# ACE3P Application in High Gradient Structure Research

**Zenghai Li**

*Advanced Computations Group*
*SLAC National Accelerator Laboratory*

*US High Gradient Research Collaboration Workshop*
*Feb. 10, 2011*

Work supported by US DOE Offices of HEP, ASCR and BES under contract AC02-76SF00515.

# Outline

- **Parallel Finite Element Code Suite ACE3P**
- **ACE3P Application to High Gradient R&D**

  (1) PBG Structure

  (2) X-Band Gun

  (3) X-Band klystron

  (4) CLIC Cell MP

  (5) CLIC PETS & structure

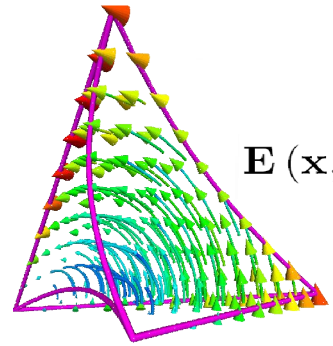
- **Summary**

# Parallel Finite Element Code Suite ACE3P

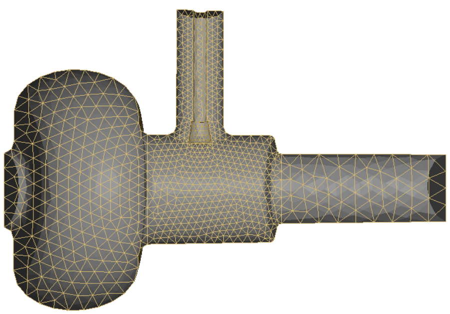
# Parallel Higher-order Finite-Element Method

## Strength of Approach – Accuracy and Scalability

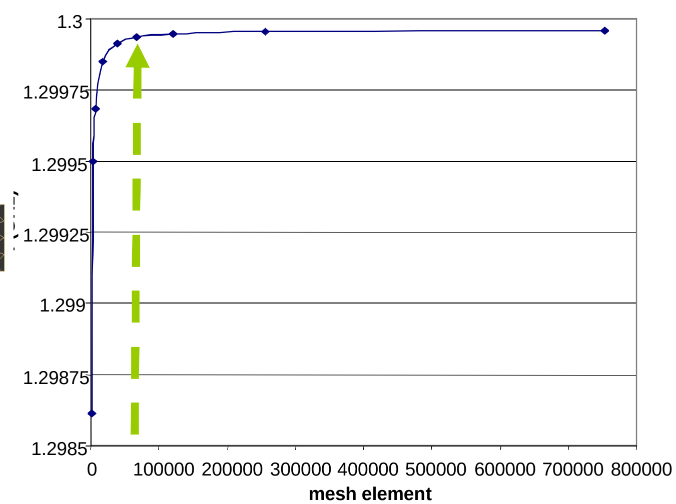
- Conformal (tetrahedral) mesh with quadratic surface
- Higher-order elements (p = 1-6)
- Parallel processing (memory & speedup)

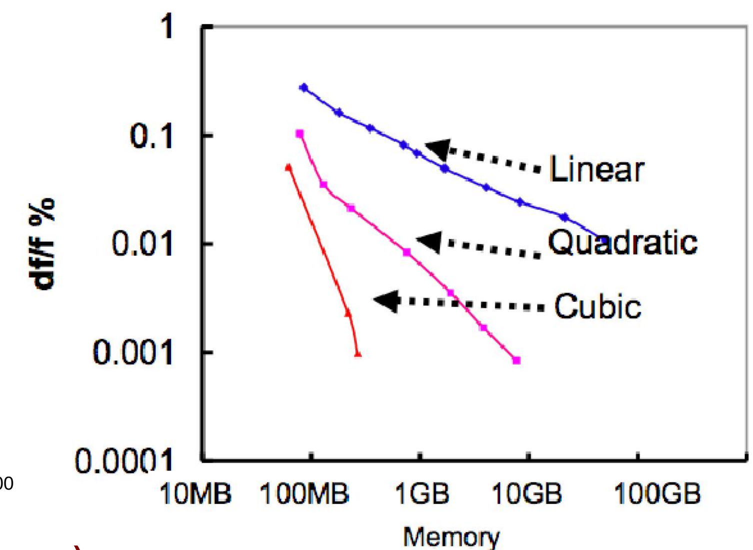


$$\mathbf{E}(\mathbf{x},t)=\sum_i e_i(t)\cdot\mathbf{N_i}(\mathbf{x})$$



*End cell with input coupler only*




*67k quad elements (<1 min on 16 CPU,6 GB)*
*Error ~ 20 kHz (1.3 GHz)*

# Accelerator Modeling with EM Code Suite ACE3P

***Meshing* - *CUBIT*** *for building CAD models and generating finite-element meshes*
*http://cubit.sandia.gov*

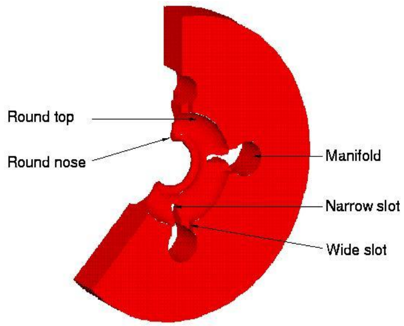
***Modeling and Simulation*** – *SLAC's suite of conformal, higher-order, C++/MPI based parallel finite-element electromagnetic codes*
*https://slacportal.slac.stanford.edu/sites/ard_public/bpd/acd/Pages/Default.aspx*

**ACE3P (Advanced Computational Electromagnetics 3P)**

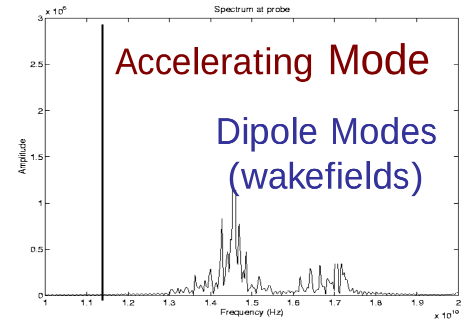
| | | |
|---|---|---|
| *Frequency Domain*: | **Omega3P** | **– Eigensolver (damping)** |
| | **S3P** | **– S-Parameter** |
| *Time Domain*: | **T3P** | **– Wakefields and Transients** |
| *Particle Tracking*: | **Track3P** | **– Multipacting and Dark Current** |
| *EM Particle-in-cell:* | **Pic3P** | **– RF guns & klystrons** |
| *Multi-physics:* | **TEM3P** | **– EM, Thermal & Structural effects** |

***Postprocessing* - *ParaView*** *to visualize unstructured meshes & particle/field data*
*http://www.paraview.org/*

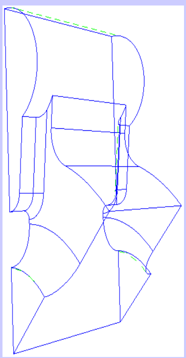
# Accelerator Design and Analysis with ACE3P



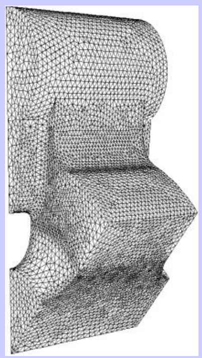

**Constraint**
**$f = f_0$ ;**
**Maximize (R/Q , Q)**
**Minimize**
**(surface fields etc.)**



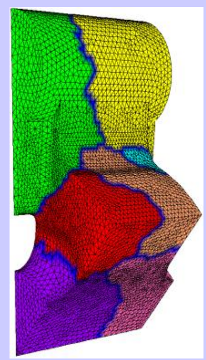

**Minimize Wakefields**



**Model CAD**



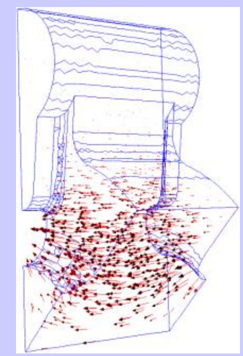
**Meshing Cubit**



**Partitioning ParMetis**

**ACE3P**

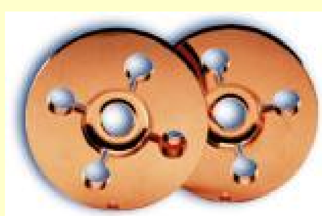
**Solvers**



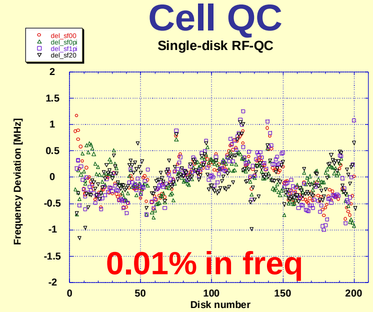
**Visualization ParaView**

**ACE3P EM Field Computations Determine Cavity Dimensions**

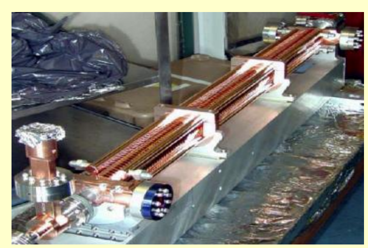
**Fabrication**

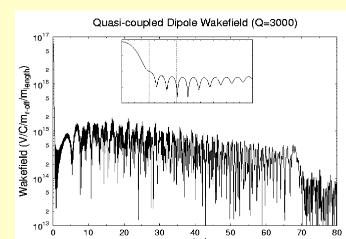


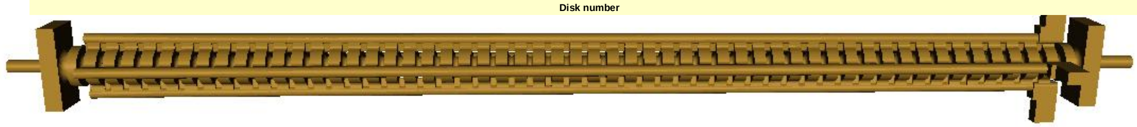
**Cell QC**




**Wakefield Measurement**





# ACE3P Capabilities

- **Omega3P** can be used to
  - optimize RF parameters
  - reduce peak surface fields,
  - determine HOM damping, trapped modes & their heating effects
  - design dielectric & ferrite dampers, and others
- **S3P** calculates the transmission (S parameters) in open structures
- **T3P** uses a driving bunch to
  - evaluate the broadband impedance, trapped modes and signal sensitivity
  - compute the wakefields of short bunches with a moving window
  - simulate the beam transit in large 3D complex structures
- **Track3P** studies
  - multipacting in cavities & couplers by identifying MP barriers & MP sites
  - dark current in high gradient structures including transient effects
- **Pic3P** calculates the beam emittance in RF gun designs
- **TEM3P** computes integrated EM, thermal and structural effects for normal cavities & for SRF cavities with nonlinear temperature dependence

# ACE3P Application to High Gradient R&D

(1) PBG Structure

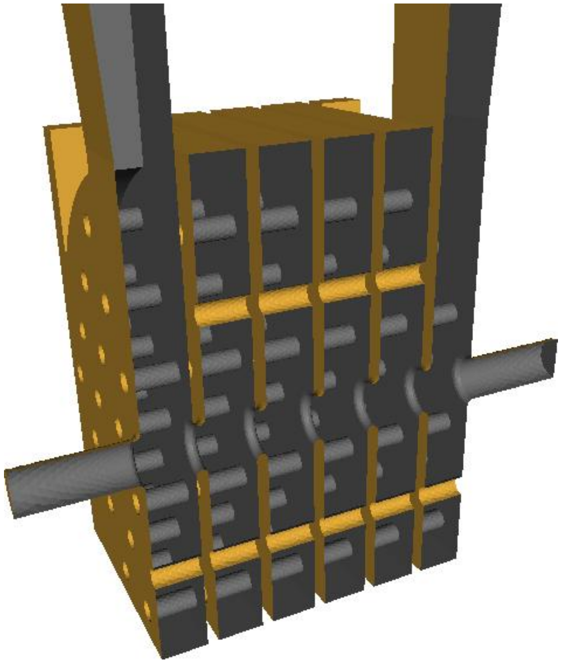
(2) X-Band Gun

(3) X-band klystron

(3) CLIC Cell – Multipacting

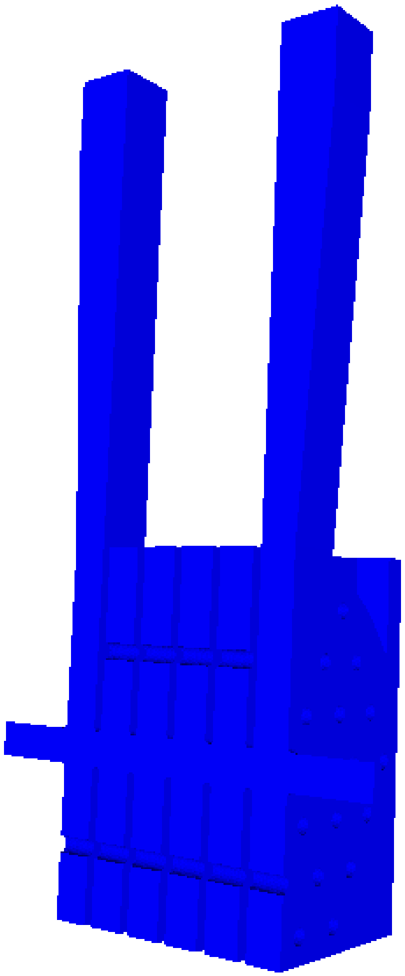
(4) CLIC PETS & Structure

# T3P – Photonic Bandgap Structure

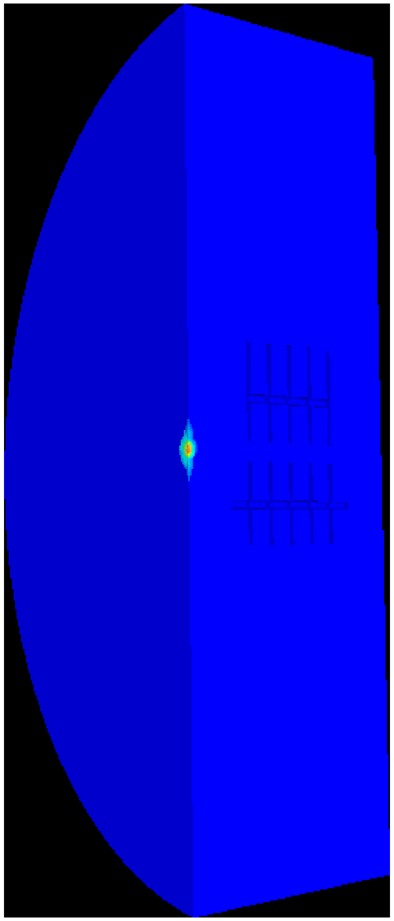


MIT PBG structure

- Operated at 17 GHz for high gradient acceleration
- Study effects of transients of drive pulse on dark current
- Evaluate power radiation from multi-beam transit



Power coupling

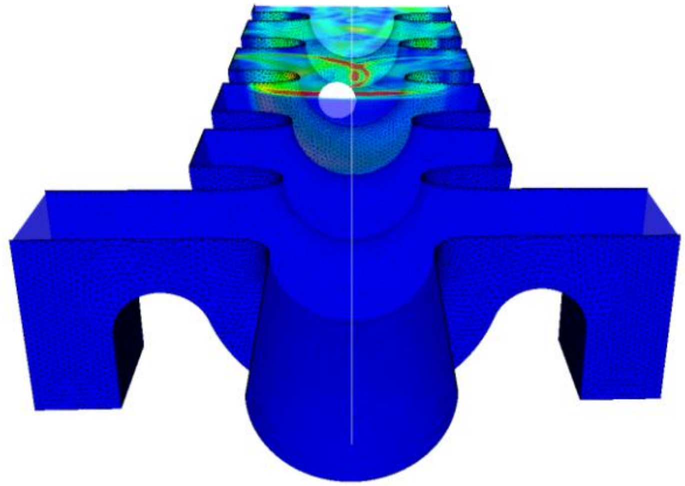


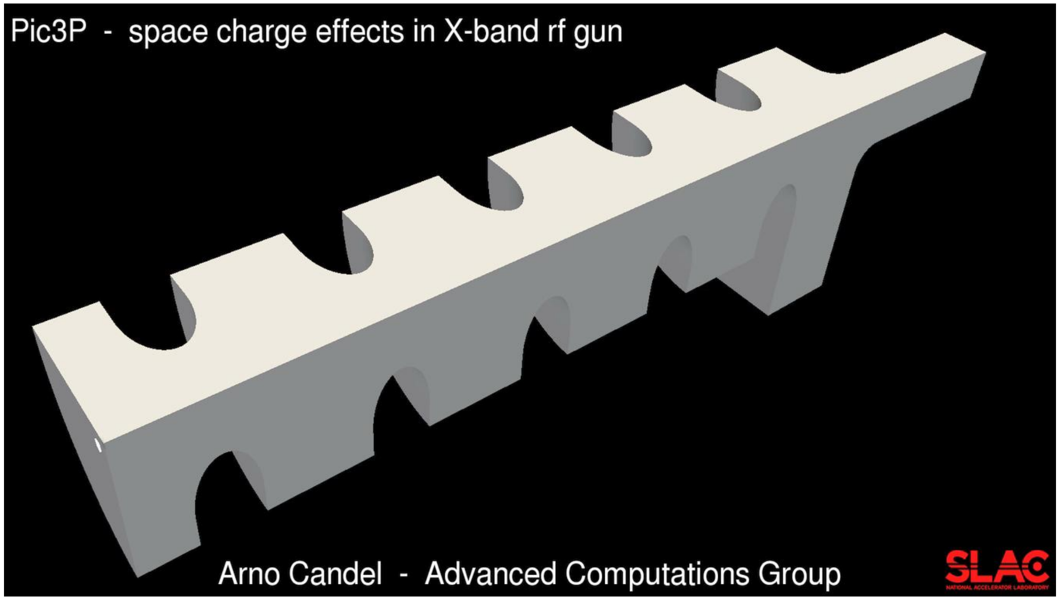
Multi-beam transit

# Pic3P – SLAC/LLNL X-Band Gun

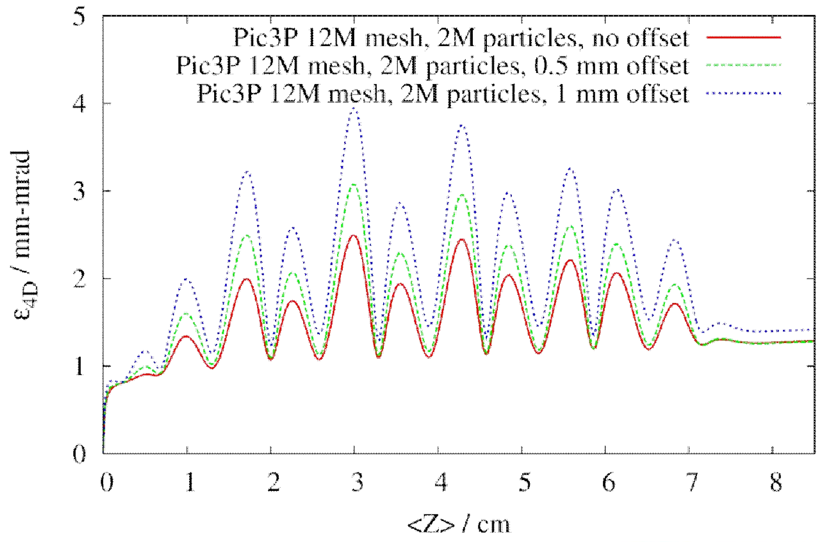
**3D Emittance Calculations for Bunch with Offset**

- f=11.424 GHz, 200 MV/m peak Ez on cathode
- Solenoid Bz_max = 0.5658 T at Z=6.3 cm
- Beer can (r=0.5 mm, 2 ps flat top, 0.4 ps rise time), 250 pC
- Bunch injected 30 degrees after zero-crossing






4D Emittance vs <Z>



# Pic3P/Gun3P – X-Band Klystron Design

( Collaboration with Aaron Jensen – Klystron Dept)

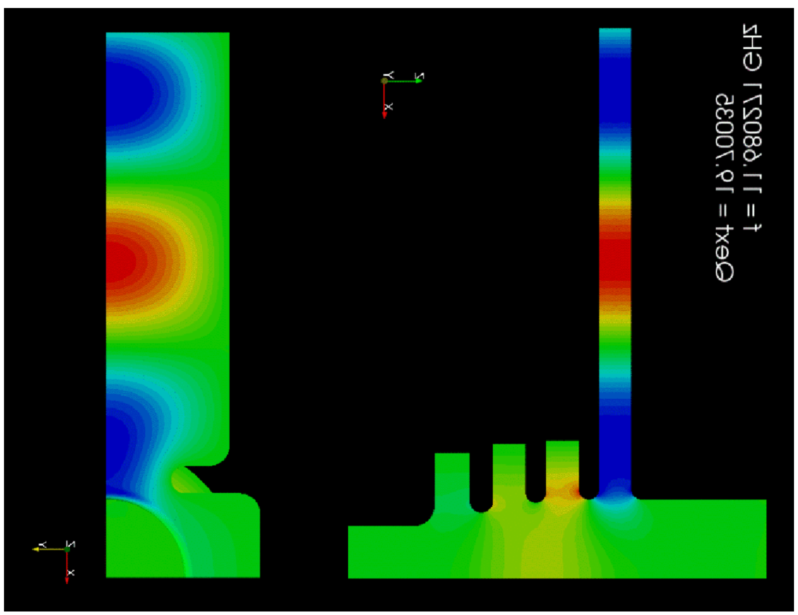
Goal is to perform 3D end-to-end simulation using High Performance Computing

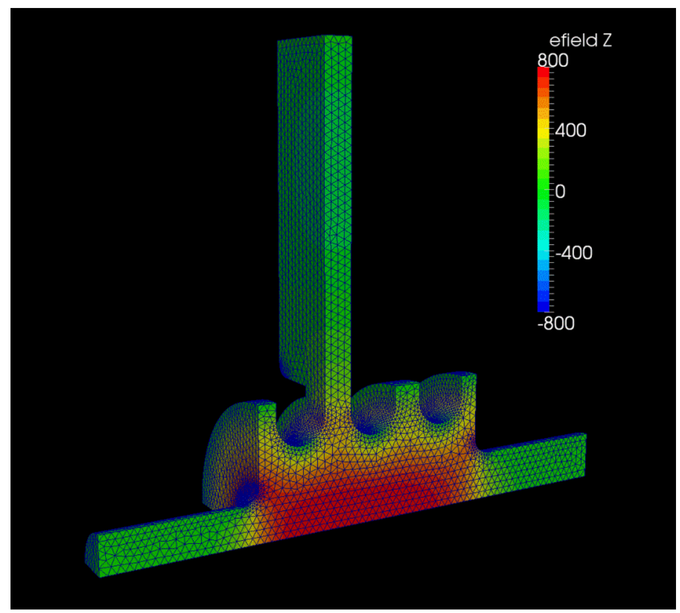
**XL4 Output cavity**

- Comparing efficiency with MAGIC

**XC8 Output Cavity**

- Comparing start oscillation with measurement

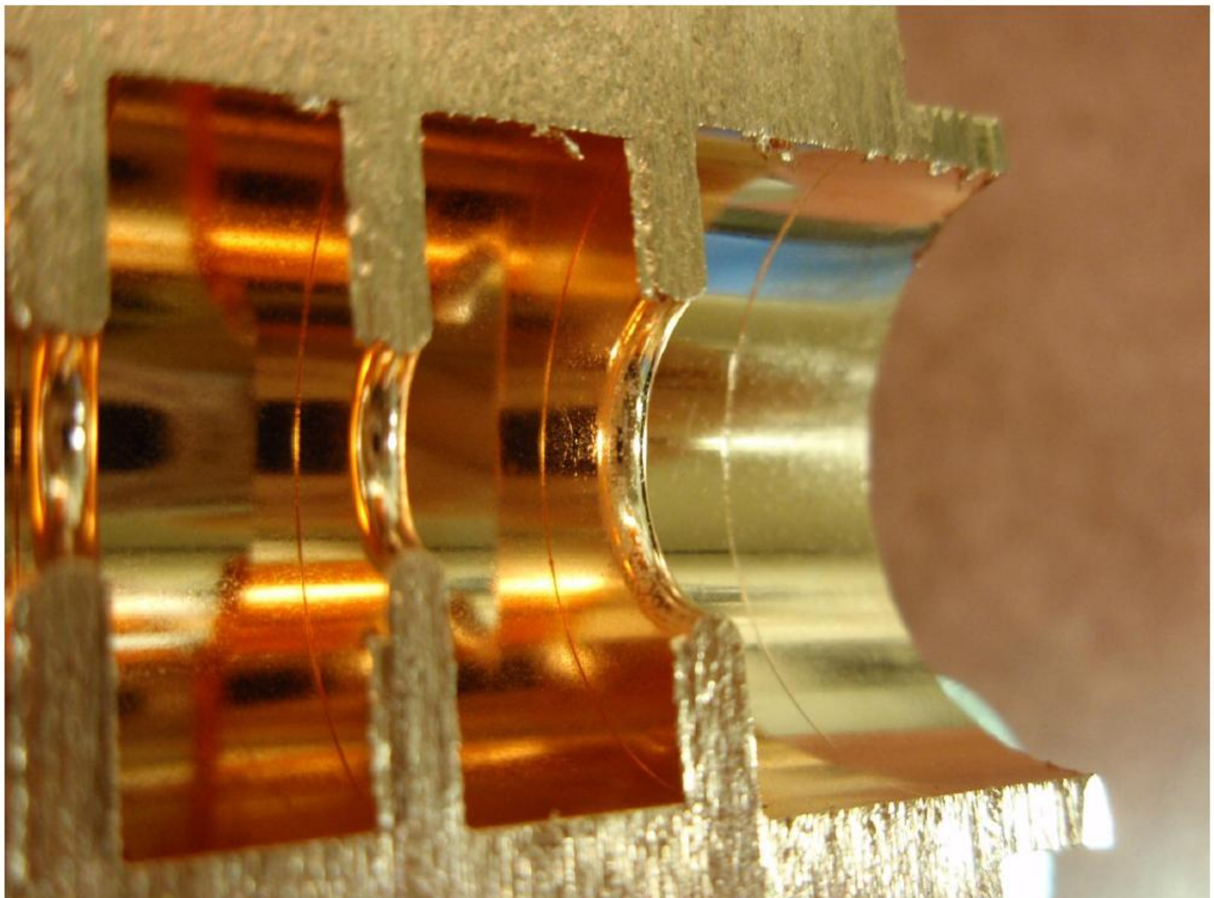




# CLIC TD18(24) Multipacting Analysis

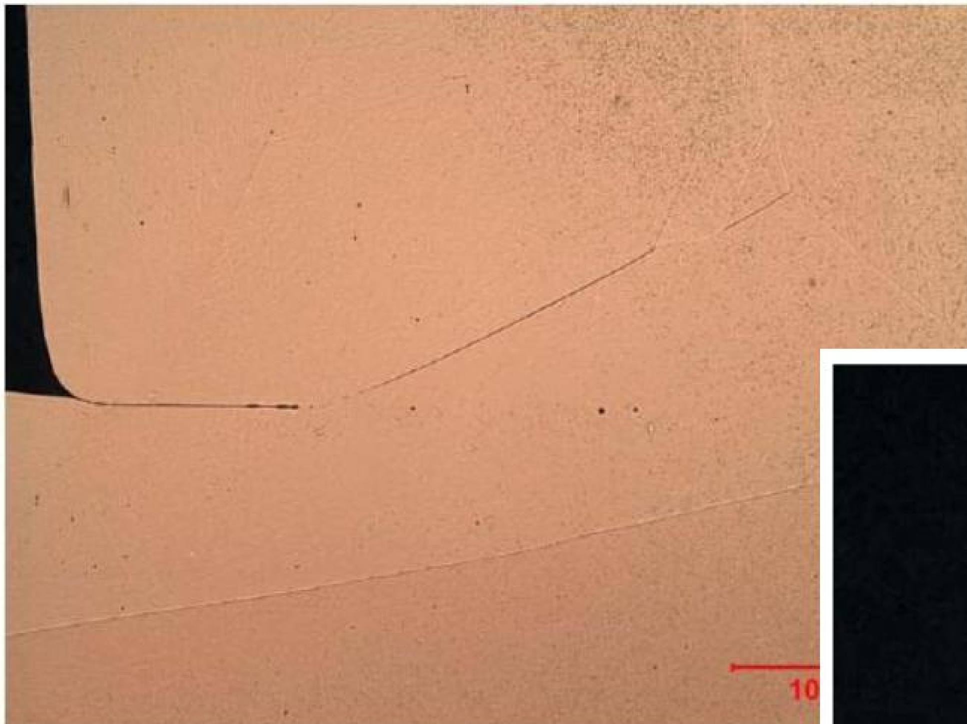
# Brazing Gap – Multipacting Analysis

## Cutoff Picture Reveals a Possible Bonding Problem



Juwen Wang, IWLC2010, & this workshop

# Metallographic Pictures for Bonding Area in a C10 Structure



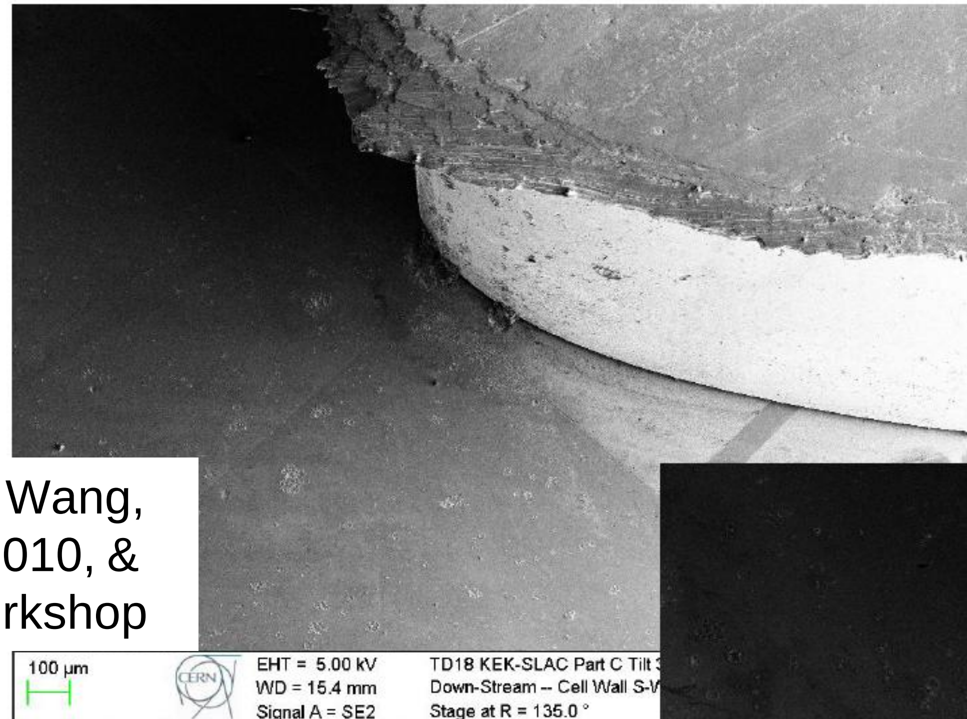

- Very good bonding
- Corner radius is much smaller than drawing specified 0.005" (127 microns). The red bar is 254 microns.

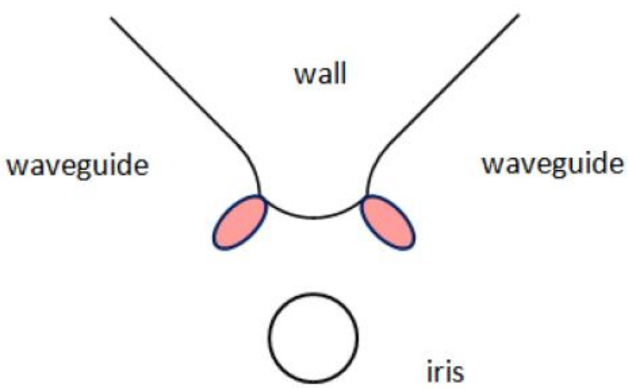

Juwen Wang, IWLC2010,
& this workshop

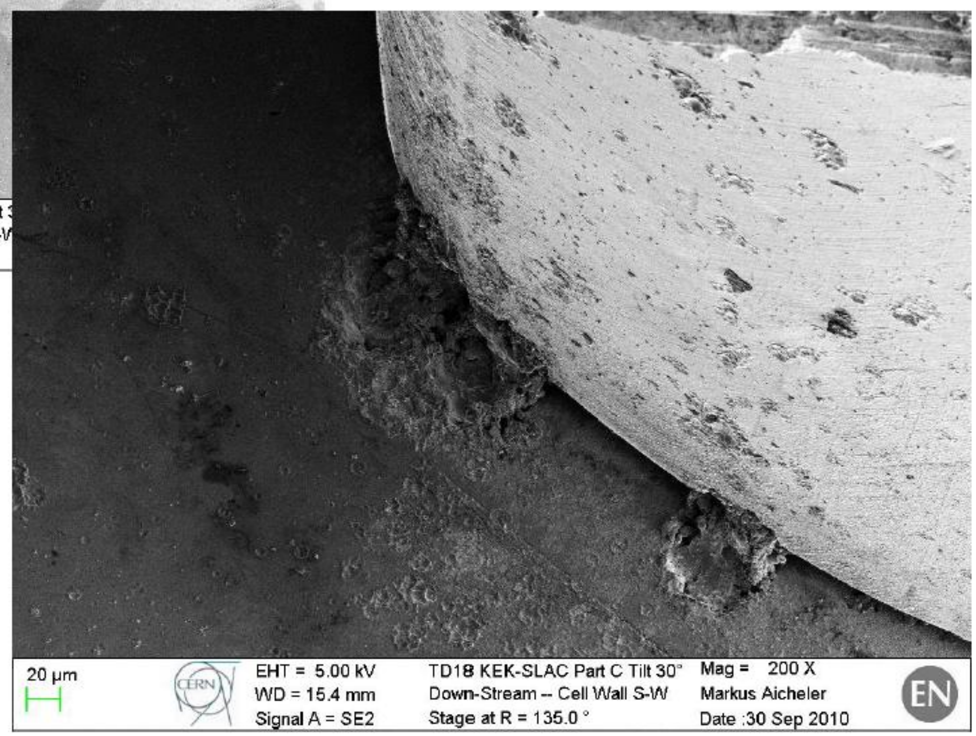
# CERN Pictures for TD18 Structure after High Power Test

Part C
Down-stream side - Cell Wall S-W!
Tilt 30°

Juwen Wang, IWLC2010, & this workshop

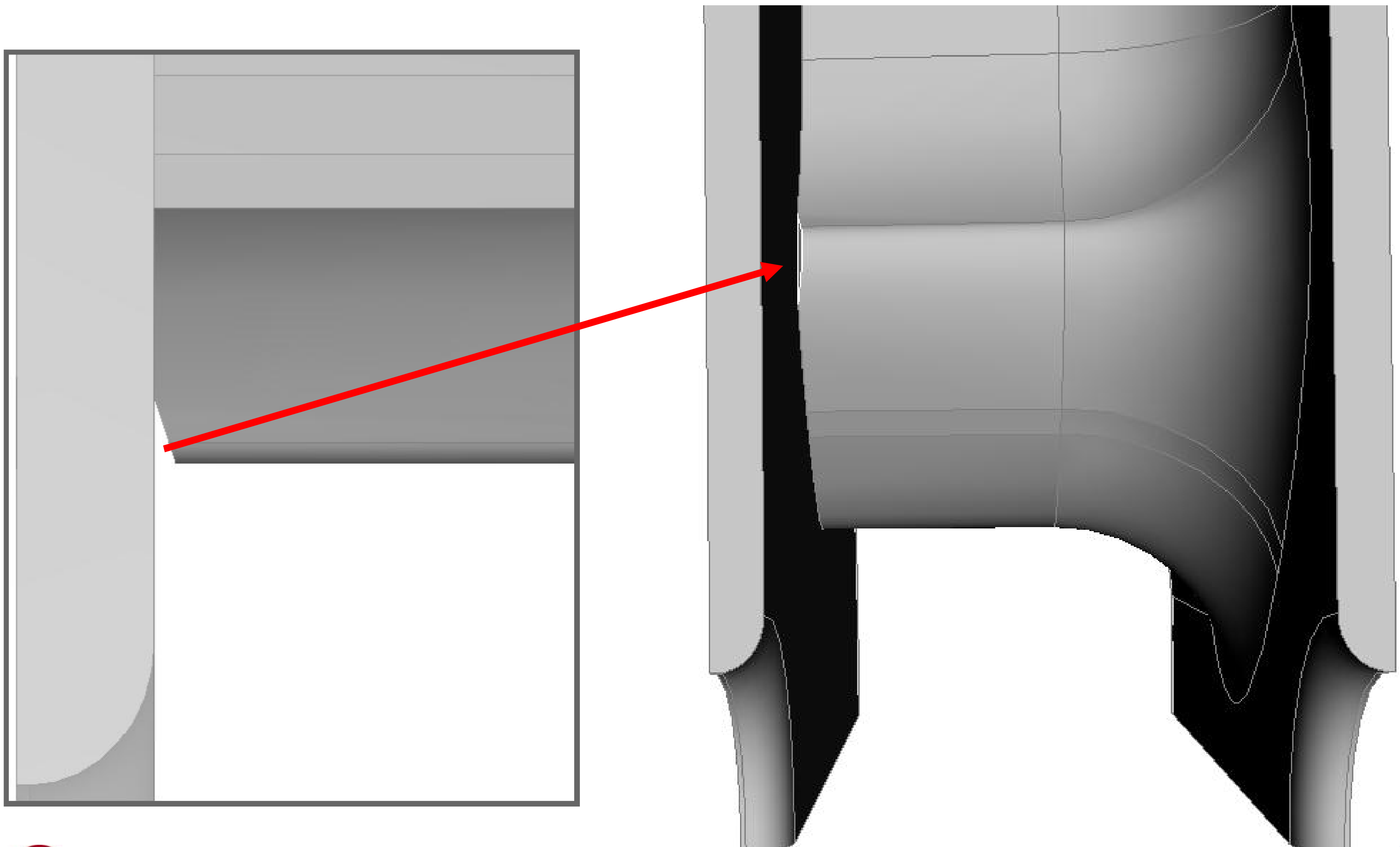


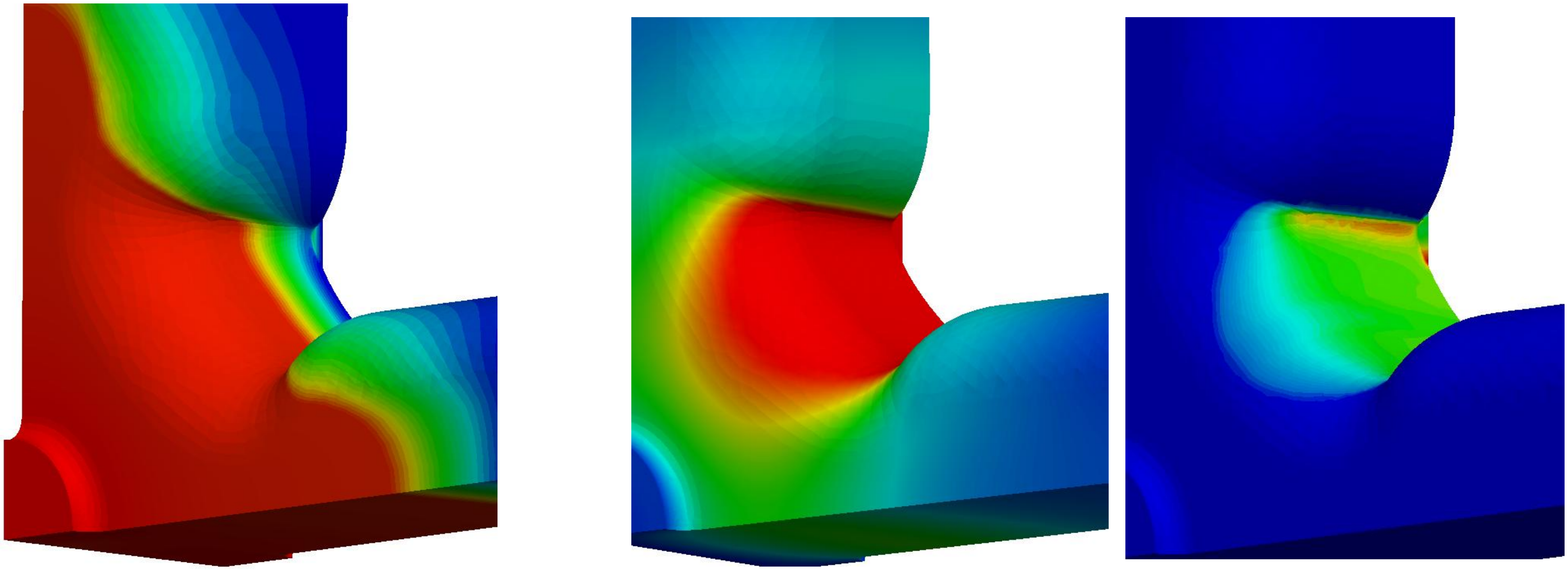
# Model With "Gap"

- Gap – local chamfer
- Primary electrons emitted around the gap region



# CLIC TD24 Cell

* E&B fields



# Multipacting Simulation Around the Gap

- Primary electrons emitted around the gap region
- Identify resonant trajectories
- Use impact energy to estimate potential SEY

(Copper SEY, variations from different docs)

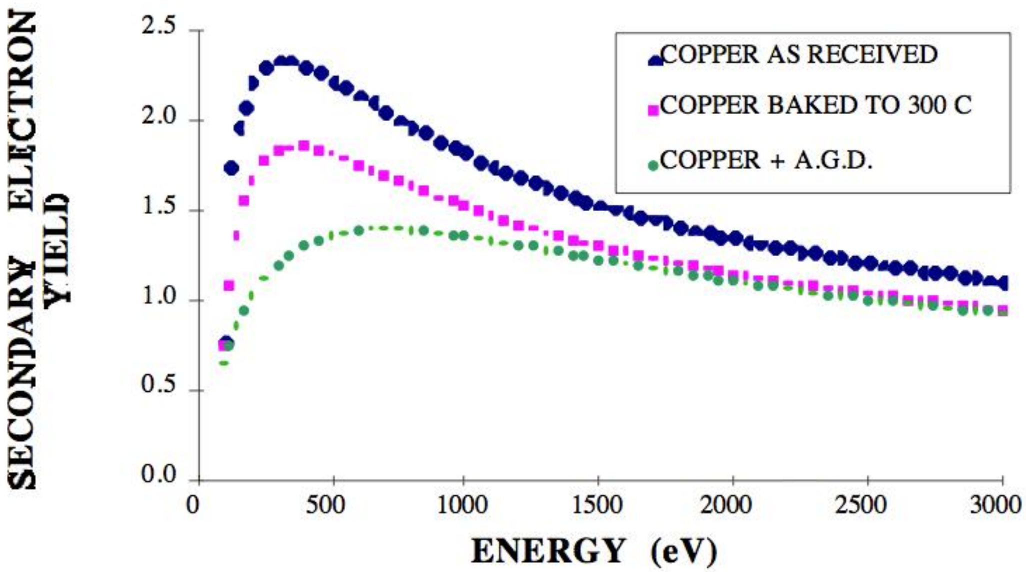
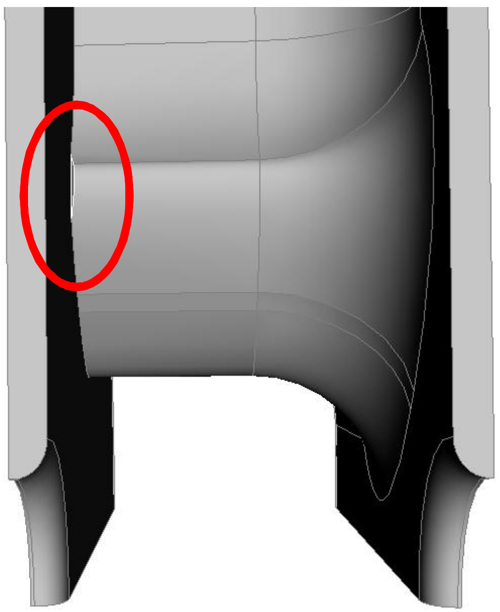
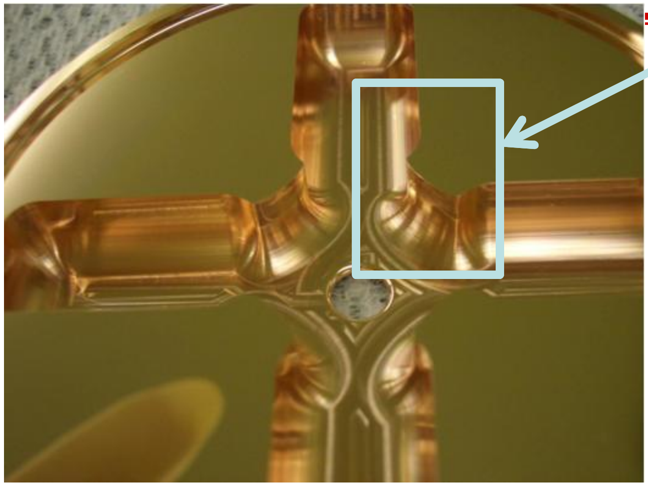


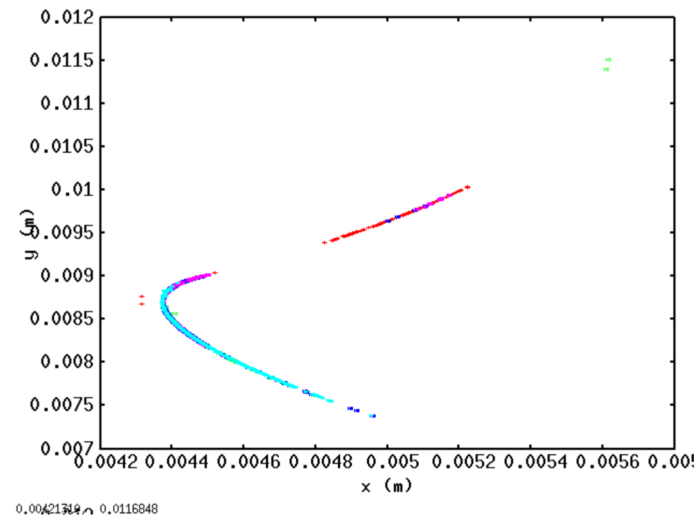

Figure 2: The S.E.Y. of copper for various surface treatments

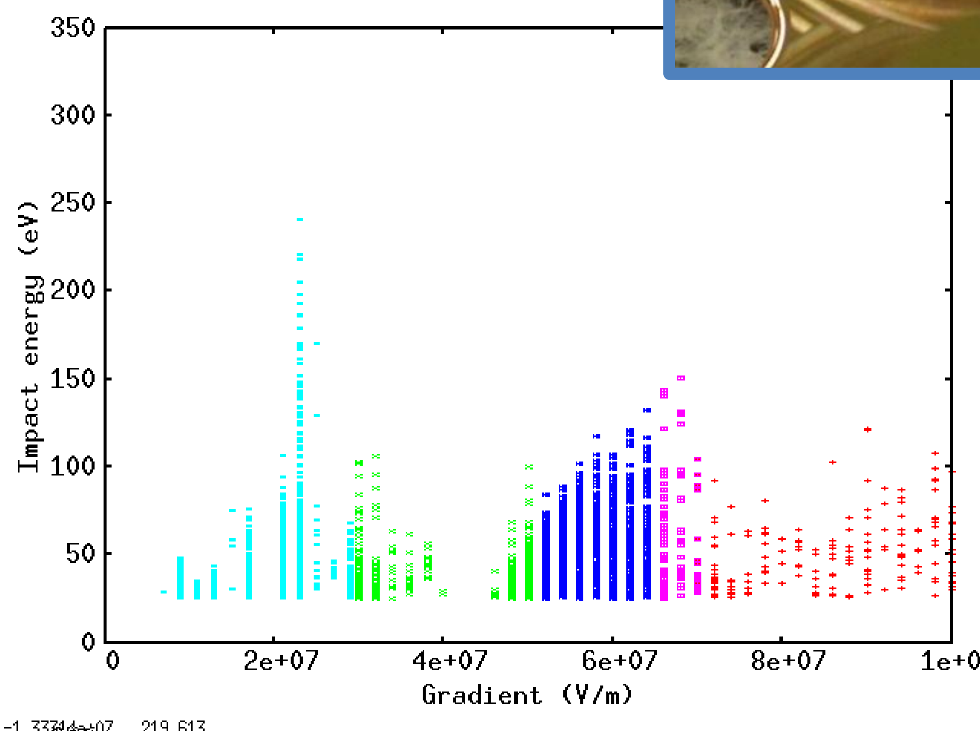


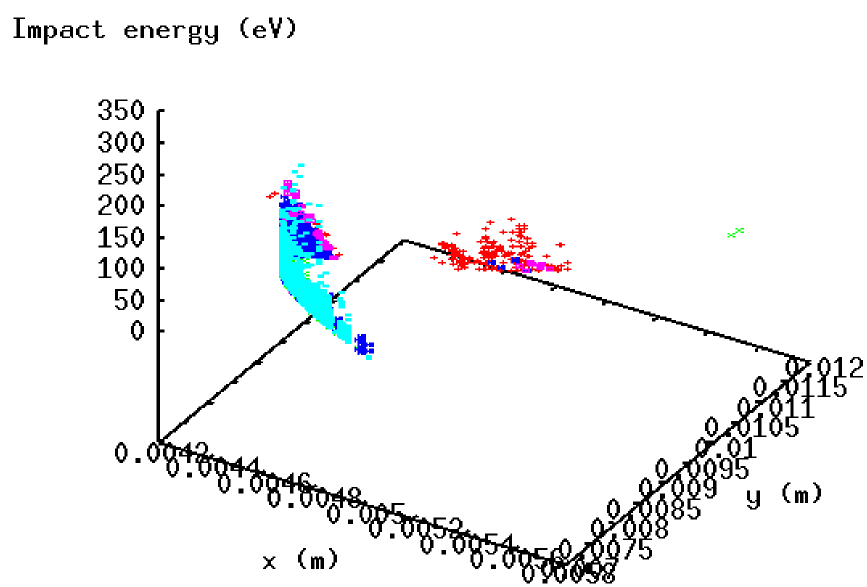

THE SECONDARY ELECTRON YIELD OF TECHNICAL MATERIALS AND ITS VARIATION WITH SURFACE TREATMENTSV. Baglin, J. Bojko1, O. Gröbner, B. Henrist, N. Hilleret, C. Scheuerlein, M. Taborelli CERN, Geneva, Switzerland

# Gap: opening=0.05mm,d=0.2mm

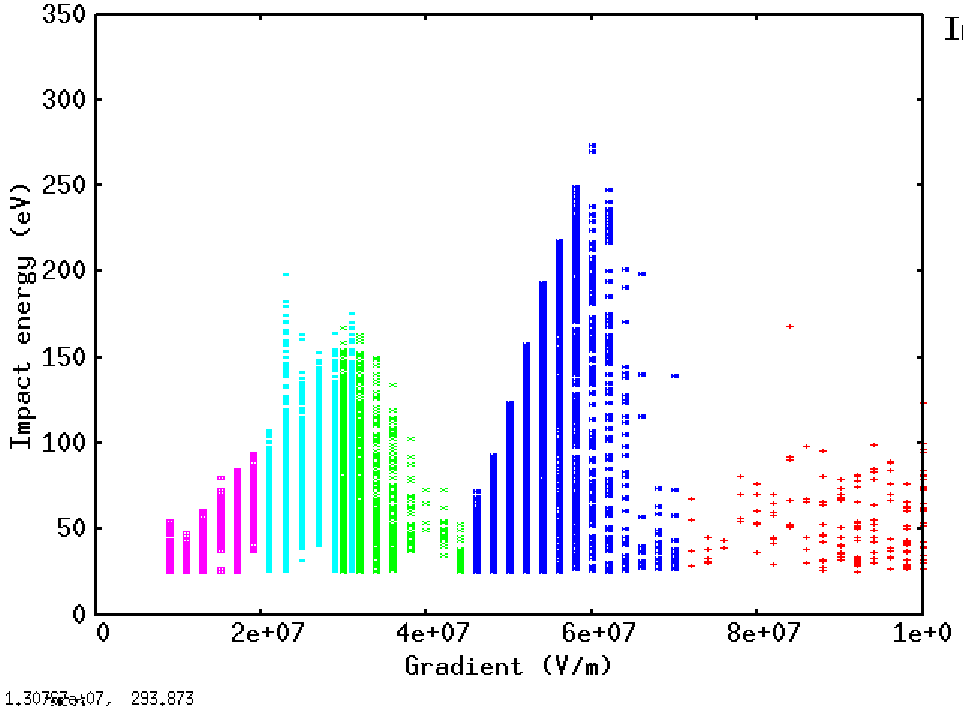


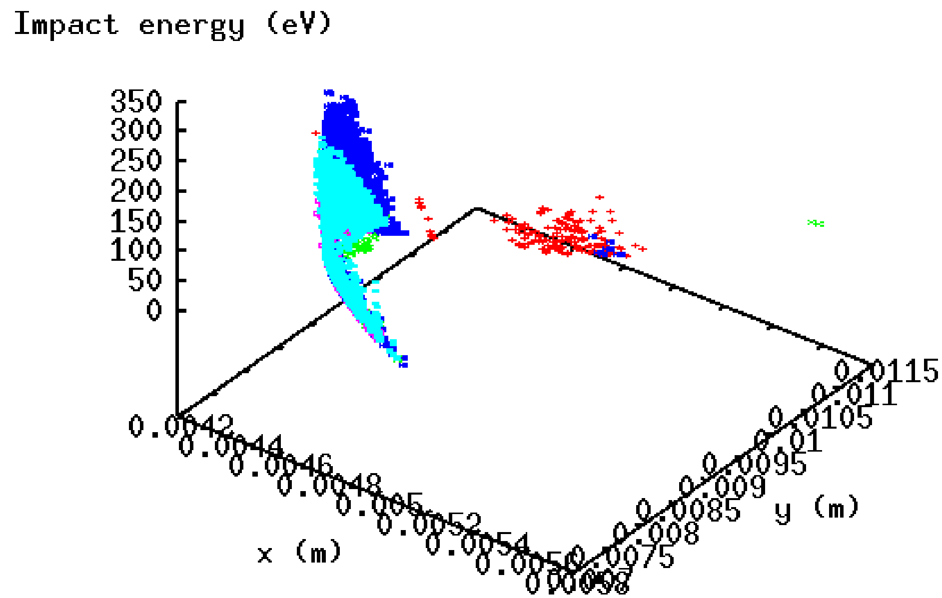


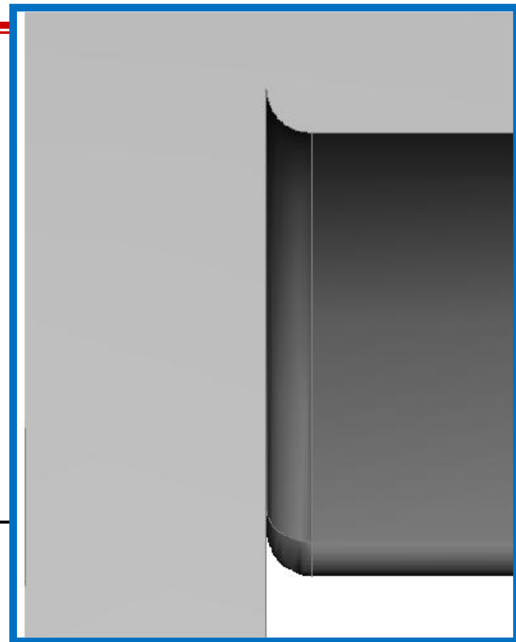
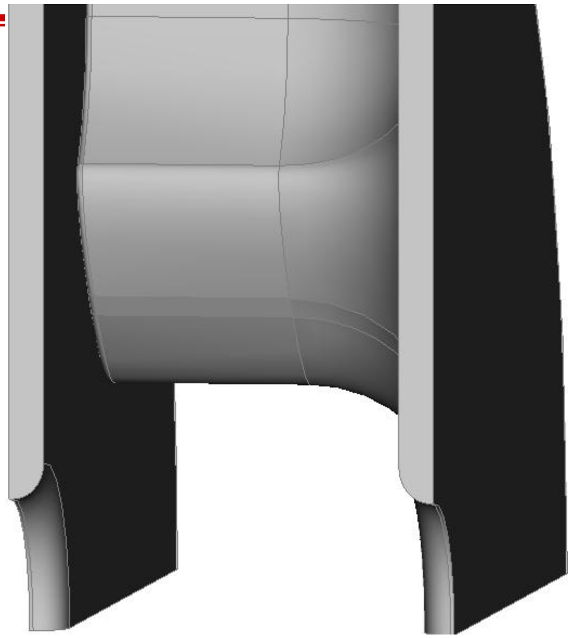
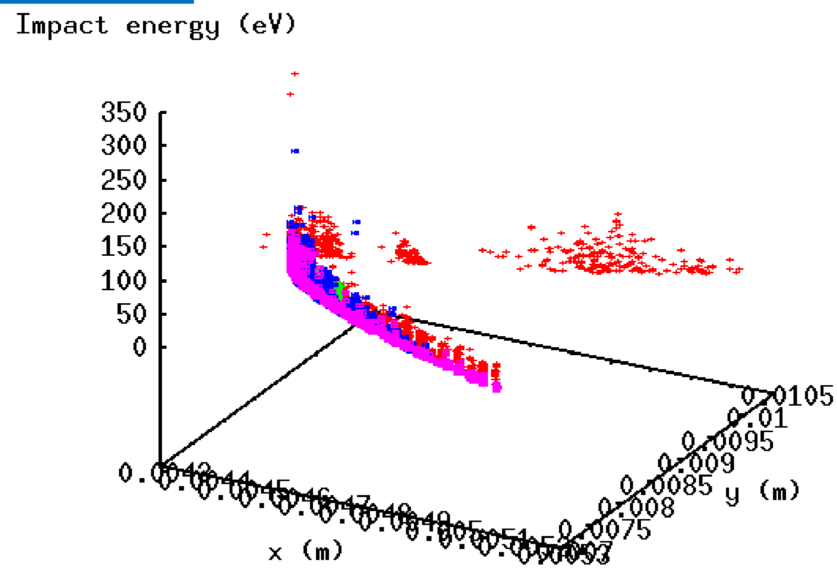
# Gap: opening=0.1mm,d=0.3mm

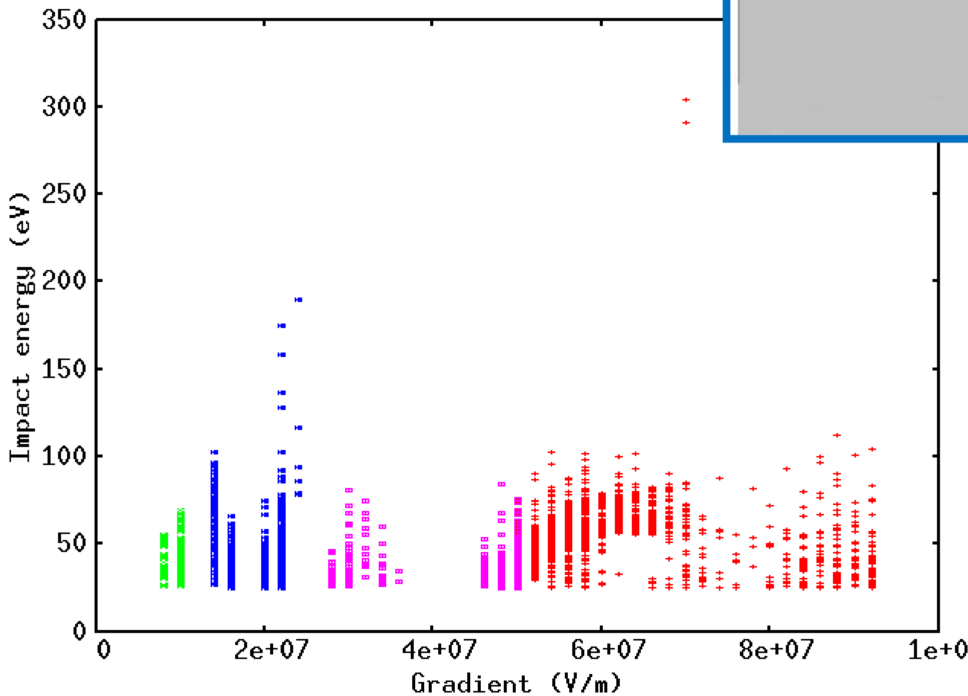


# Gap due to rounded corner

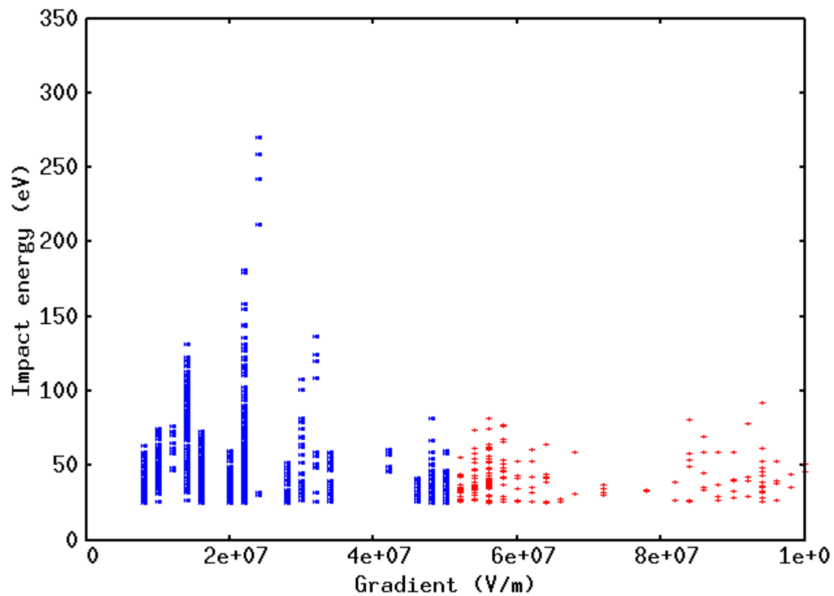
* Rounding radius: 0.125mm

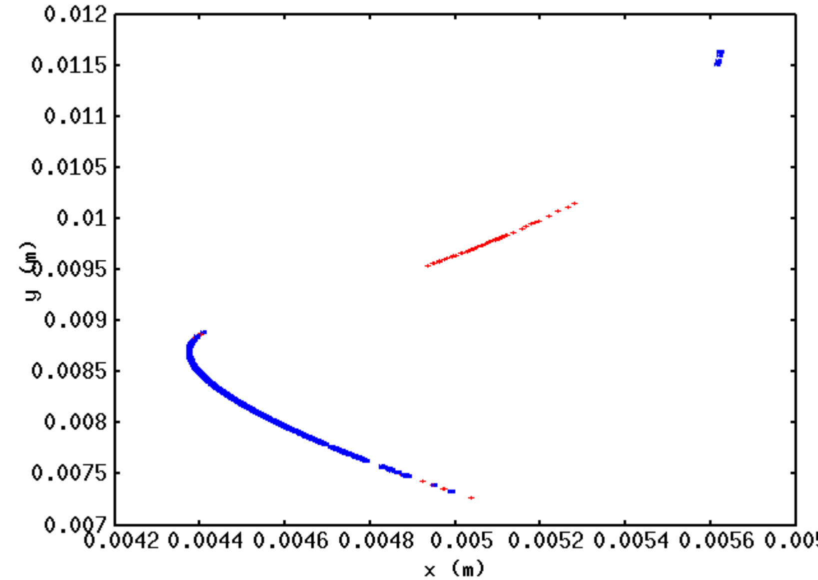




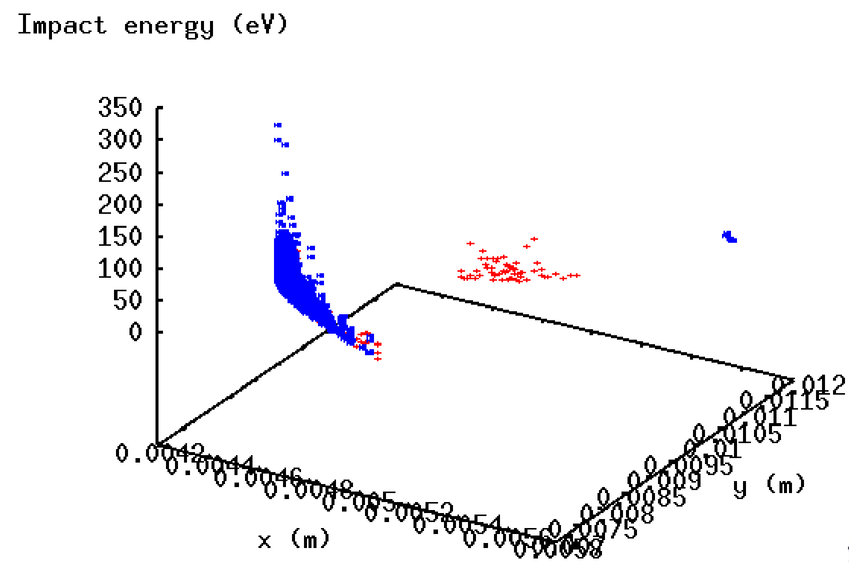



# No Brazing Gap

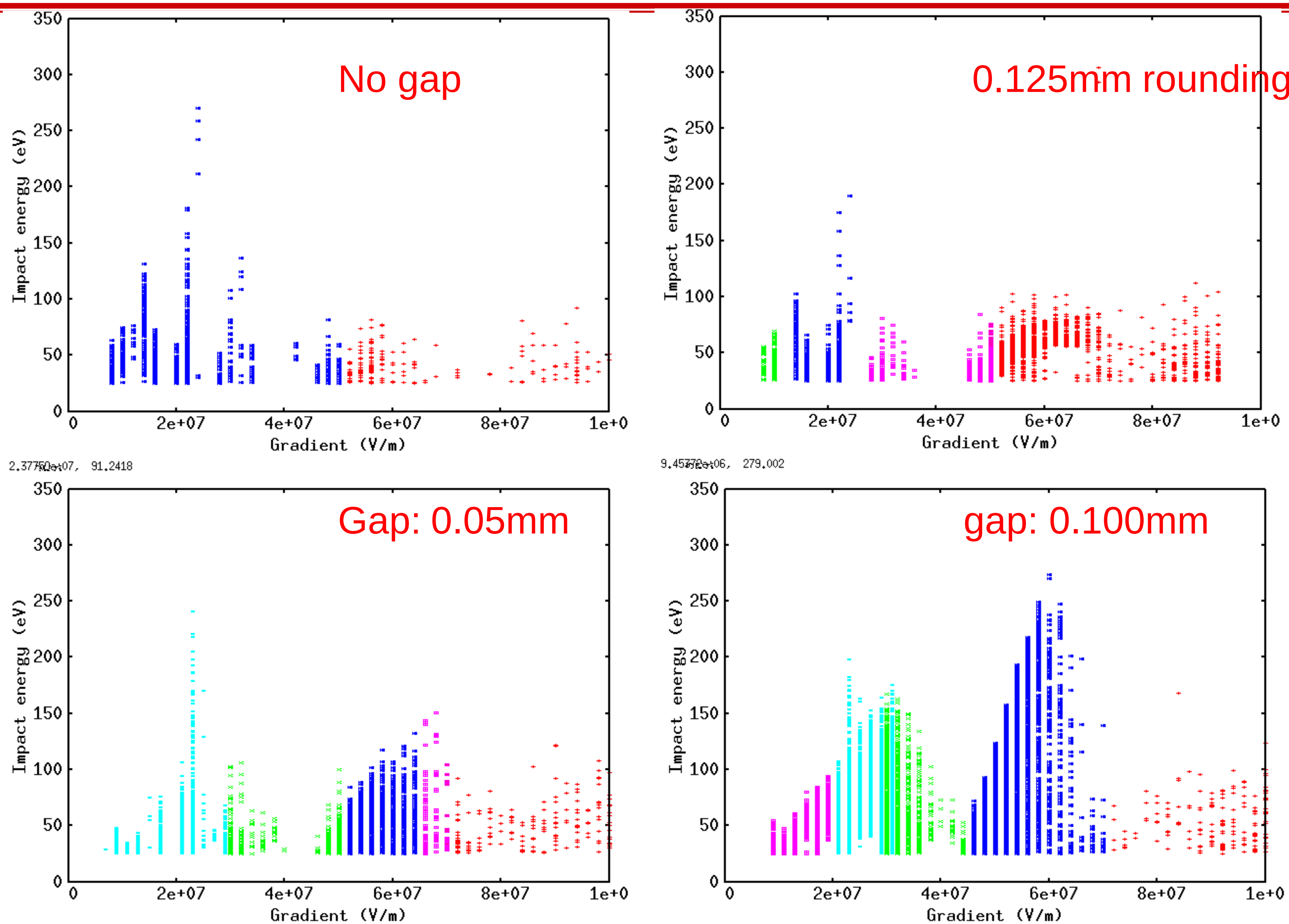
Primaries emitted in the area around the HOM coupler opening corner



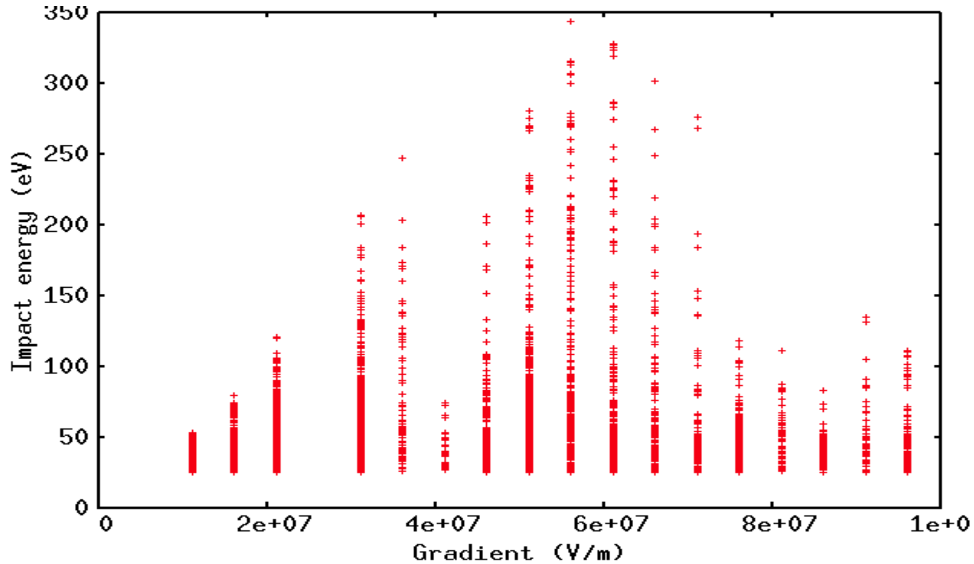



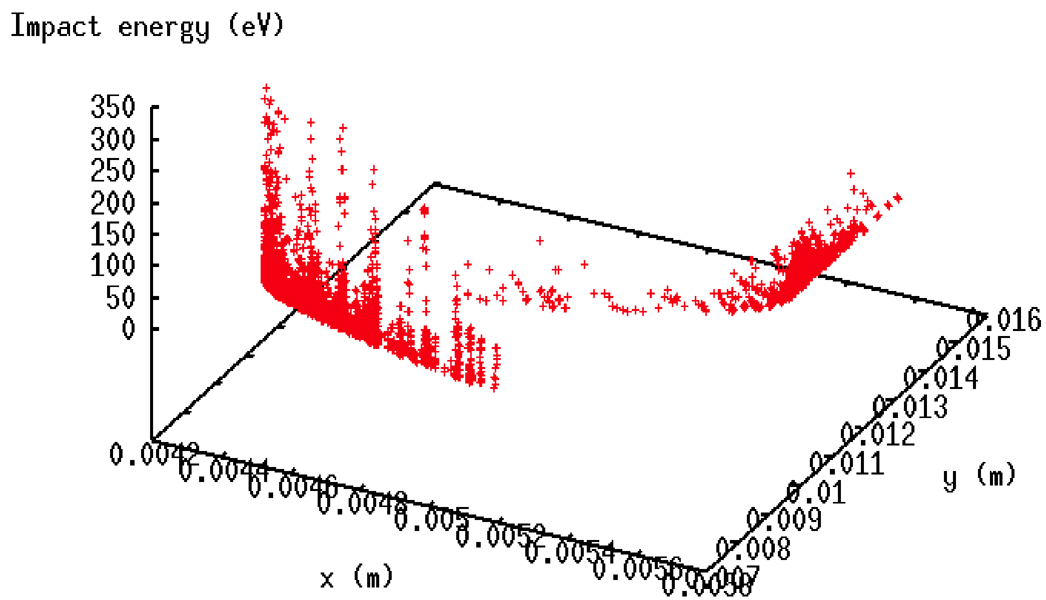
# MP Comparison (gap region)



# No Brazing Gap – Larger Area Scan

- Will scan more surface areas for primary emission
- MP analysis continues

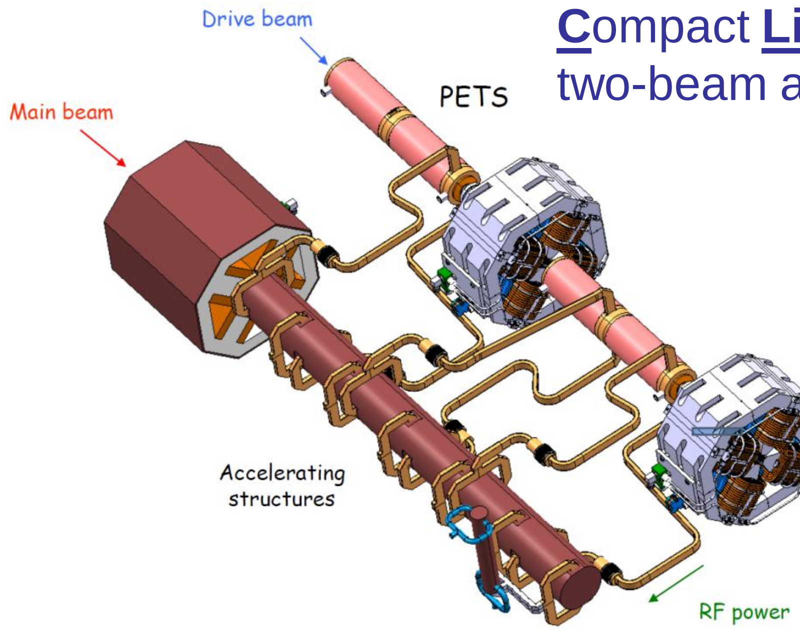


# CLIC PETS and Accelerator Structure

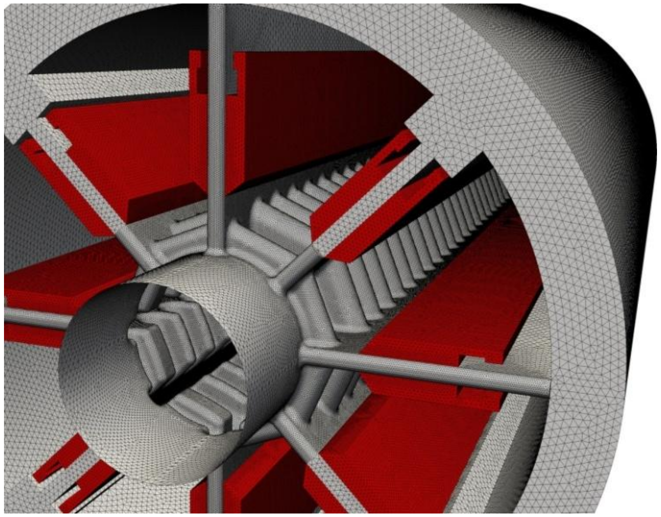
# - Wakefield Simulation

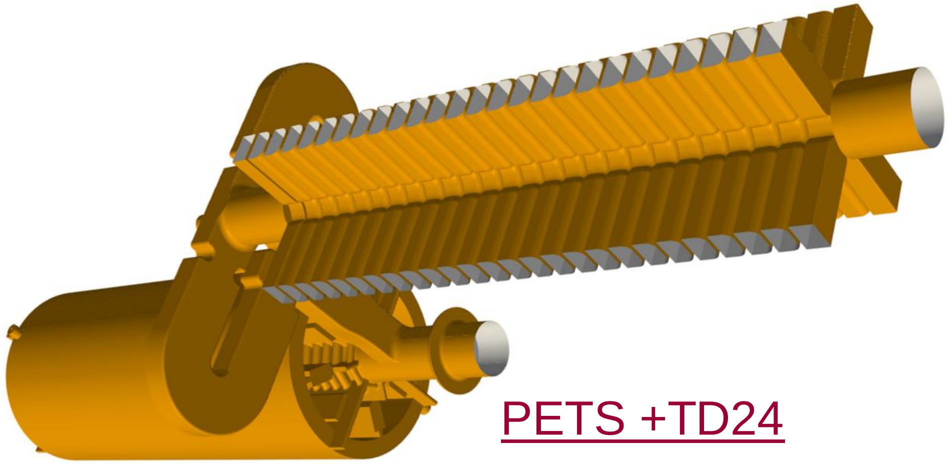
# T3P – CLIC Two-Beam Accelerator



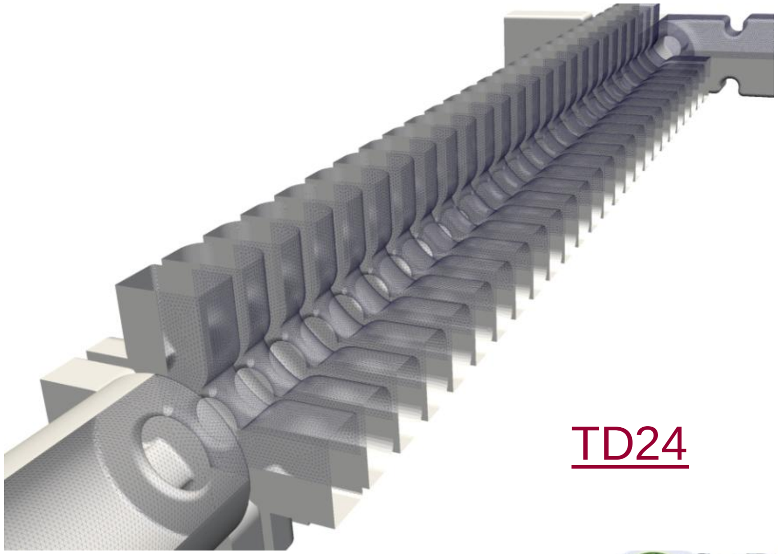

**C**ompact **Li**near **C**ollider
two-beam accelerator unit

PETS



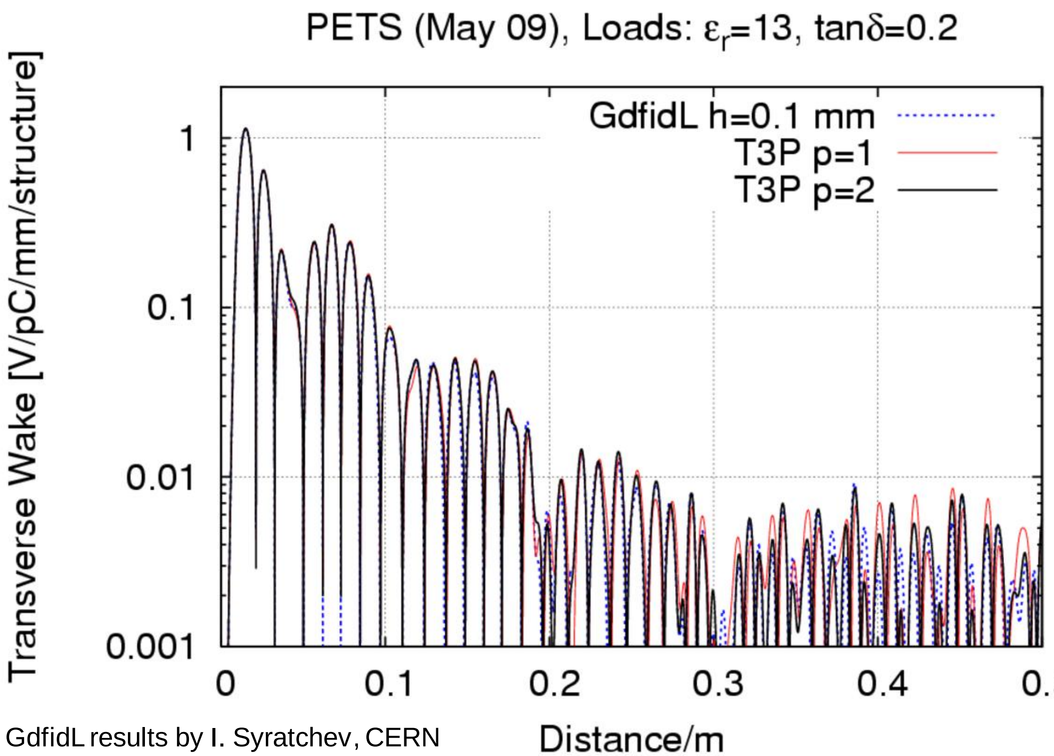


PETS +TD24



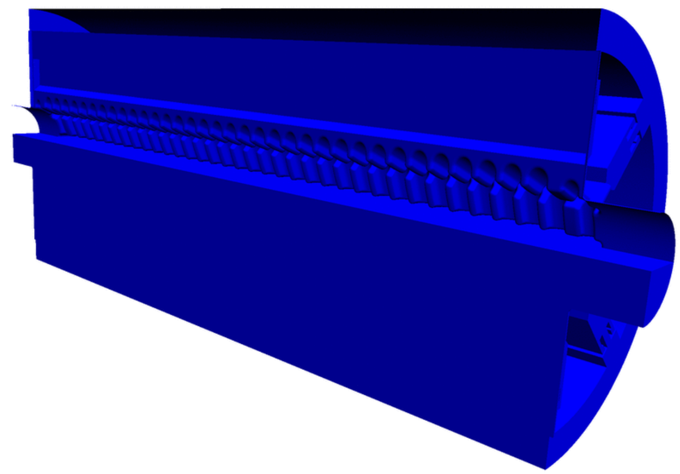
TD24

# T3P – PETS Wakefield Benchmarking




GdfidL results by I. Syratchev, CERN

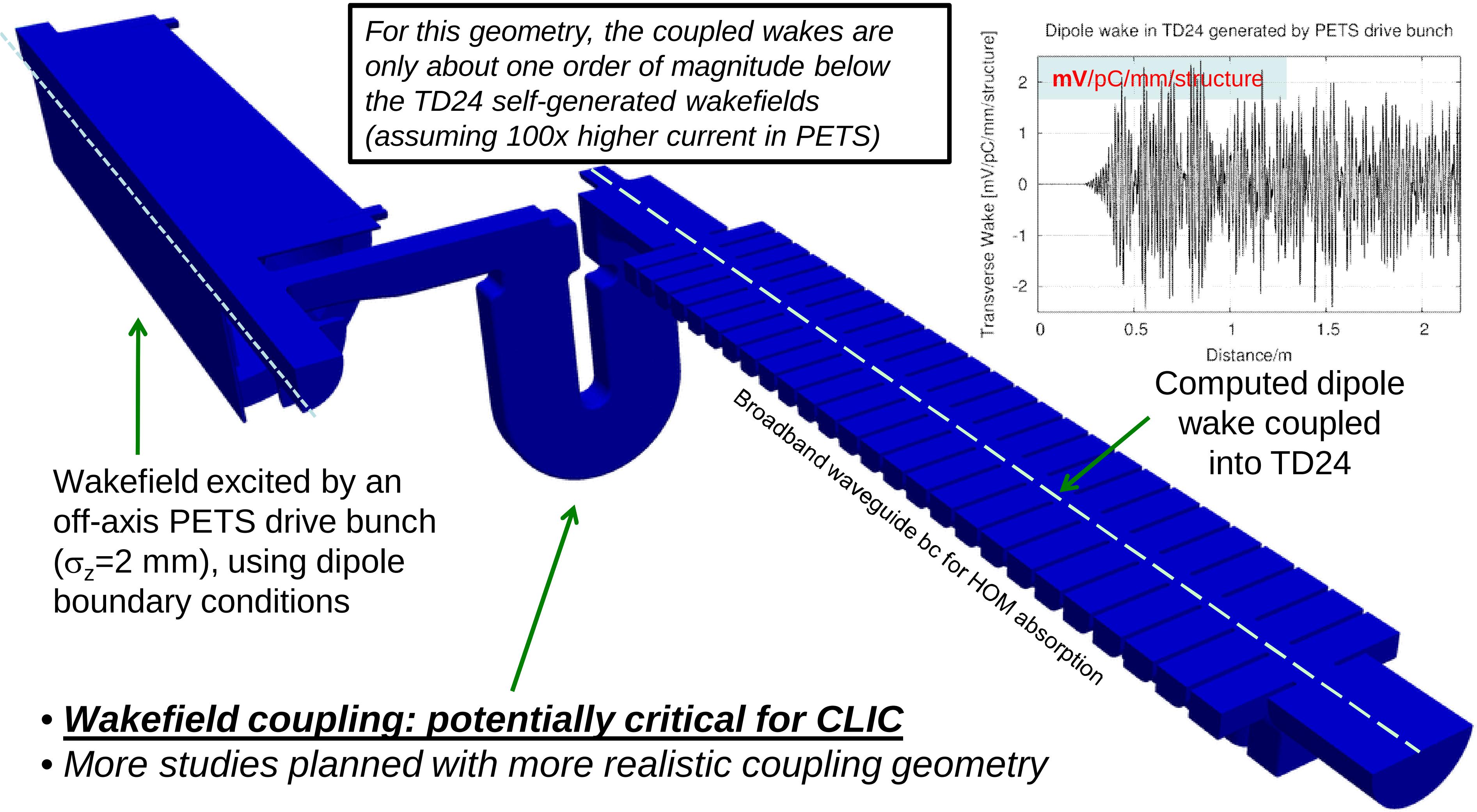
***Typical runtime:***
***20 hours, 80 CPUs***
***0.6 hours, 1200 CPUs***
***6 hours, 4800 CPUs***



- **Converged SLAC results have served as a reference for CERN**
- ***Led to CERN's improved understanding of GdfidL results and its usage***
- **Now the codes agree well – Important cross-check for CLIC design**

# T3P – Dipole Wakefield Coupling

*For this geometry, the coupled wakes are only about one order of magnitude below the TD24 self-generated wakefields (assuming 100x higher current in PETS)*




Computed dipole wake coupled into TD24

Wakefield excited by an off-axis PETS drive bunch ($\sigma_z$=2 mm), using dipole boundary conditions

- ***Wakefield coupling: potentially critical for CLIC***
- *More studies planned with more realistic coupling geometry*

# Summary

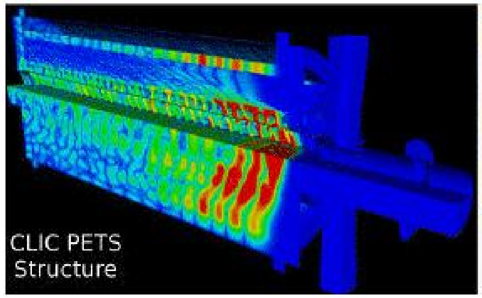
- Parallel finite-element (FE) electromagnetics (EM) method demonstrates its strengths in high-fidelity, high-accuracy modeling for accelerator design, optimization and analysis.
- ACE3P code suite has been benchmarked and used in a wide range of applications in Accelerator Science and Development, including High Gradient Research.
- Track3P for multipacting and dark current simulations provides an effective tool for observing quantities inside structure, helping to understand the HG processing process.
- Progress is being made in simulating MP in CLIC TD18 structure using Track3P.
- Will simulate other high gradient structures by using Track3P to understand MP and dark current issues.

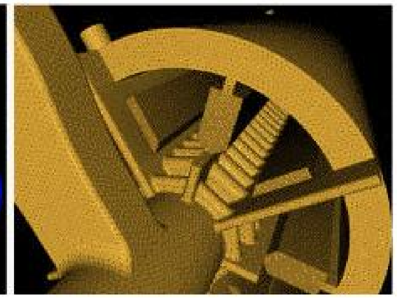
# ACE3P User Community – CW10 Code Workshop

## CW10 @ SLAC

CW10 ACCELERATOR CODE WORKSHOP — SLAC NATIONAL ACCELERATOR LABORATORY

- Home
- Agenda
- Attendees
- Software
- Workshop Materials
- SLAC Computer Accounts



Accelerator Code Workshop (CW10) at SLAC for the ACE3P (Advanced Computational Electromagnetics 3P) Code Suite organized by the Advanced Computations Group (ACG)

Date — September 20-22, 2010
Time — See agenda
Place — SLAC National Accelerator Laboratory
Menlo Park, California

Contact — ACD-CW10@slac.stanford.edu
650-926-2864
650-926-4603 (FAX)

**SLAC ACCESS**

All visitors must have a valid photo ID to enter the Laboratory. The SLAC Main Gate is open 24 hours a day, 7 days a week.

**MAPS AND DIRECTIONS**

» More Information

**SLAC GUEST HOUSE**

» More Information

SLAC National Accelerator Laboratory, Menlo Park, CA
Operated by Stanford University for the U.S. Dept. of Energy

(http://www-conf.slac.stanford.edu/CW10/default.asp)

# CW10 Attendees & Agenda

## CW10 @ SLAC

CW10 ACCELERATOR CODE WORKSHOP — SLAC NATIONAL ACCELERATOR LABORATORY

- Home
- Agenda
- Attendees
- Software
- Workshop Materials
- SLAC Computer Accounts
- NERSC Computer Accounts

### Attendees

| Institution | Name | Email |
|---|---|---|
| Beam Power | Jing Zhou | jzhou@beampower.com |
| CERN | Oleksiy Kononenko<br>Erik Adli | Oleksiy.Kononenko@cern.ch<br>erik.adli@cern.ch |
| Cornell | Sergey Belomestnykh<br>Vadim Veshcherevich<br>Yi Xie<br>Sam Posen<br>Valery Shemelin | sab24@cornell.edu<br>vgv1@cornell.edu<br>yx39@cornell.edu<br>samposen@gmail.com<br>vs65@cornell.edu |
| FAR-TECH | Nick Barov | barov@far-tech.com |
| IHEP | Jiyuan Zhai | zhaijy@ihep.ac.cn |
| JLab | Gary Cheng | cheng@jlab.org |
| LBNL | Gang Huang | GHuang@lbl.gov |
| LLNL | Scott Anderson<br>Roark Marsh | anderson131@llnl.gov<br>marsh19@llnl.gov |
| NSCL | John Popielarski<br>Jeremiah Holzbauer | popielar@nscl.msu.edu<br>holzbaue@nscl.msu.edu |
| ODU | Subashini De Silva | sdesilva@jlab.org |
| PSI | Micha Dehler<br>Alessandro Citterio | micha.dehler@psi.ch<br>Alessandro.Citterio@psi.ch |
| SFTC Daresbury | Peter McIntosh<br>Philippe Goudket | peter.mcintosh@stfc.ac.uk<br>philippe.goudket@stfc.ac.uk |
| SLAC | Stephen Weathersby<br>Joel England<br>Valery Dolgashev<br>Chris Nantista<br>Aaron Jensen<br>Kai Tian<br>Stephen Gierman<br>Jeffrey Neilson<br>Johnny Ng<br>Ziran Wu | spw@slac.stanford.edu<br>england@slac.stanford.edu<br>Dolgashev@slac.stanford.edu<br>nantista@slac.stanford.edu<br>aaron@slac.stanford.edu<br>ktian@slac.stanford.edu<br>gierman@slac.stanford.edu<br>jeff@slac.stanford.edu<br>jng@slac.stanford.edu<br>wzr@slac.stanford.edu |
| Univ. of London | Steve Molloy<br>Joshi Nirav | stephen.molloy@rhul.ac.uk<br>J.Nirav@rhul.ac.uk |
| Univ. of Manchester | Roger Jones<br>Ian Shinton | rmj@slac.stanford.edu<br>ian.shinton@manchester.ac.uk |
| Univ. of Oslo | Kyrre Ness Sjøbæk | k.n.sjobak@fys.uio.no |

## CW10 @ SLAC

CW10 ACCELERATOR CODE WORKSHOP — SLAC NATIONAL ACCELERATOR LABORATORY

- Home
- Agenda
- Attendees
- Software
- Workshop Materials
- SLAC Computer Accounts
- NERSC Computer Accounts

### Agenda

All sessions are 1 hr 45 min

| | 9/22 Monday | 9/23 Tuesday | 9/24 Wednesday |
|---|---|---|---|
| | | | Parallel Sessions |
| **8.30-10.15** | **Intro/CUBIT** | **Track3P** | **Pic3P \| Applications** |
| *10.15-10.30* | *break* | *break* | *break* |
| **10.30-12.15** | **ACE3P/ParaView** | **Track3P** | **TEM3P \| Applications** |
| *12.15-1.30* | *lunch* | *lunch* | *CW10 Ends* |
| **1.30-3.15** | **Omega3P/S3P** | **T3P** | |
| *3.15-3.30* | *break* | *break* | |
| **3.30-5.15** | **Omega3p/S3P** | **T3P** | |

SLAC National Accelerator Laboratory, Menlo Park, CA
Operated by Stanford University for the U.S. Dept. of Energy

CW11 is being planned