Beam Loss Simulations for the Proposed TATTOOS Beamline at HIPA

HB 2023 workshop

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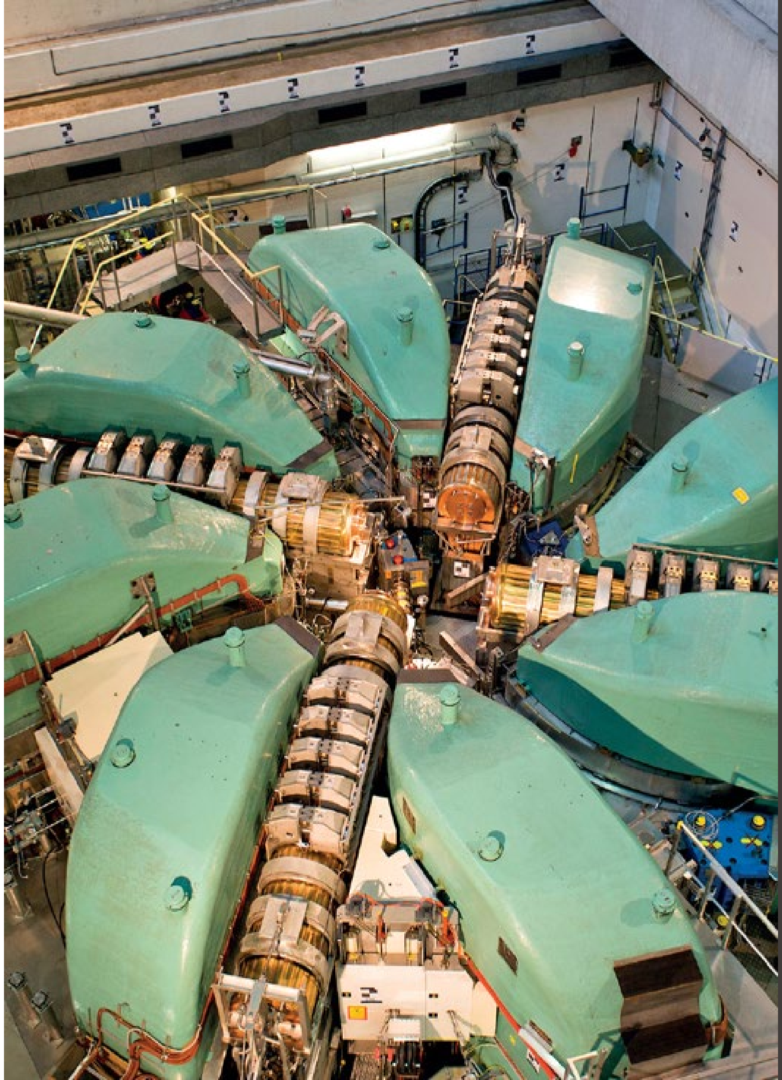
11th October, 2023



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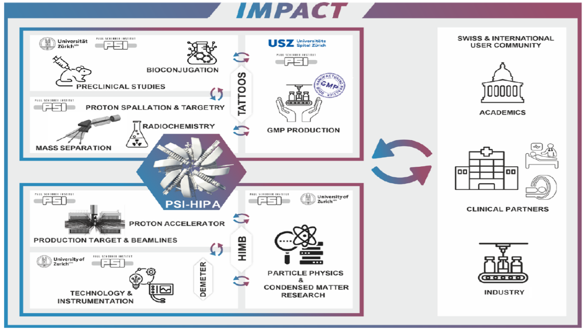
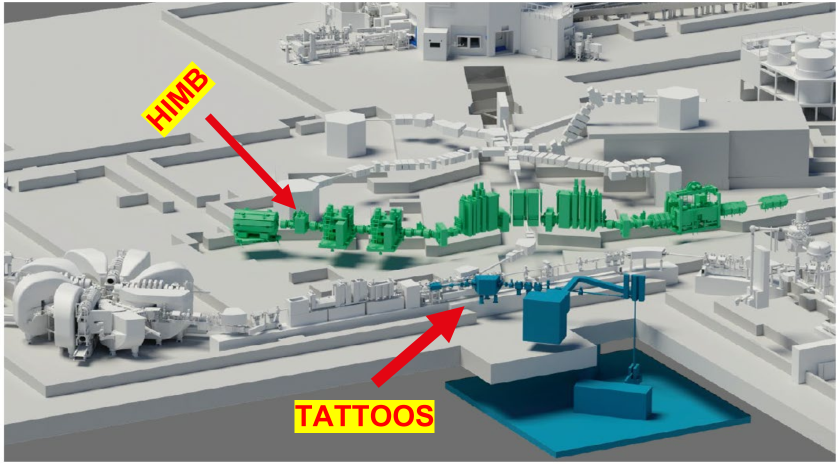
Outline of the TATTOOS Initiative

- High Intensity Proton Accelerator (**HIPA**) at PSI – 590 MeV CW proton beam, currents up to 2.4 mA.
- **IMPACT** (Isotope and Muon Production with Advanced Cyclotron and Target Technologies) – proposed initiative for HIPA.
- IMPACT:
  - ➢ HIMB (High Intensity Muon Beams) – Replacing existing target to increase surface muon production.
  - ➢ **TATTOOS** (Targeted Alpha Tumour Therapy and Other Oncological Solutions) – new beamline to produce **promising radionuclides** for therapeutic and diagnostic purposes.
- TATTOOS beamline intensity – **100 µA** → Requires continuous splitting of main HIPA beam via electrostatic beam splitter.

Overview of IMPACT initiative (TATTOOS and HIMB).



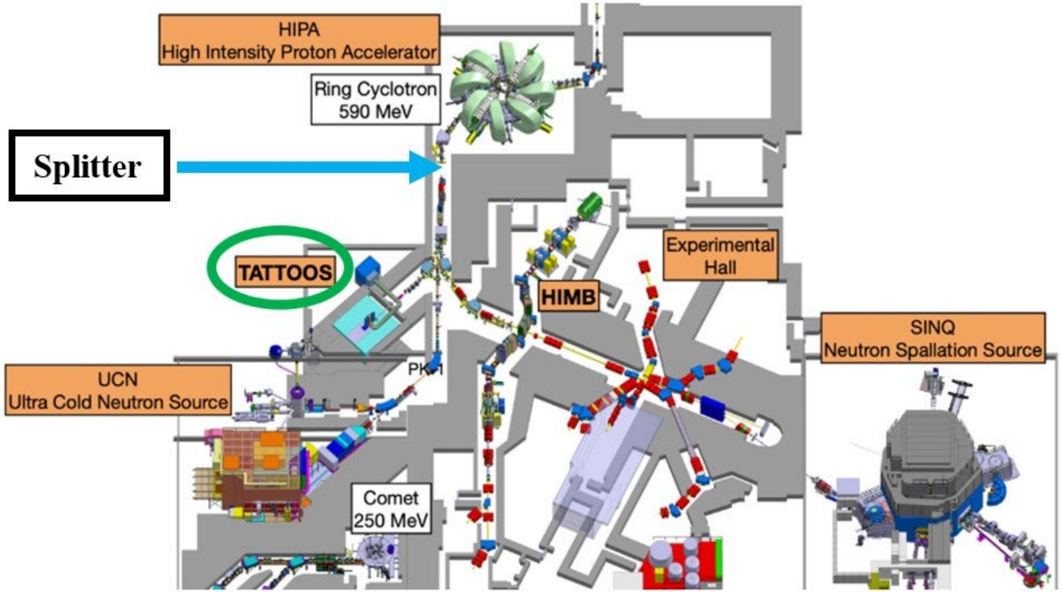


R. Eichler et al., "IMPACT conceptual design report", Paul Scherrer Institute, Villigen PSI, Switzerland, PSI Rep. No.22-01, Jan. 2022.

Overview of the HIPA facility

- Proton beam extracted from the Ring Cyclotron and delivered to :
  - Two meson production targets (TgM and TgE).
  - Two spallation sources:
    1. Swiss Spallation Neutron Source (SINQ).
    2. Ultra Cold Neutron source (UCN).
- Beamline from extraction to SINQ : P-Channel.
- Kicker magnet diverts beam from TgM, E and SINQ to UCN.
- Beam splitter, peels off small portion of beam, to be sent to TATTOOS target.

HIPA facility and foreseen TATTOOS location.



R. Eichler et al., “IMPACT conceptual design report”, Paul Scherrer Institute, Villigen PSI, Switzerland, PSI Rep. No.22-01, Jan. 2022.

Main Requirement and Challenges for TATTOOS Beamline

- Requirement → transport beam without large losses to allow "hands-on" maintenance (loss levels should be < 1 W/m to limit activation of components).

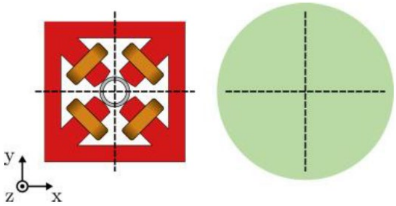
- Main physics challenge and innovation → unprecedented power of split beam (60 kW beam power).

- Residual activity by lost beam particles is :
  - Source of exposure for personnel.
  - Source of damage and reduced lifetime of radiation sensitive components.

- For TATTOOS:
  - Splitter has to withstand significant power deposition.

Beam Delivery Simulation (BDSIM)

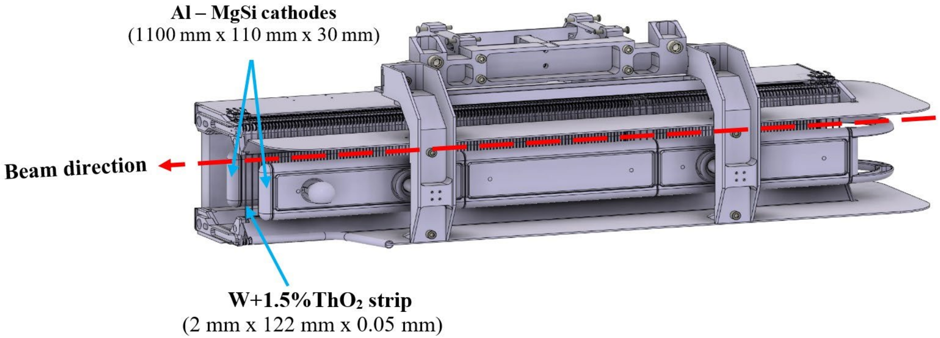
- Need to perform tracking simulations in EM fields and accurately predict interaction processes with TATTOOS components.
- → BDSIM (Geant4 based) delivers optimal and complete simulation from beam splitter to TATTOOS target.

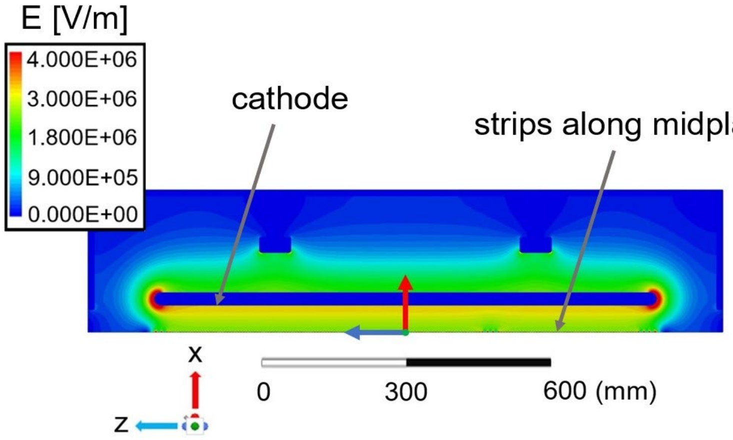


Beam Splitter

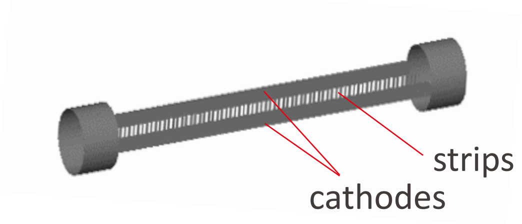
- Peels off high power beam in the horizontal plane.
- Septum : series of 175 electrically grounded tungsten alloy strips (2 mm x 122 mm x 0.05 mm).
- 2 cathodes at -172 kV create E-fields on either side of strips.
- Protons pulled away from strips for each beam.
- Detailed electric field map with ANSYS and implemented in BDSIM.
- Viability of the splitter - Splitter can withstand power deposition (first strip can handle max. 20 W).
- At the moment, splitter not used in normal operation.

Computer aided design (CAD) of splitter (courtesy of D. Goetz).





Splitter electric field map, resolution : 25 µm by 3000 µm by 500 µm.

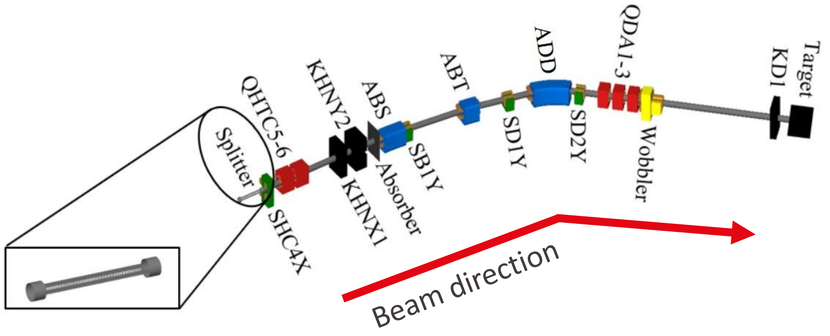


Splitter geometry (GDML) implemented in BDSIM.

TATTOOS Beamline Description

Component	Use for TATTOOS
ABS	Septum magnet. Diverts peeled beam to the UCN beamline (6.5° bend).
ABT	Dipole magnet. Diverts peeled beam from UCN line into TATTOOS (6.5° bend).
ADD	Dipole magnet. Bends beam by further 32°.
QDA1-3	Quadrupole triplet shapes beam on target.
SB1Y, SD1Y , SD2Y	Steering magnets. Steer the beam in vertical plane.
"Wobbler"	Two fast dipole magnets driven by AC current. Flattens beam footprint to homogenise target temperature (frequency ~ 30 Hz).
KHNX1, KHNY2	Jaw collimators acting in *x* and *y* planes.
KD1	Protection collimator for off-axis beams.

Complete TATTOOS beamline implemented in BDSIM.

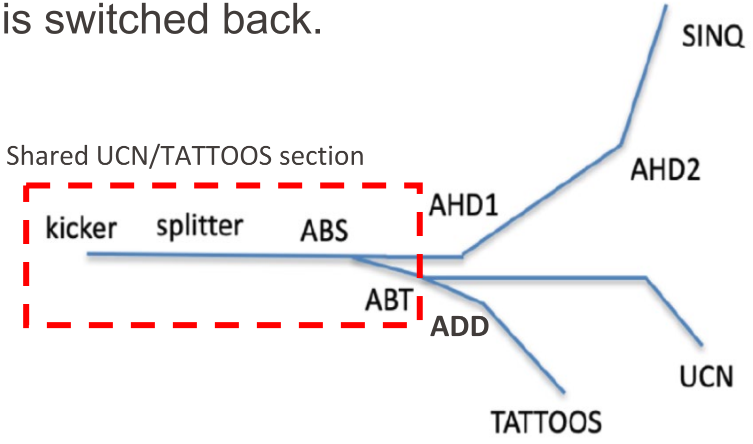


TATTOOS Operation

- First section of TATTOOS beamline is shared with the UCN beamline.

→TATTOOS and UCN cannot operate simultaneously.

- To switch from TATTOOS to UCN operation and vice versa:
  - ➢ Retract splitter from beam while ABT changes its polarity.
  - ➢ Kicker is activated for usual UCN operation.
  - ➢ Polarity of ABT is switched back.

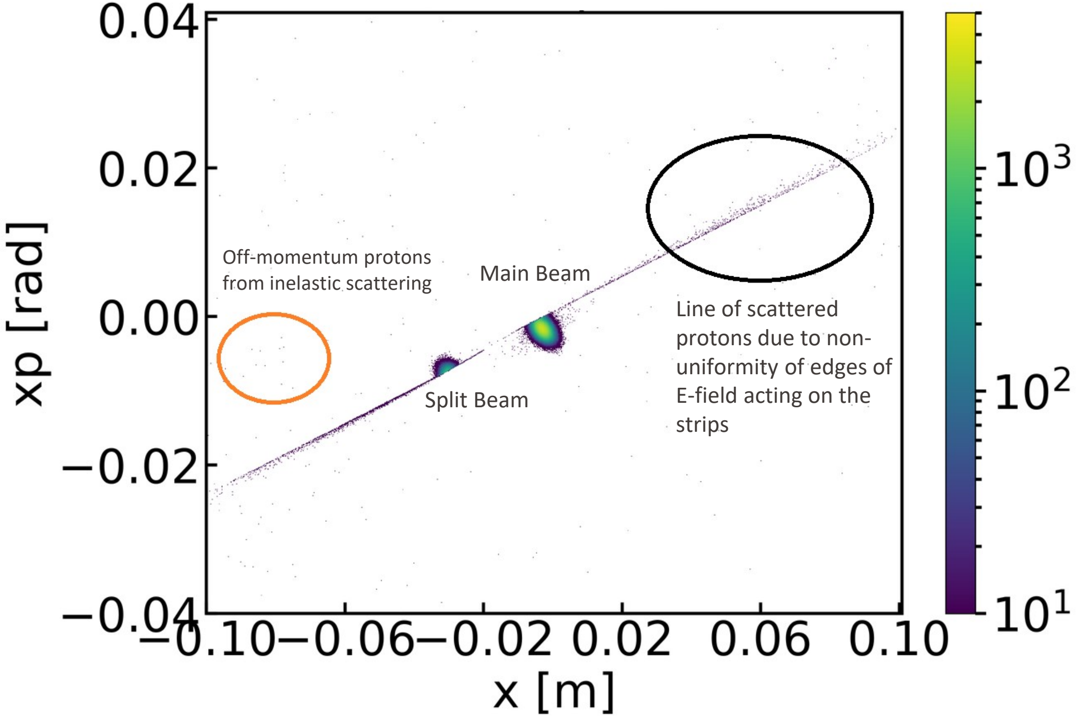


UCN/ TATTOOS alternating beam operation.

Input File and Horizontal Beam Profile

- Initial beam – Gaussian distribution.
- In BDSIM - wide range of physics processes included.
- Clear distinction between main and split beams.
- Various scattering processes visible.

Horizontal phase space approximately 4 m downstream of splitter.

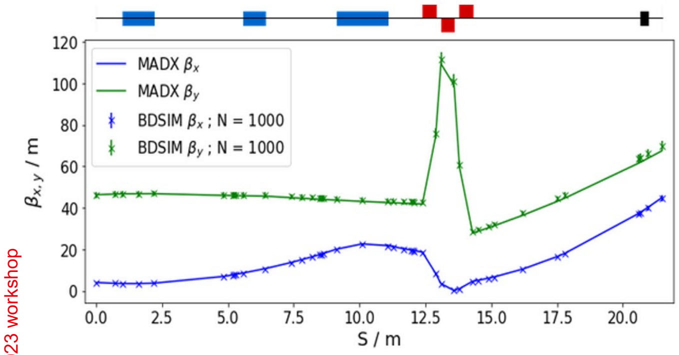


Beamline Optics Validation

- Beamline lattice designed with TRANSPORT code.
- Beam optics from BDSIM benchmarked with MAD-X.
- Excellent agreement between BDSIM and MAD-X.
- Beam size and transmission calculated from splitter to target for different split beam currents.

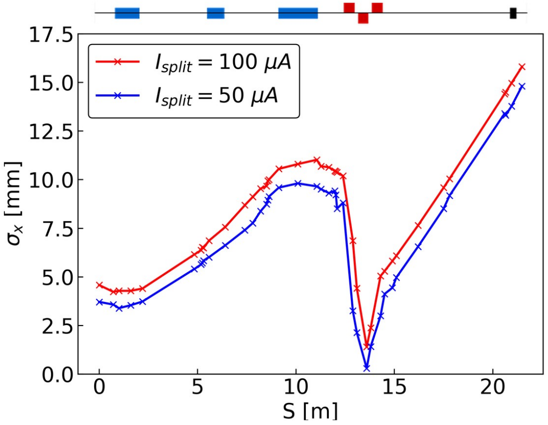
→ For a larger split beam current, beam size is larger as core of beam is more dense than halo → higher transmission to target.

Benchmarking between BDSIM and MADX - beta function validation

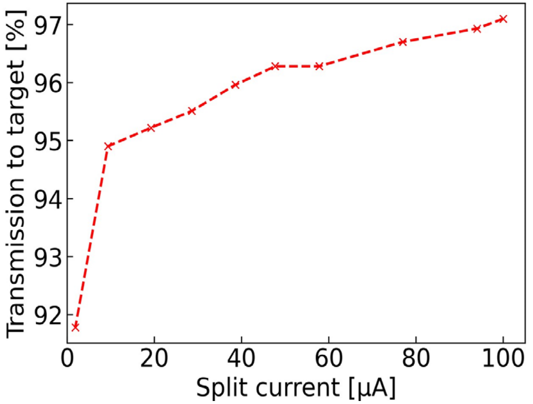


M. Hartmann et al., "Design of the 590 MeV proton beamline for the proposed TATTOOS isotope production target at PSI", in Proc. IPAC'22, Bangkok, Thailand, Jul. 2022, pp. 3000- 3003. doi:10.18429/JACoW-IPAC2022-THPOMS02

Horizontal beam size along the TATTOOS beamline.



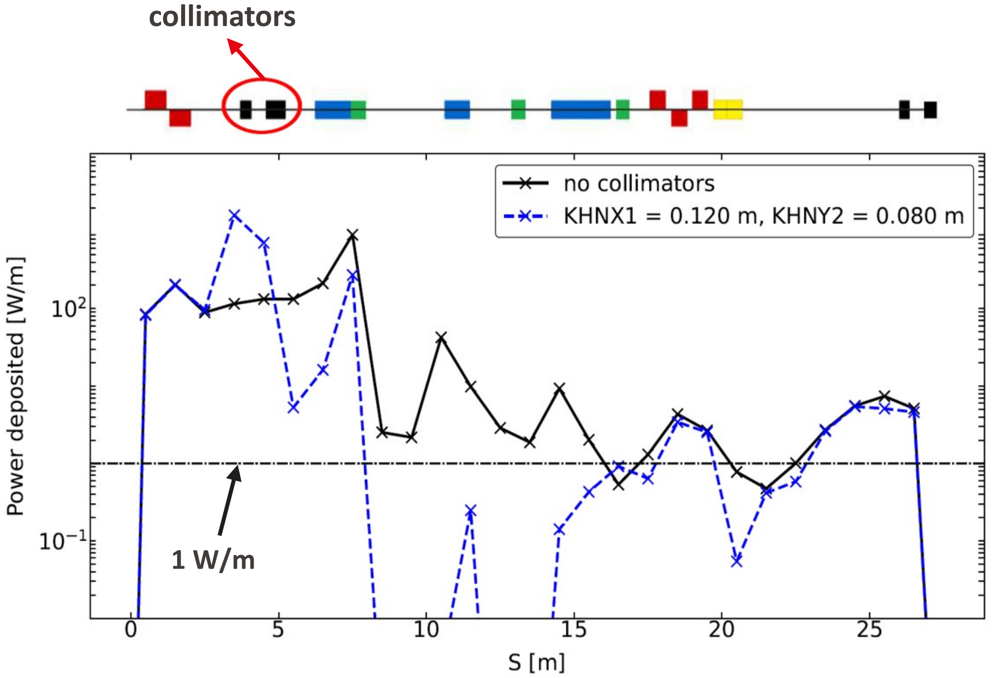
Transmission of split beam to target vs split beam current.



TATTOOS Beam Loss Simulations

- Main source of beam losses: proton head on collisions with splitter strips → scattered particles lost downstream.
- Apertures of collimators KHNX1 and KHNY2 optimised to reduce power deposition.
- Power deposited is highest at collimators (indicated with an arrow).
- Lower power deposited when collimators present compared to when there are none.

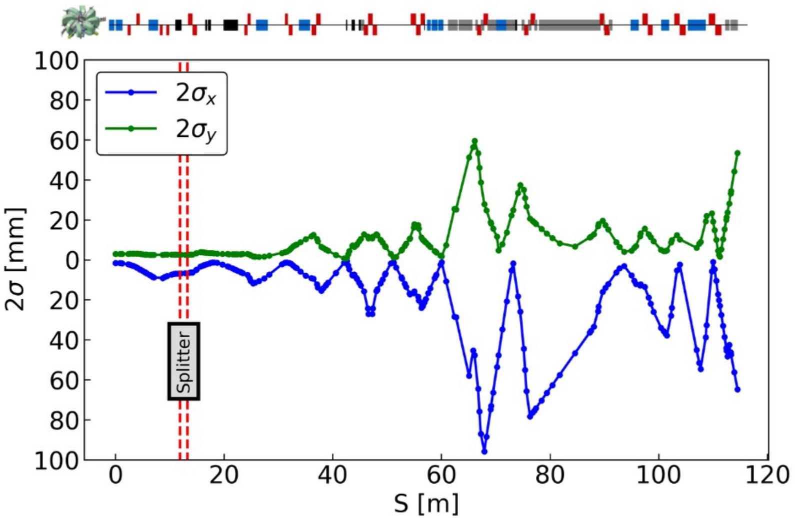
Power deposition from splitter to target with optimised collimator settings.



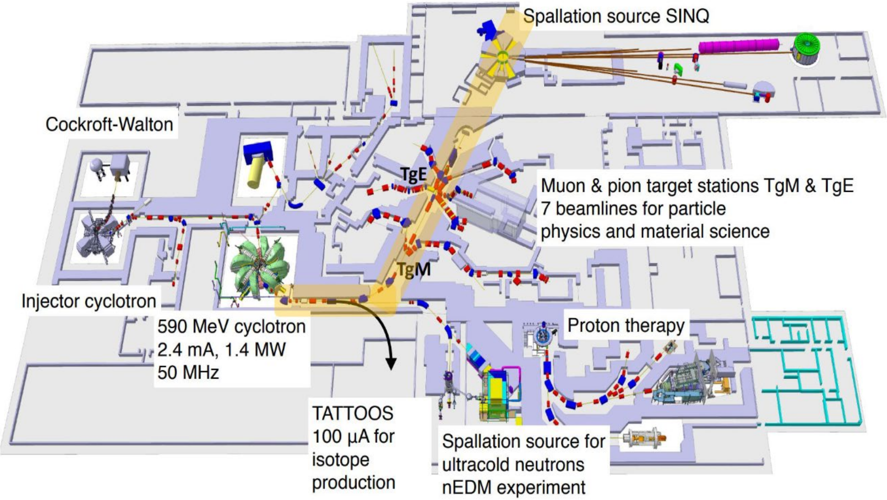
P-Channel Model and Beamline Optics

- P-channel simulated with BDSIM from extraction to SINQ.
- Goal: losses in P-Channel with splitter not significantly larger compared to current situation without splitter.

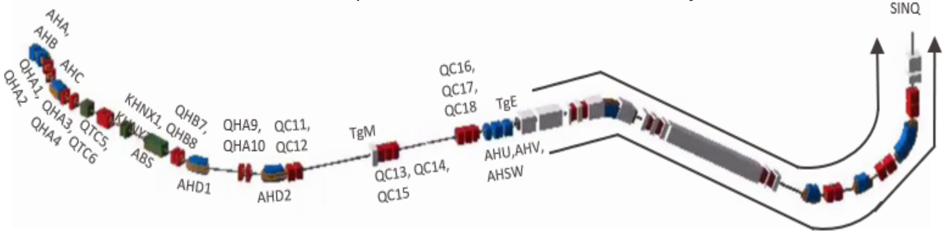
Beam sizes from extraction to SINQ target (splitter location marked with dashed lines).



HIPA facility and P-channel location.



M. H. Tahar et al., “Probing the losses for a high power beam”, Nucl. Instrum. Methods. A, vol. 1046, p. 167638, Jan. 2023. doi:10.1016/j.nima.2022.16763

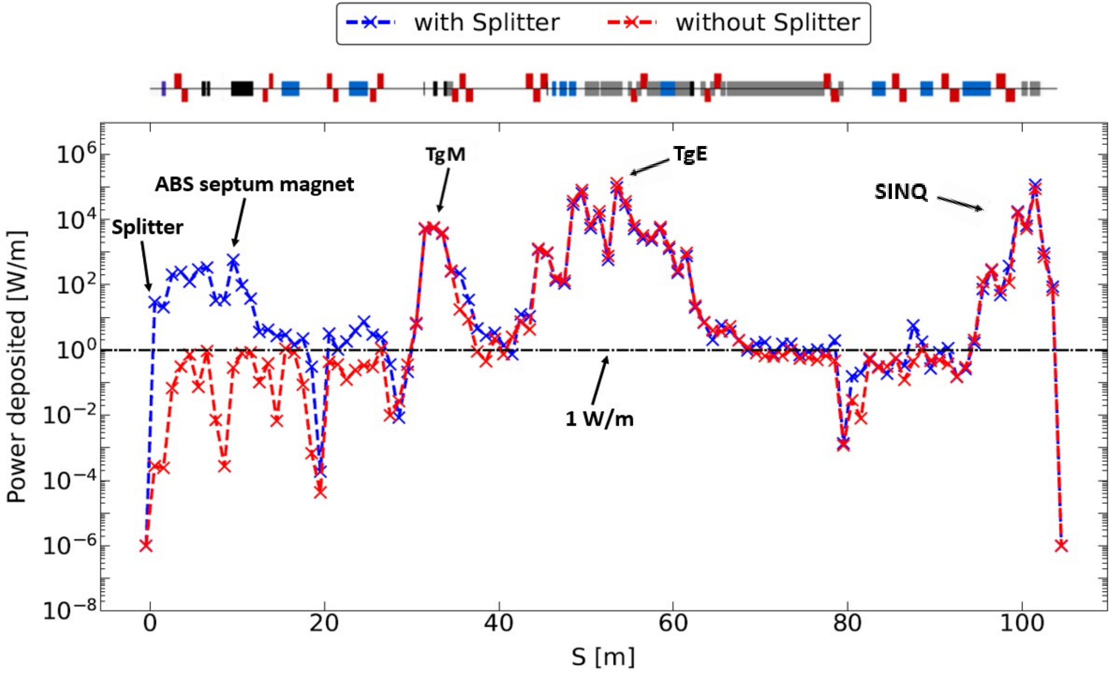


Overview of P-Channel beamline in BDSIM.

P- Channel Beam Loss Simulations

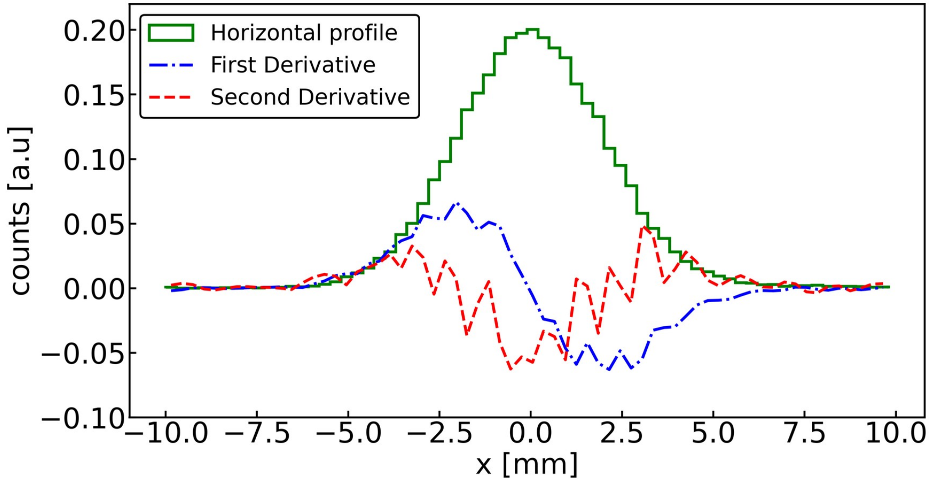
- Losses calculated in P-channel calculated with and without splitter.
- Losses up to TgM are larger with splitter, as expected → further studies needed.
- Up to SINQ → losses dominated by beam scattering on targets→ losses with and without splitter are comparable.

P-Channel losses for a 2 mA beam with (100 µA split current to TATTOOS) and without splitter.



Beam halo - Definitions and Characterisation Methods

- High intensity beams produce beam halo → beam losses.
- "Distribution method" : beam core-halo limit defined only by 2D phase space distribution.
- Typically : $\frac{m\ RMS}{n\ RMS}$ (n = 1, m = 3) with reference Gaussian distribution.
- However, split beam is not Gaussian – beam tail can be more or less significant compared to standard Gaussian.
- "Second derivative method": beam core-halo limit defined by location of steepest density gradient, i.e. max. of 2nd derivative in 1D.
- Visually halo location corresponds to tails of the beam distribution.



Normalised horizontal beam profile after the ABS septum magnet (about 8 m downstream of the splitter).

Beam Halo - Method Comparison

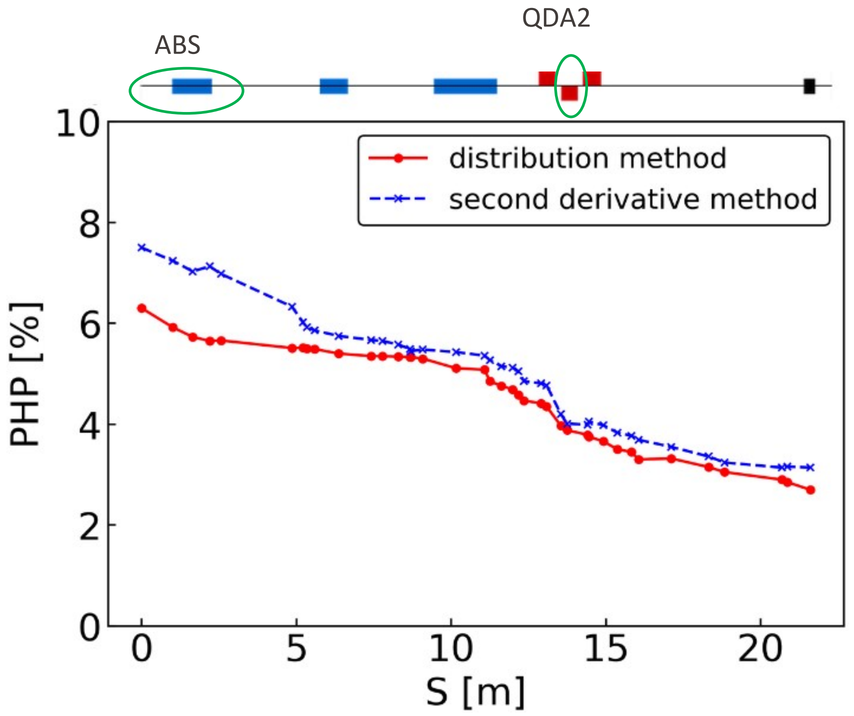
- Percentage of halo particles (PHP) :

$$PHP = 100 \cdot \frac{N_h}{N_c}$$

- Significant decrease in halo at :

1. ABS septum magnet (where main and split beam separate).
2. QDA2 quadrupole where phase advance changes abruptly.

→ These locations correspond well to peaks in power deposition.



Evolution of beam halo along the TATTOOS beamline for 100 µA split beam current using two different methods.

Conclusion and Outlook

- TATTOOS beamline lattice designed and simulated with BDSIM.
- Biggest challenge for TATTOOS beamline is high beam power → Extremely important to simulate losses along beamline.
- Power deposits both for TATTOOS and P-Channel calculated.
- Beam halo characterised using two independent methods.
- Simulations will serve as model predictions for future TATTOOS beamline measurements.
- Activation calculations to be performed in the splitter – TgM regions. Realistic shielding to be introduced and effects on power deposition to be determined.

Thank you!