Fixed Target Beams & Challenges for the Future

Beam dynamics modelling ← → Operation

P. Arrutia

with contributions from S. Albright, M. Algelly, C. Antuono, F. Asvesta, D. Banerjee, M. Calviani, H. Damerau, G. P. Di Giovanni, Y. Dutheil, L. Dyks, M. Fraser, A. Gorn, A. Huschauer, L. Le, B. Mikulec, T. Prebibaj, S. Rothe, F. Velotti, Q. Vuillemin

JAPW 2024 (15’ + 10’)

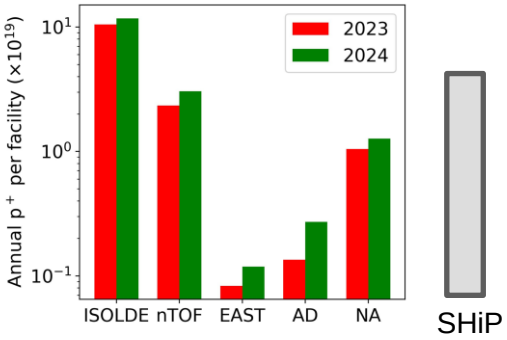
11/12/2024

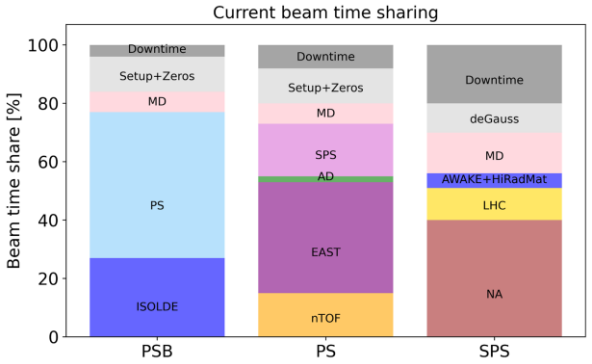
Introduction

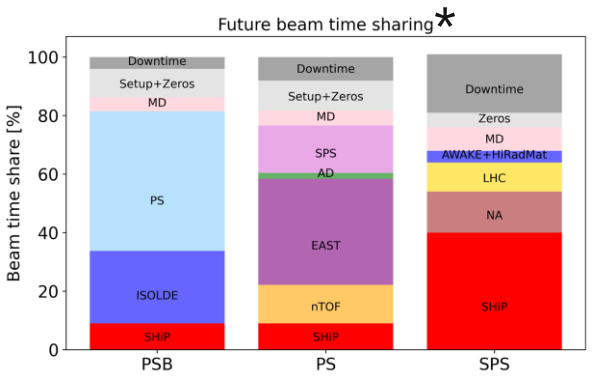
Fixed target destinations are the largest "particle and cycle consumers" across the complex.

- Demand expected to increase post LS3, with SHiP entering the North Area.
- Requests to extend ion runs (incl. proton+ion parallel operation) must also be considered within this landscape.
- Efforts split across different projects and working groups: IPP, SLAWG, bSAC, SOX, CONS, Future Ions, Hi-ECN3…

Challenge for the future: make the particle-pie bigger and/or share it more effectively.







[1]

*Underlined references typically contain hyperlink

Outline

Outline

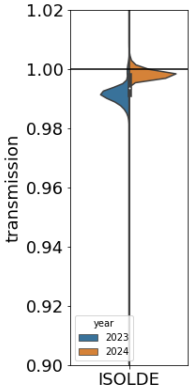
ISOLDE → nTOF → North Area

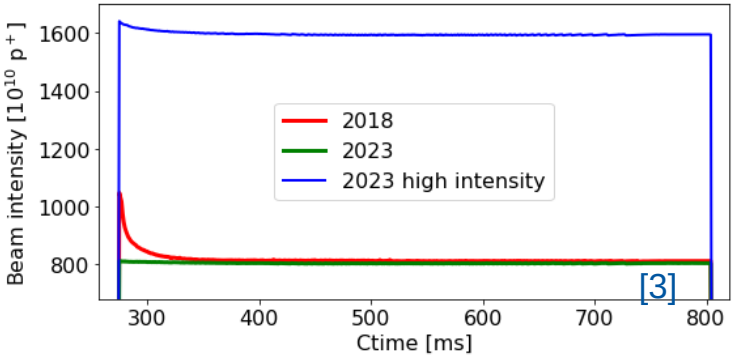
High(er) intensity

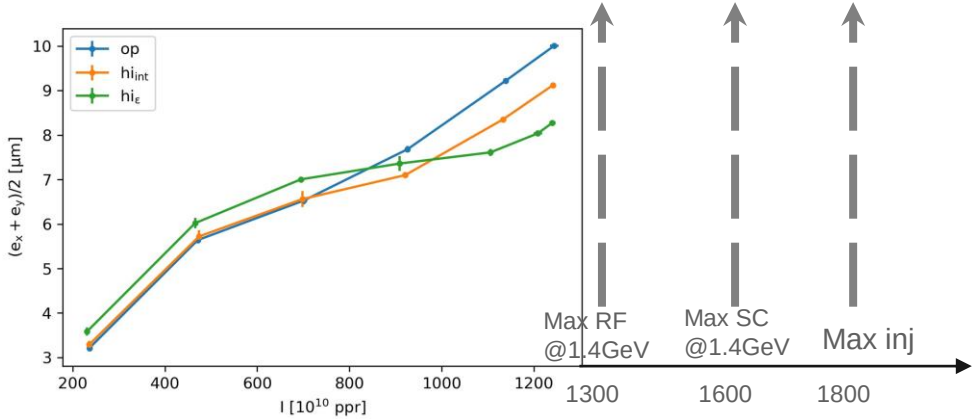
Successful ISOLDE operation, with better transmission w.r.t. 2023 (e.g. improved octupole resonance correction) [1]. High intensity MDs:

- **Up to 5e13 protons per pulse both to HRS and GPS** (nominal 3.2e13).
- Exploration of maximising transmission and minimising emittance w.r.t. Intensity.

Remaining: emittance limits due to extraction apertures, exploration of limitations for 2 GeV (impedance/instabilities & RF).





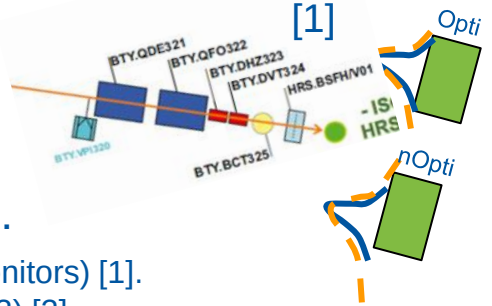


[1] F. Asvesta, PSB MPC 2024

[2] F. Asvesta, G.P. Di Giovanni, 2024

[3] T. Pebibaj, IEFC 2024

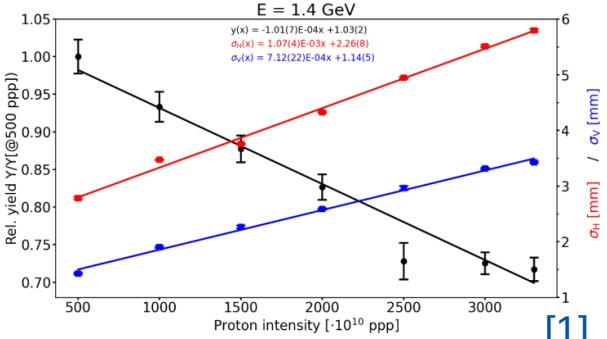
Facility upgrade



Aiming to have multi-energy/target/intensity operation -> with great flexibility comes…

- Ongoing: Auto-optimisation of BTY steerers and final focus (using yield and/or RP monitors) [1].
- Ongoing: optics models for low-energy lines -> migrate to LSA paradigm (planned LS3) [2].
- Ongoing: design limit for ISOLDE Beam Dump Replacement need to be finalised.
- Post LS3: HRS/GPS parallel operation (software and/or hardware upgrades needed) [3].

Yield vs. pulse intensity



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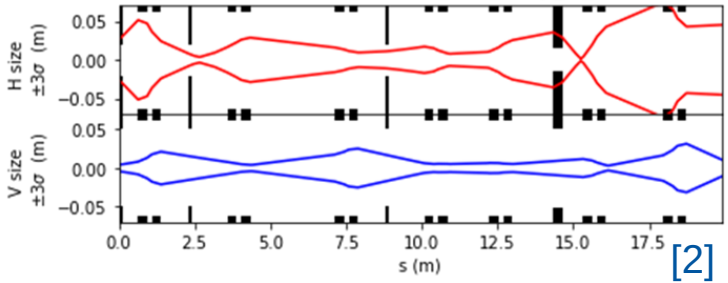
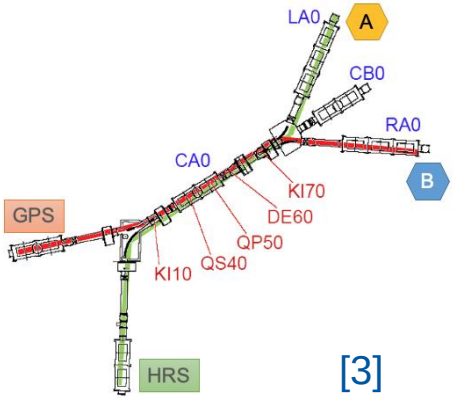


[2]



[3]

[1] S. Rothe, IPP 2024

[2] Q. Vuillemin, ITC 2024

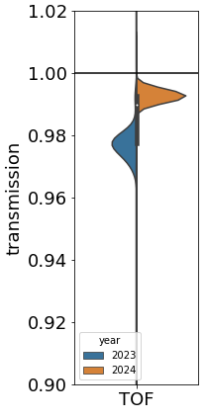
[3] L. Le, S. Rothe

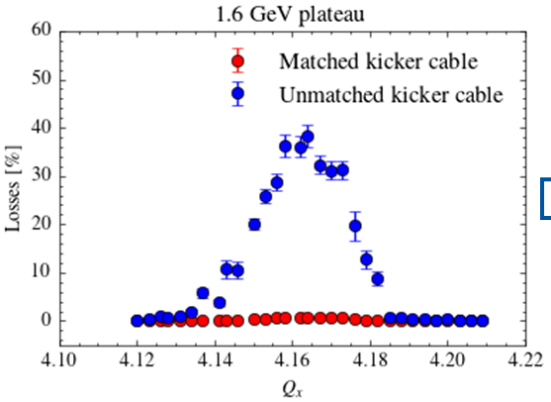
Outline

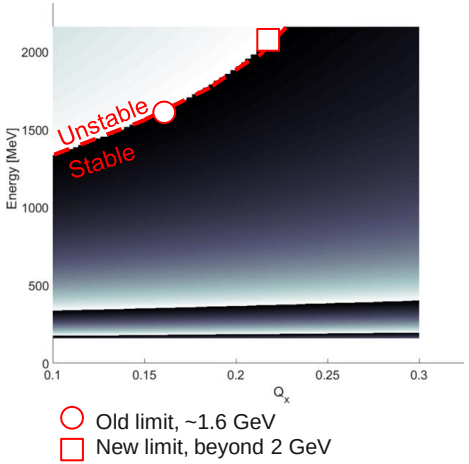
@ PSB

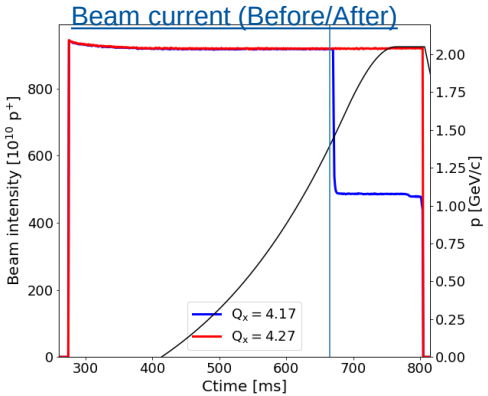
Successfully **operated @ 2GeV with better transmission w.r.t. 2023** [1].

- Identified cause of instability found @1.6 GeV -> unmatched kicker impedance.
- Found new Qx working point, pushing instability threshold beyond 2 GeV.









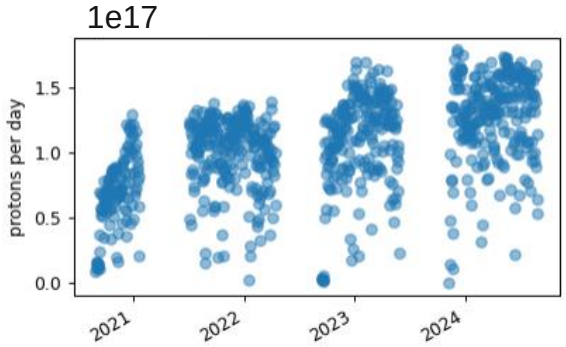
[1] F. Asvesta, PSB MPC 2024

[2] C. Antuono, IPP MD 2023

High-flux TOF @ PS

High-flux run Aug-Sep 2024, pushing the limits for all TOF cycles [1].

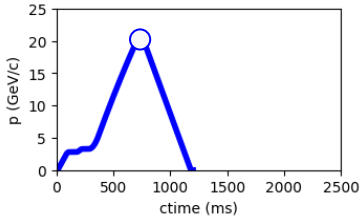
- Running close to target limit (2.2e12 p+/s -> 1.9e17 p+/day).
- Double-TOF as option to sustain high-flux during supercycles with high demand from ISOLDE -> interlocks being discussed to avoid extracting both bunches together.

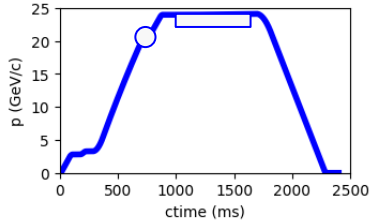


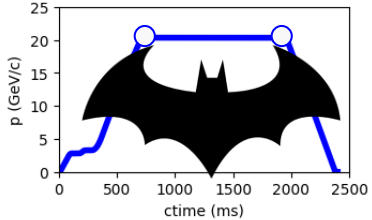
	Dedicated	Parasitic
Pre high-flux ppp	0.85e13	0.35e13
High-flux ppp	0.92e13	0.82e13 (T9, TN), 0.35e13 (T8)

Double (formerly BAT)
2x0.7e13

TOF extr.
EAST extr.



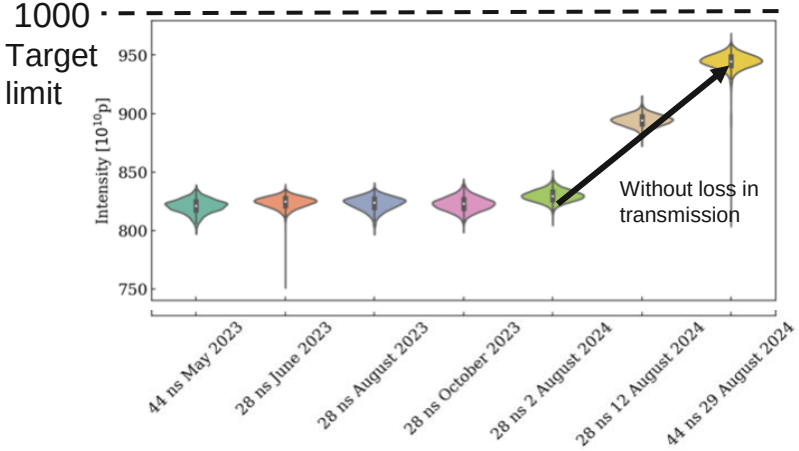


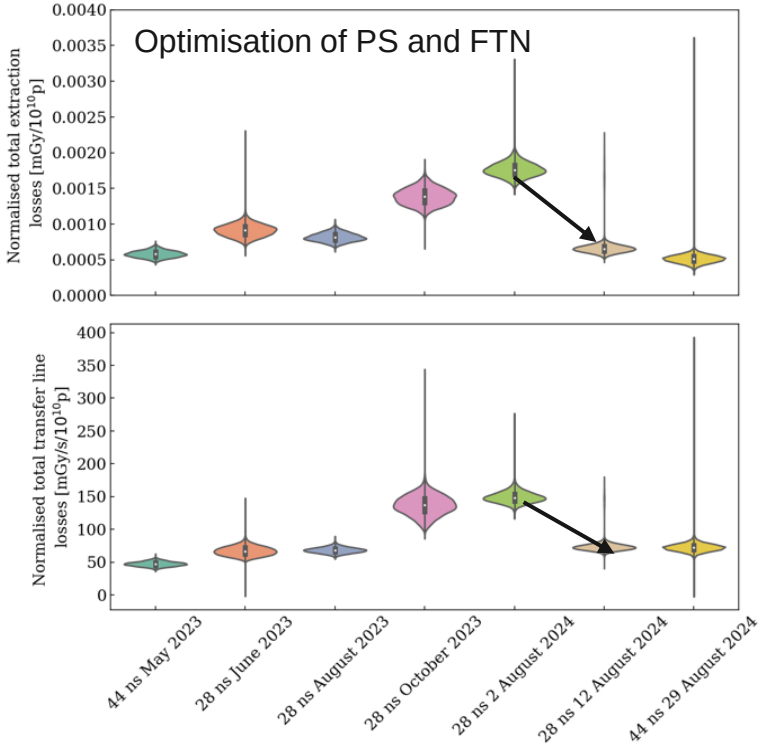


High-flux TOF @ PS: Losses

Transmission and norm. losses kept under control. Ongoing:

- Interlock update to use brightness instead of beam size just upstream of target (remains a software interlock*).
- Assessment of required RP cooldown time in case of equipment failure requiring intervention in FTN.





Outline

PSB Ring sharing

Idea since 2000s to **provide nTOF and ISOLDE beams within same PSB cycle using ring-by-ring destinations** [2].

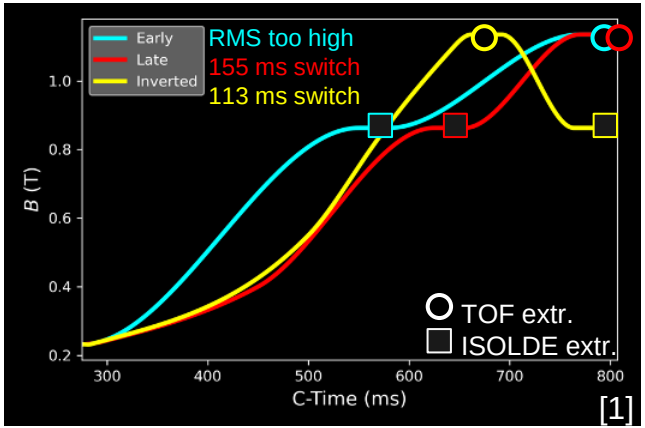
Option 1, "slow" switching:

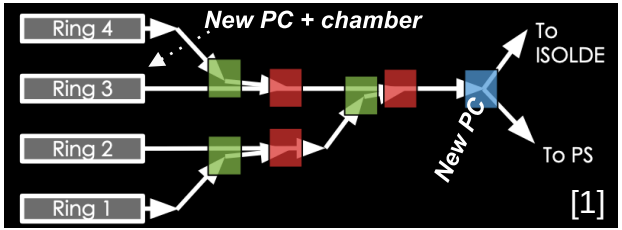
- Hardware required: BT.BHZ10 power converter for polarity switch (? CHF), BE3.SMH15 separate tank (100kCHF) and converter (100kCHF).
- Condition: ISOLDE 1.4GeV* **AND** TOF + ISOLDE in SCycle **AND** not double-TOF

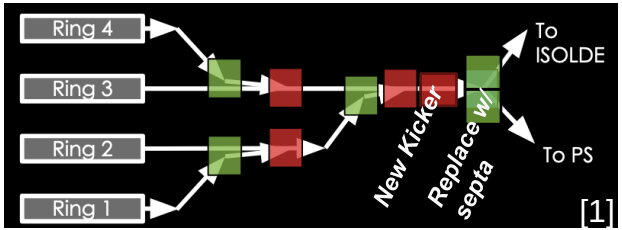
*Due to mains RMS current limit

Option 2, "fast" switching:

- Hardware required: kicker, 2 septa replacing BHZ deflecting into 2 independent dipoles (one to BTM, one to BTP) -> 2.5 MCHF in 2000
- Condition: TOF + ISOLDE in SCycle **AND** not double-TOF







Kicker
Septum
Switching magnet

[1] S. Albright, IPP 2024

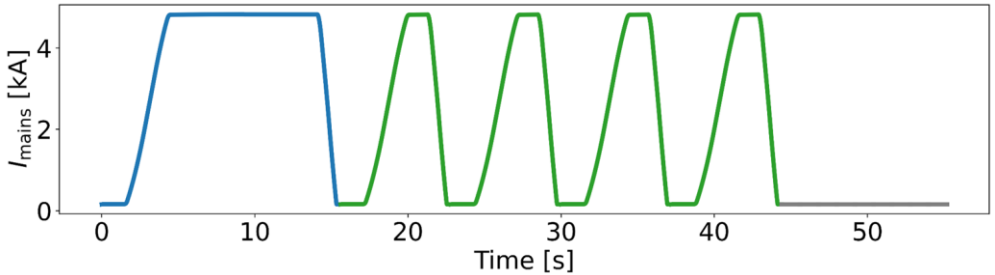
[2] C. Carli, PPC 2000

Outline

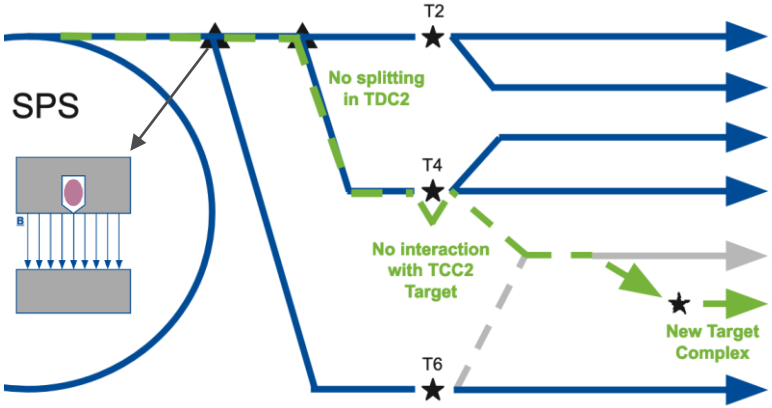
Sharing scenarios

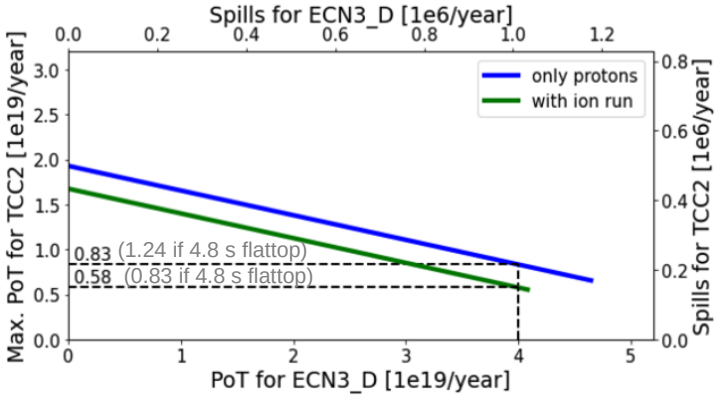
Post-LS3, the SPS will aim to provide **4e19 p/year to SHiP in the HI-ECN3 facility, in addition to 1e19 p/year to T2+T4+T6** (comparable to 2023, 2024).

- Baseline: 4.2e13 p/spill slow extracted for both SHIP (not shared in TT20) and SFTPRO (shared in TT20) [1].
- bSAC and SOX efforts developing “super-cycle models” to further optimise situation -> MDs requested pre-LS3 for super-cycle composition.



SFTPRO: 9.6 s flattop (4.8 s flattop also possible: worse for other PS/PSB users)
SHIP: 1.2 s flattop
deGauss: required to stay within NA RMS current limit (more constraining than SPS mains)



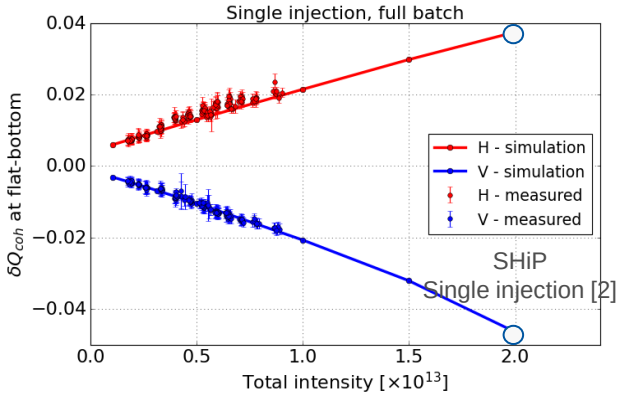


[1] T. Prebibaj, IPP 2024

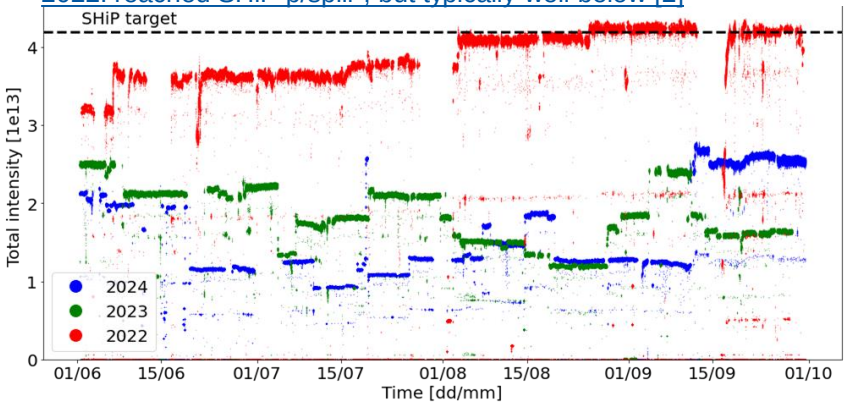
High intensity

To run at 4.2e13 p/spill and 5e19 PoT/year, extensive studies and upgrades performed and under way [1, 2].

- **@PSB:** experience delivering intensities well beyond SHiP -> working on smaller V-emittance.
- **@PS:** running reliably with barrier bucket, demonstrating extractions at/beyond SHiP intensity.
- **@PS-to-SPS, ongoing:** beam loss between PS extraction and SPS flat-bottom.
- **@SPS, ongoing:** systematic understanding of intensity-dependent tune shift.
- **@SPS sloex, ongoing:** systematic understanding of spill quality and losses at high-intensity (not easy to study since it requires extraction all the way to the targets).



2022: reached SHiP p/spill*, but typically well below [2]



[1] M. Fraser, IPAC 2024

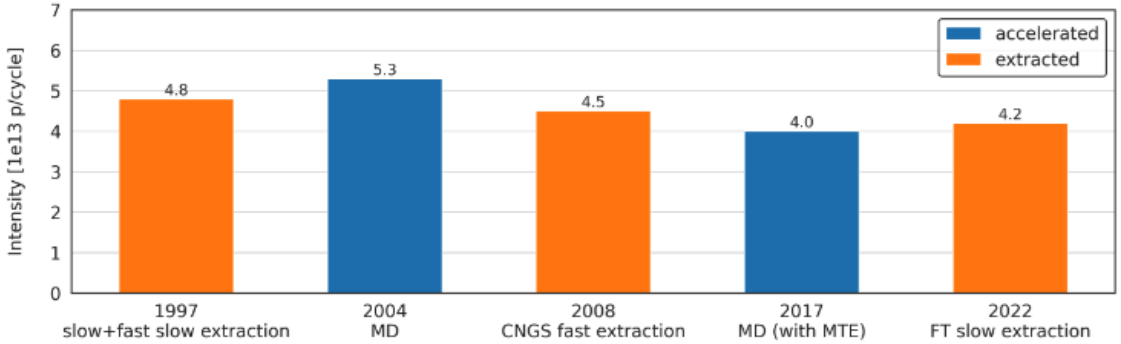
[2] T. Prebibaj, IPP 2024

*Additionally, transmission was rather low across the complex.

(Even) High(er) intensity

Moving **beyond 4.2e13 p/spill would provide a means to provide more PoT/year or reduce the number of spills***. In addition to limitations in previous slide [2]…

- **@SPS:** SPS internal dump (TIDVG#5) limit at 7e13 p/spill (while respecting also average power limits).
- **@NA, ongoing:** power limits for NA interceptive devices. SHIP: BDF target. SFTPRO: TCSC, TAX, T2/T4/T6 targets.
- **@PS, ongoing:** beam-loading compensation of Finemet to avoid barrier bucket distortion.



[1] Figure 1: Intensity per cycle achieved in the SPS.

	CNGS	RECORD	CN2PY
E_{SPS} [GeV]	400	400	400
Bunch spacing [ns]	5	5	5
I_{bunch} [$\times 10^{10}$]	1.05	1.3	1.7
$N_{bunches}$	4200	4200	4200
I_{SPS} [$\times 10^{13}$]	4.4	5.3	7.0
I_{PS} [$\times 10^{13}$]	2.3	3.0	4.0
PS cycle length [s]	1.2	1.2	1.2/2.4
SPS cycle length [s]	6.0	6.0	6.0/7.2
E_{PS} [GeV/c]	14	14	14
Beam power [kW]	470	565	747/622

CN2PY aiming at 7e13 p/pulse FAST EXTRACTED (CDR)

[1] T. Prebibaj, PBC 2023

[2] BDF/SHiP, 2023

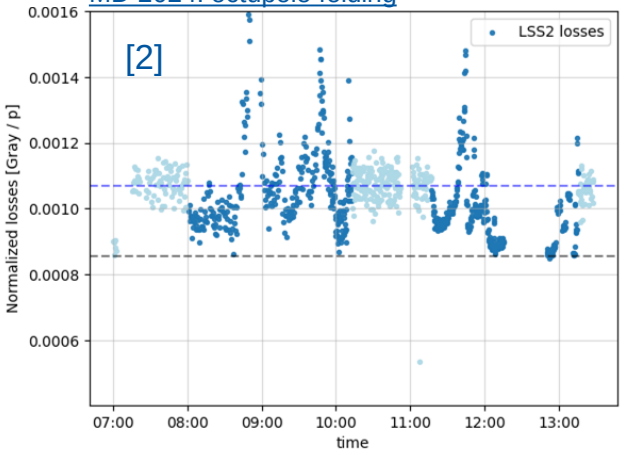
*SHiP searches extremely rare processes and is thus not rate limited. The same is NOT true for other users.

Extraction losses

Goal to keep dose to LSS2 unchanged, even when POT will be increased by 4x.

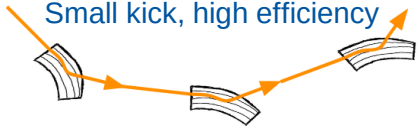
- Crystal shadowing of ZS: DECRYCE project advancing to build optimised single crystals and multi-volume array (possibly pre-LS3) [1].
- MD: bump, septa, octupole-folding optimisation -> 20% loss reduction [2].
- Building Al ZS tank (-40% activation w.r.t. stainless steel), after extensive R&D [3,4].

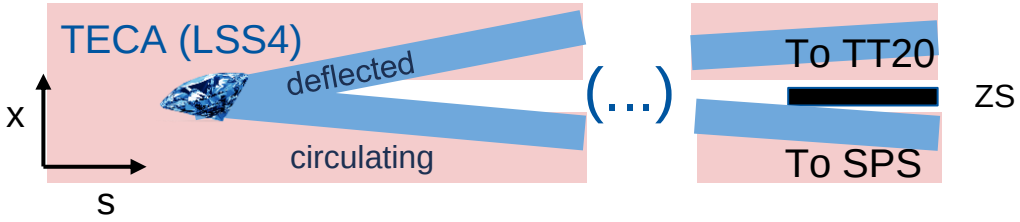
MD 2024: octupole folding



Channelling
Big kick, low efficiency

Volume reflection
Small kick, high efficiency





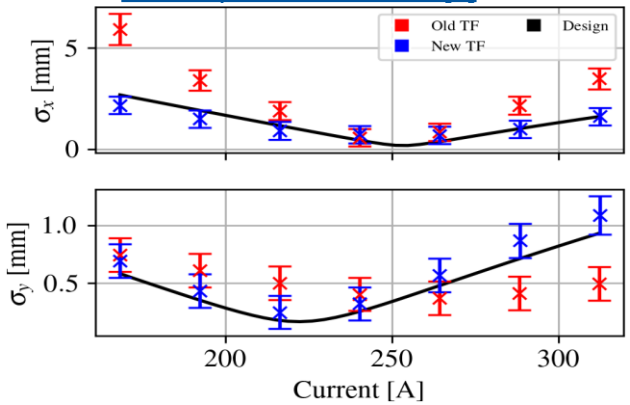
FEA Ansys model
(iteration with 4 stiffeners)

TT20 optics

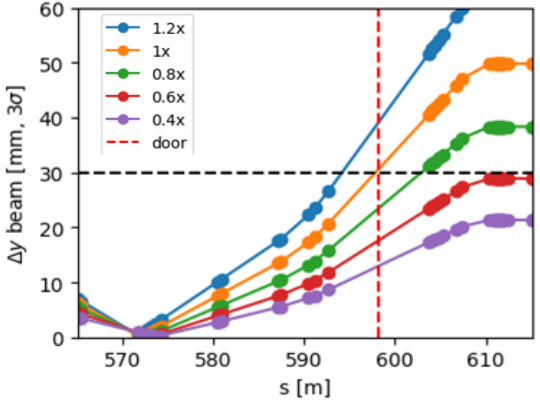
Identified errors in I-to-B transfer functions for QTN, QTL (4%), QTA (1%). Deployment planned in 2025 commissioning (LHC B1 and HiRadMat lines also contain QTL).

- Significantly improved agreement between model and measurements [1,2].
- MD/Commissioning 2025: correct vertical beam size at splitters using optics, instead of requesting large V-emittance from PSB (would improve transmission, especially at SPS inj.).

Meas: quad scan in P42 [2]



Sim: V-size at splitter [3]
(controlled with optics)



[1] F. Velotti, SPS MPC 2024

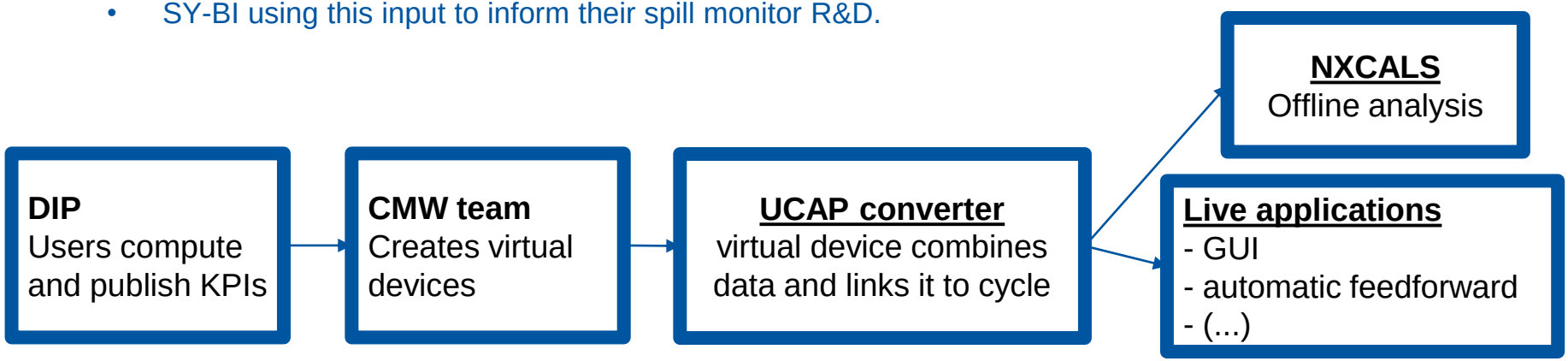
[2] L. Dyks, 2024

[3] Y. Dutheil, 2023

Input from users

To ensure efficient operation and R&D, **tight collaboration with users is crucial. Spill Optimisation for eXperiments (SOX) effort ongoing [1]**:

- Collected requirements & limitations from NA62, SHiP, AMBER, MUonE and NA64 -> direct input for beam sharing scenarios, report being written.
- Developing online analysis pipeline to profit from user-relevant KPIs -> minimal example to be tested before LS3.
- SY-BI using this input to inform their spill monitor R&D.



Outline

Conclusion

- Exciting fixed-target beams program ahead, pushing new limits for intensity and beam quality.
- Challenges spread across all machines & FT beam types.
- R&D opportunities over all aspects: beam dynamics, operations, equipment, automation & controls.
- Need to combine input from this presentation with input from users to prioritize amongst different options.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WHACK-A-MOLE BEAM SHARING
"Second quarter is up. No, fourth quarter.
Now second again. OK, it's third now..."

Extra slides

Topics:

- Prospect of running ISOLDE with higher intensity per shot in 2025 in view of future proton sharing, and status of upgrade project
- Higher intensity for TOF
- Fixed-target beams: bunch length/momentum spread/beam size (PSB, PS), spill quality (PS/SPS), losses
- Higher intensity requests for North-Area post-LS3 + Beamline acceptance.
- Beam for BDF/SHiP and intensity increase to 7e13, future beam sharing (different scenarios for proton sharing in the SHiP-BDF time) MDs related and proposed tests before LS3.
- Where do we stand concerning losses and activation for high intensity beams?
- Check BPT: https://bpt.web.cern.ch

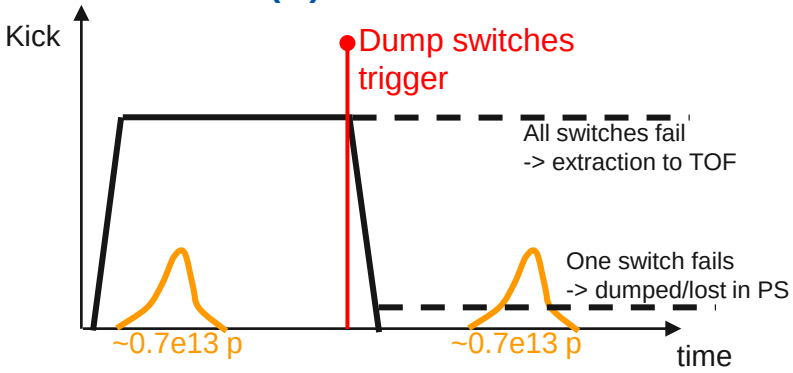
CodiMD: https://codimd.web.cern.ch/2DjlMqkCQ3uI1X-RiXJkKw?both#

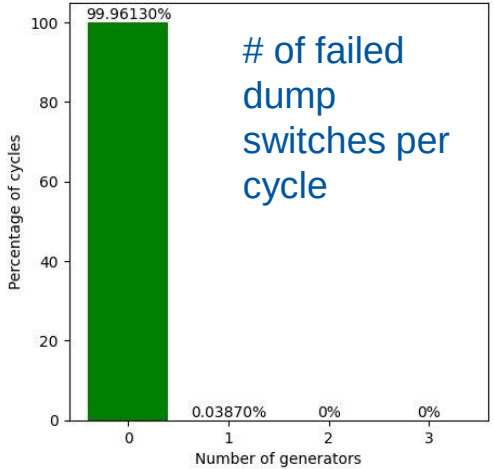
double-TOF @ PS

Not the cycle CERN deserves, but the one it needs right now?

Cycle ready & nTOF DAQ modified to take both bunches**. Ongoi** nsure bunches are not extracted together*. Collecting failure modes:

- **(i) all twelve KFA71-79 dump switches fail to trigger.**
  - Preliminary analysis of 10 million shots indicates this is highly unlikely to happen**.**
  - Trim range can be limited and protected by MSC settings (standard across other kickers at CERN).
- **(ii) bunches spaced too closely from PSB**.
- **(iii) Others**





[1] A. Huschauer, Y. Dutheil, IPP 2024

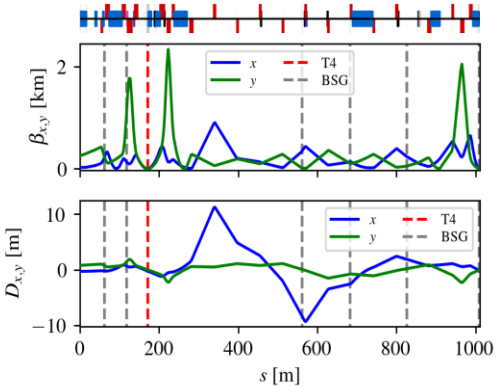
[2] M. Algelly, 2024

*SY-STI: Target limit 1e13 ppp. 10-20% excess may be tolerated for a single shot. Needs further study.

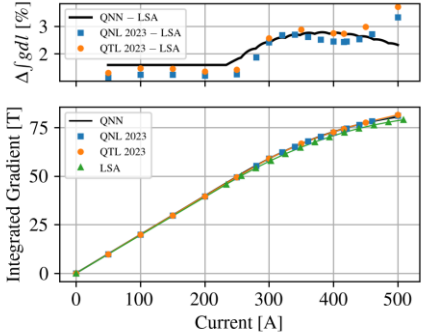
TT20-P42 Optics Measurements

L. Dyks

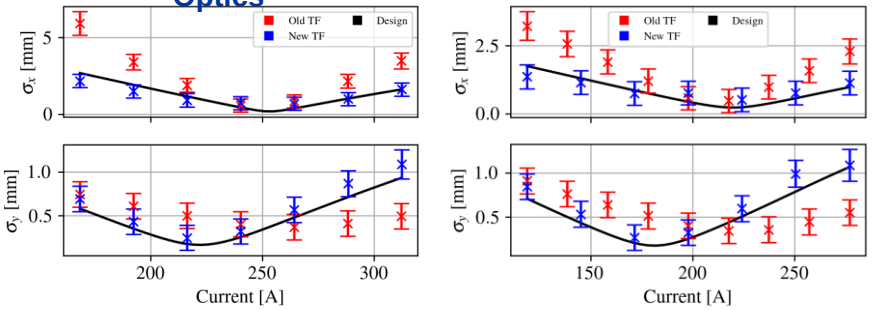
- Beam to HI-ECN3 will use dedicated optics
  - Beam is not split
  - Optics changed cycle to cycle
- Beam loss prompted optics studies in TT20-P42 [JAPW23]
  - Implied error source → QNL/QTL settings in TT20.
  - P42 was already using the new QNL transfer function.
  - Further studies showed QTA as 2nd leading source of error.
- Big effort under NACONS to measure the transfer functions of various magnets.
  - Measurements showed ~4% error in TF for QNL/QTL and ~1-2% error in TF for QTA.
- MDs done using measured magnet TFs for the TT20 magnets.
- **Optics substantially closer to design**



TT24-P42 Dedicated Optics

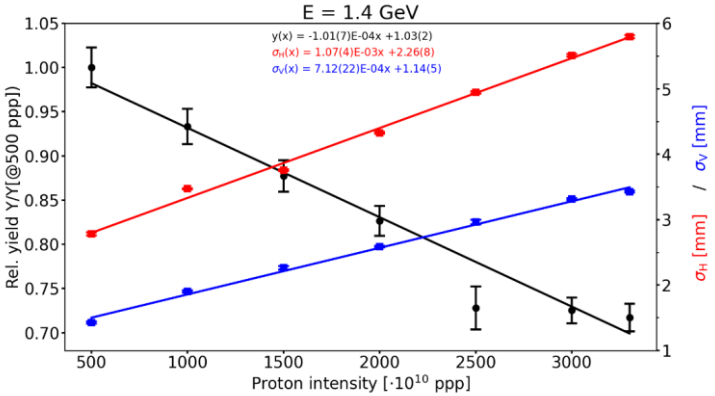


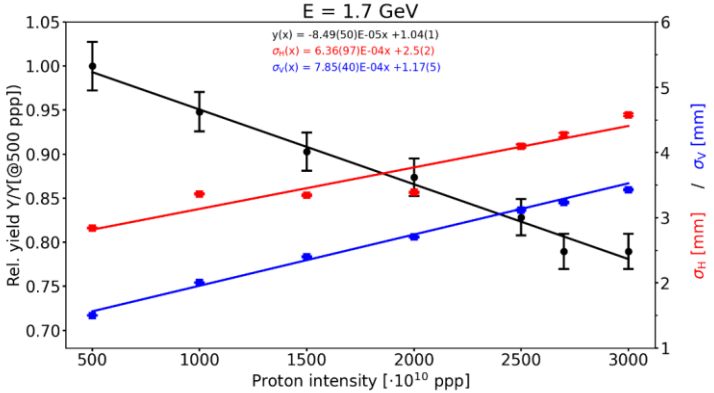
QTL-QNL magnetic transfer functions



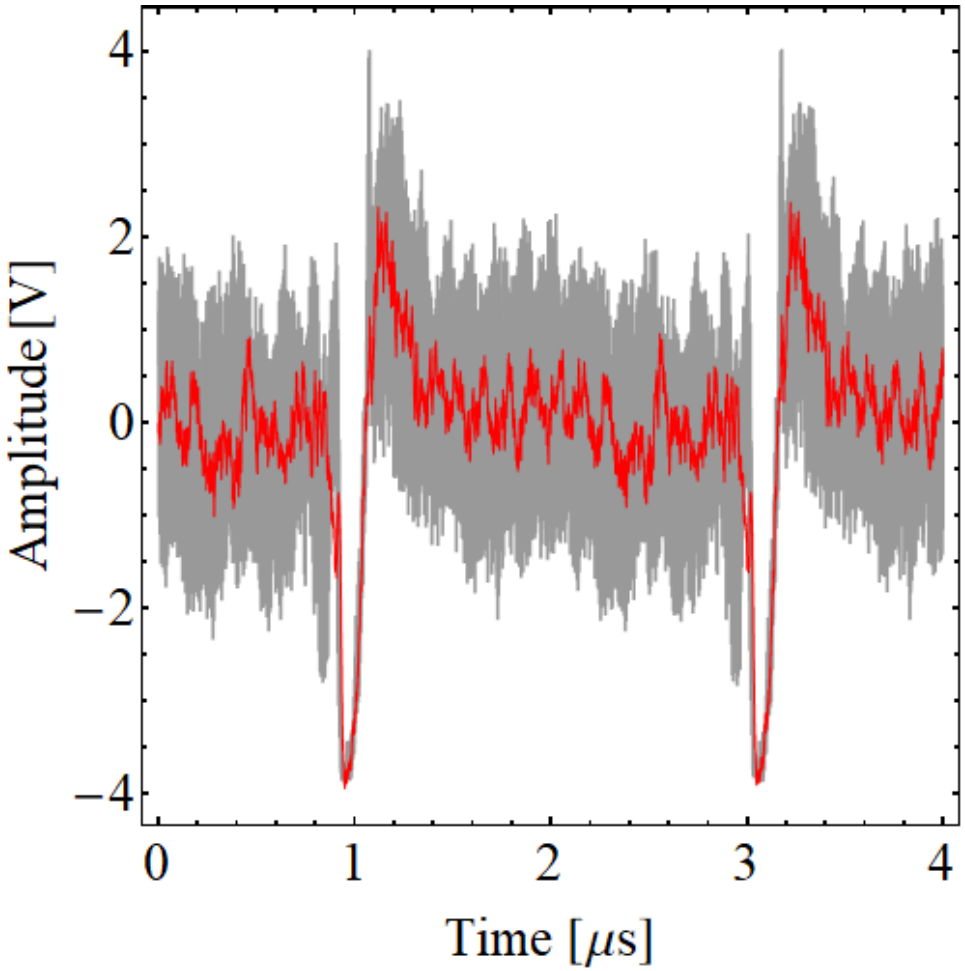
Example quadrupole scans: New Vs old TFs
Measuring beam size as a function of magnet current

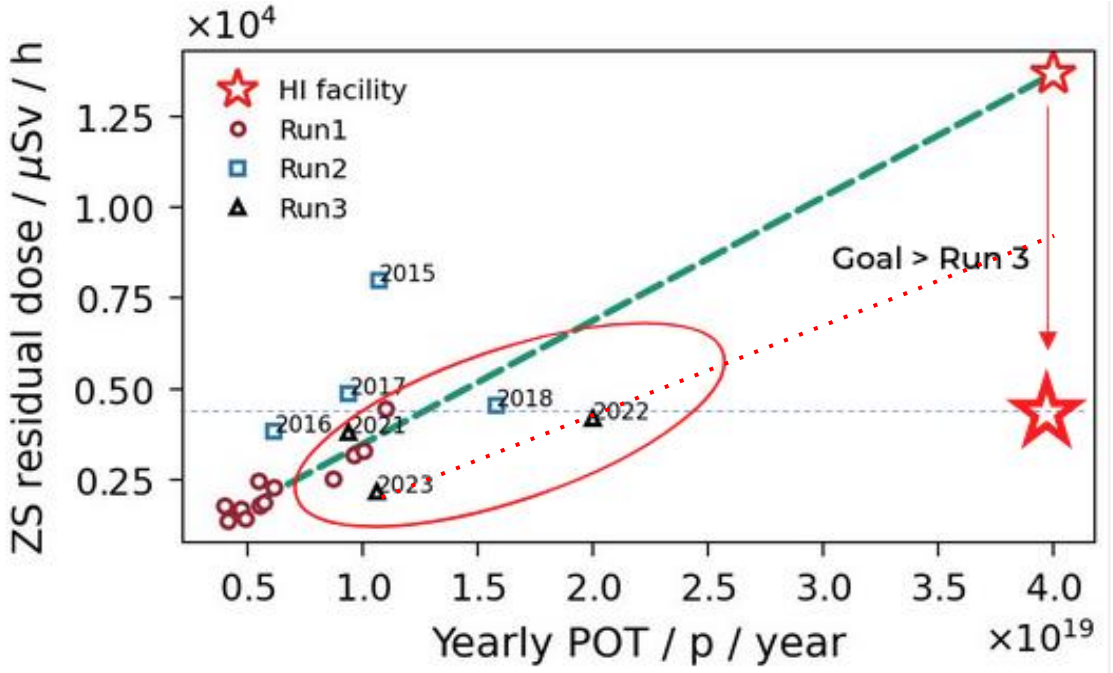
Beam size vs. yield





- Better focus with higher energy – as expected
- -> MD


Amplitude [V]
4
2
0
−2
−4
0
1
2
3
4
Time [μs]


×10^4
ZS residual dose / μSv / h
1.25
1.00
0.75
0.50
0.25
HI facility
Run1
Run2
Run3
2015
2017
2018
2016
2021
2022
2023
Goal > Run 3
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Yearly POT / p / year
×10^19

New septum materials

Hazards related to residual dose can be tackled by looking for viable **low-Z materials for different septum components.**

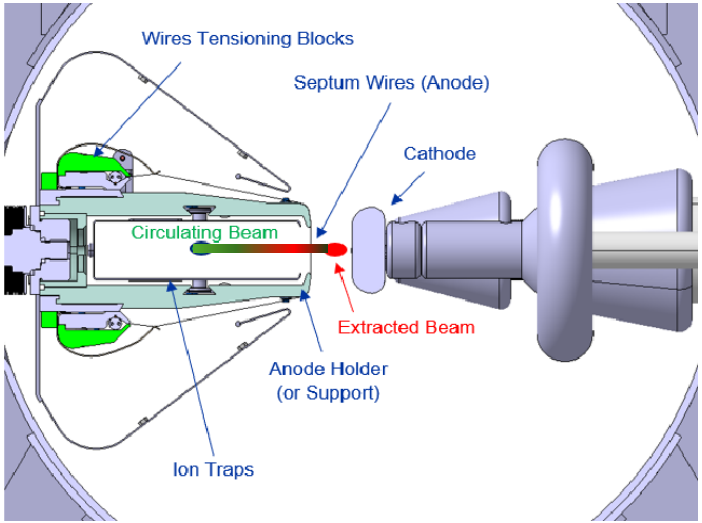


Table 6: Radiological beneficial component material exchanges for extraction equipment.

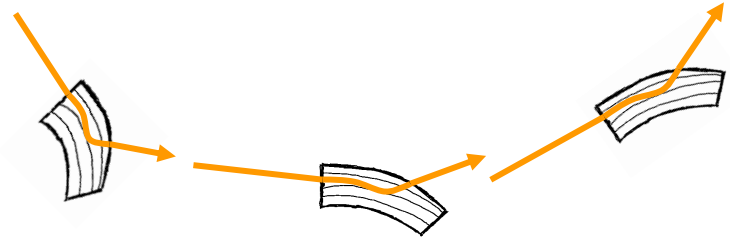
Element	Component	Current material	Beneficial material	Dose rate reduction factor
ZS	Anode wires	Rhenium/ Tungsten	Titanium or Graphite	0.2-0.6 integrated reduction after 30 hours. 0.1-0.001 anode contribution at 1 metre distance (Figs. 72 and 74)
ZS	Anode support	Stainless steel or Invar	Titanium	0.25-0.33 after 1 week, 1 metre distance (Fig. 73)
ZS	Vacuum tank	Stainless steel	AL6061	0.6 after 1 week, 1 metre distance (Fig. 75)

In-house crystals

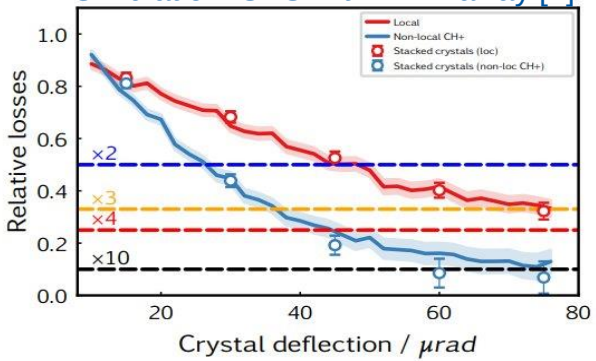
DECRYCE (DEvelopment of CRYstals for Collimation and Beam Extraction) project established **for CERN's crystal needs [1]**: LHC collimation, septum shadowing…

- Procurement of crystal wafers
- Cutting and polishing
- Bender system and integration
- Validation with X-ray and particle beams

Multi-volume reflection



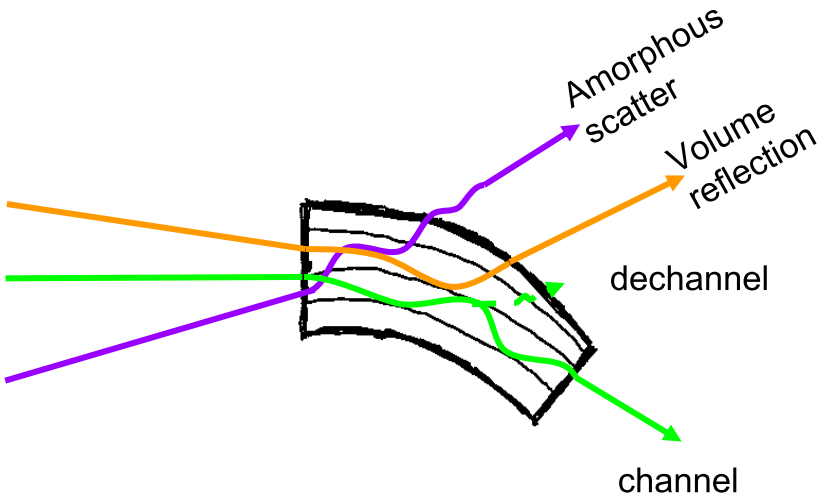
Simulation: SPS with MVR array [2]

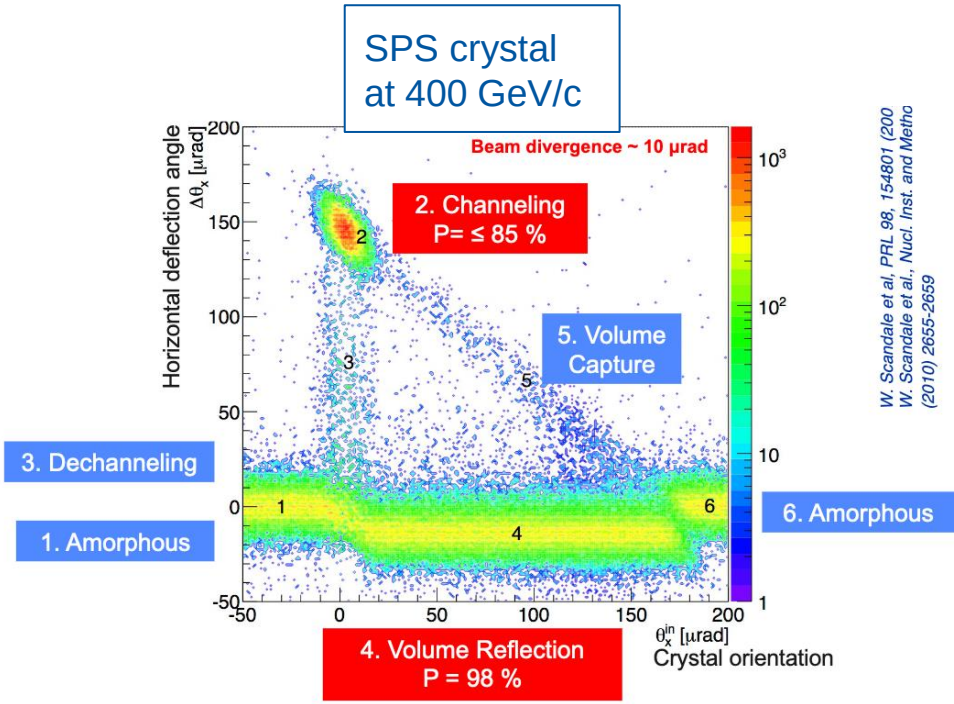


Crystal shadowing (ii)

Two regimes can be exploited for bending:

- Channelling: large kick, low efficiency
- Volume reflection: small kick, high efficiency





Spa review: great dry sauna, humid sauna does not get hot enough