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Excellence Cluster Universe

TECHNISCHE UNIVERSITÄT MÜNCHEN

Production of $CaWO_4$ Crystals for the CRESST Experiment & Development of Neganov-Luke Amplified Cryogenic Light Detectors

HAP Dark Matter 2015

Michael Willers
TU München & Excellence Cluster Universe

22.09.2015

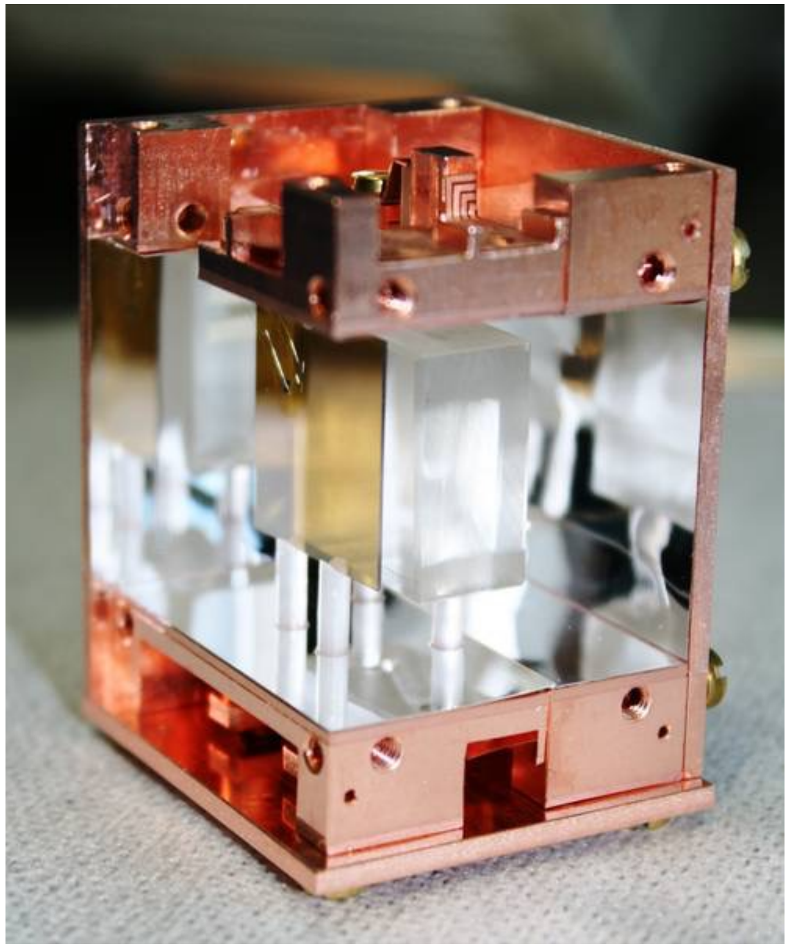
Production of $CaWO_4$ Crystals for the CRESST Experiment

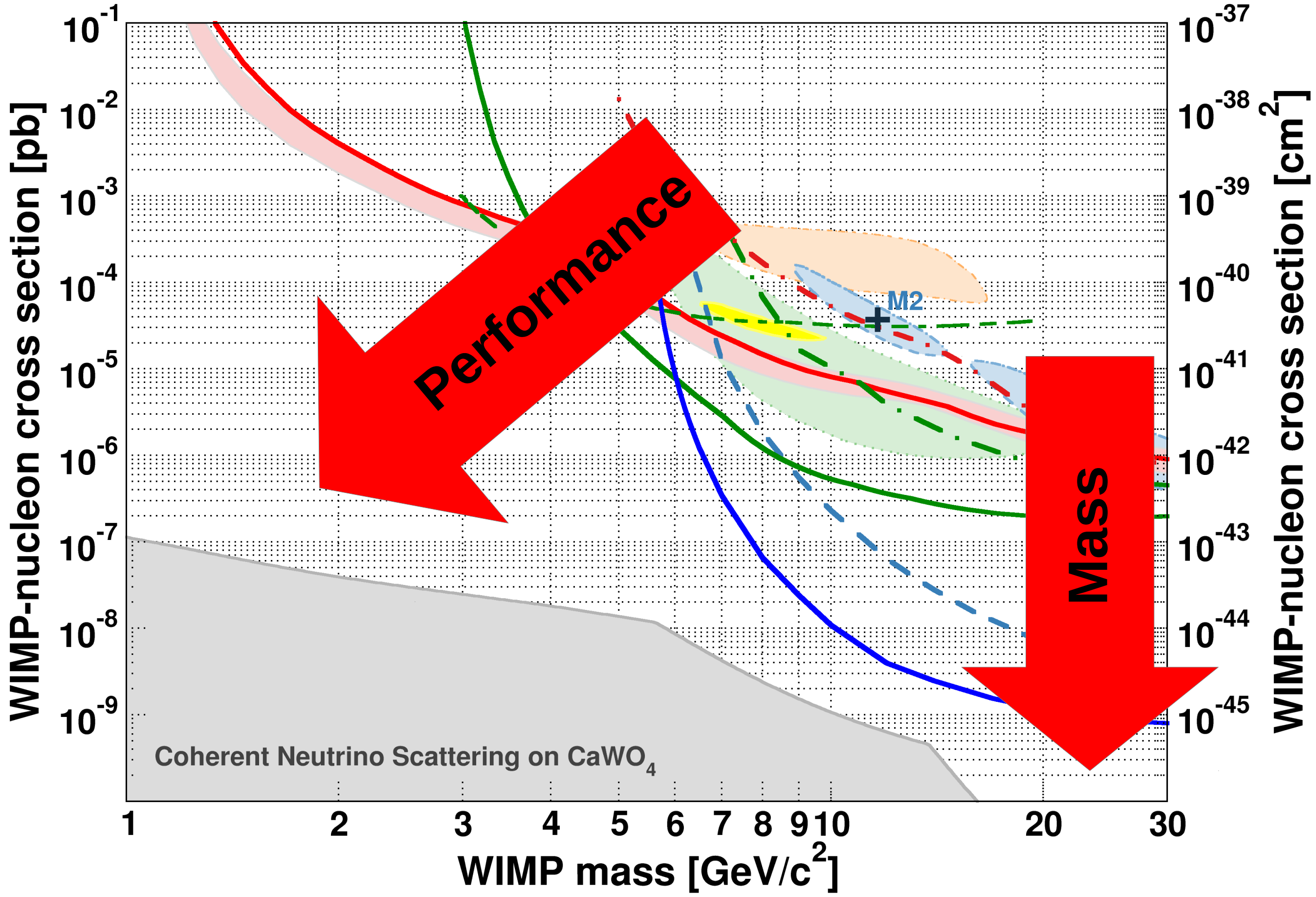
CRESST III

- Already introduced by H. Kluck
- Focus on low-mass WIMPs

  (see also: Probing low WIMP masses with the next generation of CRESST detectors, `arXiv 1503.08065`)

  → important factors: **Performance (Threshold)** & **Radiopurity**
- New, fully scintillating, detector modules (crystal mass ~ 25g)





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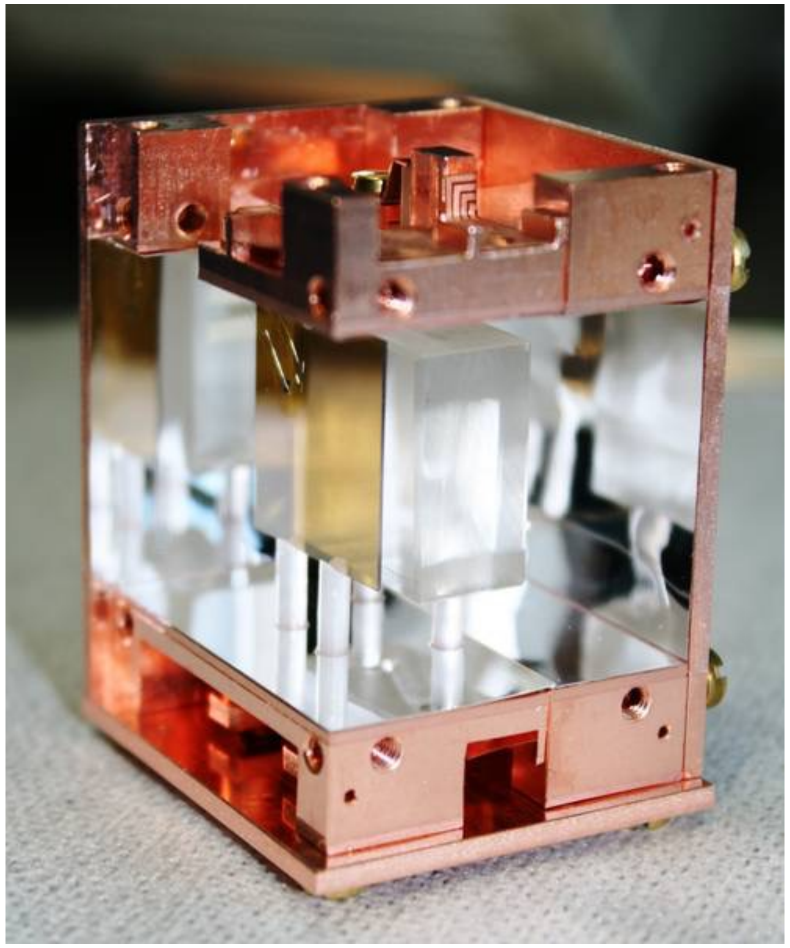
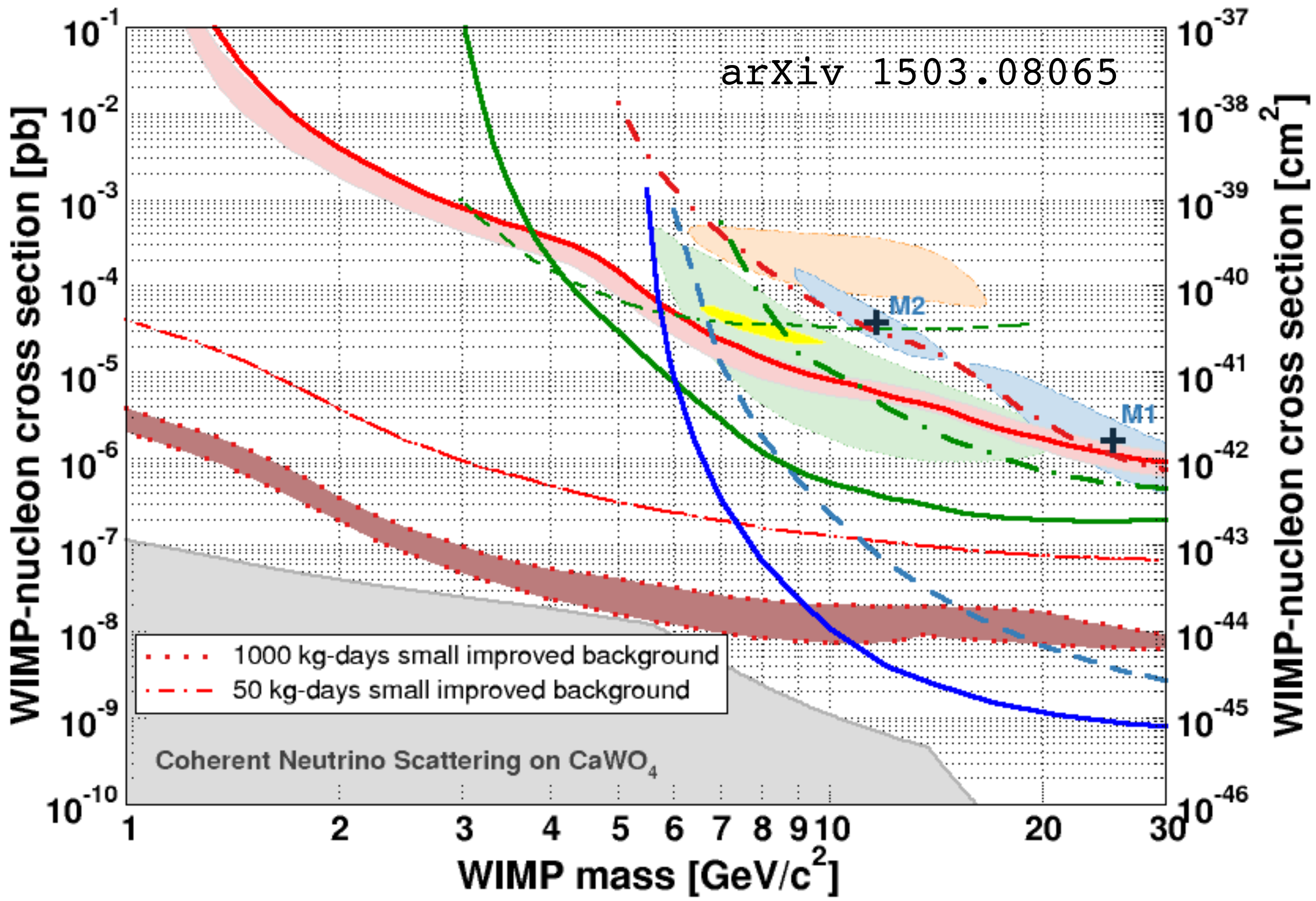
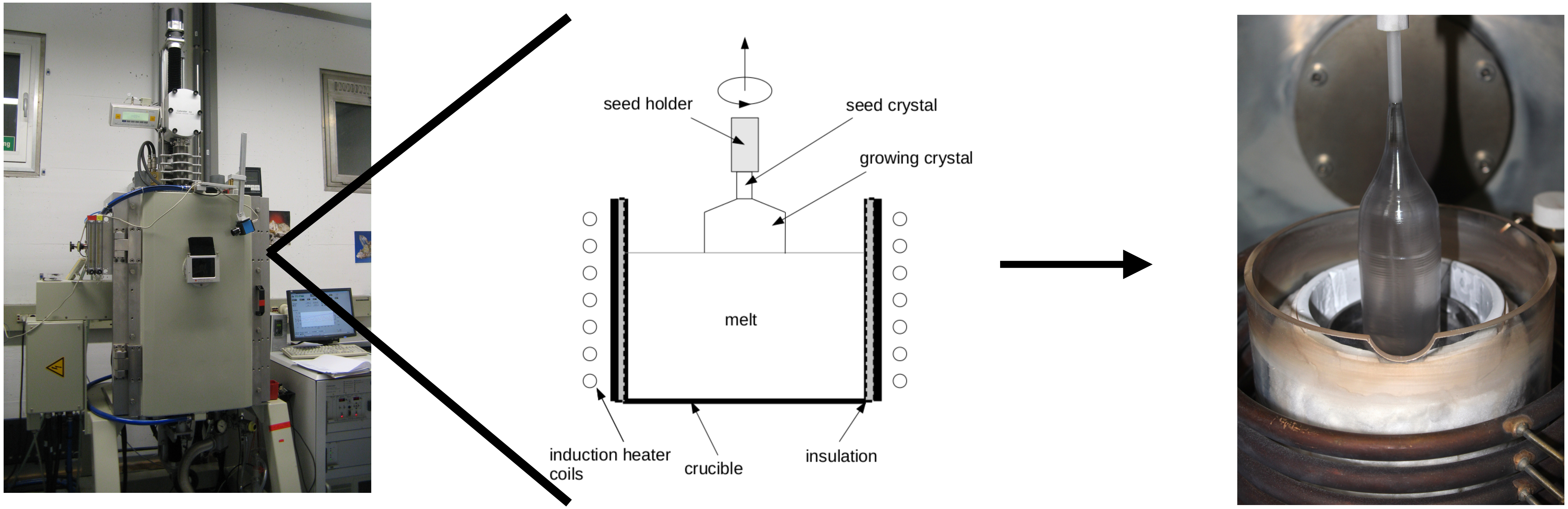




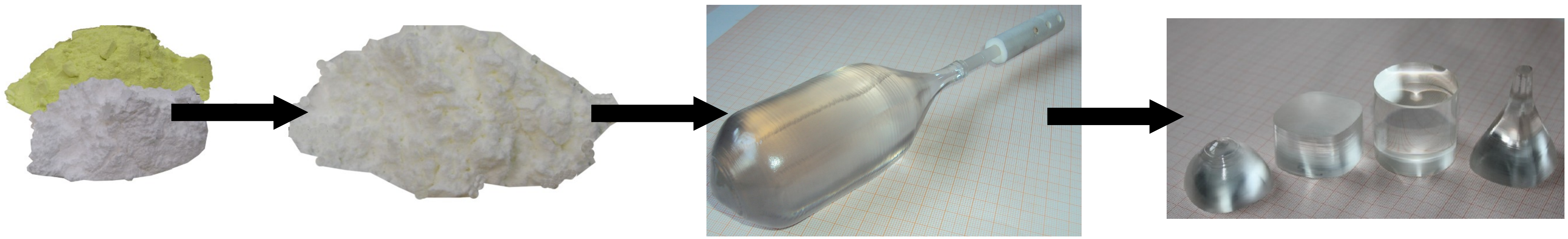
Production of $CaWO_4$ Crystals

- **Before CRESST-II Phase 2:** only commercial $CaWO_4$ crystals (Russia & Ukraine)
  - Difficult: influence on selection of raw materials
  - No influence on crystal growth parameters
- **Since ~ 2011:** in-house production of $CaWO_4$ crystals at TUM for *CRESST & EURECA**
  - *Full control over raw materials (screening & selection)*
  - *Full control of growth / post-growth treatment parameters!*
- **Dedicated Czochralski furnace** for $CaWO_4$ crystals



* A. Erb and J.C. Lanfranchi, Growth of high-purity scintillating CaWO4 single crystals for the low-temperature direct dark matter search experiments CRESST-II and EURECA, CrystEngComm, 2013

Production of $CaWO_4$ Crystals



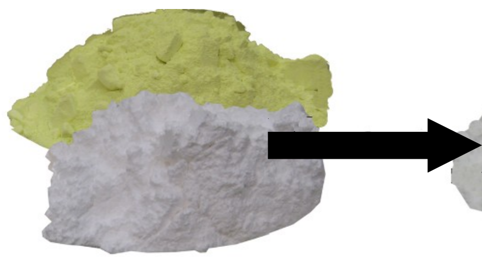
$CaCO_3$ + WO_3 | $CaWO_4$ | Crystal growth | Cutting & Polishing

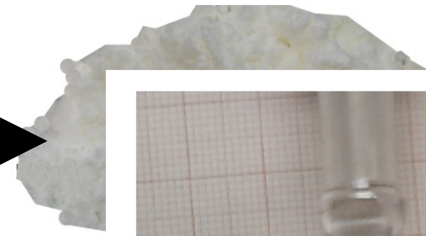
- Steady development towards complete in-house production of $CaWO_4$ crystals ✔
  - Production of raw powder: **$CaCO_3 + WO_3 \rightarrow CaWO_4 + CO_2$**
  - Crystal growth (Czochralski method) in Rh crucible (99%Ar / 1% O_2)
  - Post growth treatment (annealing) to improve optical quality (100% O_2)
  - Cutting & polishing of crystals

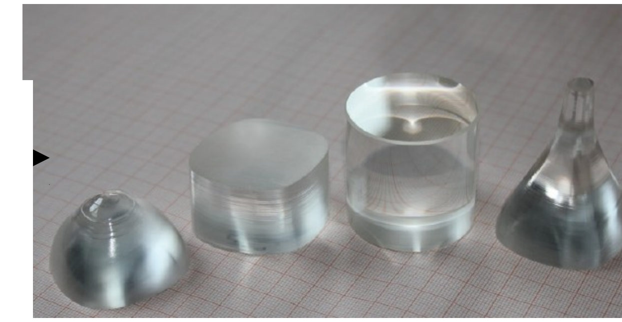
- Dedicated oven & powder grinding machine to produce $CaWO_4$ powder
- Dedicated annealing oven
- CRESST-II Phase 2 : 4 TUM-grown crystals

  CRESST-III : majority of crystals foreseen to be TUM-grown

Production of $CaWO_4$ Crystals







$CaCO_3$ + WO_3

Cutting & Polishing

- Steady developmen WO_4 crystals ✔
  - Production of rav
  - Crystal growth ((% O_2)
  - Post growth treat 00% O_2)
  - Cutting & polishi

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- Dedicated annealin
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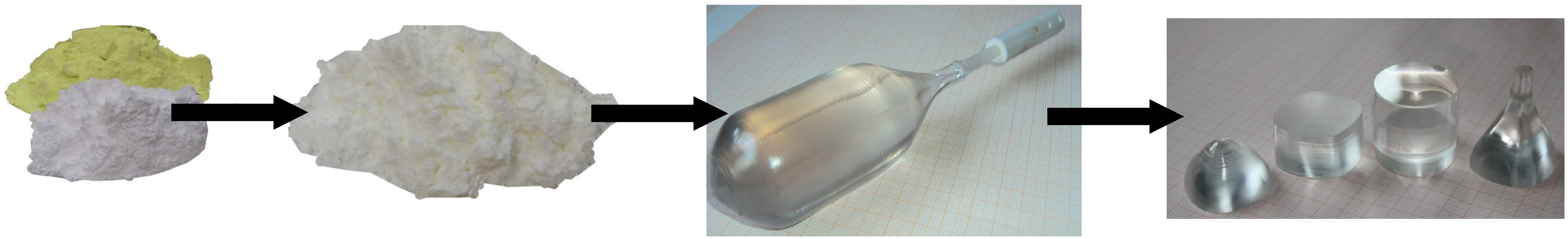
  CRESST-III : majority of crystals foreseen to be TUM-grown



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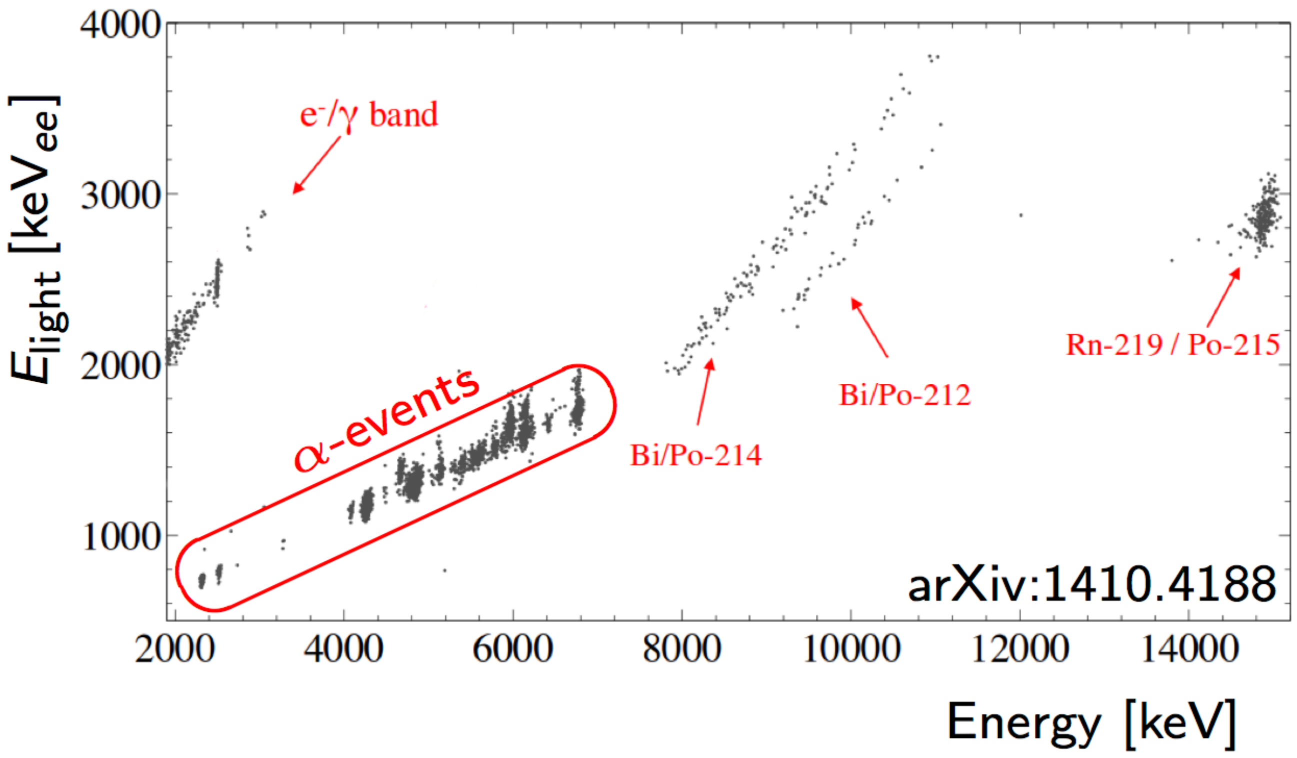
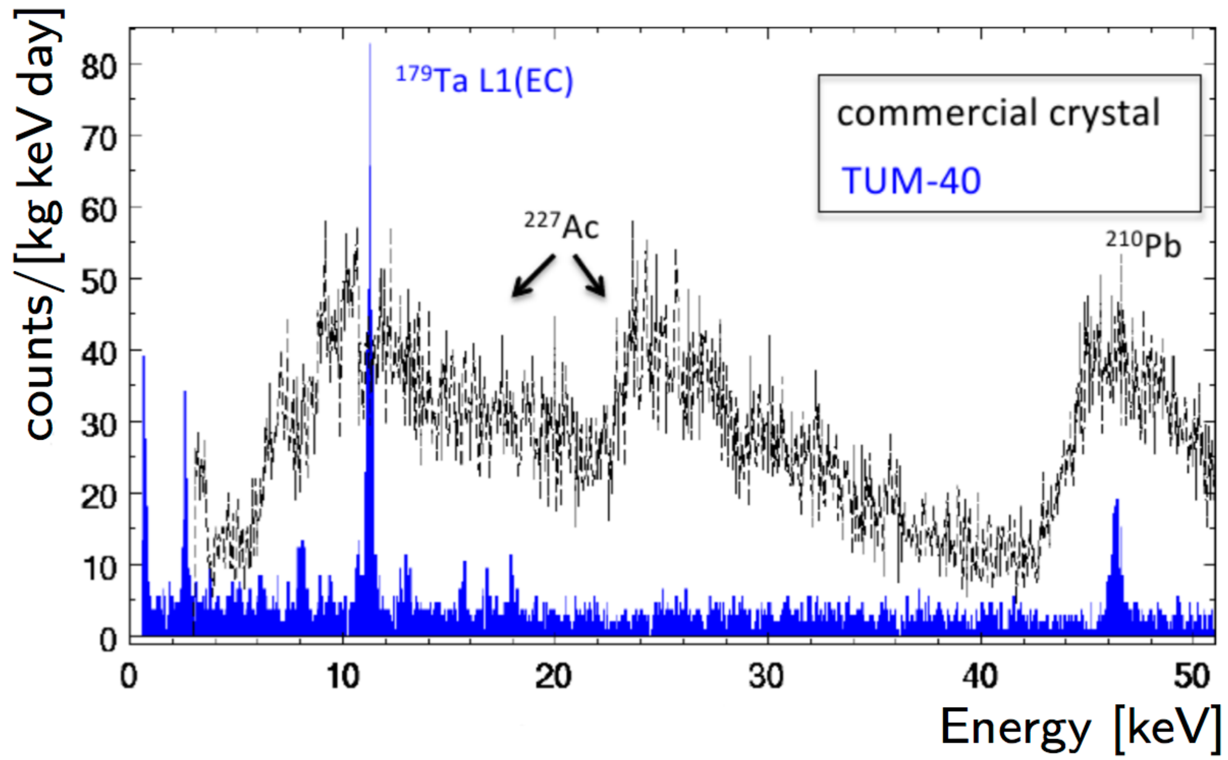
Improved Radiopurity: TUM40

Total α - Activities (1.5 - 7 MeV)



e-/γ Background events below 50 keV



TUM40: 3.07 ± 0.11 mBq/kg

commercial crystals: 3 - 107 mBq/kg

(Münster et al., JCAP05(2014)018)

TUM40: 3.51 / (keV kg day)

commercial crystals: 6 - 30 / (keV kg day)

(Strauss et al., JCAP06(2015)030)

→ Significant improvement in radiopurity!

For TUM40 results see: EPJC (2015) 75:352

Further Improvement of Radiopurity

- **recrystallisation of $CaWO_4$ crystals**
  - growth of multiple crystals
    (segregation of impurities during crystal growth)
  - cleaning of crucible / removal of remaining melt
  - recrystallisation of produced crystals

  → growth of crystal with improved radiopurity

- **chemical cleaning of raw materials**
  - $CaWO_4$ powder cannot be cleaned (due to chemical / physical properties)
    → cleaning of raw materials (currently $CaCO_3$)
  - Preliminary results: U extraction factor ~ *5000*, Th extraction factor ~ *1000*
    (detailed ICP-MS / HPGe measurements ongoing, check that no new impurities are introduced!)

  → growth of crystal with improved radiopurity

- **both methods currently under investigation** (PhD thesis A. Münster (in preparation))

  → operation of crystal with further improved radiopurity planned for CRESST III

Production of $CaWO_4$ Crystals

Further activities:

- Study influence of crystal growth / annealing on optical properties of $CaWO_4$ crystals

  (PhD thesis, A. Münster, in preparation)
- Investigate radiopurity of $CaWO_4$ via scintillation spectroscopy

  (PhD thesis, M. v. Sivers, TUM 2014 (now University of Bern))
- Investigate scintillation mechanisms in $CaWO_4$

  (PhD thesis S. Roth, TUM 2014 (now Queens University, Kingston), in collaboration with A. Ulrich, TUM E12)
- Investigate scintillator non-proportionality

  (Master thesis C. Bruhn, TUM 2015)

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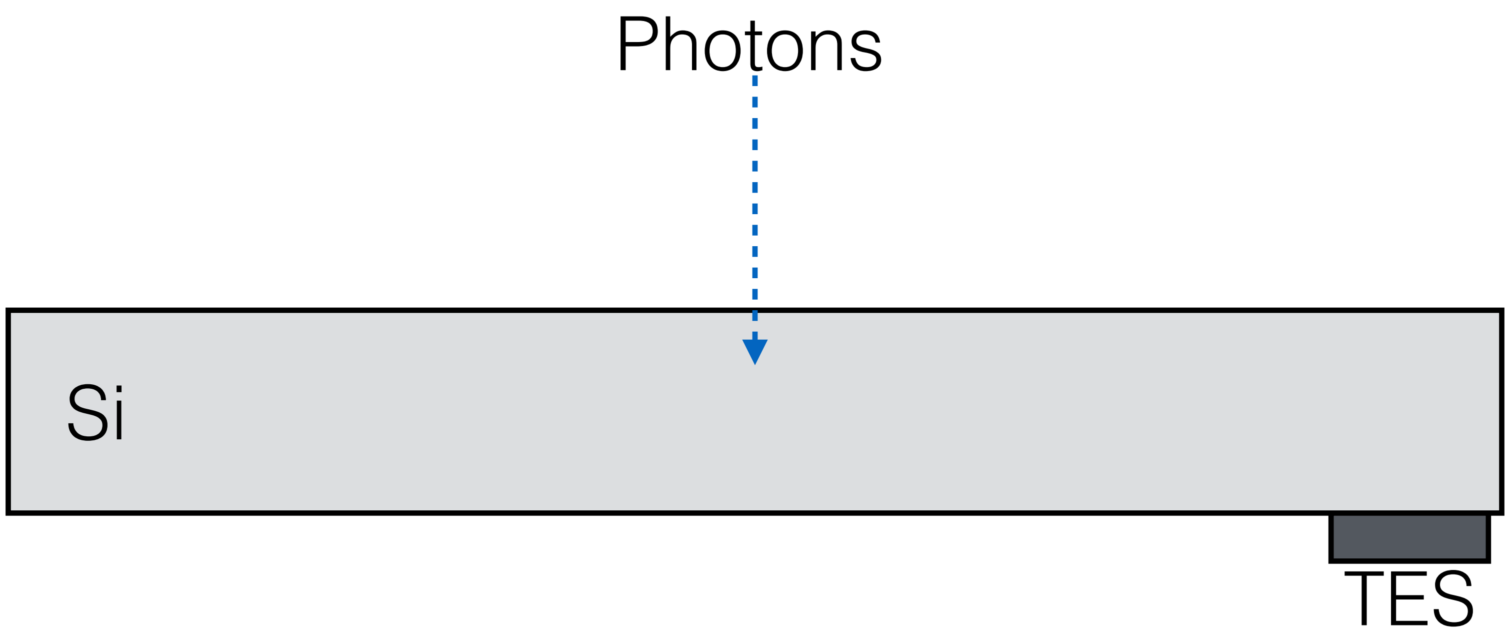
Summary:

- Complete in-house production of CaWO4 crystals for CRESST / EURECA ✔
- Significant improvement in radiopurity ✔ (+ further potential for improvement!)
- Ongoing activities to study scintillation mechanism & optical properties

Development of Neganov-Luke Amplified Cryogenic Light Detectors

Neganov-Luke Amplified Cryogenic Light Detectors

→ **Goal: Improve sensitivity (threshold / resolution) of cryogenic light detectors**
relevant for background suppression in both DM (e^--γ/ nuclear-recoil separation)
and 0$\nu\beta\beta$ (e^- / α separation) experiments!



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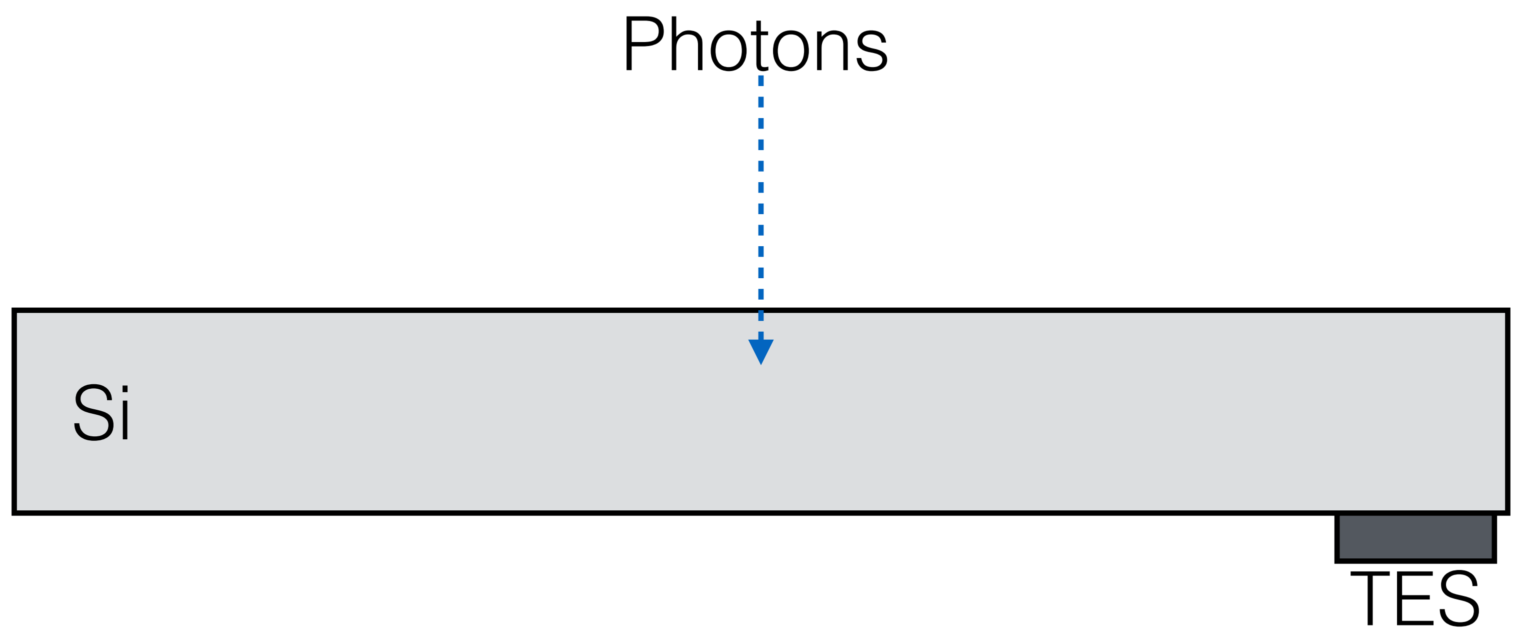

→ **Drifting of charge carriers in Electric field leads to increased phonon signal**

$$G_{th} = 1 + \frac{eV_{NL}}{E_{ph}/\eta}$$

Ideally: no increase in el. noise → improvement in S/N ratio → improved sensitivity

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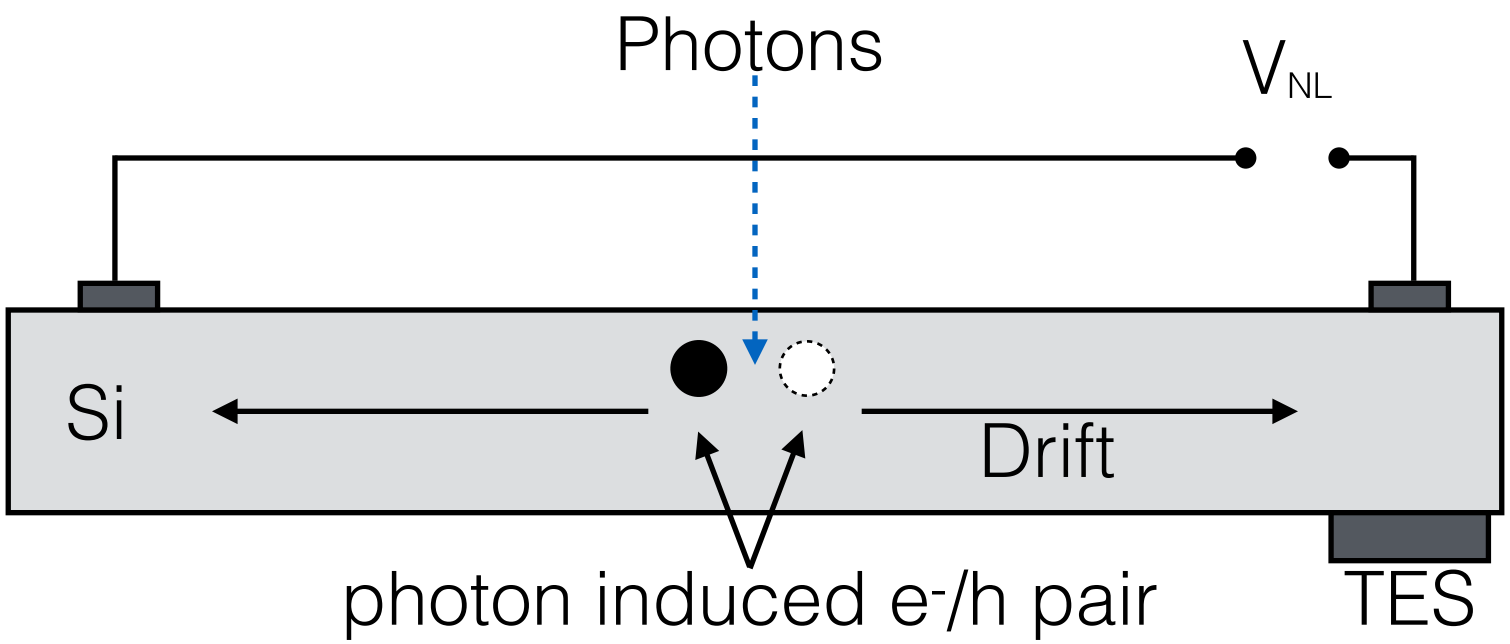

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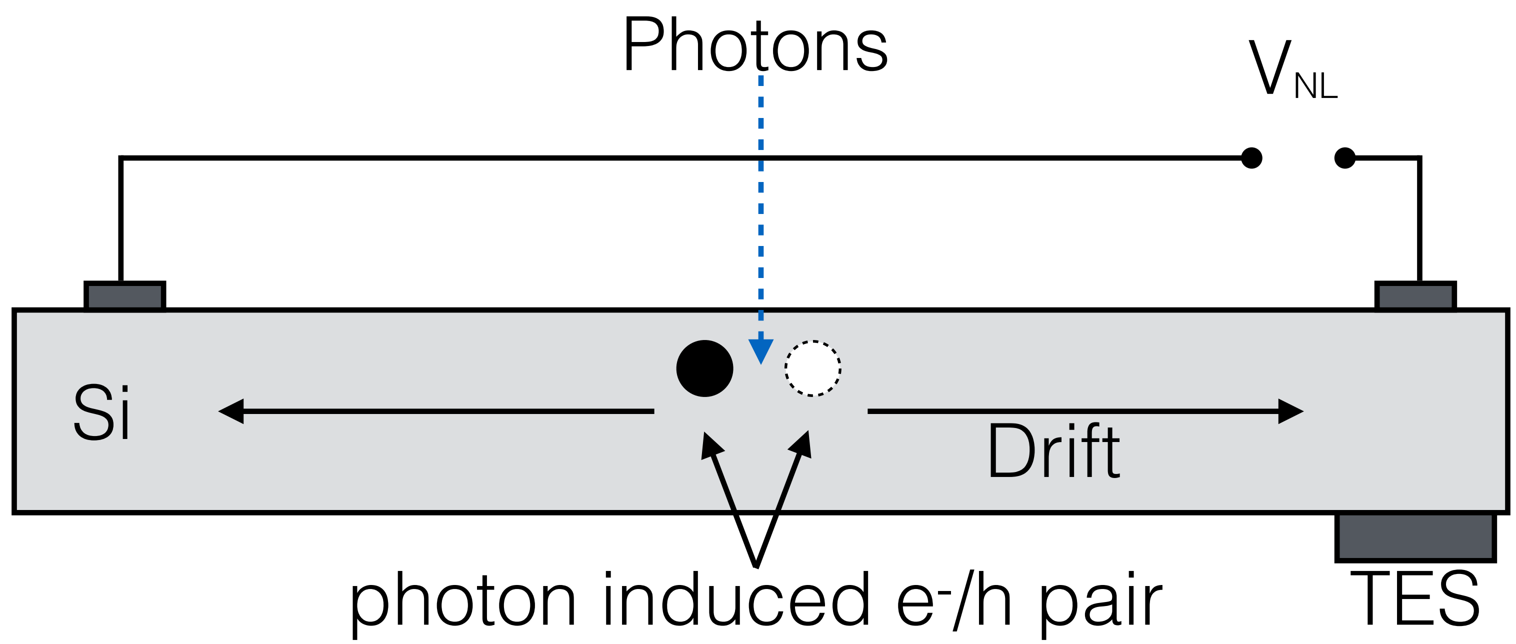

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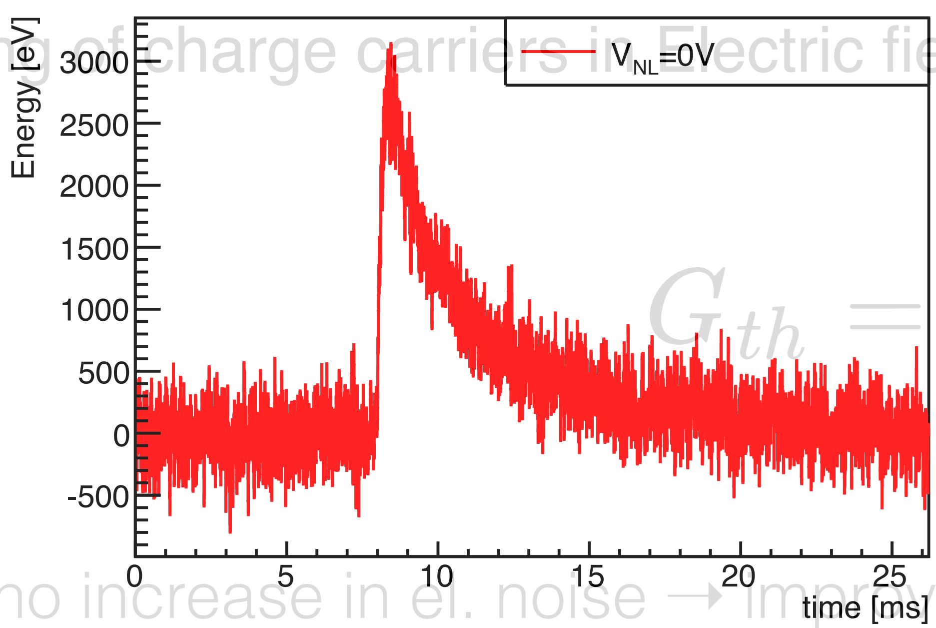

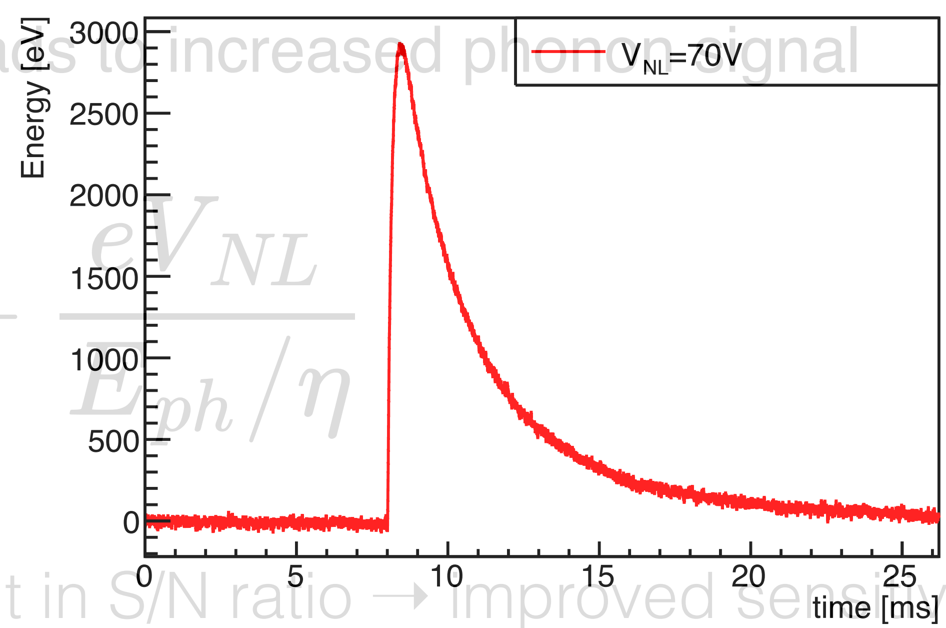

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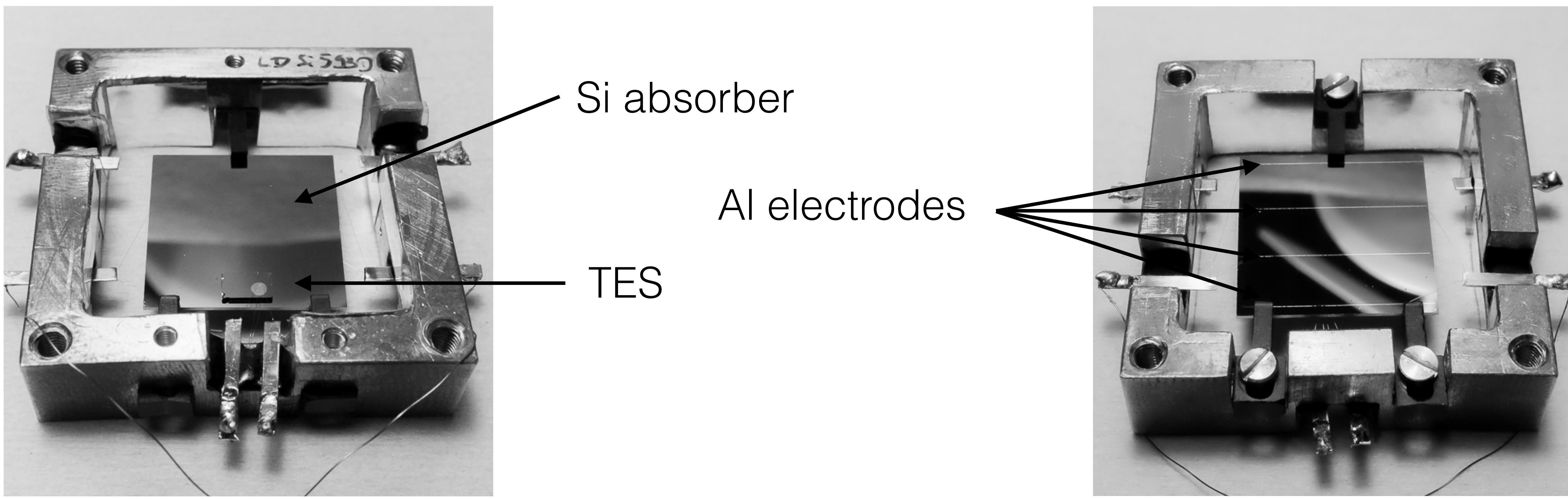
Neganov-Luke Amplified Cryogenic Light Detectors

- <u>A typical silicon-based NL light detector:</u>

  light absorber: 20 x 20 x 0.5 mm^3 , p-type, ρ > 10kΩcm
  aluminum electrodes ~ 20 mm x 0.2 mm x 250 nm, d ~ 6-18 mm
  (produced using a photolithographic shadow mask and Ar-Sputtering / EBE of Al)



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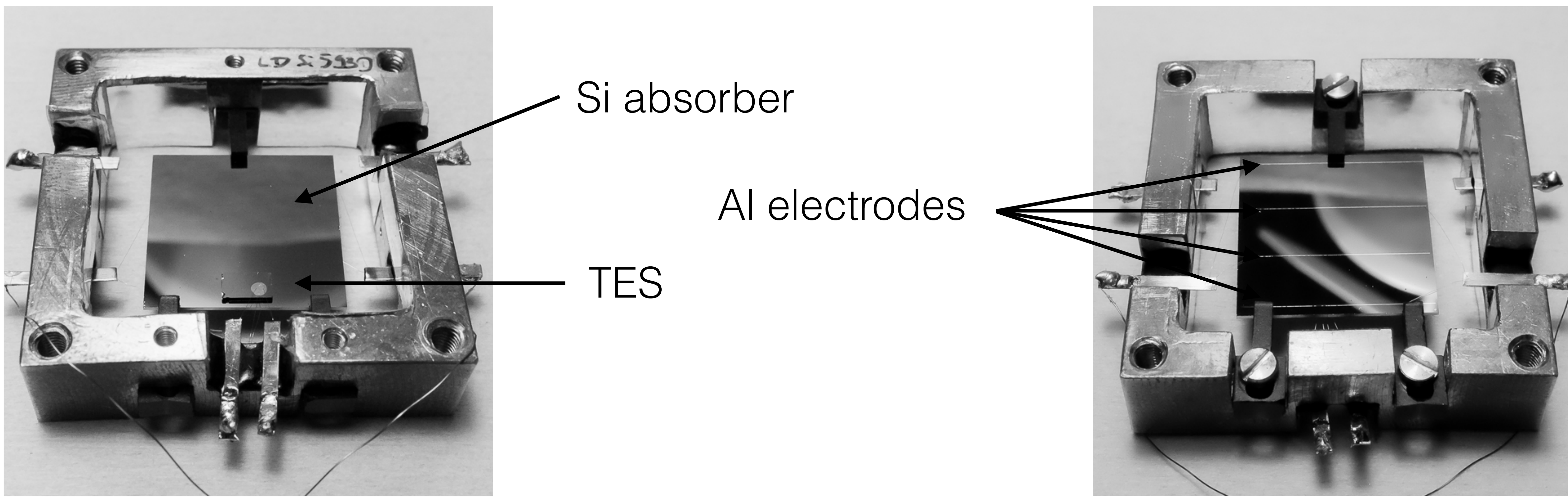

- Typical NL voltages: **~ 70 - 150 V**
- NL amplification: **~ 10 @ 70V (~ 25 expected)**
- additionally: reduction of amplification with time - solved now ✔
- Currently under Investigation: Why can we apply "only" up to 150V?
  Why is the amplification lower than expected?

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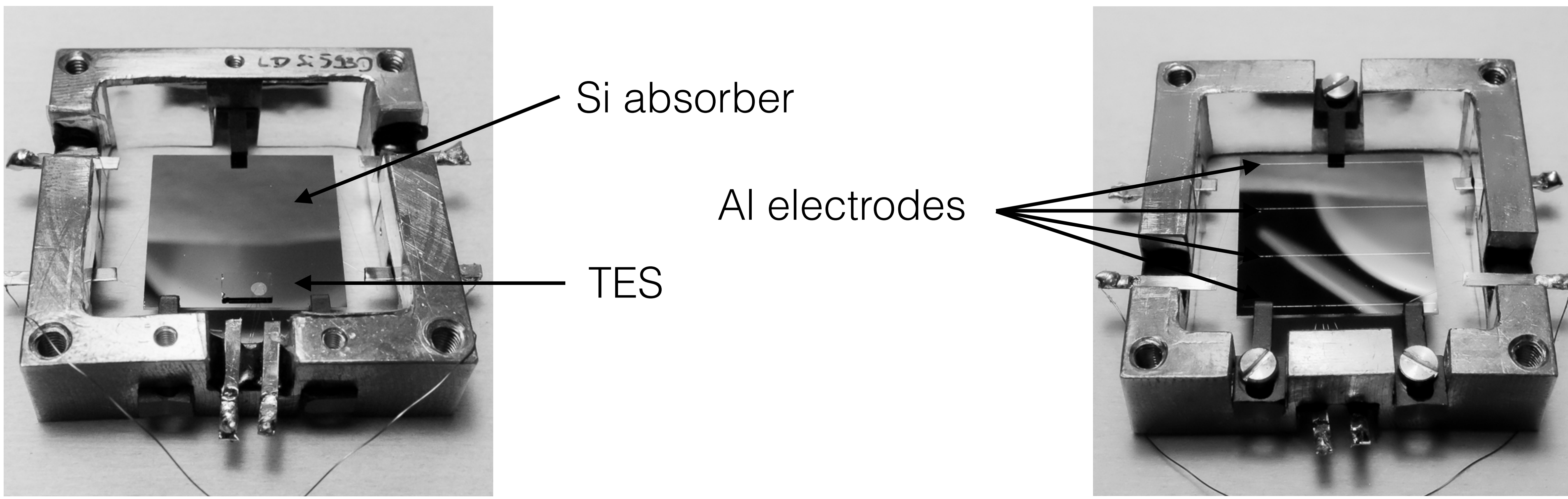

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Neganov-Luke: Effective Gain

$$G_{eff} = 1 + \frac{eV_{eff}(t)}{E_{ph}/\eta} \cdot \frac{l_{drift}}{d}$$

Stark et. al,
NIM A 545 (2005)

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Reduced drift length ($l_{drift} < d$):

- trapping of charge carriers (→ $G_{eff} < G_{th}$)

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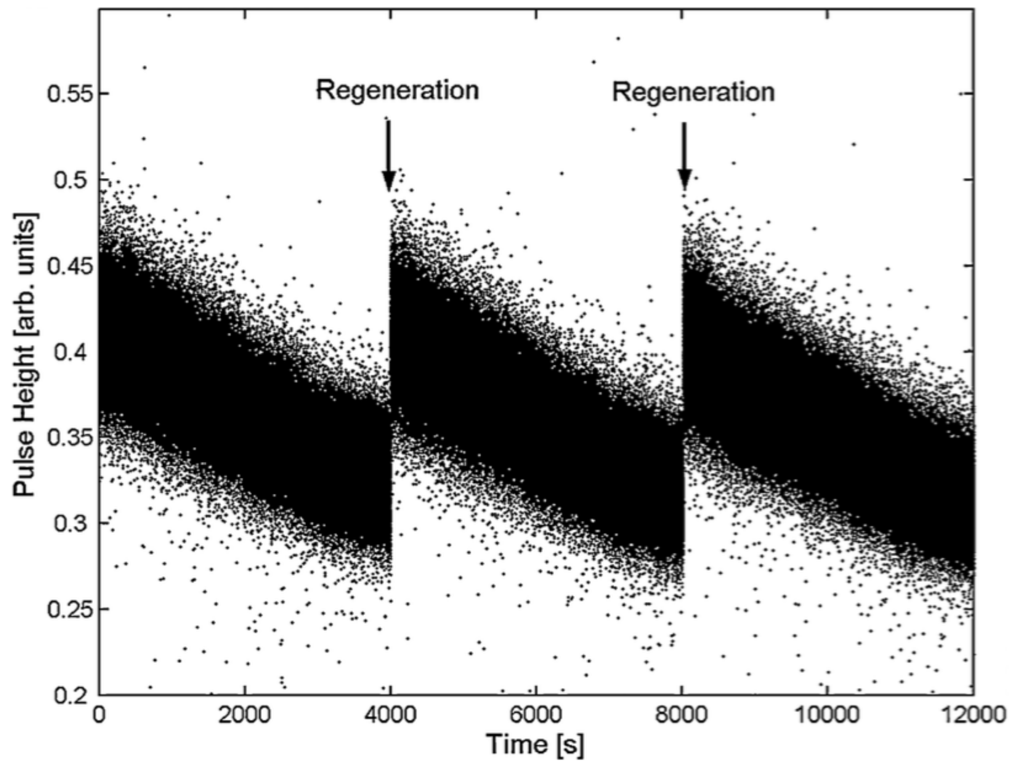
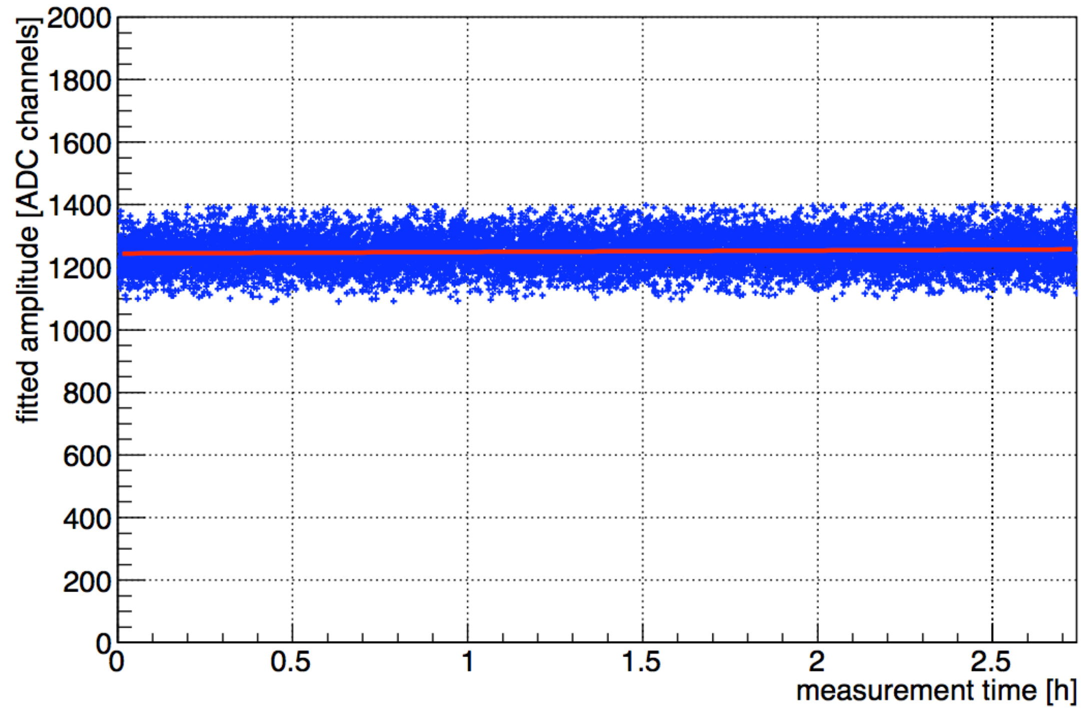
Reduction of signal amplitude:

- Accumulation of drifted charge carriers close to aluminum electrodes
  → Reduction of V_{eff} (& G_{eff}) over time
- Annealing of substrates (PhD S. Roth TUM 2014) → Significant improvement

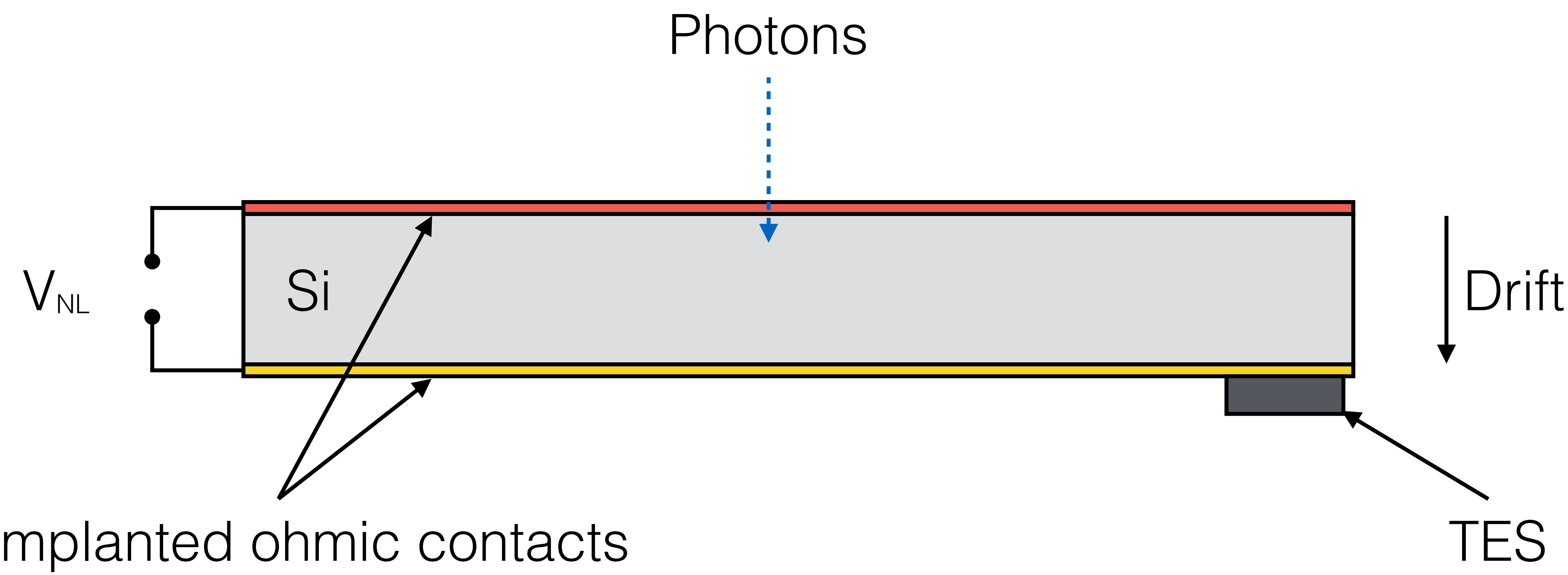


Isaila et al. Physics Letters B 716 (2012)



PhD Thesis S. Roth, TUM 2014

Neganov-Luke Light Detectors - Planar Electrode Geometry



- Planar electrode geometry (shallow (implanted) ohmic contacts) V_{NL} applied between top/bottom face of light detector

→ Drift of e/h pairs through bulk / *no drift across surface* of substrate!

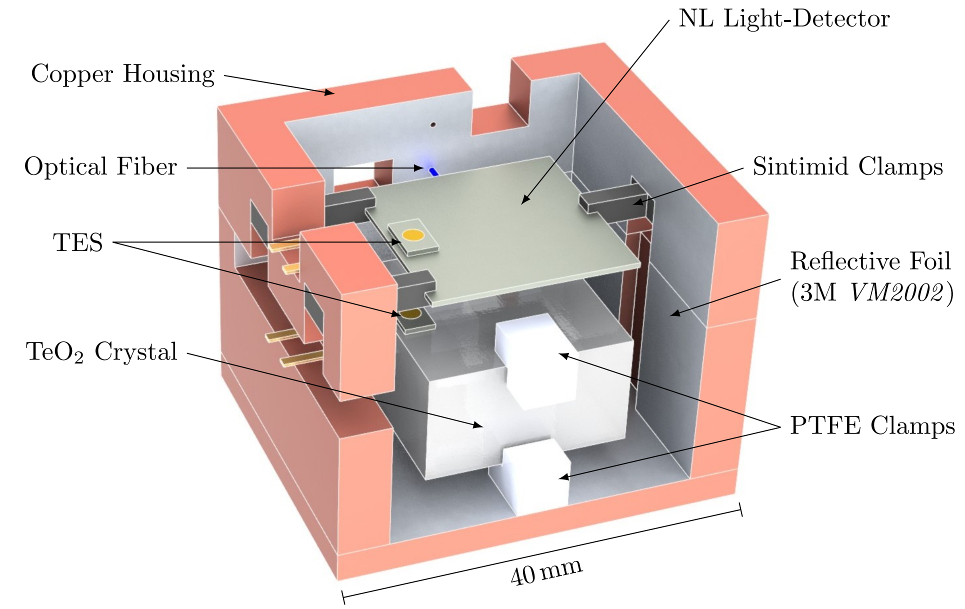
- Very high electric fields possible (~ 6.5 kV/cm)
- First measurements promising: no increase in noise / linear amplification / no charge trapping
- Detailed measurements in preparation!

In collaboration with X. Defay (Excellence Cluster Universe & TUM)

`"Cryogenic silicon detectors with implanted contacts for the detection of visible photons using the Neganov-Luke Effect", arXiv 1509.06266`

Application: Background Suppression in TeO_2 Crystals

- ^{130}Te (TeO_2) promising $0\nu\beta\beta$ candidate
- α-events expected to be dominant background contribution in next-gen. experiments
- future-gen. experiments (CUPID - `arxiv 1504.03599`) plan to employ active background suppression techniques
  → detection of Cherenkov photons for e^- / α discrimination (expected signal at $Q_{\beta\beta}(^{130}Te)$: ~ 100eV)



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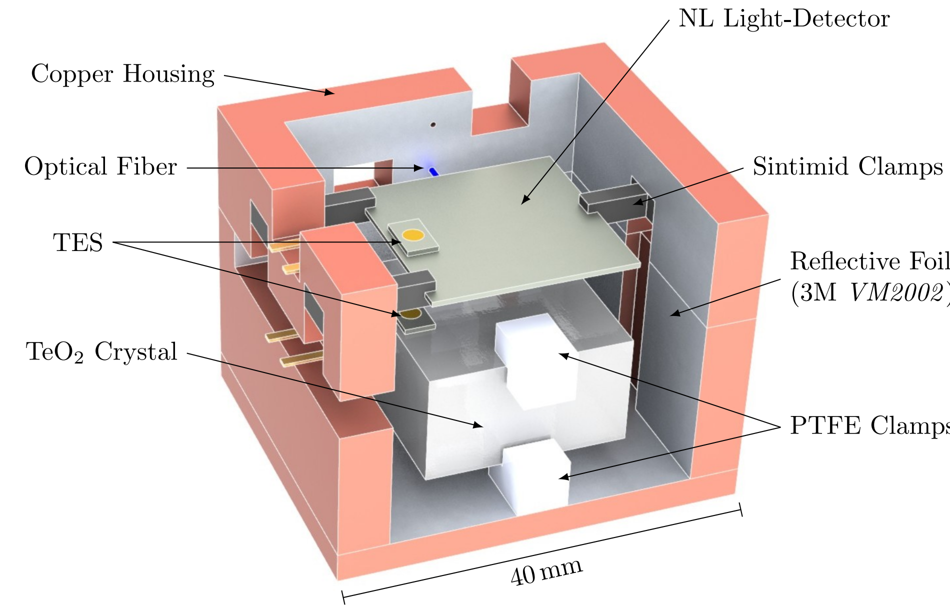
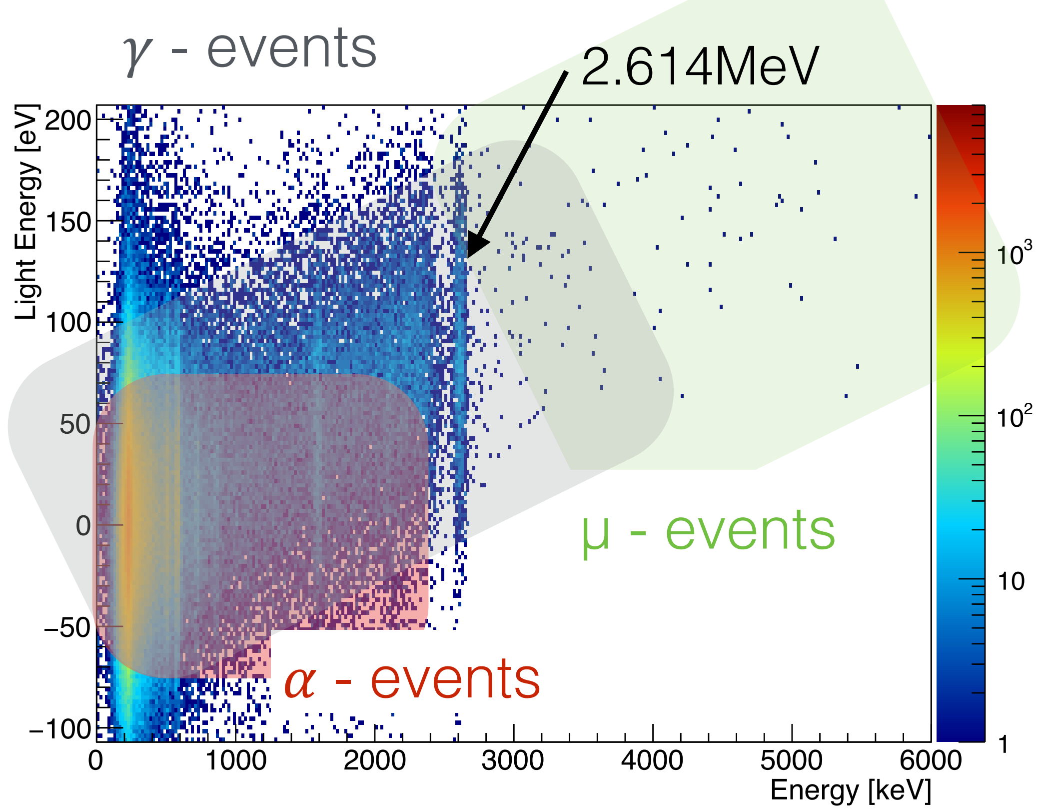
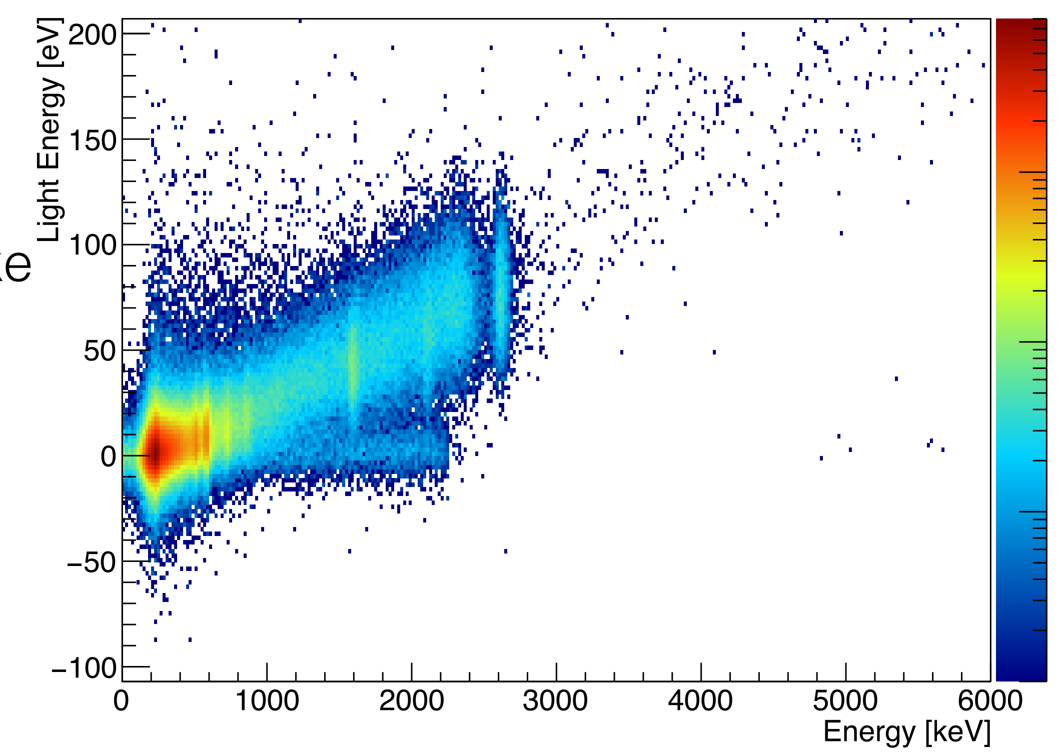


@TUM: first measurements showing feasibility of Cherenkov detection from TeO_2 using NL light detectors (`2015 JINST 10 P03003`)



Neganov-Luke Effect →



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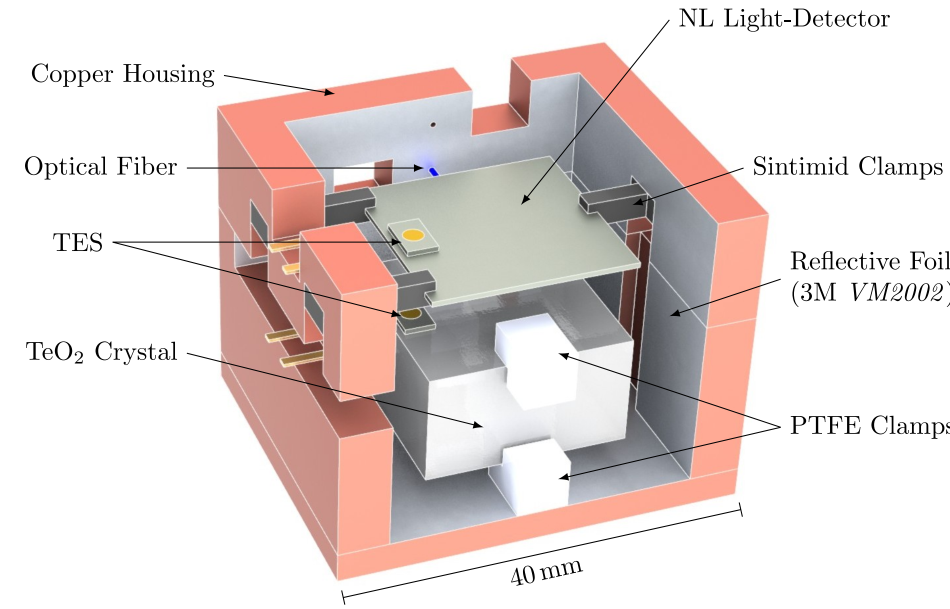

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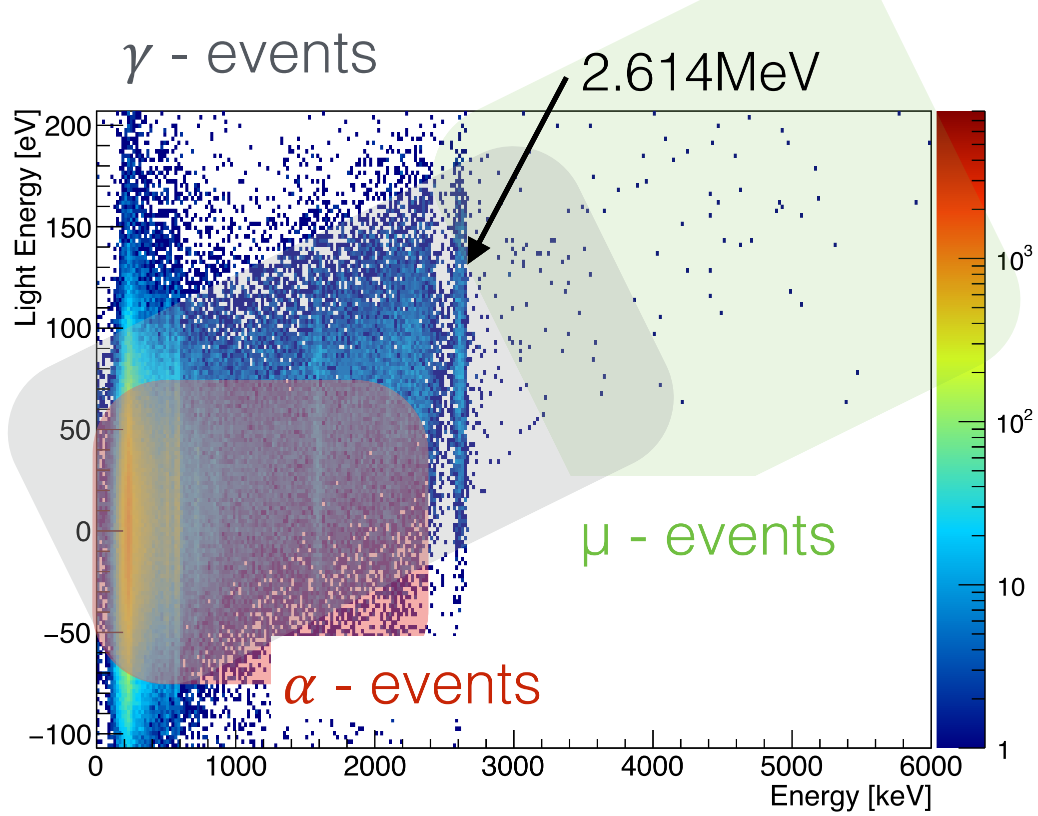

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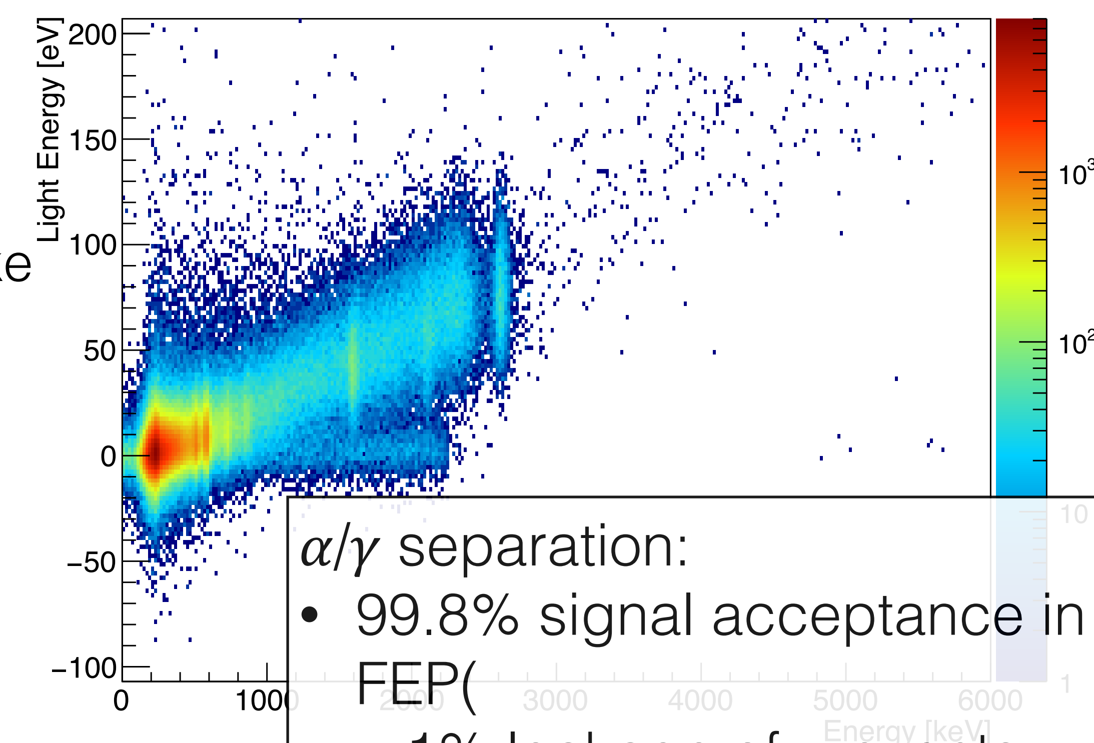

α/γ separation:
- 99.8% signal acceptance in FEP(
- ≲ 1% leakage of α events

Thank you for your attention!