



### Atomic Parity Violation in muonic atoms Feasibility of a 2S1S parity violation experiment around Z=30

**Frederik Wauters** 

Revisit PV for  $Z \approx 30 \rightarrow$  Why  $Z \approx 30$  ?

TABLE II. Decay rates for various transitions.<sup>a</sup>



PSI Workshop, October 2016

<u>This Talk</u>: Revisit PV for  $Z \approx 30$ 

- 1. Can we see the 2s1s?
- 2. Can we get the statistics for a PV 2s1s experiment?

4p	4d
3p 284 keV	3d 283 ke\



# JGU Progress in HPGe technology





### JG MC background estimation from the cascade

#### the 'ideal' singles spectrum



## JG MC background estimation from the cascade

the 'ideal' singles spectrum



### HOWTO suppress the BG with a factor > 20







# JGU Nov 2015 TestBeam



### Prompt Zn Spectrum



From ratio between 3P2S / other lines, Fribourg measurement on Fe:

2S population = 
$$\frac{B.R.(3P1S)}{N.R.(2P1S)}$$
\*4 = 6(1) %

From Fe data (Hartmann et al.)



# JGU Detector performance





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### JG Background > 2.2 MeV

Cut: Michel electron after 50-100 ns

- Very clean prompt window. No Bremsstrahlung and nuclear capture products
- Can use electron to get muon polarization
- Loose 93 % events!



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How much background reduction can we achieve in the ROI?

1. Practice on 2P1S : broad cut



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(n>2)P1S X-rays suppressed by factor 8 or more



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How much background reduction can we achieve in the ROI?

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- 3. Targeted 2S feeding cut





Energy Ge1 Versus Energy Ge2, time coincidence, Vs Muon Tme (Good Ge hits + muon PP) yx projection

- 1. Wide  $\rightarrow$  Narrow coincidence window: Eff. loss of < 0.5 (From 2P1S)
- Wide →Narrow coincidence window: Background in ROI goes down by a factor of 10

## JG Background suppression



### Total BG suppression

Prompt:

Non-Prompt

- Factor 3 from Compton shield
- Factor 8 x 10/2 from X-ray coincidences
  → S/B of 2S1S > 1
- Delayed electron (but efficiency loss!)
- Scales with timing resolution HPGe

0.05(From MC) \* 8 \* 5 = 2 S/B for 2S1S should now be O(1) or better

# JG Background suppression



### Total BG suppression

Prompt:

- Factor 3 from Compton shield
- Factor 8 x 10/2 from X-ray coincidences

Non-Prompt

- Delayed electron (but efficiency loss!)
- Scales with timing resolution HPGe >50 ns  $\rightarrow$  10 ns  $\rightarrow$  ...

#### Testbeam October 2016: 10 ns FWHM from SIS3316, out of the box

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01010 0101010

A METRODO





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### Where is the 2S1S?



Energy Ge1 Versus Energy Ge2, time coincidence, Vs Muon Tme (Good Ge hits + muon PP) yx projection

I expect < 1 count after all cuts (0.6 in most optimistic case) Background in ROI = 0.26 counts/keV

Check = Expect ~ 3000 counts in 2P1S after all cuts, I see 2600 2P1S behaves as expected

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# JG<mark>U</mark> Scaling up

#### Next Step: Observing 2S1S:

- Current S/B 1-2
- We can still improve
  - Factor 3 from Compton shielding
  - Factor of 5(?) from timing
- $\rightarrow$  One week at 50 kHz  $\mu^{-}$
- $\rightarrow$  6 high-efficiency HPGe detectors @ 20 cm
- $\rightarrow$  250(20) Counts in 2S1S after cuts
- $\rightarrow$  6 10<sup>6</sup> neutrons/cm<sup>2</sup>



From this we would learn:

- See the 2S1S
- Establish S/B
- Establish Branching Ration

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## JG Scaling up, estimating some numbers

- 1. Observing 2P 1S:
- $\rightarrow$  One week at 50 kHz  $\mu^{-}$
- $\rightarrow$  6 high-efficiency HPGe detectors @ 20 cm

feasible

- $\rightarrow$  800 Counts in 2S1S after cuts
- $\rightarrow$  6 10<sup>6</sup> neutrons/cm<sup>2</sup>

- 2. Observing 2P 1S:
- $\rightarrow~$  100 days at 100 kHz  $\mu^{\rm -}$
- $\rightarrow$  50 % solid angle for HPGe
- $\rightarrow$  8 10<sup>-4</sup> statistical error on 2S1S = O(PV)
- → 3.0 10<sup>8</sup> neutrons/cm<sup>2</sup>

μ detectors

(here the MiniBall detectors act as a generic placeholder)

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### + PV observable

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#### Challenges with HPGe detectors JG U

### Neutron damage

- Few times 10<sup>8</sup> becomes problematic
- Depends on the detector type (GMX is • better than n type is better than p type)
- Is 'fixable', but not to be taken lightly

Resolution (keV) FWHM

60

30

10

6

3

107

A precise SM PV violation > 10<sup>9</sup>



3 10<sup>9</sup> n/cm<sup>2</sup>

### JGU Challenges with HPGe detectors in a muon experiment

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- We observe 2 keV  $\rightarrow$  3-4 keV FWHM, rising with rate
- BLR history
- Good resolution with O(10 kHz) detector rate is possible



Table 2. Energy resolution vs. rate for the algorithm in FPGA.

Filter Set	Input Rate (Kcps)	Energy resolution (FWHM, keV)
A	5.0	2.09
	32.4	2.43
	54.3	3.29
	73.2	4.20
	100.3	<b>5</b> , 4.23
В	100.3	3.69
	195	5.58
	425	10.15
	500	21.49

### JGU Challenges with HPGe detectors in a muon experiment

#### Neutron damage

- Few times 10<sup>8</sup> becomes problematic
- GMX is better than n type than p type
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- A precise SM PV violation > 10<sup>9</sup>

#### Time resolution

- 10 ns comes out of the box for > 1 MeV
- For 'low' energy pulses, i.e. ca. 300 keV, one need the waveform

### **Energy resolution**

- We observe 2 keV  $\rightarrow$  3-4 keV FWHM, rising with rate
- BLR history
- Good resolution with O(10 kHz) detector rate is possible



### JG U 2S1S around Z=30

**BSM Physics?** What is the reach of such a project ? 0.245 v deep-inelastic scattering E158 MOLLER 0.240 (JLab) MESA (Mainz) TT Qweak (JLab)  $\sin^2 \theta_w(Q)$ EIC (statistical error only) SoLID (JLab) 0.235 APV (Cs) LEP 4<sub>FB</sub> (bb) ± a little below the Standard Model value by about **1.5** $\sigma$ . 0.230 SLD New experiments on Ra (Z=88) and Fr (Z=87) 0.225 0.0001 0.01 1 100 10,000 Q(GeV)

'O(1) SM test ', Pospelov

#### JGU 2S1S around Z=30

#### TOC

- Explain the situation for 2S1S around Z=30 : short!
  - Why revisit: Gamma spectroscopy did get a lot better (refer to question dave)
- X ray BG ٠
  - MC -> S/B, The not case for Compton suppression
  - coincidence idea. Point out pitfalls ٠
- Test beam 2015
  - Show picture. Real spectrum: show. Also more BG ٠
  - 2S population ٠
  - Timing: prompt, not ideal ٠
  - Electrons. Delayed electron cleanup, and the case for better timing ٠
  - **BGsuppression with coincidence** ٠
    - Rough coincidence, remove X rays. Factor 8 with current timing ٠
    - Illustrate with 2P1S. Target 2P1S ٠
    - Total BG suppression in ROI. Eff is a lot lower than in the ideal case. ٠
    - Should I have seen the 2S1S (~50 counts) ٠
- Scaling up
  - Numbers. phase 1: see 2s1s: looks ok. phase 2: PV: large scale
  - Suppression ٠
  - How would it look like: lots of HPGe. > 10% solid angle ٠
- Challenges for the HPGe detectors
  - Neutrons ٠
  - Timing and E resolution at high rate IPA, September 2016, Orsay

### JGU Challenges with HPGe detectors



0.25 10-3 for 2P1S exp, 0.4 estimated

0.25 10-3 for 2P1S exp, 0.4 estimated

9.2 10<sup>5</sup> counts in singles spectrum

50 counts in 2S1S expected in coincidence spectrum

Loos about 0.003 due to wide cut, was expecting 0.5-1%

Fe data: Hartmann, F. J., von Egidy, T., Bergmann, R., Kleber, M., Pfeiffer, H. J., Springer, K., and Daniel, H. Phys. Rev. Lett. 37, 331–334 Aug (1976)

### JGU Challenges with HPGe detectors



# JG<mark>U</mark> Work plan

#### Roadmap towards PV 2S1S experiment

- 1. Understand cascade BG with MC simulations
- 2. Suppress BG utilizing X-ray coincidences
  - + 2S population
    - 2015 Test Beam

detector response, and full event generator

next: Monte Carlo with realistic setup,

- Scale up to experiment with large solid-angle segmented HPGe detectors
  ? Can we achieve a S/B of O(1) ?
- 3. Make first measurement of the 2S1S 1γ transition with low BG
- 4. Design PV experiment
  ? Can we measure a PV observable with O(100 days), O(10<sup>5</sup> μ/s)
- 5. Large scale PV experiment