Study of electron emission from cathodic wires in a double-phase xenon detector

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LZ COLLABORATION

Imperial College London

LZ = LUX + ZEPLIN

32 institutions currently
About 190 people

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MEPhI (Russia)
Edinburgh University (UK)
University of Liverpool (UK)
Imperial College London (UK)
University College London (UK)
University of Oxford (UK)
STFC Rutherford Appleton Laboratories (UK)
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Texas A&M
Washington University
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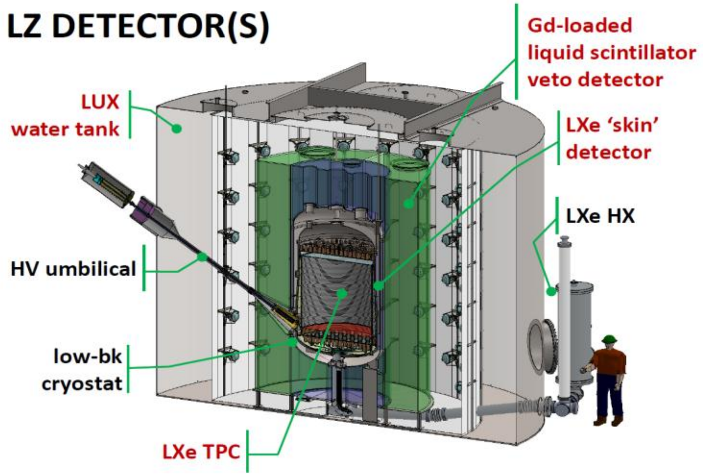
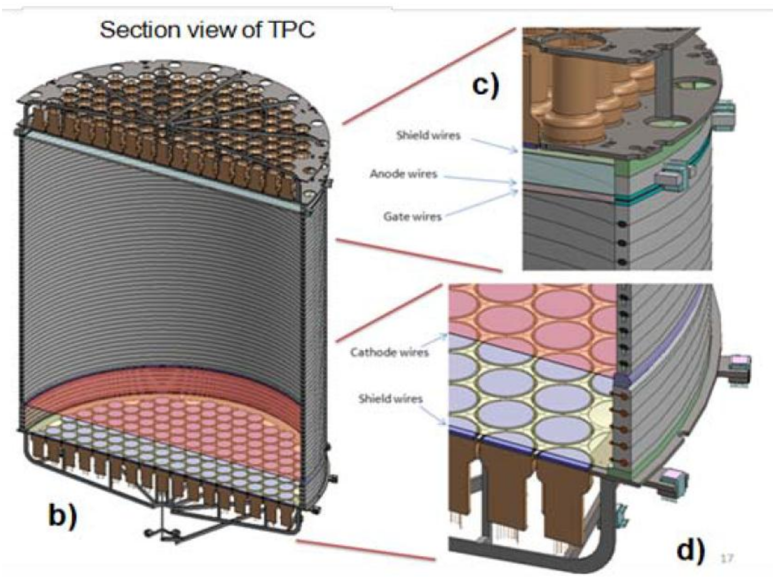
Outline

- *Spurious* emission of electrons in noble liquid TPCs
- Wire tests in double-phase chamber
- Results
- Outlook

Multi-tonne LXe TPC for WIMP searches





LUX-ZEPLIN (LZ)

- Double-phase Xe detector
- 7 tonne active LXe mass

See Dan McKinsey's talk on Thursday

The TPC wire grids

- 1.5 m diameter
- -100 kV @ cathode
- ΔV gate-anode = 8 kV (1 cm gap)
- Wires ~100 μm diameter.

LZ adopts 50 kV/cm max field for metals in LXe (design self-impossed restriction)

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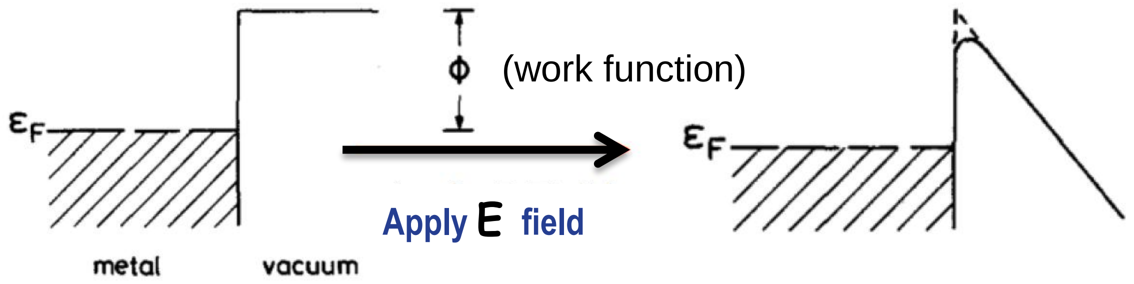
Spurious emission of electrons (past experiments)

How may it happen?

Field emission **(tunneling effect)**



I-V caracteristic (Fowler-Nordheim eq.),

studied in the range 10^{-13} to 10^{-9} A *(this work $\sim 10^{-17}$ A)*

Theoretically $E \geq$ 10 MV/cm ; in practice 50 kV/cm!?

Spurious emission requires an addititional mechanism:

Local enhancement of field

Lowering of the work function

Insulator layers (oxidation)

Surface material, finishing and handling

Impact on grid design and sensitivity

Spurious emission of electrons from cathodic grids: increases with field on wires, changes from single to increasing number of emitters (eventual breakdown)

Limits the drift field of the TPC ↔ important parameter in NR/ER discrimination.
→Impact on experiment background.

Limits the field on the wire surface
→ Constrains the design of the grids (wire diameter, pitch, materials, coatings)/
→ Reduces the extraction efficiency of electrons from liquid to gas.
→ Impact on the light yield (S1 threshold).
→Impact on S2 threshold and energy resolution .
→ Impact on manufacturing techniques and procedures.

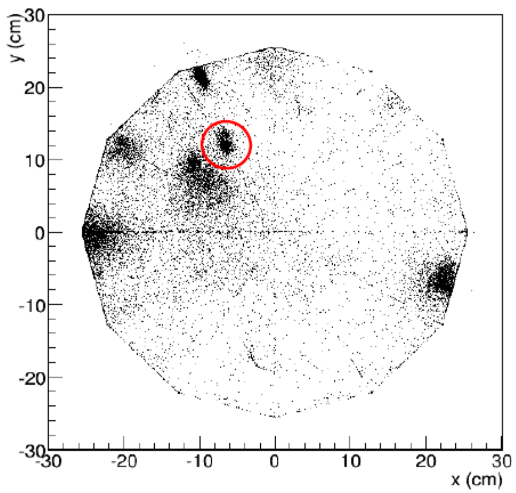
Additional background in few-electron regime.
→ Accidental coincidences: "S1 only" + "S2 only"(due to emission)
→ Impact on sensitivity for light WIMP searches.

IMPACT ON DESIGN, COMPONENT HANDLING AND SENSITIVITY OF THE EXPERIMENT

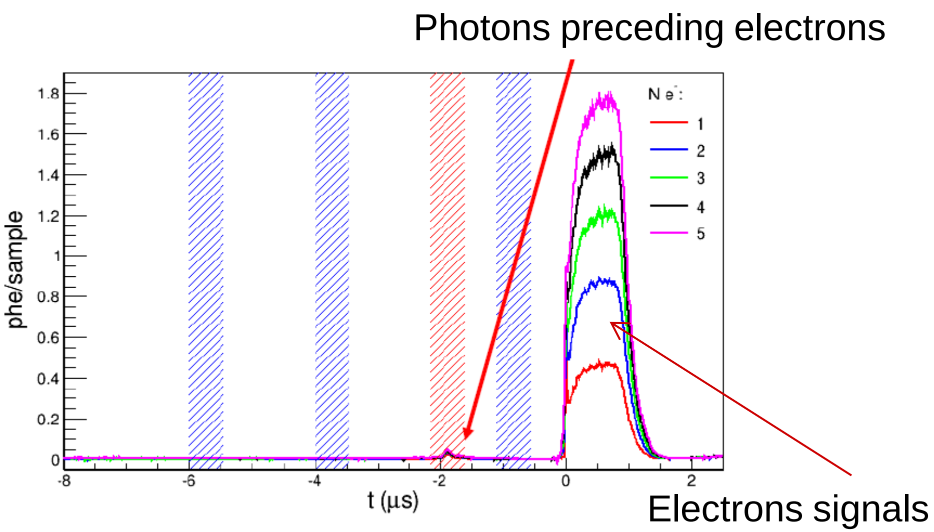
An example: LUX

HV limitation of the cathode and gate grids.

Characterisation of emitters in the LUX gate grid during special HV test/conditioning campaign



Emitters localized in space.



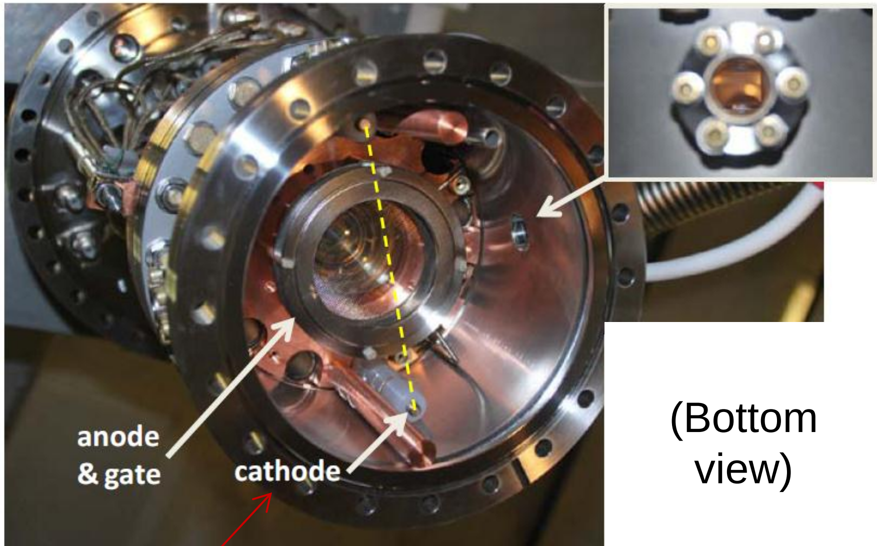
Evidence of electroluminescence in liquid

See A. Bailey et al. IoP 2015

Confirms local enhancement of field

(Electroluminescence threshold in LXe = 410 kV/cm)

Imperial College wire test chamber



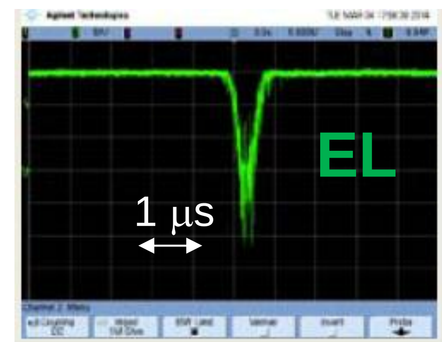
(Bottom view)

A single wire as cathode

High field on wire surface at reasonably low voltage

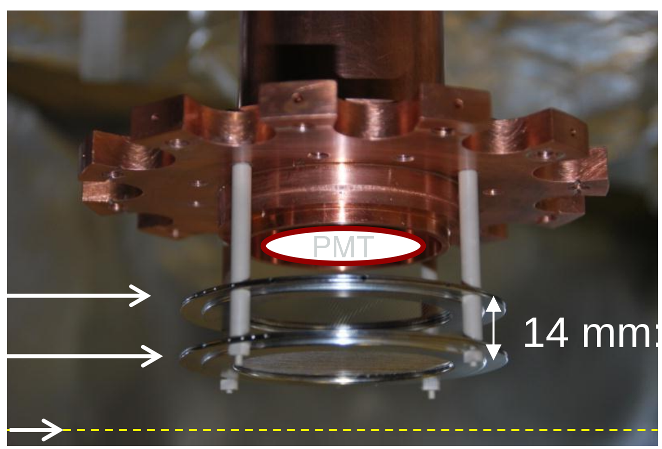
4.3 kg of LXe; -101°C.
1 PMT viewing down from gas.

Single 12 cm wire
~6 cm tested length
~100 μm diameter



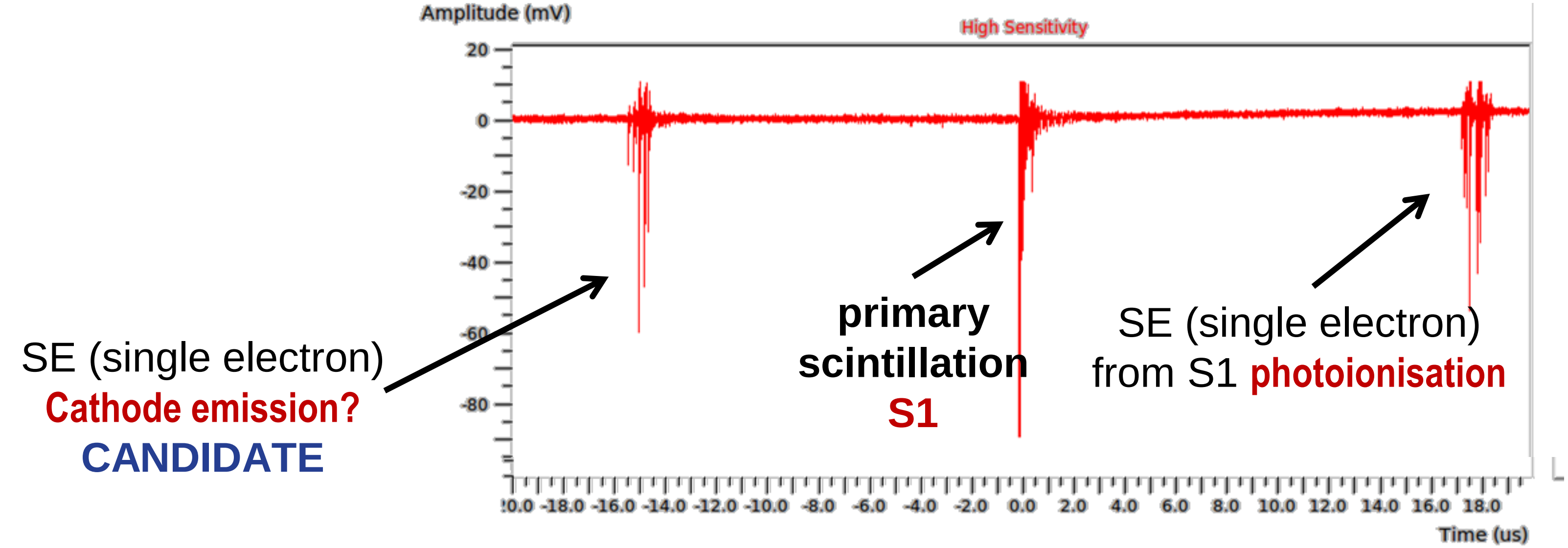
Electroluminescence

anode
gate
cathode

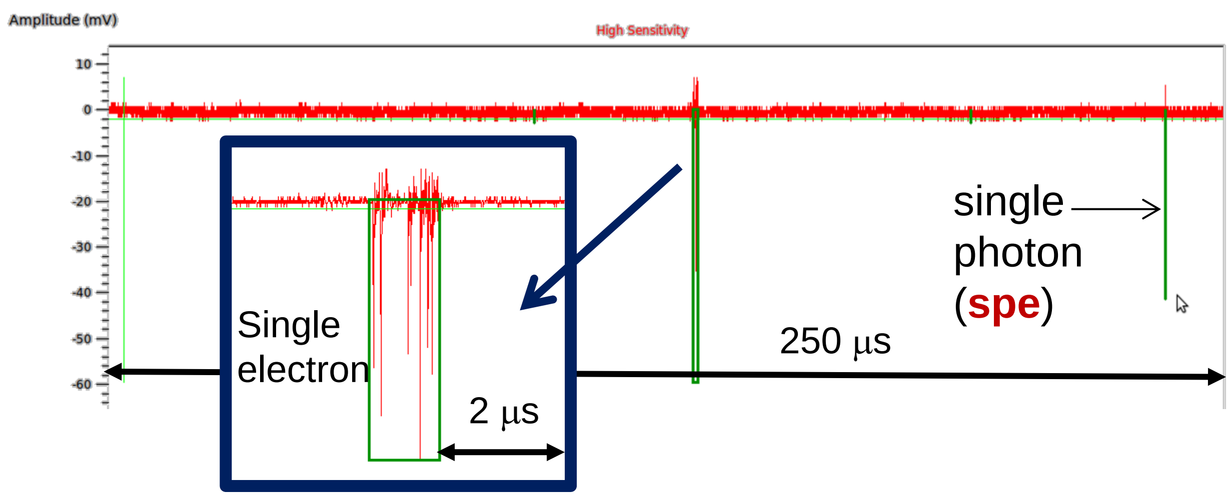


14 mm: ~10 mm LXe + ~ 4 mm GXe

Waveforms: candidates for emission events

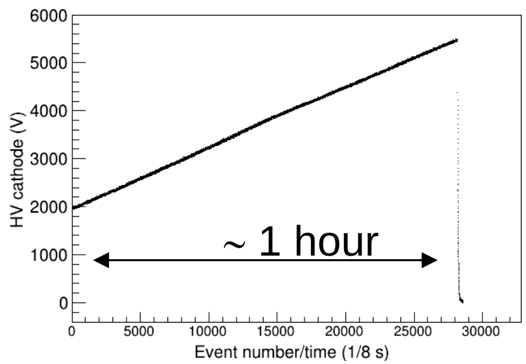


If there is an electroluminescence pulse (S2) > 6 electrons the event discarded.

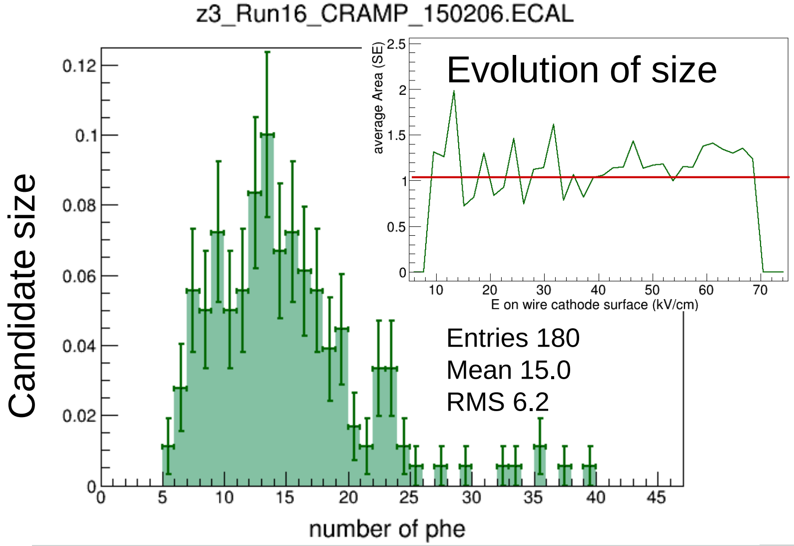


Wire test: emission peaks

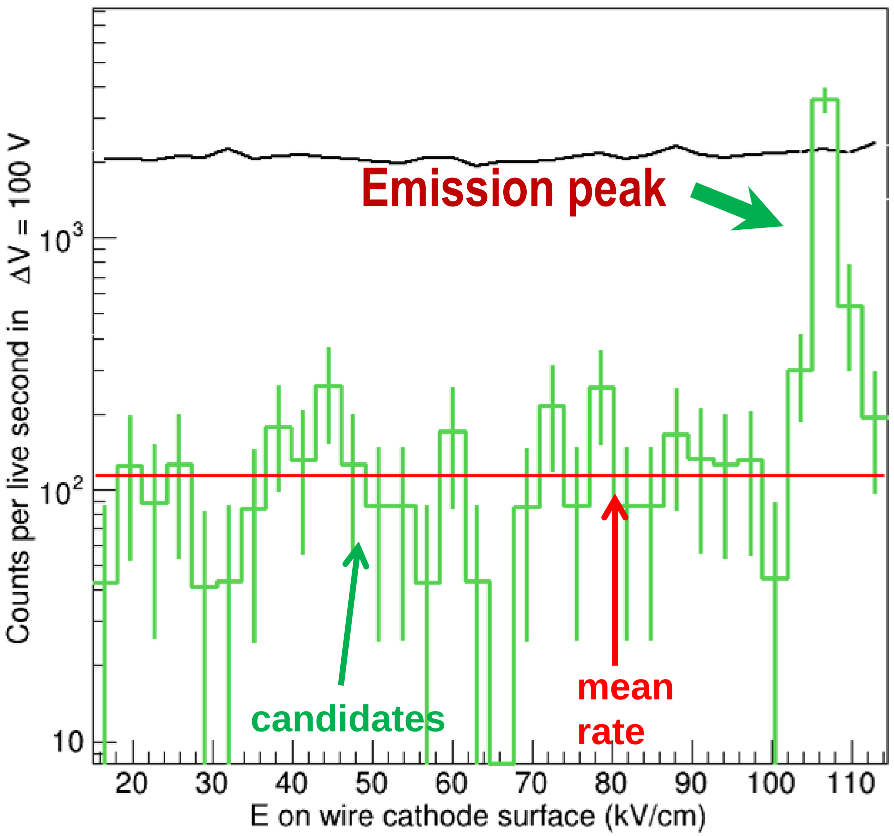
Slow ramp up of cathode voltage (1 V/s) while acquiring at constant rate (8 Hz).



Maximum voltage/field determined by cathode feedthrough limitation (~5.5 kV).



Run#12: LUX gate wire, SS304 100 μm



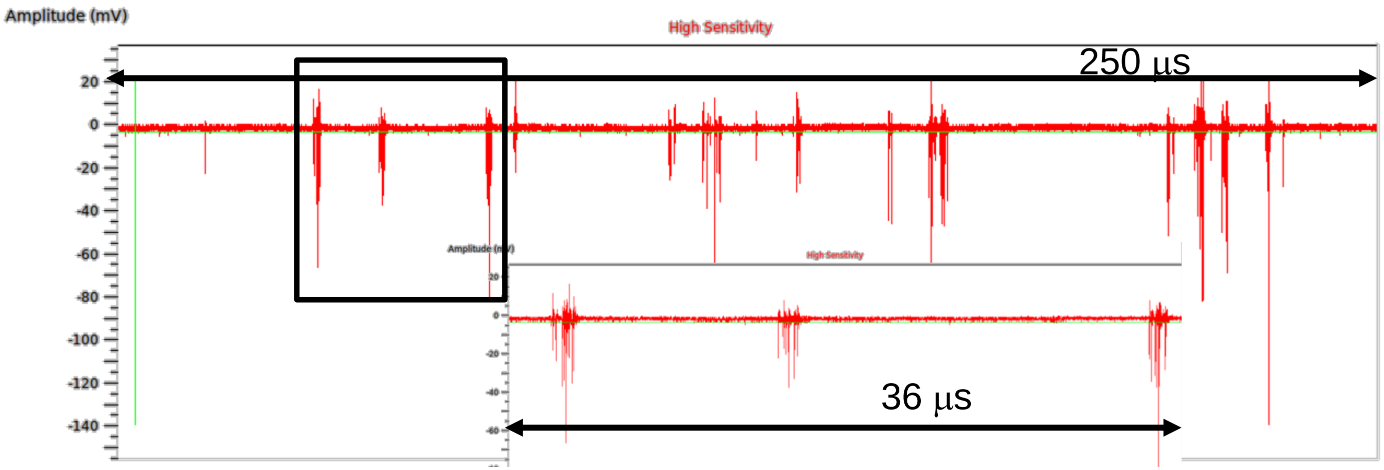
Emission peak defined as ≥ 2 σ excursion over background.

In a bin of few kV/cm width covering ~ 10^3 recorded events.

Emission is never wider than 1-3 bins.

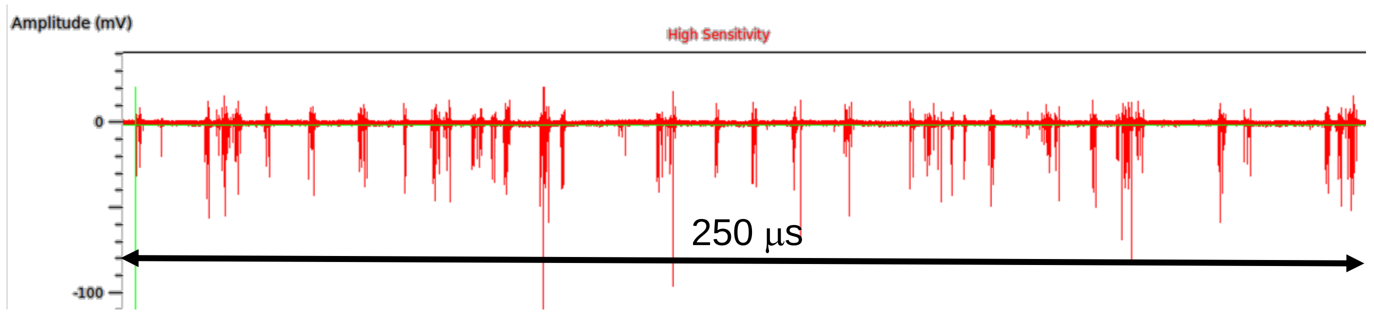
Other pulses (S1, spe, S2, etc, studied in order to check correlations)

Wire test: periods of very intense emission



Can reach ~MHz (as in LUX HV tests).
Can affect several events in a row.

Time between events: 125 ms
~500 x maximum drift time.



Events from LUX cathode wire 200 μs.
Field on wire surface around 60 kV/cm.

Wire Test Summary

Preliminary DAQ settings

Optimized DAQ settings

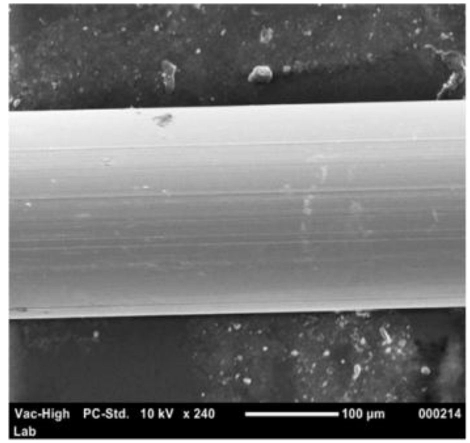
Wire	Diameter	Material	Run	Max E_w*	Min E_w Emission Peak
ZEPLIN-III	**100 μm**	SS316L	#9	163 kV/cm	Not seen
			#17	131 kV/cm	**111 kV/cm**
ELECTROPOLISHED			#20		Not seen
XED/CWRU	**40 μm**	BeCu	#10	**310 kV/cm**	Not seen
LUX GATE	**100 μm**	SS304	#12	123 kV/cm	105 kV/cm
			#13	122 kV/cm	112 kV/cm
			#14	124 kV/cm	**20 kV/cm**
LUX CATHODE	**200 μm**	SS302	#15	70 kV/cm	**10 kV/cm**
			#16	69 kV/cm	57 kV/cm
ELECTROPOLISHED			#19	66 kV/cm	Not seen
GOLD PLATED	**125 μm**	W (Au)	#22	96 kV/cm	93 kV/cm **

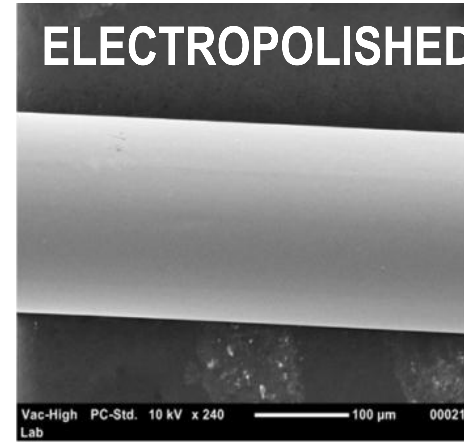
(*) Always defined by the cathode feedthrough ~constant voltage limitation

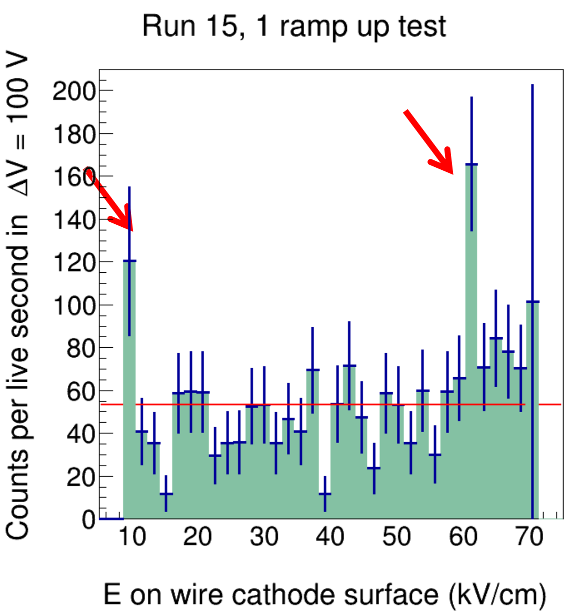
(**) At 3rd ramp up with gate at ground (lower sensitivity)

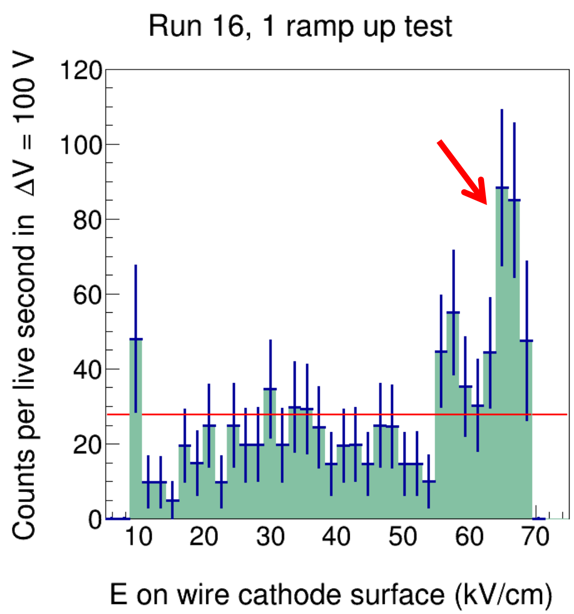
Electropolishing

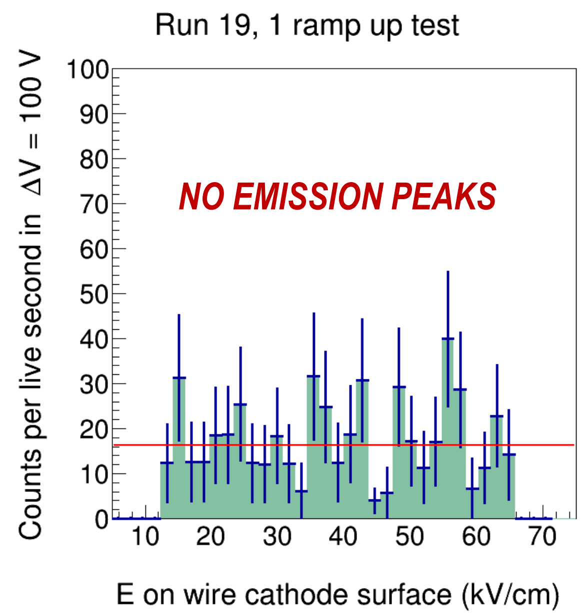
TESTS with the LUX CATHODE WIRE
SS 302, 200 μm



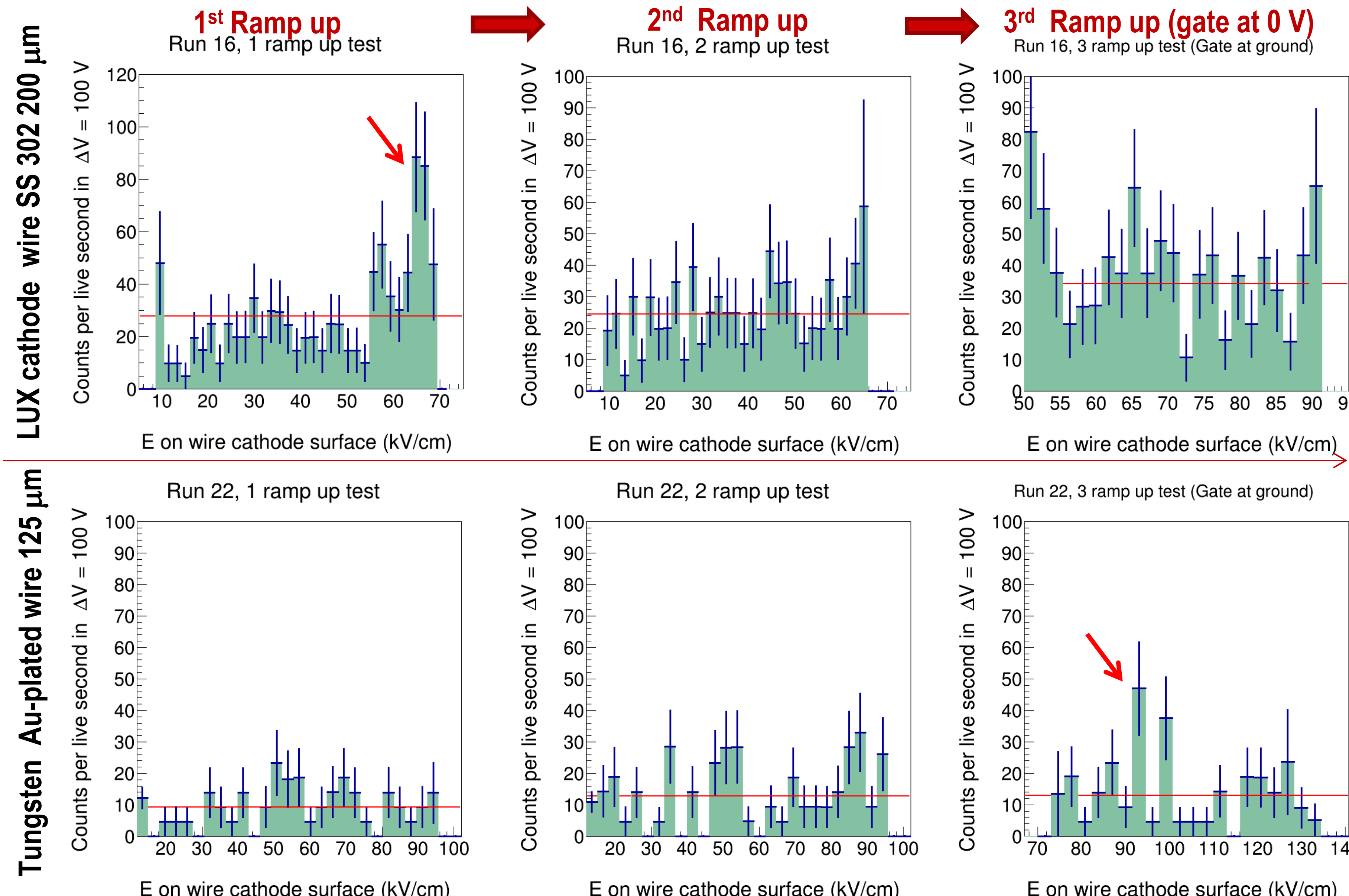








Conditioning and Au-plating



Outlook

Understanding spurious electron emission is key to designing electrically-resilient electrode grids for the new LXe DM detectors.

Fields significantly in excess of 50 kV/cm sustained by single short wires.

Electron emission observed for different types of wire with sensitivity for identifying emitters with ~100 electron/s (~10^{-17} A).

Emission has a steep rise and decays in few kV/cm and is not reproducible. Some differences in behaviour can be established and related to features of the wires, showing hints of:

- Dependence with type of stainless steel.
- Some conditioning effect observed.
- Evidence of improvement after electropolishing.
- Benefit from gold-coating, but possible observation of subsequent degradation.

Although origins remain unclear, the solutions start being suggested by the results.
The surface quality and handling seem to be the main concern instead of the absolute value of the field on the wire.

Larger setups within LZ R&D will test grids of various sizes.

Back up slides

Operation and electron lifetime tests

About one week preparation.

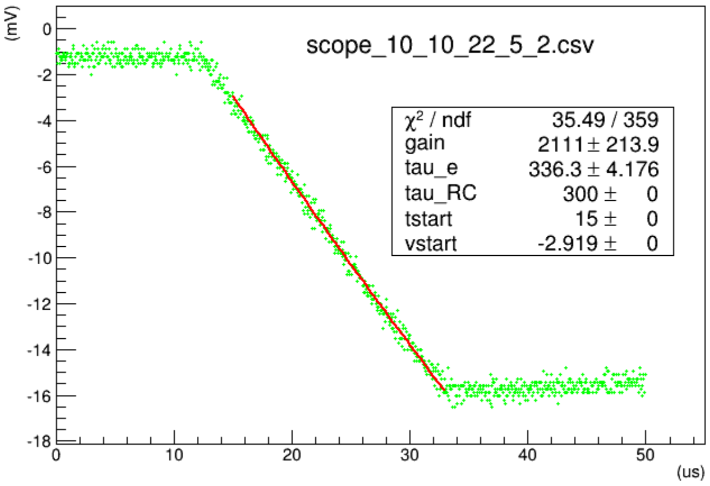
Pumping the chamber and the gas handling system.
Monitoring impurities levels with Mass Spectrometer.
At least 3 days recirculation with hot SAES getter.

One day operation.

Cooled via coldfinger. Filling during the morning. No recirculation during run.

Electron Lifetime Monitor Checks

ZEPLIN-III ELM used to test the *Xe collected from the previous run* of our 2 data taking campaigns

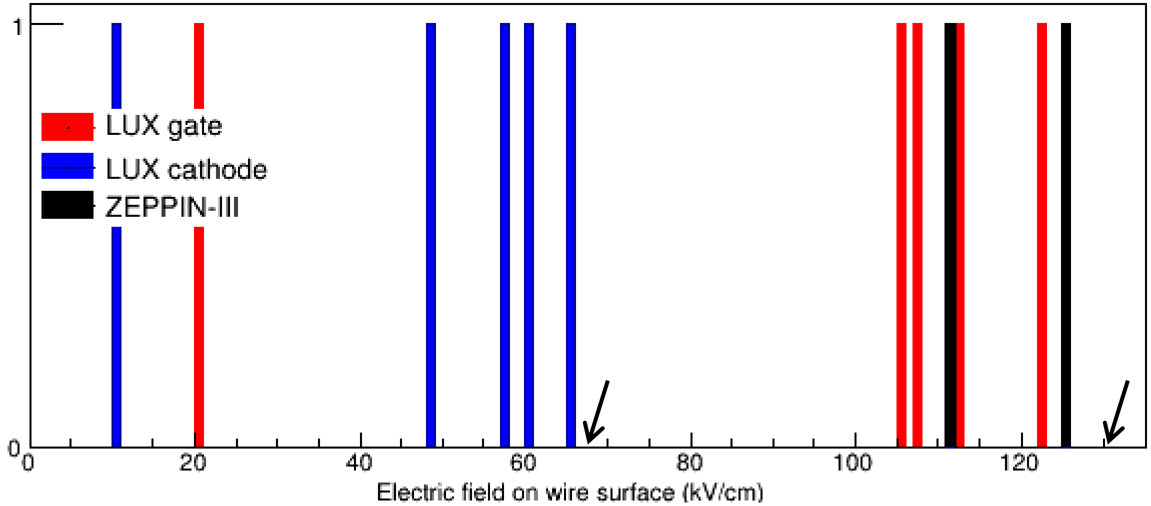


Both times obtained a limit above ELM sensitivity

$\tau > \sim 300\ \mu s$

Drift time from wire $\sim 12\ \mu s$

Distribution of emission peaks vs field



Distribution of emission peaks for different wires along runs

Arrows showing the maximum testable field for each diameter