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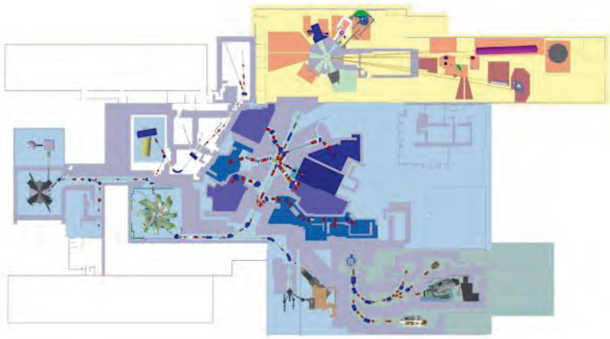
Paul Scherrer Institut

Davide Reggiani

Extraction, Transport and Collimation of the PSI 1.3 MW Proton Beam

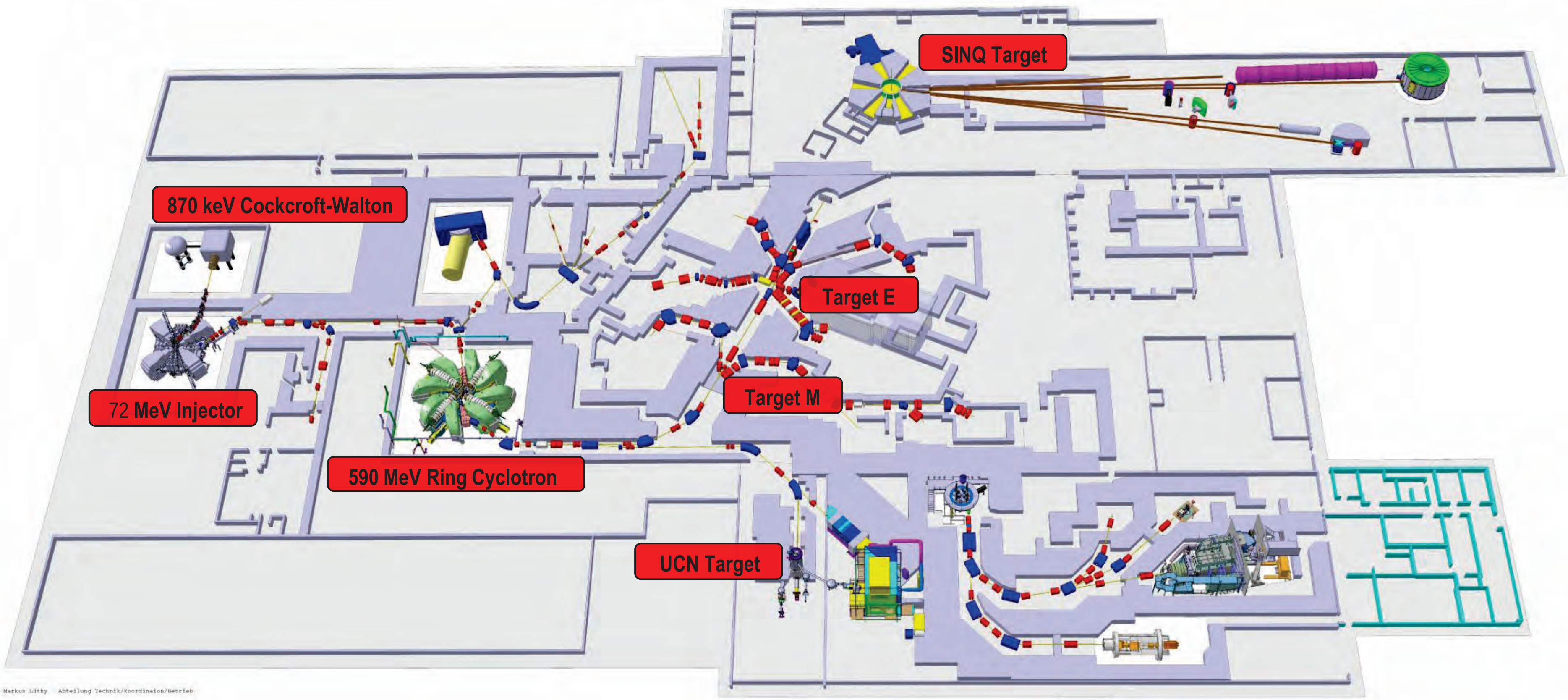
Outline

- Introduction to the PSI High Intensity Proton Accelerator (HIPA)
- Extraction from the Ring Cyclotron
- Beam Transfer to the Meson Production Targets M and E
- Collimation and Transfer to the Neutron Spallation Source SINQ
- 1.3 MW Beam Switchover to the UCN source



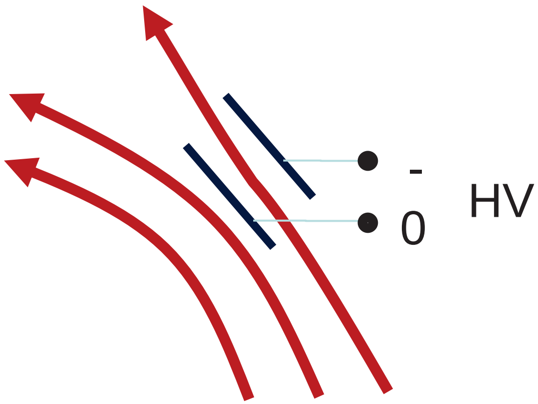
The PSI Proton Accelerator Facility

- CW, 590 MeV, 2.2 mA (1.3 MW) to meson production targets M and E (7 beam lines)
- CW, 575 MeV, 1.5 mA (0.86 MW) to neutron spallation target SINQ (18 beam lines)
- Macro-Pulsed, 1% duty-cycle, 590 MeV, 2.2 mA (1.3 MW) to UCN target (3 beam lines)
- Upgrade program towards 3.0 mA (1.8 MW) launched!



Extraction from Ring Cyclotron

Extraction electrode placed between last two turns



Extraction losses: limiting factor of any high power cyclotron!

Losses minimization through:

- «Thin» extraction device
- Large turn separation →

Turn separation

- Radius increment per turn

Orbit Radius: Large Machine!

Energy gain per turn: Powerful RF System!

$$\frac{dR}{dn_t} = \frac{R}{\gamma(\gamma^2 - 1)} \frac{U_t}{m_0 c^2}$$

Higer Energy disadvantageous
Limit: E < 1 GeV

- Off-center orbit Extraction:

Exploit betatron oscillation to increase turn separation by a factor of 3!

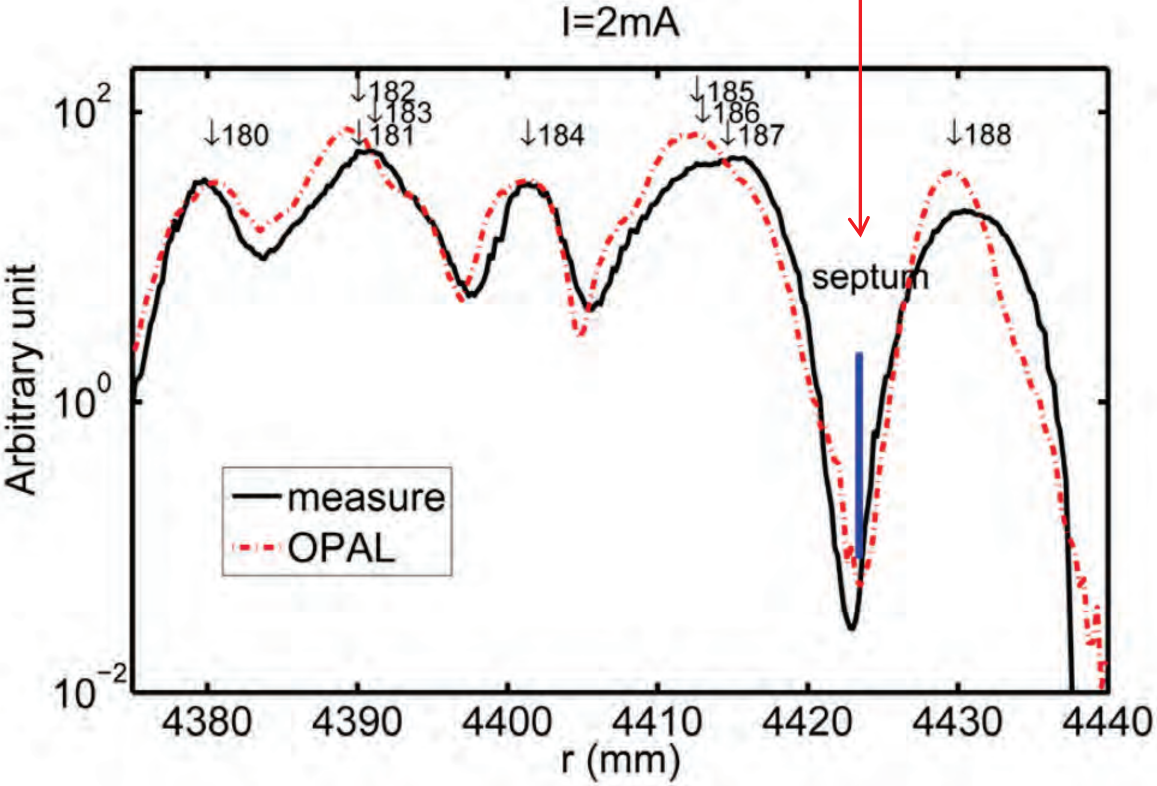
Turn Separation at PSI Ring

- Aceleration term:

$$\frac{dR}{dn_t} = \frac{R}{\gamma(\gamma^2-1)}\frac{U_t}{m_0c^2} \xrightarrow[R\,=\,4460\,mm,\;U_t=\,3MeV,\;\gamma\,=\,1.63]{at\ exctraction} \approx 6\ mm$$

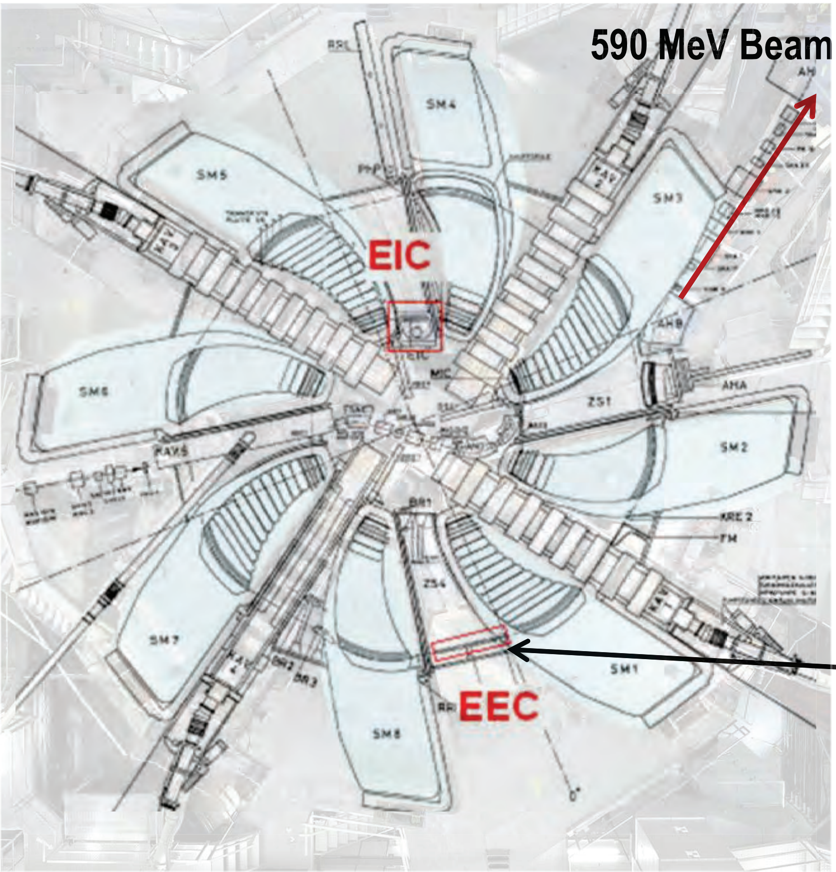
- Including off center orbit extraction: ***ΔR = 18 mm***

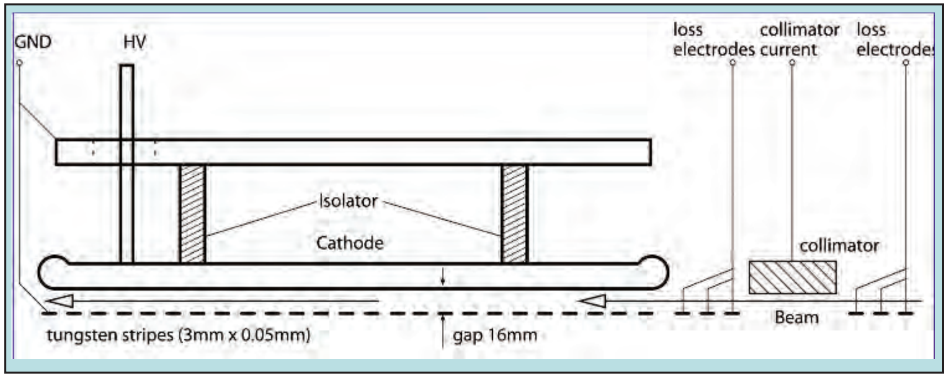
See Talk by M. Seidel: TH01C01



Y.J. Bi et al., Proceedings HB2010

Principle of Extraction Channel





EEC: Electrostatic Extraction Channel

Gap = 16 mm θbeam = 8.2 mrad

Extraction Efficency: 99.98 %

The 590 MeV Proton Channel

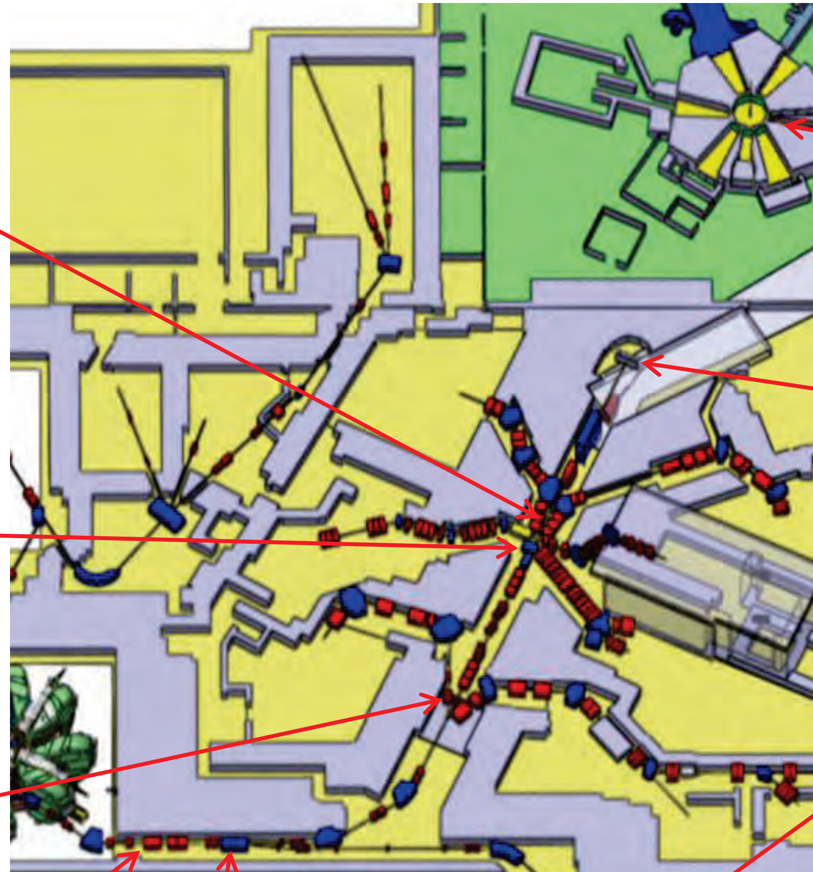
Cu-Collimator

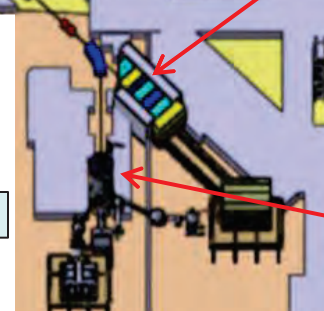
Target E

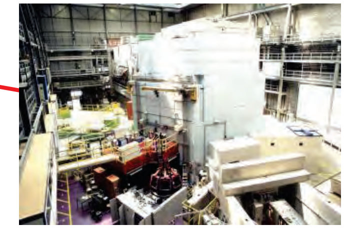
Target M

UCN Kicker

Septum







SINQ Spallation Source

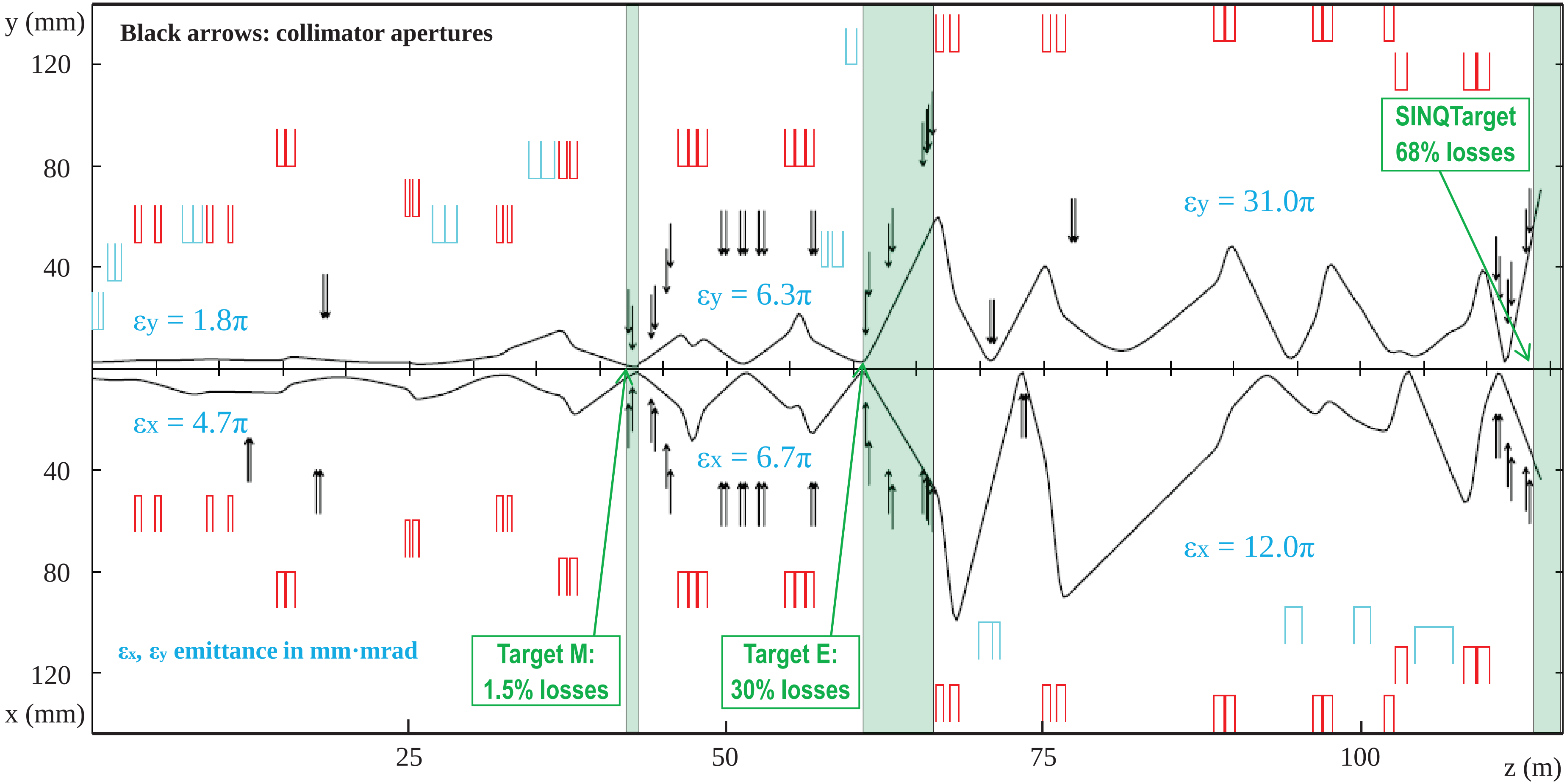
SINQ Beam-Dump

UCN Beam-Dump

UCN Spallation Source

1.3 MW Beam Transport

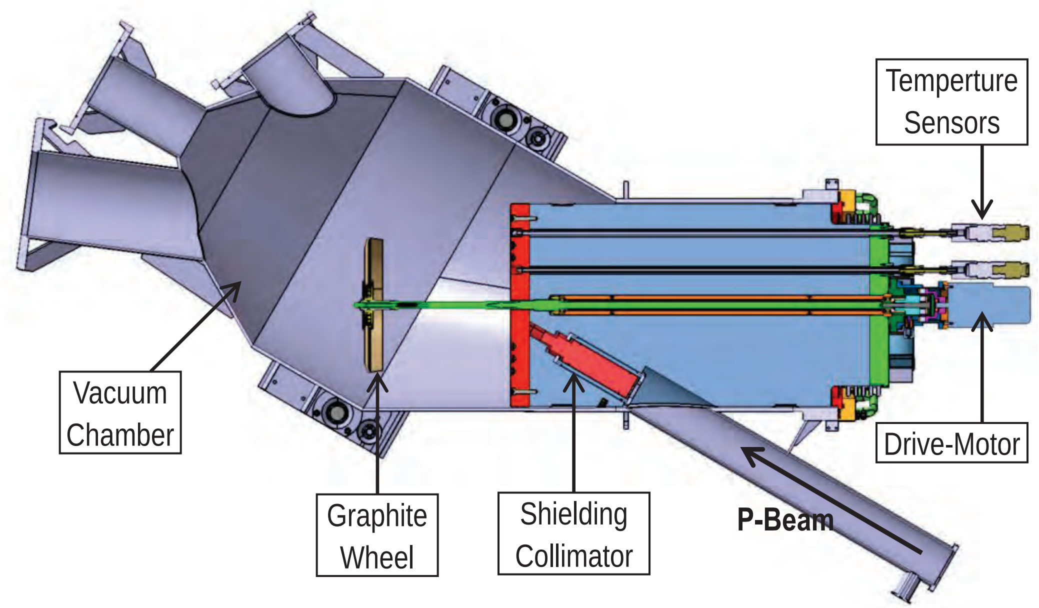
1.3 MW Beam Envelopes from Cyclotron Extraction to SINQ Target (with Magnet and Collimator Apertures)

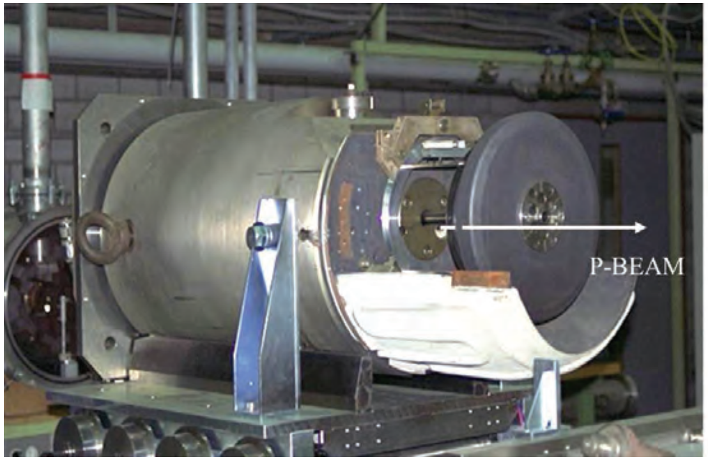


Peak beam current density on target M and E: 200 kW/mm^2

Average losses away from targets: 0.6 W/m

Target-M Design

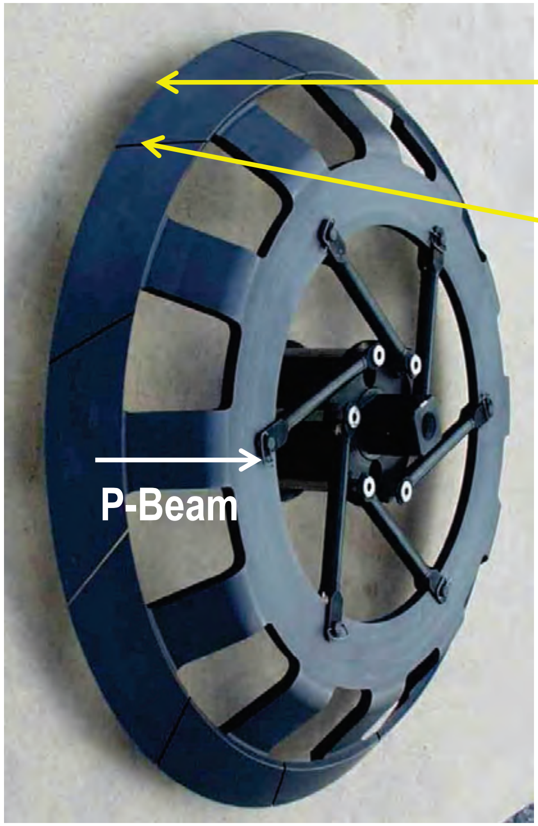




Specifications:

Mean diameter:	320 mm
Target thickness:	5.2 mm
Target width:	20 mm
Graphite density:	1.8 g/cm^3
Beam loss:	1.6 %
Power deposition:	2.4 kW/mA
Operating Temperature:	1100 K
Irradiation damage rate:	0.12 dpa/Ah
Rotational Speed:	1 Turn/s
Current limit:	5 mA
Life time:	50000 h

Target-E Design

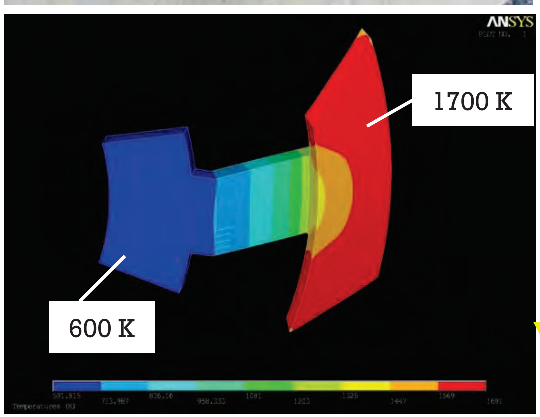


Target width: 6 mm, Beam width (1σ) ≈ 1 mm
Beam transverse range ≈ 4 mm

New design (2003): **gaps** allow dimensional changes of the irradiated part of the graphite

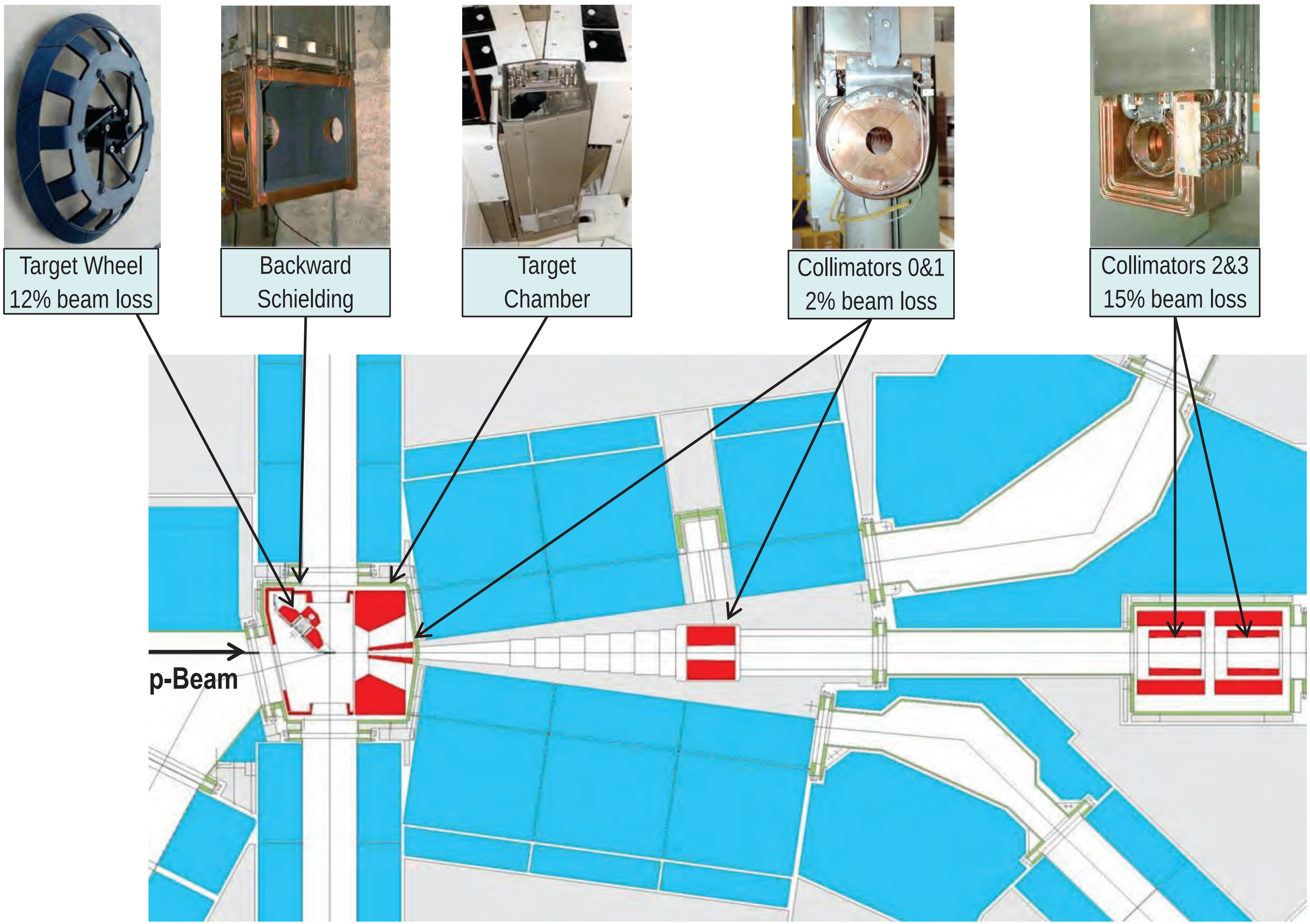
TARGET WHEEL

Mean diameter:	450 mm
Graphite density:	1.8 g/cm^3
Operating Temperature:	1700 K
Irradiation damage rate:	0.1 dpa/Ah
Rotational Speed:	1 Turn/s
Target thickness:	40 mm (7g/cm^2)
Beam loss:	12 %
Power deposition:	20 kW/mA
Cooling:	Radiation



Temperature distribution simulation

Target E Region



150 kW on a Collimator! Temperature Effect

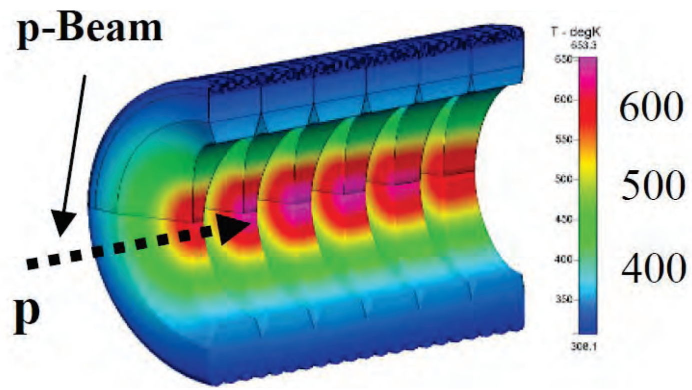
KHE2 Collimator during installation (1990)

…and after 20 years operation (120 Ah total beam charge)

KHE2 Temperature Distr. for 2.0 mA

Proton Beam on Target E

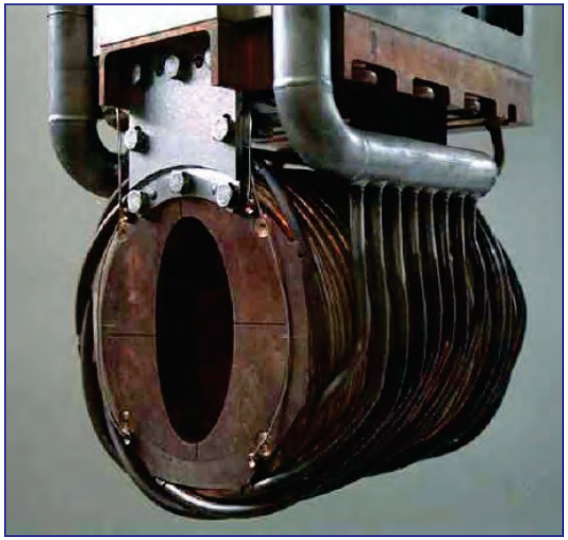
T_{max} = 653 K,   safe till 770 K (~2.6 mA)

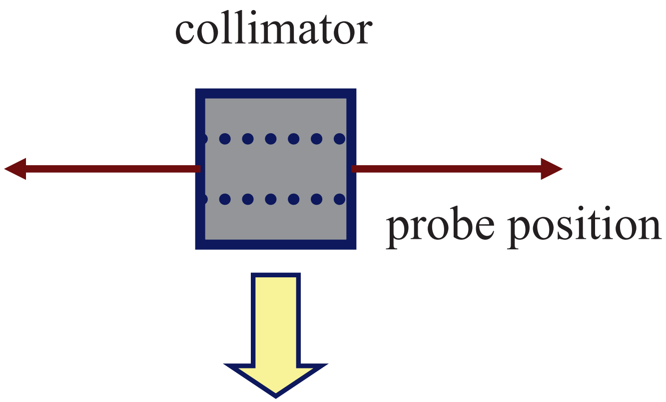


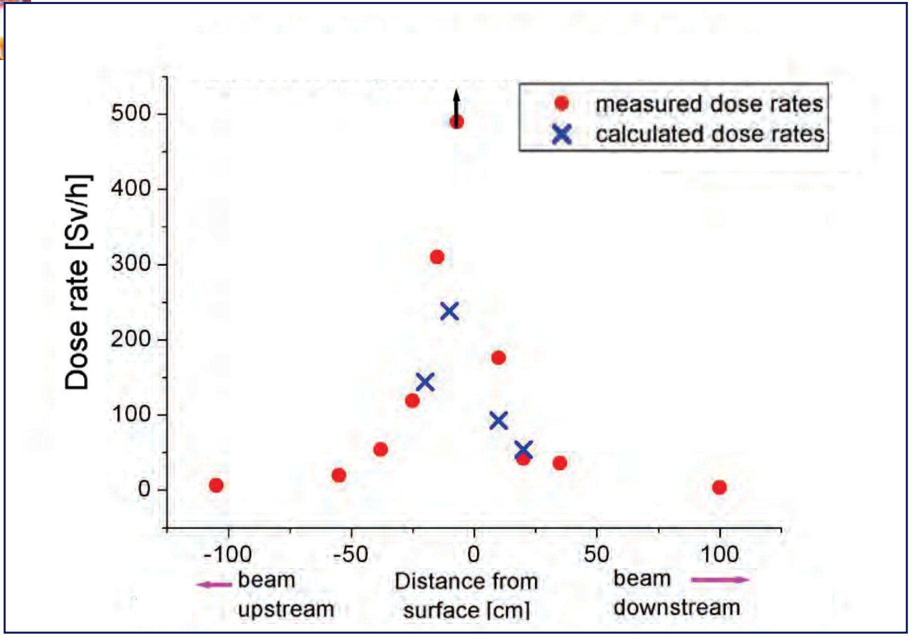
Y. Lee et al., Proceedings HB2010

Do we need a new collimator or a new running strategy for 3.0 mA?

150 kW on a Collimator! Activation



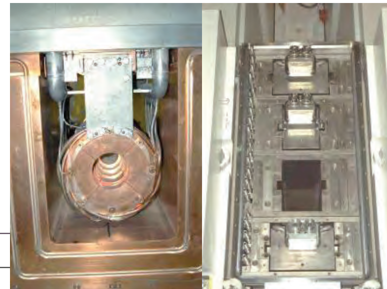




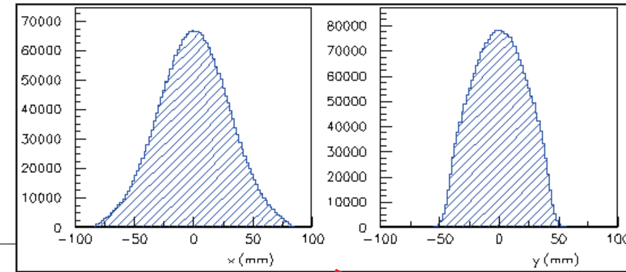
Dose rate up to 500 Sv/h measured at KHE2 during inspection in March 2010!!

Beam Transport to SINQ

700 kW beam dump (1 MW beam on target E)

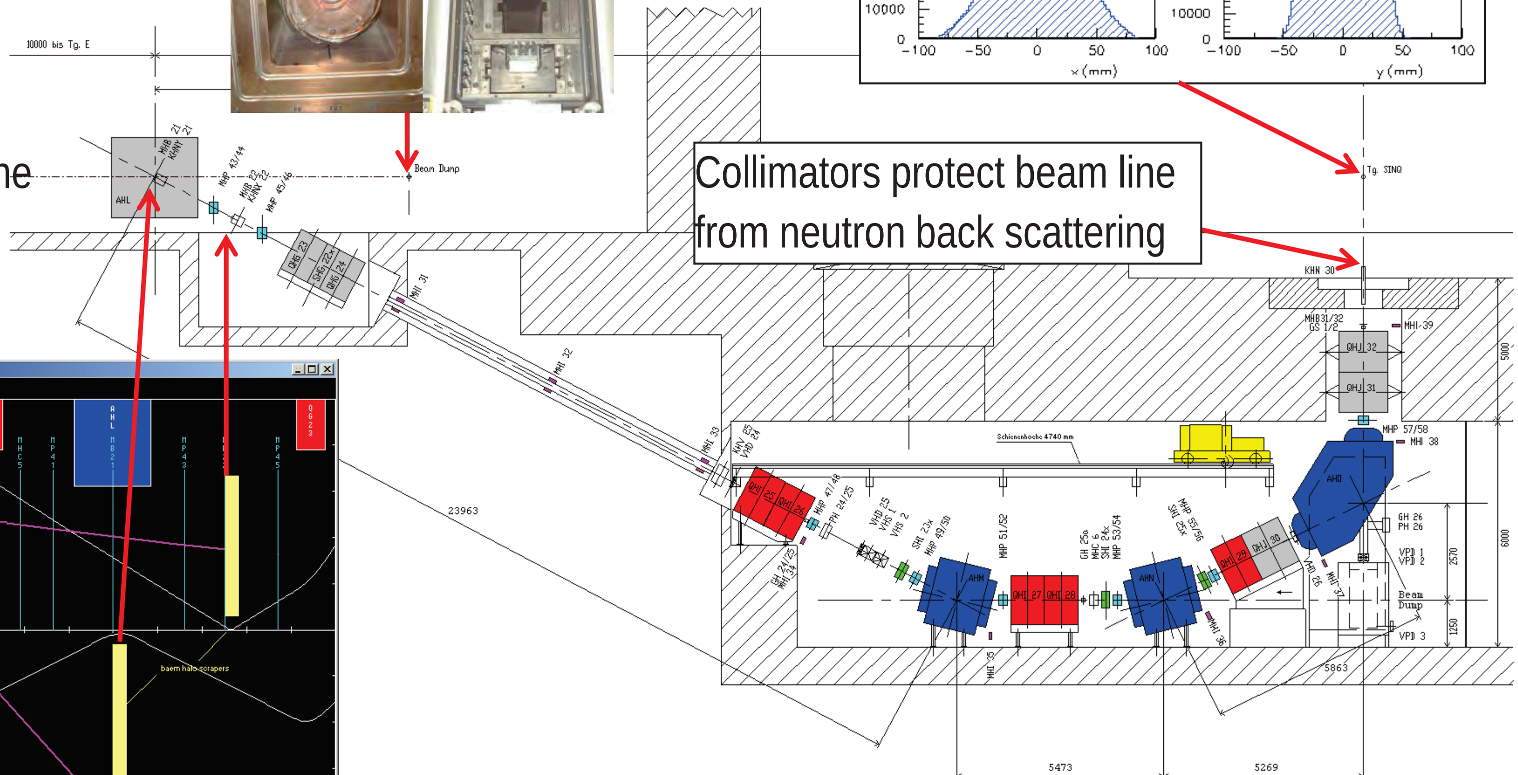


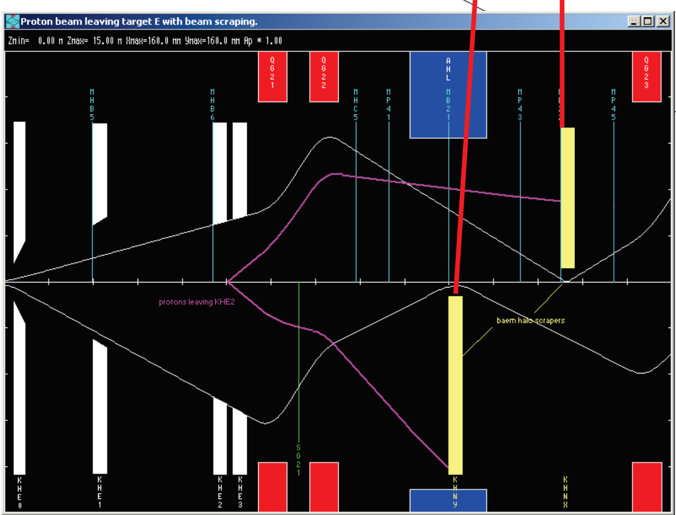
Beam distribution at SINQ target



Vertical bending plane

Collimators protect beam line from neutron back scattering





H and V movable slits (halo scrapers)

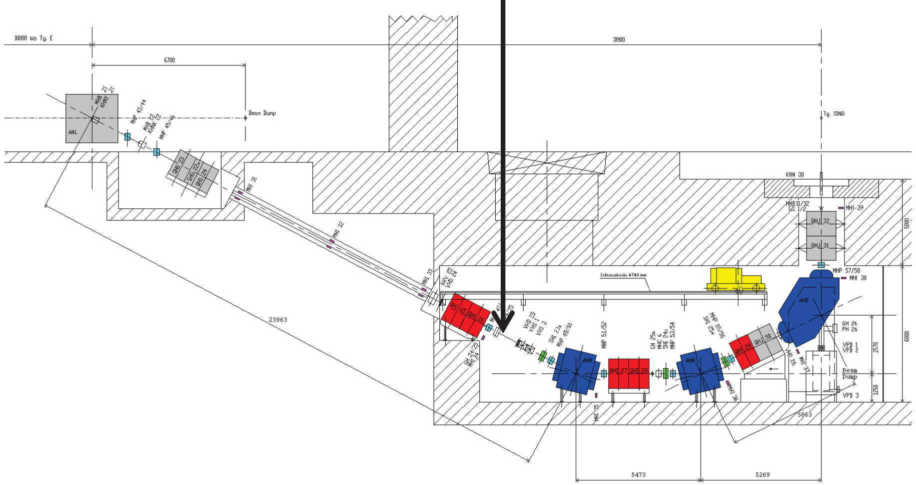
Feasibility Study: SINQ Beam Rotation System

Peak current density on the SINQ target could become an issue in view of an intensity upgrade
→ Consider a beam flattening system:

- Non linear elements (i.e. octupoles): distort beam footprint
- Fast beam rotation system: seems a good option

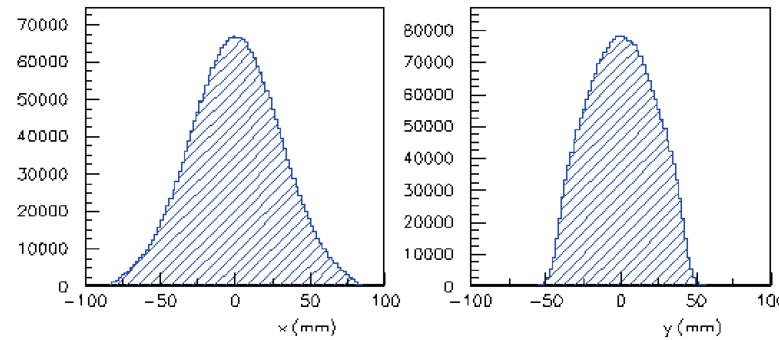
Simulation strategy

- BRS-Location: ~25 m upstream of SINQ target
- Losses from rotating beam must not be larger than standard case

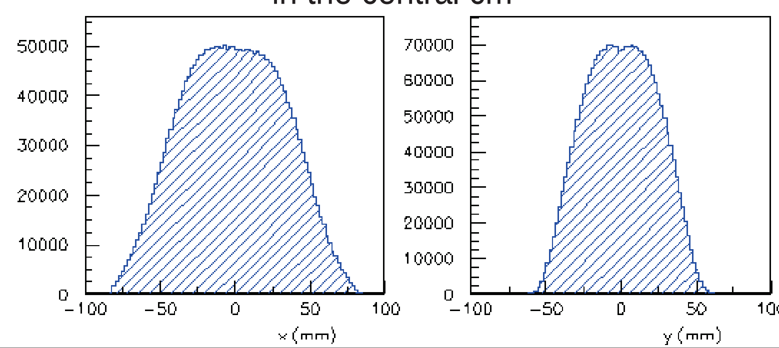


Simulation results: beam distribution on SINQ

without rotation

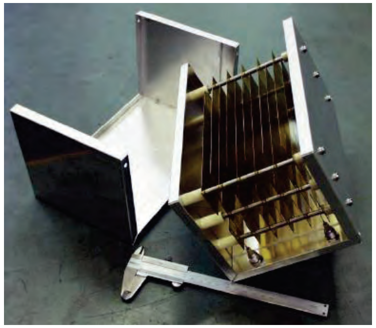


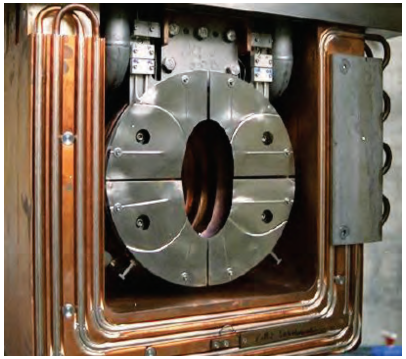
with rotation: ~ 50% less beam current density in the central cm^2

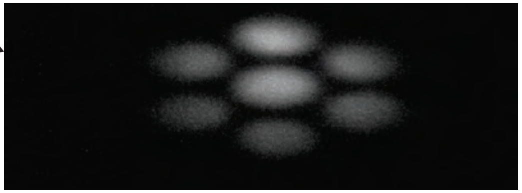


Machine Protection System

- 1.3 MW proton beam with $\sigma_x = \sigma_y \approx 1$ mm [→ TM and TE regions] melts beam pipe in **≈ 10 ms**
- PSI MPS stops the beam in **< 5 ms**
- MPS gets signals from:
  - Magnet power supplies
  - Beam loss monitors (110 ion chambers)
  - Current monitors → See Talk by P.A. Duperrex: TH03C06
  - Halo monitors
  - Temperature sensors (collimators)
  - VIMOS tungsten mesh (SINQ beam footprint)



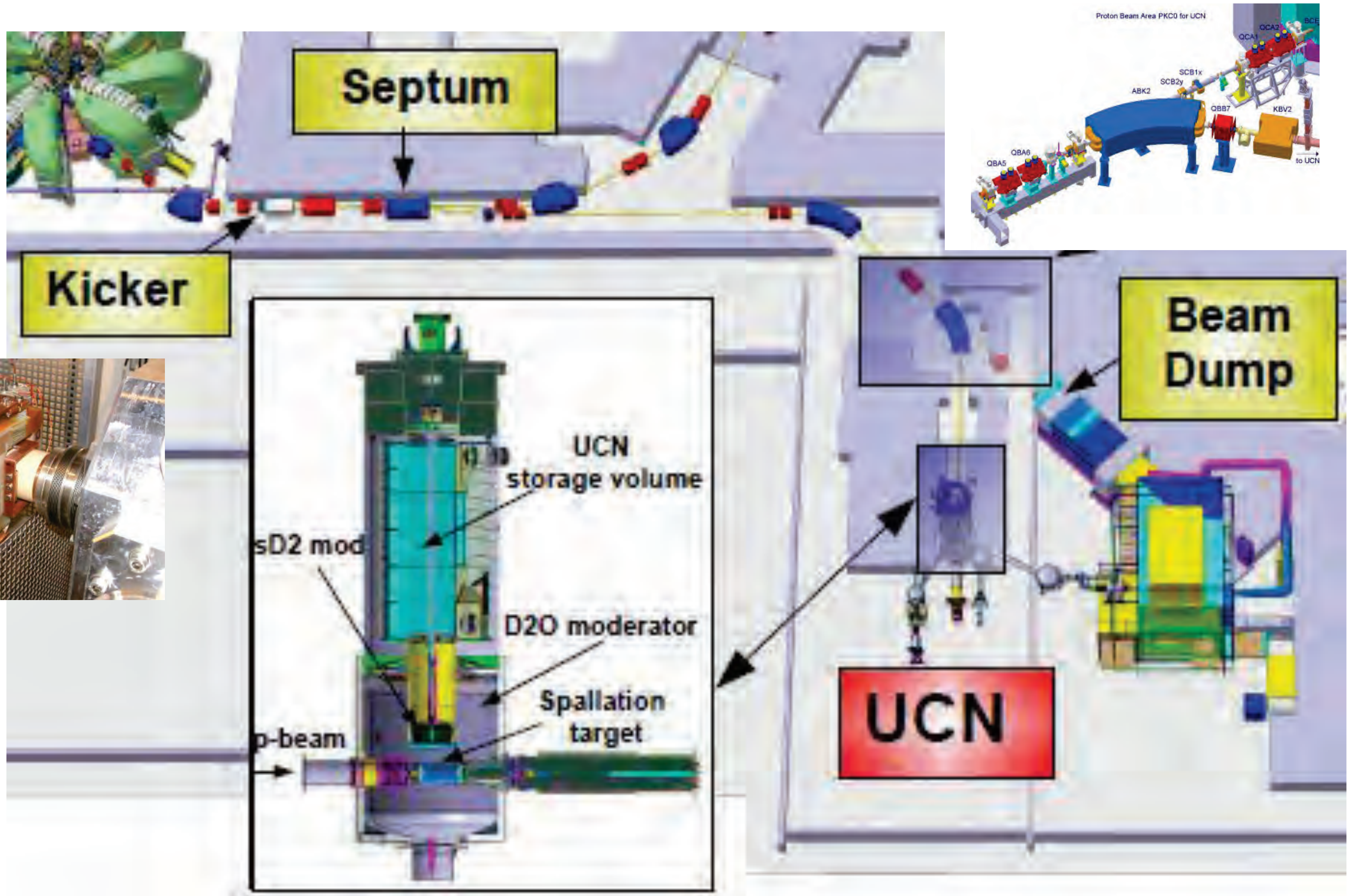


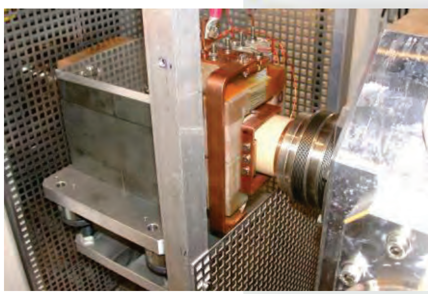


HIPA MPS Review: A. Mezger and M.Seidel, Proceedings HB2010

UCN Beam Line

1.3 MW Proton Macro-Pulses diverted to Ultra Colde Spallation Source (1% duty cycle, pulse-length$_{max}$ = 8 s)

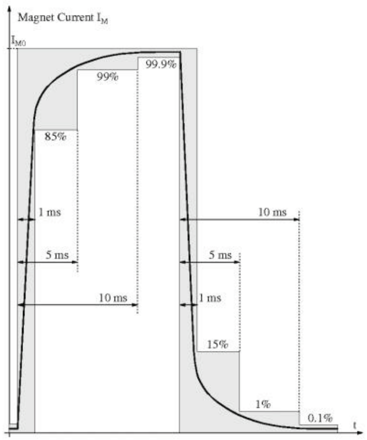


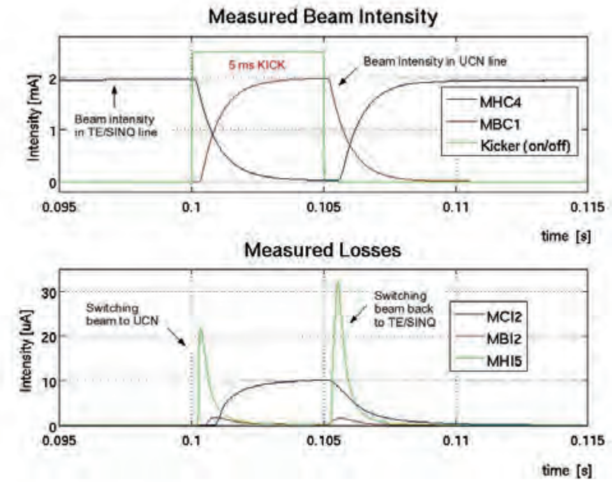


UCN Pulsing Scheme: Requirements and Solutions

- Limit beam losses

  → Fast Kicker-Magnet (Rise-Time < 1 ms)



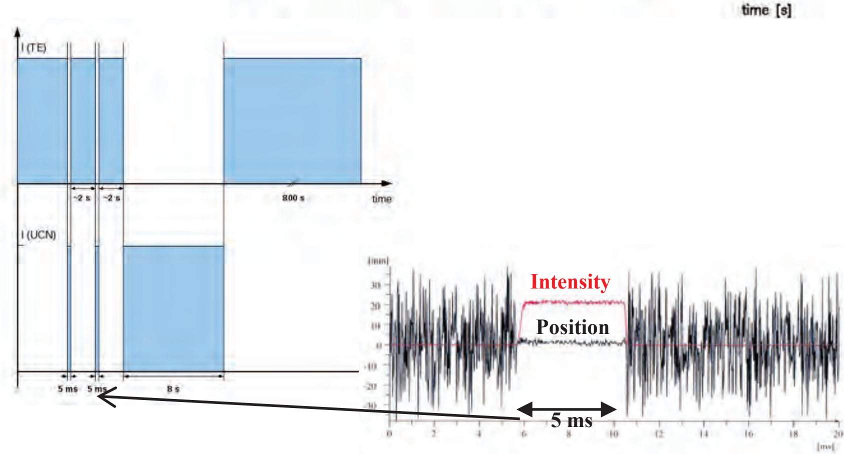


- Avoide machine interlock during switchover

  → Short (3 ms) shift of beam loss monitor interlock thresholds

- Check beam centering

  → Perform 5 ms pilot pulse before each long pulse

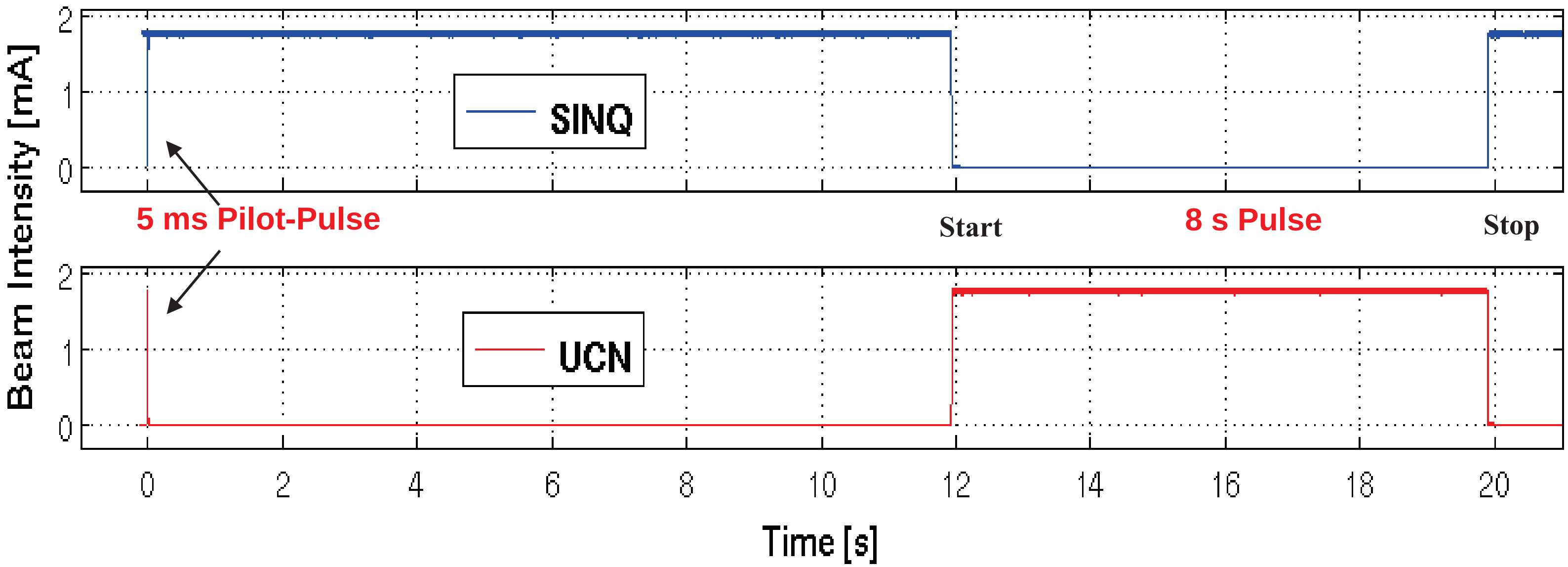


UCN Operation

22 December 2010

First successful 1 MW, 8 s long UCN Beam Pulse

(after three years beam commissioning with the UCN beam dump!)



August 2011

Start UCN production

Conclusion

- Since many years the PSI 1.3 MW proton accelerator is an established and reliable user facility
- The «production» beam current has been gradually increased from 100 µA (1974) to 2.2 mA (2008)
- High current runs at 2.4 mA take place for 2 shitfs (16 hours) every 14 days
- At 590 MeV, the main issues related to a further intensity increase (up to 3.0 mA, 1.8 MW) are:
  - **Extraction losses**
  - **Beam collimation/reshape after target E**
  - **Beam current distribution on SINQ target**

Thank you for your attention!