Status of the Diamond Light Source

Marco Apollonio – Diamond Light Source Ltd

ESLS-XXV Workshop

Dortmund, Germany

20th-22nd November 2017

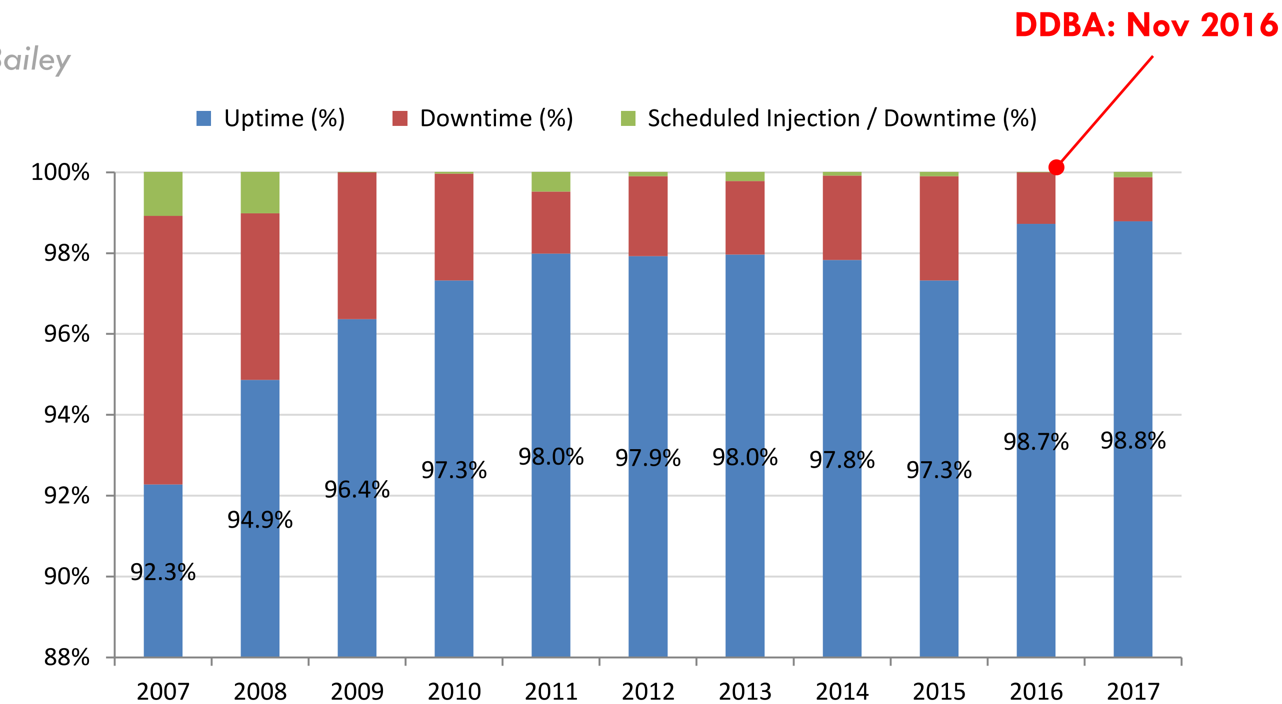
diamond

- Introduction to **Diamond**
- **Operations** update
  - Statistics
- Two new **Normal Conducting Cavities**
  - Longitudinal Multi-Bunch Feedback
- Plan for **upgrades** of existing **IDs**
- **DDBA**: 1yr of operation
- Progress with **Diamond-II**
  - **Lattices**
  - **Accumulator** Ring
- **Conclusions**

- Diamond is the UK's national **synchrotron radiation facility**
- Located at **Rutherford Appleton Laboratory,** Oxfordshire
- Construction began March 2003
- Commissioning 2005 - 2006
- Start of user operations Jan 2007

Lattice	DBA
Structure	24 cell
Symmetry	6 (reduced by mini-beta cells, I21 optics and **DDBA cell**)
Straights	18 × 5m / 6 × 8m / **1x3.4m**
Energy	3 GeV
Circumference	561.571 m
H / V Tunes	28.184 / 13.284
H / V Chromaticity	2.0 / 2.0
H / V Emittance	2.72 nm.rad / 8 pm.rad
Energy spread	0.096 %
Current	300 mA
Lifetime	>7h

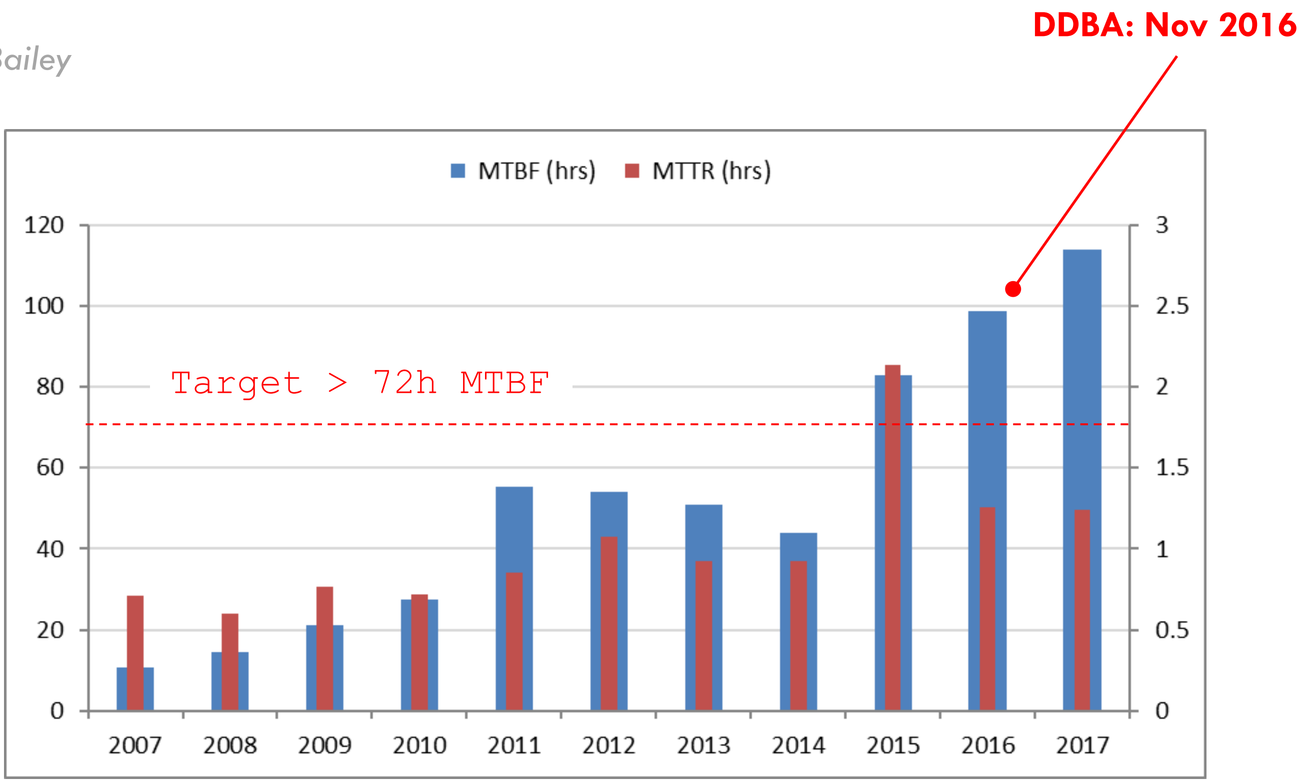
courtesy C. Bailey



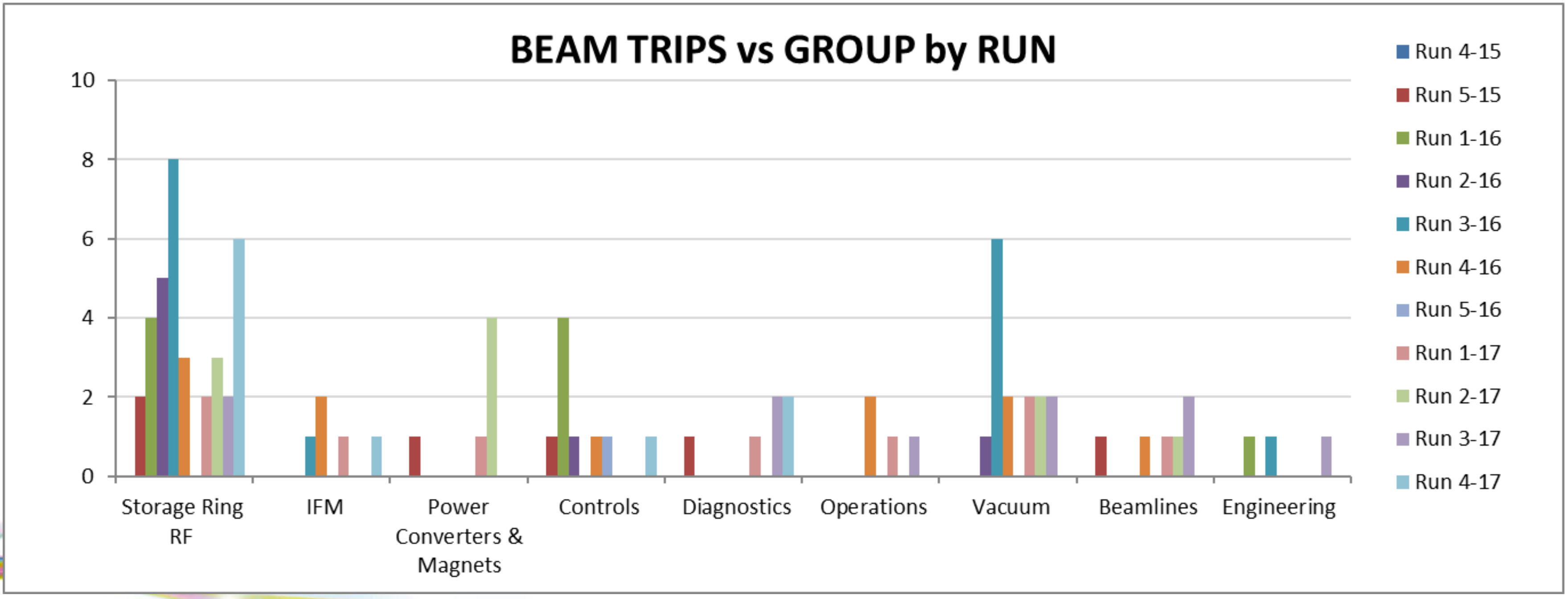
Allocated hours adjusted after cavity swap.

Data up to Run#4 2017

courtesy C. Bailey

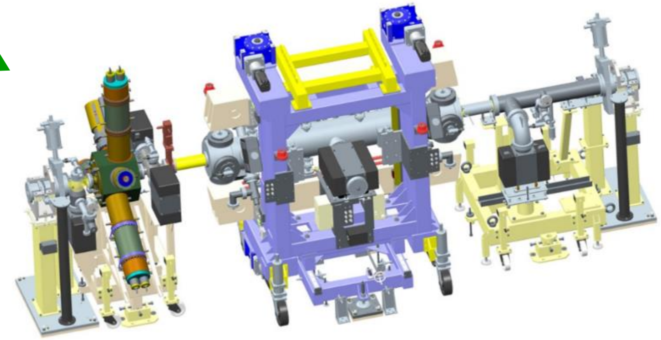


courtesy C. Bailey

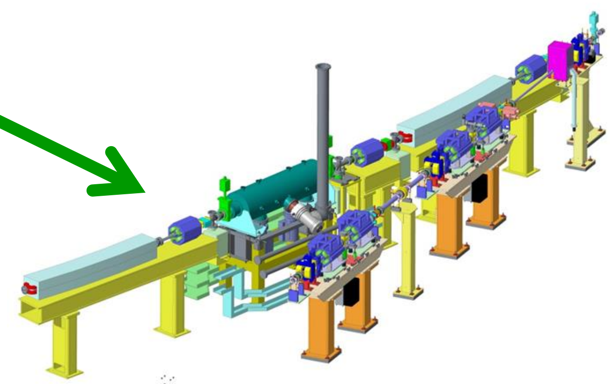


RF system upgrade

courtesy C. Christou



- **Two New Normal Conducting** cavities installed in the **SR in Aug/Nov 2017** (Bessy HOM-damped design)
  - Back-up to existing SC cavities
  - Reduce Voltage (SC)/Power (NC) requirements
  - Powered in Nov/Dec 2017
- **New cavity for booster** ring to be installed in **2018**
  - In vacant straight after booster extraction
  - Used cavity bought from DESY in 2017
  - Needs to be cleaned and conditioned

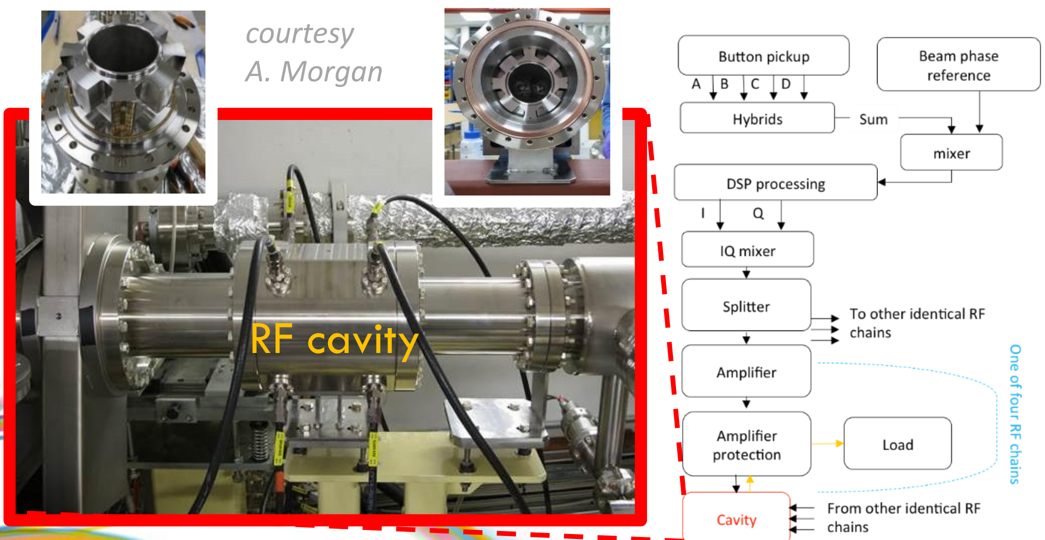


- High Power **SS amplifiers** (Ampegon)
  - for new BC and RF test facility (spring 2018)
  - Similar to SLS booster amplifier
- **New digital LLRF**
  - Required for new normal conducting cavities
  - To be rolled out for all cav. In SR/Booster
  - Collaboration with ALBA
  - Similar to systems in MAXIV/Solaris

Longitudinal multi bunch feedback (LMBF)

- concern that addition of two **new NC-RF** cavities may cause **longitudinal instabilities**

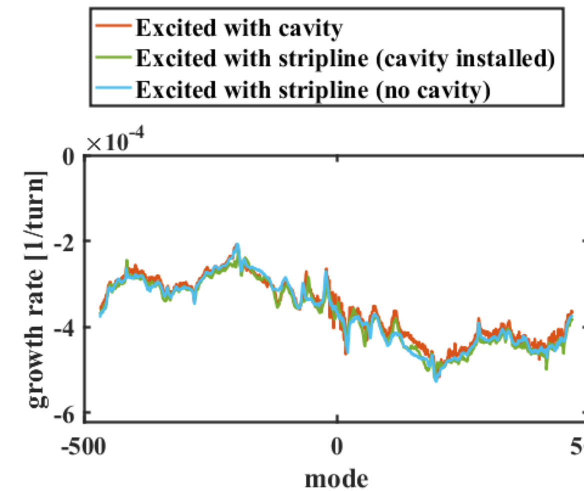
- i.o.t. mitigate these instabilities a **longitudinal feedback system** has been **designed, installed and tested.**



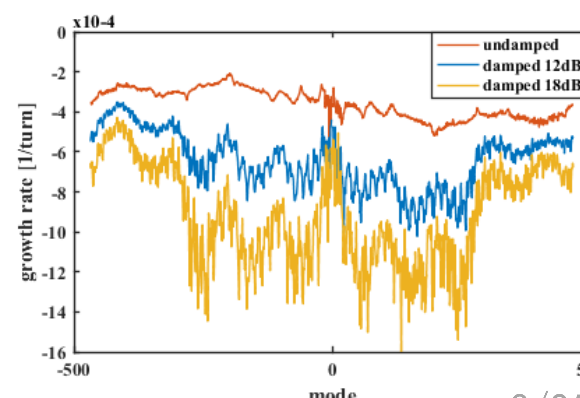
NC-RF cavities due to begin tests in November 2017. First time the **LMBF could become an operationally required system.**

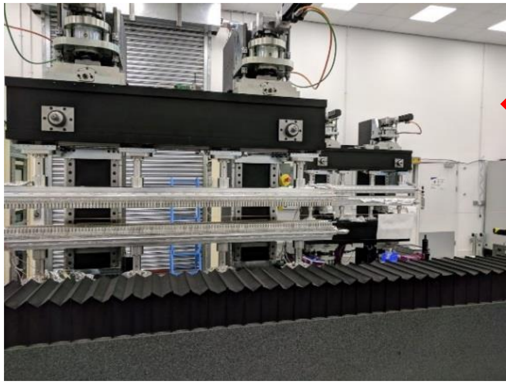
Cavity:

- no problem **when unpowered**
- expected behaviour **when powered**

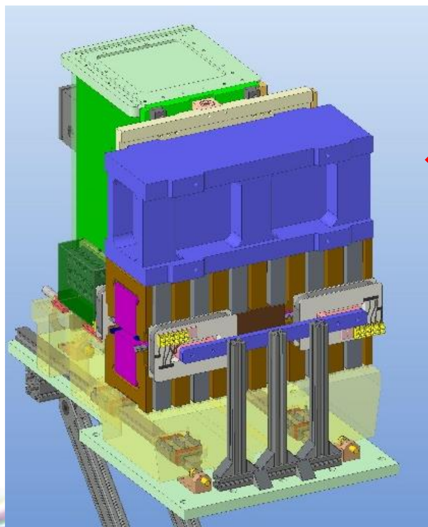


When **FB loop closed** the system **suppresses growth rates** for all modes (machine currently intrinsically stable).

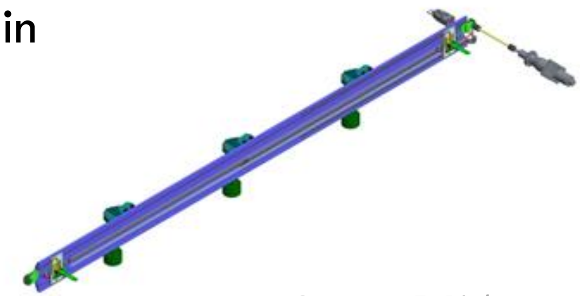




- **Two CPMU17.6** being shimmed
  - **Installation 2018**
- Further **CPMU17.6 and CPMU16.5** under procurement
  - **Installation 2019**
- **SCU15.5** under development
  - Installation **2019**

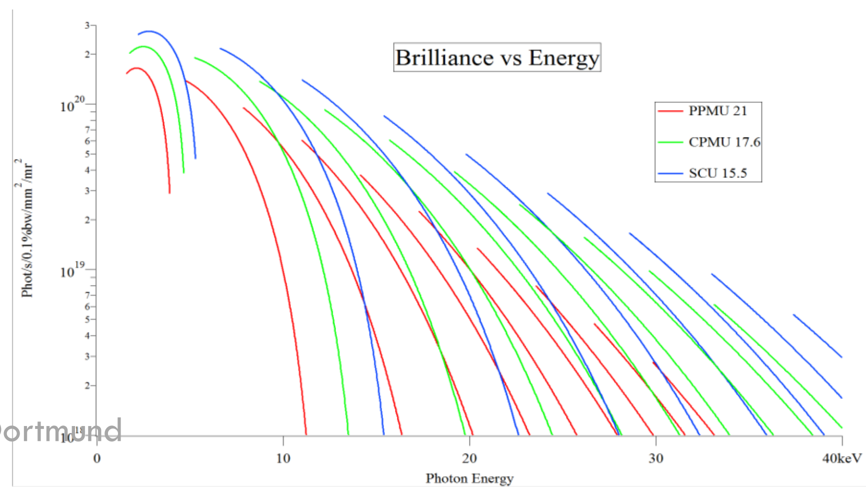


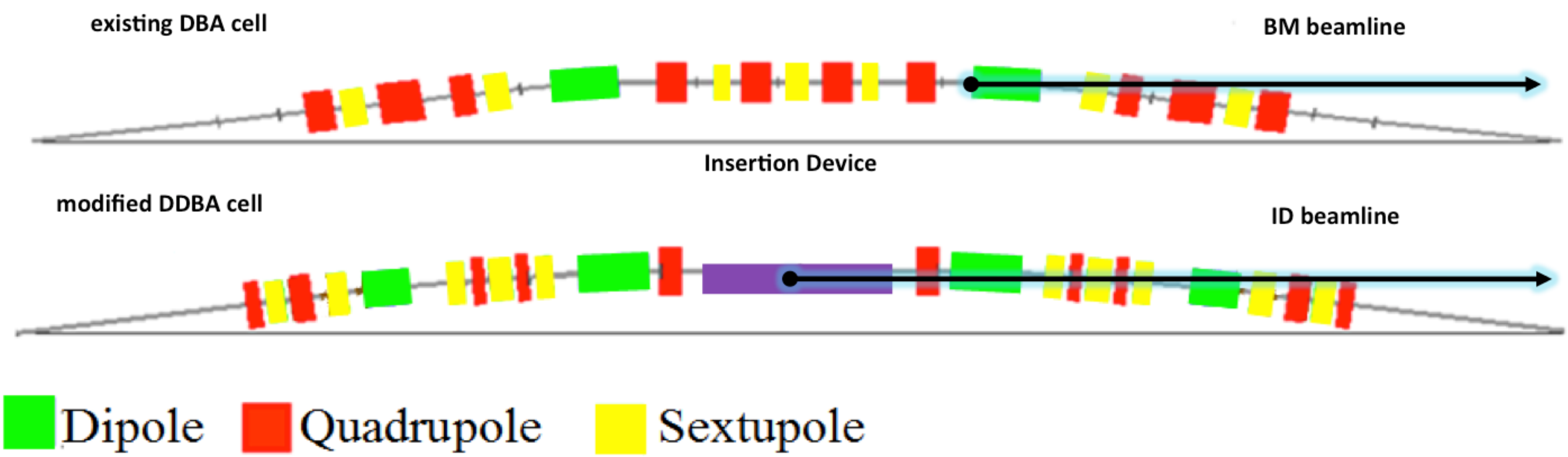
- On-Girder **10-pole Wiggler** in design
  - Installation **2018**
- **In-vacuum measurement** system
  - Measure CPMUs cold
  - Commission 2018



Courtesy E. Rial

Both technologies of **CPMU** and **SCU** are under development and will replace some of the existing IDs due to significant brightness gain over PPMU's at higher photon energies





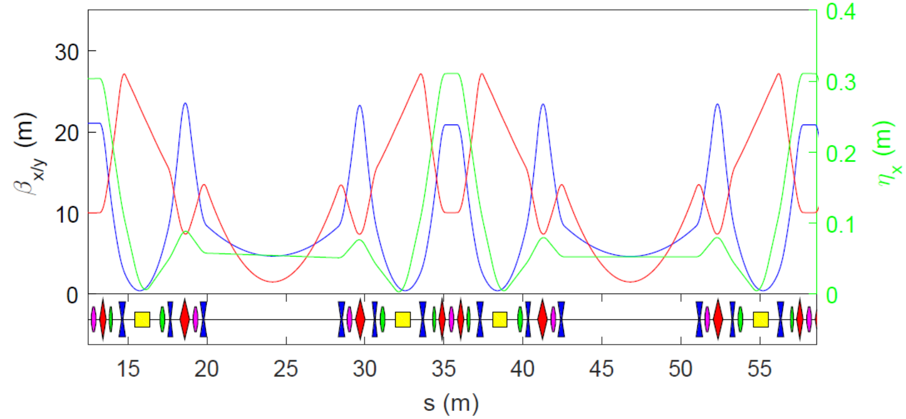
- Introduces an additional straight section
  (**VMX beamline 0.7 m ex-vac → 2.0 m in-vac**)

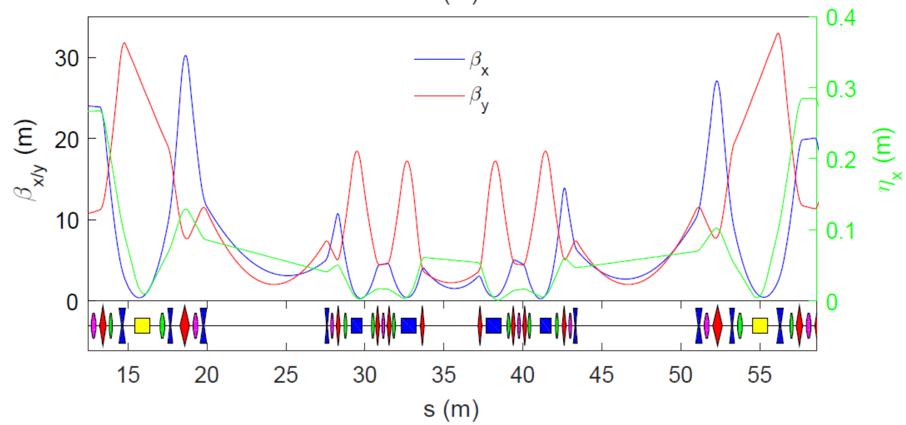
- **DDBA** cell **successfully installed** and operated at full current (300 mA) within a week (Nov. 2016)

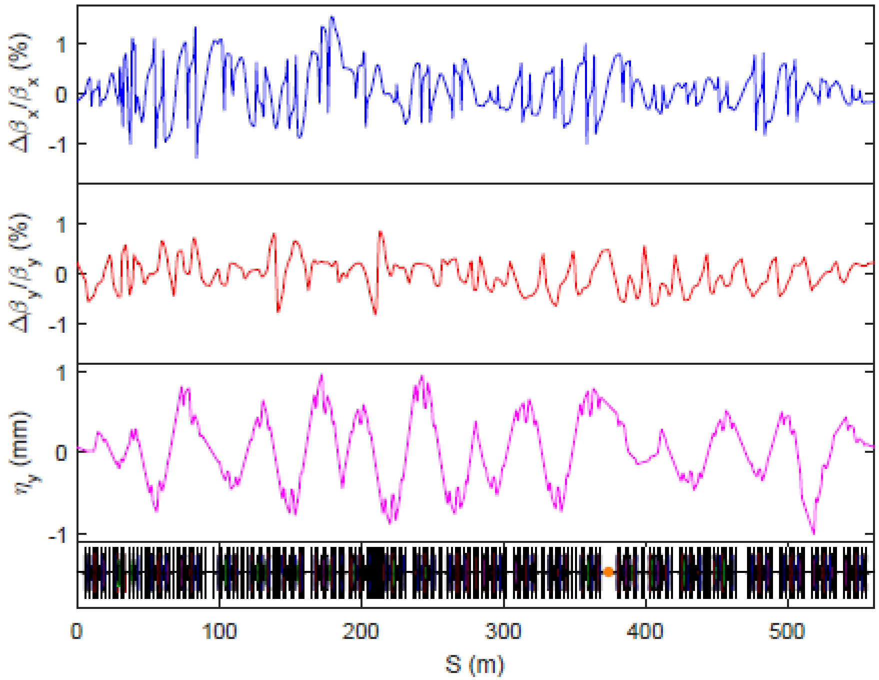
- All software such as SOFB, FOFB, TMBF, vertical emittance FB are working well

- **Reduction** in LT (~-1.5hr) and IE (-5%/10%) observed

Parameter	Pre-DDBA	Post-DDBA
Lattice	24×DBA	1×DDBA + 23×DBA
Circumference	561.600 m	561.571 m
Periodicity	6	1
Harmonic Number	936	936
Energy	3 GeV	3 GeV
Horizontal Emittance	2.52 nm.rad	2.70 nm.rad
Vertical Emittance	8.0 pm.rad	8.0 pm.rad
Energy Spread	9.63×10^{-4}	9.60×10^{-4}
Tunes (Q_x / Q_y)	27.210 / 13.364	28.172 / 13.273
Natural Chromaticity (ξ_x / ξ_y)	-79.4 / -38.1	-78.8 / -41.2
Operating Chromaticity (ξ_x / ξ_y)	2.0 / 2.0	1.5 / 2.0
Energy loss per turn (without IDs)	1.005 MeV	0.988 MeV
Momentum Compaction Factor (α_1/α_2)	1.60×10^{-4} / 1.78×10^{-3}	1.57×10^{-4} / 1.70×10^{-3}
Maximum β_x / β_y	31.52 m / 29.66 m	31.57 m / 33.74 m

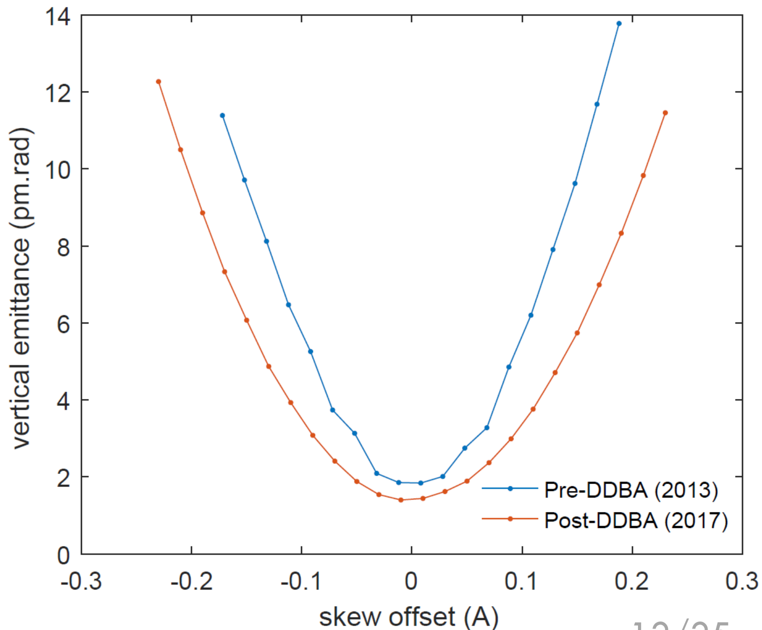






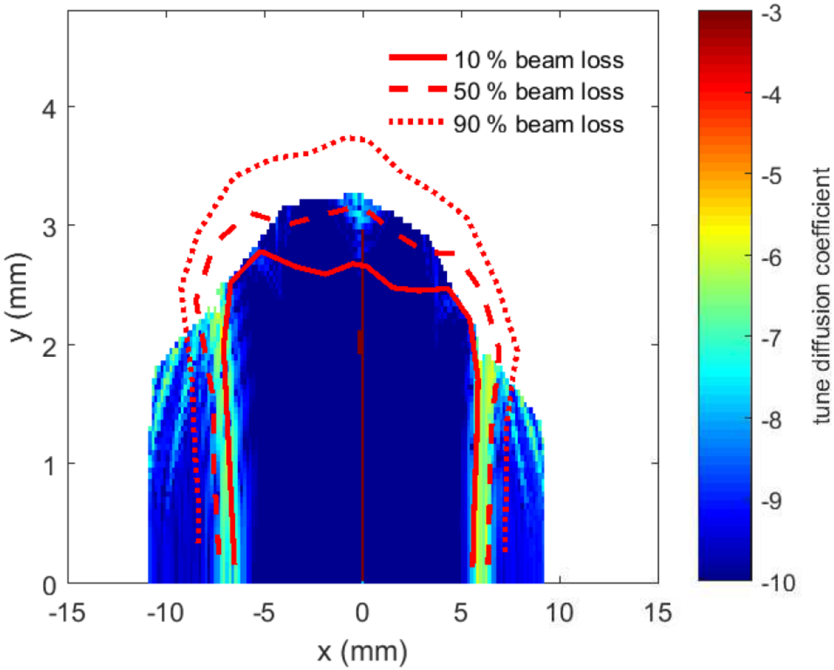
Linear Optics well under control after **LOCO corrections** applied:

- $\Delta\beta/\beta < 1\%$
- $\Delta\eta_y < 1$mm



Excellent control **of vertical emittance (coupling)**

- **Lower** minimum ε_y
- **vertical re-alignment:** 12/71 girders [2013-2017]



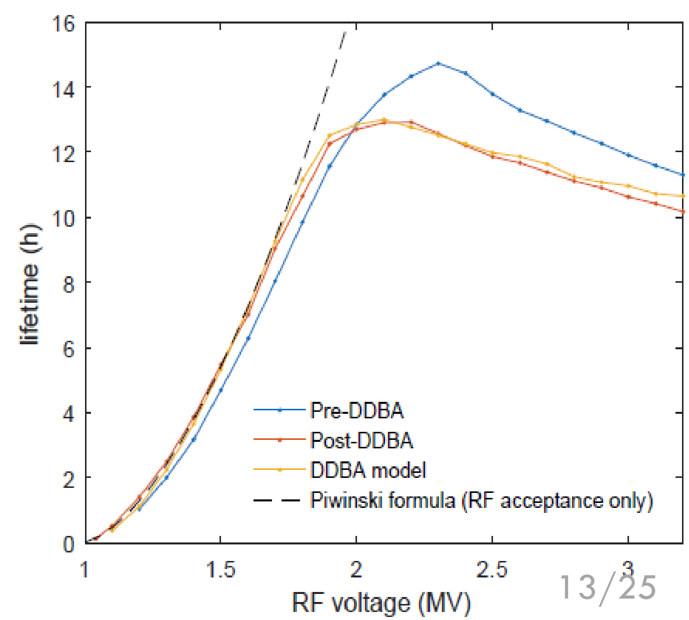
Dynamic Aperture measured with single turn ***pinger* magnets** (H/V) at the end of ID straight-23

- Fill pattern 100/936 bunches (~uniform kick)
- I = 10mA (good signal / reduced collective effects)
- TBT data collected at each kick
- BPM button data ➔ positions
- Transport to injection point via AT model
- Comparison with ELEGANT model

$$\frac{1}{\tau} = \left\langle \frac{r_e^2 c N_p}{8\pi\gamma^2\sigma_s\sqrt{\sigma_x^2\sigma_y^2 - \sigma_E^4\eta_x^2\eta_y^2}\,\tau_m} F\left(\tau_m, B_1, B_2\right) \right\rangle$$

(Touschek) LT reduction

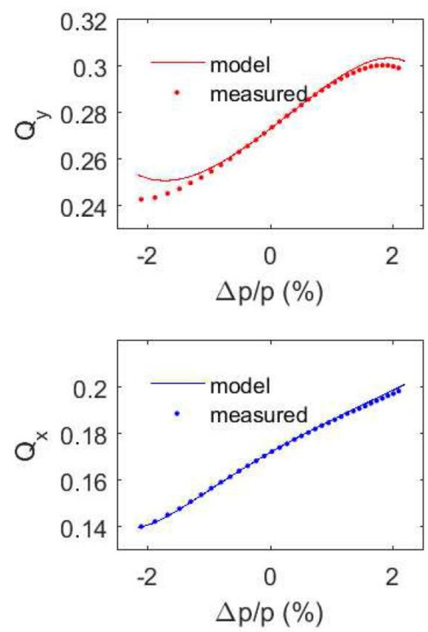
- Low V_{RF}: Momentum Acceptance dominated by RF bucket size (Piwinski formula)
- Large V_{RF}: combination of RF bucket size and Momentum Aperture (+vacuum chamber)
- Remarkable **agreement in shape**
- **Scaling factor** needed to reproduce model uncertainties
- Peak Lifetime: post-DDBA ~ 85% pre-DDBA

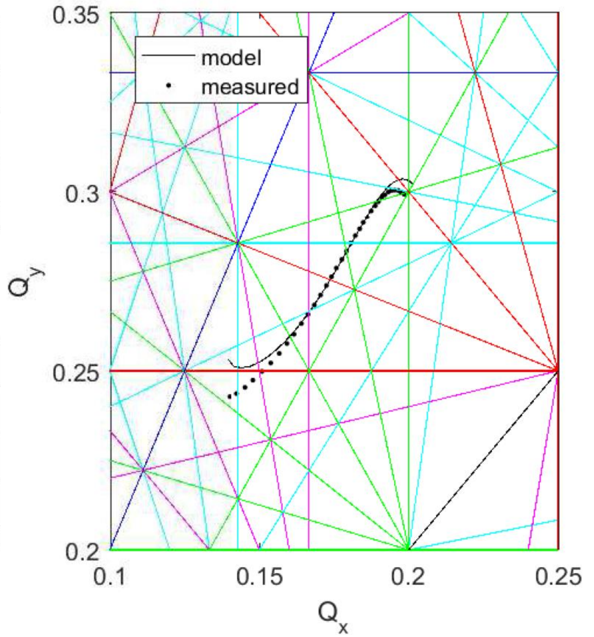


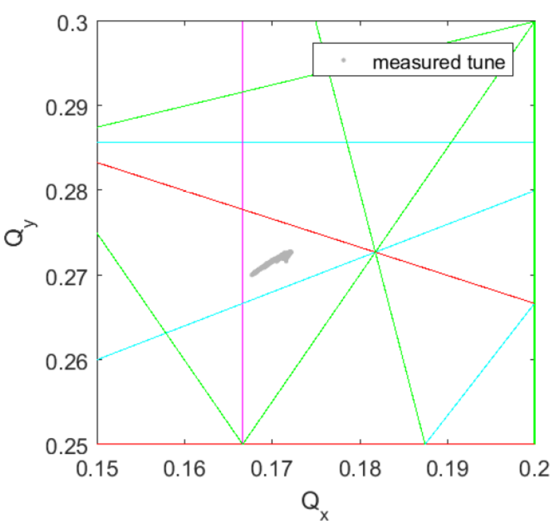
Tune Shift vs Momentum

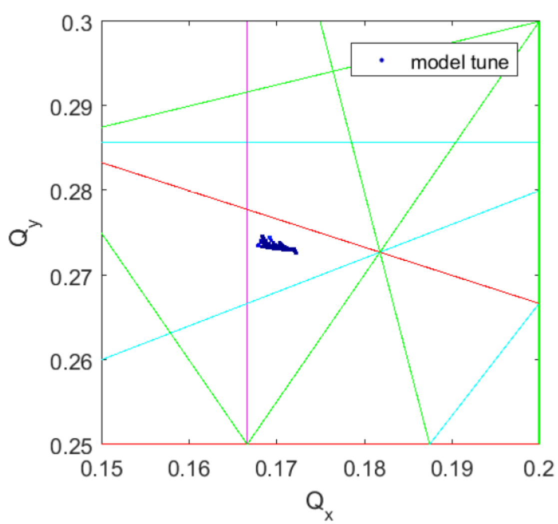
ν_x, ν_y recorded at different RF frequencies

$$\frac{\Delta p}{p} = \frac{1}{2\alpha_2}\left(-\alpha_1 + \sqrt{\alpha_1^2 - 4\alpha_2 \frac{\Delta f_{RF}}{f_{RF}}}\right)$$



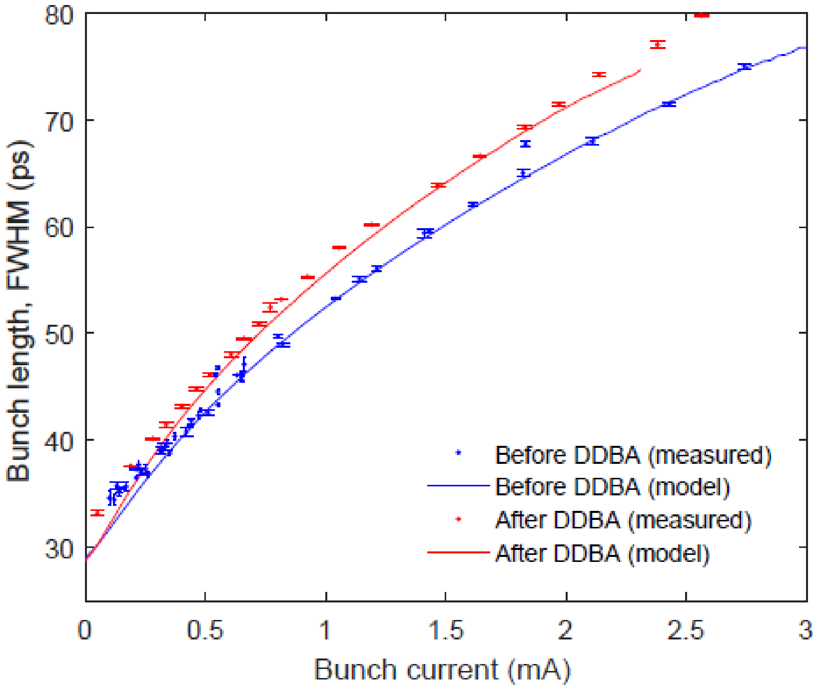






Frequency Maps

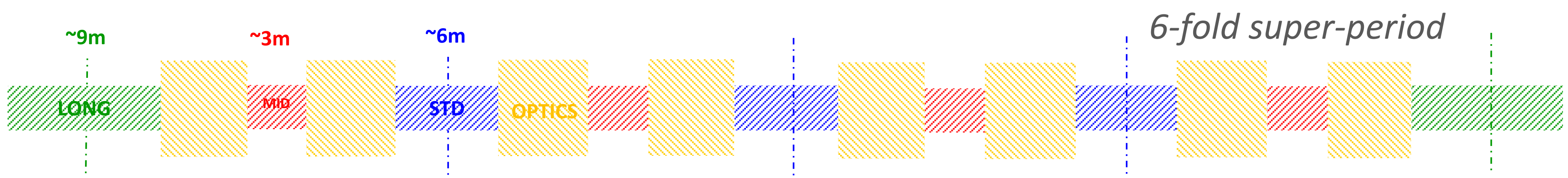
- Corresponding to the DA seen before
- fair **qualitative** agreement



FWHM bunch length vs I_{bunch}

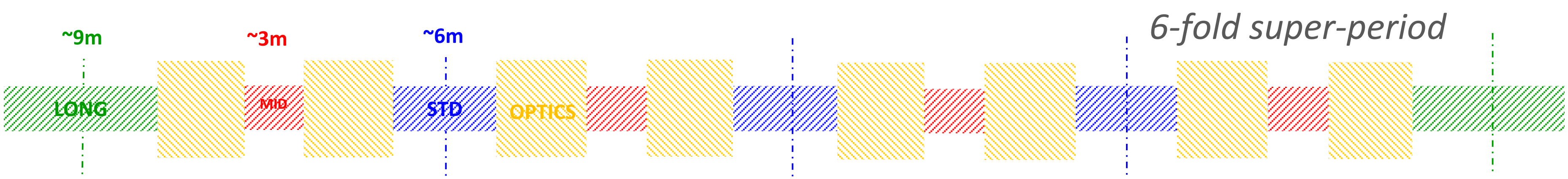
- **SBTRACK** simulation in **good agreement** with data
- Inductive Impedance parameter changed (80nH→100nH) i.o.t. match BL with I_{bunch}

Impedance Type	Parameter	Pre-DDBA	Post-DDBA
Broadband Resonator	R_x	50 kΩ/m	90 kΩ/m
	R_y	200 kΩ/m	250 kΩ/m
	$R_{\|\|}$	0.5 kΩ	0.5 kΩ
Resistive Wall	b_x	40.8 mm	40.2 mm
	b_y	15.6 mm	15.3 mm
Inductance	L	80 nH	100 nH



- **DDBA (4BA)** concept **initial design for DII (fits in tunnel)**
  - DA ~ 3mm / LT ~ 7hr / ε_x **~ 270pm**
  - mid-straight for extra ID (non-dispersive)
- **DTBA (6BA)** concept (from ESRF-HMBA) evolution of DDBA for a **smaller emittance (fits in tunnel)**
  - DA ~6mm / LT < 3hr/ ε_x **~ 130pm**
  - proved **difficult** when trying to keep the **mini-beta** scheme (beamlines I09 / I13)
    - In particular LT **~ 0.5** hr highly penalized

Off-Axis Injection



- **Stepped back** to a **6-fold case** exploring other schemes too (while keeping the same straight/optics structure):
  - Emphasis on **robust design** with cancellation of higher order terms (H.O. Achromat)
  - **8BA – HMBA, ε_x ~ 105pm**
  - **6BA – TME + AntiBend (AB), ε_x ~ 75pm**
  - **~~Off-axis~~ → On-axis** injection scheme with **Accumulator Ring**

On-axis Injection

DTBA (6BA)

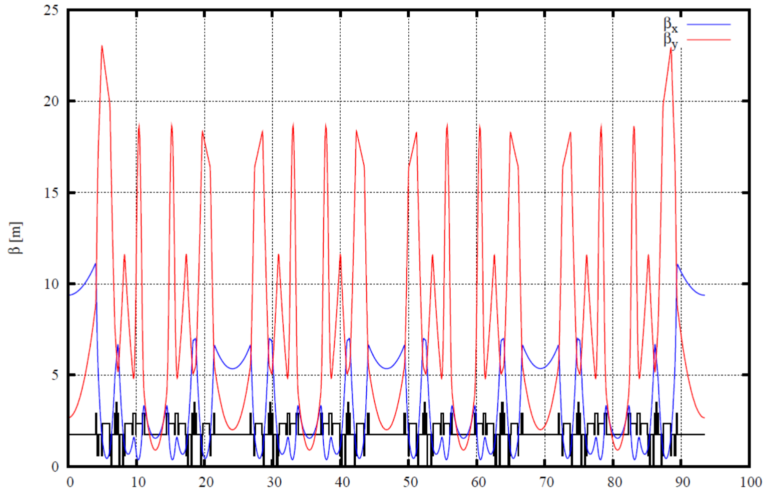
- large tune footprint with amplitude
- large tune footprint with momentum (not shown)

ε_x = 130pm
ν_x =58.16, ν_y =21.29
ξ_x =-82.2 ξ_y = -123.6
α_c=0.99e^{-4}

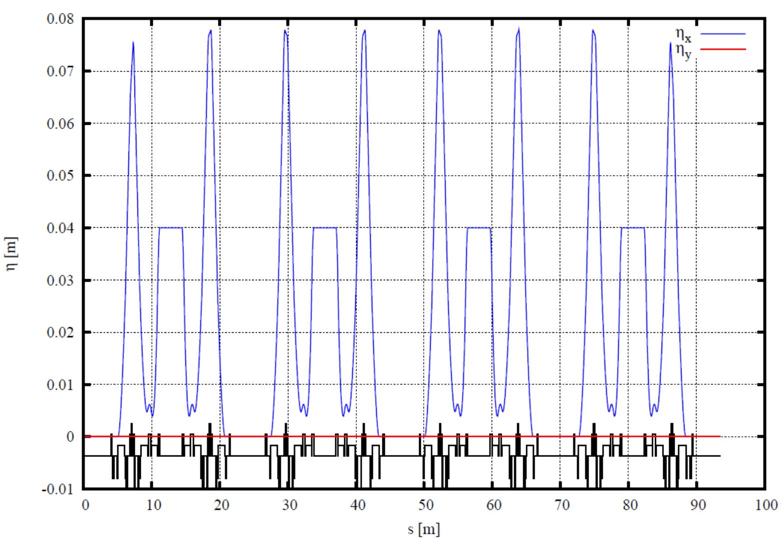
courtesy J. Bengtsson

Lattice re-optimization (HOA)

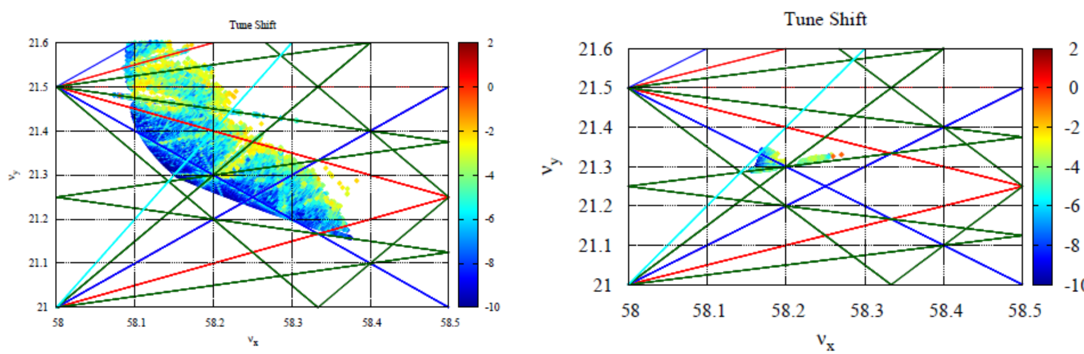
6BA - BETA FUNCTIONS



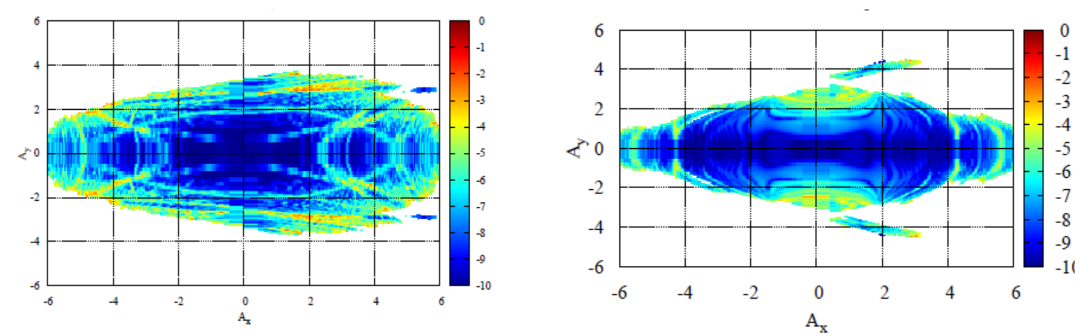
6BA – DISPERSION



6BA – TUNE SHIFT with AMPLITUDE (bare lattice)



6BA – DIFFUSION MAP with AMPLITUDE (bare lattice)

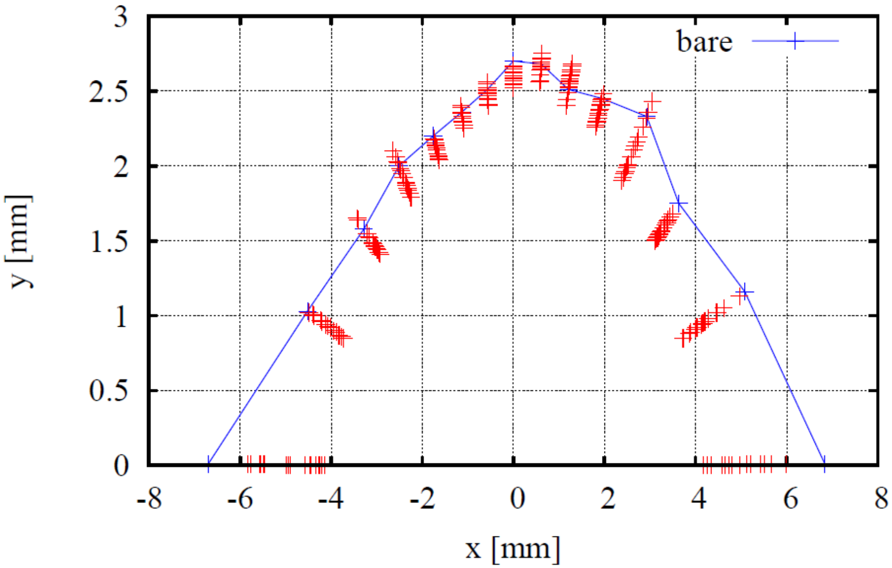


DTBA (6BA)

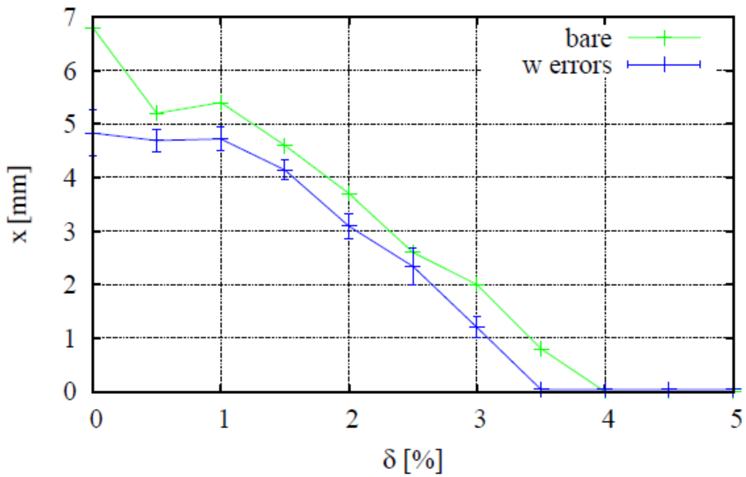
ε_x = 130pm
ν_x =58.16, ν_y =21.29
ξ_x =-82.2 ξ_y = -123.6
α_C=0.99e^{-4}

- DA ~ 6mm (with errors) [off-axis option still possible]
- Robust design

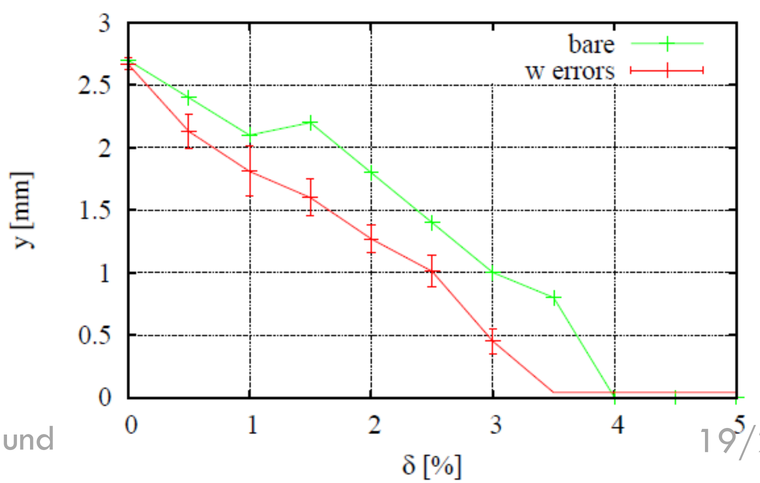
6BA – DYNAMIC APERTURE (bare/real latttice) - RFon



6BA – DYNAMIC APERTURE (w/wo errors)
horizontal



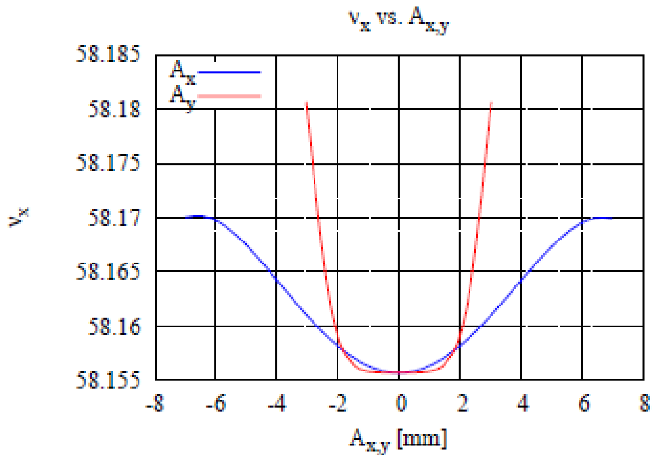
vertical

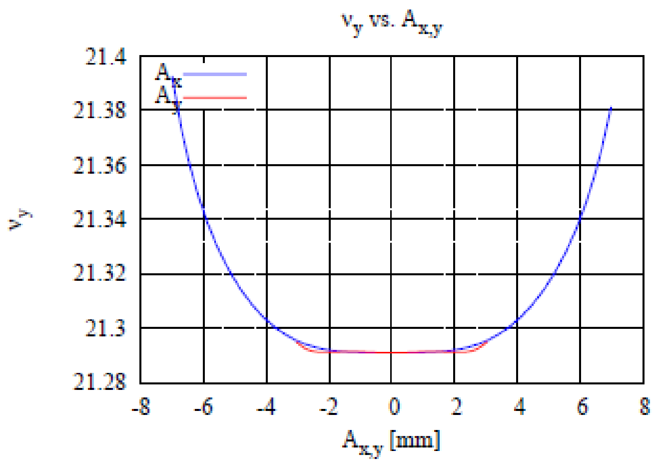


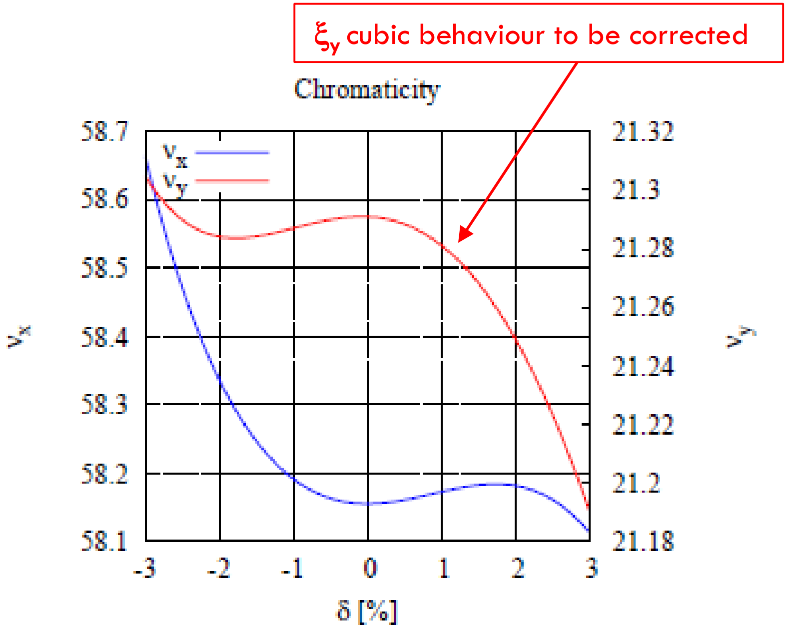
DTBA (6BA)

ε_x = 130pm
ν_x =58.16, ν_y =21.29
ξ_x =-82.2 ξ_y = -123.6
α_C=0.99e^{-4}

- Closer look to tune vs amplitude
- Non-linear chromaticity → vert nat chrom to be reduced … w.i.p.





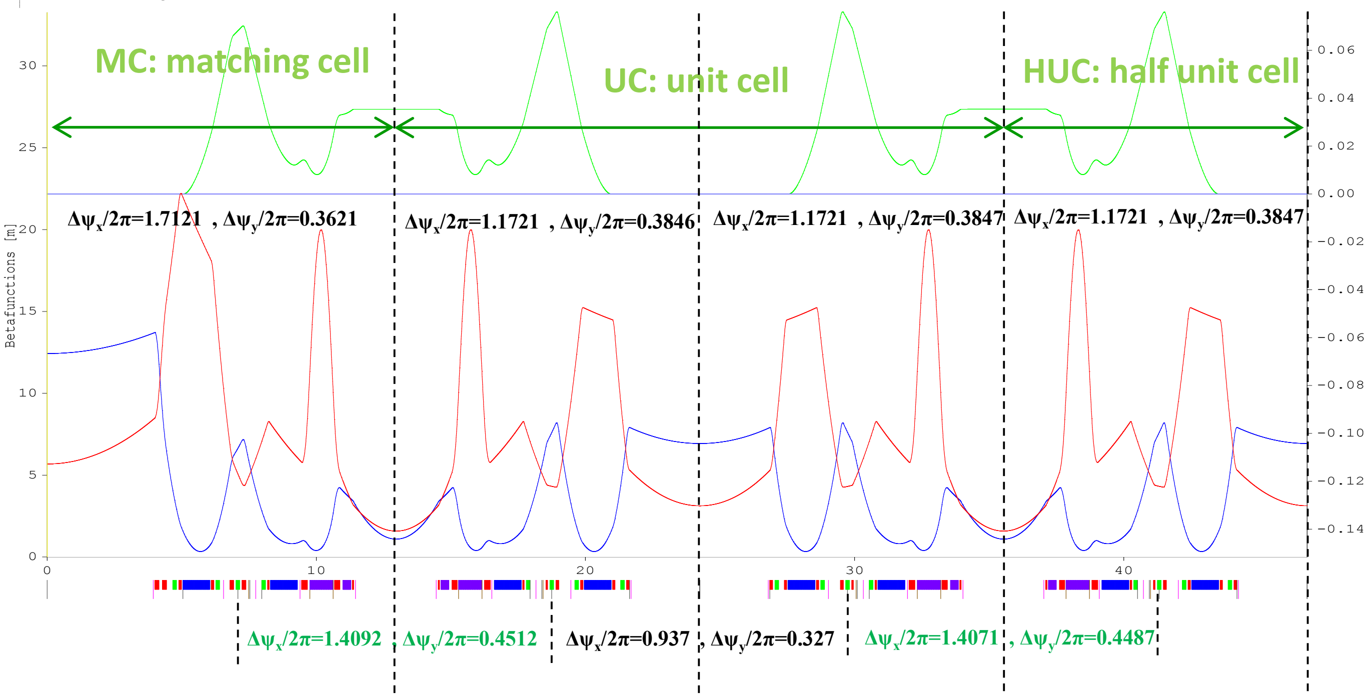


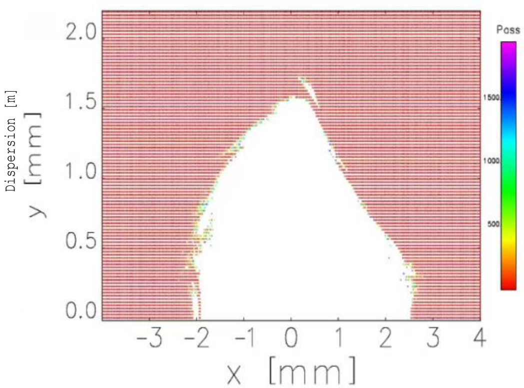
8BA lattice

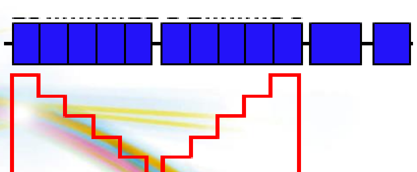
Courtesy H. Ghasem

ε_x = 105pm
ν_x =56.26, ν_y =18.19
ξ_x =-83, ξ_y = -98
α_C=1.38^{-4}

Half super period: {MC+UC+HUC}







Name	LGB1	LGB2	DQ1	DQ2
Angle [Deg]	2.66	2.66	2.66	0.3
ε [%]	21.223	21.223	24.58	32.974

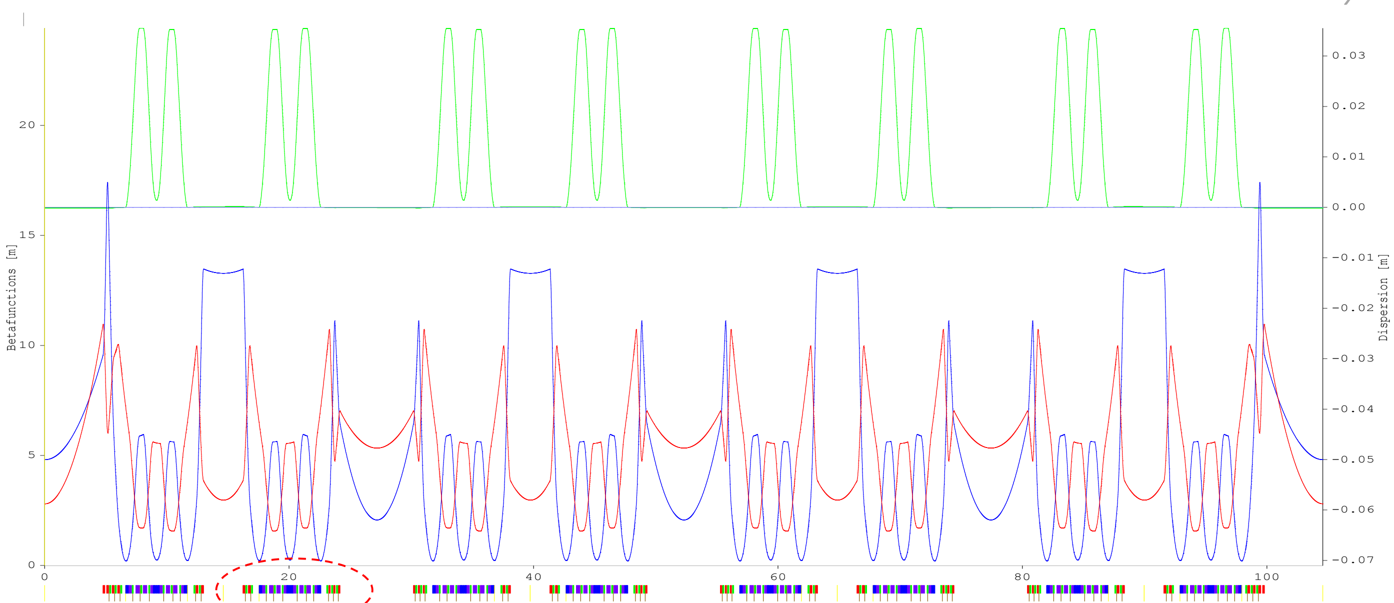
Parameters	8BA
Circumference [m]	561.766
Nat. emittance [pm rad]	105
Hor./Ver. tune	56.60/22.16
Hor./Ver. chromaticity	-83.01/-97.75
Energy spread	0.732 E-3
Energy loss/turn [MeV]	0.323
Momentum compaction	0.138 E-3
Max. βx/βy/ηx [m/m/m]	13.68/21.98/0.074

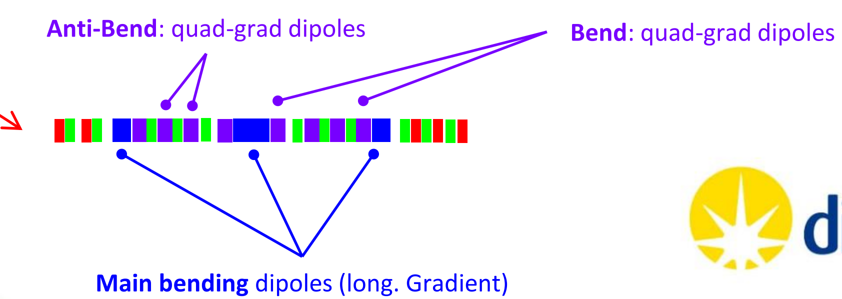
6BA anti-bend lattice (SLS-2 concept)

ε_x = 75pm
ν_x =11.77 , ν_y =4.2
ξ_x =-33, ξ_y = -11.5
α_C=-4.2e^{-5}

Length of SP (m) = 104.57 ← *to be reduced to match ~561m !*
Length of Straights: Long = 9.54m, Standard = 6m, Mid = 3.12m
Further linear and non-linear optimization is under progress

Courtesy B. Singh





diamond

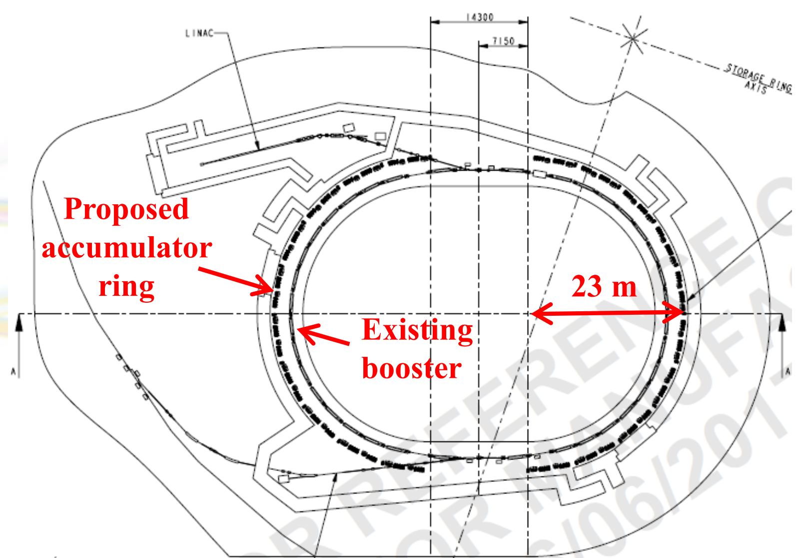
Accumulator Ring

Diamond-II likely to be characterized by a **low Dynamic Aperture**

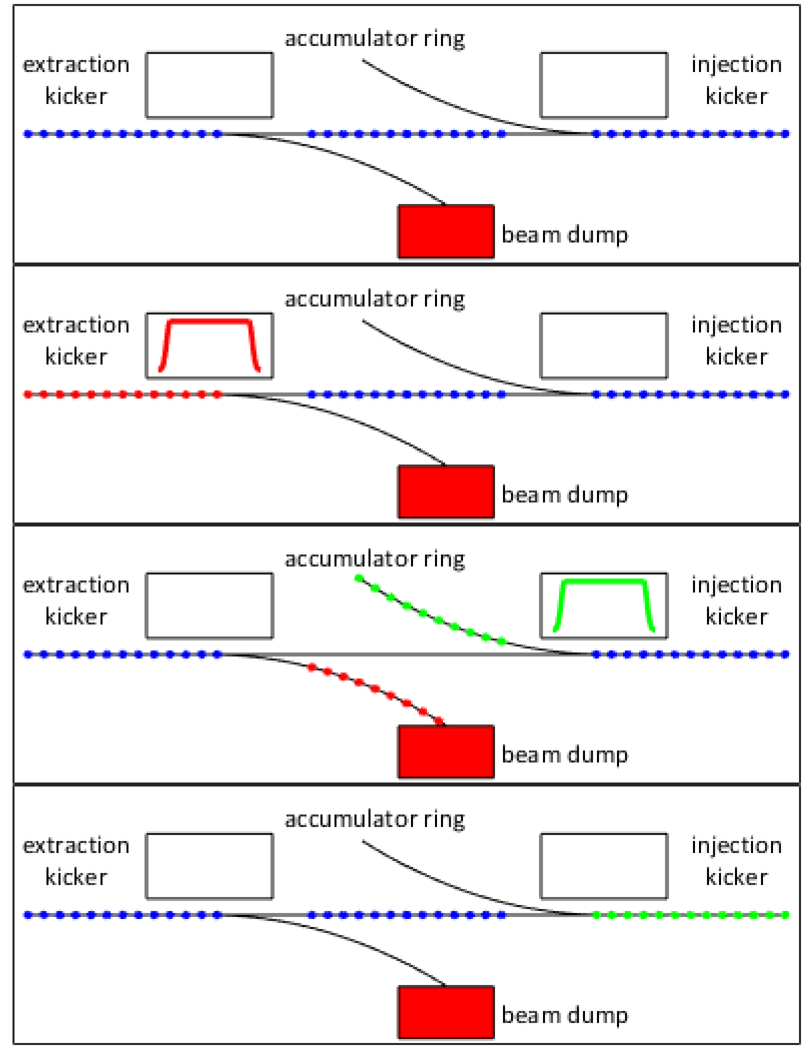
This might require a **swap-out injection scheme**

Present Diamond booster not capable of delivering the required charge per shot => **new accumulator ring** required

New ring could be placed inside storage ring tunnel, but **inside booster tunnel** is preferred option at present for logistical reasons

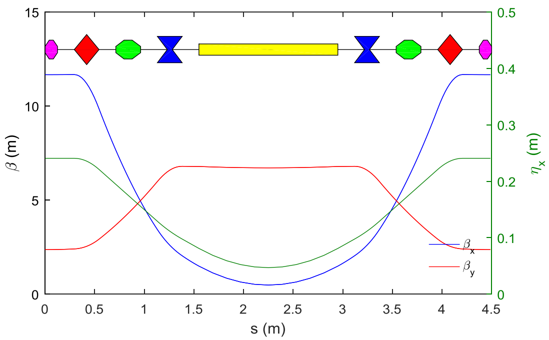


Courtesy I. Martin



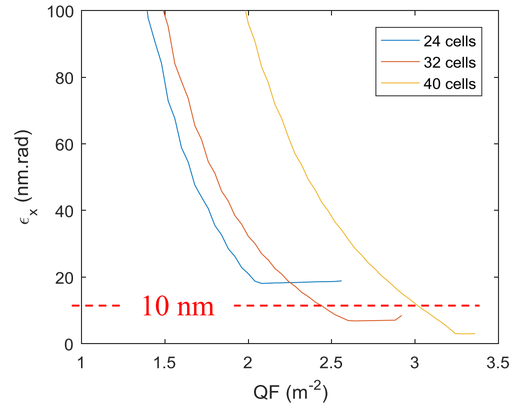
Accumulator Ring TME-style Unit Cell

Courtesy I. Martin

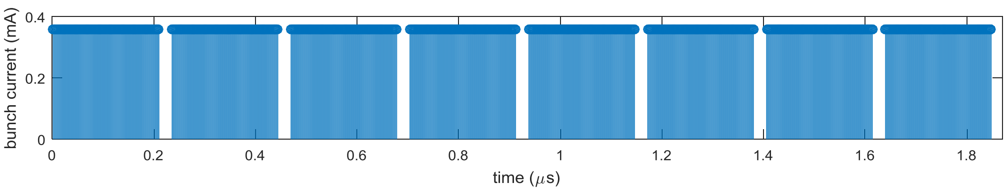


Cell optimized for:

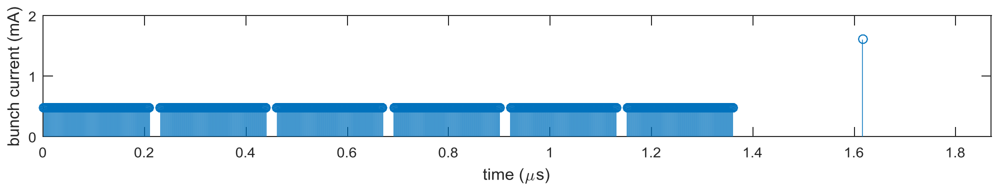
- Total number / length of dipoles to reduce emittance
- Quad / sext length for moderate gradients
- Horizontal tune for low emittance [$\varepsilon_{x,inj} \sim$ 10 nm.rad]
- Vertical tune to minimise natural chromaticity
- Horizontal / vertical tune for dynamic aperture [13.591, 5.139]



Standard filling pattern:
8 trains of 105 bunches, gaps of 12 bunch
⇒ **22 ns rise / fall** time for kicker, **110 ns flat top**
⇒ 840 bunches filled, 0.3571 mA / bunch for 300 mA



Hybrid filling pattern:
6 trains of 105 bunches, gaps of 10 bunches + single bunch
⇒ **20 ns rise / fall** time for kicker, **110 ns flat top**
⇒ 630+1 bunches filled, 0.4762 mA/bunch for 300 mA



- **DDBA** upgrade **biggest change** to the Diamond Storage Ring since its commissioning (2006)
- **Successful year of operations** after commissioning.
- RF and ID upgrade
- **Reduced LT/IE** did not impact normal operations significantly.
- Work on **DII progressing**
  - review of initial ideas (DDBA/DTBA) and investigation of alternative lattices (6BA/8BA w/wo anti-bends)
  - Small emittance from **Accumulator**-ring with on-axis injection scheme
  - Investigation on elimination of miniBeta sections

thanks for your attention