Localization of field emitter in a 9-cell cavity

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1. 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

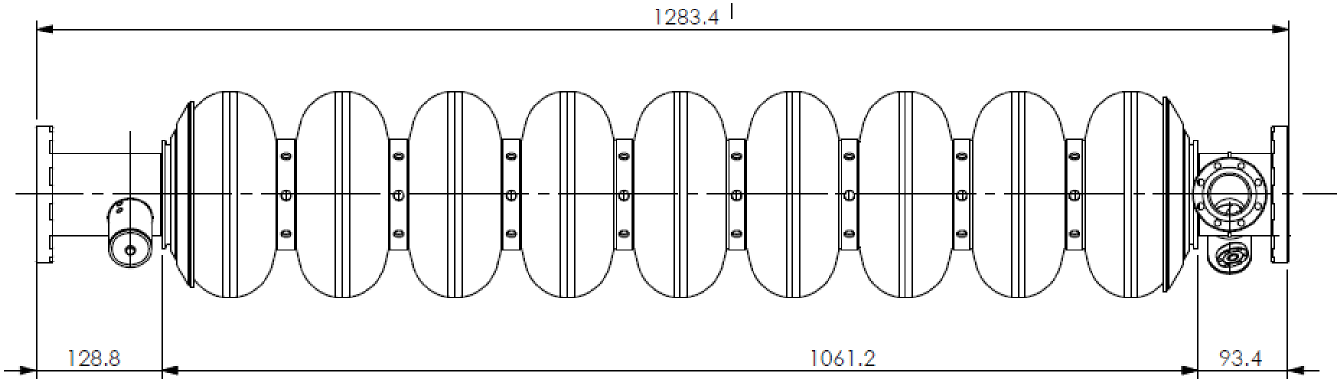
- Complete understanding and reliable control of the issue is still needed in particular in multicell practical cavities
  - Dark current in multicell cavity
    - Where are the emitters
    - Origin of emitters
    - Impact to cryogenic load and machine operation

Goal

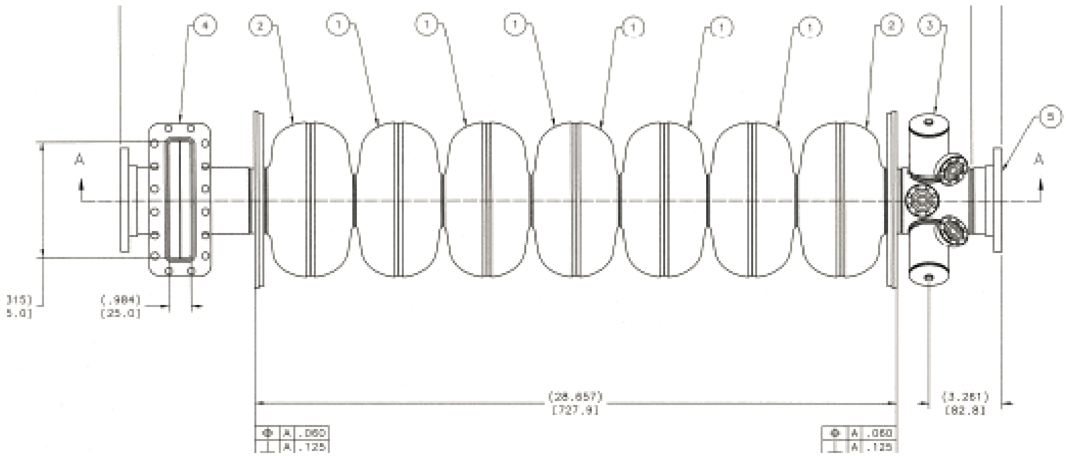
- Locate field emitter in multi-cell cavity
  - Develop a generic producer
  - Benchmark with vertically mul-ticell cavity test
  - Close loop by optical inspection of predict emitter site
  - Provide feedback for cavity string assembly

- Ultimate goal– to reduce & eliminate filed emission in multi-cell cavity

2. Full Scale multicell cavities and FN Law



ILC 9cell cavity
TTF shape

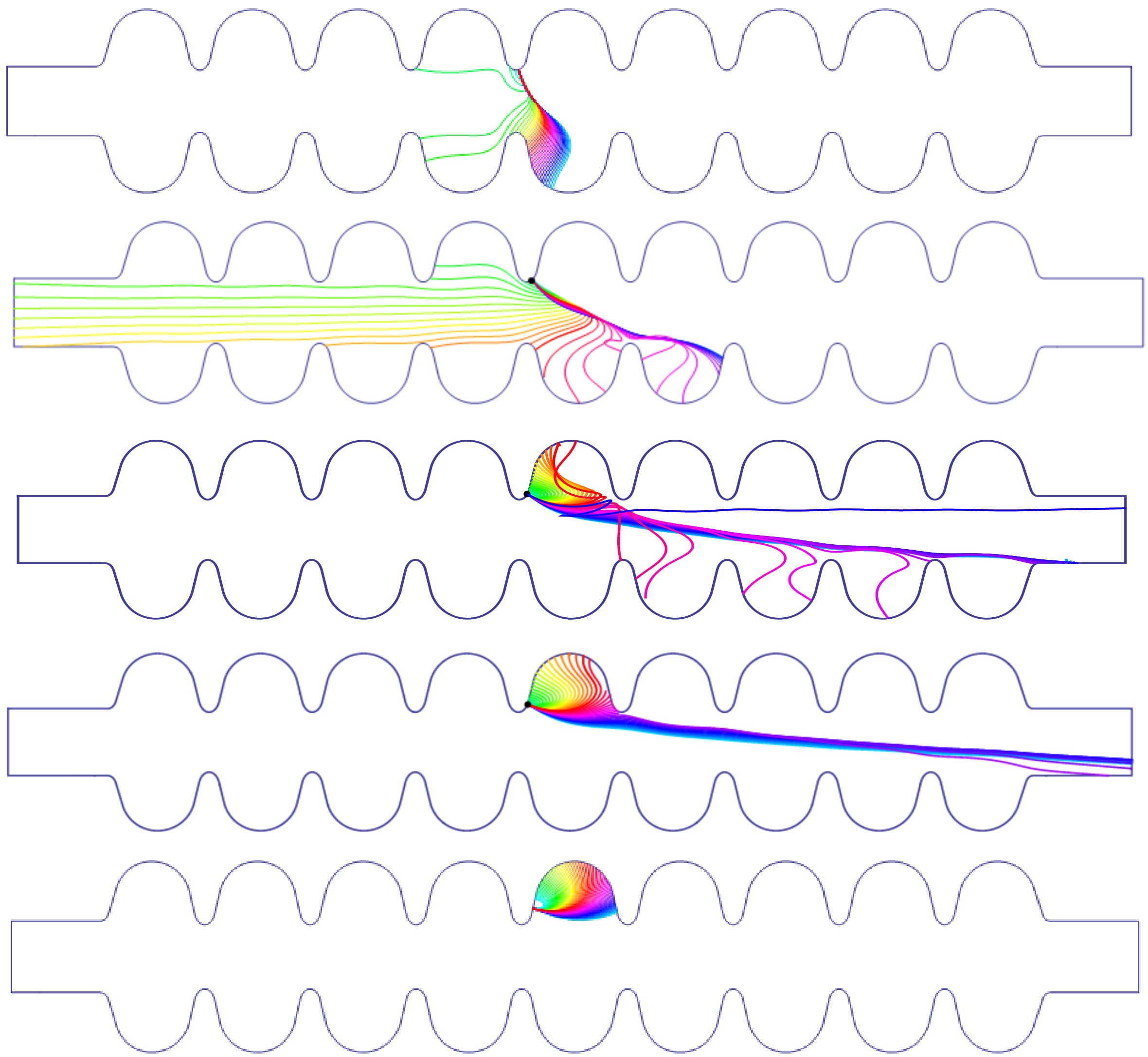


CEBAF Upgrade 7cell cavity
LLC shape

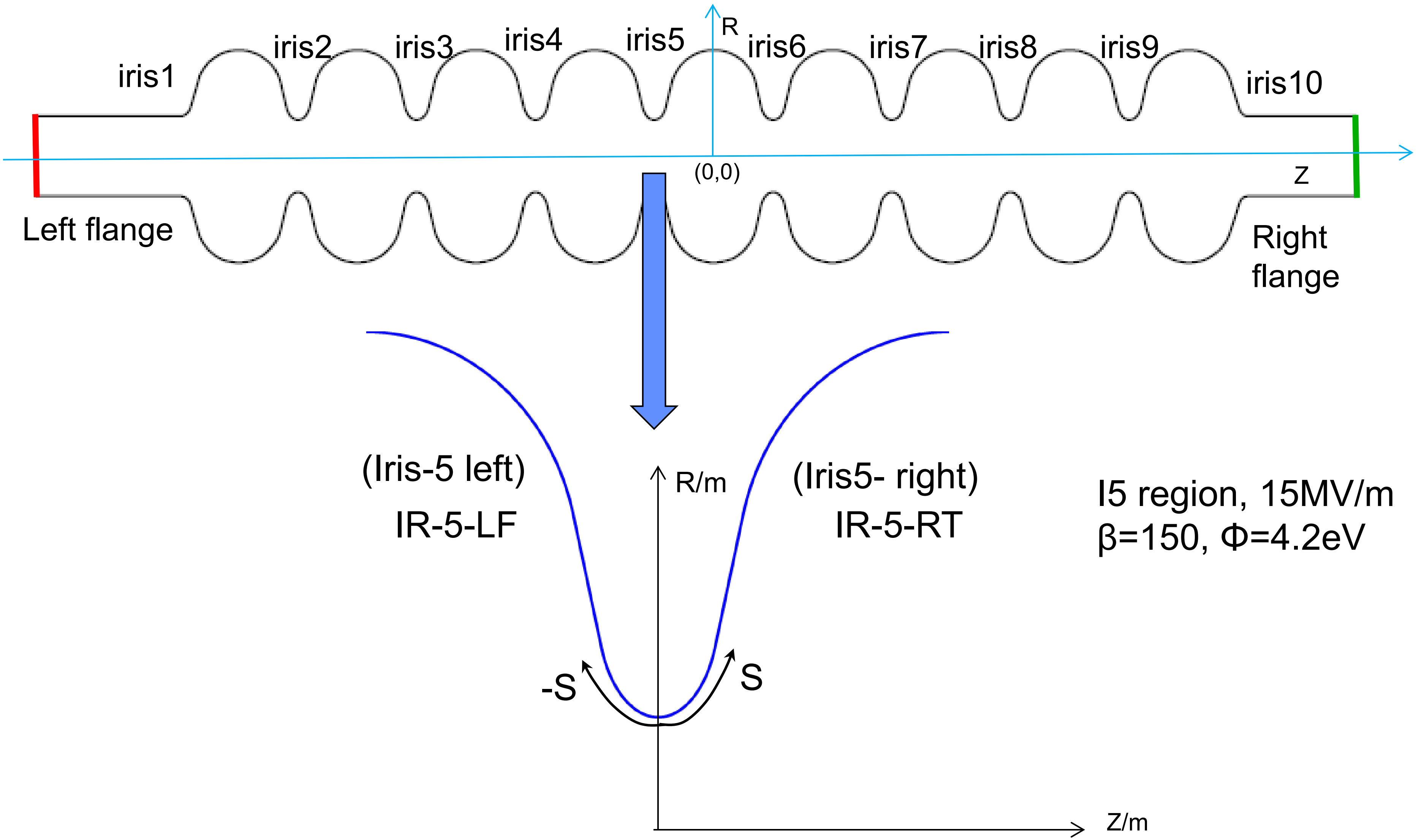
QM tunneling theory predicts exponential Fowler-Nordheim emission current density

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

Trajectories of different Emitters

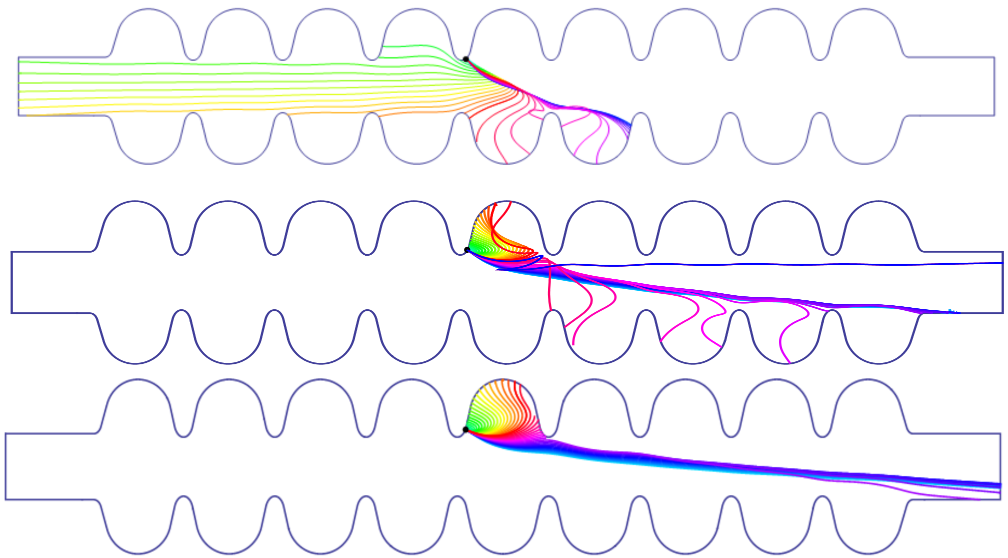


9-cell Model and Definition of Coordinate



I5 region, 15MV/m
β=150, Φ=4.2eV

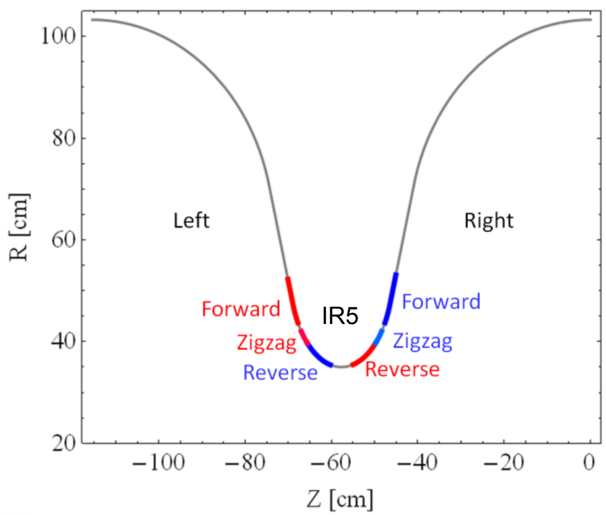
3 Types of "Long Range" Trajectories

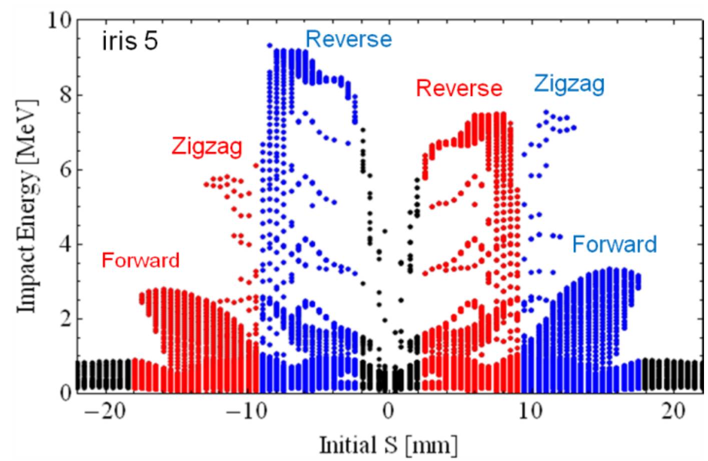


Emission in region
>>> "Reverse type"

Emission in region
>>> "Zigzag type"

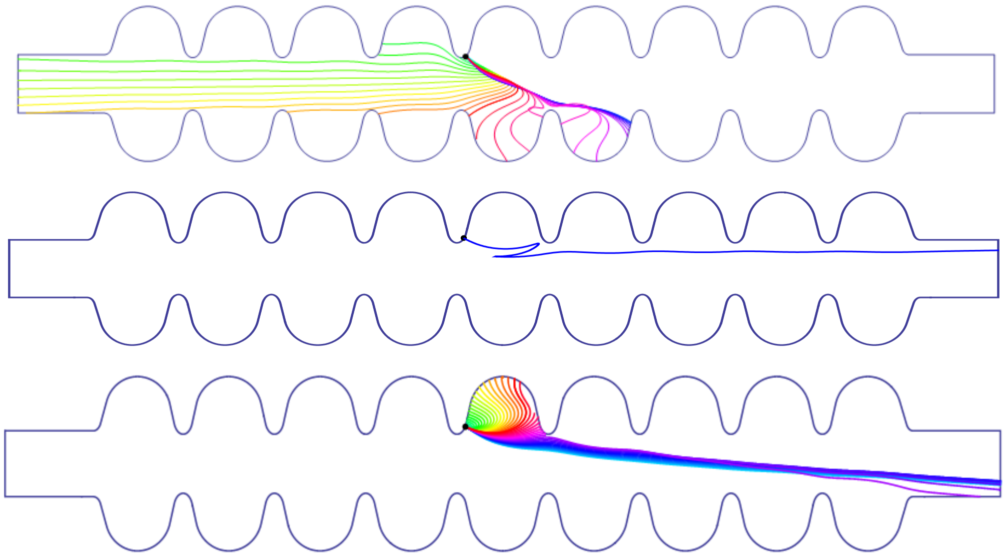
Emission in region
>>> "Forward type"





Impact position VS impact energy distribution

3 Types of “Long Range” Trajectories



Emission in region
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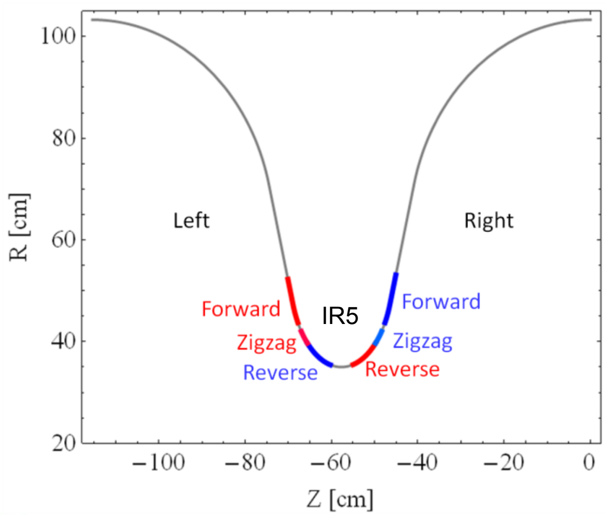
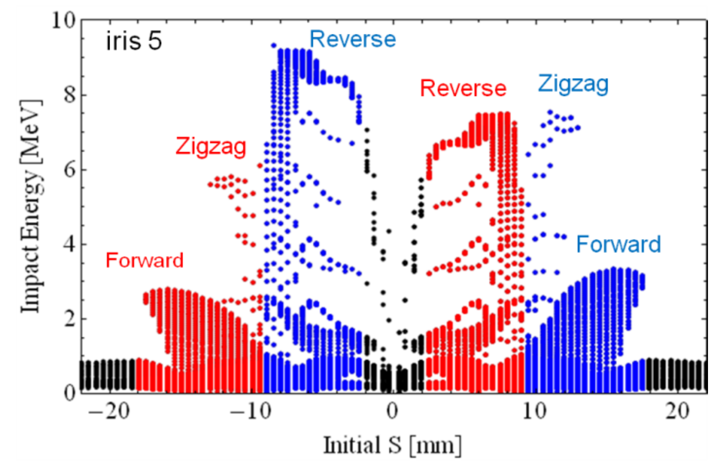
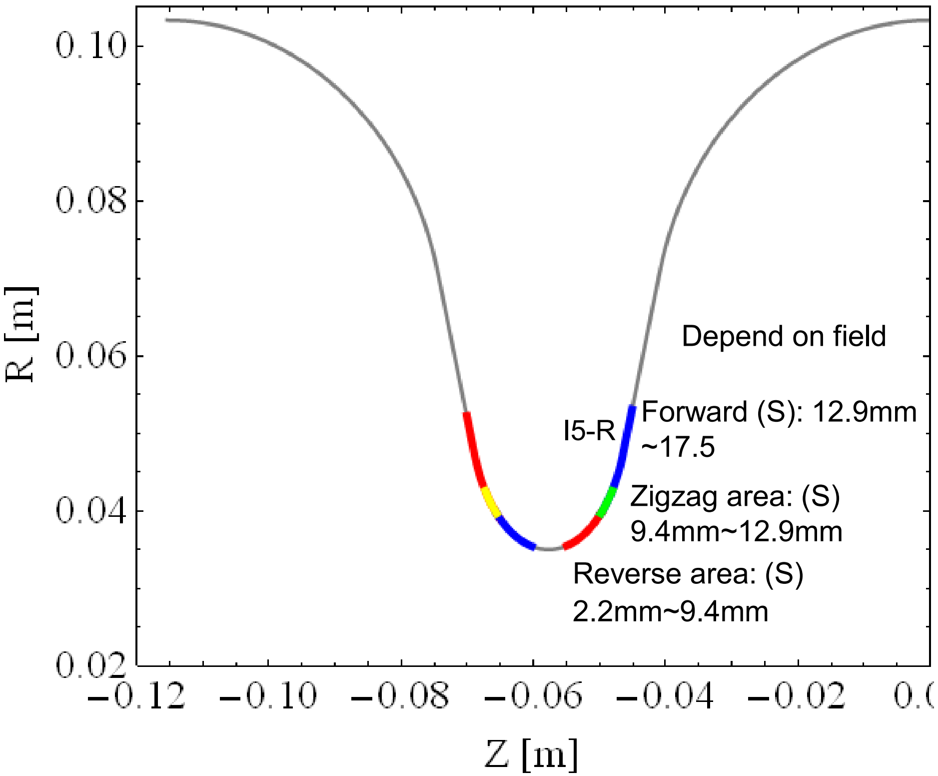
>>> “Forward type”



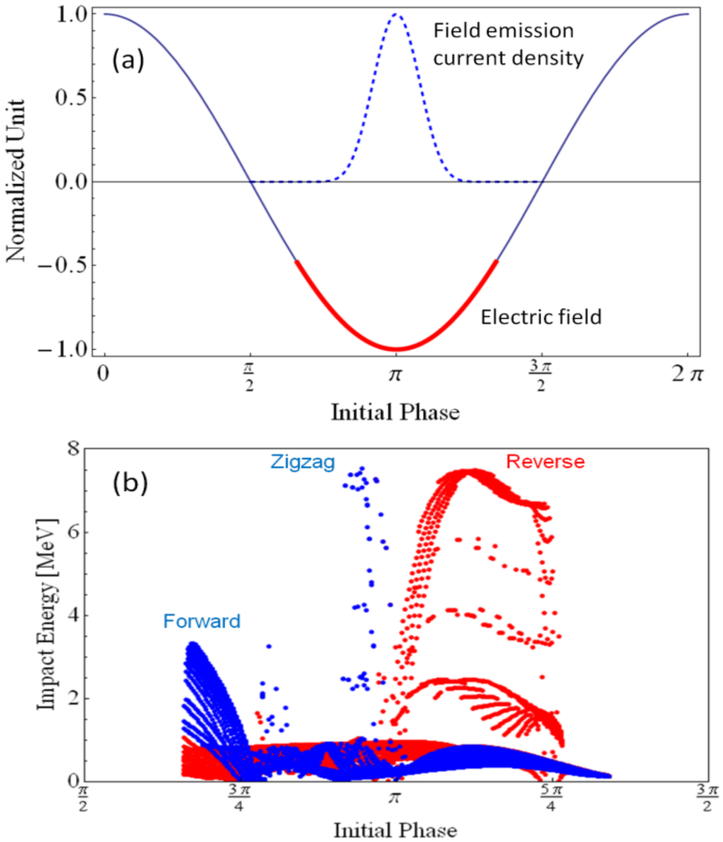


Impact position VS impact energy distribution

Position and phase distribution

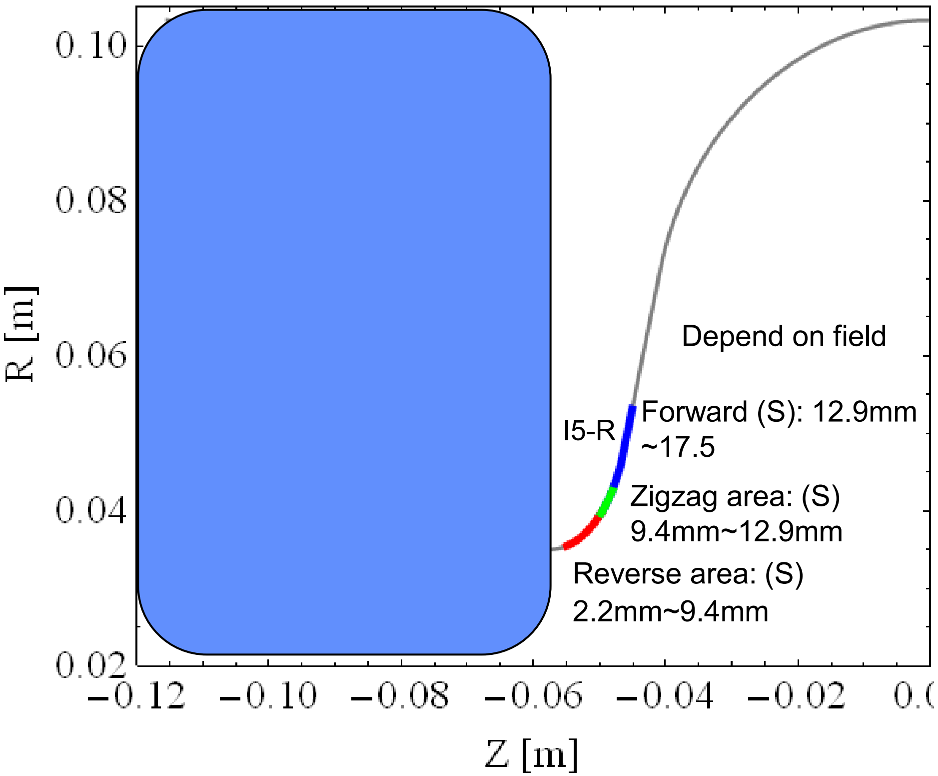


Position distribution

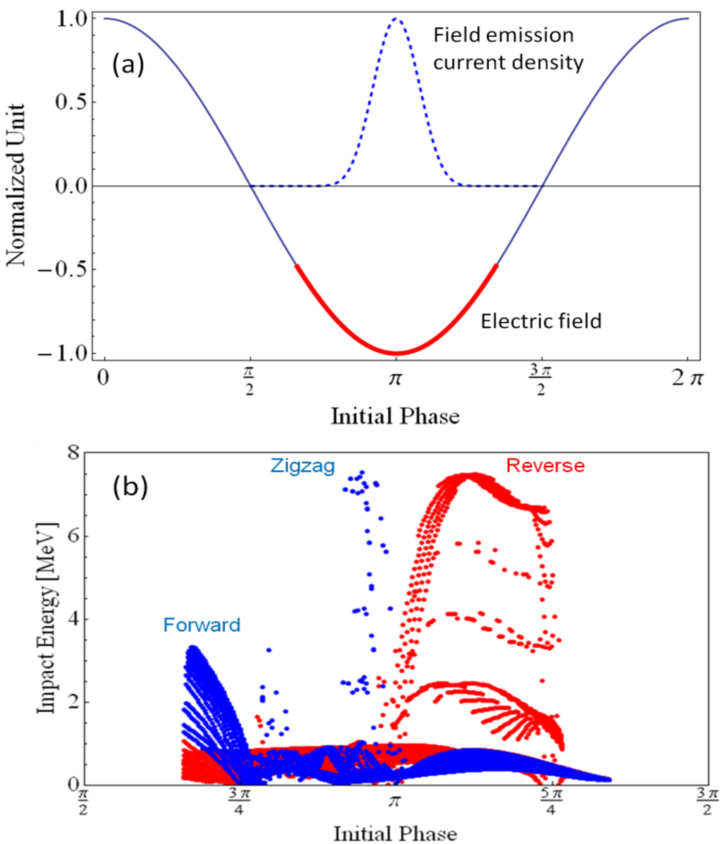


Phase distribution

Position and phase distribution



Position distribution



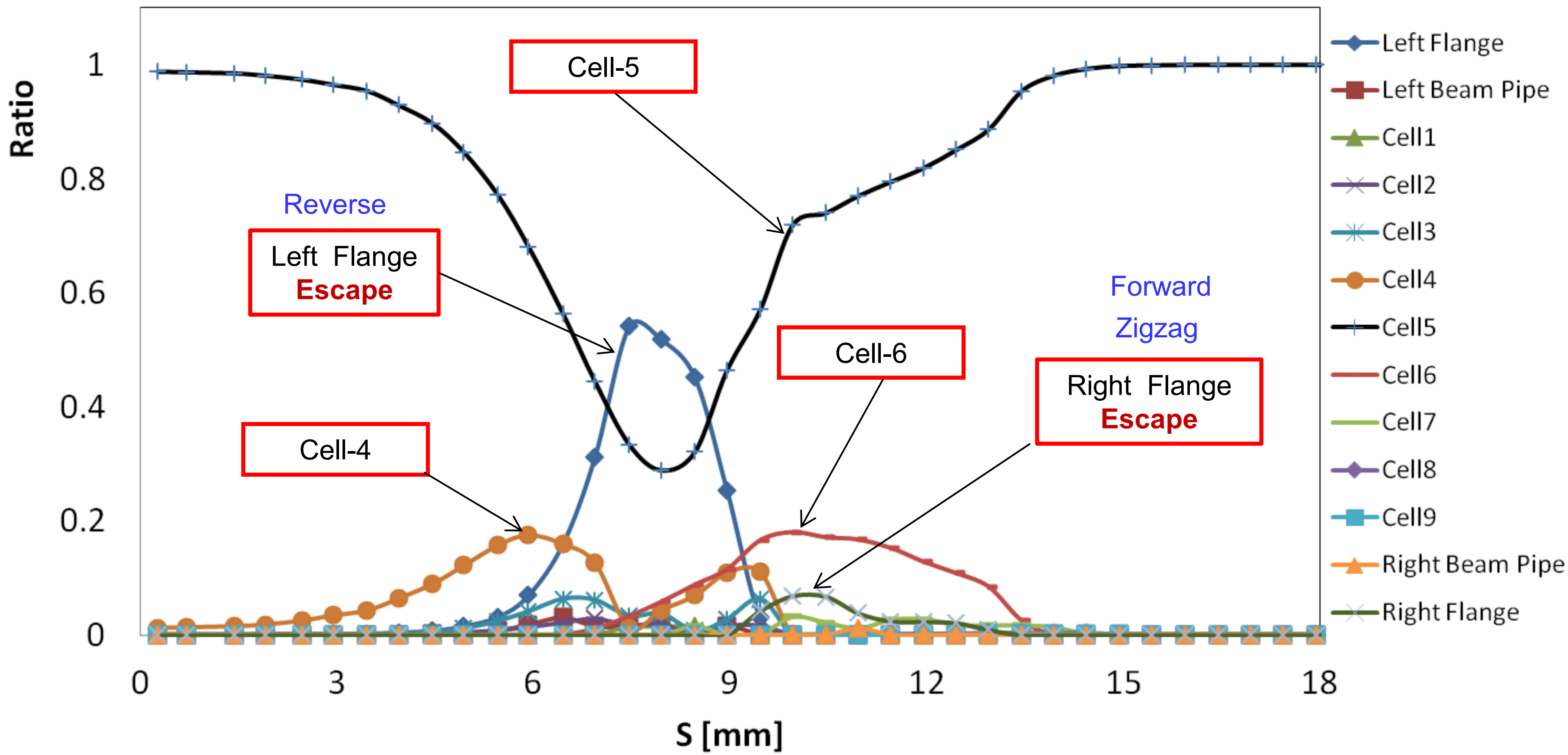
Phase distribution

Ratio of Electrons Escaping Cavity

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

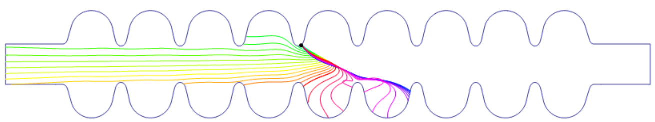
$R_{hc}=N_{hc}/N_{total}$

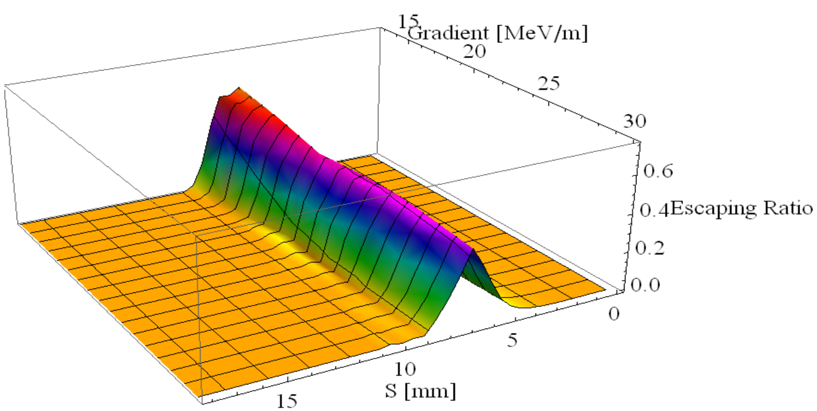
1. R2 electron escaping rate is very high (0.5 at s=0.008m)
2. Most of electrons at hitting at cell 5 (emitter: IR5_RT)
3. R1 escaping is low compare with R2 (less than 8%)



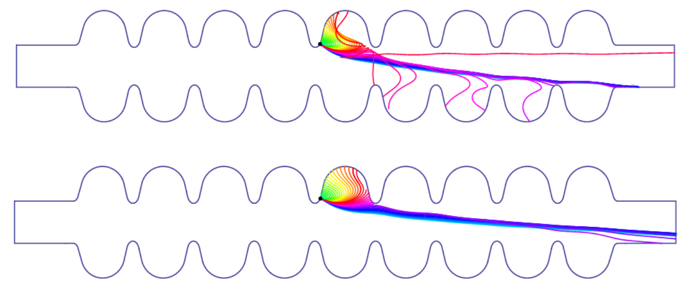
Escaping Ratio

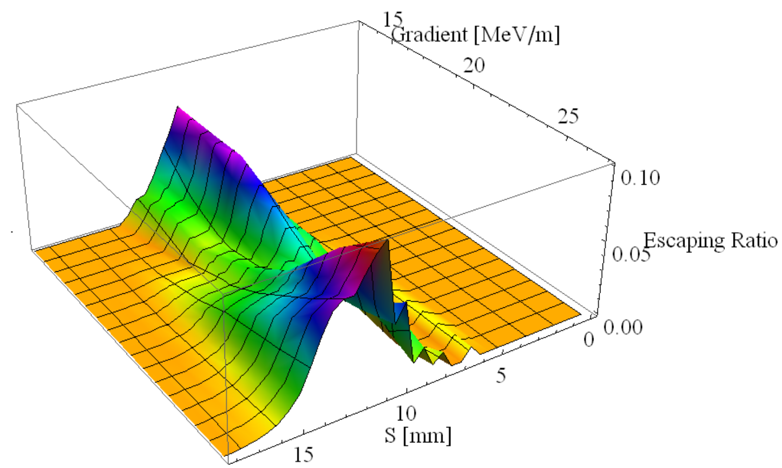
Escaping from Left Flange
“Reverse type” trajectory



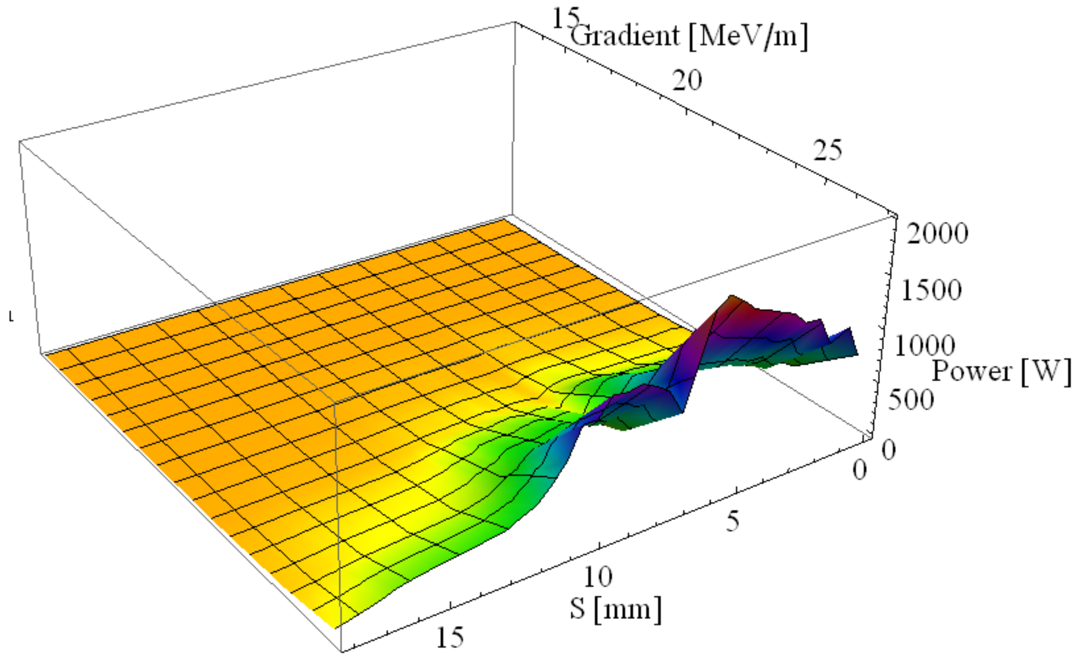


Escaping from Right Flange
“Zigzag type” & “forward type” trajectory



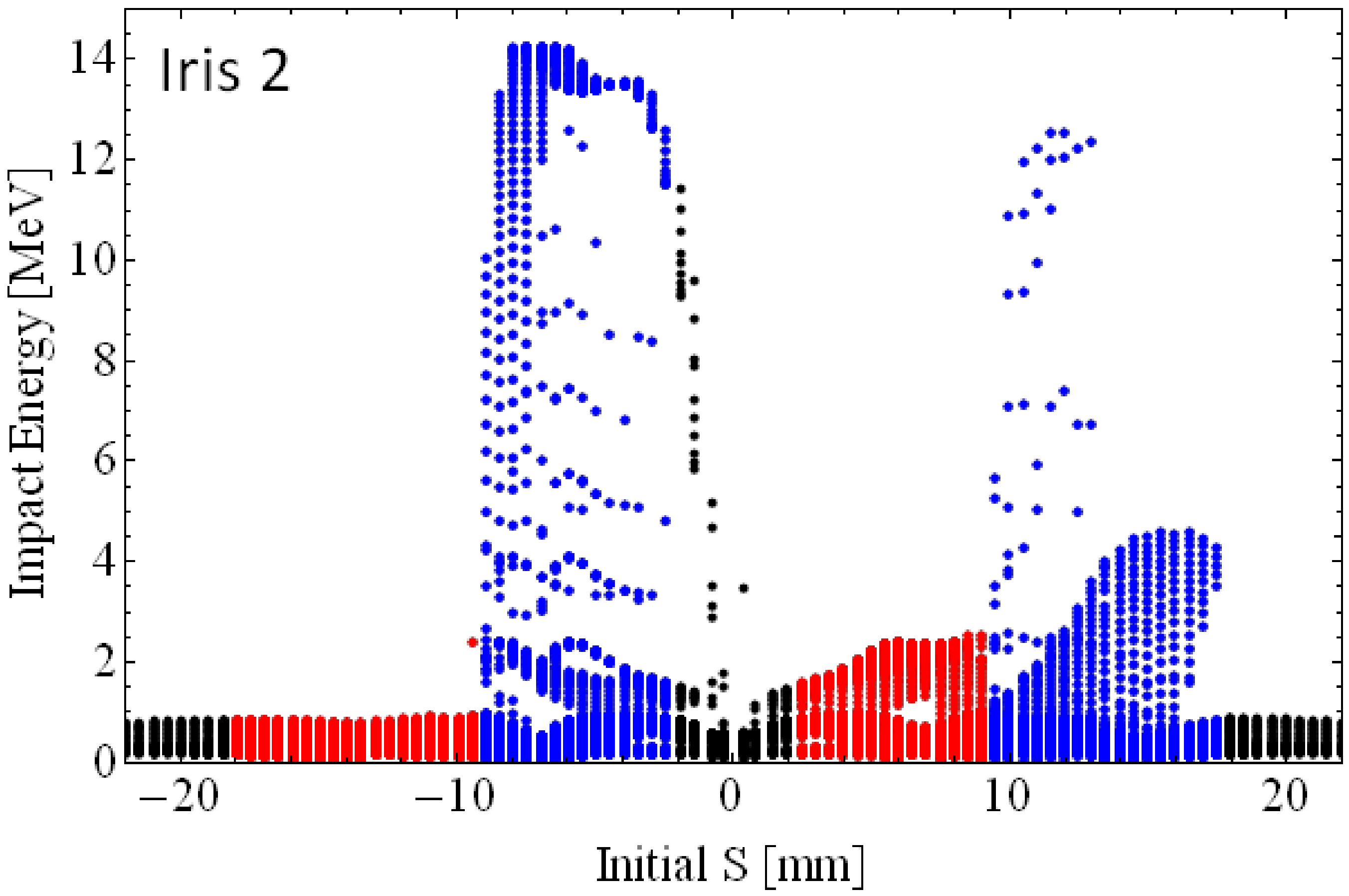


Energy Deposit in Cavity

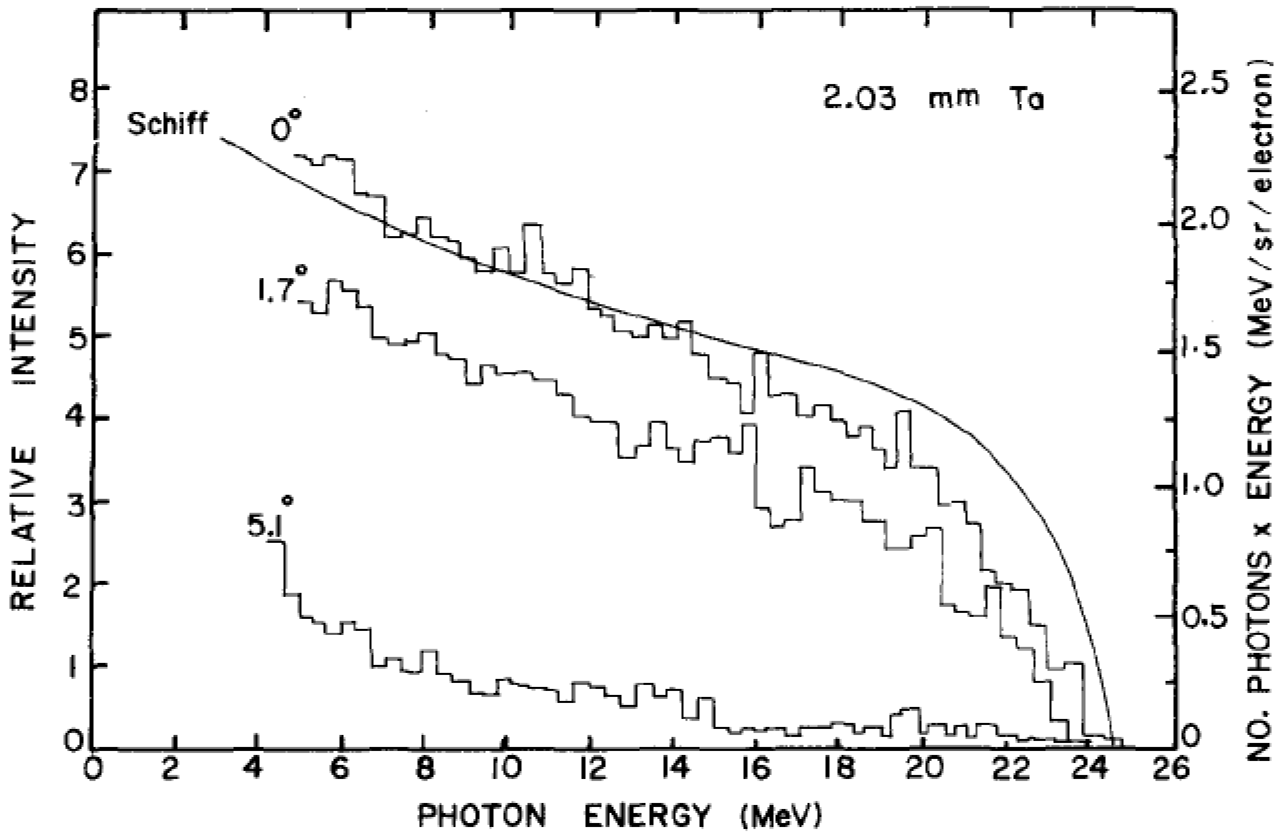


Emitter from reverse and zigzag regions [s] is very important considering the energy deposit in the cavity and escaping ratio of the electron.

Impact Energy with Iris



Bremsstrahlung



Electron Energy=25 MeV

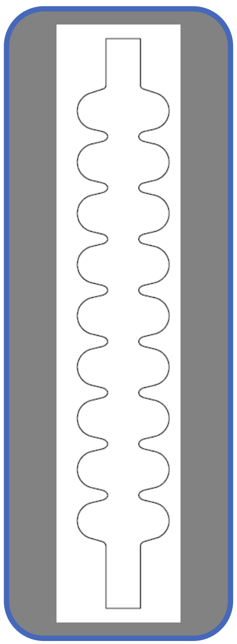
[1] R.P Lambert, J.W. Jury and N.K. Sherman, Nuclear Instruments and Methods 214 (1983) 349-360

Experiment: 9-cell cavity RI23

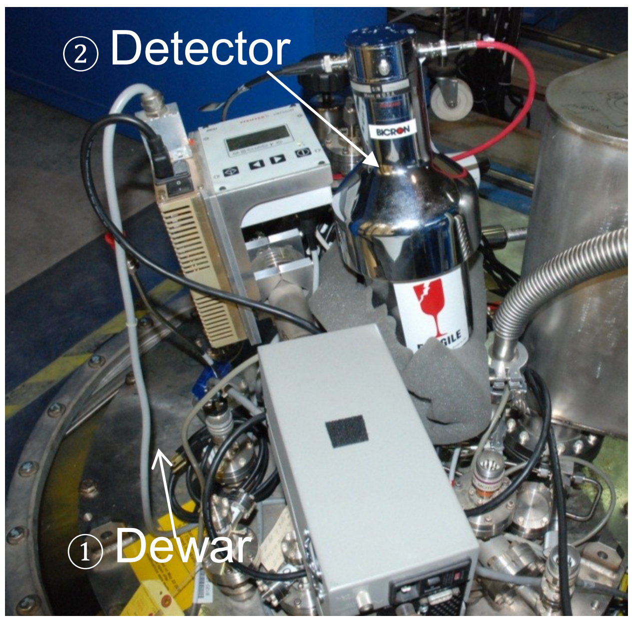
γ energy spectrum measurement system

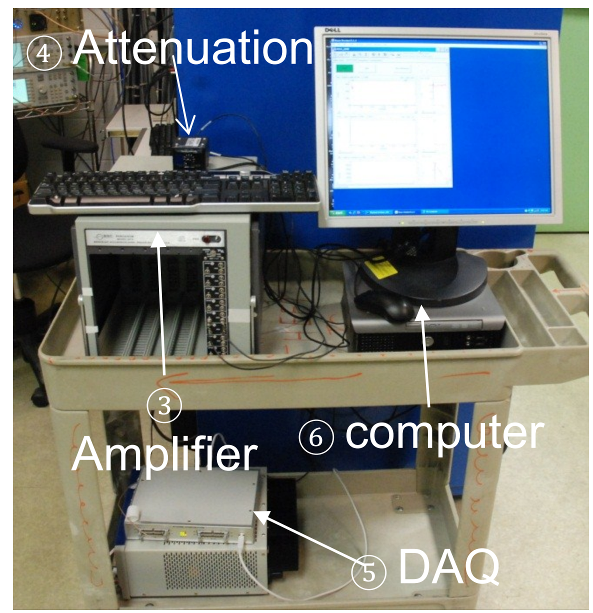
High Voltage

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



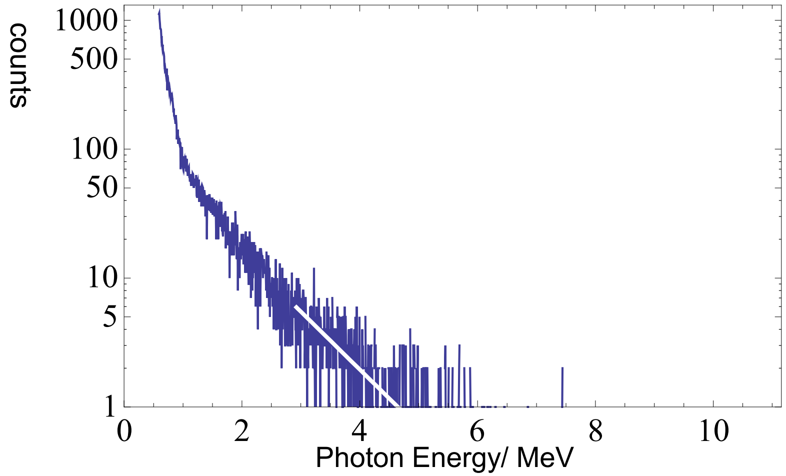
① Dewar



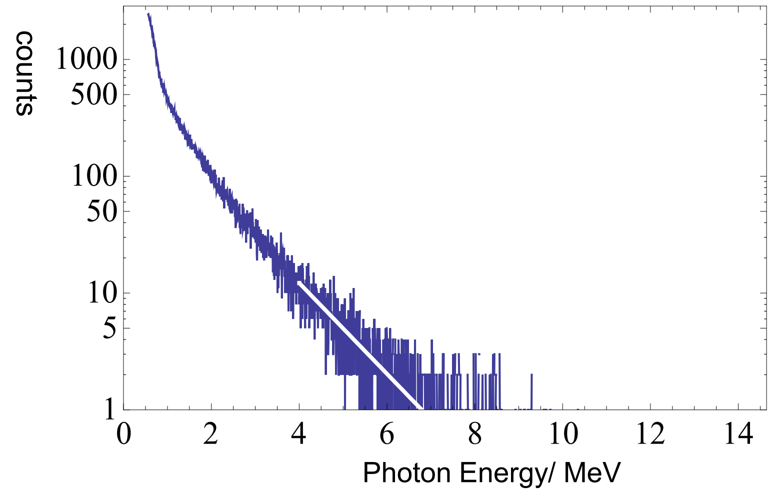


Energy Spectrum from NaI(Tl) Crystal

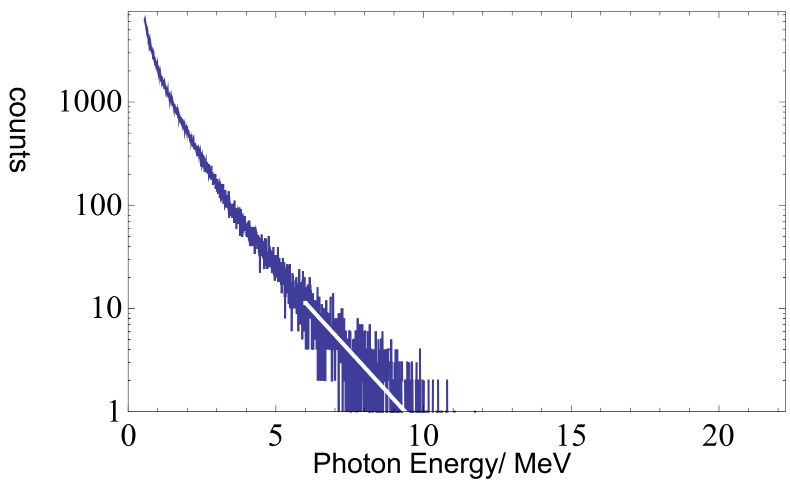
End Point Energy Fitting



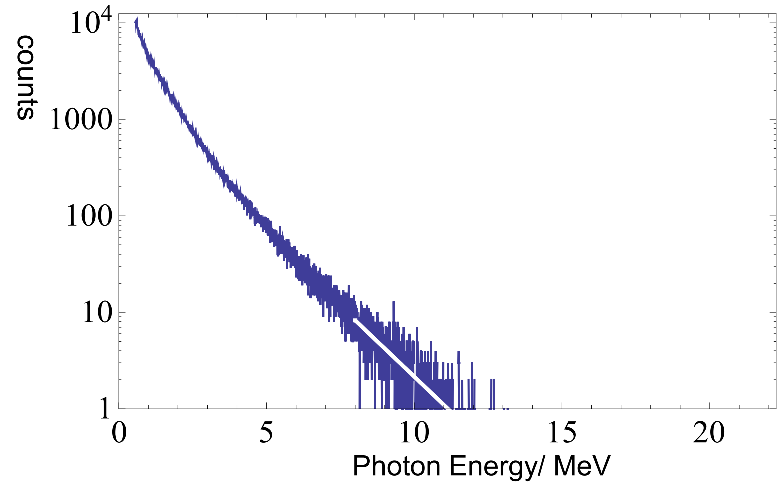
Pi mode 10MV/m Ep=4.3MeV



Pi mode 11MV/m Ep=6.8MeV



Pi mode 12MV/m Ep=9.4MeV



Pi mode 13.1MV/m Ep=11.14MeV

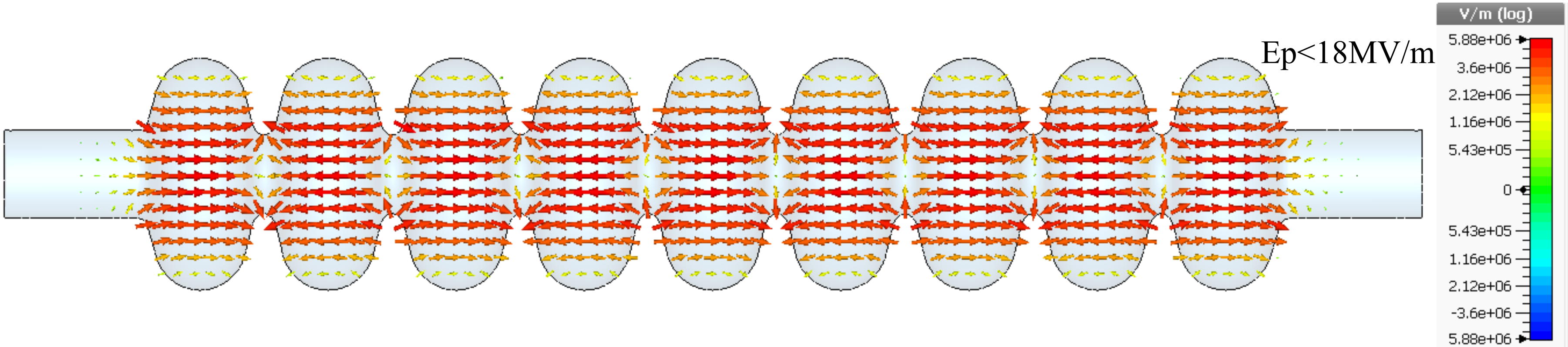
End point Energy

π measurement		
Field Gradient MV/m	End point Energy MeV	Note
10	4.5	Field emission starts at about 9 MV/m
11	7.0	
12	9.1	
13	11.0	
14	13.0	
15	15.1	detector saturated
16	17.9	detector saturated

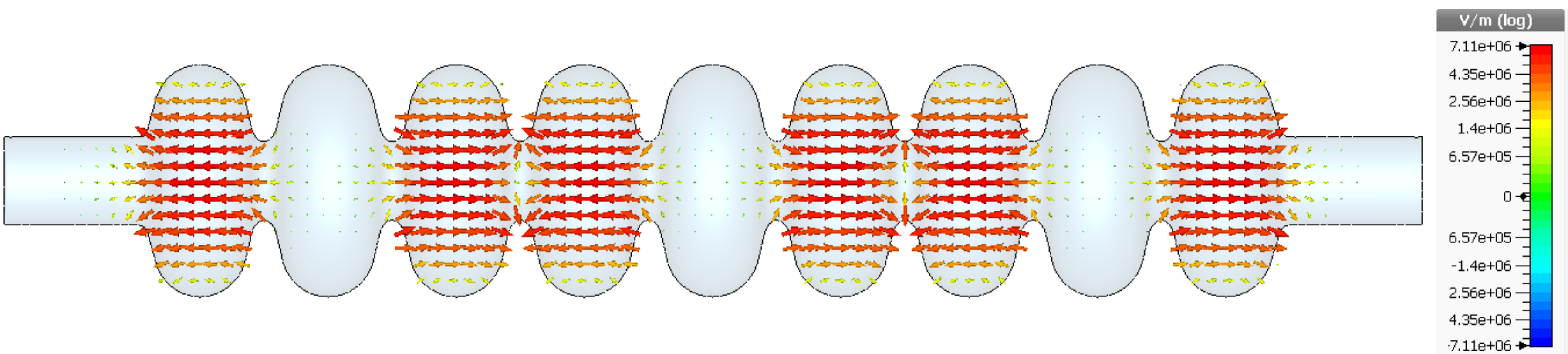
7/9 π mode measurement		
Field Gradient [end cell] MV/m	End point Energy MV/m	Note
14	2.3	Field emission starts at about 13.5MV/m
16.2	3.2	
18	3.9	
21	5.8	
22	6.8	
24	8.9	
26	12.1	detector saturated

Field emitter location

1. π mode Field emission onset about 9 MV/m

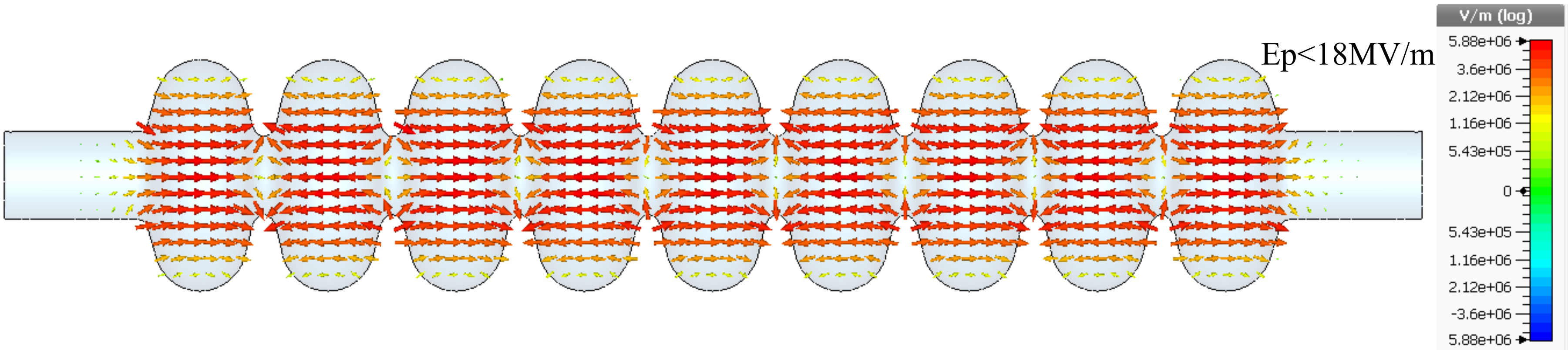


2. 6/9 π mode Field emission onset 30MV/m (end cell)



Field emitter location

1. π mode Field emission onset about 9 MV/m



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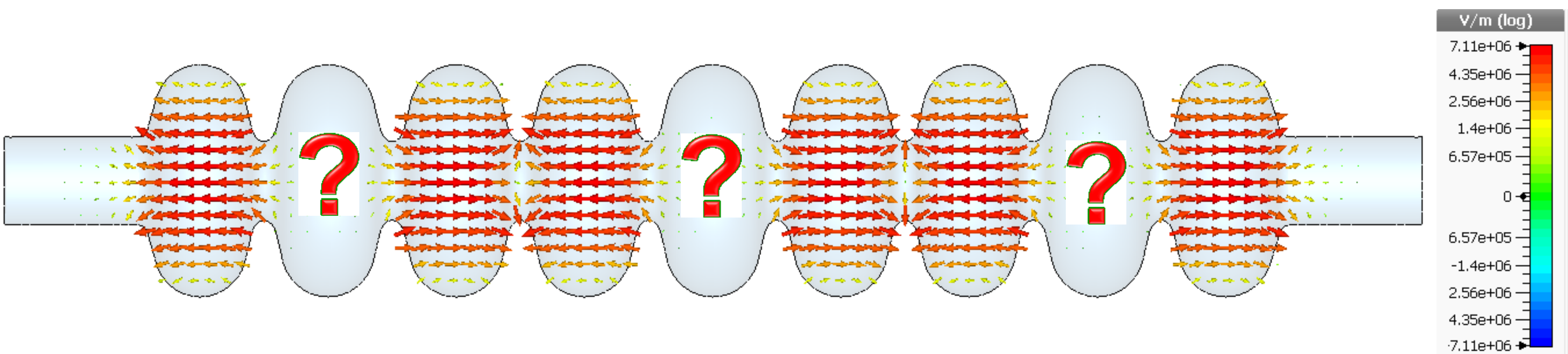
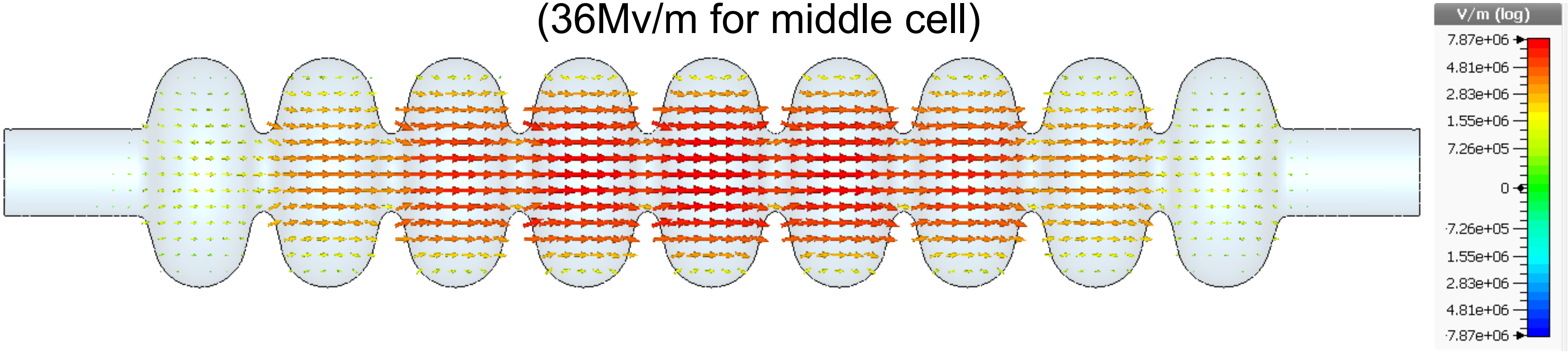


Field emitter location

3. 1/9 π mode Field emission onset 5.7MV/m (end cell)
(36Mv/m for middle cell)



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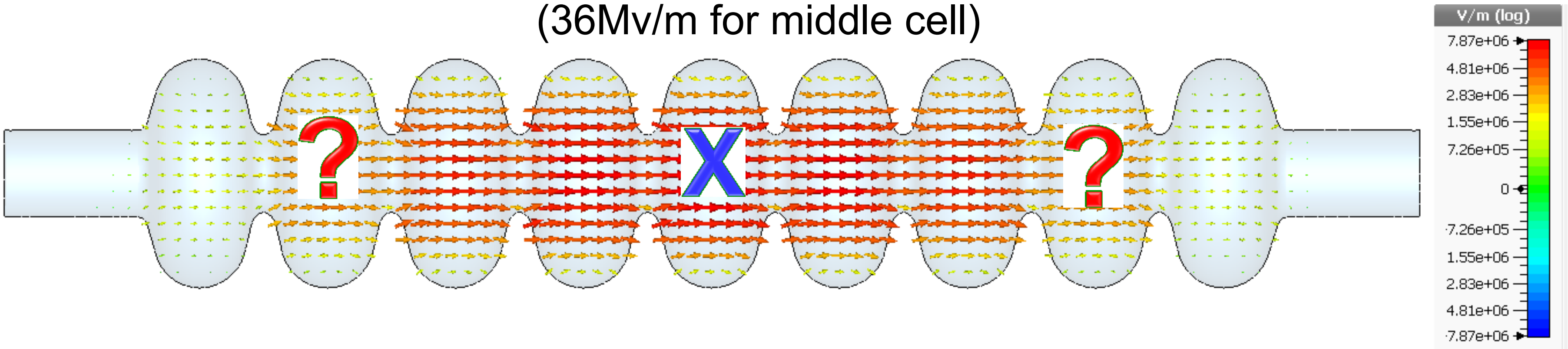
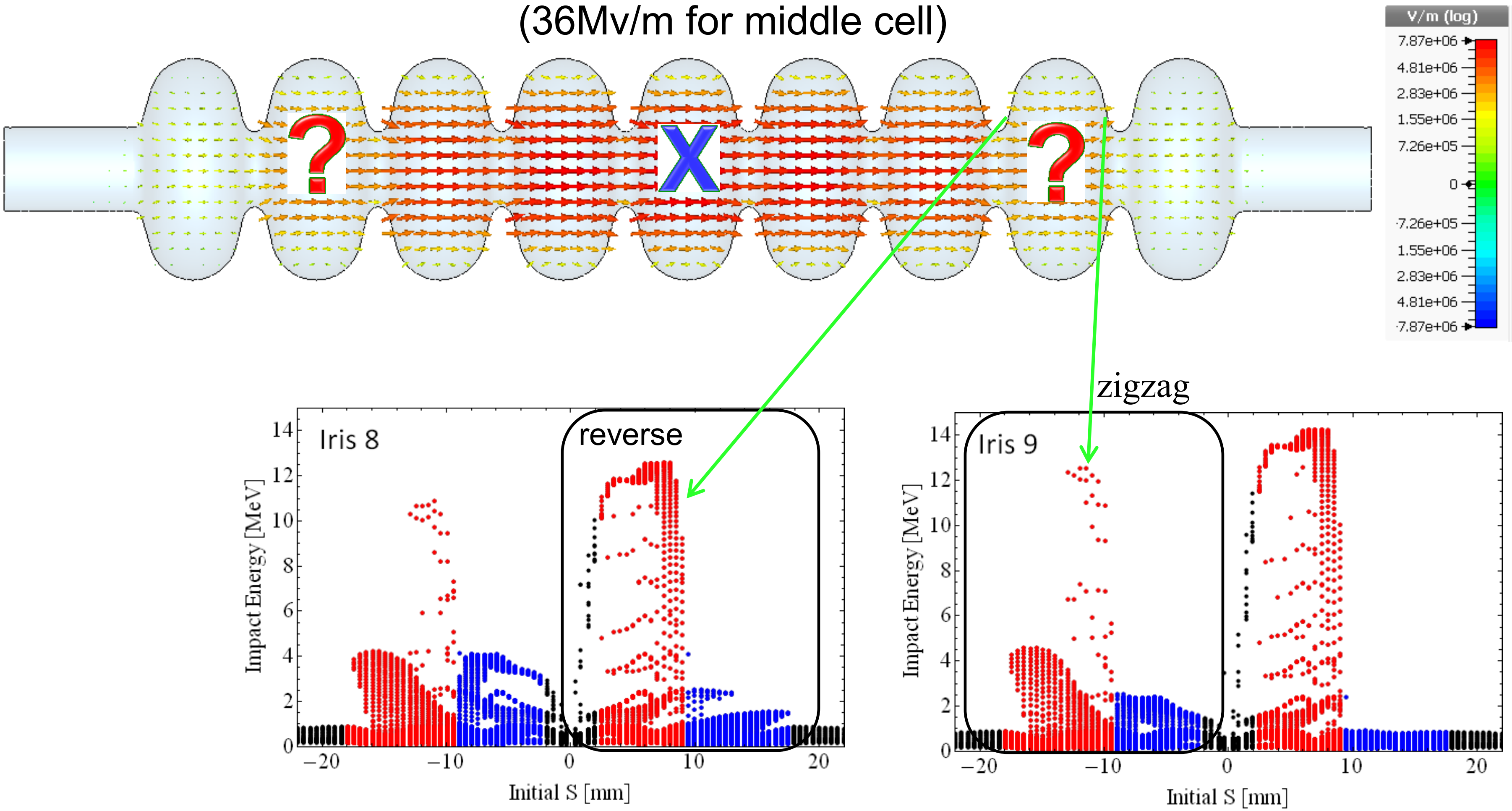


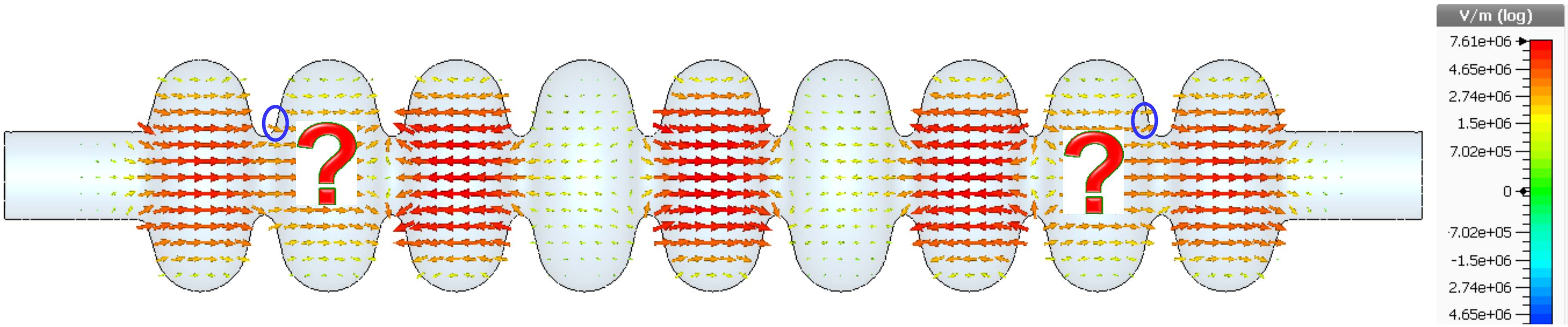
Field emitter location

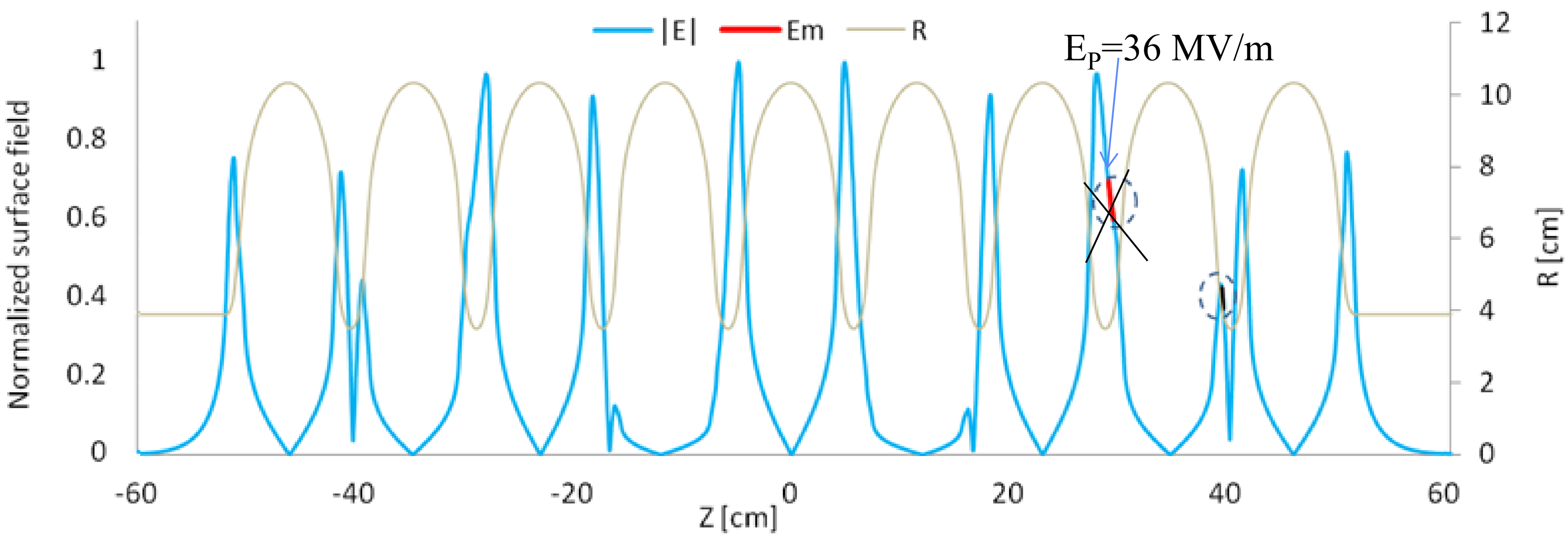
3. 1/9 π mode Field emission onset 5.7MV/m (end cell)
(36Mv/m for middle cell)



Field emitter location

4. 5/9 π mode Field emission onset 28MV/m (end cell)



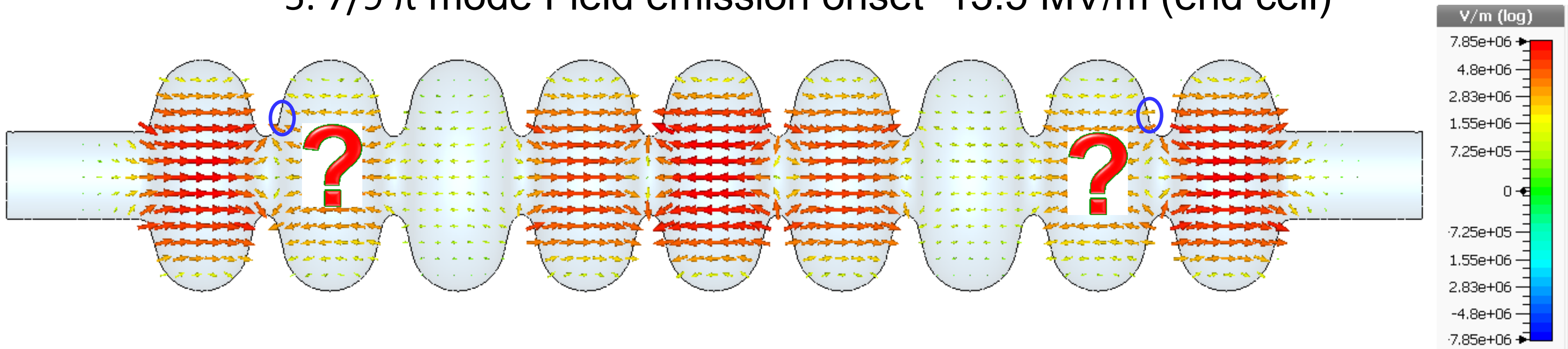


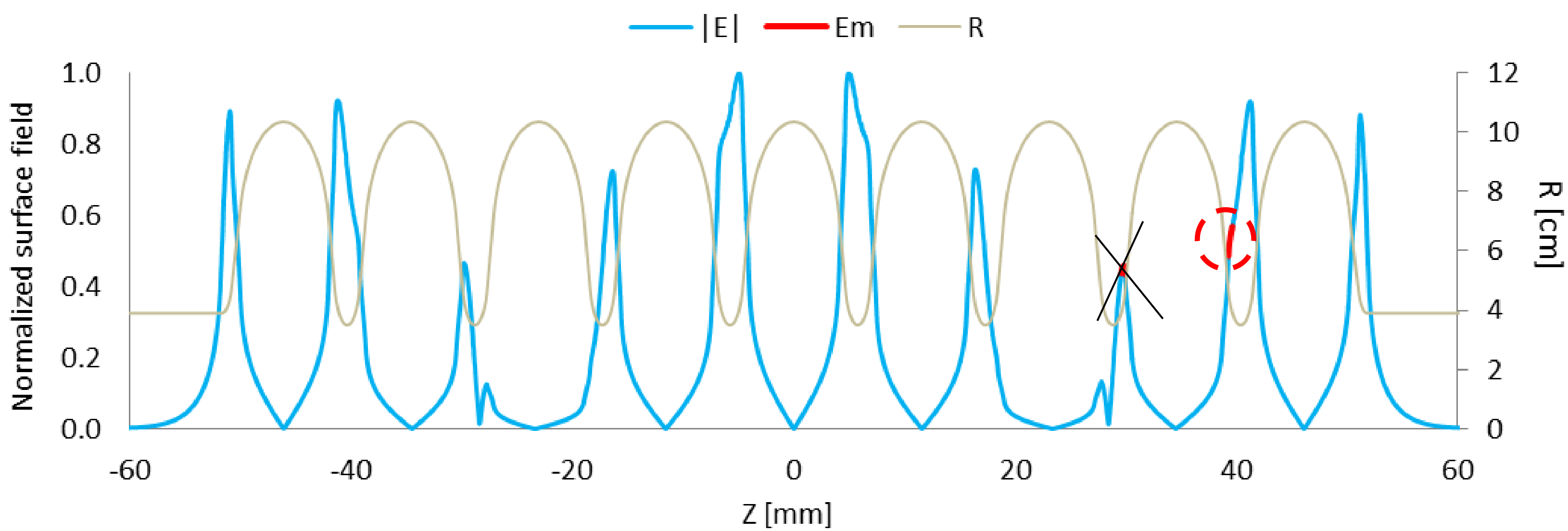
Jefferson Lab

Peking University

Field emitter location

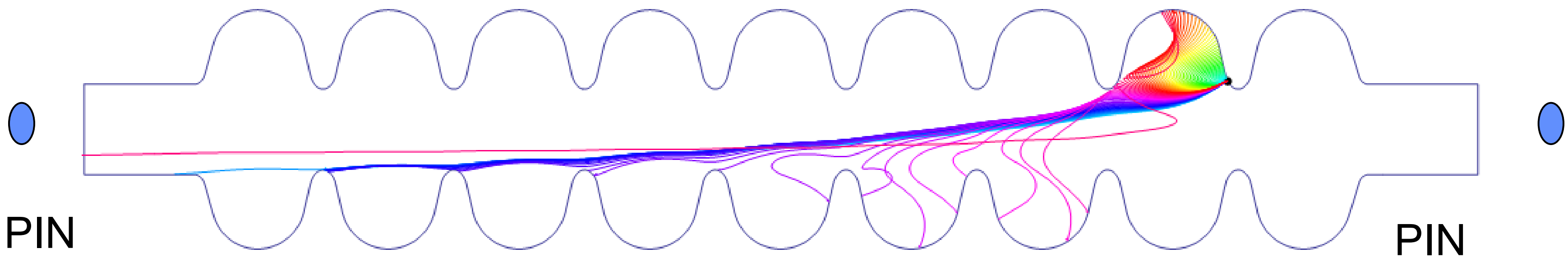
5. 7/9 π mode Field emission onset 13.5 MV/m (end cell)





Field emitter location

Radiation measurement



PIN detectors LF

PIN detector RT

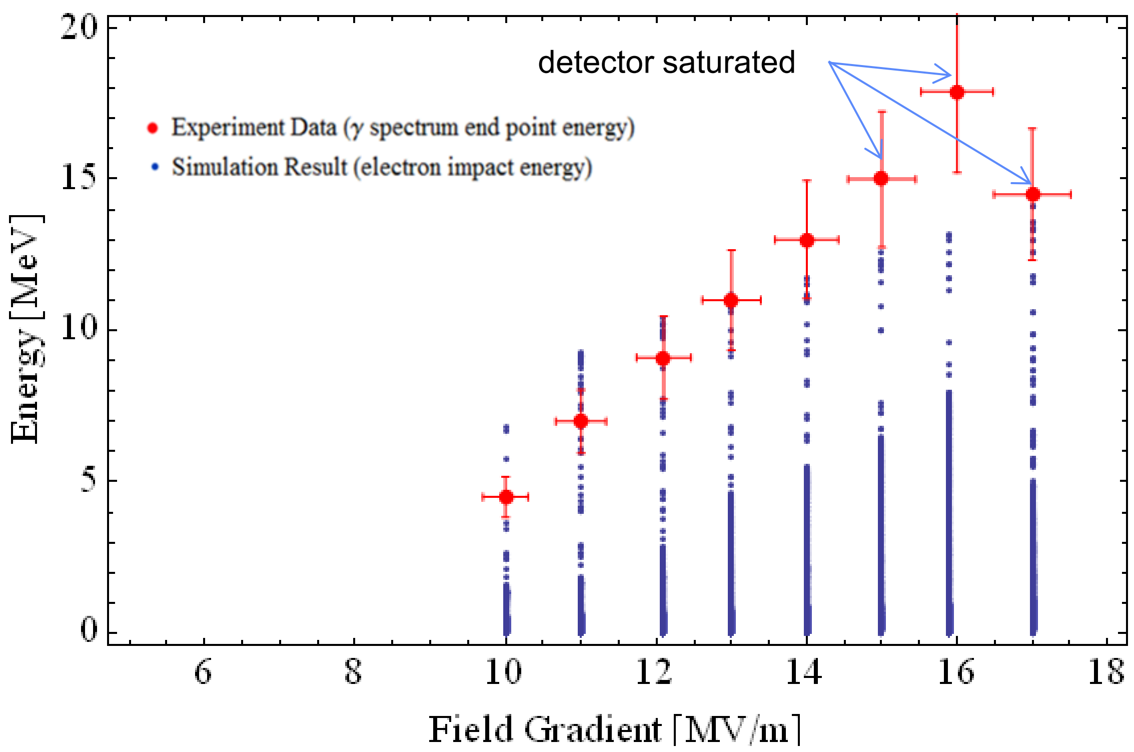
Field emission region is: Iris 9, -9.9mm~-12.2mm [S]

Correlation between Simulation and Measurements

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

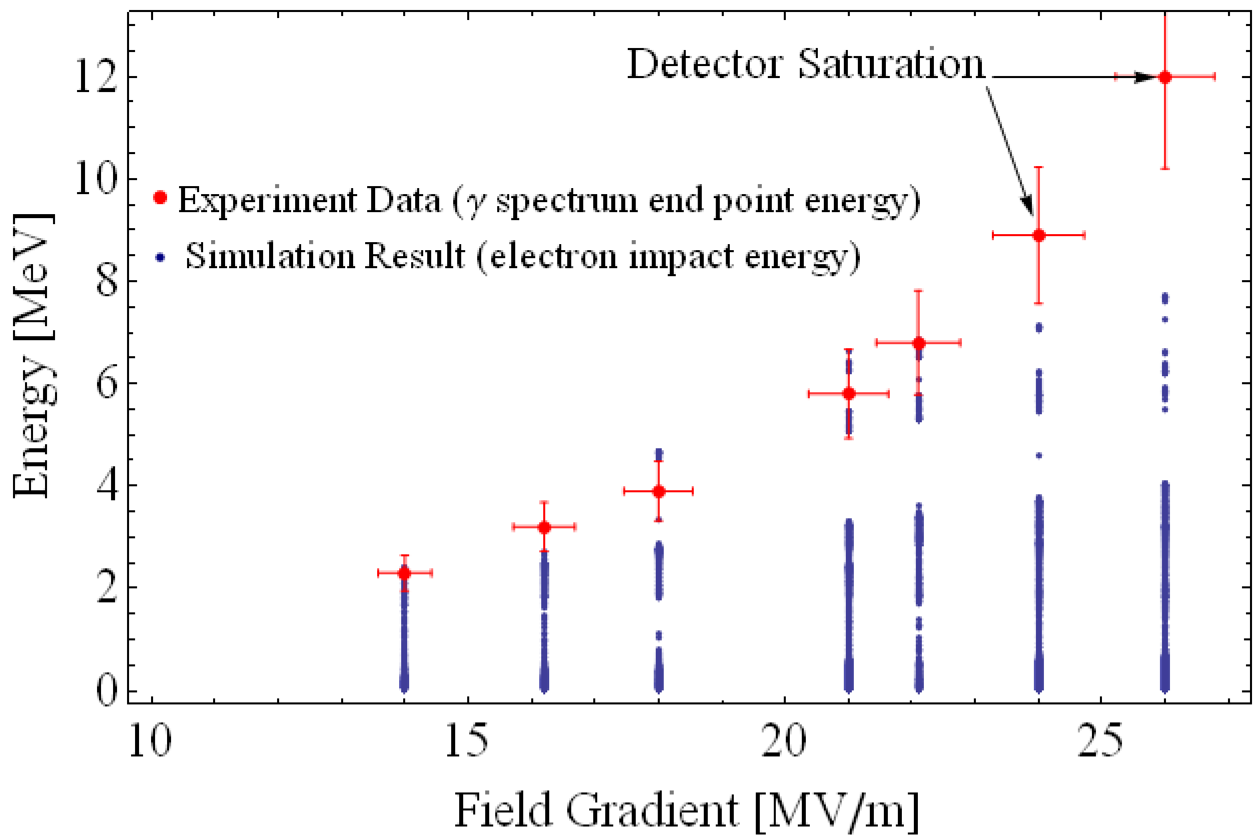
Identification

Field emission onset
1.π mode 9MV/m
2.6/9 π mode 30MV/m
3.1/9 π mode 5.7MV/m
4.5/9 π mode 28MV/m
5.7/9 π 13.5MV/m
6.Radiation at bottom is much higher than that at top

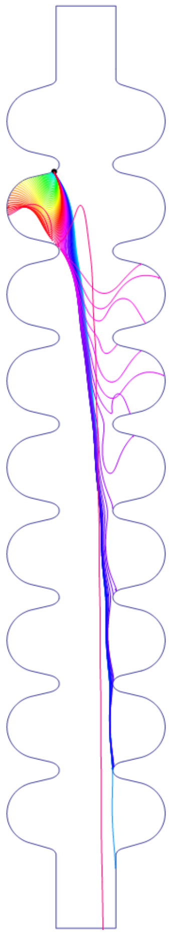


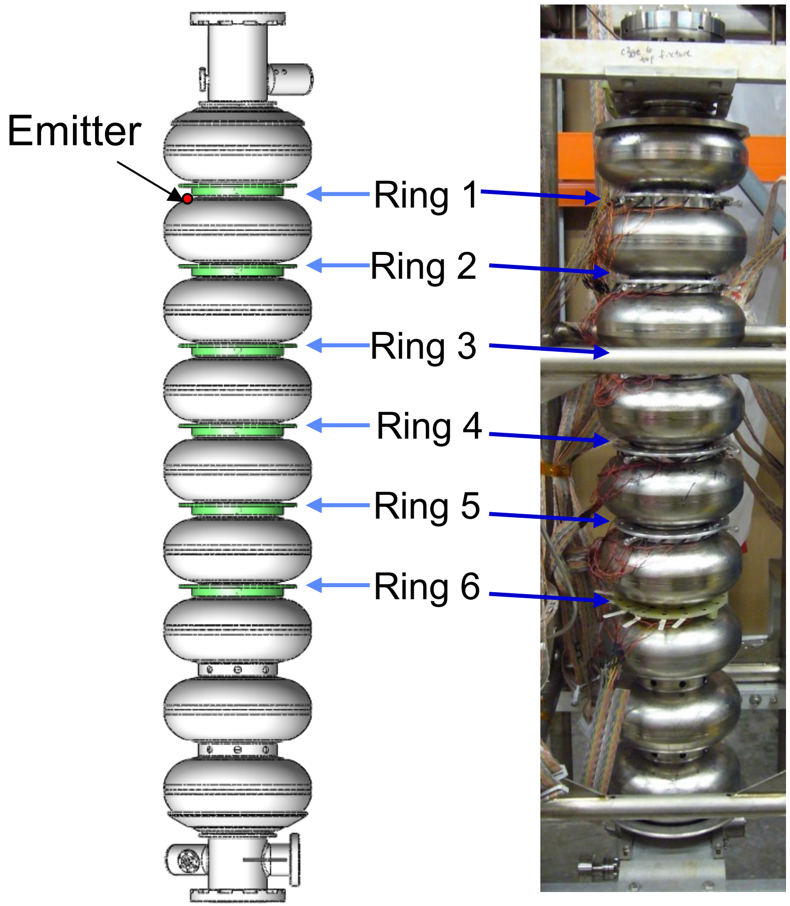
Correlation at another Pass-Band Mode

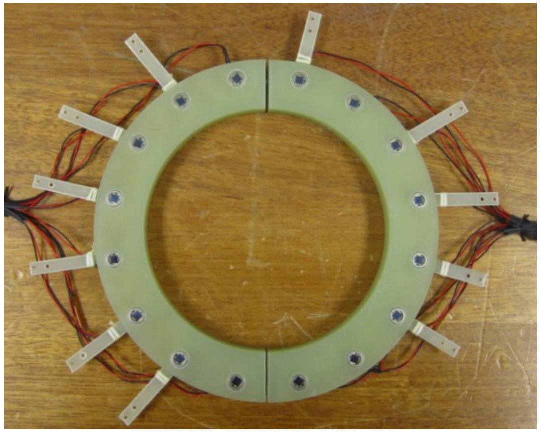
Calculated impact energy of field emission electrons and measured end point energy in γ spectrum 7/9**π** mode



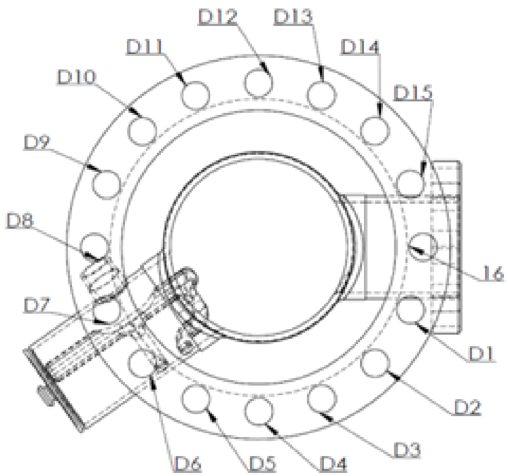
Radiation angular location measurement system





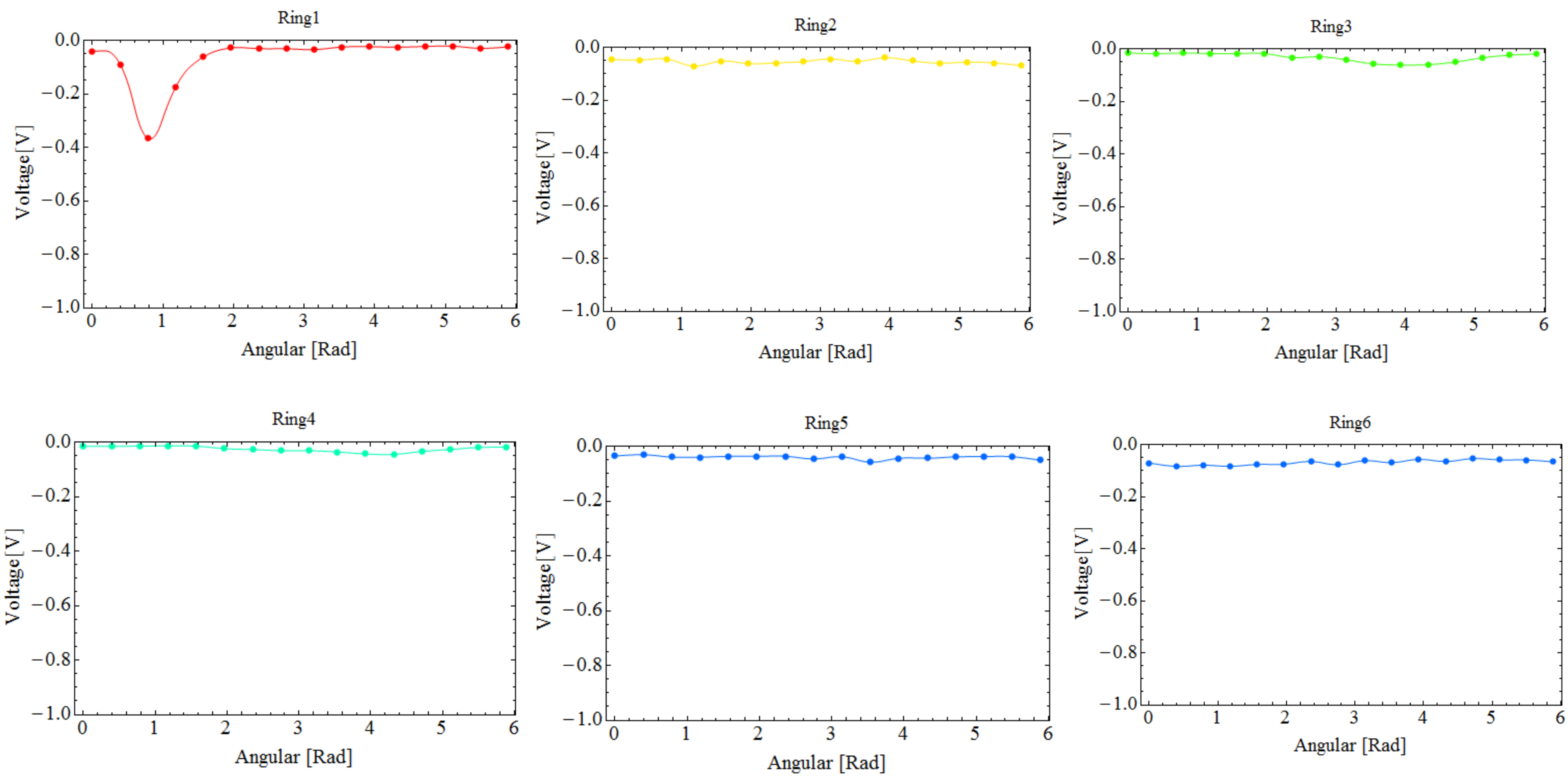


Hamamatsu S1223-01



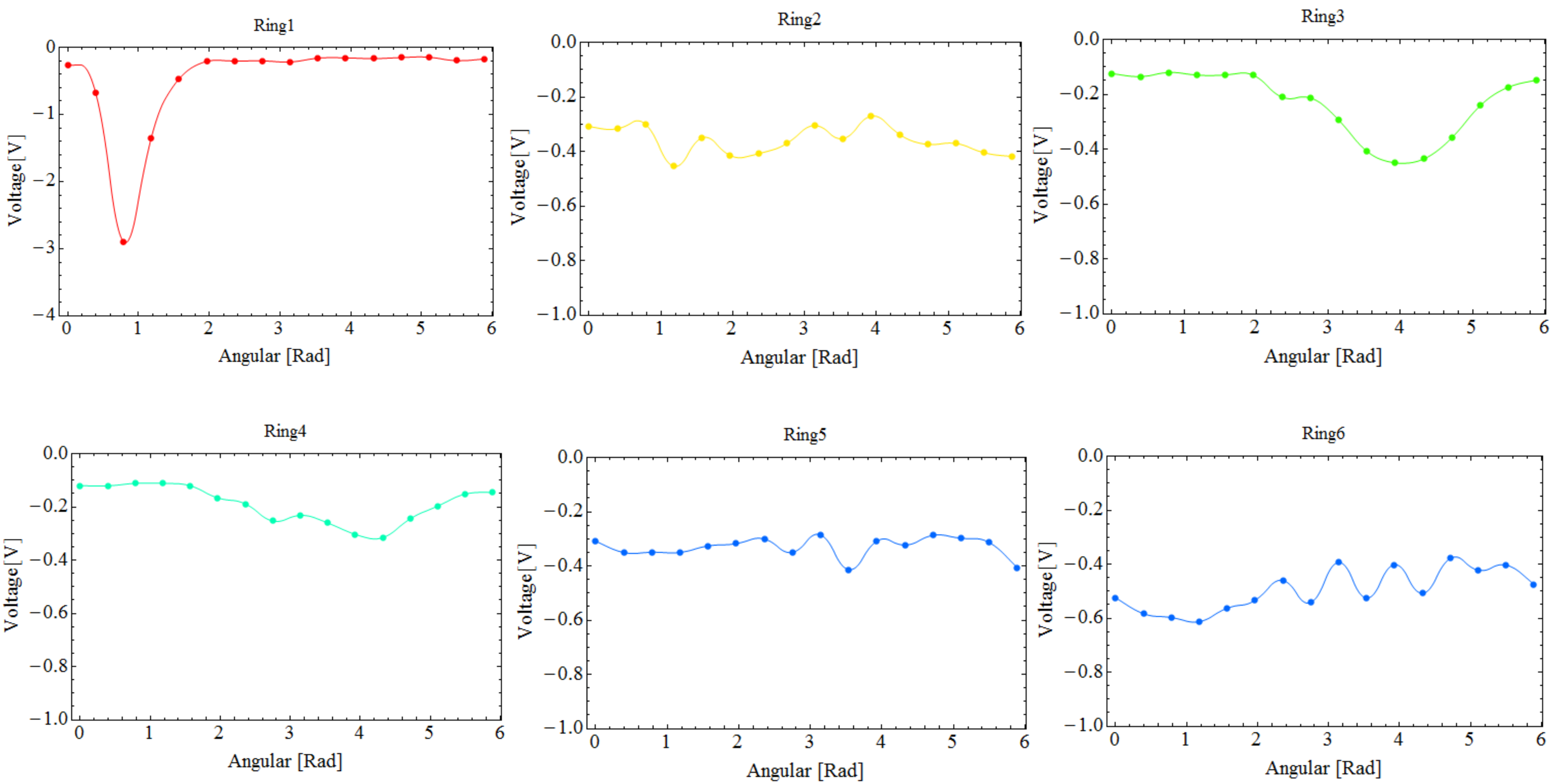
Detector Signal Angular Distribution

Eacc=14.9 MV/m

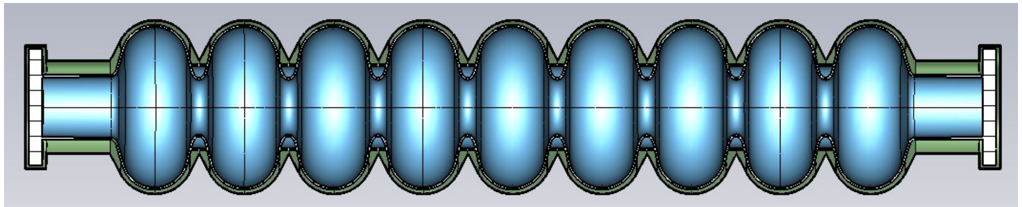


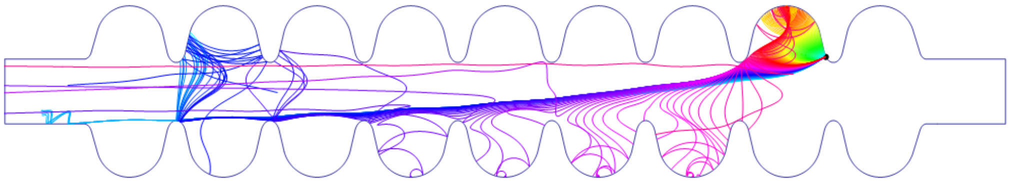
Detector Signal Angular Distribution

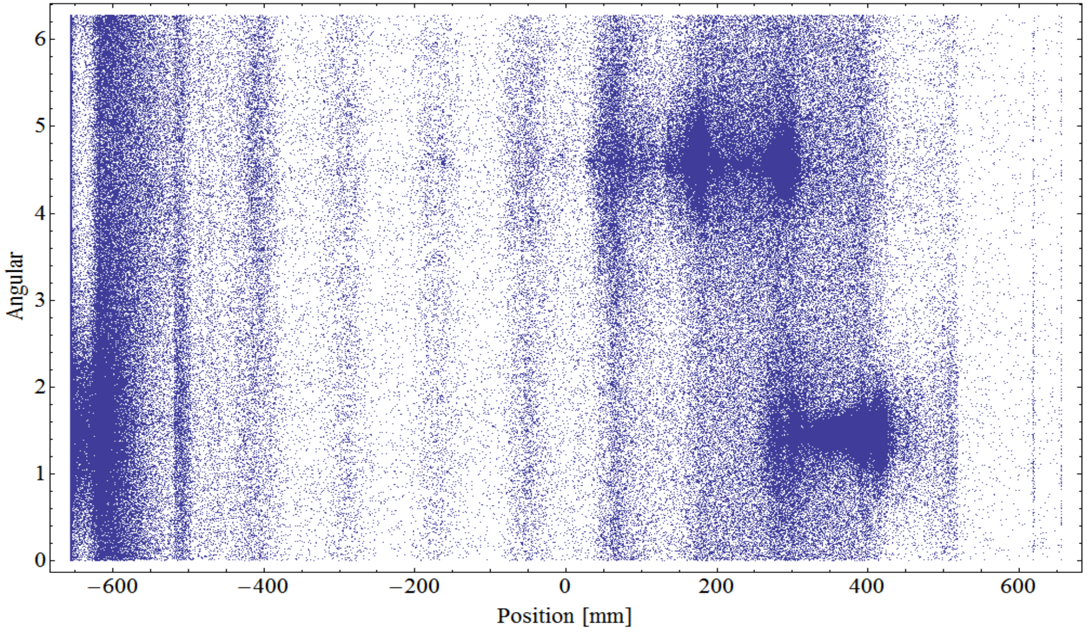
Eacc=17.5 MV/m

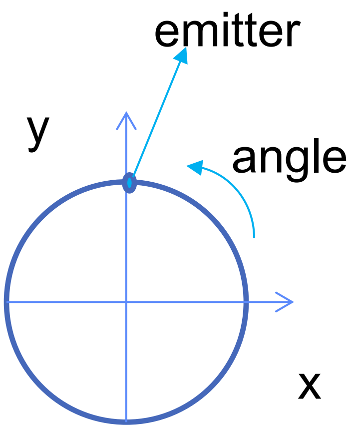


Photon Simulation from emission electrons





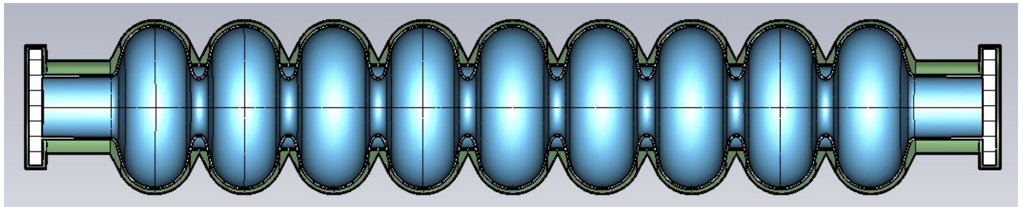


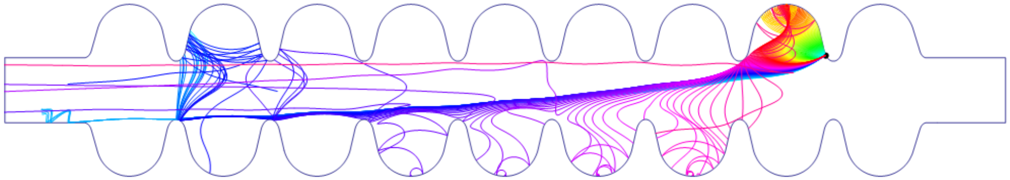


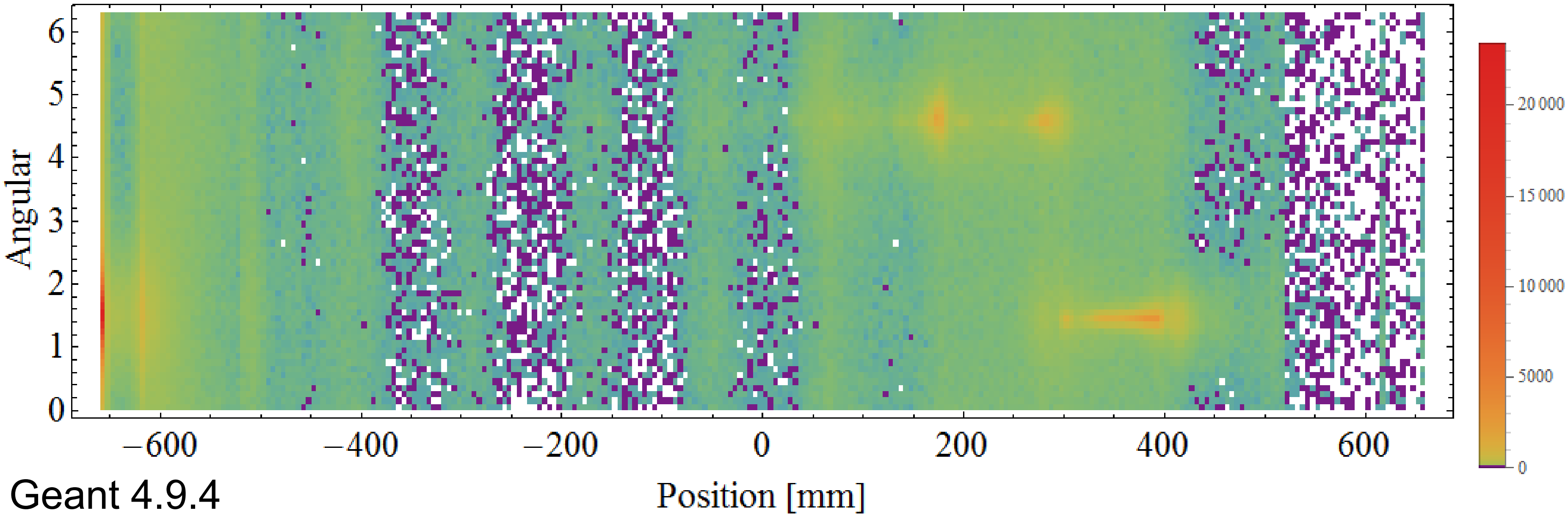
Photon distribution

Geant 4.9.4

Photon Simulation from emission electrons

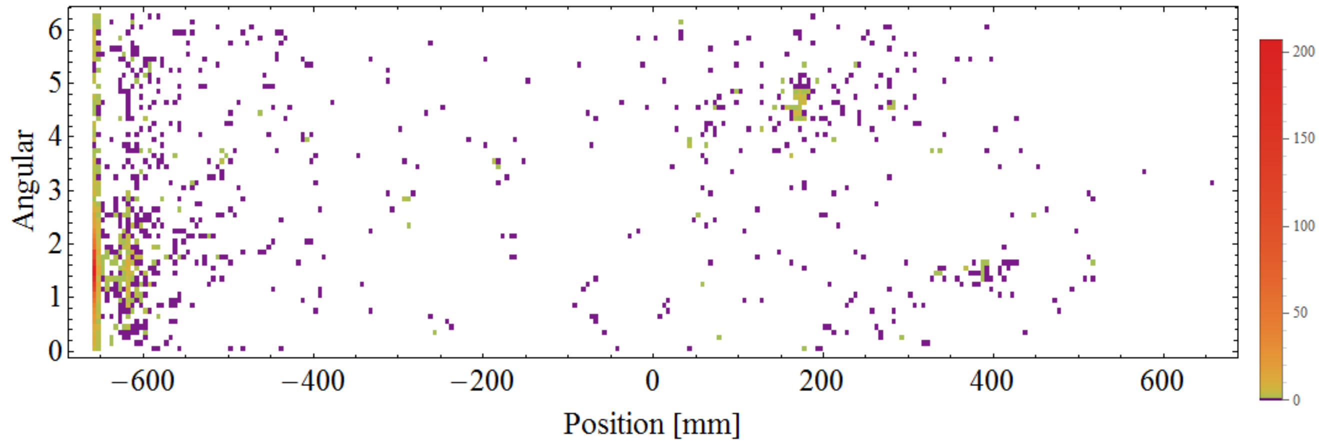




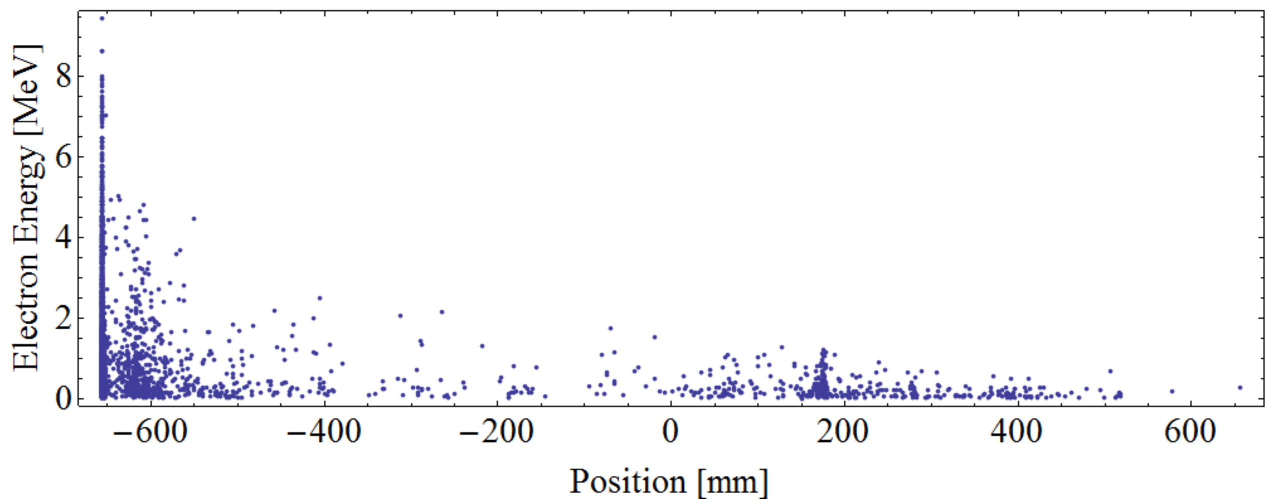


Geant 4.9.4

Electrons escaping from the cavity

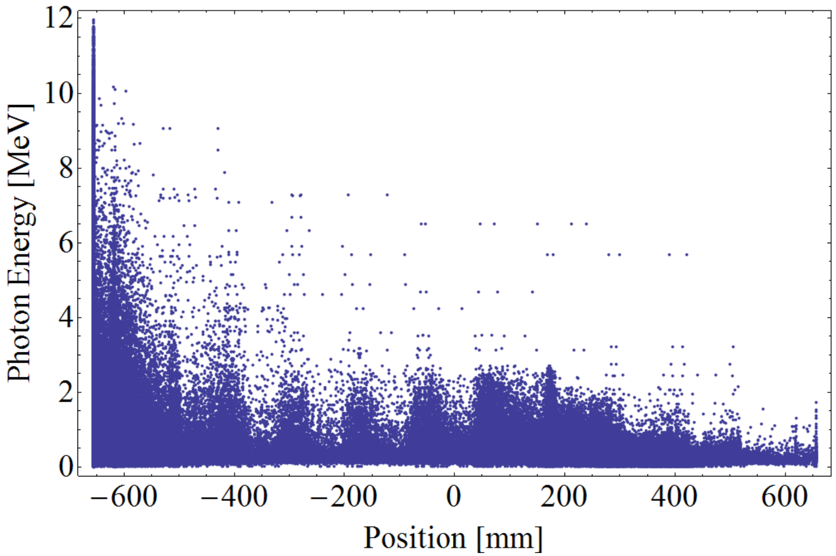


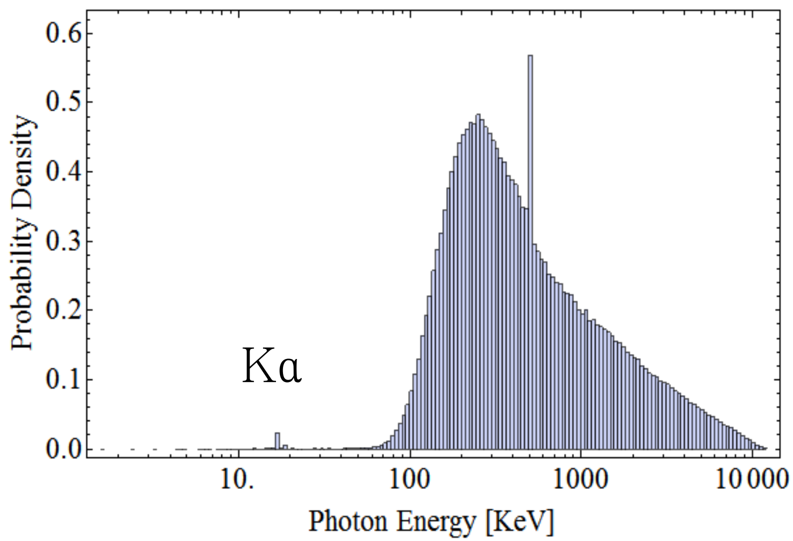
electron density distribution



electron energy distribution

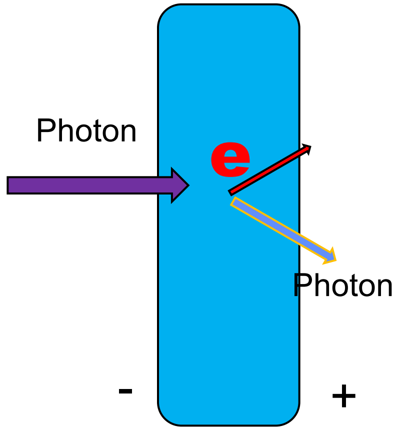
Photon Distribution



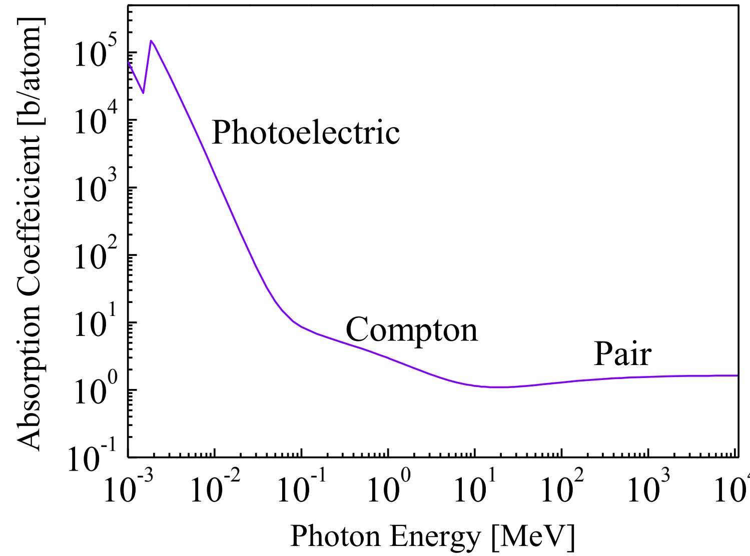


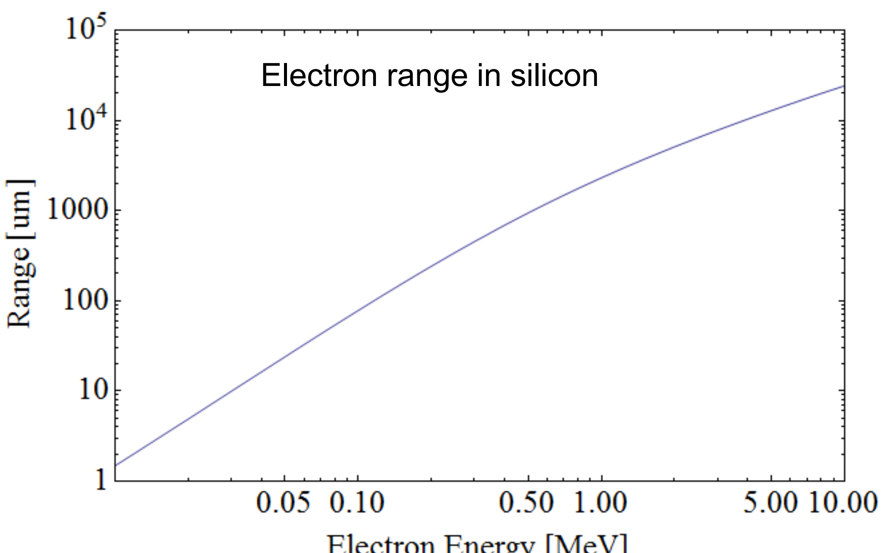
Detector response

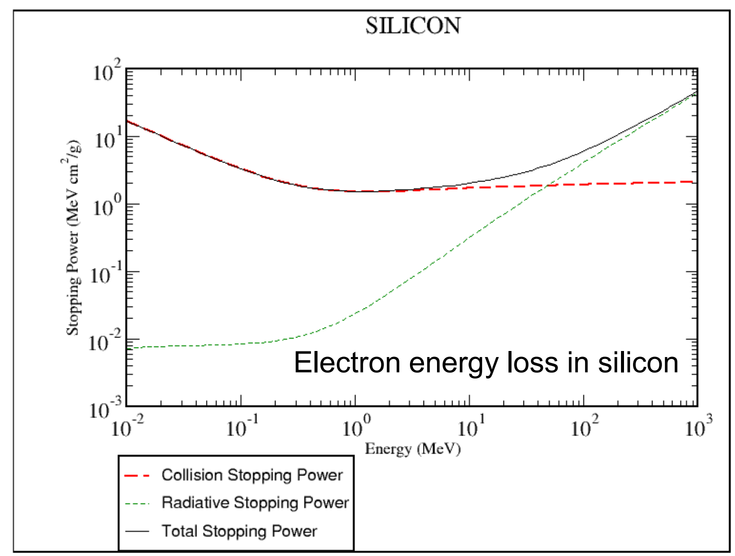
Depletion: 50um @ 20 V



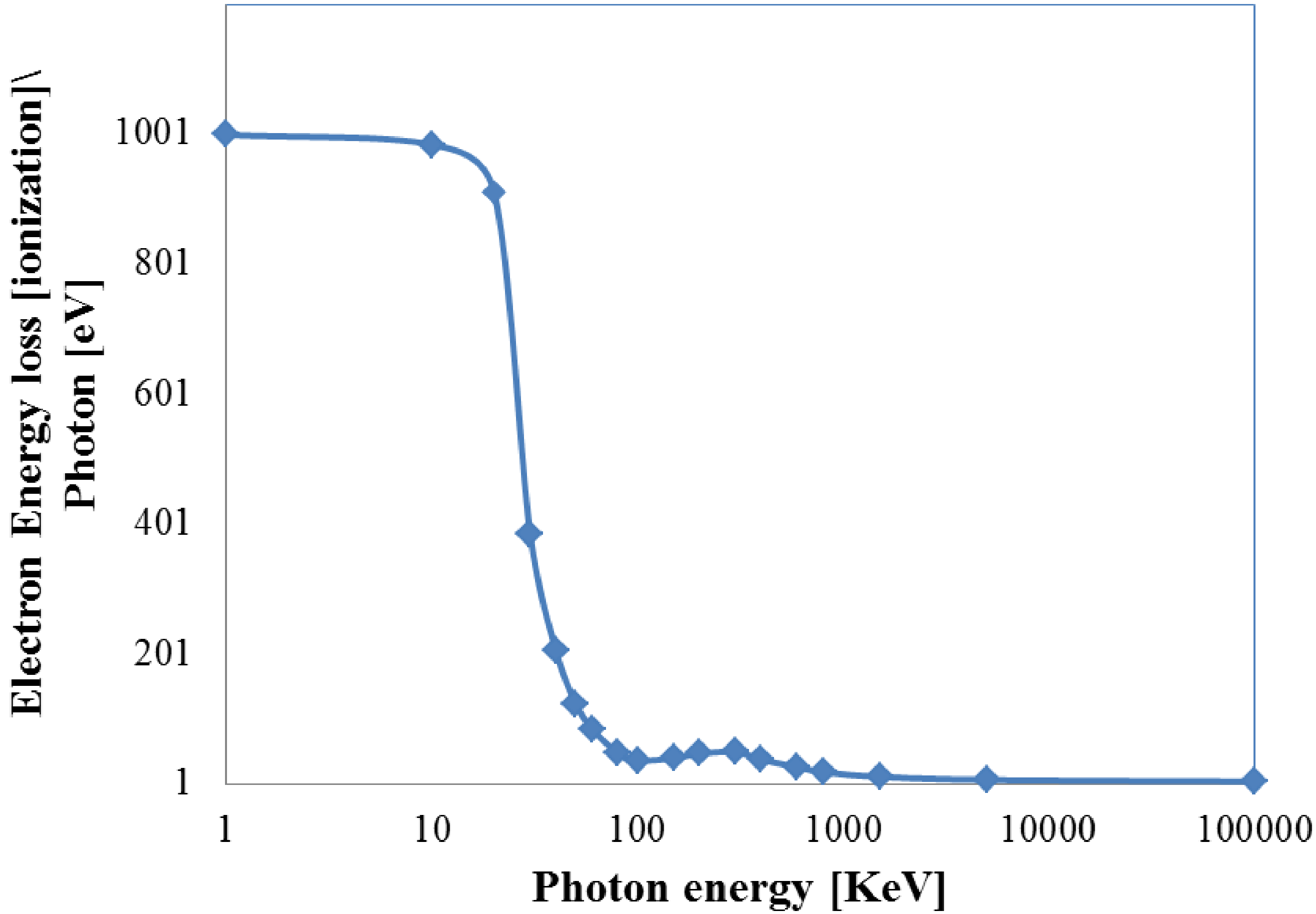
Depletion (Si)
3.6 eV /(electron and hole pair)





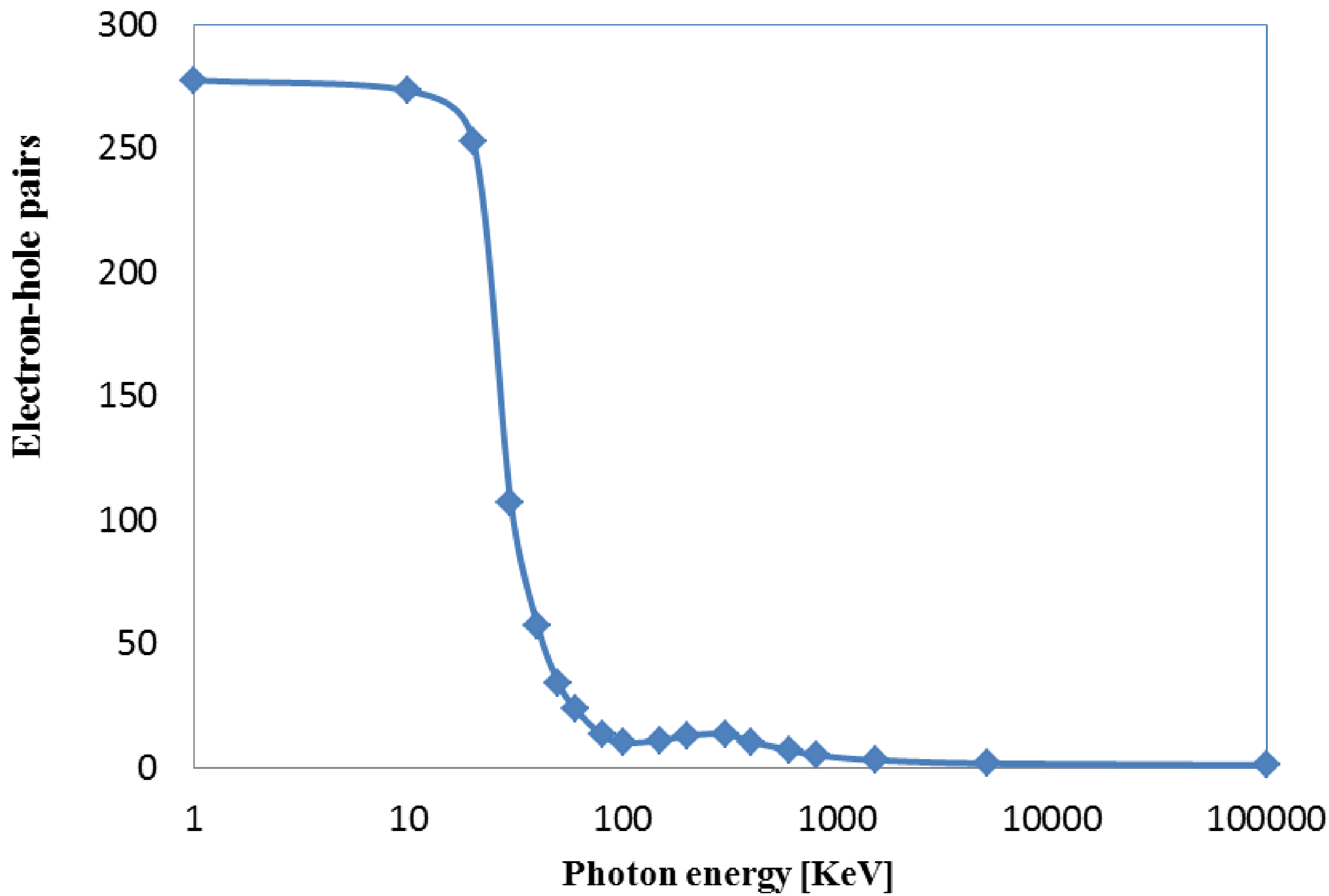


Detector response to photon



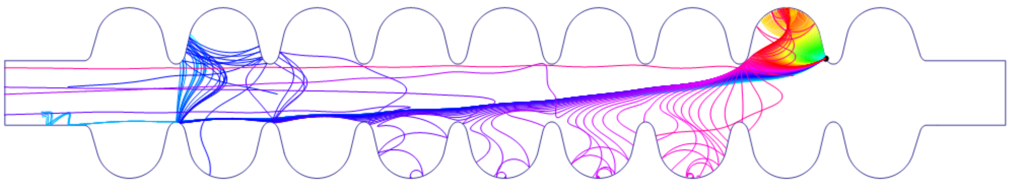
Geant 4.9.4

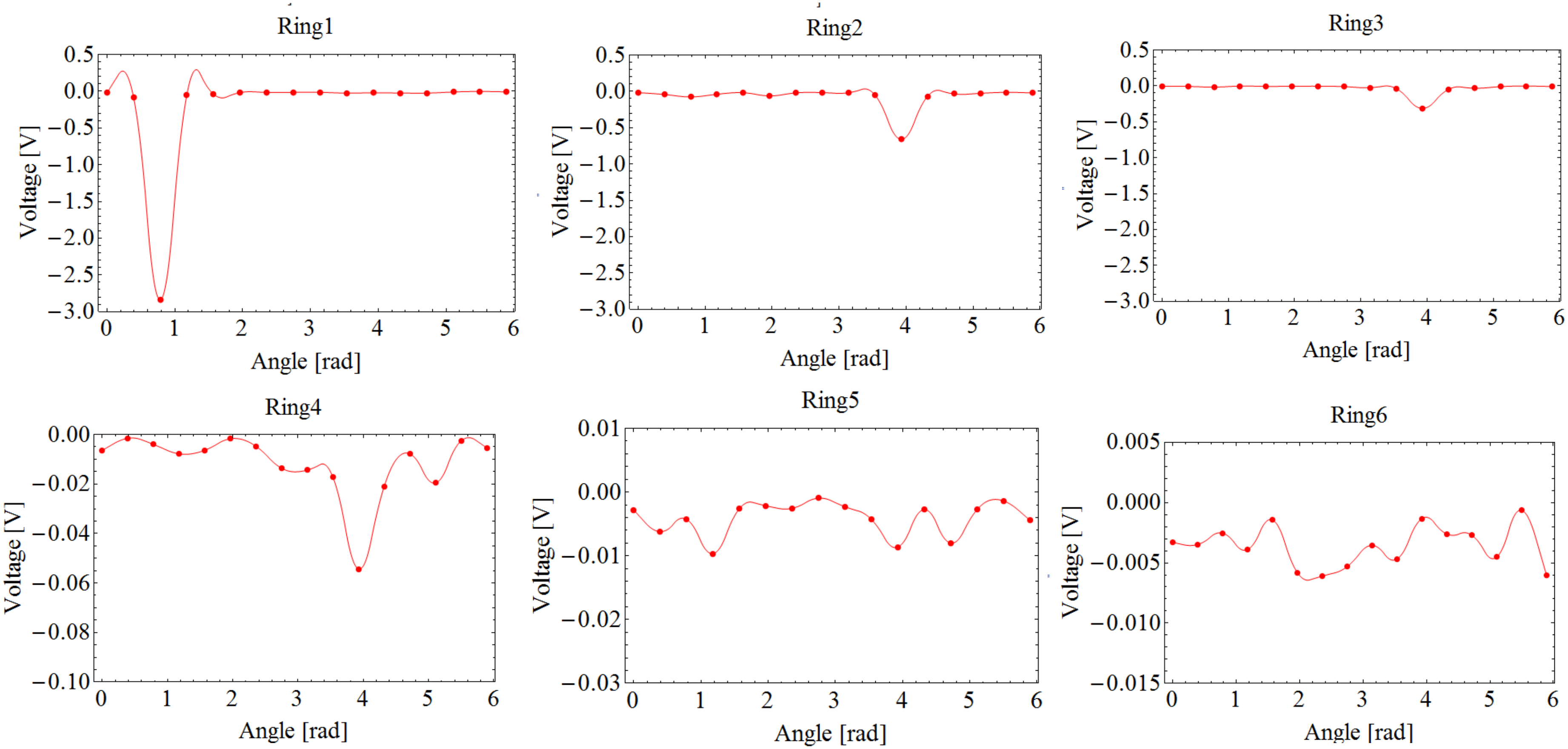
Detector response to photon



Geant 4.9.4

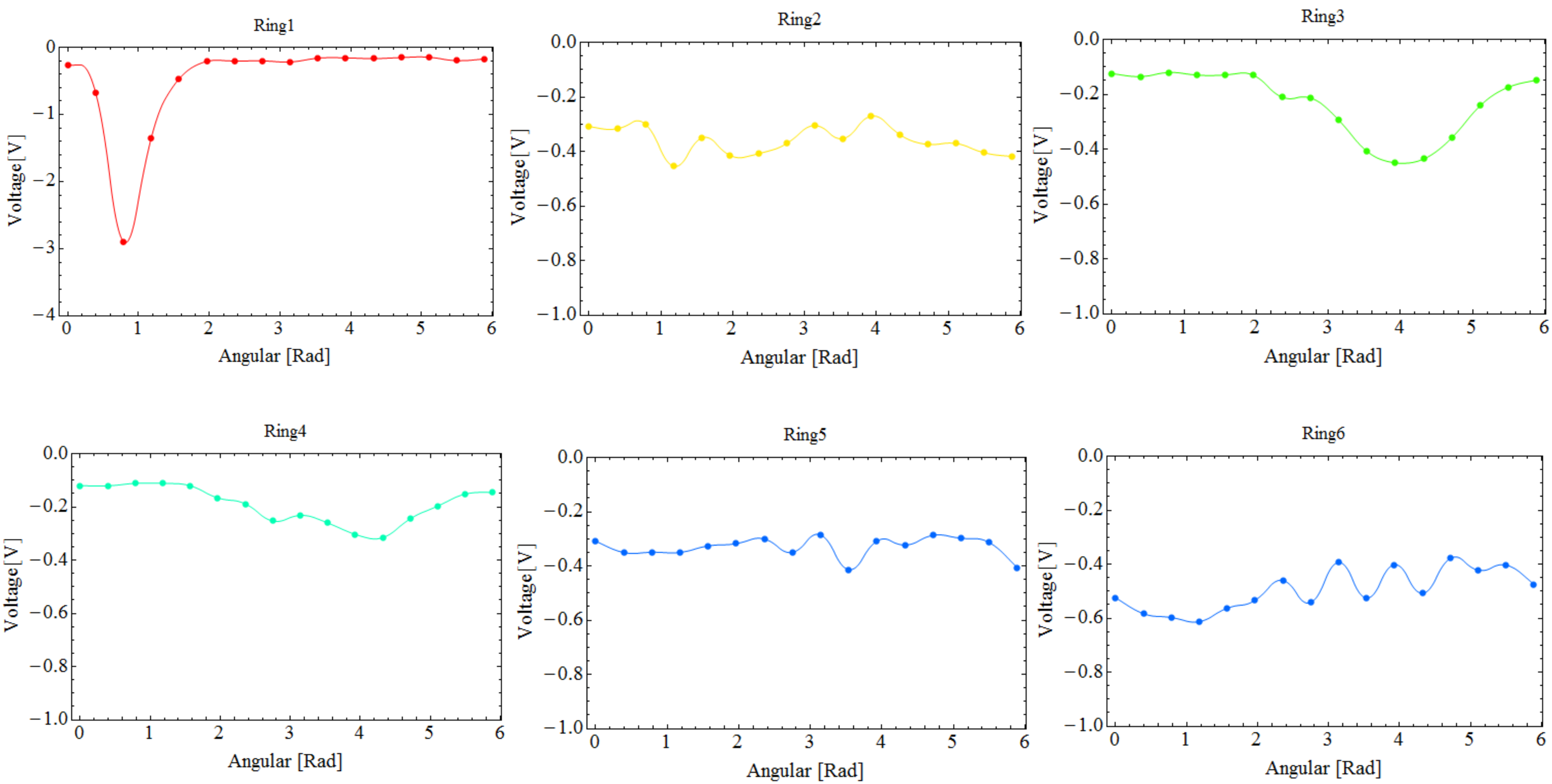
Preliminary Simulation Result





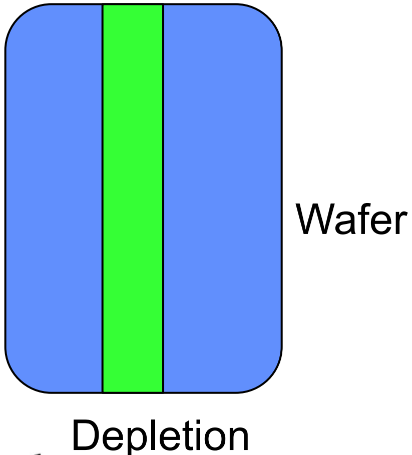
Detector Signal Angular Distribution

Eacc=17.5 MV/m

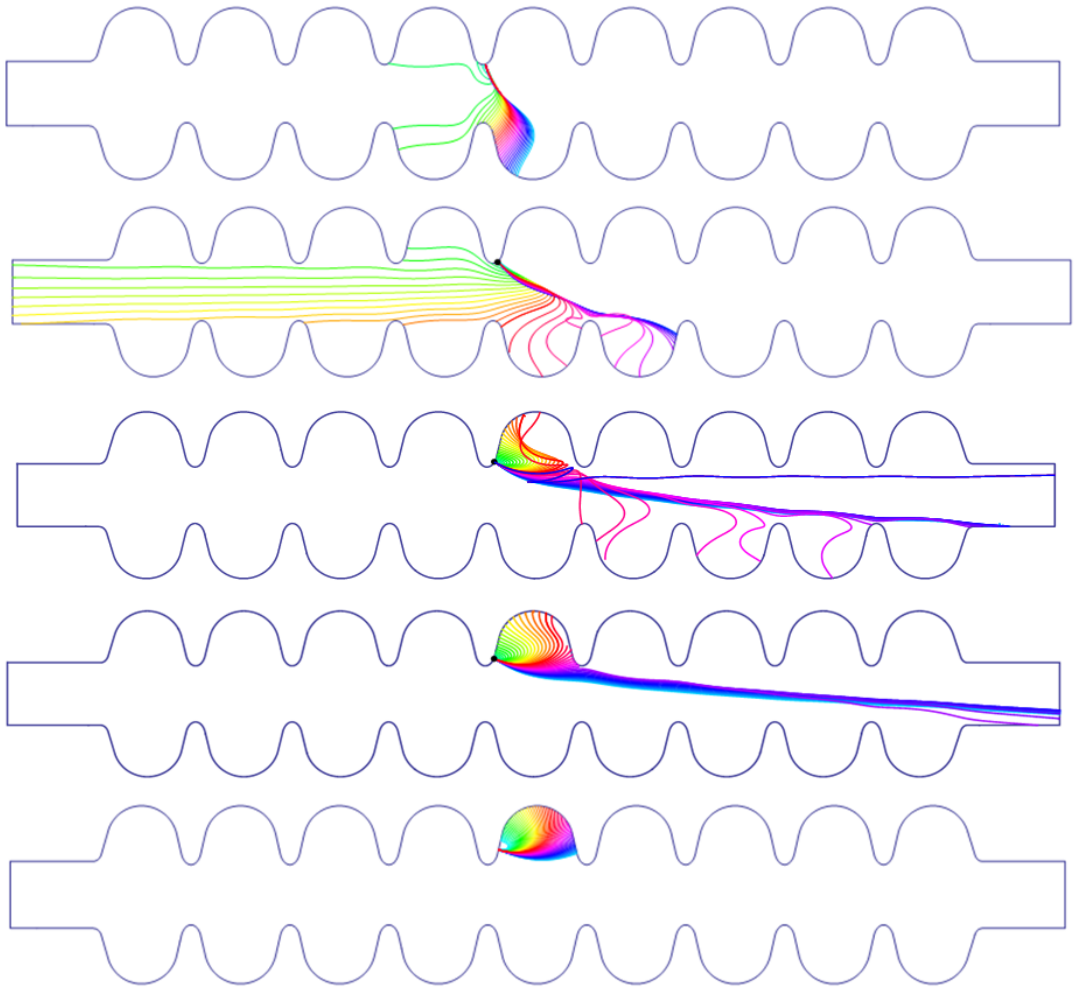


Simulation Analysis

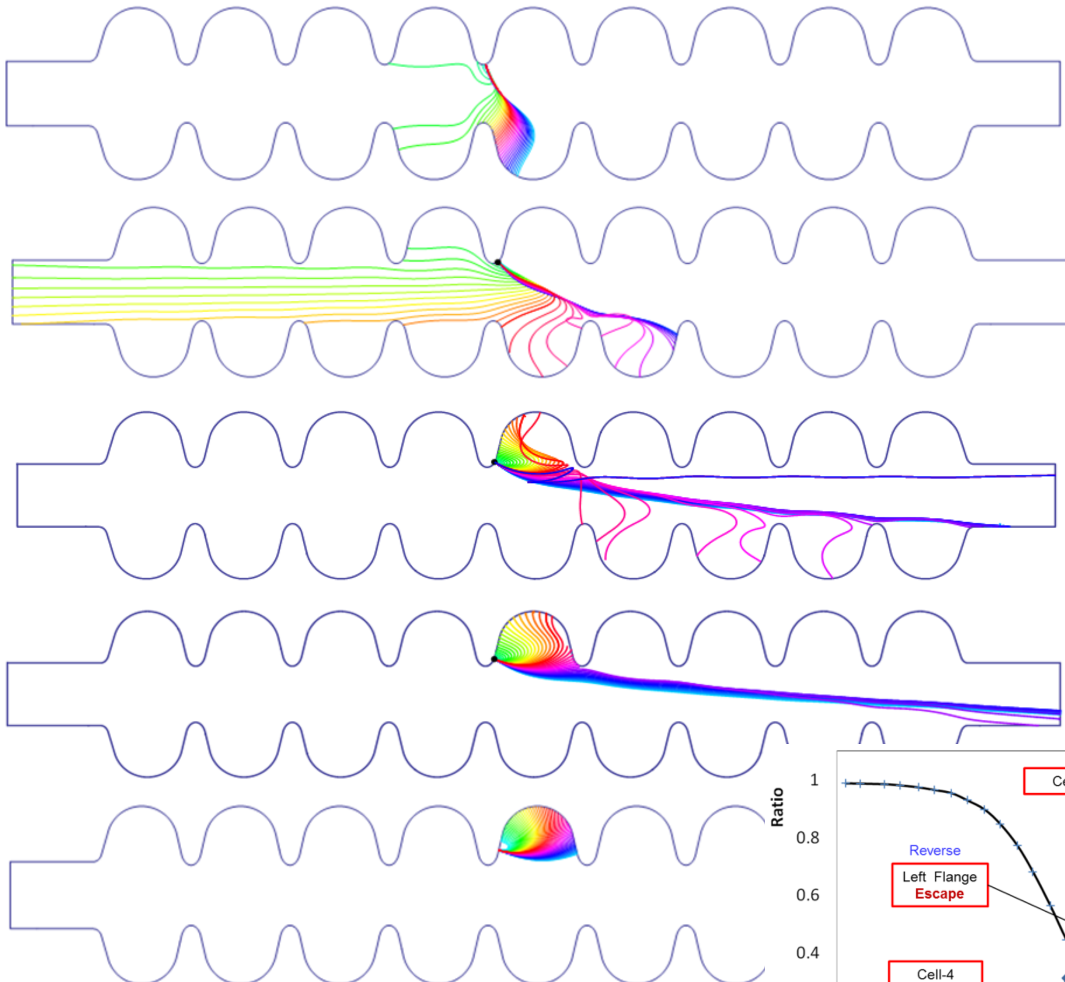
1. Emitter is one point chosen in the Zigzag region. More simulation of the emitter location within Zigzag region will be done in the next step.
2. The beta of the field emitter is 150. This data will be fitted by the measured diode data with different gradient.
3. The diode simulation model is simple. The wafer dimension and the window or the package did not consider in the simulation. For the next step, these factors will be considered.
4. Space charge effect is not consider for the field emission electrons.

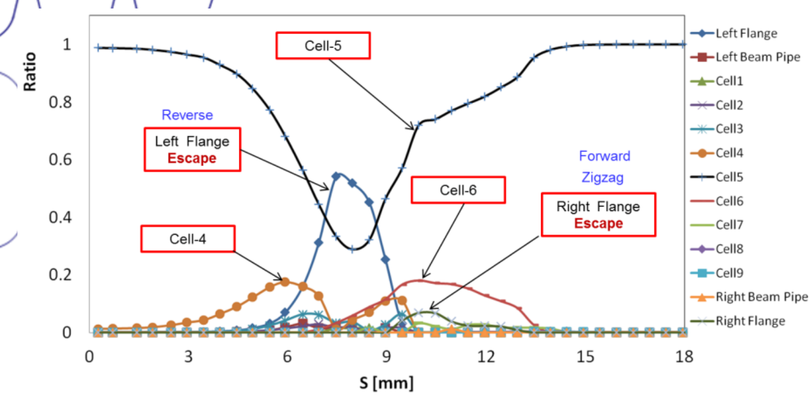


Plan for the next step

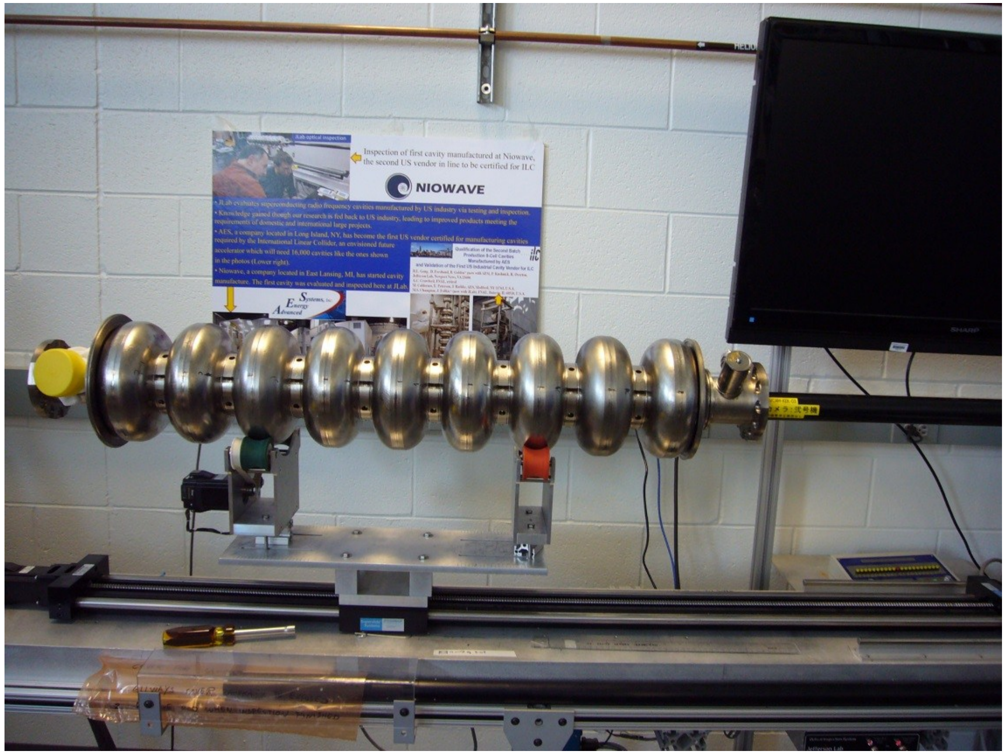


Plan for the next step





Optical Inspection



Resolution: 7.4um/pixel

No distinguished feather was observed within the limitation.

3.Summary

- Energy measurement in RI-23 9cell cavity are agreed very well with the simulation result.
- Angular location of field emitter are done by six 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