LXe R&D for Dark Matter Searches

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b UNIVERSITÄT BERN

AEC ALBERT EINSTEIN CENTER FOR FUNDAMENTAL PHYSICS

Direct Detection with LXe in CH

www.xenon1t.org

darwin.physik.uzh.ch

Bern
4 members

U Zürich
11 members

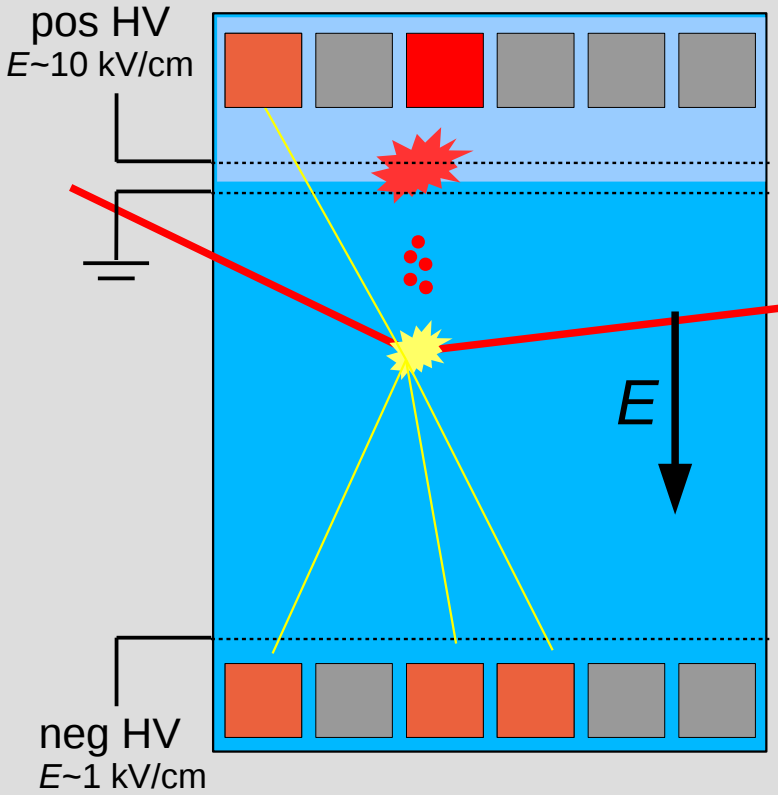
www.physik.uzh.ch/groups/groupbaudis/darkmatter

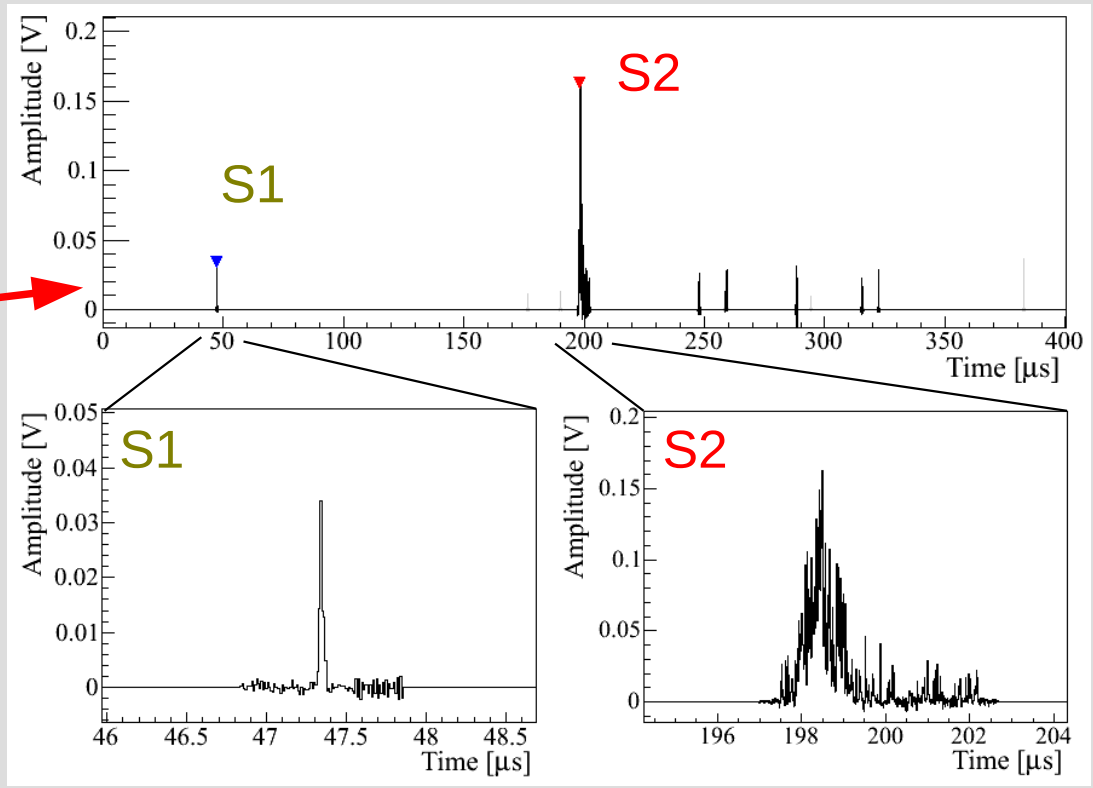
www.lhep.unibe.ch/darkmatter

Dual Phase TPC

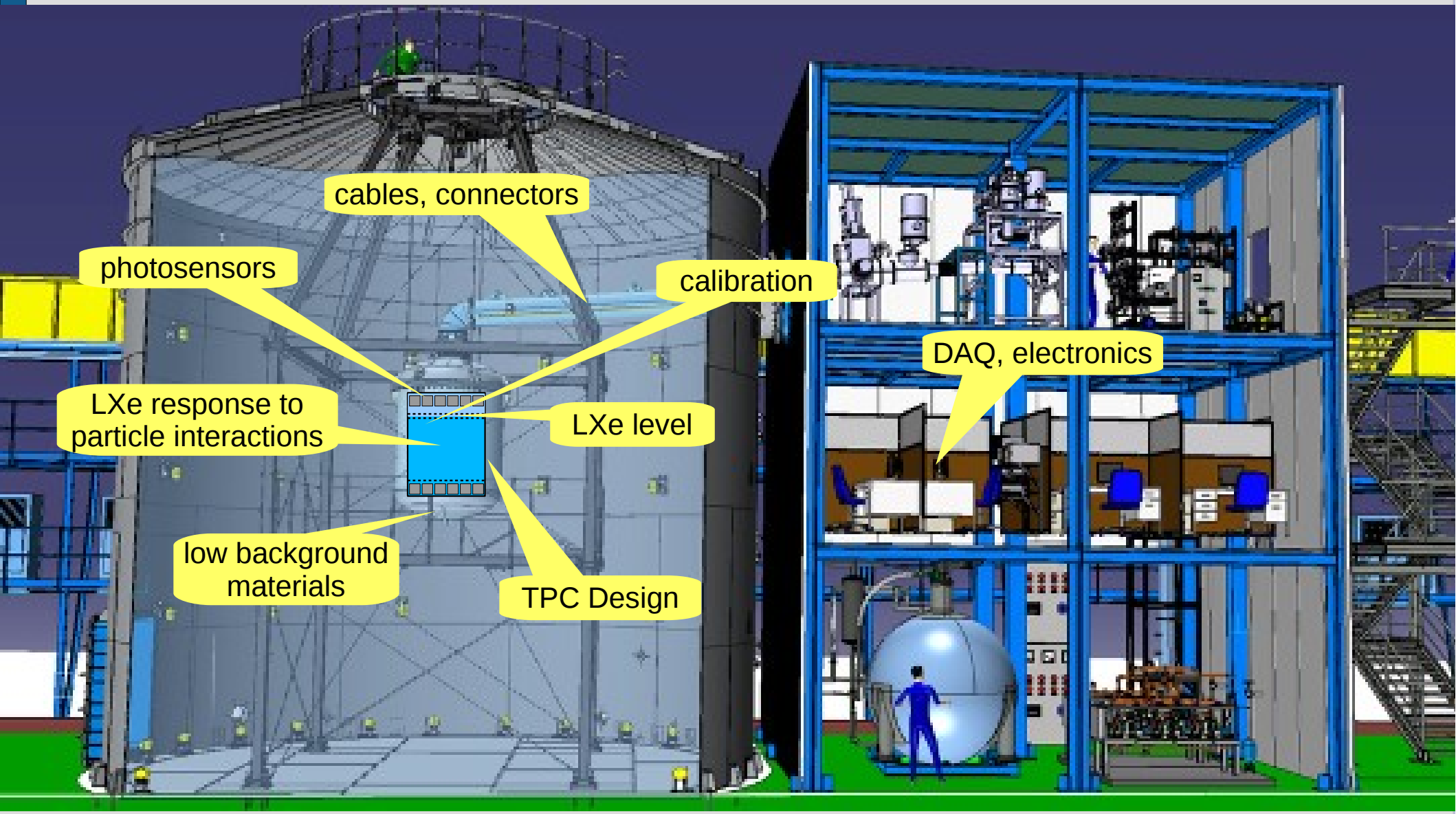
Dolgoshein, Lebedenko, Rodionov, JETP Lett. 11, 513 (1970)

TPC = time projection chamber





R&D on LXe in Switzerland

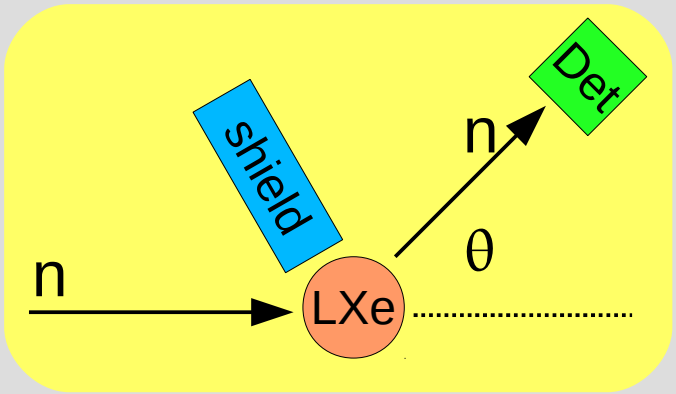


Nuclear Recoil Energy Scale

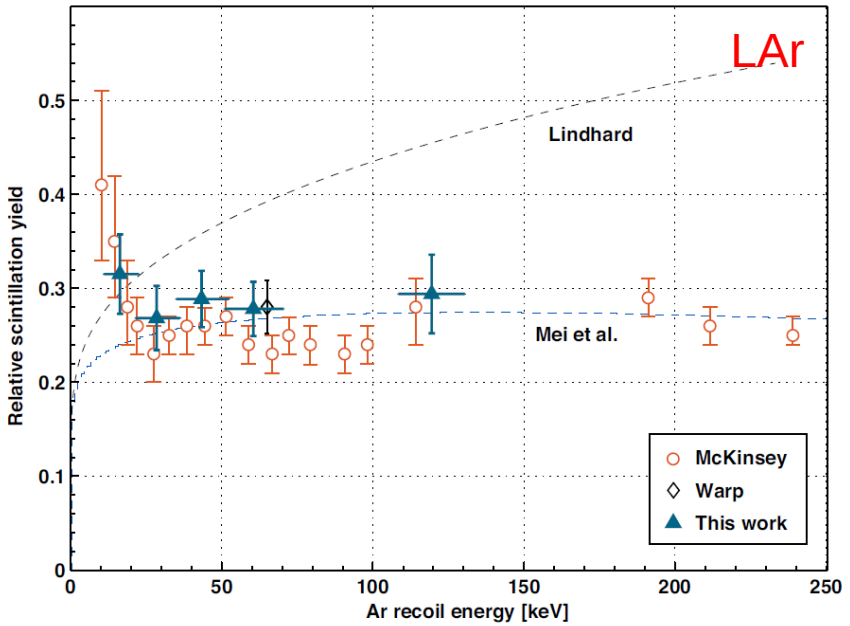
- WIMPs interact with target nucleus
  - ➞ nuclear recoil (*nr*) scintillation
    (β and γ's produce electronic recoils)
- absolute measurement is difficult
  - ➞ measure relative to ^{57}Co (122keV)
- relative scintillation efficiency L_{eff}:

$$\mathcal{L}_{\mathrm{eff}}(E_{\mathrm{nr}}) = \frac{\mathrm{LY}(E_{\mathrm{nr}})}{\mathrm{LY}(E_{\mathrm{ee}} = 122\ \mathrm{keV})}$$

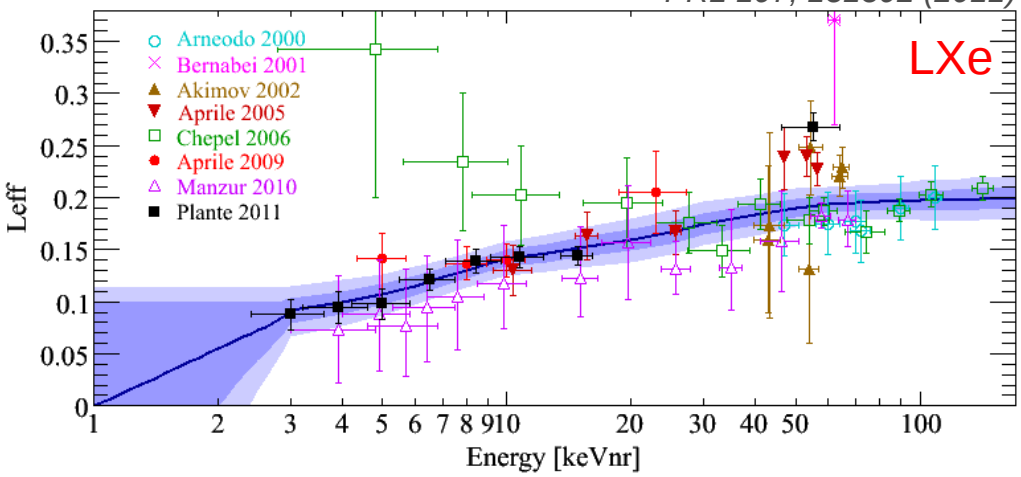
measurement principle:



arXiv:1203.0849



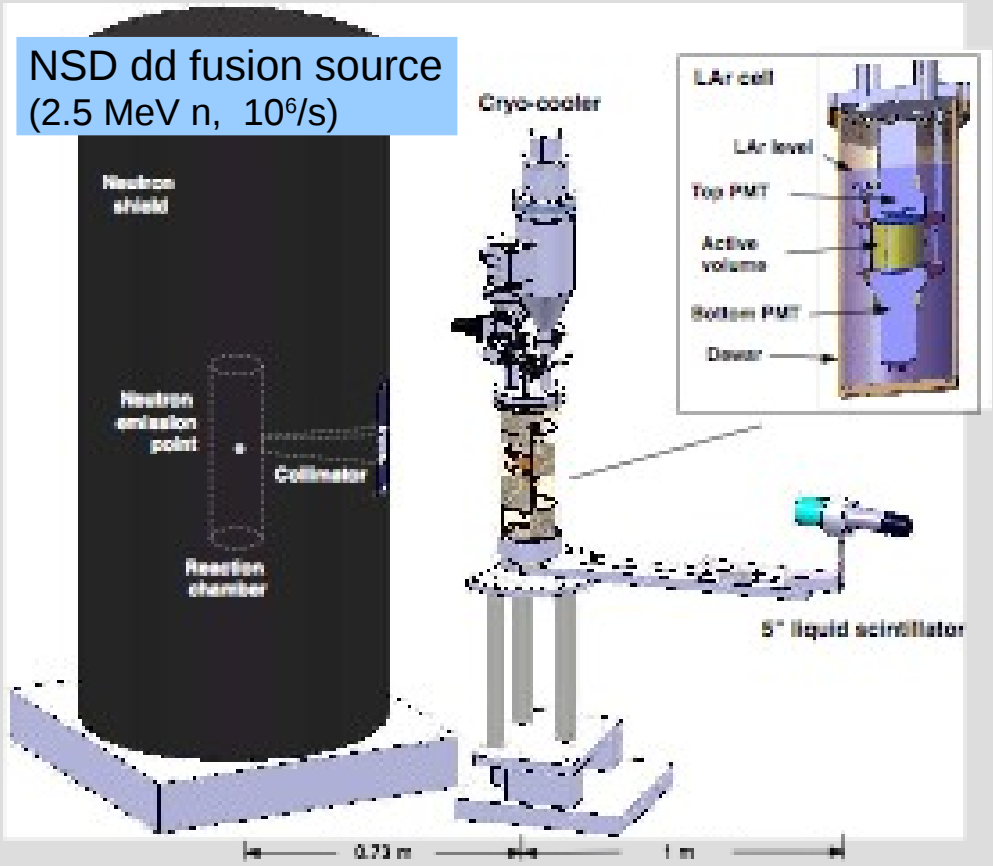
PRL 107, 131302 (2011)

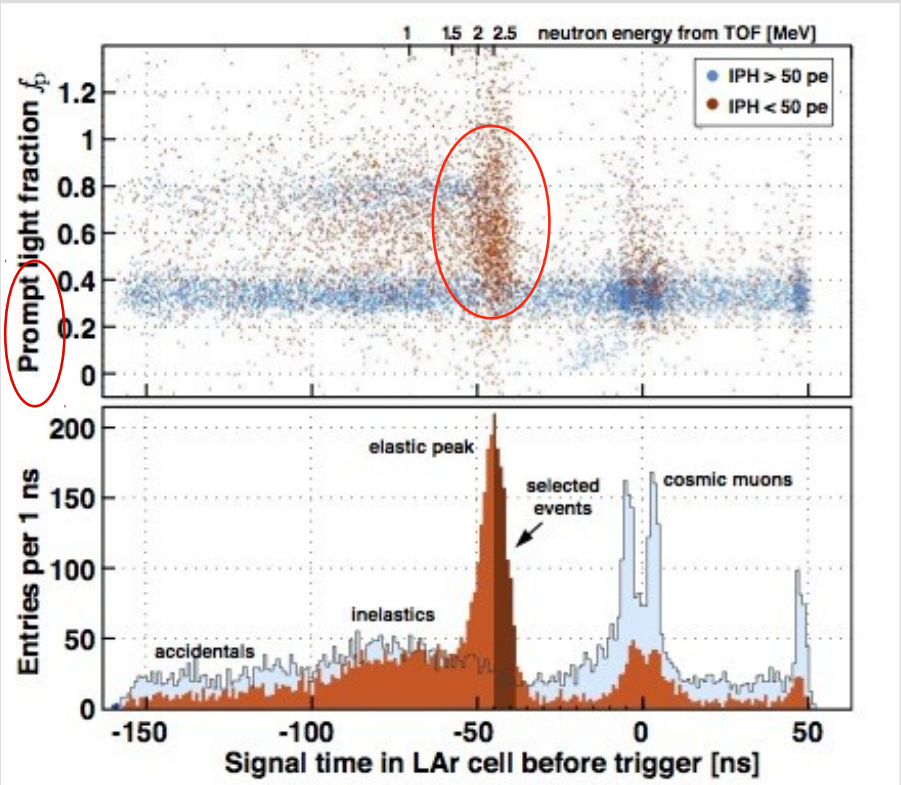


LAr NR Quenching

UZH

- Active volume surrounded by 30 mm LAr
- Active volume 0.2 l
- 2 x R6091 3” Hamamatsu (Pt underlay, QE ~15%)
- PMT coating: evaporated TPB, 0.08 mg/cm^2
  Side reflector: Tetratex/TPB, 1 mg/cm^2





LY in LAr for a given n scattering angle, coupled to TOF measurements

C. Regenfus, Y. Allkofer, C. Amsler, W. Creus, A. Ferella, J. Rochet, M. Walter, arXiV:1203.0849 (TAUP 2011)

C. Amsler, arXiv:1105.4524 (WIN'11)

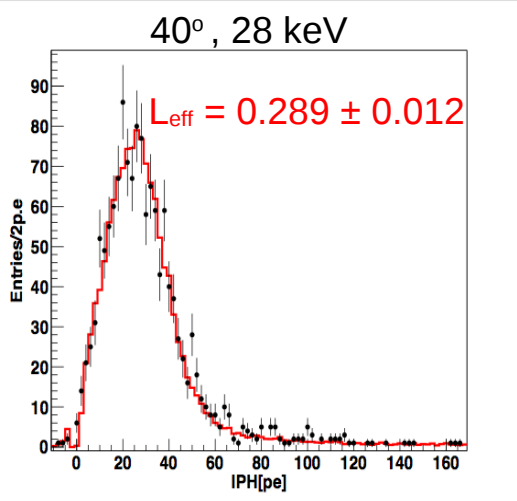
W. Creus, PhD thesis, UZH 2013

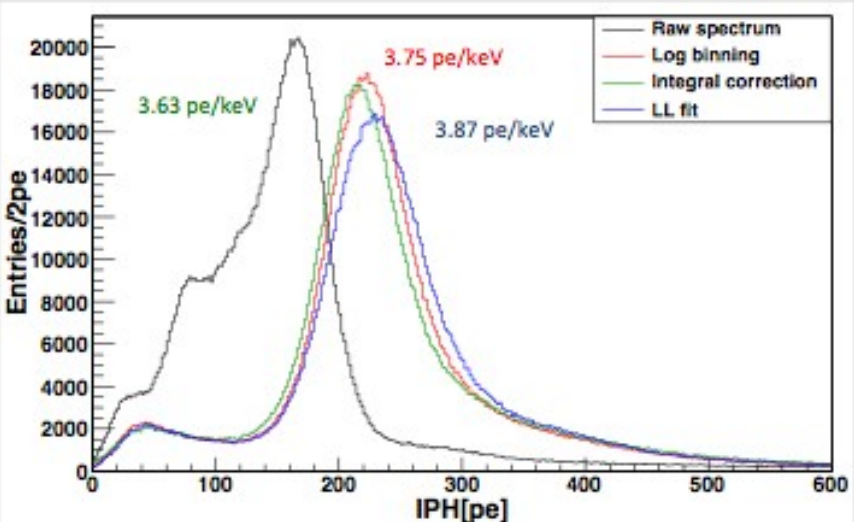
LAr NR Quenching

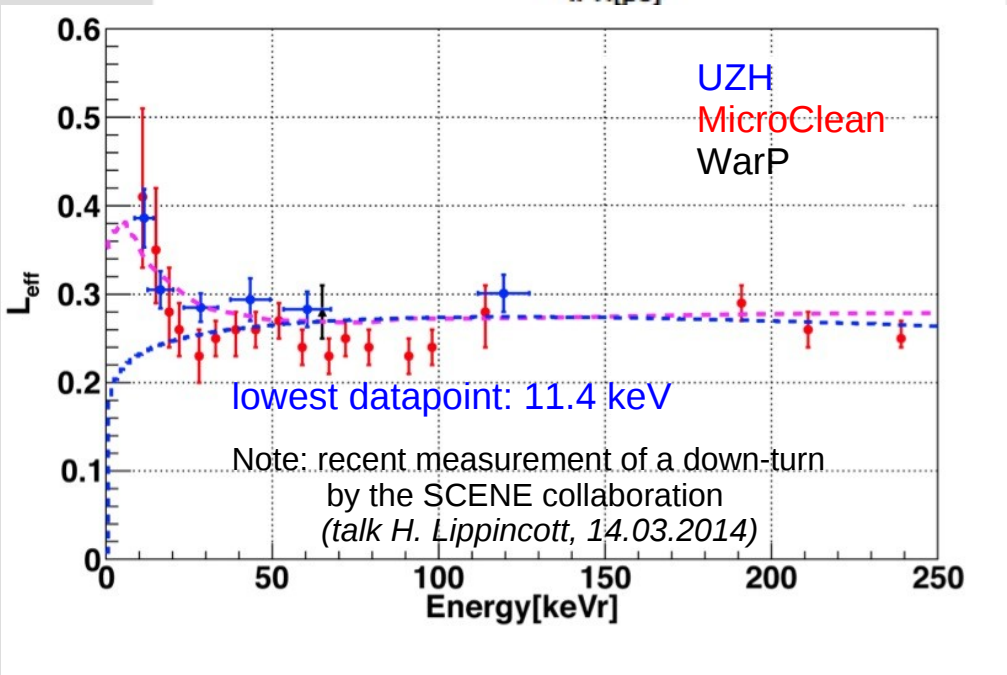
UZH
ETHZ

Analysis:
- Geant4 MC simulation
- correction for LAr impurities
  slow component is very sensitive to impurities
  JINST 3, P02001 (2008)
  fast component dominates for NRs

→ strong reduction of systematics reached
→ indication for rising LY



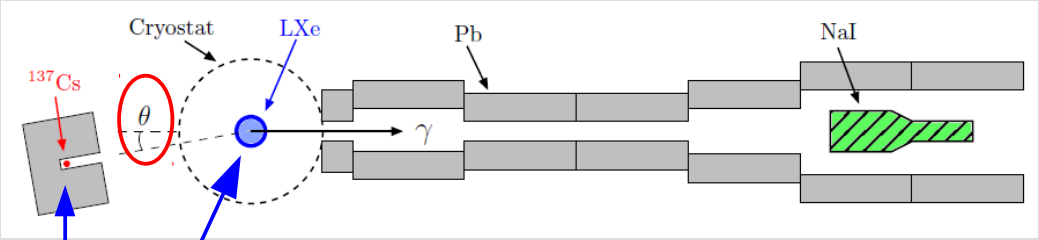




Plans at ETHZ (new LAr cell)**:**
- repeat measurements with E-field
- ER quenching
- impact of E-field on decay times etc.

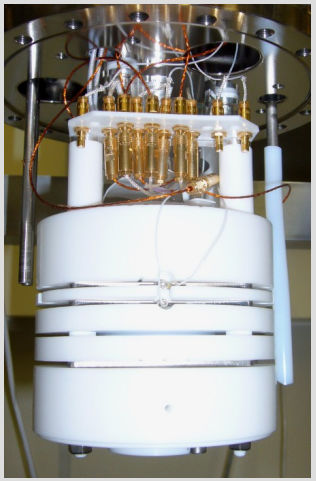
LXe Response to electronic recoils

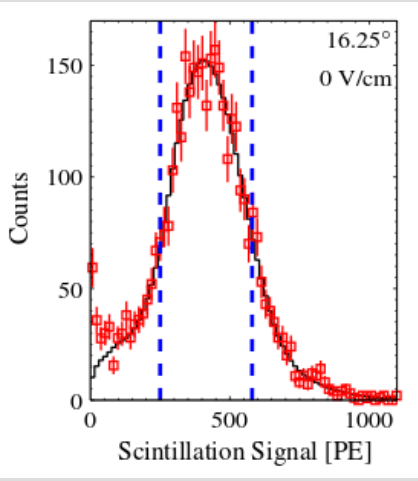
UZH

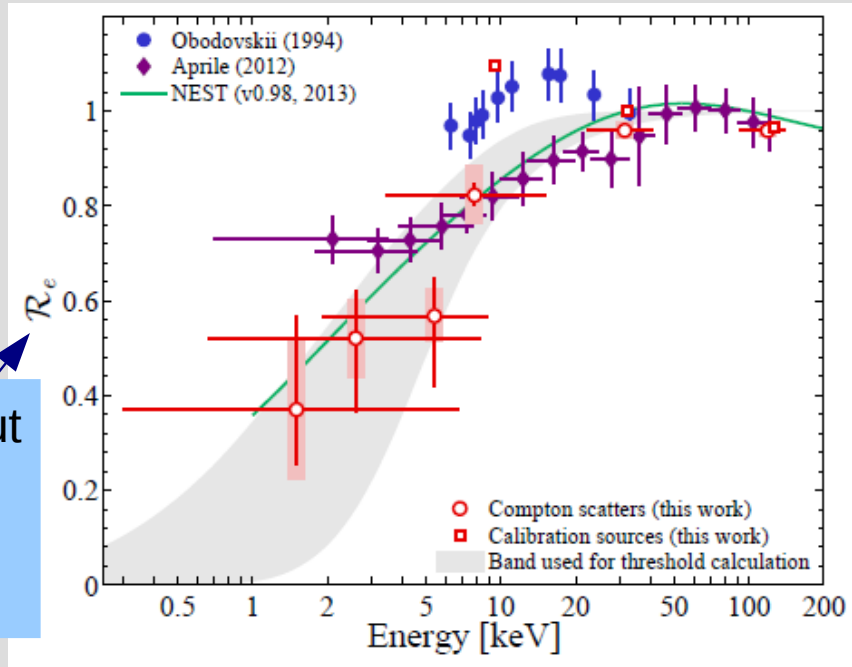


$$E'_e(\phi) = E_\nu \left(1 - \frac{1}{1 + \frac{E_\nu}{m_e c^2}(1 - \cos(\phi))}\right)$$

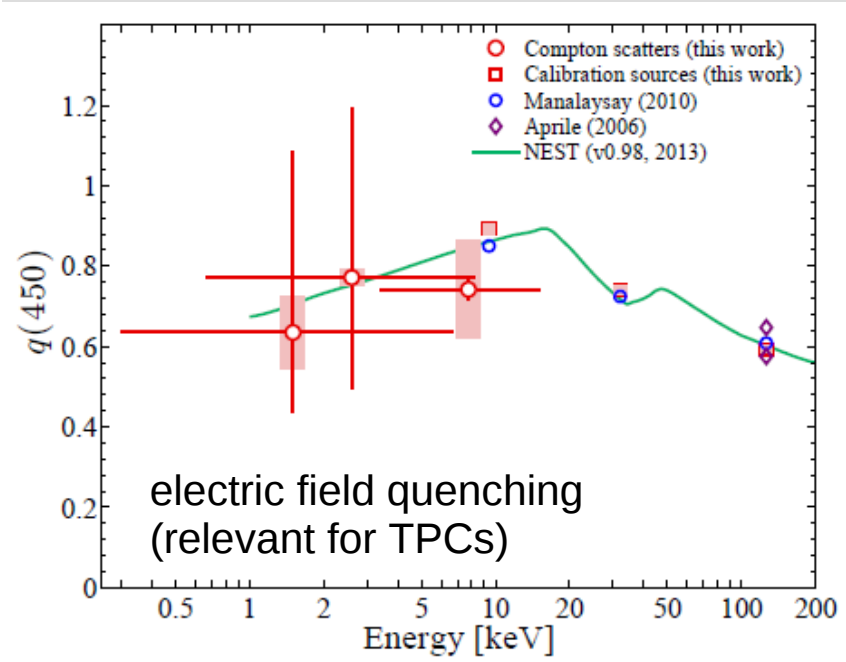
PRD 87, 115015 (2013)







Light output relative to ^{83m}Kr (32.1 keV)



electric field quenching (relevant for TPCs)

A new calibration standard: ^{83m}Kr

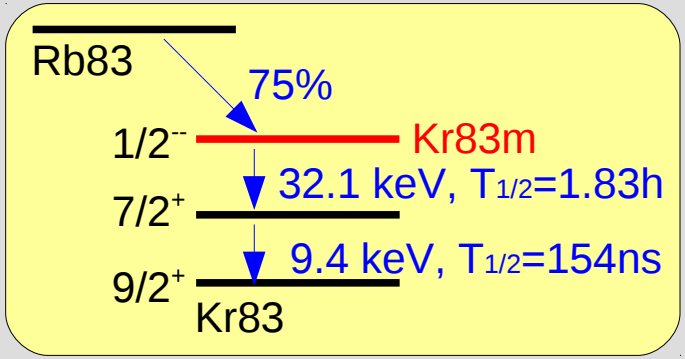
UZH

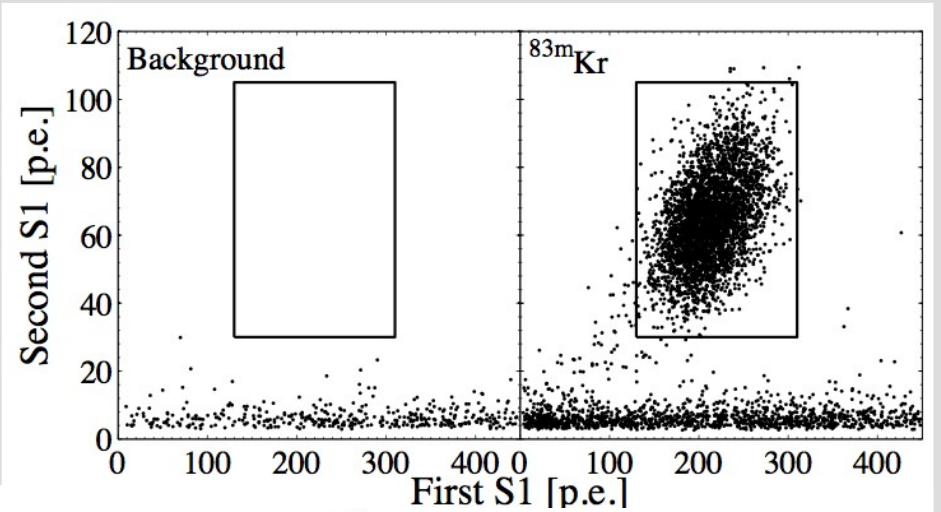
expect signal <40 keV (calibration from outside very difficult)

⇨ intrinsic sources: n-activated Xe131, Xe129m

was used for Xe10, τ~O(10d)

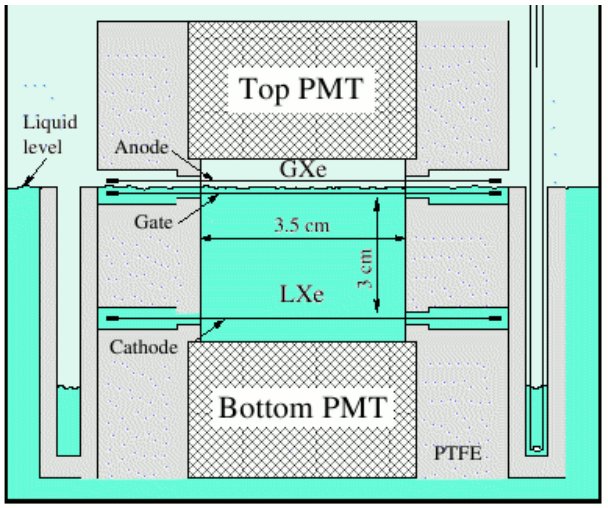
⇨ Kr83m



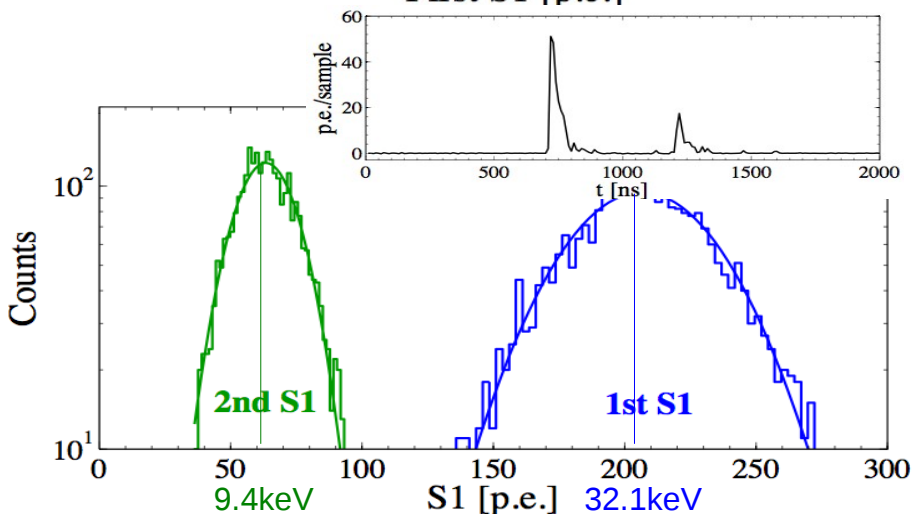


R&D in Zürich:

XURICH-I



Rev.Sci.Instr. 81, 073303 (2010)



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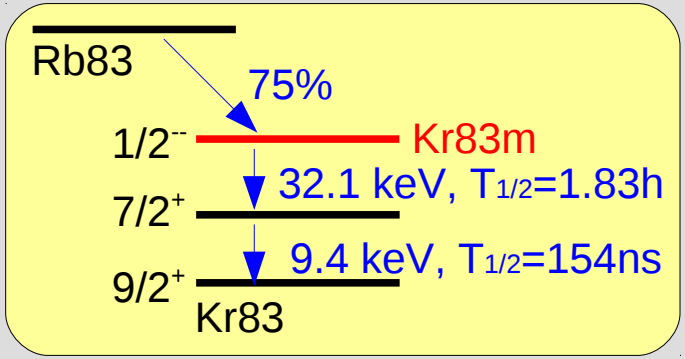
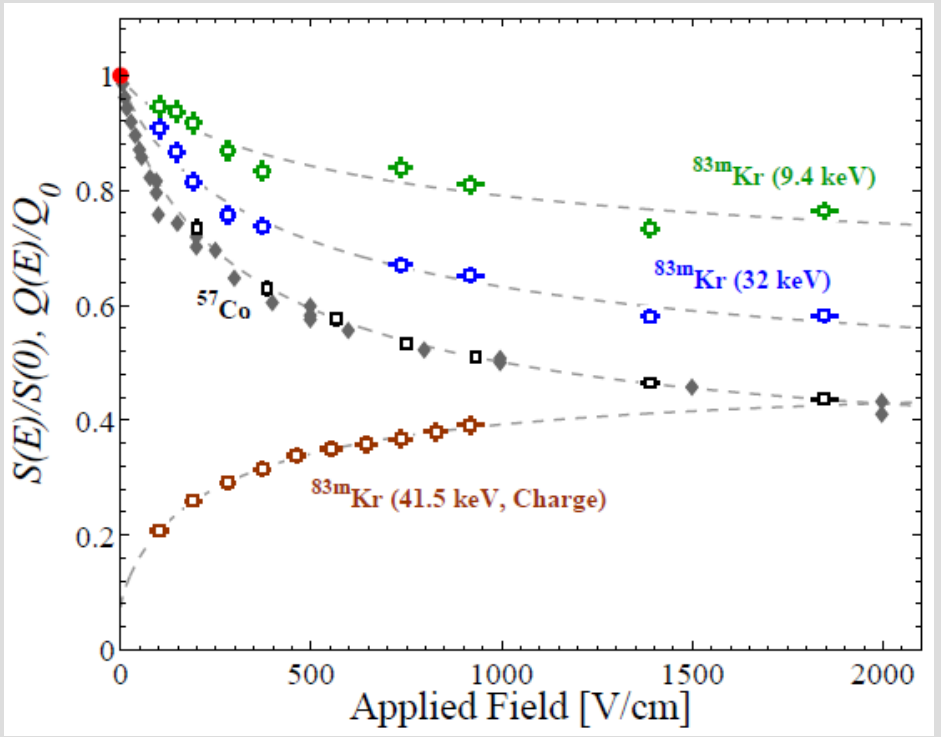
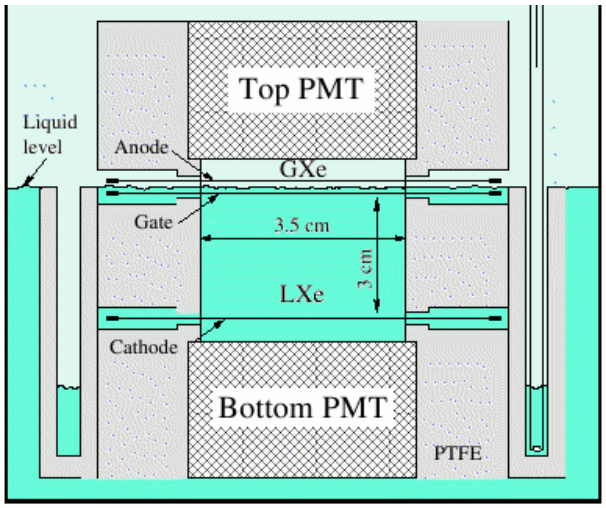




R&D in Zürich:
XURICH-I

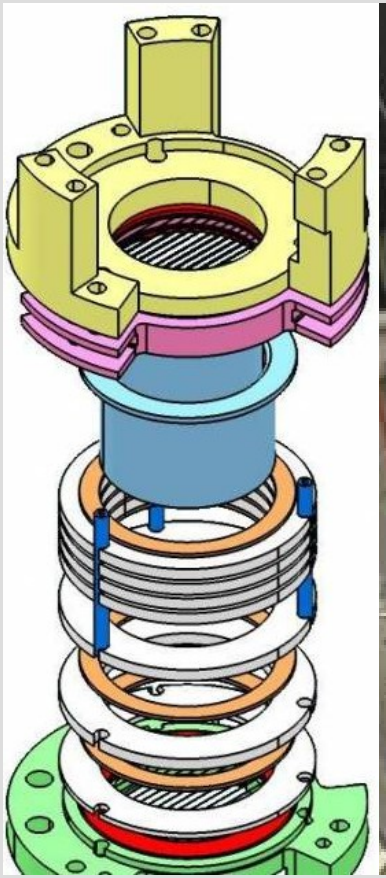


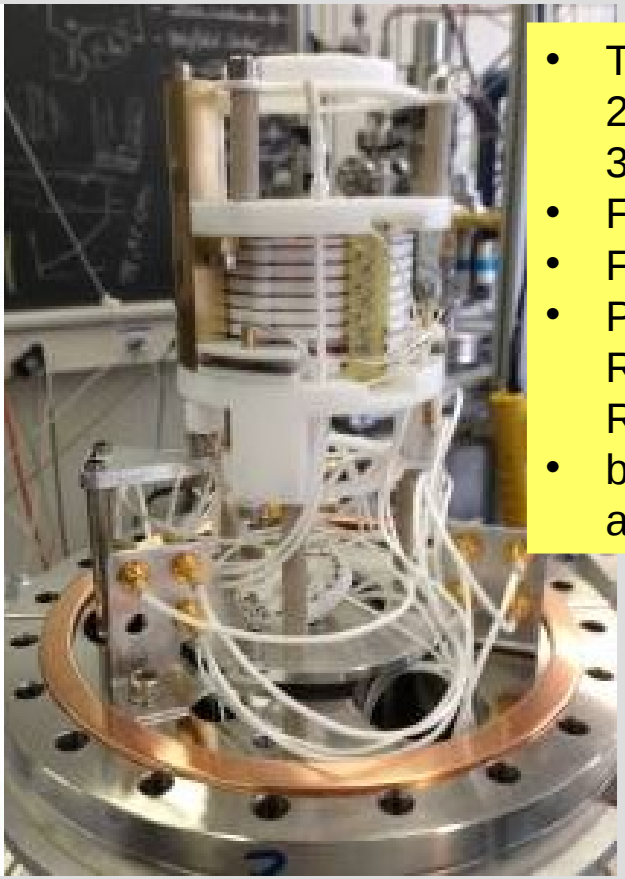
Rev.Sci.Instr. 81, 073303 (2010)

No emanation of radiactive Rn isotopes from Rb83 source was observed
JINST 6, P10013 (2011)

XURICH II

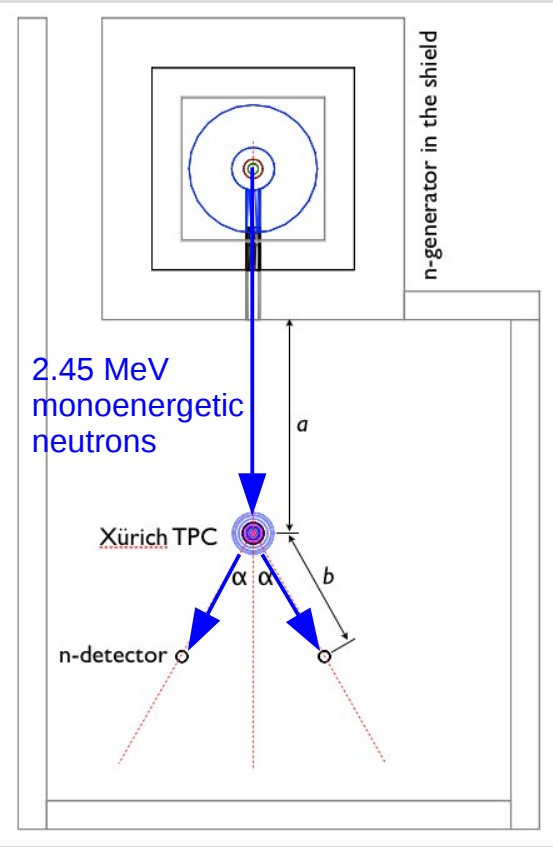
UZH





- TPC:
  28 mm height
  35 mm diameter
- Field: 1kV/cm
- Field uniformity: <4%
- PMTs:
  R9869MOD,
  R6041-06MOD
- built-in radial cut against edge events

Neutron Facility at UZH



Planned measurements:

^{88}YBe	–	response of LXe to very low E neutrons
L_{eff}, Q_y	–	scintillation efficiency, charge yield
S_{nr}	–	field quenching of nuclear recoils

Field-quenching of S1 Light?

energy in keVr

$$E = \frac{\mathrm{S1}}{L_y} \frac{1}{\mathcal{L}_{\mathrm{eff}}(E)} \frac{S_{ee}}{S_{nr}}$$

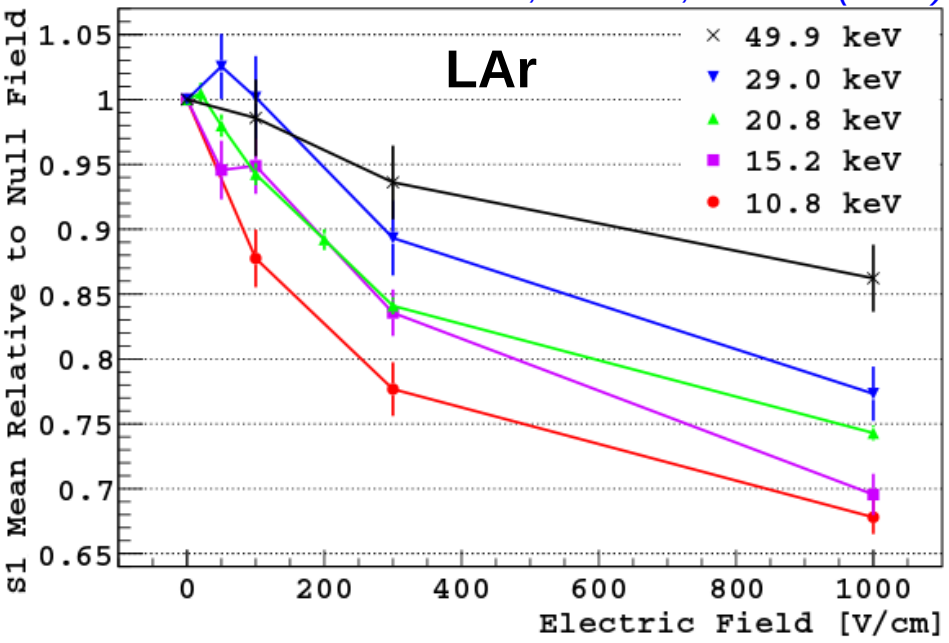
field quenching of 122 keVee
→ very well measured (simple)

light yield @ 122 keVee
→ measured in situ
(depends on detector)

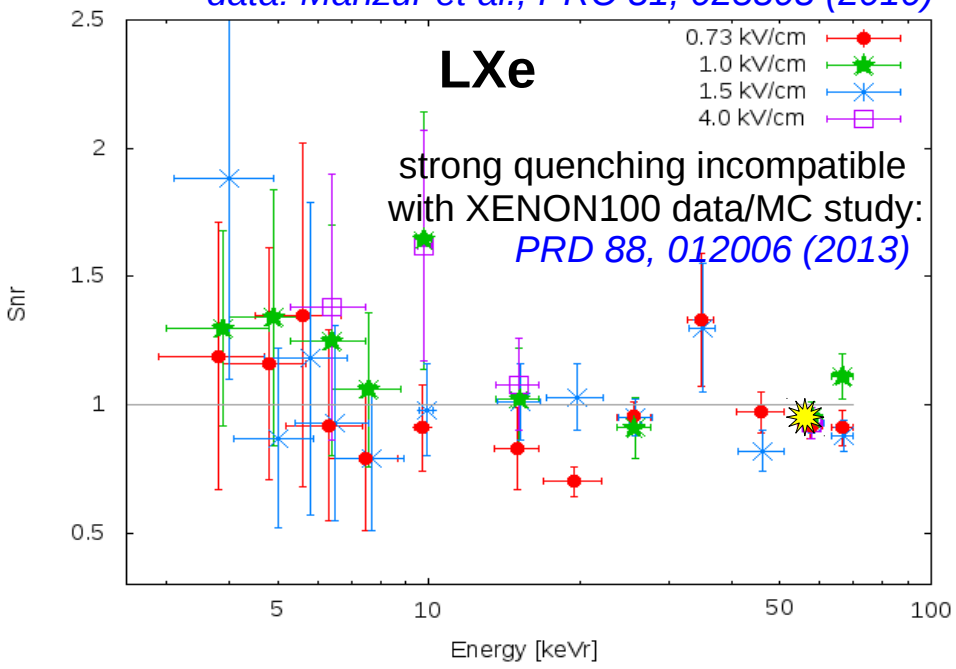
relative scintillation efficiency
→ dedicated measurements

field quenching of NRs, *Snr*(*E*)?
→ XENON uses *Snr*=0.95
→ recent measurements in LAr found strong *E* dependence
→ not seen in LXe so far

SCENE, PRD 88, 092006 (2013)

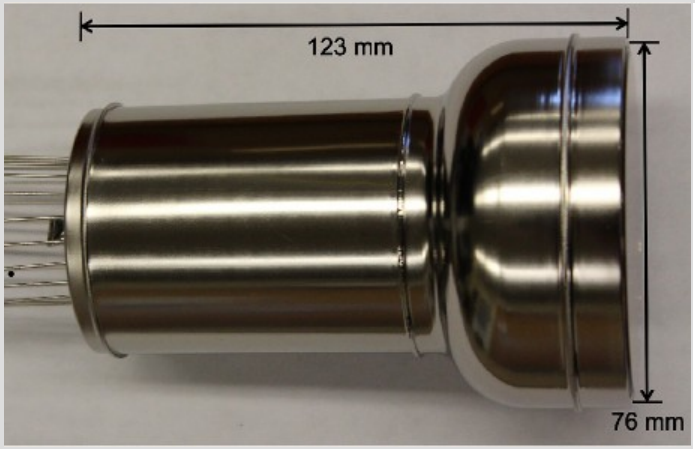


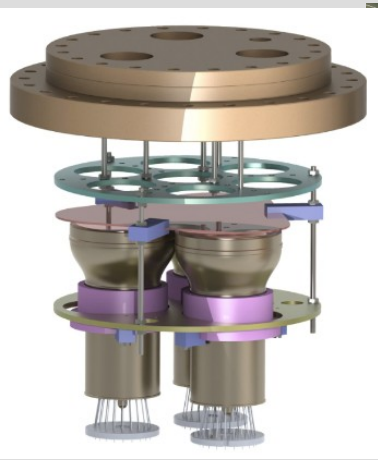
data: Manzur et al., PRC 81, 025808 (2010)

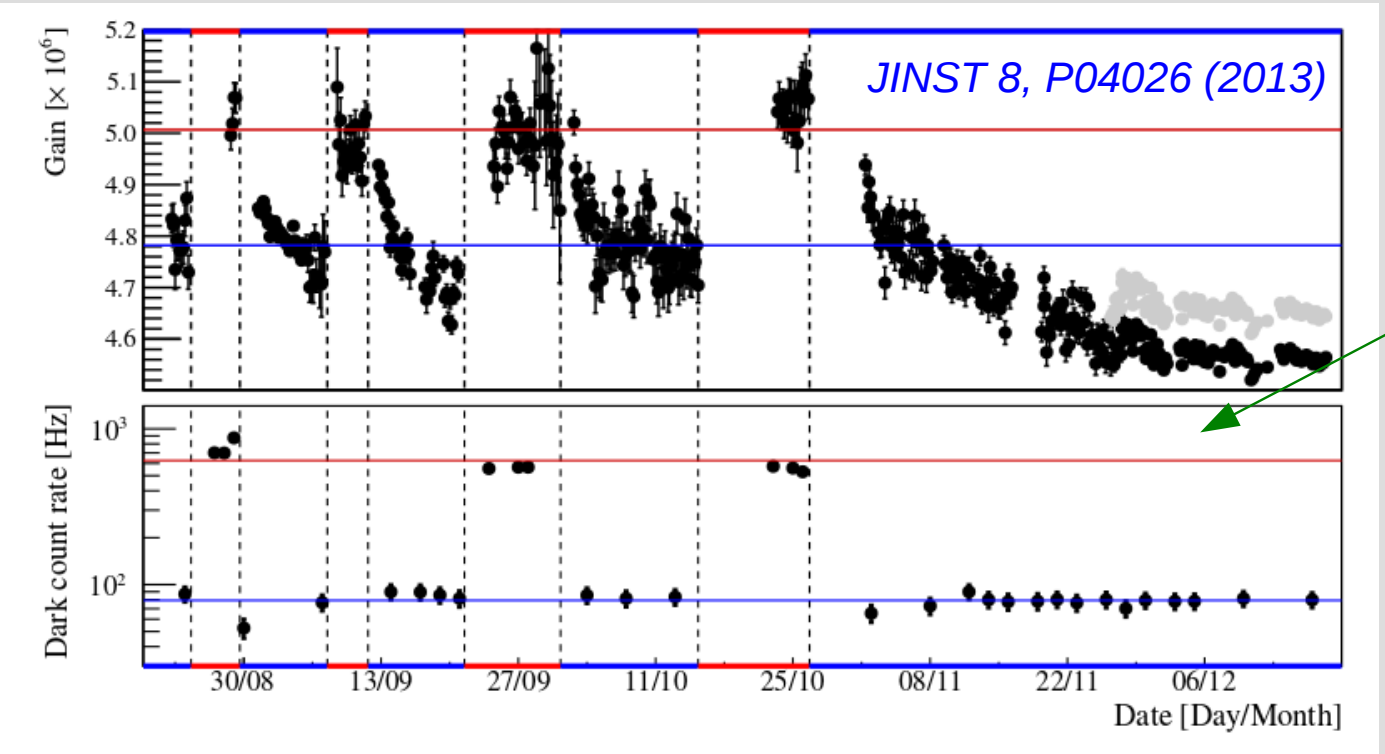


XENON1T: PMT Studies

UZH







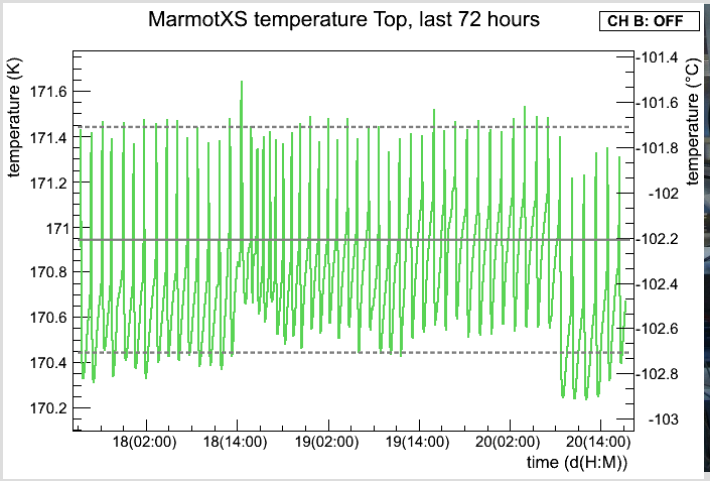
Hamamatsu R11410-21
- high QY (~35%)
- high CE (~95%)
- LXe operation
- low radioactivity

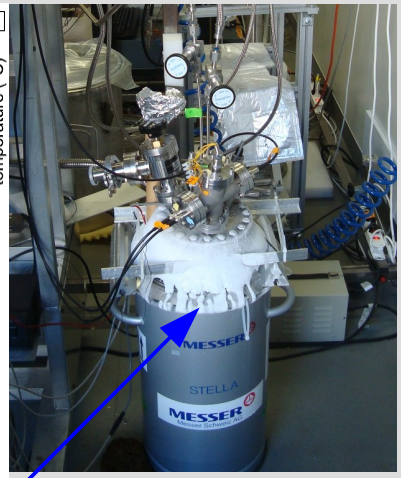
Tests at UZH in realistic LXe/GXe environments:
- gain, P/V in warm/cold
- afterpulses
- radioactivity
- performance in *E* field
- long-term LXe stability
- thermal cycling

→ 248 of these PMTs will be used in XENON1T
→ a subset is tested in LXe at UZH (ongoing)
→ all are being screened in HPGe (ongoing)

Photosensor R&D

UZH

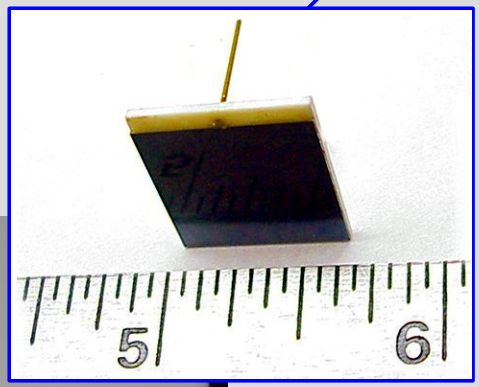


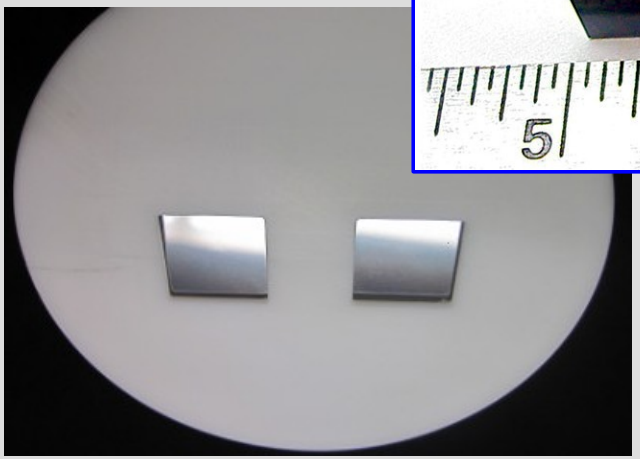


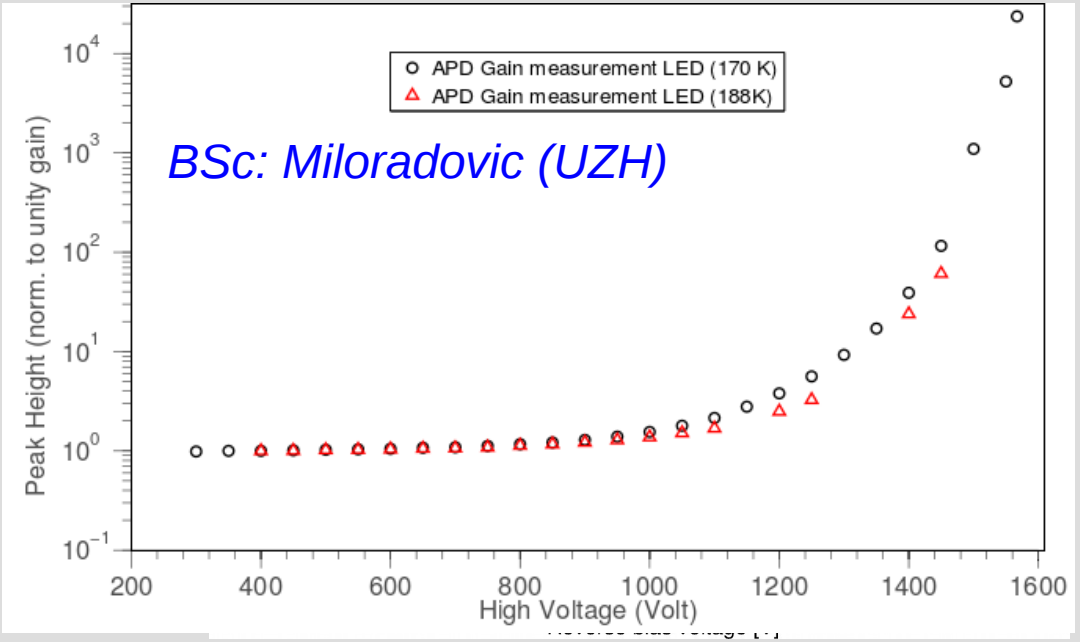
Avalanche Photodiodes (APDs) @ UZH

- APDs (RMD S1315-P), 14x14 mm² area
- optimized for VUV light
- gain tests in LXe, 1K T stability, resolution and *E* calibration
- <u>conclusion:</u> limited use for single photon counting, but maybe useful for S2 signal

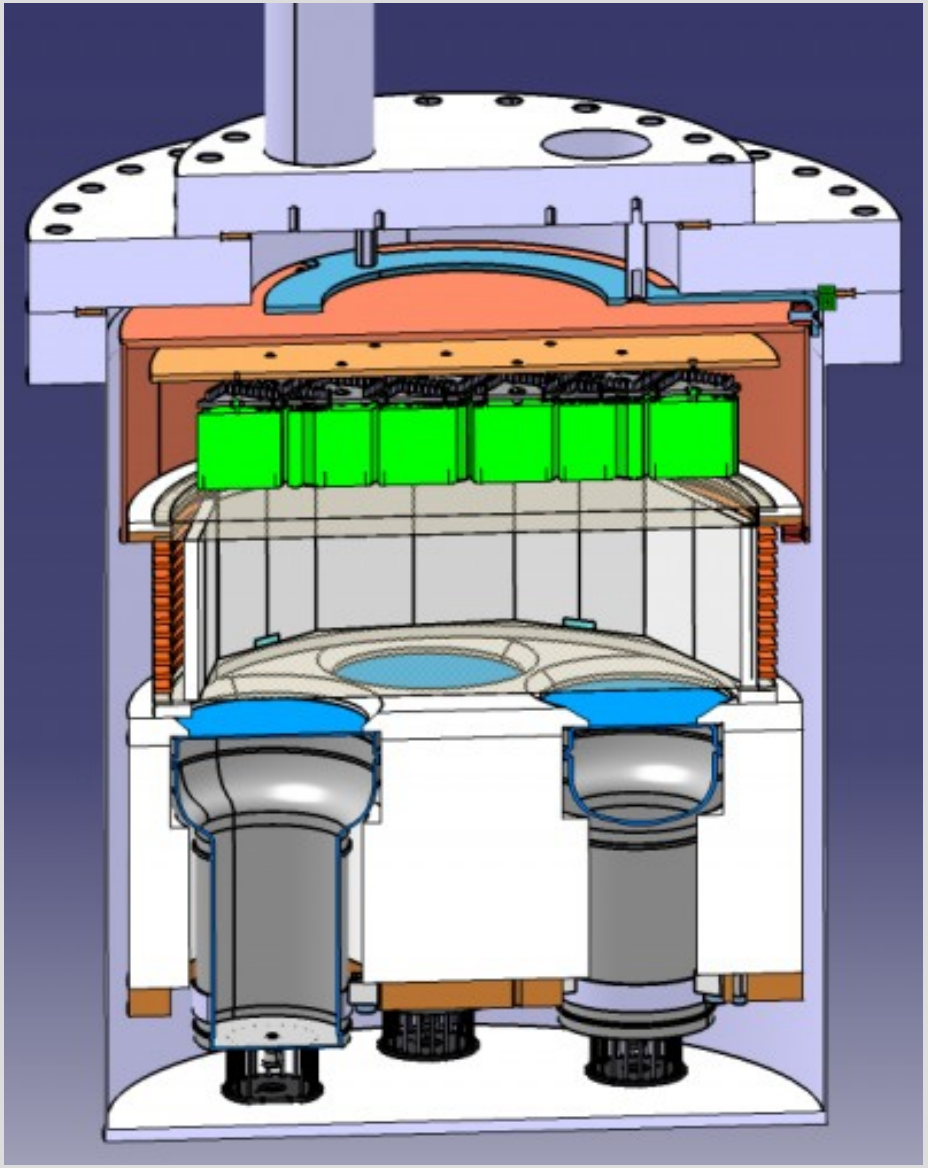
SiPMs tested as well







A future mid-scale TPC @ UZH



UZH

Preliminary Design

- 5 R11410 on bottom array
  (XENON1T-type)
- 20-30 R8520 on top array
  (XENON100-type)
  plus SiPMs (MPPCs) on top array
  → good xy-position resolution
- TPC: ~21 cm diameter
  (~6 kg LXe) ~6 cm height
  → optimized for high drift fields

Science Goals

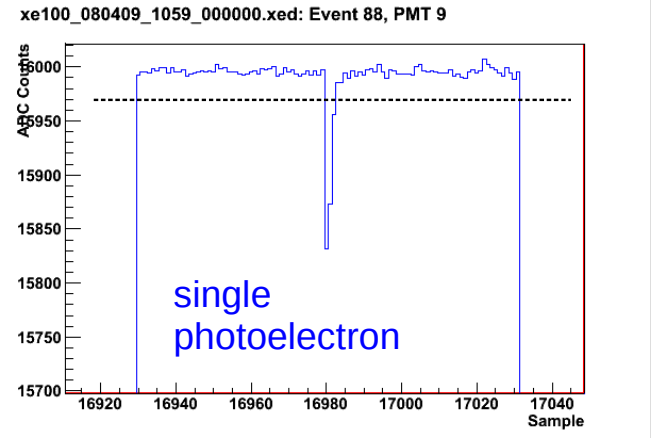
- R&D detector with excellent capabilities for fiducialization
- demonstrate linearity over very large dynamic range (PMT+APD)
- field quenching studies (S_{nr}, S_{ee})
- calibration studies
- ...

DAQ Development: Paradigms

Bern

- Measure everything which comes out of the detector
  everything = single photoelectron level
- Lowest possible trigger threshold
  lowest = single (few) electron S2 level

measuring everything above SPE level in XENON1T:
~50 MB/s „noise“ (measured with XENON100)
→ does not include any signal yet!

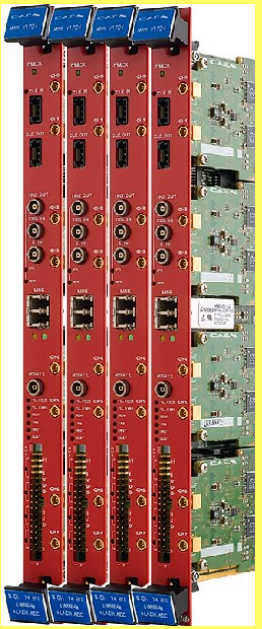


- The need for speed (300 MB/s)
  → parallelization
  → software trigger
  → self-triggering at hardware level

trigger
= extract events (S1 + S2) from data stream

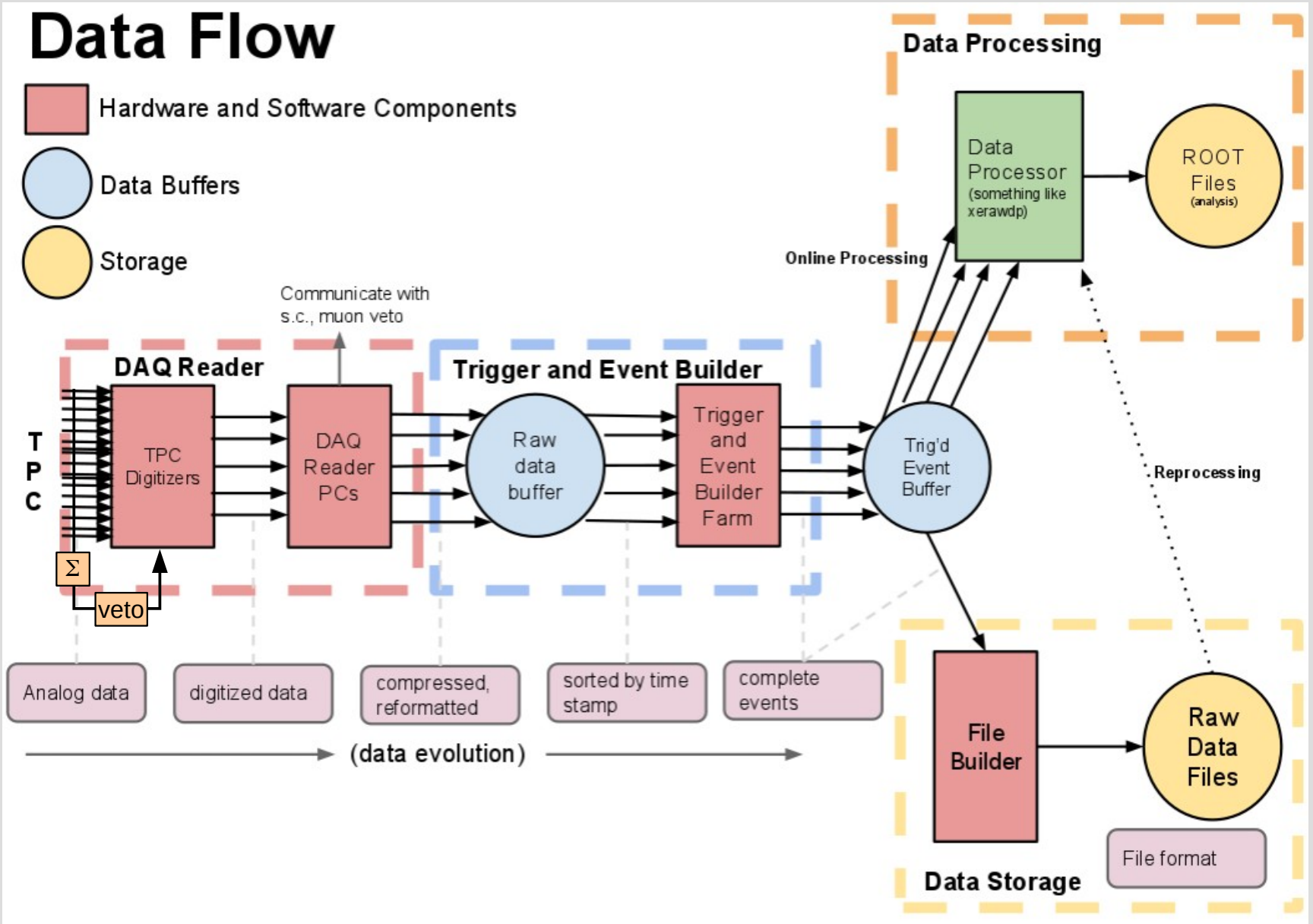
Design Goals:

+ no deadtime in dark matter mode
+ allow for high calibration rate
+ (low) no trigger threshold
+ flexible event handling
+ improved timing information
+ low noise
+ reasonable cost
+ re-use proven XENON100 techniques/algorithms



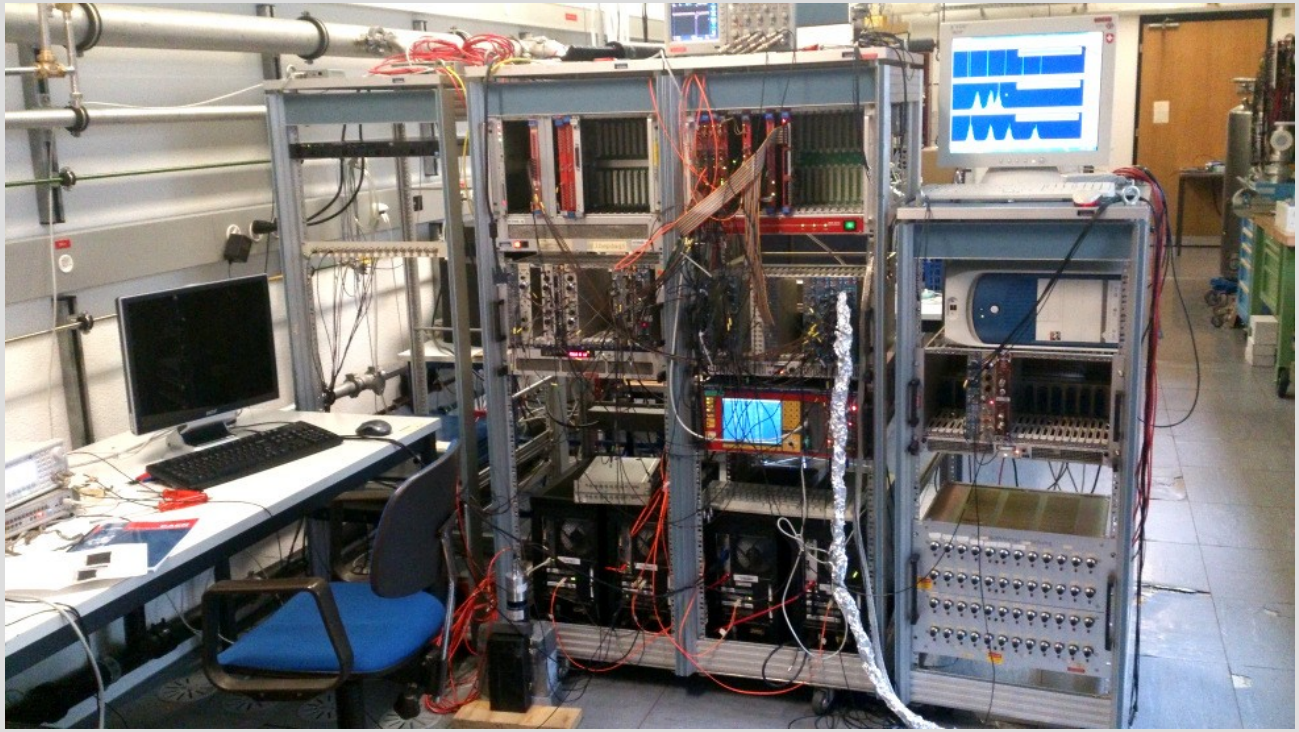
Readout: DAQ Development

Bern



Readout & Electronics: R&D

Bern



- development of DAQ Reader (front-end)
  commercial hardware + custom firmware (CAEN)
- development of high energy veto, busy
  commercial hardware + custom firmware
- software: GUI, File Builder, data processor

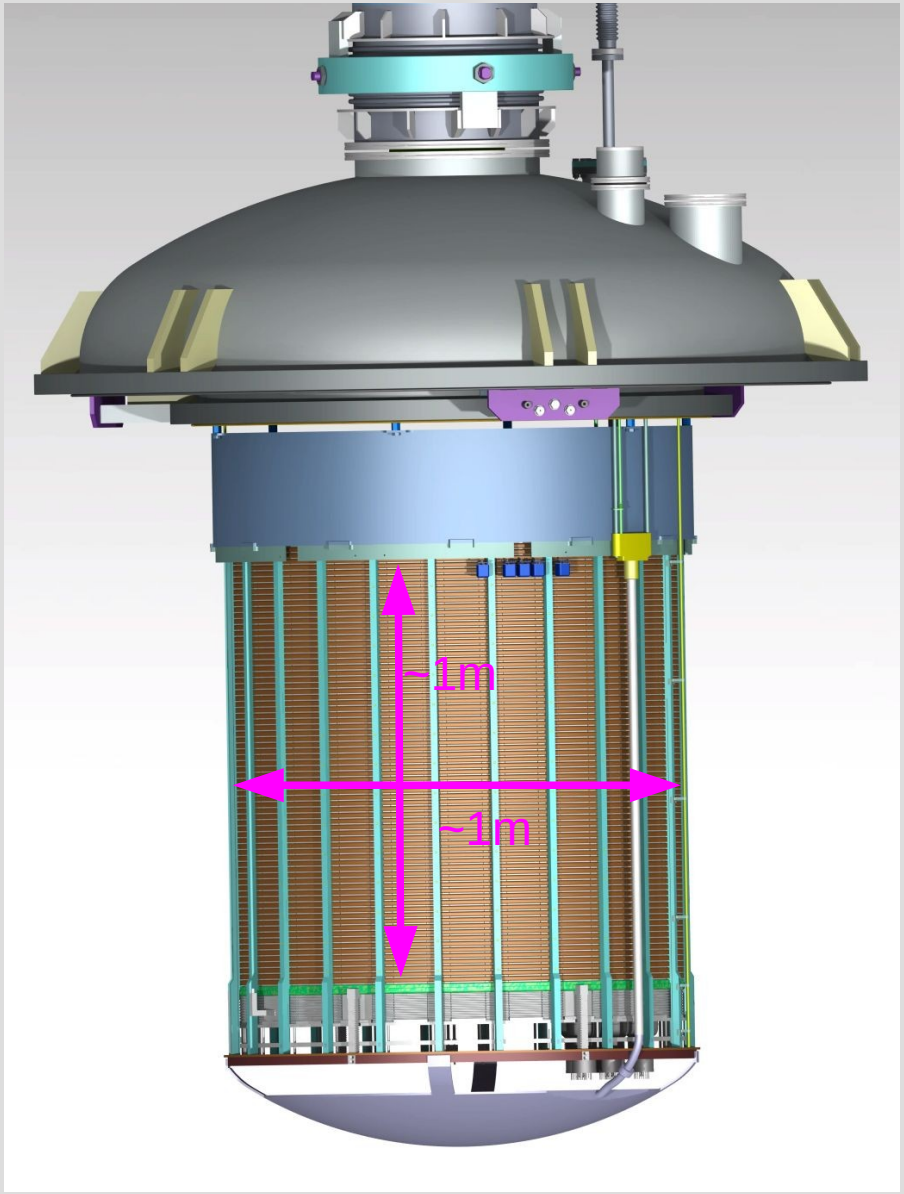
→ full DAQ system (40ch) operational in Bern for tests and benchmarks

Readout Demonstrator

- test readout/grounding using final XENON1T equipment
  ADCs, HV, amps, PMTs+bases, cables, connectors, etc
- investigate details

XENON1T: TPC Design

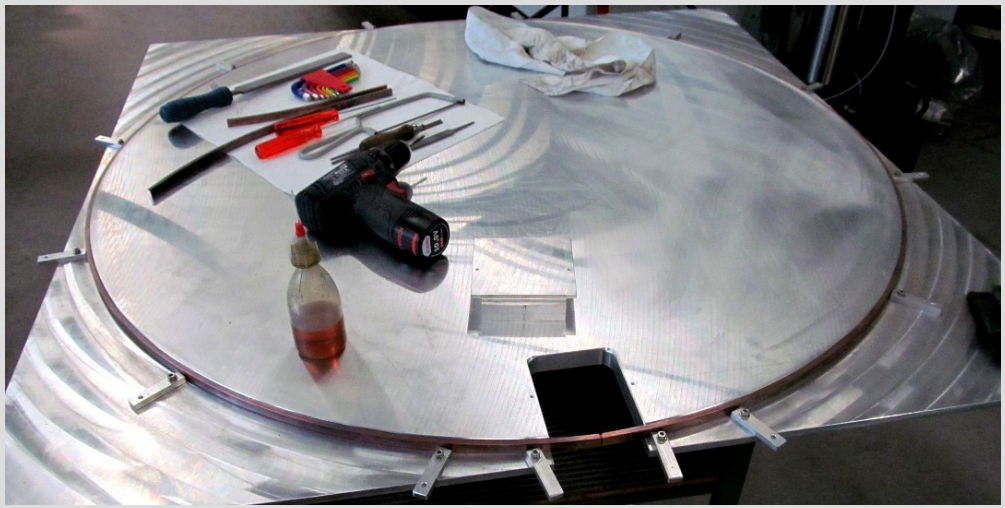
Bern
UZH



leading involvement of CH-groups in XENON1T TPC design:

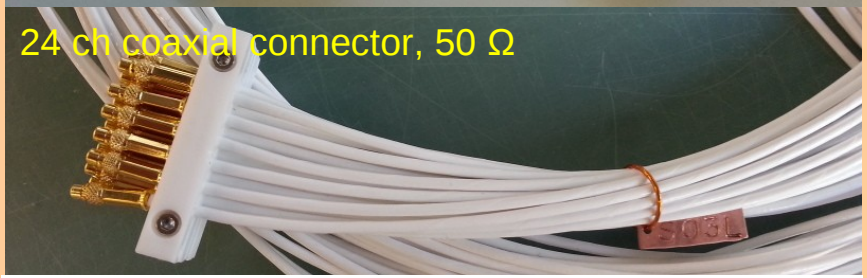
- working group lead
- most of the design realized in CH
- TPC will be produced @ UZH
- prototyping at UZH and Bern
- e/m field simulations (FEM, BEM)
- assembly procedures

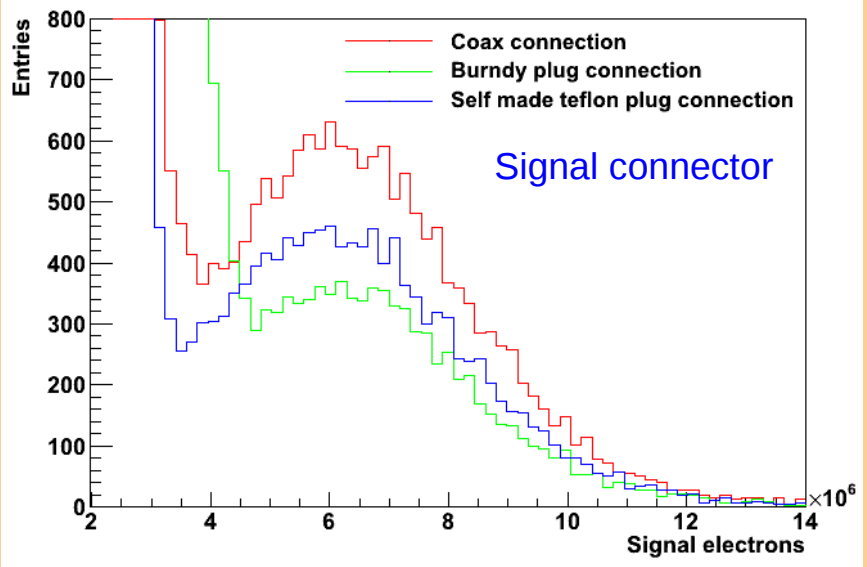
TPC will contain 2.2 t of LXe
1m drift, 1m diameter, –100kV
only low-background materials

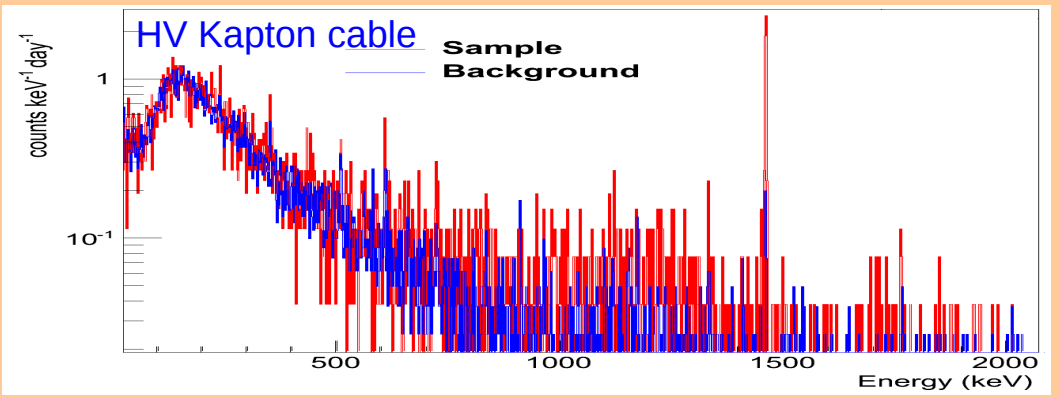


TPC: Cables and Connectors

UZH Bern







- large detectors require readout+bias of many channels
- detector assembly requires connectors
- R&D in terms of signal quality, background (γ-screening, Rn, etc.)

- first cables+connectors for **XENON1T** recently installed

TPC: stable gas amplification

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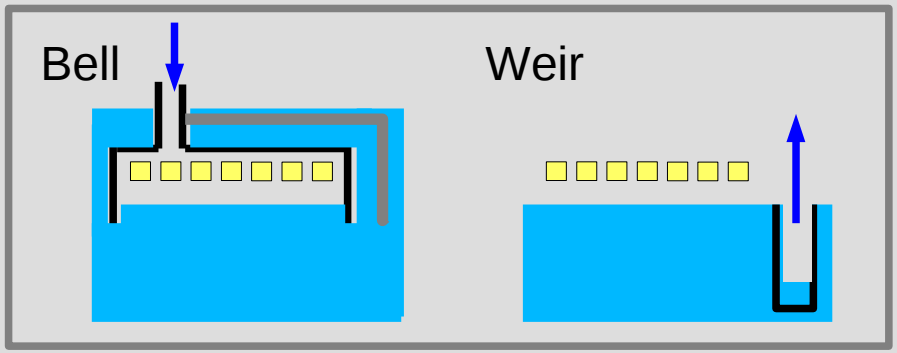
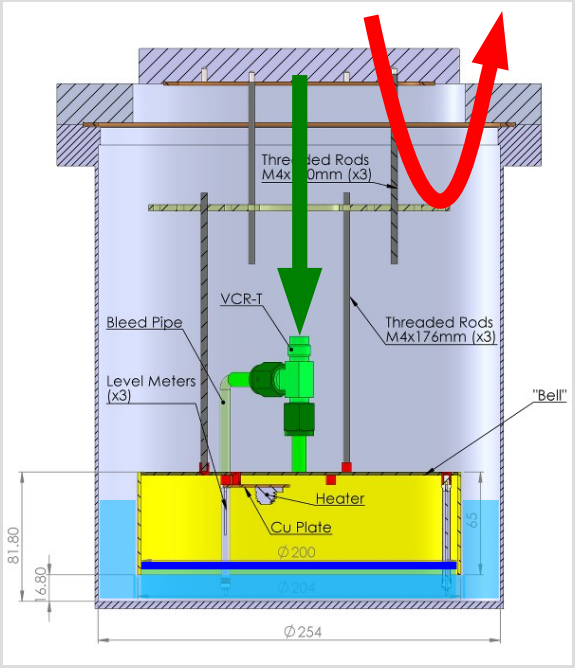
Stable liquid-gas interface is crucial for S2 amplification

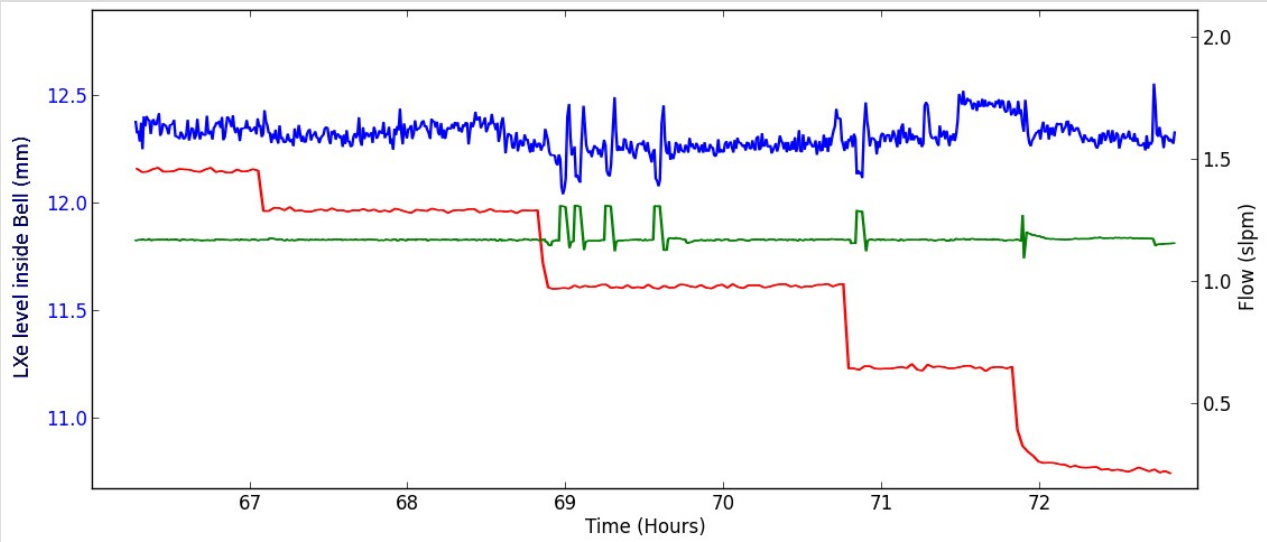


$$n_{\mathrm{ph}} \propto \left(\frac{E}{P} - 1.0\right) Px$$



Ongoing bell tests @ UZH, using MarmotXL

- liquid level stability
- de-coupling of purification and levelling
- power consumption, effect of bell diameter



Material Selection

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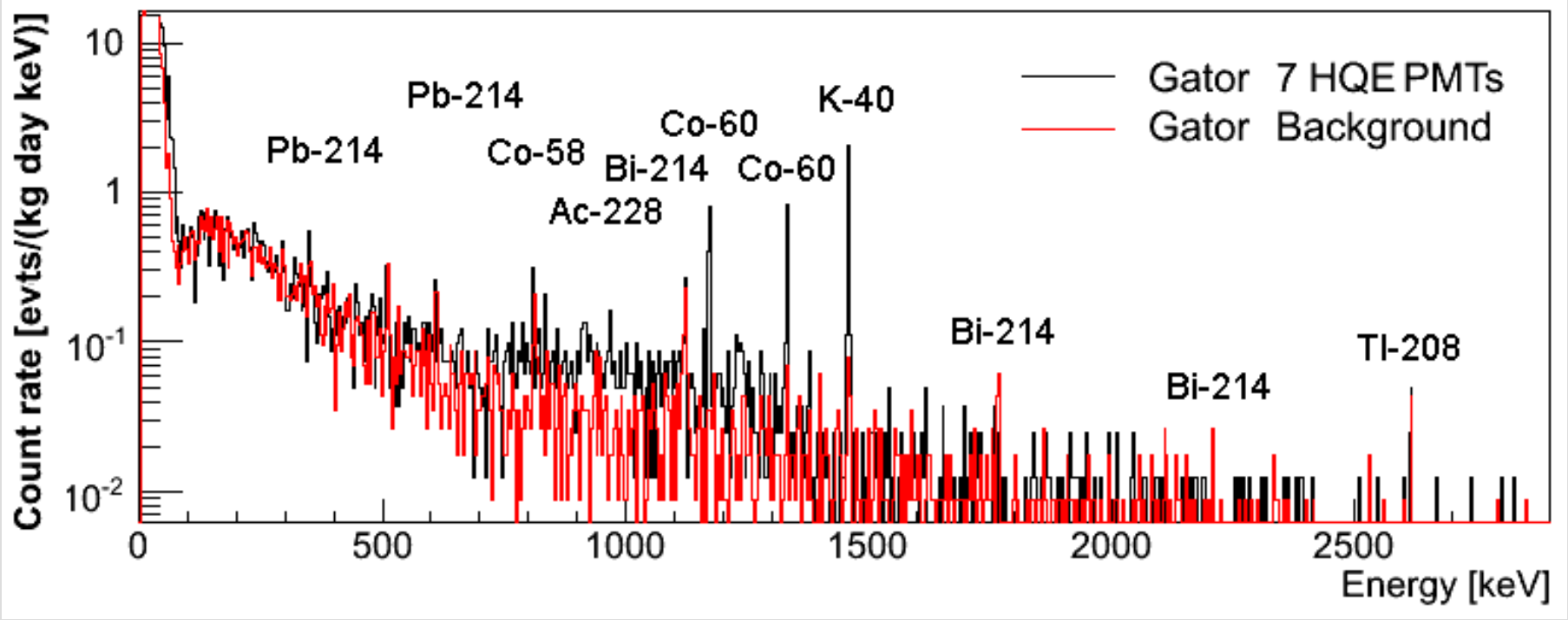
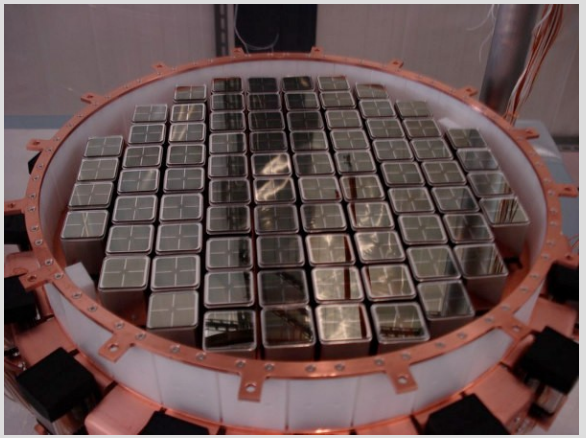


- mainly primordial isotopes (U-238, Th-232 chains)
- long lived K-40
- anthropic origin: Co-60, Cs137

→ gamma-screening crucial to control and estimate background of rare event searches



UZH is co-leading XENON screening team

HPGe Spectrometers

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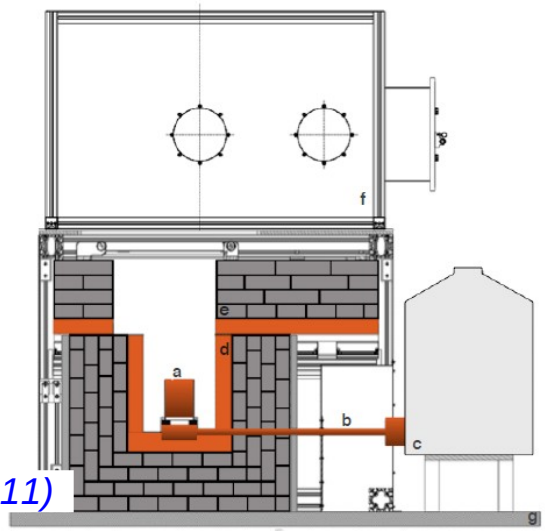
Gator @ LNGS (UZH)

2.2 kg p-type
low-background
(~0.16 evts/min)
100.5% efficiency

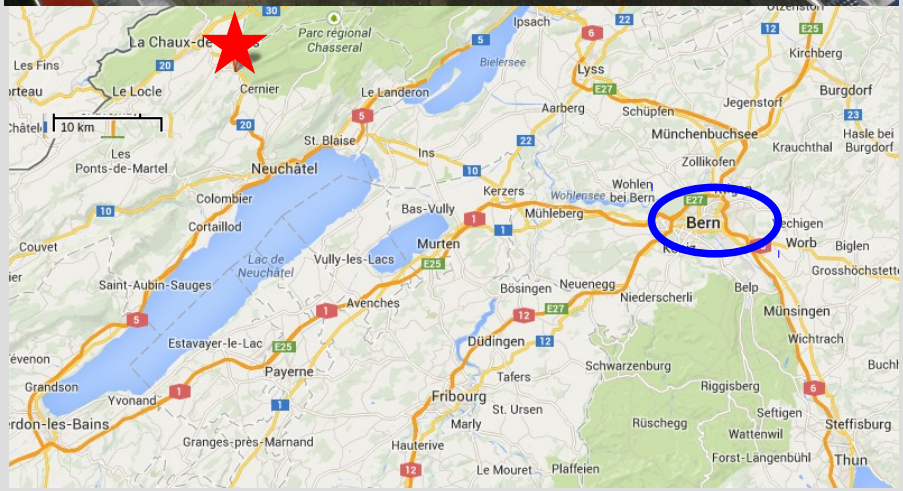
heavily used for
XENON material
selection

JINST 6, P08010 (2011)



New Facility in CH (Bern)

- new SNF-funded interdisciplinary project
- aim for similar sensitivity as Gator
- Swiss laboratory (Bern, Vue des Alpes, Gotthard)



Cosmogenic activation

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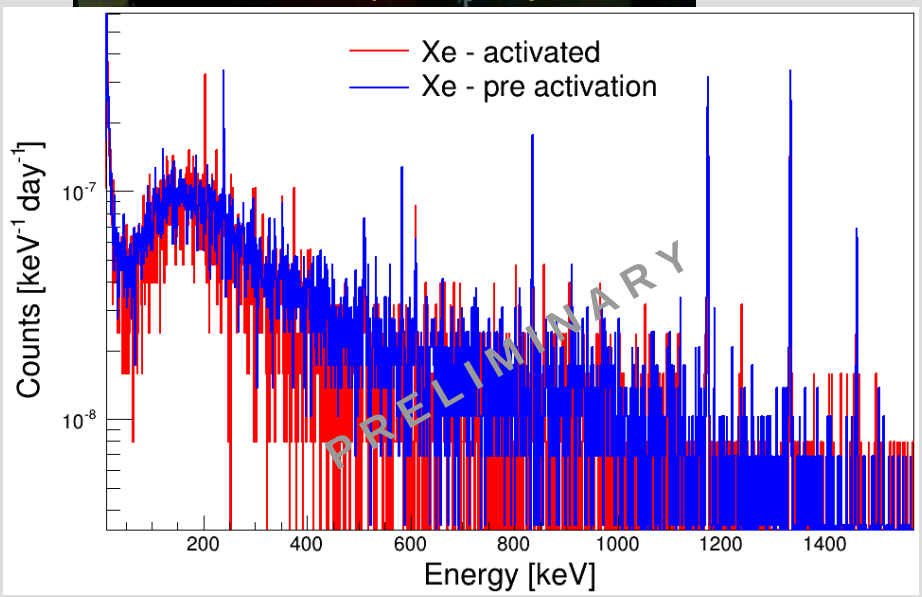
LXe intrinsic backgrounds are the most serious limitation for future DM searches.

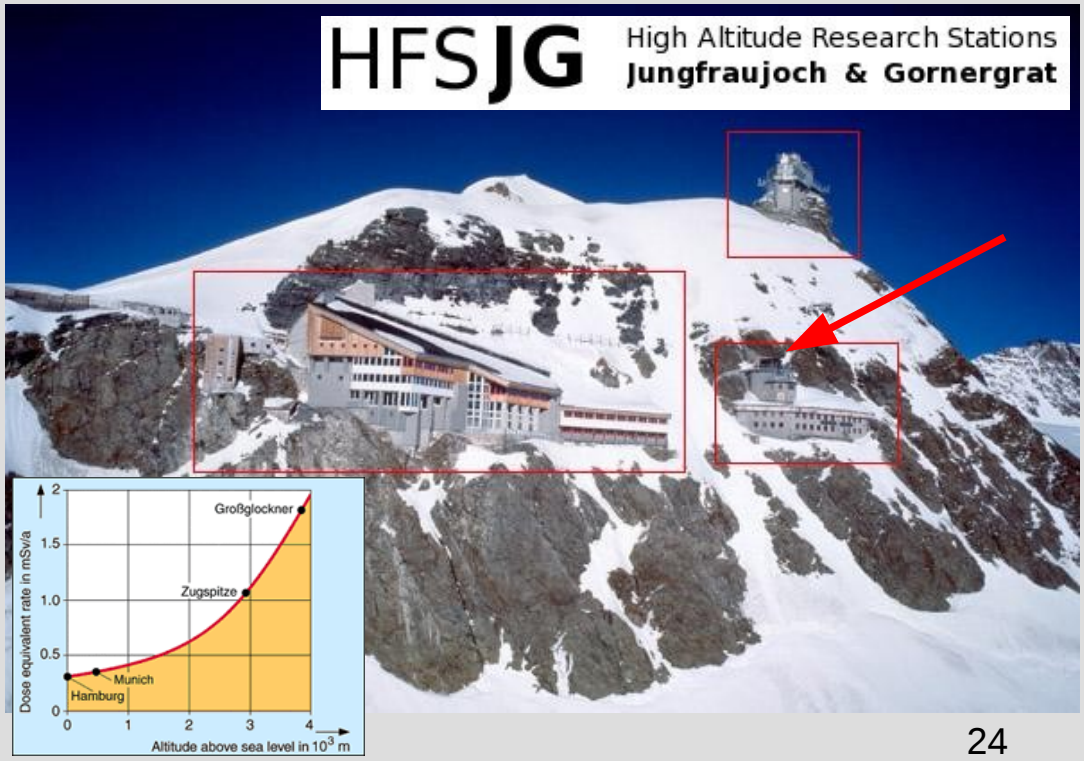
→ existing codes do not agree regarding the expected activation


Gator at LNGS, operated by UZH



Xenon and OFHC copper have been measured with a HPGe detector @ LNGS **before and after** their exposure to cosmic rays at the Jungfraujoch (3471 m)

→ data analysis is ongoing



Summary: R&D on LXe in Switzerland