Mitigation of spurious electron emission from cathodic wires in noble liquid TPCs

Based on

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Paris, Dec 13th 2018

Spurious electron emission

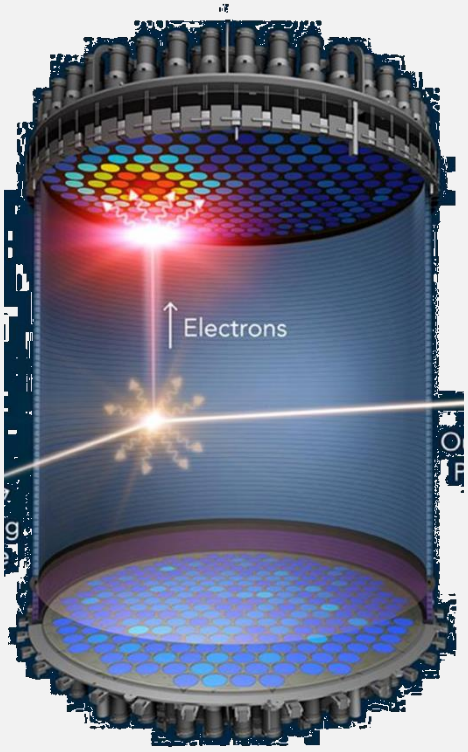
Theoretically E > ~10 MV/cm; **in practice** <~ 50 kV/cm *!?

Very long-standing issue for almost all noble liquid detectors for decades.

(*) LUX-ZEPLIN design criteria for ALL cathodic surfaces.

From cathodic elctrodes:

(in a 2-phase detector)



Time Projection Chamber (LZ)

- Gate (extraction) grid:

electron extraction from liquid/ electroluminescence

- Cathode grid:

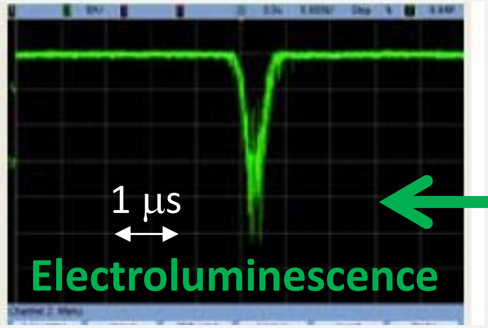
drift field

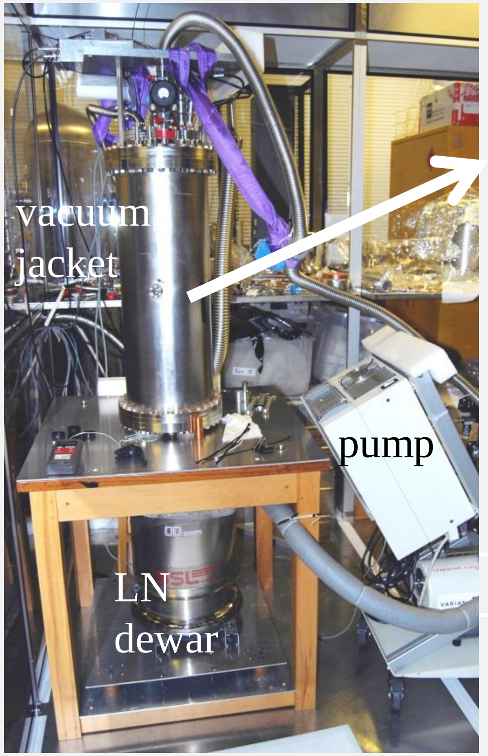
Impact on:

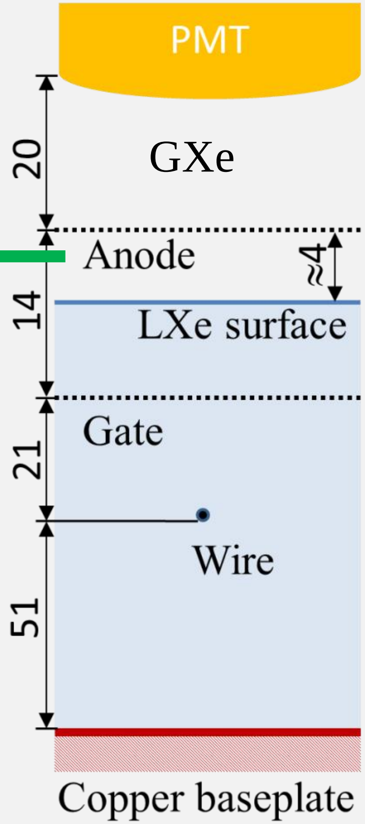
- operation parameters
- detector background
- experiment sensitivity

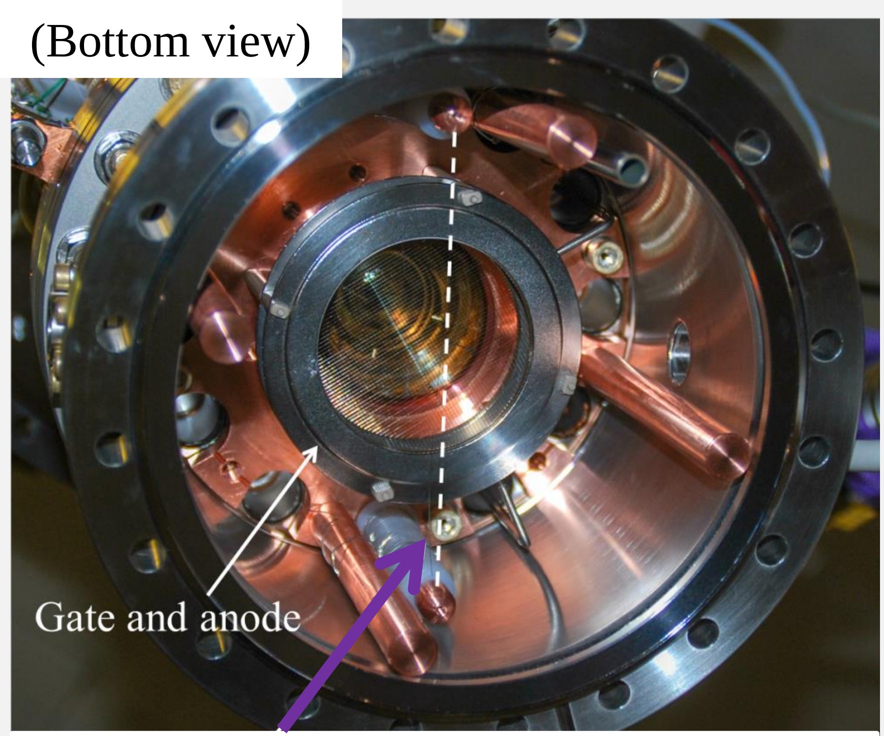
Most critical for **light WIMP searches**

A 2-phase Xe chamber for wire tests









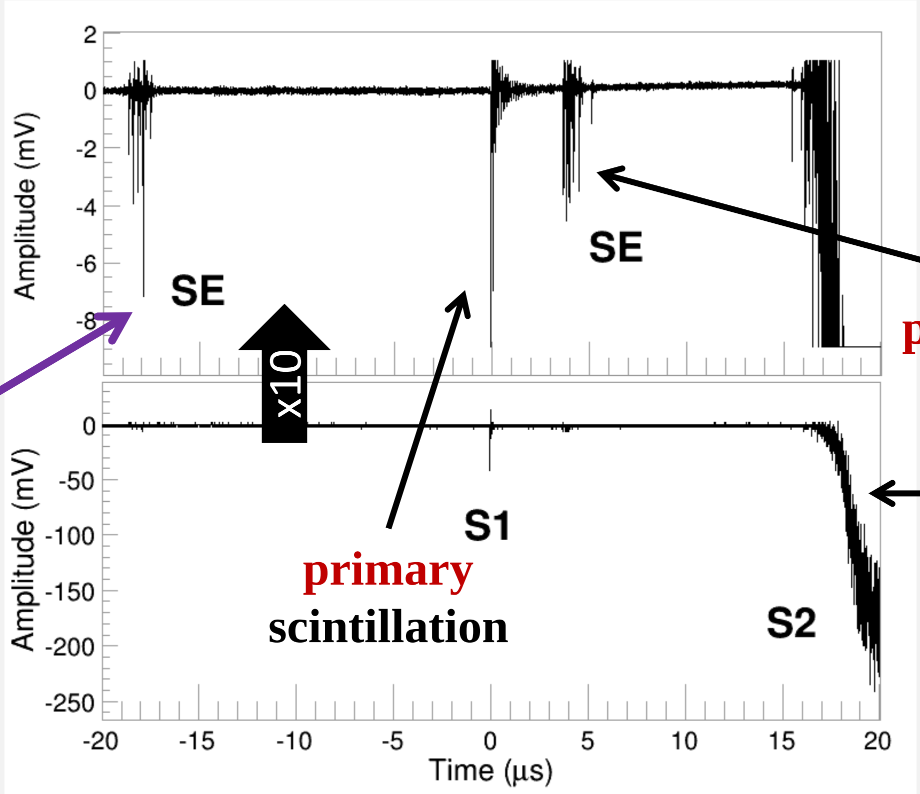
A single wire as cathode

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

High field on wire surface
at reasonably low voltage
~ 6 cm tested length
~ 100 µm diameter

Wave forms and emission candidates

single electron
Cathode
emission?
CANDIDATE

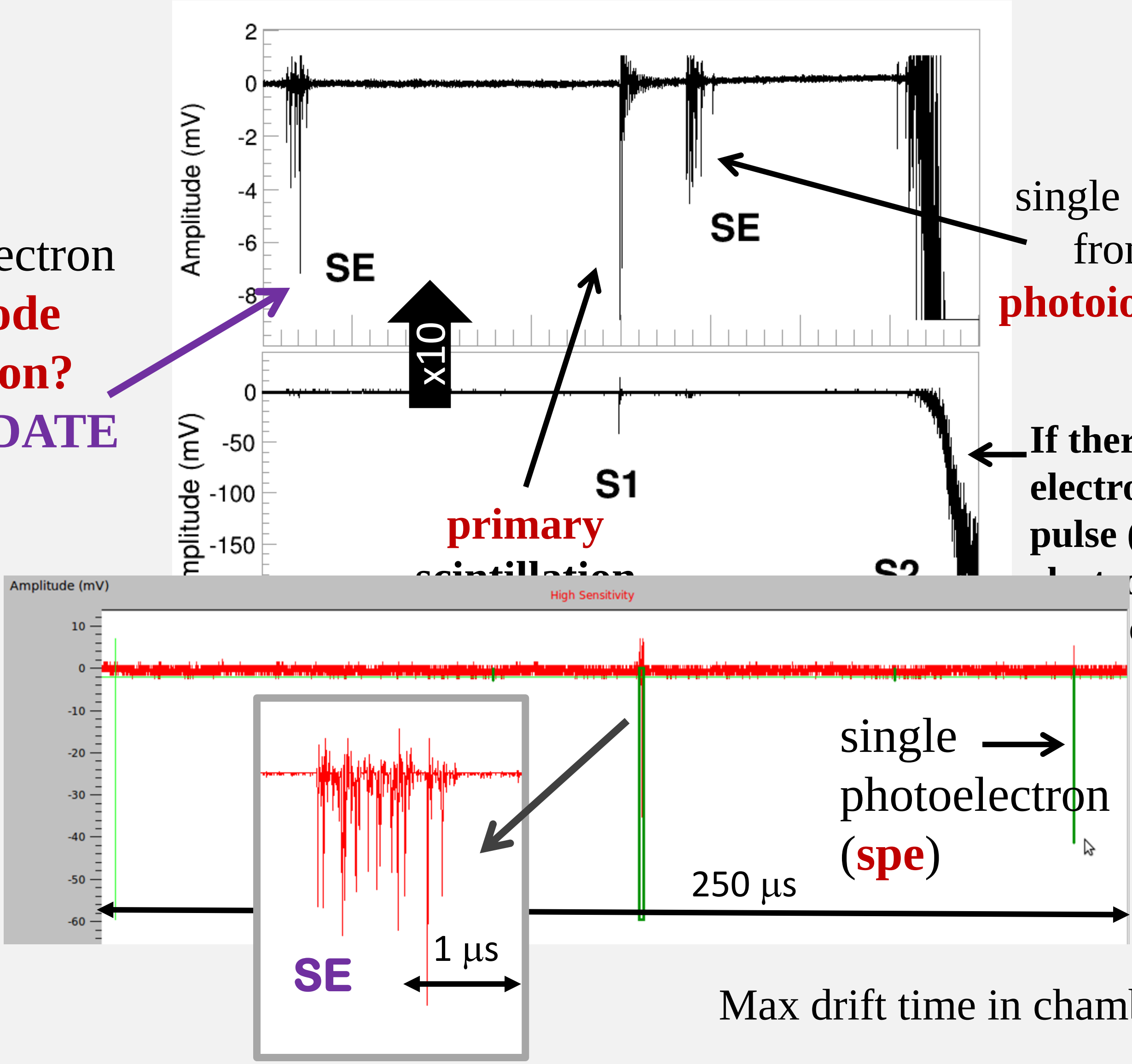


primary
scintillation

single electron
from S1
photoionisation

secondary
scintillation
(**electroluminiscence**)
Event is discarded.

wave forms and emission candidates



single electron
Cathode
emission?
CANDIDATE

single electron
from S1
photoionisation

primary
scintillation

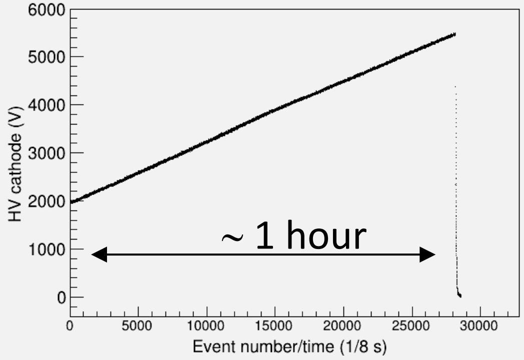
If there is an electroluminescence pulse (S2) > 6
ons
ent discarded.

single
photoelectron
(**spe**)

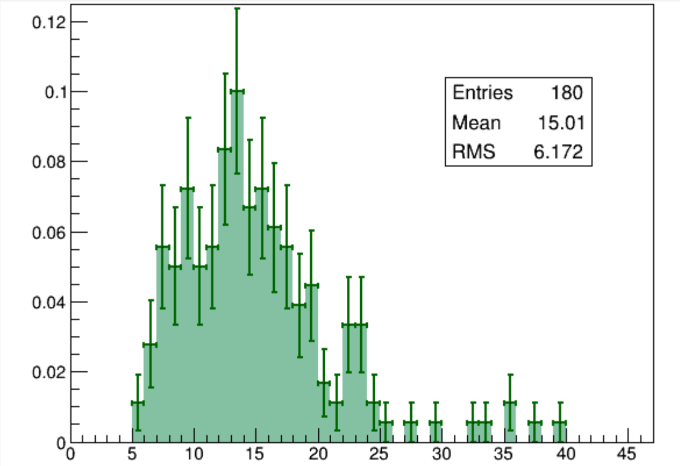
Max drift time in chamber ~ 20 μs

A wire test

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

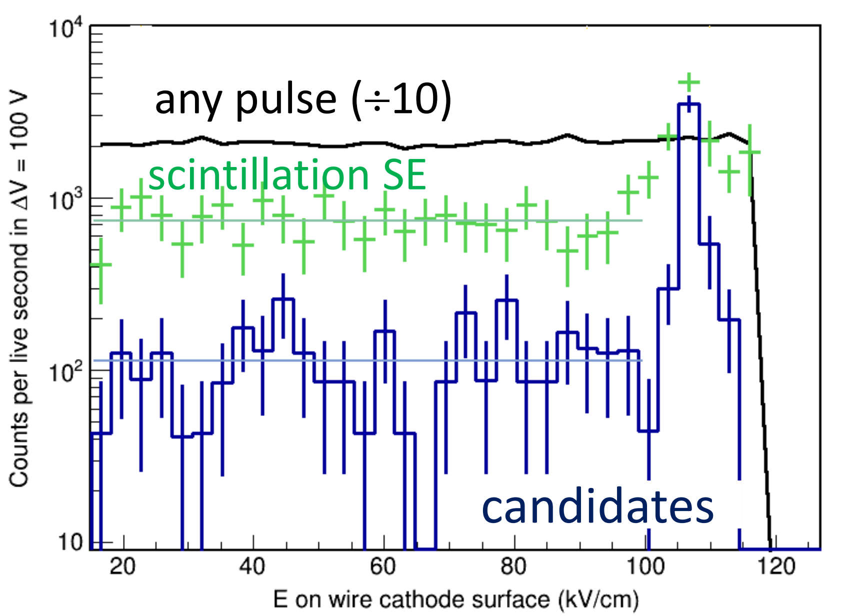


Maximum voltage/field determined by cathode feedthrough limitation ~5.5 kV



CANDIDATE SIZE (number of spe)

Run#12: LUX gate wire, SS304 100 μm



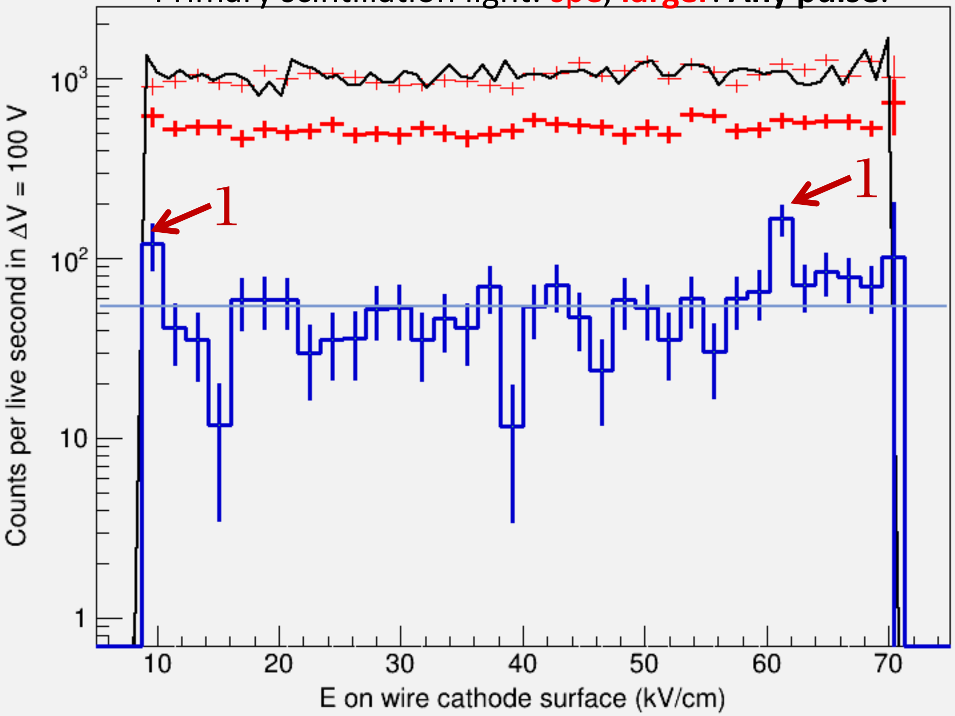
Detect emission currents as low as ~10^{-18} A (previous studies ~10^{-13}-10^{-9} A)

- A bin of few kV/cm width covers ~10^3 recorded events
- Other pulses (S1, spe, S2, etc) also studied to check correlations)

Observation of emission

1. **Extended Emitters**: significant enhancement of average over ΔE

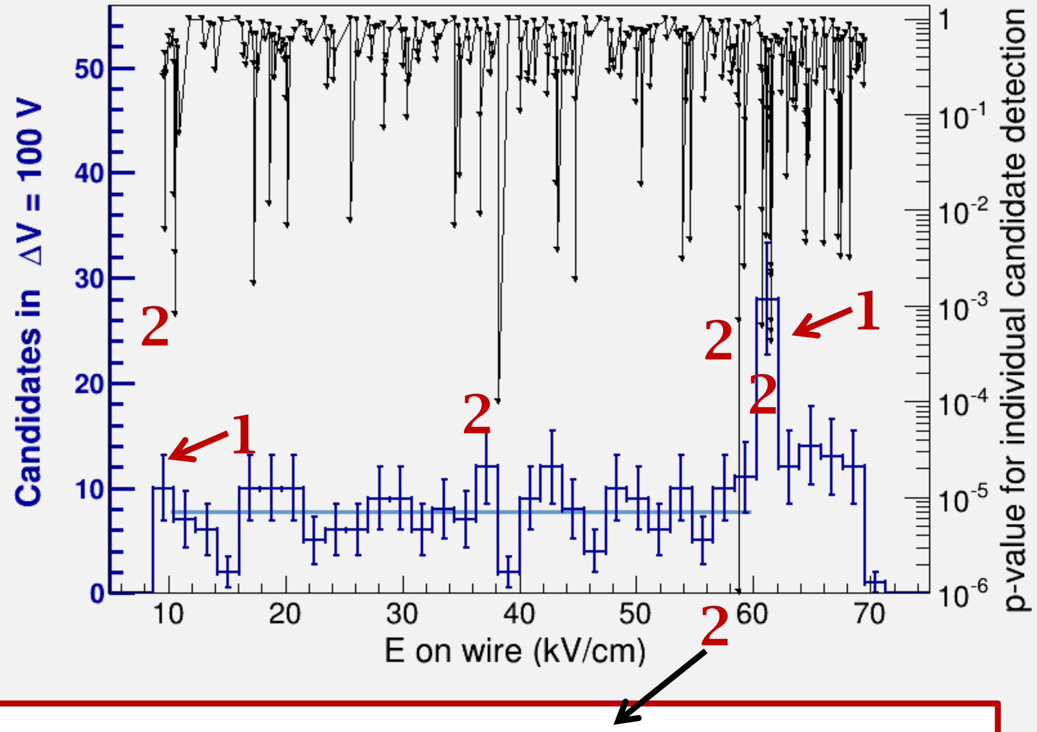
Primary scintillation light: spe, **larger**. **Any pulse**.

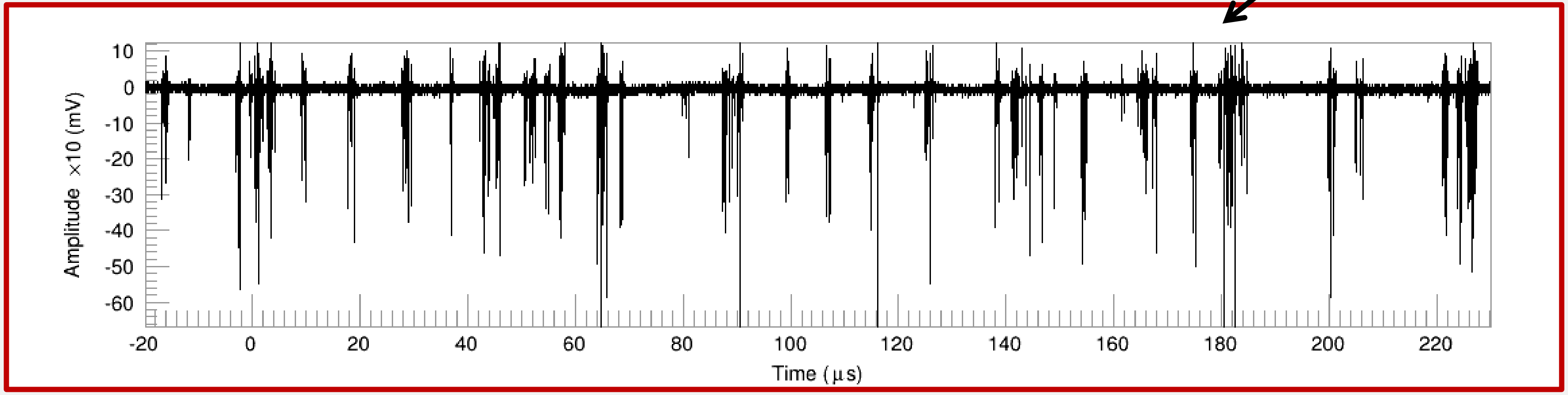


Observation of emission

1. **Extended Emitters**:
   significant enhancement of average over ΔE

2. **Impulsive Emitters**:
   very high rate
   for a short instant



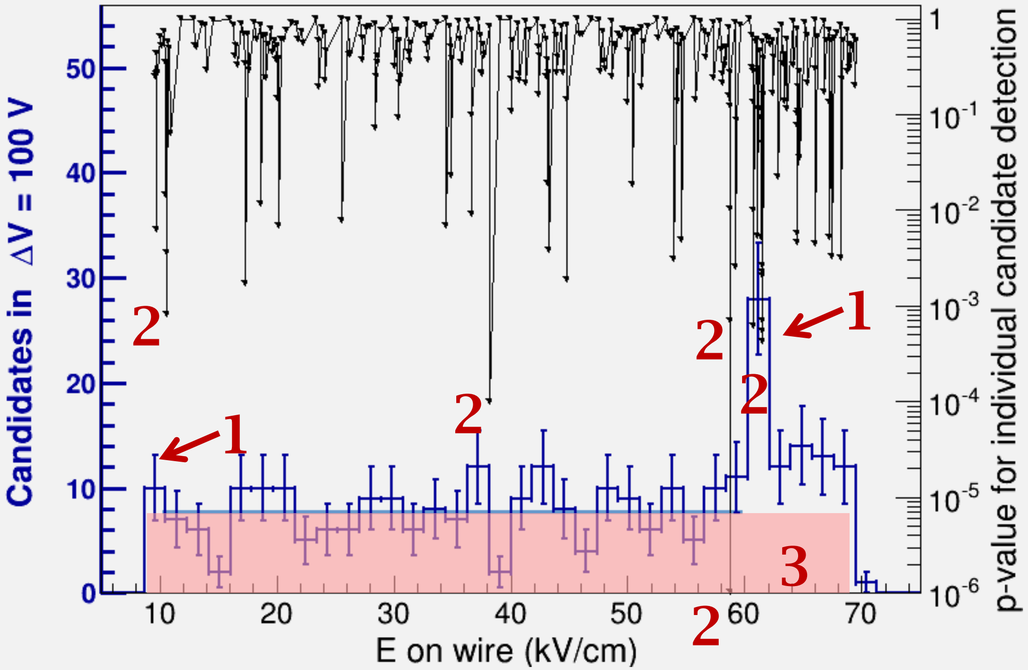


Observation of emission

1. **Extended Emitters**: significant enhancement of average over ΔE

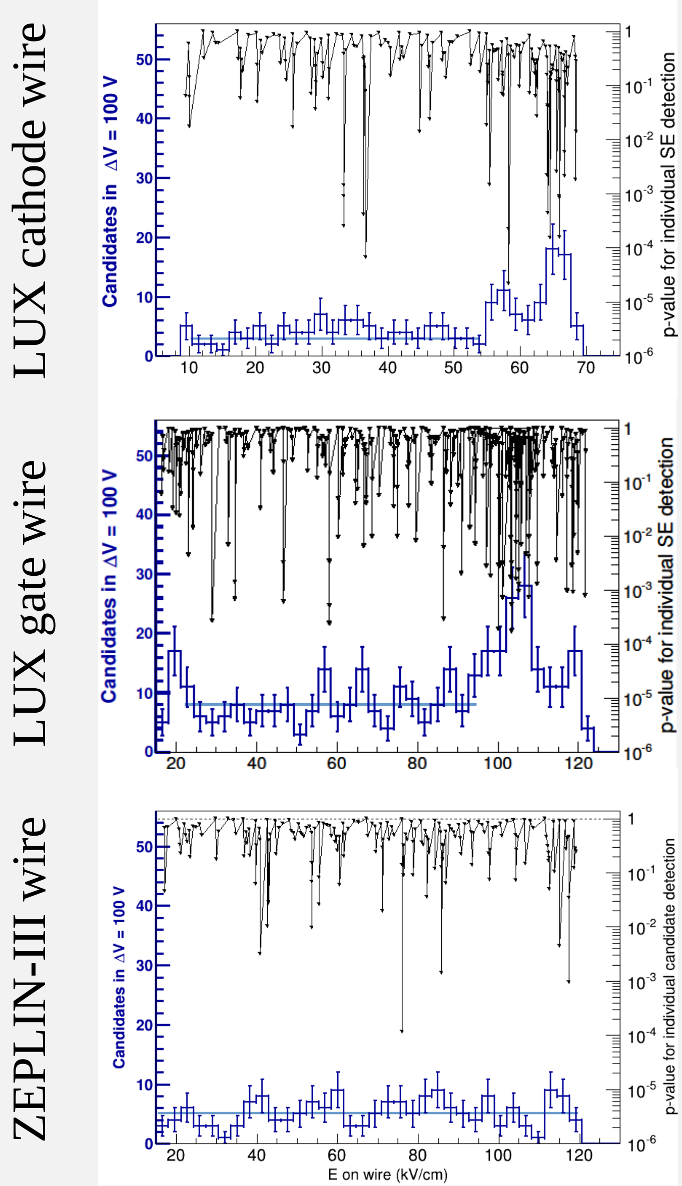
2. **Impulsive Emitters**: very high rate for a short instant

3. **Faint Emission**: relatively steady, field-independent emission rate



Correlation with the kind of wire (response to wire treatment)

observation of emission



No intrinsic emission threshold found (up to 160 kV/cm)

The three types of emission observed are correlated

All three have been observed at relatively low fields of ~10 kV/cm

Those occurring over a narrow field (**extended** and **impulse emitters**):

- present a **clear dependence on the field** on the wire surface
- are not reproducible in a second ramp up test (but new ones may appear)

Summary of tests

Wire (*TREATMENT*)	Diameter	Material	Max E_w*	FAINT (Hz)	EXTENDED	IMPULSIVE
LUX GATE	**100 µm**	SS304	124 kV/cm	**52**	**3**	**33**
ZEPLIN-III	**100 µm**	SS316L	119 kV/cm	**27**	**0**	**2**
LUX CATHODE	**200 µm**	SS302	70 kV/cm	**45**	**2**	**30**
			69 kV/cm	**19**	**2**	**8**
			86 kV/cm	**24**	**0**	**3**
GOLD PLATED	**125 µm**	W (Au)	96 kV/cm	**12**	**0**	**2**

(*) Always defined by the cathode feedthrough near constant voltage

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GOLD PLATED	**125 µm**	W (Au)	96 kV/cm	**12**	**0**	**2**

Can this be improved?

(*) Always defined by the cathode feedthrough near constant voltage

Summary of tests

Wire (*TREATMENT*)	Diameter	Material	Max E_w*	FAINT (Hz)	EXTENDED	IMPULSIVE
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ZEPLIN-III	**100 μm**	SS316L	119 kV/cm	**27**	**0**	**2**
ELECTROPOLISHED			119 kV/cm	**6**	**0**	**4**
LUX CATHODE	**200 μm**	SS302	70 kV/cm	**45**	**2**	**30**
			69 kV/cm	**19**	**2**	**8**
			86 kV/cm	**24**	**0**	**3**
ELECTROPOLISHED			66 kV/cm	**16**	**0**	**4**
ACID-CLEANED + PASSIVATION			65 kV/cm	**3**	**0**	**0**
ACID-CLEANED + PASSIVATION and aged (1st run)			70 kV/cm	**4**	**0**	**0**
ACID-CLEANED + PASSIVATION and aged (3rd run)			67 kV/cm	**5**	**0**	**1**
GOLD PLATED	**125 μm**	W (Au)	96 kV/cm	**12**	**0**	**2**

(*) Always defined by the cathode feedthrough near constant voltage

Summary of tests

Wire (*TREATMENT*)	Diameter	Material	Max E_w*	FAINT (Hz)	EXTENDED	IMPULSIVE
LUX GATE						**33**
ZEPLIN-III						**2**
ELECTROPOLISHED						**4**
LUX CATHODE						**30**
						8
						3
ELECTROPOLISHED						**4**
ACID-CLEANED + PA						**0**
ACID-CLEANED + PA						**0**
ACID-CLEANED + PA						**1**
GOLD PLATED						**2**

TAKE HOME MESSAGE:

Absolute value of field on surface not as critical as surface handling and quality

Resistance to corrosion seems a key feature (e.g., emission seems less severe on more corrosion-resistant SS types (SS316) and far better for the gold-platted wire).

Remedial treatments found successful in decreasing all three types of emission. In particular acid-cleaning followed by passivation on SS wires

(*) Always defined by the cathode feedthrough near constant voltage

Acid-cleaning and passivation

'Picking': removal of oxides and corrosion products.

If enhanced (type of acid, time, temperature, cavitation):

'Acid-cleaning': promotion of a **chromium-enriched surface** layer

(controlled) 'Passivation': creation of a new **homogeneous oxide surface**

Recipe

35% HNO_3 ultrasound bath at 45°C (30 min long)

\+ Immediate immersion in DI water

\+ Drying with N2 gun

Tested on the **LUX cathode wire**
SS302, 200 μm
(**different samples from the same spool**)

Acid-cleaning (passivation) results

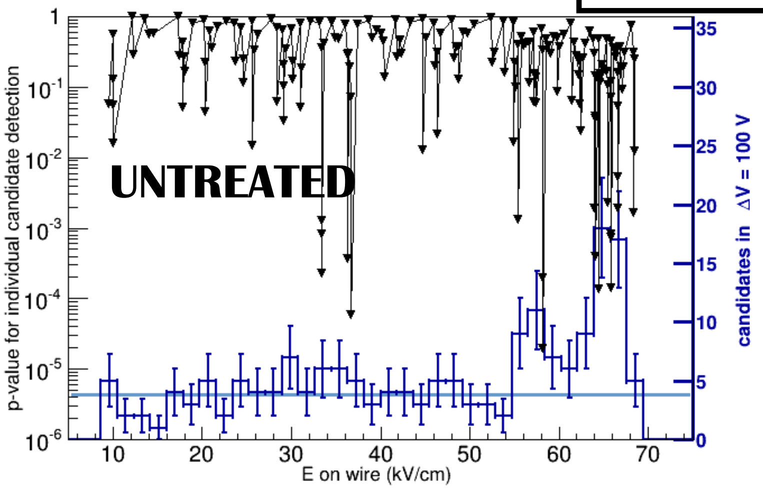
All **LUX cathode wire** SS 302, 200 μm
(different samples from the same spool)

REPRODUCTION

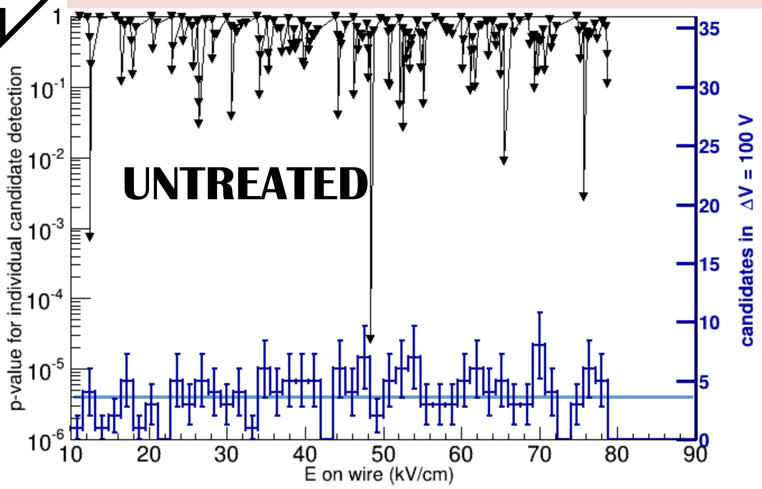
PASSIVATION

AGEING?

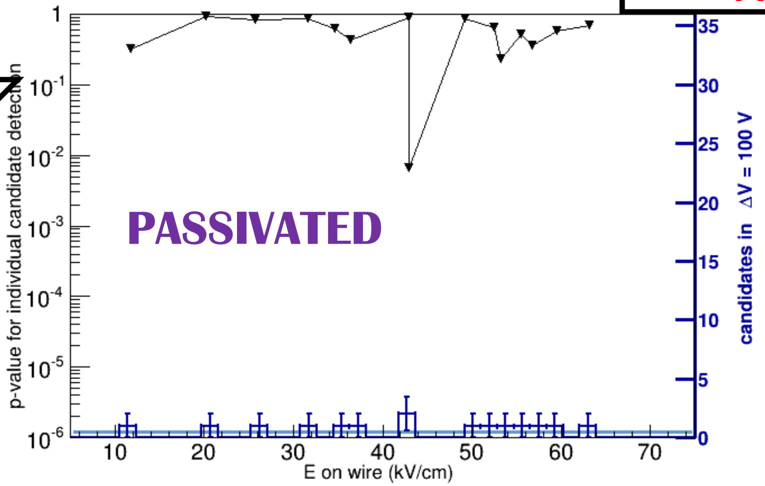
(different samples)



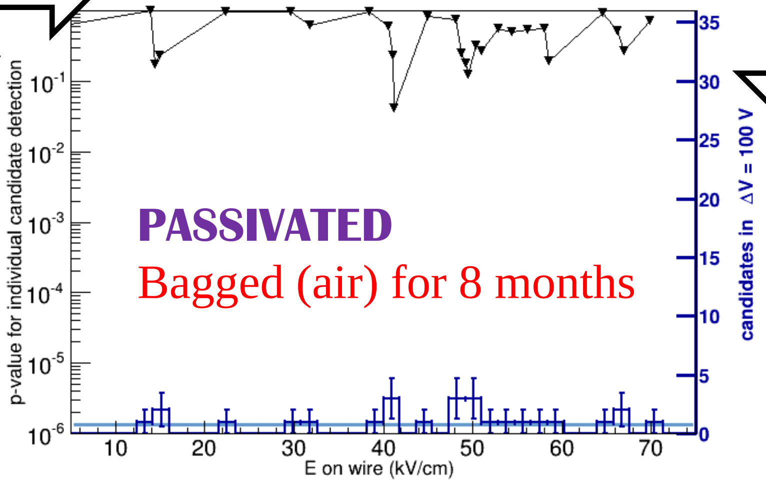
Run#16: mean rate **19.8 ± 1.6 Hz**



Run#26: mean rate **23.5 ± 1.8 Hz**



Run#25: mean rate **2.5 ± 0.7 Hz**

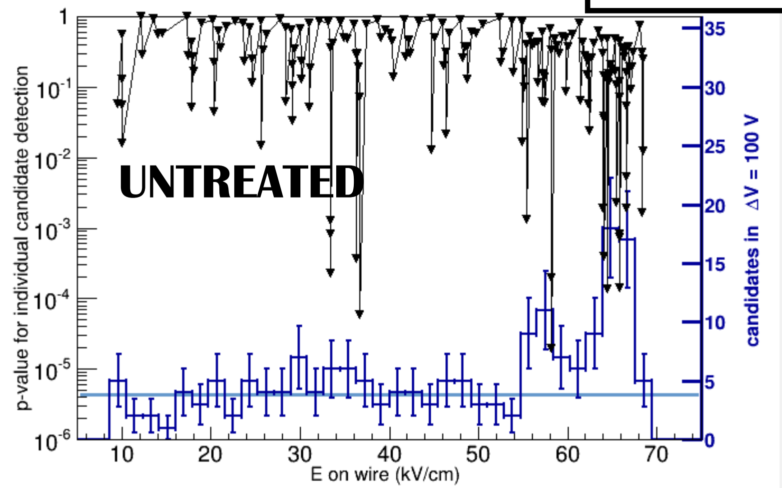


Run#27: mean rate **3.8 ± 0.8 Hz**

Acid-cleaning (passivation) results

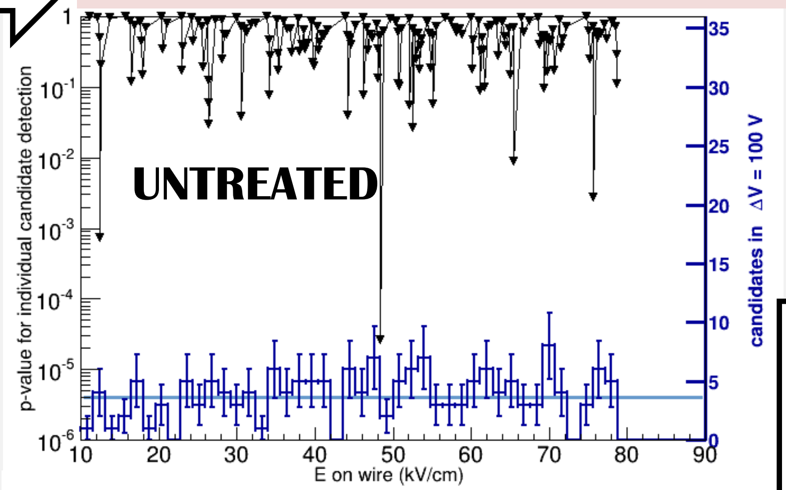
All **LUX cathode wire** SS 302, 200 μm
(different samples from the same spool)

REPRODUCTION



UNTREATED

Run#16: mean rate **19.8 ± 1.6 Hz**



UNTREATED

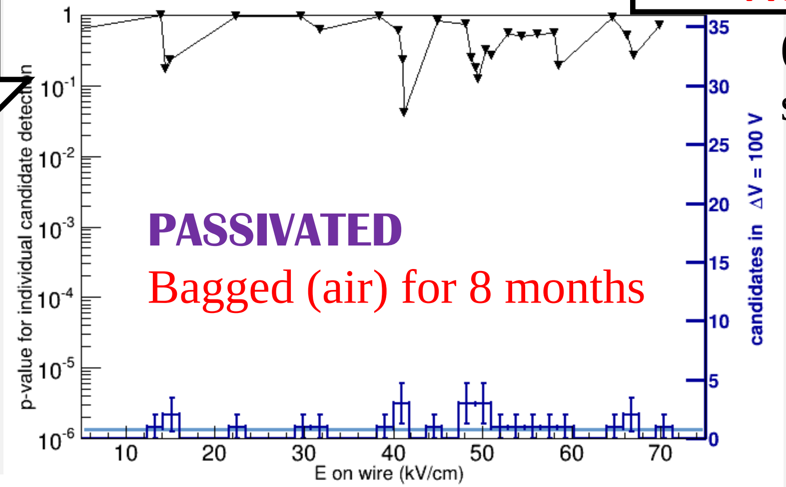
Run#26: mean rate **23.5 ± 1.8 Hz**

PASSIVATION

PASSIVATION

AGEING?

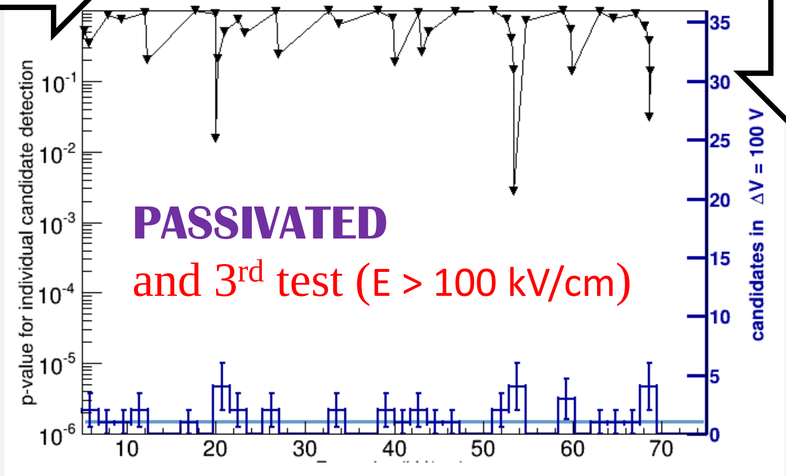
(same sample)



PASSIVATED

Bagged (air) for 8 months

Run#27: mean rate **3.8 ± 0.8 Hz**



PASSIVATED

and 3rd test (E > 100 kV/cm)

Run#29: mean rate **5.3 ± 0.9 Hz**

Conclusion

Spurious emission presents a complex phenomenology, even at relatively low fields.

But fields well above 50 kV/cm can be sustained (at least in short wires).

Emission related with the quality of the oxide layer.

Corrosion as the agent that aggravates emission.

Acid cleaning + controlled passivation works as **mitigation**
(and it is relatively easy to apply to grids).

Further work is needed on

- i) precise microscopic causes
- ii) scaling laws to large grids
- iii) long-term evolution.

c.f. final discussion at
Astropart. Phys. 103 (2018) 49–61

- Back up -

Operation and electron lifetime tests

About one week preparation.

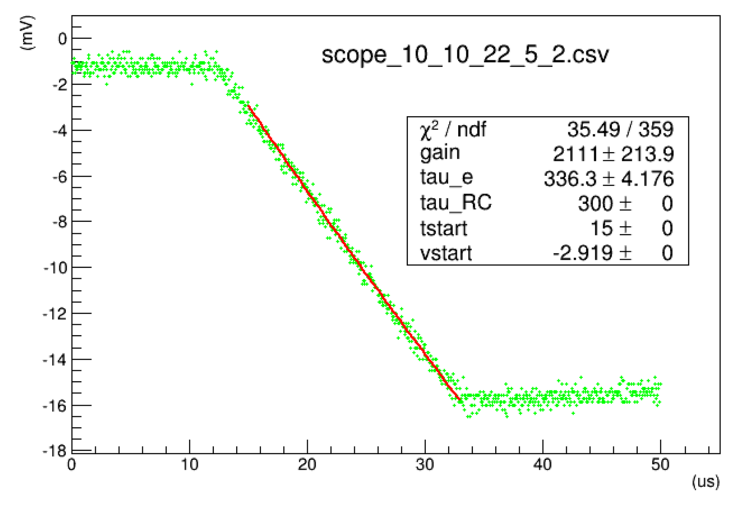
- Pumping the chamber and the gas handling system.
- Monitoring impurities levels with Mass Spectrometer.
- At least 3 days recirculation through heated Zr getter.

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 chamber after 3 runs.*



All tests obtained a limit above ELM sensitivity:

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

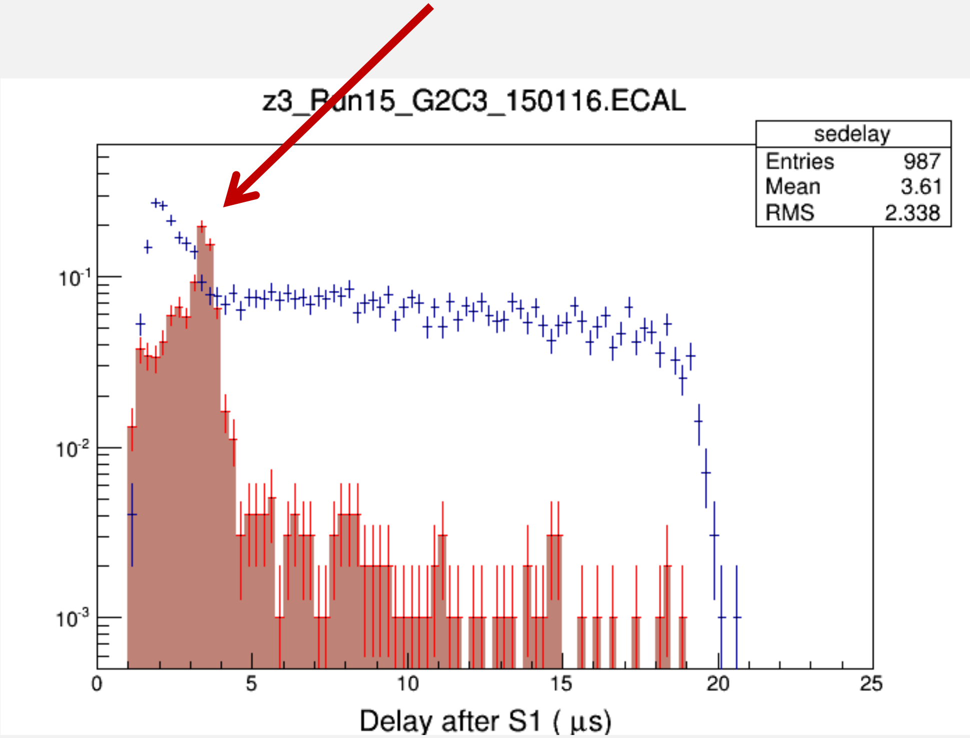
Drift time form wire

$\sim 12\ \mu s$

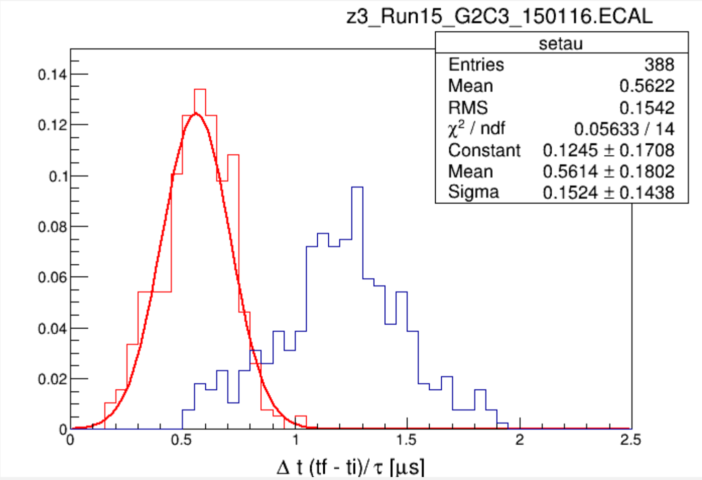
Chamber calibration

Data is taken with trigger threshold at several photoelectrons (S1 mostly) for calibration purposes for every run and chamber configuration.

Electrons produced by photoelectric effect on the chamber gate wires are identified by their typical delay after S1.

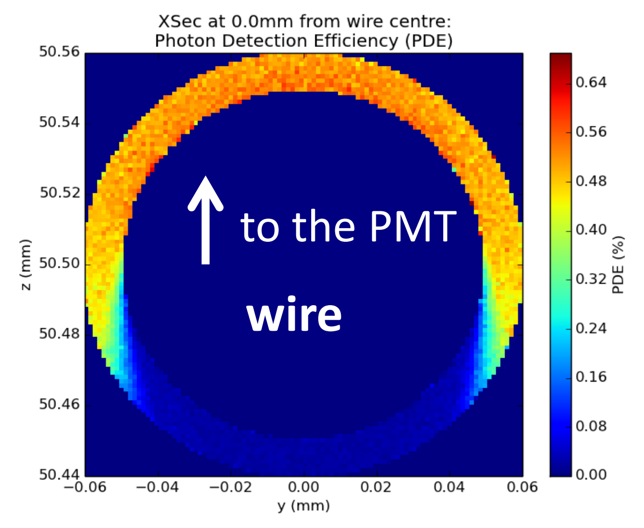


τ (weighted time width) distribution for the SE from the gate: definition of selection criteria for SE



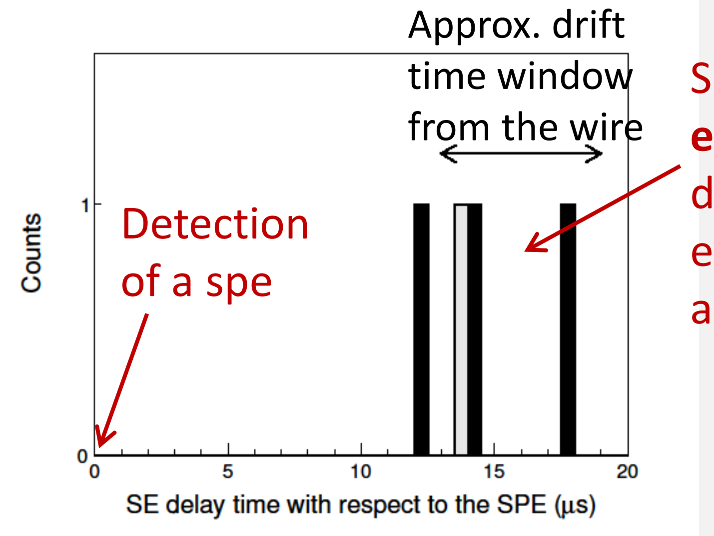
More on the identification of emission

Probability of detecting a photon emitted in coincidence with the SE



↑ to the PMT

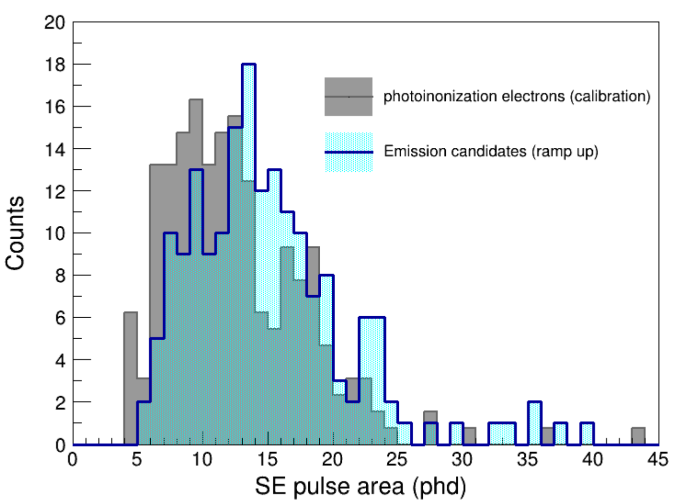
wire



Approx. drift time window from the wire

Detection of a spe

SE (identified as **emission candidates**) detected in the expected time delay and number



Noticeable change on the distribution of the SE sizes:

- During calibration from photoionization (smaller)
- During test from emission (larger)

Explainable from the change on the spatial distribution of the events and the inhomogeneous gain of the chamber