Design of the 1 MeV D- SINGAP accelerator for ITER neutral beam injection

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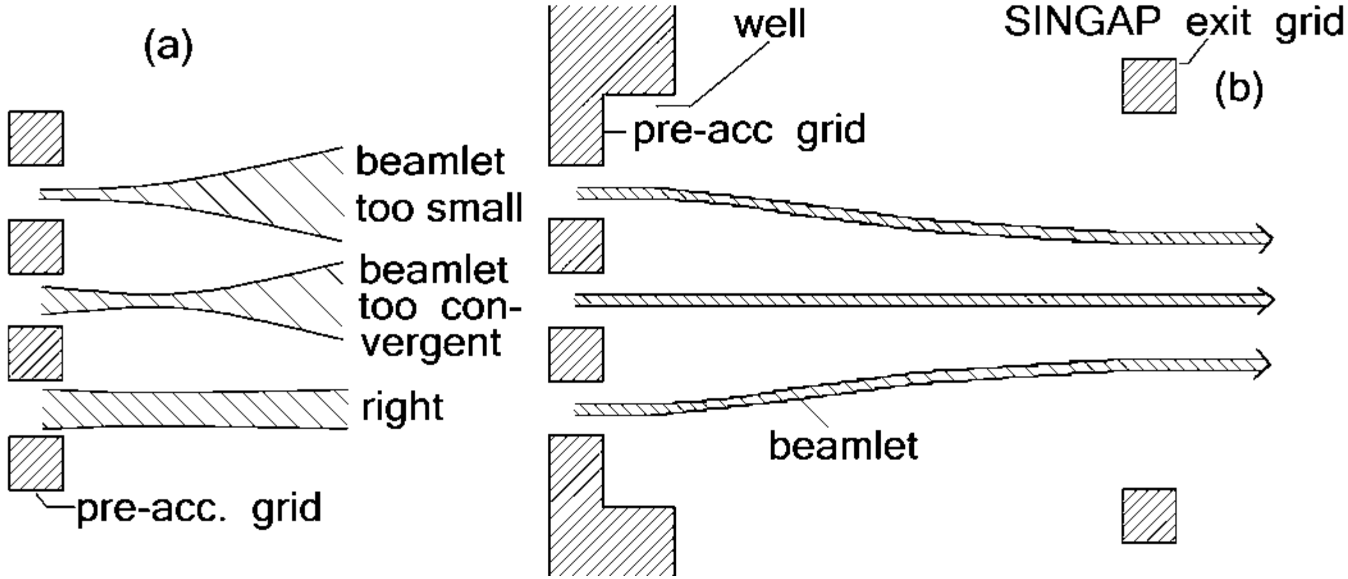
Introduction

- The SINGAP accelerator design for ITER has been reviewed and improved.
  - Running larger models allowed problems in the old design from 2001 to be identified and corrected.
- The design now includes the following new features:
  - Beam steering is provided by the shape of the post-acceleration grid, which is now slightly V-shaped.
  - By moving the post-acceleration grid vertically, the beams can be steered between on-axis and off-axis heating.
- A problem has been identified with electrons producing high power on the neutraliser.

- The talk will detail the design, discuss the expected beam optics and the stripped electrons.

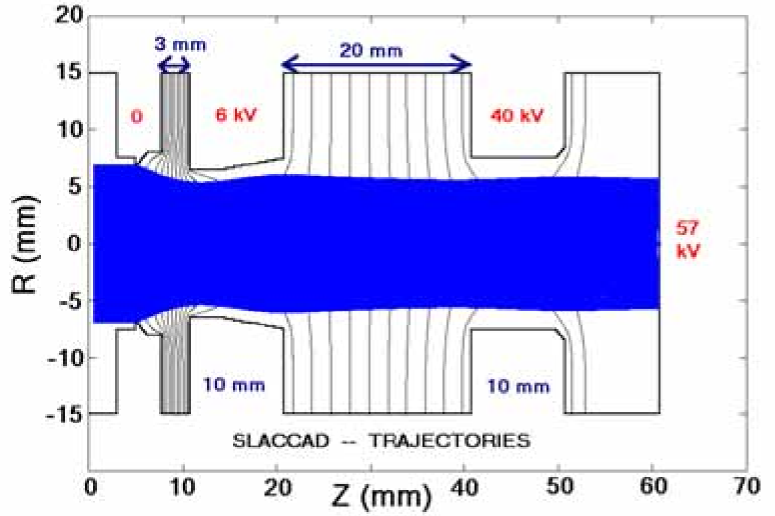
SINGAP beam optics in a nutshell

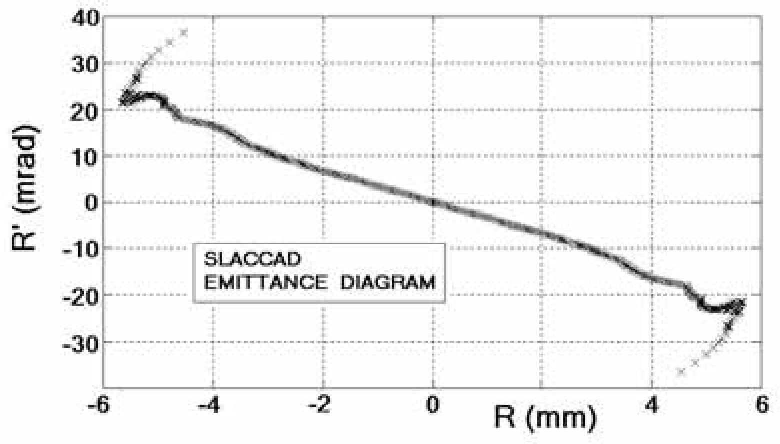


- The beamlets must leave the pre-accelerator ***convergent*** and with a ***large diameter*** (a) to keep the internal space charge forces low. When they leave the post-accelerator they must be nearly ***parallel*** (b).

- The 16 beam groups must also have the correct alignment.

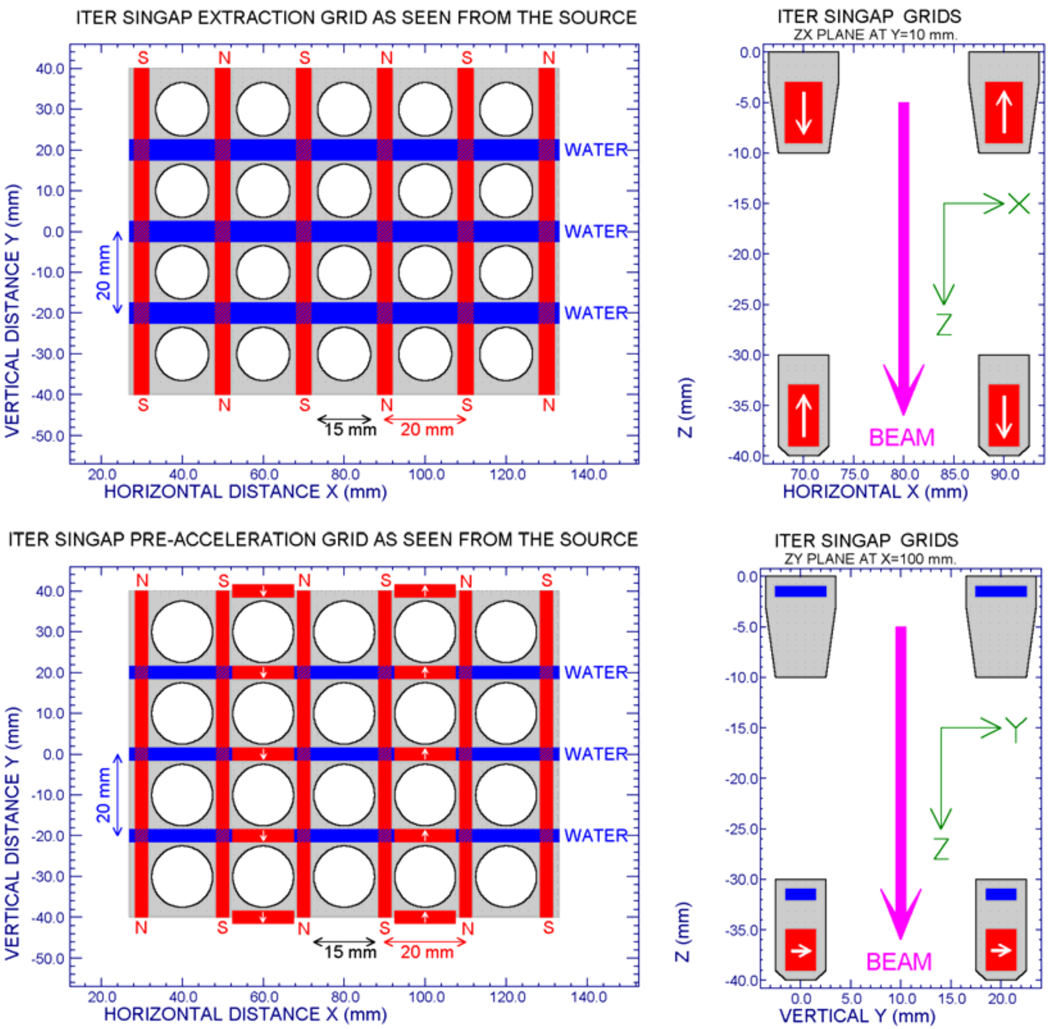
Converging Beamlets from pre-accelerator





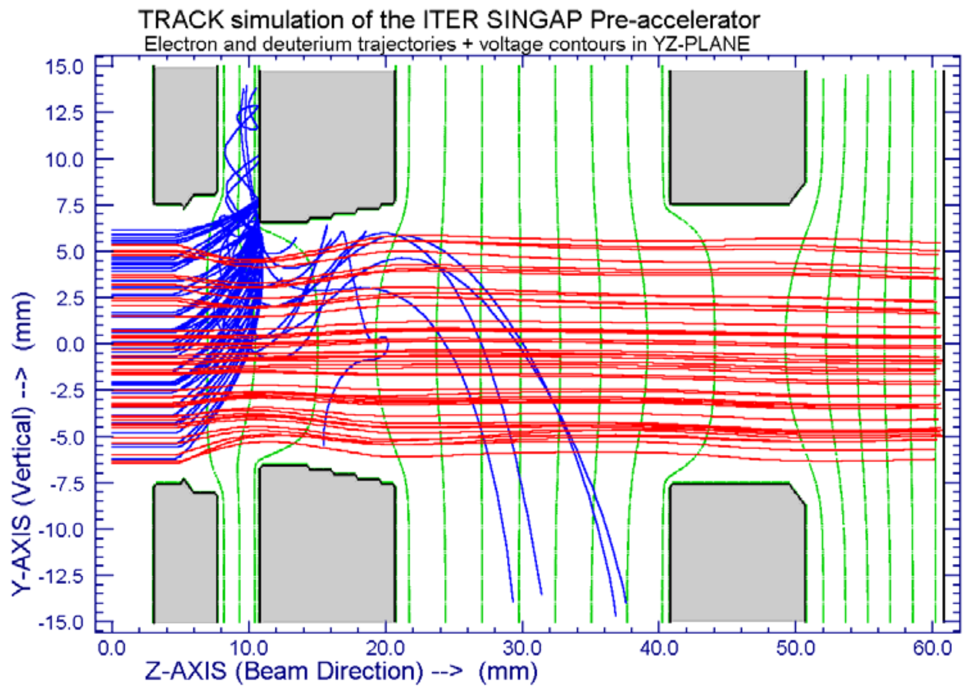
- SLACCAD simulation: 26 mA/cm^2 D$^-$ extracted
  - gaps are 3 and 20 mm,
  - Voltages are 6 kV and 40 kV,
- Stripping losses included
- pre-accelerated beamlet:
  - beamlet diameter 11.4 mm, converging by 1.3 degrees.
- Using PBGUNS: need 7 kV extraction voltage.

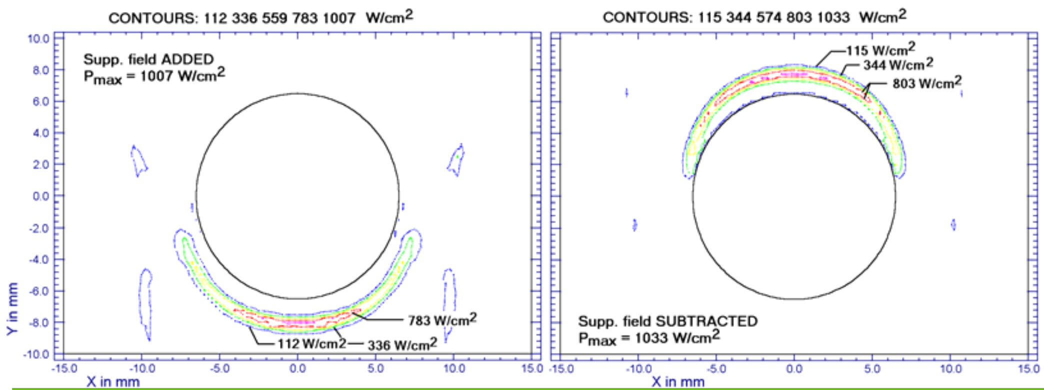
Extraction and pre-acceleration grids



- Water cooling.
- Magnets to deflect electrons to the grid surface.
- Extraction and pre-acceleration grid have opposite magnet polarities.
- steering magnets in pre-acceleration grid.

Electron and D⁻ trajectories



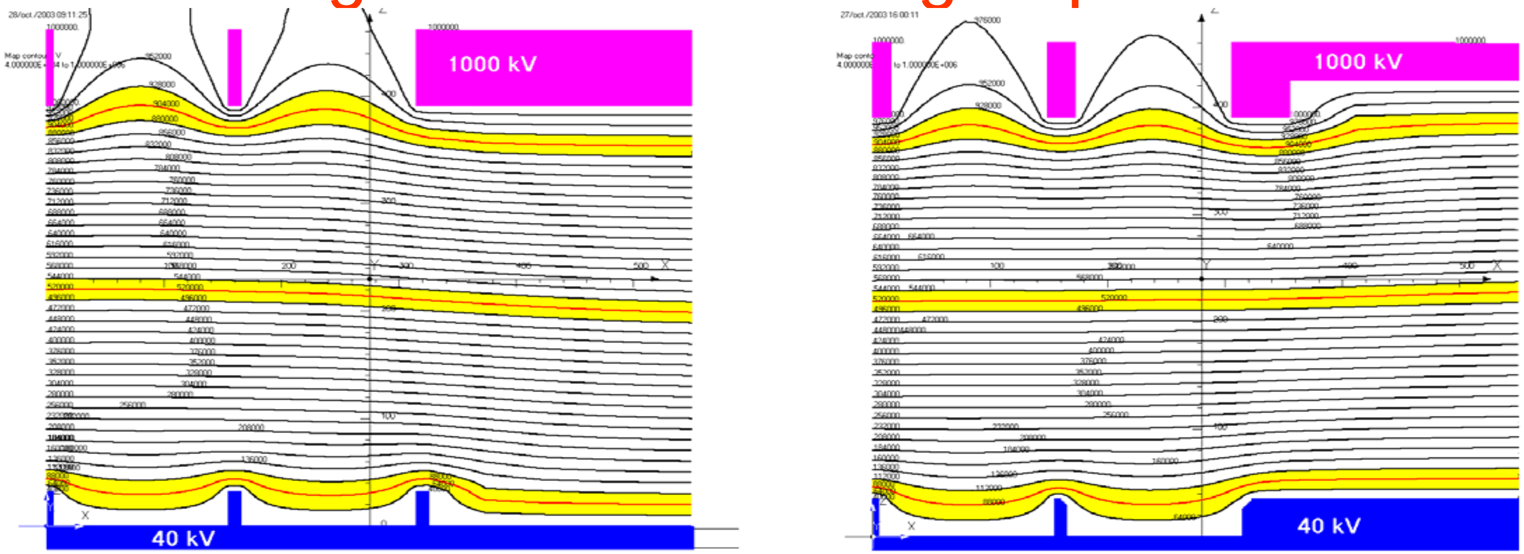


- Tracking of e^-, D^-
- included suppresion and filter fields
- 4% e^- leakage beyond extr. grid.
- 0.02% e^- leakage beyond pre-acc. grid.

- Very peaked e^- power density on extraction grid.
- Pmax=1000 W/cm^2.
- Pmax= 600 W/cm^2 if averaged over 1 mm^2.

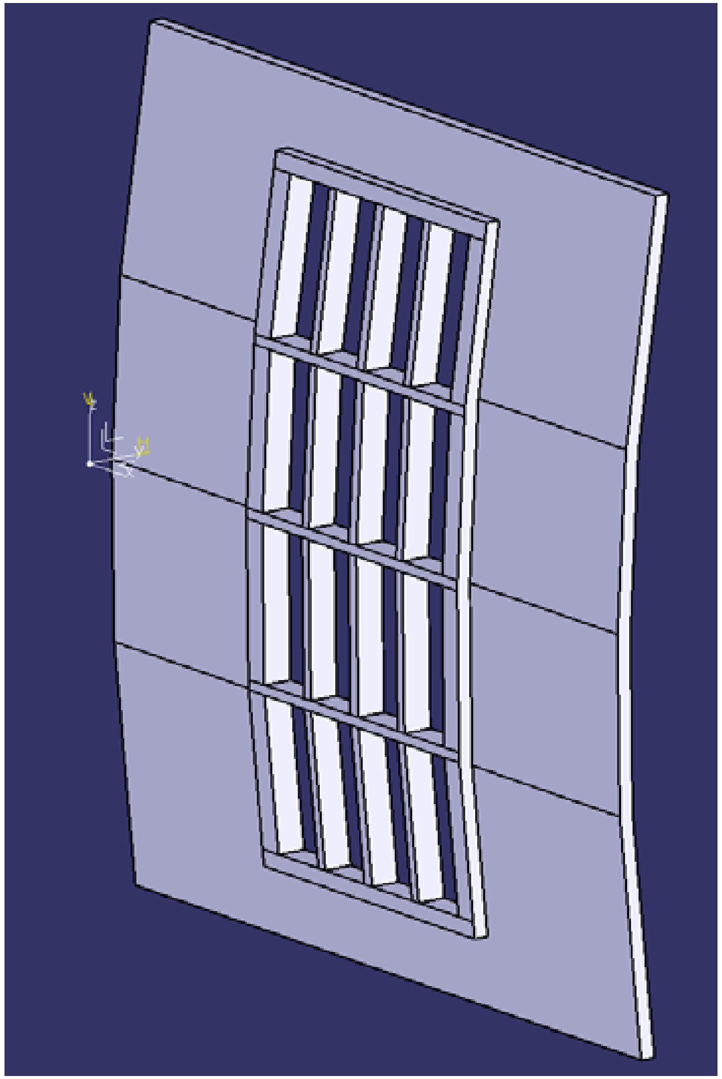
- RFX is calculating how well the grid can take this

New design deflects beam groups inwards



- Horizontal section of the previous and the new SINGAP design.
  - ➢ The old design deflected entire beam groups outwards.
  - ➢ The new design deflects entire beam groups inwards, which is desirable.
- This is due to:
  - ➢ Replacing pre-accelerator kerbs with wells,
  - ➢ Adding kerbs to the post-acceleration grid.

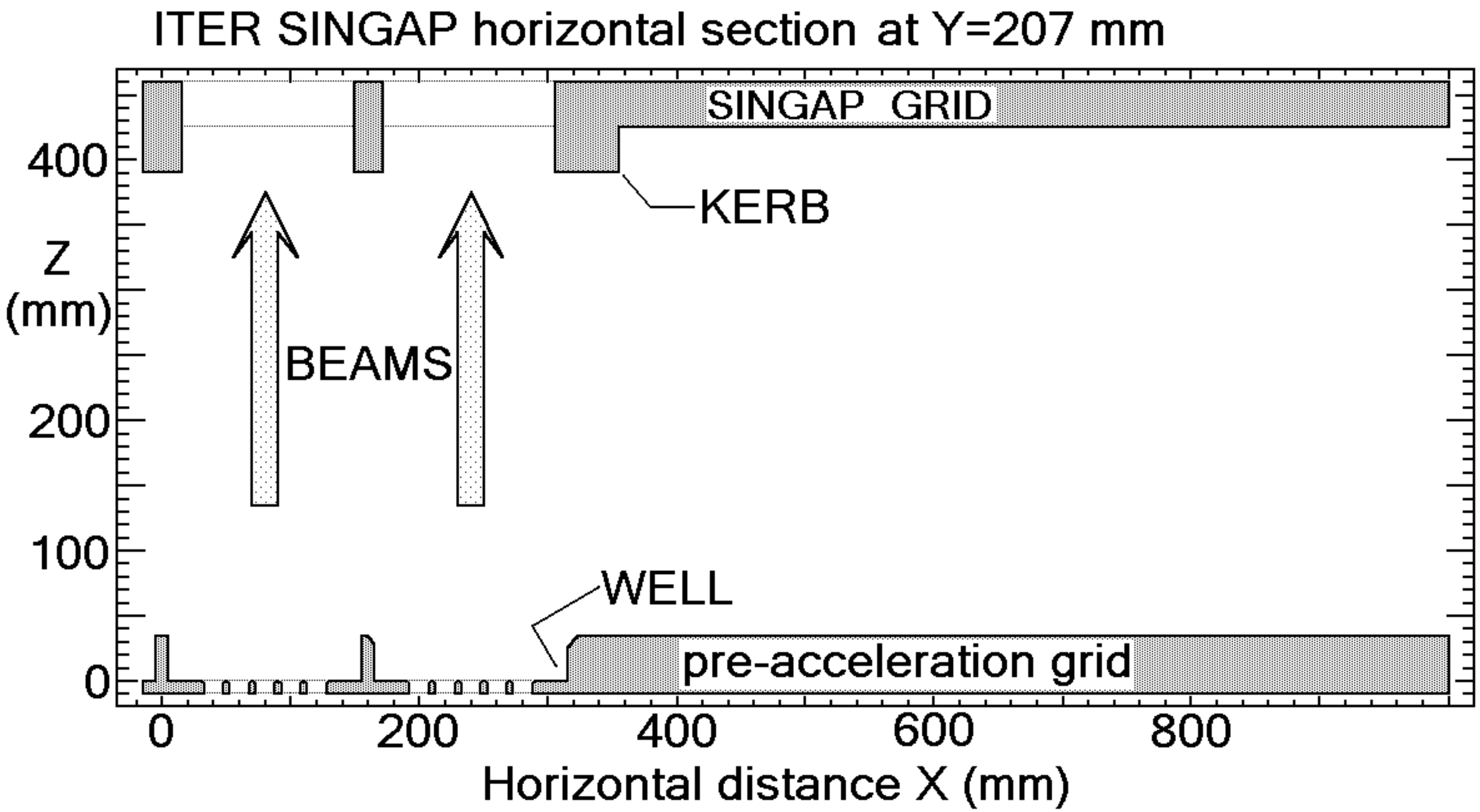
SINGAP: post-acceleration grid



- To provide vertical beam group steering, the SINGAP post-acceleration grid ("SINGAP grid") is "V"-shaped.
- View, looking down the beamline, on the "V"-shaped ITER-SINGAP grid.

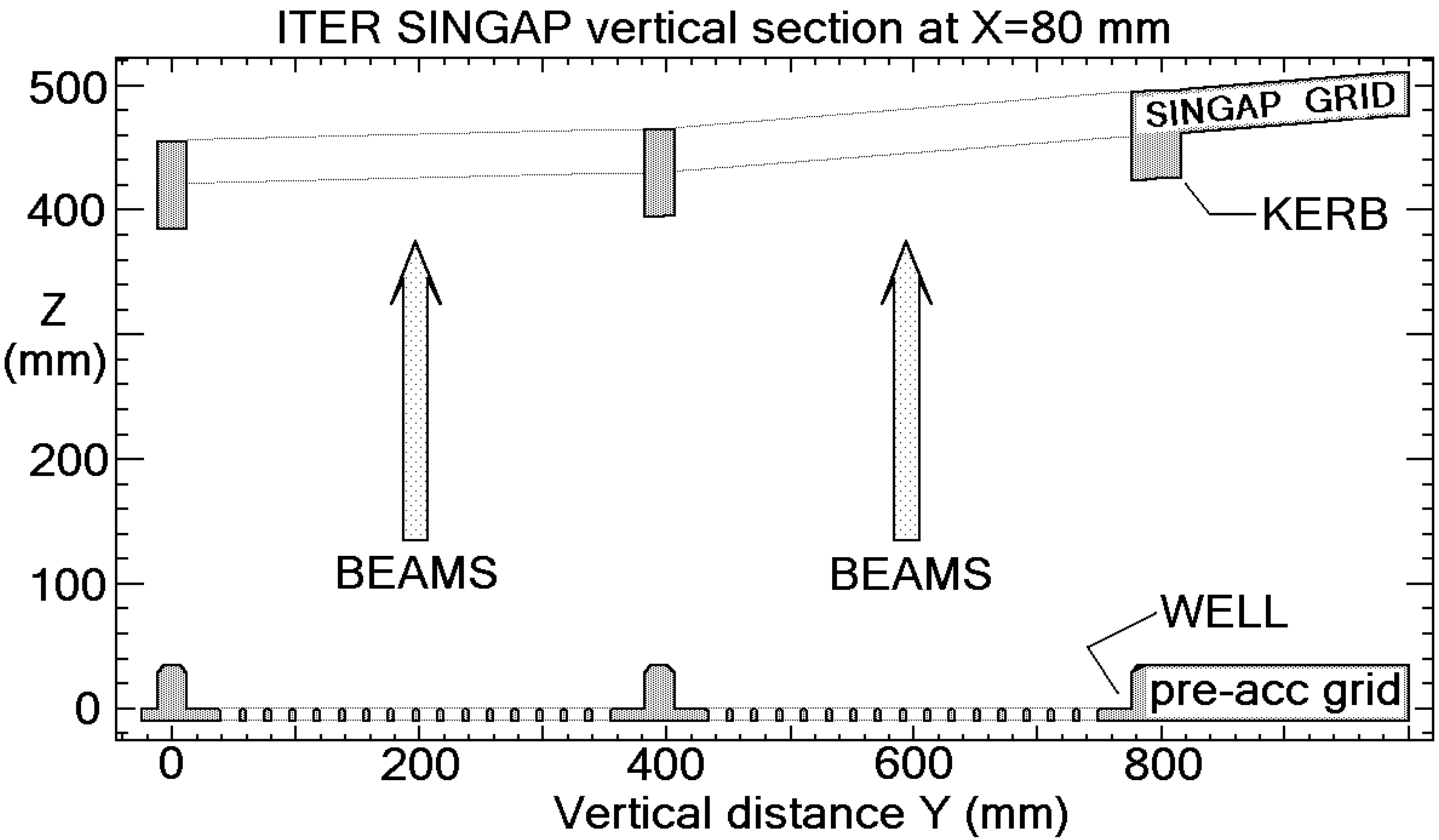
- Picture courtesy Consorzio RFX.

SINGAP: horizontal section



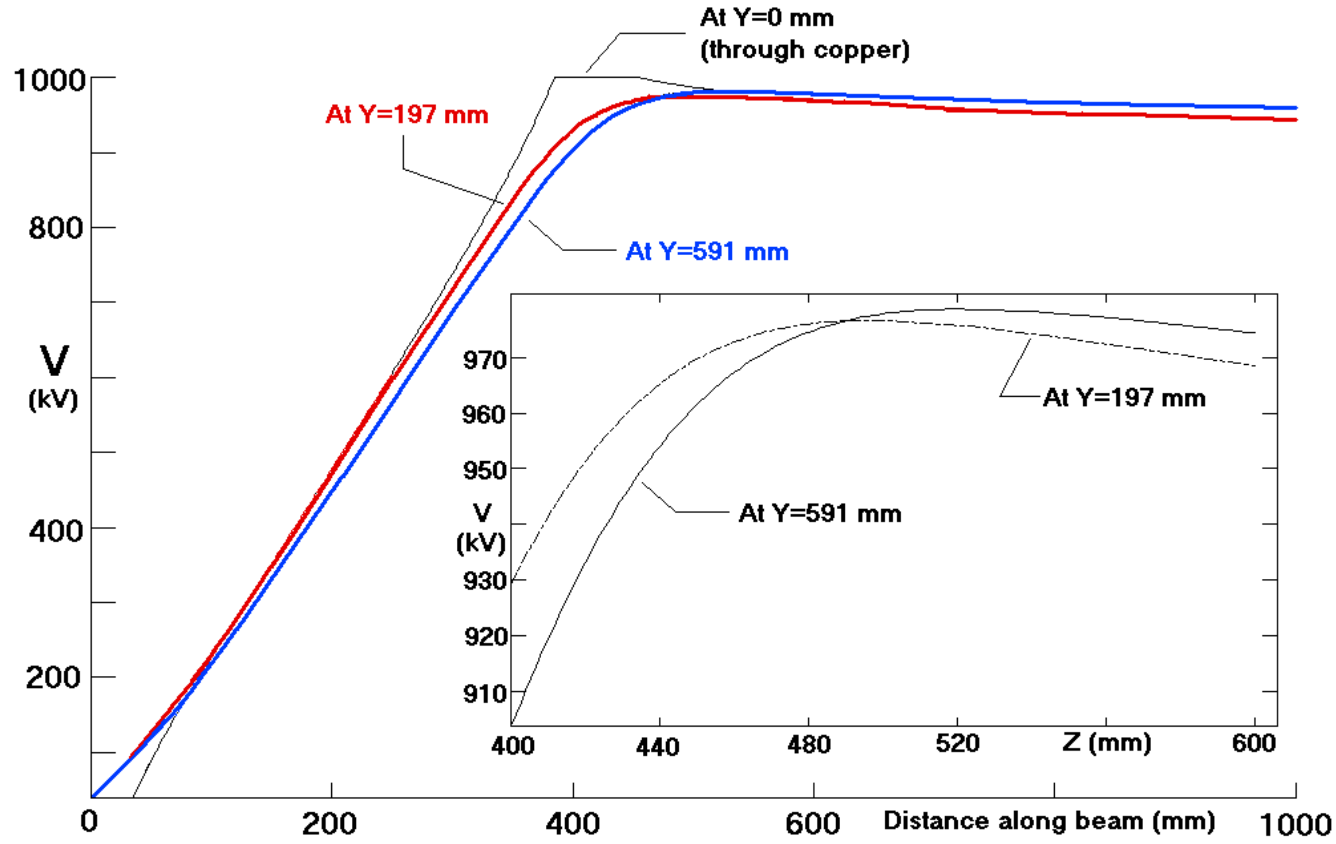
- Horizontal cross-section through the new SINGAP post-accelerator taken at Y=207 mm above the accelerator midplane.

SINGAP: vertical section



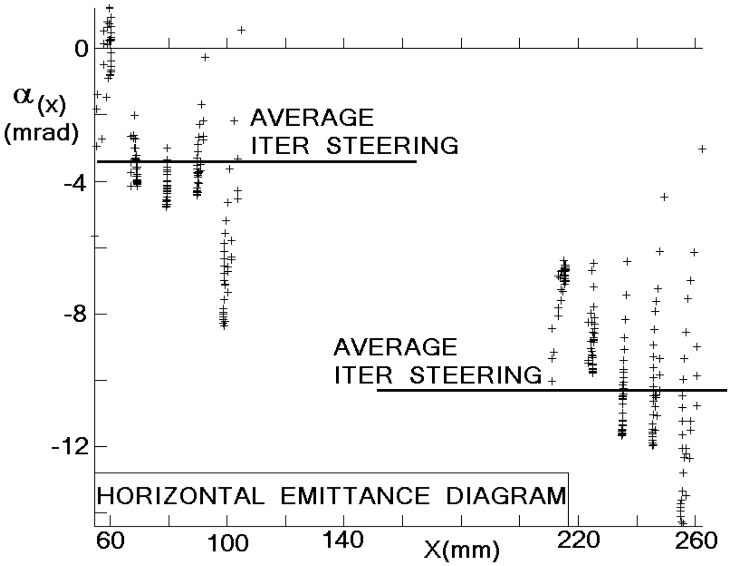
• Vertical cross-section through the new SINGAP post-accelerator taken at X=80 mm from the accelerator midplane.

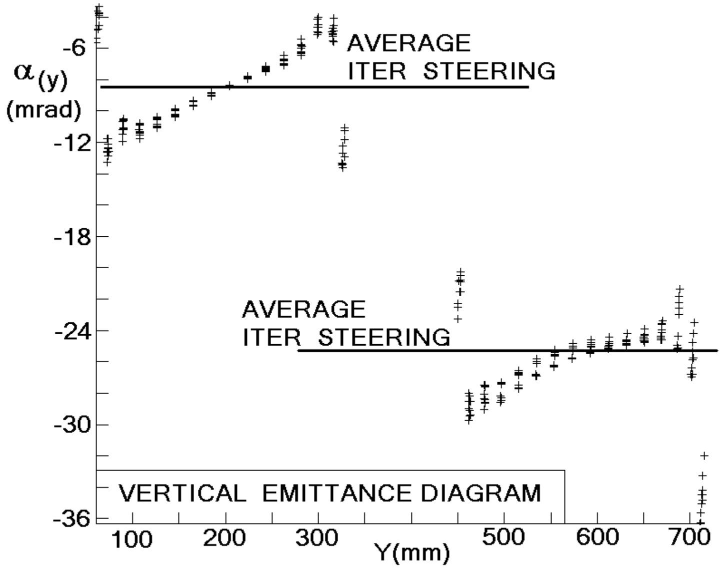
SINGAP accelerator potential



- Through the middle of two beam groups, Y=197 mm and Y=591 mm.
- Space charge compensation assumed to start at maximum V.

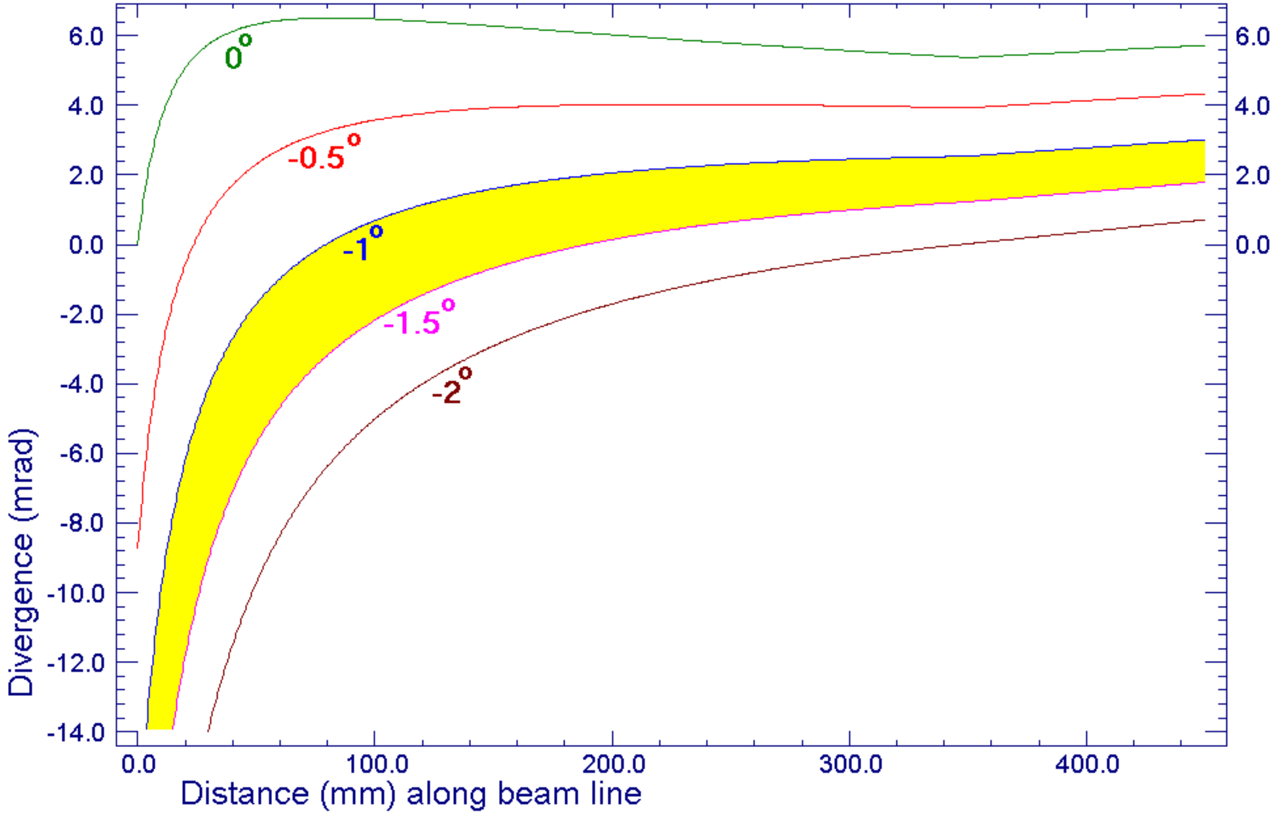
SINGAP beamlet steering





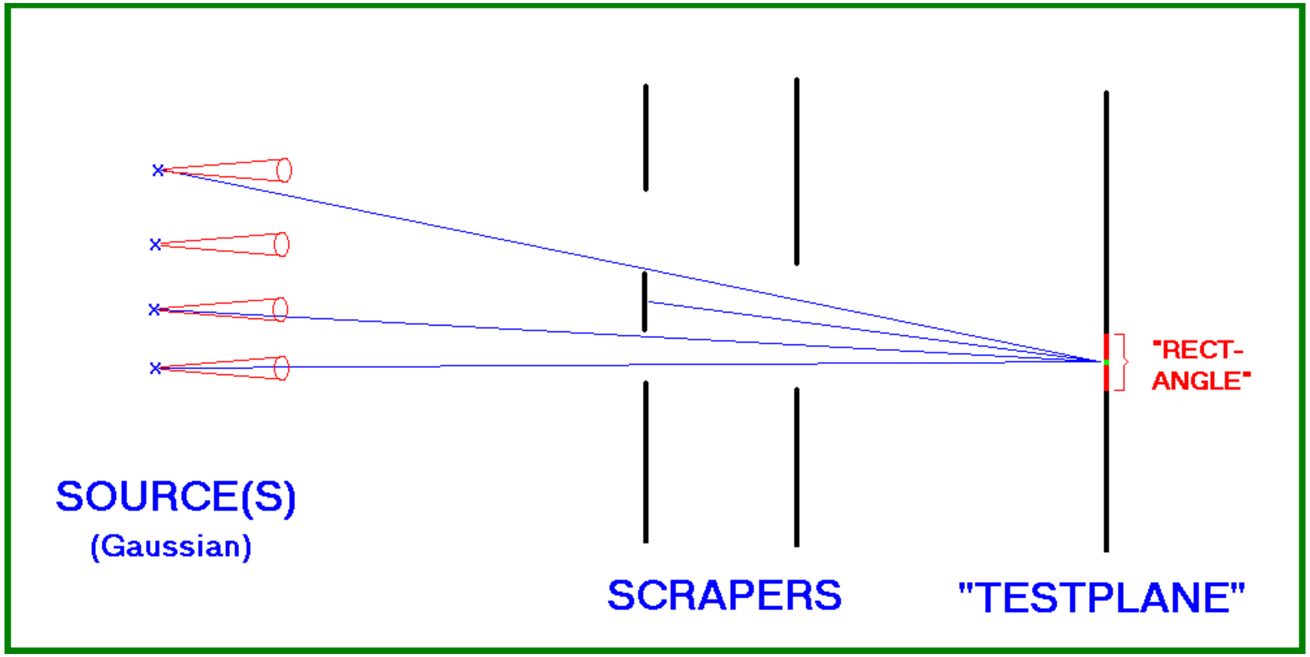
- ¼ of the system.
- The required beam group steering for ITER is indicated.
- Each point represents position and direction of 1 beamlet.
  - ➢ Note the horizontal convergence of beamlets in one beam group.

SINGAP divergence for ∅11.4 mm beamlets



- Acceleration of converging beamlets through the SINGAP accelerator
- Semi analytical calculation gives ~2.5 mrad (yellow band)
- SCALA calculates in the range 2.0 - 3.5 mrad.

Beam Transmission to ITER



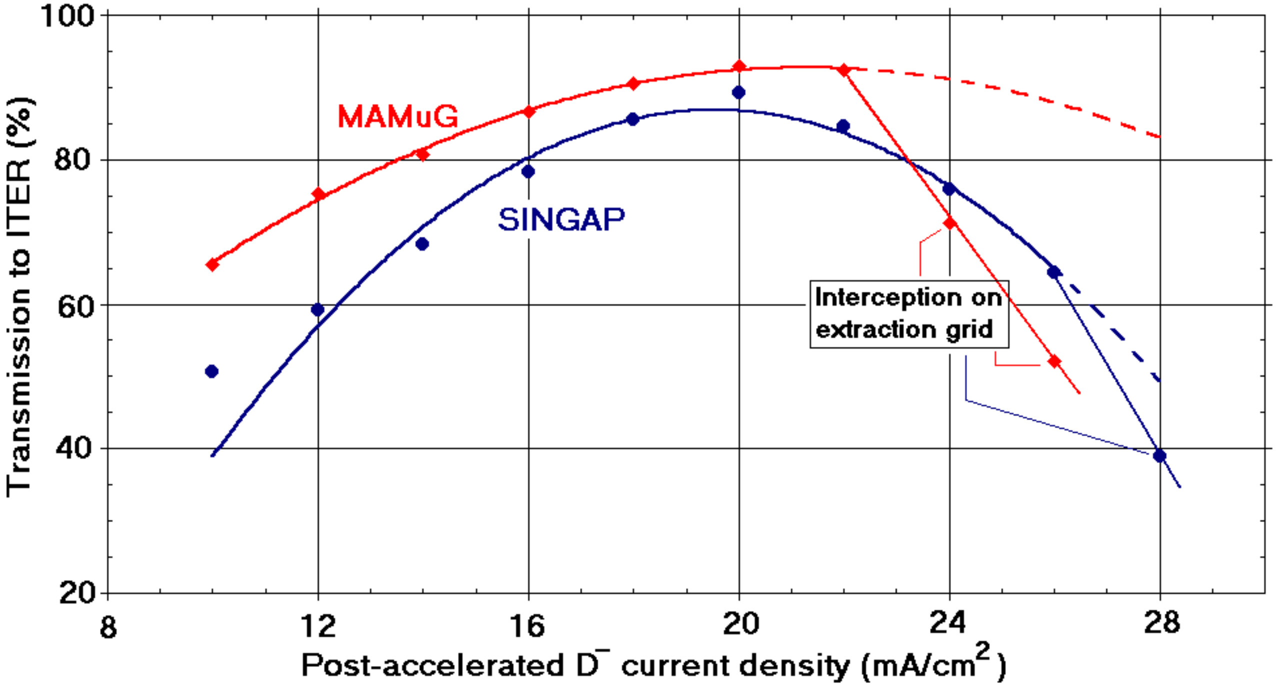
- Assuming Gaussian beamlets, TRANSMIT calculates for 1280 beamlets how much power is seen on each rectangle of a testplane.
- Scrapers intercept power by blocking the view on some beamlets.

"Realistic" beams

- Because a calculation is always idealised in some way (finite ion temperature, machining tolerances, thermal expansion, lateral pressure gradient, source non-uniformity, etc. are not included), the real divergence is likely to be worse than calculated.
- Therefore we introduce "**realistic beams**":
  - The calculated divergence is increased by 2 mrad,
  - A random divergence between 0 and 1 mrad is added,
  - A random direction between –1 and 1 mrad is added.

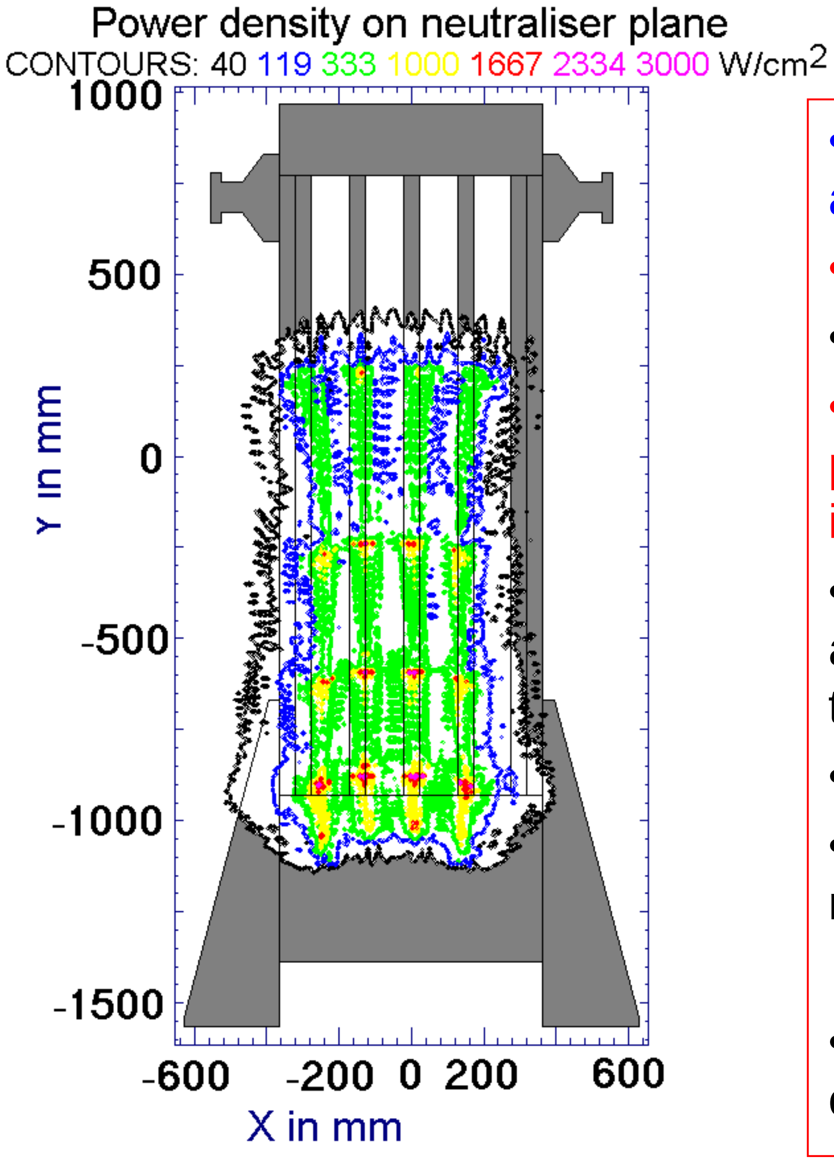
- For both SINGAP and MAMuG we take a calculated 3 mrad divergence at optimum perveance.
- "realistic" beams then imply an optimum divergence of ~5.5 mrad.

Transmission to ITER: SINGAP and MAMuG



- Variation of extracted D$^-$ current at 1 MeV.
- For MAMuG, all beam steering angles are assumed to remain fixed.
- For SINGAP they vary with the current.
- At high current interception on the extraction grid occurs.

Electrons to neutraliser



- Electrons from stripped D^- are accelerated up to 960 keV.
- Their power is 2.7 MW.
- Also 1.0 MW in stray neutrals.
- Additional backstreaming positives and electrons not included.
- The filter field from the source and stray field from ITER bends the electron trajectories.
- Their impact causes X-rays.
- Up to 3.3 kW/cm² locally on the neutraliser leading elements.
- RFX and UKAEA are calculating if all this is acceptable.

CONCLUSIONS

- The proposed SINGAP accelerator is based on the post-acceleration of pre-accelerated large-diameter converging beamlets. The geometry provides the correct steering of the beamlets.
- The post-acceleration grid is V-shaped in order to deliver vertical steering. It can be moved vertically to switch the beams between on-axis and off-axis.
- Extracted electrons are dumped on the extraction and pre-acceleration grids. The power density profile on the extraction grid is very peaked.
- Megawatts of stripped electrons are expected to be dumped on the neutraliser; they must be dealt with appropriately.
- Consorzio RFX and UKAEA are calculating the consequences of the power deposited by the electrons.