RD52 Status report
Dual Readout Calorimetry

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RD52 goal

RD52 is a generic detector R&D project, not linked to any experiment

Goal:
• Investigate and eliminate factors that prevent us from measuring hadrons and jets with similar precision as electrons and photons
• Develop a calorimeter that is up to the challenges of future particle physics experiments
Dual REAdout Method (DREAM):
Simultaneous measurement, during shower development, of:
• Scintillation light \((\text{d}E/\text{d}x\text{ charged particles})\)
• Cherenkov light \((\text{em part of the shower})\)
→ Measurement, event by event, of \(\text{em}\) fraction of hadron showers
→ Reduction of fluctuations in \(\text{em}\) fraction

Same advantages as for compensating calorimeters \((e/h=1)\), without their limitations (sampling fraction, integration volume, time)

Result:
• Correct hadronic energy reconstruction \((\text{detector calibrated with electrons})\)
• Linearity
• Good energy resolution for hadrons and jets
• Gaussian response functions
Results since 2015 LHCC

+ 2 in preparation (data taken during test beam Nov 2015)

- **Hadron detection** with a dual-readout fiber calorimeter
- **Characteristics of the light** produced in a dual-readout fiber calorimeter

Published in 2016, most of the results already presented last year
Scintillators to detect leaking showers (20)

Trigger, tracking, preshower, interaction target

72 towers, 20 leakage detectors

**Hadron detection with RD52 fiber calorimeter**

**Experimental setup (H8)**

**RD52 Pb prototype (INFN Pavia)**

3*3 Pb modules, each of them:
- 9.3 * 9.3 * 250 cm$^3$ (10 $\lambda_{\text{int}}$)
- Fibers: 1024 S + 1024 C, 8 PMT
- Optimized sampling fraction: 5%
Hadron detection with RD52 fiber calorimeter

Hadronic energy resolution

Dominated by
- leakage fluctuations

Analysis of each energy in progress
Hadron detection with RD52 fiber calorimeter

Hadronic energy resolution

Fraction of total leakage signal in the upstream ring of L counters

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Dominated by
- leakage fluctuations
- **Light attenuation (S)** due to fiber cladding

Shower starts deeper inside calorimeter

Shower starts early

Dual-readout calorimeter signal for 60 GeV pions
Hadron detection with RD52 fiber calorimeter

Proton/Pion comparison

π showers:
- more em fraction
- more fluctuations

Energy response: Raw data

80 GeV π
Cerenkov
\( \alpha/E = 24.5\% \)

Energy response: Dual readout corrected

80 GeV p
Cerenkov
\( \alpha/E = 22.0\% \)
Hadron detection with RD52 fiber calorimeter

Proton/Pion comparison

**π showers:**
- more em fraction
- more fluctuations

**Energy response:**
- Raw data
- Dual readout corrected

Differences vanishes if dual readout corrected energy
Characteristics of the light produced in a dual-readout fiber calorimeter

Experimental setup (H8)
Characteristics of the light produced in a dual-readout fiber calorimeter
MCP + DRS readout for fast signals

![Graph showing time (ns) vs. average signal amplitude (arbitrary units)]

- **a)**
  - Direct component
  - Reflected component
  - Čerenkov signal

- **b)**
  - Scintillation signal

**Graphs:**
- Time (ns) vs. Average signal amplitude (arbitrary units)
- DRS channel vs. Average signal amplitude (arbitrary units)
Characteristics of the light produced in a dual-readout fiber calorimeter

Measurement of C fiber characteristics

- Cherenkov light attenuation
- ... and reflection

![Graph showing Cerenkov light attenuation and reflection](image)

- Analysis in progress
1) **Measure proton/π differences in time signal time structure** (Pb matrix + DRS readout)

Can calorimeter data be used to identify p/ π event by event?
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Can calorimeter data be used to identify p/ π event by event?

2) **Test SiPM readout on a new small Cu module. Proof of principles**
- Get rid of the “fiber forest” antennas
- RO closer to the end face
- Transversal segmentation as small as needed
- Possible longitudinal segmentation
- Possible operation in magnetic field

Important for a 4π calorimeter

Fiber bunches + **PMT**

**SiPM** matrix coupled to end of detector
2016 test beam preparation

**Practical problem:**

- two kind of fibers, very different light yields:
  - **C**: $\sim 50$ p.e./GeV (large efficiency)
  - **S**: $\sim 1000$ p.e./GeV (large dynamic range)

**Ongoing preparation:**

- two small modules (skived Cu) $15*15*100$ cm$^3$, 10*10 fibers. (Iowa State University)
- Hamamatsu: matrix 8*8 SiPm 1mm$^2$
- M.Caccia (Como) in charge of readout board

*Hopefully everything will be ready to be tested in October 2016 testbeam (still not 100% granted)*
Long term plans

Idea to build a **full containment Cu dual readout calorimeter** (same structure as the few tested modules).

On the way of finding the **best technology to machine 1 mm grooves in Cu**. Need to be industrial compatible to lower prices
Toward industrial Cu production

- geometry: high grooves density, sampling fraction (5%)
- Cu as absorber for energy resolution performances
- Reduce inhomogeneity (constant term at high E)
- Cu not easy to be machined
Toward industrial Cu production

Cu grooving techniques investigated:

Abandoned for Cu

- Rolling
- Extrusion (Used techniques for Pb calo: KLOE, ATLAS LAr, SPACAL)

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Promising
To be more investigated, better if couple to rolling for fine adjustments
- Water jet (industrially compatible)
- Chemical milling (industrially compatible)
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**Used**
- Saw scraping with rotating calibrated disks (not industrially compatible)
- Skiving (used for a small prototype but not imperfect and expensive)
- Drilling

2015, ISU
2012, INFN Pisa
RD52 prototypes
2015, CERN PCB workshop
2016, ISU ongoing trials
Long term plans

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Problem: no new funding, few resources

Since beginning of RD52 project (2012) tested almost everything one can do with relatively small prototypes (dual readout crystals, fiber calorimeters).

A future experiment interested in dual readout calorimetry could complete the work, starting from solid basis.
From RD52 fiber prototypes to a $4\pi$ calorimeter

**Best solution found:**
- Copper Dual Readout (em + had) fiber calorimeter
- high fiber filling fraction
- not longitudinally segmented
- read out with fast electronics (< ns)
From RD52 fiber prototypes to a 4π calorimeter

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Suggestions on what needs to be done/completed:
• Projective geometry  \((NIM A337 (1994) 326-341)\)
• Use/optimization of SiPm
• Rad hardness Cherenkov clear fibers
• Industrial production of grooved Copper
• Custom fast electronics
• …
More Slides
Choice of the RD52 fiber calorimeters components

**Scintillating fibers**: doped SCSF-78, (produced by Kuraray) + **YELLOW filter** to eliminate effect of self absorption in the short wavelength region ($\lambda_{\text{att}} > 5\text{m}$)

**Cherenkov fibers**: PMMA based SK40 (produced by Mitsubishi), measured $\lambda_{\text{att}} \sim 6\text{m}$. Good numerical aperture **Aluminized front end** (in only one Cu prototype). With Sputtering, at Fermilab.

- more C light,
- more uniform response as a function of interaction depth
- With precise time information, possible to know the interaction depth

**Phototubes**: Hamamatsu R8900, a 10-stage, super-bi alkali photocathode, 21 mm size of active area.

- Largest possible ratio (85%) between the photocathode surface and the total surface to minimize dead zones between towers;
- Squared section cathode to have the best fiber packing
Absorber choice: Cu vs Pb

- Detector mass: $\lambda_{\text{Cu}} = 15.1 \text{ cm}$, $\lambda_{\text{Pb}} = 17.0 \text{ cm}$
  Mass $1\lambda^3$: Cu/Pb $= 0.35$

- $e/mip \rightarrow$ Čerenkov light yield Cu/Pb $\sim 1.4$
  (Showers inefficiently sampled in calorimeters with high-Z absorber)

- Non-linearity at low energy in calorimeters with high-Z absorber
  Important for jet detection
Small-angle em performance

Em showers very narrow at the beginning;
Sampling fraction depends on the impact point (fiber or dead material)

If particles enter at an angle the dependence disappears

Fluctuations on different impact point

Effect NOT seen in Cherenkov signals since early part of the shower do not contribute to the signal (outside numerical aperture C fibers)
Small-angle em performance

S, C: sample INDEPENDENTLY the em showers

→ We can sum their contributions
→ em energy resolution improves by a factor $\sqrt{2}$

Good em energy resolution
Time structure (1)

Average Cherenkov signal (40 GeV mixed beam) from tower around the beam axis

- Depth shower max ~ 5 cm
- Depth shower max ~ 25 cm
- Average depth light production ~125 cm

Particle ID possibility in longitudinally unsegmented detector.
Time structure (2)

Comparison signal shape leakage counters (average signal)

- Prompt charged shower particles escaping the calorimeter
- Signal produced by recoiled protons from elastic neutron scattering
  time constant 10-20 ns

- Near shower maximum
- Deep in tail

Sensitivity to the neutrons → Possible to improve resolution

Leakage counters → Shower max

40GeV pi
Monte Carlo simulations

*Nucl. Instr. Meth. A762 (2014) 100* DREAM method simulated with GEANT4

2015: Repeated some of these simulations with high precision version of had. showers (neutrons followed in details)

W/Z hadronic decay separation, high precision GEANT4 full-size Cu RD52

Goal for future e+e- accelerators