the INSULAb telescope

a modular and versatile tracking system for beam tests

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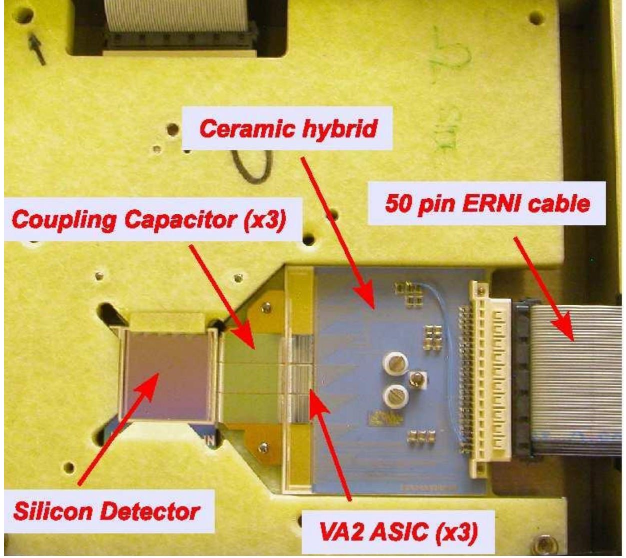
outline

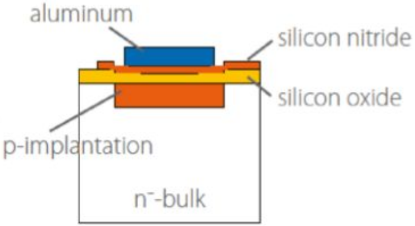
- the INSULAb telescope **detectors**
  - sensors and electronics
  - modular mechanics (to its highest!)

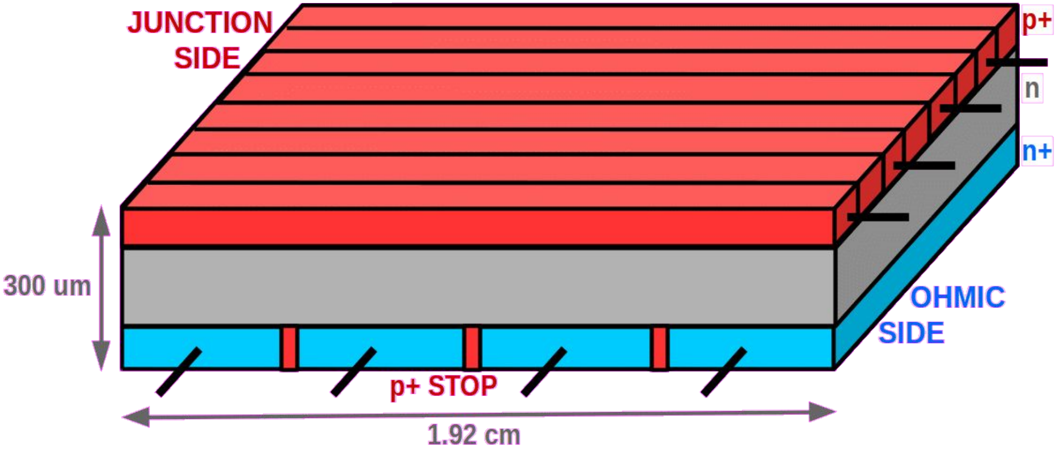
- the (very!) wide range of **applications**
  - high performance tracking and multiplicity measurement at many energies and intensities
  - particle physics, crystal characterization & detector R&Ds in 2018

the detectors

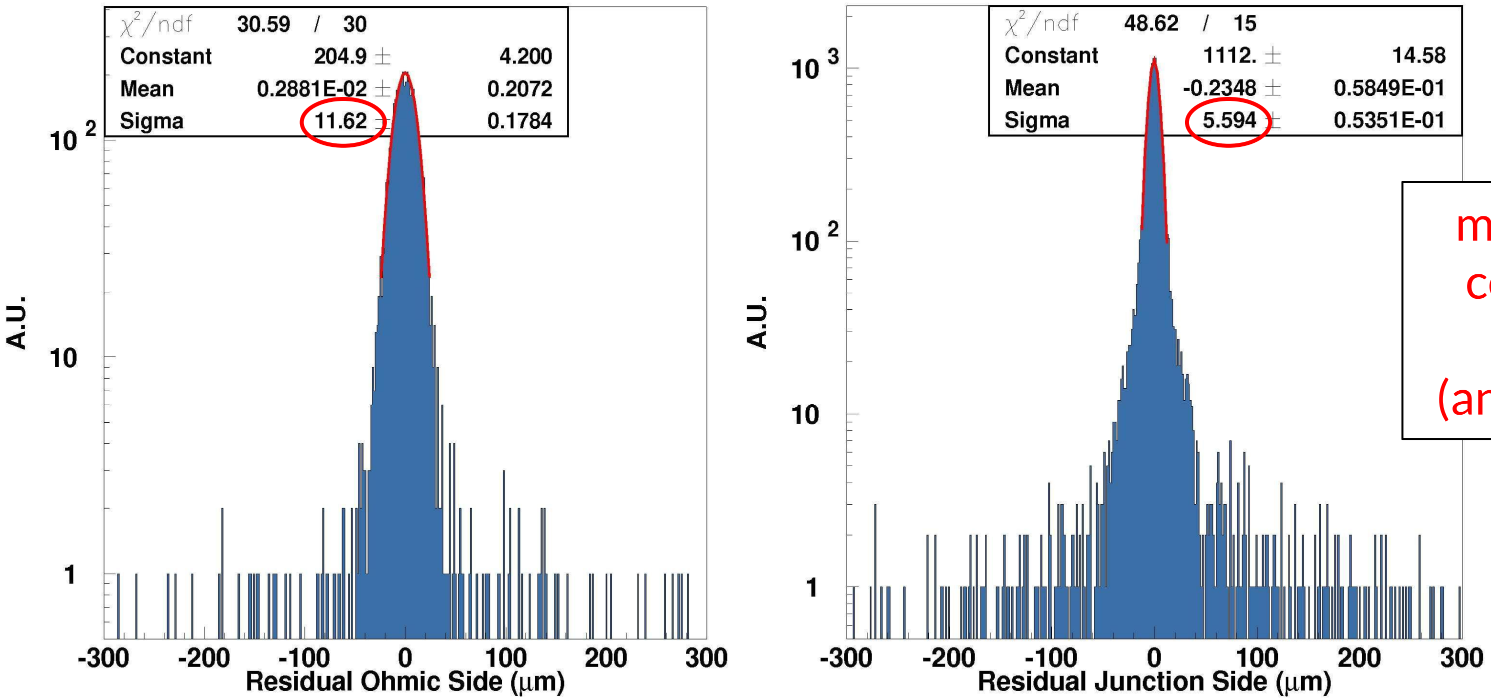
- double side CSEM sensors
- 1.92cm×1.92cm×300µm → **low material budget**
- 384 channels per side — physical pitch is 25**µ**m on junction side (½ floating) and 50**µ**m on ohmic side → **high spatial resolution**
- full depletion in (36,54)V → **low voltage requirement**, along with the ±5V levels for the electronic chain
- strips-capacitors and capacitors-ASICs direct bonding; all on the same fiberglass support → **robust**







the detectors

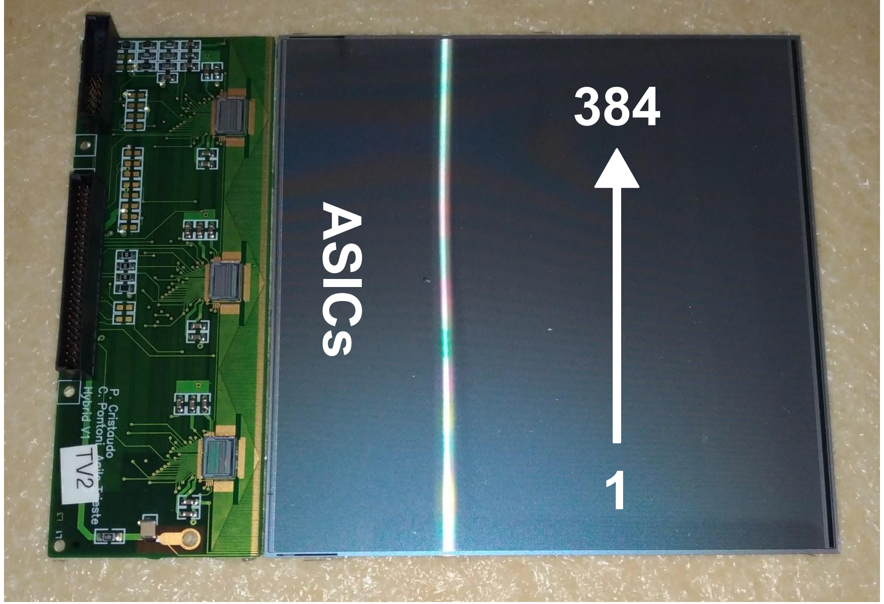


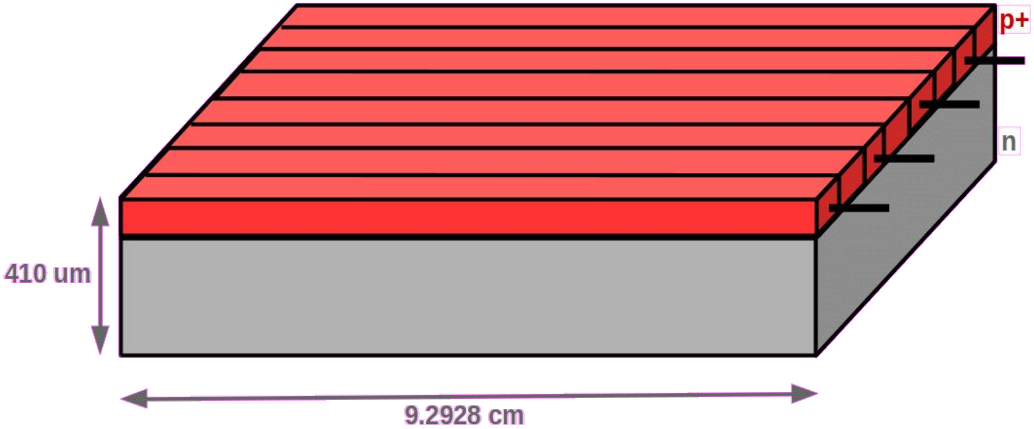
measured at T9 computed with COG method (analog readout)

→ very high spatial resolution at the price of a small transverse area — ideal for input beam characterization and precise angle measurement

the detectors

- single side AGILE spare sensors → 2 layers per module with different vistas
- **large active area**: ~9.29×9.29cm^2
- 384 channels per side with physical pitch 121μm and readout pitch 242μm → spatial resolution is ~30μm
- thickness is 410μm per layer → 820μm per module
- same **robustness** (direct bonding, ASICs and sensor on the same fiberglass board) and **low voltage requirement** as the single side telescope modules

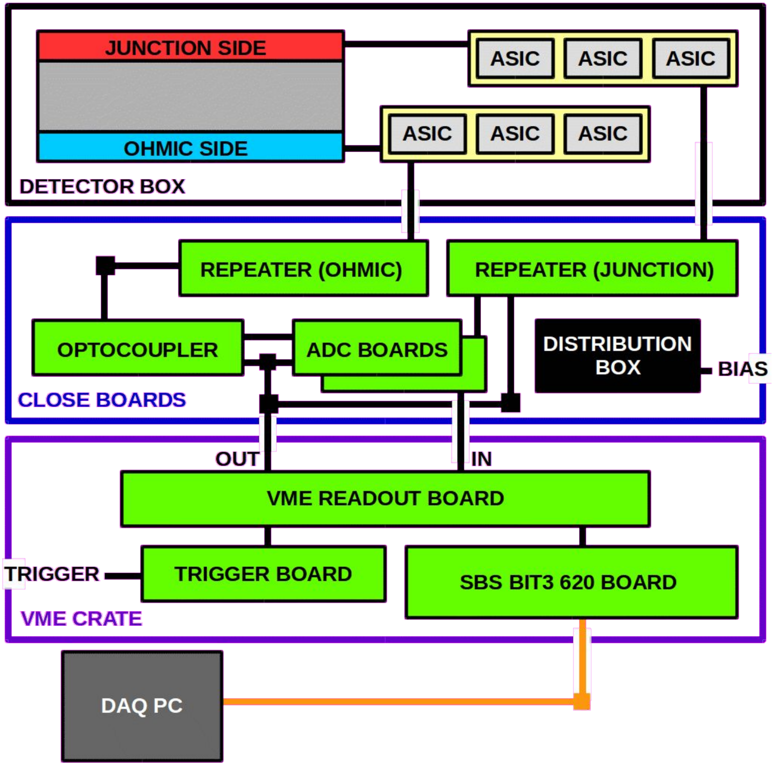




the readout electronics chain

optocoupler for bias adaption — only for double side sensors

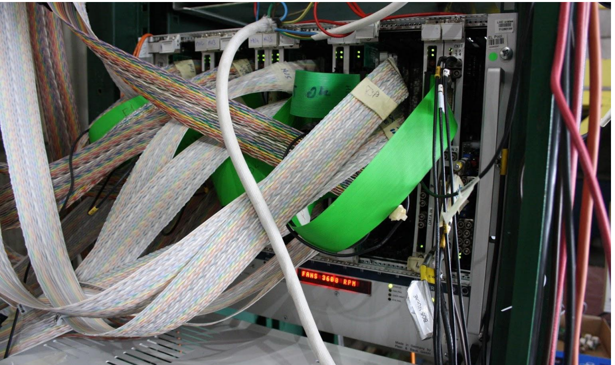
VME readout boards for trigger transmission to the detector and output digital signal storage → out-of-spill transmission to the PC



3 128 channel **ASICs** per vista — 2 vistas in each box

repeater (1 per layer) for ASICs configuration & bias delivery

ADC boards for signal digitalization and transmission to VME crate (via flat ribbon cables)



the readout electronics chain

in-spill DAQ timing:

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

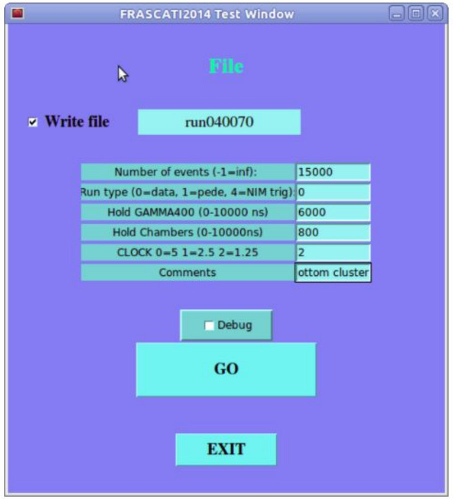
incompressible shift time; *fCLK* is 2.5MHz or 5MHz

initialization time for VRBs and digitizers

digitizers data readout; depends on digitizers features

→ typically (300,500)μs in a crystal characterization beam test setup

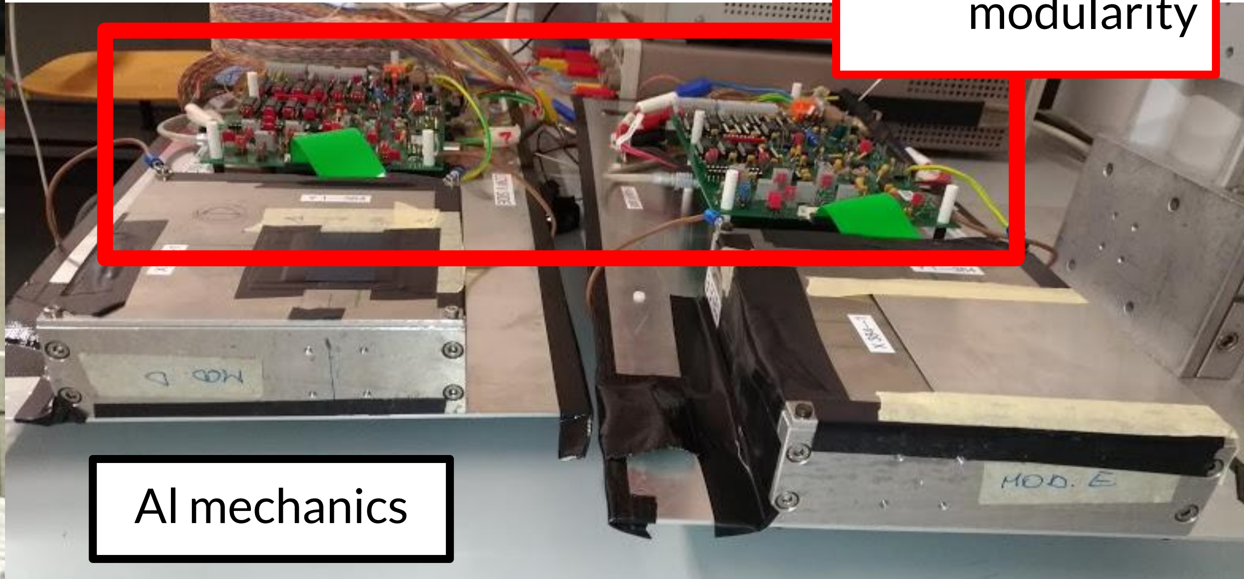
storage in VRB memory banks & out-of-spill readout in (2,10)s → raw ntuples ready to use in few seconds!



boxes and structures

Bosch & Newport holders and rails → easy mounting and coupling with plinths (multiple orientation options!)

frontend electronics bonded to each detector box → robustness and modularity



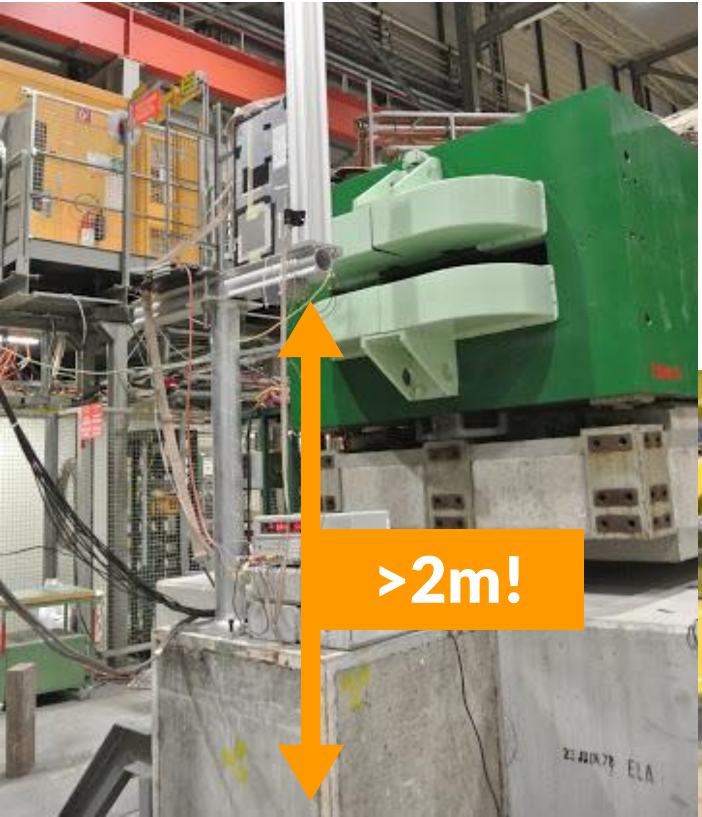
Al mechanics

boxes and structures

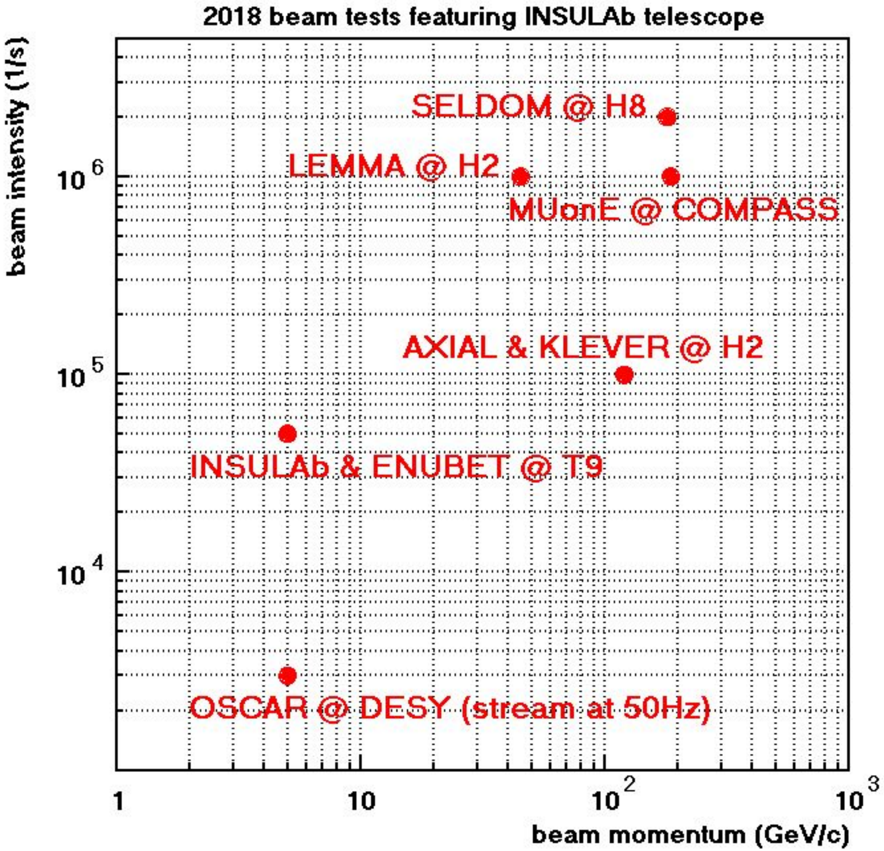
2018 LEMMA beam test @ H2

EVEN IN EXTREME CONDITIONS!

beam at high y & limited space along z for concrete blocks (rail on the upstream floor, magnet downstream) → robust solution with long plinth and Newport rails

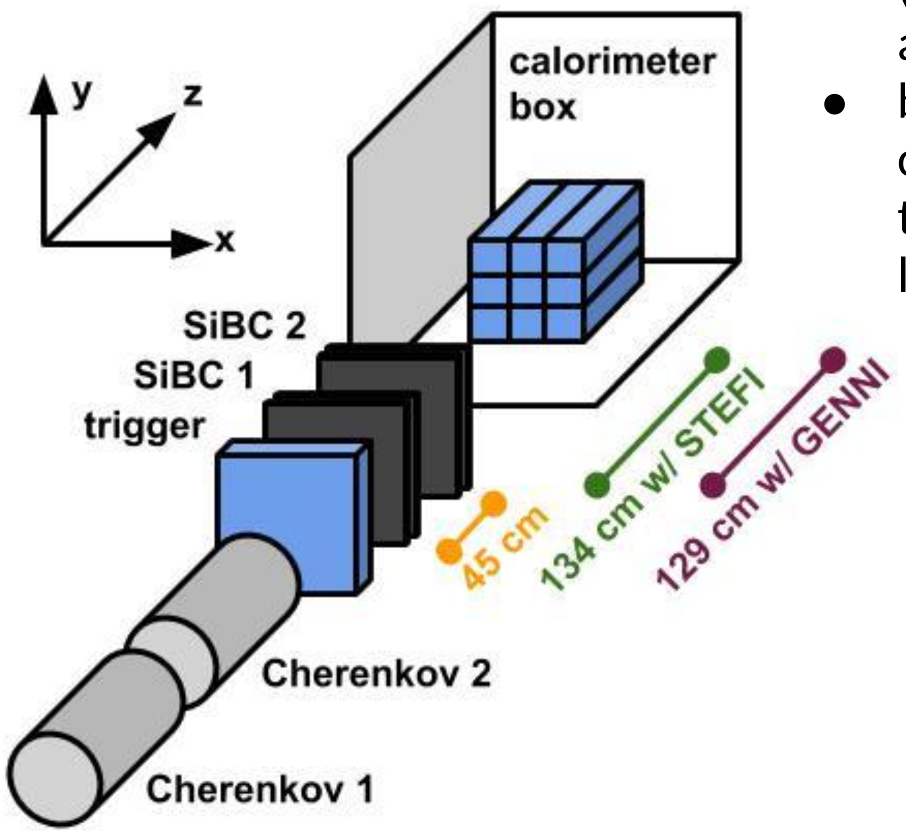


anywhere and anyhow

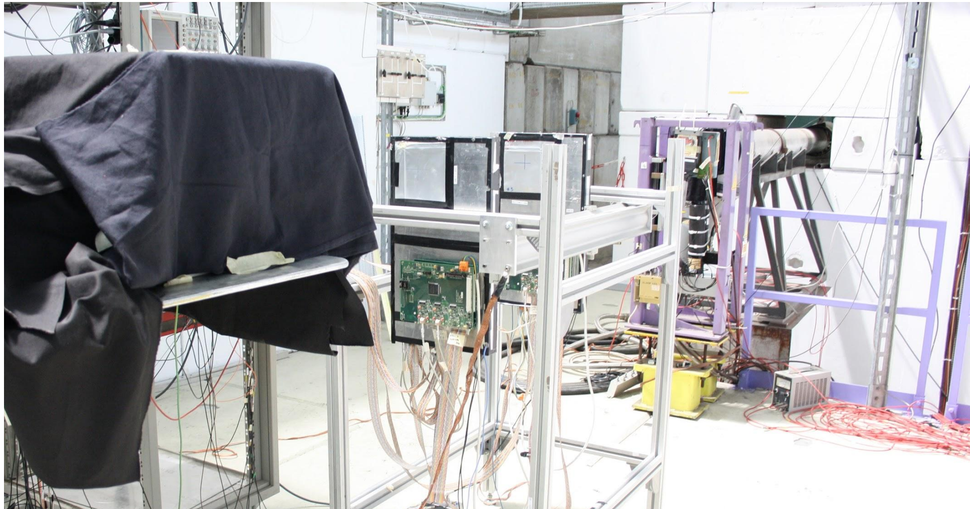


several beam tests in many different beams and experimental area conditions @ CERN (most of the lines), DESY and LNF between 2016 & 2018…

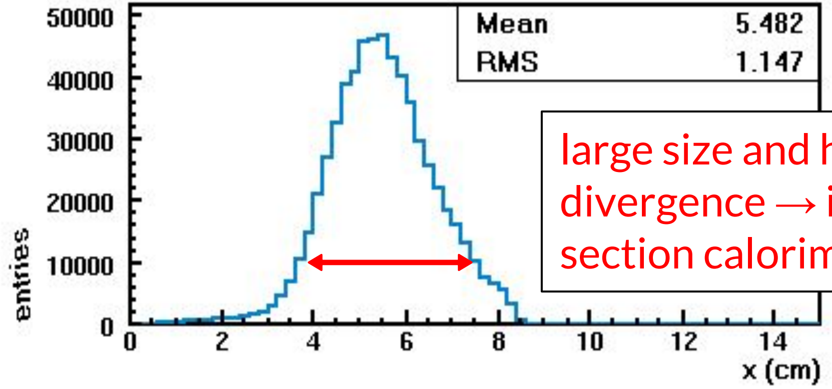
INSULAb & ENUBET @ T9



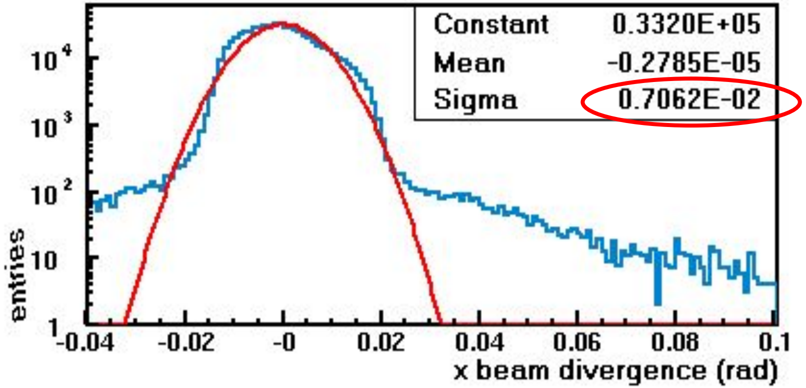
- (0.5,10)GeV/c low intensity electron, muon and pion beam
- beam tests for calorimeters characterization → tracking system needed to draw efficiency and response maps, so large active area of the layers is needed

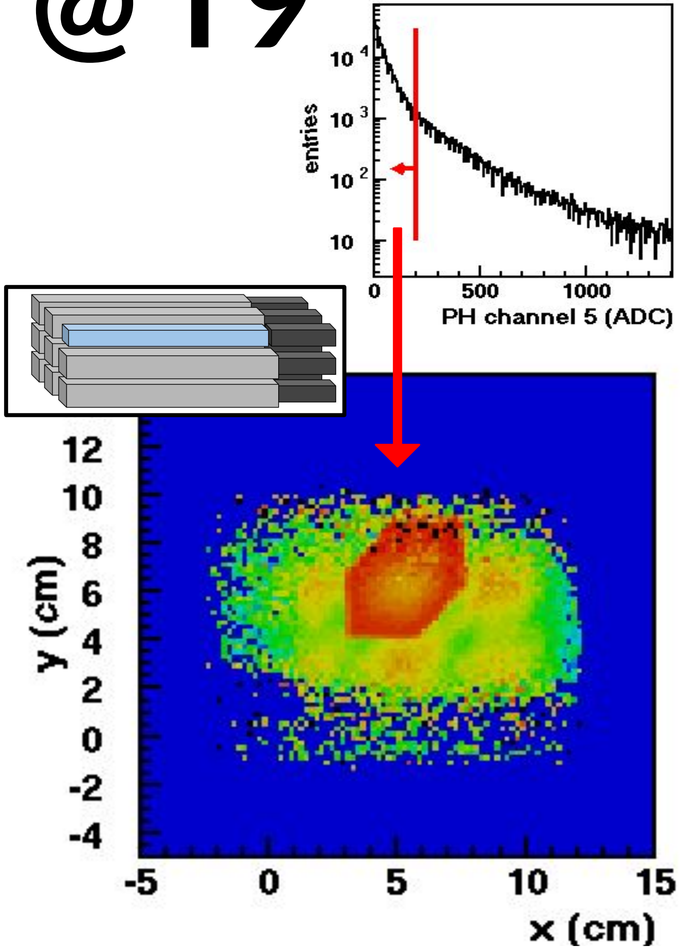


INSULAb & ENUBET @ T9

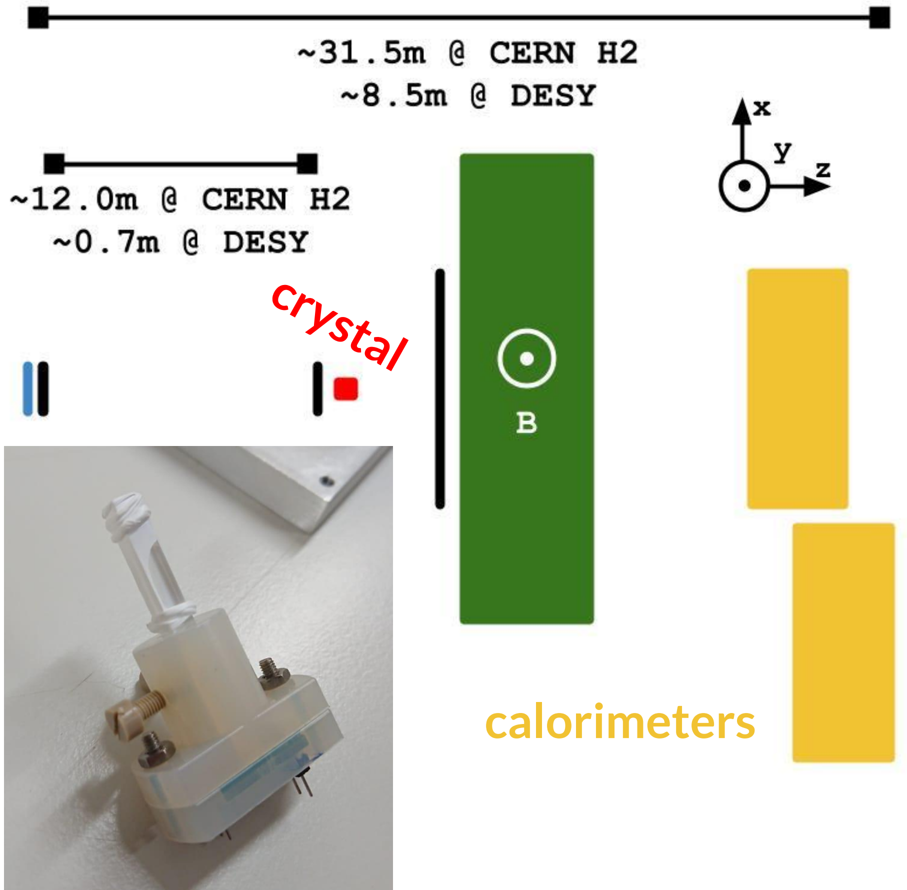


large size and high divergence → ideal for large section calorimeter mapping





AXIAL @ H2 & OSCAR @ DESY

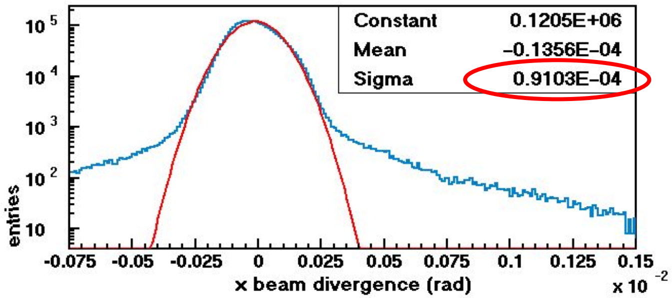


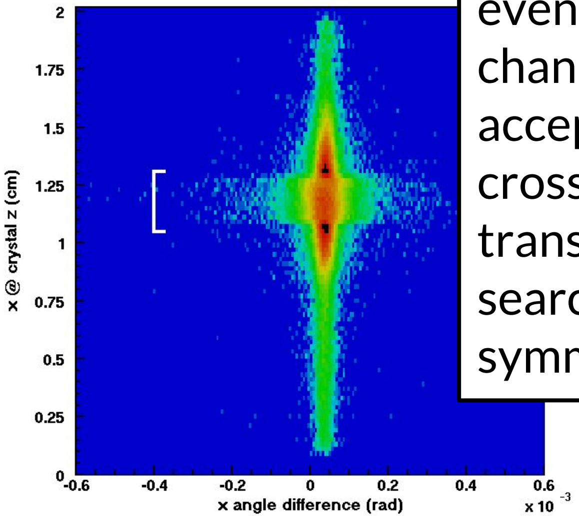
120GeV/c electrons & positrons for many crystal studies – (1,6)GeV @ DESY

input tracking performed with small high resolution double side sensors, larger ones in output

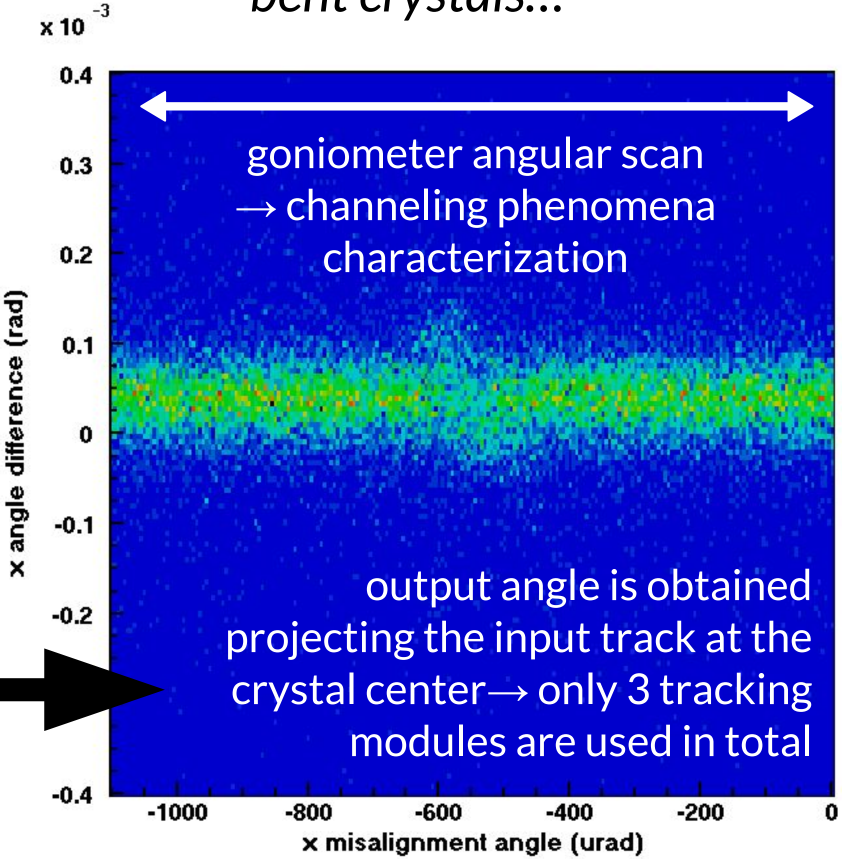
AXIAL @ H2 & OSCAR @ DESY

bent crystals…





events within the channeling input angle acceptance and crossing the crystal transverse surface → search for crystal symmetries…

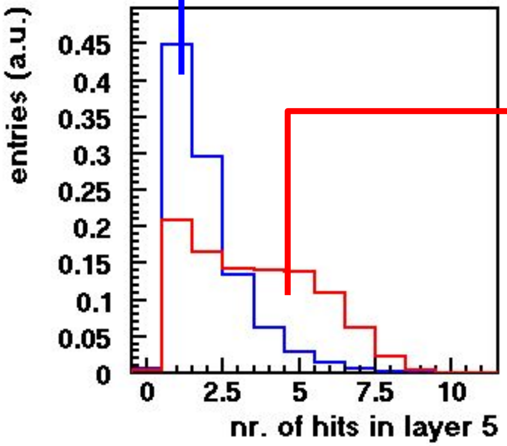


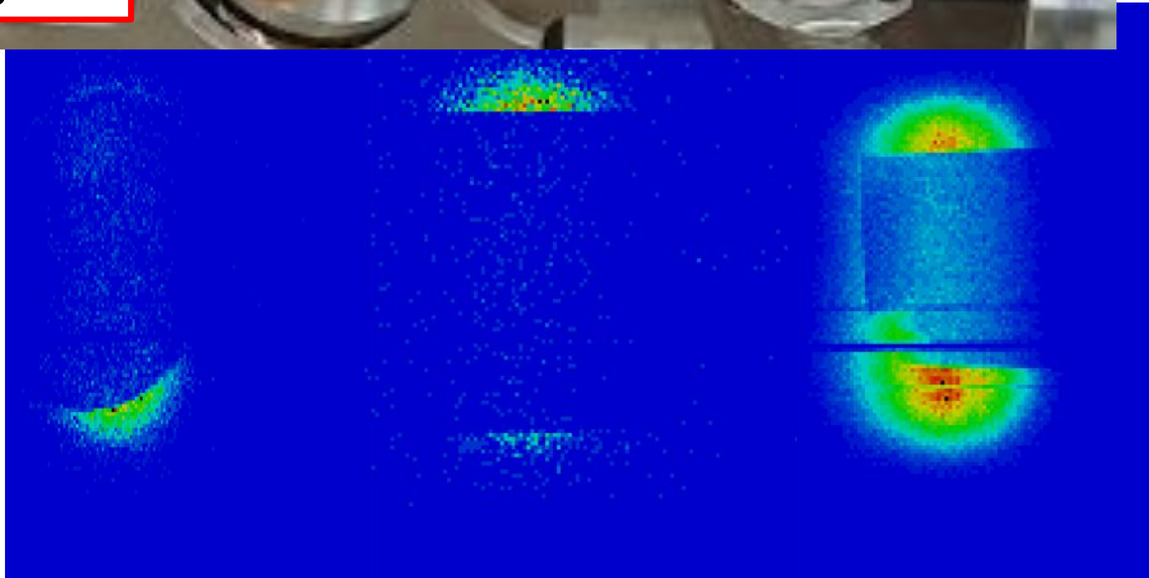
AXIAL @ H2 & OSCAR @ DESY

& straight crystals…

~4mm thick Si bent (benchmark)

W straight – many crystals of various shapes and thicknesses

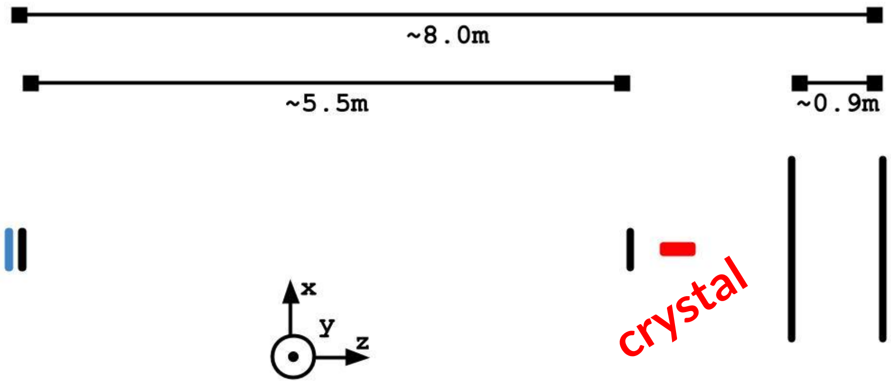


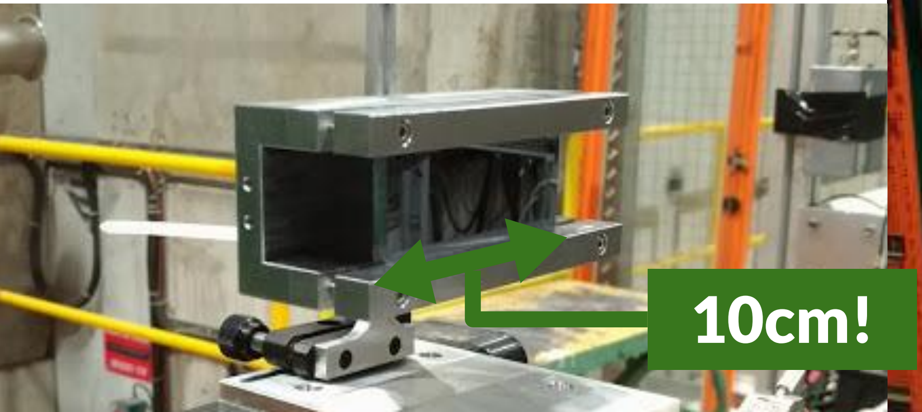


SELDOM @ H8

180GeV/c low divergence pion beam

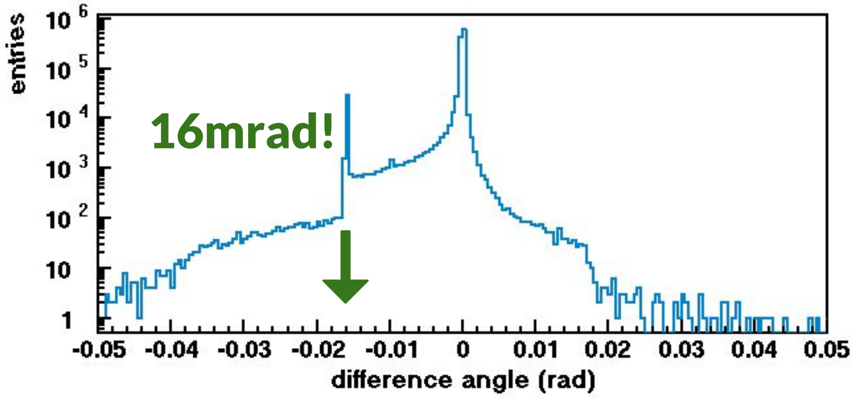
no calorimetry, only the telescope in order to characterize channeling in long (up to 10cm!) bent crystals → this time the usage of 2 modules (large, single side) for output tracking is mandatory

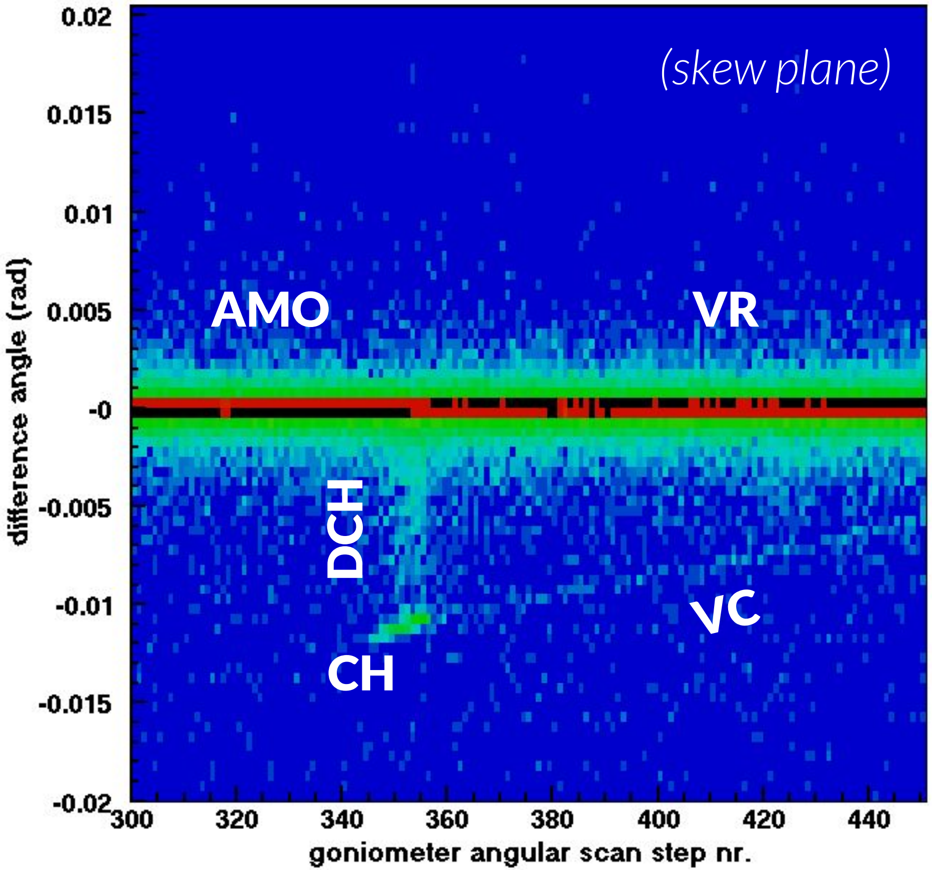




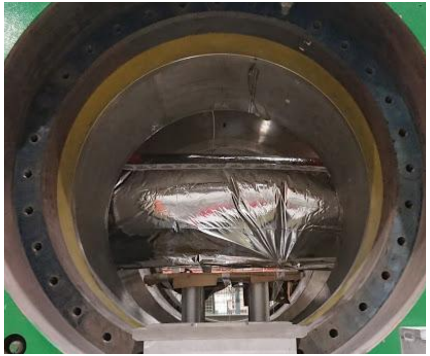
SELDOM @ H8

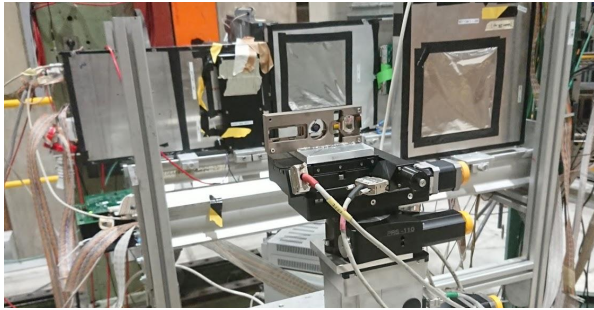
enormous bending angles, up to 16mrad
→ it is fundamental that output modules (which are positioned at ~1m and ~2m respectively from the crystal center) have large transverse coverage → sensors with resolution of ~30μm are enough to make all the channeling phenomena clearly distinguishable





KLEVER @ H2

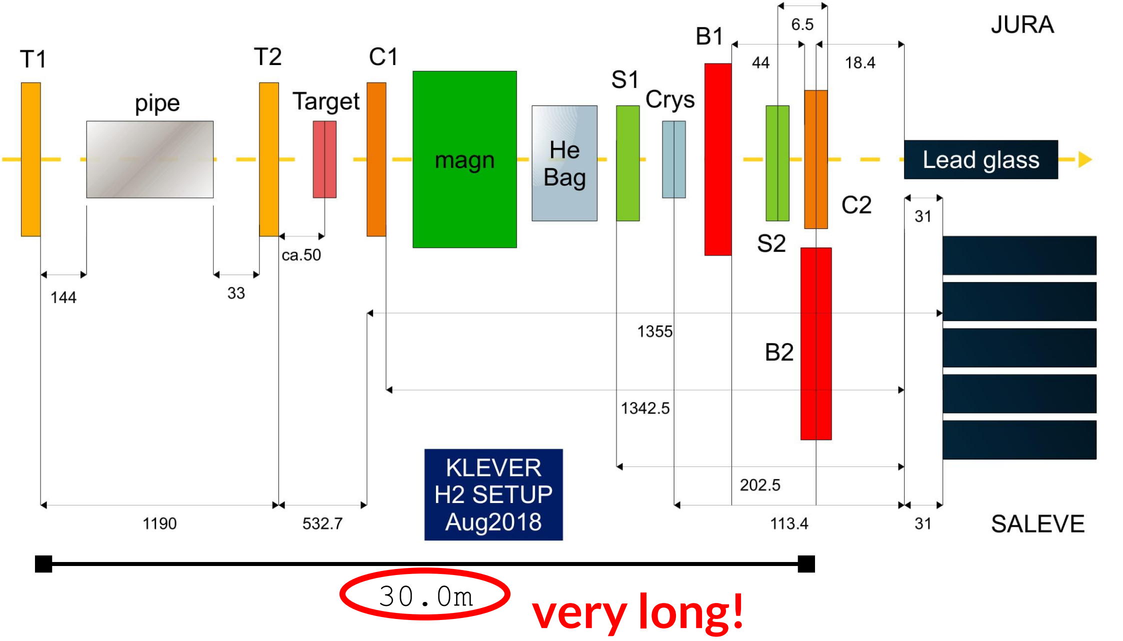




120GeV/c electrons for the production of Bremsstrahlung photons → characterization of thick straight W crystals for the enhancement on photoconversion

intricate setup with

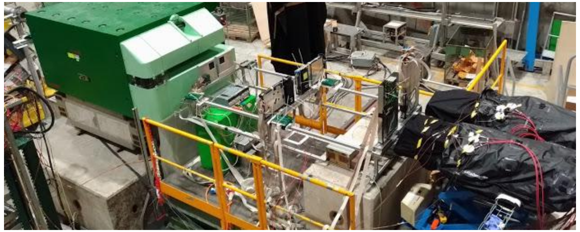
- multiple stages of Si sensors — output stage mainly for multiplicity measurement
- trigger system based on scintillators coincidence & anticoincidence in order to deal with the central neutral stage

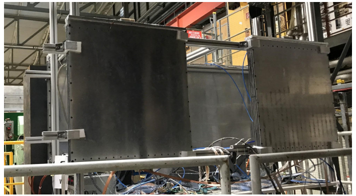


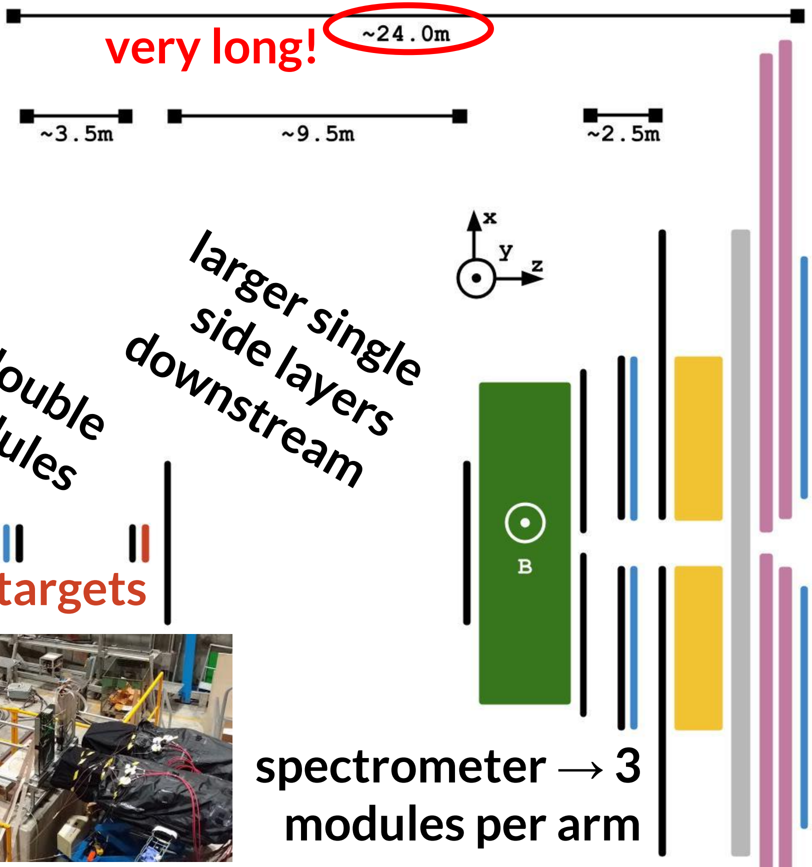
LEMMA @ H2

intricate setup for $e^+e^- \rightarrow \mu^+\mu^-$ studies with 45GeV/c high intensity positron beam:

- 20 telescope vistas for input and output pattern reconstruction $\rightarrow$ complicated mechanical and cables configuration & careful alignment procedure needed
- coincidence of 5 trigger signals from scintillators
- many calorimeters and muon DT chambers

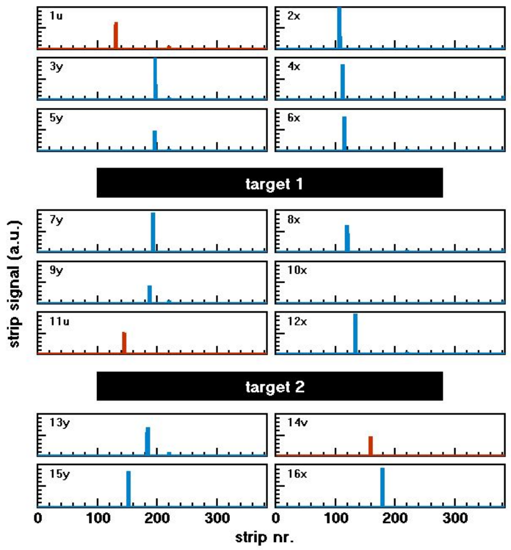


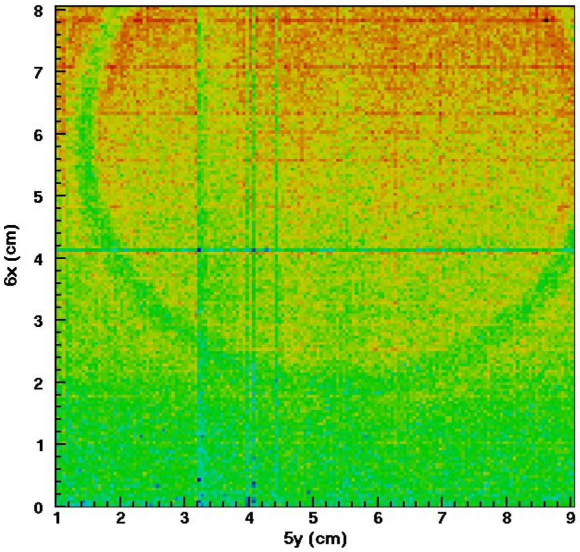


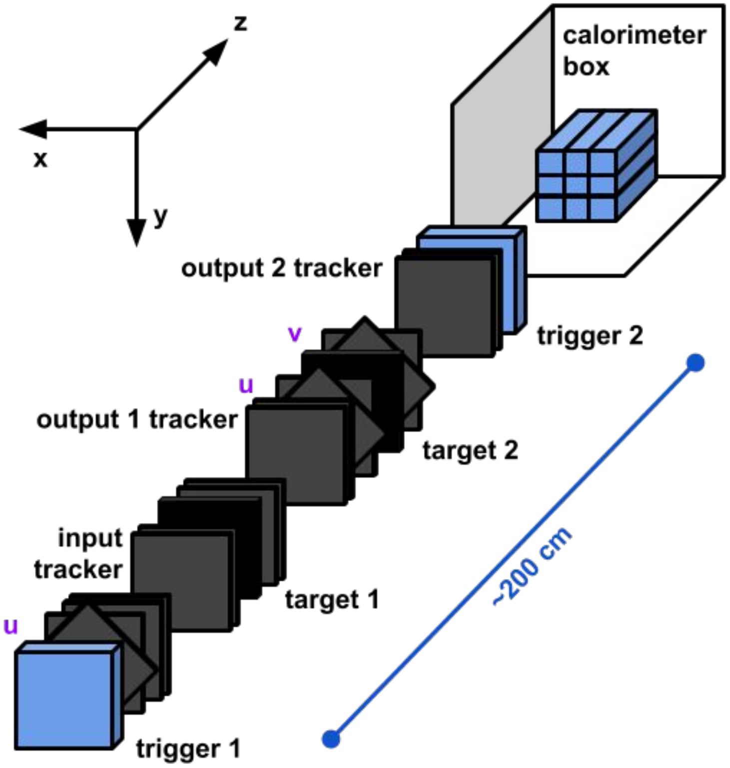


MUonE @ COMPASS

186GeV/c muon wide (size of several tens of cm) and intense beam hits a series of 16 tracking layers → ~8 months feasibility test of a setup for muon-electron elastic scattering kinematics studies → stability over time & DAQ remote control!







outlook

planning many upgrades in the readout chain — new boards, replacement of flat ribbon cables with optical fibers, etcetera...

development of multiple hit disambiguation methods — signal correlation in double side layers, stereo layers, etcetera...

beam tests at LNF, DESY and Fermilab are under planning for 2019/2020

the INSULAb telescope:

- **up & running off the shelf**
- **tracking with high spatial resolution**
- **tracking with wide transverse coverage**
- **multiplicity counting**
- **modular → many configurations**

conclusions

thank you!

the detector — technical specs

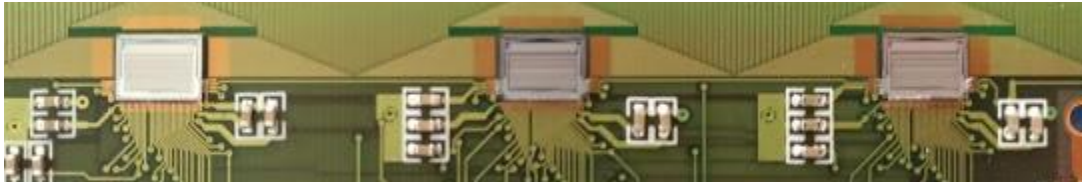
Detector	Double
Produced by	CSEM
ASIC	VA2
Detector dimensions [cm^2]	1.92×1.92
Number of readout channels	384
Bulk thickness [μm]	300
Resistivity [kΩ·cm]	> 4
Leakage current [nA/strip]	1.5-2.0
Full depletion bias voltage [V]	36-54
AC coupling	no (150 pF ext. cap.)
p-side - *junction*	
physical pitch [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]	$\sim$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]	$\sim$25

the detector — technical specs

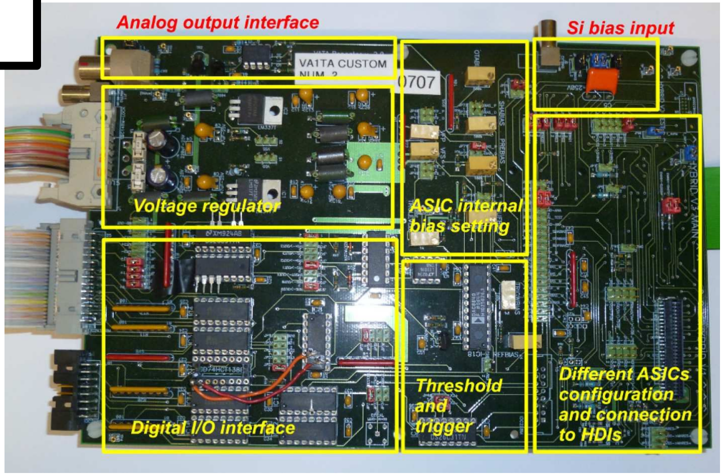
Item	Value
Dimension (cm^2)	9.5×9.5
Thickness (μm)	410
Readout strips	384
Readout pitch (μm)	242
Physical pitch (μm)	121
Bias resistor (MΩ)	40
AC coupling Al resistance (Ω/cm)	4.5
Coupling capacitance (pF)	527
Leakage current (nA/cm^2)	1.5

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

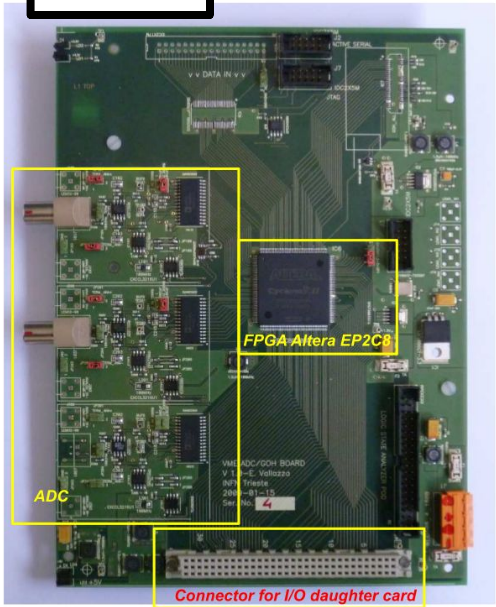


the readout electronics chain

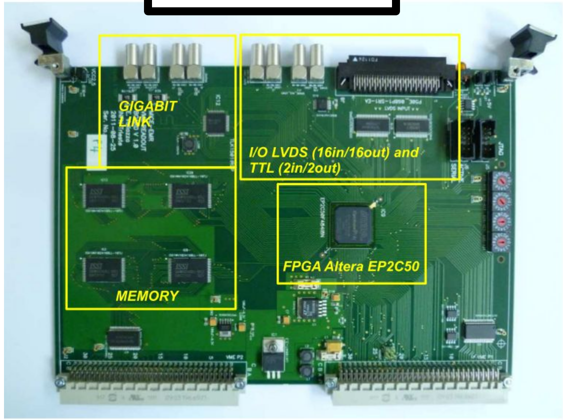
repeater

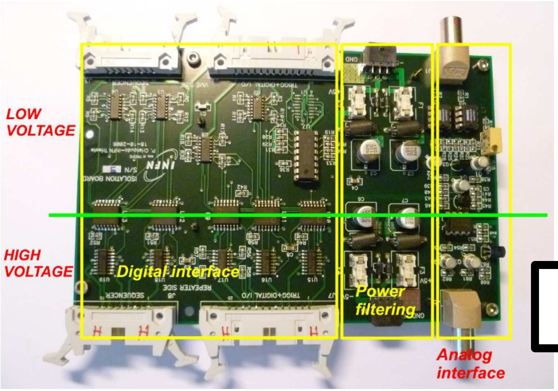


ADC



VME readout board





optocoupler

acronyms

- **E**nhanced **N**e**U**trino **BE**ams for kaon **T**agging
- **O**riented **SC**intill**A**to**R** crystals
- **S**earch for the **EL**ectric **D**ip**O**le **M**oment of strange and charm baryons at LHC
- **K_L** **E**xperiment for **VE**ry **R**are events
- **L**ow **EM**ittance **M**uon **A**ccelerator