Electronics for NEXT: a neutrino experiment with a Xenon gas TPC

A solution based on RD-51 electronics

J. Toledo on behalf of the NEXT collaboration

Who are we?

We are several spanish institutions

- IFIC CSIC-University of Valencia
- Universidad Politécnica de Valencia
- IFAE - Barcelona
- University of Zaragoza
- CIEMAT - Madrid
- Universidad Santiago de Compostela

and three foreign institutions

- Universidade de Coimbra, Portugal
- IRFU - Saclay. France
- LBNL, Berkeley USA

Others may join …

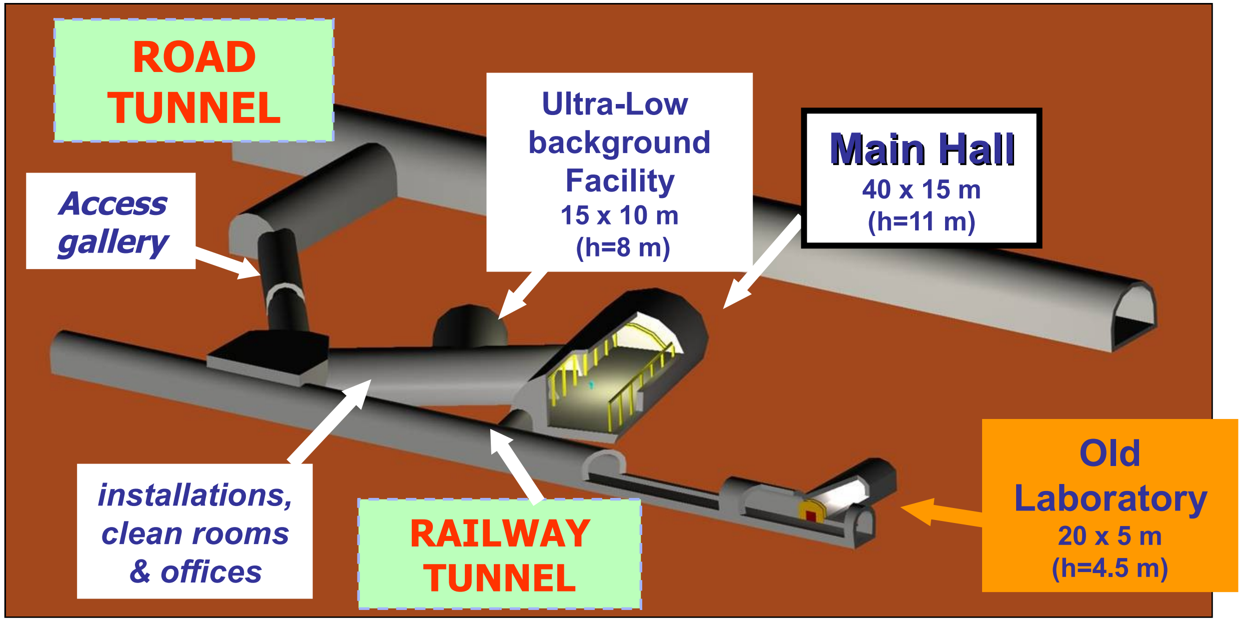
NEXT is a new double beta experiment

funded and approved in July 2008 for operation in the new Canfranc underground facility

Institutional support

Partially funded by the Ministry of Science and Innovation with the approval of the project CUP (Canfranc Underground Physics) and the funding program CONSOLIDER-INGENIO in 2008

The experiment site: the new Canfranc Underground Laboratory (LSC)



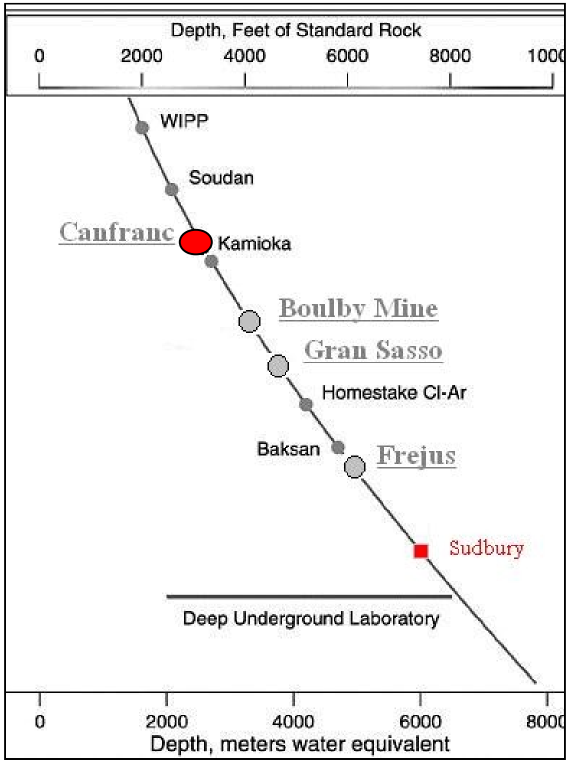
Depth: 2400 m.w.e.

Surface: 1000 m^2

Muon flux 2.4 10^{-3} µ.m^{-2}.s^{-1}

Neutrons: 2 10^{-2} n.m^{-2}.s^{-1}

Radon: 50 - 80 Bq/m^3



Our leading idea

Goal: **build and operate a TPC filled with 100 kg HPGXe enriched with ^{136}Xe to measure its $\beta\beta0\nu$ decay.**

Gas-filled TPC allows high energy resolution with xenon gas <0.55 g/cm^3 and 3D track topology for background rejection.

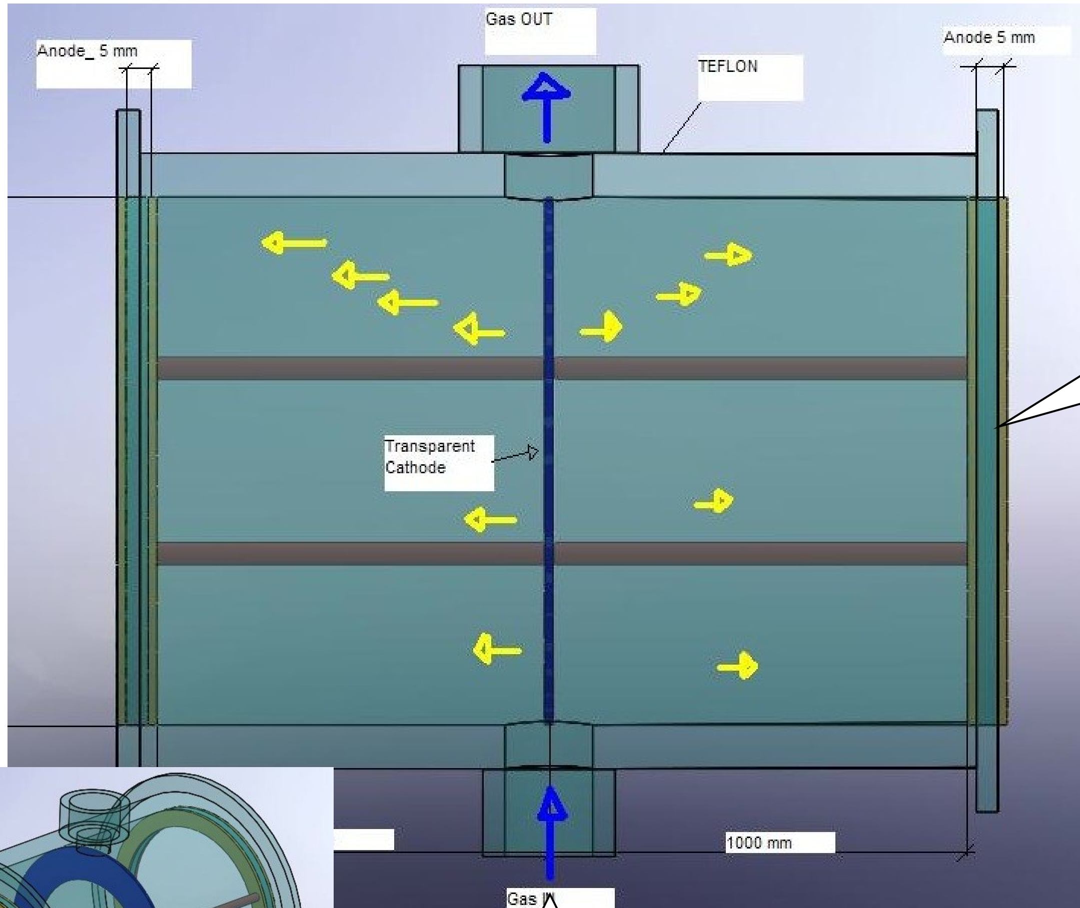
SOFT (Separate-Optimized Function for Tracking) electroluminiscent TPC concept

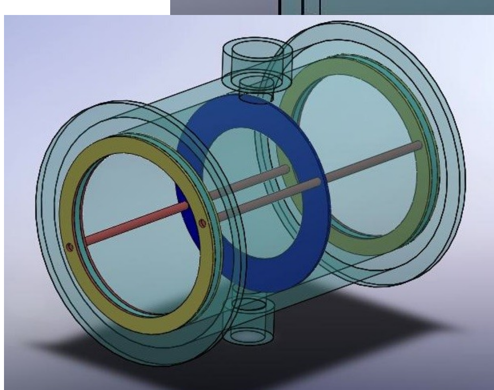
Time schedule

- ✓ $1^{1/2}$ years from now for the NEXT-1 prototype operation
- ✓ $2^{1/2}$ years from now for the 1:10 prototype NEXT-10 to prove feasibility
- ✓ $4^{1/2}$ years from now for NEXT-100 with full operation in the LSC

We plan to use RD-51 electronics already in NEXT-1

Conventional EL TPC





Anode : wire grid
UV PMT readout
at each endcap

Cathode -HV

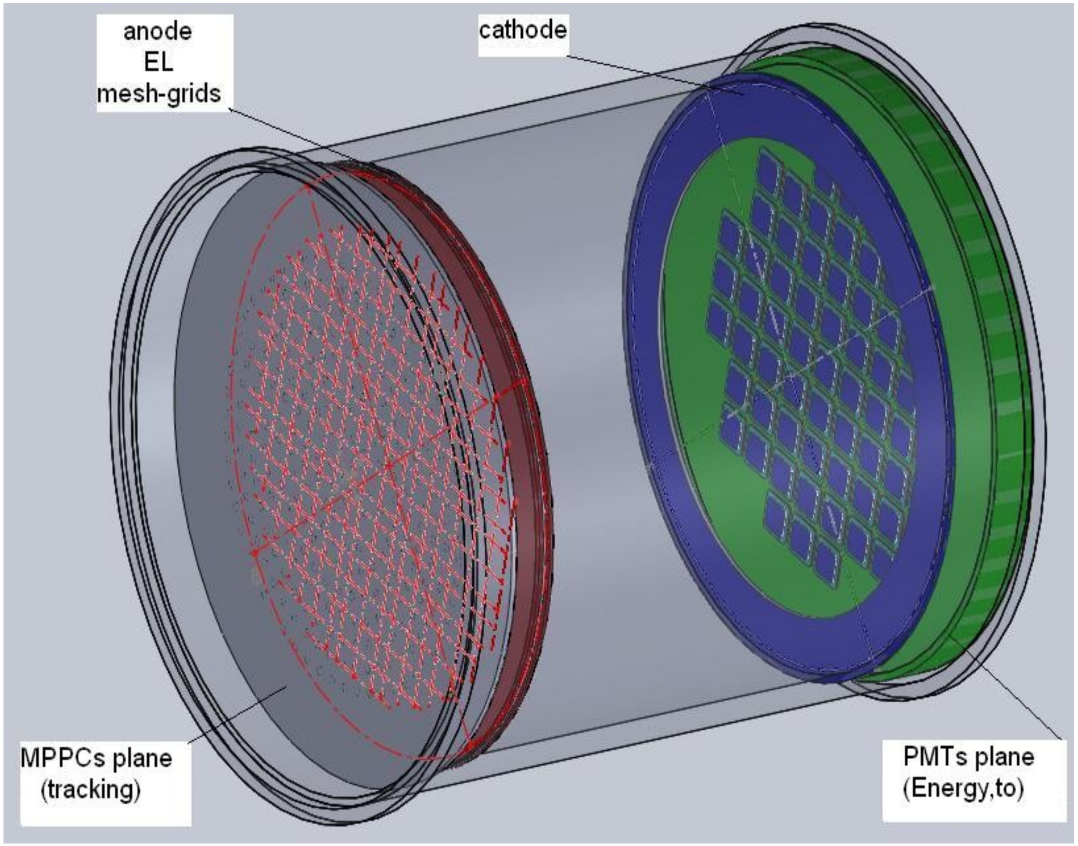
Drawbacks

- Low optical gain ≈ 300
- Very large number of PMTs (~2500) high cost, radioactivity)
- Large dynamic range for PMT readout

NEXT conceptual design: SOFT TPC

Separate-Optimized Function for Tracking (SOFT)

- ✓ Uses EL mesh-grid (3-5 kV/cm) at the anode to convert ionization into proportional UV Light
- ✓ High optical gain with voltage tuning in the EL gap
- ✓ One volume totally active
- ✓ Separate technology for energy and tracking:
  - > PMTs behind the cathode for Energy, t0
  - > Tracking plane behind the anode

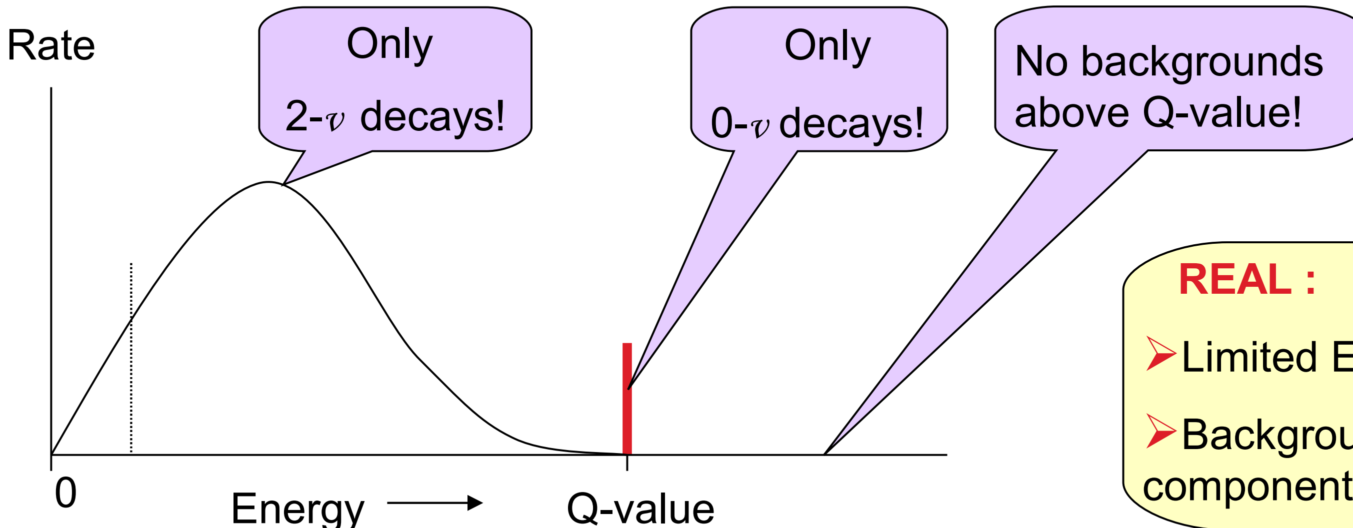


Dimensions

- ✓ drift length : 140 cm
- ✓ diameter : 140 cm
- ✓ xenon mass : 108 kg (10 bar)

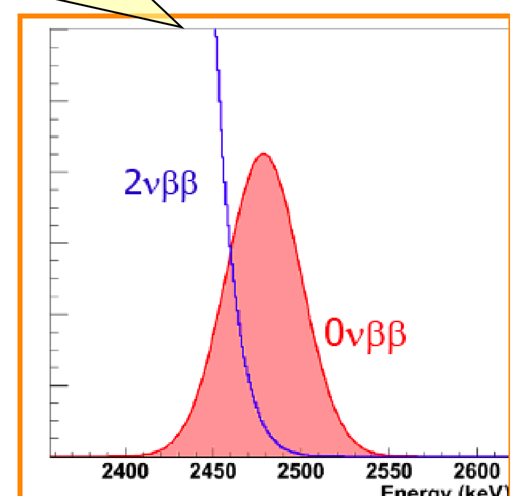
Energy measurement

Goal: measure how much energy is collected (±1%) in cathode PMTs



REAL :

- Limited Energy resolution
- Background in detector components and surroundings



IDEAL :

- Optimal separation of ββ-2ν and ββ-0ν populations
- No background

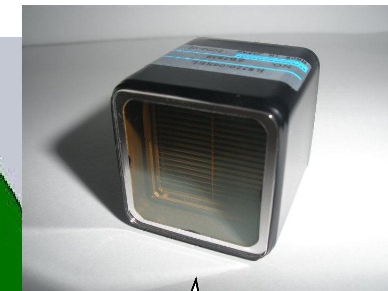
Energy measurement with PMT plane behind the cathode

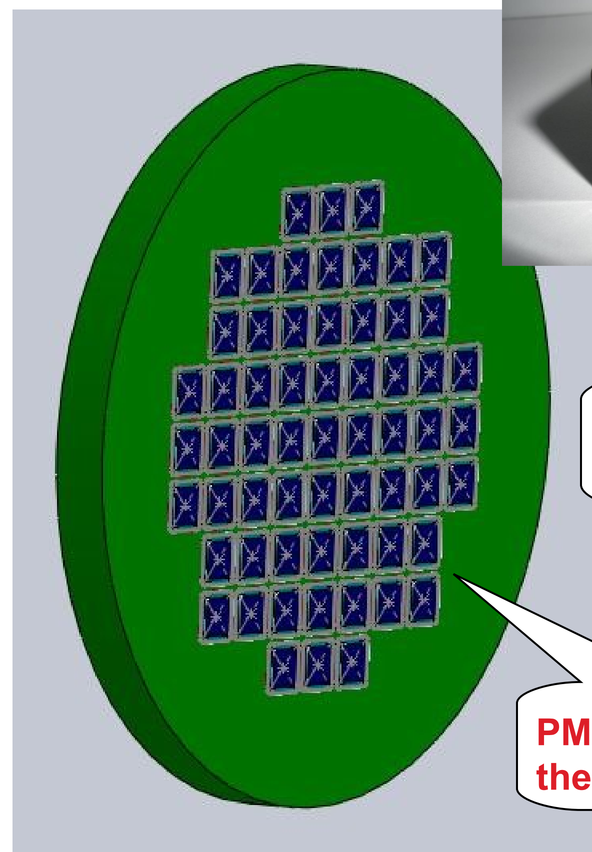
NEXT PMT: **R8520-06SEL from Hamamatsu**

This is a modified version of XENON PMT R8520-06-AL

Main characteristics:

- ✓ Radioactivity: **0.5 mBq for U and Th chains**
- ✓ Pressure resistance**: 5 bar**
- ✓ Spectral response: **160 - 650 nm**
- ✓ Quantum efficiency**: 30% at 175 nm**
- ✓ Gain: **1.0 x 10^6**
- ✓ Window material: **fused silica**
- ✓ Anode dark current: **2 to 20 (max) nA**





R8520-06SEL Hamamatsu

PMTs plane behind the TPC cathode

What do we expect from Hamamatsu?

- ✓ increase pressure resistance up to 10 bar
- ✓ increase size → optimize coverage at lower number of channels and lower price

What do we need to develop?

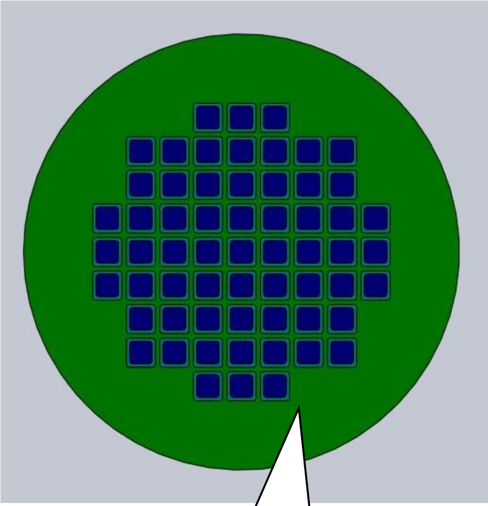
- ✓ FE for 1% energy resolution !!!!

Start of event time (t0) measurement

Goal: measure with ~20 ns resolution when has the primary scintillation occurred

- The primary xenon scintillation (λ_{max}= 175 nm) readout provides the start-of-event time t0.
- t0 is necessary to place the event in the drift direction and to provide a complete 3D track-topology
- Such faint optical signal (150 pe expected at Qββ have to be recorded by high-gain, high-sensitivity and low-noise devices: **PMTs**

- The PMT plane will perform the primary scintillation readout. This occurs several μs prior to the secondary scintillation (EL) for the energy measurement.

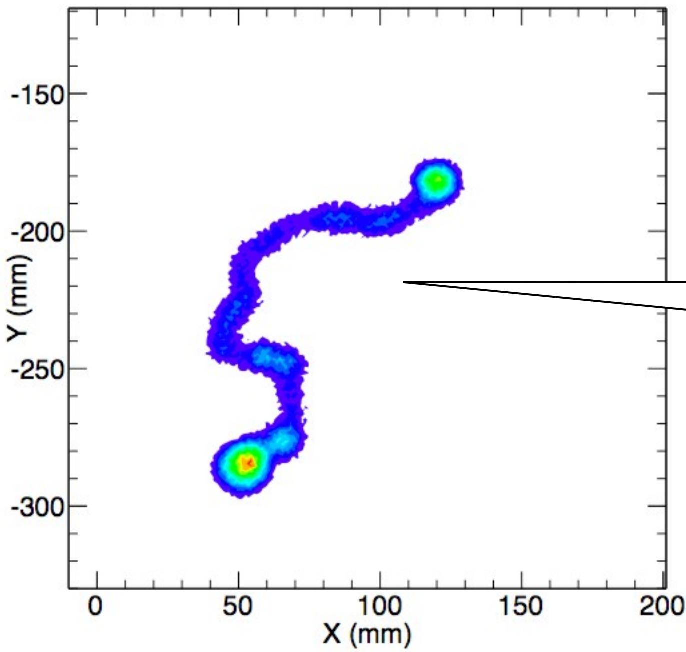


PMTs plane behind the TPC cathode

- **PMTs gain should be high to record light of 1-3 pe per PMT**
- **Scintillation attenuation in the HPXe should be studied**
- **A large reflectivity in the vessel walls is required**

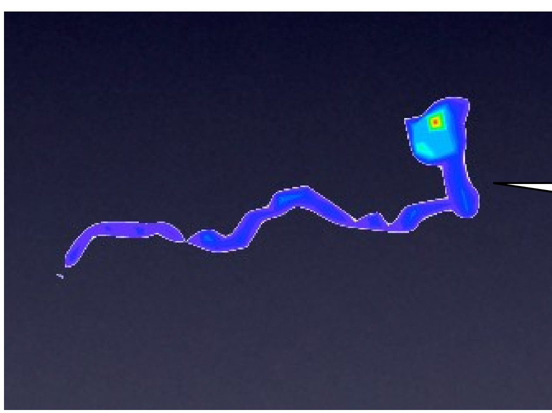
Tracking for background rejection

Goal: measure how much charge is (roughly) collected per μs in each tracking sensor



Double beta

The track length at 10 bar is 30 cm. The ββ event track is a tortuous cord because of the multiple-scattering. The cord is ended by two blobs of energy.



One beta

This pattern is distinguishable from the one electron track with energy near Qββ

LXe cannot resolve blobs

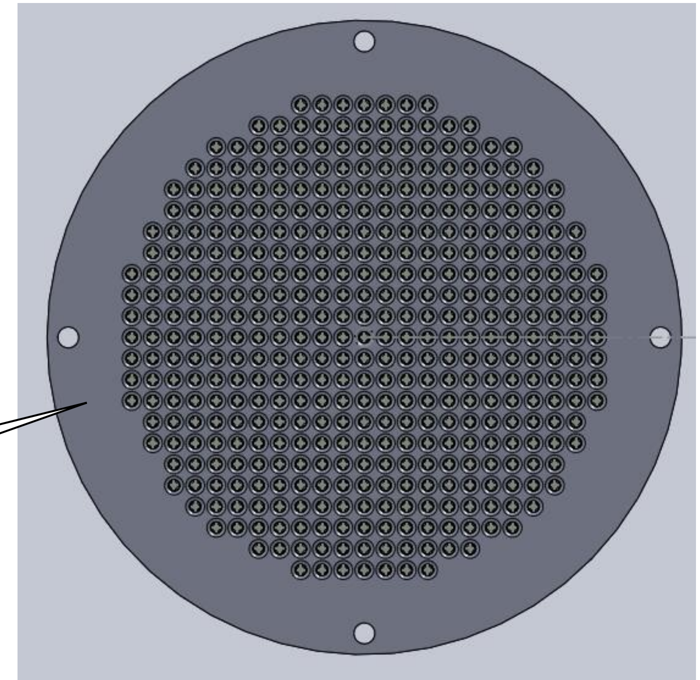
First possibility for tracking: SiPM plane behind anode

Main advantages:

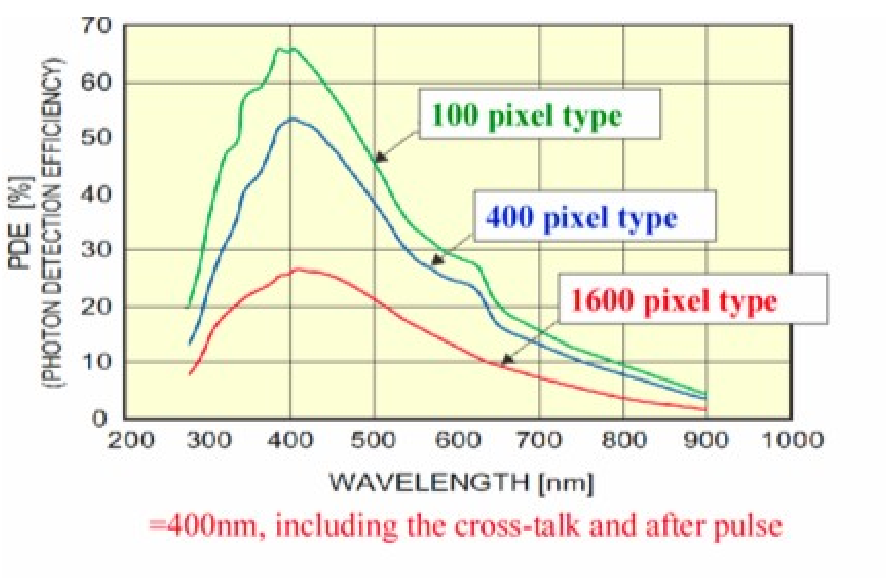
- ✓ Radio-pure device
- ✓ low cost per unit sensitive area
- ✓ small size suitable for tracking
- ✓ High PDE
- ✓ High Gain : 10^5 - 10^6

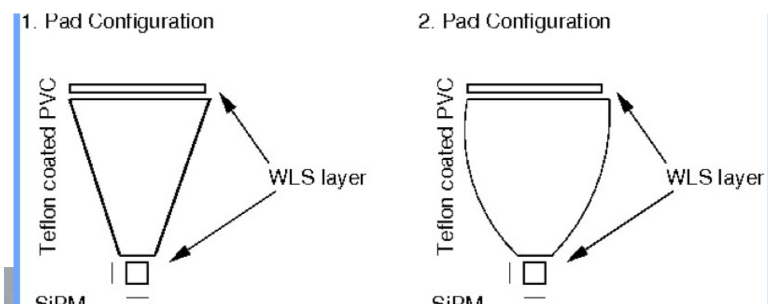
Drawback:

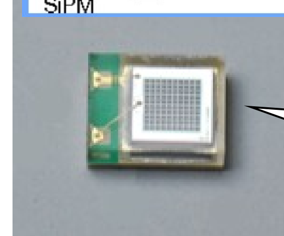
- ✓ High sensitivity to temperature



SiPM plane







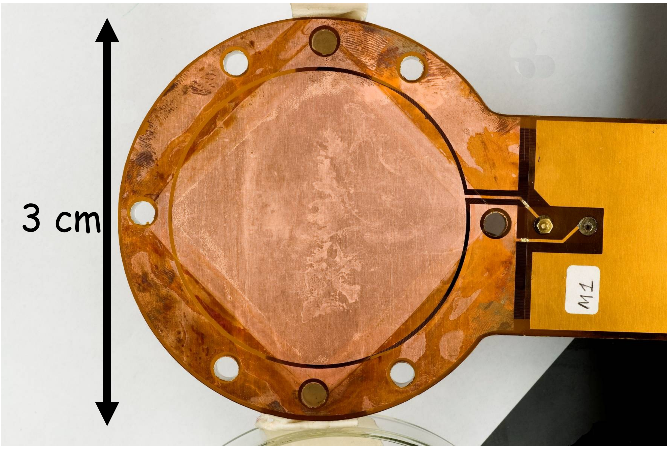
S10362-11-025p
Hamamatsu

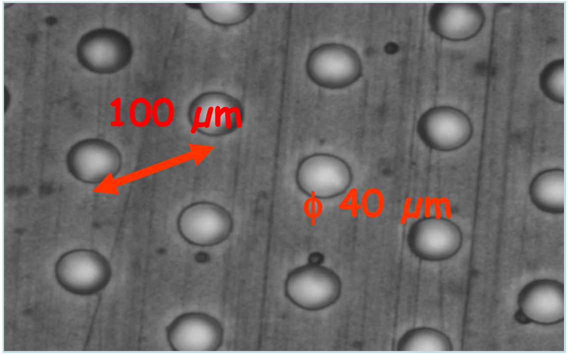
Second possibility for tracking: Micromegas

Tracking with Micro-Megas is also investigated as a competitive alternative to the baseline choice of SiPM.

Expertise at the University of Zaragoza with collaboration of Saclay.

Many questions related the operation of MM in a EL TPC are addressed: gain, quencher, presence of EL grid...





- Prototype: FE and DAQ based on Saclay's T2K electronics (AFTERchip + FEC card + FEM card + DCC interface to DAQ PC)

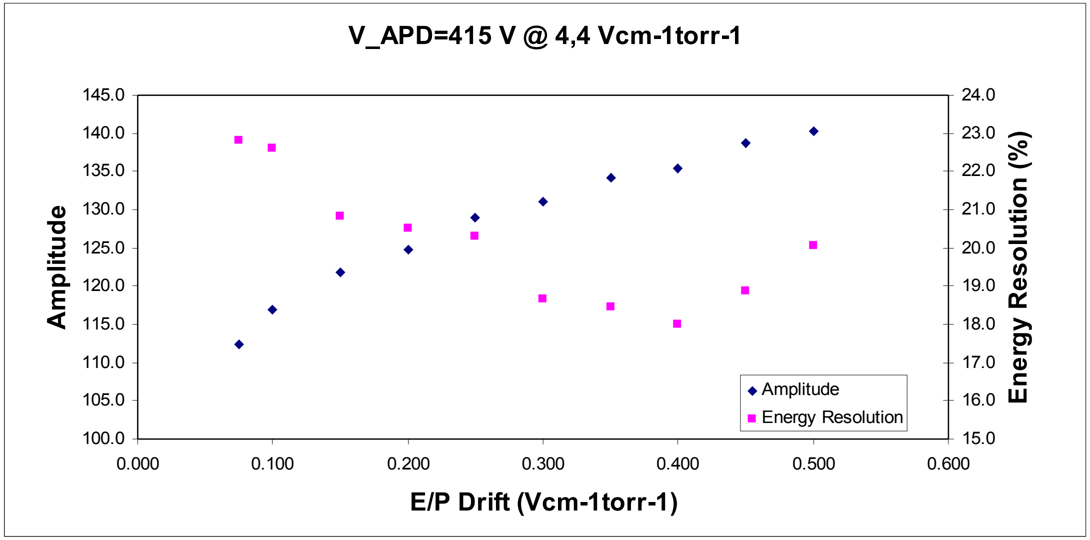
- We need a convergent path to RD-51 electronics => FEE support for AFTER and/or FEC

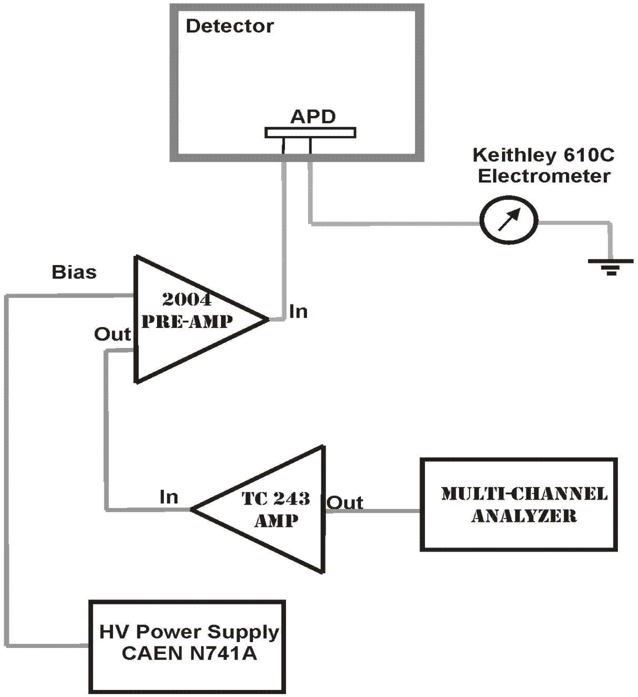
Third possibility for tracking: APD plane behind anode

Tested devices
API (used in EXEO experiment, large, cheaper)
Hamamatsu (smaller, more expensive, lower energy resolution)

Tests in Coimbra and IFAE Barcelona => good results
Qeff measurement
Energy resolution

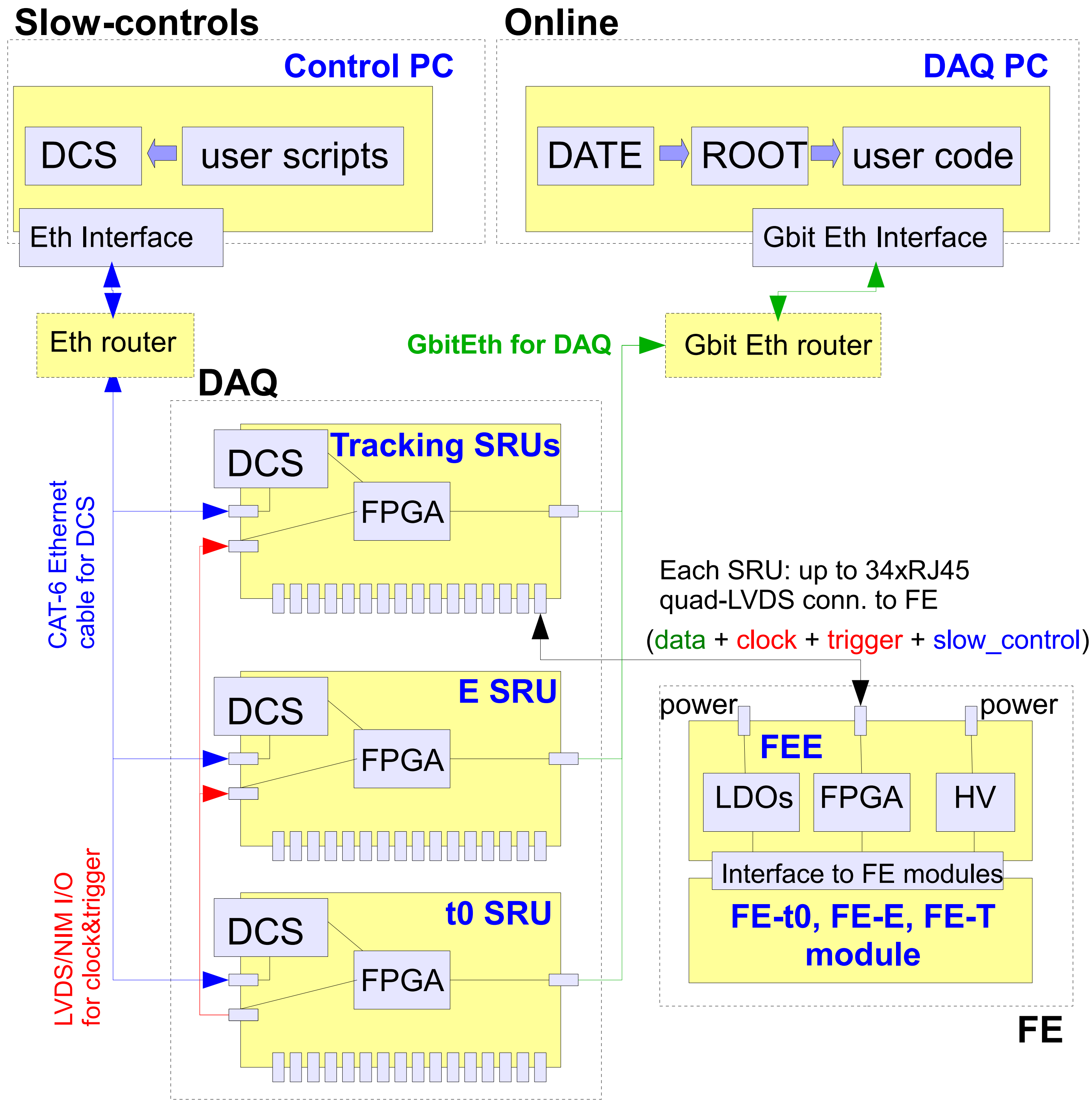
From Thorsten Lux's (IFAE) talk, last NEXT meeting:



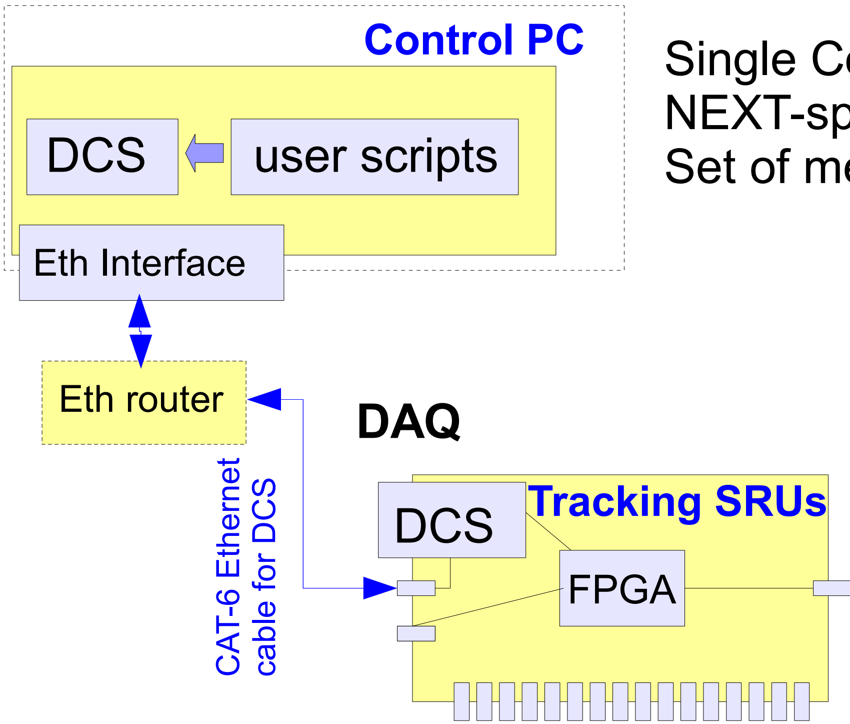


The energy resolution improves with increasing E/P until the optimum (≈ 18%@22 keV) at about 0.4 V/cm/torr == 300 V/cm/bar

RD51-based electronics for NEXT


Slow-controls
Control PC
DCS
user scripts
Eth Interface
Online
DAQ PC
DATE
ROOT
user code
Gbit Eth Interface
Eth router
GbitEth for DAQ
Gbit Eth router
DAQ
DCS
Tracking SRUs
FPGA
CAT-6 Ethernet cable for DCS
Each SRU: up to 34xRJ45 quad-LVDS conn. to FE
(data + clock + trigger + slow_control)
DCS
E SRU
FPGA
power
power
FEE
LDOs
FPGA
HV
Interface to FE modules
FE-t0, FE-E, FE-T module
DCS
t0 SRU
FPGA
LVDS/NIM I/O for clock&trigger
FE

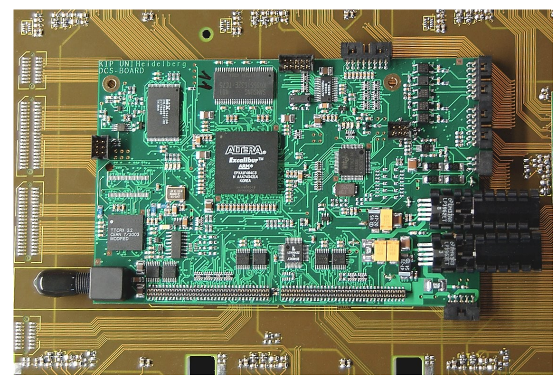
Slow-controls



Single Control PC
NEXT-specific user scripts
Set of memory-mapped registers for DAQ, FE and sensors

Ethernet connection to DAQ
DCS card (existing) in each DAQ module

FE, sensors accessible via DAQ as memory-mapped registers

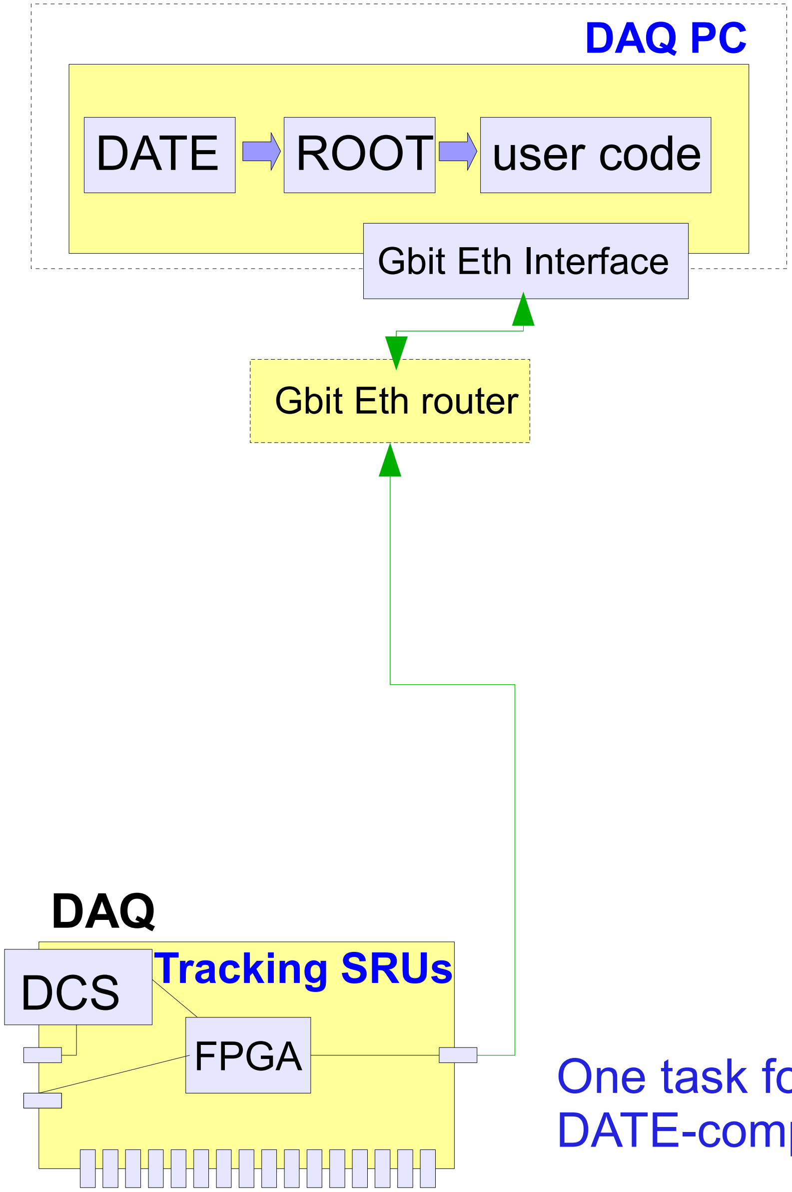


DCS card: embedded ARM processor running Linux

Development setup: PC + SW + DCS card + (Xilinx ML505 board or DAQ board) by Q3'09

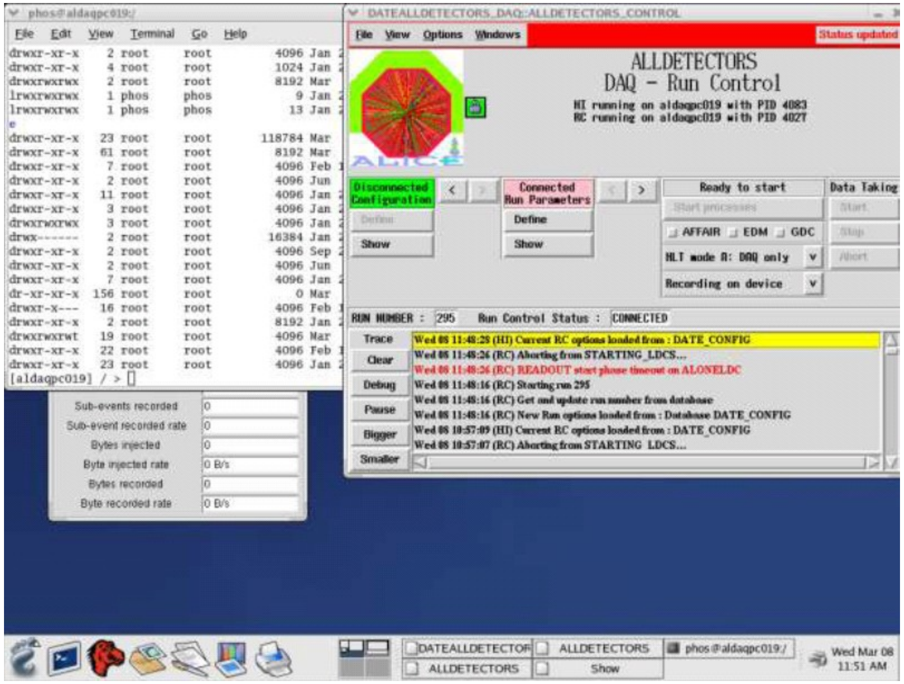
Monitoring and control functions are defined and basic scripts available by Q1'10
Slow-control is fully functional by Q2'10

Online system



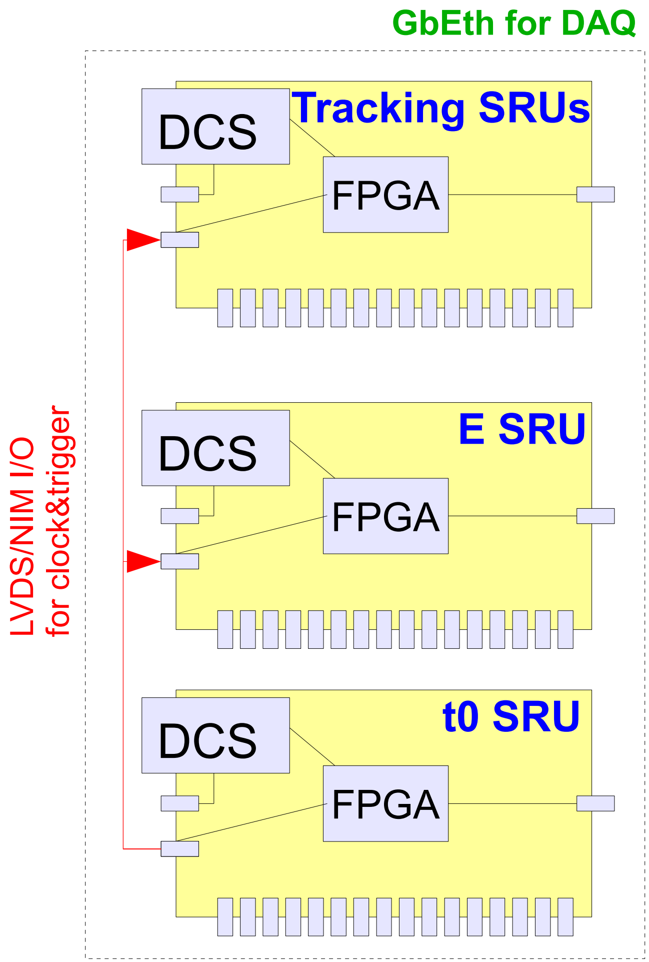
DAQ PC running ALICE DATE (Data Acquisition and Test Environment)

DATE produces ROOT compatible files
Soon: DATE support for Gigabit Ethernet (Q4'09)



One task for NEXT in RD-51:
DATE-compatible Gbit Ethernet frames generation from FPGA

DAQ system



SRU module (Scalable Readout Unit)

Same HW as ALICE LCU unit

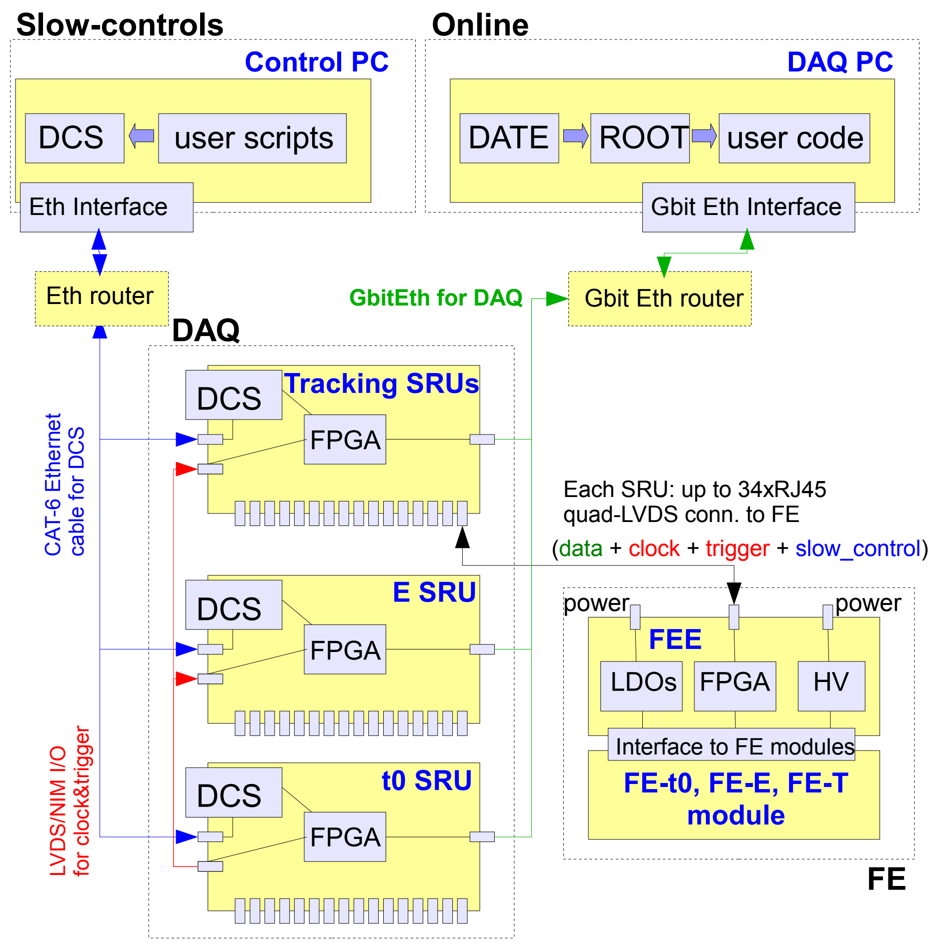
Available in Q3-Q4'09

Basic RD-51 FW in Q4'09

Firmware to be customized for NEXT (Q1'10)

Our task for RD-51: help in module test, as one of the first users

Data flow



Tracking partition

400ch, single SRU, all ch active for 100 us per event, 2 bytes/us: 625Kbit event size. One event can be stored in the SRU-1 buffer (FPGA memory is 2,1 Mbit)

Energy partition

16ch, single SRU, 70 MHz, all ch active for 100 us per event, 2 bytes/us: 1,2 Mbit event size. One event could be stored in the SRU-1 buffer

t0 partition

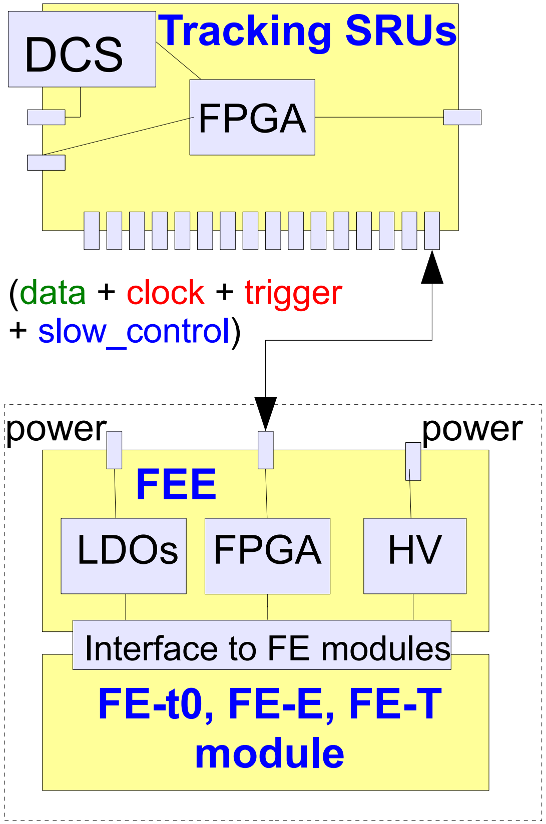
Low event size if PMT signals combined

¿t0 and/or E Trigger?

t0 trigger seems feasible for medium-to-high energies. This results in low buffering requirements.

E trigger requires larger circular buffers. SRU buffer size is enough for NEXT-1. A buffer should be added in the SRU for NEXT-10 and NEXT-100.

Front-End Electronics



Front-end interface unit (FEE)

Scheduled Q4'09

NEXT customization foreseen for Q1'10

We may use the optional high voltage control for sensors

It may also support Saclay's AFTER chip and/or FEC card

FEE connector pinout definition is not closed yet

Our task for RD-51: help in FEE module test, as one of the first users

FE-t0, FE-Energy, FE-Tracking

Designed by NEXT (available by Q1'10) following RD-51 FEE connector specs

Designed to allow a path for analog signal extraction in a backup-solution DAQ

Conclusions

- NEXT is a new double beta decay experiment using a TPC filled with 100 kg high pressure xenon gas enriched in ^{136}Xe

- The conceptual design of NEXT is a SOFT electroluminiscent TPC: Energy and tracking are performed with different technologies

- Small prototypes are under construction for R&D. NEXT-10 will demonstrate feasibility and performance of the experiment

- NEXT-100 schedule: $4^{1/2}$ years

- A solution based on existing and ongoing CERN and RD-51 developments has been proposed for DAQ, Online and Slow-controls systems

- Strong points: matches our schedule, good support, flexible, may be able to read out the micromegas FE from Saclay

- Our schedule for NEXT-1 is tight: we'd like to avoid delays in the RD-51 schedule