Double Readout
sandwich calorimeter

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• Homogeneous calorimeter simulation
  T. Takeshita et al 2020 JINST 15 C05015

• Double Readout Sandwich Calorimeter

Segmented in three dimensions according to the physics requirements

- Heavy scintillator such as PWO
- Cherenkov radiator & absorber such as Lead Glass
- Silicon photo sensor such as MPPC
- Embedded read-out electronics

DoubleRO Sandwich CAL @ LCWS2023 : T.Takeshita
Higgs Factory Cal.

- $H \rightarrow b\bar{b} \rightarrow 4$ jets: Jet energy resolution (JER) is a matter to separate W/Z/H
- to improve JER, PFA plays a role
- PFA requires fine segmentation to calorimeters separation of showers
- performance of PFA depends on particle energy resolution at lower energy JETs
Homogeneous CAL

- simulation with GEANT4.11.0 with FTFP_BERT photon statistics is not taken into account (2mx2mx2m)
- two parameters are to be measured
  - sum of Track Length (TL) ~ Cherenkov lights
  - sum of Energy Deposit (ED) ~ Scintillation lights traditional cal.
- correlation: linear behavior without passing the origin \( \frac{dE}{dx} \)
  - intercept → linearity calorimeter linearly
  - slope → constant independent of energy
  - common for e/\pi/K/p/n

\[ \text{PbWO}_4 + \text{pions} \]

\( \text{sim.} \)

\[ \text{ED} \quad \text{(MeV)} \]

\[ \text{TL} \quad \text{(mm)} \]

\[ \pi \& e \]

\[ 1 \text{GeV} \]

\[ 3 \text{GeV} \]

\[ 5 \text{GeV} \]
Homogeneous CAL

start from

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\[ \text{PbWO}_4 + \text{pions sim.} \]

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Intercept & Slope

**homo-cal**

- good linearity on intercept
  work as a calorimeter
- slopes are fairly constant
  - common for particles

![Graph showing intercept and slope variations for different particles](image)
energy resolution

- good correlation between ED and TL
- Energy measured by the intercept
- energy resolution is expressed by intercept width: projected to fitted line
- fine energy resolution is achieved
Cherenkov light

- Track Length ~ Cherenkov lights
- Cherenkov is low light and $1/\lambda^2$ (UV)
- need heavy and UV transparent material
- will be absorbed and converted to scintillation light
- difficult to separate lights
- timing or signal shape

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a new idea : DRSC

- separate Cherenkov radiator and Scintillation material with sandwich style
  - TL active absorber
  - ED

- with highly granular option for PFA

- DRSC
  - Double
  - Readout
  - Sandwich
  - Calorimeter

Segmented in three dimensions according to the physics requirements

Double RO Sandwich CAL @ LCWS2023 : T. Takeshita
a new idea: DRSC

- separate Cherenkov radiator and Scintillation material with sandwich style
- with highly granular option for PFA

DRSC
Double Readout Sandwich Calorimeter
Segmented in three dimensions according to the physics requirements

Inexpensive glass cal.

Heavy scintillator
Cherenkov radiator &
embedded readout electronics

Silicon photo sensor such as MPPC

DoubleRO Sandwich CAL @ LCWS2023: T. Takeshita
performance of DRSC
(2mx2mx2m cal)

- ED vs TL relation holds for sandwich calorimeter
- for both e’s and pions
- LG10mm+GSci.10mm
performance of DRSC (2mx2mx2m cal)

- ED vs TL relation holds for sandwich calorimeter
- for both e’s and pions
- LG10mm+GSci.10mm
Resolution of DRSC

- ~9%/√E (GeV) with DRSC for electrons & hadrons
- close to homo-cal
- much better than dEdx (traditional) calorimeter (const. term)

study: photon statistics and prototype
Cherenkov light detection

- **Lead glass**: $1 \text{cm}^t \times 10 \times 10 \text{cm}^2$
  for test calorimeter
- unpolished 10x10 surface diffusion
- polished at 1x10 side
- air coupled normal MPPCs
- 3cmx3cm trigger
- with cosmic muons
- 7p.e. by 6x6 mm
  for test calorimeter

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**Cherenkov light detection**

- **LG**: 2cm$^t \times 3 \times 3$cm$^2$
  - PFA cal.
- all polished & 1 non-pol.
- air coupled MPPCs
- UV and normal MPPC
  - 6mm$\times$6mm
- trigger (3cm$\times$3cm)
- with cosmic muons

<table>
<thead>
<tr>
<th></th>
<th>normal (p.e.)</th>
<th>UV (p.e.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>all polish</td>
<td>1.2</td>
<td>1.1</td>
</tr>
<tr>
<td>1 non-polish</td>
<td>3.3</td>
<td>3.0</td>
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summary and outlook

- Double Readout sandwich calorimeter
- a relation between sum of Track Length (Cherenkov) and Energy Deposit leads fine energy resolution from sim.
- actual implementation is proposed as DRSC
- R&D for DRSC is on going
  - Cherenkov light detection
electrons on DRScal

- electron energy resolution
- $\sim 4.8%/\sqrt{(E)} \sim$ Lead Glass ECAL of OPAL
• Inetercept
homogeneous cal.

- effect of punch through pions (muon)
- fitting deteriorated
reason of intercept

- when particles stop in a shower
- Bragg peak will be detected by scintillator
- no peak for Cherenkov
- intercept corresponds to number of stopping particles
Different detector material

- Liquid Argon, & CsI are simulated
- ED vs TL
- Slopes are same
- Intercept $\propto E$

ED vs TL for liquid Argon

Intercept vs energy (GeV)

ED (MeV) vs TL (mm)
Different detector material

- Liquid Argon, & CsI are simulated
- ED vs TL
- Slopes are same
- Intercept $\propto E$

ED vs TL for CsI

Intercept: $y = 52.043 + 510.8x, R=0.99999$

ED(MeV)

TL(mm)

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TL vs Cherenkov light

- nice correlation: we can use track length instead of number of Cherenkov light which consume CPU power for simulation.
DRSC

- LG 4mm + Plastic Scintillator 8mm sandwich calorimeter

- NO correlation

- need heavier scintillator
wave length features

- Cherenkov detection in Lead Glass and UV transparent radiator
- VUV-MPPC

UV grade Fused Silica is synthetic amorphous silicon dioxide of extremely high purity

Transmittance
visible light

Glass
Lead Glass

\[ \lambda \text{ (nm)} \]

PDE

PDE

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energy resolution

- compare dEdx cal. and DRSC in terms of $1/\sqrt{E}$
- dEdx cal. suffers from Hadron model interference?
test module

- Double read Sandwich Calorimeter
- test module

![Diagram of test module with layers labeled: lead glass layer, glass scintillator layer, and silicon photo sensor.]