the INSULAb telescope
a modular and versatile tracking system for beam tests

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• 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 25μm on junction side (½ floating) and 50μm 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

→ 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:** $\sim 9.29 \times 9.29 \text{cm}^2$
- 384 channels per side with physical pitch $121 \mu\text{m}$ and readout pitch $242 \mu\text{m}$ → spatial resolution is $\sim 30 \mu\text{m}$
- thickness is $410 \mu\text{m}$ per layer → $820 \mu\text{m}$ 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:

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

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

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
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

goniometer angular scan → channeling phenomena characterization

bent crystals...

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

output angle is obtained projecting the input track at the crystal center → only 3 tracking modules are used in total
AXIAL @ H2 & OSCAR @ DESY

~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
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 $\rightarrow$ 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
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 → complicated mechanical and cables configuration & careful alignment procedure needed
- coincidence of 5 trigger signals from scintillators
- many calorimeters and muon DT chambers
MUonE @ COMPASS

186 GeV/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

<table>
<thead>
<tr>
<th>Detector</th>
<th>Double</th>
</tr>
</thead>
<tbody>
<tr>
<td>Produced by</td>
<td>CSEM</td>
</tr>
<tr>
<td>ASIC</td>
<td>VA2</td>
</tr>
</tbody>
</table>

### 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

<table>
<thead>
<tr>
<th>physical pitch [μm]</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>readout pitch [μm]</td>
<td>50</td>
</tr>
<tr>
<td>floating scheme</td>
<td>yes</td>
</tr>
</tbody>
</table>

### n-side - ohmic

<table>
<thead>
<tr>
<th>physical pitch [μm]</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>readout pitch [μm]</td>
<td>50</td>
</tr>
<tr>
<td>floating scheme</td>
<td>no</td>
</tr>
</tbody>
</table>

### Fiberglass support

<table>
<thead>
<tr>
<th>shape</th>
<th>square</th>
</tr>
</thead>
<tbody>
<tr>
<td>dimensions [cm$^2$]</td>
<td>12.5 × 12.5</td>
</tr>
<tr>
<td>thickness [cm]</td>
<td>1.0</td>
</tr>
<tr>
<td>ASIC connection</td>
<td>direct bonding</td>
</tr>
</tbody>
</table>

### 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 · $C_d$

### 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/iC]

~25
the detector — technical specs

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension (cm²)</td>
<td>9.5x9.5</td>
</tr>
<tr>
<td>Thickness (µm)</td>
<td>410</td>
</tr>
<tr>
<td>Readout strips</td>
<td>384</td>
</tr>
<tr>
<td>Readout pitch (µm)</td>
<td>242</td>
</tr>
<tr>
<td>Physical pitch (µm)</td>
<td>121</td>
</tr>
<tr>
<td>Bias resistor (MΩ)</td>
<td>40</td>
</tr>
<tr>
<td>AC coupling Al resistance (Ω/cm)</td>
<td>4.5</td>
</tr>
<tr>
<td>Coupling capacitance (pF)</td>
<td>527</td>
</tr>
<tr>
<td>Leakage current (nA/cm²)</td>
<td>1.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>ASIC name</td>
<td>TAA1</td>
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<tr>
<td>process (N-well CMOS)</td>
<td>0.8µm</td>
</tr>
<tr>
<td>die surface</td>
<td>5.174mmx6.919mm</td>
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<tr>
<td>die thickness</td>
<td>~600µm</td>
</tr>
<tr>
<td>nr. of channels</td>
<td>128</td>
</tr>
<tr>
<td>input pad pitch</td>
<td>100µm</td>
</tr>
<tr>
<td>output pad pitch</td>
<td>200µm</td>
</tr>
<tr>
<td>power consumption</td>
<td>&lt;400µW/channel</td>
</tr>
</tbody>
</table>
the readout electronics chain

- **ADC**
- **VME readout board**
- **repeater**
- **optocoupler**
acronyms

- **Enhanced NeUtrino BEams for kaon Tagging**
- **Oriented SCintillAtoR crystals**
- **Search for the ELectric DipOle Moment of strange and charm baryons at LHC**
- **$K_L$ Experiment for VEry Rare events**
- **Low EMittance Muon Accelerator**