



Wir schaffen Wissen – heute für morgen

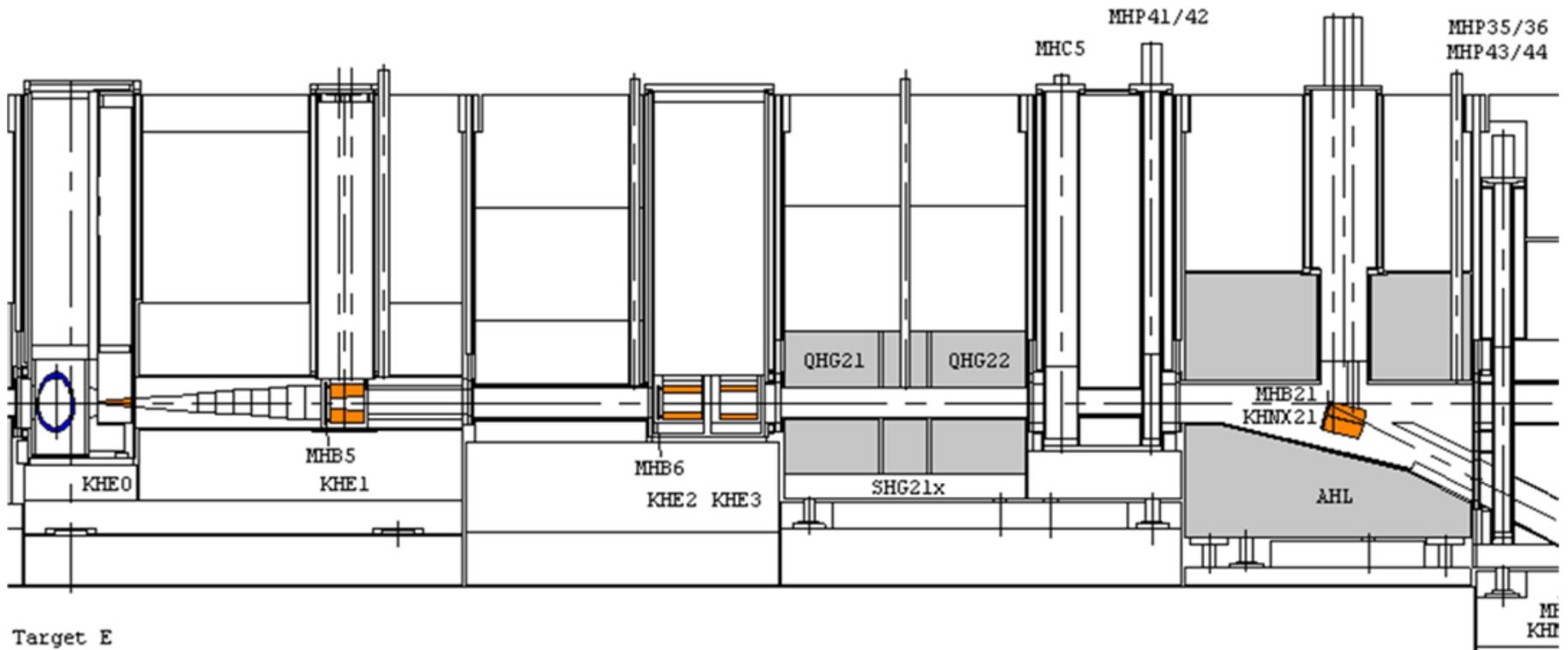
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New Design of a Collimator System at PSI Proton Accelerator

Beamline elements from Target E up to AHL

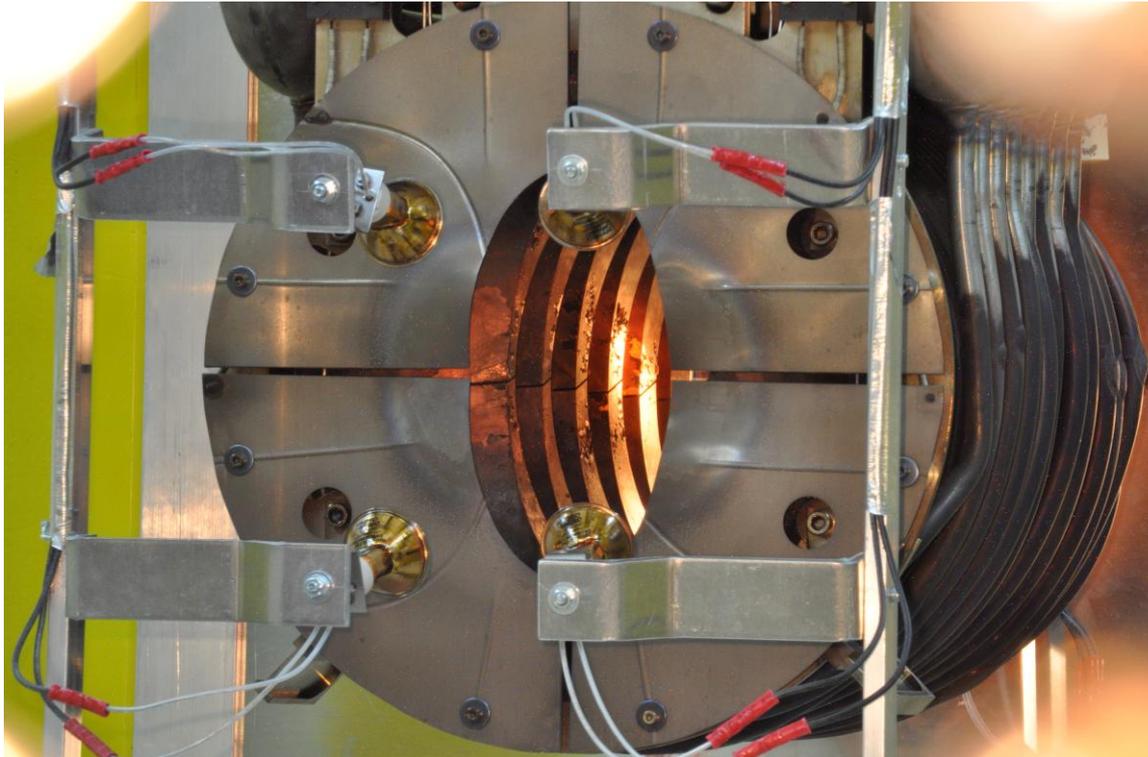
- ❖ The muon production target E generates strongly divergent proton beam.
- ❖ The collimator system composed of KHE2 and KHE3 protects the quadrupole magnets (QHG21 & QHG22) and the bending magnet (AHL) from direct proton beam exposure.



- ❖ Gradual upgrade of proton beam power from the present 1.4 MW (590 MeV/2.3 mA) towards 1.8 MW (590 MeV/3.0 mA) is in plan.
- ❖ Critical issue is the reliability at high proton beam power operation.

Challenge to collimator system reliability

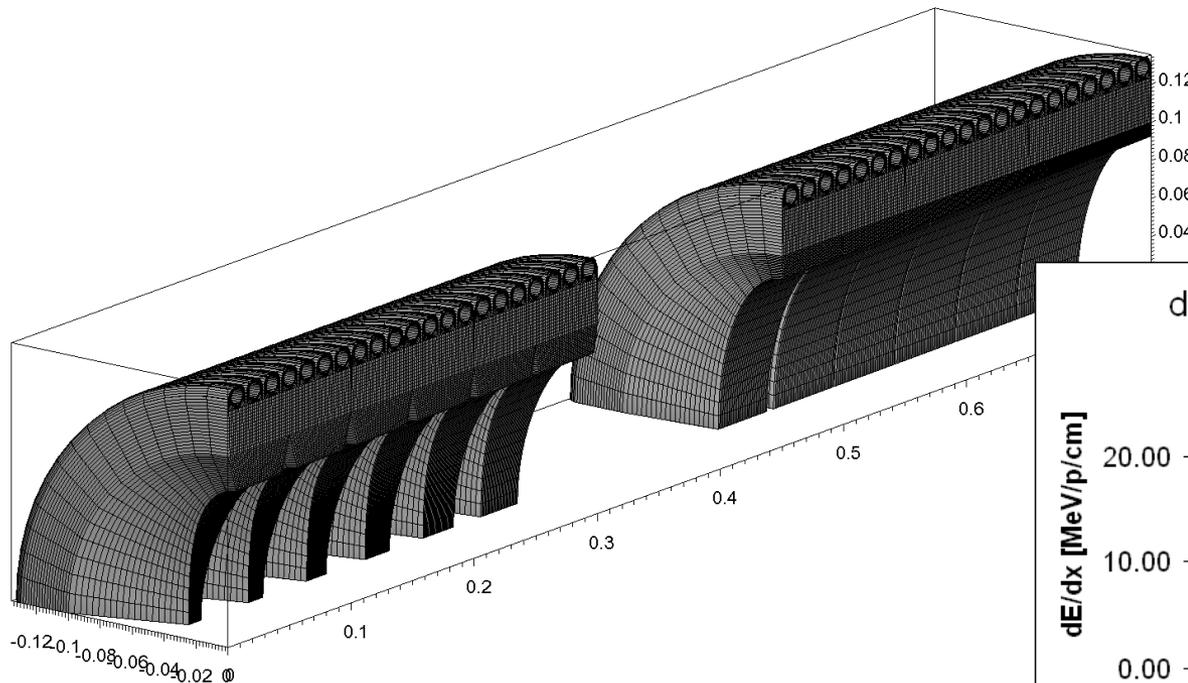
- ❖ The collimator system KHE2 & KHE3 absorbs ~14 % of beam power.
- ❖ For 1.3 MW (590 MeV/2.2 mA) beam power, the power deposition in KHE2 & KHE3 is expected to be ~190 kW, with the peak temperature exceeding 400 C.



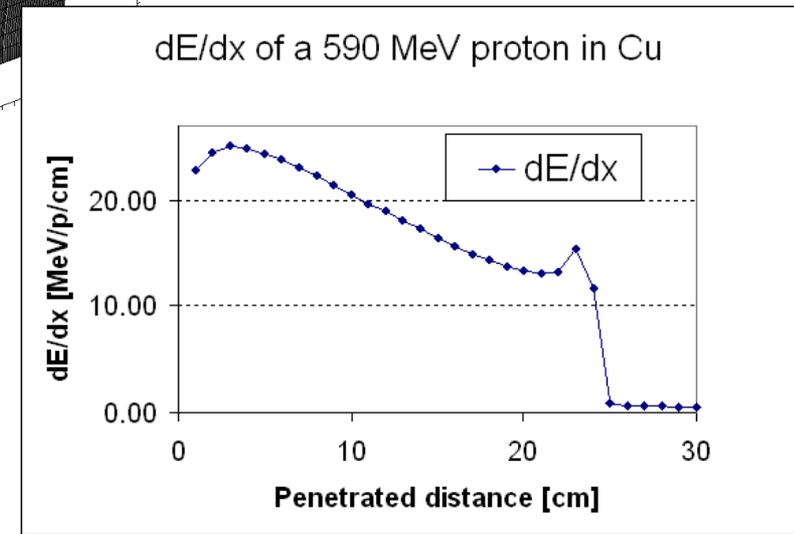
Photos taken by A. Strinning & M. Gandel during 2009-2010 shut down; see Poster MOPD64 for details.

- ❖ The generally accepted limit for safe operation is the peak temperature below 50 % (405 C) of the melting point of OFHC-Cu.

- ❖ KHE2 & KHE3 must provide the proton travel length longer than the projected stopping range of a 590 MeV proton in Cu.
- ❖ Distribute the thermal loads from the proton stopping power uniformly along the teeth, in order to avoid excessive hot spot.



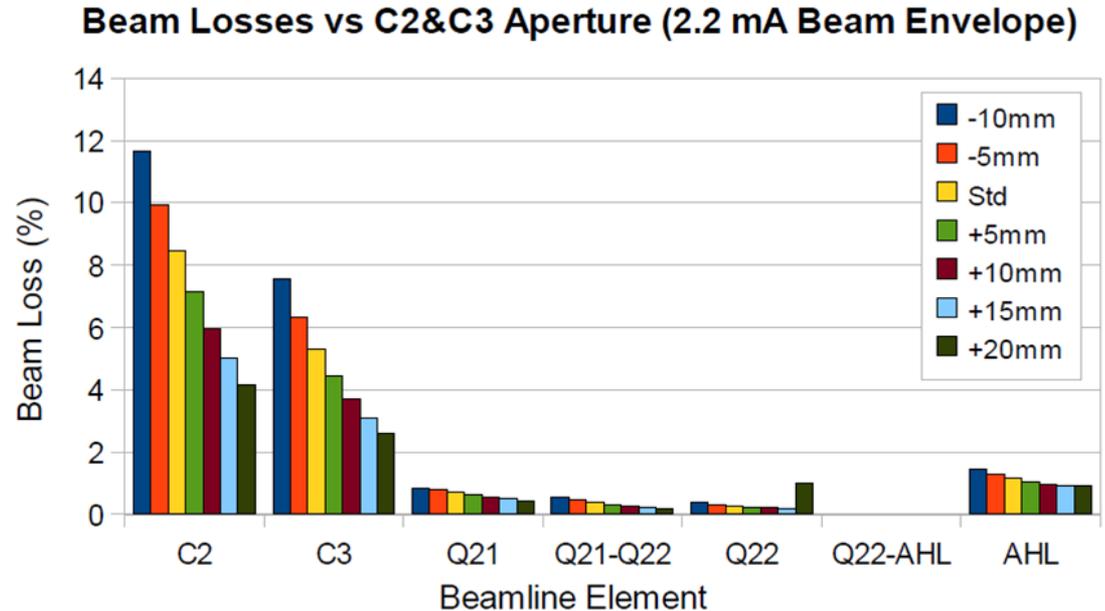
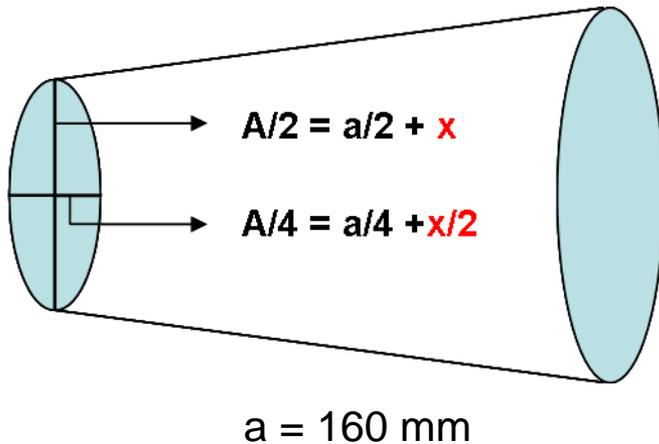
MCNPX simulation: D. Kiselev



- ❖ Water cooling via brazed water pipes made of stainless steel.

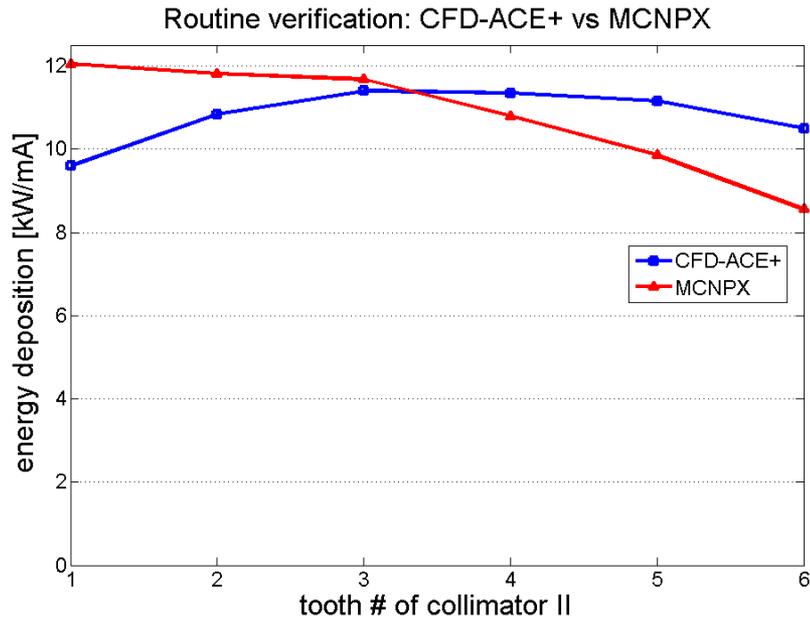
Sensitivity analysis regarding collimator aperture I

- ❖ Numerical simulations with the ray tracing program TURTLE (D. Reggiani).
- ❖ For “x” larger than 20 mm, the particles directly lost onto the quadrupole magnet Q22.



- ❖ Taking engineering safety margin into account, the realizable optimal aperture is chosen to be the option with $x = 10 \text{ mm}$.

- ❖ Fortran user subroutine for proton stopping power calculation is developed for CFD-ACE+.
 - MC simulations are computationally expansive and inadequate for optimization studies involving large number of geometry parameters.
 - Input: beam directional vector, grid connectivity, differential stopping power, beam current profile.
 - Output: Volumetric power source in W/m^3 .

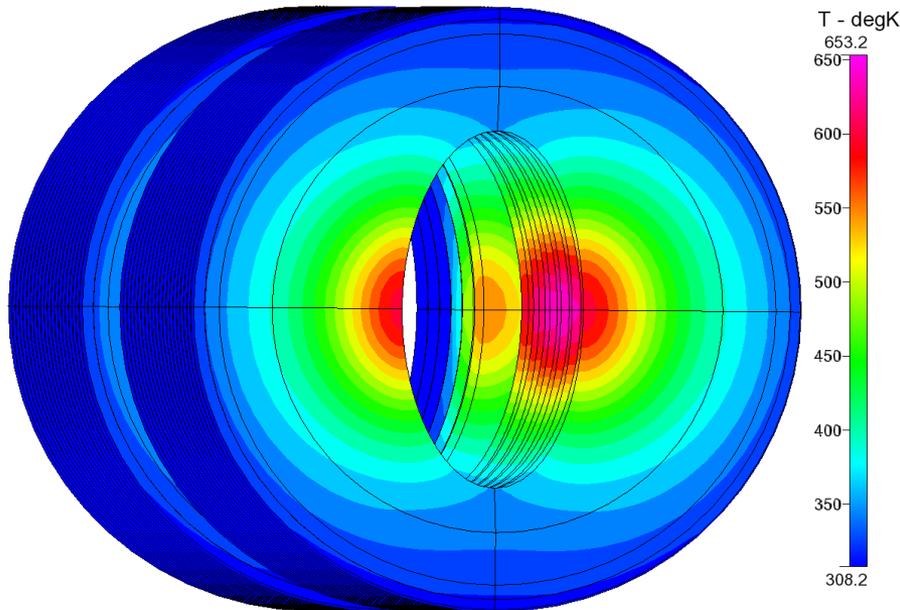


Q [kW/mA]	CFD-ACE+	MCNPX
Teeth Collimator II	64.85	64.76
Ring Collimator II	0.96	6.67

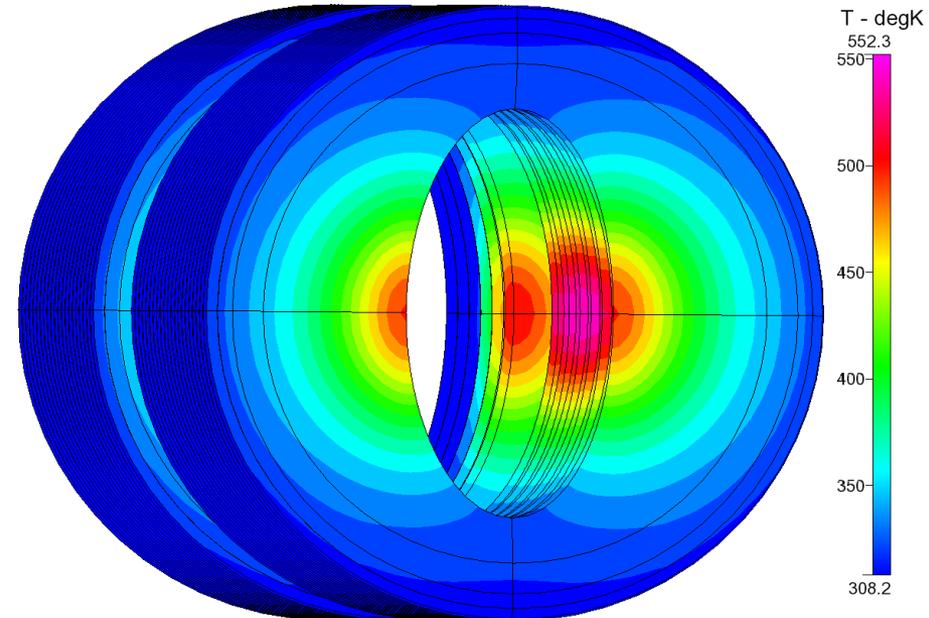
- ❖ The FORTRAN subroutine assumes 'zero' scattering angles of proton in Cu.
 - Smaller power deposition in teeth at beam entry region and in the outer ring region.

- ❖ Thermal calculations are done at 2 mA.

Type 0: Present system



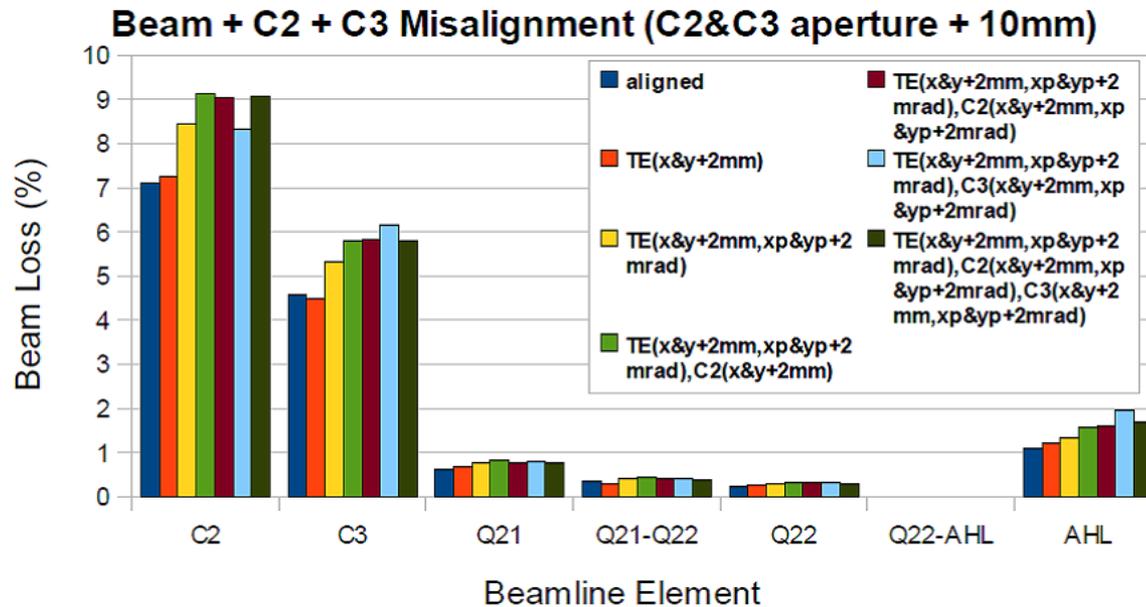
Type 1: System with 12.5% larger aperture



- ❖ Type 1 shows better thermal characteristics:

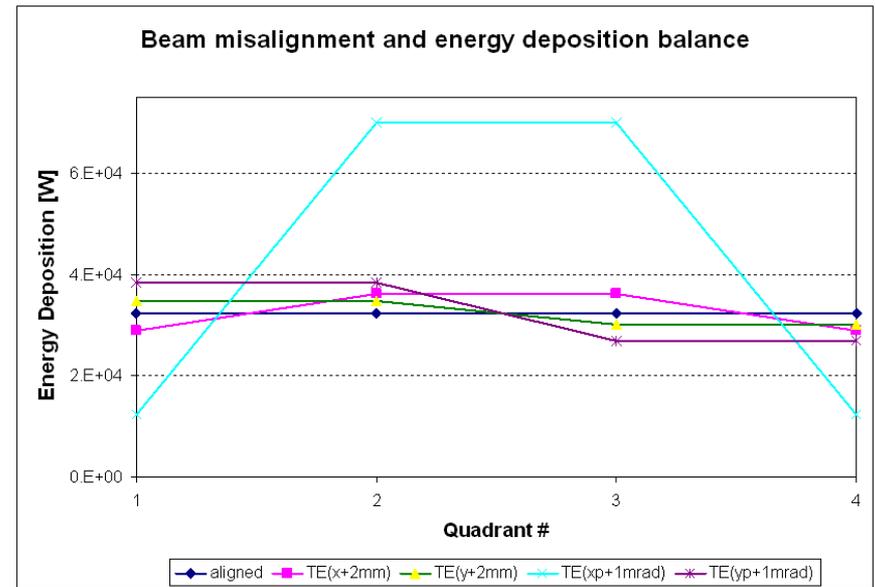
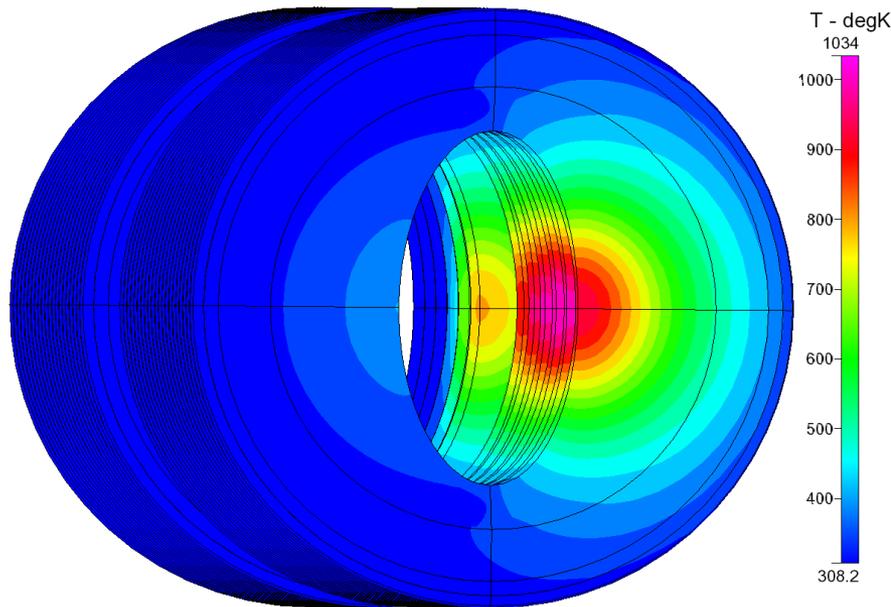
- The peak temperature decreases from 653 K to 552 K.
- The power deposition decreases from 170 kW (14.4 %) to 122 kW (10.3 %).
- Approximately 5 % higher proton beam transport to SINQ.

- ❖ Numerical simulations with the ray tracing program TURTLE (D. Reggiani).
- ❖ Combination of three different beam misalignment types:
 - Beam **position dislocation** at Target E [**TE(x&y+2mm)**] in “x” and “y” direction by 2 mm each.
 - Beam **tilt** at Target E [**TE(xp&yp+2mrad)**], in “x” and “y” by 2 mrad each.
 - KHE2 and KHE3 **position** and **angle misalignments** [**C2(x&y+2mm,xp&yp+2mrad); C3(x&y+2mm,xp&yp+2mrad)**], offset in “x” and “y” by 2 mm and 2 mrad each.



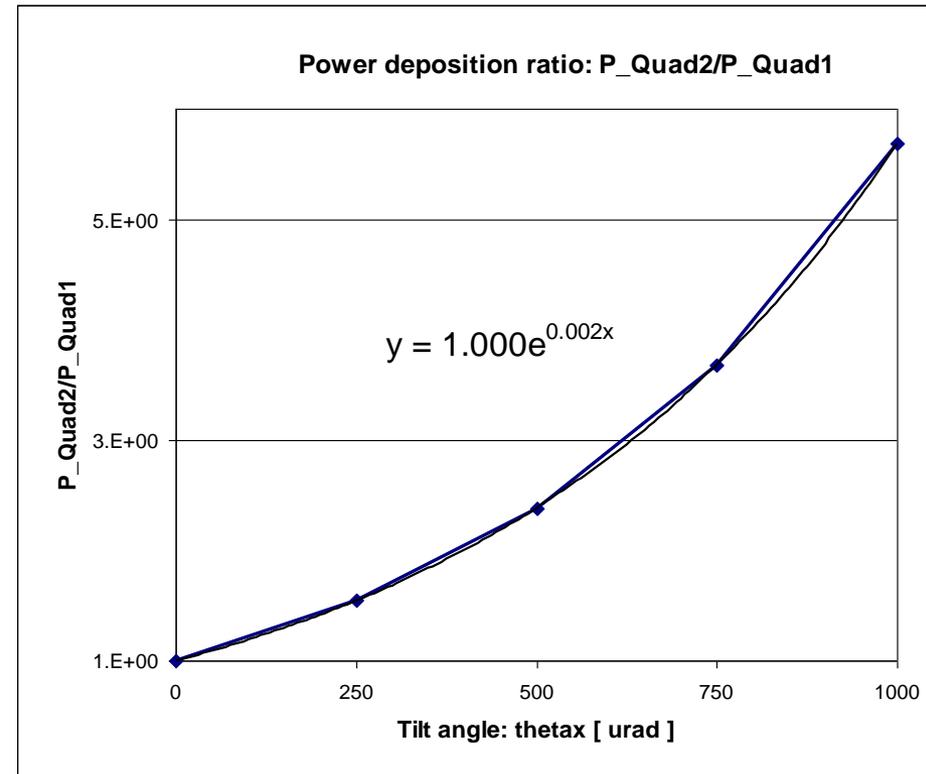
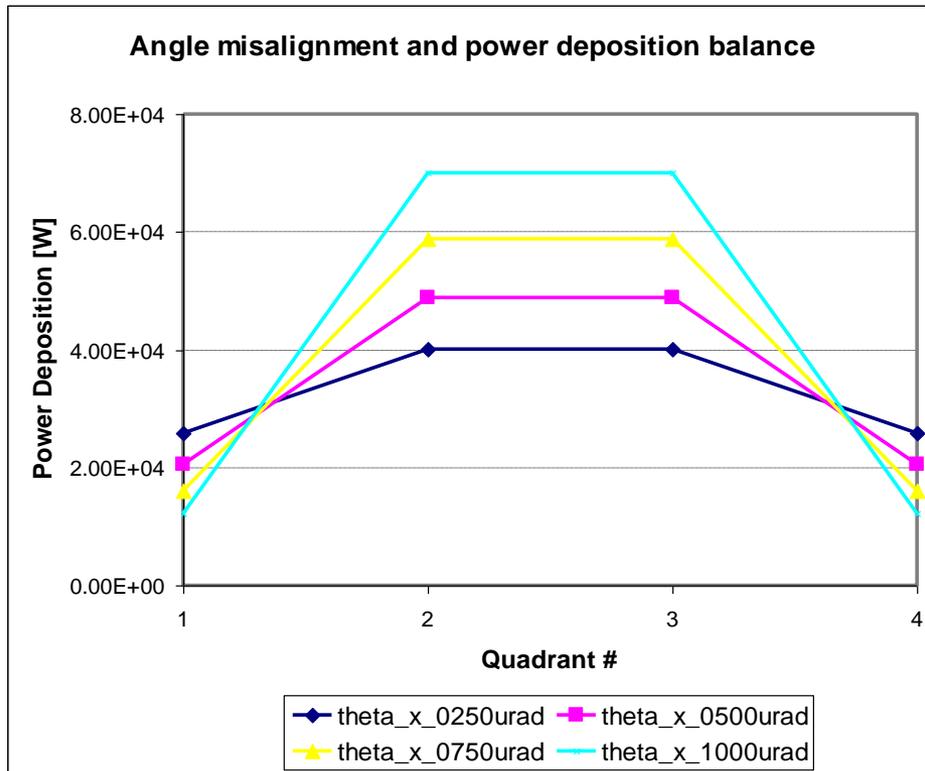
- ❖ Sudden increase of beam losses at beamline elements is not expected for the collimator system with 12.5 % larger aperture.

- ❖ Thermal calculations are done for **Type 0** and **Type 1** collimator systems at 2 mA.
- ❖ Five different beam misalignment types are studied.



- ❖ Worst case is the angular beam misalignment in the x-direction by 1 mrad.
 - The maximum temperature of **Type 1** collimator system is lower by ~100 K.
 - **Type 1** has additional angular tolerance by 0.3 mrad or 30 s time margin.

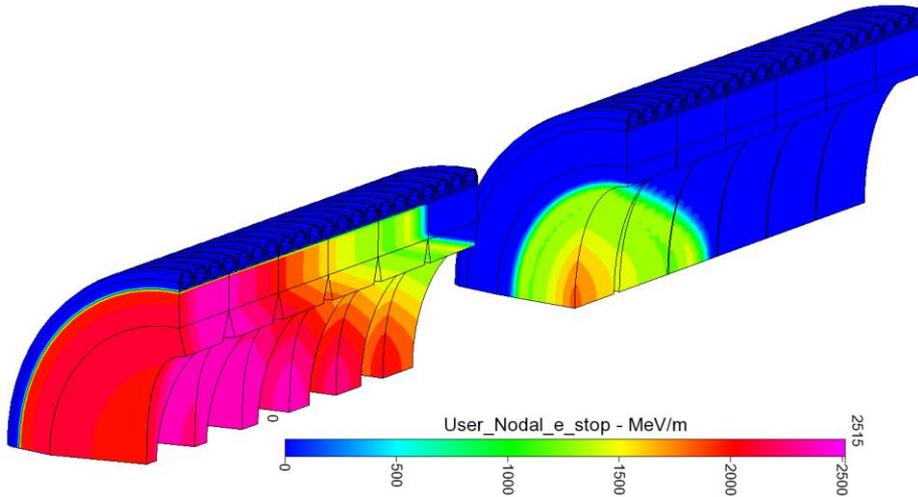
- ❖ There is a correlation between the beam angle misalignment and the degree of power deposition imbalance in four quadrant volumes of KHE2.
 - The interlock limit can be correlated to the beam angle misalignment tolerance limit.



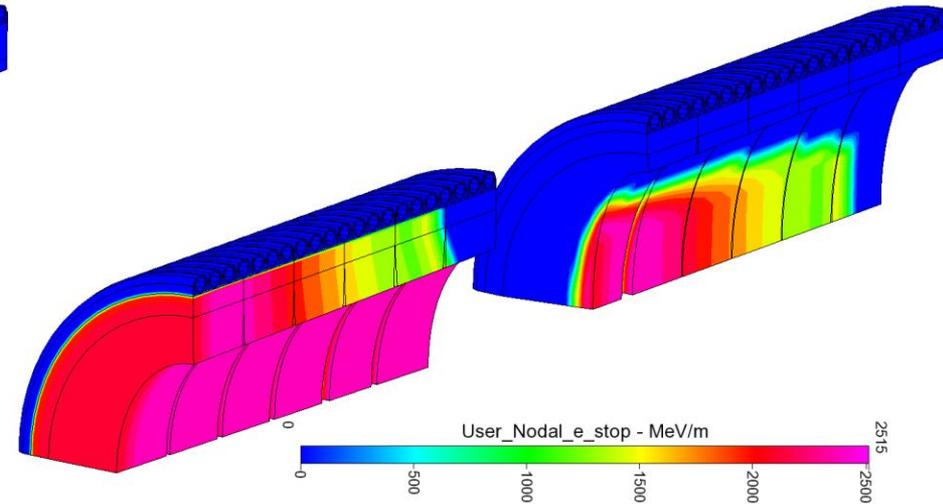
Optimized collimator: Thermal aspect

- ❖ More balanced distribution of thermal load distribution between KHE2 and KHE3.

Present collimator system



Optimized collimator system



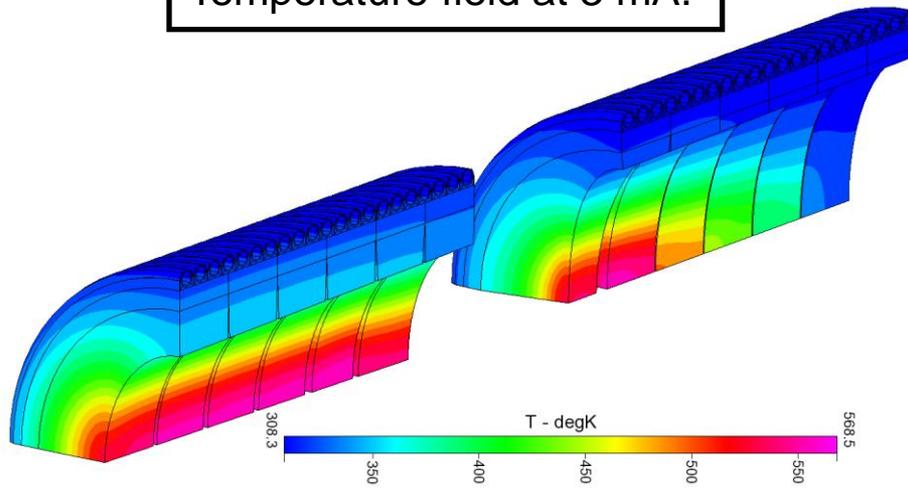
The deposited beam stopping power balance between KHE2 & KHE3

Type	KHE2 [kW (%)]	KHE3 [kW (%)]	Total [kW (%)]
Present system (Type 0)	197 (77%)	58 (23%)	255 (100%)
With 12.5% larger aperture (Type 1)	130 (71%)	53 (29%)	183 (100%)
Optimized system (Type 2)	128 (69%)	58 (31%)	186 (100%)

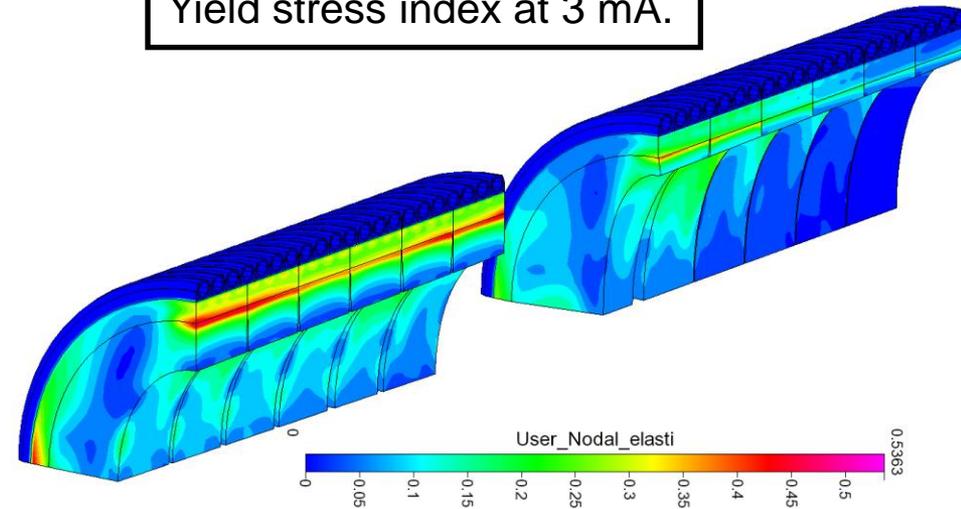
Optimized collimator: Material aspect

- ❖ Material uncertainties of OFHC-Cu after heat treatment for water pipe brazing:
 - Prediction of the material reliability at high temperature collimator operations difficult.
- ❖ Glidcop retains its mechanical strength up to 80 % of the melting temperature:
 - Predictable material behavior at high temperature collimator operations.

Temperature field at 3 mA.



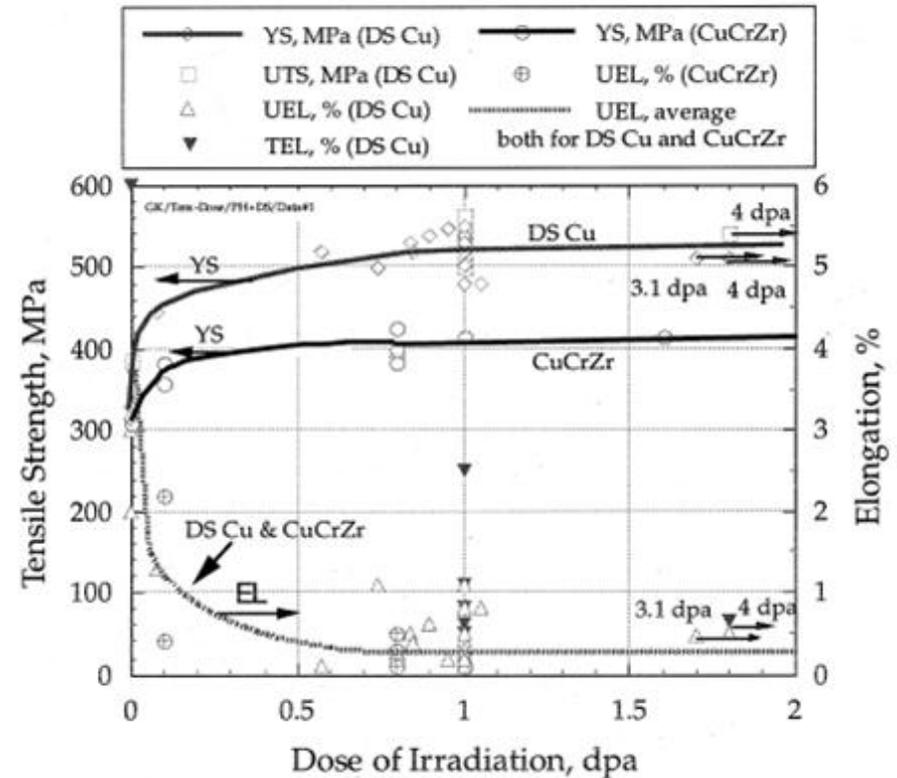
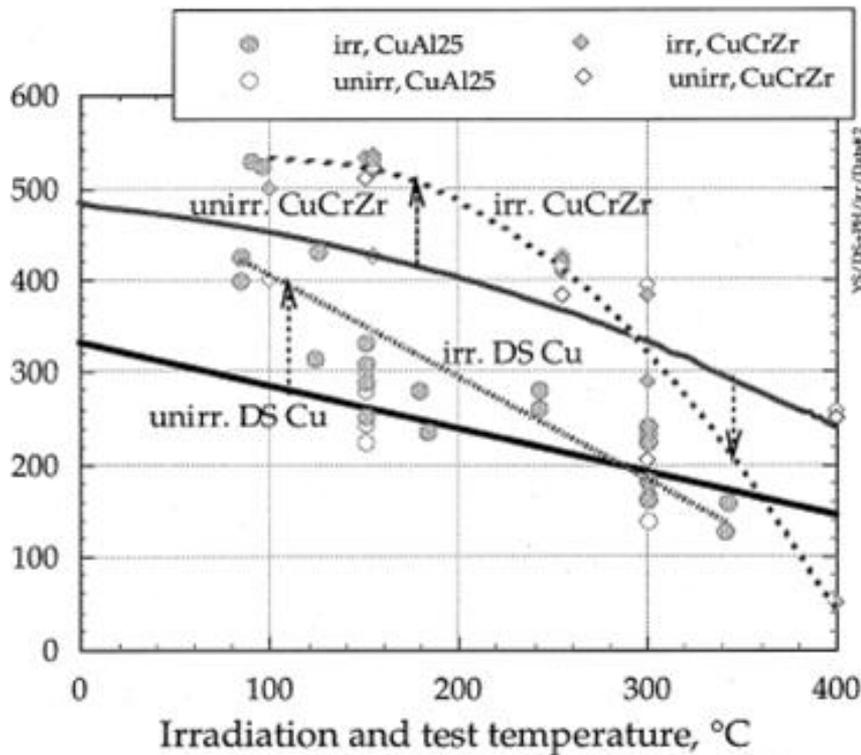
Yield stress index at 3 mA.



❖ The glidcop collimators are expected to operate at 3 mA reliably, without thermomechanical failure!

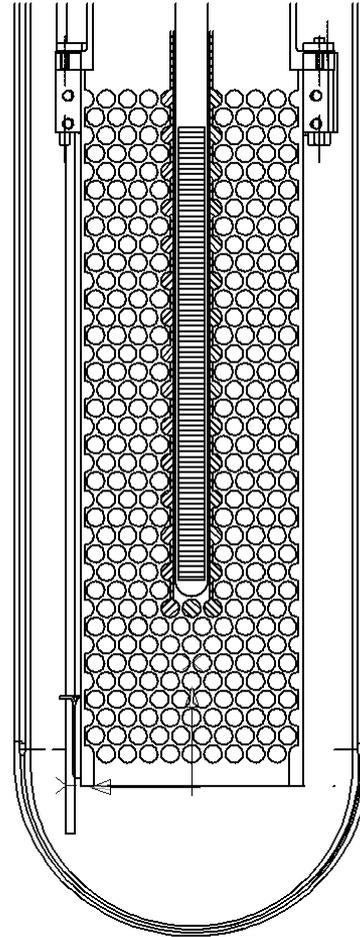
Type	Max. Temp. [K] OFHC-Cu	Max. Temp. [K] Glidcop	Max. Yield Str. Index
Type 0	825.8	851.3	1.23
Type 1	674.3	692.3	0.67
Type 2	556.7	568.5	0.54

- ❖ Uncertainties in the change of material properties under proton irradiation is an important issue to be solved, for OFHC-Cu and glidcop.

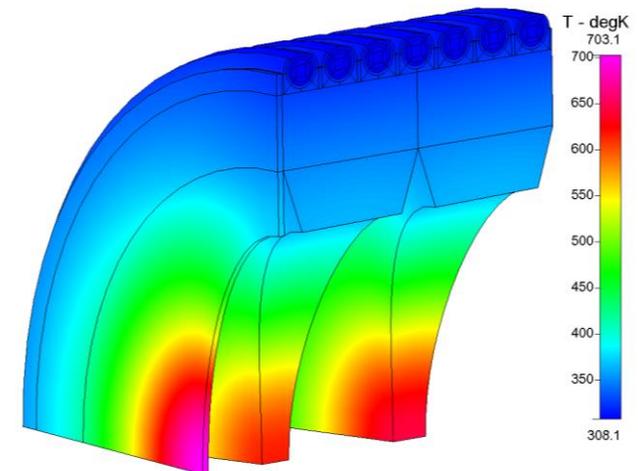
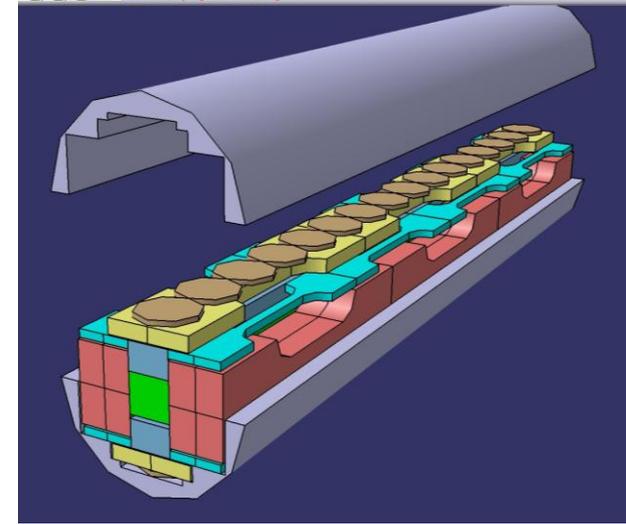


J. W. Davis & G. M. Kalinin, J. of Nucl. Materials vols. 258-263 (1998) p. 323-328

- ❖ STIP (SINQ Target Irradiation Program) probe: Proton irradiations on OFHC-Cu and glidcop samples are planned at the SINQ.
- ❖ Proton irradiations at the Collimator beam entry and exit regions.
- ❖ Detailed specification of the collimator system will be defined, once the uncertainties in material properties are solved.



CAD illustration by M. Gandel



Many thanks to the audience and to the PSI collimator team colleagues:

D. Reggiani, M. Gandel, D. C. Kiselev, P. Baumann, M. Seidel, A. Strinning, S. Teichmann

