PAUL SCHERRER INSTITUT PSI

DFG Deutsche Forschungsgemeinschaft

muX collaboration meeting

2s-1s status and plans

Frederik Wauters

Johannes Gutenberg University Mainz

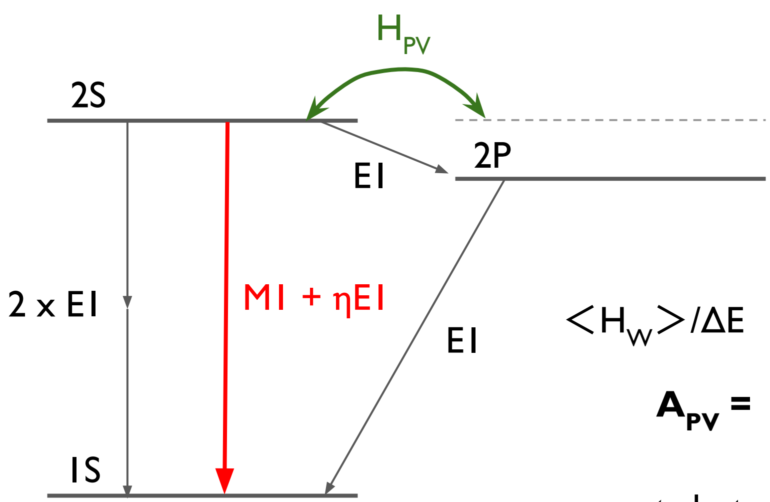
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

JG|U

Cluster of Excellence PRISMA+ Precision Physics, Fundamental Interactions and Structure of Matter

Why is the 2S1S interesting

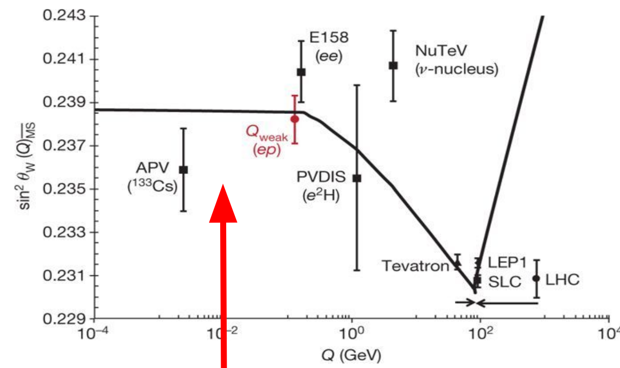
- Atomic parity violation (APV) in muonic atoms arises from an admixture of the opposite-parity 2P state in the 2S state, allowing for E1-M1 interference in the 2S-1S transition
- Is the muon special?
- New physics ~ SM effect?



$<H_W>/\Delta E$

$$A_{PV} = \eta \cdot I_{E1}/I_{M1} \cdot f$$

correct photon fraction



Need < 1% of the SM amplitude

<u>Is the muon special?</u>

Extending theories on muon-specific interactions
Carl E. Carlson and Michael Freid
Phys. Rev. D **92**, 095024 – Published 23 November 2015

Constraints on muon-specific dark forces
Savely G. Karshenboim, David McKeen, and Maxim Pospelov
Phys. Rev. D **90**, 073004 – Published 13 October 2014; Erratum Phys. Rev. D **90**, 079905 (2014)

Testing Parity with Atomic Radiative Capture of μ^-
David McKeen and Maxim Pospelov
Phys. Rev. Lett. **108**, 263401 – Published 29 June 2012

arXiv.org > hep-ph > arXiv:2107.13569

High Energy Physics - Phenomenology

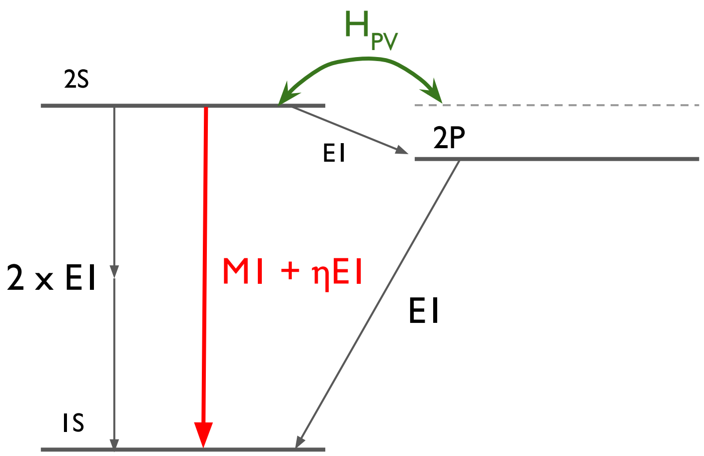
[Submitted on 28 Jul 2021 (v1), last revised 28 Oct 2021 (this version, v2)]

First-Generation New Physics in Simplified Models: From Low-Energy Parity Violation to the LHC

Andreas Crivellin, Martin Hoferichter, Matthew Kirk, Claudio Andrea Manzari, Luc Schnell

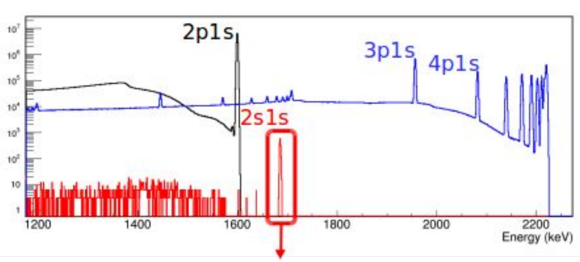
O(1%) New Physics? ⟷ O(1) New Physics?

2S1S μAPV Reach?



- A_{PV} scales with $1/\Delta E_{2P2S} \sim Z^4$, **% level for Z =5-10, 10^{-4} for Z=30**
- BR(1γ)/BR(other) < 10^{-4} → > 10^{-3}
- Low-Z → low P gas target (get rid Auger transitions)
- Big compton Background
- muX @ PSI:
  - Can we get good S/B ?
  - Reach APV experiment? O(SM) or better?

> - Low Z: % Level APV, hard to isolate the 2s1s X-ray
> - Z≃30: Well separated 2S1S with good B.R., low APV amplitude



MC estimate of signal to background: 0.05

muX (Phase I?) has been chasing Z ≃ 30

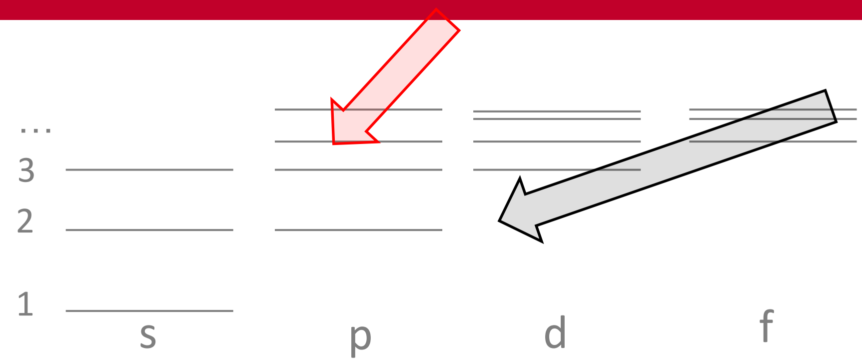
Goal:

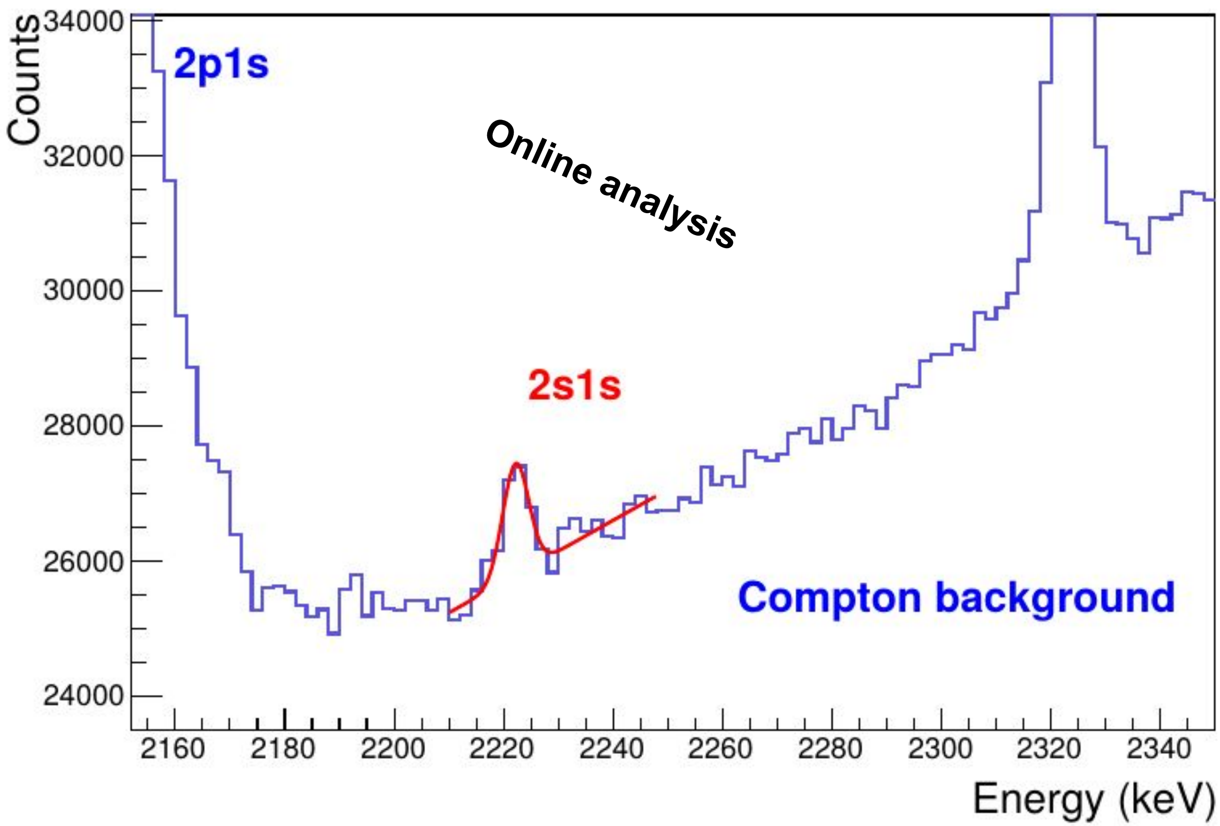
- **Observe 2S1S**
- **Improve SB**
- **Reach APV experiment**

2S1S In Kr

2S1S Kr run

- ❏ Increase 2S population by μH → μKr
- ❏ ~4 fold increase in 2S population
- ❏ 2mm lead shielding against 2s2p + 2p1s PU





2×10^9 muons

6×10^{-4} B.R.

ε = 1.4% @ 2.2 MeV

S/B ~ 1/10, σ_{stat} ~ 10%

2S1S In Kr

2S1S Kr analysis

- ❑ Nilesh Deokar Thesis project
- ❑ Determine 2S population
    - ❑ Detector efficiency
    - ❑ Reconstruct X-ray cascade
    - ❑ Timing and understand Backgrounds

Alex' Run 2017 analysis

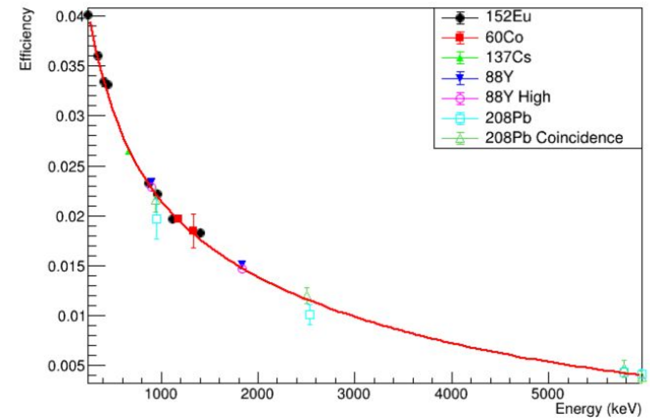
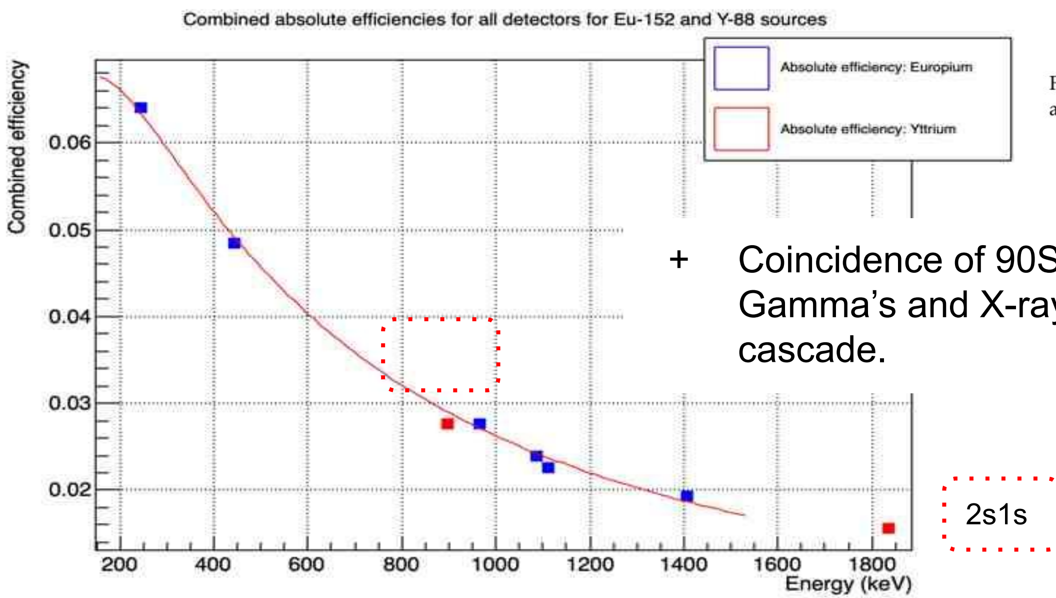


Figure 3.53: The efficiency calibration of the Ge detector array without Ge1B and Ge11 for 2017.



\+ Coincidence of 90Sr Gamma's and X-ray cascade.

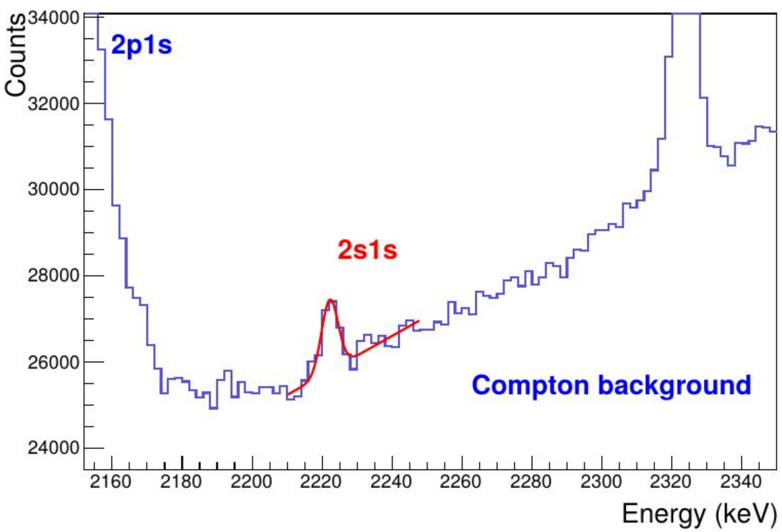
The systematic error on the detector efficiency at E_{2s1s} = 2.2 MeV and at the feeding lines (around 400 keV) propagates to the Branching ratio.

2S1S In Kr

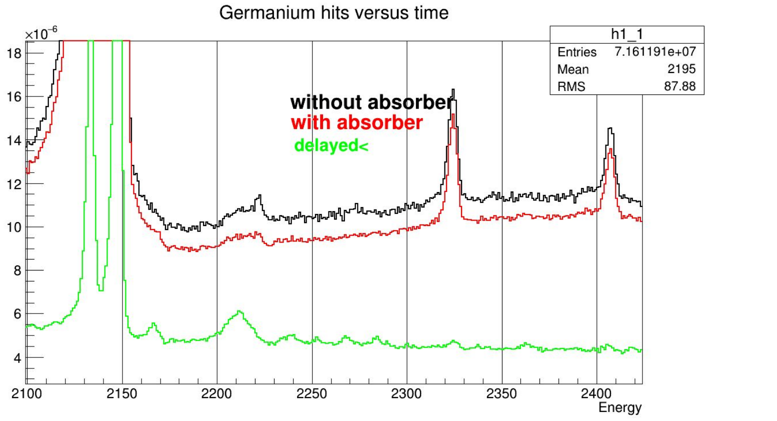
2S1S Kr analysis

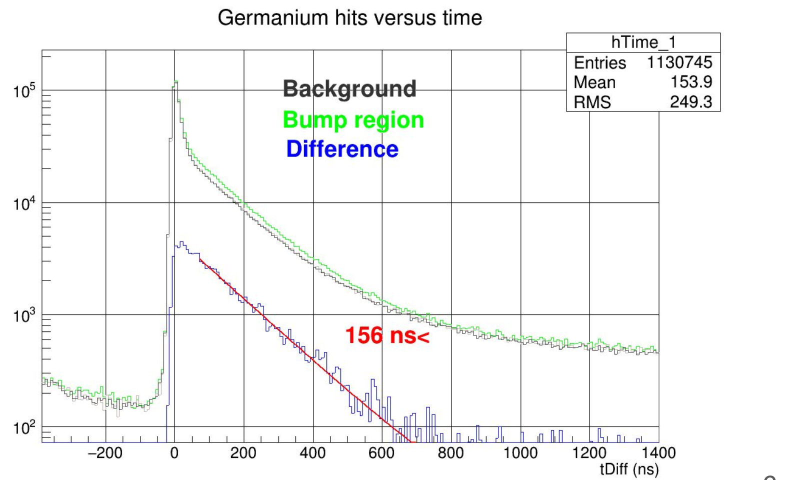
- Nilesh Deokar Thesis project
- Determine 2S population
    - Detector efficiency
    - Reconstruct X-ray cascade
    - Timing and understand Backgrounds

Quick online analysis gives clear peak:



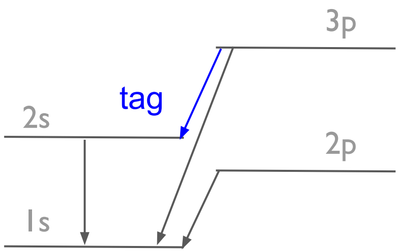
Neutrons & Michel electrons, Compton from >3p1s, and a *nuclear bump*

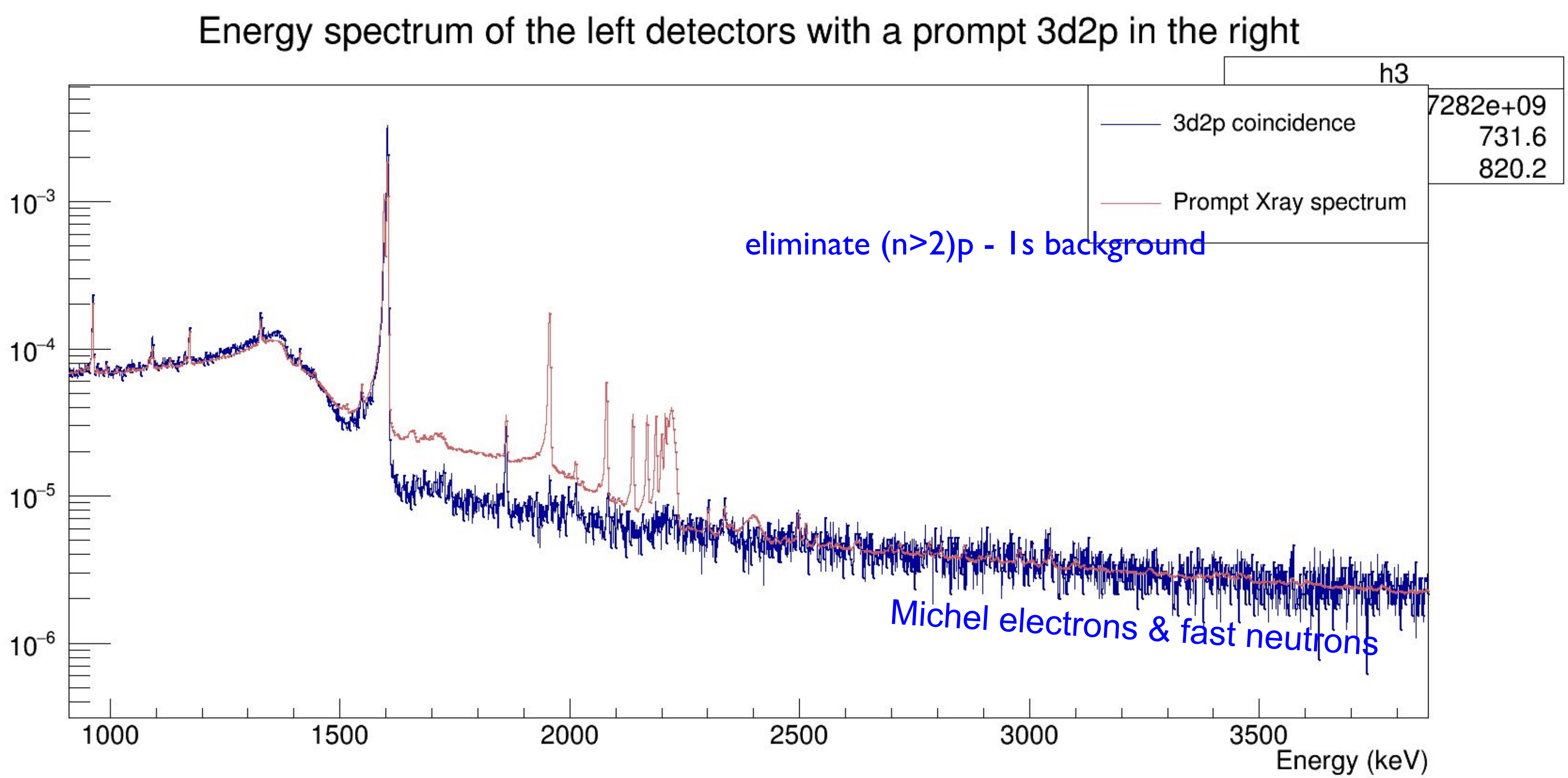




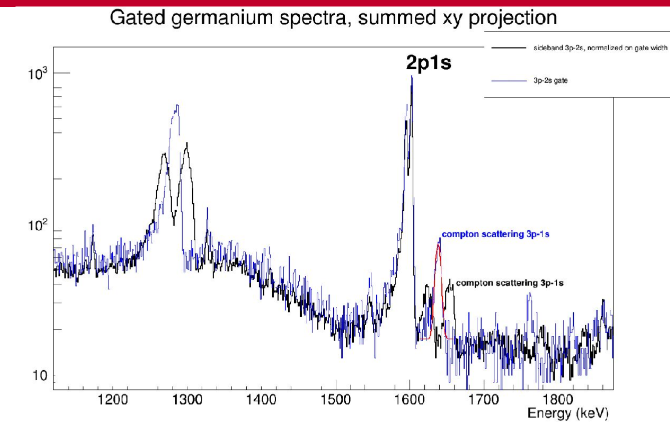
2S1S in Zn (γ tagging)

γ-γ coincidences



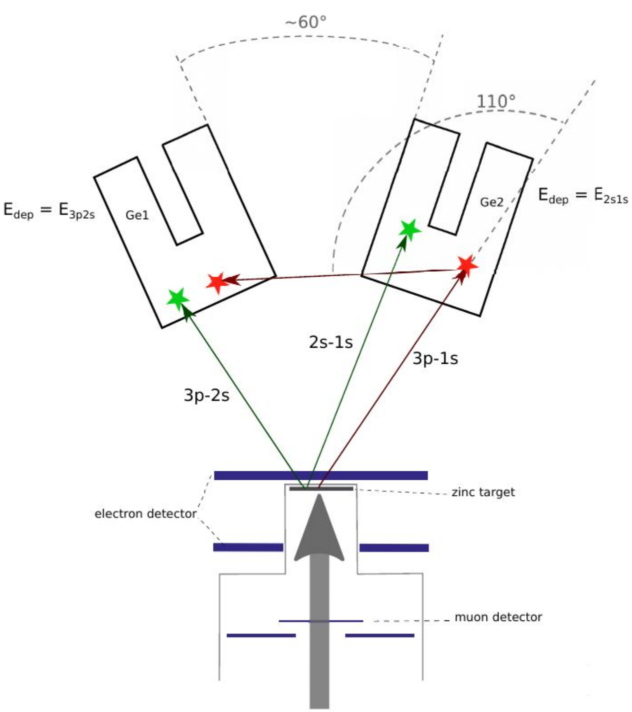


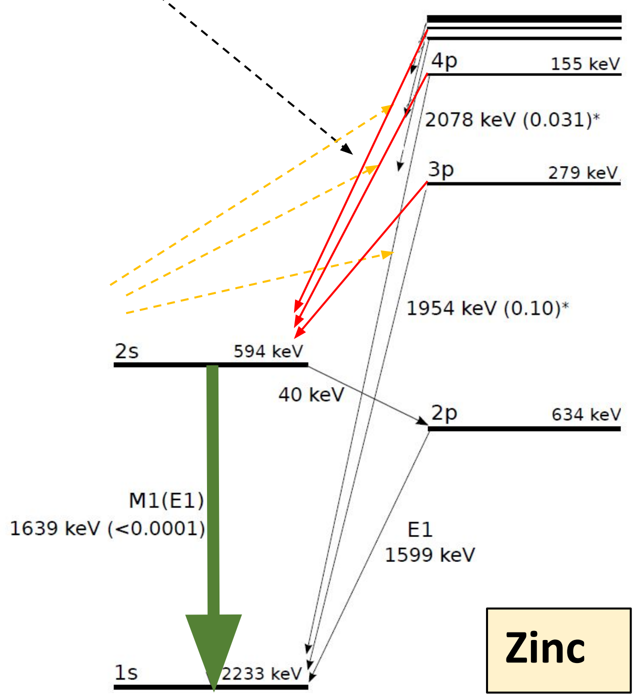
2S1S in Zn (γ tagging)



2S Tagging

- ❑ Obtain a purified 2S sample
- ❑ Efficiency^2 dependence
- ❑ 180 degree detector pairs **2019 run**



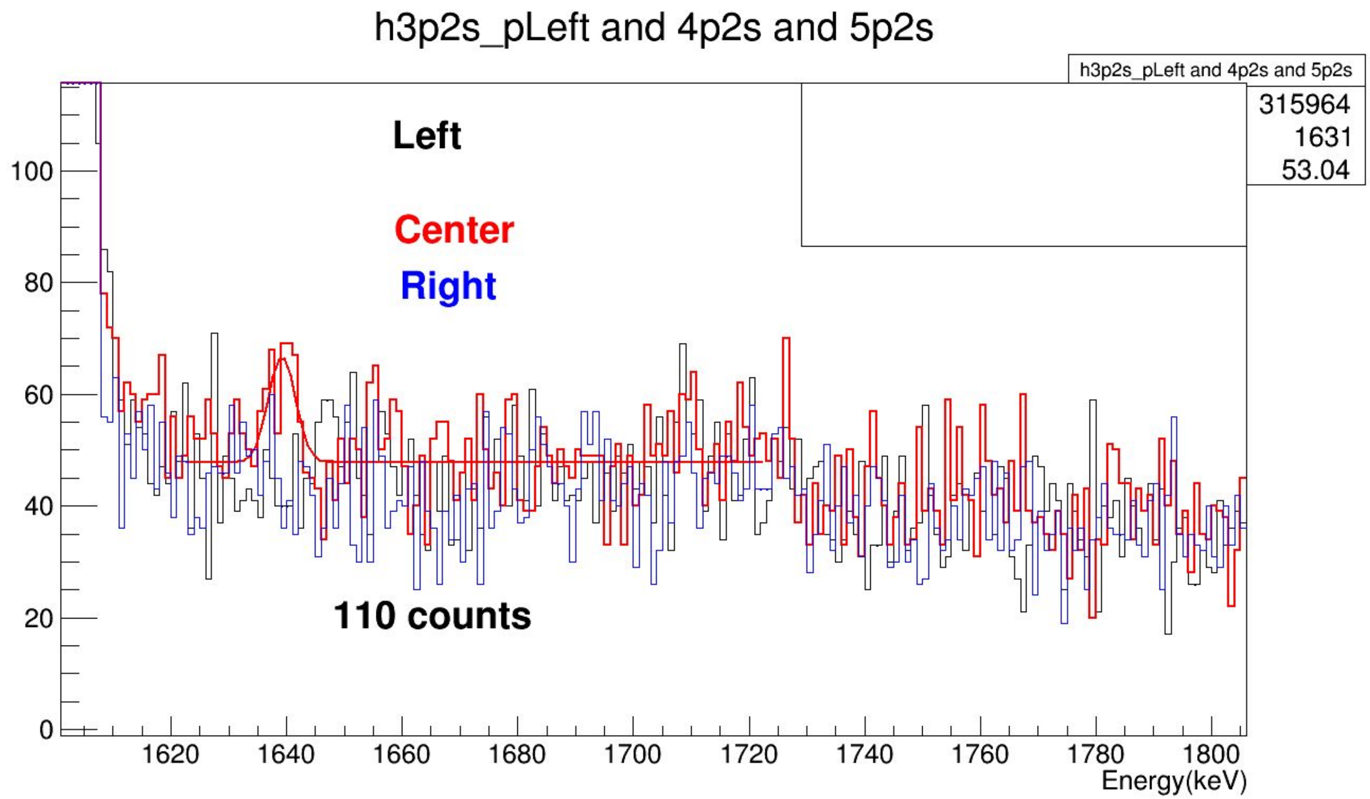


2S1S in Zn (γ tagging)

2S Tagging

- ❑ Obtain a purified 2S sample
- ❑ Efficiency^2 dependence
- ❑ 180 degree detector pairs
- ❑ 10^{10} muon stops after cuts

S/B = ⅓ ?

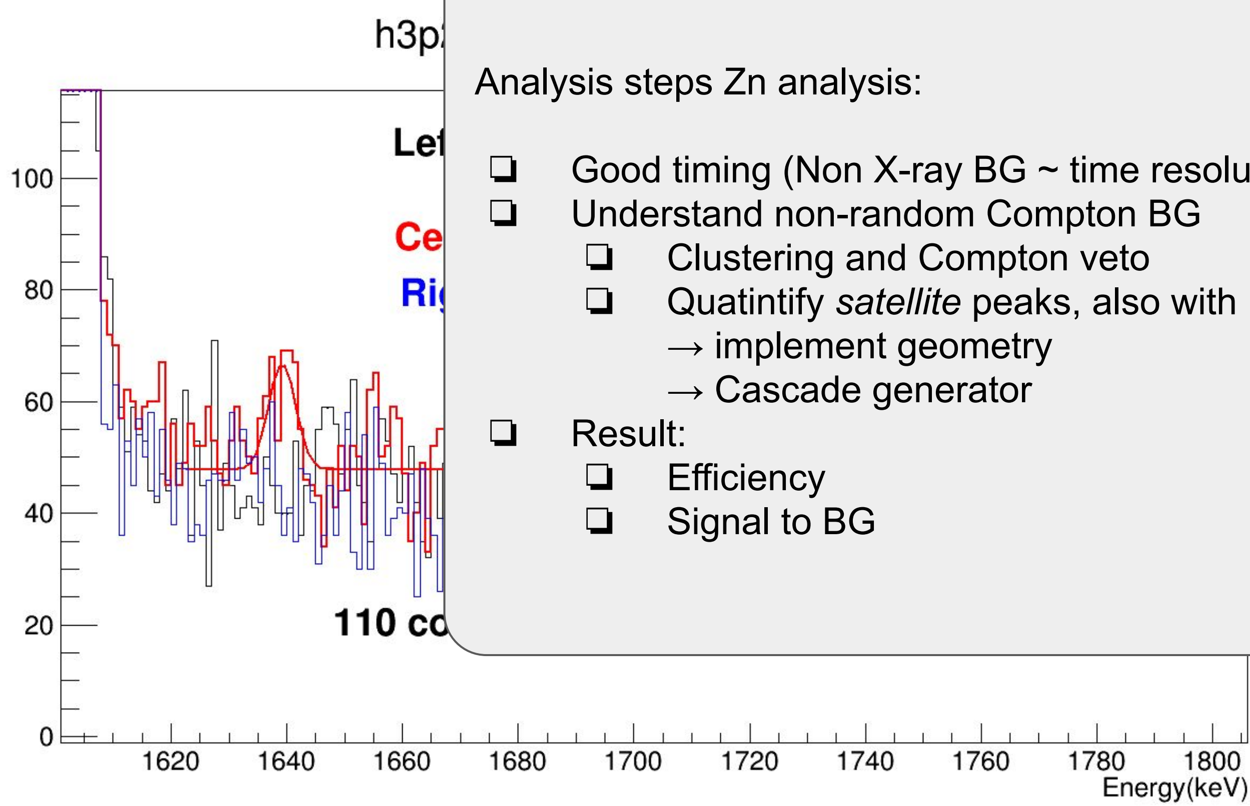


2S1S in Zn (γ tagging)

2S Tagging

- ❏ Obtain a purified 2S sample
- ❏ Efficiency^2 dependence
- ❏ 180 degree detector pairs
- ❏ 10^{10} muon stops after cuts

S/B = ⅓ ?



Analysis steps Zn analysis:

- ❏ Good timing (Non X-ray BG ~ time resolution)
- ❏ Understand non-random Compton BG
  - ❏ Clustering and Compton veto
  - ❏ Quatintify *satellite* peaks, also with **MC**
    → implement geometry
    → Cascade generator
- ❏ Result:
  - ❏ Efficiency
  - ❏ Signal to BG

Outlook

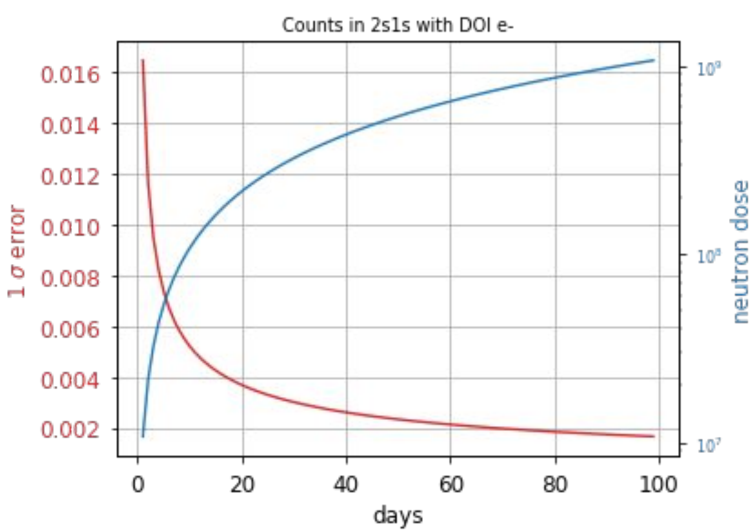
- Bring Kr analysis up to publication level. First observation of 1S2S photon!
- Zn analysis is trickier (challenge to finish within Nilesh thesis time frame)
- Technical TODOs awaiting:
  - An Efficiency we fully trust
  - Monte-Carlo, X-ray cascade generator
  - Machine learning timing implementation

Outlook

- Bring Kr analysis up to publication level. First observation of 1S2S photon!
- Zn analysis is trickier (challenge to finish within Nilesh thesis time frame)
- Technical TODOs awaiting:
  - An Efficiency we fully trust
  - Monte-Carlo, X-ray cascade generator
  - Machine learning timing implementation

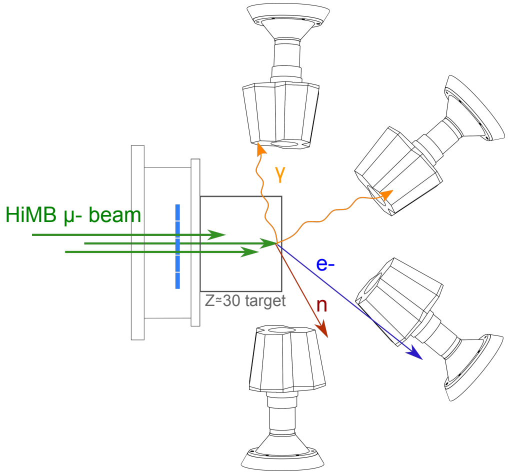
Beyond

- Reach of μAPV experiment explored at HiMB physics case workshop.
  - With γ tagging and HPGe detector array, we can`t fully exploit high beam intensities.
  - 10^{-4} < reach < 10^{-3} possible with HPGe- HiRes Scintillator combo
- Low Z interesting again?
- Beyond HPGe detectors
  - Higher resolution with e.g. transition edge det
- Are BSQED tests more feasible



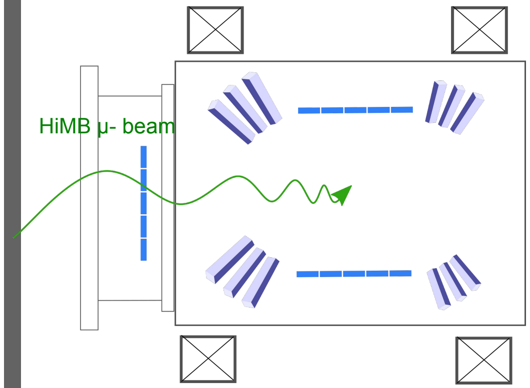
μAPV with HiMB

and other precision muonic atom experiments



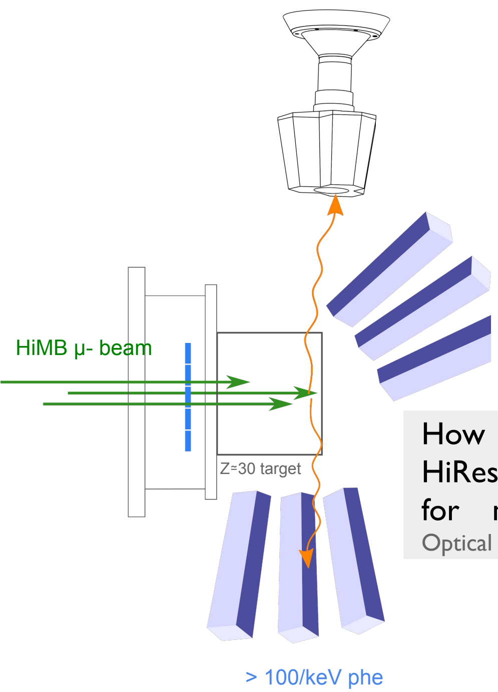
- HPGe detectors have both high resolution and efficiency
- n-dose and rate limited
- > πE1 intensities are beneficial

With a HPGe-array, one can **not** fully exploit HiMB intensities.



- Z = 5-10 APV experiments have a potential < SM reach
- Building on work of L. Simons and Co
- Need to suppress Auger transitions
- Need to develop additional techniques to differentiate 2s1s from 2p1s X-rays, such as K-edge absorption

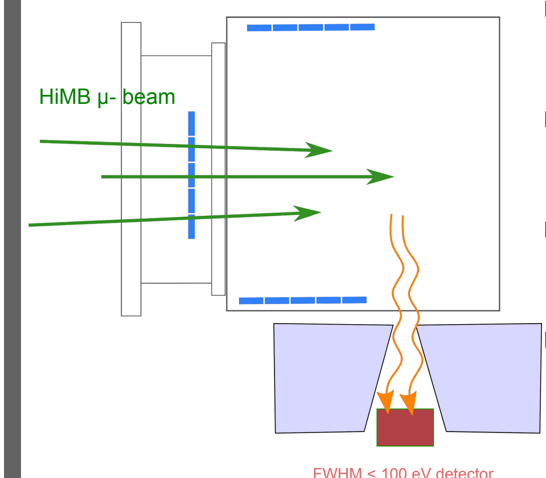
Can we stop a HiMB beam in a low pressure gas target?



- A coincidence experiment with a close scintillator and a HPGe far detector has a 10^{-3} reach
- A pure high-resolution has a potential 10^{-4} reach
- SM μAPV ≤ 10^{-4}

How well can current and future HiRes scintillator detectors perform for muonic X-ray measurements?
Optical Materials: X 1 (2019) 100021

Solid ≥O(SM) amplitude APV experiment motivation?



- < 100 eV resolution can separate in energy most transitions of interest
- For Z≈5, 10^{-3} precision is worth-while (1 cm2 at 1m for 100 days)
- Other high-resolution measurements such as BSQED? arXiv:2011.09715
- Can we efficiently operate new detector technologies such as cryogenic microcalorimeter NIMA **770**, 203-210 (2015)

Should we bring high-resolution (<100 eV) X-ray spectroscopy techniques to muonic X-ray studies @ PSI?