First Results of the SDHCAL technological prototype

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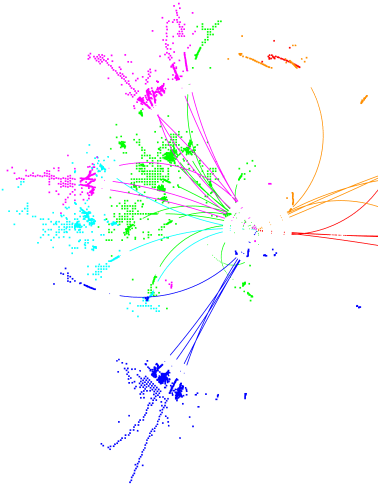
Outline

1. The Semi-Digital HCAL concept
2. SDHCAL Test beam
3. Reconstruction
4. Performance measurement
5. Event selections, and particle identification
6. First Results
    1. Binary mode
    2. Multi-threshold mode
7. Conclusion

Semi-Digital HCAL Motivation

- Particle Flow Approach (PFA) require high longitudinal and transverse granularity in calorimetry for precise JET measurement
- It implies a highly segmented sampling hadron calorimeter (HCAL)
- Digital calorimeter (DHCAL) can provide fine segmentation ($1\ cm^2$)
  - 1-bit readout system
  - Enough for pattern recognition & muon ID
  - Energy estimation → Hit Counting
    → Saturation effect @ high energy
- 2-bit readout ≡ 3 thresholds → Semi-digital HCAL (SDHCAL)
  - Can correct the saturation effect & improves the energy resolution @ high energy



SDHCAL $1m^3$ technological prototype

A technological prototype has been build to validate the SDHCAL concept.

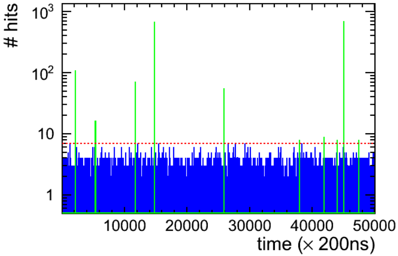
- Size : 51 stainless steel plates + 48 detector cassettes $\rightarrow 1\ m^3$
- Sensitive medium
  - Gaseous detector : GRPC (Glass Resistive Plate Chamber) of $1\ m^2$
  - Gas : 93% TFE, 5 % $\mathrm{CO_2}$, 2% $\mathrm{SF_6}$
  - HV :~ 7 kV in avalanche mode $\rightarrow$ Rate up to $100\ \mathrm{Hz/cm^2}$
  - readout pads $1 \times 1\ \mathrm{cm}^2 \rightarrow \sim$ 450 k of channels for full detector
  - Efficiency $\geq 95\%$
- Radiator : $50 * 200$ mm stainless steel $\rightarrow \sim 6\ \lambda_I$
- See Gerald's presentation for more details

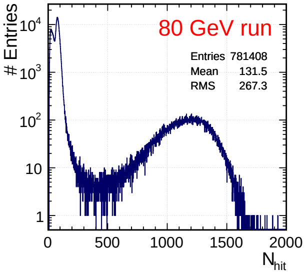
Test beam

- Test Beam periods & statistic
  - May 2012 : 2 weeks @ SPS H2
  - August & September 2012 : 2 weeks @ SPS H6
  - November : 2 weeks @ SPS H2
  - Totally : $>$ 400k of π, $>$ 1M of μ
- Beam setup
  - Beam energy known with $\Delta E_{beam}/E_{beam} \sim 1\%$
  - Low rates (lose efficiency when rate $\geq 100\ Hz/cm^2$)
  - Beam shape and rate monitored by the wire chambers and PM's respectively. (Only run with $R < 1000\ particle/bunch\ train$)
- GRPC set-up :
  - The MIP (minimum ionizing particle) induced charge ~ 1.1 pC
  - The threshold set at 114 fC, 5 pC, 15 pC (0.1 ; 4 ; 12.5 mip)
  - No gain correction (All set to 1)

Reconstruction

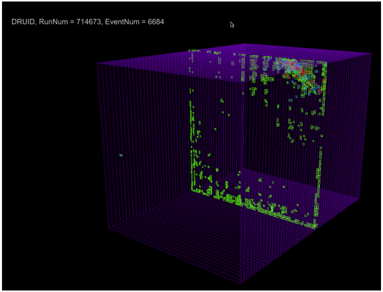
- Trigger-less mode
  - Records everything coming into the detector until the memory is full
  - Power pulsed mode according to the beam bunch train time Structure
    - for SPS : 10 s every 45 s
- 200 ns clock tick
- GRPC almost noise free ~ 0.35 hits$/200$ ns for the full detector
- The physical event is built as follows :
  - Determine the peaks on time spectrum with $N_{hit} \geq 7$
  - Take hits with $t_{peak} \pm 200$ ns as physical event





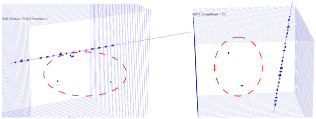
Event Quality Control

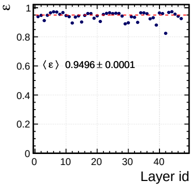
- Online control :
  - Monitoring during the run
  - Chip occupancy → chip noise
  - Efficiency by layer
- Offline control :
  - Noise out physical event measurement
  - Coherent noise
    - Electronic noise due to grounding problem in some layers
    - Easy id → hits concentrated on one layer

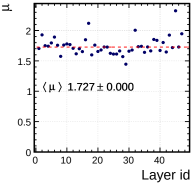


Detector performance measurement

- Use muon reconstructed tracks
- Reconstruction steps
  - Hits clustering in each layer using nearest neighbor clustering
  - Center of gravity of hit on each cluster
    $\Rightarrow$ The position of cluster
  - Isolated clusters are dropped
  - Track reconstruction based on χ^2 minimization
  - Only tracks with
    - $\chi^2 < 20$
    - $N_{cluster} \leq 1$
    - $N_{hit}(cluster) < 5$
- Efficiency & multiplicity estimation
  - Efficiency $=$ presence of at least one hit within 2 cm-radius around the projected impact point
  - Multiplicity $=$ number of hit
  - This estimation is done for each layer using the clusters of other layers to reconstruct the track







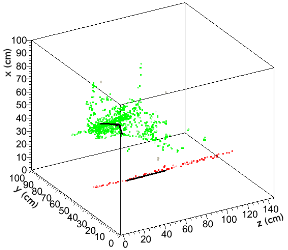
Particle identification (PID)

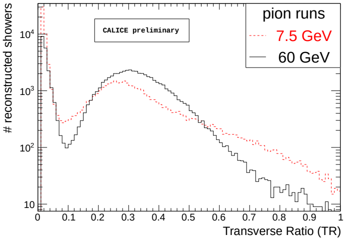
To study the hadronic showers & reconstruct their energy $\Rightarrow$ select the hadronic shower variables based on the topology, density and nature of the event

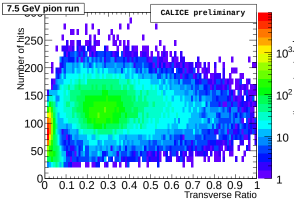
- Topological
  - Principal component analysis (PCA)
    - Principal axes are computed $\Rightarrow$ eigenvalues $\lambda_1, \lambda_2, \lambda_3$
    - $\lambda_1 < \lambda_2 < \lambda_3$ with $\lambda_i \equiv \sigma(hits)$ on axis i
    - Transverse ratio $TR = (\lambda_1 \oplus \lambda_2)/\lambda_3$
  - First interaction Plane (FIP)
    - PCA applied to each plane $p \Rightarrow \lambda_{1,p}, \lambda_{2,p}$
    - The 1^{st} interaction layer corresponds to $\lambda_{1,p} \oplus \lambda_{2,p} > 1.5\ cm$ and $N^p_{hit} > 5$
- Density
  - $V_1 = \sum_{layer} N^{layer}_{25} / N_{hit}$
    - with N^{layer}_{25} = number of hit in 5×5 pad around the barycenter
  - $V_2 = FD_{3D} / \ln(N_{hit})$
    - FD_{3D} = 3D Fractal dimension

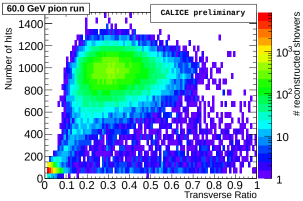
PID : Muons rejection

- Transverse ratio $TR \geq 0.1 \Rightarrow 98\%$ rejection of muons





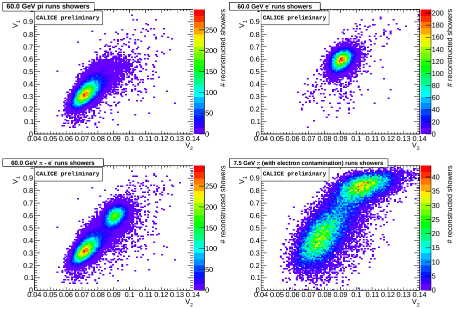




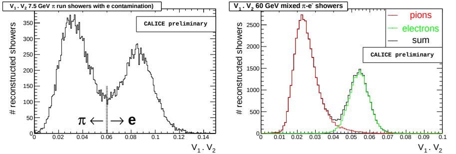
e/π separation

- $V_1 \cdot V_2$ variable gives powerful electron contamination rejection
  - Negligible loss of pions @ HE
  - few % of e^- residual contamination $E < 20$ GeV
  - Variation of the cut with E_{beam} :

E_{beam}(GeV)	cut ($V_1 \cdot V_2$)
5	0.065
7.5 - 15	0.06
20 - 25	0.055
30 - 40	0.05
50 - 60	0.045
70 - 80	0.04

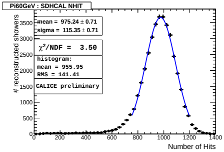


- Leakage reduction
  - FIP $< 15 \Rightarrow$ removal of late interacting hadrons
  - N_{hit}(last 7 planes)/N_{hit}(first 30 planes) < 0.15

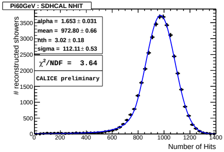


Binary mode : energy response

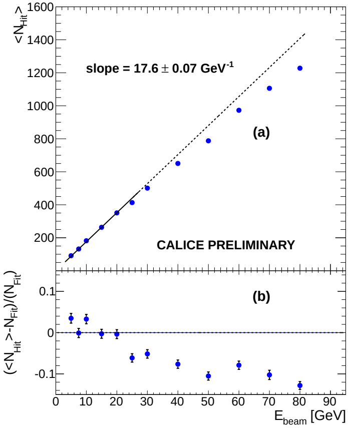
- Binary mode ⇒ Hit counting (pure DHCAL)
- 2 functions tested for N_{hit} mean estimation
  - Gauss fit in range $\pm\sigma$ → fig (a)
  - Crystal Ball (CB) fit → fig (b)
- Saturation observed for $E_{beam} \geq 30$ GeV ⇒ non linearity
- Can be corrected by a quadratic function
  - $E_{reco} = (C + D \cdot N_{hit}) \cdot N_{hit}$



1 Gauss fit

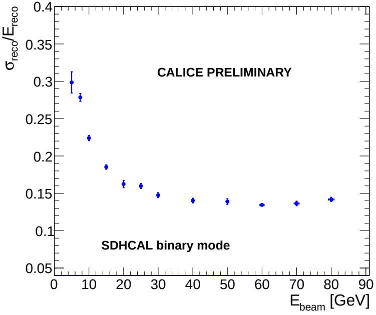


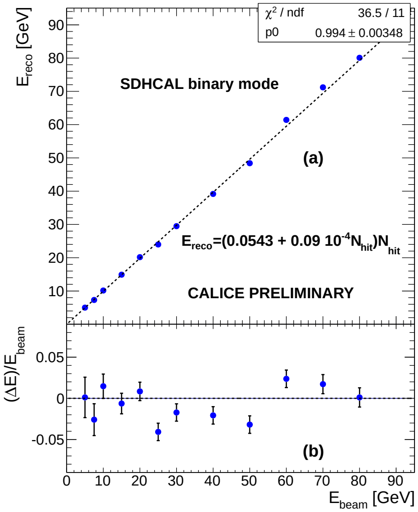
2 CB fit



Binary mode : linearity & energy resolution

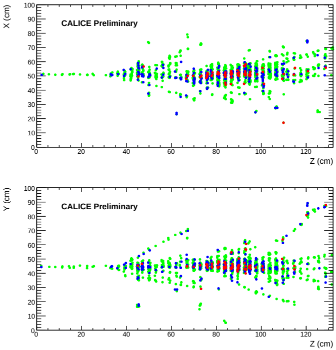
- C & D are determined by χ^2 minimization with $\chi^2 = \sum_i^{N_{event}} \frac{(E^i_{beam} - E^i_{reco})^2}{E^i_{beam}}$
- linearity restored ($\sim 5\%$)
- Energy resolution $\equiv \sigma(E)/E$ ($\sigma(E)$ = width of CB fit)
    - flat resolution over 50 GeV



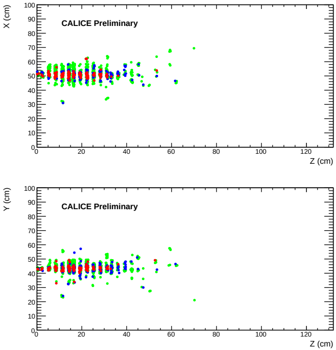


Multi-threshold mode

- 2 additional thresholds $\equiv N_{hit}$ on each threshold
- 2^{nd} & 3^{rd} threshold hits are fired in the heart of shower
  $\Rightarrow$ Additional information



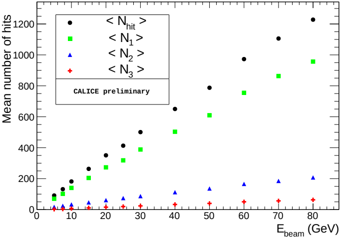
80 GeV Pions

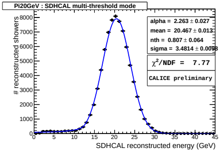


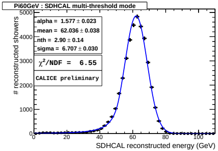
70 GeV Electrons

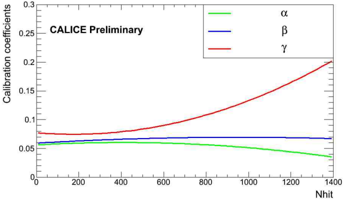
Multi-threshold mode : energy response

- $N_i =$ number of hits for Thr$_i$
- The total number of hit $N_{hit} = N_1 + N_2 + N_3$
- The reconstructed energy
  - $E_{reco} = \alpha N_1 + \beta N_2 + \gamma N_3$
  - $\alpha, \beta, \gamma = \mathrm{f}(\mathrm{N_{hit}})$
  - Parameterized as quadratic function of N_{hit} is chosen
- Same minimization as binary mode
- CB fit on the E_{reco}

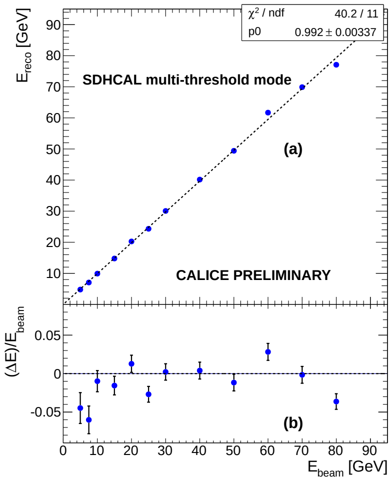




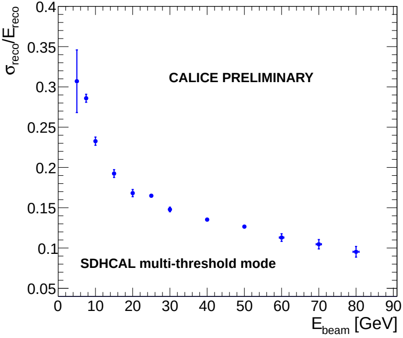




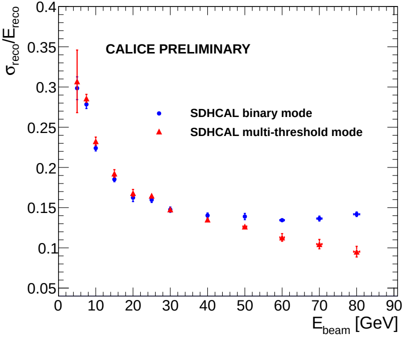
Multi-threshold mode : linearity & resolution



- Linearity $\leq 5\%$ over full range
- Significant impact on the energy resolution



Binary vs Multi-threshold



- Raw resolution (**untuned** calorimeter) in two modes Binary and Multi-threshold
- Raw performances ⇒ no pattern recognition
- Response to single pions
  - electron and muon rejection
  - leakage reduction
- Visible improvement of resolution for $E_{beam} \geq 50$ GeV $(\sigma(E)/E \leq 10\%$ at 80 GeV)

Conclusion

- The CALICE technological SDHCAL prototype using 48 GRPC with its 6 λ_I was successfully tested @ CERN
  - Power-pulsing was the running mode during the 2012 TB→ optimal condition on temperature, noise
- Preliminary results without local calibration/correction
- Multi-Threshold mode brings significant brings significant improvement @ $E_{beam} \geq 50$ GeV
- Comparison with simulation is ongoing

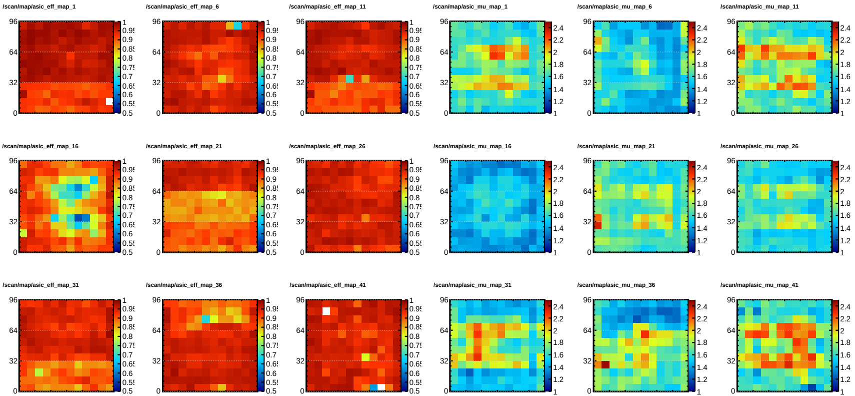
Back-up slides

Beam Conditions

- Beam of π, $e^{\pm}$, μ at CERN
  - 2 weeks in May 2012 @ SPS line H2
    - π^+ : 20, 30, 40, 50, 60, 70, 80 GeV
    - e^- : 10, 20, 30, 40, 50, 60 GeV
    - μ dedicated runs
  - 2 weeks in August+September 2012 @ SPS H6
    - π^+ : 5, 7.5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, 100 GeV
    - μ dedicated runs

Efficiency maps/ASIC's

- Example of ASIC's efficiency & Multiplicity maps for few layers.



Charge threshold scan

- Threshold scan for efficiency and multiplicity.
- for each run, the value of the threshold 1, 2 and 3 are changed in the same time for different chamber (3 chambers each).

Threshold	chamber no
t1	6, 18, 30
t2	10, 22, 34
t2	14, 26, 38

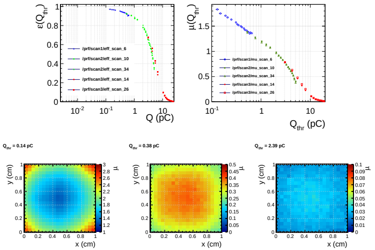
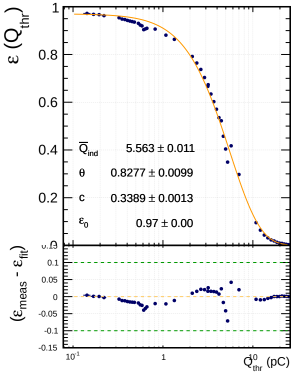


FIGURE: Distribution of the multiplicity on function of position of reconstructed on the pad.

- The colors corresponds to the scanned threshold.
- DAC vs Q is not linear at the end of 1st and 2nd threshold.

Charge threshold scan



- The polya function :
  - $\mathrm{P}(q;\theta,\bar{q}) = \left(q\frac{(1+\theta)}{\bar{q}}\right)^{\theta}\ \exp\left\{-q\frac{(1+\theta)}{\bar{q}}\right\}$
  - $\bar{q}$: mean charge.
  - θ : width of P.
- The measurement of efficiency vs the threshold means that you're integrating the charge spectrum as (polya-CDF function),

$$\varepsilon(q_{thr}) = \varepsilon_0 - c\int_0^{Q_{thr}} p(q;\theta,\bar{q})\mathrm{dq} \qquad (1)$$

ε_0 is the detector efficiency when the threshold on $0\ pC$ and c is the normalization constant.

Shower statistic

E_{beam} [GeV]	# of π's showers
5	9504
7.5	15074
10	20406
15	33405
20	78391
25	59495
30	53179
40	48720
50	76566
60	38917
70	30893
80	32964

Binary mode response (DHCAL mode)

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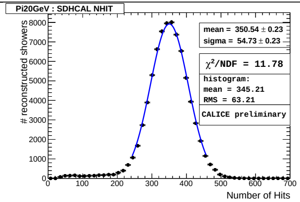
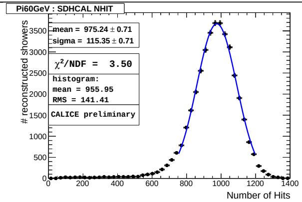
<tr><th>—</th><th>20 GeV π's</th><th>60 GeV π's</th></tr>
<tr><td>$\pm 2\sigma$ Gaussian fit</td><td>
</td><td>
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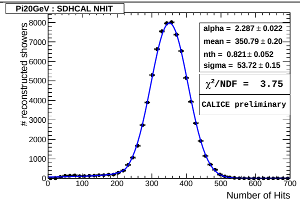
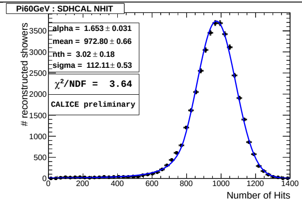
<tr><td>Crystal ball fit</td><td>
</td><td>
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Binary vs Multi-threshold