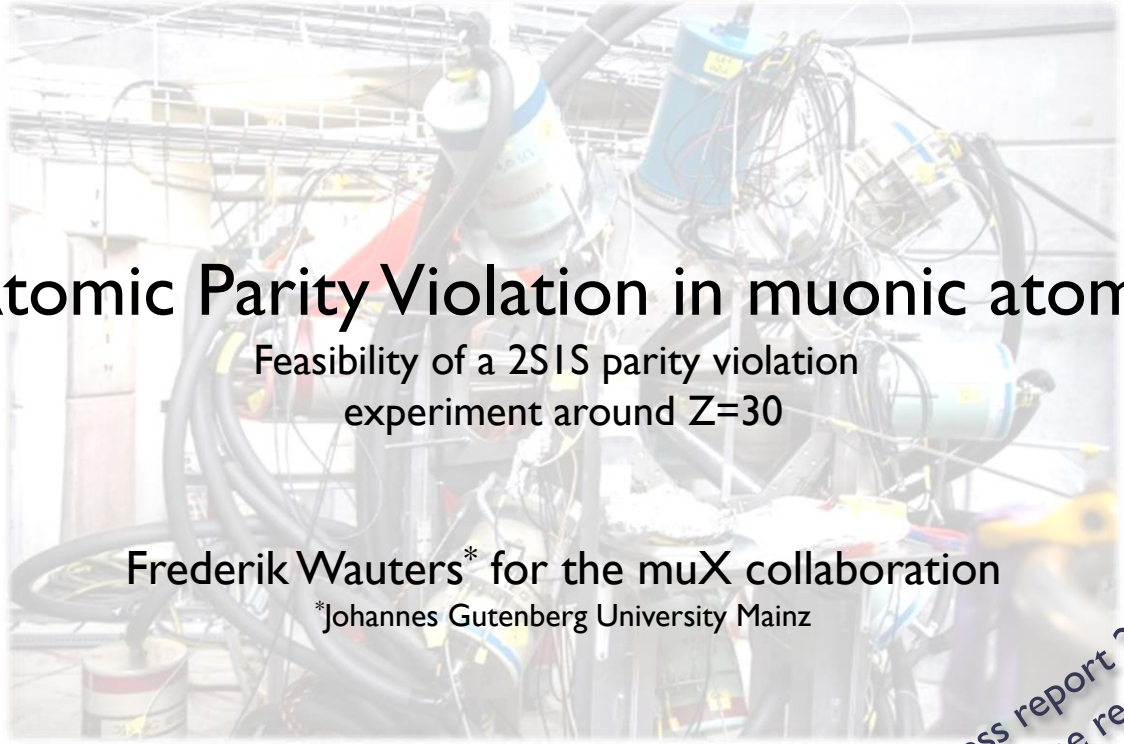

Atomic Parity Violation in muonic atoms

Feasibility of a 2S1S parity violation experiment around Z=30

Frederik Wauters* for the muX collaboration

*Johannes Gutenberg University Mainz

Progress report 2017-2018
Beam-time request 2019

JOHANNES GUTENBERG UNIVERSITÄT MAINZ
JG|U
PAUL SCHERRER INSTITUT PSI
DFG Deutsche Forschungsgemeinschaft
Cluster of Excellence PRISMA Precision Physics, Fundamental Interactions and Structure of Matter

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Can we measure APV in muonic X-rays?

- Proposed by Feinberg and Chen (1974)
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- 2S1S 2γ in μB, stopping muon in B_2H_6 + He
  - Low pressure target limits rate.
  - E(2S1S) ≈ E(2P1S)

PHYSICS REPORTS (Review Section of Physics Letters) 118, No. 4 (1985) 179–238. North-Holland, Amsterdam

THE NEUTRAL WEAK CURRENT IN MUONIC ATOMS

John MISSIMER*

*Institut für Physik, Johannes-Gutenberg Universität, 6500 Mainz, Federal Republic of Germany and Swiss Institute for Nuclear Research,** 5234 Villigen, Switzerland*

Leopold M. SIMONS

Kernforschungszentrum Karlsruhe, Institut für Kernphysik und Universität Karlsruhe, Institut für Experimentelle Kernphysik Karlsruhe, Federal Republic of Germany

PHYSICAL REVIEW D VOLUME 10, NUMBER 1 1 JULY 1974

$2S_{1/2} \to 1S_{1/2}$ + one-photon decay of muonic atoms and parity-violating neutral-current interactions*

G. Feinberg†

Physics Department, Rockefeller University, New York, New York 10021 and Physics Department, Columbia University, New York, New York 10027

M. Y. Chen

Physics Department, Columbia University, New York, New York 10027

(Received 5 February 1974)

VOLUME 78, NUMBER 23 PHYSICAL REVIEW LETTERS 9 JUNE 1997

Metastability of the Muonic Boron 2*S* State

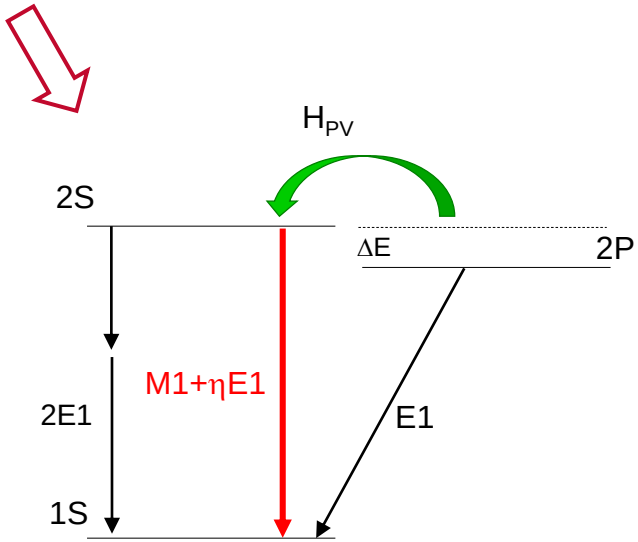
K. Kirch,[1] D. Abbott,[2,*] B. Bach,[2] P. DeCecco,[1,†] P. Hauser,[1] D. Horváth,[1,‡] F. Kottmann,[3] J. Missimer,[1] R. T. Siegel,[2] L. M. Simons,[1] and D. Viel[2]

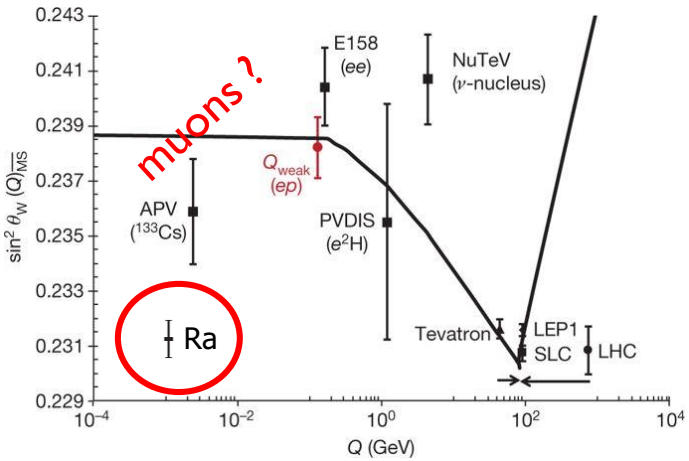
[1]*Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland*

[2]*College of William and Mary, Williamsburg, Virginia 23185*

[3]*Institut für Teilchenphysik, ETH-Hönggerberg, CH-8093 Zürich, Switzerland*

(Received 18 December 1996; revised manuscript received 8 May 1997)





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  - ➢ Lepton Universality
    - OK at Z pole
    - SM like at 50 GeV^2 (muon scattering)
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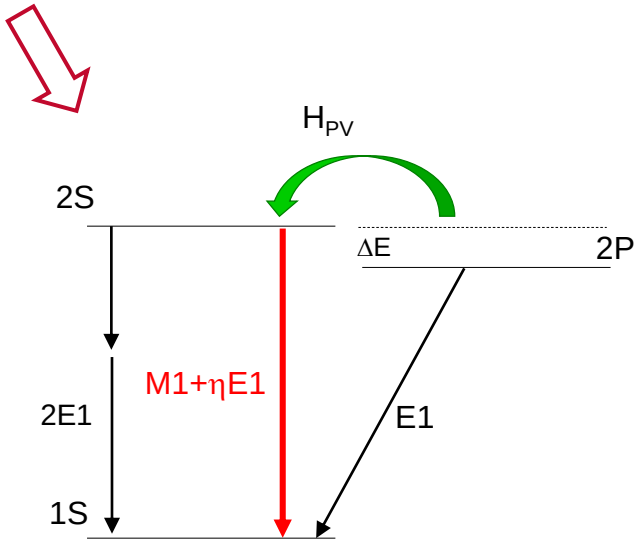

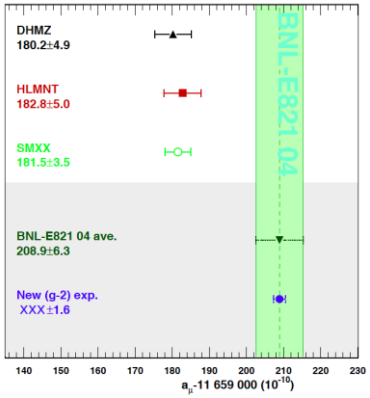

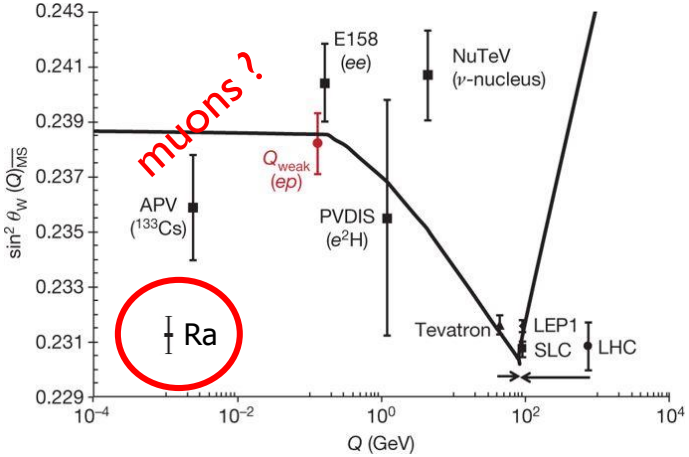

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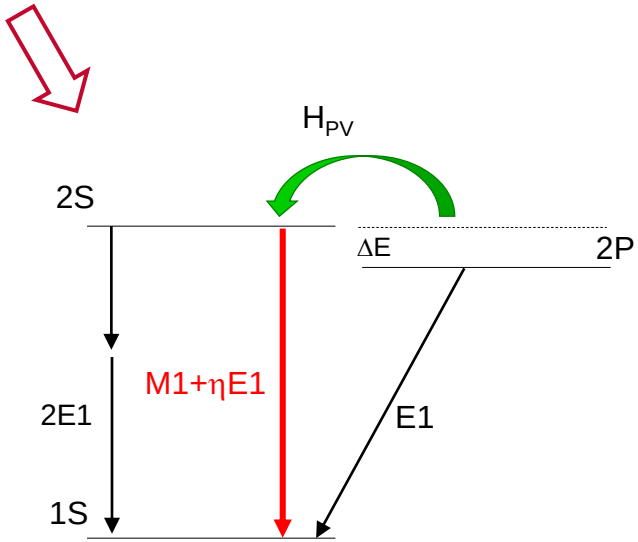
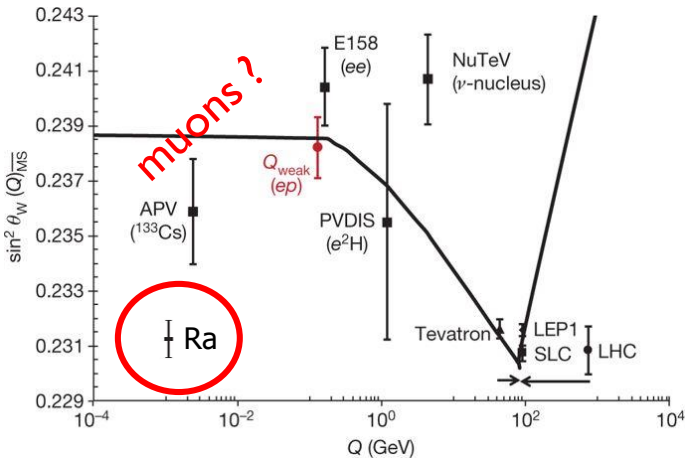
- New U(1) forces for right-handed muons





"It would be quite foolish not to explore additional possibilities of testing "NC-like" signatures in muons at low energy." (M. Pospelov)

Testing Parity with Atomic Radiative Capture of μ^-

David McKeen and Maxim Pospelov
Phys. Rev. Lett. **108**, 263401 – Published 29 June 2012

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

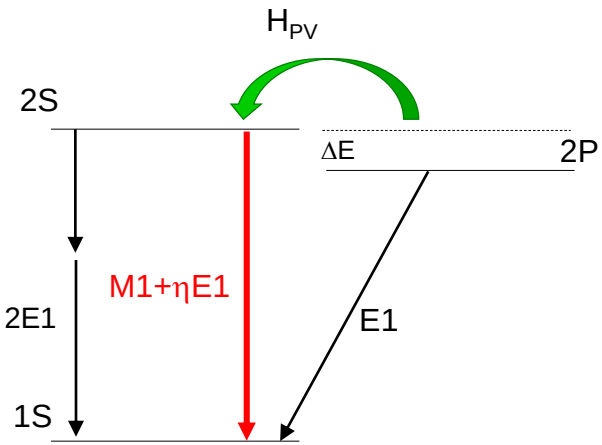
Savely G. Karshenboim, David McKeen, and Maxim Pospelov
Phys. Rev. D **90**, 073004 – Published 13 October 2014; Erratum Phys. Rev. D **90**, 079905 (2014)

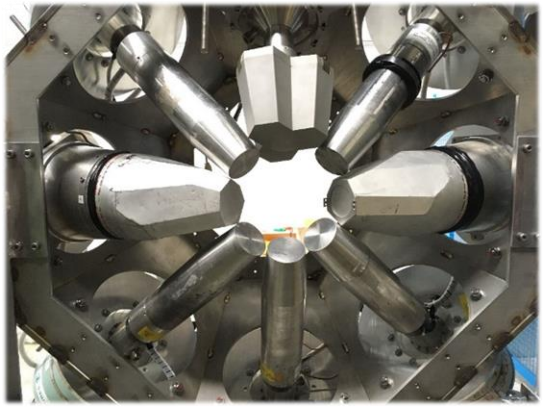
Why the 2S1S X-ray?

A case (and compromise) for Z≈30

<u>The good</u>

- ΔE is O(50 keV) = no overlapp with 2P1P
- Natural B.R. to 2S1S $\frac{\Gamma^{1\gamma}_{2S1(S/P)}}{\Gamma_{2S1(S/P)}} \approx 1.4\ 10^{-3}$
  - ➢ *Auger* depopulation no longer dominating
- X-ray energies 300-2500 keV:
  high efficiency HPGe detectors can be used





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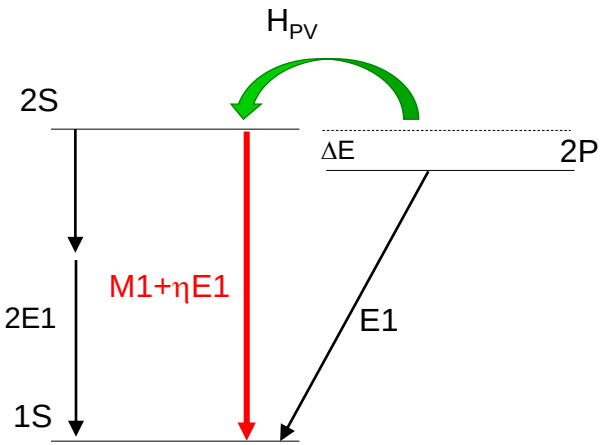
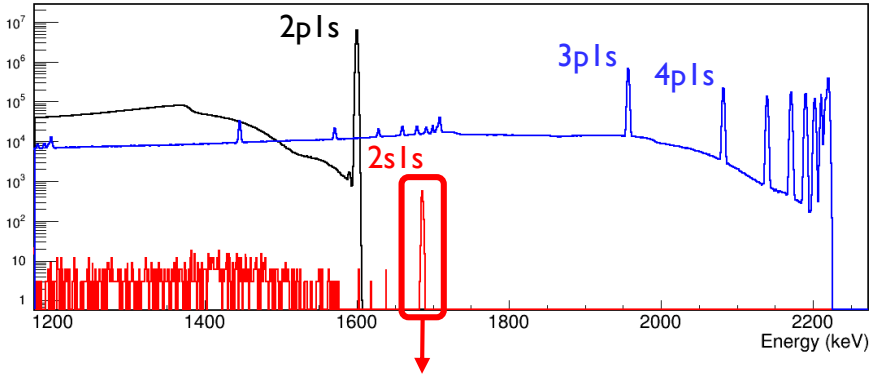


The bad/ugly

- Total BR 10^{-4} x SM APV of 10^{-4} = quite small
- Compton background from (n>2)P1S transition



MC estimate of signal to background: 0.05

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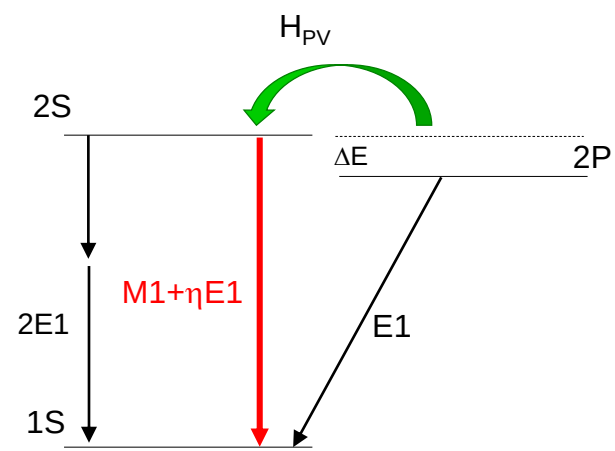

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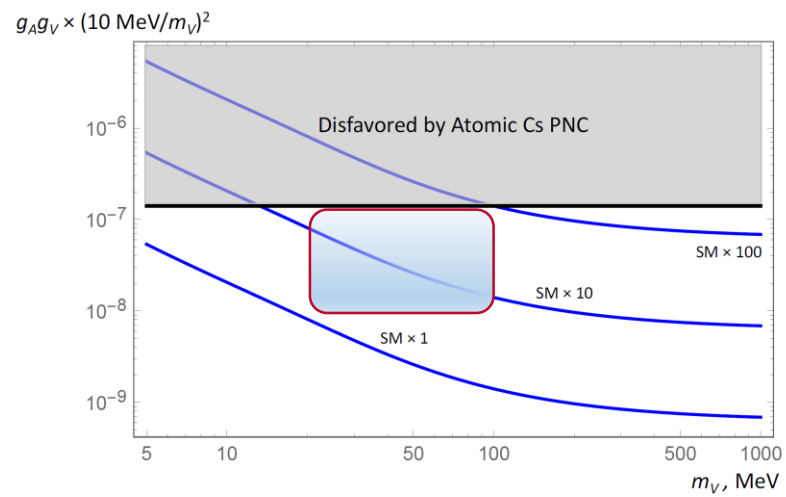

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Thus:

- With ~100 days, 100 kHz μ^- (aka typical πE1 experiment)
  - O(1) SM experiment
  - A first generation experiment will be a search for new physics

2S1S within muX

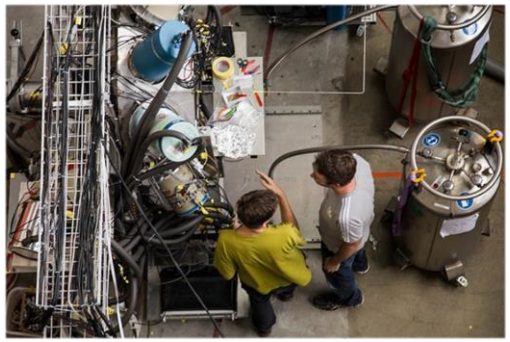
What is 2s1s within muX?

- Operating HPGe detectors at PSI, initial measurements ← 2015-2016
- Observe the single photon M1 transition for the **first** time ← 2017-2018, reported here
- Achieve a signal to background of O(1) on the transition ← ongoing, this beam time request!
- Determine the optimal APV odd observable
- Determine the reach of a APV experiment

} PhD project

- Mainz effort, but very close collaboration with the 226Ra efforts at PSI

Supported by DFG, 3 year project WA4157/1-1,
Looking for a motivated PhD student!



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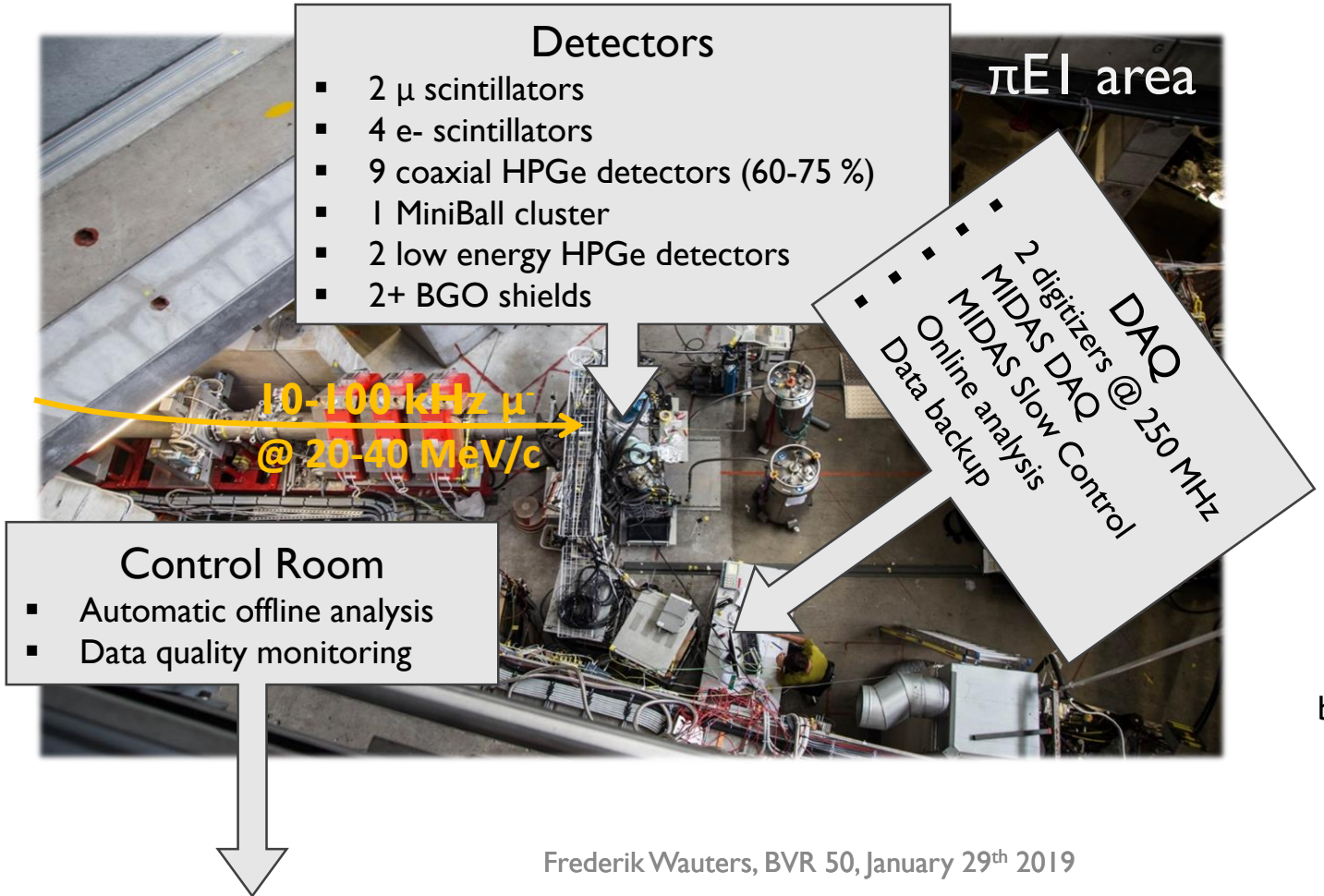


Detectors

- 2 μ scintillators
- 4 e- scintillators
- 9 coaxial HPGe detectors (60-75 %)
- 1 MiniBall cluster
- 2 low energy HPGe detectors
- 2+ BGO shields

DAQ

- 2 digitizers @ 250 MHz
- MIDAS DAQ
- MIDAS Slow Control
- Online analysis
- Data backup

Control Room

- Automatic offline analysis
- Data quality monitoring

<u>Common</u>

Detector
DAQ
Analysis framework
Shifts

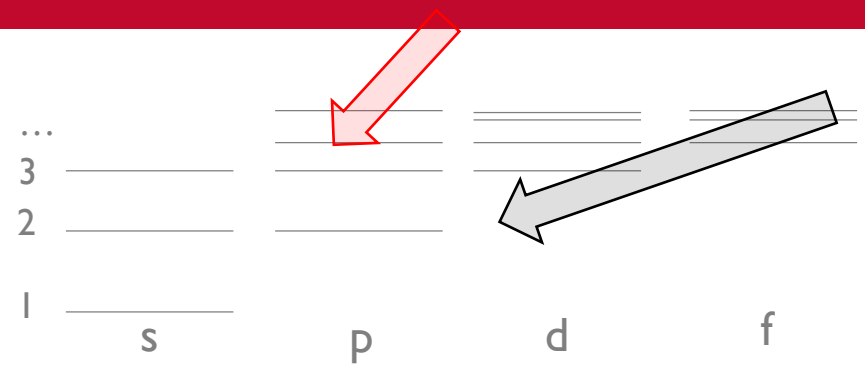
<u>Separated</u>

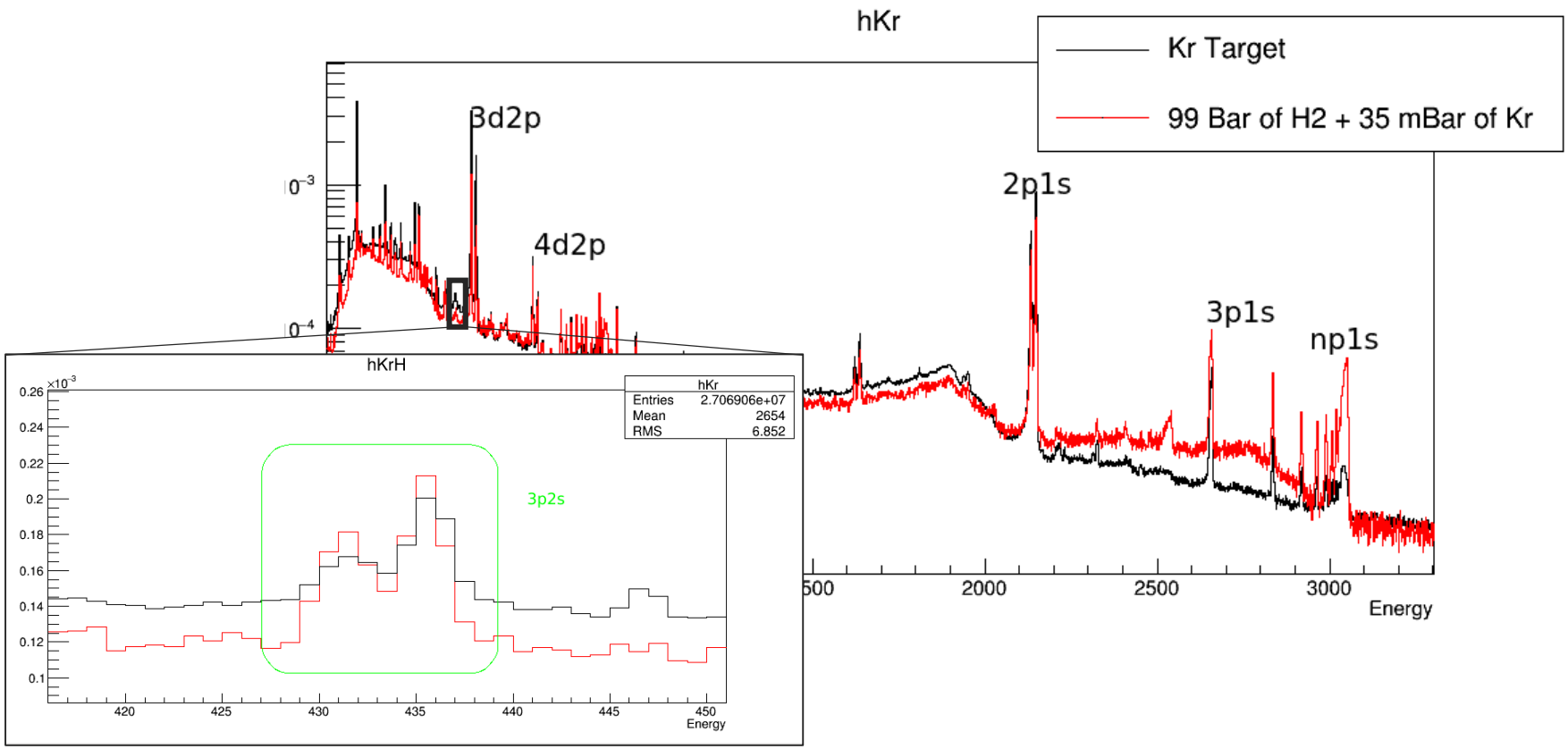
Target
beam rate
2nd stage analysis
beam-time application

2017-2018 Results

2S1S in Kr

- $\mu^- \rightarrow \mu H \rightarrow \mu Kr$ (with our gas target)
- ~3 fold increase of 2S population





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- $\mu^- \rightarrow \mu H \rightarrow \mu Kr$ (with our gas target)
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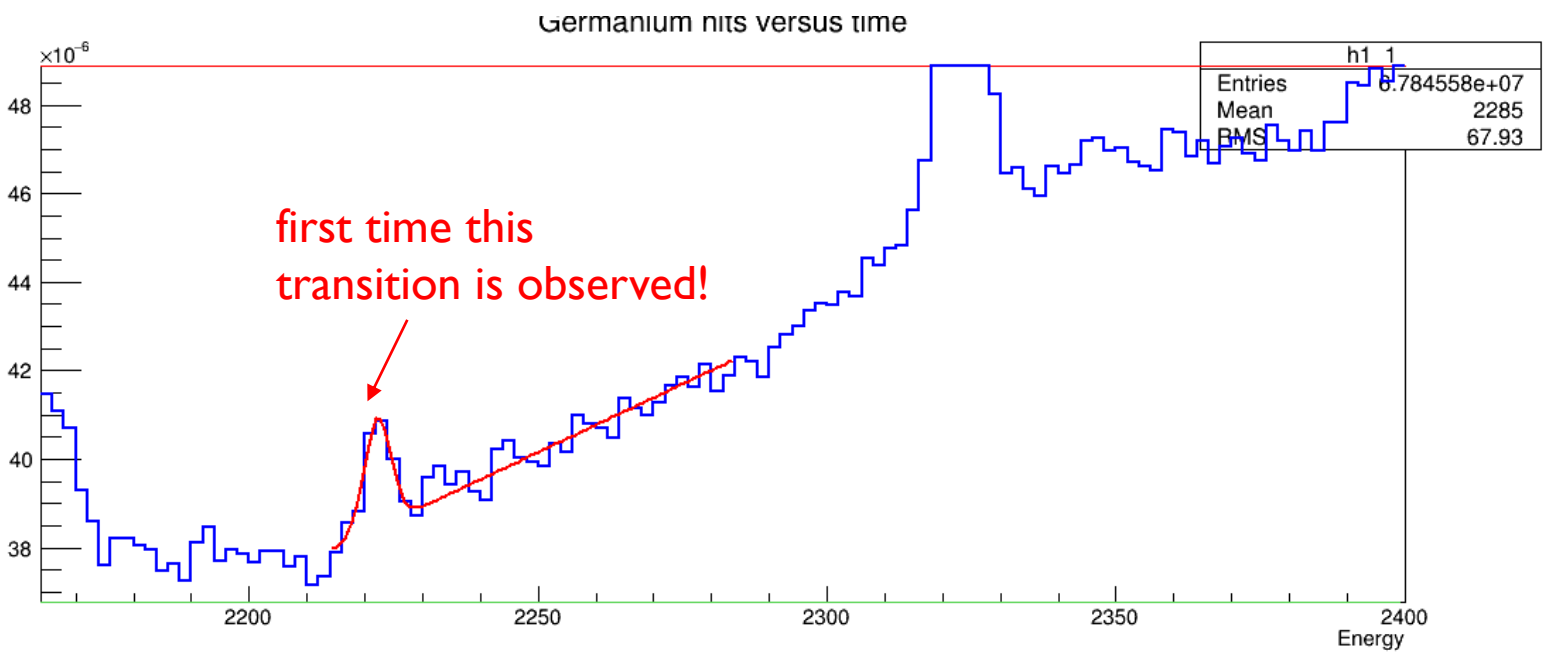
- Clear 2S1S peak in singles spectrum! BR ≈ 6 • 10^{-4}



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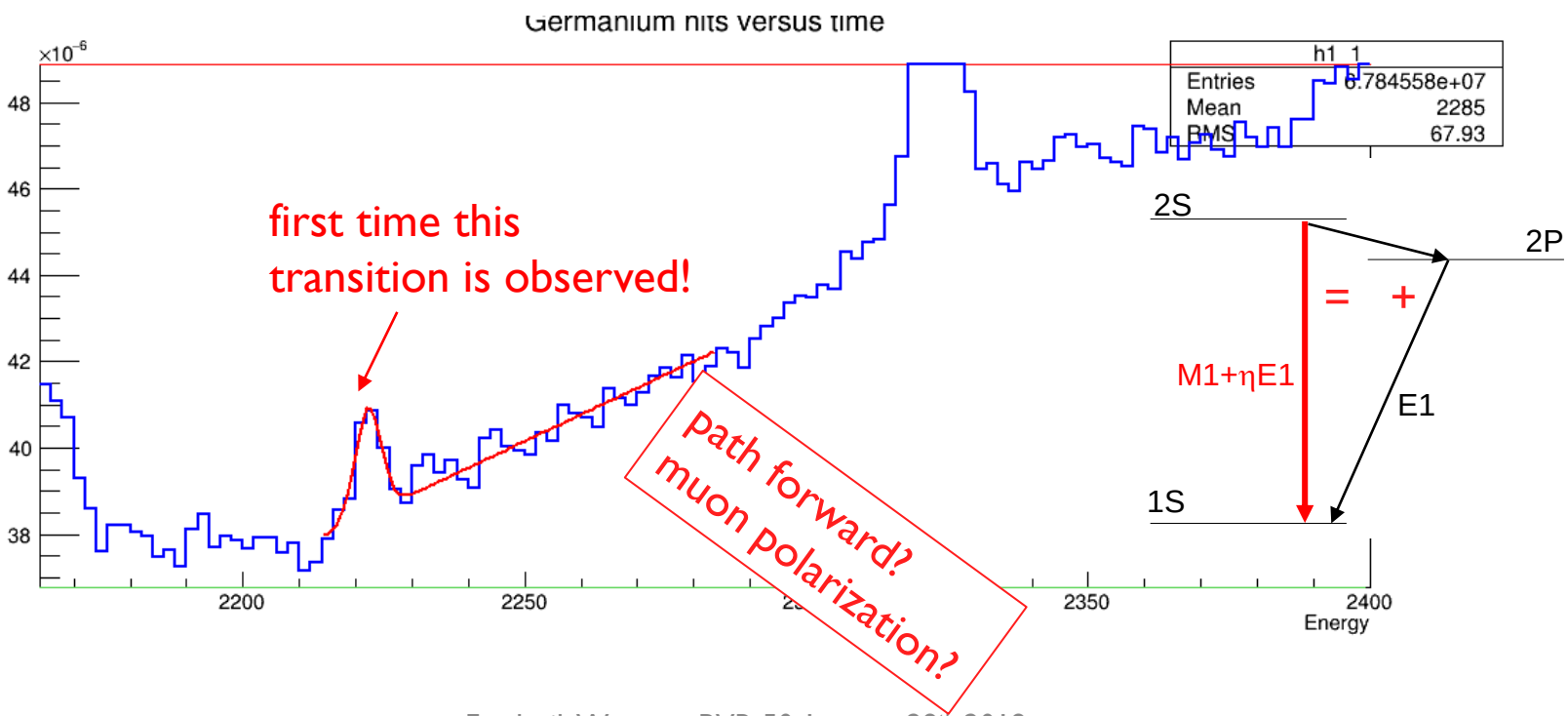
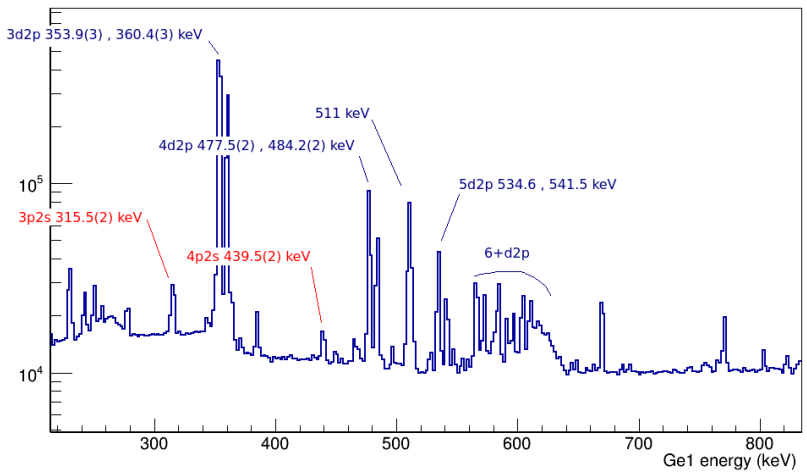
Main background

- 2S2P + 2P1pile up → 2mm of Pb (2018)
- Nuclear capture BG → delayed window
- Compton Scattered (n>2)P1S ☹

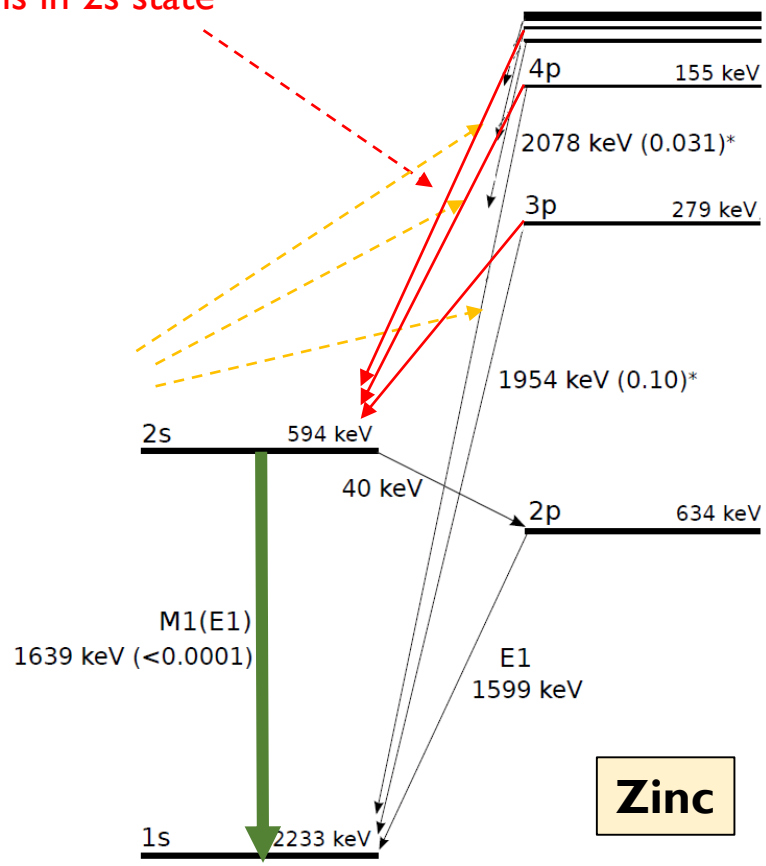


2017-2018 Results

2017 beam time request



approach: tag muons in 2s state

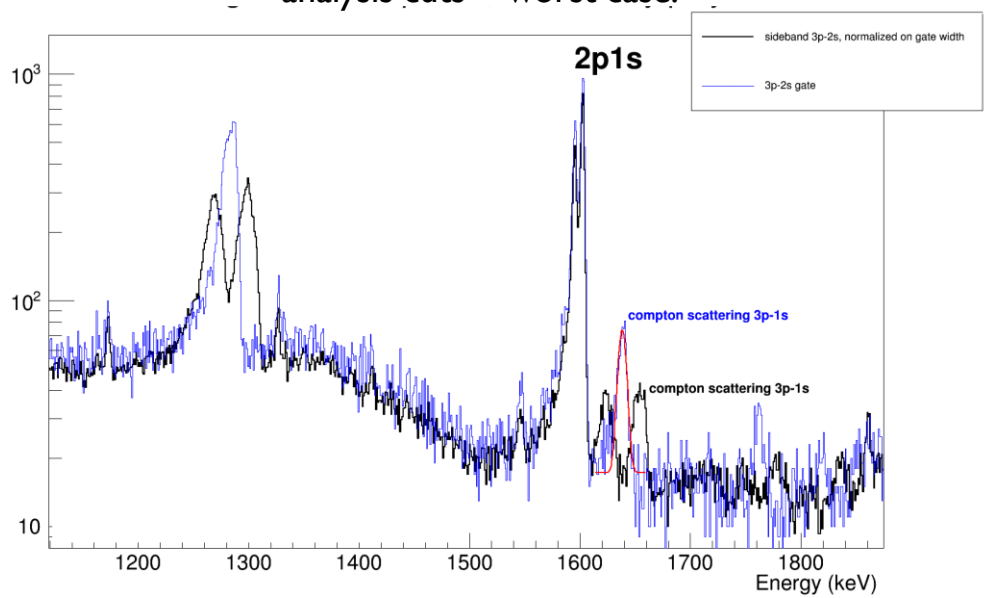


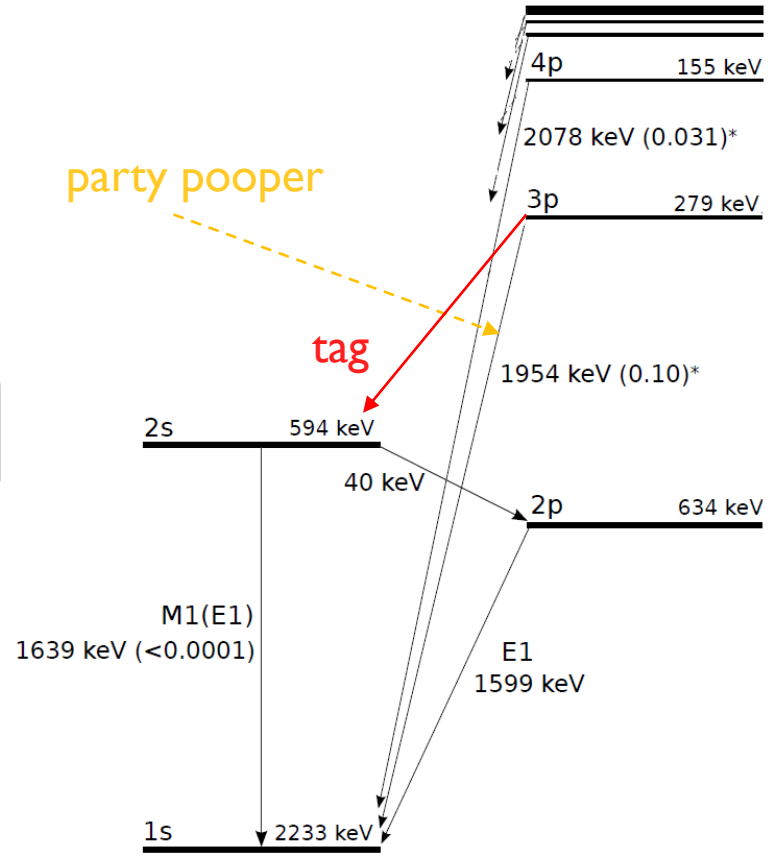
2017-2018 Results

A success?

- partially, dominated by scattered (n>2)P1S

analysis cuts = worst case:



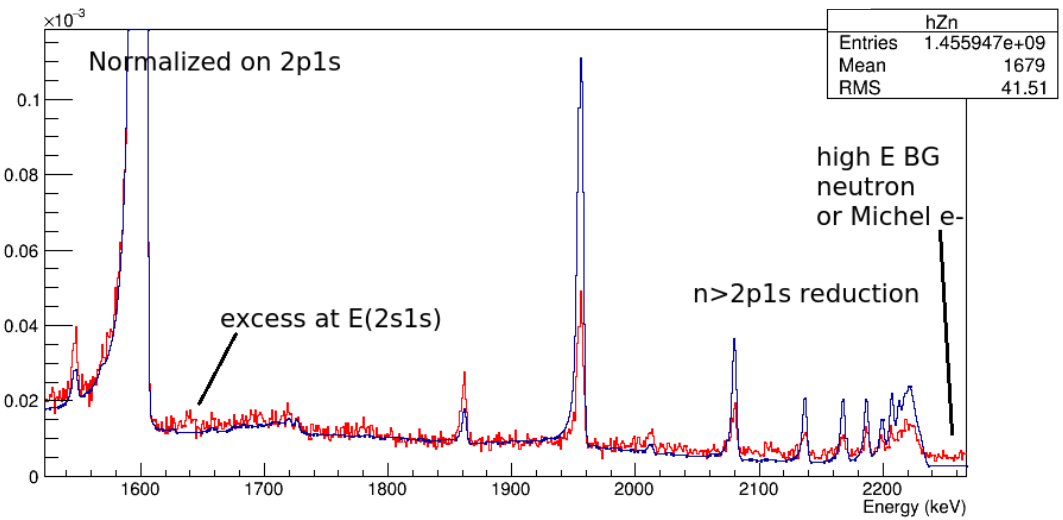


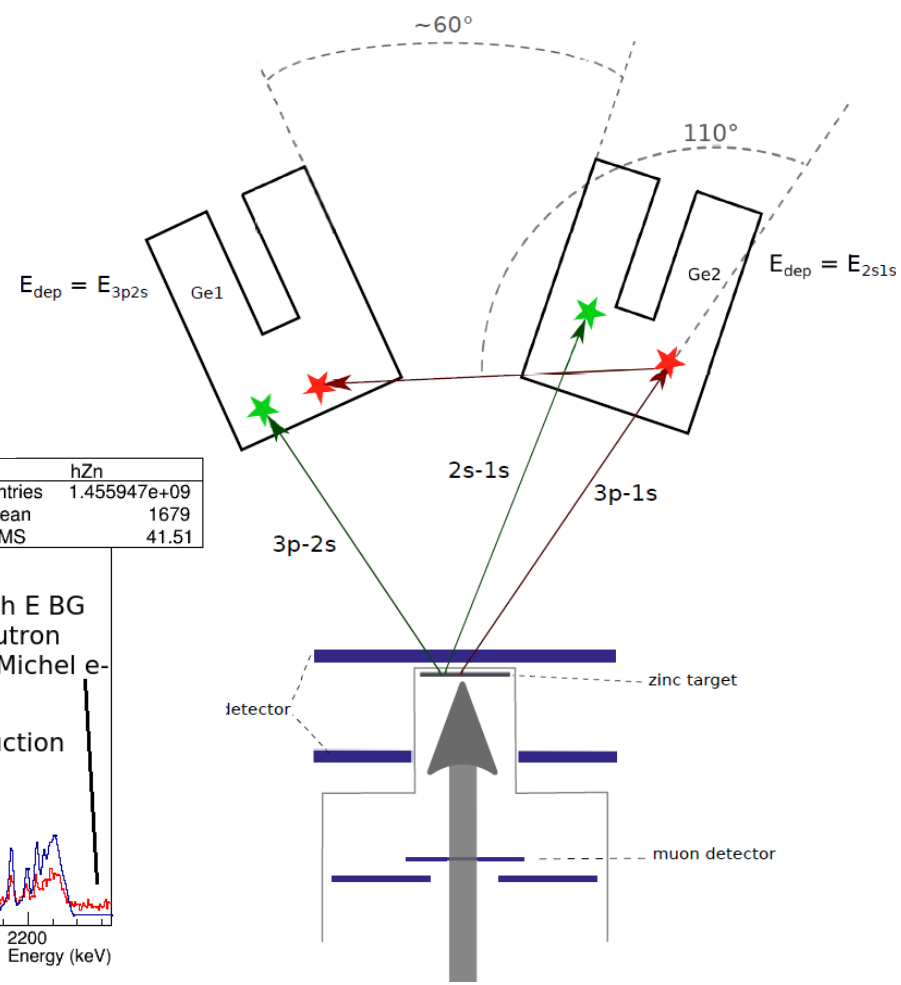
2017-2018 Results

A success?

- partially, dominated by scattered (n>2)P1S
- In principle: only at one specific scattering angle
  BUT: finite target and detector size
- Unacceptable efficiency loss

analysis cuts = choose wisely:





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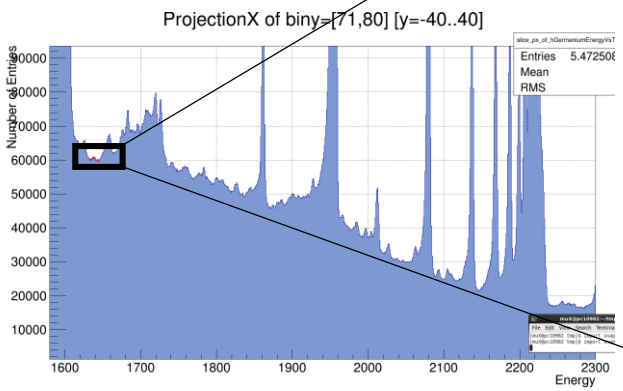
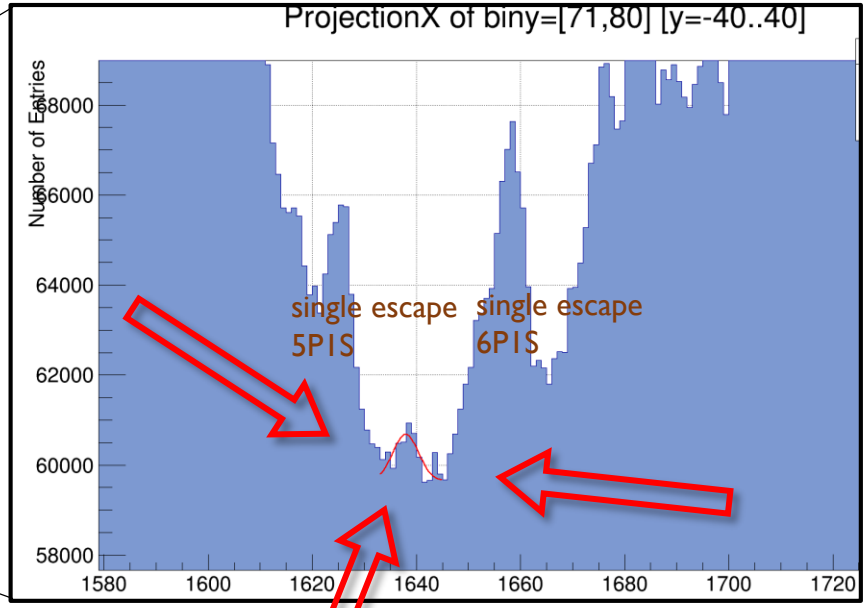
A success?

- partially, dominated by scattered (n>2)P1S
- In principle: only at one specific scattering angle
  BUT: finite target and detector size
- Unacceptable efficiency loss
- 2S1S visible in *singles* spectrum
  BG unacceptable for precision physics

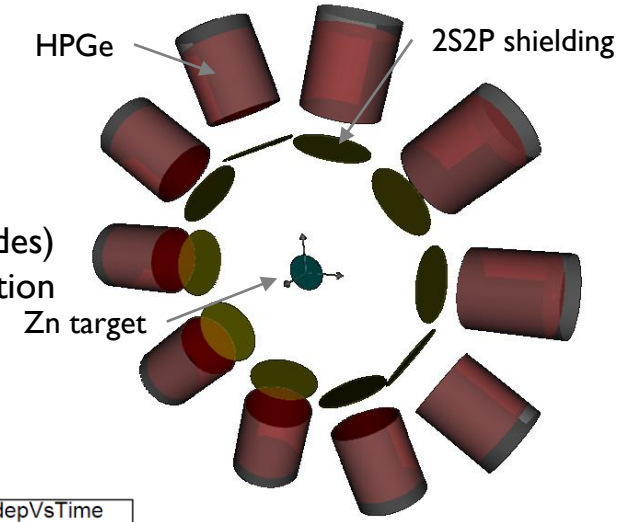
Sort off jay (?):





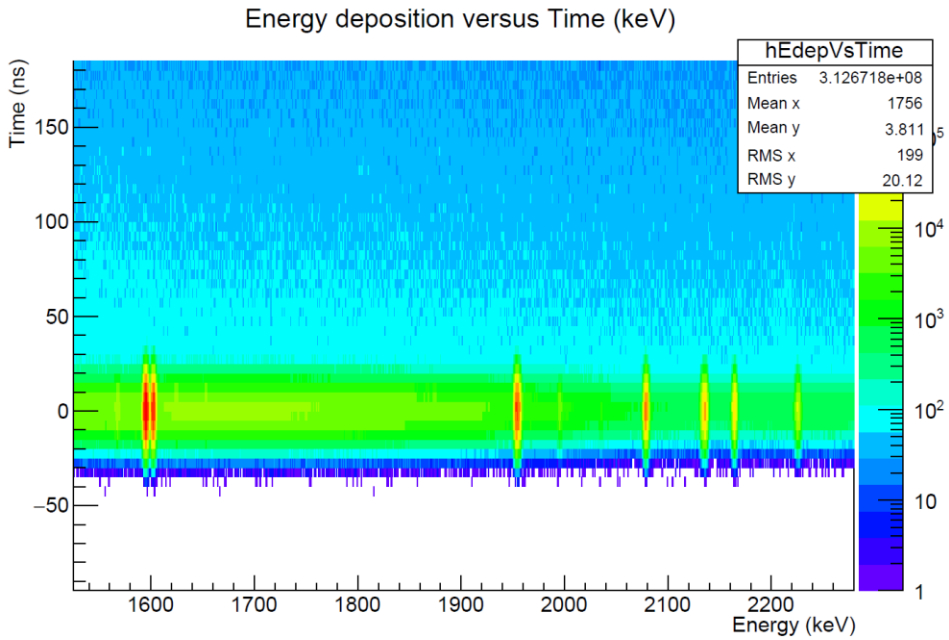
2019 Proposal

ToDo: MC background (reduction) study



- Event generator:
  - Full cascade starting at n=15 (our CASCADE and MUON codes)
  - Michel e^- (standard spectrum) and capture neutrons (evaporation + exponential spectrum)

- 2π detector geometry



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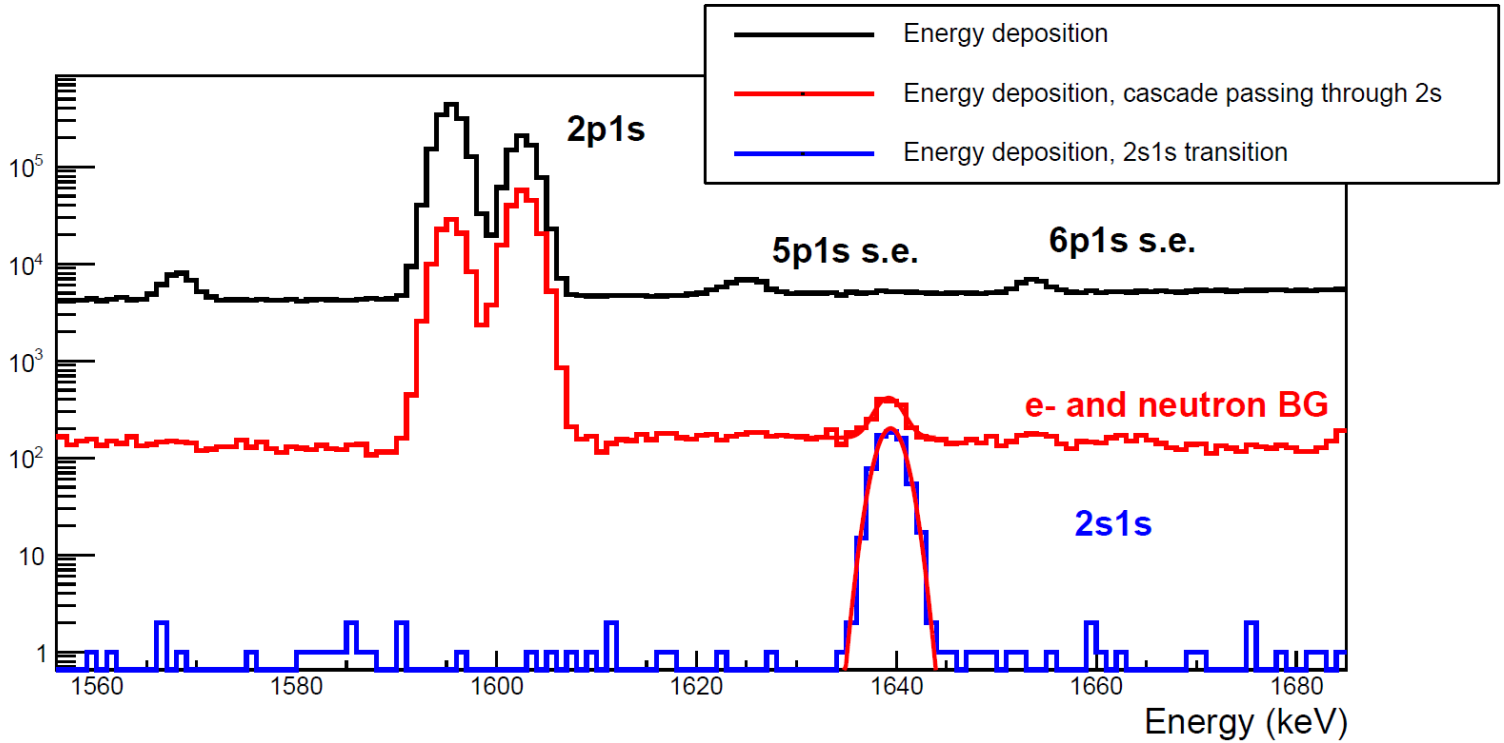

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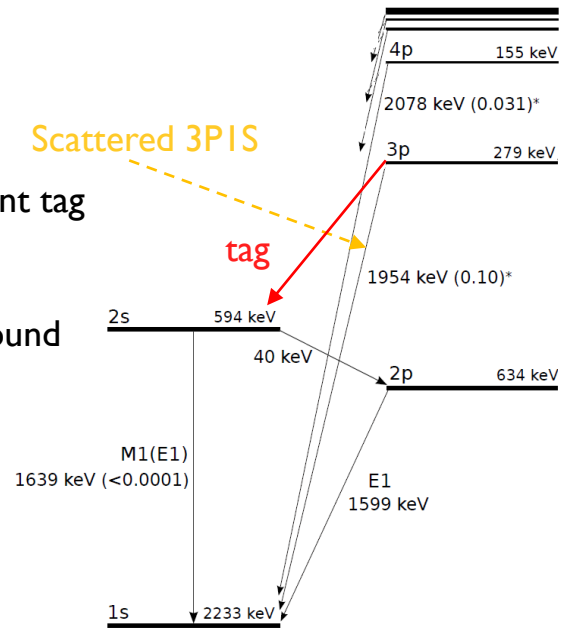

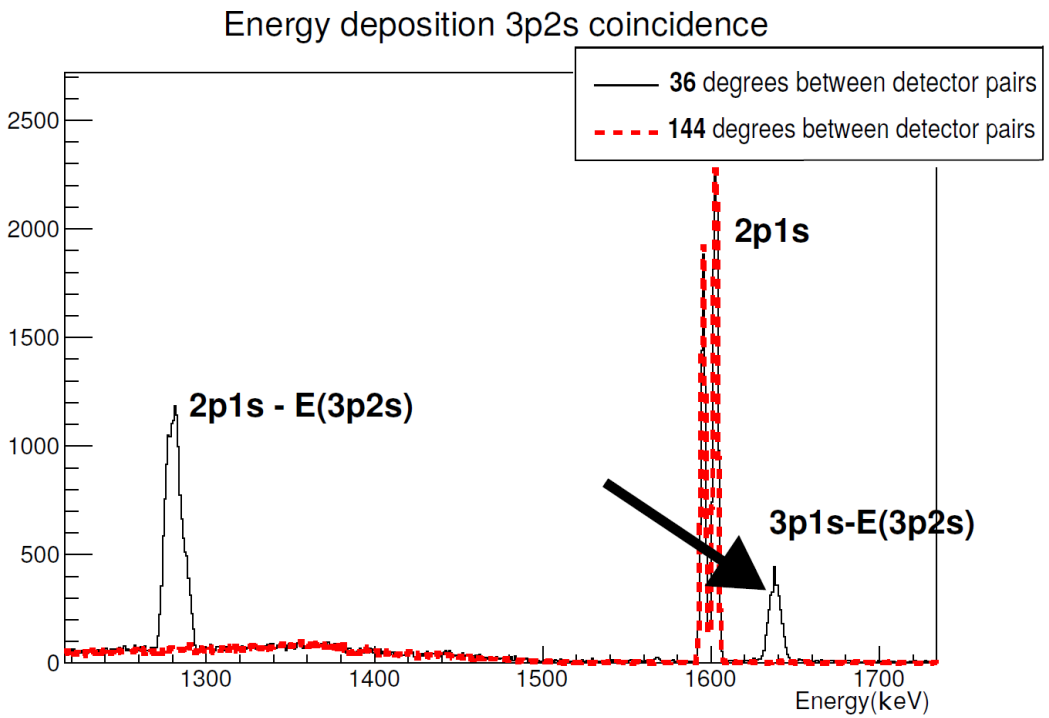

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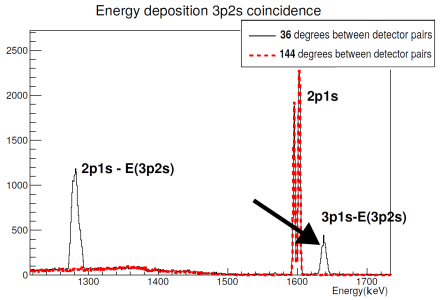

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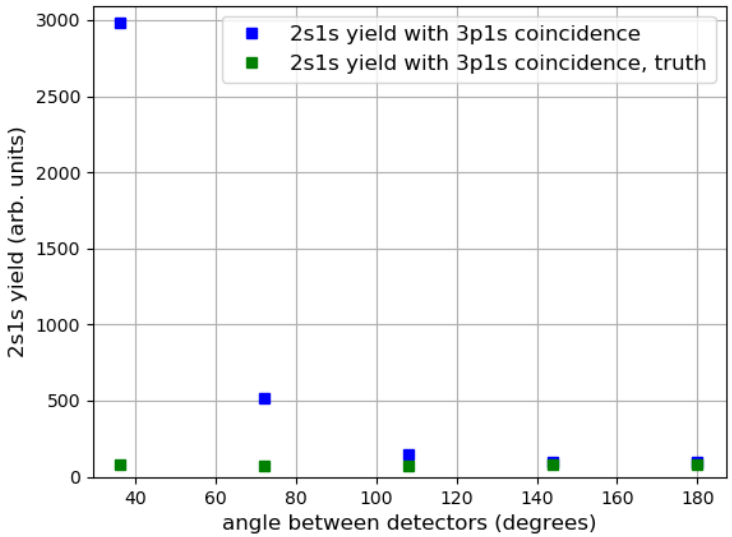
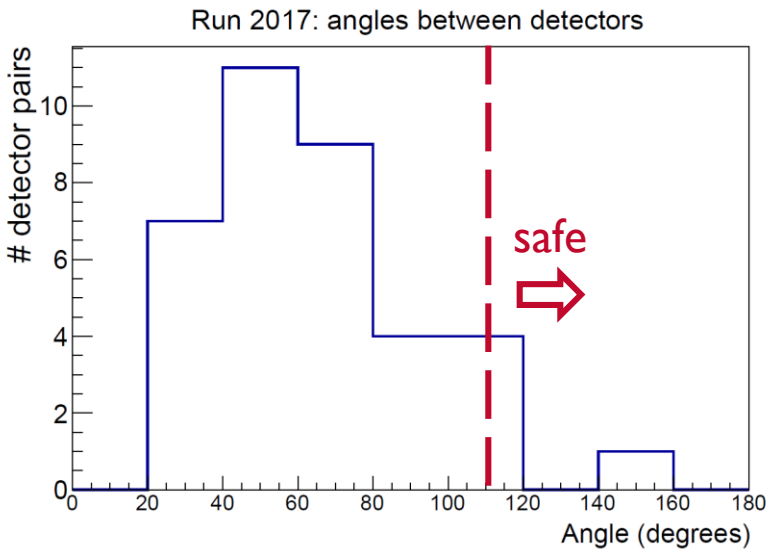
  - Way forward are detector-detector coincidences > 120°
  - Signal/Background > 2/1





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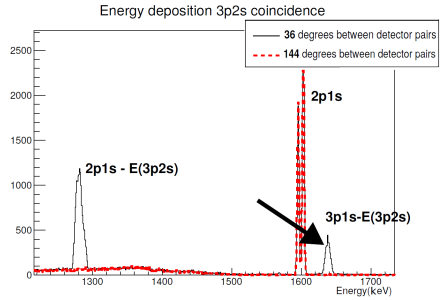

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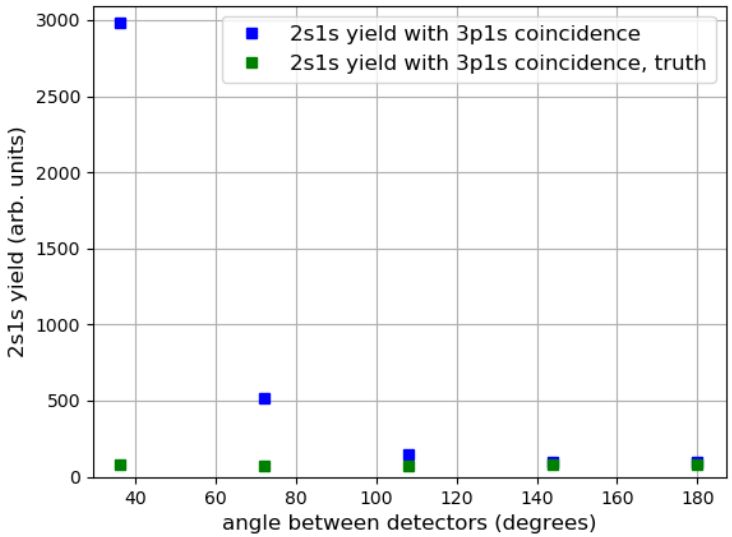
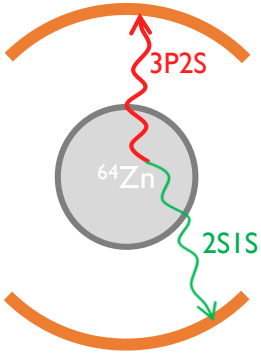


Two half-shells as an optimized geometry:



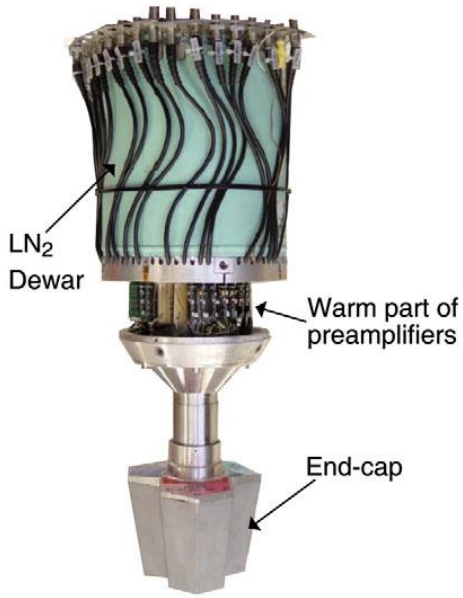
100 counts in 6 days data taking

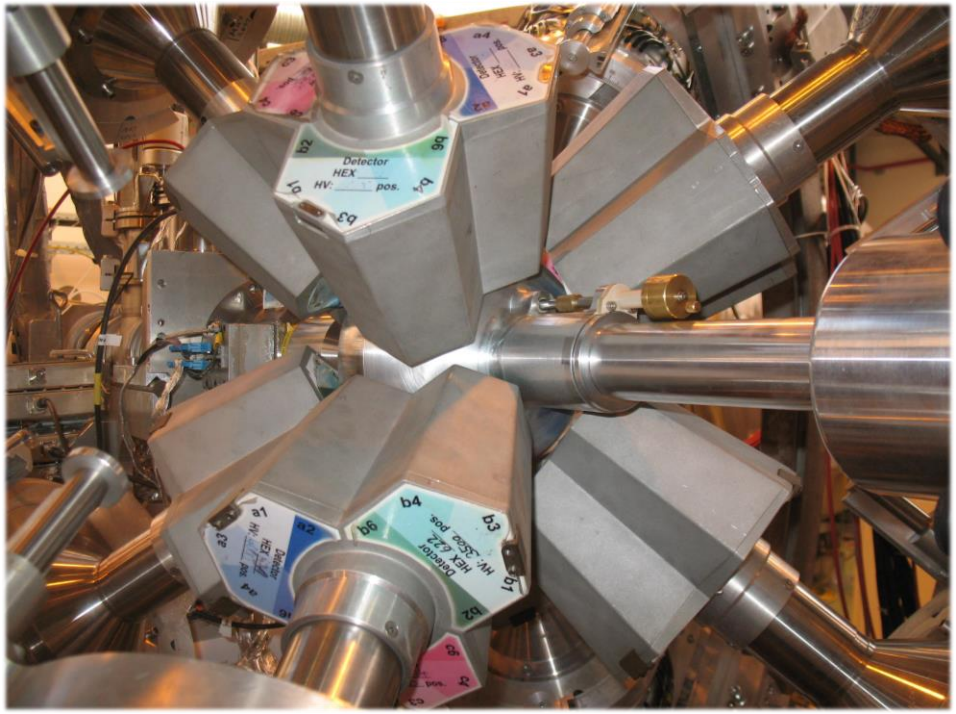
- 2017 detector efficiencies
- <u>conservative</u> analysis cuts

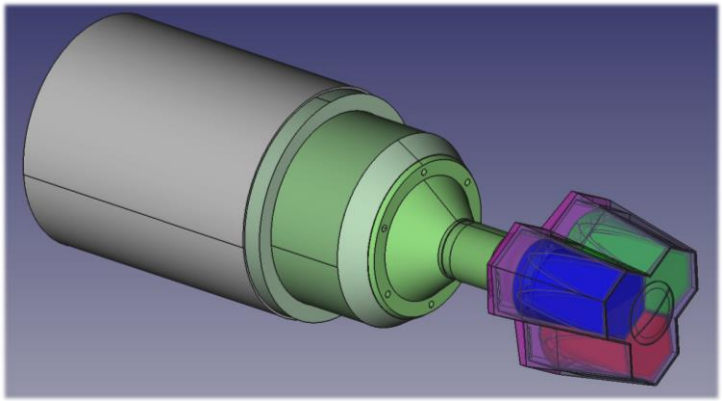
MiniBall @ PSI

Miniball cluster detectors

- CERN shutdown. 2019 → PSI 2020 → RIKEN
- 3 crystals per cluster, ~~segmented~~ core readout

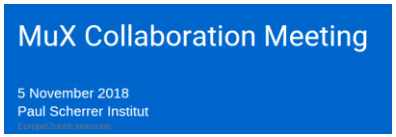


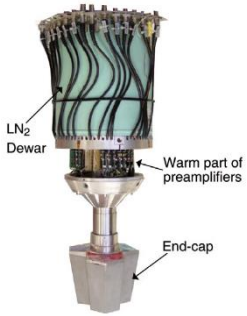




MiniBall @ PSI

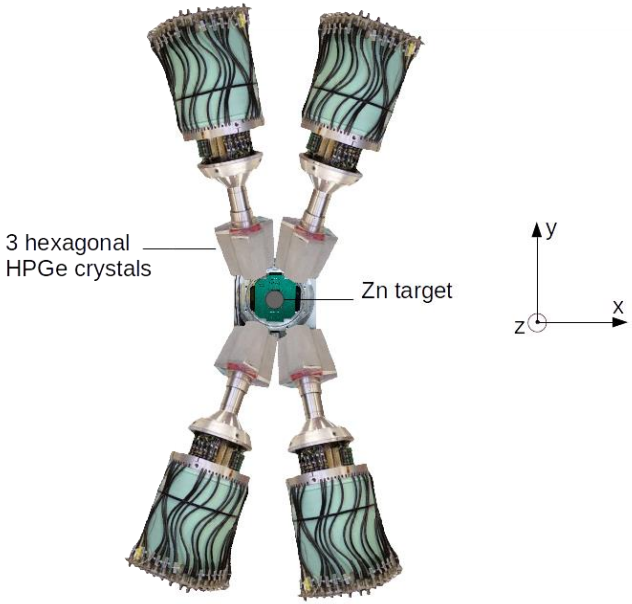
Miniball for muX





- Deployment discussed with MiniBall collaboration
  - Expression of Interest in 2016
  - 2018 Collaboration meeting

- 4 cluster detectors ≈> 2017/2018 efficiency
- 6 cluster detectors ≈> extra head room (e.g. for neutrons)



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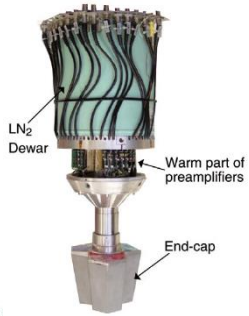
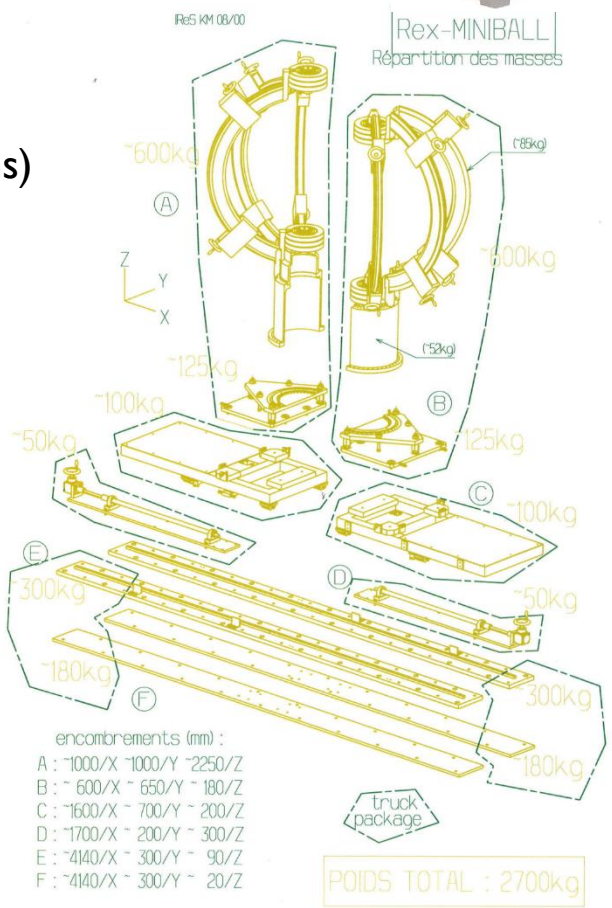
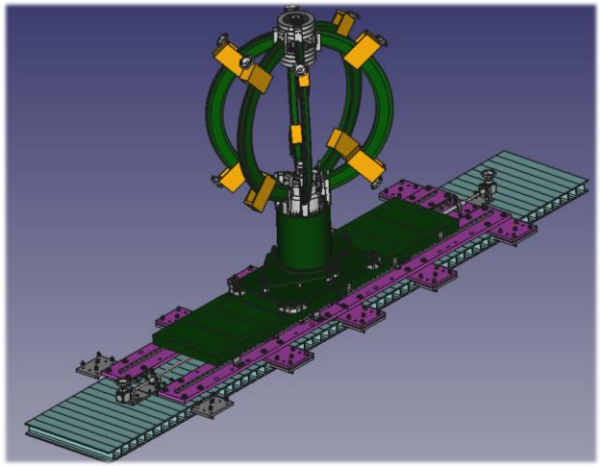
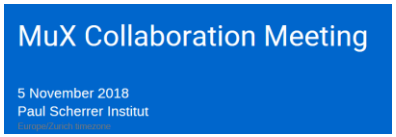


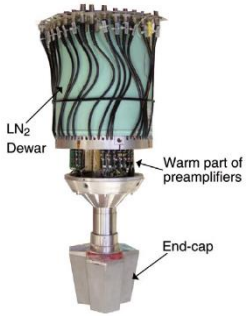




MiniBall @ PSI

Miniball for muX





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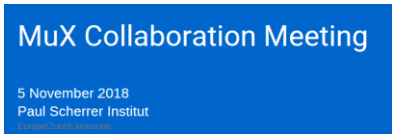
- Install/adapt mounting structure for πE1: PSI engineering

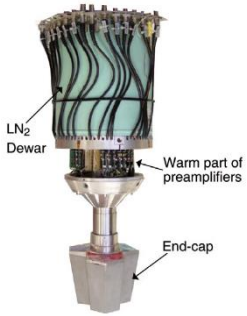
- Miniball:
  - Power supply
  - Frame
  - extra HV card

- muX:
  - Cooling system
  - All other detectors
  - Readout

2S1S beam time application

Miniball for muX





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  - Power supply
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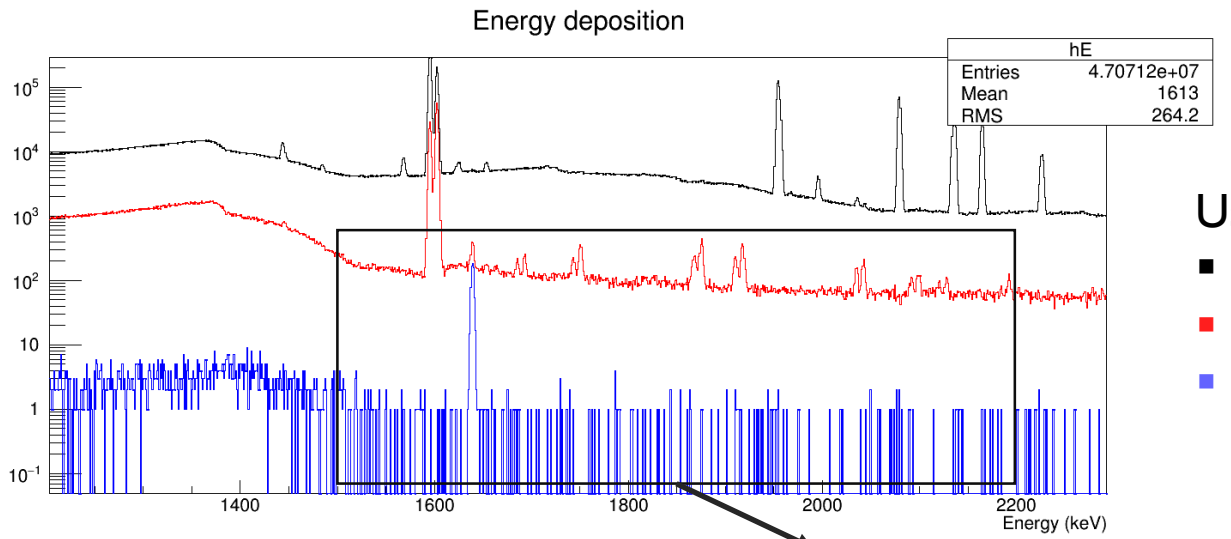
- muX:
  - Cooling system
  - All other detectors
  - Readout

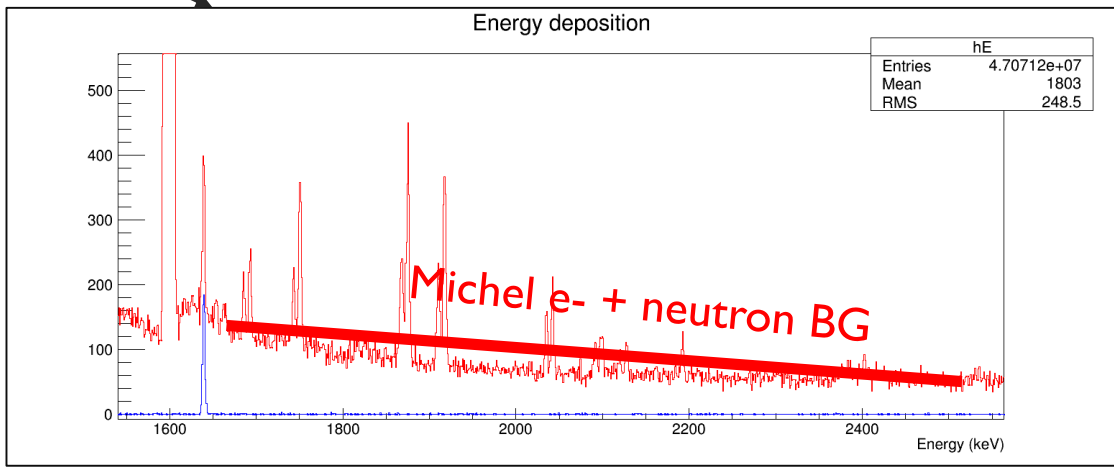
Observe 2S1S in ^{64}Zn with S/B > 1

7 days of beam time
- Assuming running after ^{226}Ra muX run
- 5-6 days of data taking
- 1 day to switch targets, tune beam
- 100+ counts

BACKUP

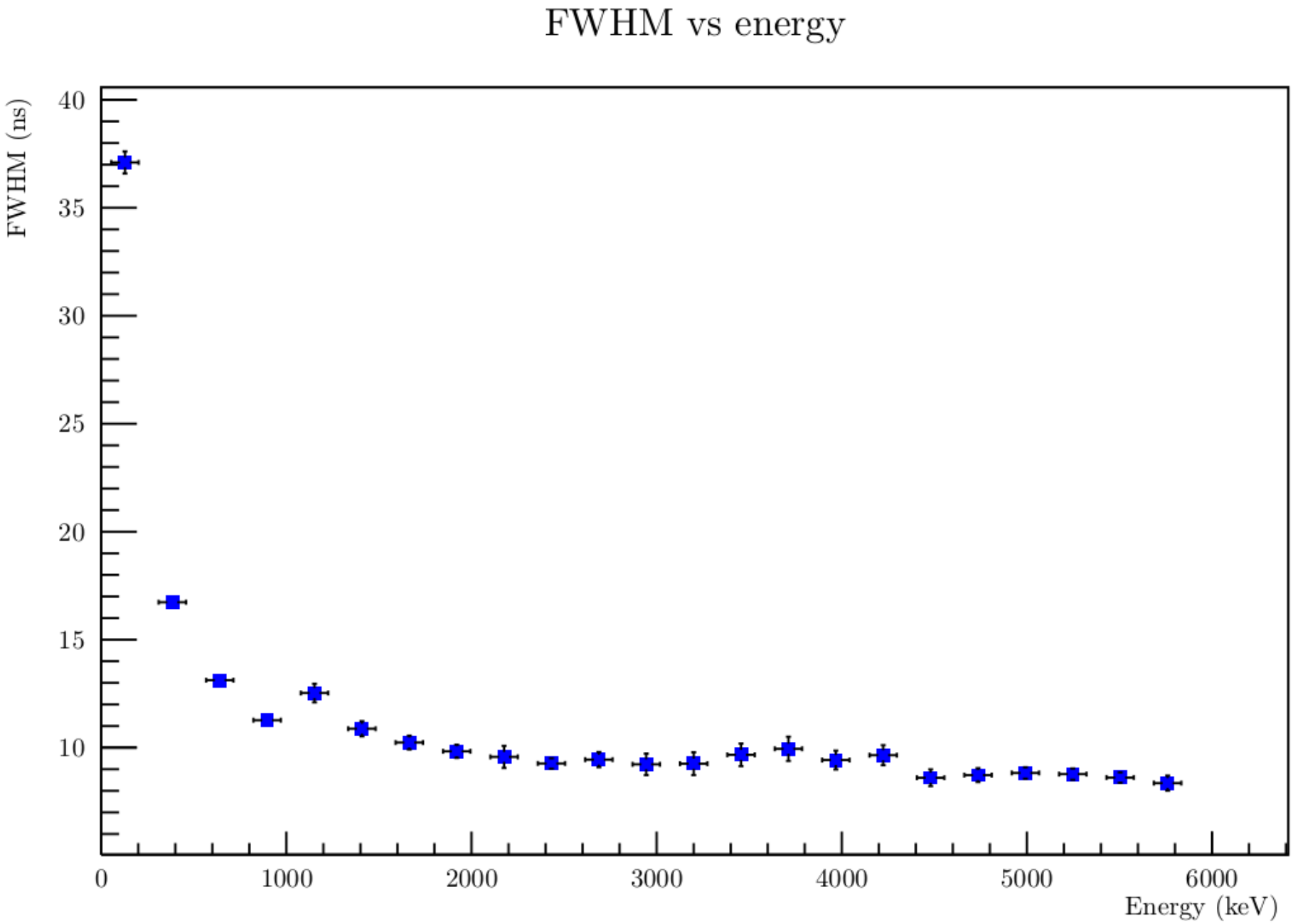
Full MC to do it properly:

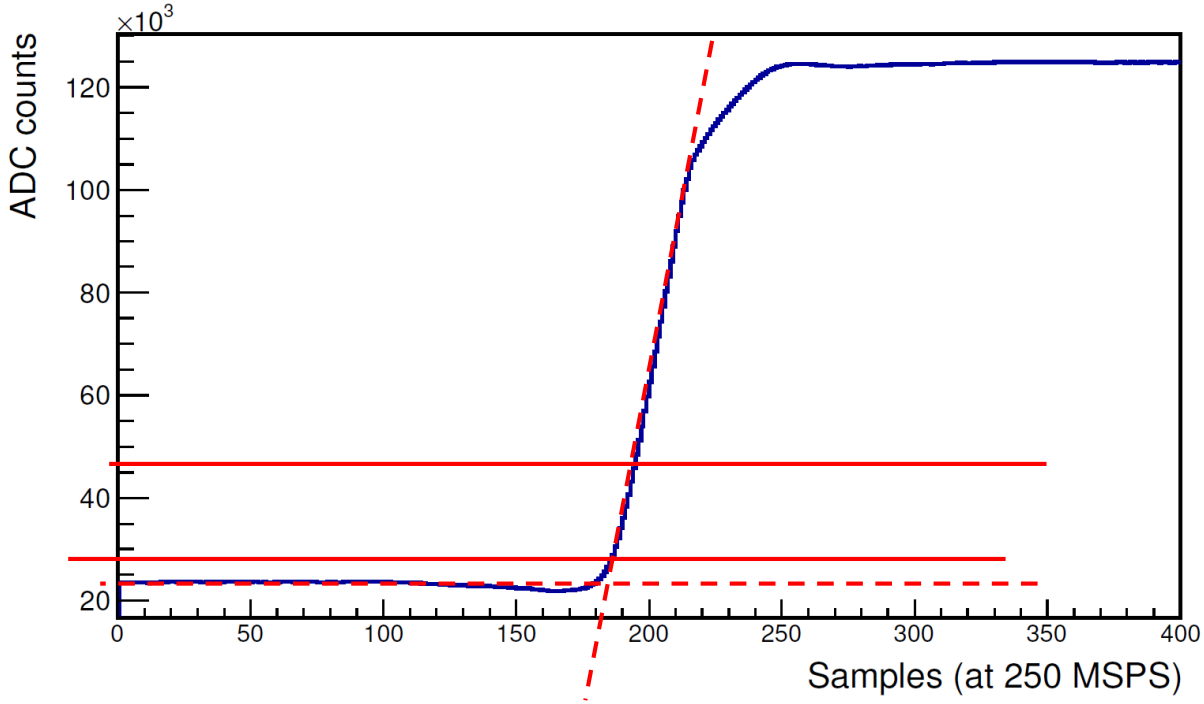


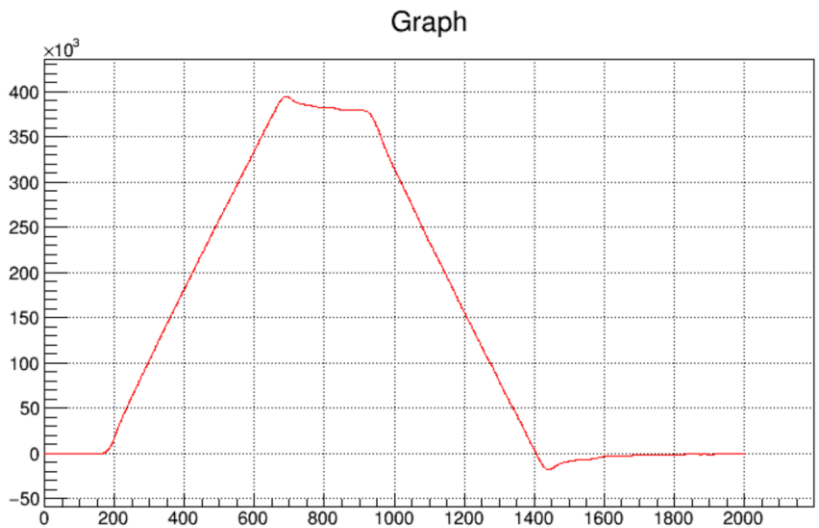


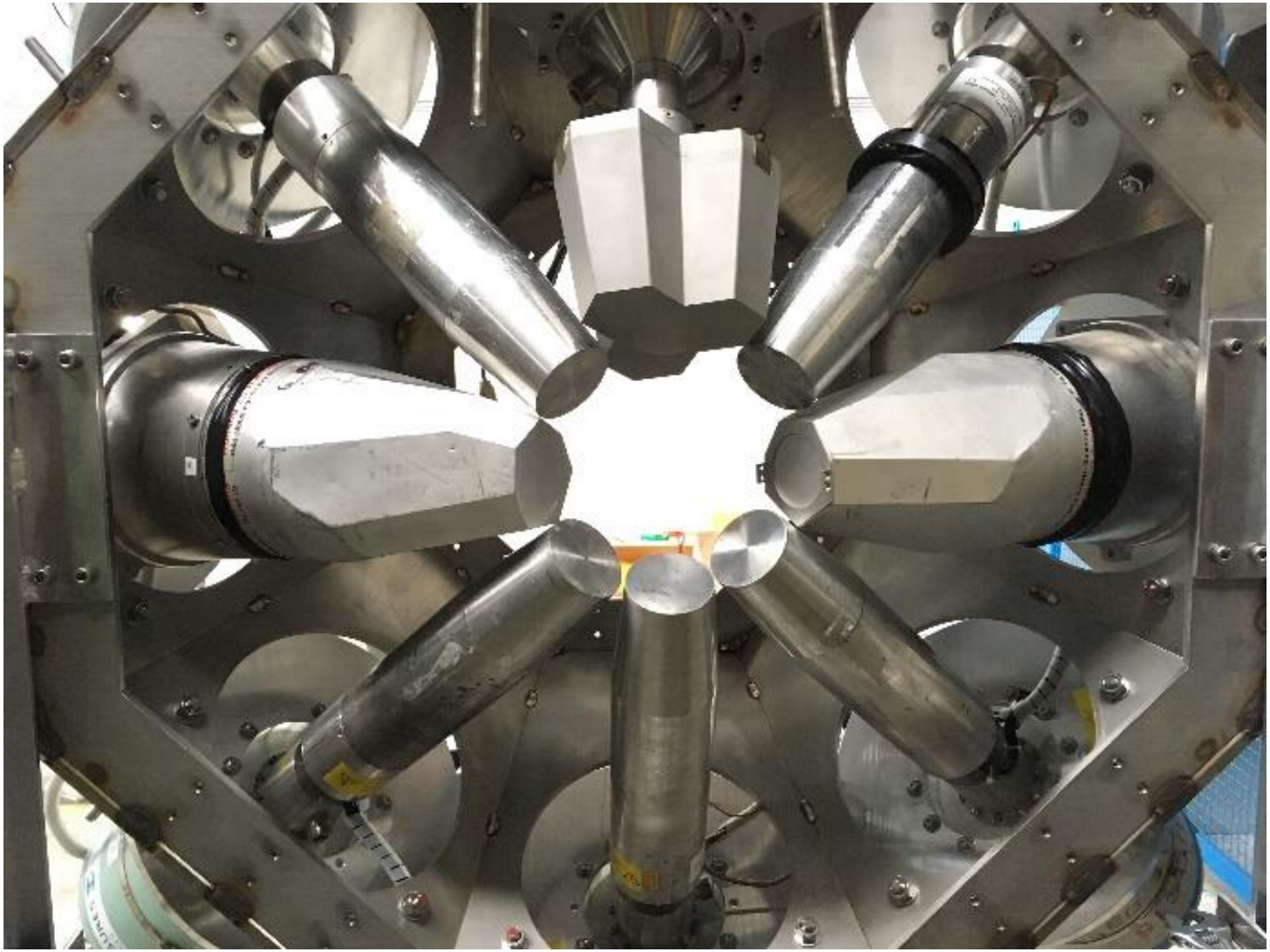
Use truth information:

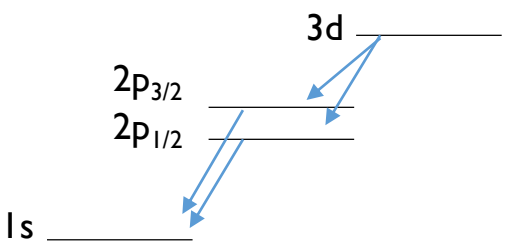
- all
- has 2s level in cascade
- has 2s1s transition

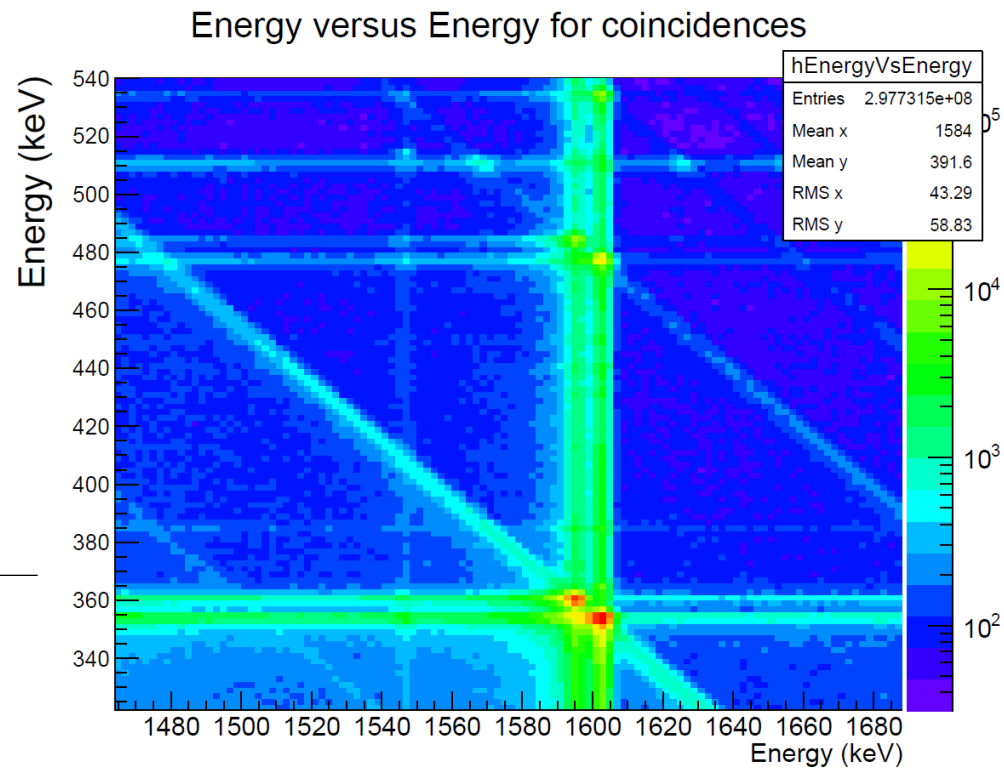

FWHM vs energy
FWHM (ns)
40
35
30
25
20
15
10
0
1000
2000
3000
4000
5000
6000
Energy (keV)


×10^3
ADC counts
120
100
80
60
40
20
0
50
100
150
200
250
300
350
400
Samples (at 250 MSPS)


Graph
×10^3
400
350
300
250
200
150
100
50
0
−50
0
200
400
600
800
1000
1200
1400
1600
1800
2000




3d
2p3/2
2p1/2
1s


Energy versus Energy for coincidences
hEnergyVsEnergy
Entries 2.977315e+08
Mean x 1584
Mean y 391.6
RMS x 43.29
RMS y 58.83
Energy (keV)
540
520
500
480
460
440
420
400
380
360
340
1480 1500 1520 1540 1560 1580 1600 1620 1640 1660 1680
Energy (keV)
10^4
10^3
10^2

Observe 2S1S in ^{64}Zn with S/B > 1

- 7 days of beam time
  - Assuming running after ^{226}Ra muX run
  - 1 day to switch targets, tune beam
  - 100+ counts

TODO before run

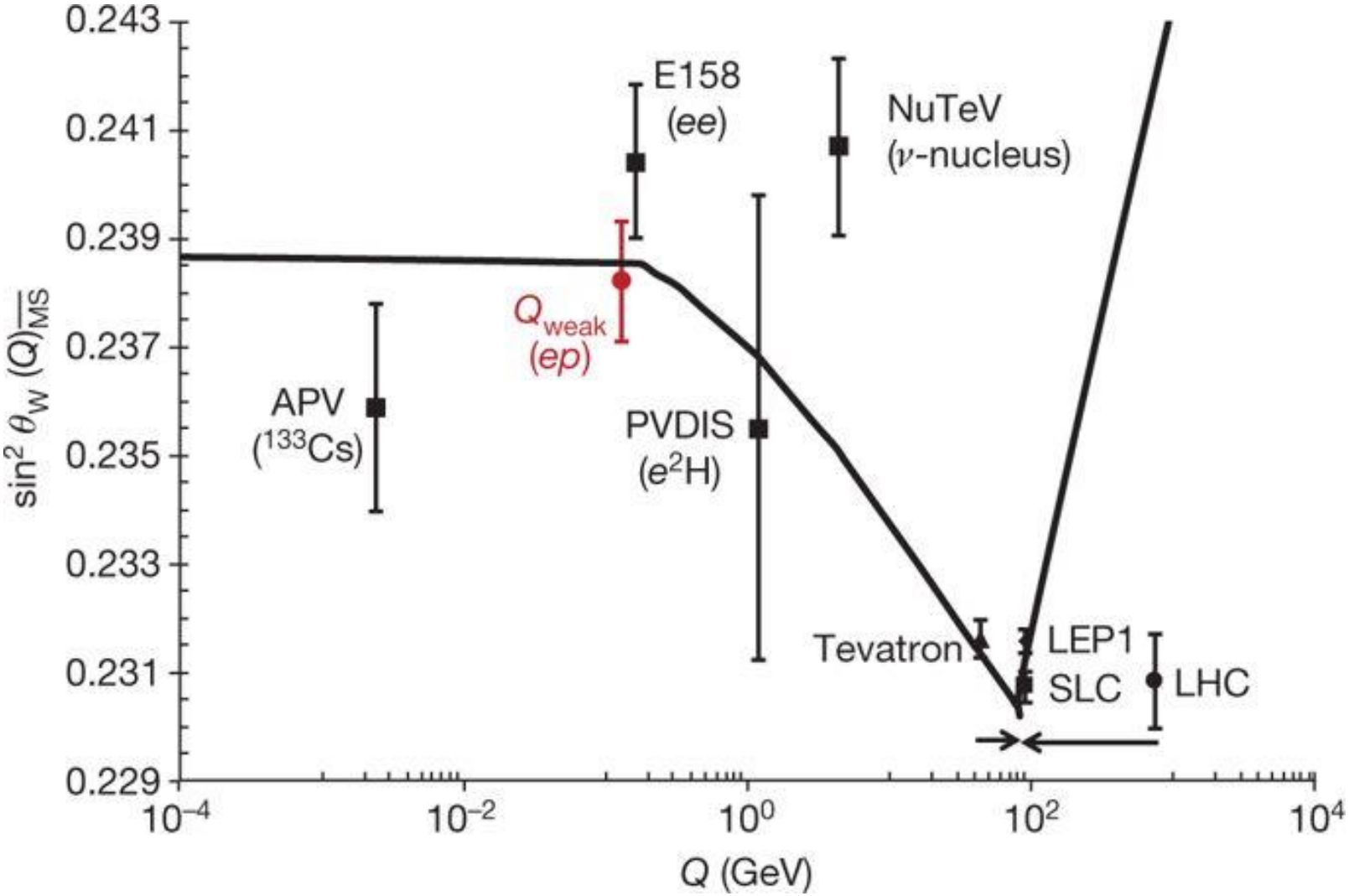
- MiniBall detectors
  - Install frame
  - One extra digitizer (6 detectors), now we have 2x16 channels
  - Detector test

- Monte Carlo
  - Optimize geometry with *real world* setup
  - Do we need absorbers in between detectors?

- Other
  - Install neutron detector
  - Timing strategies

The most serious background arises from the degrading due to Compton scattering of photons produced in transitions in the muon cascade with more energy than the magnetic dipole transition. This background prevented the detection of the magnetic dipole transition in a preliminary experiment.

(Simons)


0.243
0.241
0.239
0.237
0.235
0.233
0.231
0.229
$\sin^2\theta_W(Q)_{\overline{MS}}$
E158
(ee)
NuTeV
(ν-nucleus)
Q_{weak}
(ep)
APV
(^{133}Cs)
PVDIS
(e^2H)
Tevatron
LEP1
SLC
LHC
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}
Q (GeV)