The INSULAb beam test setup

Federico Ronchetti
Università degli Studi dell'Insubria - Como, Italy

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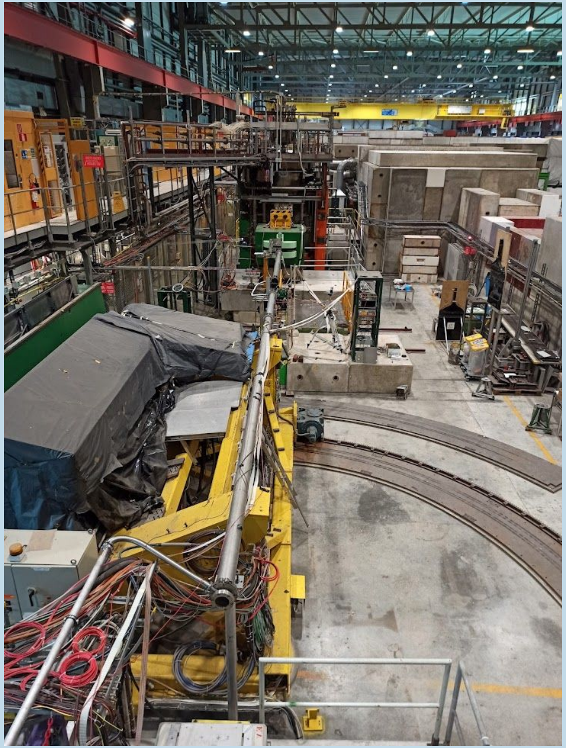
Outline

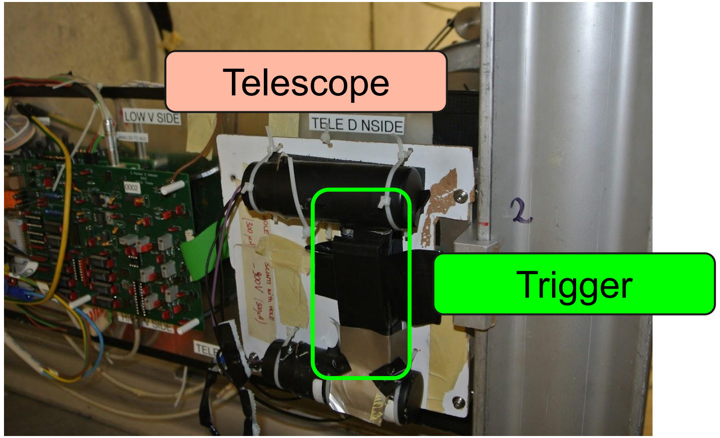


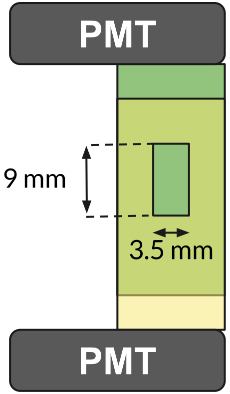
- The INSULAb detectors:
  - Silicon trackers
  - Triggers
  - Calorimeters
- The readout electronics
- The experimental setups during the 2021-2022 beamtests

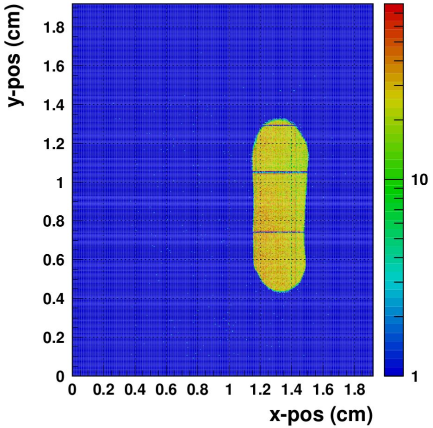
The trigger

Small area trigger

- 2 plastic scintillators (with and without a hole) readout by PMTs
- Anticoincidence to select a small beam spot: **9 × 3.5 mm²** → maximize the statistics of the triggered beam
- **Ideal for crystals characterization**
- Directly mounted on the first beam telescope of the line → **easy mechanics** and **already aligned**
- Possibility to select only the no-hole scintillator for a larger triggered beam



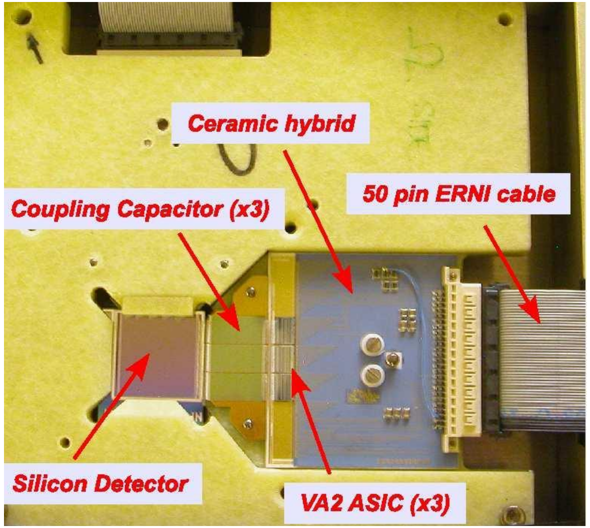


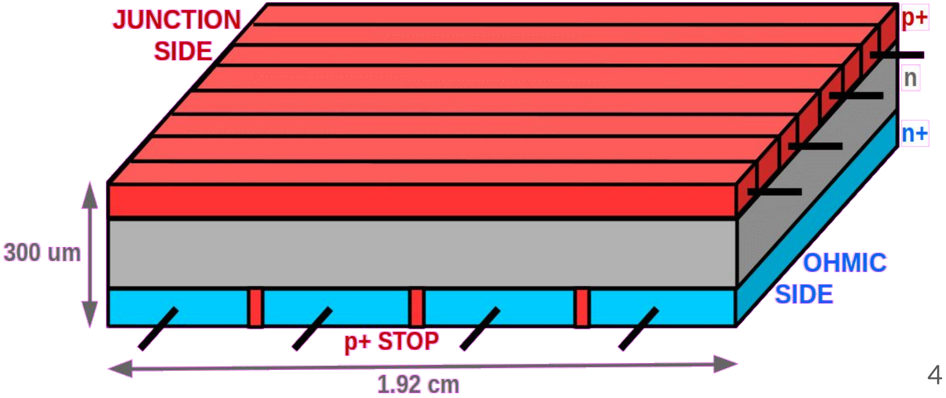


The tracking detectors

The INSULAb silicon telescopes

- double side **1.92 cm × 1.92 cm × 300 μm** CSEM sensors → **low material budget**
- 384 channels per side — physical pitch is 25μm on junction side (50μm in floating scheme) and 50μm on ohmic side → **high spatial resolution** (measured at T9, Lietti 2015):
  - **Ohmic side = 11.62 ± 0.18 μm**
  - **Junction side = 5.59 ± 0.54 μm**
- full depletion in (36,54)V → **low voltage requirement**
- Ideal for input beam characterization and **precise beam divergence measurement**

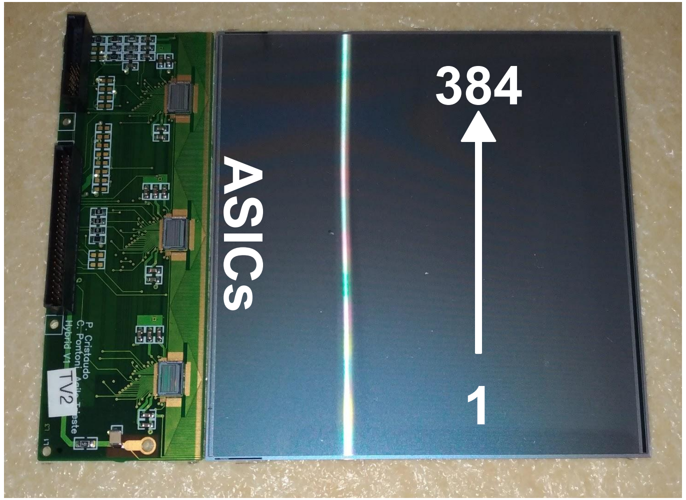




The tracking detectors

The INSULAb Beam Chambers (BC)

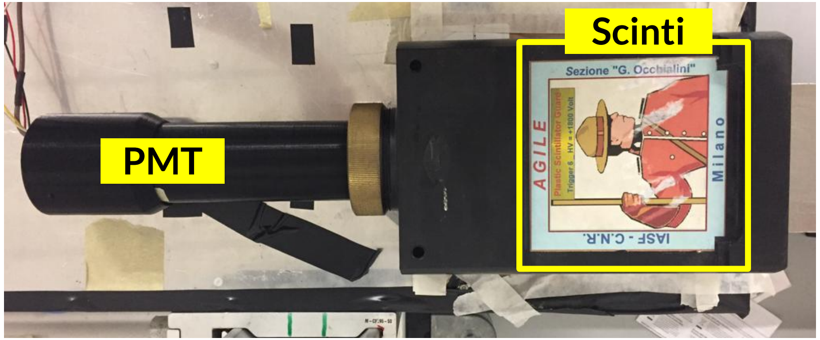
- single side AGILE spare sensors → 2 layers per module in XY configuration
- **large active area**: **~ 9.29 × 9.29 cm²**
- 384 channels per side with physical pitch 121 µm and readout pitch 242 µm → **spatial resolution is ~ 30 µm**
- Thickness is 410 µm per layer → 820 µm per module
- **Robustness** and **low voltage requirement** as the double side telescope modules
- Detector, FEB and connections inside an Al box → **easy to mount**

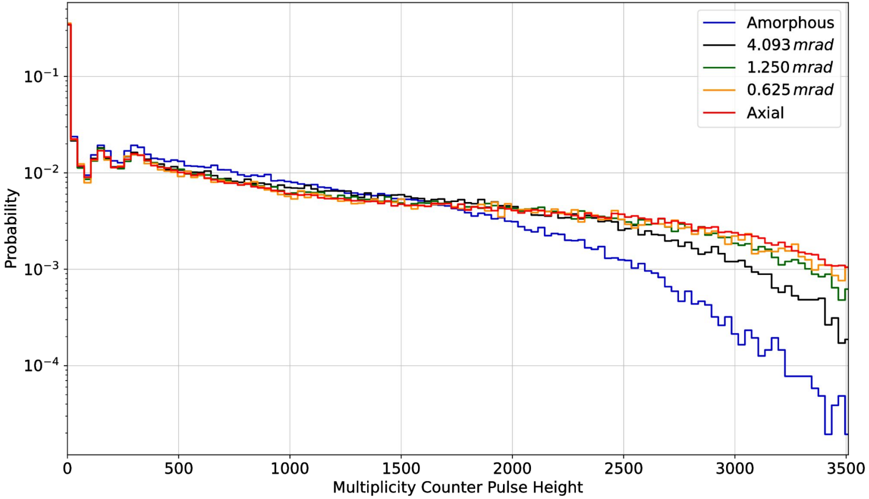


The scintillating detectors

Multiplicity counting

- $10 \times 10 \times 4$ cm^3 **plastic scintillator**, readout by PMT
- PMT with +5V power supply → no HV needed!
- Used as **trigger scintillator** and to **count the particles multiplicity** in oriented crystals experiments



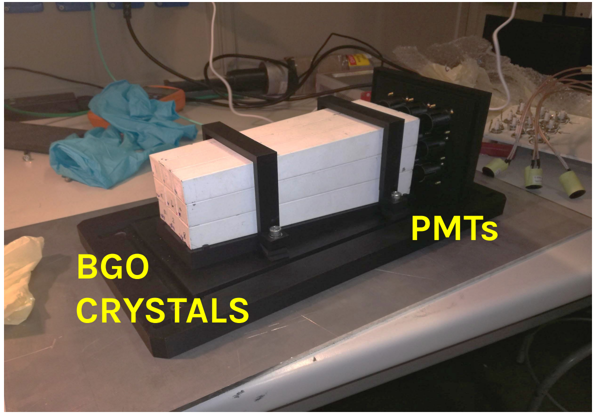


The electromagnetic calorimeters

BGO and Lead Glass calorimeters

The BGO calorimeter GENNI

- $9 \times 2.1 \times 2.1 \times 23\ \mathrm{cm}^3$ **BGO crystals** from the L3 endcap calorimeter
- Readout by **9 Photonis XP1912 PMTs** @850 V
- **High energy resolution → (3.1±0.3)%/√E ⊕ (2.7±0.1)%**



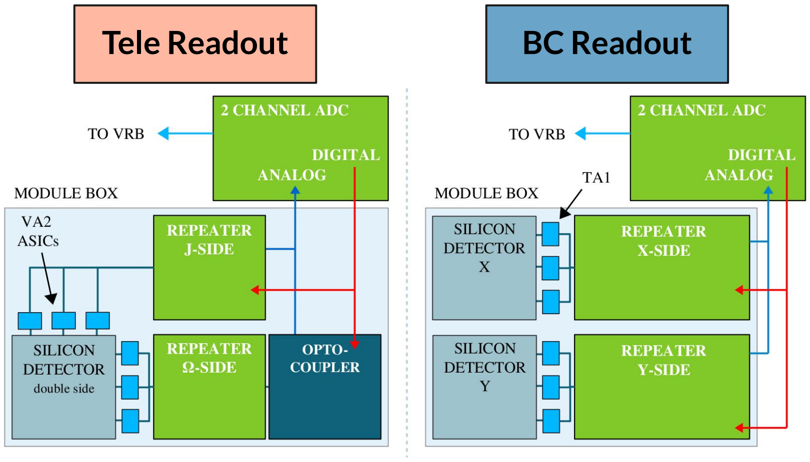
The lead glasses

- OPAL homogeneous Cherenkov **lead glass** calorimeters
- High energy resolution: **(16.6±0.4)%/√E ⊕ (0.9±0.1)%**
- Up to 7 lead glasses to build an **electromagnetic spectrometer**

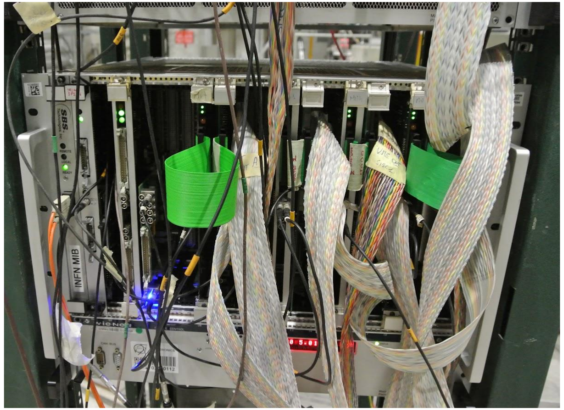
The Data AcQuisition

The readout electronics chain

- Silicon detector FEBs:
    - 3 x 128 channels ASICs per side
    - **Repeater boards** → ASIC configuration + bias delivery
    - If double side → **opto-coupler**
    - **ADC boards** + communication with the VME boards with flat differential cables
- CAEN V1730 digitizer family → scintillators and calorimeters
- **Custom VME readout boards** → trigger transmission to the detector and output digital signal storage + busy signal for the digitizers
- PC data storage during inter-spill time



Ballerini 2018



The Data AcQuisition

Acquisition software and DAQ rate

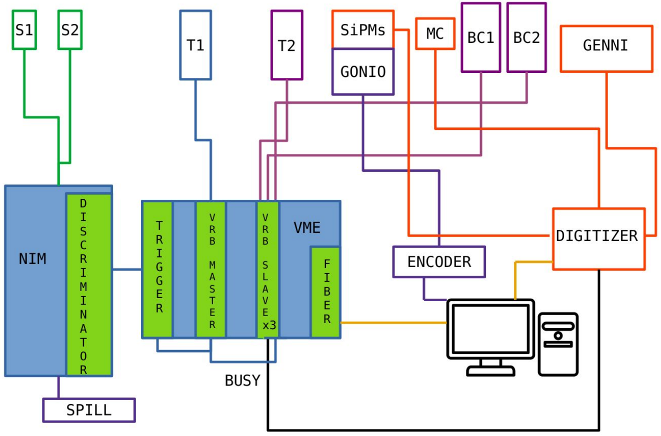
In-spill timing

$$\frac{400}{f_{CLK}} + (10,20)\mu s \times N_{VRB} + 10\mu s \times N_{DIGI} + (200,1200)\mu s\,|_{DIGI}$$

Incompressible shift time

VRB and digitizer initialization time

Digitizer readout



Selmi 2022

typically ~ **950 Hz DAQ rate** → (2000,4000) particles per spill (depending on the beam intensity)

Inter-spill period

Readout VRB memory banks + data storage → ~(2,10) s

Data saved in **raw HBOOK ntuples** and ready to use in few secs

→ **online analysis!**

and conversion in ASCII or root files

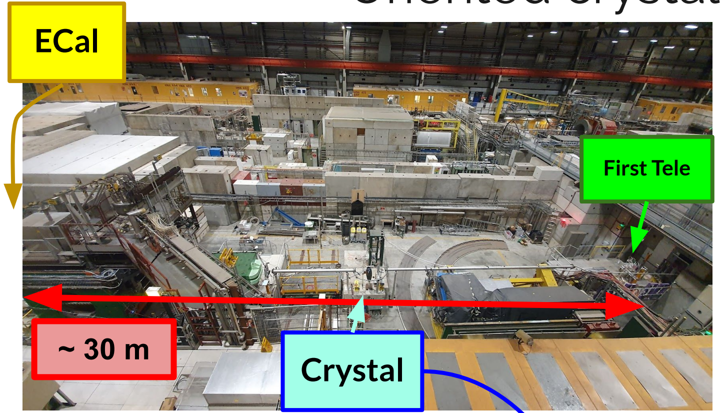
A versatile experimental setup

Different setups used in several beamtests in 2021-2022

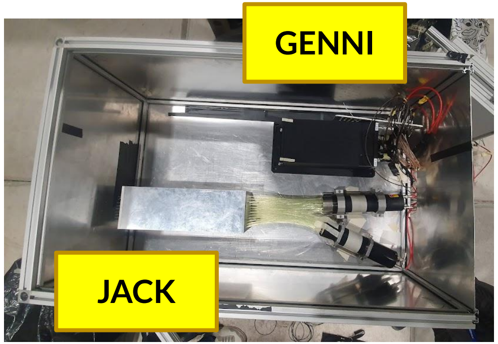
- **STORM @H2** → electrons @(20,120) GeV
- **K_LEVER @H2** → electrons @120 GeV
- **SELDOM @H8** → pions @180 GeV
- **INSULAb @T9** → electrons @(0.5,6) GeV

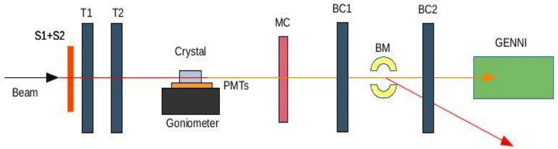
STORM @H2 line - CERN

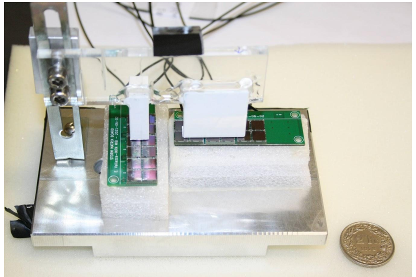
Oriented crystal tests



- **Very long setup** → detectors very far from each other
- (20,120) GeV/c electrons for many crystal studies
- High spatial resolution input tracking + output multiplicity and energy measurement

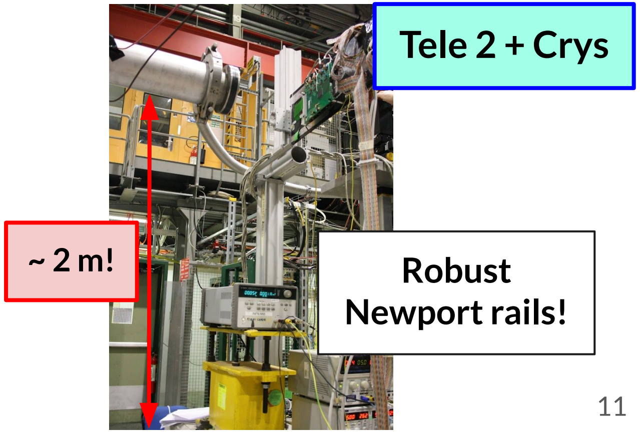






Instrumented crystals

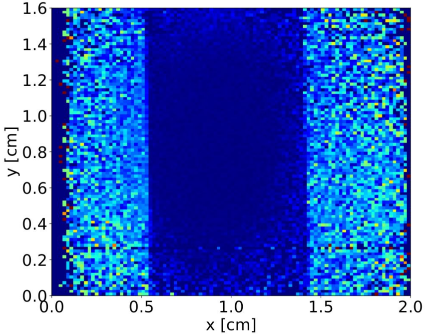
Not obvious assembly!



STORM @H2 line - CERN

Oriented crystal tests

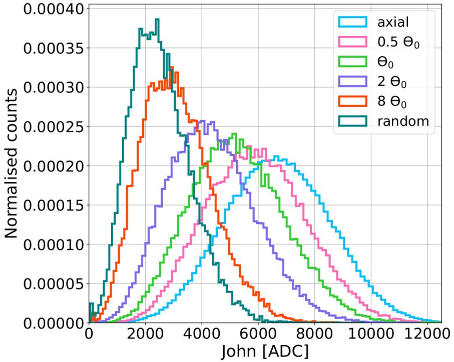
Precise measurement of the position of the crystal → useful to **select the interacting particles**



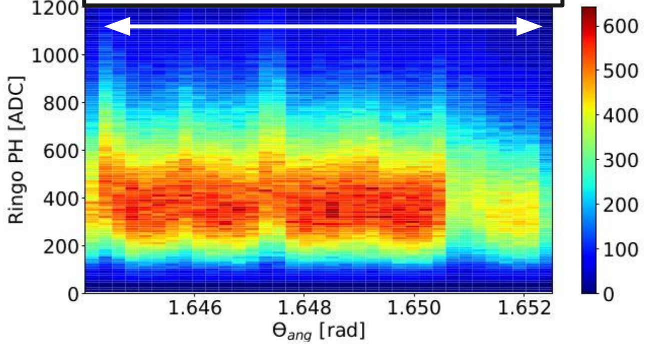
Selmi 2022

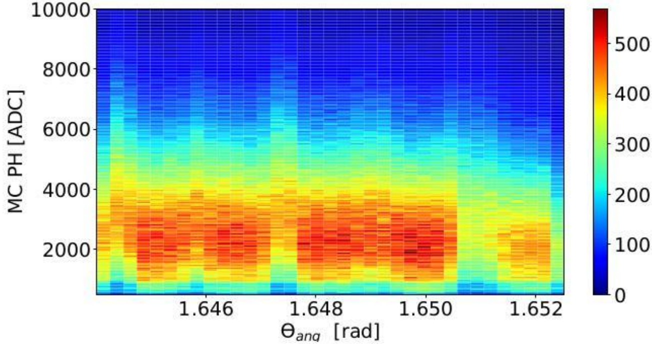
Alignment with the **crystal axes** using both the **Multiplicity Counter (MC)** and the **SiPMs (Ringo)**

Energy deposit enhancement in the crystal



Goniometer angular scan

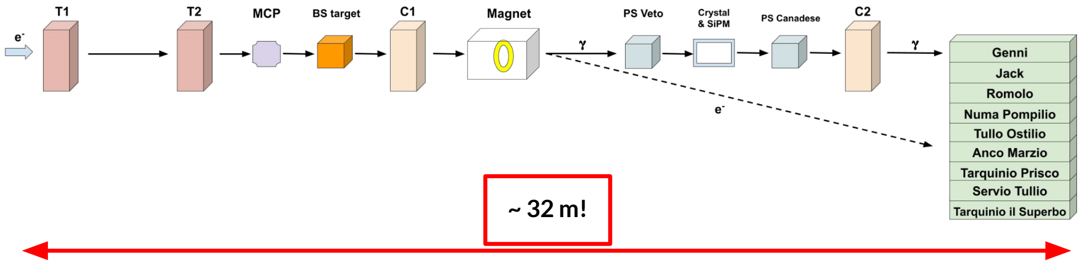




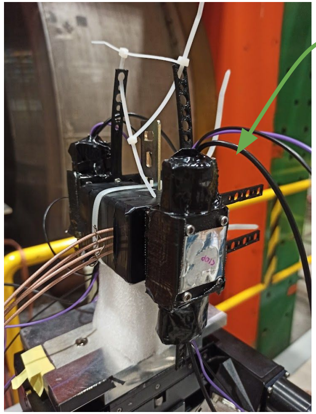
Selmi 2022

K_LEVER @H2 line - CERN

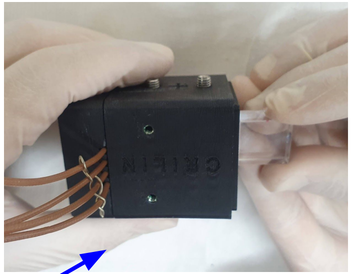
Oriented crystals and tagged photon beam

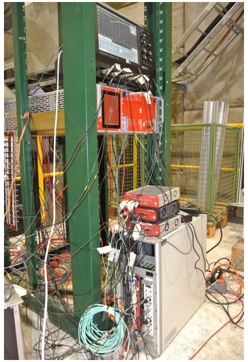


- Setup similar to the STORM one
- 120 GeV/c electrons for the **production of Bremsstrahlung photons** → characterization of instrumented PbF_2 oriented crystals
- Large number of detectors and **electromagnetic spectrometer** → several digitizers in the DAQ



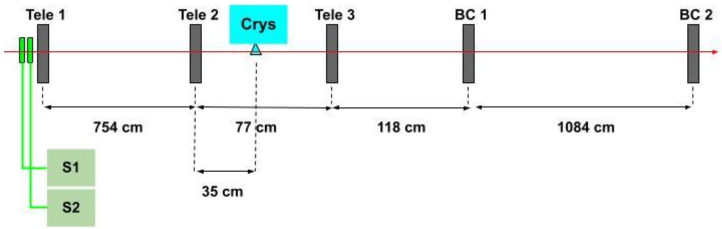
"mini"- scintillators → help for the fine alignment of the crystals



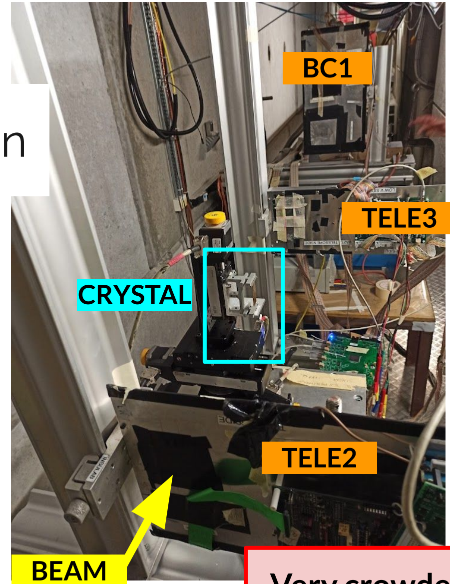


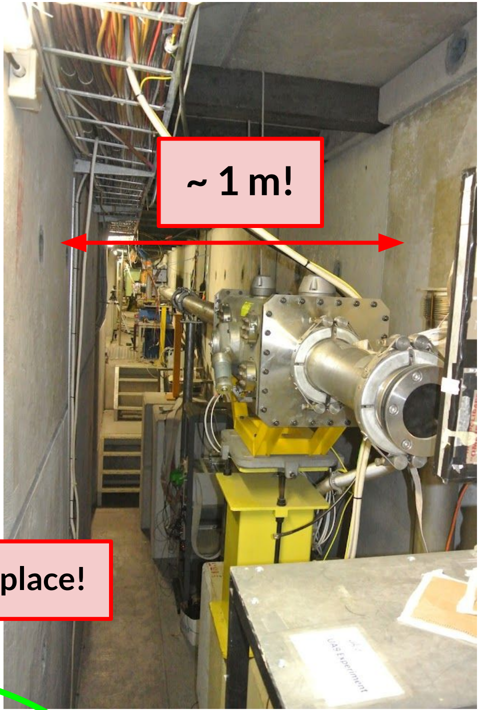
SELDOM @H8 line - CERN

Bent crystals characterization

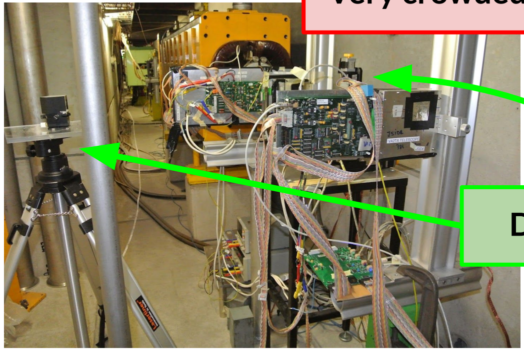


- 180 GeV/c low divergence pion beam
- Experimental setup in the **PPE 128 area of the H2 line**
- No calorimetry, only the **telescopes** in order to characterize **channeling in long (up to 10cm!) bent crystals**
- enormous bending angles, up to 16 mrad → output modules (positioned at ~35 cm and ~120 cm from the crystal center) need to be **precise** and to have **large transverse coverage** → near small sensor with high spatial resolution (~10μm) and far large sensors with resolution of ~30μm





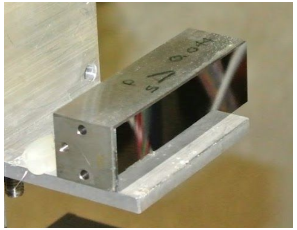
Very crowded place!

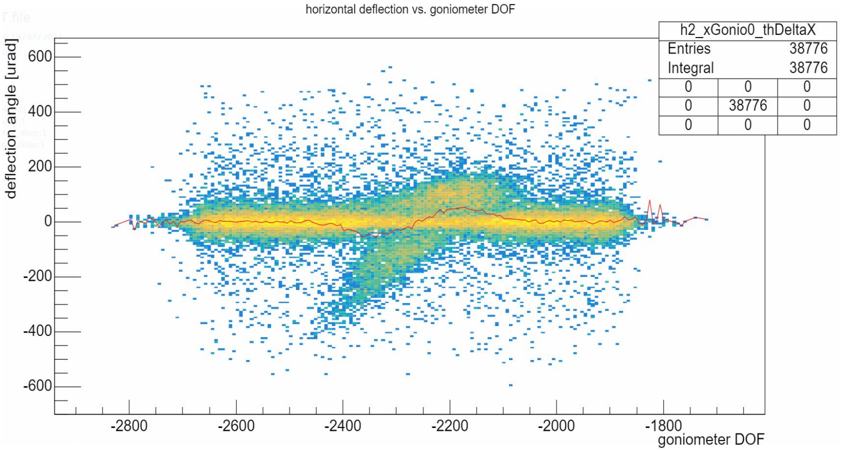


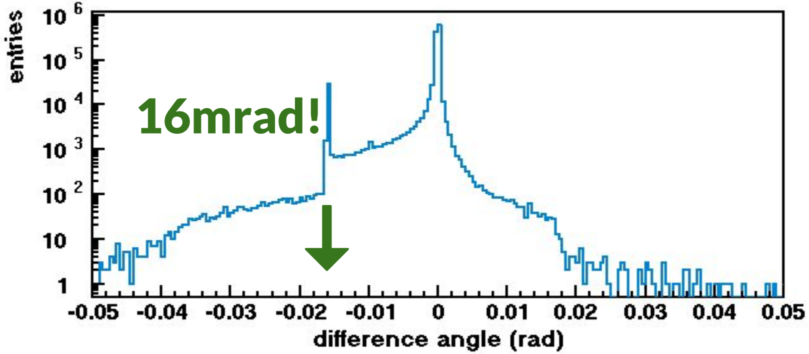
SELDOM @H8 line - CERN

Bent crystals characterization

Series of **strip crystals**
and **long crystal**







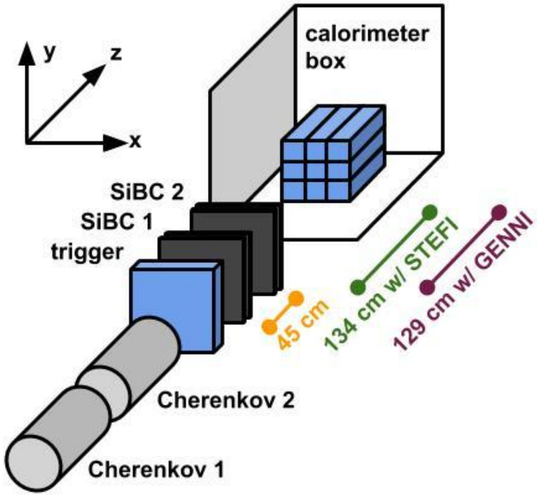
Very good setup for crystal **channeling phenomena** characterization

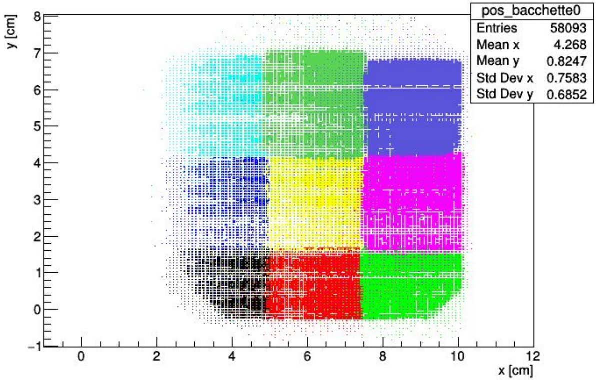
→ even for **large angles**

INSULAb @T9 line - CERN

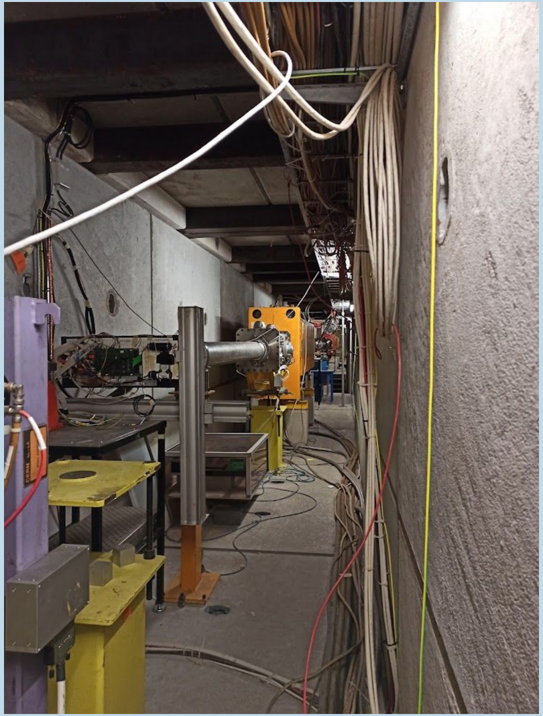
Calorimeters characterization

- **Calorimeter tests** and characterization with electrons @(0.5, 6) GeV
- **Modular simple setup** for tracking and particle ID (T9 line Cherenkov)
- Test of an **Active Photon Converter**





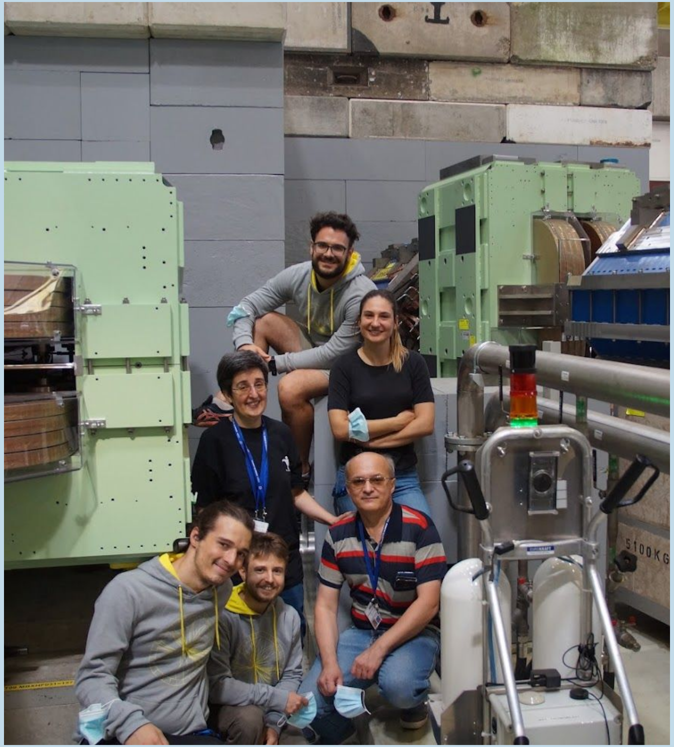
Conclusions and outlooks



- The **INSULAb beam test setup** is up and running off the shelf and **versatile** for different experimental configurations
- **Modular setup** for an easy installation and for intricate experimental areas
- Wide range of **microstrip silicon detectors** for precise tracking (**σ**~5μm) or wide transverse coverage (~10×10 cm^2 & **σ**~30 μm)
- Ideal for **crystals characterization** and **detector tests**

- **Upgrade of the readout chain** → Gigabit links by fibers or ethernet cables
- Design and development of a **custom digitizer** to replace the commercial ones
- Several **beamtests in 2022** at CERN

Thanks for your attention



CSEM detector specs

Detector	Double
Produced by	CSEM
ASIC	VA2
Detector dimensions [cm^2]	1.92×1.92
Number of readout channels	384
Bulk thickness [μm]	300
Resistivity [kΩ·cm]	> 4
Leakage current [nA/strip]	1.5-2.0
Full depletion bias voltage [V]	36-54
AC coupling	no (150 pF ext. cap.)
p-side - *junction*	
physical pitch [μm]	25
readout pitch [μm]	50
floating scheme	yes
n-side - *ohmic*	
physical pitch [μm]	50
readout pitch [μm]	50
floating scheme	no
Fiberglass support	
shape	square
dimensions [cm^2]	12.5×12.5
thickness [cm]	1.0
ASIC connection	direct bonding

ASIC name	VA2
Process (N-well CMOS)	1.2 μm
Die surface [mm^2]	6.18×4.51
Die thickness [μm]	~600
Number of channels	128
Input pad size [μm^2]	50×90
Output pad size [μm^2]	90×90
ENC at 1 μs of peaking time [e^- rms]	$80+15 \cdot C_d$
Power consumption [mW]	170
Slow shaper peaking time [μs]	1-3
Fast shaper peaking time [μs]	not present
Dynamic range [# MIPs]	±4
Current gain [μA/fC]	~25

AGILE detector specs

Item	Value
Dimension (cm^2)	9.5×9.5
Thickness (μm)	410
Readout strips	384
Readout pitch (μm)	242
Physical pitch (μm)	121
Bias resistor (MΩ)	40
AC coupling Al resistance (Ω/cm)	4.5
Coupling capacitance (pF)	527
Leakage current (nA/cm^2)	1.5

ASIC name	TAA1
process (N-well CMOS)	0.8um
die surface	5.174mm×6.919mm
die thickness	~600um
nr. of channels	128
input pad pitch	100um
output pad pitch	200um
power consumption	<400uW/channel

Acronyms

- **STORM: ST**r**O**ng c**R**ystalline electro**M**agnetic field
- **K_LEVER: K_L E**xperiment for **VE**ry **R**are events
- **SELDOM: S**earch for the **EL**ectric **D**ip**O**le **M**oment of strange and charm baryons at LHC