LHC Crab Cavities

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- Introduction
- Some Simulations & Experiments
- Outlook

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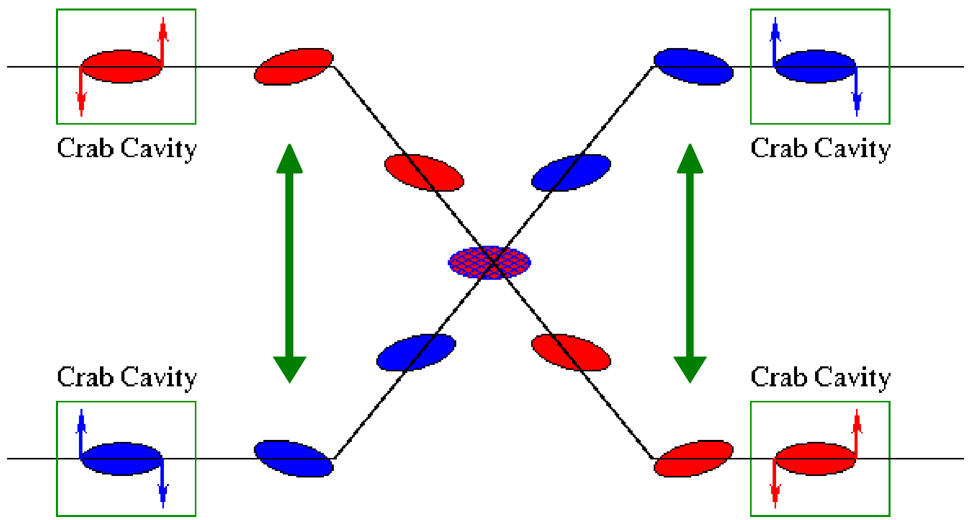
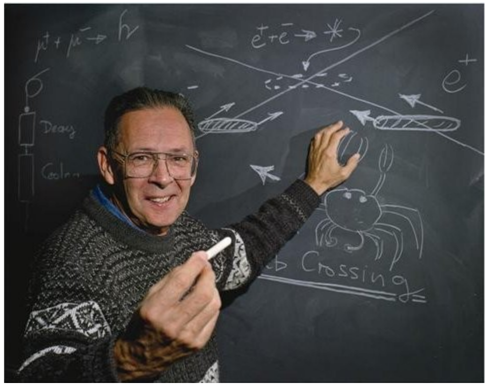
Ack: LHC-CC Team

Why crab the LHC





Proposed by Palmer, 1988

+20 yr

KEK-B

+5 yr ?

LHC

Two Phase approach

Upgrade scenarios aim at x10 Lumi increase ($\beta^*\downarrow$, Current $\uparrow$)

Finite crossing angle due to parasitic interactions

Luminosity reduction $\rightarrow$ Recover from crab crossing

Crab Crossing, Phase I

Prototype Tests (5-7 TeV):

- Feasibility
- Luminosity gain (15-21%)
- Luminosity leveling

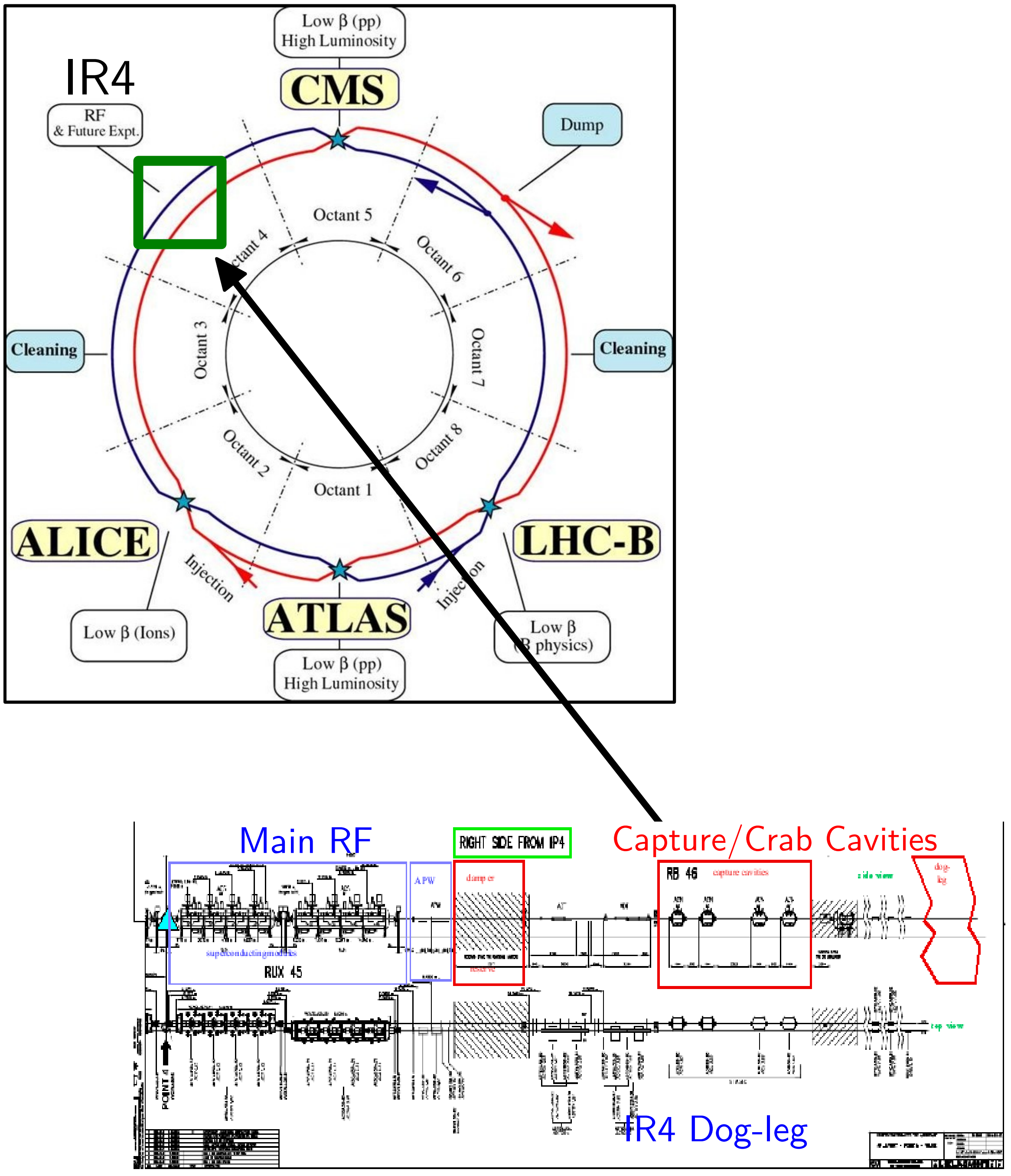
$\beta^* \leq 30$ cm

Bunch length: 7.55 cm

IR4 beam-line Separation: 42 cm

Crab RF frequency: <u>800 MHz</u>

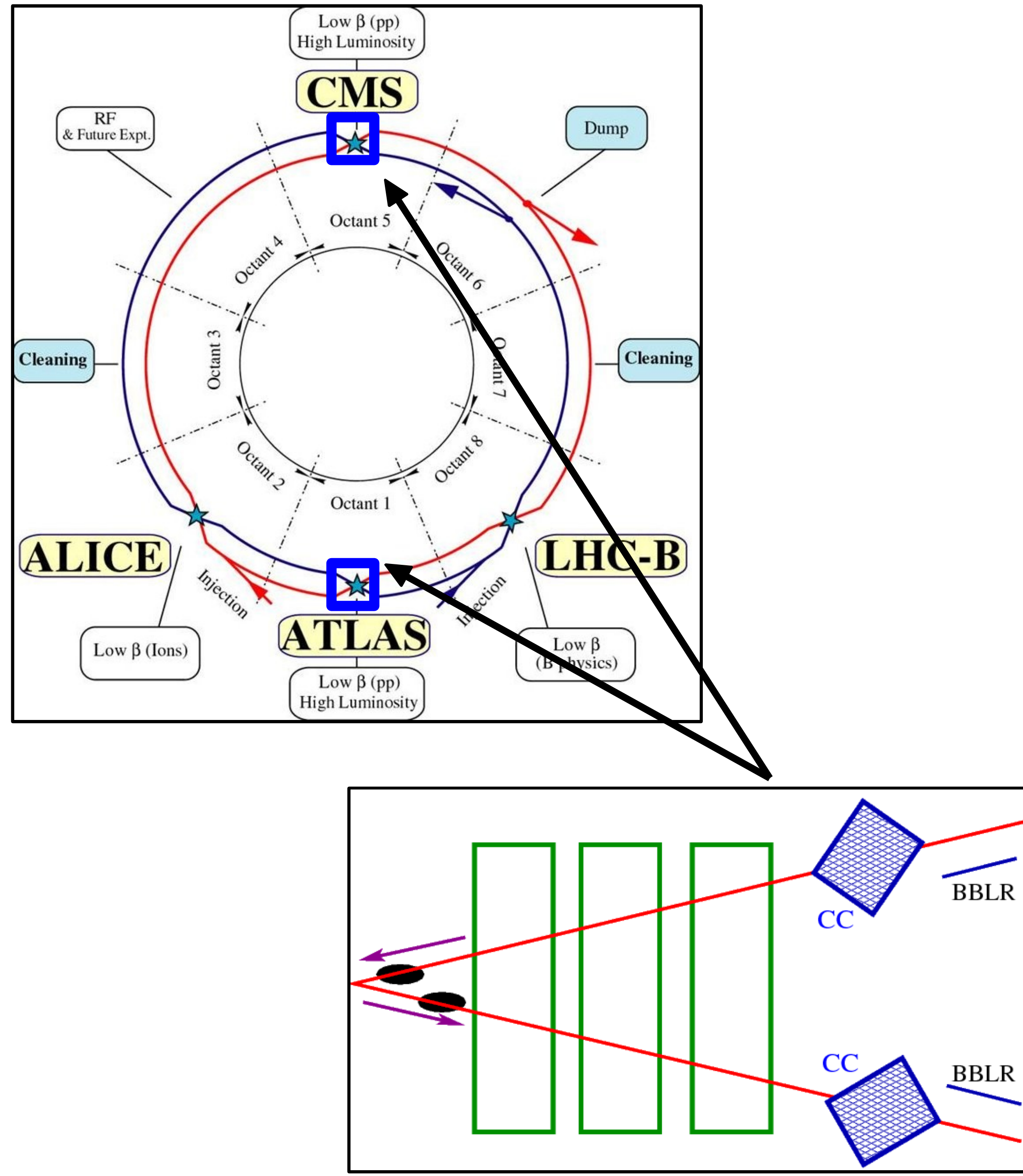
1 cavity/beam: 2.5 MV kick



Crab Crossing, Phase II

Full Crossing Scheme

- Luminosity gain: 43-62%
- Leveling on



$\beta^* \leq 25$ cm

Crab Freq: 800 (or 400) MHz

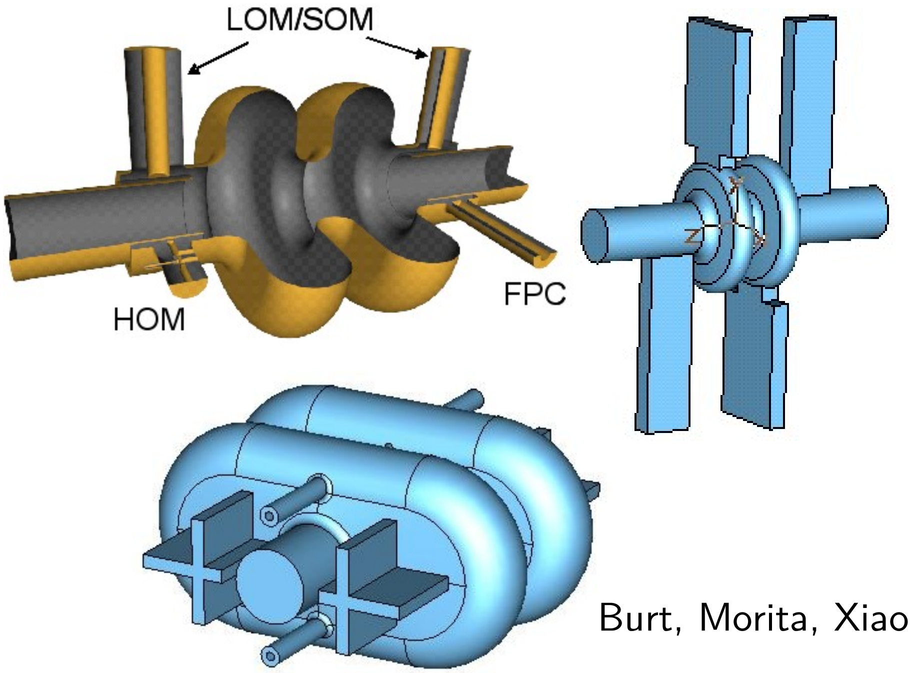
Kick Voltage: ~5 MV

\# cavities/IP: 4-8

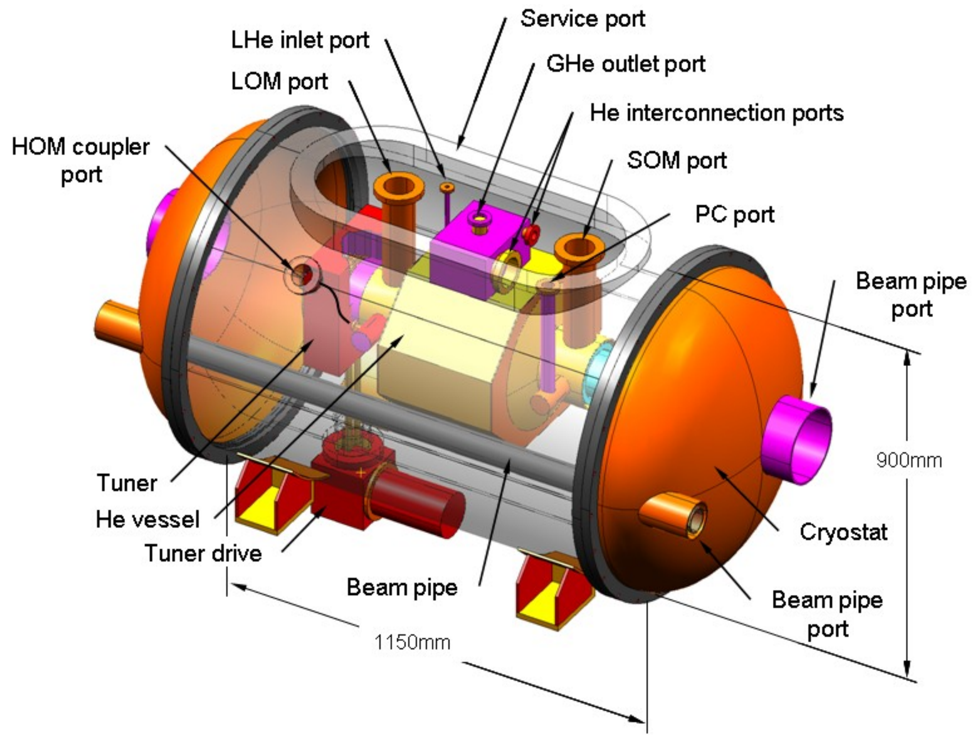
Cavity & Cryomodule

- 2 cell SRF cavity @800 MHz
- 3 aggressive damping schemes
- Down selection

Multipacting, thermal, mechanical etc...



Burt, Morita, Xiao et al.



Cryostat development underway, interfaces, RF-cryogenic-mechanical constraints

Impedance Estimates

Longitudinal criteria:

Narrow band impedance threshold, $R_{sh} < 200\ k\Omega$

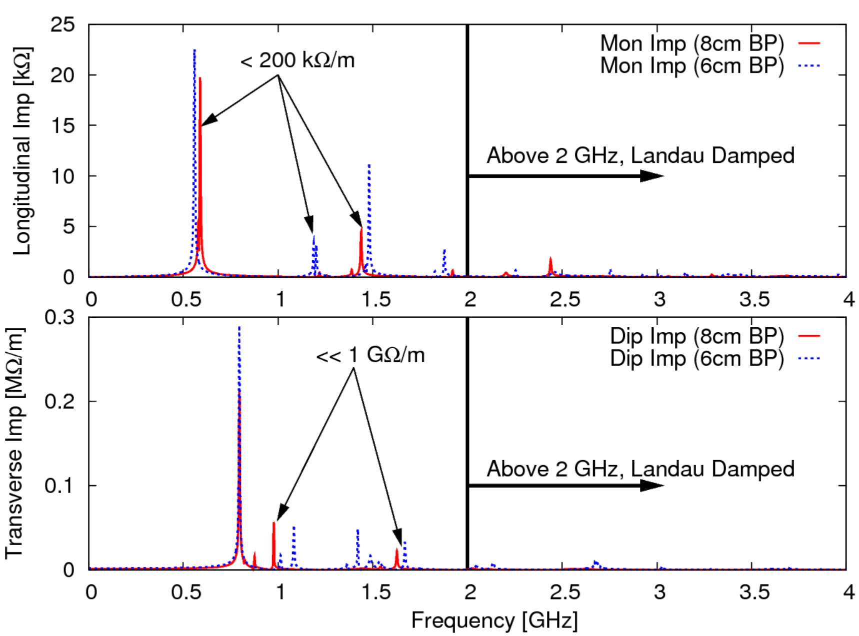
Inductive low freq & broadband $\rightarrow Im\{Z/n\} < 0.15\Omega$ (loss of landau damping)

Landau damped for ≥ 2 GHz (synchrotron freq. spread)

Transverse criteria:

Landau octupoles, chromaticity, feedback (Landau damped ≥ 2 GHz)

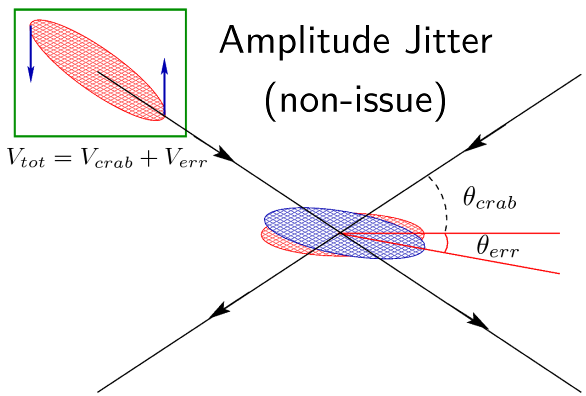
Re, $Im\{\Delta Q\} < 10^{-4,}$ Coupled bunch $(\beta_{\perp}/{}^{Av}\beta_{\perp})R_{\perp}/Q << 1\ G\Omega/m$

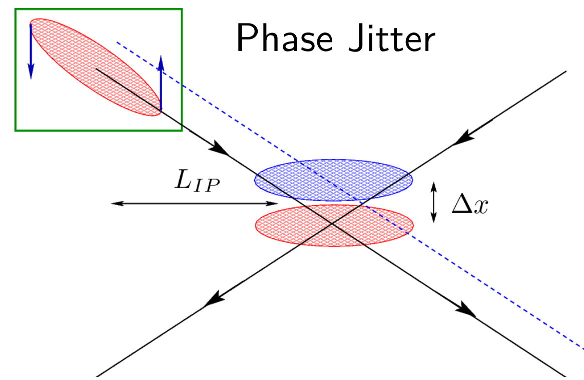


	Freq [GHz]	R/Q [Ω]	Q_{ext}
Monopole	0.54	35.17	~10^2
	0.69	194.52	
Dipole	0.80	117.26	10^6
	0.81	0.46	~10^2
	0.89	93.4	
	0.90	6.79	

** Main RF cavities, $Q_{ext} \sim 10^2 - 10^3$

Crab Noise, Tolerances





Modulated noise (measured, ex: 32 kHz)

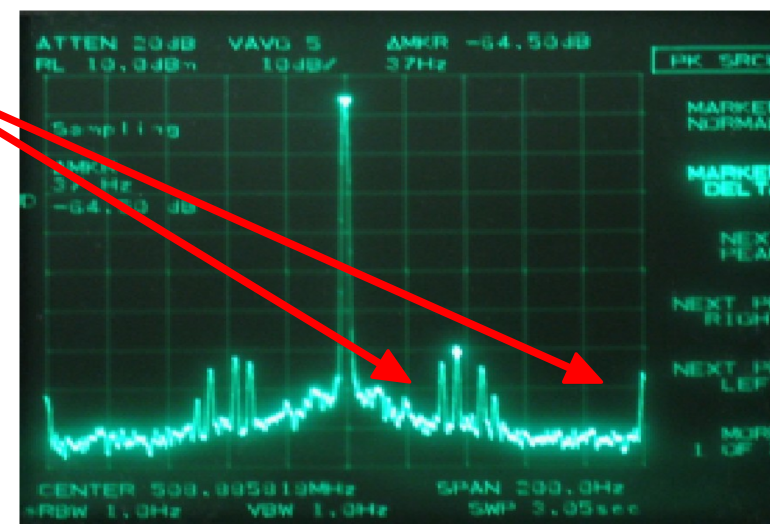
Strong-strong BB $\leq$ 0.01σ (1%/hr)

Weak-strong BB $\leq$ 0.01-0.1σ

White noise (pessimistic)

Strong-strong BB $\leq$ 0.002σ.(τ)

correlation time



KEK-B crab spectrum

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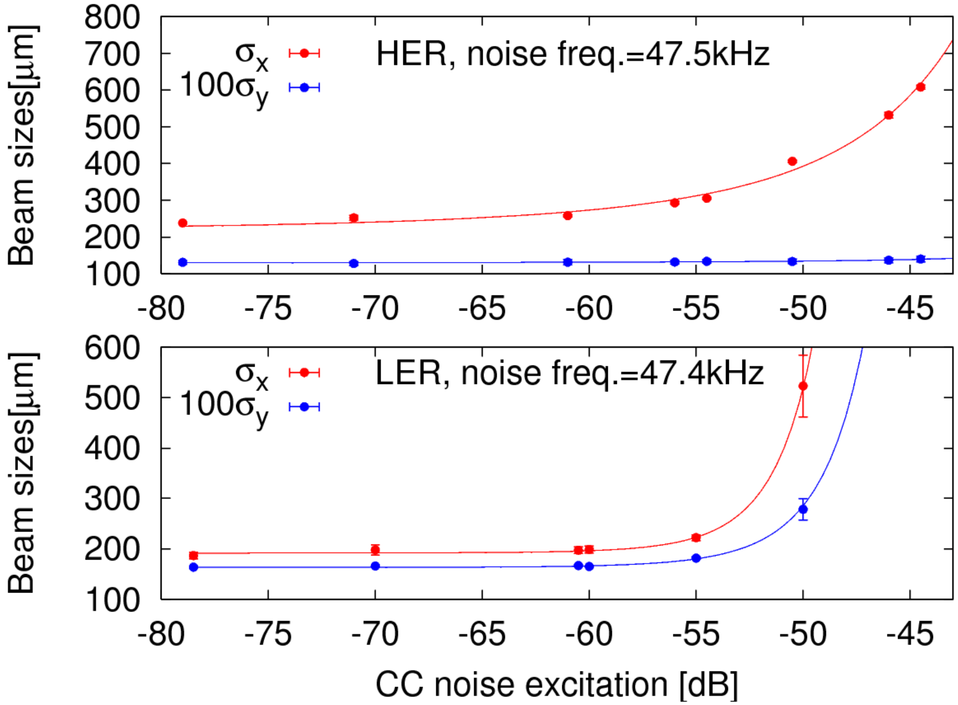
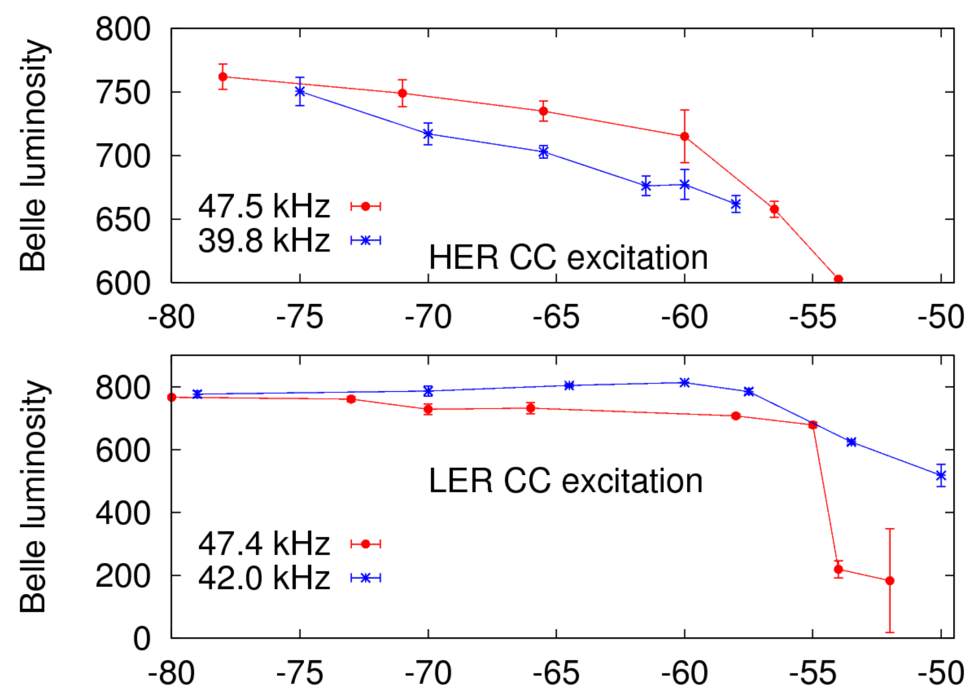
Noise Experiments, KEK-B



Single beam noise excitation

Visible effect $\sim$ -60 db $\rightarrow$ 0.1^0



Noise excitation with beam-beam

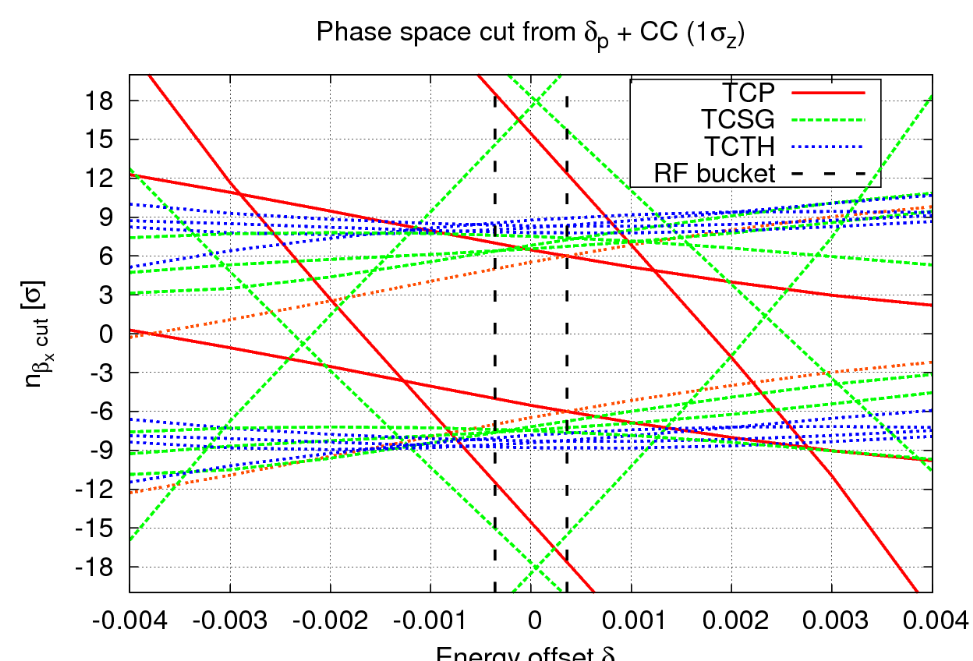
Visible effect $\sim$ -70 db $\rightarrow$ 0.03^0

R. Tomas et al.

Collimation, Prototype Tests

- Loss maps with crabs similar to nominal LHC
  - Heirarchy preserved, impact parameter investigation
- Not a serious concern for prototype tests
  - Fine tuning with crabs-collimator setup maybe needed

		Nominal		Crab Cavity	
		$2\sigma_z$	$3\sigma_z$	$2\sigma_z$	$3\sigma_z$
$\delta p/p=0$	1^{st} turn [μm]	0.78	0.78	3.84	3.84
	All turns [μm]	0.153	0.154	0.147	0.147
	Part. absorbed.	70.2%	70.2%	68.5%	68.5%
$\delta p/p\neq0$	1^{st} turn [μm]	50.61	59.82	76.16	79.03
	All turns [μm]	36.1	40.44	66.47	67.03
	Part. absorbed	96.5%	97%	99.56%	99.56%



Y. Sun et al.

Operational Scenarios

- Injection/Ramp (detuned/dephased & "zero" voltage)
  - First turn, capture efficiency, emittance growth
- Top energy
  - Cavity re-tuning -or- re-phasing
  - Cavity ramping (9-90 ms)
  - Crab-β squeeze
- Beam Studies (single → multiple)
  - Emittance growth, closed orbit, RF phasing, feedback, filling scheme
  - Sp. luminosity gain & leveling, collimation optimization

Single Prototype

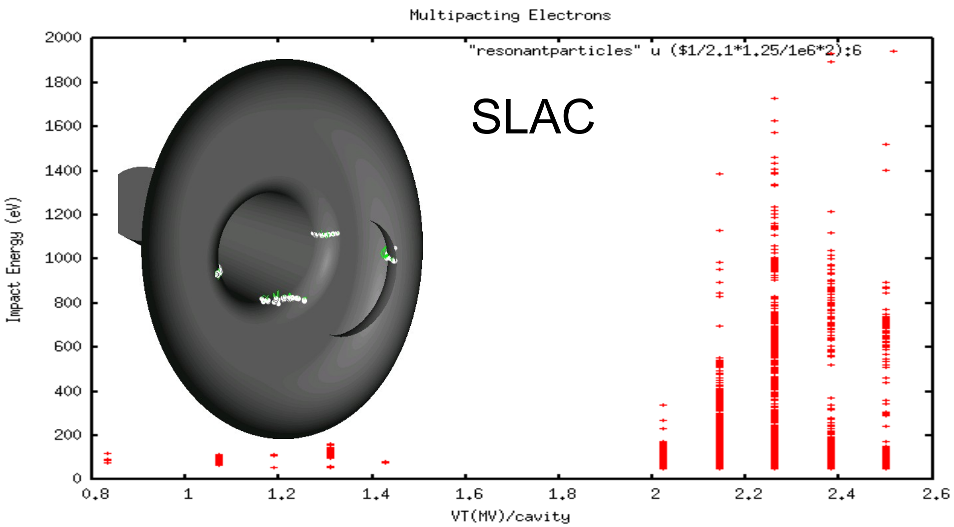
Crab Voltage: 2.5 MV

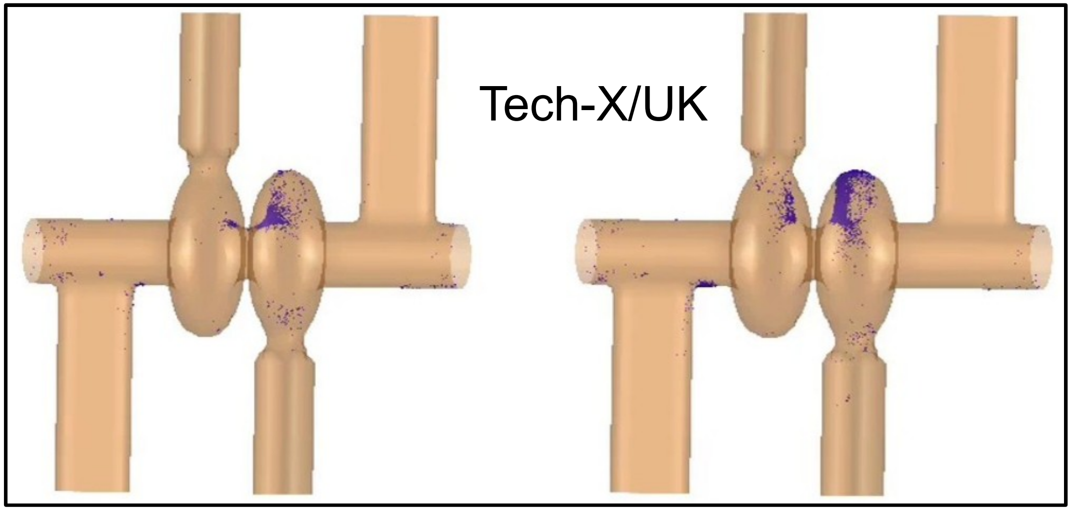
β_{cc} [km]	β^* [m]	θ_c [μrad]	E_b [TeV]	L/L_0 [%]
3.0	0.25	439	7.0	21%
3.0	0.30	401	7.0	19%
3.0	0.55	296	7.0	12%
2.0	0.42	401	5.0	15%
1.0	0.7	401	3.0	8%
0.2	10.0	273	.45	0.04%

Conclusions

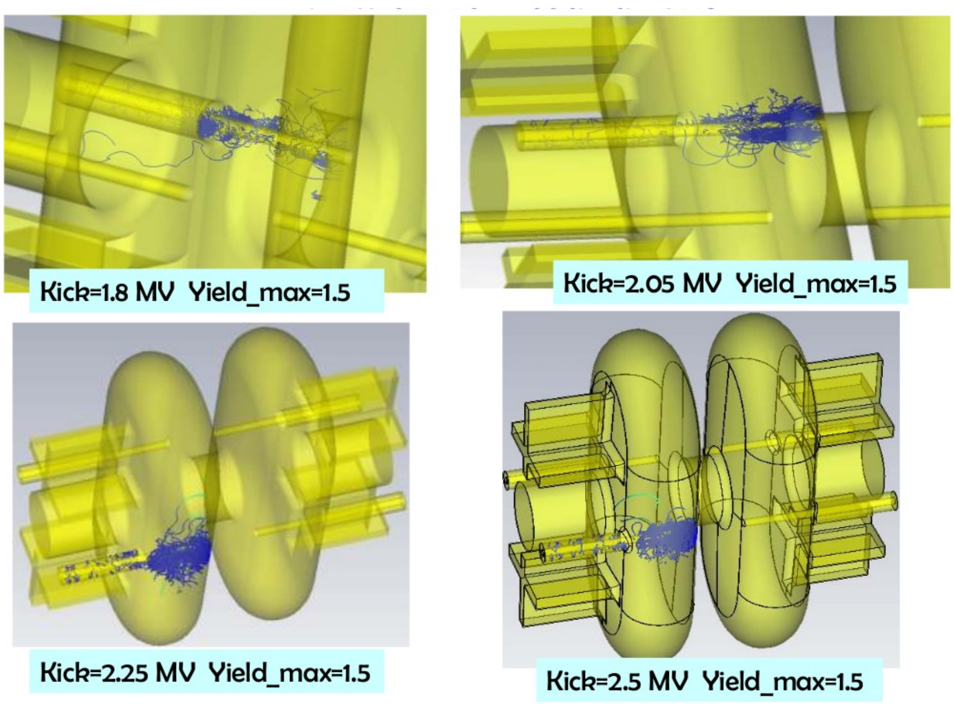
- Large potential for Luminosity gain & leveling
- Conceptually simple, but technically challenging
- KEK-B experience vital for LHC
  - Successful commissioning and operation with high currents
  - Noise experiments, OP scenarios
- R&D progressing at a rapid pace
  - No show stopper from simulations/measurements so far
  - "TDR": cryomodule, integration, OP procedures, simulations - 2010

Multipacting



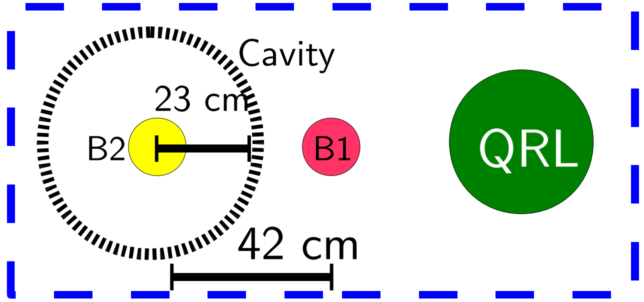


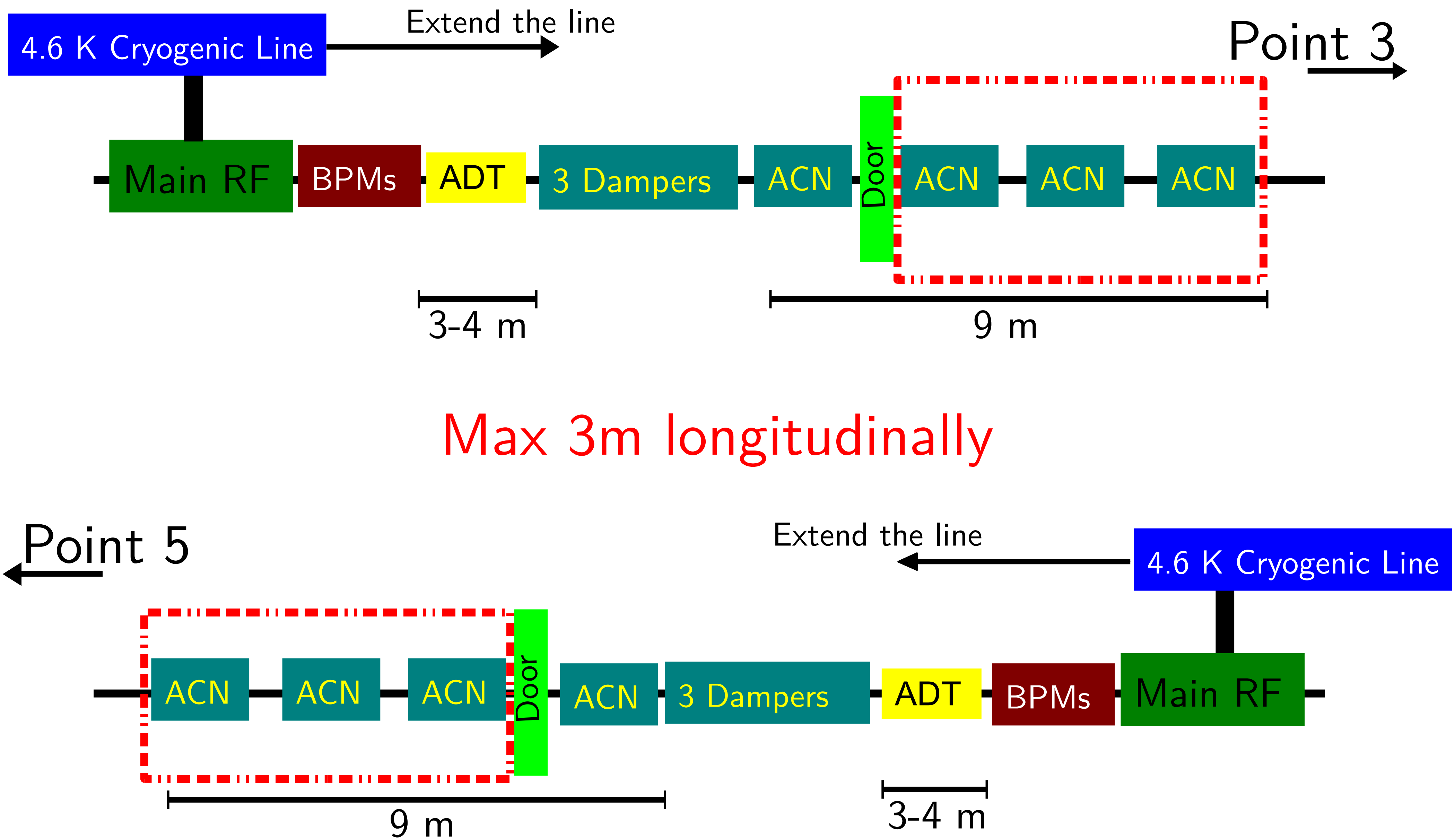
FNAL/KEK



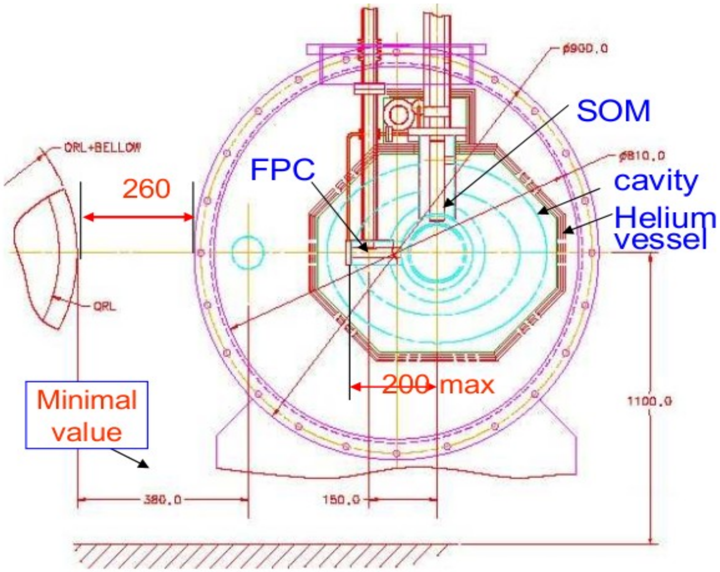
Multipacting in complex structures & deflecting mode needs more investigation. Benchmarks with KEK-B cavity is vital

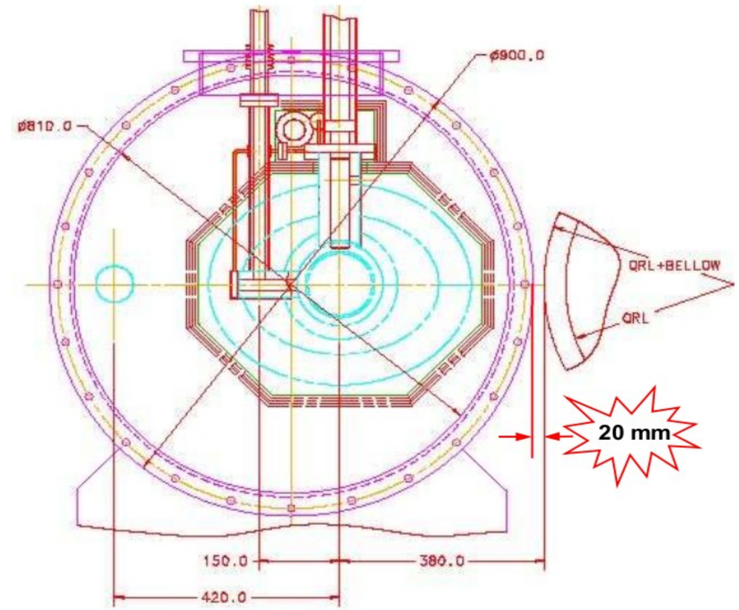
IR4 Dog-leg

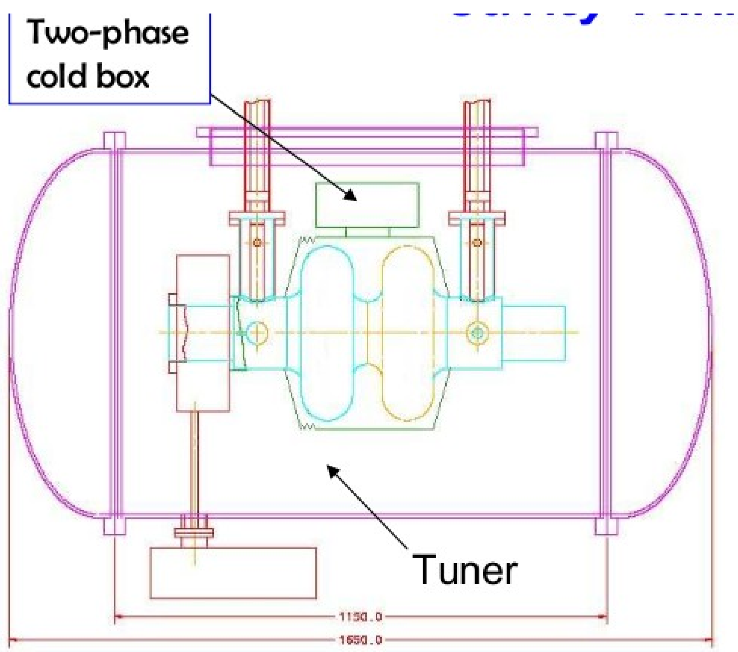

Cavity
23 cm
B2
B1
QRL
42 cm


4.6 K Cryogenic Line
Extend the line
Point 3
Main RF
BPMs
ADT
3 Dampers
ACN
Door
ACN
ACN
ACN
3-4 m
9 m
Max 3m longitudinally
Point 5
Extend the line
4.6 K Cryogenic Line
ACN
ACN
ACN
Door
ACN
3 Dampers
ADT
BPMs
Main RF
9 m
3-4 m

Cryostat Development







Tight constraints for the cryostat, but feasible. Detailed design of interfaces (inside & outside) is underway

Failure Scenarios

Before prototype tests:

- Fabrication, cryostat
- Cavity-coupler performance, compliance

Beyond prototype tests:

- Cavity phasing-tuning limits and non-adiabatic ramping
- Cavity trips & power supply problems
- Vacuum degradation
- Cavity and component quench
- RF loops & feedback $\rightarrow$ instabilities
- Alt: two cavity system vs. damp/dephase/detune
- Misc