Localization of field emitter in a 9-cell cavity

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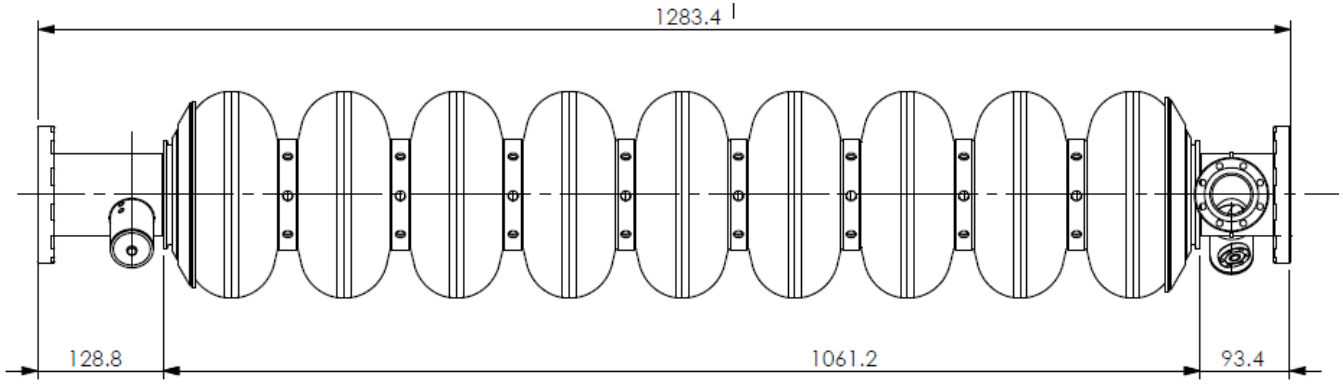
Motivation

- Field emission/dark current issue of concern for SRF cavity performance and SRF linac operation
  - ILC, pulsed, pushing high gradient, driven by Epk
  - CEBAF and other future CW SRF linacs, driven by DF

- Complete understanding and reliable control of the issue is still needed in particular in multicell practical cavities
  - Where are the emitters
  - Origin of emitters
  - Impact to cryogenic load and machine operation
  - Targeted solution

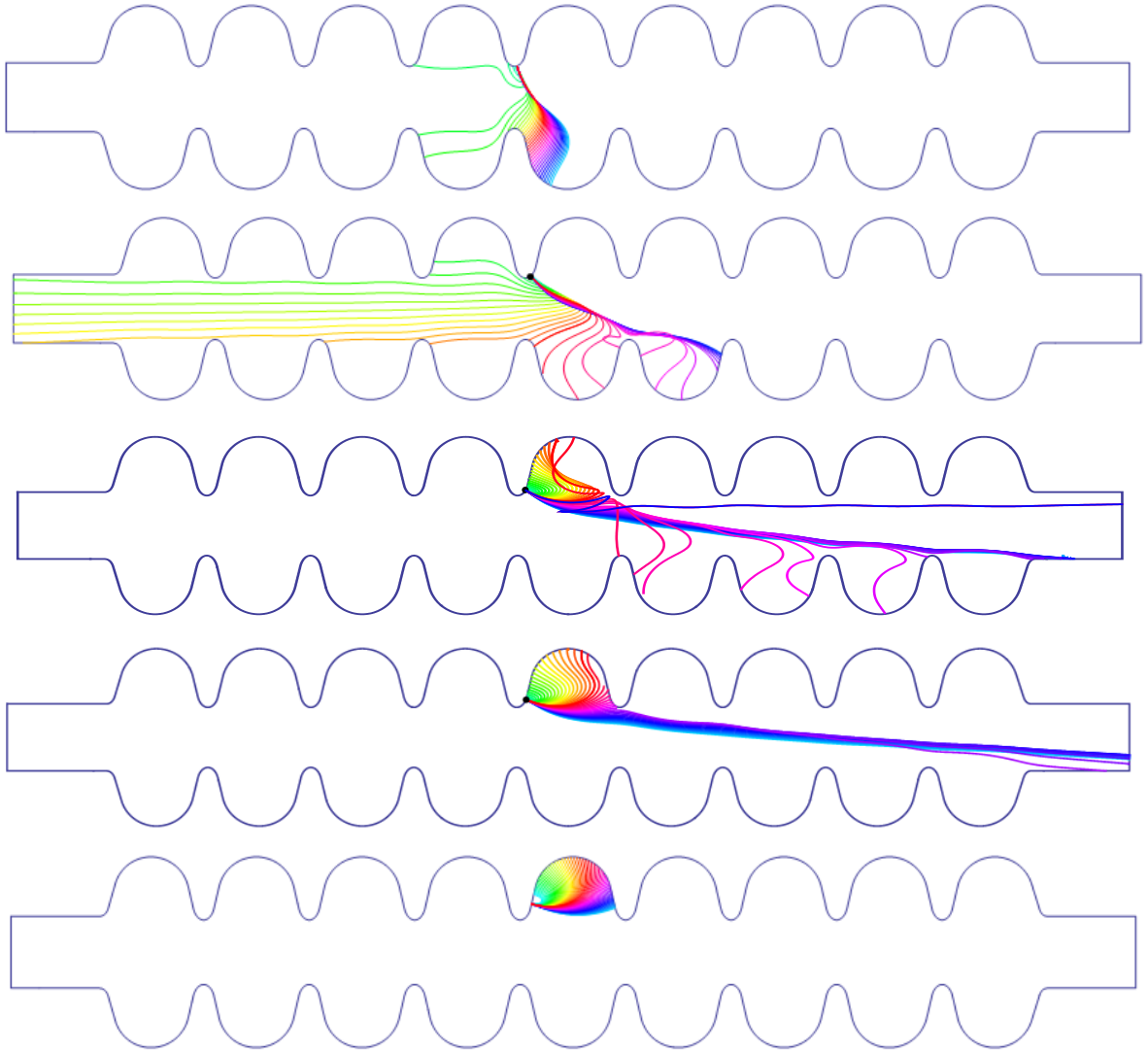
ILC 9-cell Cavity and FN Law



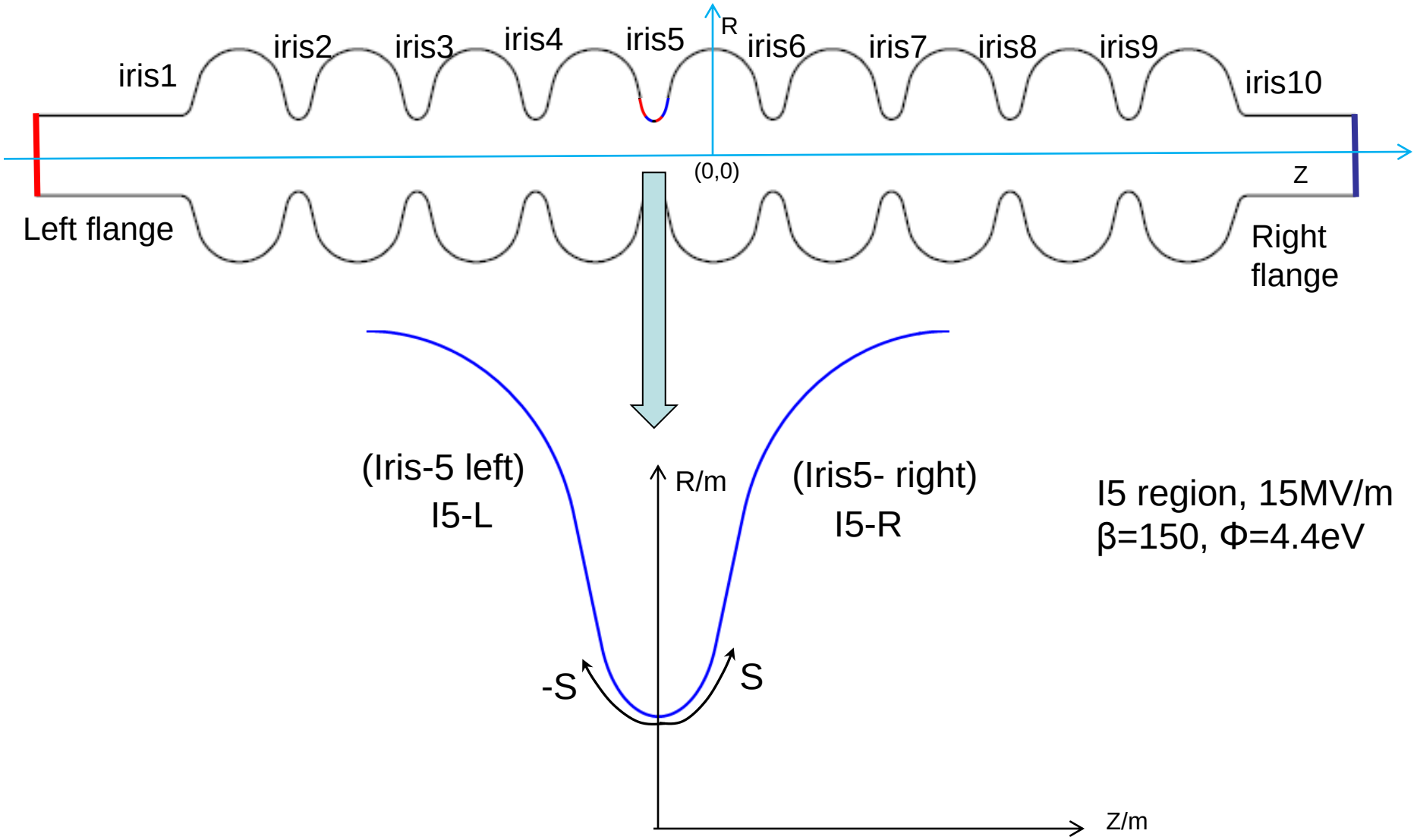
QM tunneling theory predicts exponential Fowler-Nordheim emission current density

$$j(E) = \frac{A_{FN}(\beta_{FN}E)^2}{\varphi}\exp\left(-\frac{B_{FN}\varphi^{\frac{3}{2}}}{\beta_{FN}E}\right)$$

Trajectories of different Emitters

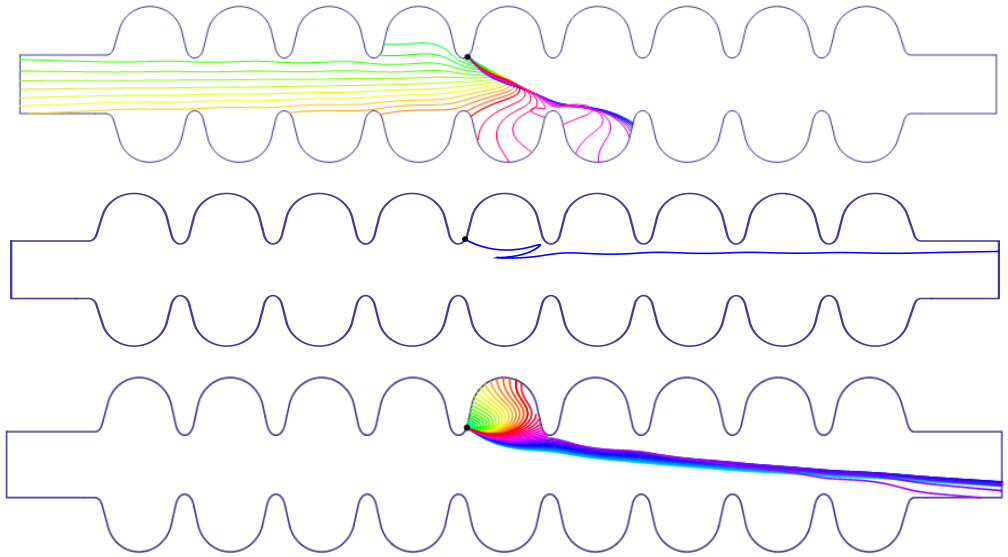


9-cell Model and Definition of Coordinate



I5 region, 15MV/m
β=150, Φ=4.4eV

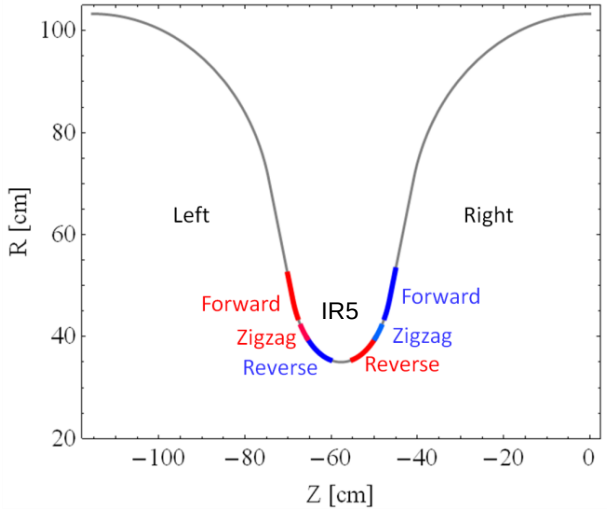
3 Types of "Long Range" Trajectories

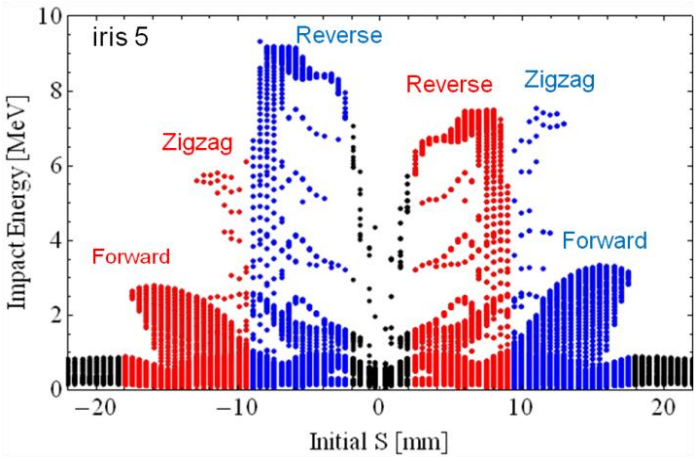


Emission in region
>>> "Reverse type"

Emission in region
>>> "Zigzag type"

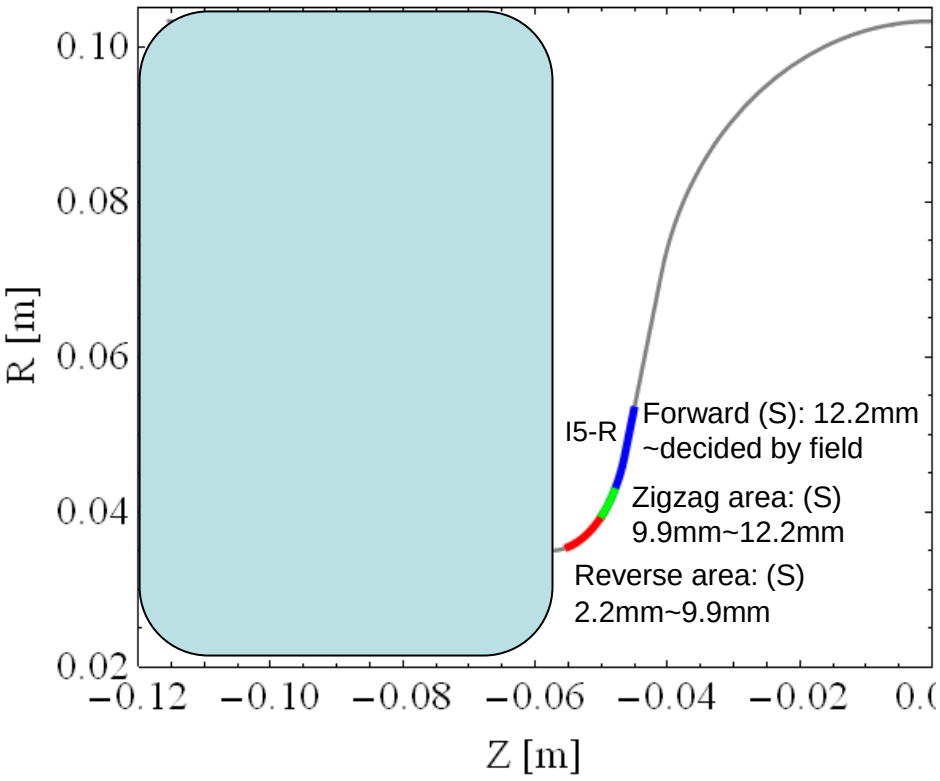
Emission in region
>>> "Forward type"



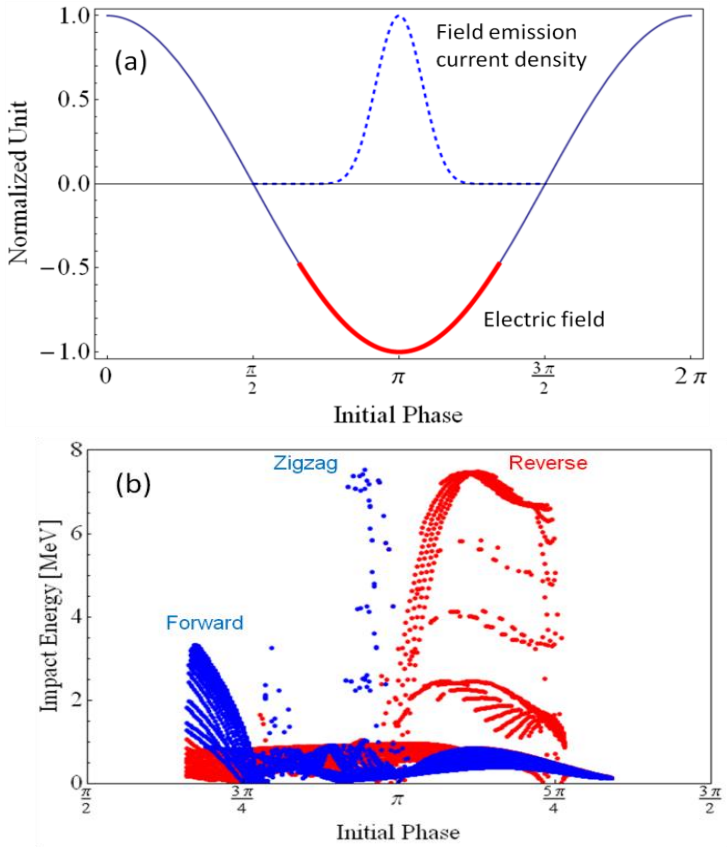


Impact position VS impact energy distribution

Position and phase distribution



Position distribution

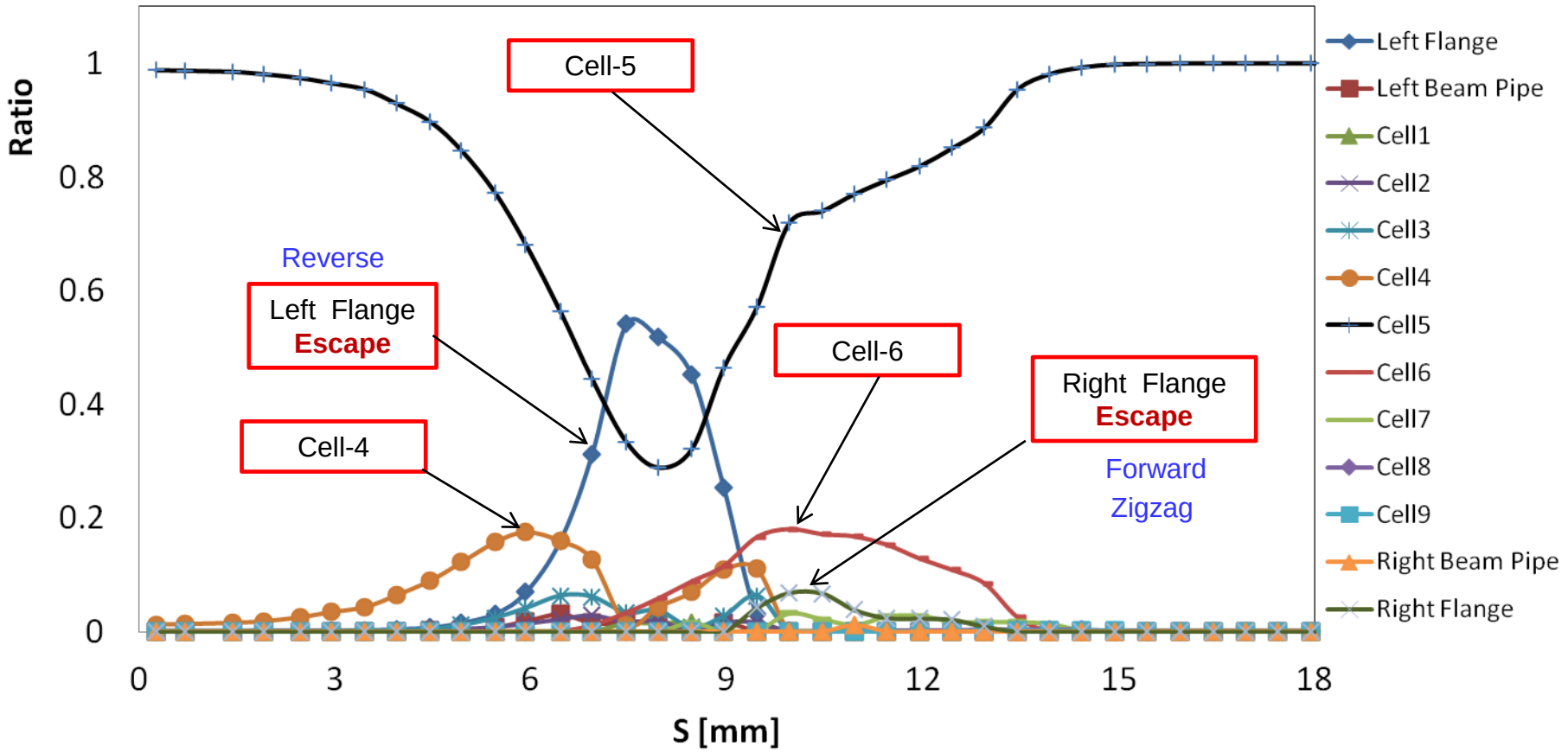


Phase distribution

Ratio of Electrons Escaping Cavity

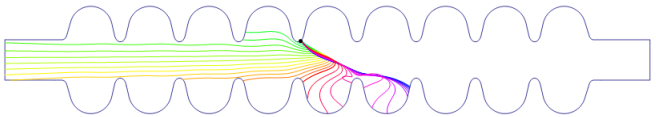
$R_{esp}=N_{esp}/N_{total}$ $R_{hc}=N_{hc}/N_{total}$

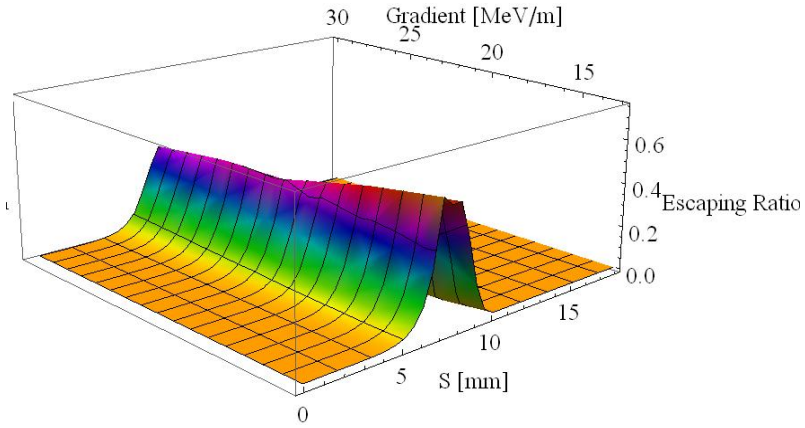
1. R2 electron escaping rate is very high (0.5 at s=0.008m)
2. Most of electrons at hitting at cell 5 (emitter: IR5_RT)
3. R1 escaping is low compare with R2 (less than 8%)



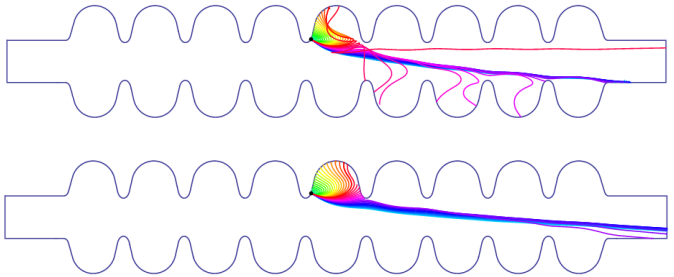
Escaping Ratio

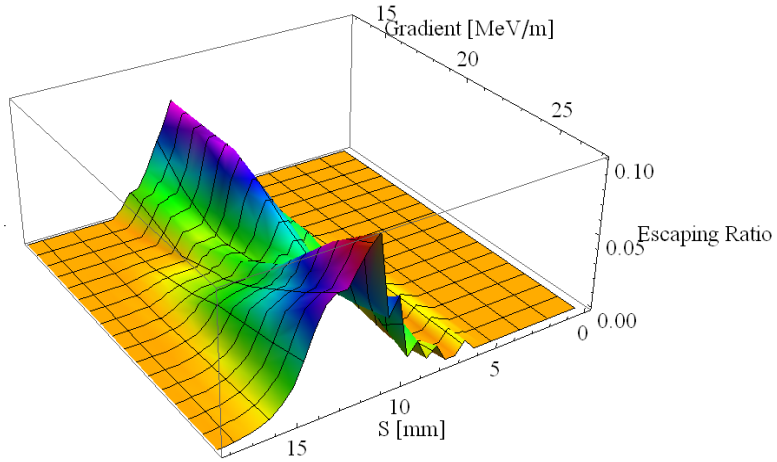
Escaping from Left Flange
"Reverse type" trajectory



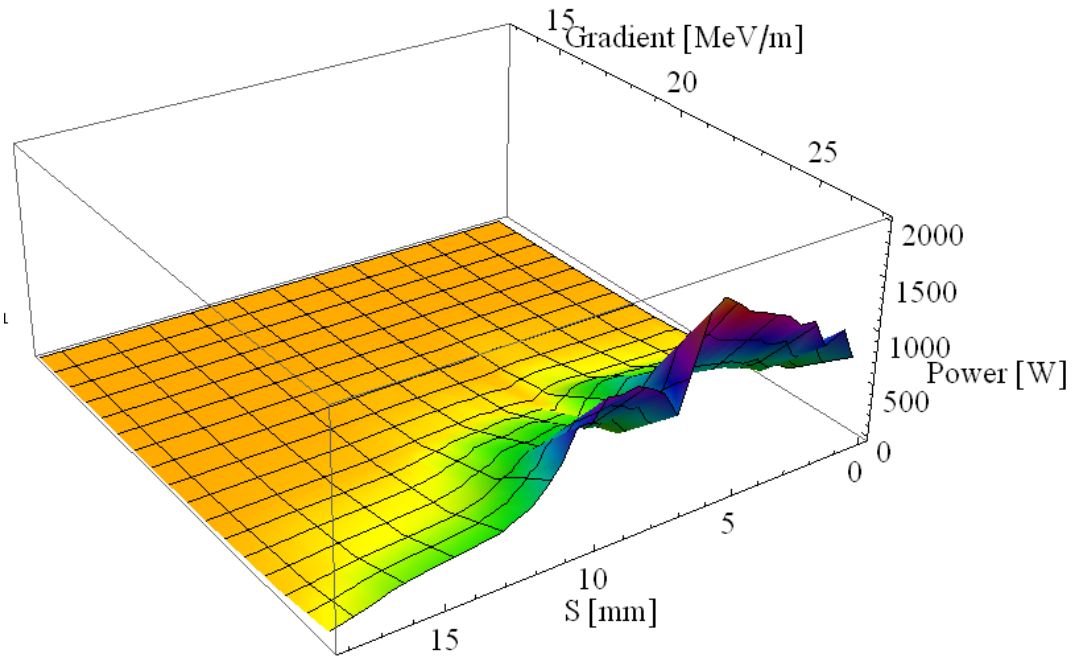


Escaping from Right Flange
"Zigzag type" & "forward type" trajectory





Energy Deposit in Cavity



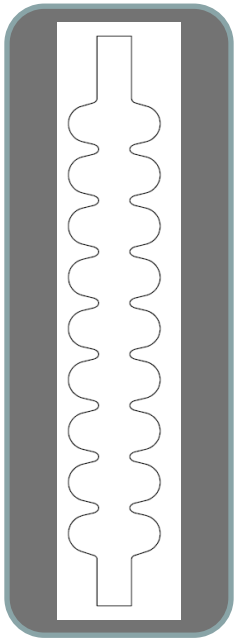
Emitter bellow10mm [s] is very important considering the energy deposit in the cavity and escaping ratio of the electron.

Experiment: 9-cell cavity RI23

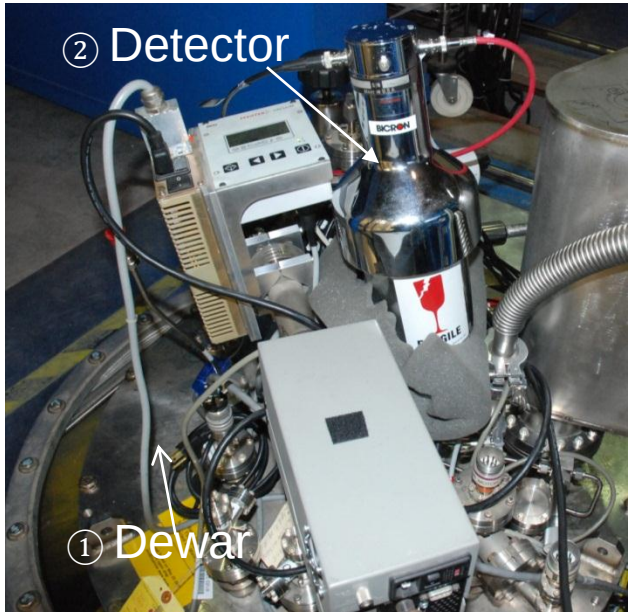
γ energy spectrum measurement system

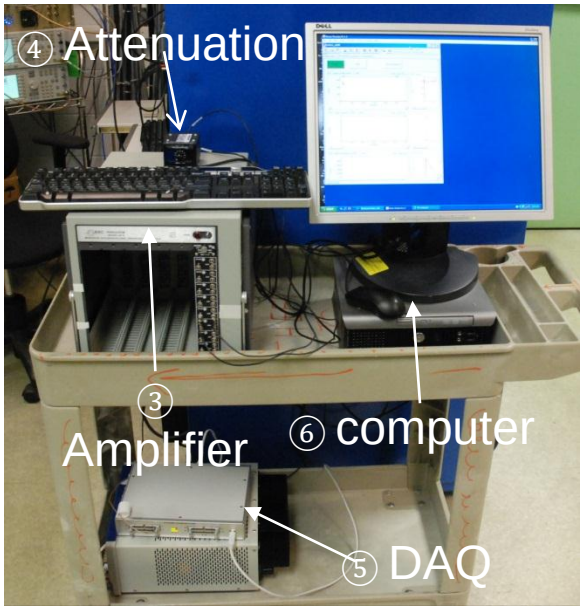
High Voltage

② Detector — ③ Amplifier — ④ Attenuation — ⑤ DAQ — ⑥ computer



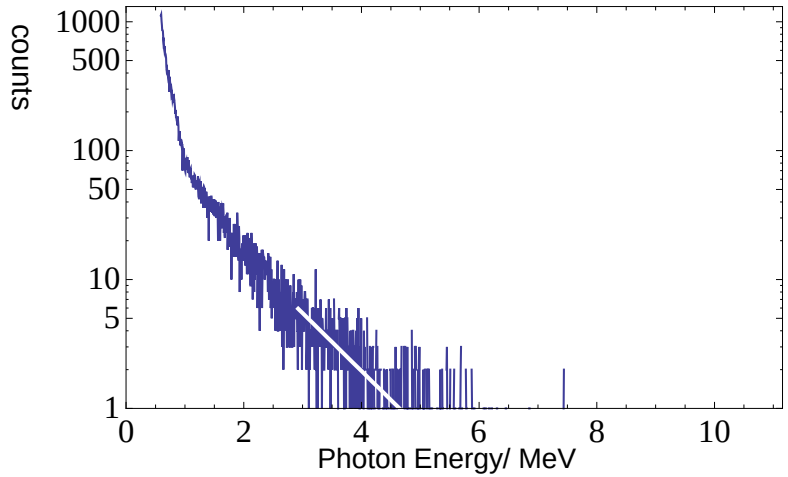
① Dewar



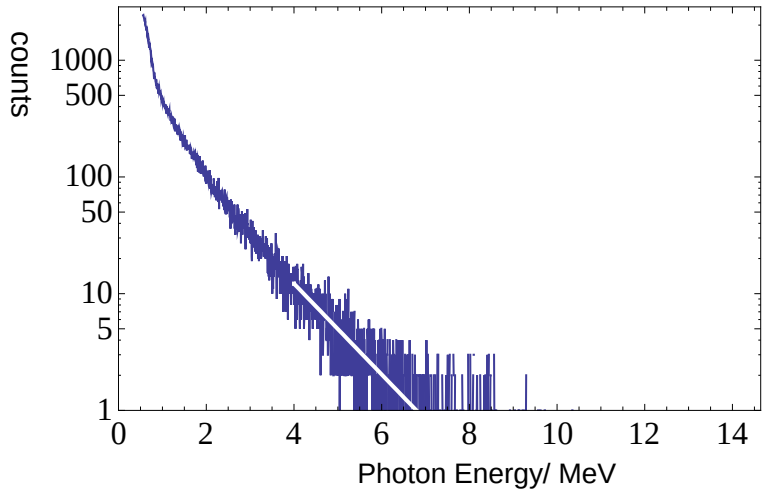


Energy Spectrum from NaI(Tl) Crystal

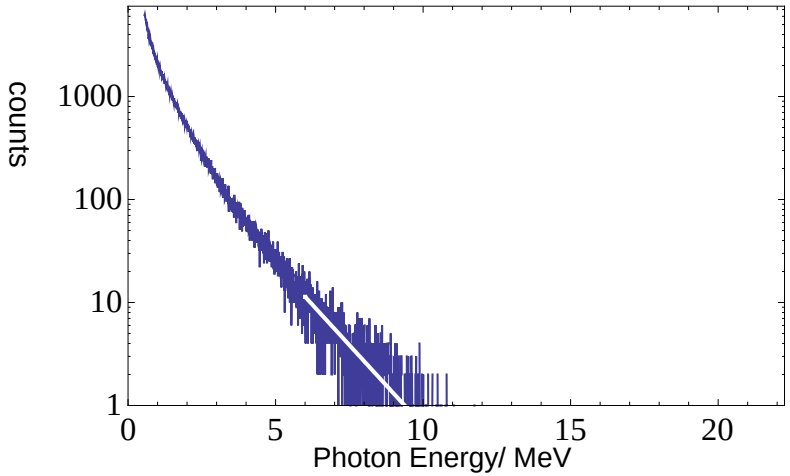
End Point Energy Fitting



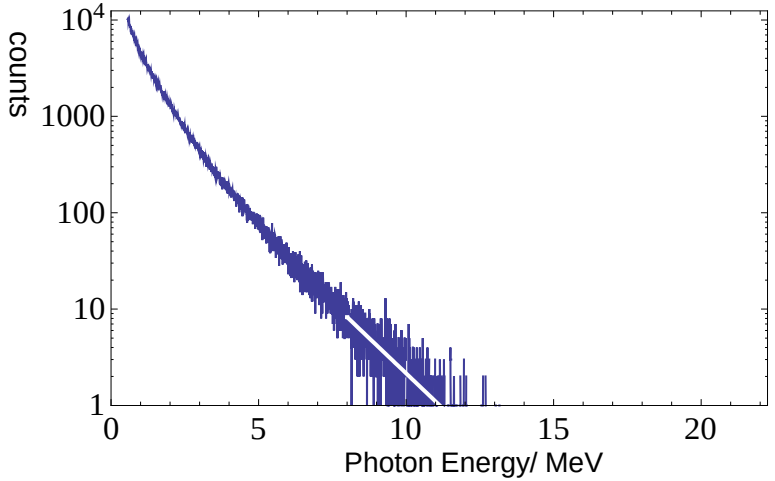
Pi mode 10MV/m Ep=4.3MeV



Pi mode 11MV/m Ep=6.8MeV



Pi mode 12MV/m Ep=9.4MeV



Pi mode 13.1MV/m Ep=11.14MeV

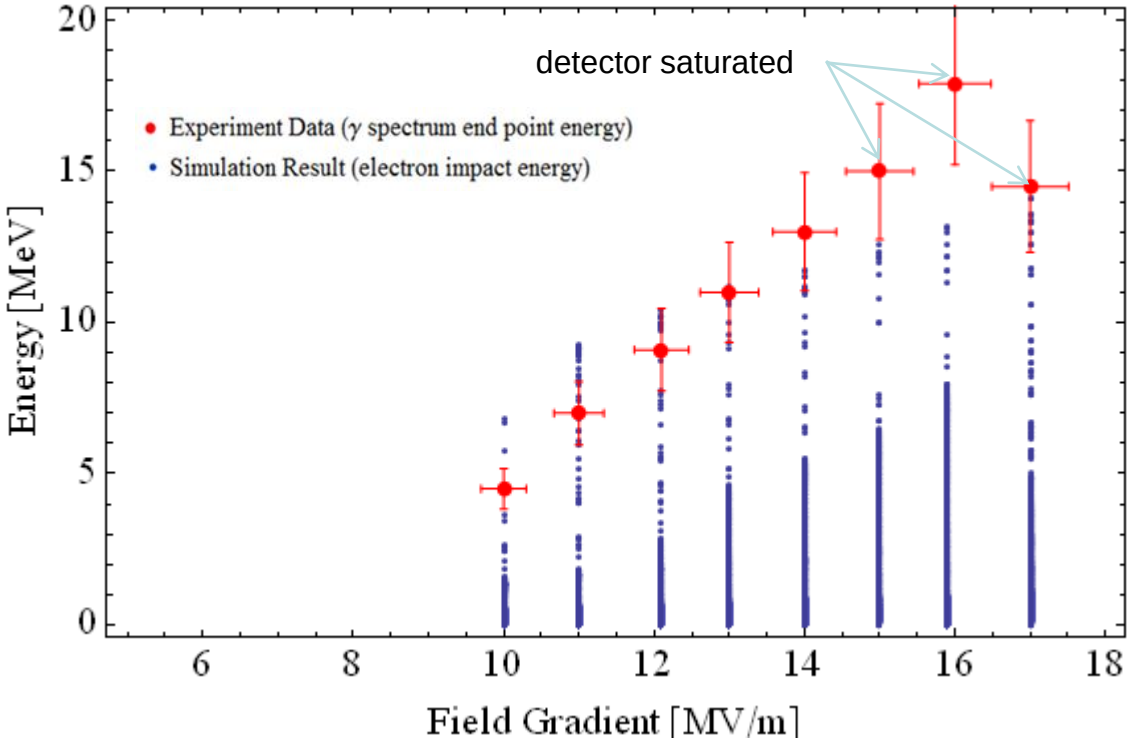
Correlation between Simulation and Measurements

Calculated impact energy of field emission electrons and measured end point energy in γ spectrum **π** mode

Identification

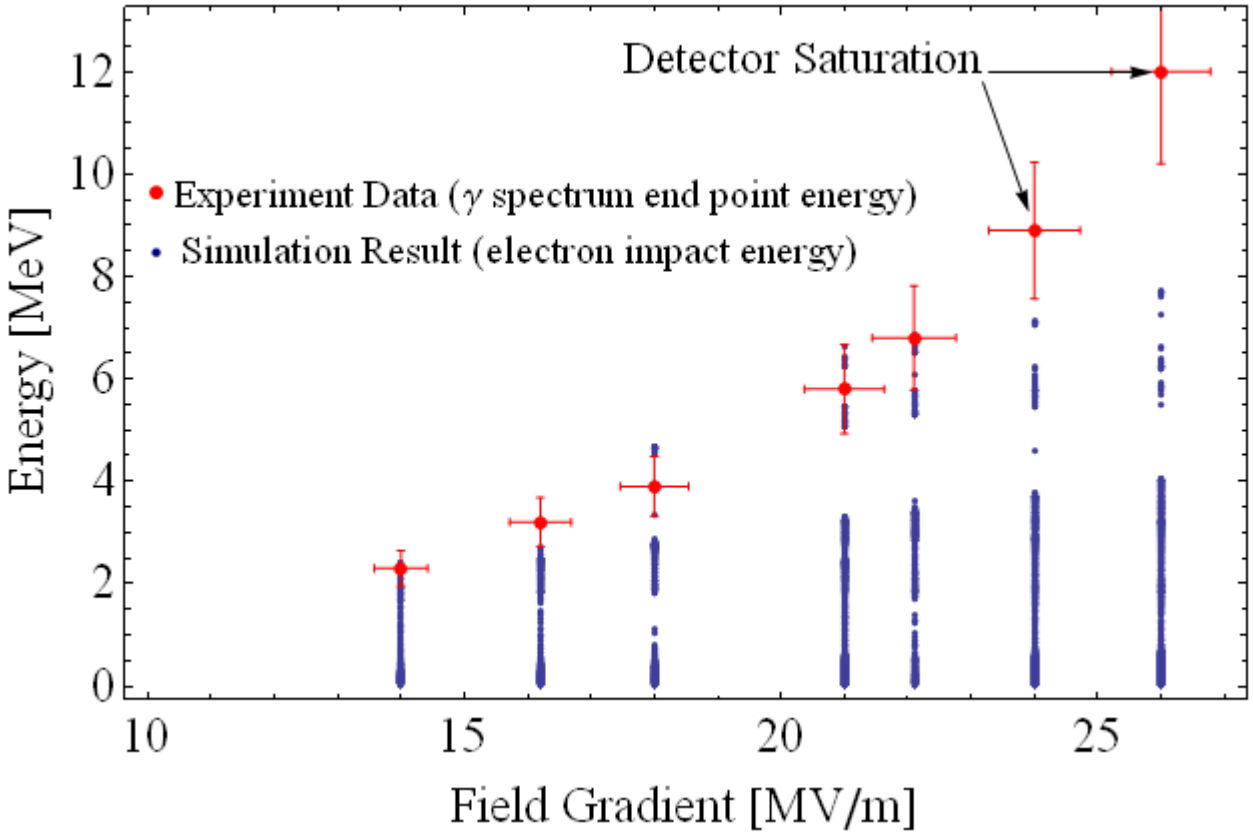
Field emission onset

1. π mode 9MV/m
2. 6/9 π mode 30MV/m
3. 5/9 π mode 28MV/m
4. 7/9 π 13.5MV/m
5. Radiation at bottom is much higher than that at top

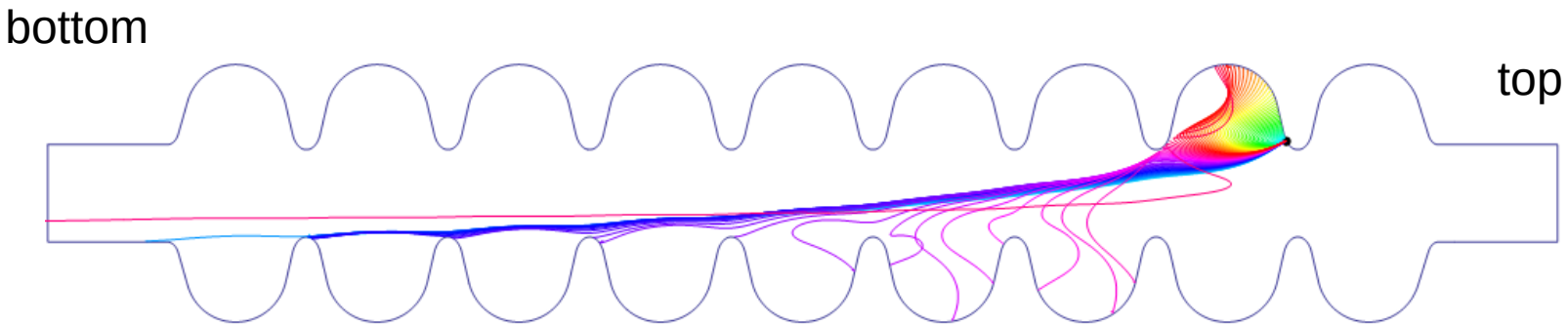


Correlation at another Pass-Band Mode

Calculated impact energy of field emission electrons and measured end point energy in γ spectrum 7/9π mode



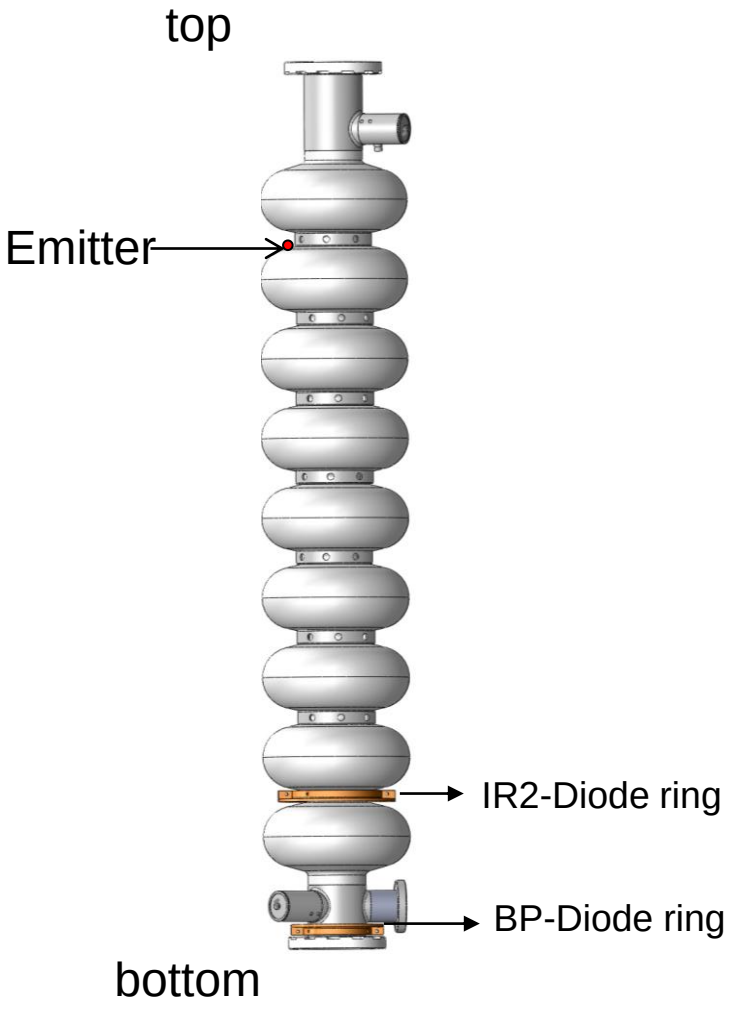
Final Answer: Emitter in Cell8/Iris9

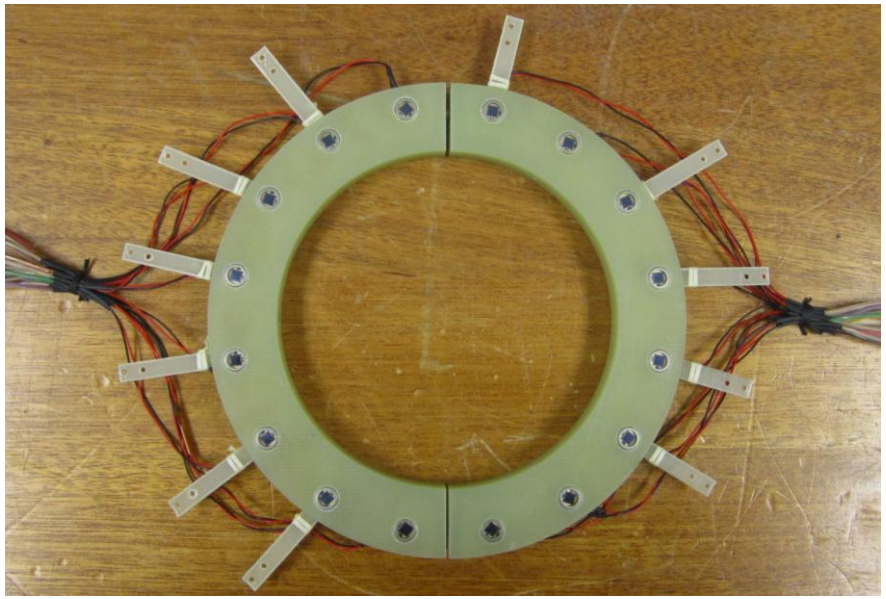


Field emitter area

Field emission region is: [S] 9.9mm~12.2mm
@ I9-L-Zigzag region

Radiation angular location measurement system

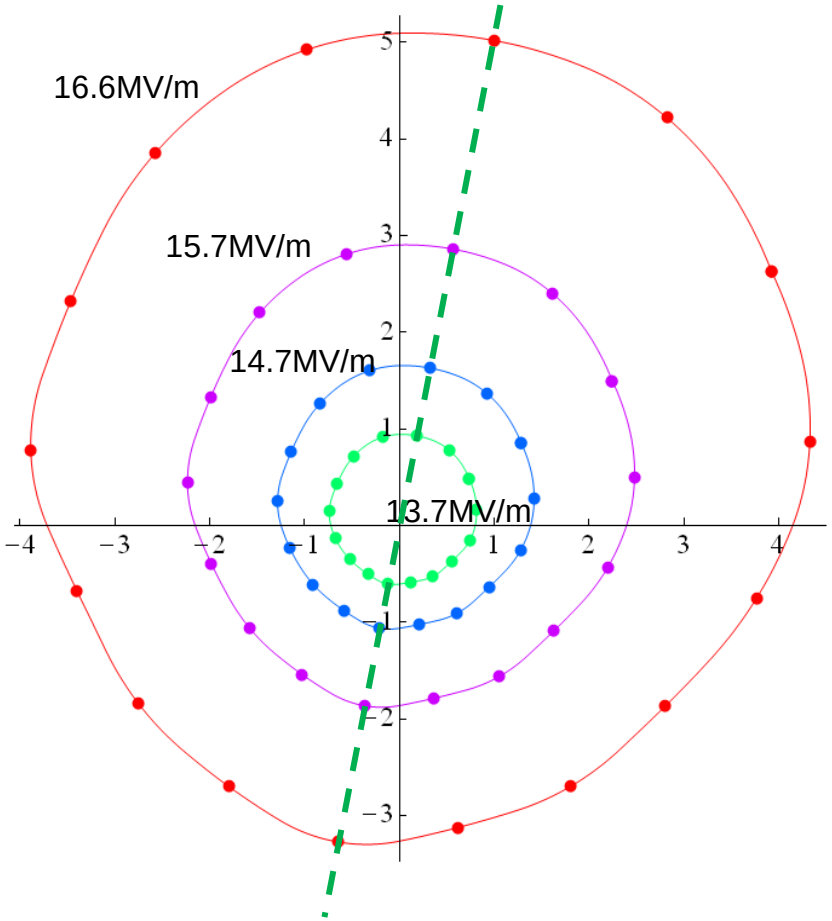




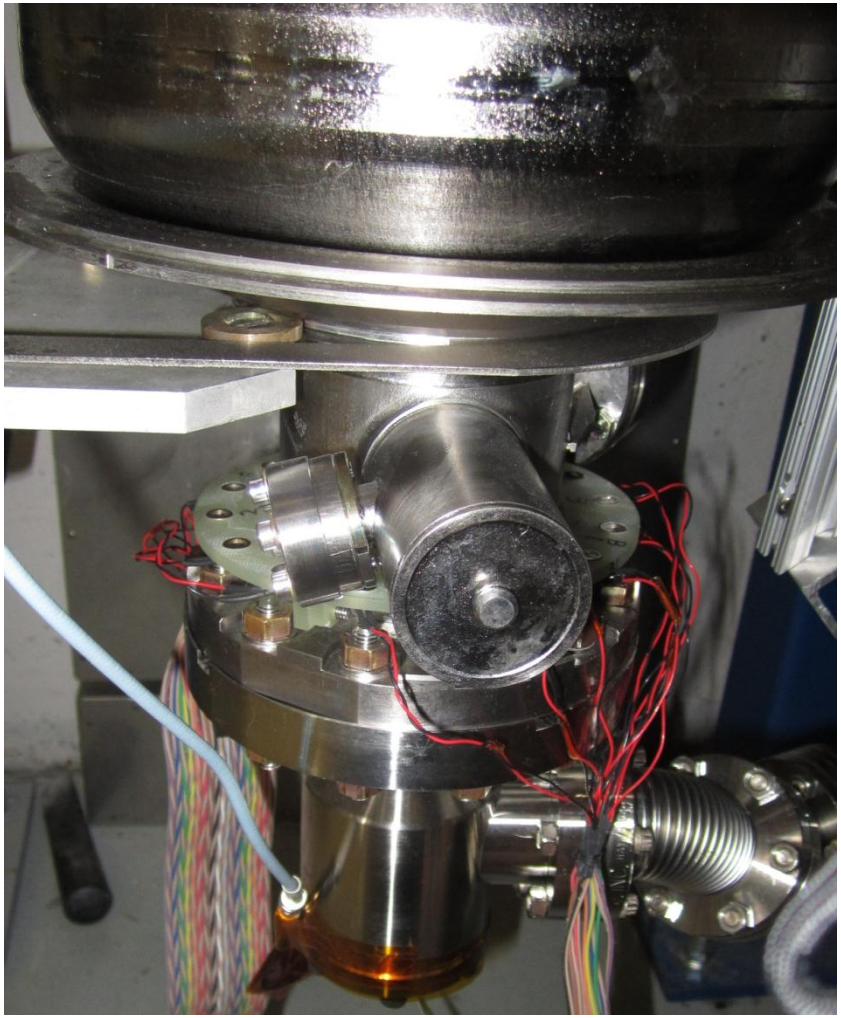
Diode ring

X-ray Angular Distribution

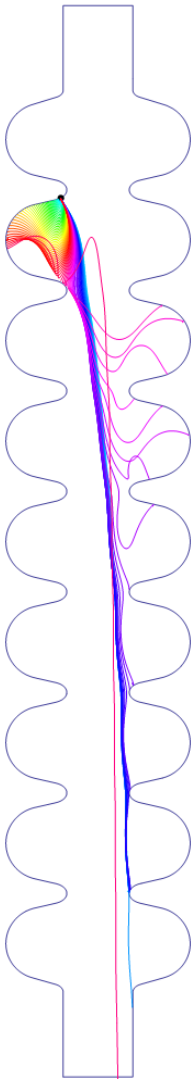
Pi mode—IR2 Diode ring

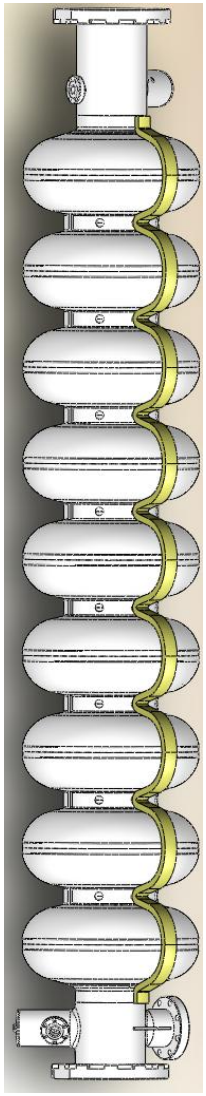


Pi mode—BP Diode ring



Rotating X-ray Mapping – Under Construction





Rotating x-ray mapping system to record all of the information of the x or γ ray generated by electrons hitting on the niobium.

Summary

- Energy measurement in RI-23 9cell cavity are agreed very well with the simulation result.
- Angular location of field emitter are done by two diode rings.
- It has been demonstrated that field emitter can be located during vertical test; the method has potential to be generalized
- Work also extended to calculate CEBAF 12 GeV upgrade cavities

Plan for the next step

1. RI23 to be optically inspected at location of predicted field emitter.

2. From the impact information to simulate the radiation information by Geant4.

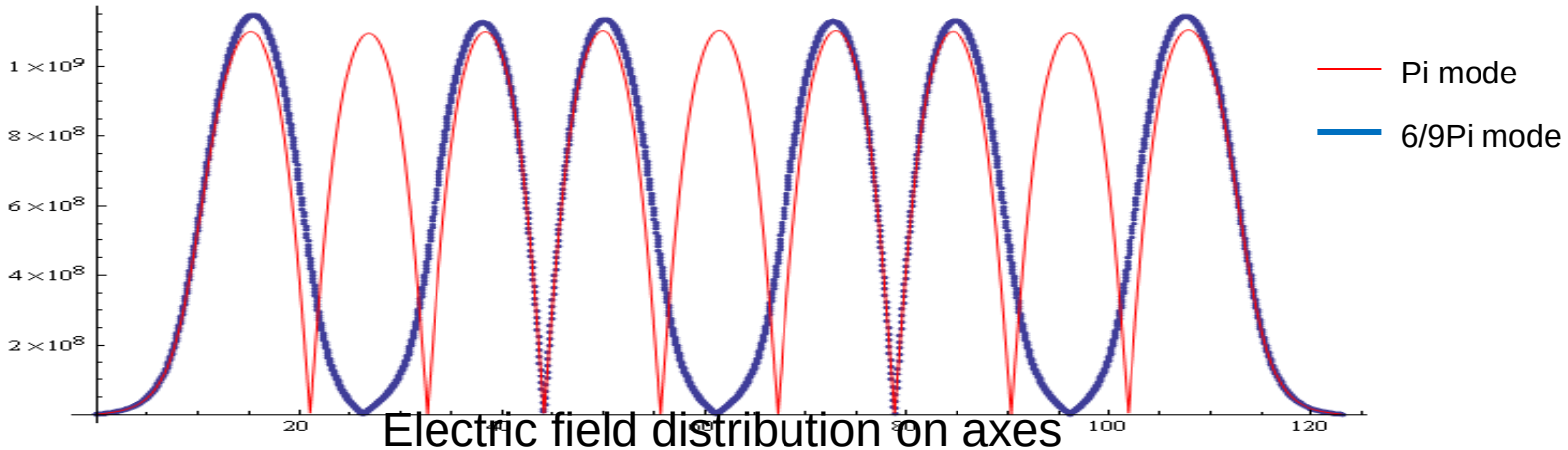
3. Benchmark calculation results against rotating X-ray mapping (under construction)

4. Develop a general method for identification of field emitter location

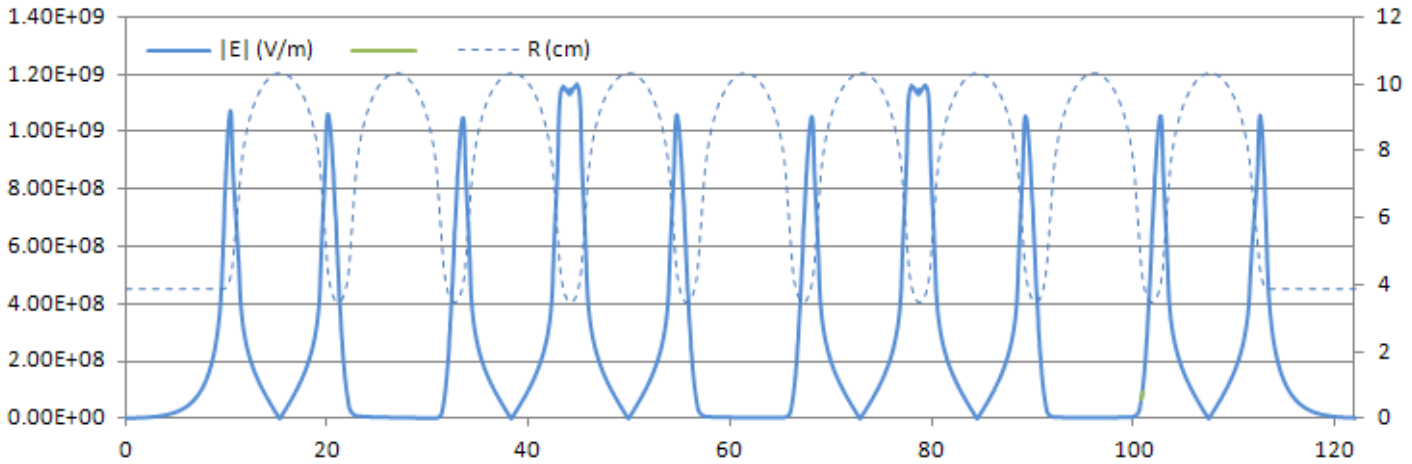
Backup

6/9Pi mode

Field emission onset: 6/9 π mode 30MV/m



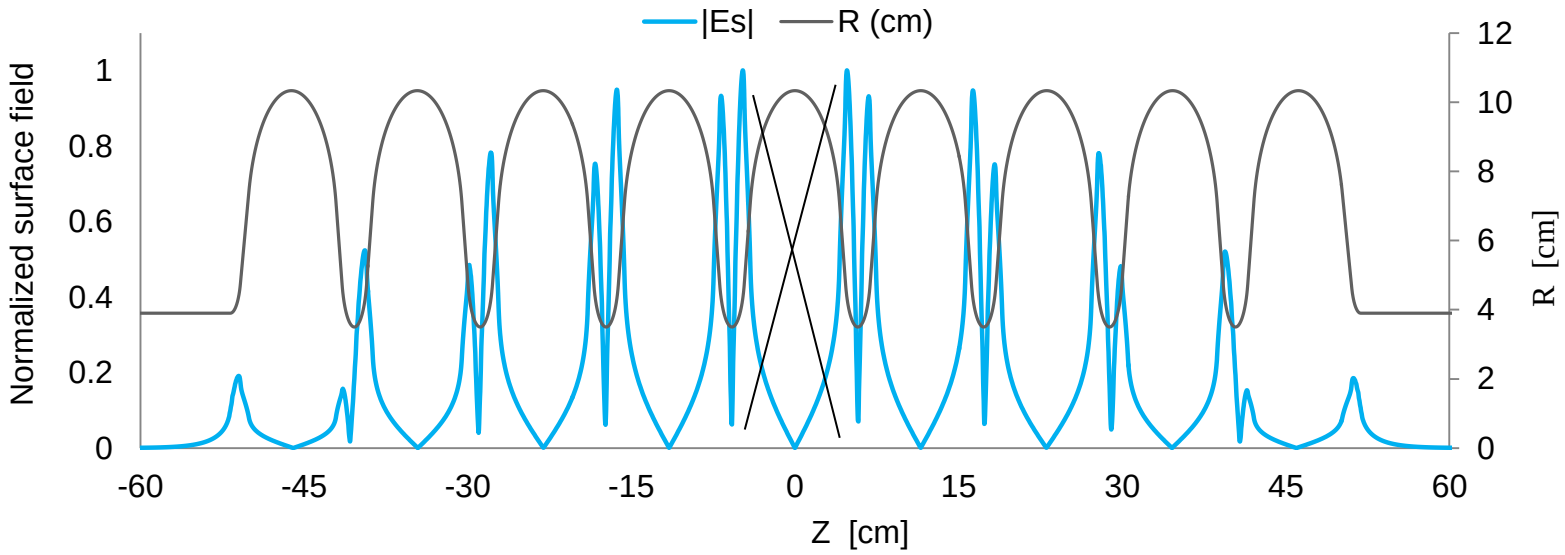
Electric field distribution on axes



surface electric field distribution

Backup

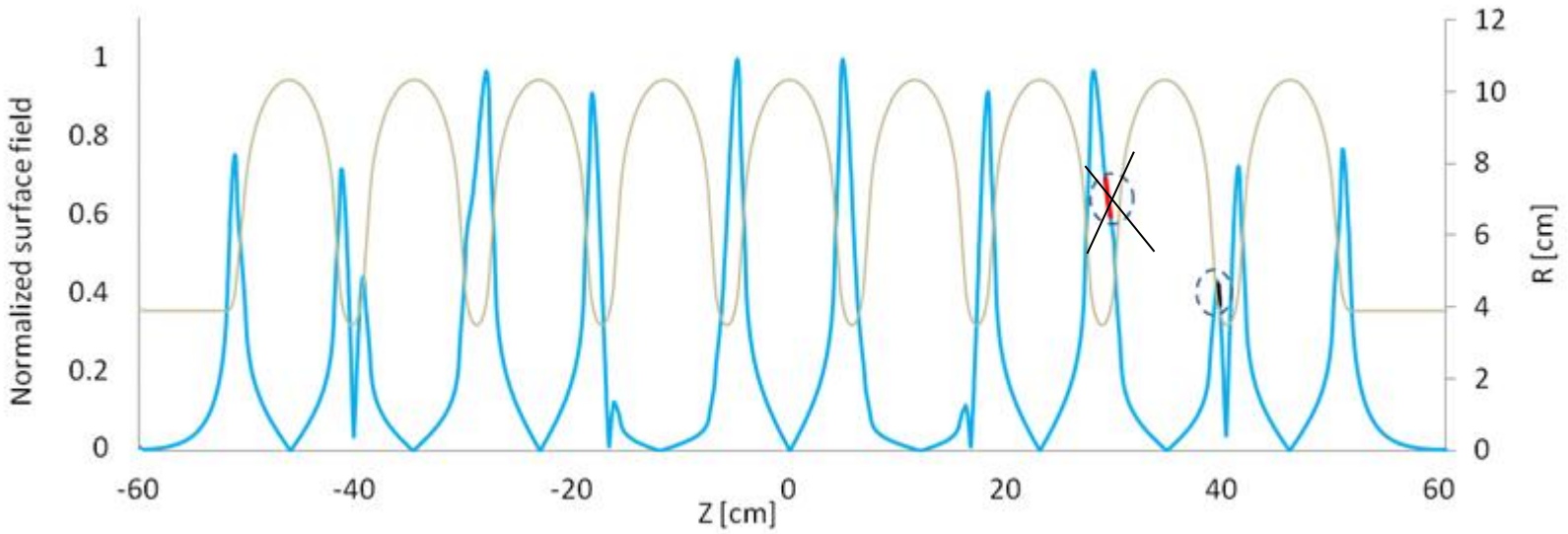
1/9Pi mode



Field emission onset: 1/9 π mode 5.7MV/m (end cell gradient)

Backup

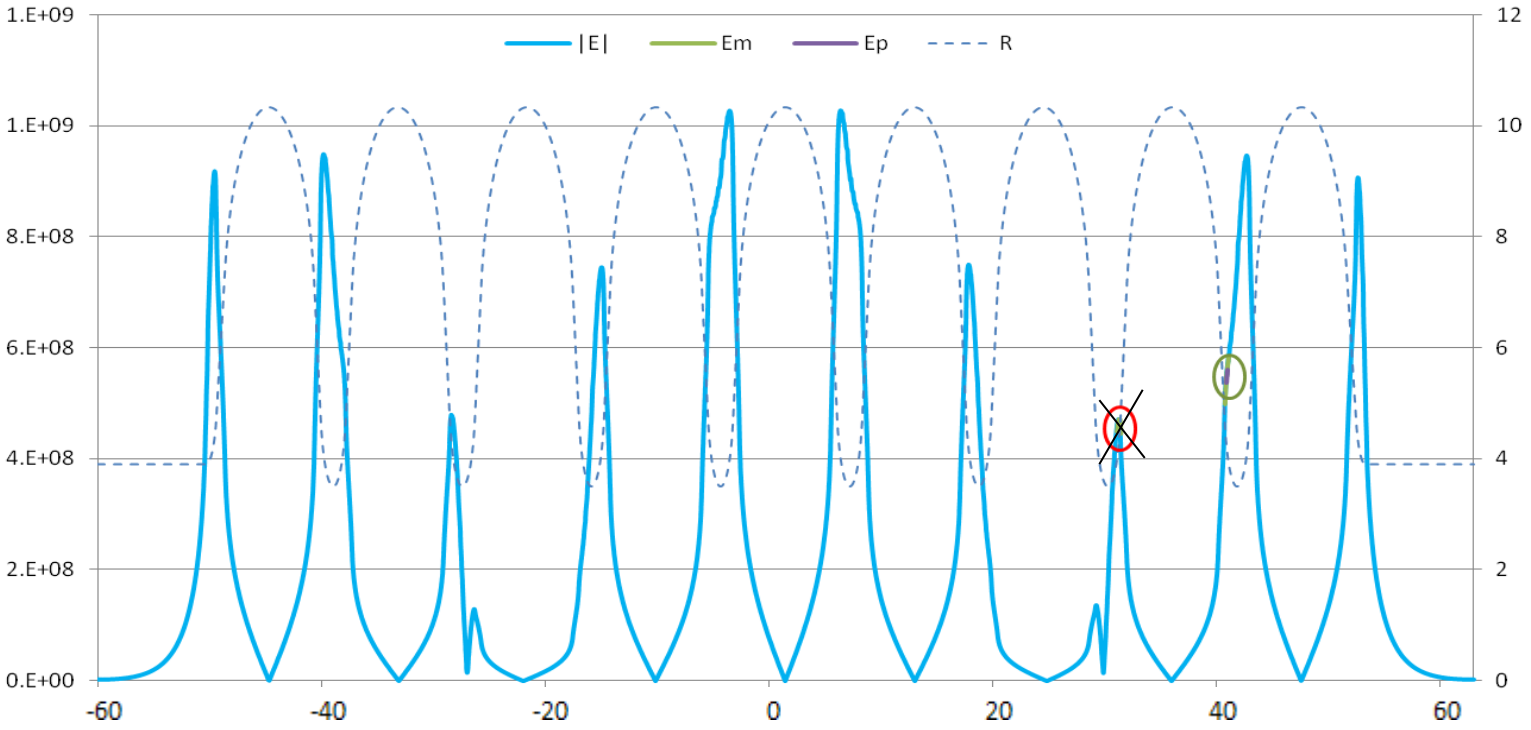
5/9Pi mode



Field emission 5/9 π mode 28MV/m (end cell gradient)

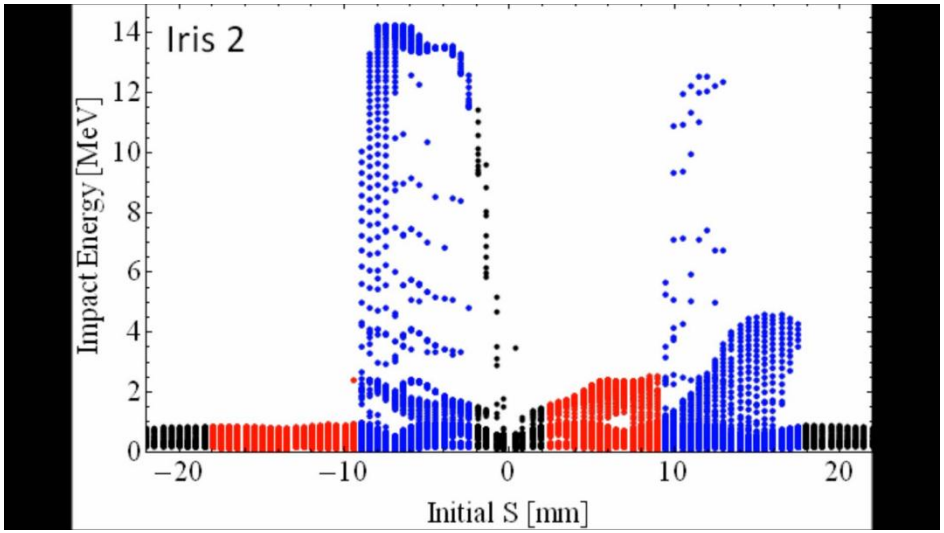
Backup

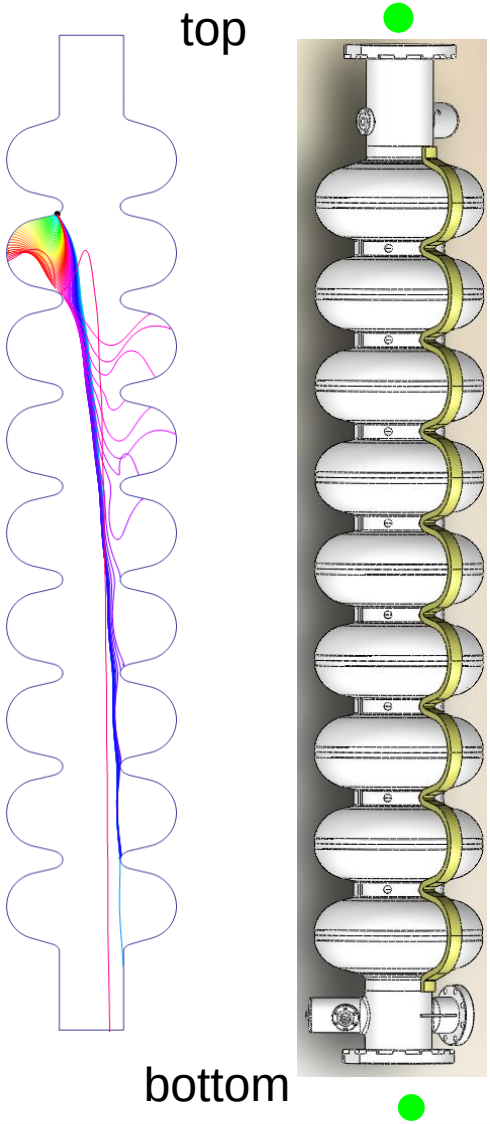
7/9Pi mode



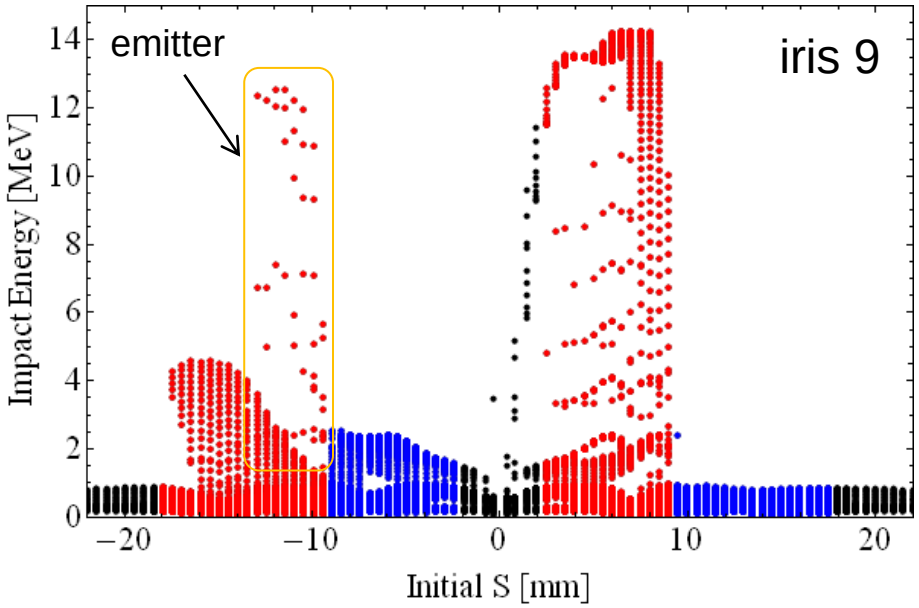
Field emission onset: 7/9 π 13.5MV/m

Backup


Iris 2
Impact Energy [MeV]
Initial S [mm]
0
2
4
6
8
10
12
14
−20
−10
0
10
20


top
bottom

Backup



Pi mode iris 9 impact energy with position