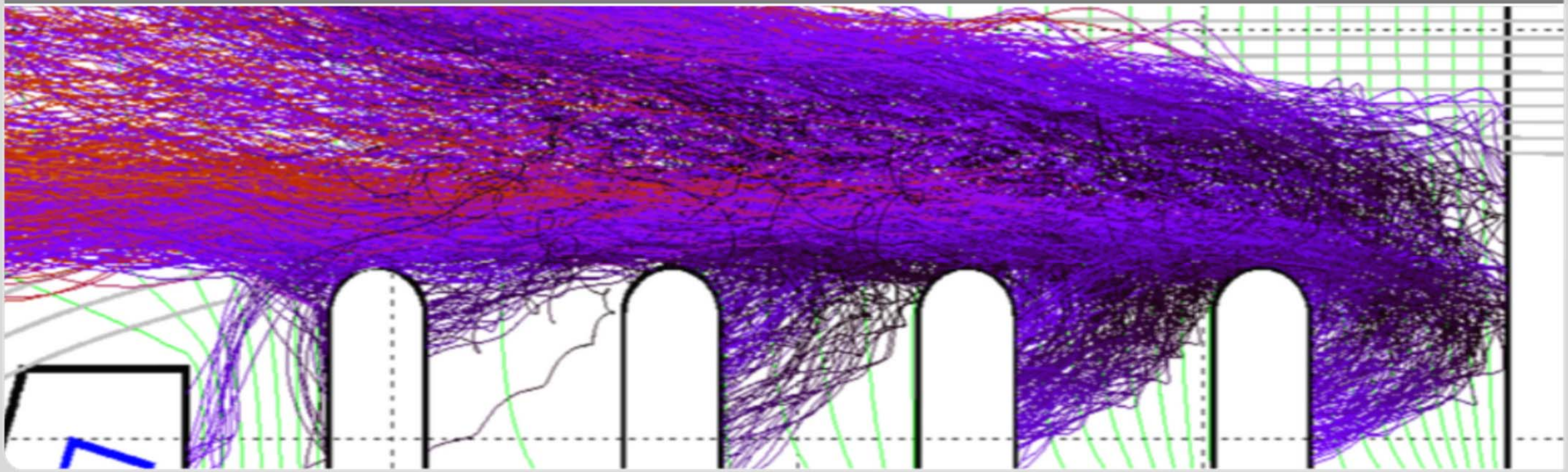
Karlsruhe Institute of Technology

The 6th International Vacuum Electronics Workshop 2018,
Bad Honnef (DE), September 2018

Multistage Collector Design Based on E×B Drift Concept for High Power Gyrotrons

Benjamin Ell, Ioannis Gr. Pagonakis, Chuanren Wu, and John Jelonnek

Institute for Pulsed Power and Microwave Technology



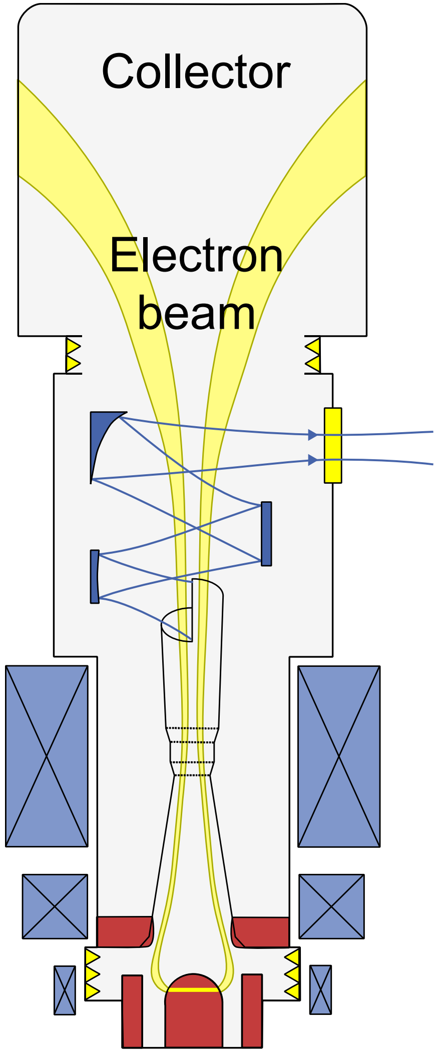
Contents

Introduction – Gyrotrons for Fusion

- ITER Gyrotrons (today)
  - 170GHz, 1MW, CW
  - Efficiency: $\eta_t \sim 50\ \%$
- DEMO Gyrotrons (future)
  - Up to 240 GHz, 2 MW, CW
  - Efficiency: $\eta_t > 60\ \%$

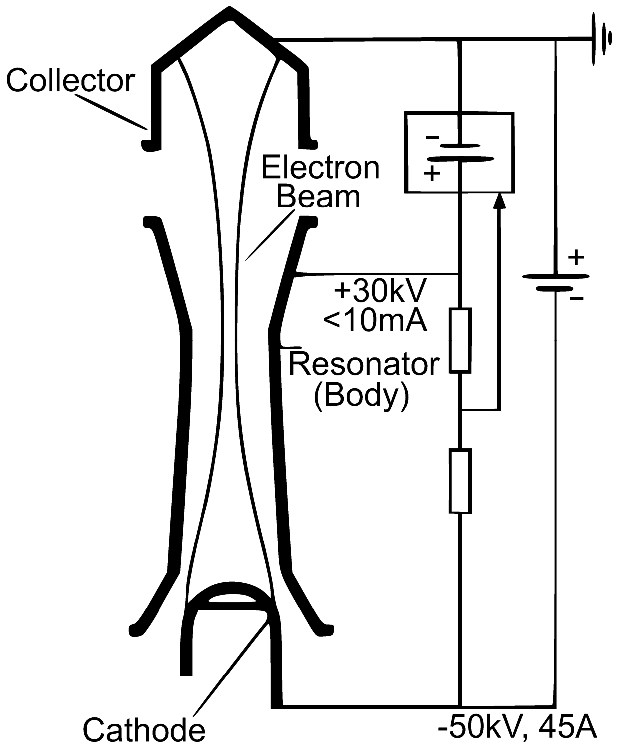
Multistage Depressed Collector (MDC) is required

Collector efficiency $\eta_c > 75\ \%$

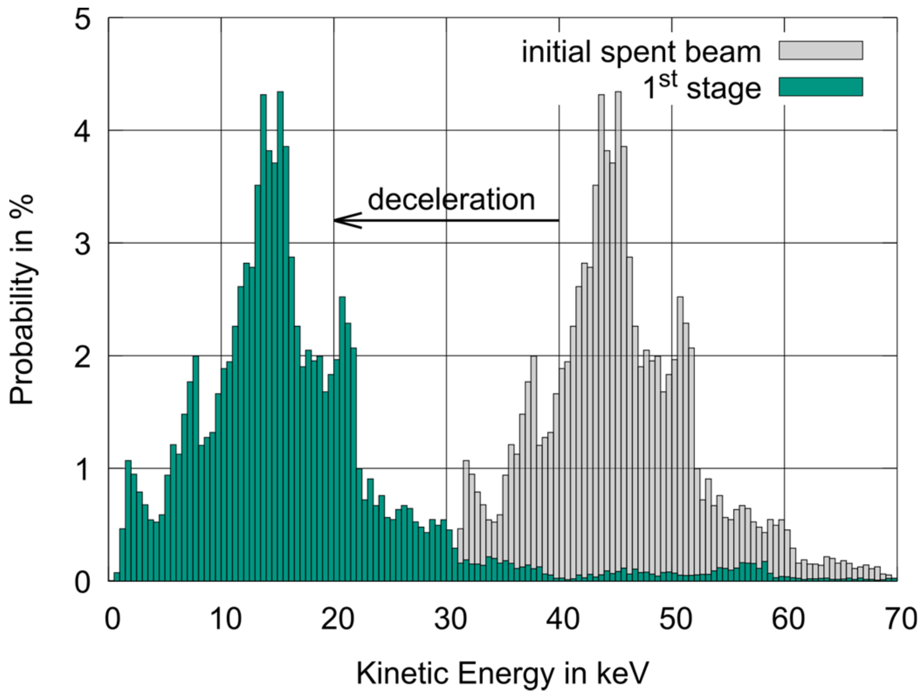


Introduction – Single-stage Collectors

- Energy recovery with an SDC is limited to the slowest electron
- Collector efficiency η_c ~ 60 %

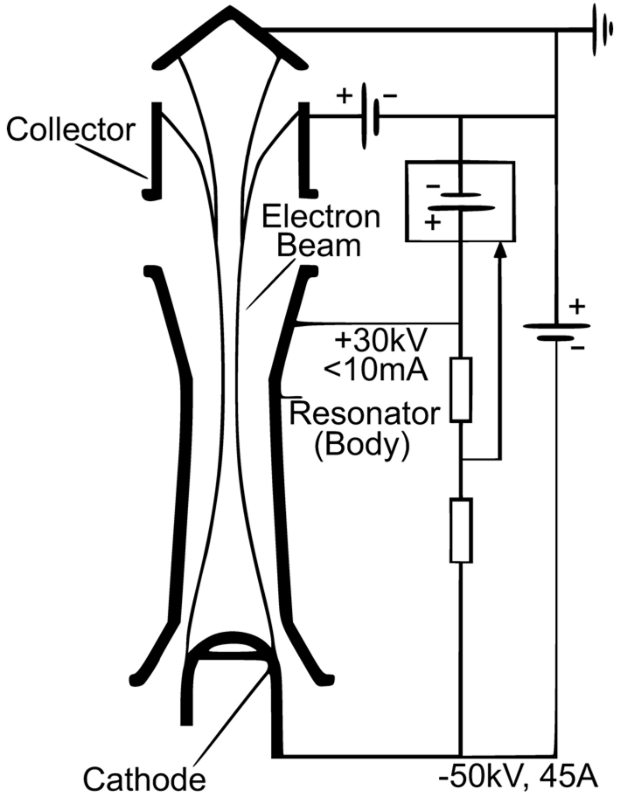


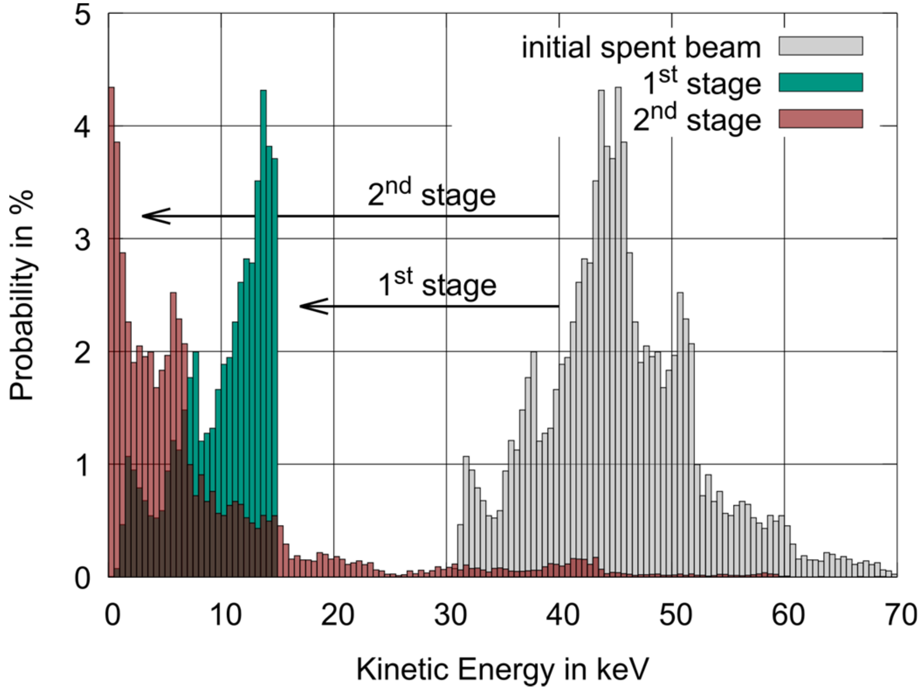
M. Thumm, Fusion Engineering and Design 2003



Introduction – Multistage Collector

- More efficient energy recovery with MDC





Introduction – MDC Principles

- MDC technology is used since many years ago in space TWT and Klystron devices increasing significant the efficiency
- In gyrotrons, the axis-symmetric hollow cylindrical electron beam is confined by a strong magnetic field
- Two concepts for the distribution of the gyrotron beam electrons on the electrodes have been proposed:

  ➡ **Axisymmetric concept**
  Singh et al., US Patent, Number 5,780,970, 1998

  ➡ **Non axisymmetric concept with E×B drift**
  Pagonakis et al., IEEE TPS, 2008

Introduction – MDC Principles

- No multi-stage collector has been build for gyrotron
- Separation due to E×B drift:

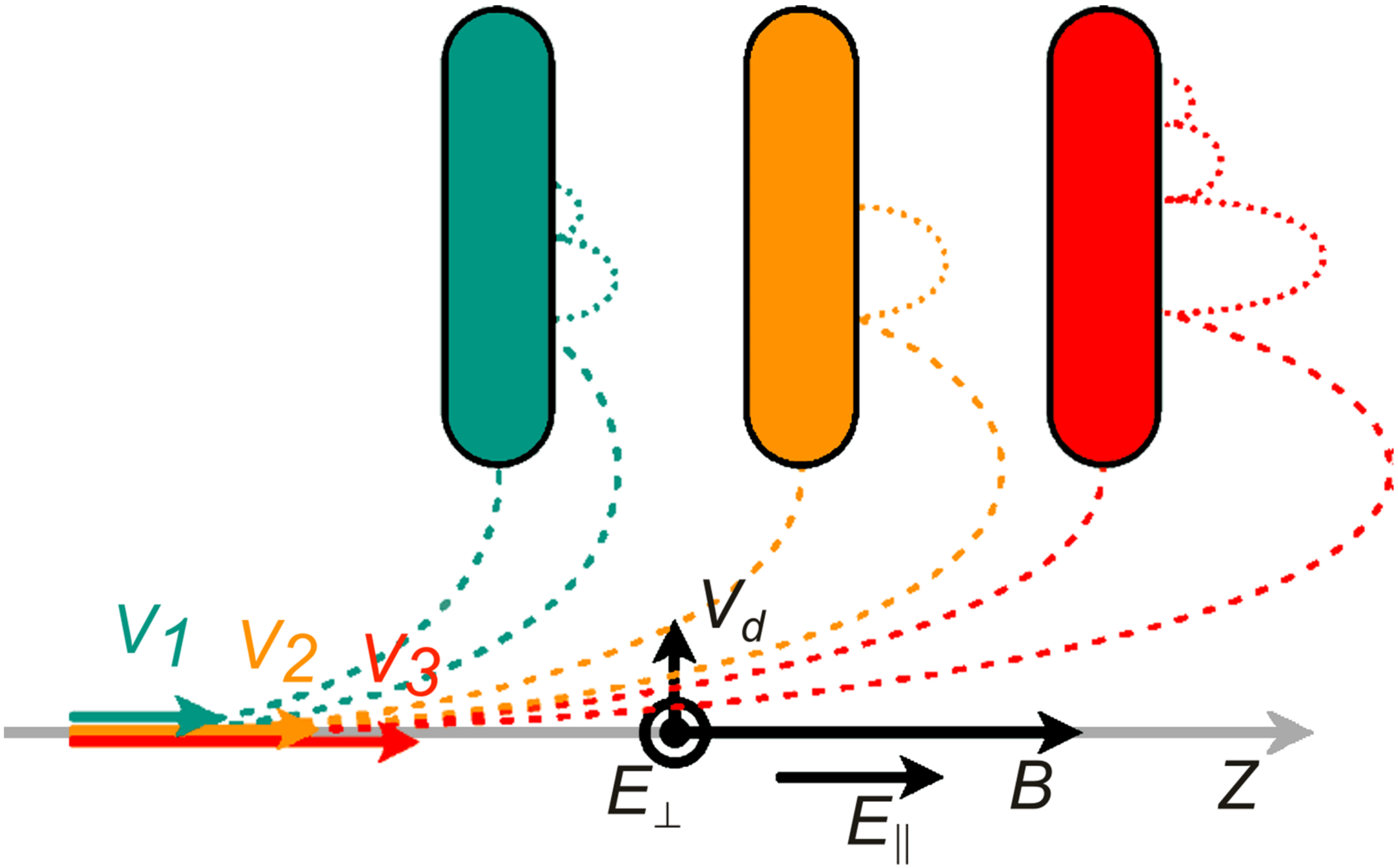
$$\overrightarrow{v_{dr}} = \frac{\vec{E} \times \vec{B}}{B^2}$$

- Trajectories dependent on the initial velocity

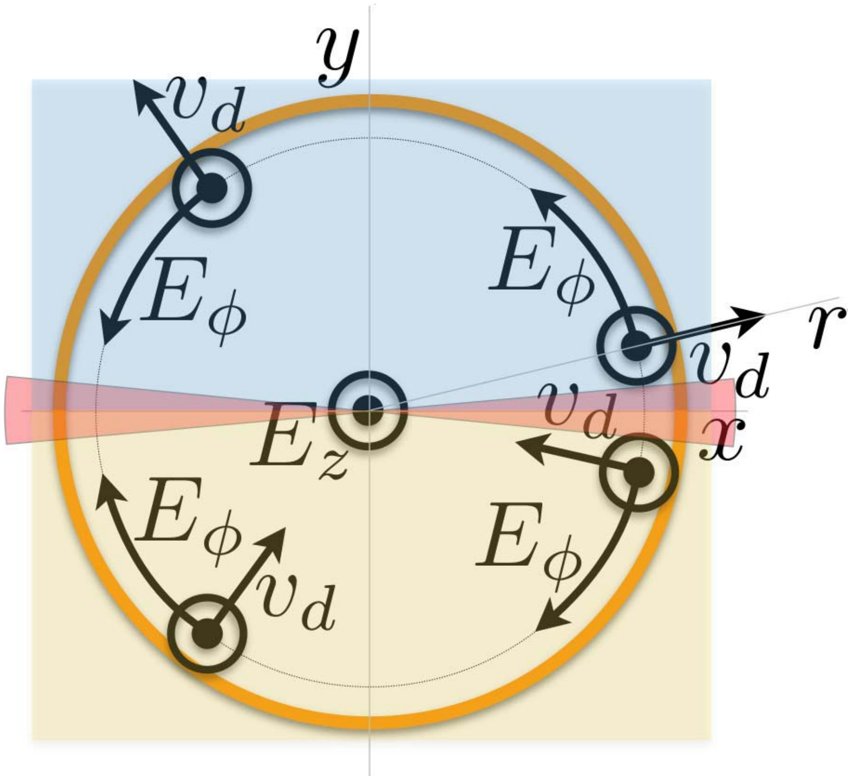
⇓

Electrons are collected according to their kinetic energy

E×B Concept

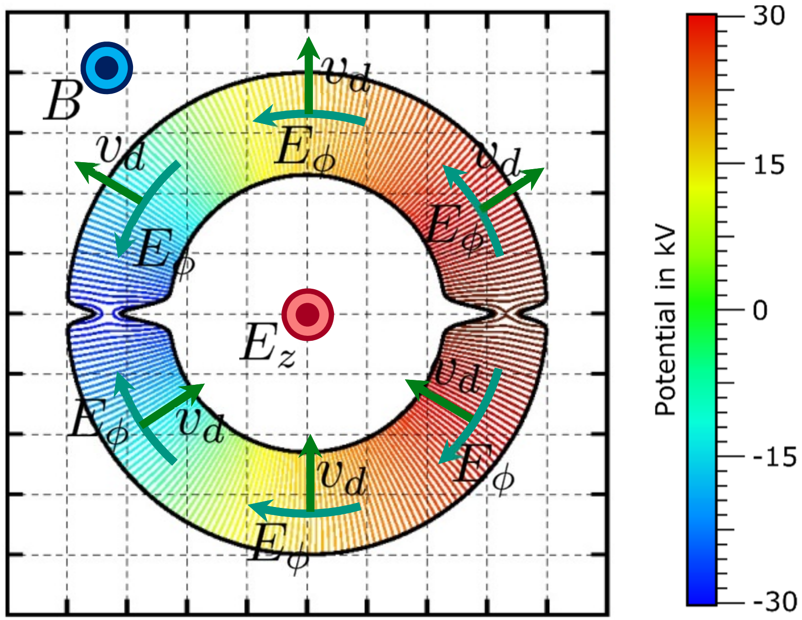


E×B Based on Azimuthal Electric Fields



- Non-axisymmetric field
- Faraday's law:

$$\oint_C \mathbf{E} \cdot d\mathbf{l} = -\int_S \cancel{\frac{\partial \mathbf{B}}{\partial t}} \cdot d\mathbf{S}$$

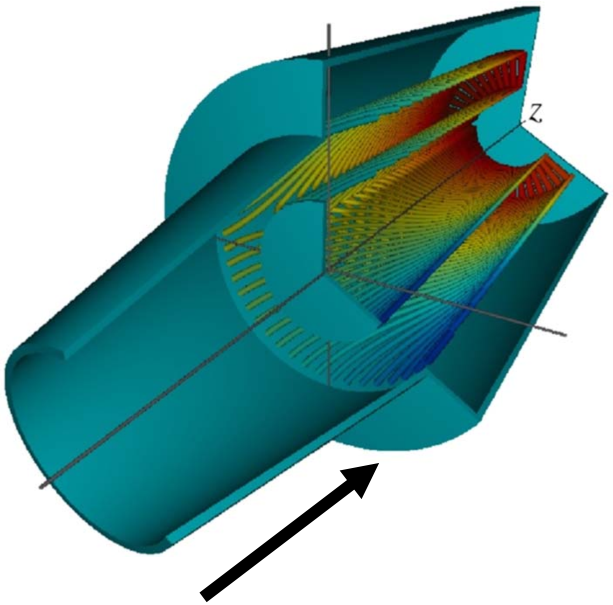


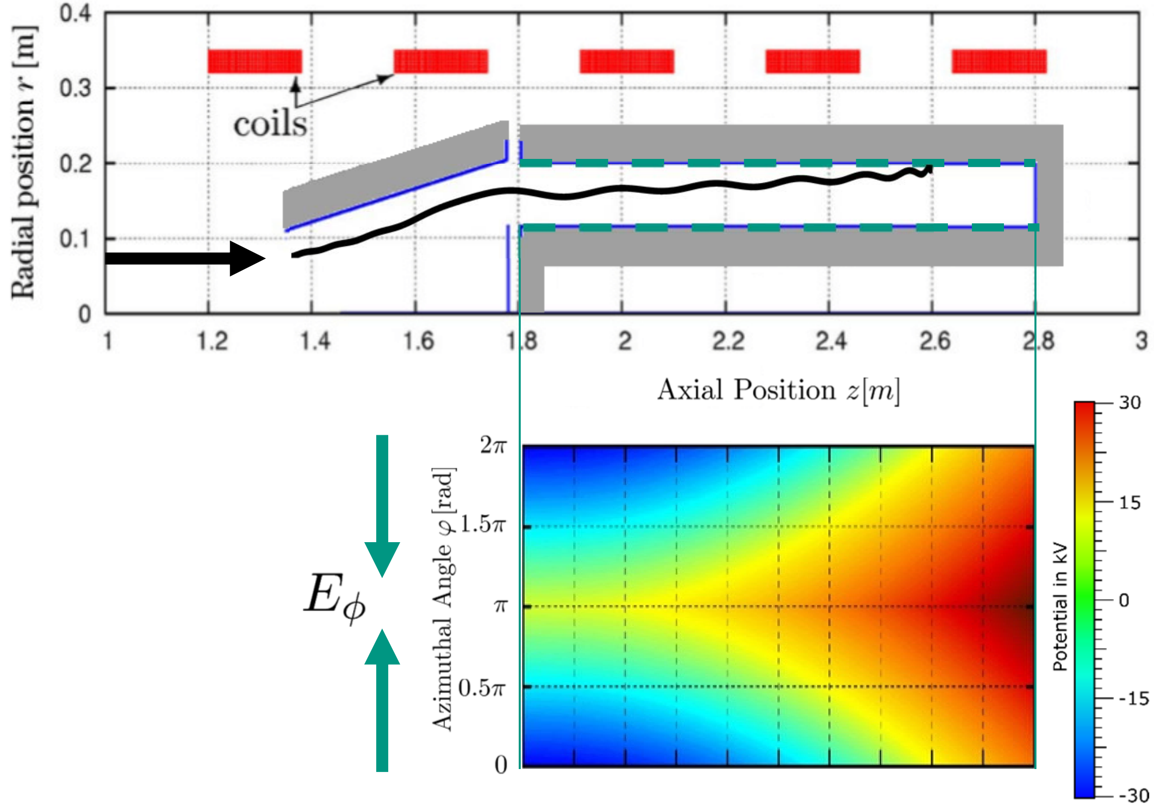
Pagonakis et al., IEEE TPS 2008

Geometry Definition

- A theoretical design was proposed in 2008
- Infinite number of electrodes
  - Fully 3-D code was not available

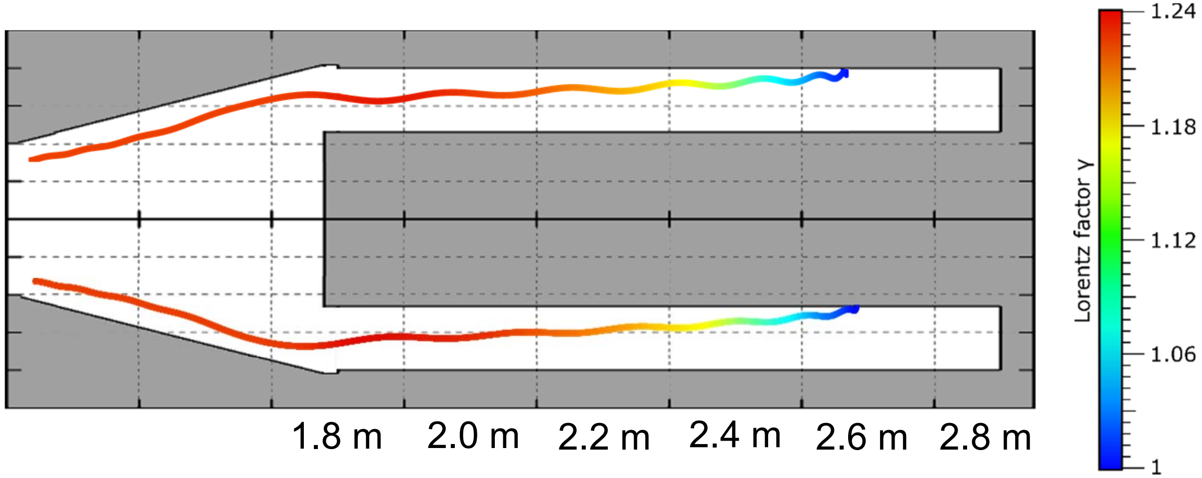
3-D representation

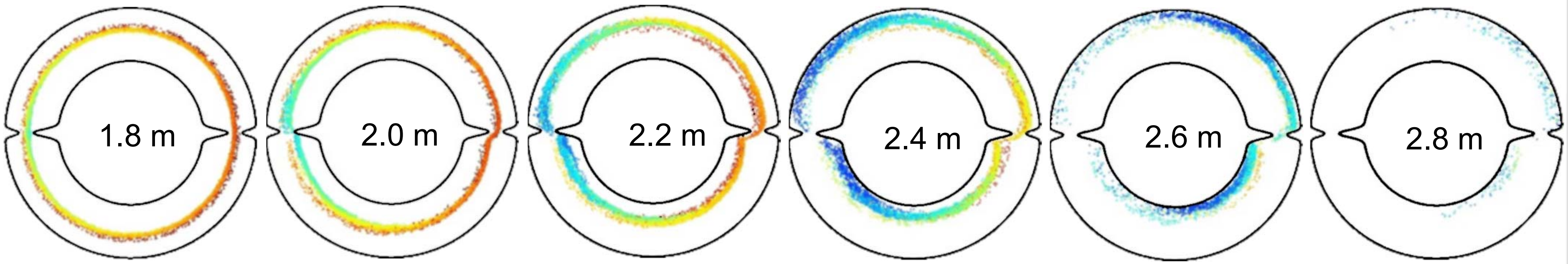




Trajectories of Electrons

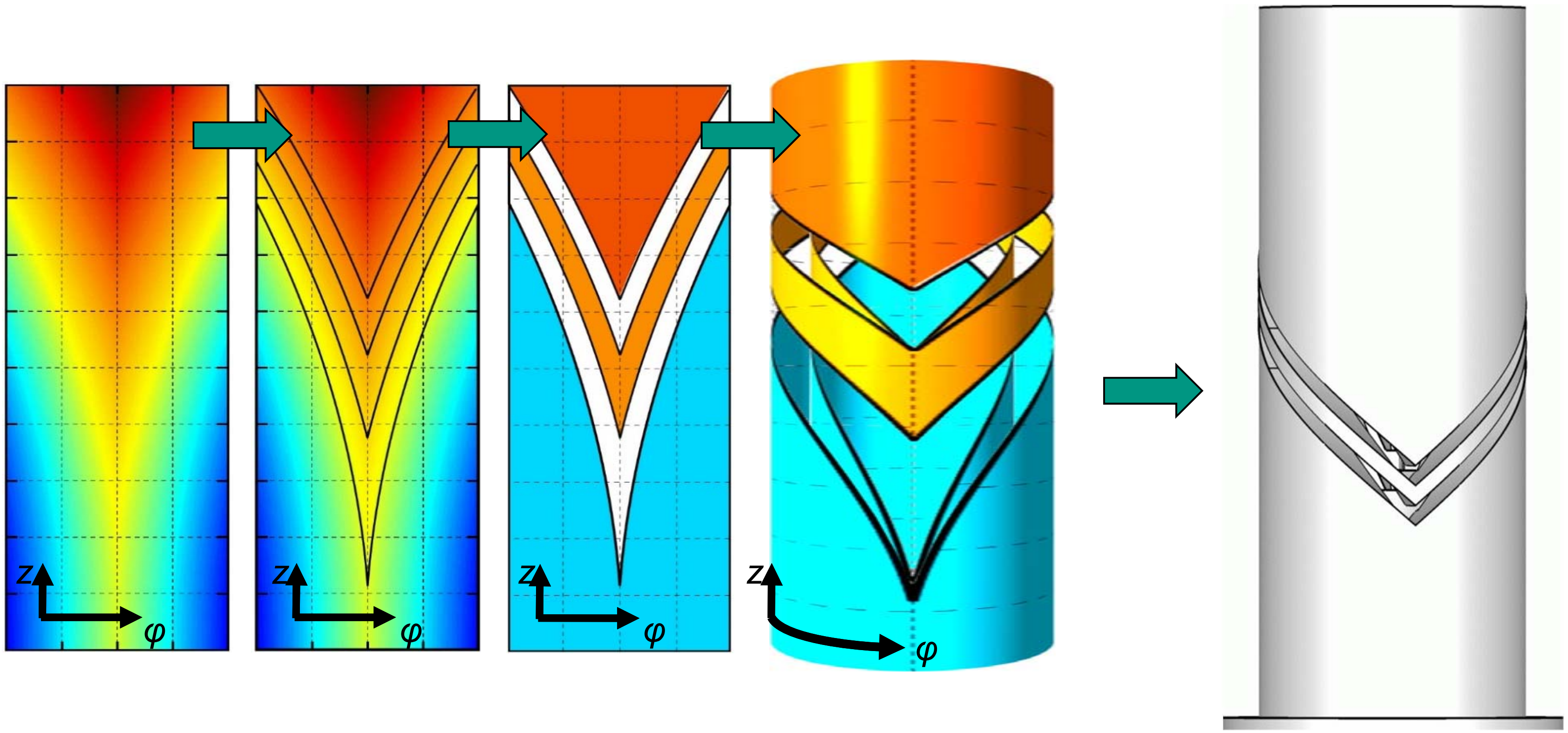
- 170 GHz, 2 MW, Coaxial Cavity Gyrotron
- η_c ~ 91 % (simulation)





From Infinite to Finite Number of Electrodes

- Towards real electrodes



CAD model

Design Studies

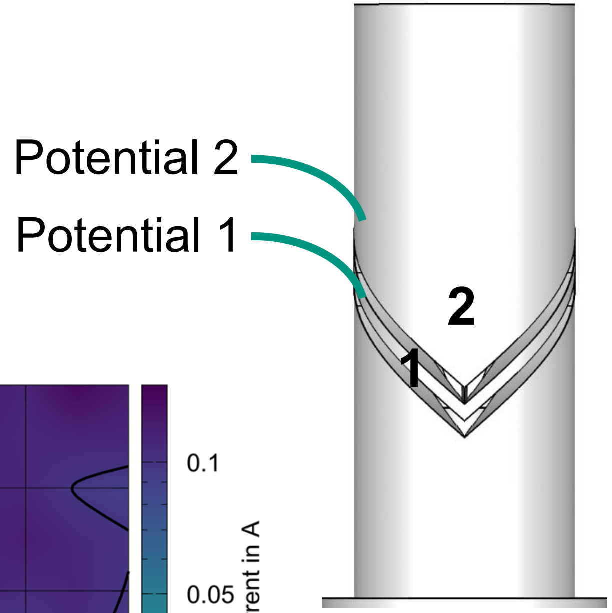
- Simulation setup
  - Trajectory tracing with CST PARTICLE STUDIO
  - Space charge and secondary electrons
  - Realistic spent electron beam
- Important parameters
  - Radius
  - Length
  - Voltage

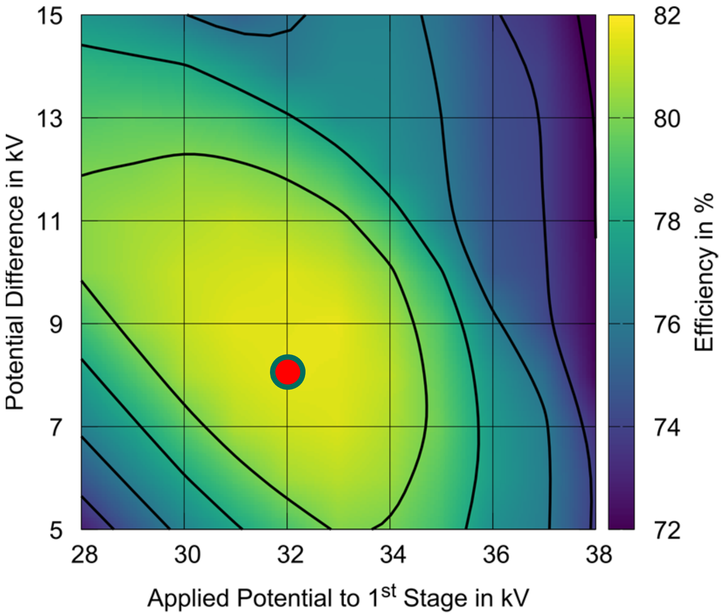
Design Studies – Optimization

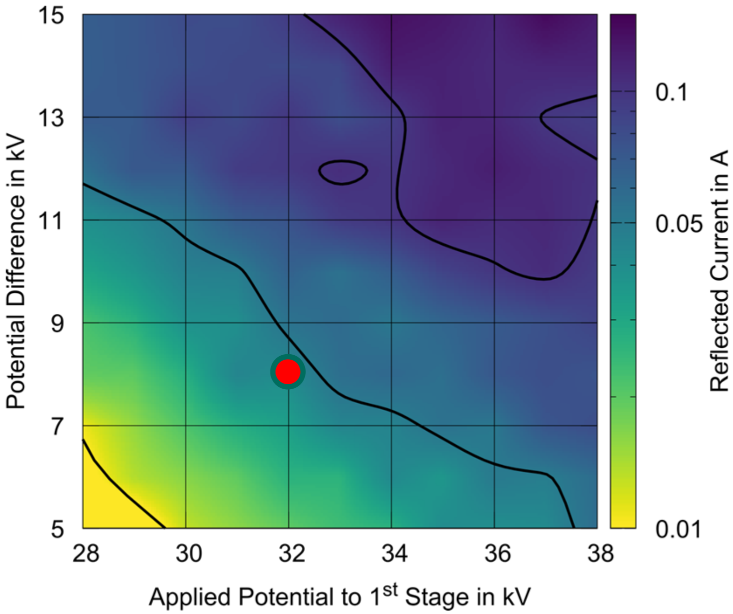
- Maximum efficiency

  ≠ minimum reflected current

  ≠ uniform wall loading

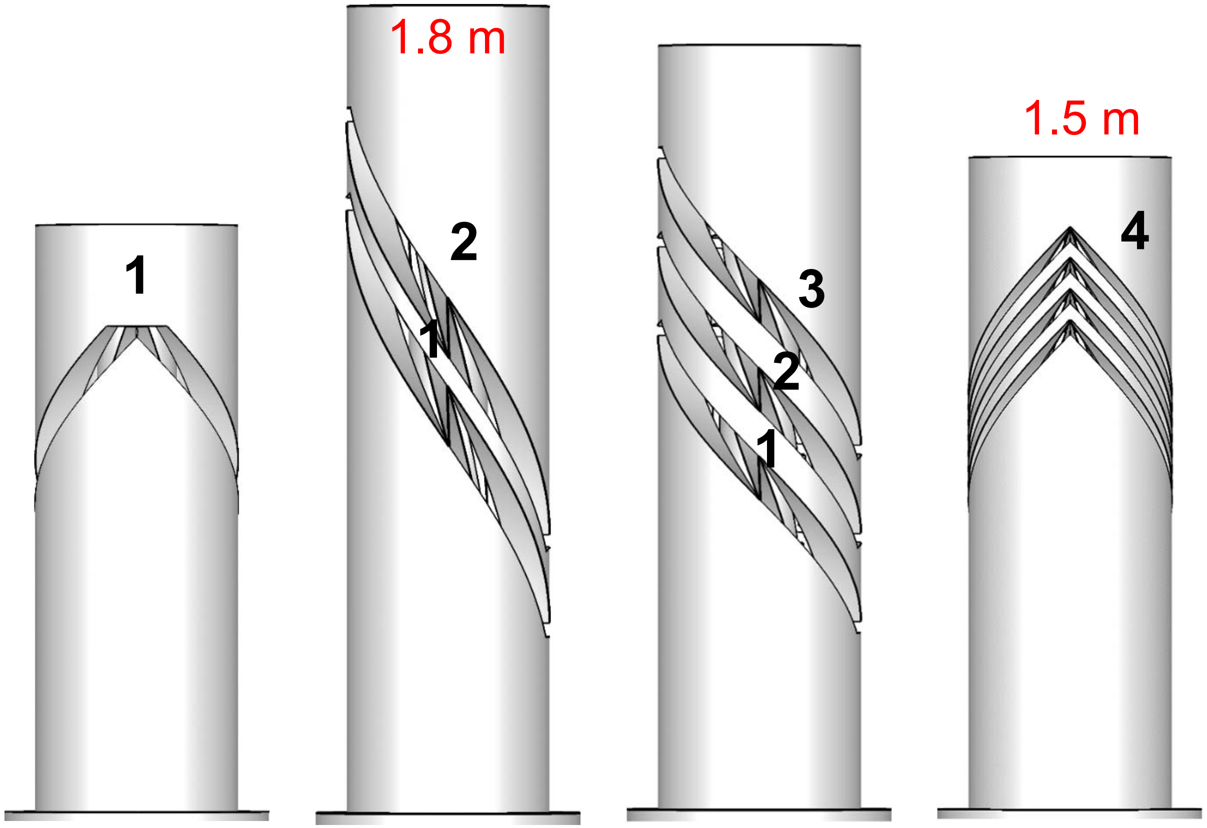






Design Studies – Stages

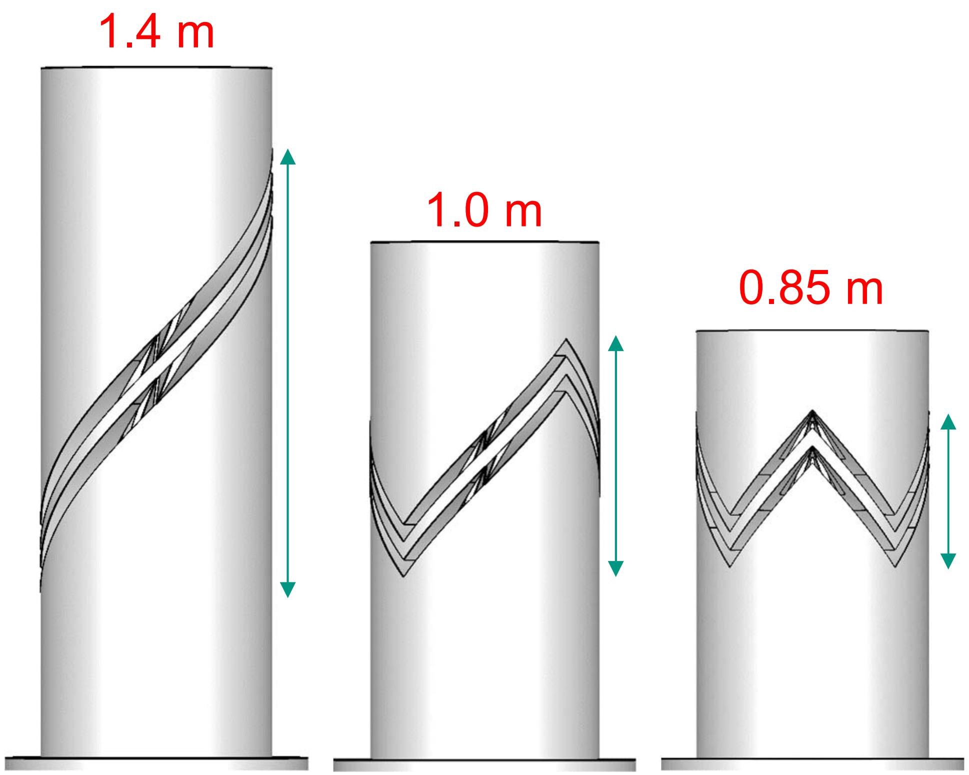
- Increasing number of stages
  - Significant increase of the efficiency
  - Reflected current at low level



Stages	Efficiency	Reflected current
1	73 %	65 mA
2	82 %	46 mA
3	83 %	41 mA
4	87 %	39 mA

Design Studies – Compression of Size

- Folded helical shape
  - Significant decrease of collector length
  - Efficiency and reflected current depend on optimization

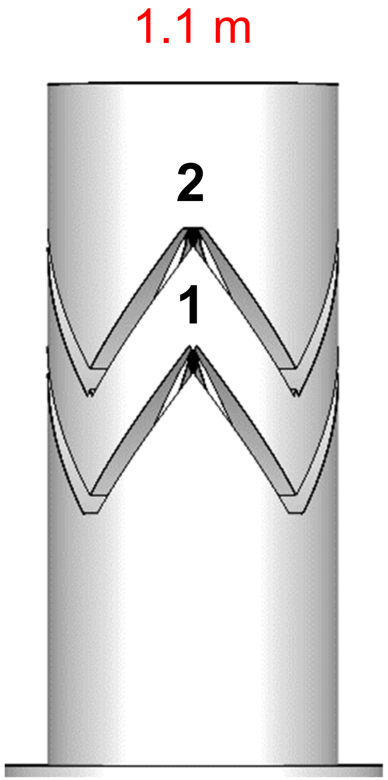


Repetitions	Efficiency	Reflected current	Spiral length
1	81 %	65 mA	0.74 m
2	80 %	41 mA	0.47 m
4	80 %	98 mA	0.31 m

Wu et al., POP 2018 (in submission)

Design Studies – Space Charge

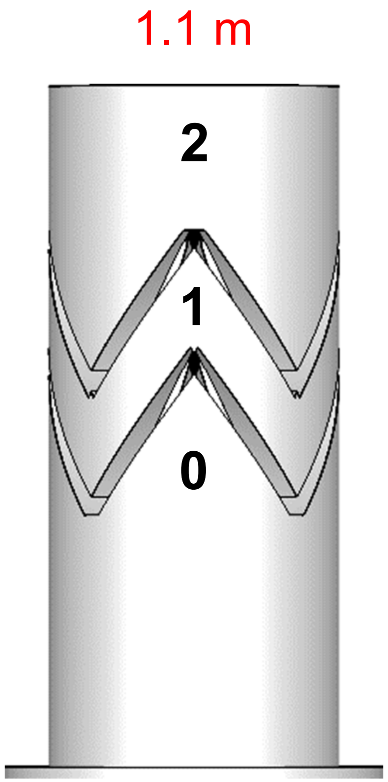
- Low influence of space charge (SC) and secondary electron emission (SEE)
- Material for SEE is copper

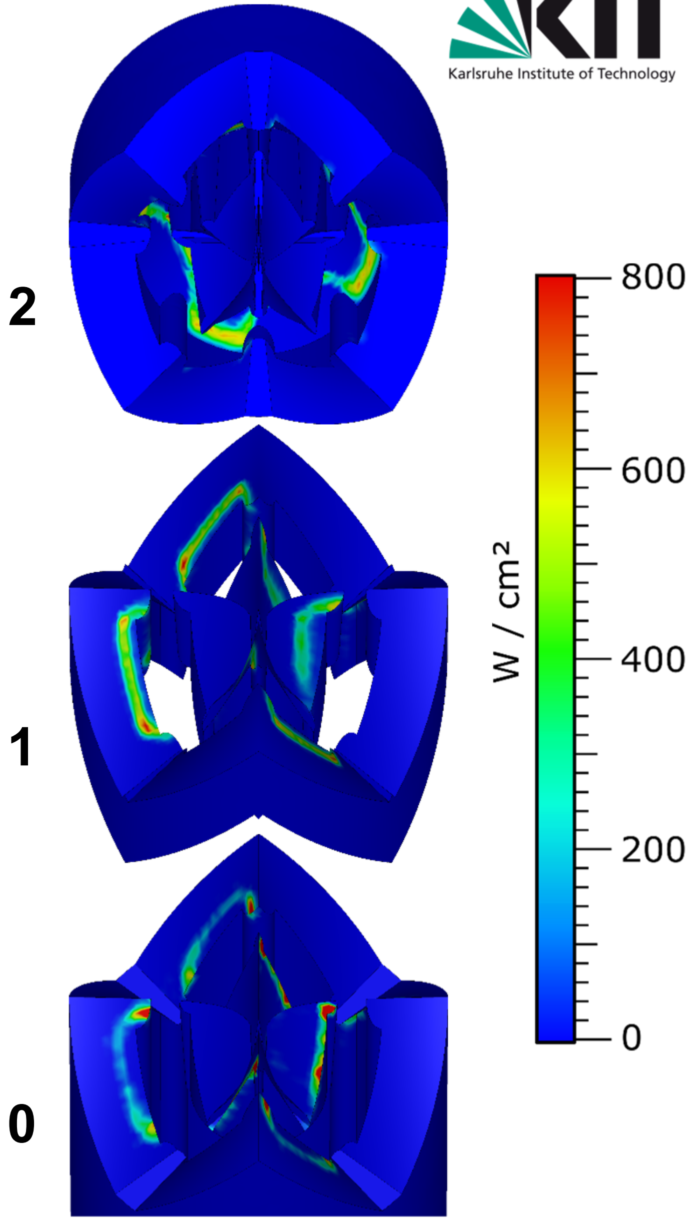


	Efficiency	Reflected current
no SC	81 %	71 mA
with SC	80 %	42 mA
SEE with SC	78 %	68 mA

Design Studies – Wall Loading

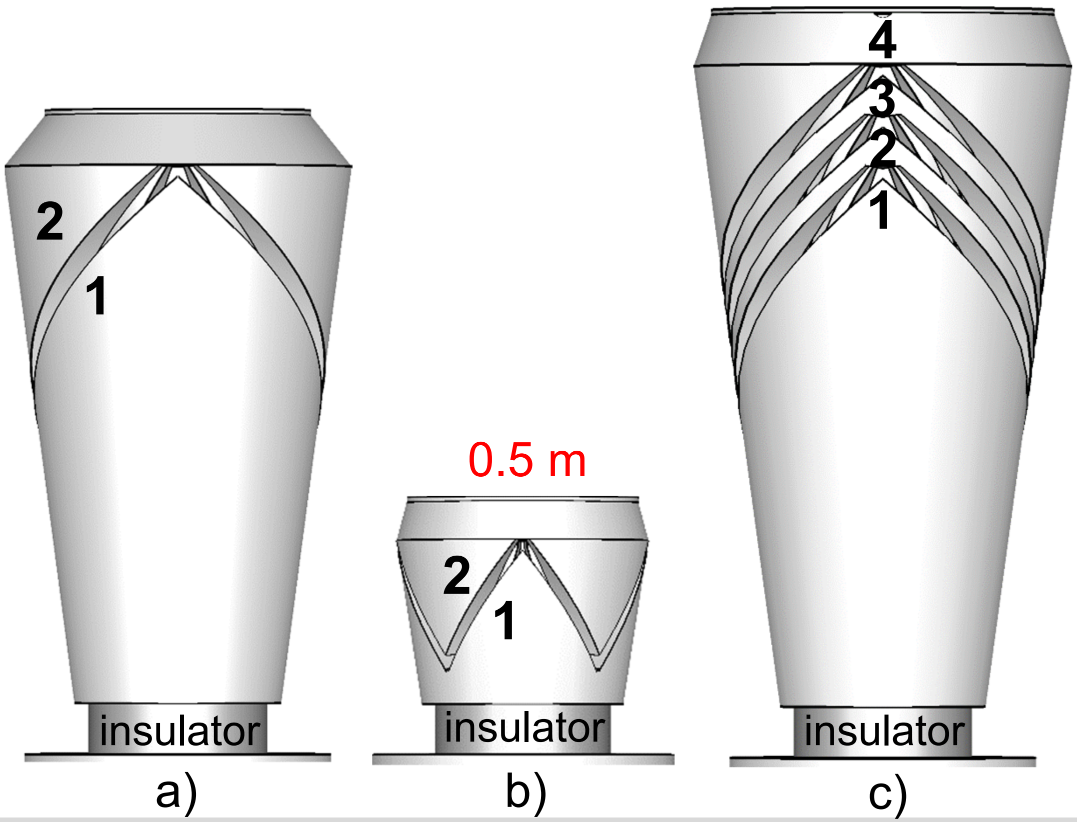
- 2 MW initial beam power
- Hotspots of up to 800 W/cm^2
- Cooling needed





Design Studies – Alternative Approach

- MDC geometry adapted to gyrotron magnetic field
- Insulator at the entrance
  - ➡ one helical electrode less (simpler geometry)



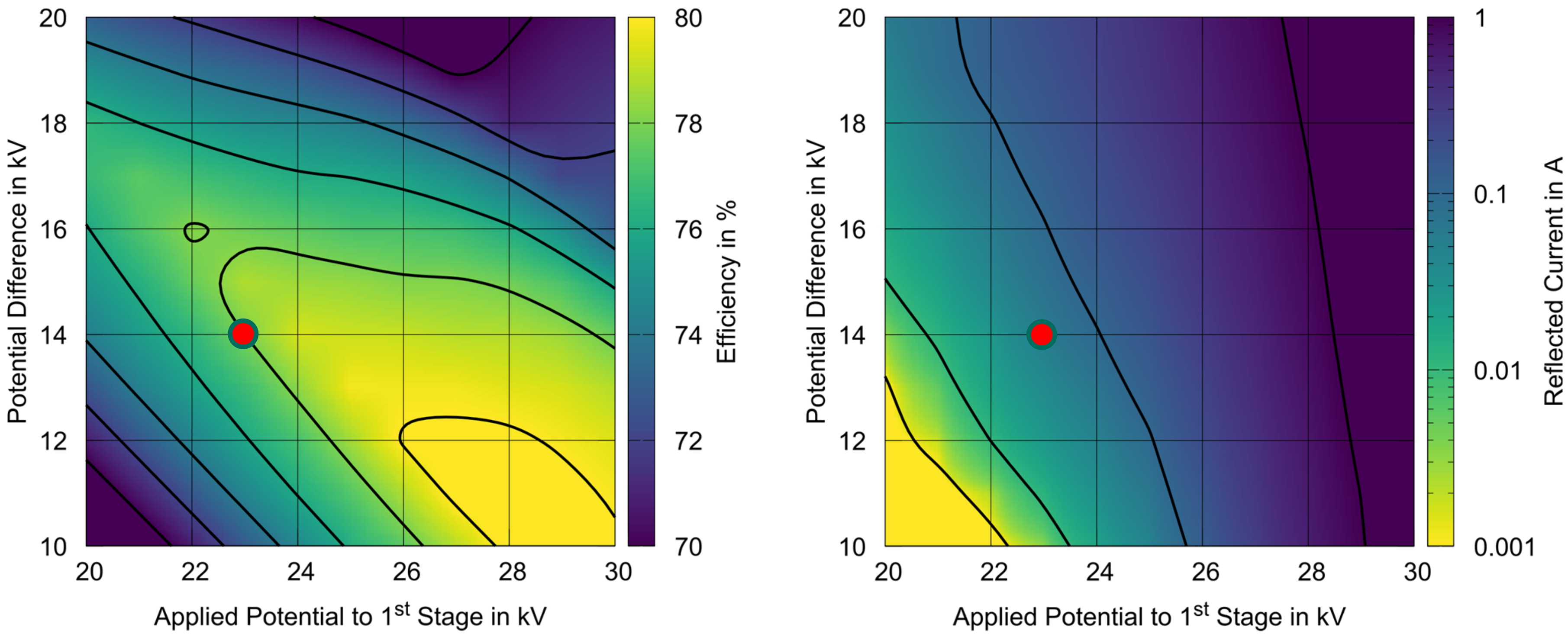
	Efficiency	Reflected current
a)	78 %	53 mA
b)	77 %	90 mA
c)	85 %	20 mA

Design Studies – Alternative Approaches

Karlsruhe Institute of Technology

- Deceleration at the entrance of the collector

Lower efficiency with a similar reflected current



Conclusion/Discussion

- A high collector efficiency can be achieved with a low reflected current
- The effect of the secondary electrons was also investigated
- The thermal loading on the collector wall is under investigation

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training program 2014–2018 under grant agreement No. 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.