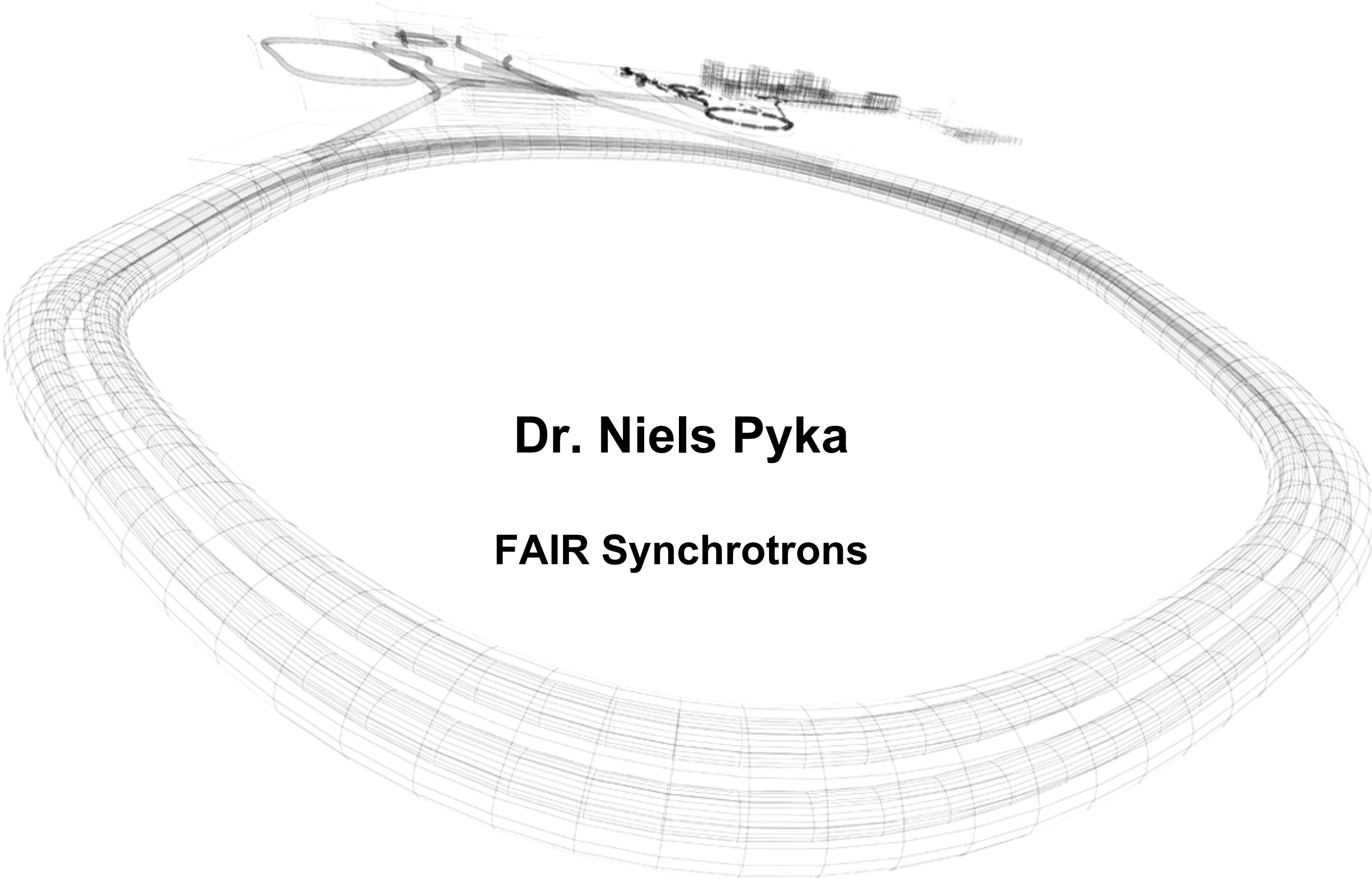
Technical Studies for a Radiation Hard Slow Extraction System of SIS100



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FAIR Synchrotrons

Challenges associated with slow extraction

Inherent beam loss and energy deposition at the electrostatic septum wires

- Risk of septum wire rupture and short-circuit between the electrodes

Extraction flattop down to 1 s

- Very high temperature load of the septum wires
- Ion optical settings have to be very well suited

Large energy deposition into the quadrupole doublet behind the septum

- The use of sc-magnets seems impossible (magnet quench, heat load in the cooling system)
- Deterioration of the magnet structure due to heavy ions and neutrons impact

A shower of high energy neutrons will leave the magnet structure

- High radiation charge of the technical infrastructure in the synchrotron tunnel

Emergency case: full beam has to be removed inside of the synchrotron tunnel

- Internal beam dump in the extraction straight section necessary

Other effects to be considered: beam halo collimation

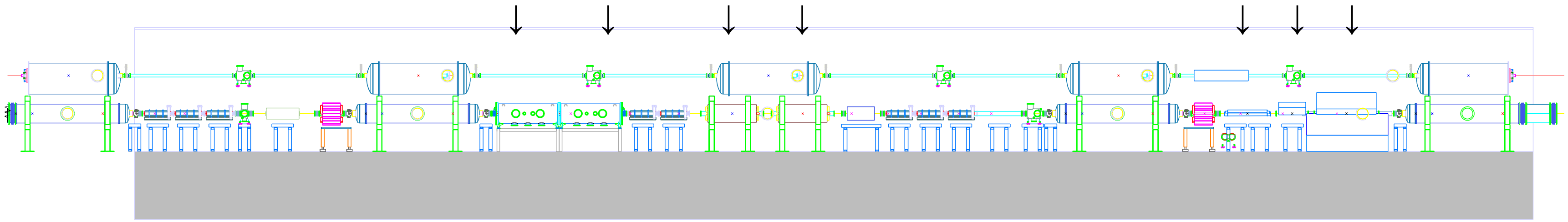
Measures taken in the extraction straight section

I Electrostatic septum

II Warm quadrupole doublet

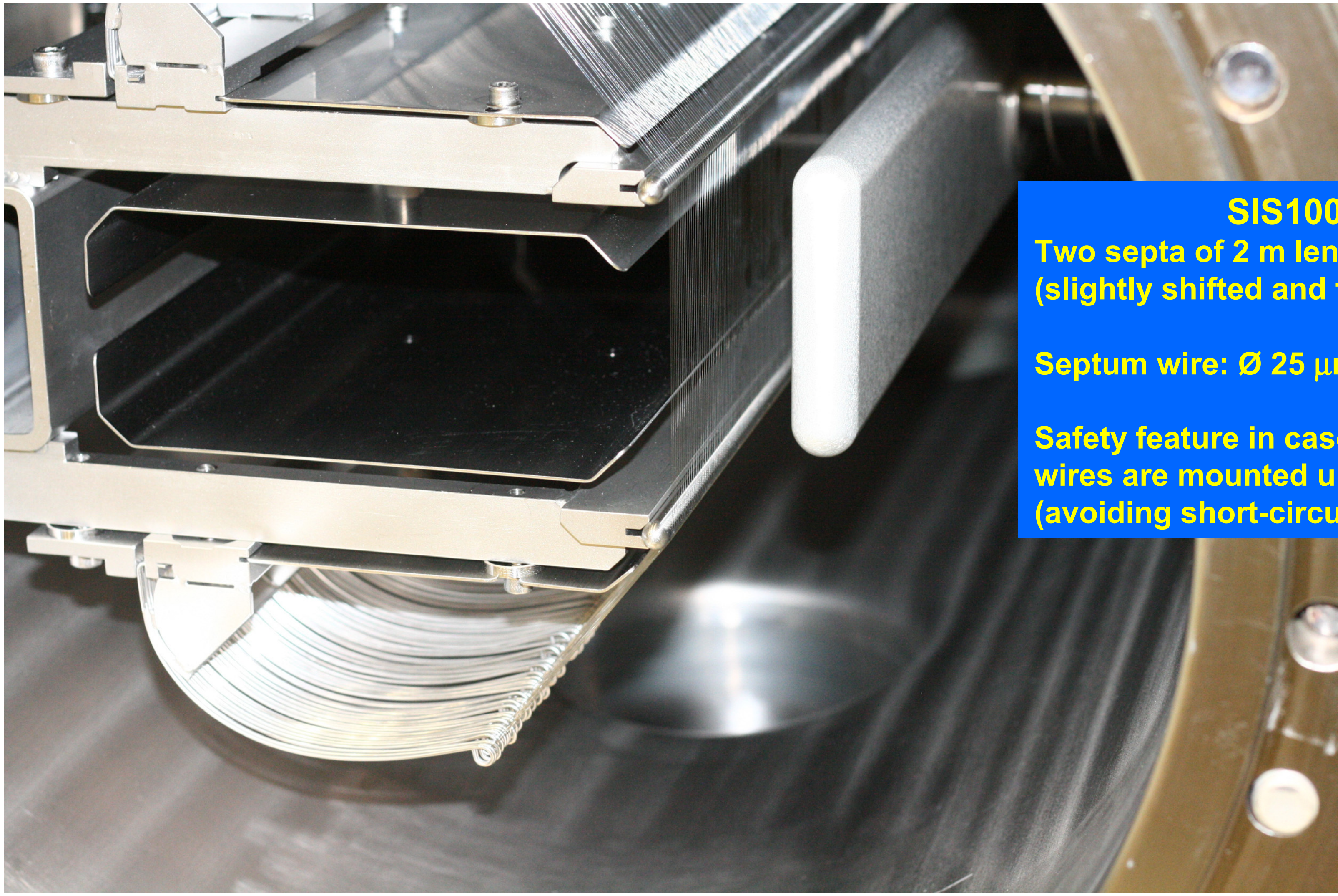
III Internal beam dump

IV Halo collimator



I Electrostatic septum

example SIS18



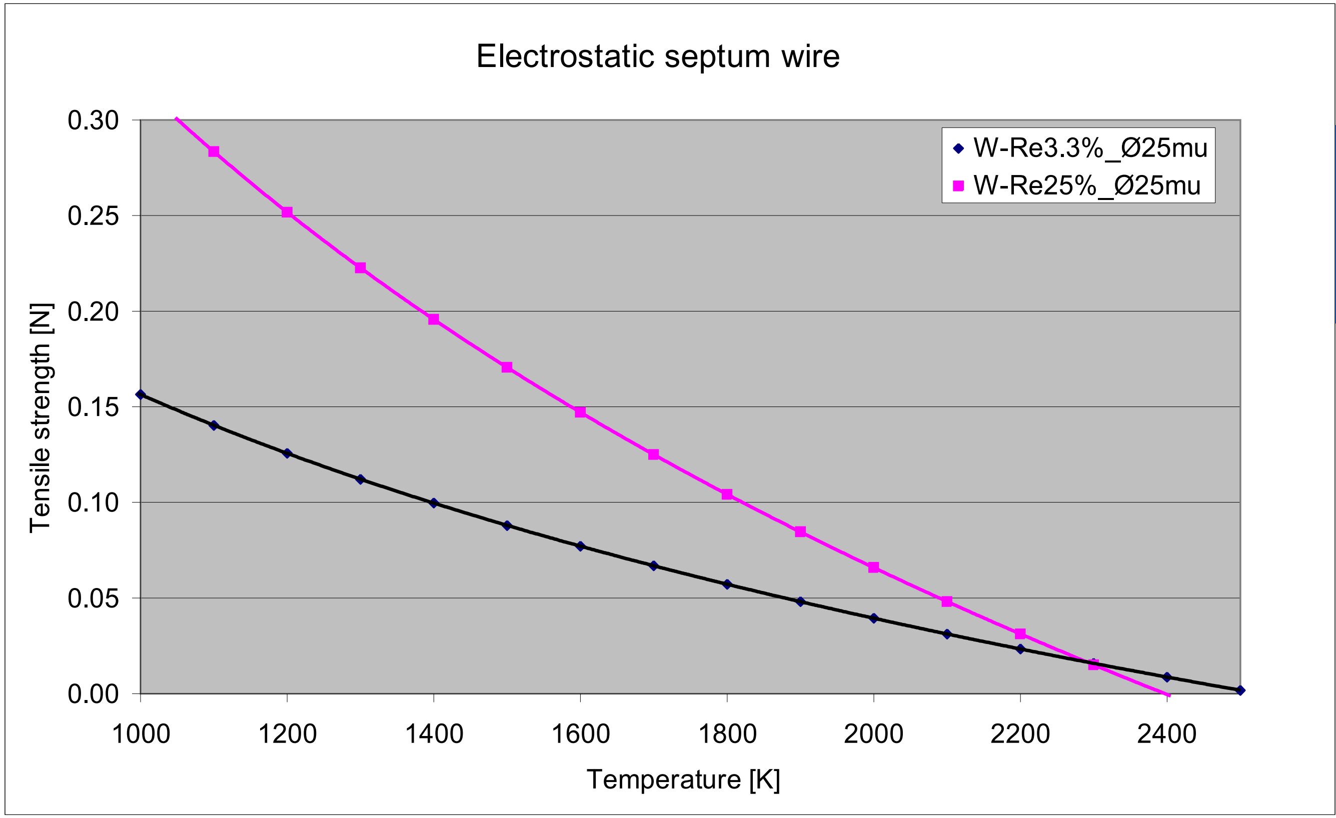
SIS100

Two septa of 2 m length each (slightly shifted and tilted)

Septum wire: Ø 25 µm, W-Re alloy

Safety feature in case of rupture: wires are mounted under tension (avoiding short-circuit)

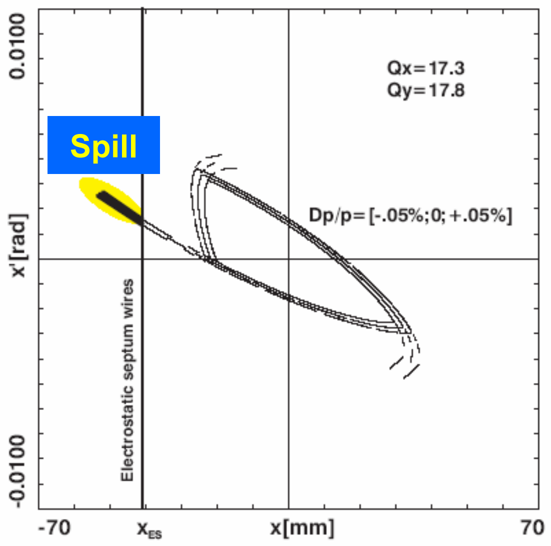
Tensile strength of W-Re alloys used for septum wires



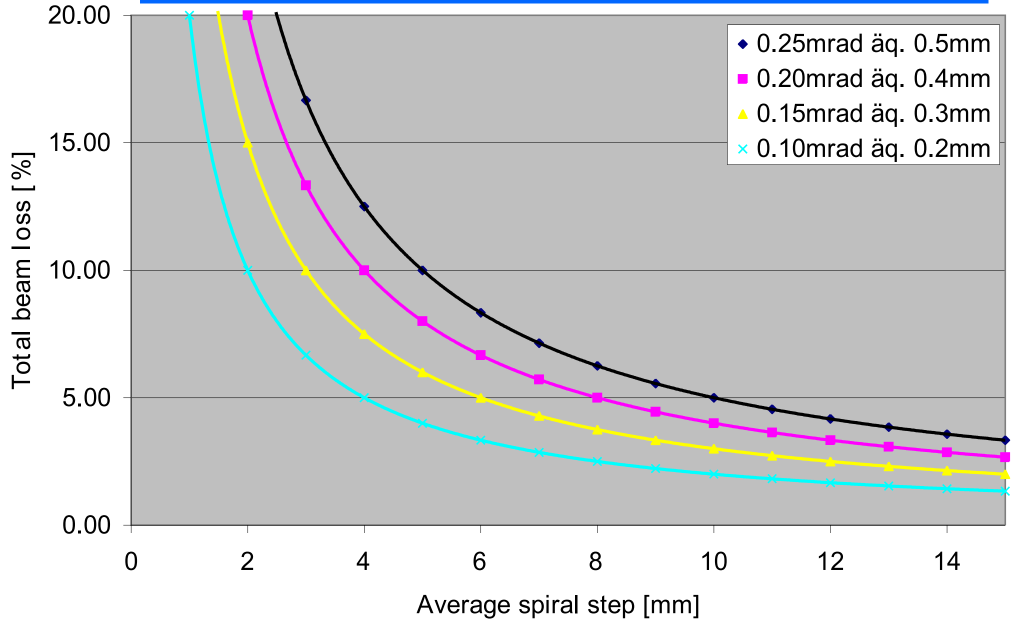
Re fraction of ~25% gives sufficient safety margin in tension for the pull-spring construction

Total beam loss due to the "effective" septum width

Separatrix at slow extraction



Total beam loss depending on the beam divergence at the entrance of the electrostatic septum



Control of the total beam loss

- **Transmission monitoring**

Standard extraction conditions

- **10-12 mm average spiral step**
- **~ 0.25 mm effective septum width**

Maximum energy deposition in one electrostatic septum wire

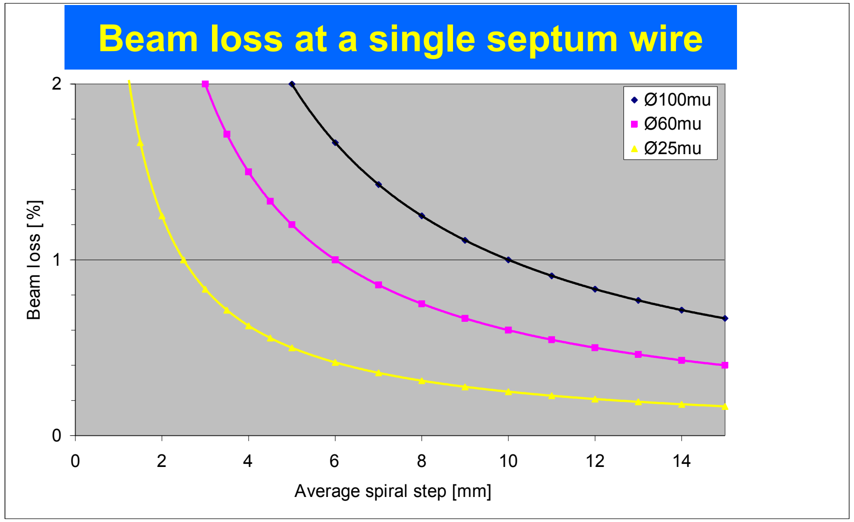
Beam ion	A	Z	Energy [MeV/u]	Magnetic rigidity (U^{28+}) [Tm]	dE/dx [MeV/(mg/cm^2)]	Energy transfer per lost ion **[GeV]**	Range [mg/cm^2]
				Target W74Rh26:		**1.738**	
U	238	92	2700	100	11.23	**1.707**	51388
			1500	64	11.30	**1.718**	26054
			500		13.77	**2.099**	6279
			400	27	14.80	**2.259**	4618
			300		16.45	**2.518**	3094
			200	18	19.42	**2.994**	1760
			100		26.22	**4.143**	689
Xe	131	54	400		5.04	**0.768**	6991
			200		7.01	**1.077**	2461
			80		11.57	**1.849**	634
Kr	84	36	400		2.20	**0.336**	9955
			200		3.13	**0.480**	3380
			70		5.92	**0.947**	660
Ar	40	18	400		0.54	**0.082**	18993
			200		0.78	**0.118**	6269
			50		1.94	**0.312**	651
Ne	20	10	6500		0.13	**0.019**	1041185

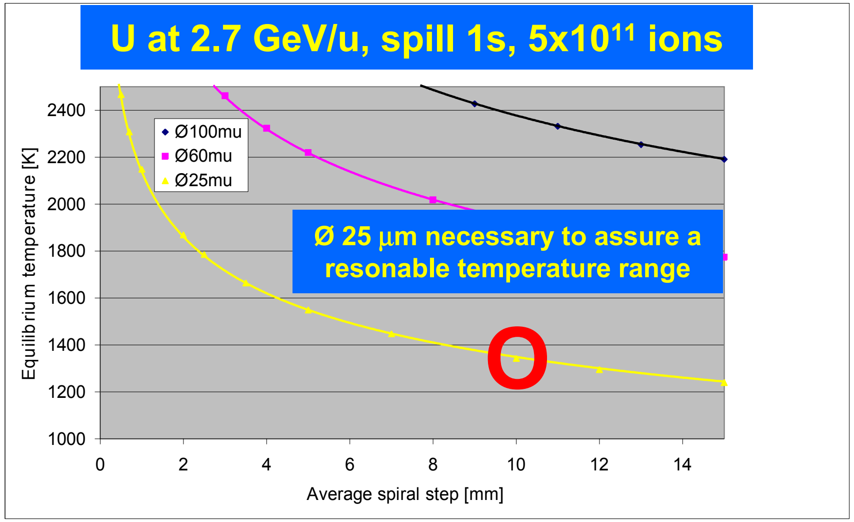
dE / dx ~ Z^2

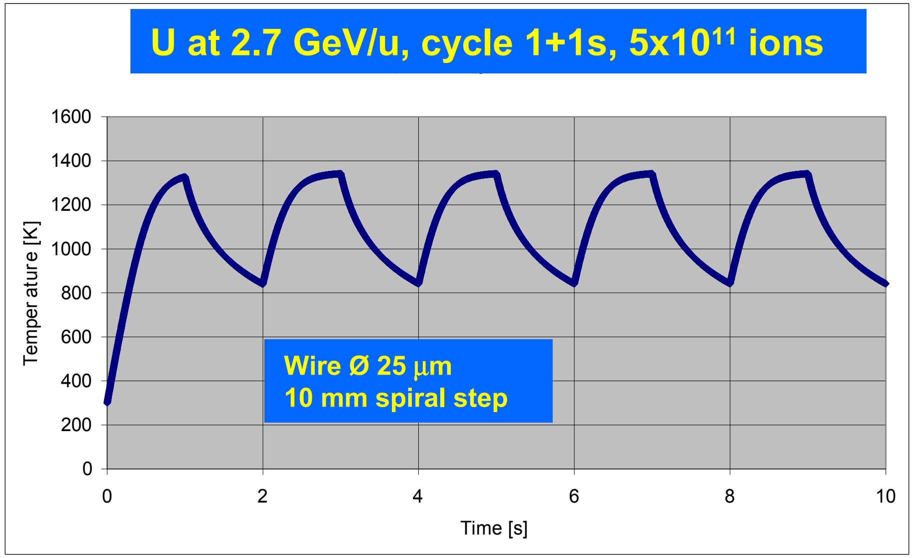
ATIMA results

Septum wire:
Tungsten Ø 100 µm

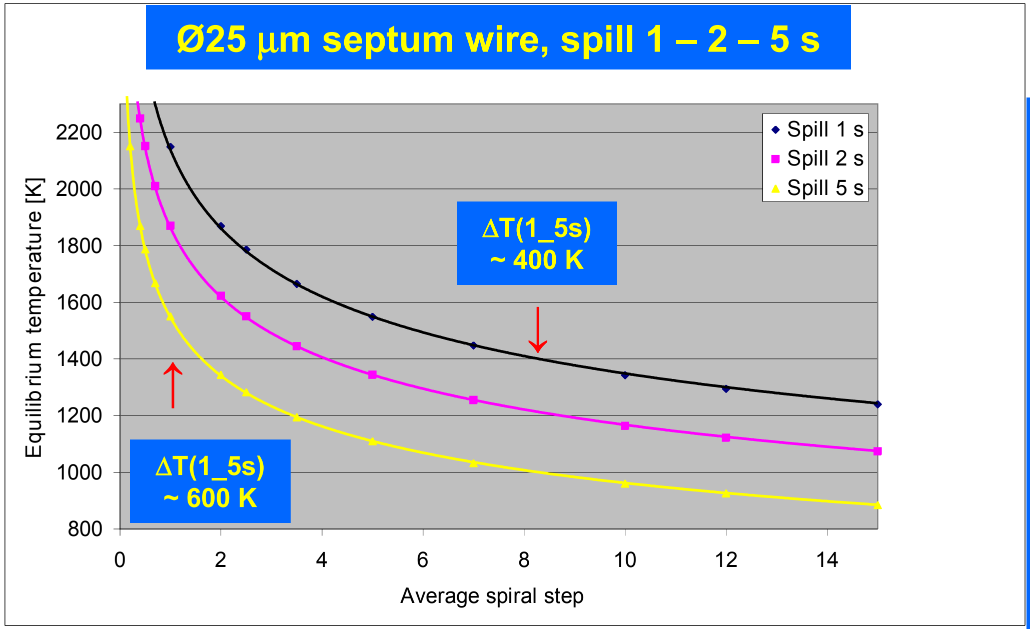
Maximum beam loss at one electrostatic septum wire







Preventive measures during slow extraction setting, U 2.7 GeV/u, 5x10[11] ions

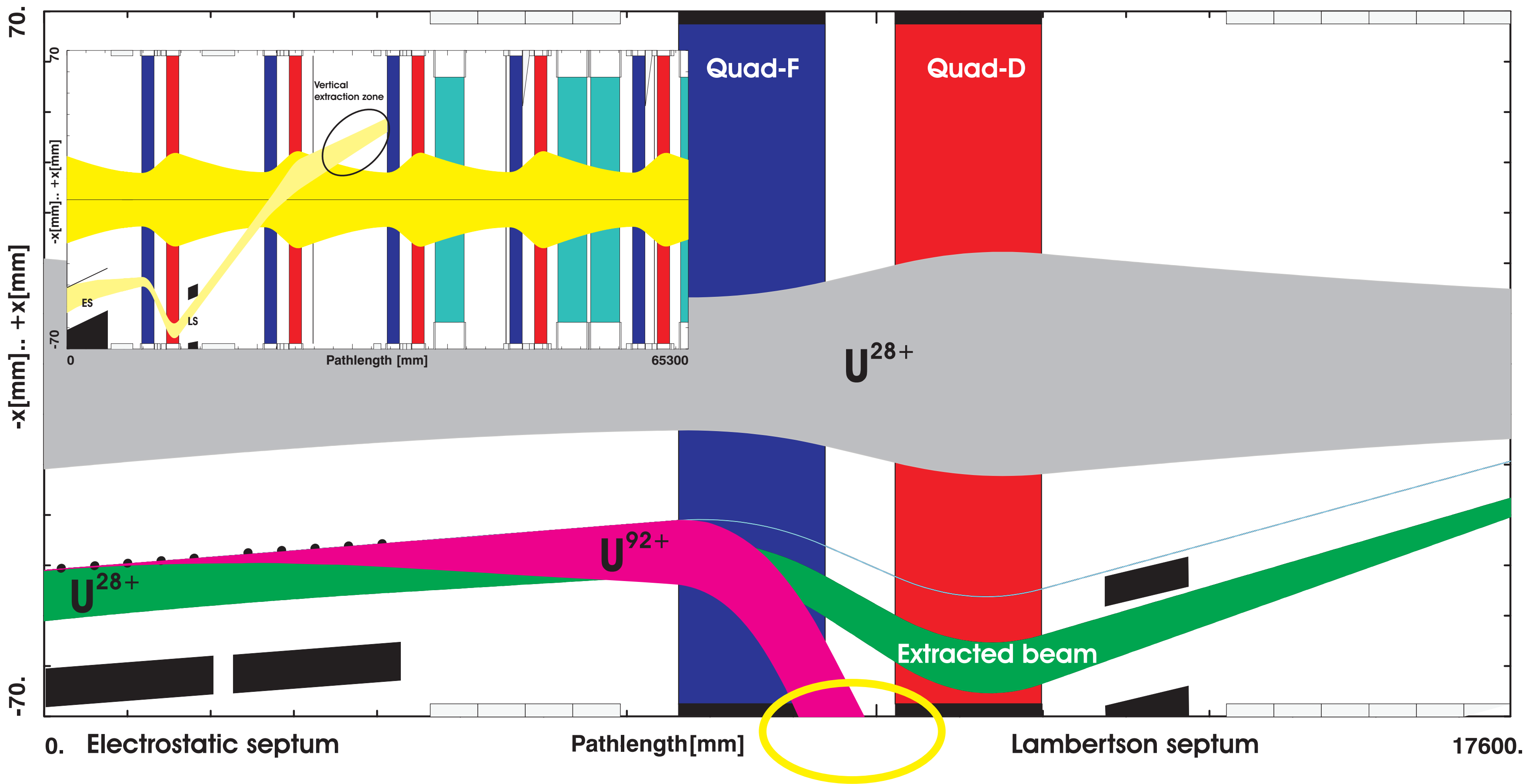


5 s extraction flattop >>>
big temperature buffer at small spiral steps

Preventive measures

- **KO-extraction: constant ion optical conditions**
- **Extraction flat top ≥ 5 s (permission of: spiral step > 0.2 mm, T<2100 K, tensile strength >.05 N)**
- **Setting of extraction parameters such that the spiral step should be >2 mm and the divergence at the septum <0.3 mrad**
- **Septum is placed at the outside of the normal orbit (protection against RF failure)**

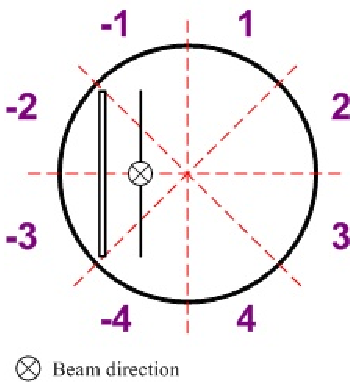
II Warm quadrupole doublet

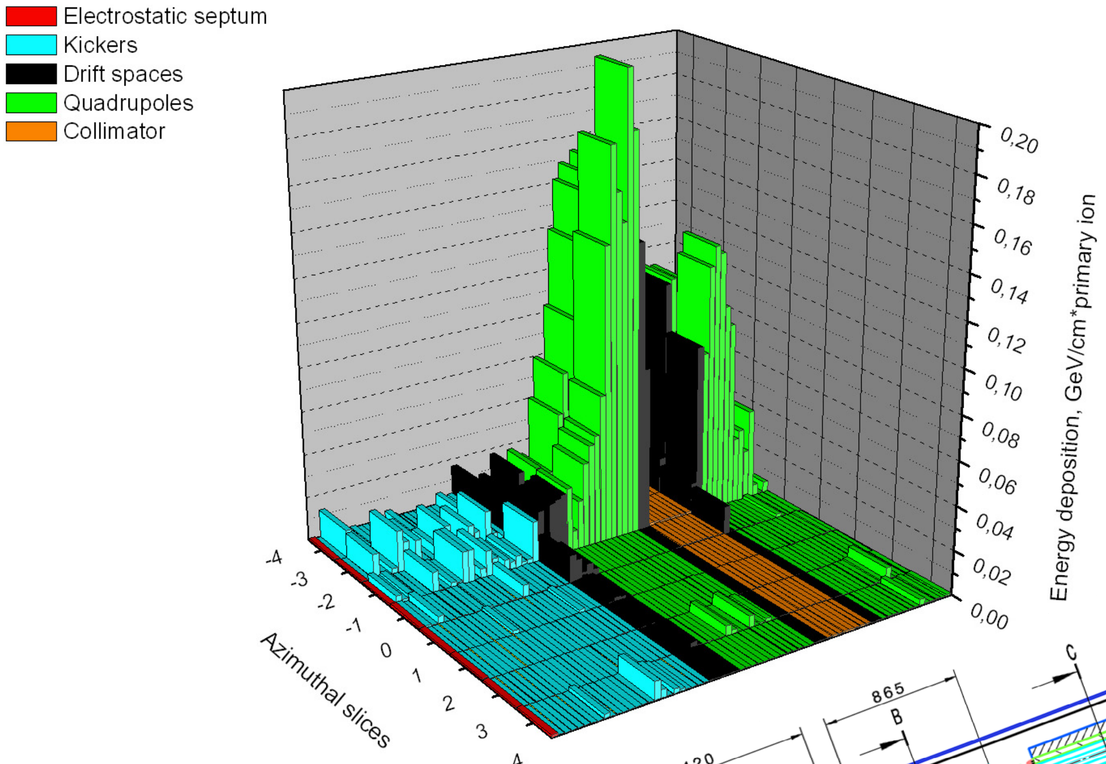


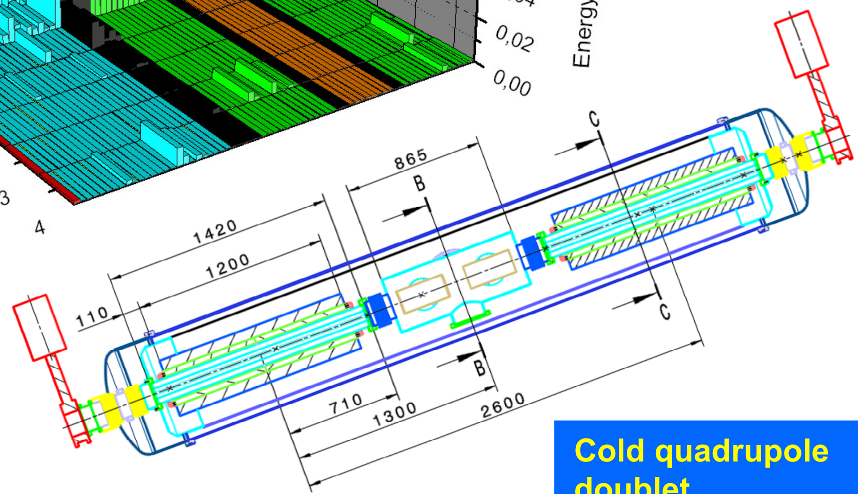
Beam loss at the electrostatic septum wires (stripping of ions)
Energy deposited in the following quadrupole magnets

Distribution of lost ions in the adjacent quadrupole doublet of the electrostatic septum

A. Smolyakov et al., ITEP&GSI
FLUKA simulations
GSI Reports, 2007 and 2008







Energy deposition seems to be too high for a sc-quadrupole doublet
=> warm solution

Cold quadrupole doublet

Warm quadrupole doublet

The design of the magnets will take into account the following measures depending on the simulated radiation load (direct and via albedo from the circumjacent radioprotection) and the consequential deterioration of magnetic field quality

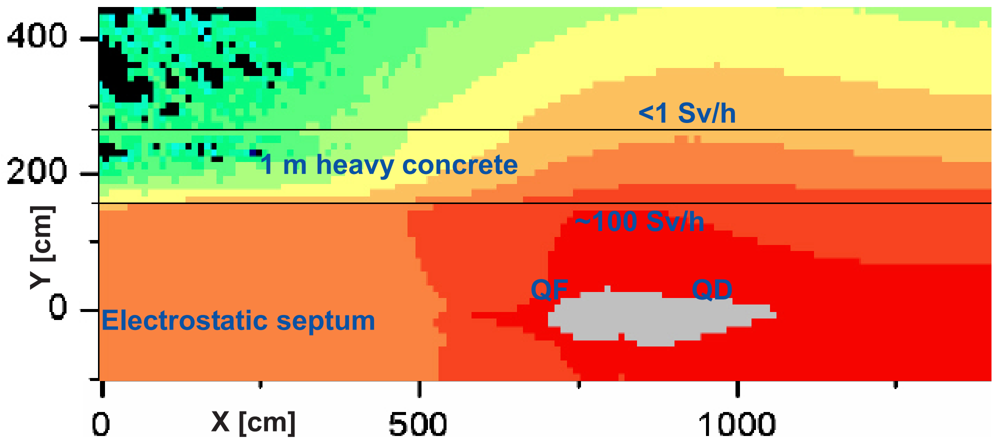
- **Starting point for the design is a scaled HEBT magnet with reduced aperture and increased pole tip field**

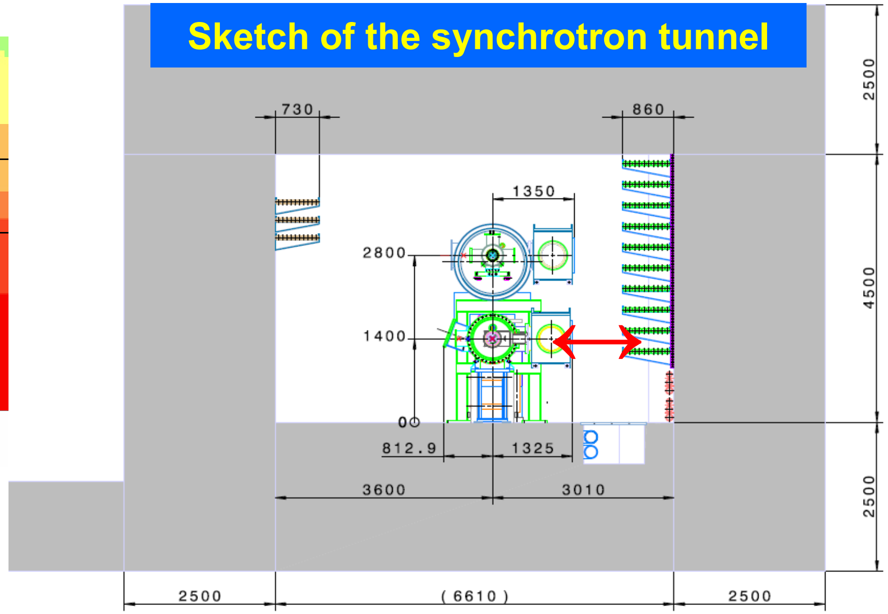
- **Reduction of the direct radiation field into the magnet structure**
  - split-coil and / or split-yoke

- **Radiation hardness of the magnet**
  - exchange of epoxy resin (yoke lamination) or epoxy fibre glass (coil) to polyimid (like Kapton) structures
  - if necessary exchange of all organic by inorganic materials, e.g. isolation of each coil by MgO with Cu sheath or other compositions

Additional radiation shielding to protect technical infrastructure

Example of a dose map around the warm quadrupole magnets

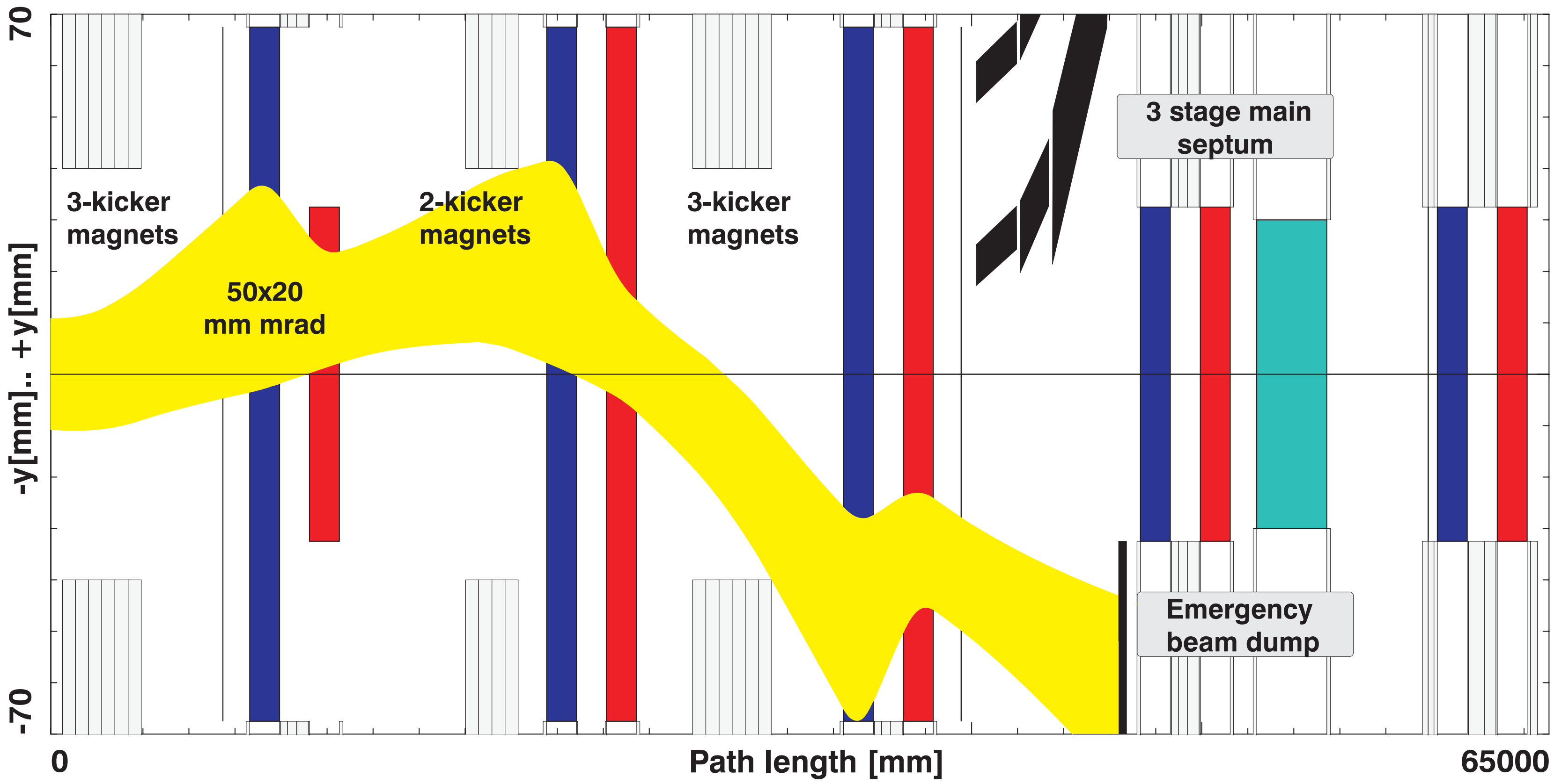




- Installation of an additional radiation shielding, e.g. heavy concrete, in the "hot" areas: around the warm quadrupole magnets and the internal beam dump
- Continuing simulations of different material combinations to minimize the shielding dimensions and costs

III Internal beam dump: emergency extraction

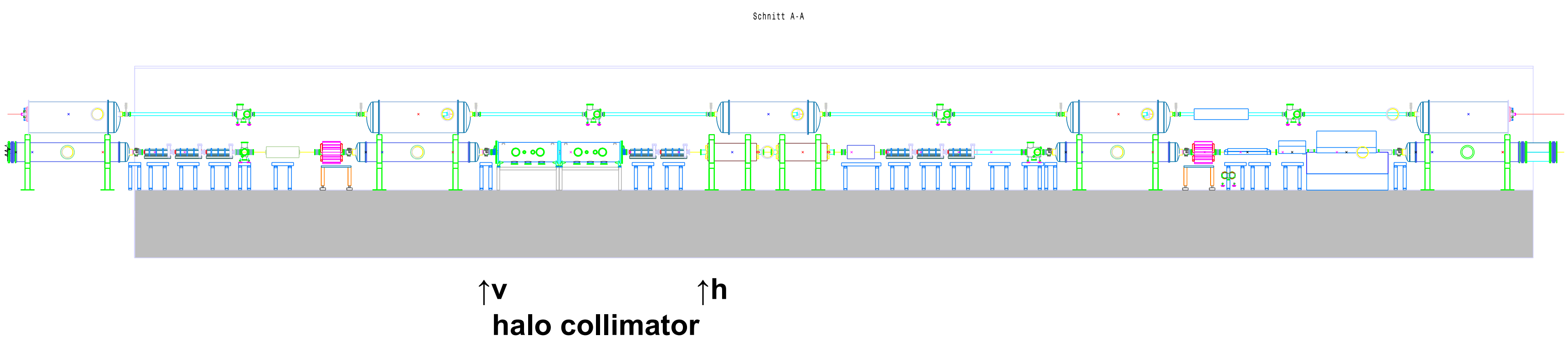
- Fast bipolar kicker magnets can extract the full synchrotron load within one turn
- Target: internal beam dump at the end of the extraction straight section
- Up to E = 51.5 kJ may be deposited within 3 µs



IV Halo collimator

(very slow transverse amplitude growth of ions forming a halo)

- Ions will be stripped and dumped in the warm quadrupole doublet
- Two possible positions in the 2nd cell of the extraction straight
  - Vertical: first element (top & bottom) considering fast & emergency extraction
  - Horizontal: last element (inner side only) considering the flight path of resonant particles



Machine protection measures in the extraction straight of SIS100

I Electrostatic septum

- KO-extraction assures constant ion optical conditions: easier and stable beam handling
- Ø 25 μm septum wires assure a "low" temperature regime
- $W_{75}Re_{25}$ composition of the septum wires assures high tensile strength
- Pull-spring construction of the septum wires avoids short-circuits in case of rupture
- Extraction flat top of 5s proposed during setting of slow extraction assures wire protection
- Transition monitoring combined with interlock limits total beam loss at the electrostatic septum

II Warm quadrupoles

- Installation of a warm quadrupole doublet in the "hot" area, serves as "dump" of lost ions
- Special design (split-coil, split-yoke, radiation hard) of the warm quadrupole magnets
- Installation of a matched radiation protection installation around the warm quad's to protect the technical infrastructure in the synchrotron tunnel

III Internal beam dump

- Installation of an internal beam dump to exceptionally dump the full synchrotron load

IV Halo collimator

- Horizontal and vertical halo collimator at different positions in front of the warm quadrupole doublet