Electron Cloud Issues for the 3.2km Positron Damping Ring

Mark Palmer (Cornell University)
GDE

January 18, 2011

ILC Baseline Assessment Workshop 2
SLAC

EC Working Group Tasks & Status

Reduced DR Circumference – ILC Low Power Scenario

Evaluation of reducing the DR circumference to one-half that specified for the RDR

Corresponding reduction in bunch count to one-half of the RDR specification

☑

March 2010

Baseline Mitigation Recommendation

Evaluation of EC Mitigation R&D Results

Identify the most promising mitigation schemes

Identify candidates and issues for further R&D

☑

October 2010

Restored Bunch Count

Evaluation of options to restore the RDR bunch count for *high luminosity* operation

Identify ***safe*** path to restore bunch count ✓

Evaluate performance limits in low power configuration

Under Evaluation

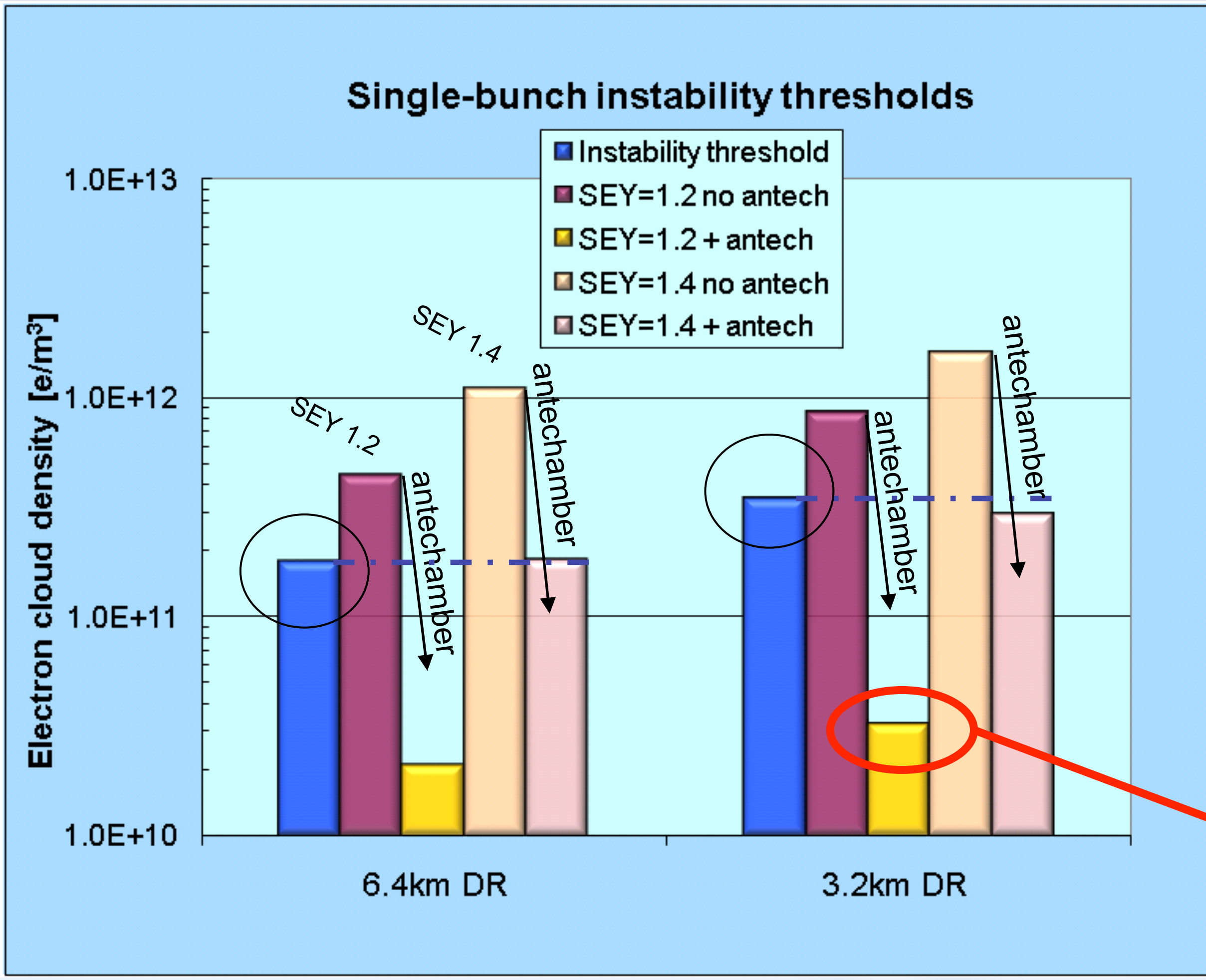
Participating Institutions:
ANL, Cornell, INFN, KEK, LBNL, SLAC

Circumference Evaluation I

	DCO4 High Power 5Hz	SB2009 Low P. 5Hz
Particle	e^+/e^-	e^+/e^-
Circumference (m)	6476	3238
N bunches	2610	1305
N part./bunch	2×10^{10}	2×10^{10}
Damping time τ_x (ms)	21	24
Emittance ε_x (nm)	0.44	0.53
Emittance ε_y (pm)	2	2
Energy loss/turn (MeV)	10.2	4.5
Energy spread	1.3×10^{-3}	1.2×10^{-3}
Momentum compaction	1.6×10^{-4}	1.3×10^{-4}
B wiggler (T)	1.6	1.6
Wiggler period (m)	0.4	0.4
Wiggler length (m)	2.45	2.45
Total wiggler length (m)	216	78
Number of wigglers	88	32
Bunch length (mm)	6	6
RF Voltage (MV)	21	7.5

Circumference change with reduced bunch count maintains beam current and bunch spacing
⇨ expect minimal changes in EC instability thresholds

Comparison of 6.4 and 3.2 km DR Options



Summer 2010 Evaluation

- Comparison of Single Bunch EC Instability Thresholds for:
  - 6.4km ring with 2600 bunches
  - 3.2km ring with 1300 bunches
  - ⇨ same average current
- Both ring configurations exhibit similar performance

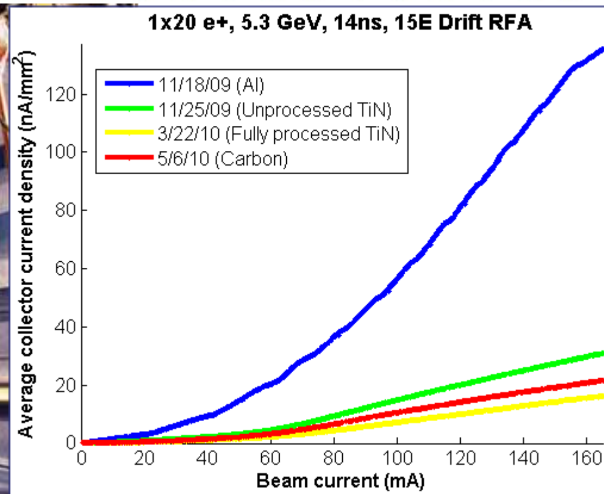
⇨ 3.2km ring (*low current option*) is an **acceptable** baseline design choice

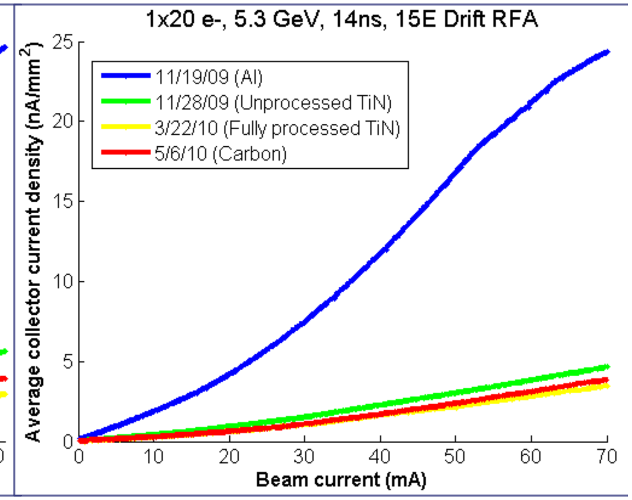
S. Guiducci, M. Palmer, M. Pivi, J. Urakawa on behalf of the ILC DR Electron Cloud Working Group

CESRTA Mitigation Tests

	Drift	Quad	Dipole	Wiggler	VC Fab
Al	✓	✓	✓		CU, SLAC
Cu	✓			✓	CU, KEK, LBNL, SLAC
TiN on Al	✓	✓	✓		CU, SLAC
TiN on Cu	✓			✓	CU, KEK, LBNL, SLAC
Amorphous C on Al	✓				CERN, CU
Diamond-like C on Al	1/2011				CU, KEK
NEG on SS	✓				CU
New NEG Formulations	Phase II ?				Cockroft, CU
Solenoid Windings	✓				CU
Fins w/TiN on Al	✓				SLAC
Triangular Grooves on Cu				✓	CU, KEK, LBNL, SLAC
Triangular Grooves w/TiN on Al		Phase II ?	✓		CU, SLAC
Triangular Grooves w/TiN on Cu				1/2011	CU, KEK, LBNL, SLAC
Clearing Electrode		Phase II ?		✓	CU, KEK, LBNL, SLAC

EC Mitigation Options I (Drift Studies)

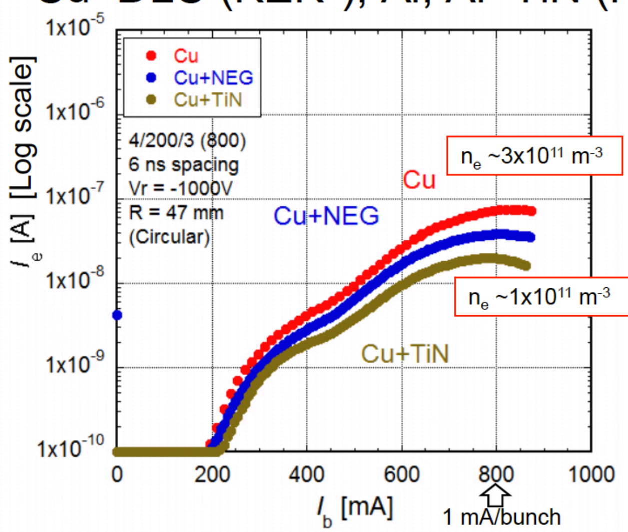


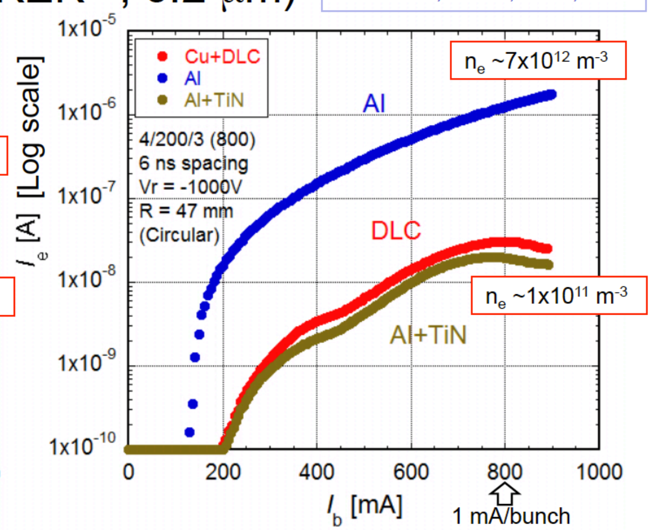


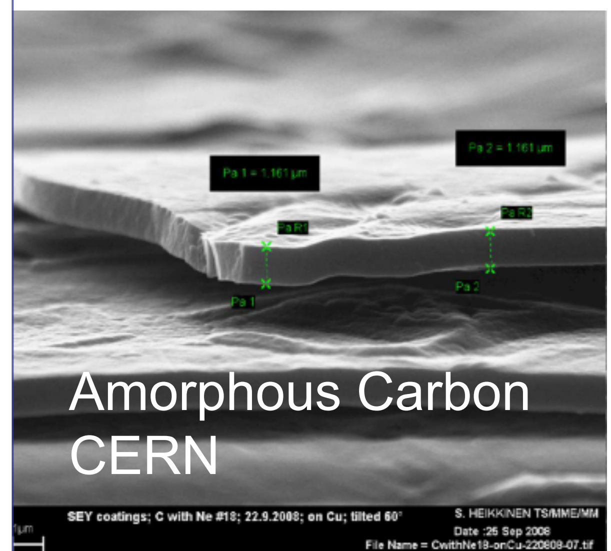
- Straight section (contd.) [~2009]
  - Drift space, Photons= 3×10^{12} ph/s/m/mA
- Cu+DLC (KEK*), Al, Al+TiN (KEK**, 0.2 μm)

KEK

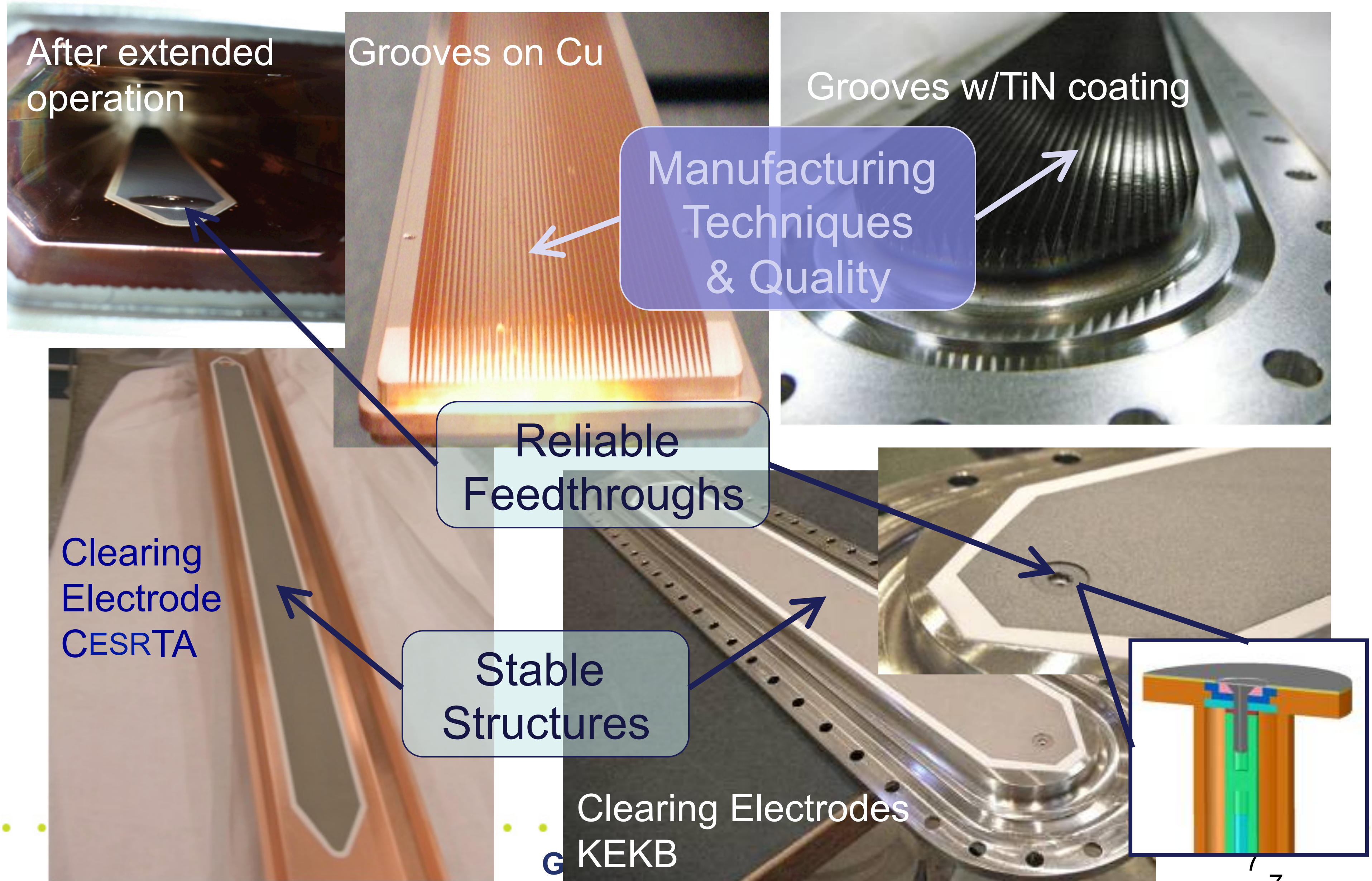
*S.Kato, AEC'09, CERN, 2009
**K. Shibata, AEC'09, CERN, 2009







EC Mitigation Options II



EC Mitigation Evaluation – 4 Criteria

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**
  - **Ex: No long-term durability study for a-C in synchrotron radiation environment**
- Reliability
  - **Durability of mitigation**
  - **Ex: Damage of clearing electrode feed-through**
  - **Ex: Failure of clearing electrode PS**

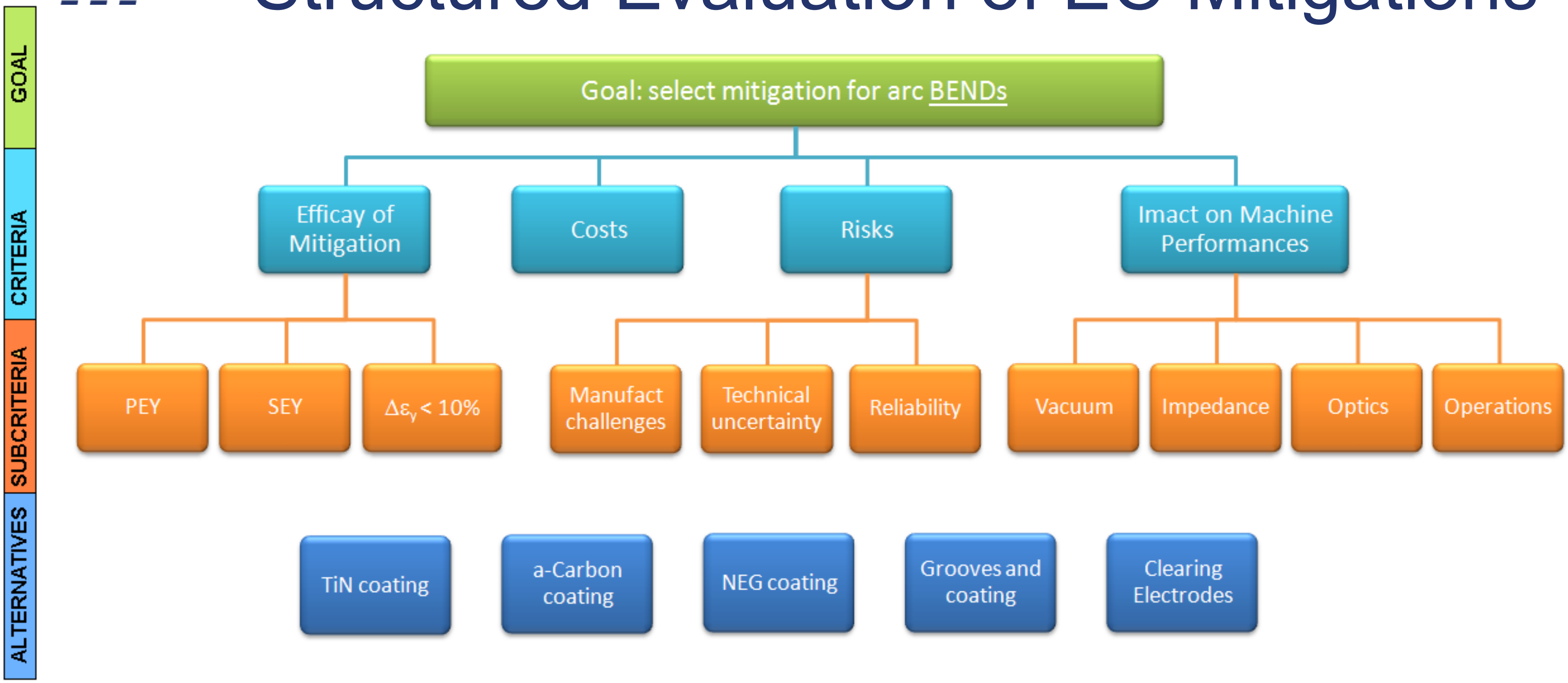
Cost

- 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: Grooves ⇨ added surface for pumping**
  - **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**
  - **Ex: Mitigation availability**
  - **Ex: Replacement time for damaged components**

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**

Evaluation

- Mitigations rated on a scale from -4 (poor) to 4 (good) for each criteria and overall rankings evaluated
- Working group plus additional EC experts carried out evaluations at the conclusion of ECLOUD10 on Oct. 13, 2010.
- Final evaluation included detailed discussion to confirm recommendation in addition to the numerical rankings
- Need to pursue an aggressive mitigation plan causes a heavy weighting on efficacy
  - **Baseline targets $\delta_{max} \leq 1.2$**
  - **Move to higher beam current will require even better performance (will return to this later)**

Drift Region Evaluation

Evaluation of mitigations in DRIFT regions: Working Group rating				
	Efficacy (0.53)	Costs (0.05)	Risks (0.21)	Impact on machine (0.21)
Al	-4	1	1	0
TiN coating	2	0	1	0
C coating	2	0	-1	0
NEG coating	1	1	0	2
Grooves & coating	3	-1	0	-2

⇨ **TiN is the recommended baseline mitigation**

- Good efficacy
- Risks for its implementation are the lowest
- No significant impact on other aspects of machine performance

⇨ **Solenoids recommended as an additional mitigation**

- Maximize efficacy – particularly important for higher current operation

⇨ **NEG coating is recommended as the alternate mitigation**

- Somewhat lower mitigation efficacy
- Advantage of providing vacuum pumping in the long straights

Dipole Region Evaluation

Evaluation of mitigations in BEND magnets: Working Group rating				
	Efficacy (0.53)	Costs (0.05)	Risks (0.21)	Impact on machine (0.21)
Al (reference)	-4	1	1	0
TiN coating	1	0	1	0
C coating	1	0	-1	0
NEG coating	1	-1	0	1
Grooves & coating	3	-1	-1	-1
Clearing Electrodes	4	-3	-2	-2

⇨ **Grooves with TiN coating are recommended as the baseline mitigation**

- Very good efficacy

⇨ **Antechambers recommended as additional mitigation**

- Important for photoelectron control

⇨ **TiN coating without grooves recommended as alternate**

- Clearing electrodes offer best efficacy but have risks and machine impact
- Further R&D could result in an updated choice in this critical region

Wiggler Region Evaluation

Evaluation of mitigations in WIGGLER region: Working Group rating				
	Efficacy (0.53)	Costs (0.05)	Risks (0.21)	Impact on machine (0.21)
Al (reference)	-4	1	-1	0
Cu	0	0	1	0
TiN coating	1	0	-1	0
C coating	1	0	-2	0
Grooves & coating	3	-1	-1	-2
Clearing Electrodes	4	-2	-1	-1

⇨ **Clearing Electrodes deposited via thermal spray on Cu chambers are the recommended baseline mitigation**

- Best efficacy (required in this region)
- Risks and impact are limited due to having fewer affected chambers

⇨ **Antechambers recommended as additional mitigation**

- Important for photoelectron control and for power removal

⇨ **Grooves with TiN coating recommended as the alternate mitigation scheme**

Quadrupole Region Evaluation

Evaluation of mitigations in QUAD regions: Working Group rating				
	Efficacy (0.53)	Costs (0.05)	Risks (0.21)	Impact on machine (0.21)
Al (reference)	-4	1	1	0
TiN coating	1	0	1	0
C coating	1	0	-1	0
NEG coating	0	-1	-1	0
Grooves & coating	3	-1	-2	-2
Clearing Electrodes	4	-3	-2	-3

⇨ TiN is the recommended baseline mitigation

- Good efficacy
- Risks for its implementation are the lowest
- No significant impact on other aspects of machine performance

Concerns about long-term build-up in the quadrupoles

- Requires particularly effective EC suppression ⇨ either grooves or electrodes
- Further R&D required to validate either option

Summary of Mitigation Plan

Mitigation Evaluation conducted at satellite meeting of ECLOUD`10
(October 13, 2010, Cornell University)

EC 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

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

Further Comments

- A concern for meeting the emittance specifications is a steady incoherent emittance growth at low electron cloud densities below the threshold for the head-tail instability.
- Recent simulations and CesrTA measurements suggest that this effect may be significant and are leading to a re-evaluation of the acceptable electron densities.
- While considerable work remains to precisely quantify this issue, initial results suggest that the acceptable cloud densities may need to be lowered by a factor of several.
- This further emphasizes the need to employ the most effective mitigation techniques, consistent with risk and cost constraints, possible in each region of the ring.
- However, the present mitigation scheme is consistent with the performance requirements of the 3.2km ring design

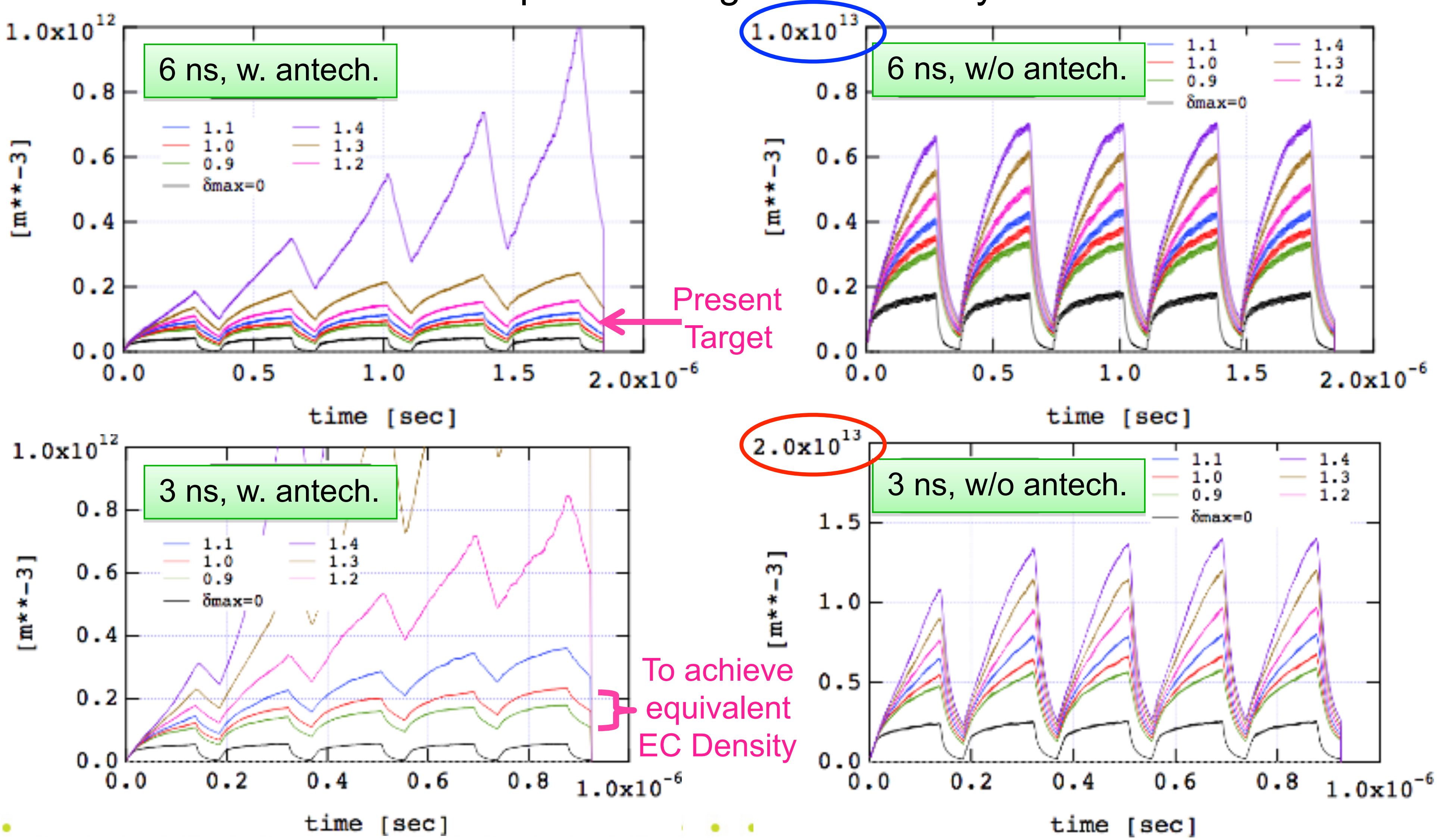
Restoration of Bunch Count

- Fall-back plan *(safe option)* is to add a second positron damping ring

- However, the EC working group is actively studying the possibility of 3ns bunch spacing in a single positron damping ring
  - **Achieving this goal requires pursuit of the most efficacious mitigation scheme**
  - **A look at the dipole region on the following slide…**

Dipole Region Evaluation (DSB3) for Possible High Current Operation

Space-averaged EC Density



Summary

- Preliminary recommendations for the EC mitigation scheme are in place
- The proposed plan is consistent with the choice of a 3.2km ring in the low power option
- The acceptable EC threshold to prevent emittance growth may depend significantly on issues that are still under investigation
  - **Possibility of incoherent emittance growth below the head-tail instability threshold *(continued experimental and simulation effort)***
  - **The effective photoelectron production rate *(improved simulations being prepared)***
  - ⇨ ***Warrants an aggressive EC mitigation plan***
- The possibility of restoring the high luminosity bunch count without resorting to an additional positron ring requires further evaluation ***and the most aggressive approach to the mitigation scheme.***
- ***Good News*** – we expect that an equivalent mitigation scheme will be tested in SuperKEKB prior to ILC construction