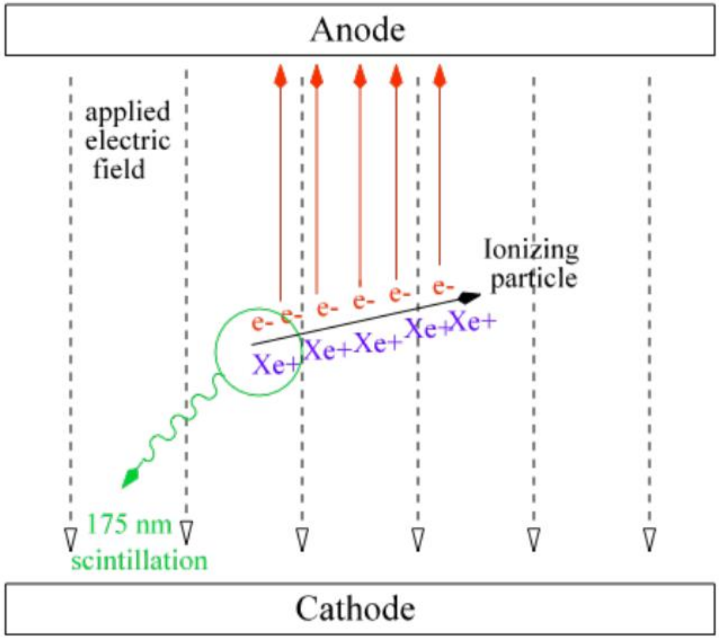
nEXO: The Next Generation Double-Beta Decay Experiment

Results of nEXO detector development

Thomas Brunner for the nEXO collaboration

TAUP2017– July 25, 2017

Searching for $0\nu\beta\beta$ in ^{136}Xe with EXO



Liquid-Xe Time Projection Chamber

- Liquid Xe at 168K
- Cryogenic electronics in LXe
- Detection of scintillation light and secondary charges
- 2D read out of secondary charges at segmented anode
- Full 3D event reconstruction:
    1. Energy reconstruction
    2. Position reconstruction
    3. Event Multiplicity

See talks by
C. Licciardi and
R. MacLellan

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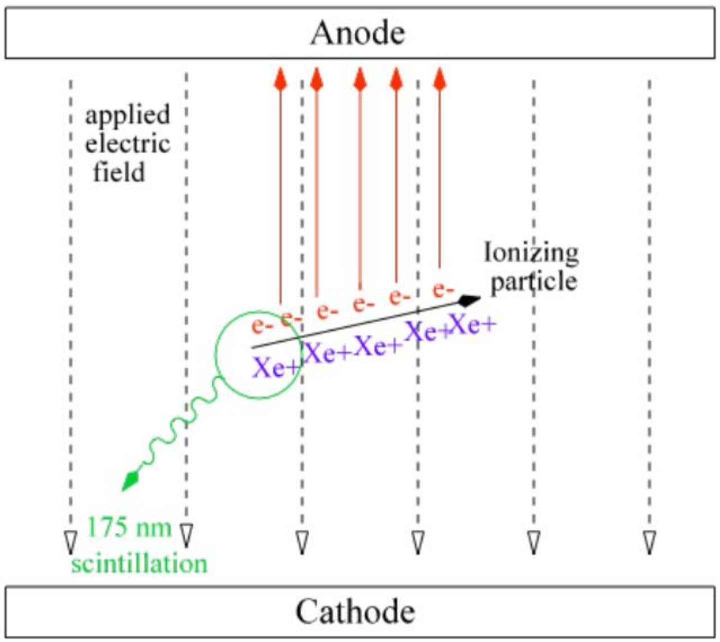

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See talks by C. Licciardi and R. MacLellan

$T_{1/2}^{0\nu} > 10^{25}$ years !!
→Need:
- high target mass
- high exposure
- low background rate
- good energy resolution

Development focuses on:
- High voltage
- Light detection
- Charge detection
- Radioassays
- (Ba-tagging)

See talk by Chris Chambers

Advantages of nEXO

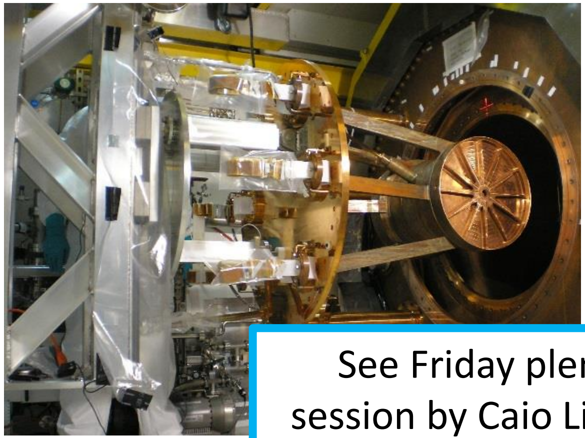
Build on the experience gained and the success of EXO-200 using well established techniques

1. **Energy measurement**
2. **Event multiplicity (γ's Compton scatter depositing energy in more than one site in large detectors).**
3. **Depth in the detector (or distance from the walls) is (for large monolithic detectors) a powerful parameter for discriminating between signal and (external) backgrounds.**
4. **α discrimination (from e^- / γ), possible in many detectors.**

Take full advantage of monolithic detector!

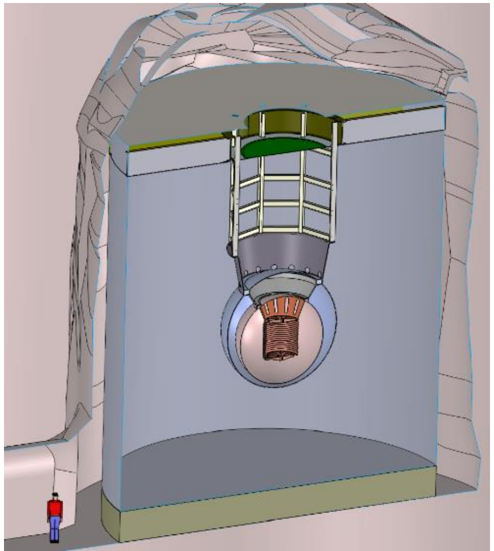
Phased approach:

1. EXO-200: 200kg liquid-Xe TPC



See Friday plenary session by Caio Licciardi

2. nEXO: 5-ton liquid Xe TPC with Ba tagging option (SNO lab cryopit)



The nEXO TPC

Long, single drift

- HV
- Xe purity (low outgassing)

Novel charge tiles

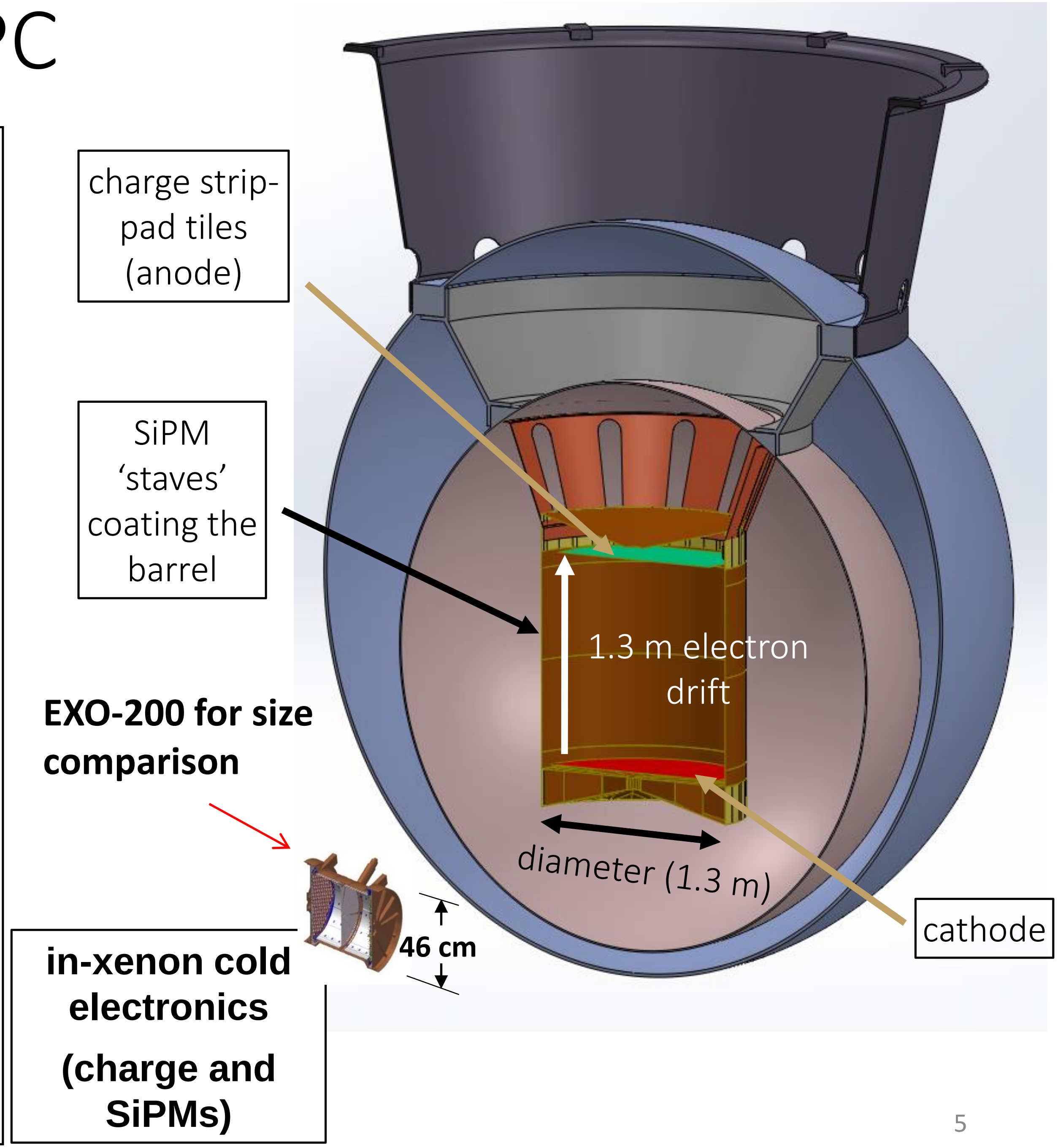
- very low noise
- modularity
- self-supporting

SiPMs on the barrel

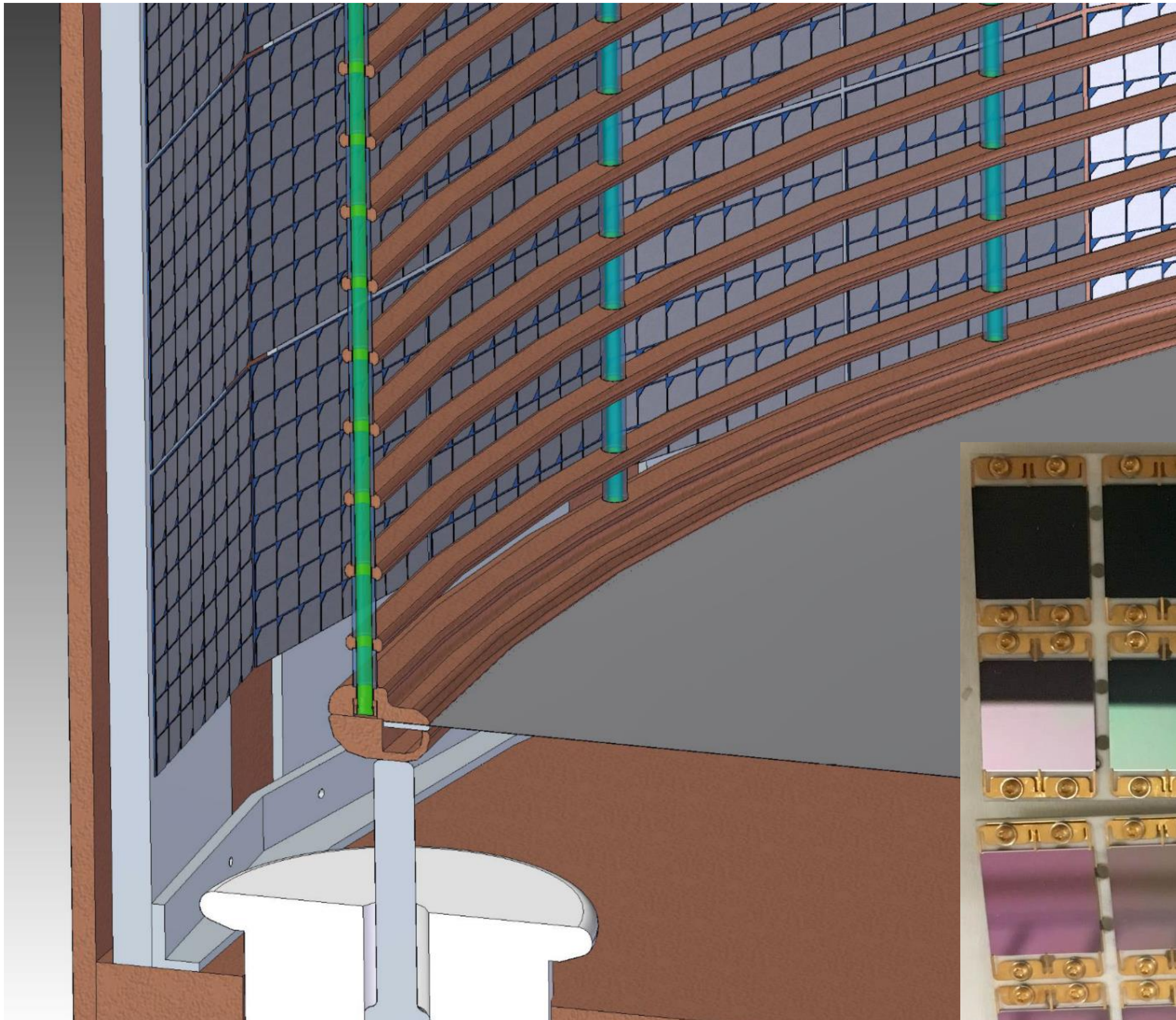
- optically open, reflective field cage
- no HV required
- Robust
- larger gain
- large scale production

In-Xe electronics

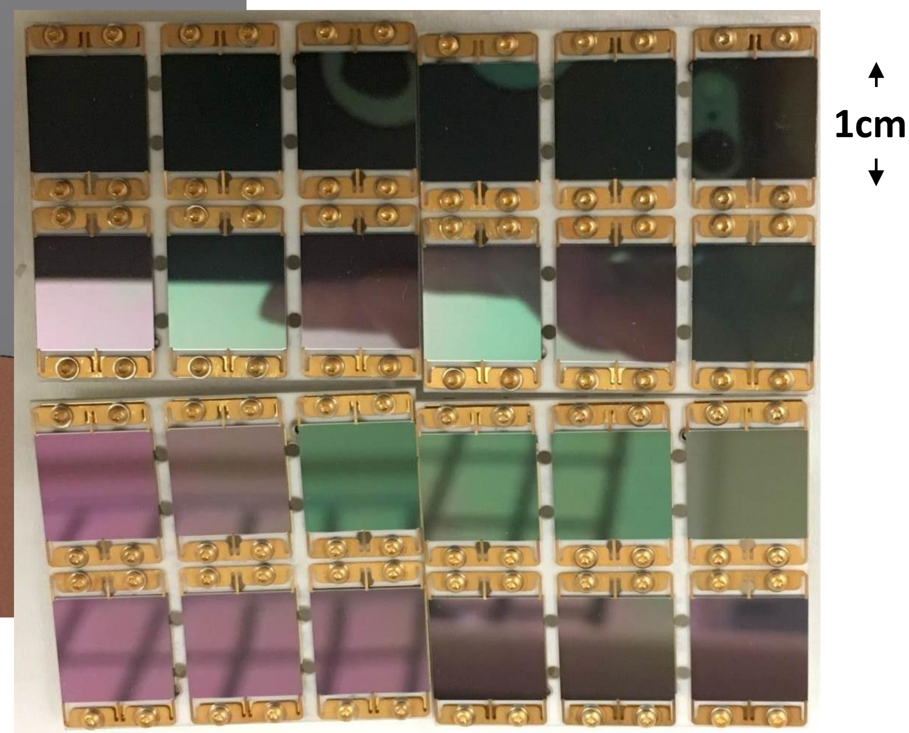
- radioactivity



Photon sensors

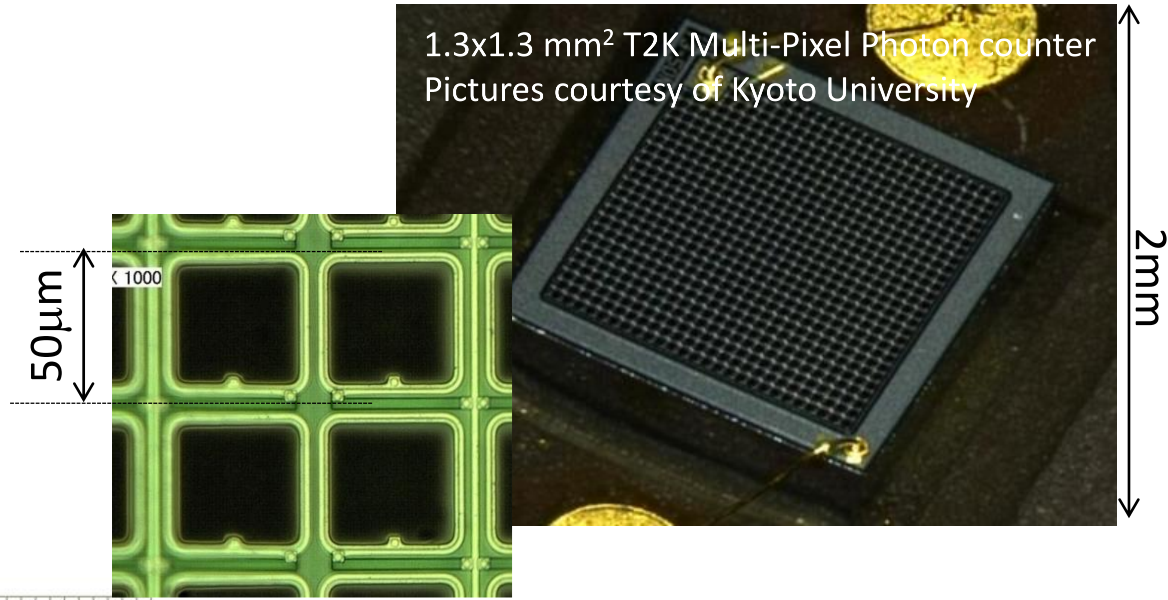


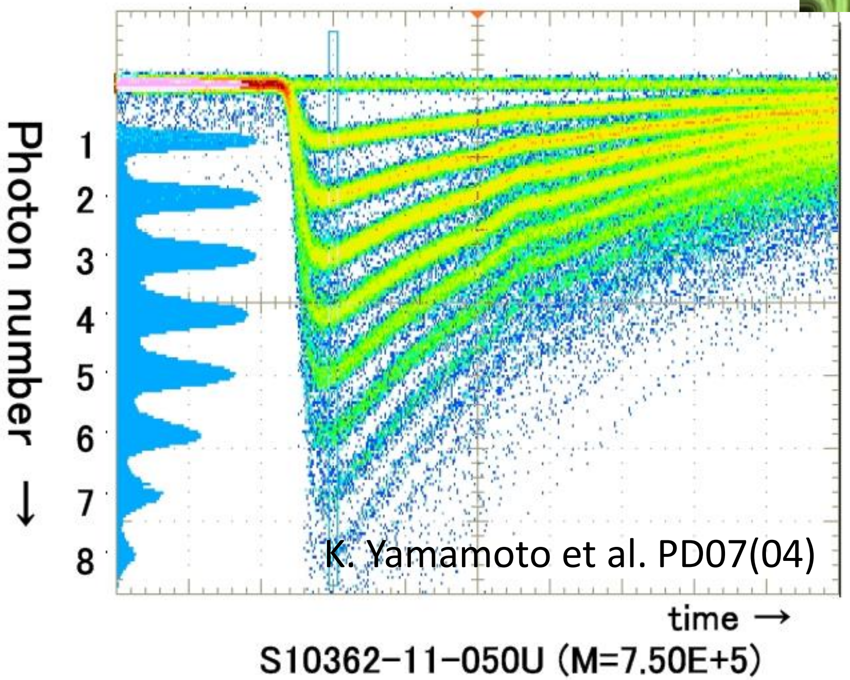
- **Need ~4m² of VUV-sensitive SiPMs**
- **SiPMs and electronics mounted in LXe**
- **Increase photon detection efficiency through reflective surfaces**



Analog SiPMs - baseline solution for nEXO

- High gain (low noise)
- Large manufacturing capabilities (> 4 m^2)
- But efficiency and radioactivity need work

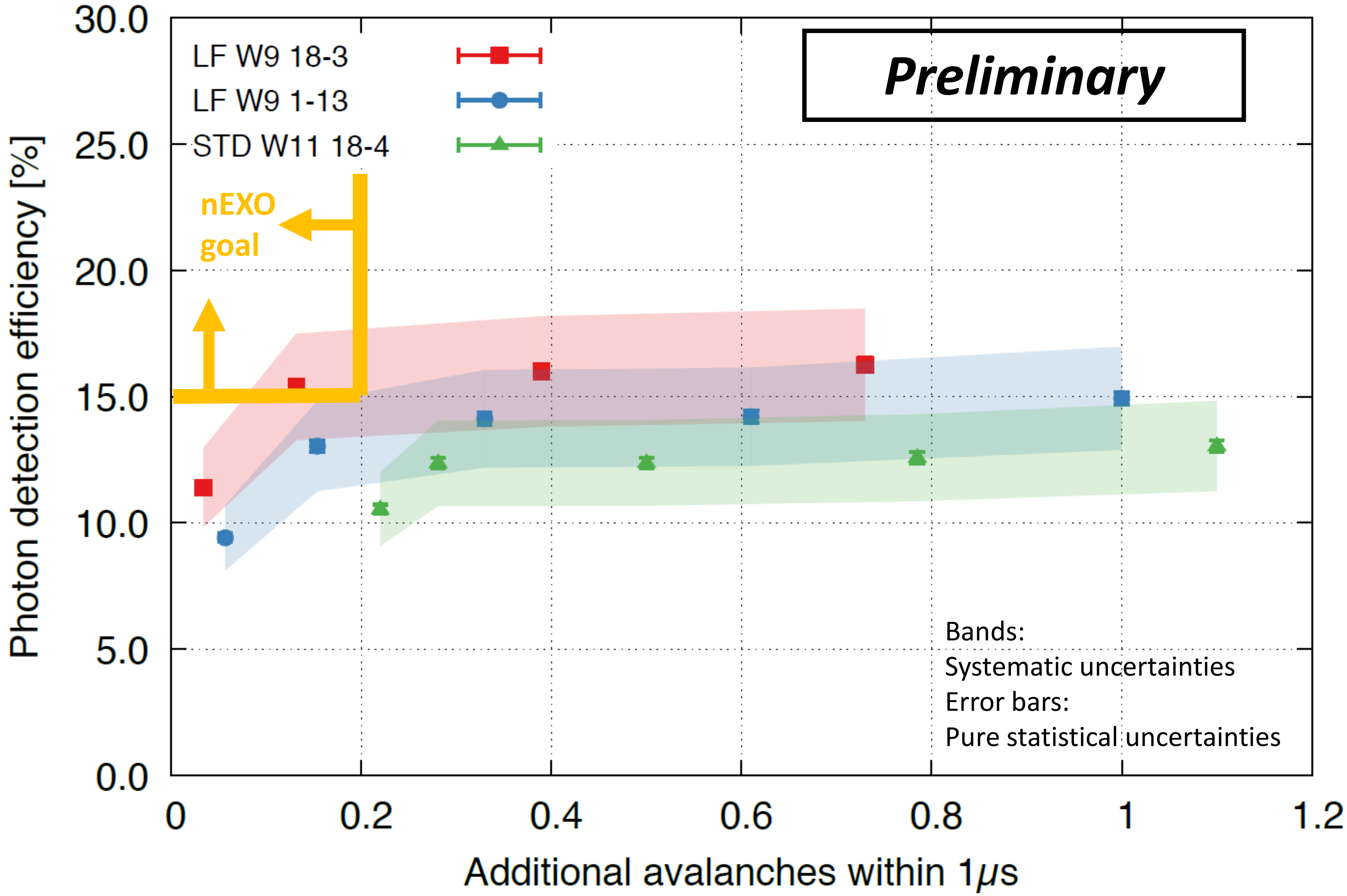




Requirements:
- Efficiency at 175nm > 15%
- Correlated avalanche rate < 20%
- Dark noise rate < 50Hz/mm^2
- Low radioactivity

SiPM Photodetector

At least one type of 6 x 6 mm² VUV devices now match our desired properties, with a bias requirement ~30V (as opposed to the 1500V of EXO-200 APDs)



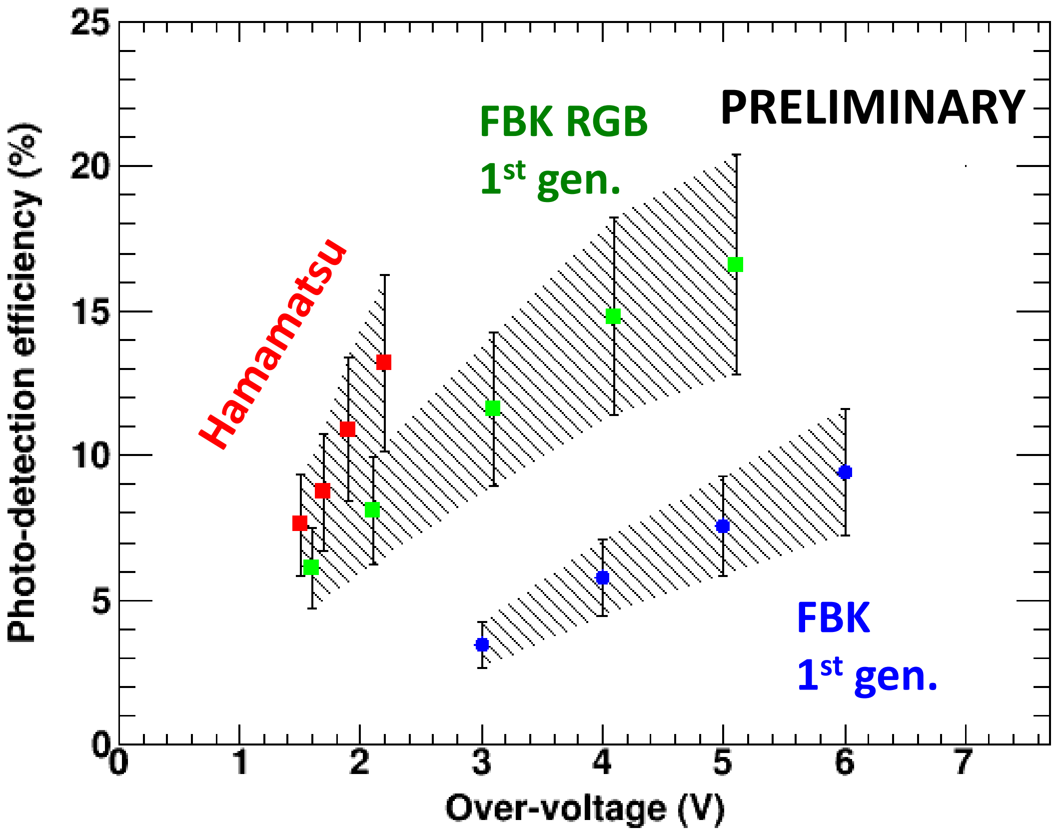
FBK low field SiPM: Th = 0.45+/-0.12 ppt, U = 0.86+/-0.05 ppt

FBK standard field SiPM: Th = 0.44+/-0.05 ppt, U = 0.99+/-0.02 ppt

SiPM Photodetector

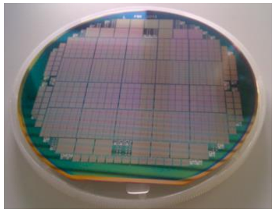
- Hamamatsu produces devices with QE>15% @ 175nm but encapsulation is too radioactive → trying to procure un-encapsulated devices

- First nEXO-specific run at FBK (Italy) provided ~10% QE *[I.Ostrovskiy et al. IEEE TNS 62 (2015) 1825.]*
- New FBK "RGB" devices reach 15% QE with 7.7 x 7.7mm^2.



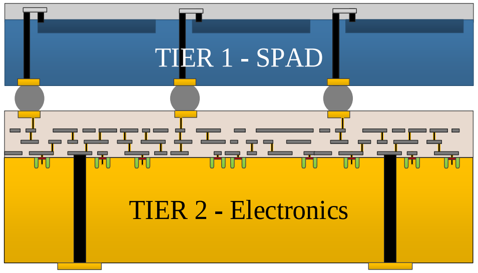
- Working closely with manufacturers to develop SiPMs to reach >15% QE at 175nm
- ^{232}Th and ^{238}U content of FBK SiPMs found to be <1 ppt
- Development of integration of 1x1cm^2 SiPMs into 10x10cm^2 tiles
- **First tests in liquid Xe**

Hamamatsu MEG MPPC



FBK SiPM

3D-integrated dSiPM for nEXO



nEXO radio assay showed sub-ppt Th/U purity

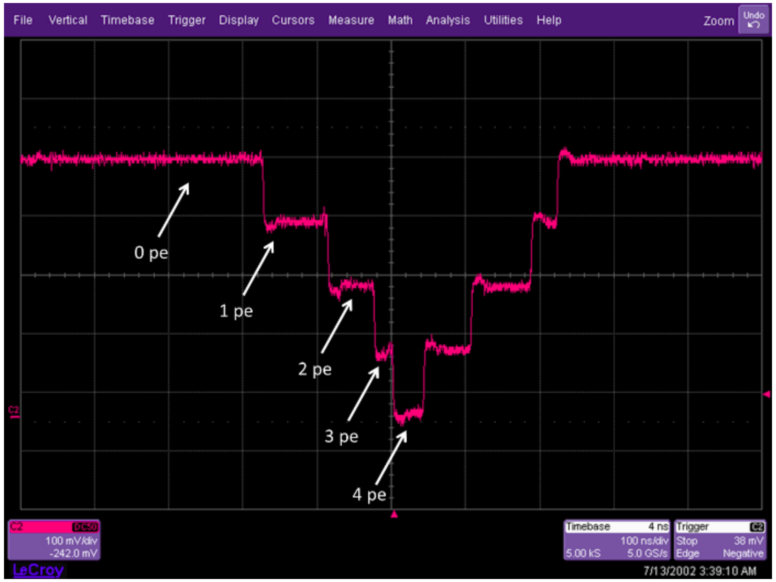
Advantages over analog SiPM + analog electronics

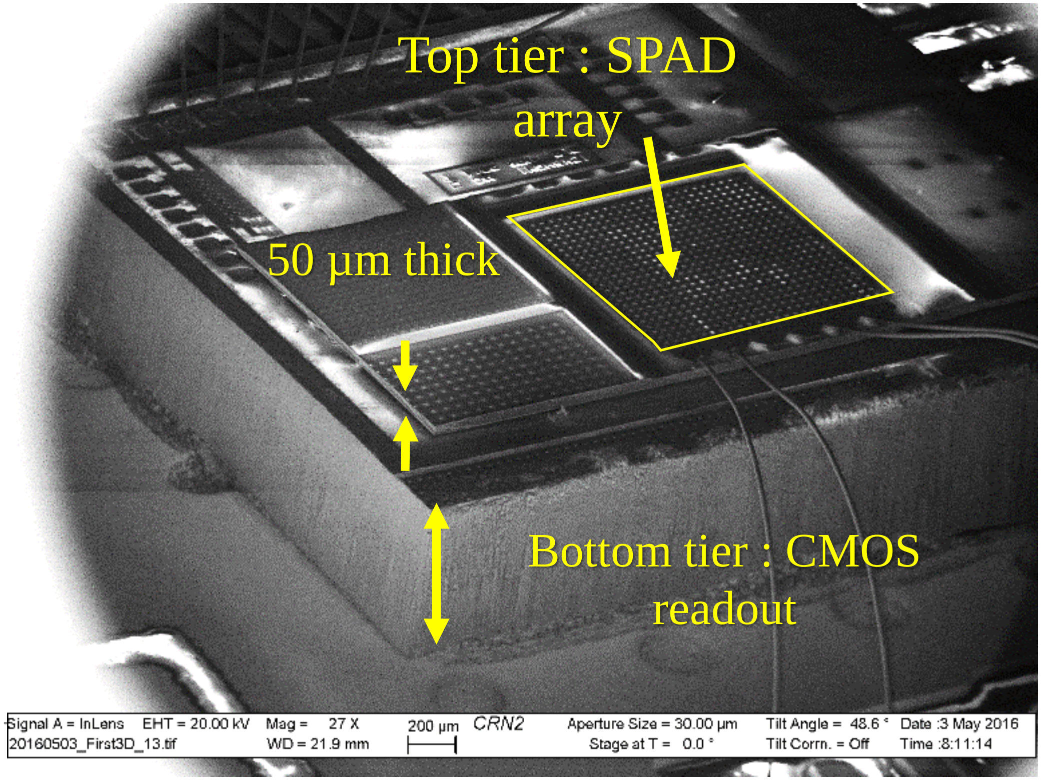
- All in one chip assembly: **photon come in, bits come out**
- Power scales with avalanche count not with capacitance
- Allow lower power or better timing resolution and granularity
- After-pulsing can be completely eliminated for a given time scale

Challenges

- Need custom SPAD array
- Large scale scaling
- Significant R&D required

See talk by Serge Charlebois

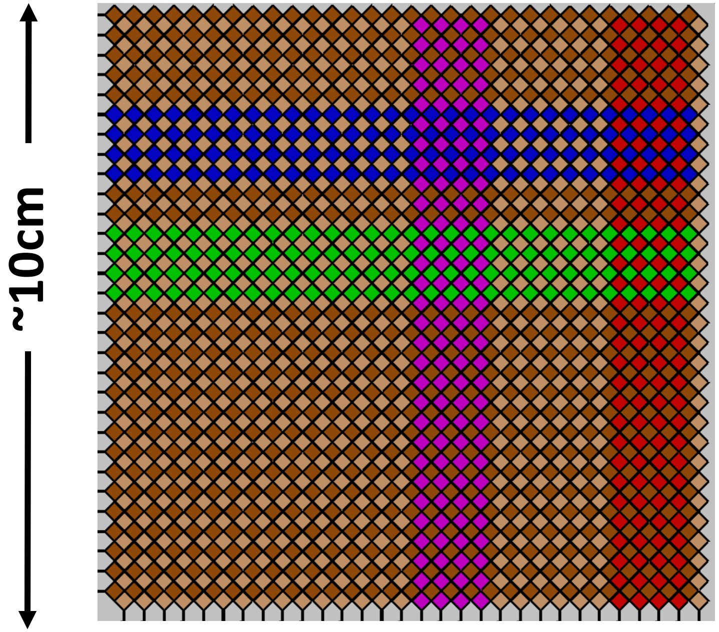


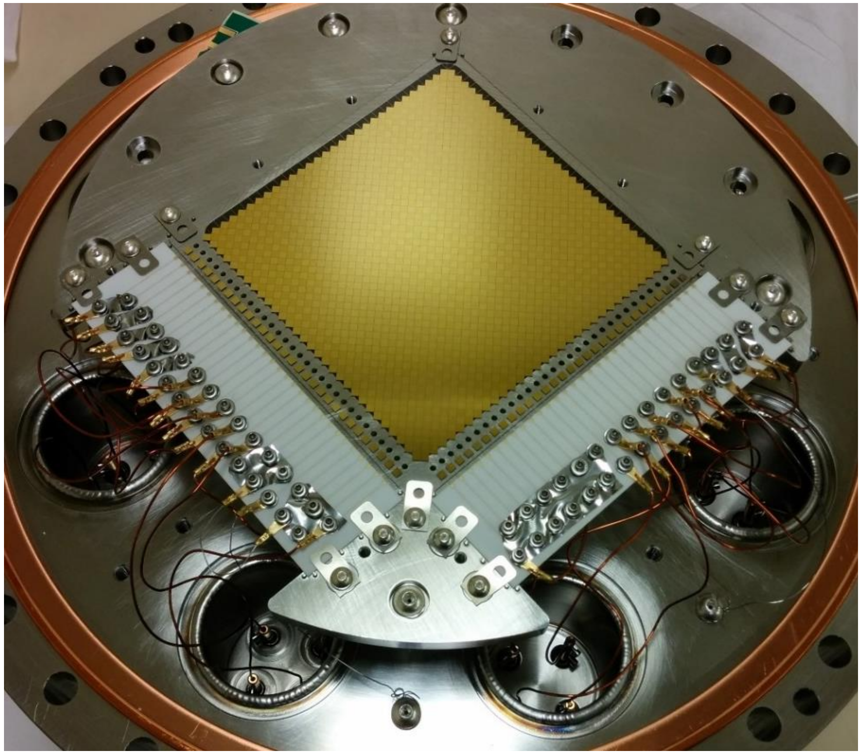


Charge Readout

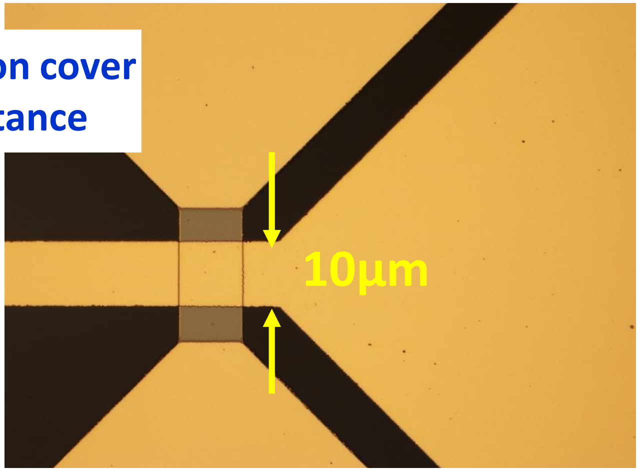
Charge will be collected on arrays of strips fabricated onto low background dielectric wafers (low radioactivity quartz has been identified)

- **Self-supporting/no tension**
- **Built-on electronics (on back)**
- **Far fewer cables**
- **Ultimately more reliable, lower noise, lower activity**



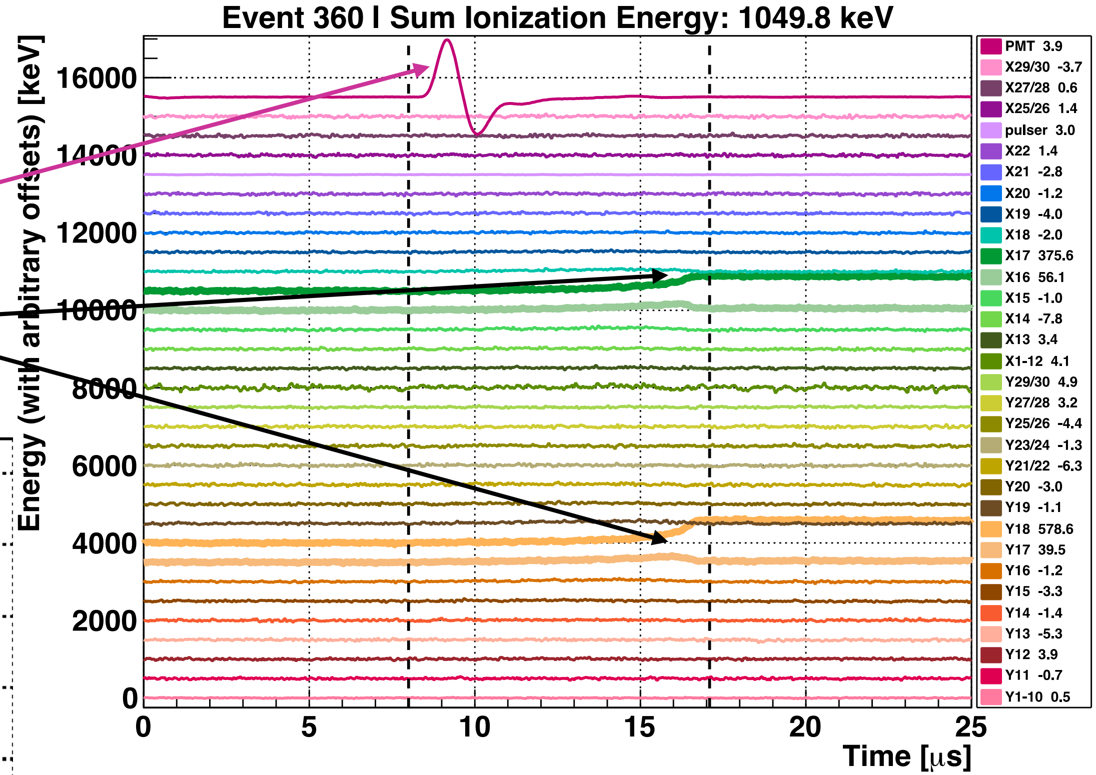


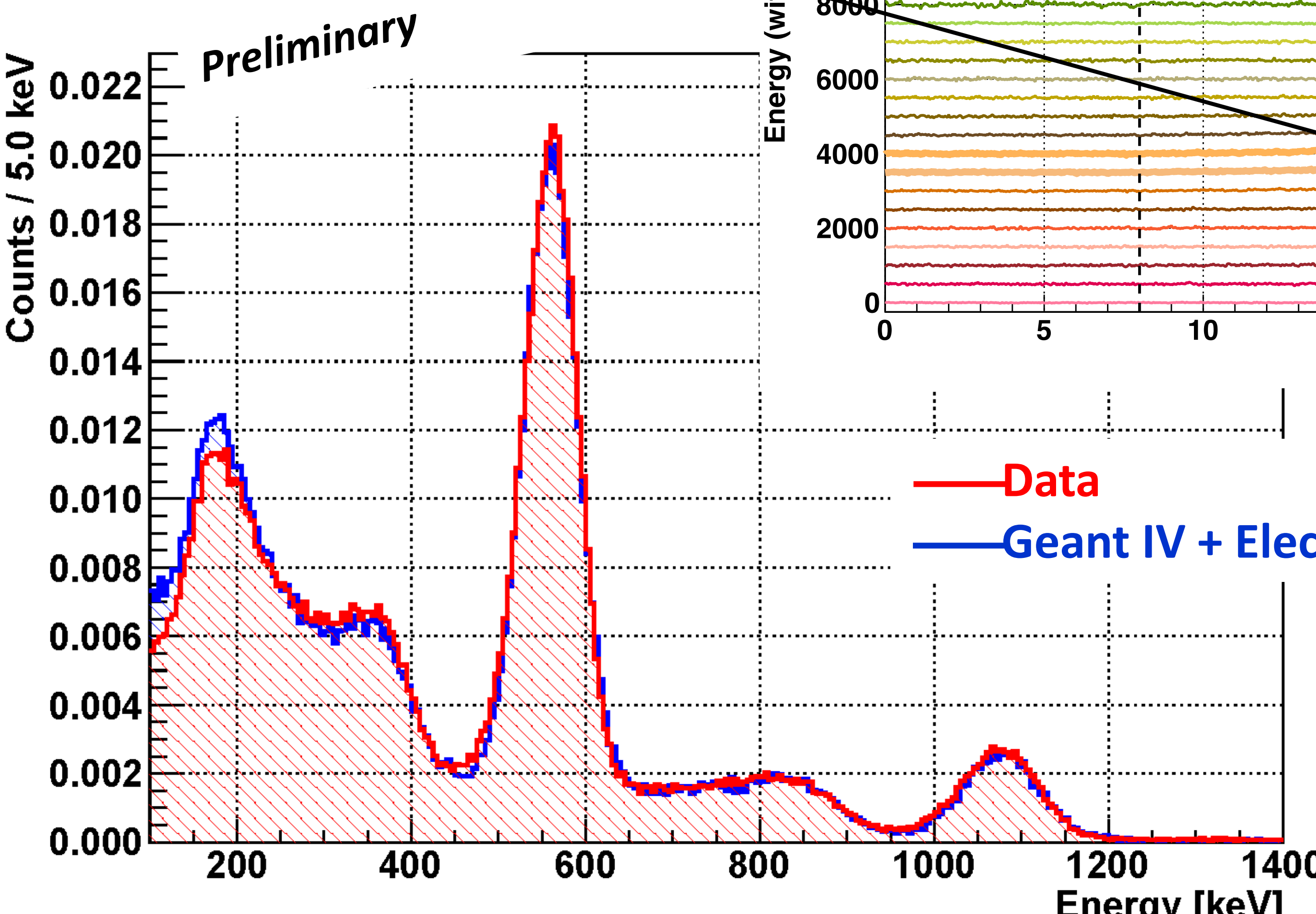
Max metallization cover with min capacitance



- 10 x 10cm^2 Prototype Tile
- Metallized strips on fused silica substrate
- 60 orthogonal channels (30 x 30), 3mm strip pitch
- Strip intersections isolated with SiO_2 layer

Charge Readout

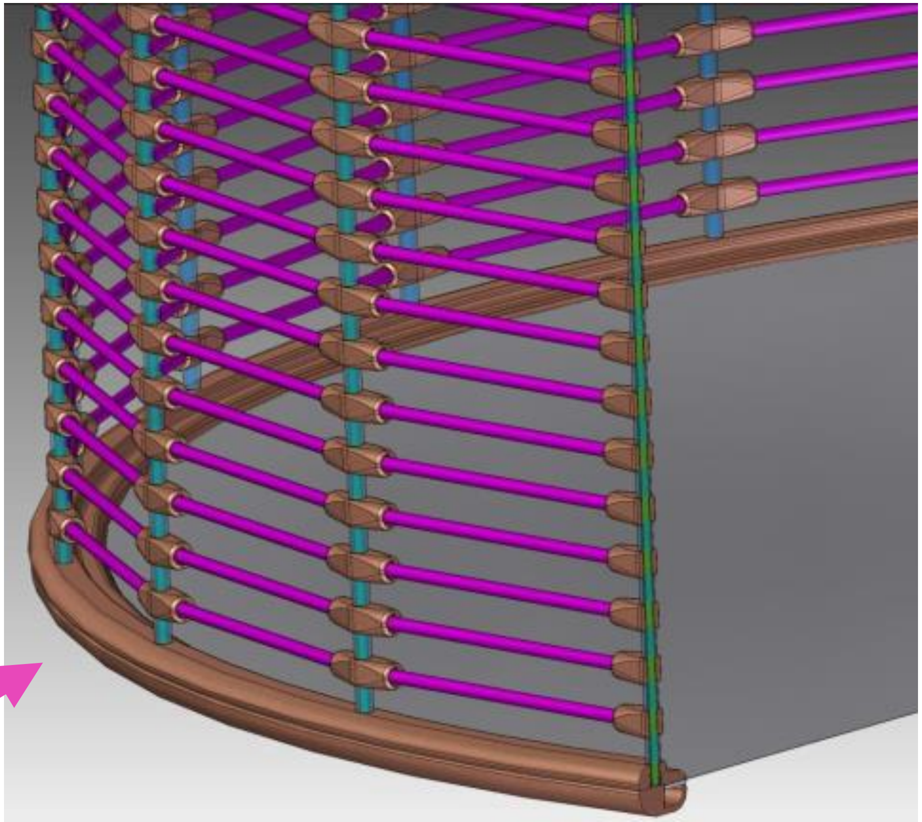




High Voltage R&D

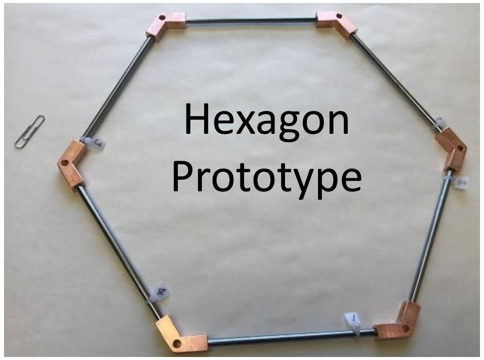
Focus of development

- Spark mitigation → stable operation up to -100 kV
- Protection of electronics and detector in case of HV breakdown
- High reflectivity at 175 nm
- Low radioactivity



Ideas:

- High-resistivity Si field shaping rings to limit spark current
- Reflective coating of cathode and field-shaping rings

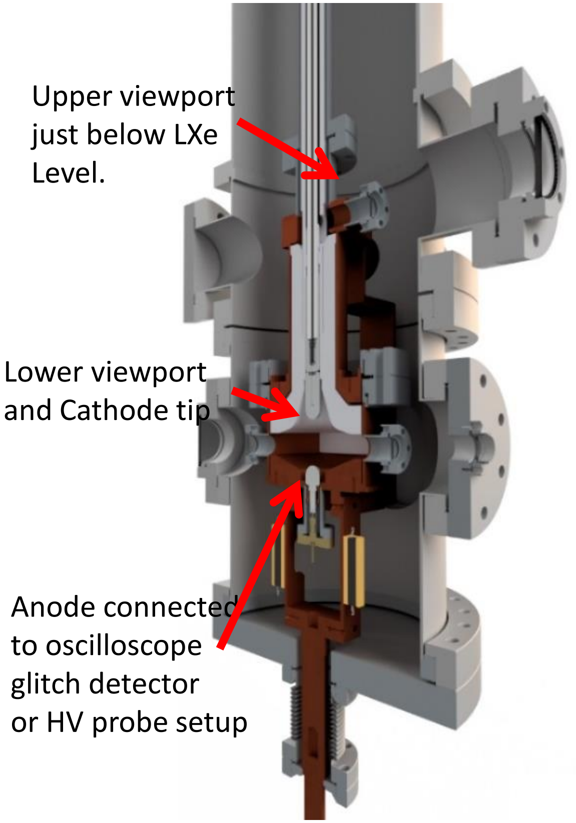


High Voltage R&D test setups

30l LXe Bern HV test setup now at **Carleton U.** with cryogenic cameras

HV tests of ~30cm scale geometries

400 cc LXe HV setup at **SLAC**



Test of breakdown voltage in LXe for different small size geometries

Max 800 kg LXe setup at **LLNL** to accommodate full or near-full size parts horizontally (under development)

HV tests in LXe for different full-nEXO diameter size geometries

Radioactivity studies of materials for nEXO

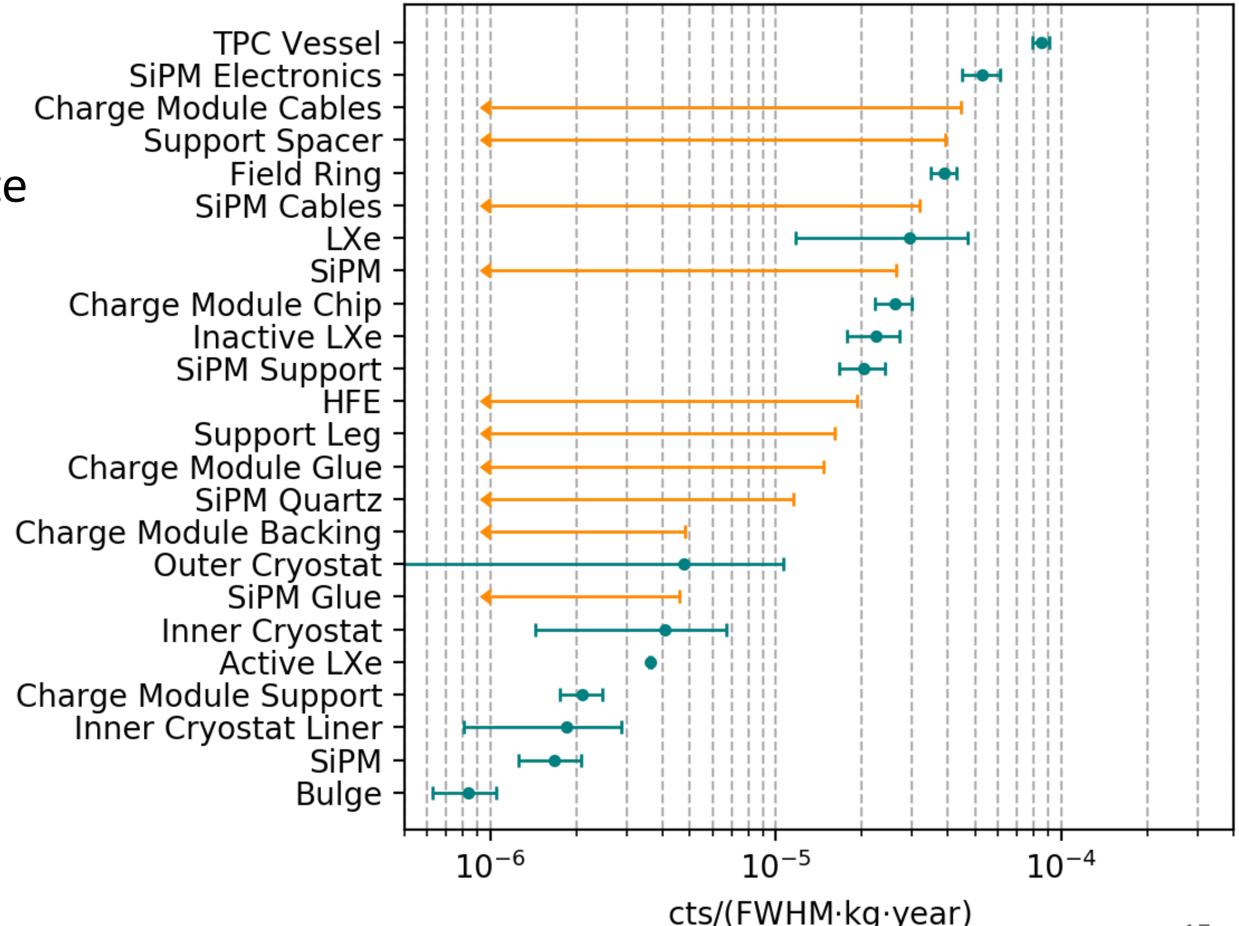
Techniques applied:

- Ge detector counting
- Neutron-activation analysis
- Inductively-Coupled Plasma Mass Spectrometry (IC PMS)

See talk by Ryan MacLellan
See poster by John Orrell

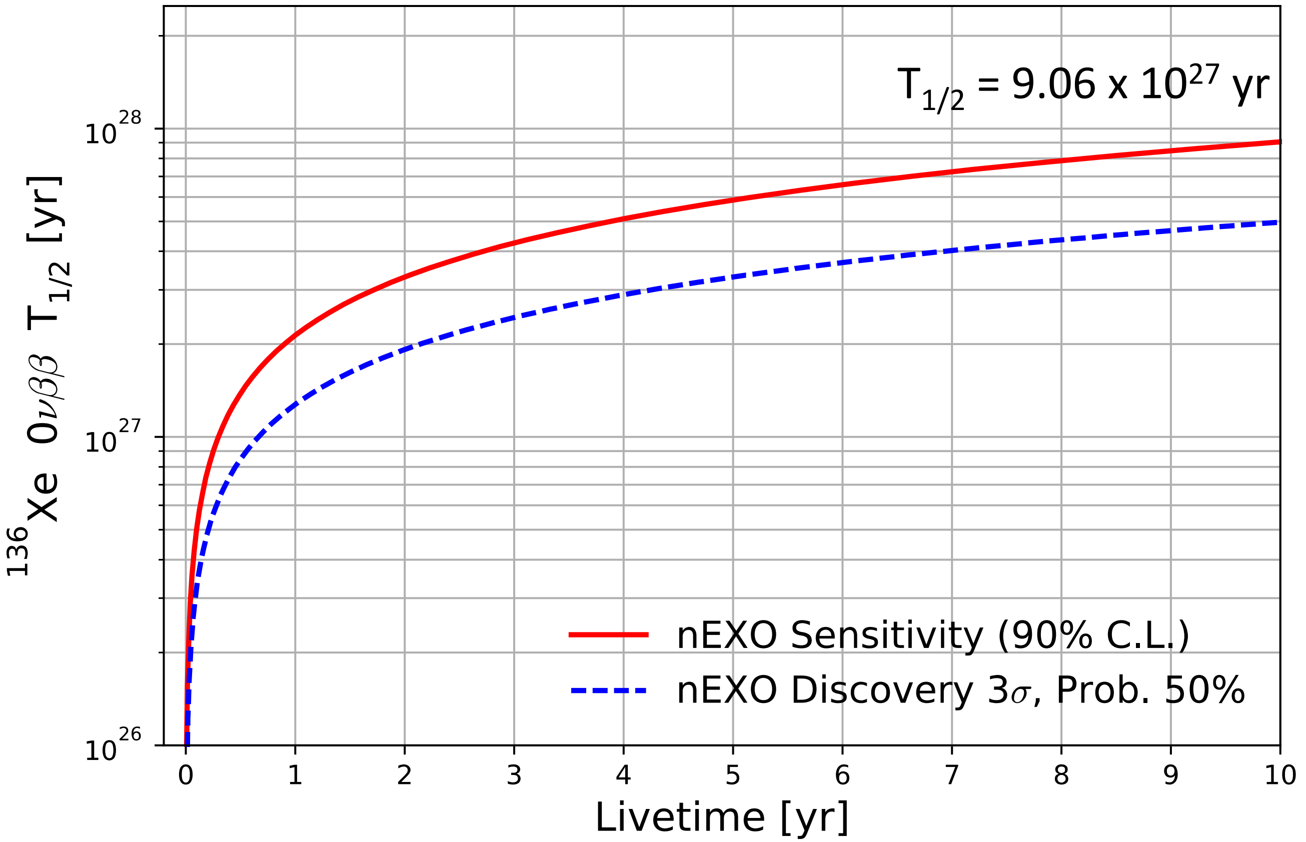
nEXO background budget by component

- TPC internals dominate (as expected)
- Several radioassay entries with only 90% CL limit



Great effort spent on measuring radioactive backgrounds and identifying suitable materials for nEXO.

nEXO Sensitivity & Discovery Potential



Methodology:

- 90% enrichment
- 1% σE/E resolution
- **Realistic background projections based on measurements**
- EXO-200-like analysis

- nEXO is the next generation $0\nu\beta\beta$ experiment with 5 T enriched LXe
- nEXO expands on the success of EXO-200 and improves performance via R&D efforts
- nEXO baseline R&D is well advanced

The nEXO Collaboration

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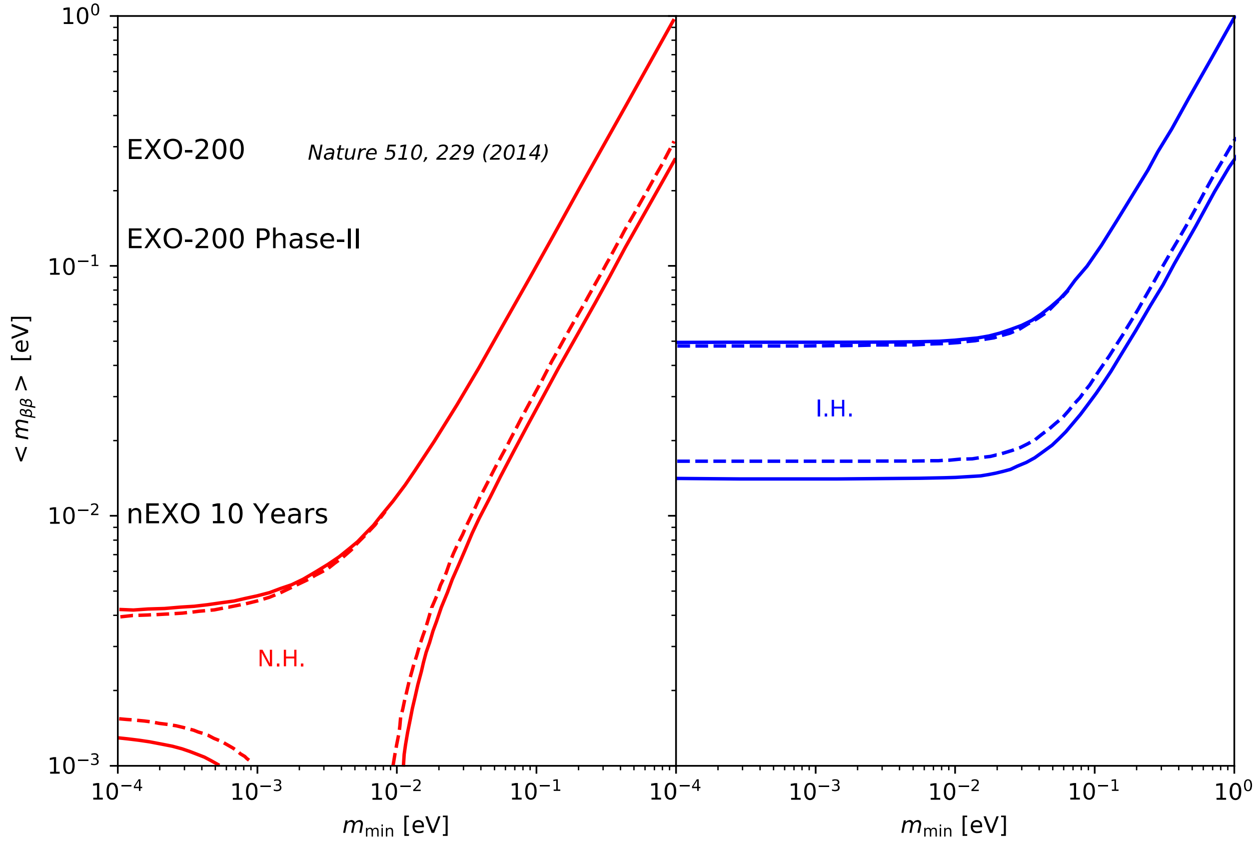
Backup

nEXO Sensitivity to Neutrino Mass



- Allowed neutrino mass bands:
  90% CL, Forero et al., PRD 90 (2014)
  Forero et al., private comm.
- Based on 10yr Sensitivity of 9.06 x 10^{27} y

Calculation	Value	Mass (meV)		
Skyrme-QRPA	1.55	17.78	PRC.87.064302.2013	
QRPA-Tu	2.18	12.64	PRC.91.034304.2015	
RQRPA	2.54	10.85	PRC.91.024316.2015	
NREDF	4.77	5.78	PRC.91.024316.2015	
REDF	4.32	6.38	PRC.91.024316.2015	
ISM	2.32	11.88	NPA.818.139.2009	
IBM-2	3.05	9.04	PRC.91.034304.2015	