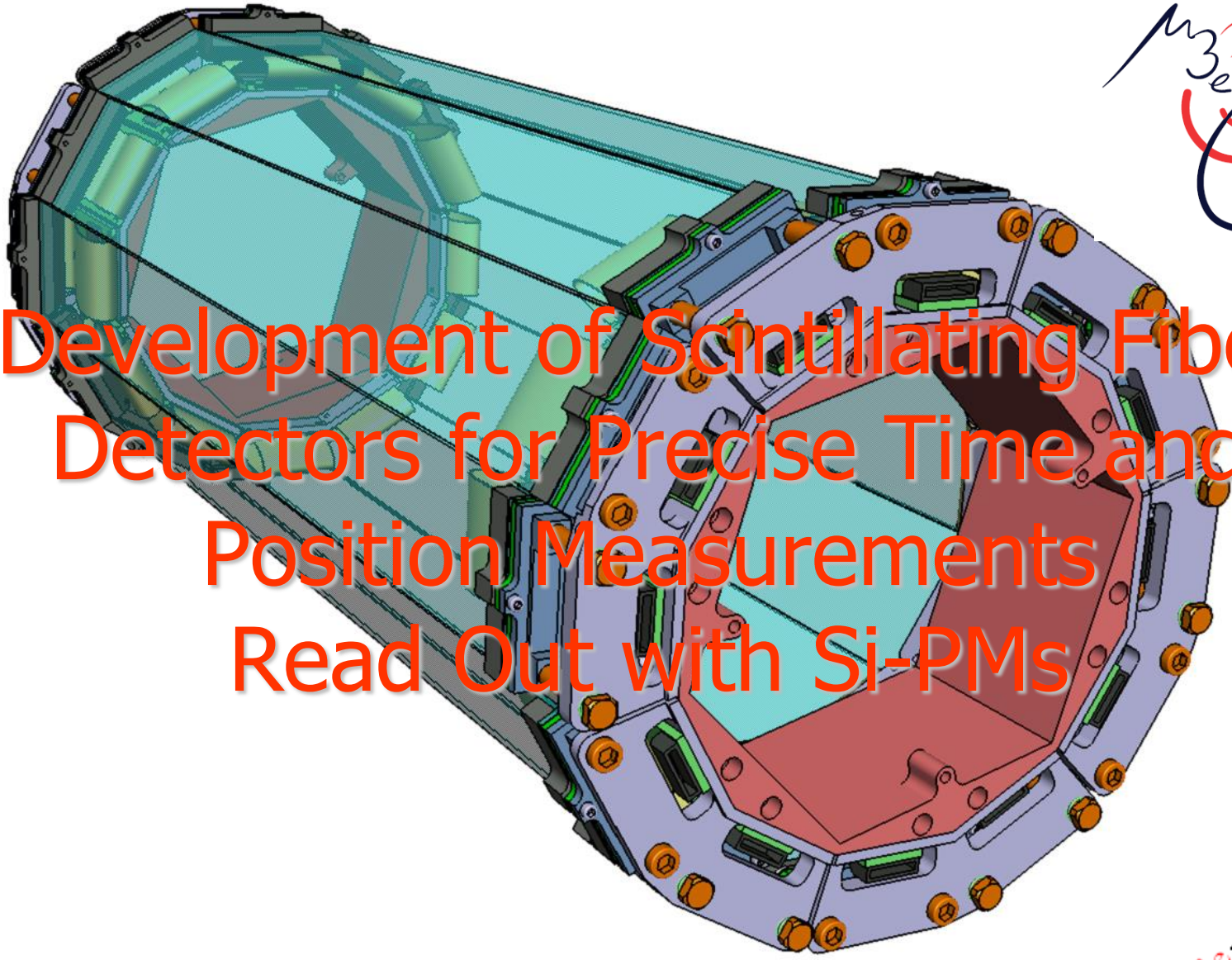


Development of Scintillating Fiber Detectors for Precise Time and Position Measurements Read Out with Si-PMs

ICHEP 2020
Prague
July 31, 2020

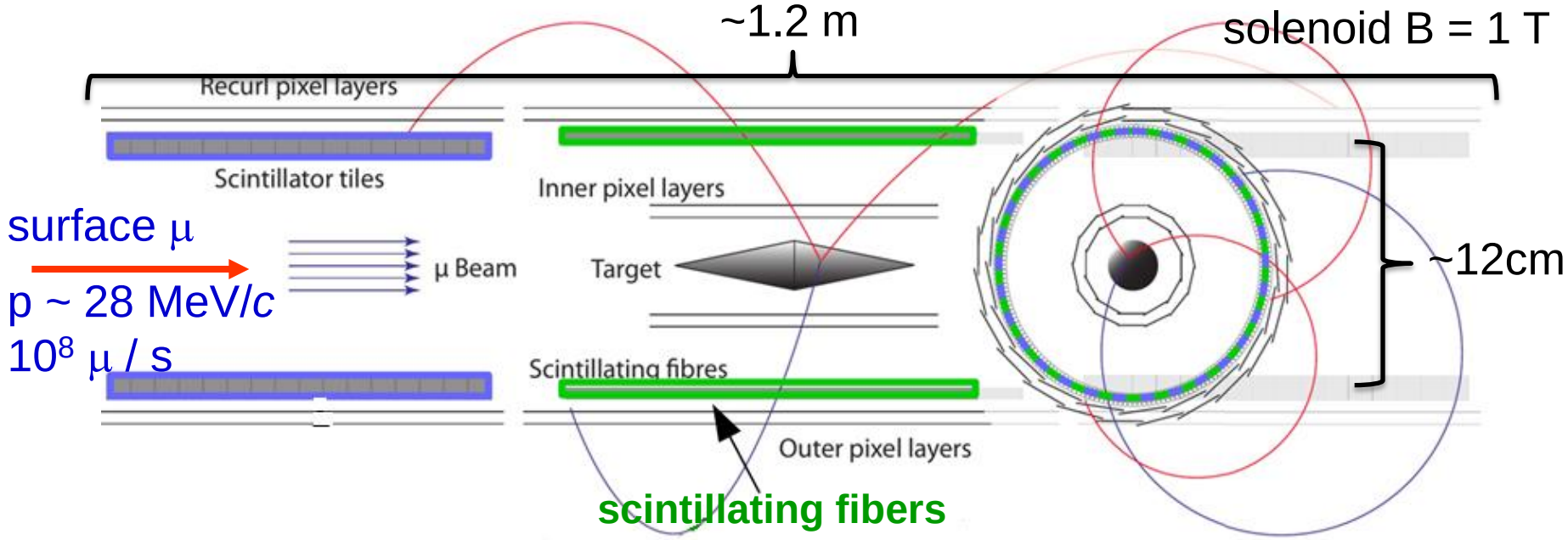
Alessandro Bravar
for the Mu3e SciFi team

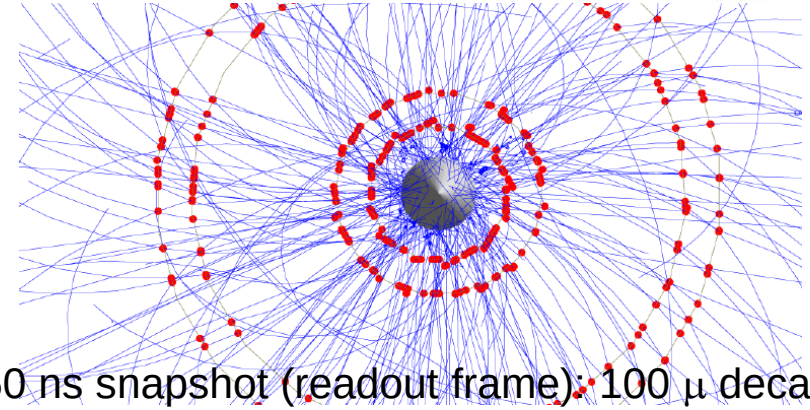
The Mu3e SciFi Timing Detector

precise timing measurement: critical to reduce accidental BKGs

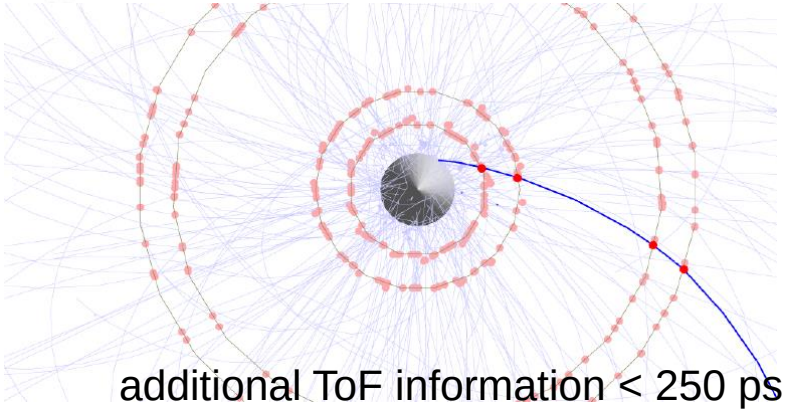
determine sign of re-curling tracks (SciFi)

scintillating fibers (SciFi) ~250 ps, detection efficiency > 95 %





50 ns snapshot (readout frame): 100 μ decays



additional ToF information < 250 ps

SciFi Detector Design Parameters

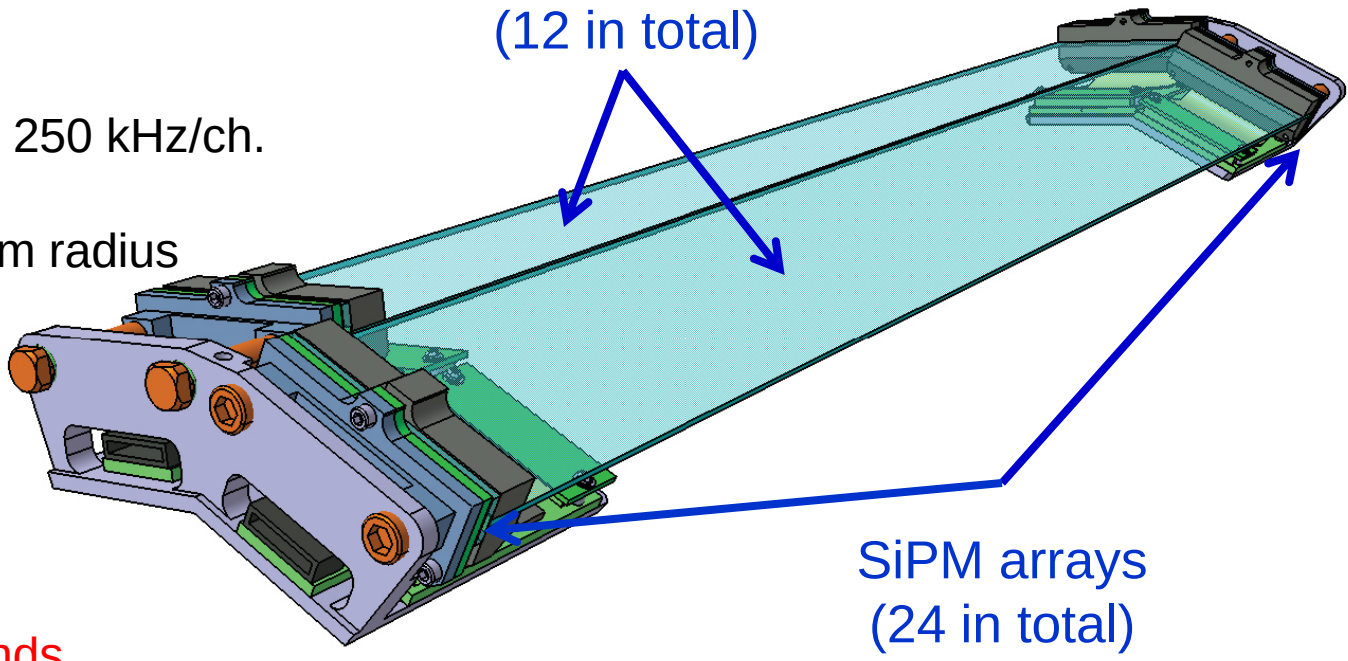
Requirements

handle very high rates (> 10^8 μ decays / s)
thickness x/x_0 < 0.3% (<1 mm)
time resolution ≤ 250 ps
efficiency > 95%
limited space
high occupancy up to 250 kHz/ch.

12 SciFi ribbons at ~ 6 cm radius
32.5 mm x 300 mm
3 staggered layers
250 μm ϕ fibers
SCSF-78MJ
very thin ~0.2% x_0

Si-PM readout at both ends
128 ch SiPM array (LHCb design)
250 μm pitch

Readout
MuTRiG ASIC
~ 3000 readout channels



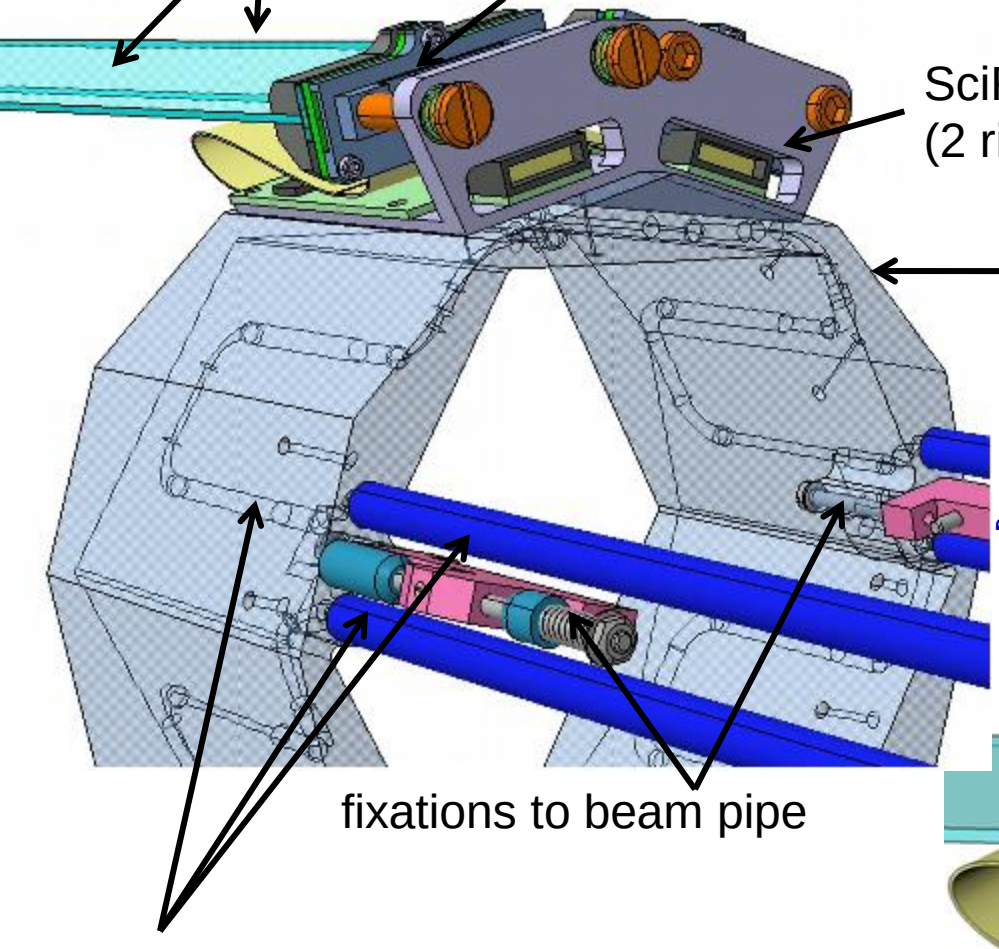
SciFi Detector Mechanics

SciFi ribbons
longitudinally staggered to minimize dead space between ribbons

SiPM spring loaded support

SciFi module support structure
(2 ribbons per module)

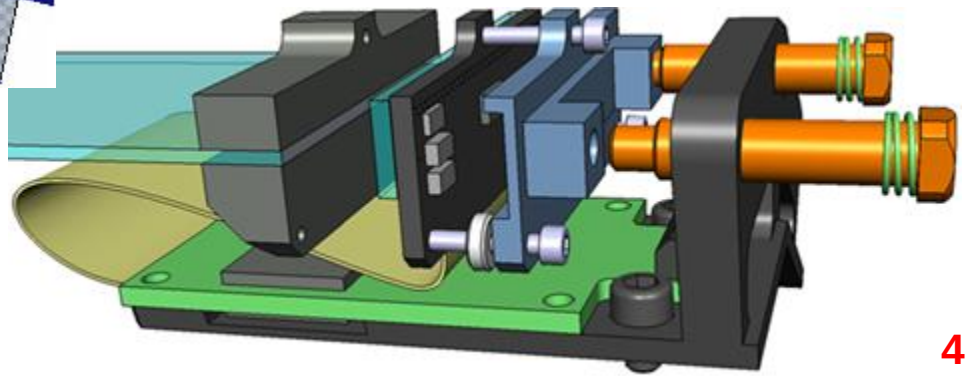
3D printed Al cooling ring
it supports the SciFi modules



fixations to beam pipe

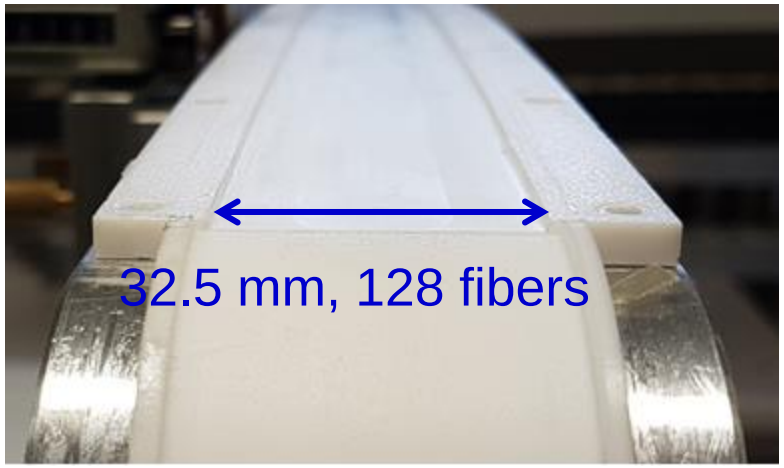
cooling pipes

"expanded" view of SciFi – SiPM coupling
+ spring loaded SiPM support
+ Front End board

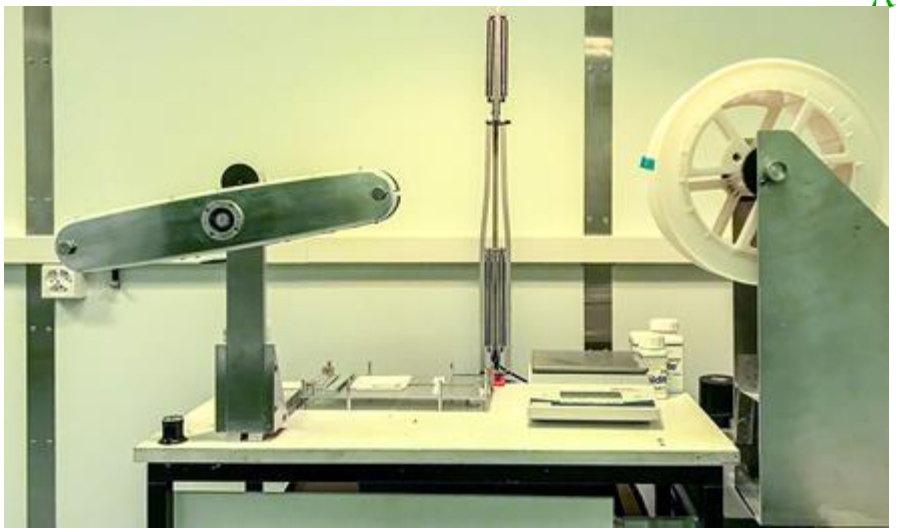


SciFi Ribbon Production

U channel

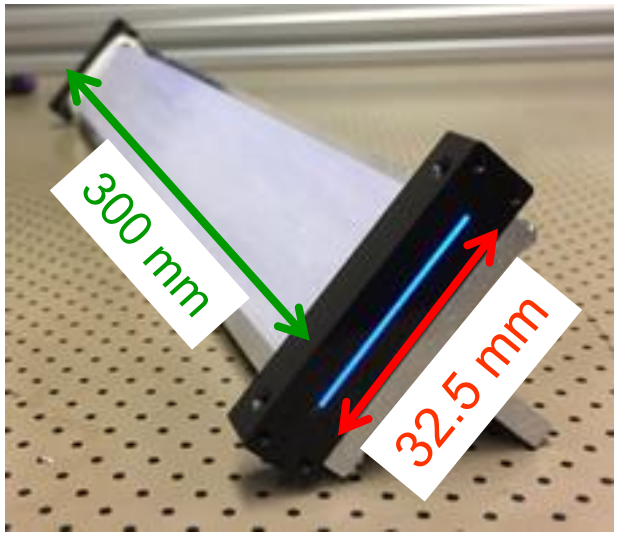


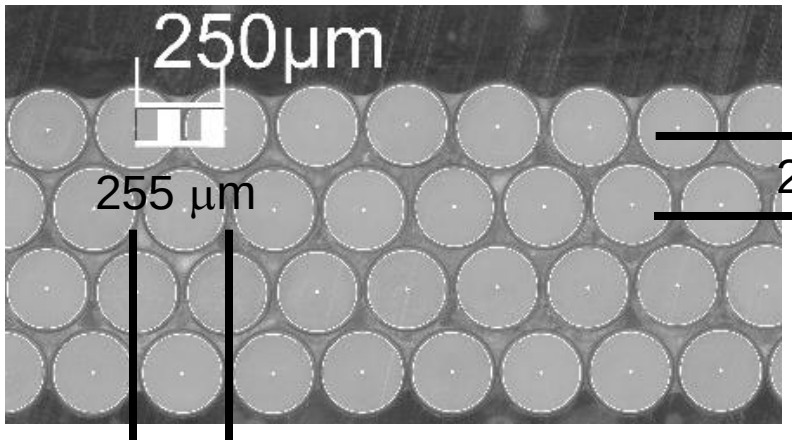
ribbon winding tool



ribbon profile: 3 x ~128 fibers (prototype)

(full size) ribbon prototype

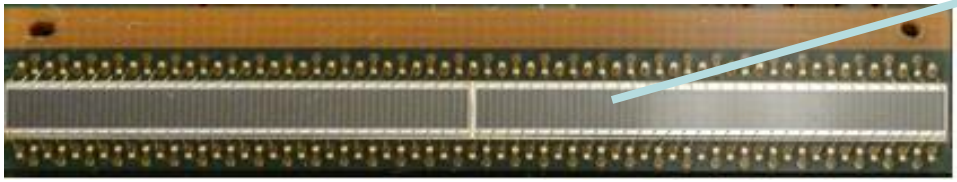




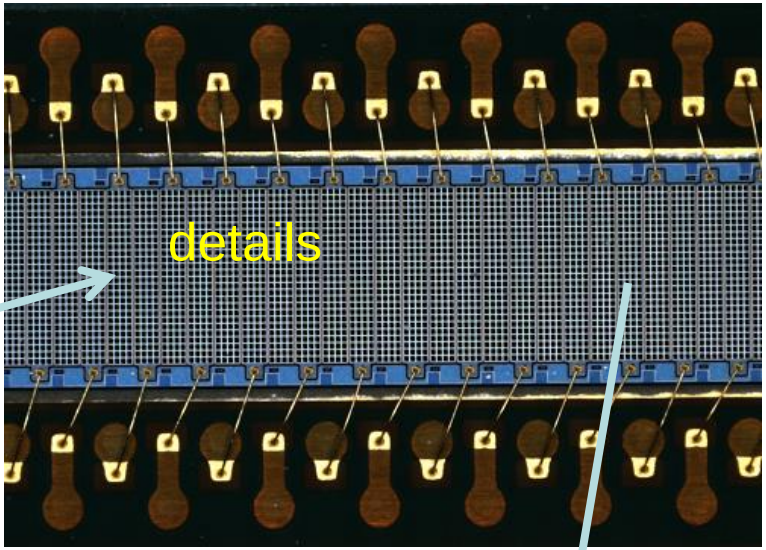
Si-PM Arrays

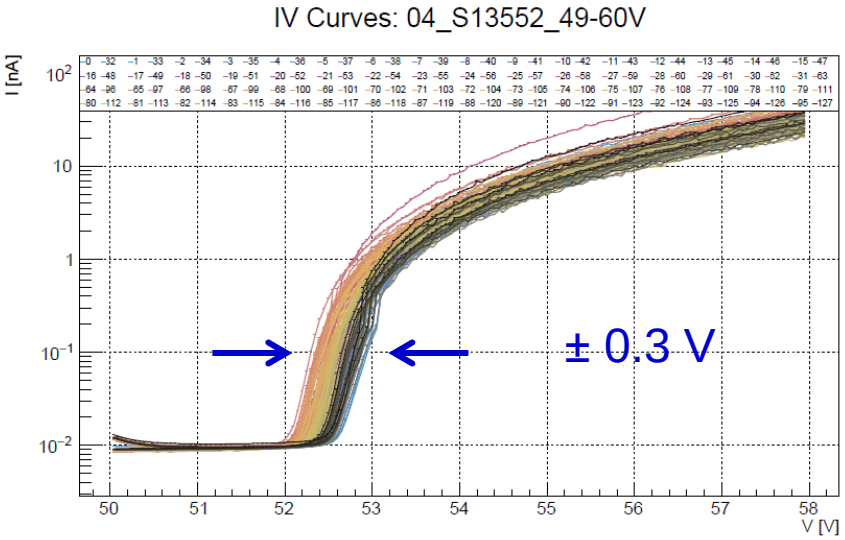
128 ch SiPM array from Hamamatsu (LHCb type) S13552HRQ

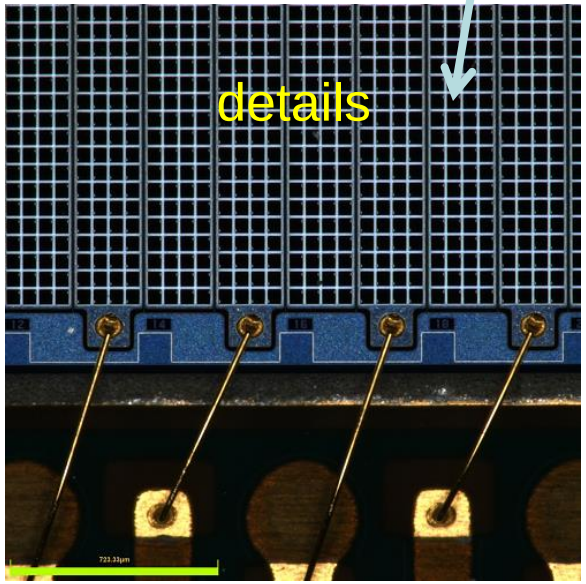
- 250 μm pitch
- pixel size 57.5 μm x 62.5 μm
- 4 x 16 pixels per column
- 230 μm x 1625 μm column area
- V_{break} ~52.5 V (± 0.3 V same array)
- high quenching resistor



32.5 mm (two 64 ch. dies)







Selecting the Scintillating Fiber

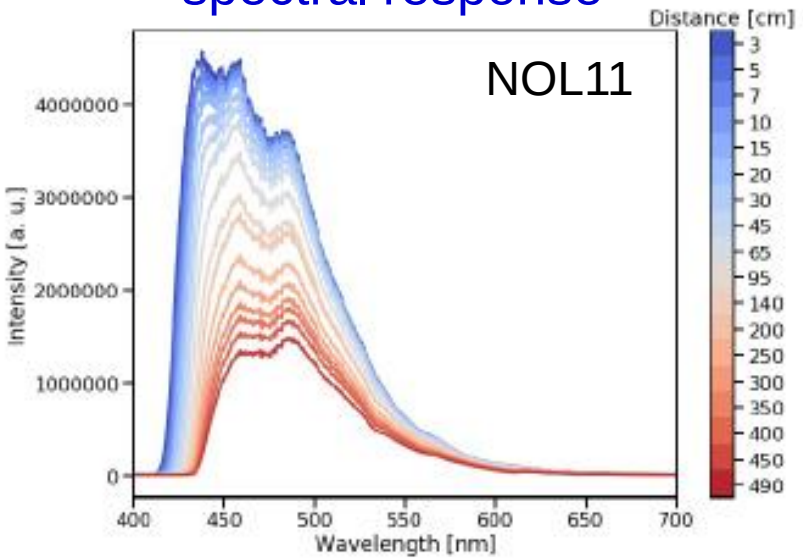
criteria:

high light yield

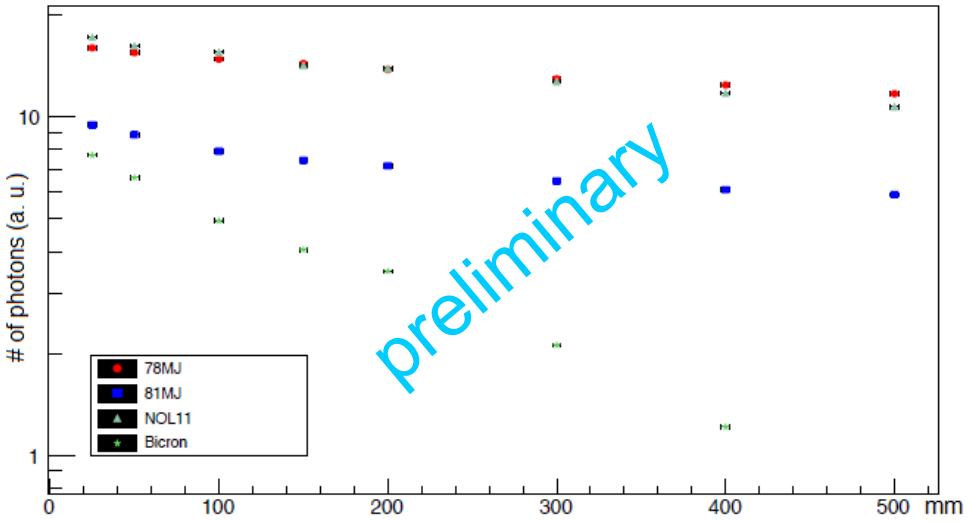
best time performance

type	att. l. λ (cm)	τ_{decay} (ns)
Kuraray SCSF-78	> 400	2.8
Kuraray SCSF-81	> 350	2.4
Kuraray NOL-11	> 250	1.0
Bicron BCF-12	270	3.2

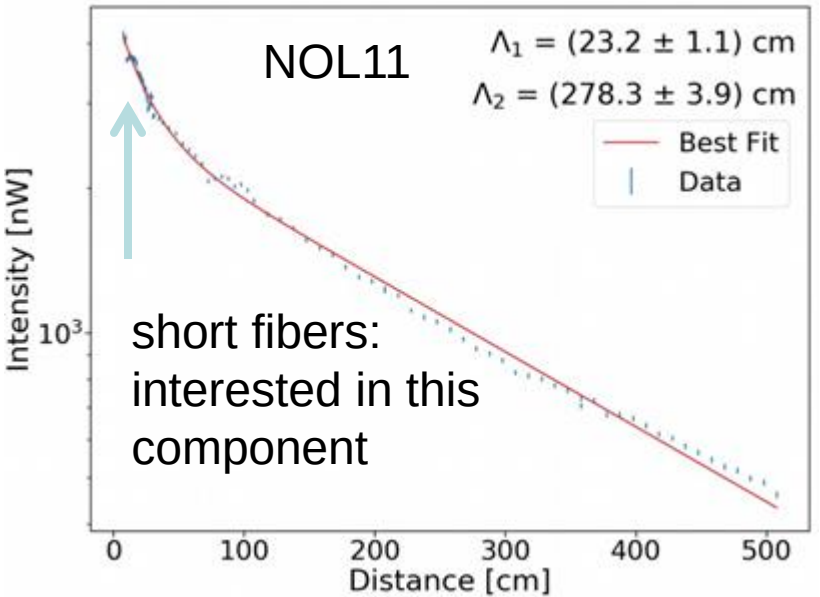
spectral response



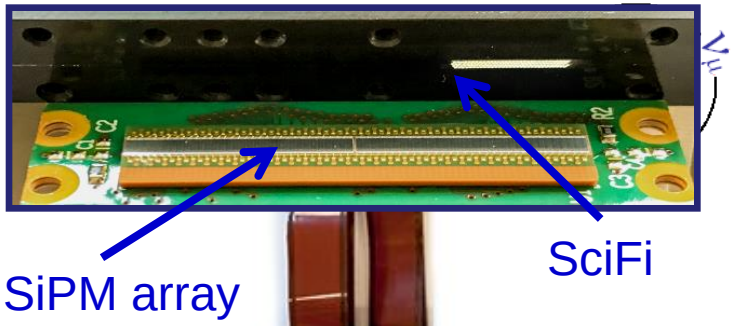
light attenuation (Sr source)

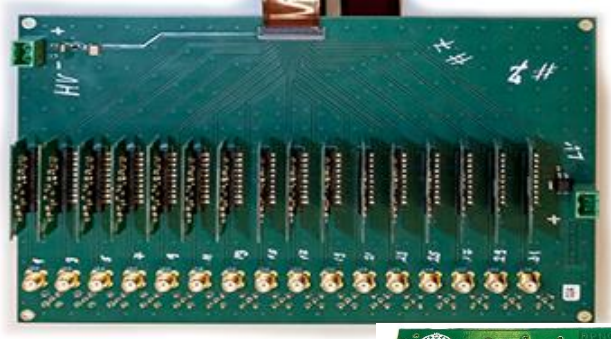


light attenuation (LED)

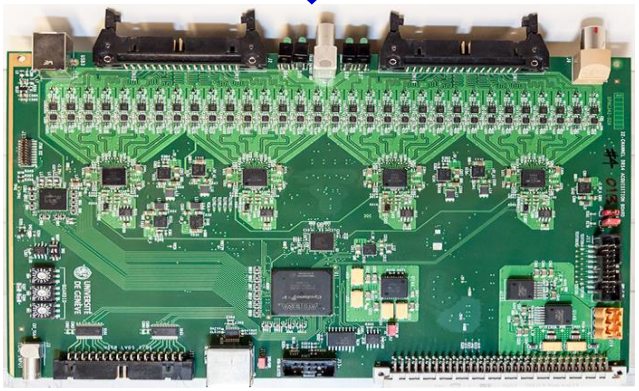


Waveform Analysis



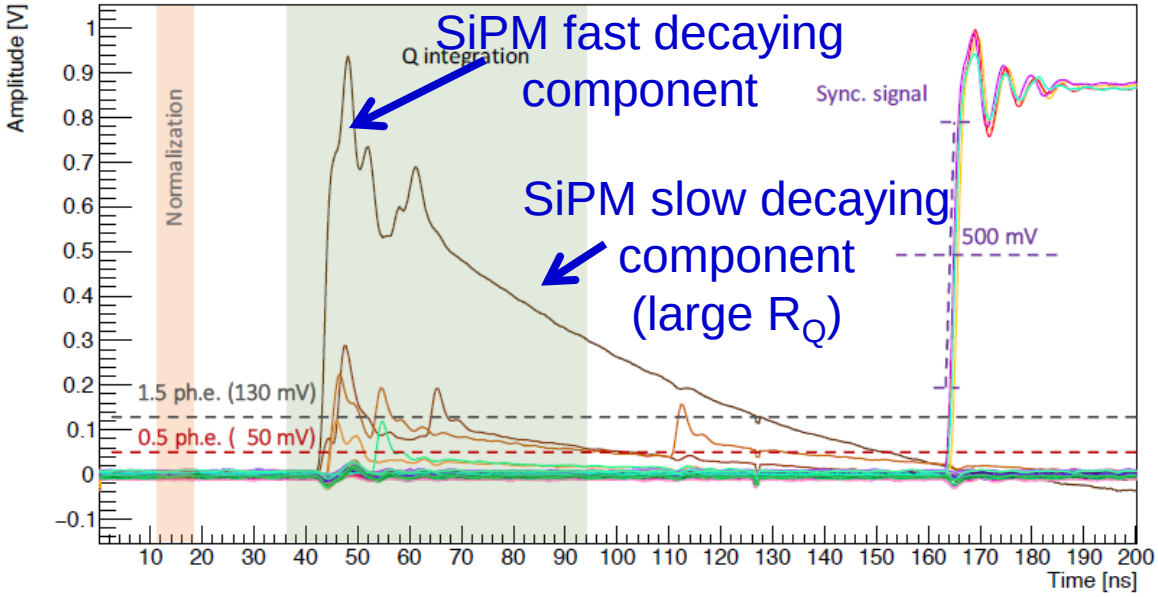


hybrid
fast amplifiers



waveform digitizer
4 x DRS4 ASIC (32 ch.)

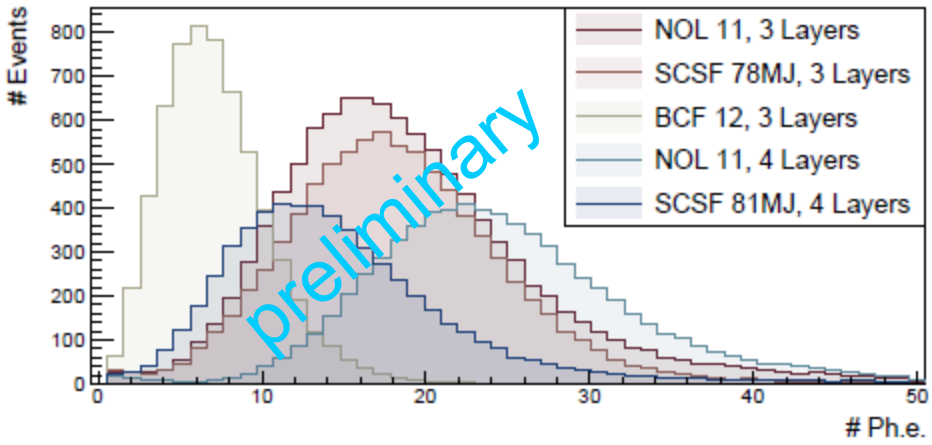
Waveforms 5 GHz sampling

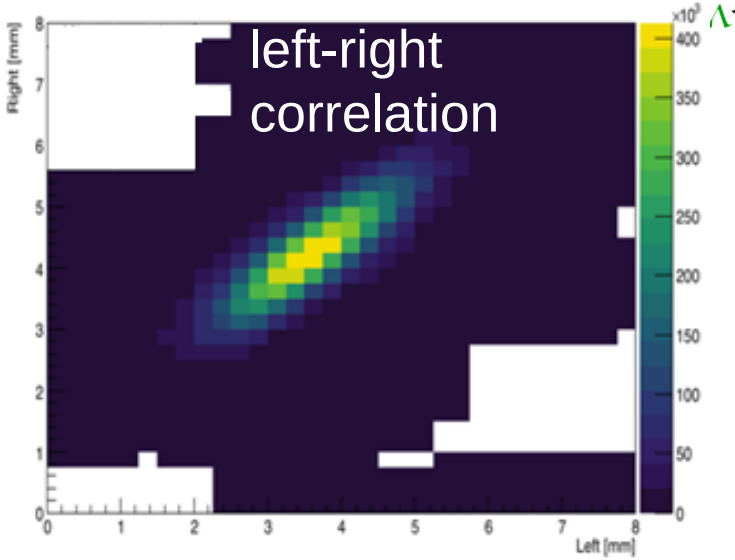


Timing: use a fixed threshold
to simulate the functioning of the MuTRiG ASIC

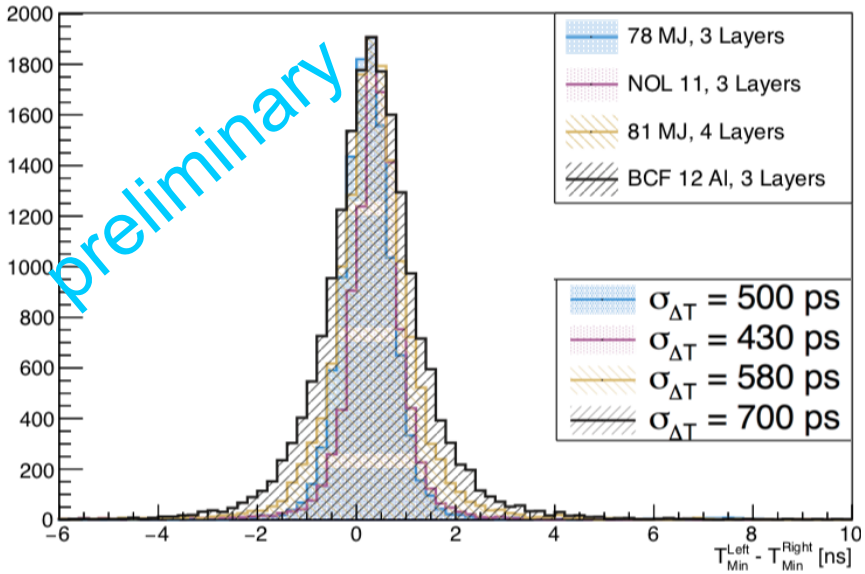
Performance of SciFi Ribbons

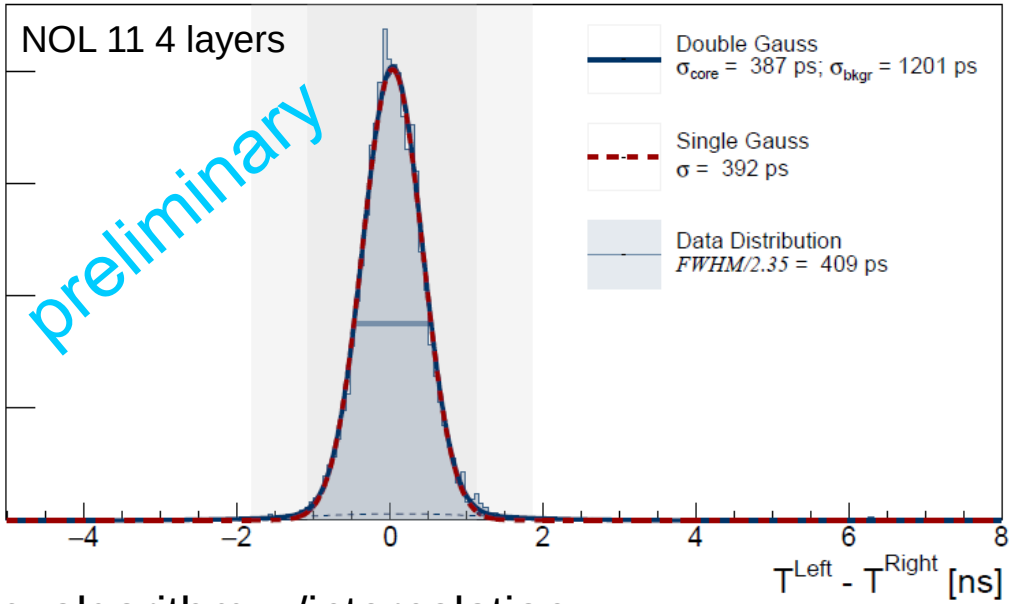
light yield





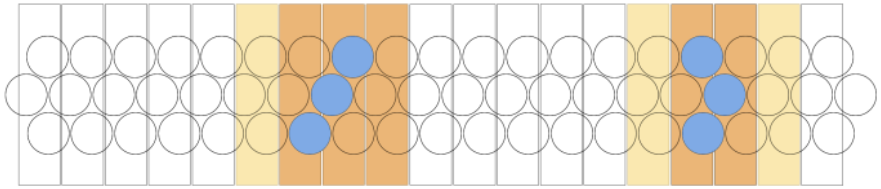
time resolution ($\Delta T = T_{left} - T_{right}$)



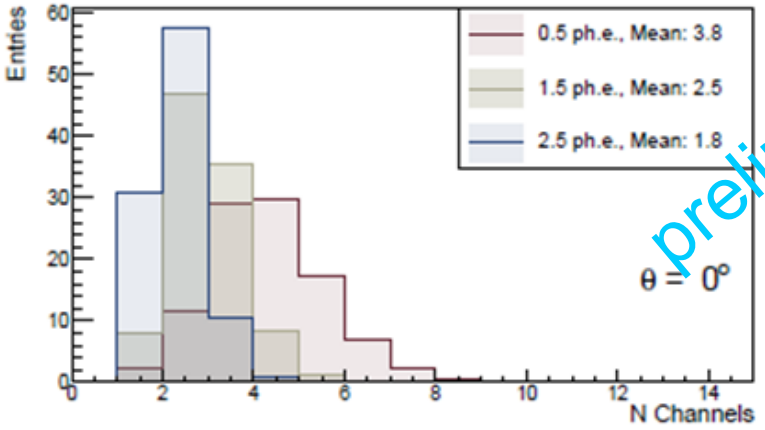


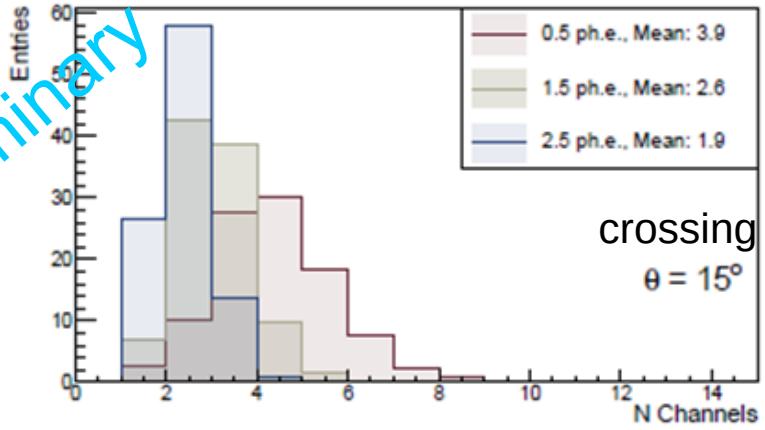
using L.E. disc. algorithm w/interpolation

Cluster Size



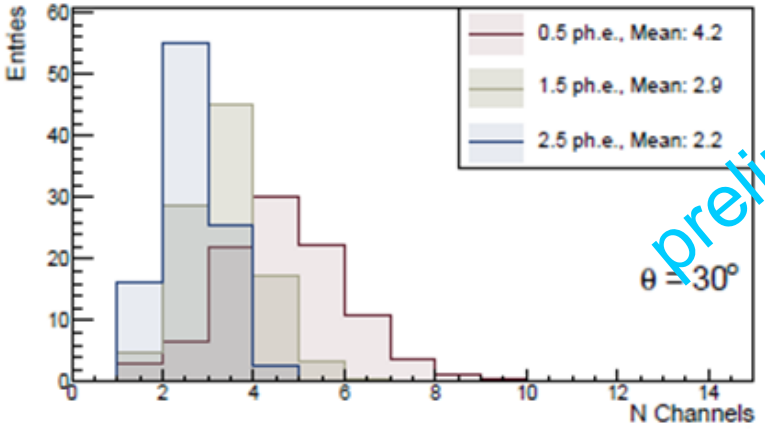
"cluster size" for different thresholds (SCSF-78MJ fiber, 3 layers)
use clear glue because of material budget

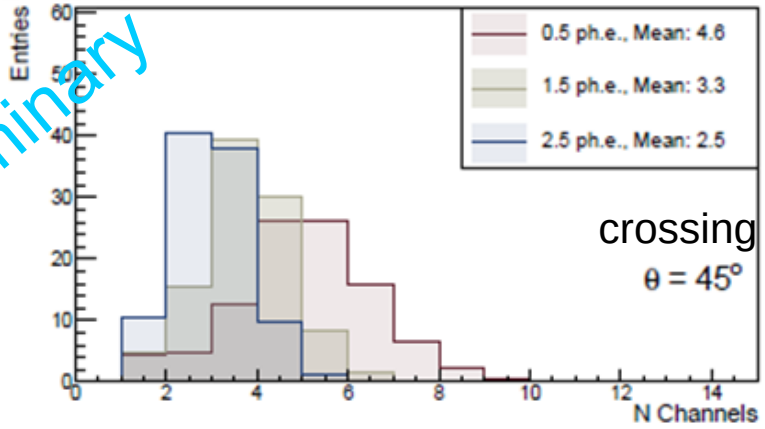




preliminary

crossing angle





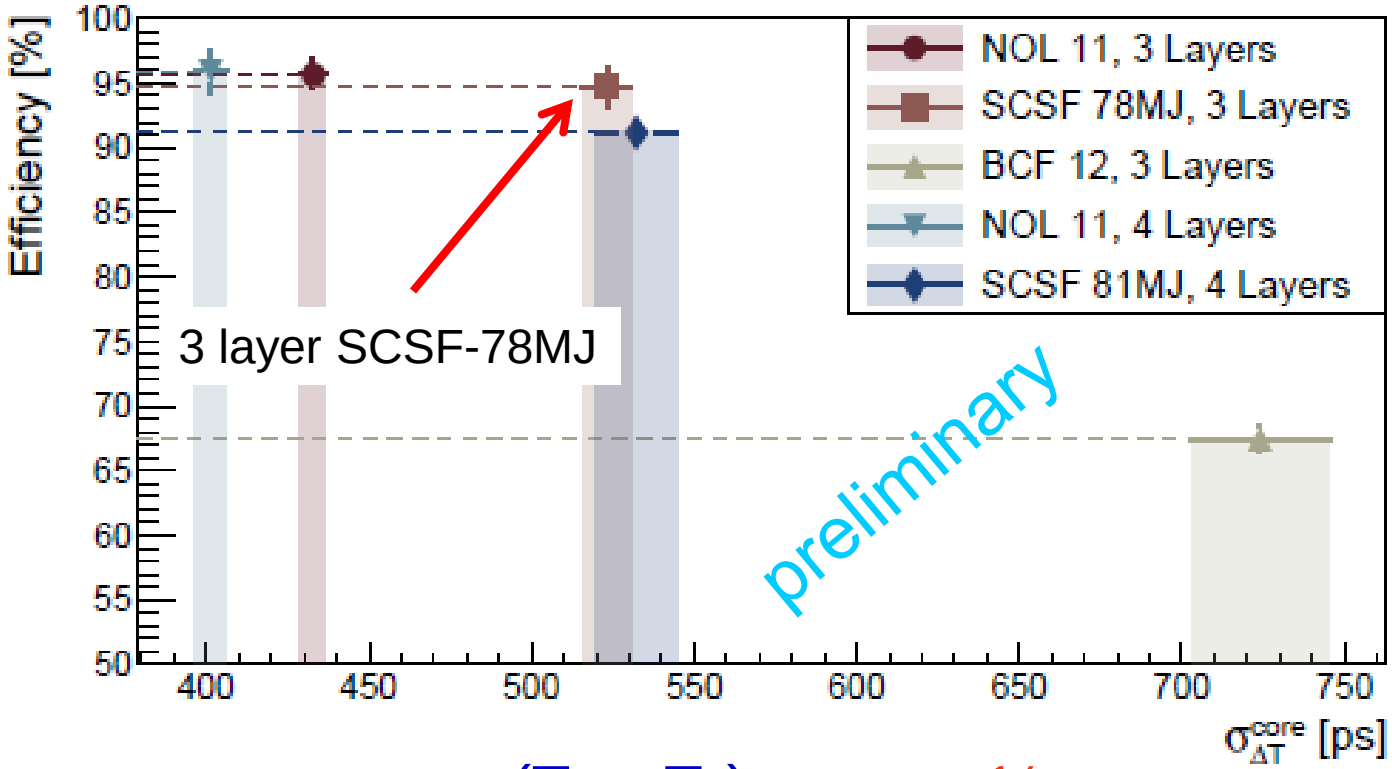
preliminary

crossing angle

important for reducing the data rate:
lower the threshold, larger the cluster → higher the occupancy and the data rate
(lower the light yield of fibers → smaller the cluster size)

SciFi Performance Summary

comparison of different fiber ribbons: efficiency vs timing



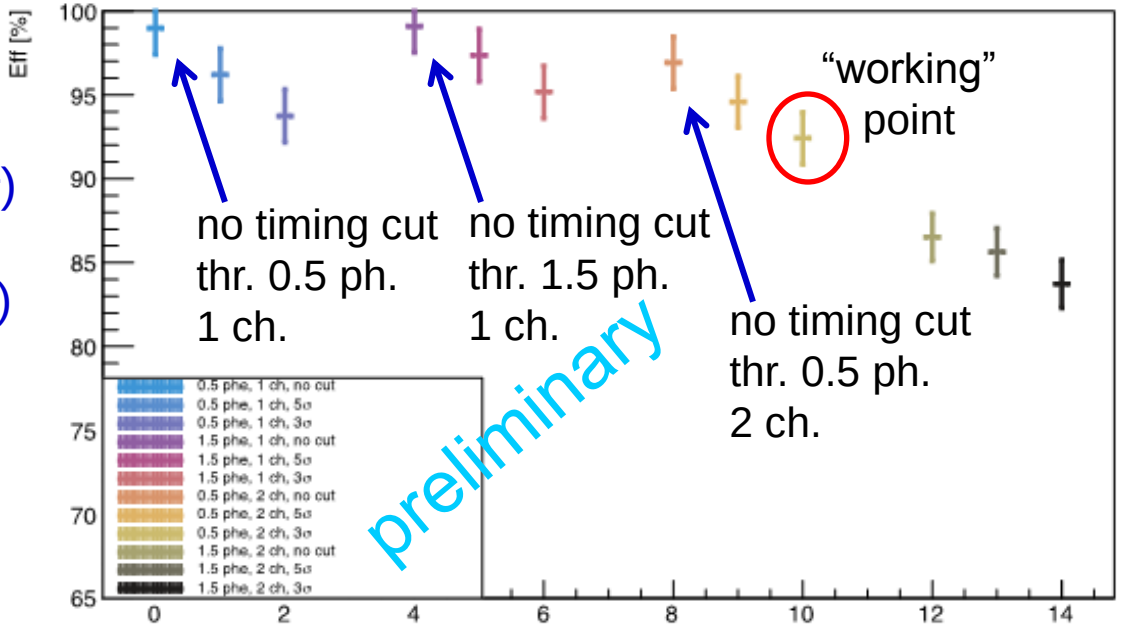
$\sigma_{\Delta T} = \sigma(T_1 - T_2)$; $\sigma_{MT} = \frac{1}{2}\,\sigma_{\Delta T}$

we require a cluster on each SciFi ribbon end (coincidence)
cluster: at least two adjacent SiPM channels > 0.5 ph. el. threshold
coincidence: ± 3 σ timing cut
timing with L.E. disc. algorithm w/ interpolation to simulate the MuTRiG functioning

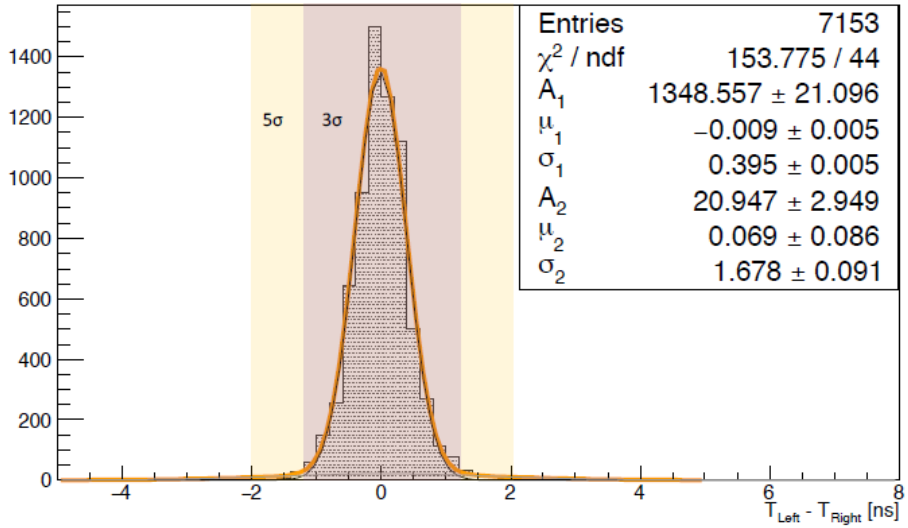
Detection Efficiency

SCSF-78MJ 3 layer ribbon efficiency for different cuts:

1. threshold (0.5, 1.5, or 2.5 ph.)
2. timing cut (no cut, +3σ, or + 5σ)
3. min. cluster size (1 ch. or 2 ch.)



timing cut



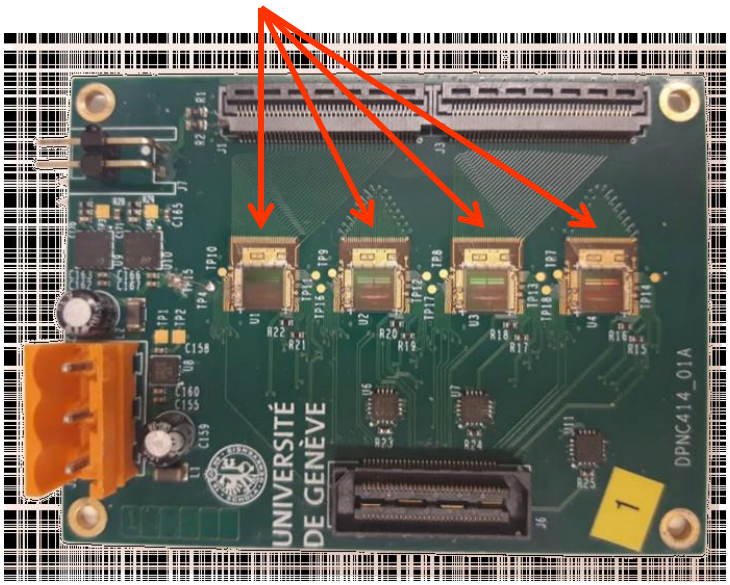
if we drop timing cut
efficiency close to 100 %

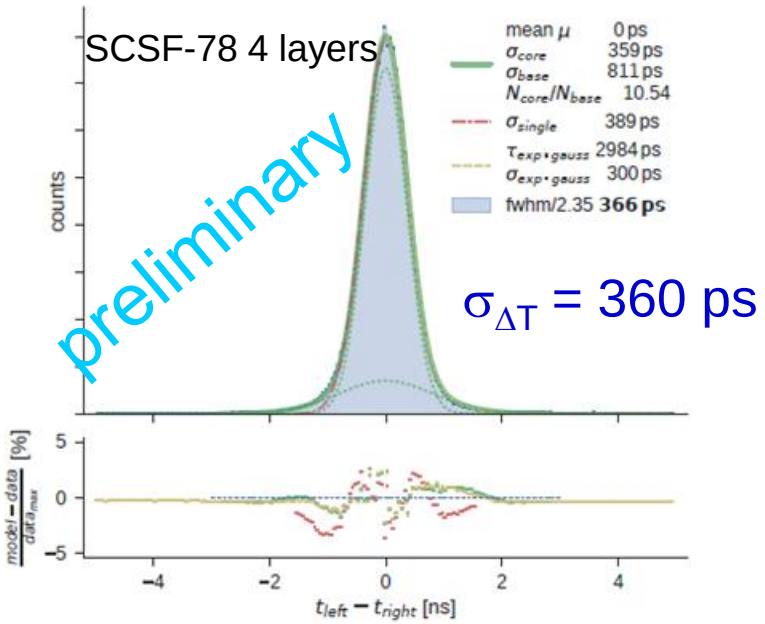
The MuTRiG ASIC

Muon Timing Resolver w/ Gigabit link

- mixed mode ASIC for precise timing applications
- 32 differential inputs / chip
- individual SiPM bias tuning
- 50 ps time bin
- Gigabit serial data link (1.25 Gbps)
  - up to 1.1 MHz hit rate / channel

current version of the FE board:
4 MuTRiG chips are required to read out one SiPM array (128 h.)





$\sigma_{\Delta T}$ = 360 ps

SciFi timing performance w/ MuTRiG
reproduced timing resolution obtained with analogue electronics (DRS)
(using only one channel at each fiber end)

Summary

We developed a very thin SciFi timing tracker with SiPM readout

- different scintillating fibers have been studied in detail
- best performance observed with NOL11 fibers from Kuraray, but not yet commercially available, use SCSF-78 fibers instead (Kuraray)
- 3 staggered layers of 250 μm ϕ fibers SCSF-78 (Kuraray)
- thickness ~700 μm, < 0.2 % x_0
- time resolution ≤ 250 ps (mean time)
- efficiency > 95 % (w/ both ends coincidence measurement + timing cut)
- spatial resolution ~100 μm

MuTRiG ASIC v1 fully operational

- developed FE boards with 4 chips to read out one full SiPM array (128 ch.) (not final size yet)
- excellent analog front-end
- full chain jitter < 30 ps (charge = 480 fC and rate < 15 MHz)

Construction will be completed by the end of 2020

Commissioning in 2021

The Team

UNIVERSITÉ DE GENÈVE

A. Bravar, K. Briggl, A. Damyanova(*), Y. Demets

University of Zurich[UZH]

R. Gredig*, P. Owen, P. Robmann

ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

S. Corrodi*, L. Gerritzen, C. Grab

PAUL SCHERRER INSTITUT

PSI

M. Hildebrandt, A. Papa, G. Rutar*

PhD students (*already graduated)