R&D for innovative calorimeters with optical readout

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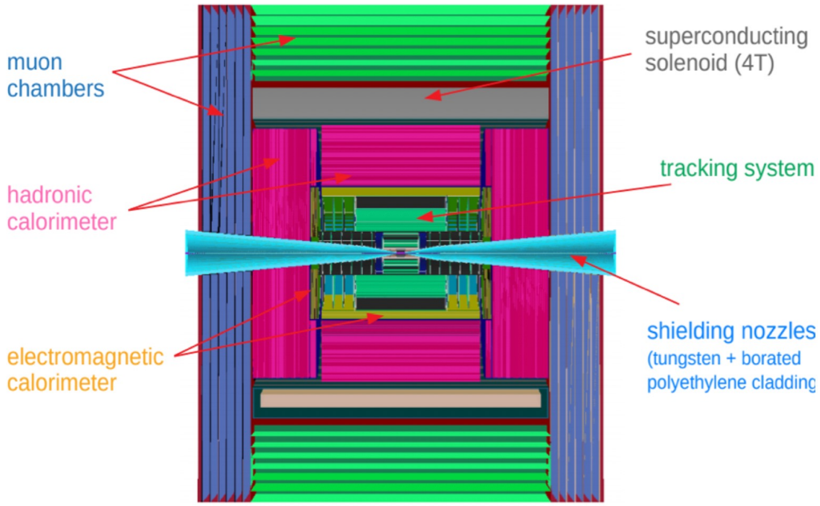
The case of Muon Collider

- At the ECAL barrel surface the BIB flux is 300 particles/cm², most of them are photons with <E>=1.7 MeV.
- The BIB produces most of the hits in the first centimeters of the calorimeter

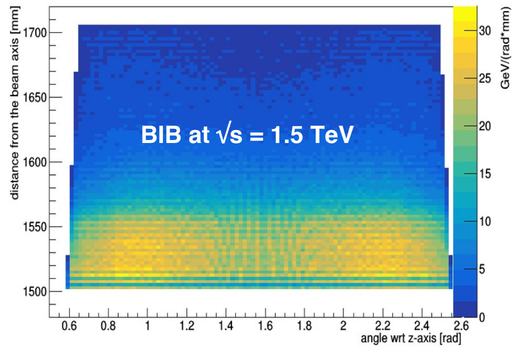
Timing and longitudinal segmentation play a key role in BIB suppression
→ fast response (small integration window) is essentially to **reduce energy contribution** from BIB

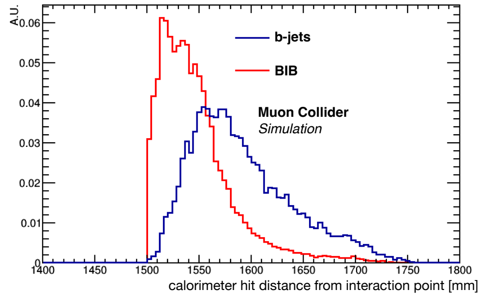
- Since the BIB hits are out-of-time w.r.t. the bunch crossing, a **measurement of the hit time performed cell-by-cell** can be used to **remove most of the BIB:**

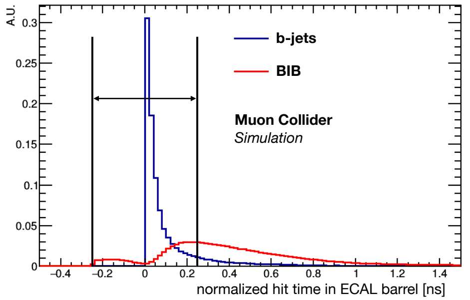
Actual design of the ECAL:
40 layers of 1.9 mm W absorber + silicon pad sensors
(~64M channels for the Barrel)
- 5x5 mm^2 cell granularity
- 22 X_0 (1 λ_i)



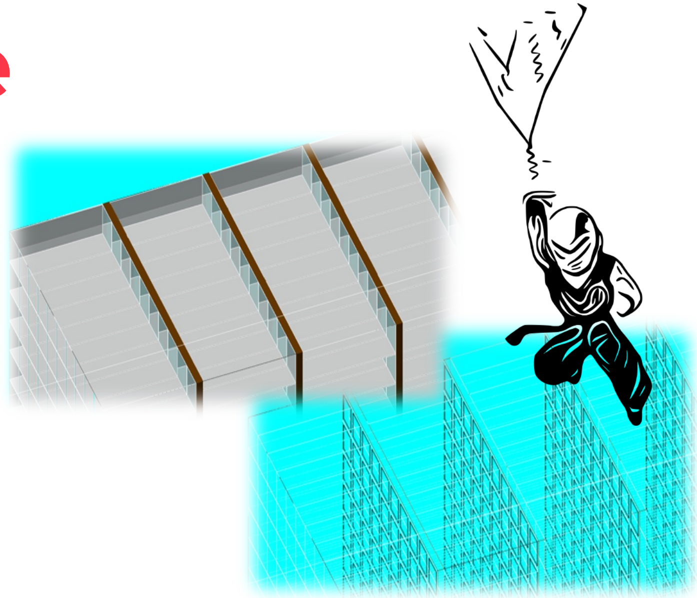
Energy released in ECAL barrel by one BIB bunch crossing





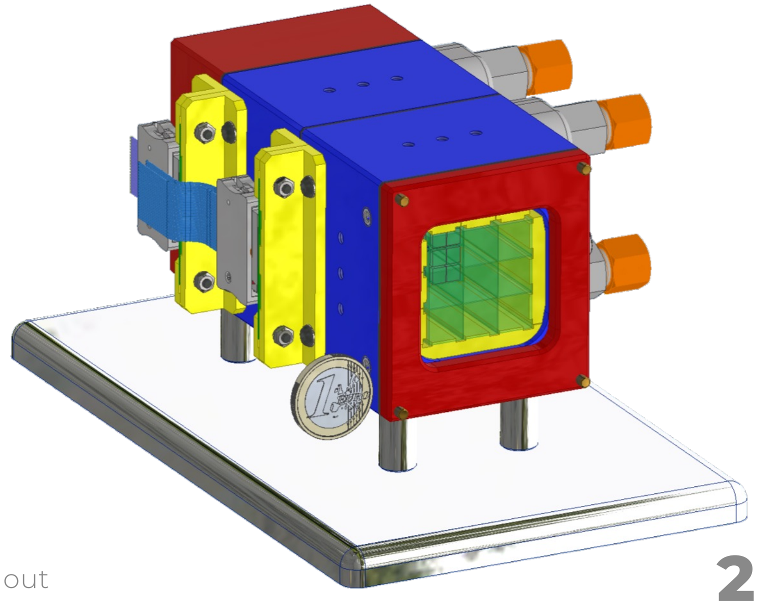


Crilin prototype

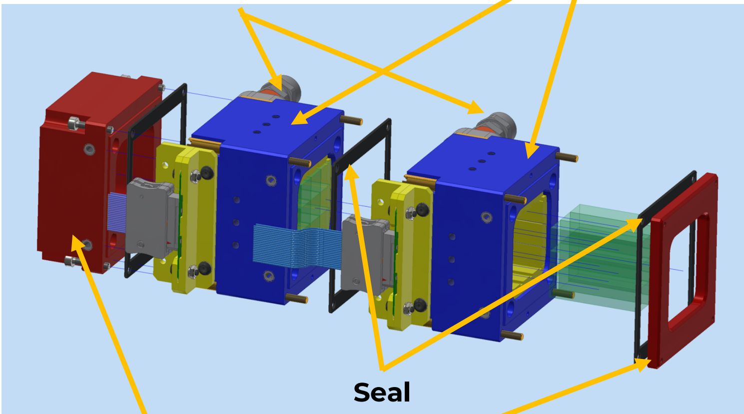


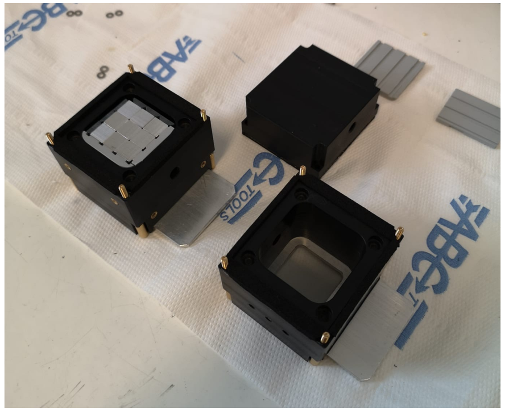
- Crilin (Crystal calorimeter with longitudinal information) represent a **valid** and **cheaper backup solution**
  - Based **on Lead Fluoride** (PbF_2) crystals readout by **2 series of two UV-extended 10μm pixel SiPMs each.**
  - Crystal dimensions are 10x10x40mm^3 and the surface area of each SiPM is 3x3 mm^2, to closely match the crystal surface.
  - Modular architecture based on stackable submodules

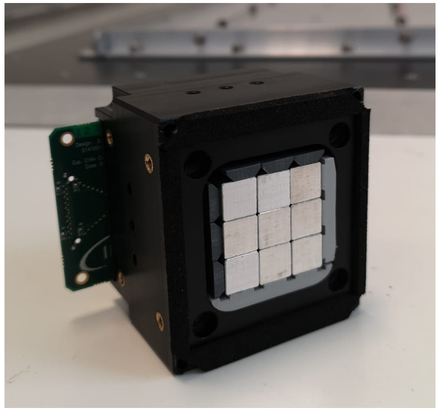
- **Proto-1:** 2 submodules assembled by bolting, each composed **of 3x3 crystals+36 SiPMS** (2 channel per crystal)
  - light-tight case which also embeds the front-end electronic boards and the heat exchanger needed to cool down the SiPMs.
  - SiPMs are connected via 50-ohm micro-coaxial transmission lines to a microprocessor-controlled Mezzanine Board which provides signal amplification and shaping, along with all slow control



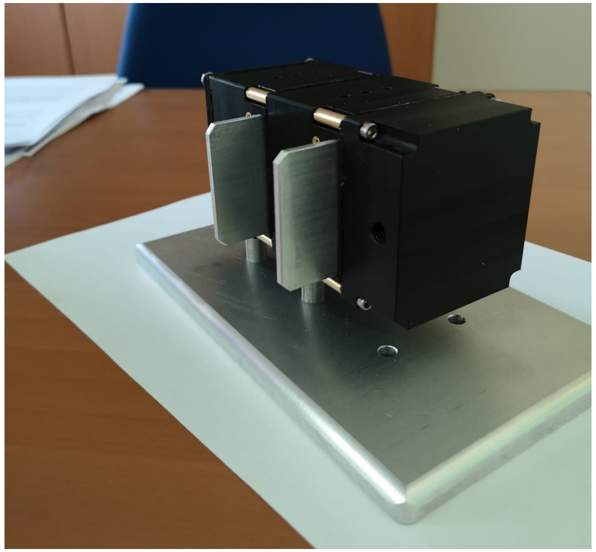
Mechanics and cooling system

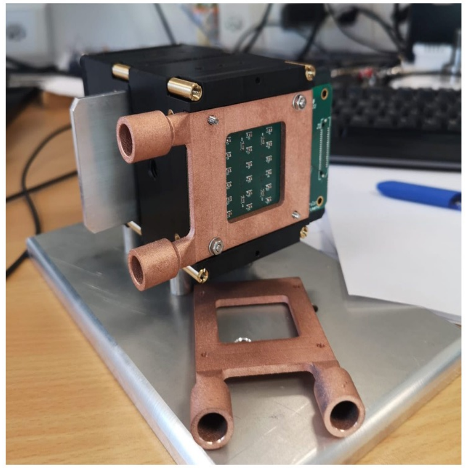






- Total heat load estimated: **350 mW per crystal** (two readout channels)
- Cold plate heat **exchanger** made of copper mounted over the electronic board.
- **Glycol based water solution** passing through the deep drilled channels.



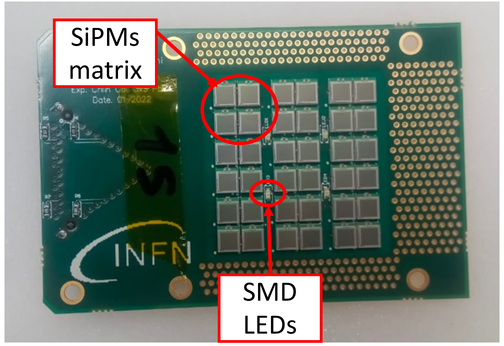


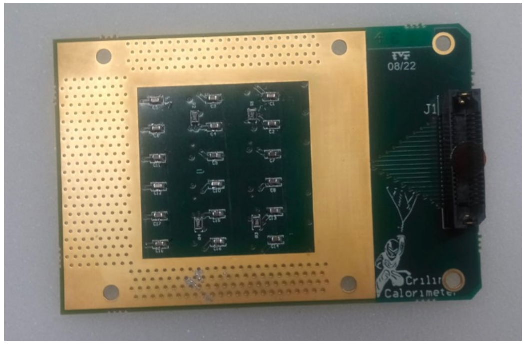
Copper exchanger

Electronics
SiPMs Board and FEE/Controller

The SiPMs board is made of:

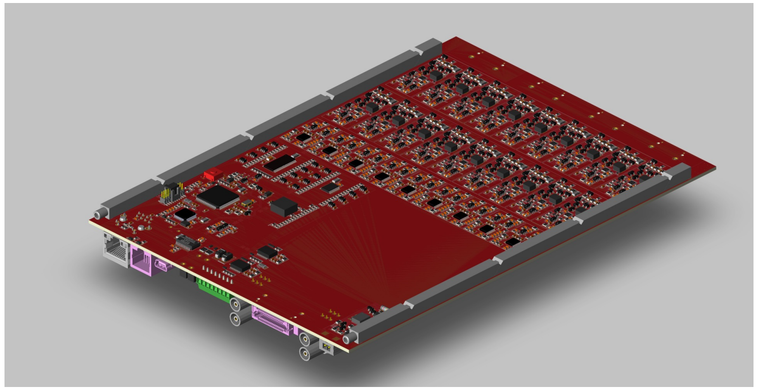
- 36 **10 μm Hamamatsu SiPMs**
  ⟶ each crystal has **two separate readout channels connected in series**.

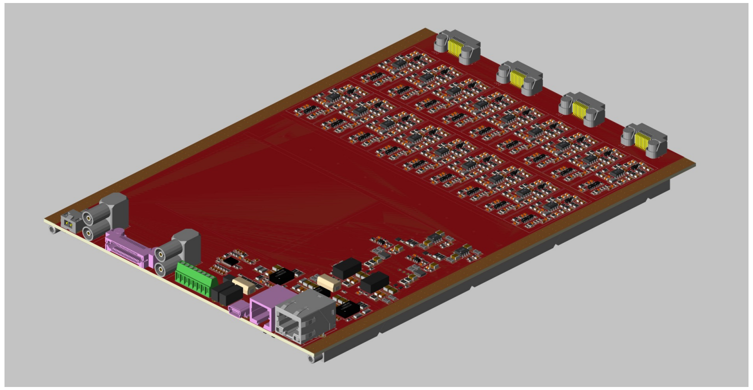




- Four SMD blue LEDs nested between the photosensor packages.

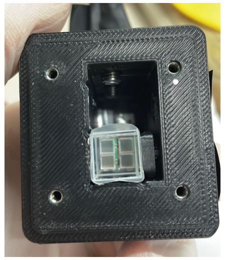
- Controller - 18 Front End electronics channels → under production

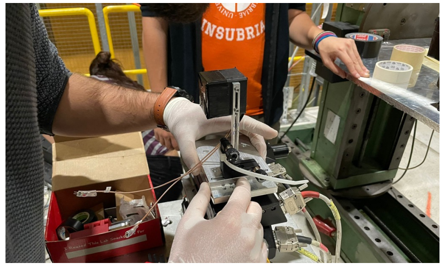


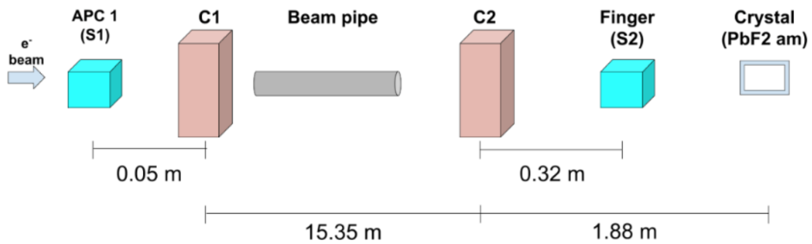


Test beam: PbF_2 and PWO-UF

- Validate CRILIN readout electronics and readout scheme
- Study systematics of light collection in small crystals with high *n*
- Measure time resolution achievable for PbF_2 and PWO-UF

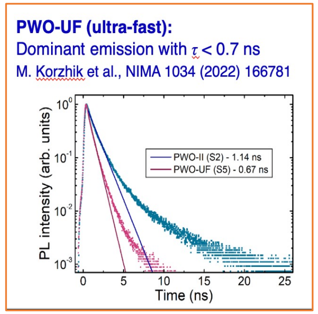






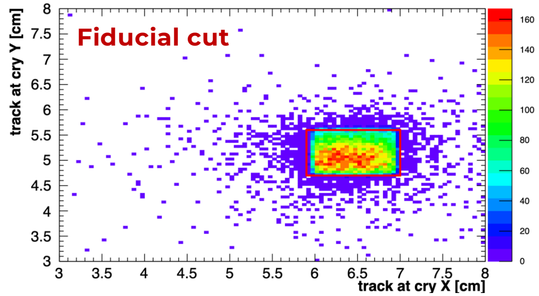
- 80 GeV electrons beam
- Tracking with C1 C2 silicon strips
- Start trigger with S2 scintillator
- Signals digitized at **5 GS/s**

For reference

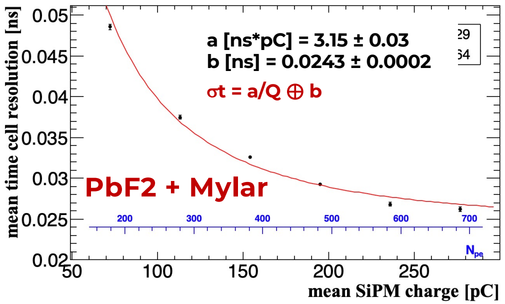


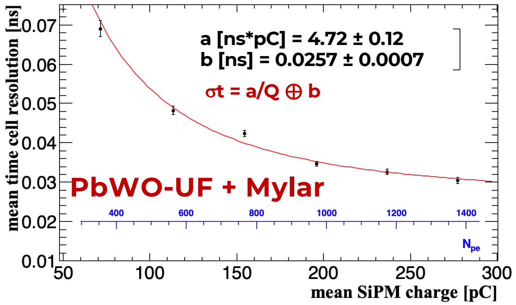
Very Preliminary

Deposited energy vs 1 single particle in C1 and C2



Time Resolution per charge slices after asymmetry correction

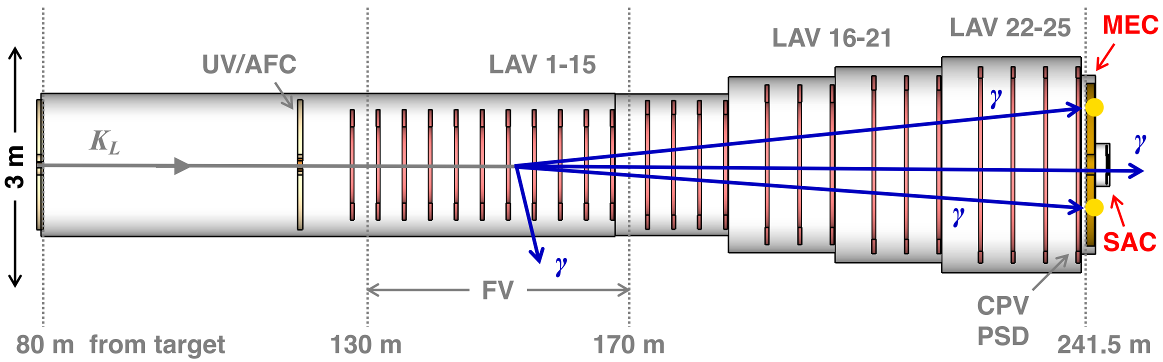




Attenuator of -6dB used for PWO-UF → Double of LY respect to the PbF2

Innovative calorimeters for KLEVER

- **KLEVER will measure BR($K_L \to \pi^0\nu\nu$) ~ 3 10^{-11}**
  Must reject decays with extra photons ($K_L \to \pi^0\pi^0$) at 10^{-8} level!



Small-angle calorimeter (SAC)

- Rejects extra photons escaping through beam pipe
- Sits directly in neutral hadron beam
- Must be transparent to 450 MHz of beam neutrons

- **Good photon detection efficiency for *E*>5 GeV**
- **Excellent time resolution (<< 100 ps)**
- **Radiation resistant**

Synergy with Crilin

Compact, ultra-fast crystal calorimeter

Main electromagnetic calorimeter (MEC)

- Reconstructs π^0 in $K_L \to \pi^0\nu\nu$ decays
- Rejects events with extra photons
- Establishes event time (total event rate ~ 100 MHz!)

- **Excellent photon detection efficiency**
- **Excellent time resolution (< 100 ps)**
- **Radiation resistant**

High-performance Shashlyk calorimeter

NanoCal project: AIDAinnova WP13.5 (Blue Sky)

Realize first calorimeter with NC scintillators:

$CsPbBr_3$, 0.05-0.2% w/w in UV-cured PMMA

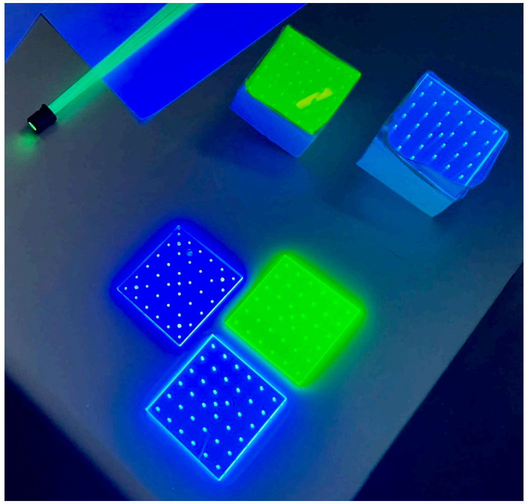
- 50% of light emitted in components with τ < 0.5 ns
- Radiation hard to O(1 MGy)
- **Light yield? O(few k) photons/MeV deposit?**

Nano composite scintillators for shashlyk

KLEVER

Quantum dots used as emitters for bright, ultrafast, robust scintillators:

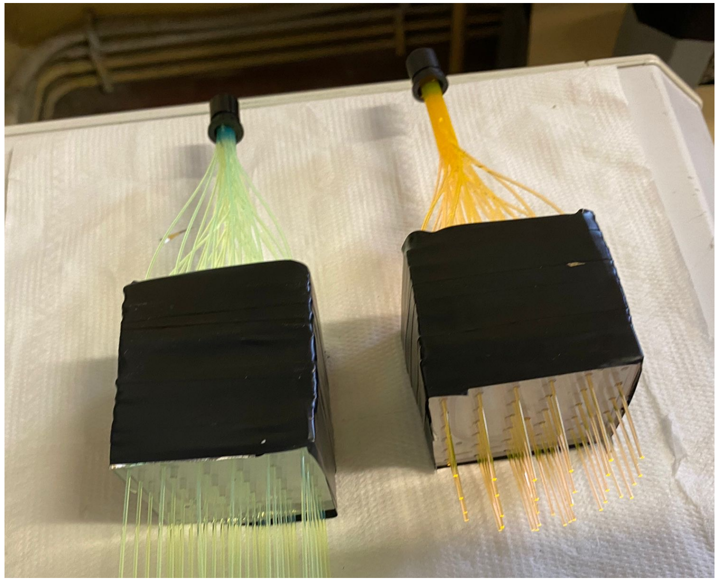
- Calorimetry
- Timing-plane detectors



Trial production of tiles in Protvino format (55 x 55 mm^2)

- Two identical modules, 12 layers, very fine sampling
- *Comparison of performance with conventional scintillator before constructing full-scale prototype*

- Both have 12 fine sampling layers: 0.6 mm Pb + 3 mm scintillator
- Each 1.3X_0 in depth: expected mip energy deposit = 10 MeV
- Each read out with a single Hamamatsu 13360-6050 SiPM

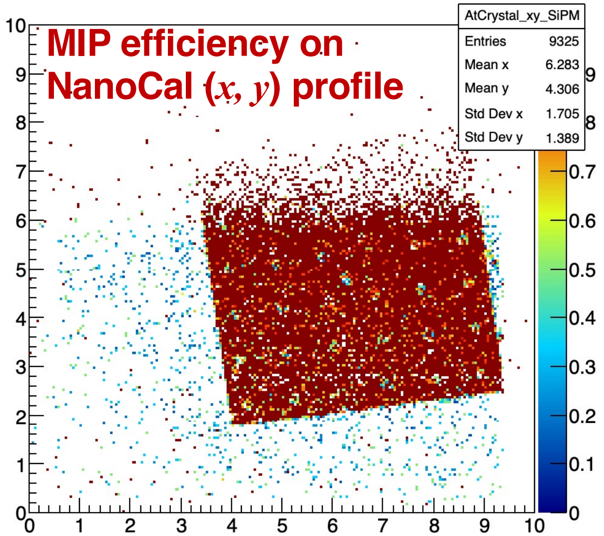


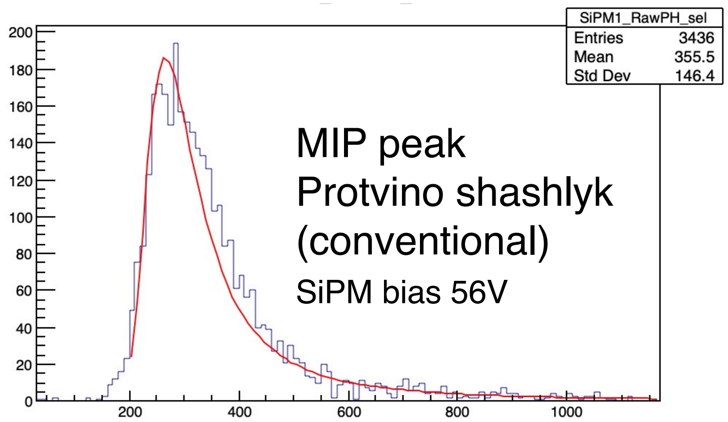
Nano Cal scintillator
PMMA
0.2% $CsPbBr_3$
Kuraray O-2(100) fibers

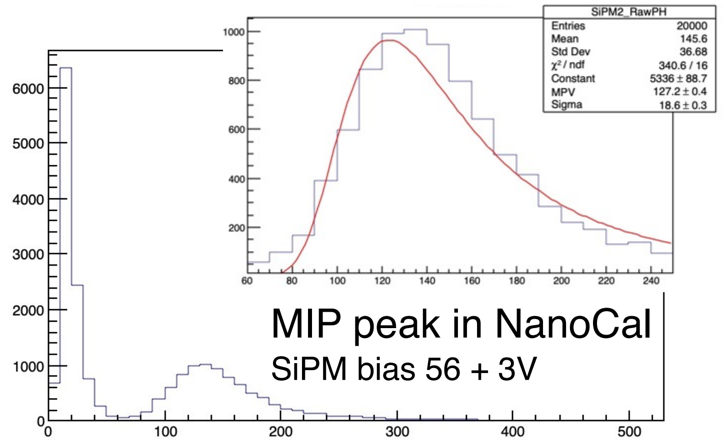
Protvino scintillator
Polystyrene
1.5% PTP/0.04% POPOP
Kuraray Y-11(200) fibers

Shashlyks: Conventional vs NanoCal

KLEVER







Preliminary (undigested) observations:

- NanoCal signal output significantly smaller than Protvino (x10?)
- **NanoCal time resolution for mips 30% worse than Protvino**
  Correlated with signal output: less light = worse resolution

Influence of fibers

- QE of SiPM drops by 25% from 480 → 550 nm
- Don't know relative LY of O-2 vs Y11 fibers

Also need direct measurements of NanoCal vs. Protvino scintillator