Electron Cloud Evaluations for ILC DR

Mauro Pivi on behalf of the ILC Electron Cloud Working Group

- by Webex -

KILC12 – Daegu Korea

April 25, 2012

Technical Design Report TDR 2012

- The DR Working Group has given recommendations on electron cloud technical mitigations
- Goal is to evaluate electron cloud effect with mitigations implemented in each DR region.
- Build-up simulations should include “Baseline Mitigation I” and “Baseline Mitigation II” as next slide

Summary of Electron Cloud Mitigation Plan

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	NEG Coating	TiN Coating	Grooves with TiN Coating	Clearing Electrodes or Grooves

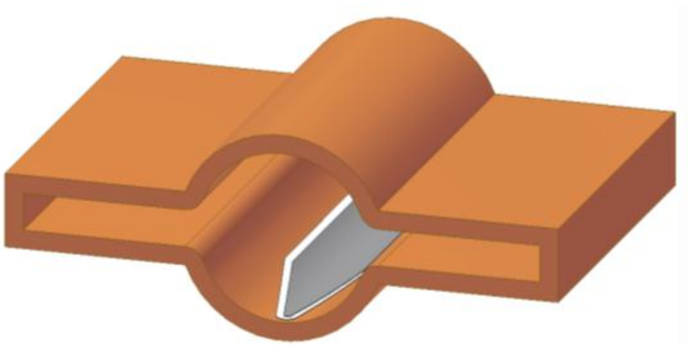
*Drift and Quadrupole chambers in arc and wiggler regions will incorporate antechambers

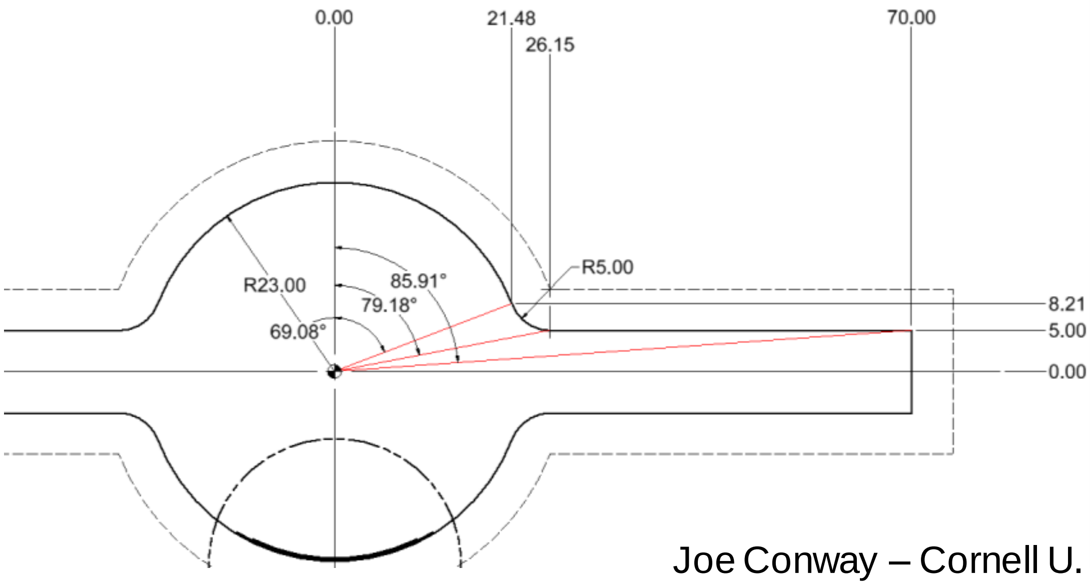
- Preliminary CESRTA results and simulations suggest the possible presence of *sub-threshold emittance growth*
  - Further investigation required
  - May require reduction in acceptable cloud density ⇨ reduction in safety margin
- An aggressive mitigation plan is required to obtain optimum performance from the 3.2km positron damping ring and to pursue the high current option

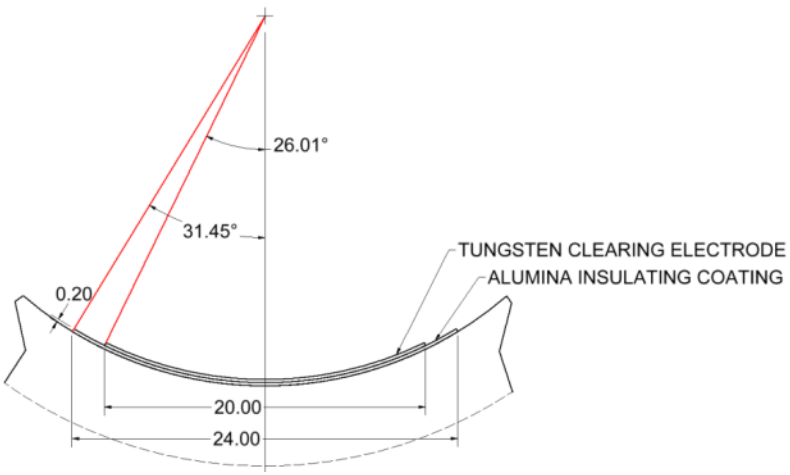
M. Pivi, S. Guiducci, M. Palmer, J. Urakawa on behalf of the ILC DR Electron Cloud Working Group

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

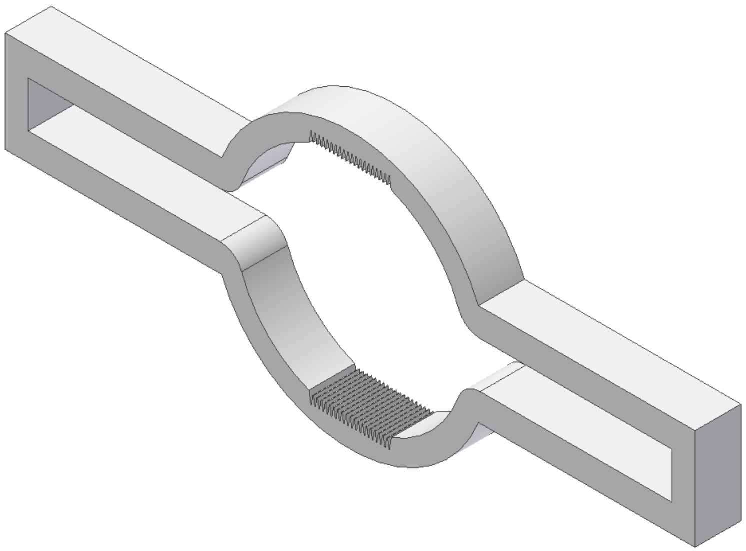


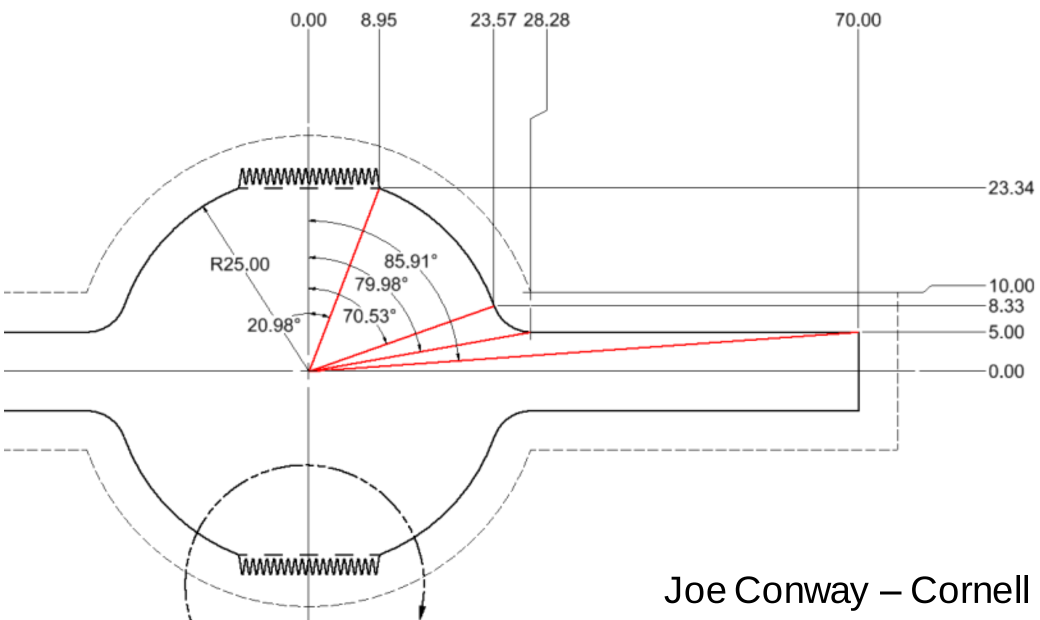


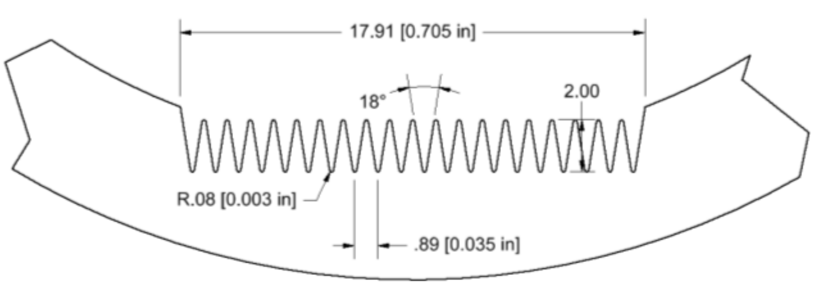


Mitigations: Dipole Chamber with Grooves

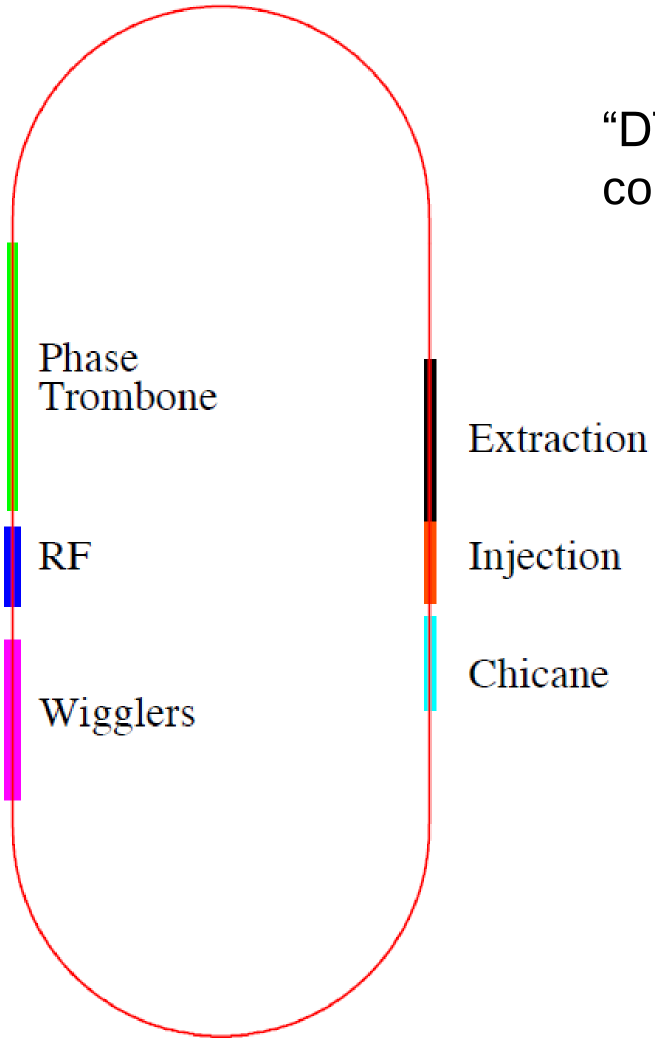
- 20 grooves (19 tips)
- 0.079in (2mm) deep with 0.003in tip radius
- 0.035in tip to tip spacing
- Top and bottom of chamber







DTC03 layout

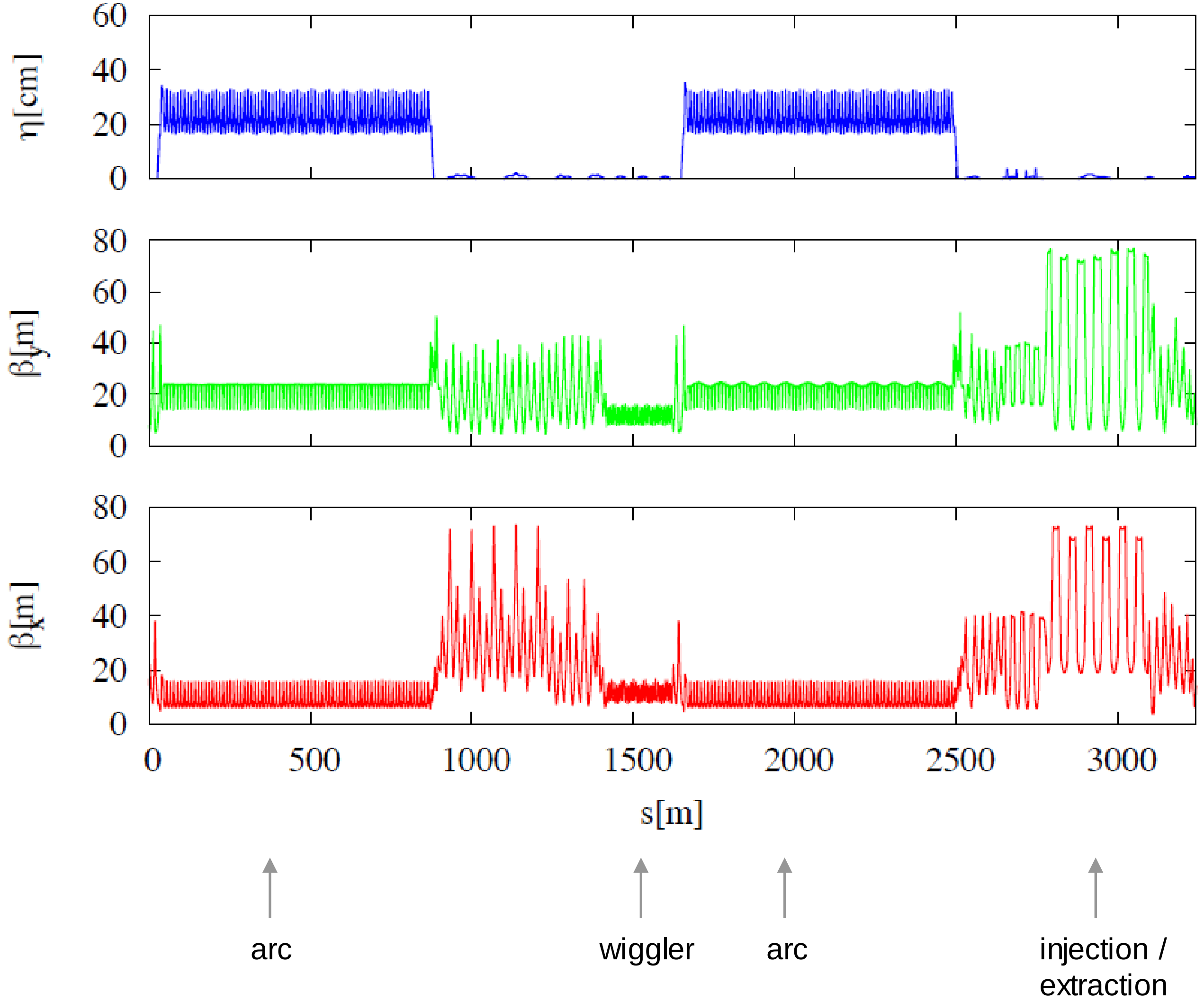


"DTC03" is the most recent lattice design, considered to evaluate the electron cloud effect

1. Circumference = 3238.68m, 710.22m straights
2. ~ 6 phase trombone cells
3. 54 – 2.2 m long wigglers
   wiggler period = 30cm
   14-poles
   B_{max} = 2.16 T
4. Space for 16 RF cavities
   Cryostats for upper and lower positron rings are interleaved

David Rubin, Cornell U.

DTC03 lattice functions



DTC03

Parameter	10 Hz(Low)	5 Hz (Low)	5 Hz (High)
Circumference	3.238 km	3.238 km	3.238 km
RF frequency	650 MHz	650MHz	650 MHz
τ_x/τ_y [ms]	12.86	23.95	23.95
T_z [ms]	6.4	12.0	12.0
σ_s [mm]	6.02	6.02	6.02
σ_δ	0.137%	0.11%	0.11%
α_p	3.3×10^{-4}	3.3×10^{-4}	3.3×10^{-4}
$\gamma\varepsilon_x$ [μm]	6.3	5.8	5.8
RF [MV] (12 cavities) Total/Per cav	20.4/1.7	13.2 /1.1	13.2/1.1
ξ_x/ξ_y	-50.9/-44.1	-51.3/-43.3	-51.3/-43.3
Wigglers- N_{cells}@B[T]	27@2.16	27@1.51	27@1.51
Energy loss/turn [MeV]	8.4	4.5	4.5
sextupoles	3.34/-4.34	3.34/-4.23	3.34/-4.23
Power/RF coupler @400mA [kW]**	280	150	300

Radiation parameters (damping times, emittance, energy spread, etc. based on map-type wiggler

**(400mA X 8.4 MeV/turn)/12

Electron Cloud Density

From build-up simulation, we are interested in the near beam "central" <u>cloud density</u>:

1. At equilibrium after electron cloud evolution
2. At head of the bunch
3. Cloud density "near beam" (± 20 σx, ± 20 σy)

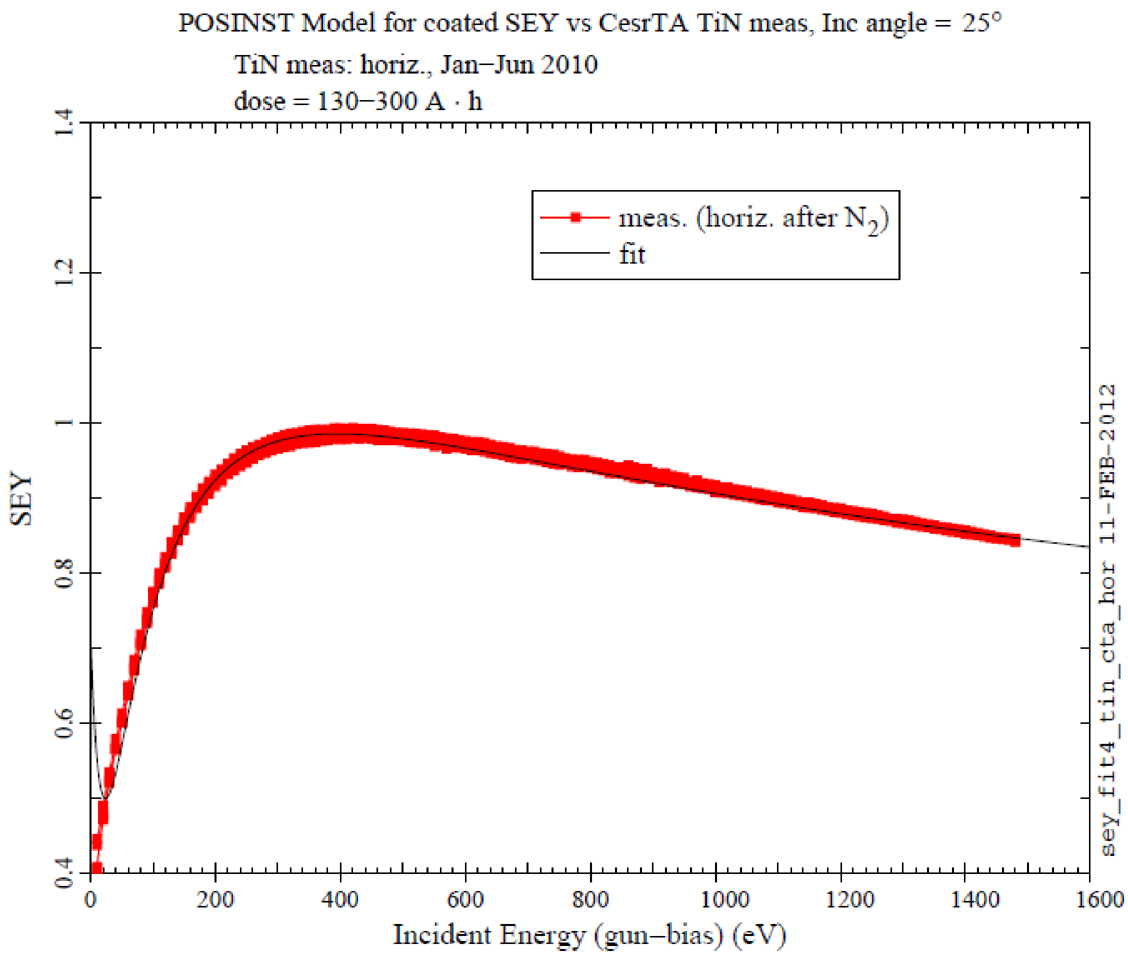
Secondary Emission Yield

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

- For the simulation 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

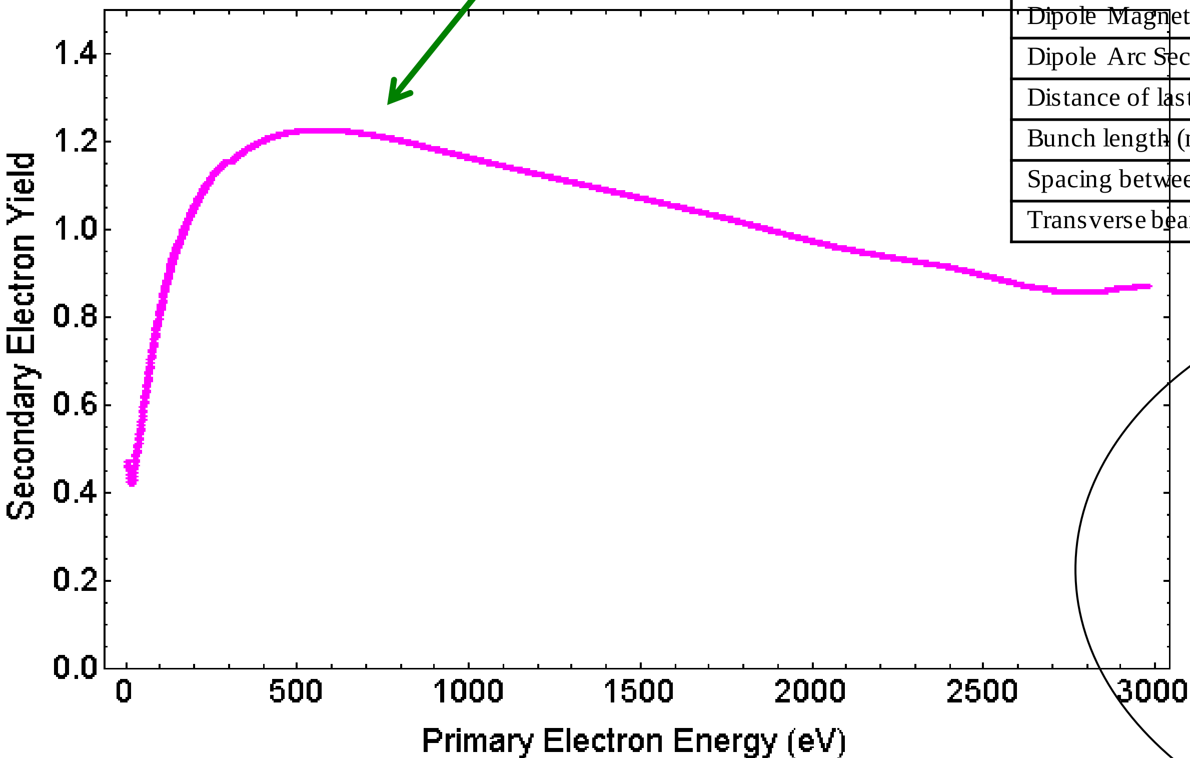


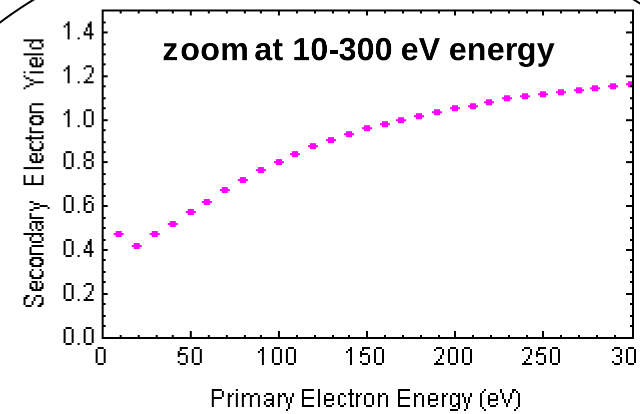
email Walter Hartung (wh29@cornell.edu) or Joe Calvey (jrc97@cornell.edu) for data files

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





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

Electron cloud assessment for TDR: plan

Electron cloud Build-up

Photon distribution

Photon generation and distribution
PI: Cornell U.

In BENDs with grooves
PI: LBNL

In WIGGLERS with clearing electrodes
PI: SLAC

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

Beam Instability

Input cloud density from build-up
PI: SLAC

Electron cloud assessment for TDR

ILC DR simulations ACTION ITEM 2012:

- **Provide ILC DR "wall" file for Synrad3D** - **Completed**
- **Validate ILC DR "wall" input file for Synrad3D** - **Gerry Dugan, Laura Boon**
- **Benchmark Synrad3D with data** - **Jim Crittenden; end of January**
- **Photoelectron ILC DR Synrad3D simulations** - **Gerry Dugan, Laura Boon, mid-Feb**
- **Post DTC03 lattice and parameters list** - **David Rubin, ASAP**
- **Provide beam parameters and SEY models for simulations** - **Mauro Pivi, by mid-February**
- **Build-up simulations BEND with TiN and GROOVES** - **Venturini / Furman, mid-March**
- **Build-up simulations DRIFT: 1) fully & 2) partially conditioned** - **Jim Crittenden, by mid-March**
- **Build-up simulations QUADRUPOLE and SEXTUPOLE** - **Jim Crittenden, by mid-March**
- **Benchmark build-up simulations for QUADRUPOLE** - **Lanfa Wang, by mid-March**
- **Build-up simulations WIGGLER (as BEND) with cl. ELECTRODES** - **Lanfa Wang, by mid-March**
- **Instability simulations for DTC03** - **Mauro Pivi, by mid-March**
- **Write up simulation results for TDR: total (3) paragraphs** - **All, by mid-April**

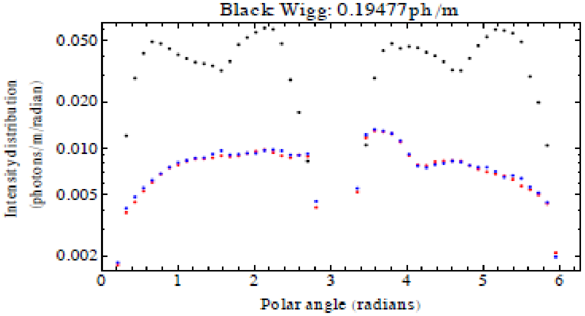
Photon distributions

- 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.

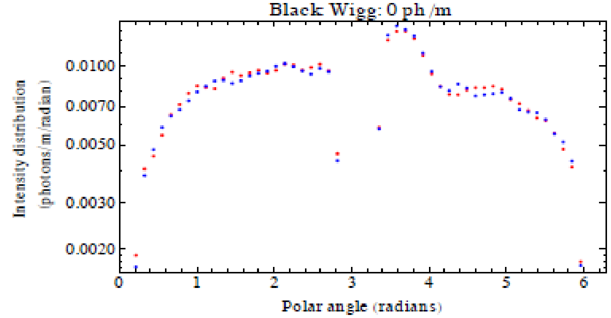
Cornell University
Laboratory for Elementary-Particle Physics

Comparison of photon distributions-dtc03

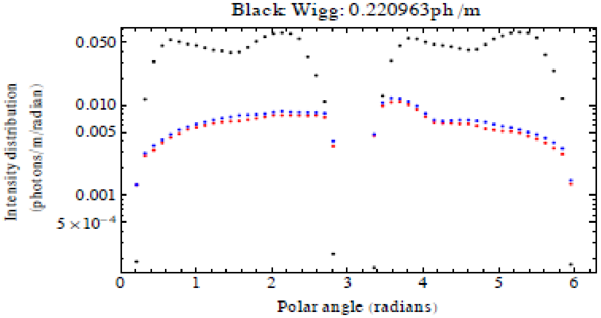
QUADRUPOLE
Red: Arc1: 0.0418442ph/m
Blue: Arc2: 0.0428004ph/m
Black Wigg: 0.19477ph/m



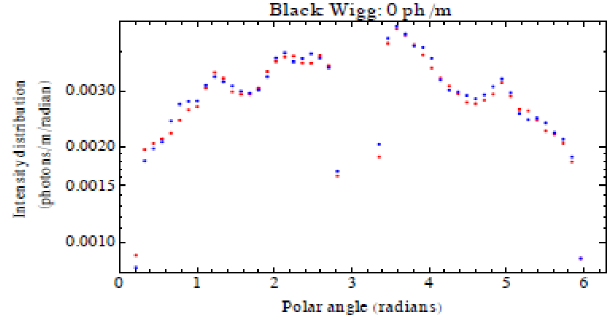
SEXTUPOLE
Red: Arc1: 0.0437614ph/m
Blue: Arc2: 0.0435829ph/m
Black Wigg: 0 ph/m



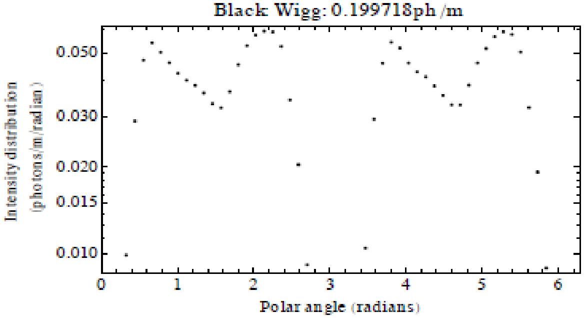
DRIFT
Red: Arc1: 0.0326384ph/m
Blue: Arc2: 0.0358304ph/m
Black Wigg: 0.220963ph/m



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

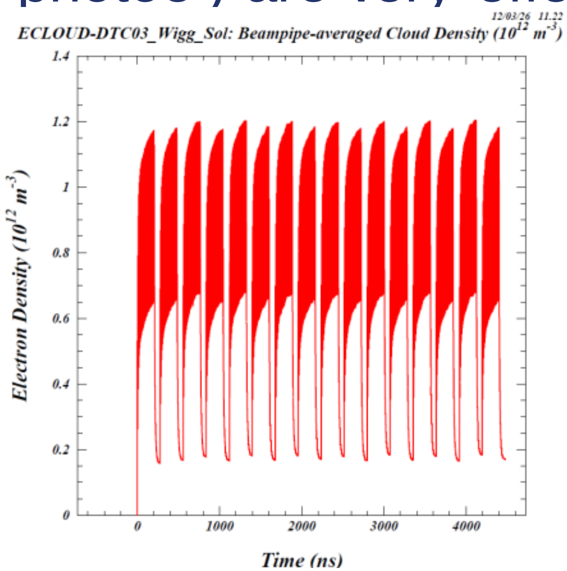


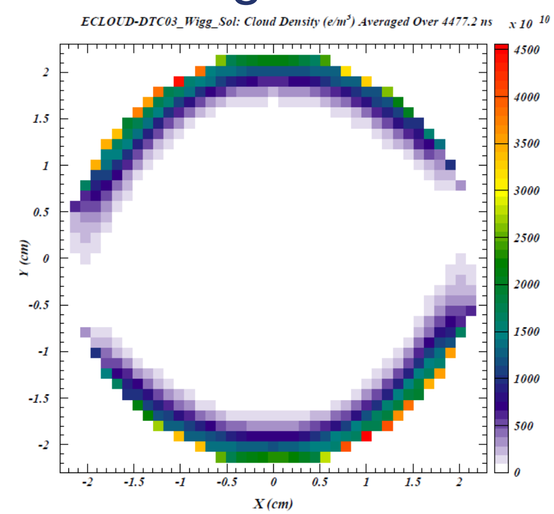
Recommended approximate photon distributions for EC simulations for dtc03

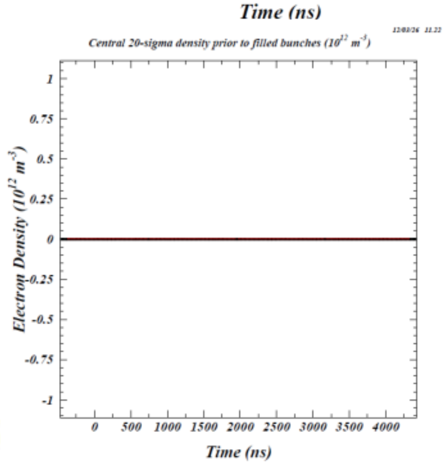
- Distribution: approximately uniform in azimuth (i.e., 100% “reflectivity”)
- Arcs: By magnet type:
  - Quadrupoles (288 m): 0.042 photons/m/positron
  - Sextupoles (180 m): 0.044 photons/m/positron
  - Drifts (770 m): 0.036 photons/m/positron
  - Dipoles (454 m): 0.018 photons/m/positron
- Wiggler cells: By magnet type:
  - Quadrupoles (17 m): 0.195 photons/m/positron
  - Drifts (91 m): 0.221 photons/m/positron
  - Wigglers (118 m): 0.204 photons/m/positron
- (Previous simulations: 0.0085 ph/m)

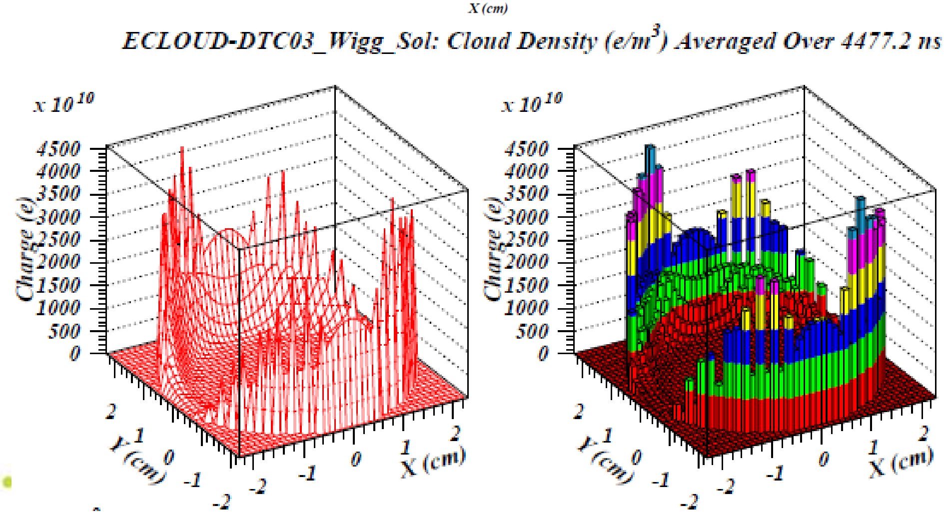
Electron Cloud in Drifts of Wiggler Regions, with Solenoid field (40 G)

- Solenoid fields in drift regions of wiggler sections (highest photoe$^-$) are very effective at eliminating the central density





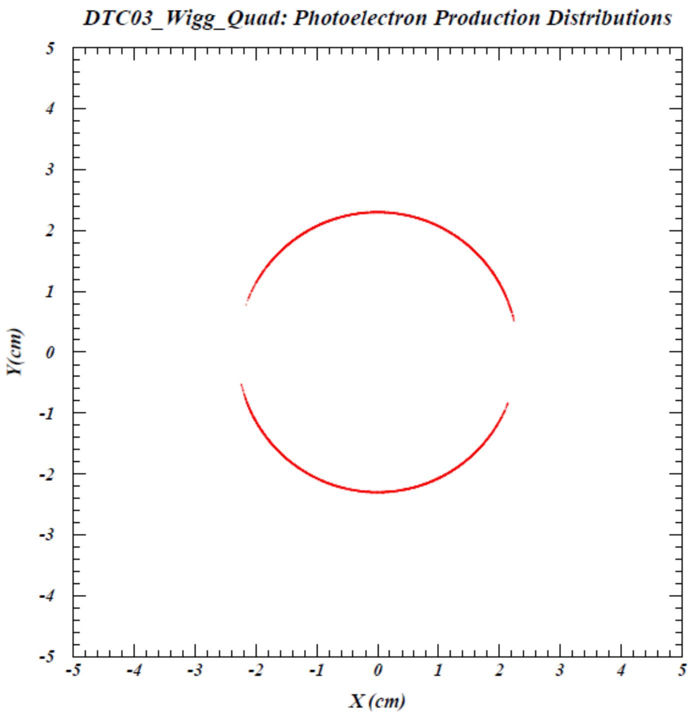


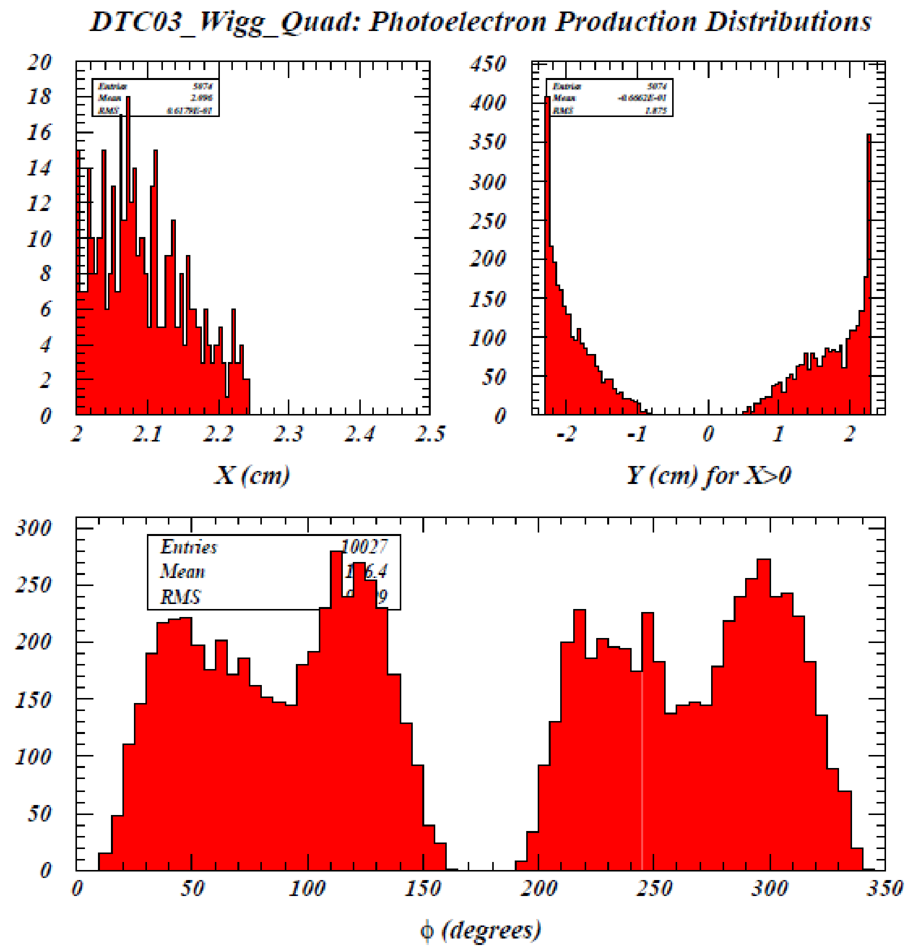


J. Crittenden, Cornell U.

Quadrupole in wiggler section

- Details of the photoelectron distribution in the quadrupoles

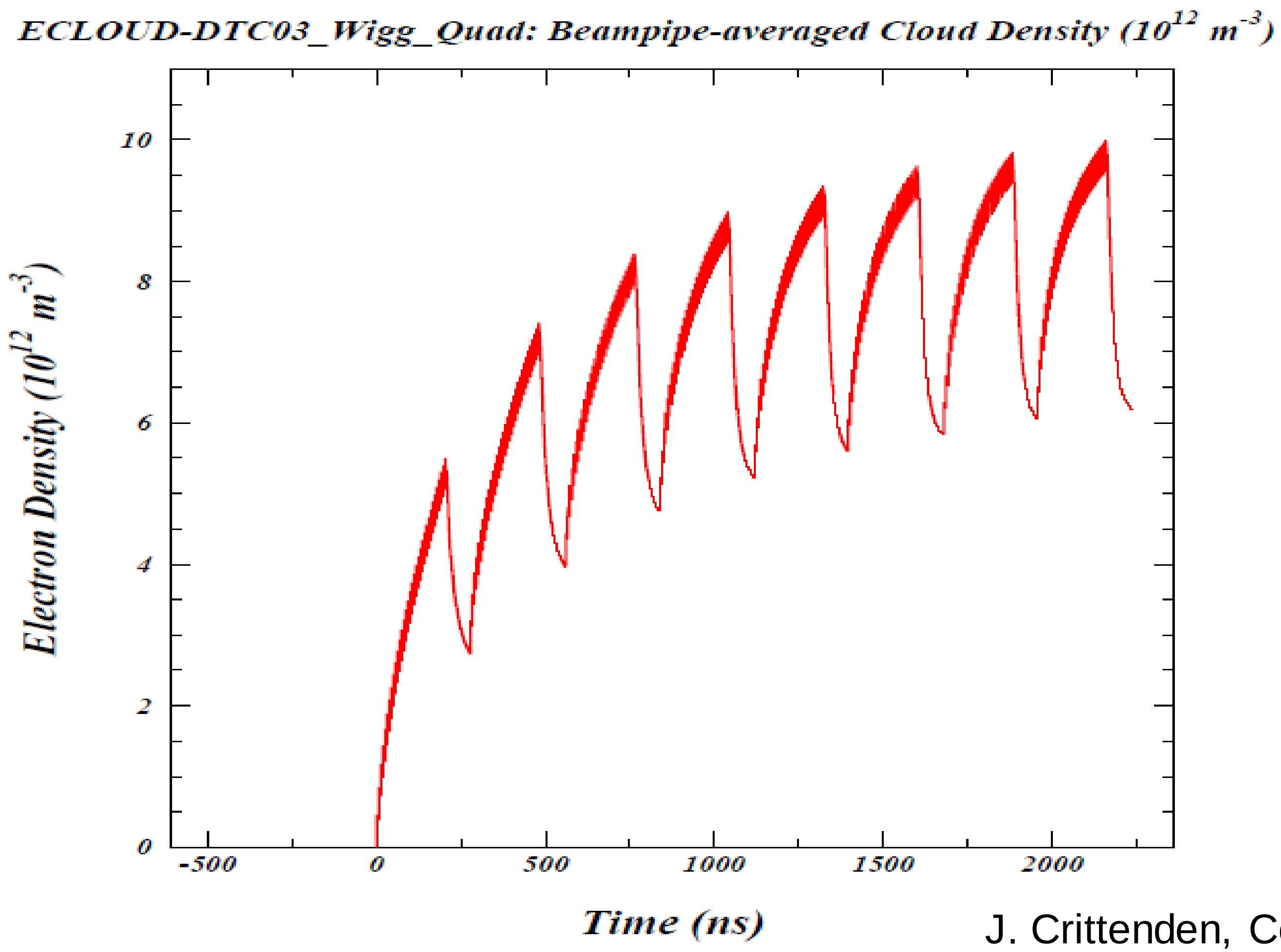




J. Crittenden, Cornell U.

Quadrupole in wiggler section

- The calculated beampipe-averaged cloud densities does not reach equilibrium after 8 bunch trains.



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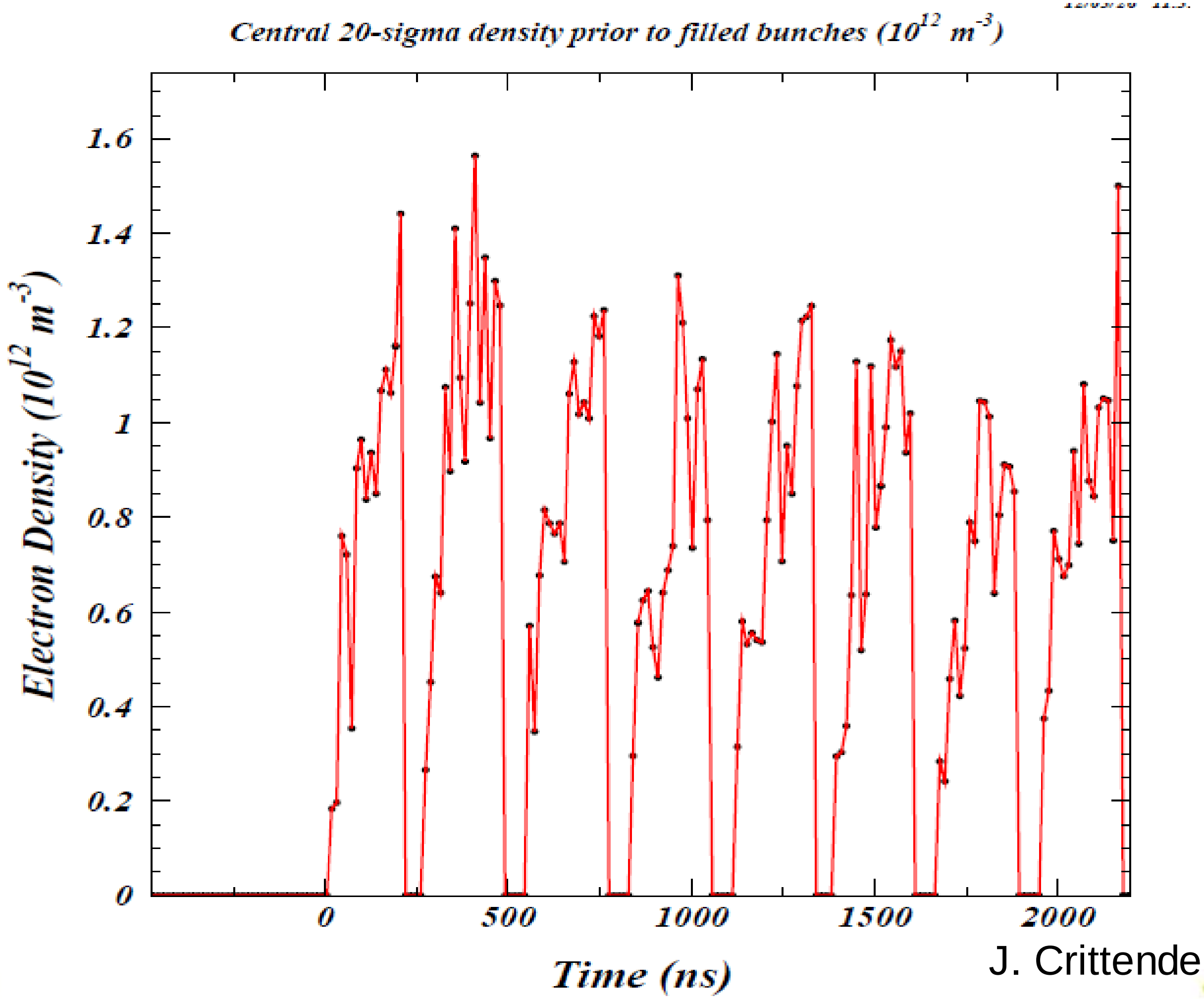
Quadrupole in wiggler section

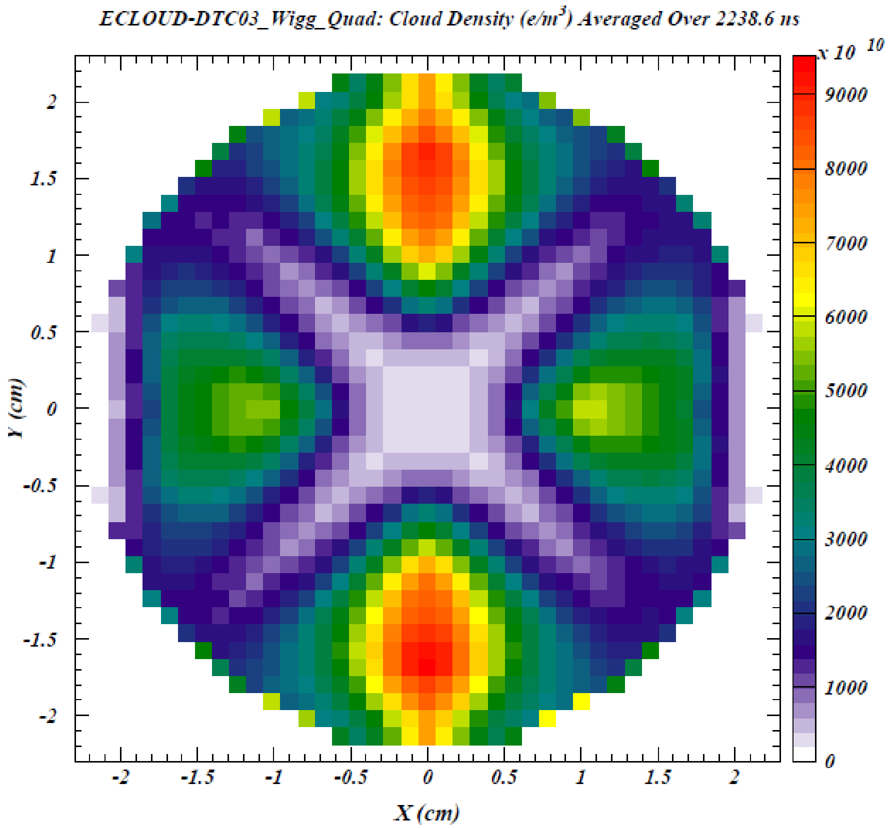
- The central cloud density reaches equilibrium in the Quadrupoles after few bunch trains



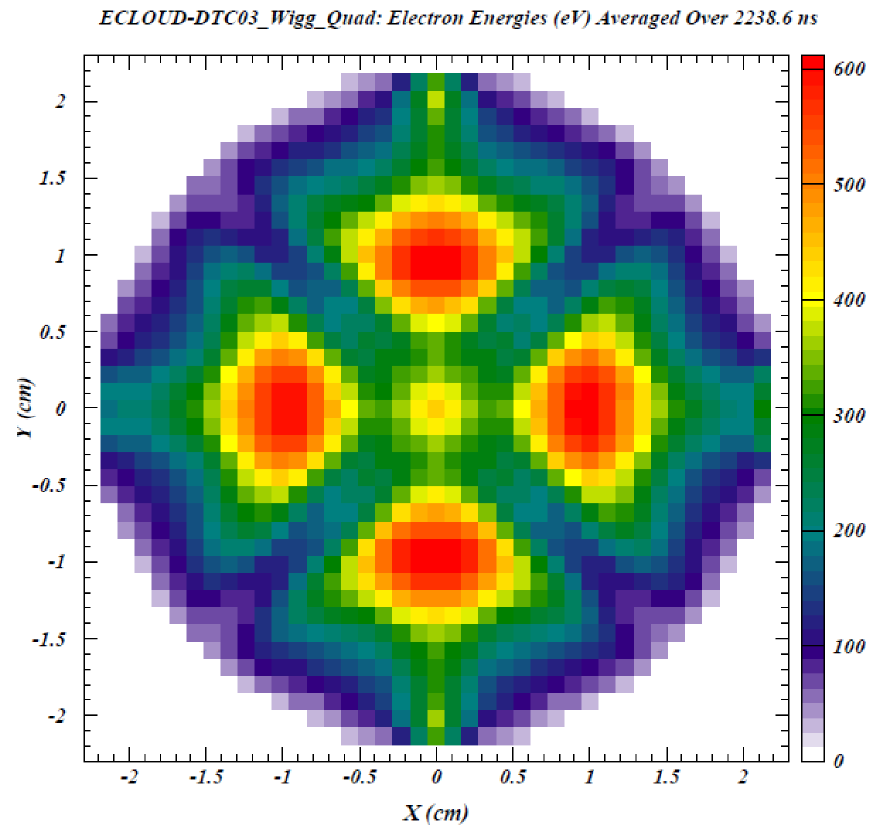
J. Crittenden, Cornell U.

Quadrupole in wiggler section

Electron cloud density (e/m^3)



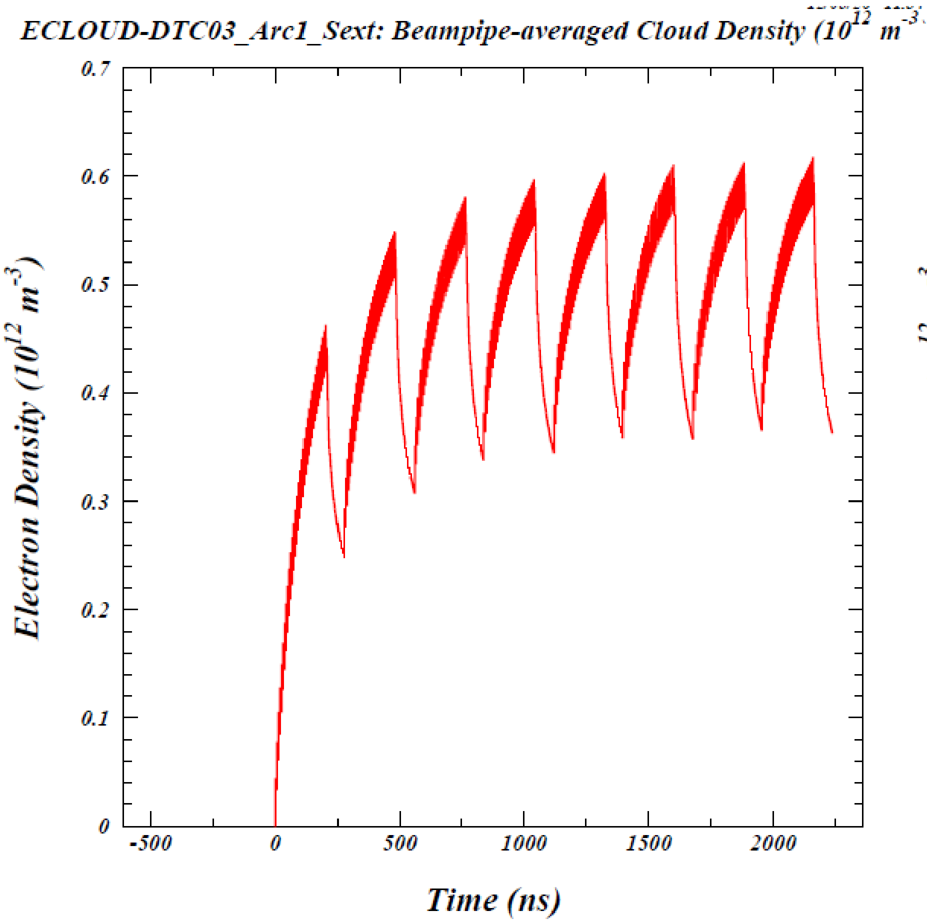
Electron energies (eV)

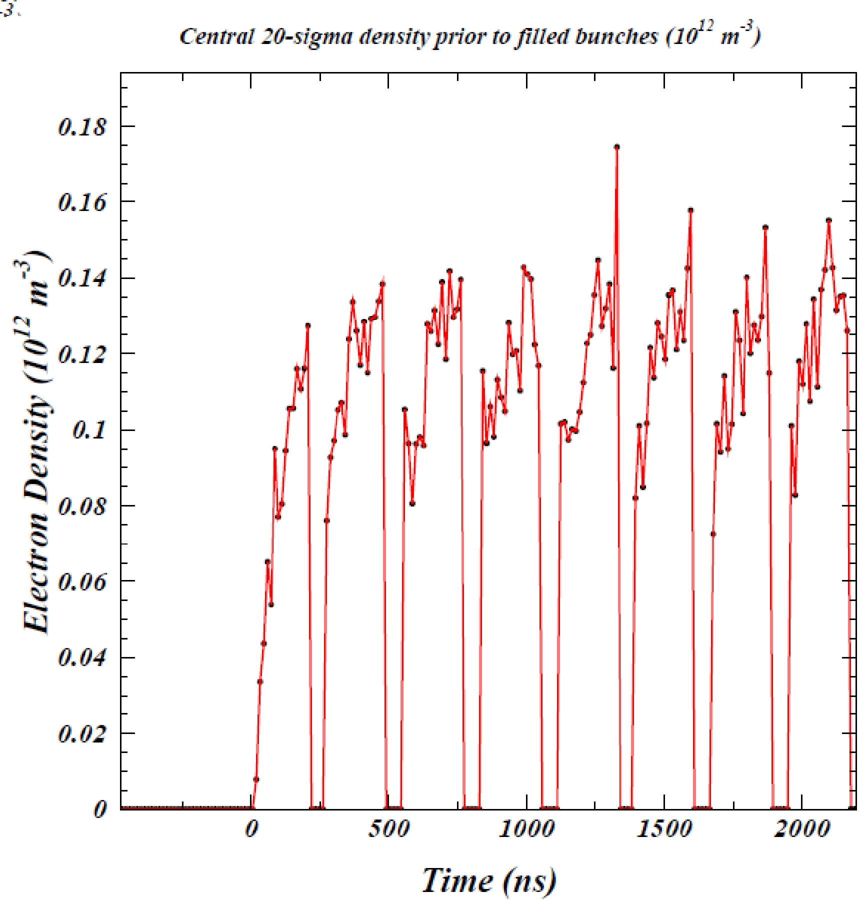


J. Crittenden, Cornell U.

Sextupole in TME arc cell

- Again in Sextupoles, the central cloud density reaches equilibrium (R), while the beam-pipe averaged (L) not.

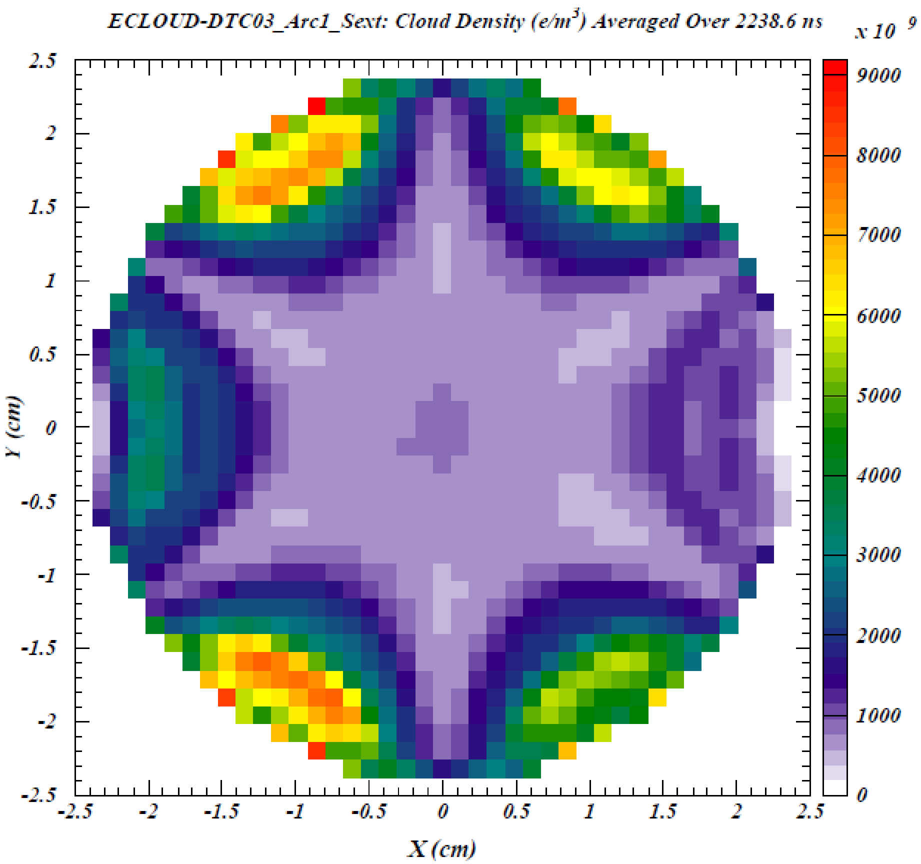


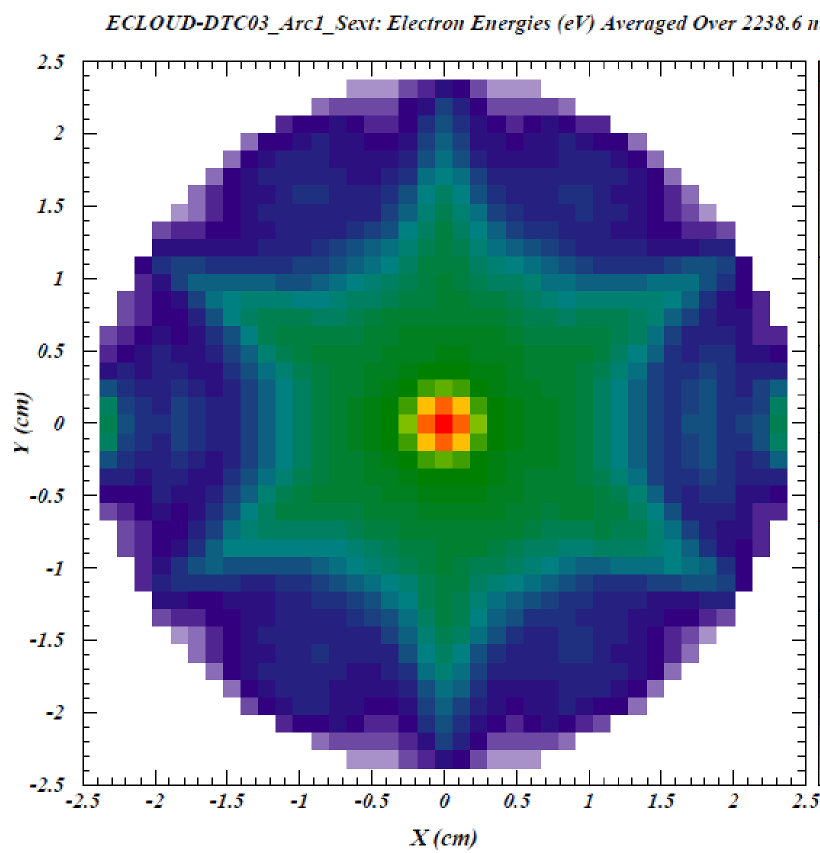


J. Crittenden, Cornell U.

Sextupole in TME arc cell

Electron cloud density (e/m³) | Electron energies (eV)





J. Crittenden, Cornell U.

Summary Electron Cloud in Drift , Quadrupoles and Sextupoles

Electron Cloud Buildup Analysis for the DTC03 ILC Damping Ring Lattice

Parameters for Electron Cloud Buildup and Instability Simulations 2012, M.T.F. Pivi 29.02.2012

Photon Absorption Rates and Distributions for the ILC Damping Ring (dtc03) by Ring Region, G. Dugan, 02.03.2012

Electron cloud density averaged over 20-sigma beam region

Secondary yield model for rediffused and elastic components for an uncoated aluminum vacuum chamber ($\delta_{rediffused} = 0.19$, $\delta_{elastic} = 0.5$)

	Drift	Solenoid (40G)	Quadrupole (10 T/m)	Sextupole (70 T/m^2)
Wiggler Region	4.0e12	0	1.2e12	None
Arc1 Region	0.25e12	0	0.15e12	0.14e12
Arc2 Region	0.25e12	0	0.17e12	0.13e12

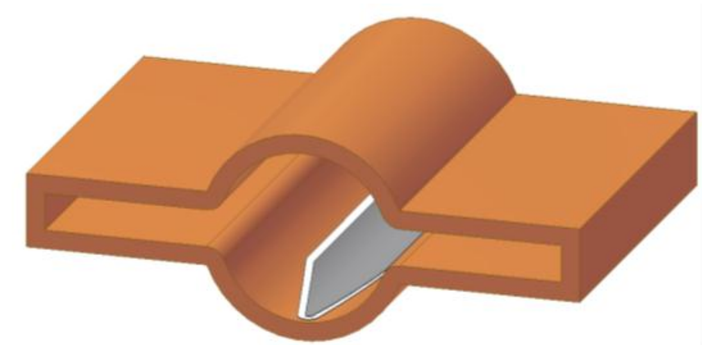
Secondary yield model for rediffused and elastic components from cloud lifetime measurements in a TiN-coated aluminum vacuum chamber ($\delta_{rediffused} = 0.1$, $\delta_{elastic} = 0.2$)

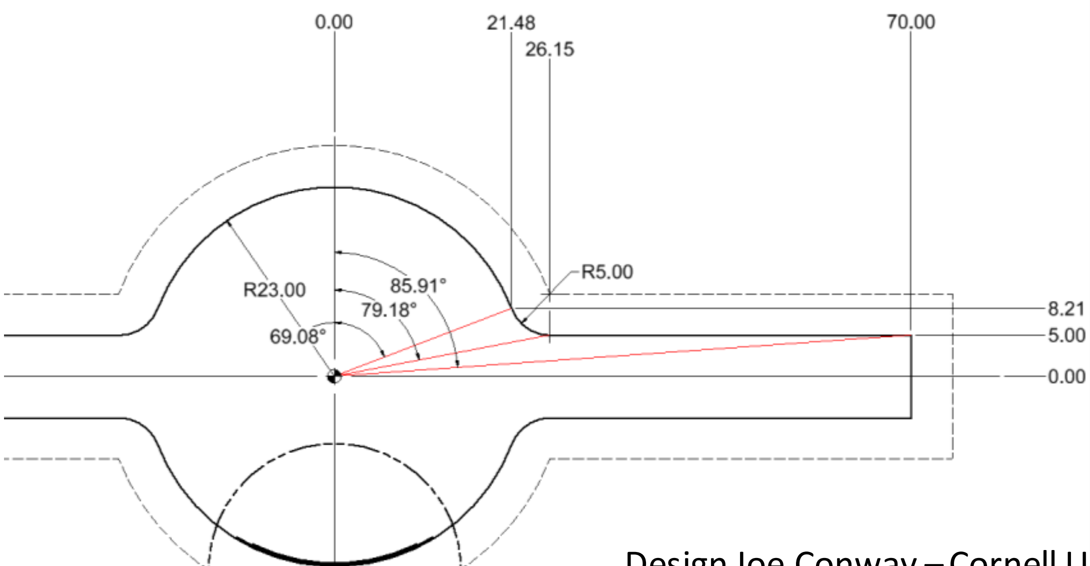
	Drift	Solenoid (40G)	Quadrupole (10 T/m)	Sextupole (70 T/m^2)
Wiggler Region	2.5e12	0	0.8e12	None
Arc1 Region	0.20e12	0	0.10e12	0.10e12
Arc2 Region	0.20e12	0	0.10e12	0.10e12

J. Crittenden, Cornell U.

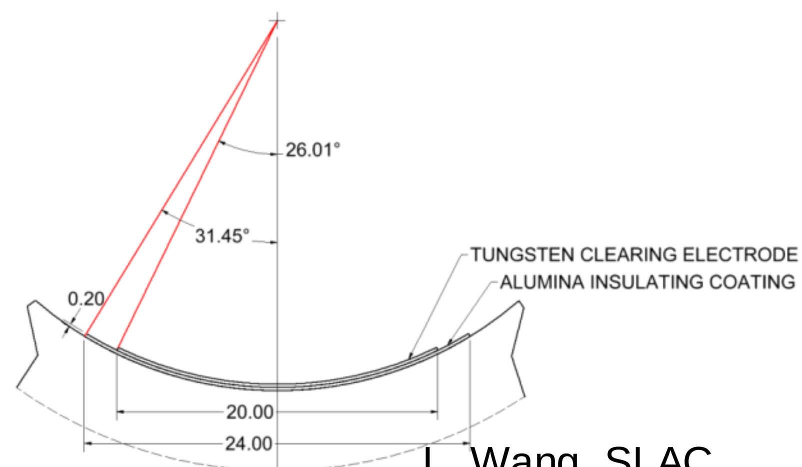
Evaluation of Electron cloud in Wiggler Chamber with Clearing Electrode

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





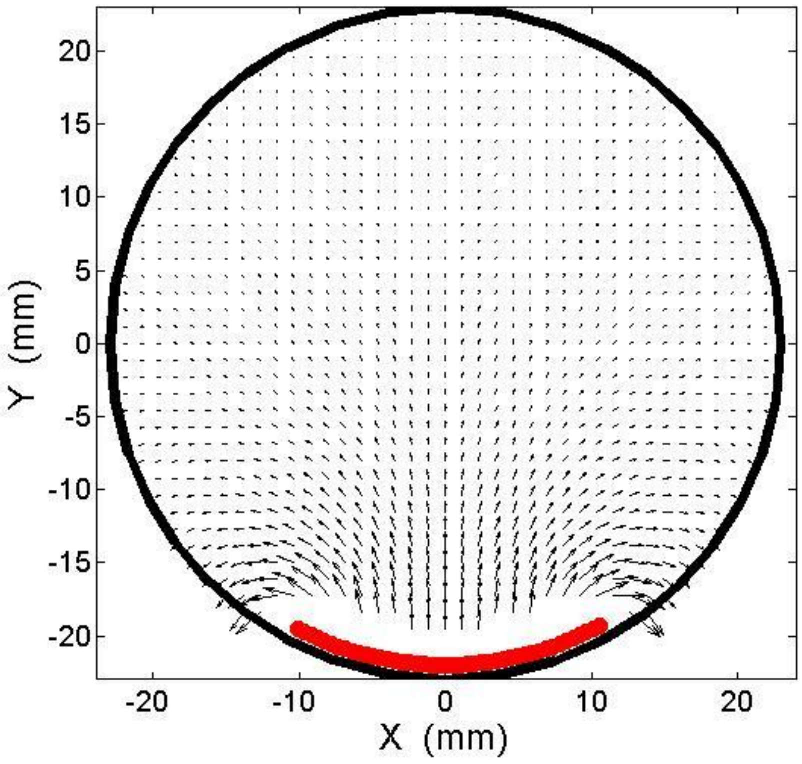
Design Joe Conway – Cornell U.

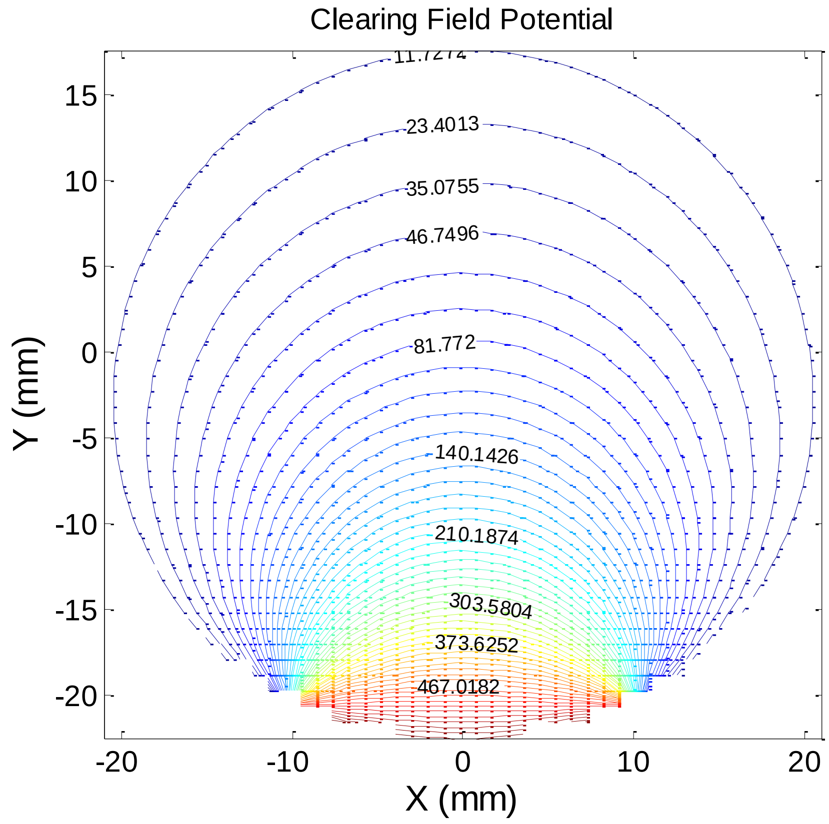


L. Wang, SLAC

Clearing electrode in wiggler magnet

Modeling of clearing electrode: round chamber is used

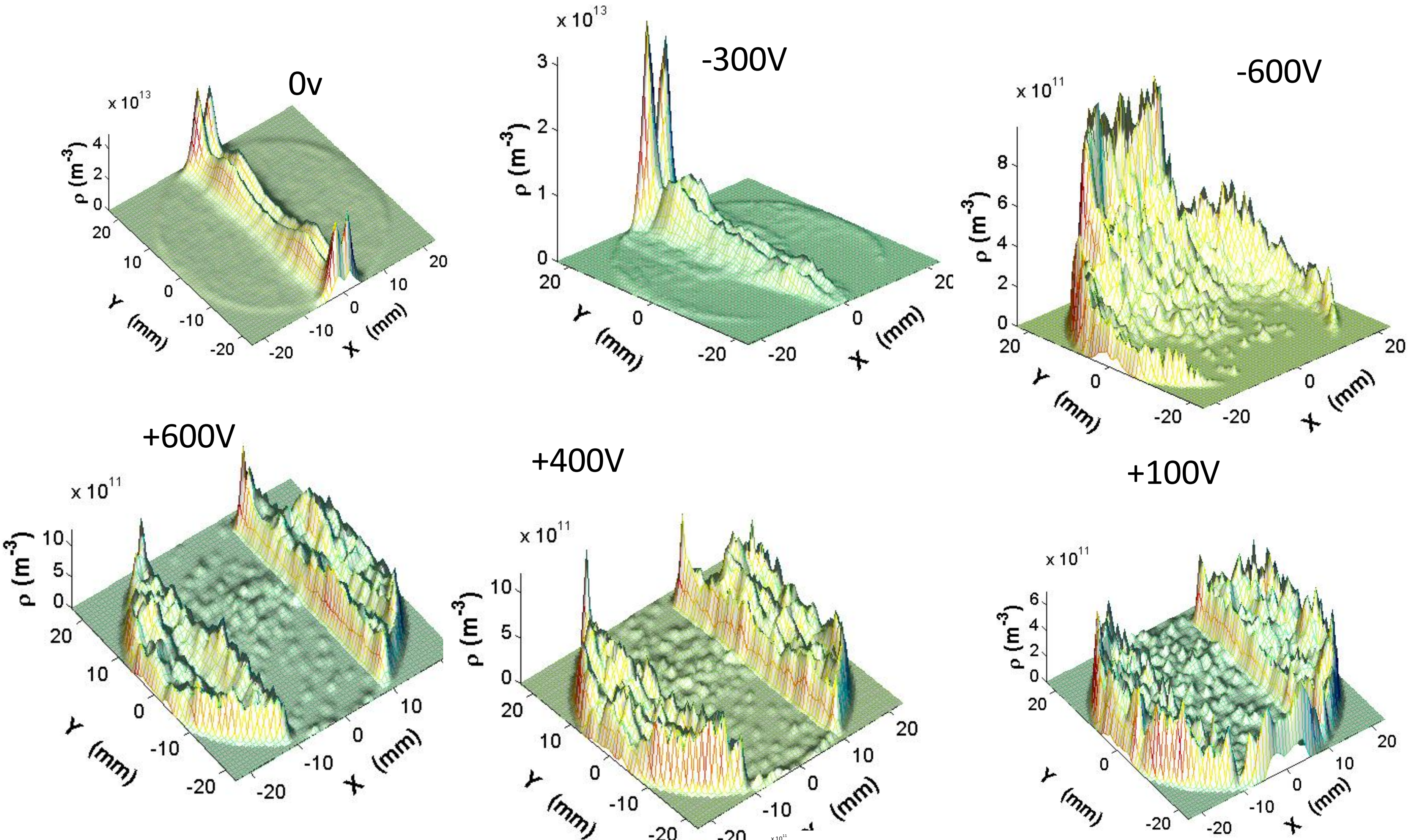


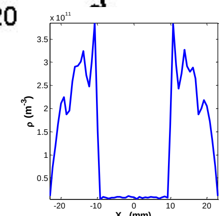


Clearing Field (left) & potential (right)

L. Wang, SLAC

Electrodes with negative (above) or positive (below) potential





L. Wang, SLAC

With positive potential

- ❑Electrodes with a positive voltages (relative to the ground, which is the chamber here) is very effective
- ❑100Volts is good enough, even better! There are no much difference for a voltage ranges from 300Volts ~600Volts
- ❑Note there is only a few macro-particles near the beam, therefore, the density near the beam is very noisy. The density see by the positron beam is below 1.0e10/m^3, although the average density is below 1.0e10/m^3 level.

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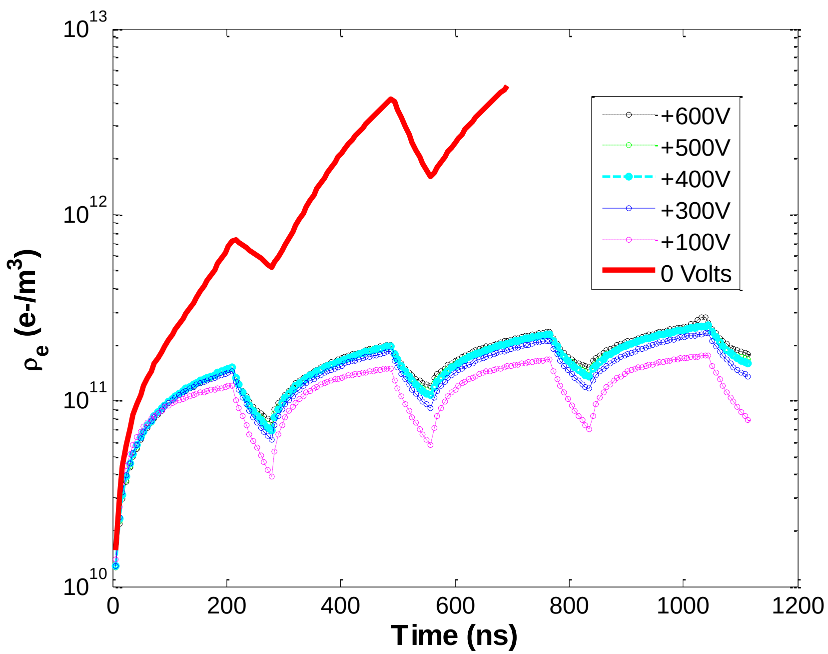
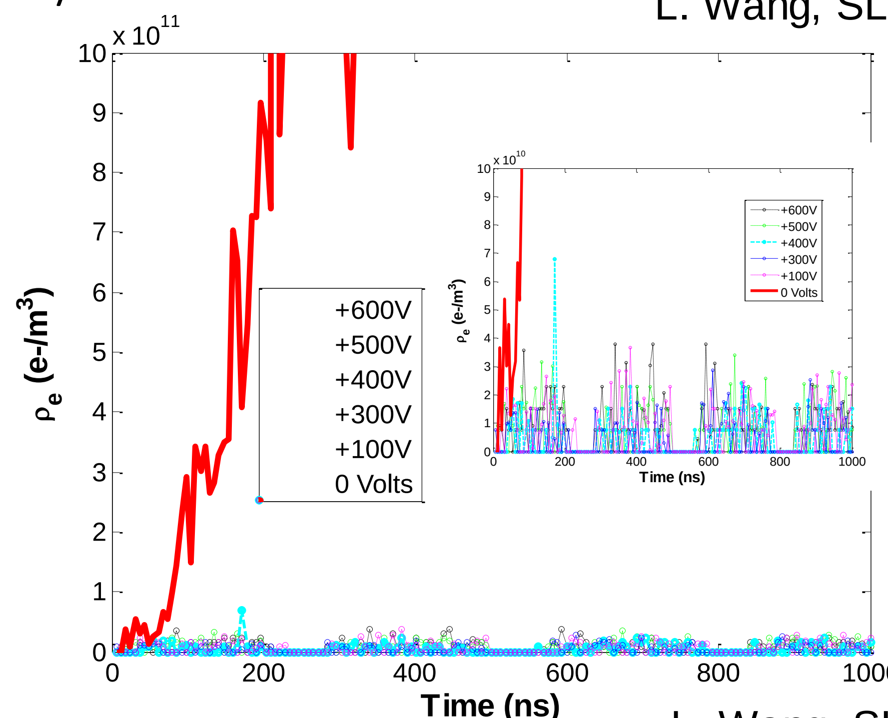


Average e-cloud density



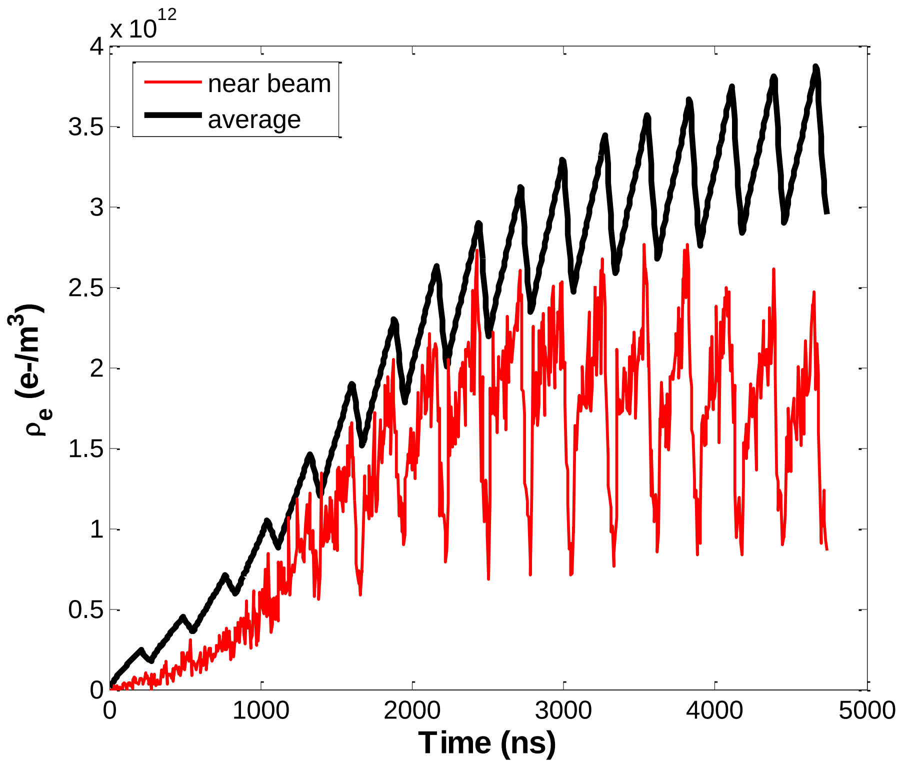
L. Wang, SLAC

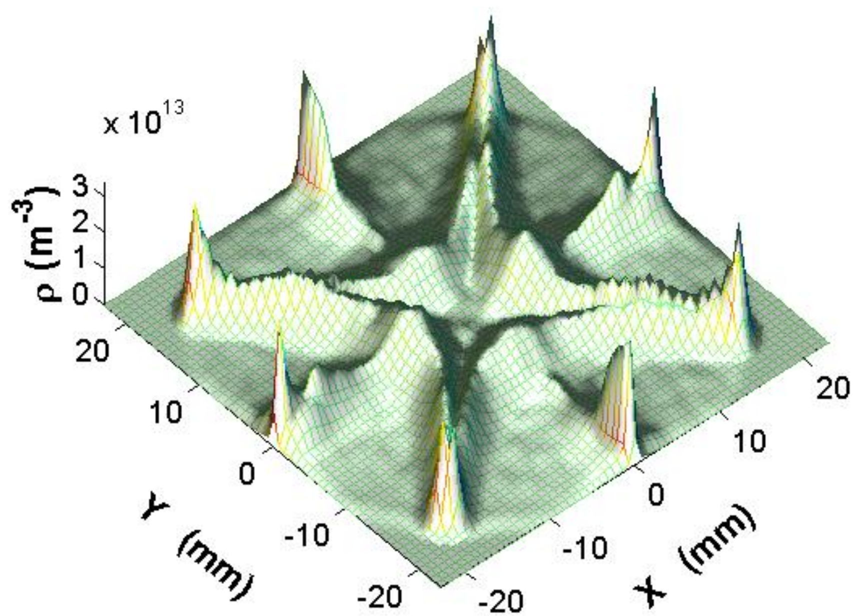
e-cloud density near the beam

Build-up in quadrupoles of wiggler region

Slow build-up due to mirror field trapping, the density is not low due to trapping even with a low sey of 1.0

Note: The simulated central density is in agreement wrt previous ECLOUD simulations (J. Crittenden, Cornell U.)





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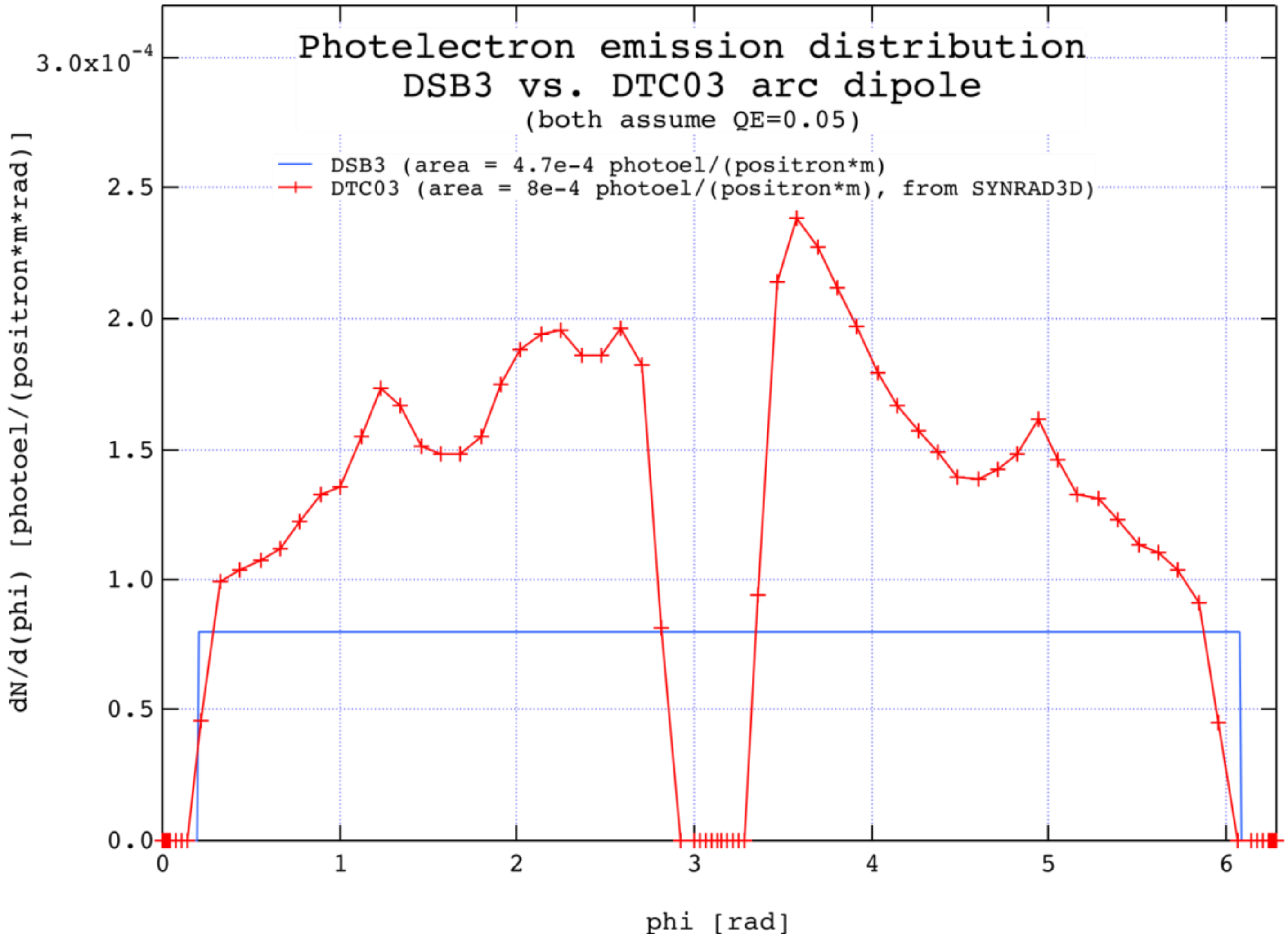
Arc Bend: Photoelectron emission distribution along the perimeter of the chamber cross section



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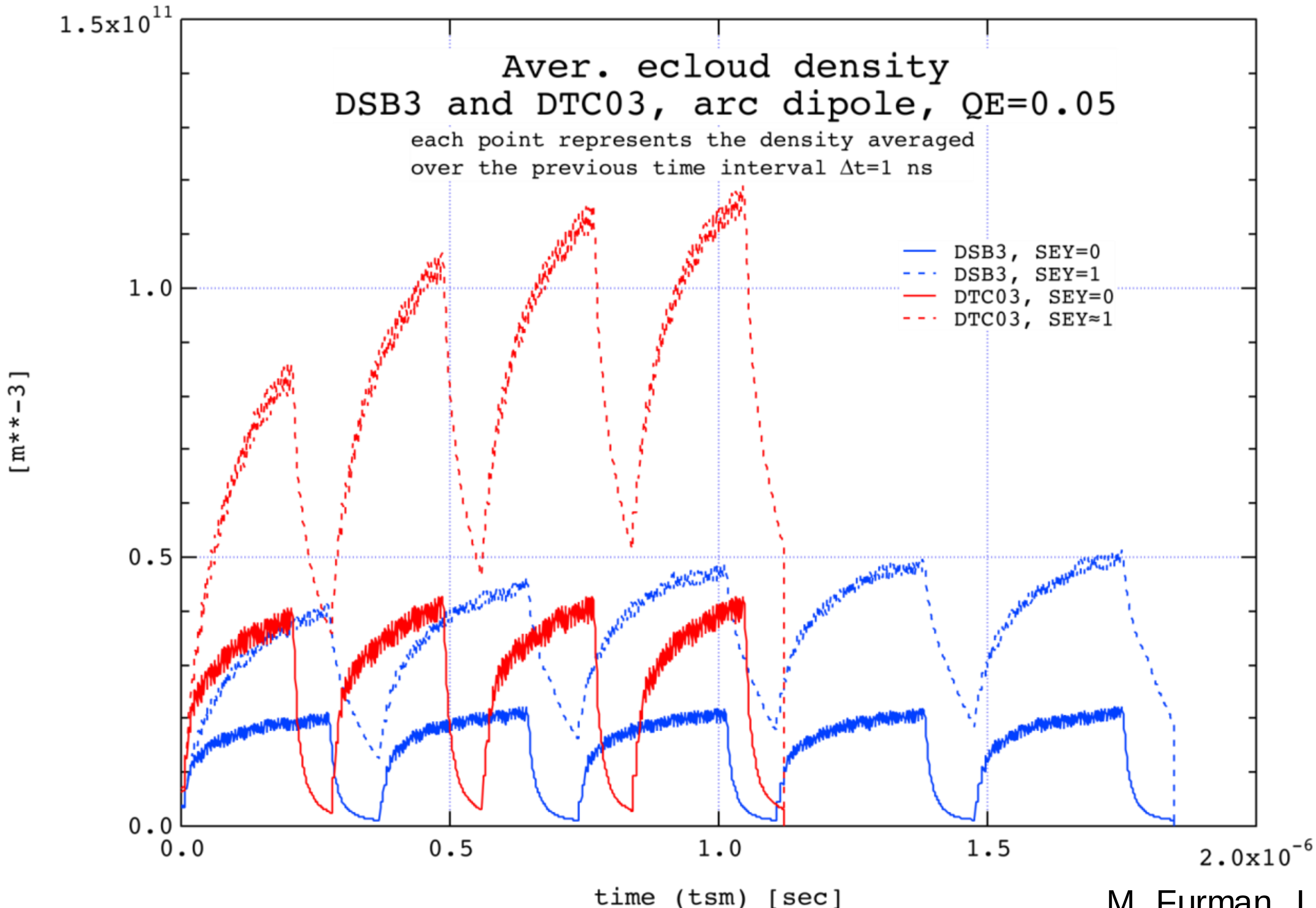
Bends: Overall average EC density: all cases (QE=0.05)



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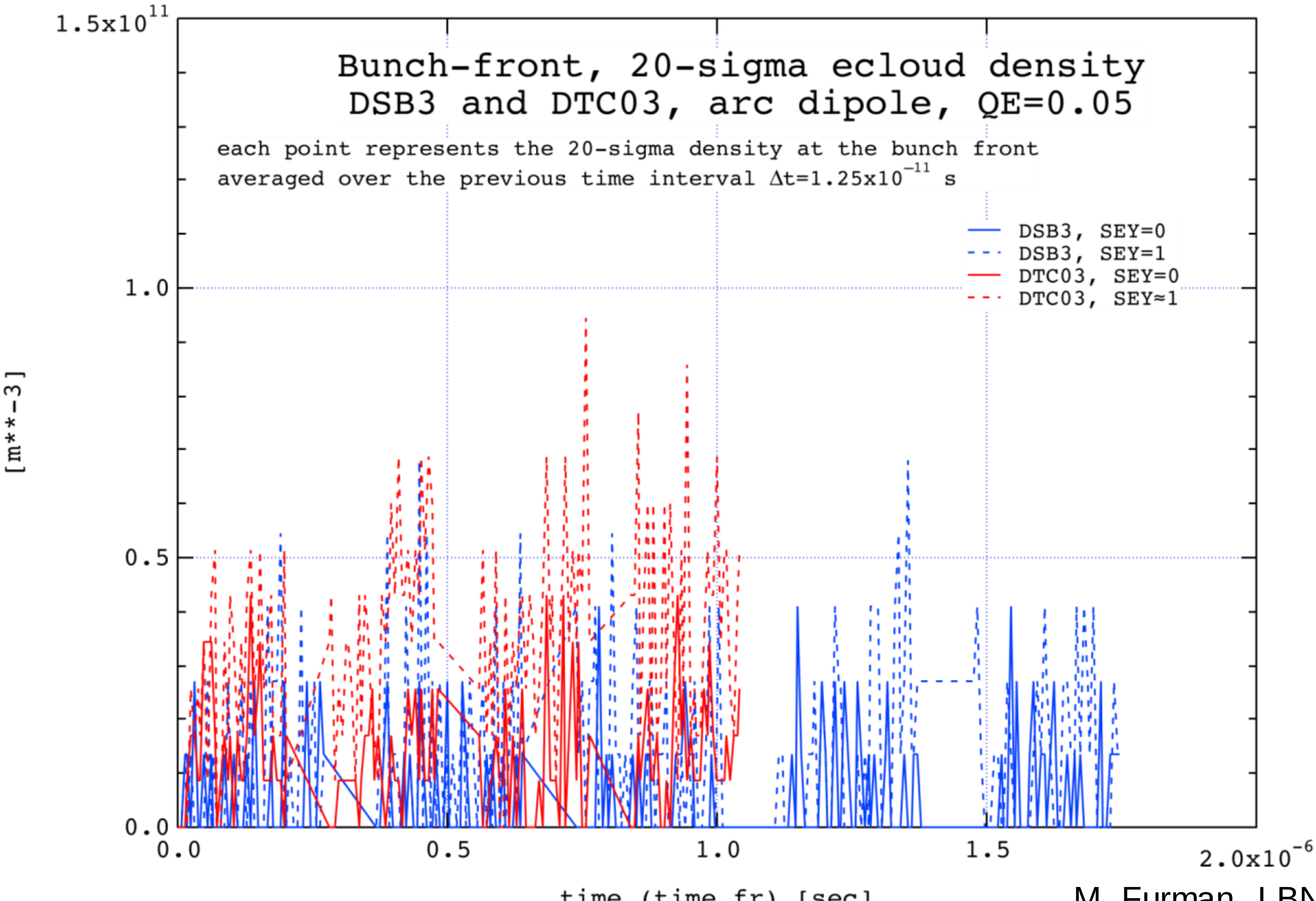
Bunch-front 20-sigma EC density
(QE=0.05)



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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**

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Next Steps to complete evaluation

- NOTE: so far, the ring-average cloud density is $< 4 \times 10^{10}$ e/m^3 (a factor 3 lower than the evaluated instability threshold in 2010 ...)

Next steps:

1) Include surface grooves in bends
2) Evaluate beam stability by simulations using electron cloud densities from build-up simulations.

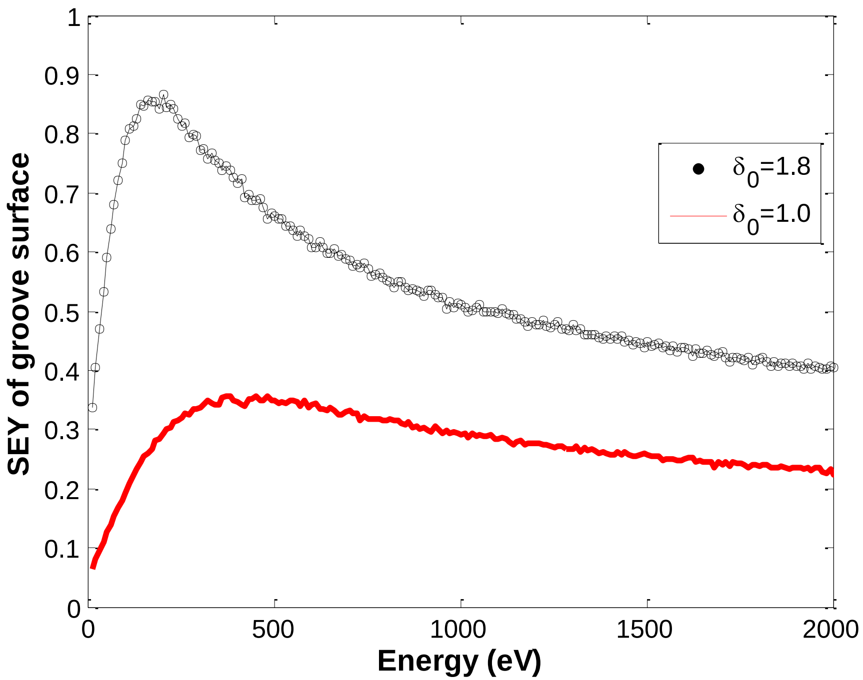
- Instability simulations: we are finalizing the parameters for simulations with very flat beams ($R = \sigma x/\sigma y \sim 100$)

Summary

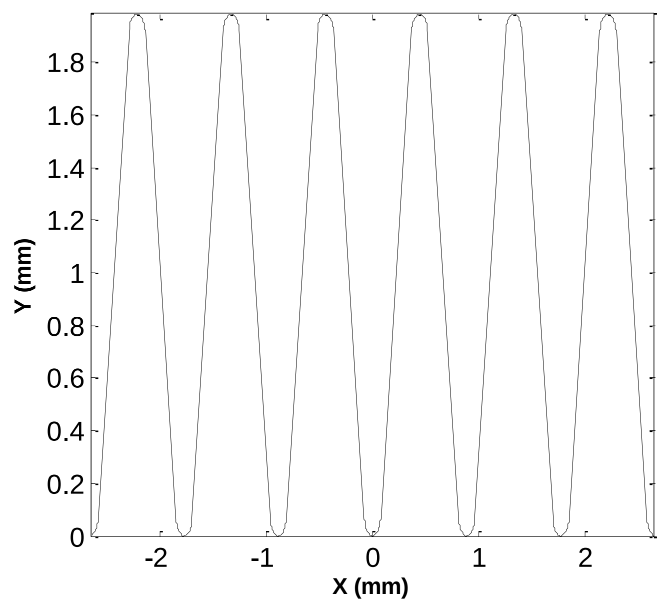
- Evaluation of the electron cloud effect in the ILC DR with implemented technical mitigations:
- Evaluated photon rates and distributions with newly developed 3D code.
- Electron cloud density in all drifts with solenoid ~ 0.
- Evaluated cloud density in quadrupoles and sextupoles in whole ring.
- Evaluated cloud density in arc bends.
- Evaluated cloud density in wigglers.
- Coming: grooves and instability evaluations.
- News: Cloud density already promisingly low.
- Concern: incoherent emittance growth is possible even at very low cloud density (more about it soon)

SEY of Grooved Surface in Dipole magnet(b=2.28kG)

1st case: Sey0=1.0, emax=570eV; (Processed TiN);
2nd case: Sey0=1.8, emax=250eV; (Un-processed TiN ,before installation in CesrTA)



Simulated SEY of Grooved Surface



Groove shape used in simulation

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Build-Up Simulations 3.2 km DR

Electron cloud build-up simulation parameters:

	Section	Vacuum chamber radius (from RDR)	Antechamber full height	Beam sizes $\sigma x,\sigma y$ (μm)	Surface + mitigation	peak SEY
arcs	Arc Dipole	25 mm	10 mm	215, 6.9	TiN + Grooves	**1**
arcs	Arc Quadrupole	25 mm	10 mm	290, 6	TiN	**1**
arcs	Arc Sextupole	25 mm	10 mm	290, 6	TiN	**1**
arcs	Arc Drift	25 mm	10 mm	290, 6	TiN + solenoid	**1**
straights	Quadrupole in straigth	25 mm	none	110, 6.4	TiN	**1.2**
straights	Drift in straigth	25 mm	none	110, 6.4	TiN + solenoid	**1.2**
wiggler	Wigglers	23 mm	20 mm	80, 5.5	Cu + clearing electrodes	**1.22**
wiggler	Quadrupole in wiggler region	23 mm	20 mm	80, 5.5	TiN	**1**
wiggler	Drift in wiggler region	23 mm	20 mm	80, 5.5	TiN + solenoid	**1**

Fill pattern

Damping Ring Fill Patterns			
			KCS
Circumference		m	3239
Harmonic number	h		7022
RF frequency	f_{DR}	MHz	650
RF bucket length		ns	1.54E-09
Bunch separation in buckets	n_b		4
Bunch spacing	n_b/f_{DR}	ns	**6.15**
Periods	p		19
Trains per period			2
Trains in total			39
Bunches *	N_{bunch}		1312
Fill Pattern (1 period)	gap (number of empty buckets)		**45**
	train (number of bunches)		**34**
	gap		**49**
	train		**34**
	gap		
	train		
	gap		
	train		

Remark: Filling scheme for 2 positron rings assumes that 29-30 consequtive bunches from ring 1 are extracted, then from ring 2
Fill pattern: "gap" gives number of empty RF buckets, "train" gives number of filled bunches in train
* The maximum number of bunches for KCS and FP upgrade (e+) is 1326 and 1327 respectively but the nominal value is 1312: the last train has a few missing bunches

Fitting data with POSINST model to SEY of "processed TiN" coating

Fitting of measured SEY curves from CesrTA in-situ system

- Three parameters for "true secondaries" component of SEY were varied: $\hat{\delta}_{ts}$, $\hat{E}_{ts}$, s
- Other SEY parameters were kept fixed.
- Based only on SEY measurement for middle point at 25°. Data points with incident energy ≤ 0 were omitted.
- Tried for good fit at medium and high energies; did not worry about low energies.
- For TiN Sample #1, fitted "after N_2" measurements; for TiN Sample #2, fitted "before contamination" measurements.

Material	Fitting
Al	each of 3 samples
TiN	each of 2 samples
Amorphous C	1 fit for all data

"Fit 3"

Material	Starting parameters
Al	JRC "best fit" of RFA data
TiN	JRC "baseline" for coated
Amorphous C	JRC "baseline" for coated

Fit 3 typically undershoots the data at low energies.

"Fit 4": Table and Comparison Plots on Next Slides

- Starting point for all cases (Al, TiN, and amorphous C): "default" parameters for Al from GFD.
- Fit 4 typically better at low energy than Fit 3 (for Al and TiN, at least); typically overshoots the data at low energy.

POSINST SEY parameters: default vs Fit 4

Param.	Def.	Fit: Al	Fit: TiN	Fit: aC
$\hat{\delta}_{ts}$	1.8	1.21, 1.33, 1.58	0.73, 0.95	0.76
$\hat{E}_{ts}$	310 eV	270, 280, 290 eV	370, 330 eV	300 eV
s	1.54	1.49, 1.55, 1.58	1.32, 1.25	1.77
(t_1, t_2)	(0.66, 0.8)			
(t_3, t_4)	(0.7, 1)			
$\hat{P}_e$	0.5			
$P_e(\infty)$	0.01902			
$\hat{E}_e$	0			
W	15.0 eV			
p	1			
(e_1, e_2)	(0.26, 2)			
$P_r(\infty)$	0.1902			
E_r	0.041 eV			
r	2			
(r_1, r_2)	(0.26, 2)			

The fitted parameters for the horizontal sample are:

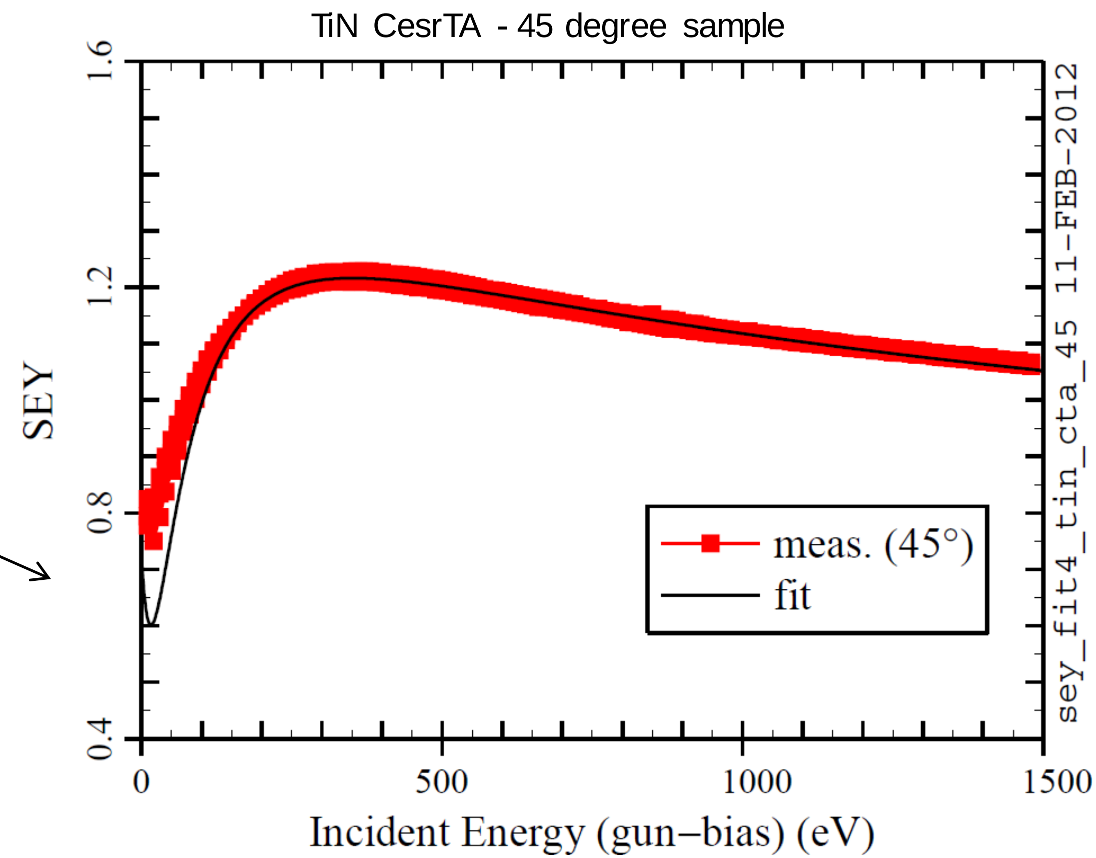
delta hat ts = 0.73
E hat ts = 370 eV
s = 1.32

and the fitted parameters for the 45 degree sample are:

delta hat ts = 0.95
E hat ts = 330 eV
s = 1.25

Walter Hartung Cornell U.

SEY for non-fully processed TiN film coating



Fitting the low energy part of the spectrum might be improved …

TiN with peak SEY~1.2 to simulate regions with less conditioning only: i.e. drift and quadrupole in straights

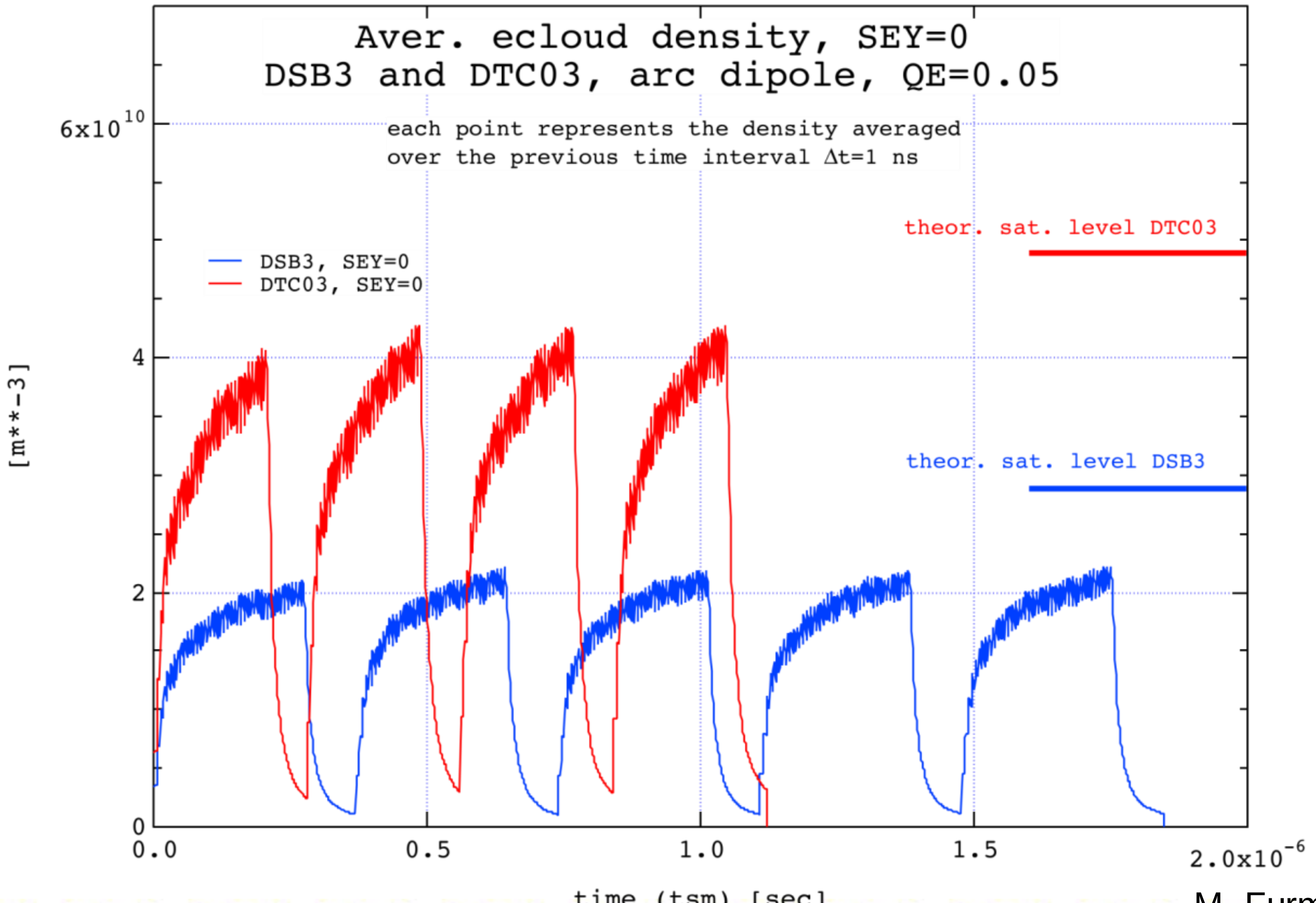
(Note: drift and quadrupole in wiggler regions should use instead TiN with SEY~1).

Simulation parameters

- Peak sey =1.2
- Energy at peak sey=250eV
- Photon reflectivity=100%
- Photon flux=0.198ph/m/positron
- Sigx/sigy of beam=80/5.5um
- Bunch population=2e10
- Peak wiggler field=2.1Tesla
- Bunch spacing : 6.15ns
- Beam filling pattern: 34bunches/per train followed by a gap of 45 rf bucket
- Electrode Voltage: varies from -600V to +600V

Bends: Overall average EC density for SEY=0

(SEY=0, QE=0.05)



M. Furman, LBNL

Bends: Central EC density
(QE=0.05)