Neutron EDM Measurement with a Pulsed Beam

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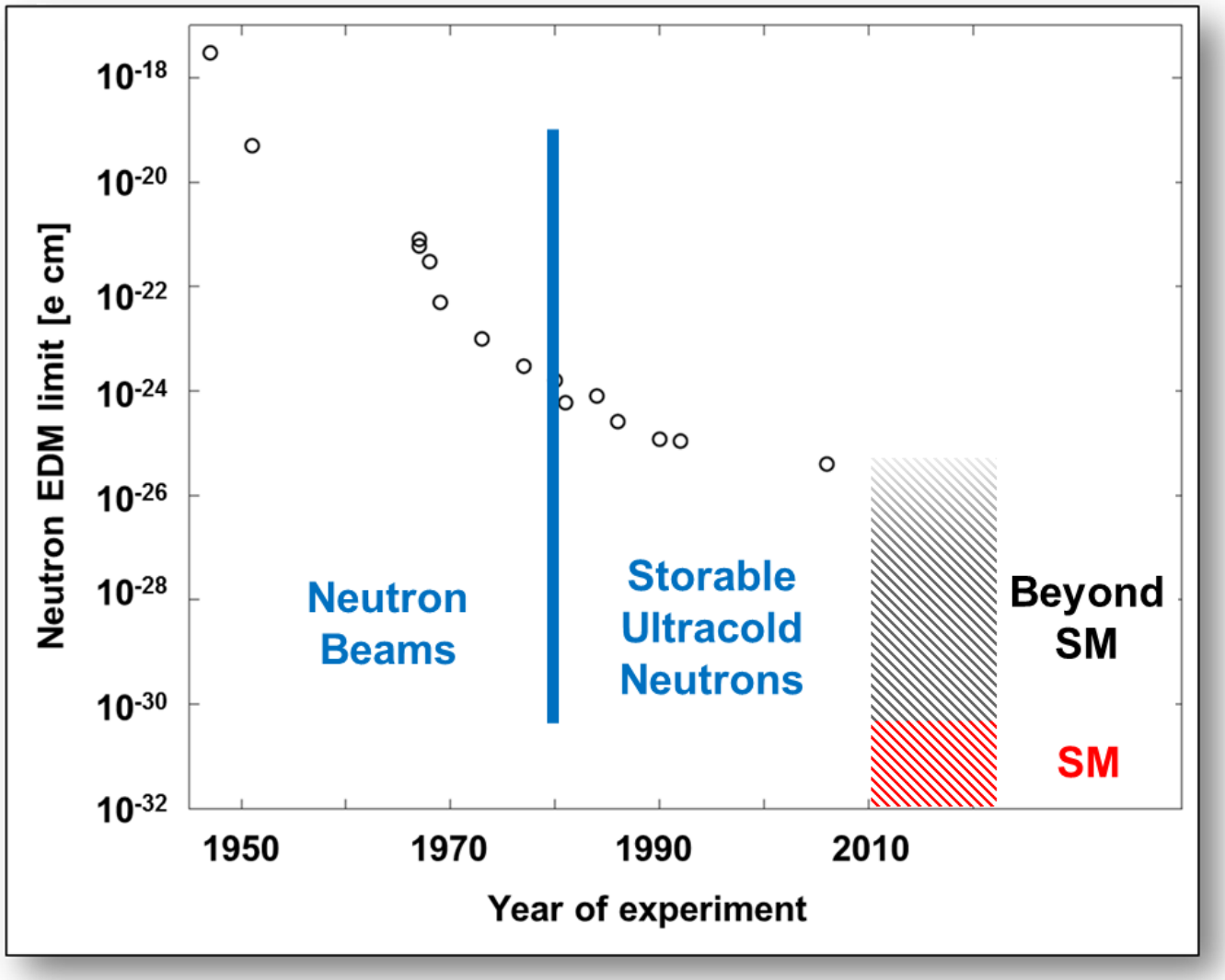
Neutron Beam EDM

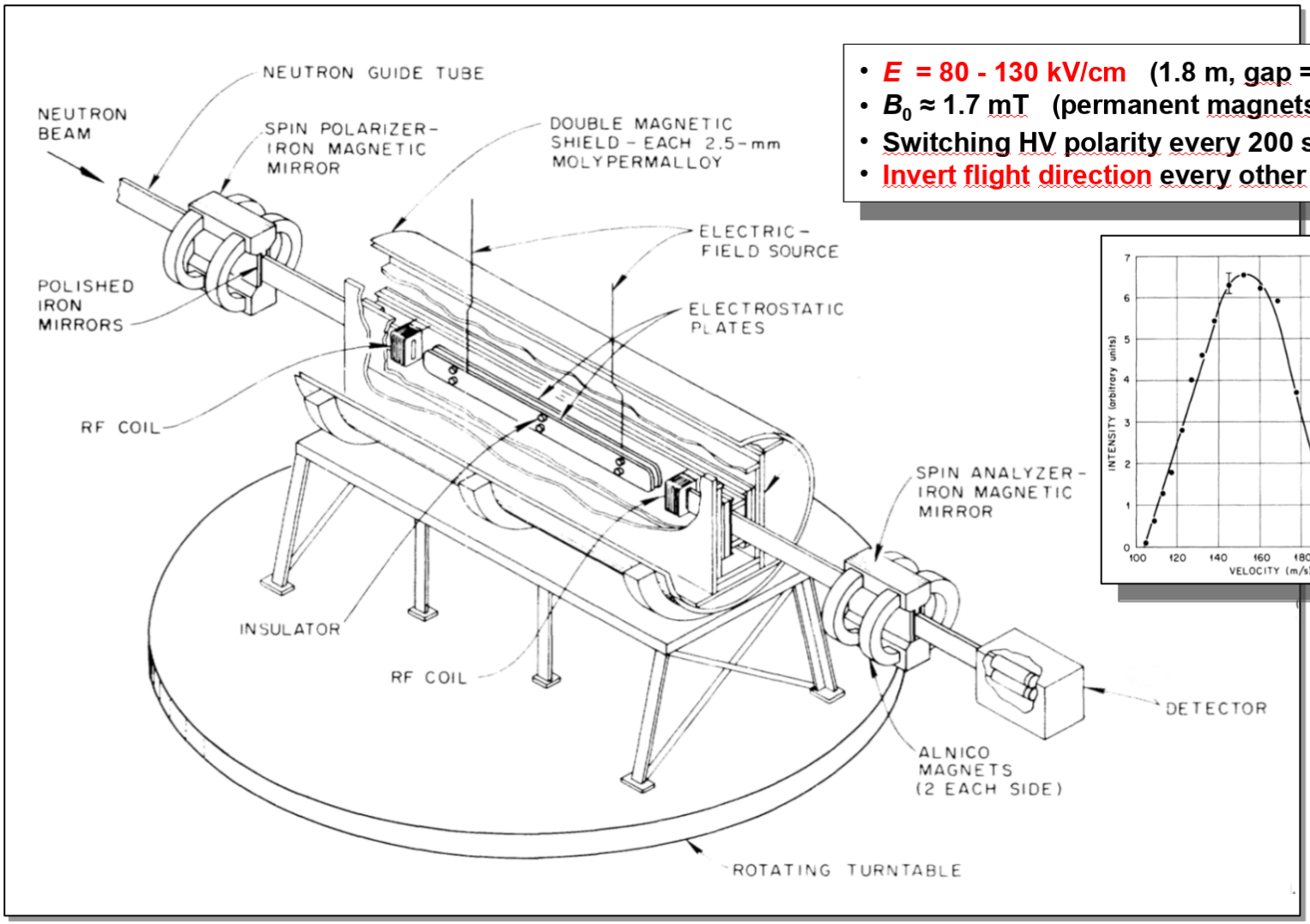
“All nEDM experiments are equal,
but some nEDM experiments are less equal than others.”

~~George Orwell, 1945~~

History


Neutron EDM limit [e cm]
10-18
10-20
10-22
10-24
10-26
10-28
10-30
10-32
1950
1970
1990
2010
Year of experiment
Neutron Beams
Storable Ultracold Neutrons
Beyond SM
SM

1977



- E = 80 - 130 kV/cm (1.8 m, gap = 1 cm)
- $B_0 \approx 1.7$ mT (permanent magnets)
- Switching HV polarity every 200 s
- Invert flight direction every other day

Dress et al., PRD 15, 9 (1977)

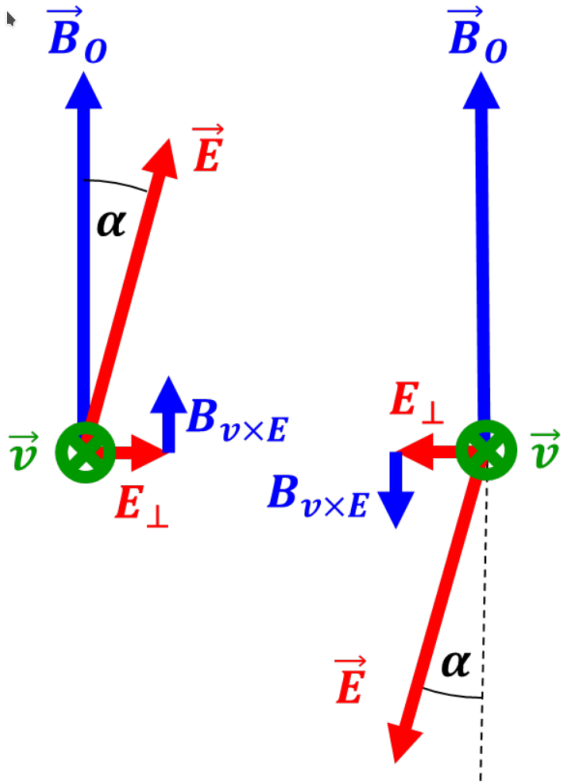
Why switch to UCN?

$$\vec{B}_{\vec{v}\times\vec{E}} = -\frac{\vec{v}\times\vec{E}}{c^2}$$

$$\Downarrow$$

$$d_{\text{false}} \approx 10^{-20}\,\text{e cm}\cdot\sin\alpha$$

$$\text{for } v = 100\,\text{m s}^{-1}$$



Time Dependence

$$\Delta\omega \propto d_n E + \mu_n E \frac{v}{c^2} \sin(\alpha)$$
$$\Leftrightarrow$$
$$\Delta\varphi = \Delta\omega T \propto d_n E T + \mu_n E \frac{L}{c^2} \sin(\alpha)$$

with T the interaction time and L the length of the experiment.

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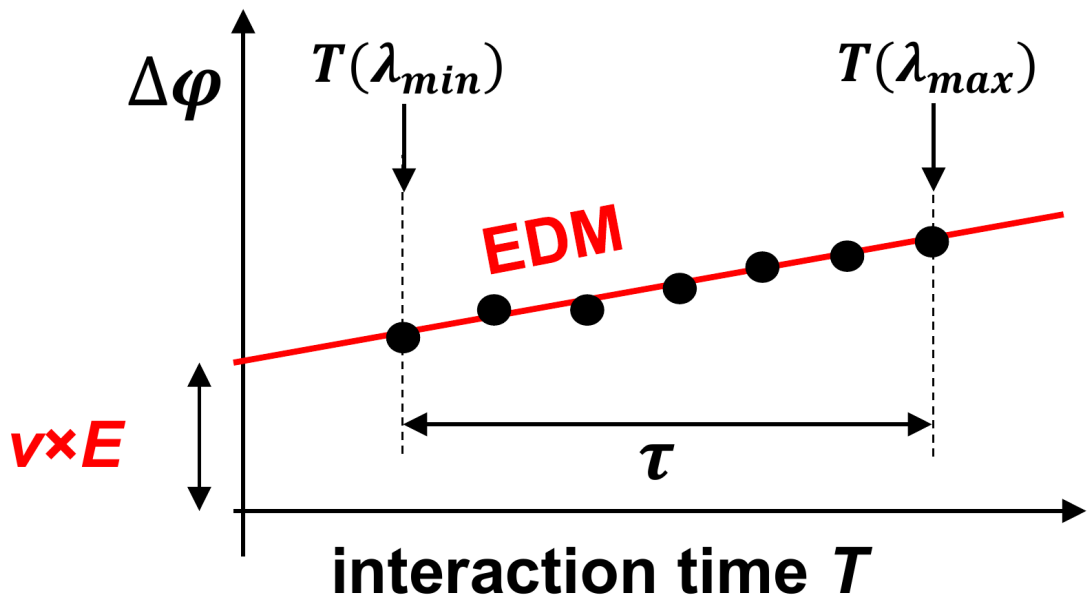
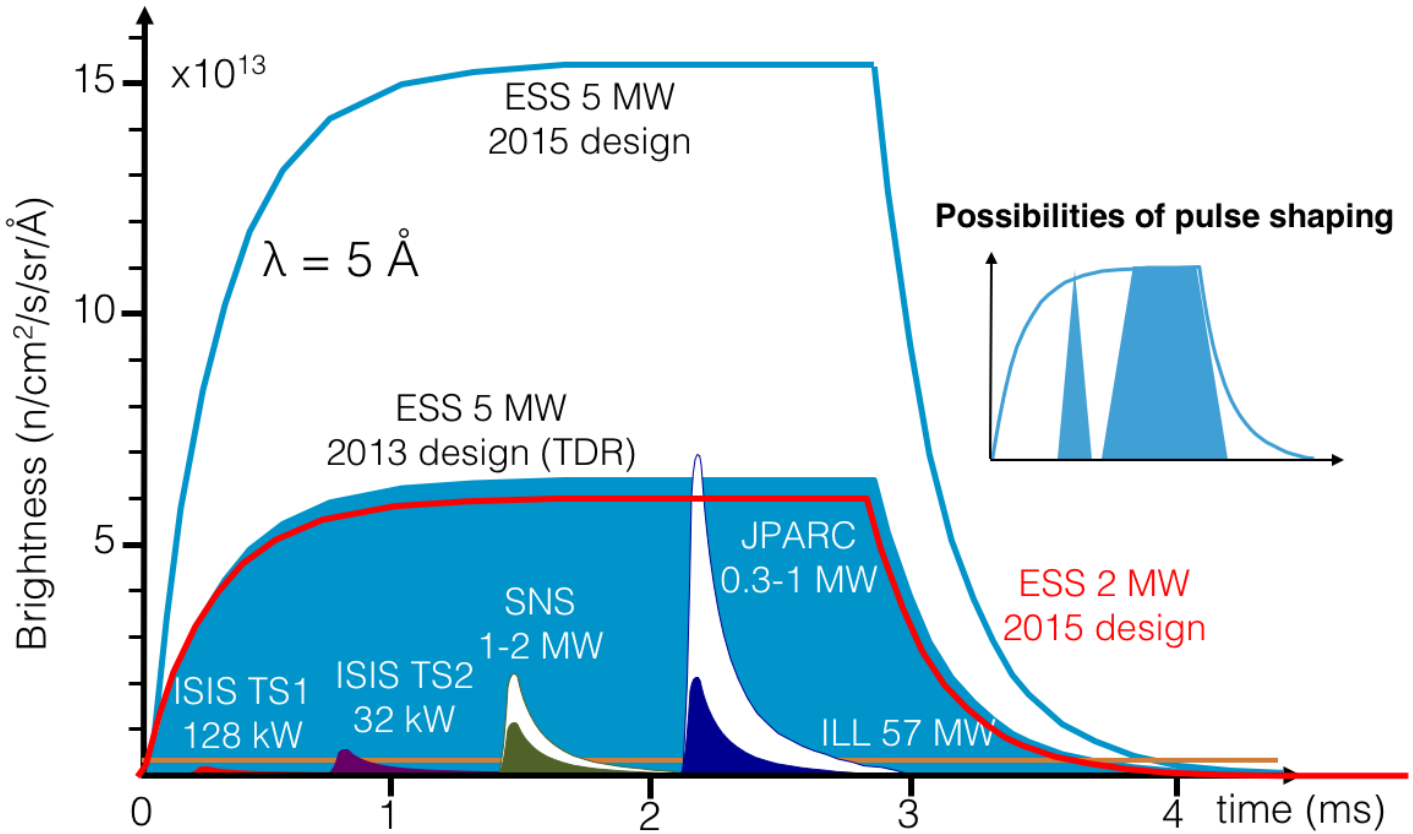
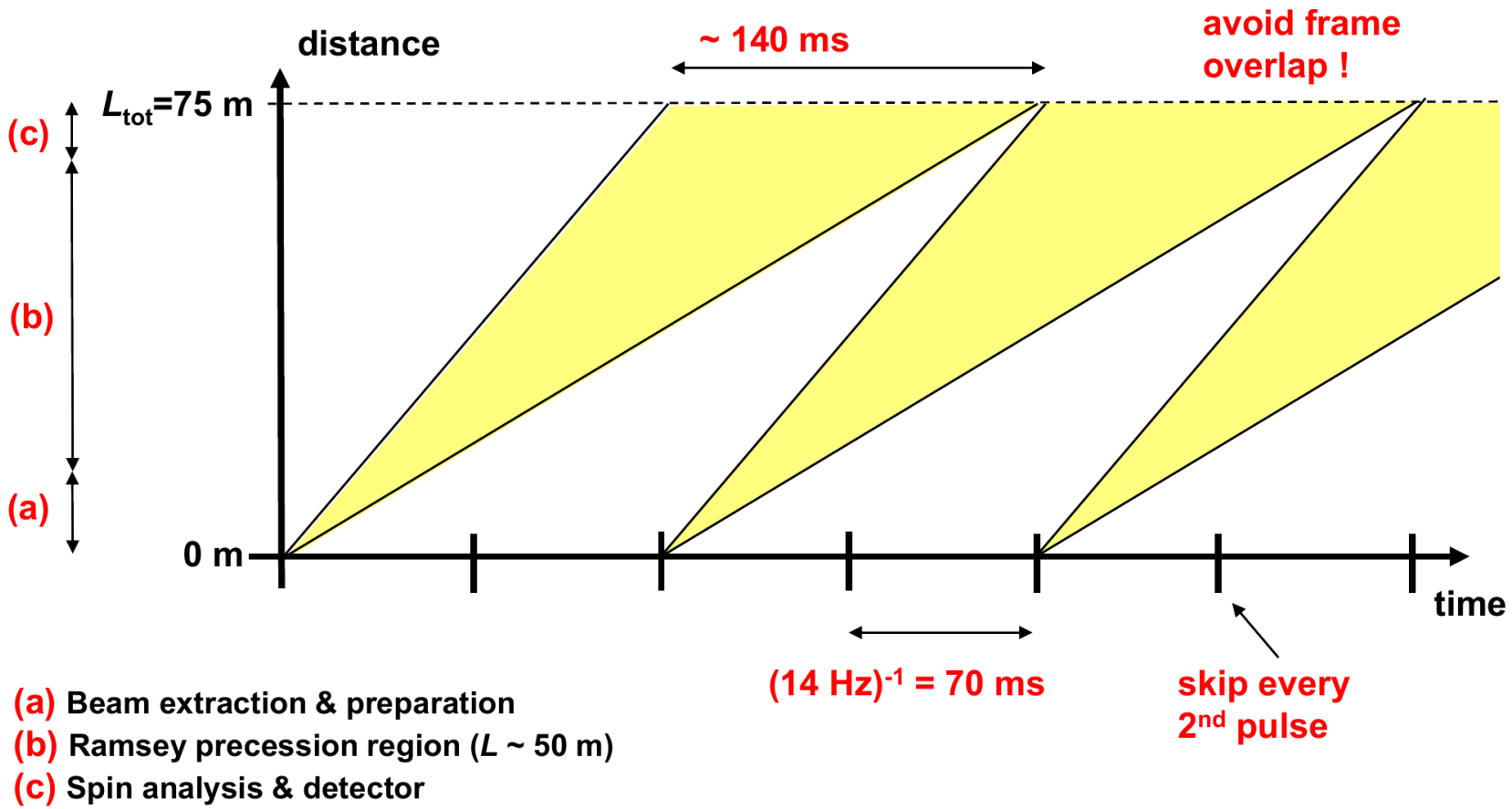


European Spallation Source ESS



https://europeanspallationsource.se

nEDM at ESS?


distance
~ 140 ms
avoid frame overlap !
L_{tot}=75 m
(c)
(b)
(a)
0 m
time
(14 Hz)$^{-1}$ = 70 ms
skip every 2nd pulse
(a) Beam extraction & preparation
(b) Ramsey precession region (L ~ 50 m)
(c) Spin analysis & detector

Experimental Concept

- Use neutron source's intrinsic pulses
- Fixed installation
- Lenght: 50 m
- $\frac{dN}{dt} > 100\,\mathrm{MHz}$
- ...

More Realistic Concept

Phase I

- Existing DC sources + chopper
- Mobile + Beamtimes
- Lenght: 5 m
- $\frac{dN}{dt} > 1\,\mathrm{MHz}$
- ...
- Proof of Concept

Phase II

- Use neutron source's intrinsic pulses
- Fixed installation
- Lenght: 50 m
- $\frac{dN}{dt} > 100\,\mathrm{MHz}$
- ...
- Pushing the Limit

Sensitivity Potential?

	T	η	E [kV/cm]	N	M (no. cycles)	σ / day [10^{-26} ecm]
@ PF1b/ILL *	8 ms	0.75	50	2 x 2 MHz	1	~ 800
@ ESS	90 ms	0.75	100	2 x 20 - 200 MHz	1	3 - 10
ILL/RAL /Sussex **	130 s	0.45	8.3	14000 per cycle	360	30

Sensitivity

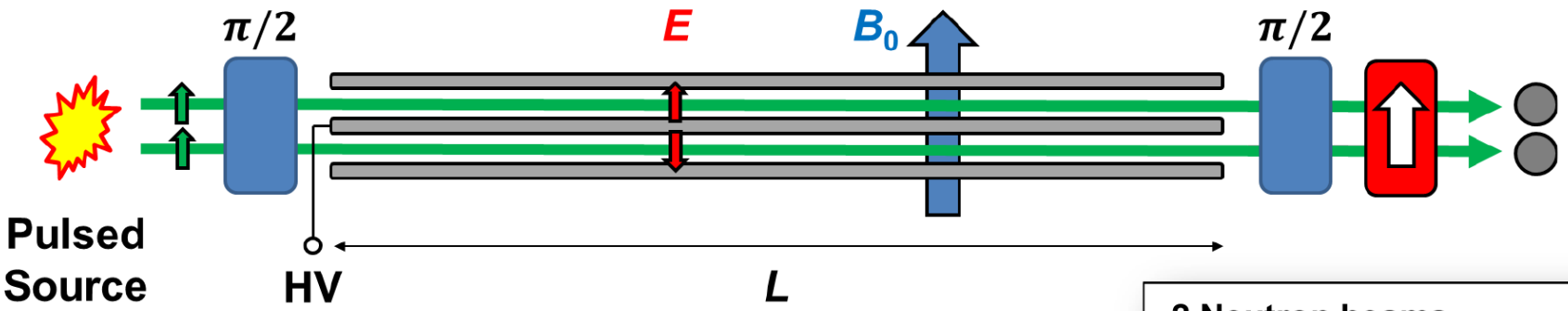
$$\sigma(d) \propto \frac{1}{E\,T\,\sqrt{NM}}$$

* **Realistic proof-of-principle experiment at PF1b/ILL with a velocity selector**

** **Baker et al., PRL 97 (2006) 131801**

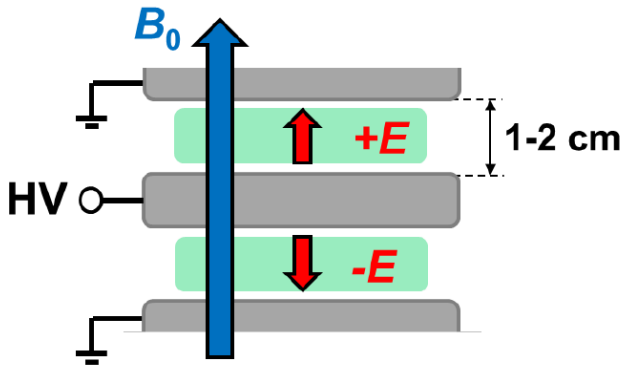
Schematics

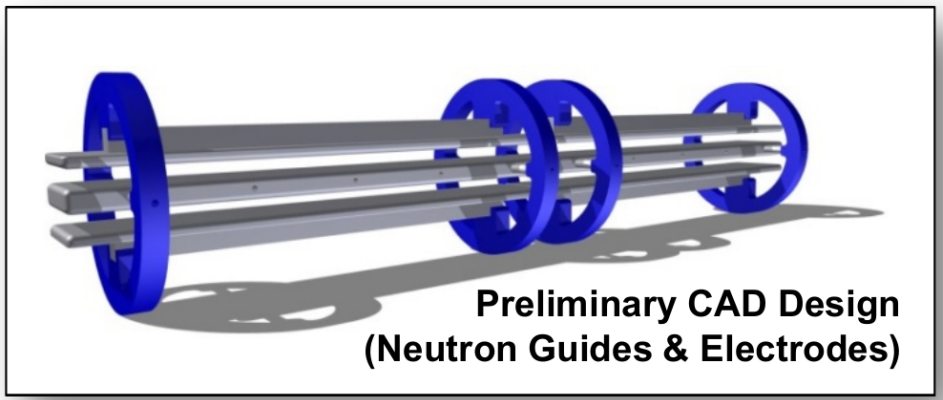
SIDE VIEW



2 Neutron beams
E > 50 kV/cm
B_0 = 200 µT
L = 5 m (proof-of-prin.)
L = 50 m (full-scale)

CROSS SECTION

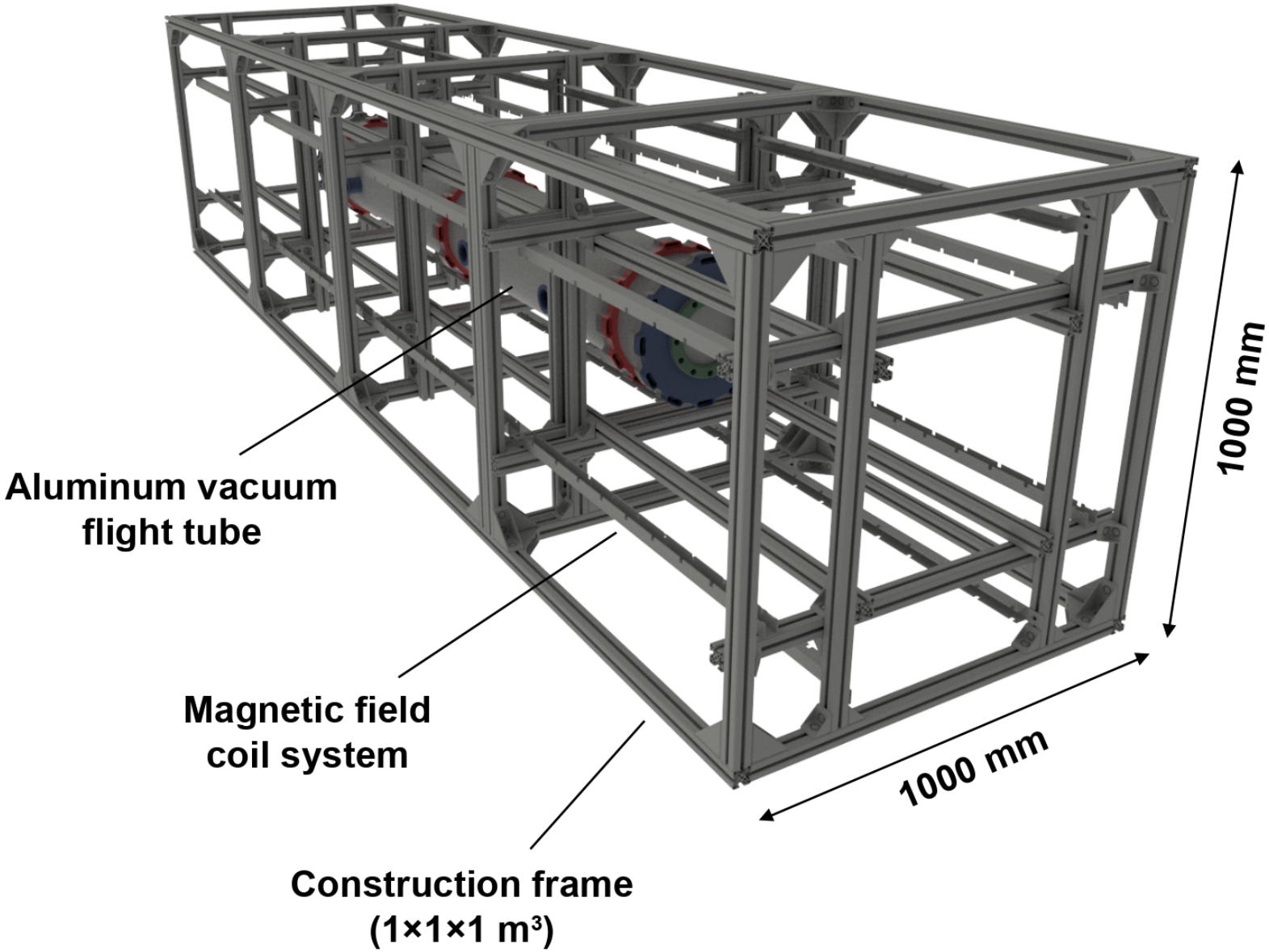




Mechanical Challenges

- 5 m long ...
  - Support Structure
  - Flight Tubes
  - Electrodes
  - B_0-Coil
  - Field Trim Coils
  - Active Field Stabilization
  - ...
- Mobility
- Weight
- Lab Doors

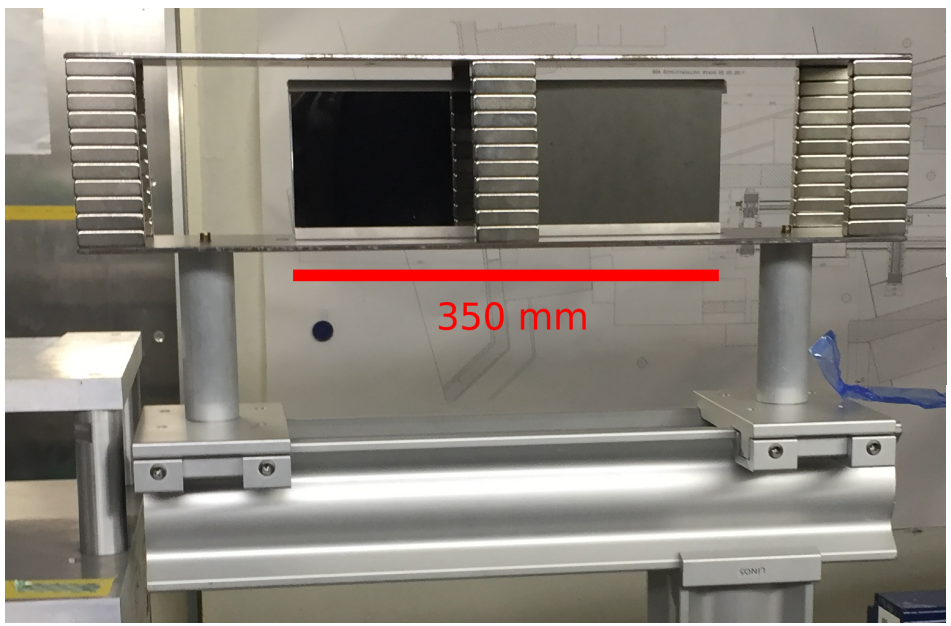
CAD Design

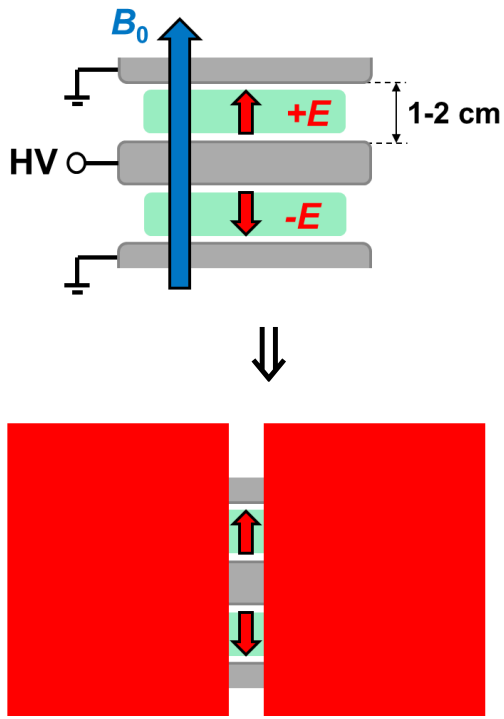

Aluminum vacuum flight tube
Magnetic field coil system
Construction frame (1×1×1 m³)
1000 mm
1000 mm

Reality

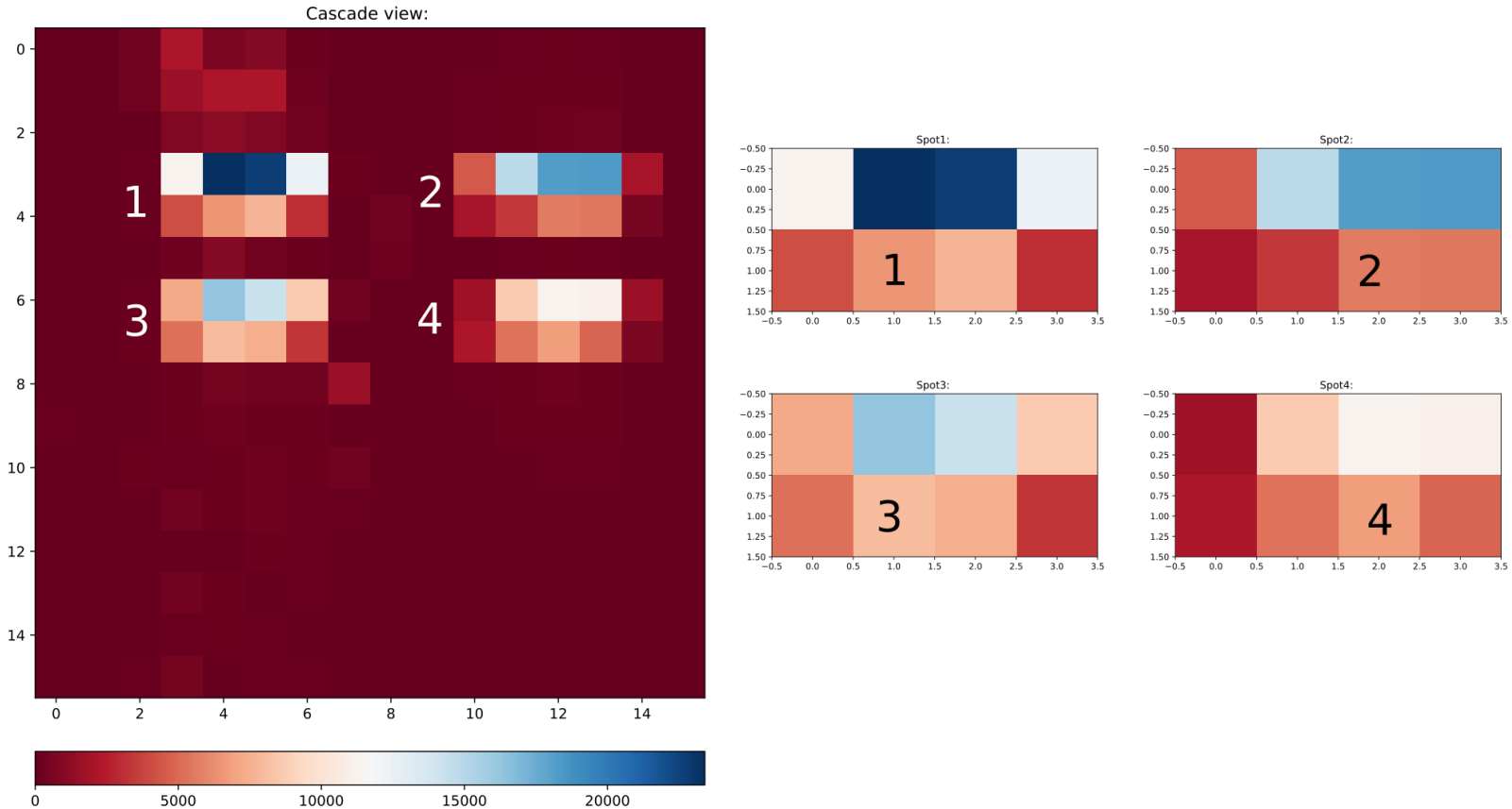
Spin Analysis

- Spinfilter + Monitor Detector
  - Intensity Reduction (Monitor Statistics)
- Polarizing Mirror:
  - 2 beams × 2 polarizations = 4 beam spots





Detector View



Beams nicely separated by one row of pixels (6.25 mm).

Neutron Detector

Requirements:

- High Rate (> 1 MHz) Capability
- Large Area (100×100 mm^2)
- Pixelated
- High Efficiency

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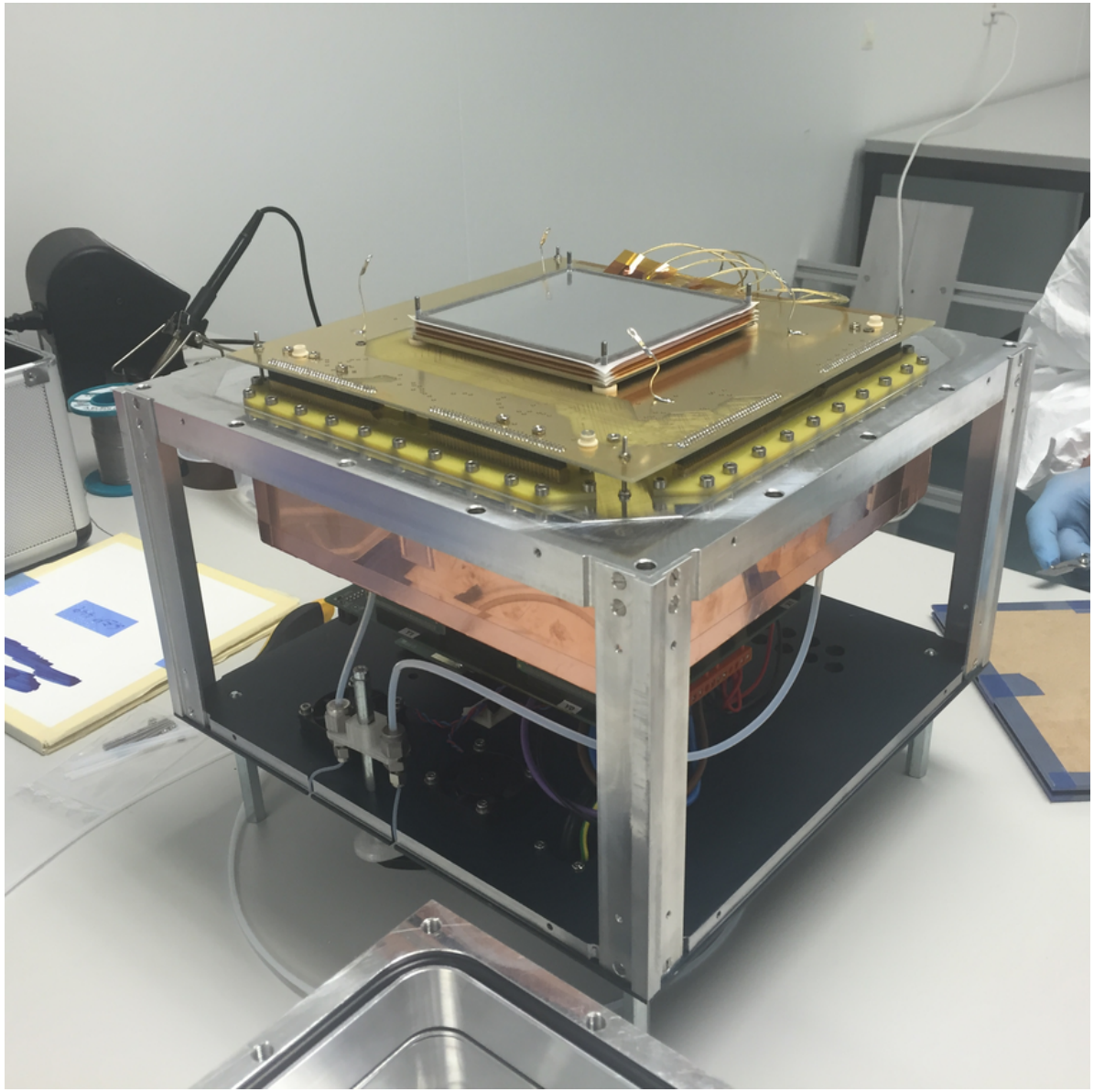
Commercially Available: CDT Cascade Detector

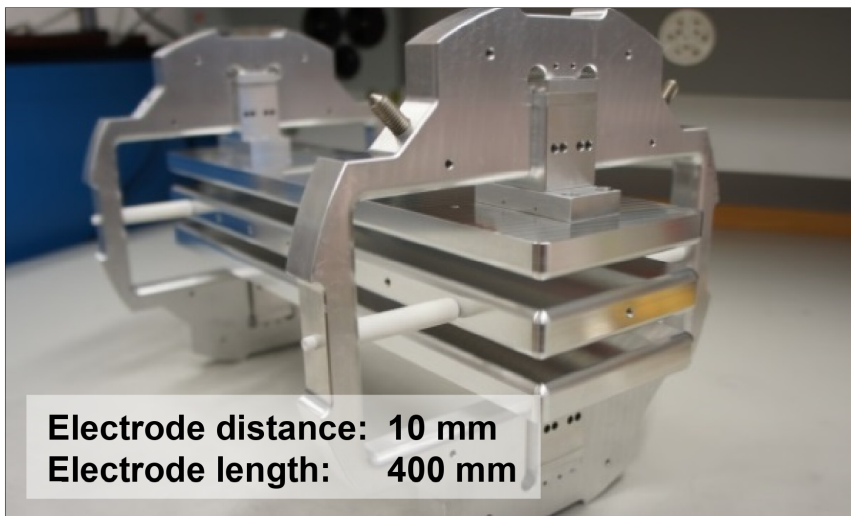
- Up to 10 MHz (GEM Technology)
- 100×100 mm^2
- 16×16 Pixels (Can be Arbitrarily Distributed)
- ~ 35 % Efficiency at 5Å (5 ^{10}B layers)

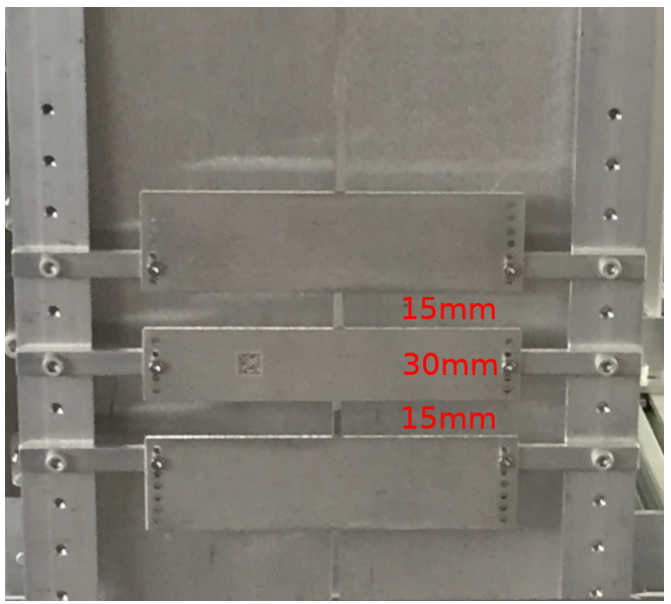
Detector



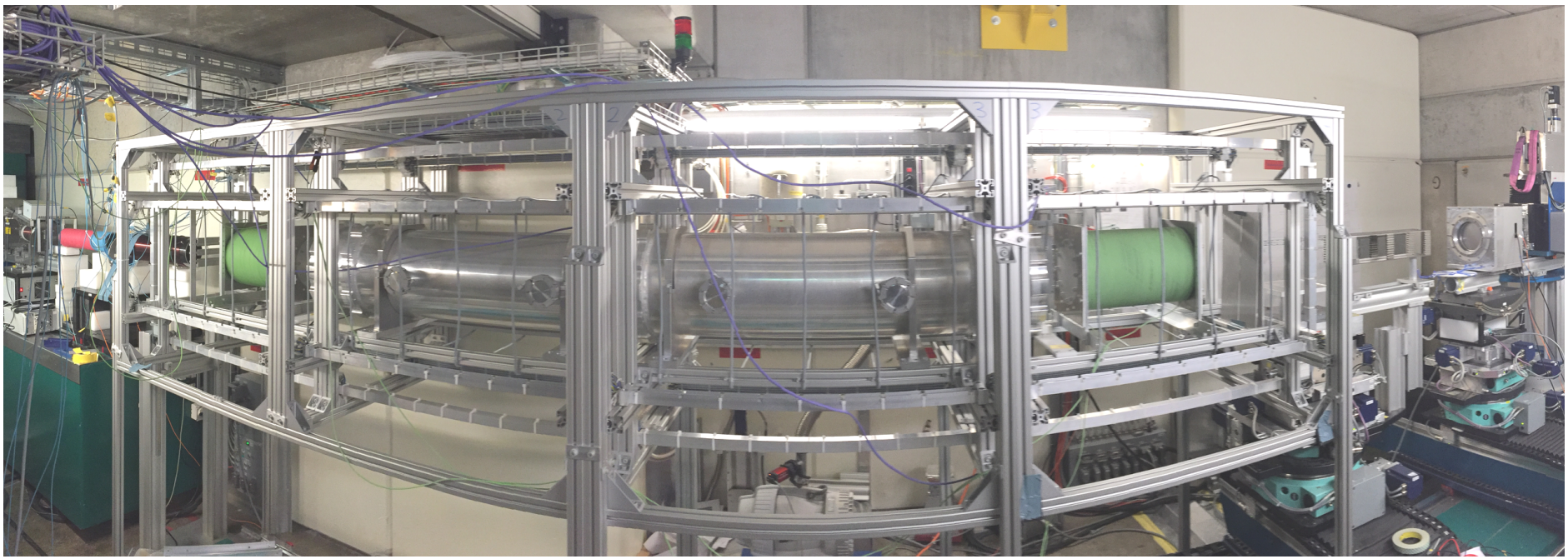
High Voltage

- Electrodes
  - Material
  - Coating
  - Contacts
  - Under Investigation





Beamtime at PSI Aug/Sep 2017



Neutron Rate

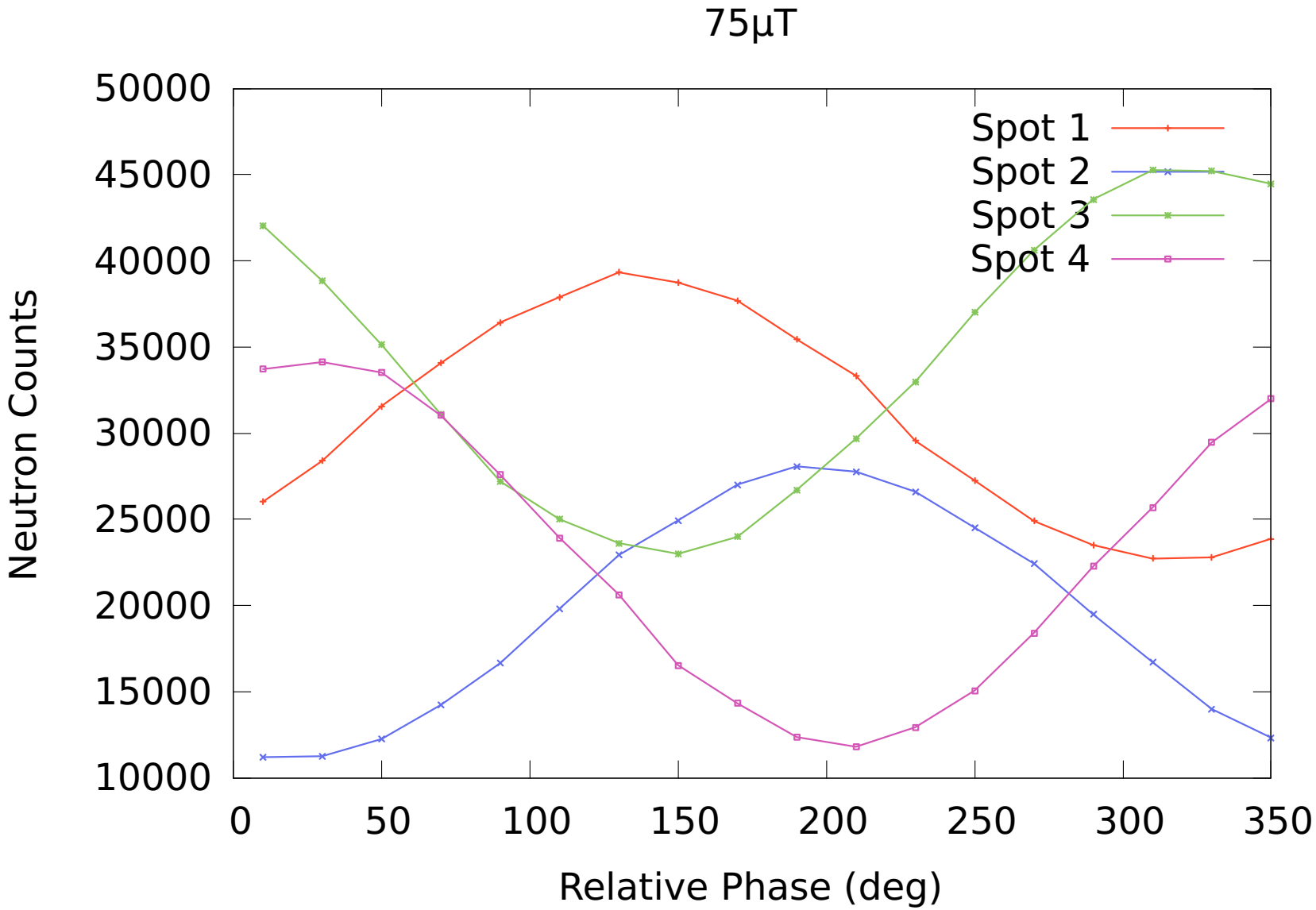
Conditions:

- Proton Beam on SINQ Target: 1 mA
- No Electrodes (No Guiding of Neutrons)
- Suboptimal Chopper
- 3 mm wide Beam for Spin Analysis)

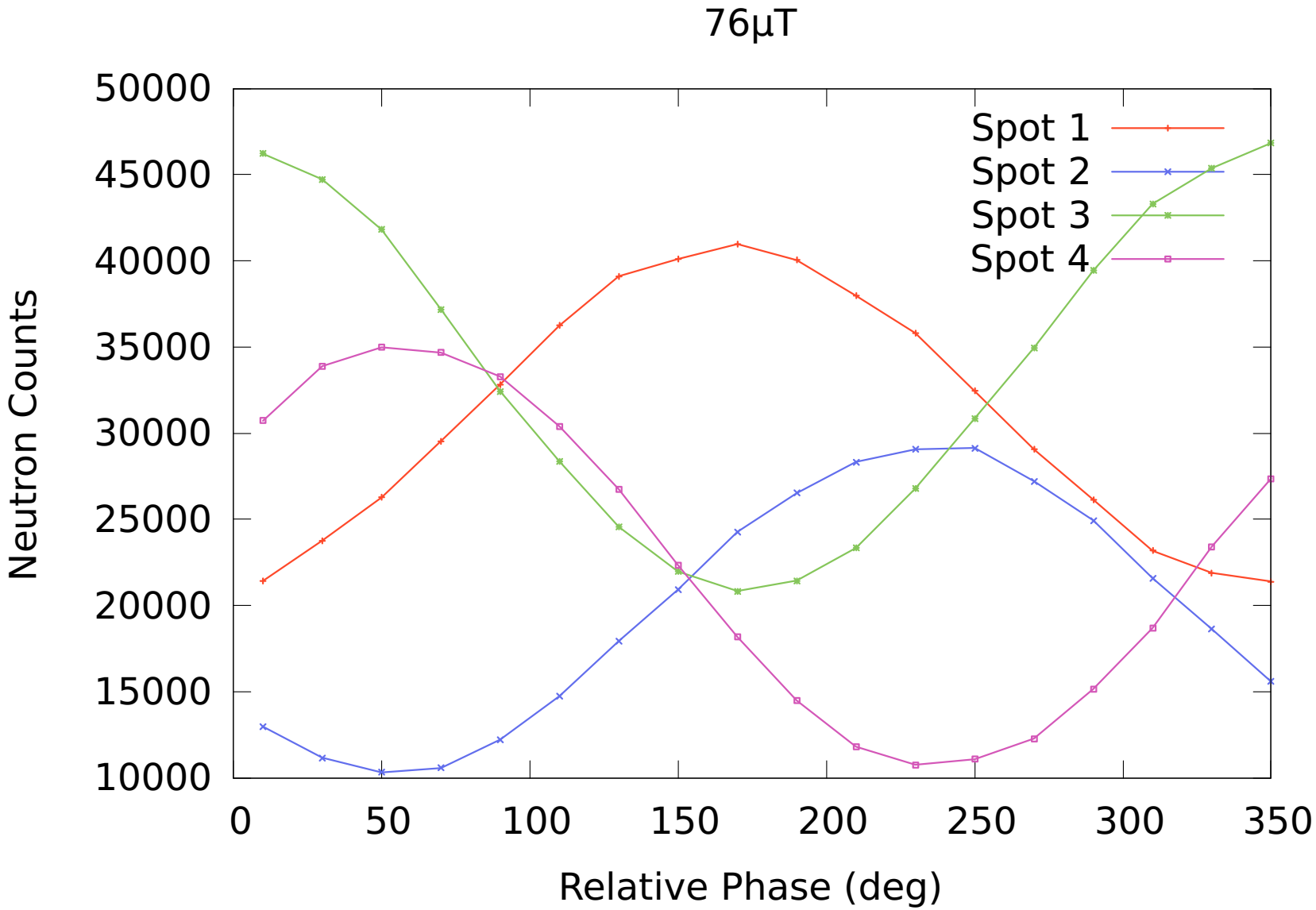
Chopper + Spin Analysis: > 100 Hz
Spin Analysis: 40 kHz
Open Beam 2.8 MHz

Phase Ramsey

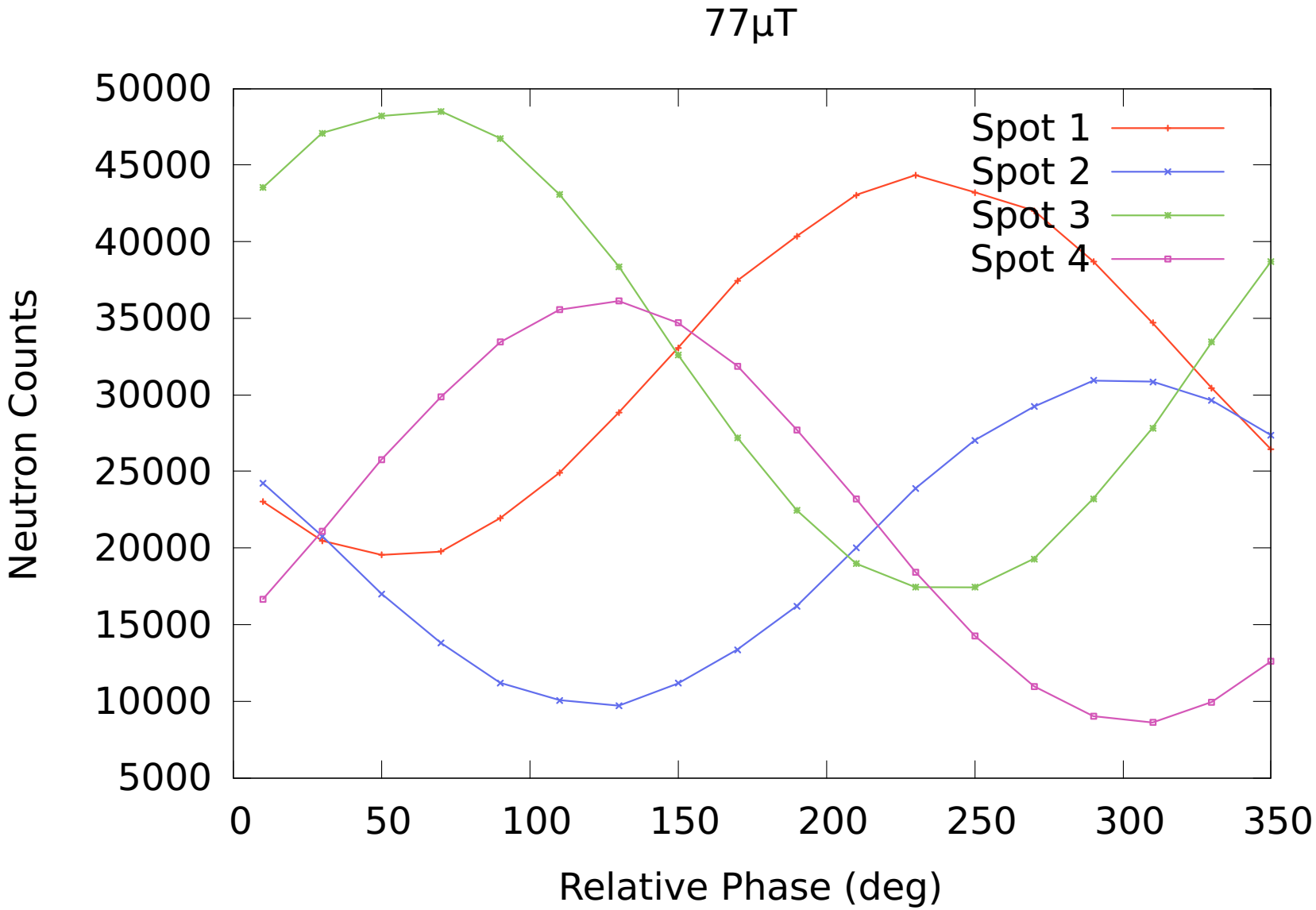
Phase Ramsey



Phase Ramsey



Phase Ramsey



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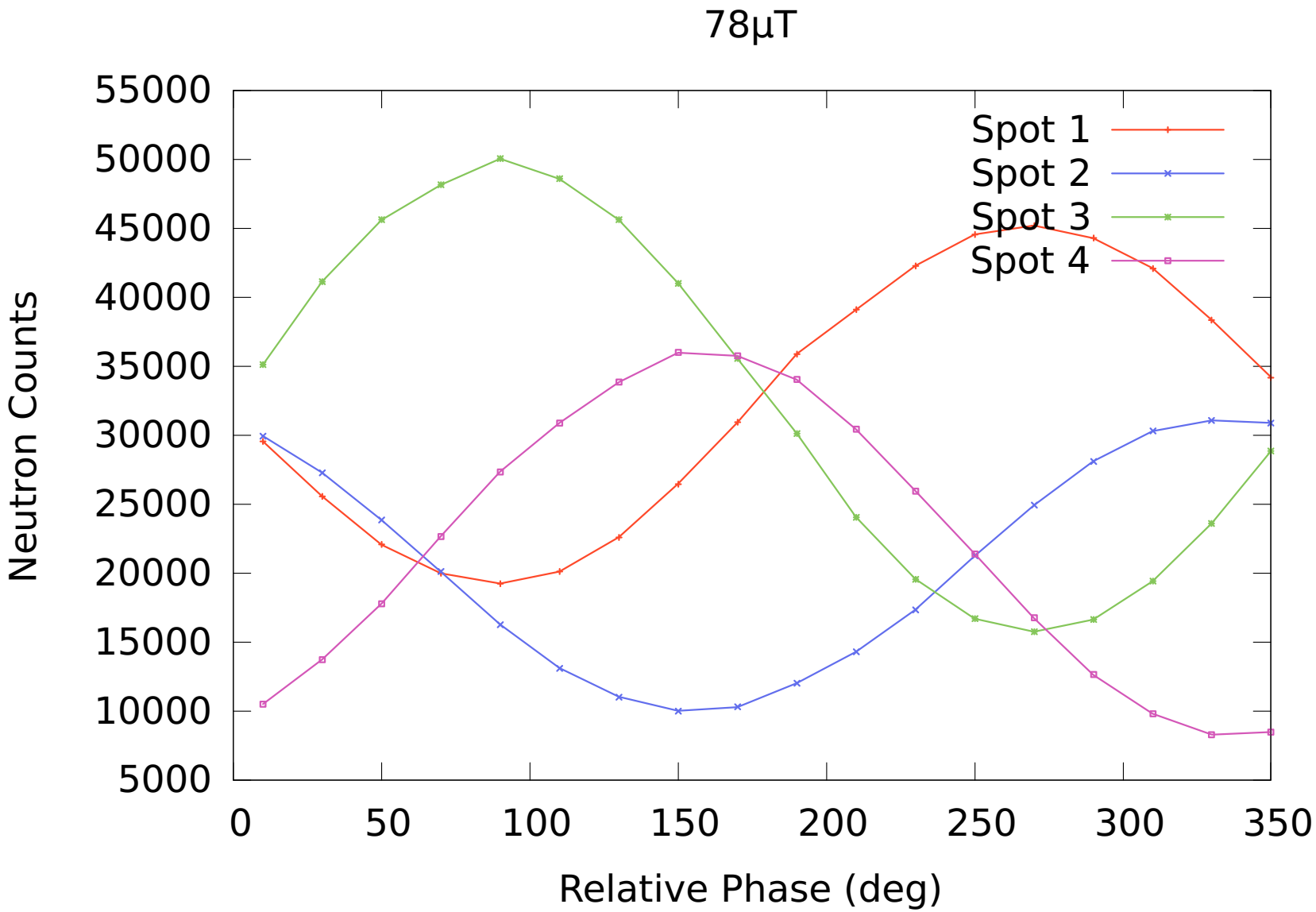

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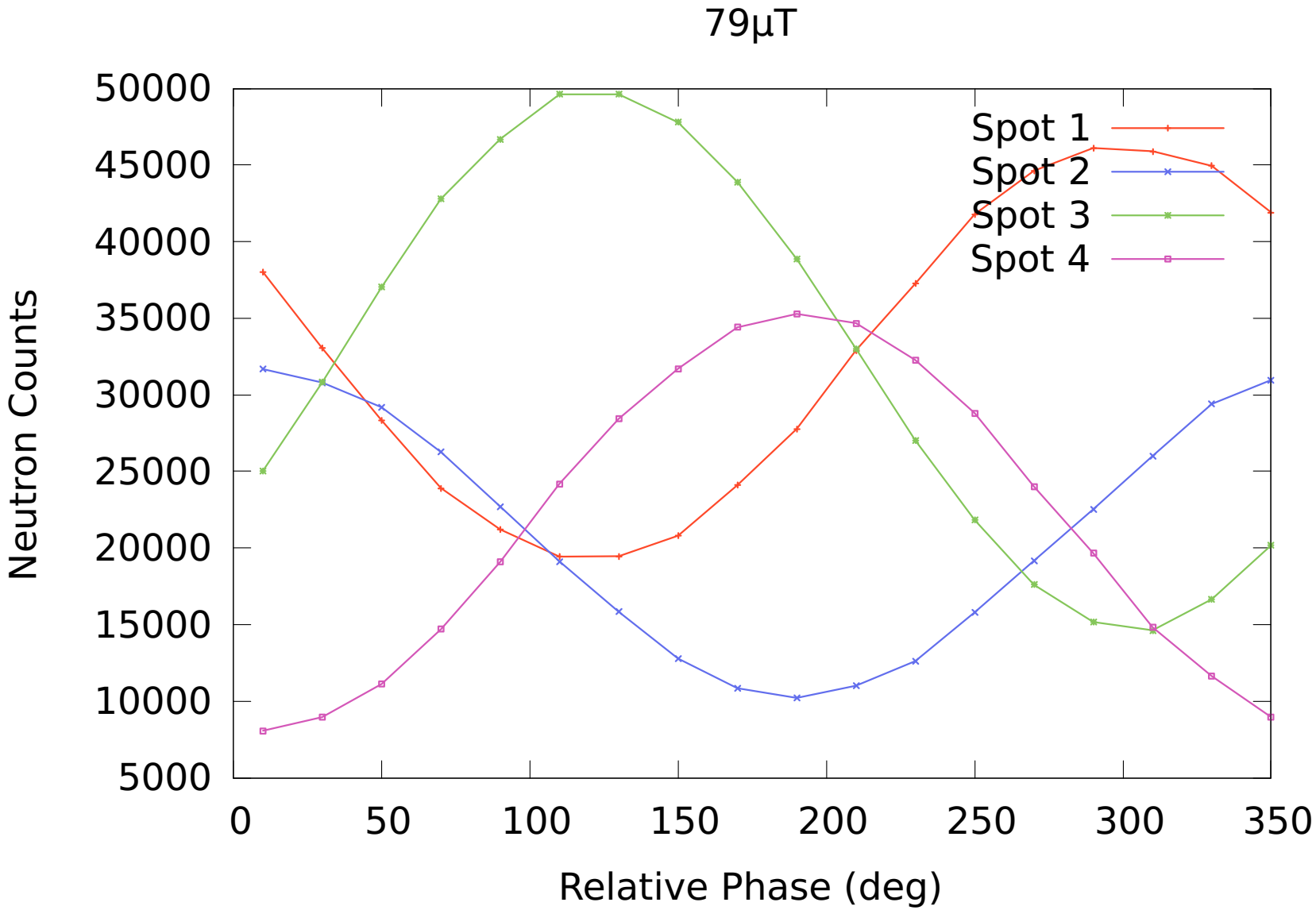

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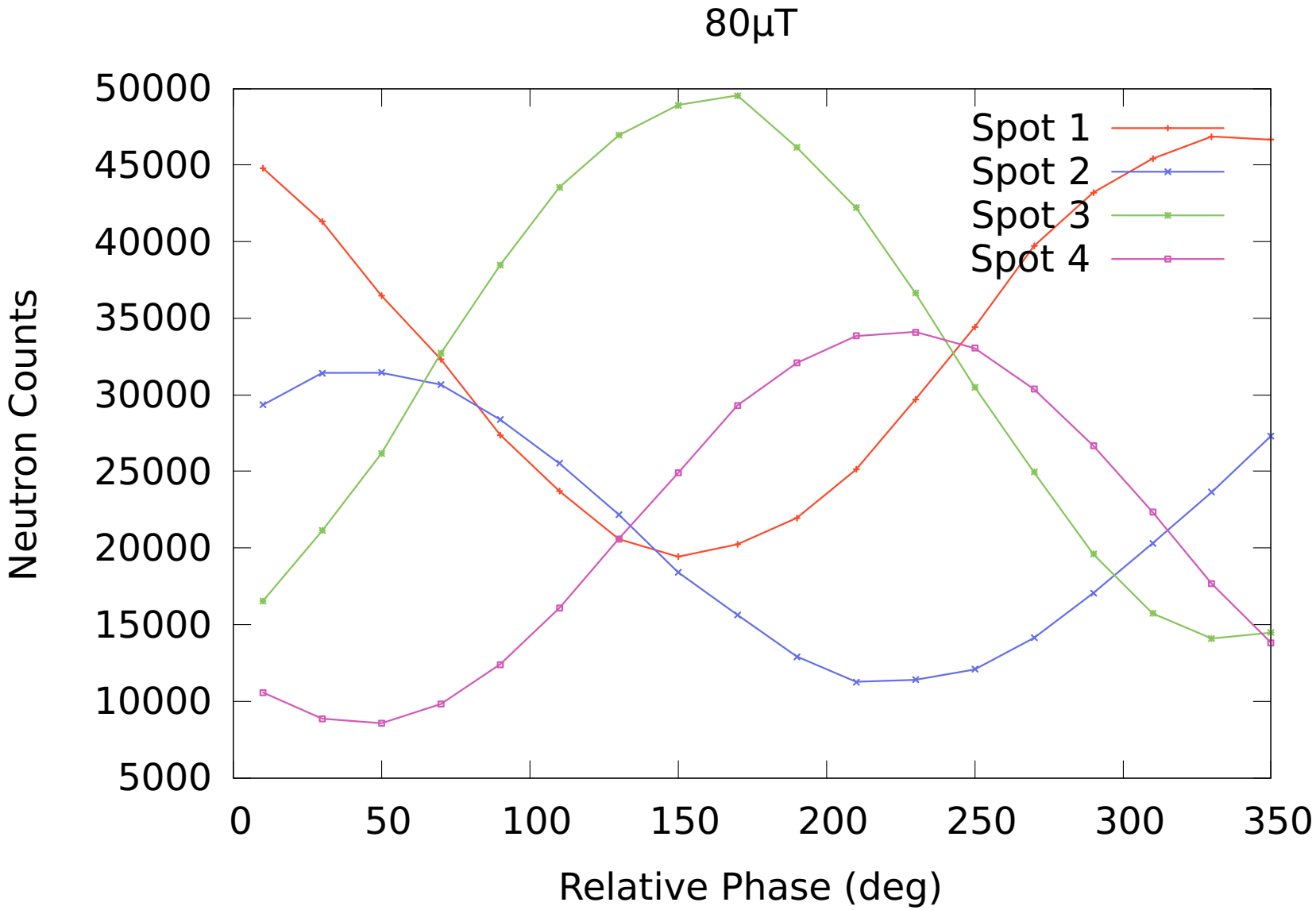
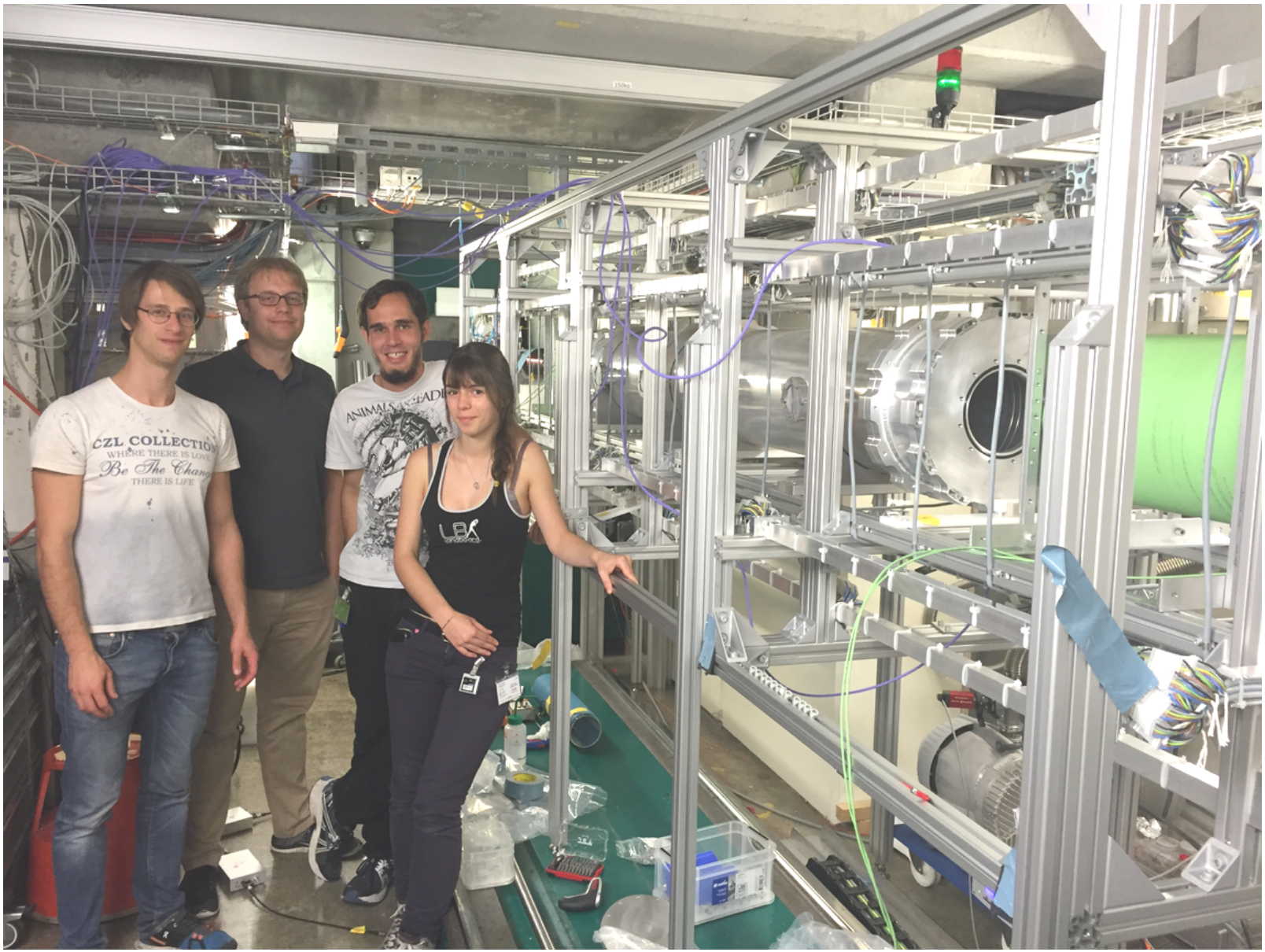


Summary

- $v \times E$ Killed Beam nEDM Experiments
- TOF nEDM Experiment Immune to $v \times E$
- Intense Pulsed Neutron Sources Upcoming
- Proof of Concept effort @unibe since 1 year:
  - Mechanical Concept: ✓
  - Neutron Detector: ✓
  - Magnetic Field Stabilization: (✓)
  - Time of Flight: (✓)
  - High Voltage & Eletrodes: TBD
- First Beamtime at PSI in September 2017: ✓
- Upcoming Beamtimes at PSI and ILL (PF1b)

Acknowledgements

The Team



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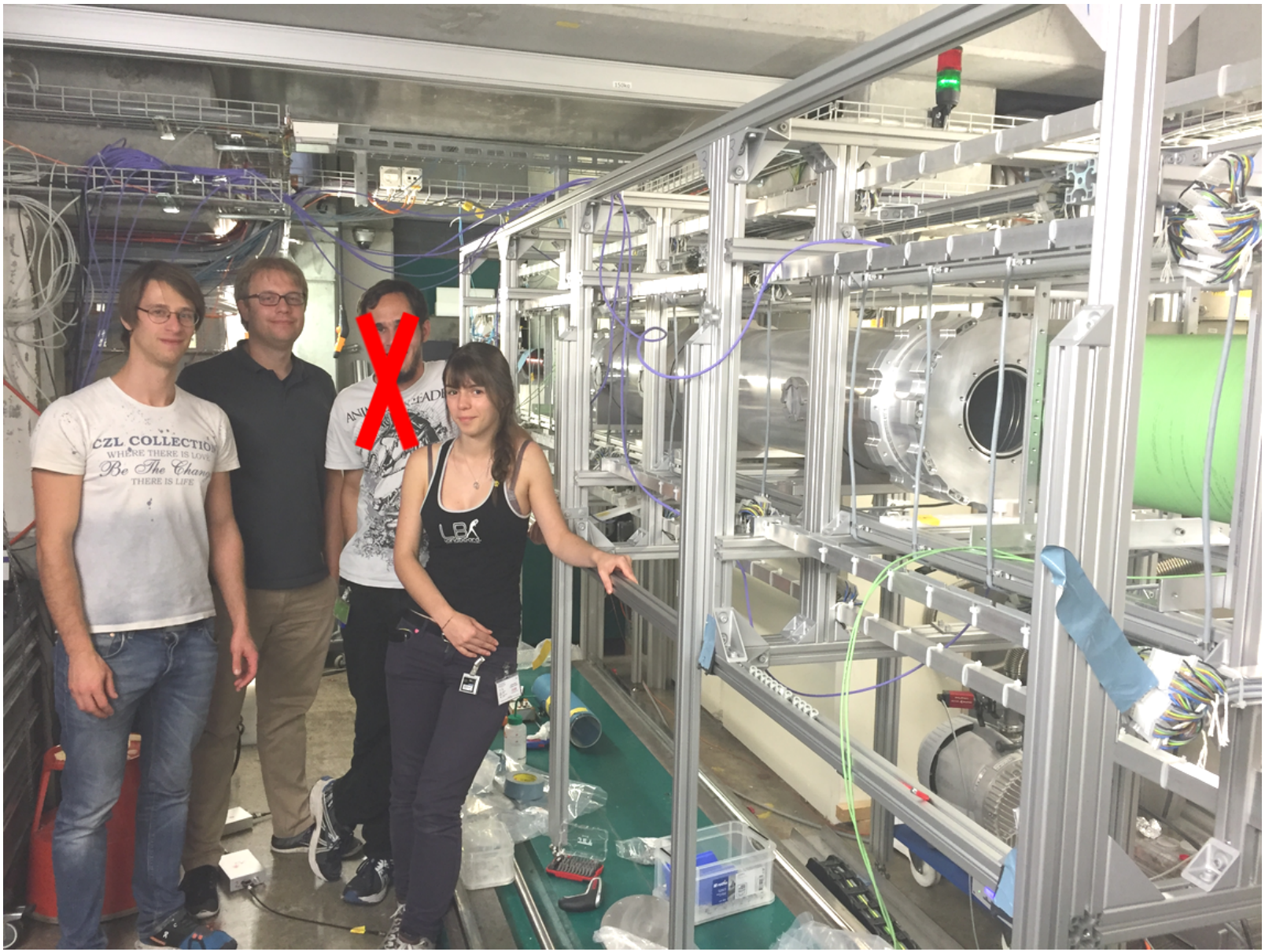

Thank you for your attention!

Backup

Statistical Sensitivity

$$\sigma_{\text{Beam}}(d_n) \approx \frac{2\hbar}{\eta \tau E \sqrt{N}}$$

- η: Visibility of Ramsey Patterrn
- τ: Interation Time
- E: Electric Field
- N: Neutron Counts

Neutron Wavelength Spectrum @ BOA