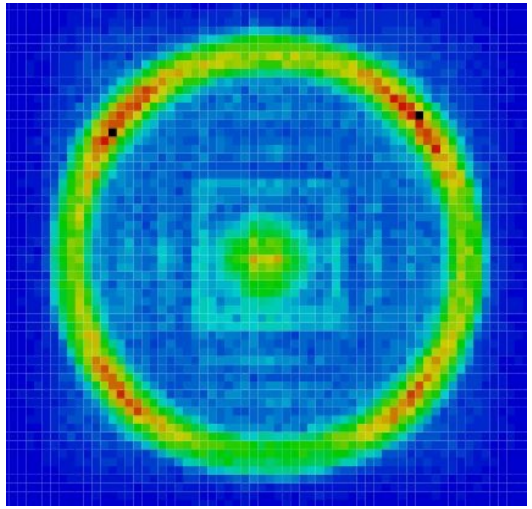
- Detection of single photos
  - Ring Imaging Cherenkov detectors
    - Highly irradiated environments
    - High photon fluxes
- 2 possible applications, both requiring pixelated readout – Gen II LAPPD:
  - LHCb RICH
  - Belle II Aerogel RICH

Low level light sensors for new generation of PID detectors

Requirements:

- Detection of **single photons** with
- High detection efficiency in visible range
- High granularity – mm^2
- High timing resolution – 100 ps
- High rate – LHC 40 MHz
- Large areas – 1- 10 m^2
- High magnetic field – up to 1.5 T
- Low material budget - 4π detectors
- Confined space - ~5cm at the backside
- Radiation resistance – 10^{13} neq/cm^2



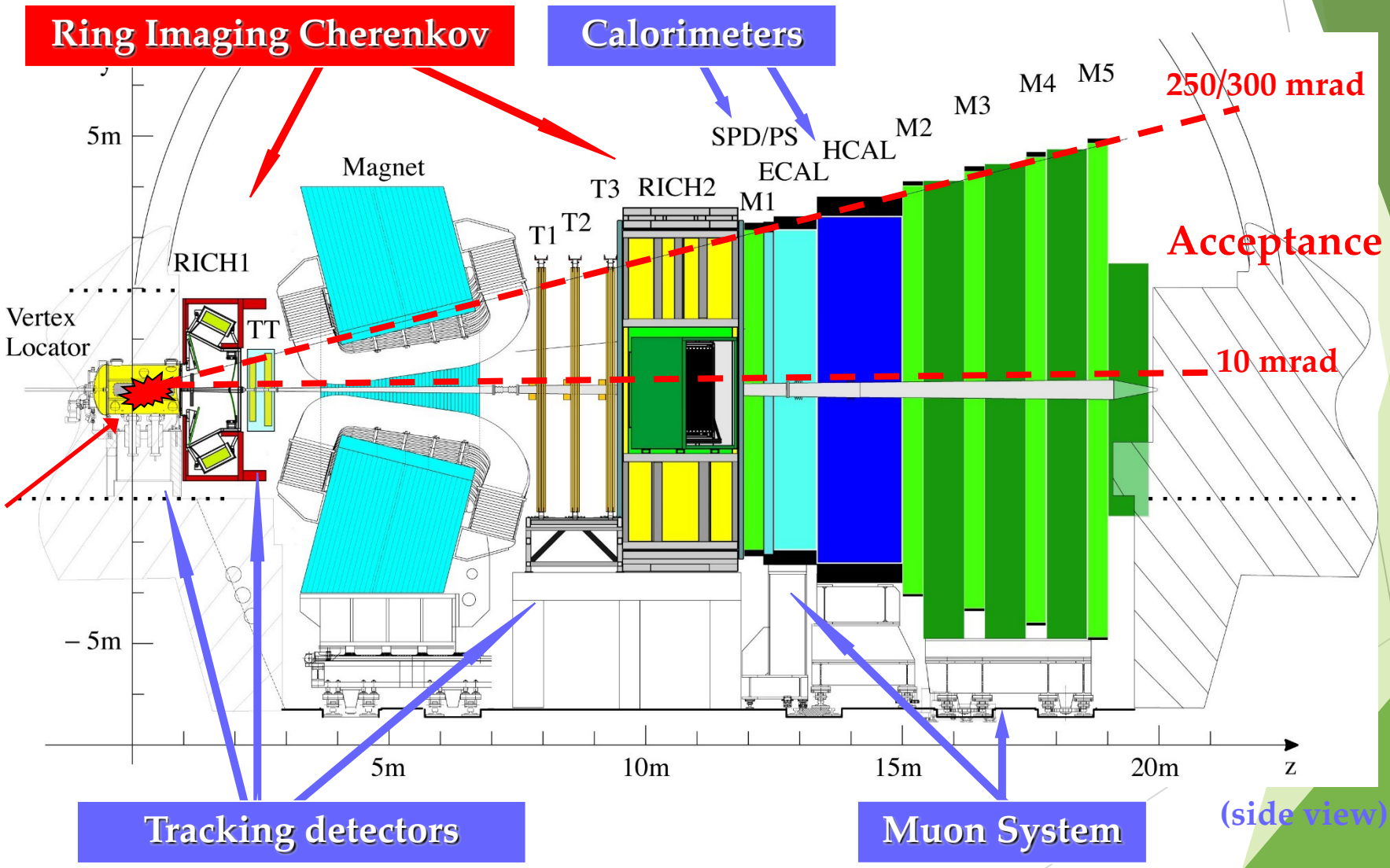


Vacuum sens. PMT MA-PMT LAPPD

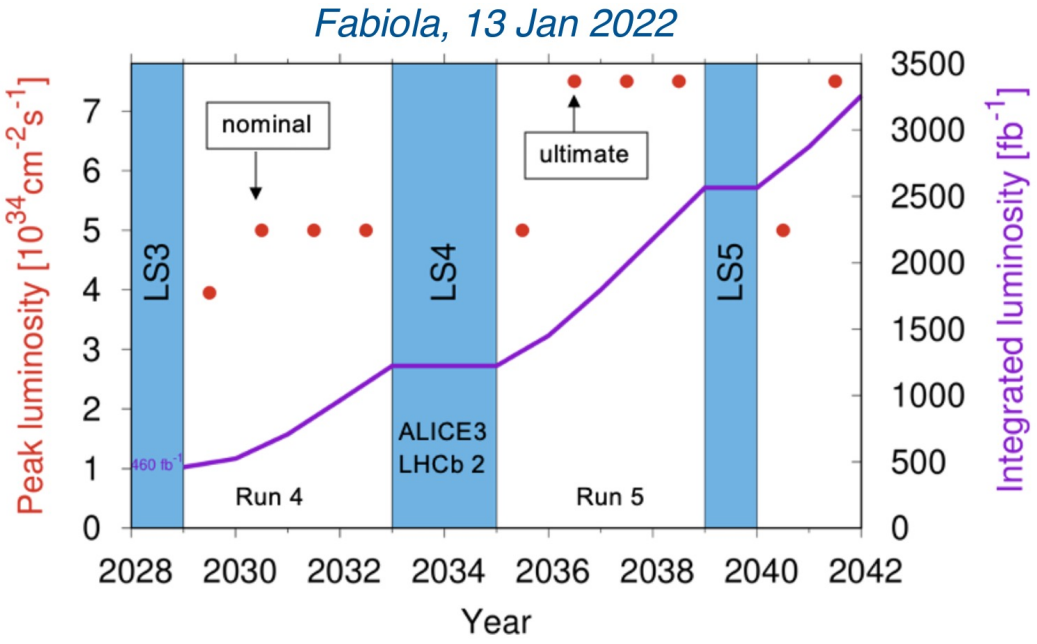
Solid state sensors Silicon photomultipliers

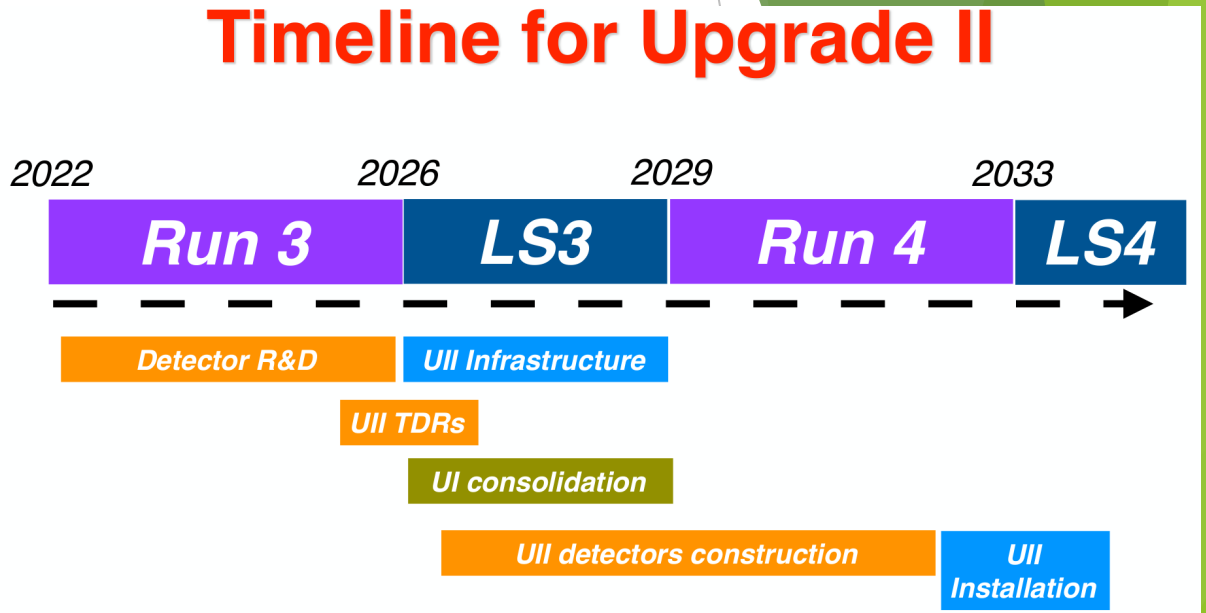
LHCb

single-arm spectrometer, dedicated to precision studies of CP asymmetries and of rare decays in the B-meson system



LHC plan and LHCb Upgrades



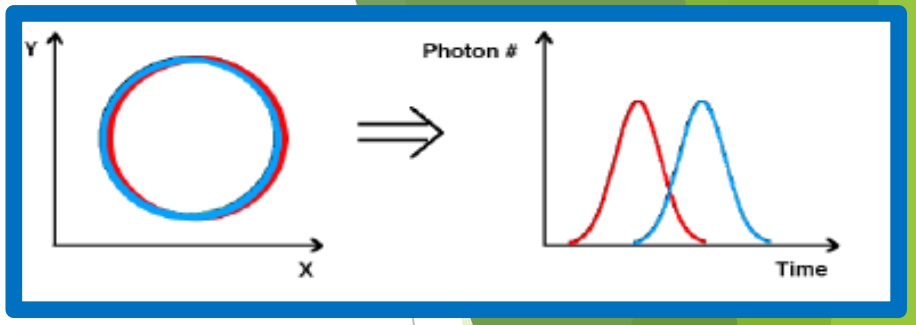


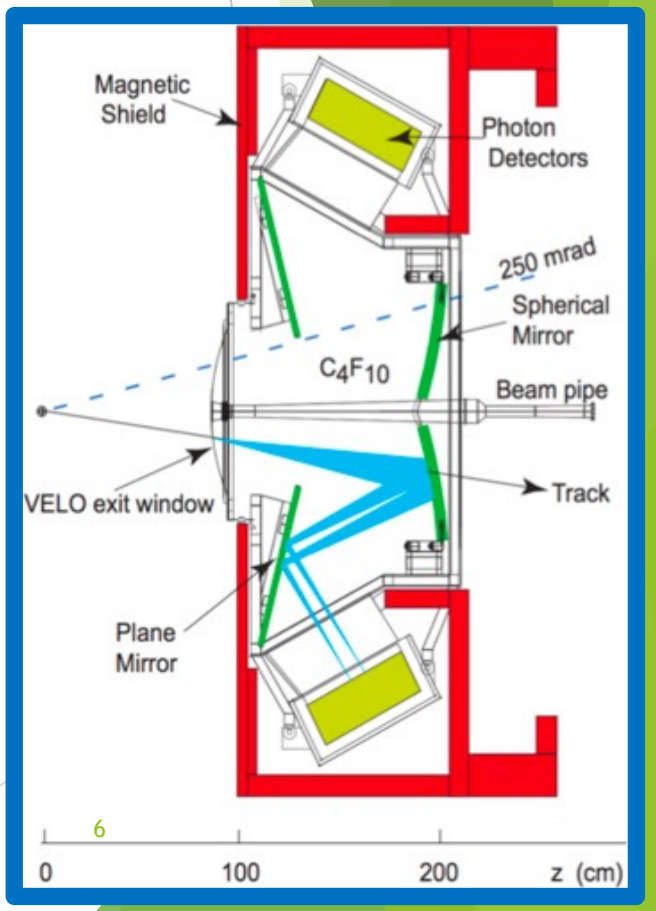
- ~4 year period for detector R&D, make technology choices and optimise the detector design
- ~6 year period for detector construction
- During LS3: Significant infrastructure preparation and Limited-size detector consolidations
- end of 2023 to 2024 - finalise TDRs

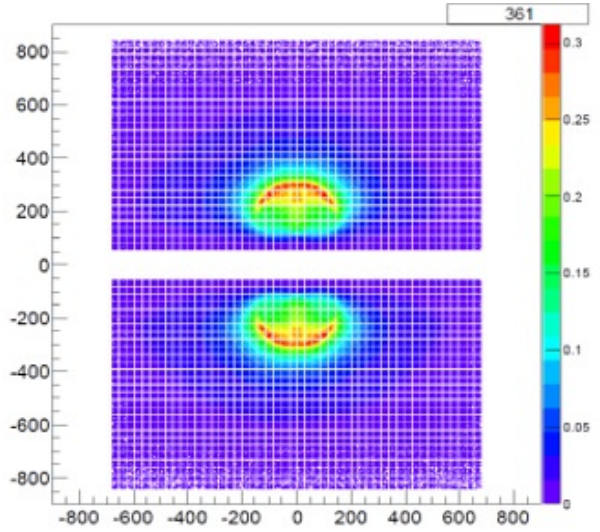
LHCb RICH upgrades

- Upg1 - RICH 1 and 2 - MA-PMTs
- Upg2a 2026-2029 upgrade – preparation
  - Timing of photons
- 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

Measure time of arrival of photons ~150 ps





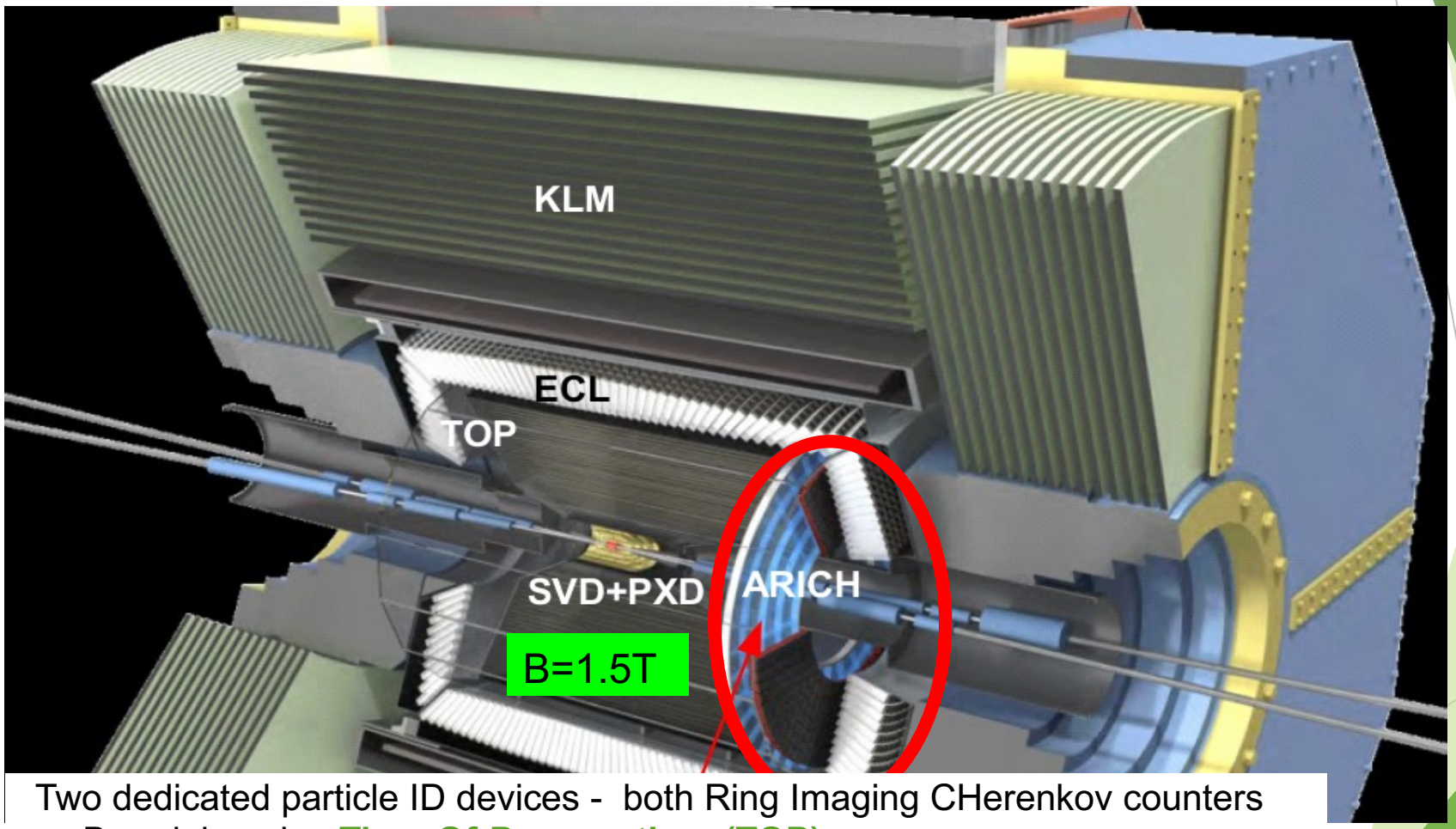


CERN-LHCC-2021-012 ; LHCB-TDR-023

Framework TDR for the Upgrade of LHCb ,2021

https://cds.cern.ch/record/2776420

Belle II precision measurements in rare decays of B, D and tau



Two dedicated particle ID devices - both Ring Imaging CHerenkov counters

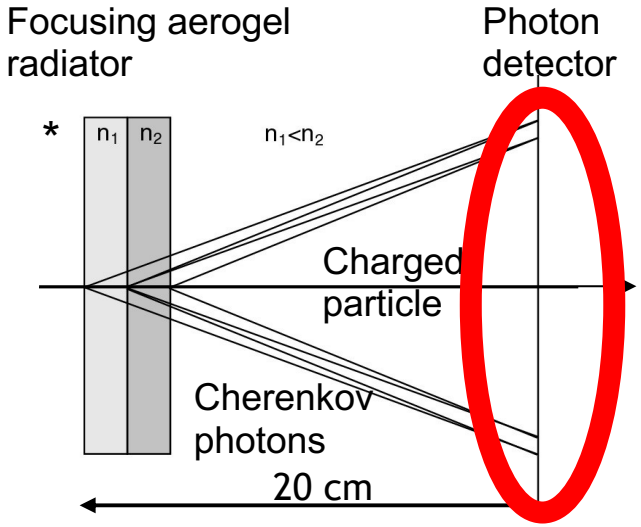
- Barrel: imaging **Time-Of-Propagation (TOP)**

End-cap: **Proximity focusing Aerogel RICH (ARICH)**

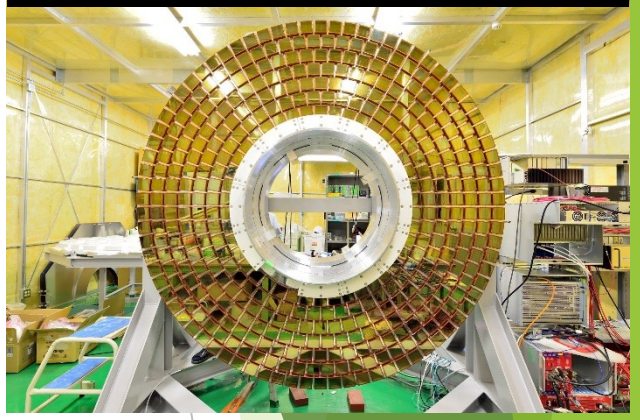
Belle II Aerogel RICH upgrade

- 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



Assuming pixels 5x5mm2
20 x 20 cm2 : 1600 ch x 64 modules = 102400 ch.
10 x 10 cm2 : 400 ch x 16 modules = 6400 ch.
Total ch. 108800 <= now 60480



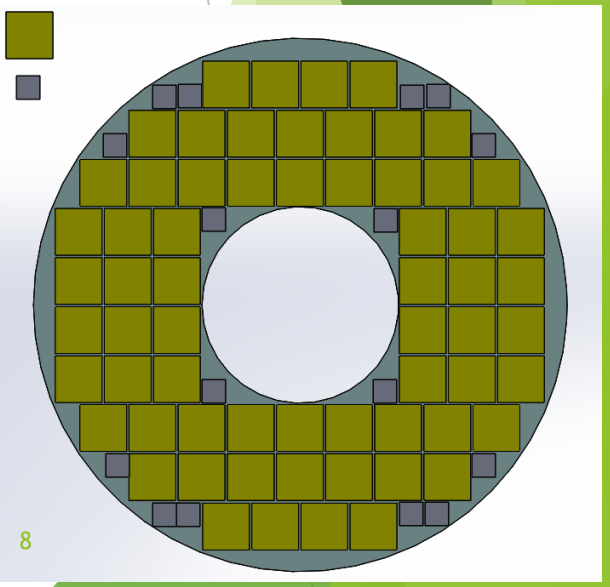


Photo sensor requirements for RICH detectors

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

Evaluation of LAPPD capabilities: status and future plans

- Laboratory bench test with single photons
  - Timing measurements
  - Charge sharing
  - Optimization of distances
- Prepare for the beamtest after the LAPPD is ready
  - Establish pixelated readout with small pitch
- Conceptual design report (LHCb) technical design report (ARICH)

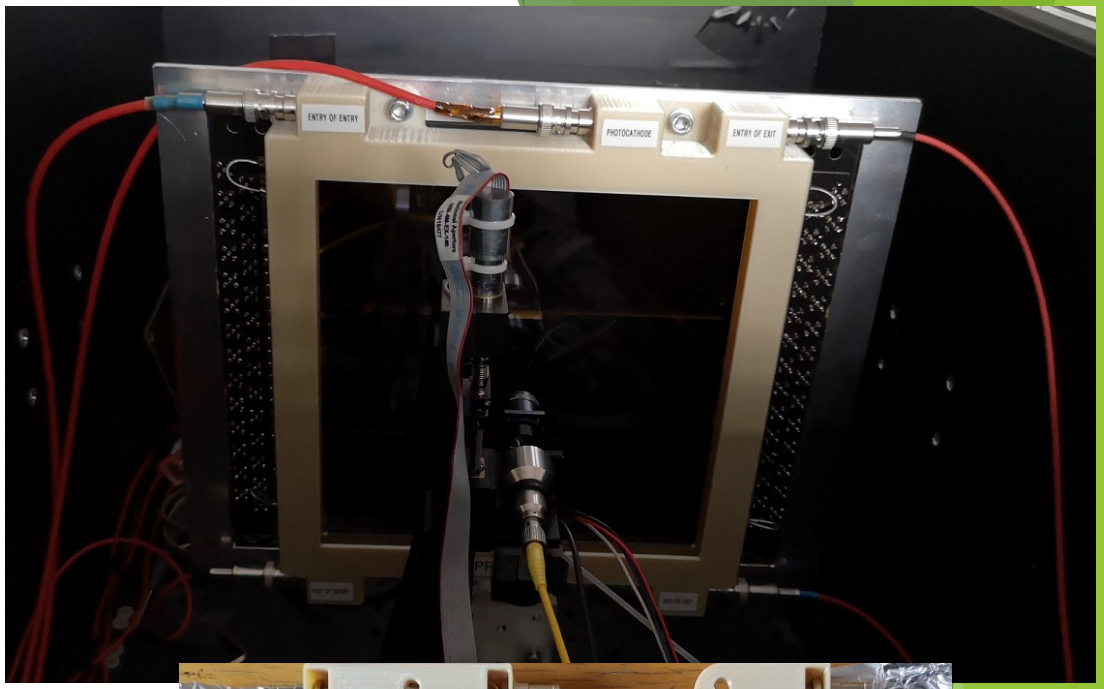
LAPPD #109 laboratory test

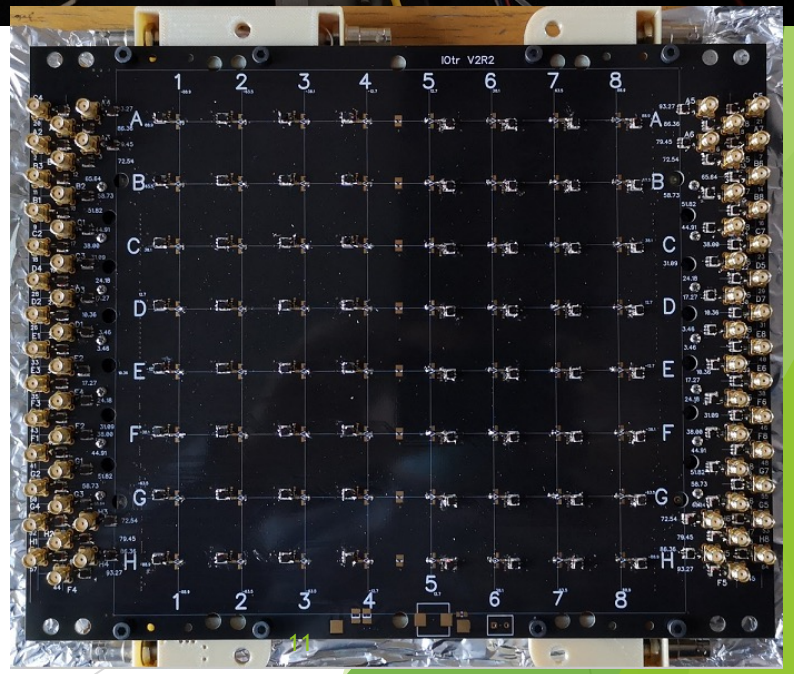
- $\approx 200 \times 200\ mm^2$
- $20\ \mu m$ pores @ $25\ \mu m$ pitch
- resistive anode plane, capacitive coupled readout
- 5 HV levels: PC, MCP1in, MCP1out, MCP2in, MCP2out and resistive anode at ground potential

- Standard setup with QDC, TDC, 3D stage ...
- starting with 4 channels
- TDC value corrected for time-walk

- ALPHALAS PICOPOWER™-LD Series of Picosecond Diode Lasers – 405 nm
- FWHM $\approx$ 20 ps
- light spot diameter on the order of $100\ \mu$m

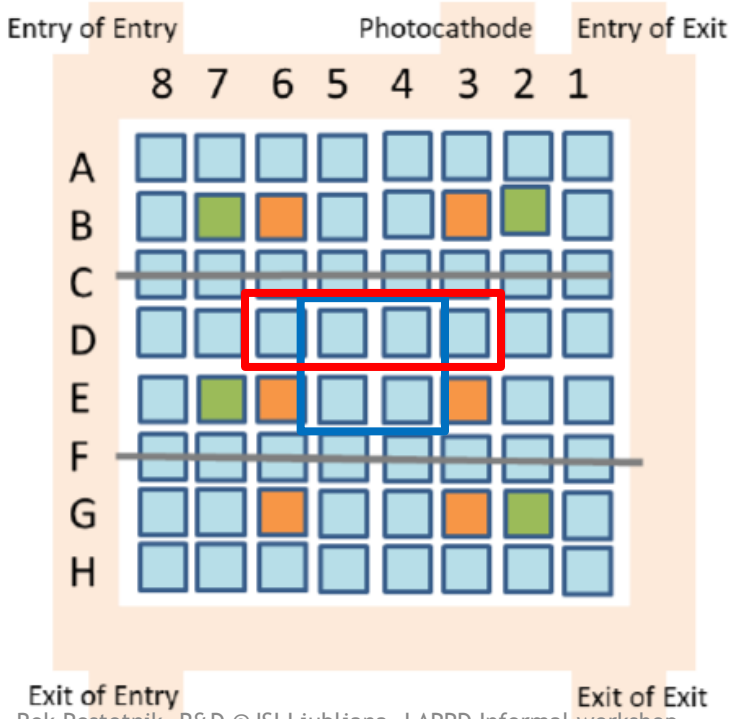
- **Very preliminary** results with no calibration of signals or light intensity. For internal use.

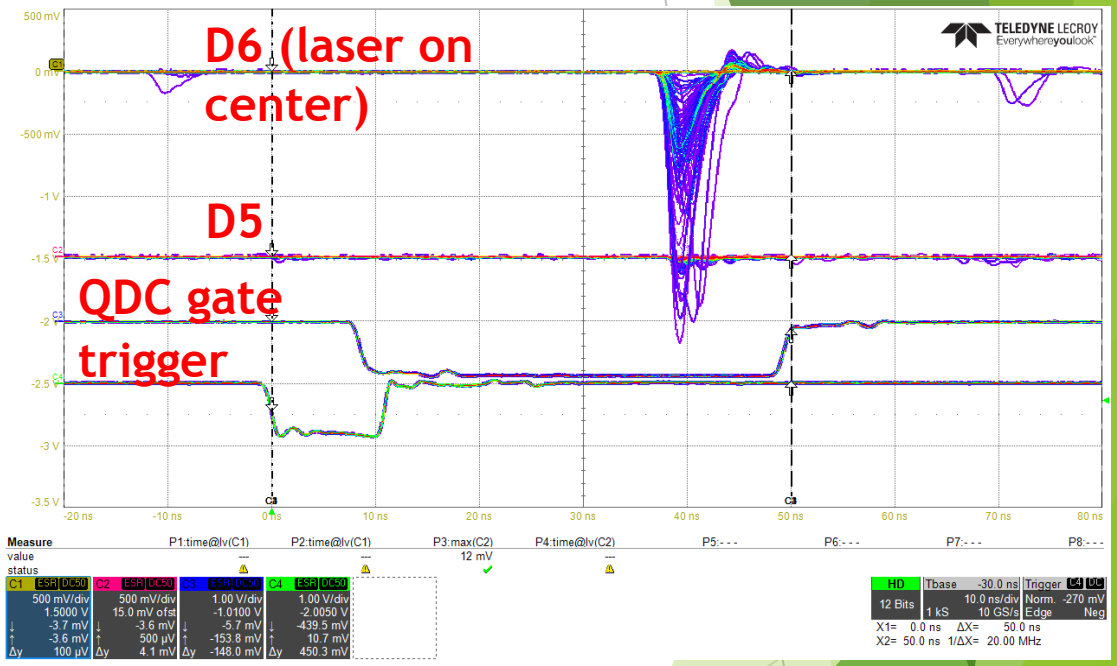




Signal inspection

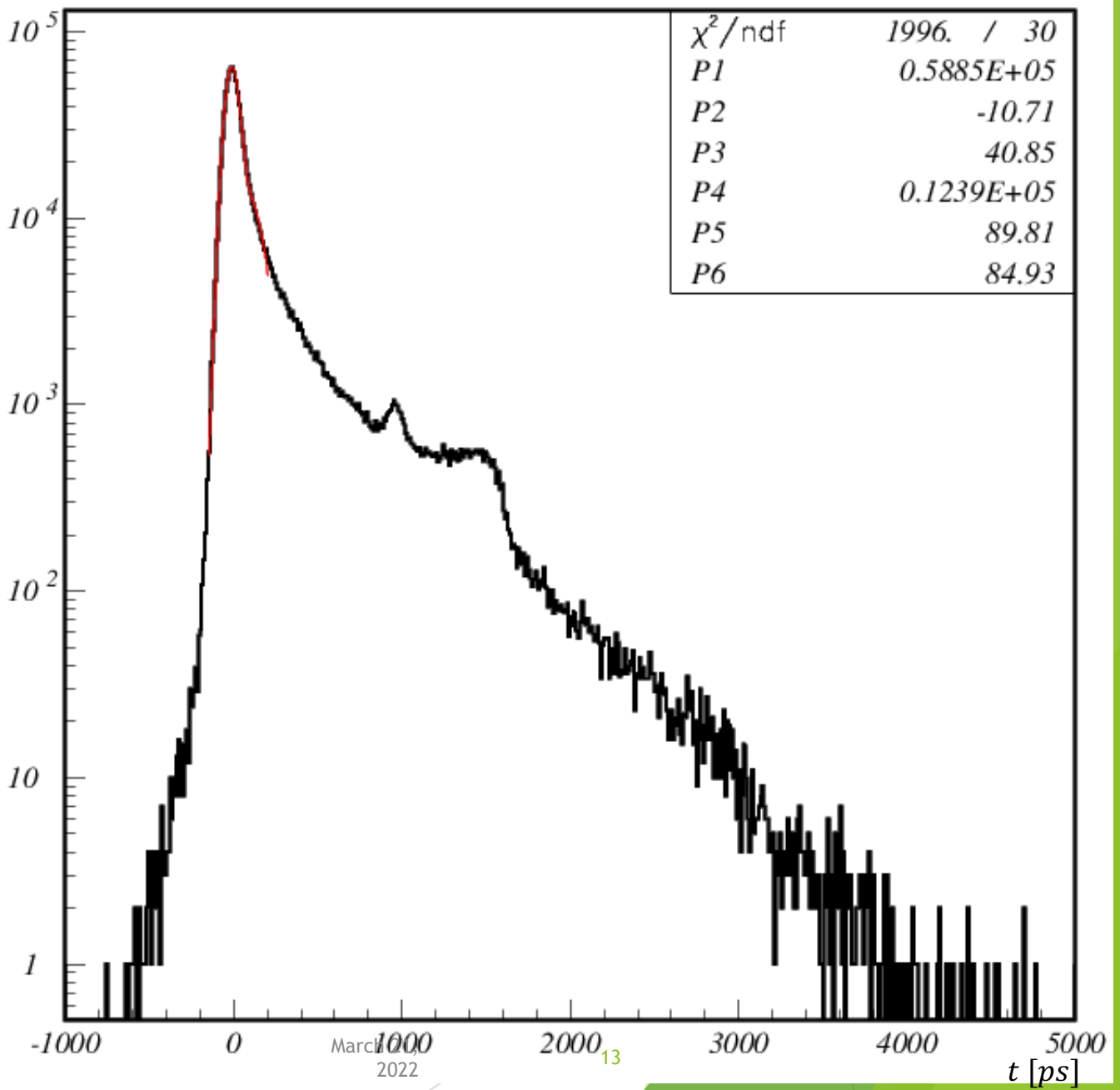
- readout configuration with channels **D6 – D3**
- signals D6, D5 and D4 are OK and D3 is distorted – probably bad connection on the backplane





Timing response

- measured timing distribution typical for MCP-PMT - $\sigma = 40\ ps$
- main prompt peak with some inelastic and elastic backscattering contribution
- plot is for the PC-MCP1 voltage of 150 V and ROP for others

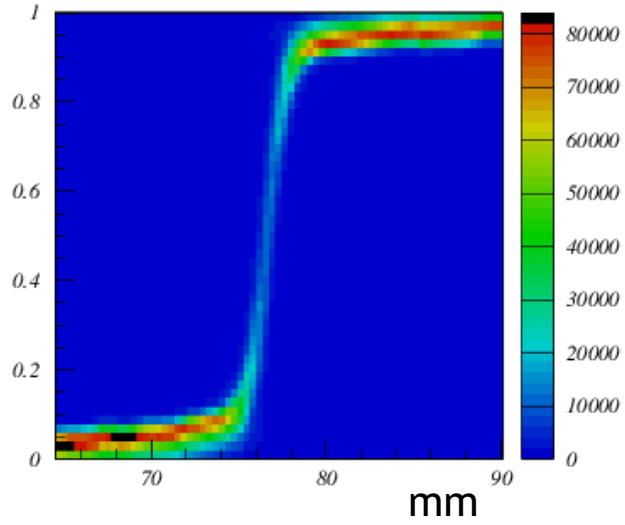


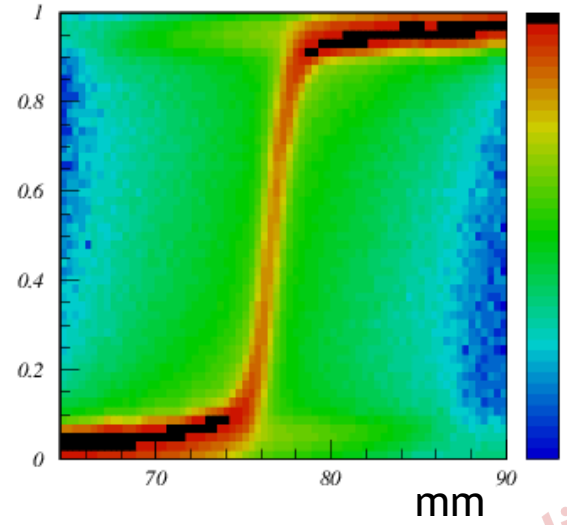
Signal spread comparison

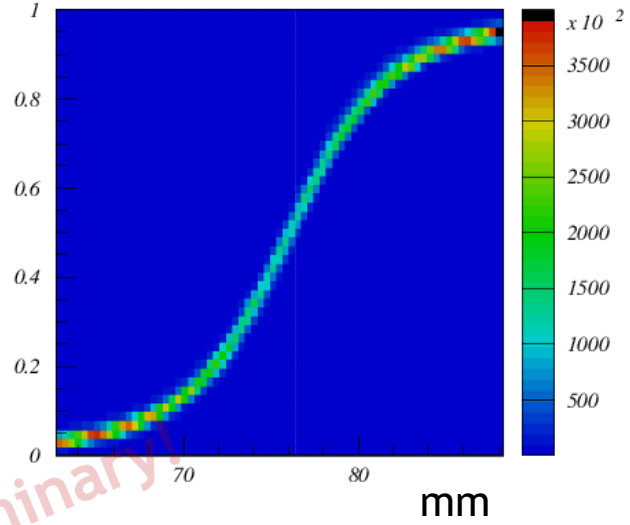
LAPPD (capacitive coupling) – BURLE PLANACON (internal anodes) – same pad size, same range

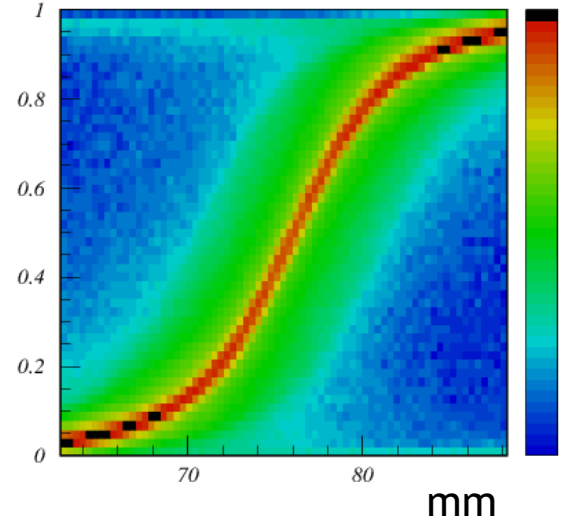
BURLE

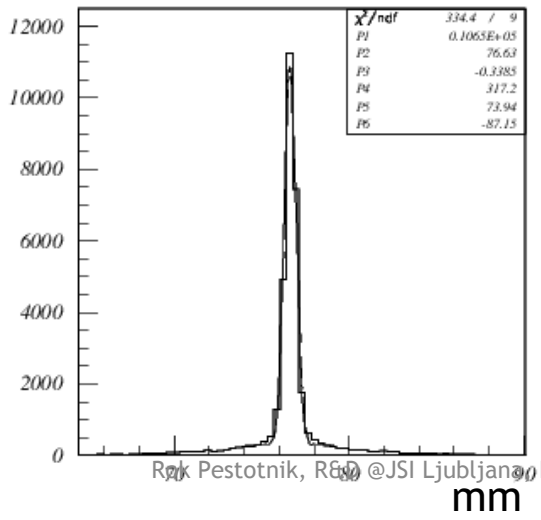
LAPPD

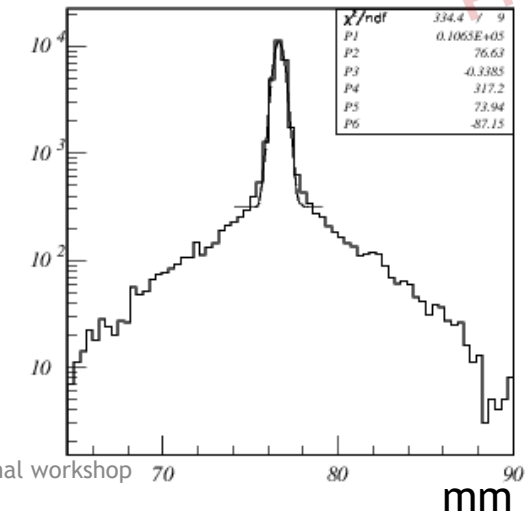


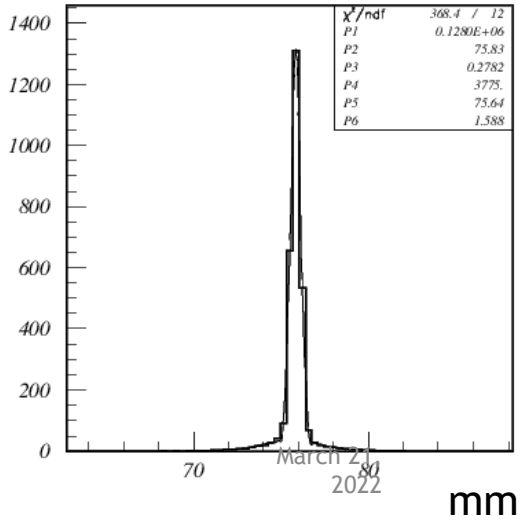


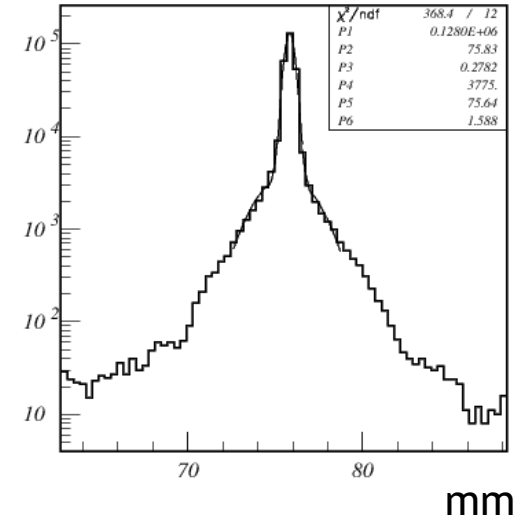








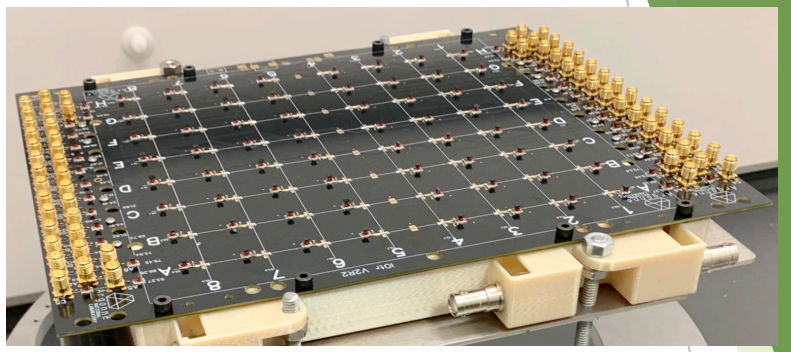


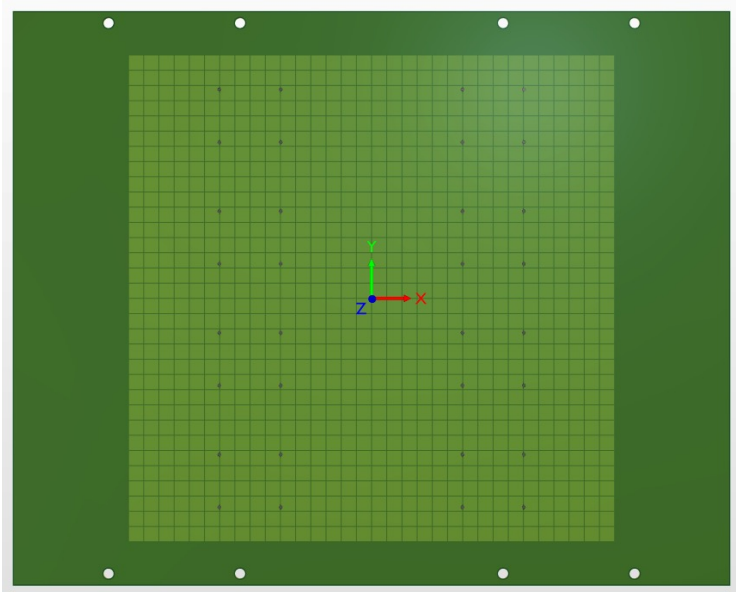


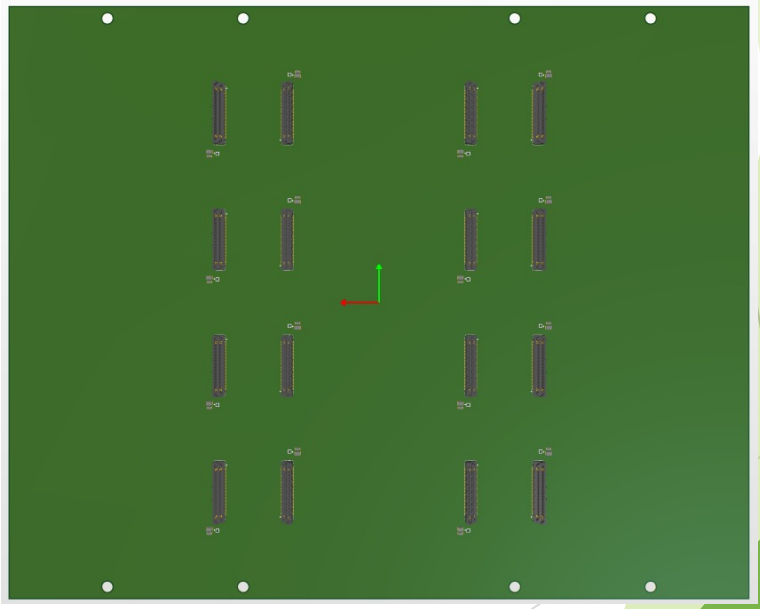
Preliminary

Capacitively coupled readout board

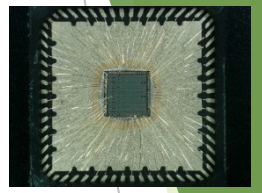
- Gen II – pixel readout
- Custom PCB design
- 6 mm readout pitch







Readout: FastIC



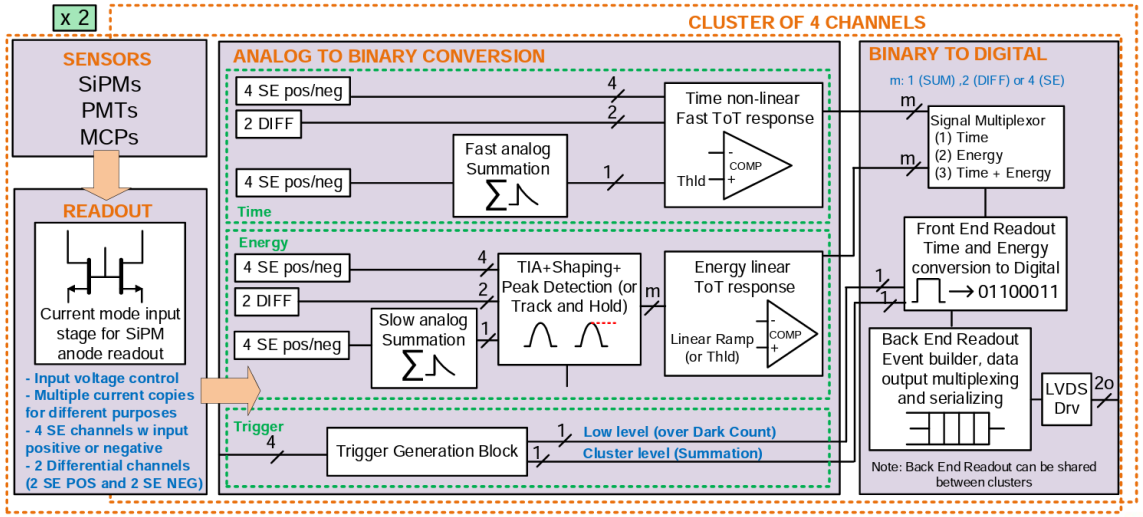
- FastIC - A highly configurable multi-channel ASIC for fast-timing applications has been designed (CERN – University of Barcelona collaboration)
- Enables timing and energy (charge) measurements
- Similar role as NINO, but with completely different architecture.
- Multi-detector compatible (SiPMs, PMTs, MCPs)
- Technology: CMOS 65 nm
- Configurable 8 SE channels OR 4 Diff channels OR 2 SUM4 channels
- Single ended / differential / SUM4 configurability, for positive or negative polarities
- Linearized ToT and fast analog summation
- Possible high density readout
- First version of the chip under test at Barcelona and CERN
- First measurements with Ma-PMT and SiPMs @ SPS LHCb RICH Testbeam – October 2021

Optimization of FastIC for single photon detection

S. Gomez: FastIC developments for LHCb and Belle RICH upgrades (UB)

https://indico.cern.ch/event/1064182

- FASTIC+TDC.
  - Approved project to include a low power TDC together with FastIC as a CERN KT funded Medical Applications grant (2 year project).
  - Work ongoing on TDC design with ~25ps time bin (20 possible in most corners).
  - Target power consumption is around 1mW/ch (still under development).
  - Larger channel density (32?)



29 September 2021

Summary

- LAPPD is being considered as a photon detector candidate for the upgrades of LHCb RICH and Belle II ARICH
- First tests to determine the timing and position resolution for 20x20cm device under way
- Timing resolution as expected ~ 40 ps
- Spatial resolution is limited due to charge spread – might be a limitig factor
- Plans:
  - Coupling of LAPPD to fast multi channel electronics (FastIC)
  - Test of the LAPPD in the testbeam