Mitigation Strategy: Overview, including LHC and ILC

Mauro Pivi

on behalf of the ILC and LHC Electron Cloud Working Group

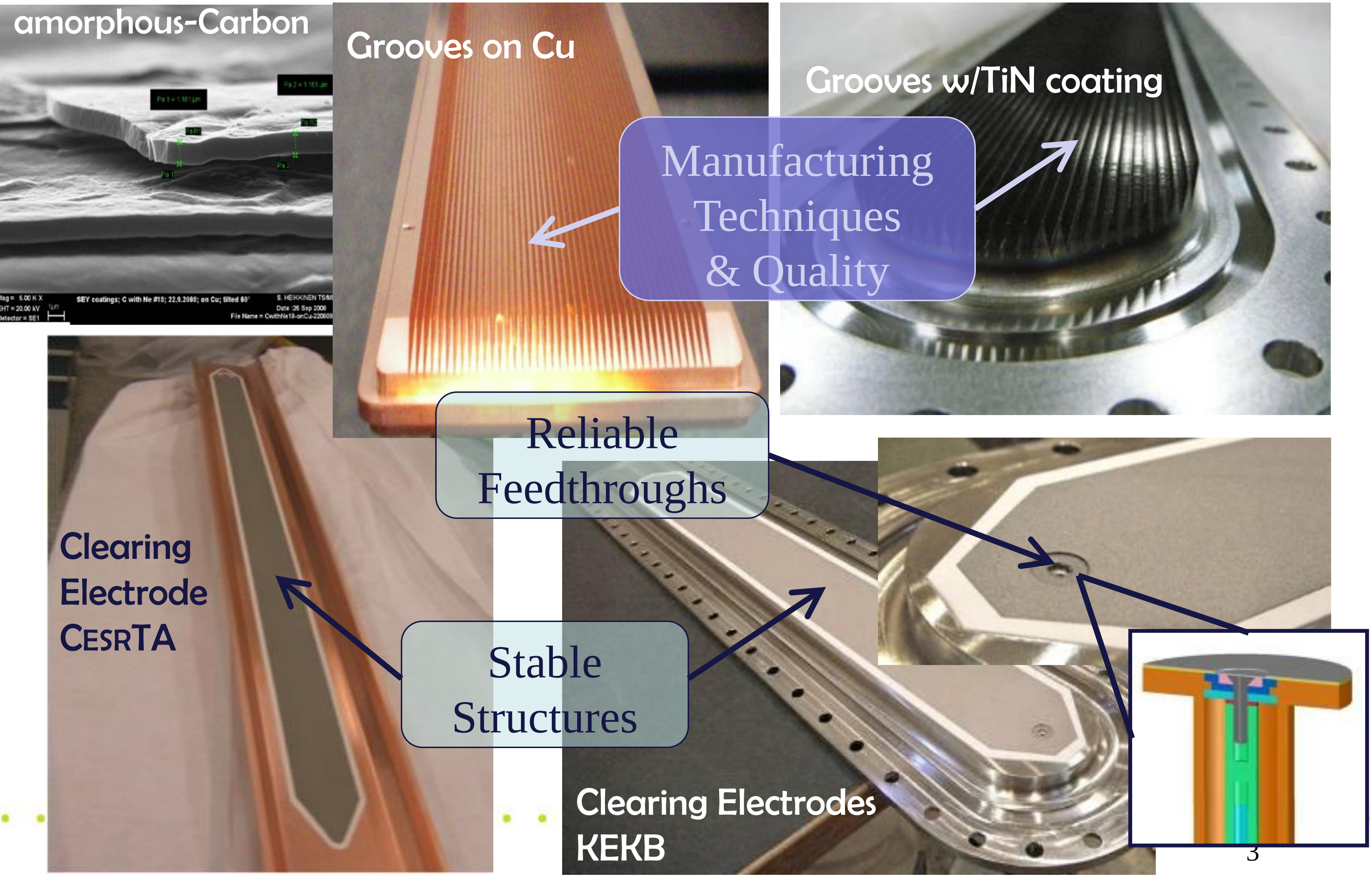
ECLOUD12 at Isola D'Elba Italy

5-8 June, 2012

Electron cloud in the Linear Colliders

- SLAC is coordinating the ILC electron cloud Working Group (WG)
- WG milestones: evaluations and recommendations on electron cloud mitigations that lead to reduction of ILC DR circumference from 17km to 6km (2006) and from 6km to 3km (2010)
- 2012 goal is to evaluate electron cloud effect with mitigations implemented in each DR region, in preparation for the ILC Technical Design Report 2012.

Recommendation of Electron Cloud Mitigations



Structured Evaluation of EC Mitigations

Criteria for the evaluation of mitigations: Working Group rating				
	Efficacy of Mitigation	**Costs**	**Risks**	**Impact on Machine**
Rating	**10**	**1**	**4**	**4**
Normalized Weighting	**0.53**	**0.05**	**0.21**	**0.21**

EC Mitigation Evaluation – 4 Criteria

- Dedicated ILC DR Working Group Workshop Meeting to evaluate technologies and give recommendation on electron cloud mitigations

Efficacy

- Photoelectric yield (PEY)
- Secondary emission yield (SEY)
- Ability to keep the vertical emittance growth below 10%

Risk

- Mitigation manufacturing challenges:
  - **Ex: ≤1mm or less in small aperture VC**
  - **Ex: Clearing electrode in limited space or in presence of BPM buttons**
- Technical uncertainty
  - **Incomplete evidence of efficacy**
  - **Incomplete experimental studies**
- Reliability
  - **Durability of mitigation**
  - **Ex: Damage of clearing electrode feed-through**

Cost

- Design and manufacturing of mitigation
- Maintenance of mitigation
  - **Ex: Replacement of clearing electrode PS**
- Operational
  - **Ex: Time incurred for replacement of damaged clearing electrode PS**

Impact on Machine Performance

- Impact on vacuum performance
  - **Ex: NEG pumping can have a positive effect**
  - **Ex: Vacuum outgassing**
- Impact on machine impedance
  - **Ex: Impedance of grooves and electrodes**
- Impact on optics
  - **Ex: x-y coupling due to solenoids**
- Operational
  - **Ex: NEG re-activation after saturation**

Summary of Electron Cloud Mitigation Plan for the International Linear Collider

Mitigation Evaluation conducted at ILC DR Working Group Workshop meeting

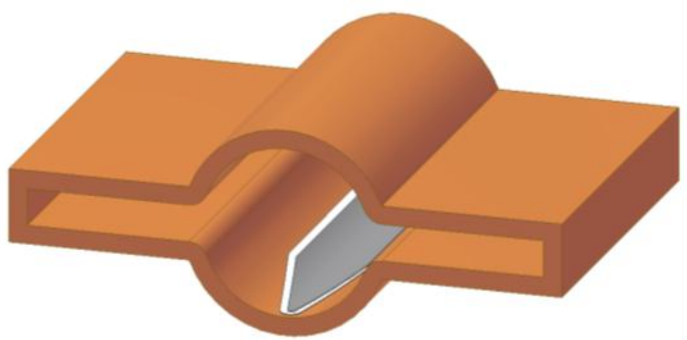
ILC Working Group Baseline Mitigation Recommendation				
	Drift*	Dipole	Wiggler	Quadrupole*
Baseline Mitigation I	**TiN Coating**	**Grooves with TiN coating**	**Clearing Electrodes**	**TiN Coating**
Baseline Mitigation II	**Solenoid Windings**	**Antechamber**	**Antechamber**	
Alternate Mitigation	Amorphous Carbon/ NEG Coating	TiN Coating	Grooves with TiN Coating	Clearing Electrodes or Grooves

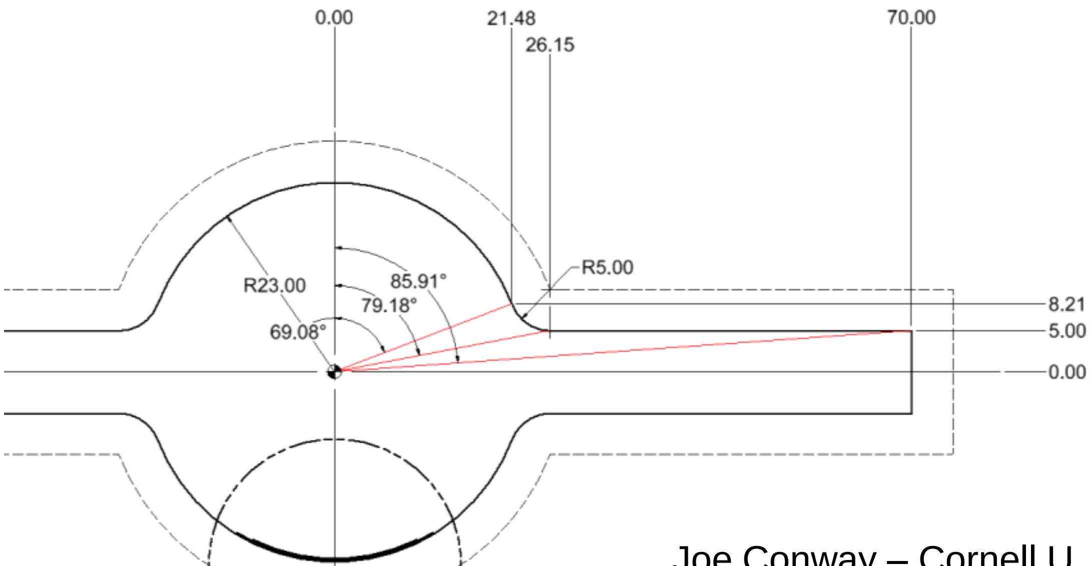
- Amorphous carbon not sufficiently tested in lepton machines under high radiation, yet
- Aggressive mitigation plan needed to obtain optimum performance for 3.2km positron damping ring and to pursue the high current option

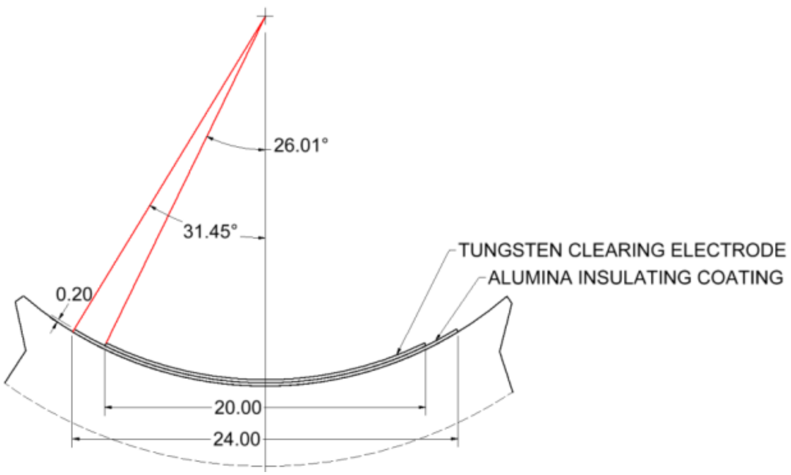
M. Pivi, S. Guiducci, M. Palmer, J. Urakawa on behalf of the ILC DR Electron Cloud Working Group

Mitigations: Wiggler Chamber with Clearing Electrode

- Thermal spray tungsten electrode and Alumina insulator
- 0.2mm thick layers
- 20mm wide electrode in wiggler
- Antechamber full height is 20mm

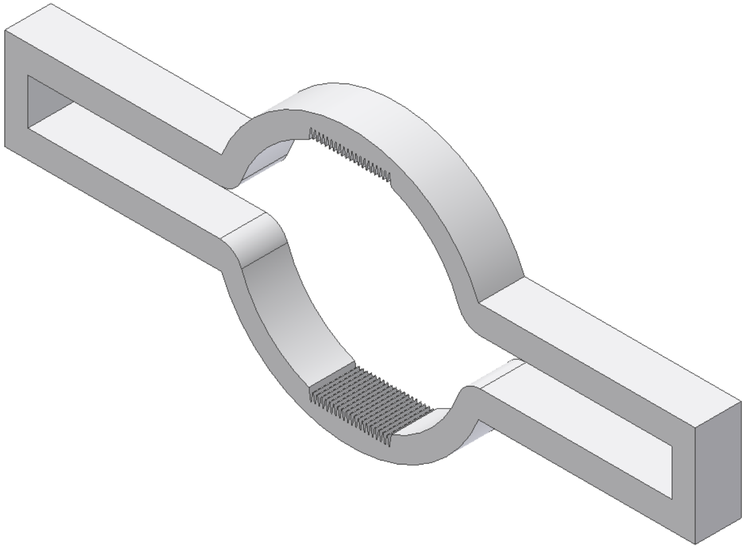


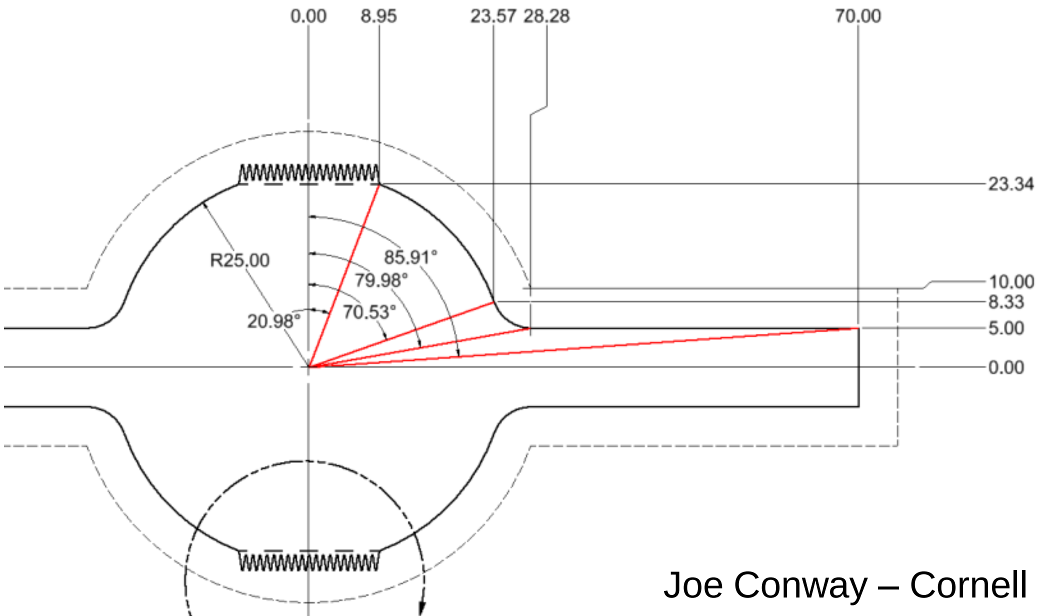


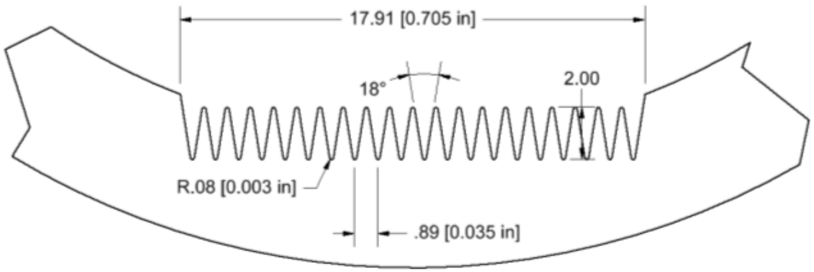


Mitigations: Dipole Chamber with Grooves

- 20 grooves (19 tips)
- 0.079in (2mm) deep with 0.003in tip radius
- 0.035in tip to tip spacing
- Top and bottom of chamber







Electron cloud assessment for ILC 2012 TDR: Plans

Electron cloud Build-up

In BENDs with grooves
PI: LBNL

Photon distribution

Beam Instability

Photon generation and distribution
PI: Cornell U.

In WIGGLERS with clearing electrodes
PI: SLAC

Input cloud density from build-up
PI: SLAC

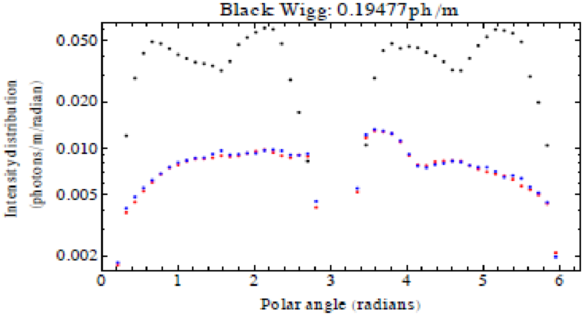
In DRIFT, QUAD, SEXT with TiN coating
PI: Cornell U.

Photon distributions

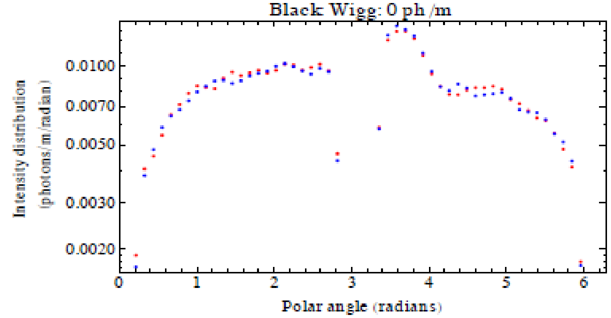
- Used **Synrad3d** (Cornell U.) a 3D simulation code that include the ring lattice at input and chambers geometry
- Used lattice: DTC03 (latest)
- Computed absolute values of photon intensity distributions around the vacuum chamber for 4 magnetic environments
- Computed for realistic chamber (v2a, with antechambers and totally absorbing photon stops) with diffuse scattering and specular reflection
- Looked at dependence of rates on ring sections.
- Did not assume top-bottom symmetry, and included sextupoles.

Comparison of photon distributions-dtc03

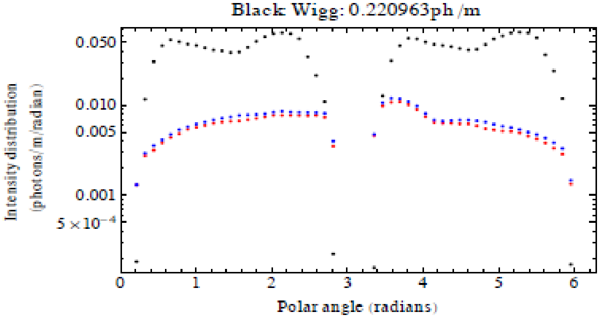
QUADRUPOLE
Red: Arc1: 0.0418442ph/m
Blue: Arc2: 0.0428004ph/m
Black Wigg: 0.19477ph/m



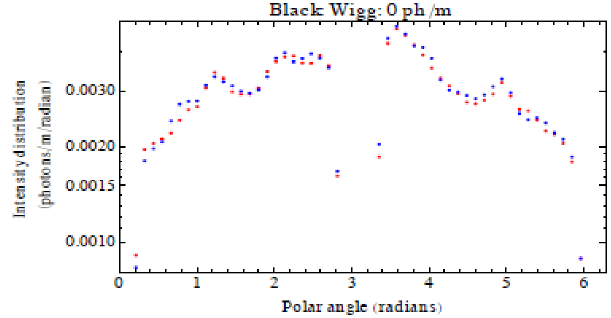
SEXTUPOLE
Red: Arc1: 0.0437614ph/m
Blue: Arc2: 0.0435829ph/m
Black Wigg: 0 ph/m



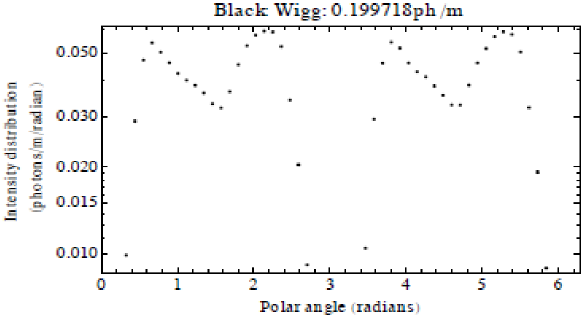
DRIFT
Red: Arc1: 0.0326384ph/m
Blue: Arc2: 0.0358304ph/m
Black Wigg: 0.220963ph/m



SBEND
Red: Arc1: 0.0158338ph/m
Blue: Arc2: 0.0160908ph/m
Black Wigg: 0 ph/m



WIGGLER
Red: Arc1: 0 ph/m
Blue: Arc2: 0 ph/m
Black Wigg: 0.199718ph/m



G. Dugan Cornell U.

Use **Synrad3d** a 3D simulation code that includes the ring lattice at input and chambers geometry (photon stops, antechambers, etc.)

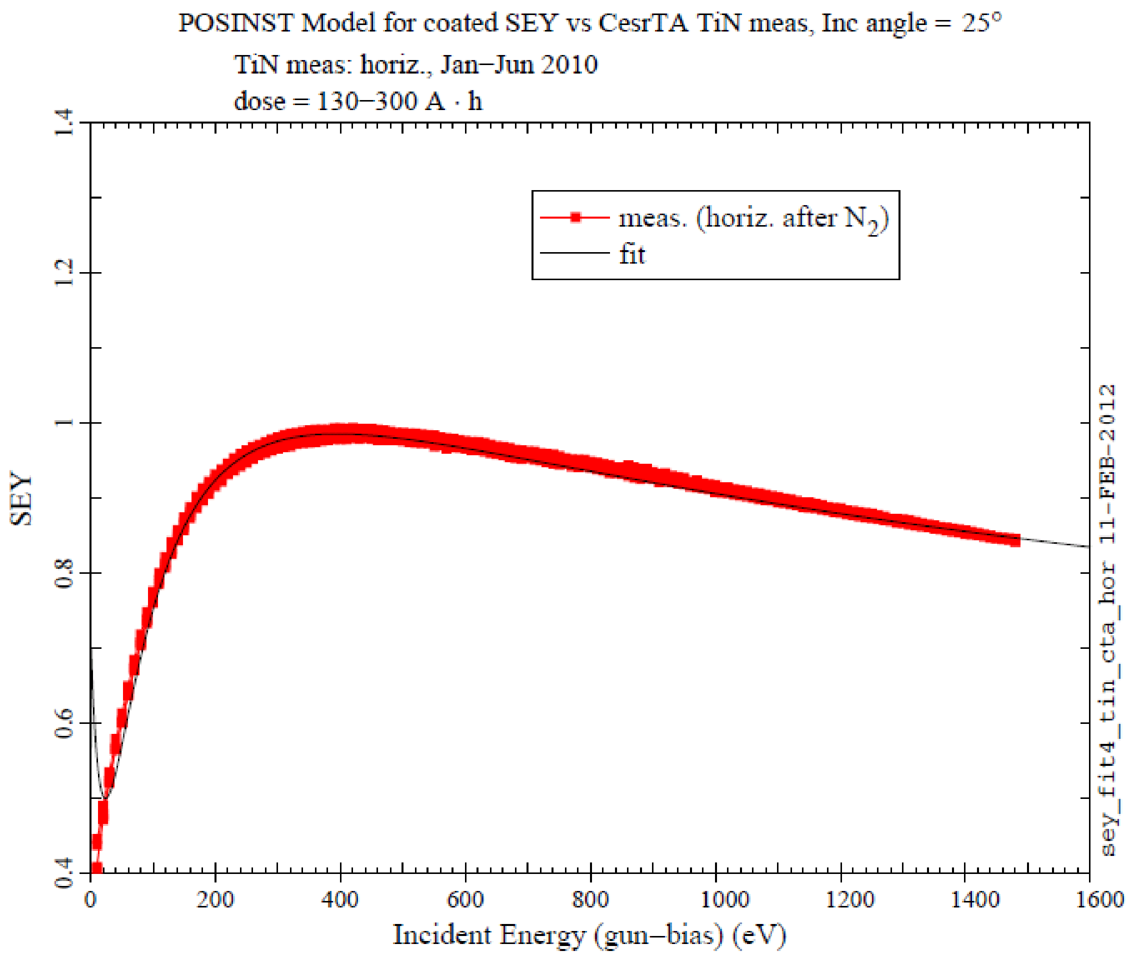
Assumptions for the Secondary Electron Yield (SEY)

- In the ILC DR, surface materials consists of:
  - **TiN on aluminum substrate, in most of the ring**
  - **Copper in wiggler sections**

- For our systematical evaluations, we have used SEY curves from in-situ measurements at CesrTA, PEP-II and KEK-B:
  - **Conditioned TiN with SEY peak ~1**
  - **Conditioned Cu, with SEY peak ~1.2**

SEY for processed TiN film coating

TiN CesrTA - “horizontal sample” 0 degree

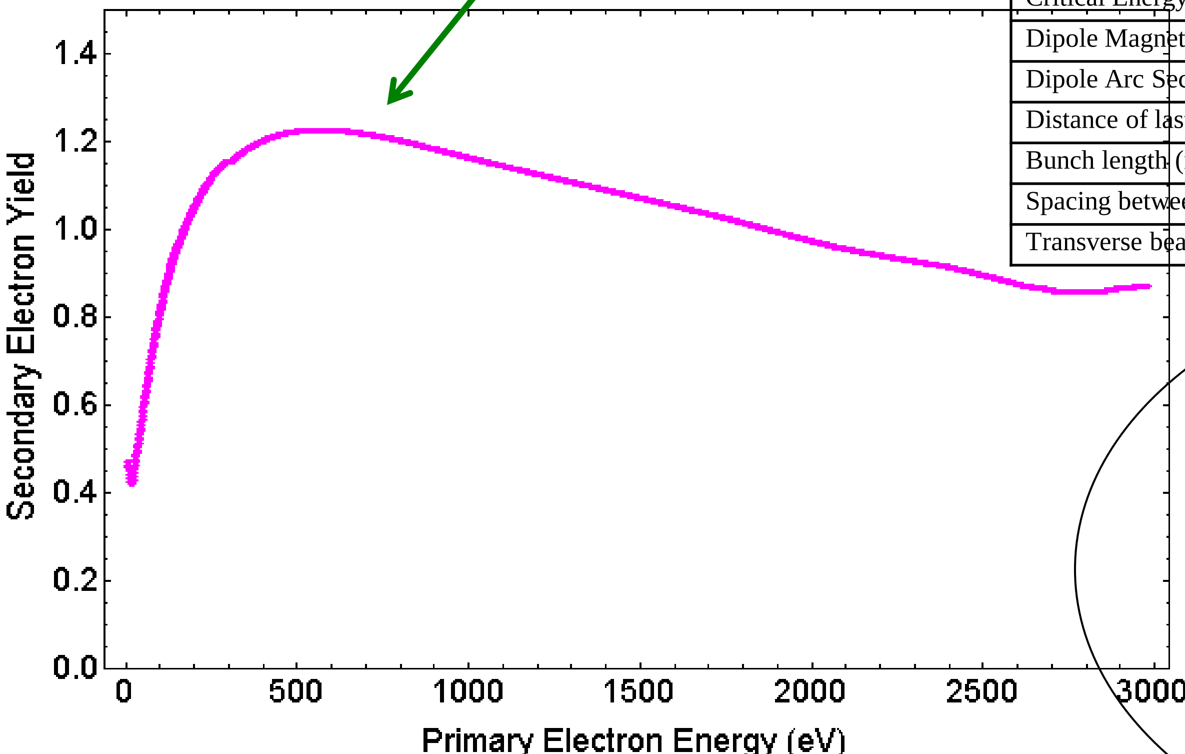


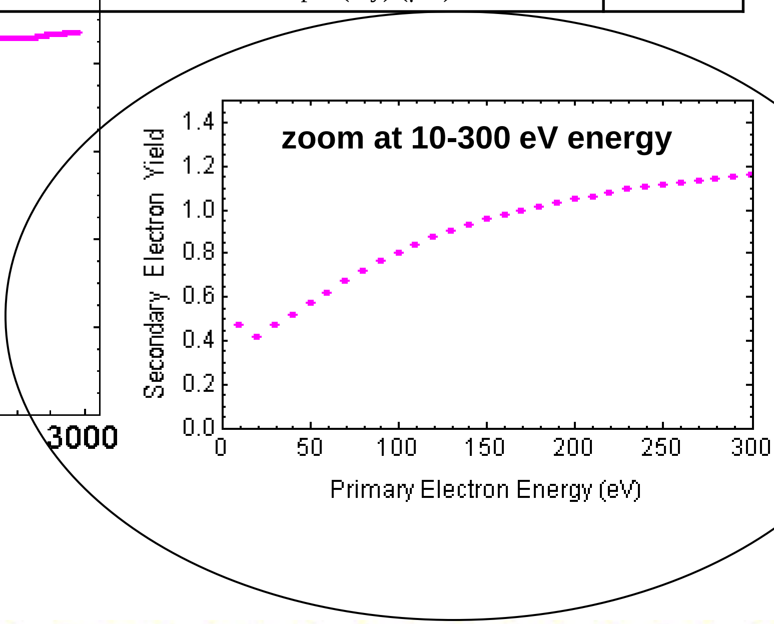
email Walter Hartung (wh29@cornell.edu) or Joe Calvey (jrc97@cornell.edu) for data files

SEY for processed Copper surface

PEP-II beam parameters	
Beam Energy, *E* (GeV)	3.1
Relativistic Factor, γ	6066.5
Nominal Beam Current, *I* (A)	4.7
Dipole Magnet Field, *B* (Tesla)	0.765
Critical Energy, E_{crit} (keV)	4.8
Dipole Magnet Arc Section, $\Delta\theta$ (mrad)	32.7
Dipole Arc Section of photons hitting sample, $\Delta\theta$ (mrad)	$7.5\ 10^{-6}$
Distance of last bend magnet to SEY station location, (m)	10.1
Bunch length (mm)	12
Spacing between bunches (ns)	4.2
Transverse beam size at the sample (x/y) (µm)	228/840

Peak 1.22, Energy at peak ~ 570 eV



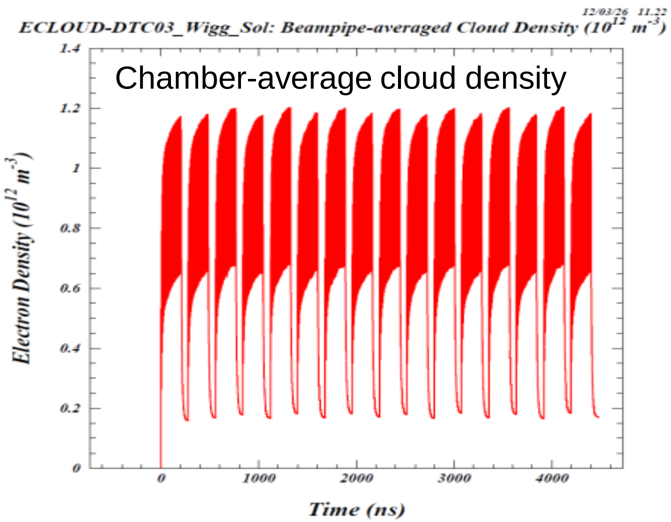


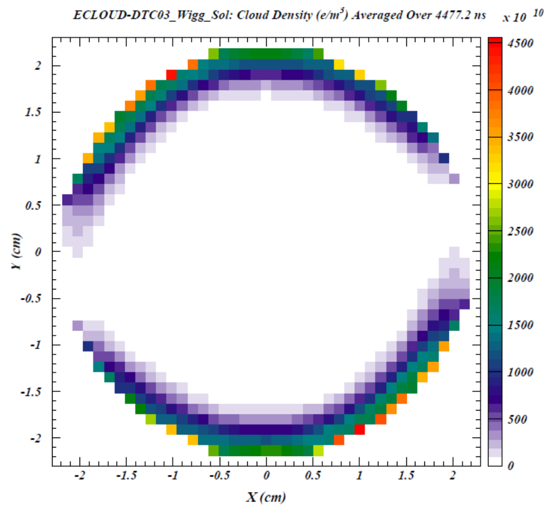
C:\\ Physics SEY \\ Mauro_Fred _SEY _Data _ 2003-2008\\ ASCII TRANSLATED FILES \\ 006061.DAT

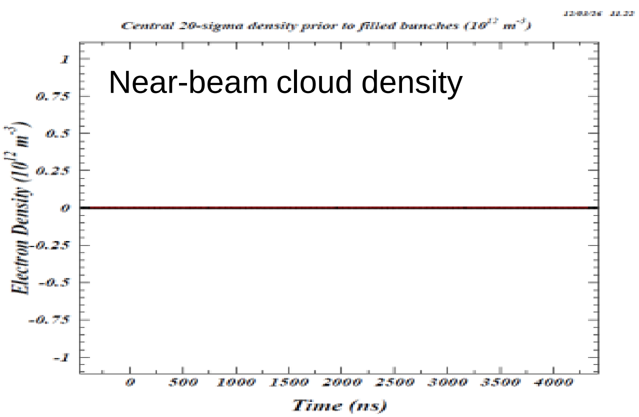
email: mpivi@slac.stanford.edu for data file

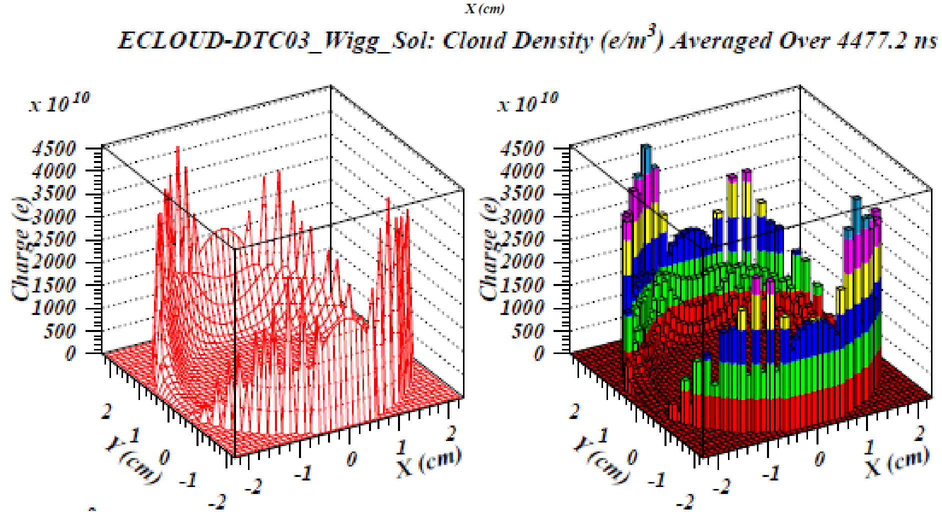
Electron Cloud in Drift Regions, with Solenoid field (40 G)

- Solenoid fields in drift regions are very effective at eliminating the central cloud density







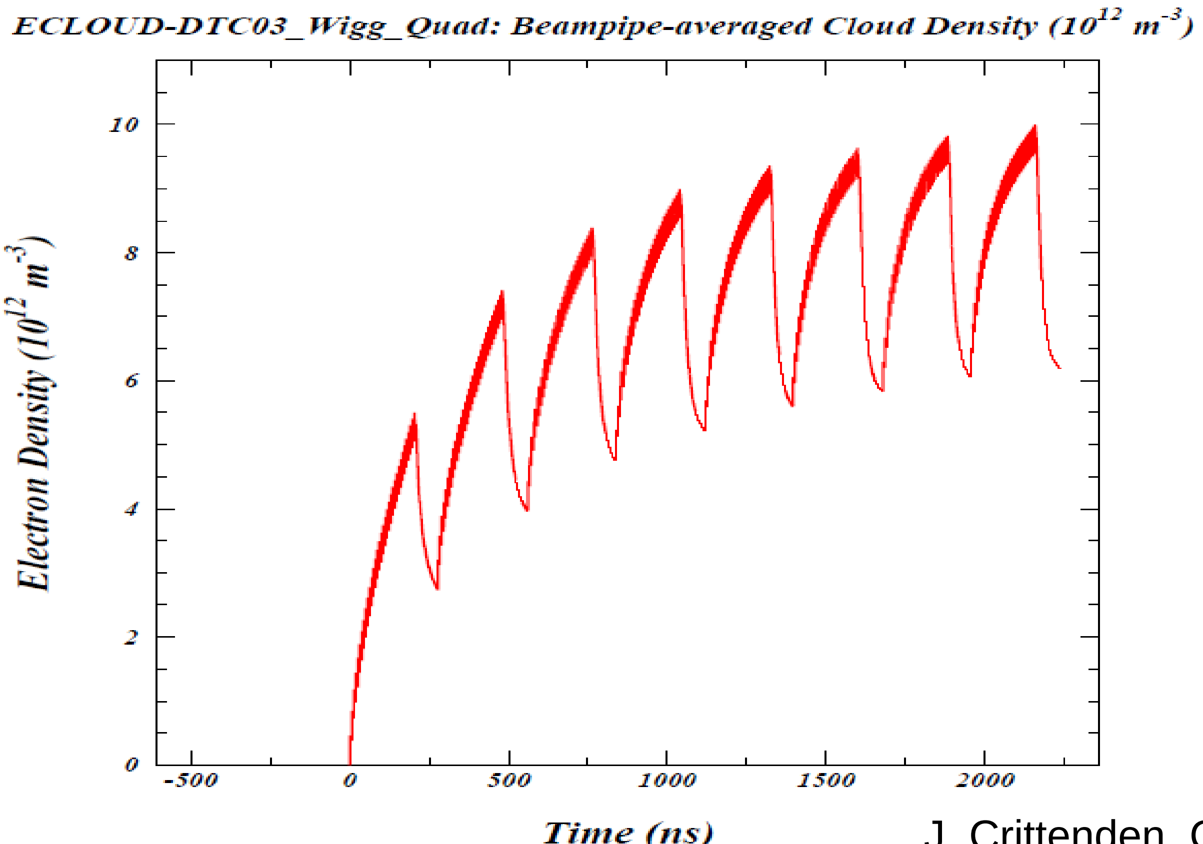


ECLOUD12

J. Crittenden, Cornell U.

Electron Cloud in Quadrupoles

- Trapping of electron in quadrupole field: the electron cloud density does not reach equilibrium after 8 bunch trains.



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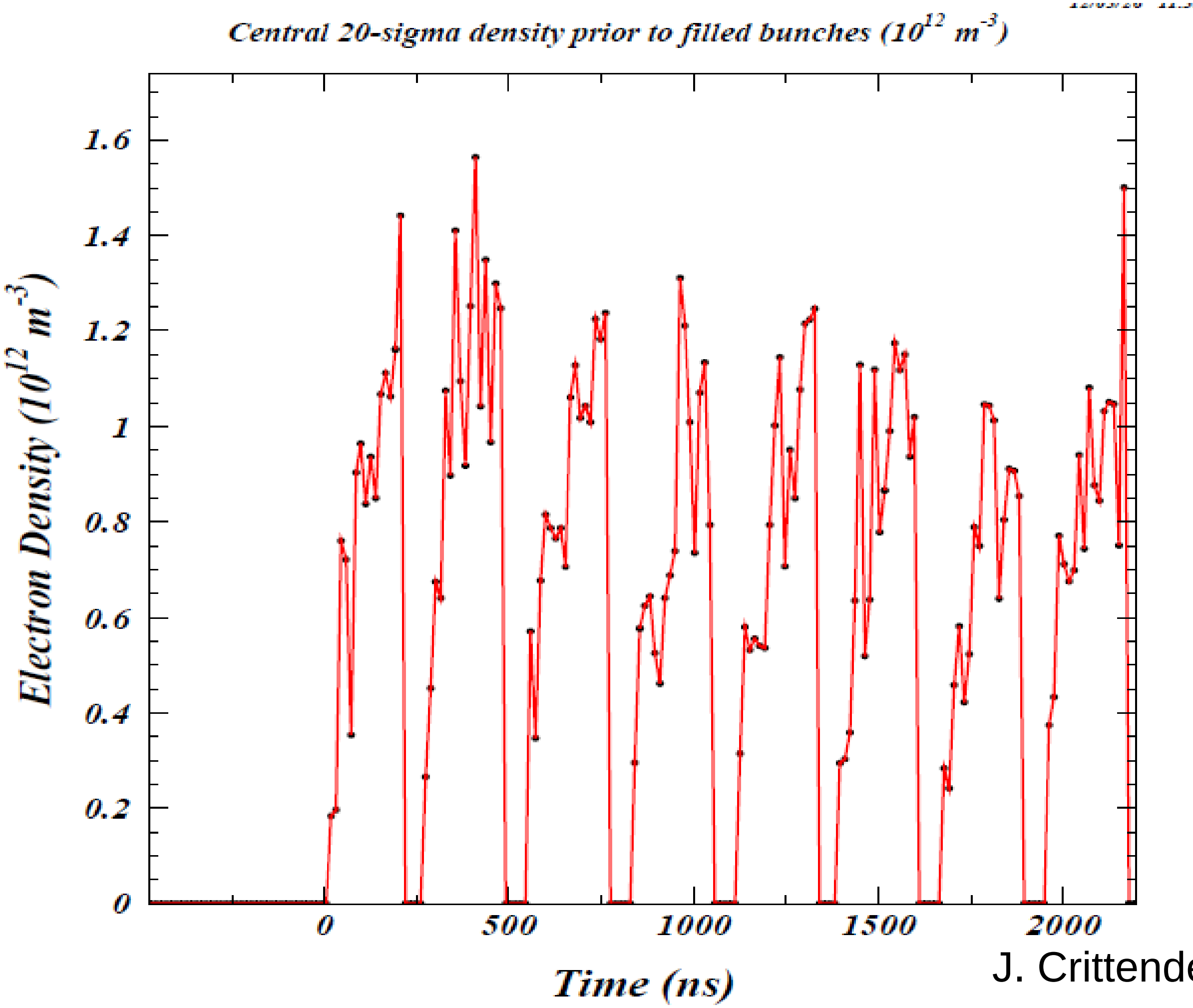
Quadrupole in wiggler section

- The central cloud density reaches equilibrium in the Quadrupoles after few bunch trains



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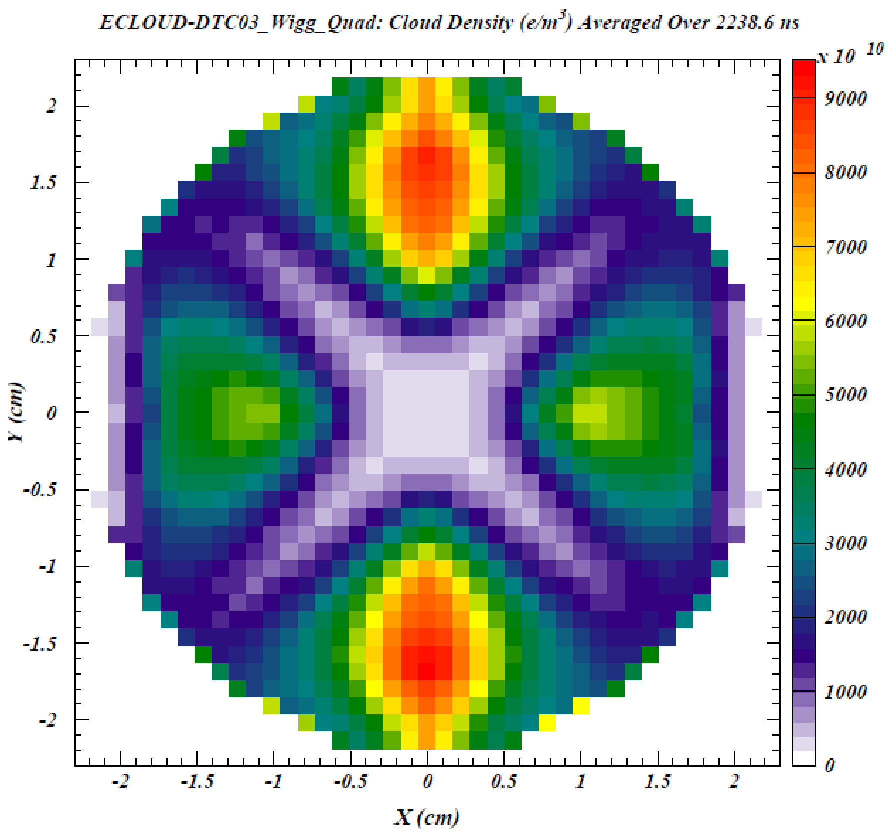
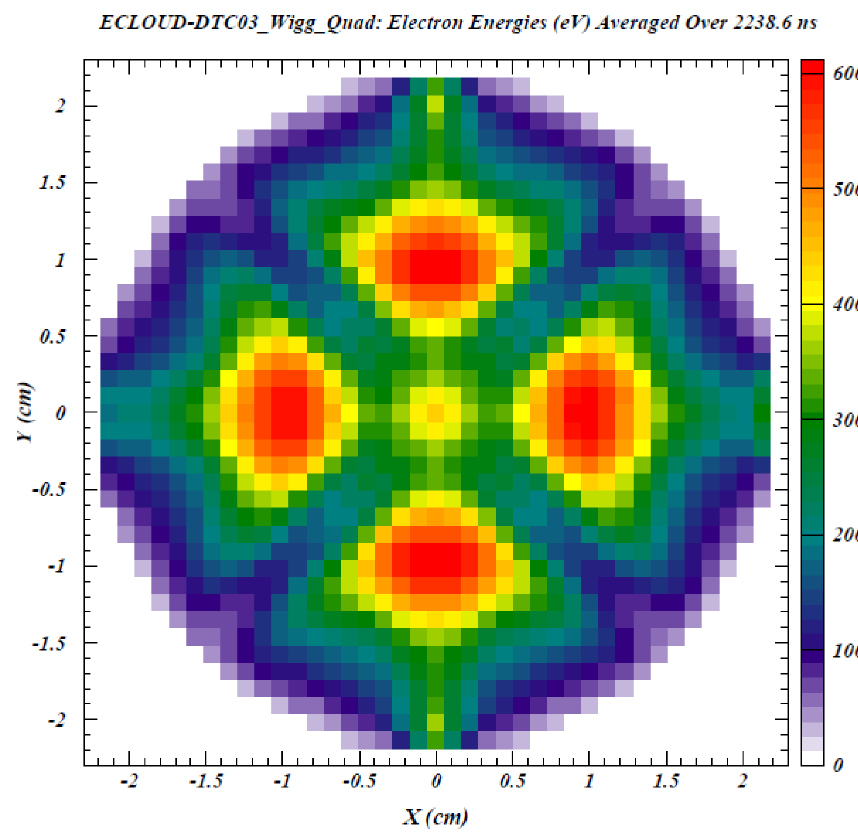
Electron Cloud in Quadrupoles

Electron cloud density (e/m³)

Electron energies (eV)





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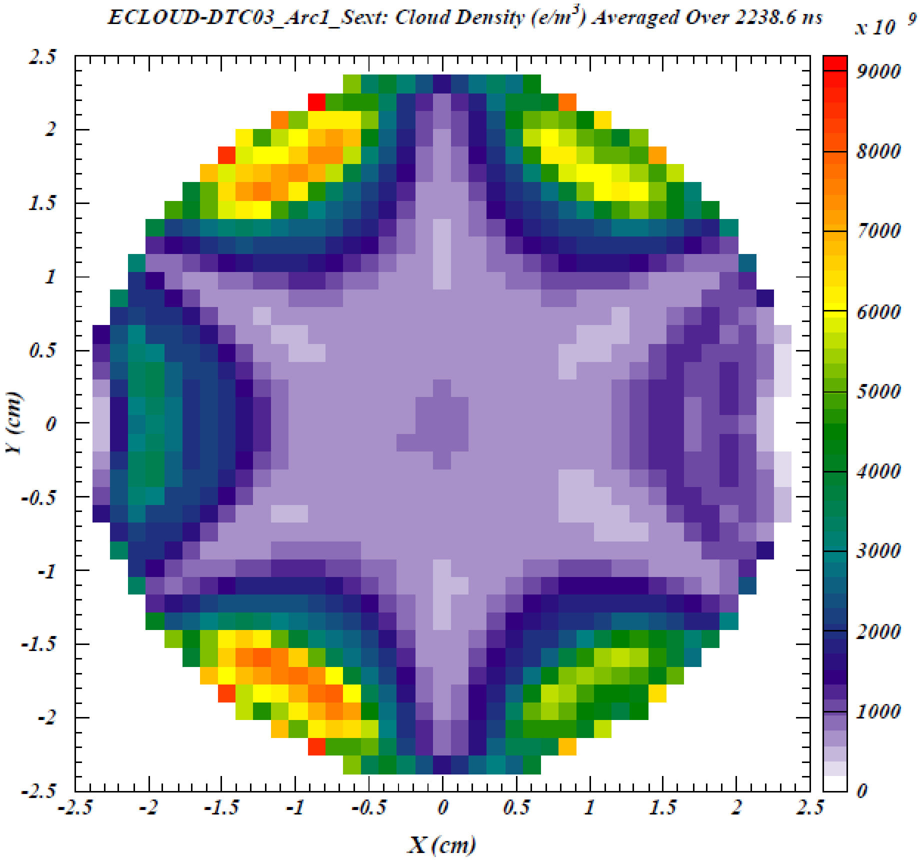
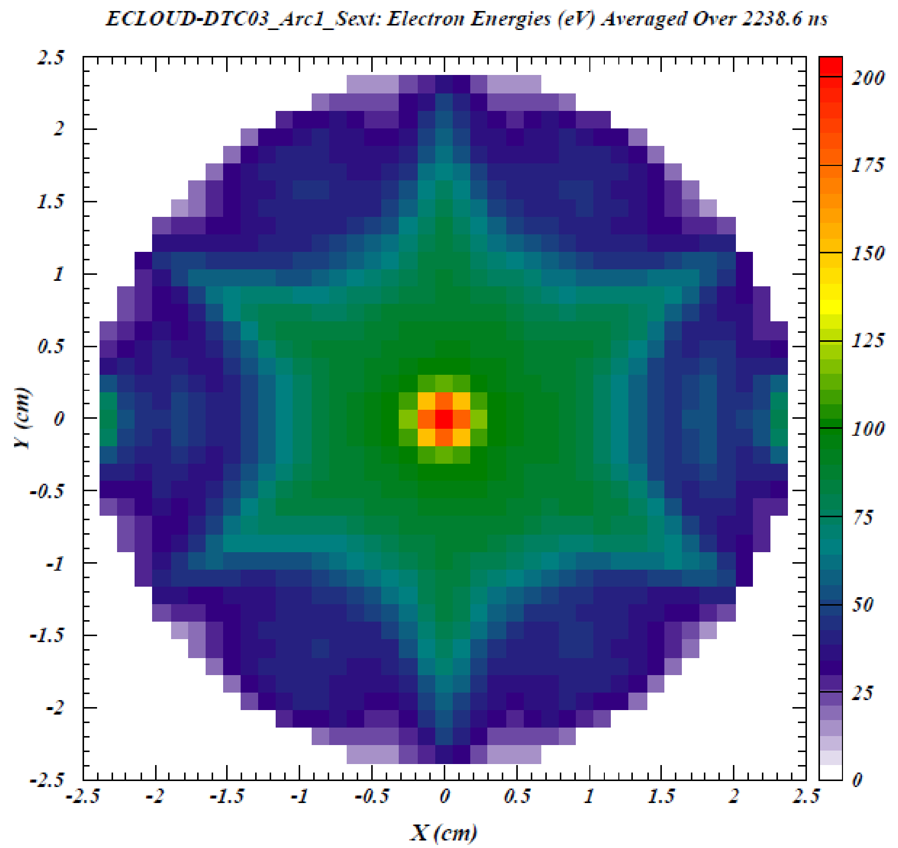
Electron Cloud in arc Sextupoles

Electron cloud density (e/m³)



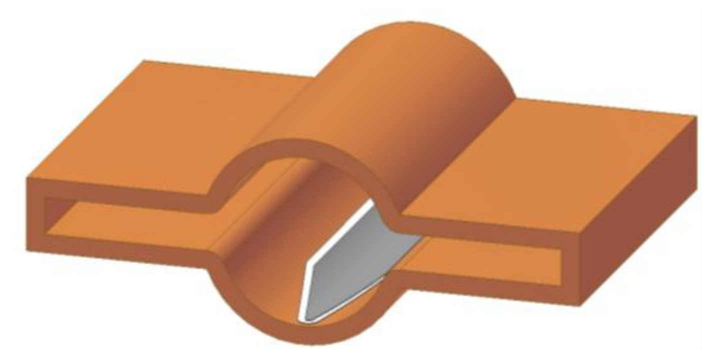
Electron energies (eV)

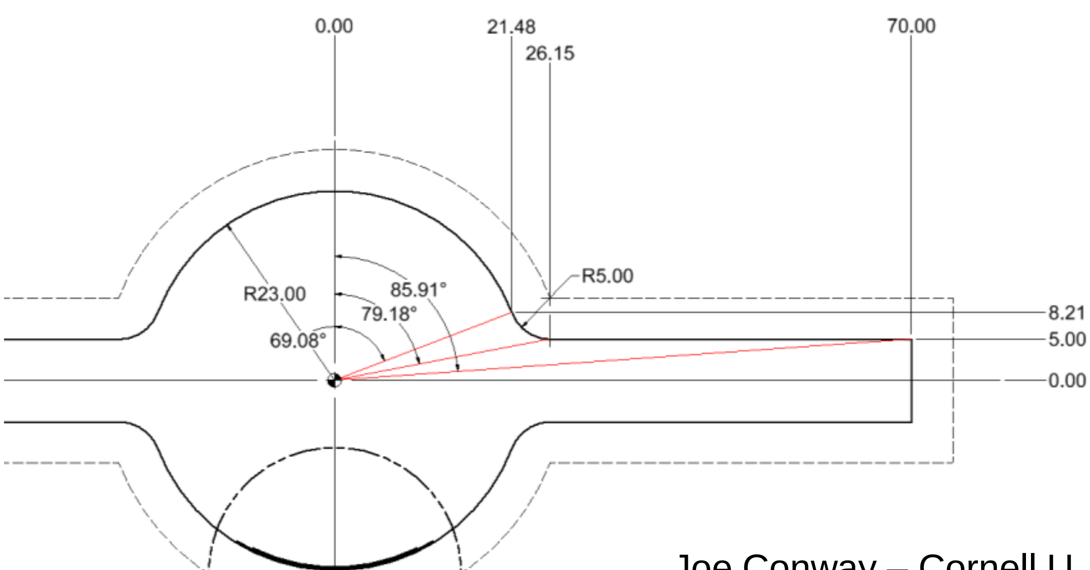


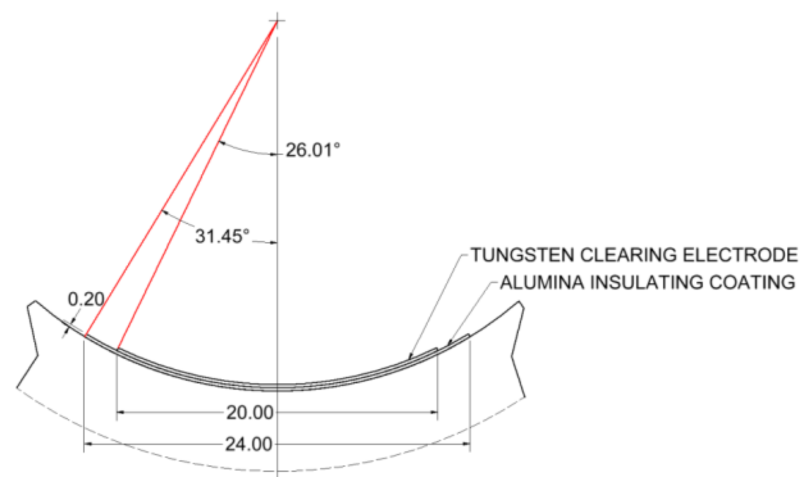
J. Crittenden, Cornell U.

Mitigations: Wiggler Chamber with Clearing Electrode

- Thermal spray tungsten electrode and Alumina insulator
- 0.2mm thick layers
- 20mm wide electrode in wiggler
- Antechamber full height is 20mm

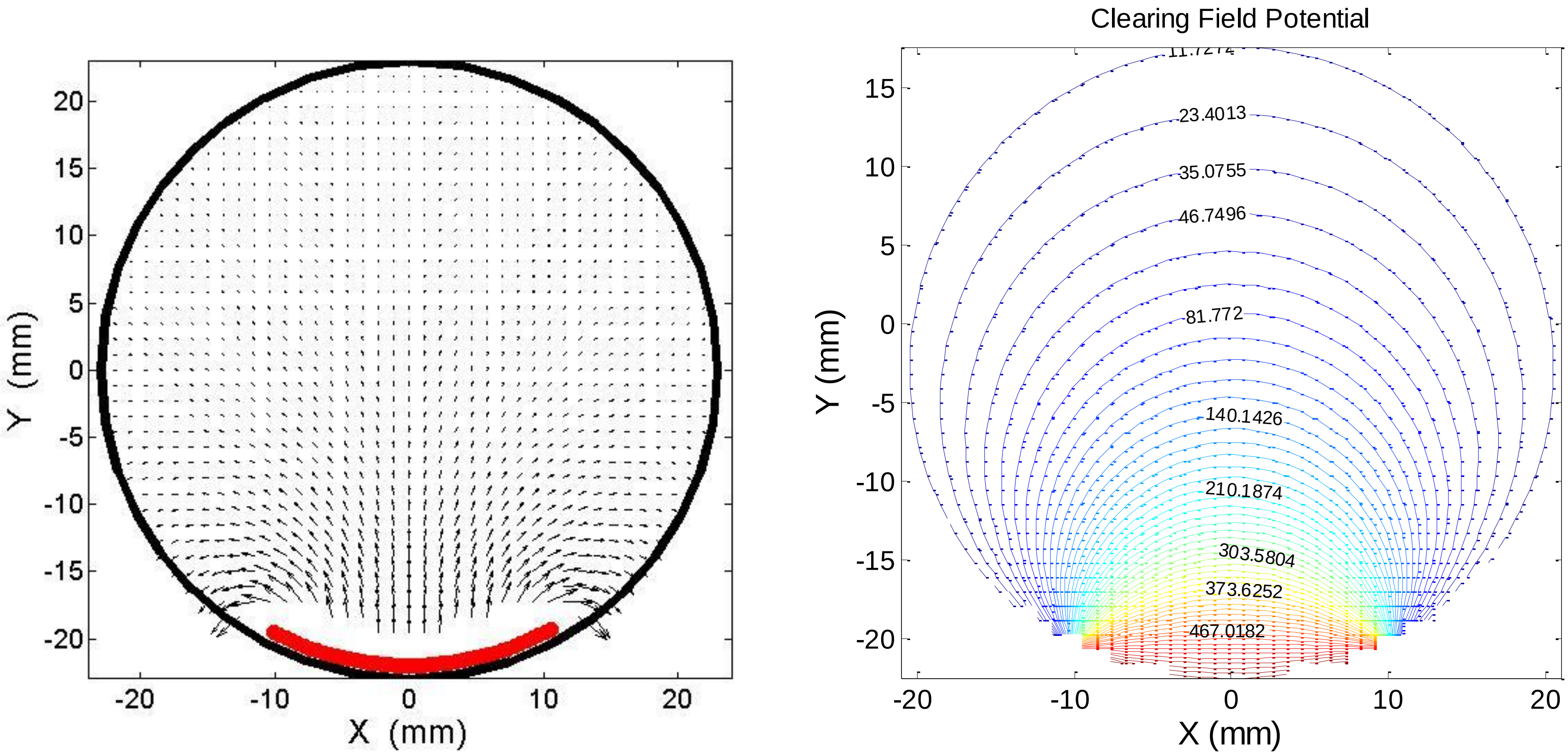






Effect of Clearing Electrodes in Wiggler Magnets

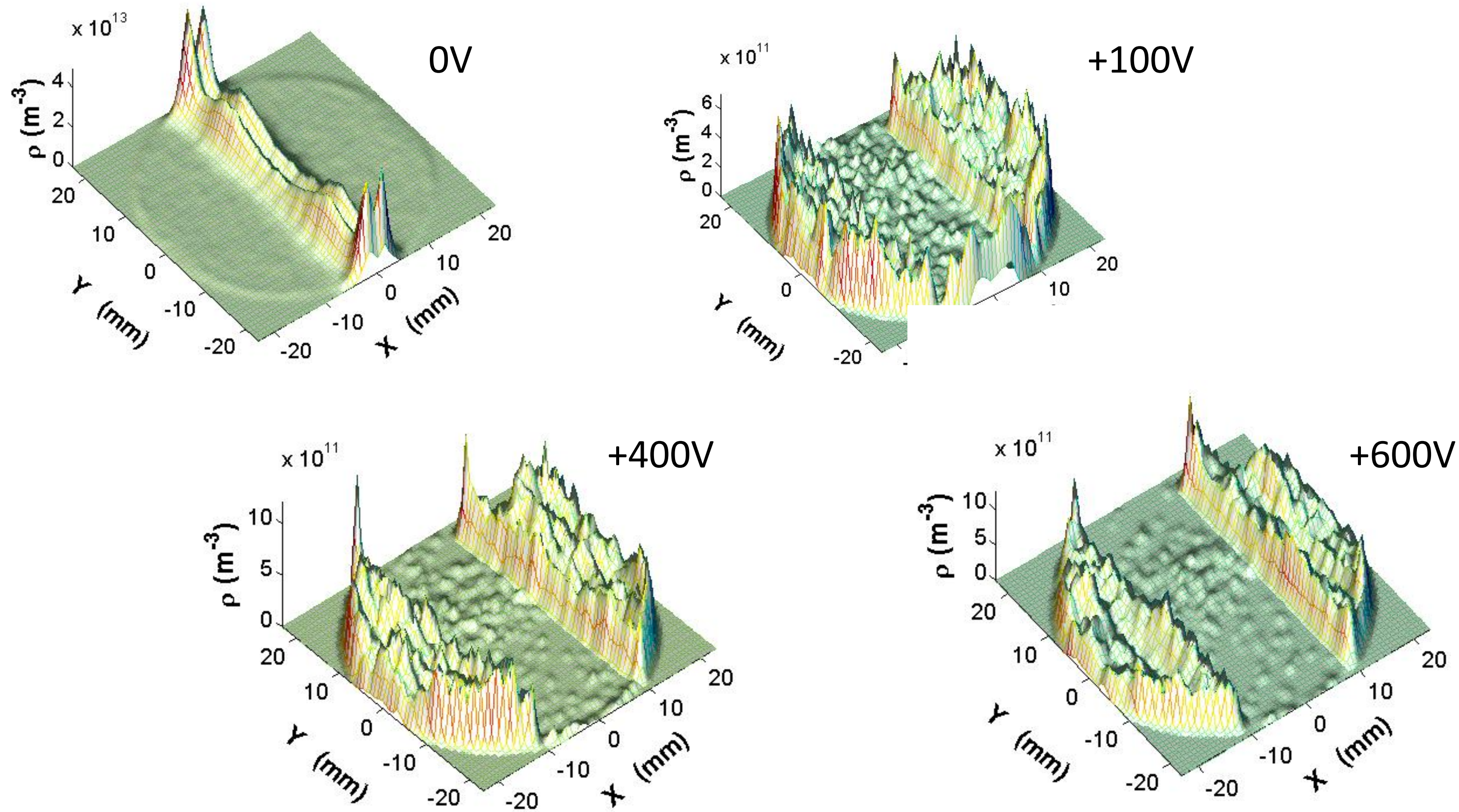
Modeling of clearing electrode: round chamber is used



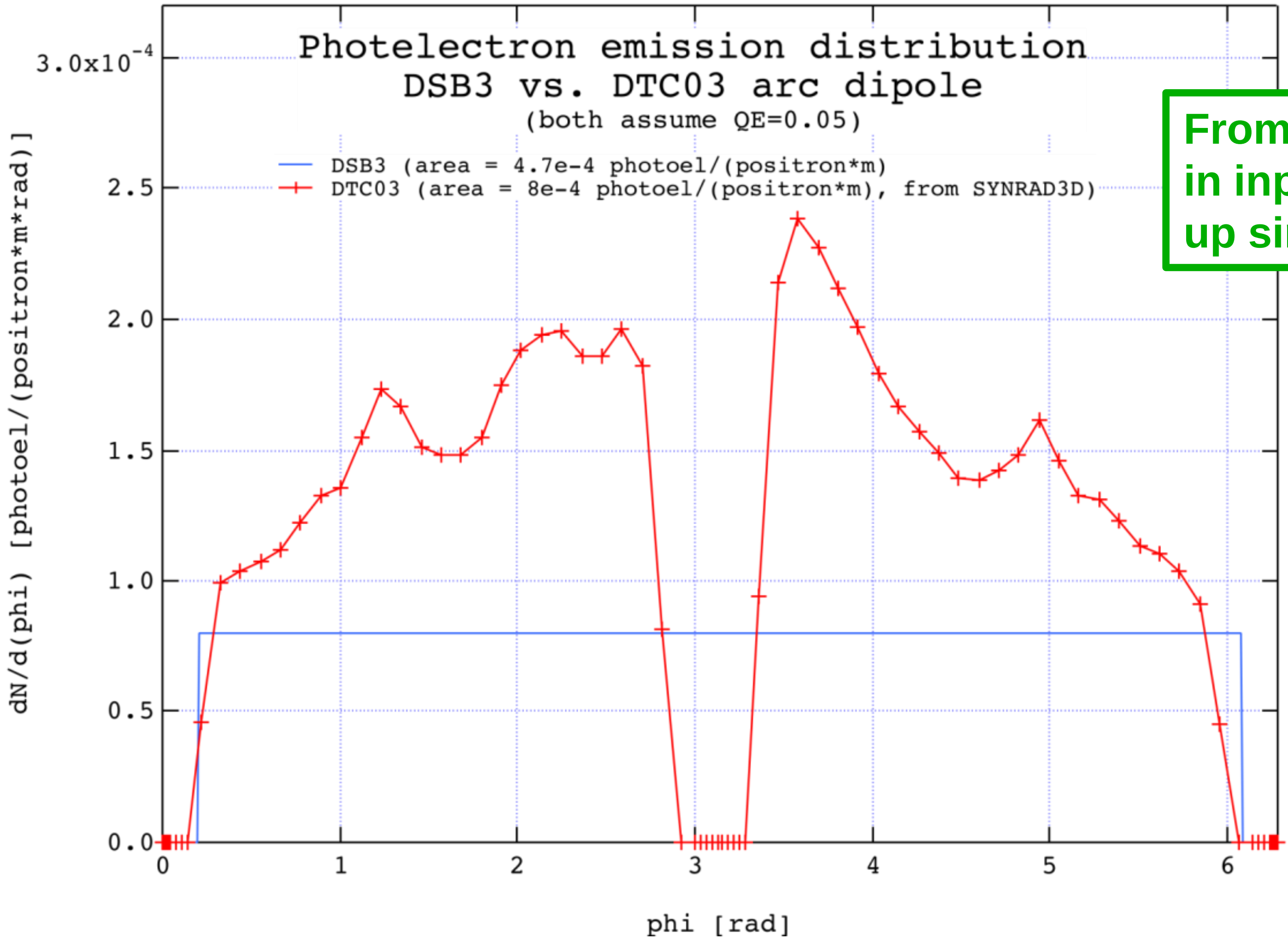
Clearing Field (left) & potential (right)

L. Wang, SLAC

Effect of Clearing Electrodes on Electron Cloud in a Wiggler magnet



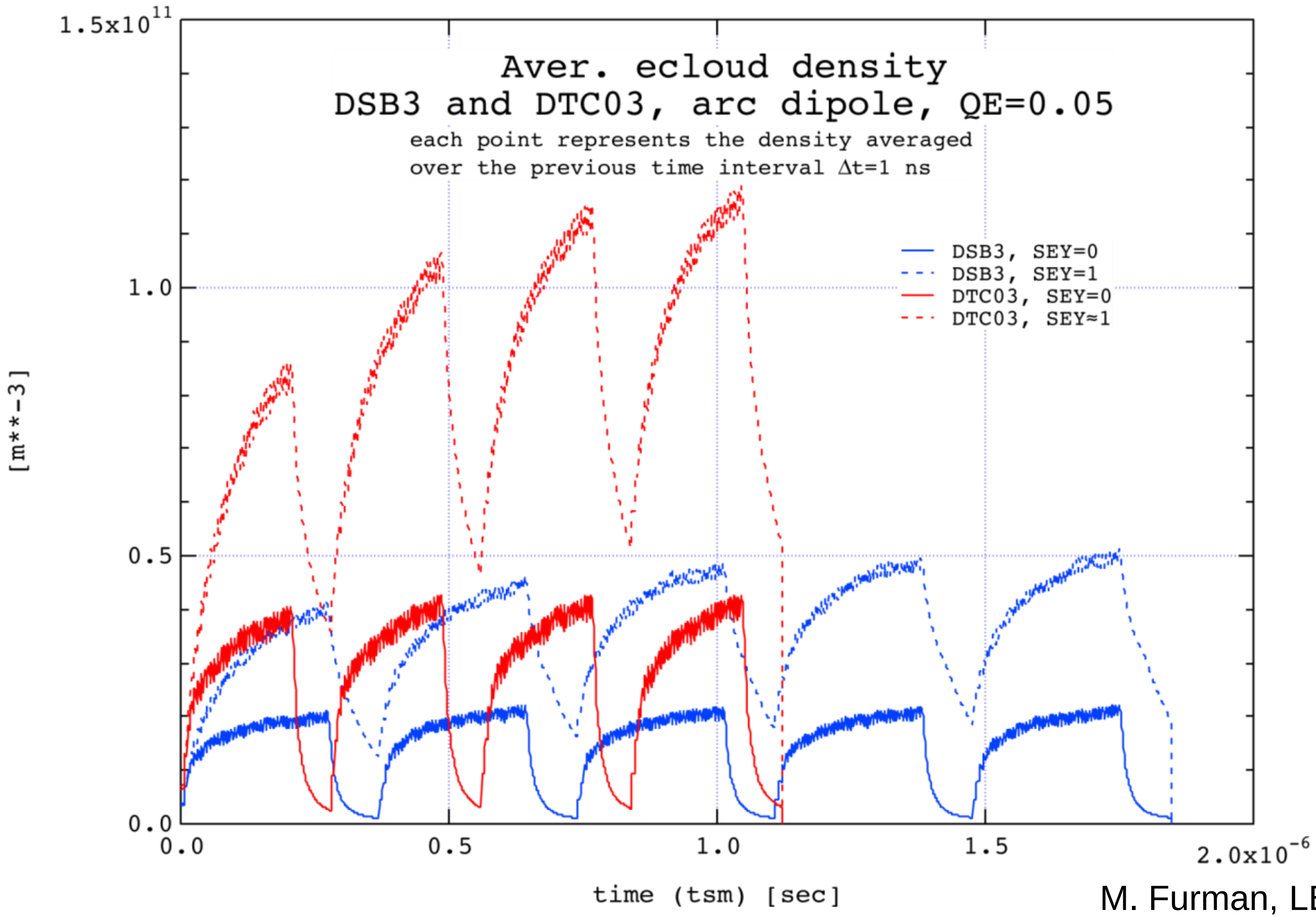
Arc Bend: Photoelectron emission distribution along the perimeter of the chamber cross section



From Synrad3D in input to build up simulations

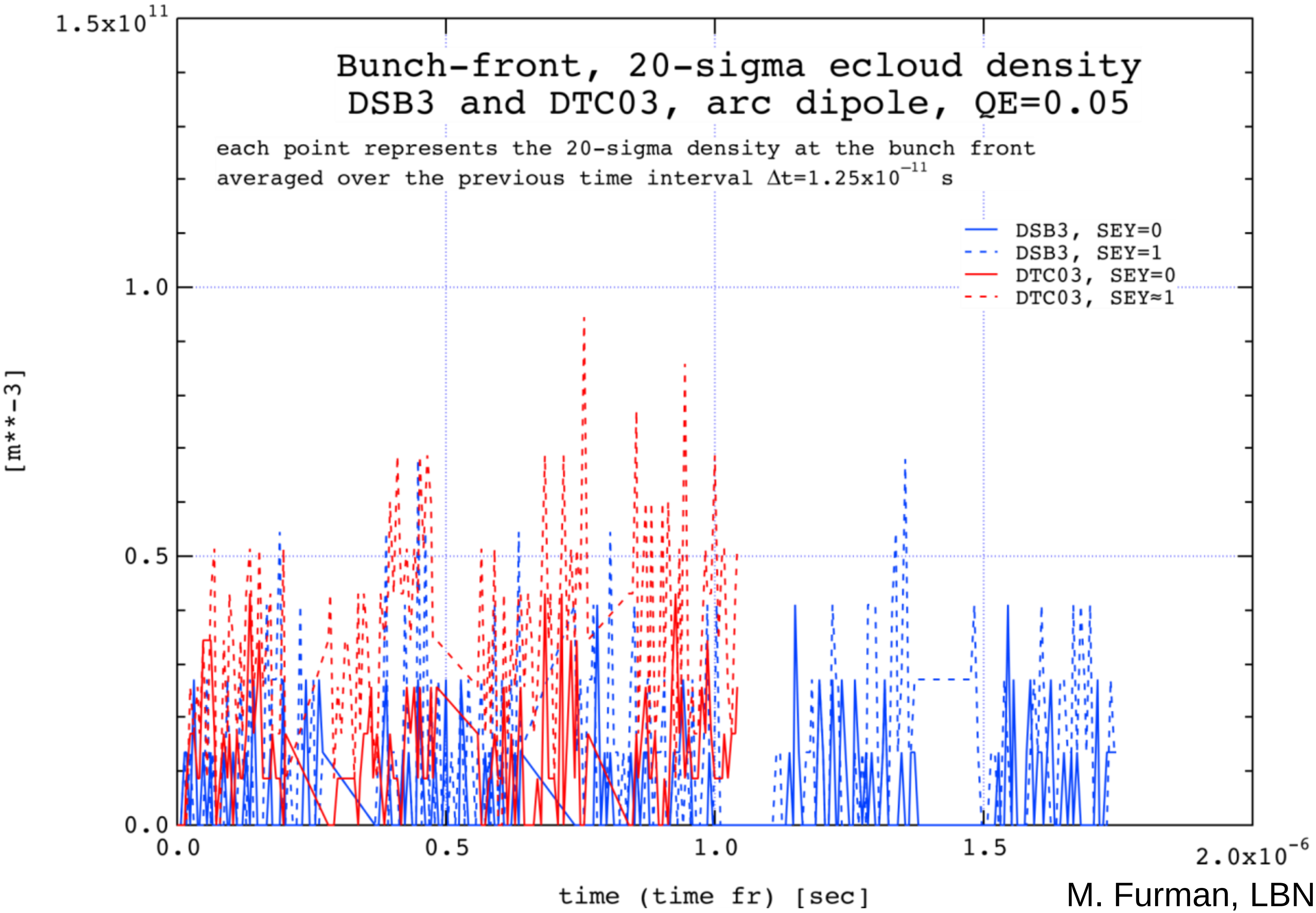
M. Furman, LBNL

Bends: Overall average EC density: all cases
(QE=0.05)



M. Furman, LBNL

Bunch-front 20-sigma EC density
(QE=0.05)



M. Furman, LBNL

Bends: Summary table of results for n_e Compare SEY=0 and SEY=1 (units: 10^{10} m^{-3})

	DTC03
Overall density at end of train **peak SEY=0** **peak SEY=~1**	 **~4** **>~12**
20-sigma density during train **peak SEY=0** **peak SEY=~1**	 **~2** **~5**
Bunch-front, 20-sigma density **peak SEY=0** **peak SEY=~1**	 **~2** **~4**

M. Furman, LBNL

Completing evaluation for ILC

Two more steps:

1) Estimate electron cloud in Bends with grooves implemented in vacuum chambers
2) Evaluate beam stability with the predicted level of electron cloud density for each element in the ring

- Before completing these studies, with implemented mitigations the ring cloud density is $\sim 4 \times 10^{10}$ e/m^3 a factor 3 lower than the instability threshold estimated earlier in 2010 ... !

Choices of groove geometry

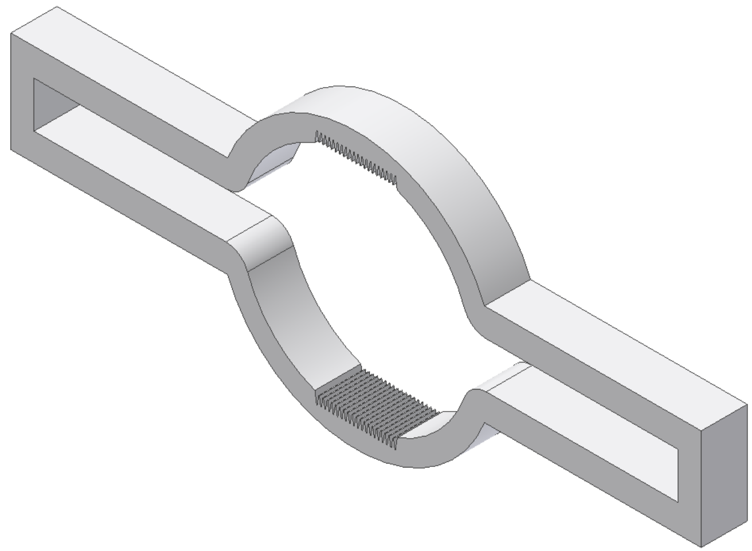
Let us be clear:

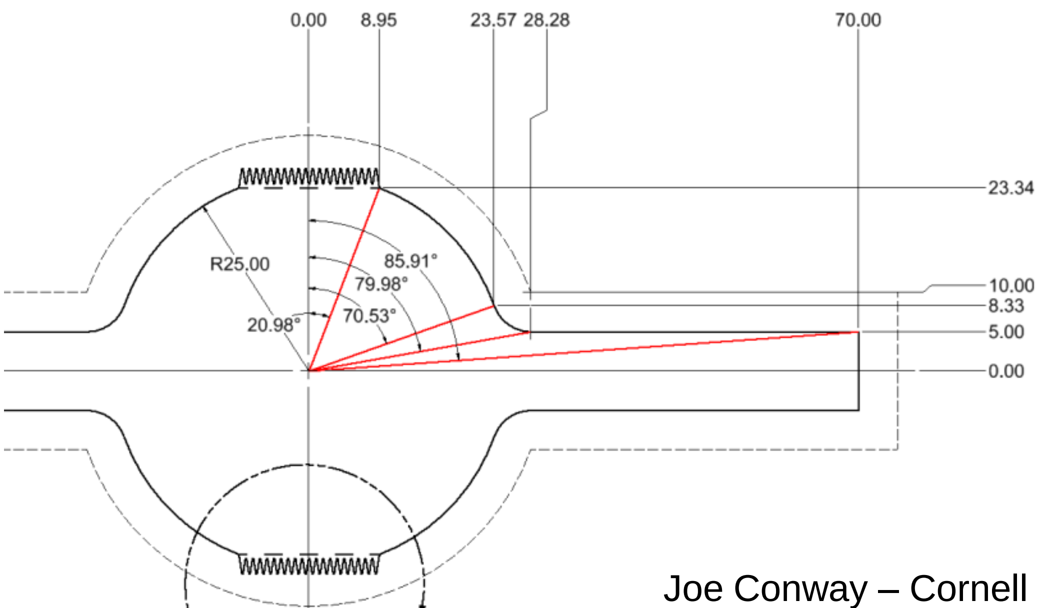
- In magnetic field regions: **Triangular** grooves are very effective and rectangular grooves are not as effective.

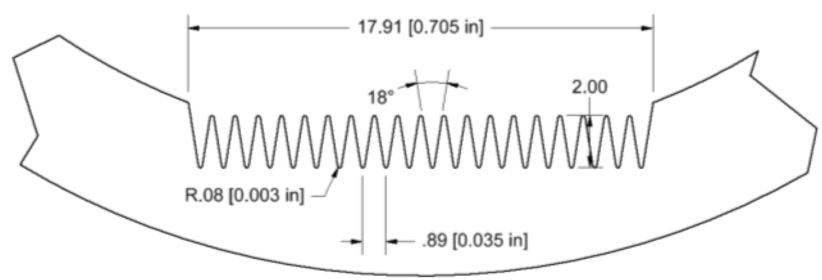
- In field-free regions: **Rectangular** grooves are very effective and triangular grooves are not as effective

Mitigations: Dipole Chamber with Grooves

- 20 grooves (19 tips)
- 0.079in (2mm) deep with 0.003in tip radius
- 0.035in tip to tip spacing
- Top and bottom of chamber



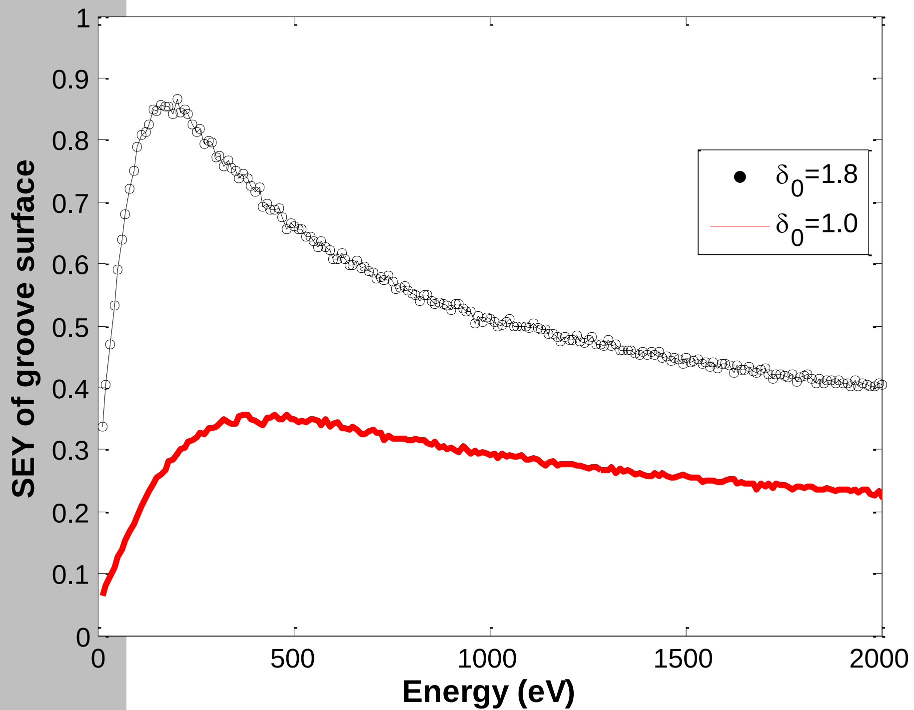




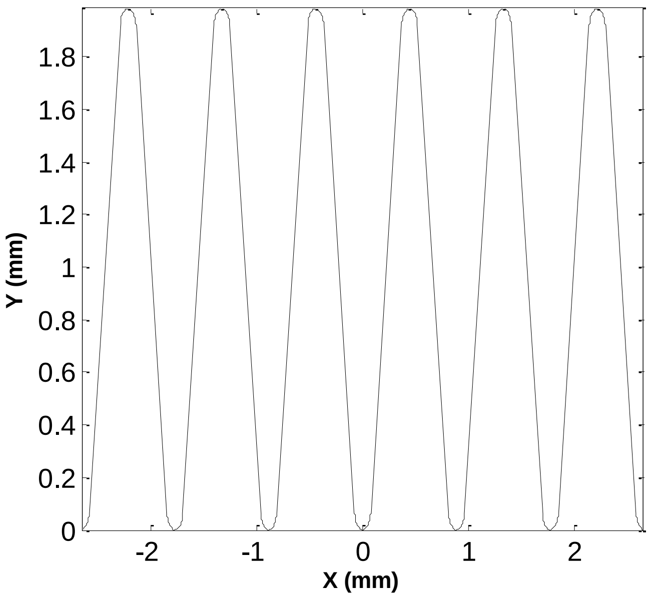
SEY simulation: grooved surface

SEY of Grooved Surface in ILC Dipole magnet (2.28kG)

1st case: Sey0=1.8 (Un-processed TiN ,before installation in CesrTA)
2nd case: Sey0=1.0 (Processed TiN);



Simulated SEY of Grooved Surface



Groove shape used in simulation

Electron cloud mitigations in LHC complex

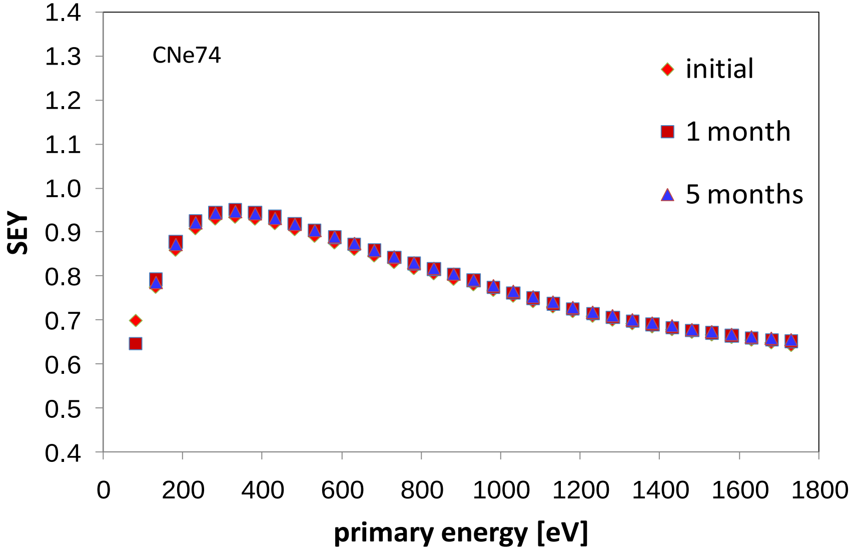
Main focus on:

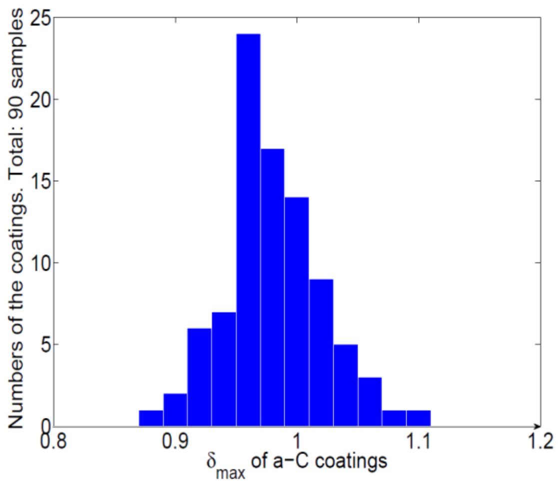
- Scrubbing or conditioning in the LHC
- Amorphous Carbon coating for the SPS
- Single-bunch Feedback system under development for the SPS → LHC

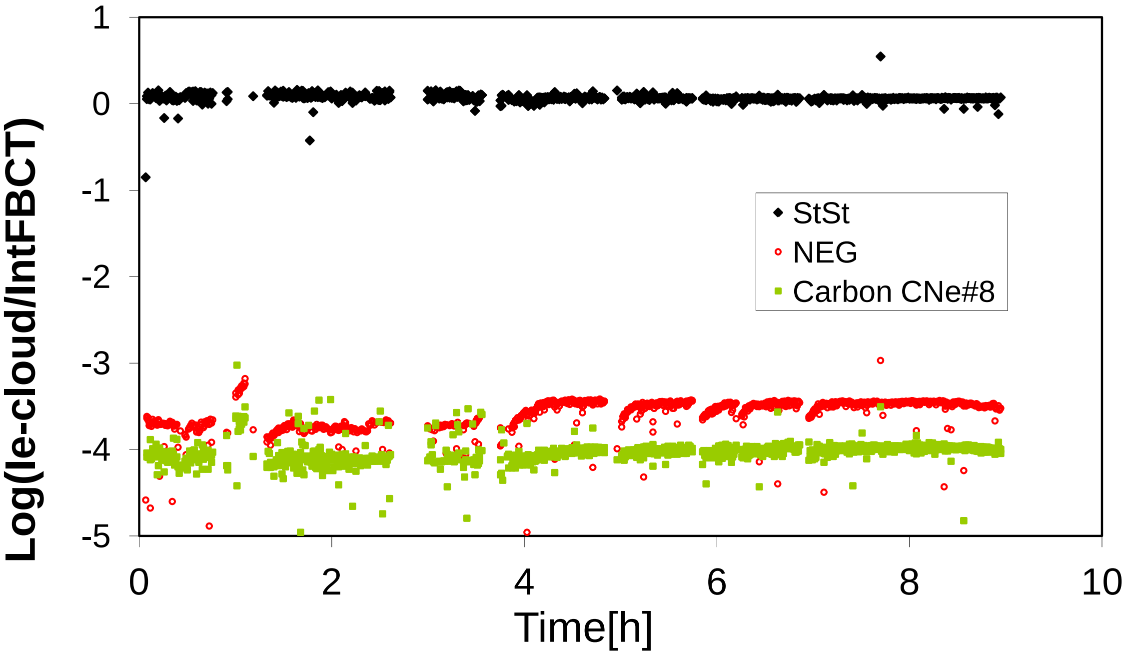
Scrubbing

- Scrubbing: combined effect of stimulated gas desorption and carbon graphitization on surface
- Estimated 2 weeks of scrubbing for LHC
- (Comments. Additional effects to be considered: as electron cloud decrease, effect of scrubbing also diminishes =asymptotic behavior near SEY threshold, and slow desorption and evacuation of surface molecules in cold surfaces due to cryogenic re-pumping)

Demonstrated a-C coatings performance:





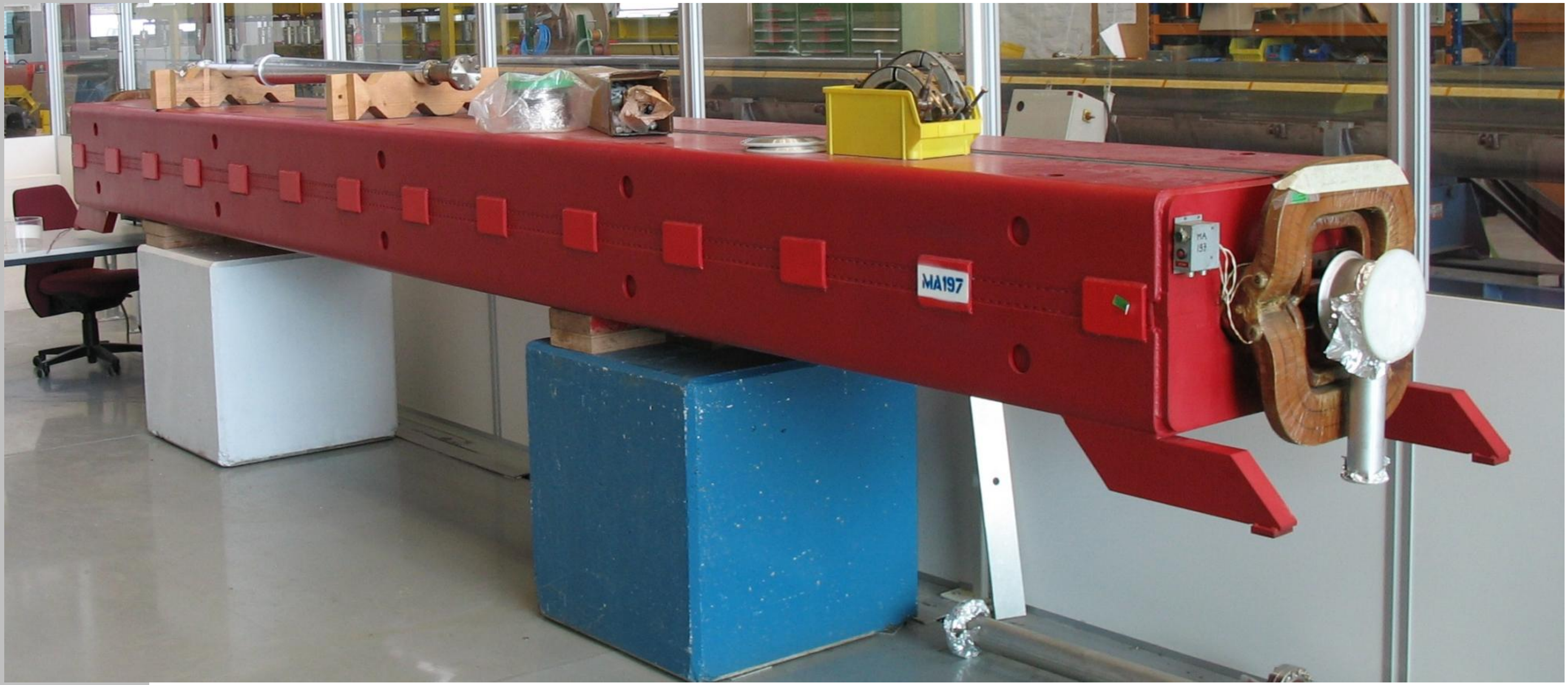


Coatings with maximum SEY close to 1 can be produced with high reliability

Reduction by 10^4 of the e-cloud current in SPS e-cloud monitors with LHC beam at 25 ns

M. Taborelli, CERN

Preparation for SPS magnet prototype coating



Amorphous carbon coating plans in the SPS

Plan 2013 (Long Shutdown 1):

- Coated Half cell already installed
- Coating of 12 main dipoles of SPS + 3 Quadrupoles to obtain 2 coated full cells. Instrumented with pressure gauges etc..

Plan 2018 (long shutdown 2):

- Coating of all main dipoles and quadrupoles (still under evaluation for half of the dipoles, possible conditioning)

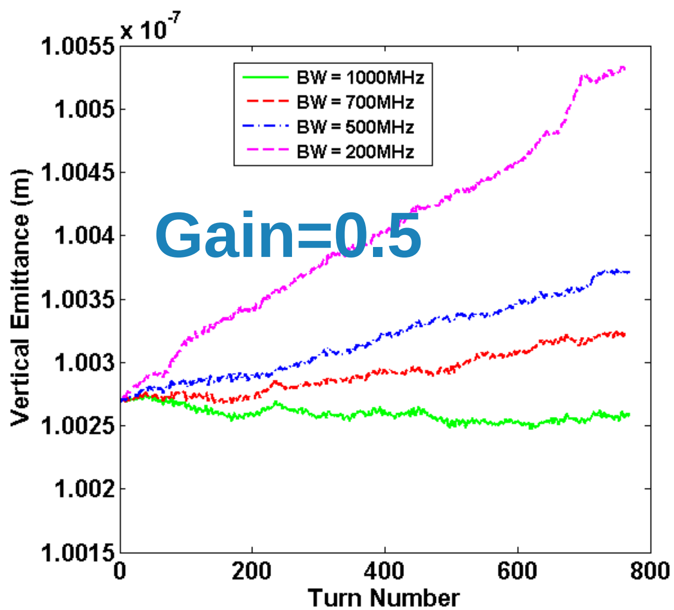
[1] P. Costa Pinto and N. Bundaleski talks at ECLOUD12

Single-bunch Feedback system

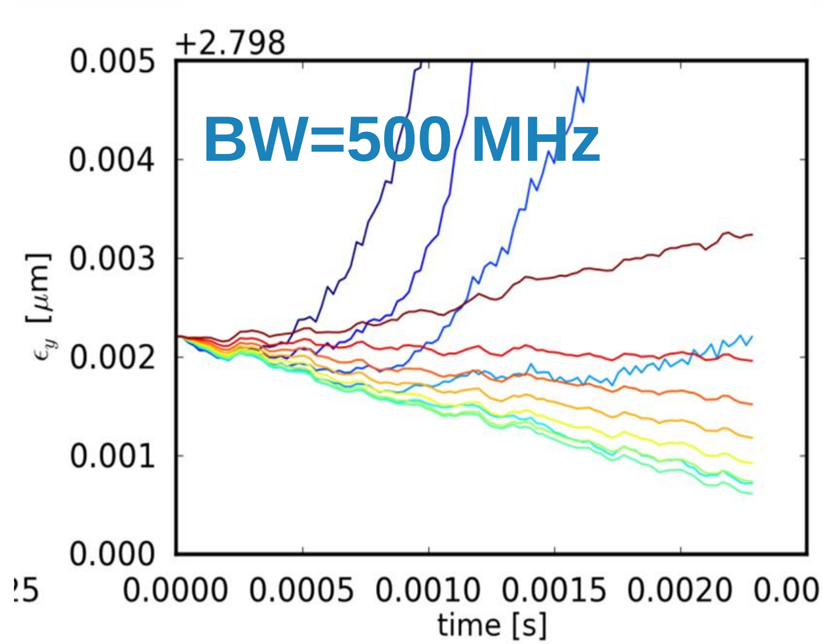
SPS – simulations with feedback

- E-cloud density: 5-6e11e/m³, 1.1e11 ppb, Bandwidth =200MHz-1GHz

Fixed gain, vary bandwidth



Fixed bandwidth, vary gain



Damped emittance. Very encouraging preliminary results from simulations (HeadTail, CMAD, WARP)

Summary

- Methodical evaluation of electron cloud in ILC ongoing for Technical Design Report (2012)
- Evaluated photon rates and distributions with newly developed 3D code.
- Electron cloud density in all drifts with solenoid ~ 0.
- Evaluated cloud density in ILC DR quadrupoles of arc and wiggler sections, in sextupoles, in arc bends and in wigglers.
- Coming next: grooves in bends and instability evaluations.
- News: Cloud density already promisingly low.
- Concern: **additional effect of incoherent emittance growth** observed even at very low cloud density (more about it soon)
- Mitigations for LHC/SPS: soon scrubbing, then α-C coatings and single-bunch feedback