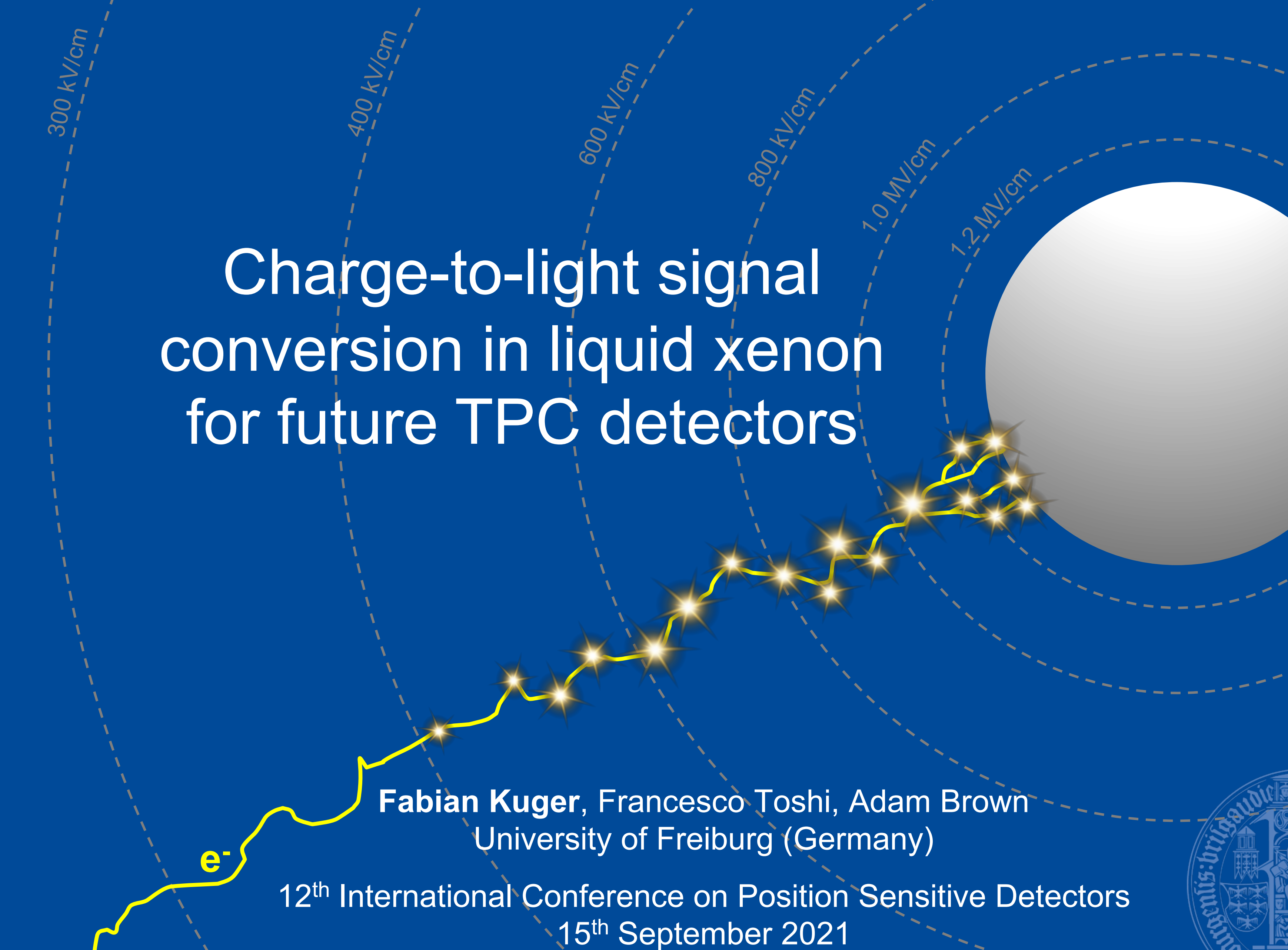

Charge-to-light signal conversion in liquid xenon for future TPC detectors

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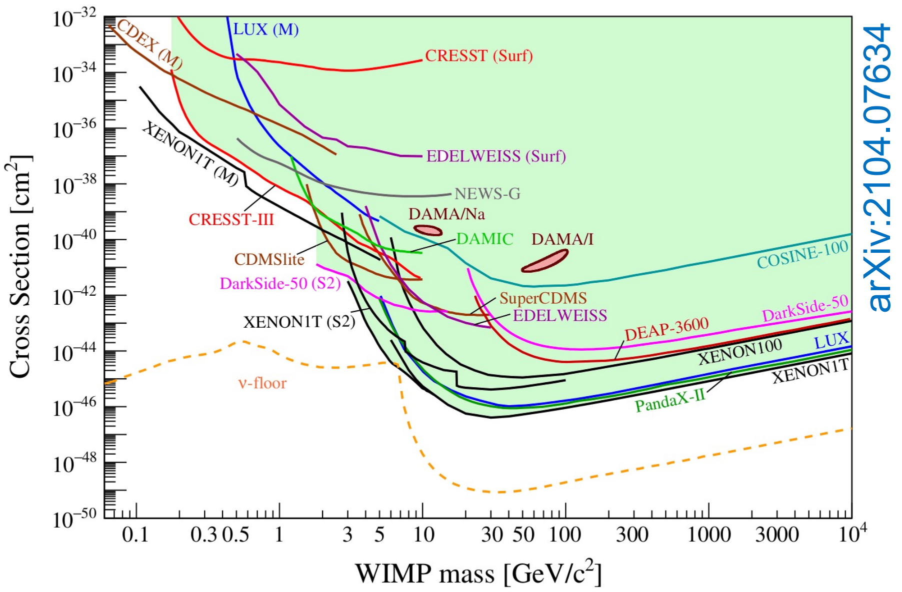
UNI FREIBURG

LXe target TPCs for Dark Matter direct detection

Time Projection Chambers provide **3D position reconstruction** and good **energy resolution** for rare event searches.

Liquid xenon (LXe) target TPCs lead the field on WIMP Dark Matter direct detection (and other rare event searches)



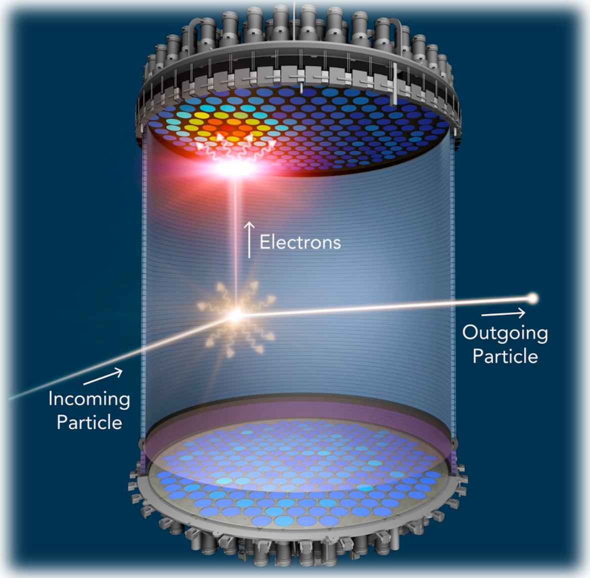
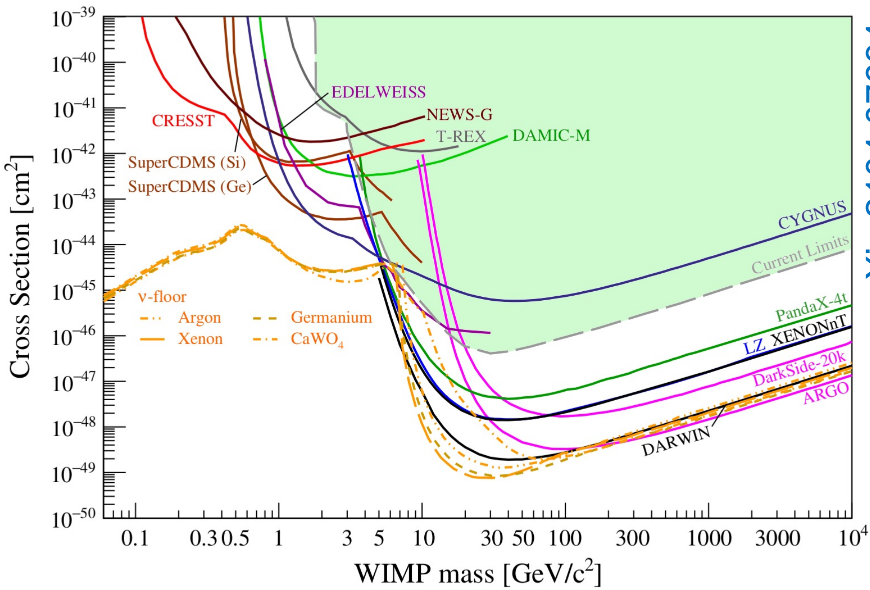


Photo sensors detect the prompt light signal and the delayed charge signal by scintillation (charge-to-light conversion + amplification)

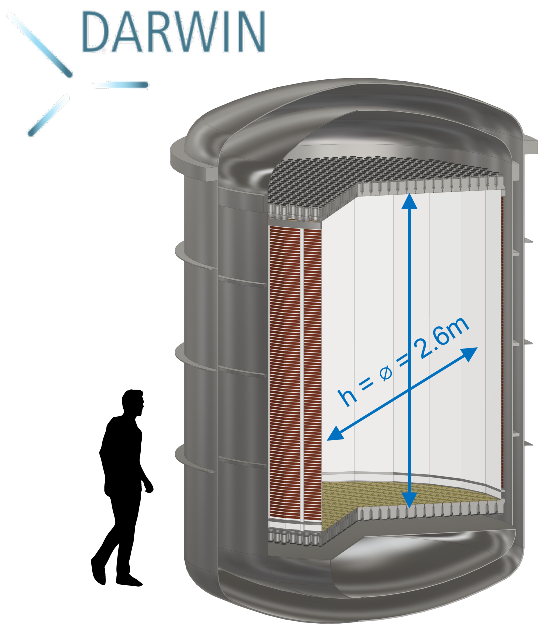
LXe target TPCs for Dark Matter direct detection

Time Projection Chambers provide **3D position reconstruction** and good **energy resolution** for rare event searches.

Future experiments – like DARWIN – will increase in TPC size, liquid xenon target mass to increase science reach.



arXiv:2104.07634



arXiv: 2003.13407

Photo sensors detect the prompt light signal and the delayed charge signal by scintillation (charge-to-light conversion + amplification)

Dual Phase → Single Phase TPCs

State-of-the-art: **Dual phase**

requiring electron extration into gas gap

+ scintillation in gaseous xenon

over 2-5 mm in O(8-10)kV/cm

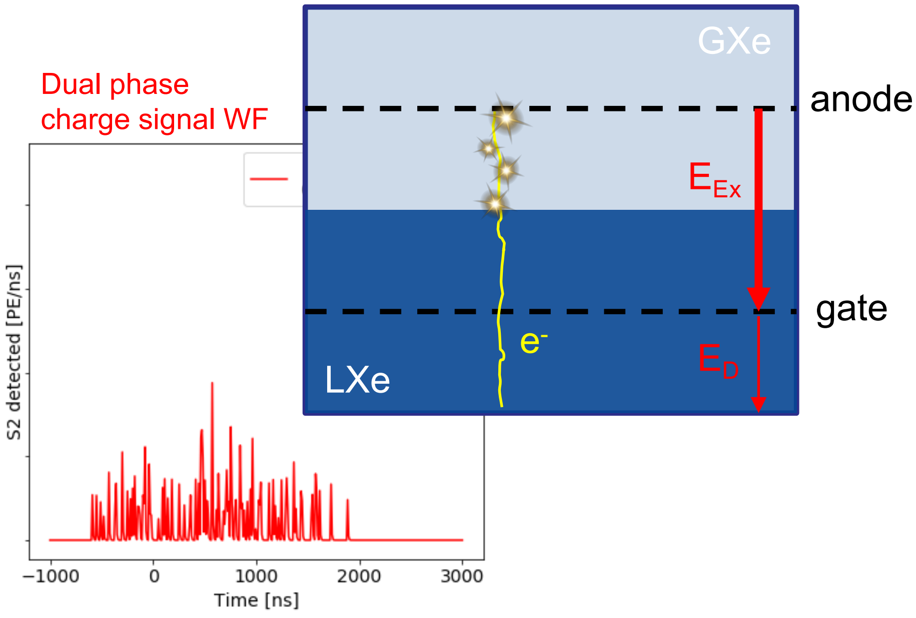
New approach: **Single phase**

with scintillation in liquid xenon

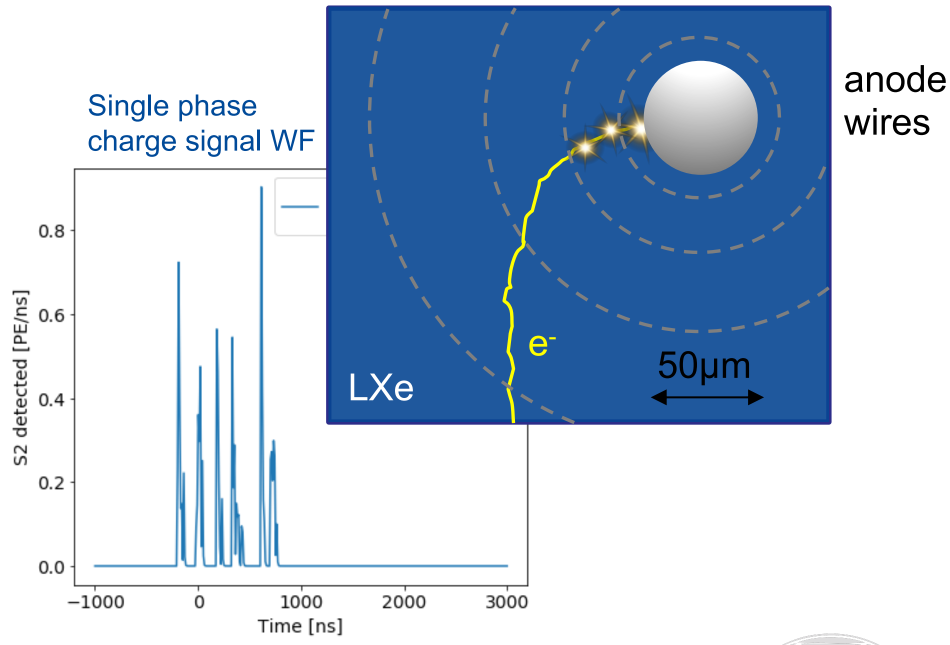
along O(10μm) in E ~ 400-1000kV/cm

while electrons approach thin wires

Dual phase
charge signal WF



Single phase
charge signal WF

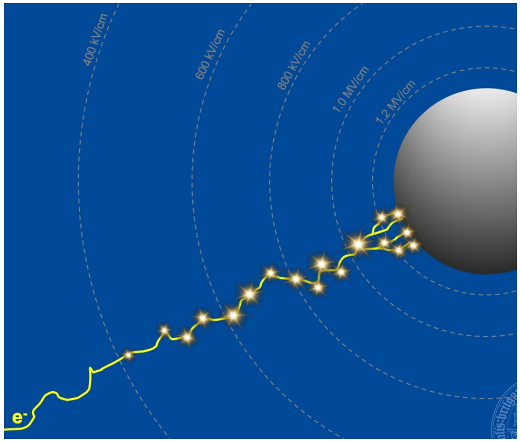


➔ Scintillation yield 100-200 photons per electron (~15% detected)

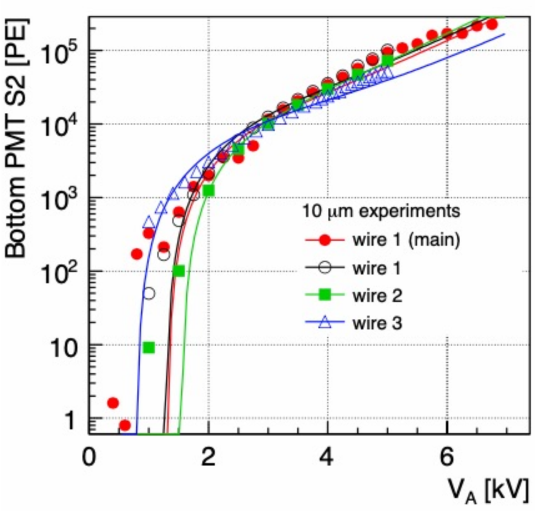
New scintillation mechanism – established detector design

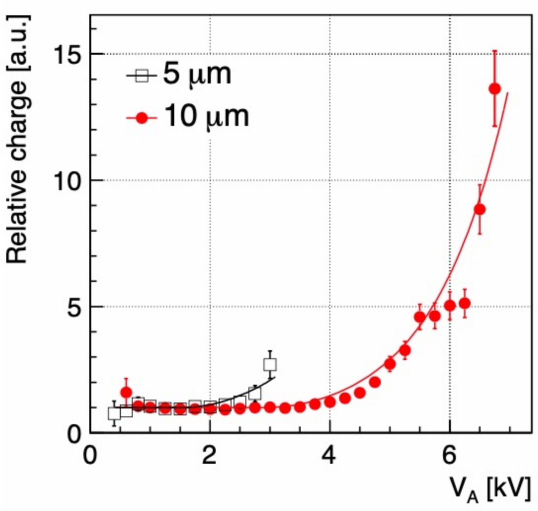
Proof-of-principle for scintillation in liquid xenon on a single 10µm wire (no TPC features) with α source [JINST 9 P11012 (2014)]

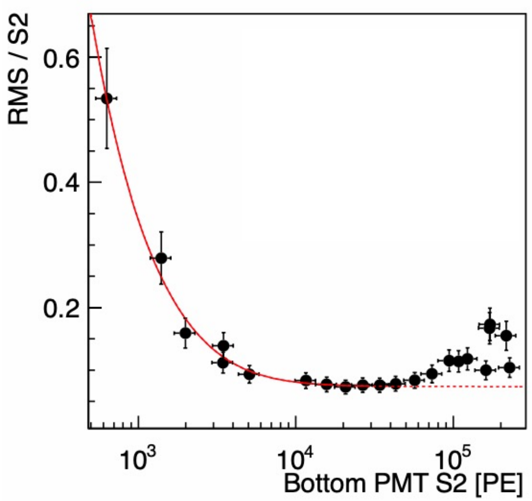
→ Empirical model for SY and charge multiplication:



$$\Delta N_\gamma = N_e \theta_3 \left(E(\vec{x}) - \theta_4\right) \Delta\vec{x}, \qquad \Delta N_e = N_e \theta_0 \exp\left(-\frac{\theta_1}{E(\vec{x}) - \theta_2}\right) \Delta\vec{x}$$







JINST 9 P11012 (2014)

→ Charge multiplication must be limited ≤ 3 to maintain energy resolution

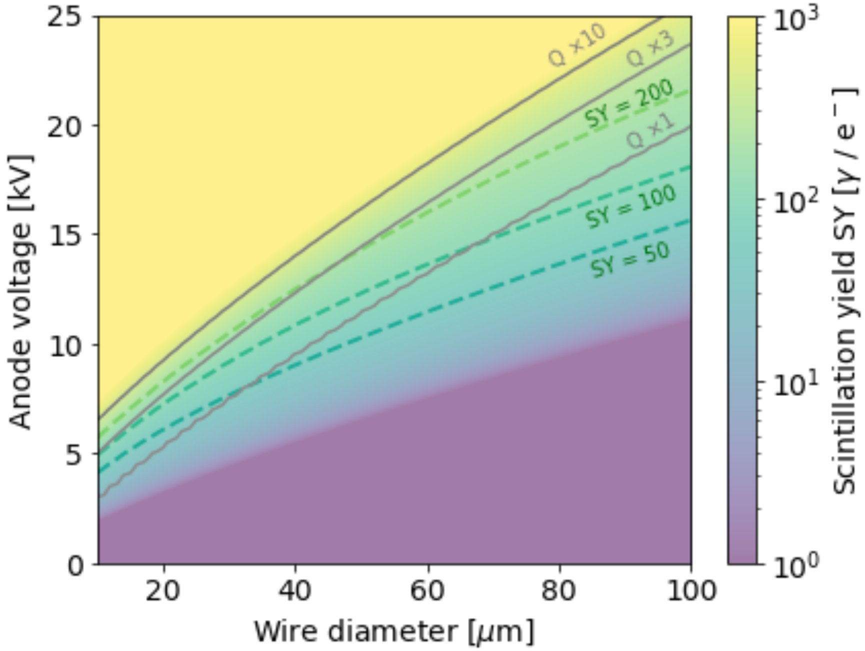
New scintillation mechanism – **established detector design**

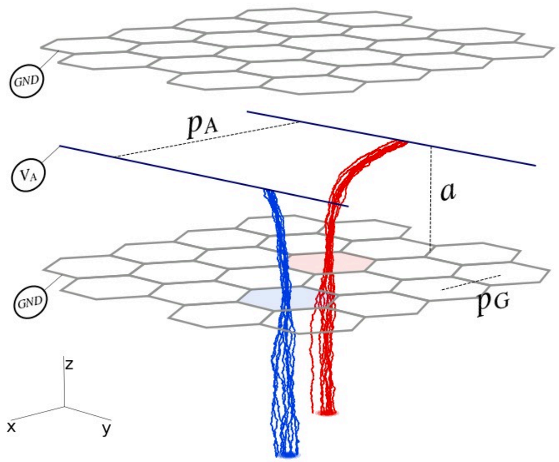
Minimal design modification w.r.t. state-of-the-art dual phase detectors (LZ, XENONnT):

use thin anode wires --- fill with liquid --- apply high voltage

➔ Maintain successful detection and analysis scheme of these experiments

Electrode stack: $p_{G/S}$ = 3mm, a = 5mm, p_A = 9mm



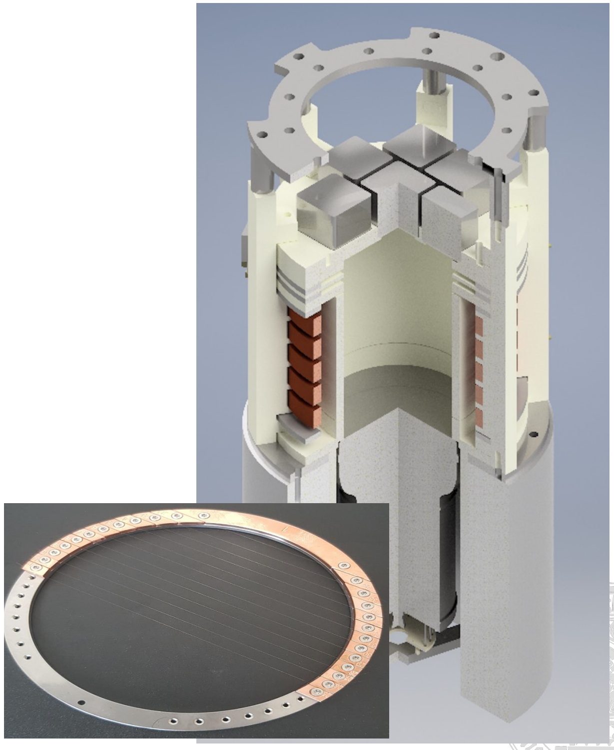


➔ Configurations with Q x3:

- SY = 100 with 10μm wire at 5kV
- SY = 200 with 50μm wire at 15kV

XeBRA Single Phase TPC prototype
- Preliminary experimental results -

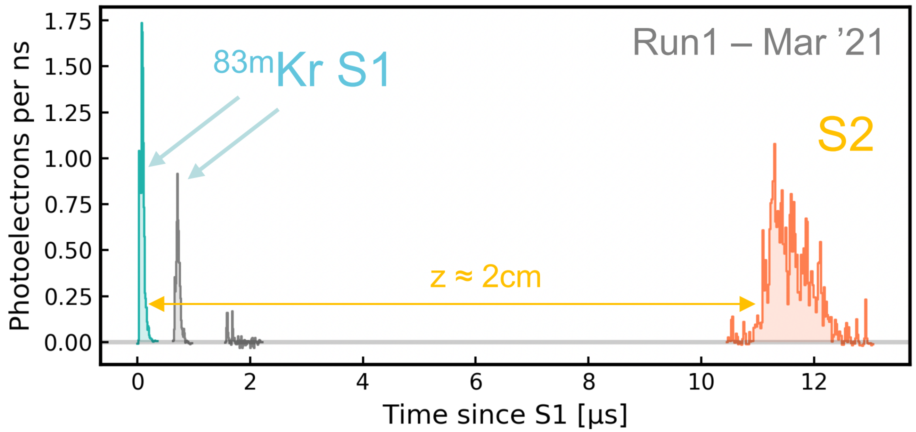
Can we operate a single phase TPC with 10μm wires?

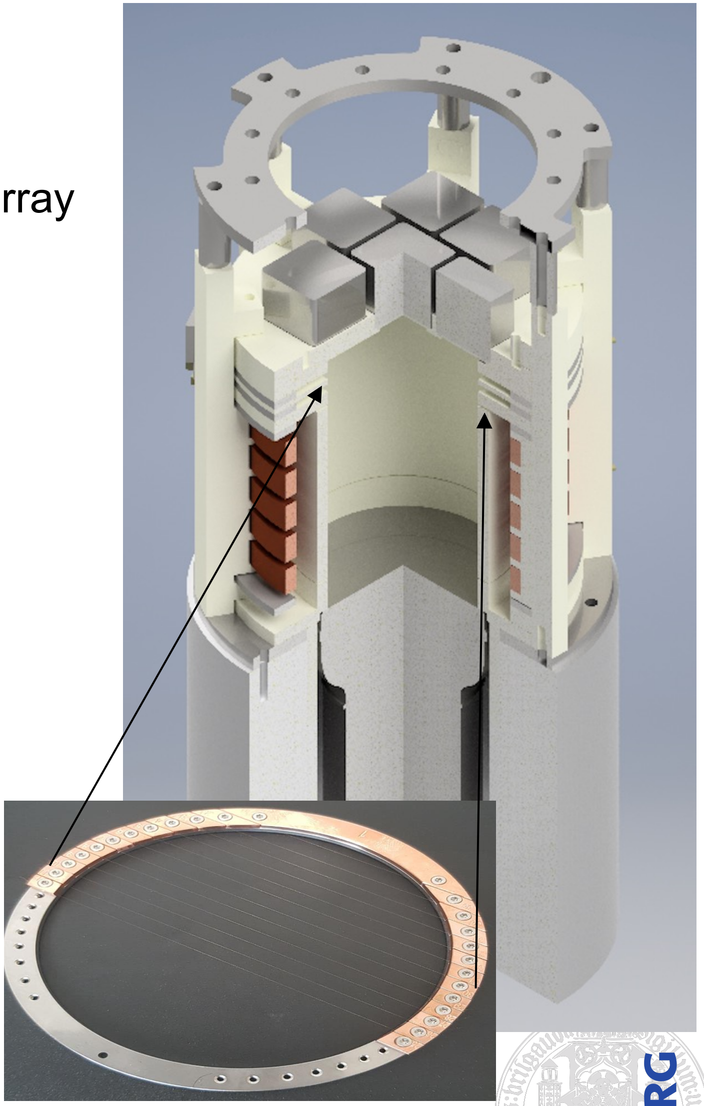


Single Phase TPC prototype (Run1 – Mar'21)

XeBRA single phase TPC at University of Freiburg:

- 7 x 7 cm instrumented LXe
- 1x3" circular PMT at bottom, 7x1" squared PMTs in top-array
- 10μm wire anode for scintillation in liquid





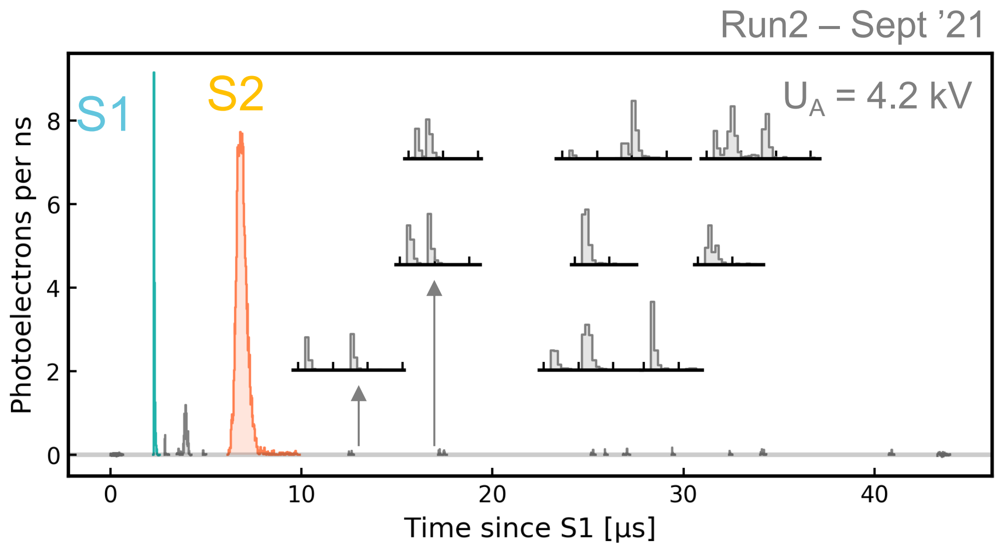
- TPC functionality demonstrated: 3D position reconstruction, purity determination, 83mKr calibration

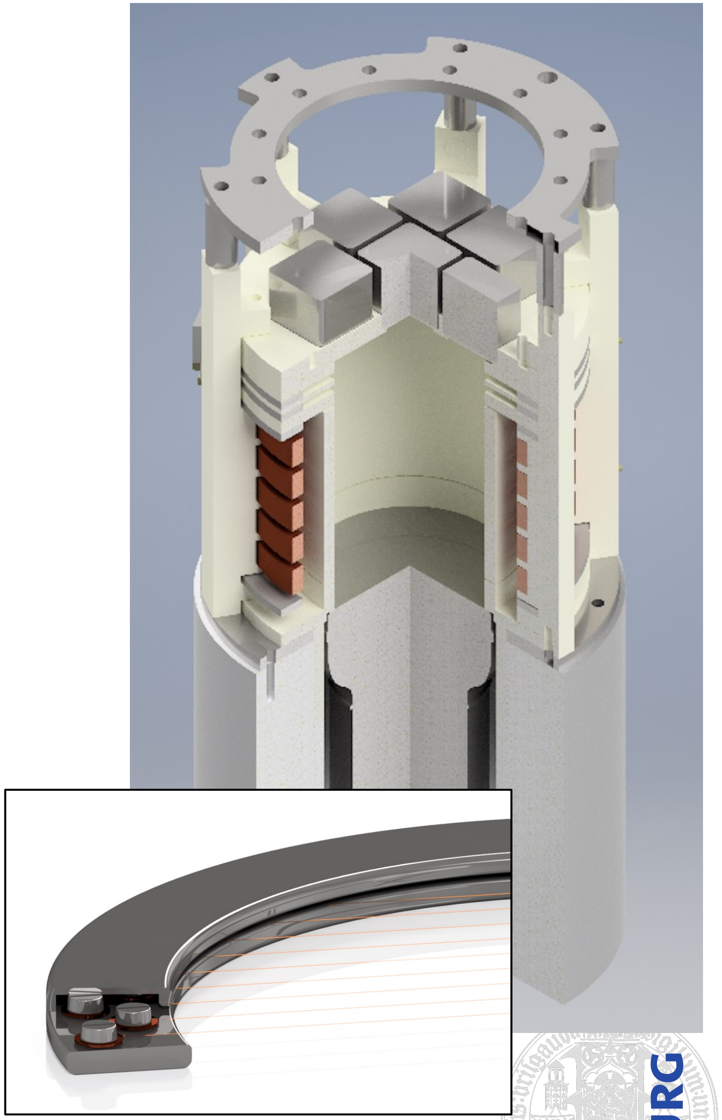
- BUT: limited scintillation yield ≤ 10 photons / e^-, for HV breakdown / sparking hot spots.

➔ Redesign & rebuild critical parts, improve cleanliness

Single Phase TPC prototype (Run2 – Sep'21)

New - preliminary - data from the weekend shift:





- S2 size comparable with dual phase TPC
- single electron signals confirm sharp peak signal
- Stable operation with up to U_A = 4.8 kV

➔ closing in on Scintillation 100 photons / electron

Single Phase TPC prototype (Run2 – Sep'21)

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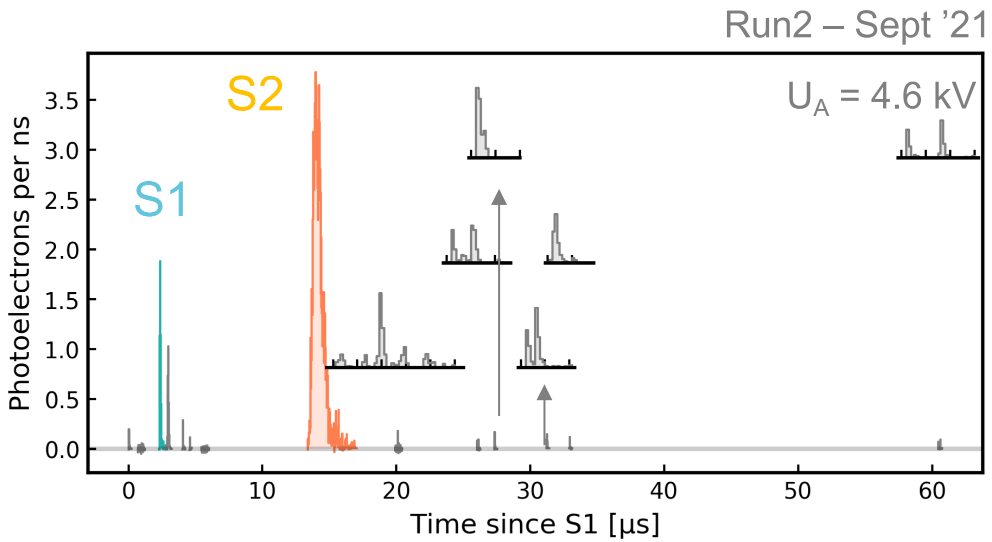

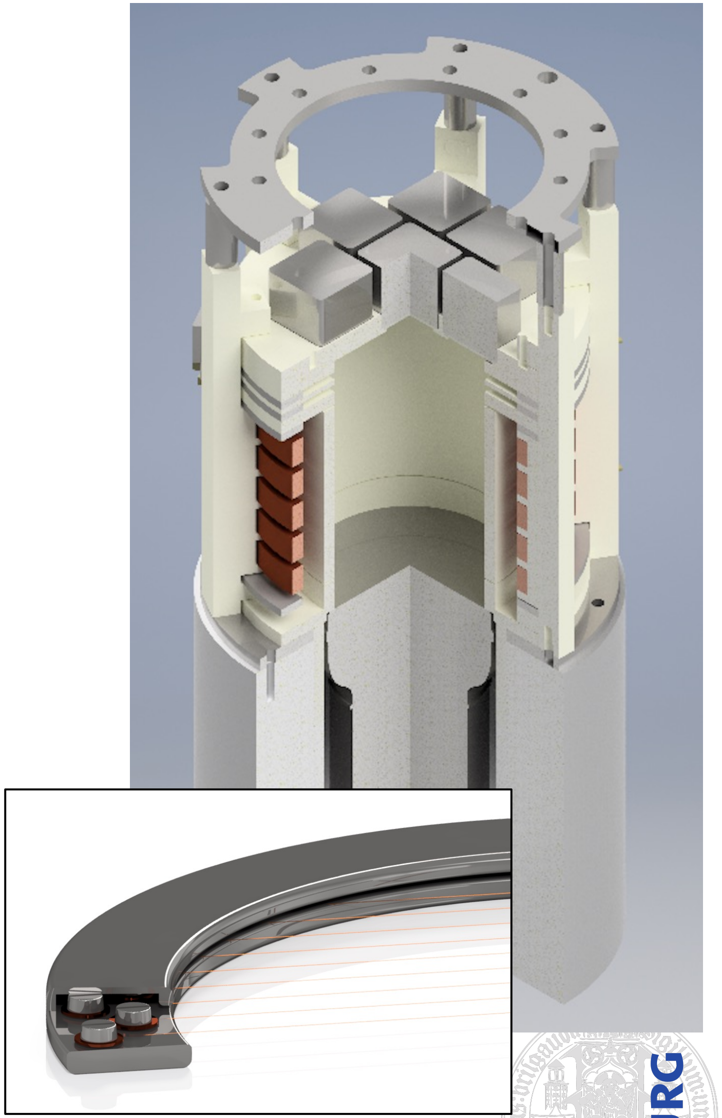

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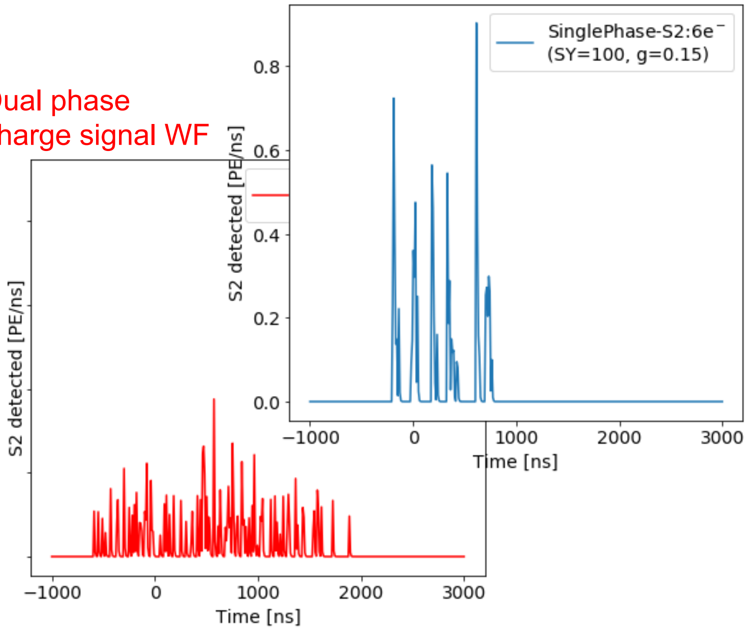
➔ closing in on Scintillation 100 photons / electron

DARWIN as single phase
- prospects of new S2 analysis -

Single phase
charge signal WF

Dual phase
charge signal WF



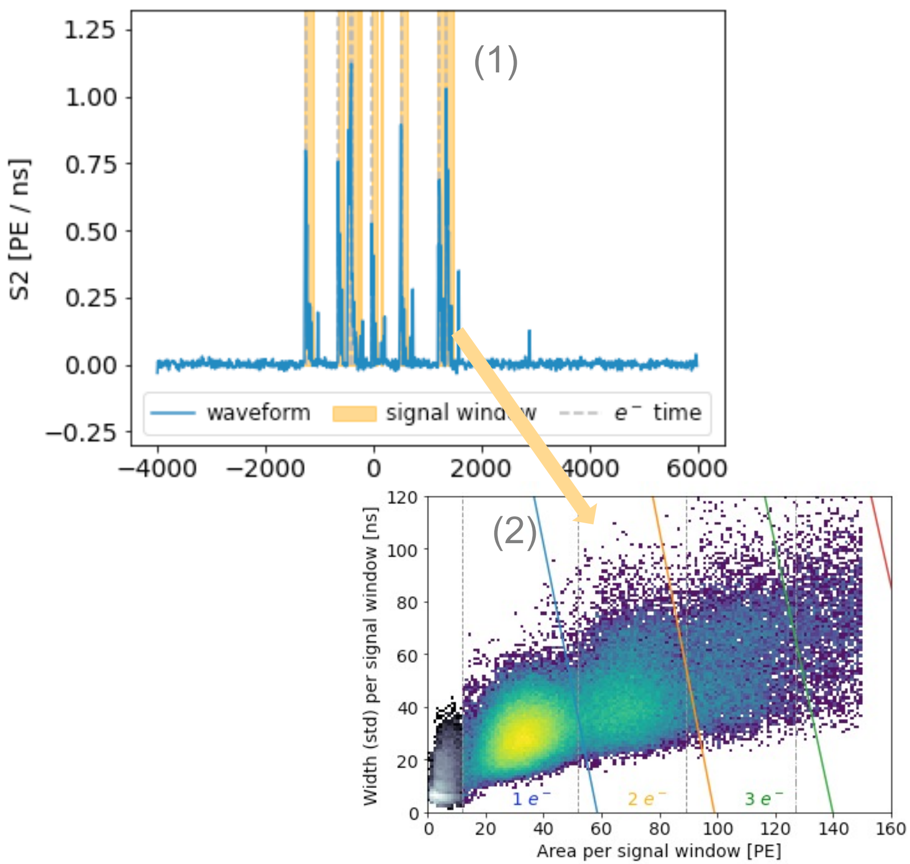
How to profit from the peaked signal per electron?

Improved charge resolution by electron counting for low E

Counting electrons in the WF:

(1) Search signal windows in peaked WF

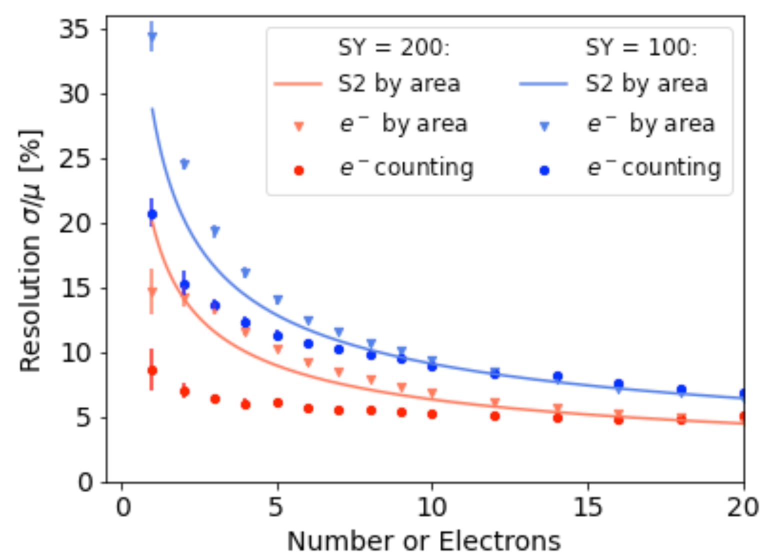
(2) determine #e$^-$ per window



➔ Improved resolution for small signals,

- compared to (rounded) integrated signal:

< 15e$^-$ (SY = 200) or < 10e$^-$ (SY=100)



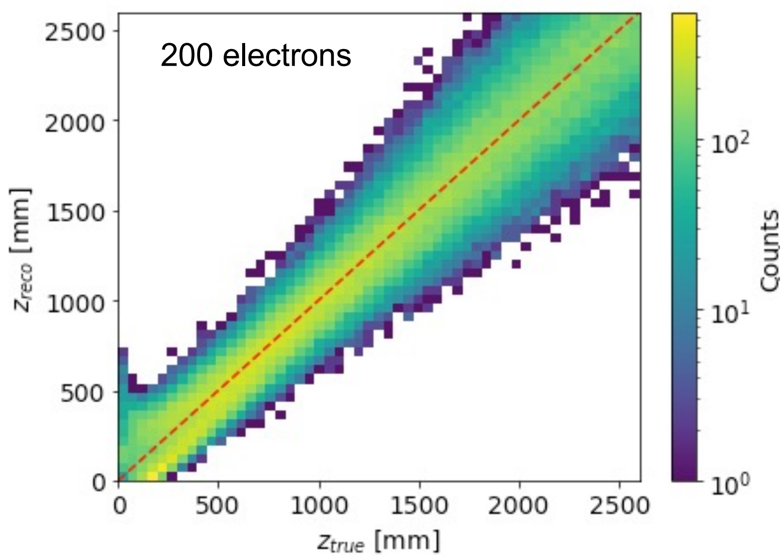
➔ Benefit for **sub-GeV WIMPs, …**

Charge-only z-position reconstruction

Measure σ_t in e^- arrival time distribution

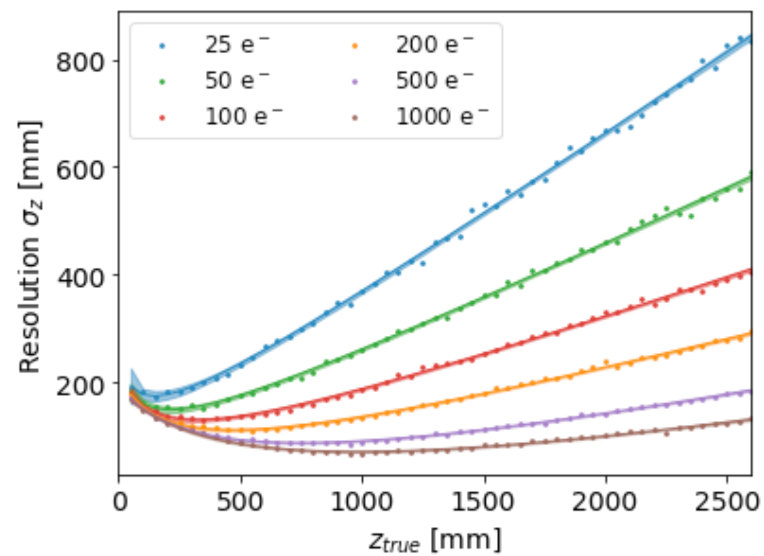
→ reconstruct *z* from diffusion pattern

$$z_{\text{reco}} = \frac{\sigma_t^2 \cdot v_D^3}{2D_L} - F_{\text{corr}}(z_{\text{reco}}),$$



➔ Additional *z*-measurement, independent from the S1 Signal, but limited resolution:

21% ($50e^-$), 12% ($200e^-$)



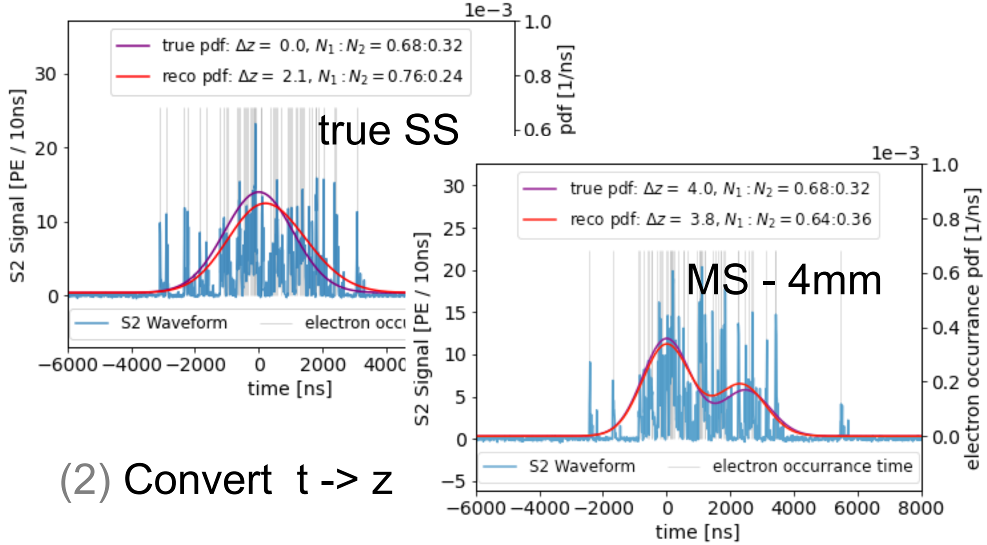
➔ > 50% accidental coincidence rejection, crucial for future WIMP searches

Single site vs. multiple site discrimination

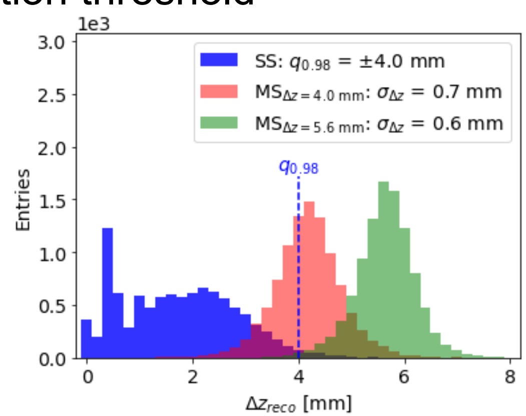
Test one vs. two populations in e^- timing:

(1) Determine most likely arrival time pdf

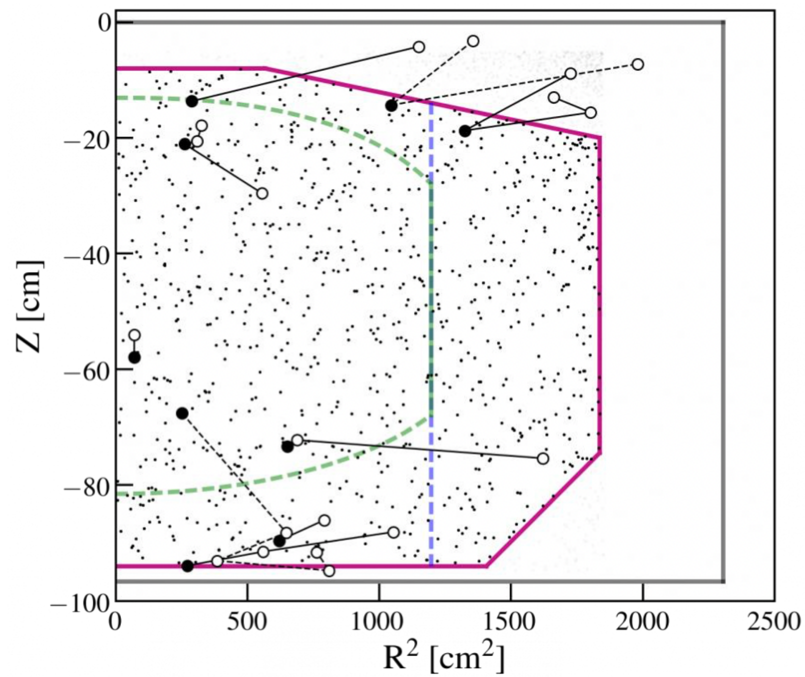
(2) Convert t -> z



(3) Define discrimination threshold with fixed single site acceptance = 98%



Multiple site neutron events in XENON1T [1]

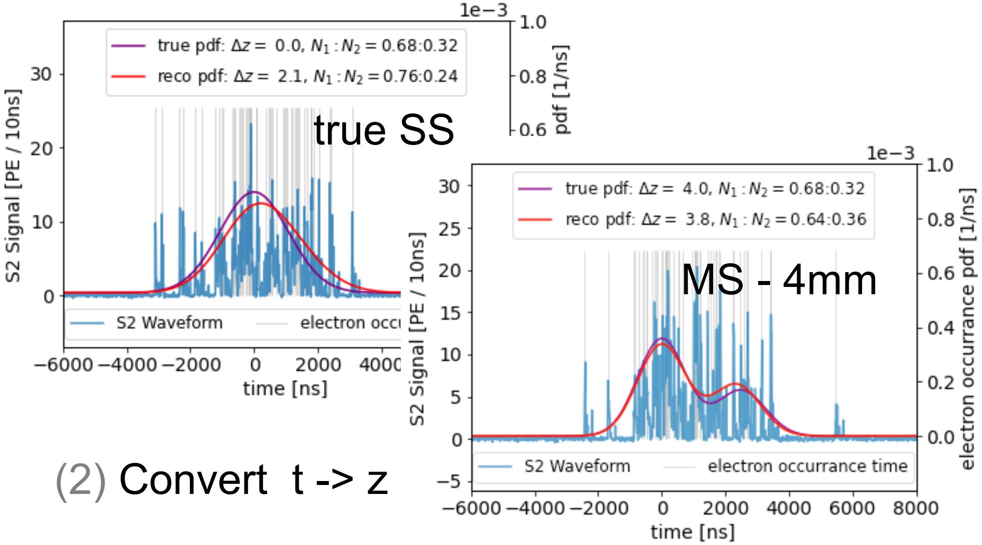


[1] Talk by L. Swordy, DMSS July 18

Single site vs. multiple site discrimination

Test one vs. two populations in e⁻ timing:

(1) Determine most likely arrival time pdf



(2) Convert t -> z

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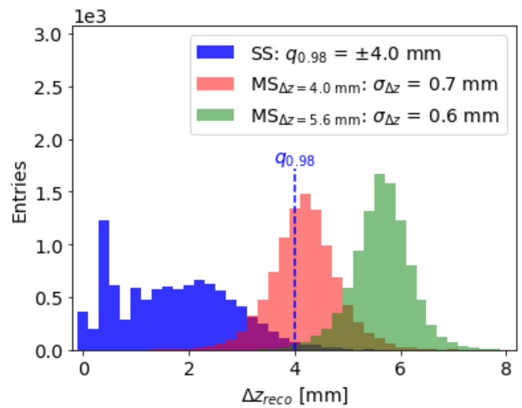
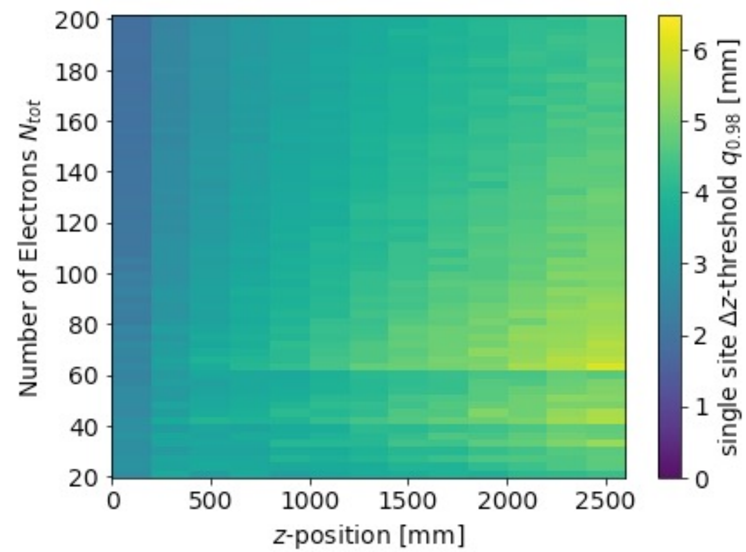


➔ SS / MS discrimination with 2-6 mm z-spacing throughout 2.6m TPC:



➔ Essential for neutron rejection

[1] Talk by L. Swordy, DMSS July 18

Summary

- Scintillation in liquid xenon is a promising charge-to-light conversion mechanism for future LXe target TPC experiments

- Significant benefits over the state-of-the-art dual phase scheme with scintillation in a gas gap:

Not covered in this talk

❖ fast scintillation per electron

- single electron counting → improved resolution for small signals
- *z*-reconstruction by electron arrival → rejection to AC background
- SS-MS discrimination → suppression of neutron background

❖ no gas gap required

- avoid mechanical & electrostatic challenges to maintain precise, thin gap with high E
- no total reflection or delayed electron extration at the liquid-gas interface
- new TPC design possibilities:
  - segmented TPC → higher E_D
  - free orientiation towards gravity

- Experimental R&D projects have started and first results look promising

Thank you

for your time, interest and attention

Questions and comments are welcome

-- Now, in the coffee break or offline* --

*Fabian.Kuger@physik.uni-freiburg.de