Multipacting & Dark Current Simulations For The CLIC HDX Structure

Zenghai Li

Volkan Akcelik, Arno Candel, Andreas Kabel, Kwok Ko, Lixin Ge, Lie-Quan Lee, Cho Ng, Greg Schussman, Liling Xiao

Advanced Computations Department
SLAC National Accelerator Laboratory

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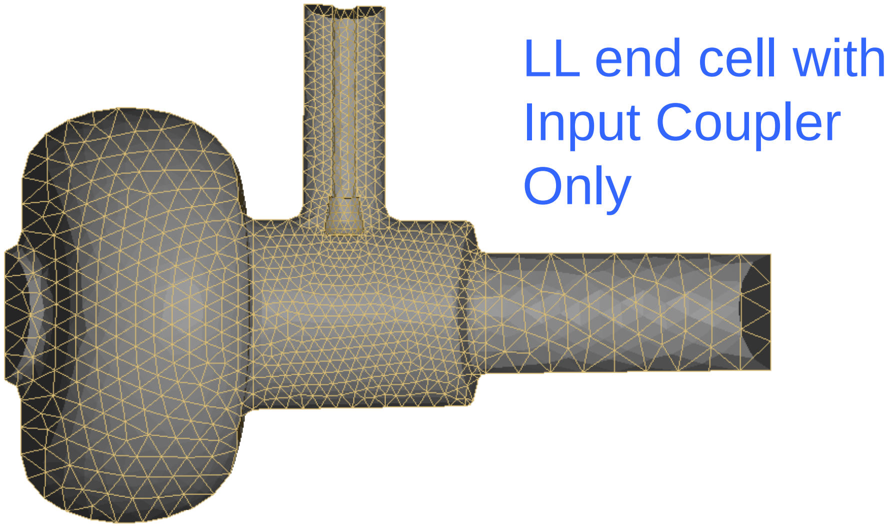
Outline

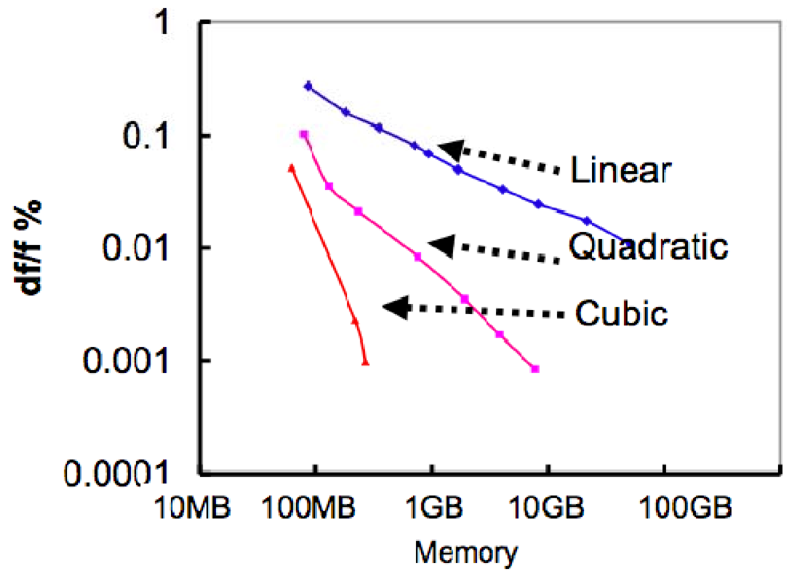
- *SLAC Parallel Finite Element Codes*
- *Code Benchmarks & Examples*
- *CLIC HDX Structure Simulation*

SLAC/ACD Parallel Finite Element Codes

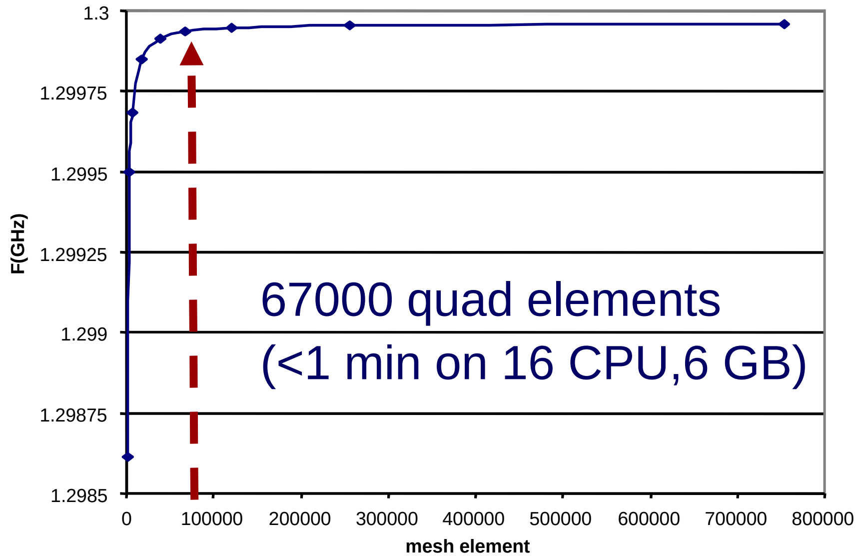
Omega3P	*Complex Eigensolver*
S3P	*S-Parameter*
T3P	*Transients & Wakefields*
Track3P	*Dark Current and Multipacting*
Pic3P	*Self-Consistent Particle-In-Cell*
Gun3P	*Space-Charge Beam Optics*
TEM3P	*Multi-Physics EM-Thermal-Mechanical*
V3D	*Visualization of Mesh, Field and Particles*

Key Strength of SLAC's EM Codes





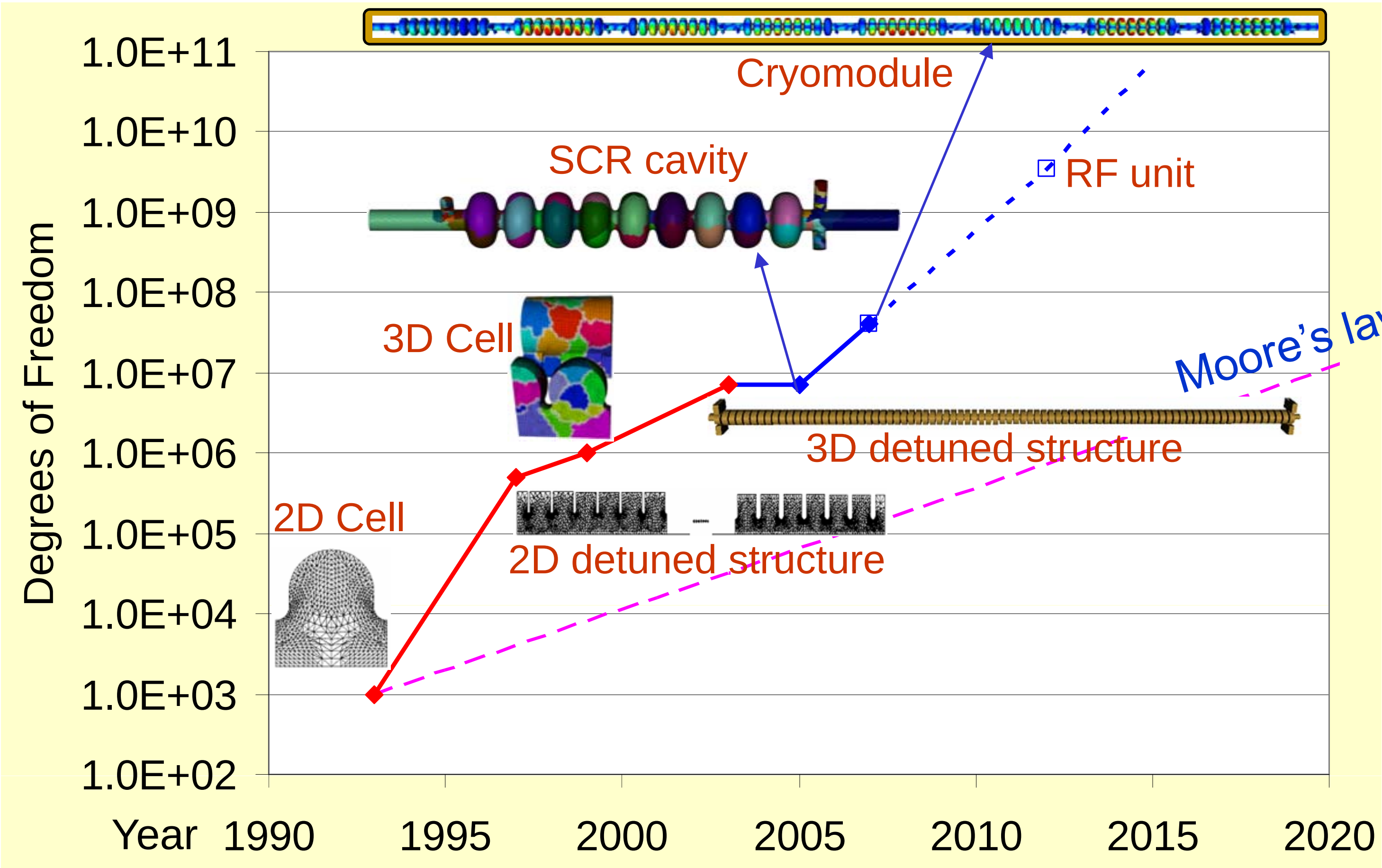
- **Tetrahedral Conformal Mesh**
  w/ quadratic surface
- **Higher-order Finite Elements**
  p = 1-6
- **Parallel Computing**
  large memory & speedup



Development of *Omega3P*

Goal: High Fidelity simulation -> CAD drawing -> hardware fabrication
- from single 2D cavity to a cryomodule of eight 3D ILC cavities

<u>An increase of 10^5 in problem size with 10^{-5} accuracy over a decade</u>



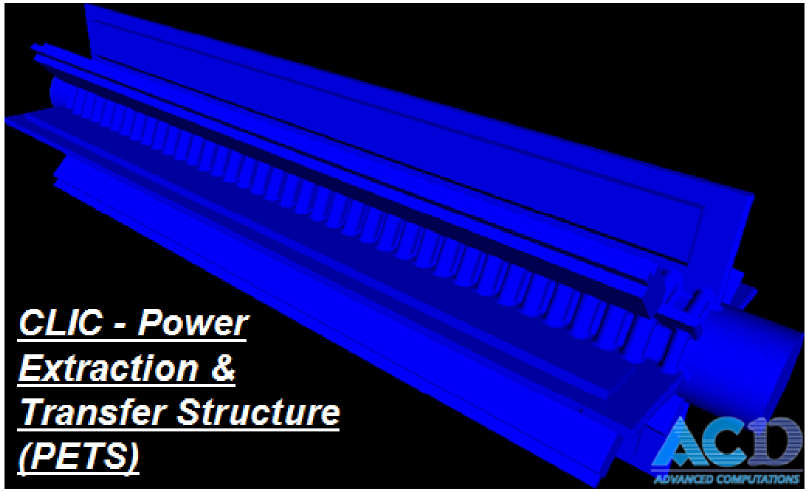
MP and DC Simulation Using *Track3P*

- Track3P
  - 3D parallel high-order finite-element particle tracking code for dark current and multipacting simulations
  - Traces particles in resonant modes – **Omega3P** fields
  - Traces particles in steady state or transient fields – **S3P** and **T3P** fields
  - Accommodates several emission models: thermal, field and secondary
  - Curved surfaces for accurate surface fields

- Benchmarked extensively
  - Rise time effects on dark current for an X-band 30-cell structure
  - Prediction of MP barriers in the KEK ICHIRO cavity

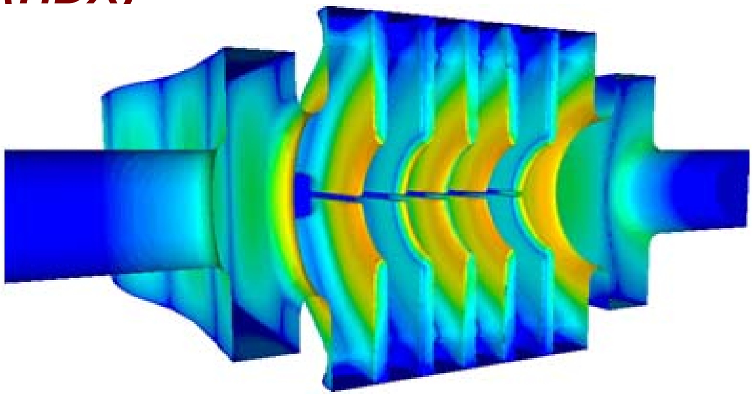
Omega3P, T3P, Track3P – High Gradient

HOM damping & Multipacting studies are needed for High Gradient Structures

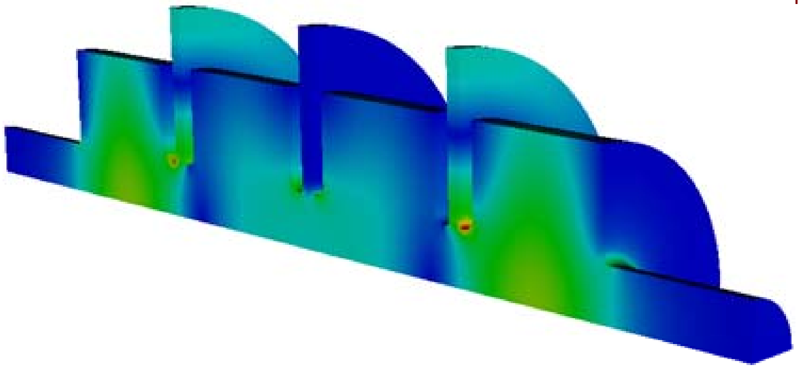


CLIC - Power Extraction & Transfer Structure (PETS)

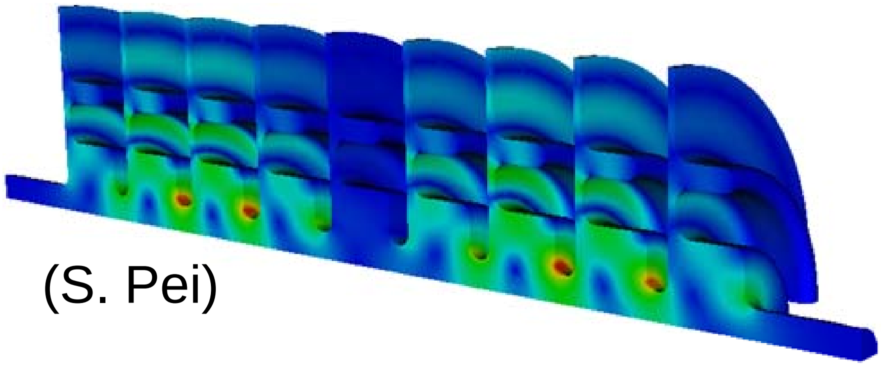
CLIC – Hybrid Damped Structure (HDX)



Slotted-Disk Structure



Choke-Mode Structure



(S. Pei)

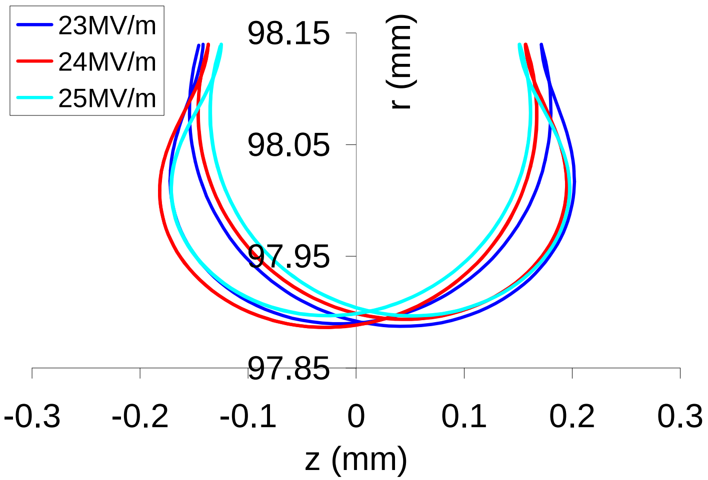
In collaboration with ATR and CERN

MP Module In *Track3P*

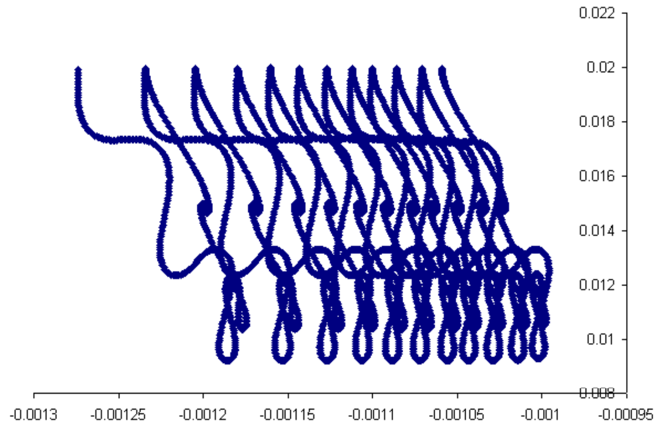
- Analyze resonant conditions – particle initiated at all surfaces and RF phases
- Calculate multipacting map using impact energy and SEY data
- Simulation procedure
  - Launch electrons on specified surfaces with different RF phase, energy and emission angle
  - Record impact position, energy and RF phase; generate secondary electrons and continue tracking
  - Determine “resonant” trajectories by consecutive impact phase and position
  - Calculate MP order (#RF cycles/impact) and MP type (#impacts /MP cycle) and MP level (impact energy, SEY)

Example of MP Particles

- Resonant trajectory …



SRF Cavity



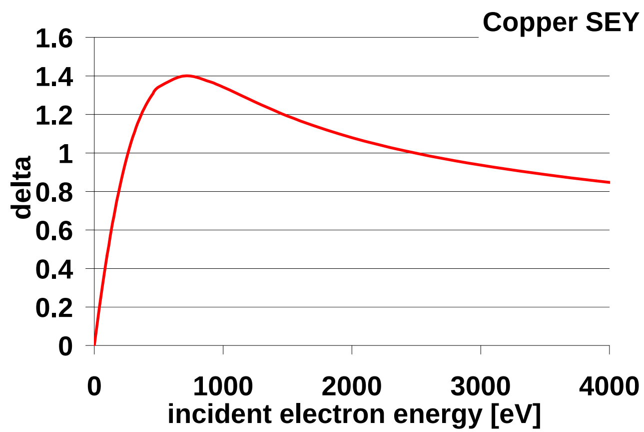
Coax with reflection

Dark Current Module In *Track3P*

- Particle generated by field and secondary emissions
  - Field Emission - Fowler - Nordheim

$$J(r,t) = 1.54\times 10^{\left(-6+\frac{4.52}{\sqrt{\varphi}}\right)} \frac{(\beta E)^2}{\varphi} e^{\left(\frac{-6.53\times 10^9 \varphi^{1.5}}{\beta E}\right)}$$

  - Secondary emission

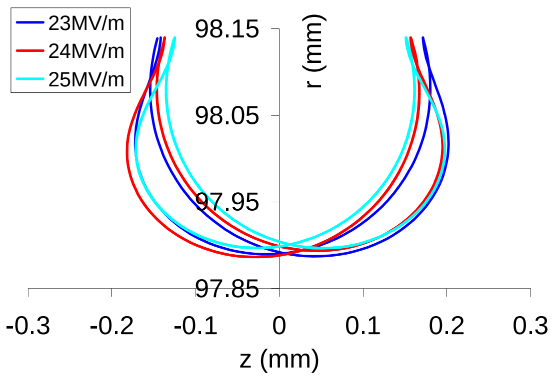


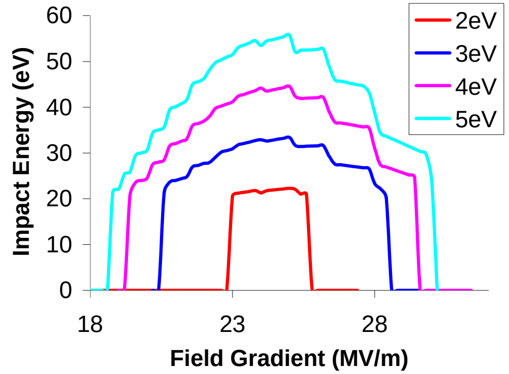
- Analyze accumulated effects of DC current & power
  - DC current monitor
  - DC surface power monitor

Multipacting Benchmarking

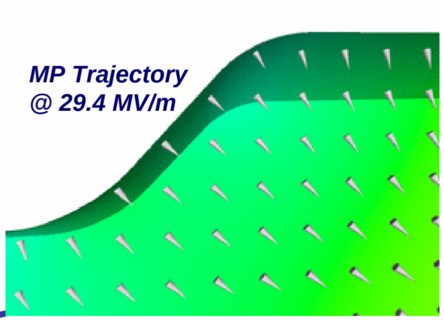
- ICHIRO SRF cavity
- SNS high-beta cavity
- TTF-III coupler components

MP Simulation for ICHIRO Cavity





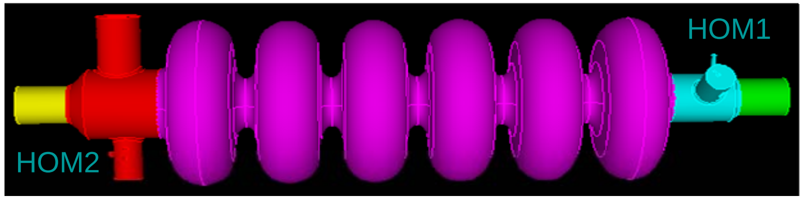
MP trajectories (left) and barriers (right) in regular SRF cells.
Soft barrier at around 23MV/m agrees with RF tests.



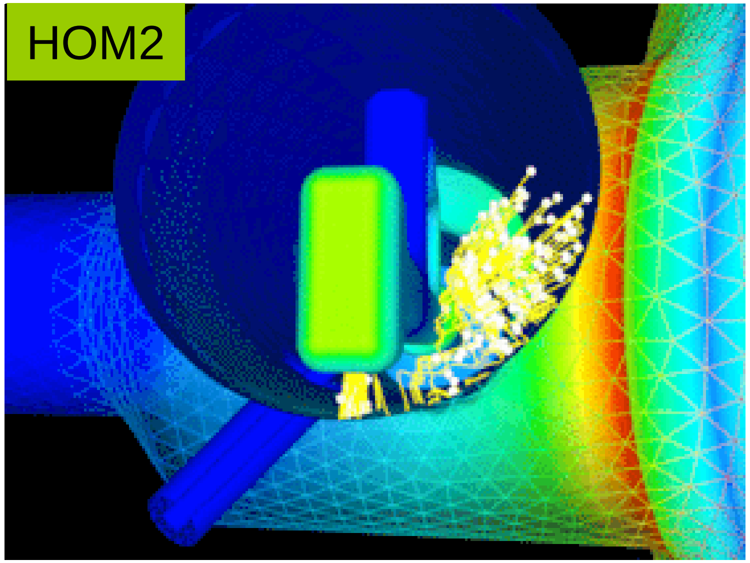
Track3P MP simulation		ICHIRO #0 (K. Saito,KEK)
Impact Energy (eV)	Gradient (MV/m)	X-ray Barriers (MV/m)
300-400(6 order)	12	11-29.3 12-18
200-500 (5 order)	14	13, 14, 14-18, 13-27
300-500(3 order)	17	(17, 18)
300-900(3 order)	21.2	20.8
600-1000(1.5 order)	29.4	28.7, 29.0, 29.3, 29.4

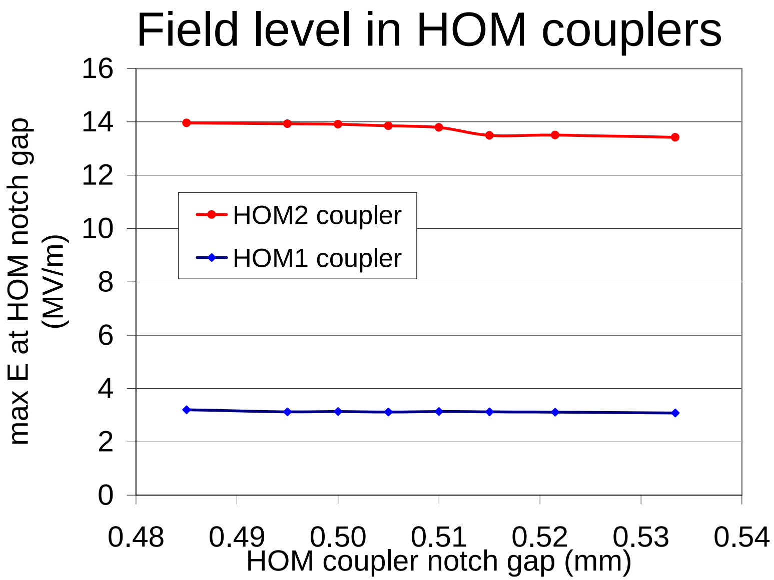
MP barriers in the beam pipe step region

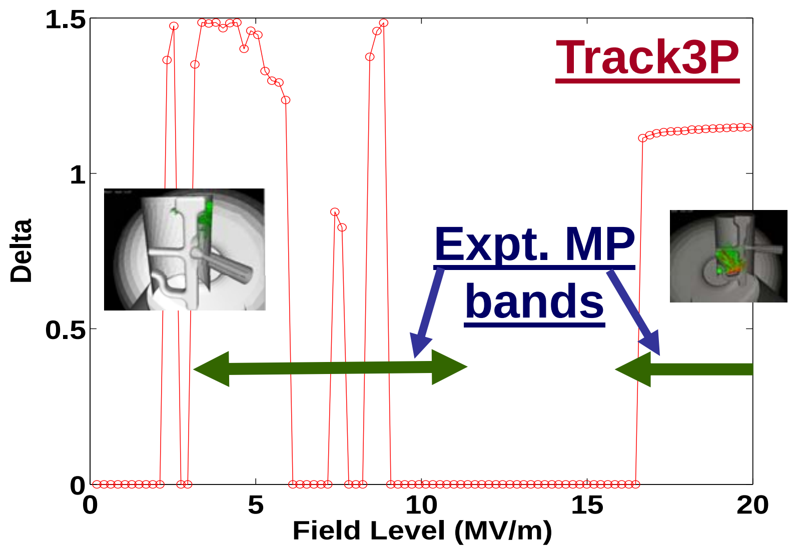
Multipacting in SNS HOM Coupler



- SNS SCRF cavity experienced RF heating at HOM coupler
- 3D MP simulations showed MP barriers closed to measurements
- Similar analysis are carried out for ILC ICHIRO and crab cavity

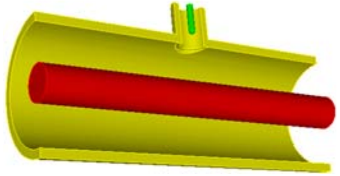




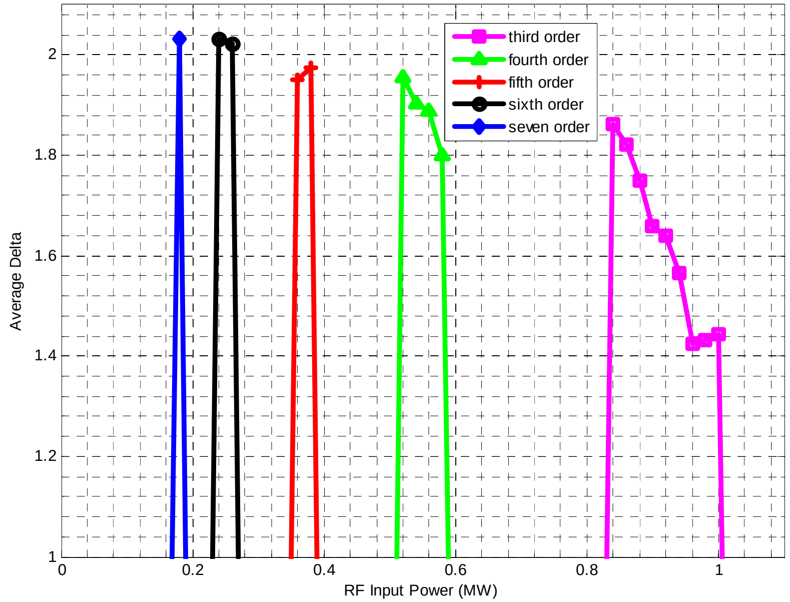


Mulitpacting in Coax of TTFIII Coupler

Cold coax

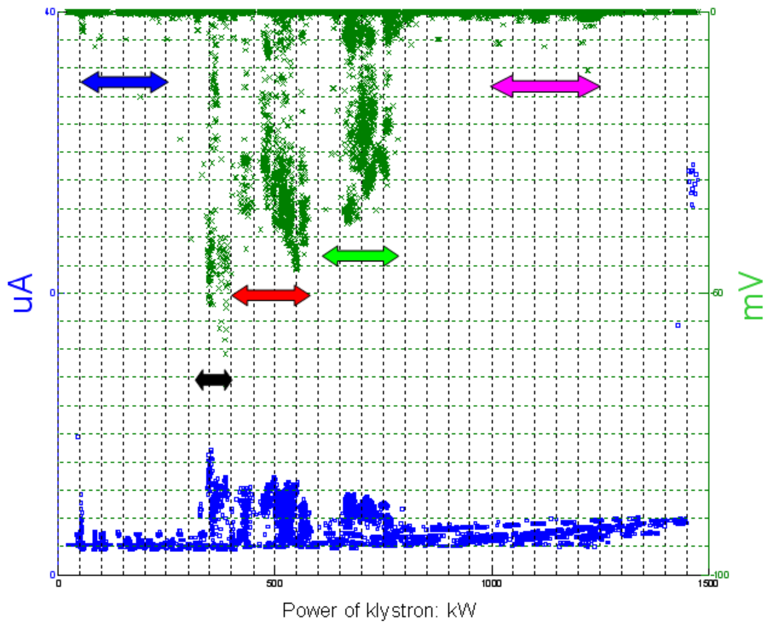


Track3P simulation



(F. Wang, C. Adolphsen, et. al)

After high power processing

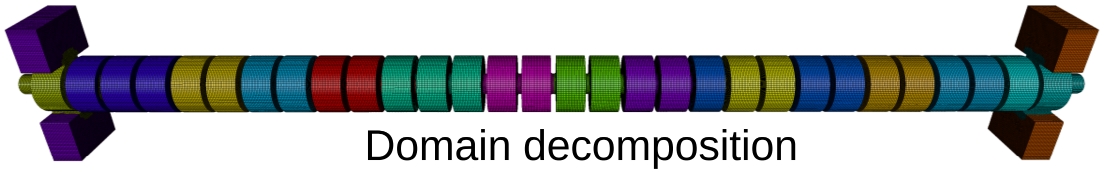


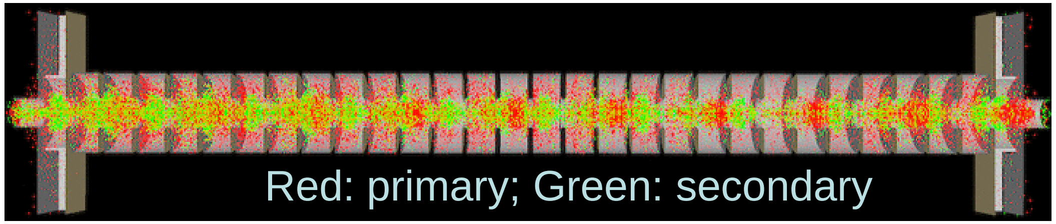
Simulated power (kW)	170~190	230~270	350~390	510~590	830~1000
Power in Coupler (kW)	43~170	280~340	340~490	530~660	850~1020

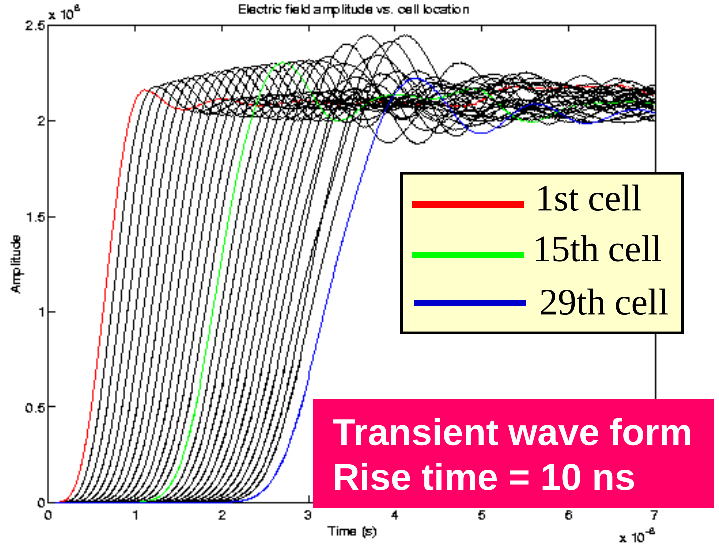
Dark Current Benchmarking

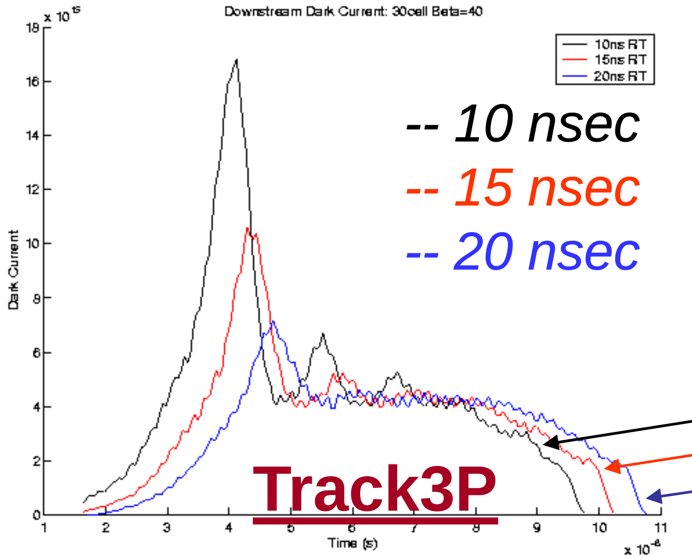
- 30-cell NLC X-Band structure
- X-Band waveguide bend

X-Band 30-Cell Structure Dark Current Simulation









Dark current @ 3 pulse risetimes

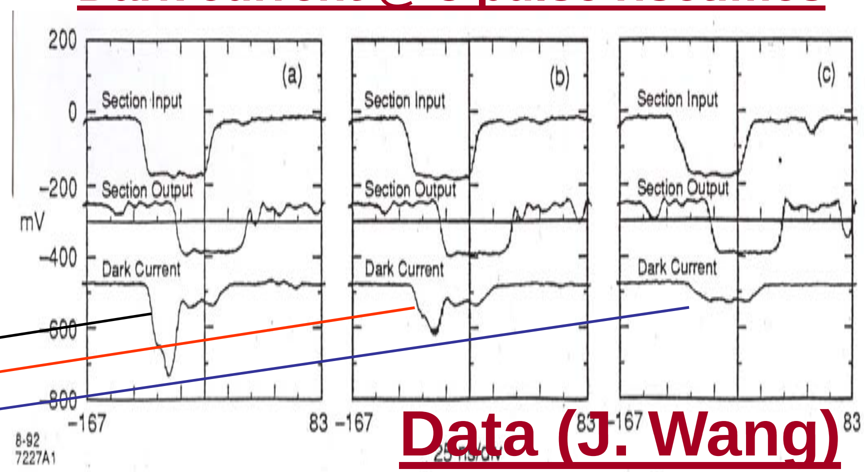
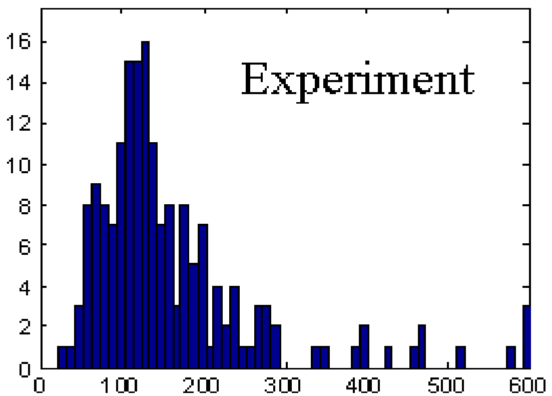


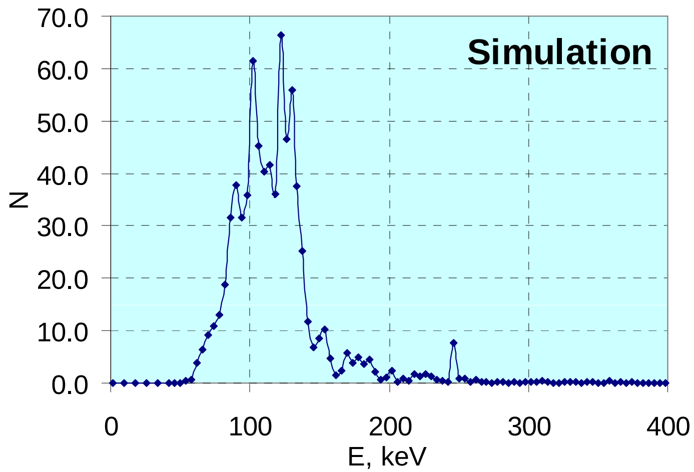
Fig. 7. Pulse shapes of section input, output and dark current for three different rise times of the RF pulse for 30-cavity TW section tests.

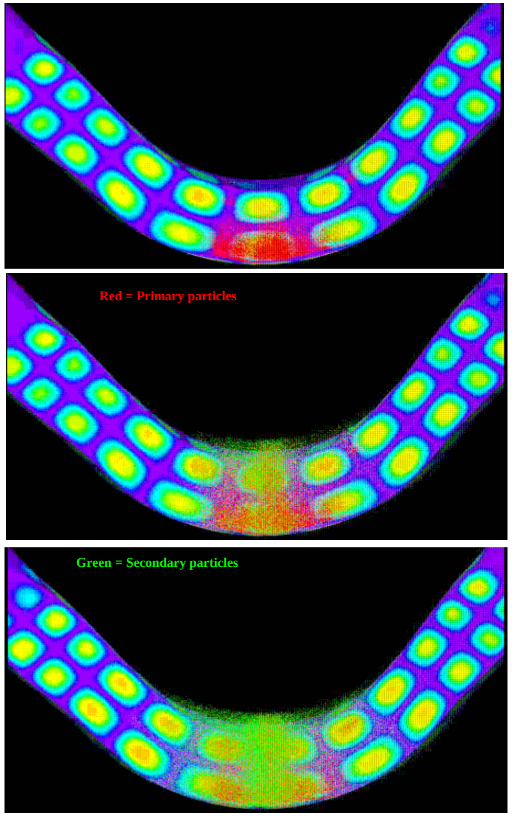
Surface Physics Benchmark in *Track3P*

High power tests on a NLC waveguide bend provided measured data on the X-ray spectrum to allow benchmarking of the surface physics module in *Track3P* that consists of primary and secondary emission models.



(C Adolphsen)



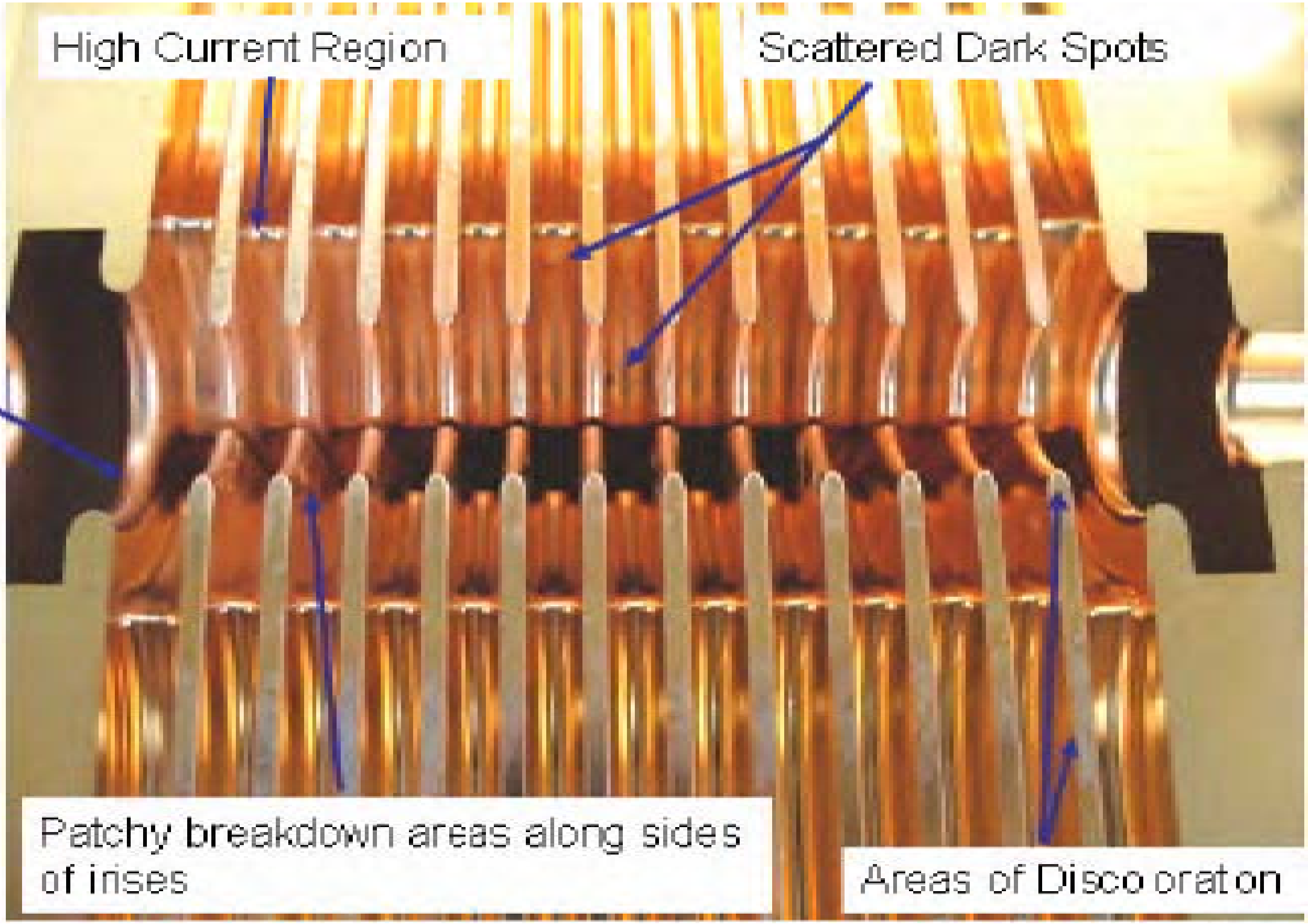


Evolution to steady -state

CLIC HDX simulation

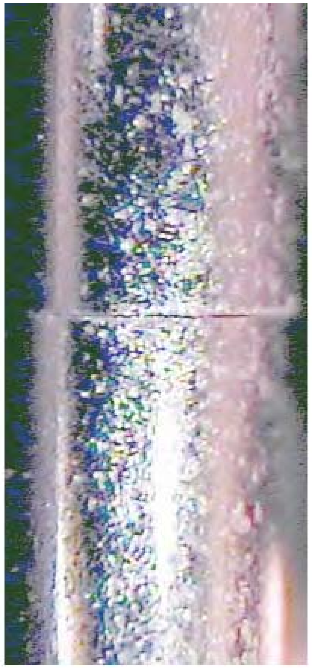
– in collaboration with CERN (A. Grudiev, W. Wuensch…)

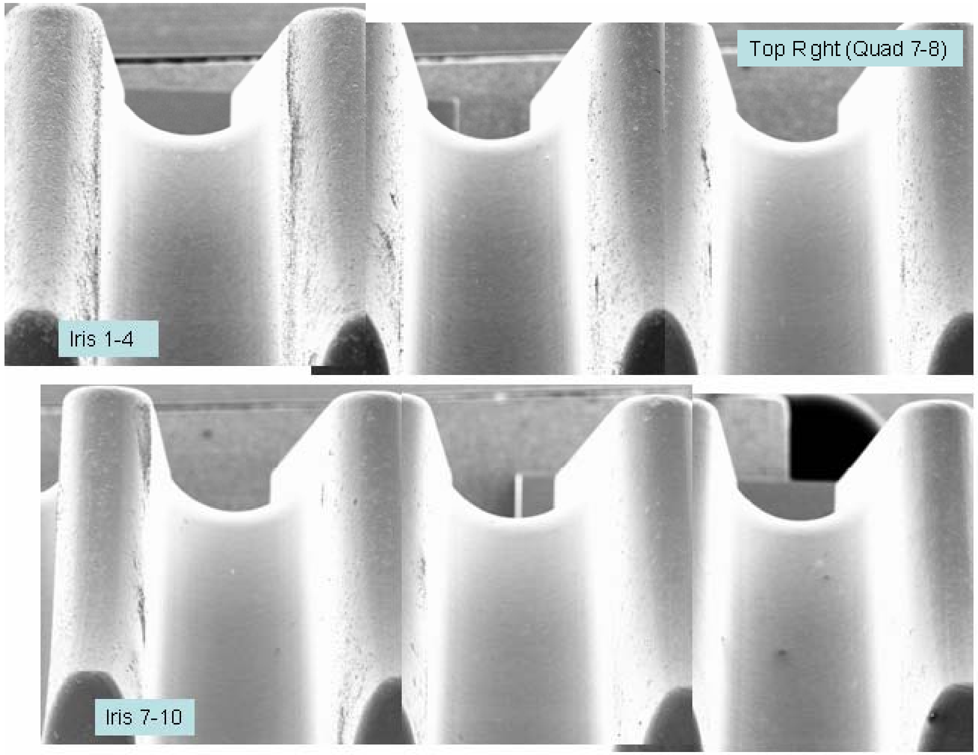
HDX-11 After RF Testing



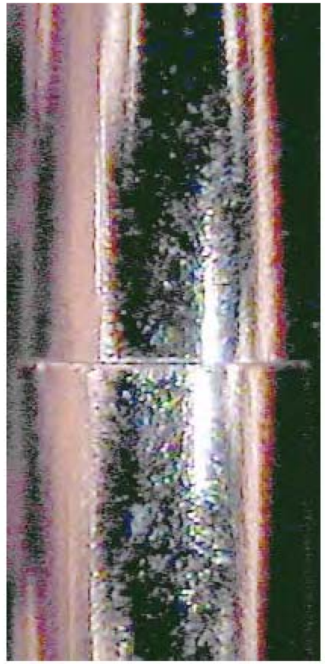
(C. Adolphsen, S. Döebert, R. Fondos, L. Laurent, F. Wang, J. Wang)

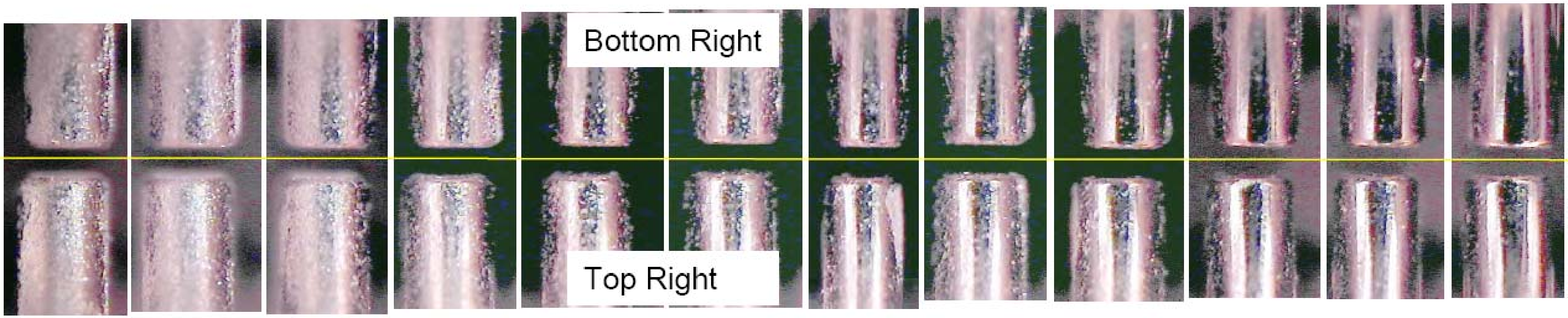
Input





Output



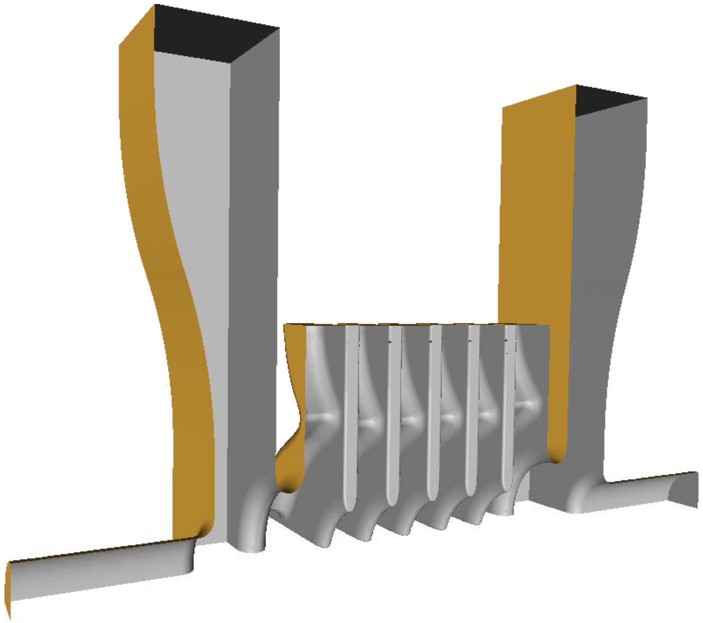


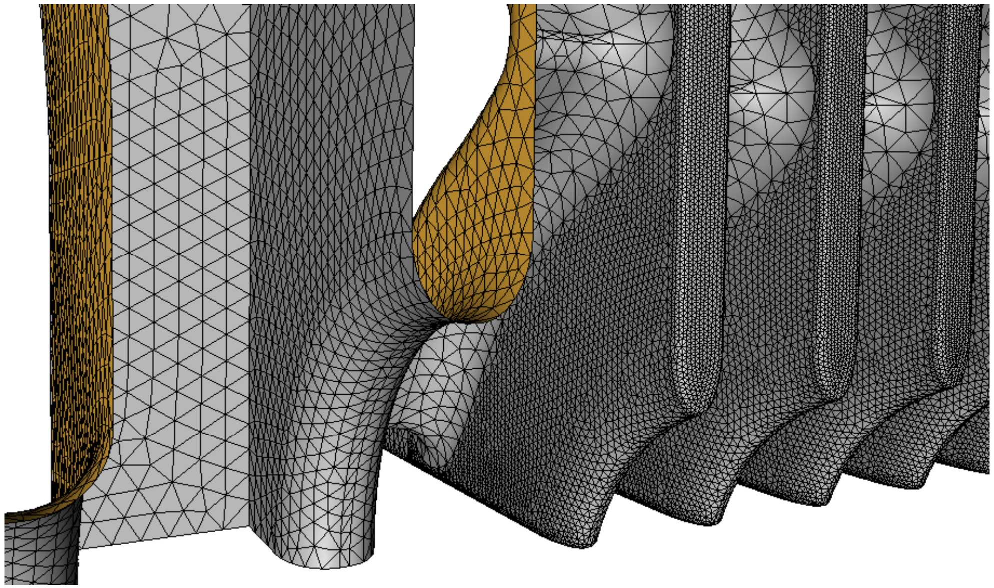
1 2 3 4 5 6 7 8 9 10 11 12

(C. Adolphsen, S. Döebert, R. Fondos, L. Laurent, F. Wang, J. Wang)

CLIC HDX-11 Simulation

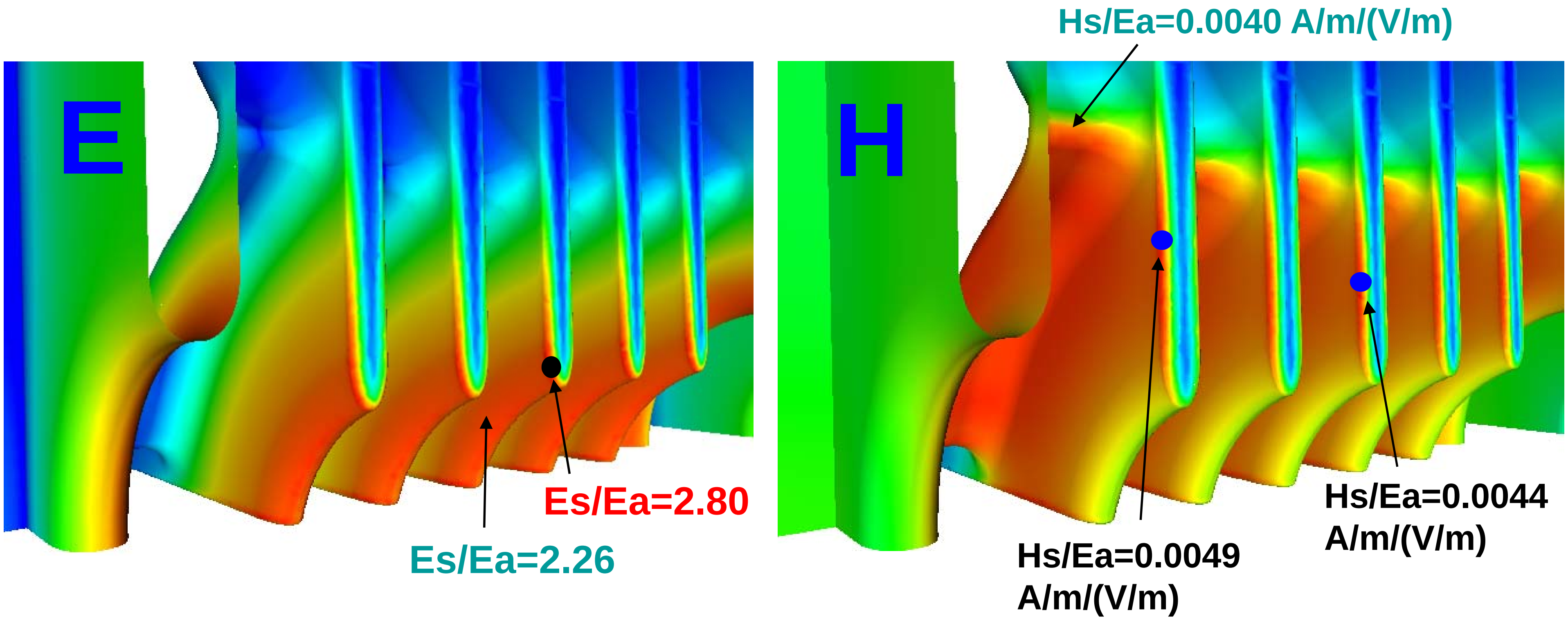
- HDX-11: 11 regular cells plus 2 matching cells
- Track3P simulation: 4 regular cells plus 2 matching cells. Will simulate full HDX structure
  - to analyze MP in ideal and misaligned geometries
  - to calculate dark current surface heating





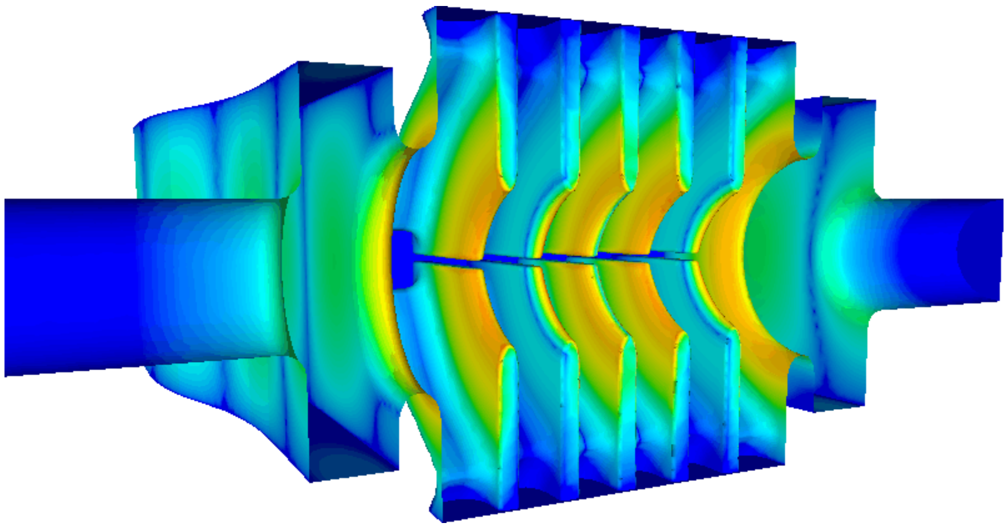
Quadratic element with local refinement around the slots

HDX Surface E & B Fields

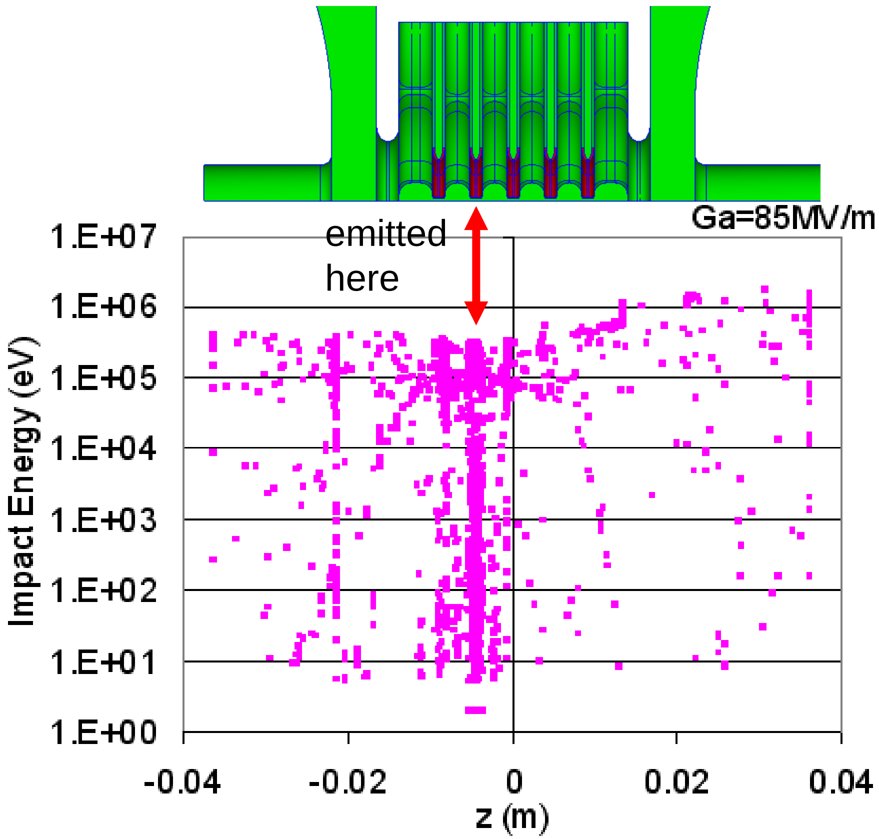


Fields enhanced around rounded slot

Electron Trajectory & Impact Energy

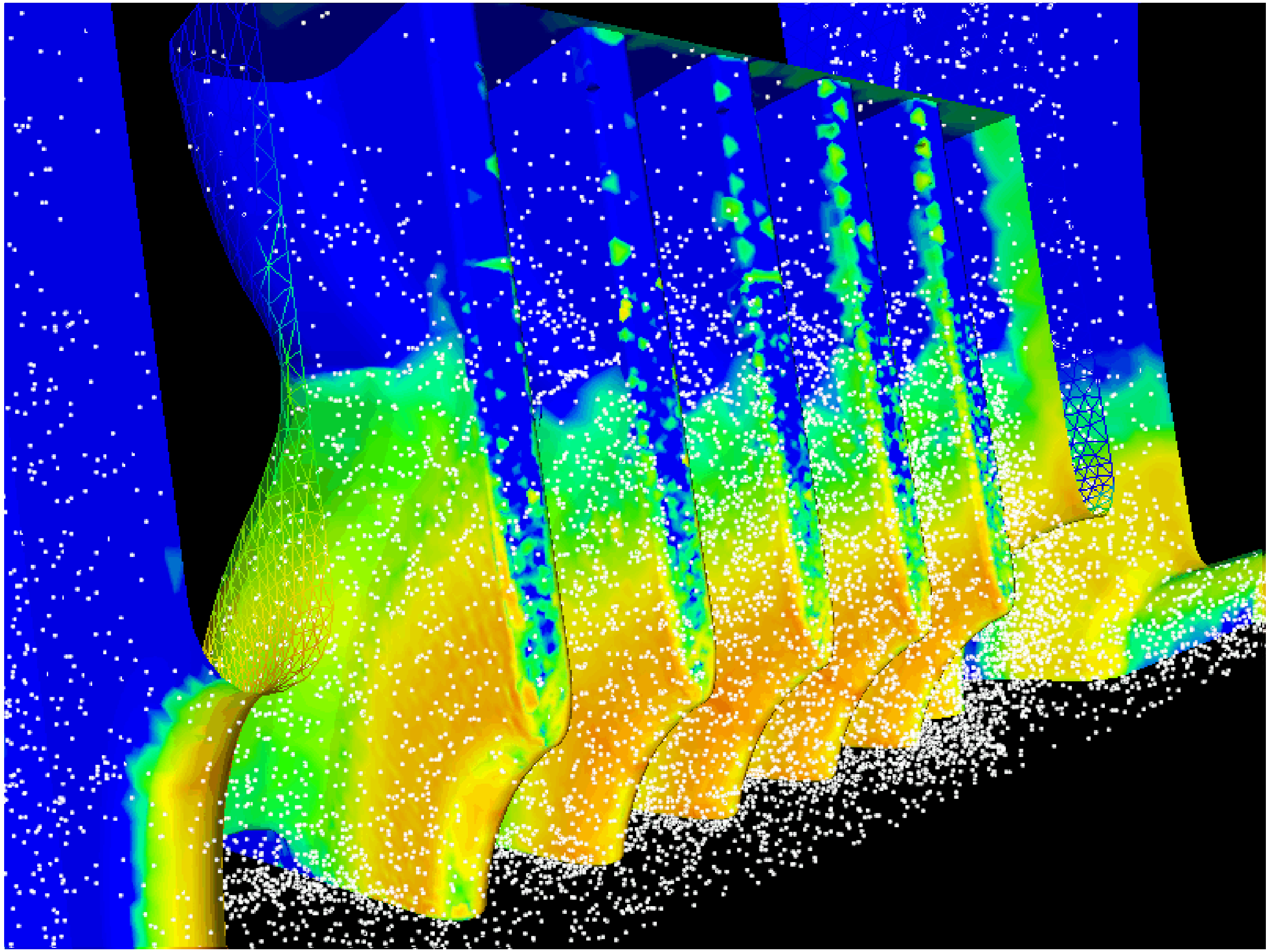


Particles emitted from one of the irises



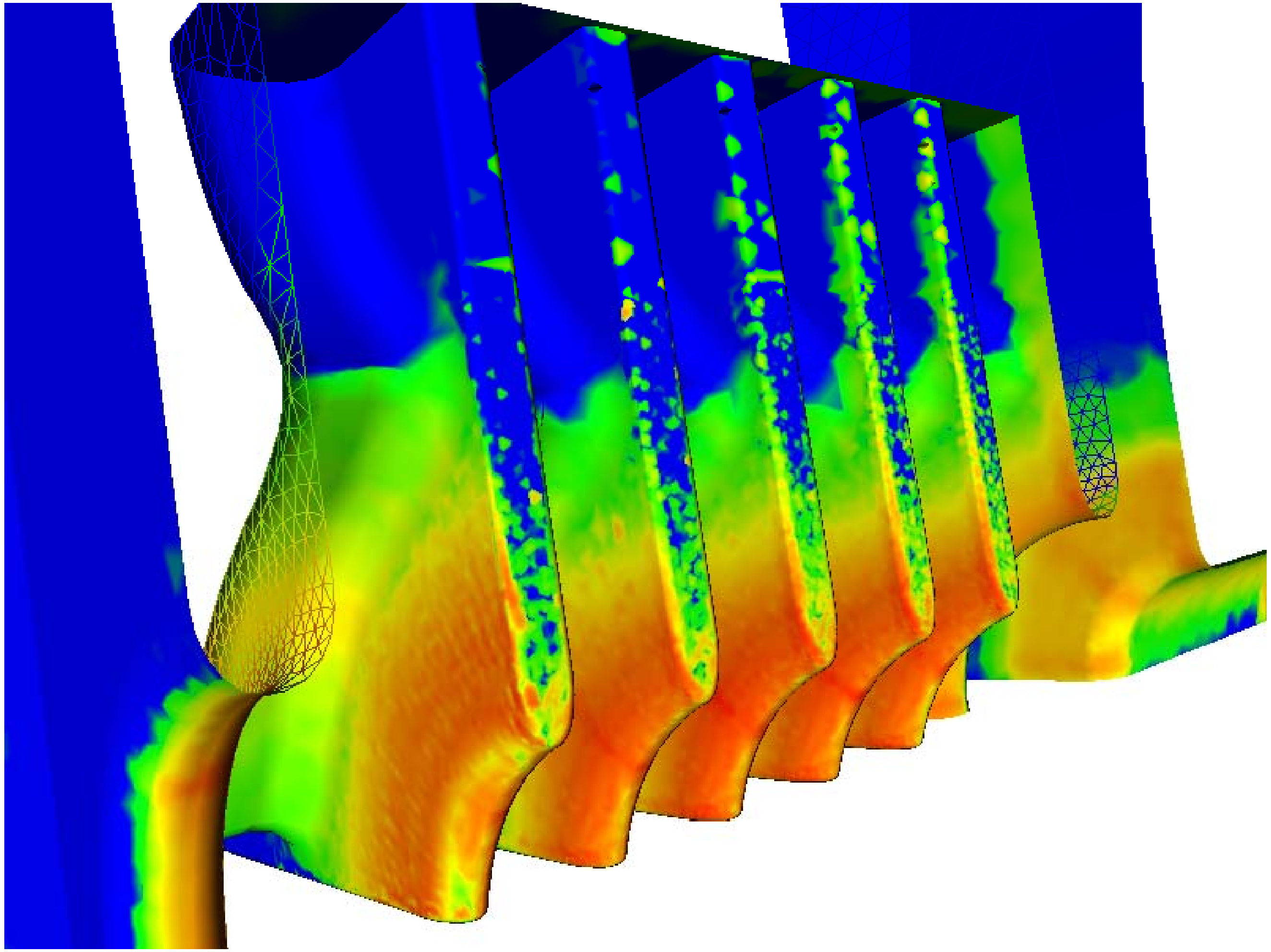
At 85 MV/m gradient, energy of dark current electrons can reach ~0.4 MeV on impact

Dark Current Particles and Heating



Field emitted and secondary electrons and surface heating

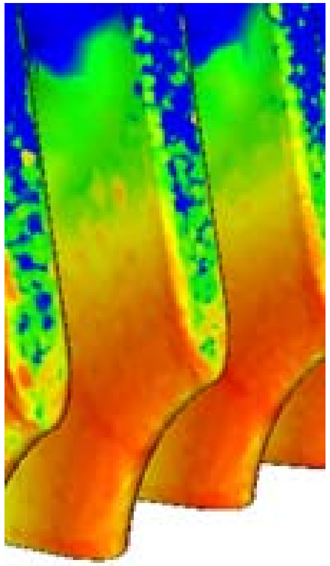
Dark Current Heating Monitor



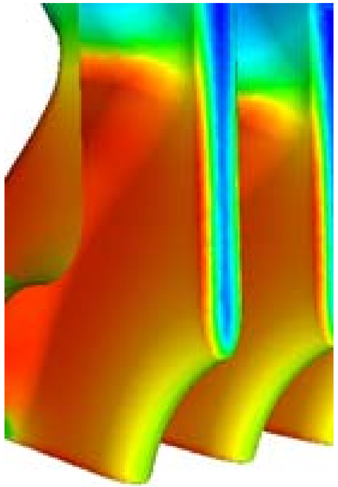
Dark current heating distribution

DC and RF Heating

- Dark current heating concentrated around the high E region on iris
  - high impact energy at high gradient
  - significant power if high field emission
  - Will analyze dependence on iris aperture and iris tapering
- Dark Current Heating may play an important role in surface degradation…, (DC+RF)



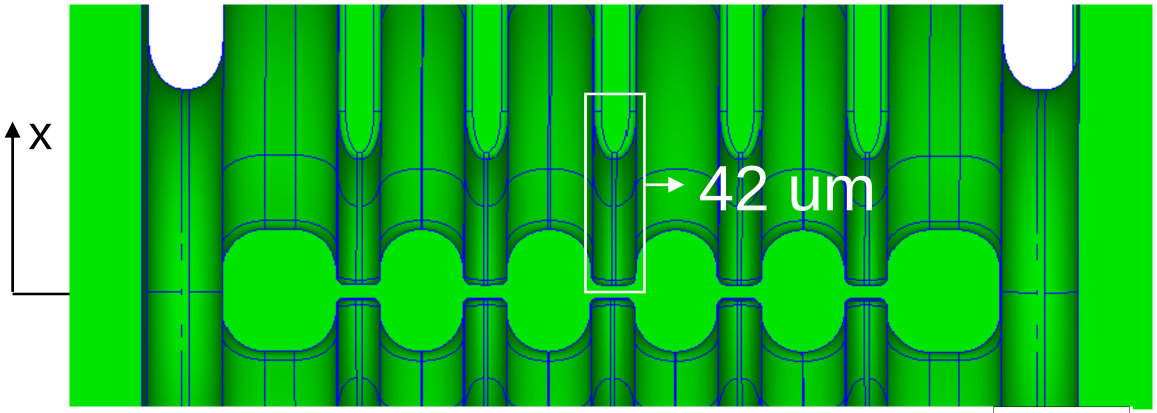
DC

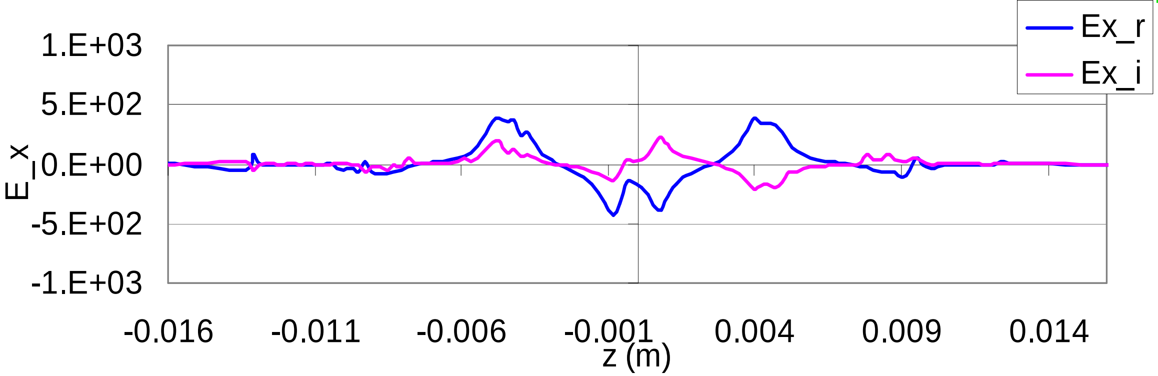


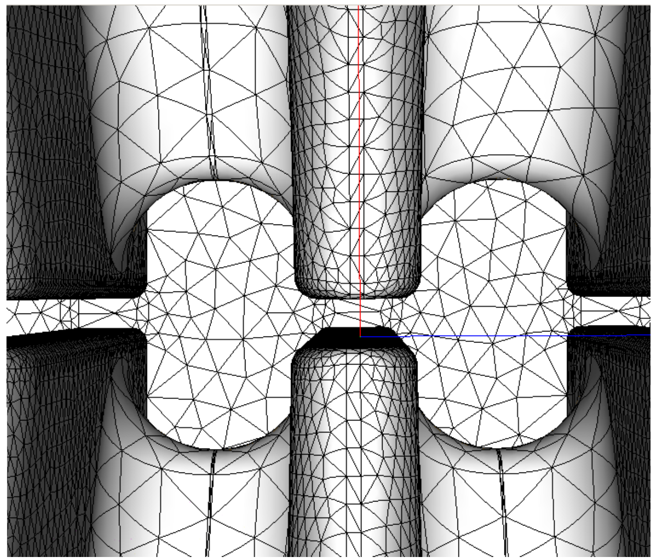
RF

HDX with Misalignment

- Model: top half of the center disk shifted 42μm in +z
- Finite element mesh ideal for modeling such small geometry features



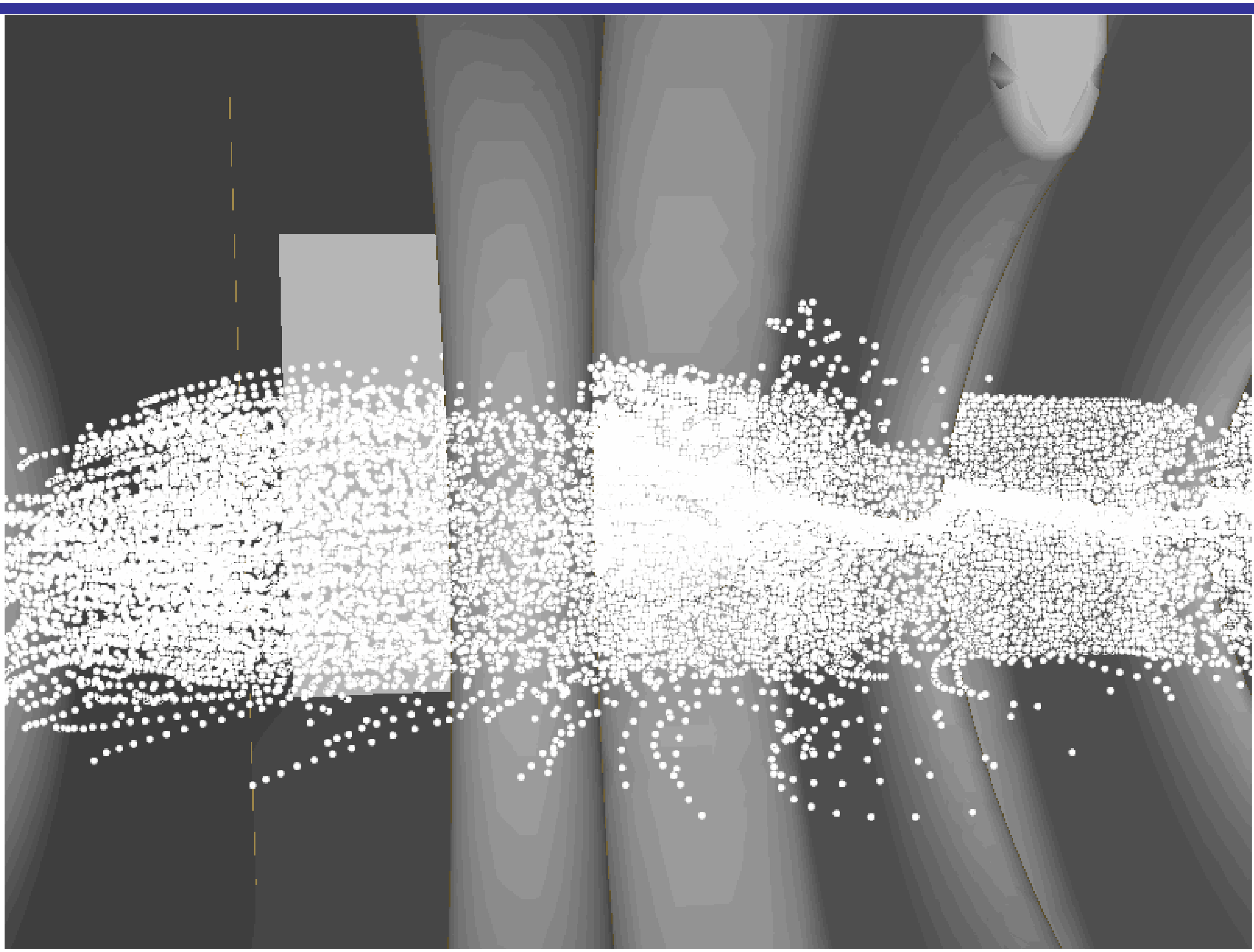




Mesh around misaligned disk

Non zero Ex field on symmetry plane in misaligned geometry

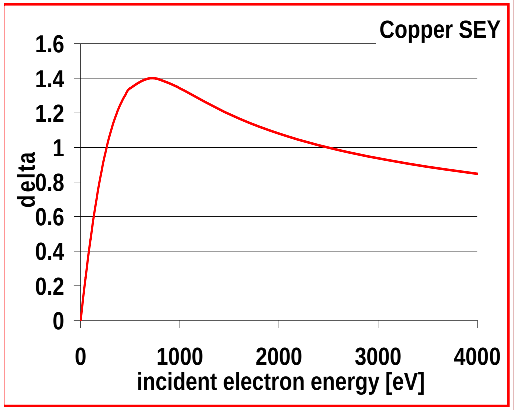
HDX Multipacting Simulation



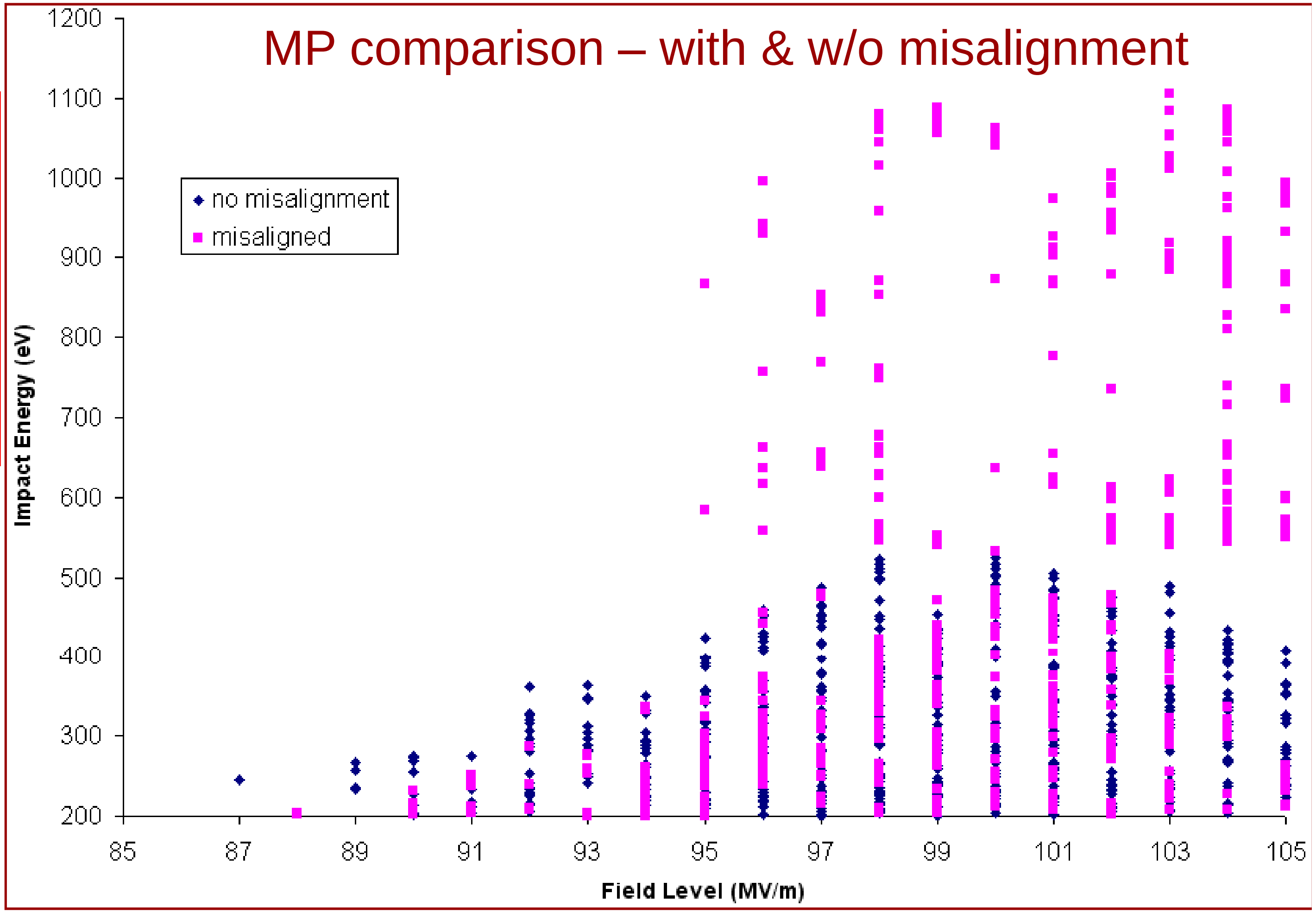
- HDX with misalignment
- Multipacting in coupler and disk slot

Multipacting In HDX

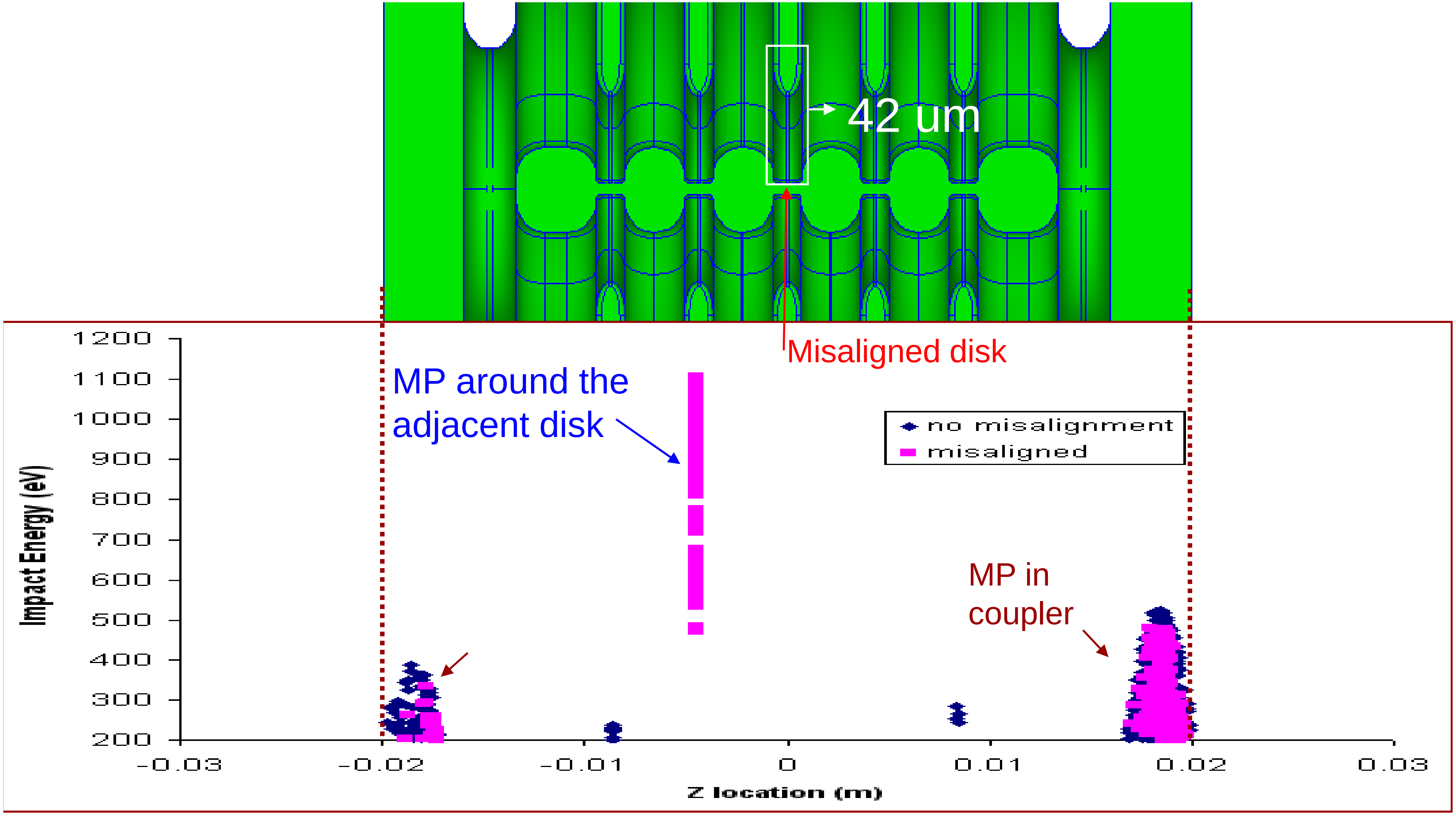
Gradient level scanned from 85 MV/m to 105 MV/m



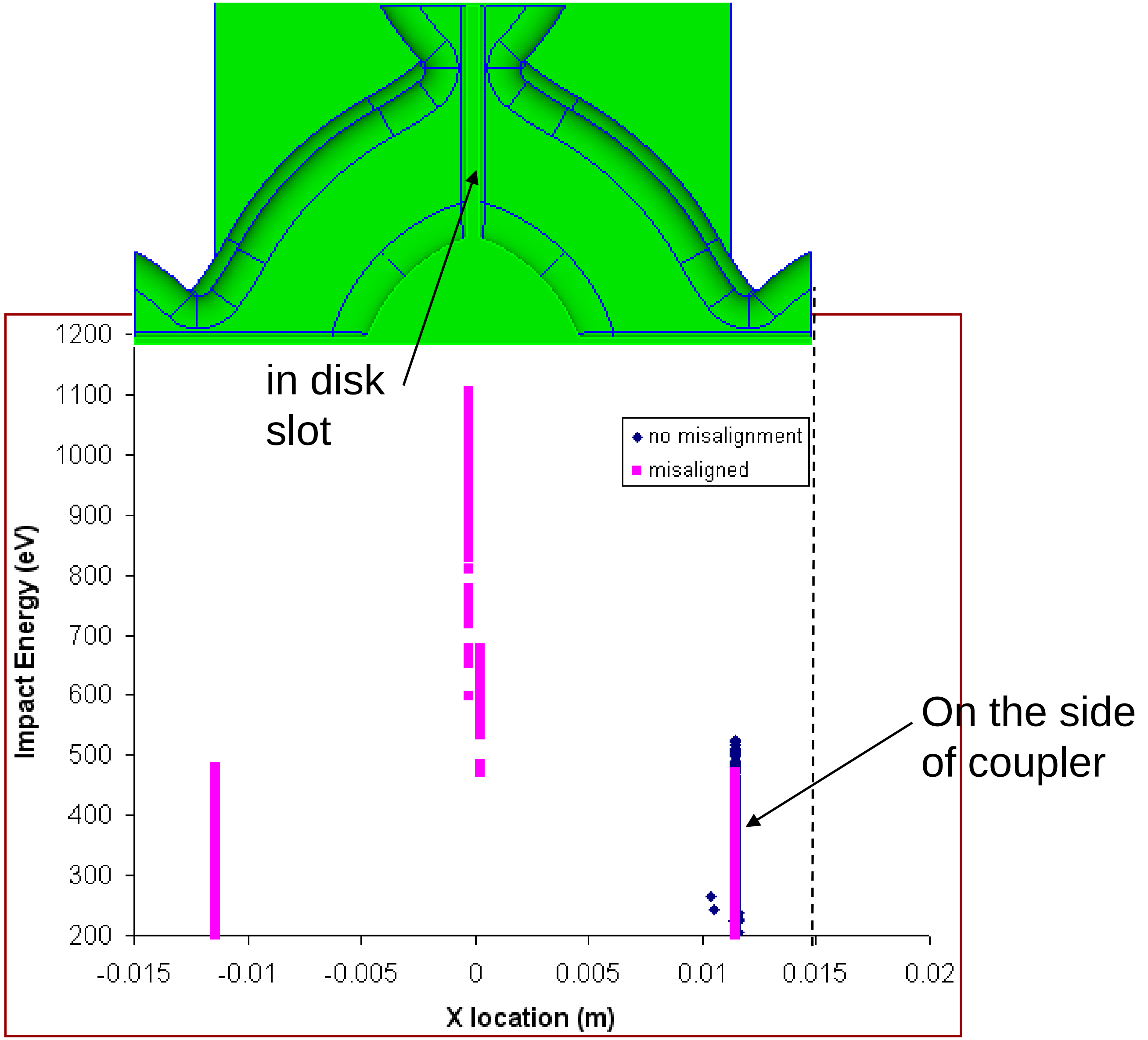
SEY peaked at around 800 eV for copper



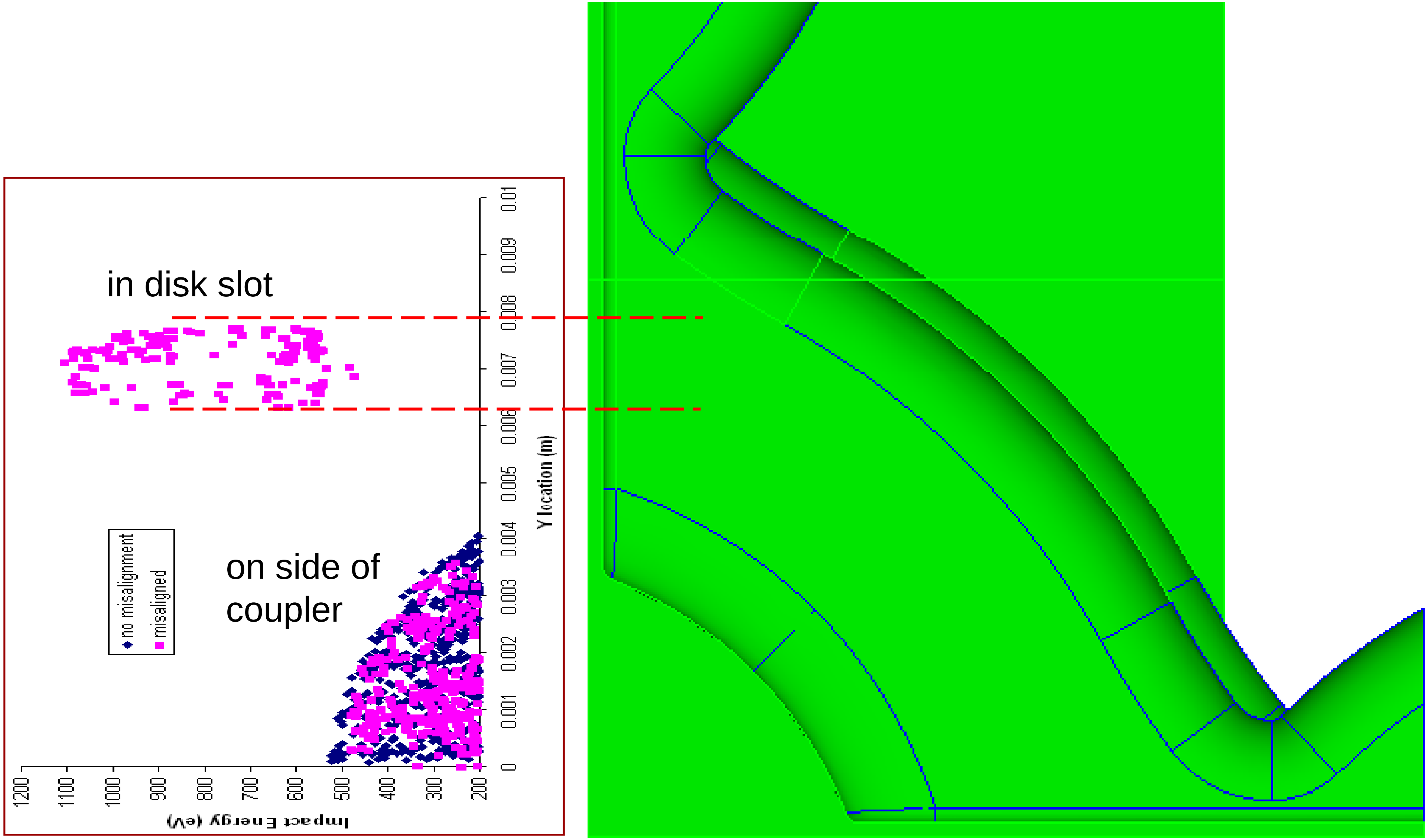
MP z Location



MP X Location



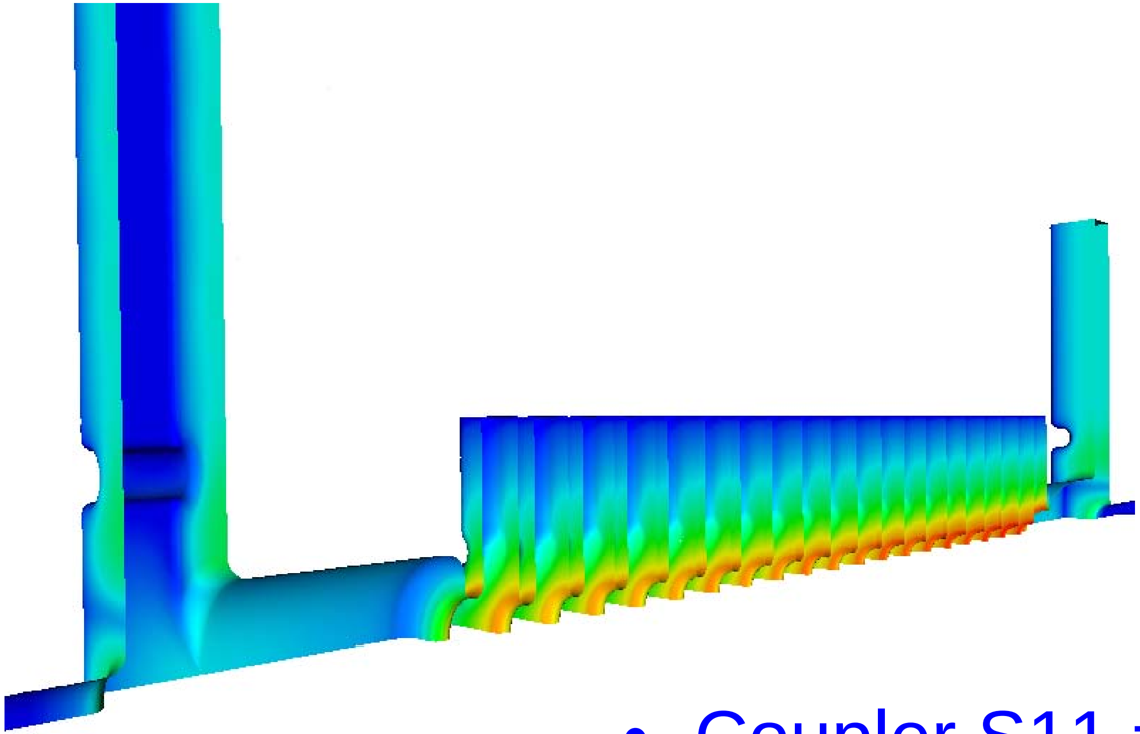
MP Y Location



Summary

- The Advanced Computations Dept. (ACD) has developed a comprehensive set of ***parallel* EM codes** that have been benchmarked and applied to R&D of major accelerator projects
- Mutipacting & Dark Current simulations are effective tools, in complementary to experimental measurement, help to gain insight of RF processes in the accelerator structure
- Progress is being made in simulating HDX and other HG structures using these codes

DWS Structure



- Coupler S11 = 0.04
- Heavily tapered structure
  - Cell-to-cell mismatch?
  - Dark current?

DWS Structure

no significant cell-to-cell mismatch