ECFA

European Committee for Future Accelerators

ECFA Detector R&D Roadmap Symposium of Task Force 4
Photon Detectors and Particle Identification Detectors

Overlapping technologies and summary

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Overlapping topics

-PID with dE/dx, dN_{cl}/dx (TF1)

-PID with TRD (TF1)

-LGADs (TF3) → in this symposium discussed in the talk by R. Forty

-New fast scintillators (TF5+TF6) → in this symposium discussed in the talk by R. Forty

-Novel optical materials for fiber trackers

-Fast read-out for low light level sensors (TF7+TF6)

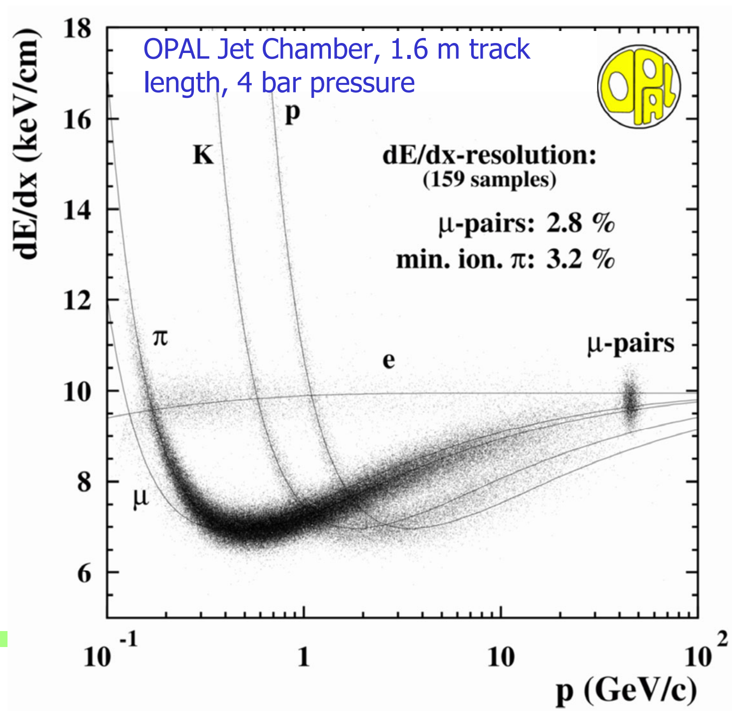
A brief overview with pointers to corresponding talks in other Symposia,
https://indico.cern.ch/category/13388/

PID with dE/dx, dN_{cl}/dx

Talks in TF1 Symposium:

- *PID: TPC, TRD, RICH and other large area detectors* - Emilio Radicioni
- *TPCs at future lepton and lepton-hadron colliders (TPC, drift chambers, large volume gaseous detectors)* - Piotr Gasik

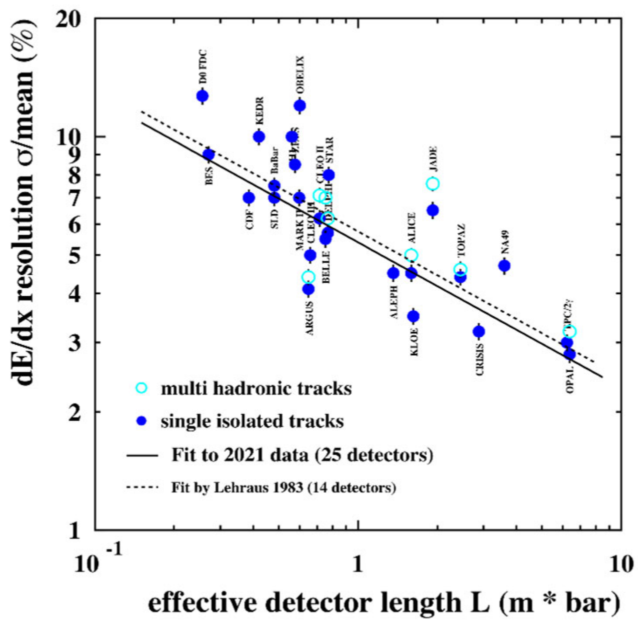
A recent review: Michael Hauschild, *dE/dx, classical and with cluster counting*, RD51 Workshop on Gaseous Detector Contributions to PID, February 2021



PID with dE/dx

TF1 Symposium: PID: TPC, TRD, RICH and other large area detectors - Emilio Radicioni

dE/dx resolution around 5% is routinely reached, in excellent conditions and with accurate calibration. It relies on truncated mean techniques or max likelihood.



Lehraus plot: 5.4% typical dE/dx resolution for 1m·bar track length. No significant change since 1983, i.e. since the first TPCs

dE/dx resolution = 5.4% * $(LP)^{-0.37}$

L length in m, P pressure in bar

The dependency on P has not been exploited much since the first TPCs.

The interest in the P term is renewed where excellent PID is needed together with a large mass of gas (TPC-as-a-target). R+D topics: suitable gas mixtures for high-P operation; light pressure-containment vessels.

N.B. Relevant is the separation power, rel. rise reduced by higher pressure, optimal P at 3-4 bar

PID with dN_{cl}/dx – cluster counting

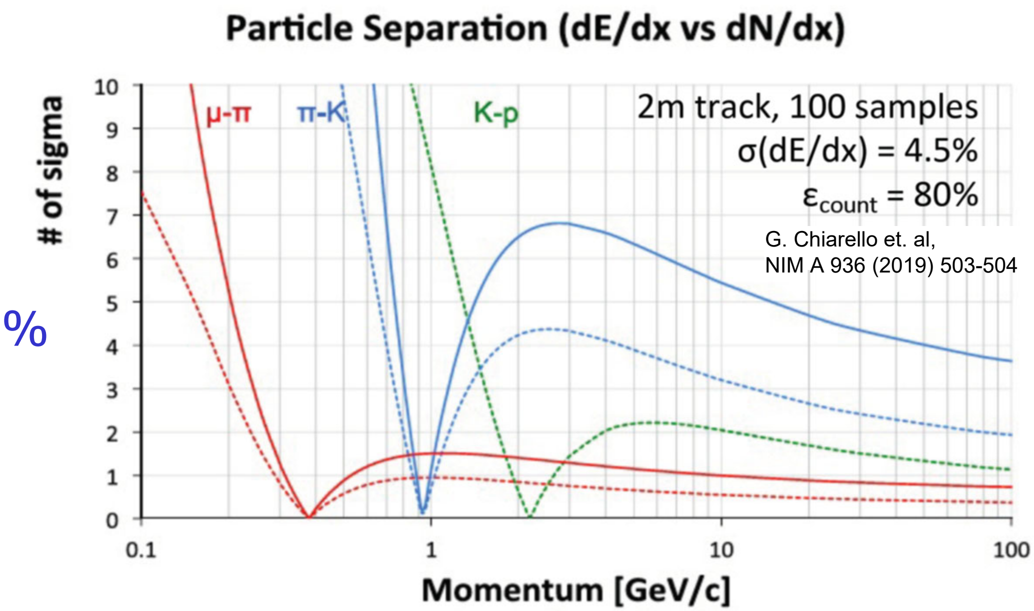
TF1: PID: TPC, TRD, RICH and other large area detectors - Emilio Radicioni

TF1: TPCs at future lepton and lepton-hadron colliders (TPC, drift chambers, large volume gaseous detectors) - Piotr Gasik

dN_{cl}/dx resolution is potentially better than dE/dx (by a factor of ~2). Cluster counting requires fast electronics and sophisticated counting algorithms, or alternative readout methods. It has the potential of being less dependent on other parameters.

IDEA Drift Chamber (for FCC-ee or CEPC): PID resolution can be considerably improved using cluster counting:

- Standard trunc. mean dE/dx : $\sigma \simeq 4.2\%$
- Cluster counting : $\sigma \simeq 2.5\%$ (assuming 80% cluster counting efficiency)



PID with dN_{cl}/dx – cluster counting

TF1: PID: TPC, TRD, RICH and other large area detectors - Emilio Radicioni

TF1: TPCs at future lepton and lepton-hadron colliders (TPC, drift chambers, large volume gaseous detectors) - Piotr Gasik

$$\frac{\sigma_{\mathrm{d}N/\mathrm{d}x}}{\mathrm{d}N/\mathrm{d}x} = (\varepsilon_{\mathrm{count}}\delta_{\mathrm{clusters}}L_{\mathrm{track}})^{-0.5}$$

Typically δ=30 clusters/cm at 1 bar in Argon mixtures
→about 300 µm separated along track on average
→time separation in fast gases (v_d~ 50 µm/ns) about 6 ns
Cluster-counting efficiency $\varepsilon_{\mathrm{count}}$

- Some gases (He, Ne) better suited than others (Ar) due to their primary ionization characteristics (more single electron clusters)
- The relativistic rise is flattened out in the primary cluster count → a hybrid approach (dE/dx + dN/dx) may be better suited
- Long drift lengths in TPCs (longitudinal diffusion) tend to de-cluster the primary ionization. Potential source of systematics.
- Optimize the gas also for the longitudinal diffusion

PID with dN_{cl}/dx – cluster counting

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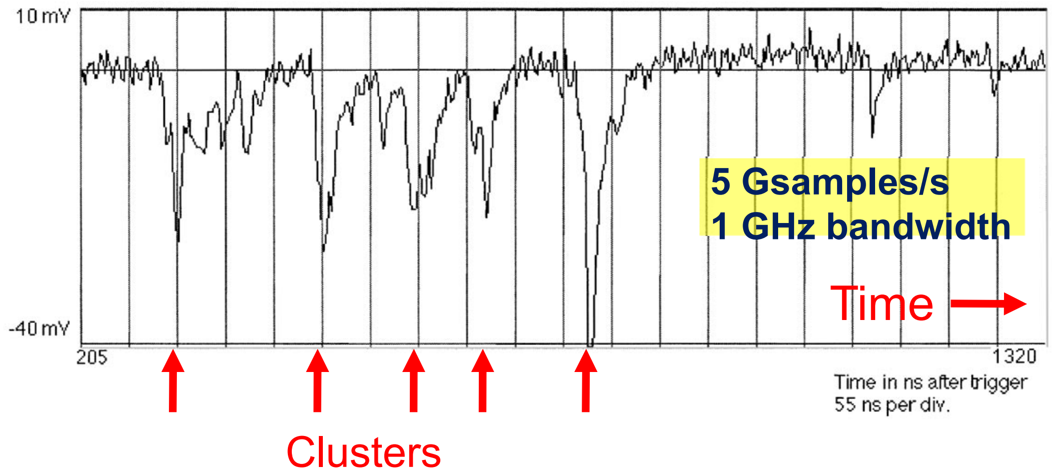
How to count?

- Cluster counting in time
- Cluster counting in space

PID with dN_{cl}/dx – cluster counting in time

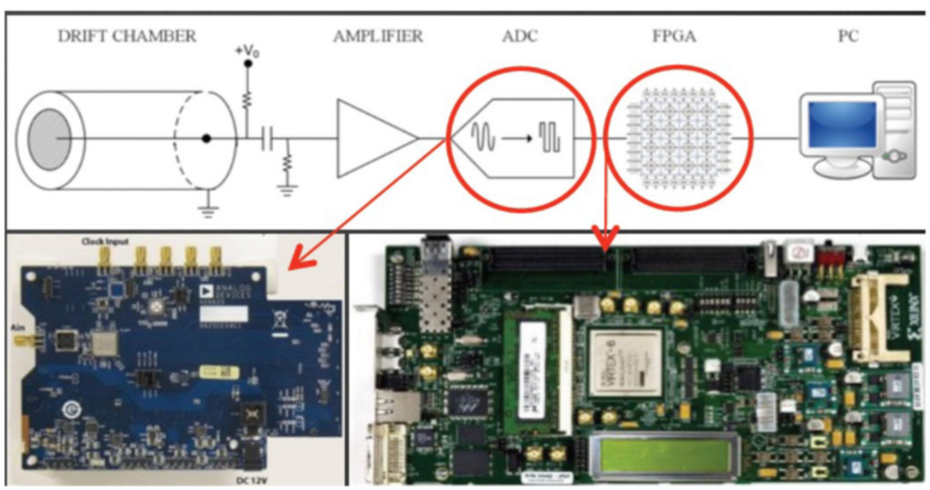


L. Cerrito et. al, NIM A 436 (1999) 336-340

Test beam measurements 1998 using He/CH_4 (80/20)

→Cluster counting works in test beam under controlled conditions

→But not yet used in large scale particle detectors



FEE for cluster counting (in time): at present, single channels solutions available.

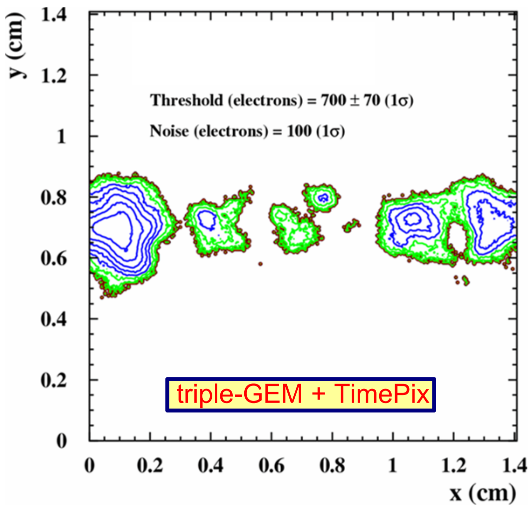
Further developments (R&D):

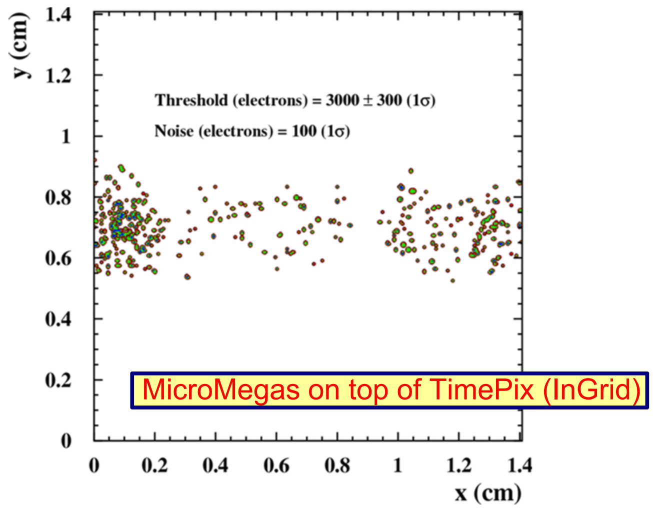
- Development of suitable FEE for IDEA and SCTF (INFN, BINP)
- Data reduction (peak finder) and pre-processing at high-rates on FPGA

PID with dN_{cl}/dx – cluster counting in 2D

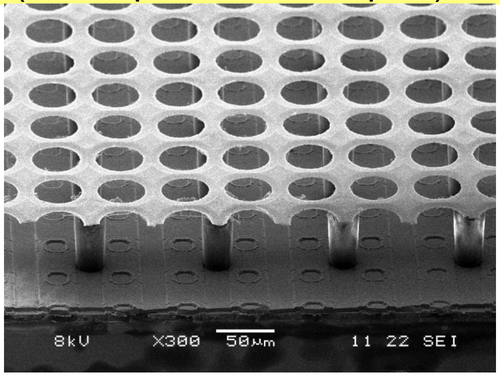
TPC with different micropattern endplate technologies for cluster counting

ILD-TPC simulated 100 GeV muon, 100 cm drift
identical events: same generated primary clusters/electrons

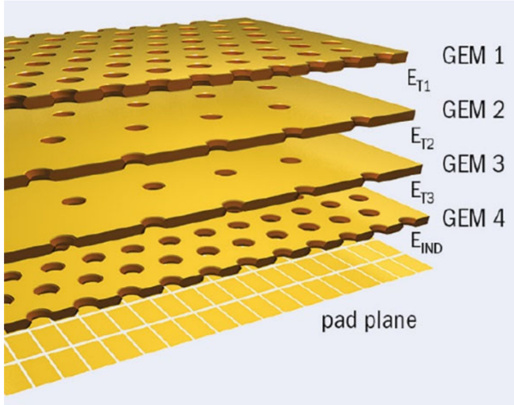




InGrid / GridPix = MicroMegas on top of TimePix (active pads, 55 x 55 μm²)



Multiple-GEMs with conventional (passive) or active (TimePix) pads



How to properly count clusters in space (2D)?

- *need cluster finding algorithm*
- *difficult to find clusters dissolved by diffusion*
- *efficiency also strongly depending on drift length*
- \+ electronics thresholds + noise

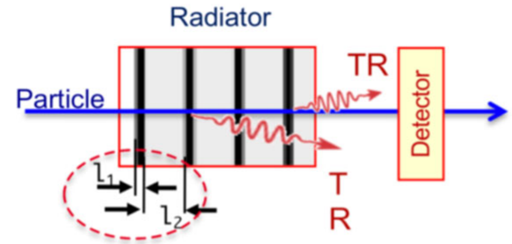
→ Cluster counting in space sensitive to quite some systematics

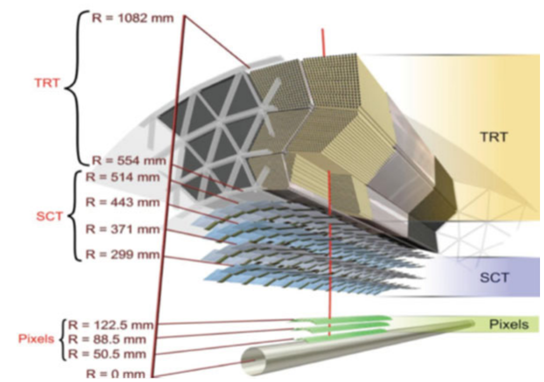
PID with TRD

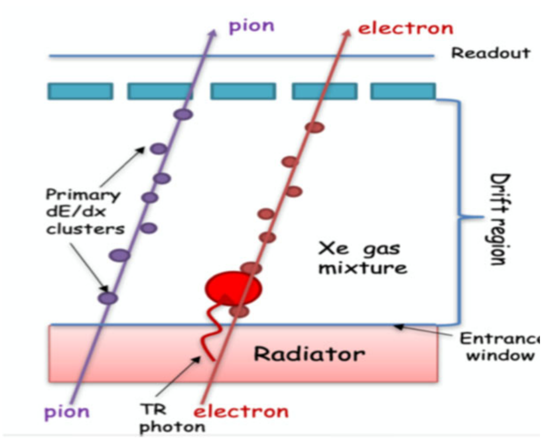
TF1: PID: TPC, TRD, RICH and other large area detectors - Emilio Radicioni

- TRDs are almost everywhere: ATLAS, ALICE, AMS, CBM, EIC
- Gas TRDs are considered a mature instrument for PID at high energies.
- The limitation of the gaseous detectors are related to the electron diffusion and photo/delta-electron production in the active gas. It is difficult to obtain a TR cluster size on the anode plane (or along the particle track) below few mm
- Due to the very small TR emission angle, the TR signal generated in a detector is overlapping with the ionization due to the specific energy loss dE/dx and a knowledge (and proper simulation) of dE/dx is a must
- Advantage: dE/dx improves PID at low momentum, and tracking information is provided. The problem is how to separate the TR radiation and the ionization process.
- --> Simulation is of prime importance
- GEMs are making their way in the technique

- TRD properties with Timepix3 J. Alozy et al, NIMA 961 (2020) 163681



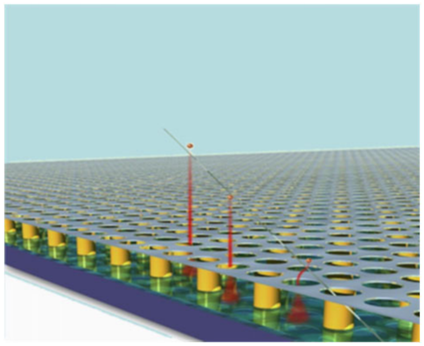


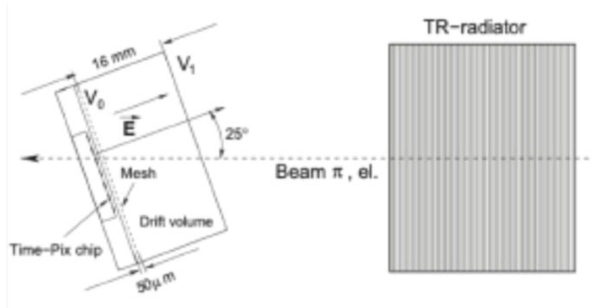


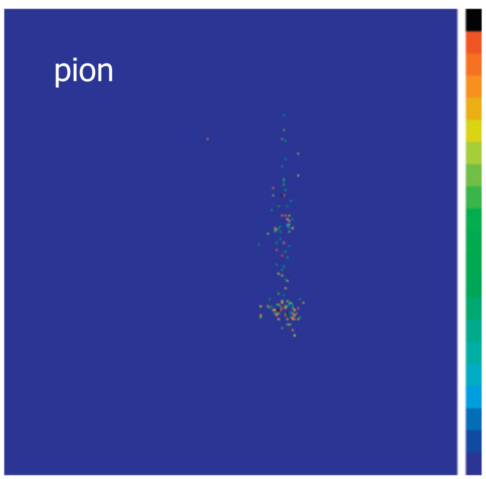
PID with TRD

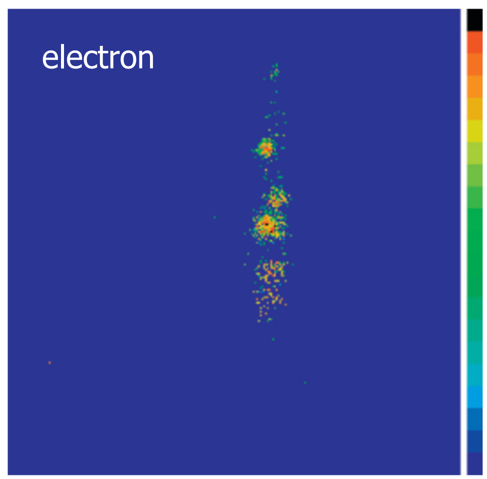
TF1: PID: TPC, TRD, RICH and other large area detectors - Emilio Radicioni

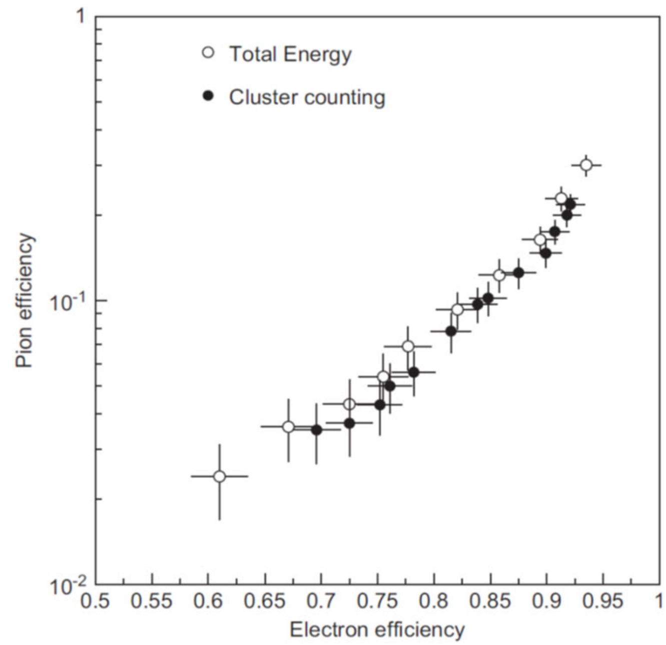
An attempt has been made to improve cluster counting by means of a GridPix.
Some improvement is possible, although not drastic. → NIM, A 706 (2013) 59











Potential improvement may be reached by differentiating the response to X-ray photons and to particle ionization → Extensive R&D required!

Fast scintillators

Talks in TF5 and TF6 Symposium:

- TF6 (tomorrow): Crystal calorimetry - Marco Lucchini
- TF6 (tomorrow): Scintillators with timing - Nural Akchurin
- TF5: Quantum scintillation materials - Etiennette Auffray Hillemans

This symposium: discussed in the talk by Roger Forty.

Novel optical materials for fiber trackers

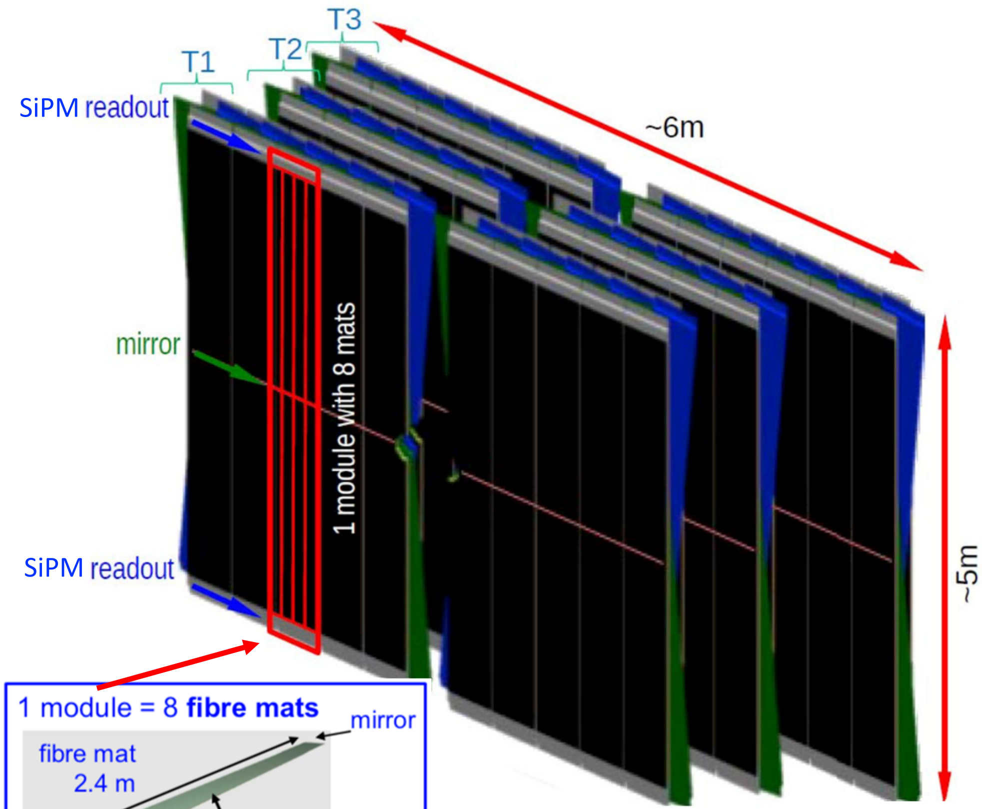
Scintillating fibres offer a cost-effective way of instrumenting large areas for charged particle tracking at relatively low material budget. With the availability of small-pitch SiPM arrays, high resolutions are possible, as shown with the LHCb SciFi tracker upgrade just being completed.

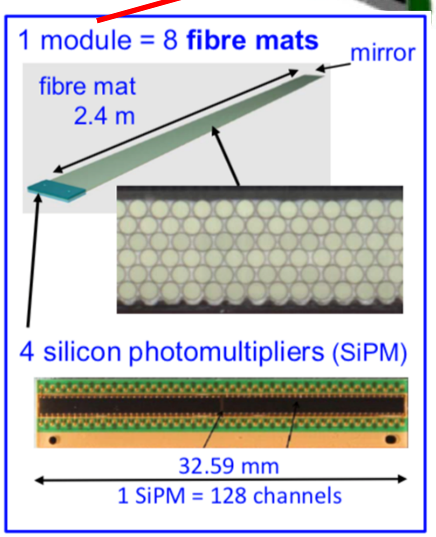
To further advance the technology, e.g. for a second upgrade of the tracker envisaged for the High-Luminosity LHC, not only the photo-sensor but also the optical fibers need to be optimised to obtain higher light yield, allowing for smaller diameters and thus higher precision and improved radiation tolerance.

Open issues:

- Radiation tolerance
- Speed
- Emission spectrum

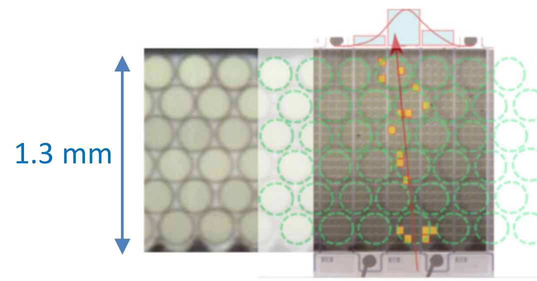
The LHCb SciFi tracker





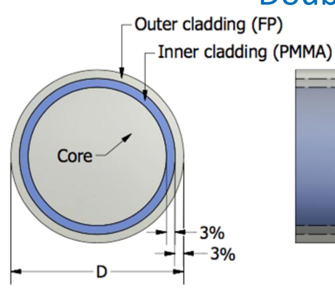
16-20 p.e. for 6-layer mat
(for particles near the mirror)

- → 3 stations with 4 layers (X-U-V-X)
- → 340 m^2 total area
- → **10,500 km of scintillating fibre**
  (Kuraray SCSF-78MJ, ⌀ = 250 µm)
- → **~ 4.5 million fibres of 2.4 m length**
- → 128 fibre modules (à 8 mats)
- → 4096 custom-made SiPM arrays
- → 524k readout channels

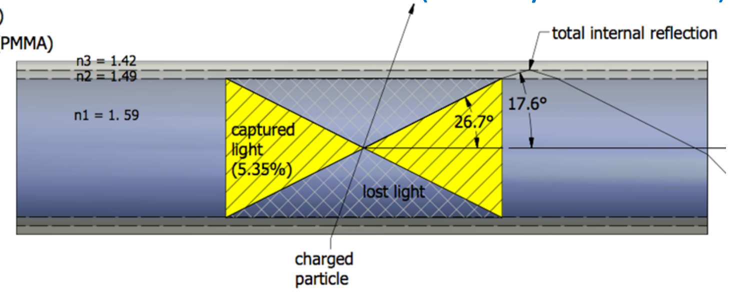


Fibre mat with SiPM

Double cladded round fibres (Kuraray SCSF-78MJ)



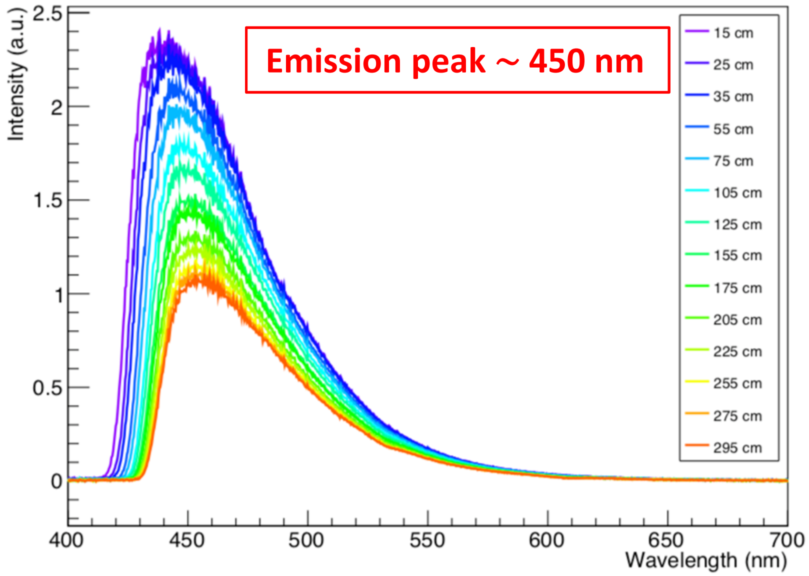
D = 250 µm

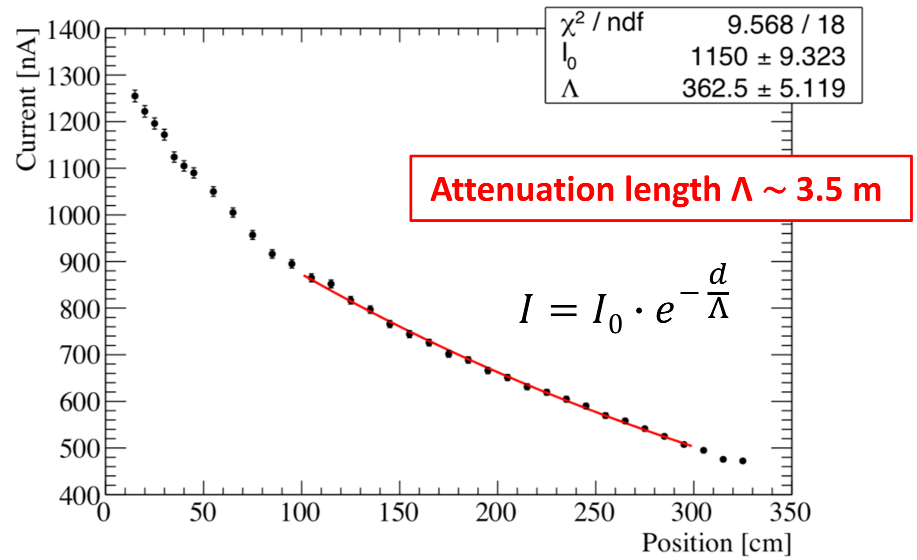


Solvent (Polystyrene) + activator (PTP) + WLS (TPB)

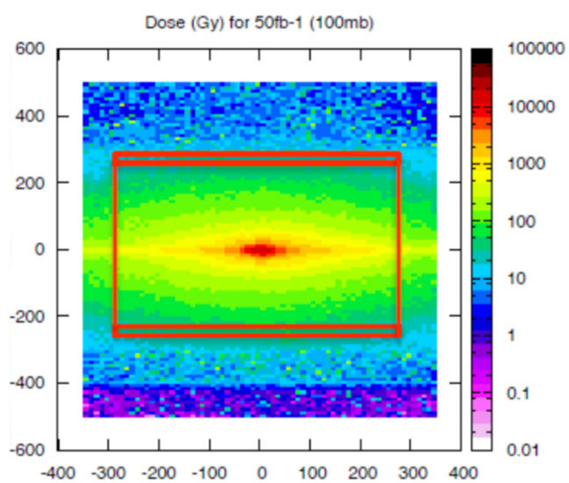
From: L. Gruber @ VCI 2019 - 21 Feb. 2019

LHCb SciFi tracker: scintillating fibres

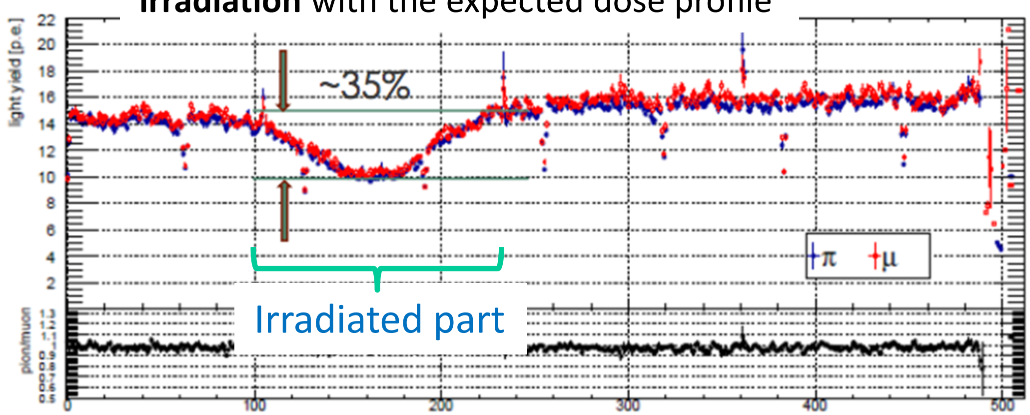




Ionization dose: 35 kGy in hottest region



Scan across one fibre mat after irradiation with the expected dose profile



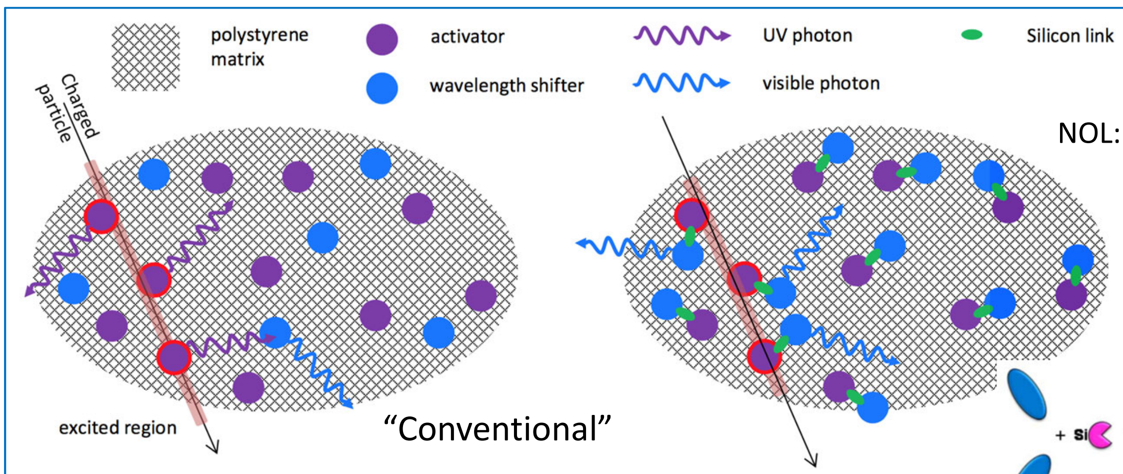
35% signal drop. 10 p.e. expected at end of lifetime is already the minimum for optimum hit efficiency!

From L. Gruber, VCI 2019

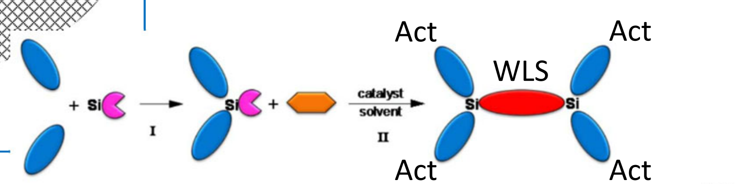
Novel optical materials for fiber trackers

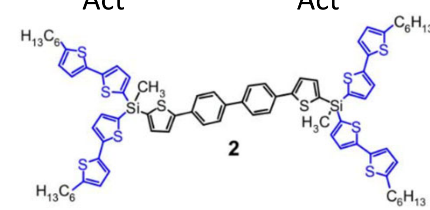
Innovative materials such as Nanostructured-Organo-silicon-Luminophores (NOL) scintillators, exhibit stronger and faster light output than presently achieved.

Energy transfer from the primary excitation to the wavelength shifter is enhanced by silicon links with respect to the radiative processes in standard materials



NOL: Nanostructured Organo-silicon Luminophores





Activator and WLS are chemically coupled using silicon links

→ Non radiative energy transfer (Förster mechanism)

→ Faster and more efficient

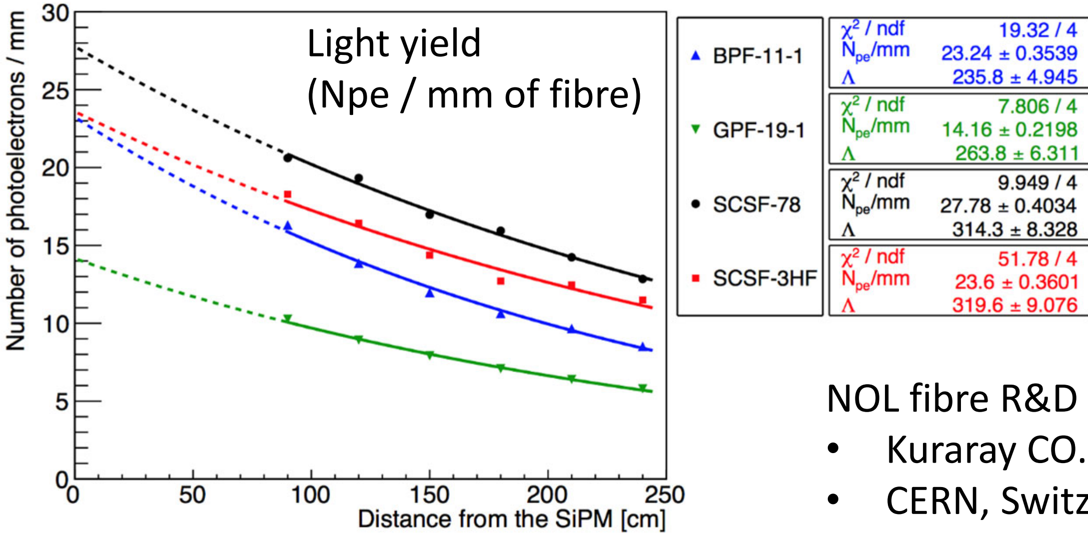
→ Higher light yield

S.A. Ponomarenko et al., Nature Sci. Rep. 4 (2014) 6549

From L. Gruber, VCI 2019

NOL prototype fiber performance

O. Borshchev et al., 2017 JINST 12 P05013



Best blue NOL prototype fibre

Best green NOL prototype fibre

Best blue standard fibre

Best green standard fibre

NOL fibre R&D among 3 institutes/companies

- Kuraray CO., Japan
- CERN, Switzerland
- ISPM, Russian Academy of Sciences, Russia

Components and contents need to be carefully selected and adjusted! The used materials must be of high purity!

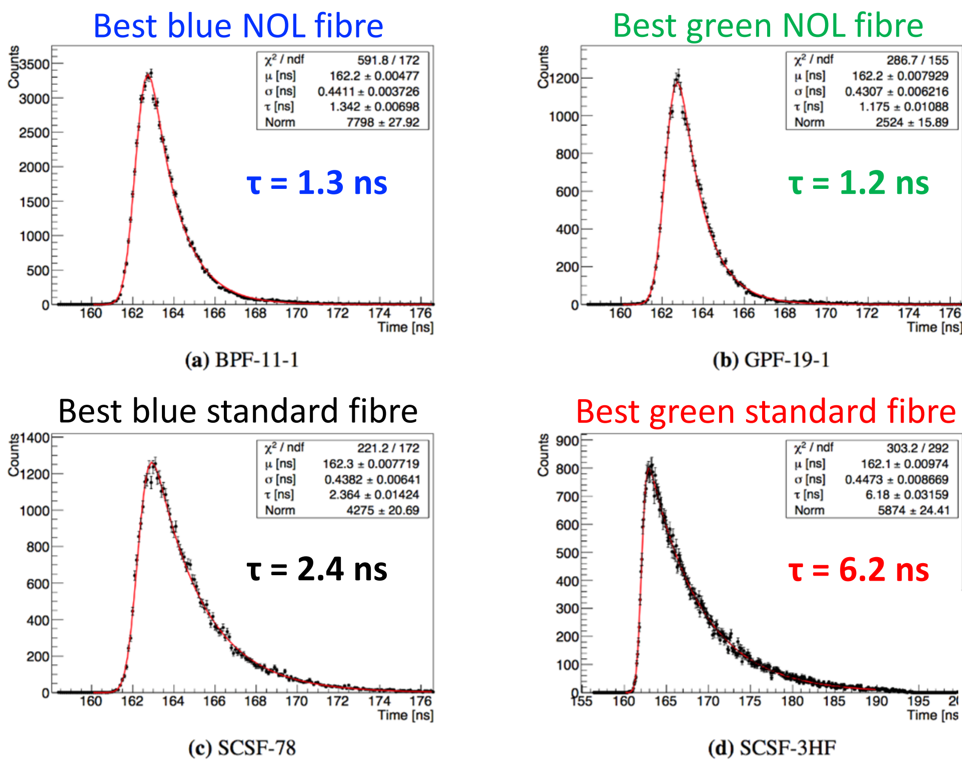
- After 8 iterations NOL fibres clearly improved but still a bit behind in terms of light yield and attenuation length

- Λ(NOL) ~ 300 cm
- Λ(standard) ~ 350 cm
- Self absorption, i.e. choice of materials, contents and purity are key issues

From L. Gruber, VCI 2019

NOL prototype fiber performance

O. Borshchev et al., 2017 JINST 12 P05013



Decay time: NOL fibres are almost a factor 2 (6) faster than the best blue (green) standard fibres, which makes them very interesting for time critical applications!

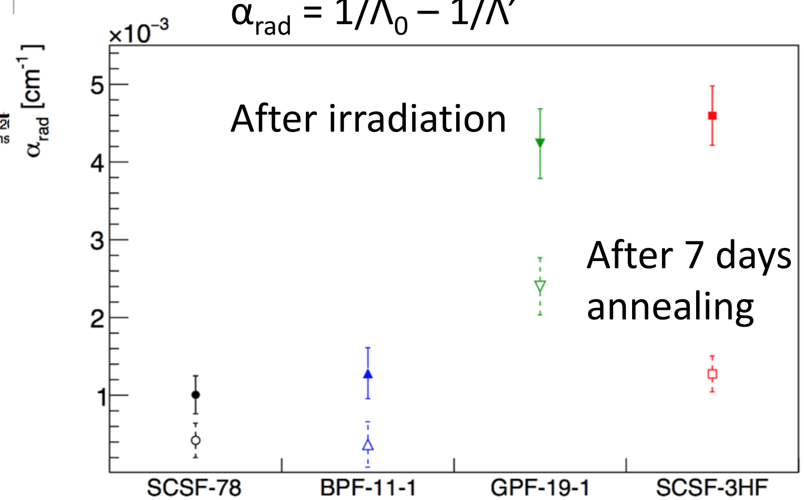
Radiation hardness (X-rays to a dose of 1 kGy):

- Damage is as expected on a level comparable to reference fibres

Promissing results but clearly more R+D needed

Add. attenuation coefficient

$\alpha_{rad} = 1/\Lambda_0 - 1/\Lambda'$



Fast read-out for low light level sensors (TF7+TF6)

Requirements (e.g. upgraded RICHes of LHCb)

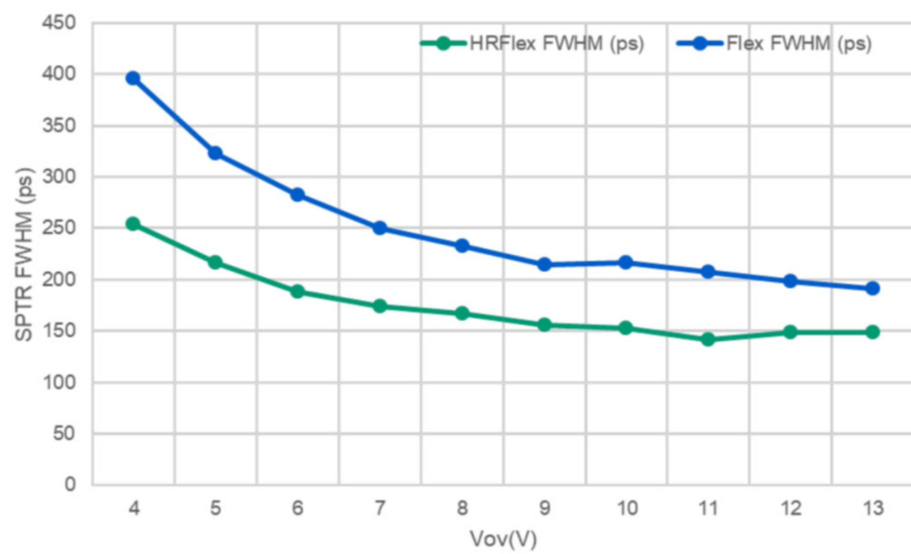
- Timing: contribution from electronics ~10ps
- Granularity: ~1-3 mm
- Energy: not really needed for RICH detectors – maybe double threshold to remove background hits?

Fortunate circumstance: fast readout also needed for SiPMs in the medical imaging TOFPET application.

Example: HRFlexToT, R+D by ICCUB, Ciemat, CERN

Tested on a 3x3 mm2 HPKK device (50um) cell, S13660.

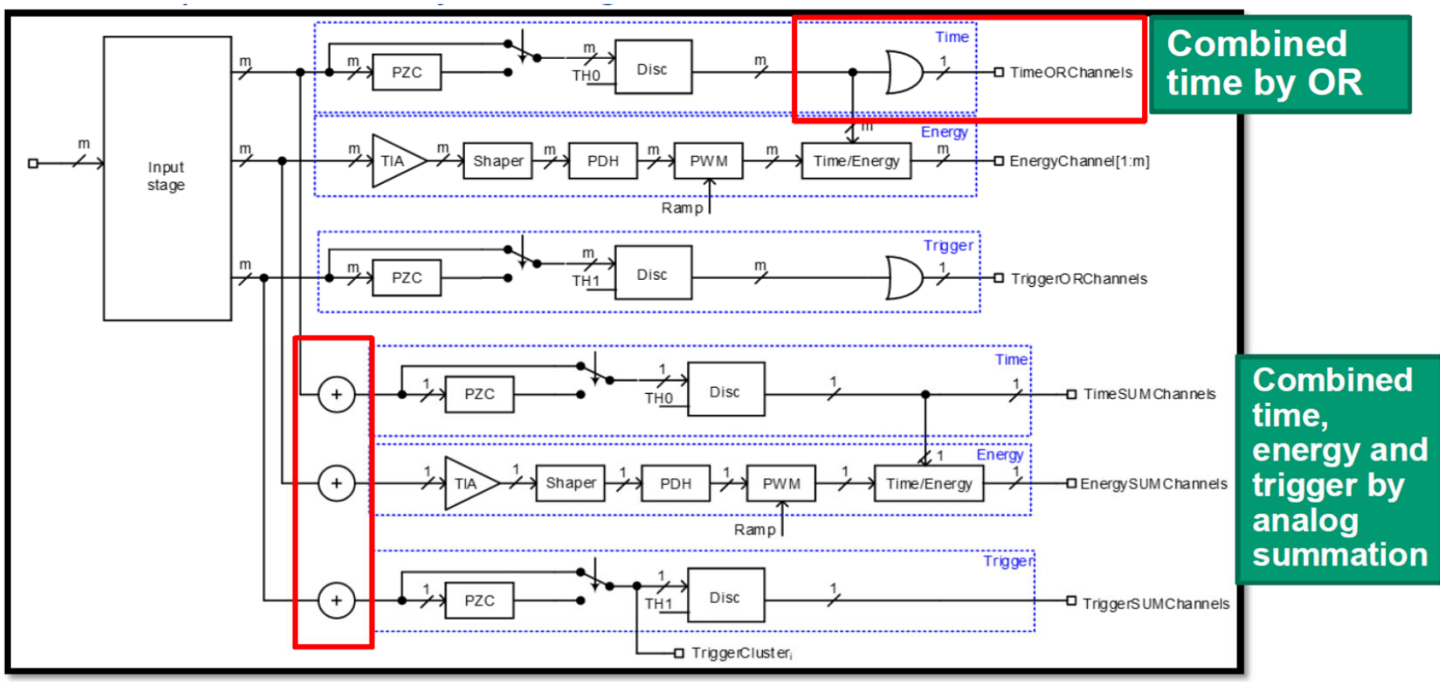
→SPTR of about 60 ps rms (<150 ps FWHM) with 3.5 mW/ch



Fast read-out for low light level sensors (TF7+TF6)

New ASIC FastIC in the 65 nm technology is being developed by ICCUB and CERN, combined with picoTDC

First step towards a Hybrid Single Photon Pixel Detector



Challenges:

-Power consumption: 6mW per channel → 600mW/cm² for 1x1mm² channels → 6kW/m² (could be reduced if no energy is measured)

-Cooling system, in particular for 4π detectors (challenge similar to the LGADs)

Summary

Both particle identification methods and photosensors are very vibrant research areas.

Both research areas have a strong overlap with other TFs - particle identification profiting for development of components, and photosensors supplying tools for complex detection systems.

New challenges are waiting for us as has been pointed out by the speakers today.