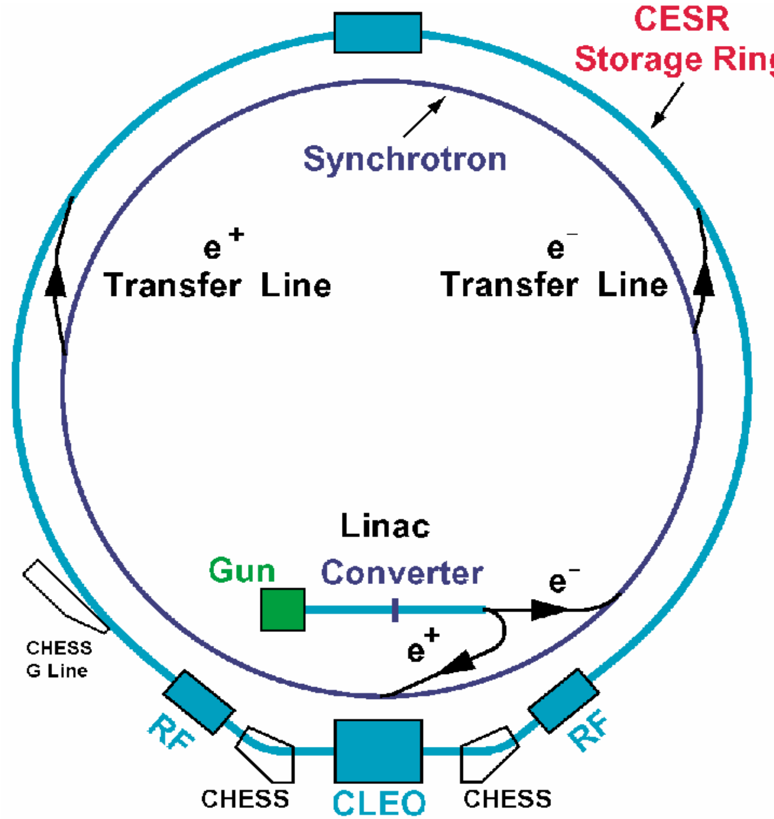
CESR Test Accelerator

February 6, 2014

D. Rubin

CESR Test Accelerator

- CESR operates with single or counterrotating beams of electrons and positrons
- $1.5 < E_{beam} < 6.5$ GeV, 250 mA/beam
- 768 m circumference
- Minimum bunch spacing – 4ns
- Superconducting RF (6.5 MV at 500 MHz)
- Superconducting damping wigglers (1.9T)
  - increase radiation damping rate X 10, and decrease emittance X 4 to 2.6 nm at 2.1 GeV beam energy
- ~ 35 days/year devoted to damping ring beam physics studies (operates for CHESS as x-ray source at 5.3 GeV for most of the rest of the year)



Program

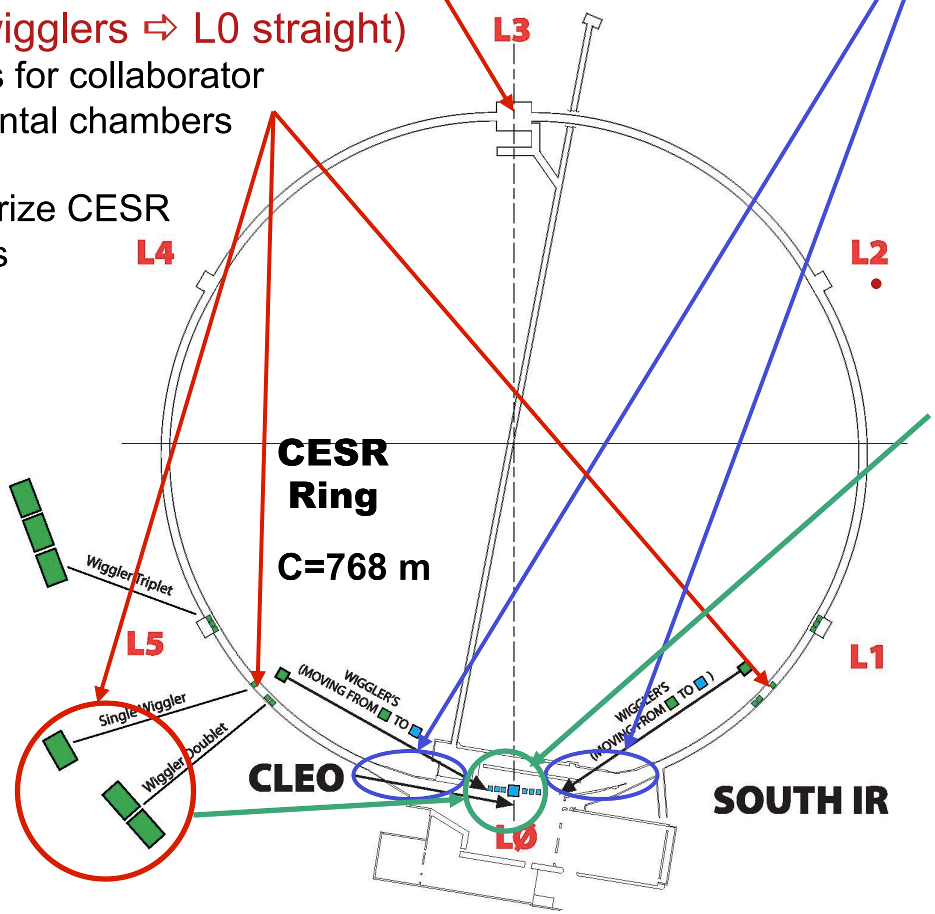
- EC dynamics
  - Electron cloud induced - single and multibunch instability, incoherent emittance growth, tune shifts
- RFA studies
  - Measurement of cloud growth in drifts, dipoles, quadrupoles, model parameters. Mitigation tests
- TE wave
  - Measurement of cloud with microwaves
- SPU and TR-RFA and trapped cloud
  - Measurement of cloud model parameters, growth and decay in drift, dipole and quadrupole.
- FII
  - Single and multibunch instability, emittance growth, dependence on train length, bunch spacing, bunch charge, residual gas pressure, gas species
- IBS
  - Intra-beam scattering. Dependence on vertical emittance, beam energy, species,
- LET
  - Techniques for routine identification and minimization of sources of emittance dilution
- Visible light beam size monitor
  - Interferometer for horizontal beam size, interferometer and pi-polarization for vertical
- Xray beam size monitor
  - Bunch by bunch measurement of vertical beam size, coded aperture,
- Diffraction radiation beam size monitor (CLIC)
  - => Xray diffraction radiation

Instrumentation

- X-ray beam size monitor (vertical)
- Visible synchrotron light beam size monitor (horizontal and vertical)
- Retarding Field Analyzers – measurement of electron cloud position distribution and energy spectrum
- Shielded pickups and time resolving analyzers – ns resolution of electron cloud growth and decay
- TE-wave (microwave) measurement of cloud distribution and density
- Beam position monitors – bunch by bunch (4ns) and turn by turn capability
- Diffraction radiaiton beam size monitor
- In situ SEY

CESR Reconfiguration

- L3 EC experimental region
  - PEP-II EC Hardware: Chicane, upgraded SEY station
  - Drift and Quadrupole diagnostic chambers
- New EC experimental regions in arcs (wigglers ⇨ L0 straight)
  - Locations for collaborator experimental chambers
  - Characterize CESR chambers

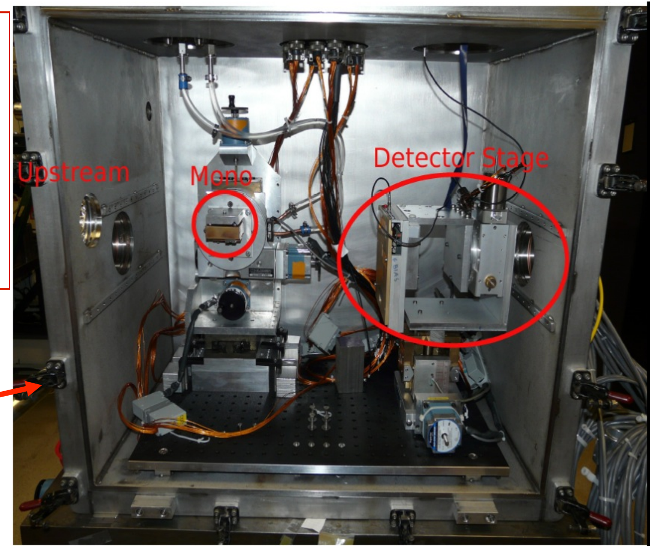


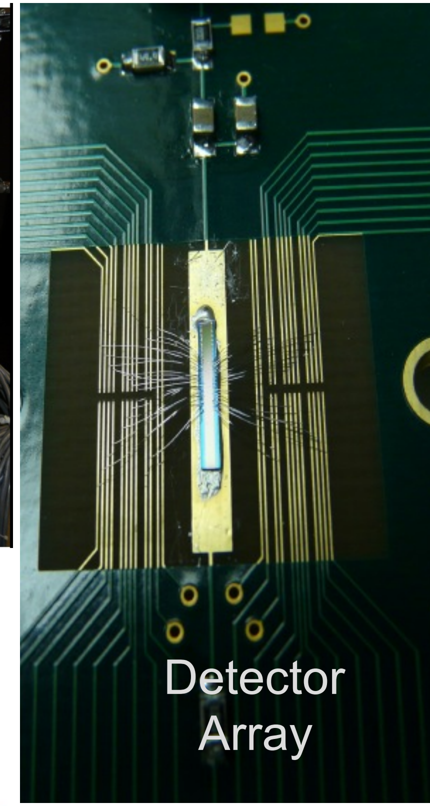
- CHESS C-line & D-line Upgrades
  - Windowless (all vacuum) x-ray line upgrade
  - Dedicated x-ray optics box at start of each line
  - CesrTA xBSM detectors share space in CHESS experimental hutches
- L0 region reconfigured as a wiggler straight
  - CLEO detector sub-systems removed
  - 6 wigglers moved from CESR arcs to zero dispersion straight
  - Region instrumented with EC diagnostics and mitigation
  - Wiggler chambers with retarding field analyzers and various EC mitigation methods (fabricated at LBNL in CU/SLAC/KEK/LBNL collaboration)

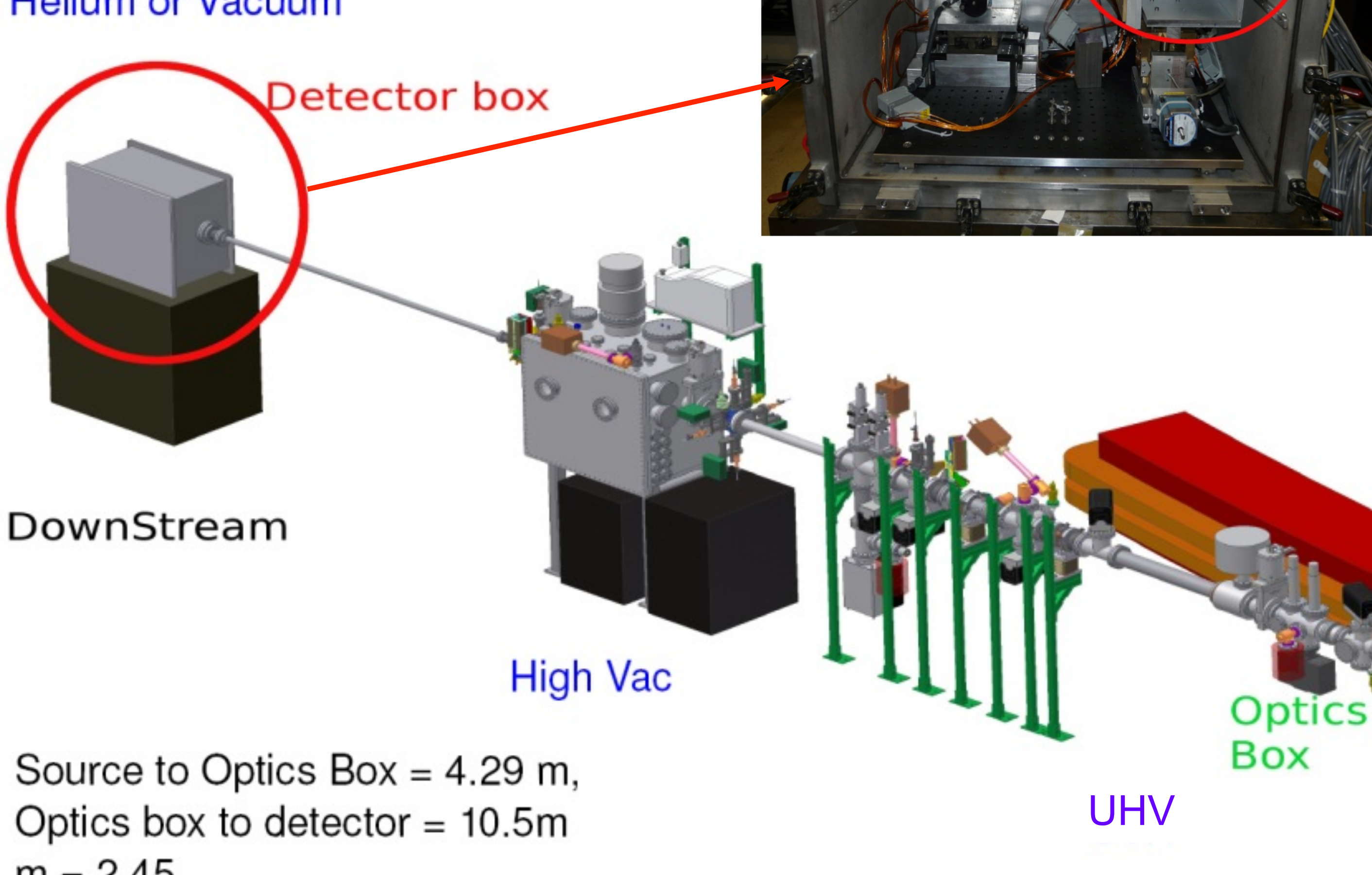
xBSM Optics Line & Detector

New all-vacuum optics line for e+ beam in collaboration with CHESS

2nd line for e- beam in progress

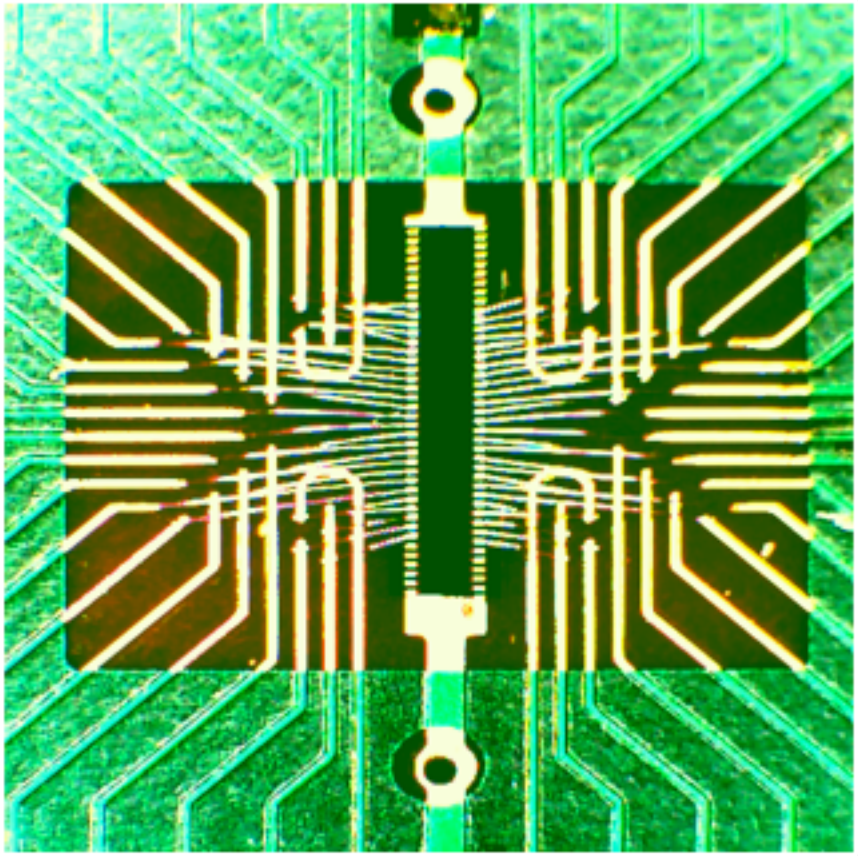


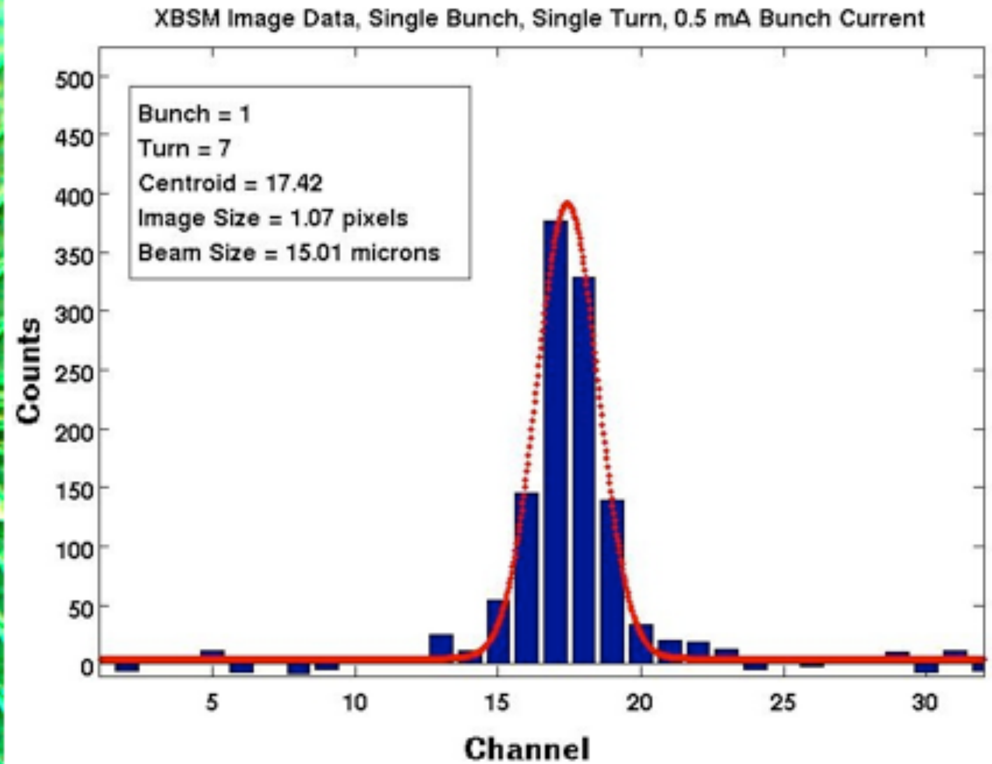




Source to Optics Box = 4.29 m,
Optics box to detector = 10.5m
m = 2.45

Xray beam size monitor



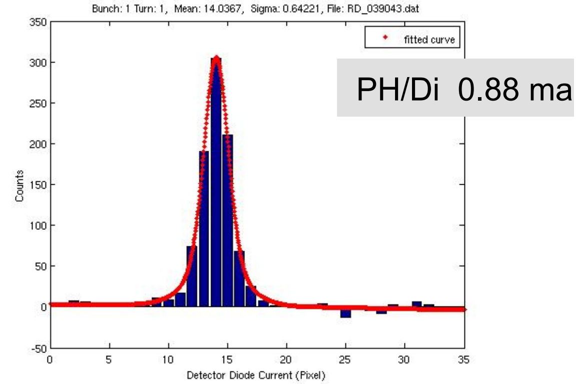


32 channel photodiode array - 50μm pitch
Single bunch-single pass – unique to CesrTA

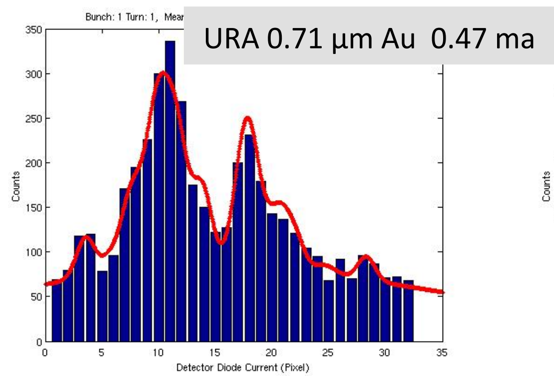
Single pass pin hole image
σ ~ 20μm

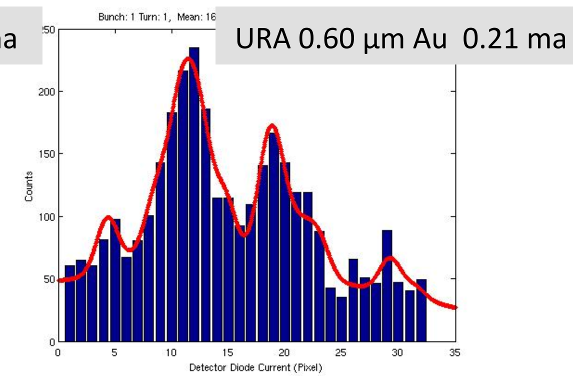
X-ray beam size monitor

The xBSM development work was a test the new coded aperture at 2.085 GeV.

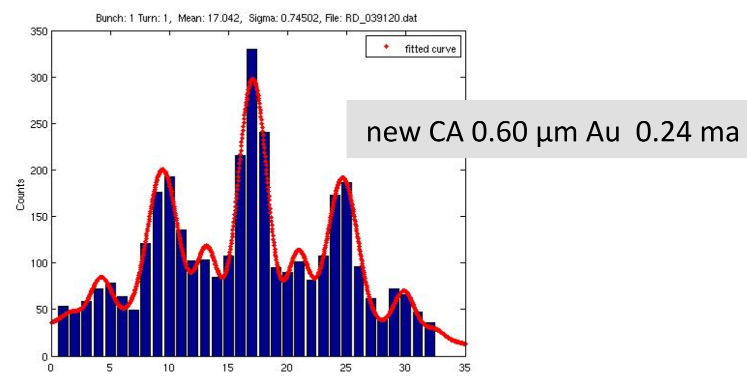


4 elements were available in the run
- pinhole
- URA CA on the old chip, “CA1”
- URA CA on the new chip, “CAN1”
- new design Coded Aperture , CAN2”





The new CA is optimized for the xBSM photon energy range and takes diffraction into account.



We use a normalized FoM

The FoM is normalized such that

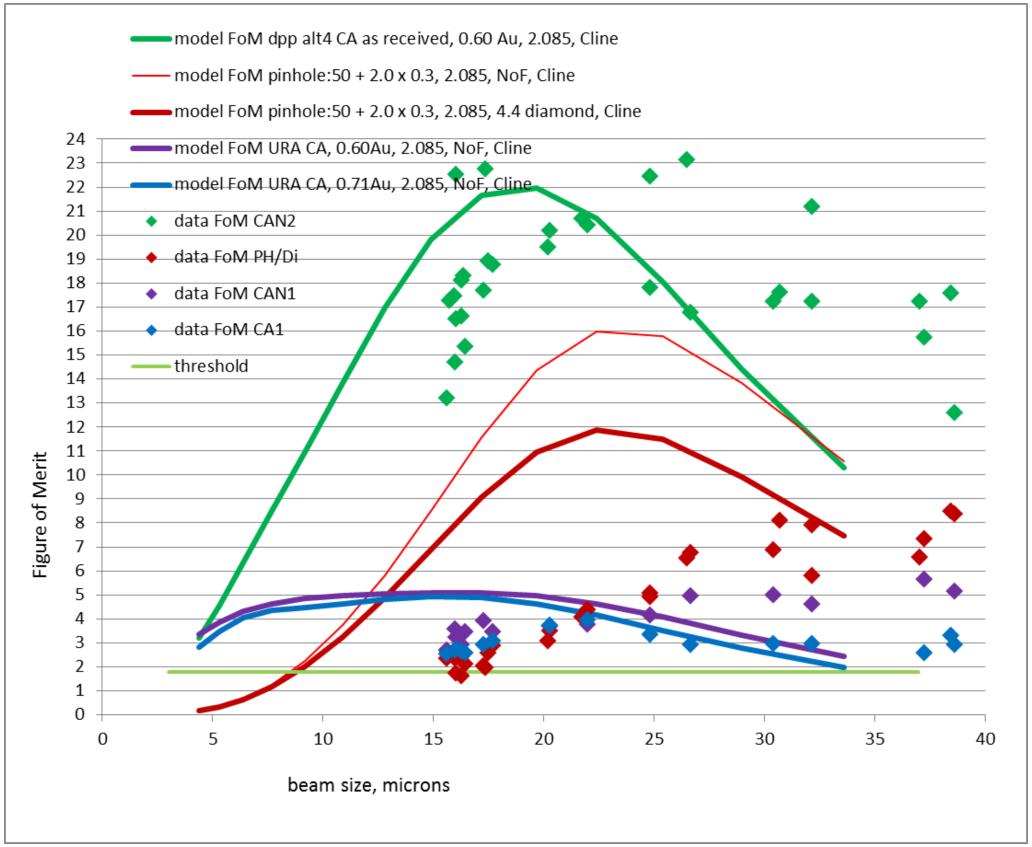
at the smallest beam current, $I_B = 0.1$ ma ,

and
with a "barely acceptable" measurement ,

$(\delta\sigma / \sigma) = 1/\sqrt{10}$,

(The separation from zero is 3.16 σ .)

then **FoM = 1 .**



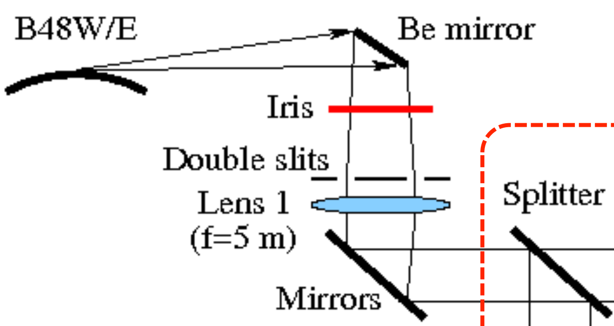
With the normalization,

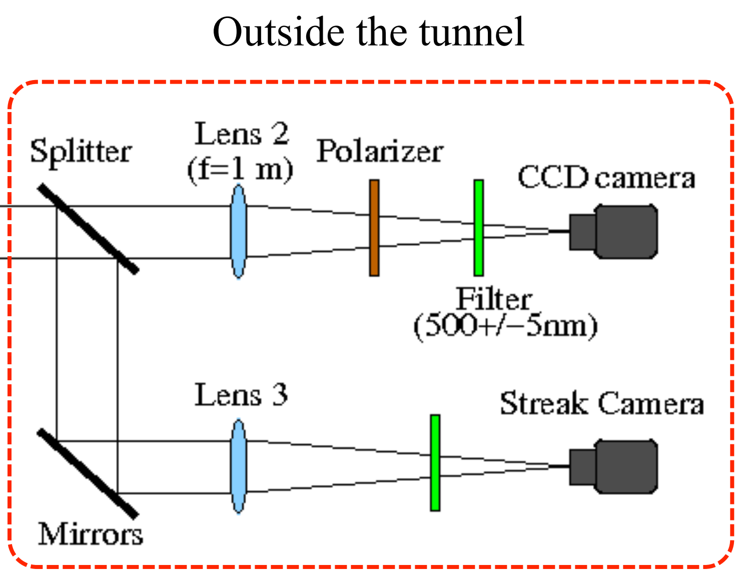
$$FoM = 0.01\, (\sigma / \delta\sigma)^2 \;/\; I_B \,.$$

to agree with the measurements ~on average,

and thus illustrate the expected ratios of the FoM for the various optics elements.

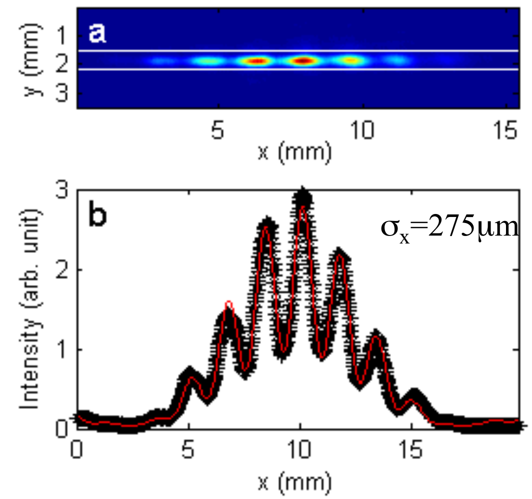
Visible-light beam size monitor (vBSM)



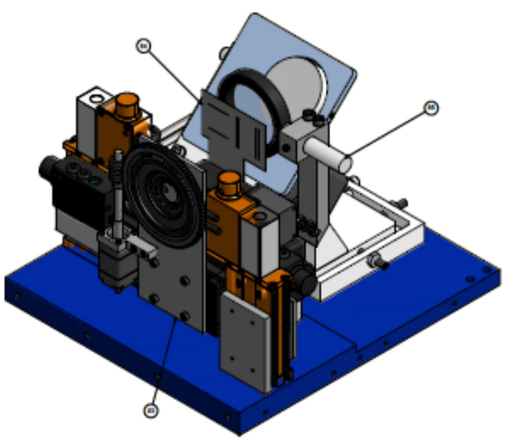


- Be mirror: 16x12 mm² (HxV)
- Adjustable iris: 3.0 - 22 mm
- Replaceable sets of double slits
  Horizontal D=2.0, 2.5, 3.0 mm
  Vertical D=5, 8, 10 mm
- Motorized stages to control the positrons of iris and slit sets

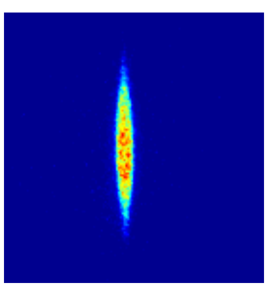
Horizontal beam size



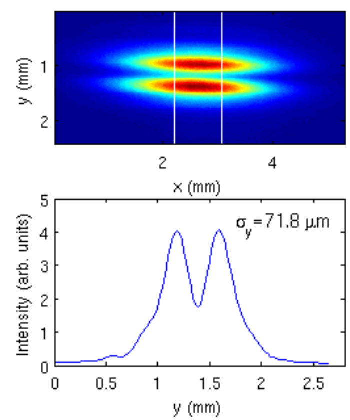
Optics box in the tunnel



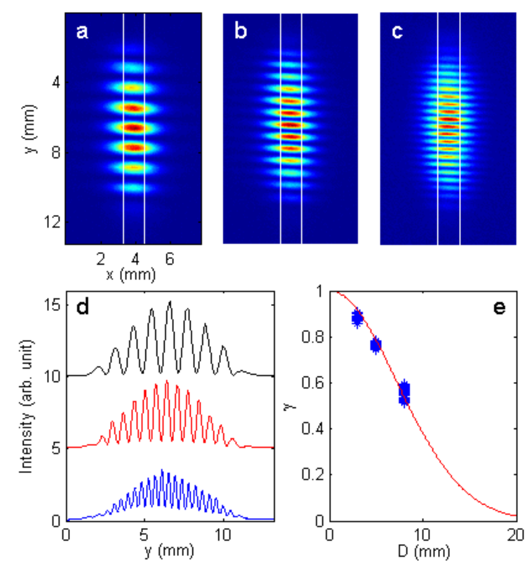
bunch length



Vertical beam size using π-polarization



Vertical beam size



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Visible synchrotron light beam size monitor

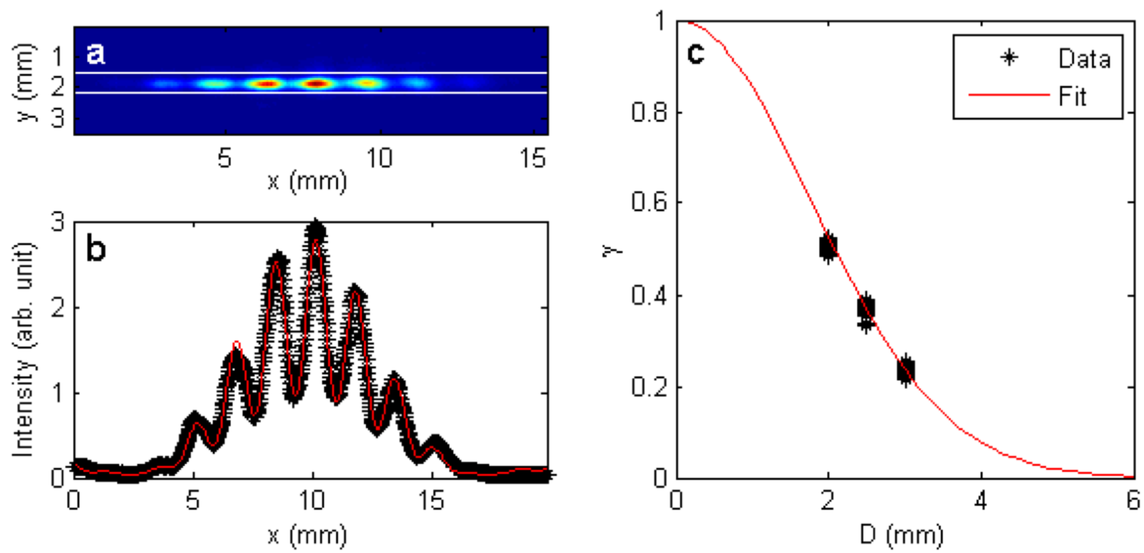
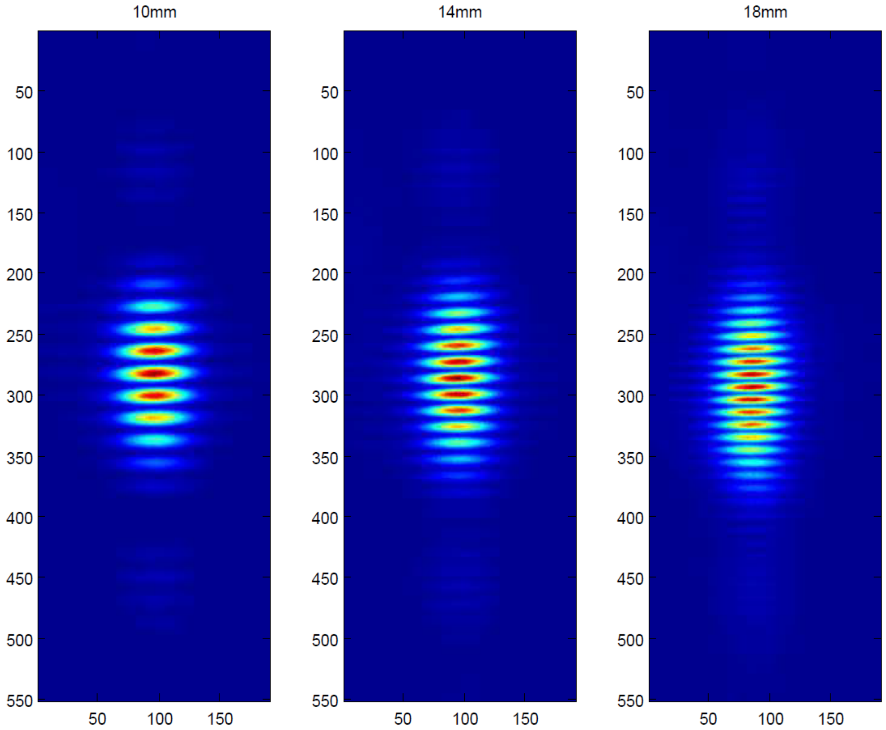
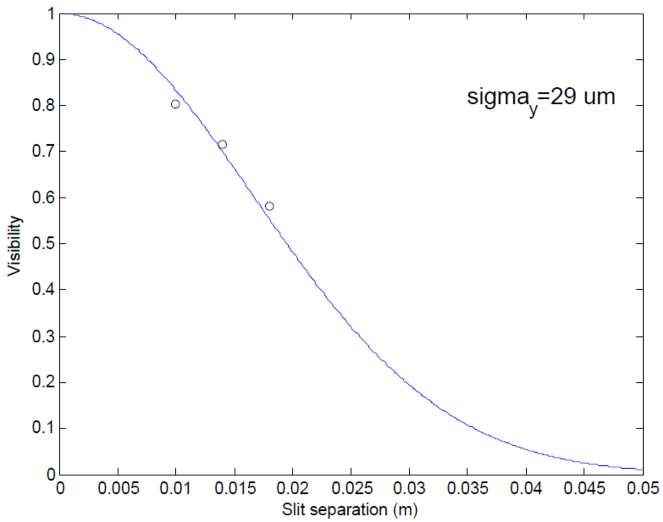
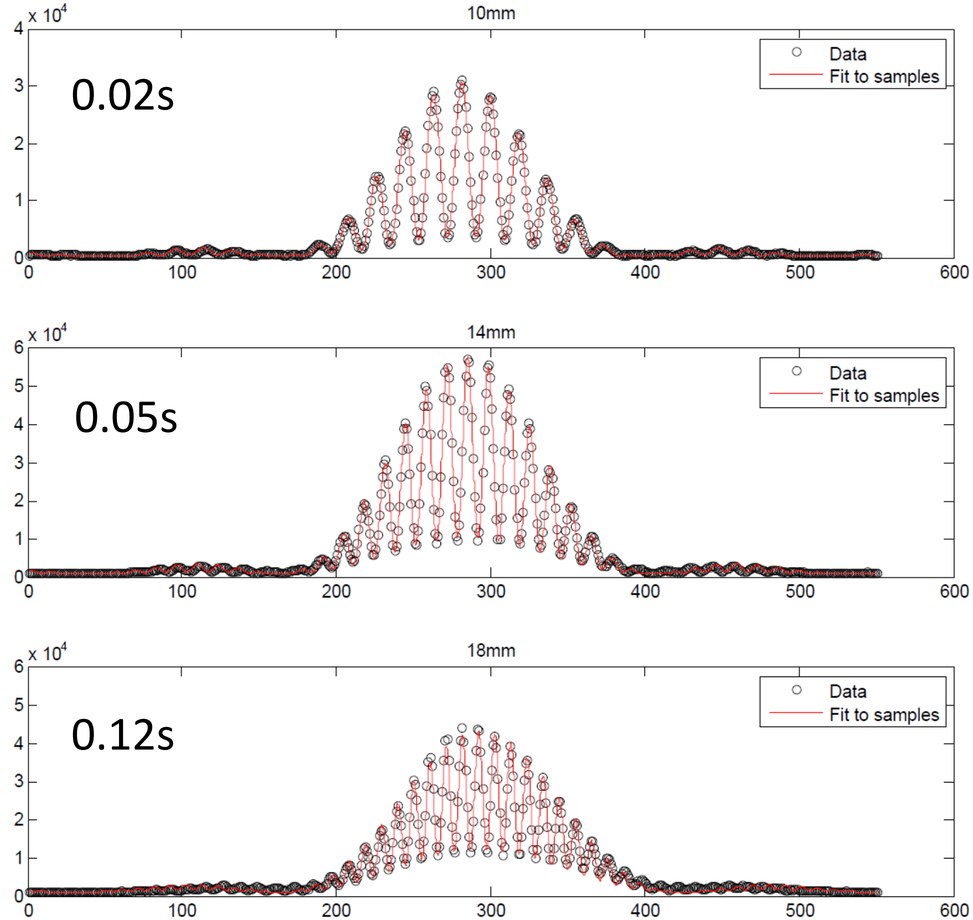


Fig. 5. (a) A typical interference pattern of SR using a *D*=2.0 mm double slits. (b) The horizontal intensity profile integrated between two white lines in (a) and the best fit. (c) The visibility measured using three different sets of double slits (*D*=2.0, 2.5, and 3.0 mm). The red line is the best fit.

VBSM -Interference pattern





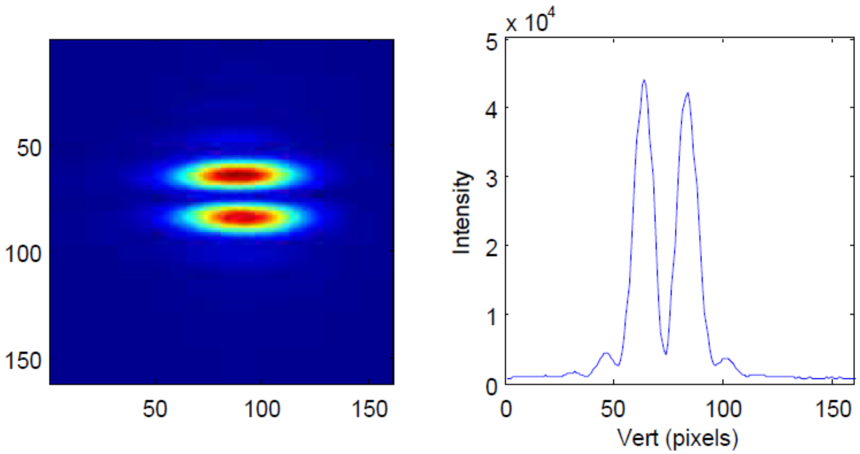


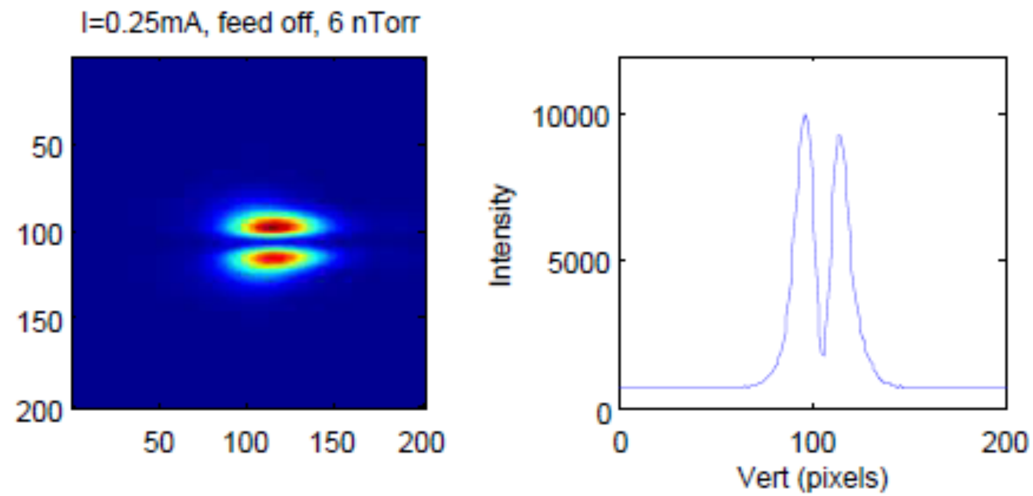
In BIGD route, ~0.7mA positron

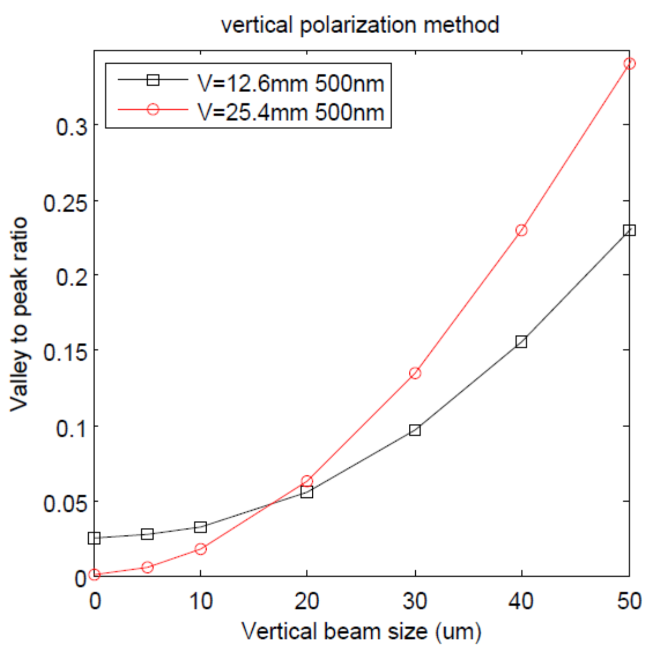
VBSM π-polarization method

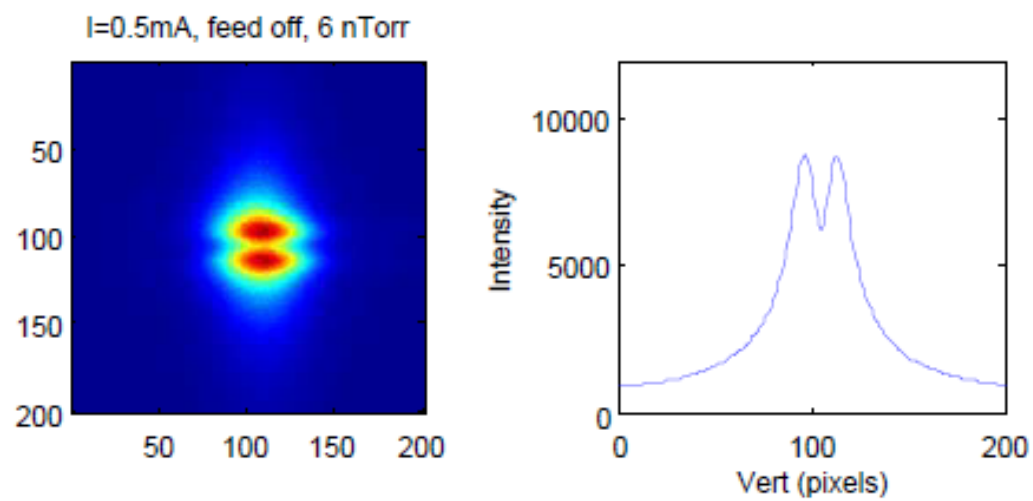
Image from old 0.5” mirror

Image from new 1.0” mirror





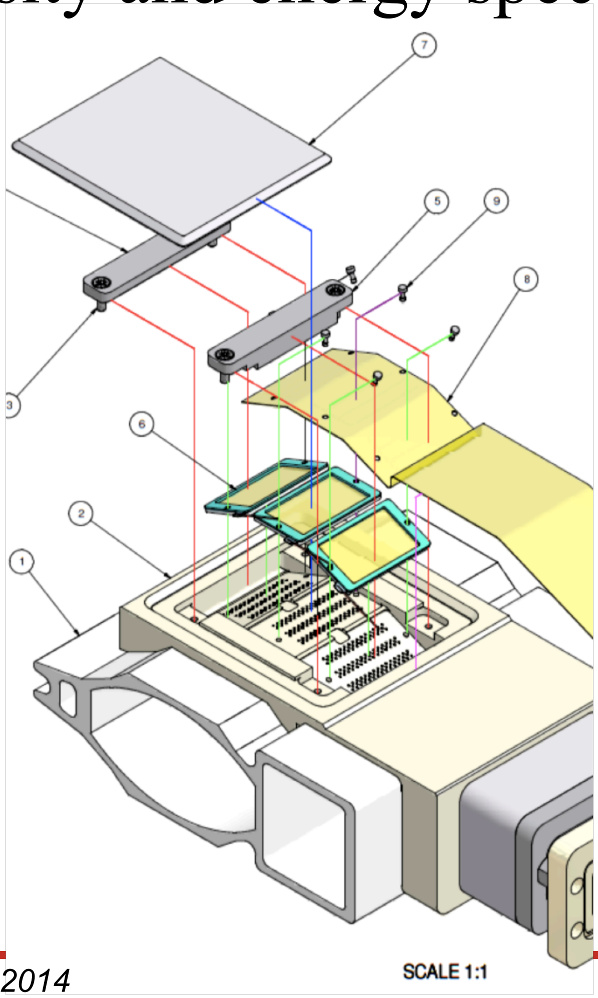


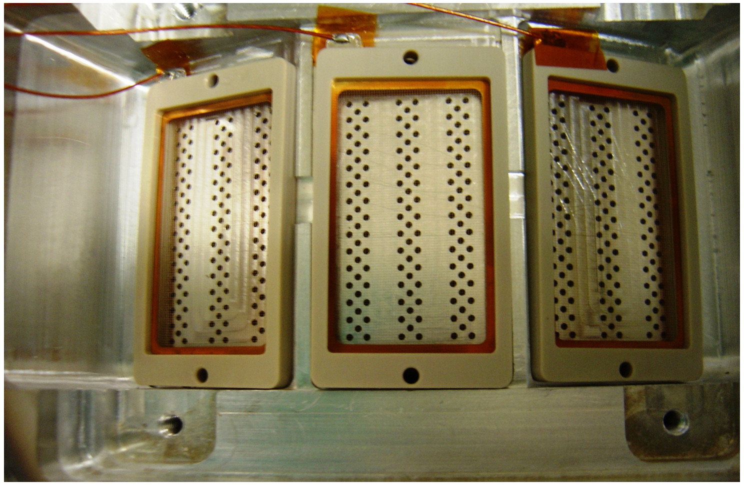


New mirror eliminates the diffraction effect and increases the sensitivity

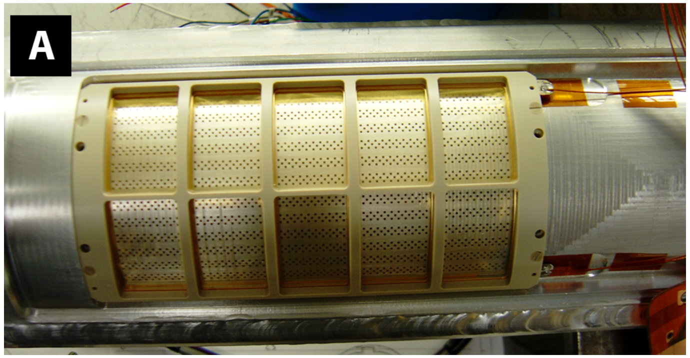
Electron cloud diagnostics

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





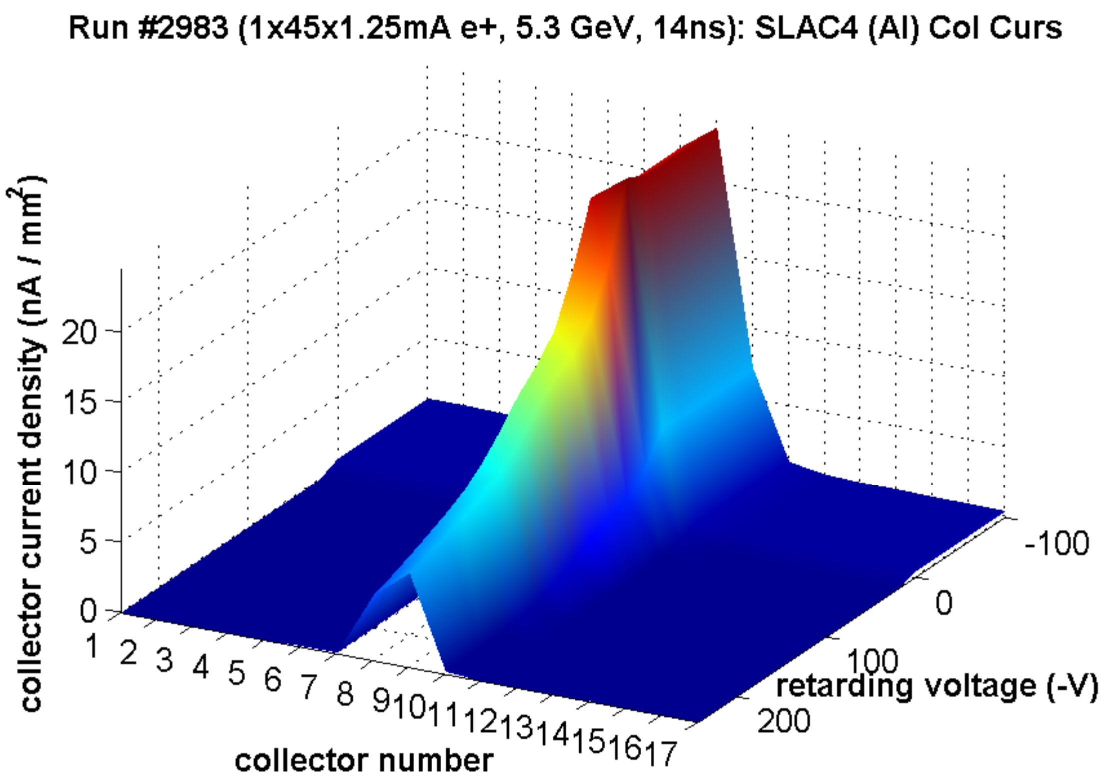
View of from outside vacuum chamber of dipole style RFA with 9 independent collectors. The fine mesh wire grid is in place (but transparent)



Quadrupole RFA

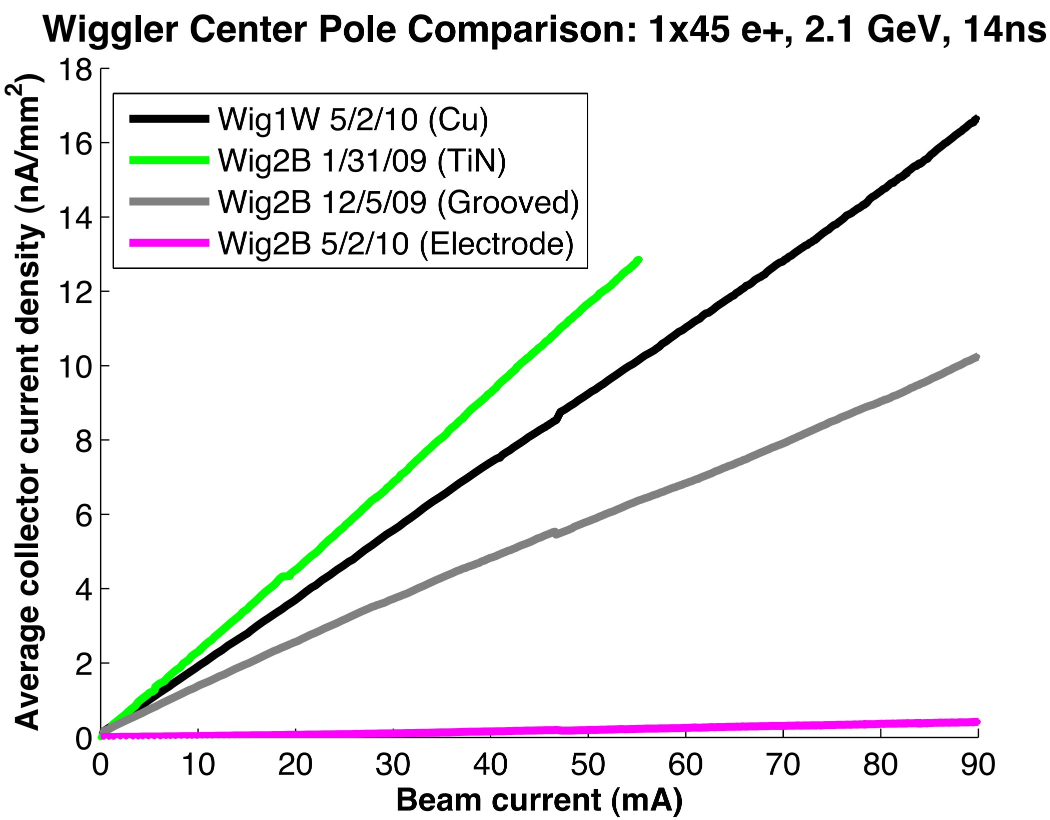
Retarding Field Analyzer

Dipole RFA data with characteristic central peak



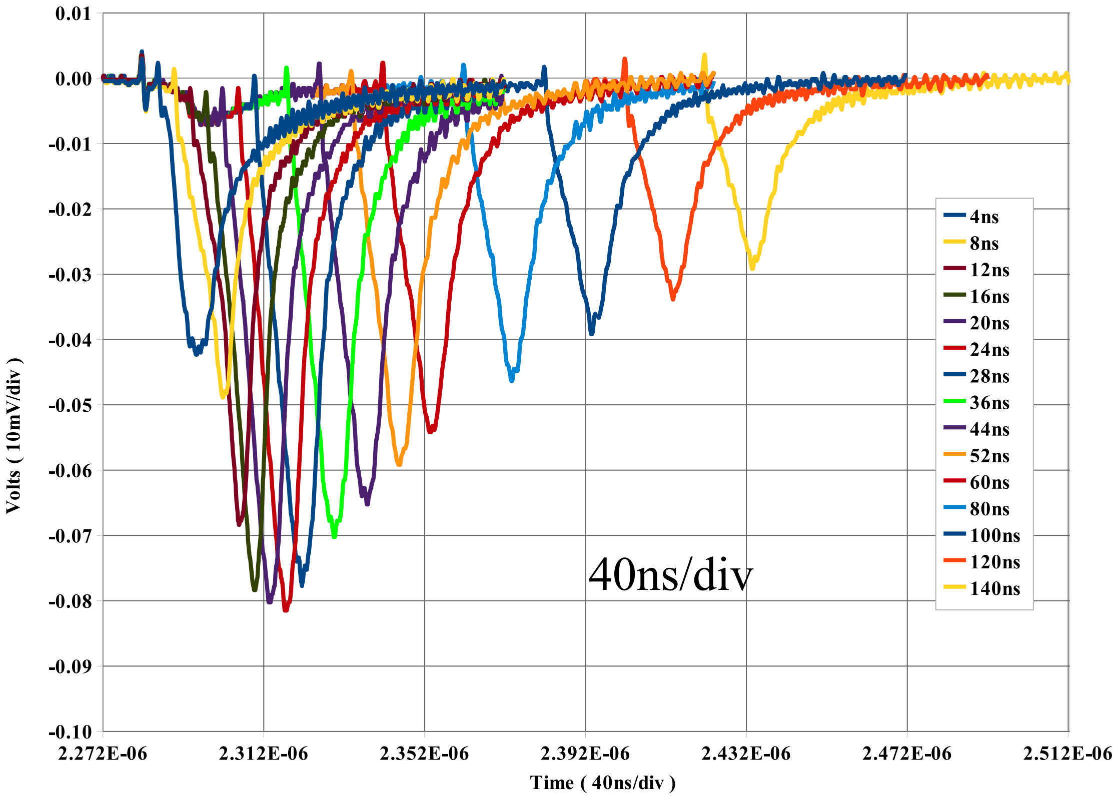
Aluminum chamber
45 bunches, 1.25mA/bunch
14ns spacing, 5.3GeV

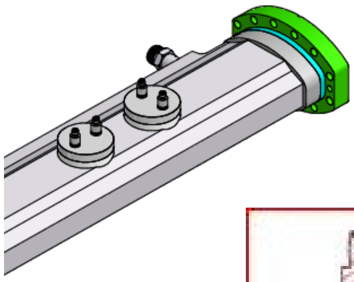
Electron cloud mitigations in damping wiggler

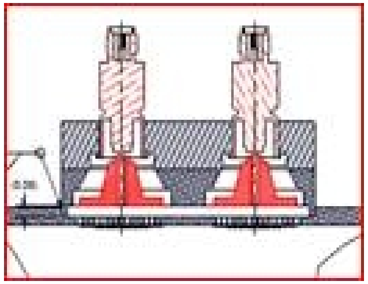


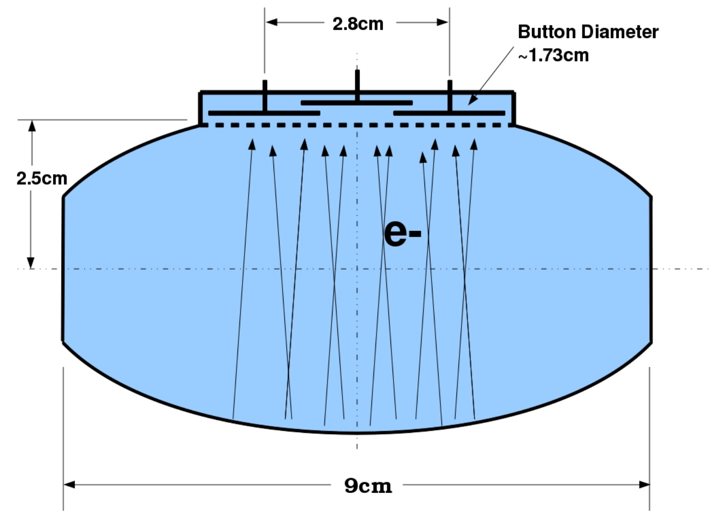
Joe Calvey (grad student)

Shielded pickup - Time Resolved Measurement



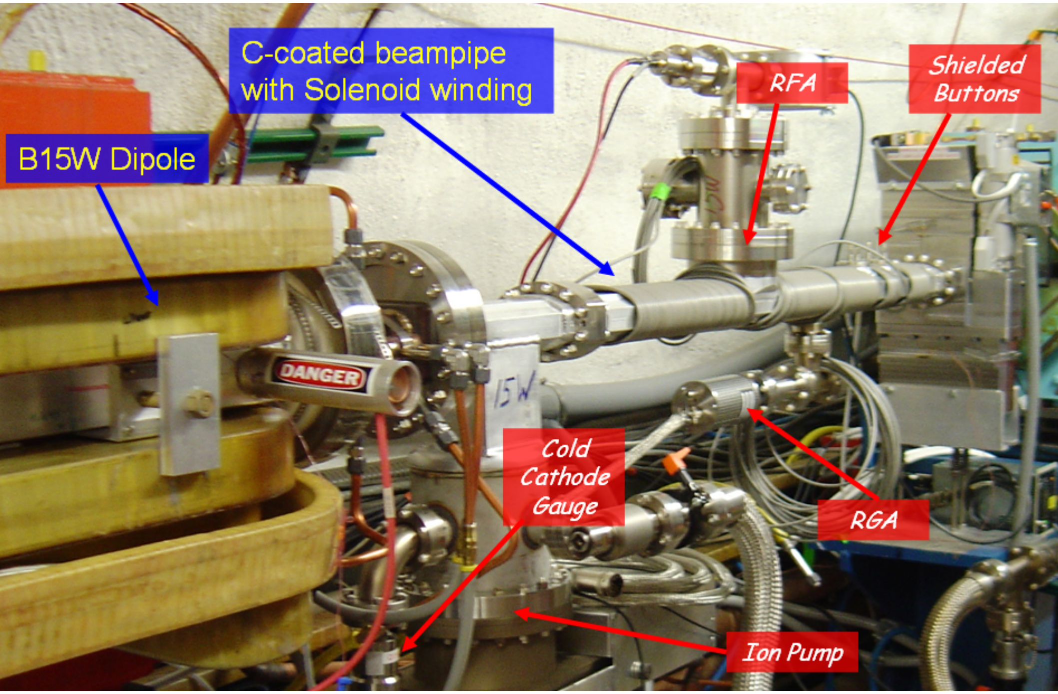


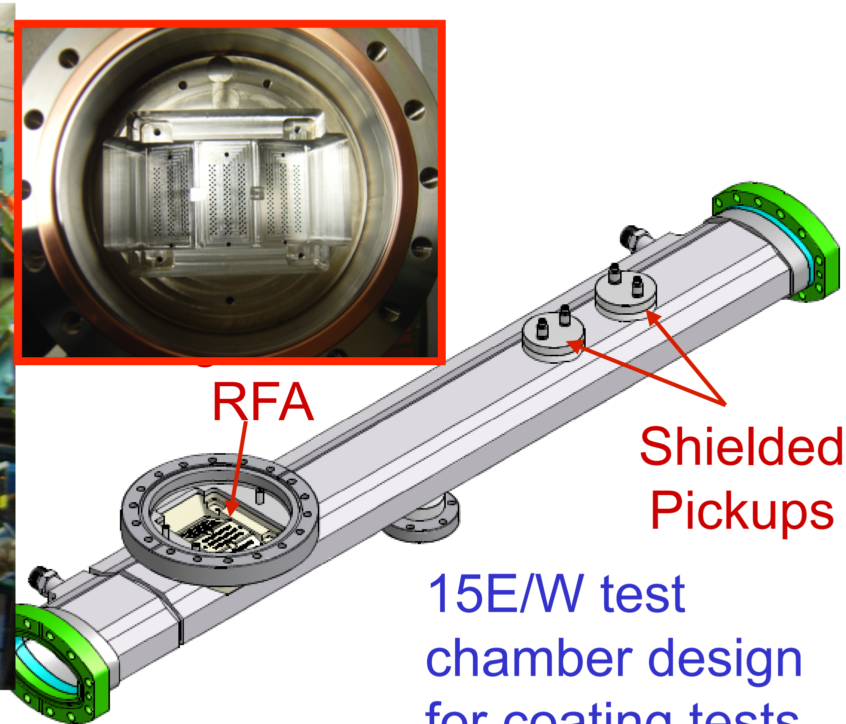




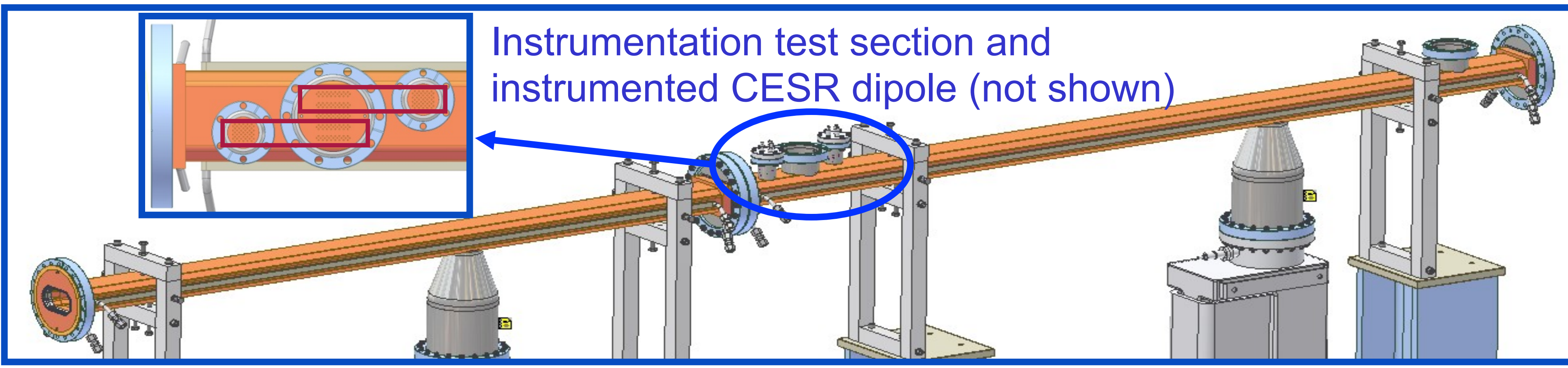
- Overlay of 15 two bunch measurements with varying delay of second bunch
- First bunch initiates cloud
- Second bunch kicks electrons from the bottom of the chamber into the pickup
- Yielding time resolved cloud growth and decay

Mitigation test regions



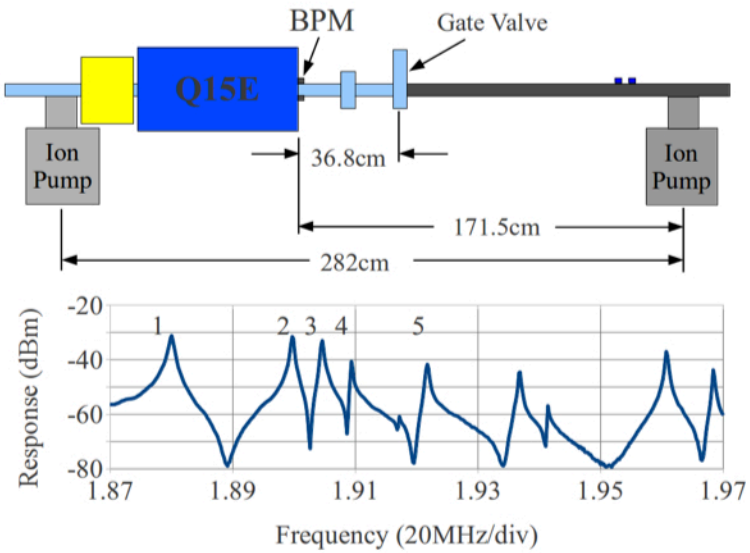


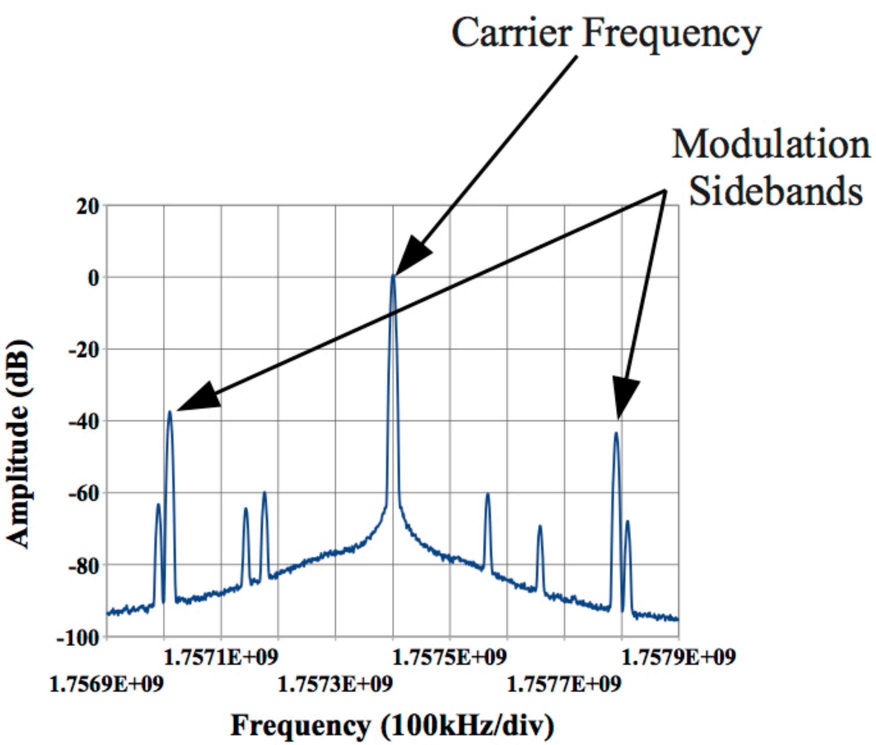
15E/W test chamber design for coating tests



Instrumentation test section and instrumented CESR dipole (not shown)

Resonant TE Wave Excitation

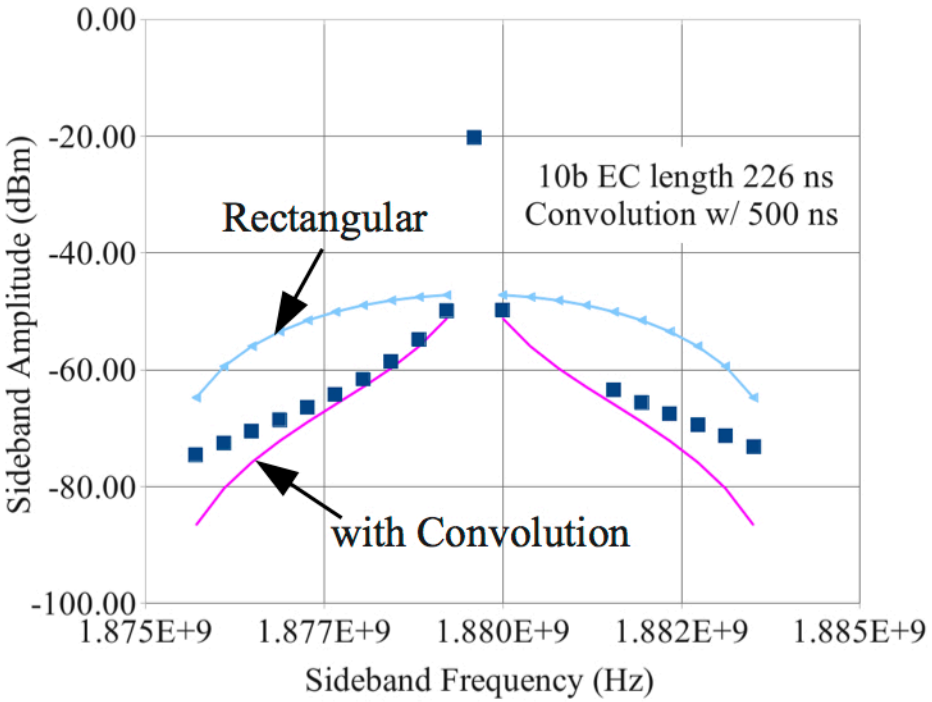


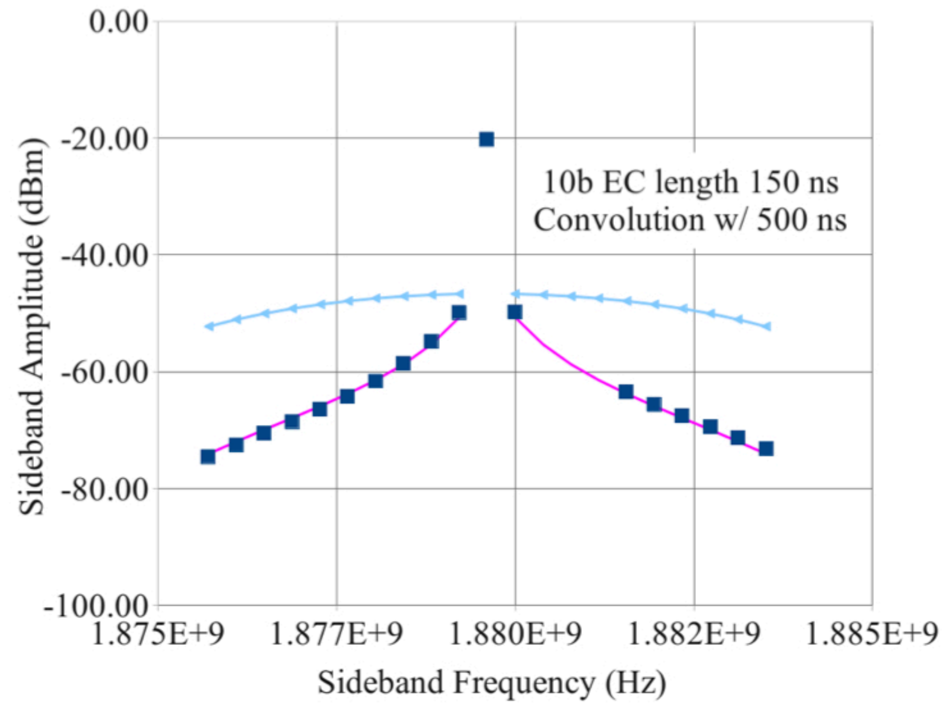


- Longitudinal slots at the ion pumps produce standing waves at several frequencies.
- .When excited with a fixed frequency, modulation sidebands are observed with stored beam.

TE wave diagnostic

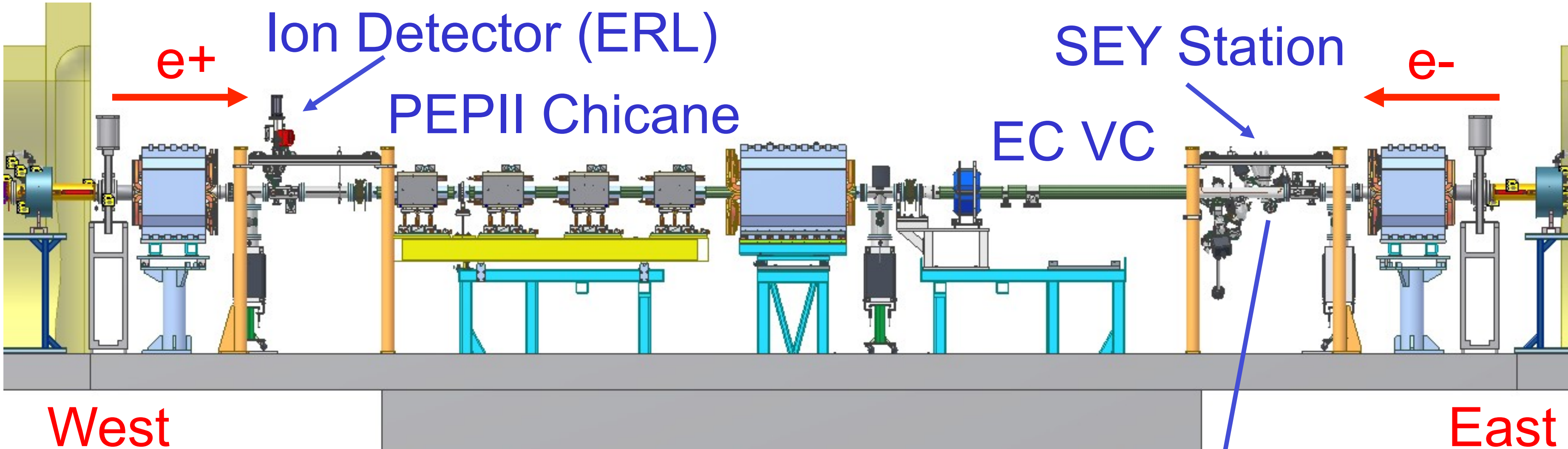
10 Bunches of 5.3 GeV Positrons (14 ns), 85 mA total

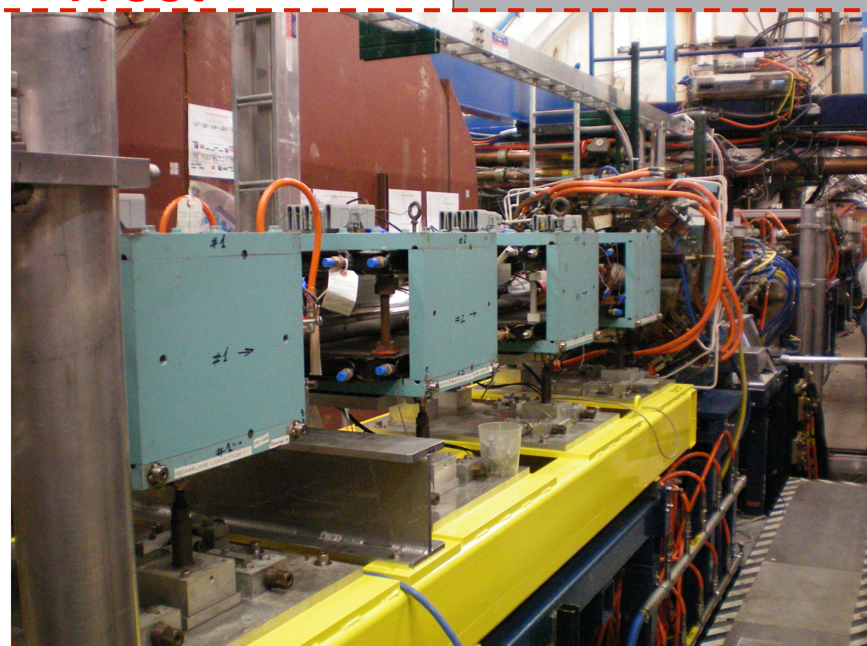


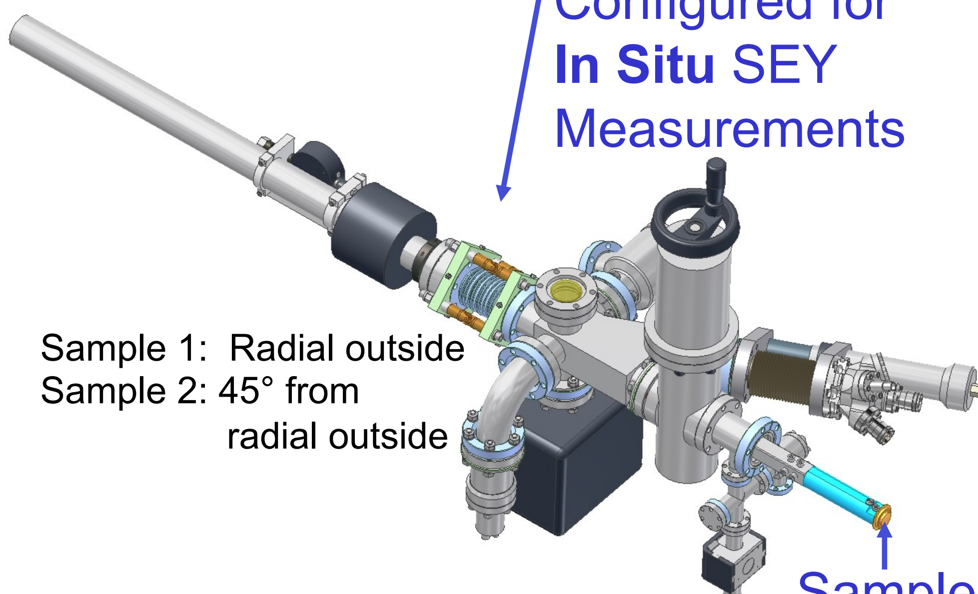


- Blue symbols are data from 15E, the curves are calculations (with arbitrary vertical offsets).
- The rectangular approximation is a poor match to data beyond the first sideband.
- Sidebands calculated after convolution using an EC duration of t_0 = 226 ns (train length + 100 ns) is better, but diverges at higher sideband frequencies.
- An EC duration of t_0 = 150 ns (right) gives fairly good agreement over the measured range.

In situ SEY measurement

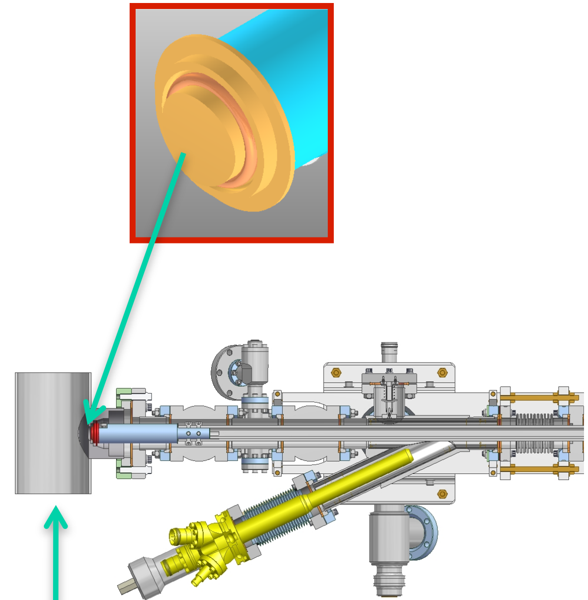




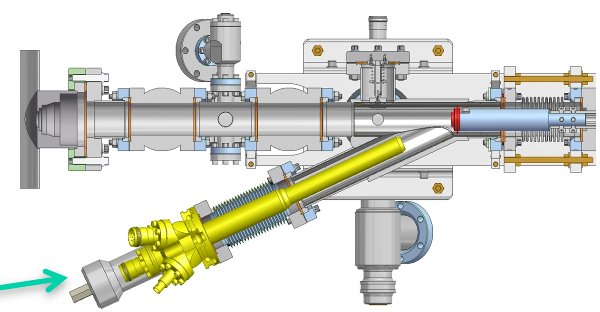


In situ – SEY measurement

Measure secondary emission yield
And the effect of beam processing



Positron beam



Electron gun

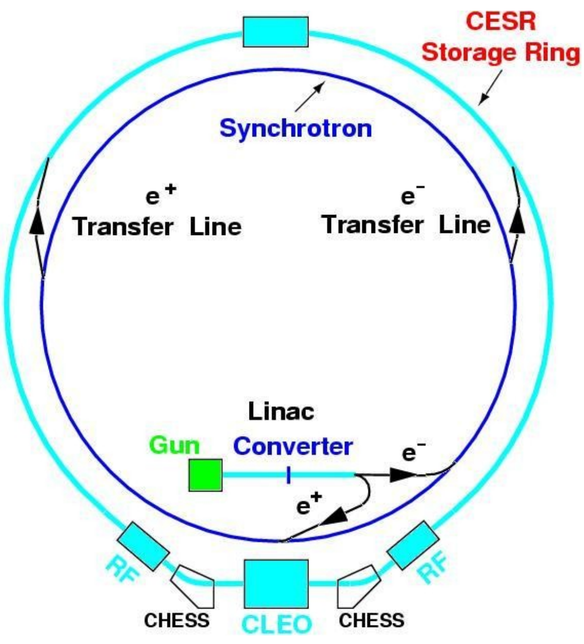
ODR Experiment

Project aim:

To design and test an instrument to measure on the micron-scale the transverse (vertical) beam size for the Compact Linear Collider (CLIC) using incoherent Diffraction Radiation (DR) at UV/soft X-ray wavelengths.

Cornell Electron Storage Ring Test Accelerator (CesrTA) beam parameters:

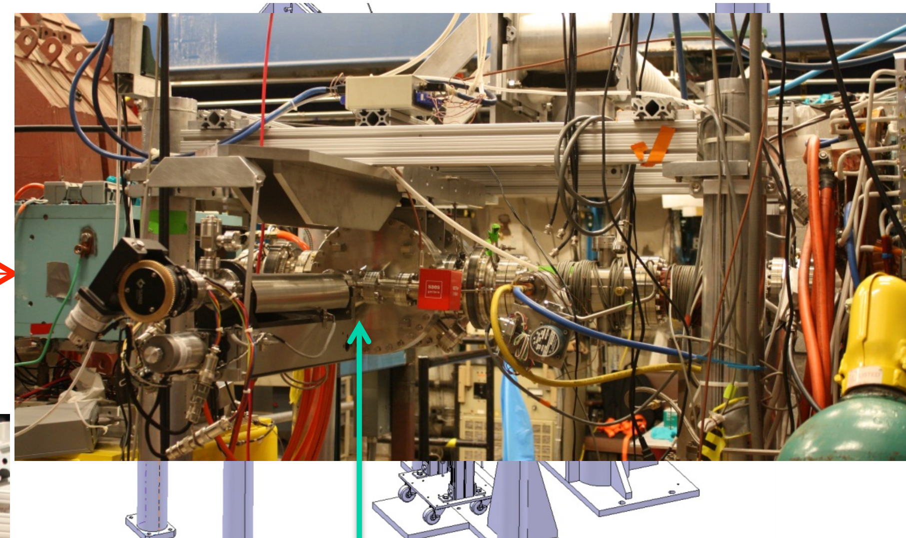
	E (GeV)	σ_H (μm)	σ_V (μm)
CesrTA	2.1	320	~9.2
	5.3	2500	~65



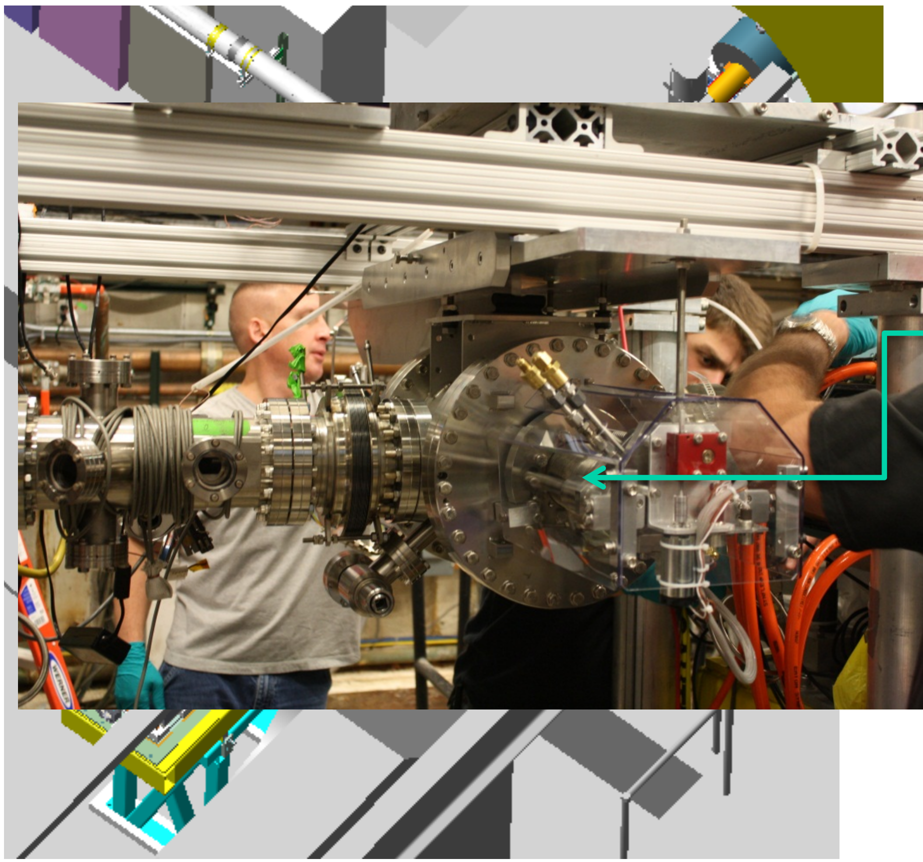
http://www.cs.cornell.edu

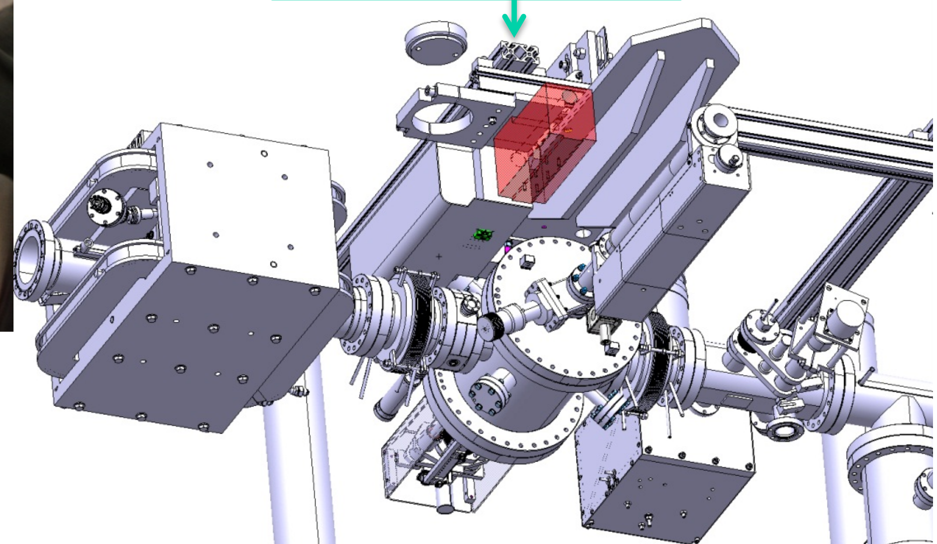
ODR - L3 Layout

Electron beam direction



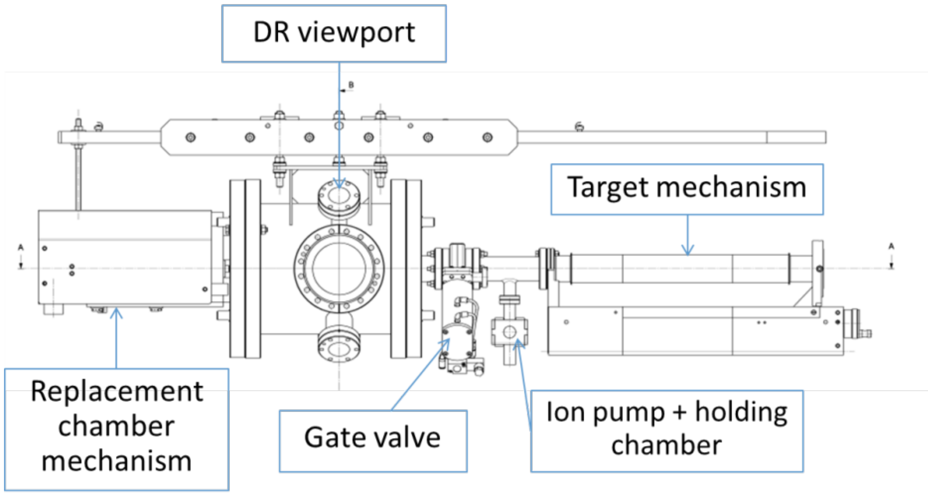
DR experiment

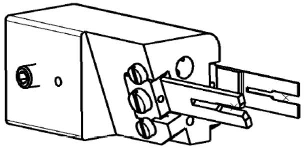


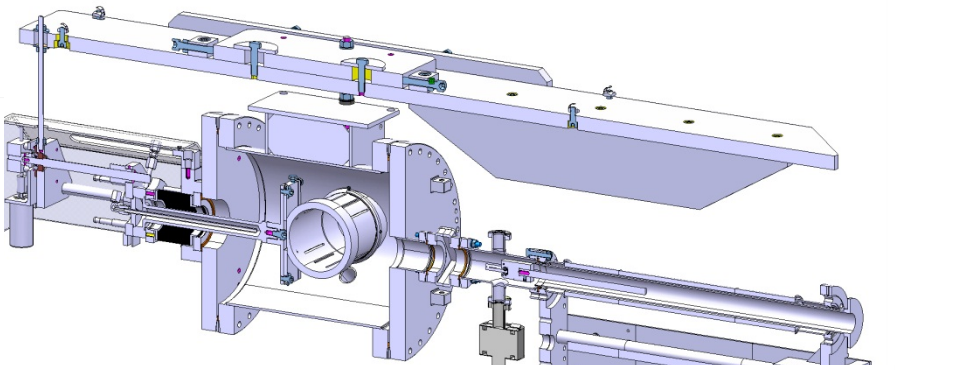


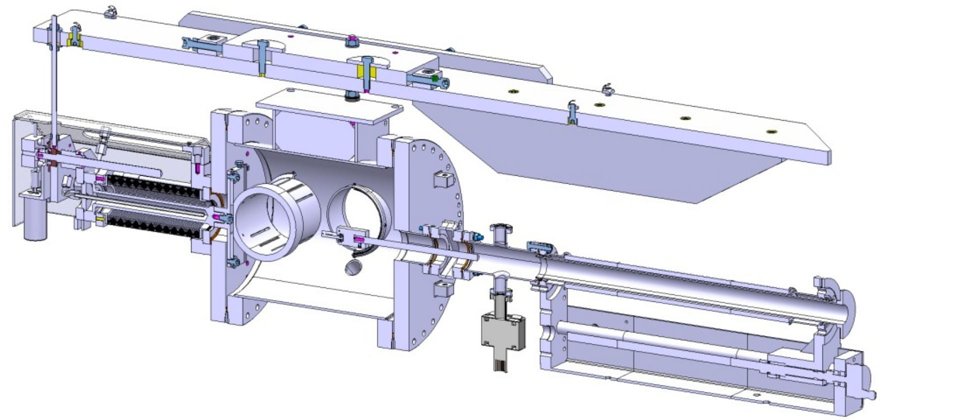
Technical drawings by N. Chritin

Vacuum Chamber Assembly





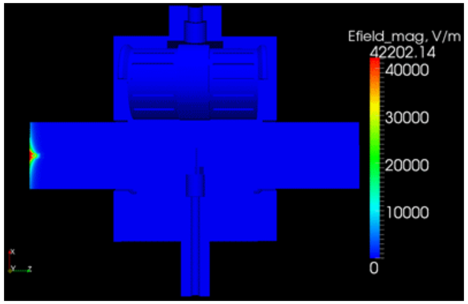


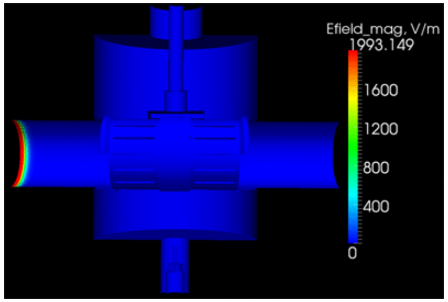


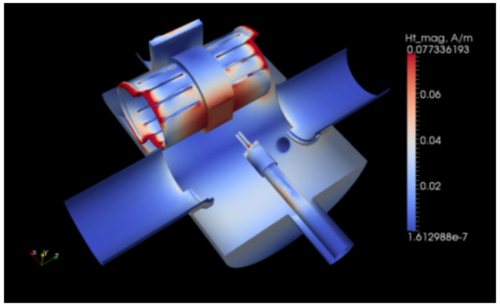
Simulations by A. Nosych
Technical drawings by N. Chritin

E-field magnitude of a single bunch pass in time domain (Gaussian bunch, length = [-4σ, 4σ], σ = 10mm)

H-field surface tang complex magnitude (Loss map) Mode F = 1.19 GHz, Q = 3309, P-loss = 0.075 W



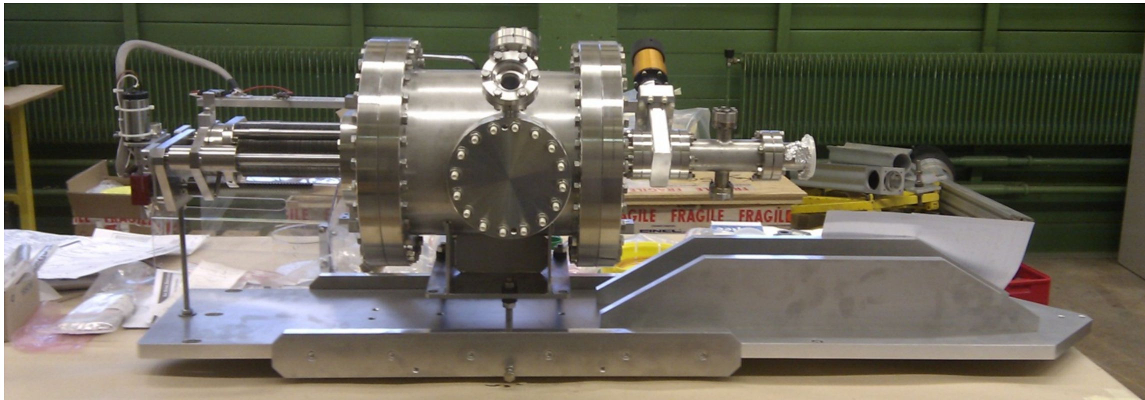




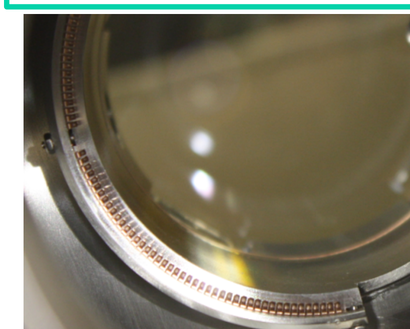
Total power loss for CHESS Operations ~ 35 W

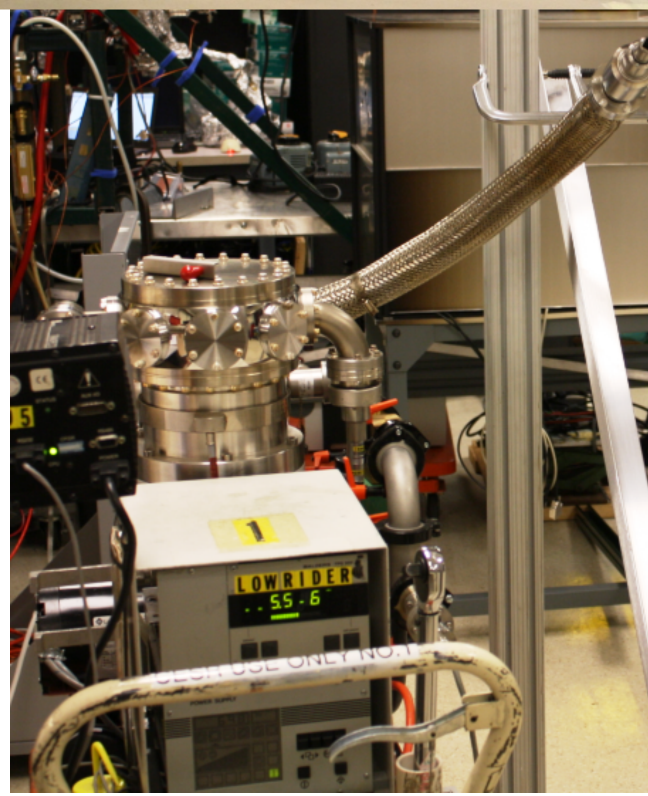
ODR Experiment: single10 mA bunch = 0.6 W

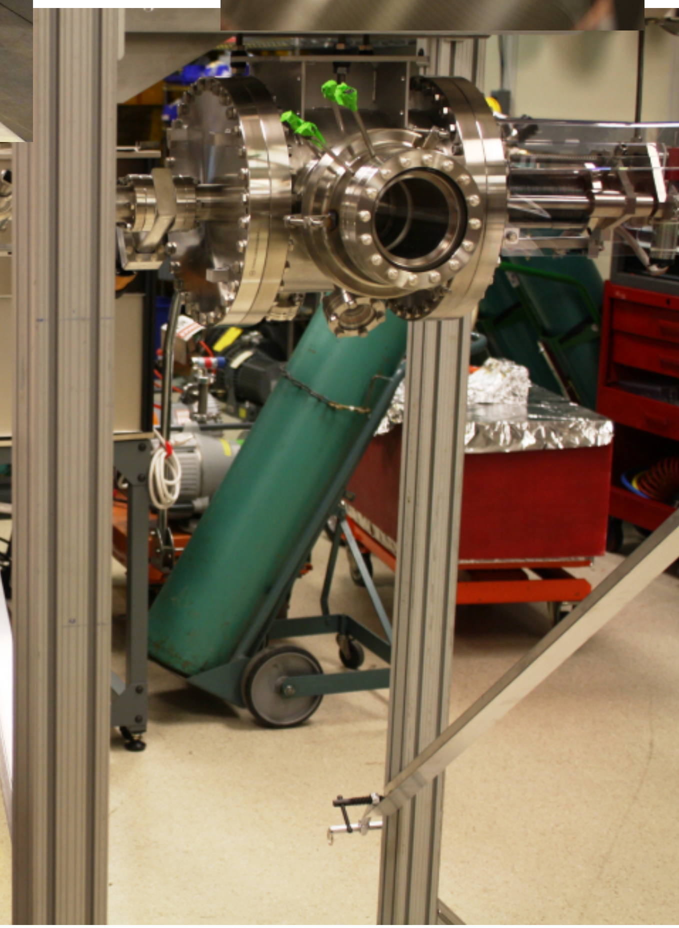
Vacuum Chamber Assembly



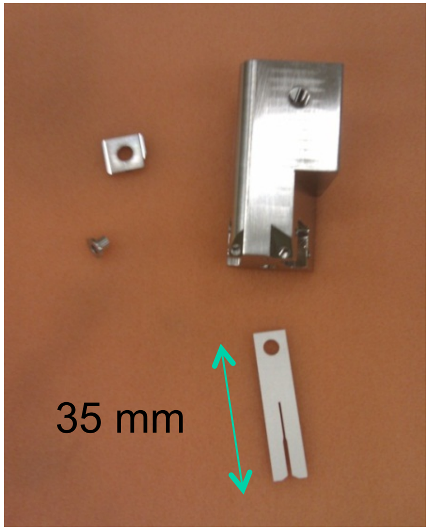
Images taken during assembly at CERN and Dec '12 testing at Cornell.







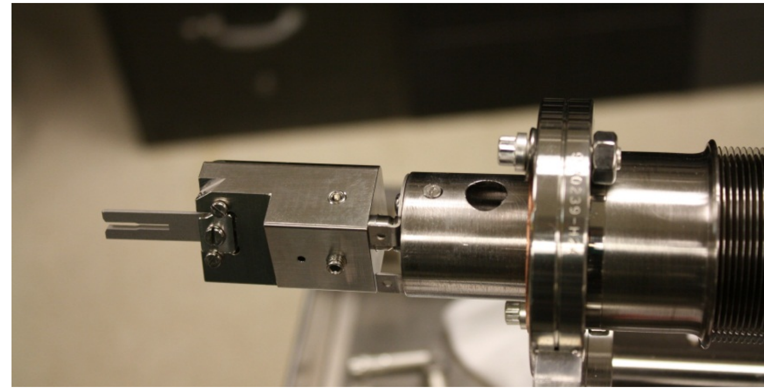
ODR Dummy Target

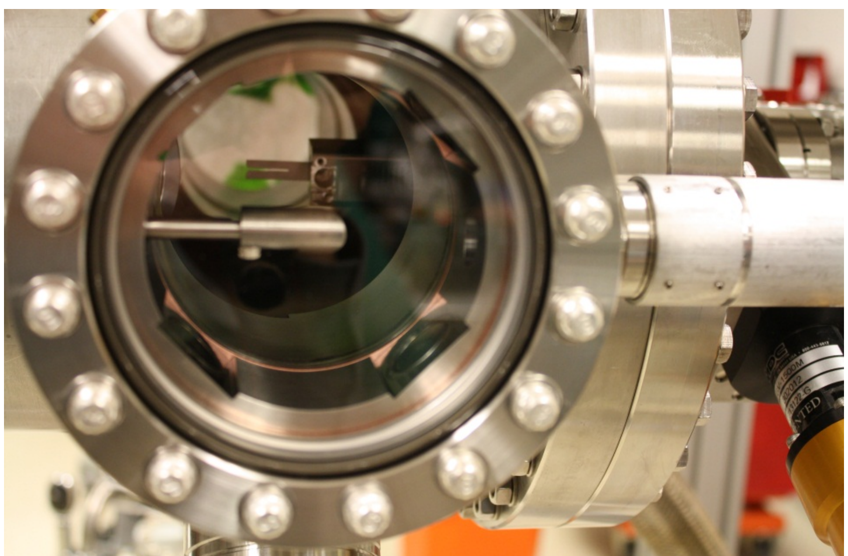


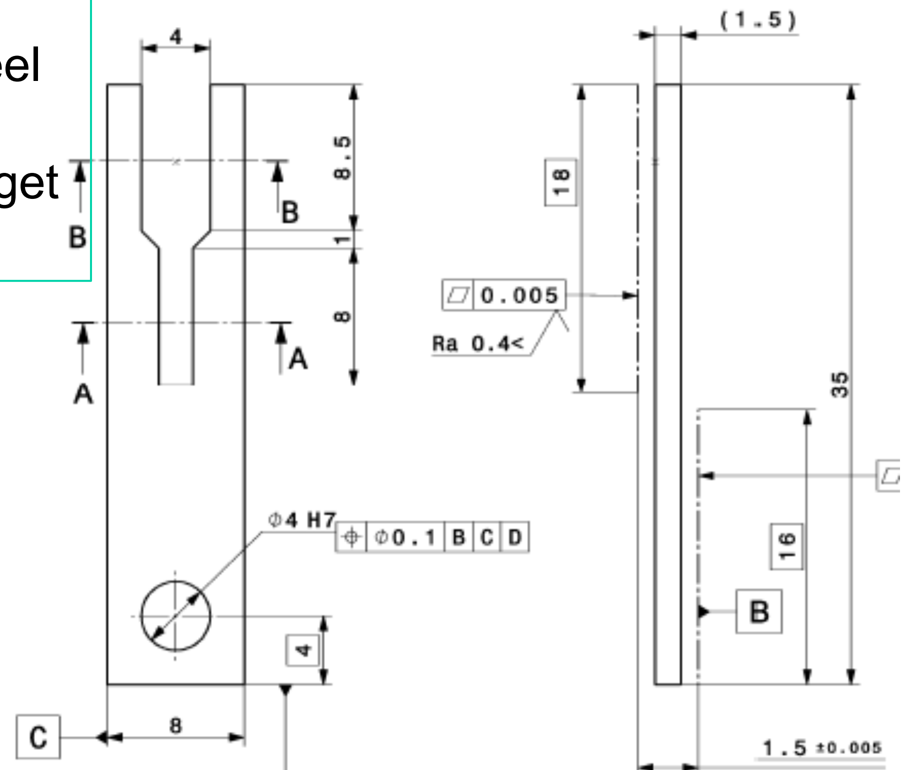
Planned aperture sizes: 2 mm and 4 mm
{Actually was 0.4 mm and 1 mm}

Material: Stainless steel

Note: This dummy target was not polished







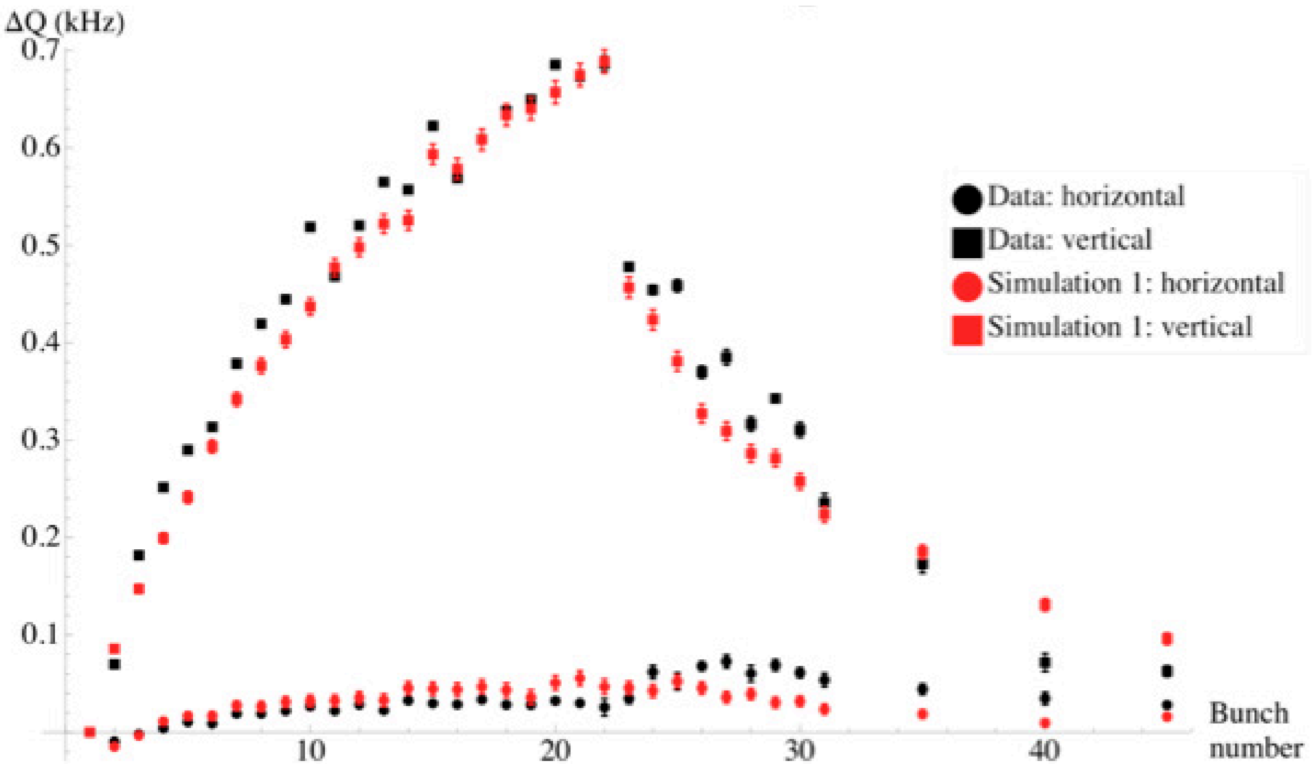
Technical drawings by N. Chritin

Images by Y. Li

Global Measurement of Electron Cloud

Cloud density increases along a train of bunches

The cloud electrons focus the traversing positron bunch, shifting the tune

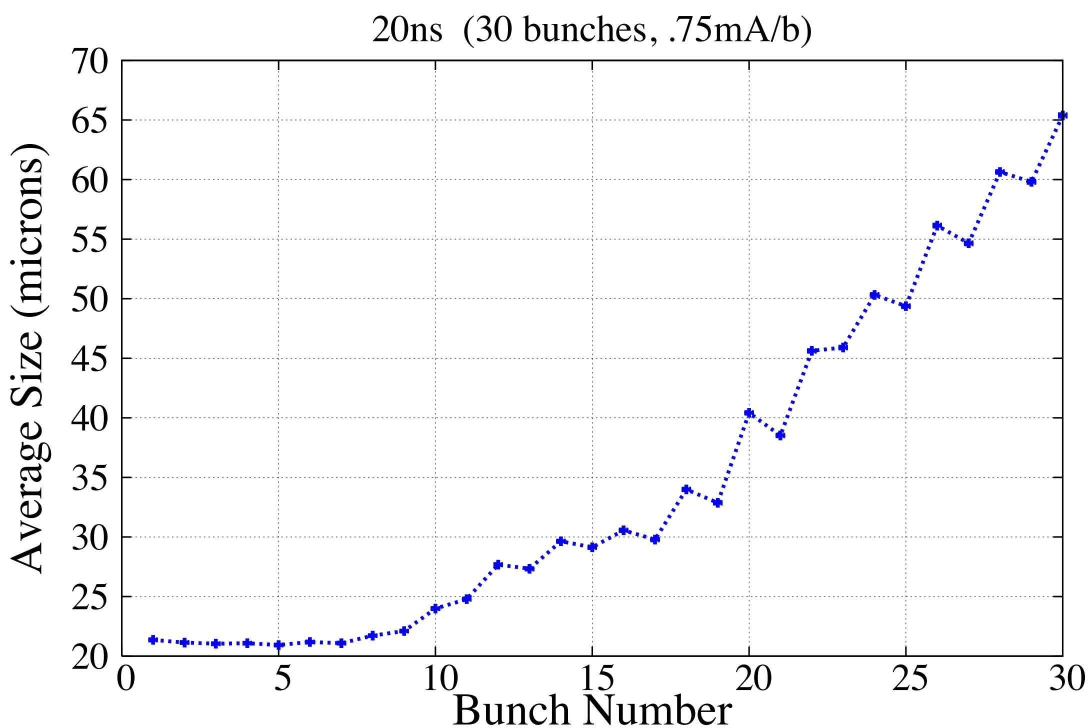


The differential focusing (tune shift) is our measure of the cloud density along the train of bunches

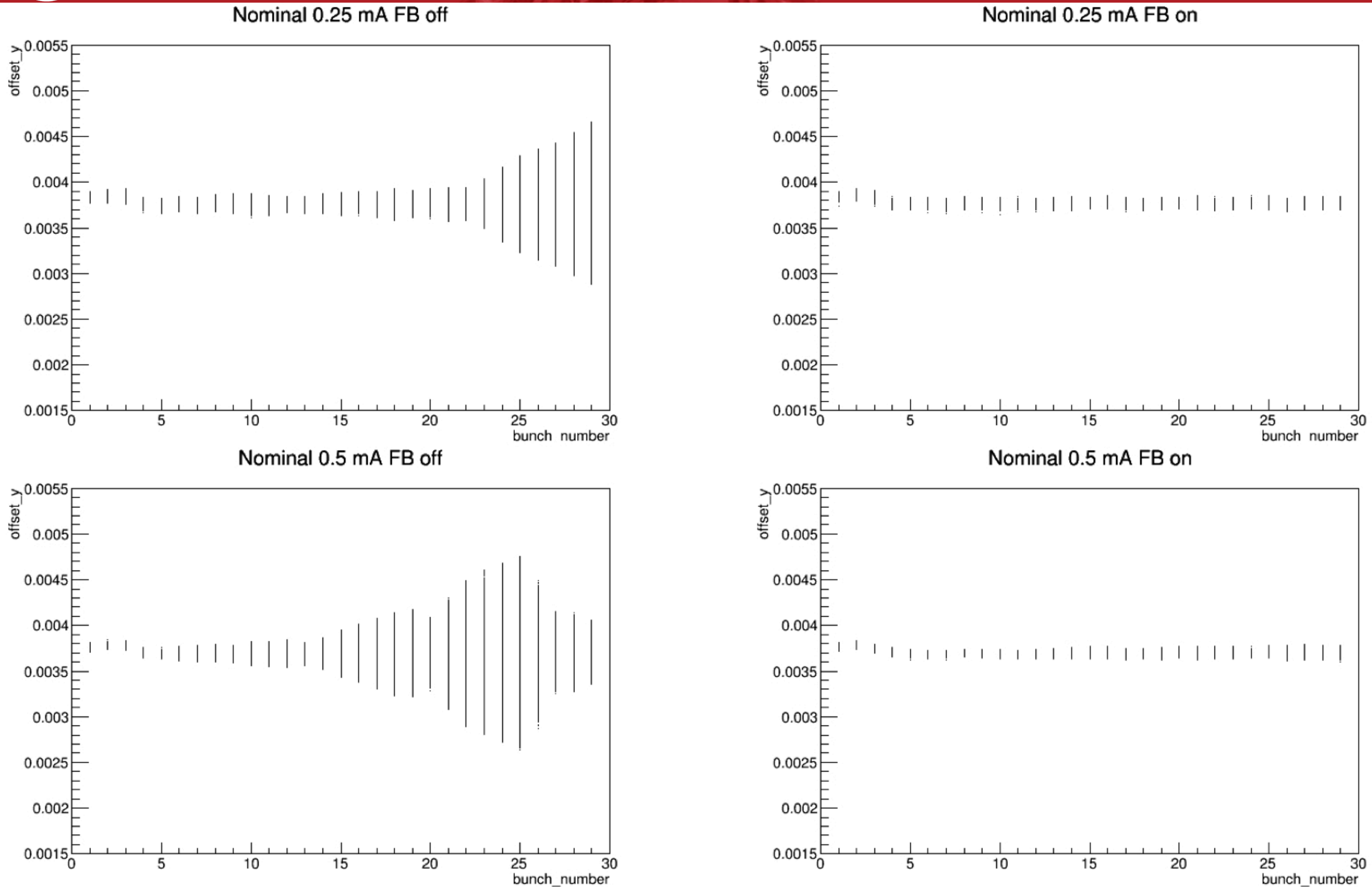
Electron cloud emittance dilution

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

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

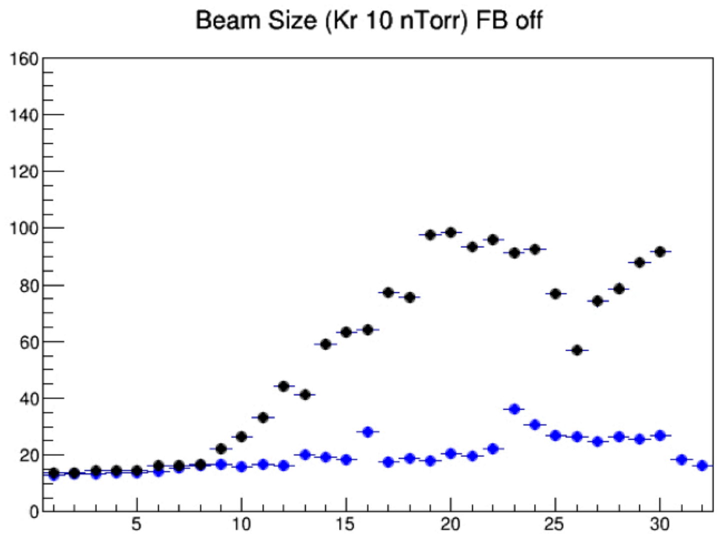


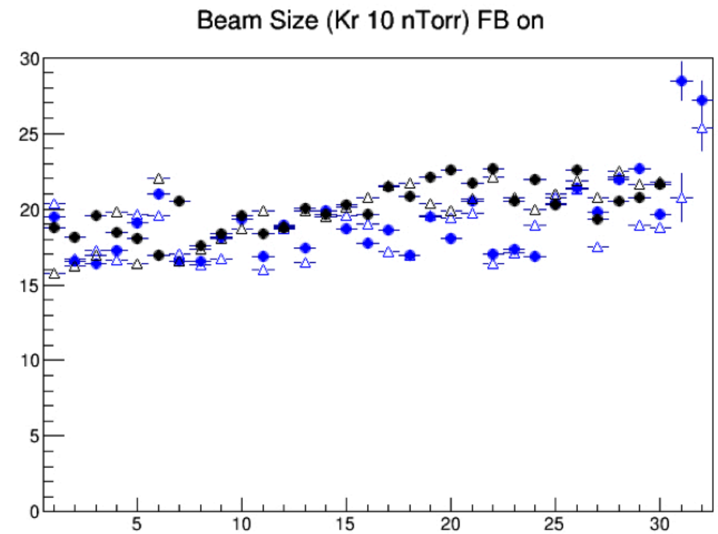
Fast Ion Instability



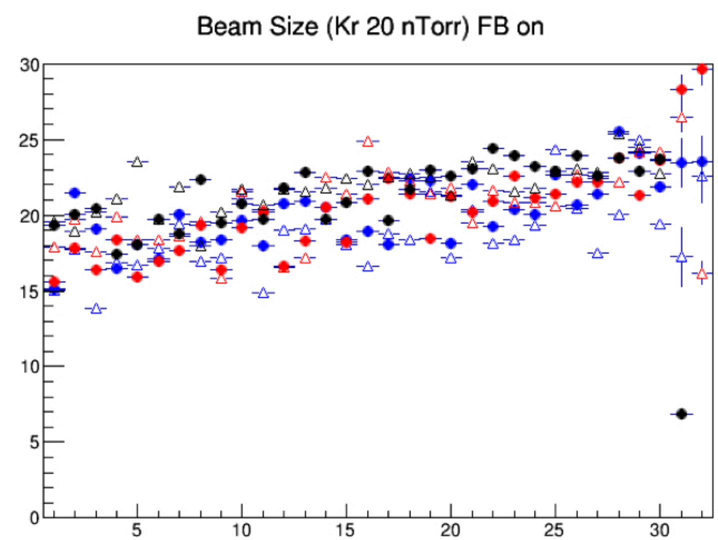
30 bunches electrons, 14ns spacing, turn by turn position

Fast Ion Instability





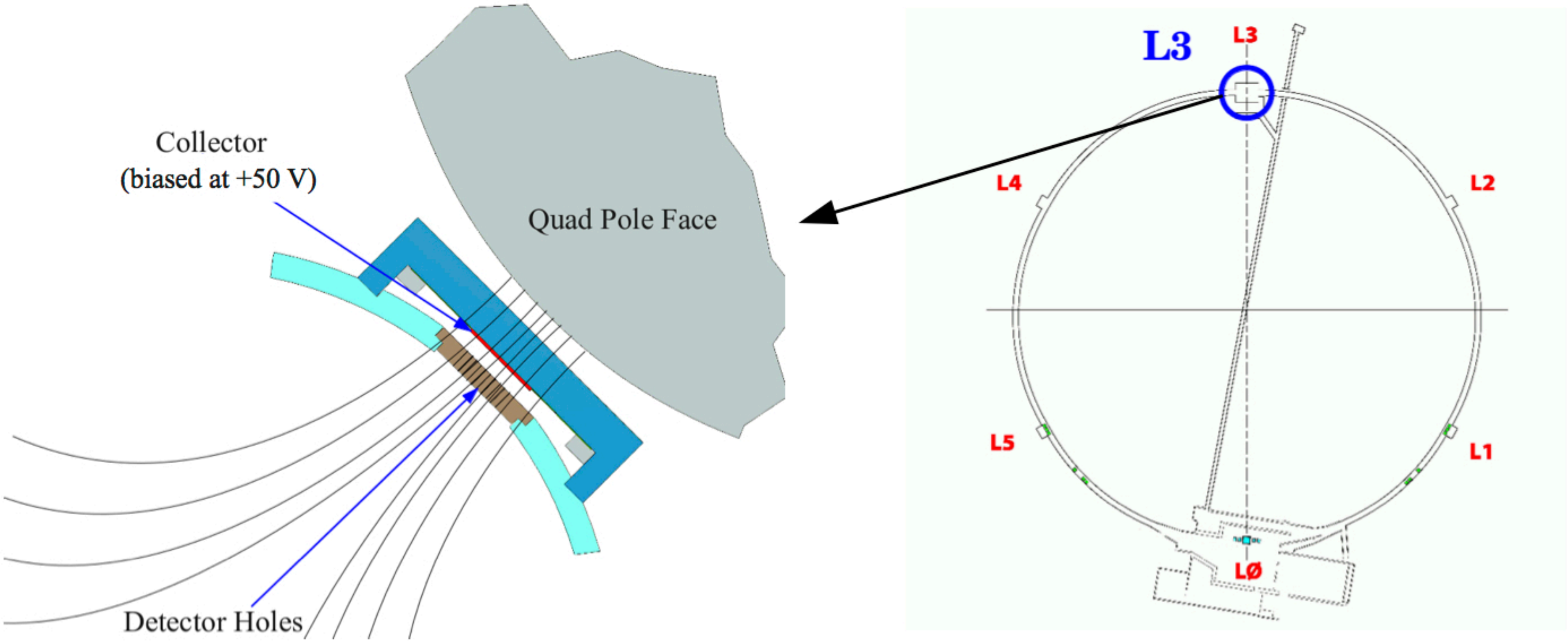
0.25 mA
0.5 mA
0.75 mA



- Kr 20 nTorr w/ vertical FB off does not have xBSM plot because the data was bad even for 0.25 mA.
- For other cases, there's one RD file per current with FB off, and two RD files per current with FB on (filled circle and open triangle).

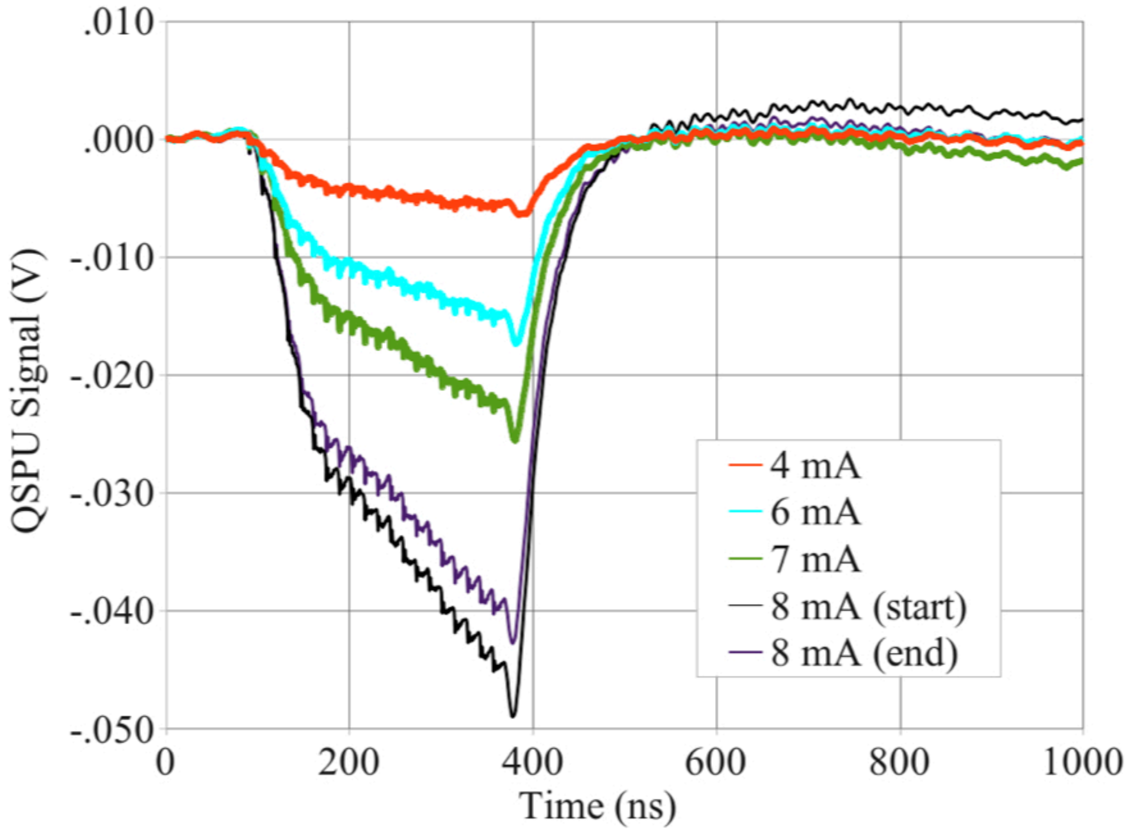
Simulation developed for CLIC Linac by A. Oeftgier and G. Rumolo and adapted for ring by A. Chattergee

Shielded Pickup installed in Q48W at CesrTA



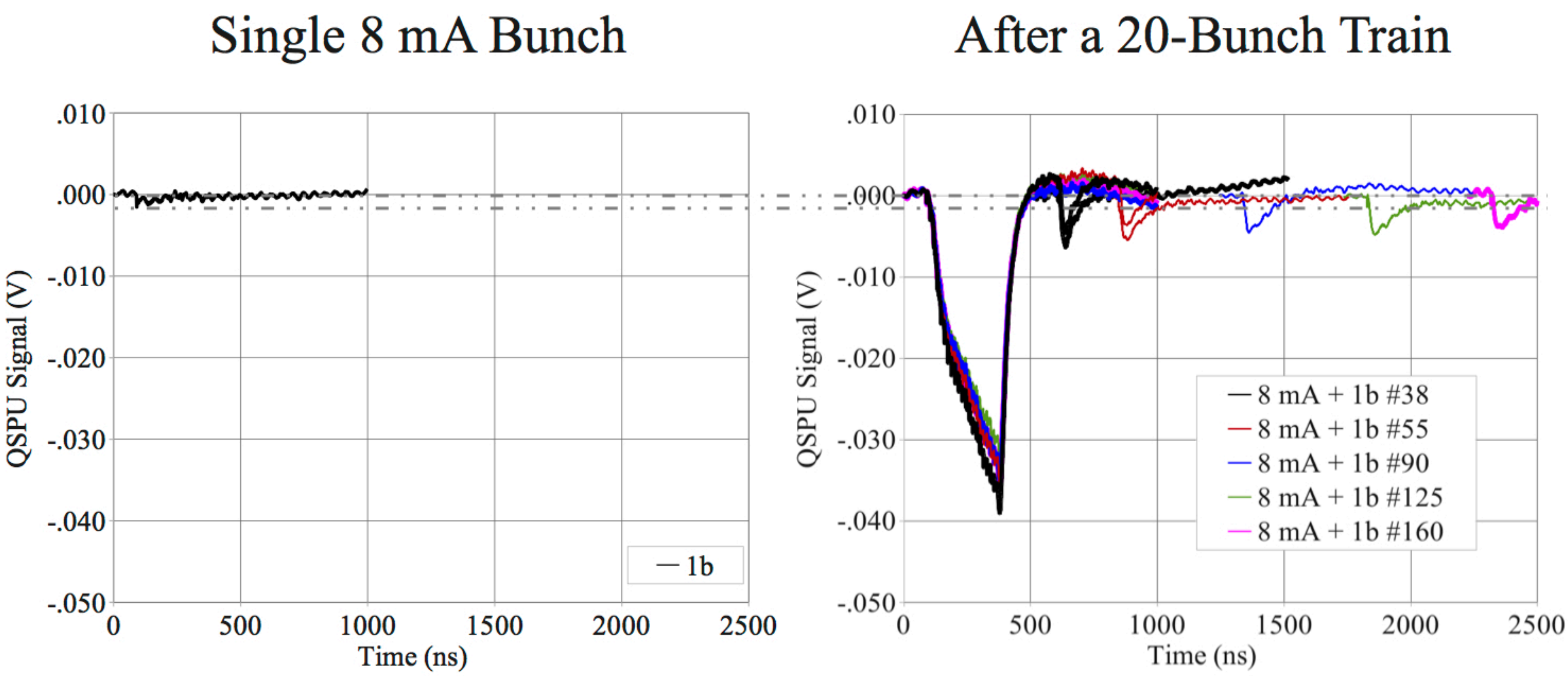
- This collector is centered on the quad pole face and centered longitudinally in the magnet.
- 300 holes of 0.79 mm dia. allow the electrons to pass from the beam-pipe onto the collector.
- The collector is biased at +50 V and signals are amplified by 40 dB before being digitized.
- In this experiment, all trains are comprised of 14 ns spaced positron bunches.
- All data has been filtered (12 ns) to reduce sensitivity to the direct beam signal.

20-Bunch Data versus Bunch Current



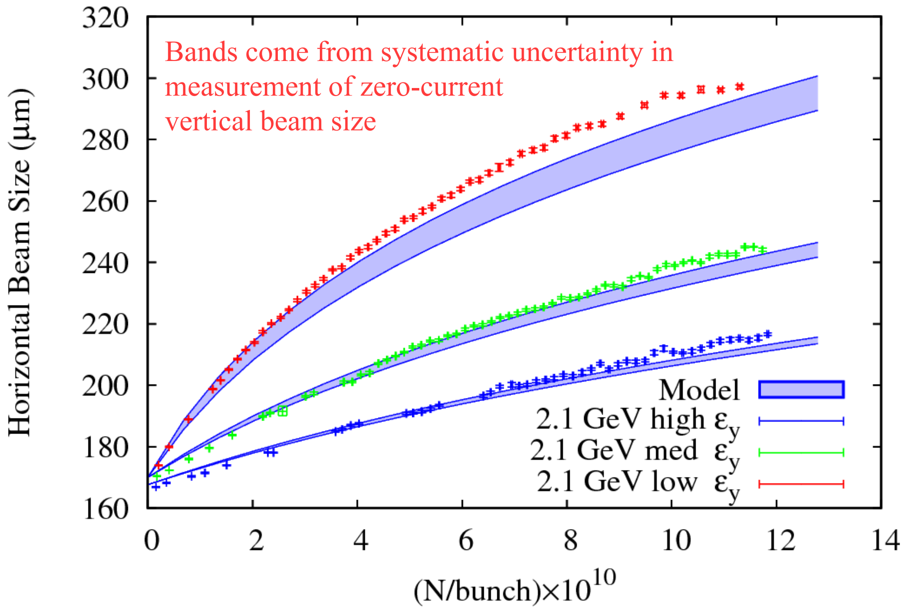
- The collector signal increases rapidly with bunch current.
- The 8 mA/bunch signal changed between the start and the end of the experiment (< 3 hours). We had just changed from 2.1 GeV to 5.3 GeV operation.

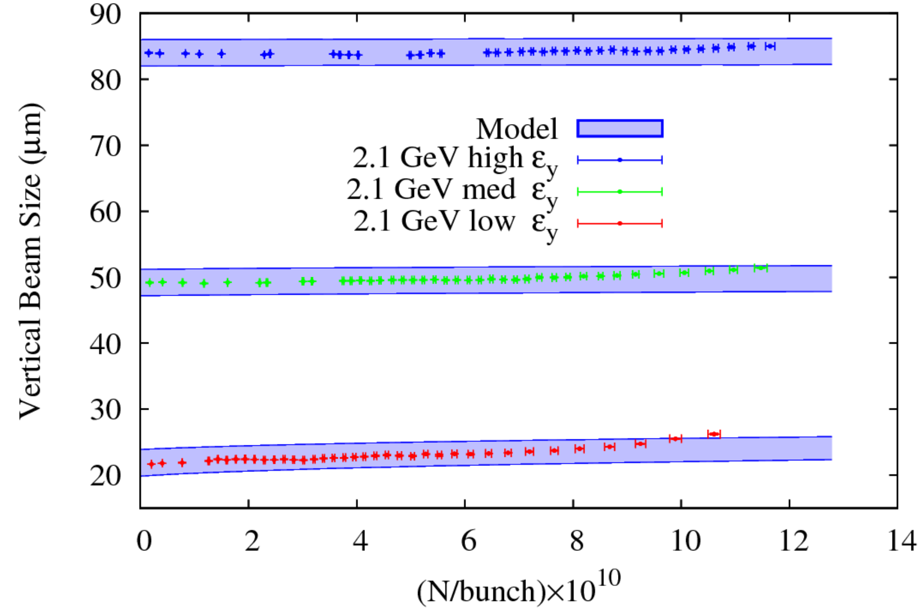
Quadrupole electron cloud pickup



- The plot at right is an overlay of signals from a 20-bunch train followed by a single witness bunch at different spacings after the train.
- The single bunch signals (right) are significantly larger than they were without the 20-bunch train (left). The difference is due to the (additional) trapped cloud.

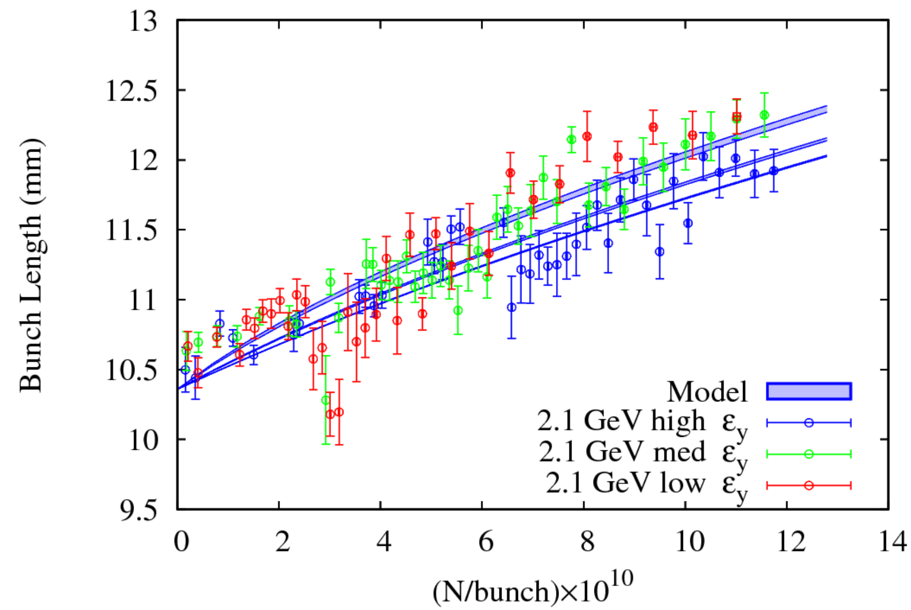
Intra-beam scattering - 2.1 GeV Results





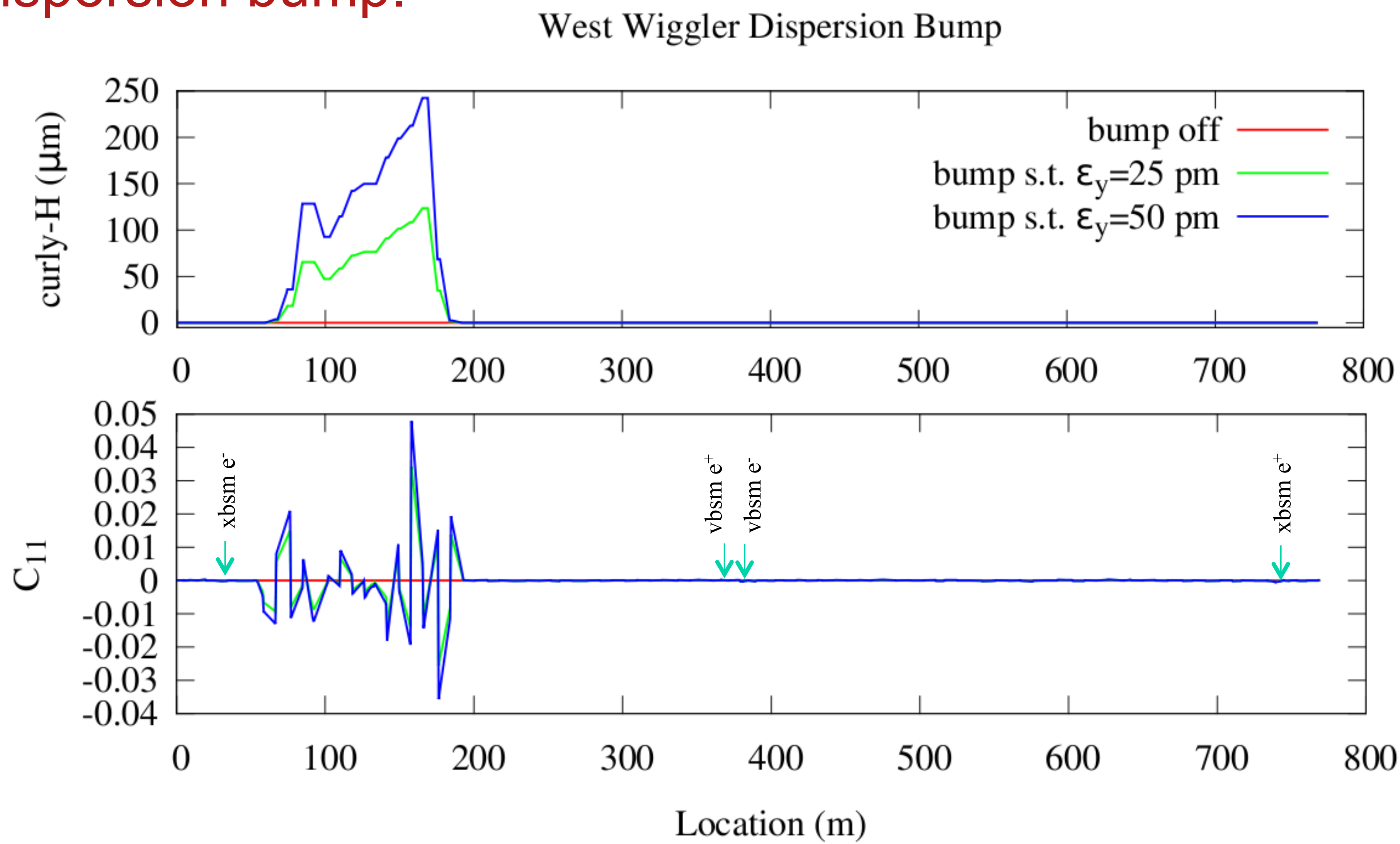
	Zero Current		High Current (data)
Run ID	ε_{y0} (pm)	ε_{x0} (nm)	ε_x (7.5 10^{10} part) (nm)
Low ε_{y0}	9.6 – 13.9	3.6	7.25
Med ε_{y0}	54.2 – 63.8	3.6	6.55
High ε_{y0}	163.6 – 179.9	3.5	5.18

$^*7.5 \times 10^{10}$ part. ≈ 12 nC ≈ 5 mA

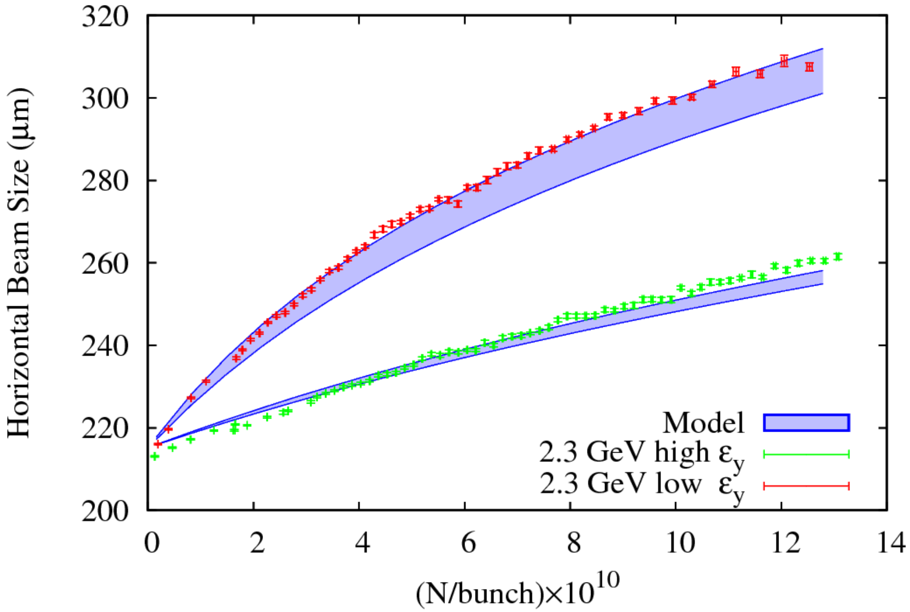


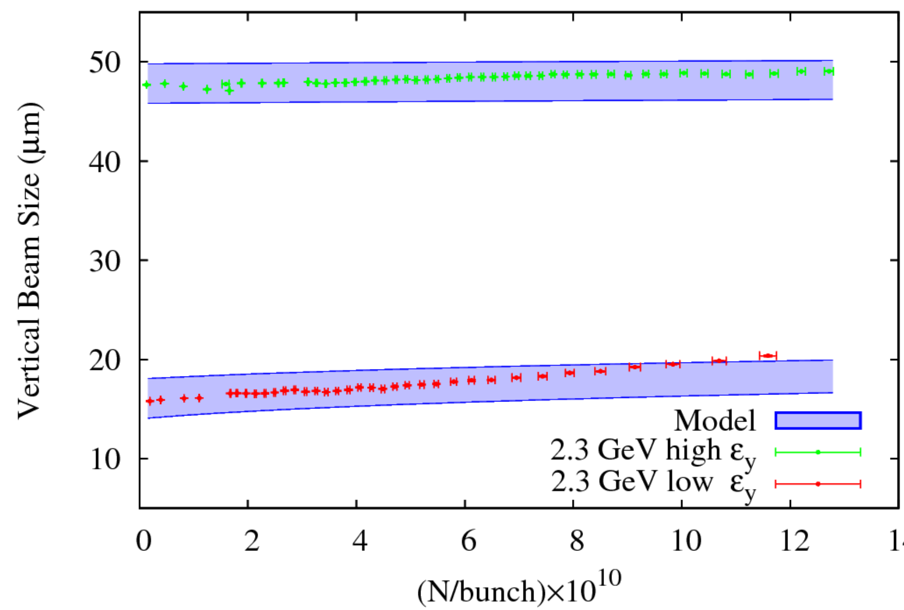
Emittance Adjustment for IBS …

7 skew quads are used to create a closed coupling and dispersion bump.



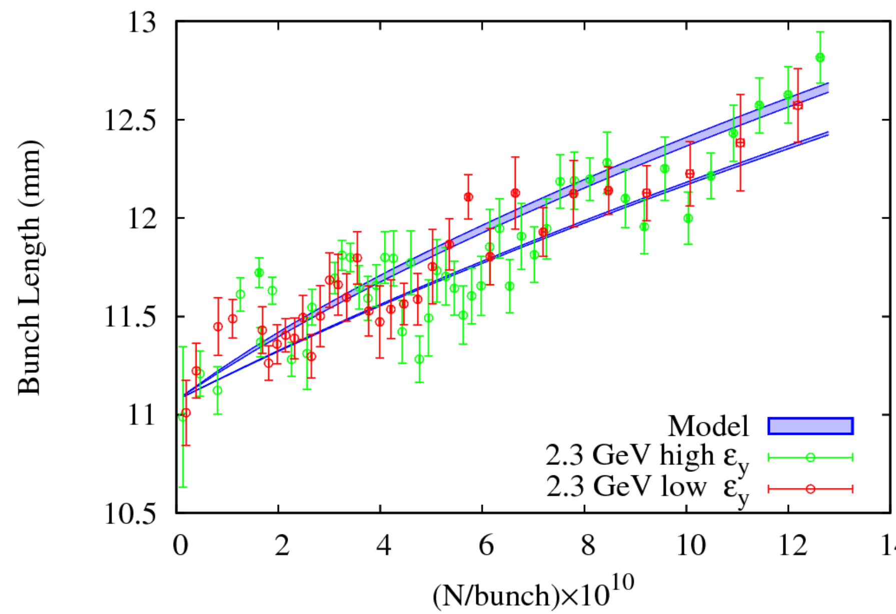
IBS - 2.3 GeV Results



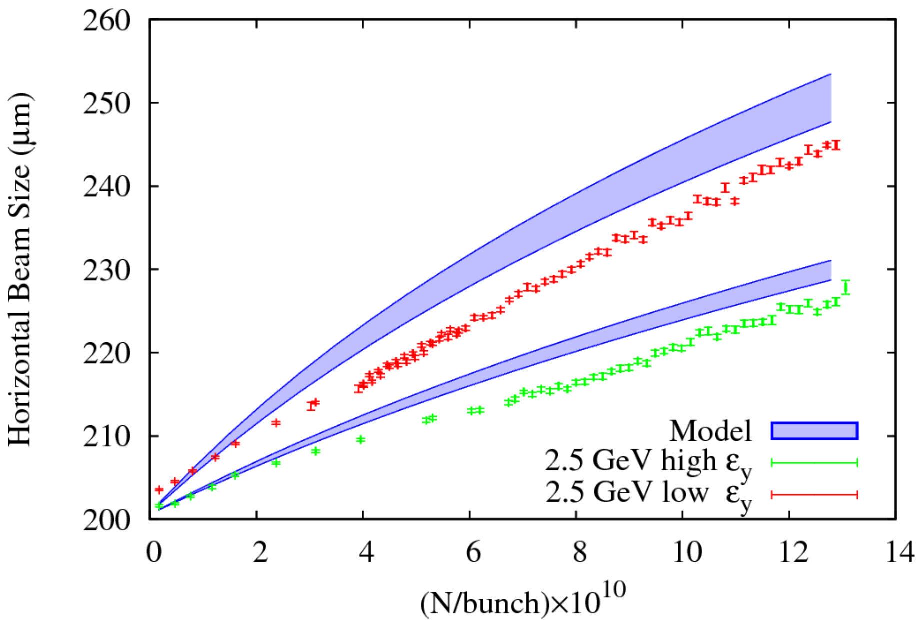


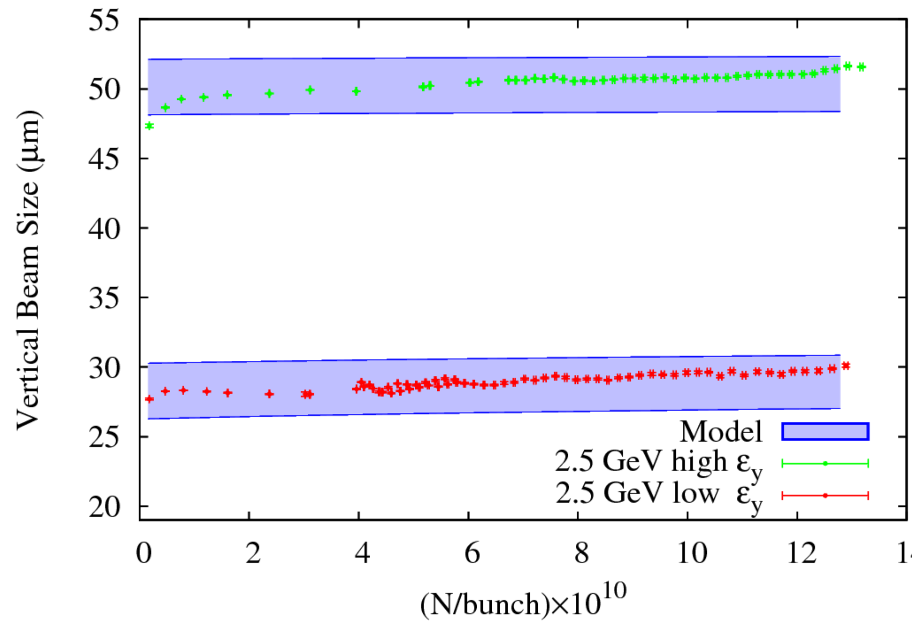
	Input Parameters		Result at high current
Run ID	ϵ_{y0} (pm)	ϵ_{x0} (nm)	ϵ_x (7.5 10^{10}) (nm)
Low ϵ_{y0}	4.9 – 8.1	5.7	10.4
High ϵ_{y0}	52.3 – 61.8	5.7	7.62

$^*7.5 \times 10^{10}$ part. ≈ 12 nC ≈ 5 mA

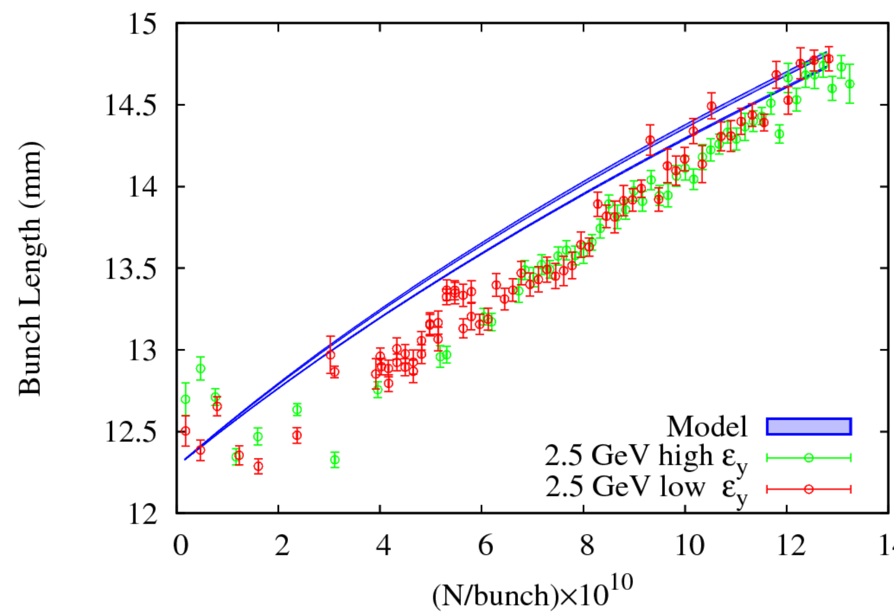


IBS - 2.5 GeV Results



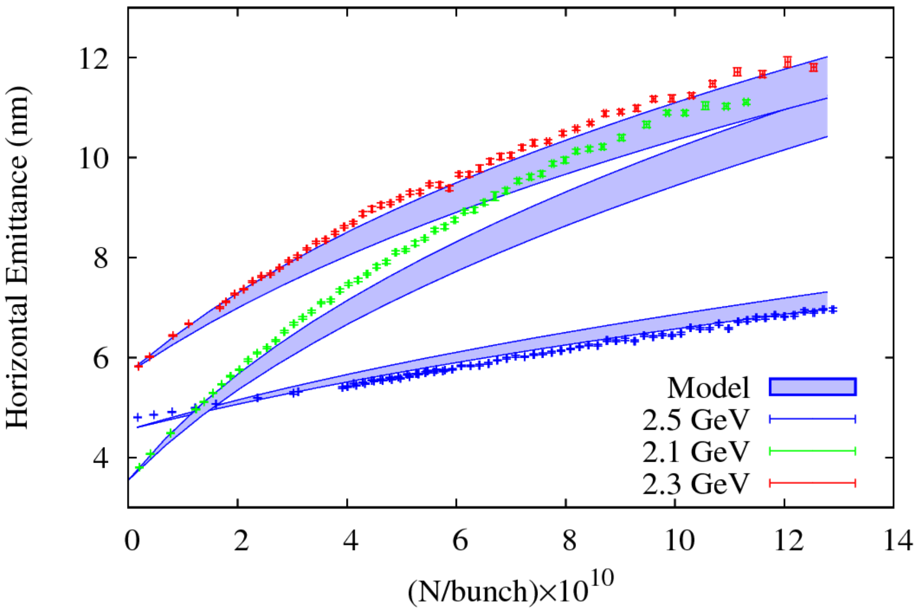


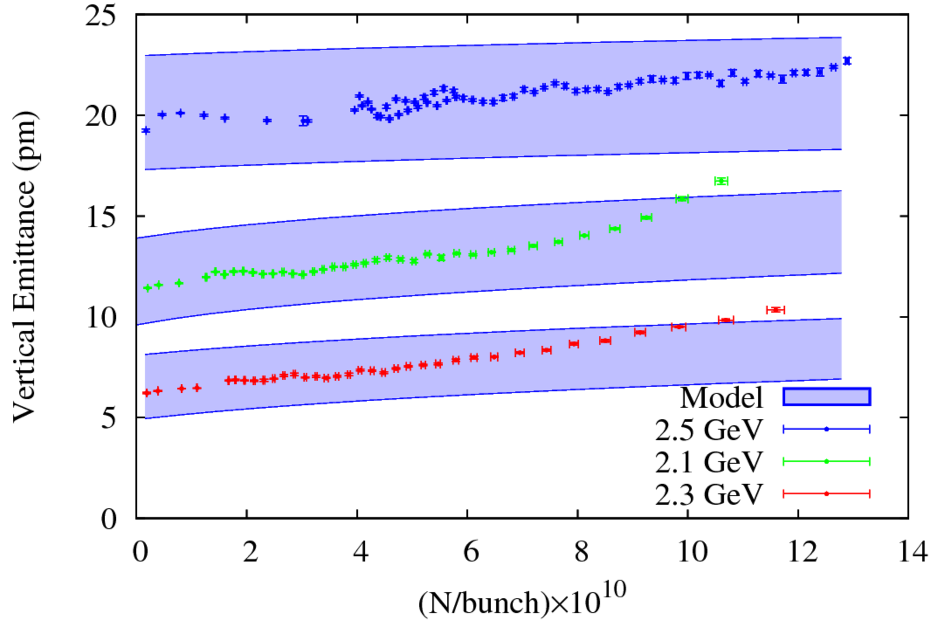
	Input Parameters		Result at high current
Run ID	ε_{y0} (pm)	ε_{x0} (nm)	ε_x (7.5 10^{10}) (nm)
Low ε_{y0}	17.29 – 23.0	4.6	6.6
High ε_{y0}	58.1 – 68.1	4.6	5.84



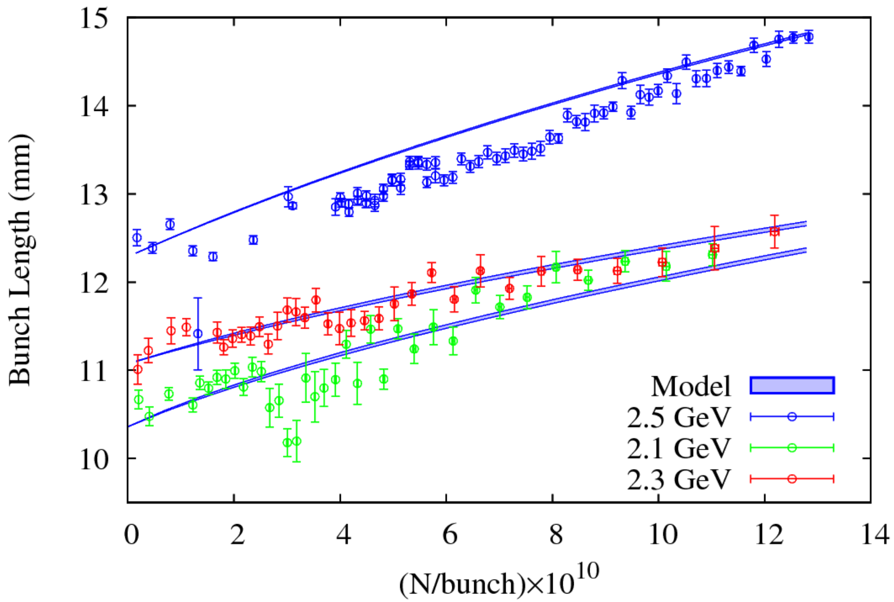
$^{*}7.5 \times 10^{10}$ part. ≈ 12 nC ≈ 5 mA

IBS Combined Results vs. Energy





Low ε_y Conditions	
2.1 GeV	101 % ε_x Blowup
2.3 GeV	82 % ε_x Blowup
2.5 GeV	43 % ε_x Blowup
~ 50 um Vertical Beam Size Conditions	
2.1 GeV	81 % ε_x Blowup
2.3 GeV	33 % ε_x Blowup
2.5 GeV	27 % ε_x Blowup



Summary

- CESR is instrumented for study of physics and instrumentation for low emittance damping rings
- At 2.1 GeV with damping wigglers, CESR is "wiggler dominated"
- ~ 35 days/year dedicated to experimental program to investigate damping ring phenomena
- Sectors of the ring bounded by gate valves provide opportunity for testing of:
  - Electron cloud instrumentation
  - Mitigations
  - Vacuum chamber geometry
- CesrTA collaboration is exploring
  - Fast Ion Instability
  - Electron Cloud instabilities and emittance growth
  - Intra-beam scattering
  - Electron cloud mitigations
  - Techniques for measuring/monitoring electron cloud
  - Trapped cloud and implications
  - Instrumentation for measuring beam size
  - Techniques for routine and rapid emittance tuning

We Invite collaboration on all of the above and will continue to make CESR available as a test facility