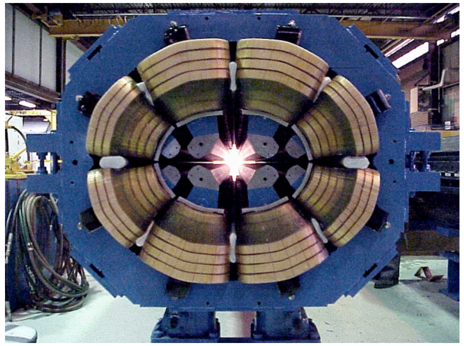
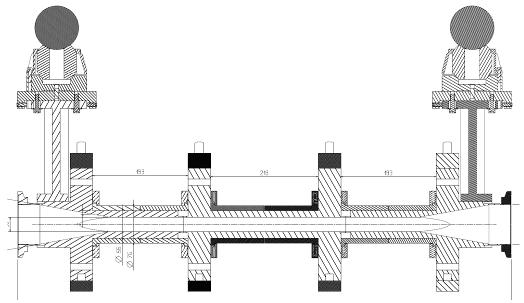
LHC Passive Absorbers: FLUKA Summary of the Technical Design Studies

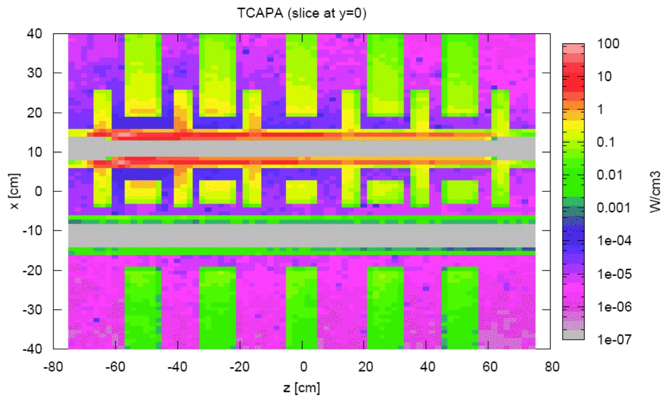
The FLUKA Team

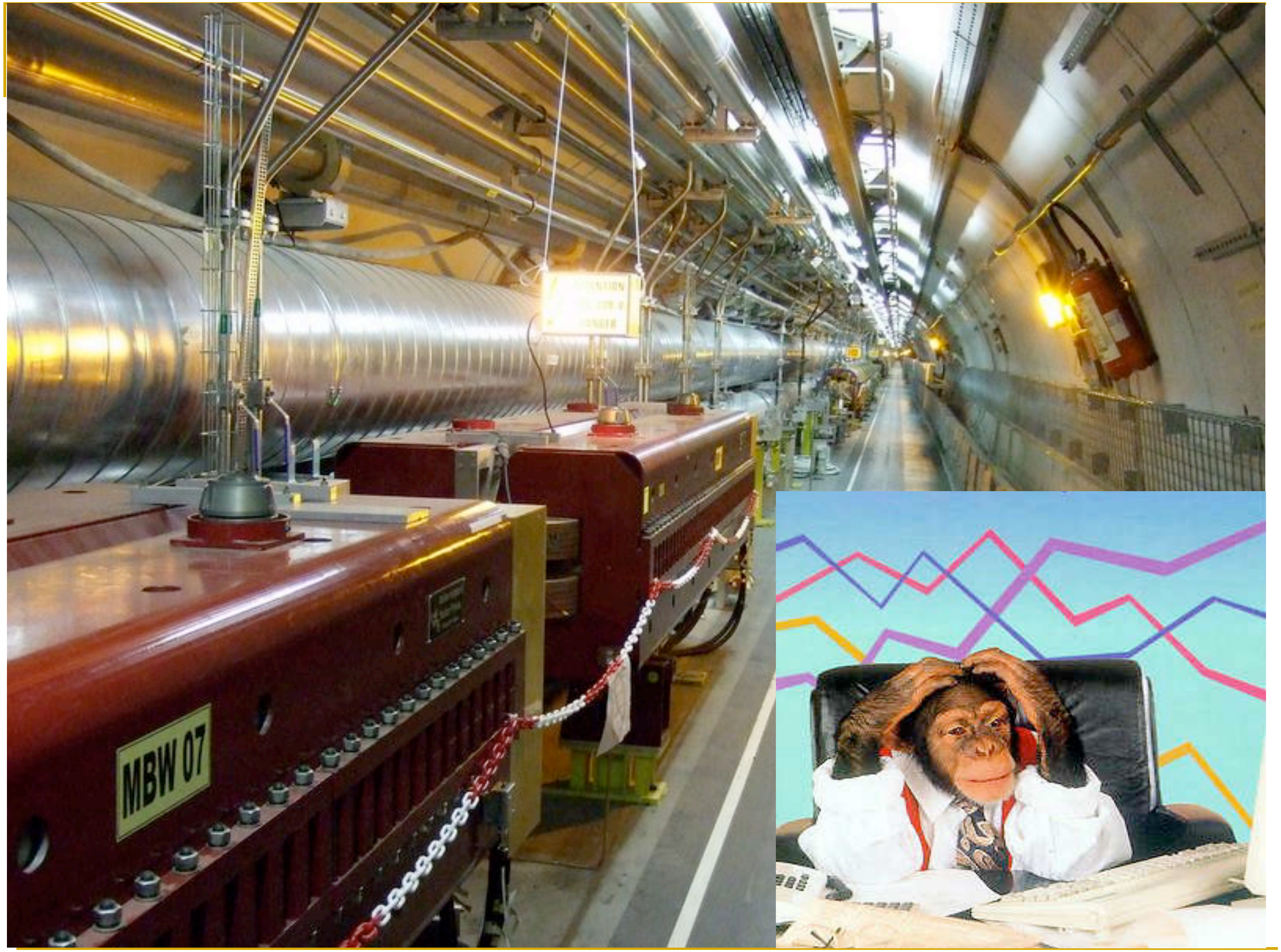
Overview

- What is it all about…
  - Protected machine elements
  - Important quantities
- A “brief” history of time…
  - From the very simple -
  - To more concrete and complicated
- The final design and respective results…
  - What was improved
  - What it means in terms of “limits”
  - Related uncertainties
- Possible further improvements for the future…








MBW 07

Limits, Constraints & Normalization

- **'Limits' & Constraints**
  - **Maximum dose to magnet coils** (rad. damage):
    - **30MGy/10year -> 3MGy/year**
  - **Total power to the magnet** (cooling):
    - **~15 kJ** (transient)
    - **~10 kW** (steady state)
  - **Peak and total power to the passive absorber** (cooling, stress & deformation)
- **Normalization of Results** (**!!! SAFETY MARGIN !!!**)
  - Peak dose -> **annual loss**
    - **1.15E16 protons/year/beam**
  - Peak power -> **“worst case” beam life-time (“transient”)**
    - **10s @ 4.E11 p/s**
  - Total power -> **~ factor of five less than peak (“steady state“)**
    - **0.8E11p/s**

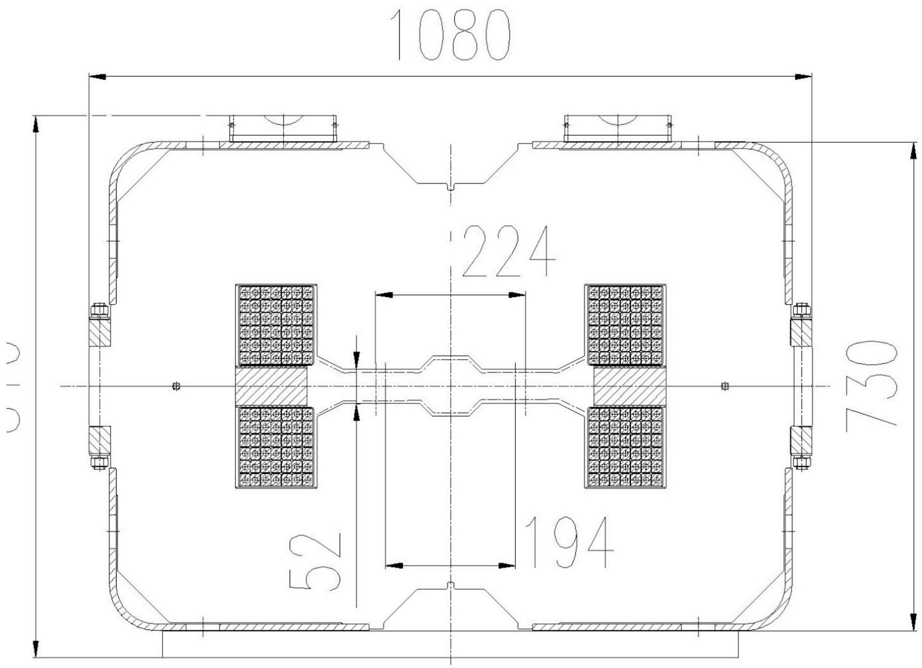
Separation Dipoles: MBW Magnets

- **~3 MGy/year, 10 years operation possible, but not guaranteed**
- **4 spare magnets**
- In case of repair need coil exchange rather straight forward
- Operating temperature ~50-55˚C (T-interlocks trip at 65˚C)
- **Maximum acceptable temperature increase 10˚K (steady state): MBW=15 kW**

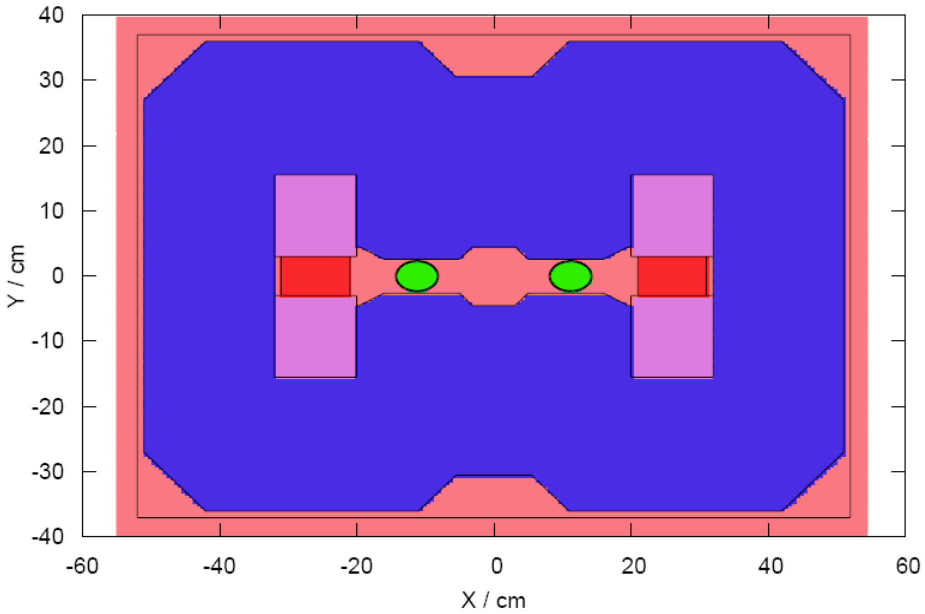
M. Karppinen

Separation Dipoles: MBW Magnets

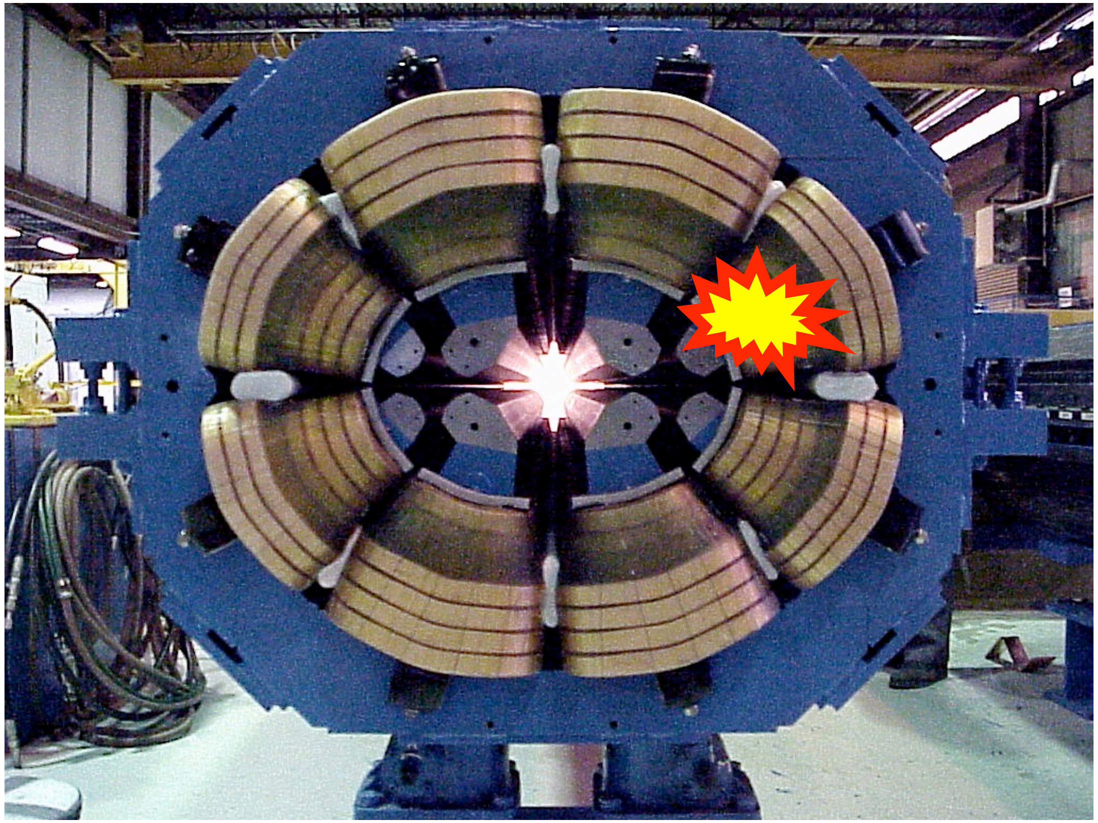
Technical Drawing



FLUKA Implementation



Quadrupoles: MQW Magnets



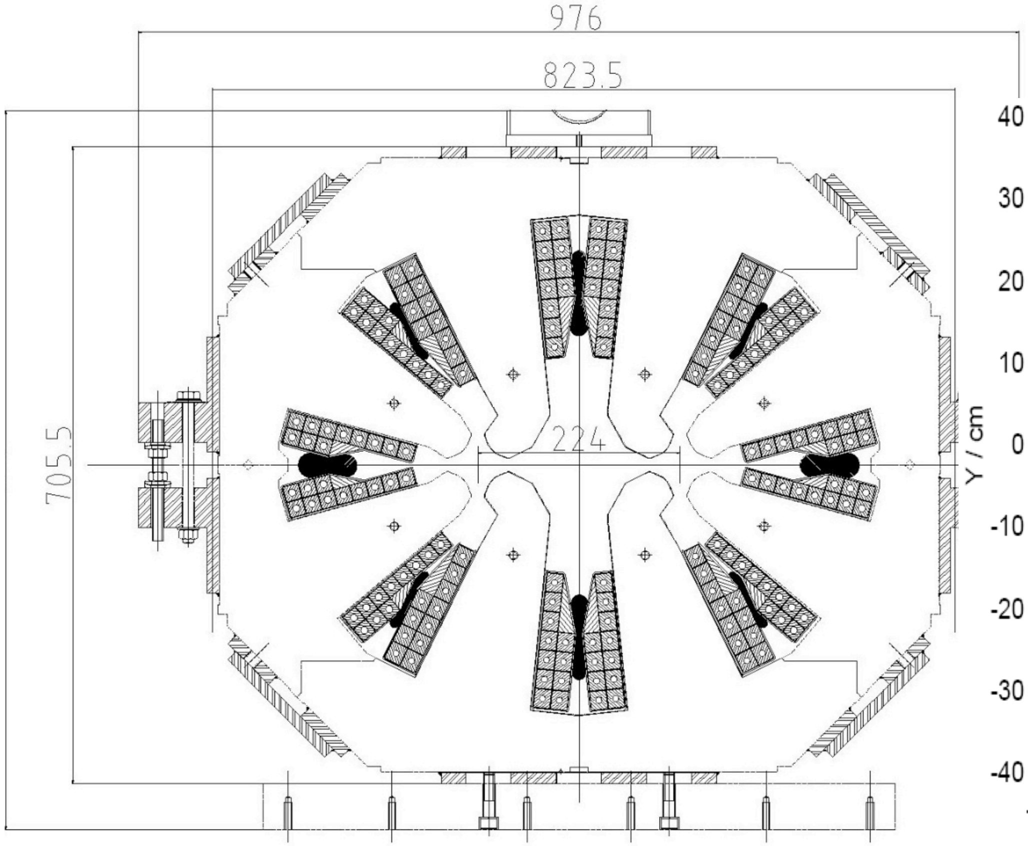
- Injected coil shims likely to fail, thus first leading to coil movements and insulation damage

M. Karppinen

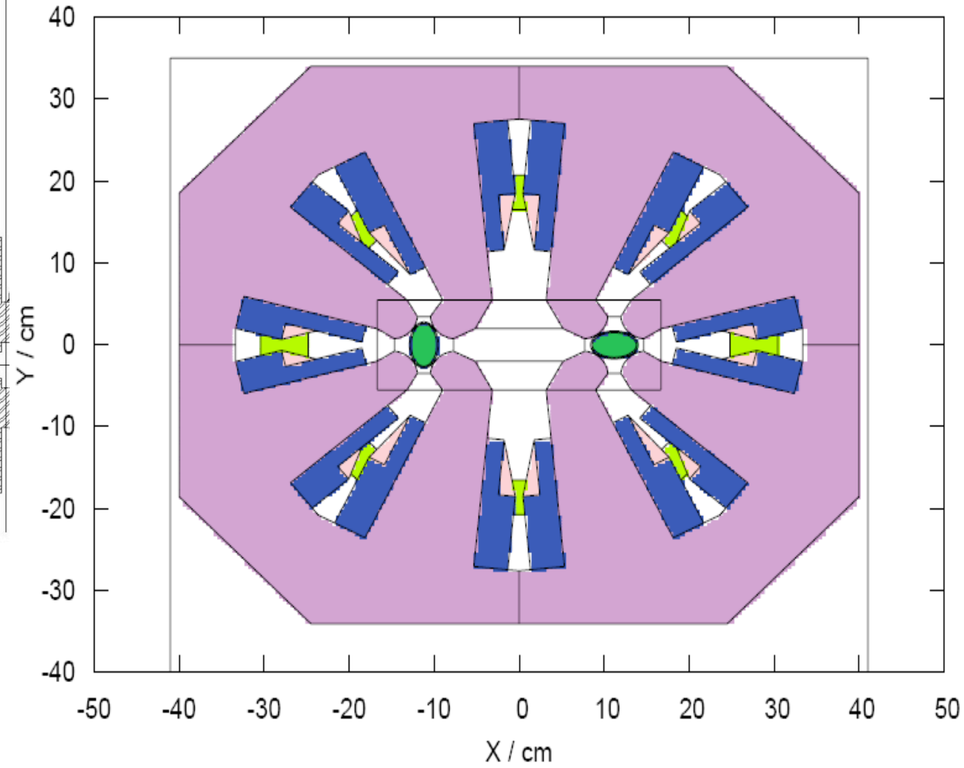
- **Even 1 MGy/year,**
  -> 10 years might be critical
- **4 Spare magnets (however, 3 out of them need repair!)**
- 1 Set of spare coils, BUT Coil exchange <u>not at all</u> easy
- Operating temperature ~50-55˚C
  (T-interlocks trip at 65˚C
- **Stored heat is ~60 MJ, thus ~14 kW over 10 s could be enough to trip the T-interlock, if close to outlets**
- **Maximum acceptable temperature increase 10 K (steady state): MQW=10 kW**

Quadrupoles: MQW Magnets

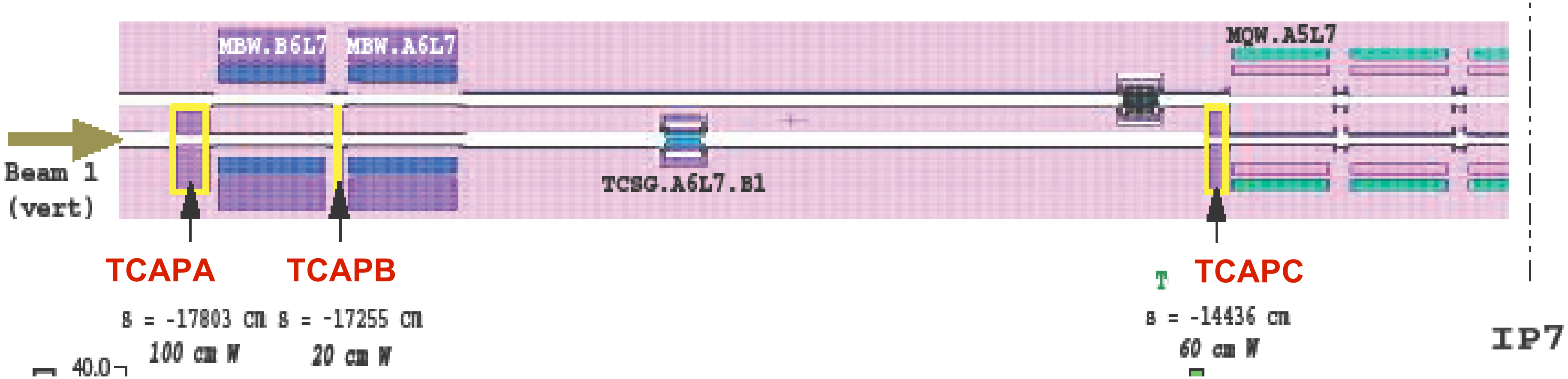
Technical Drawing



FLUKA Implementation



FLUKA Implementation



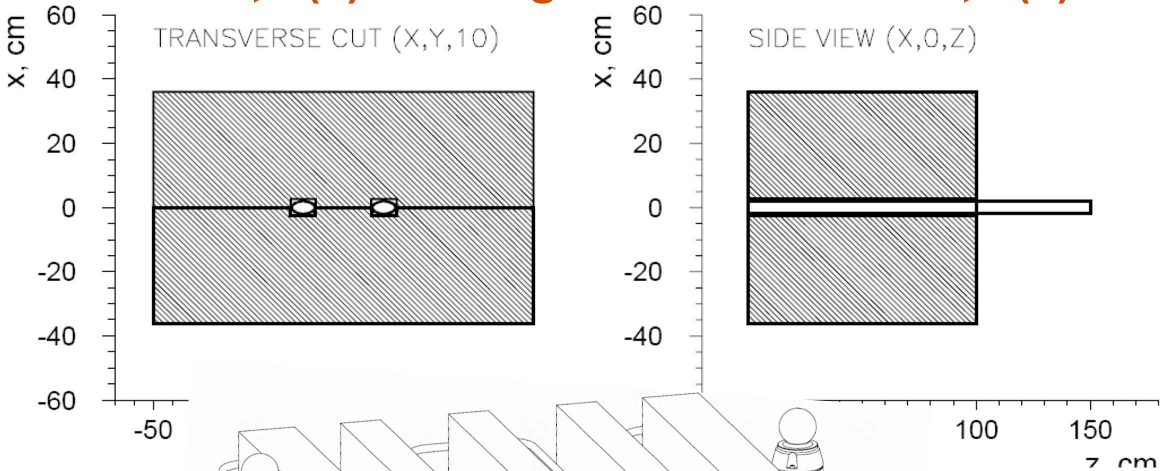
- All details were implemented in the full FLUKA IR7 geometry
- Latest loss distributions applied (tracking codes)
- High statistical runs for numerous configurations, evaluations and final design changes
- Continuous comparison between configurations

Design Evolution

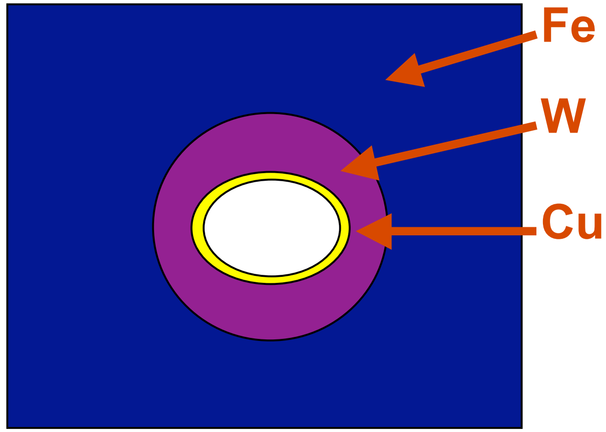
- **Constraints, limitations, loss assumptions**
  - Final loss assumptions
  - Surprises
    - aperture, alignment, ‘new’ coordinate system
  - Magnets (esp. MQWs) might stand less than expected
- **IR7 Layout**
  - 60cm long primary collimators
  - Separation of D3, additional passive absorber (TCAPB)
  - Various loss scenarios
- **Technical layout**
  - simple concept (simple block, no cooling)
  - first ideas (close aperture, cooling is needed)
  - more sophisticated (sandwich structure)
  - technically possible (Swiss cheese, but sufficient)
- **All respective FLUKA implementations**

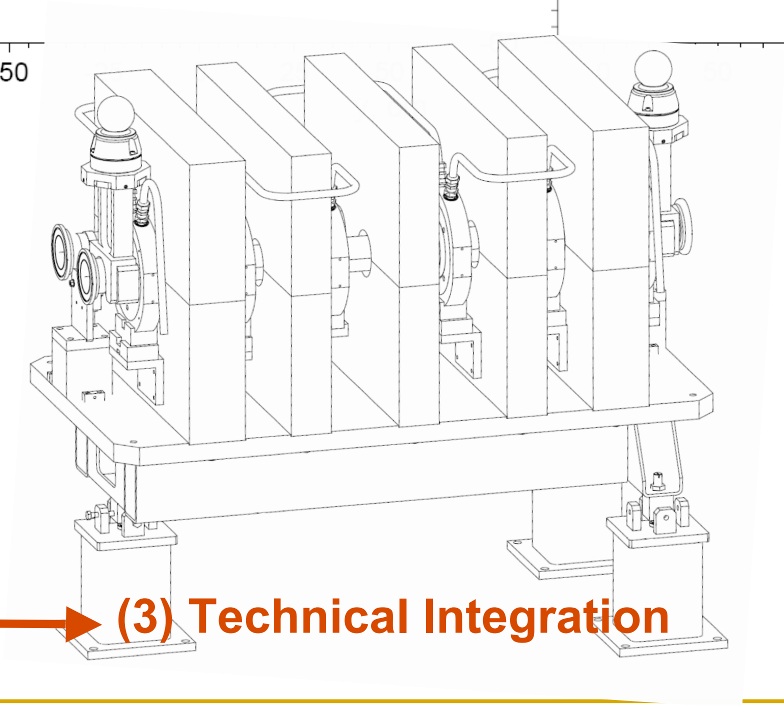
Evolving Designs

(1) Starting Point

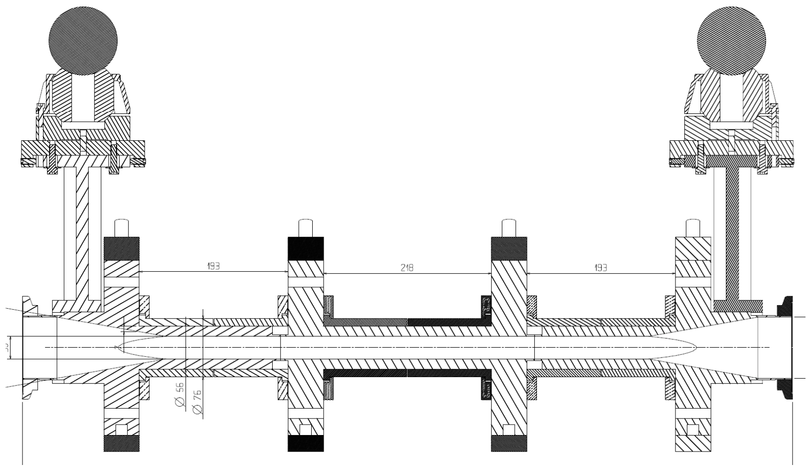


(2) Conceptial Design





(3) Technical Integration



(4) Final Choice ???

Introduction

- **Preliminary Studies (1 - 2 years ago):**

Total power in the MBW

	TCL	MBW
No absorber		32 kW
40 mm radius	5.3 kW	29 kW
30 mm radius	17 kW	21 kW
25 mm	25 kW	15 kW
25 mm large	30 kW	13 kW
ellipses	24 kW	15 kW
ellipses ideal		11 kW
20 mm	36 kW	10 kW

Max dose, MBW coils, MGy/year

	1 cmc	Larger bin
No absorber	260	206
40 mm radius	260	200
30 mm radius	23	17
25 mm,large	17	13
ellipses	10	8
ellipses ideal	1.3	0.5
20 mm radius	11	8

- **New Design Studies: general effect of three modules**
  - **1 m long tungsten TCAP(A)** shielding the first MBW of the second dogleg pair reduces the annual dose peak in the front crossing of its coils by a factor **> 40**
  - **second 20 cm W TCAP(B)** between the two elements of the pair provides an additional **factor 2** for the second MBW
  - **third 60 cm W TCAP(C)** in front of the MQW reduces the peak by a factor 5 and the total power by a **factor 2.5** in the first quadrupole

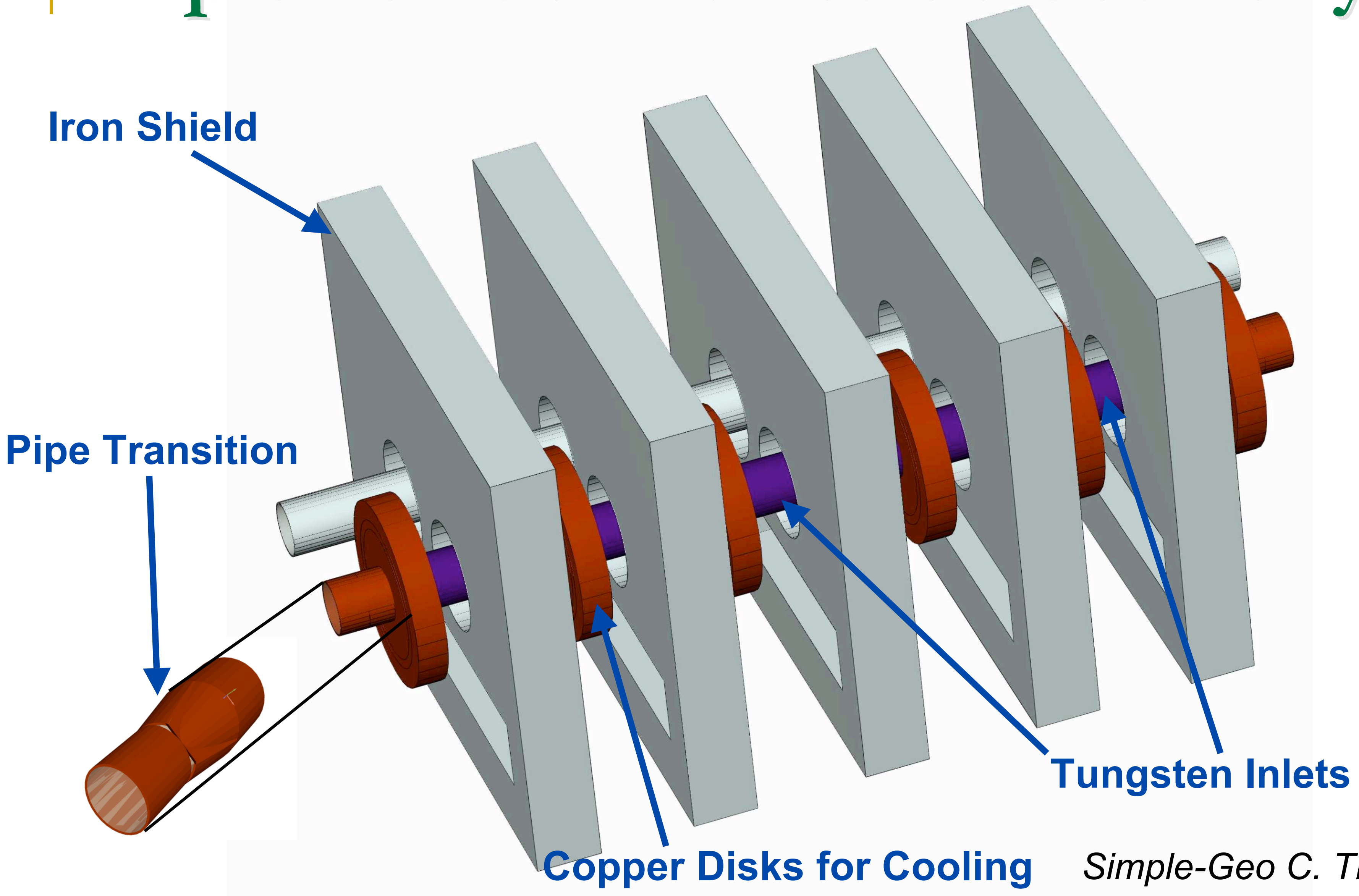
Final Aperture Specifications

element	vacuum chamber aperture [mm] (horiz. axis x vert. axis) beam 1	beam 2	length [mm]
TCAP.A6L7	59 x 44	80 x 80	1500
TCAP.B6L7	59 x 44	80 x 80	400
TCAP.C6L7	52 x 30	80 x 80	1000
TCAP.C6R7	80 x 80	52 x 30	1000
TCAP.B6R7	80 x 80	59 x 44	400
TCAP.A6R7	80 x 80	59 x 44	1500
TCAP.A6L3	59 x 44 *	80 x 80	1500
TCAP.A6R3	80 x 80	59 x 44 *	1500

Design Evolution

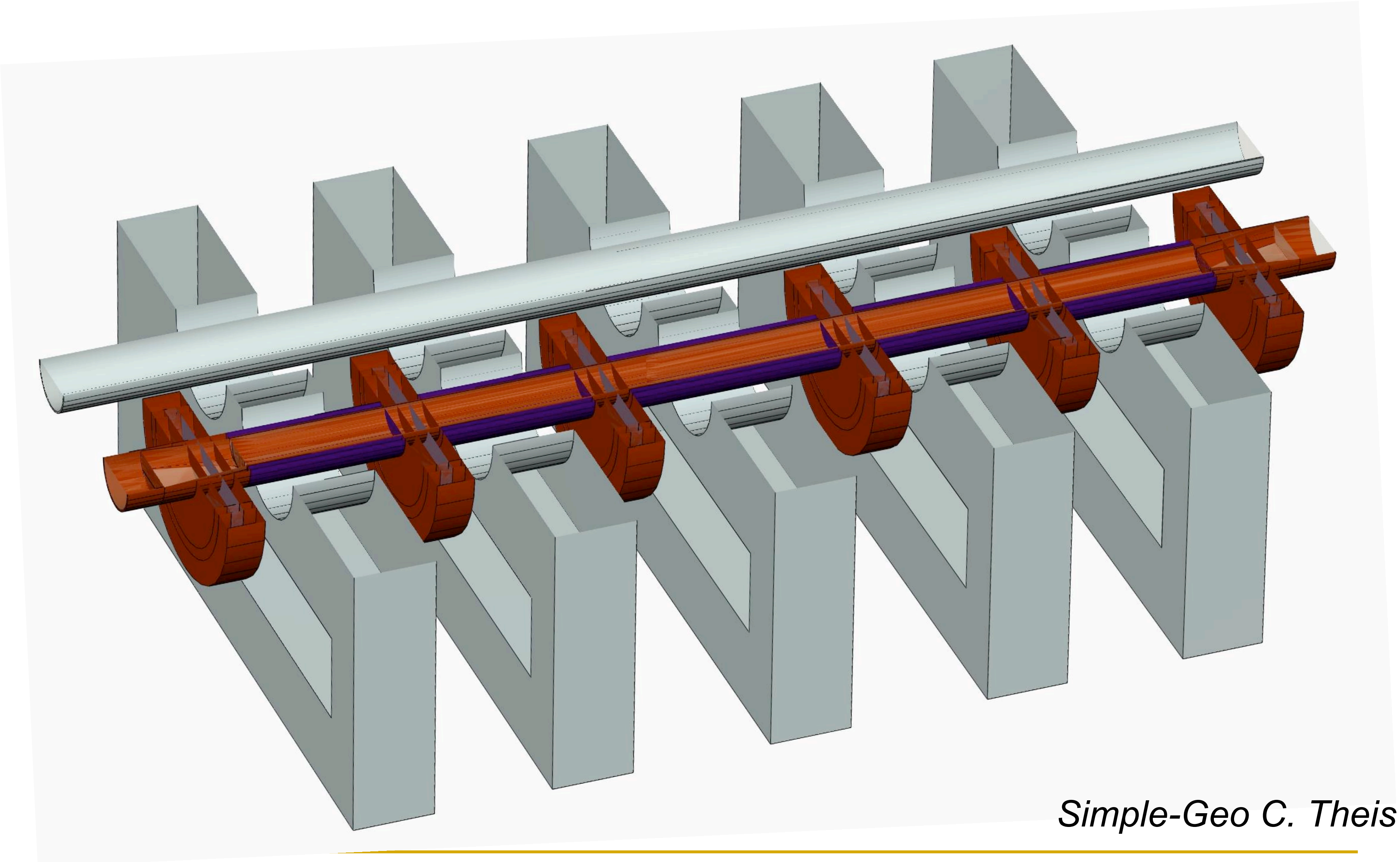
- Sandwich structure studies
  - all tungsten -> **not feasible**
  - inner pipe -> **small effect**
  - reduced tungsten core -> **1cm is the best trade-off**
  - spacing needed between Cu, W and iron (thermal expansion, bake-out equipment) -> **ok**
  - reduced lateral size of the tungsten absorber -> **possible**
- Technical Design
  - needed transition piece -> **does not see the peak**
  - reduced vertical W thickness -> **small effect**
  - significant spacing for bake-out required -> **acceptable**
  - needed spacing between different materials -> **acceptable**
  - Cu disks for cooling -> **no problem for cooling**
- Additional questionmarks
  - alignment of the TCAPs -> **small influence**

Implemented and Tested Geometry



Simple-Geo C. Theis

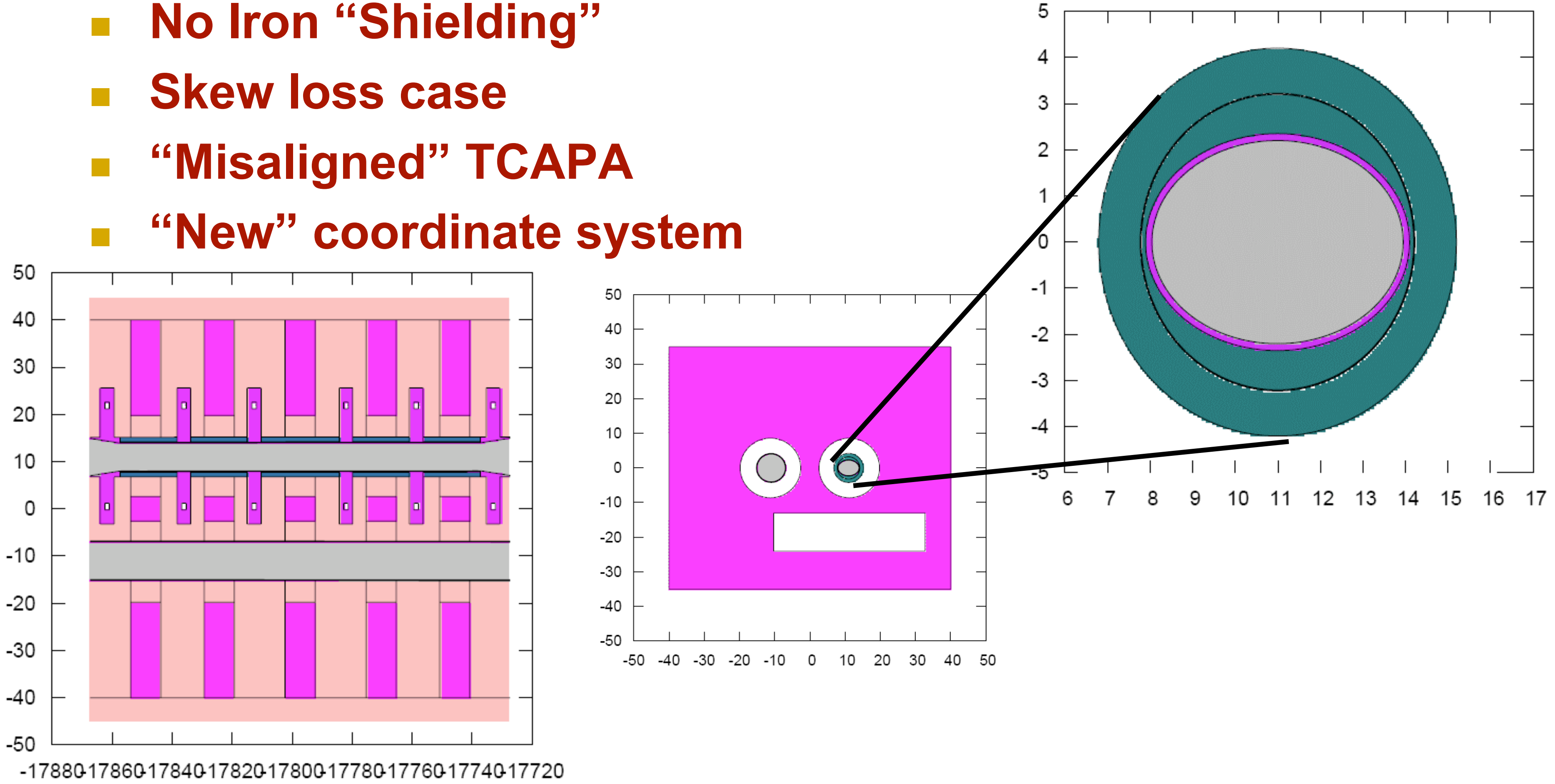
Implemented and Tested Geometry



Simple-Geo C. Theis

Latest Studied Cases

- Standard Case (high statistics)
- Beam Pipe (Cu) + “Transition” (W) + Tungsten
- No Iron “Shielding”
- Skew loss case
- “Misaligned” TCAPA
- “New” coordinate system



Total Power Deposition

element	*actual* [kW]	*ell W*	*no iron*	*misal*	*x->-x*	*skew*
TCAP.A6L7.B1	28.7	+1%	-26%	-1%	=	+26%
MBW.B6L7.B1	15.4	-2%	+28%	+2%	+2%	+20%
TCAP.B6L7.B1	2.7	+4%	-24%	-2%	-2%	+4%
MBW.A6L7.B1	14.7	-2%	+2%	=	-2%	+22%
TCAP.C5L7.B1	32.4	+2%	-21%	=	-2%	+19%
MQW.E5L7.B1	13.8	-5%	+23%	=	-1%	+17%
MQW.D5L7.B1	6.1	-1%	+1%	+1%	-4%	+16%

- **small effect for the elliptical W-shield**
- **idem for the "misaligned" case**
- **no dramatic effect for the iron removal**
- **little impact due to the 'new' coordinate system**
- **the skew case is to be considered the worst one (however, horizontal losses are more likely)**

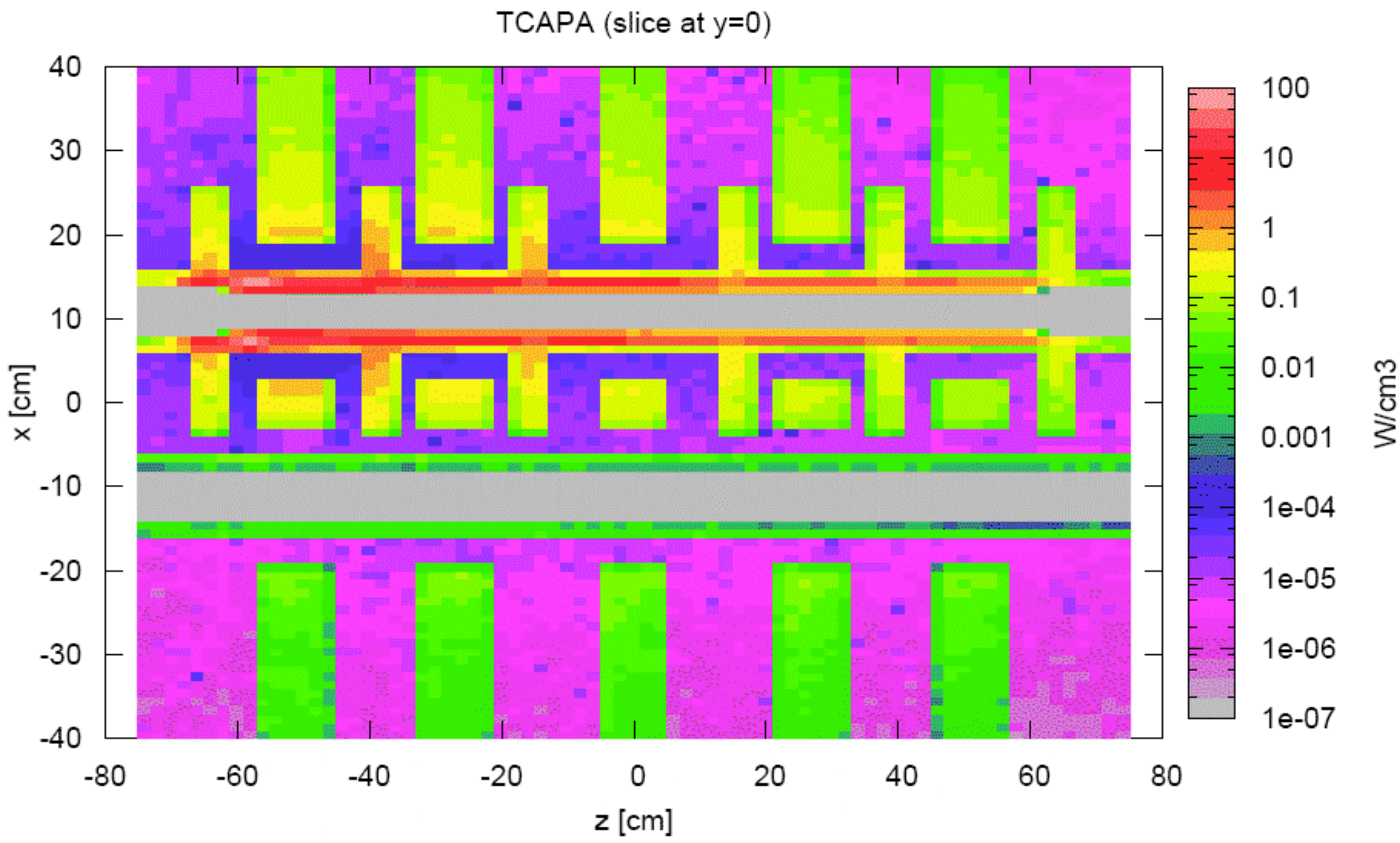
Peak Values

element	*actual* [W/cm^3/MGy/y]	*ell W*	*no iron*	*misal*	*x->-x*	*skew*
TCAP.A6L7.B1	86.4	+61%	/	+9%	-5%	-13%
MBW.B6L7.B1	$\boxed{3.3}$	-9%	/	-12%	+3%	+9%
TCAP.B6L7.B1	48.0	-1%	/	=	=	+9%
MBW.A6L7.B1	3.0	-4%	/	+7%	-4%	+11%
TCAP.C5L7.B1	183.4	+67%	/	+3%	-18%	+4%
MQW.E5L7.B1	$\boxed{0.9}$	-4%	/	+8%	-3%	+18%
MQW.D5L7.B1	0.51	+3%	/	+14%	-5%	+22%

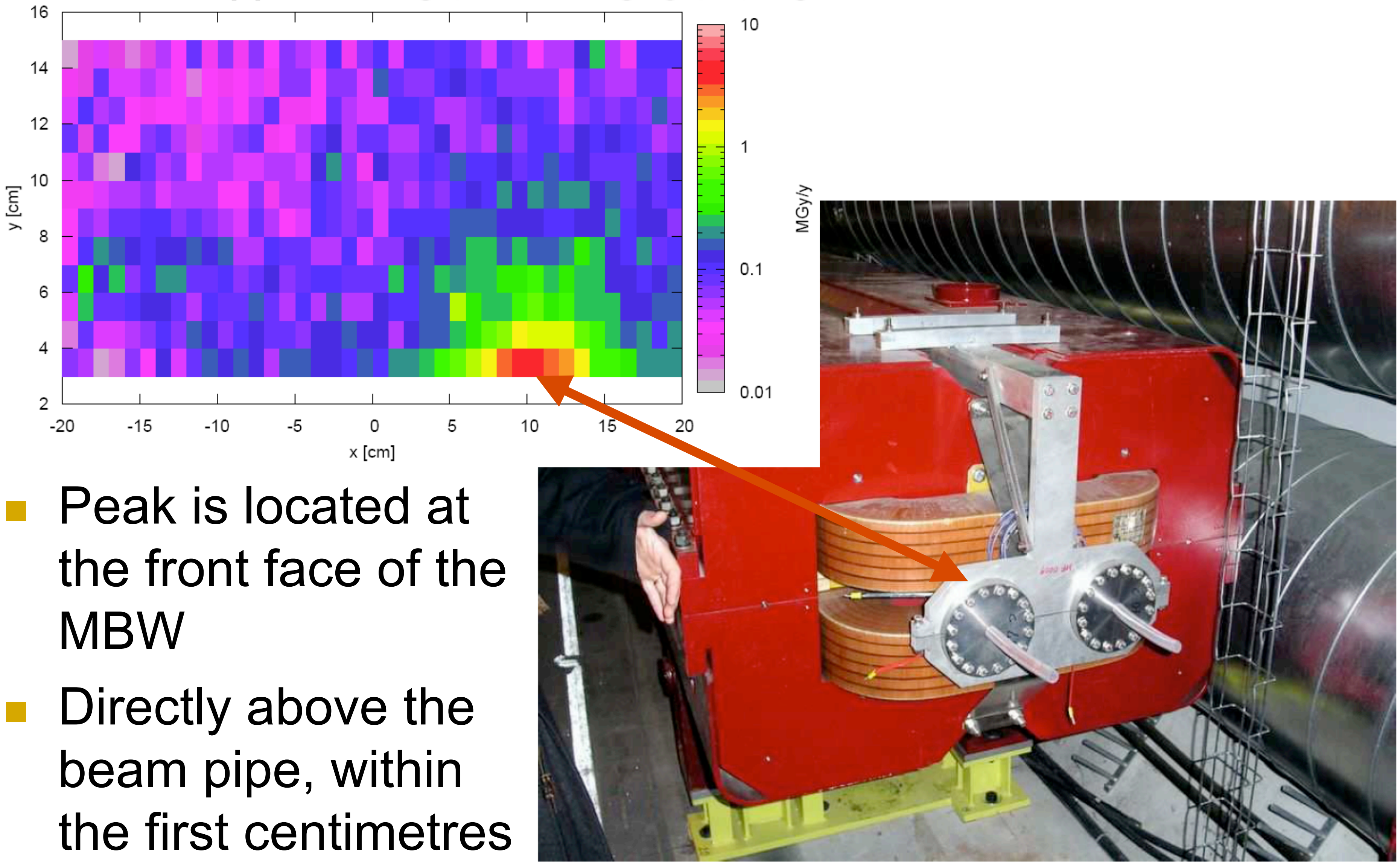
- **Dose value at the defined annual limit**
- **Only small impact for the studied final scenarios**
- **Skew case shows dependencies in the order of 10% only**

Peak Location in the Absorber

- TCAPA – horizontal cut through the beam axis

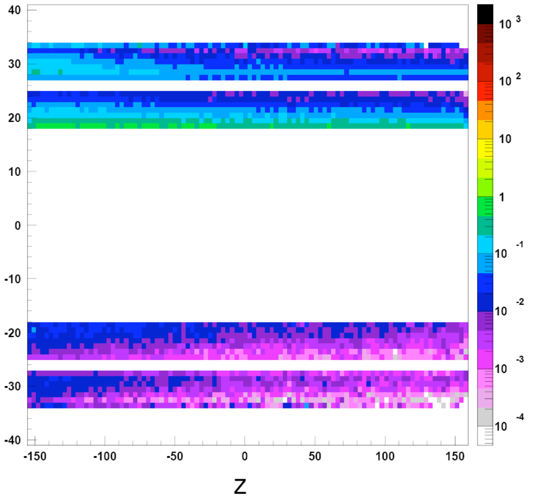


MBW - Peak Location

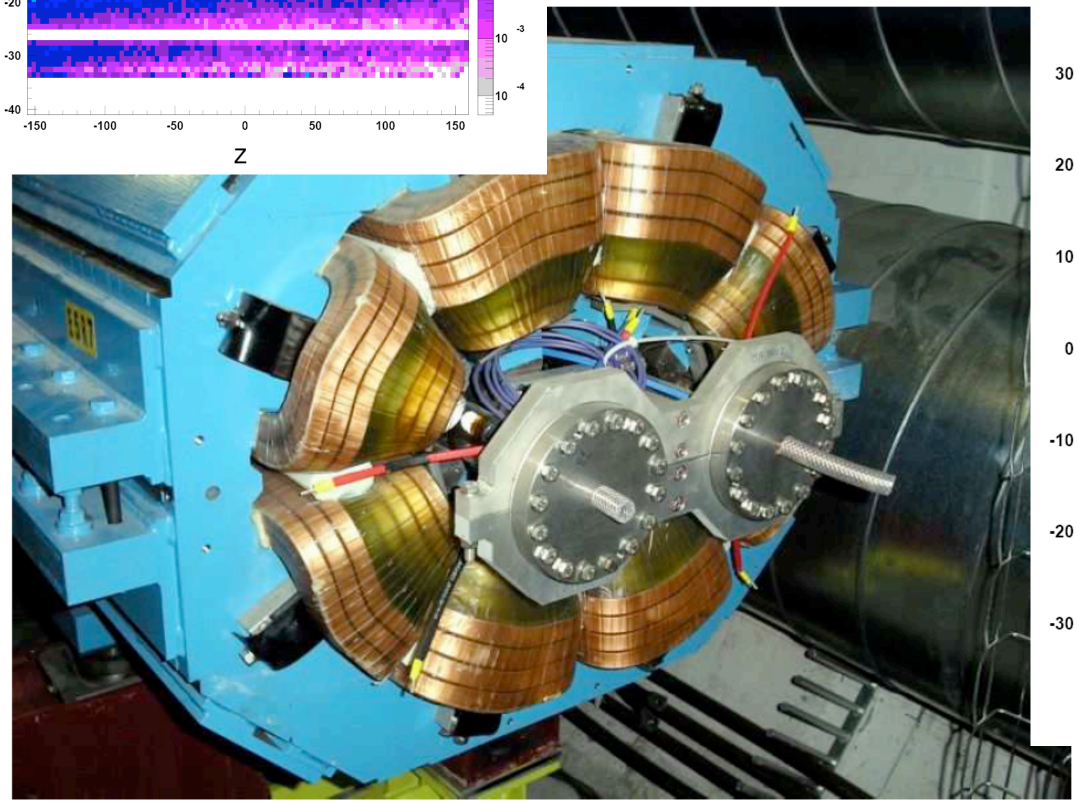


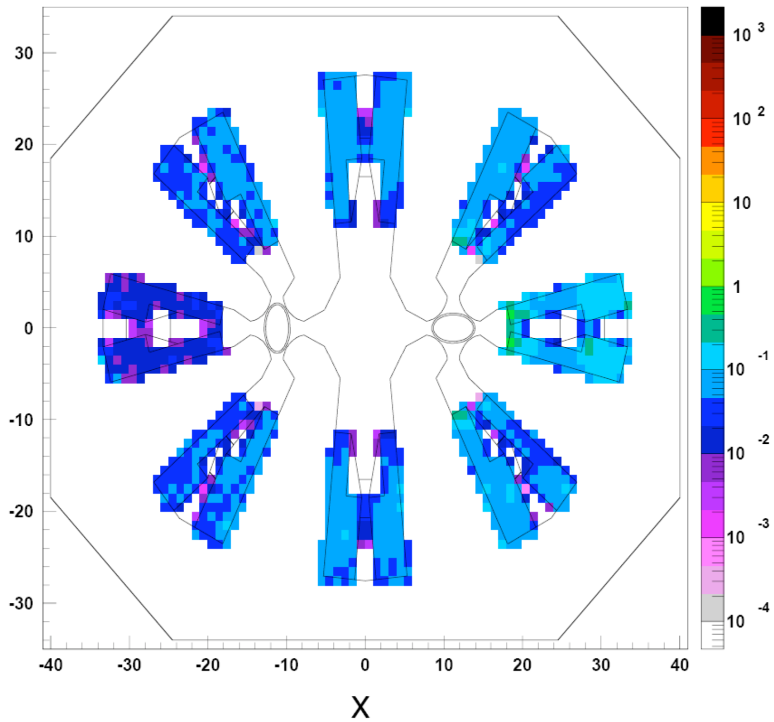
- Peak is located at the front face of the MBW
- Directly above the beam pipe, within the first centimetres

MQW –Peak Location

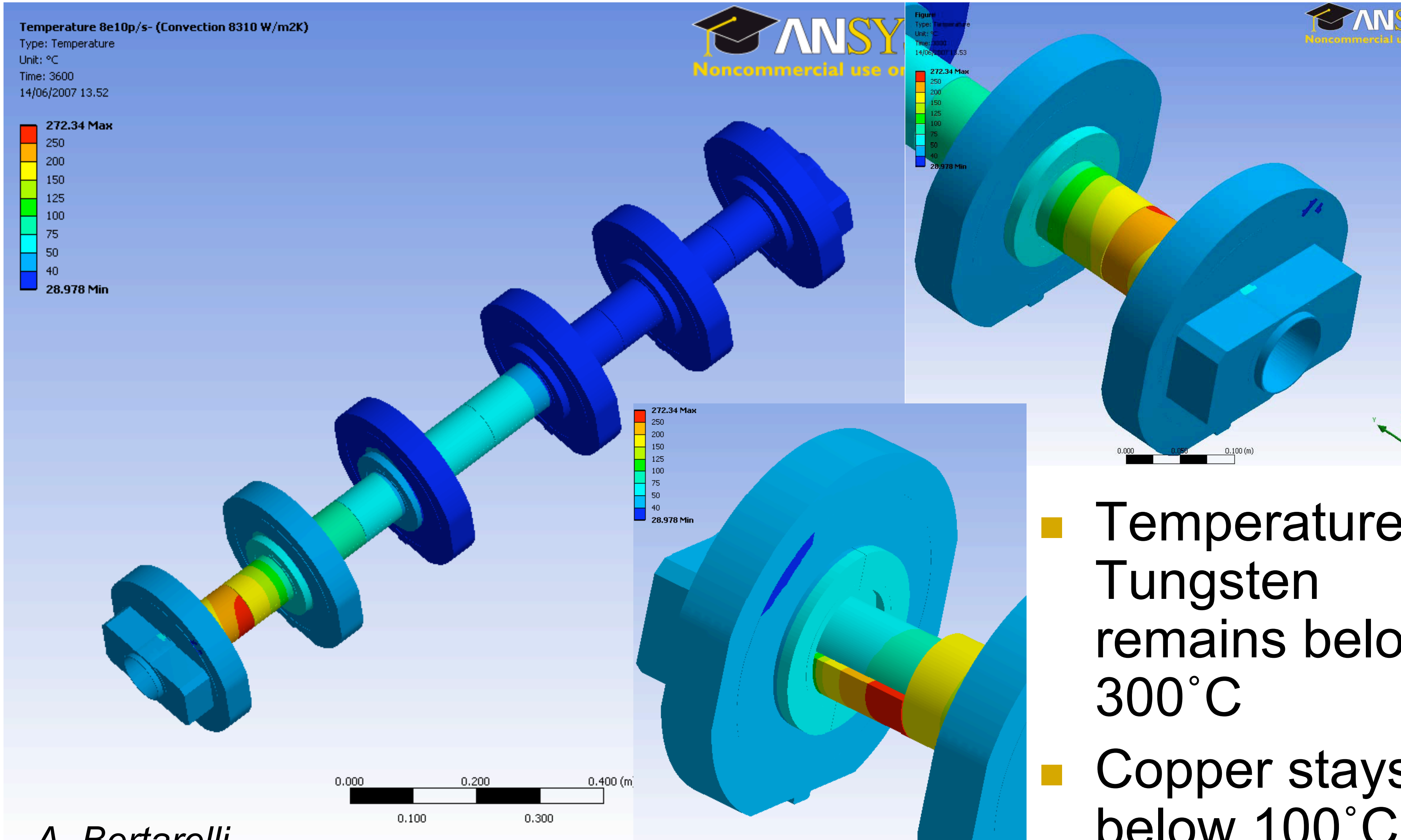


- Peak is located inside the MQW
- Laterally at the closest distance to the beam pipe





ANSYS Studies – Maximum T



A. Bertarelli

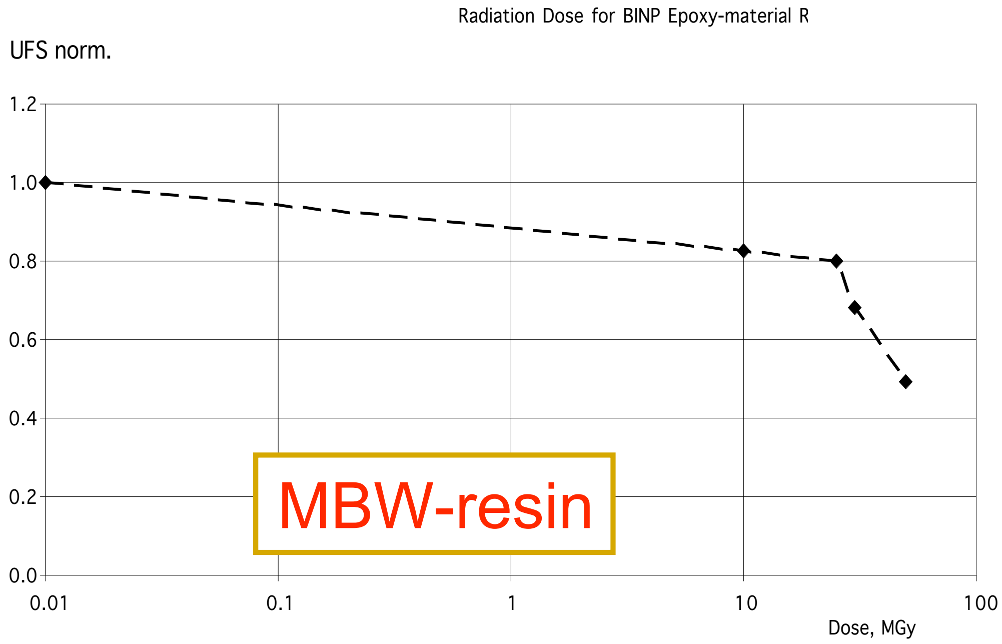
- Temperature in Tungsten remains below 300˚C
- Copper stays below 100˚C

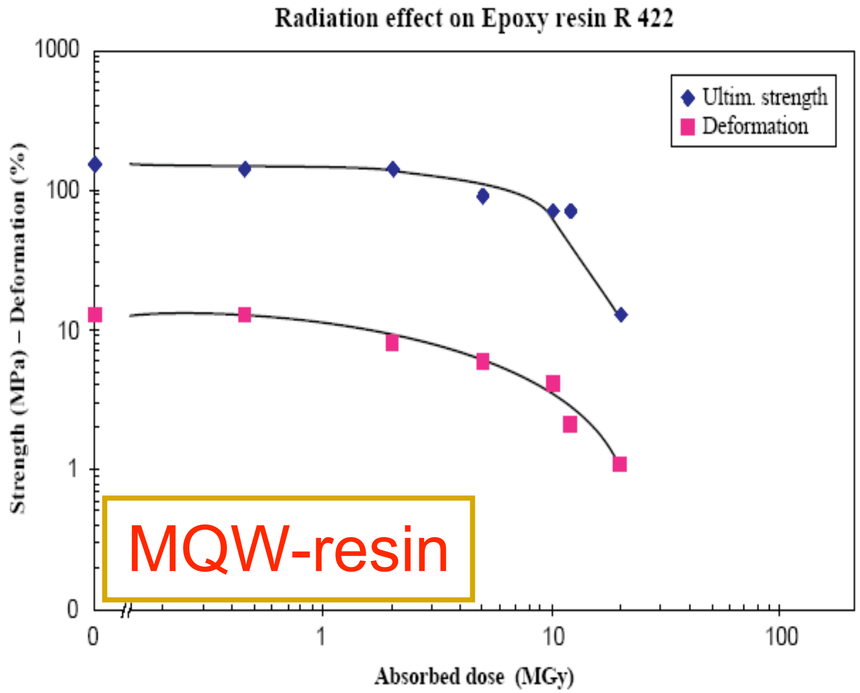
Intrinsic Uncertainties (Peaks)

- Even though **statistical uncertainties of the FLUKA calculations are small** (< percent level for the total power estimates, < 10% for the peak levels) **it is important to consider the following SYSTEMATIC uncertainties**:
  - Loss assumptions (**at least 50%**)
  - Important distances, grazing impacts on collimators **(~40%)**
  - Material transitions, *i.e.*, dose to copper as compared to dose to the insulator **(~20%)**
  - FLUKA implementation and models **(~30%, part. corr.)**
  - Knowledge about considered "limits" and their translation into real lifetime **(???)**
- **A total safety factor of 2-3 is realistic for peak values!!!**

e.g., Dose Limits

- Performed in laboratory conditions
- Dose-rate effect: Less degradation than from long-term irradiation. (Oxygen/humidity diffusion, dT)
- Depends on resin processing.

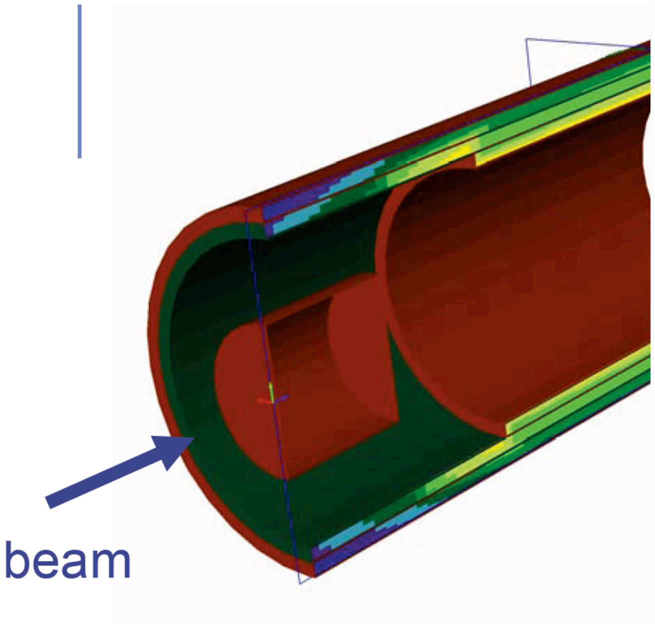


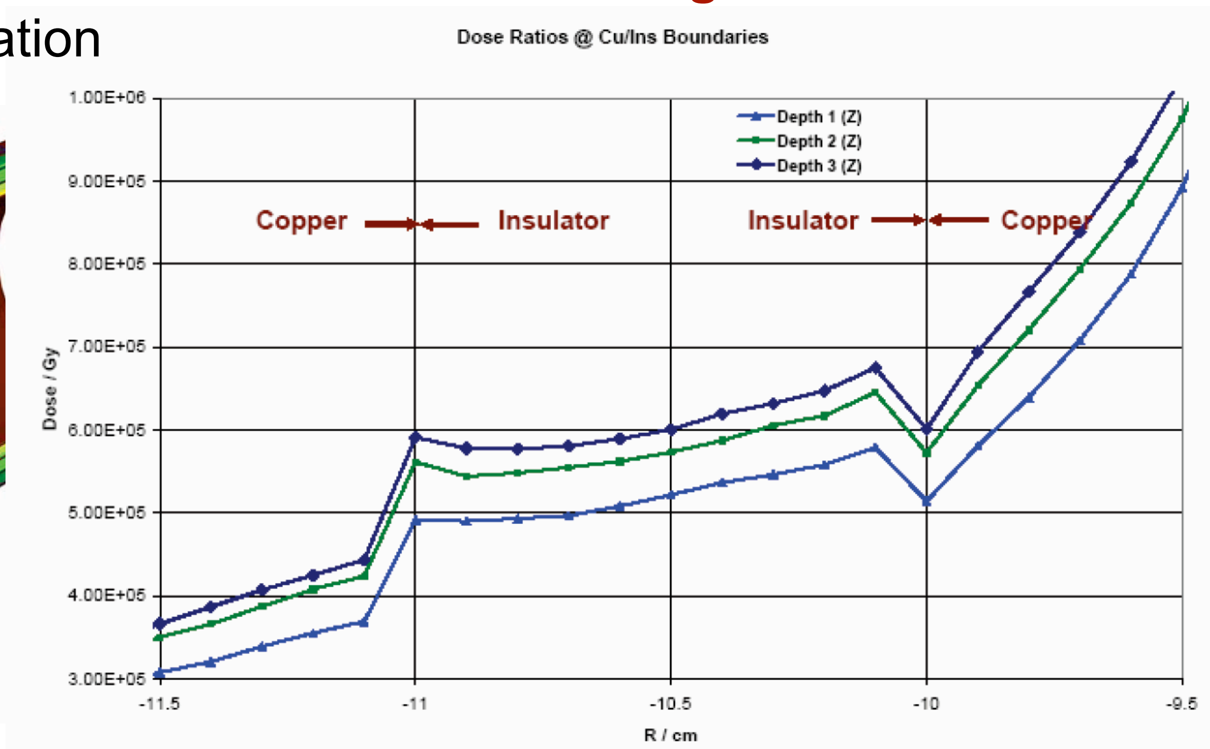


M. Karppinen

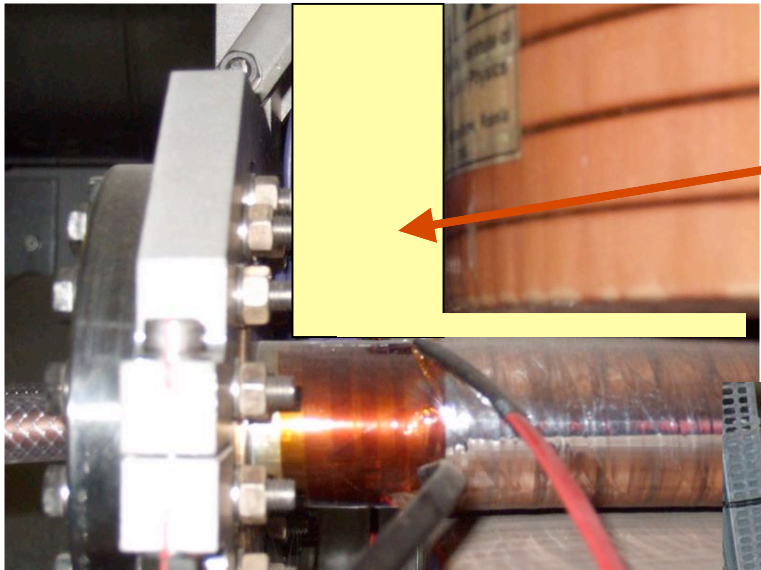
e.g., Dose in Cu and Insulator

- Epoxy is the delicate element in the magnet coils, but the dose peak is evaluated in copper
- Dedicated simulation considering an insulator layer between two copper layers around a copper target irradiated by a 7 TeV proton beam
- The dose in the insulator comes out to be **20-25% higher** than the dose in copper at the same location



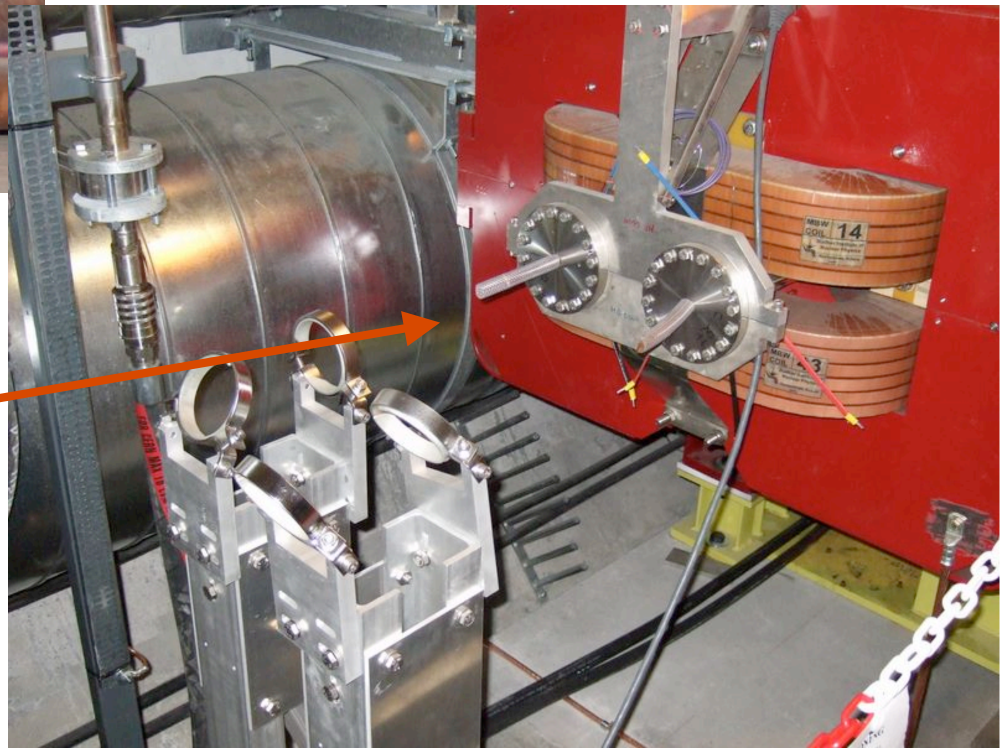


MBW – Special Bellow Design

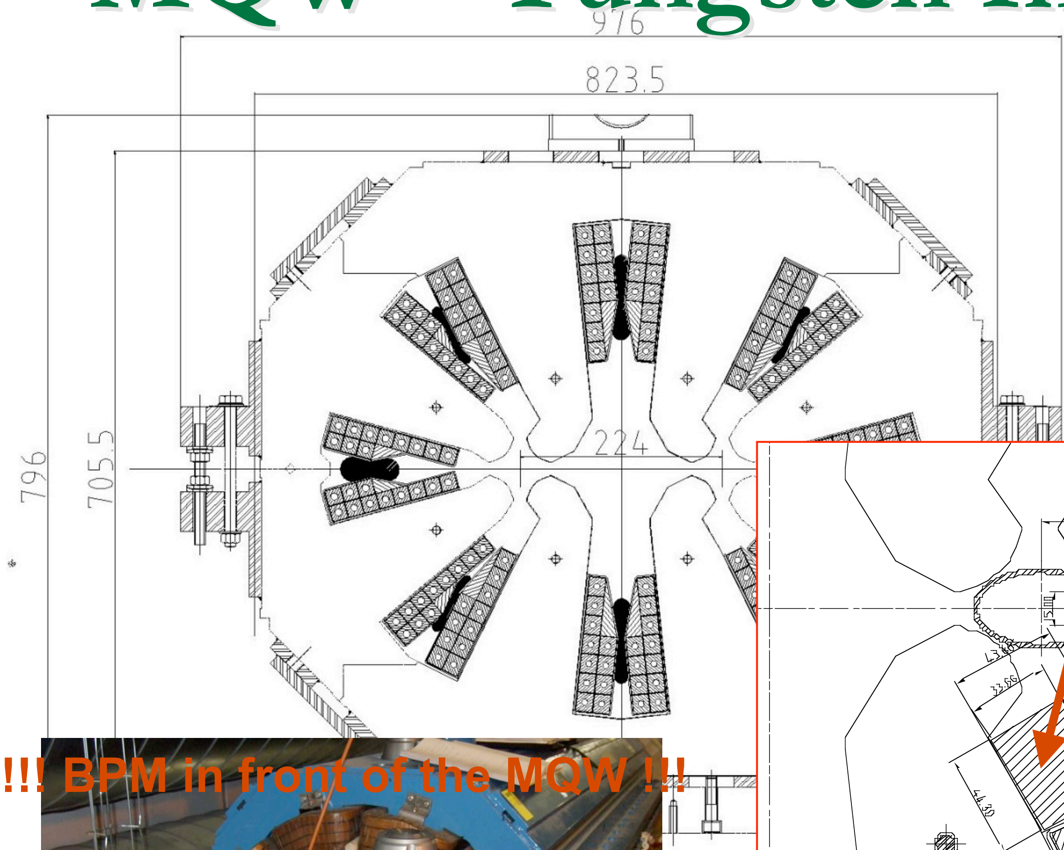


- **Additional shielding** in front of the MBW magnet modules in order to reduce the total dose to the coils

- And/Or special bellow in order **to extend the passive absorber shielding (tungsten)** as close as possible to the MBW (no vacuum pump is installed?)

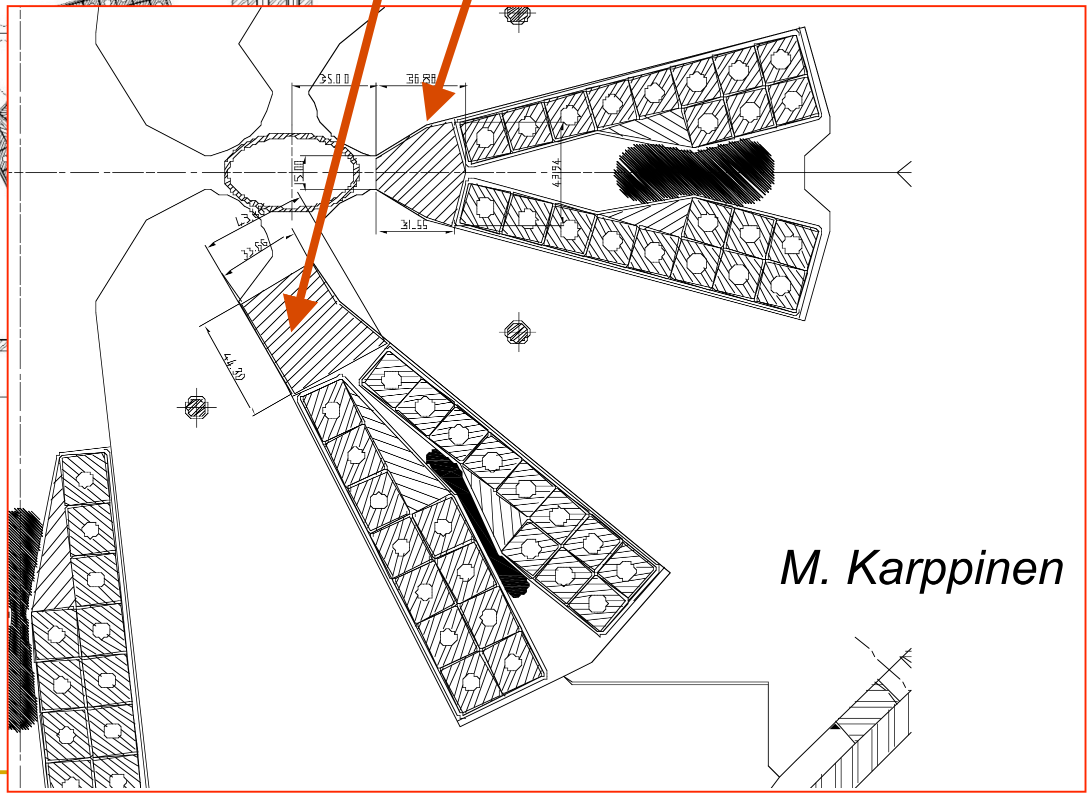


MQW – Tungsten Inlets



- Additional shielding inside the MQW magnet modules in order to reduce the total dose to the coils

!!! BPM in front of the MQW !!!



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