Combining Cherenkov Angle and Timing Measurements in One Detector

E. Nappi
on behalf of INFN-BARI/CERN/UNAM teams

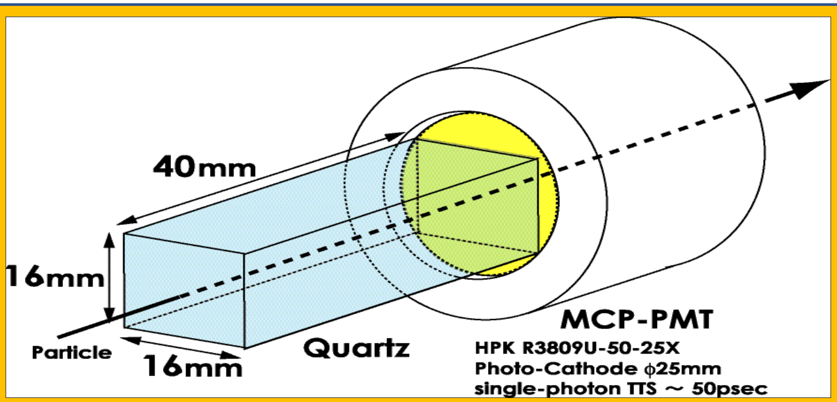
TOF DETECTORS BASED ON CHERENKOV LIGHT

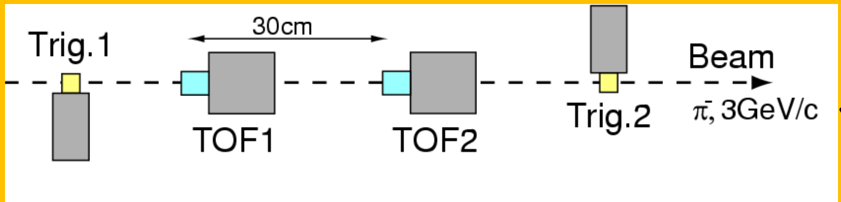
Why Cherenkov light for TOF devices?

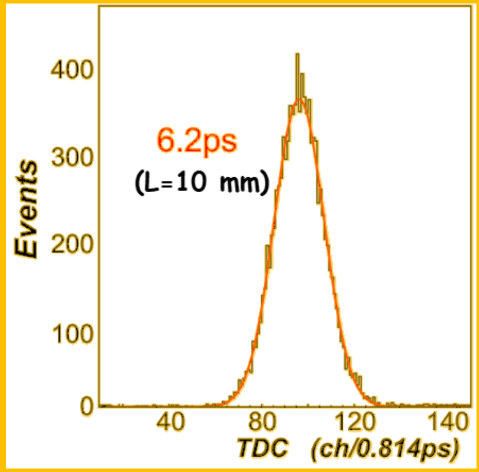
- Produced promptly
- Almost no time jitter (directionality)
- Single photoelectron statistics

Conventional TOF with scintillators

- ☐ Long decay time O(ns) in photon emission
- ☐ Time jitter due to photon paths

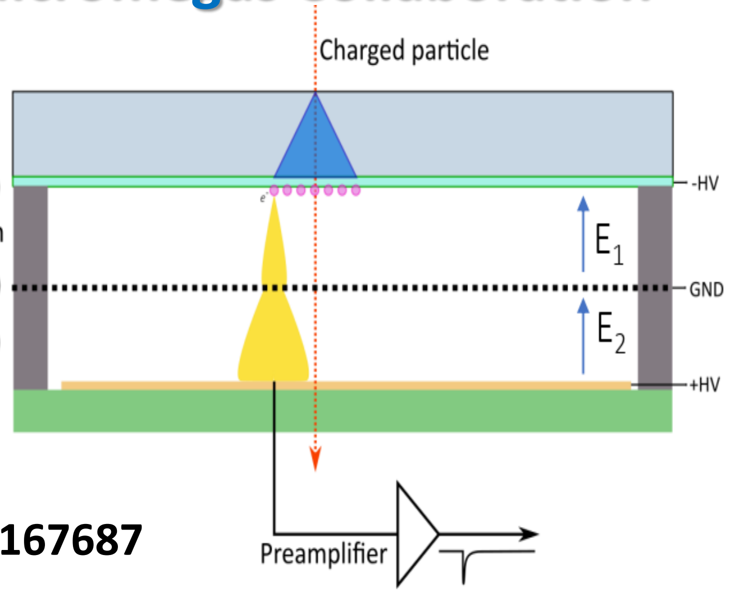




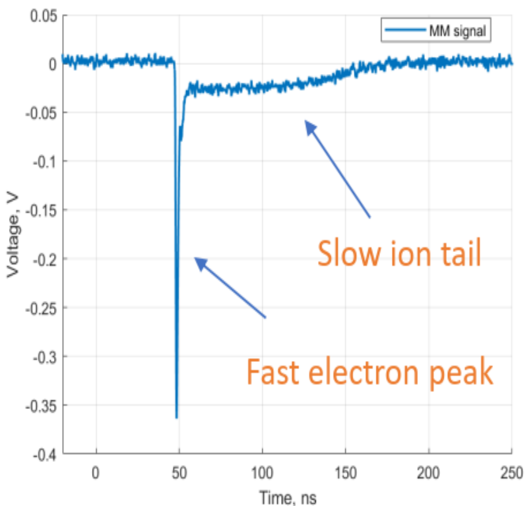


Y.Enari NIM A547 (2005) 490
K.Inami NIM A560 (2006) 303

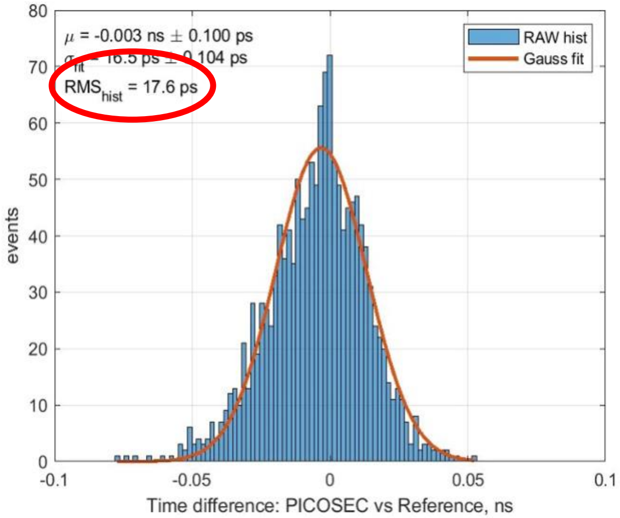
RD51 Picosec Micromegas Collaboration



M. Lisowska et al.
NIM A1046 (2023) 167687



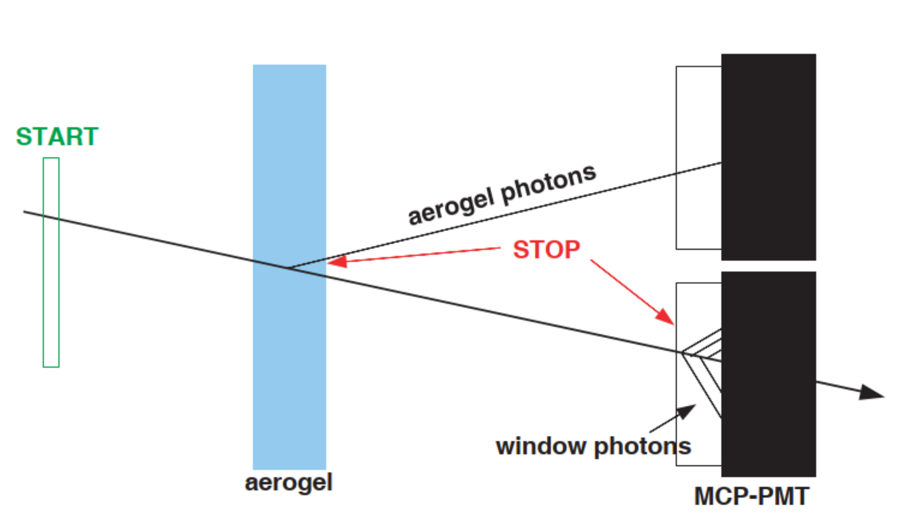
Time resolution of a 100-channel prototype (10x10 cm^2)



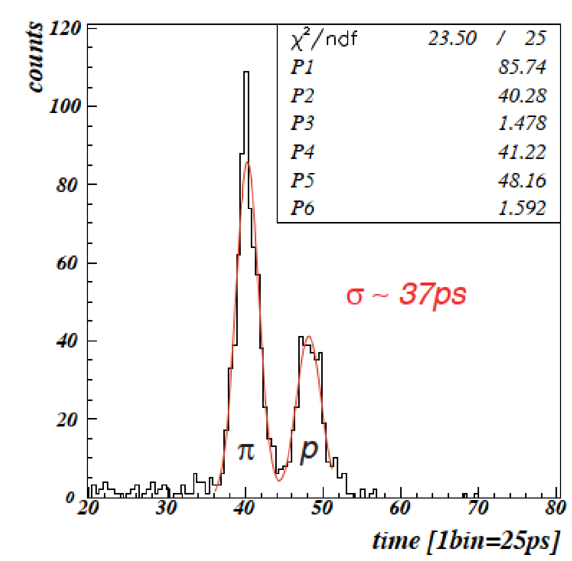
Proximity focusing RICH detector with TOF capabilities

P. Krizan et al.,
Nuclear Physics B (Proc. Suppl.) 172 (2007) 227–230

Belle II Technical Design Report



2 GeV/c pions and protons



Vacuum Photon Detectors (MCPs, LAPPDs)

Main limitation:

- Sensitivity to B (no gain at all for a barrel geometry PID system embedded in a solenoidal magnetic field)

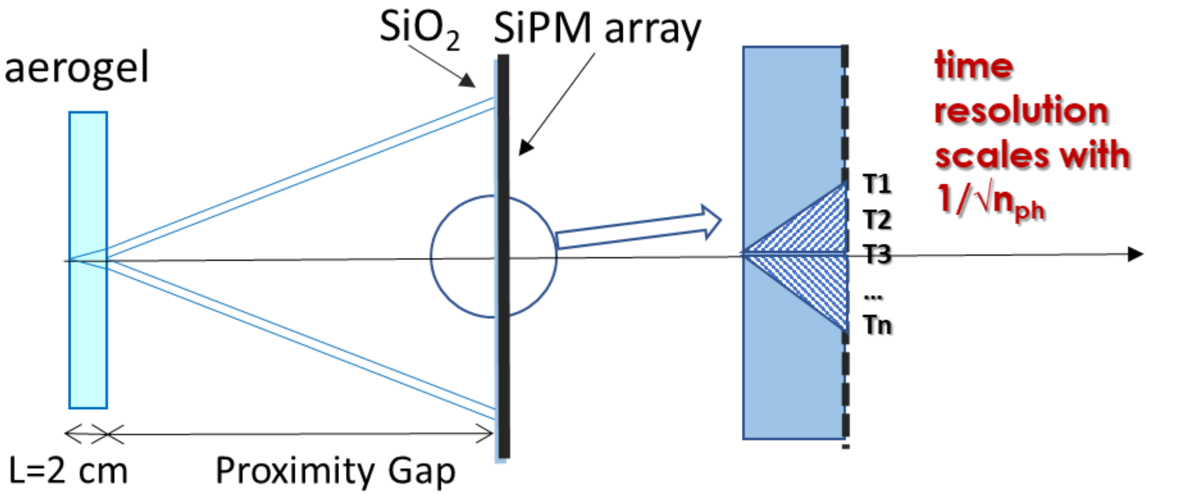
Gaseous Photon detectors (i.e. PICOSEC MM)

Main Limitation:

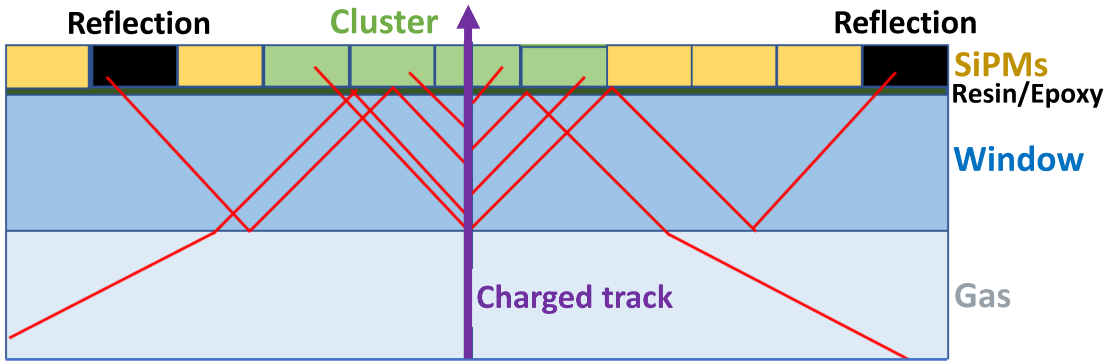
- Unable to detect visible photons (cannot be used aerogel as Cherenkov radiator)

Both gaseous and vacuum photon detectors are bulky (large X0)

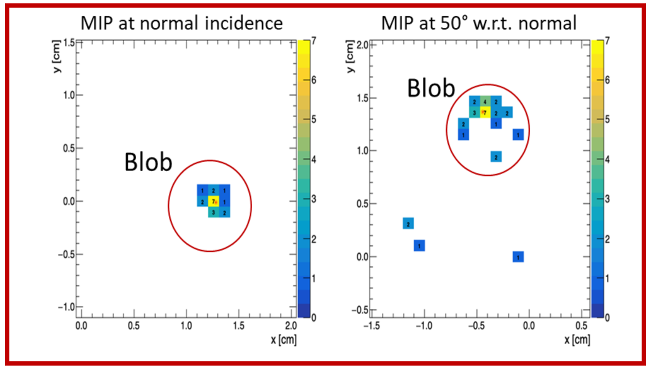
SiPMs



TOF Measurements by SiPMs

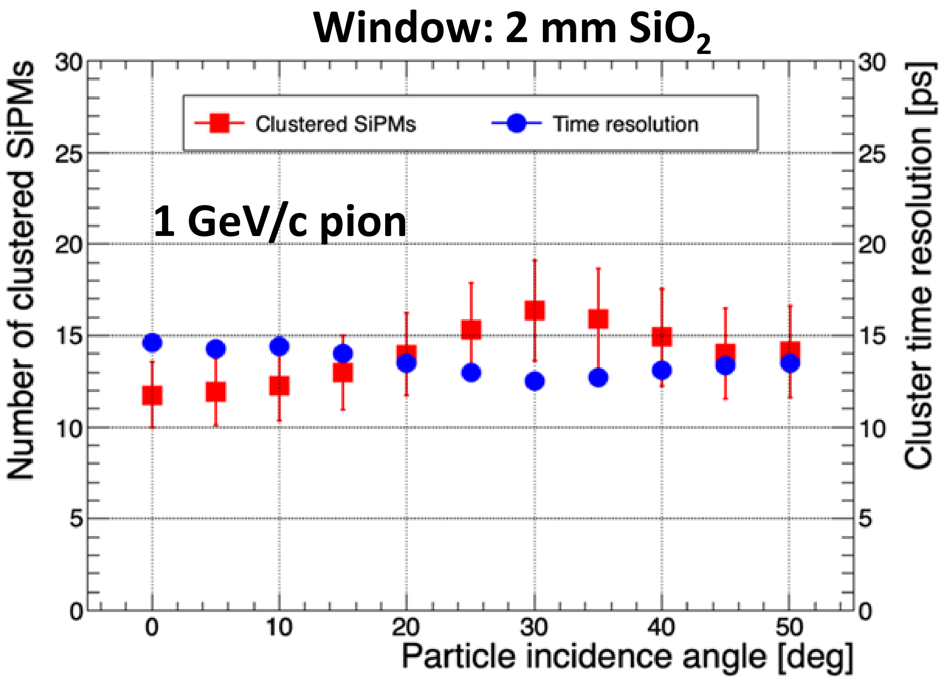


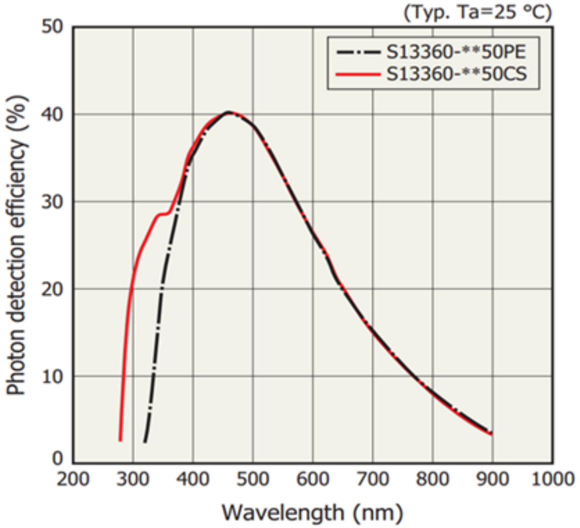
- Fresnel reflection between
  - Window and resin/epoxy
  - Resin/epoxy and silicon
  - Window and gas
- Window chromatic dispersion
- SiPM Fill Factor 90%, SPTR=50 ps
- Dark count rate ~ 50 kHz/mm^2 @ room temperature

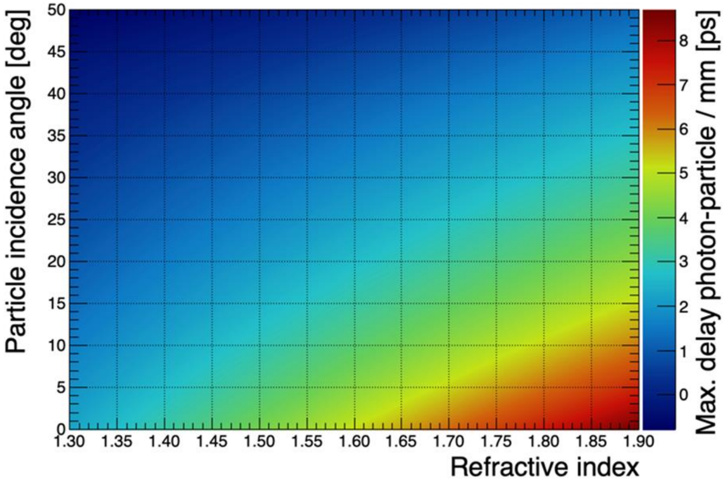


1 mm SiO_2 + 0.45 mm epoxy resin, 1x1 mm^2 cells

Material	Refractive Index at 400 nm	$\beta_{thr.}$	$p_{thr.,pion}$ [MeV/c]	Max θ_c [degree]	$N_{p.e.}$ at saturat. [mm^{-1}]
NaF	1.33	0.75	159	41.3	13
MgF_2	1.40	0.71	142	44.3	14
SiO_2	1.47	0.68	129	47.9	16
Silicone resin	1.50	0.66	124	48.2	16
Epoxy resin	1.55	0.64	117	49.8	17
High-n Corning	1.84	0.54	90	57.1	21





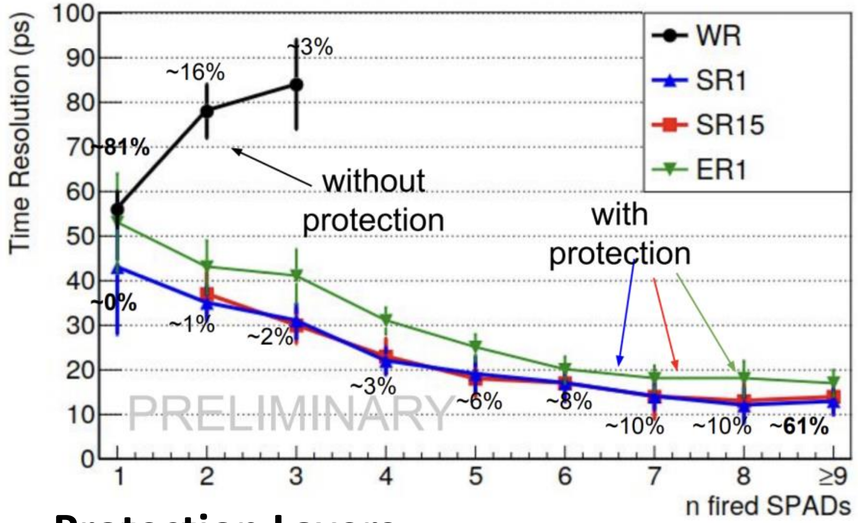


More on TOF Resolution Simulation

F. Carnesecchi, et al., **Understanding the direct detection of charged particles with SiPMs**
https://dx.doi.org/10.1088/1748-0221/17/06/P06007
https://doi.org/10.48550/arXiv.2210.13244

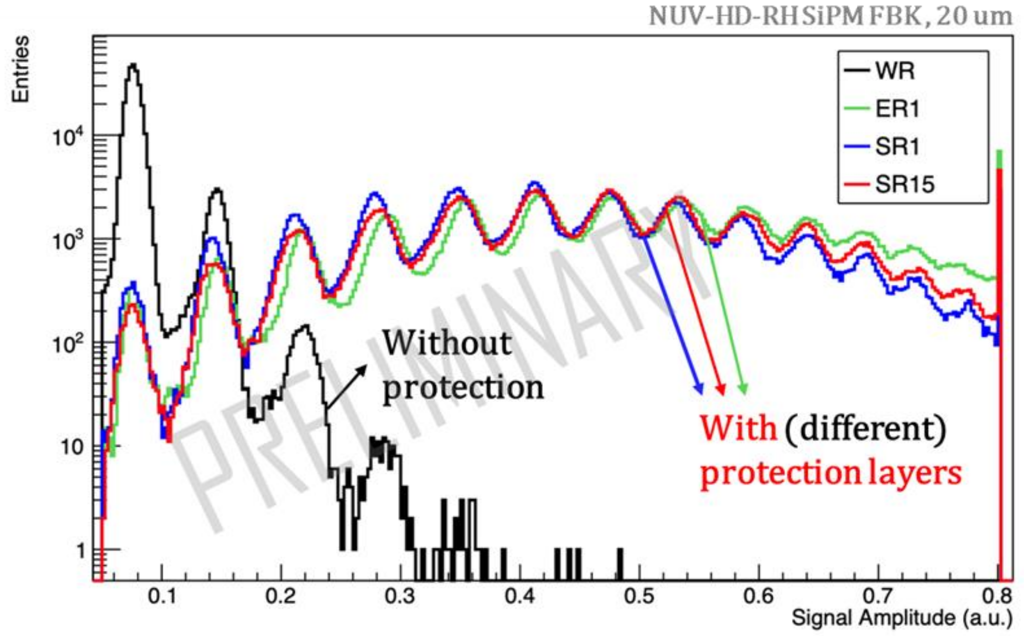
Talk by P. Antonioli tomorrow

Bianca Sabiu, Alice Upgrade Week, 05/2023

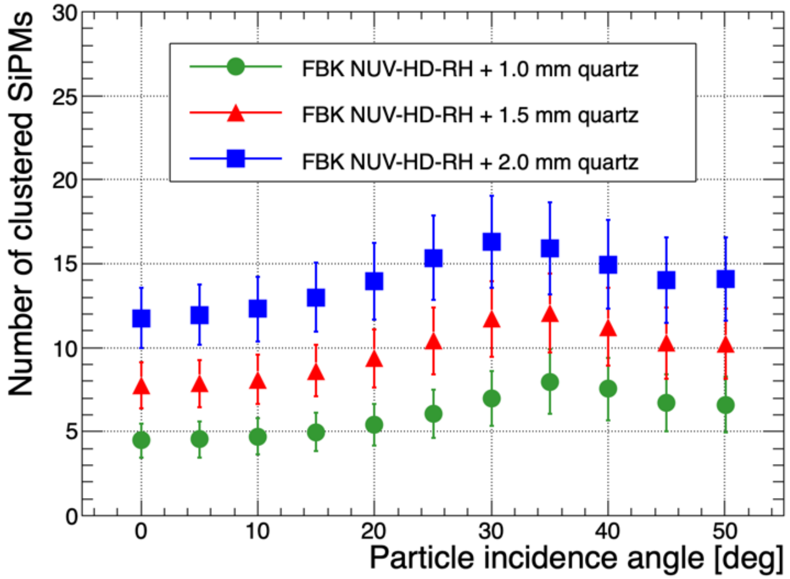


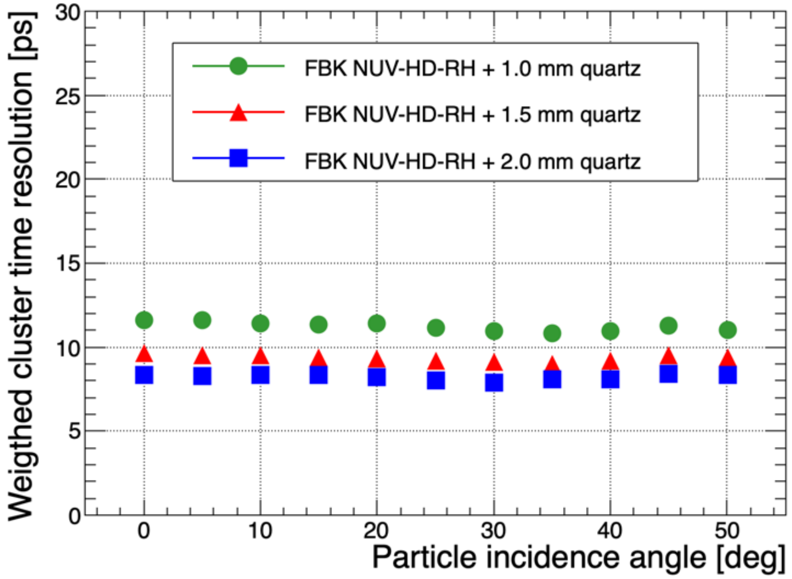
Protection Layers:
SR1 – 1 mm silicone resin (n=1.5)
SR15 – 1.5 mm silicone resin (n=1.5)
ER1 – 1 mm epoxy resin (n=1.53)
WR – without protection layer

FBK NUV-HD-RH SiPM
(1x1 mm^2, 20 μm SPADs
72% Fill Factor)

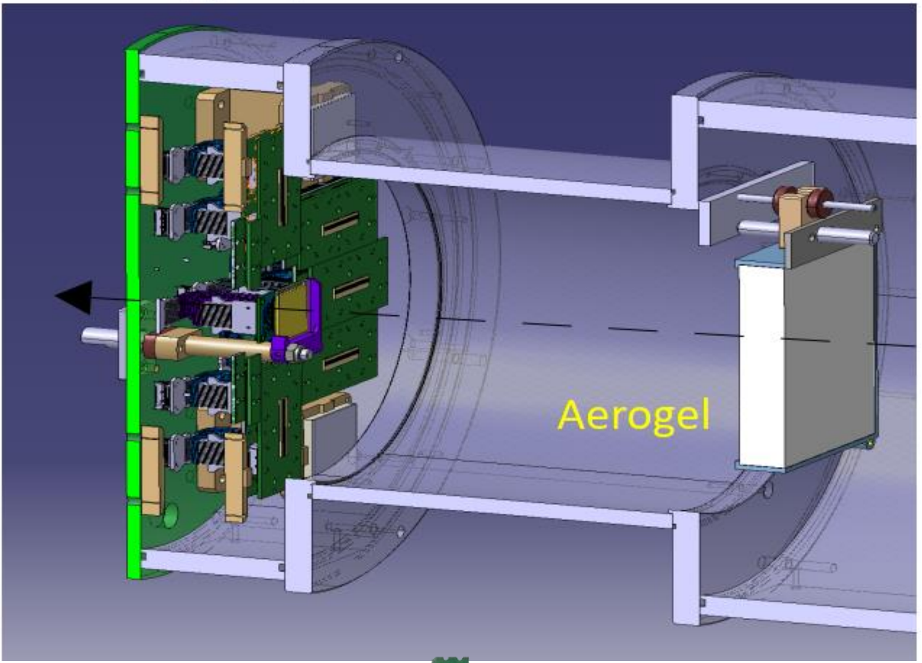


Simulation for 5 GeV/c pions

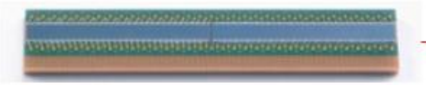




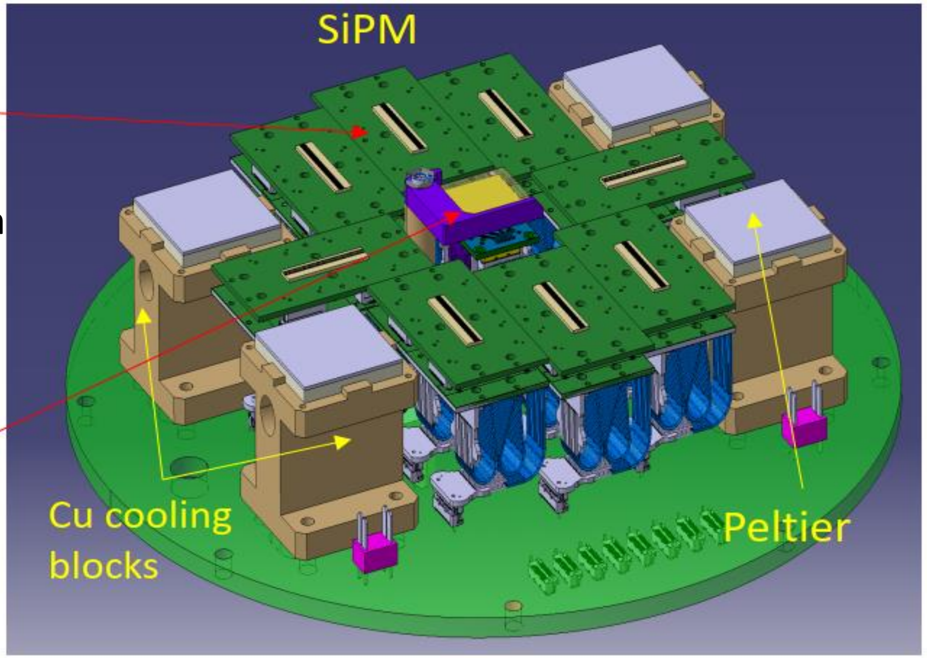
2022 Beam Test Campaign @ PS T10



Beam



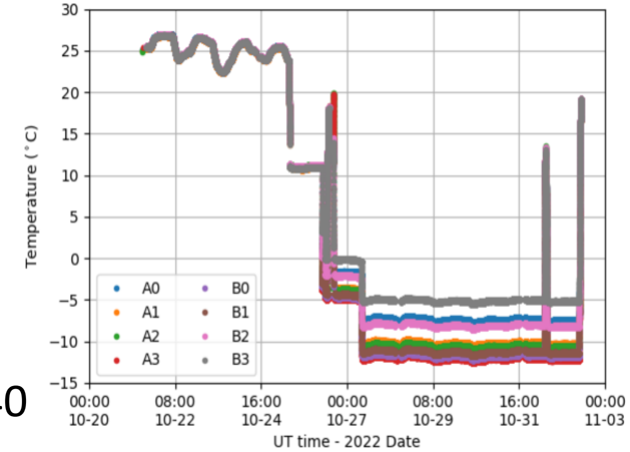
8 HPK S13552 SiPM arrays for detecting Cherenkov light from aerogel

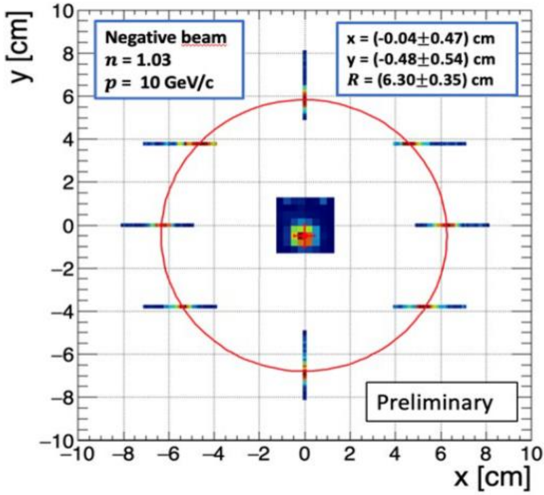


8x8 HPK S13361 SiPM matrix 3x3 mm^2 pixel with a NaF radiatior ,
3 mm thick (n = 1.3319 @ 400 nm),
for charged particles

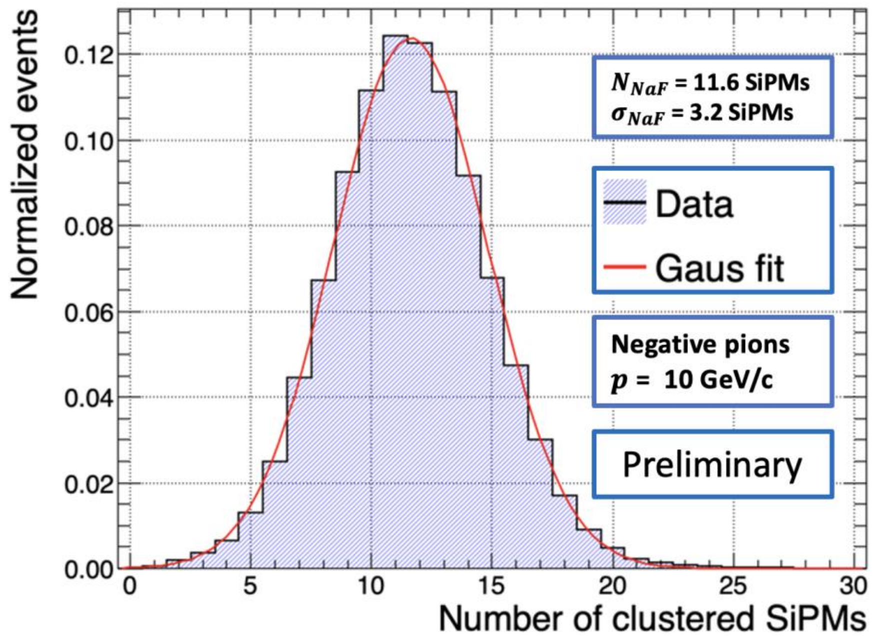
Front-End: Four PETIROC 2A ASICs

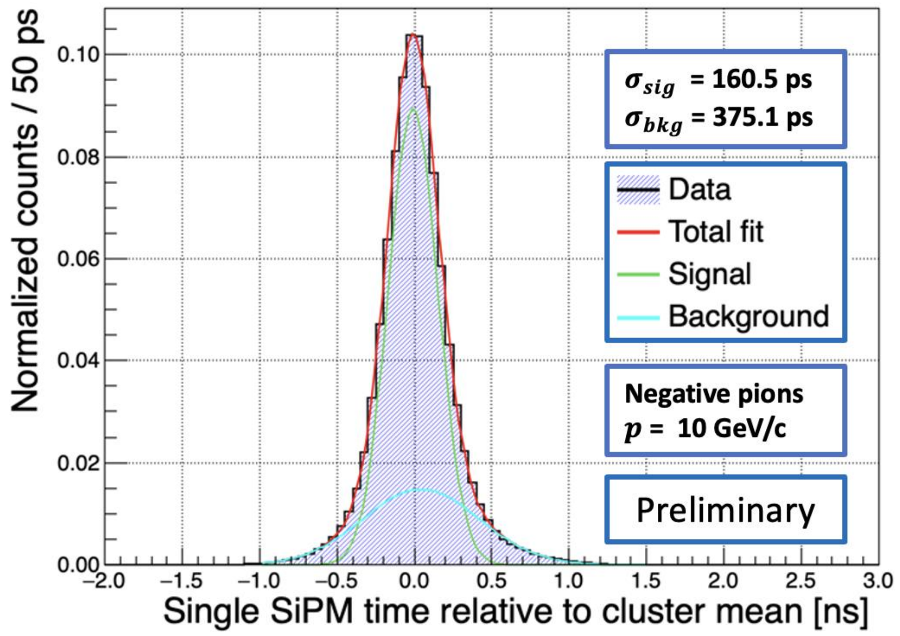
Ref. M.N. Mazziotta et al “A light tracker based on scintillating fibers with SiPM readout”, NIMA 1039 (2022) 167040
https://doi.org/10.1016/j.nima.2022.167040





Test Beam Results on Time Resolution





Measured mean number of clustered SiPMs : $\boldsymbol{N_{NaF} = 11.6}$

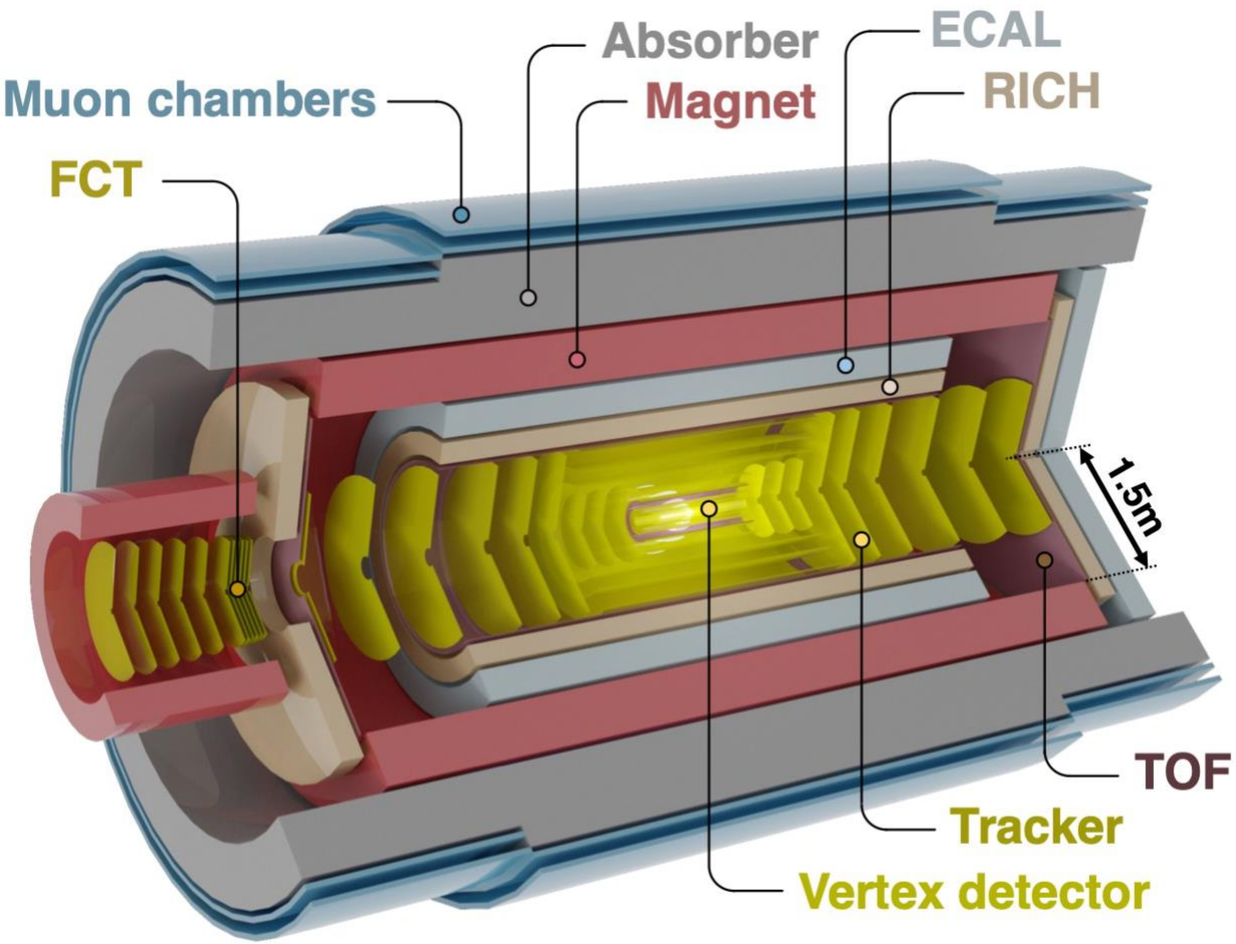
Measured single SiPM time resolution: $\boldsymbol{\sigma_{SiPM} \approx 160\ ps}$

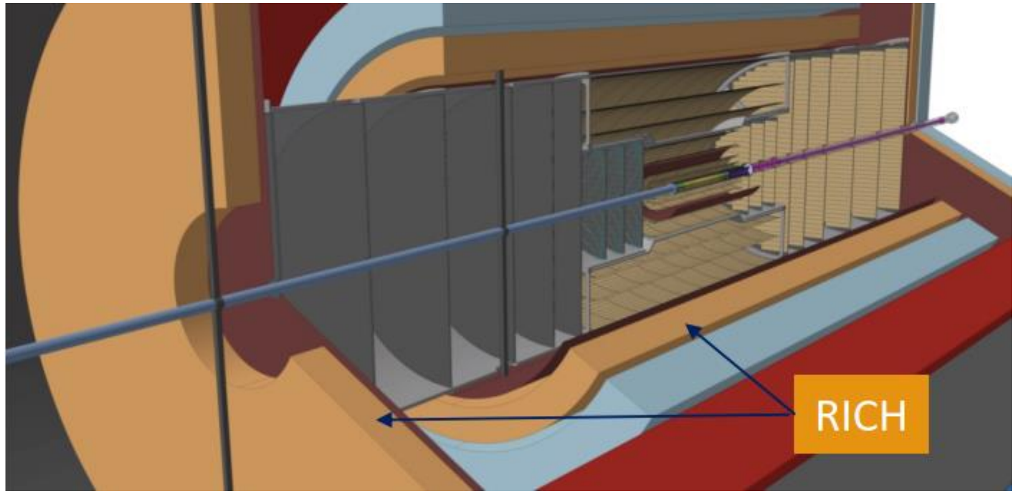
Extrapolated mean cluster time resolution: $\boldsymbol{\sigma_{\langle t \rangle} = \frac{\sigma_{SiPM}}{\sqrt{N_{NaF}}} \approx 47\ ps}$

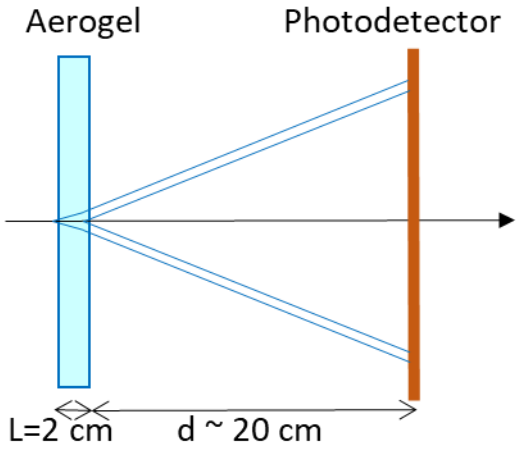
Planned 2023 beam test:

- R/O Board synchronization
- External tracking detector:
  Two X-Y upstream/downstream fiber trackers
  Two ALPIDE pixel modules
- Photon yield and timing studies with 1 mm SiO_2 radiator glued on the SiPM matrix

ALICE 3 LOI LAYOUT



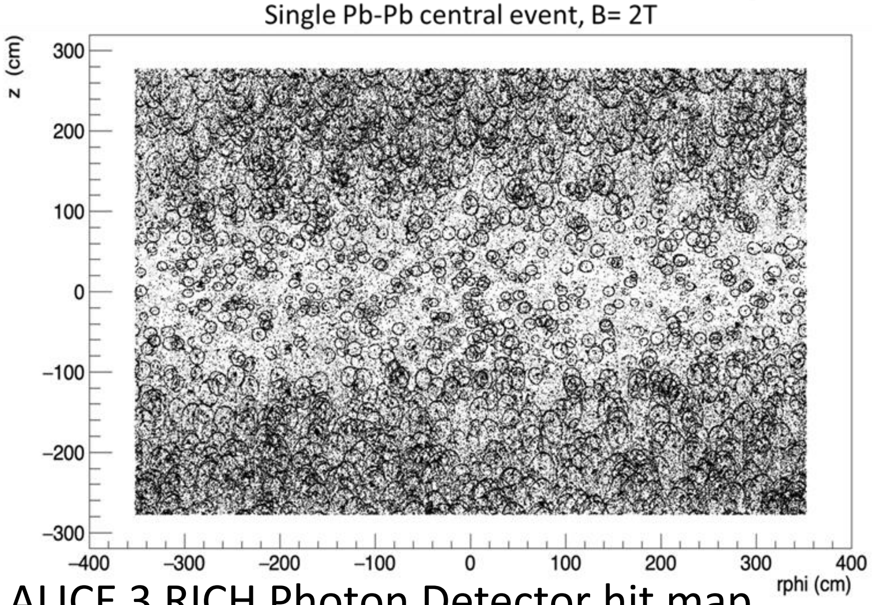




Baseline scheme: no TOF

- Barrel RICH: proximity focusing configuration with an aerogel radiator (2 cm, n=1.03), 20 cm expansion gap and SiPM array as photodetector (magnetic field up to 2 T and strong Rayleigh scattering from aerogel below 300 nm)
- Forward RICHs: same configuration, but aerogel with a lower n
- Total Photon Sensitive surface ~ 30 m2
- The TOF/RICH approach, if successful, would bring a remarkable cost saving

R&D TOPICS FOR THE TOF/RICH DETECTOR



ALICE 3 RICH Photon Detector hit map

Direct and indirect optical crosstalk is a severe drawback
Secondary photons detected by surrounding SiPMs increase the rate of accidentals

R&D studies:

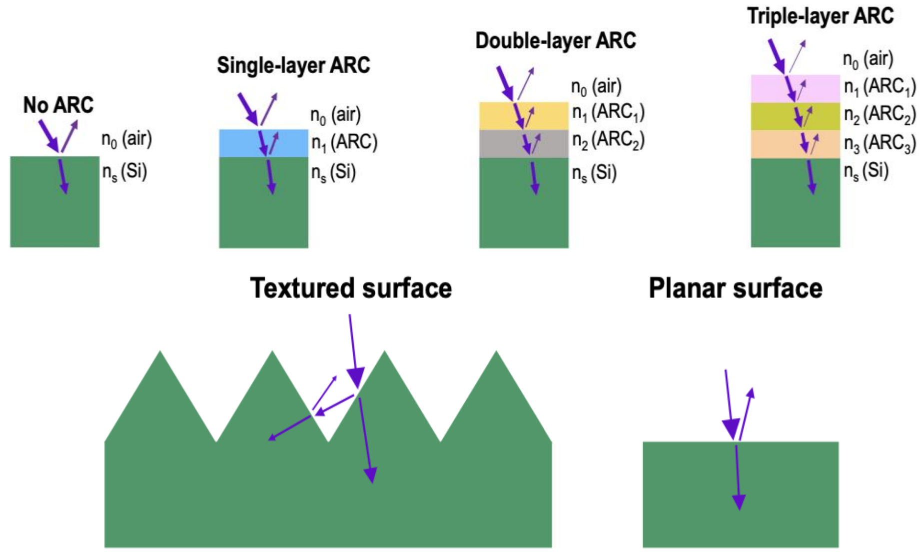
- Conventional single-layer antireflection coating (ARC)
- (Multi-layer) ARC: double-layer ARC and triple-layer ARC
- Textured Si surface with upright random nano/micro pyramids formed by anisotropic etching.

Additional benefits:

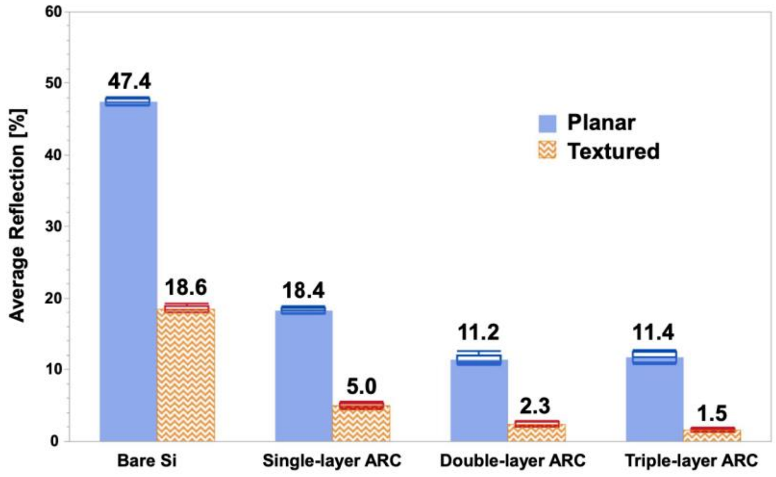
- The PDE increase allows operation at lower V_{OV} hence smaller DCR

SiPM Anti Reflective Coating

Yuguo Tao at al. doi: 10.1038/s41598-022-18280-y



Textured Si surface: upright random nano-micro pyramids made by anisotropic etching



Involvement in DRD4

R&D Project

SiPM-based TOF/RICH detector

Fields of Interest

- **CMOS SPAD development**
- **Textured anti-reflective coating (increase PDE, operate at lower Vov and decrease DCR)**
- **SiPM Module integration**
  - **System design incorporating cooling/annealing**
  - **Power, clock and control signal distribution**
  - **Local Intelligence**