Neutron Beam EDM Experiment

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EDM

PHYSICAL REVIEW C **88**, 045502 (2013)

New concept for a neutron electric dipole moment search using a pulsed beam

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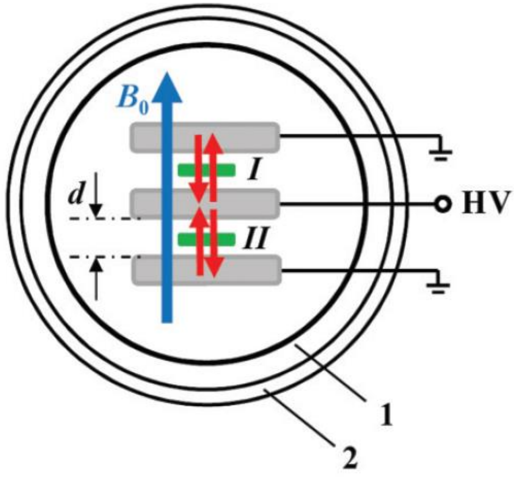
(Received 27 May 2013; published 14 October 2013)

A concept to search for a neutron electric dipole moment (nEDM) is presented, which employs a pulsed neutron beam instead of the established use of storable ultracold neutrons (UCN). The technique takes advantage of the high peak flux and the time structure of a next-generation pulsed spallation source like the planned European Spallation Source. It is demonstrated that the sensitivity for a nEDM can be improved by several orders of magnitude compared to the best beam experiments performed in the 1970s and can compete with the sensitivity of UCN experiments.



CHARGE

PHYSICAL REVIEW C **98**, 045503 (2018)

Novel concept for a neutron electric charge measurement using a Talbot-Lau interferometer at a pulsed source

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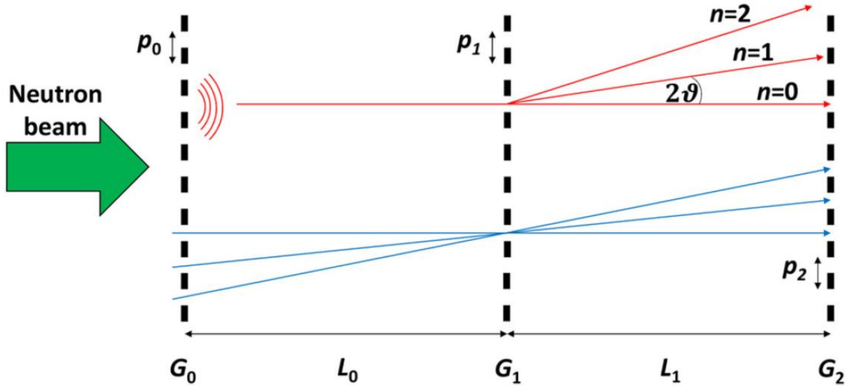
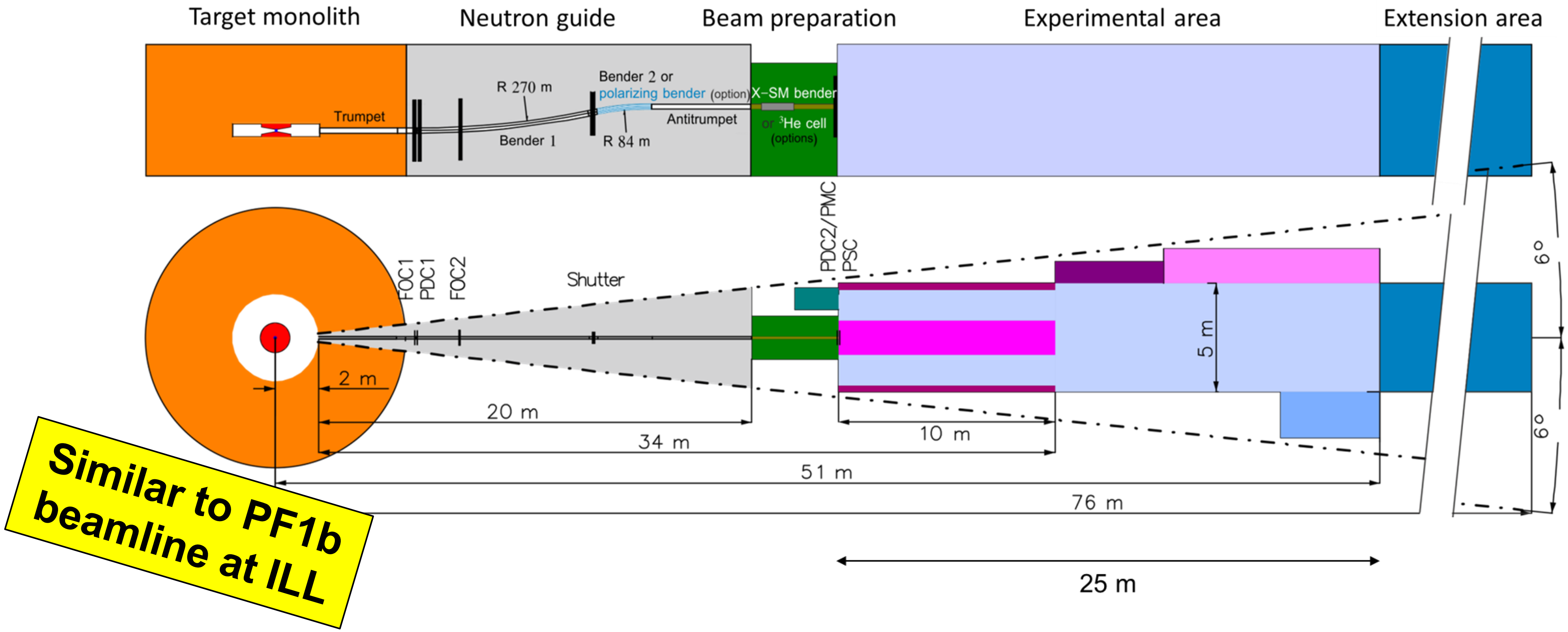
(Received 23 July 2018; published 30 October 2018)

A concept to measure the neutron electric charge is presented which employs a precision Talbot-Lau interferometer in a high-intensity pulsed neutron beam. It is demonstrated that the sensitivity for a neutron charge measurement can be improved by up to two orders of magnitude compared to the current best direct experimental limit.



ANNI – Cold Neutron Beam Facility for Particle Physics (ESS)



Science cases:

- **Neutron decay** (PERC, Perkeo, aSPECT, BRAND)
- **Hadronic weak interaction**
- **Neutron Beam EDM**
- **Neutron charge measurement**
- **nnbar-studies etc.**

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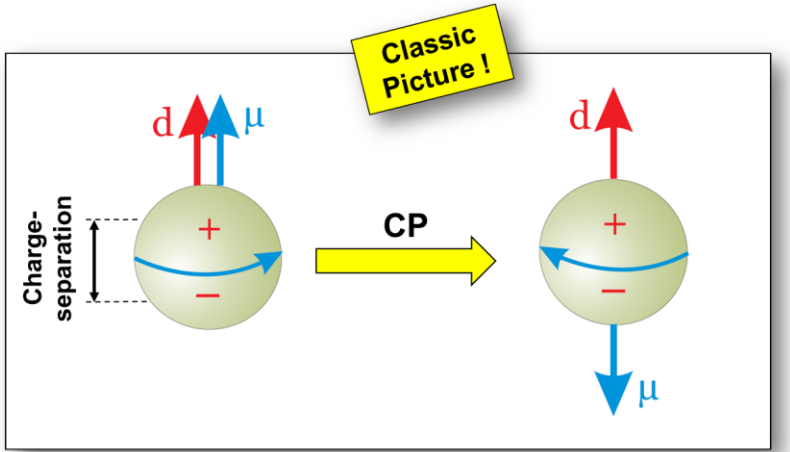
E. Klinkby, T. Soldner, J. Phys. Conf. Ser. 746, 012051 (2016)
T. Soldner et al., EPJ Web Conf. 219, 10003 (2019)

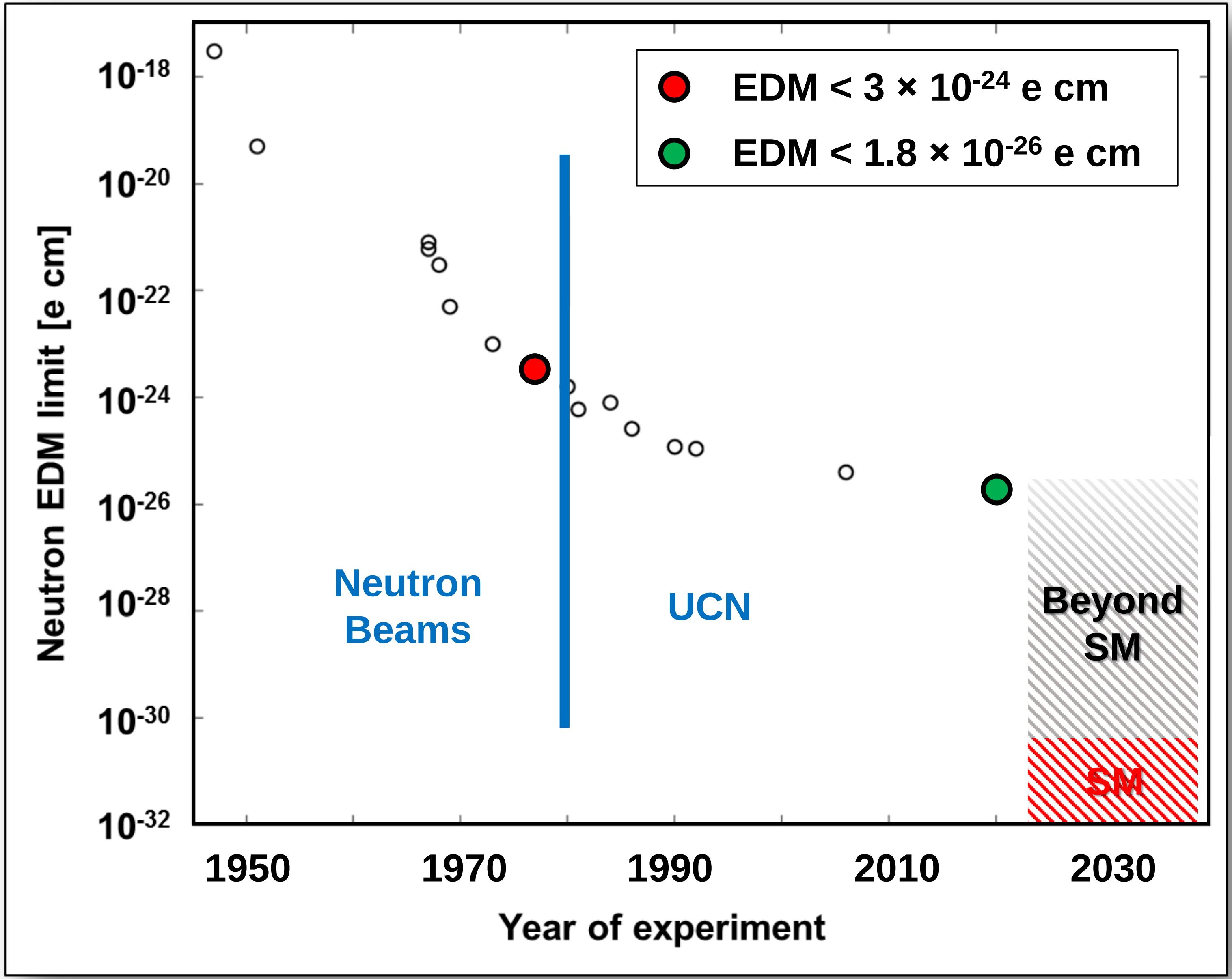
Matter-antimatter asymmetry in our universe

Sakharov criteria for baryogenesis*

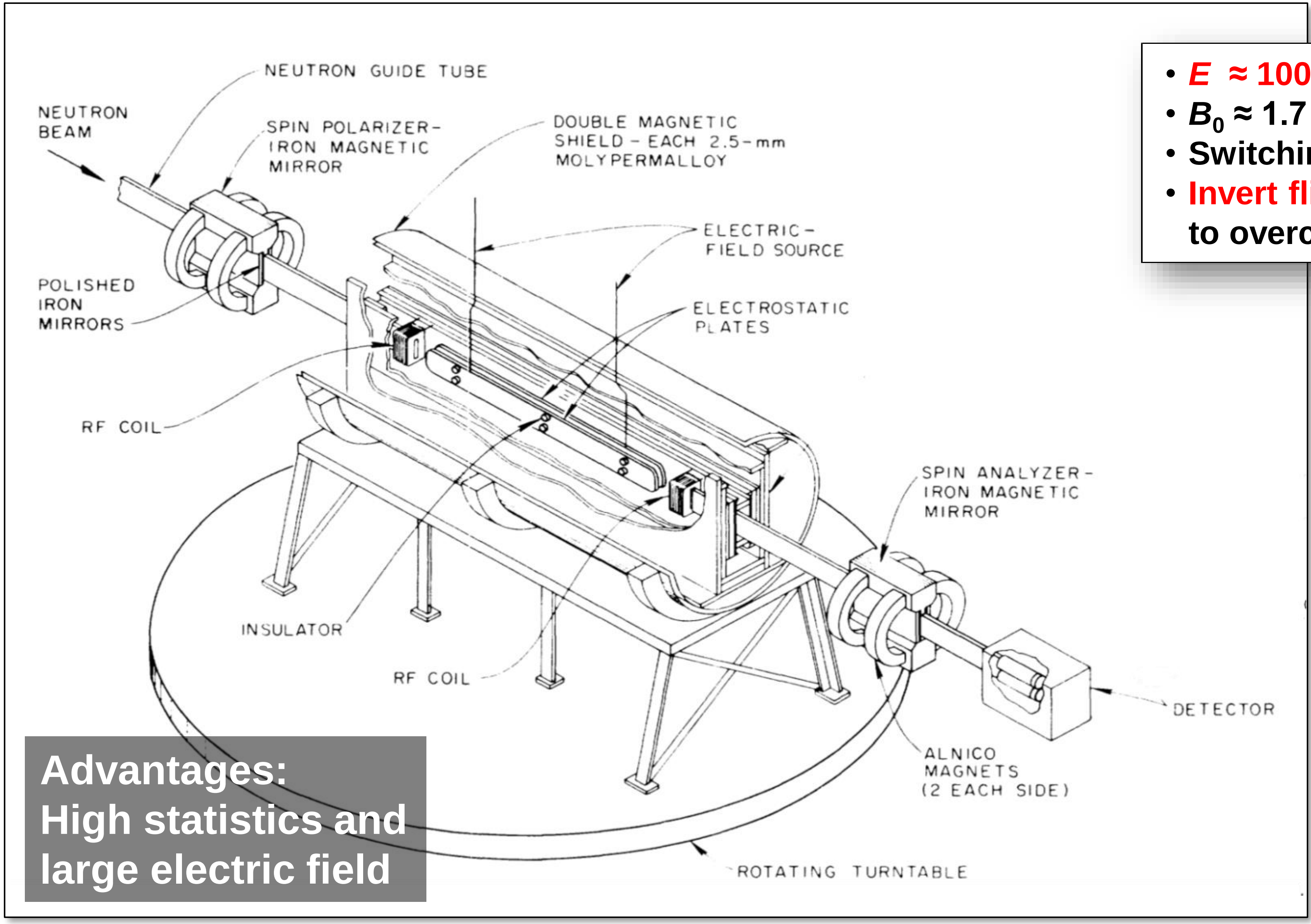


CP violation of electric dipole moments

* Sakharov, JETP Lett. 5, 24 (1967)

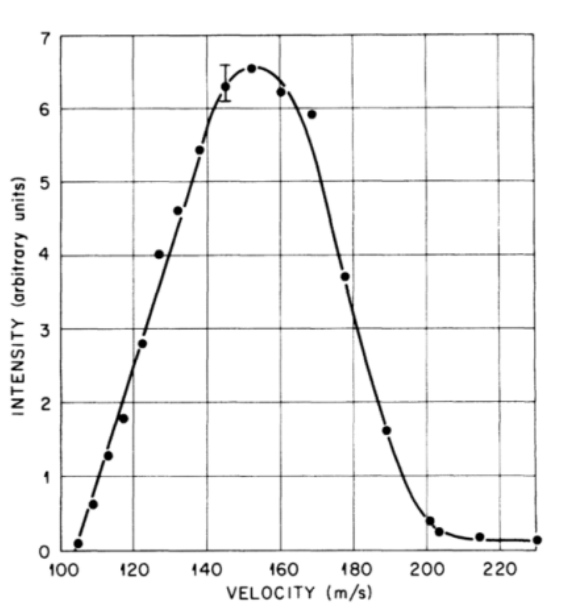


Dress et al., PRD 15, 9 (1977)
Abel et al., PRL 124, 081803 (2020)



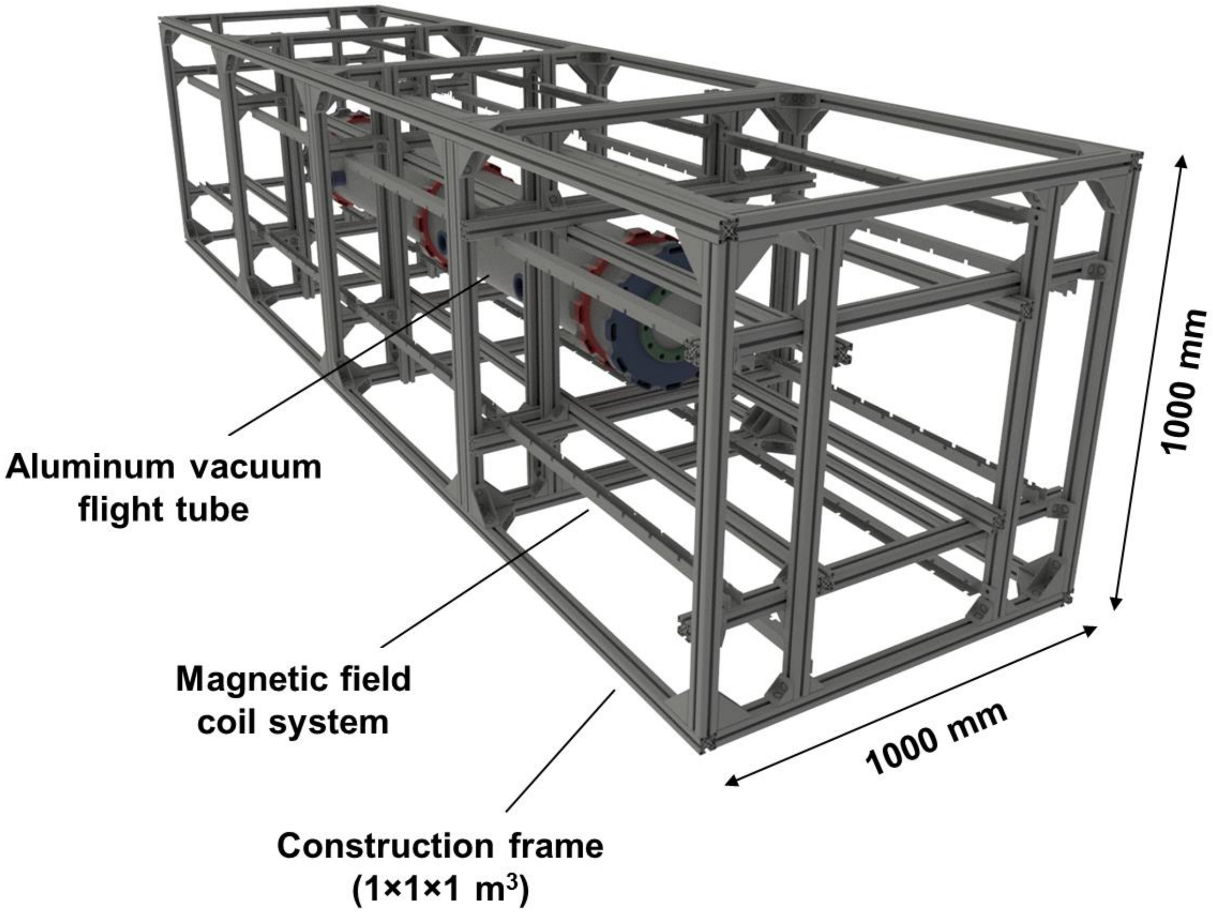
Advantages:
High statistics and large electric field

- *E* ≈ 100 kV/cm (1.8 m, gap = 1 cm)
- B_0 ≈ 1.7 mT (permanent magnets)
- Switching HV polarity every 200 s
- Invert flight direction every other day to overcome systematic *v*×*E*-effect



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

BEAM EDM CONCEPT



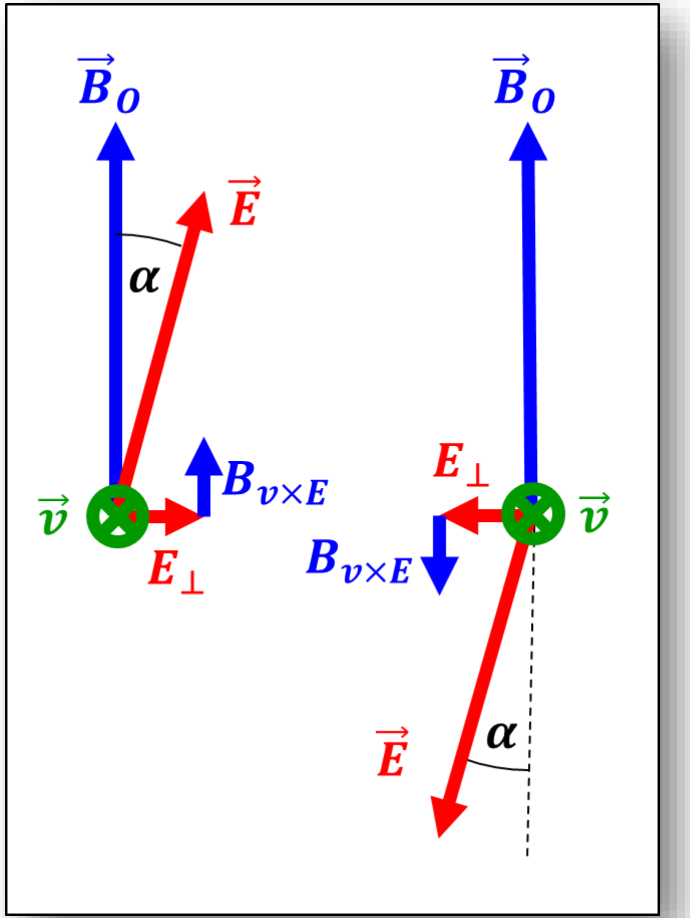
- **v×E – effect:**

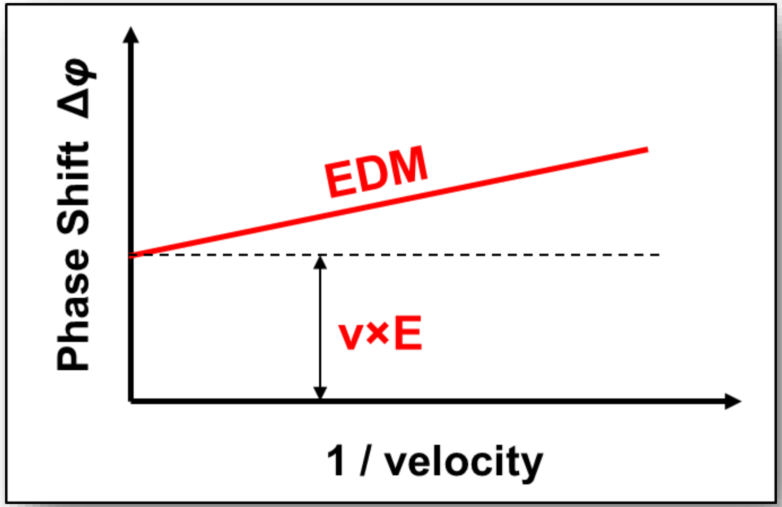
$$\vec{B}_{v\times E} = -\frac{\vec{v}\times\vec{E}}{c^2}$$

- **This can cause a false EDM signal:**

$$d_{\text{false}} \approx 10^{-20}\ \text{e cm}\cdot\sin\alpha \quad \text{for: } v = 100\ \text{m/s}$$

- **The false effect is velocity-dependent, however, a real EDM signal is not !**





Length of experiment

$$\Delta\varphi = \frac{8 d_n E}{\hbar} T + \frac{4 \gamma_n E L}{c^2} \sin\alpha$$

slope = EDM   offset = v×E

Concept is ideal for pulsed neutron spallation sources
e.g. at the European Spallation Source (ESS)

Start with proof-of-principle experiments
at Paul Scherrer Institute and Institute Laue-Langevin

Piegsa, PRC 88, 045502 (2013)

$$\sigma(d_n) \propto \frac{1}{ET\sqrt{N}}$$

BEAM

E = 100 kV/cm

N ≈ 100 MHz (ESS)

T ≈ 100 ms (50 m)

UCN*

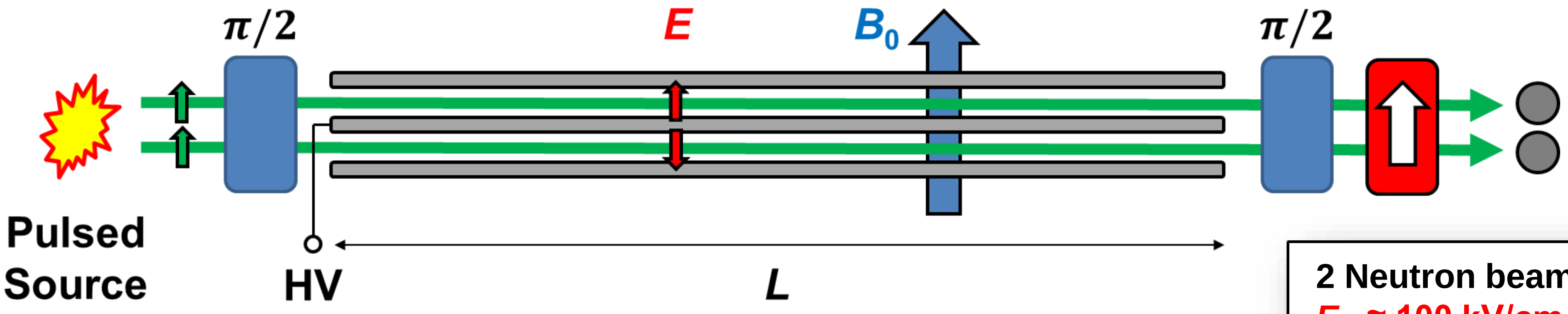
E = 10 kV/cm

N = 14’000 / 300 s ≈ 50 Hz

T = 130 s (storage)

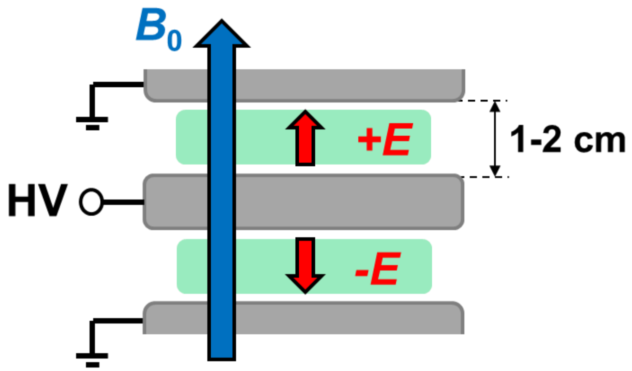
*Baker et al., PRL 97, 131801 (2006)

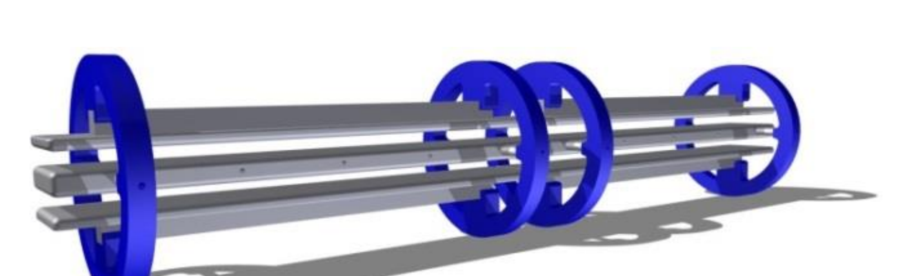
SIDE VIEW



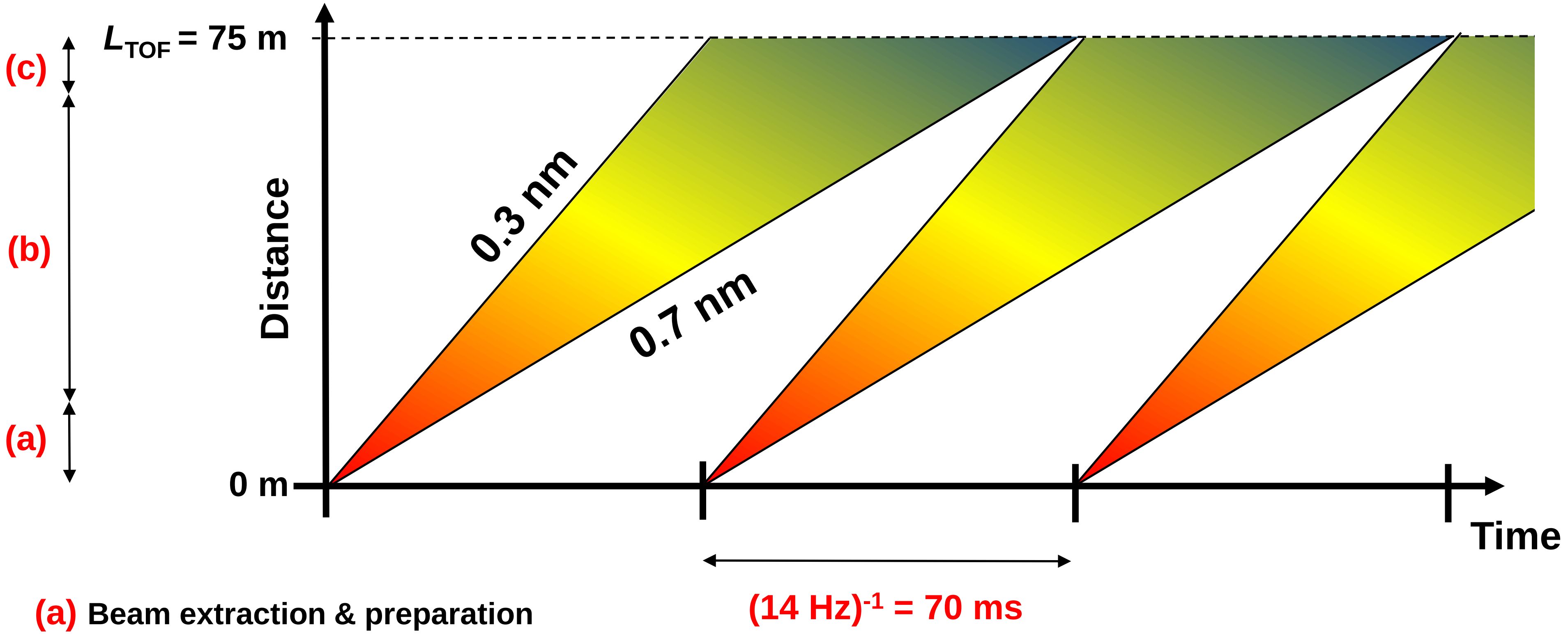
2 Neutron beams
$E \approx 100$ kV/cm
$B_0 \approx 200$ μT
$L = 5$ m (proof-of-prin.)
$L = 50$ m (full-scale)

CROSS SECTION



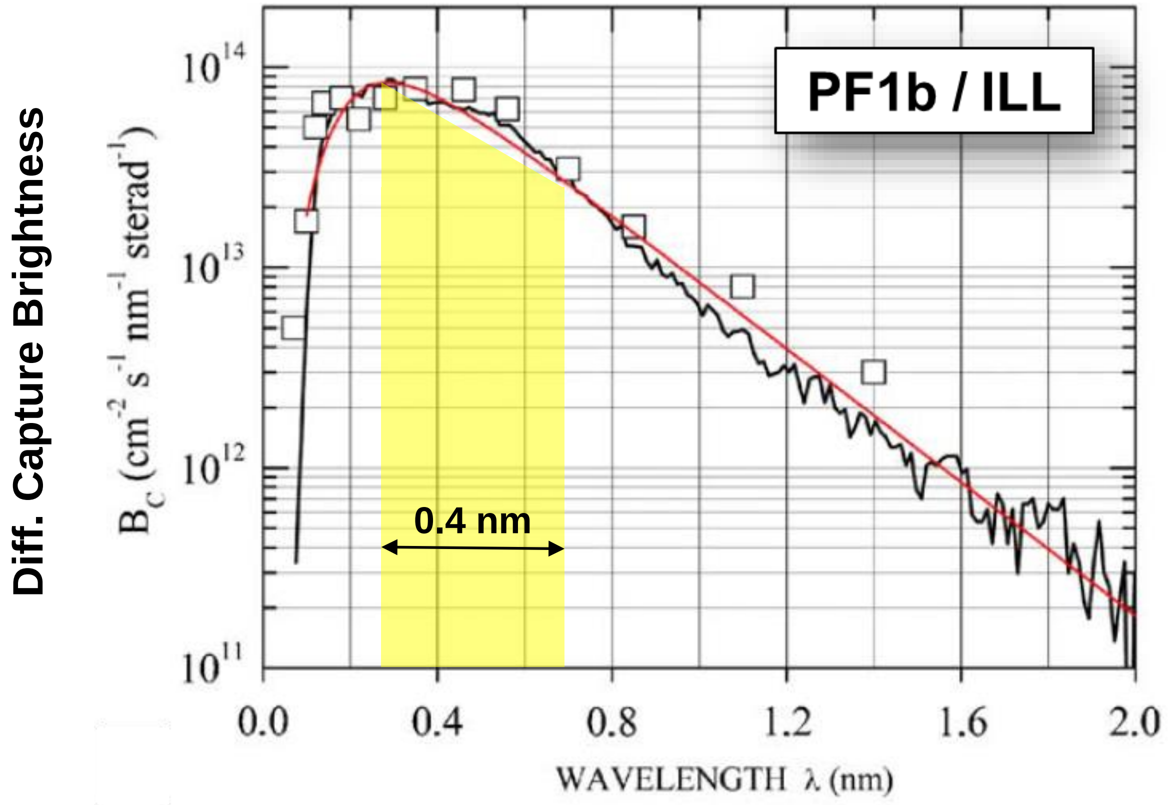


Preliminary CAD Design
(Neutron Guides & Electrodes)



(a) Beam extraction & preparation
(b) Ramsey precession region (L ~ 50 m)
(c) Spin analysis & detector

Optimization ongoing … wavelength-band, skip pulses etc.



$$B_P = \int_{0.3}^{0.7} \frac{\lambda_0}{\lambda} \frac{\partial B_C}{\partial \lambda} d\lambda \quad \Rightarrow \quad B_P \approx 1.3 \times 10^{13} \text{ cm}^{-2}\text{s}^{-1}\text{sterad}^{-1}$$

with: $\lambda_0 = 0.18$ nm

Abele et al., NIM A 562, 407 (2006)

$$\sigma_{\mathrm{Beam}}(d_{\mathrm{n}}) \approx \frac{2\hbar}{\eta\tau E\sqrt{N}}$$

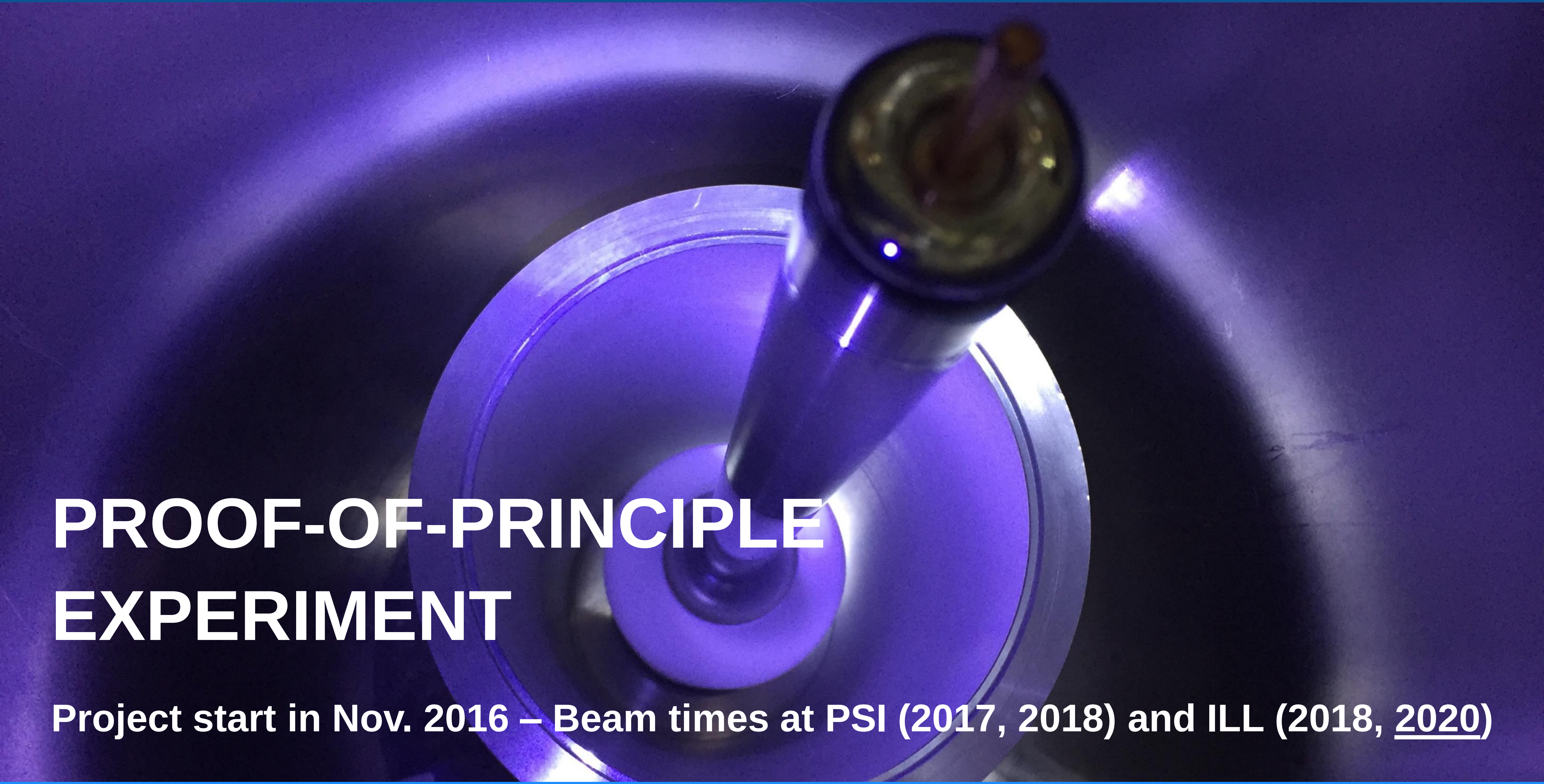
$\eta = 0.75$, $L = 50$ m, $L_{\mathrm{TOF}} = 75$ m, $\tau = 50$ ms, $E = 100$ kV/cm

$$N = \underbrace{1.3 \times 10^{13}\,\mathrm{cm^{-2}s^{-1}sr^{-1}}}_{\text{PF1B particle brightness (ILL)}} \times \overbrace{1/3}^{\text{Polarization}} \times \underbrace{1}_{\text{ESS} \approx \text{ILL}} \times \overbrace{(2 \times 20\,\mathrm{cm^2})}^{\text{Cross section of two beams}} \times \underbrace{2 \times 10^{-7}\,\mathrm{sr}}_{20\,\mathrm{cm^2}/(100\,\mathrm{m})^2} \sim 40\ \mathrm{MHz}$$

$$\sigma(d_{\mathrm{n}}) \approx 5 \times 10^{-26}\ \text{e cm per day}$$

Guiding electrodes
flux gain ~ 10

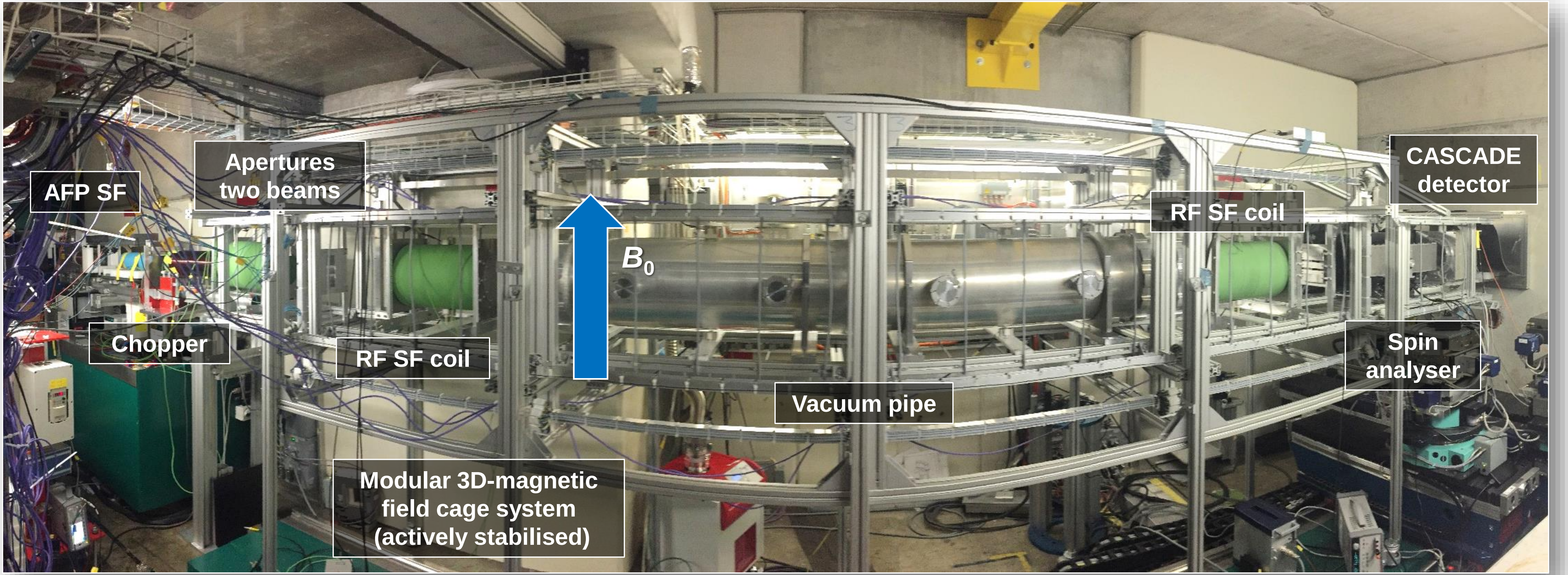
E. Chanel et al., EPJ Web Conf. 219, 02004 (2019)

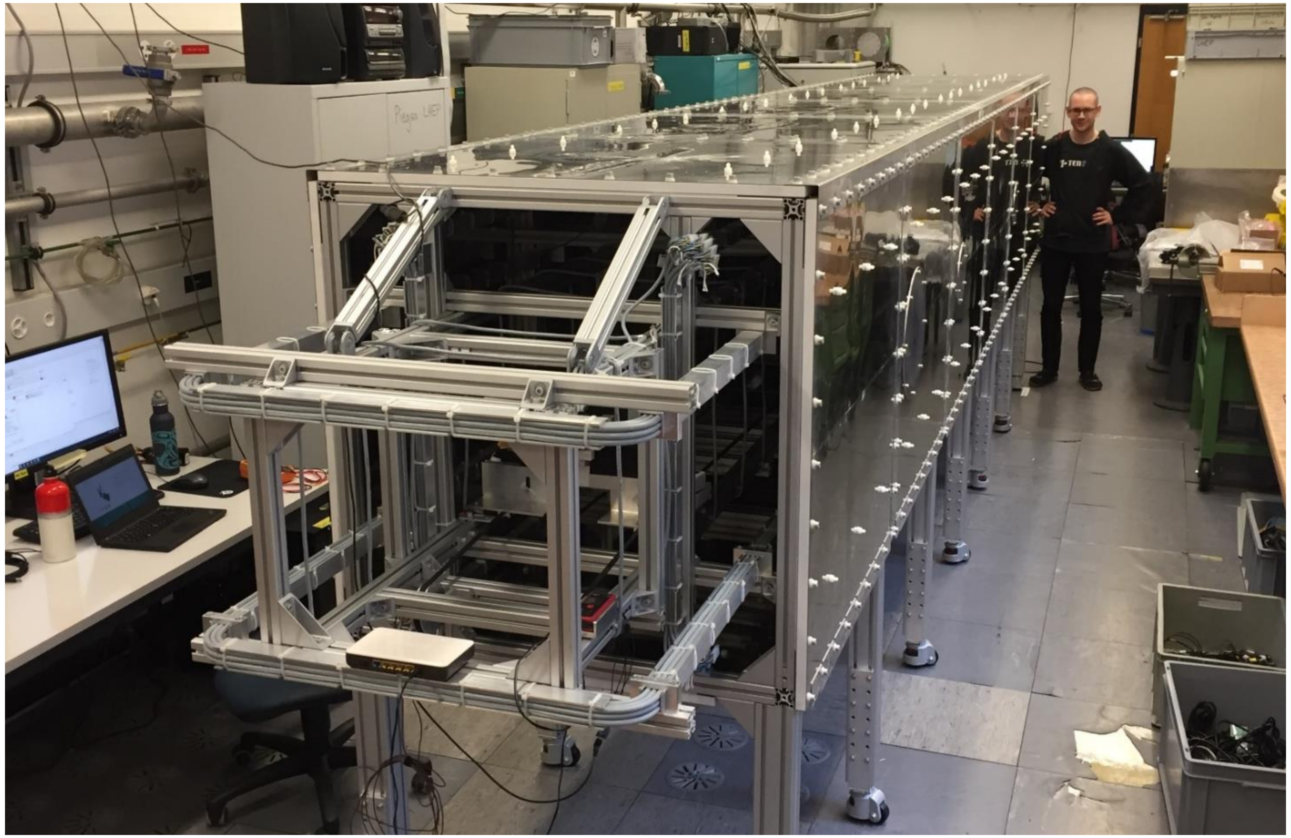


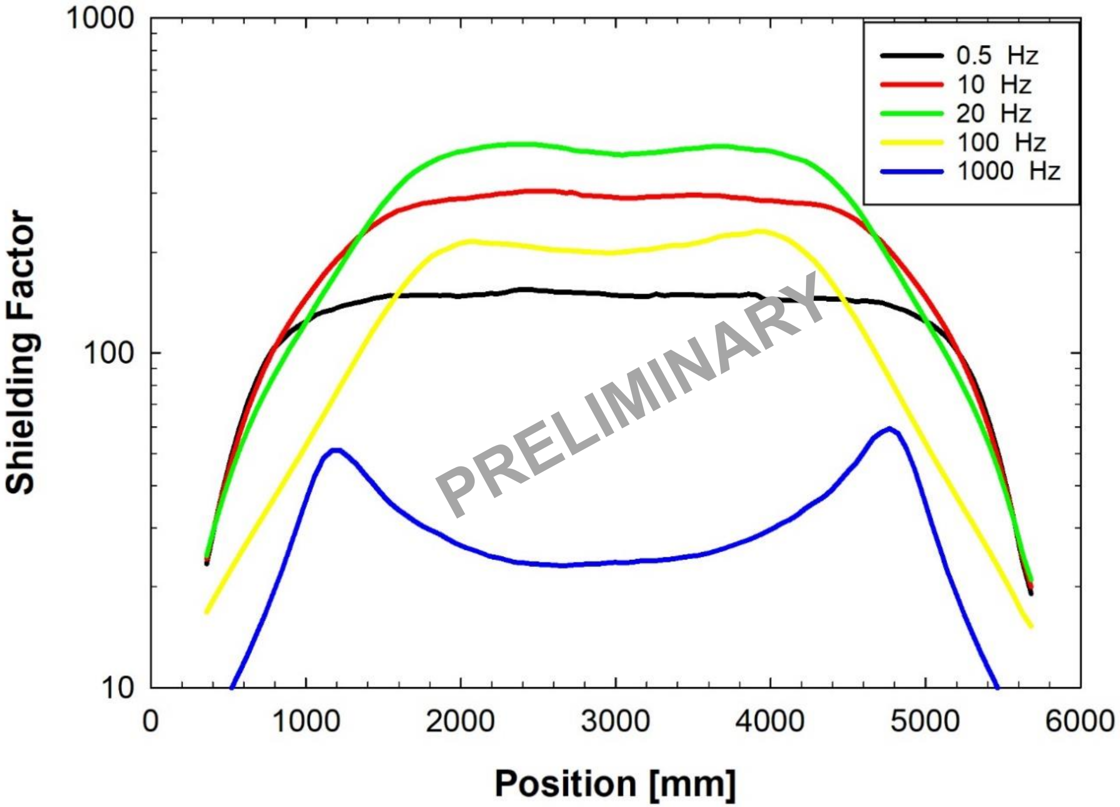
PROOF-OF-PRINCIPLE EXPERIMENT

Project start in Nov. 2016 – Beam times at PSI (2017, 2018) and ILL (2018, 2020)

Beam Time at BOA / PSI (Sept./Oct. 2018)



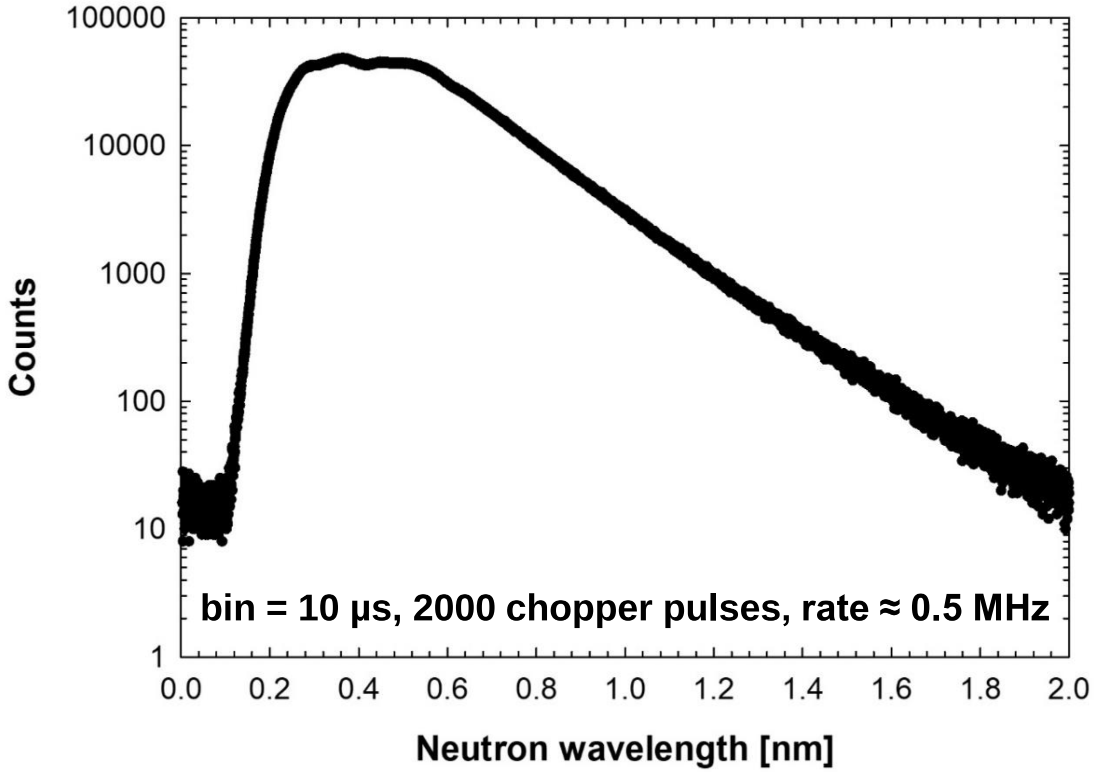




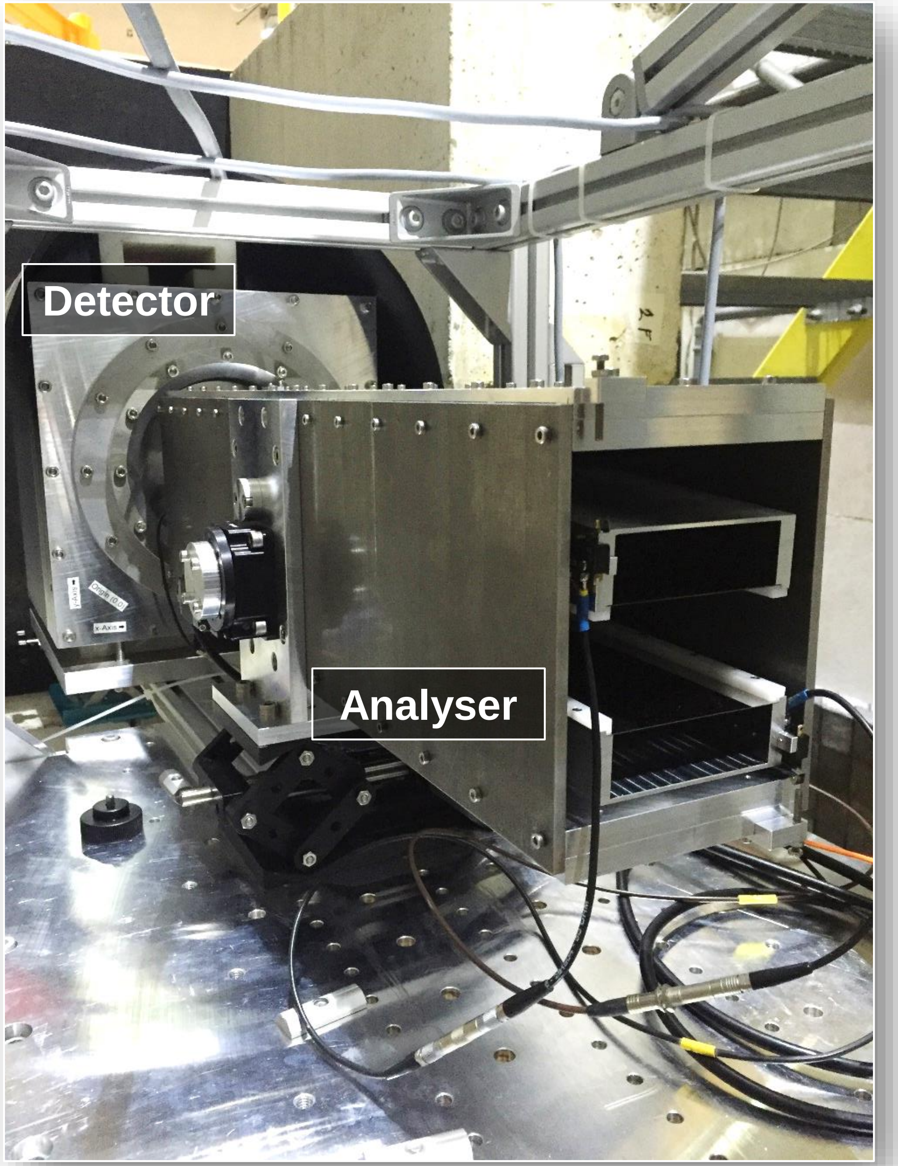
Passive shielding of external field inhomogeneities and fluctuations

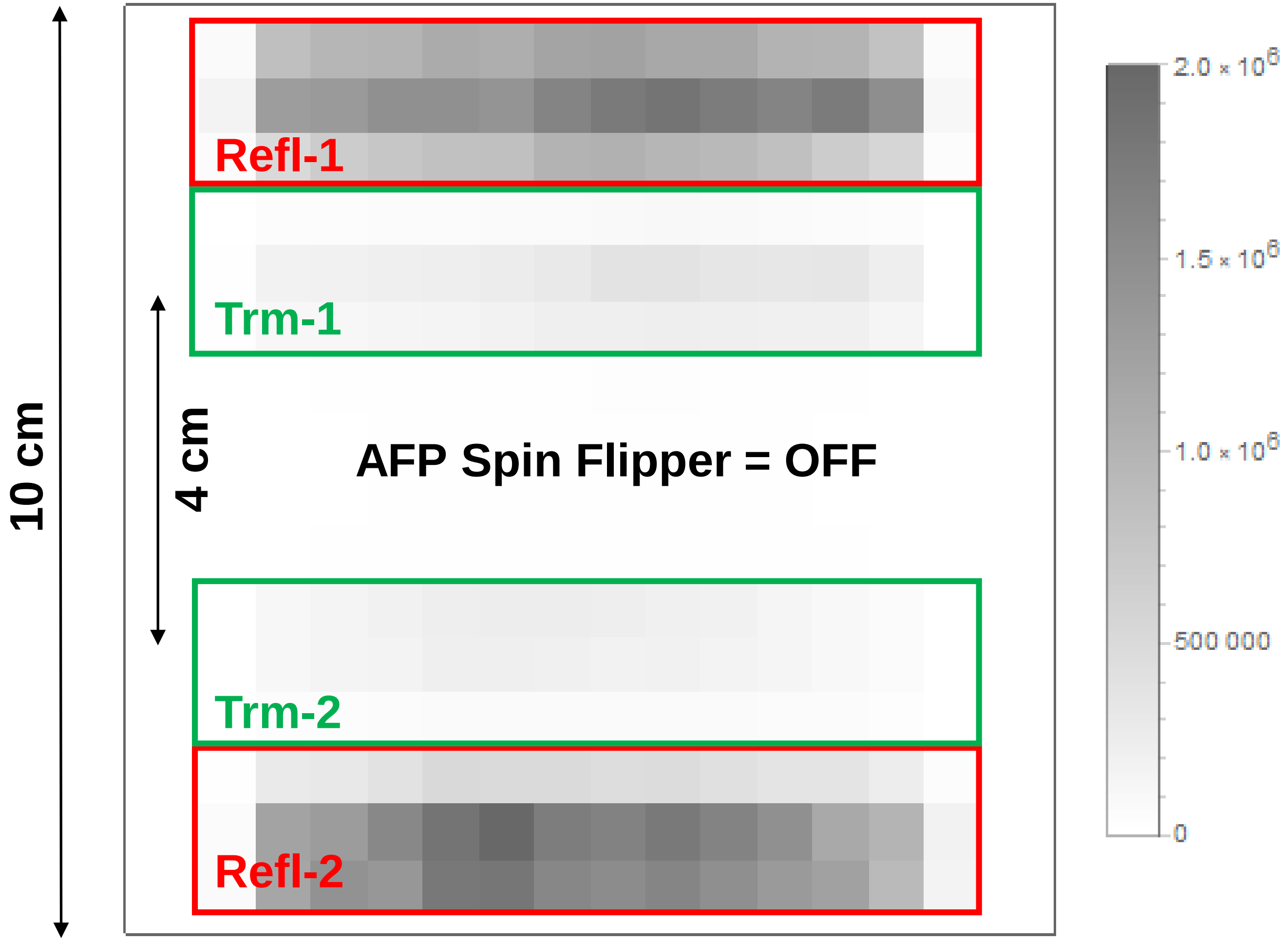
Beam Time at PF1b / ILL (2020)

Beam Time at PF1b / ILL (2020)



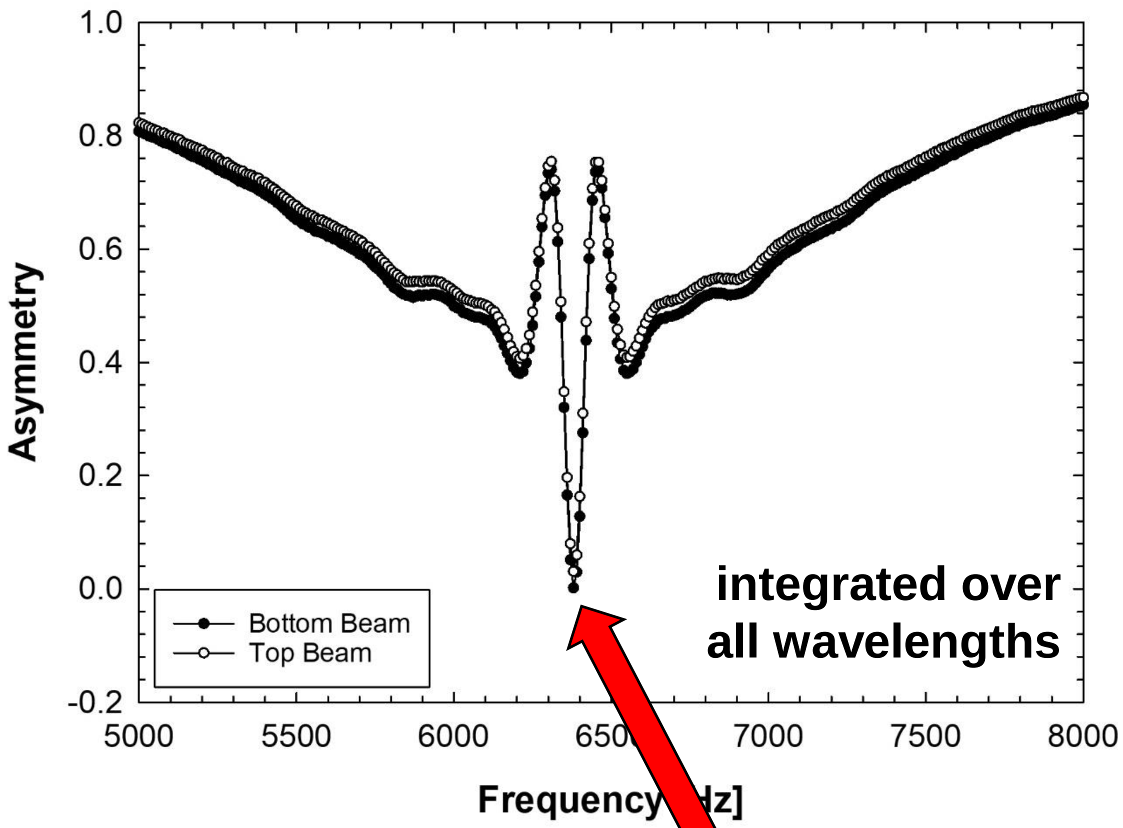
- Two beams each: 1 × 7 cm^2
- Chopper: f_{ch} = 19 Hz, duty cycle = 2%, L_{TOF} = 10.4 m
- Main magnetic field: B_0 = 220 µT
- Three one-meter-long HV-electrode sections
- 8 internal (stab.) and 5 external (monitor) fluxgates

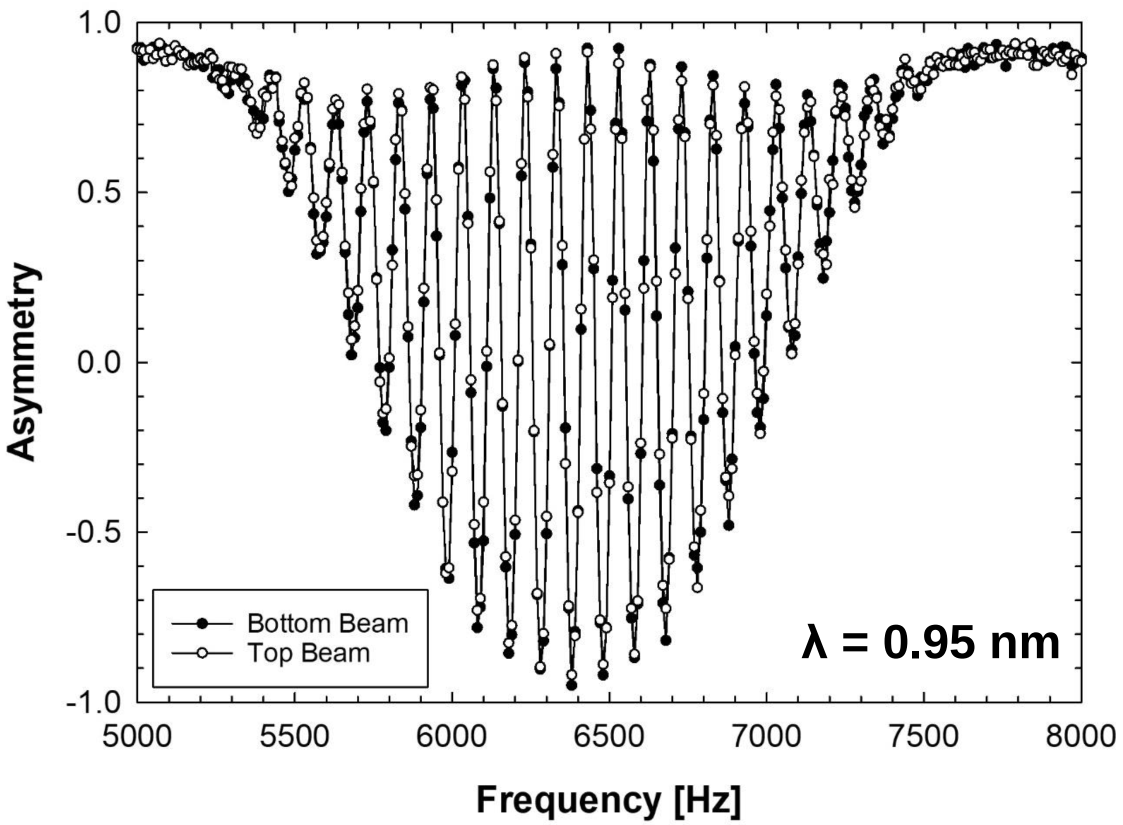




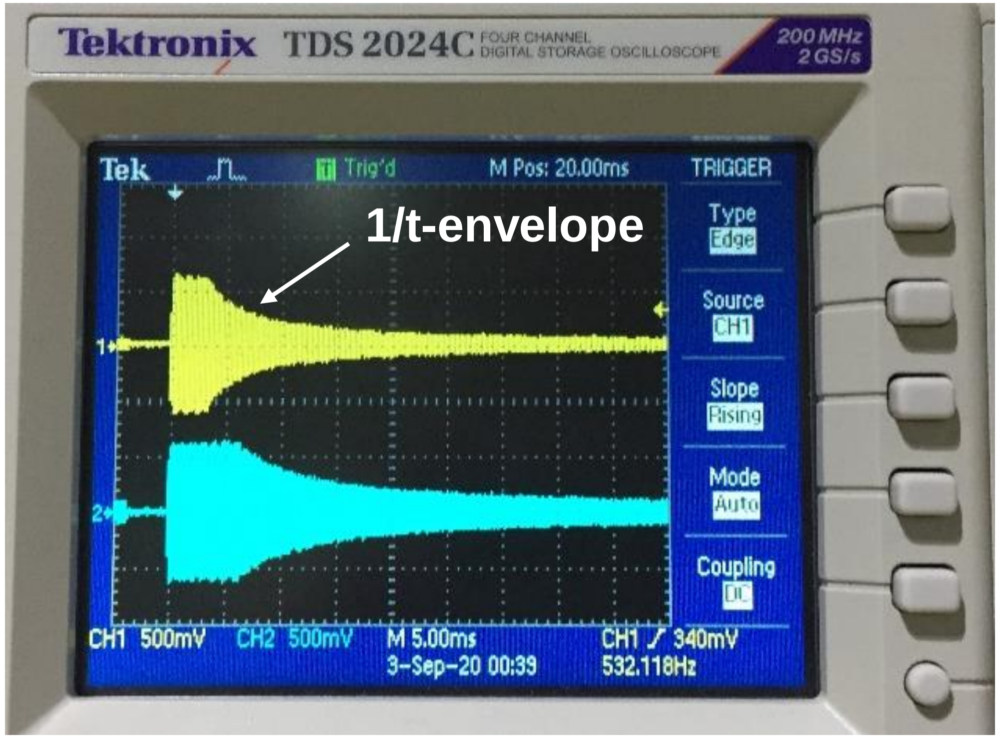
Two beams/Four beam spots
FeSi supermirror m = 5 (*SwissNeutronics*)
Cascade Detector: 16×16 Pixels, Pixel-Size = 6×6 mm^2

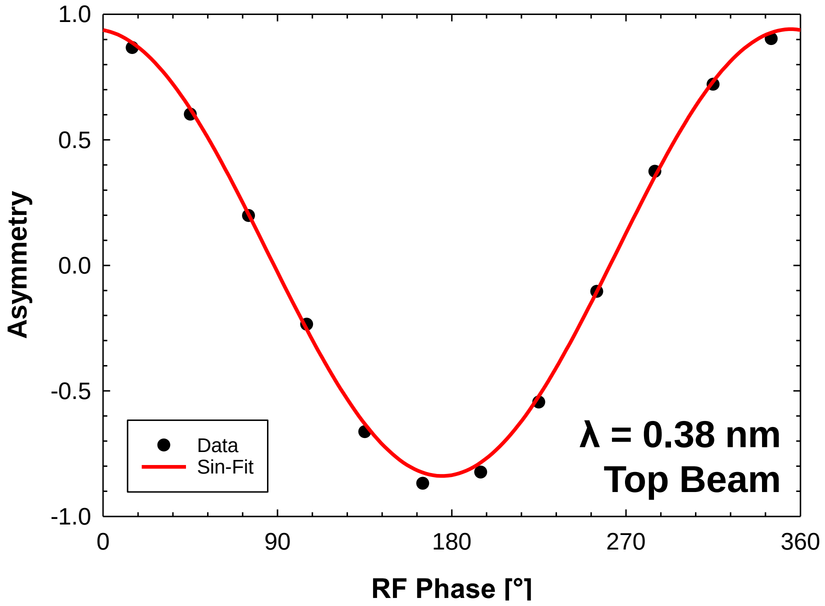
$$Asymmetry = \frac{N_{Trm} - N_{Rfl}}{N_{Trm} + N_{Rfl}}$$

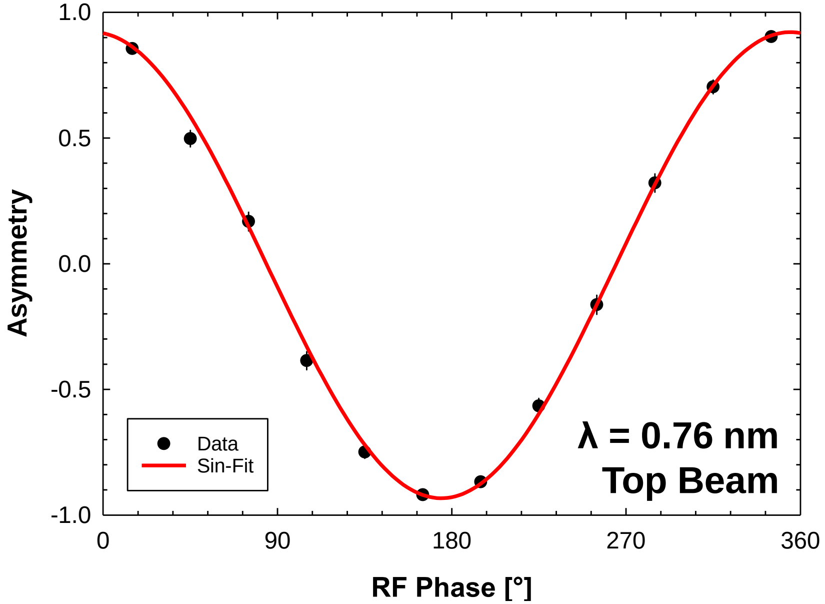




f_0 = 6380 Hz @ 220 μT

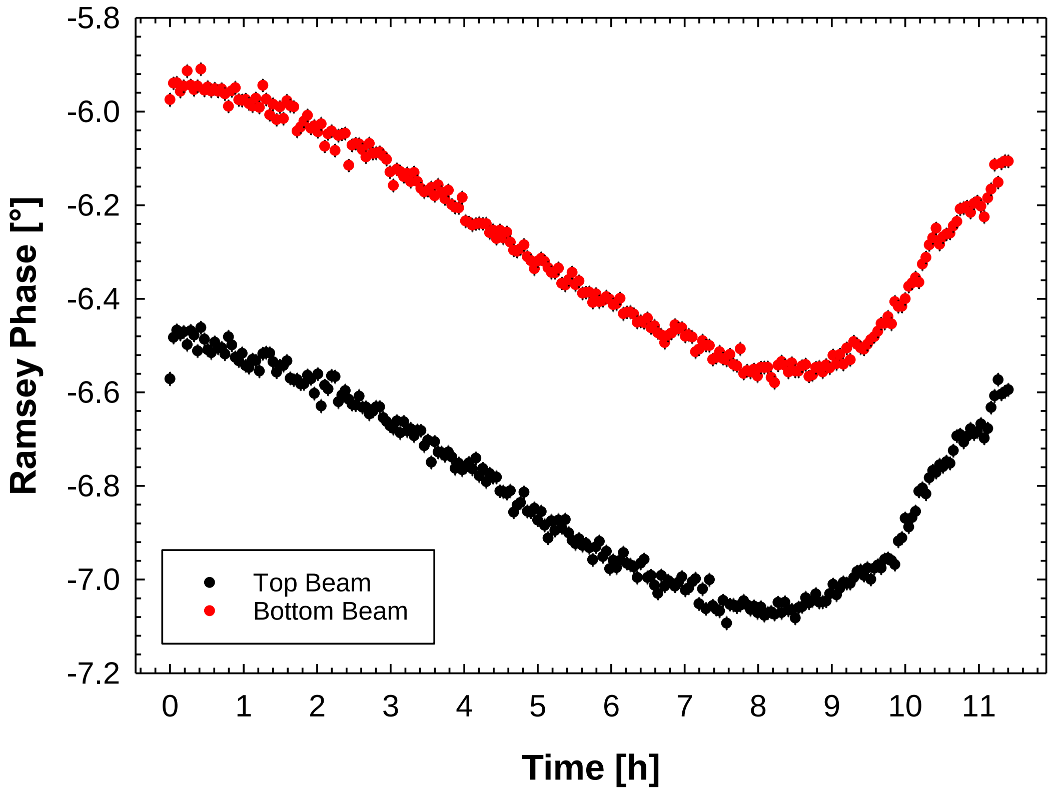




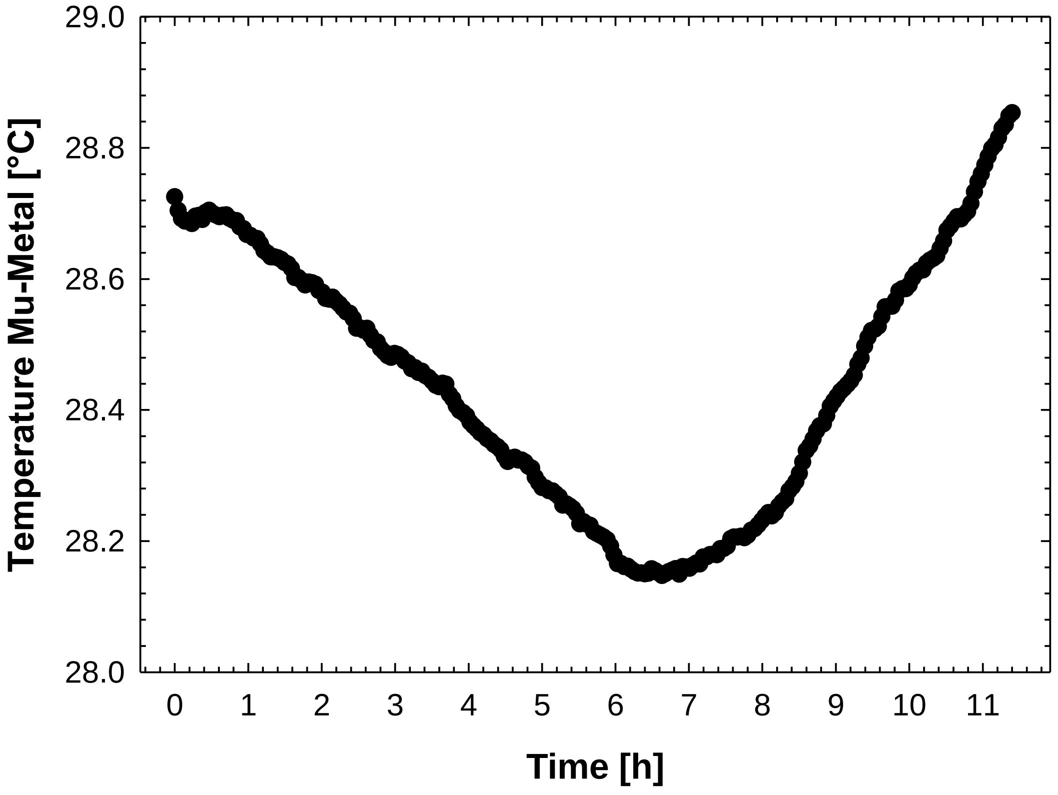


- Scan RF-phase between two spin-flippers instead of RF-frequency – always on resonance
- RF-amplitude modulated: π/2 flip for all wavelengths
  Triggered by chopper signal
- Measure only at „working point“ (i.e. Asym = 0)

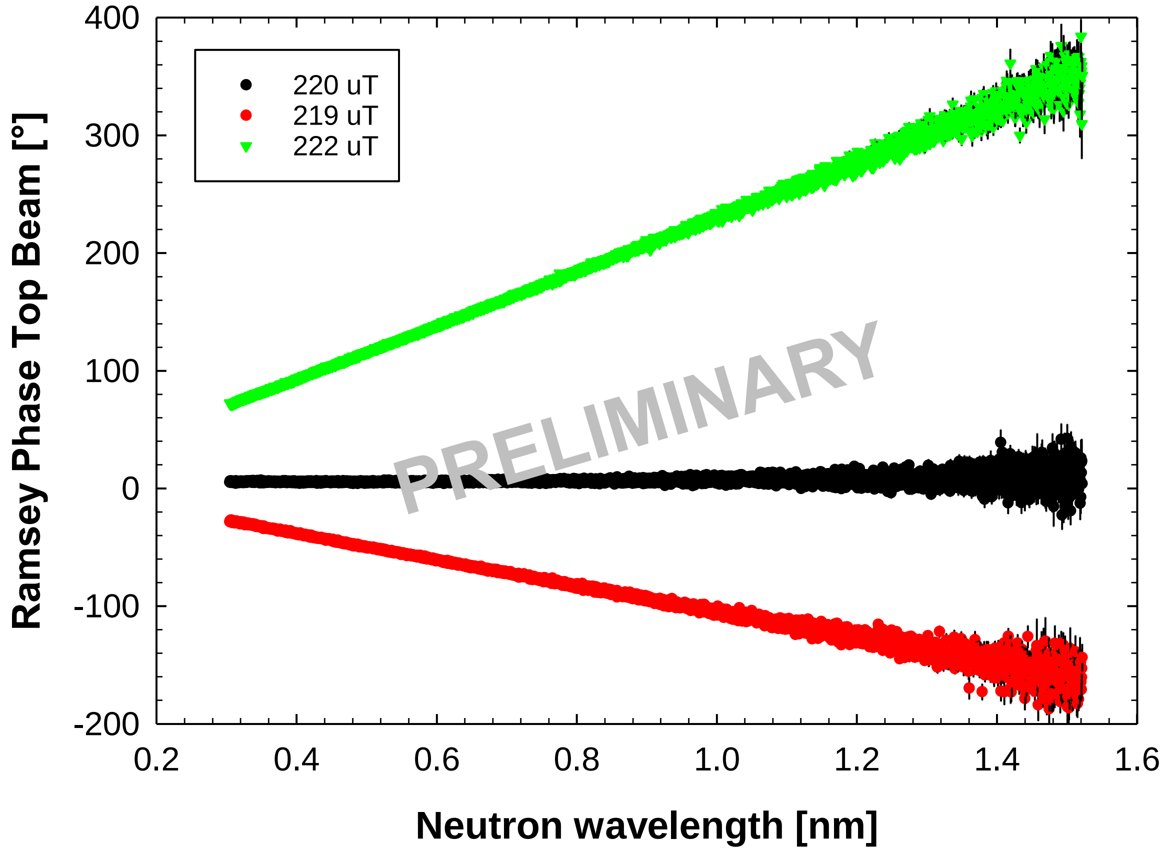
Two beams



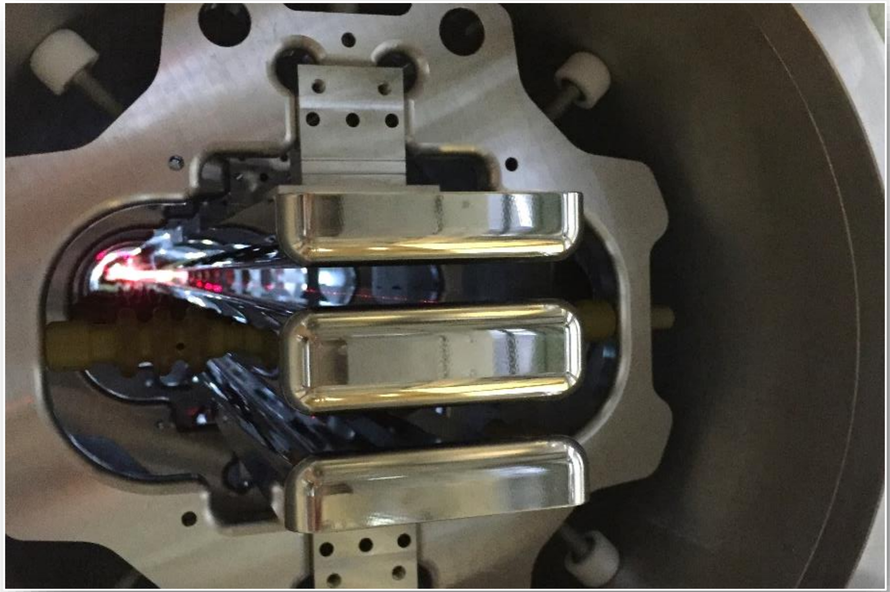
Temperature drift

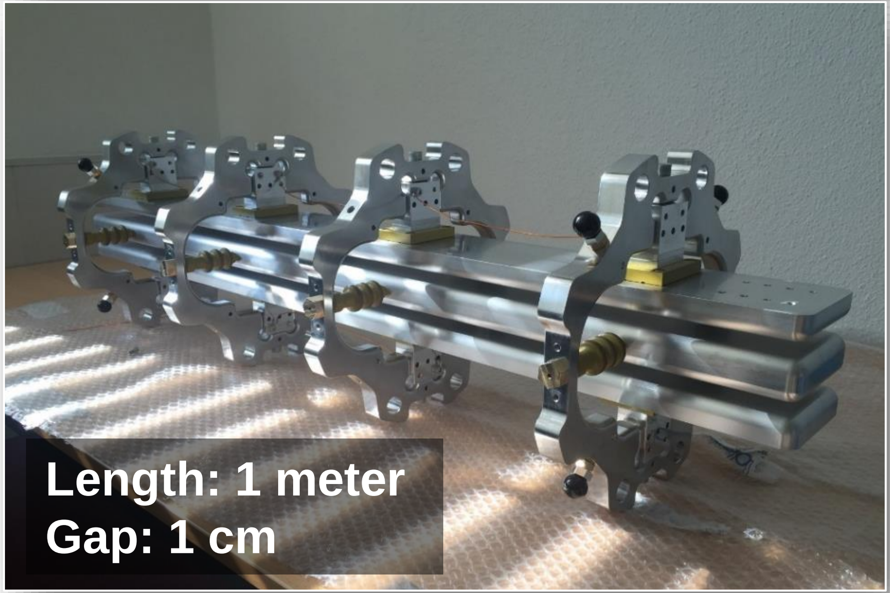


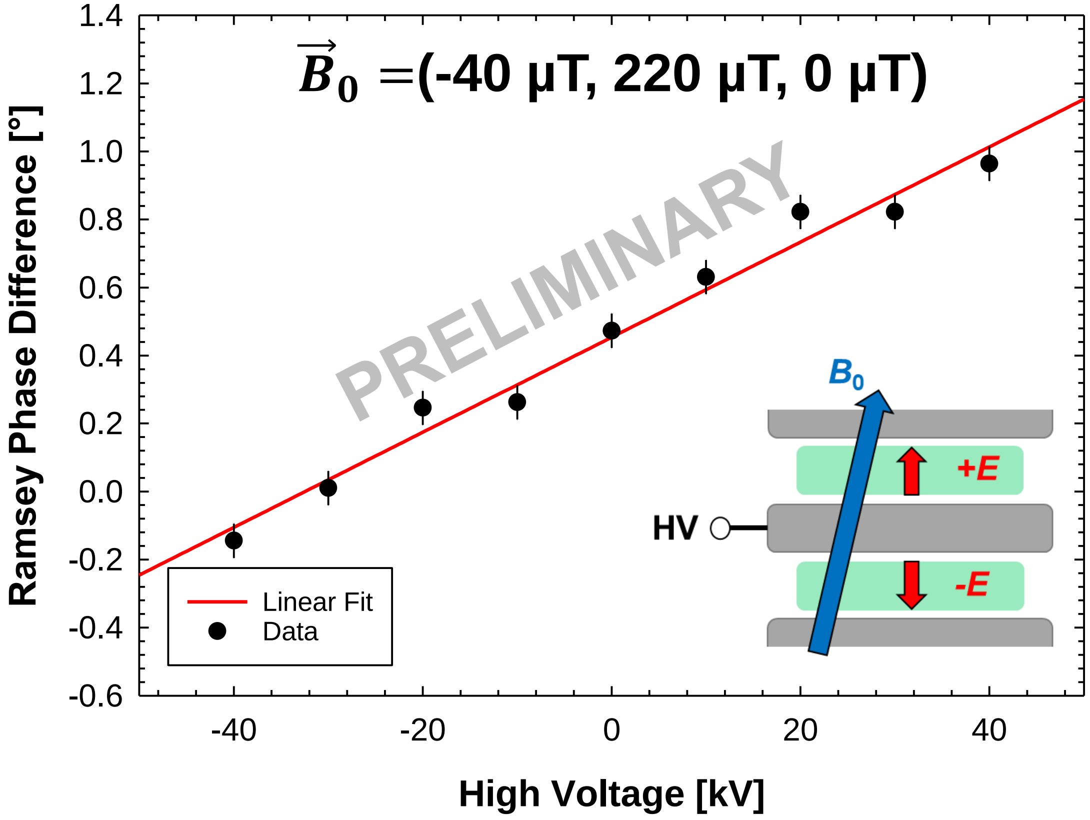
Two beam method allows for correction of (magnetic) drifts



- **Ramsey signal phase measured as a function of TOF, i.e. neutron wavelength**
- **Scan of magnetic field causes a change of the slope, similar to an EDM interaction**

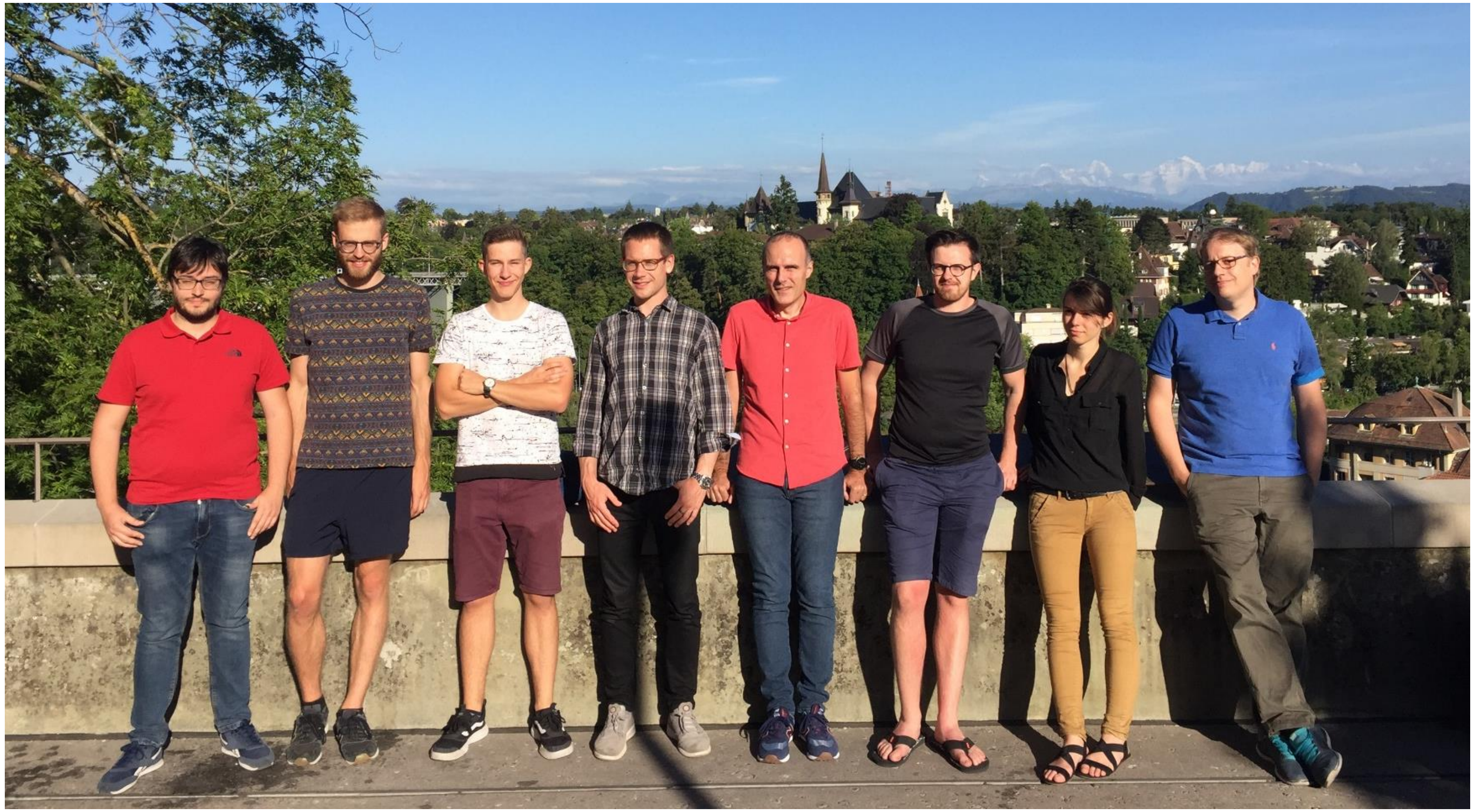






- ▶ **v×E effect allows for a direct measurement of the electric field seen by the neutrons**
- ▶ **Here, magnetic field was intentionally tilted with respect to electric field direction**

- New complimentary neutron EDM search
- Proof-of-principle experiments at ILL and PSI
- Data analysis ongoing
- Future full-scale experiment intended for ESS (ANNI)



Thank you for your attention !

Estelle Chanel, **Anastasio Fratangelo**, **Alexander Gottstein**, **Andreas Gsponer**, Zachary Hodge*, Ciro Pistillo, Dieter Ries**, **Ivo Schulthess**, **Marc Solar**, Torsten Soldner***, **Oliver Stalder**, Jacob Thorne, FP

*   now at University of Washington
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Open Post-Doc Position