SIMULATION OF X-RAY EMISSION INDUCED BY ELECTRONS IMPINGING THE PLASMA CHAMBER WALLS OF THE ASTERICS ECRIS

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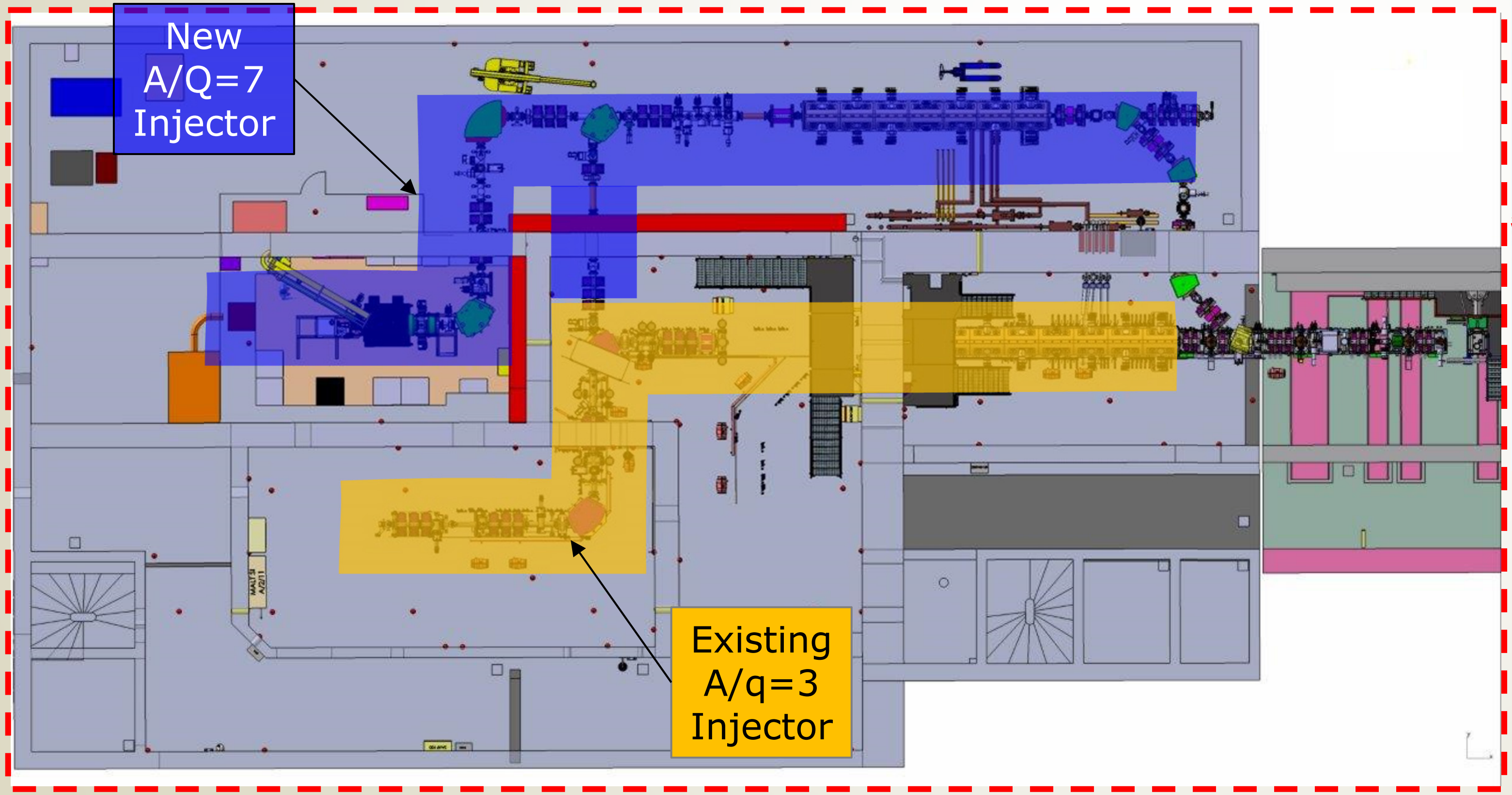
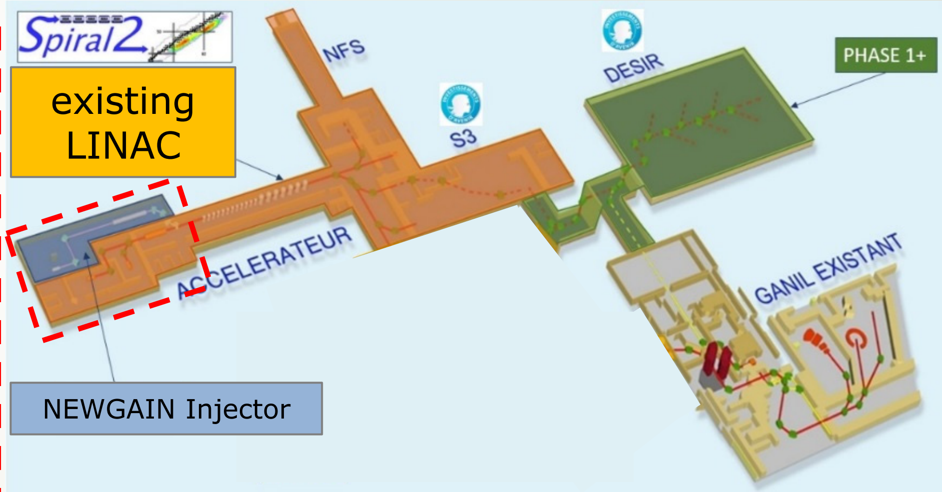
OUTLINE

- NEWGAIN Project and ASTERICS Ions Source
- Goal of the Bremsstrahlung study
- Methodology
- Results for the hot electron population
- Results for the x-ray Bremsstrahlung emission
- X-ray Shielding

NEWGAIN: NEW GAnil INjector

- Ongoing Project to design and build a second heavy ion injector with M/Q=7 for the SPIRAL2 accelerator at GANIL, Caen, France
- French multi-laboratory collaboration
- Project Timeline : 2023-2030



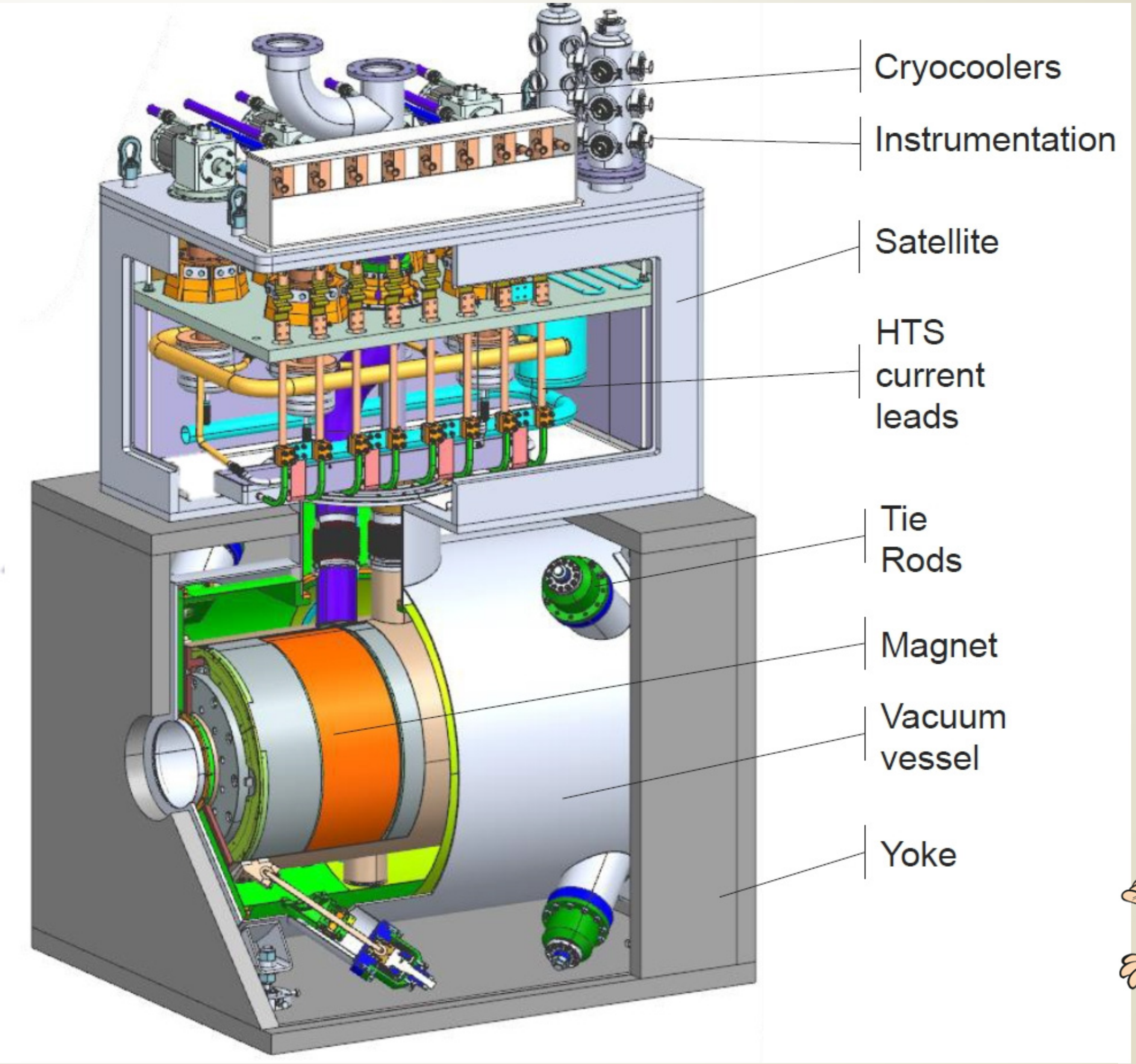


NEWGAIN
NEW GANIL INJECTOR

FRANCE 2030

ASTERICS Ion Source

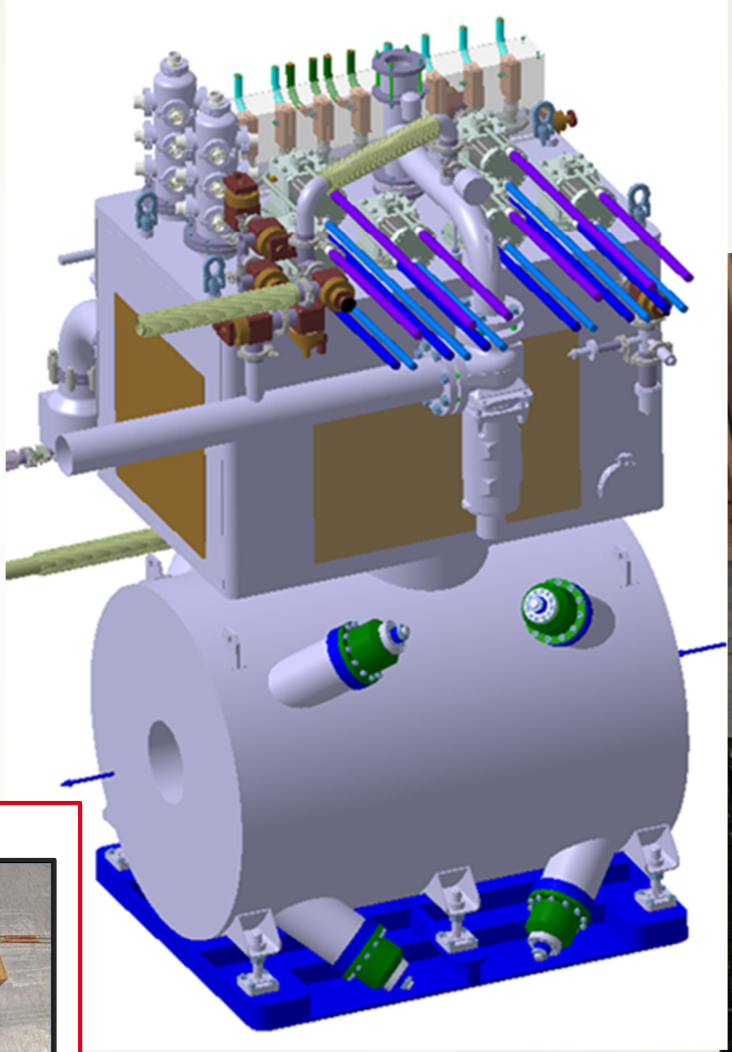
Parameter	Value
ECR frequency	*28 GHz*
Max Axial Mirror Peak Field	*3.7 – 0.1 – 2.5 T*
Radial Peak Field	*2.4 T*
Chamber length	*600 mm*
Chamber radius	*91 mm*
Chamber volume	*15.6 liter*
ECR Length @ Bmin=0.3 T	*220 mm*
ECR volume @ Bmin=0.3 T	*1.9 liter*
Cooling power@ 4.2 K	*9 W*
SC Cable	*NbTi*
Beam requirement #1	*10 pμA U^{34+}*
Beam requirement #2	*15 μA Ni,Ti,Ca*



Status of the SC Magnet project @ CEA

- Superconducting NbTI cable delivered by FURUKAWA (JPN)
  - 43 km for the solenoids
  - 20 km for the sextupole
- SC Magnet Call for Tender issued in July 2024
- Delivery expected in 2028

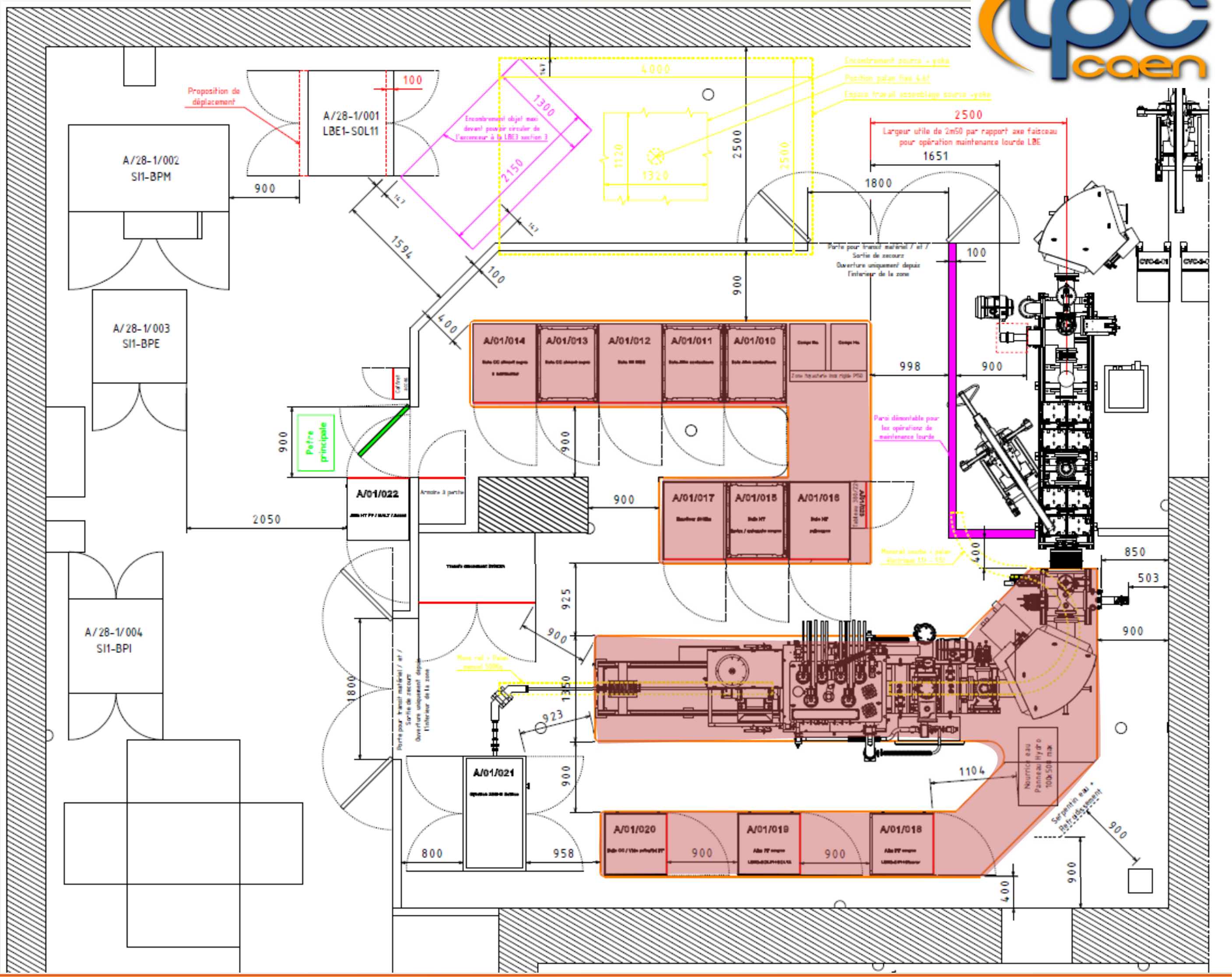
Racetrack coil built for practising in 2023



Cable delivered @ CEA in 2024

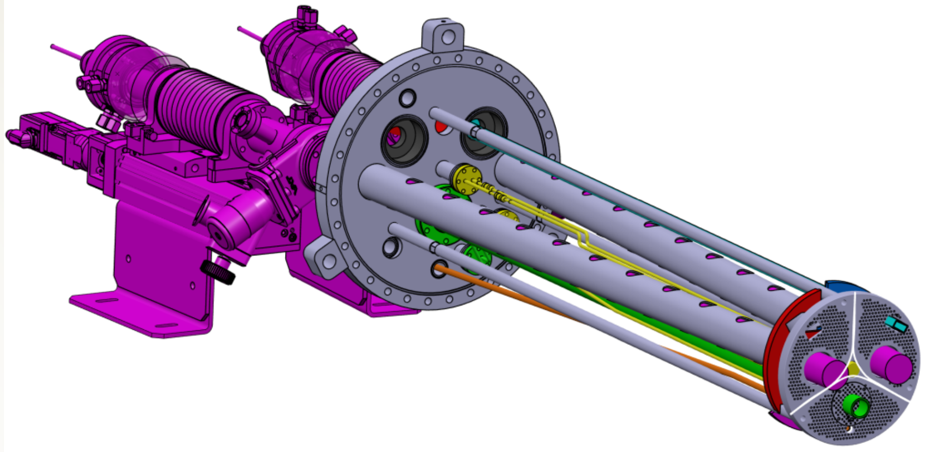
Status of the Ion Source and Platform Design

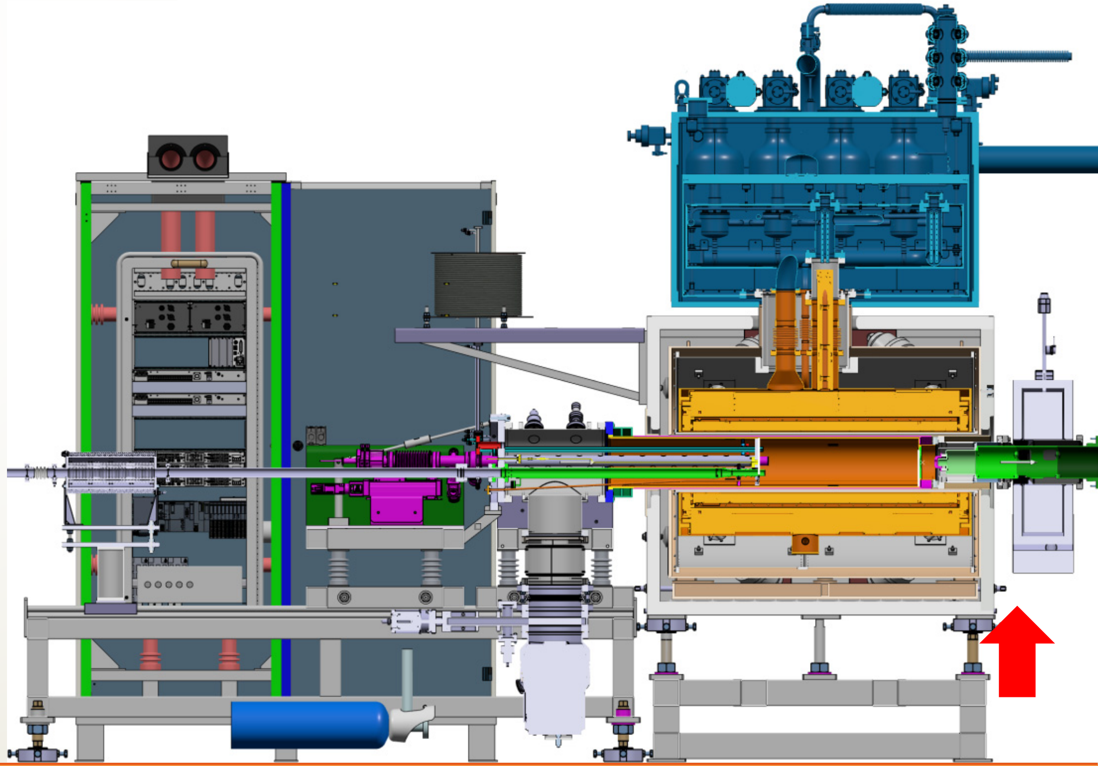
- Platform Footprint under consolidation
  - 2 HV platform islands
  - LEBT@HV
  - HV platform: 30 to 45 kV
  - Limited ceiling heigth prohibits use of a 4T overhead crane (4.5 m)
  - Source to be rolled to its final position and lifted with hydraulic actuators



Status of the Ion Source and Platform Design

- ASTERICS Mechanics under consolidation
  - Injection assy mounted on a movable/alignable cart
    - *Endoscope port added to make online video of the plasma*
    - *18+28 GHz feed, 1 RF spare port*
    - *2 motorized oven ports feed, with transfer airlock, pointing toward the plasma*
    - *1 biased disk*
  - Al plasma chamber mounted on a movable/alignable cart
    - *2 mm Ta shield*
    - *Kapton foil multilayer HV insulation*
    - *Easy dismount flange access @ extraction*





Surface Bremsstrahlung x-ray Investigation

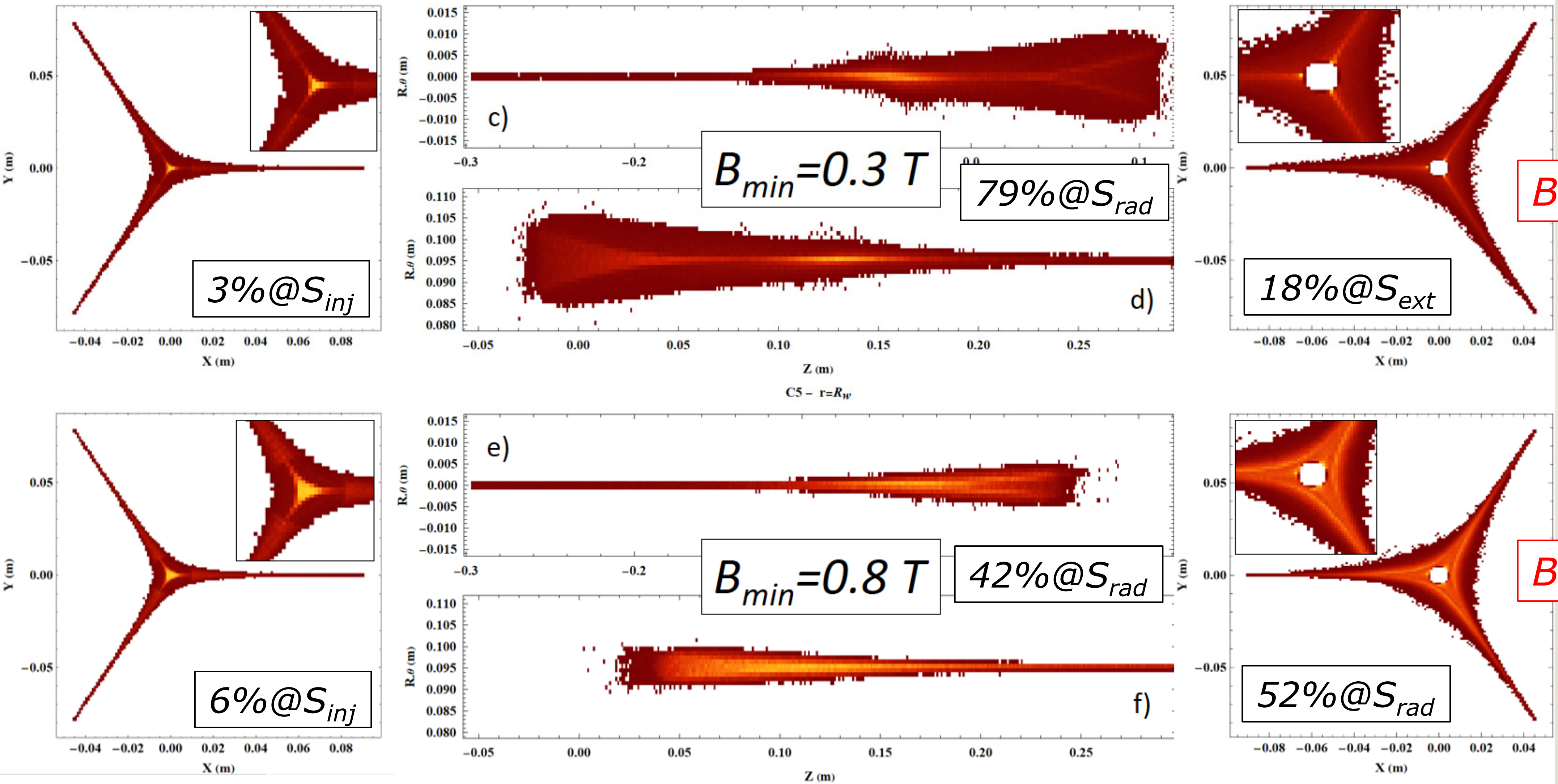
- Motivations
  - Workers Radiation protection
  - Improve knowlege of ECRIS Physics
- Objective
  - Provide a dose mapping in the source cave
  - Try and error to define the most compact x-ray shielding
- Methodology
  - Monte Carlo code of electron population in ASTERICS to output the electron density and velocity distribution hitting the plasma chamber walls
  - Input the electron information into Fluka code to study x-ray propagation inside and outside of the source

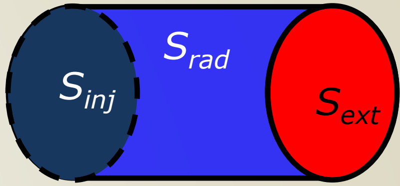
Monte Carlo Electron Simulation

- $1.25x10^6$ electrons generated
- 2 Magnetic confinement studied :
  - 3.7-0.3-2.2 T ; Radial : Br=2.4 T
  - 3.7-0.8-2.2 T ; Radial : Br=2.4 T
- 7 kW 28 GHz RF planar travelling wave, circular polarisation
- Frozen ions with a fixed charge state distribution
- Coulomb and electron Impact collisions
- Density = 15 % cut off @ 28 GHz
- Server with 80 cores
- 1 ms confinement time limit
- Initial electrons started in the ECR zone, @ low energy, random direction

See complementary presentation by Andrea Cernuschi (# TUC2)

Monte Carlo Results: e⁻ distribution at Wall





B_w=2.04 T<B_{ext}

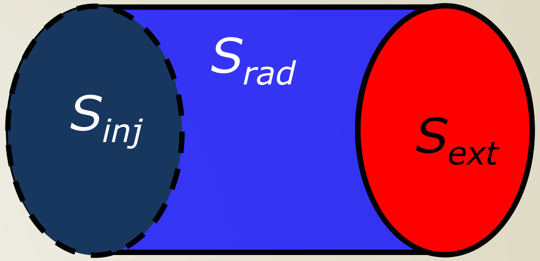
B_w=2.29 T>B_{ext}

B_{inj}=3.7 T

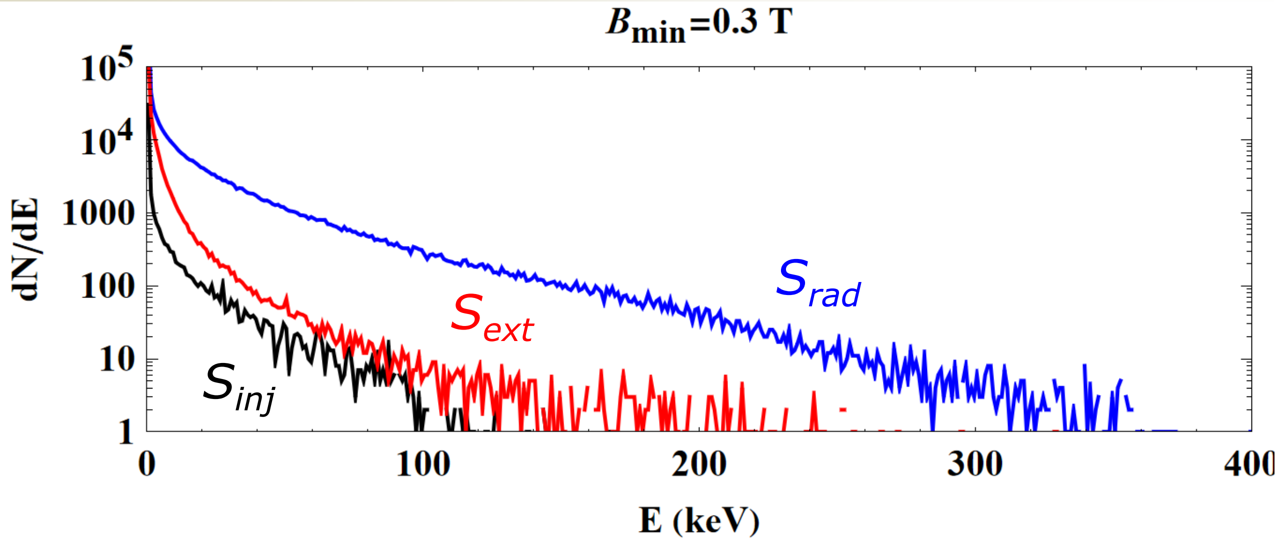
B_{ext}=2.2 T

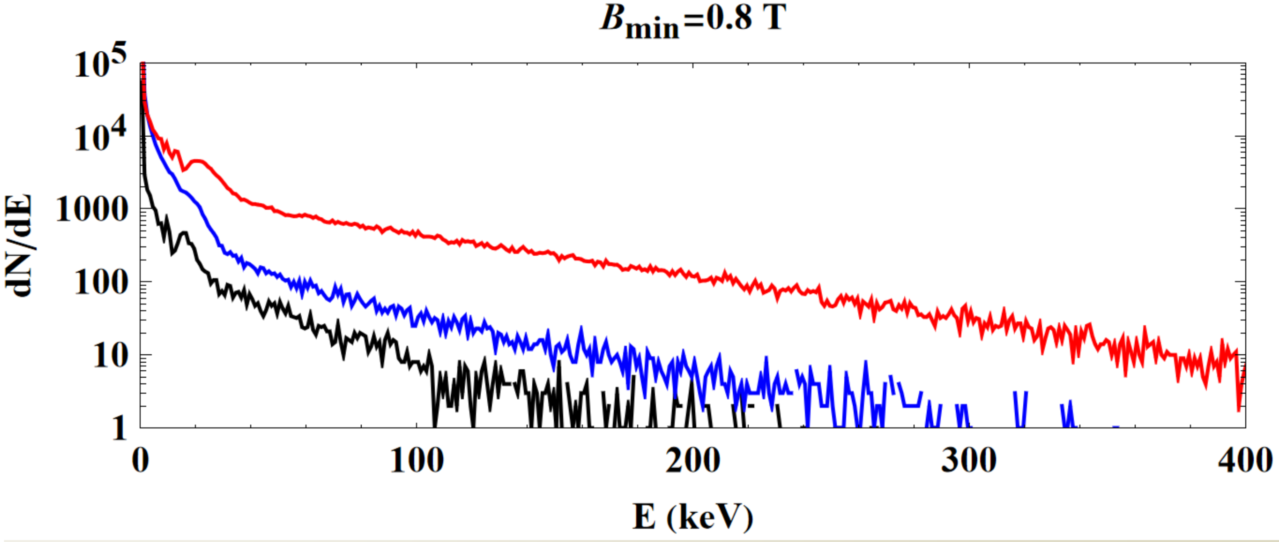
Monte Carlo Result: EEDF@Wall

- Different EEDF temperature at different walls
- Maxwell-Boltzmann fit of high energy electrons
- Wall EEDF Temperature :
  - Temperature higher where B_{wall} is minimum
  - Temperature lower where B_{wall} is maximum
- Note EEDF hump @15-20 keV for B_{min}=0.8 T
- T@wall increases with B_{min}



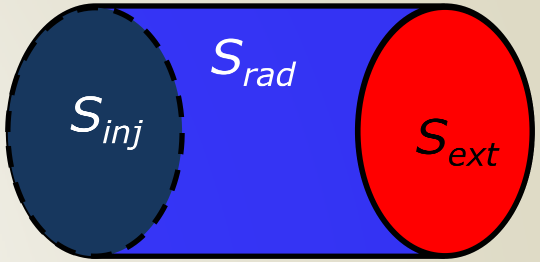
Axial profile	T_{inj}	T_{rad}	T_{ext}
3.7-0.3-2.2 T	19.8 ± 1.6	41.7 ± 1.5	44.0 ± 7.4
3.7-0.8-2.2 T	36.0 ± 8.6	52.0 ± 3.1	63.2 ± 7.9

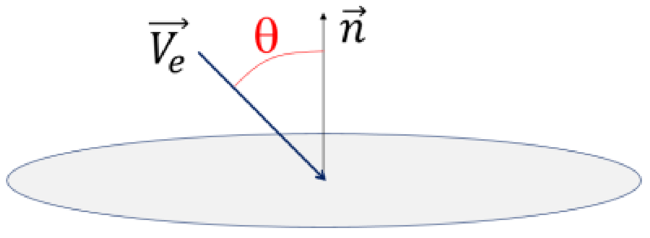


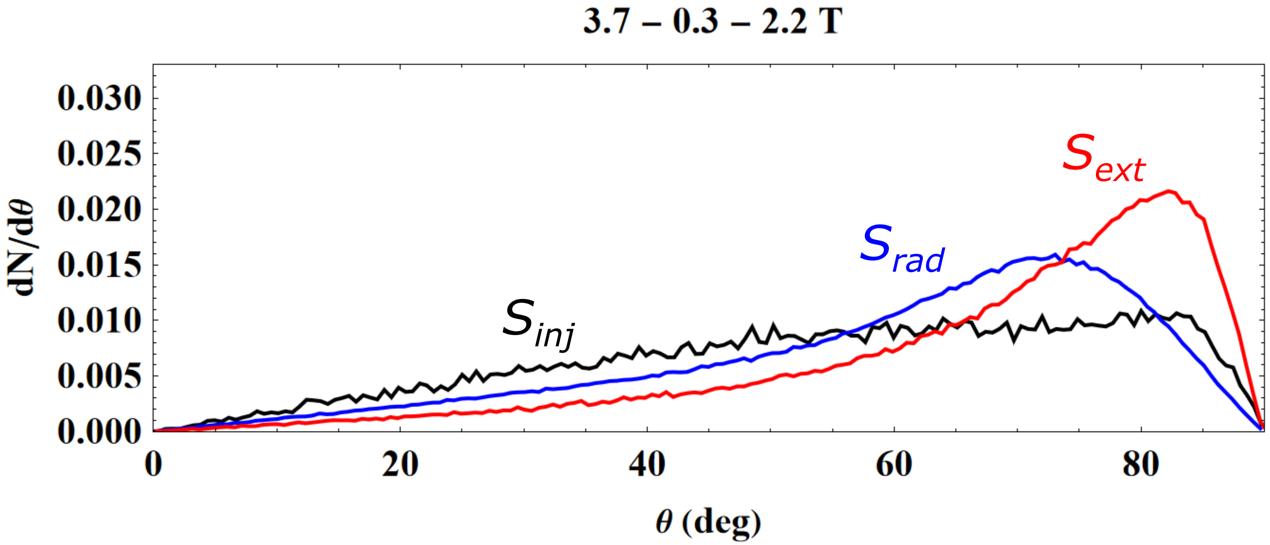


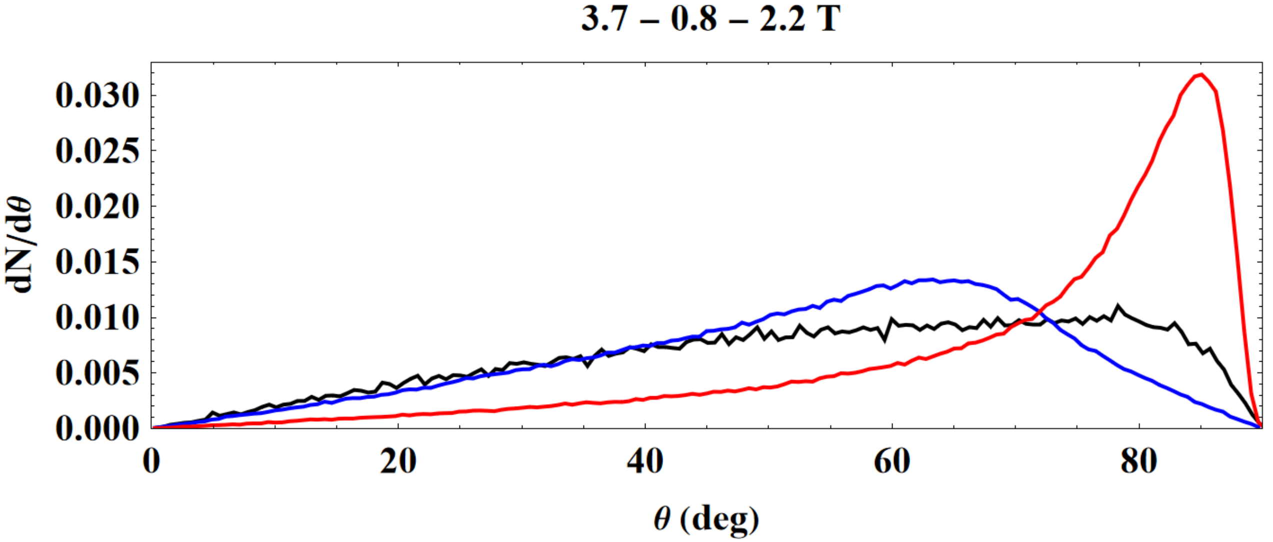
Monte Carlo Results: Angle of Impact @ Wall

- θ = angle between $\vec{v_e}$ and surface normal $\vec{n}$
- $dN/d\theta_{inj}$ flatest distribution
- $dN/d\theta_{ext}$ peaked $\theta_{ext} > 80°$
- $dN/d\theta_{rad}$ peaked $\theta_{rad} \sim$ 60-70°
- large θ values are expected to affect the x-ray creation at wall



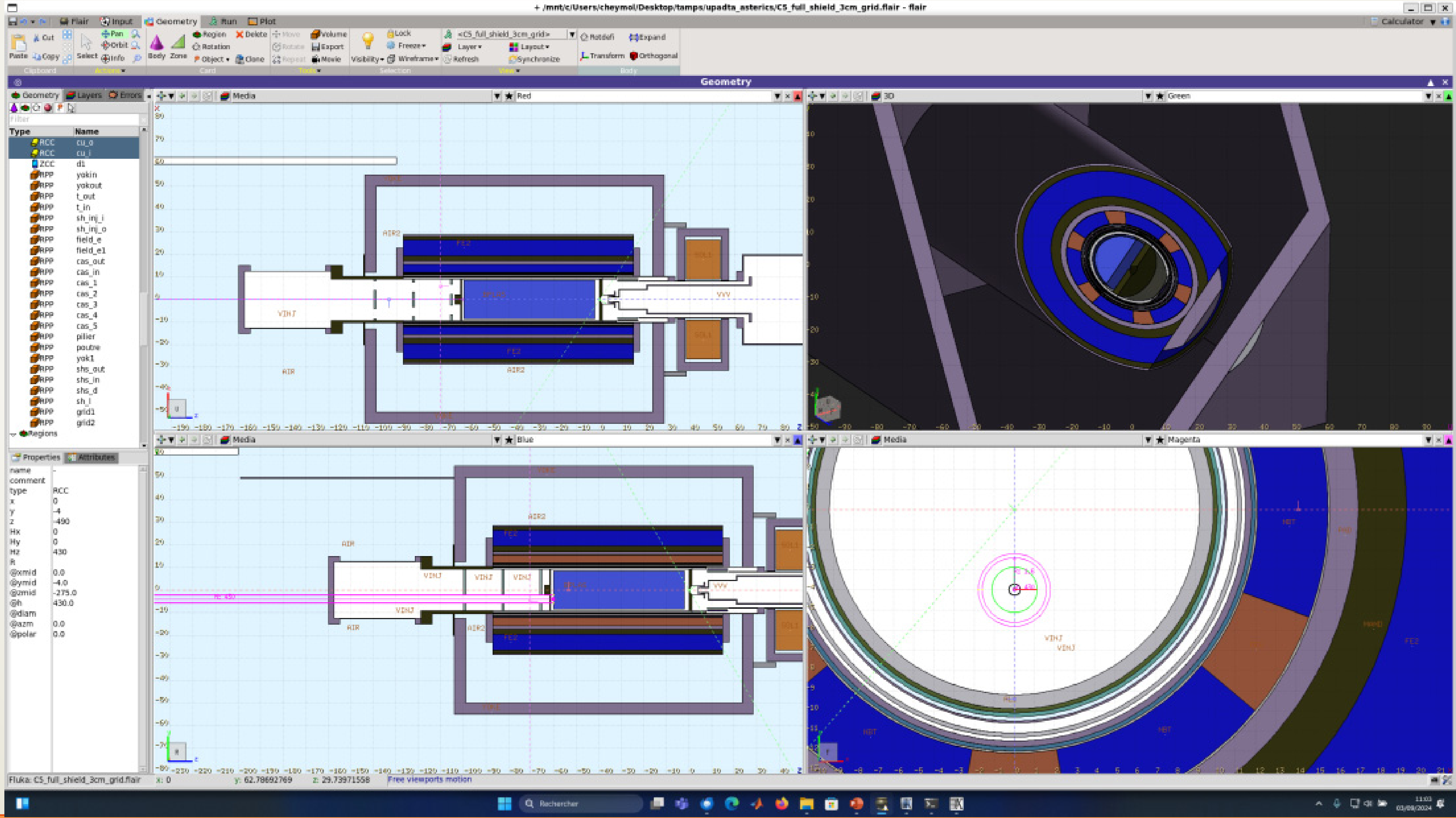






Fluka Geometrical Model

- Source with representative geometry and material modelled
  - SC magnet
  - yoke
  - Vacuum chambers
  - Extraction electrodes
  - Solenoids
  - Various shields
  - 28 GHz waveguide

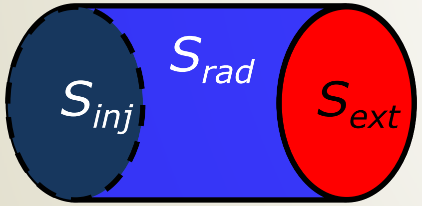


Fluka primary electron model

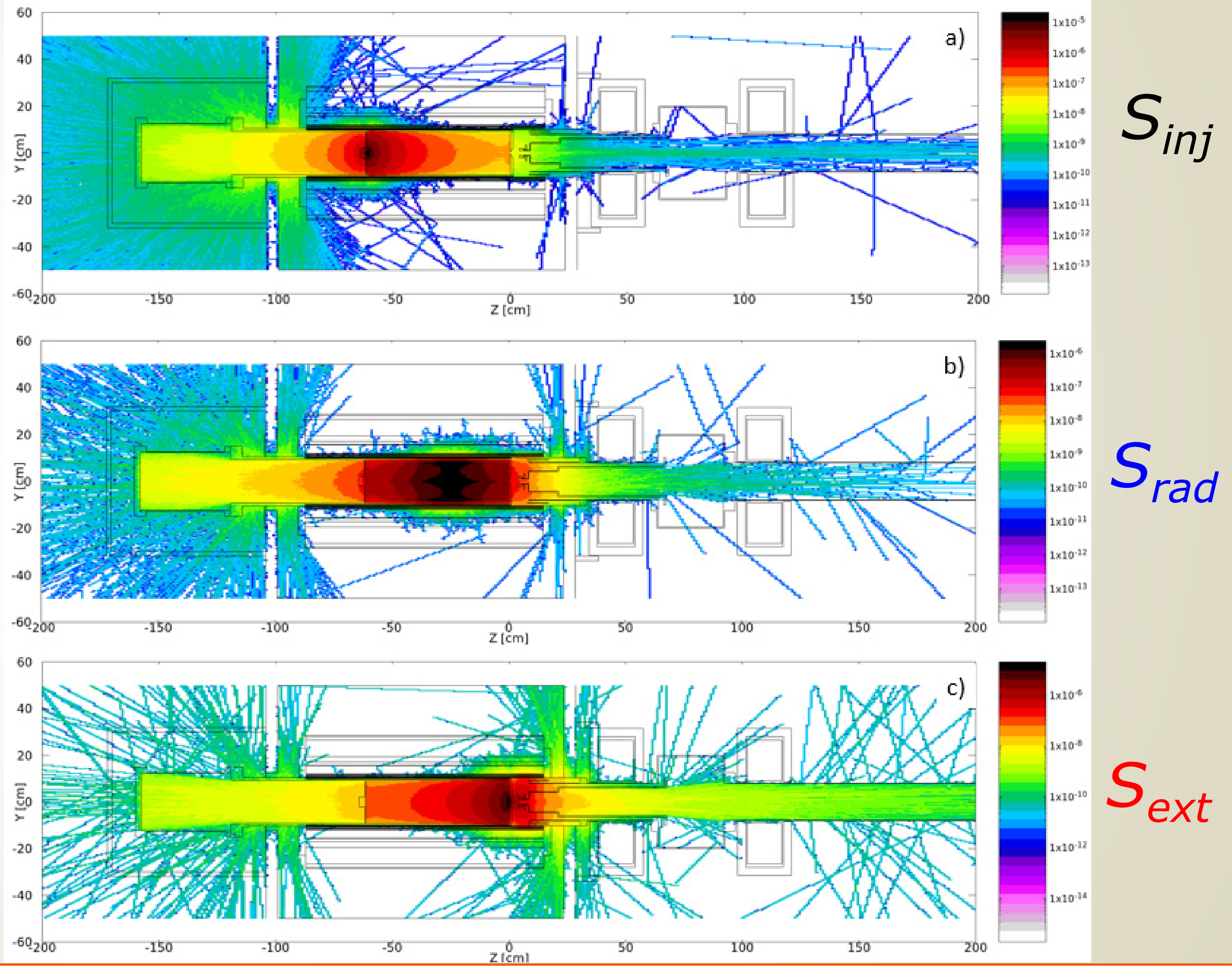
- MC output used for the electron distribution at wall
- MC output used for the electron velocity direction at wall
- Fluyka study split into 3 simulations: Injection wall, Radial wall, Extraction wall
- The direct use of the MC calculated temperature@Wall results in a very very low fraction of xray exiting the source (only hot electron energy tail contributes) and a huge, unpractical, computational time.
  - => MC output temperature was abandonned for this study
  - EEDF manually adjusted with a single Maxwell-Boltzmann (MB) function with temperature as a free parameter
- Forced EEDF MB temperature considered:
  - kT_e=50 keV for B_{min} = 0.3 T
  - kT_e=120 keV for B_{min} = 0.8 T
    - *+20% over-estimation with respect to the worst spectral temperature ever recorded in ECRIS*

X-Ray Fluence and Yield

- Radial X-ray fully stopped in the hexapole
- Very strong x-ray diffusion
  - Surface hit interplay
- Many electrons bounce
  - Mitigated by a virtual inner gas volume to stop them



$B_{min} = 0.8T$

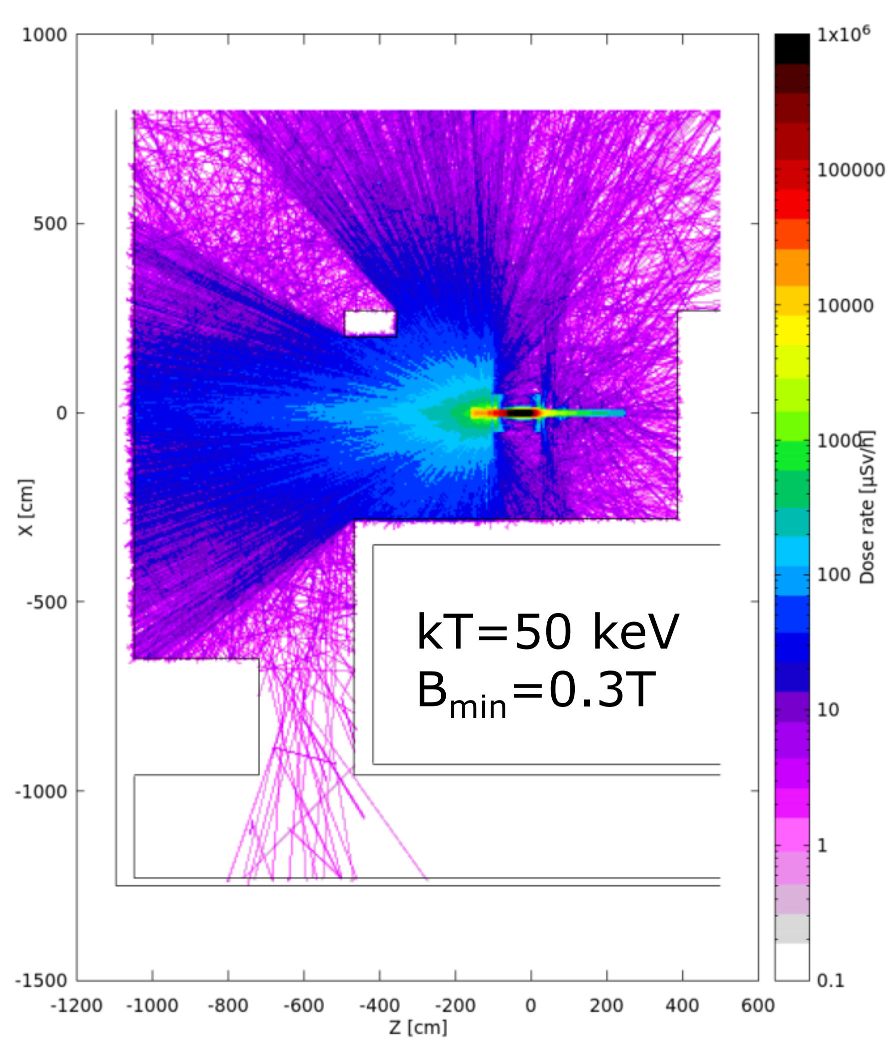


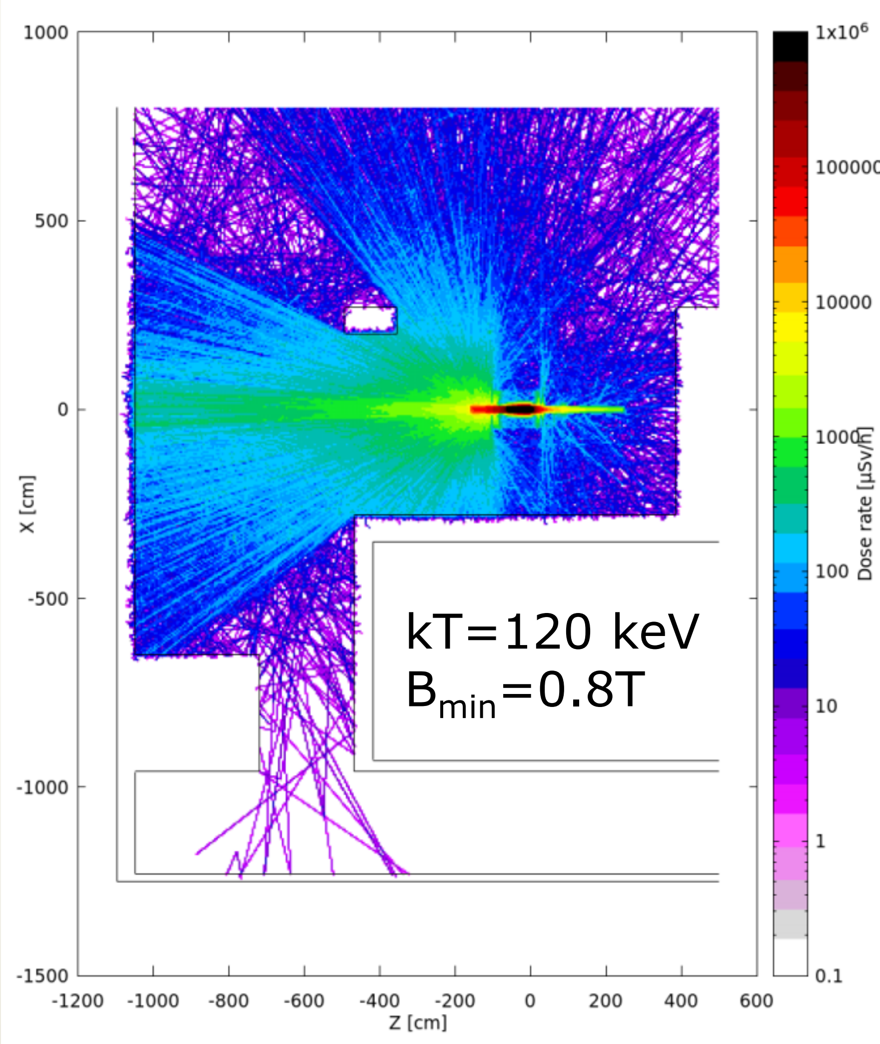
Yield of e- exiting the 1st wall layers (Al)

Axial profile	photon/e^-	%Inj	%rad	%ext
3.7-0.3-2.2 T	$5.7\ 10^{-5}$	15%	60%	25%
3.7-0.8-2.2 T	$1.6\ 10^{-4}$	27%	11%	62%

X-Ray dose in the cave per kW of e^- without shielding

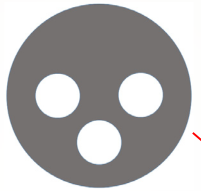
- Dose dramatically increases with kTe
- In the corridor:
  - kT=50 keV => ~50 µSv/h / kW e^-
  - kT=120 keV => ~1 mSv/h / kW e^-

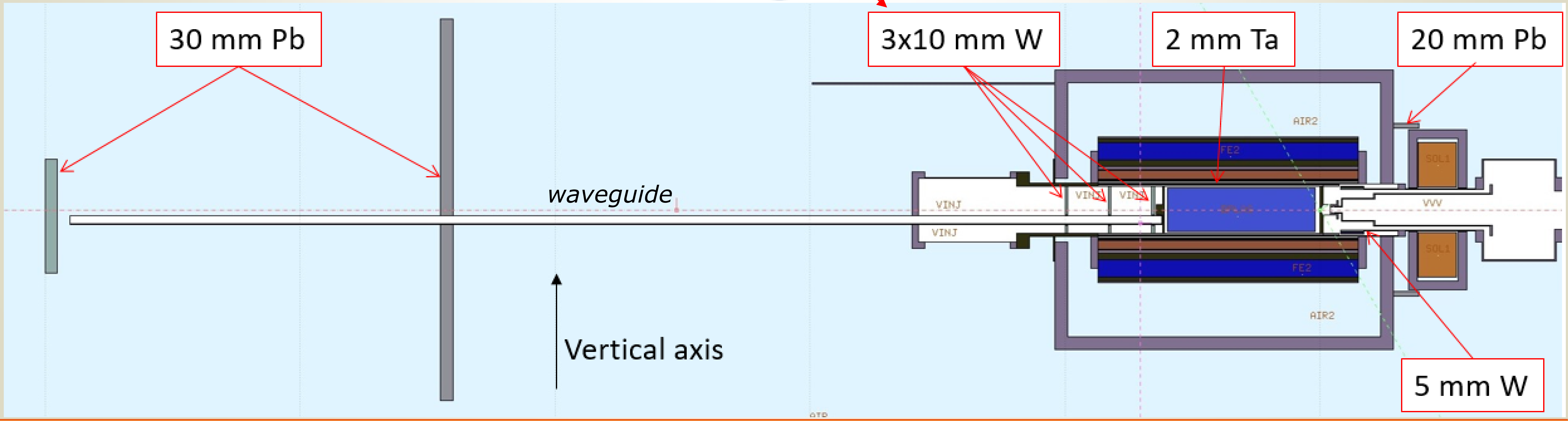




X-Ray shielding study

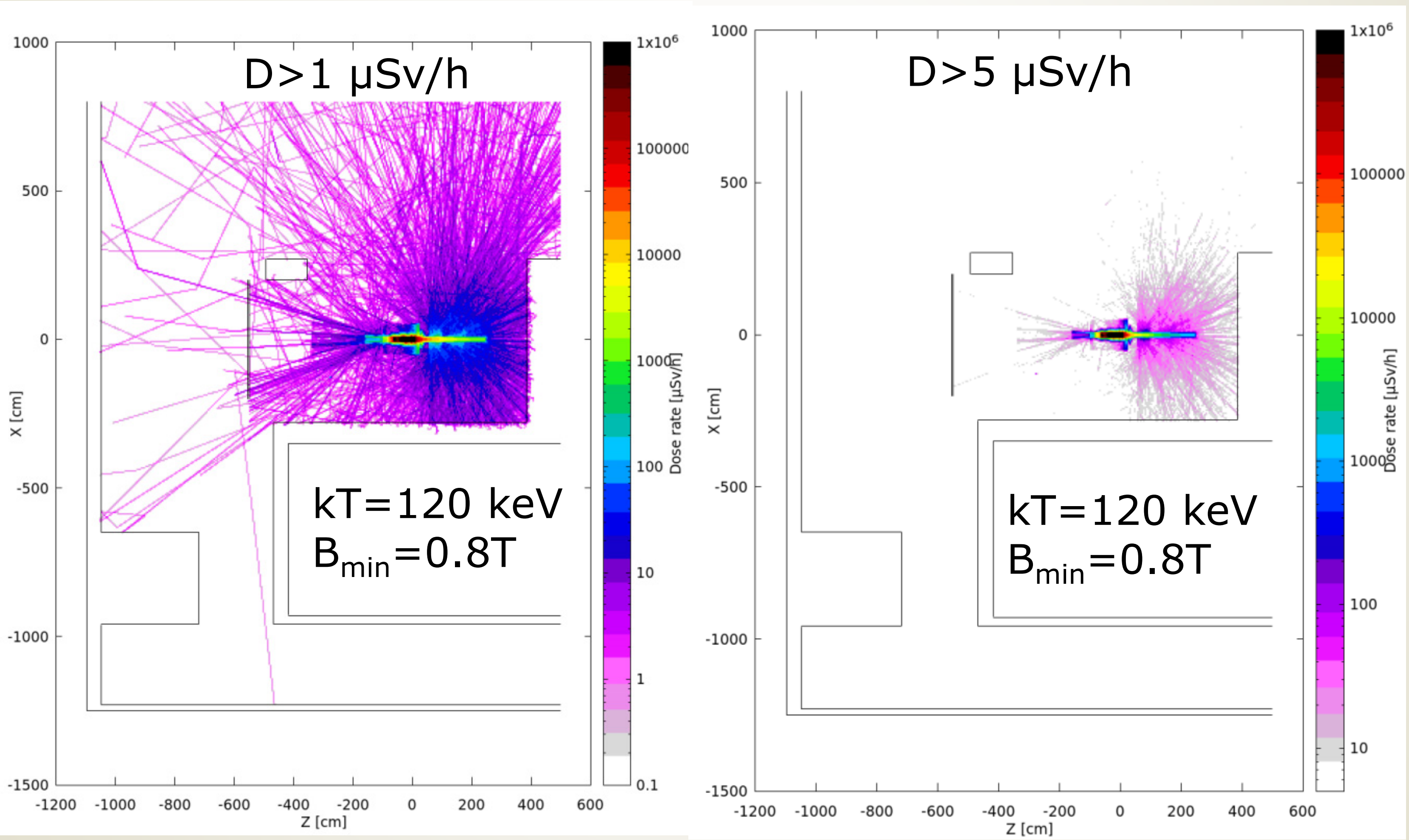
- Stopping efficiently the x-rays requires a general external 3 cm Pb thickness
  - Heavy and deemed un-practical for source maintenance
- Investigation of compact screens located inside the source to try to reduce the shilding system complexity outside
  - Mechanical Feasibility under investigation





Dose After Shielding per kW of e^-

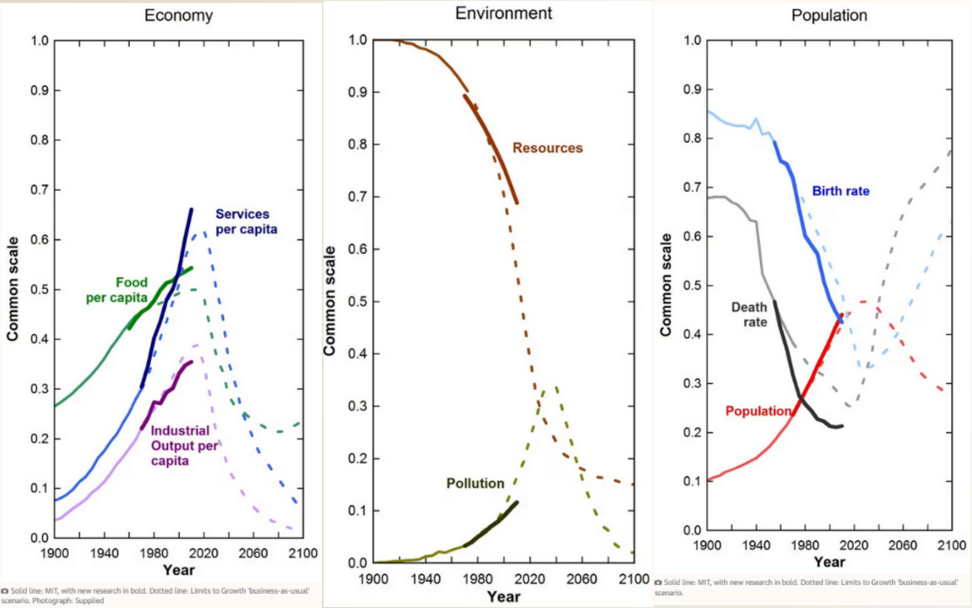
- Max Dose accepted by the safety 7.5 μSv/h

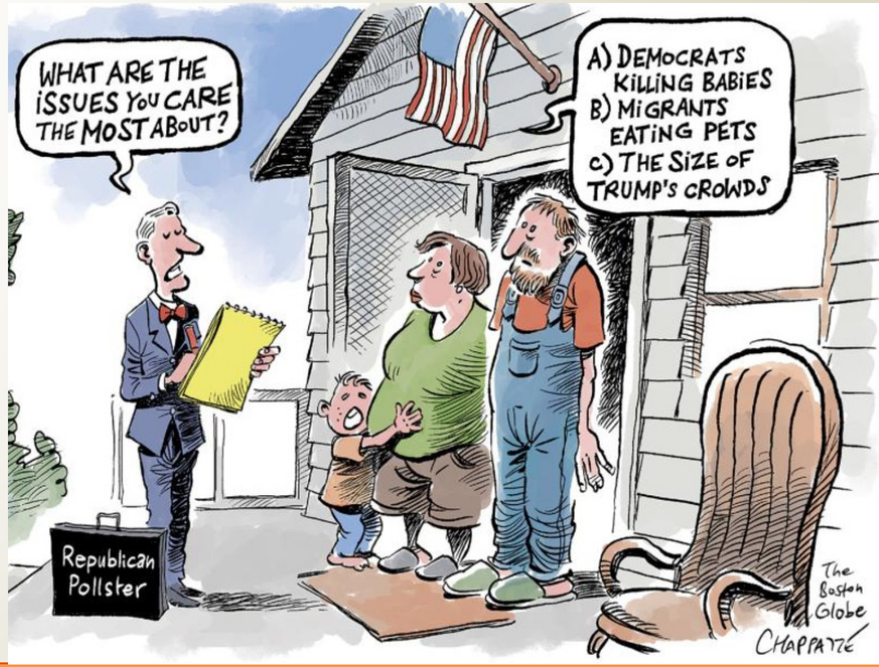


Conclusions

- Different EEDF temperature at different plasma chamber walls
  - EEDF Temperature Higher when local B is lower
  - EEDF temperature Lower when local B is higher
- High Angle of incidence of electron on the walls
- Increase Bmin favors e- losses to the extraction and axial x-ray emision
- Many electrons are bouncing
- The radial x-rays are fully stopped in the cryostat and the source yoke
- At T=120 keV, the dose without shielding is > 1 mSv/h /kW of e^- at 5 m
- Adding shields inside the source allows to significantly reduce the need for shielding outside
- 3 cm Pb as minimum required outside the source if no internal shielding is installed

THANK YOU FOR YOUR ATTENTION





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