Current and future prospects at PSI: From MEGII to muEDM and future beamline developments

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Muons in Minneapolis Workshop (UMN)
6-8 Dec 2023

Content

- The MEGII experiment
- The muEDM experiment
- Future beamline developments:
  - The HiMB project
  - The muCool project

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- **The MEGII experiment**
- The muEDM experiment
- Future beamline developments:
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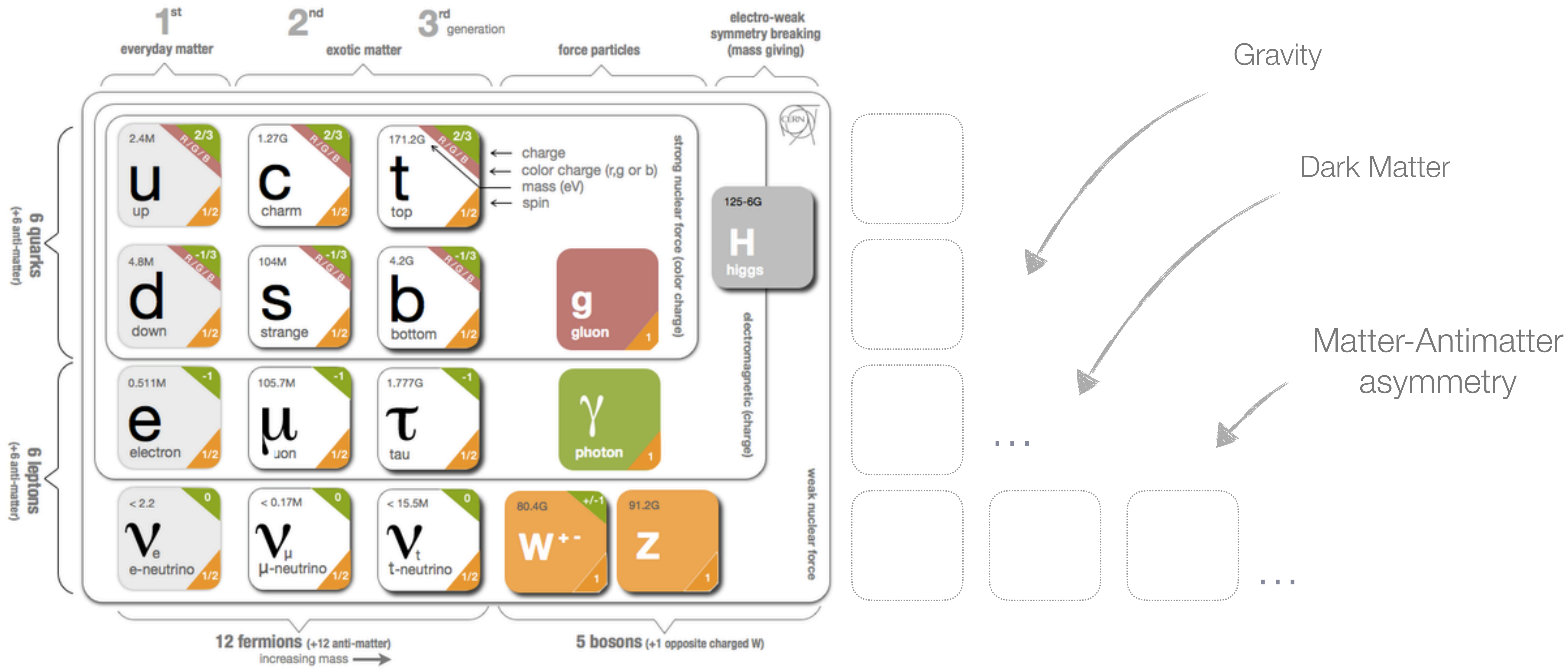
    - The muCool project

The role of the low energy precision physics

- The Standard Model of particle physics: A great triumph of the modern physics but not the ultimate theory



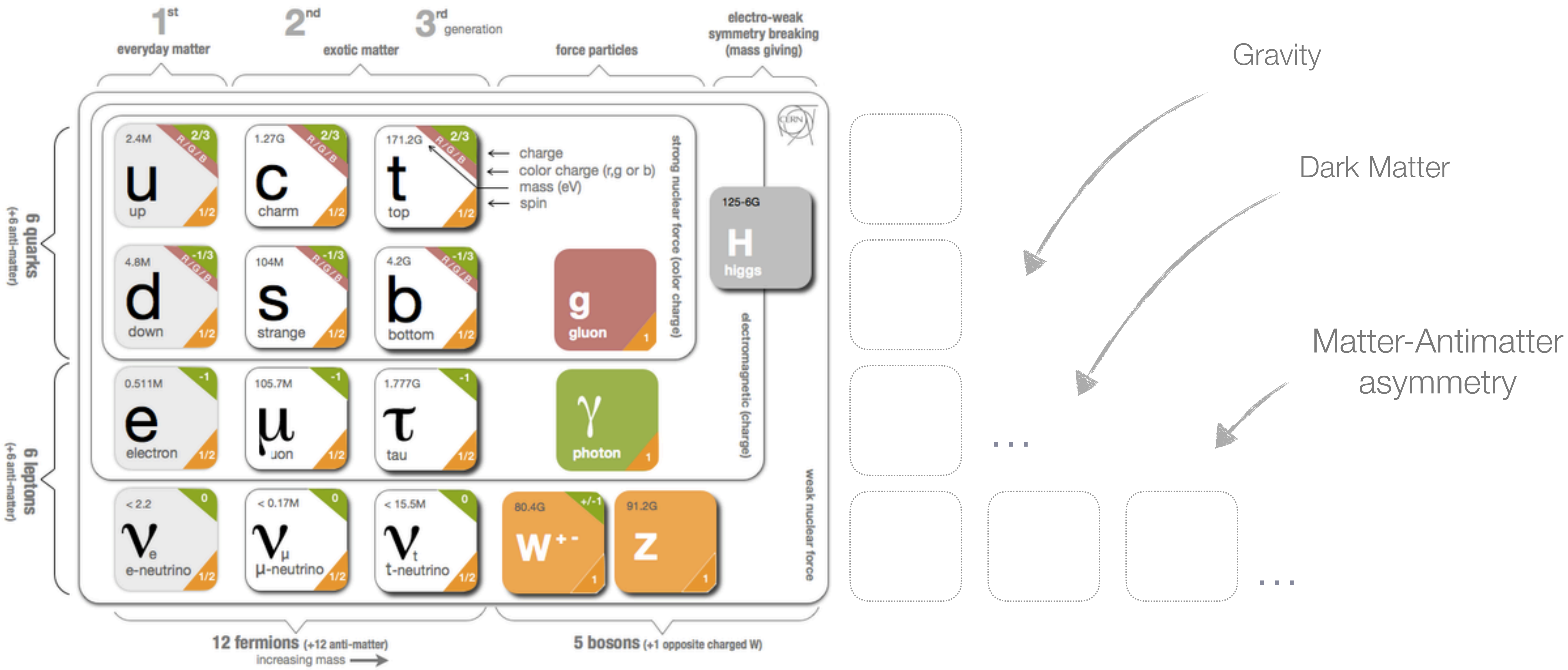
Focus here on:

- **Muon cLFV**
- **Matter-Antimatter asymmetry**

- Low energy precision physics: **Rare/forbidden decay searches**, **symmetry tests**, **precision measurements** very sensitive tool for unveiling **new physics** and probing very **high energy scale**

The role of the low energy precision physics

- The Standard Model of particle physics: A great triumph of the modern physics but not the ultimate theory



Focus here on:

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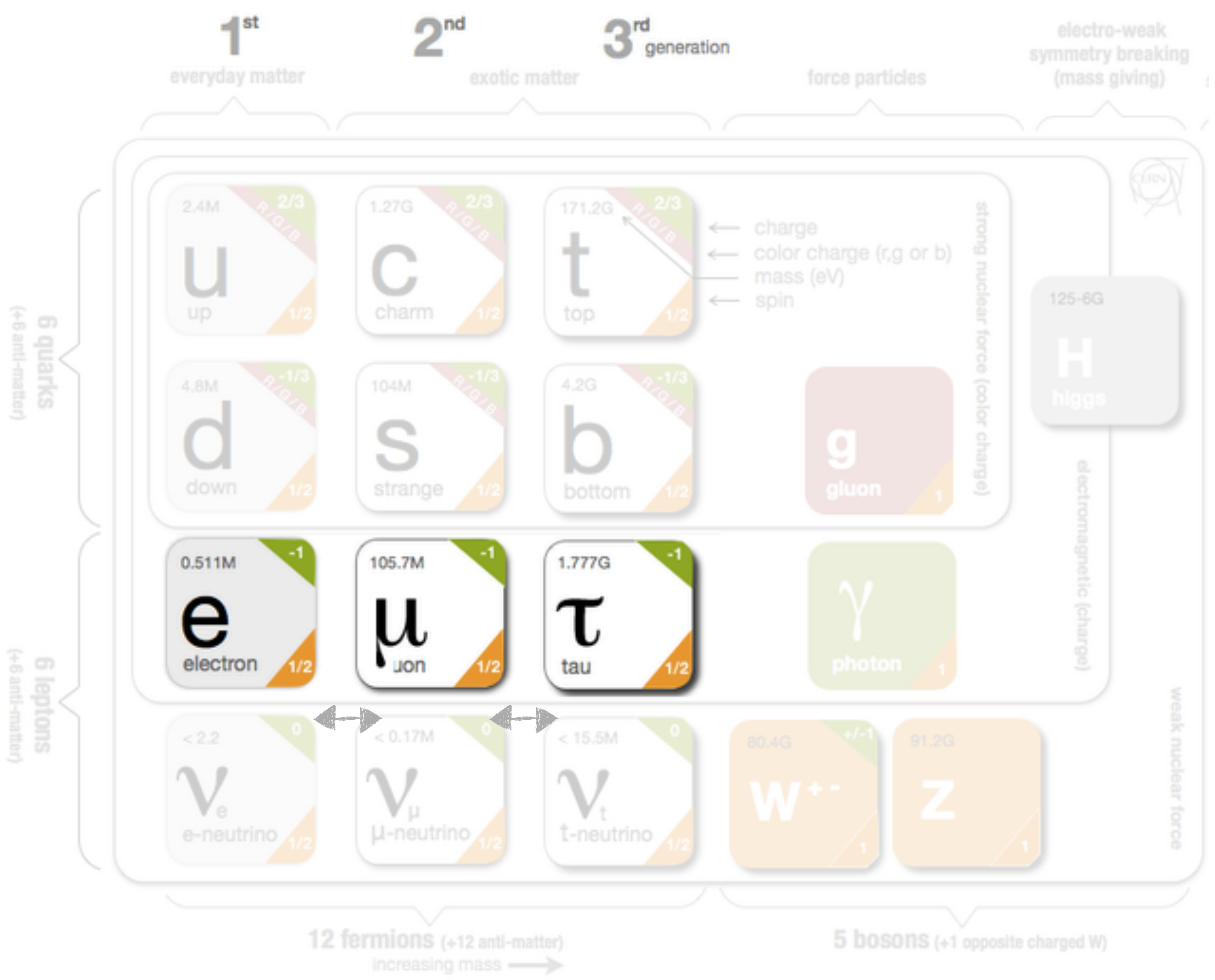
- Low energy precision physics: **Rare/forbidden decay searches**, **symmetry tests**, **precision measurements** very sensitive tool for unveiling **new physics** and probing very **high energy scale**

Charged lepton flavour violation search: Motivation

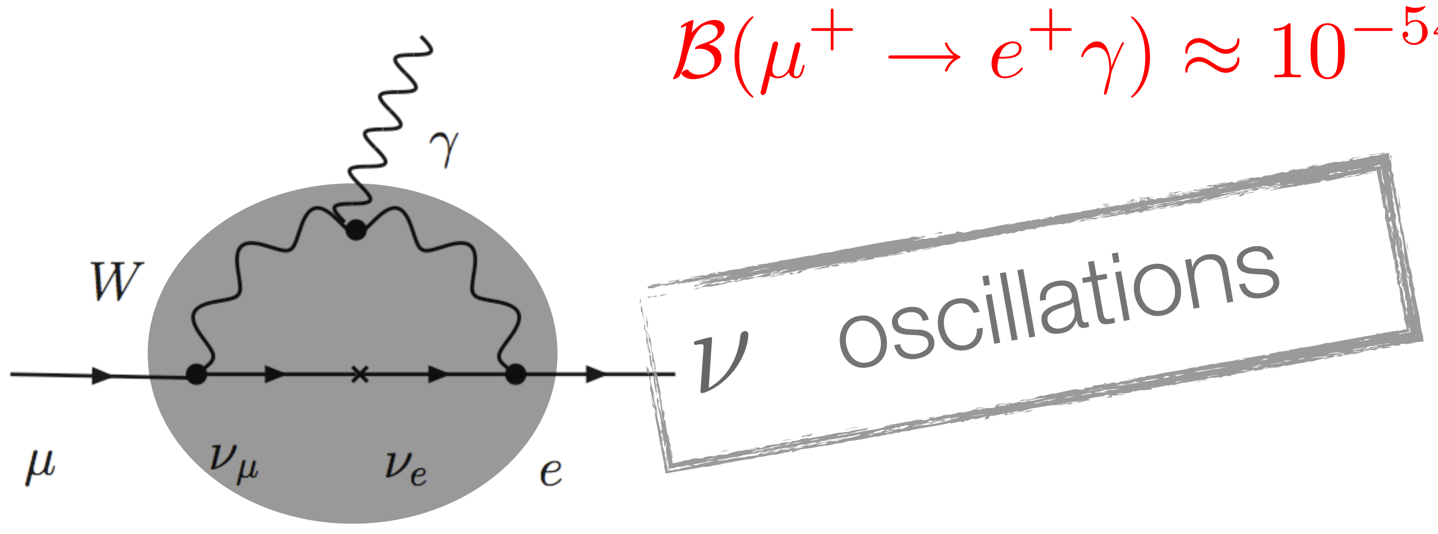
- **Neutrino oscillations**: Evidence of physics Behind Standard Model (BSM). **Neutral lepton flavour violation**
- **Charged lepton flavour violation: NOT** yet observed
- An experimental **evidence** of cLFV at the current sensitivities will be a **clear signature of New Physics**



$\Delta N_i \neq 0$ with i = 1,2,3

SM with massive neutrinos (Dirac)

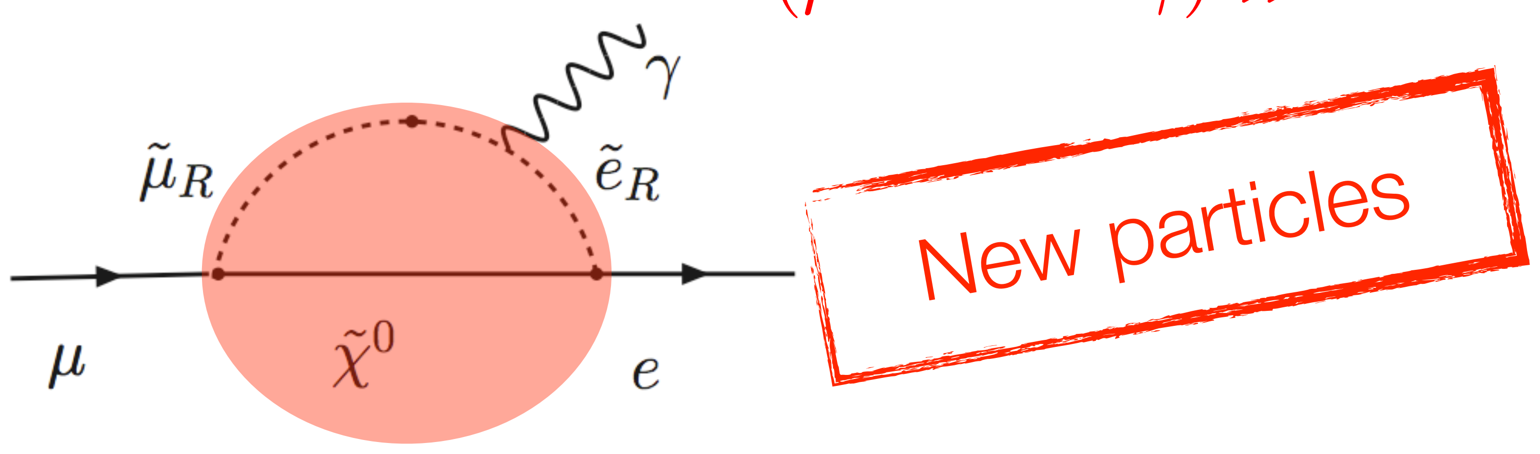
$\mathcal{B}(\mu^+ \to e^+\gamma) \approx 10^{-54}$



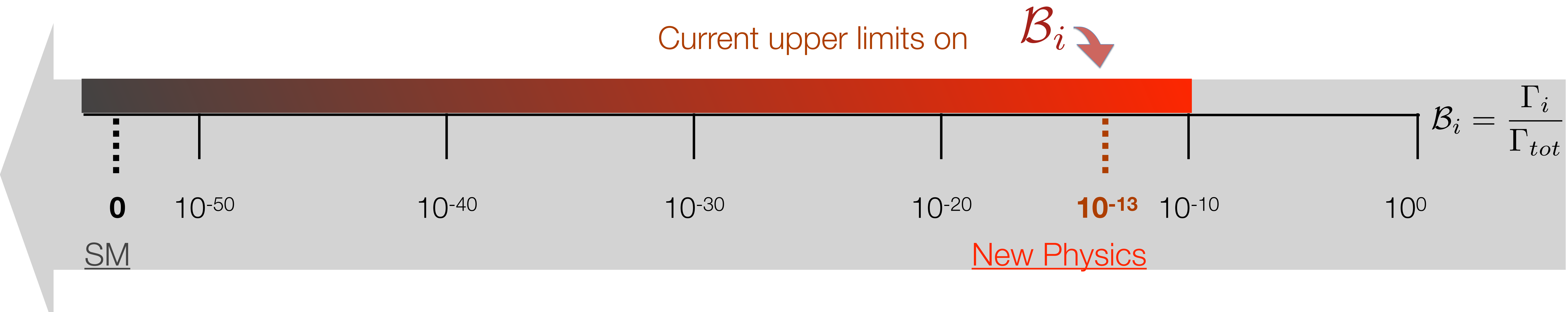
too small to access experimentally

BSM

$\mathcal{B}(\mu^+ \to e^+\gamma) \gg 10^{-54}$

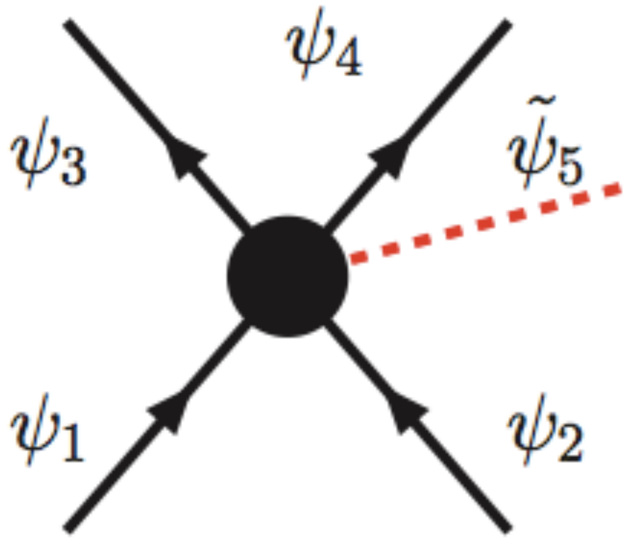


an experimental evidence:
a clear signature of New Physics NP
(SM background FREE)



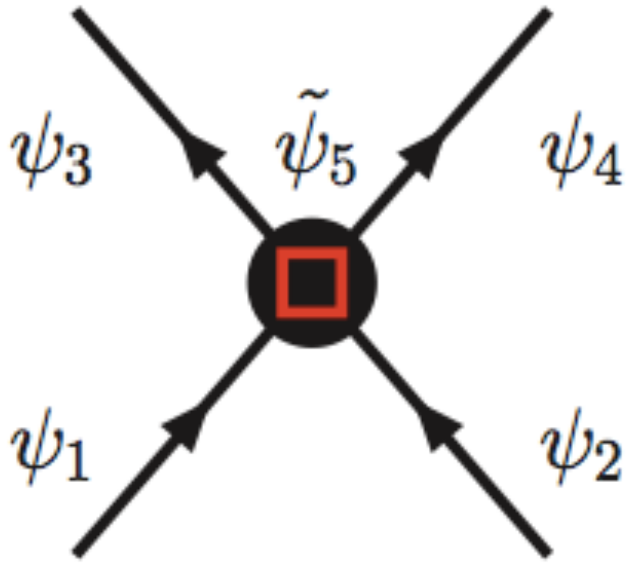
Complementary to "Energy Frontier"

Energy frontier



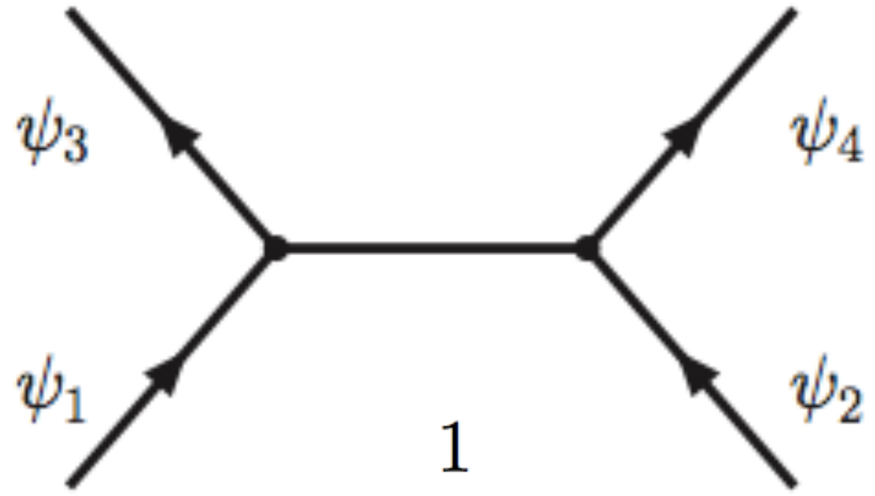
Real BSM particles

Precision and intensity frontier

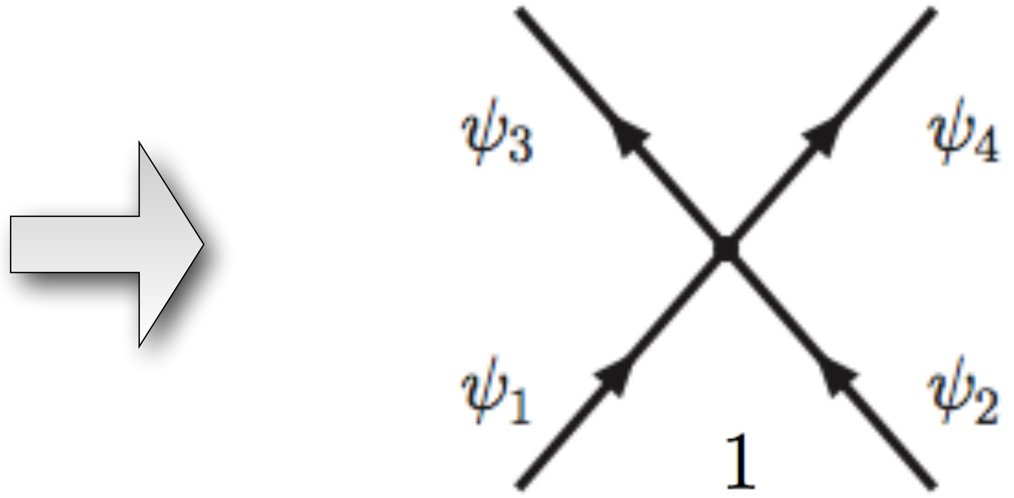


Virtual BSM particles

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_{d>4} \frac{c_n^{(d)}}{\Lambda^{d-4}} \mathcal{O}^{(d)}$$



$$\frac{1}{p^2 - M^2}$$



$$\frac{1}{\Lambda^2}$$

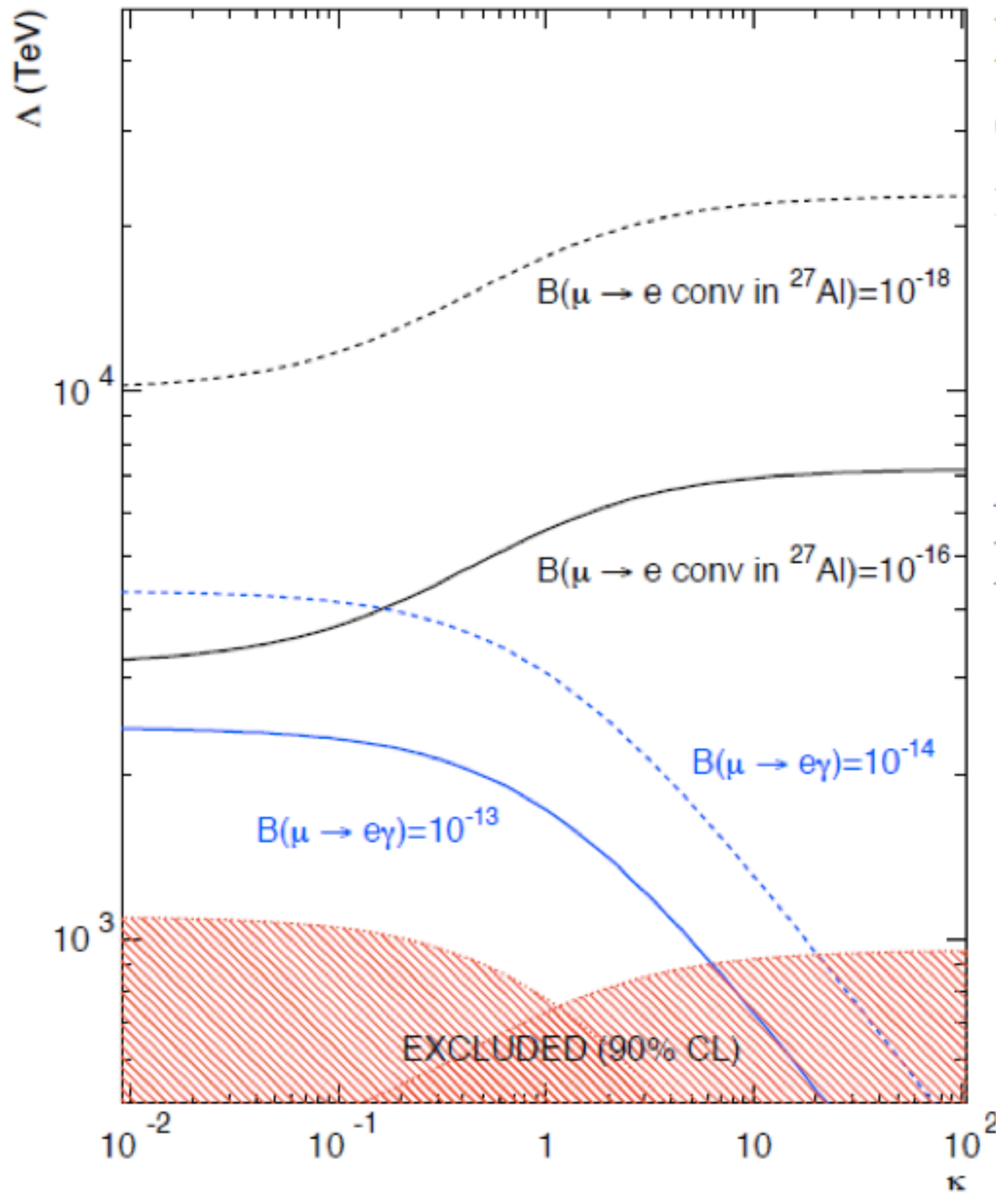
Unveil new physics

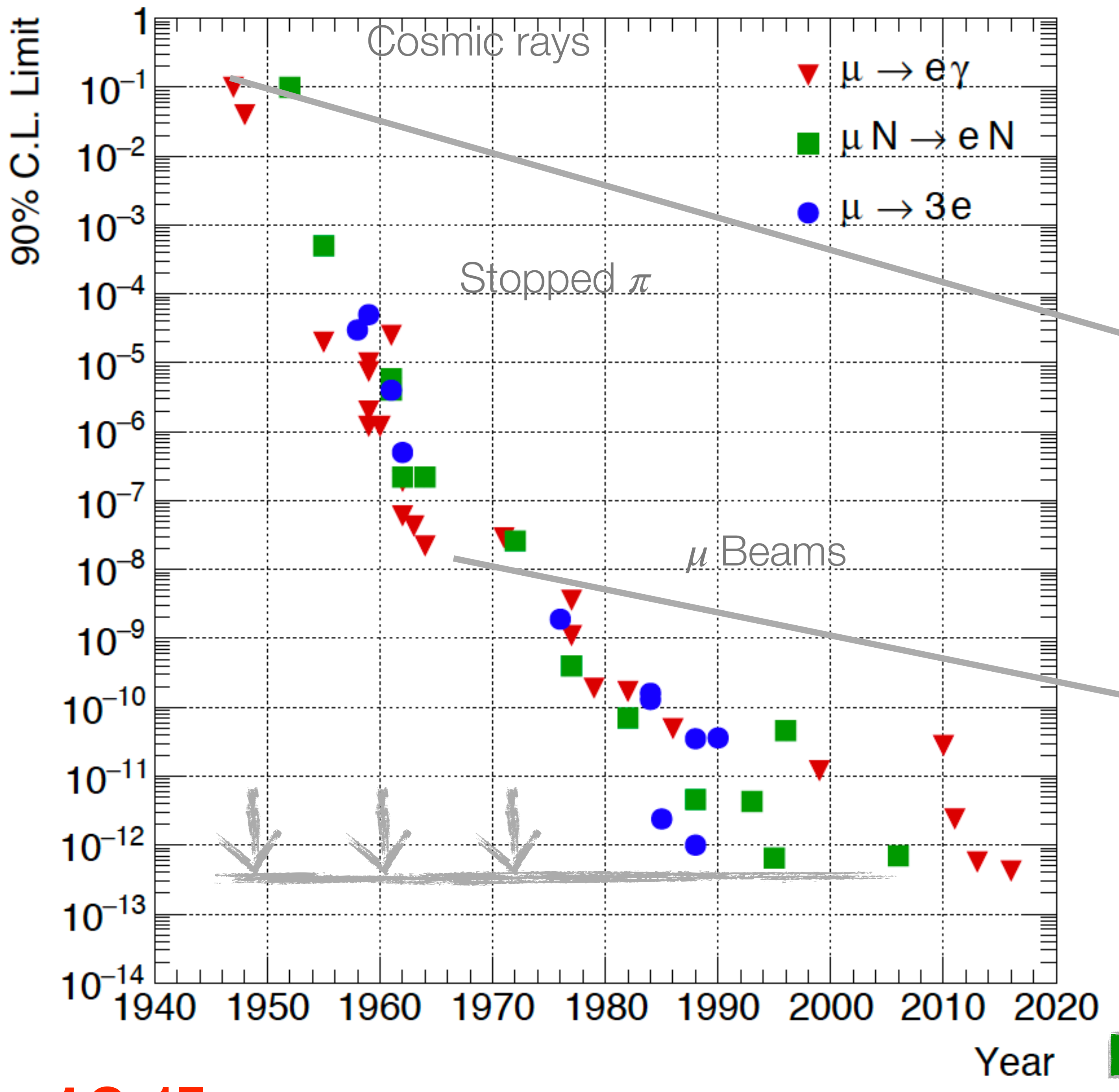
Probe energy scale otherwise unreachable

E > 1000 TeV

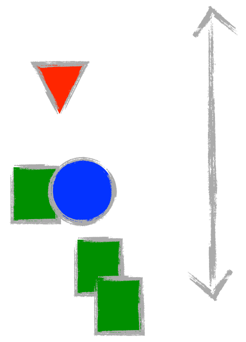
CLFV searches with muons: Status and prospects

	Current upper limit	Future sensitivity
$\mu \to e\gamma$	4.2 x 10^{-13}	~ 6 x 10^{-14}
$\mu \to eee$	1.0 x 10^{-12}	~1.0 x 10^{-16}
$\mu N \to eN'$	7.0 x 10^{-13}	few x 10^{-17}





10-17



- In the near future impressive sensitivities via the so called "golden" muon channels
- Strong complementarities among channels: The only way to reveal the mechanism responsible for cLFV
- Probing energy scale otherwise unreachable at the energy frontiers
- **Note**: τ ideal probe for NP w. r. t. μ (Smaller GIM suppression, stronger coupling, many decays). μ most sensitive probe due to huge statistics (= muon campus)

$\mu \neq e^*$

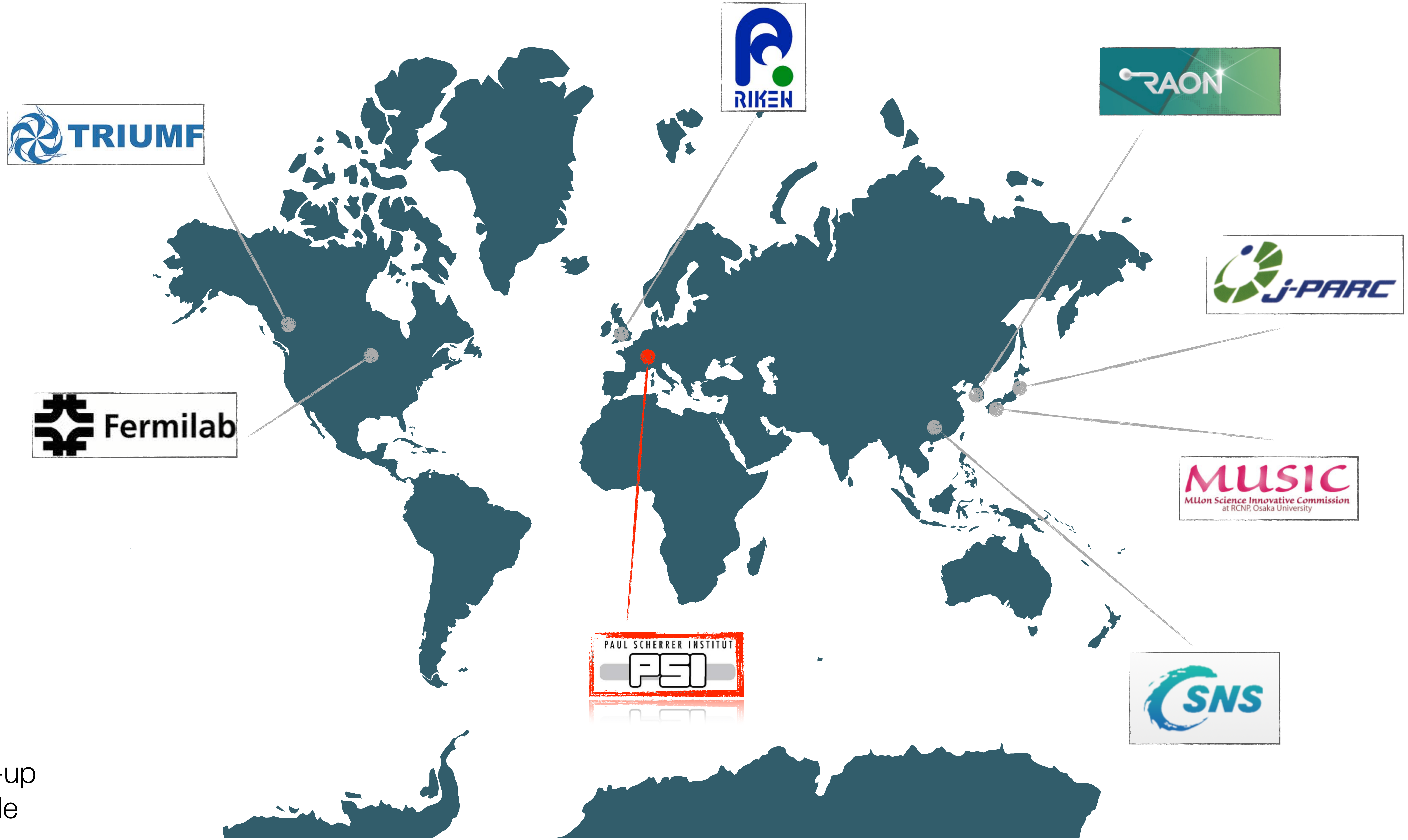
1947:
Pontecorvo and Hincks

$\nu_\mu \neq \nu_e$

1962:
Lederman, Schwartz, and Steinberger
1988 Nobel

In the near future O(5-10) years: Impressive sensitivity

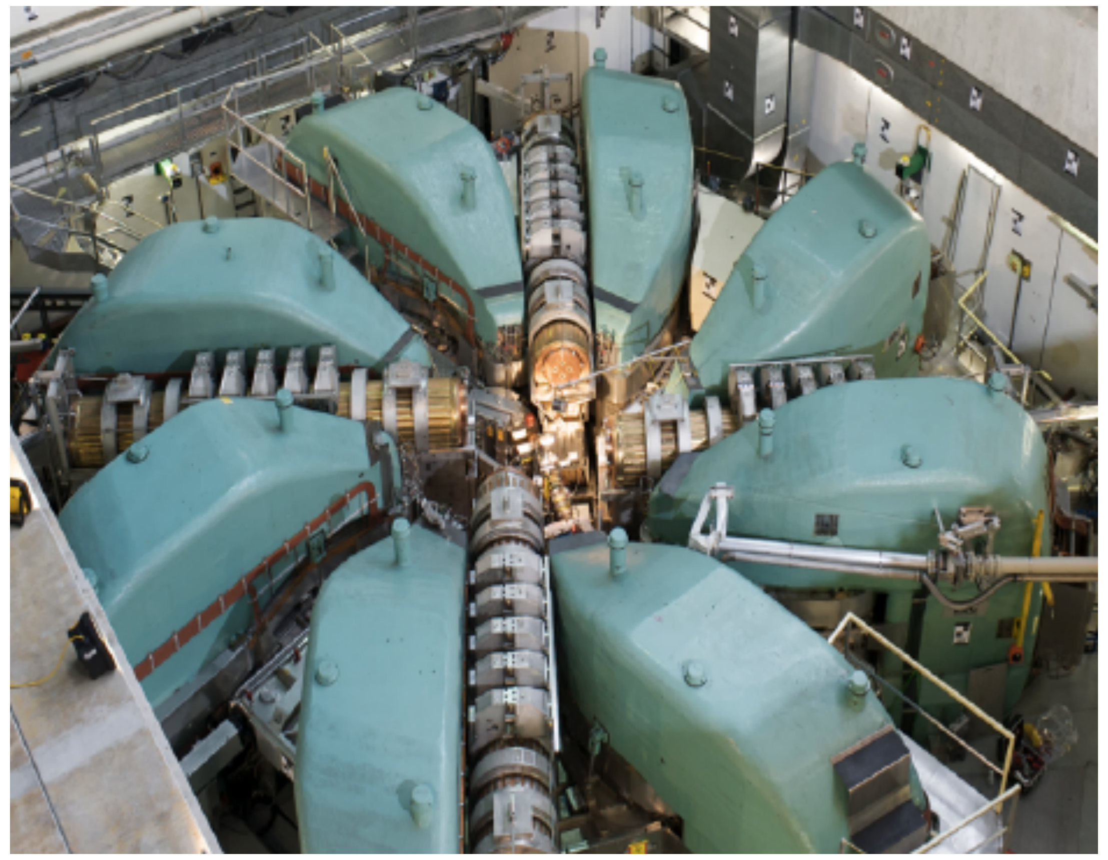
Muon beams worldwide



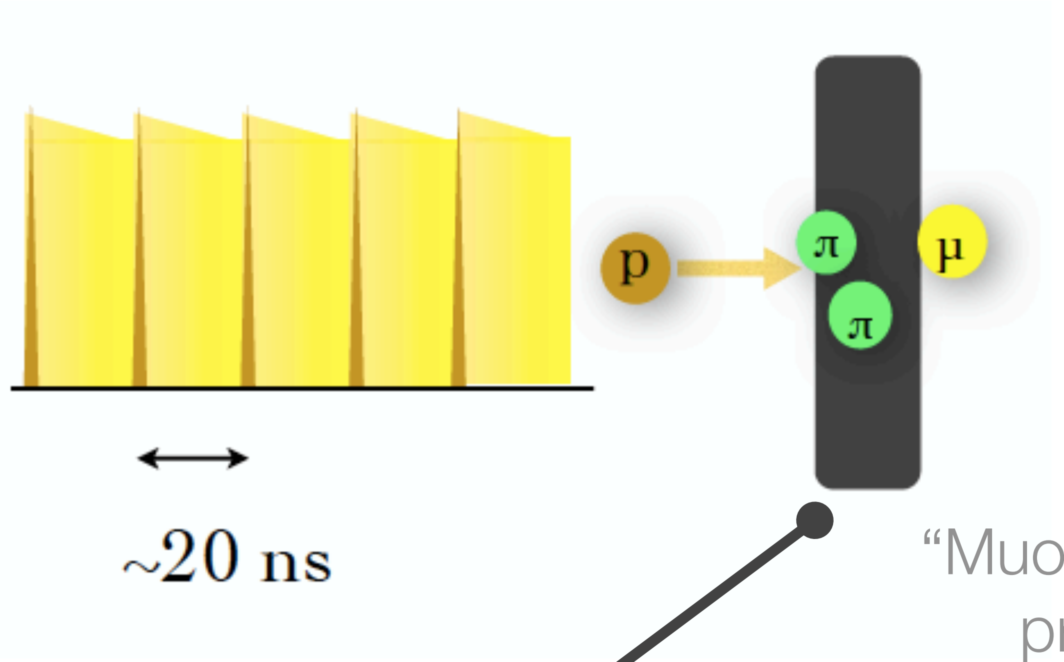
Note: See the back-up for a summary table

PSI’s muon beams

- PSI delivers the most intense continuous (DC) low momentum (surface) muon beam in the world up to few x 10^8 mu/s (28 MeV/c, polarised beam (**Intensity Frontiers**)

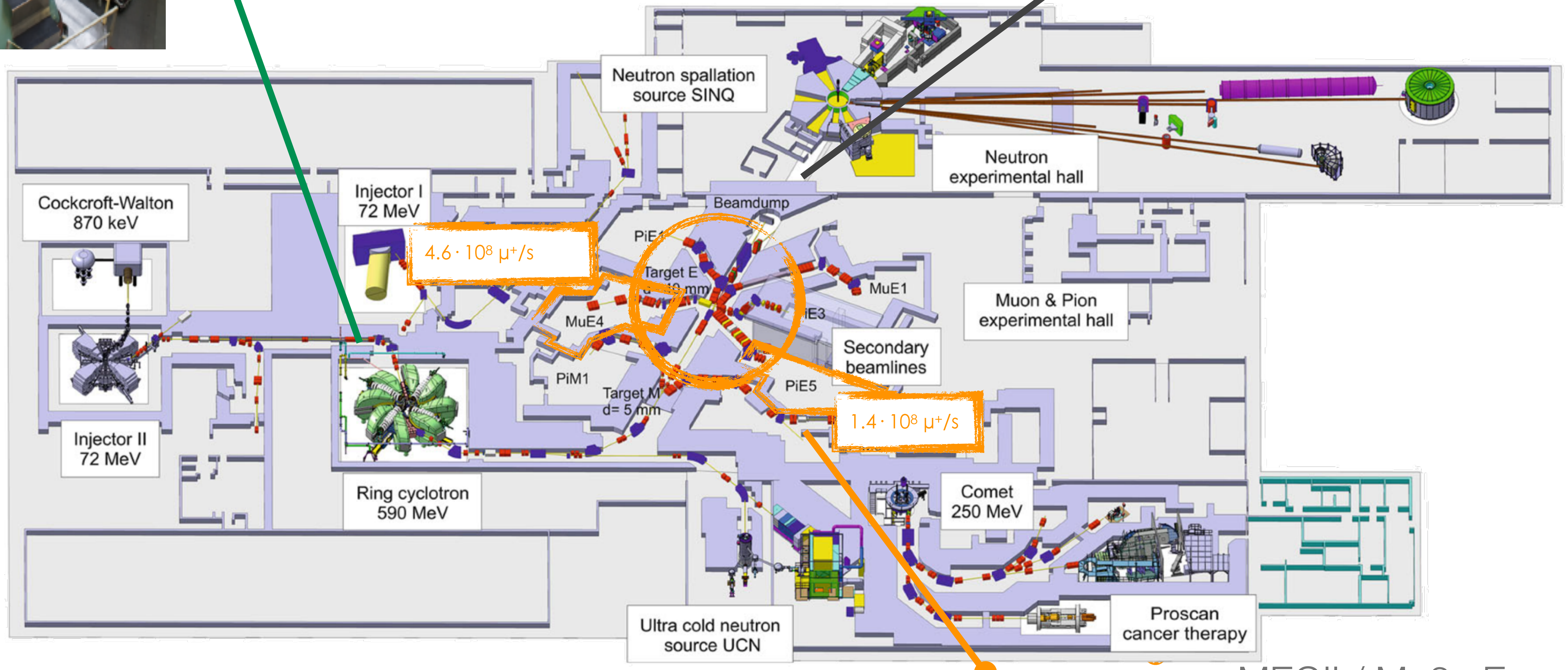


590 MeV proton
ring cyclotron
1.4 MW



Proton RF ~ 50 MHz
“DC” muon beam

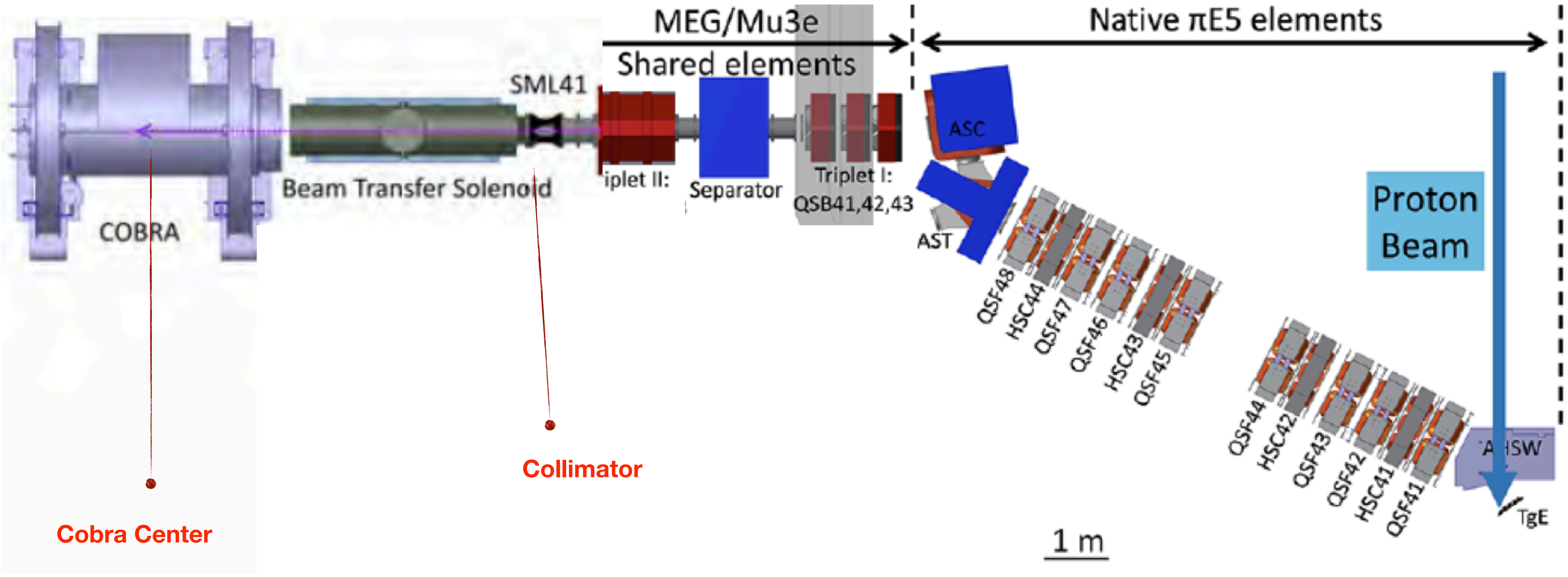
“Muon” Target “E”
production



MEGII / Mu3e Experimental area

The MEGII beam line

- MEGII beam requirements:
  - **Intensity O(10^8 muon/s), low momentum p = 28 MeV/c**
  - **Small straggling and good identification of the decay region**
- MEG II beam settings released since 2019. More then 10^8 mu/s can be transport into Cobra (**up to 2.32e8@2.2 mA during the 2023 beam time at the collimator**)



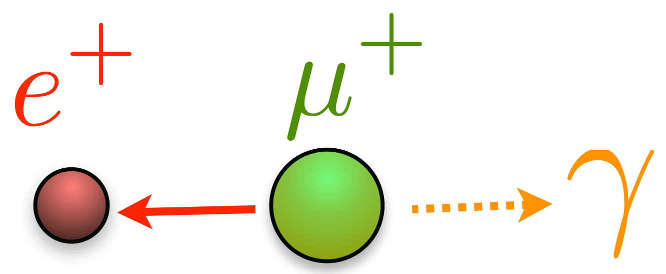
A. Baldini et al. (MEG Collaboration), Eur. Phys. J. C73 (2013) 2365

A. Baldini et al. (MEG Collaboration), Eur. Phys. J. C76 (2016) no. 8, 434

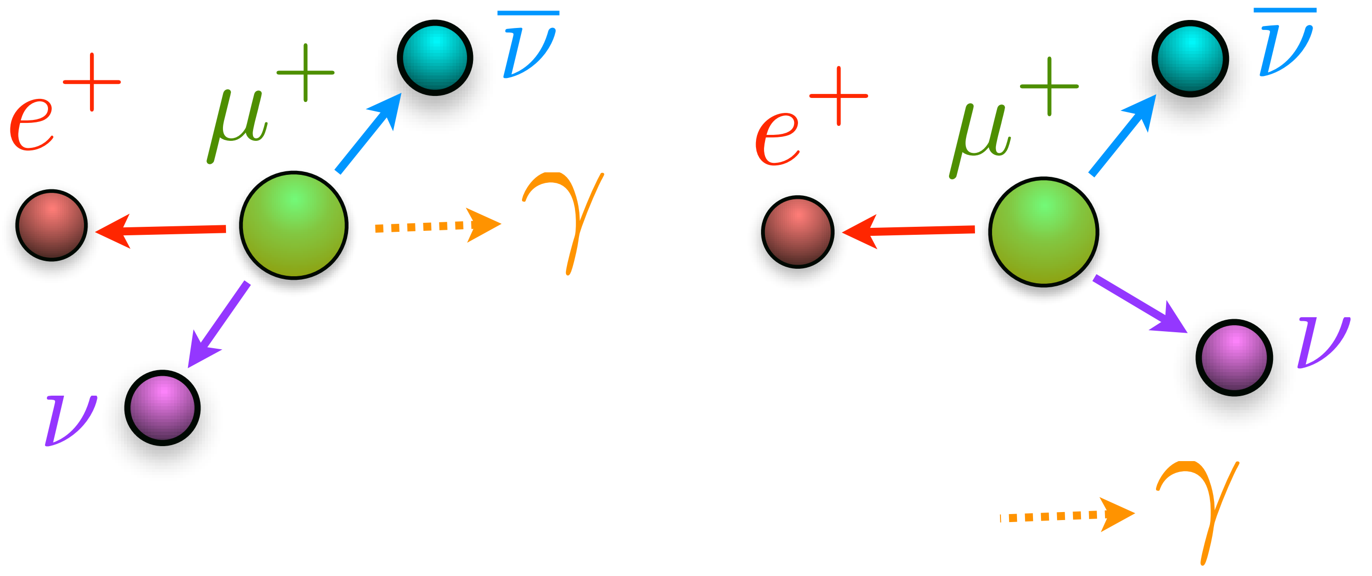
The MEGII experiment at PSI

- Best upper limit on the BR ($\mu^+ \to e^+ \gamma$) set by the MEG experiment (**$4.2\ 10^{-13}$** @90% C.L.)
- Searching for $\mu^+ \to e^+ \gamma$ with a sensitivity of ~ **$6\ 10^{-14}$**
- Five observables **(E_g, E_e, t_{eg}, ϑ_{eg}, ϕ_{eg})** to identify $\mu^+ \to e^+ \gamma$ events

Signature



Backgrounds



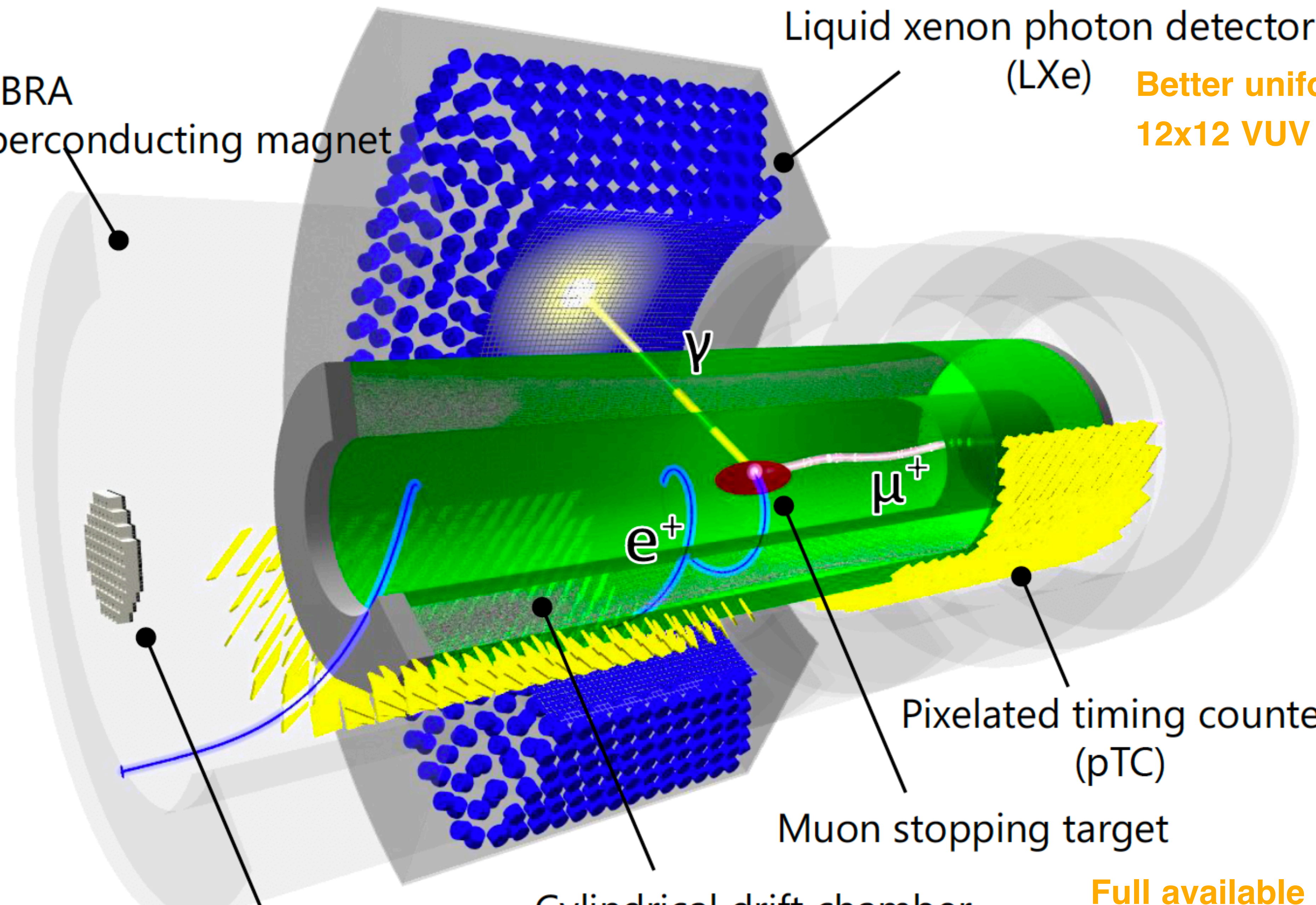
New electronics:
WaveDAQ

~9000 channels at 5GSPS

2x Resolution everywhere

Updated and new Calibration methods

Quasi mono-chromatic positron beam



Better uniformity w/ 12x12 VUV SiPM

2x Beam Intensity

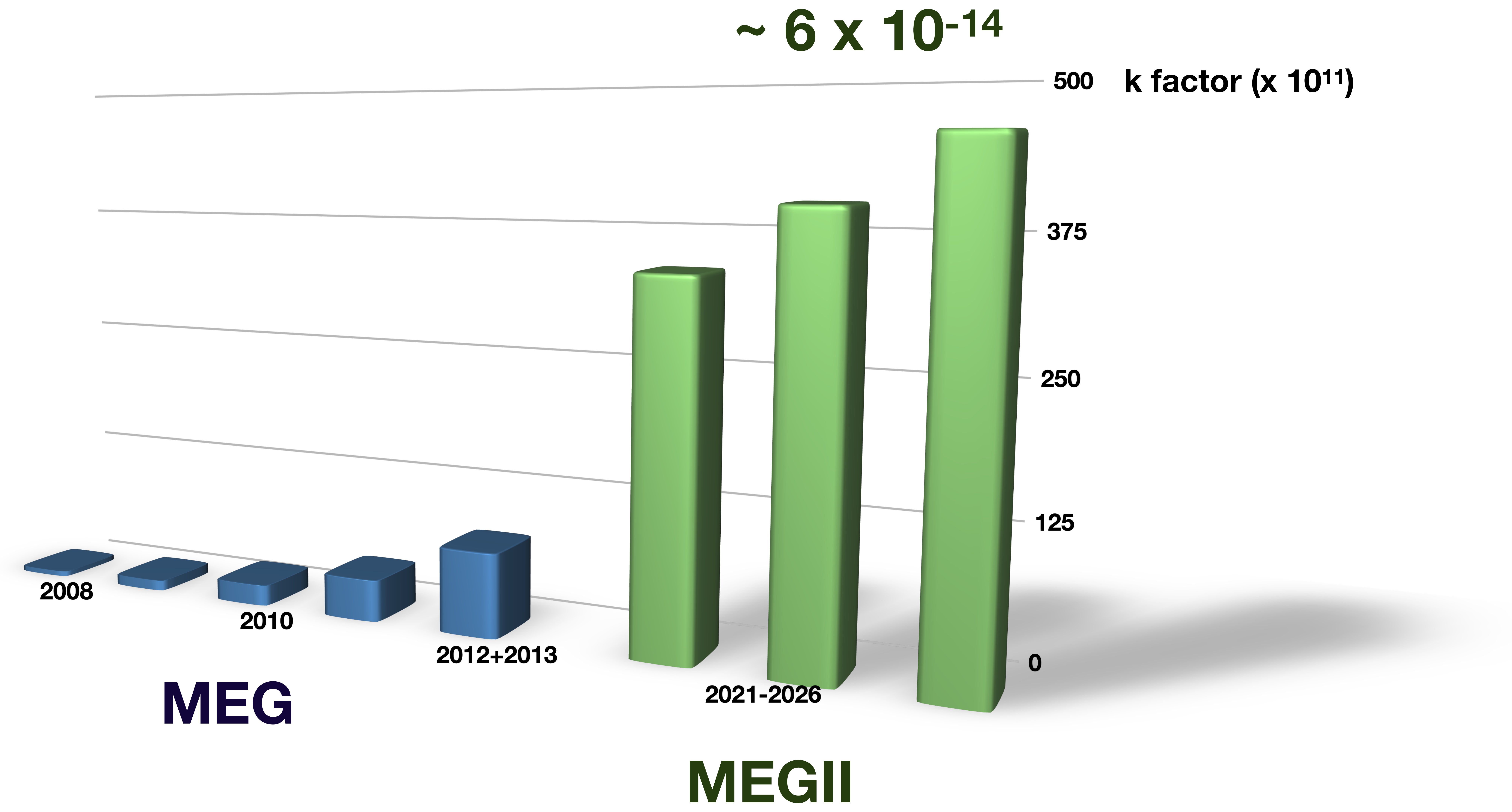
35 ps resolution w/ multiple hits

Full available stopped beam intensity 7×10^7

Single volume $He:iC_4H_{10}$

Background rejection

Where we will be



MEGII: Latest news and currents status

Key points:

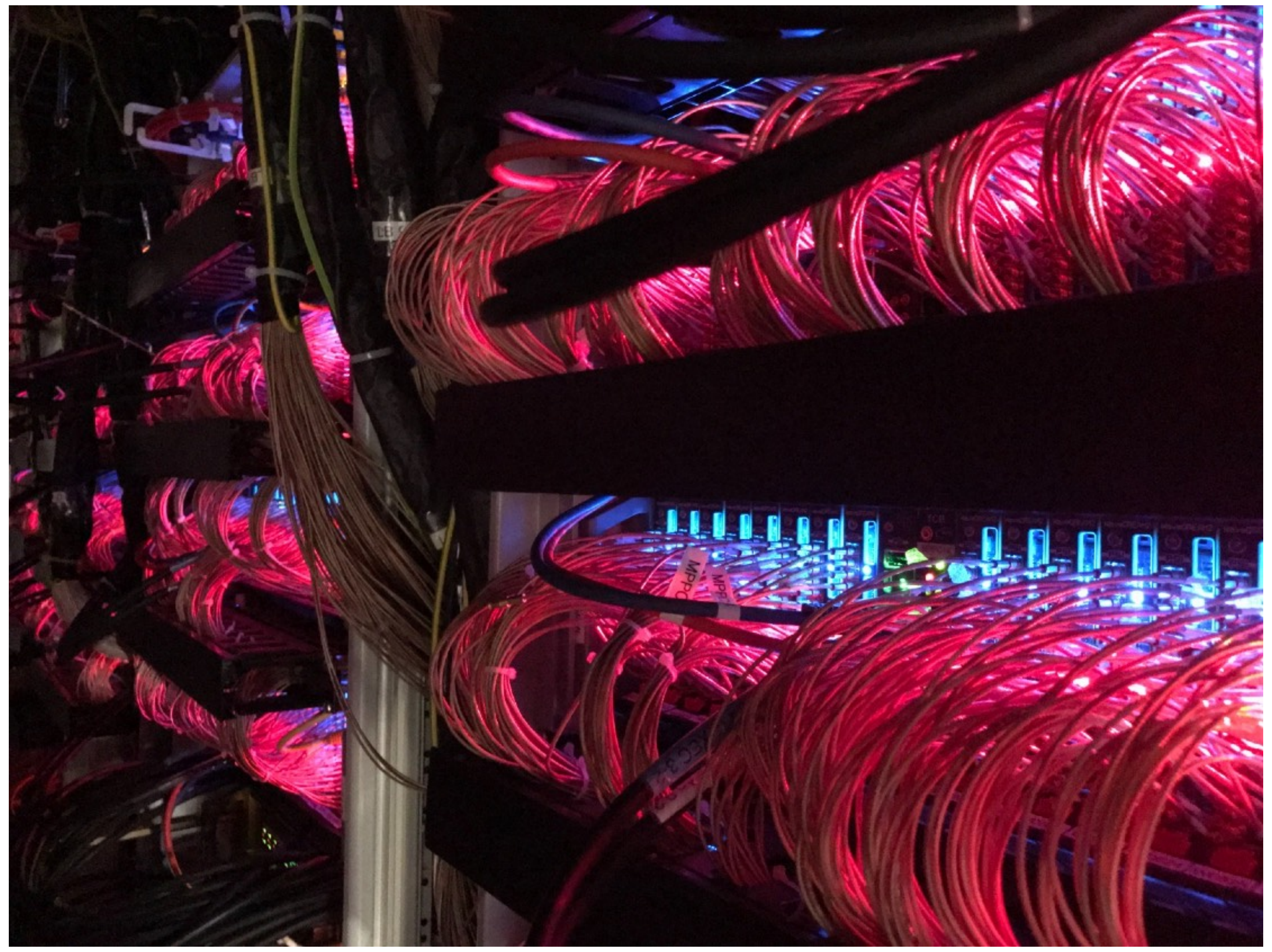
- **Run2021 very successful**
- Electronics fully installed and tested with all sub-detectors and calibration tools
- All calibration and physics trigger configurations released
- Assessed performances of each sub-detectors in the final MEG II conditions
- Collected data at different beam intensities
- Dedicated RMD at reduced beam intensity as proof-of-principle of the experiment quality

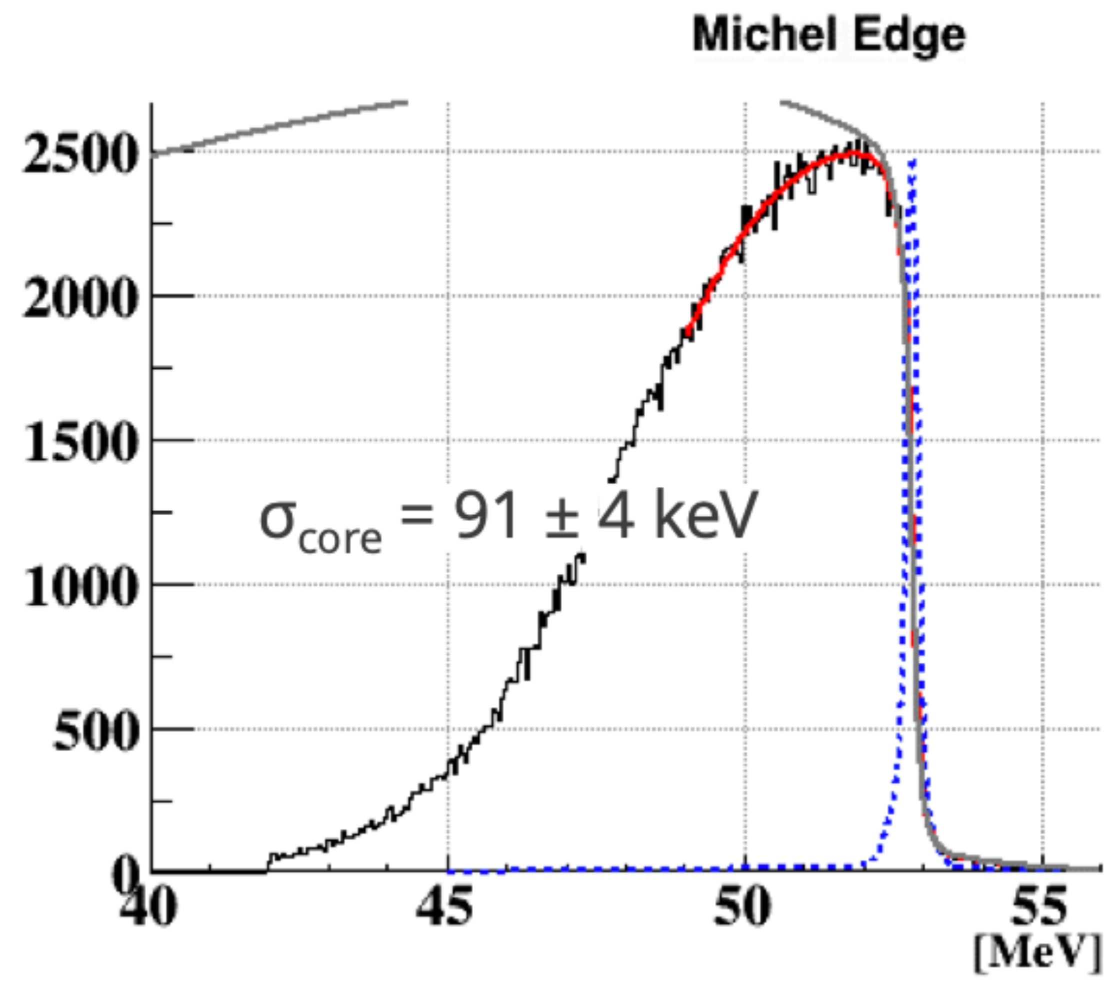
- **Physics run started at the end of September 2021**
- **MEGII beam time 2022 resumed on June 7th and data taking started on July 6th**
- **MEGII beam time 2023 resumed on May 16th and data taking started on June 7th**

Outlook:

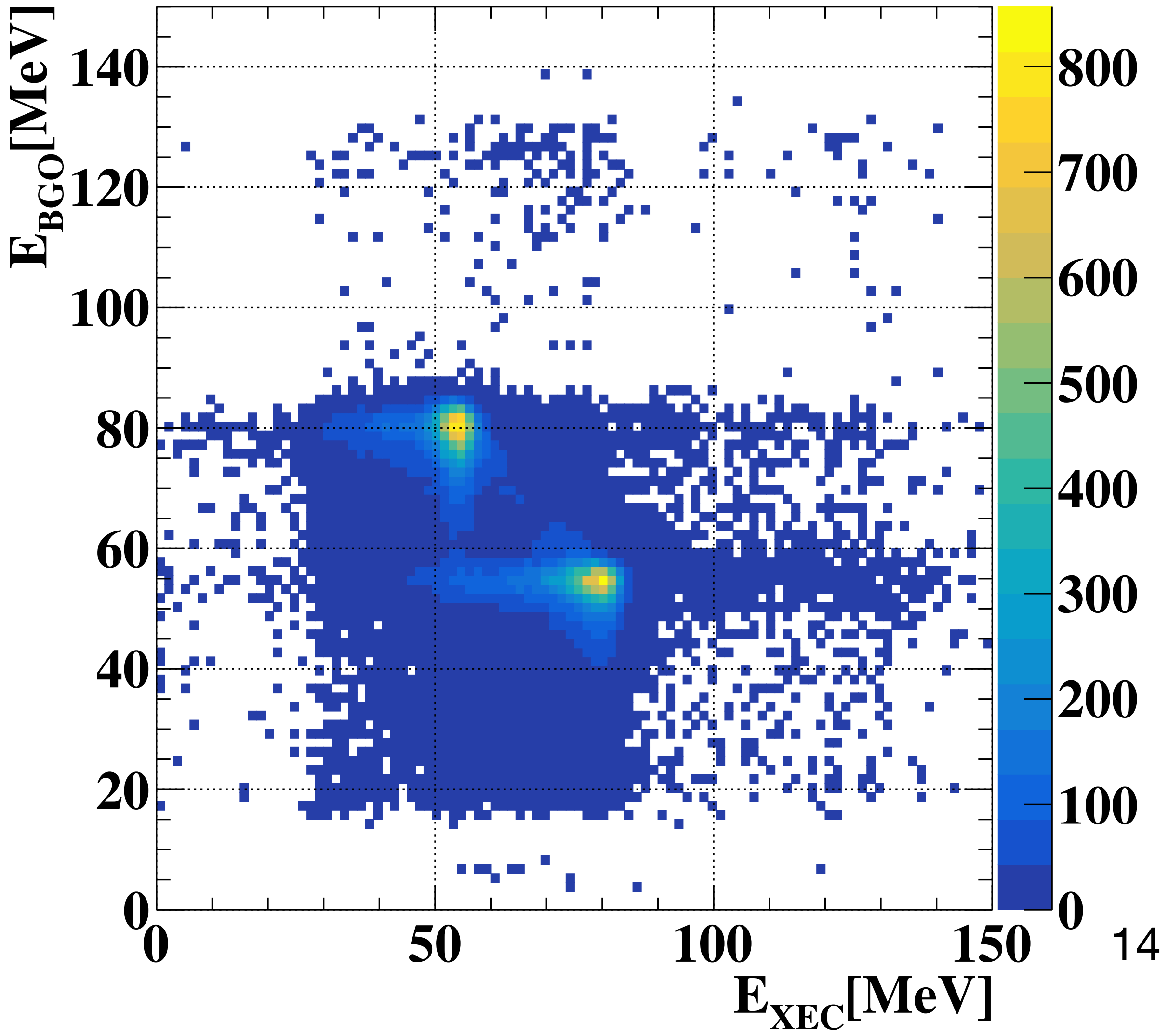
- MEG sensitivity expected to be **already surpassed with the Run 2022**

MEGII **fully** installed!



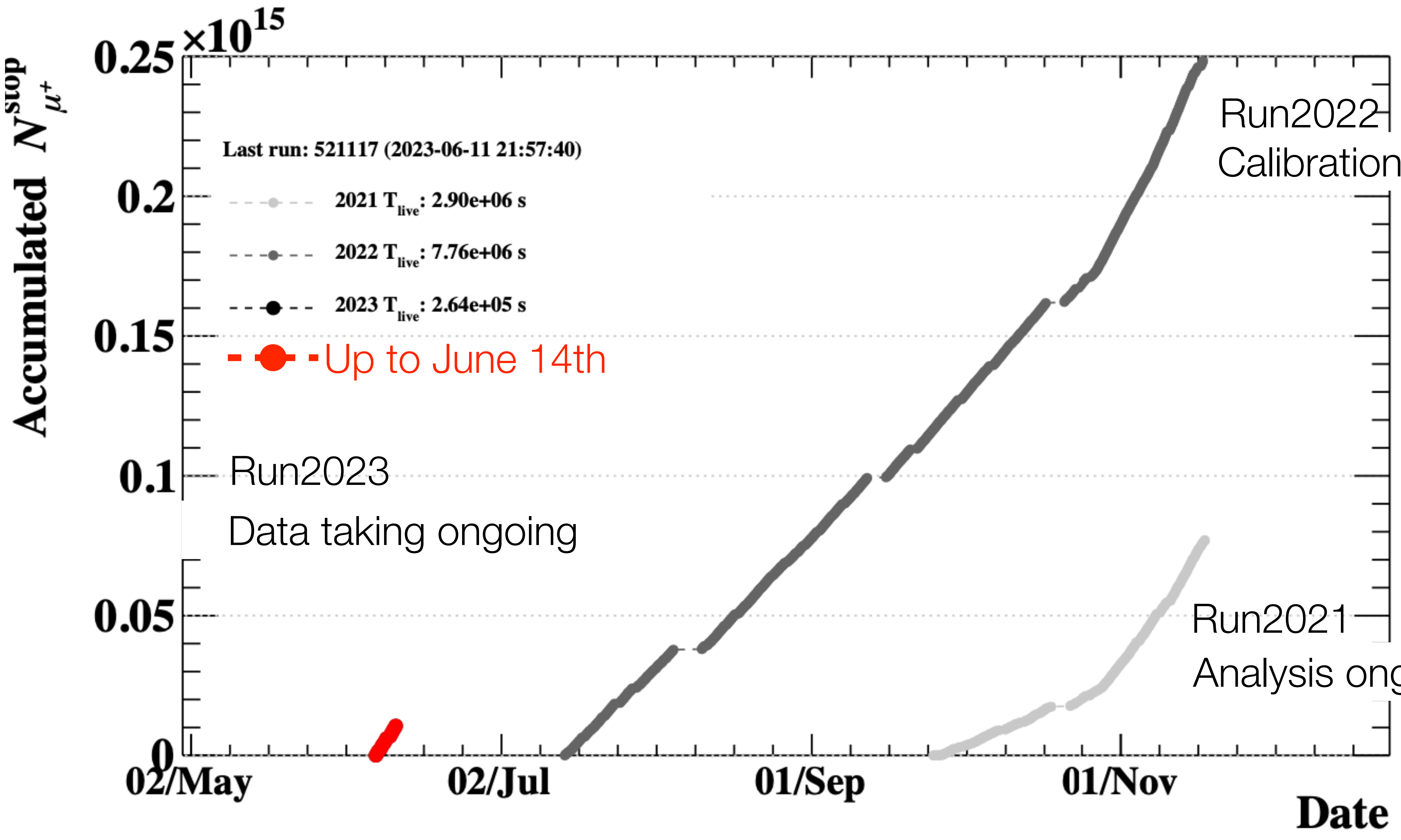


Data from the **first** Physics Run2021

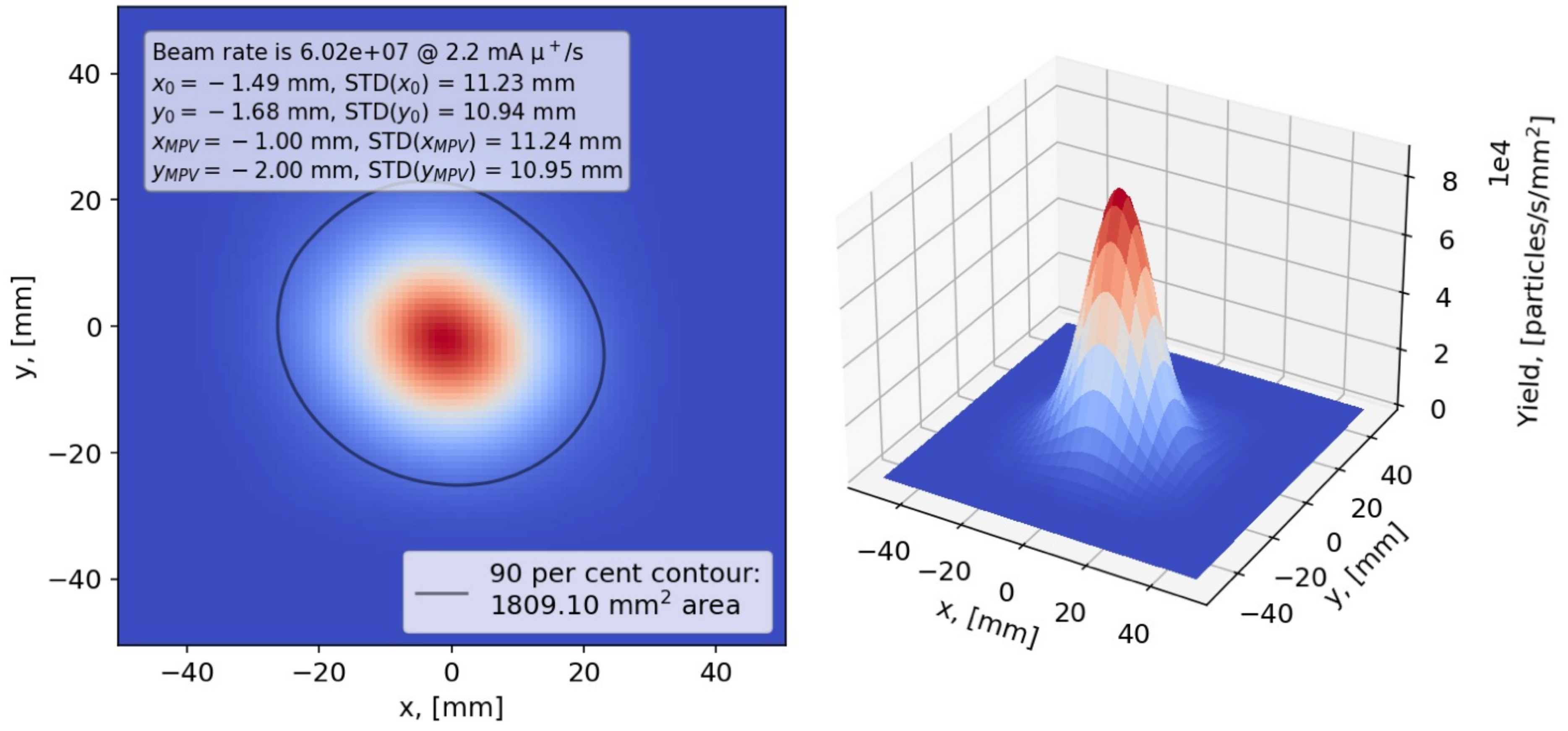


Physics run 2023: as it started…

- **June 7th 2023: Muegamma data taking started**

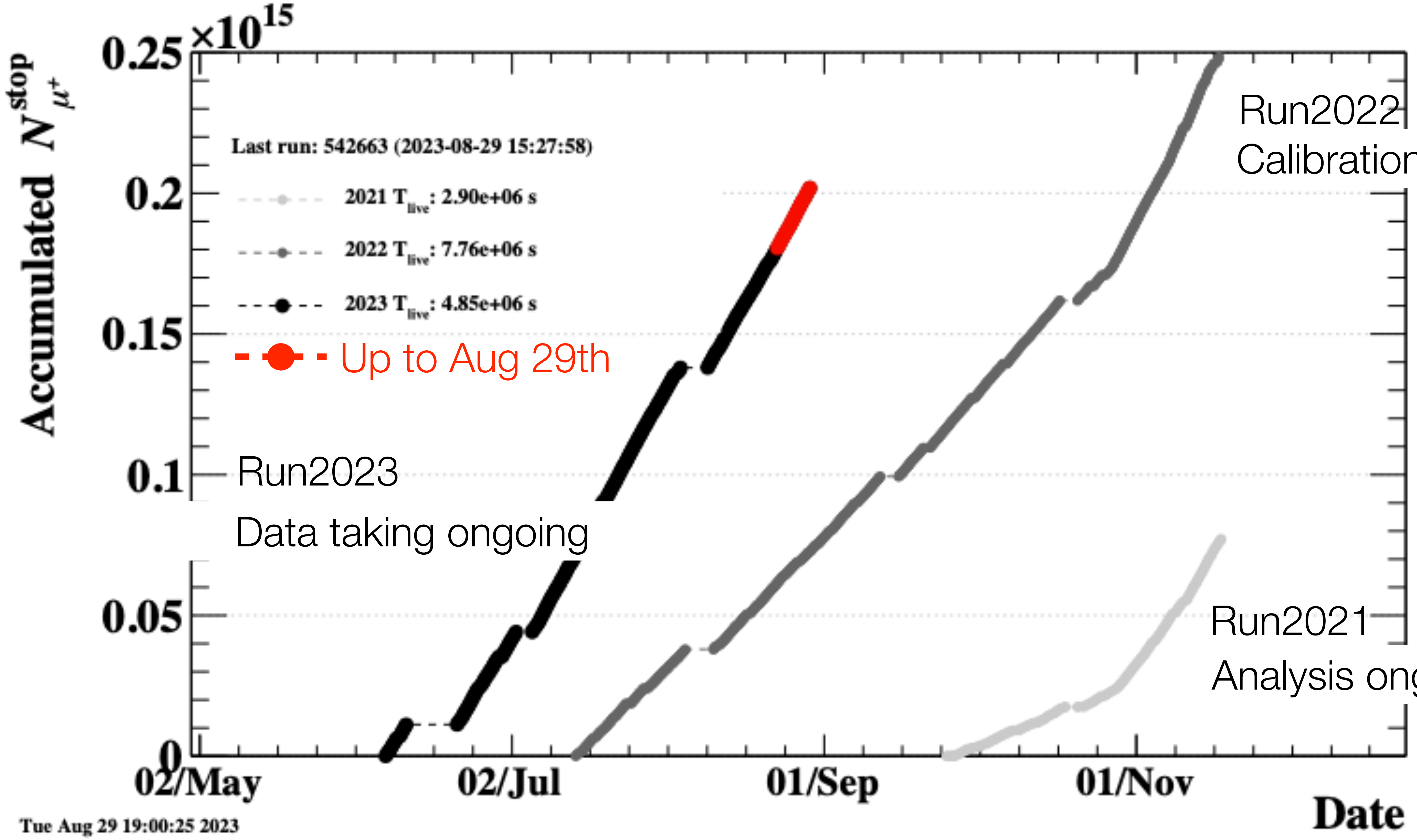


With a beam intensity = **4.27e7** mu/s@1.76 mA



Physics run 2023: as it was ongoing…

- **June 7th 2023: Muegamma data taking started**

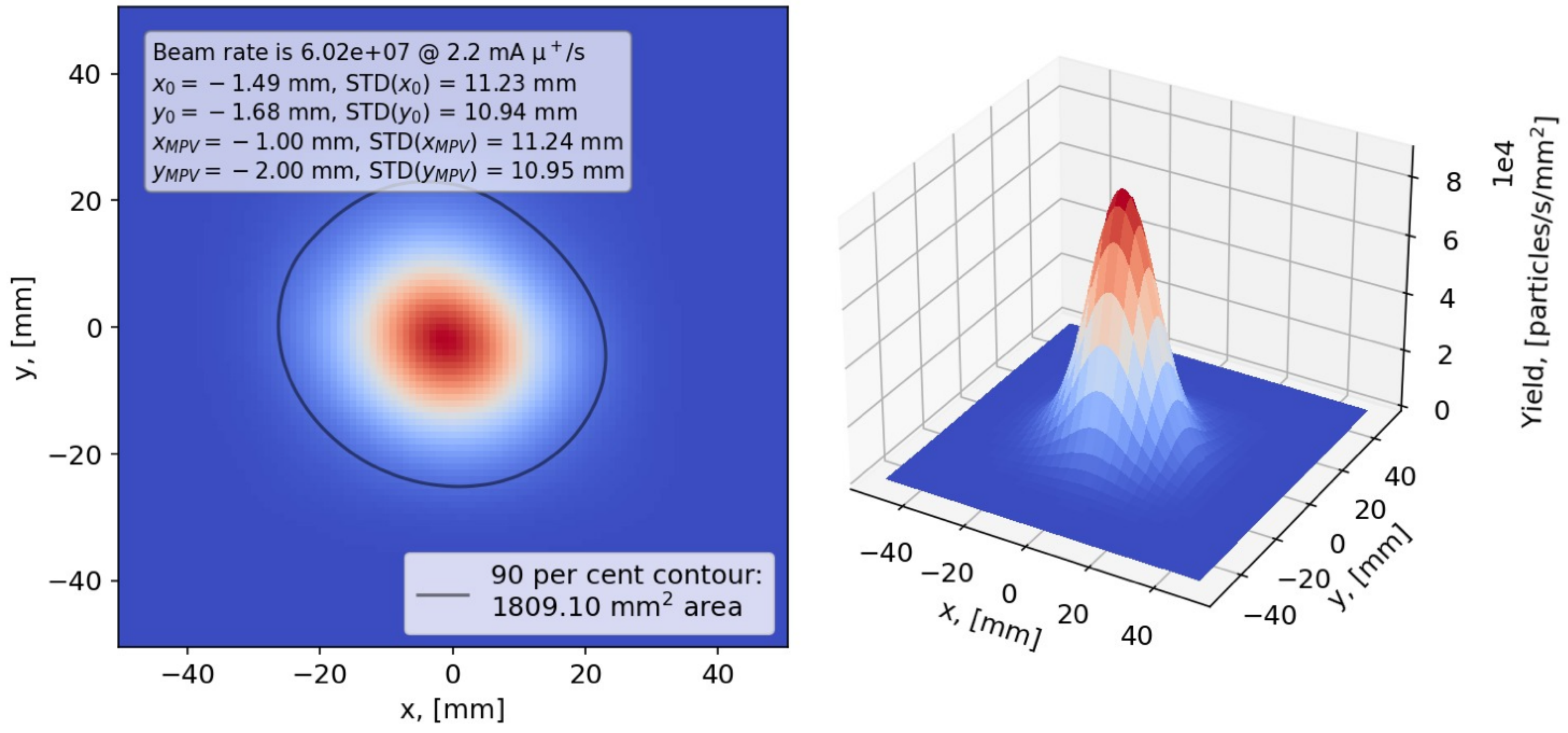


Run2023
Data taking ongoing

Run2022
Calibrations ongoing

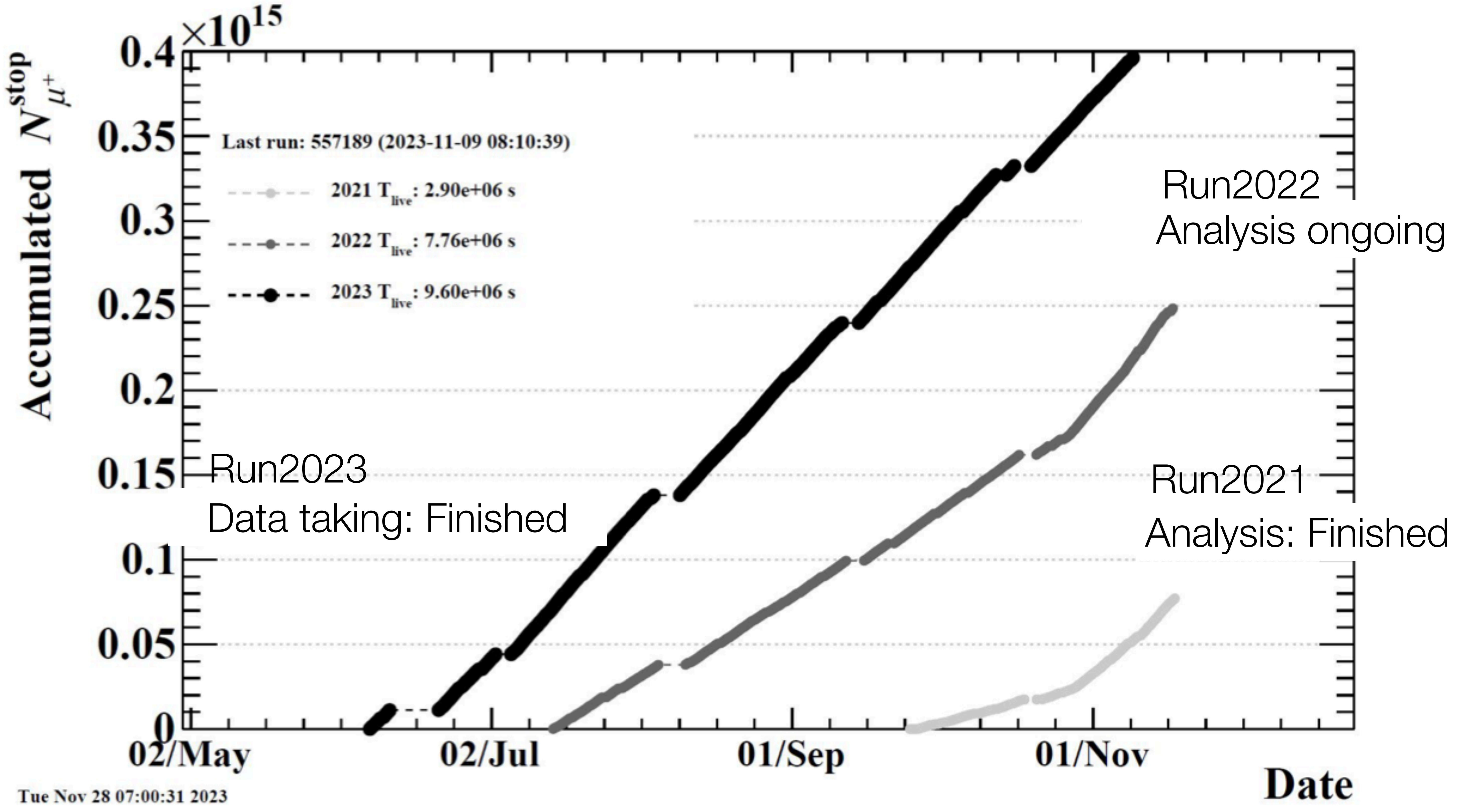
Run2021
Analysis ongoing

With a beam intensity =
4.27e7 mu/s@1.76 mA

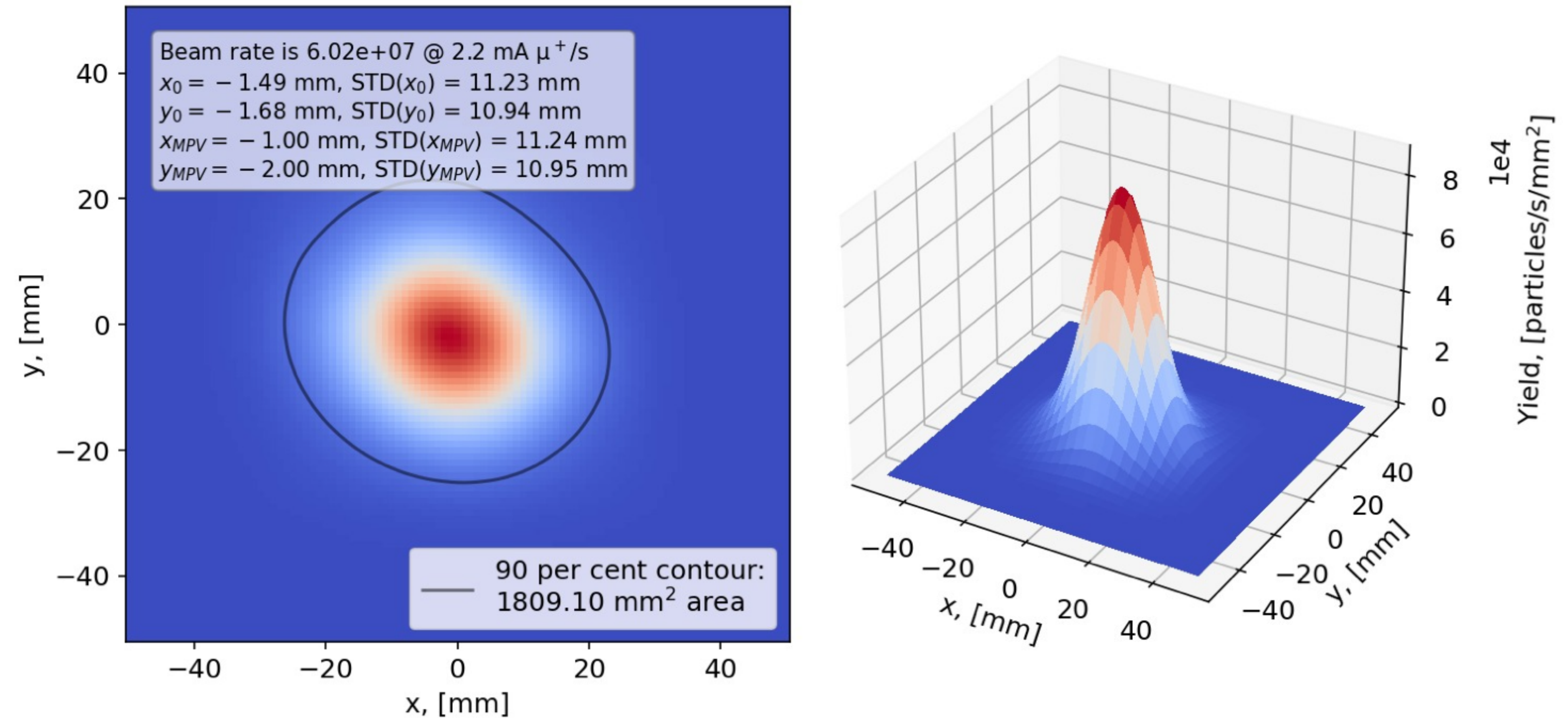


Physics run 2023: as it finished!

- **November 8th 2023: Muegamma data taking finished**



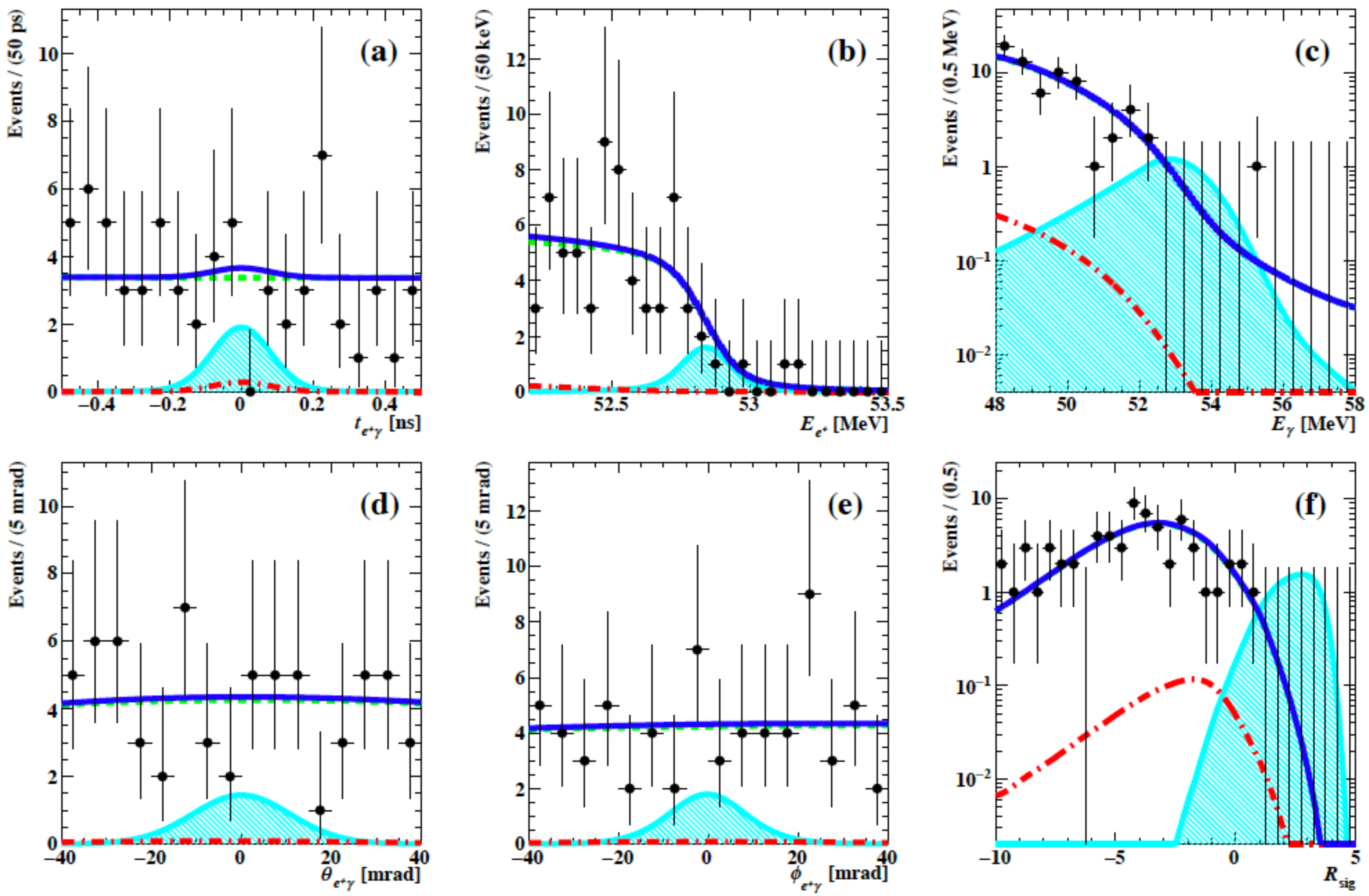
With a beam intensity =
4.27e7 mu/s@1.76 mA



https://arxiv.org/pdf/2310.12614.pdf

https://arxiv.org/pdf/2310.11902.pdf

First MEGII results - data sample “Run2021”



The projections of the best-fitted PDFs to the five main observables and Rsig, together with the data distributions (black dots)

The green dash and red dot-dash lines are individual components of the fitted PDFs of ACC and RMD, respectively

The blue solid line is the sum of the best-fitted PDFs

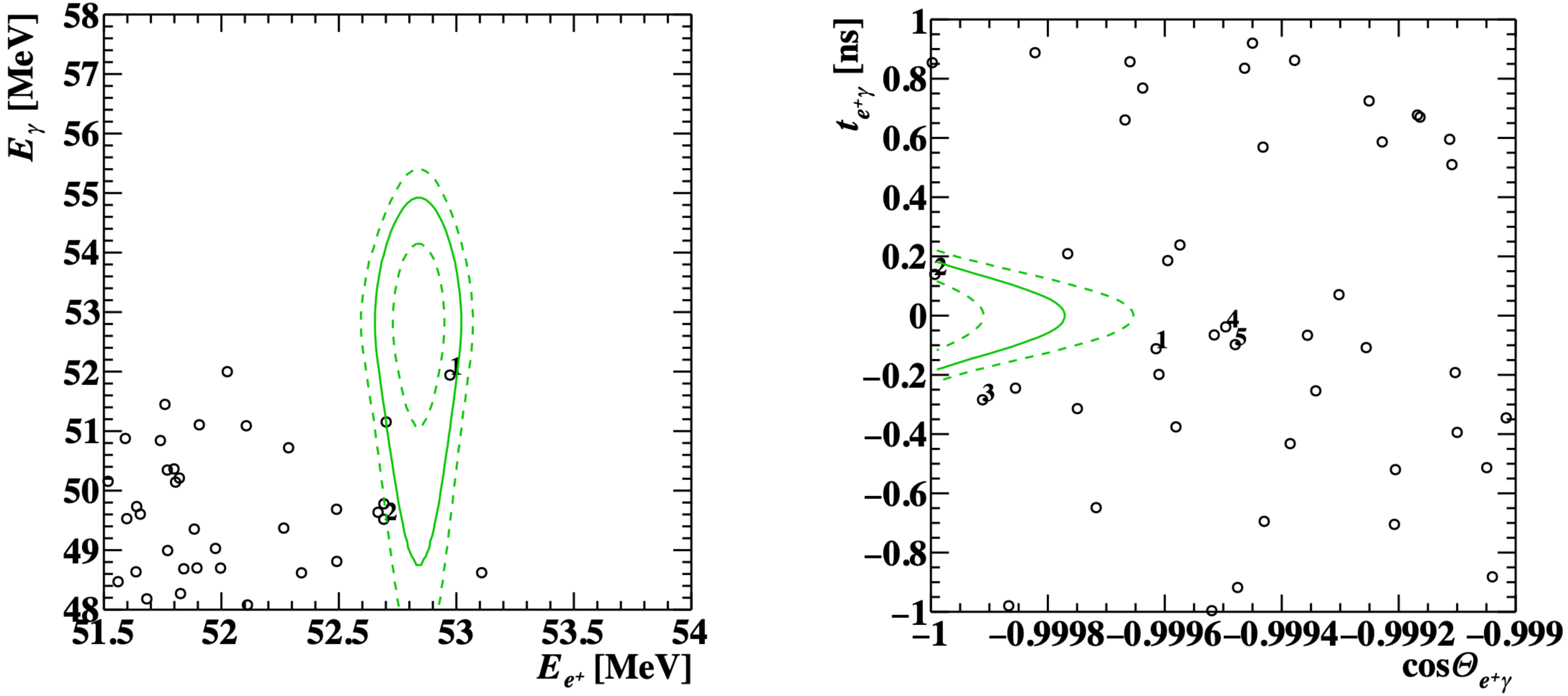
The cyan hatched histograms show the signal PDFs corresponding to four times magnified Nsig upper limit.

https://arxiv.org/pdf/2310.12614.pdf

https://arxiv.org/pdf/2310.11902.pdf

First MEGII results - data sample “Run2021”

- Event distributions on the (*E_gamma*, *E_positron*)- and (cos Θ_gamma-positron, *t_gamma-positron*)- planes
- The signal PDF contours (1σ, 1.64σ and 2σ) are also shown. The five highest- ranked events in terms of R_{sig} are indicated in the event distributions, if they satisfies the selection.

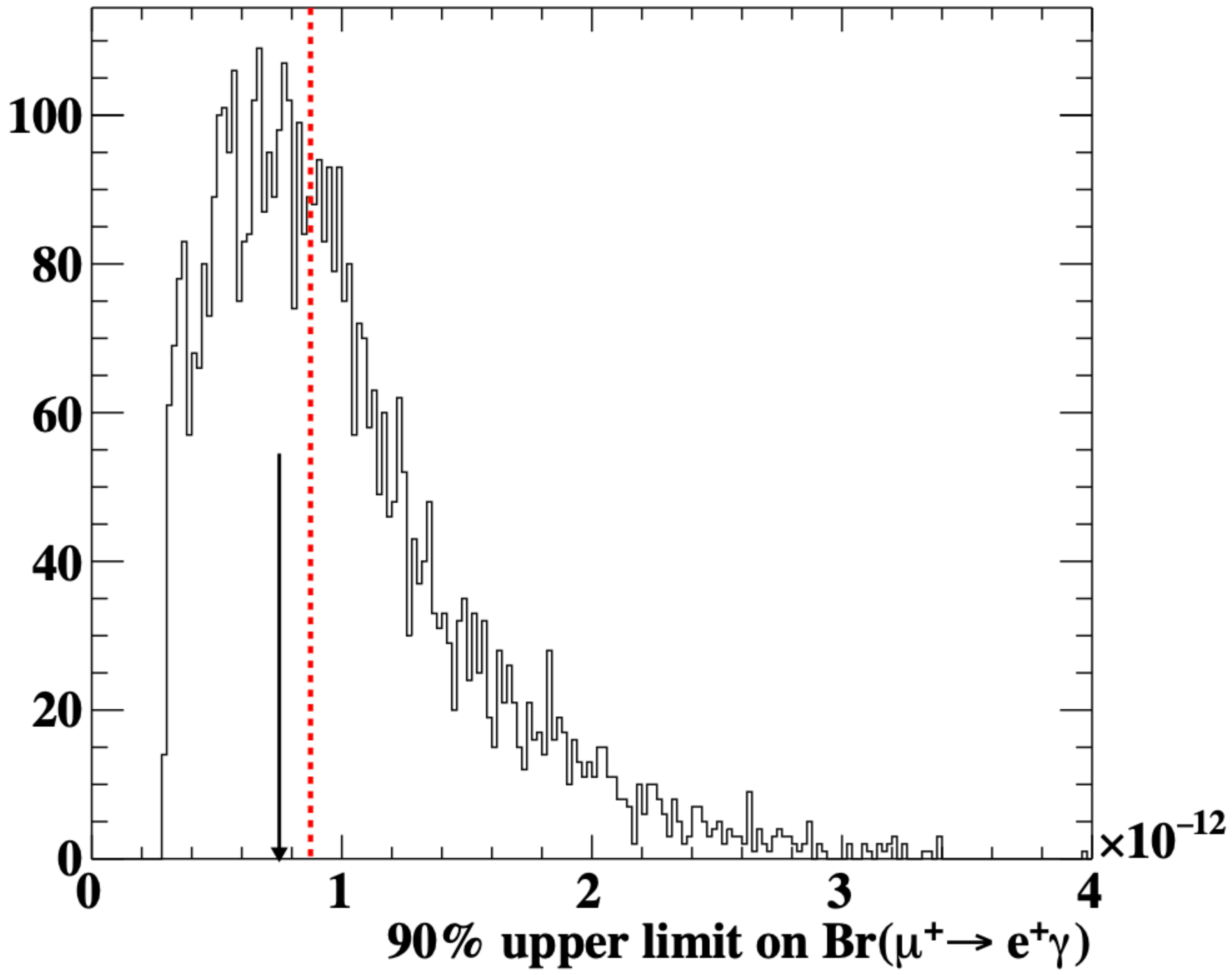


https://arxiv.org/pdf/2310.12614.pdf

https://arxiv.org/pdf/2310.11902.pdf

First MEGII results - data sample “Run2021” and MEG combination

- Distribution of the 90% C.L. upper limits computed for an ensemble of pseudo-experiments with a null-signal hypothesis
- The sensitivity is indicated by a red dashed line while the upper limit observed (Run 2021) in the analysis region with a solid black arrow



- Upper limit on the BR ($\mu^+ \rightarrow e^+ \gamma$) set by the MEGII experiment **Run2021** (**$7.5\ 10^{-13}$** @90% C.L.)
- When **combined** with the final result of MEG, we obtain the most stringent limit up to date, BR ($\mu^+ \rightarrow e^+ \gamma$) < **$3.1\ 10^{-13}$** @90% C.L.
- The final goal (by 2026) is to reach a sensitivity to the $\mu^+ \rightarrow e^+ \gamma$ decay of S_{90} ~ $6\ 10^{-14}$

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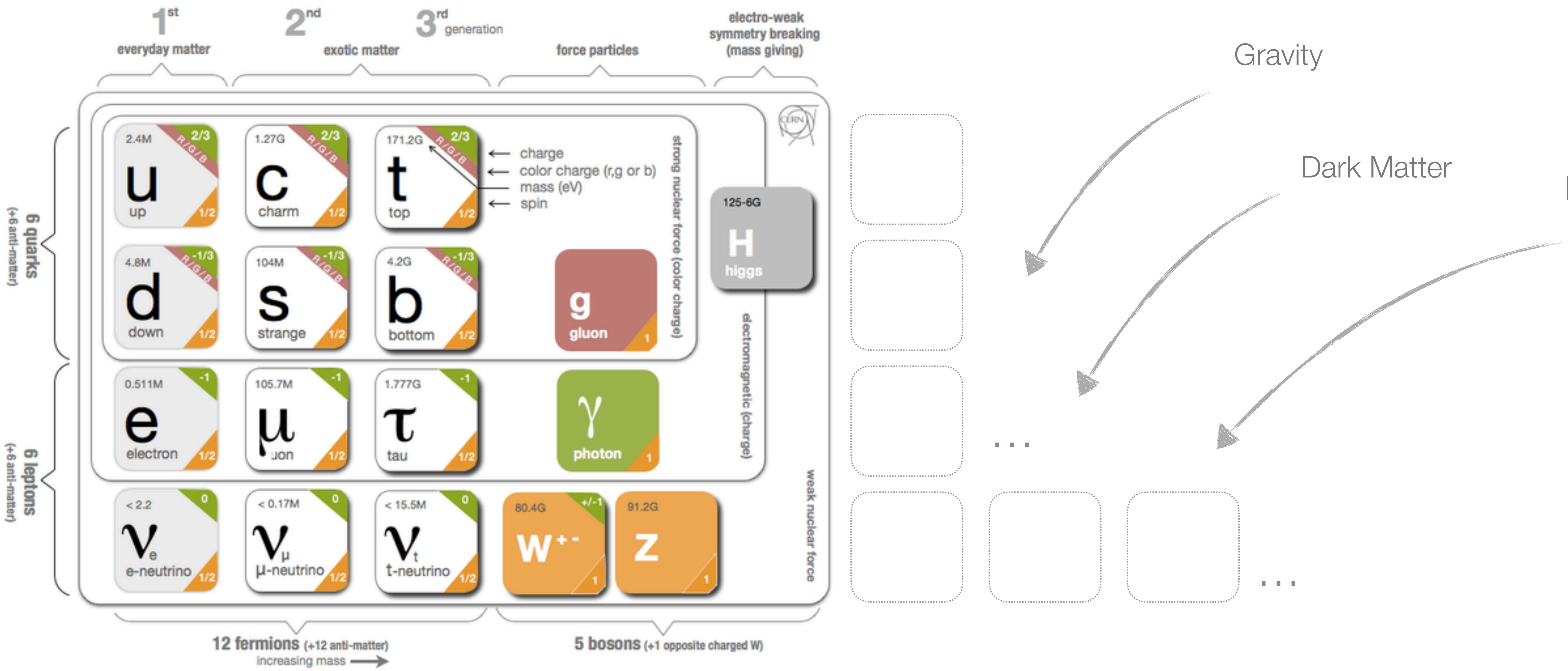
Motivations: Search for EDMs

- The Standard Model of particle physics: A great triumph of the modern physics but not the ultimate theory



Matter-Antimatter asymmetry

- Baryogenesis, the creation of more matter over anti-matter, requires additional CP violation (CPV) **beyond the SM**

- These **additional CPV** underlying interactions **would also result in Electric Dipole Moments (EDMs)** of fundamental particles at the current experimental sensitivity, **well above** the SM predictions

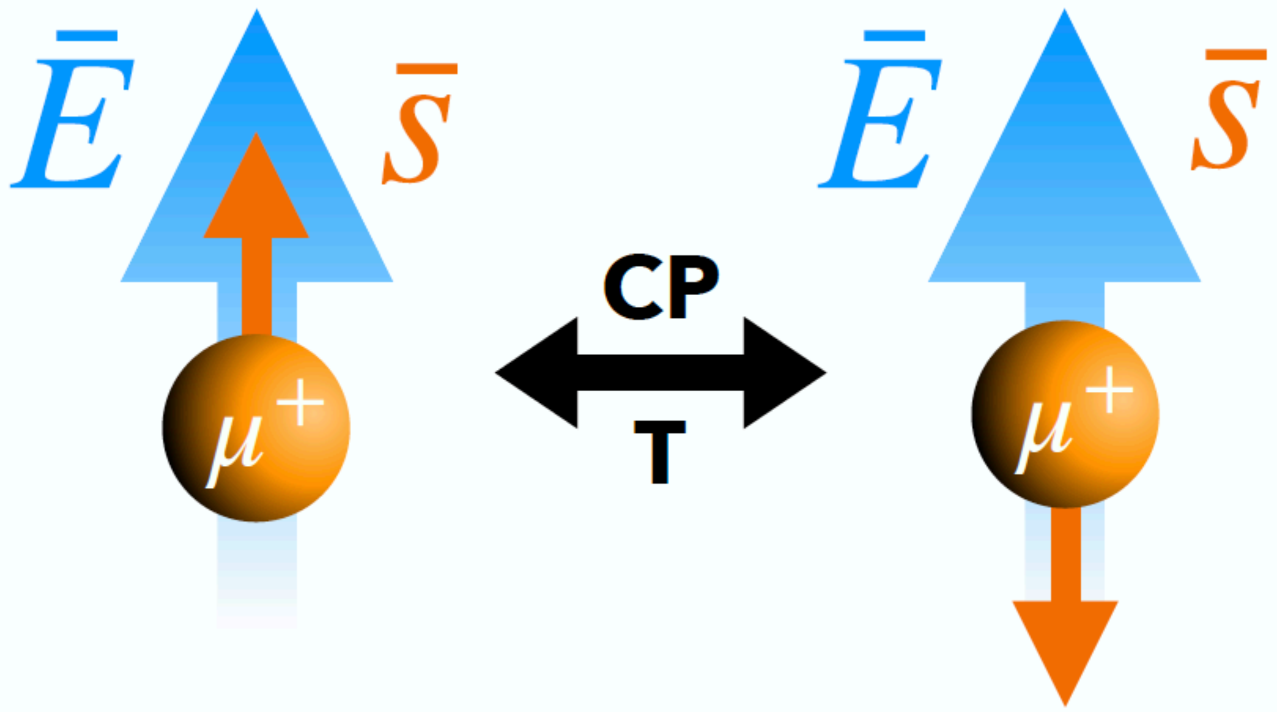
- Low energy precision physics: Rare/forbidden decay searches, **symmetry tests**, precision measurements very sensitive tool for unveiling new physics and probing very high energy scale

muEDM dedicated search: Current status

- EDMs of fundamental particles are intimately connected to the violation of time invariance and the combined symmetry of charge and parity
- The different EDM searches are sensitive to different, unique combinations of underlying CPV sources

Quite poor current direct limit
d_μ **<1.5×10^{-19} $e$cm (CL 90%)**

A permanent EDM requires T violation, equivalently CP violation by the CPT Theorem.

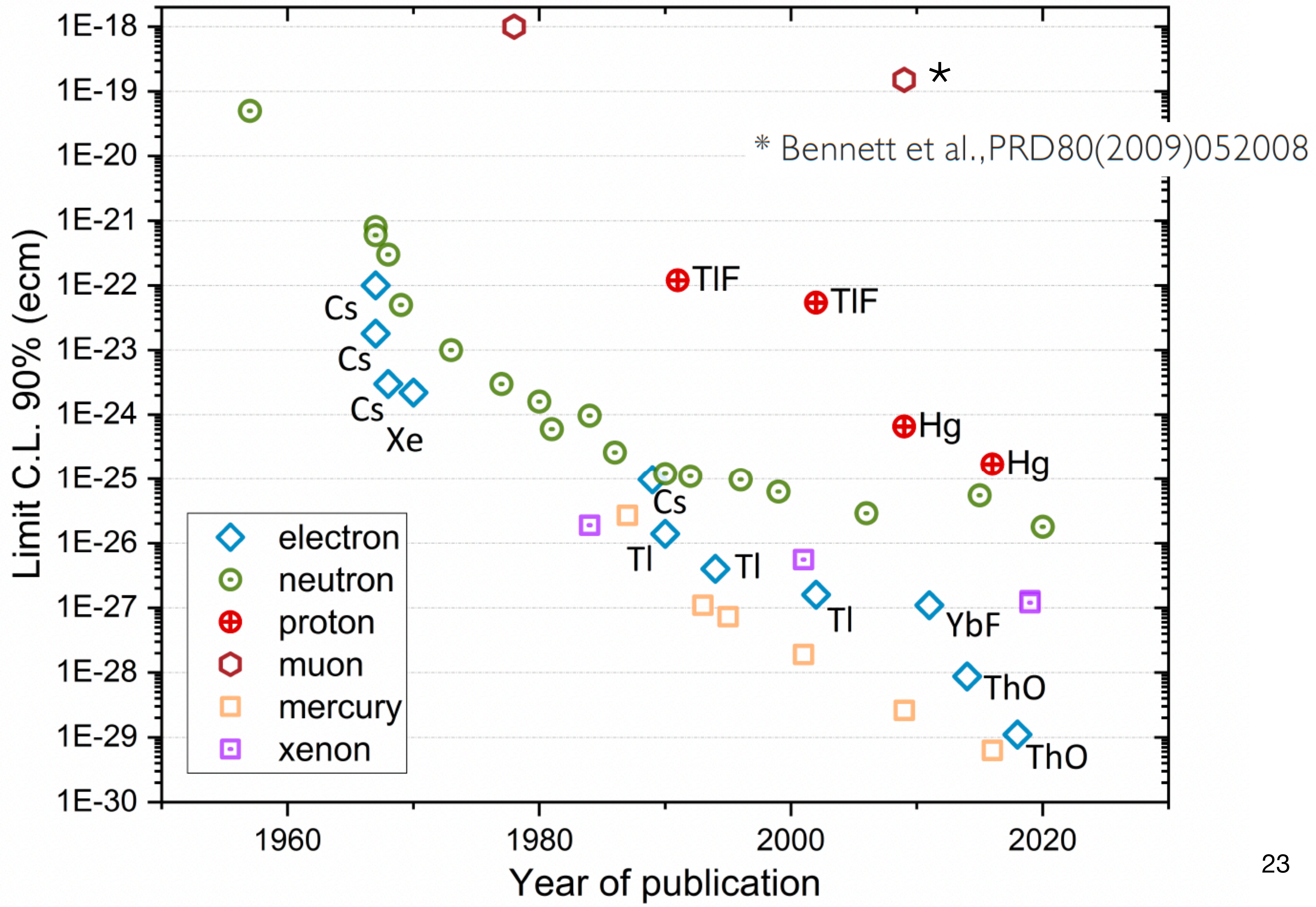


$$H_\mu^{EDM} \overset{\beta\to 0}{\propto} d_\mu \bar{\sigma}\cdot\bar{E}$$

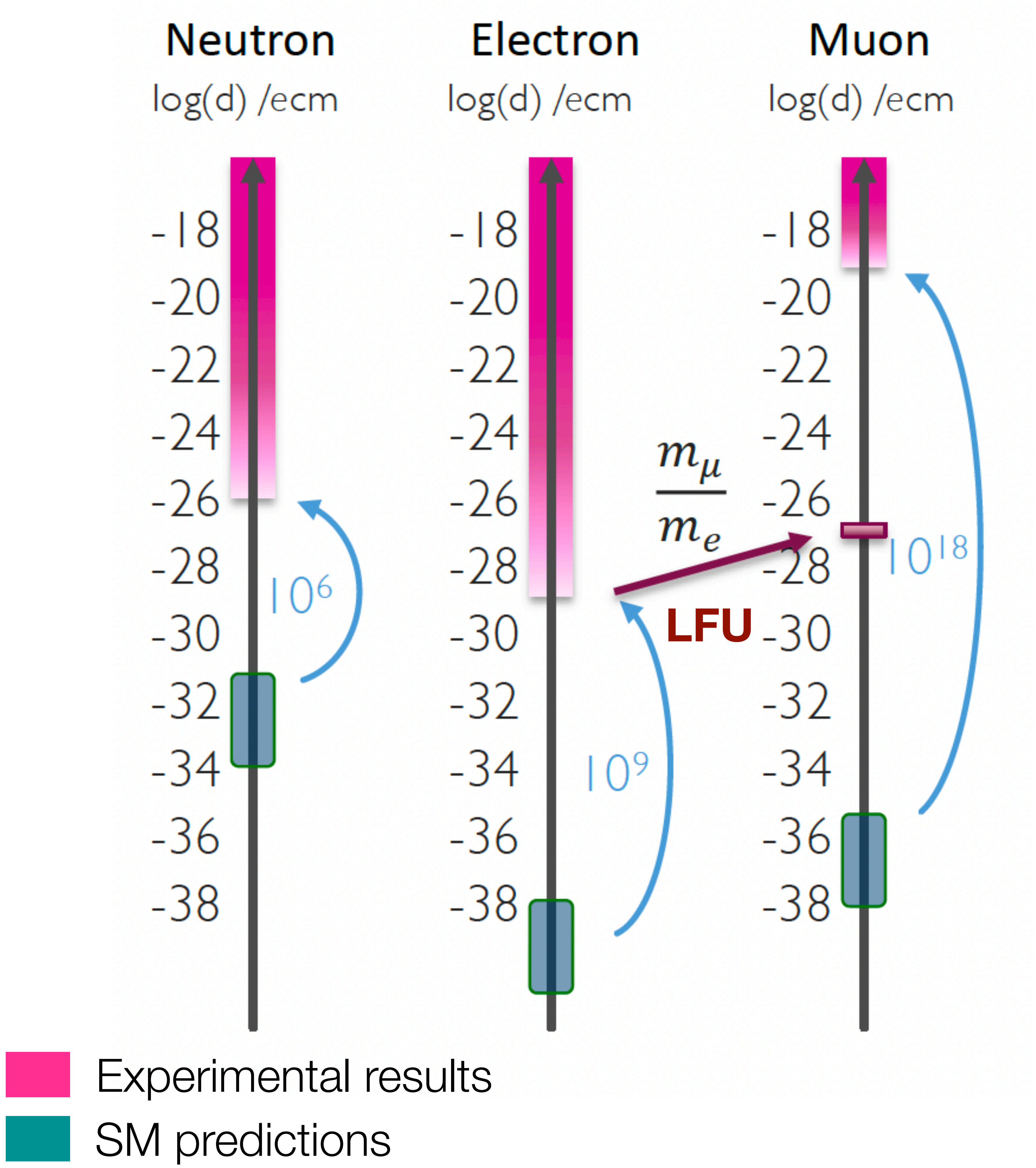
Hamiltonian EDM term is CP violating

SM Prediction: $d_\mu^{SM} = 1.4 \times 10^{-38}\, e\,.\mathrm{cm}$ (Yamaguchi & Yamanaka, 2020)

$d_e \le 1.1\times 10^{-29} e\,.\mathrm{cm} \overset{LFU}{\Longrightarrow}$? $d_\mu \le \frac{m_\mu}{m_e} d_e = 1.6 \times 10^{-27} e\,.\mathrm{cm}$



muEDM direct search: Why now?



- FNAL/JPARC g-2 experiments aims at $d_\mu \sim O(10^{-21})$ *e*cm (via g-2)
- **Direct muEDM search at PSI in stages:**
  - **Precursors: $d_\mu < 3\times10^{-21}$ *e*cm**
  - **Final: $d_\mu < 6\times10^{-23}$ *e*cm**

The frozen-spin technique for the EDM measurement: A closer look

$$\vec{\omega} = \frac{q}{m}\left[a\vec{B} - \left(a + \frac{1}{1-\gamma^2}\right)\frac{\vec{\beta}\times\vec{E}}{c}\right] + \frac{q}{m}\frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)$$

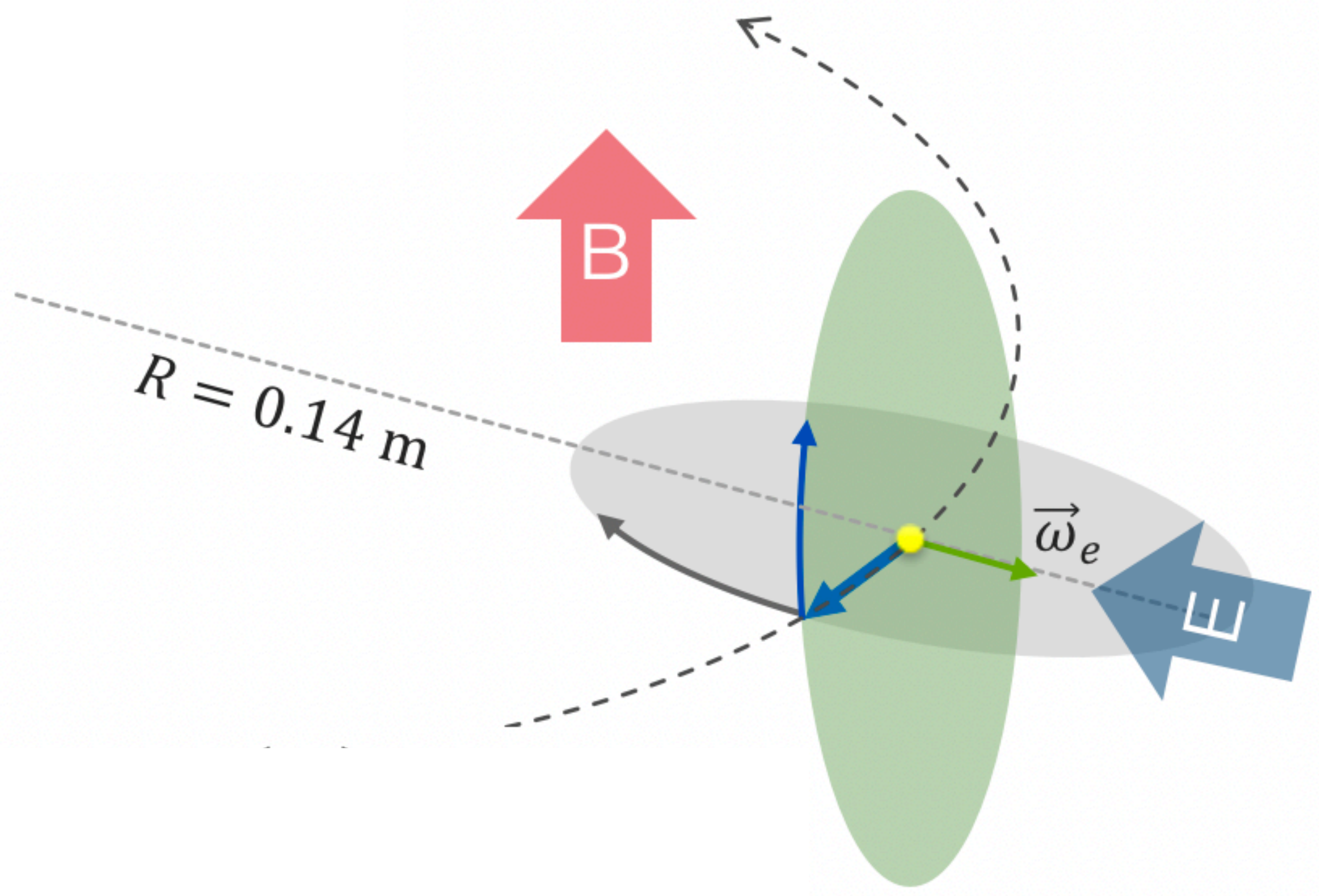
ω_a ω_e

- The frozen-spin technique uses an Electric field perpendicular to the moving particle and magnetic field, fulfilling the condition:

$$a\vec{B} = \left(a - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}_f}{c}$$

- **Without EDM**, $\omega = 0$, the spin follows the momentum vector as for an ideal Dirac spin-1/2 particle, while **with EDM** it will result in a precession of the spin with $\omega_e \parallel E$

- The sensitivity to a muon EDM is given by the asymmetry up/down of the positron from the muon decay



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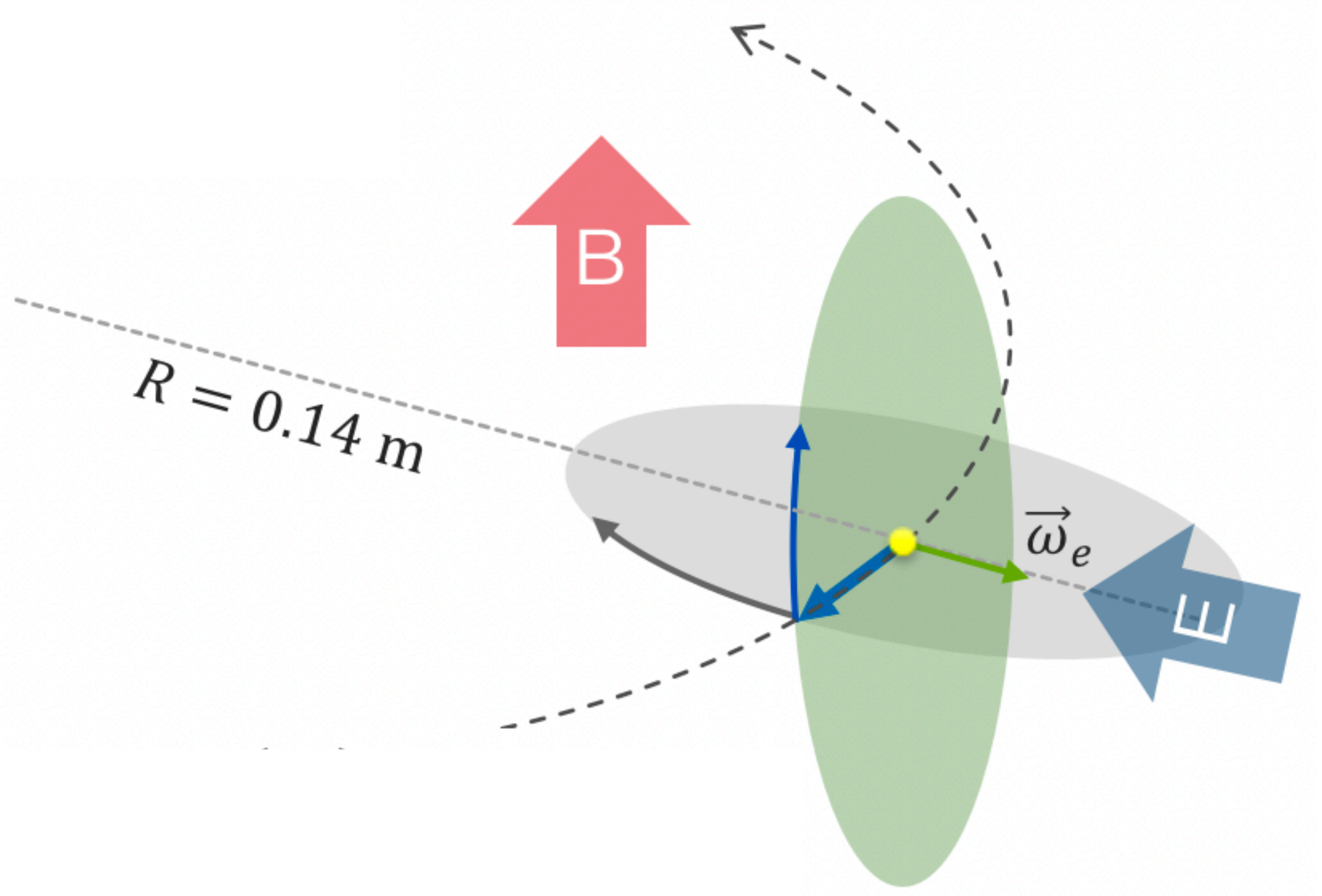
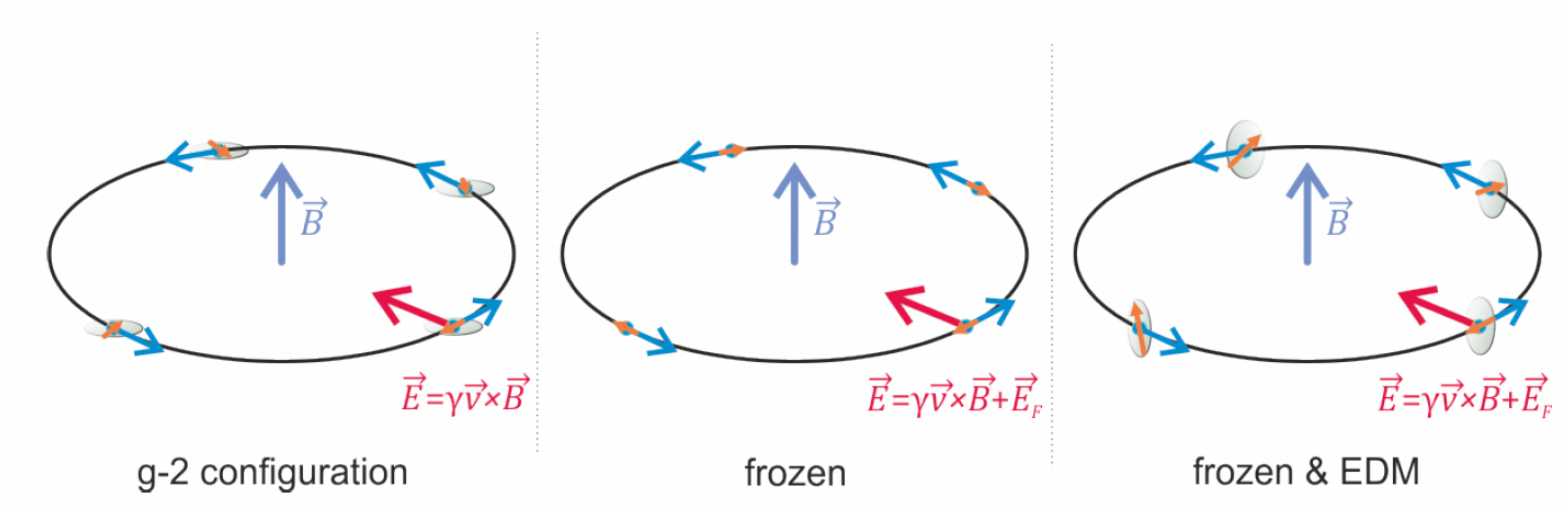


EDM: From the “frequency” approach to the frozen-spin technique

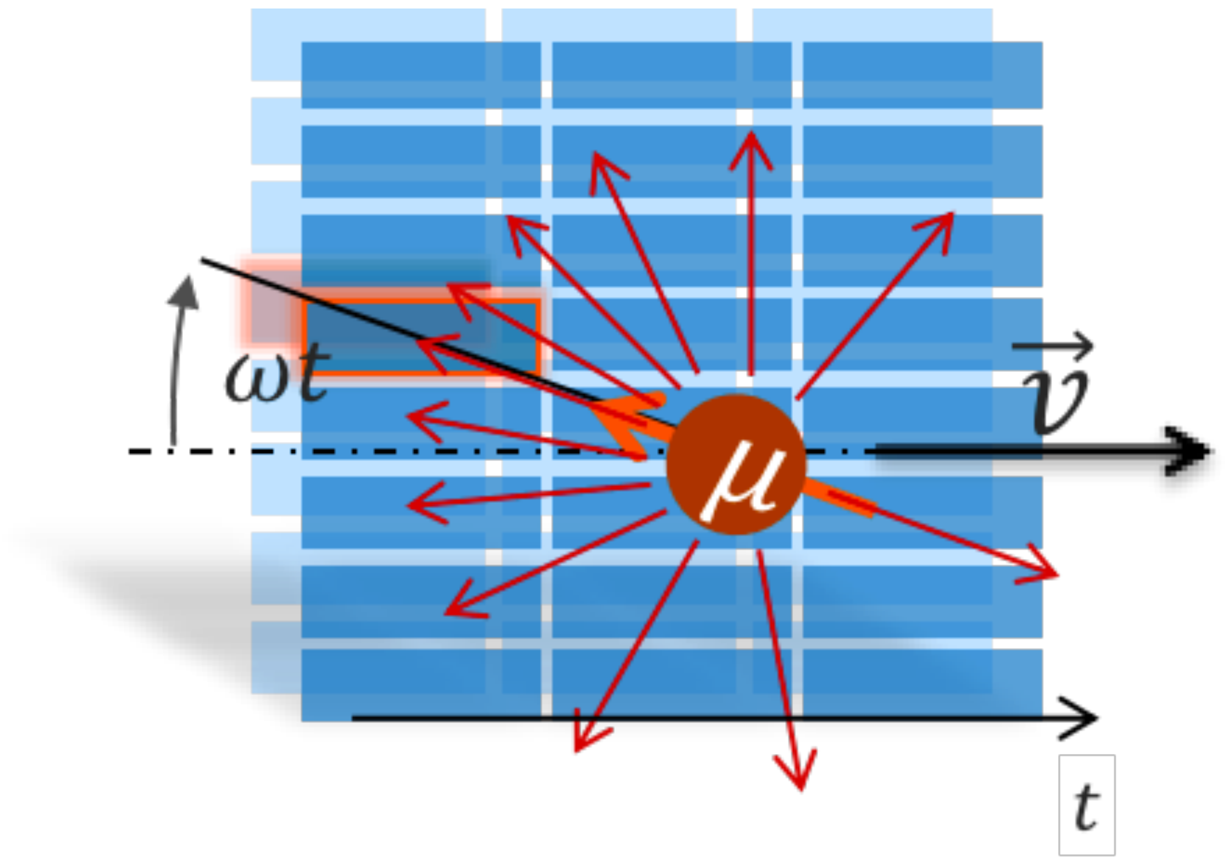
- Putting everything together, here a summary:

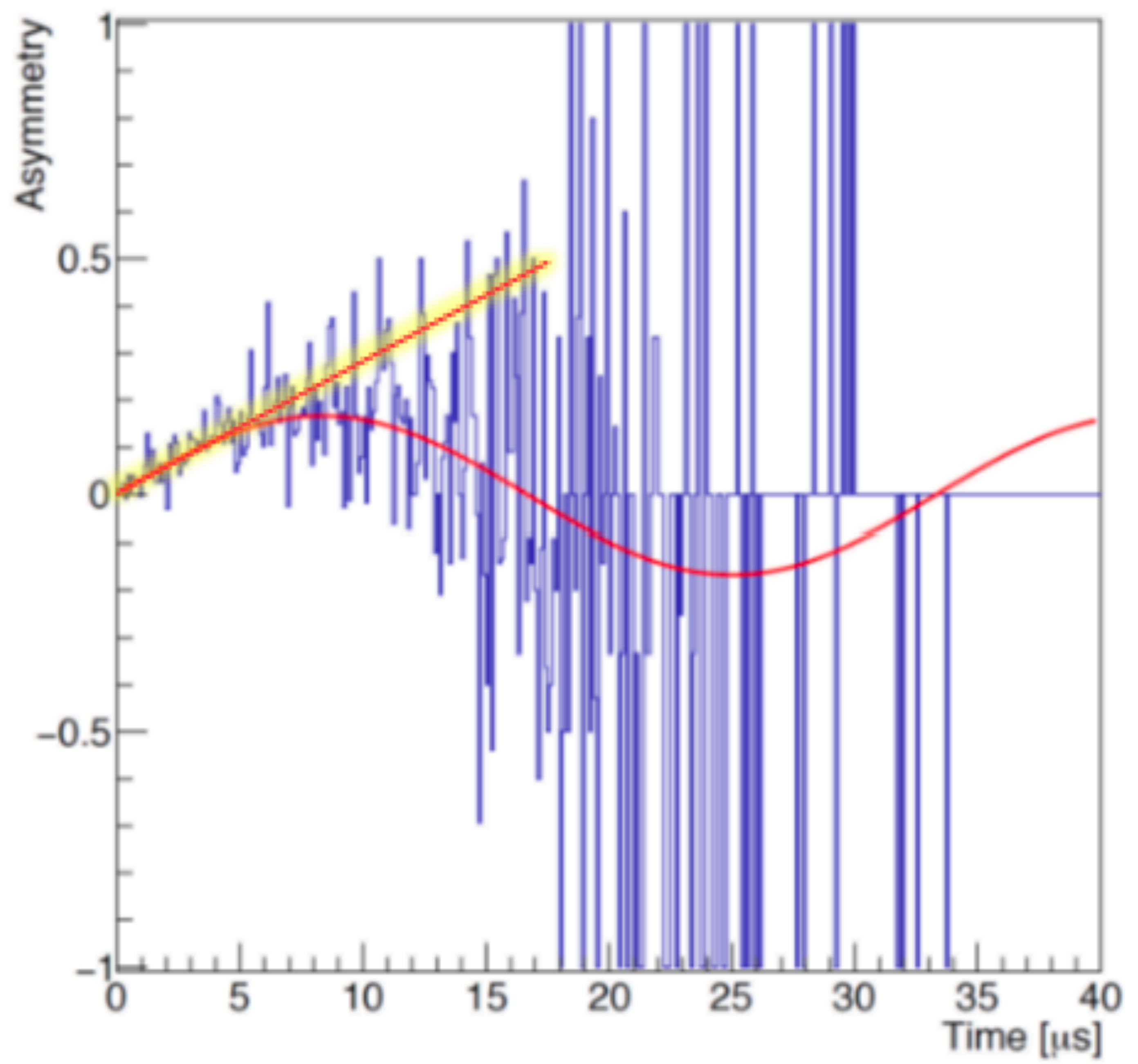


Signal: asymmetry up/down positron tracks

- The sensitivity to a muon EDM is given by the asymmetry up/down of the positron from the muon decay
- Positron are emitted predominantly along the muon spin direction

$$A(t) = \frac{N_\uparrow(t) - N_\downarrow(t)}{N_\uparrow(t) + N_\downarrow(t)} = \alpha p \sin\left(\frac{2d_\mu}{\hbar} t\right) \approx \alpha p \frac{2d_\mu}{\hbar} t$$





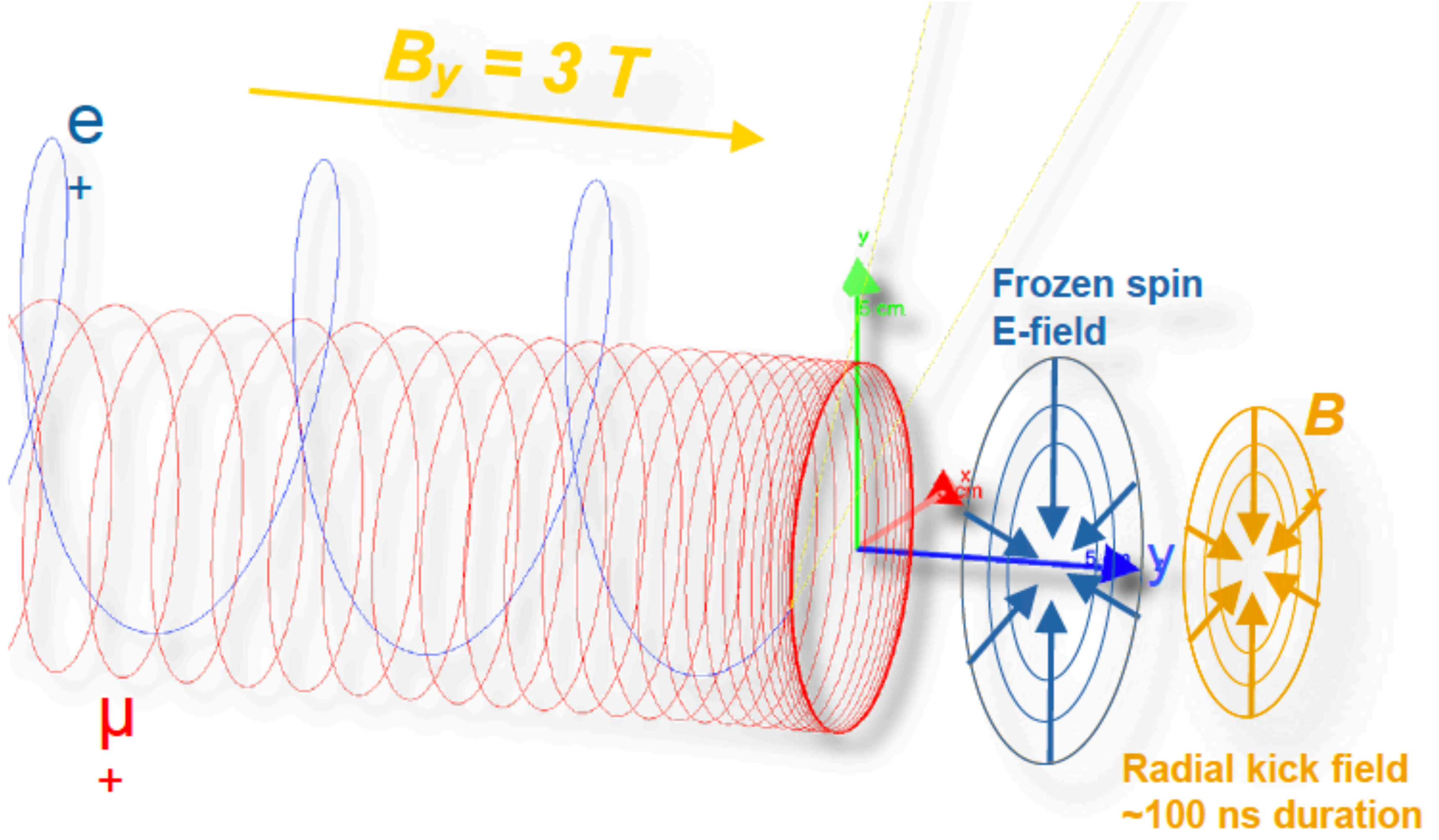
The slope gives the sensitivity of the measurement:

$$\sigma(d_\mu) = \frac{\hbar \gamma^2 a_\mu}{2 p E_f \sqrt{N}\, \gamma \tau_\mu\, \alpha}$$

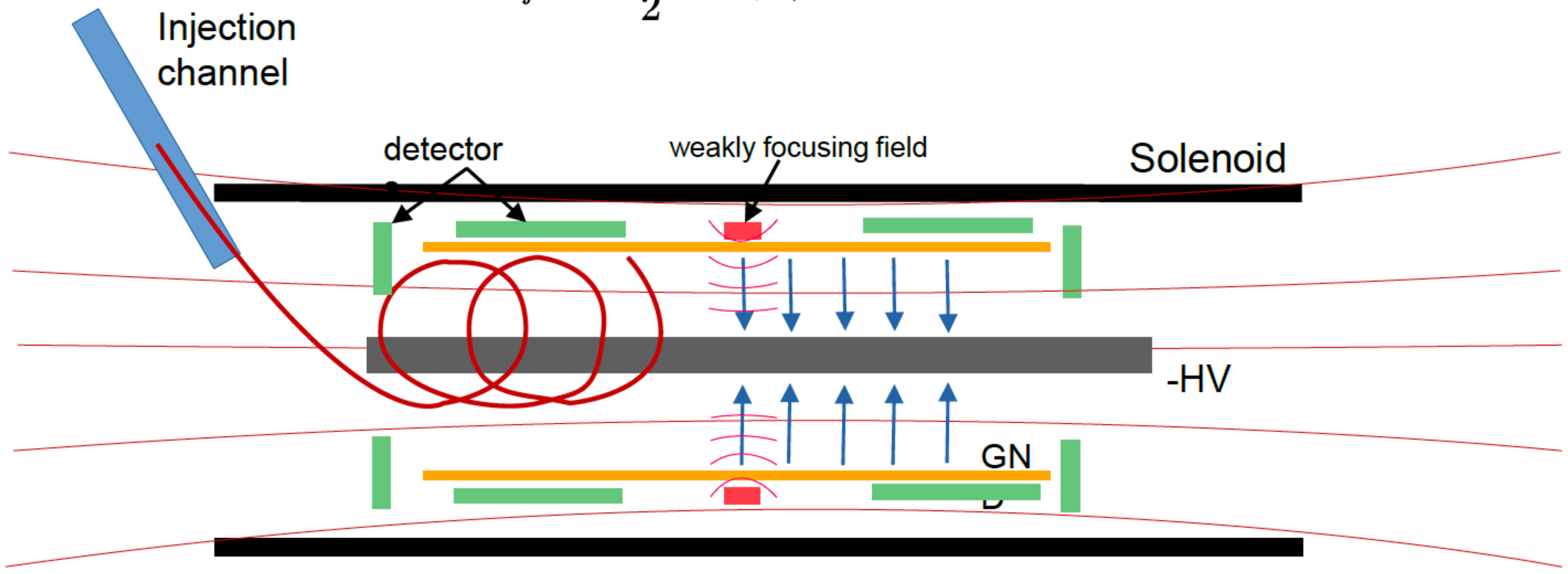
p := initial polarization
E_f := Electric field in lab
$\sqrt{N}$:= number of positrons
τ_μ := lifetime of muon
α := mean decay asymmetry

The general experimental idea

- Muons enter the uniform magnetic field
- A radial magnetic field pulse stops them within a weakly focusing field where they are stored
- Radial electric field ‘freezes’ the spin so that the precession due to the MDM is cancelled

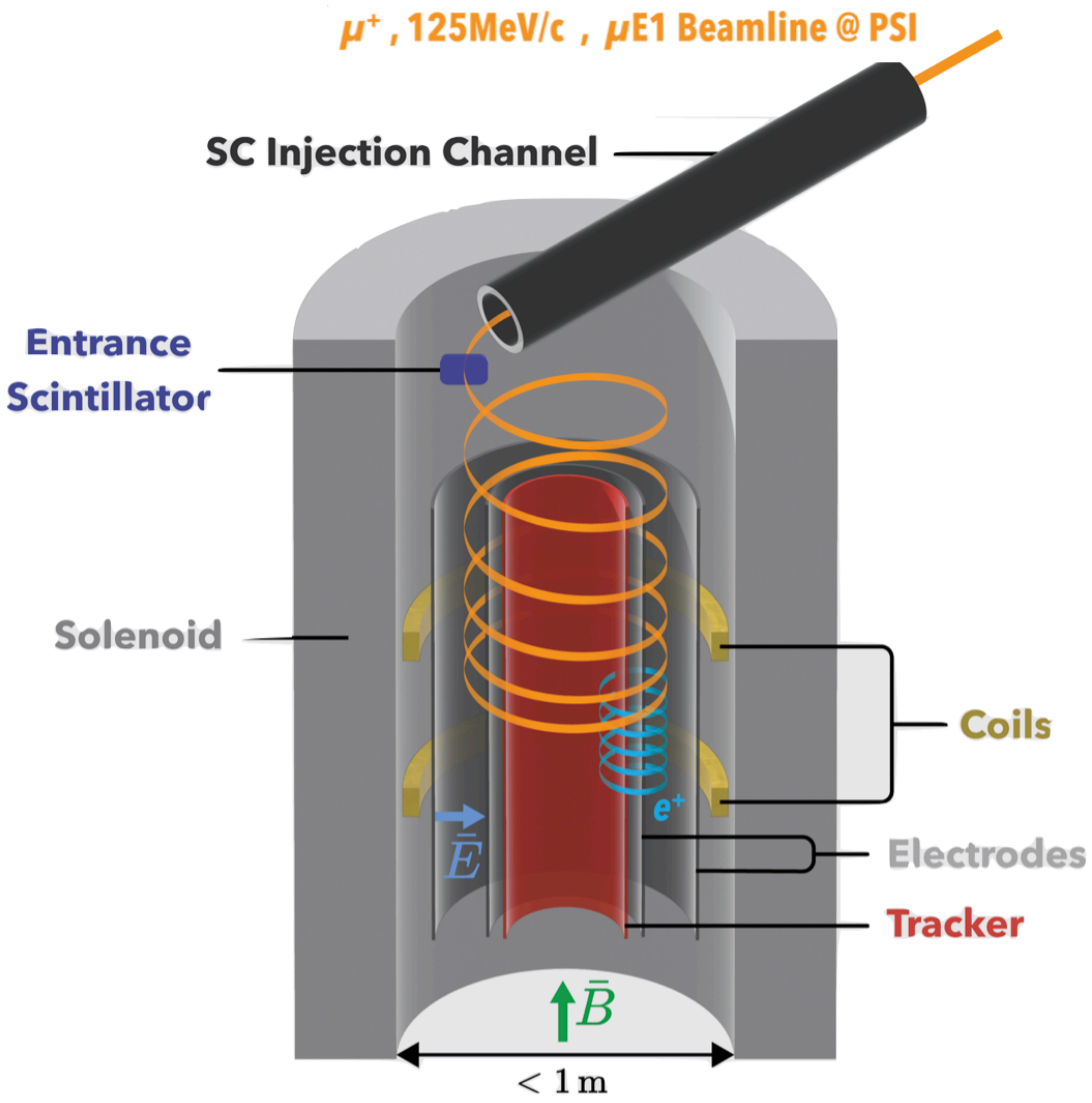


$$E_f \approx \frac{g-2}{2} B c \beta \gamma^2$$



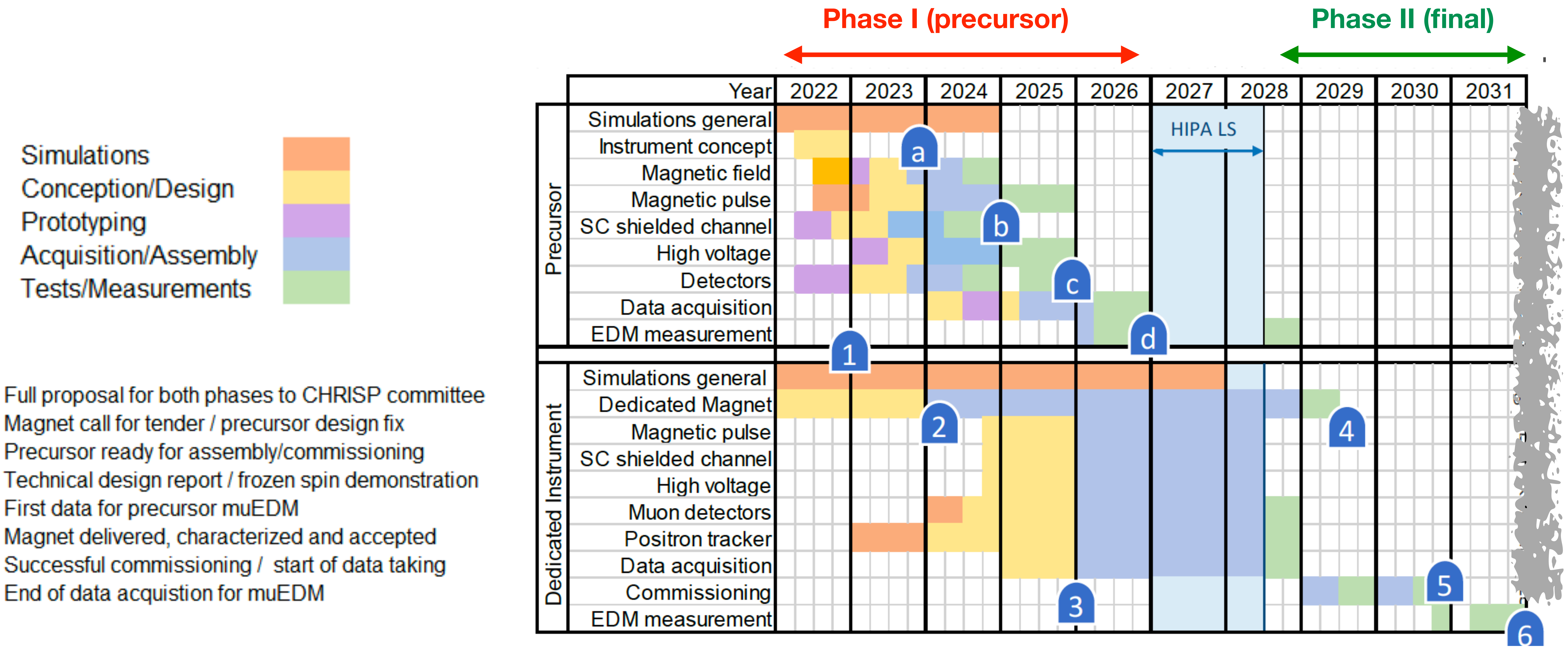
The muEDM experiment: The measurement principle in a nutshell

- The muEDM experiment at PSI aims at a **direct** muon EDM search with a sensitivity of $d_\mu < 3\times10^{-21}\, e\mathrm{cm}$ (Phase I) and $d_\mu < 6\times10^{-23}\, e\mathrm{cm}$ (Phase II)
- The muEDM signature is the asymmetry of the e^+ from the muon decay in presence of a specific configuration of electric and magnetic fields



- μ^+ from Pion–decay → high polarization $p \approx 95\%$
- Injection through superconducting channel
- Fast scintillator triggers pulse
- Magnetic pulse stops longitudinal motion of μ^+
- Weakly focusing field for storage
- Thin electrodes provide electric field for frozen spin
- Pixelated detectors for e^+– tracking

A tentative schedule



- **1** Full proposal for both phases to CHRISP committee
- **2/a** Magnet call for tender / precursor design fix
- **b** Precursor ready for assembly/commissioning
- **3/c** Technical design report / frozen spin demonstration
- **d** First data for precursor muEDM
- **4** Magnet delivered, characterized and accepted
- **5** Successful commissioning / start of data taking
- **6** End of data acquistion for muEDM

Phased approach

- **Phase I**
  - P = 28 MeV/c
  - PSI solenoid
  - Bore diam = 200 mm, Length = 1000 mm
  - Field measured in 2022 & found suitable for injection
- **Phase II**
  - P = 125 MeV/c
  - Argonne solenoid ?
  - Bore diam = 900 mm
  - Better spatial and temporal stability

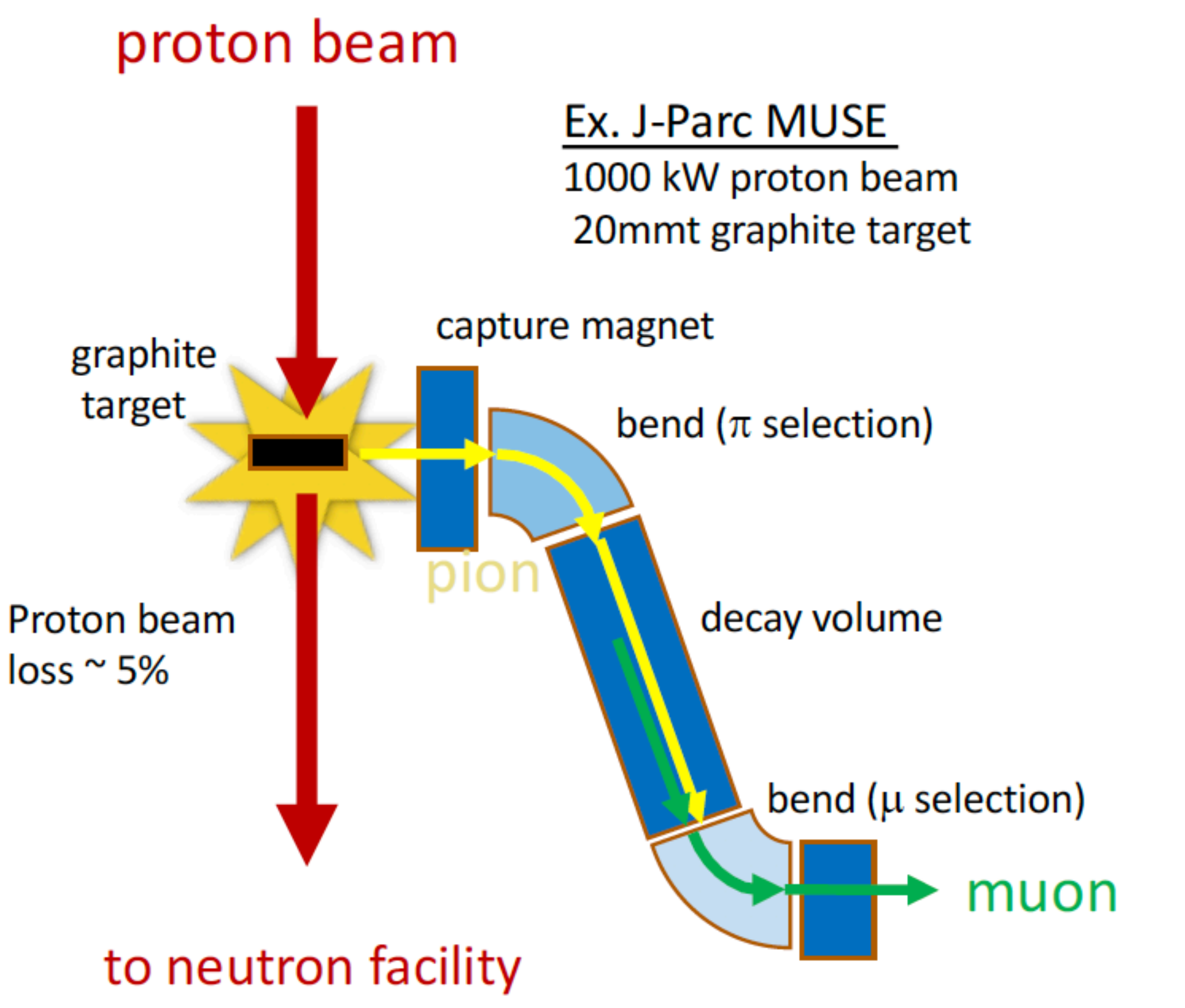
	Phase I	Phase II
	πE1	μE1
Muon flux (μ^+/s)	4×10^6	1.2×10^8
Channel transmission	0.03	0.005
Injection efficiency	0.017	0.60
Muon storage rate (1/s)	2×10^3	360×10^3
Gamma factor γ	1.04	1.56
e^+ detection rate (1/s)	500	90×10^3
Detections per 200 days	8.64×10^9	1.5×10^{12}
Mean decay asymmetry A	0.3	0.3
Initial polarization P_0	0.95	0.95
Sensitivity in one year ($e\cdot$cm)	$<3 \times 10^{-21}$	$< 6 \times 10^{-23}$

Content

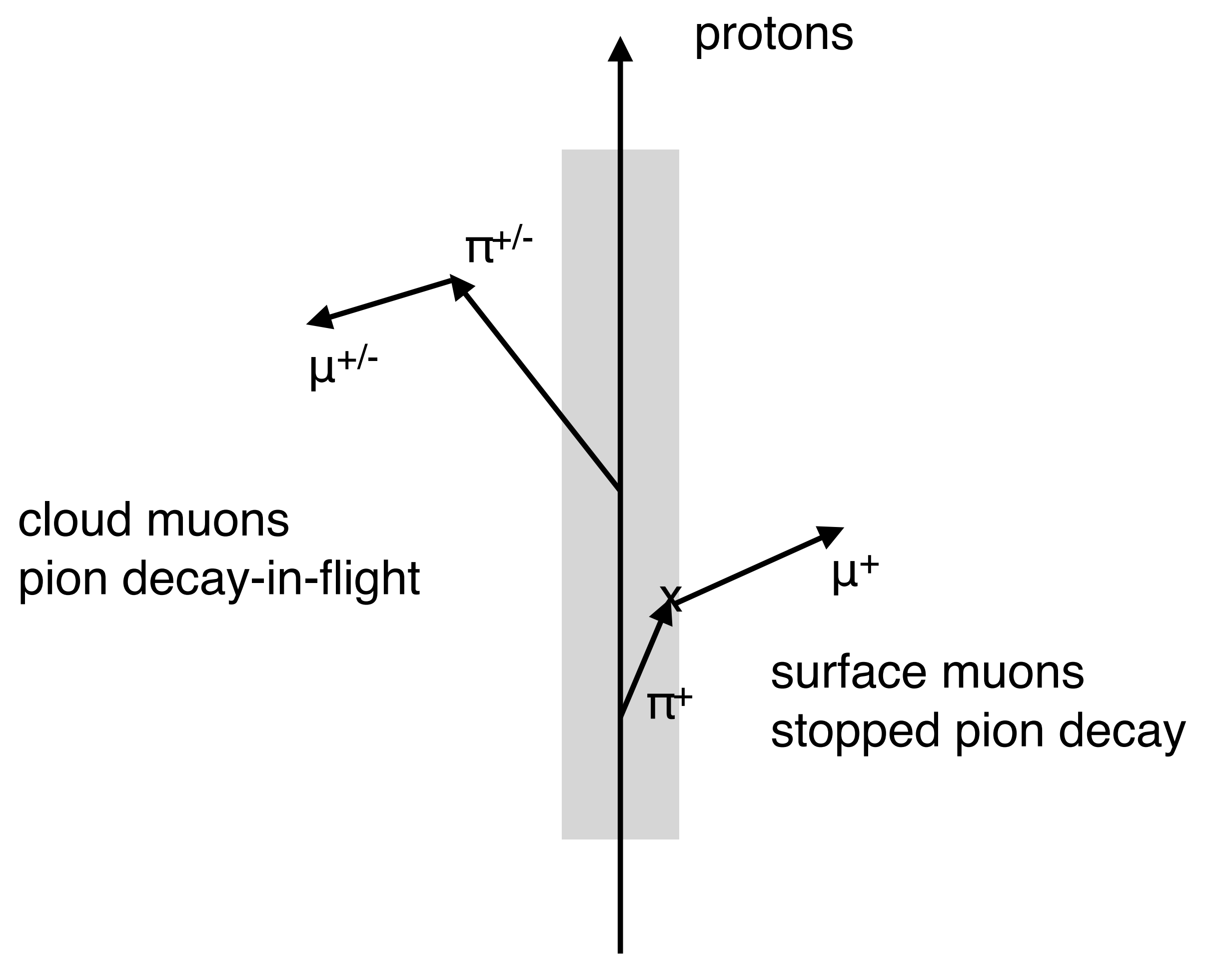
- The MEGII experiment
- The muEDM experiment
- Future beamline developments:
  - **The HiMB project**
  - The muCool project

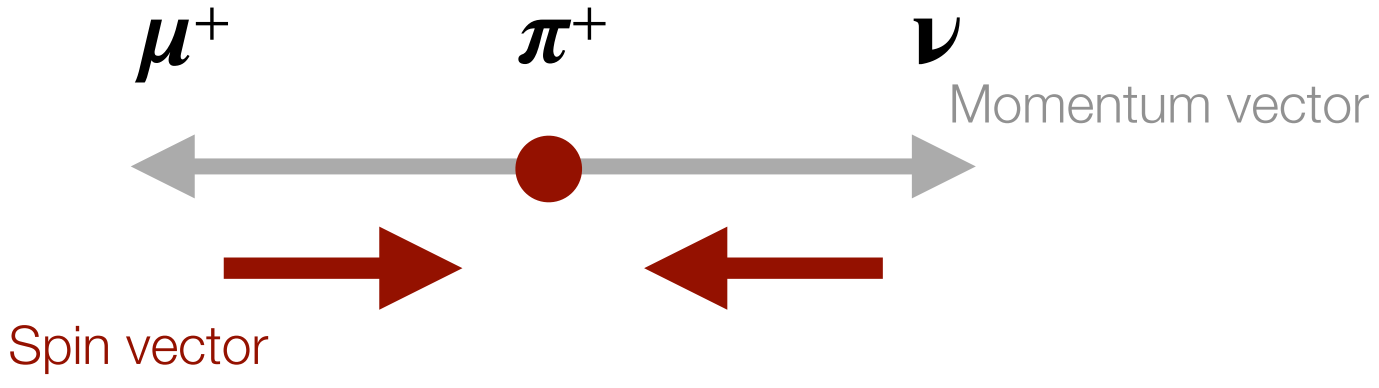
PSI's muon beams

Conventional muon beamline



- Thin target (~ 20mmt)
- Small solid angle
- Separate pion and muon momentum selection (obtain highly polarized muon beam)

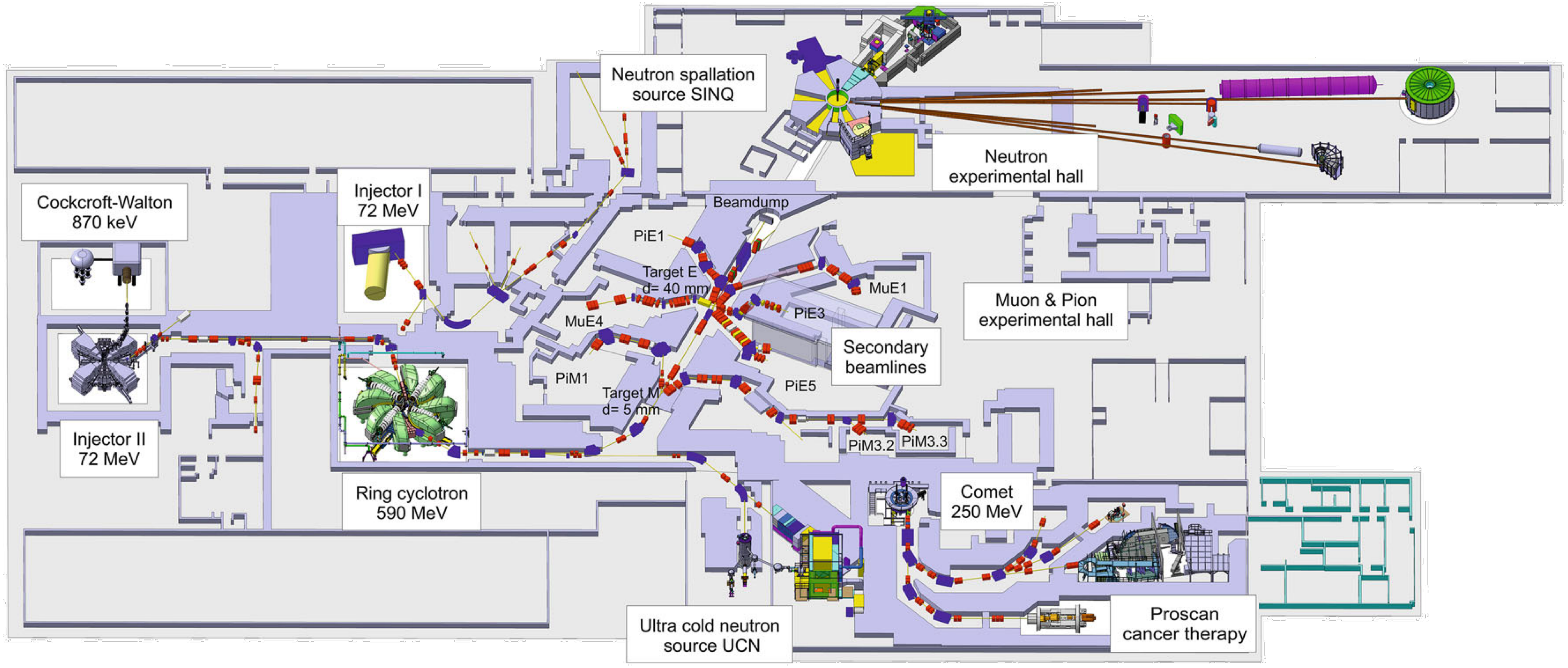




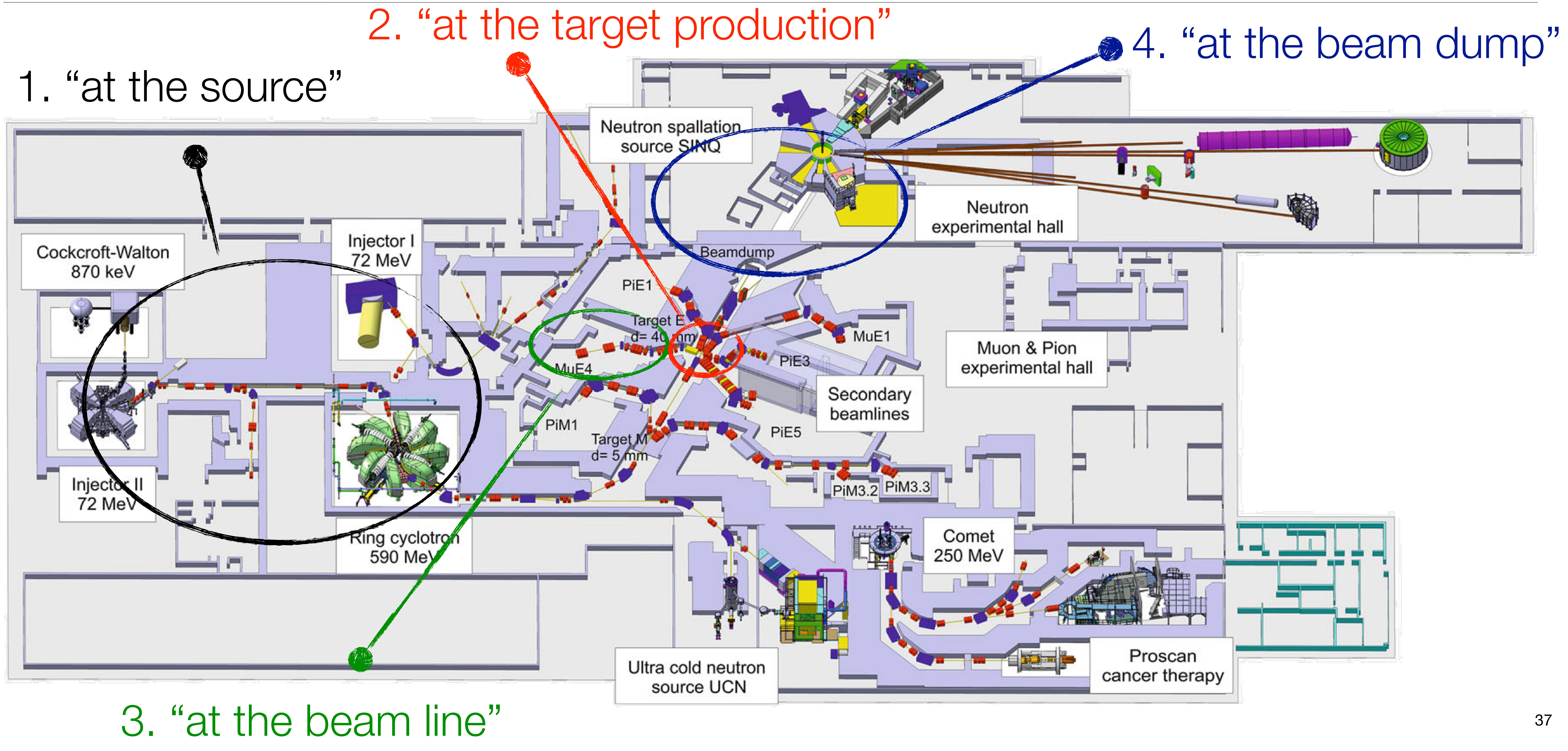
- Muon beams: **secondary** beam lines
- Low-energy muon beam lines typically tuned to surface-μ^+ at ~ 28 MeV/c
- **Note:** surface-μ —> polarised positively charged muons (spin antiparallel to the momentum)
- Contribution from cloud muons at similar momentum about 100x smaller
- Negative muons only available as cloud muons

How the beam intensity can be increased…

How the beam intensity can be increased…



How the beam intensity can be increased…

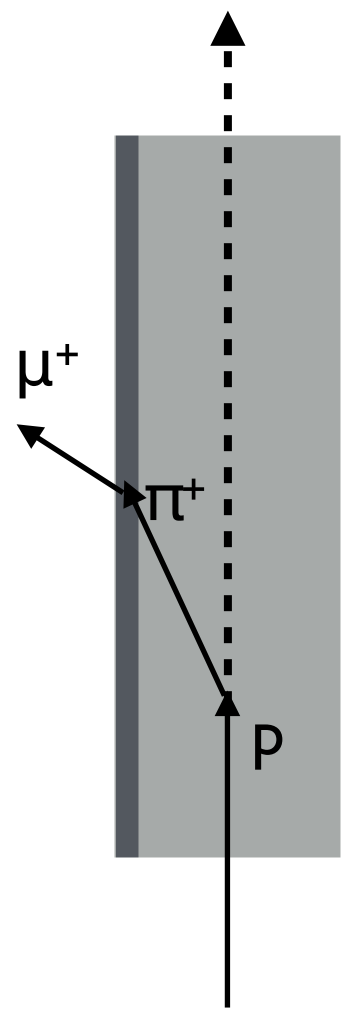


How the beam intensity can be increased…

Always looking for —> Relative “simple”, “easy”, “fast” and “cheap” solutions

At the target:

- Optimised Target: **Alternative materials** and/or different geometry
  - Search for high pion yield materials -> higher muon yield
  - Either increasing the surface volume (surface area times acceptance depth) or the pion stop density near the surface

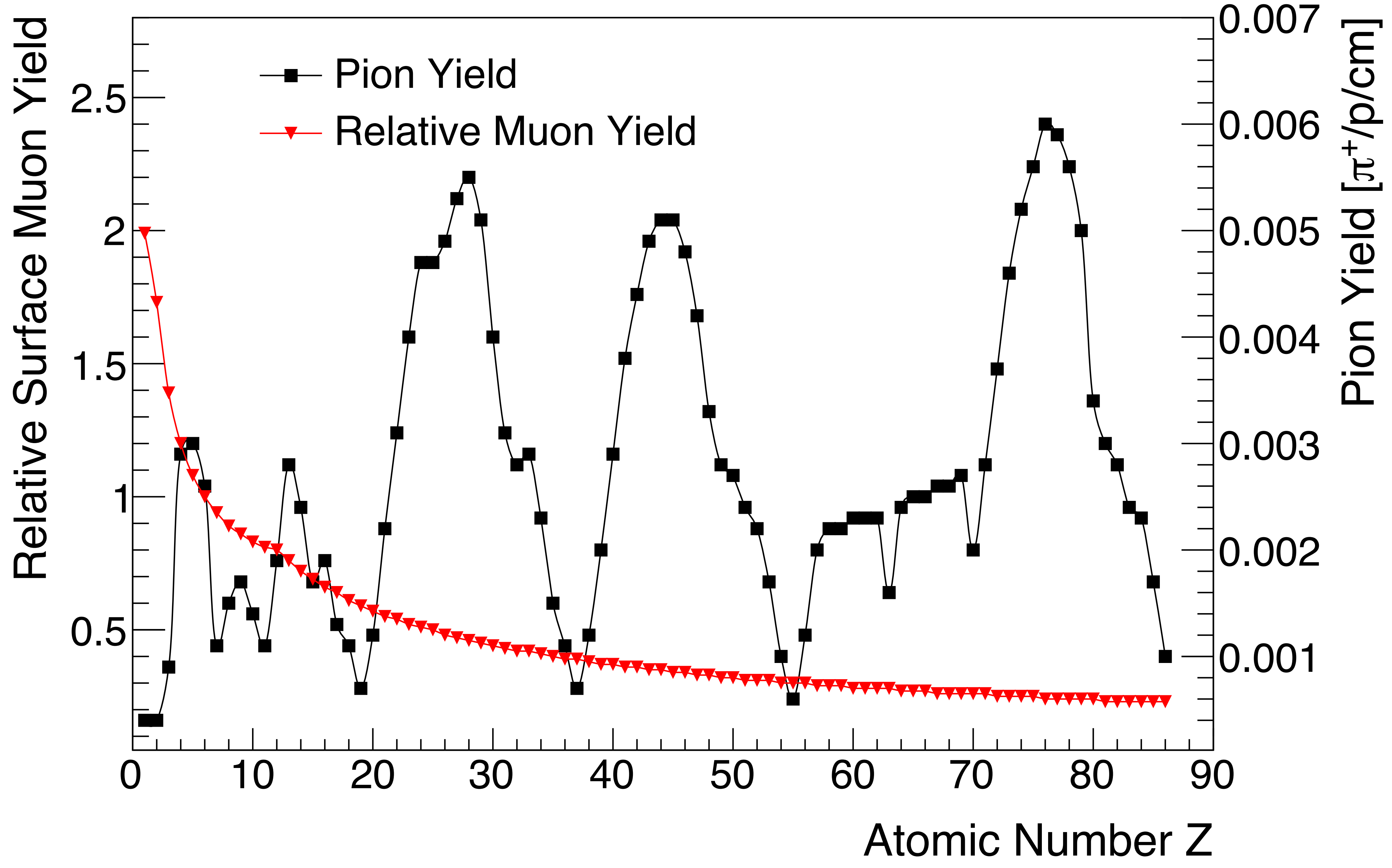


$$\text{relative } \mu^+ \text{yield} \propto \pi^+ \text{stop density} \cdot \mu^+ \text{Range} \cdot \text{length}$$

$$\propto n \cdot \sigma_{\pi^+} \cdot SP_{\pi^+} \cdot \frac{1}{SP_{\mu^+}} \cdot \frac{\rho_C (6/12)_C}{\rho_x (Z/A)_x}$$

$$\propto Z^{1/3} \cdot Z \cdot \frac{1}{Z} \cdot \frac{1}{Z}$$

$$\propto \frac{1}{Z^{2/3}}$$

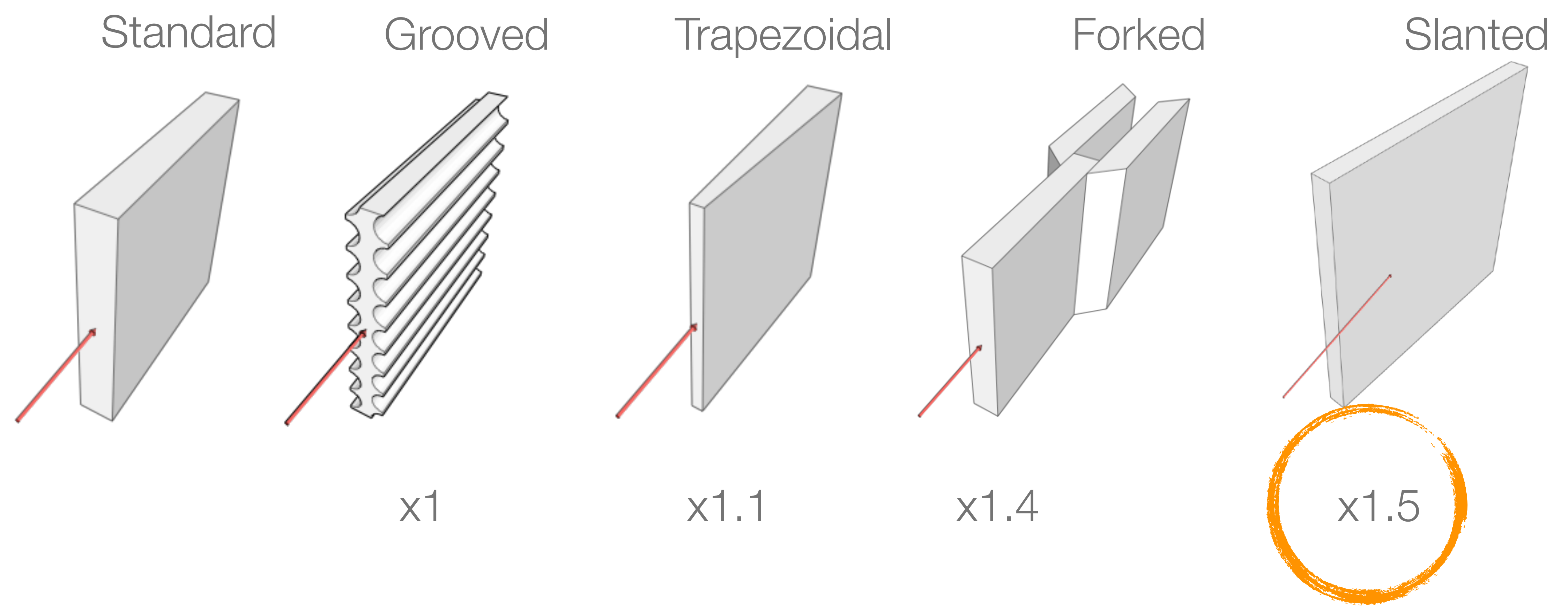


At the target:

- Optimised Target: Alternative materials and/or **different geometry**
  - Search for high pion yield materials -> higher muon yield
  - Either increasing the surface volume (surface area times acceptance depth) or the pion stop density near the surface

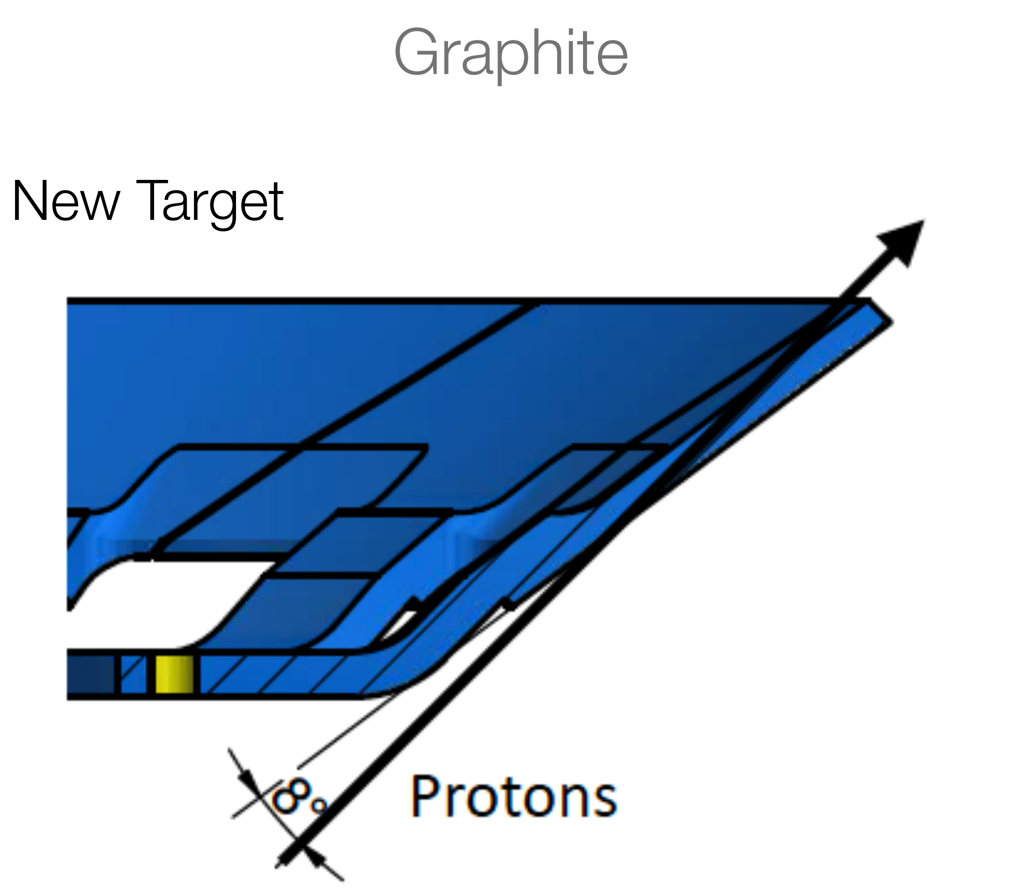
- Several materials have pion yields > 2x Carbon
- Relative muon yield favours low-Z materials, but difficult to construct as a target
- B_4C and Be_2C show 10-15% gain

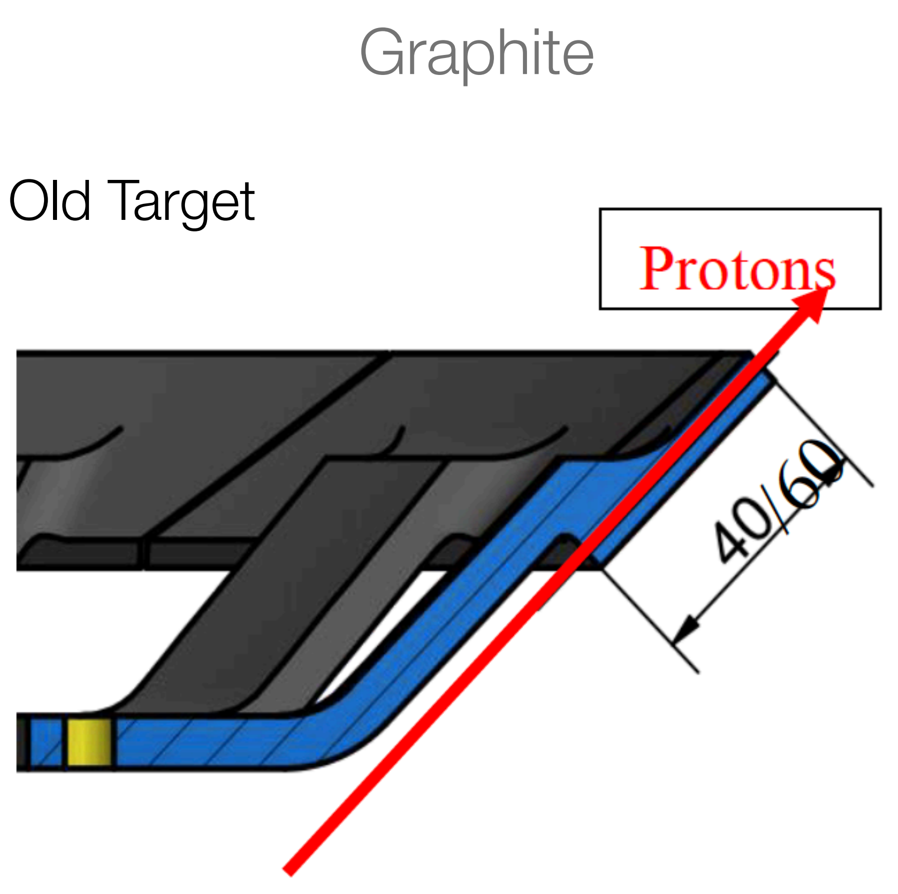
Note: Each geometry was required to preserve, as best as possible, the proton beam characteristics down-stream of the target station (spallation neutron source requirement)

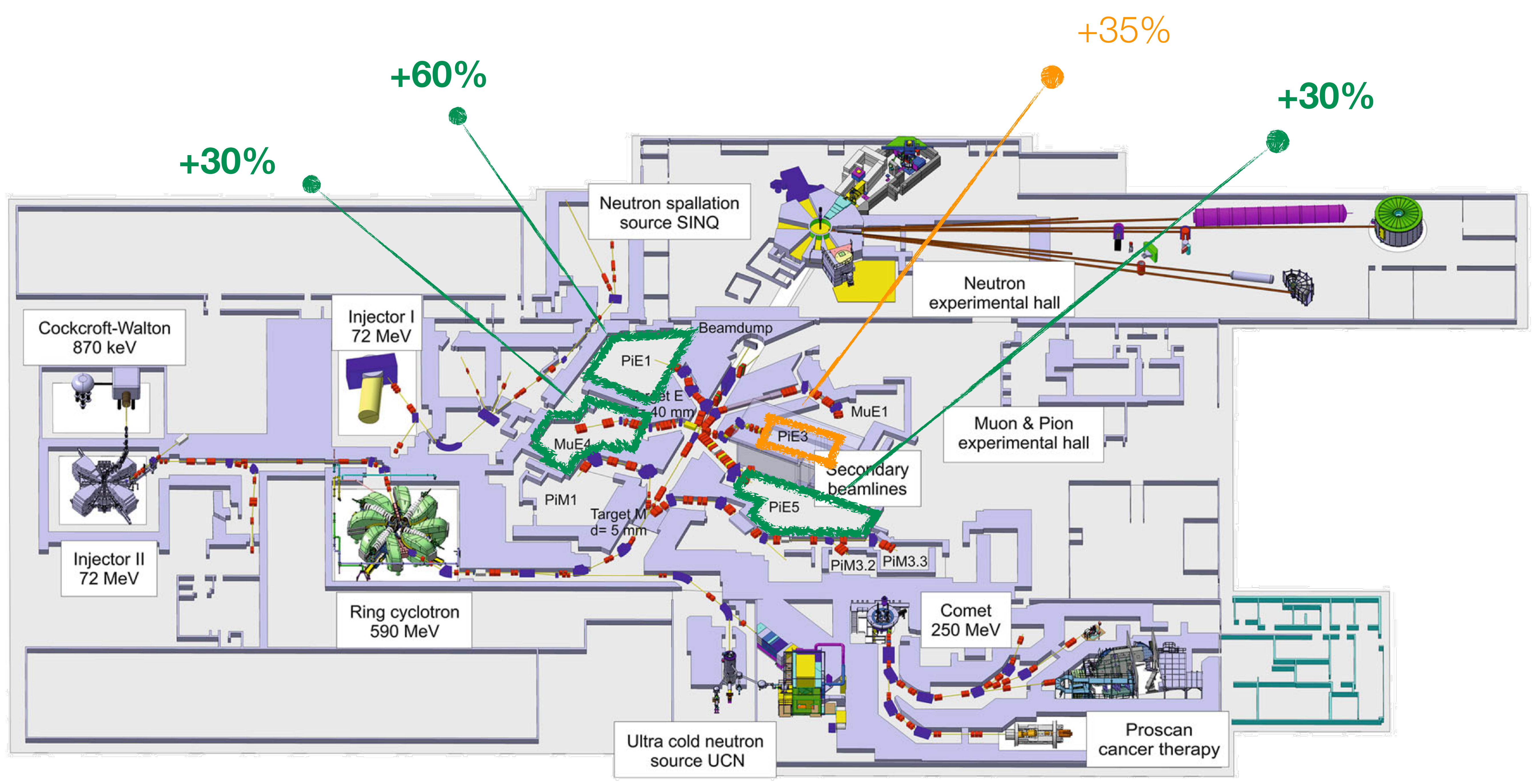


Slanted target: First test at the end of 2019

- Expect 30-60 % enhancement
- Measurements performed in three directions (forward / backward / sideways direction)
- **Increased muon yield CONFIRMED**
- **Target E as slanted target configuration since second part of 2020**

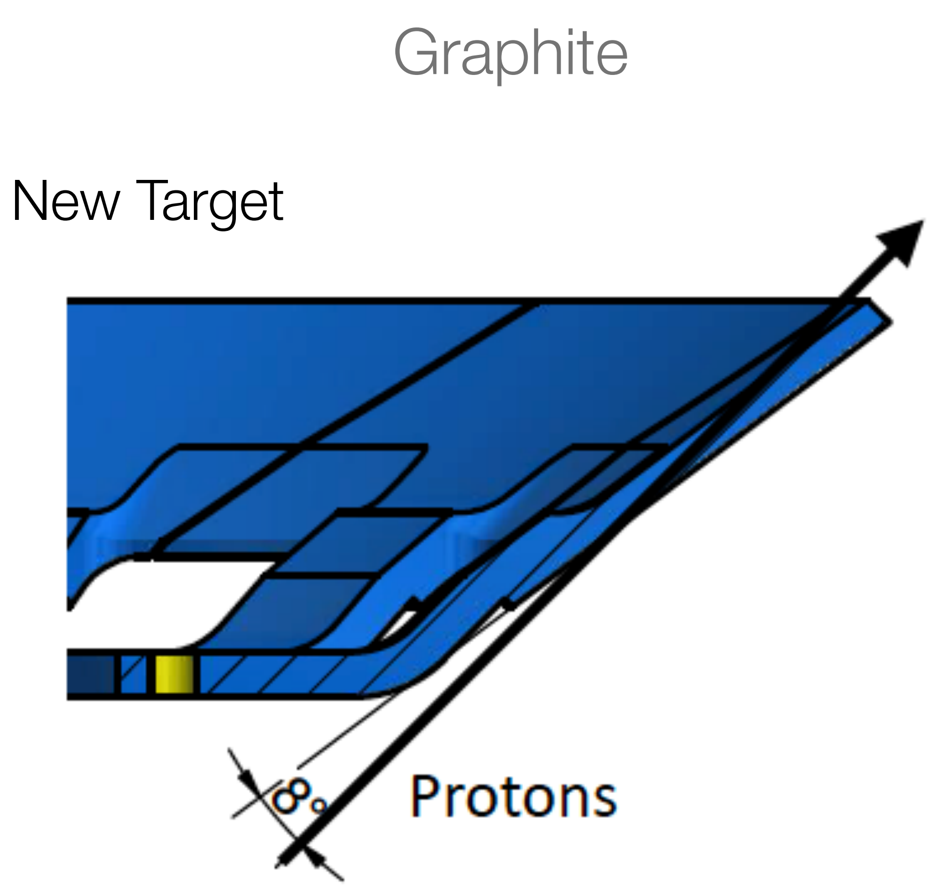


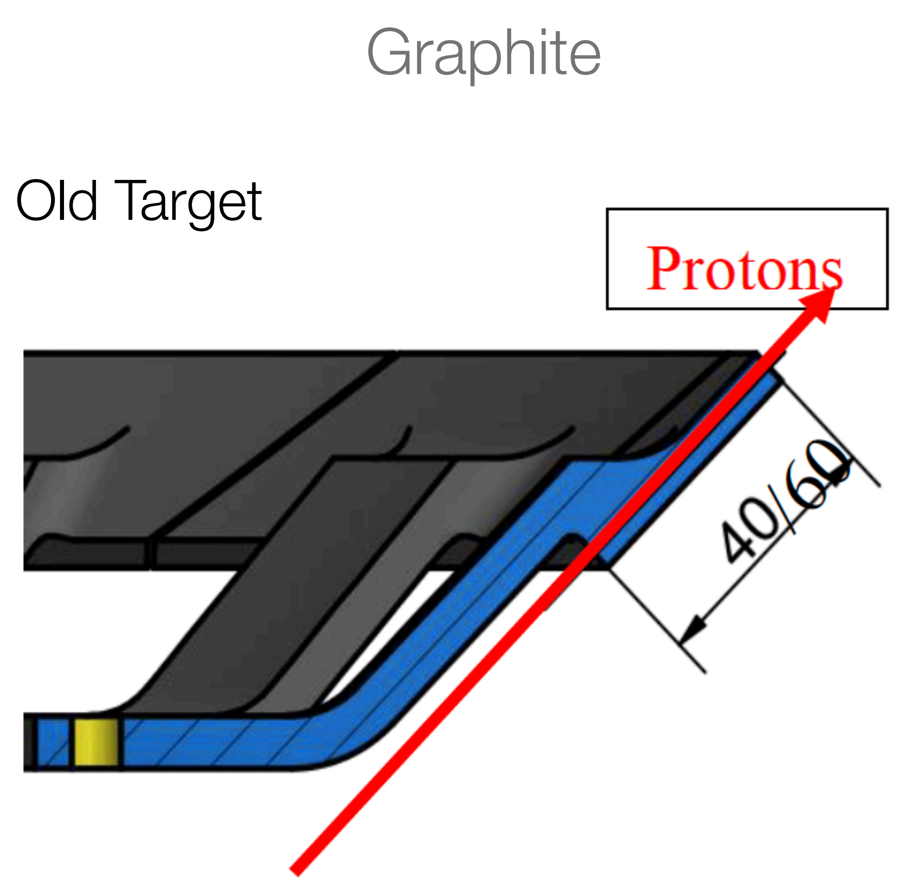


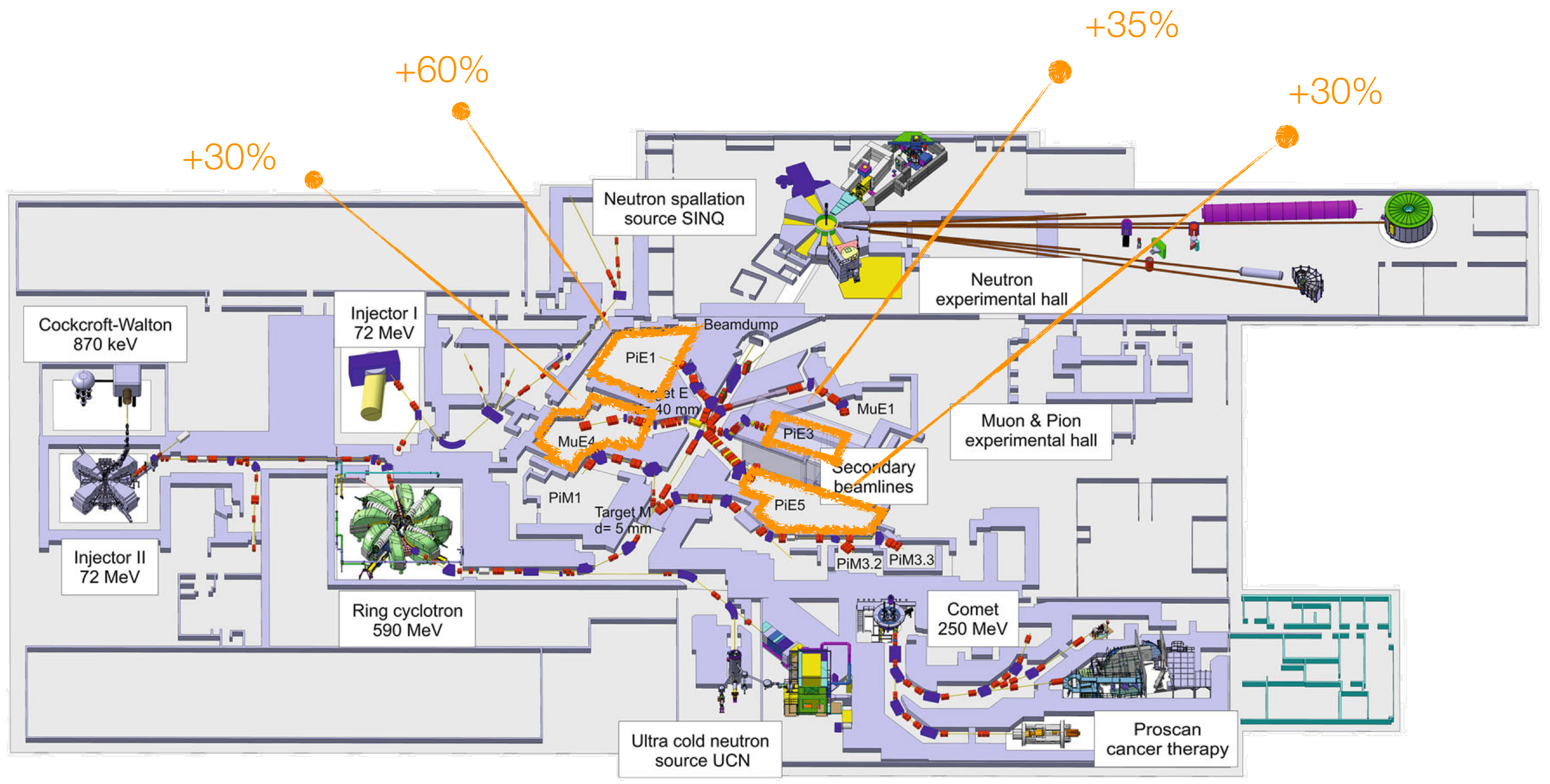


Slanted target: Impact

- Impact of the optimised target:
  - Put into perspective the target optimisation only, corresponding to **50%** of muon beam intensity gain, would corresponds to effectively raising the proton beam power at PSI by **650 kW**, equivalent to a beam power of almost **2 MW** without the additional complications such ad increased energy and radiation deposition into the target and its surroundings

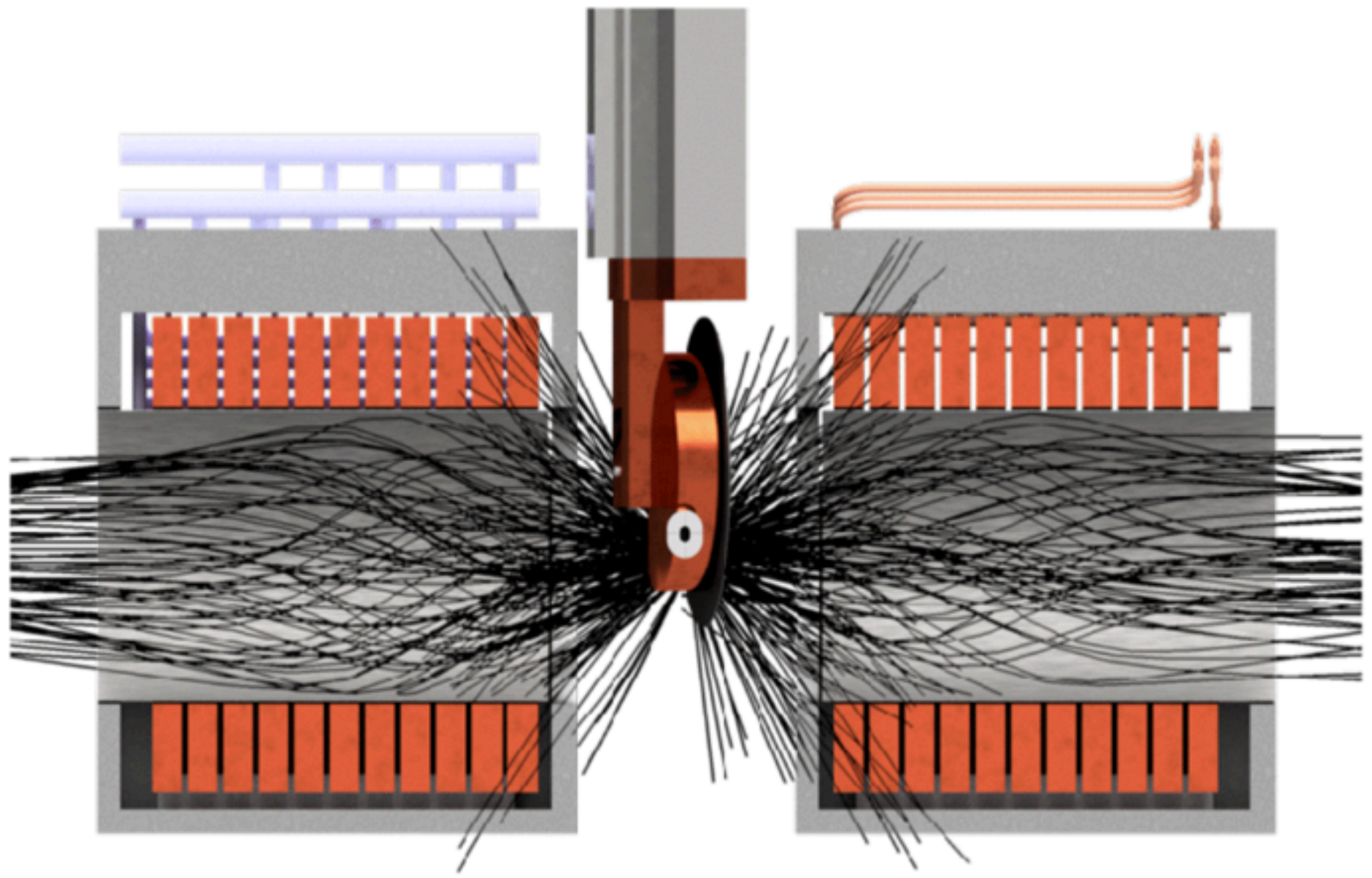


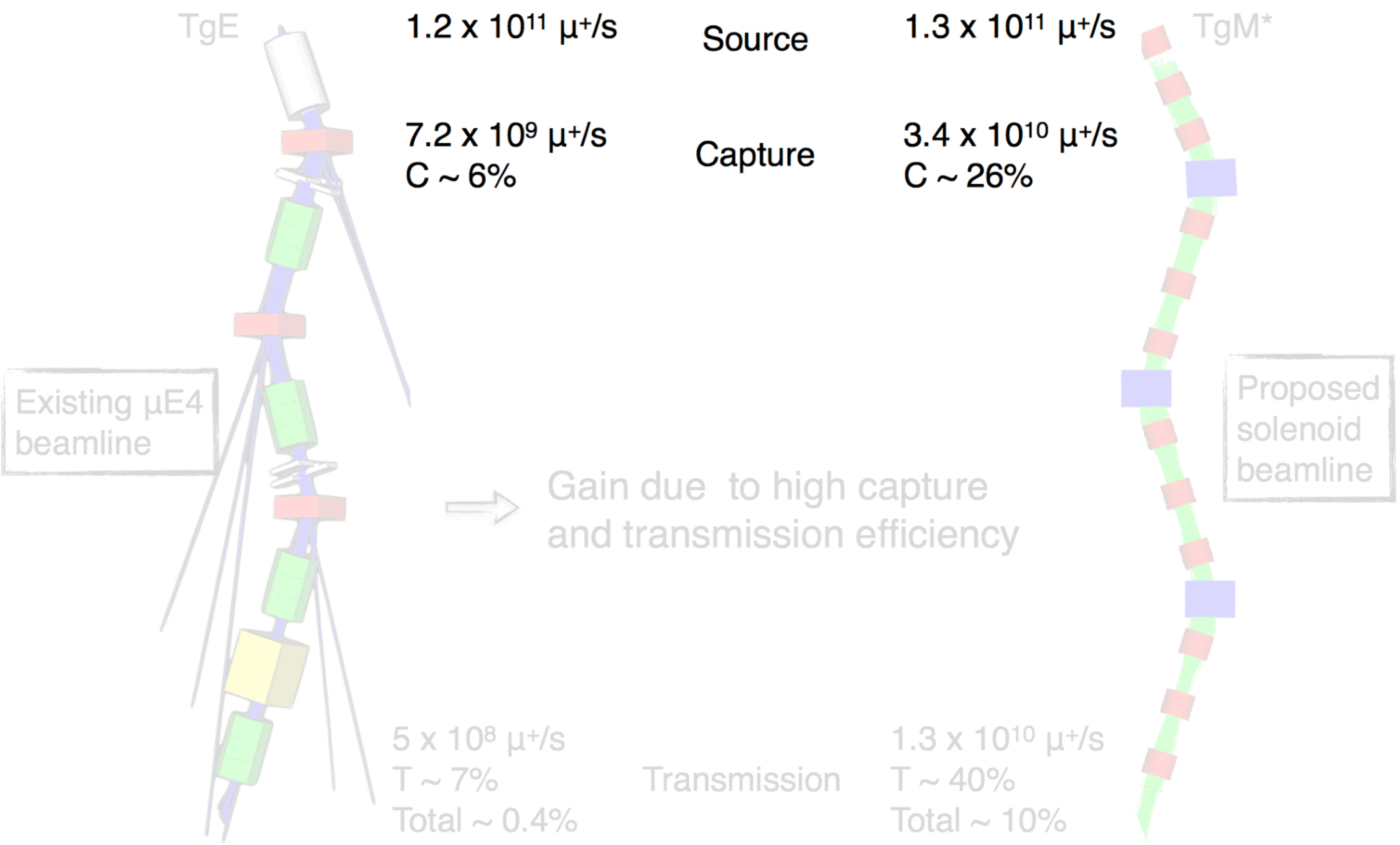




Along the beam line

- Optimised beam line: **increased capture** and transmission
  - Two normal-conducting, radiation-hard solenoids close to target to capture surface muons
    - Field at target ~0.1 T
    - Magnetic field up to 0.45 T
    - Graded field solenoid to improve the muon collection: Stronger at capture side





Along the beam line

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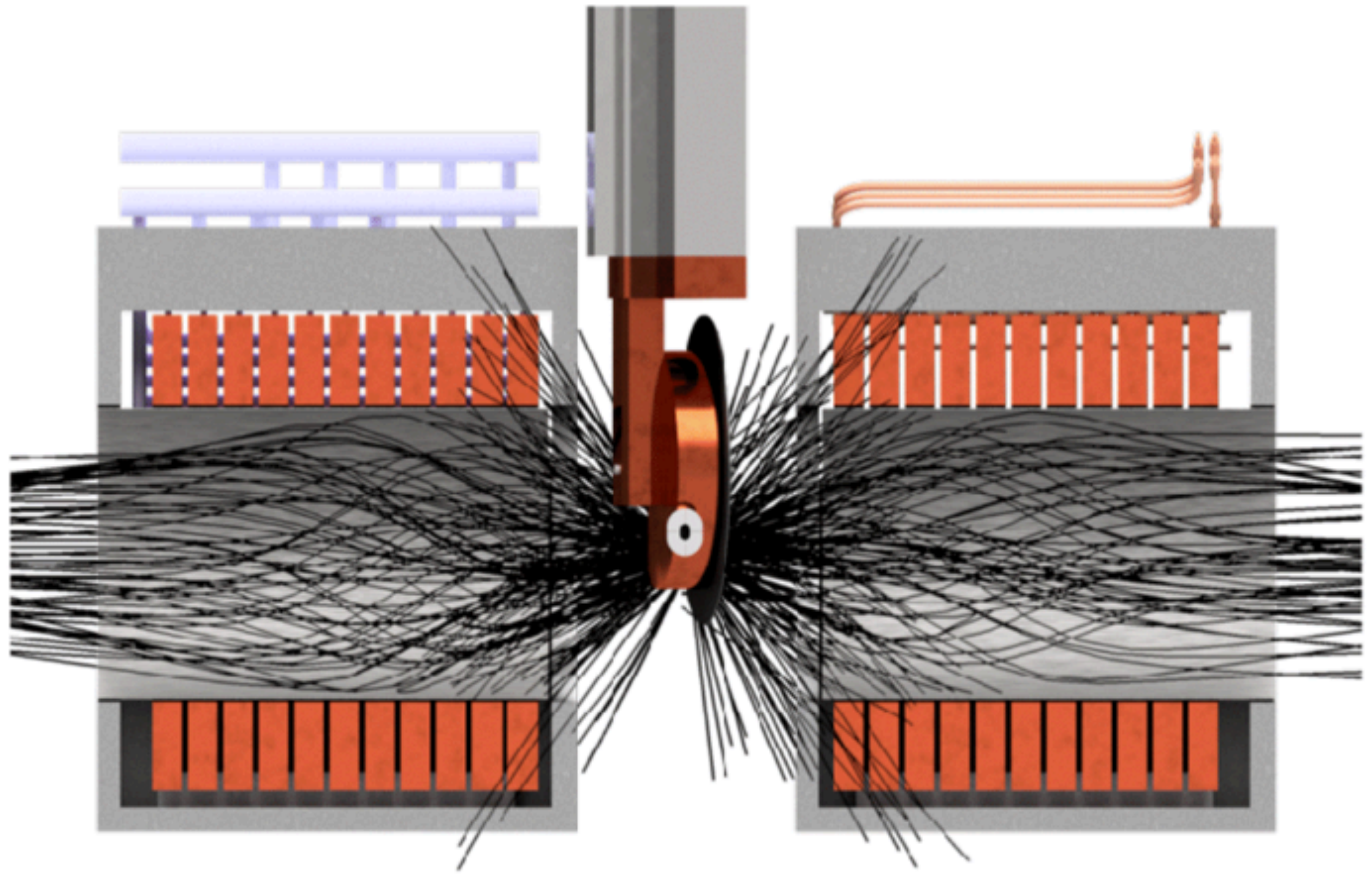
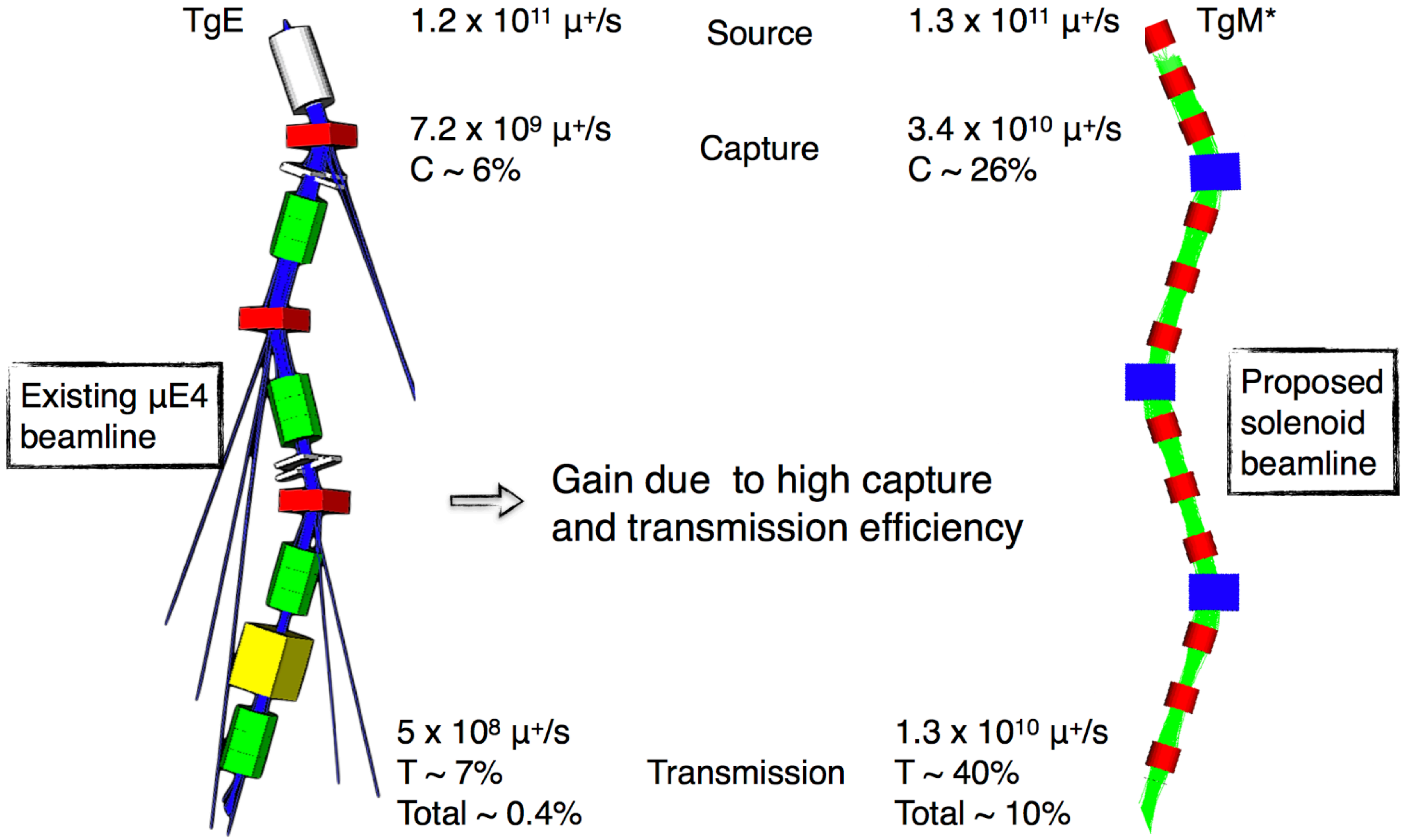
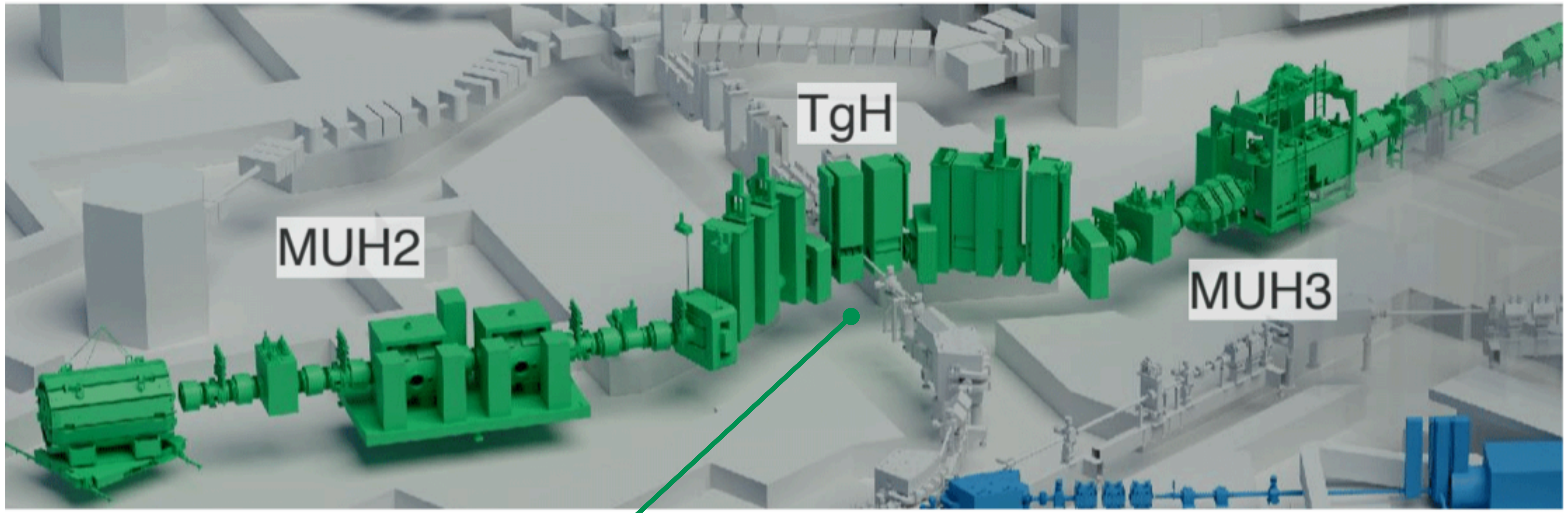
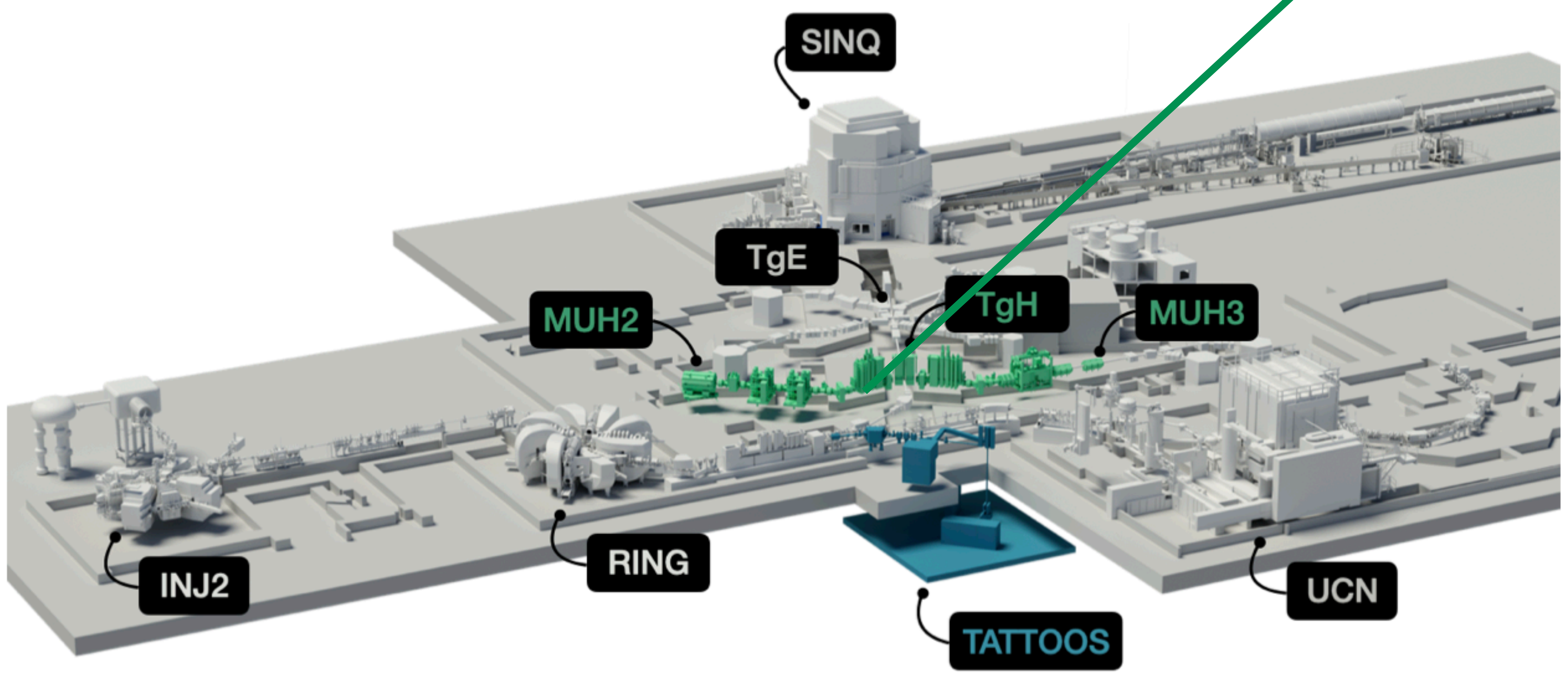




MUH2 and MUH3 beamlines



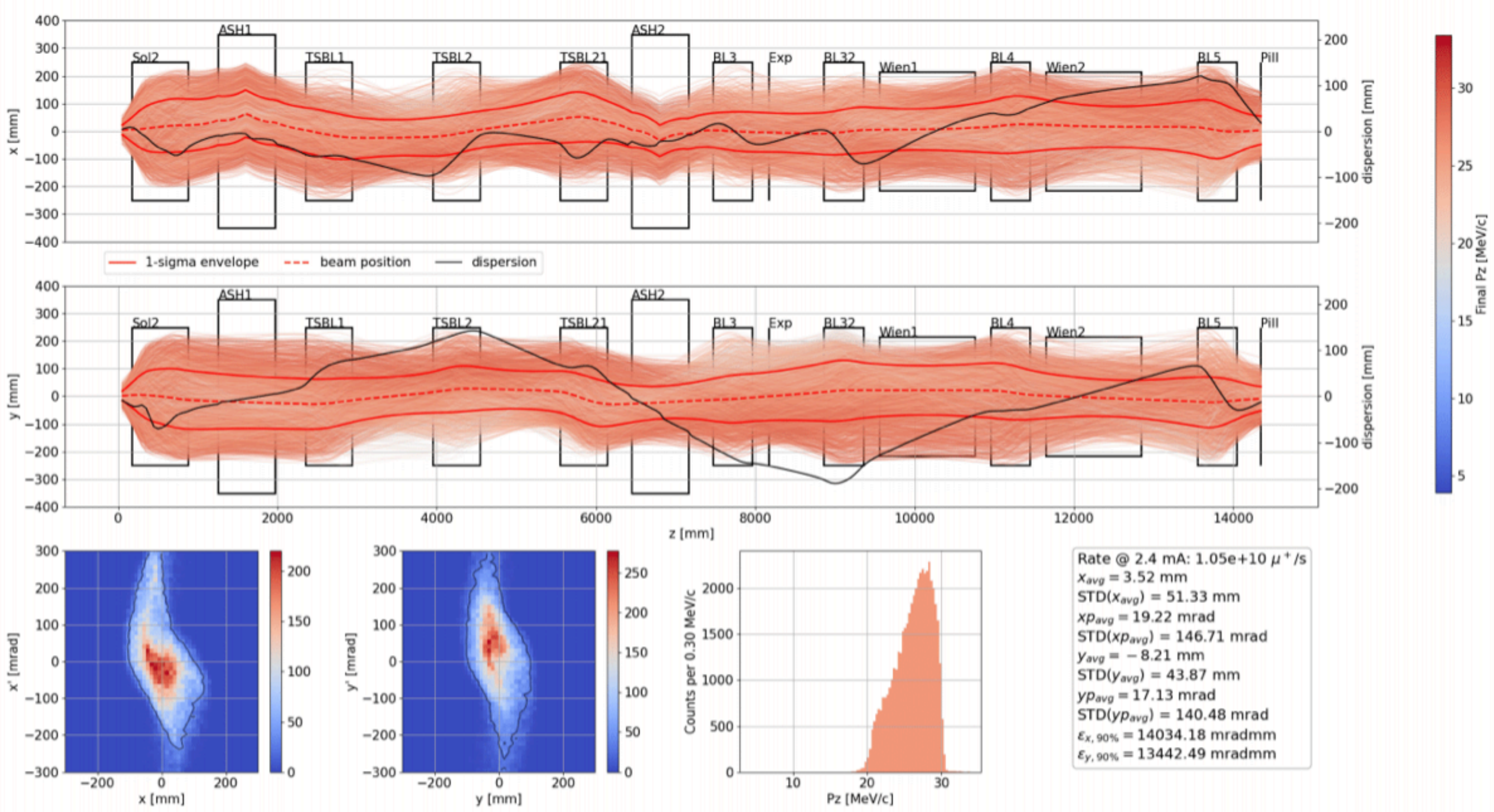


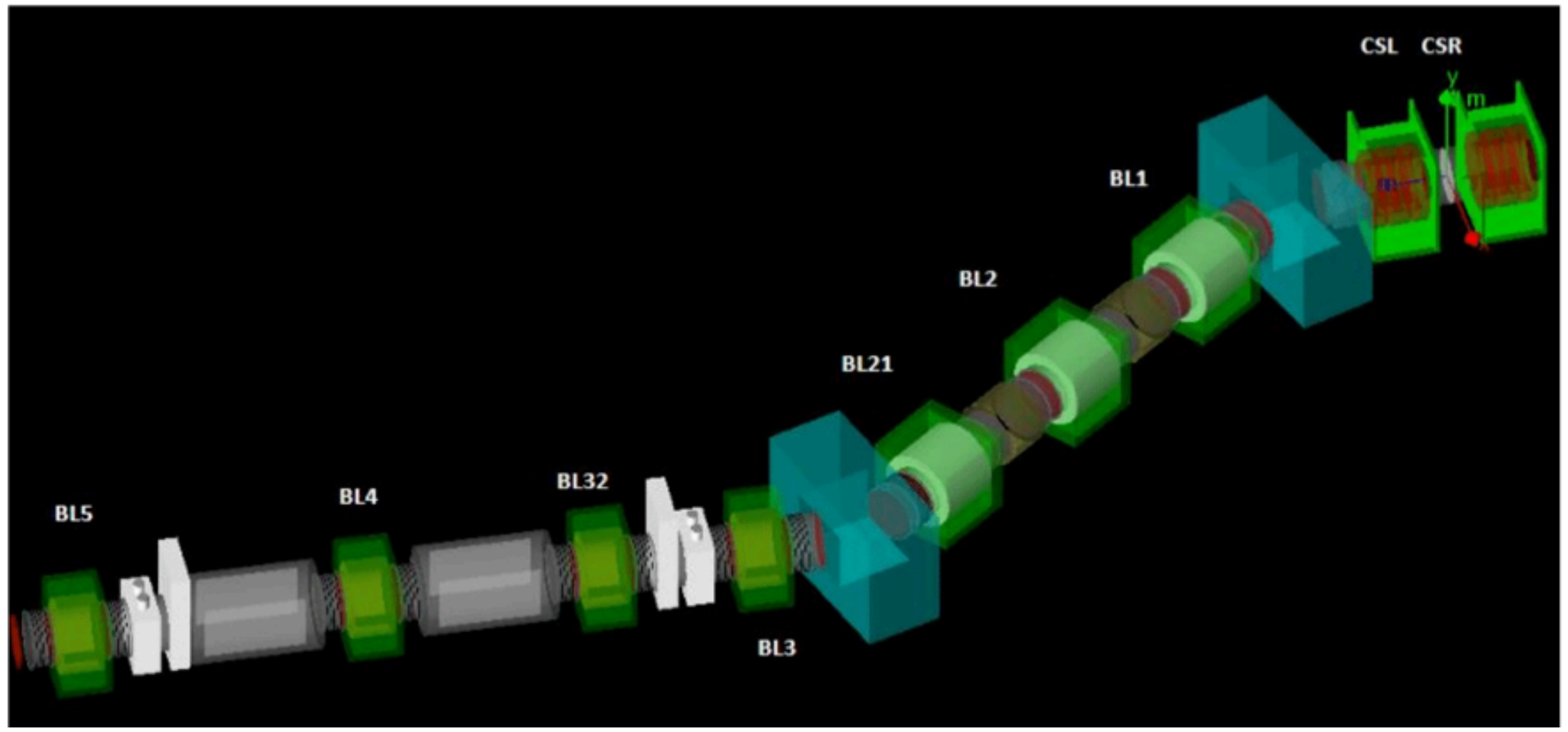
- ~90° extraction with first bend in upstream direction

- MUH2 for particle physics
- MUH3 for muSR research

Where we are…Expected performance of MUH2

- Transmitted rates to the end of the beamline at 2.4 mA proton current
    - ~1.0 x10^{10} μ^+/s at 28 MeV/c
    - Beam spot final focus: $\sigma_x = \sigma_y \sim 40$ mm
    - Positron contamination at highest muon rate 20-30% (can be further reduced at a cost of a small loss in muon rate)
- Robust results using different optimisation strategies





Content

- The MEGII experiment
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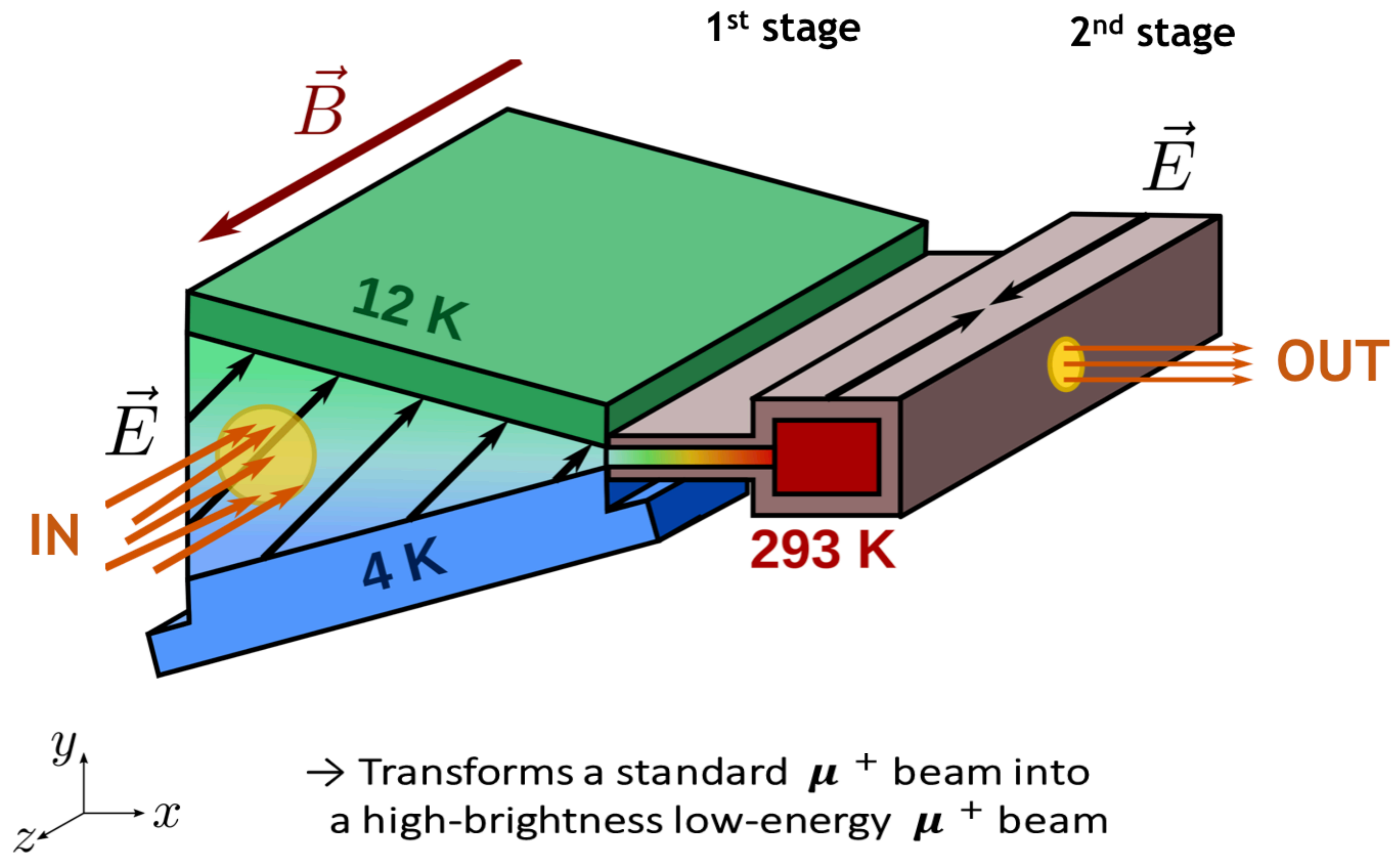
  - **The muCool project**

The muCool project at PSI

- Aim: low energy high-brightness muon beam
- Phase space reduction based on: dissipative energy loss in matter (He gas) and position dependent drift of muon swarm
- Increase in brightness by a factor **10^{10}** with an efficiency of O(**10^{-4}**)

Standard/secondary μ^+ beam
- σ = 10 mm
- E = 4 MeV
- Continuous

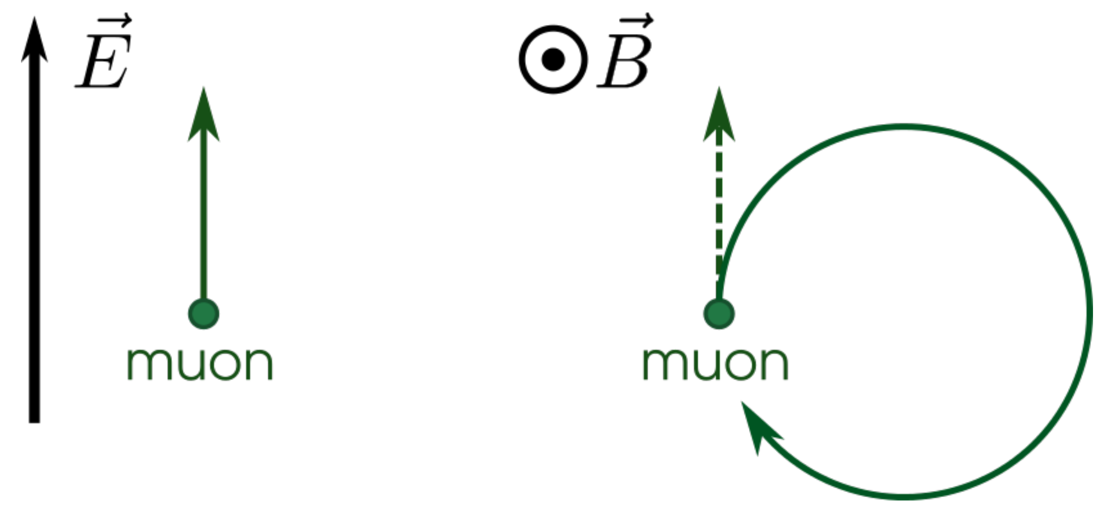


muCool/tertiary μ^+ beam
- σ < 1mm
- E < eV
- Tagged

→ Transforms a standard μ^+ beam into a high-brightness low-energy μ^+ beam

$$\vec{v}_{drift} = \frac{\mu E}{1+\left(\frac{\omega}{\nu_{col}}\right)^2}\left[\hat{\mathbf{E}} + \frac{\omega}{\nu_{col}}\hat{\mathbf{E}}\times\hat{\mathbf{B}} + \left(\frac{\omega}{\nu_{col}}\right)^2\left(\hat{\mathbf{E}}\cdot\hat{\mathbf{B}}\right)\hat{\mathbf{B}}\right]$$

Trajectories in E and B field



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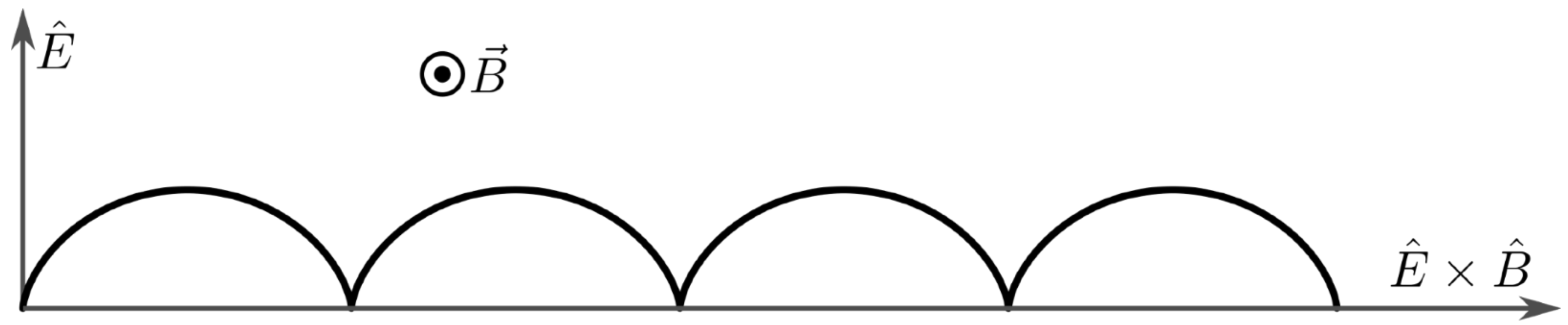
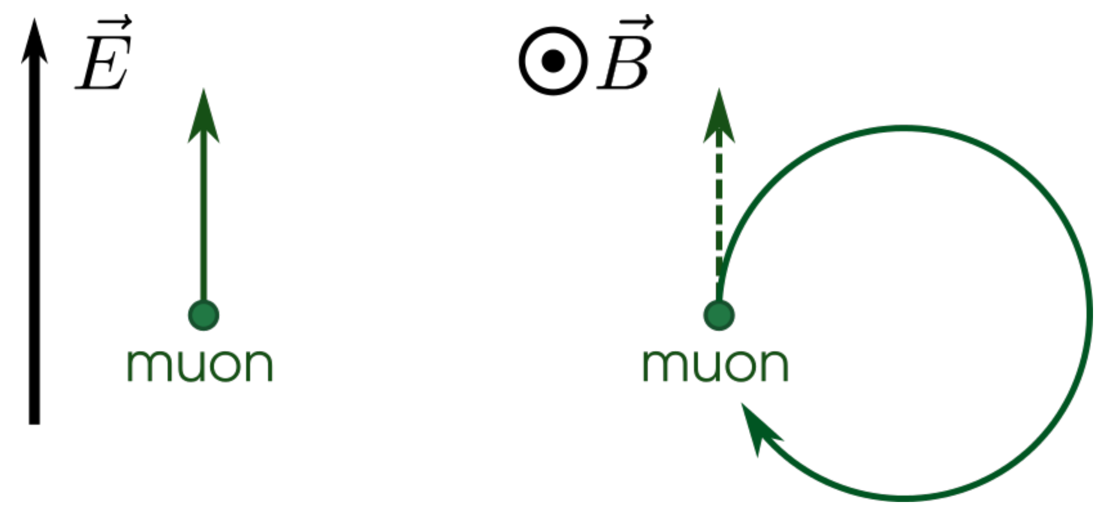
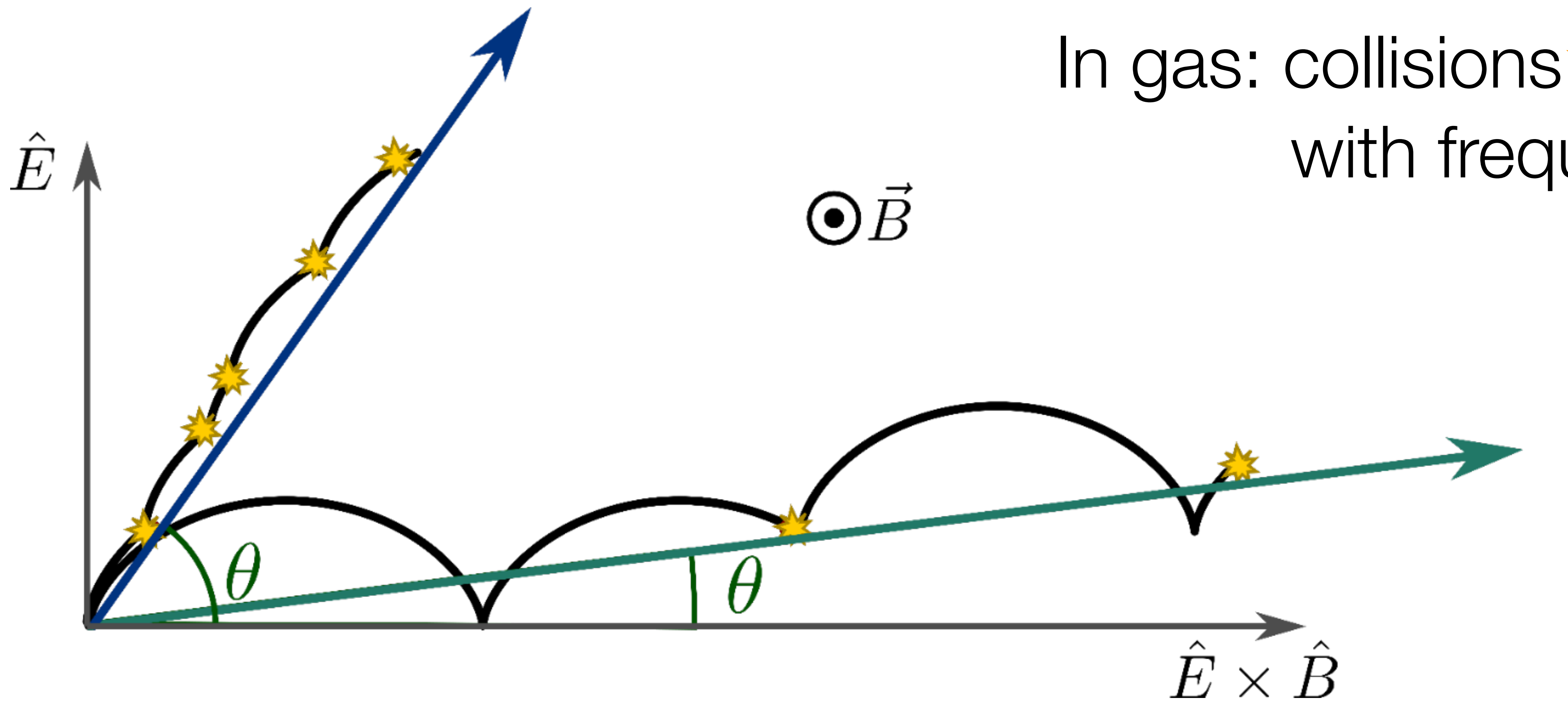


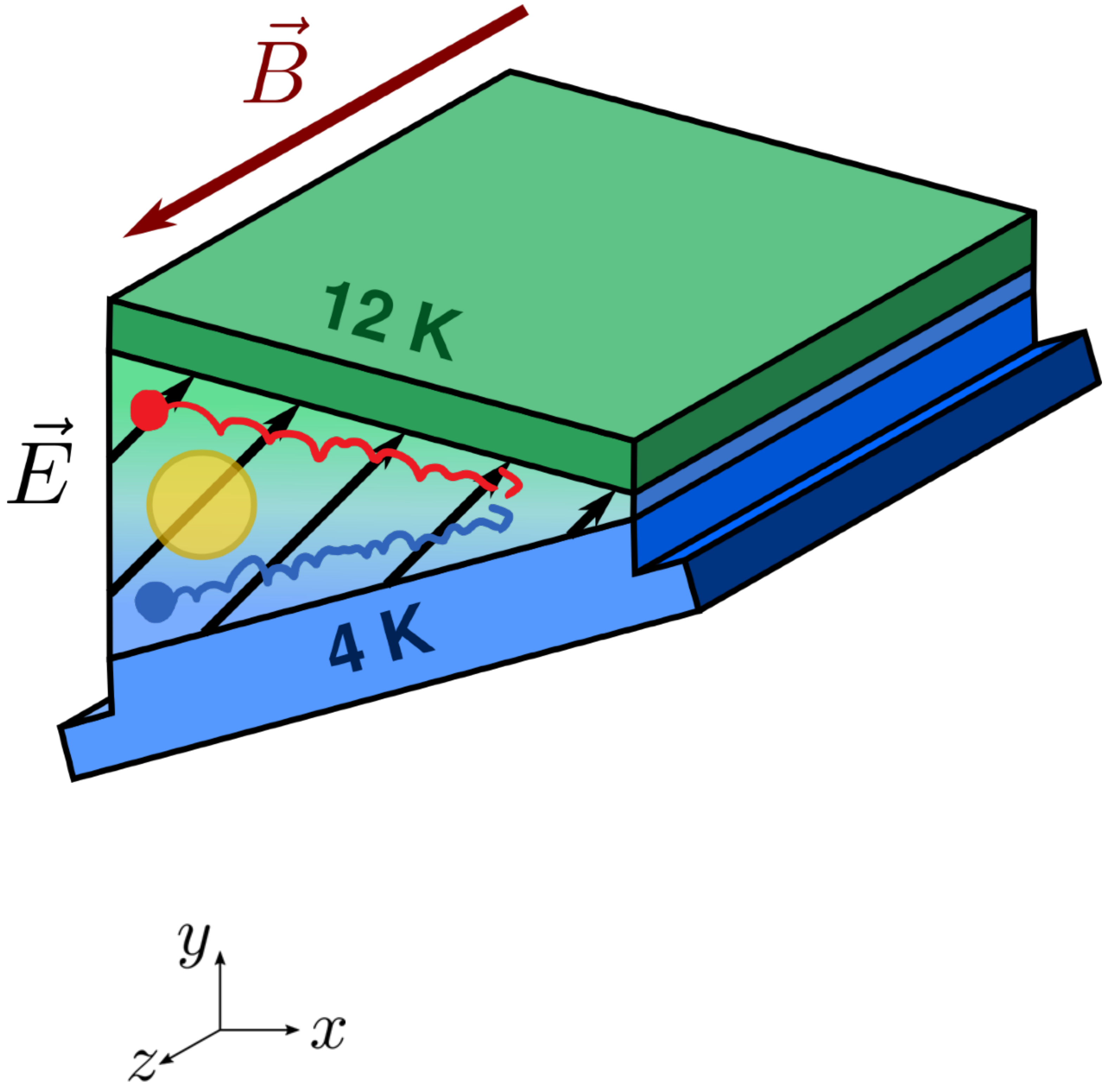


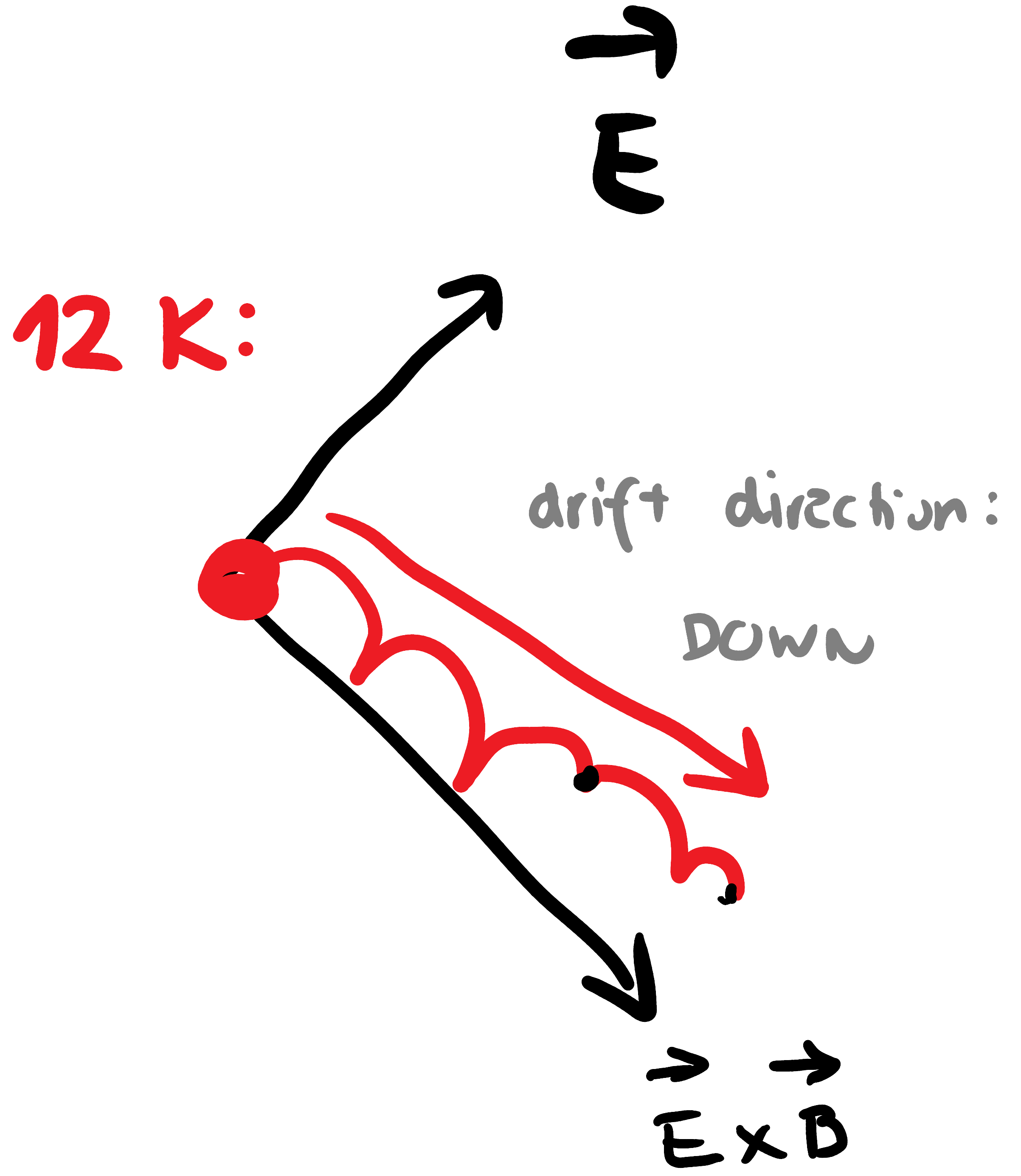
+ gas =

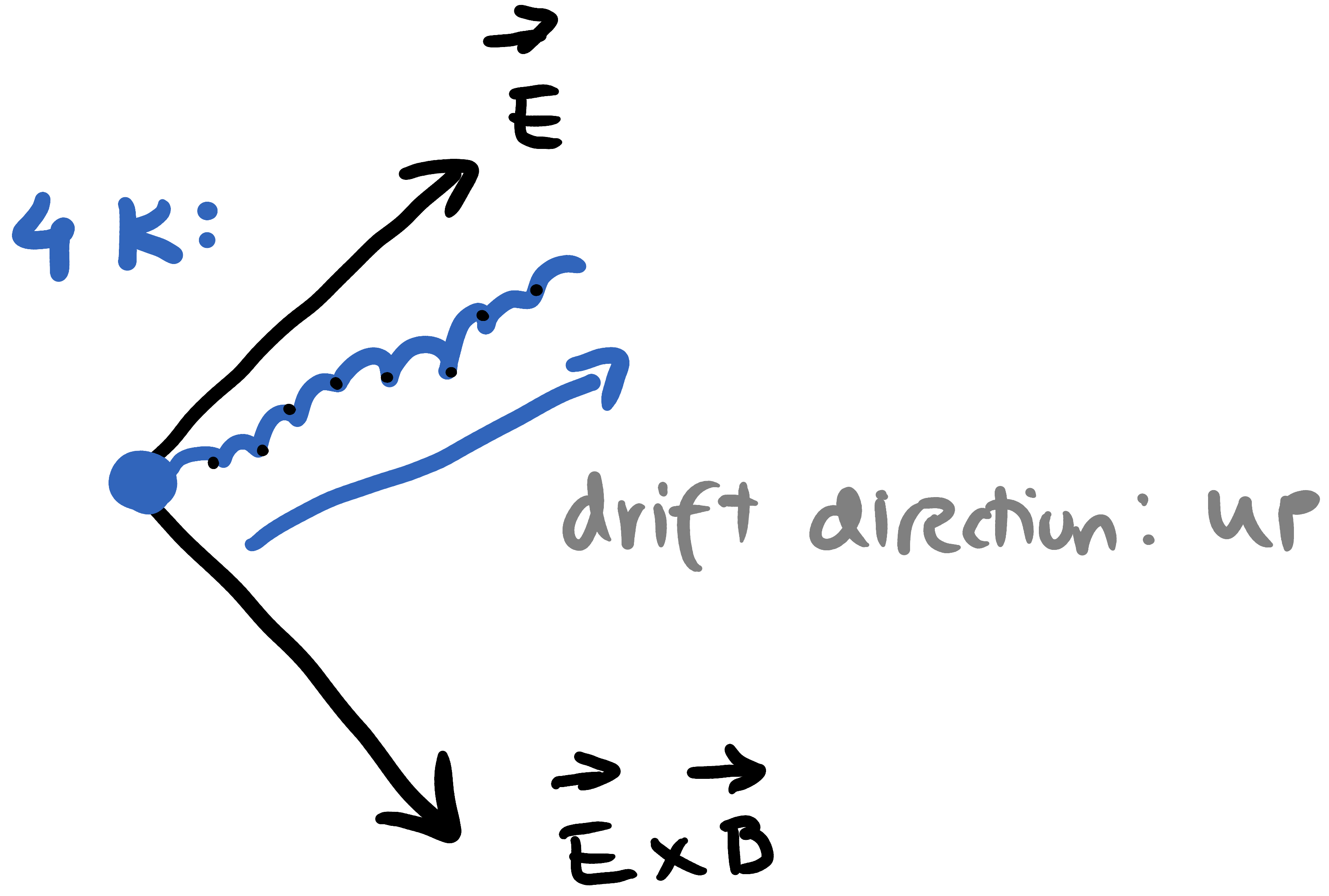


In gas: collisions ★
with frequency f_{col}

Working principle: 1st Stage

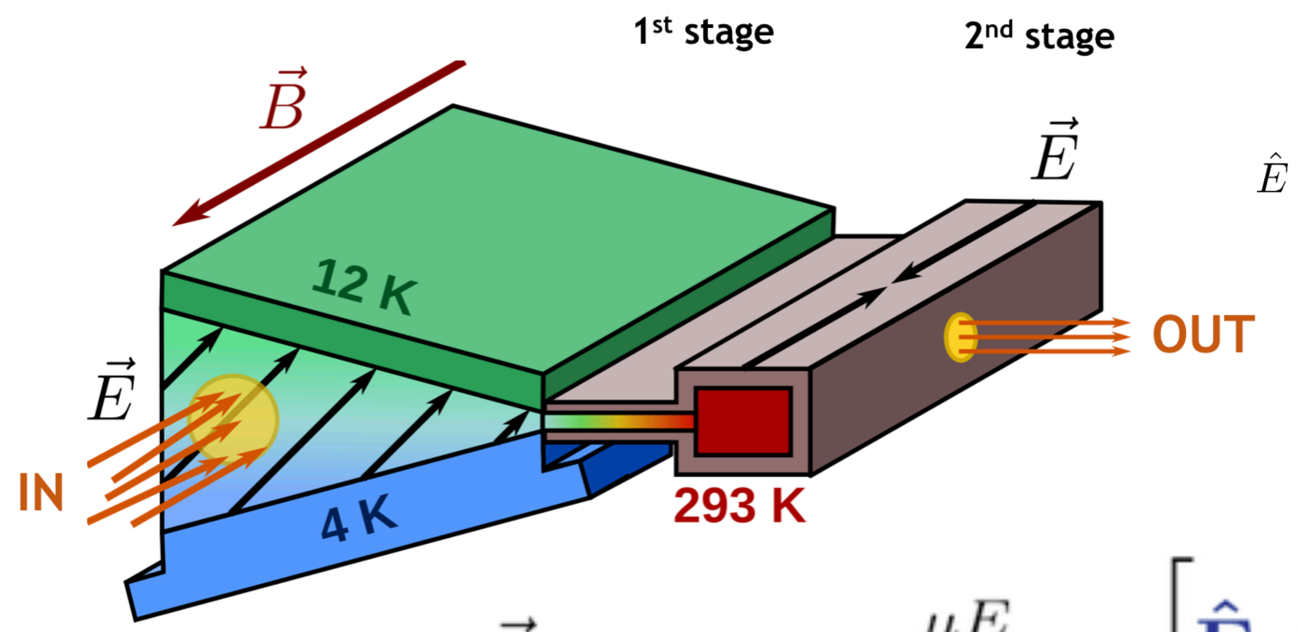


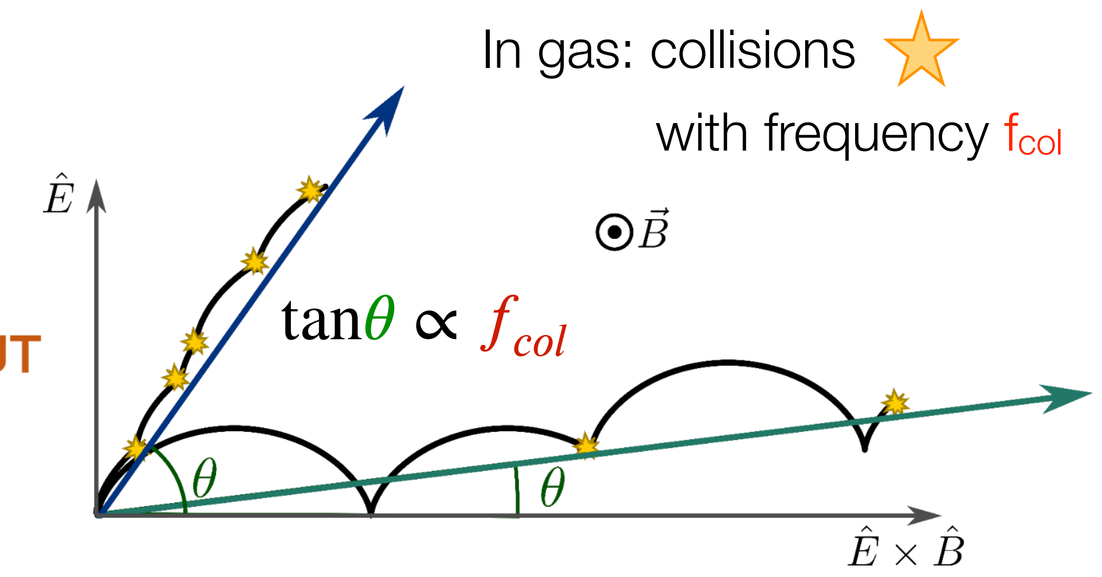




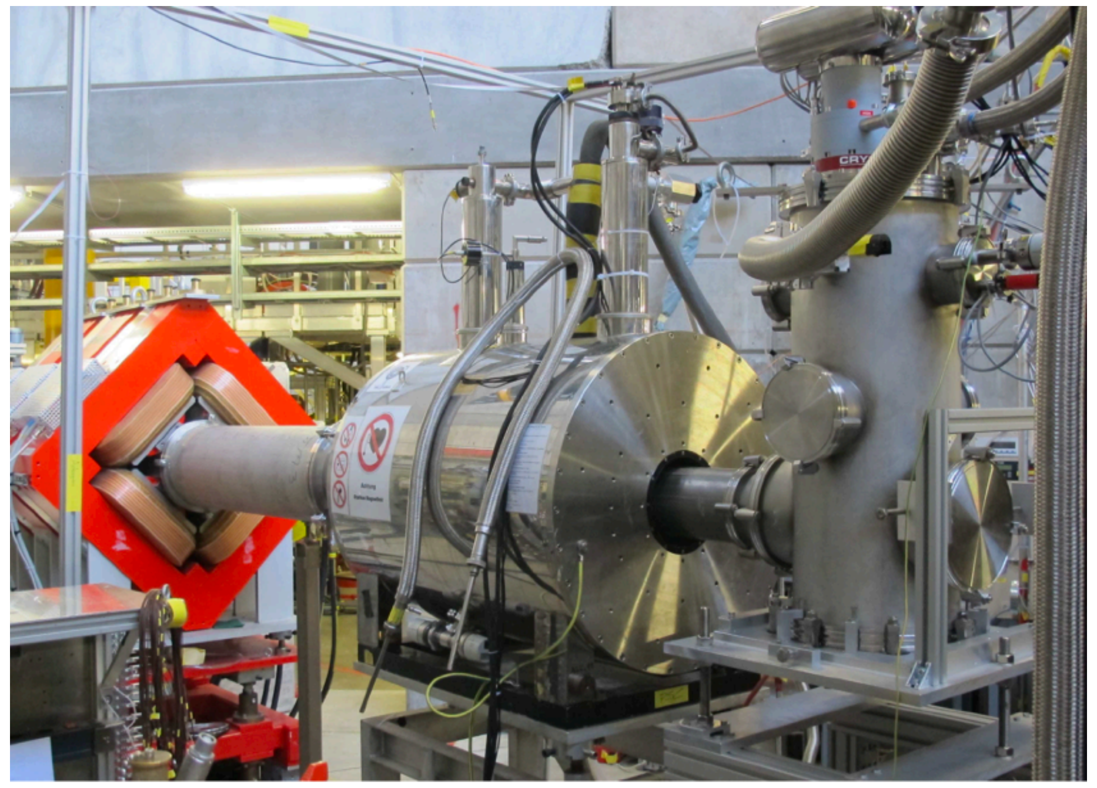
Summary: The muCool project at PSI

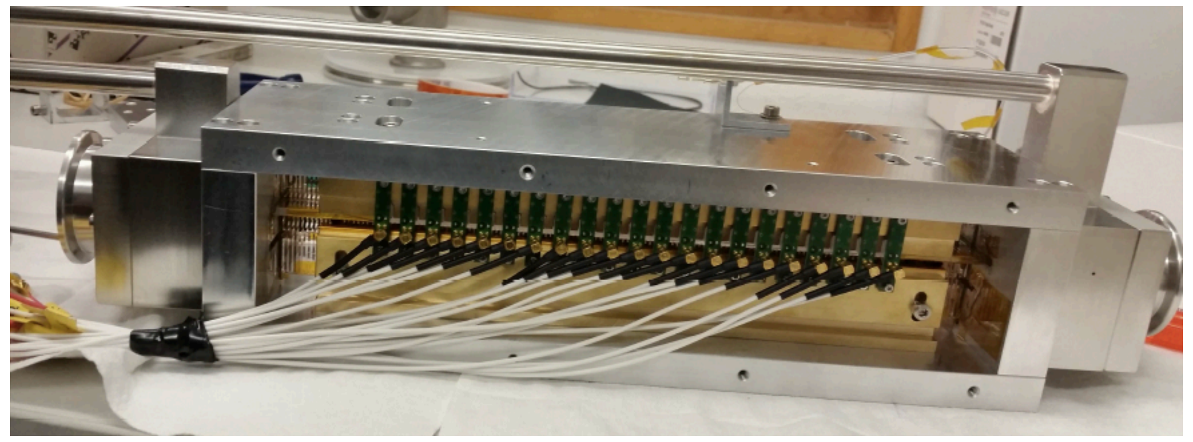
- Aim: low energy high-brightness muon beam
- Phase space reduction based on: dissipative energy loss in matter (He gas) and position dependent drift of muon swarm
- Increase in brightness by a factor **10^{10}** with an efficiency of O(**10^{-4}**)
- Longitudinal and transverse compression (1st stage + 2nd stage): experimentally proved
- **Next Step**: Extraction into vacuum
- Current activity: abundant MC simulations in order to define the detailed experimental setup for the beam extraction in vacuum and eventually the beam re-acceleration

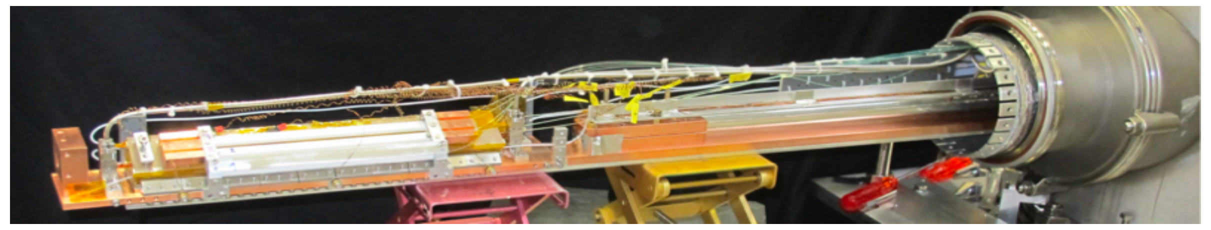




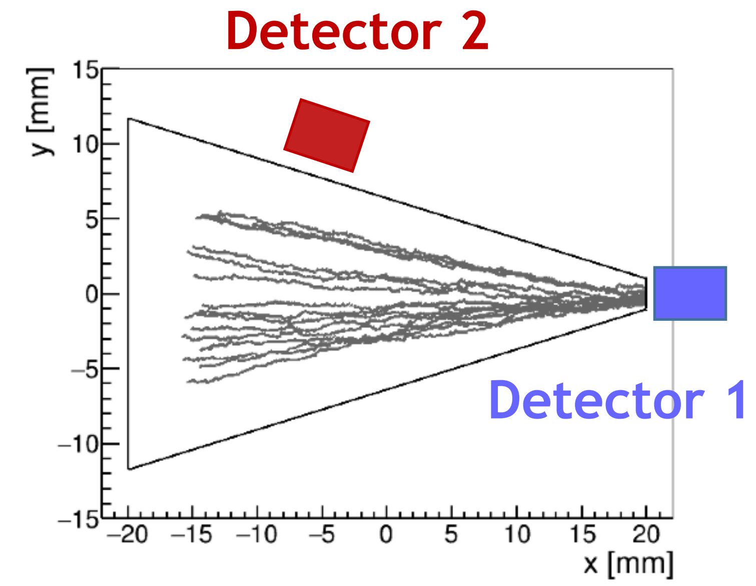
$$\vec{v}_{drift} = \frac{\mu E}{1+\left(\frac{\omega}{\nu_{col}}\right)^2}\left[\hat{\mathbf{E}} + \frac{\omega}{\nu_{col}}\hat{\mathbf{E}}\times\hat{\mathbf{B}} + \left(\frac{\omega}{\nu_{col}}\right)^2\left(\hat{\mathbf{E}}\cdot\hat{\mathbf{B}}\right)\hat{\mathbf{B}}\right]$$

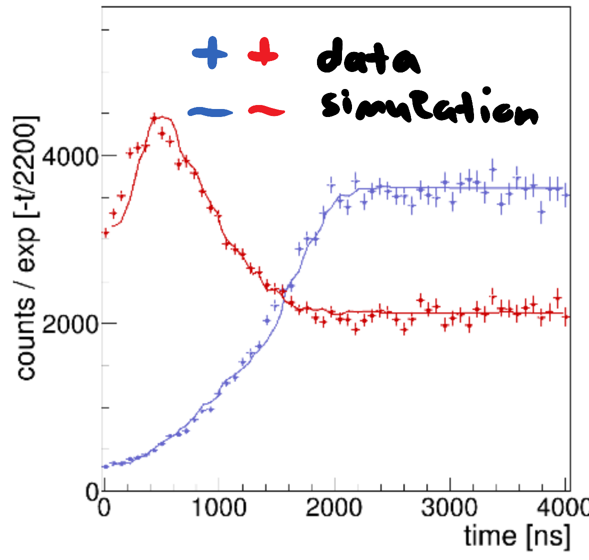




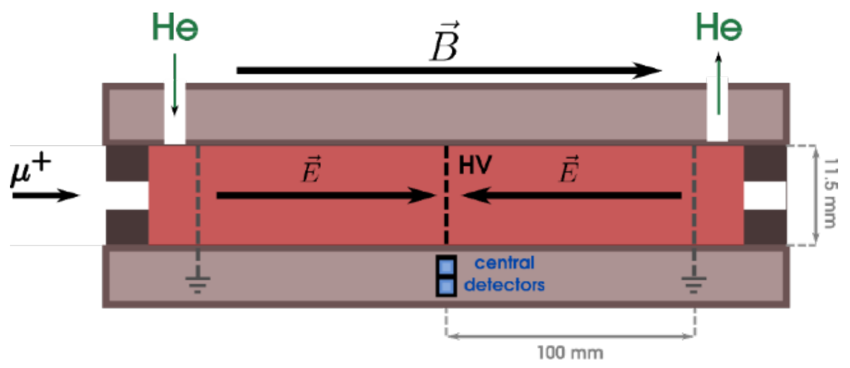


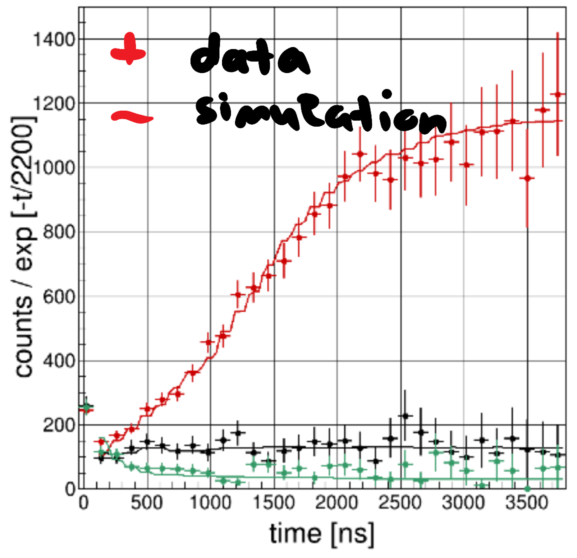
Transverse Compression



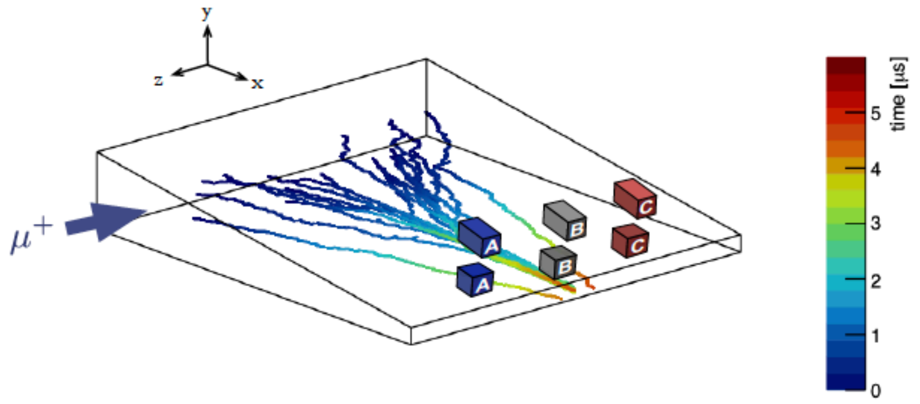


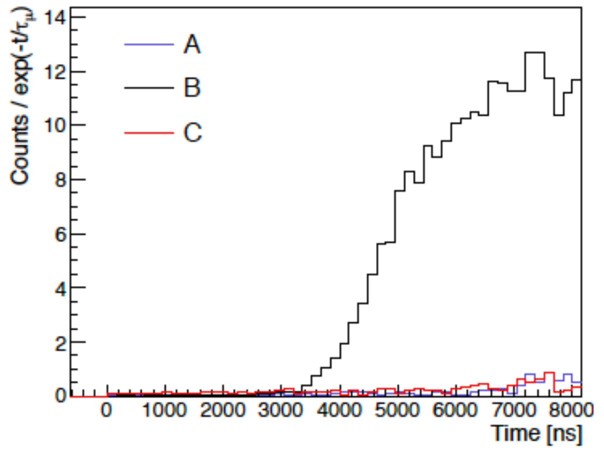
Longitudinal Compression





Longitudinal+ Transverse Compression





Outlook

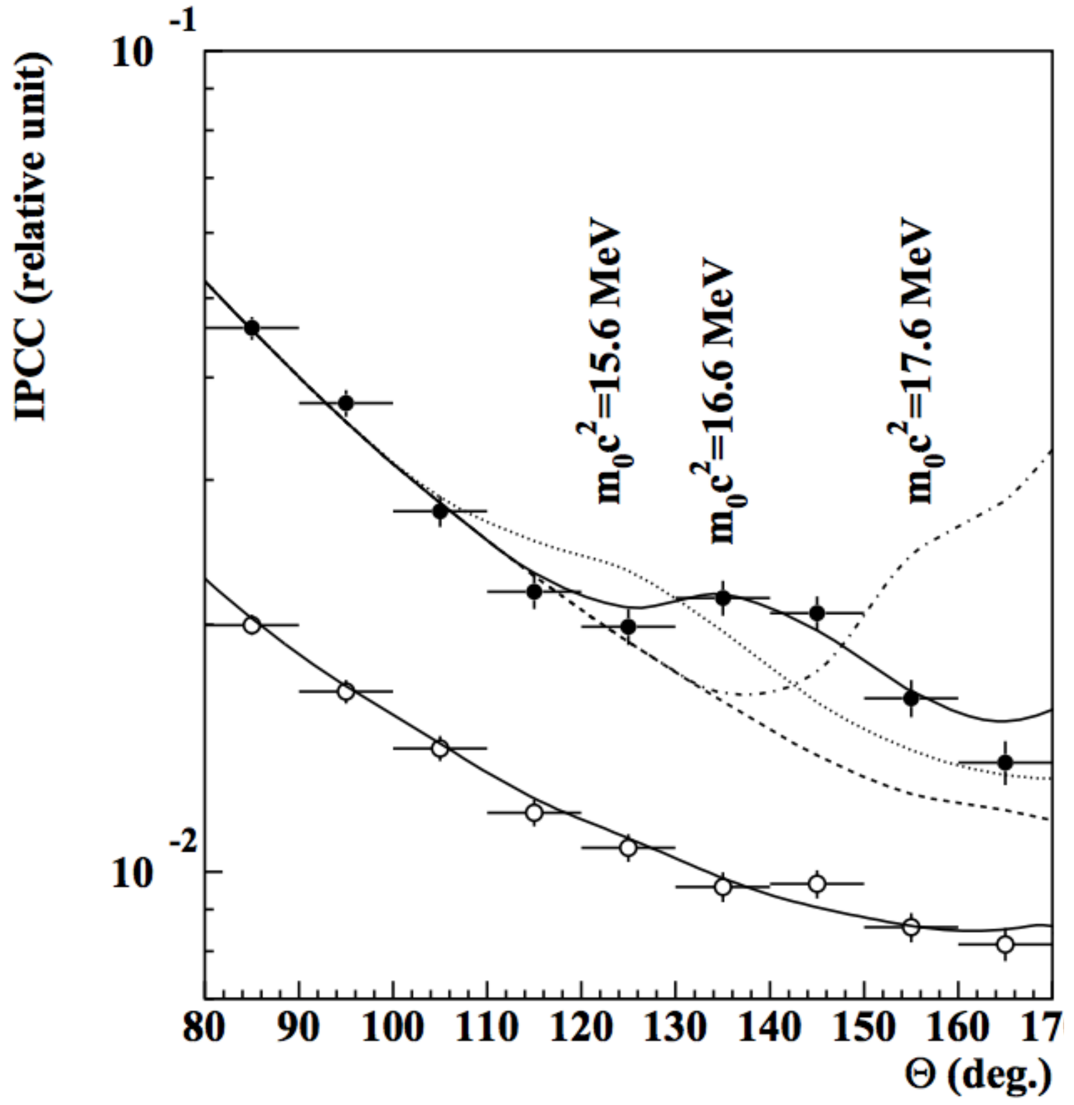
- The particle physics program at PSI remains very exciting, thanks to the running experiments and the new incoming ones
- The new beamline developments, with the HiMB and muCOOL projects, are very promising and will open the doors for more stimulating ideas
- We will be very happy to receive new inputs for new projects to be welcomed and hosted at PSI

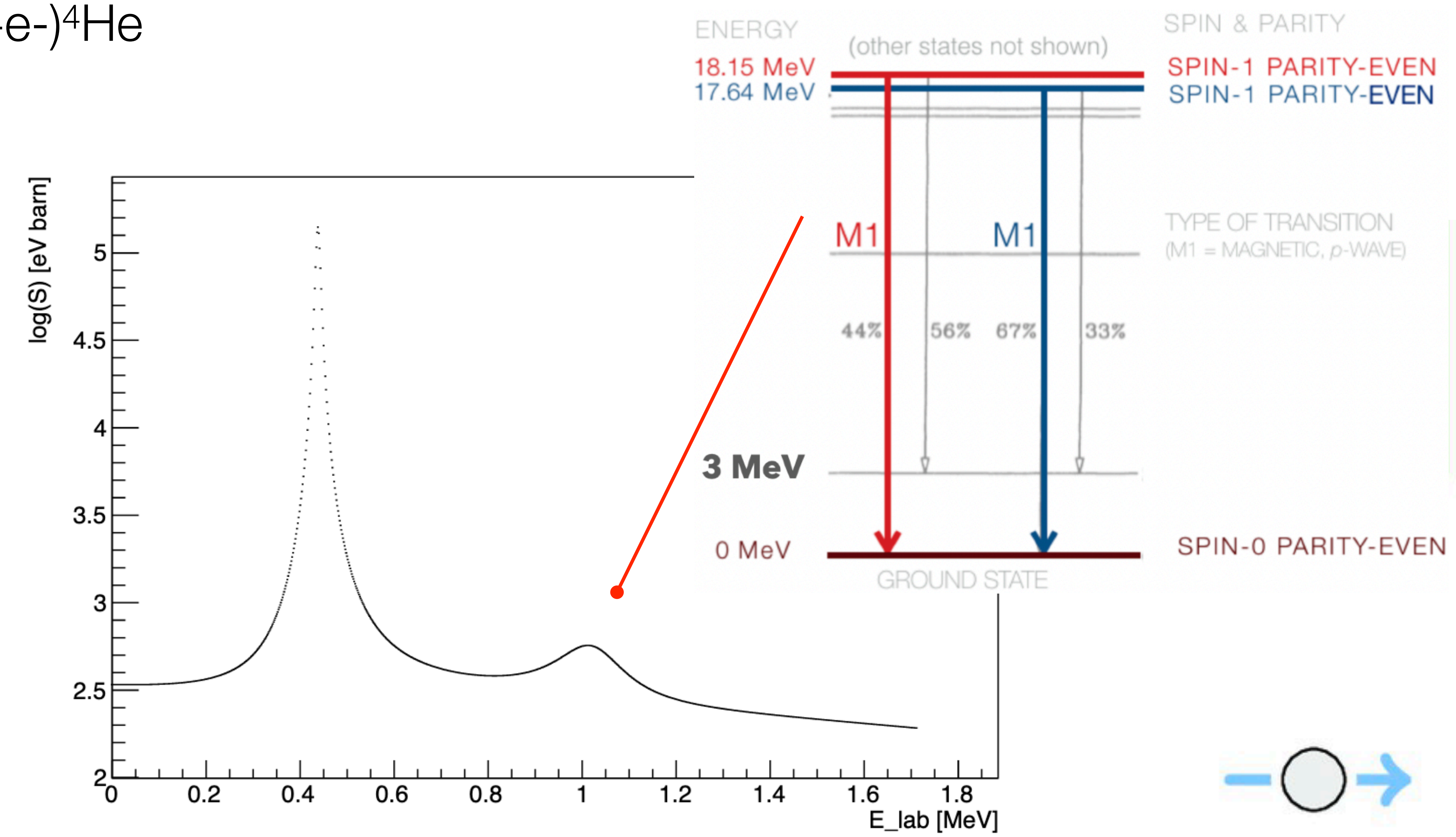
Thanks a lot for your attention

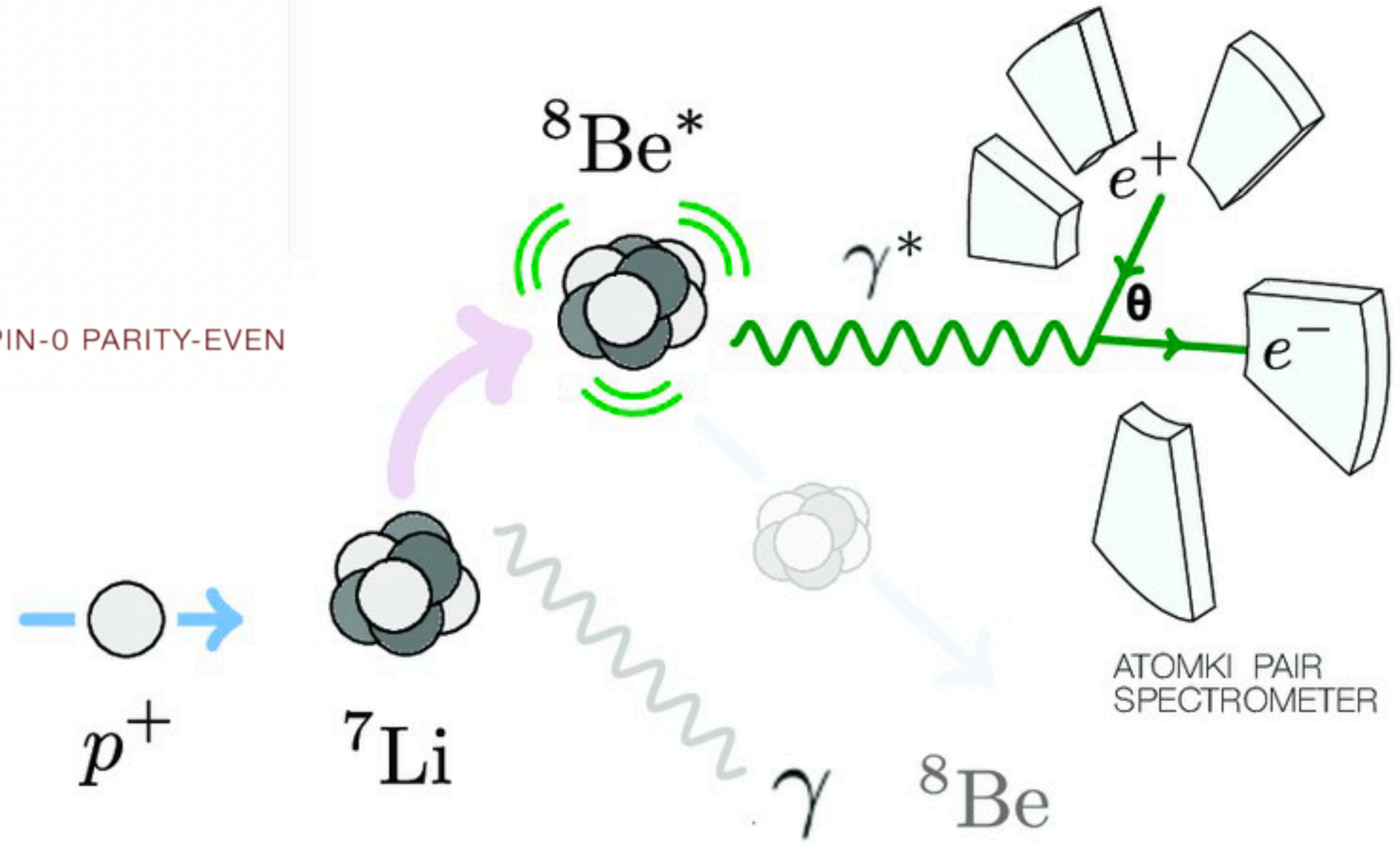
Back-Up

The beryllium anomaly

- Hint for the production of a neutral, 17 MeV boson, potential mediator ad a fifth force: X17 (ATOMKI collaboration)
  - Observed in the $^{7}Li(p, e^+e^-)^{8}Be$ reaction at 1100 keV and confirmed at other proton energies (450, 650, 800 keV)
  - Observed in the $^{3}H(p,e^+e^-)^{4}He$







Excess consistent with

- Light boson mass = 16.95 MeV/c2
- Branching ratio (X17/gamma) = 6×10^{-6}

Phys. Rev. Lett. 116, 042501
arXiv:2205.07744

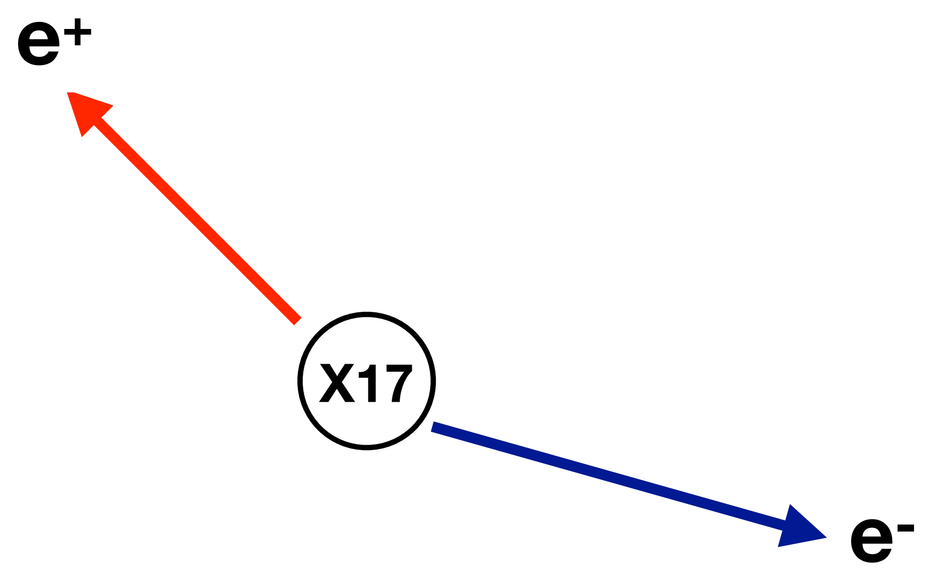
Phys. Rev. C 104, 044003

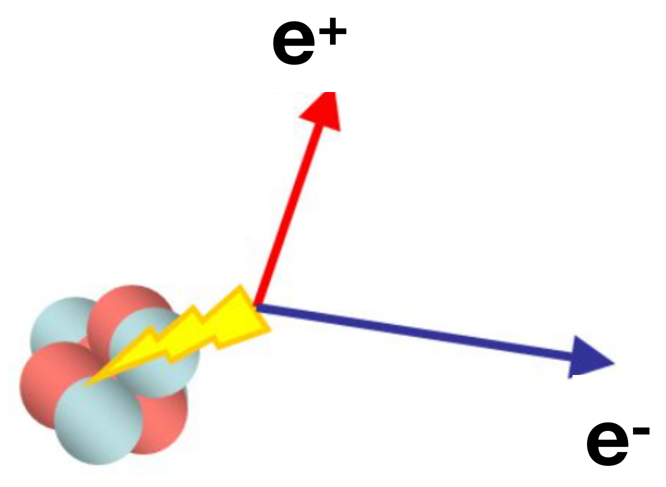
Phys. Rev. D 95, 035017

The X17 search with the MEG II apparatus

- The new MEGII spectrometer can be used for X17-Boson searches by replacing the muon target with a dedicated one for the X17-Boson production, adjusting the magnetic field and using it together with the MEGII CW accelerator, combined with the XEC and other gamma auxiliary detectors, an optimised TDAQ and an extended analysis code

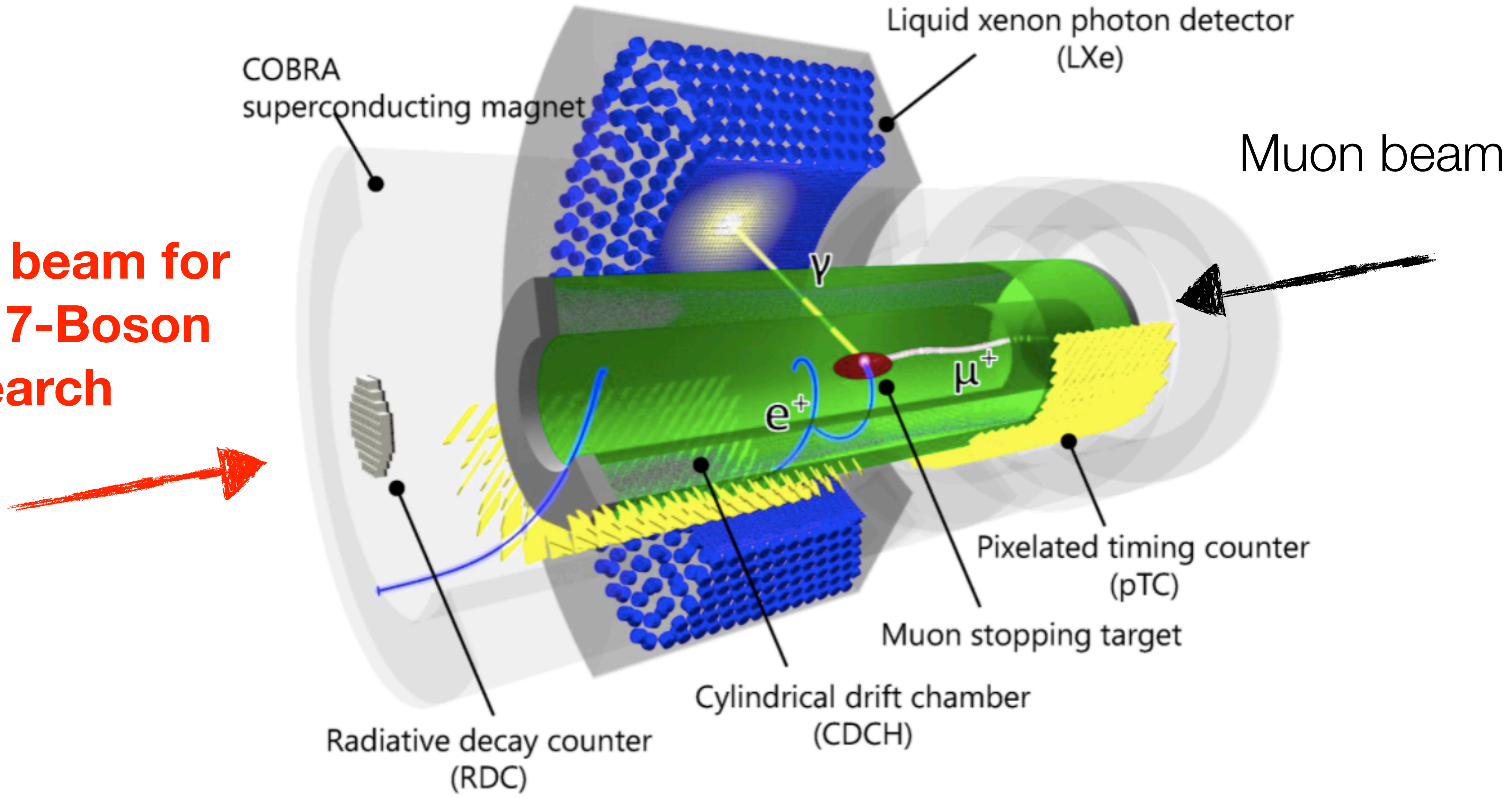
Signal





Backgrounds:
Gamma Internal and External Pair Conversion (IPC, EPC)
- IPC: Resonant and non-resonant
- EPC: Experimental setup material budget

Proton beam for the X17-Boson search



with MEG II

→ **Better** invariant mass resolution

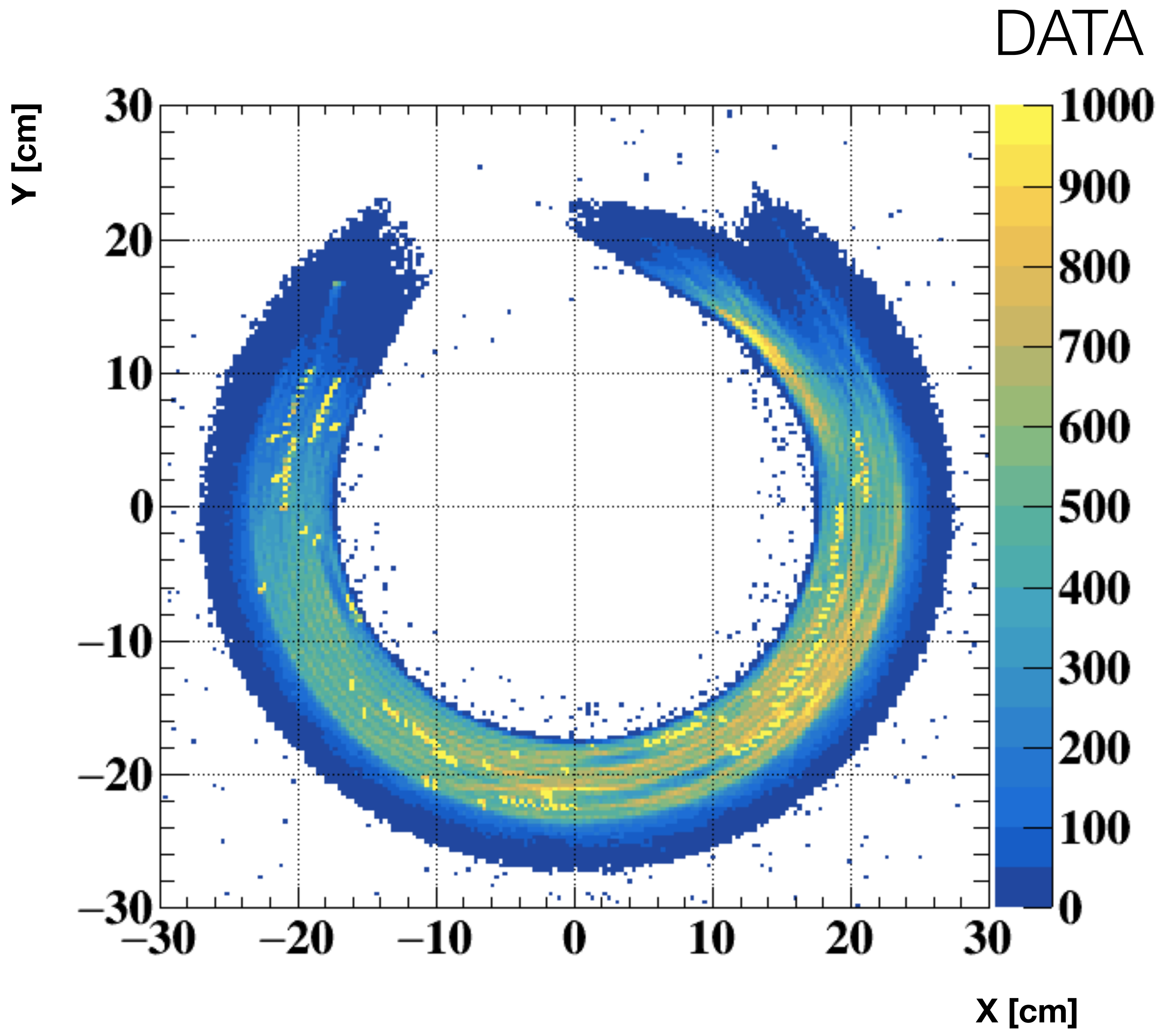
→ Detection in an **estended** angular range

Collected data sample

- Pivotal-run 2022: Proton beam tuning, Mechanical/integration test of the new parts, LiF and LiPON target test, Different trigger settings, Optimised Data Taking and Reconstruction Algorithms

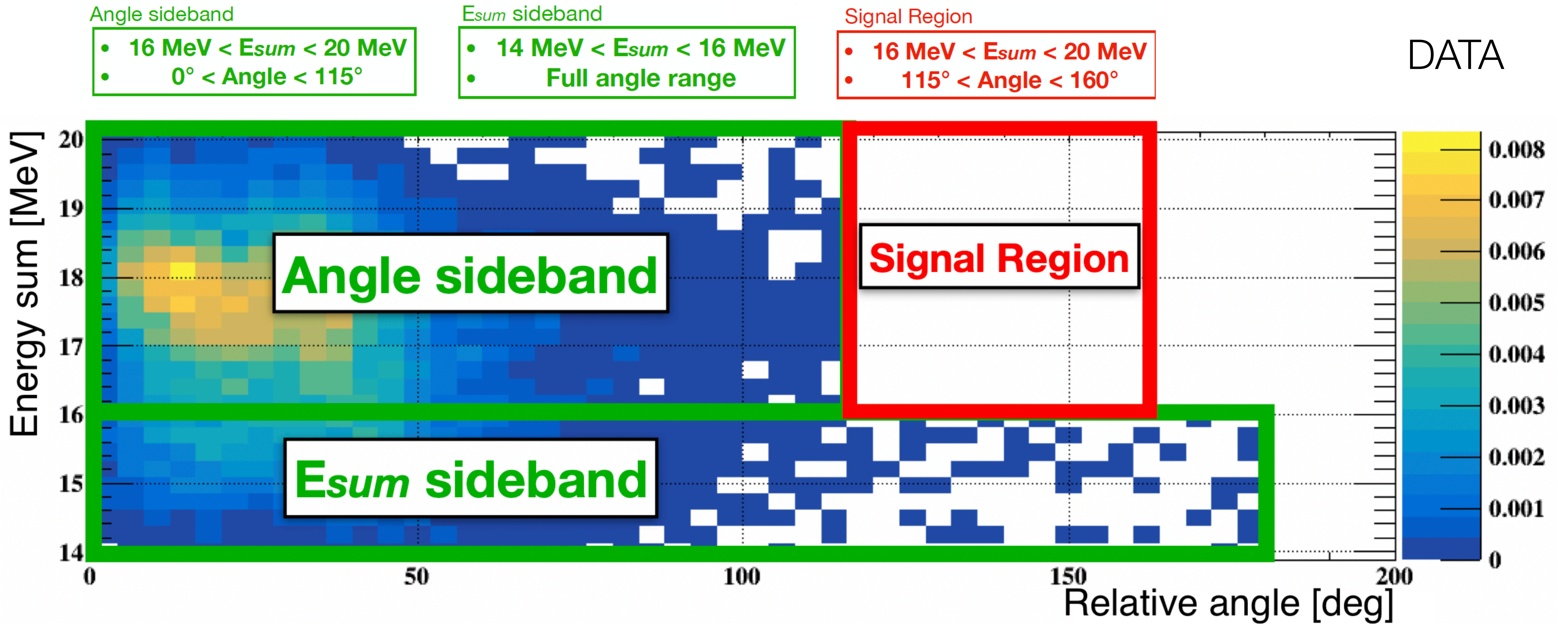
- Physics run 2023: 4 weeks at Ep = 1080 keV
  - ~75 M Events
  - ~**300 K** Events Reconstructed pairs

- On full range of the Esum and Angular Opening angle observables:
  - ~60% EPC (15 + 18 MeV)
    - Dominant at low angle, negligible in the signal region
  - ~40% IPC (15 + 18 MeV)
    - Dominant in the signal region



Analysis strategy

- 2D Likelihood maximization: **E_{sum}** vs **Angular Opening** Observables
- Blinded **Signal Region**
- Background studies on the **Side Bands**



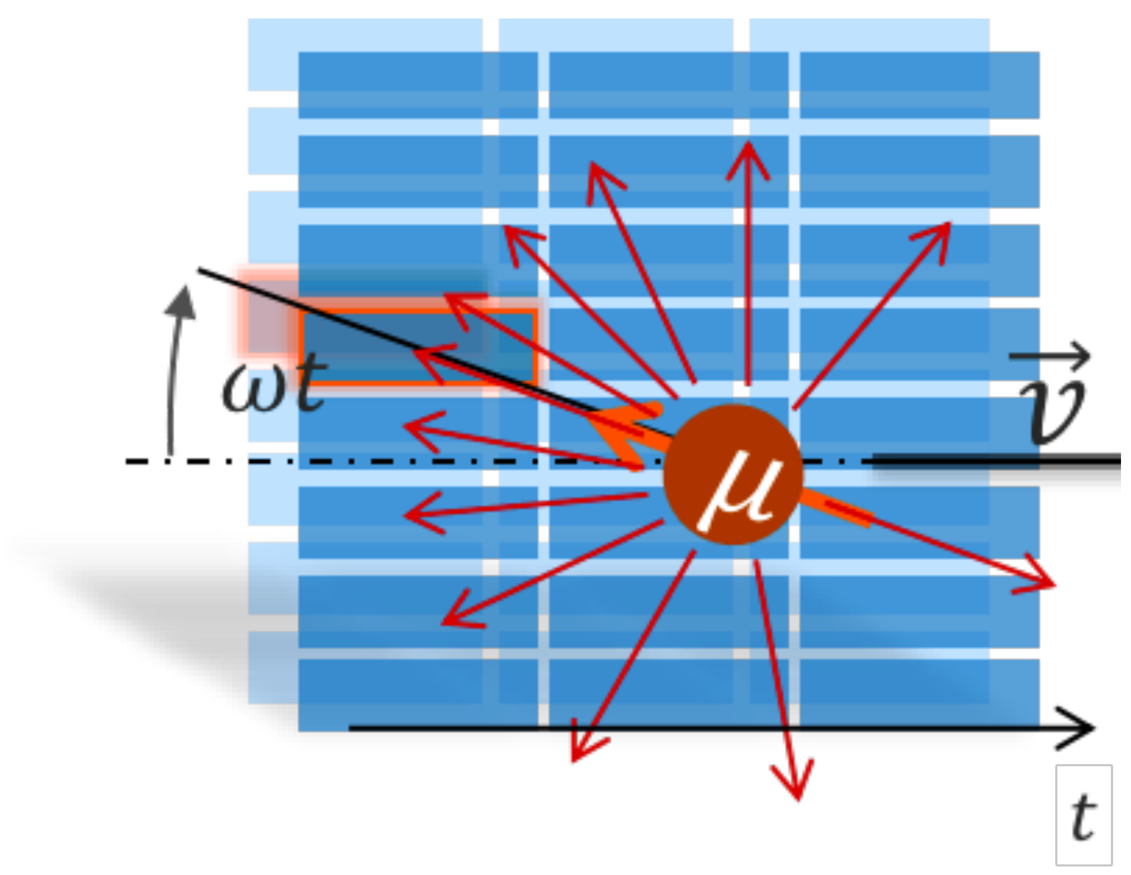
Status and next steps

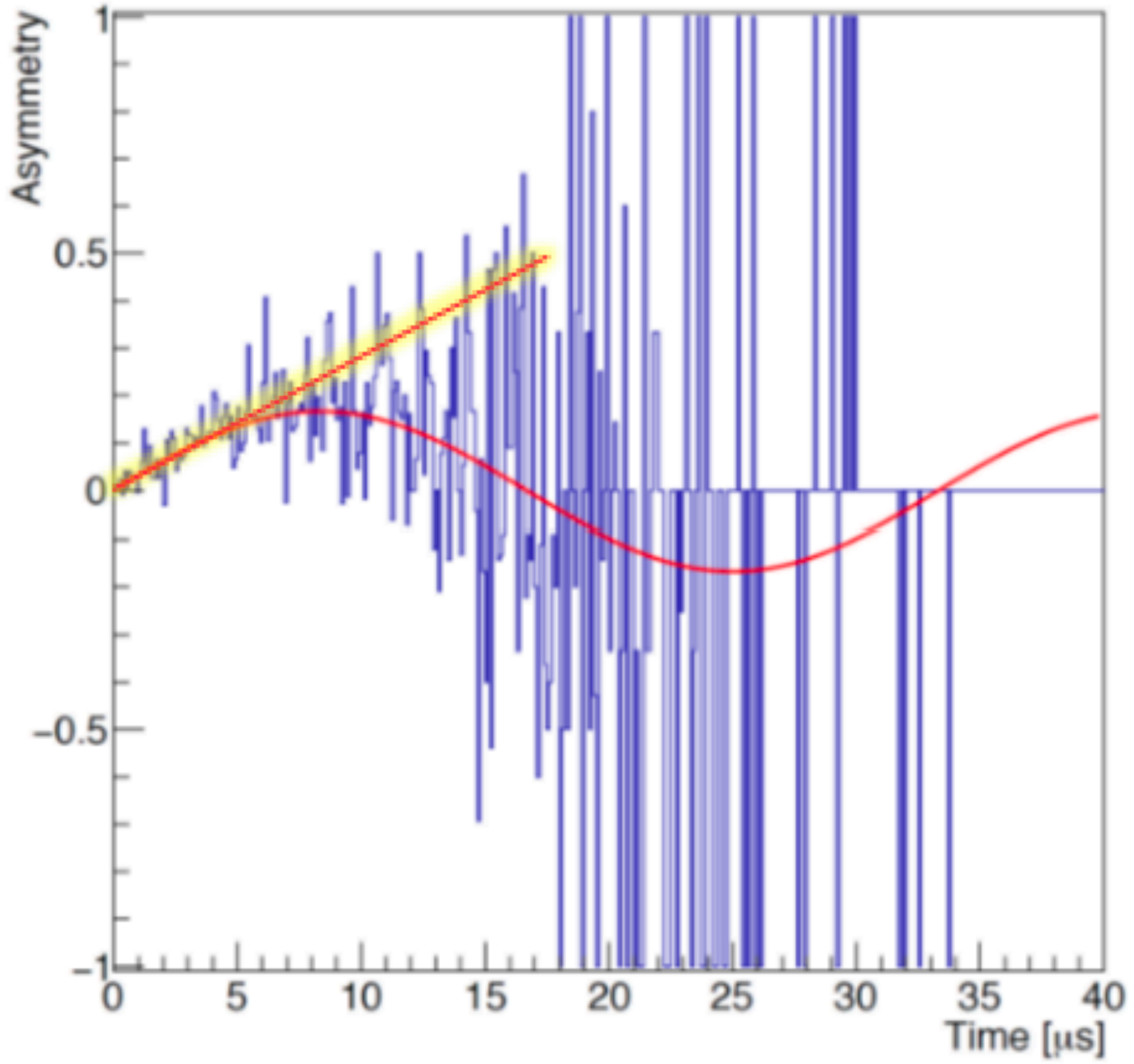
- 2022 engineering run and 2023 physics run **DONE**
- Pair reconstruction and track selection **DONE**
- 2023 data reprocessing **ONGOING**
- Sidebands check **ONGOING**
- Mass MC production **TO BE STARTED**
- Unblinding **TO BE DONE**

Signal: asymmetry up/down positron tracks

- The sensitivity to a muon EDM is given by the asymmetry up/down of the positron from the muon decay
- Positron are emitted predominantly along the muon spin direction

$$A(t) = \frac{N_\uparrow(t) - N_\downarrow(t)}{N_\uparrow(t) + N_\downarrow(t)} = \alpha p \sin\left(\frac{2d_\mu}{\hbar}t\right) \approx \alpha p \frac{2d_\mu}{\hbar} t$$





The slope gives the sensitivity of the measurement:

$$\sigma(d_\mu) = \frac{\hbar\gamma^2 a_\mu}{2pE_f\sqrt{N}\,\gamma\tau_\mu\,\alpha}$$

p := initial polarization
E_f := Electric field in lab
$\sqrt{N}$:= number of positrons
τ_μ := lifetime of muon
α := mean decay asymmetry

Final muEDM Experiment Sensitivity

μE1 Beamline Flux $2 \times 10^8 \mu^+/s$

Momenta $\gamma = 1.55$

Polarisation $P_0 \approx 0.95$

Av. Decay Asymmetry $A \approx 0.3$

Electric Field $E_f = 2\,\mathrm{MV/m}$

$$\sigma(d_\mu) = \frac{a\hbar\gamma}{2P_0E_f\sqrt{N}\tau_\mu A}$$

$\sim 6 \times 10^{-23} e\,.\,\mathrm{cm}$

(with $N = 200$ days)