Low Emittance Beams

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Emittance is the phase space volume of a bunch

- Low emittance beams are essential to achieve
  - High luminosity in colliders –
    Collider luminosity scales inversely with beam emittance
  - Brilliant x-ray beams from storage rings, FELs, and ERLs
    - The single parameter that best characterizes the quality of an xray light source is the emittance of the particle beam. All fourth generation machines promise lower emittance than their predecessors.
- Theory predicts a minimum
  - For electron/positron beams circulating in a storage ring: theoretical minimum vertical emittance is the *quantum limit* (Quantum limit is nearly 100 X smaller than achieved so far in any machine)
  - For electron beams produced from a photo-cathode:
    the minimum is the thermal limit

Research goal is to demonstrate the minima and investigate the phenomena that manifest at low emittance

- Lower emittance and higher density limited by collective effects
  - Electron cloud effect
  - Fast Ion Instability
  - Intra-beam scattering
  - Space charge

Electron cloud

- B-factories (PEPII/KEK-B) limited by blowup of positron beam due to electron cloud

E-cloud will limit new machines including:

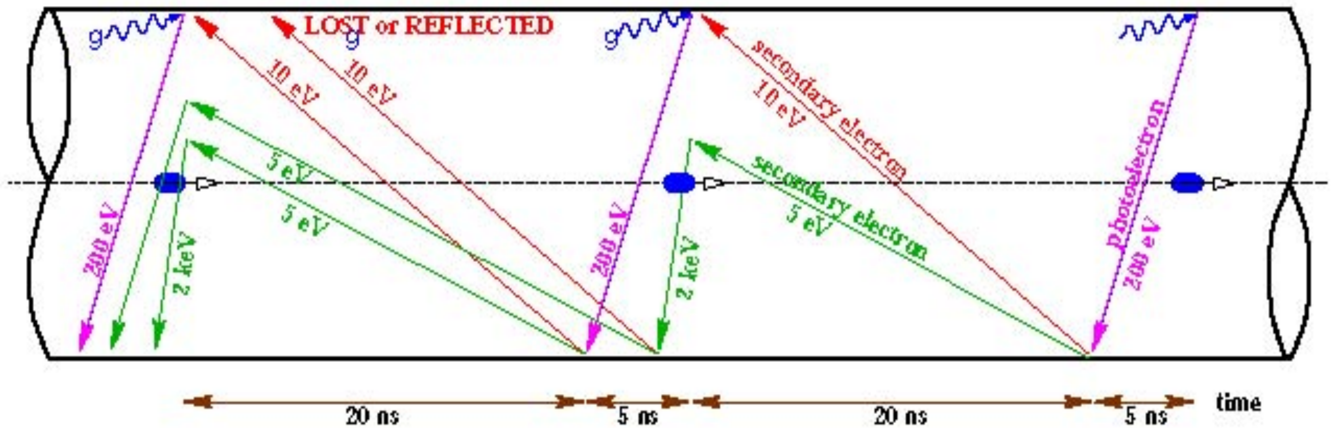
Super KEK-B, linear collider damping rings, high intensity proton accelerators (LHC, Project X)

CESR Test Accelerator (CesrTA)

- Mission to explore low emittance phenomena with CESR
  - Develop theory and methodology for minimizing emittance
  - Measure electron cloud growth
  - Develop electron cloud mitigations
  - Investigate dynamics of beam-cloud interaction in low emittance regime
  - Measure threshold for emittance growth
- Collaboration

SLAC,LBNL,Purdue U., KEK, CERN, Fermilab, INFN-LNF, Cockroft Inst., California Polytechnic Inst.

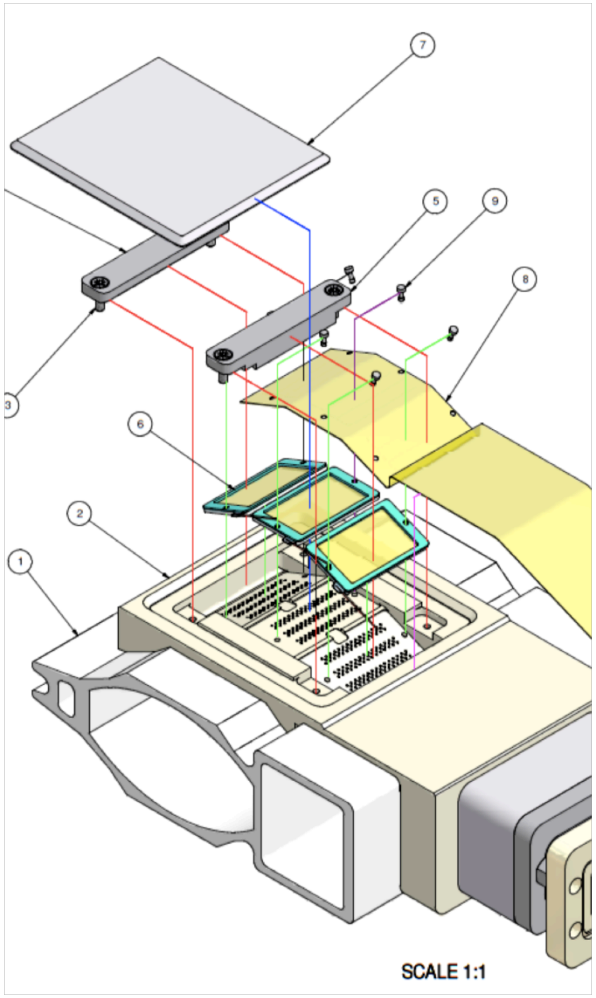
Electron Cloud

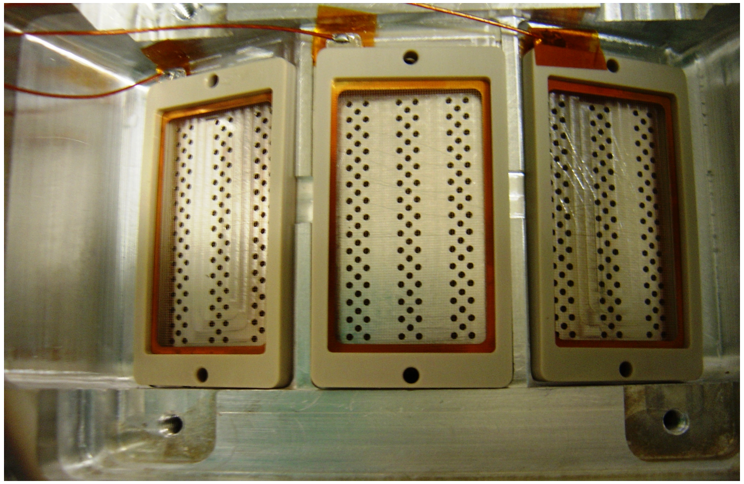


- Synchrotron radiation photons strike chamber walls emitting photo-electrons.
- Electrons are accelerated by the circulating positron bunches into the opposite wall, producing secondaries
- *Interaction of the positron beam with the accumulating cloud generates instabilities and dilutes vertical emittance*

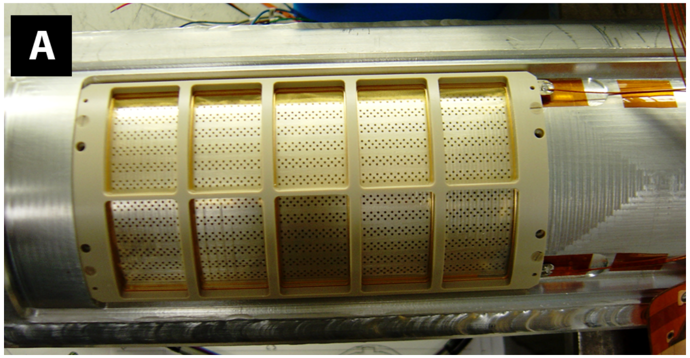
Electron Cloud Diagnostics

Retarding field analyzers (RFA) are used to measure local cloud density and energy spectrum





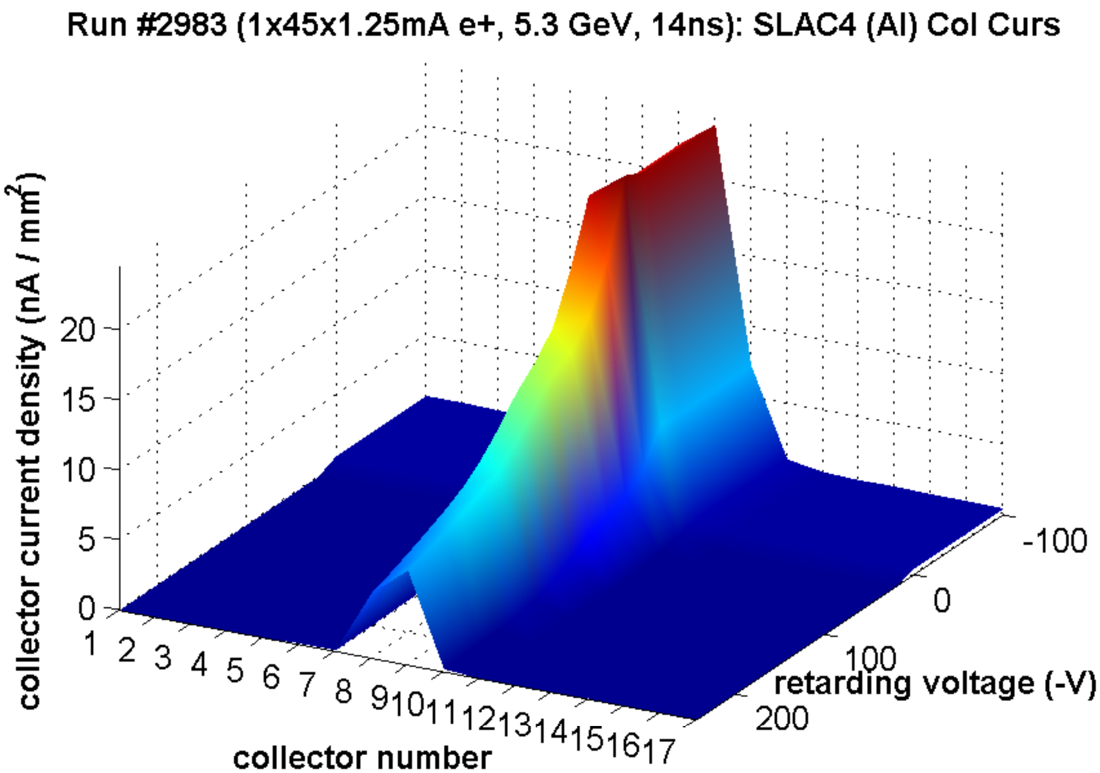
View of from outside vacuum chamber of dipole style RFA with 9 independent collectors. The fine mesh wire grid is in place (but transparent)



Quadrupole RFA

Retarding Field Analyzer (RFA)

Dipole RFA data with characteristic central peak

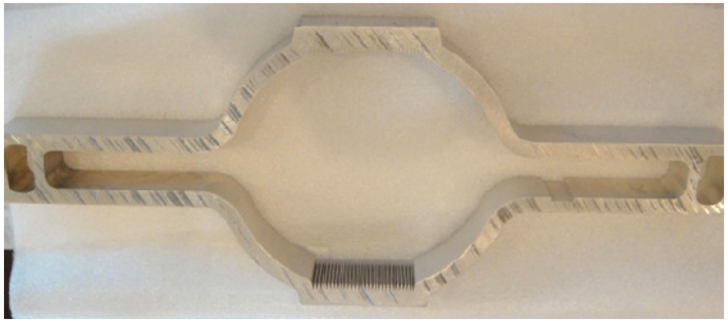


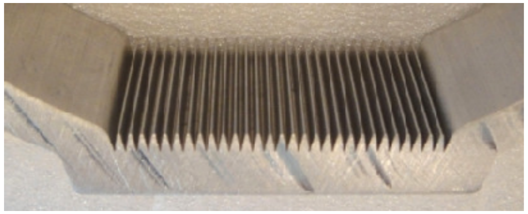
Aluminum chamber
45 bunches, 1.25mA/bunch
14ns spacing, 5.3GeV

Grad student Joe Calvey

Electron Cloud Mitigations

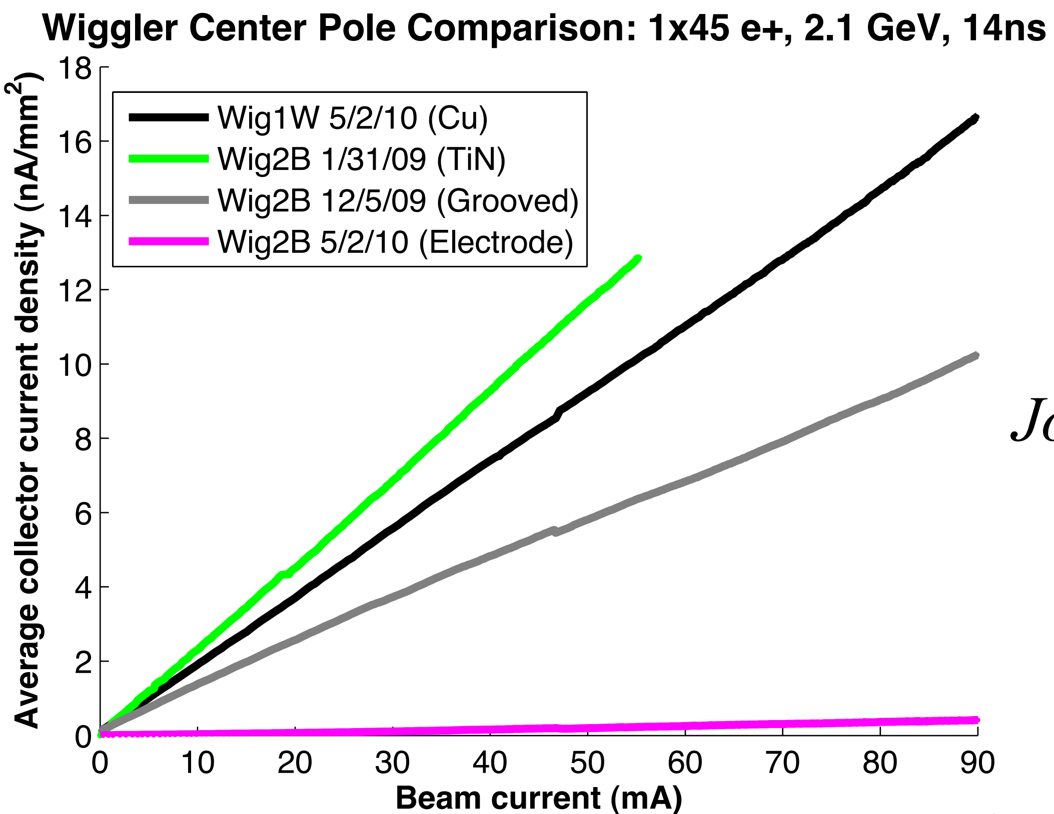
Dipole chamber with antechamber and grooves





Wiggler chamber with clearing electrode

Electron cloud mitigations in damping wiggler



Joe Calvey (grad student)

Other mitigations tested include: TiN, NEG, amorphous carbon, diamond like carbon, on Cu, Al, SS

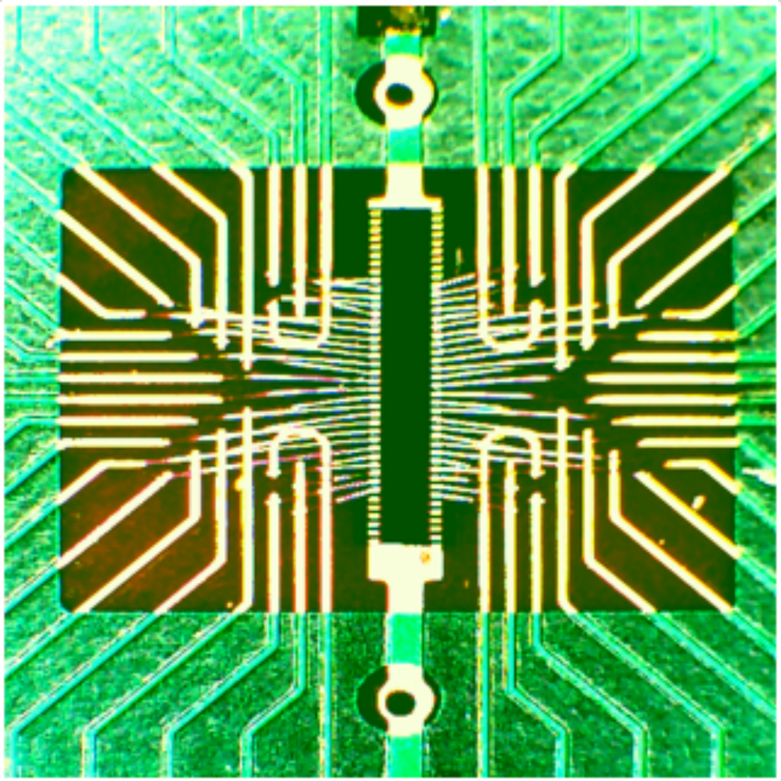
Electron cloud induced emittance growth

- What is the effect of the electron cloud ?
- What is the threshold for beam blowup ?

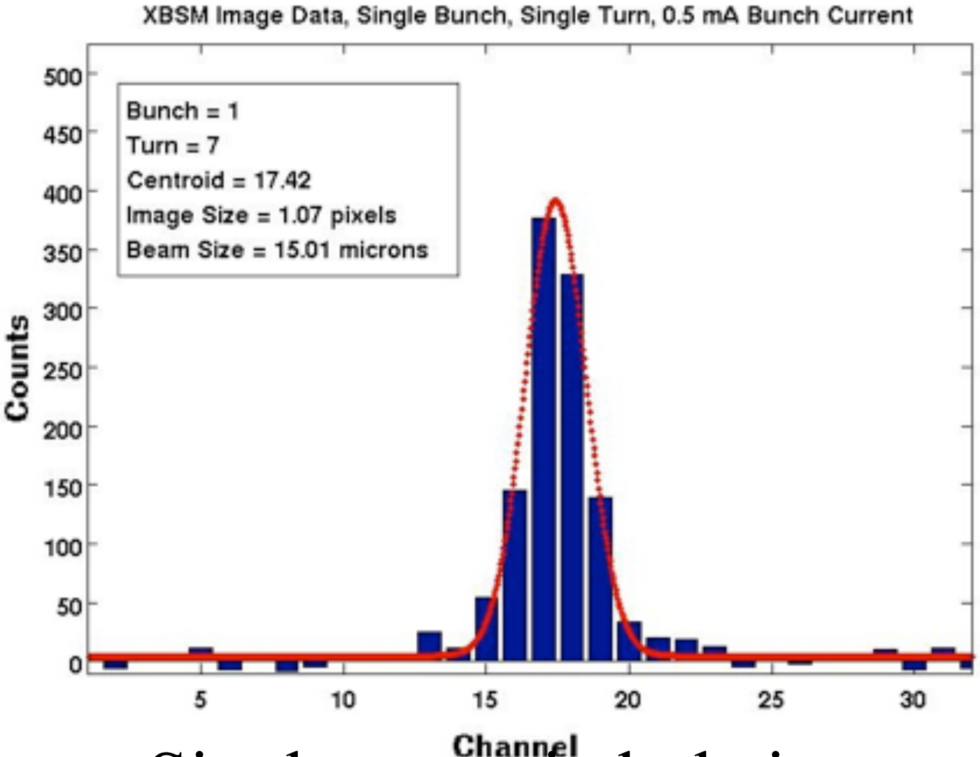
  (What is the tolerable cloud density ?)

To answer these questions we need to measure vertical emittance of individual bunches

Xray beam size monitor



32 channel photodiode array - 50μm pitch
Single bunch-single pass – unique to CesrTA



Single pass pin hole image
$\sigma \sim 20\mu m$

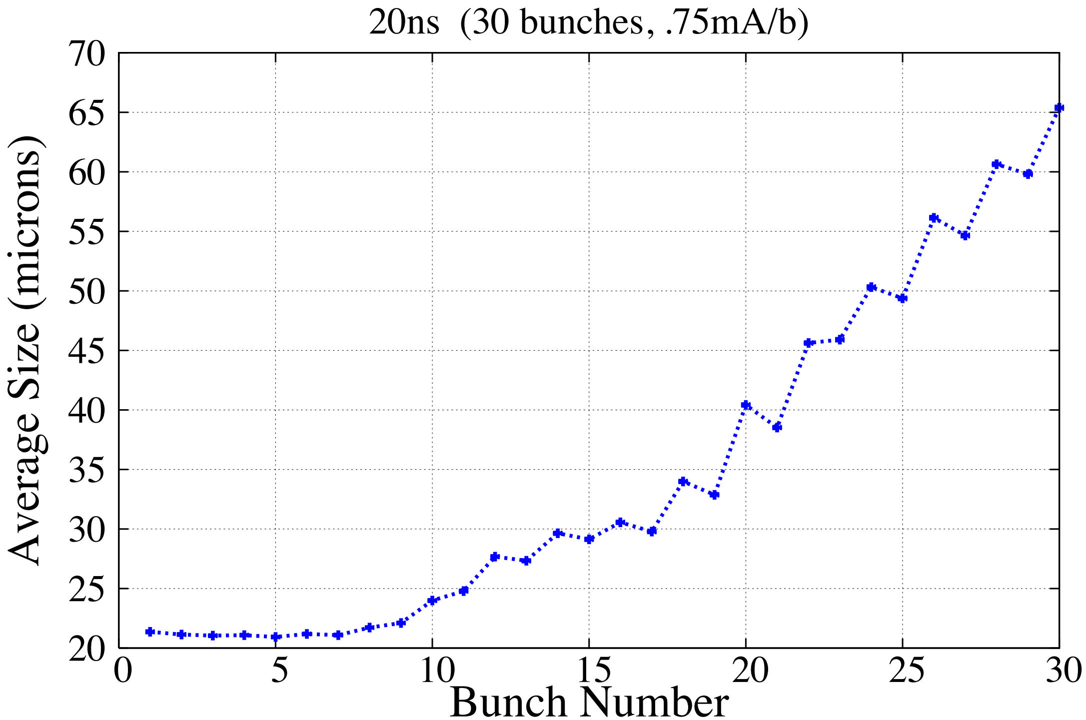
W. Hopkins, N. Eggert- grad students

Electron cloud emittance blowup

Xray beam size monitor measures vertical beam size (emittance) for each bunch on each turn for a 30 bunch train

(grad students W. Hopkins, N. Eggert)

Cloud density increases along the train. Emittance growth is observed in bunch number 10

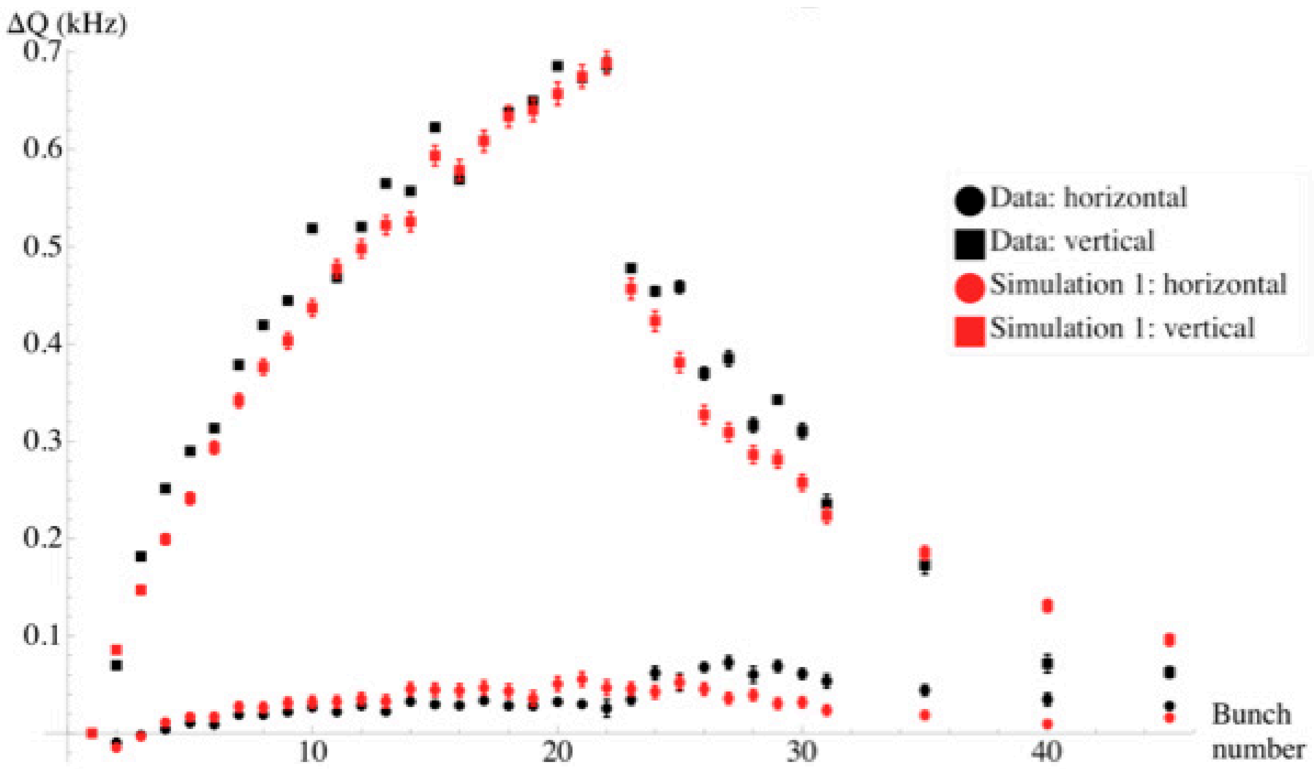


To determine the threshold for emittance growth we need to measure the cloud density traversed by each bunch in the train

- Positron bunches passing through a cloud of electrons experience a focusing force, that shifts their tune
- The focusing force (tune shift) is proportional to the cloud density
- Bunch by bunch and turn by turn beam position monitors are used to measure the tune shift

Global Measurement of Electron Cloud

Cloud density increases along a train of bunches
The cloud electrons focus the traversing positron bunch, shifting the tune



The differential focusing (tune shift) is our measure of the cloud density along the train of bunches

Status of Electron Cloud Research

- We have learned how to mitigate the growth of the electron cloud with various vacuum chamber treatments
- We can compute the density of the cloud for any configuration of bunches
- We have determined the threshold for emittance growth due to the electron cloud

Questions remain:

- How does the threshold for blowup depend on the vertical emittance ? (especially very small vertical emittance)
- Is the blowup associated with instabilities that might be damped with feedback ?
- What are the sensitivities of the threshold to lattice parameters?

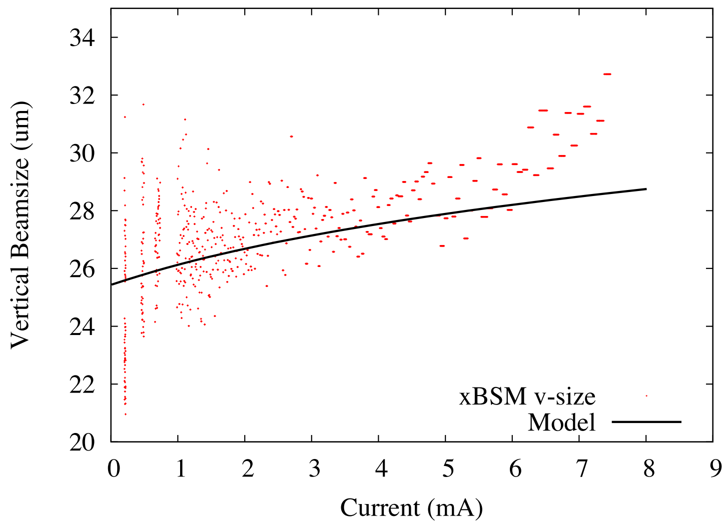
Intra –beam scattering

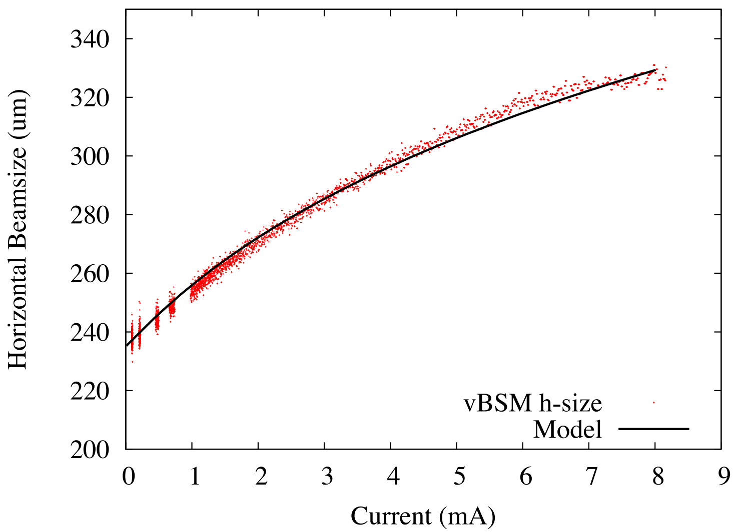
- Intra-beam scattering (IBS) contributes charge dependence to bunch emittance
  - Relative emittance growth in two transverse and one longitudinal dimension is predicted by theory
- With instrumentation for simultaneous measurement of horizontal, vertical, and longitudinal phase space

CesrTA is well suited to study of IBS

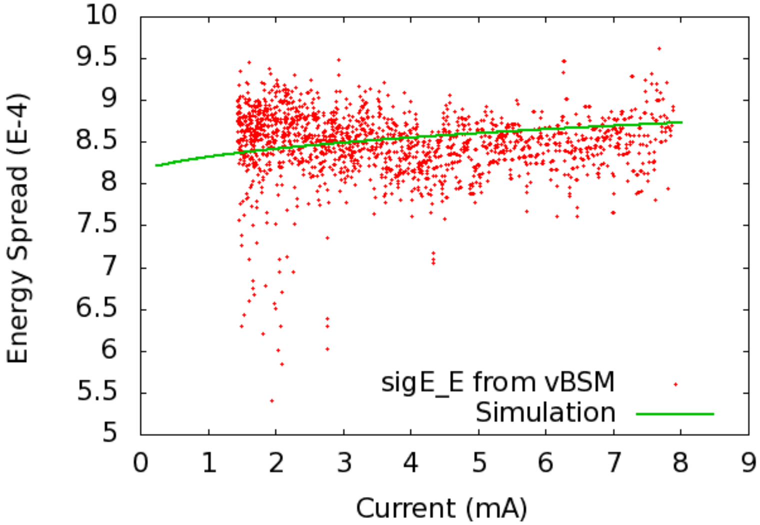
Intra Beam Scattering

- As bunch density increases, intra-beam scattering contributes to equilibrium emittance of circulating bunch





CesrTA is uniquely instrumented to measure Intra-beam scattering for electrons and positrons => world best measurement to date, Test of the theory



(Cornell grad students M. Ehrlichman, J.Shanks And CERN grad F. Antoniou)

Intra-beam scattering machine studies

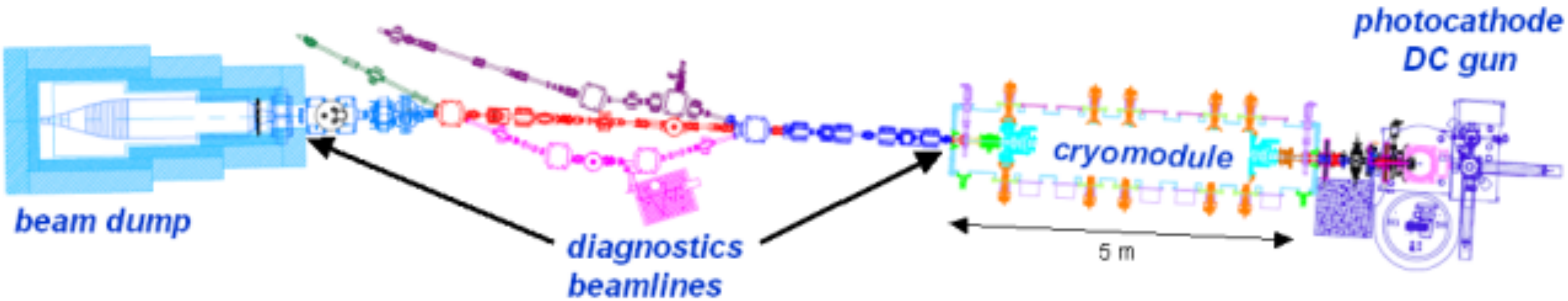
April 2012

Students, postdocs, and scientists, operating the accelerators, and monitoring instrumentation to measure current dependence of 6-D phase space

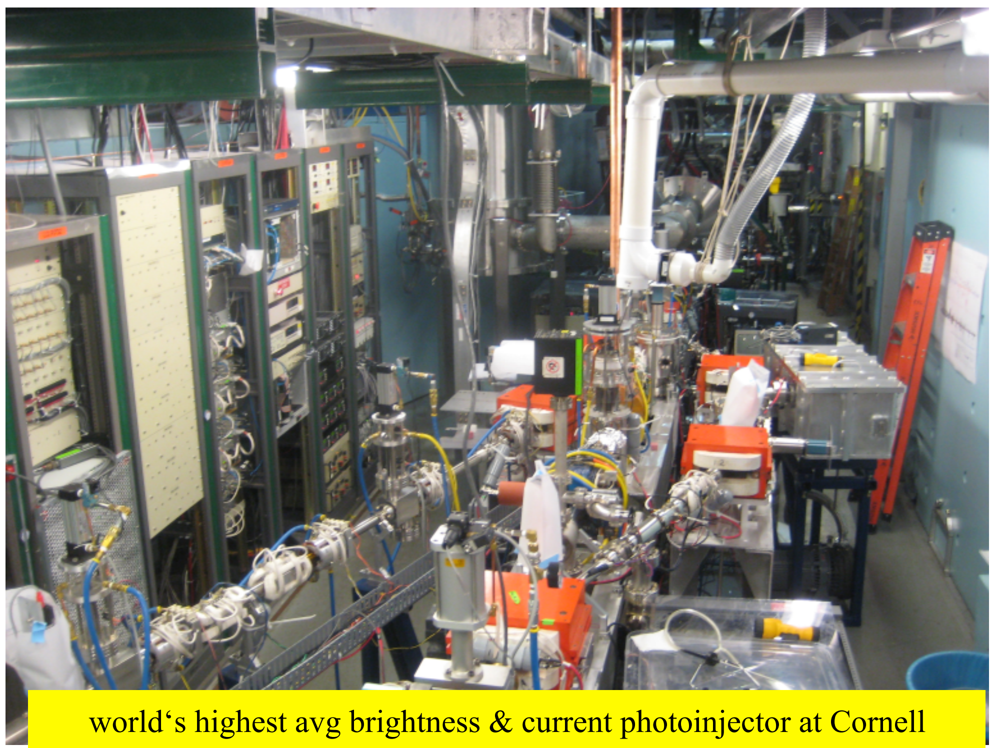
High Brightness Photo-Injector

- Ultra-low emittance in non-equilibrium regime
- Photo cathode research
  - Wide selection of photocathodes grown and analyzed
  - Towards higher quantum efficiency
  - Longer lifetime
  - Lower thermal emittance
- Testing in real accelerator

High Brightness Photo-Injector



100 mA 5-15 MeV photoinjector

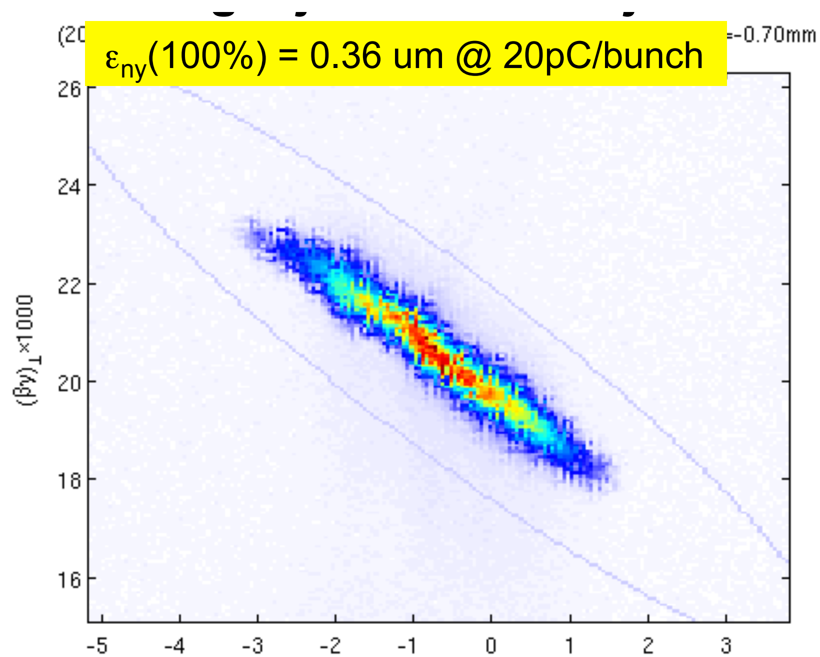


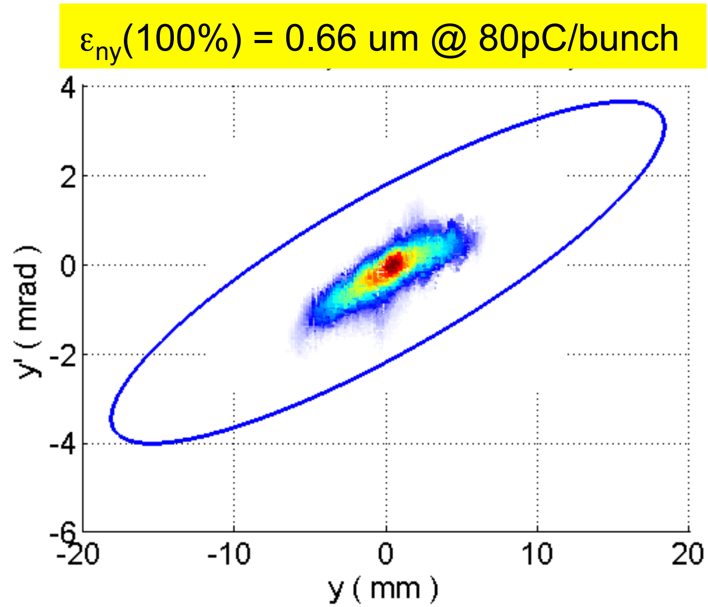
world's highest avg brightness & current photoinjector at Cornell

Grad students C. Gulliford, S. Karkare, J. Maxson, H.Lee, H. Li, & N.Valles

Low Emittance from Photo Cathode

Photo-cathode emittances near the thermal limit





1.5 times the thermal emittance and 1.2 times simulation at 5MeV

Grad students C. Gulliford, S. Karkare, & J. Maxson

Opportunities

Equilibrium regime

- Approach the quantum limit
- Explore beam physics at the ultra-low emittance frontier
  - Intra-beam scattering - anomalous blowup at “high” bunch charge
  - Electron cloud – dependence of dilution threshold on “zero current emittance”
  - Fast ion instability – likely current limit in low emittance electron rings

Non equilibrium regime

- Achieve theoretical brightness limit from photo-gun
- Develop sub-thermal sub-picosecond photocathodes

$\Rightarrow$ High coherence, high brilliance, xray beams, and high luminosity colliders

All of the above will require instrumentation with greater sensitivity, bandwidth and precision.

US Department of Energy Accelerator R&D Task Force

Pages concerning NSF

March 9, 2012

Norbert Holtkamp

Education and Workforce development for accelerator physics and technology

- NSF provides dominantly for education of accelerator experts.
- Essential is education at universities with hands-on accelerator operation – needs to be continued.
- HR departments of accelerator labs continuously report a shortage of experts for accelerator R&D and operation.
- 55000 peer-reviewed papers with accelerator as a keyword can be found on the web, but only few universities have a program.
- 6 Universities have 2 or more faculty and regular education programs and research
- 3 are establishing a program
- 11 Universities have on active faculty member but no lectures
- US PA School offers two accelerator schools per year at changing locations, 150 students each.

Education efforts need to be maintained and extended, particularly by NSF

Summary of accelerators for discovery science

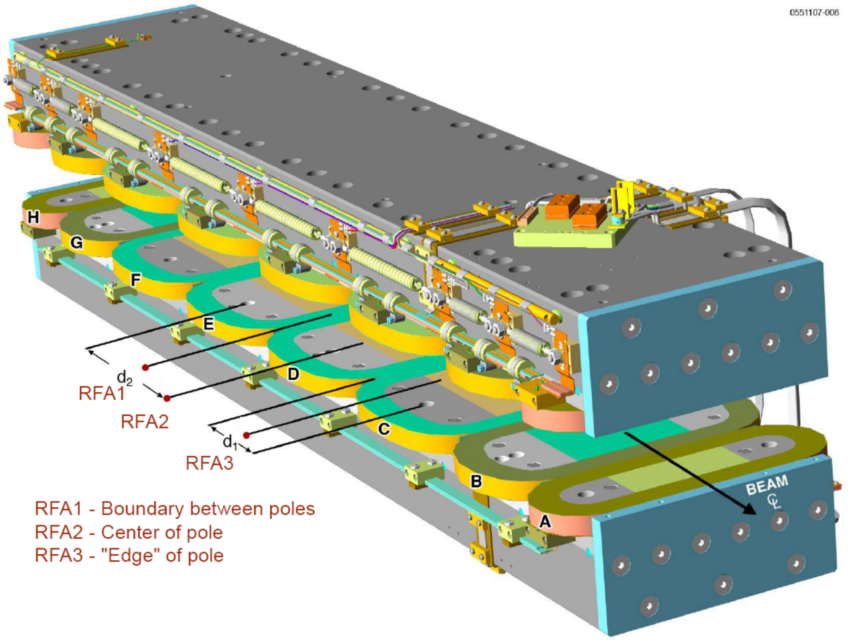
- Much of today's and tomorrow's basic knowledge of nature is due to accelerators. Advanced Accelerator R&D in many cases prepared the ground for new developments
- Historically, the US has been a global innovating force for accelerators, with world experts and great facilities
- Coordination and collaboration between existing facilities may optimize output
- Construction and support of the necessary dedicated accelerator research and development facilities will help ensure US leadership role in the future
- Support of accelerator educational opportunities is key to maintaining a healthy, vibrant US program

The US has a brilliant history, excellent experts, and forefront facilities to launch the next generation of discoveries

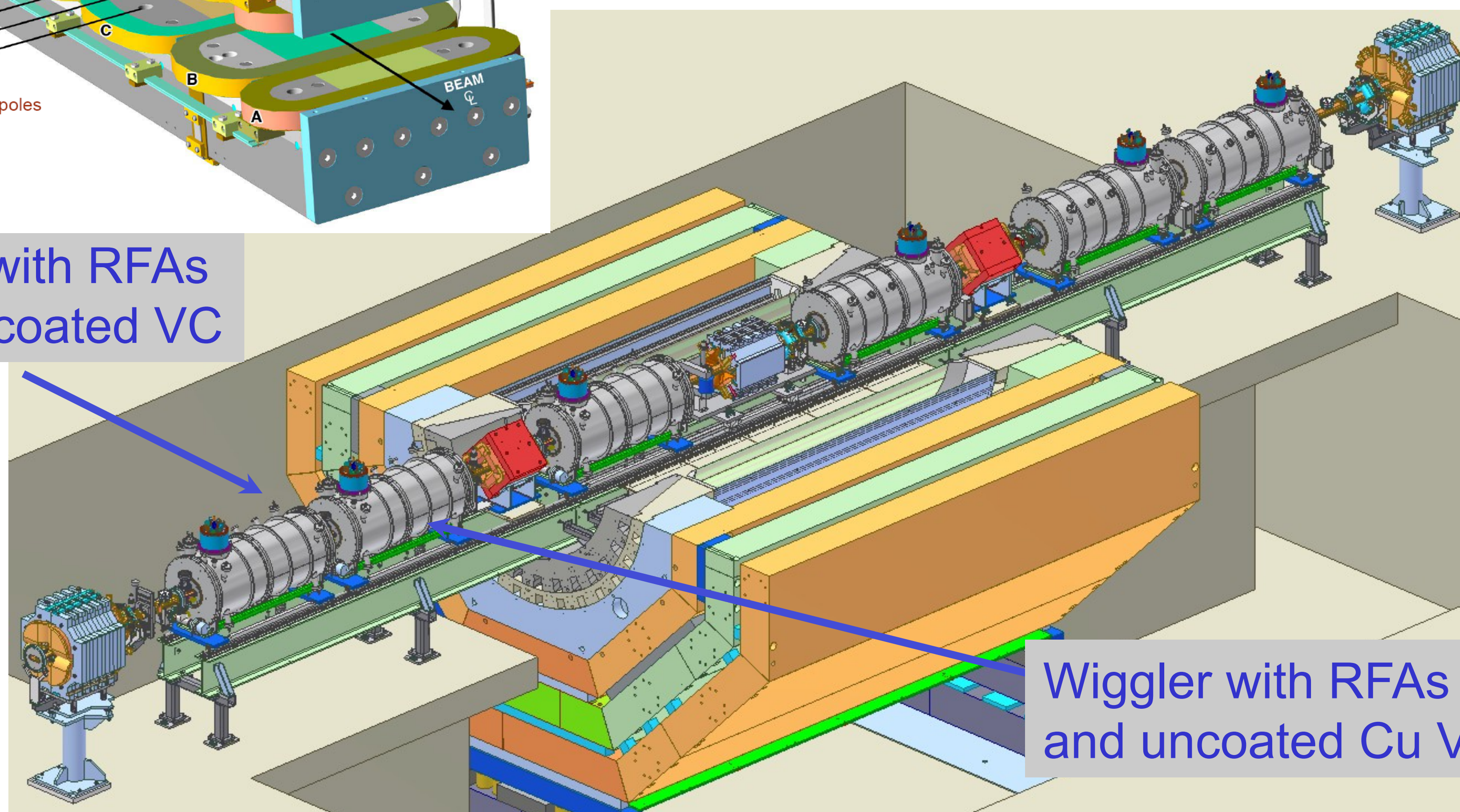
END

Thank you for listening

Superconducting Damping Wigglers



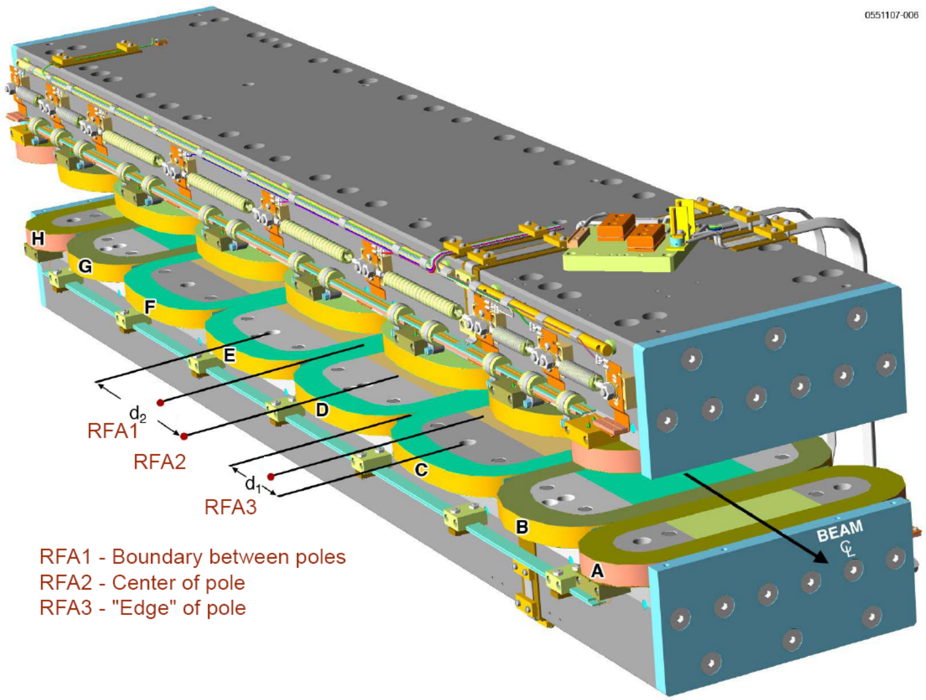
$$B_{peak} = 2.1\ \mathrm{T}$$



Wiggler with RFAs and TiN-coated VC

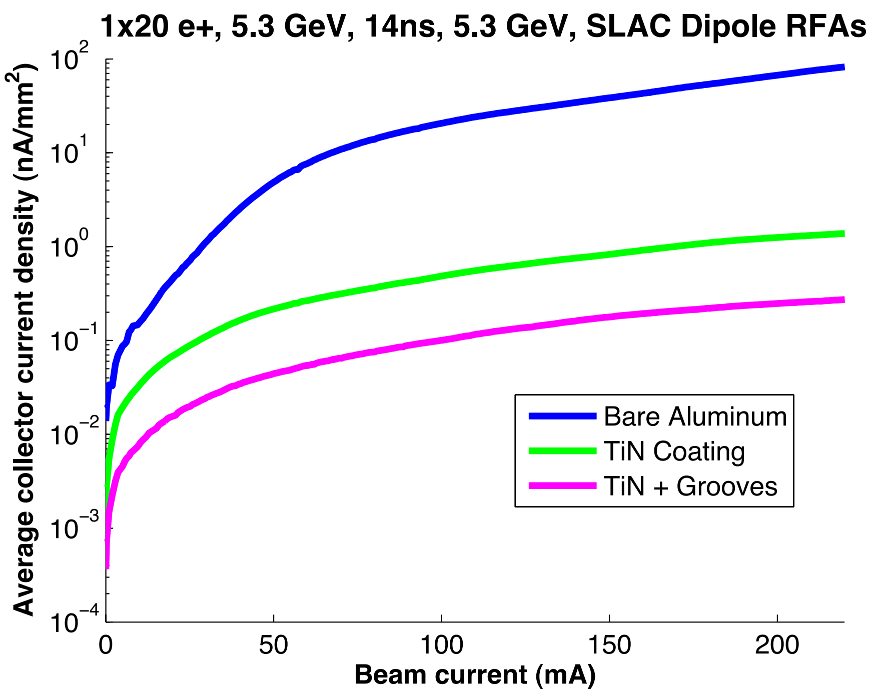
Wiggler with RFAs and uncoated Cu VC

Retarding Field Analyzer



Wiggler and vacuum chamber with RFAs

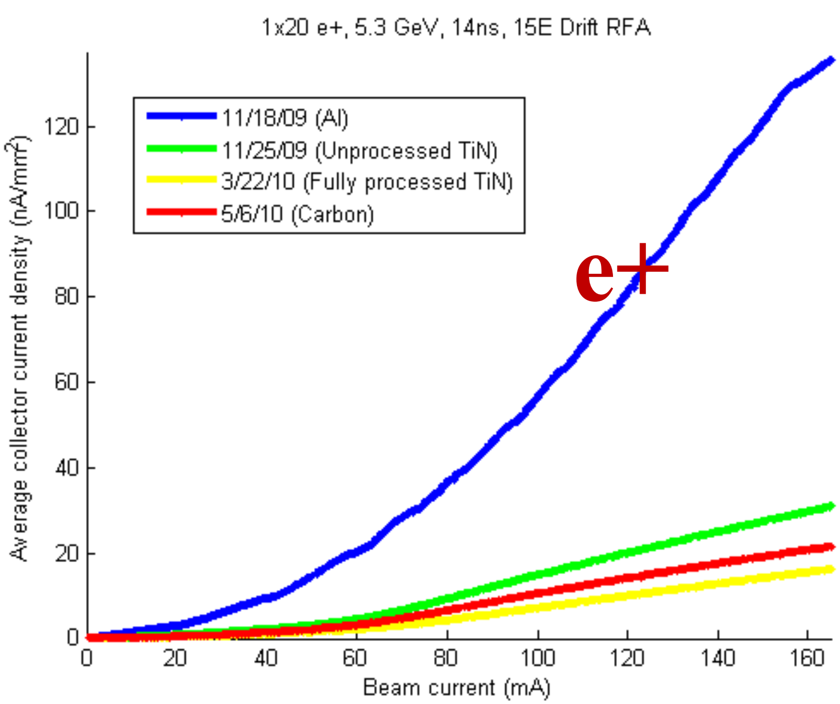
Electron cloud - RFA

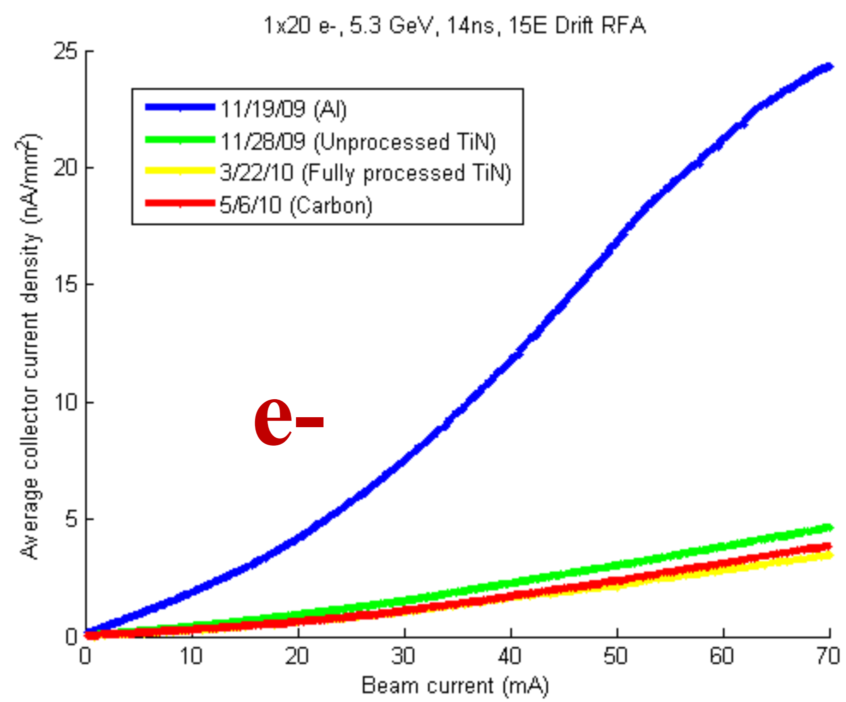


Mitigation in a dipole field

Electron cloud - RFA

- Mitigation in field free region
  - Electron cloud from positron and electron beams
  - 20 bunches – 14ns spacing – 5.3 GeV

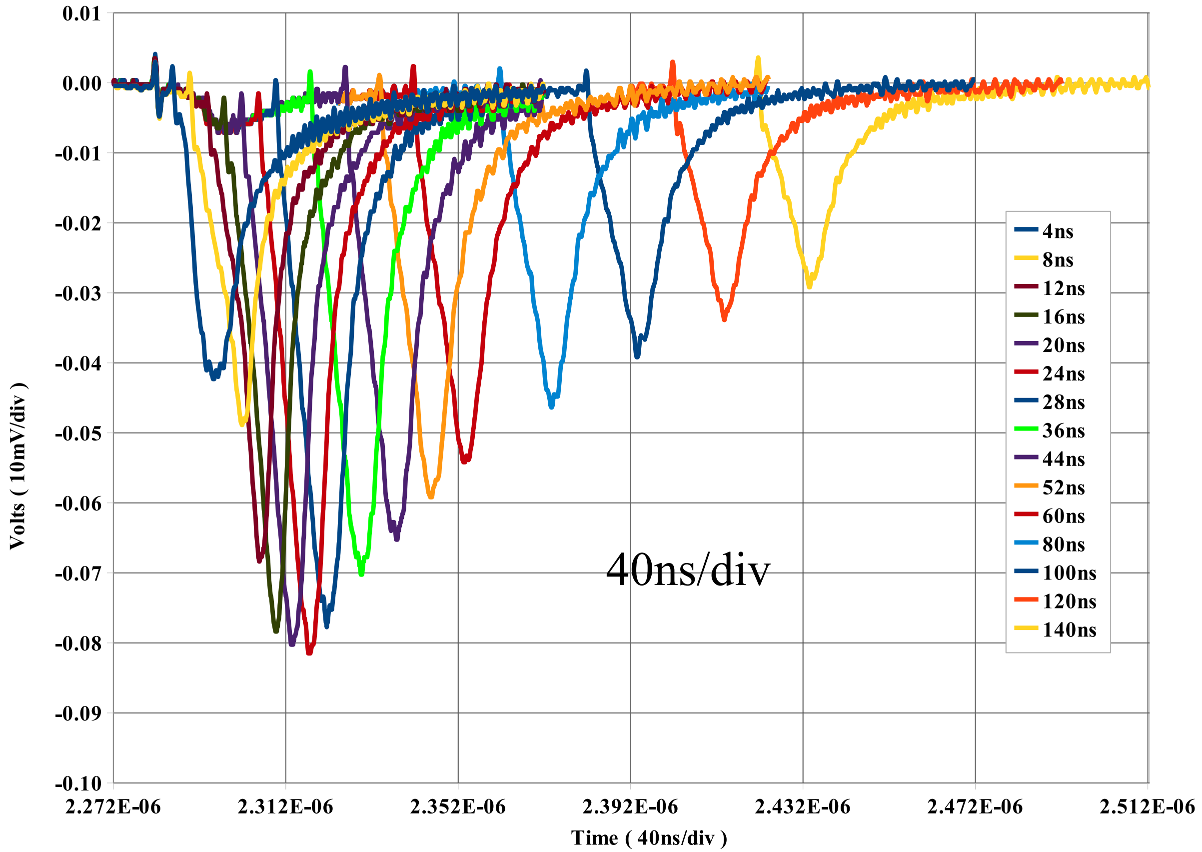




Surface Characterization & Mitigation Tests

	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	✓				CU,KEK
NEG on SS	✓				CU
Solenoid Windings	✓				CU
Fins w/TiN on Al	✓				SLAC
Triangular Grooves on Cu				✓	CU, KEK, LBNL, SLAC
Triangular Grooves w/TiN on Al			✓		CU, SLAC
Triangular Grooves w/TiN on Cu				✓	CU, KEK, LBNL, SLAC
Clearing Electrode				✓	CU, KEK, LBNL, SLAC

Time Resolved Measurements



- Overlay of 15 two bunch measurements with varying delay of second bunch
- First bunch initiates cloud
- Second bunch kicks electrons from the bottom of the chamber into the pickup
- Yielding time resolved development and decay of cloud