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Research Activities

Overview of current Accelerator Physics research involvement.

Rohan Dowd
Senior Accelerator Physicist

Science. Ingenuity. Sustainability.

Overview

- Emittance minimization and the Quantum Limit
- Beam based alignment
- Studies into IVU generated instabilities
- The CompactLight Collaboration

Vertical Emittance at the Quantum Limit

Achieving the world's flattest beams

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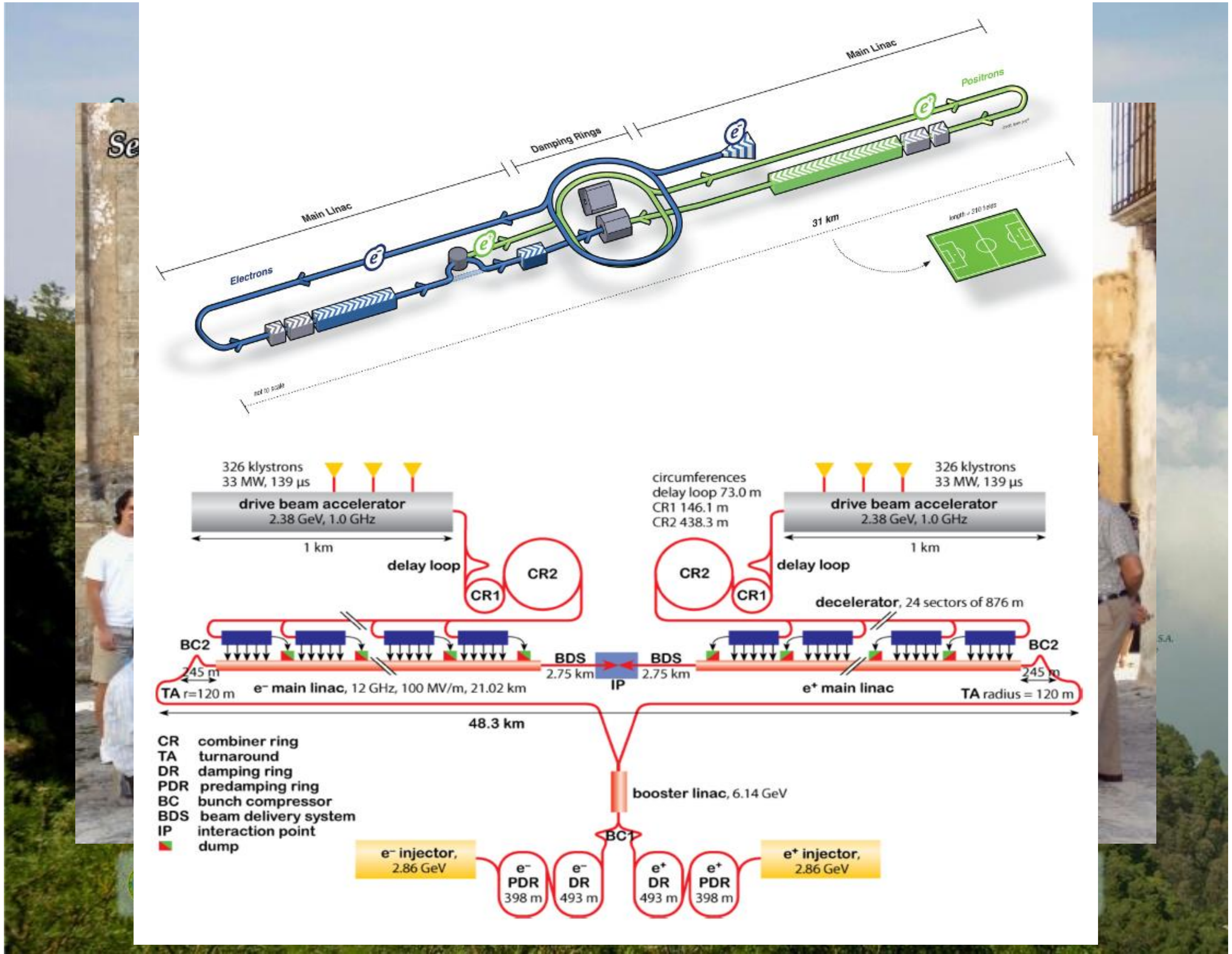
ILC School 2007



- Linear Collider Basics
- Super Conducting & Warm RF Technology
- Beam Dynamics of Collider Linac & **Damping Rings**
- ILC and its Major Systems
- CLIC
- Detectors and Physics

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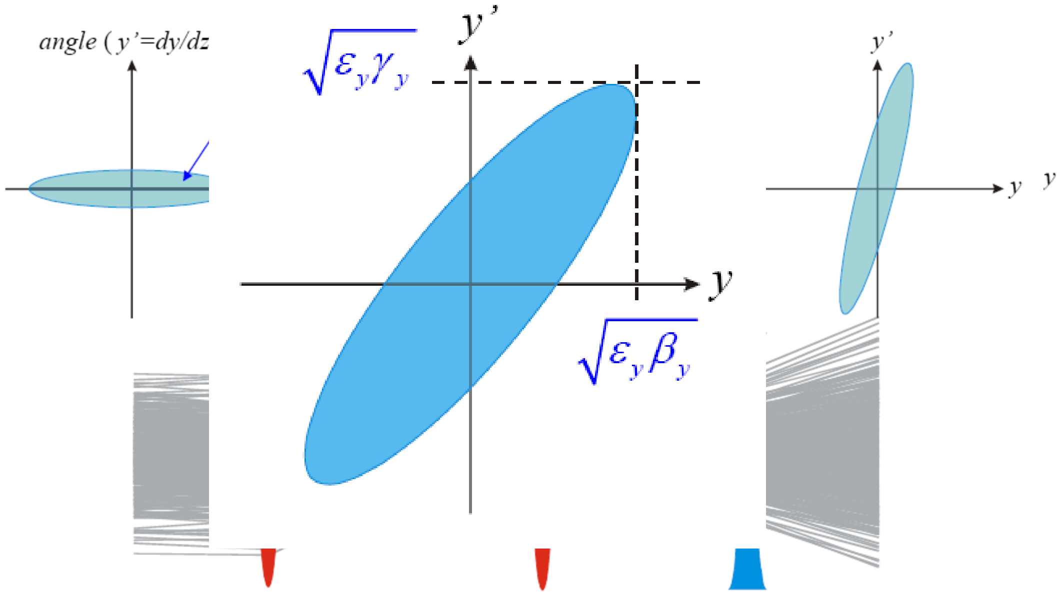
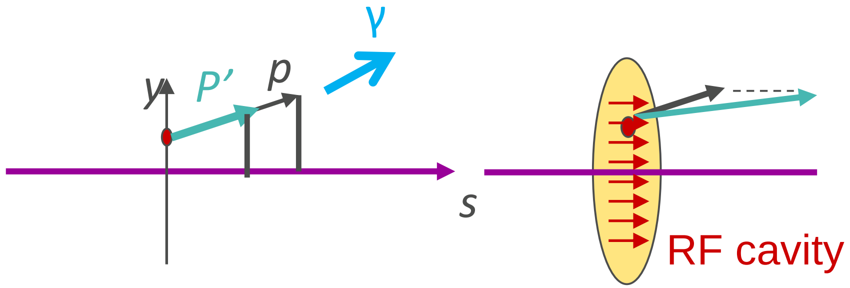
Emittance

- Emittance is the area of phase space the particles in the beam occupy.
- Emission of synchrotron radiation will 'Damp' the emittance
- Dispersion, Magnet misalignments and Quantum effects can increase the emittance
- Colliders want a very small vertical beam size, which means a very small vertical emittance.
- New colliders will employ '**Damping Rings**'





$$L \propto \frac{\eta_{RF} P_{RF} \sqrt{\delta_{BS} \sigma_z}}{E_{cm}^{3/2} \sigma_y}$$

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Low Emittance rings workshop series

- HEP community is starting to appreciate input from light sources.

Low Emittance Rings 2010 Workshop. CERN, 12-15 January:

"The workshop will profit from the experience of colleagues who have designed, commissioned and operated lepton ring colliders and synchrotron light sources."

	PDR	DR (CLIC)	DR (ILC)	LS	PF (superB)
Horizontal acceptance	10 mm mrad?	\	10 mm mrad	10 mm mrad	3 mm mrad
in sigma		\	140	300	30
Vertical acceptance	10 mm mrad?	\	10 mm mrad	1 mm mrad	0.2 mm mrad
in sigma		\	2200	300	140
Energy acceptance	3%	<1%	<1%	3..5%	>1%
Current	low	< 0.5 A	0.5 A	~0.5 A	2..3 A
Lifetime	\	\	\	10 hrs	~10 min
Horizontal emittance	~10 nm ?	0.1 nm	0.5 nm	0.1 nm	<3 nm
Vertical emittance	~30 pm ?	0.5 pm	2.0 pm	~10 pm	<10 pm
Energy spread	0.10%	0.10%	0.15%	0.10%	0.10%
Energy	3 GeV	3 GeV	5 GeV	3..6 GeV	3..8 GeV

$$L \propto \frac{\eta_{RF} P_{RF} \sqrt{\delta_{BS} \sigma_z}}{E_{cm}^{3/2} \sigma_y}$$

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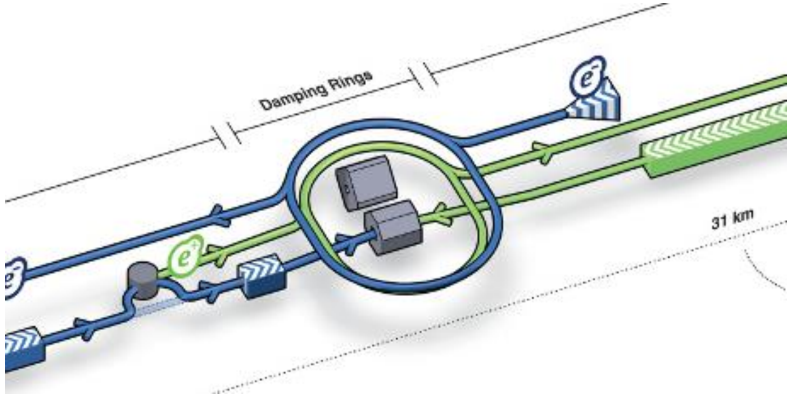
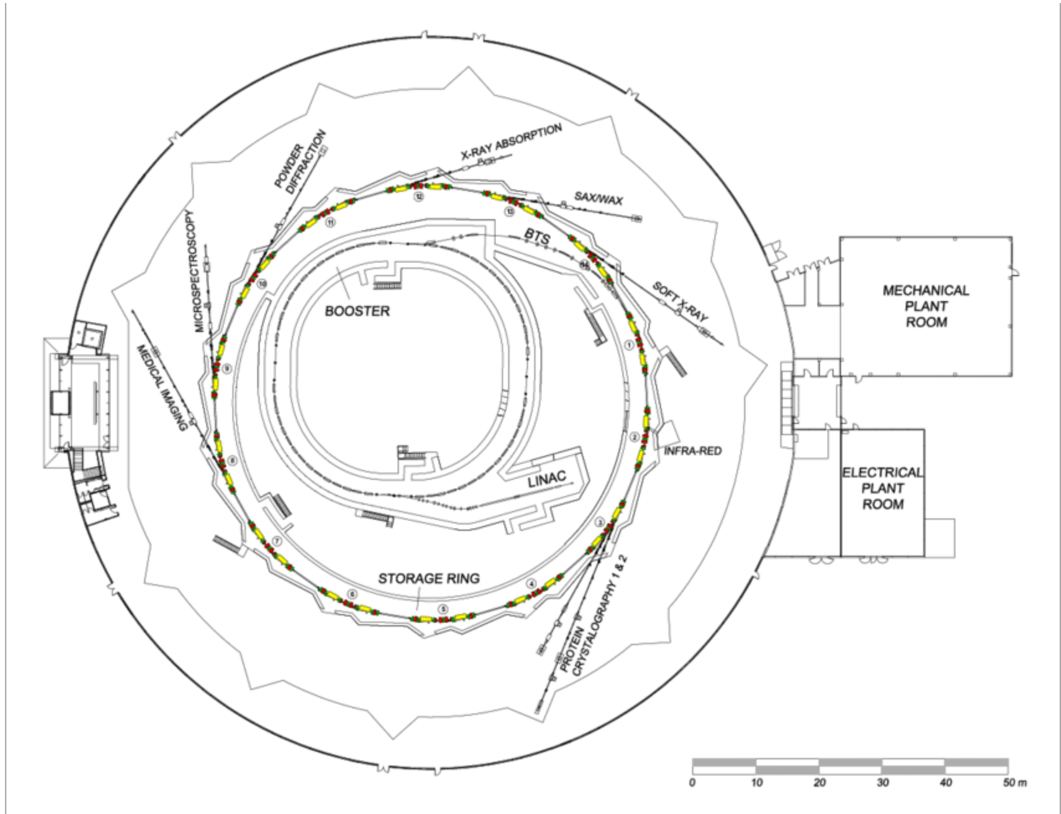
Light Sources as a testing ground

- Light sources excel at beam stability and precision. The collider community has now recognized there are many lessons to learn from them.



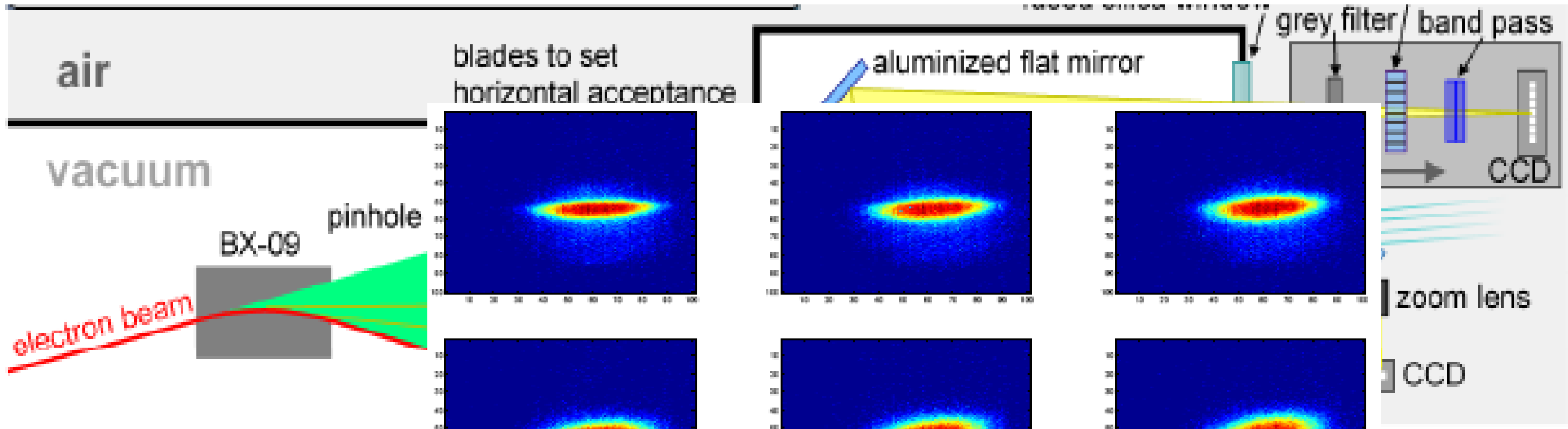
- Physicists at light sources often have the time and ability to test beam dynamics theories and hardware

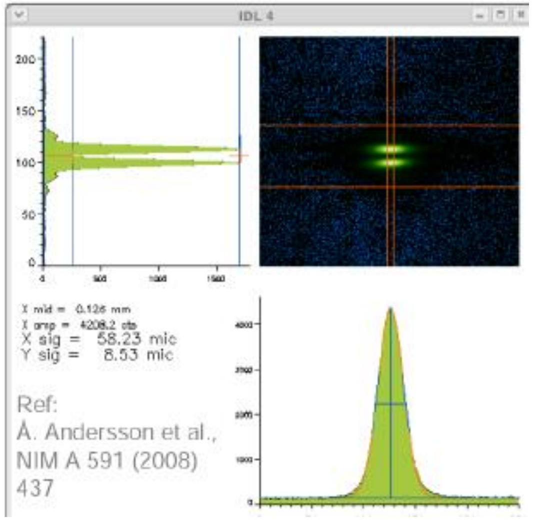
- Light Sources are very similar to damping rings. Can demonstrate techniques needed for future accelerators.

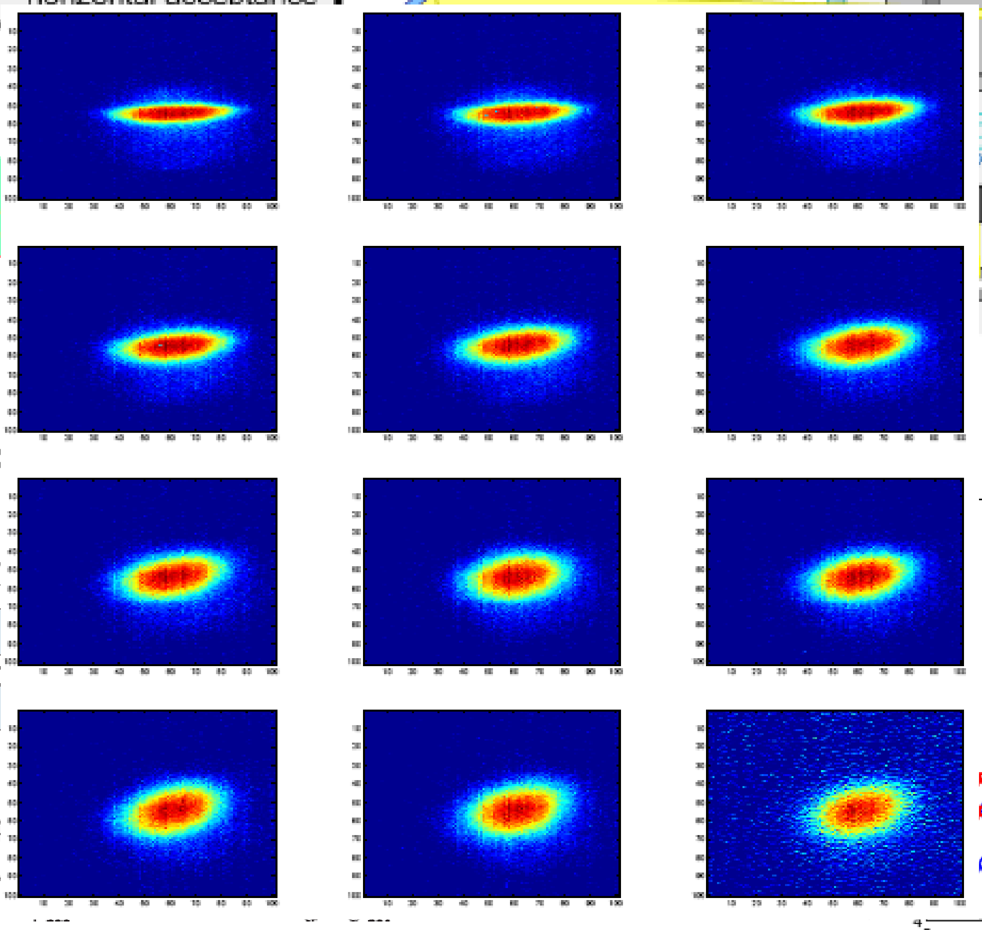


Direct emittance measurement

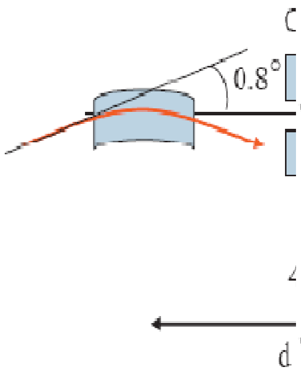
- SLS: ε_y = 2.8 pm ± 0.4 (0.05% coupling)

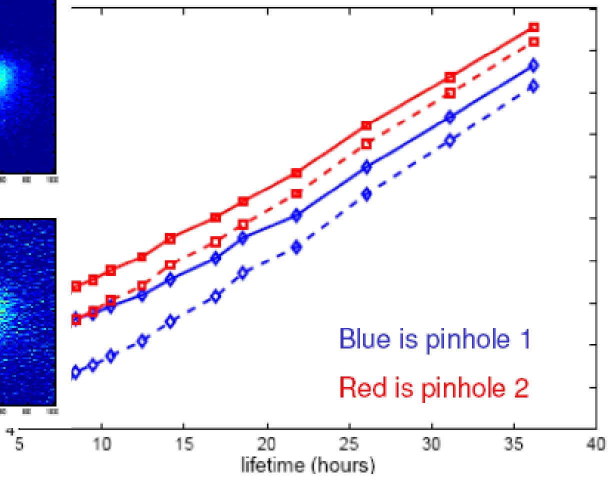






- Diamond: ε_y =





Indirect emittance measurement

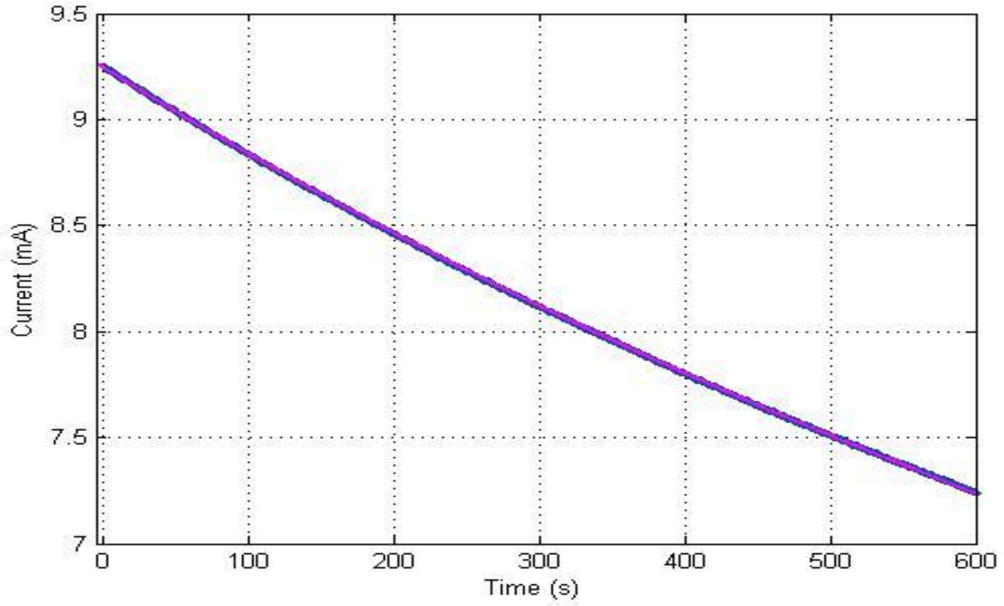
- Without the resources for a dedicated high quality diagnostic beamline, we must try indirect inference of the beam size.
- Tousheck effect is the scattering of particles within the beam from each other.

$$\frac{1}{T} = \left\langle \frac{r_p^2 c \beta_x N_p}{8\pi\beta\gamma^3 \sigma_{x\beta}\sigma_{y\beta}\sigma_z\widetilde{\sigma}_x} \int_{\tau_m}^{\infty} \left((2+\frac{1}{\tau})^2 (\frac{\tau/\tau_m}{1+\tau} - 1) + 1 - \frac{\sqrt{1+\tau}}{\sqrt{\tau/\tau_m}} - \frac{1}{2\tau}(4+\frac{1}{\tau}) ln(\frac{\tau/\tau_m}{1+\tau}) \right) e^{(-\frac{\tau\epsilon_m}{\tau_m})} \frac{d\tau}{\sqrt{1+\tau}} \right\rangle$$

$$\tau_m = \beta^2\eta_{acc}^2,\ \beta_= v/c$$

$$\widetilde{\sigma}_x = \sqrt{\sigma_{x\beta}^2 + \sigma_p^2(D_x^2 + \widetilde{D}_x^2)},\ \widetilde{D}_x = \alpha_x D_x + \beta D'_x$$

$$\sigma_{x\beta,y\beta} = \sqrt{\epsilon_{x,y}\beta_{x,y}}$$

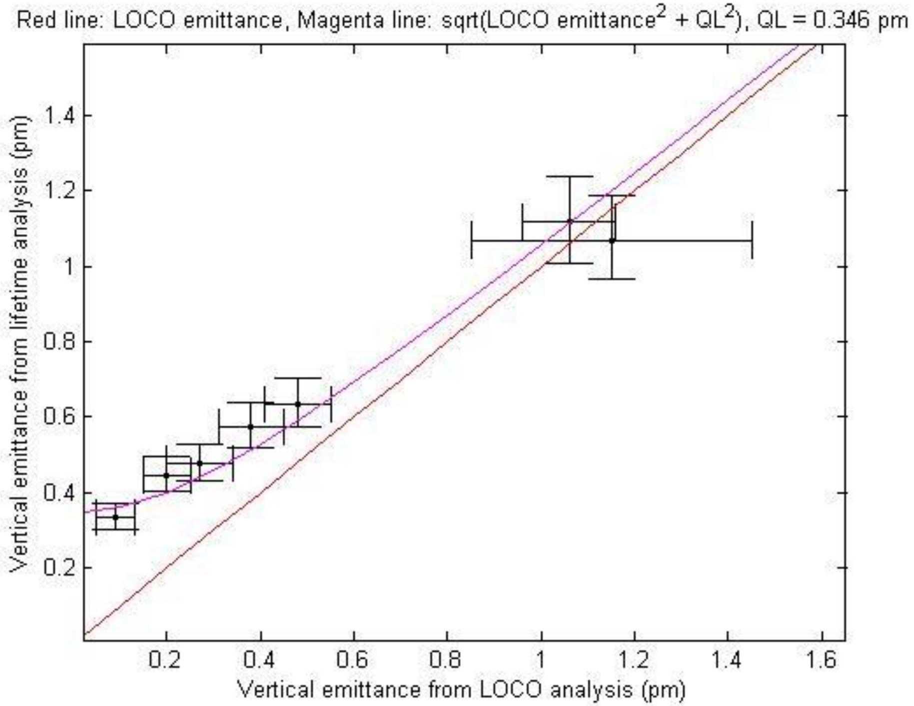


$$\frac{di}{dt} = -\frac{i}{a} - \frac{i^2}{b}$$

$$i(t) = \frac{i_0 b e^{-\frac{1}{a}}}{b + i_0 a(1 - e^{-\frac{1}{a}})}$$

Towards the Quantum Limit

- Employed a model based minimization technique and indirect measurements to achieve 1.3 pm Vertical emittance
  - Phys. Rev. ST Accel. Beams 14, 012804 (2011)
- Since then, we have refined the technique and come within spitting distance of the Quantum limit
- Some further-analysis to do.
- Lessons learned in beam control have translated to better stability of AS beam



Beam Based Alignment

Or how to start fights with mechanical engineers...

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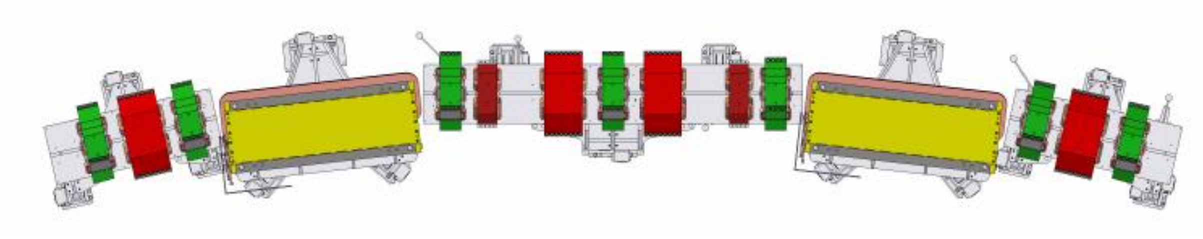
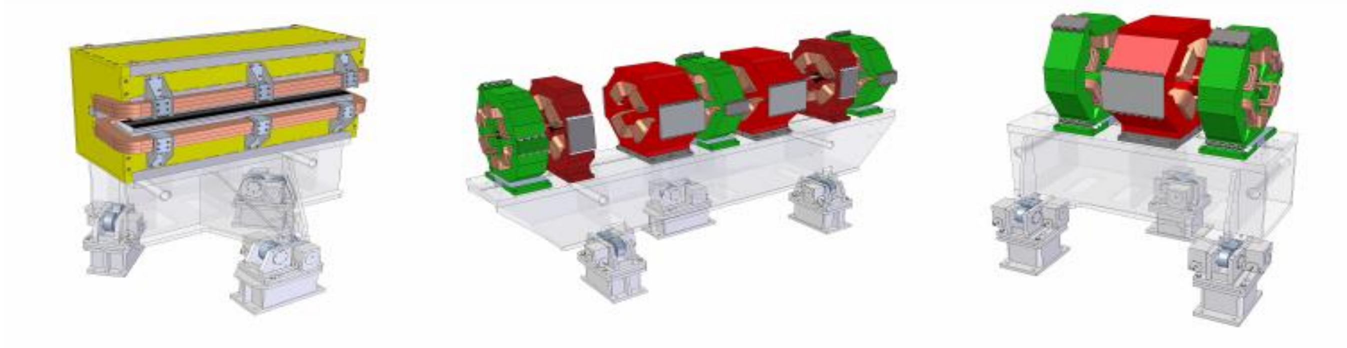
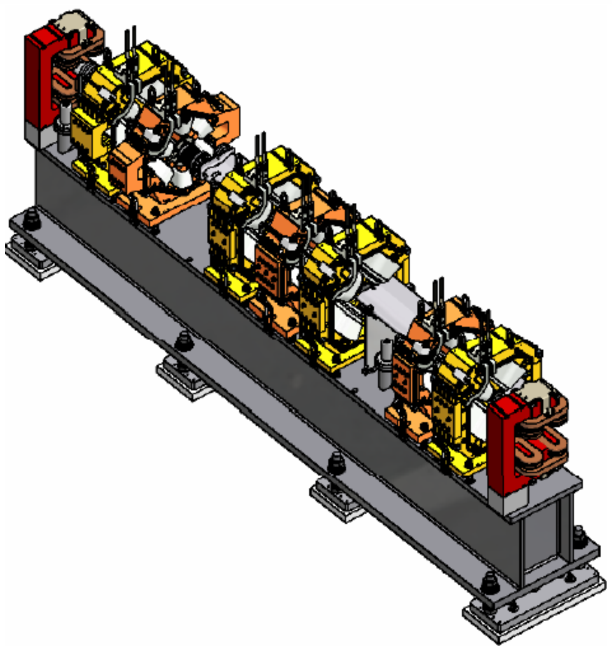
Alignment Methods Comparison

- AS uses laser tracker and magnet fiducials. Magnet to magnet resolution ~ 25-50 micron (but magnetic centre somewhat uncertain).
- NSLS II employs a vibrating wire measurement. Resolution of finding magnetic centre is 5-10 micron. Locked onto girder then installed. Overall magnet to magnet positioning claimed < 30 micron (15-20?)
- What about Beam based Alignment?







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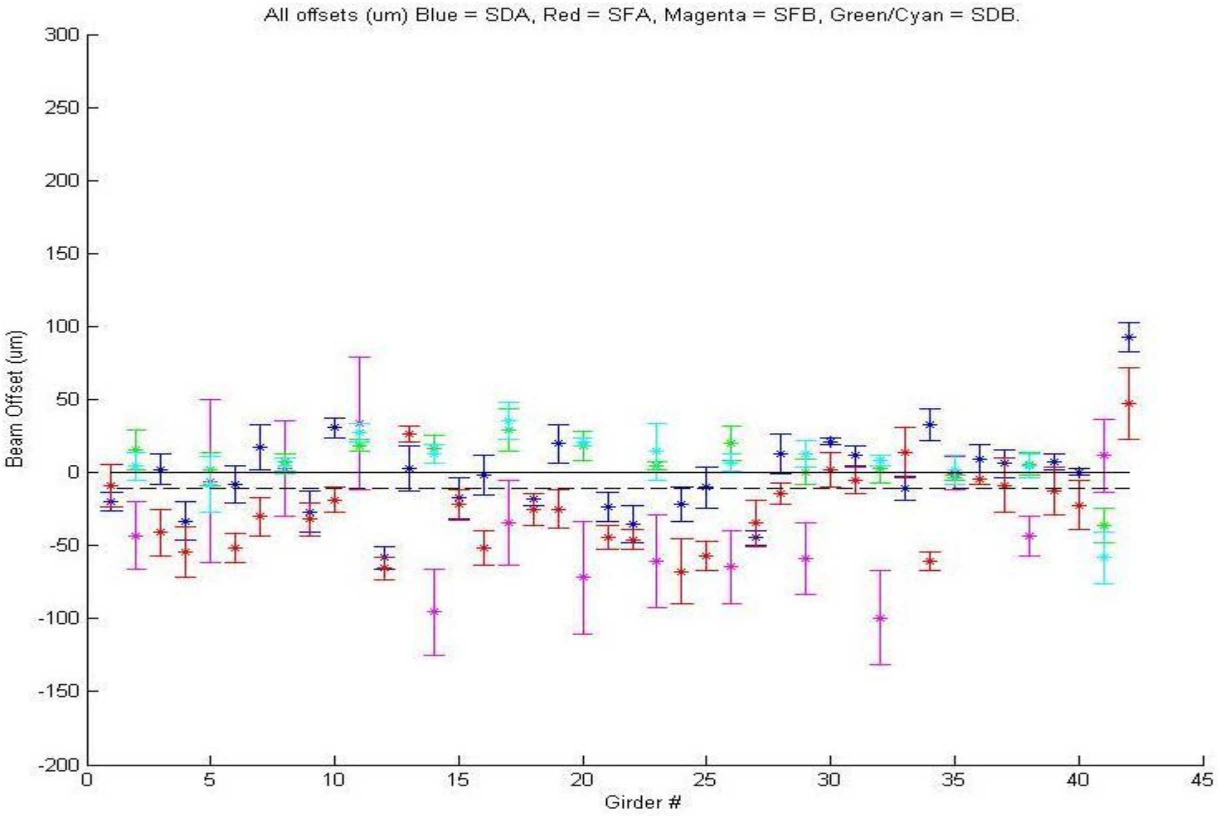
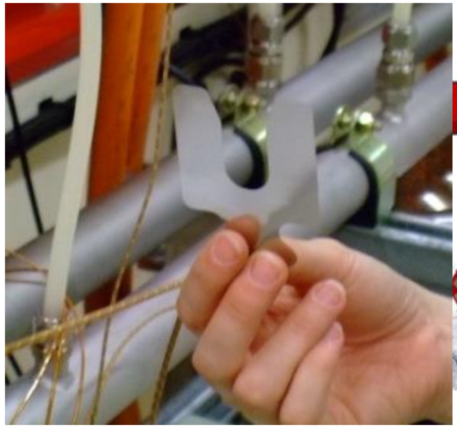
Sextupole Vertical offsets

- Shunt each sextupole magnet family to different strengths and and fit skew quadrupole terms to each sextupole.
- Gradient of skew field vs sextupole field gives vertical offset.





Magnet	Original Offset (µm)	Applied Shim (µm)	New Offset (µm)	Delta offset (µm)
Sector 9 SFB	-108.4 ± 44.6	150	-249.3 ± 7.2	140.9 ± 45.2
Sector 11 SFB	-56.7 ± 10.0	100	-120.4 ± 56.0	-63.4 ± 57.4
Sector 9 SDA	-14.6 ± 9.9	100	-118.3 ± 8.3	-103.7 ± 14.1

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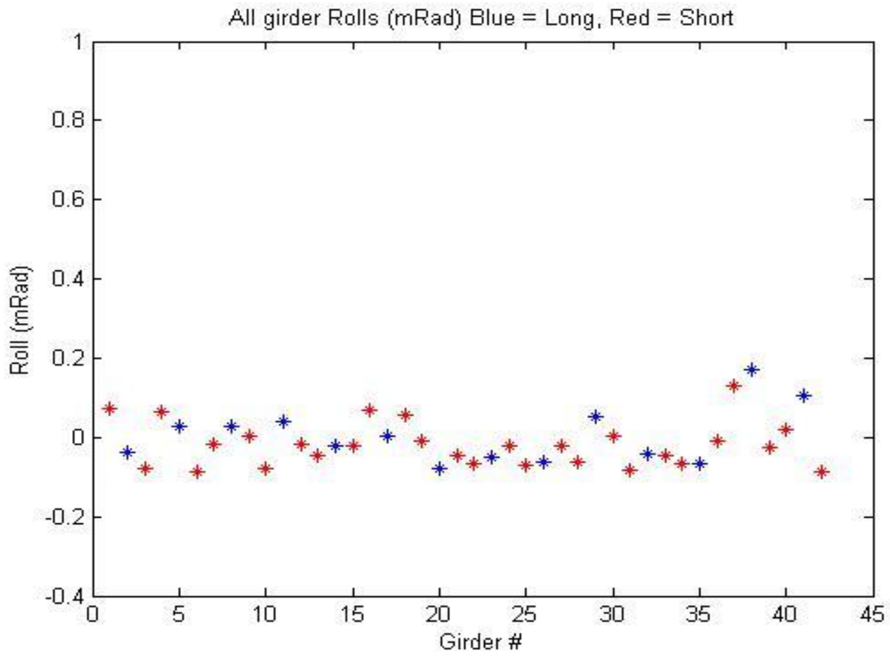
Quadrupole Rolls

- Turn off Sextupoles and perform skew analysis of quadrupoles.
- Method was found to be accurate to ±0.05 mRad. Mechanical precision of setting the girders ±0.1 mRad.
- Rolls now reduced to < 0.2 mRad.



- **Alignment through BBA methods now on par with mechanical bench top measurements**
- Further Refinement of alignment technique ongoing

MEDSI 2014
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IVU Induced Instabilties

Solving a long standing issue

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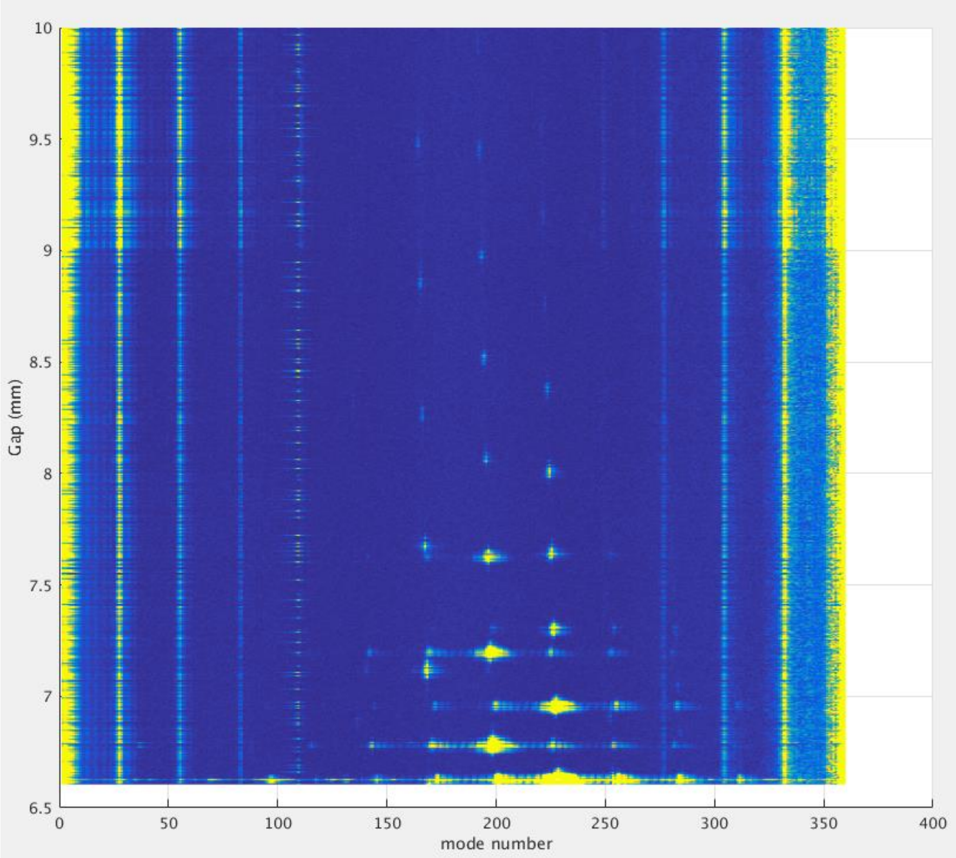
Background

- We have observed vertical beam instabilities generated when the IVUs are at small gap since they were installed in 2006.
- Have been able to control them, but mechanism was not identified.
- Risk that future IVUs will produce stronger instabilities
- This problem also reported in other facilities – of interest to global community.



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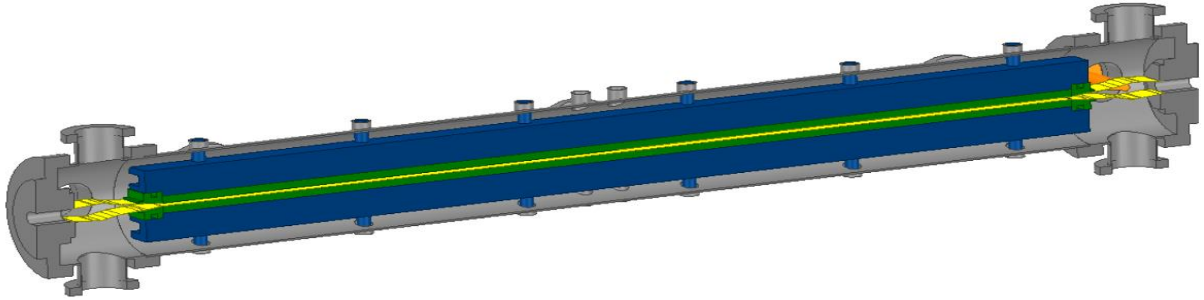
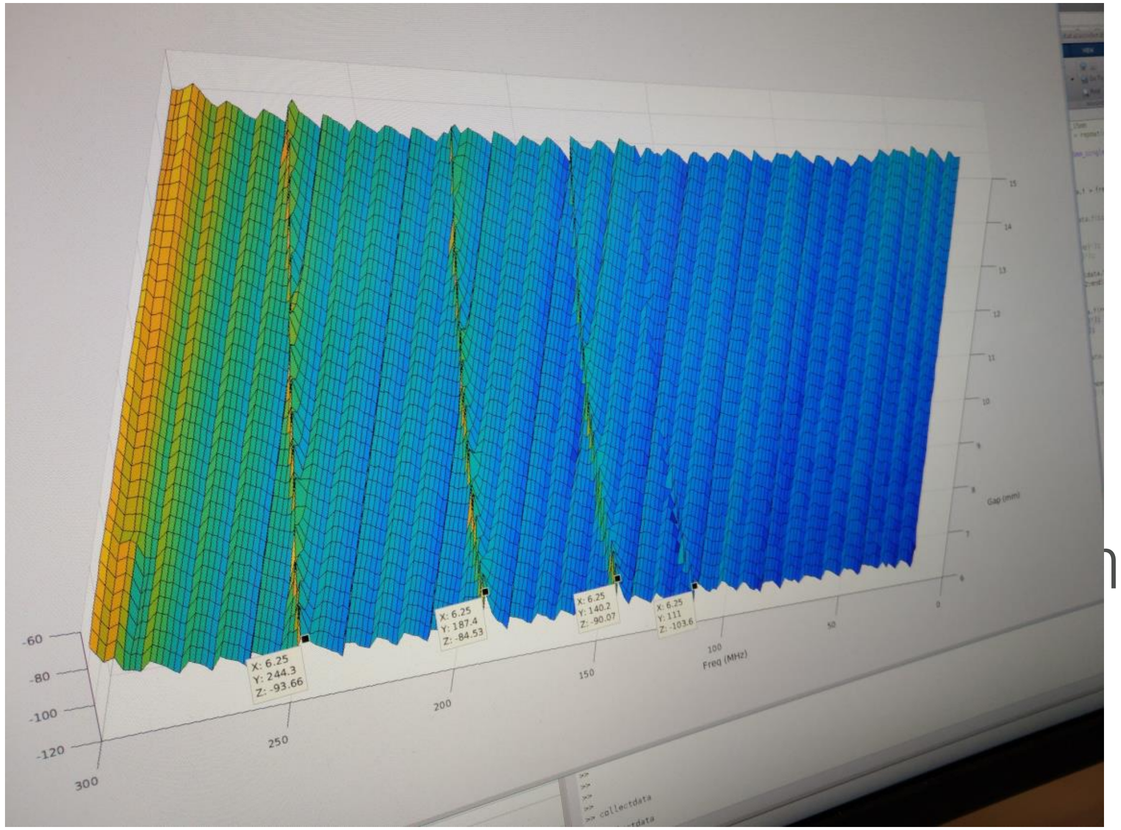
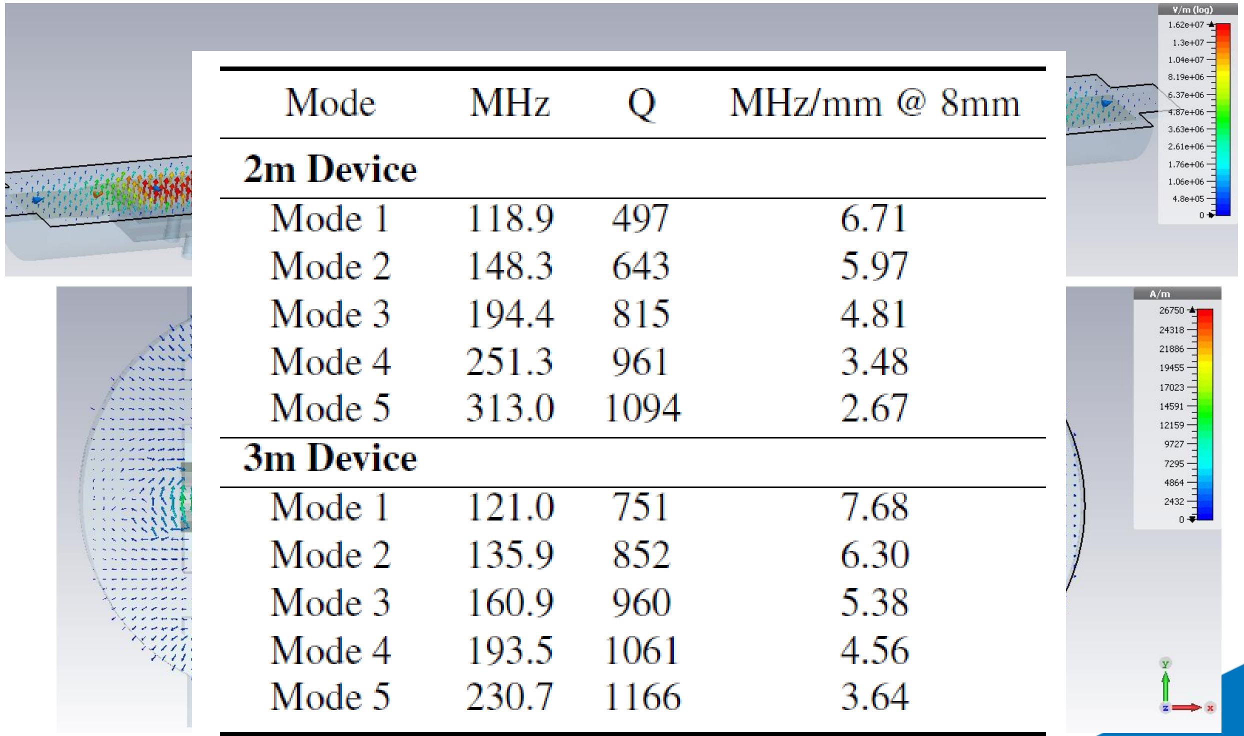
Modelling the IVUs

- A full 3D model of the IVU was created from the engineering drawings

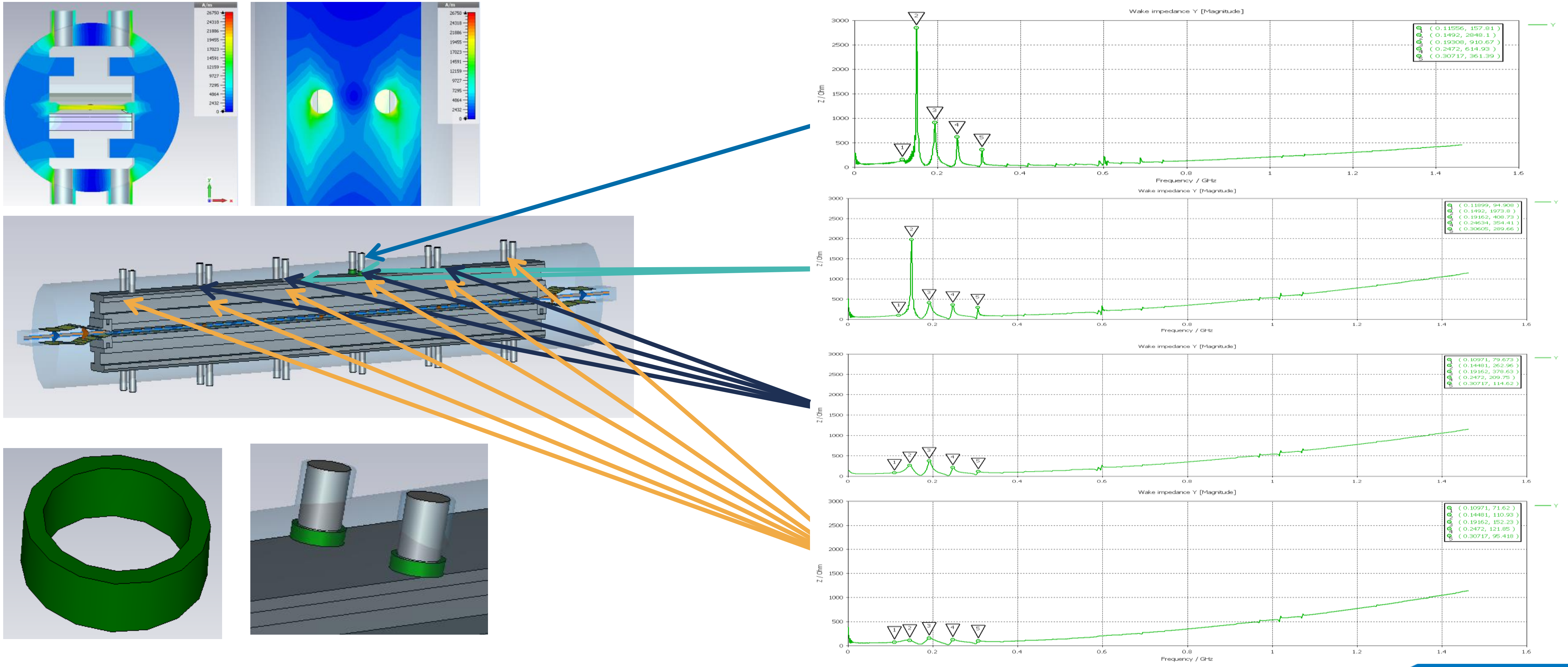






Mode	MHz	Q	MHz/mm @ 8mm
2m Device			
Mode 1	118.9	497	6.71
Mode 2	148.3	643	5.97
Mode 3	194.4	815	4.81
Mode 4	251.3	961	3.48
Mode 5	313.0	1094	2.67
3m Device			
Mode 1	121.0	751	7.68
Mode 2	135.9	852	6.30
Mode 3	160.9	960	5.38
Mode 4	193.5	1061	4.56
Mode 5	230.7	1166	3.64

Possible solution – ferrite rings



The CompactLight Collaboration

Conceptual design for a compact X-band FEL

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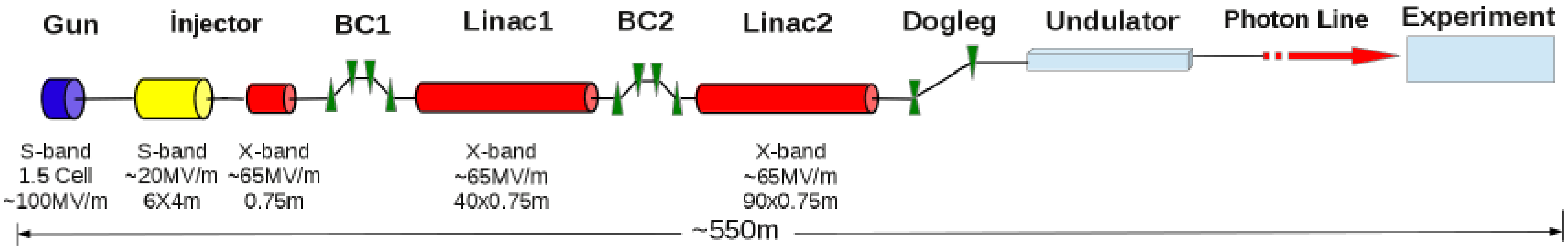
CompactLight

- “The key objective of the CompactLight Design Study is to demonstrate, through a conceptual design, the feasibility of an innovative, compact and cost effective FEL facility suited for user demands identified in the science case.”

- X–Band acceleration will be a compact, cost effective solution for a future FEL in Australia.



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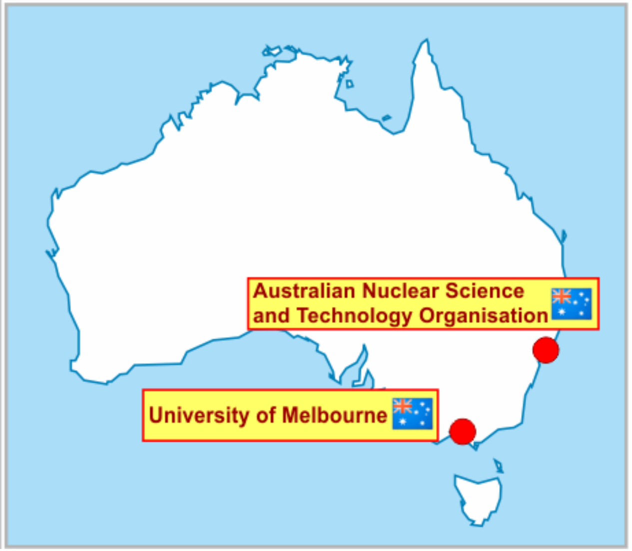
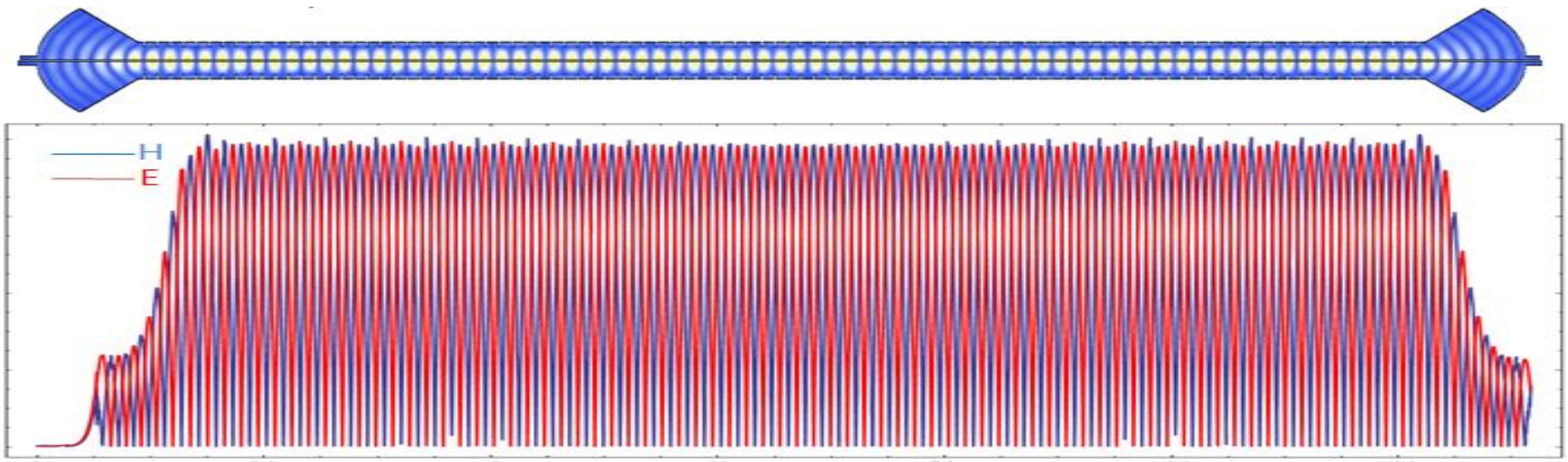
The Collaboration Members



RF Undulator Work

- David is working with Strathclyde University for RF undulator research, including simulations of electromagnetic wave fields setup in the cavity, electron beam dynamics simulations by ASTRA code, photon radiation simulations by SPECTRA code and SIMPLEX code.

- A 36 GHz microwave undulator has been chosen for producing a conceptual design report for this work package .



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Thank you.

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