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INSTITUTE OF NUCLEAR PHYSICS
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Waveform Pattern Alignment:

Reinventing time-of-flight method for beam diagnostics

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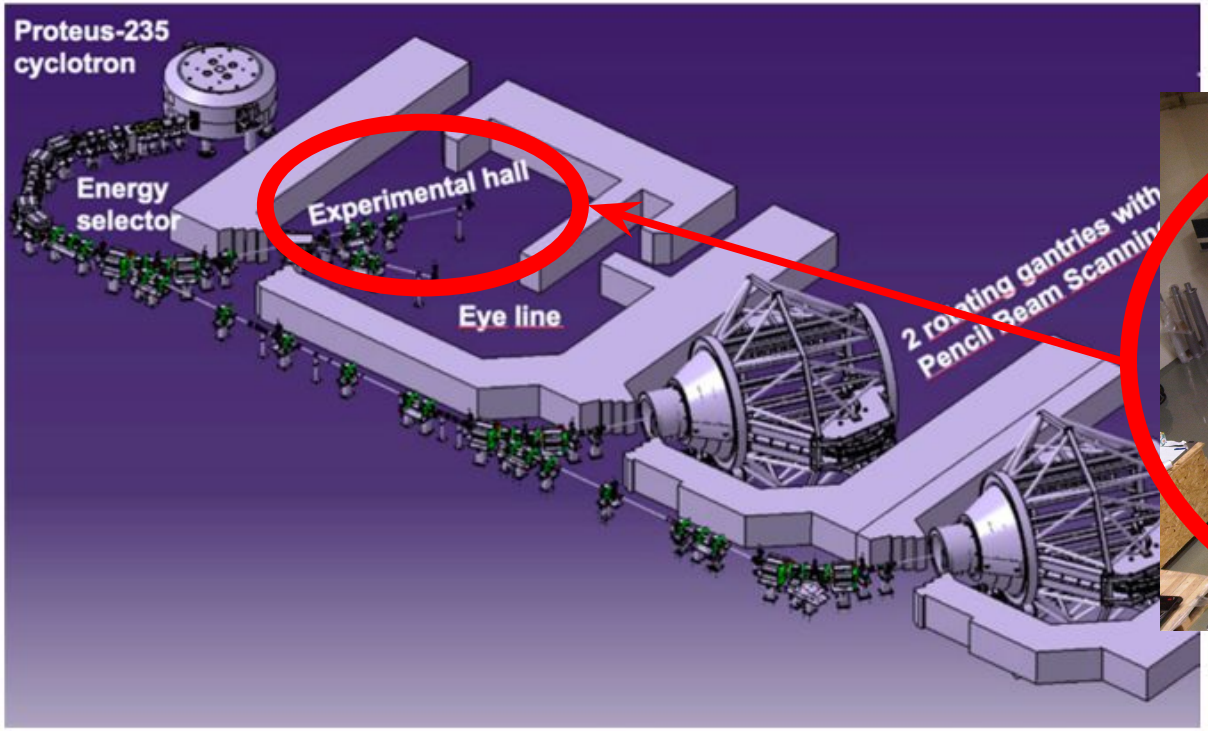
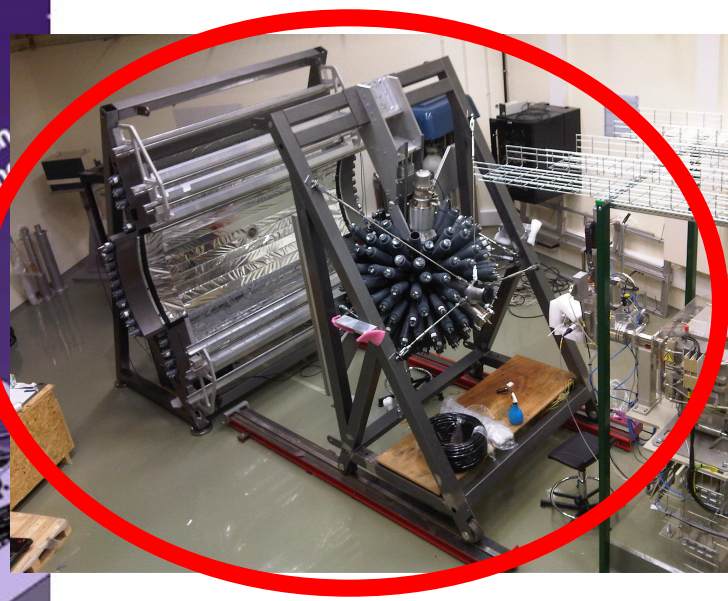
Innovation Fostering in Accelerator Science and Technology
4th Annual Meeting
April 2025, Kraków

Motivation - parameter control for experiments

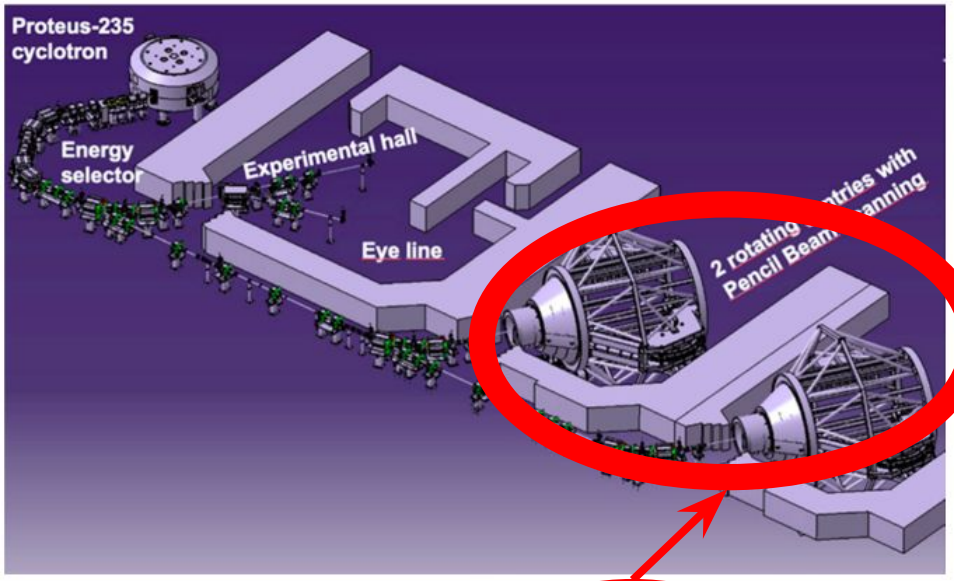
- independent energy and additionally energy smearing monitoring is an asset
- Proteus-235 is calibrated in stopping range in water
- additional feature: measurement of beam profile on the target plane

Big
Instrument for
Nuclear physics
Analysis





Motivation - Medical Diagnostics

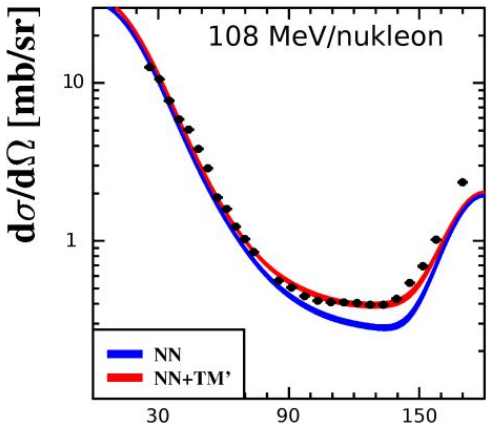


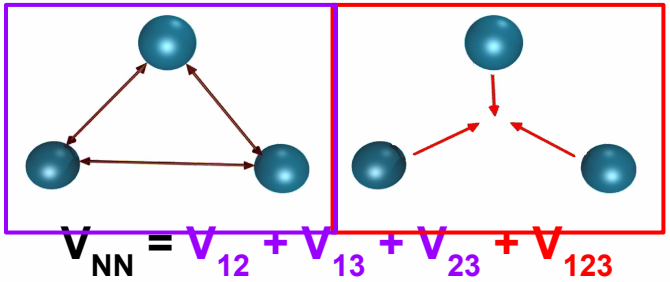
Giraffe

Time consuming measurements

at least 20 minutes for checkout

Motivation - investigation of subtle three nucleon force effects

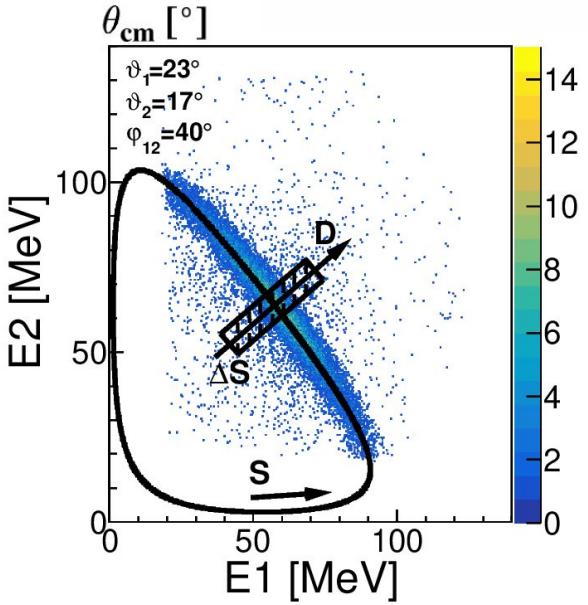


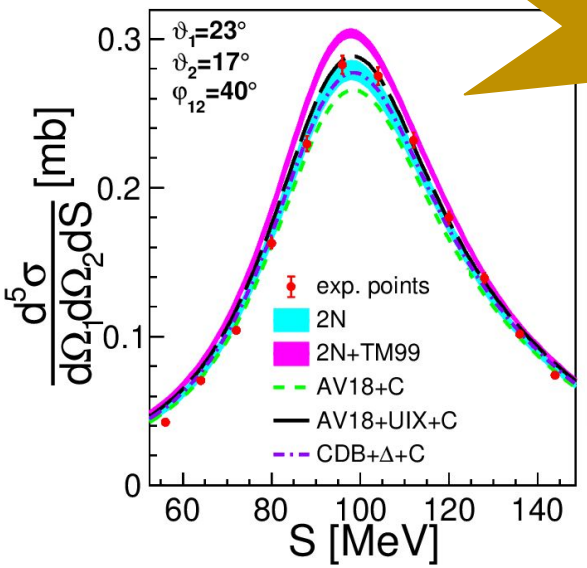


+ Coulomb force
A. Deltuva Phys. Rev. C80 064002 (2009)

+ relativistic effects
H. Witała Phys. Rev. C83, 044001 (2011)

$\delta\sigma < 1\%$

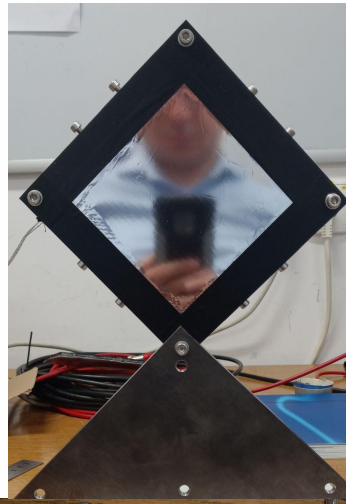


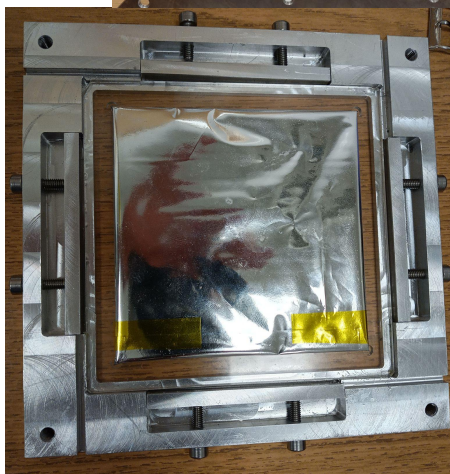


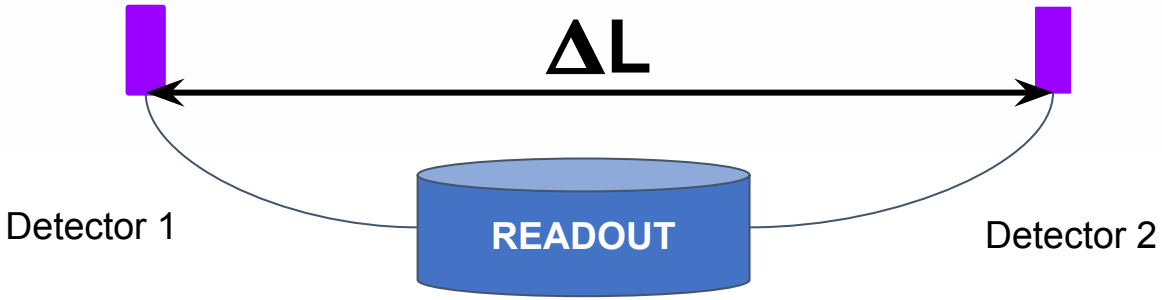
Time-of-flight method

$$E_{kin} = m_0 c^2 \left(\frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} - 1 \right)$$

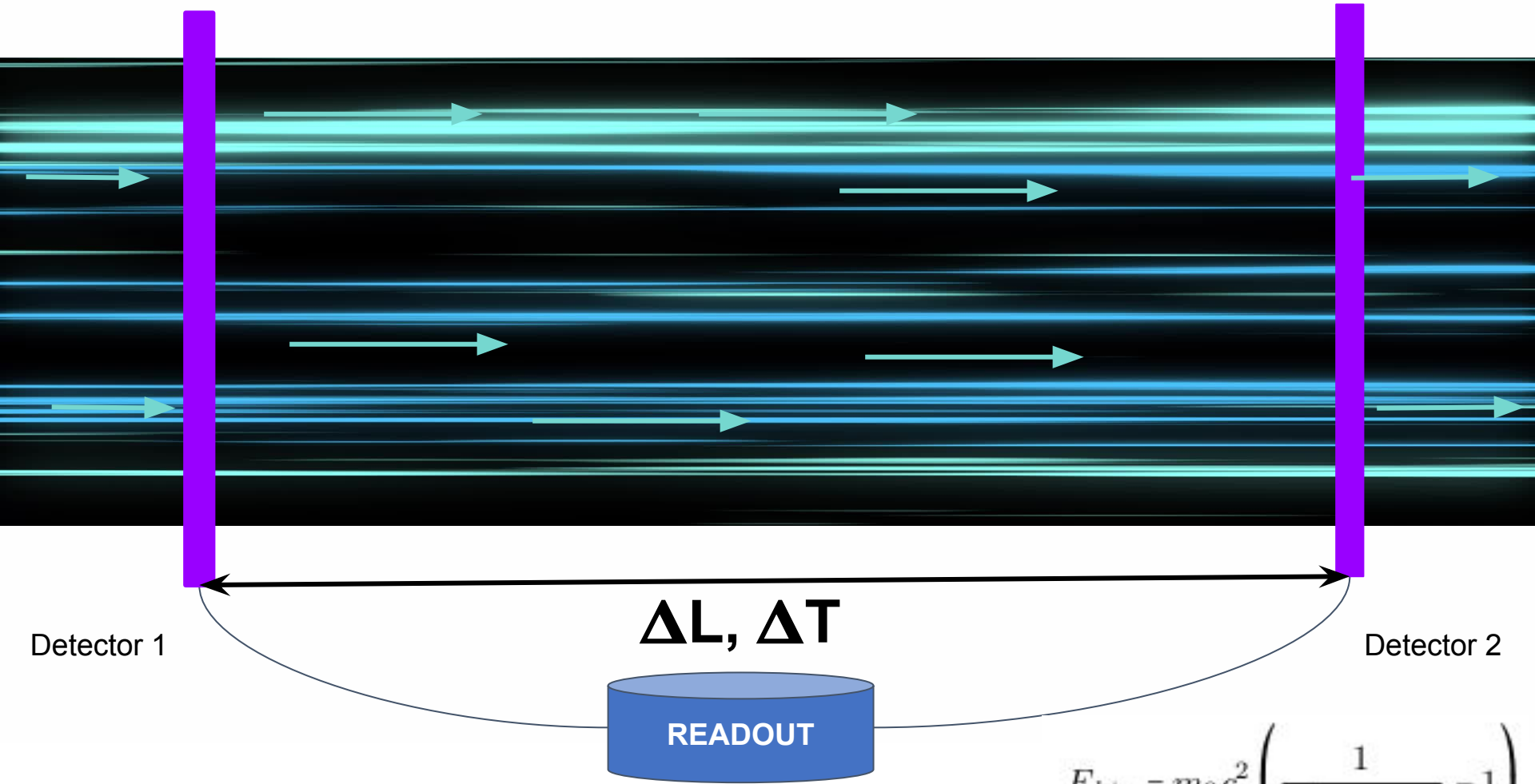
- Development of applicable beam geometry analysing method:
  - **accurate and precise** -- energy measurement (70-230 MeV)
  - **fast** -- doable on spot “during” experiment or therapy
  - **cost efficient** -- relatively to actually adopted solutions
  - sufficient XY resolution for protons distribution on target plane
- Chosen hardware:
  - Thin plastic scintillators frame
  - Oscilloscope-like acquisition
  - Boards with Silicon PhotoMultipliers (SiMP)





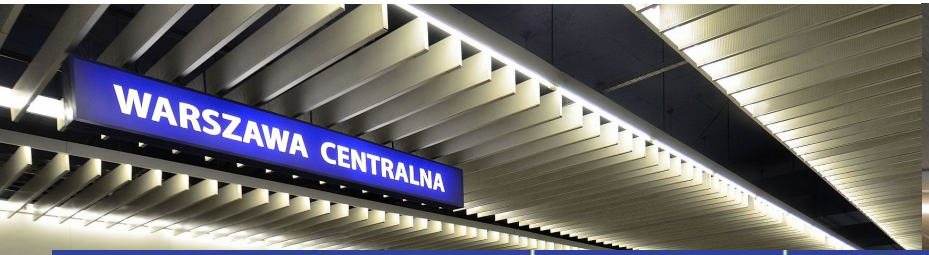


Trigger problem…



$$E_{kin} = m_0 c^2 \left(\frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} - 1 \right)$$

Idea: EIP Trains on route Krakow-Warsaw



STATION/STOP	DATE	TIME	DURATION
Kraków Główny Warszawa Centralna	09.04.25	dep19:57 arr22:20	2:23
Kraków Główny Warszawa Centralna	10.04.25	dep05:50 arr08:20	2:30
Kraków Główny Warszawa Centralna	10.04.25	dep06:23 arr09:08	2:45
Kraków Główny Warszawa Centralna	10.04.25	dep06:57 arr09:20	2:23

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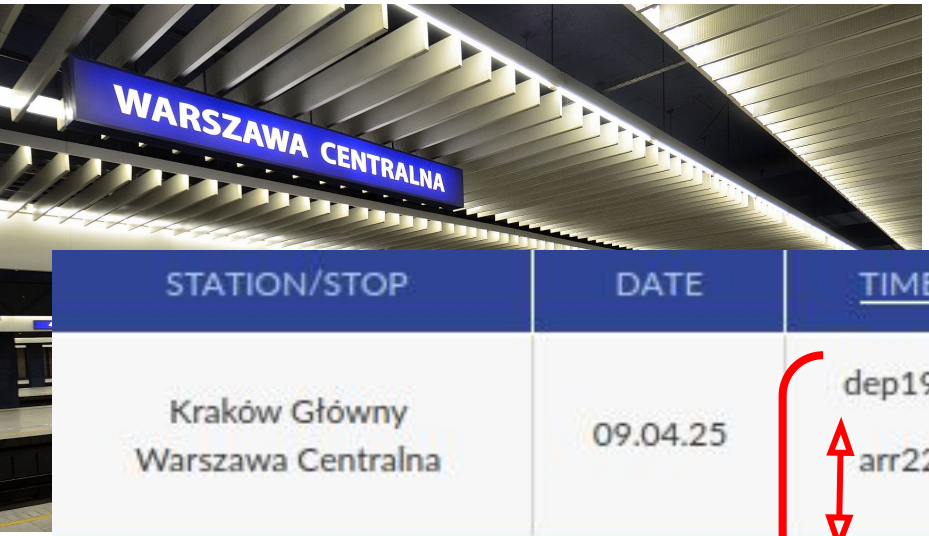

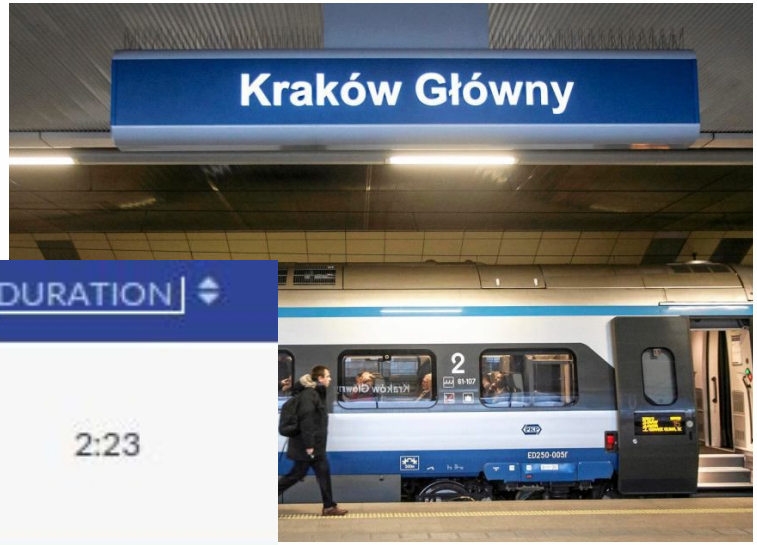

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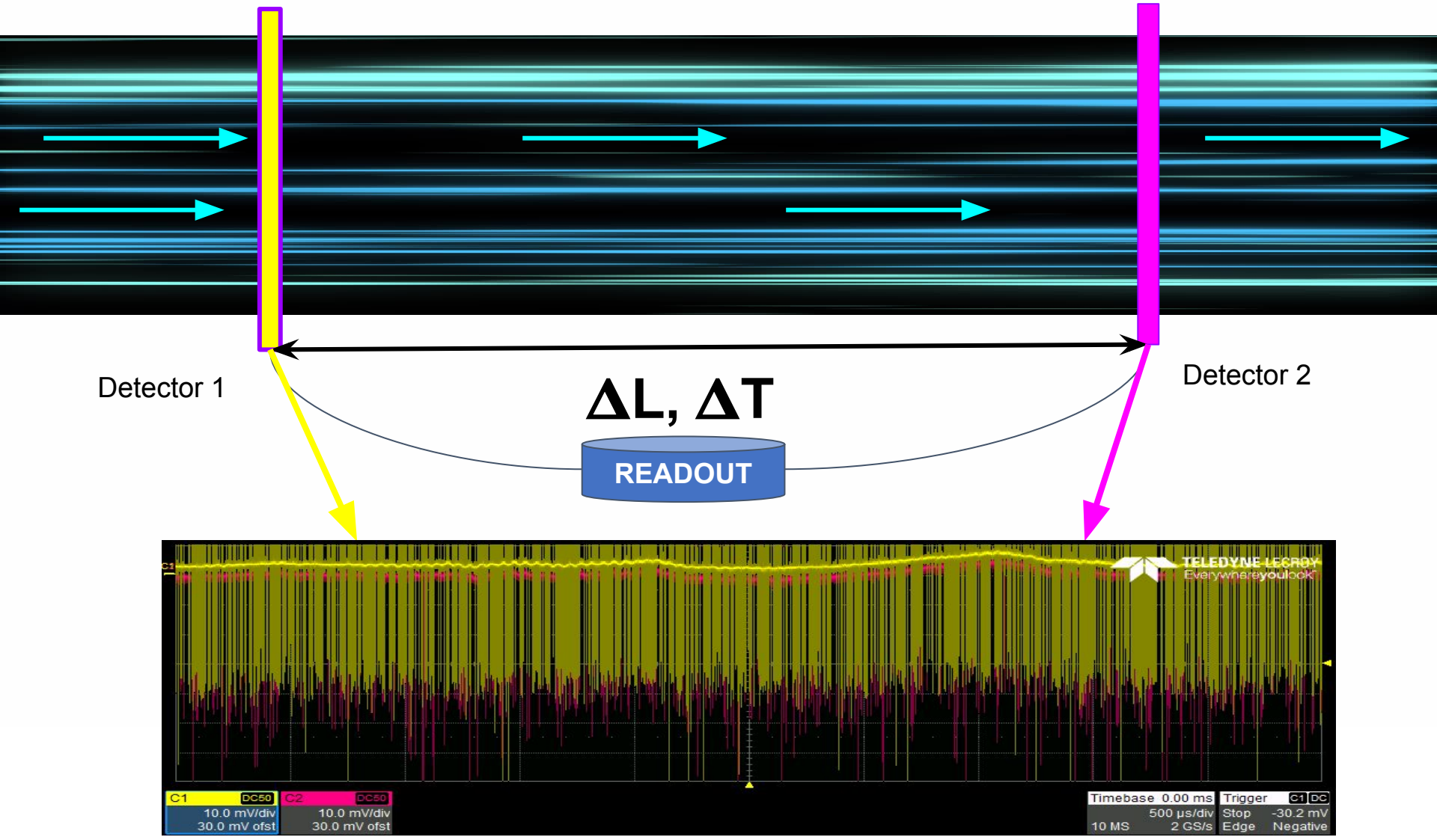
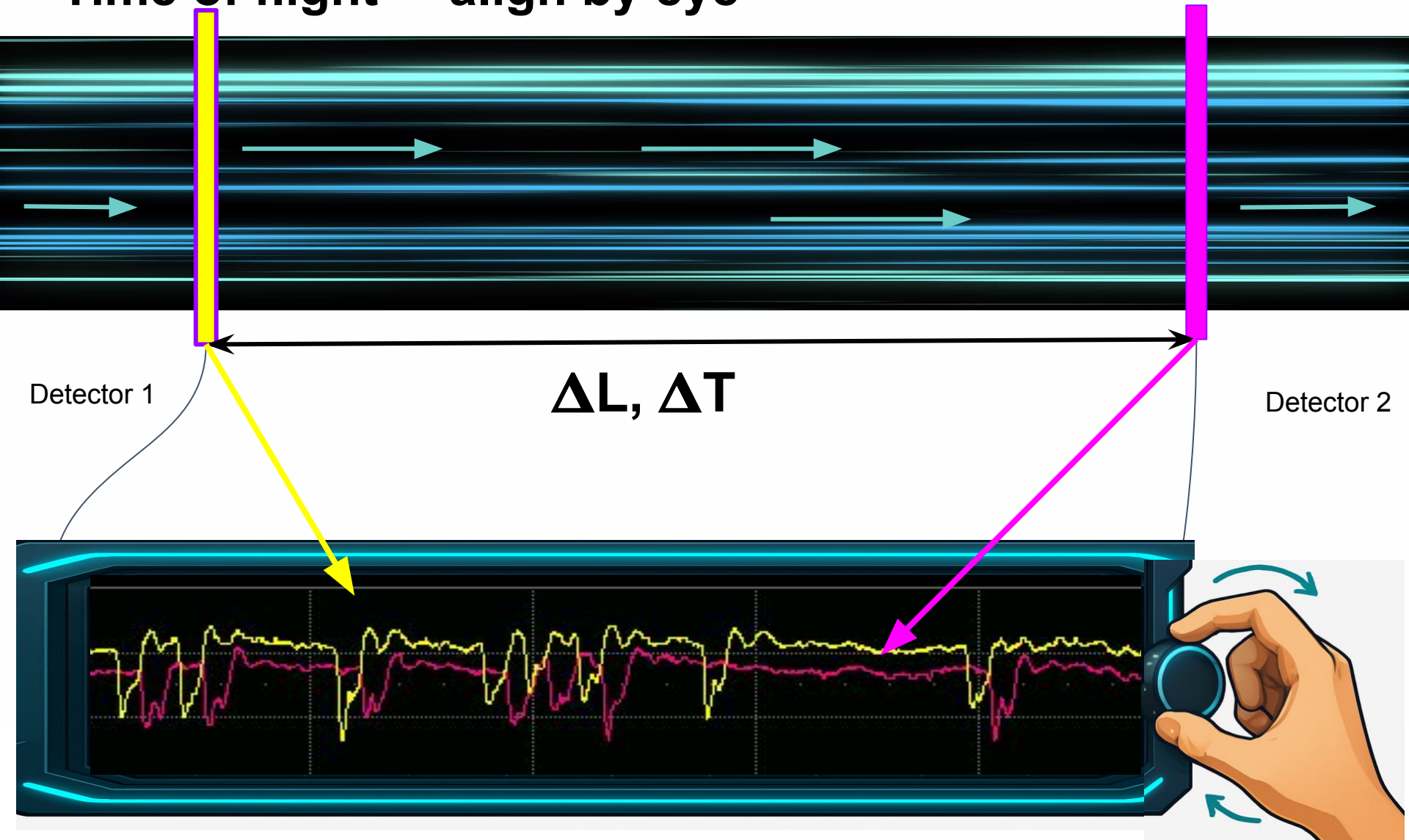
PATTERN

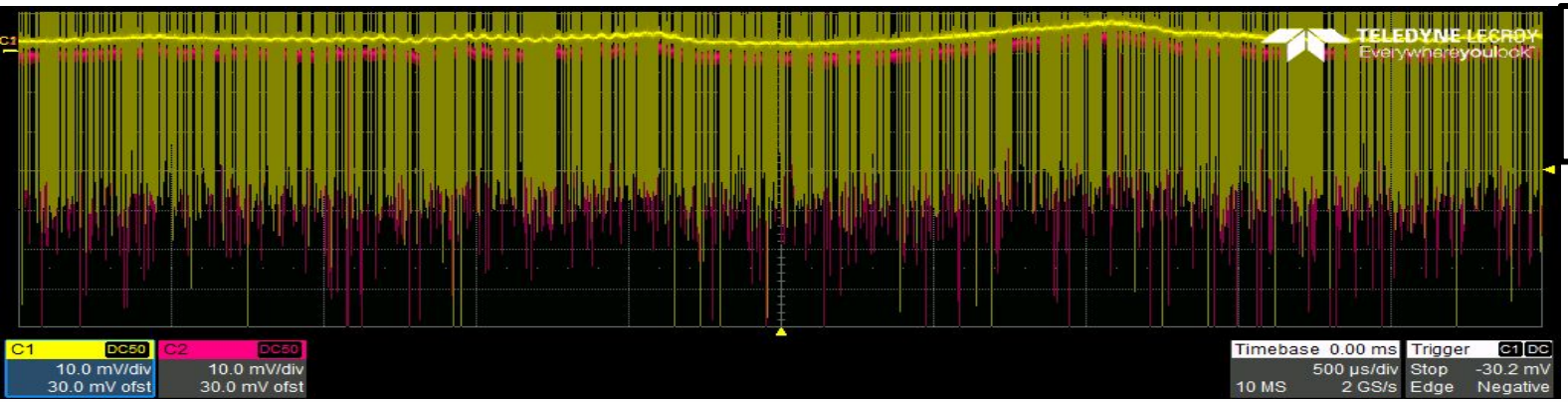
Lets treat beam as a collective state…



Time of flight - “align by eye”

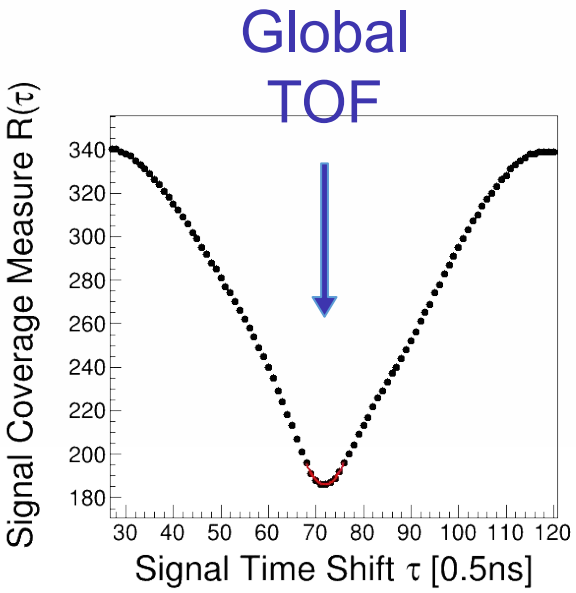


Waveform Pattern Alignment (WPA)

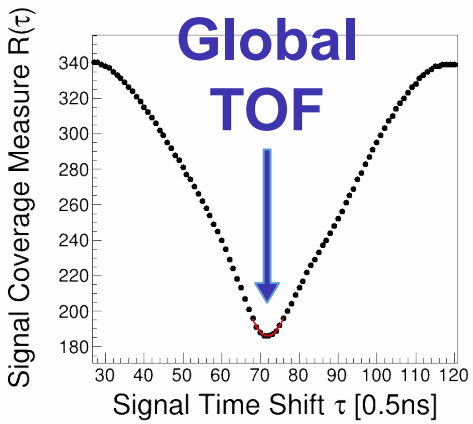


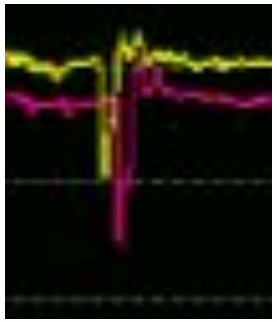
70 MeV
1 nA

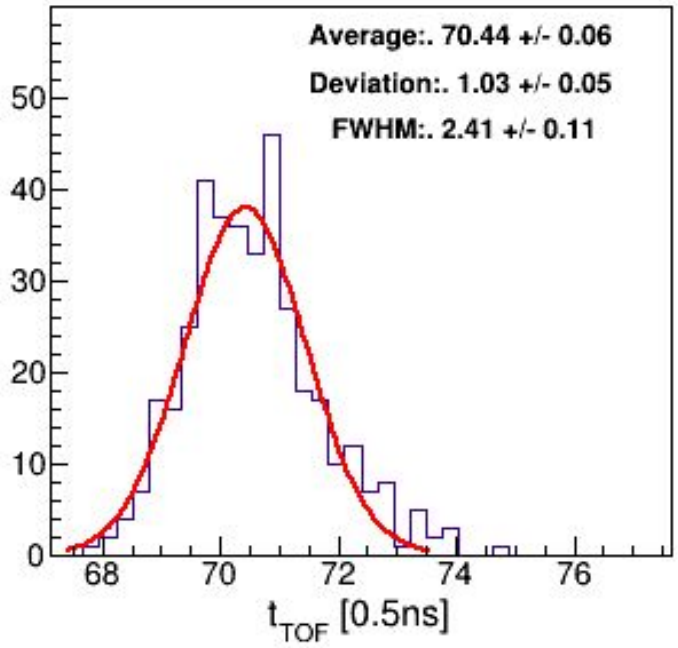
$$R(\tau) = \frac{1}{N-\tau} \sum_{k=0}^{N-\tau} \left| S^A(k) - S^B(k+\tau) \right|$$

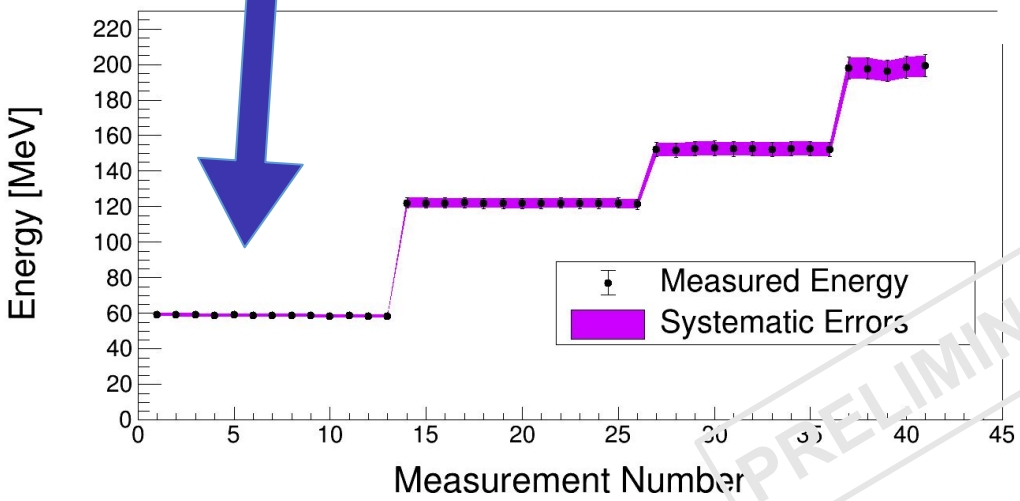


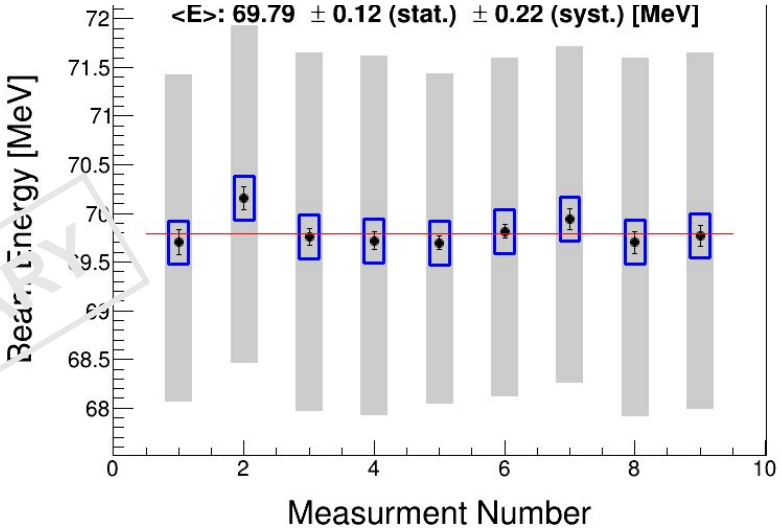
Energy of individual particles



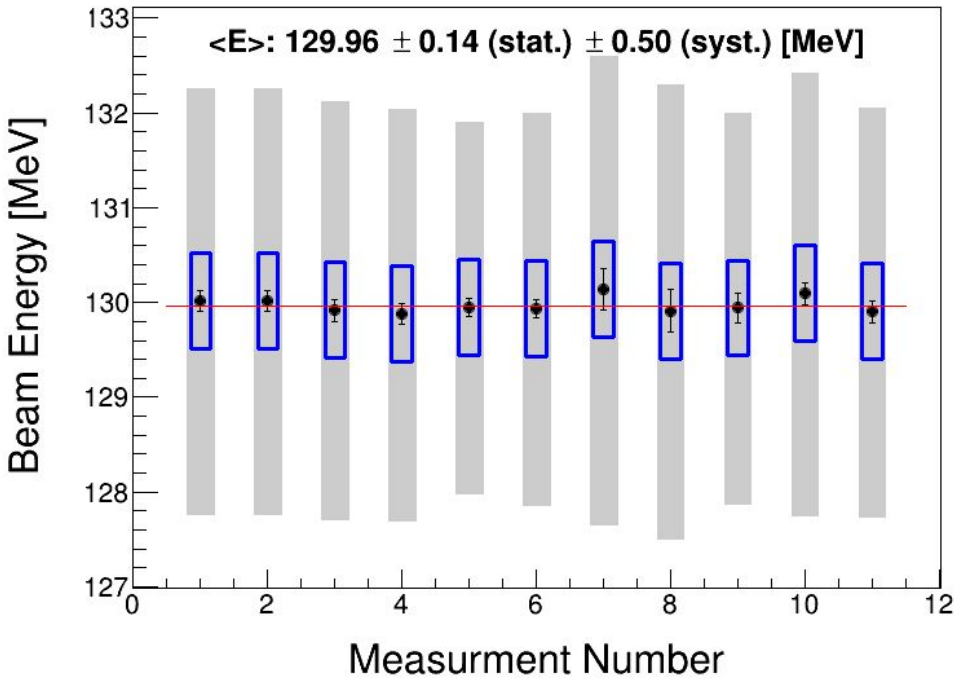


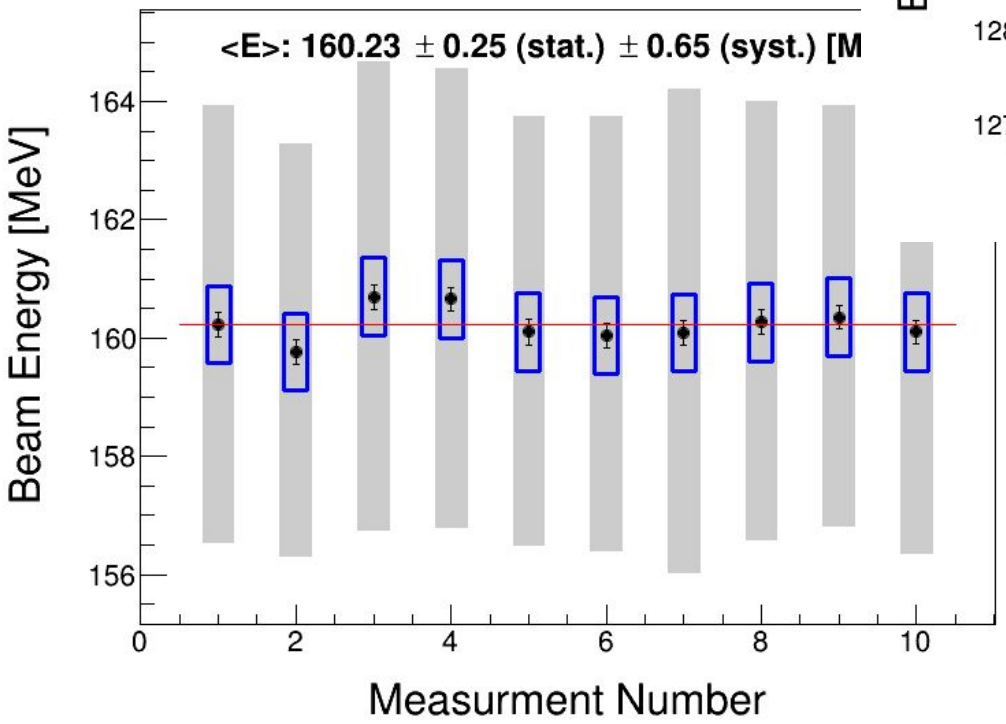






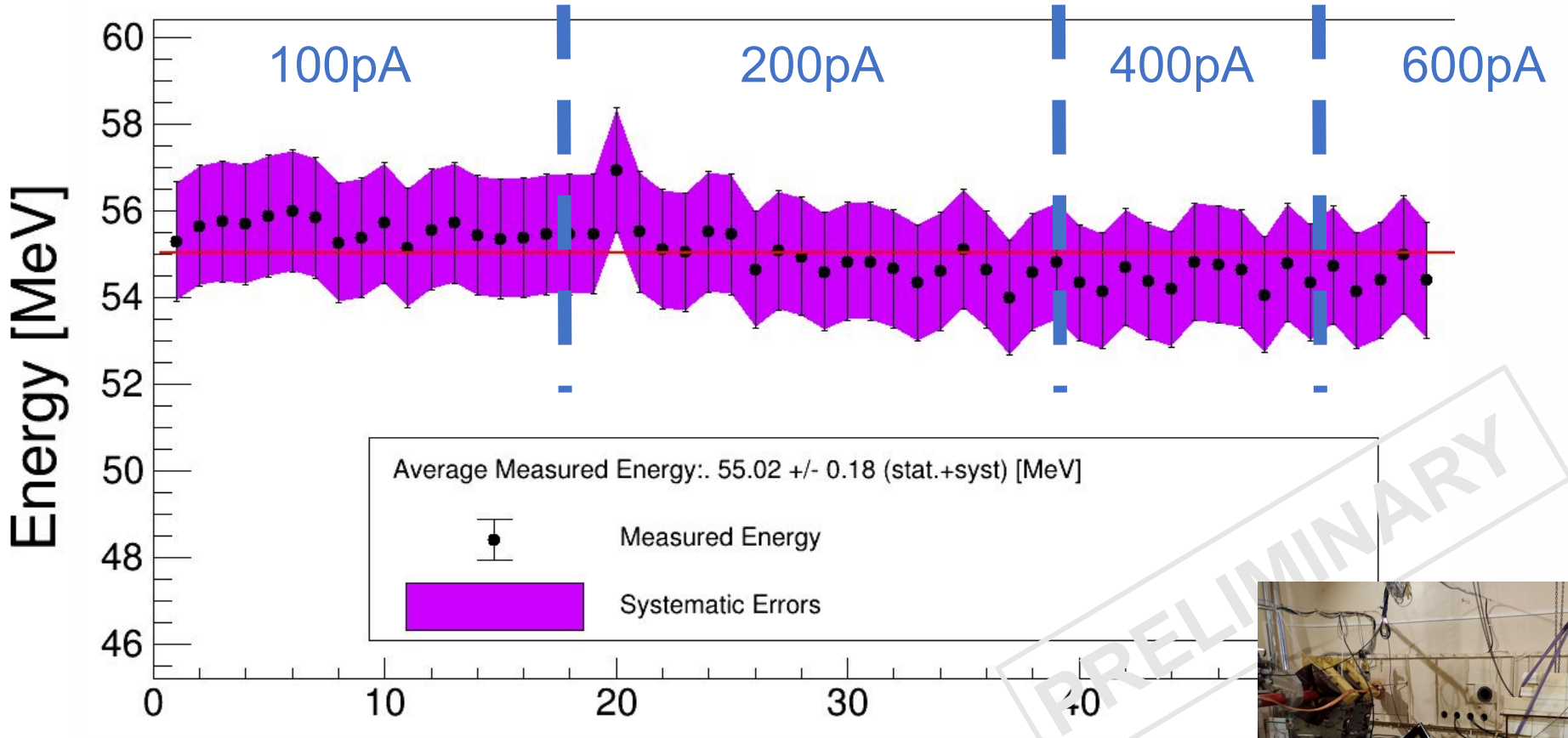
Energy and its smearing





5 ms for one point

Bursting beam test with bigger currents



Given energy: 60 MeV
(estimated loss ~5.54 MeV)

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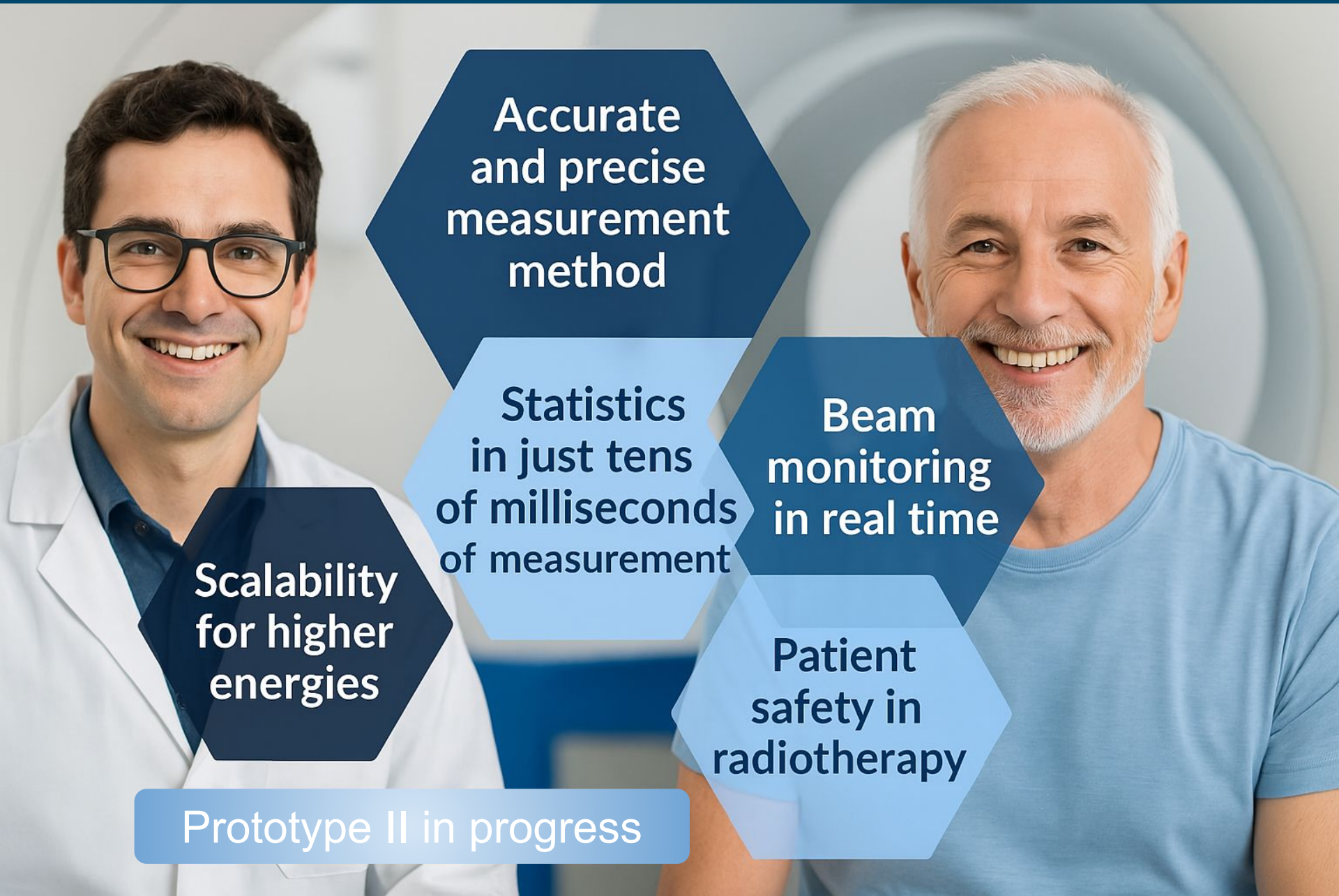

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THANK YOU FOR YOUR ATTENTION

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