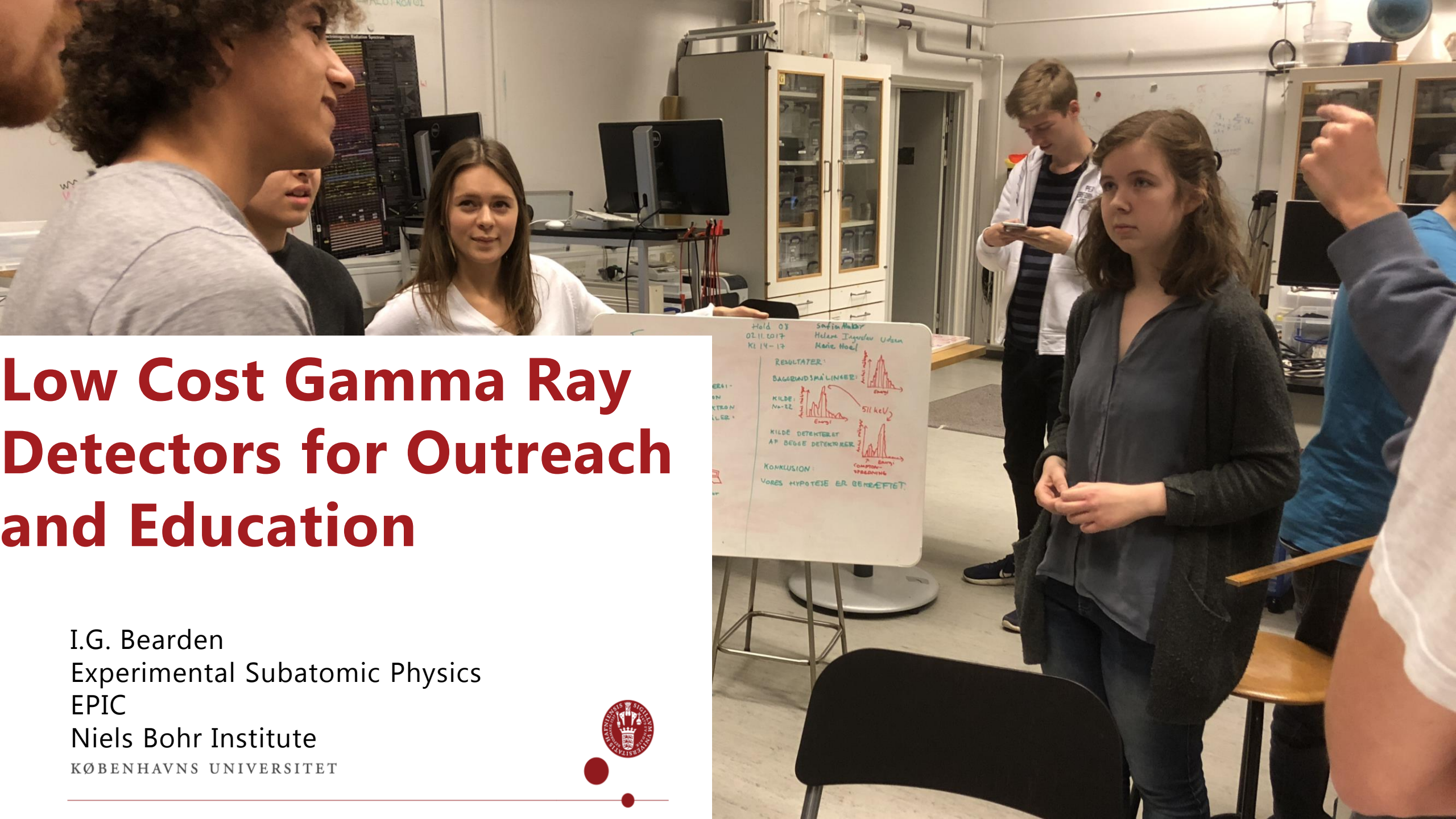

Low Cost Gamma Ray Detectors for Outreach and Education

I.G. Bearden
Experimental Subatomic Physics
EPIC
Niels Bohr Institute
KØBENHAVNS UNIVERSITET

PLAN

- INTRODUCTION:
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  - Why I am talking about this
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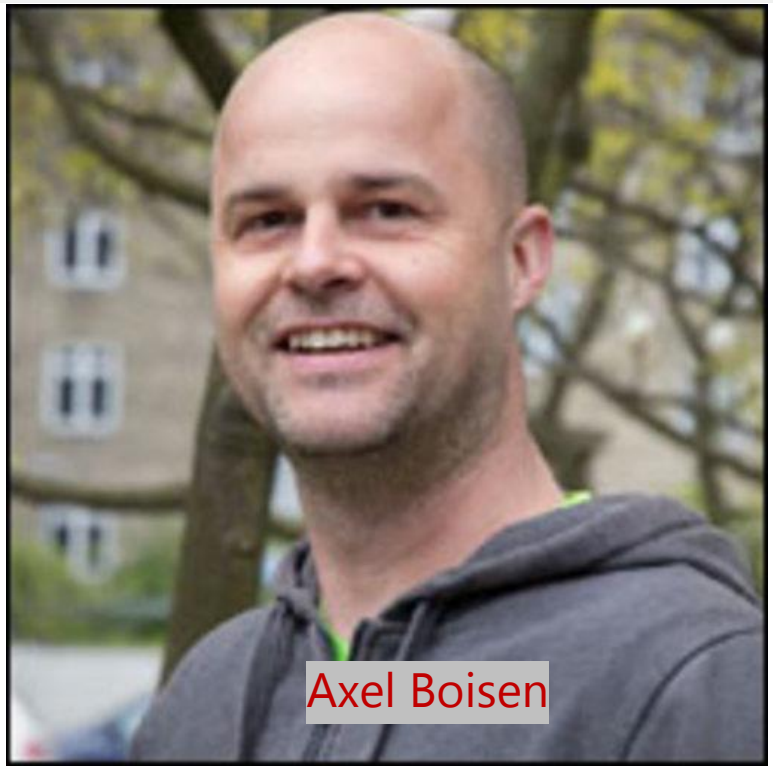
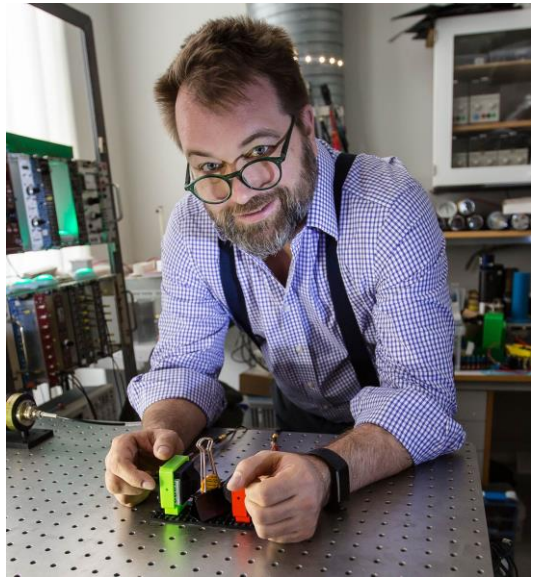
- WHAT IS "AVAILABLE"?
  - A quick non-objective, non-exhaustive market "survey"
- THE NICE-NBI SOLUTION
  - DAQ
  - HOW TO BUILD A 100€ Gamma Spectrometer
  - Mini PET Scanner
- NEXT STEPS

THE TEAM

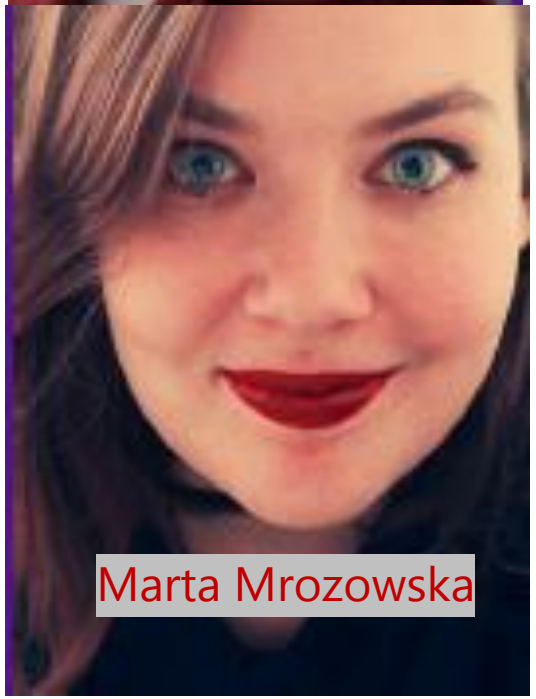




IGB

Investigating Properties of an Inexpensive Gamma Ray Detector

Anna Maria Klüssendorf, Silja Borring Låstad, and Emilia My Kjærsdam Telléus
Niels Bohr Institute, University of Copenhagen
(Dated: July 11, 2018)



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What I will talk about:

- Simple detectors for Nuclear and Particle physics
- Designed and built in-house (collaboration* between IGB and Axel Boisen from NBI's fantastic electronics shop)
- Design goals:
  - AS INEXPENSIVE AS POSSIBLE
  - ROBUST (to be used in both our teaching and outreach labs)
  - AS FEW "black boxes" AS POSSIBLE
- BASED on rather new tech (Silicon Photomultipliers) as well as old (GM tubes, PMTs) depending on the purpose.

*Typically: IGB : "I wonder if we could find a way to…" Axel, next day: "Yes, like this. I made it for you"
Not all heroes wear capes, you know,

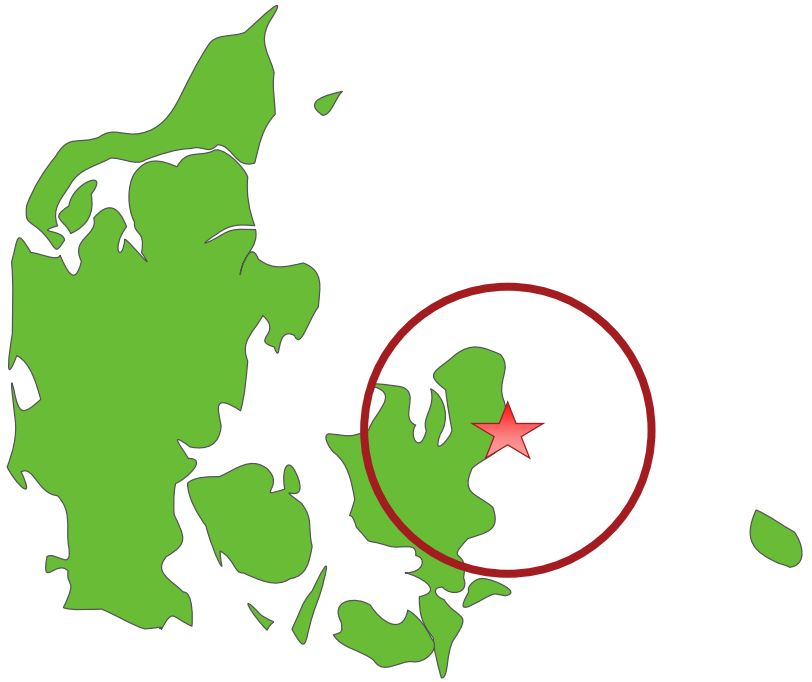
Why this?

- I am an experimental physicist.
- PhD & first post-doc: high-spin gamma spectroscopy
- Since then: Ultrarelativistic Heavy Ion Physics (presently: ALICE@LHC)
- Teaching: I want to give students "real" experimental experience as early as possible
- Outreach: I want to finds ways to make the words "nuclear" and "radiation" less mysterious and frightening.

Context

Denmark

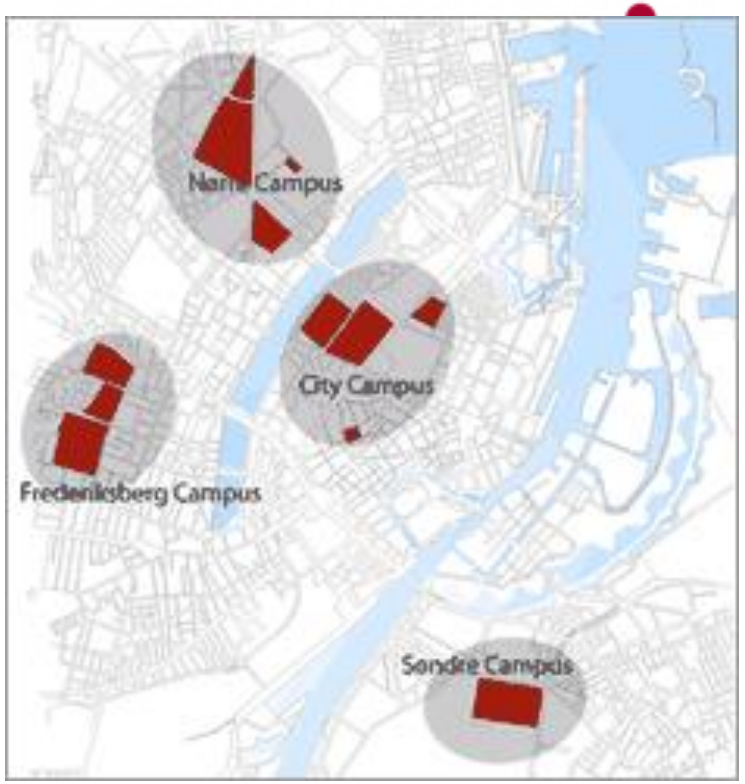
- 5.6 Mpeople
- 1/2 the size of Austria
  (unless we count Greenland)
- No tuition (also for EU residents)
- State stipend of 5500DKK



University of Copenhagen

- Roughly 40 kStudents
- 7000 faculty & staff

KØBENHAVNS UNIVERSITET



Niels Bohr Institutet

- Physics department of KU
- ~85(?) tenured faculty
- ~115 PhD students
- ~120 Post Docs
- ~600 students BSc&MSc students
- **155±10** new students/year. All physics majors (various "specializations" bio, astro,geo…)

Aside



Colliderscope: available from iTunes
Data from ATLAS inner tracker

Curriculum

Bologna 3+2 (+3)

In DK secondary shools
3 levels (A,B,C)
Our students have had
Math: A
Phys: A or B**
Chem: A or B
At least 2 of these A

**quite a bit of laboratory work. In principle, well prepared for uni lab work.

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- NEXT STEPS

MARKET "SURVEY":commercial

- Many commercially available nuclear/particle physics detector systems.
- Both "research" and "educational" solutions.
- Many of these are very good…BUT
- Typically,* "educational" solutions are expensive and not terribly flexible systems, often dependent on proprietary software.

*there may be some that are reasonably priced and open source that I have not found.

MARKET "SURVEY":commercial

- CAEN offers several nice packages, but 5-8k€/setup.
- Canberra offers good NaI+Integrated base, 4k€+closed software.
- "legacy" research equipment often requires expensive HV, DAQ, etc.
- Difficult to have large scale lab teaching based on these

MARKET "SURVEY":Open Source

- $100* Cosmic ray detector "Cosmic Watch" MIT (SiPM coupled to plastic scintillator) NEW: SensL offers $60 SiPM for students
- MUON HUNTER based on inexpensive commercial electronics and 2 GM tubes in coincidence. Working system for ≈150€, depending on availability GM tubes, etc.
- A number of web resources explaining how to build various detectors…(probably more applicable to hobbyists than to large scale lab teaching)

*$100 if you don't have to buy scintillator

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IN-HOUSE Detectors for N&P Phys.

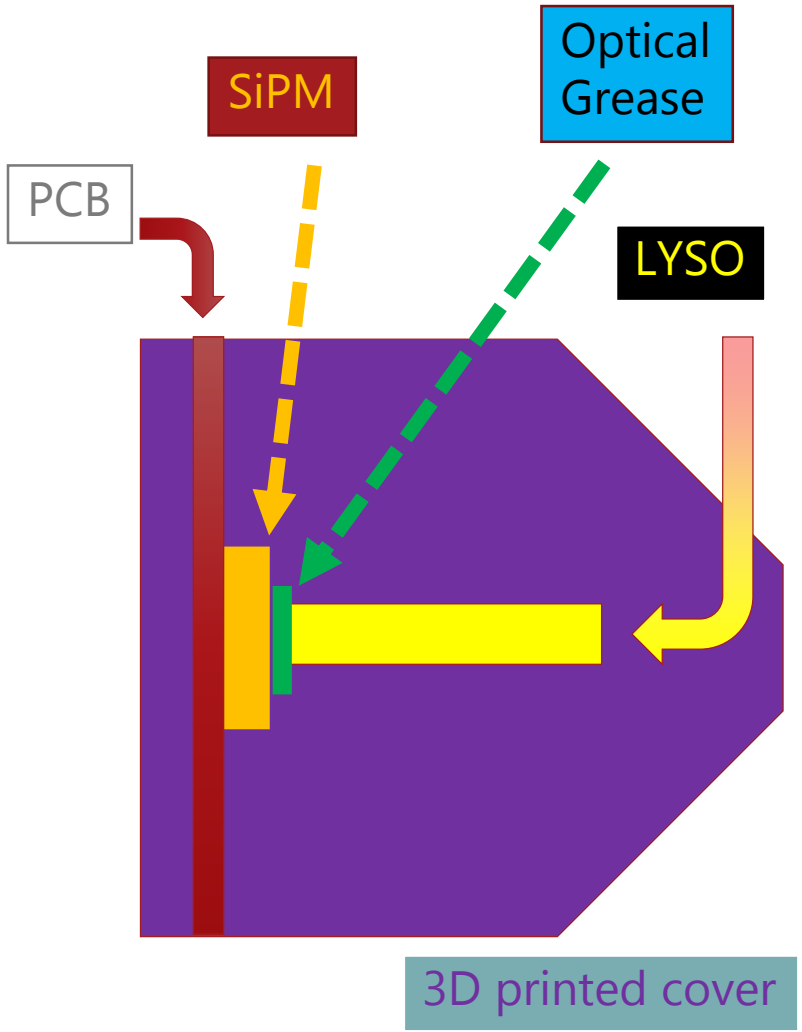
- Generous support from NICE* and the Experimental SubAtomic Physics group at NBI
- Support from NBI (technical infrastructure)
- Fantastic students
- ALLOW:
  - NBI BiGS (BILLIGE GAMMA SPECTROMETER)
  - Muon telescopes based on both SiPM+Scint & GM-tubes
  - Alpha and beta spectroscopy (in development)

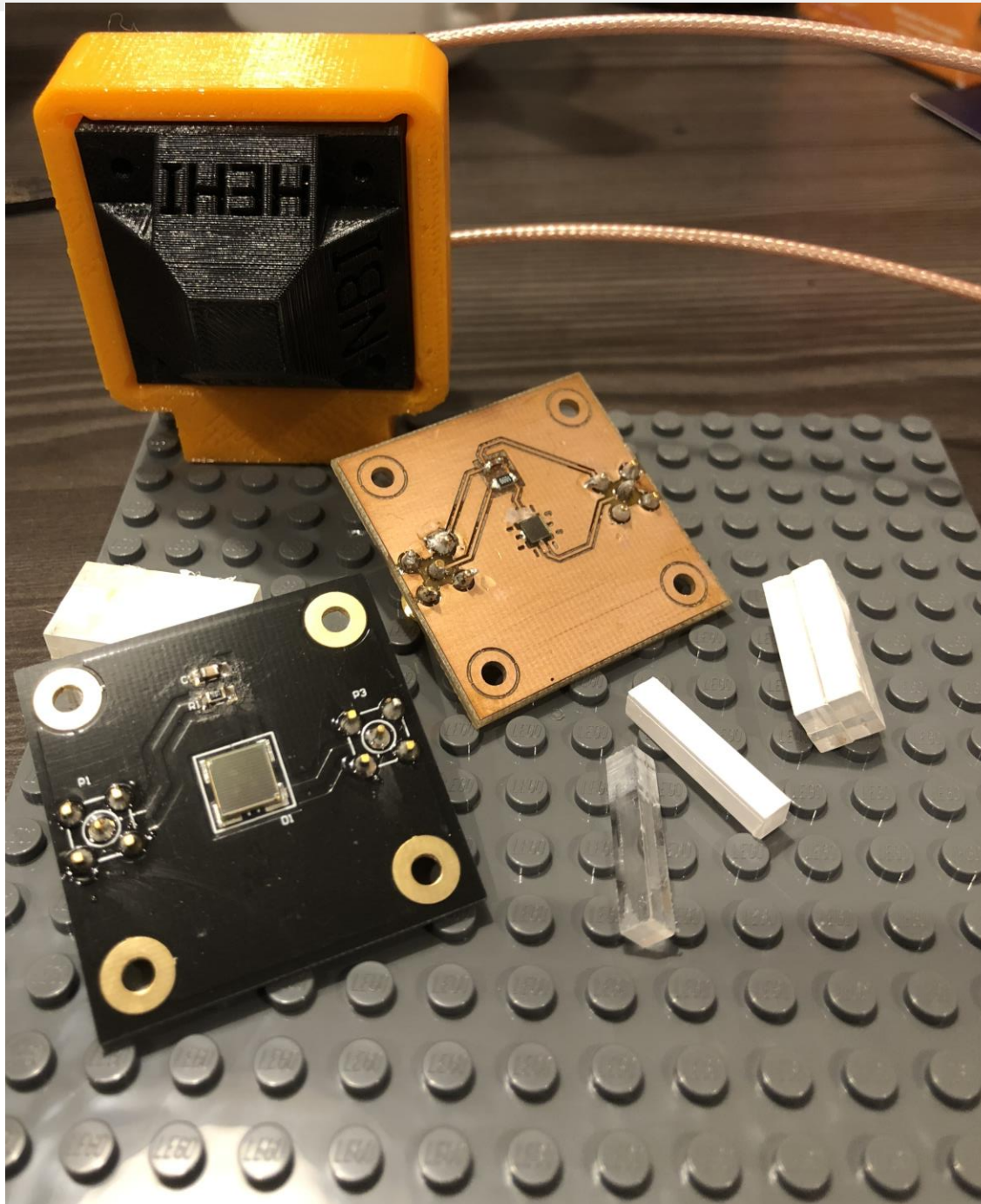
*Denmark's National Instrument Center for CERN Experiments

DAQ 100MS/s USB Oscilloscope, Logic Analyzer and Variable Power Supply

- Connects via USB
- Works on Mac, Windows, Linux
- Scripting language, allows for some real time signal processing
- $279 ($179 academic) +$15 BNC breakout

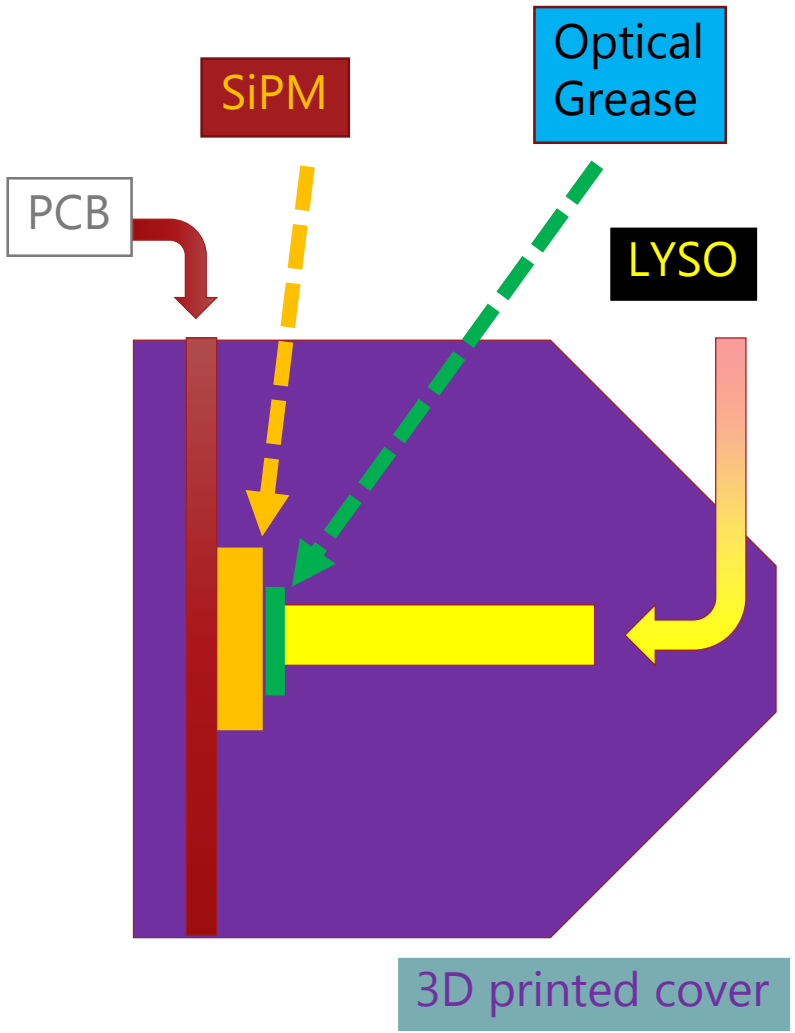
The 100€ γ spectrometer (BiGS)

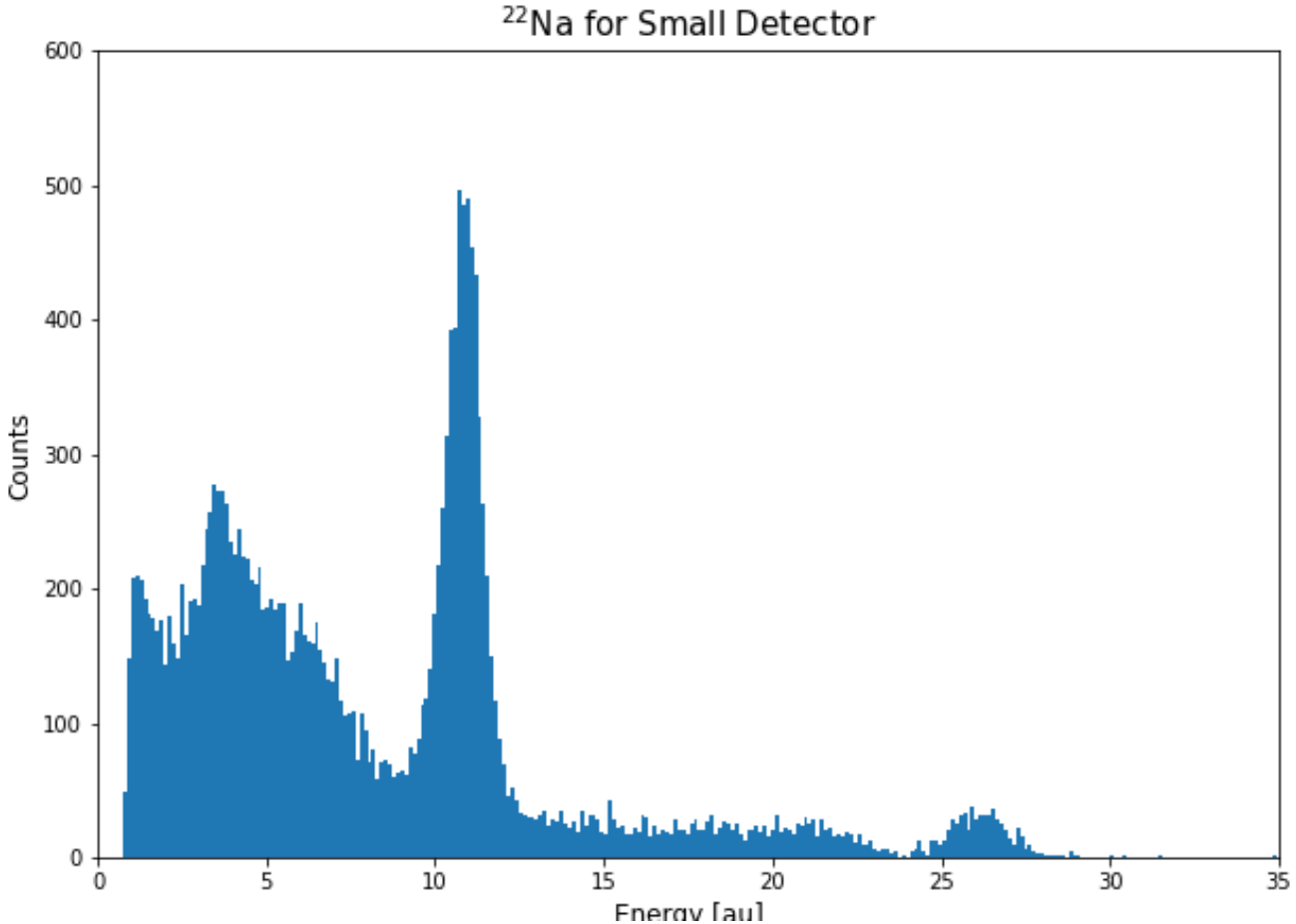




The 100€ γ spectrometer (BiGS)

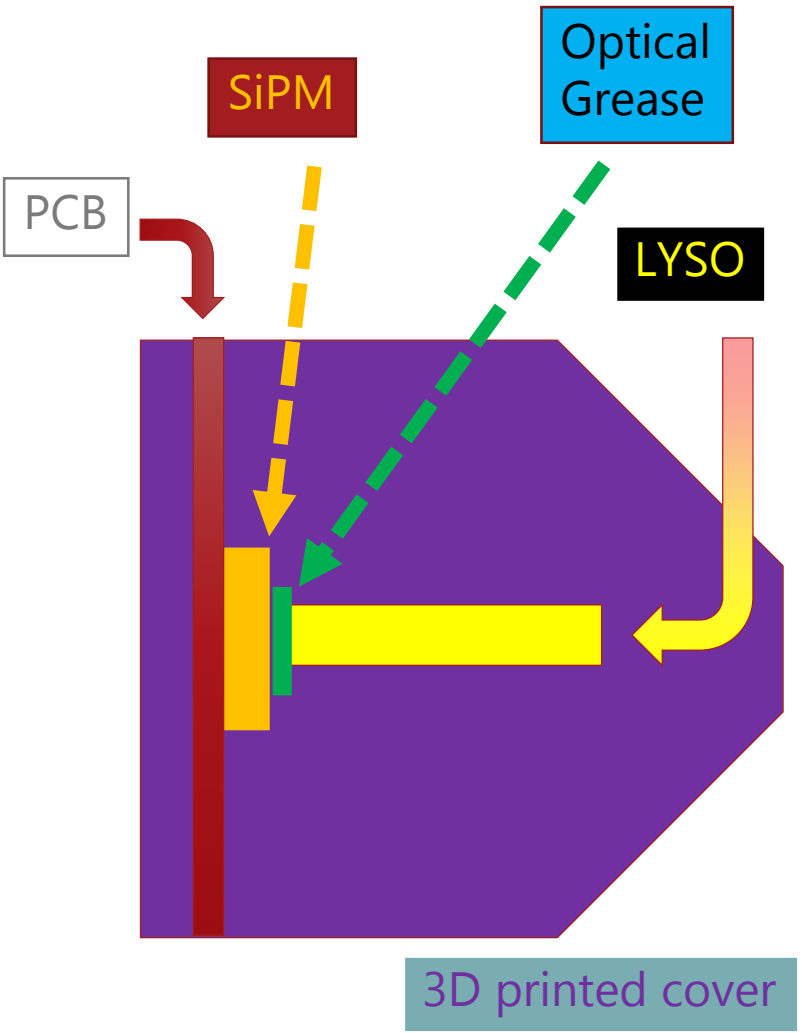
- Singles spectrum ^{22}Na:

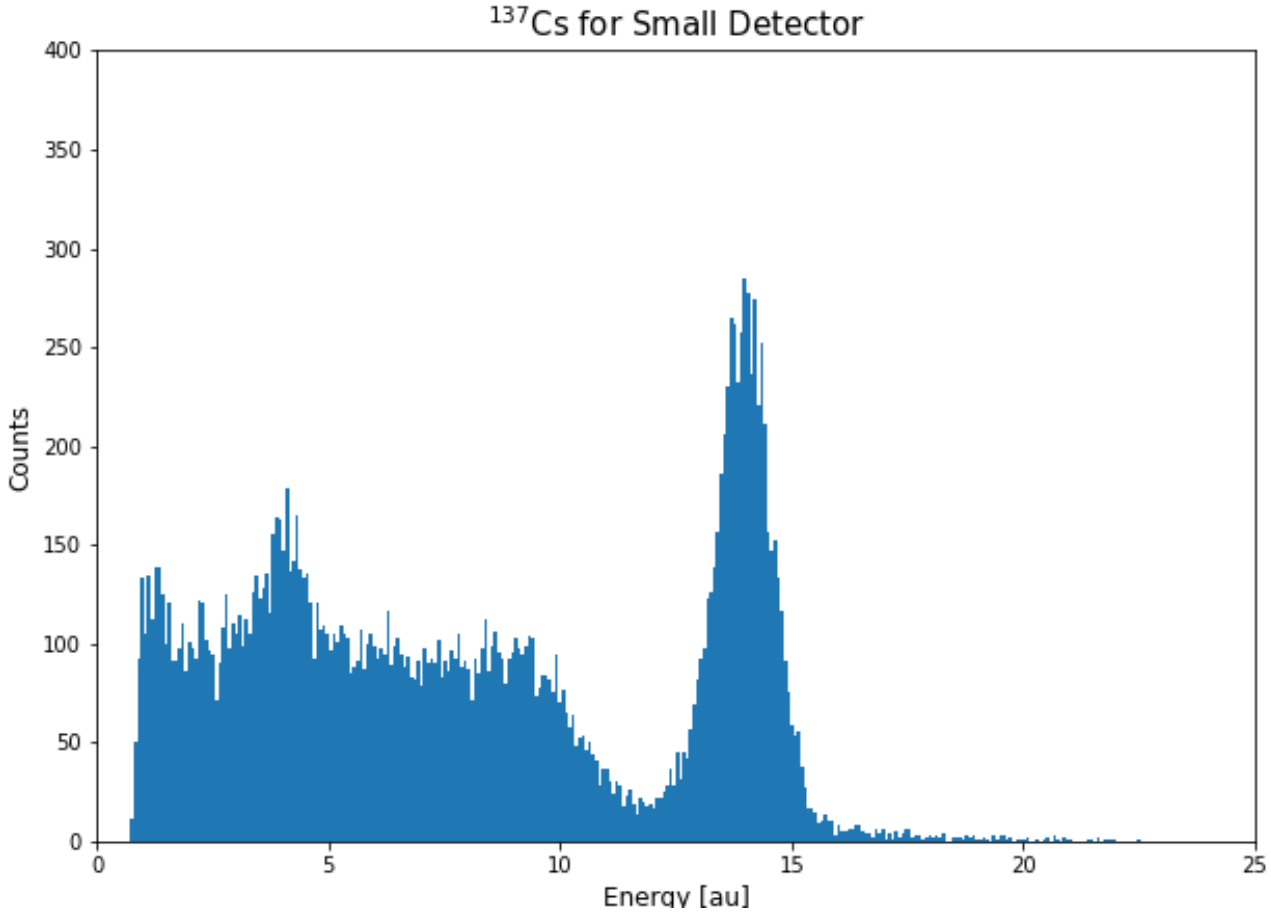




The 100€ γ spectrometer (BiGS)

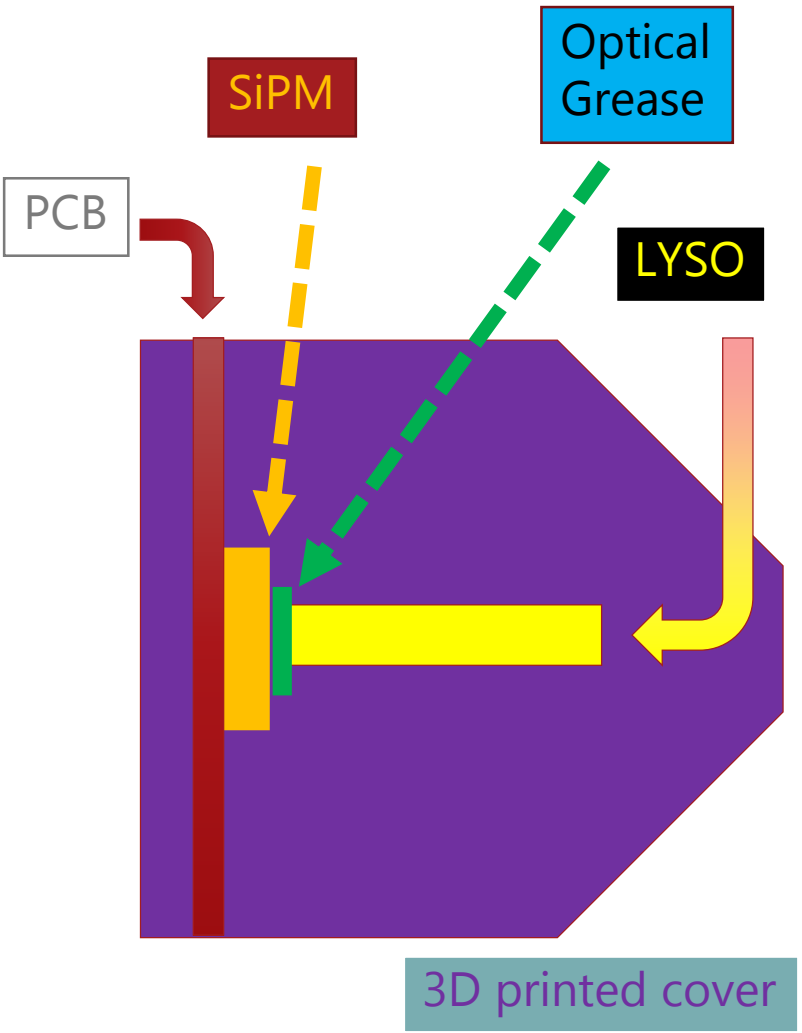
- Singles spectrum ^{137}Cs:

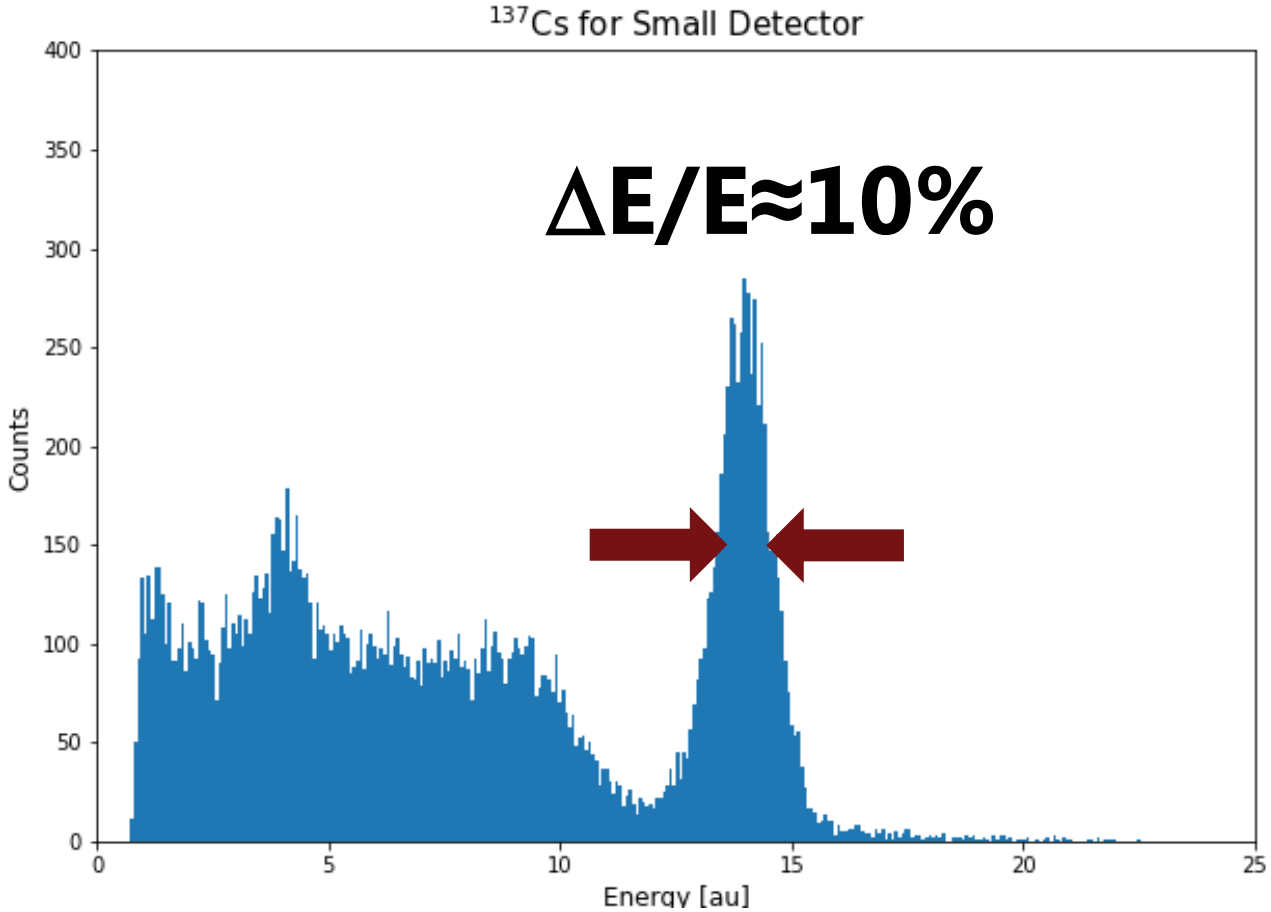




The 100€ γ spectrometer (BiGS)

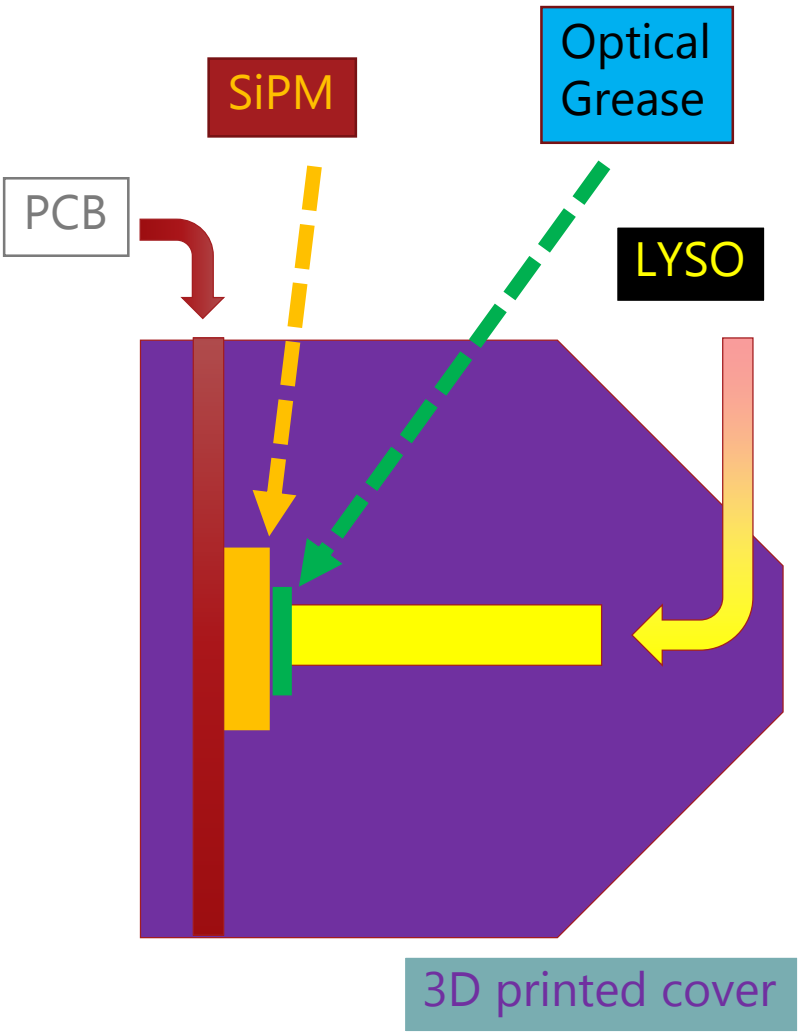
- Good resolution:

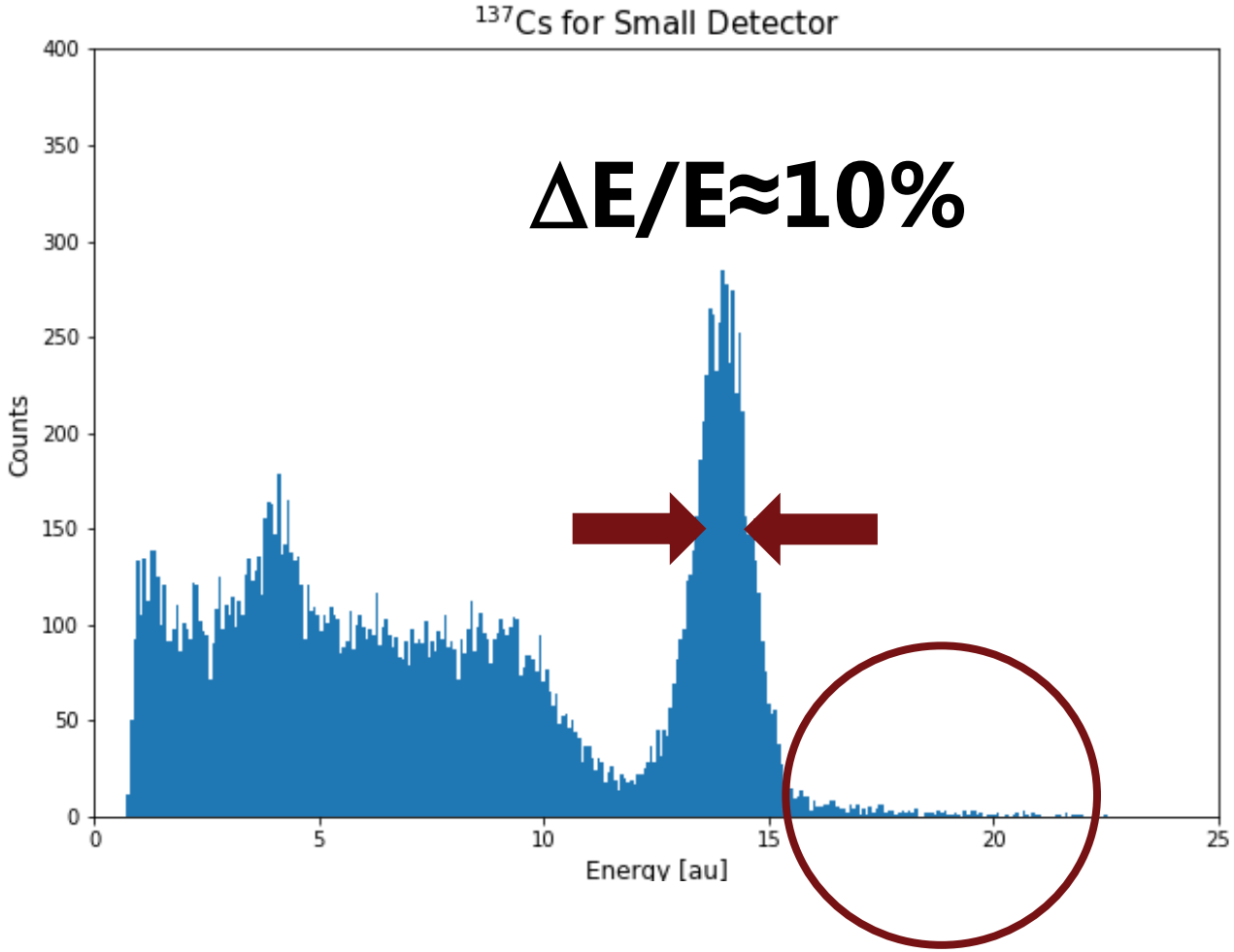




The 100€ γ spectrometer (BiGS)

- Singles spectrum:

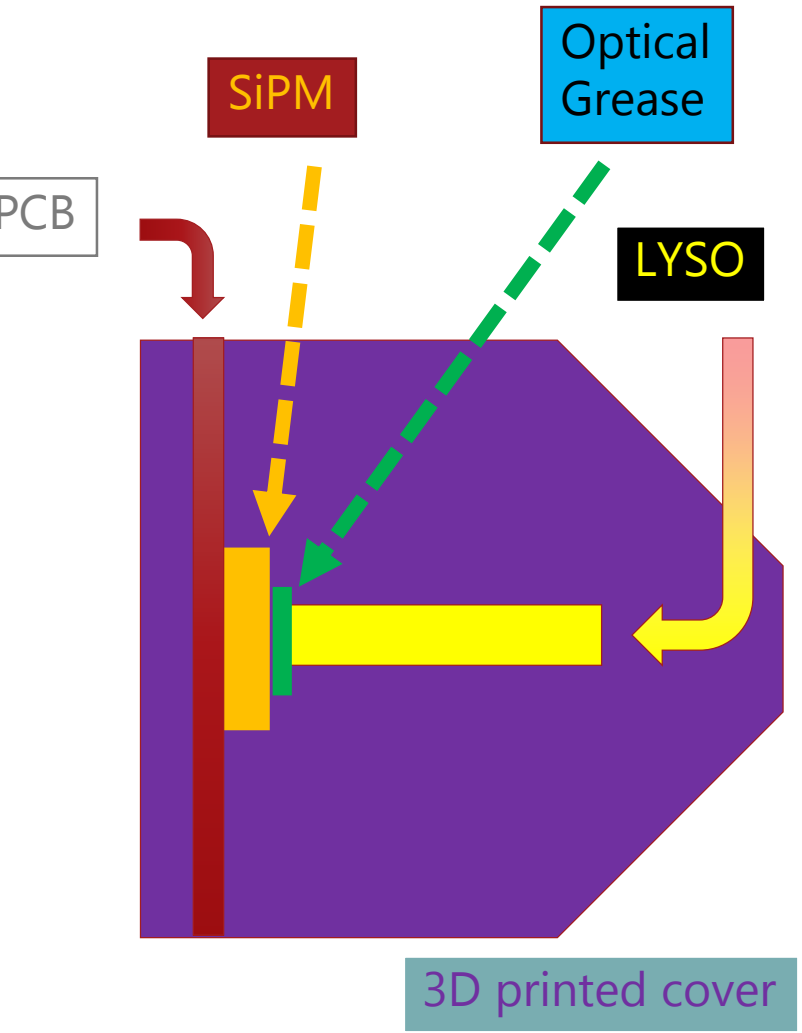


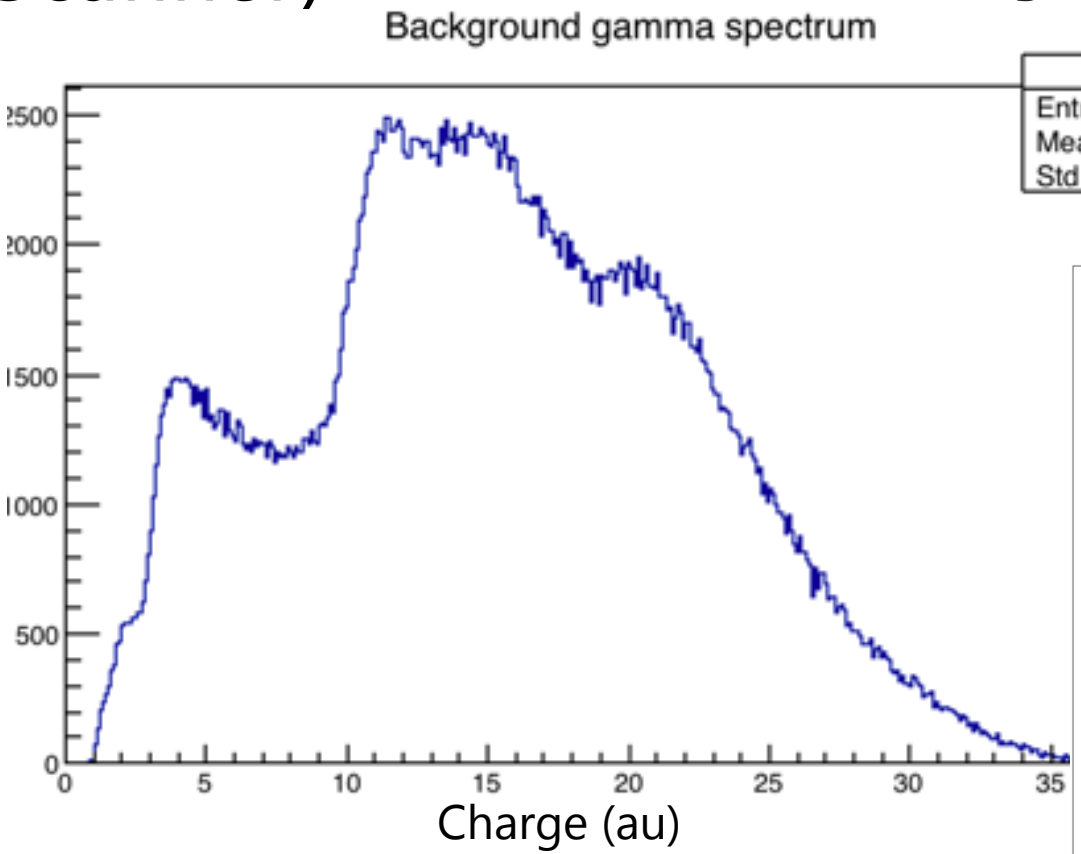


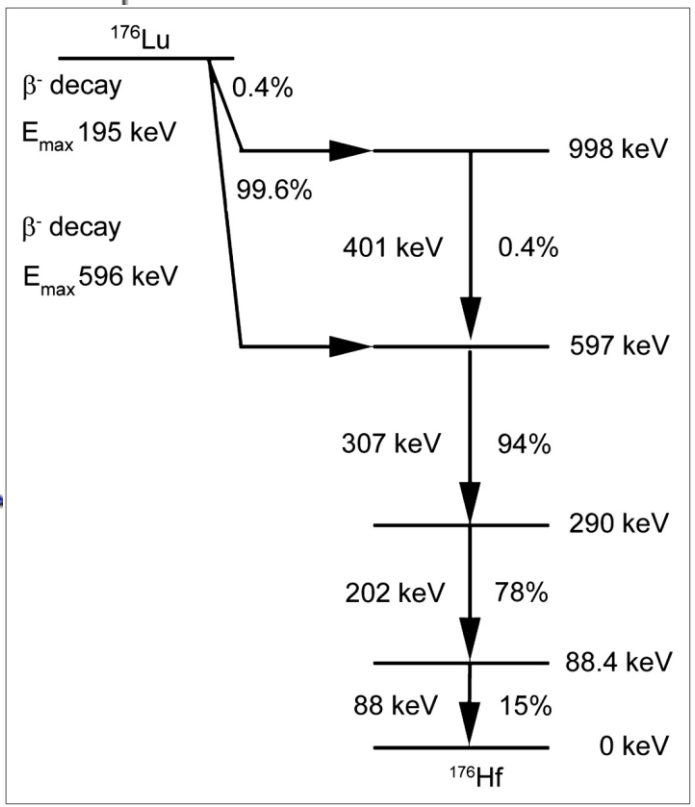
LYSO scintillator

4x4x22mm (fra PET Scanner)

Lutetium-yttrium oxyorthosilicate







LYSO scintillator

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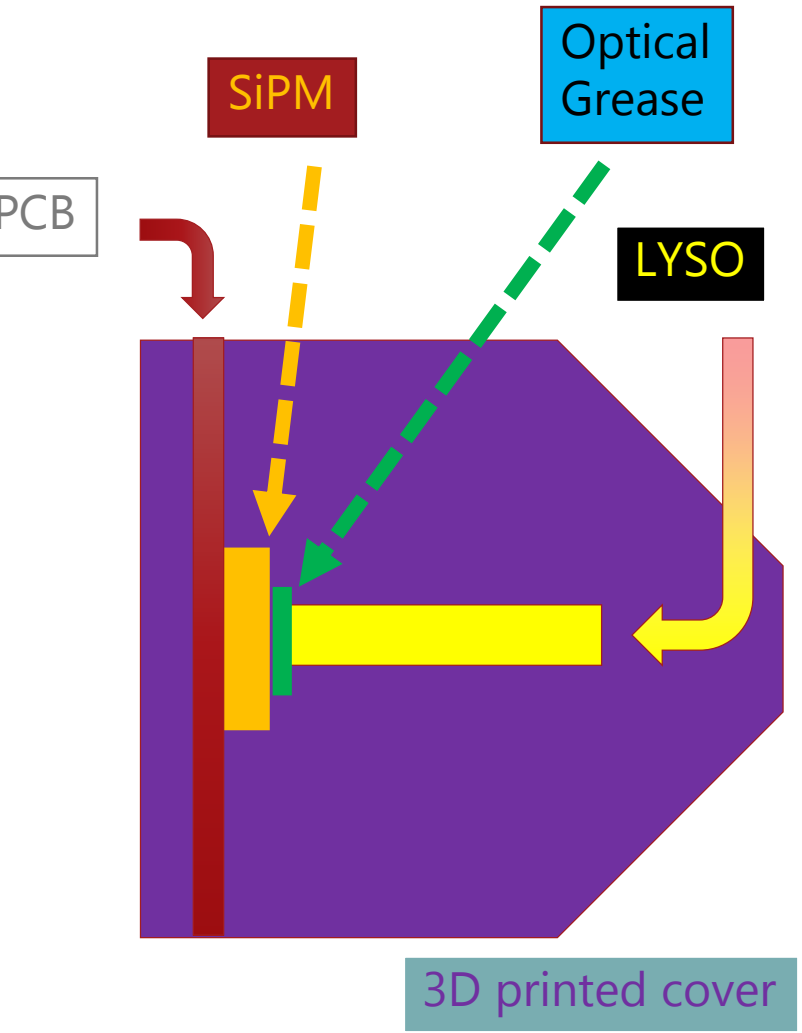
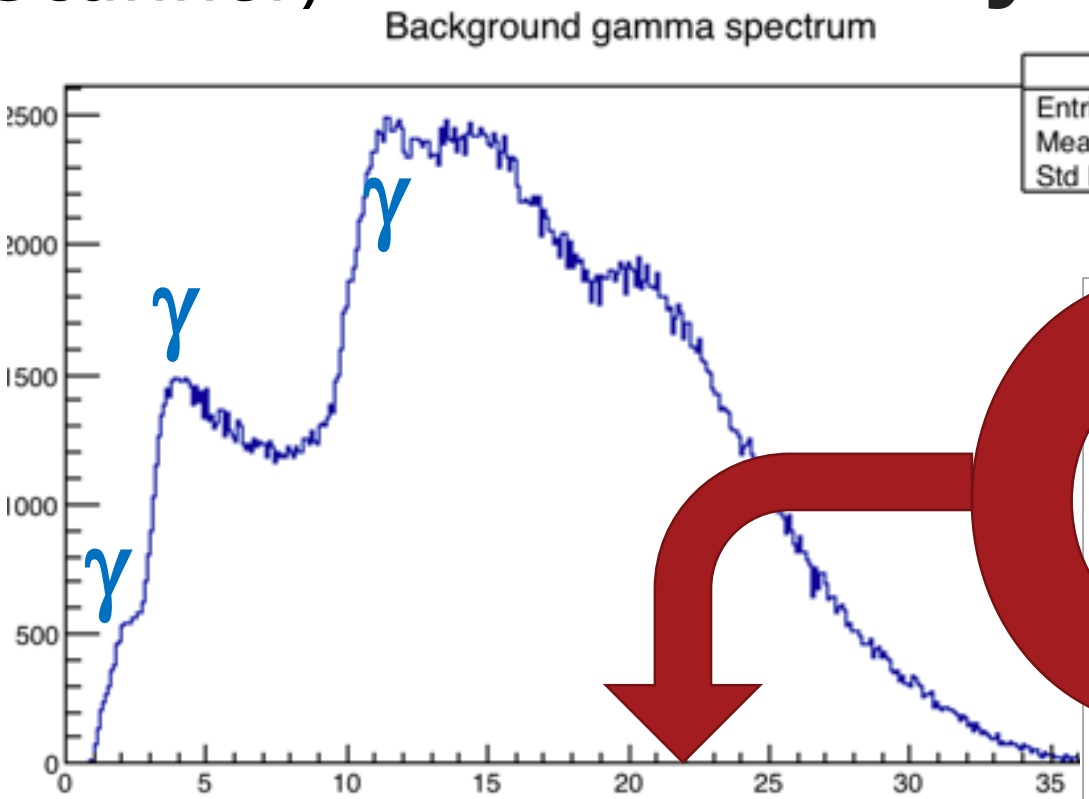
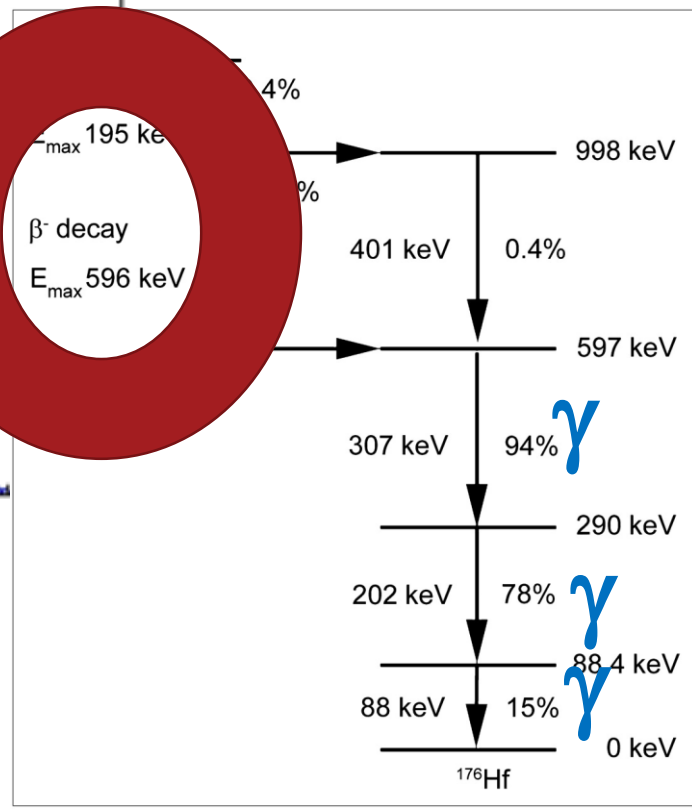




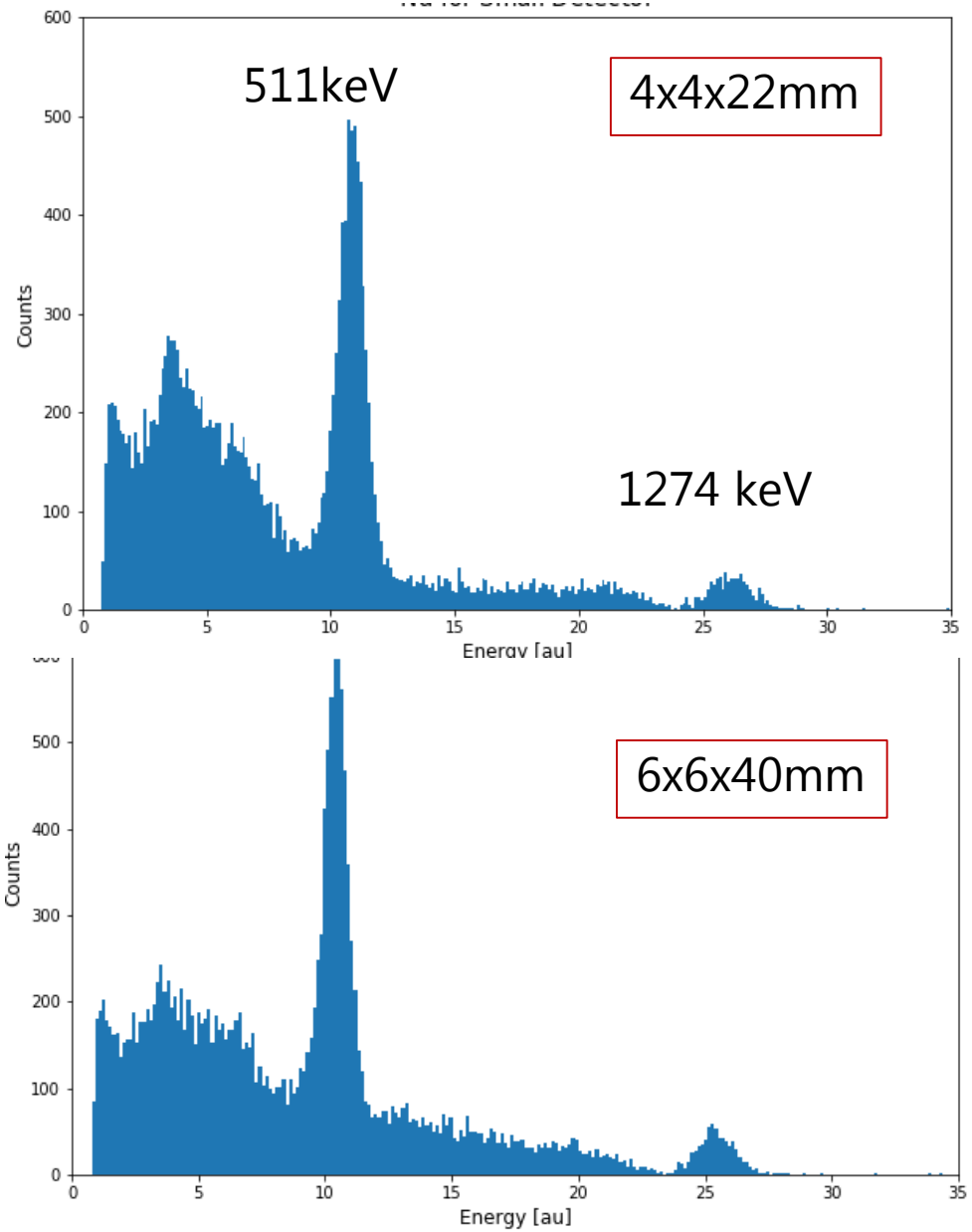


Why is this interesting for Teaching/Outreach?

- Inexpensive detectors (<10% cost of commercial alternatives)
- Don't require high voltage (SiPMs 25-30V, compared to ≈1kV for PMTs)
  - Less expensive, more safe
- Simple system that can be put together by students
- Highly transportable:
  - Detectors small and light, DAQ powered by USB
  - Detector can be powered by batteries

Not perfect, though, because

- Small scintillators, poor efficiency for higher gamma energy
- LYSO is radioactive, can make it difficult to measure low activity souces below ≈600keV
- Steeply falling background makes peaks non-gaussian (so more difficult for novices to fit
- Poor efficiency->low count rates, challenging for impatient researchers



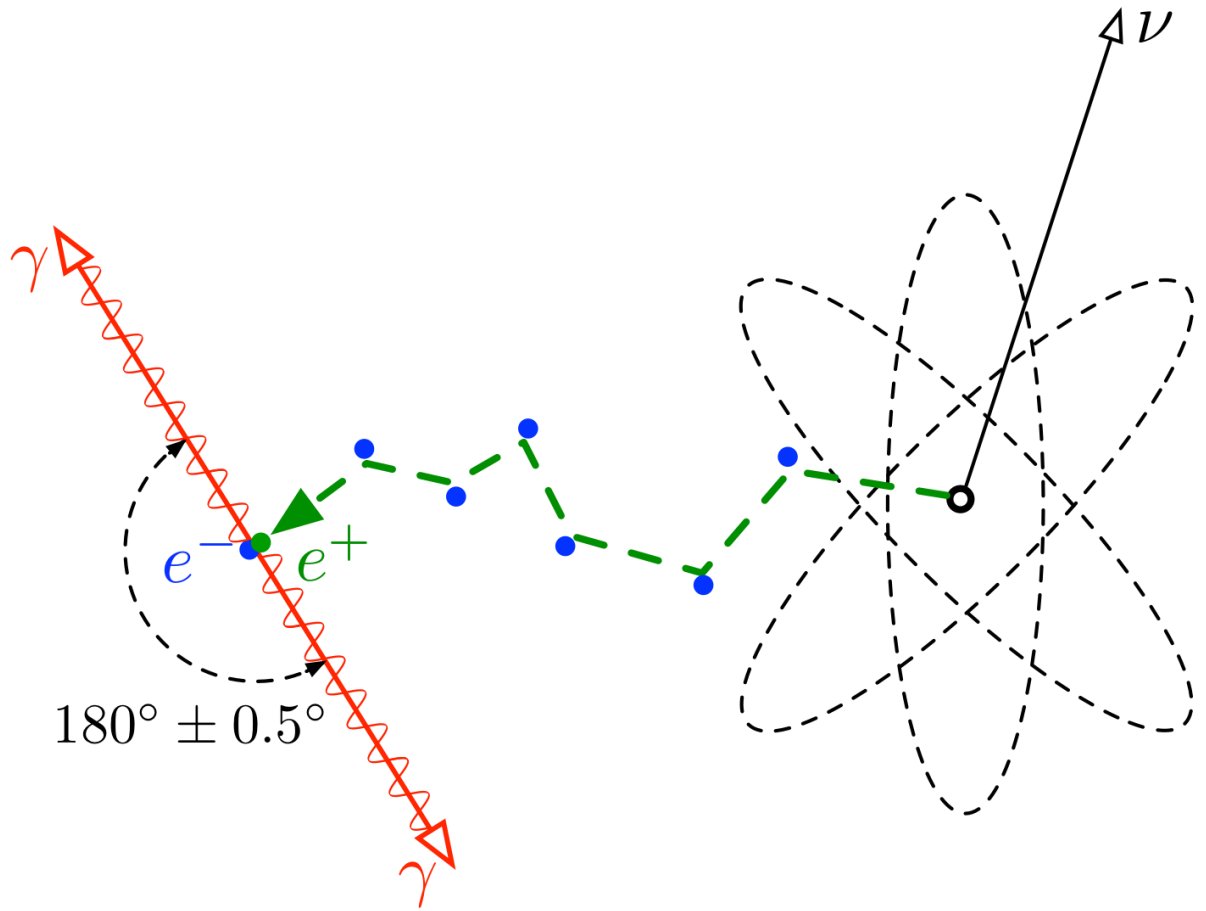
Intro course @NBI: Mechanics & Special Relativity

- How to do good SR experiments in under 3 hours?
- Need 10+ setups (30 students/section, 6 sections)
- Needs to be simple enough that students don't drown in technical details

Intro course @NBI: Mechanics & Special Relativity

- How to do good SR experiments in under 3 hours?
- Need 10+ setups (30 students/section, 6 sections)
- Needs to be simple enough that students don't drown in technical details
- **Answer: measure gammas from e+ e- annihilation!**

Beta+ decay:



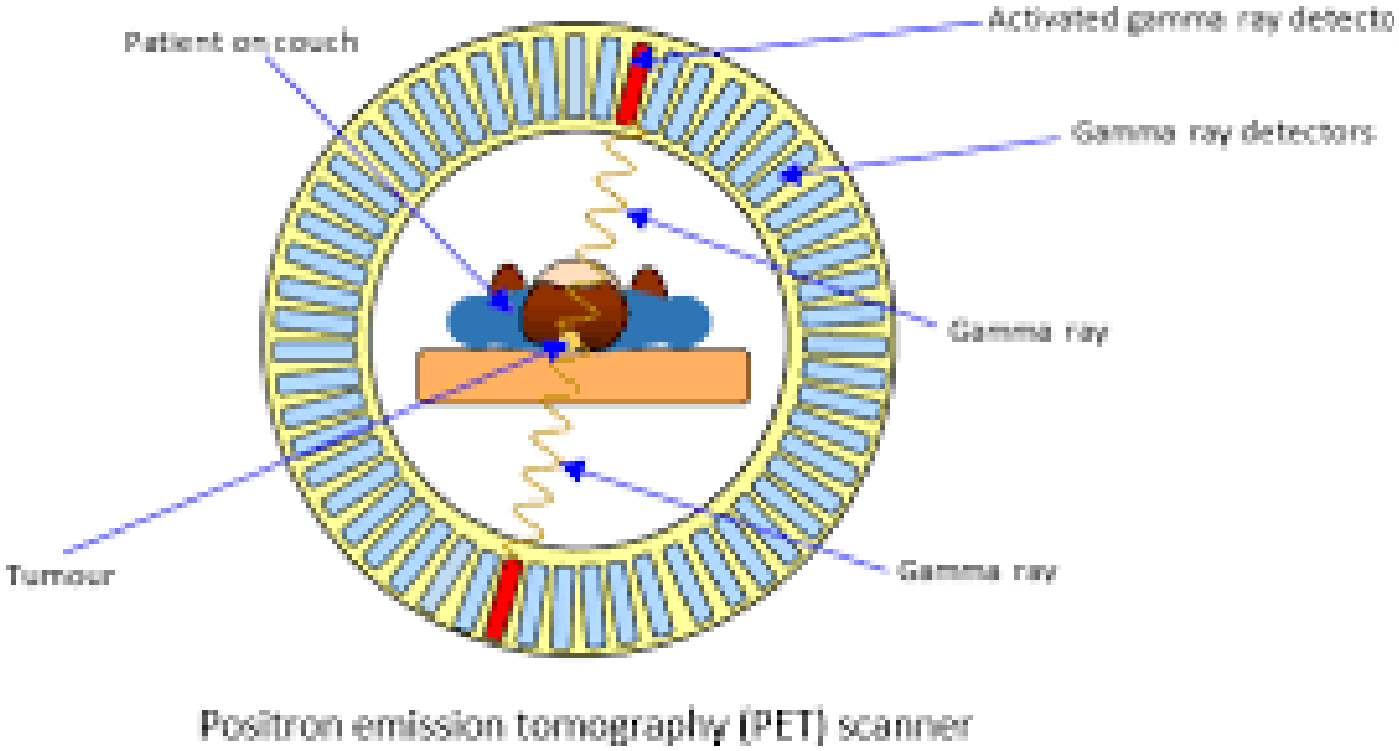
e^+ positron

e^- electron

ν neutrino

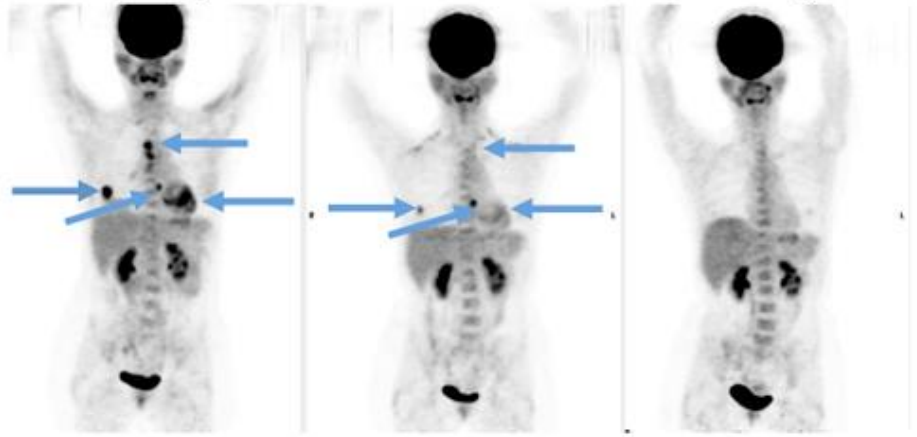
γ quantum/photon (511 keV)

PET Scanner



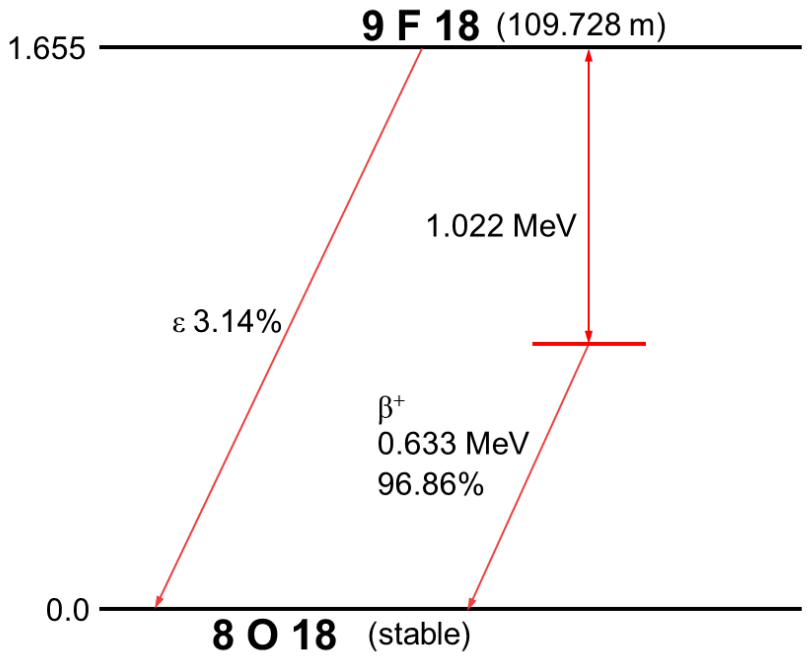
Positron emission tomography (PET) scanner

Treatment response with PET FDG in non-small cell lung cancer



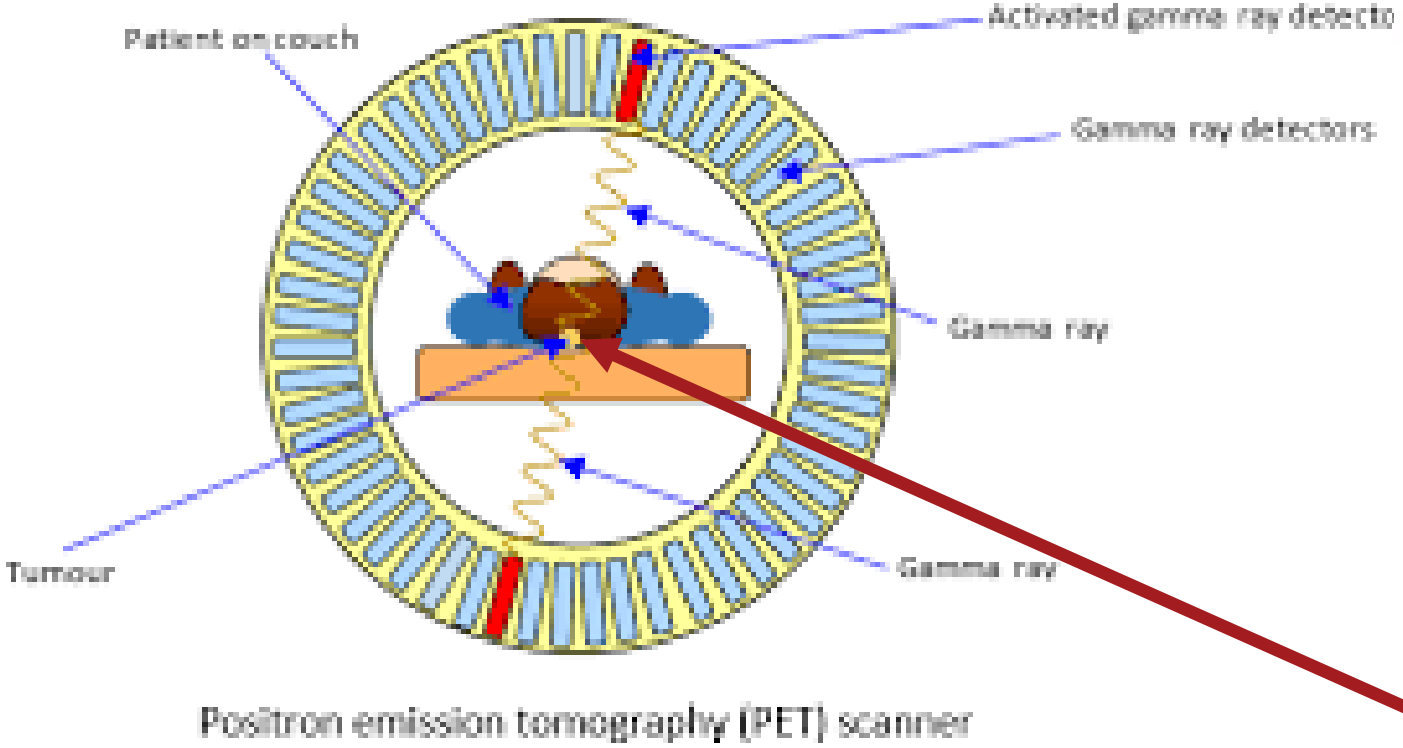
Baseline 2 weeks 6 weeks

Time after start of treatment



Fluorodeoxyglucose (^{18}F)

PET Scanner



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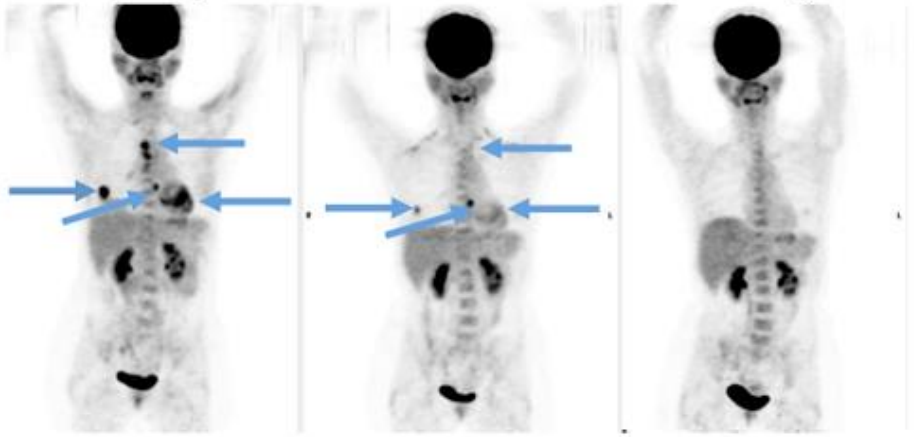

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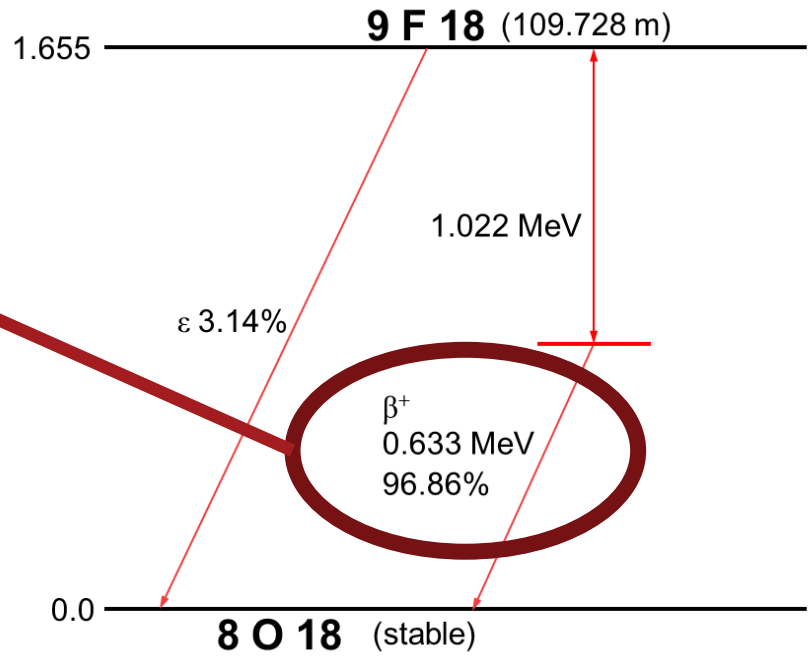
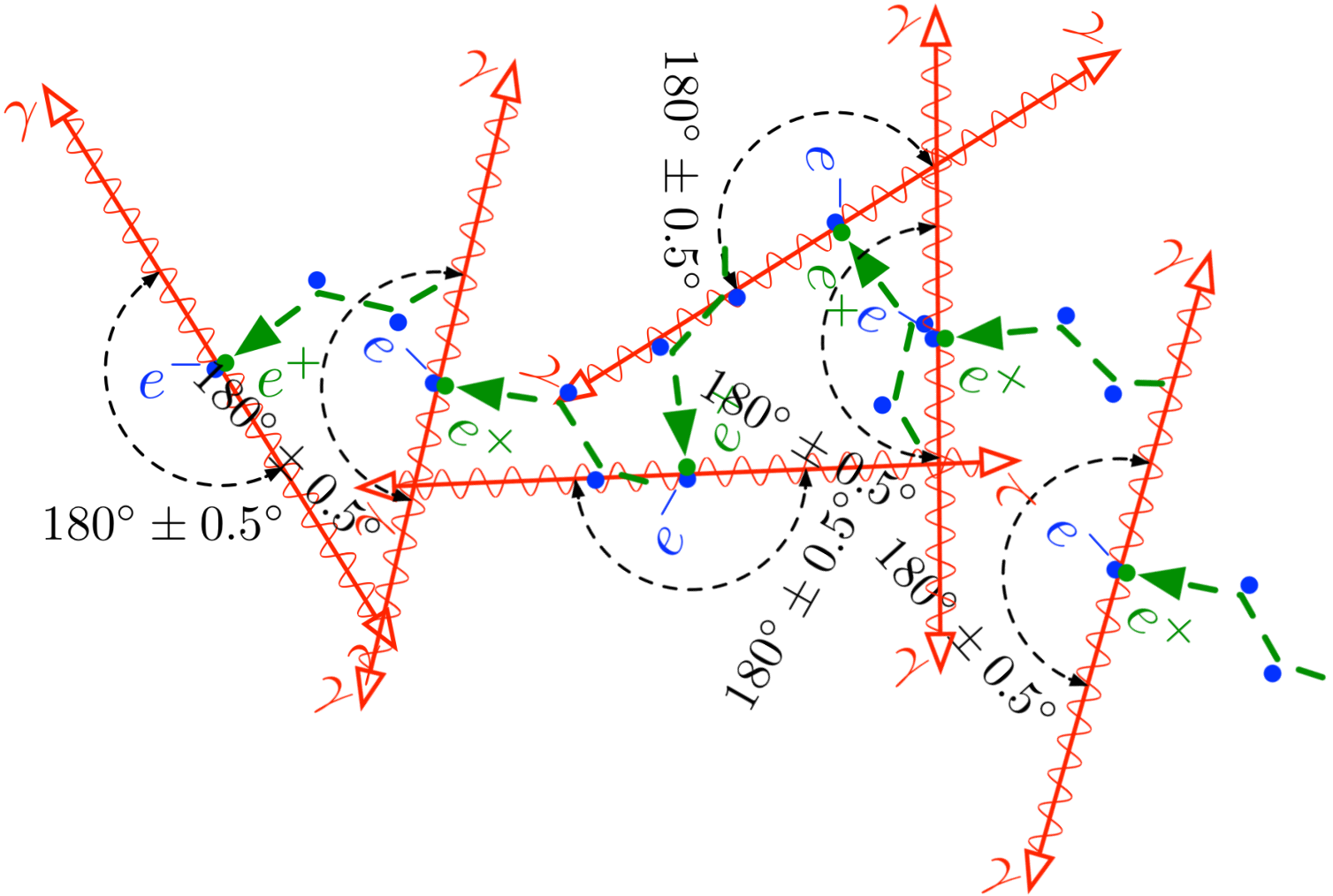


Fluorodeoxyglucose (^{18}F)

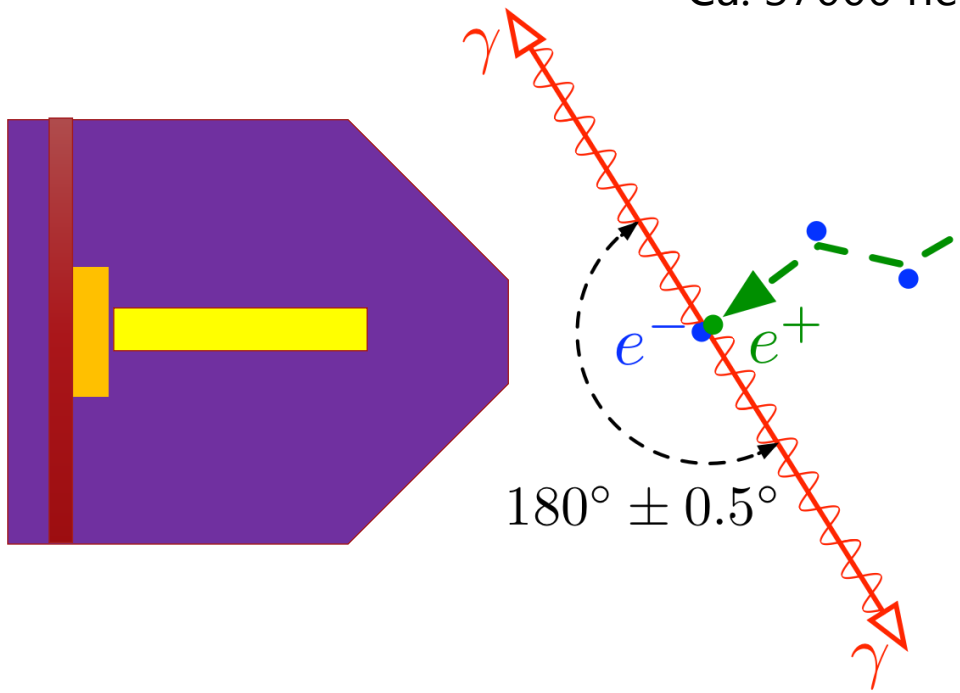
$^{18}O(p,n)^{18}F$

Many per second



Don't "see" gamma

NB: de kilder i bruger har
Ca. 37000 henfald/s



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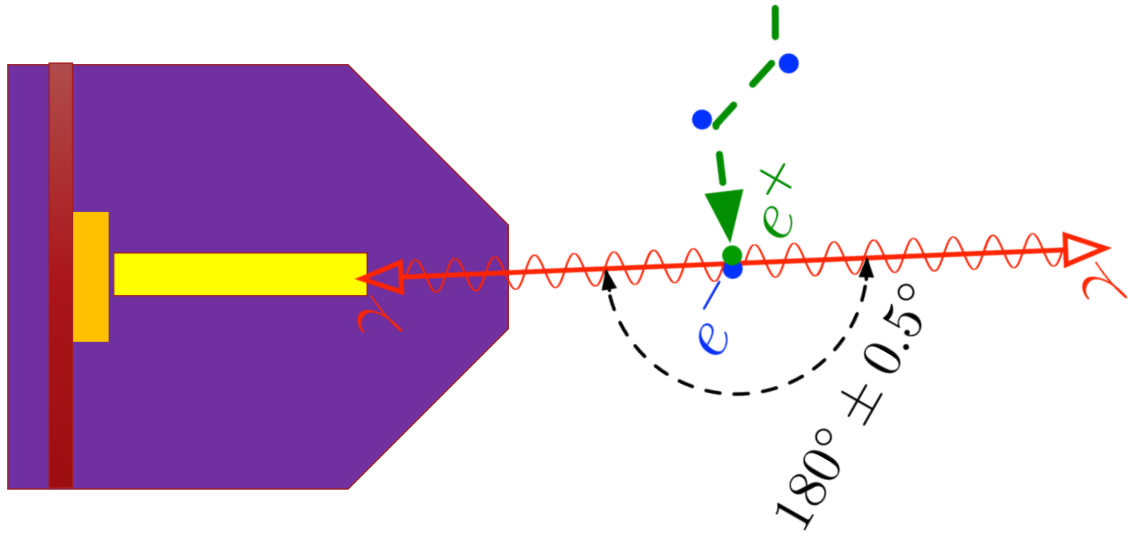
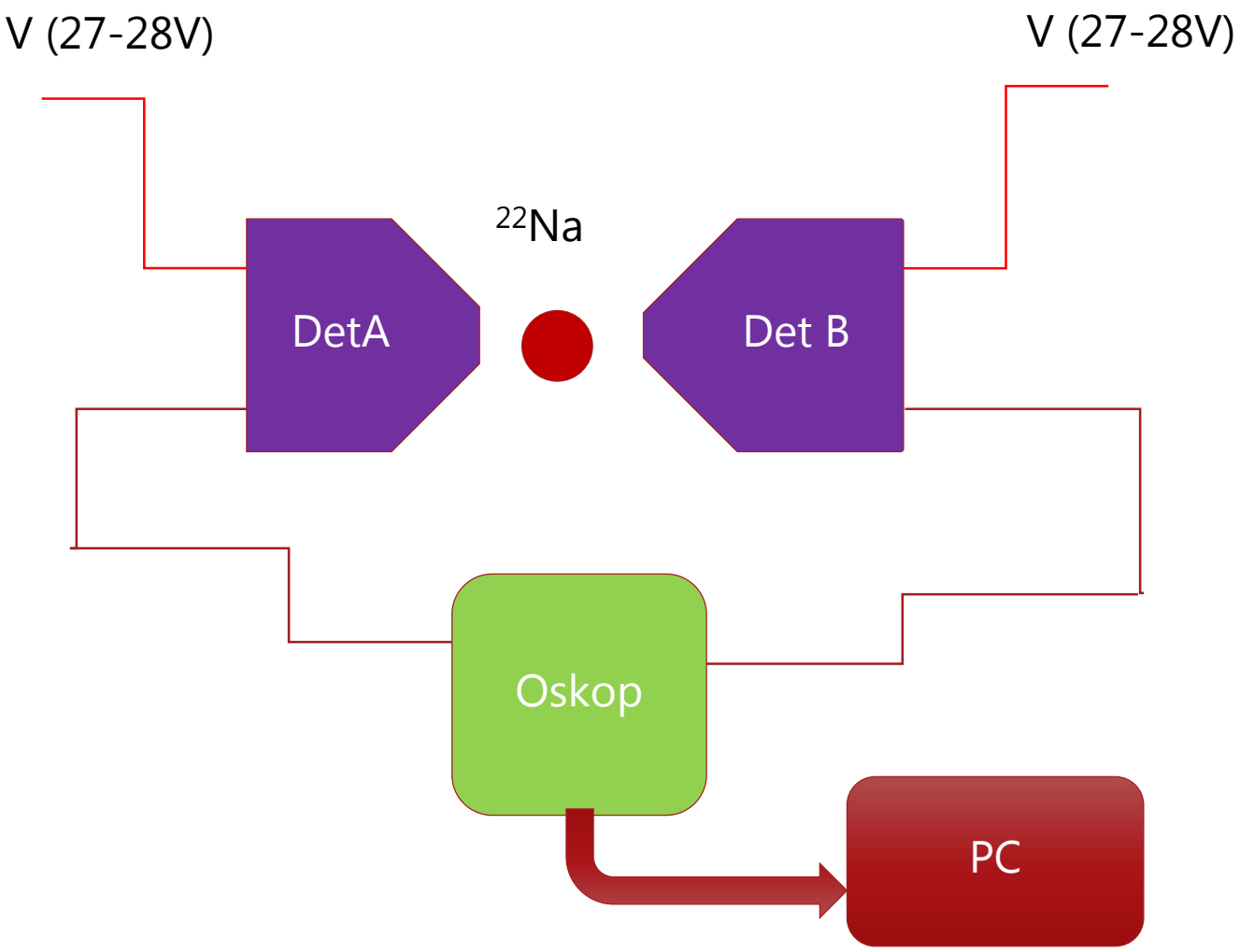
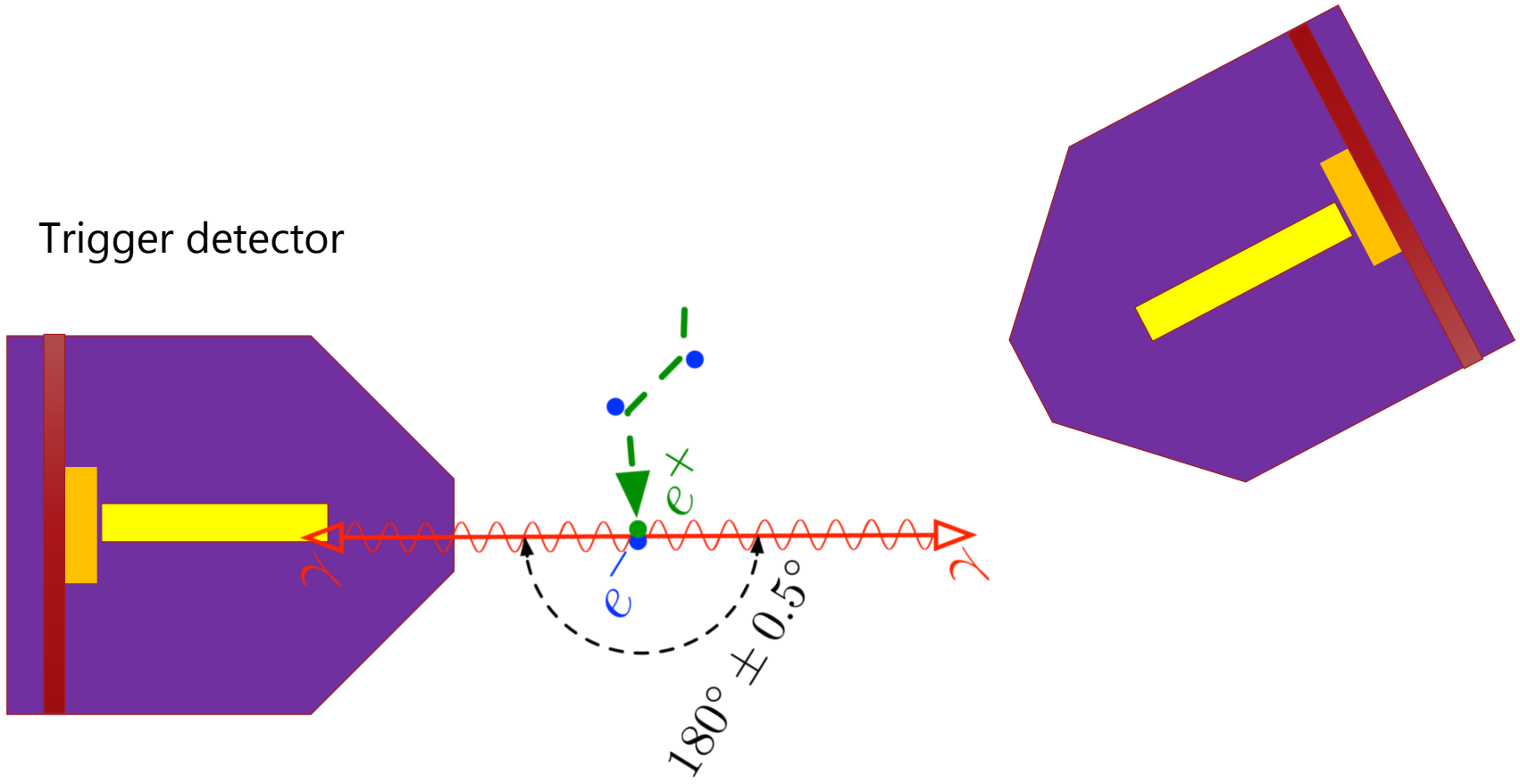


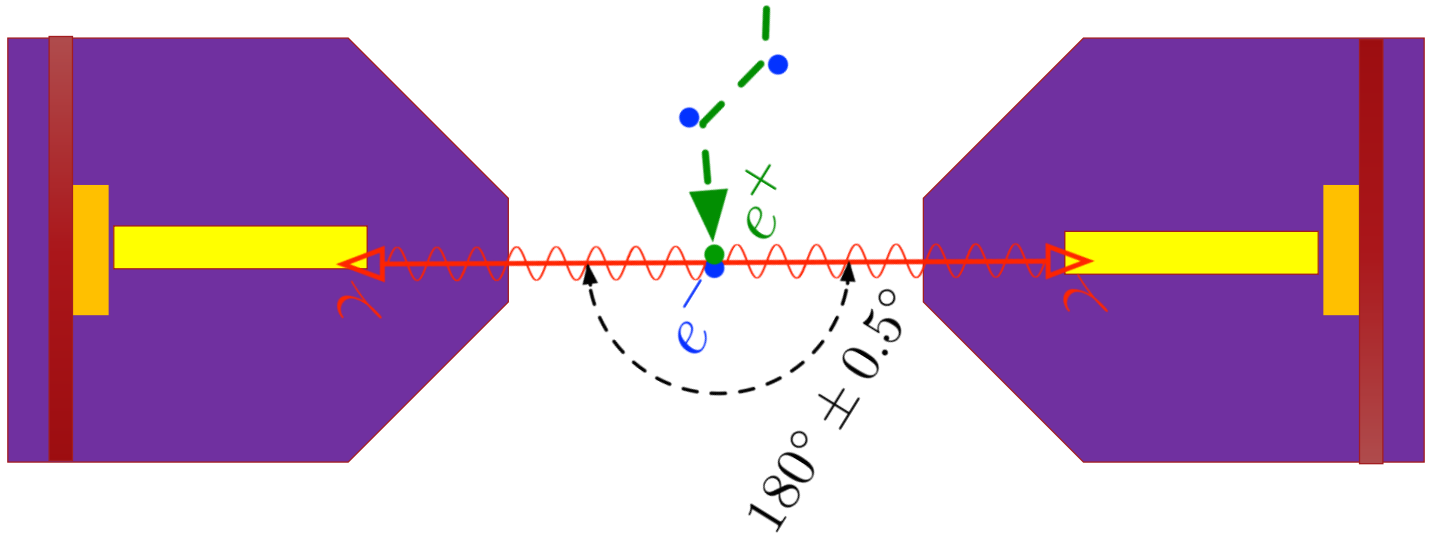
With 2 BiGS:miniPET Scanner



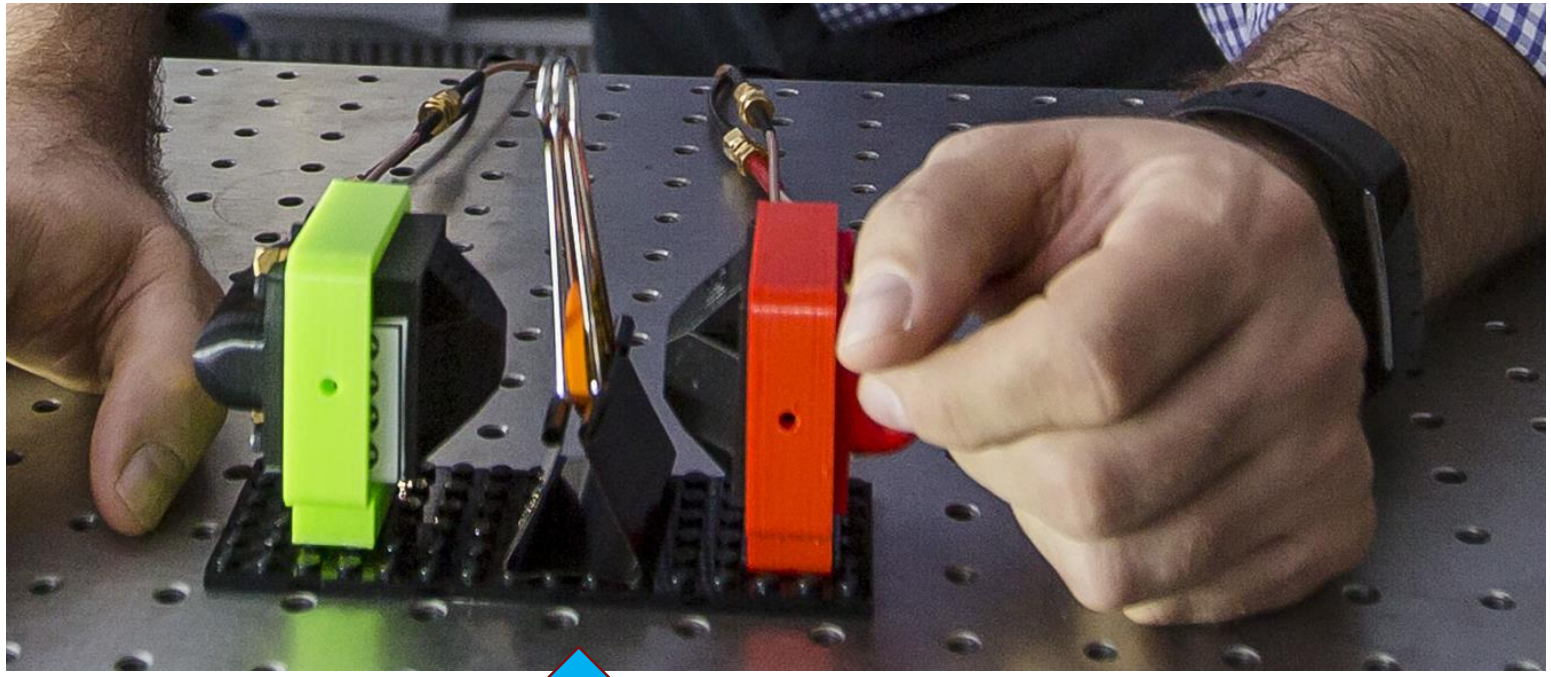
no coincendence



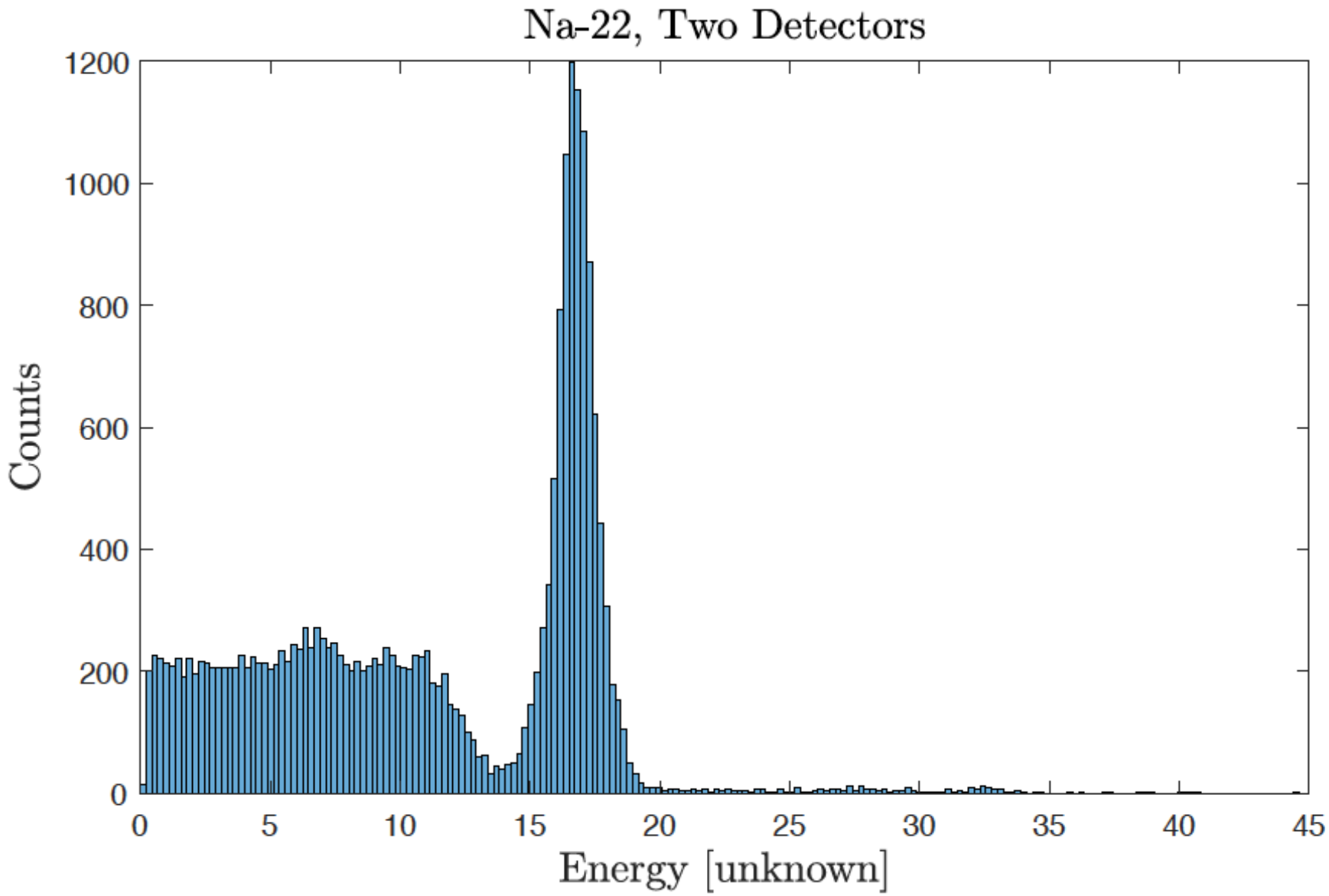
Coincendence!



In real life, it looks like this:



Coincidence* spectrum



*Need to explicitly tell students the technical meaning of ”coincidence” as it is quite different from ordinary usage

Two ways to do this:

- Maximize trigger rate in Det A
- Use DetB to measure at various angles
- **Find coincidence peak at 180°**
- Place DetA and Det B in same plane at 180°
- Move source through scanner
- **When source exactly between A & B: Coincidence!**

Students "see" that

- The two coincident gammas are each 511keV
- **Aha! Rest mass of e is 511keV/c^2**
- **And gammas are always back to back!**
- **So annihilation occurs at rest wrt lab and**
- **$E_{\gamma 1} + E_{\gamma 2} = m_{e-}c^2 + m_{e+}c^2$**
- **That Einstein guy might have been onto something!**

Can be used with younger students

- Demonstrate how PET scanners work
- NB: this is one of S'cool labs cool labs!
- Requires different scaffolding, fewer technical details

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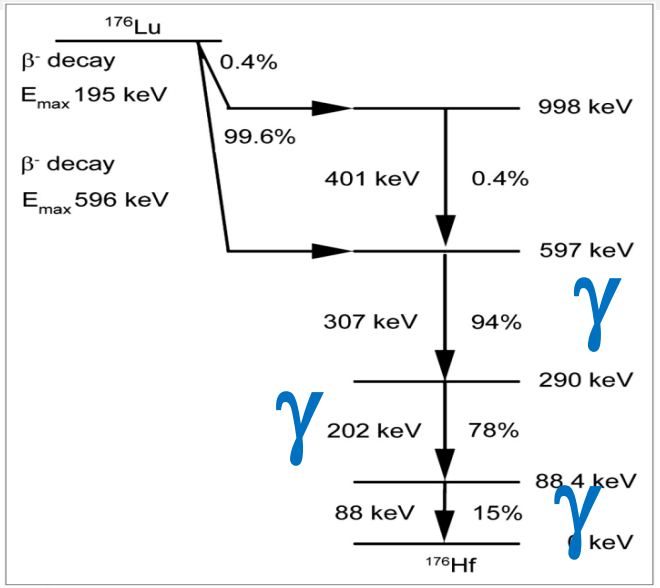
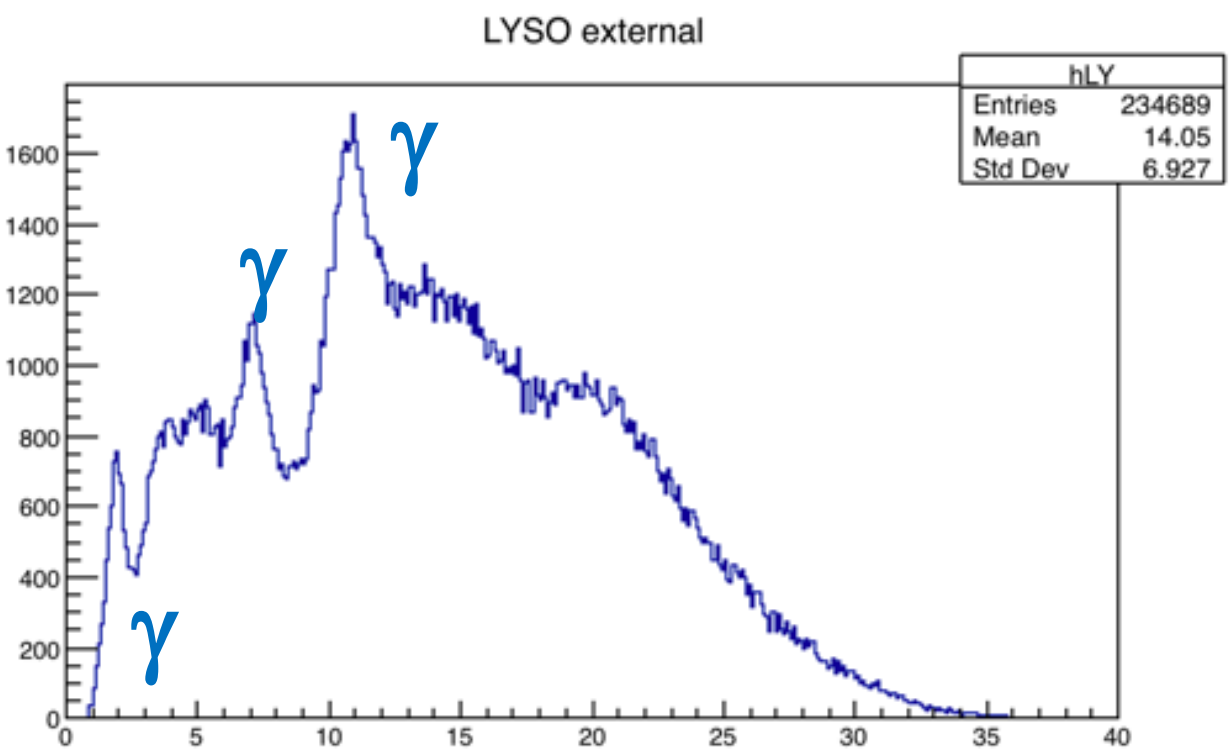
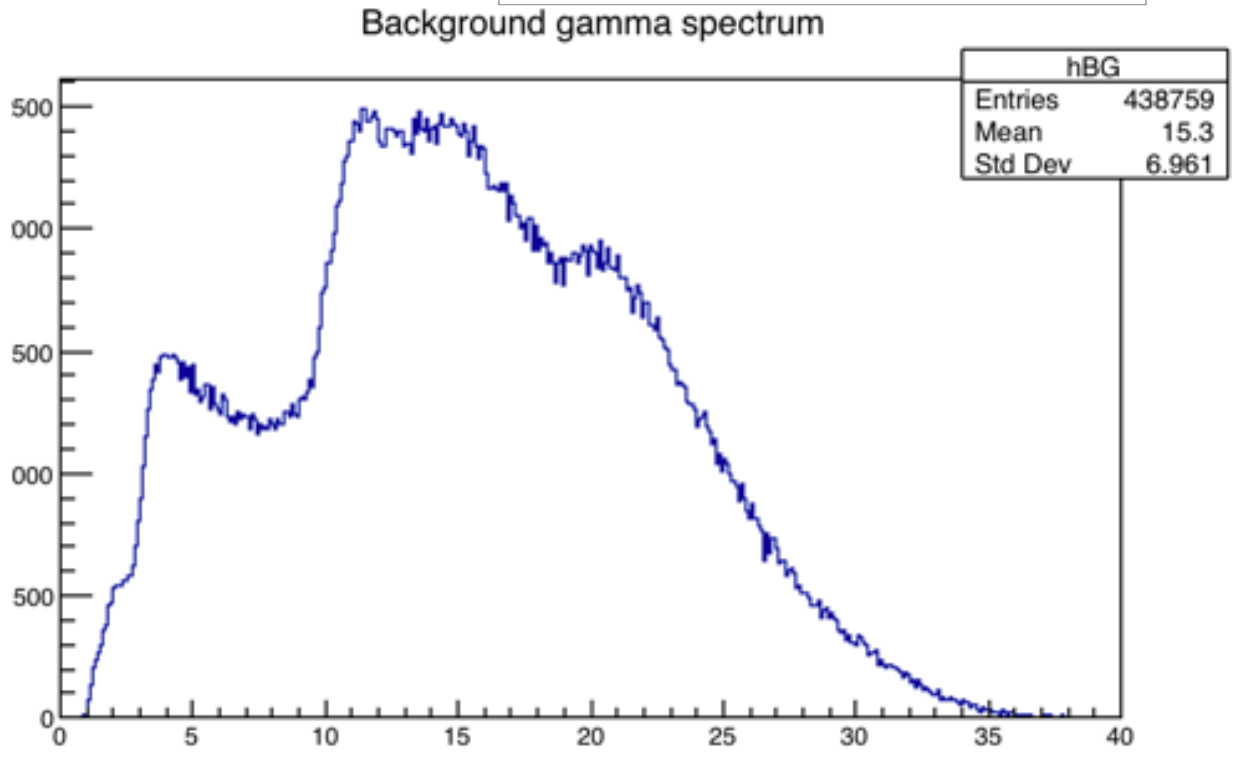
NEXT STEPS

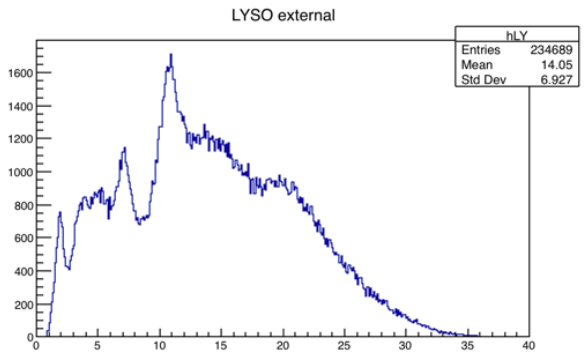
- Upper level labs: background subtraction:
- Look at ^{176}Hf gamma spectrum

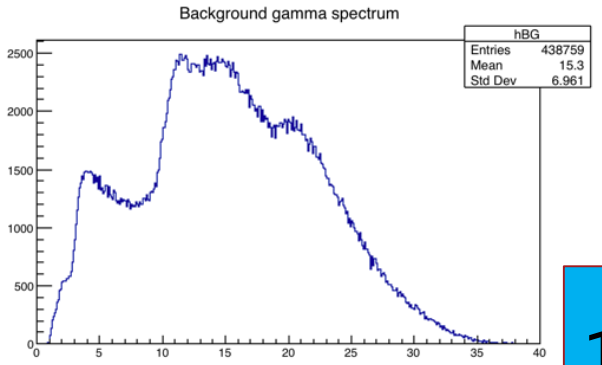




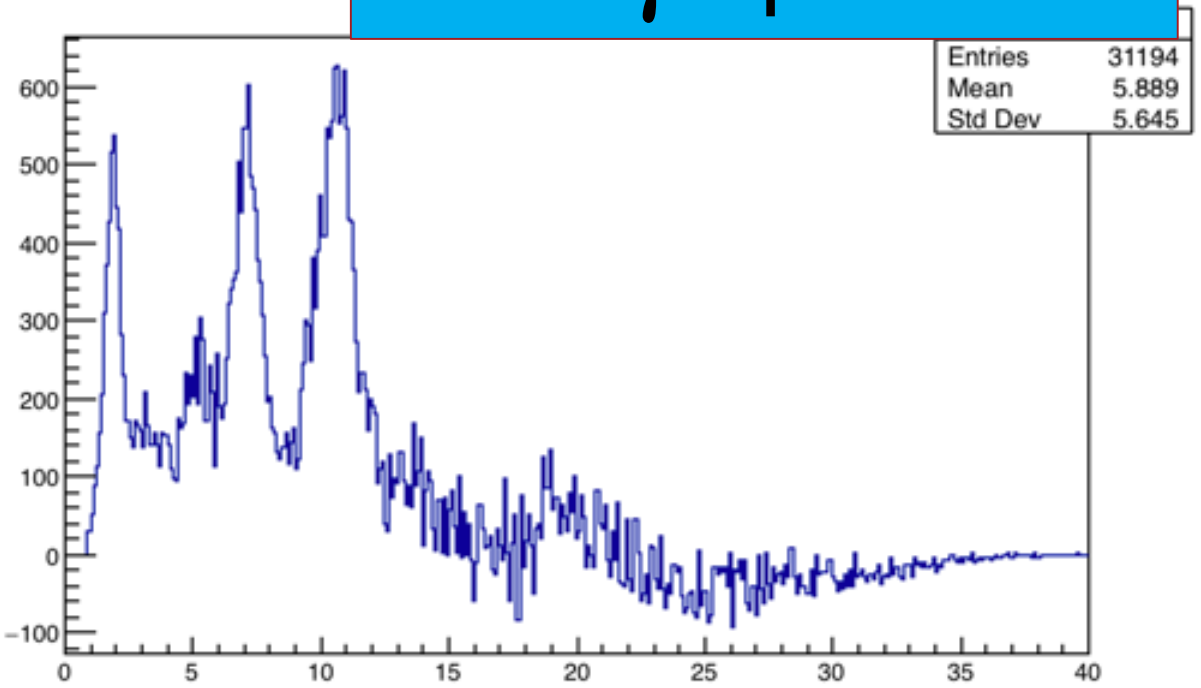


Normalize, subtract et voila!





^{176}Hf γ spectrum



Environmental measurements

- System extremely portable
- Collect gamma spectra anywhere (you're allowed to be with a computer)
- November 2018: local school group to NBI to build and characterize BiGS (resolution, efficiency, P/T)
- September 2019: Class to Fukushima.
  - Can we measure residual ^{137}Cs?

TO DO!

- EVALUATE
- How can we prove that including such activities in outreach and education improve:
- Interest in physics generally
- Interest in Nuclear & particle physics

TO DO!

- For Physics students
- How can we prove that including such activities in improve educational outcomes?
- Increase interest in Nuclear & particle physics?
- Increase technical skills?

BASIC QUESTION:

HOW SHOULD WE MEASURE IMPACT OF INDIVIDUAL ACTIVITIES?

SUMMARY

- Possible to produce performant low cost detectors.
- Consumer grade digital scopes work extremely well in teaching and outreach applications.
- **You can put together a (very small!) PET scanner demonstrator for roughly 500CHF.**
- Highly portable systems might give interesting possibilities for new activities.