The FOXFIRE liquid xenon R&D project

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SUMMARY: The FOXFIRE project (Feasibility Of liquid Xenon detector with Frontend for Ionization Real-time Extraction) aims at studying and developing techniques for the detection of rare processes in elementary particle physics by means of condensed noble gases detectors. Particles in noble liquids release energy in both scintillation light and electron-ion pair formation. The combined usage of this information is being exploited by many research groups. We are studying the extension of these techniques towards high-rate, high-energy (tens of MeV) environments with particular emphasis on real-time event reconstruction.

Liquid xenon (LXe), presents a unique set of characteristics (high density and stopping power, high light yield, relatively high boiling temperature) which makes it an ideal choice as detector active material [1].

Large LXe homogeneous scintillation detectors, such as the one of the MEG experiment, can detect photons of several tens of MeV with superior energy, position and timing resolution [2].

When the photon conversion is very close to the entrance face the resolutions are degraded because of spatial non-uniformities. Usage of smaller photo-sensors partially improves the performance (see figure).

Collection of ionization electrons was used in the past in large volumes for energy or position reconstruction [3,4]. Such large drift volume detectors are too slow for high rate applications required in high energy physics experiments.

LXe radiation length X_0 is short enough that ~65% of 50 MeV photons convert in the first 3 cm.

Instrumenting the first X_0 with a segmented TPC allows for:

- Relatively fast collection of charge (< 5 μs)
- 3D reconstruction of photon conversion
- Precise knowledge of photon conversion position
- Better timing of the photon
- Less position-dependent energy estimate

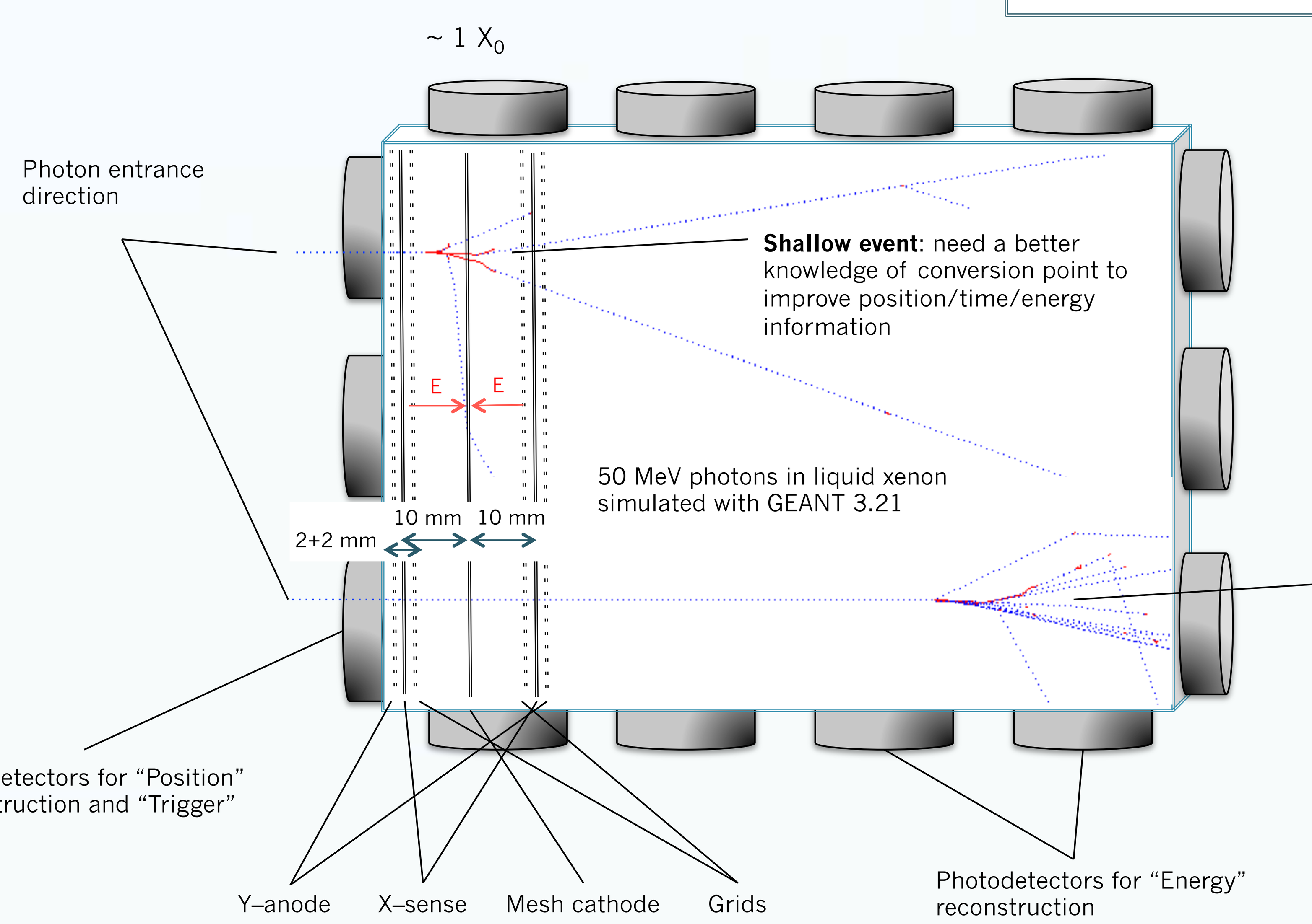
An online association and processing of light and charge signals is necessary to reject pile-up in high rate environments.

Energy release in Xe

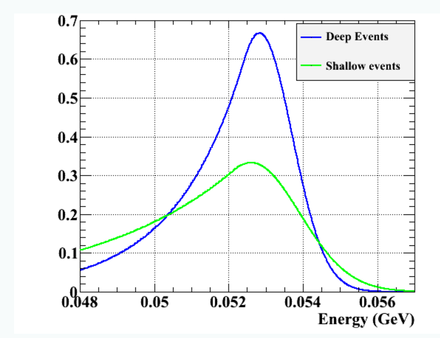
"High" energy photons interact in LXe producing
– prompt scintillation light
  · VUV (178 nm peak)
  ·measured with light detectors
– ionization
  ·drift under applied electric field
  ·sub millimeter 3D position resolution

Liquid Xenon Properties

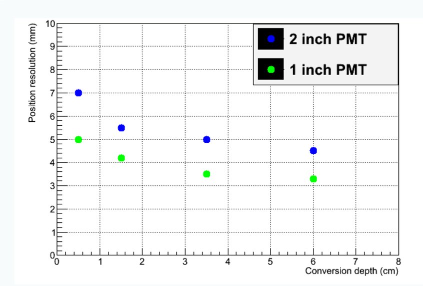
Atomic Number Z	54
Mean Atomic Weight	131.3
Density	3 g/cm^3
Boiling point	165 K
Ionization potential	12.13 eV
Light yield	40 000 phe/MeV
Radiation length X_0	2.87 cm
Electron drift velocity	$3{\cdot}10^5$ cm/s (2 kV/cm)



Energy resolution in the MEG photon detector for deep (conversion > 2 cm) and shallow (conversion < 2 cm) events. The right-tail sigma is 1.6% in the former case, 2.5% in the latter (at 52.8 MeV)



Position resolution depends both on photo-detector size and on conversion depth

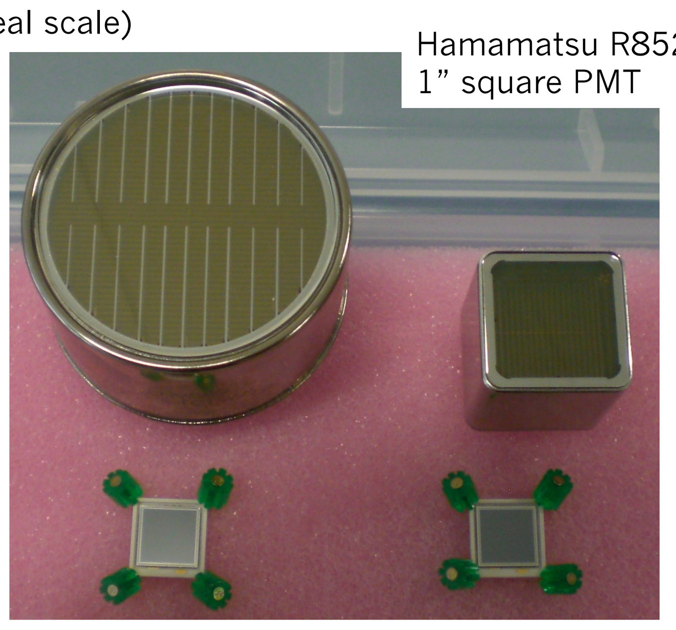


Photodetectors

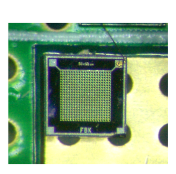
Various photo-detector candidates are presently under test for the final prototype.

Hamamatsu R9869 2" presently used in the MEG experiment (real scale)

Hamamatsu R8520-406 1" square PMT



Hamamatsu large VUV sensitive APD's 1cm x 1cm (S8664-1010VUV)



Possible usage of SiPM for detecting LXe VUV scintillation light with higher granularity. (AdvanSiD 1mm x 1mm, 400 pixel, 50μm)

Project time profile

2011 Founding granted. Started R&D, material procurement. Laboratory set-up.

2012 R&D on photo detectors, front-end electronics and read-out electronics. Definition of detector geometry.

2013 Construction of full-scale prototype (10 litre LXe). Implementation of online reconstruction algorithms.

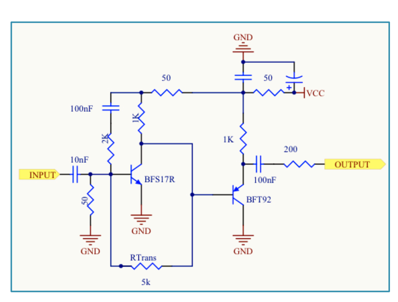
2014 Prototype ready for test-beam with photons in multi MeV range.

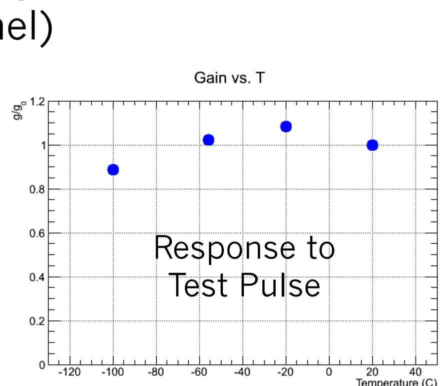
Front-end electronics

To minimize noise the front-end pre-amplifiers can be placed directly in the liquid at 165K.

Preliminary tests on a custom made trans-impedance discrete components amplifier showed a good behavior at liquid xenon temperature.

Futher optimization of single channel heat load (presently 50 mW per channel)



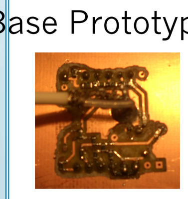


Prototype detector

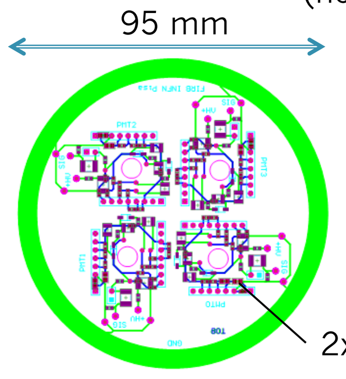
A UHV cold chamber containing 2 litre liquid Xe prototype detector is being instrumented:

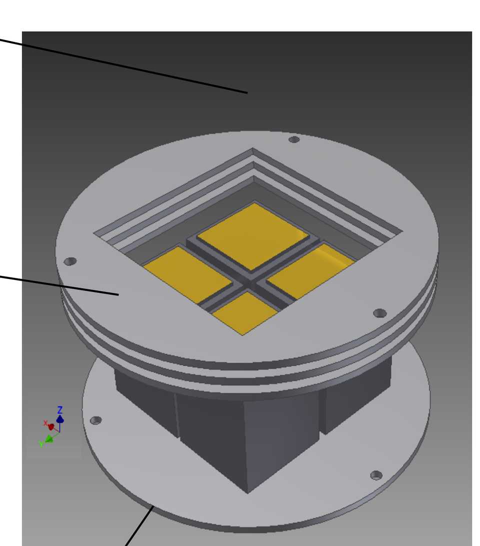
- Gas Xe is purified with circulation through a molecular sieve + heated getter
- XY charge readout from 32 + 32 sense wires
- Light read-out and trigger provided by 4 Hamamatsu R8520–406
- Adapted bleeder circuit from MEG R9869 12 stage PMTs: single PMT prototype successfully tested

Base Prototype



95 mm

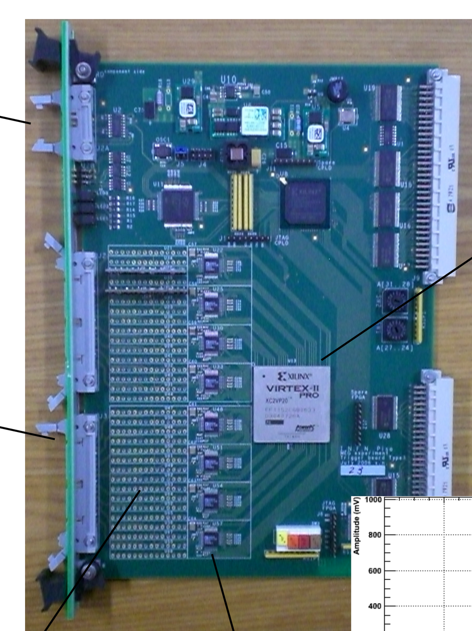




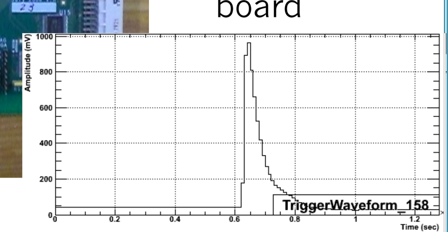
- Designed the 2x2 PMT support and the wire support (made in CIRLEX™)

Online Event reconstruction

Both light and charge information will be sampled by custom VME 100 MHz waveform digitizers evolved from those used in the MEG experiment trigger system (type 3 boards) [5].



Example of LXe scintillation waveform read by "MEG-type3" board



Provide complete trigger and read-out capabilities. Customizable design of input stage and firmware:

- Adapt front-end stage to read charge signal
- Flexible memory depth from 1 to 50 μs together with the downscale of the 100 MHz sampling in a 1-to-10 ratio can accommodate both light and charge information
- The presence of the FPGA on the board allows for online complex selection algorithms and event reconstruction (energy, time, position)

References:

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[2] S. Mihara, *J. Phys: Conf. Ser.*, **308** (2011) 012009
[3] G. Carugno, *et al.*, Nucl. Instr. Meth. A **376** (1996) 149
[4] E. Aprile, *et al.*, Nucl. Instr. Meth. A **412** (1998) 425
[5] L. Galli, *IEEE Nucl. Sci. Symp.* **NSS2009** (2009) 205

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Utagawa Hiroshige "Fox Fire on New Year's Eve at Garment Nettle Tree at Oji" 1857

FDFP FRONTIER DETECTORS FOR FRONTIER PHYSICS, La Biodola, Isola d'Elba, Italy, May 20–26 2012