Partikeldagarna - 17th September 2026

ECal Timing Studies for LHCb Upgrade II

Overview of Upgrade II and characterization of the new readout components for the ECal.

PRESENTED BY

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01

LHCb

Physics and detector.

- Matter - antimatter asymmetry (CP-violation)
- Hadron spectroscopy
- Rare decays

Out of the 80 hadrons discovered at the LHC, how many were discovered by the LHCb collaboration?

a) 28
b) 54
c) 71

https://indico.global/event/16271/contributions/148750/attachments/68822/133294/LHCb_plenary_HCliff_final.pdf

- Matter - antimatter asymmetry (CP-violation)
- Hadron spectroscopy
- Rare decays

Out of the 80 hadrons discovered at the LHC, how many were discovered by the LHCb collaboration?

a) 28

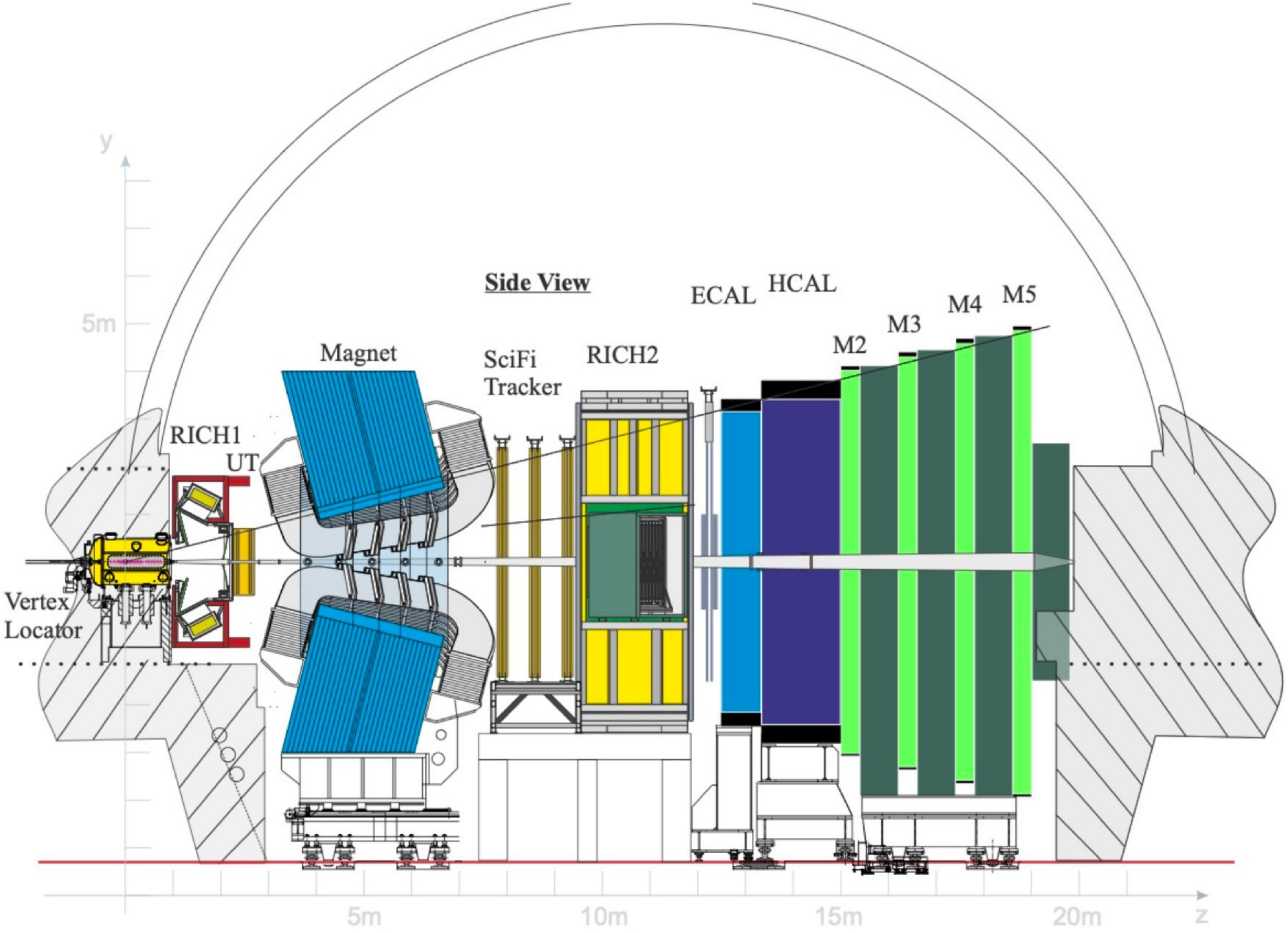
b) 54

c) 71

71 / 80 !

https://indico.global/event/16271/contributions/148750/attachments/68822/133294/LHCb_plenary_HCliff_final.pdf

The Detector



- A forward-region detector with a vertex locator around the interaction point.
- Particles are ID'd with Ring-Imaging Cherenkov (RICH) detectors, and tracked with the Upstream Tracker (UT) and SciFi Tracker.
- The energy of elemental particles and hadrons are measured with the two calorimeters. Muons are tracked with the Muon Tracker (M2-M5).

02

Upgrade II

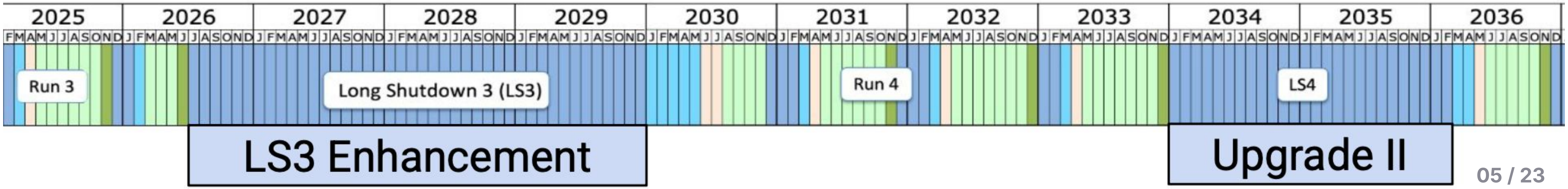
Why LHCb’s calorimeter upgrade demands better timing resolution.

ECal Requirements for Upgrade II & Run 5

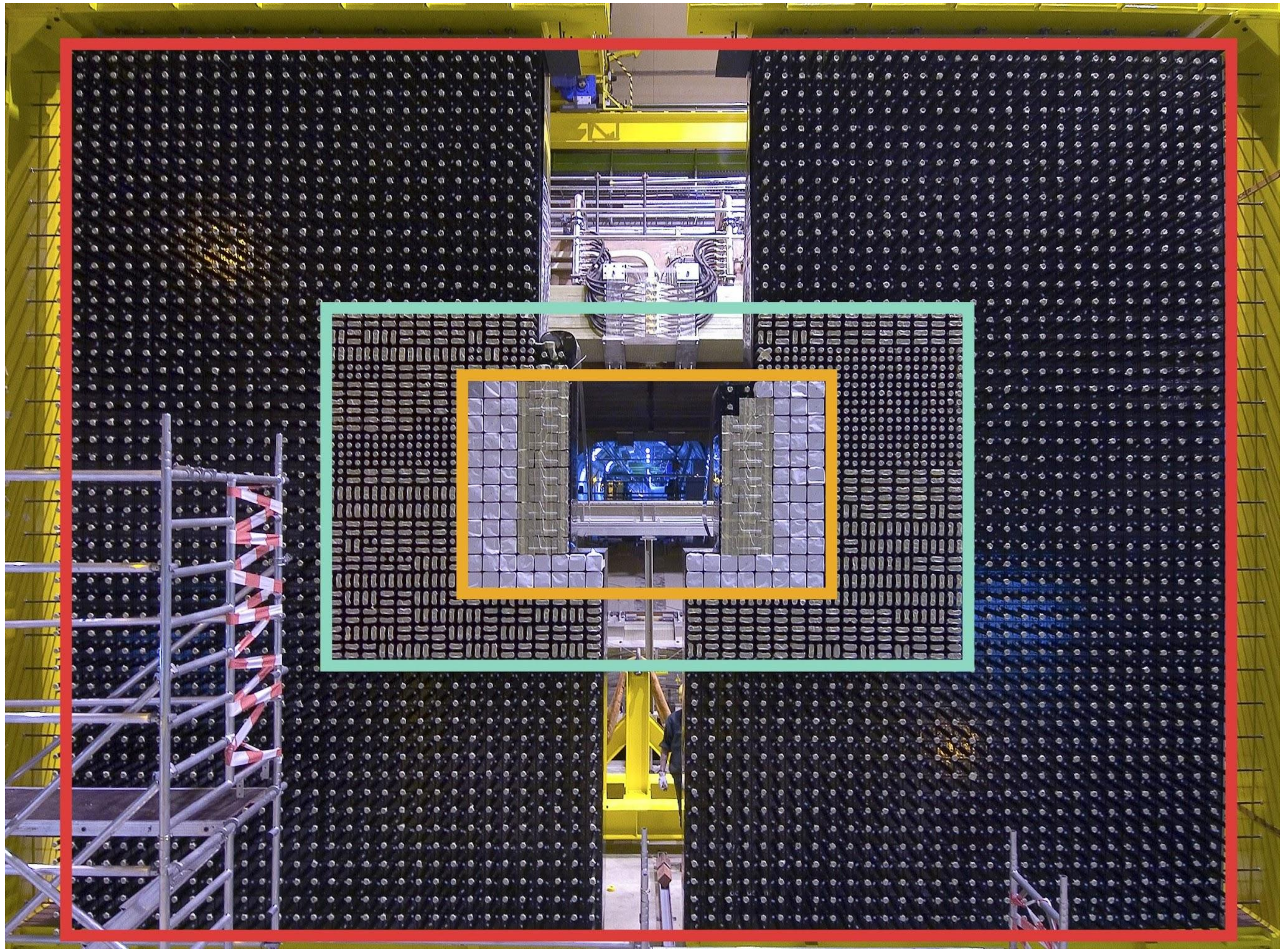
Rise in instantaneous luminosity for Run 5
from increased pile-up

Requires $\mathcal{O}$(10) ps time resolution!

Maintain energy resolution of $\frac{\sigma_E}{E} \approx \frac{10\%}{\sqrt{E}} \oplus 1\%$

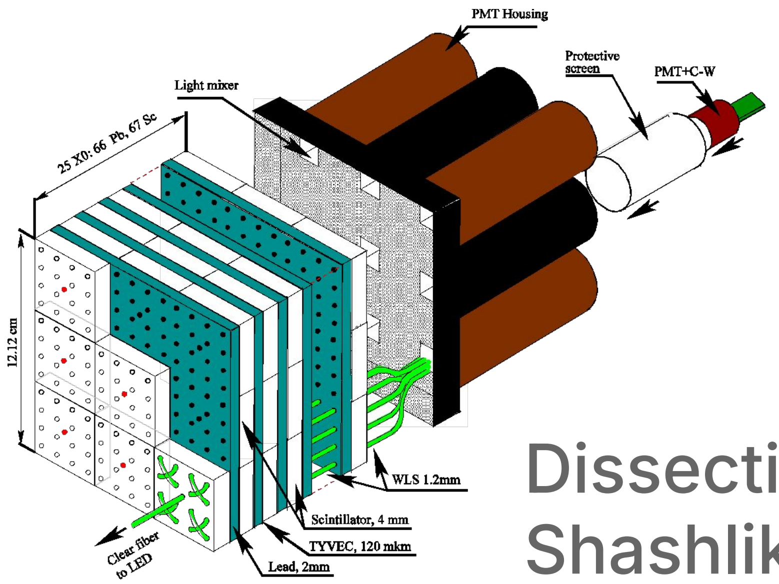


The Current ECal



ECal from the back

- Consists of Shashlik modules with different number of cells. Higher granularity closer to the center.
- Energy resolution: $\frac{\sigma_E}{E} \approx \frac{10\%}{\sqrt{E}} \oplus 1\%$
- Radiation-hard up to 40 kGy

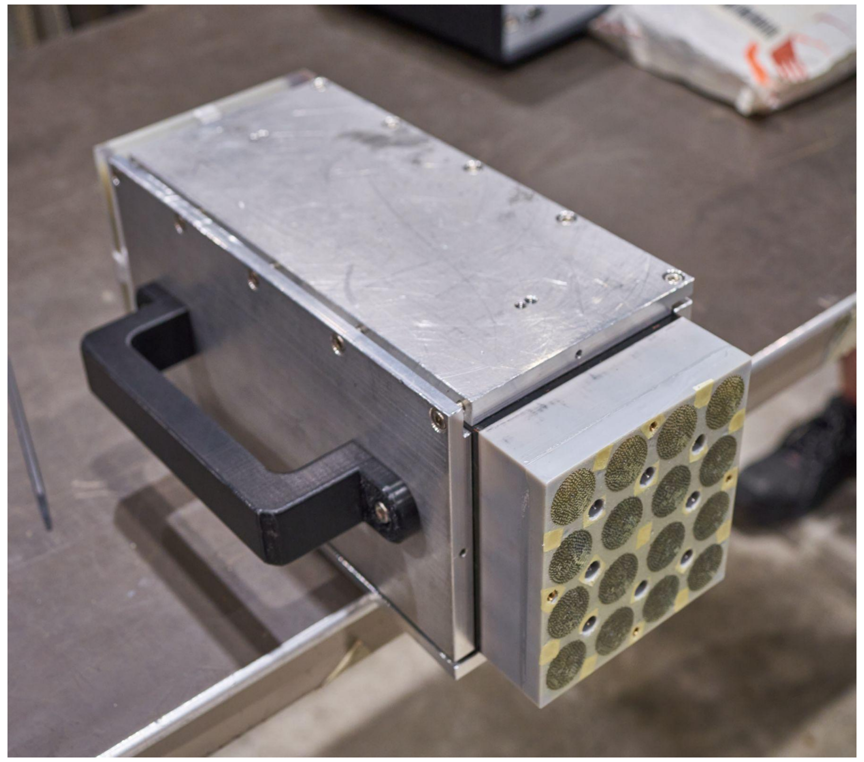


Dissection of a 3×3 Shashlik module

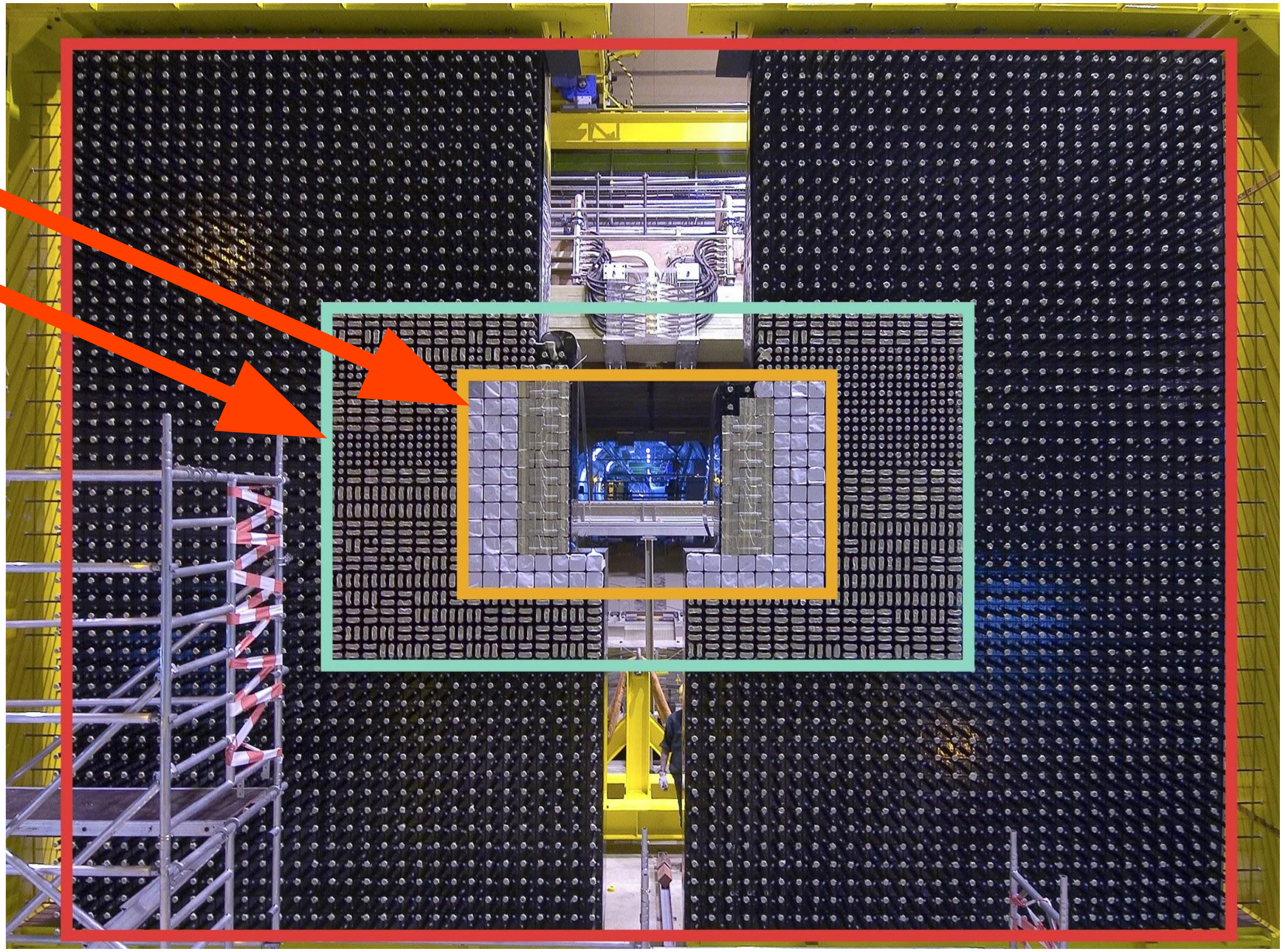
New Spaghetti Calorimeter Modules

- The **Spaghetti Calorimeter (SpaCal)** will replace the two innermost ECal regions.
- Higher granularity / smaller cell size than the Shashlik.
- **Run 5 SpaCal** will have **fast scintillating fibers**.

Credit : Manuel Franco Sevilla

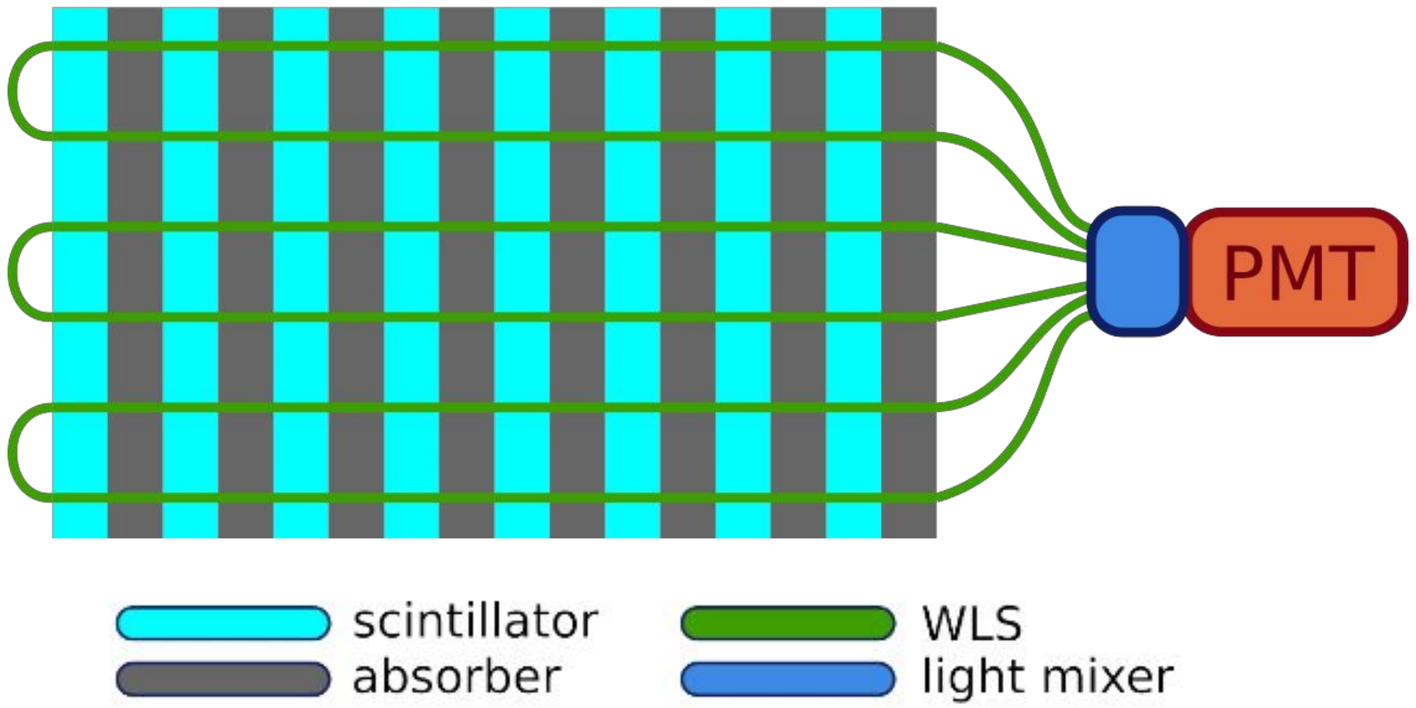


Lead SpaCal from the back

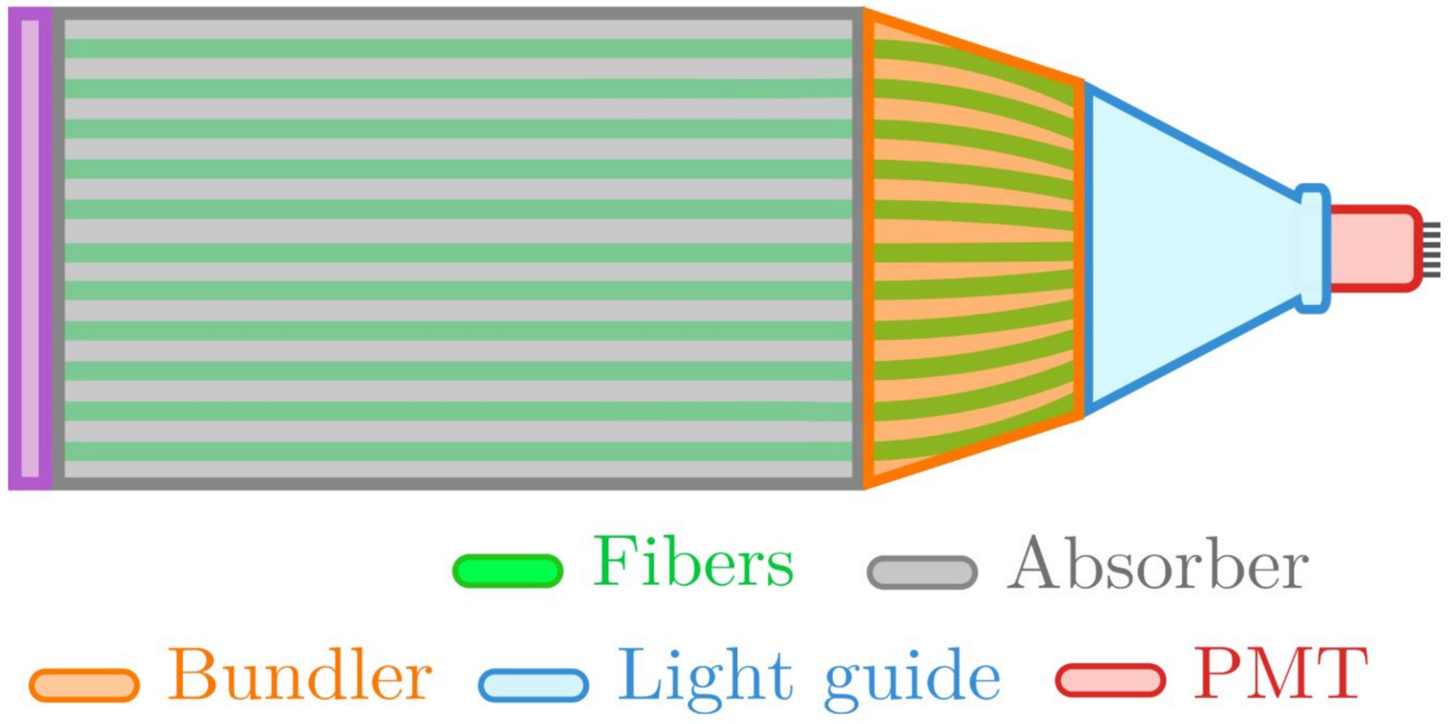


ECal from the back

New Spaghetti Calorimeter Modules



Cross-section of the Shashlik



Cross-section of the SpaCal

Energy resolution: $\frac{\sigma_E}{E} \approx \frac{10\%}{\sqrt{E}} \oplus 1\%$

No timing information :(

Radiation-hard up to 40 kGy

Energy resolution: $\frac{\sigma_E}{E} \approx \frac{10\%}{\sqrt{E}} \oplus 1\%$

Time resolution: $\mathcal{O}(10)$ ps

Radiation-hard up to 1 MGy

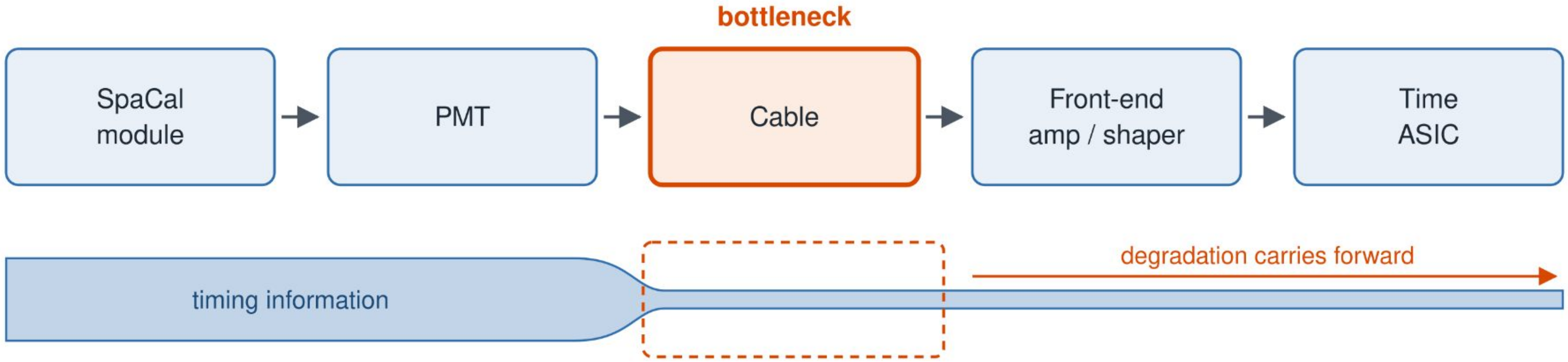
What do we have so far?

- **A SpaCal prototype,**
  demonstrating **$\mathcal{O}$(10) ps** resolution!

What do we need?

- **Readout components to meet the same requirements!**
  The readout cable, shaper and time ASIC.

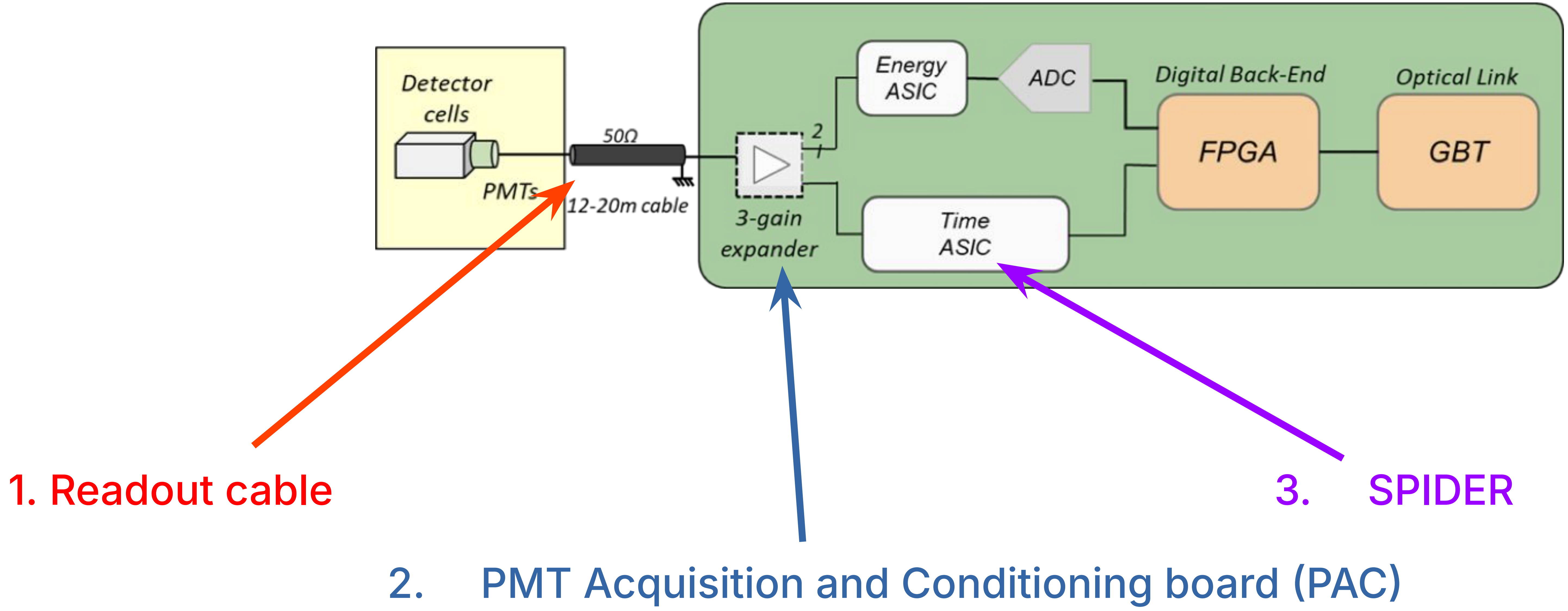
We want to avoid a bottleneck like in this example

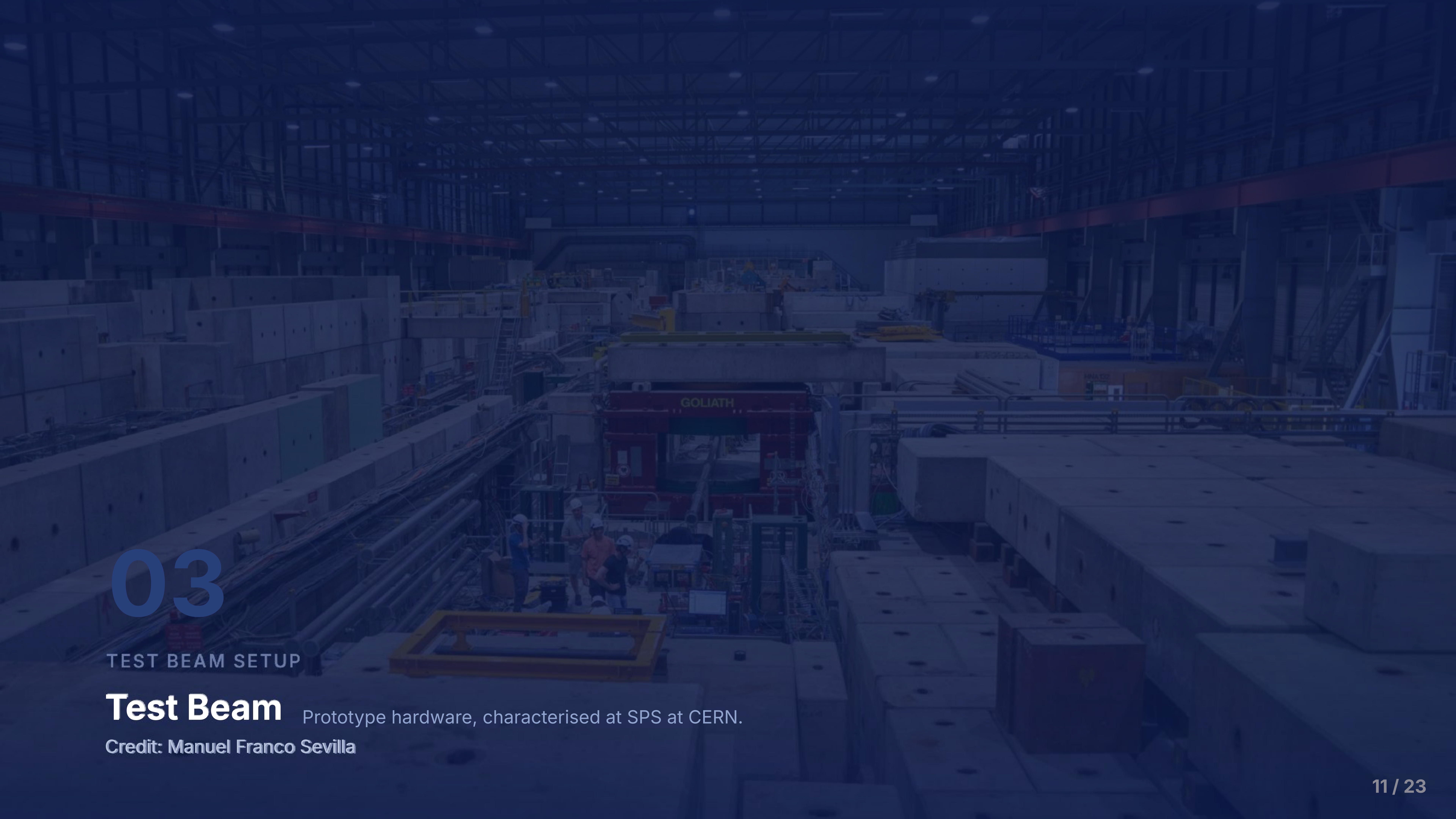


Readout Electronics

Accompanying the SpaCal, the readout electronics need improved timing capabilities. Two ASICs take time and energy measurements.

Three components in the time readout chain:





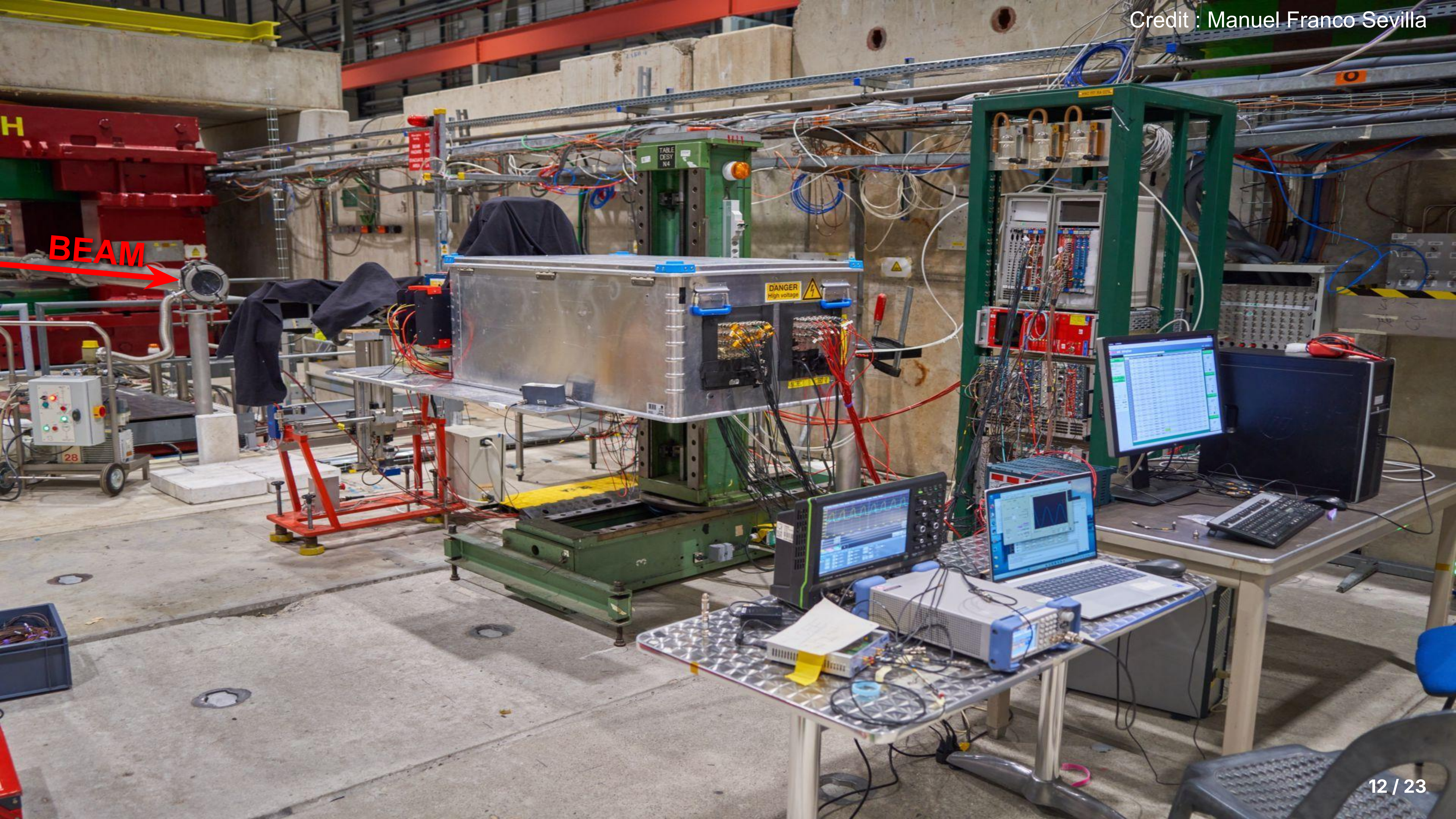
03

TEST BEAM SETUP

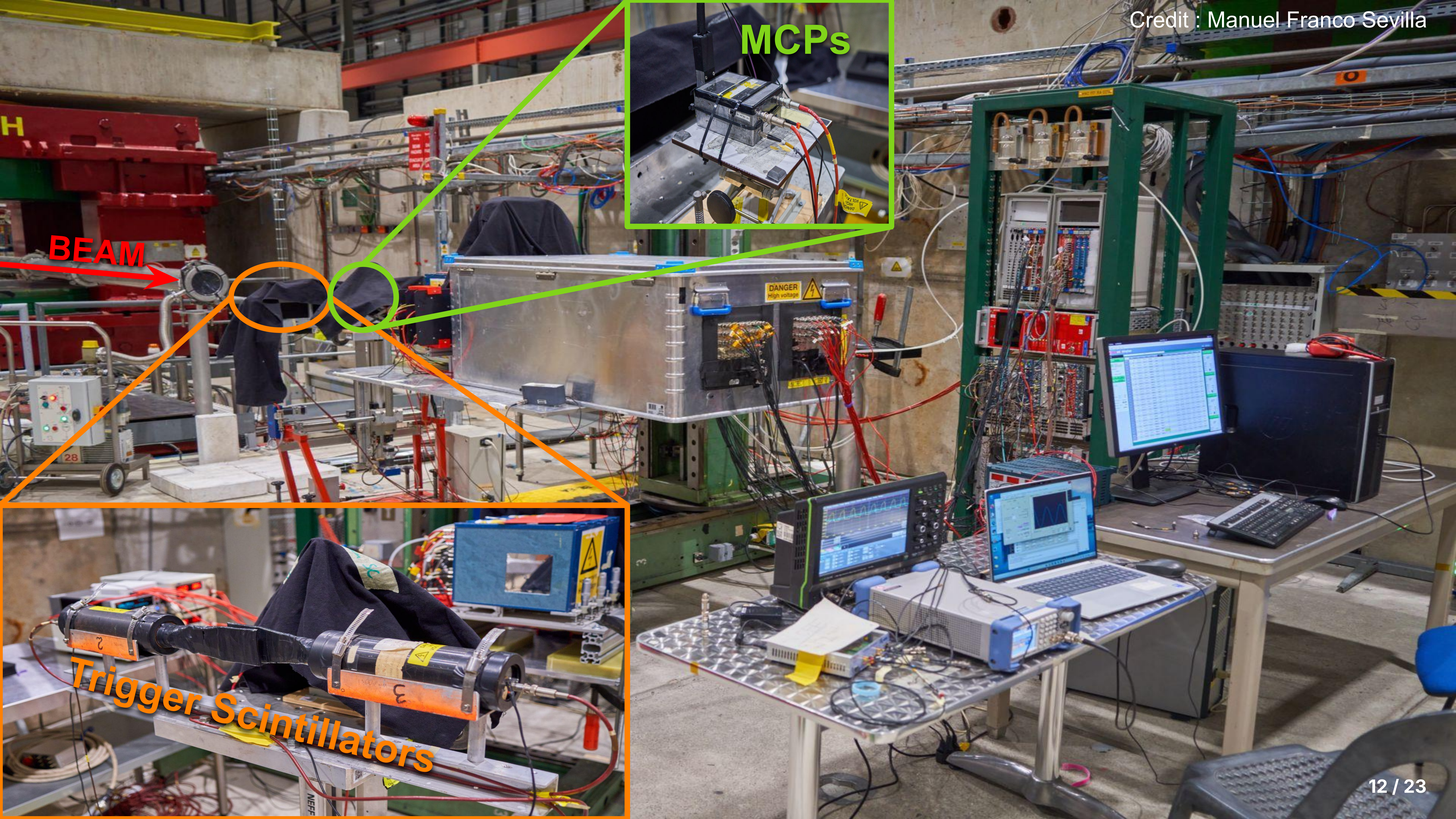
Test Beam

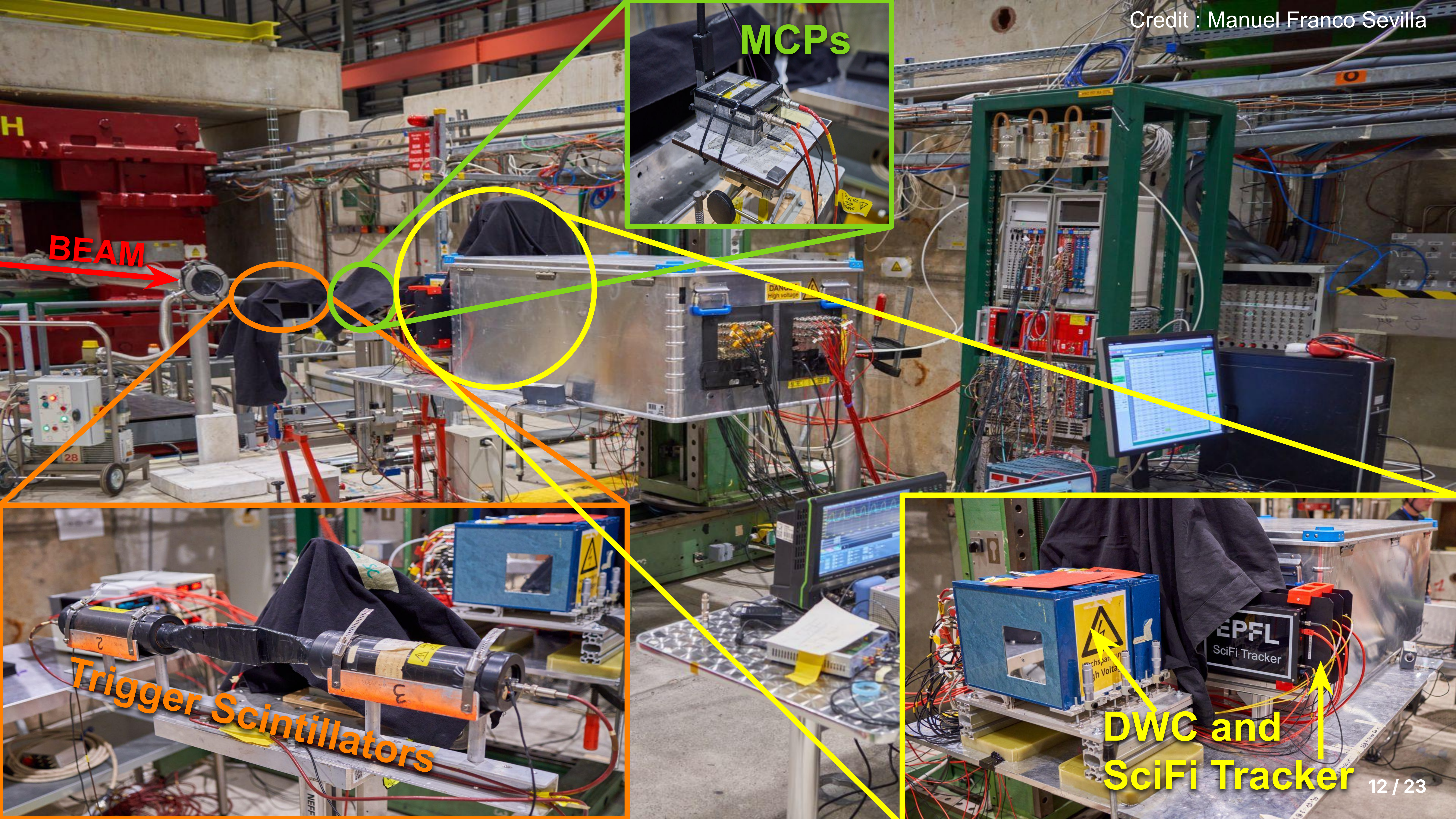
Prototype hardware, characterised at SPS at CERN.

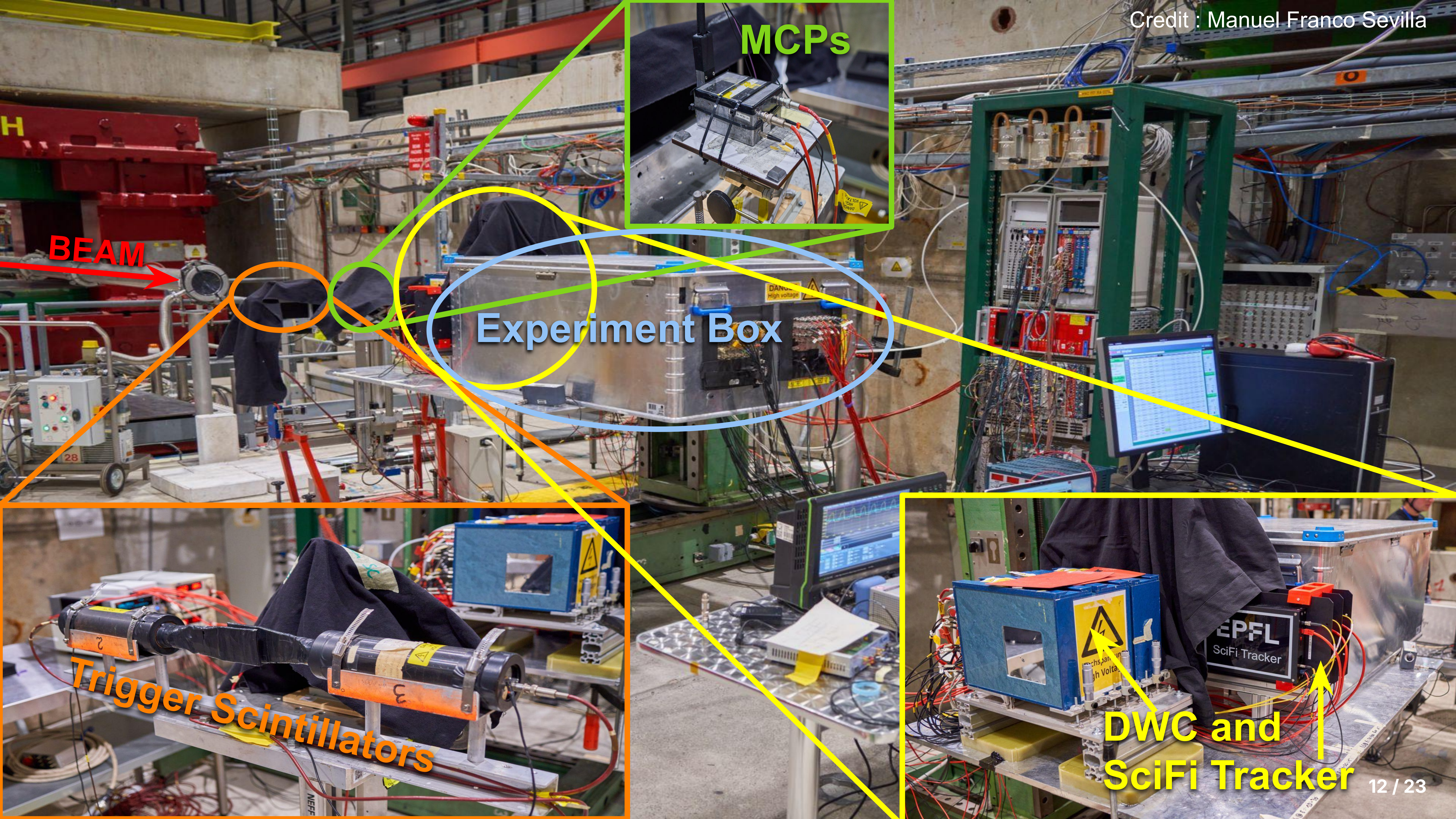
Credit: Manuel Franco Sevilla

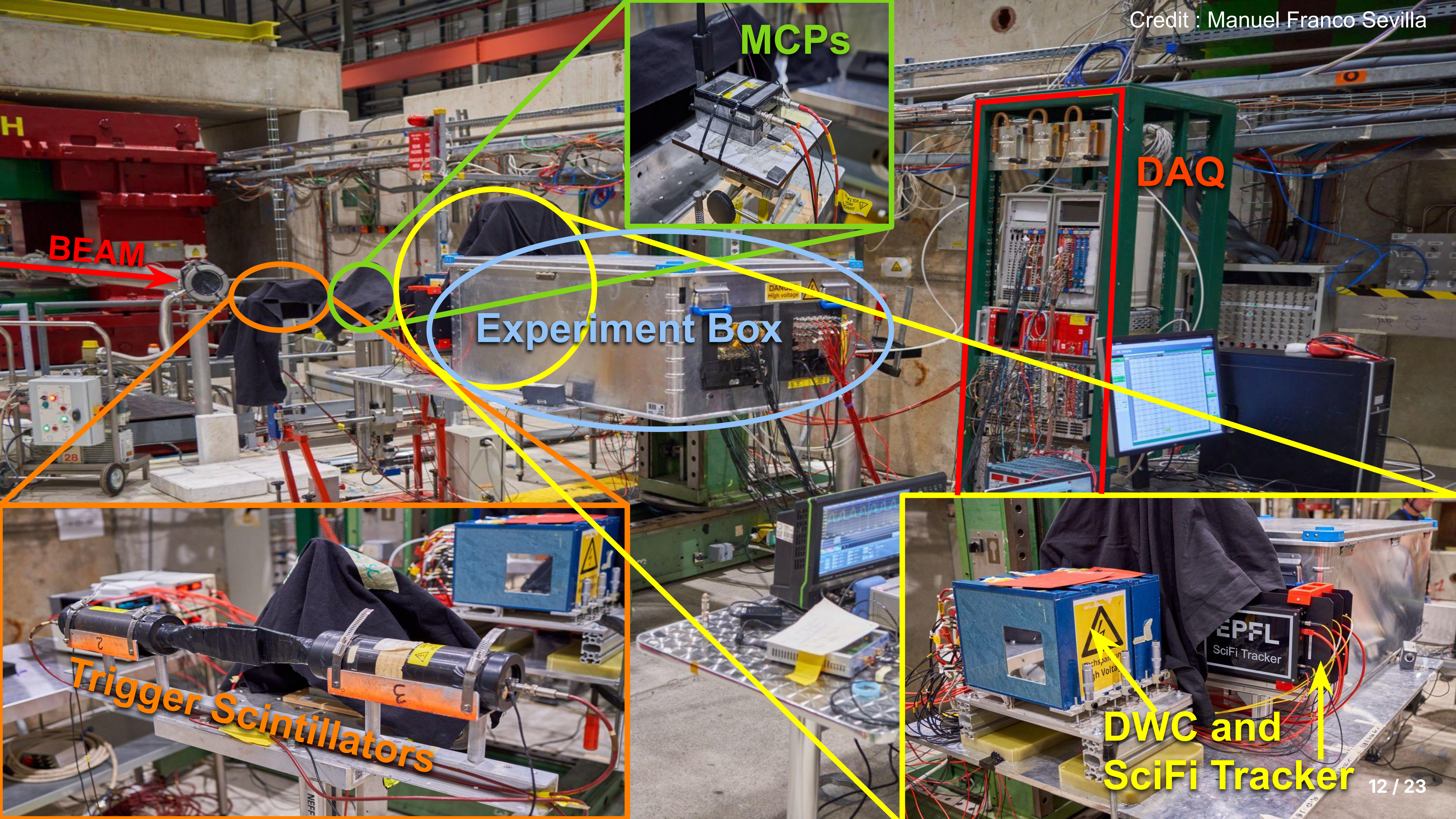

Credit : Manuel Franco Sevilla
BEAM
TABLE DESY N4
DANGER High voltage
28

Credit : Manuel Franco Sevilla


Credit : Manuel Franco Sevilla
MCPs
BEAM
Trigger Scintillators
DANGER High voltage


Credit : Manuel Franco Sevilla
MCPs
BEAM
DANGER
High voltage
EPFL
SciFi Tracker
Trigger Scintillators
DWC and
SciFi Tracker


Credit : Manuel Franco Sevilla
MCPs
BEAM
Experiment Box
Trigger Scintillators
EPFL
SciFi Tracker
DWC and
SciFi Tracker


Credit : Manuel Franco Sevilla
MCPs
DAQ
BEAM
Experiment Box
Trigger Scintillators
DWC and
SciFi Tracker
EPFL
SciFi Tracker

04

Readout Cables

Characterization of the TB cable, Draka cable and Technikabel.

Readout Cables

We have tested three readout cables:

TB cable 3.4 m ← reference cable

Draka cable 10 m

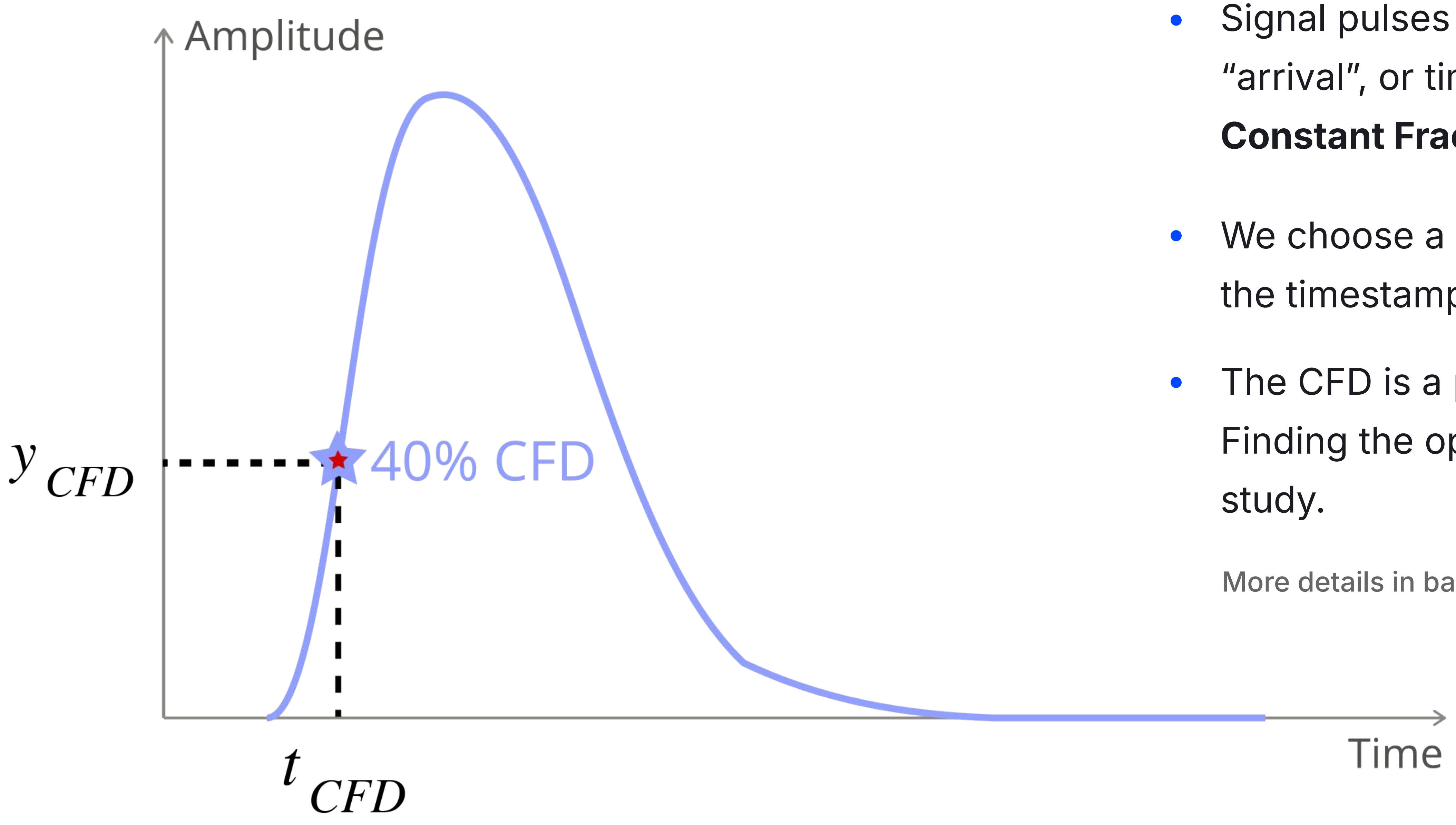
Technikabel 10 m

Different manufacturers. Main property difference is length.

Technikabel at TB

DEFINITION

How Do We Measure Time?



- Signal pulses arrive in our detector. We select the "arrival", or timestamp, of the pulse based on the **Constant Fraction Discriminator (CFD)** technique.
- We choose a certain percentage of the pulse and take the timestamp corresponding to that point.
- The CFD is a parameter that we need to optimize. Finding the optimal CFD is complex and an ongoing study.

More details in backup

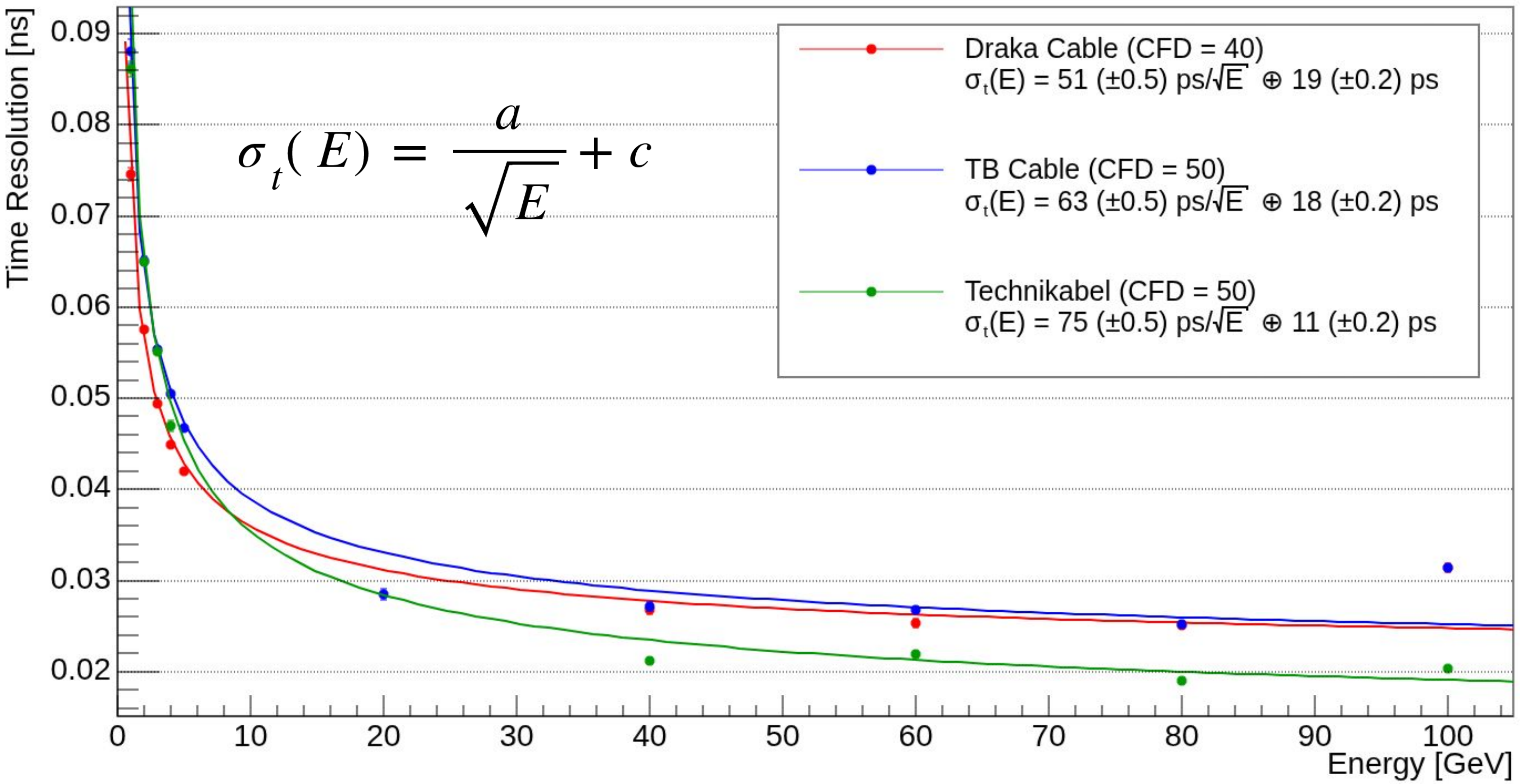
Results - Time Resolution

The TB cable shows worst resolution.

Reminder

TB cable	3.4 m	← reference cable
Draka cable	10 m	
Technikabel	10 m	

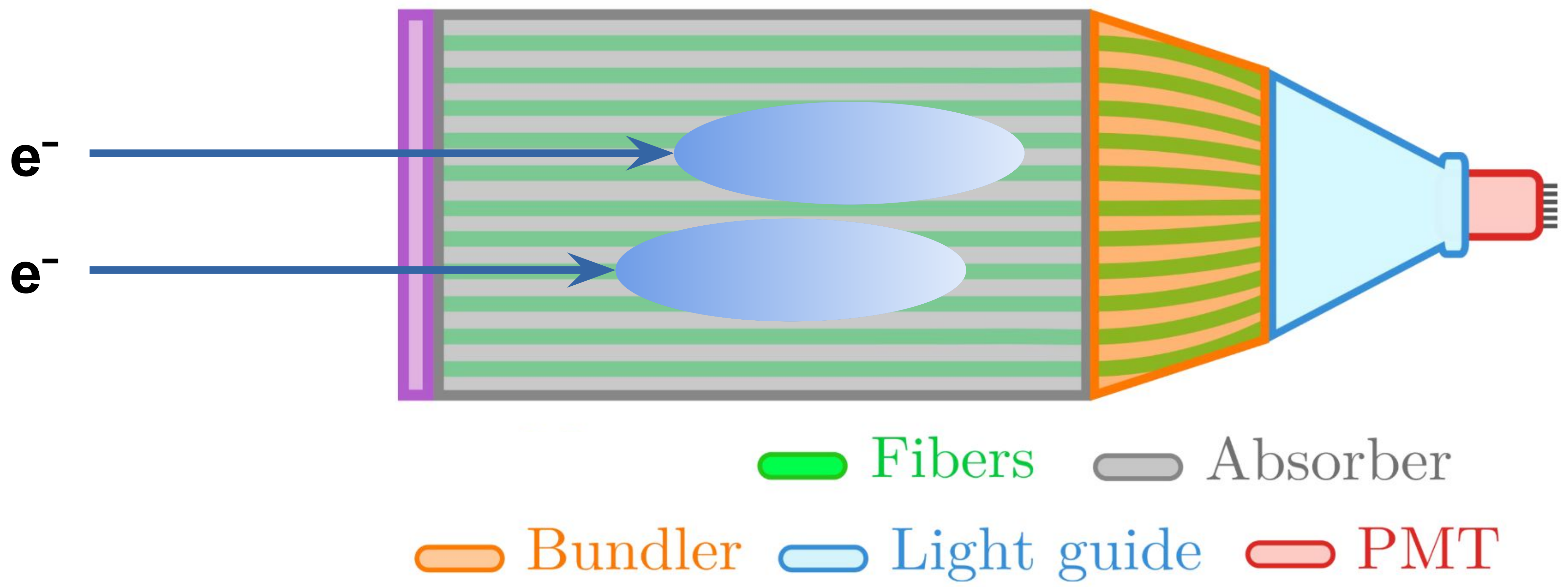
PRELIMINARY DESY TB + SPS TB



DEFINITION

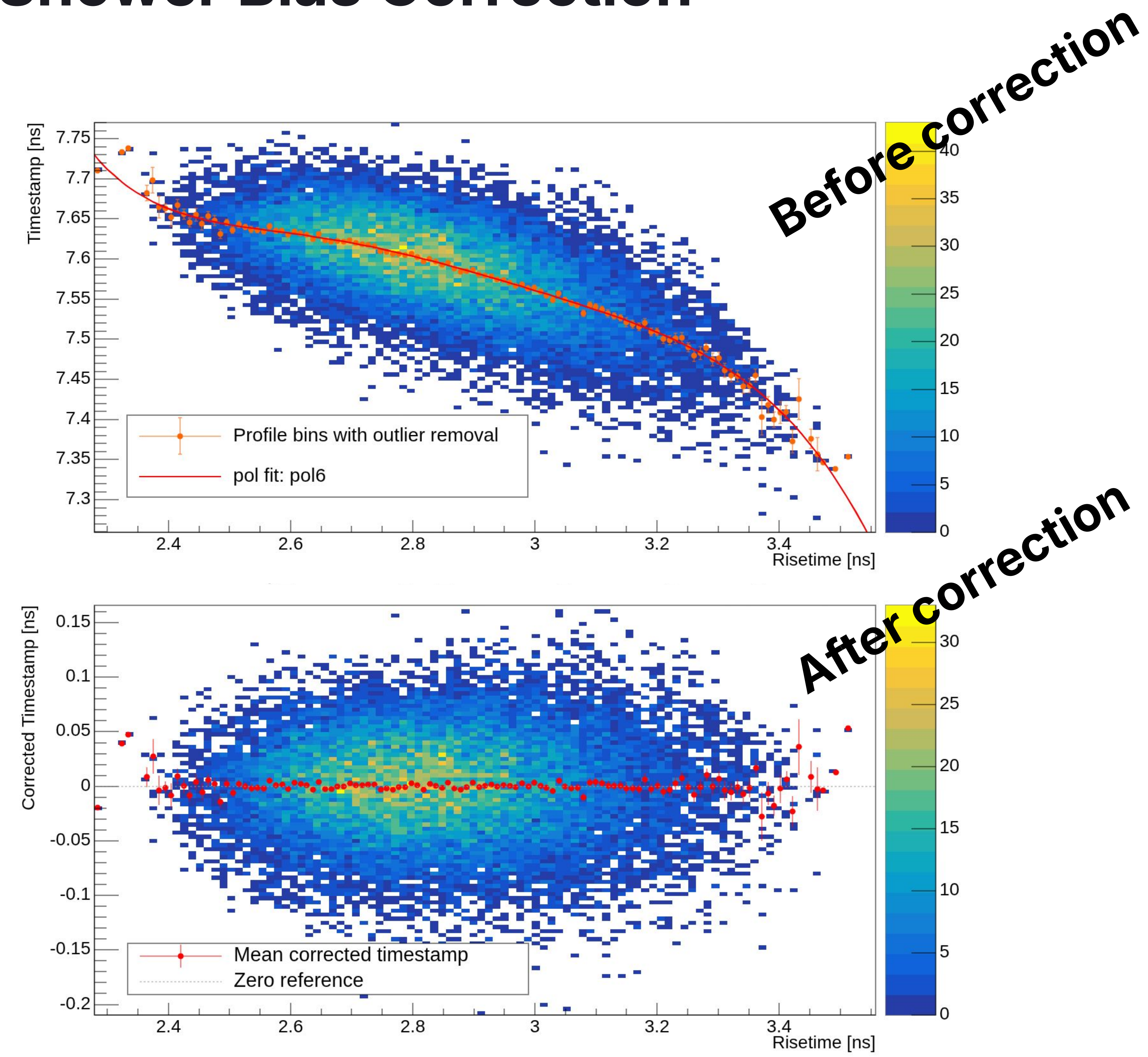
Shower Bias Correction

- Earlier start of shower in the SpaCal → longer distance to PMT → larger time diffusion.
- Pulse-shape is more spread out in time → causing a timestamp – risetime correlation.
- Risetime is taken as the difference between 10–90% of the pulse amplitude.



DEFINITION

Shower Bias Correction



To correct for the correlation, we shift the timestamp values to the model fit:

$$\mathbf{t_{i,corr} = t_i - \hat{t}_i}$$

Results - Time Resolution with Correction

After correction we **improve the constant term by up to 9 ps!**

Even with long cables, **we do not see a deterioration of time resolution!**

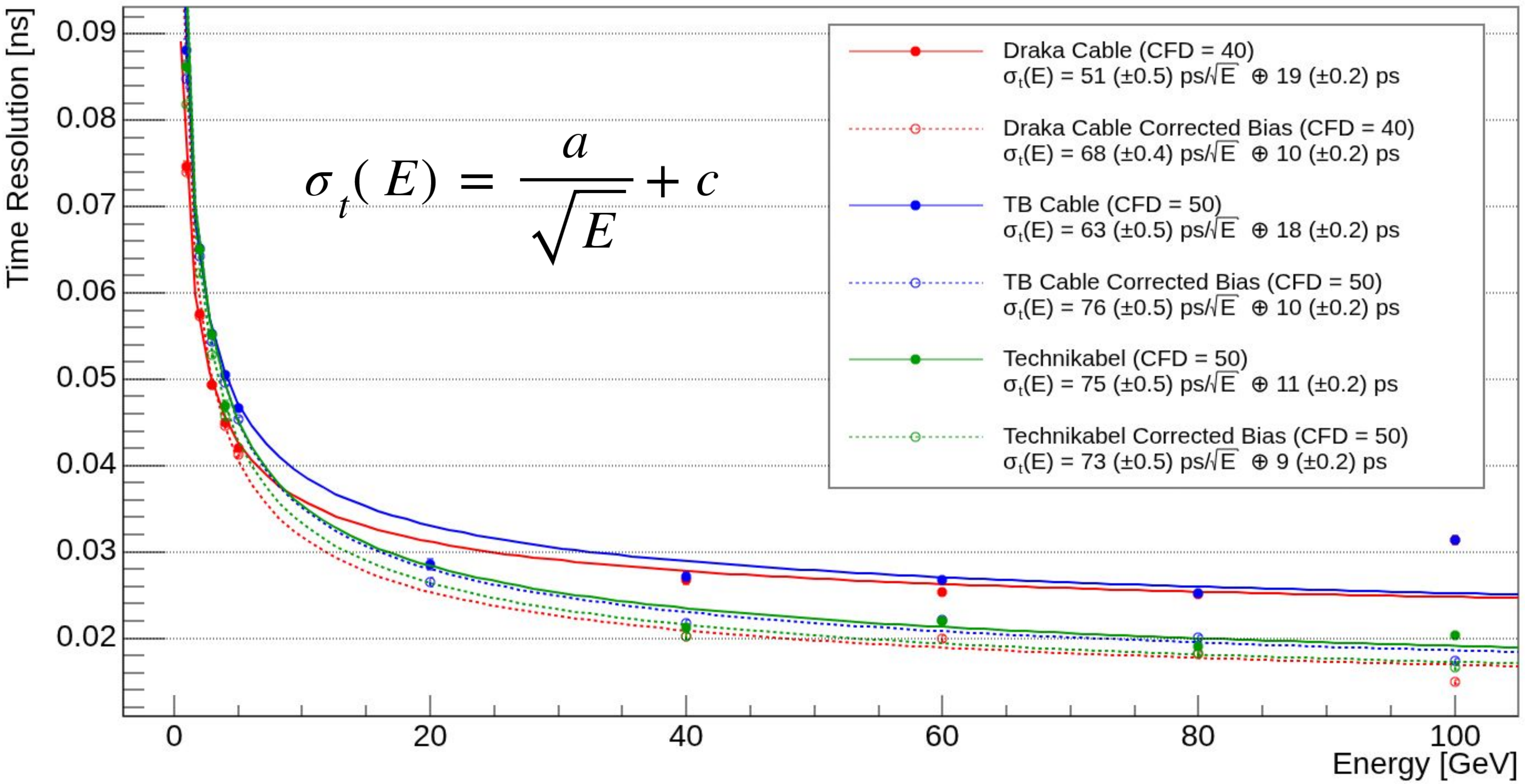
Reminder

TB cable 3.4 m ← **reference cable**

Draka cable 10 m

Technikabel 10 m

PRELIMINARY DESY TB + SPS TB



05

SPIDER

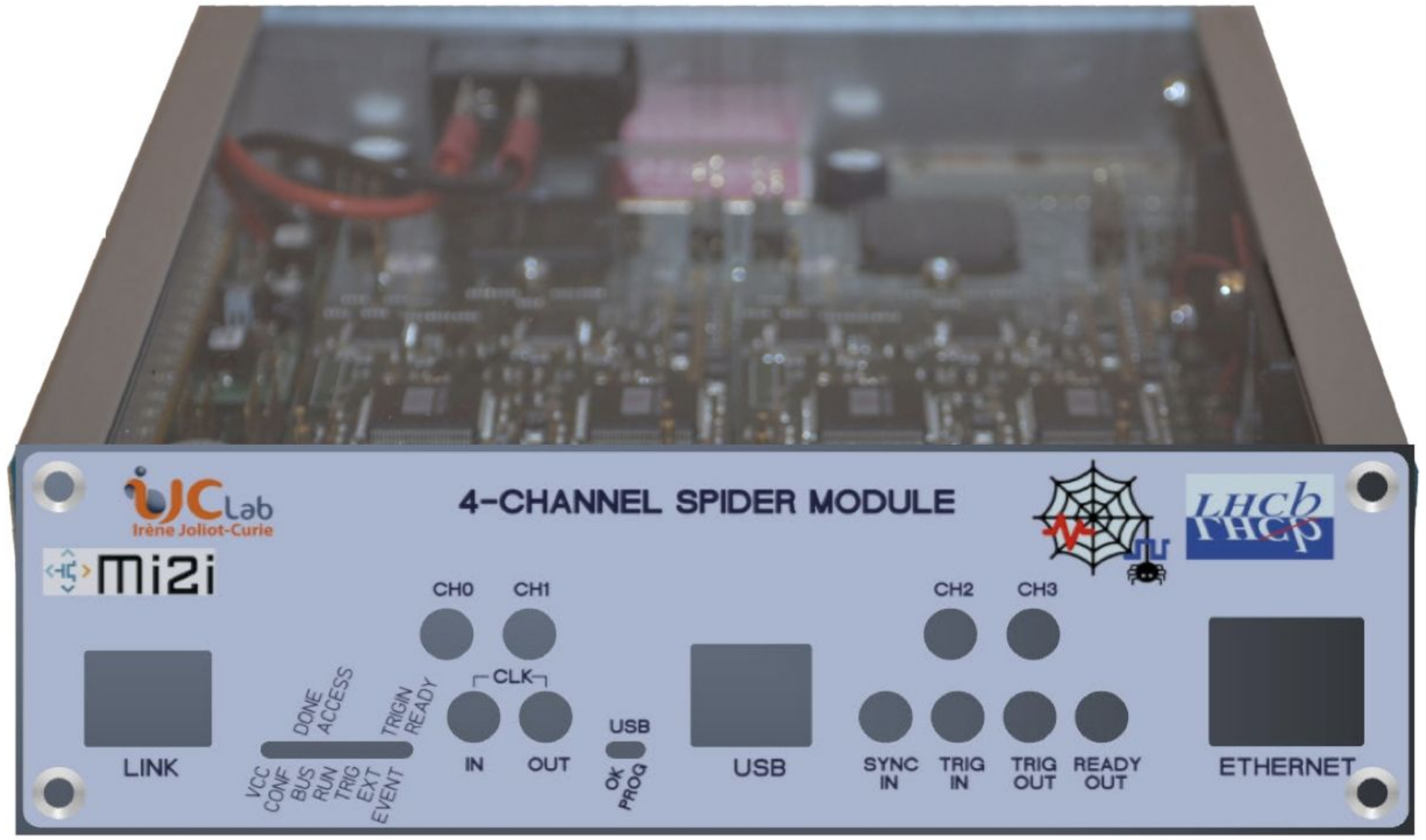
Characterization of the SPIDER in the full readout chain.

SPIDER

The SPIDER is a new digitizer prototype that samples at a fast rate. Developed at IJCLab in Orsay.

SPIDER 3.7 board, 4 channels, switched-capacitor sampler (DRS4/SAMPIC-family). Two FE-blocks, each serving 2 channels (ch0/ch1 → FE-block 0, ch2/ch3 → FE-block 1). Each channel has 8 banks, each bank = 32 physical storage cells

Tested for the first time in TB at SPS and DESY.



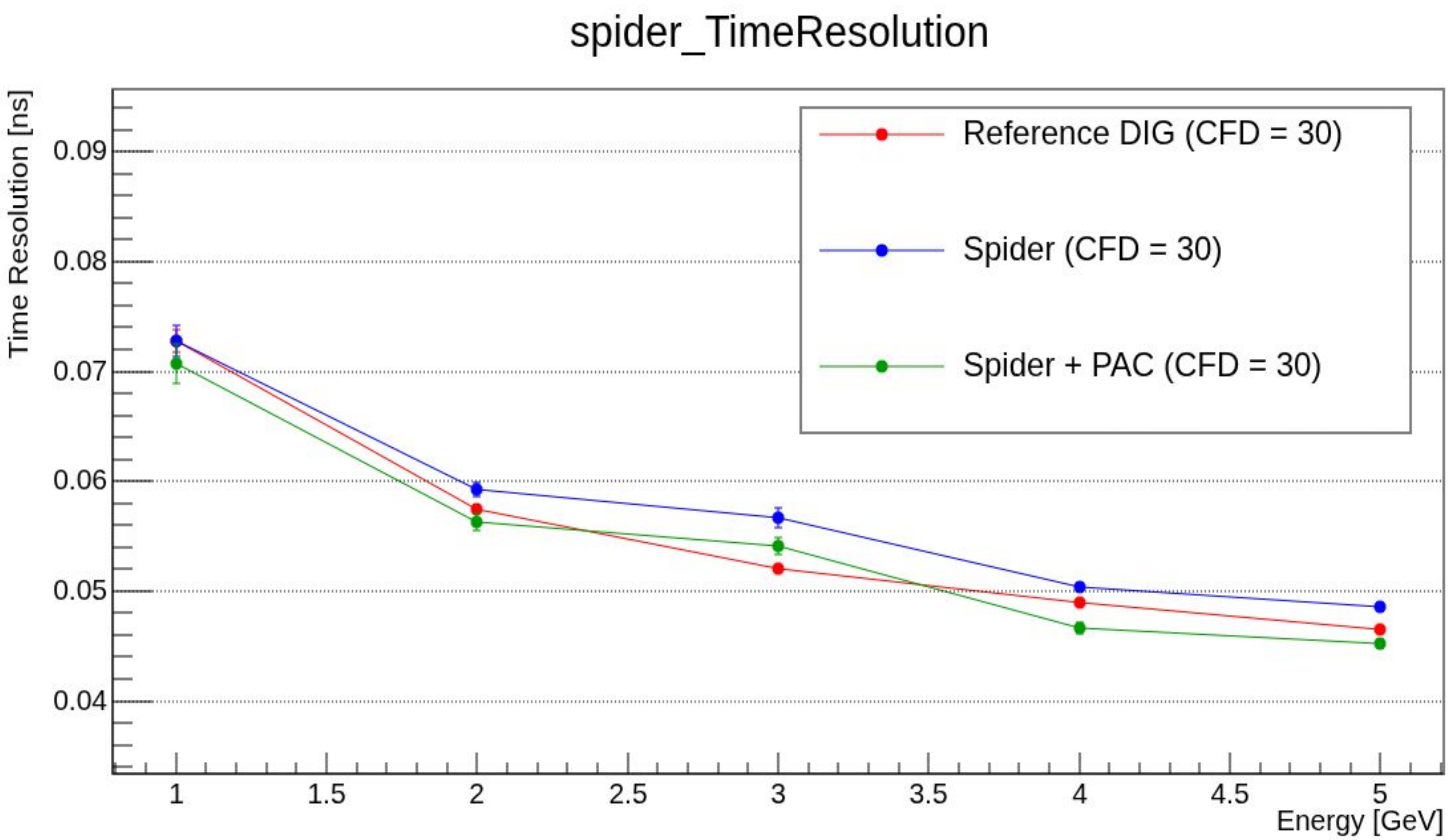
Results - Time Resolution

SPIDER + PAC, showing a **full evaluation of the readout chain for Run 5!**

Note! We are using **slow** scintillators!

Outlook: Add information from higher energies and draw a firm conclusion.

WORK IN PROGRESS DESY TB



Conclusion

All results preliminary

No bottlenecks!

Every individual readout component holds up to expectations, and the full chain performs strongly in the current state!

10 ps

shaved off with correction on the constant term!

Outlook

01 Study the SPIDER in the full energy range up to 100 GeV.

02 Continue the development of fast scintillating fibers for integration into Run 5 SpaCal modules.

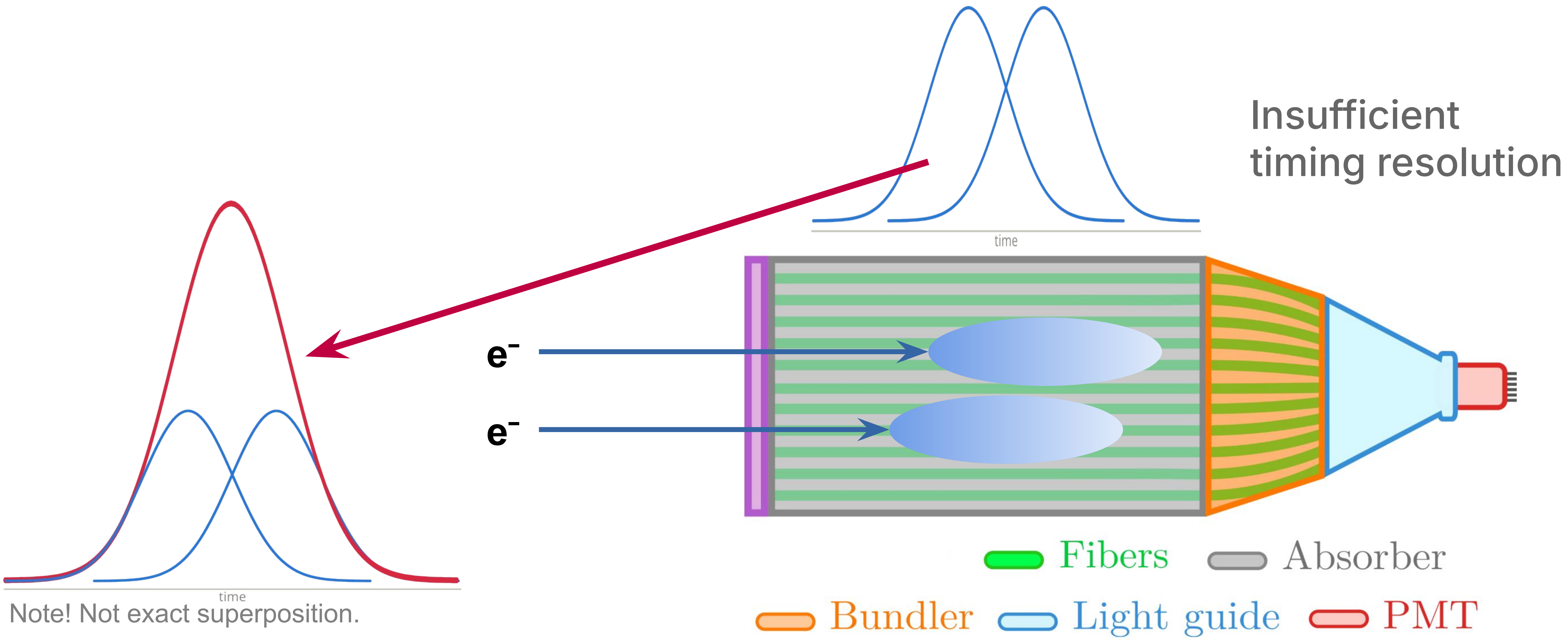
Thanks for listening!

06

Backup

ECal Requirements for Run 5

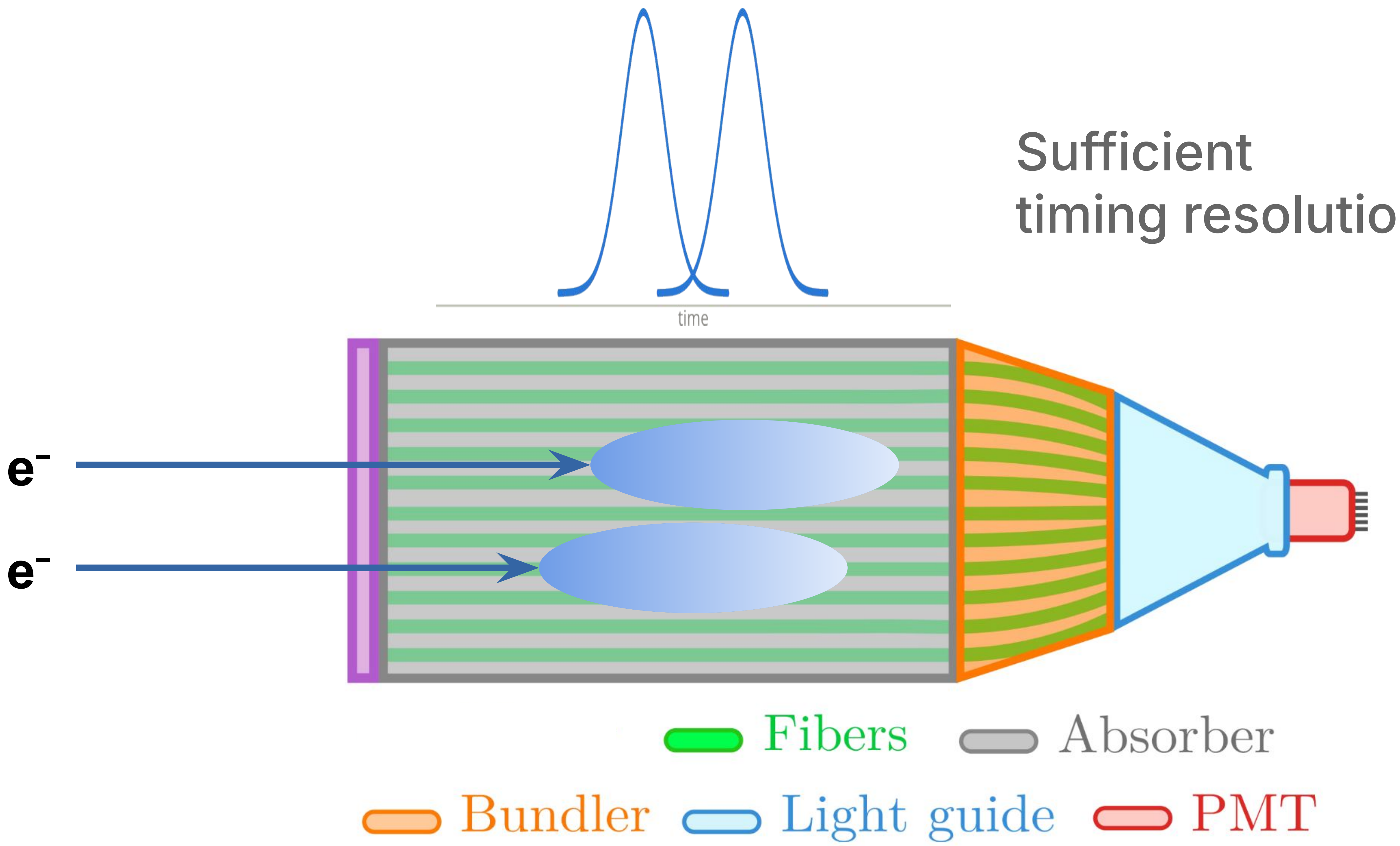
Increased pile-up makes it harder to discern between arriving particles → We need better timing resolution.



Note! Not exact superposition.

ECal Requirements for Run 5

Increased pile-up makes it harder to discern between arriving particles → We need better timing resolution.



Sufficient timing resolution

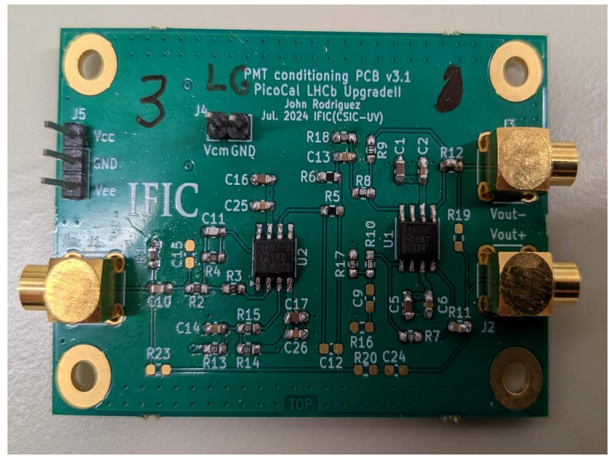
PACv3

PACv3 is a prototype that optimizes energy resolution.

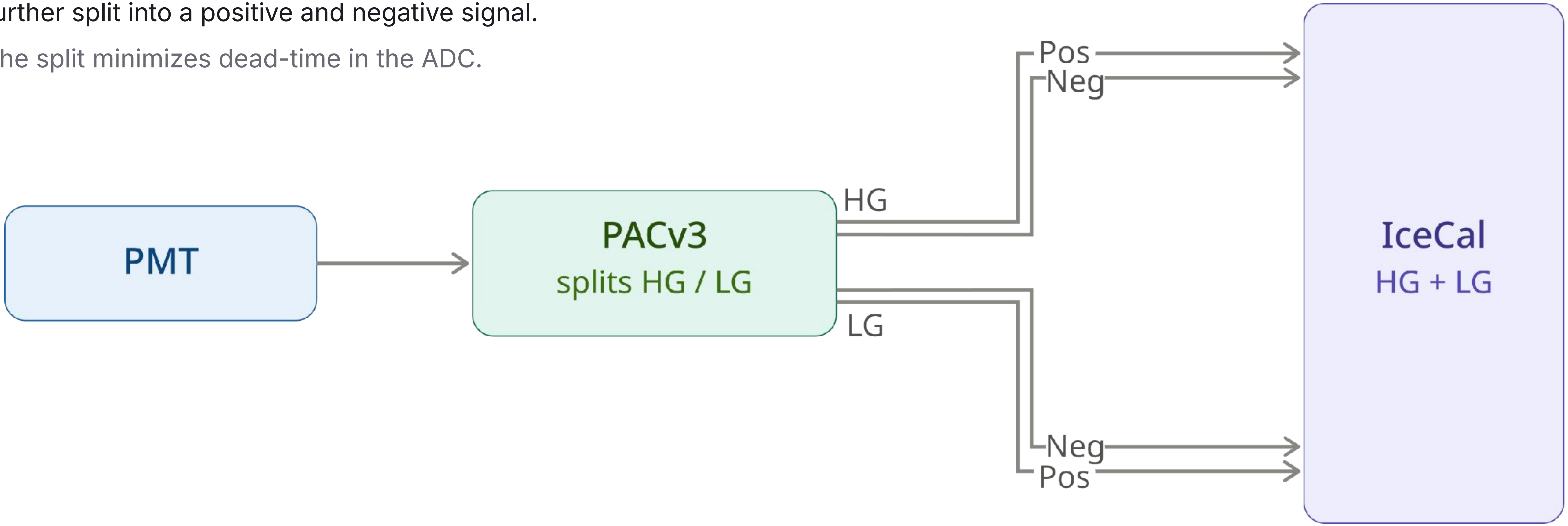
Two signals go to the front-end ADC: the IceCal.

The signals, split into High-Gain (HG) and Low-Gain (LG), are further split into a positive and negative signal.

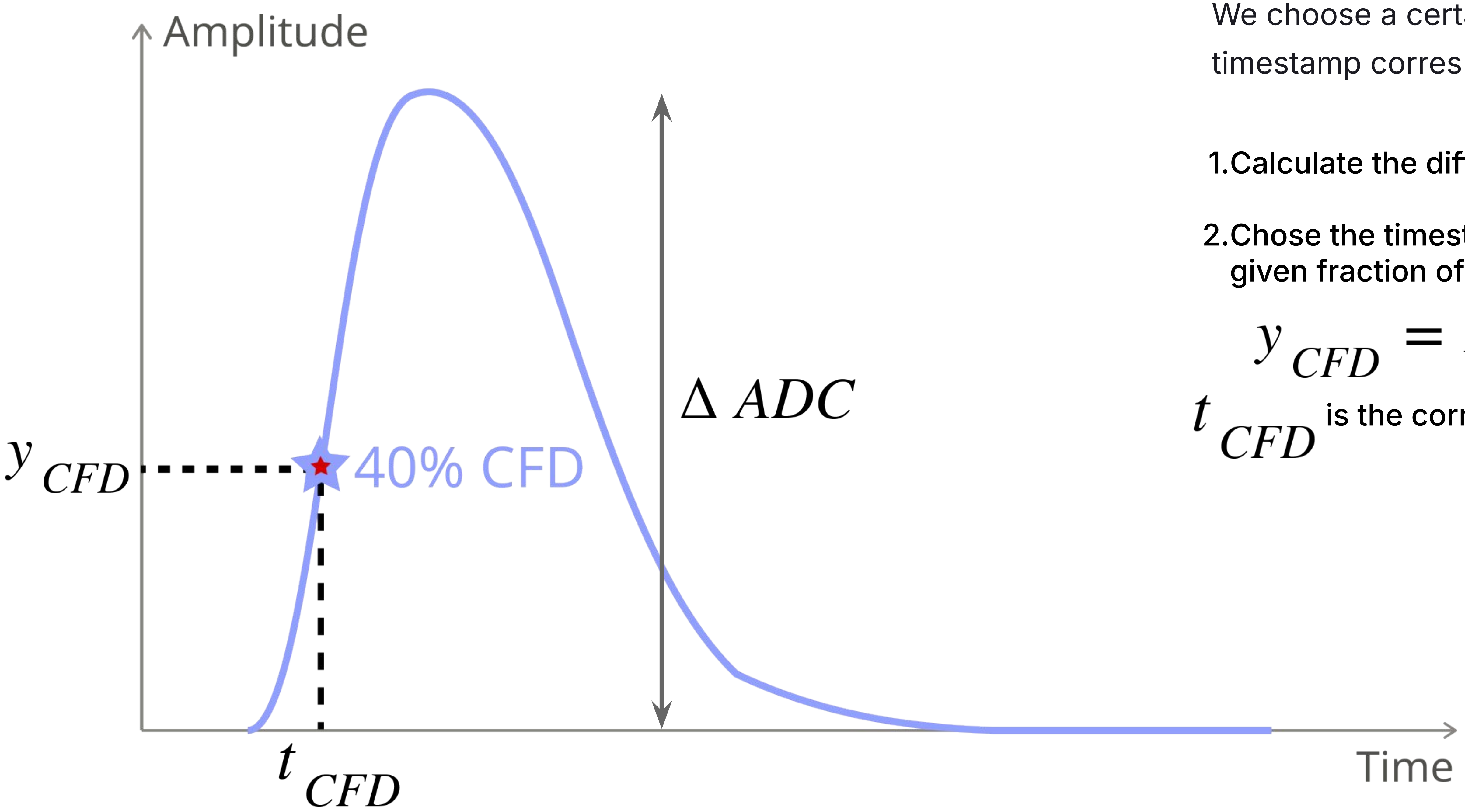
The split minimizes dead-time in the ADC.



Credit: Santiago Vico Gil & José Mazzora de Cos



How Do We Measure Time?



Signal pulses arrive in our detector. We select the “arrival”, or timestamp, of the pulse based on the **Constant Fraction Discriminator (CFD)** technique.

We choose a certain percentage of the pulse and take the timestamp corresponding to that point.

1. Calculate the difference between the peak and baseline.

2. Chose the timestamp as the time corresponding to a point at a given fraction of the difference.

$$y_{CFD} = Baseline + CFD \cdot \Delta\ ADC$$

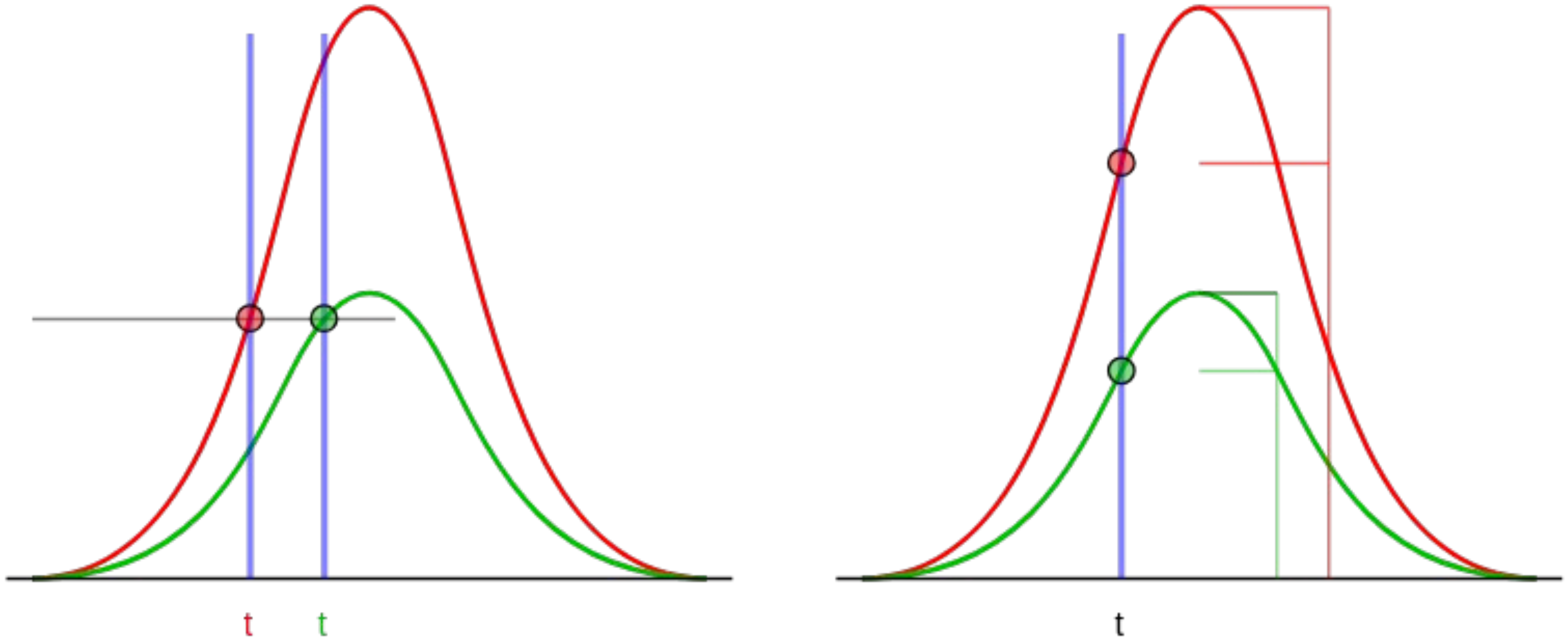
t_{CFD} is the corresponding value at y_{CFD}

Constant Threshold vs CFD

Two techniques for getting the timestamp: constant threshold discrimination and CFD. For the former, there's a resulting effect called time-walk:

- Based on the amplitude of your signal, the timestamp will vary. Correction has to be done later.

In CFD, the timestamp is independent of the pulse amplitude.



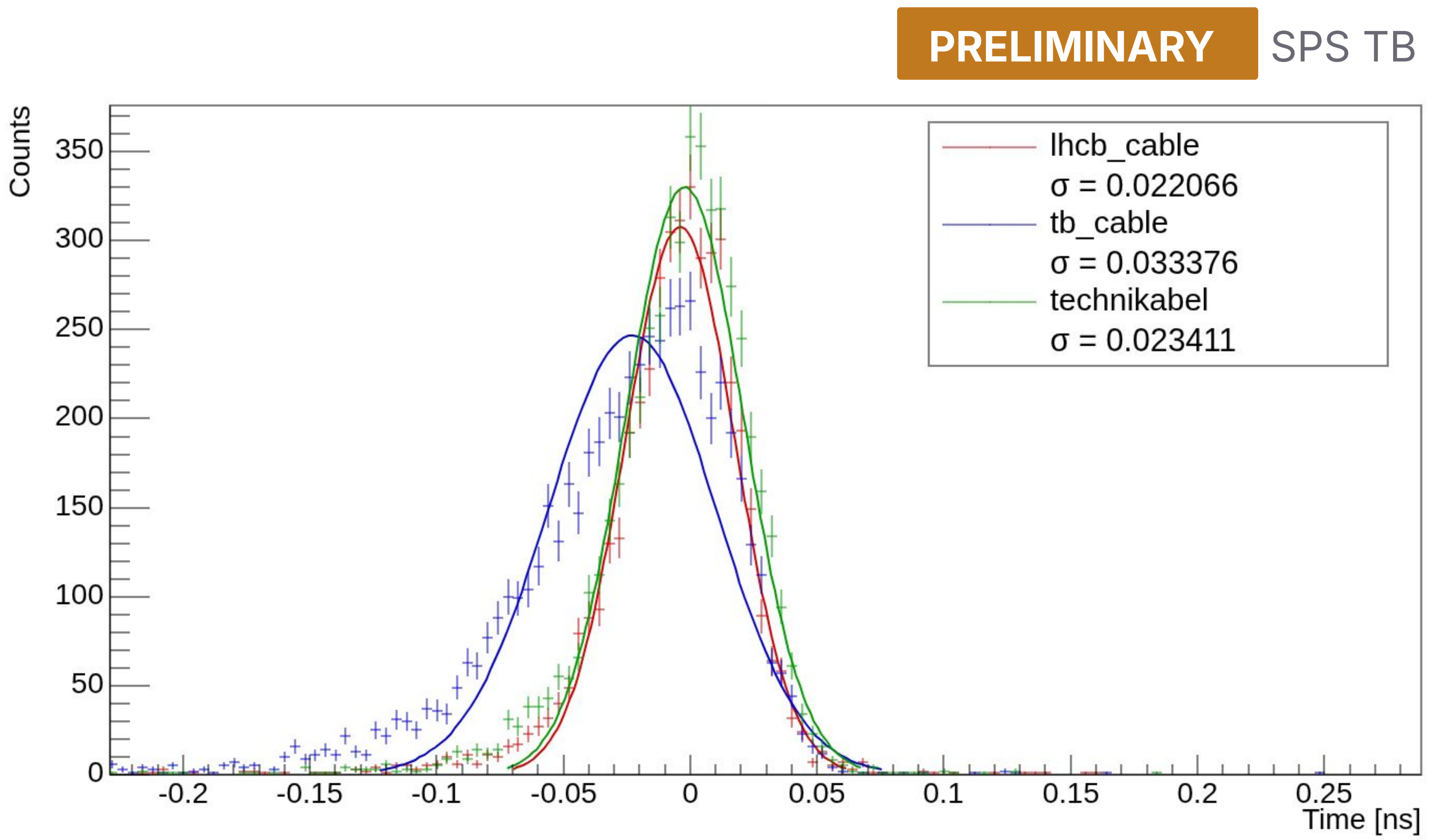
Constant threshold discrimination CFD

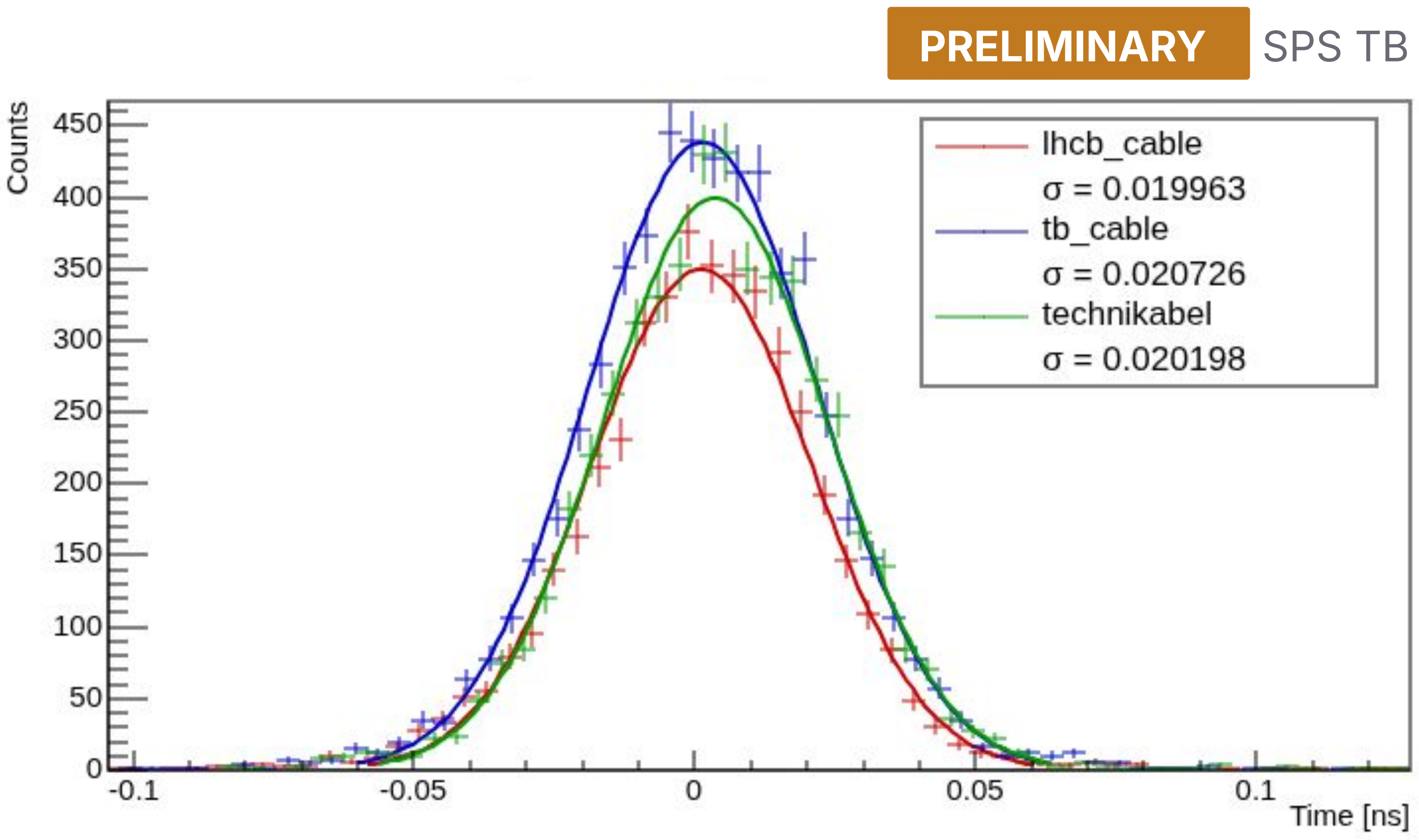
Dschwen (2006), "Constant fraction 1.svg," Wikimedia Commons. CC BY-SA 2.5.

Shower Bias Correction

We significantly reduce the leading tal with the correction → improved resolution

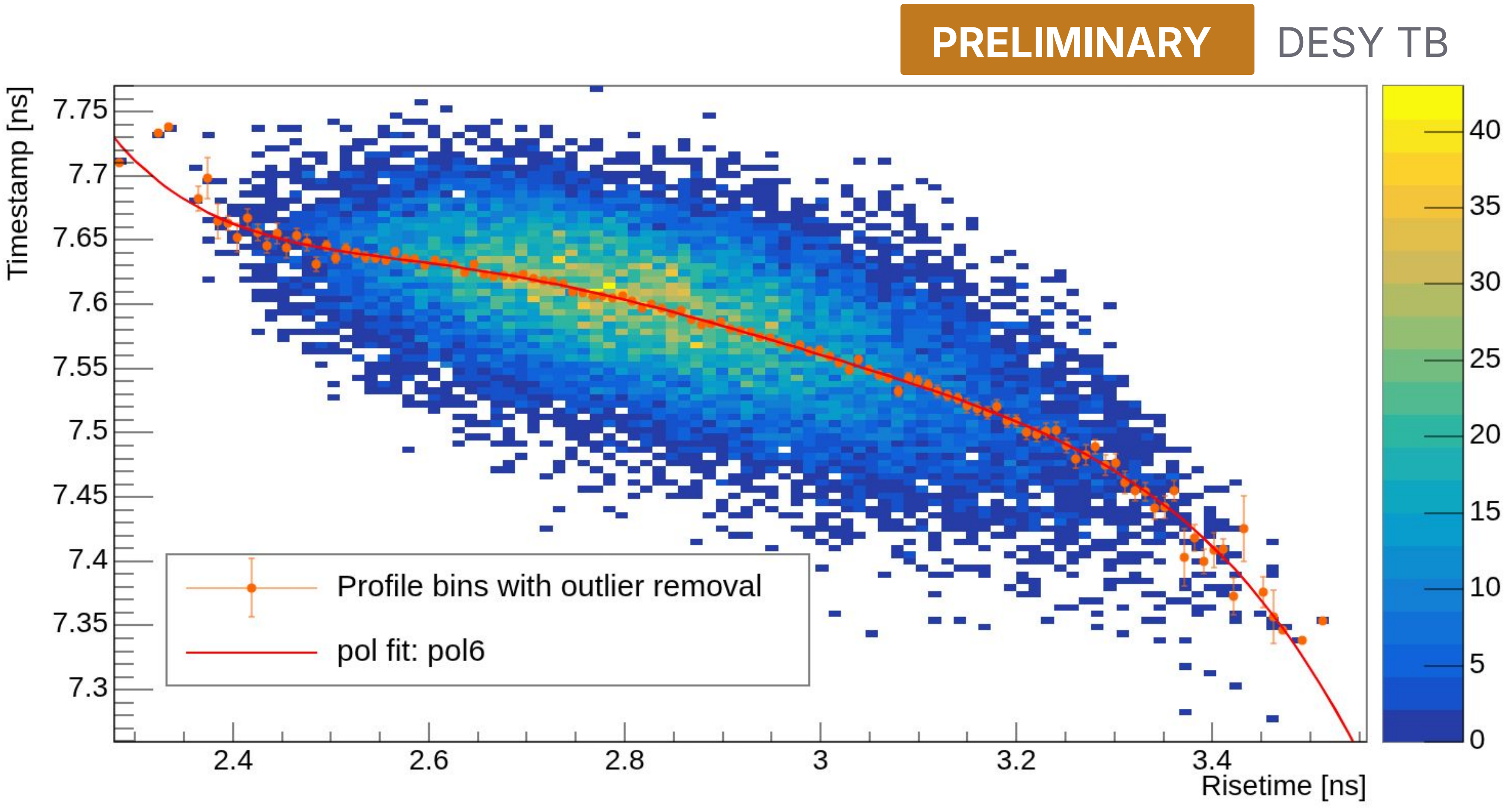
For the TB cable, we see the largest bias. The longer cables average out the bias.

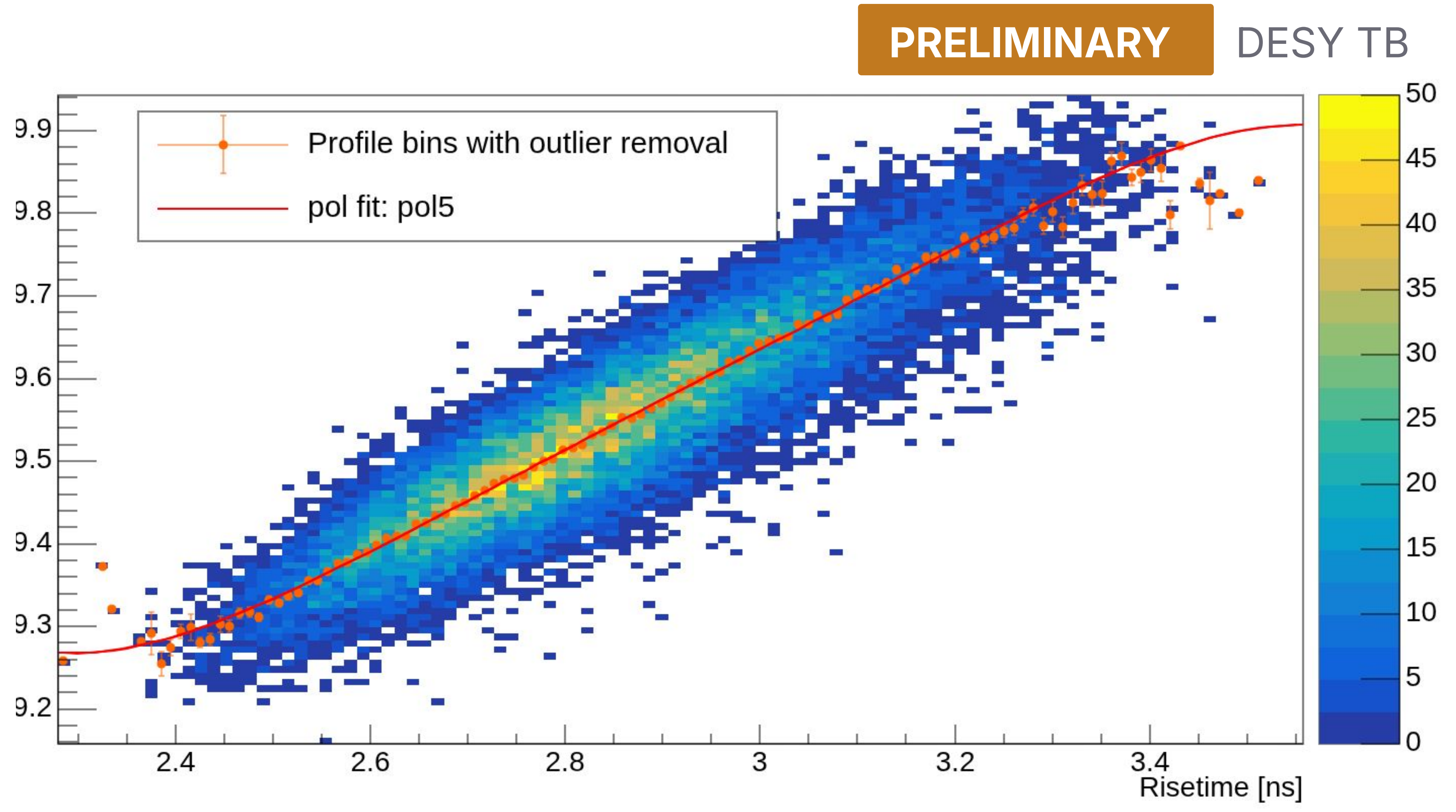




Shower Bias Correction

Correlation moves from negative to positive with increasing CFD.





What is the optimal CFD?

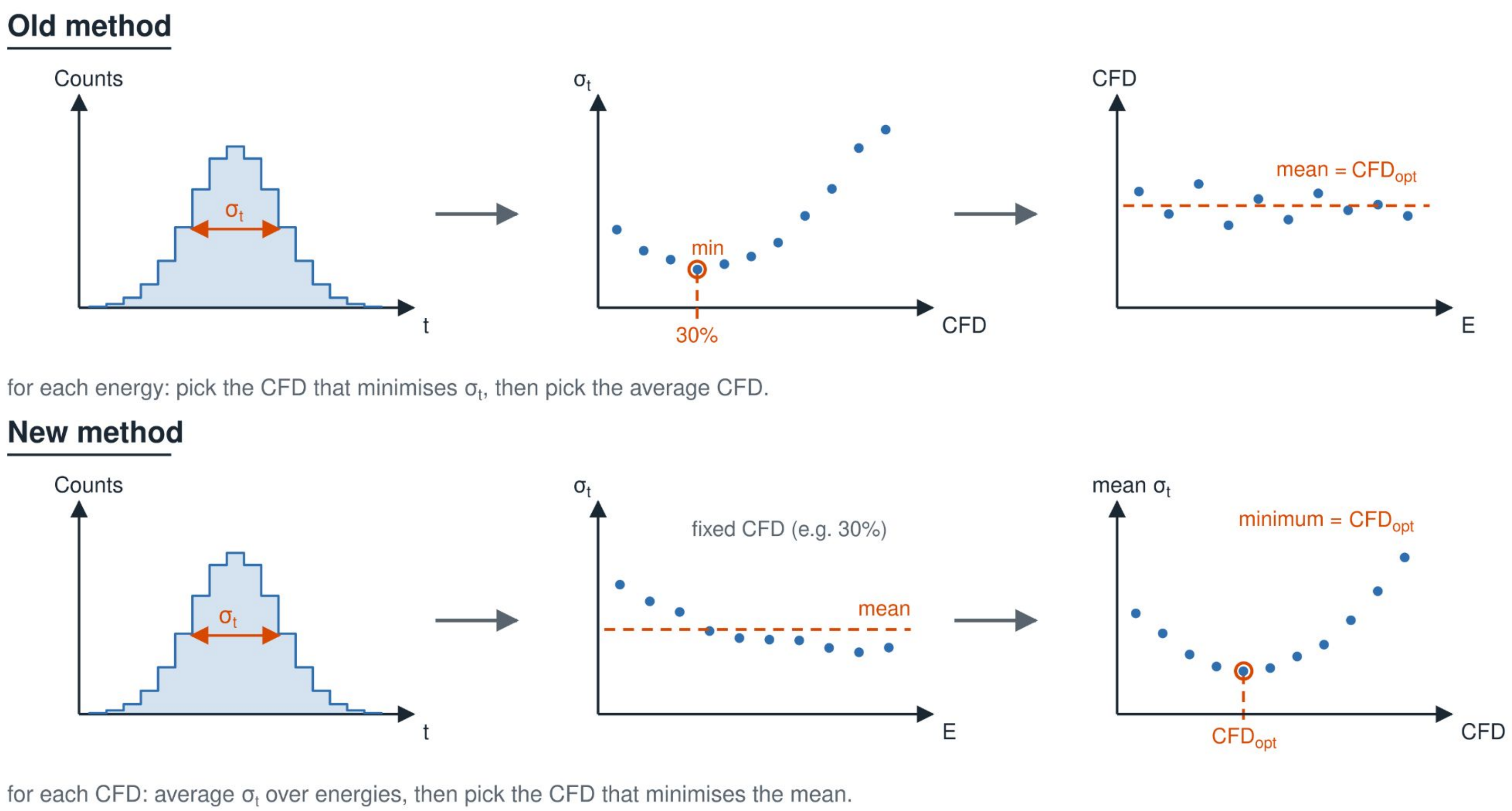
The optimal CFD minimizes the photostatistic (a) and constant (c) terms in the time resolution fit?

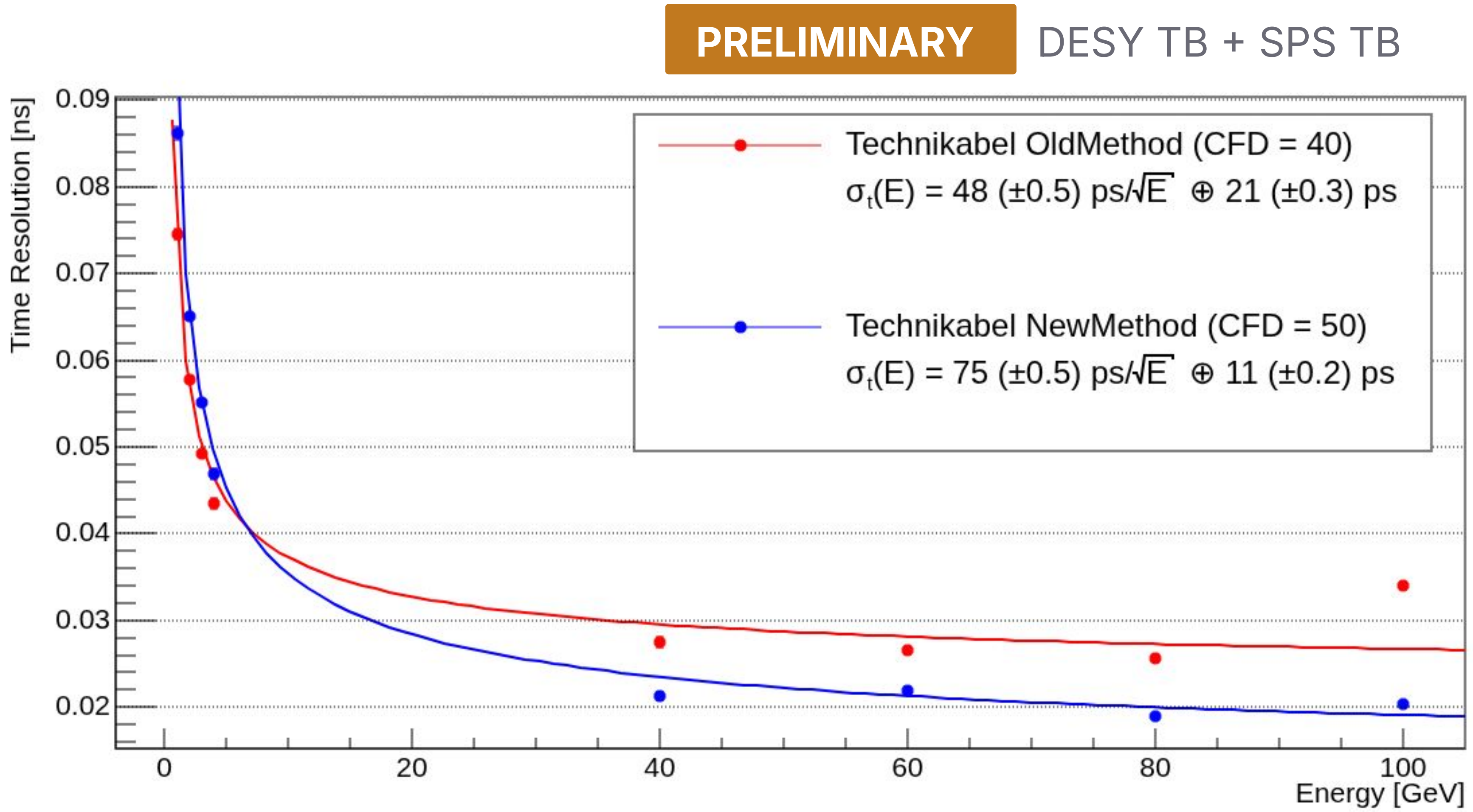
Tested a new method (blue), compared to an old method (red), that improves on the constant term but degrades the photostatistic term. Which one is optimal?

Interesting **ongoing study** for getting the best time resolution.

Time resolution formula

$$\sigma_t(E) = \frac{a}{\sqrt{E}} + c$$





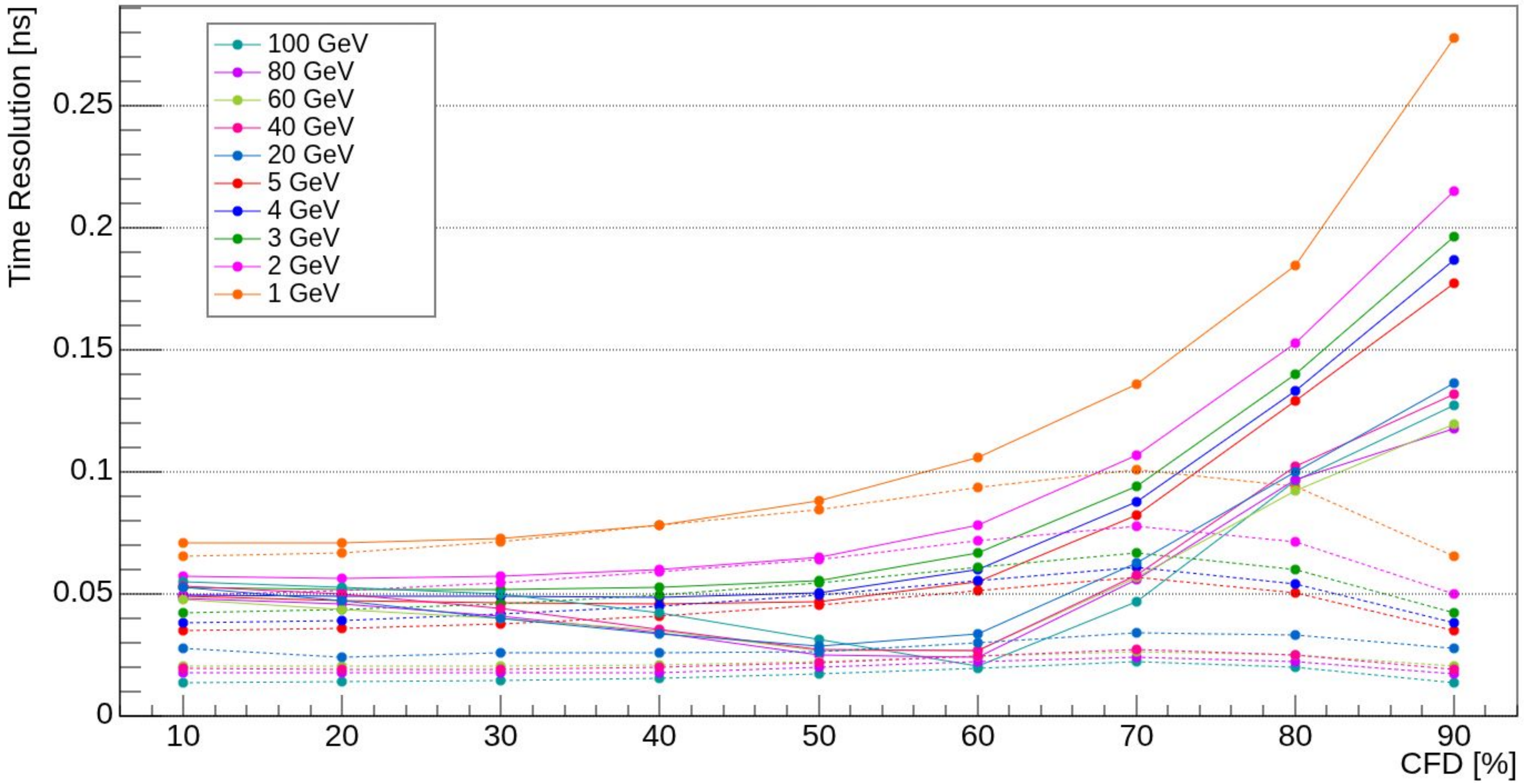
Results - Invariant CFD

Time resolution is (almost) invariant of the CFD after correction — and we get the **best time resolution for any CFD!**

In short, **we considerably reduce the CFD dependence**.

Outlook: Compare efficiency of correction algorithm with an optimal CFD algorithm.

PRELIMINARY DESY TB + SPS TB

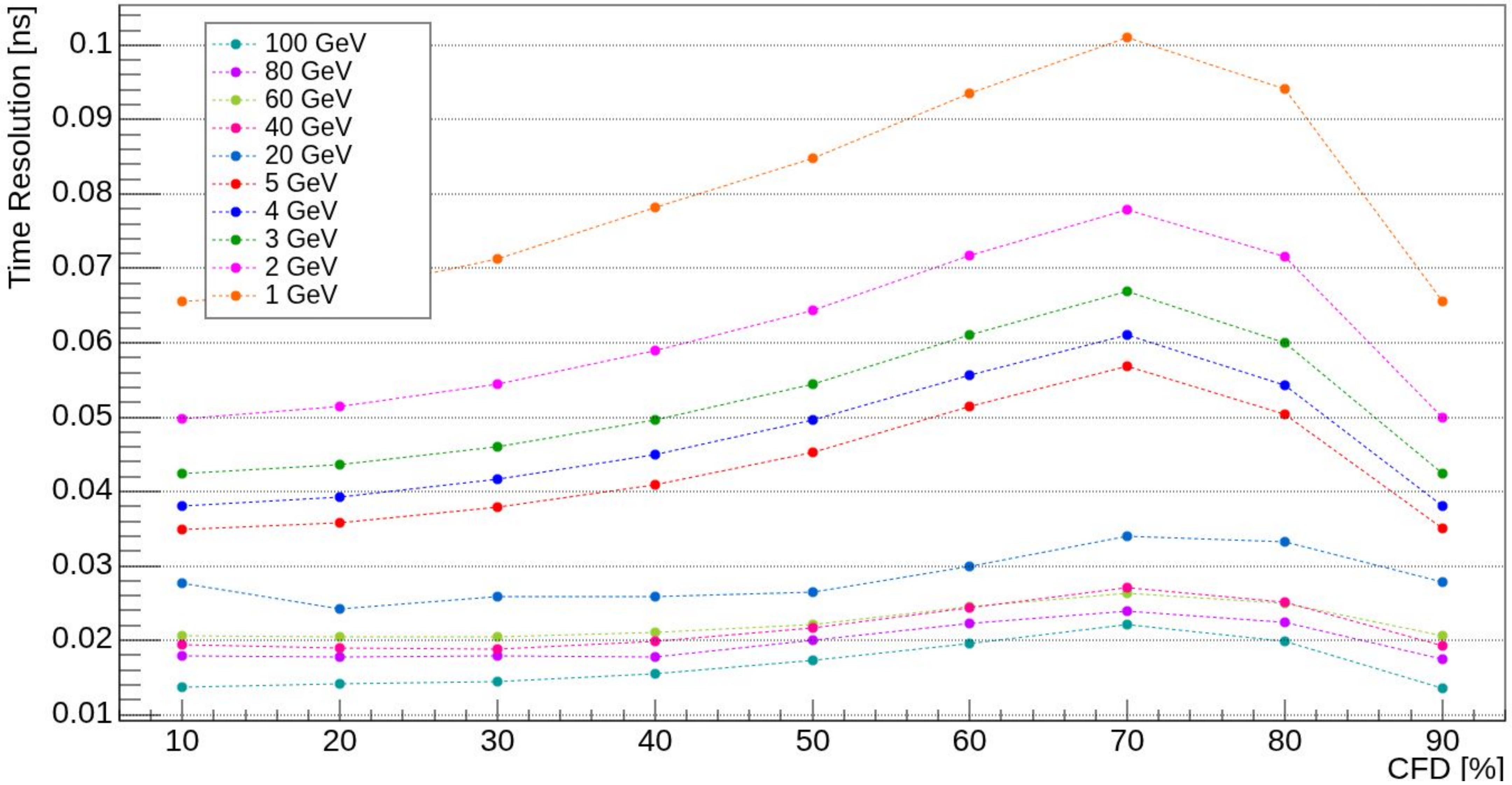


Results - Invariant CFD

Time resolution vs CFD **should be flat.** Some unknown effect is causing a bump at 70% CFD.

Outlook: Study the behaviour of this bump, e.g. with a continuous scan of the full CFD range.

PRELIMINARY DESY TB + SPS TB



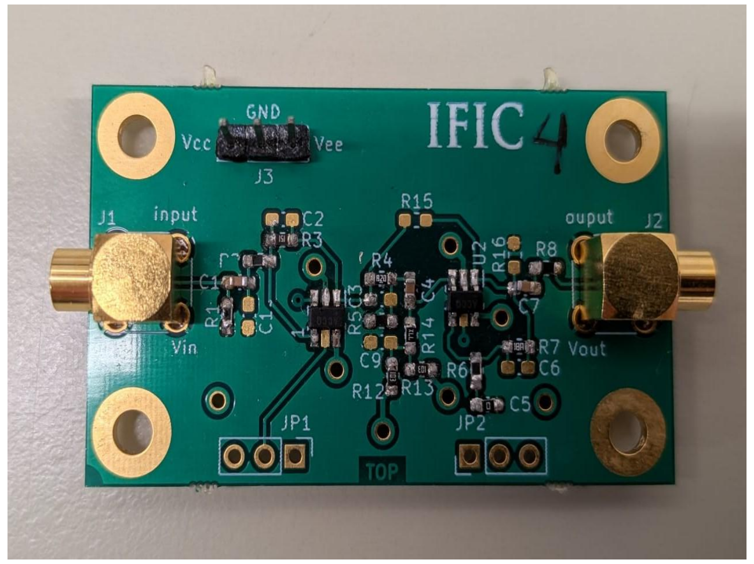
PAC

Developed at IFIC in Valencia.

A signal shaper with amplification that splits the signal into three paths: one for timing and two for energy.

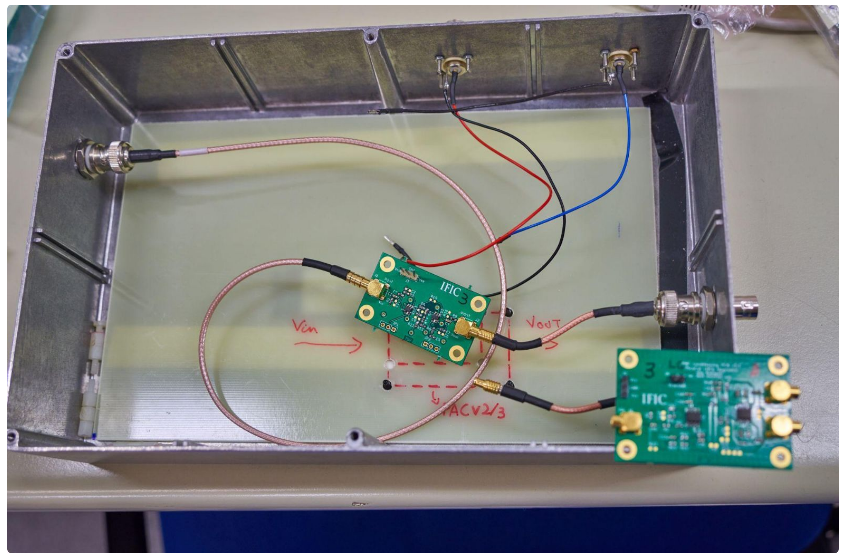
- **PACv1** is the prototype for timing.
- **PACv3** is the prototype for energy.

Credit: Santiago Vico Gil & José Mazzora de Cos

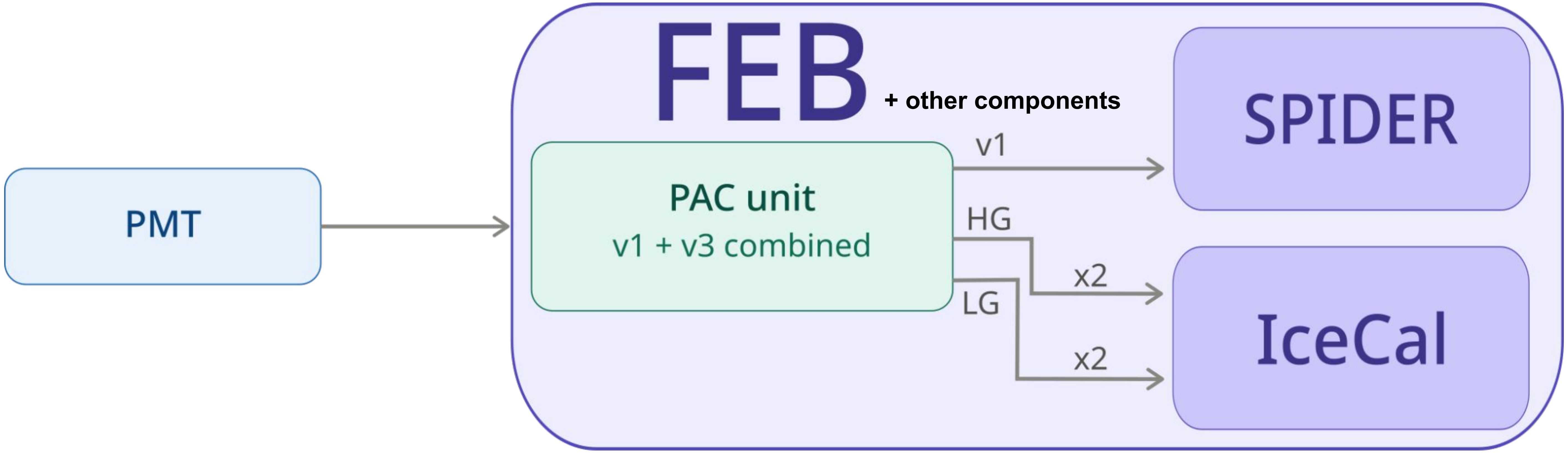


PACv1

Credit: Manuel Franco Sevilla



PAC setup at TB

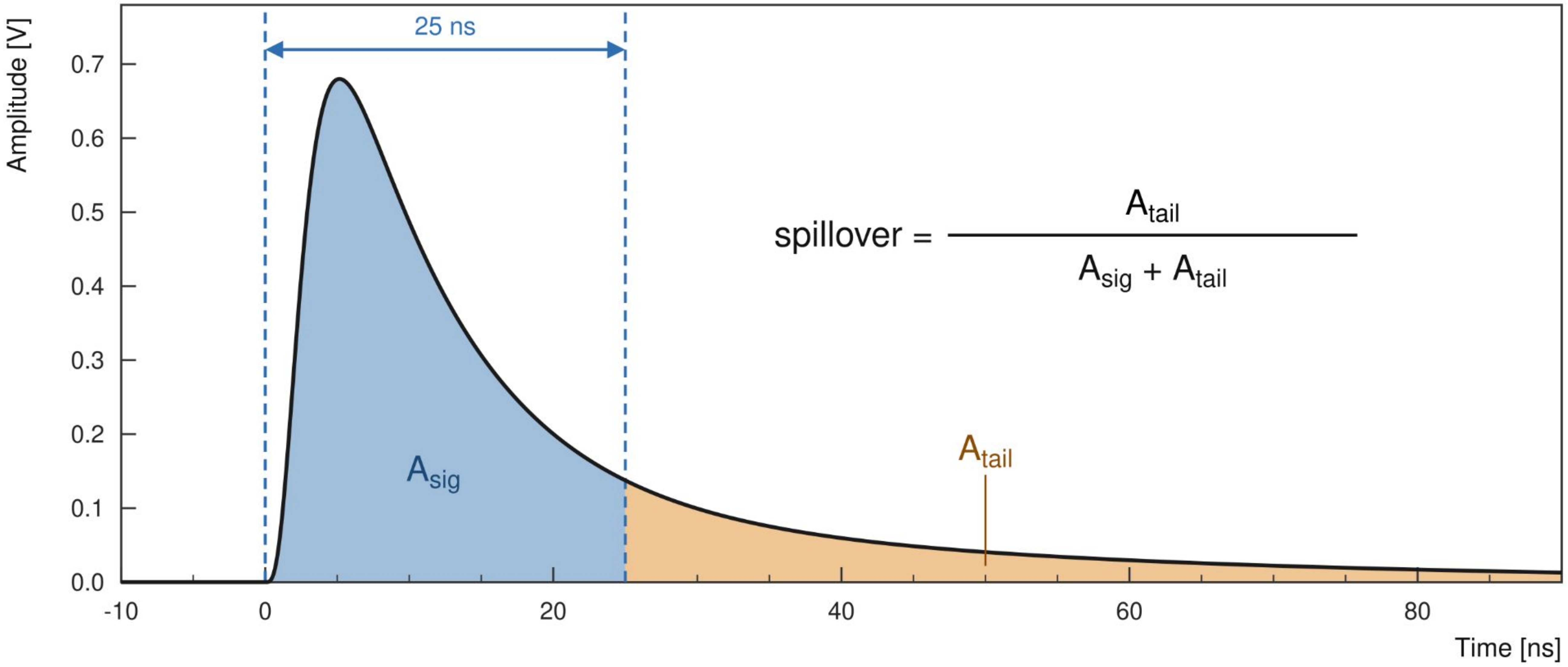


SpaCal Module → PMT → Cable → **Amp / Shaper** → Time ASIC

DEFINITION

Spillover

- The fraction of the signal outside of the 25 ns signal window.



Results - PAC Waveforms and Risetimes

PACv1 and PACv3 retains the pulse shape in the signal window (25 ns).

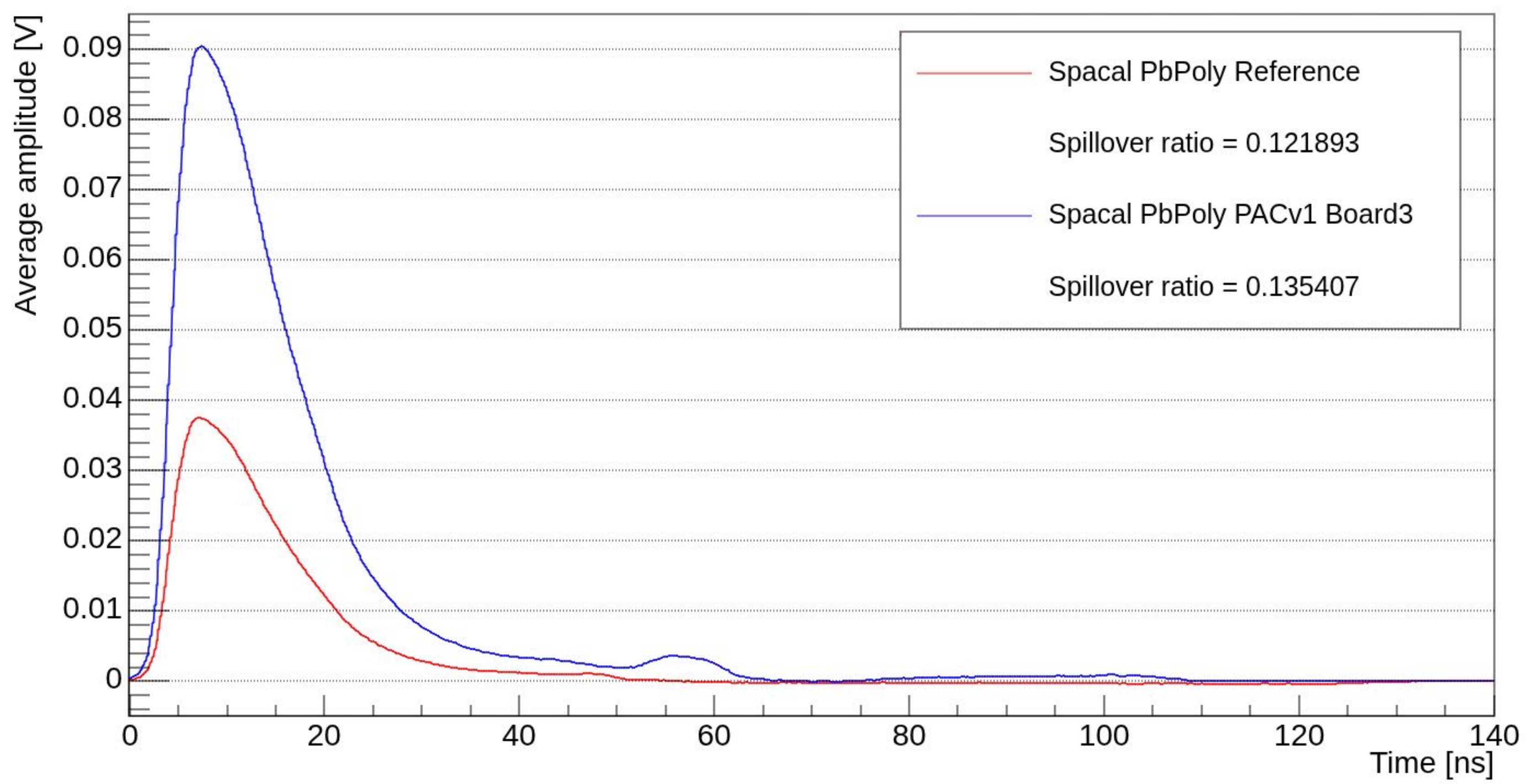
Spillover generally differs from the reference **by < 1%**.

Gain factors are as expected.

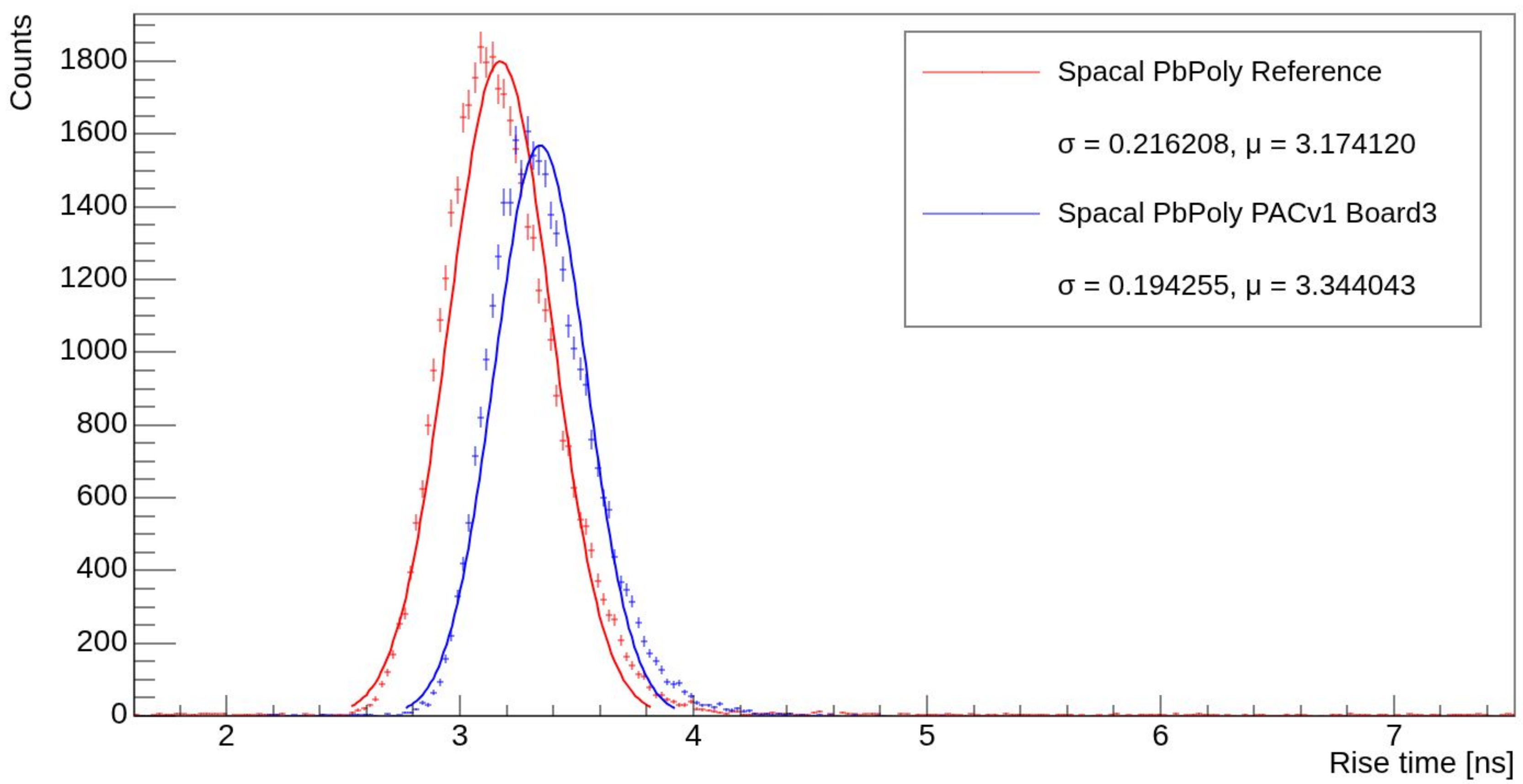
Risetimes generally differ from reference.

Ongoing study by the team in Valencia.

PRELIMINARY DESY TB



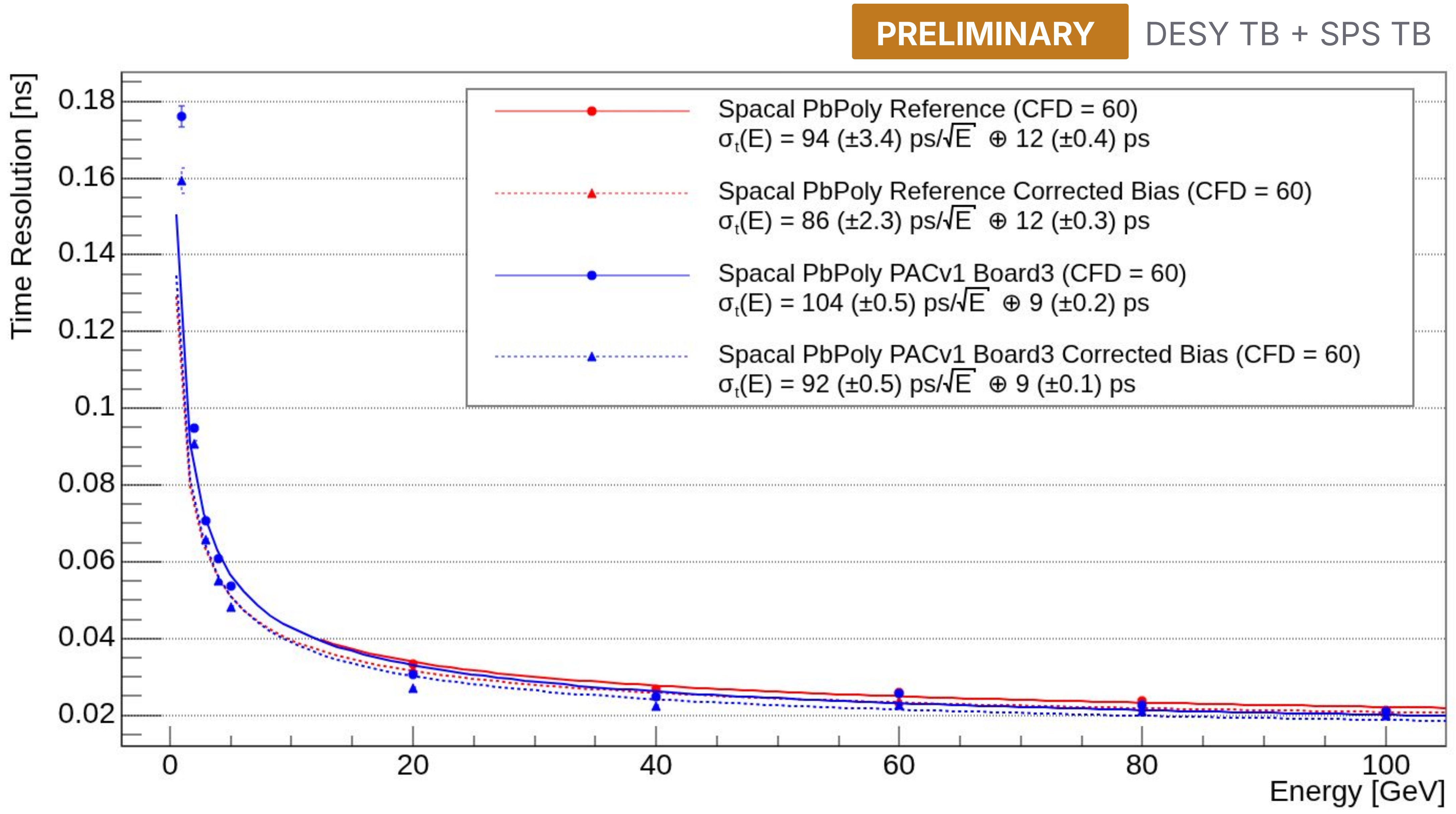
PRELIMINARY DESY TB



Results - PACv1 Time Resolution

Very encouraging time resolution results.

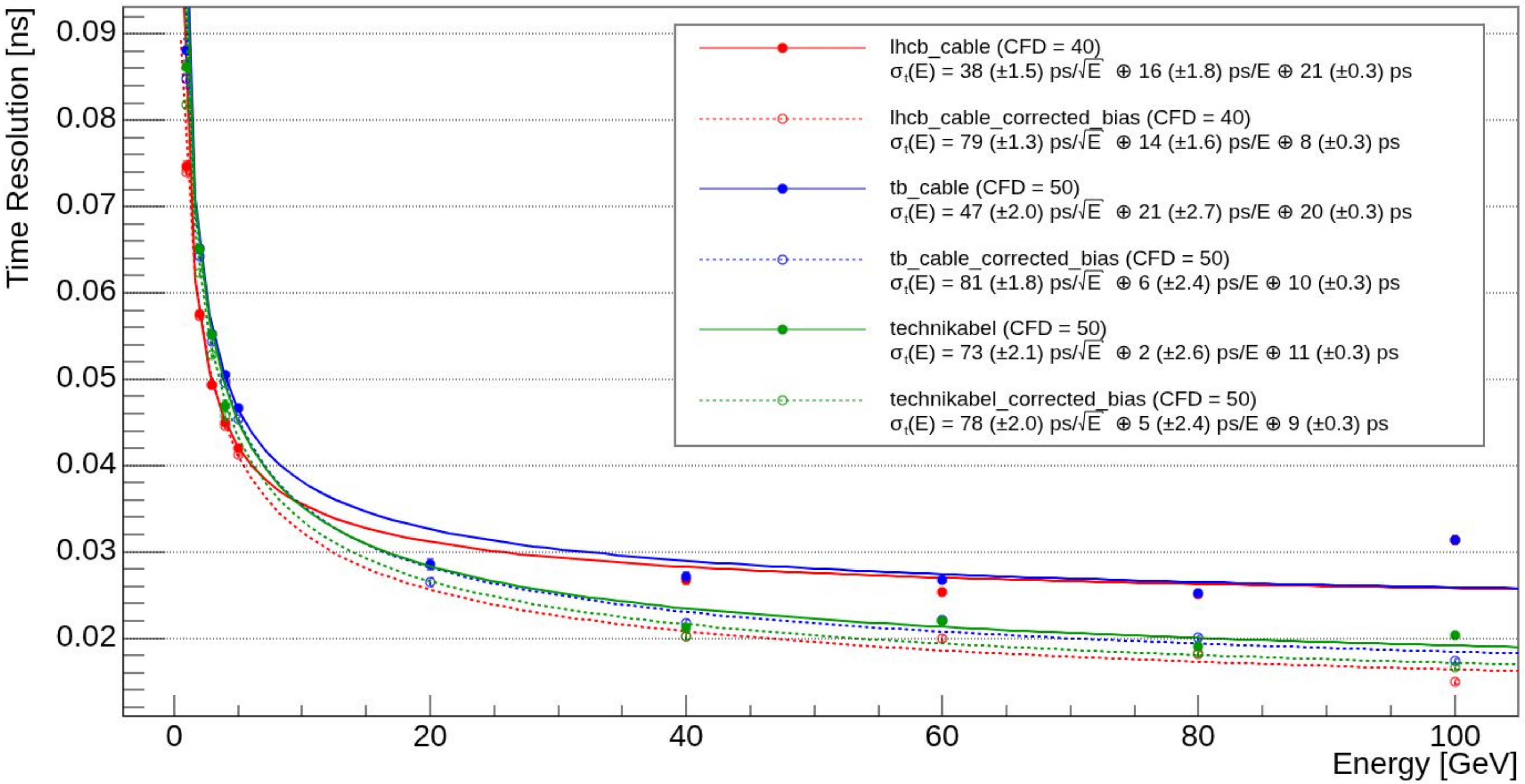
PACv1 **matches the reference** in time resolution!



Results - Time Resolution With Correction and Noise Term

The added noise term does not have a huge impact on the other terms.

PRELIMINARY DESY TB + SPS TB



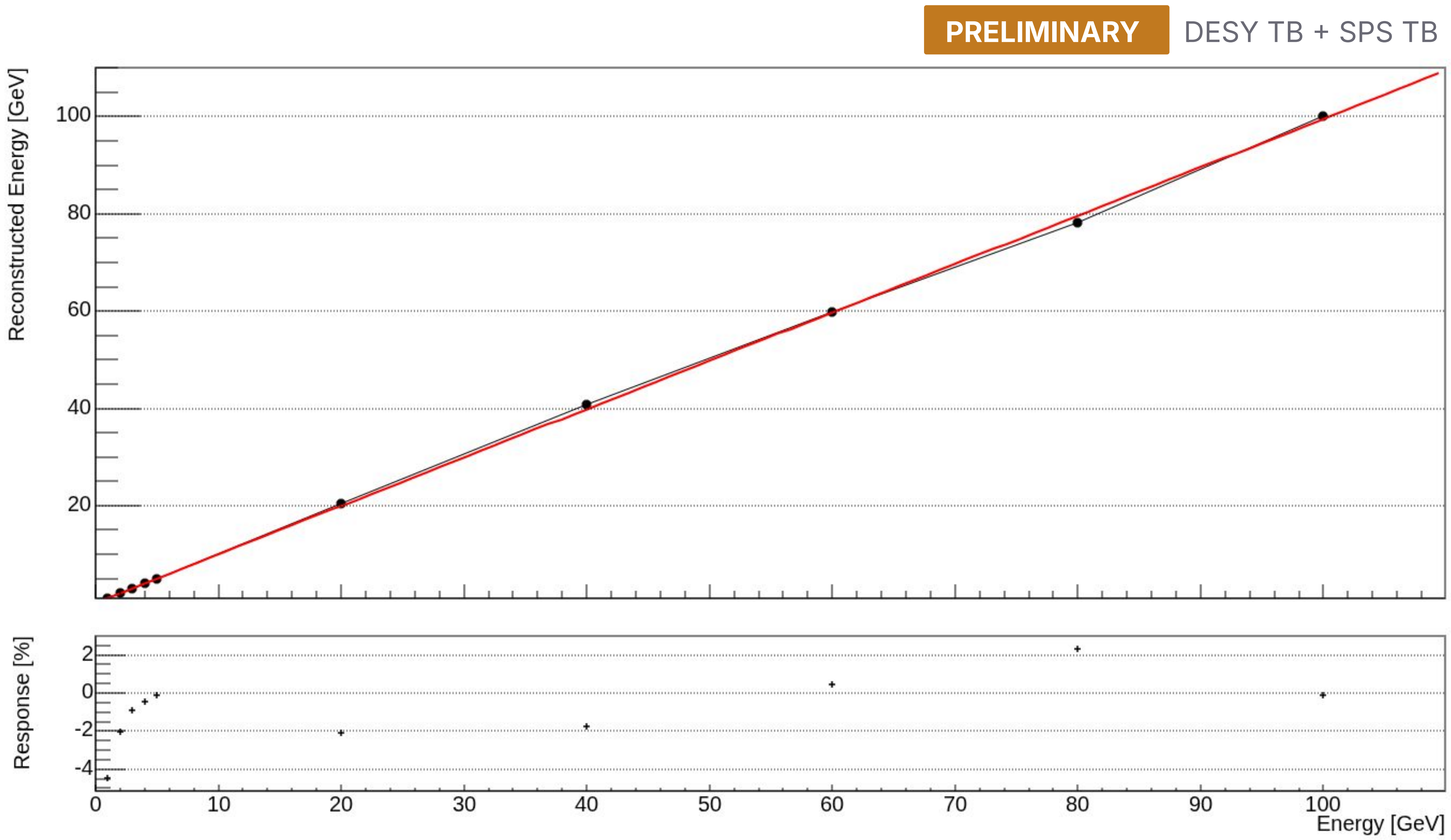
Reminder

TB cable 3.4 m ← **reference cable**

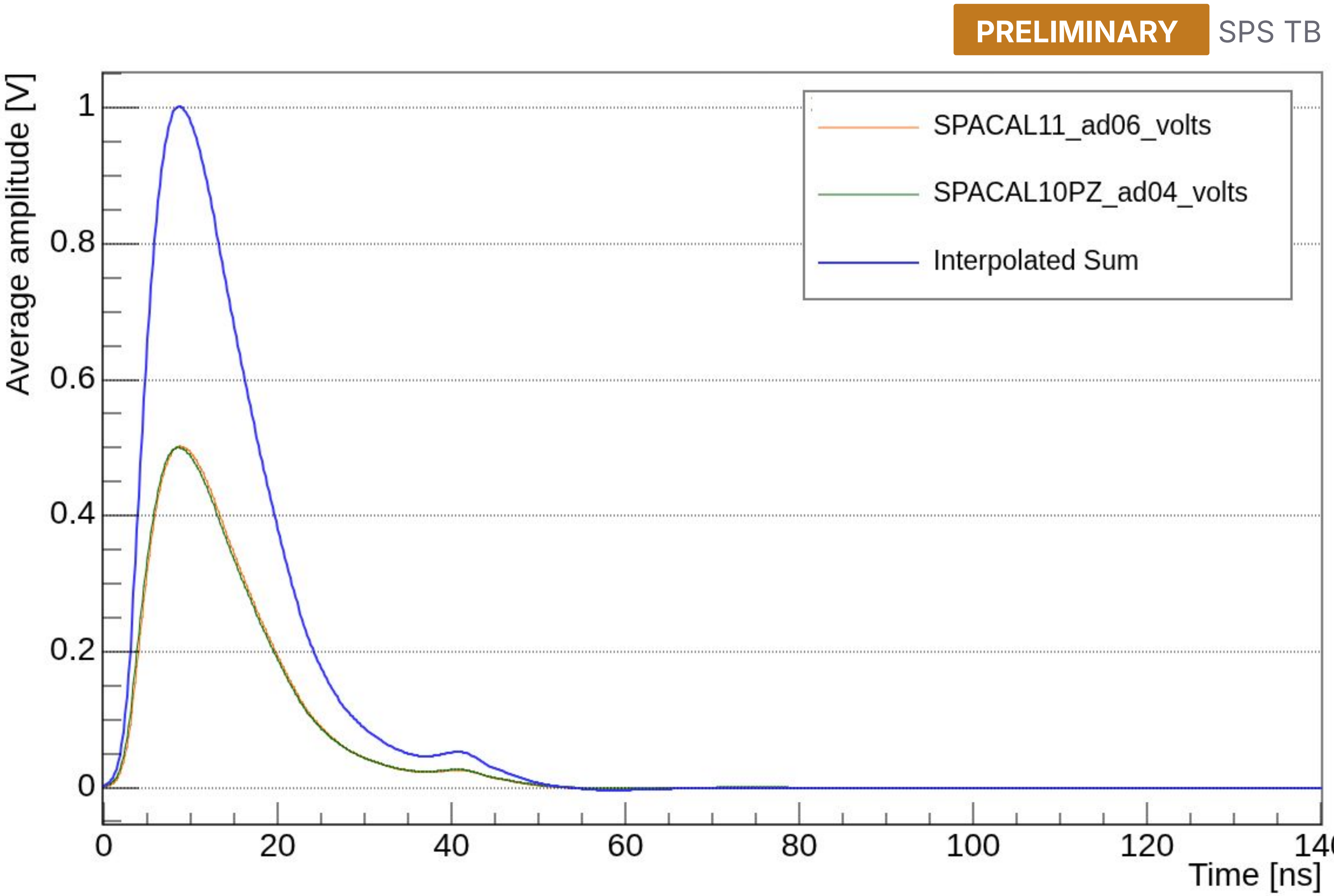
Draka cable 10 m

Technikabel 10 m

Results - PACv3 Linearity



Results - PACv3 Interpolated Sum



Results - PACv3 Amplitude Linearity