Single-Event Upsets in the PANDA EMC

Status of neutron and proton irradiations of the front-end digitiser board

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Front-end electronics in the Electromagnetic Calorimeter

$\sim$ 600 front-end digitiser boards in the EMC

375 in Barrel* 217 in Forward Endcap

(* approximate, 80 MSPS 64 channels $\rightarrow$ 65 MSPS 128 channels in barrel.)

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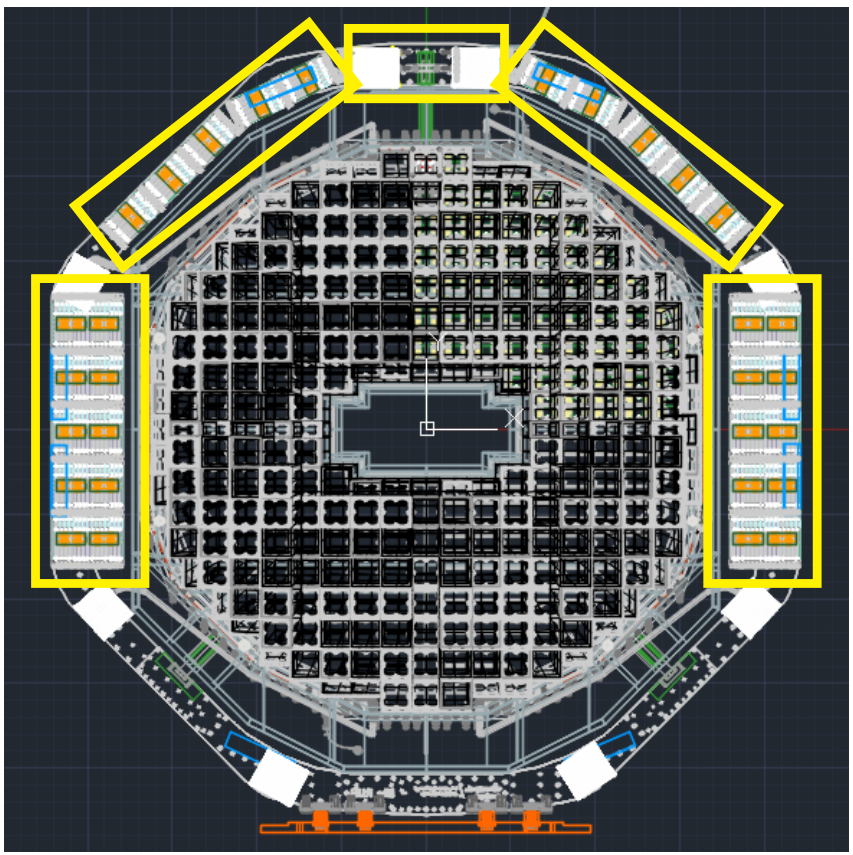

Figure courtesy of C. Schnier.

- Distributed over several crates placed around the detector perimeter (average 1.3 metres from beam pipe at the Forward Endcap).
- Exposure to a high flux of particles $\Rightarrow$ Radiation effects
- Of interest here: **neutrons and protons**

Neutron irradiation

- The board was irradiated in June 2016 at the The Svedberg Laboratory (TSL) in Uppsala.
- Proton beam $\rightarrow$ W target $\rightarrow$ Neutron beam. Board perpendicular to the beam. **One** FPGA read out.

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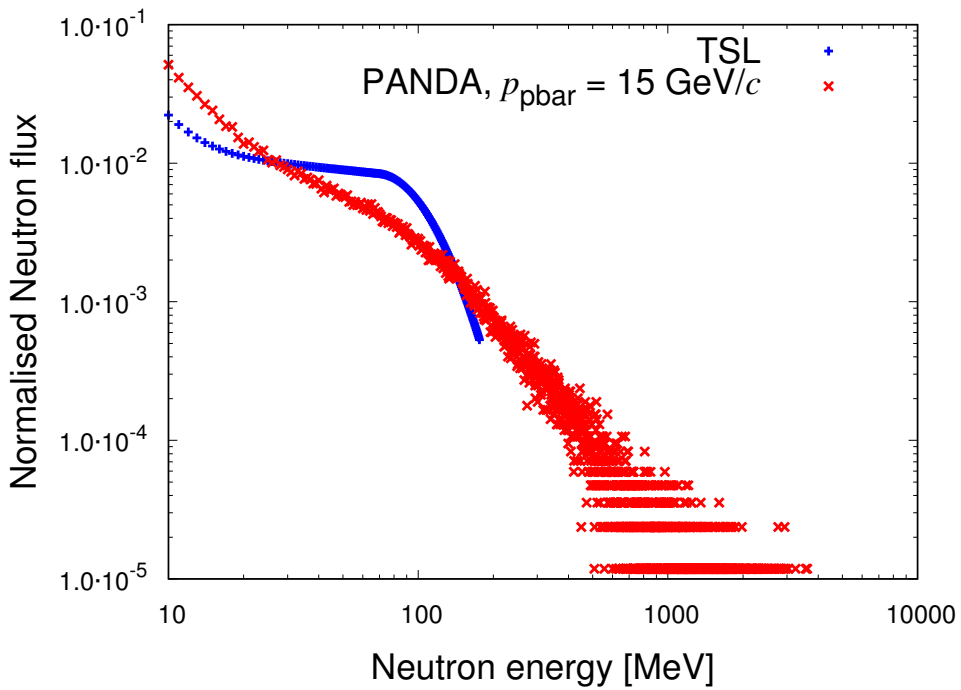
- Proton beam $\rightarrow$ W target $\rightarrow$ Neutron beam. Board perpendicular to the beam. **One** FPGA read out.
- Neutron flux between $5 \cdot 10^5$ and $1 \cdot 10^6$ $s^{-1}cm^{-2}$ (>10 MeV).



pandaROOT simulation courtesy of K. Makònyi.

Proton irradiation

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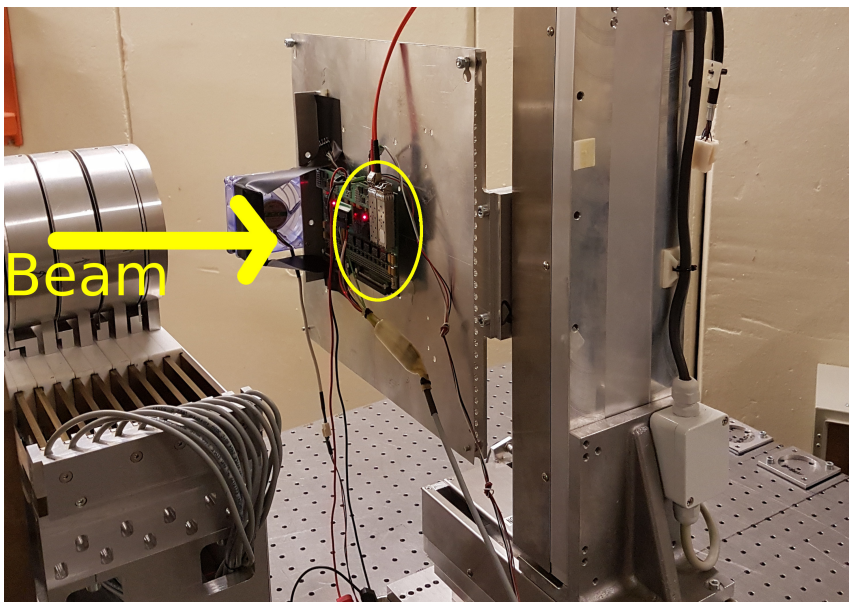
- Board perpendicular to the beam (covering half of the board). **One** FPGA read out.



- Three proton energies:
  - 184 MeV (primary beam energy)
  - 80 and 100 MeV (with degrader)
- Total proton fluence over whole irradiation: $\sim 10^{10}$ cm^{-2}.

Single-Event Upsets (SEUs)

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- The FPGA configuration memory (stores function of design)
  - Using Xilinx Soft-Error Mitigation (SEM)
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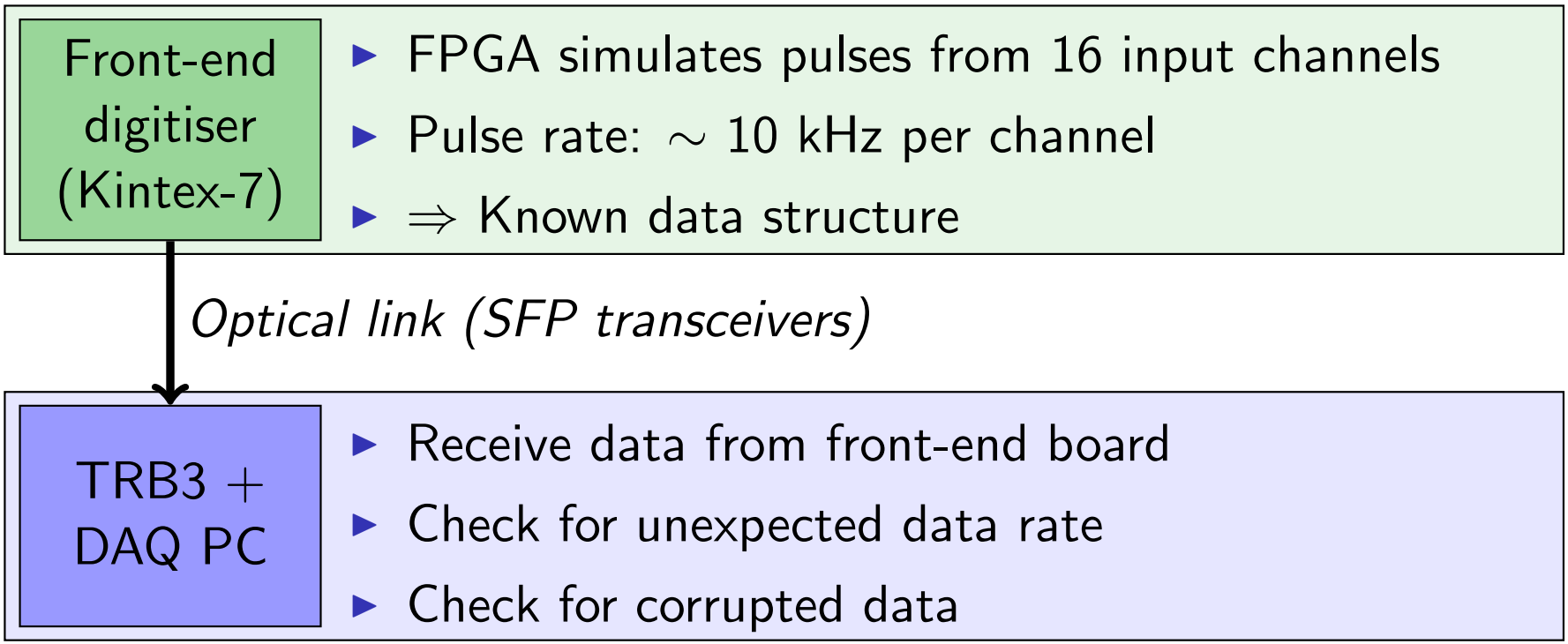
- The full readout (Digitiser + TRB3 Data Concentrator)
  - Only studied in November (protons)
  - Using custom FPGA firmware
  - Generate data stream from digitiser
  - Check for unexpected data received by data concentrator
  - Test errors related to data transfer in FPGA, optical link, etc.

Testing the full readout chain

Measurement process

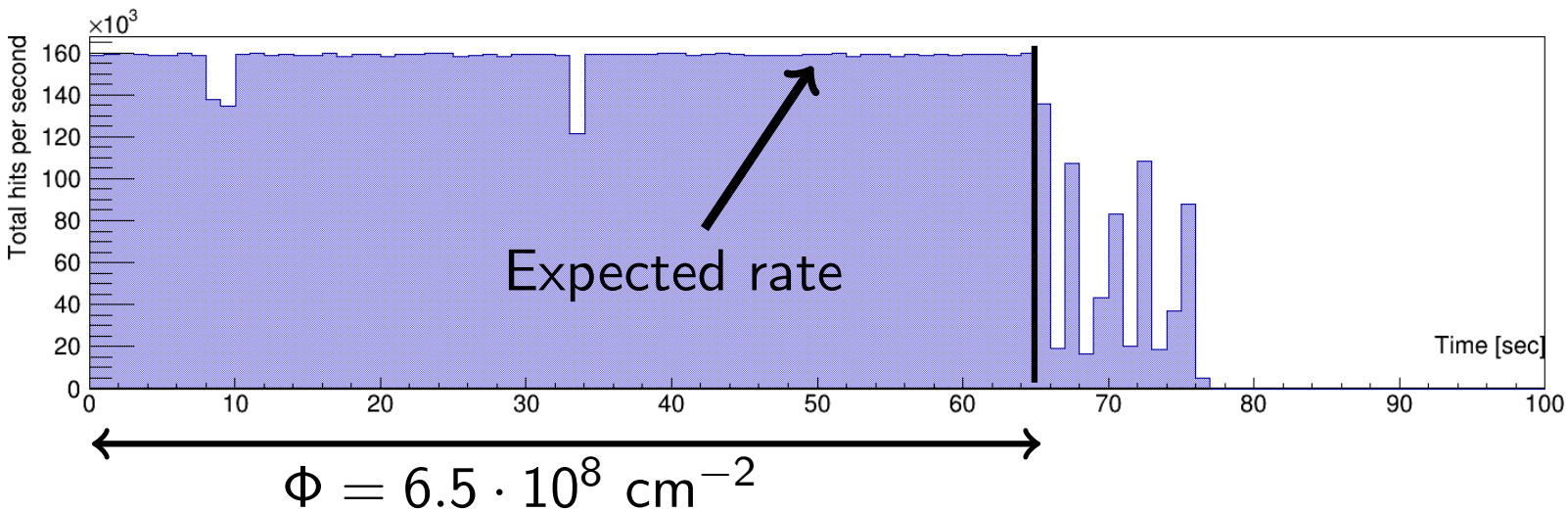


- Reasons for corrupted data during irradiation could be:
  - SEU in FPGA memory section where data is transferred
  - Radiation-induced error in optical connection

Full readout chain tests

Results

- Analysis still at an early stage.
- At low proton fluxes, no large deviation from expected data observed.
- Increase proton flux to $1 \cdot 10^7$ cm^{-2} s^{-1} $\Rightarrow$
  - Occasional errors in received data observed
  - Large drop in data rate and corruption of data observed after $\sim$ 65 seconds ($\Leftrightarrow$ total proton fluence of $6.5 \cdot 10^8$ cm^{-2}).



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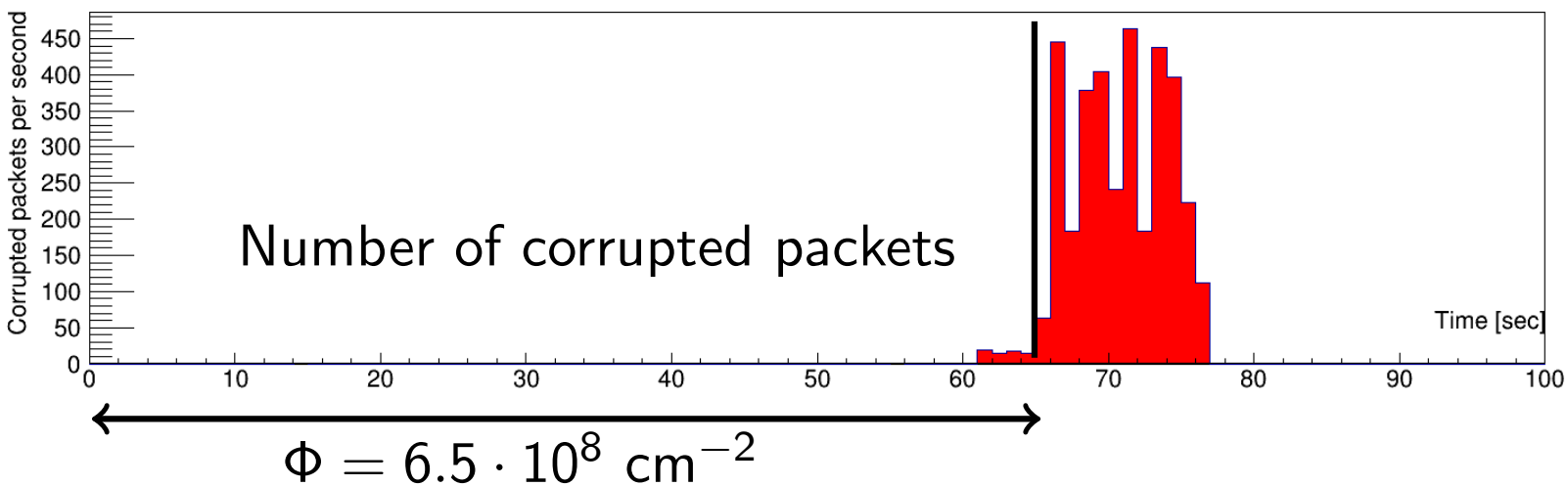
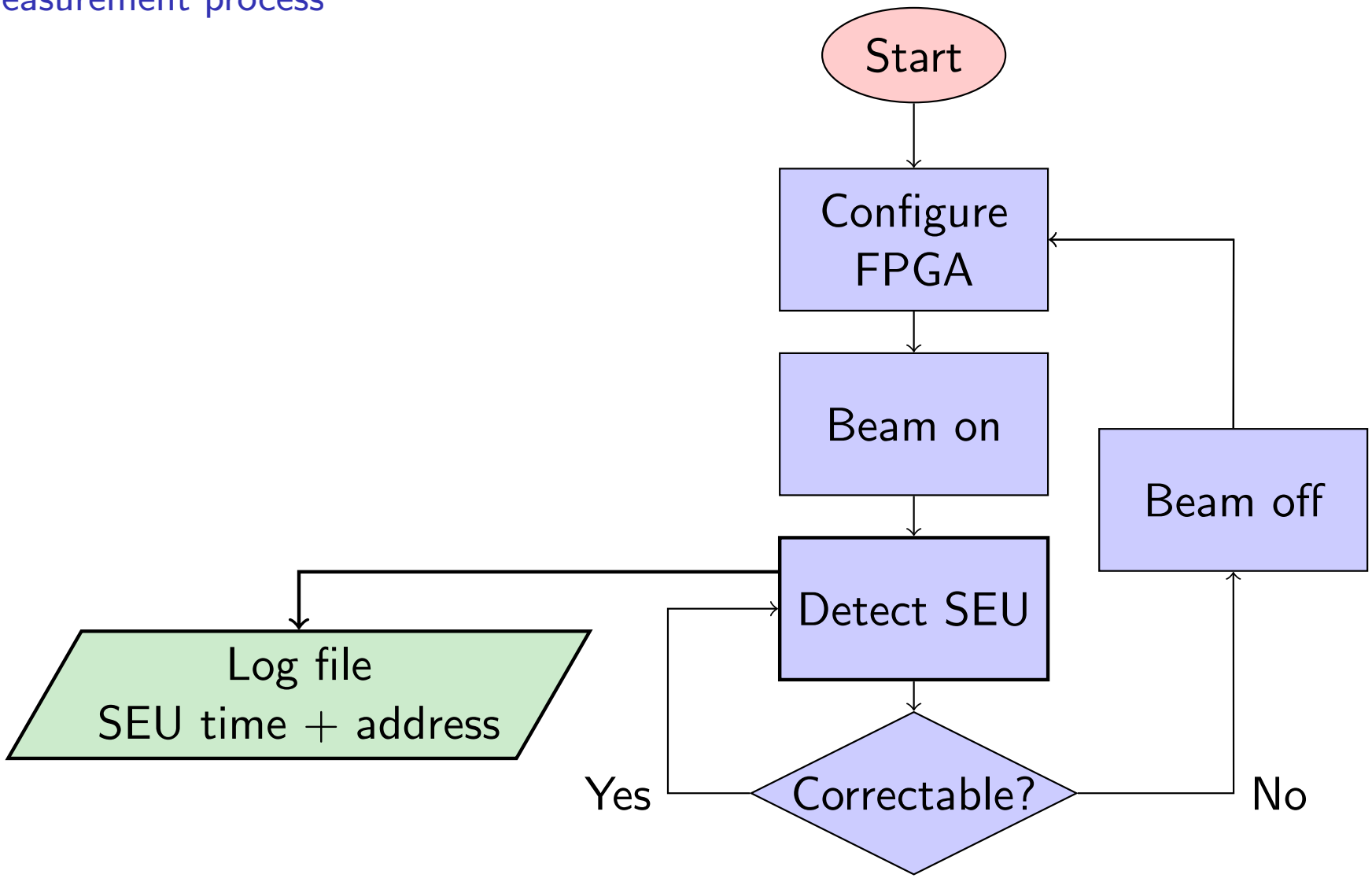


FPGA configuration memory tests

Measurement process

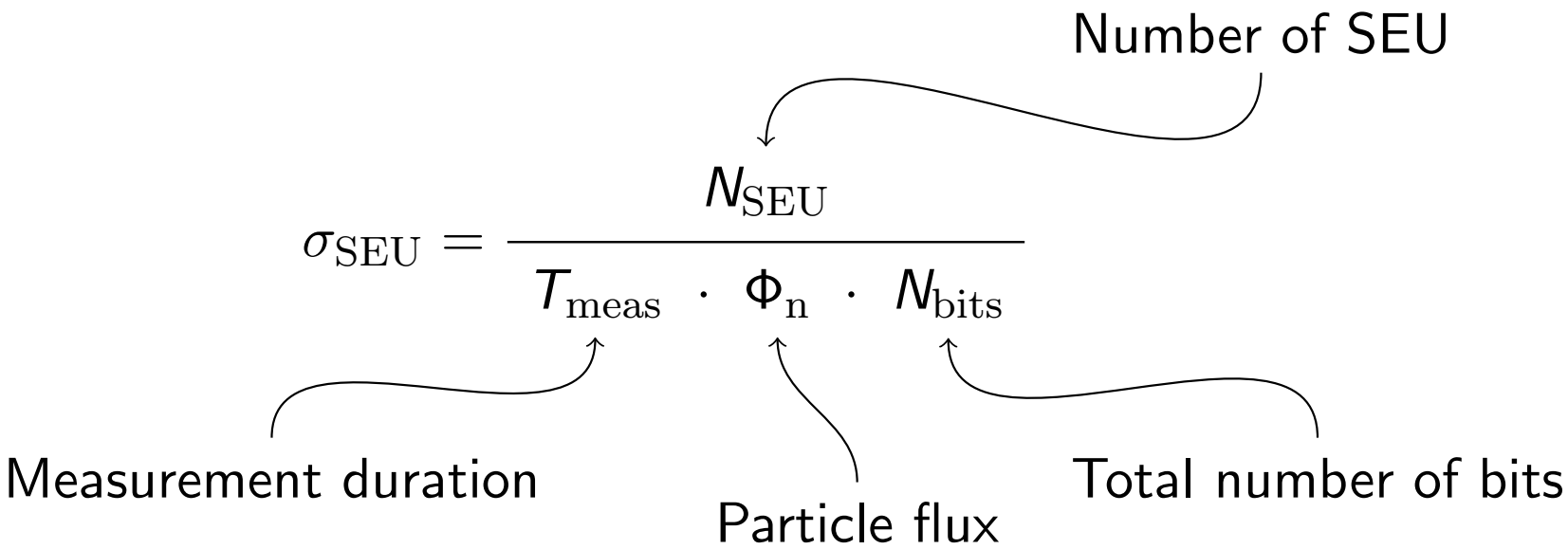


Note: during proton irradiation, SEM automatically reset after uncorrectable error.

Results

SEU cross section

The cross section for an SEU in the FPGA is given by



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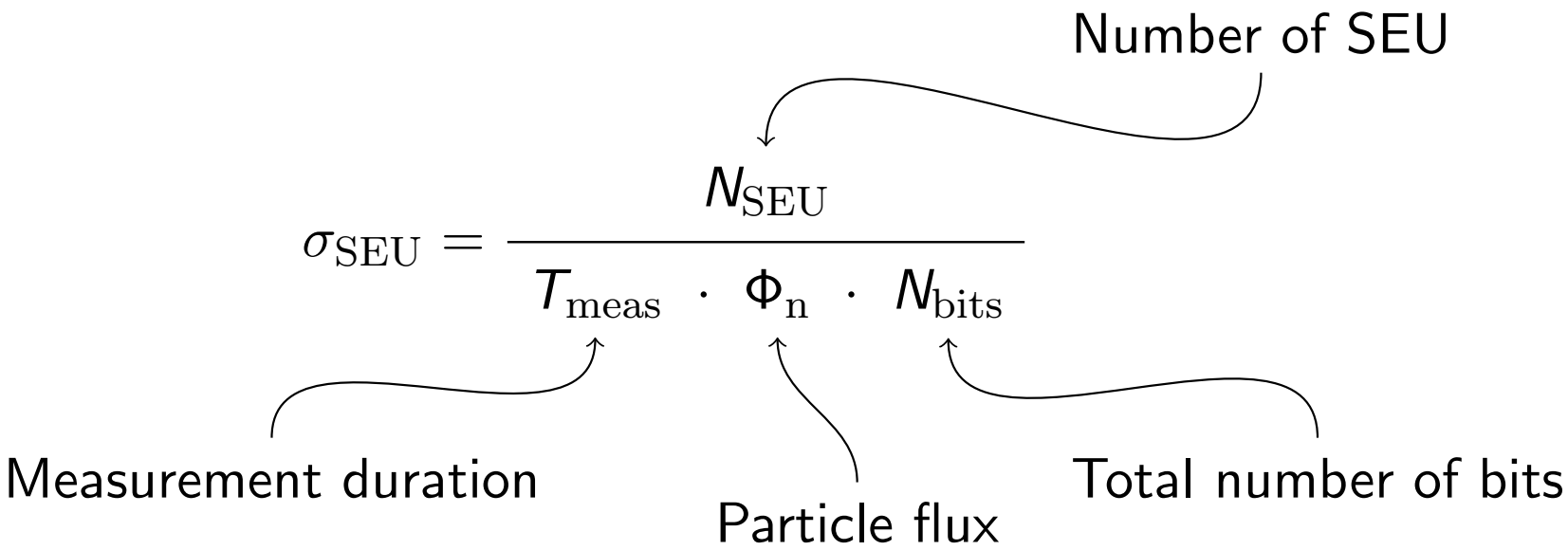

Upset rate, r_{SEU}:

$$r_{\mathrm{SEU}} = \sigma_{\mathrm{SEU}} \cdot \Phi_{\mathrm{n}} \cdot N_{\mathrm{bits}}$$

Mean Time Between Failures, $MTBF$:

$$MTBF = \frac{1}{\sigma_{\mathrm{SEU}} \cdot \Phi_{\mathrm{n}} \cdot N_{\mathrm{bits}}}$$

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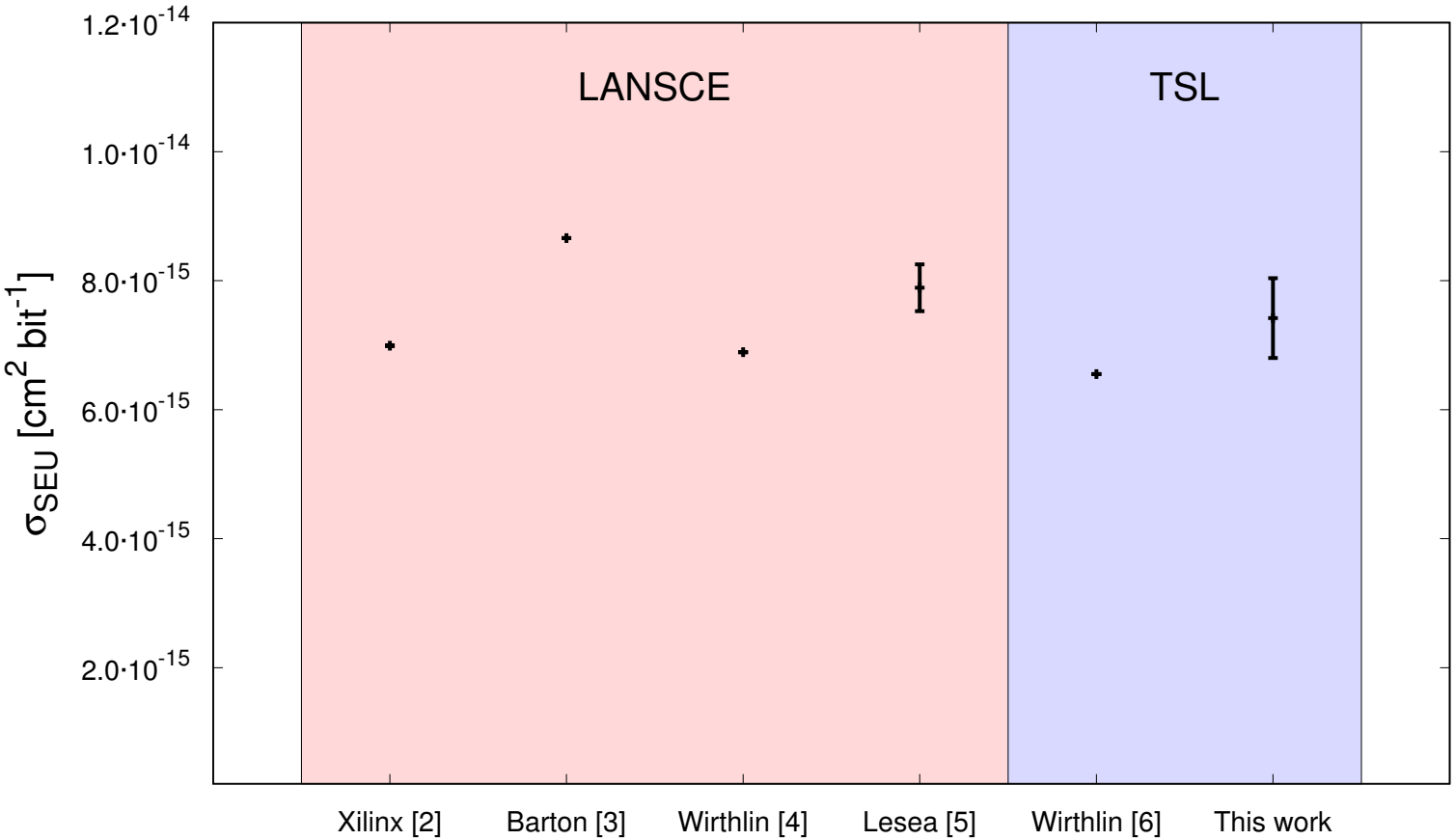
FPGA configuration memory SEU cross section - neutron irradiation

Measured cross section: $\sigma_{\mathrm{SEU}} = 7.4 \cdot 10^{-15}$ cm^2 bit^{-1}.
Good agreement with other measurements on Kintex-7:



TSL: The Svedberg Laboratory
LANSCE: Los Alamos Neutron Science Center (similar neutron spectrum)

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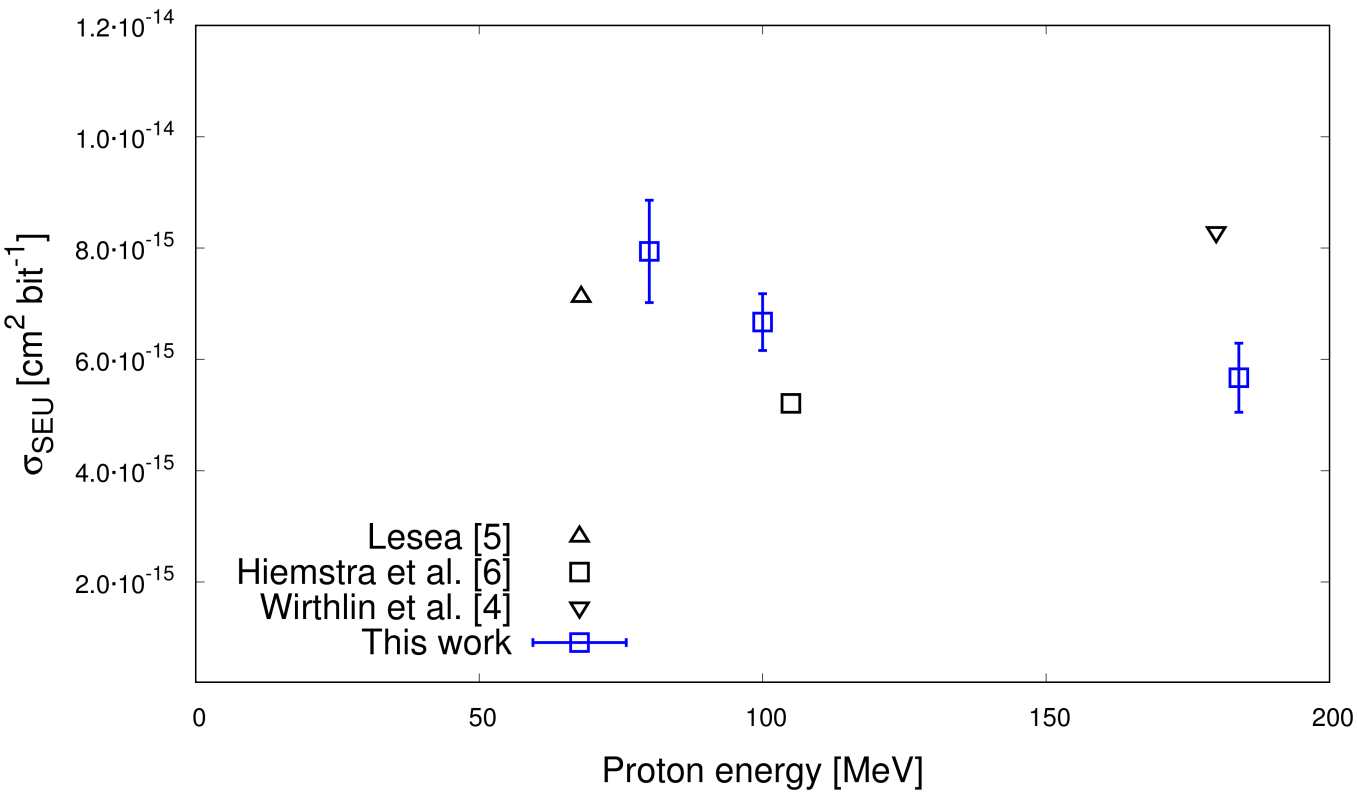

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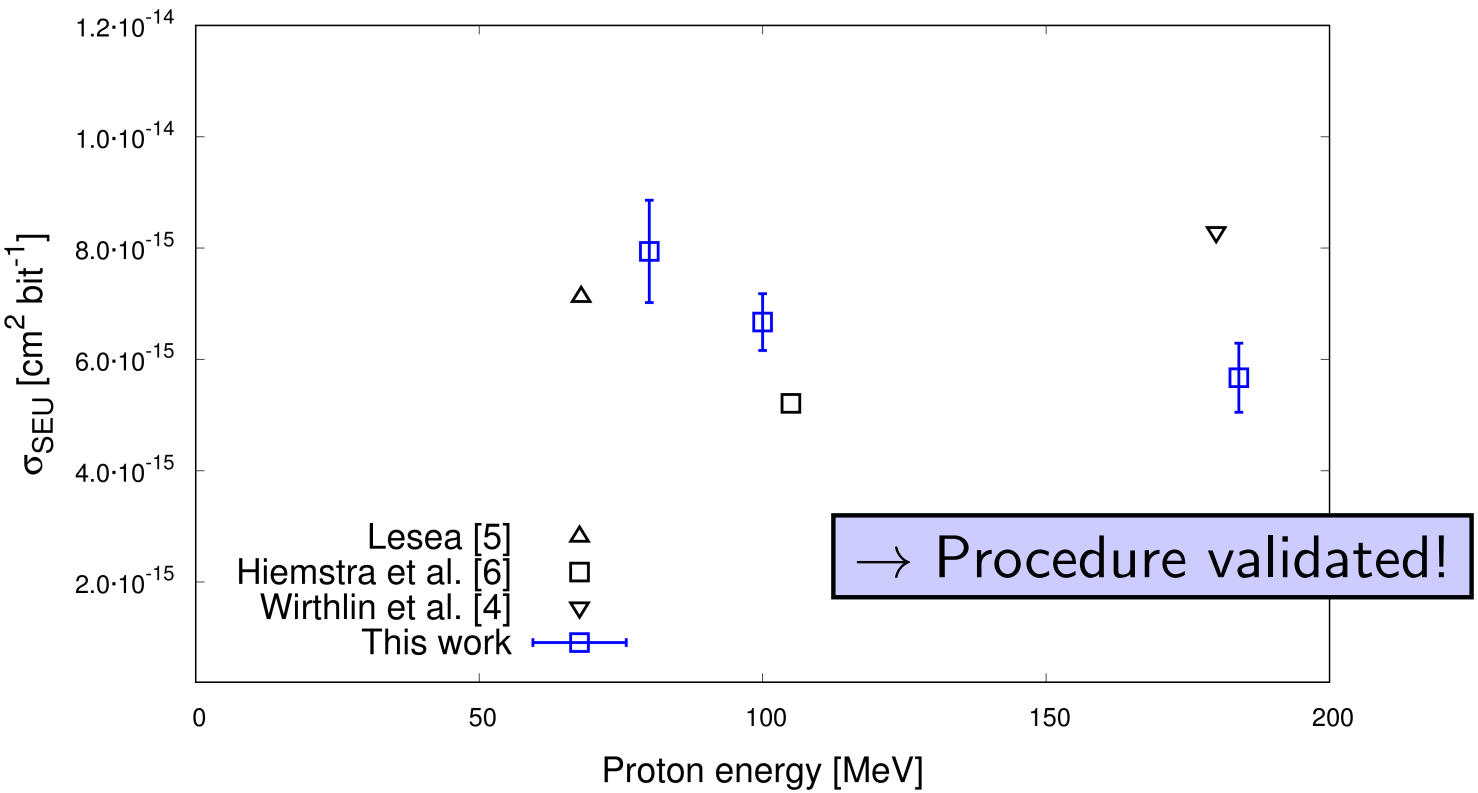

SEU rates in the Electromagnetic Calorimeter

- Simulations of particle fluxes in the forward endcap of the EMC have been made:
  - 2016 simulation of the neutron flux (K. Makònyi)
  - 2012 simulation of the proton flux (M. Kavatsyuk et al., 2012 IEEE NSS/MIC)
- $p_{\mathrm{pbar}} = 15$ GeV/c, $\mathcal{L} = 2 \cdot 10^{32}$ cm^{-2} s^{-1} $\Rightarrow$
  - Φ_{n} at position of digitisers is $\sim$150 cm^{-2} s^{-1}.
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    - Any type of SEU: 18 seconds
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- **These values describe how often the different error types would occur in the whole EMC.**

Monte Carlo simulation of SEUs in FPGA memory

- Simulating energy deposit in "memory cell" (nanometric volume in silicon) using GEANT4.
- Goal: combine with EMC flux simulations, to get better estimate of error rates in the EMC.

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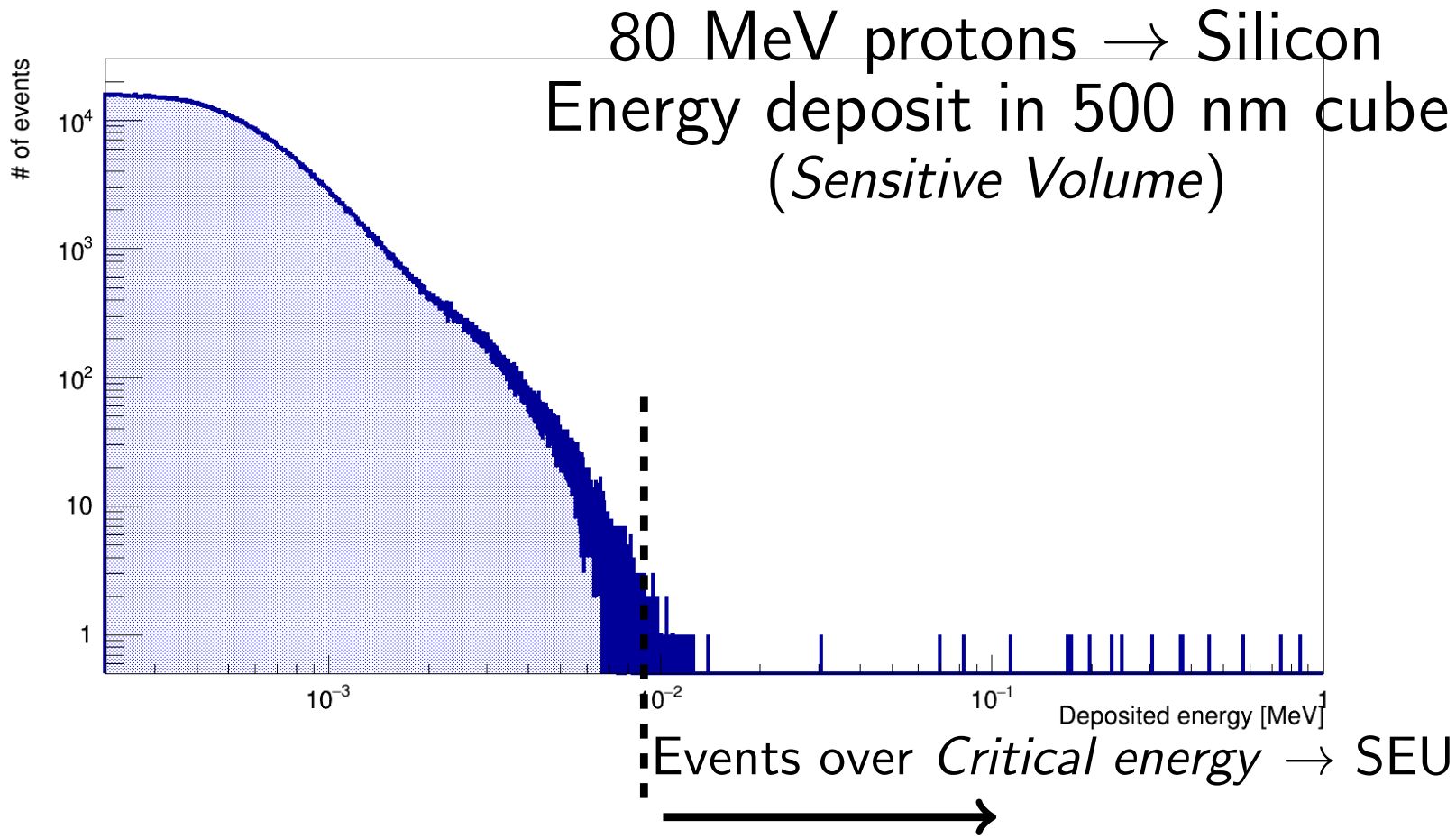

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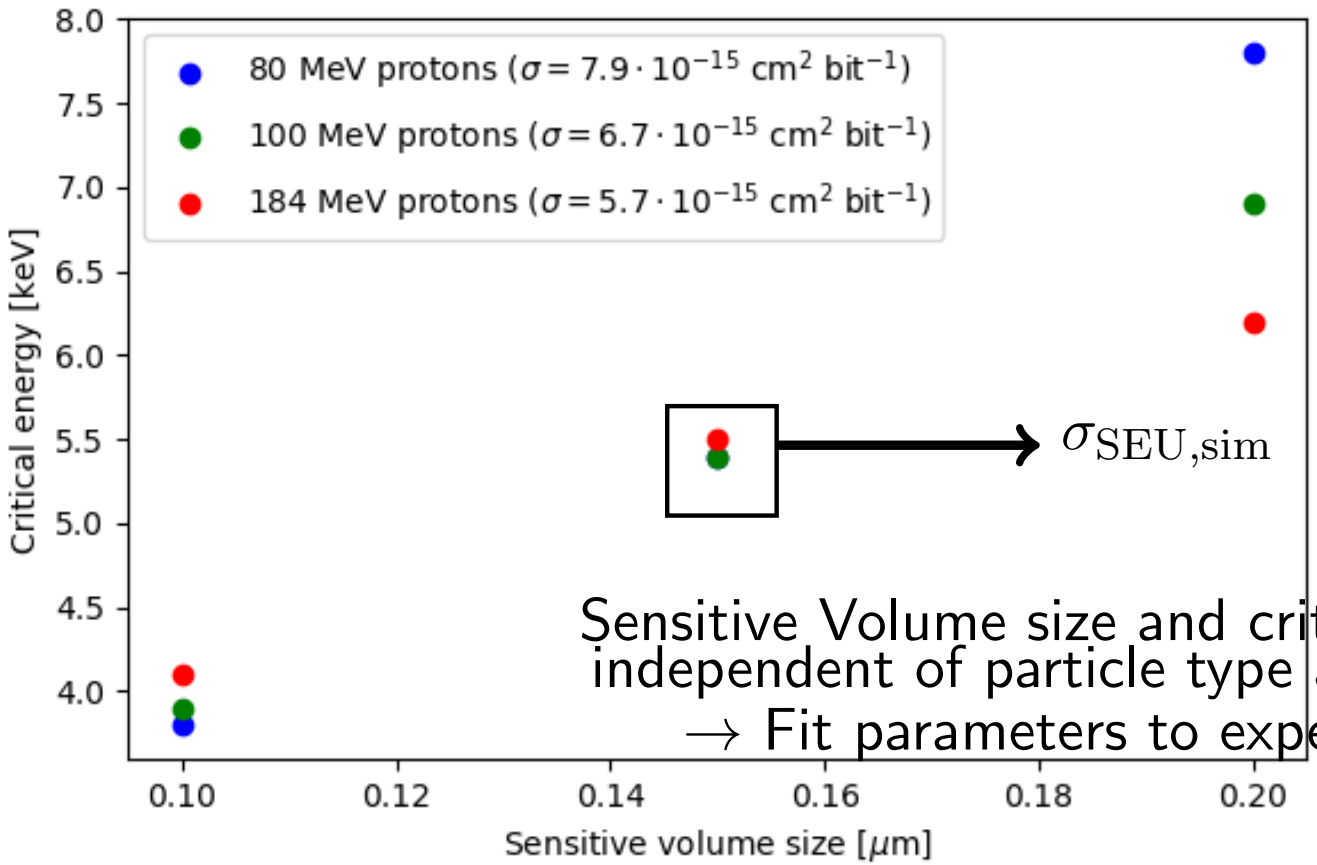

Sensitive Volume size and critical energy independent of particle type and energy
$\rightarrow$ Fit parameters to experiment

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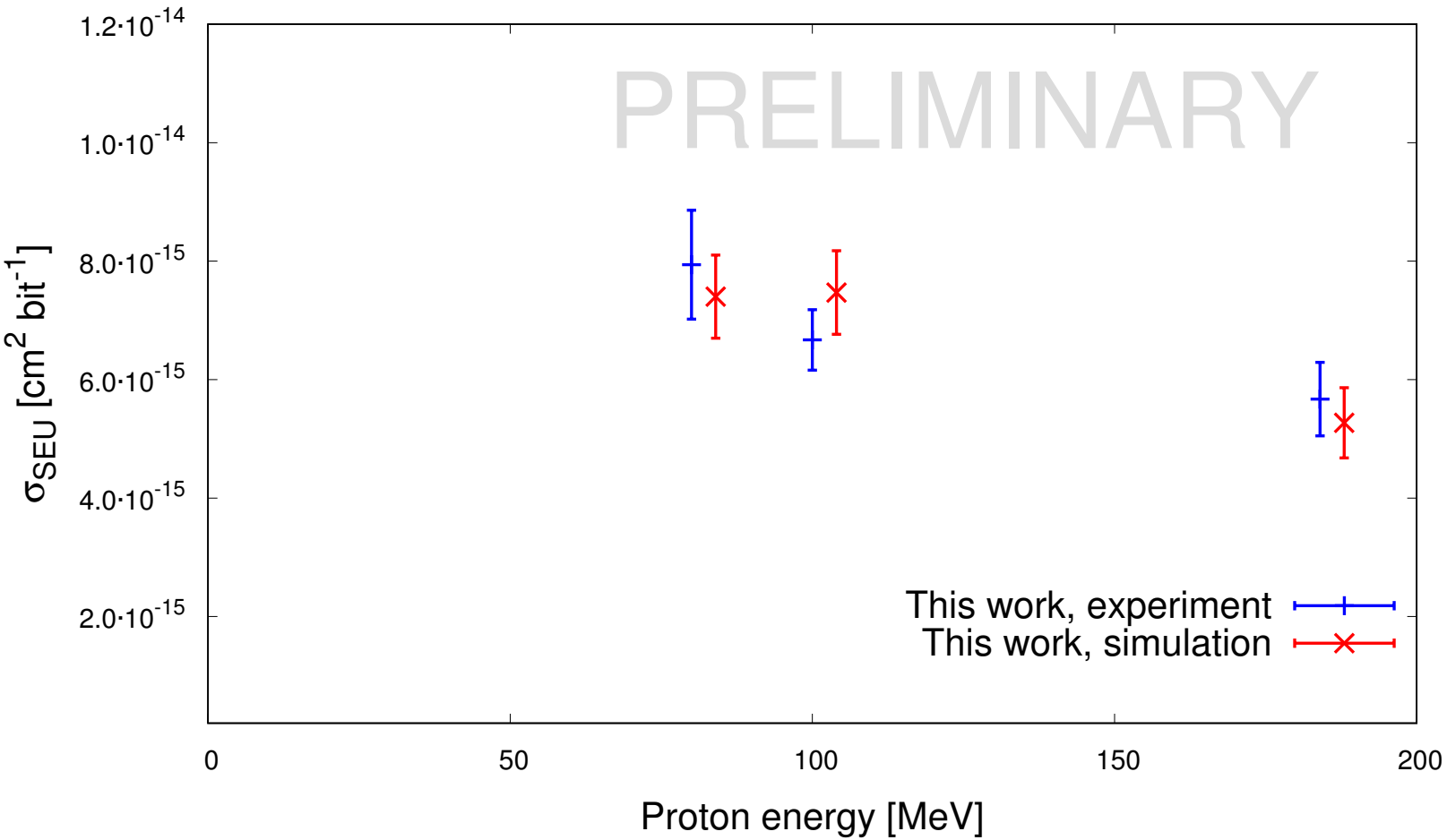

Summary

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- Monte Carlo simulation of SEUs under development.

Outlook

- Further irradiations are planned:
  - Protons at KVI
  - Thermal neutrons in Stockholm
- Sensitivity of other parts of the digitiser board should be tested.
- Analysis of measurements from November still ongoing.
- New pandaROOT-based simulation of charged-particle flux in EMC ($\rightarrow$ energy spectrum of particles) - work ongoing.
- Monte Carlo simulation of SEUs in progress
  - Future: simulation of neutron-induced SEUs

Thank you!