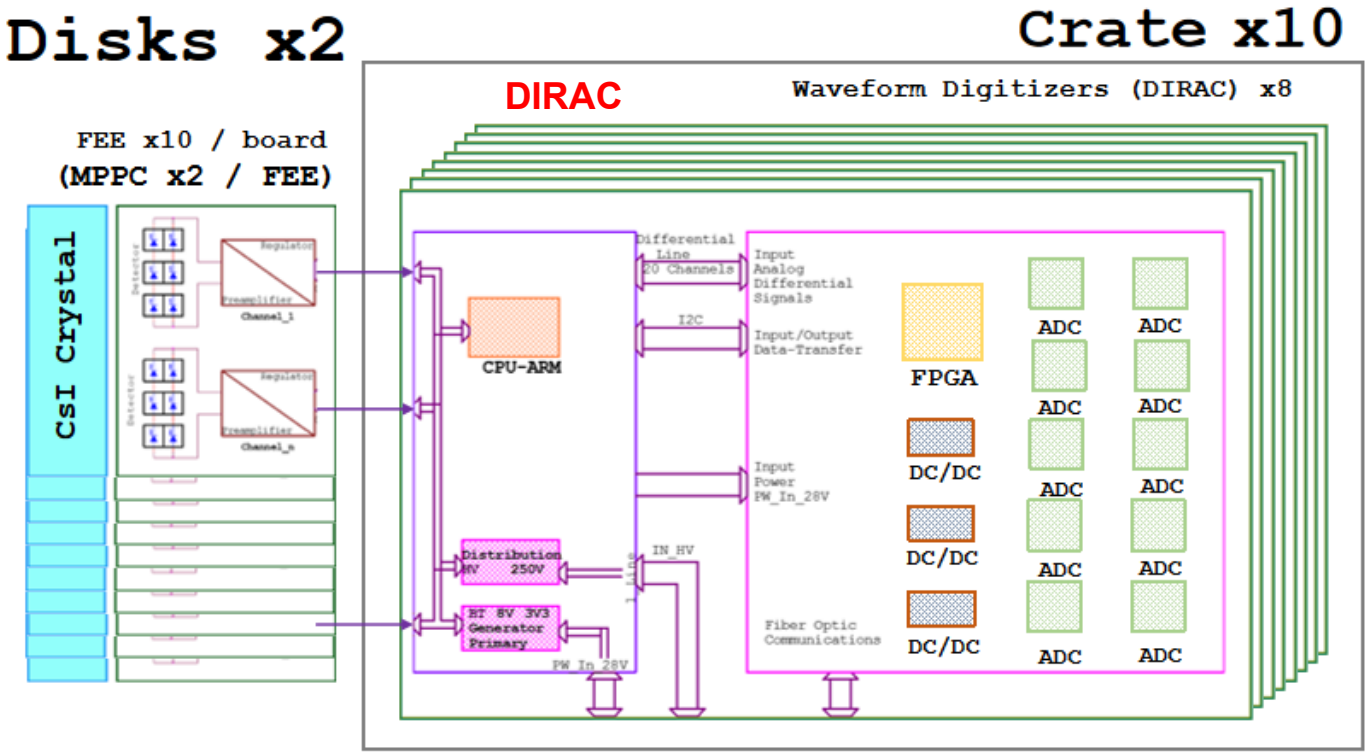
Status report DIRAC board

F.Spinella, E. Pedreschi, L. Morescalchi, A. Taffara

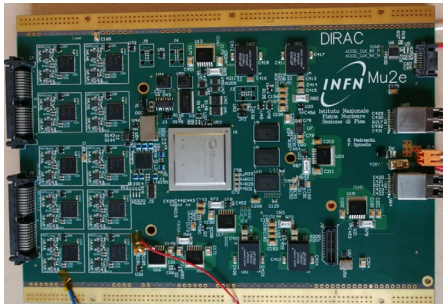
Calorimeter electronics scheme

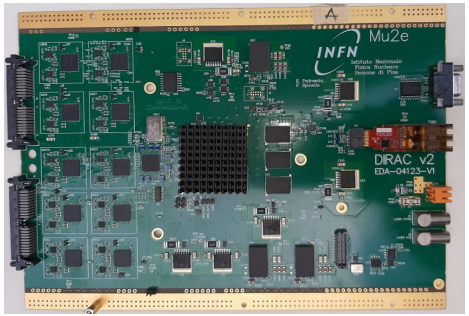


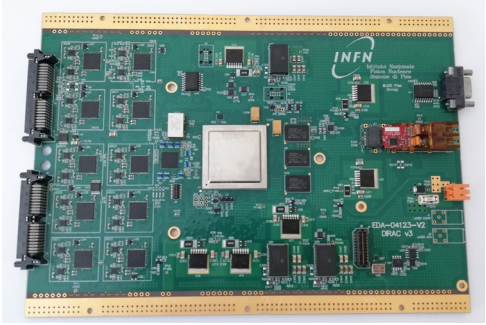
- 20 channels/DIRAC
- 200 MHz, 12 bit ADC
- fiber readout
- 28 volts

- 20 crates
- 136 DIRAC
- 4 TRAD (DIRAC + mezz)
- 160 schede prodotte
- 10% componenti spare

Dirac: versions







- V1
  - Smartfusion2 FPGA
  - Cotsworks transceivers
  - LTM8033

- V2
  - Polarfire FPGA
  - VTRX transceiver
  - LMTM33606

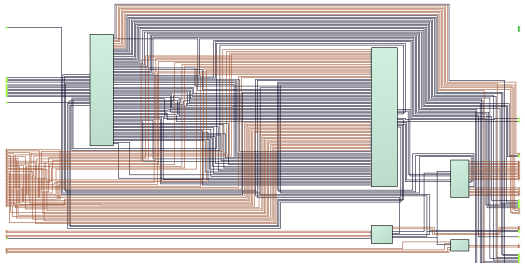
- V3
  - Similar to V2
  - Auto-reset toward mezzanine
  - Compatible with commercial transceiver (backup to VTRX see CERN reports)
  - Prototype under test since 4/2022

All versions functionally ok. Mods due to :
- **new specs from collaboration**
- **Issues due to the harsh environment (B, rad)**

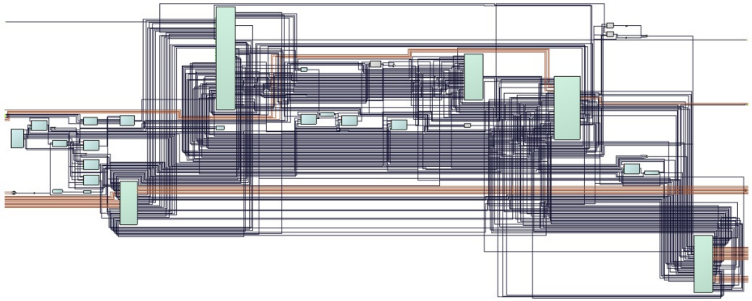
Firmware

- Quite complicate ... huge amount of data, FPGA of medium performance
-> forced solution due to radiation and cost
- Most of the firmware is written and tested
- 2 parallel designs: FE interface to ADC & data handling,compression and interface to DAQ, works fine at full speed -> fused recently, under test ..

FE

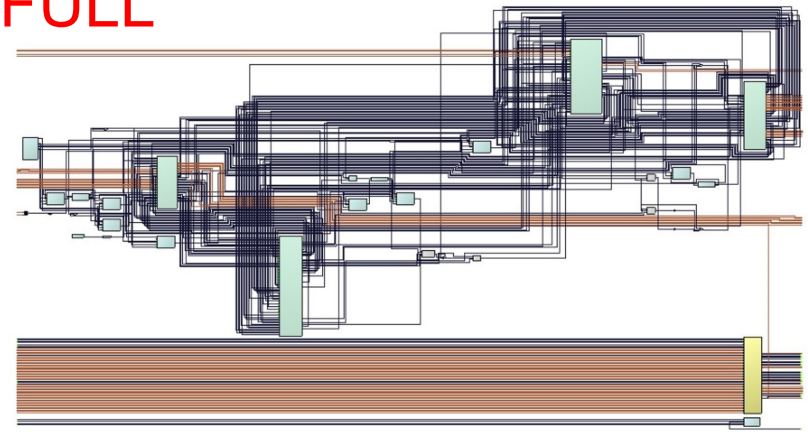


DAQ

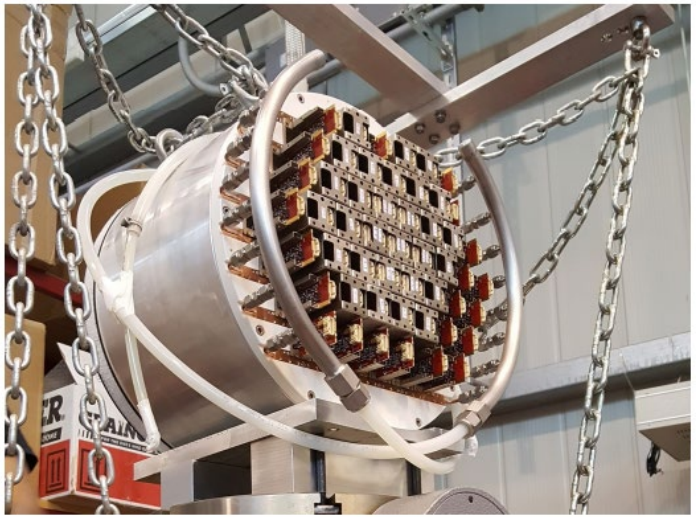


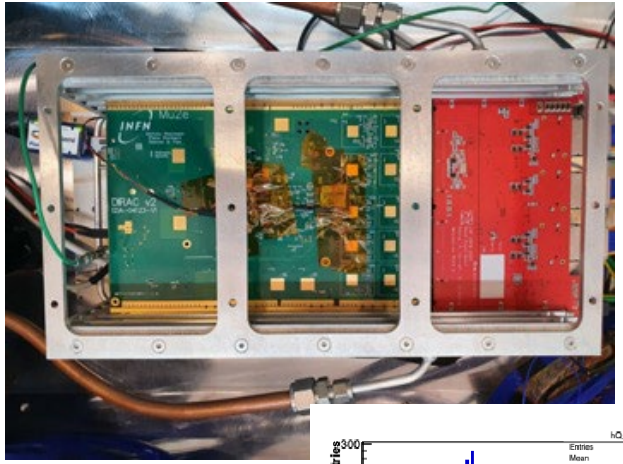
+

FULL

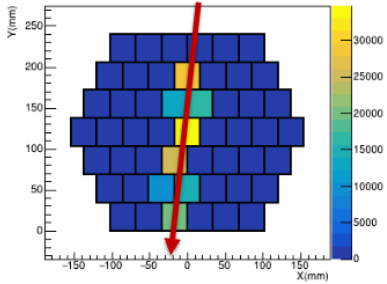


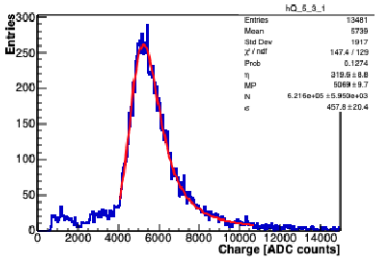
Test at M0





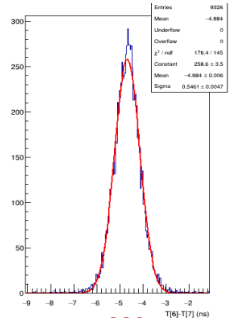
Event Display





MIP charge distributions (MPV = 21 MeV)

Time resolution of about 300 ps on MIP



Time difference of two SiPMs/Crystal

- Full electronics chain used for full Vertical Slice Test (VST)
- **Data collected in vacuum, at low T and with irradiated sensors for the last 10 months**
- **Acquisition of Cosmic Rays**
- Stable operation and reconstruction
- Data taking of CR events triggered with external scintillators

Production

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- Bid for 160 boards + spare components assigned to DF electronics in 2020
- We asked to buy all parts except FPGA (due to firmware design in progress)
- All parts arrived and stored at their facility. DDR arrived recently.
- We asked to buy also FPGA in 2021 but we were hit by the famous semiconductors shortage crisis
- Current FPGA delivery is March 2023 (increasing ...)
- Following FPGA delivery production is supposed to be fast
- All the other Mu2e subD have same problem (or worse ...)

Qualification tests

- All board versions must be qualified against dose,neutrons,B, thermal dissipation in vacuum
- V2 was fully qualified, V3 is very similar to V2.
- Recently (2020) the collaboration is asking also SEU tests with high energy hadrons (protons)
  -> they provide access to Warrenville Hospital Hadron therapy facility (high flux of 200 MeV protons)

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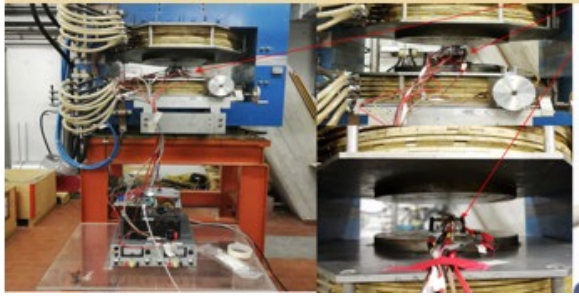
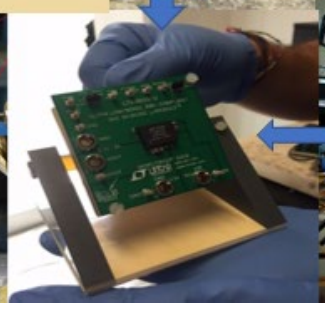
- **Calliope @ENEA**
  - Co60 source
  - Dose in function of distance: Max 2krad/h, requested 1krad/h
  - Full V1 board test

- **YELBE @HZDR**
  - γ from Bremsstrahlung (0<E<14MeV)
  - Estimated dose ≈ 20 krad/h @ 600μA
  - Single components test

- **LASA @INFN-Milano**
  - 1 T magnetic field
  - Different orientations





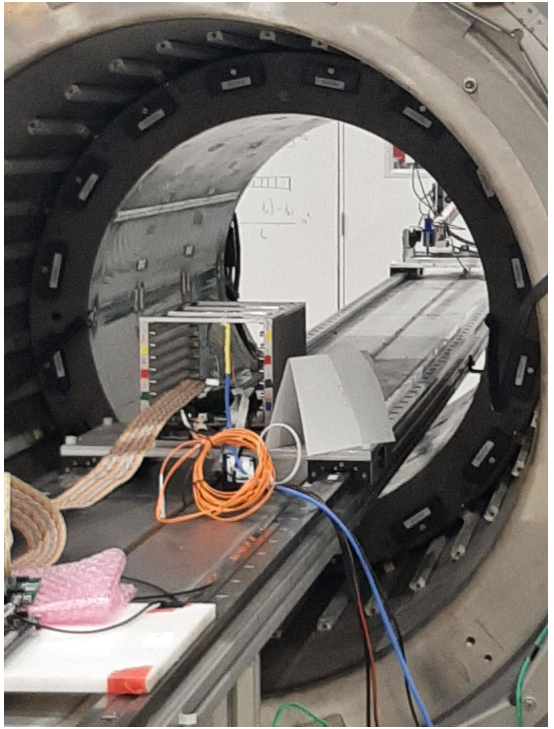
- **FNG @ENEA**
  - 14 MeV neutrons from D+T
  - Total neutron flux of 1.2 x10^12 n 1 MeV (Si) / cm^2
  - Total neutron flux of 6x10^11 n 1 MeV (Si) / cm^2

V3 qualification tests

- B field test -> Done (Argonne lab. 19 July 2022)
- SEU test -> Done (Warrenville Hospital, 21-22 July 2022)
- TID, neutrons, vacuum -> to be done next weeks

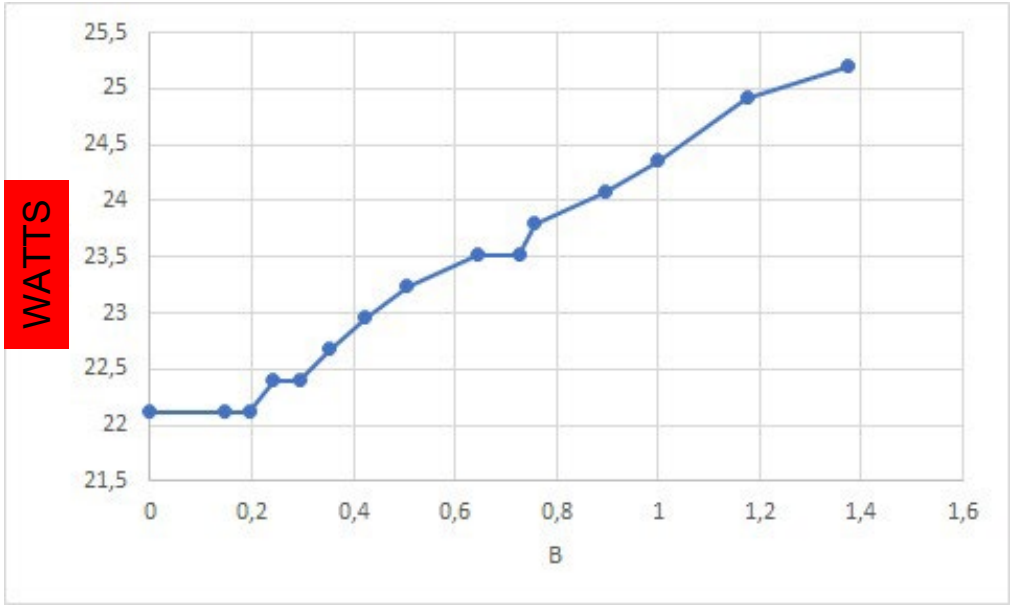
DiRAC V3 B field test

19 July 2022 B test @ Argonne National Laboratory (IL)



DIRAC V3 B field test

- Tested all directions. B ranging from 0T to 1.4T
- Slight power increase at 1T
  ~10% toward 0T in the
  “Mu2e direction”
- Confirm previous results
- Test OK



DiRAC V3 Single Event Effect test

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20 - 21 July 2022 SEU test @ North Western Medicine Proton Center Warrenville (IL)

DiRAC V3 SEU test

- First night of test:
  - Misunderstanding on the flux intensity ... we asked 1E10 p/cm2sec uniform on the board and we got a raster beam of 1 cm2 moving on the board. Istant intensity of 1E15 p/cm2sec.
  - After few seconds dataflow stopped and I raised to 0.97A (normally 0.75A) ...smell of fire
  - We verified that the flash component fired (latch-up)
  - After replacing the flash (the day after) the board was again operative

DiRAC V3 SEU test 2

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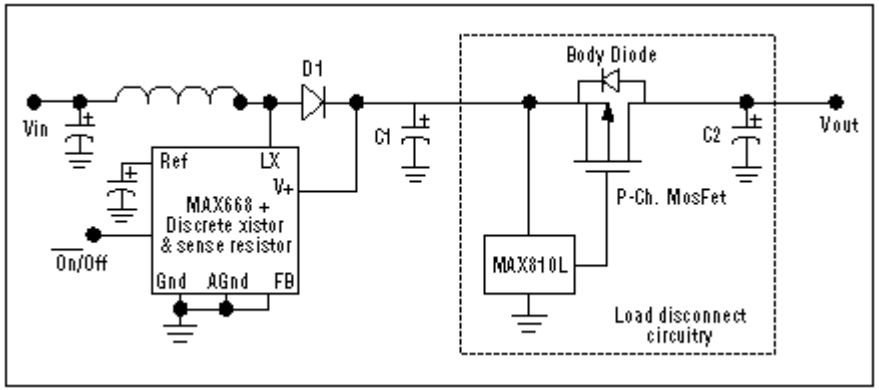
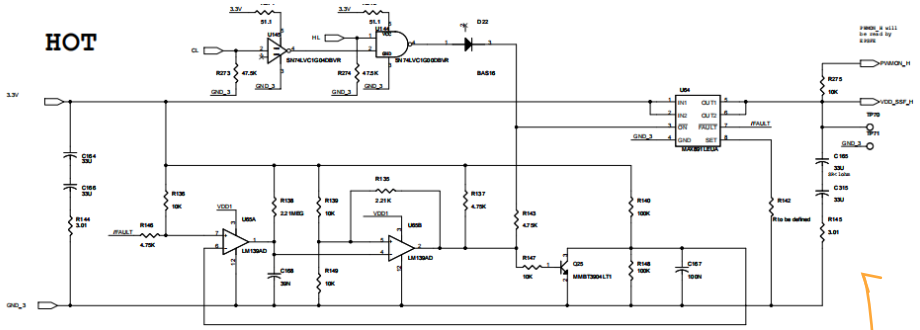
- II night, several hours of test with increasing fluxes, uniform beam all-over the board. Total fluence ≈ 1E10 p/cm2
- **We saw 4 latch-ups**. Current limited to 0.8 A on the power supply. No damage. The board worked fine again after a power cycle. Current limit was ok to save the board.
- SEU analyses under study (not so important toward latch-up... no evidence at first seen)
- Latch-up is unexpected: almost all components tested at Warrenville by the tracker group
- Mu2e Montecarlo simulations: flux of 1E10 hadrons/cm2 with E< 20 MeV in 5 years (including safety factor)
- 1 board breaks every 5 years -> 136 boards -> one board every two weeks. Evaluating 200 Mev toward < 20 Mev

- We need to protect the board with a solid state fuse (SSF)

SSF

SSF: monitor current and shut down power for a short time if it goes over a given threshold





- Standard in space boards (heavy ions...)
- Can be integrated or made of discrete components, must be very reliable ...
- We used a discrete one in AMS-2 .. does not work at 28v ...

SSF2

- We are evaluating several solutions:

1. Modify 9th crate board (power distributor)
2. Add the SSF to the DIRAC (2/ board: one for DIRAC and one for mezzanine)
   - DIRAC v4
   - At the moment seems the preferred solution (9th boards already produced,
     can't protect the mezzanine separately ...)

SSF3

- Add to DIRAC: several possibilities, we would prefer an integrated solution.
- e.g TPS26635, but must be qualified ...

- Rad hard components ... $$$ ... CERN uses a similar part to TPS26635 but it is not suitable for us ...
- Surely we need to produce another version of the prototype ...

Budget requests

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- Several solutions under study ...

prototipo scheda DIRAC V4, necessita di aggiungere circuito di protezione da latch-up dopo test di SEU con protoni 200 MeV	15.00	0.00
componenti aggiuntivi per produzione schede DIRAC V4, per la realizzazione del circuito di protezione 150 euro x (160 schede + 20 % spare) . SJ a test aggiuntivo con protoni 200 Mev e neutroni 14 MeV	0.00	25.00
estensione RAM a 4 Gbit per prdoduzione DIRAC. SJ a reale necessita' se evidenziata da MC ulteriori	0.00	6.00
prototipo scheda TRAD V2, aggiornamento per aggiunta circuito di protezione, 1 K SJ per eventuale costo componenti aggiuntivi	3.00	1.00

- V4: we know with precision: 19K all inclusive. We already have some components in hands
- Production update: SJ to technical choice (100 euro/board + VAT as a first try)
- Same for TRAD (v1 needs some small mods anyway)
- Tracker recently doubled RAM buffer from 2 to 4 Gbit. ECAL could need the same. Waiting for new Montecarlo sim. PCB already compatible. SJ to MC