A small dual-phase xenon TPC with APD and PMT readout for the study of liquid xenon scintillation

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TIPP 2014 - Amsterdam
02 june 2014

Outline

- motivation for MainzTPC
- design and status of MainzTPC
- gain and quantum efficiency avalanche photo diodes
- summary and outlook

Dark Matter results

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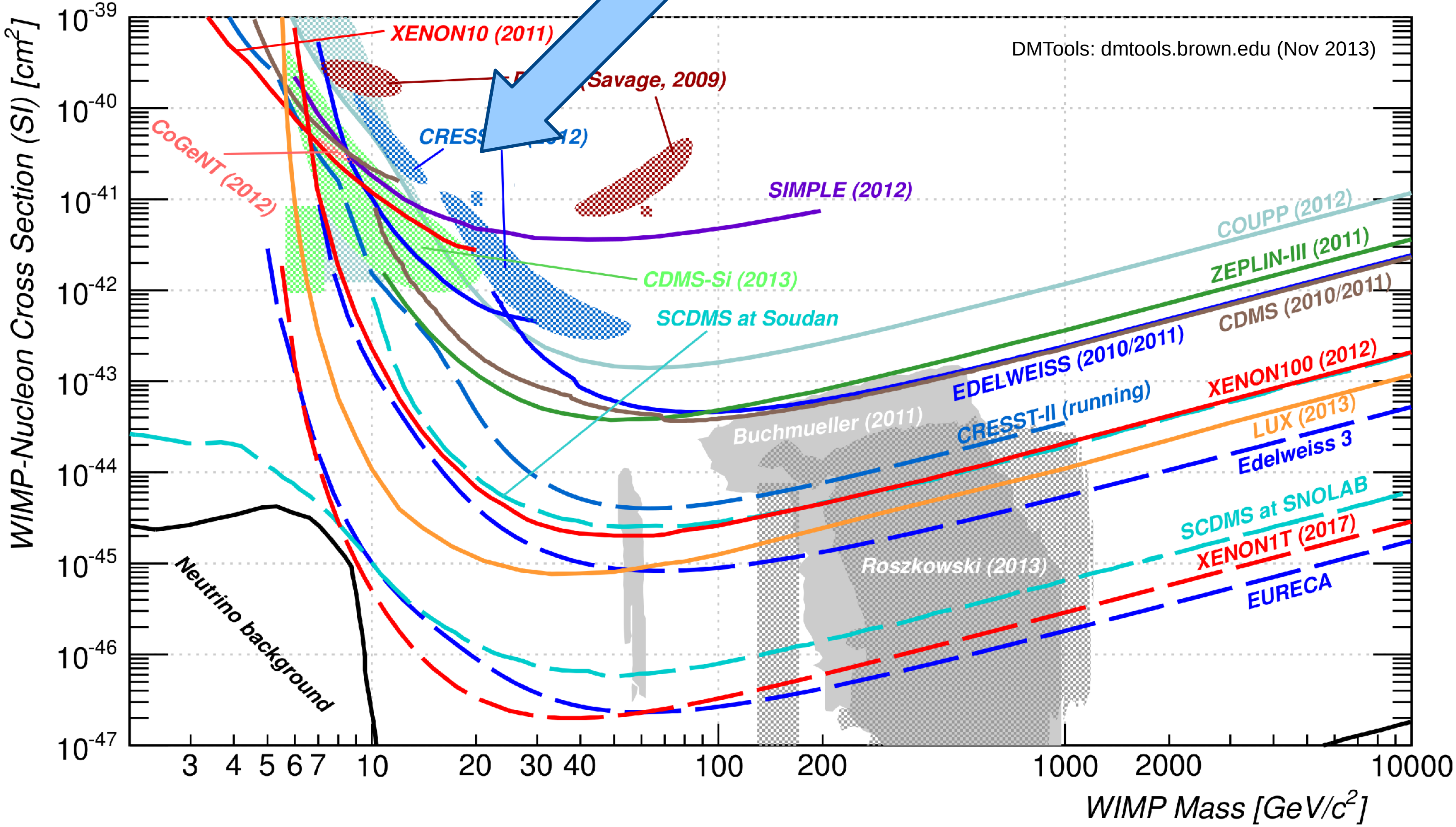
Tension in the low WIMP mass regime:
Do we understand our detector threshold well?



Principle of a dual-phase xenon TPC

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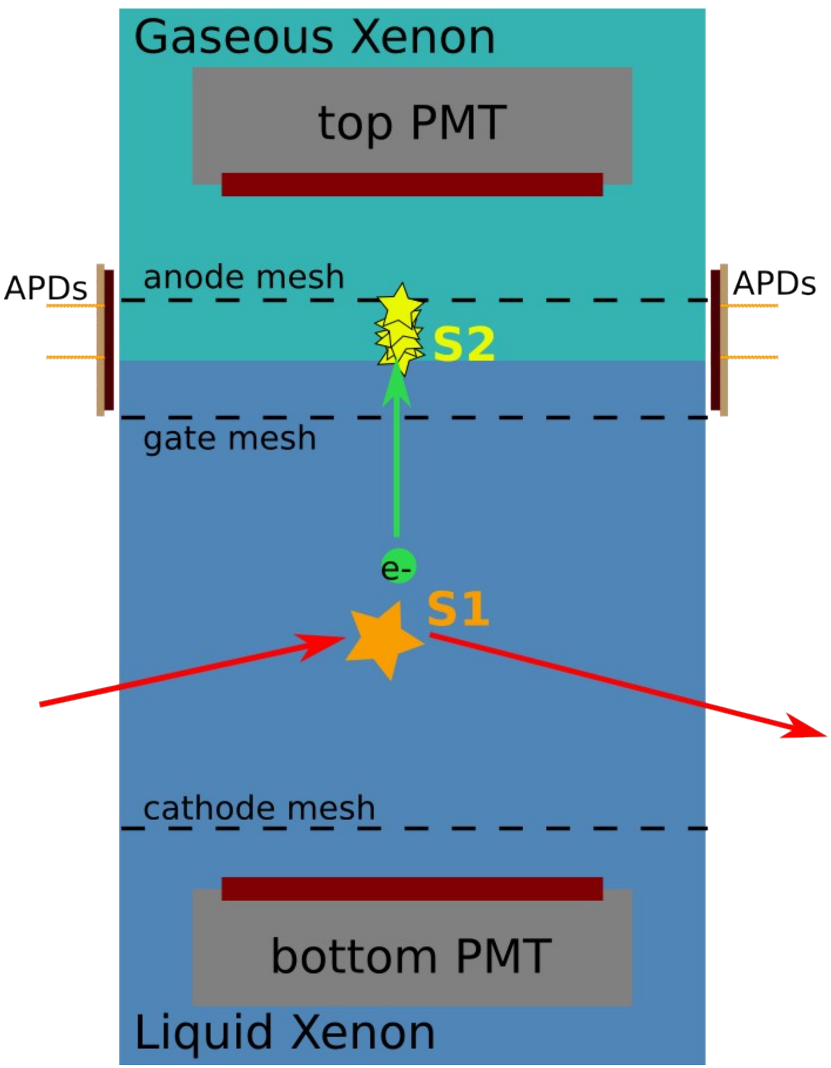
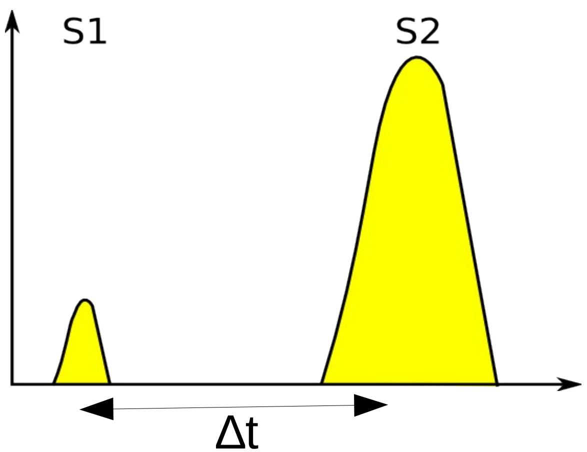
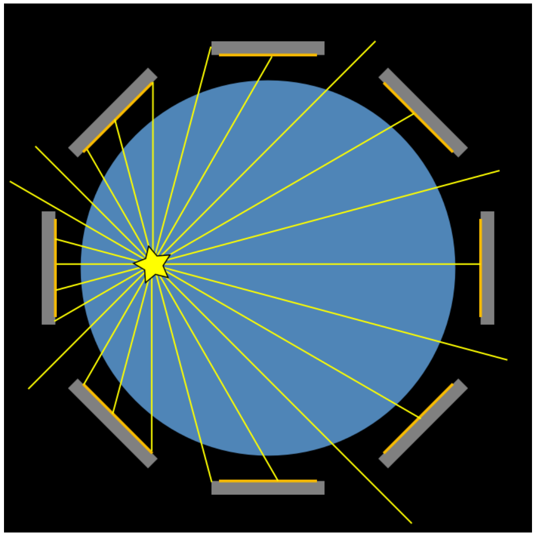


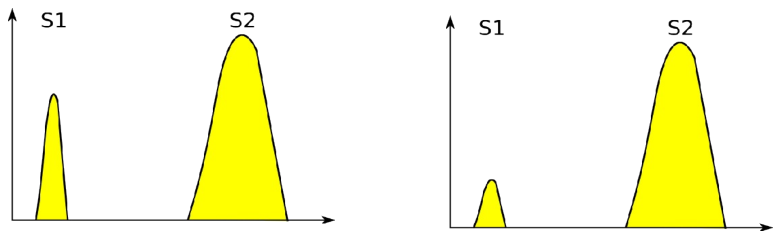
z-position
reconstructed by electron drift time:
$z = \Delta t \cdot v_{drift}$



x/y-position
position of S2 detected by a photosensor array

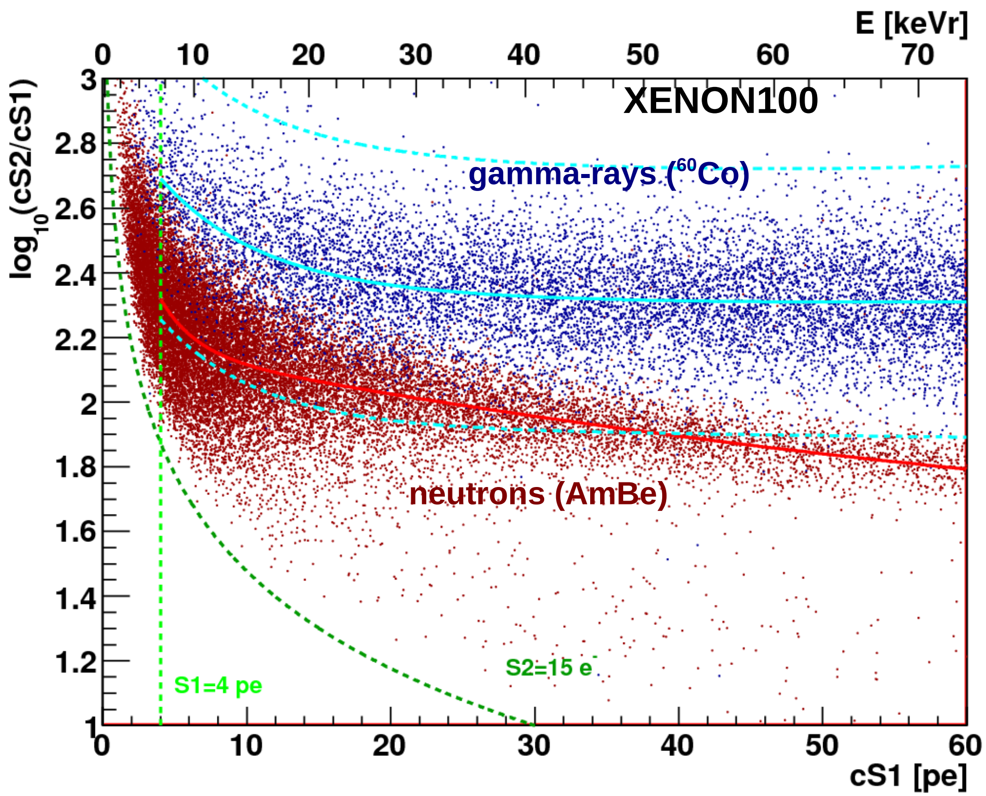


nuclear recoil (NR)
neutron, WIMP



electronic recoil (ER)
electron, gamma

S2/S1 (NR) < S2/S1 (ER)



Similar in:
2013: E. Aprile et al. (XENON100 Collab.): "*Dark Matter Results from 225 Live Days from XENON100 Data*"

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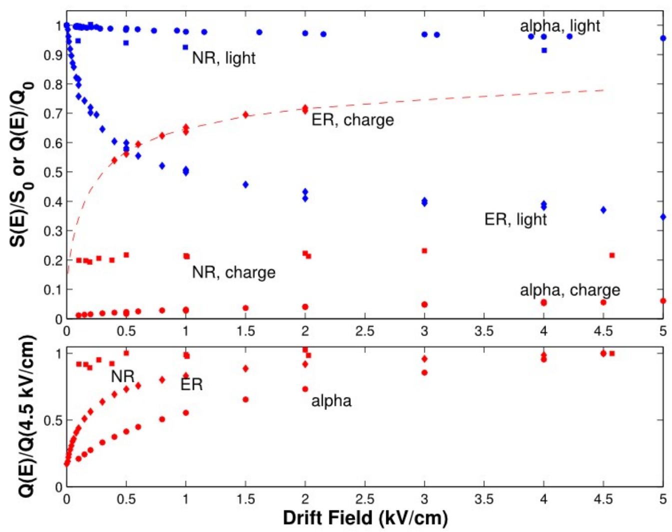
Charge and scintillation yield

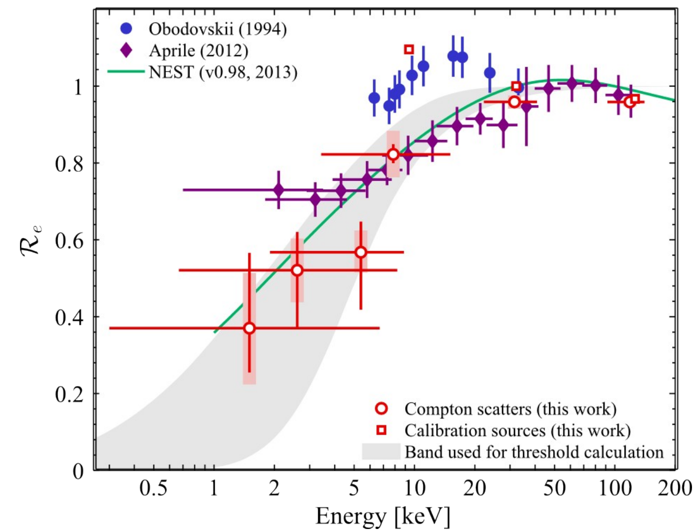
electronic recoils

charge yield



Phys.Rev. 97, 081302: E. Aprile et al.: "*Simultaneous measurement of ionization and scintillation from nuclear recoils in liquid xenon as target for a dark matter experiment*"

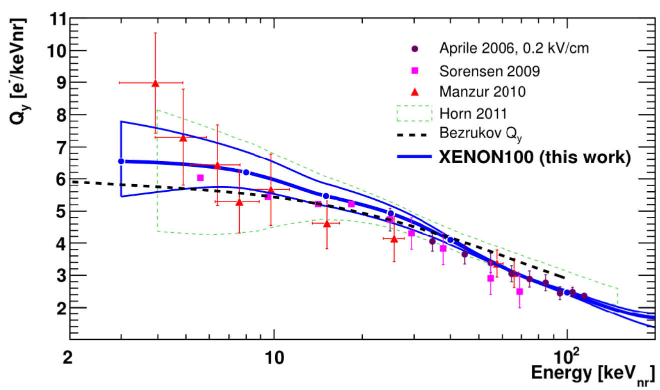
scintillation yield



Phys.Rev.D 87, 115015: L. Baudis et al.: "*Response of liquid xenon to Compton electrons down to 1.5keV*"

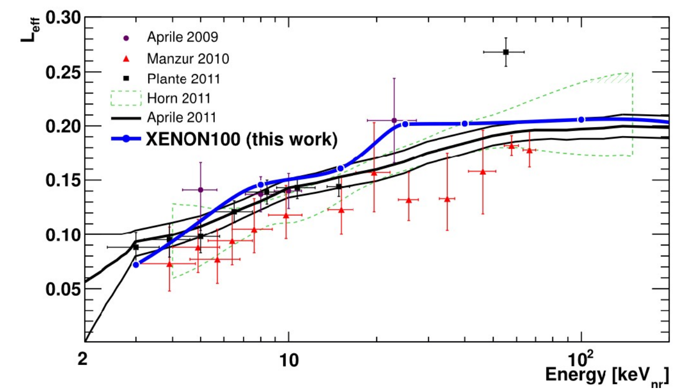
nuclear recoils

charge yield



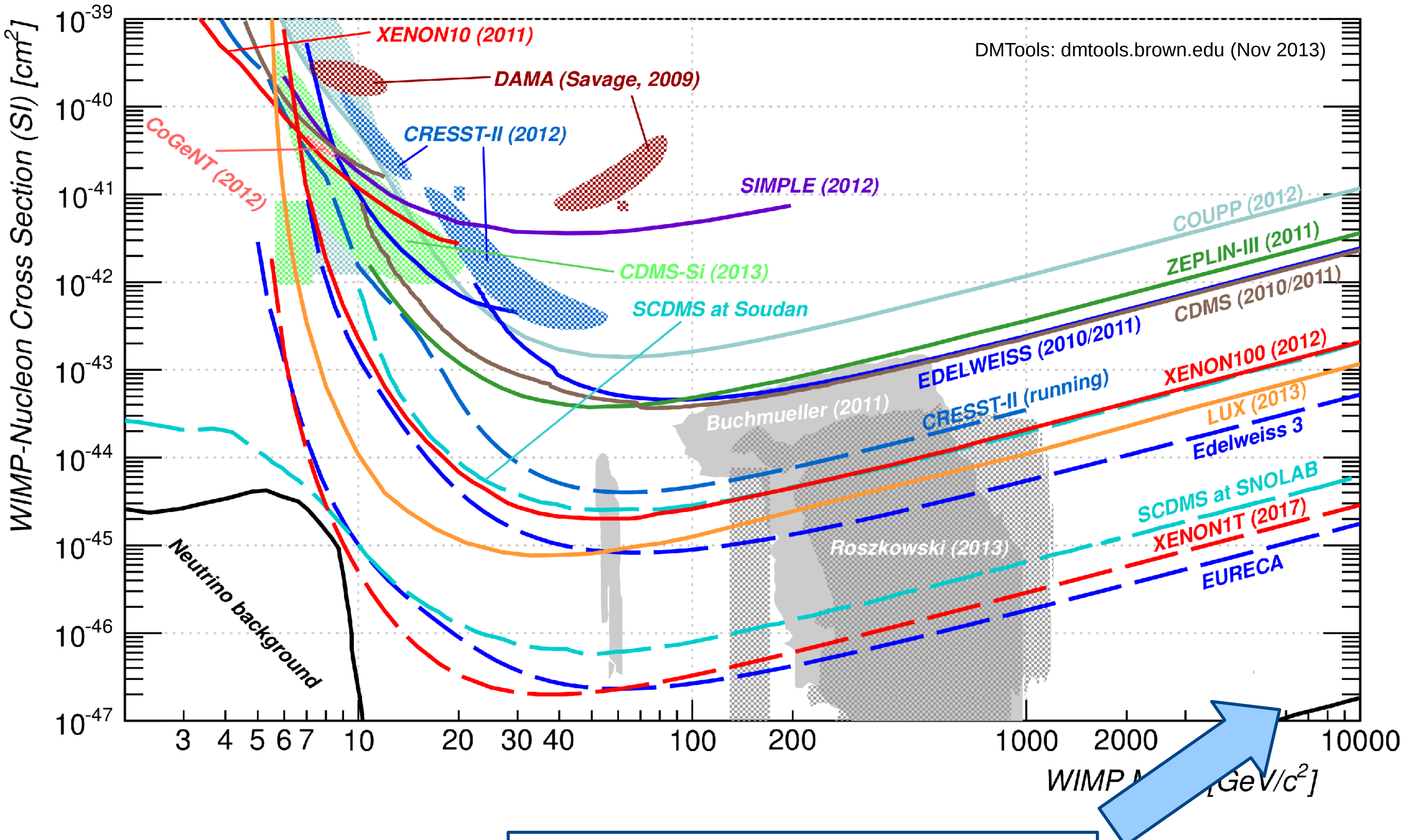
Phys.Rev.D 88, 012006: E. Aprile et al. (XENON100 Collab.): "*Response of the XENON100 Dark Matter Detector to Nuclear Recoils*"

scintillation yield



Phys.Rev.D 88, 012006: E. Aprile et al. (XENON100 Collab.): "*Response of the XENON100 Dark Matter Detector to Nuclear Recoils*"

Dark Matter results



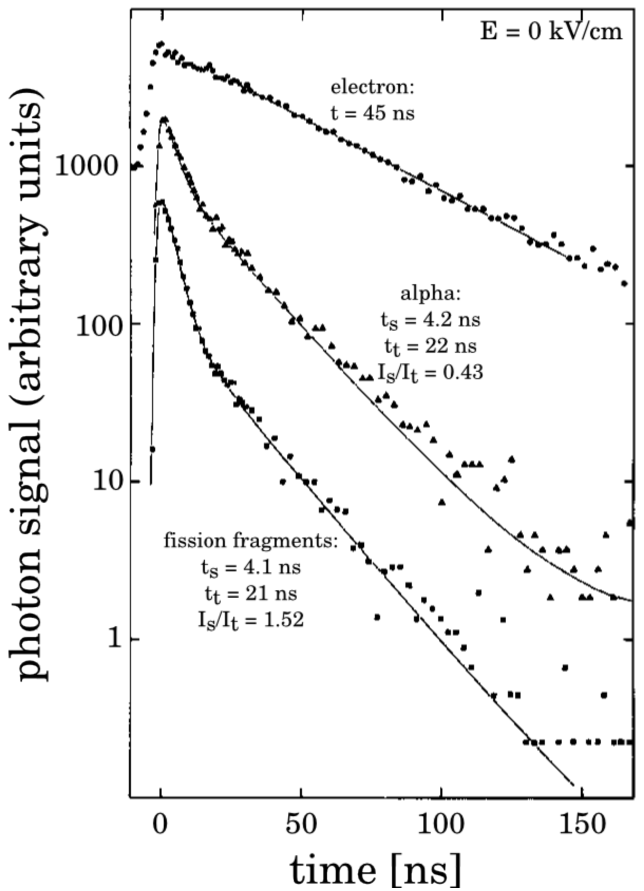
background from neutrinos

Scintillation pulse shape

A complementary background discrimination method?

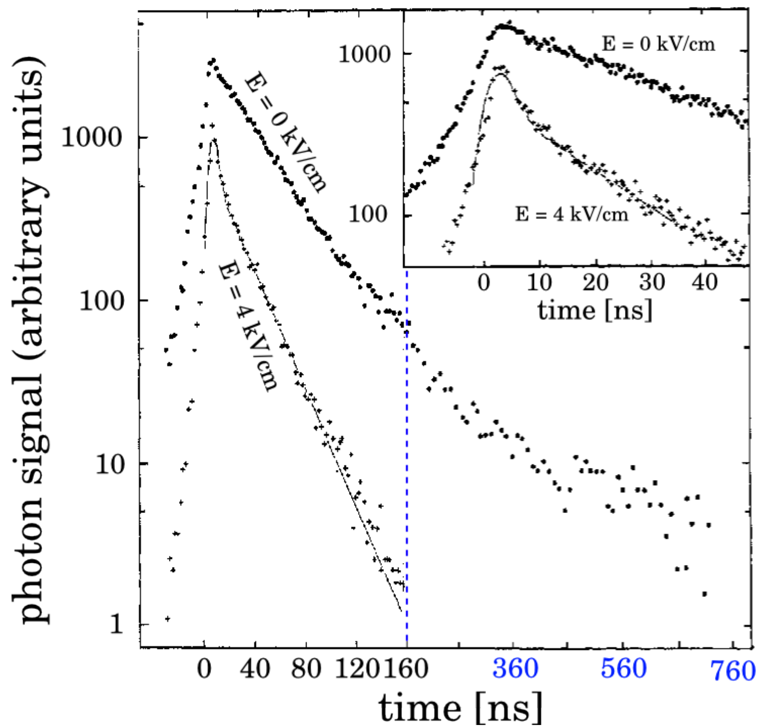
Hints from the 80's:

different scattering particles



Physical Review B - A. Hitachi, T. Takahashi: *" Effect of ionization density on the time dependence of luminescence from liquid argon and xenon"*

different drift fields



J . Phys. C : Shinzou Kubota, Masahiko Hishida and Jian-zhi Raun: *"Evidence for a triplet state of the self-trapped exciton states in liquid argon, krypton and xenon"*

different time constants need to be disentangled

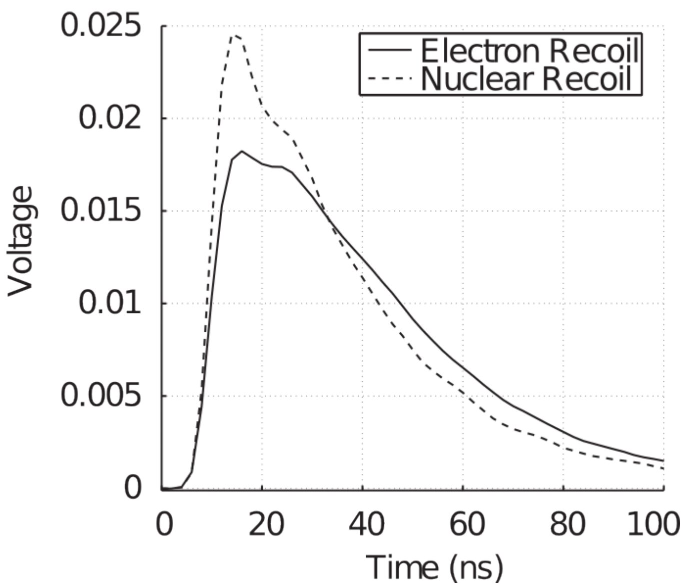
↓

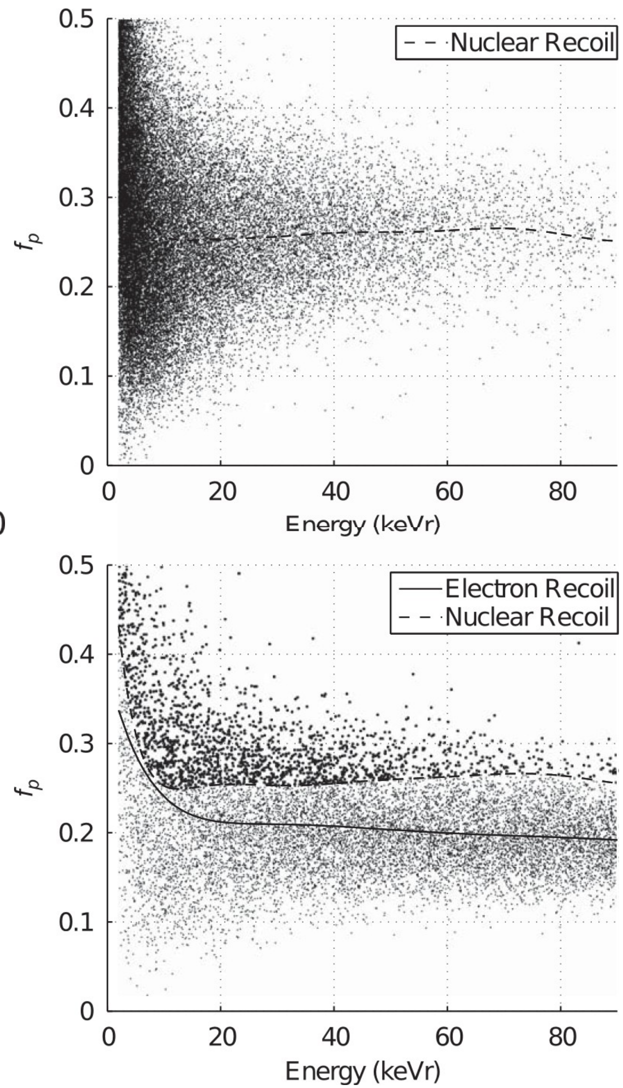
systematic tests

Scintillation pulse shape

A complementary background discrimination method?

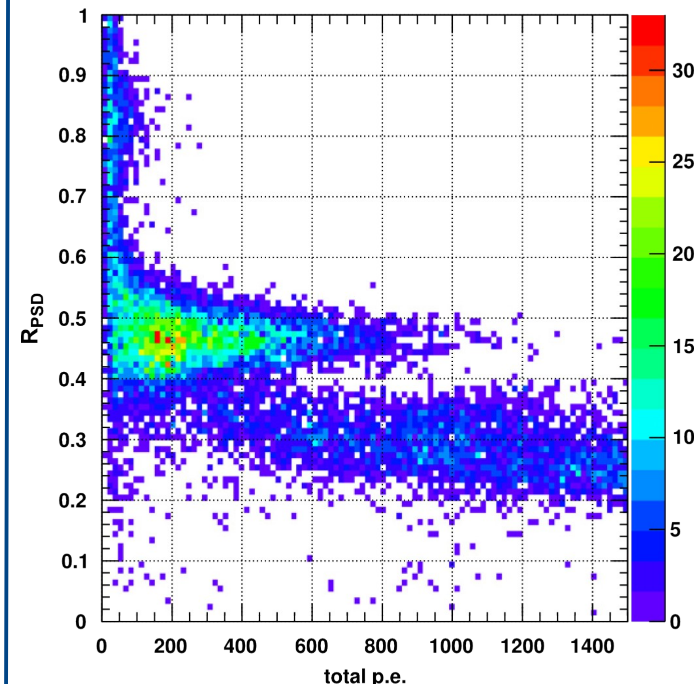
2010:
pulse shape of LXe scintillation
78keVr @ 0.06kV/cm





NIM A 612(2010): J. Kwong et al.: *"Scintillation pulse shape discrimination in a two-phase xenon time projection chamber"*

2011:
PSD in LXe without E-field
Cf252 data



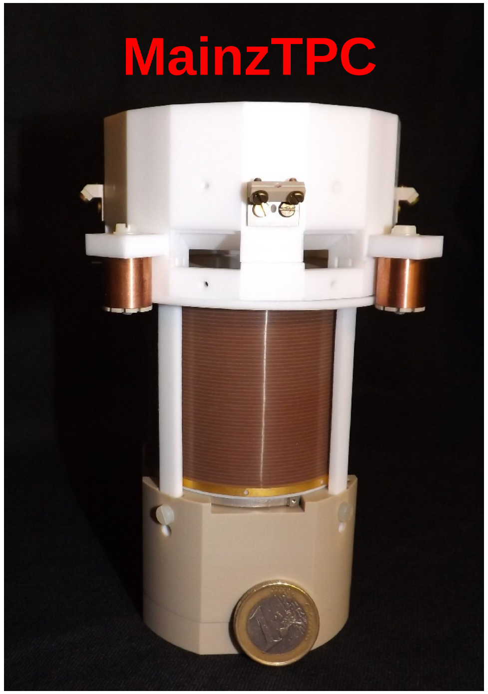
NIM A 659(2011): K. Ueshima et al.: *"Scintillation-only based pulse shape discrimination for nuclear and electron recoils in liquid xenon"*

Goals of the MainzTPC

Goal:

Measurement and understanding of low energy response of liquid xenon

- primary scintillation
- ionization
- S1 pulse shape



Means:

- Simultaneous measurement of light and charge
- 3D position reconstruction

MainzTPC:

Optimized for Compton scattering with little passive material and fast electronics.

Cryogenic system with Compton setup

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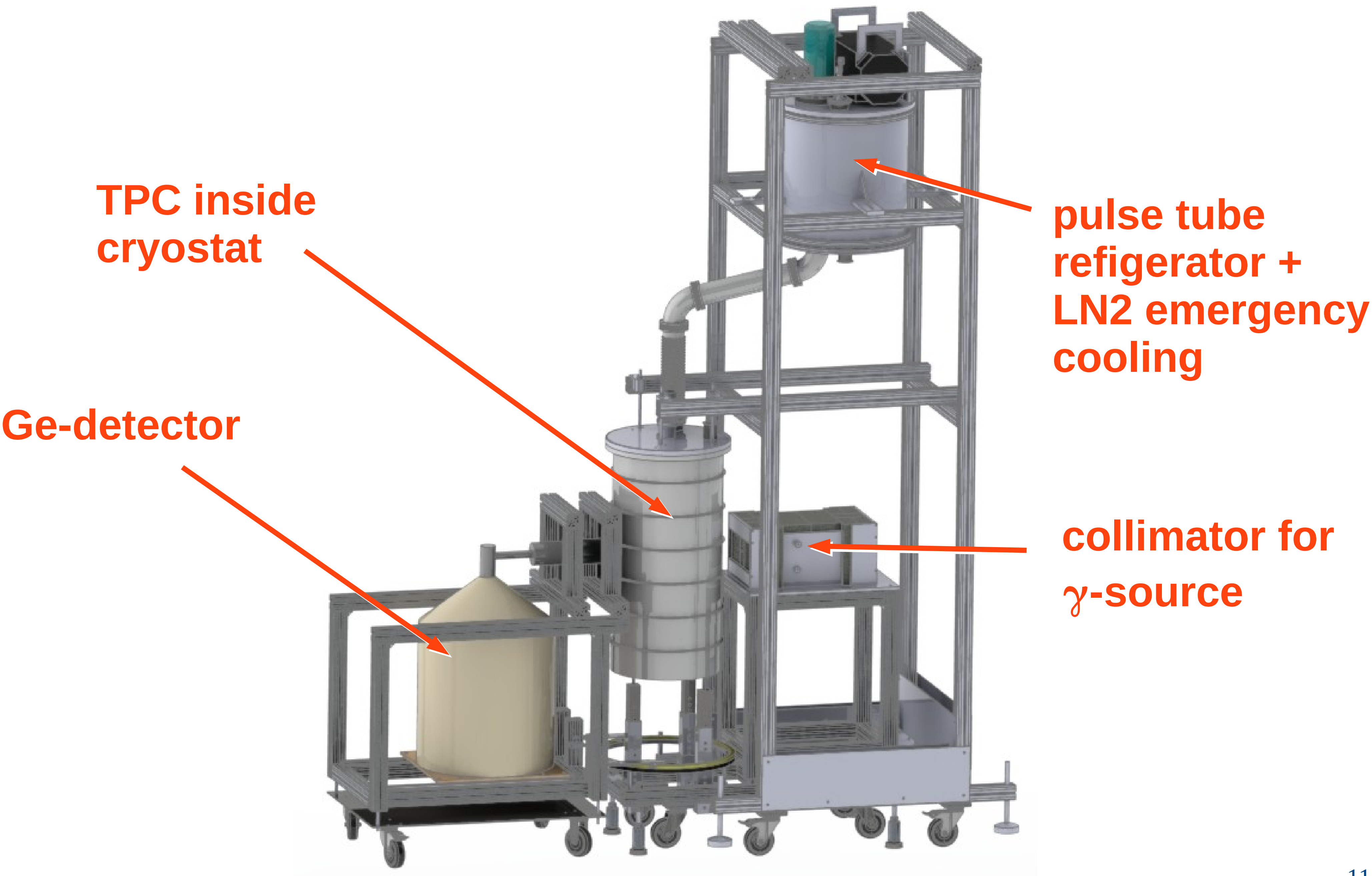
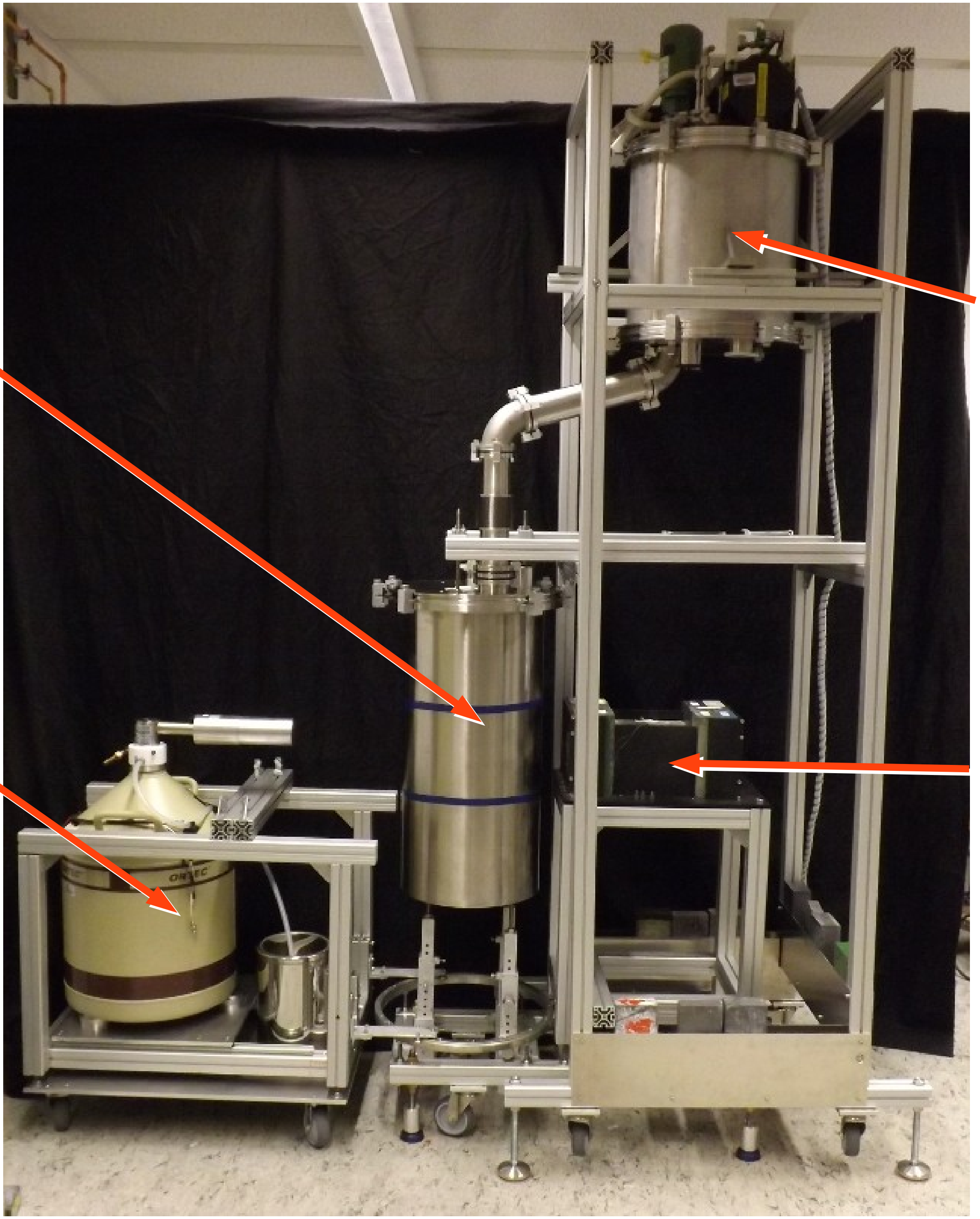


Cryogenic system with Compton setup

TPC inside cryostat

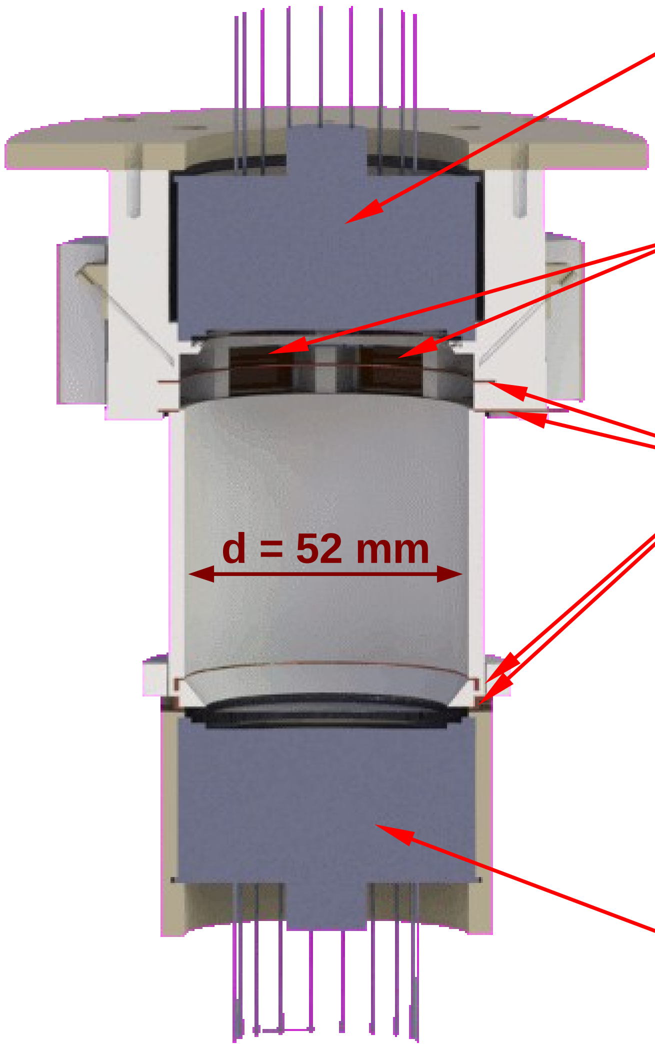
Ge-detector



pulse tube refigerator + LN2 emergency cooling

collimator for γ-source

MainzTPC: design



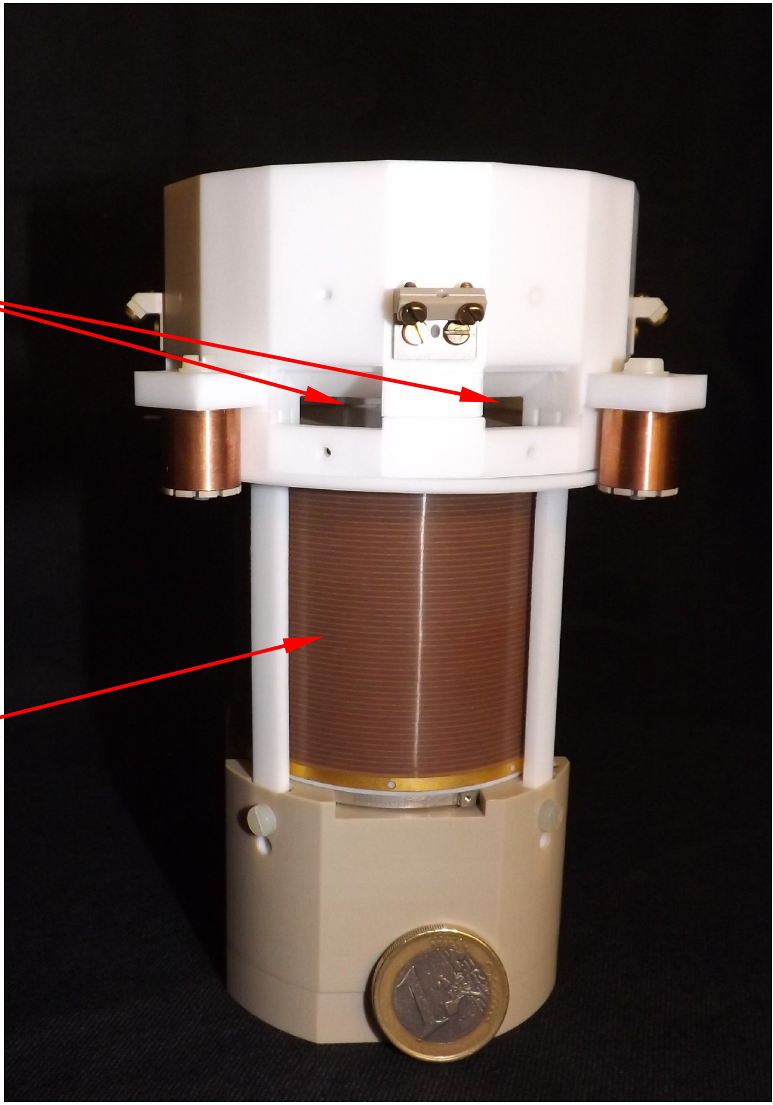
top PMT

8 APDs
x/y position resolution

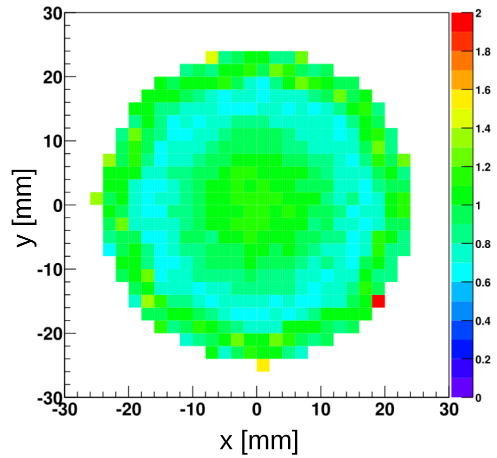
meshes
high transparency
fine pitch

field cage
PCB => low passive
mass

bottom PMT

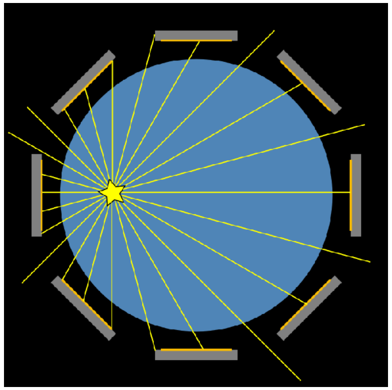


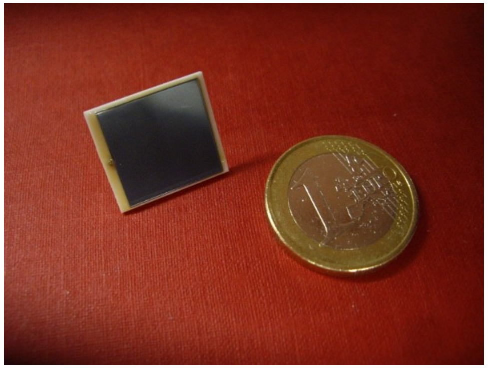
Avalanche Photo Diodes: RMD S1315



position reconstruction:

- G4: resolution < 1.3 mm
- using relative amount of light seen by each APD



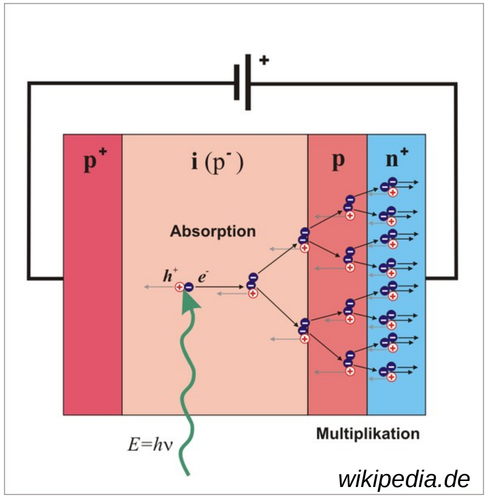


RMD S1315:

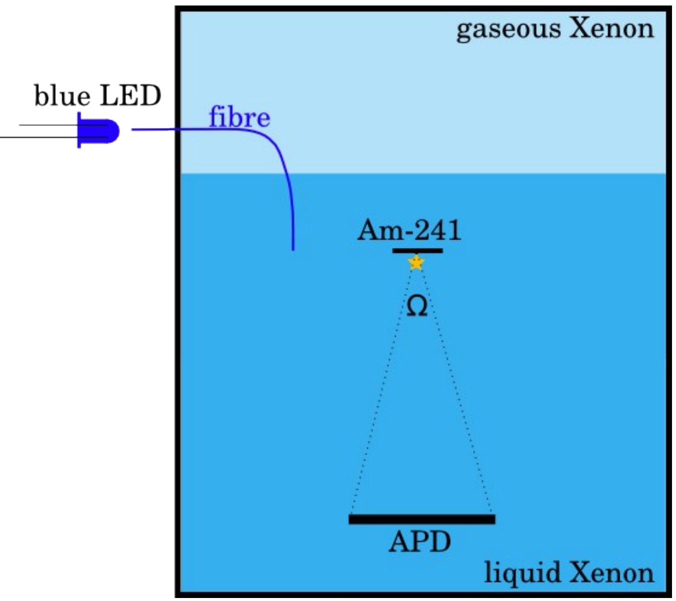
- active area: 14x14 mm²
- no housing - little passive material
- QE ~ 30% @ 178 nm
  (P. Shagin et al 2009 JINST 4 P01005)

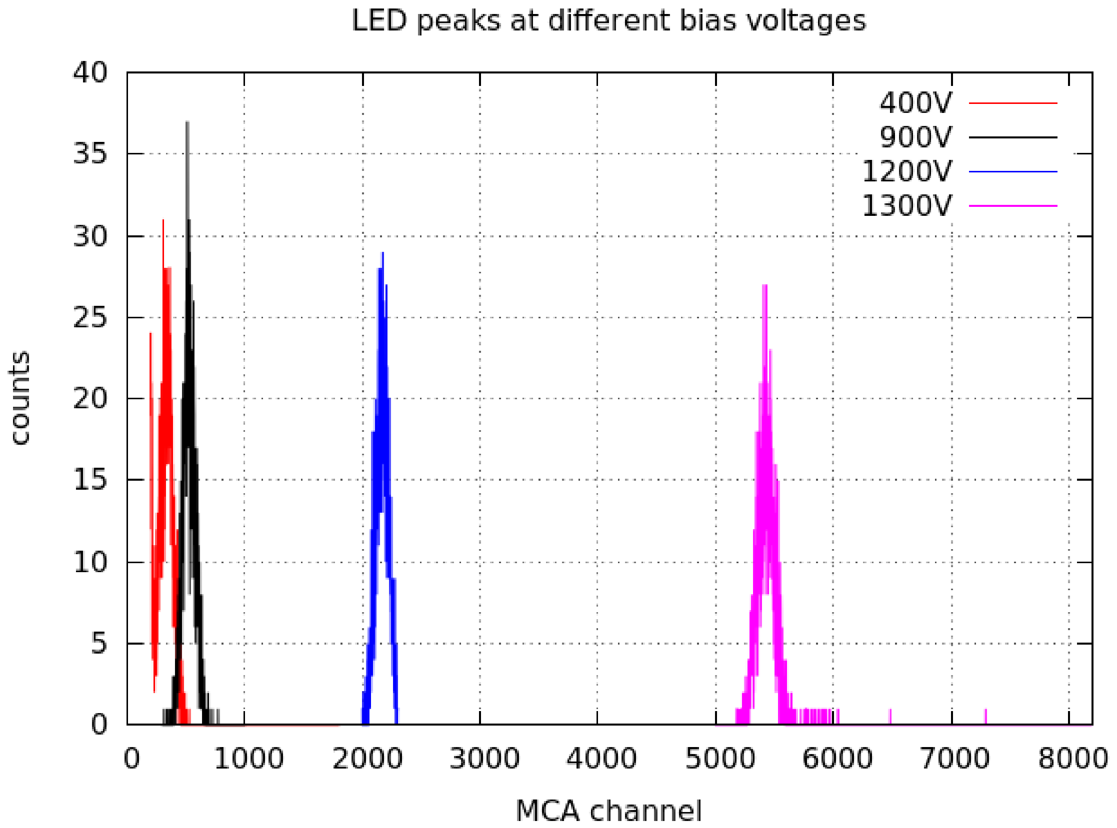
What are APDs?

- photo diodes with internal gain (typically ~10^2-10^3)
- gain depending on temperature and bias voltage



APDs: gain measurement

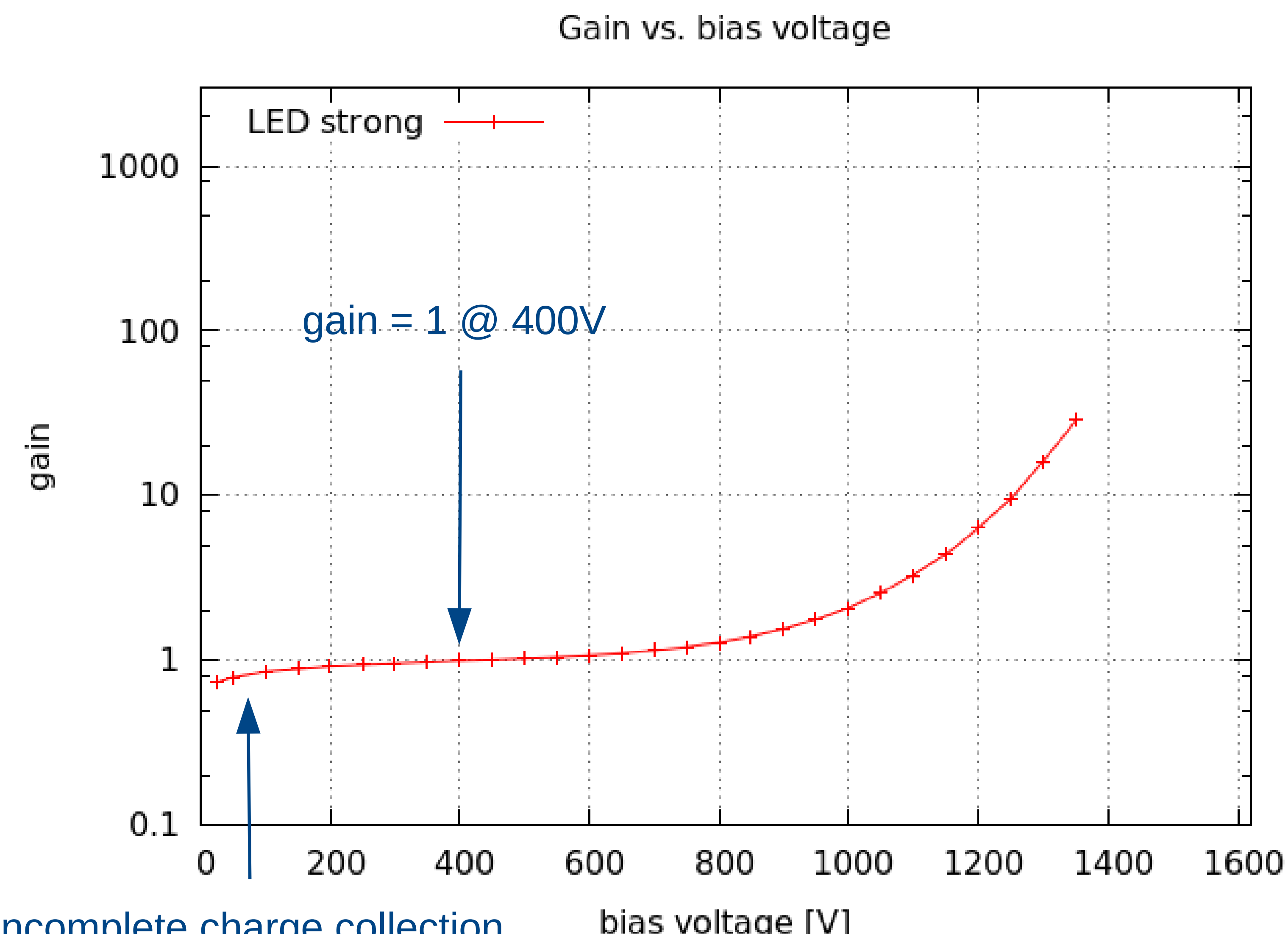




gain measurement:

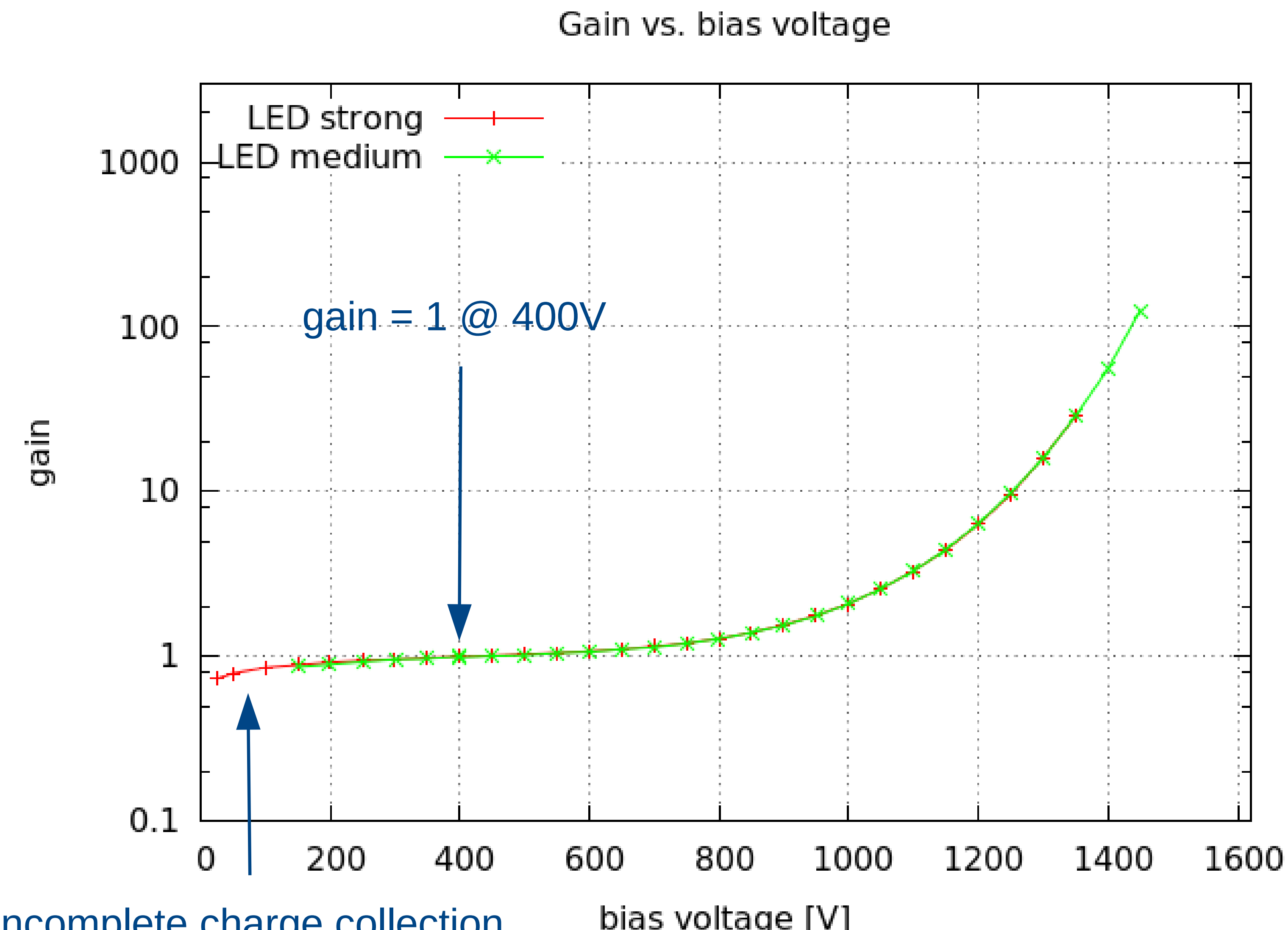
- pulsed blue LED
- measure spectra at different bias voltages
- using different strength of LED pulses to cover full gain range

gain vs. bias voltage - reference APD



incomplete charge collection
=> U_{bias} < 400V: gain < 1

gain vs. bias voltage - reference APD



incomplete charge collection
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gain vs. bias voltage - reference APD

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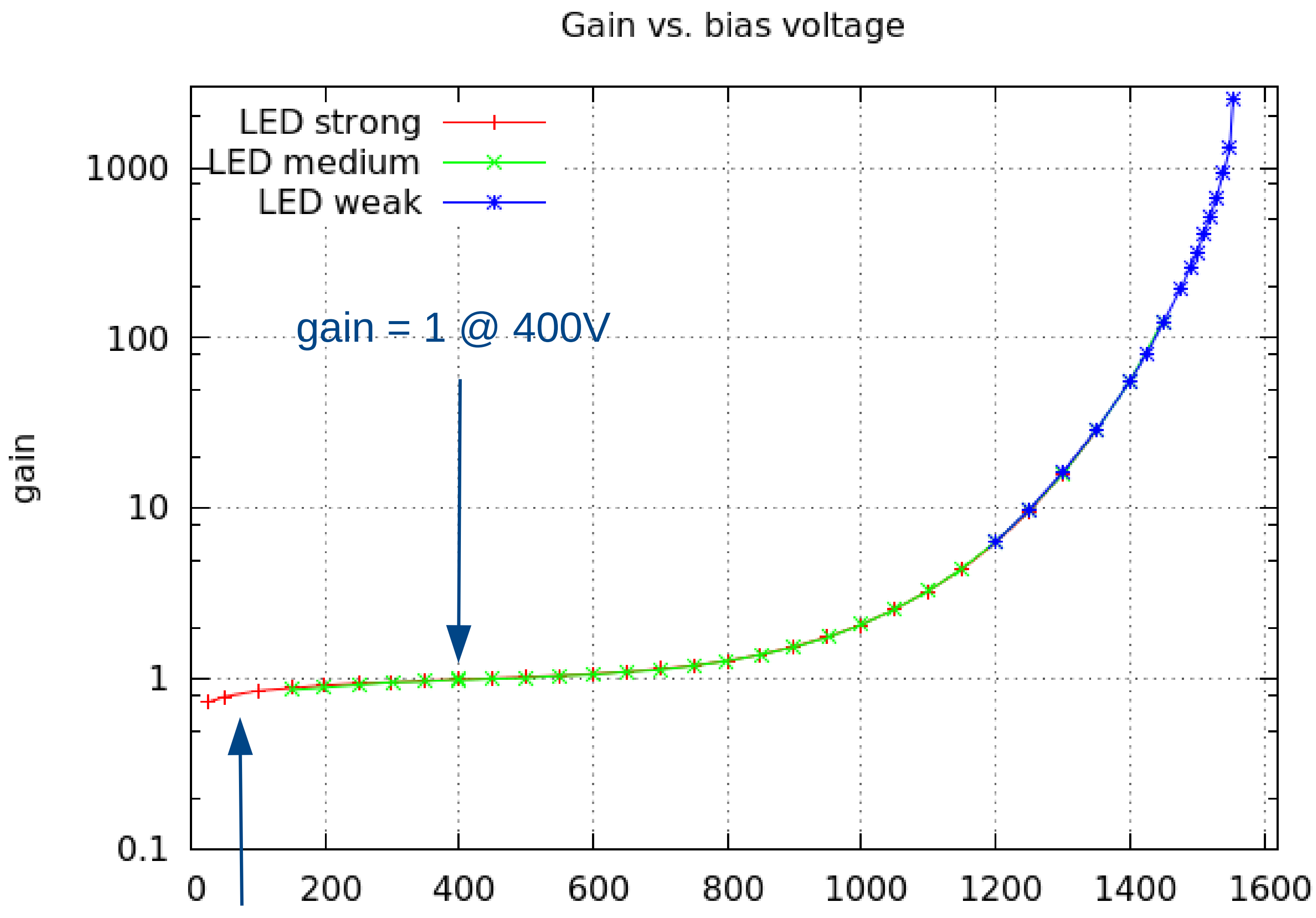

incomplete charge collection
=> U_{bias} < 400V: gain < 1

gain vs. bias voltage - reference APD

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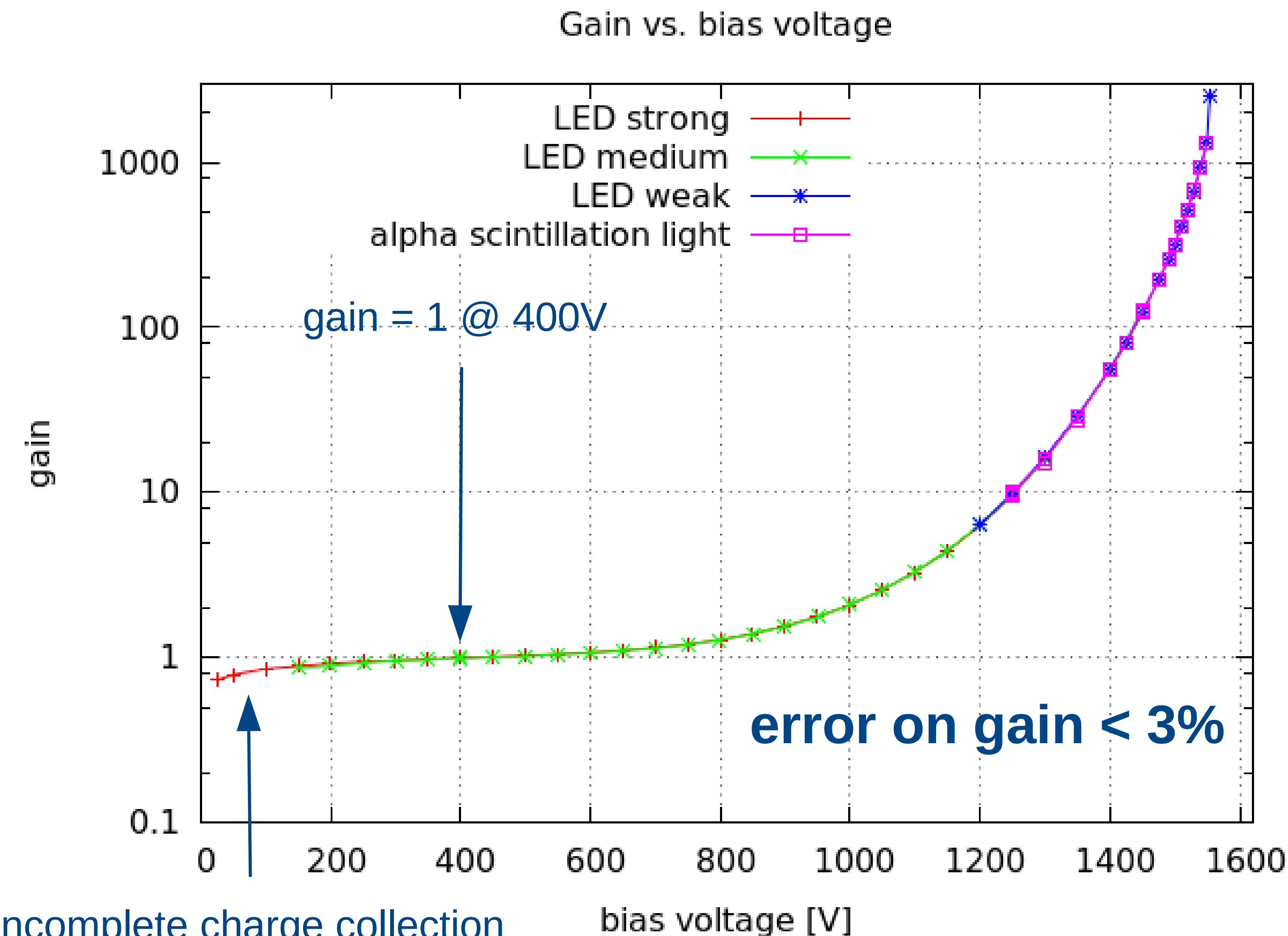
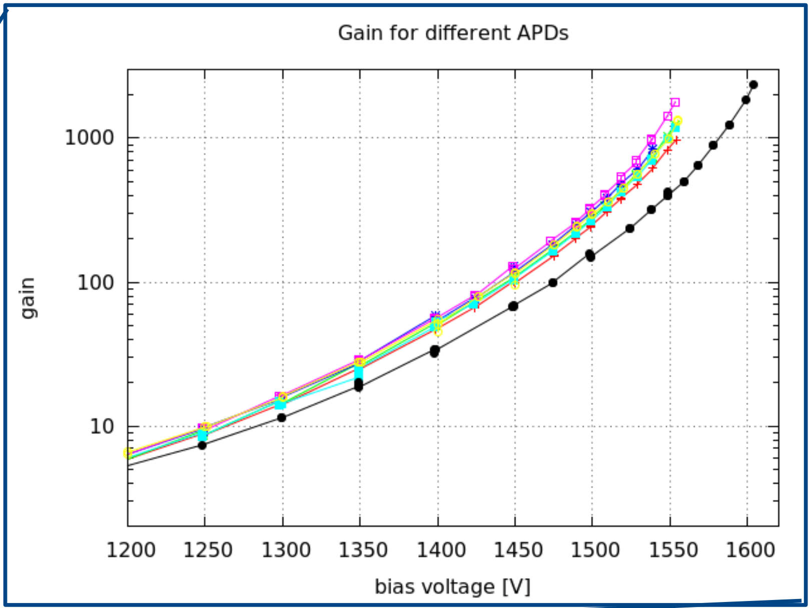
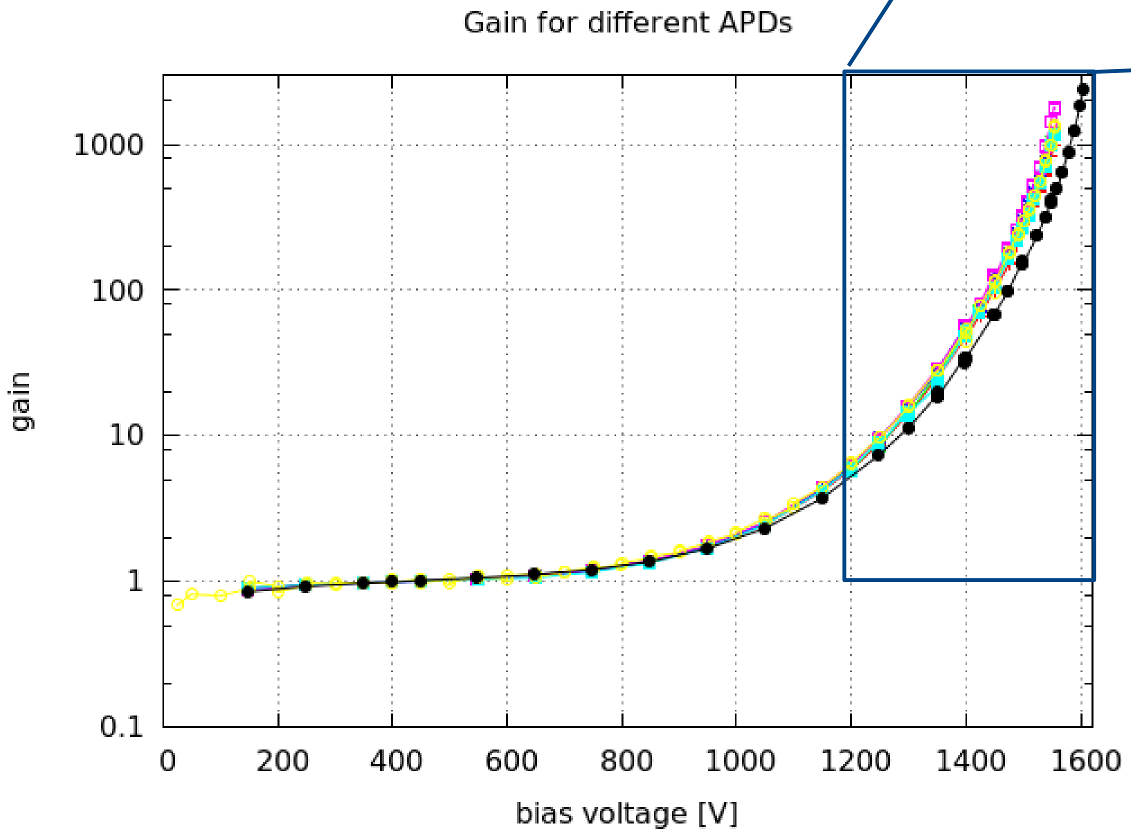


incomplete charge collection
=> U_{bias} < 400V: gain < 1

gain vs. bias voltage - all APDs

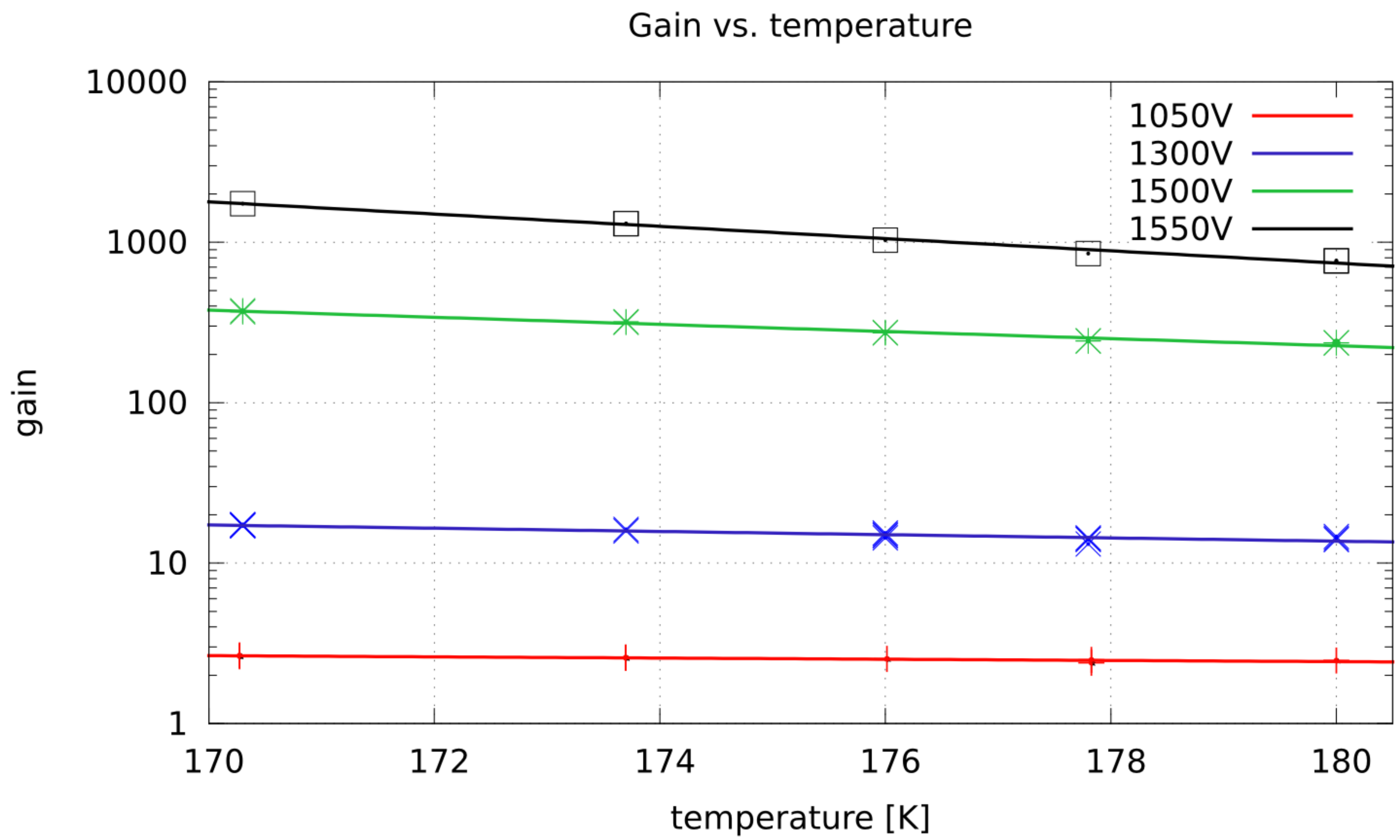
colors: APDs from wafer A
black: APD from wafer B





T = 176.3 K ± 0.3 K
ΔT < 0.1K for each APD

gain vs. temperature: reference APD



$$g(T) = g_0 \cdot \exp(-k_0 \cdot (T - T_0))$$

fixed Parameter: $T_0 = 170.3\,K$

free parameters: g_0, k_0

$$k_0 = \frac{\partial \log(g)}{\partial T}$$

k_0 (1050V) = 0.0085
k_0 (1300V) = 0.0232
k_0 (1500V) = 0.0510
k_0 (1550V) = 0.0879

APDs: measuring QE @ 178nm

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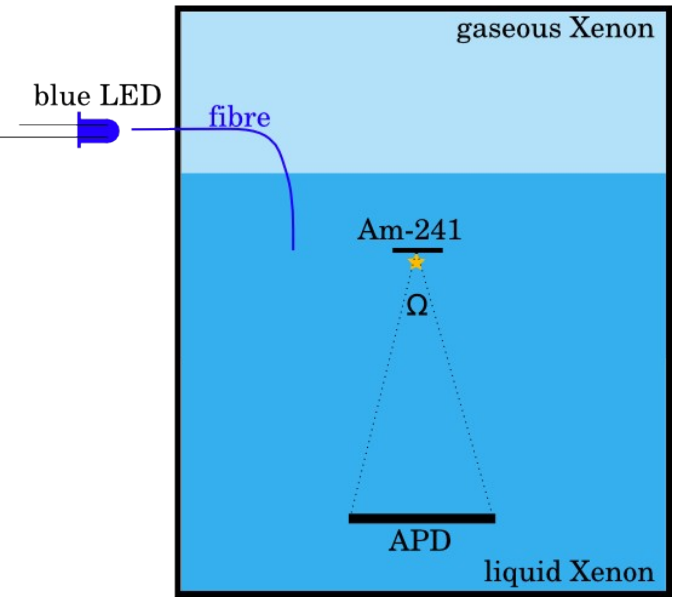
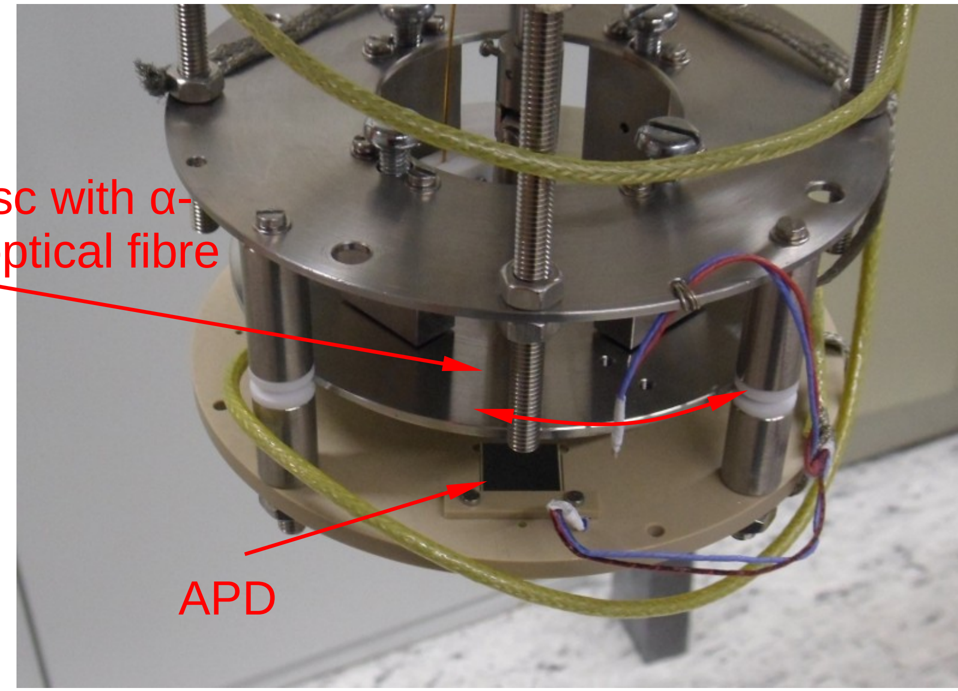


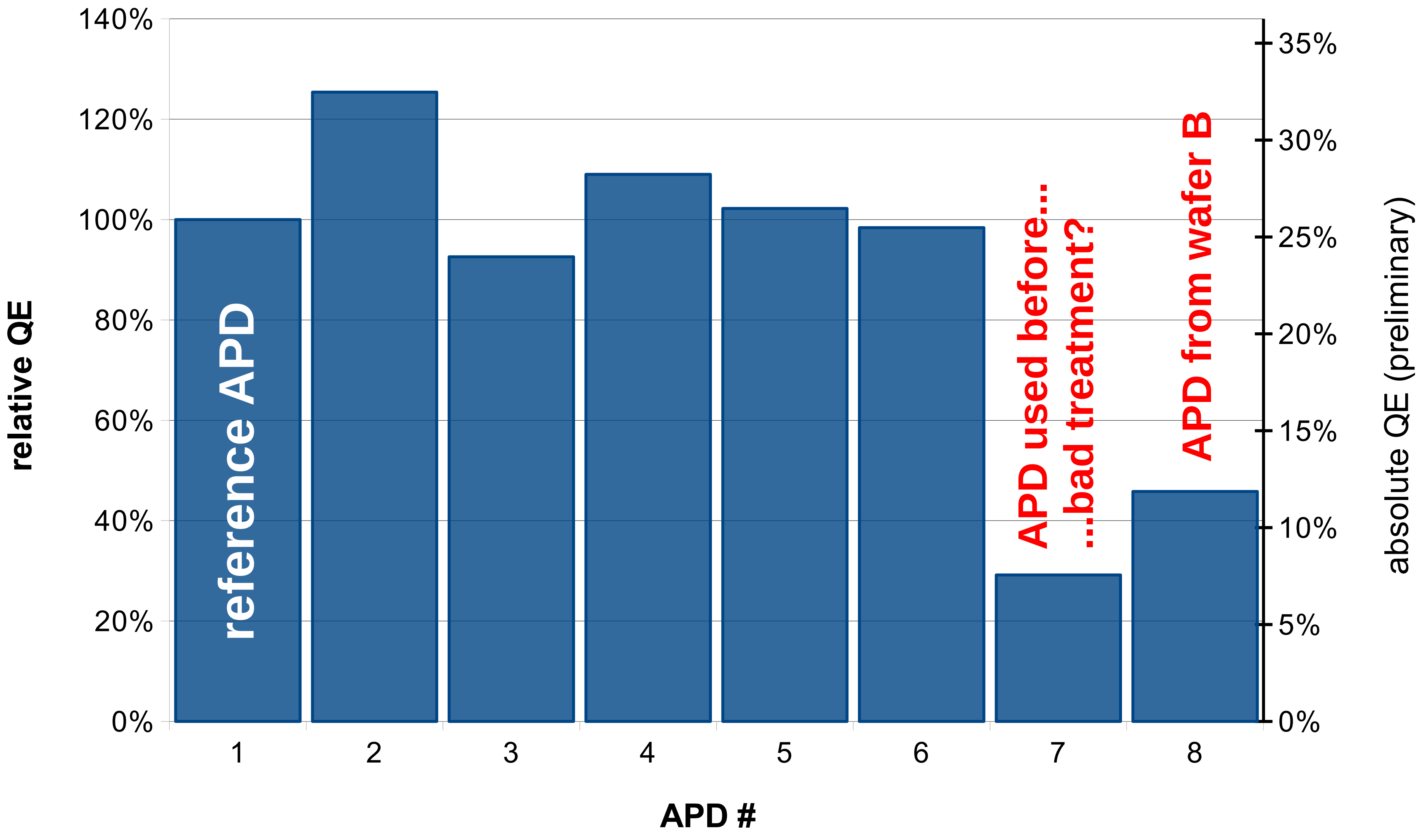


QE calculation depends on:

- number of photons generated
- solid angle
- APD gain

$$QE = \frac{N_\gamma^{measured}}{N_\gamma^{hit}} = \frac{\frac{Q_{measured}}{gain \cdot e}}{N_\gamma^{hit}}$$

APD quantum efficiencies



Summary

- TPC optimized for Compton scatter experiment built
- Compton setup built up
- light detectors characterized (APDs)
- comissioning next weeks
- measurment of light/charge yield for electron recoils this summer
- measurment of scintillation pulse shape for electron recoils this summer

Thanks to all collaborators:

Pierre Sissol
Melanie Scheibelhut
Rainer Othegraven
Christopher Hils
Dr. Cyril Grignon
Prof. Uwe Oberlack

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02. june 2014

Questions?

QUESTIONS?

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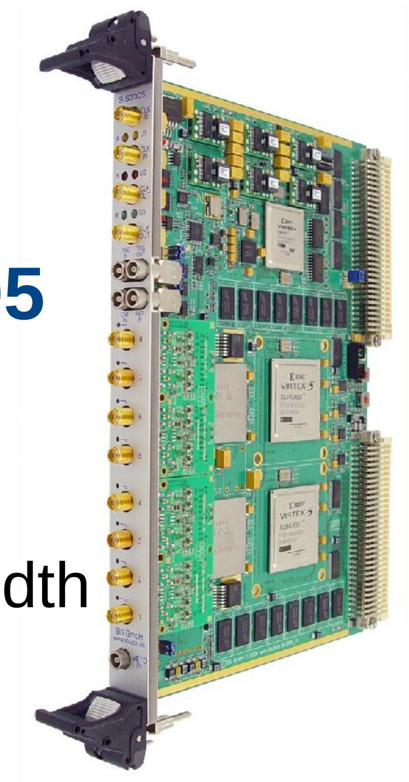
02. june 2014

Readout system

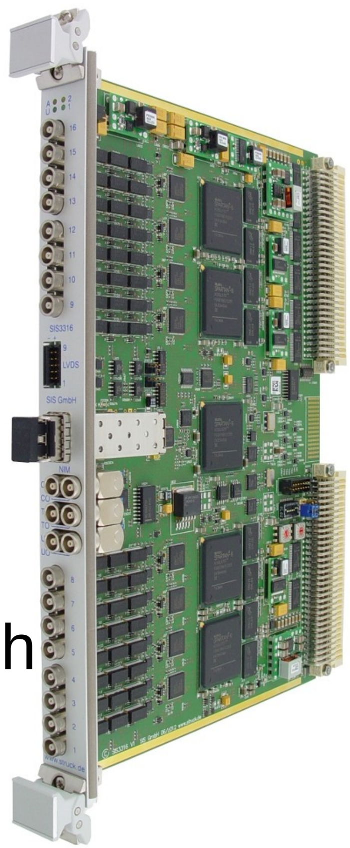
Struck SIS3305



- 10 bit FADC
- 2/4/8 channels
- 5/2.5/1.25 GS/s
- 1.5 GHz bandwidth

digitize PMT signal with good time-resolution

Struck SIS3316

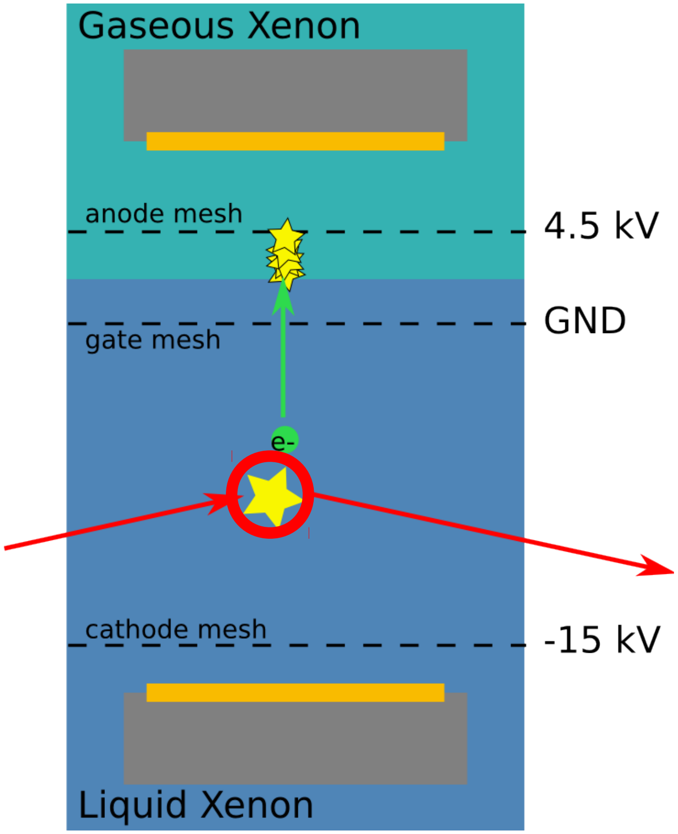


- 16 bit FADC
- 16 channels
- 125 MS/s
- 62.5 MHz bandwidth

digitize Ge-detector and APDs with good energy-resolution

principle dual-phase TPC

S1: primary scintillation



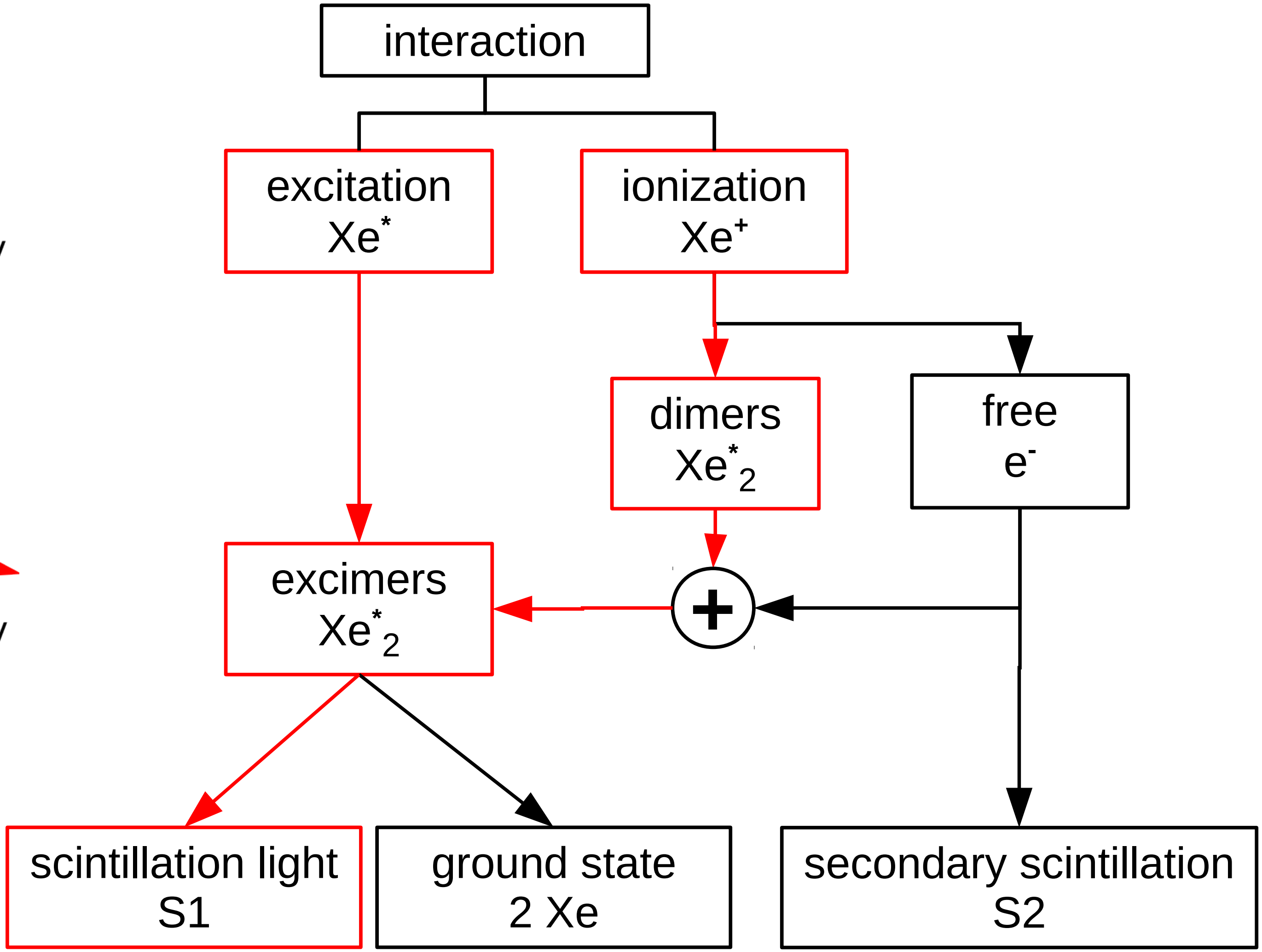


table of measured QEs

APD	realtive QE	absolute QE
426-2-7 (reference)	**100 %**	25.9 %
426-2-1	29.2 %	7.6 %
426-2-3	125.4 %	32.5 %
426-2-4	92.6 %	24.0 %
426-2-5	109 %	28.2 %
426-2-9	102.2 %	26.5 %
393-3-10	45.8 %	11.9 %

← used before;
maybe bad treatment (426-2-1)

← different wafer (393-3-10)