Test and Characterization of a silicon-tungsten calorimeter prototype at SPS-CERN

Outline:
- Physics Motivation
- Design and Geometry Optimization
- Mini-Prototype: Development and Test
- Full-Length Prototype: Fabrication and Characterization
- Summary
Physics Motivation:

✓ Test of pQCD prediction (pp collisions)
  ✓ Particle production
  ✓ Effect of small-x contribution

✓ To probe the initial condition (p-A collisions)
  ✓ Gluon density at small-x (down to $10^{-5}$ to $10^{-6}$)
  ✓ Study of Color Glass Condensate

✓ To probe the final state effects (A-A collisions)
  ✓ Opacity of medium: gamma-jets correlations.
  ✓ Parton energy loss in dense partonic matter.
Design and Geometry Optimization:

ALICE Experimental Set-up

FOCAL in ALICE
Design and Geometry Optimization:

Distance from IP in ALICE: 7 m

Radial distance
Inner: 6 cm (limited by beam pipe)
Outer: 80 cm

Rapidity Coverage
2.5<\eta<5.5

P_T range of particle detection
Up to 20 GeV/c

Choice of Configuration

- Sampling type Hybrid Calorimeter
- Detector: Silicon(1 cm^2 and 1 mm^2)sensors
- Absorber/Convertor: Tungsten
Design and Geometry Optimization:

- Opening angle between two decayed photons from $\pi^0$

- Reconstructed Invariant Mass of $\pi^0$ from its two decayed photons.
Challenges

- Measurement of physics observables
  - Measurements of Direct photons, Decayed photons and their disentanglement.

- Development of calorimeter
  - 1cm*1cm silicon pad sensors
  - Reading each and every channels individually.
  - Requirement of large dynamic readout electronics.
  - Development of data acquisition system
Mini-Prototype: Development and Test.

Si-Detector array

Two set ups used to extend the depth to 6th radiation length with four available detector plane.
Mini-Prototype: Development and Test.

Response of Pion to understand the MIP behavior

$E_{\text{dep}}$ by EM-Shower initiated by electron within prototype

Conversion Curve Expt Vs Simulation

SM et all, NIMA A764 (2014) 24-29
Full-Length Prototype: Fabrication and Characterization

- Break down voltage > 500 Volts
- Leakage current ~ 10nA/cm²
- Capacitance at full depletion ~40pF/cm²
- Full depletion voltage 40 volts
- Dead space b/w 1 cm² pads ~ 110um
- Cross Talk probability ~ 10%
- Depletion width ~ 300um

Mechanical structure has ability to hold Hybrid configuration. Read out electronics can be arranged on top or side of the frame.

19-Layer prototype calorimeter at SPS

6*6 array of 1cm*1cm Silicon detector on a single wafer

HV connector
Connector for kapton cable to FEE boards
Bias resistors and capacitors
Response of Layer-no-07 of the full-length FOCAL prototype to 20 GeV Electron (Shower). Showed a nicely developed shower with mean ADC 3616.

Reconstruction of energy (ADC) deposited by EM-Shower (electron) within the full depth of the prototype calorimeter for different incident energies.
Full-Length Prototype: Fabrication and Characterization

\[ \frac{dE}{dt} = \frac{E_0 \beta t^{(\alpha-1)} e^{-\beta t}}{\Gamma(\alpha)} \approx E_0 (t)^\alpha e^{-\beta t} \]

Secondary particle generation at smaller depth

Falling part of the profile due to collisional losses at larger depth
Full-Length Prototype: Fabrication and Characterization

Calibration of measured ADC with respect to incident energy. Found good linearity for range of incident energy probed.

Fitted with $E_{\text{dep}}(\text{ADC}) = a + b \times E_{\text{incidence}}$

$a = 4.5 \times 10^2; \ b = 1.7 \times 10^3$

Resolution $\sigma/E_{\text{deposition}}$

Fitted with $\frac{\sigma}{E_{\text{deposition}}} = a + \frac{b}{\sqrt{E_{\text{incidence}}}} + \frac{c}{E_{\text{incidence}}}$

$a = 0.06; \ b = 0.08; \ c = 0.48$

Energy Resolution can be expressed as

$\frac{\sigma}{E} = a + \frac{b}{\sqrt{E}} + \frac{c}{E} + \vartheta(E)$
Summarizing:

- An exhaustive geometry and physics simulation performed.
- A mini-prototype test has been done: A proof for the concept.
- Full depth prototype characterization was done experimentally.
- Satisfactory calorimeter performances confirmed.

Outlook

- Saturation effect seen.
- NEW ASIC ANU-INDRA is ready. Test results are satisfactory at laboratory test.
- Target: Test of full-depth prototype with the upgraded electronics, May 2017.

Saturation (signal) Effects: Well taken with large dynamic range (~2.6 pC) compare to previous one (~600 fC).
Acknowledgement

Department of Atomic Energy, Govt. Of India.  
For Financial and Technical support in carrying on the R&D.

Thanks
**Time-Line, Budget and Indian contribution for FOCAL R&D**

**Possibly construction and experiment of Mini-FOCAL with ALICE**

- **2018 (LS2)**: First half 2017: LOI discussion/approval in LHCC.
- **2017-2019 (LS3)**: Converge on realistic design.
- **3Yrs**
  - R&D in pixel/pad sensors & readout.

- **2019-2020**: Finalise design
- **2021-2024**: Construction of FOCAL
- **Test and Installation in ALICE**
- **DAQ, DCS, DQM, Analysis software development**
- **7Yrs**

- **2023 (LS3)**: Aiming Final approval by ALICE for FOCAL in the beginning.
- **2031 (15Yrs)**: Detector Running and physics outputs.
## Time-Line, Budget and Indian contribution for FOCAL R&D

<table>
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<tr>
<th>COMPONENTS</th>
<th>COST (kCHF)</th>
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<tr>
<td>TUNGSTEN</td>
<td>700</td>
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<td>UNIT MECHANICS</td>
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<td>SILICON SENSORS (PADS)</td>
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<td>MAPS + ELECTRONICS</td>
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<td>CABLES AND CONNECTIONS</td>
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<td>SUPPORT AND INTEGRATION</td>
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<td>COOLING</td>
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<td>TOTAL DETECTOR COST</td>
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India will contribute
- Half of PAD detectors and associated electronics
- 1/3 of tungsten, mechanics, cables and connections, support and cooling

### For Next 3 Years
- R&D on silicon detectors, electronics, integration and manpower
- Possibly construction of Mini-FOCAL as final prototype

### For Coming 3 Years
- ~ 60 Cr INR
- 5 Cr INR
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### Institutes showed Interests

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Si-Pad Detectors and Large Dynamic range ASIC.

Si-Pixel Detectors (MAPS).

Si-Pad Detectors. Layer added options.
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Thanks a lot for your SUPPORT