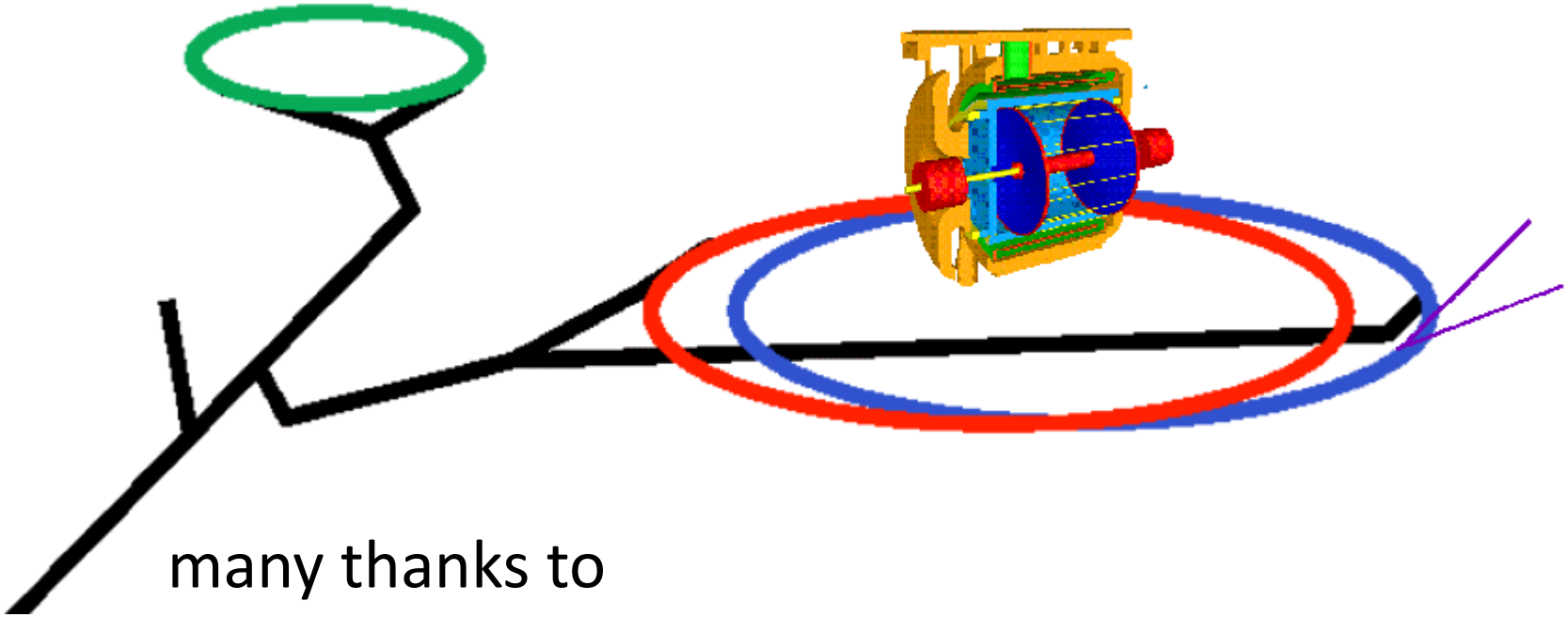
DAFNE Test Facility

Frank Zimmermann

INFN Frascati, 10 November 2014



many thanks to
Michael Benedikt, Manuela Boscolo, & Catia Milardi

*Work supported by the **European Commission** under Capacities 7th Framework Programme, Grant Agreement 312453*

proposal:

Converting DAFNE to European/Int'l high-current beam & cw SRF Test Facility

(M. Benedikt)

1. qualifying multi-cell SC cavities for high current CW operation (truly unique facility!)

- **extremely relevant for all proposed future circular colliders**, ***FCC-ee, FCC-hh***, *CepC, SppC,* ***LHeC, HL-LHC,*** *FCC-he, eRHIC, MEIC* [+ also for **ERLs, synchrotron light sources**, etc.]
  - potentially huge group or partners and users
- **key issues**: **trapped modes**, longitudinal & transverse impedance, fundamental power coupler, **HOM losses**,… cavity design optimization

Converting DAFNE to European/Int'l high-current beam & cw SRF Test Facility

2. demonstrating target SRF efficiency (wall plug to beam power)

- another key issue for all future facilities

3. impedance & HOM effects for RF cavity and other accelerator components

- qualification of vacuum chamber prototypes, collimators and masks, kickers, etc. for *e* and p colliders with various filling patterns
- qualification of novel beam diagnostics for *e* and *p* colliders

Converting DAFNE to European/Int'l high-current beam & cw SRF Test Facility

4. tests & demonstration of other essential, or proposed, **concepts** for future circular colliders

- **crab-waist collision scheme** ✓
- **novel pretzel –orbit wake field effects**
- **SR effects on vacuum for *ee* and hh colliders**
- **energy calibration methods (?)**
- **mono-chromatization schemes (?)**
- **e^+ source studies, various e+ targets, polarization issues ?**
- **Several schemes for top-up injection**

- **4-beam collisions? plasma b-b compensation? crystals?**

some of these concepts might also strengthen DAFNE physics program

big question: can we use multi-cell SC cavities with A beam current? (Ross, Yokoya)

past operation of multi (4 or 5)-cell SC cavities at KEK, CERN, and DESY

maximum beam current:
TRISTAN: ~14.5 mA
LEP: ~8.5 mA
HERA: <100 mA

more modern higher-current (*Ampere*-scale) facilities

PEP-II: only normal conducting RF.
KEKB: mostly NC storage cavities & 10 1-cell SC cavities

present/past designs of multi-cell cavities for high current

BNL eRHIC for 0.6 to 1 A, DAFNE for > 1 A

installing multi-cell SC cavities in DAFNE proposed earlier (for another purpose) - *so this could be done*

Proceedings of 2005 Particle Accelerator Conference, Knoxville, Tennessee

DESIGN OF A MULTI-CELL, HOM DAMPED SUPERCONDUCTING CAVITY FOR THE STRONG RF FOCUSING EXPERIMENT AT DAΦNE

David Alesini, Caterina Biscari, Roberto Boni, Alessandro Gallo, Fabio Marcellini, Mikhail Zobov, INFN/LNF, Frascati, Italy
Carlo Pagani, INFN/LASA, Segrate (MI) and DESY, Hamburg

Table 1: cavity parameters.

RF frequency [MHz]	1288.9
Max RF voltage [MV]	8
R/Q geometric factor [Ω]	390
Quality factor (@ 1.8 K)	10^{10}
Cavity wall power [W @ 1.8 K]	8
Loaded quality factor	$2 \div 4\ 10^{7}$
Cavity detuning for Beam Loading (@ 8 MV, I_b=1A) [kHz]	- 60
RF generator power [kW]	1
Cavity length [m]	0.8

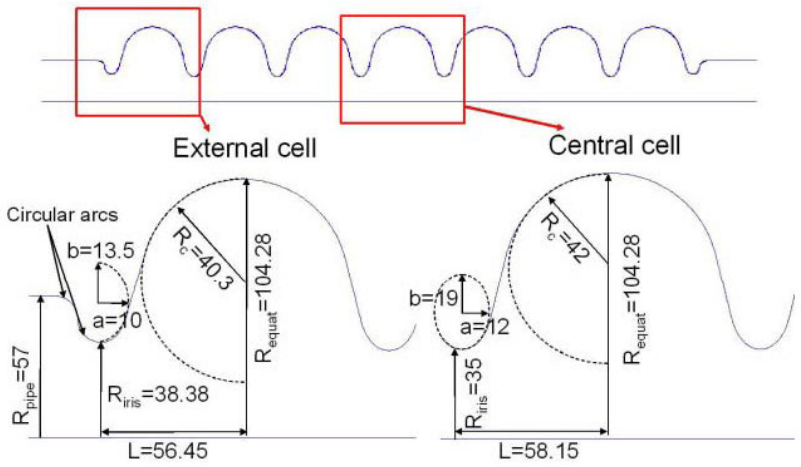


Figure 1: cavity profile and dimensions.

estimate of required cryo power

heat load per cavity = $\frac{V_{cav}^2}{Q_0(R/Q)}$

maximum voltage per cavity (1 m) ~ 20 MV

Q_0 ~ 2x10^{10}

R/Q ~400 – 1000 Ω (frequency dependent)

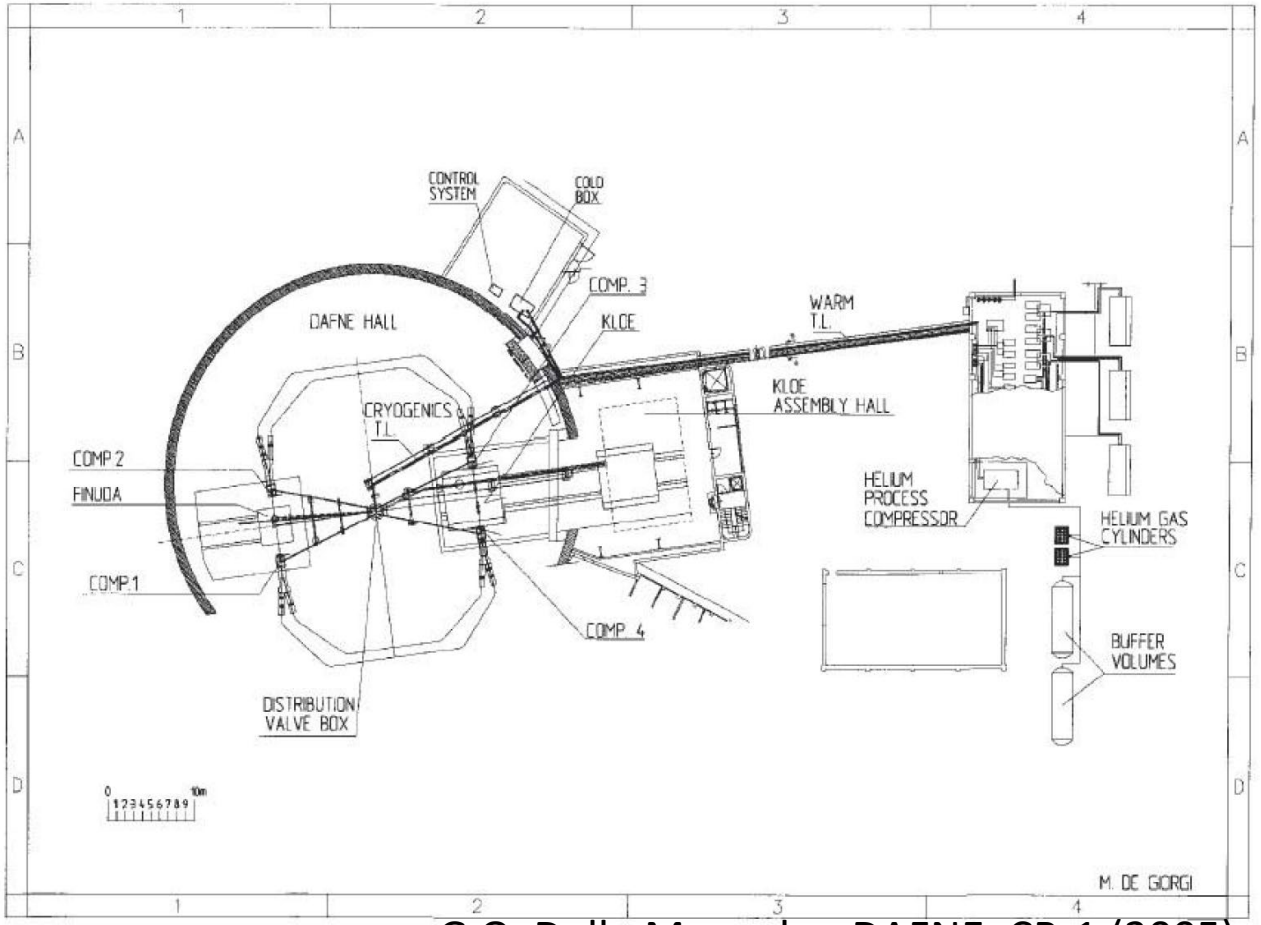
→ maximum dynamic heat load per cavity

~ 20 – 50 W at 2 K

existing DAFNE cryogenic system

layout of DAFNE cryo system for 6 SC magnets

marginal for 4.4 K operation of 1 cavity ?



G.O. Delle Monache, DAFNE, CR-1 (2005)

refrigerator plant LINDE TCF 50

nominal compressor power of 250 kW, delivering two cold He lines:

- **4.4 K @ 3.0 bar (100 W nominal power** + 1.14 g/s LHe);
- 77 K @ 10 bar (900 W nominal power).

estimated heat load at 4.5 K

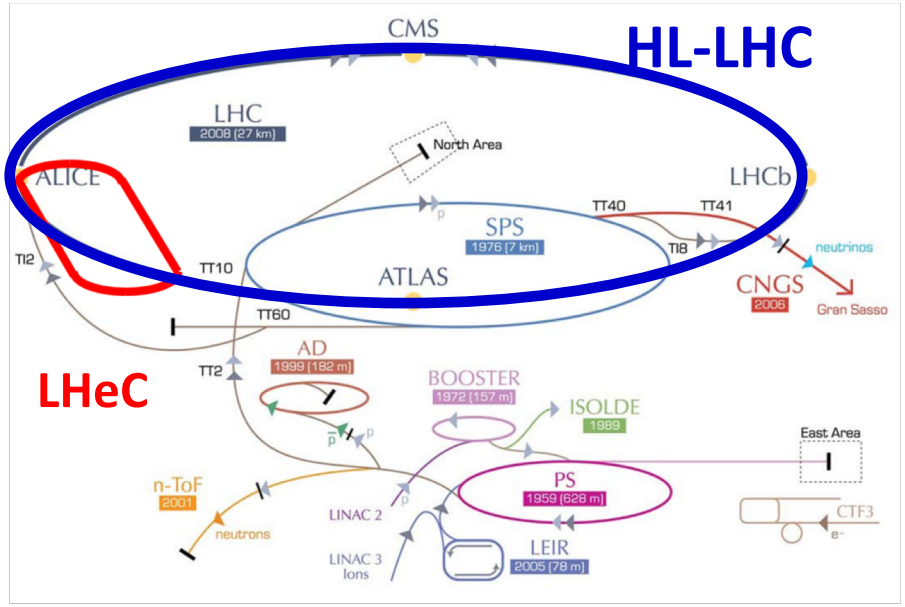
R. Calaga

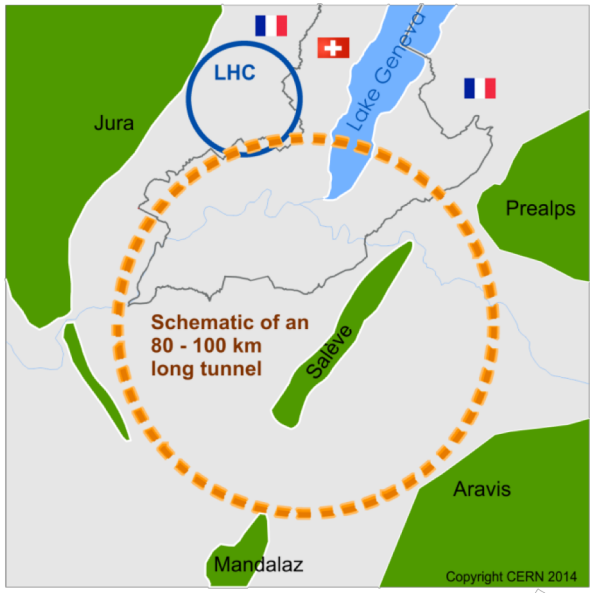
Heat Load Estimates for 400/700/1300MHz Cavities R. Calaga, Nov 10 2014						
		Nb-on-Cu	Bulk Nb	Bulk Nb	Bulk Nb	
Freq	MHz	400.800	704.000	801.600	1,322.640	
R/Q	Ohms	100	500.000	550.000	1,036.000	
Temp	K	4.5	4.5	4.5	4.5	
lambda/2	m	0.374	0.213	0.187	0.113	
Number of Cells		2	5.000	5.000	9.000	
Length	m	0.75	1.06	0.94	1.02	
Voltage	MV	10	20.000	20.000	20.000	
Acc Gradient	MV/m	13.369	18.786	21.390	19.608	
Geometry Factor	Ohms	253	250	280	270	
R_BCS	nOhms	62.54	192.95	250.16	681.07	
R_Residual	nOhms	8	5	5	5	
Rs (R_BCS+Residual)	nOhms	70.54	197.95	255.16	686.07	
Q0 @ 4.5K	10^9	3.6	1.3	1.1	0.4	
Cavity dynamic losses	**W at 4.5K**	**139.4**	**316.7**	**331.4**	**490.5**	
1FPC at 4.5K	W	10.0	10.0	10.0	10.0	
1FPC at 80K	W	50.0	50.0	50.0	50.0	
4HOM Couplers 4.5K	W	20.0	20.0	20.0	20.0	
4HOM Couplers at 80K	W	100.0	100.0	100.0	100.0	
Cryomodule Static losses at 4.5 K	W	10.0	10.0	10.0	10.0	
Cryomodule Static losses at 80K	W	100.0	100.0	100.0	100.0	
Total losses, 4.5K		**358.8**	**356.7**	**371.4**	**530.5**	
Total losses, 80K		**500.0**	**250.0**	**250.0**	**250.0**	**TBC**

beam currents around the world

	beam current I [A]	bunch population N_b [10^{11}]	rms bunch length [mm]	bunch spacing [ns]	comment
PEP-II	2.1 (e^-), 3.2 (e^+)	0.5, 0.9	12	4.2	terminated
KEKB	1.2 (e^-), 1.6 (e^+)	0.7, 0.5	7	6	not available
DAFNE	**2.4 (e^-), 1.4 (e^+)**	**0.4, 0.3**	**18 (flexibility?)**	**2.7**	**available?**
BEPC-II	0.8	0.4	<15?	8	
CesrTA	0.2	0.2	6.8	4	
VEPP-2000	0.2	1	33	80 (1 b)	
LHC (des)	0.58	1.15	75.5	25	
ESRF	0.2	0.04	6.0	2.8	
APS	0.1	0.02	6.0	2.8	
Spring8	0.1	0.01	4.0	2.0	
SLS	0.4	0.05	9.0	2.0	

future circular colliders

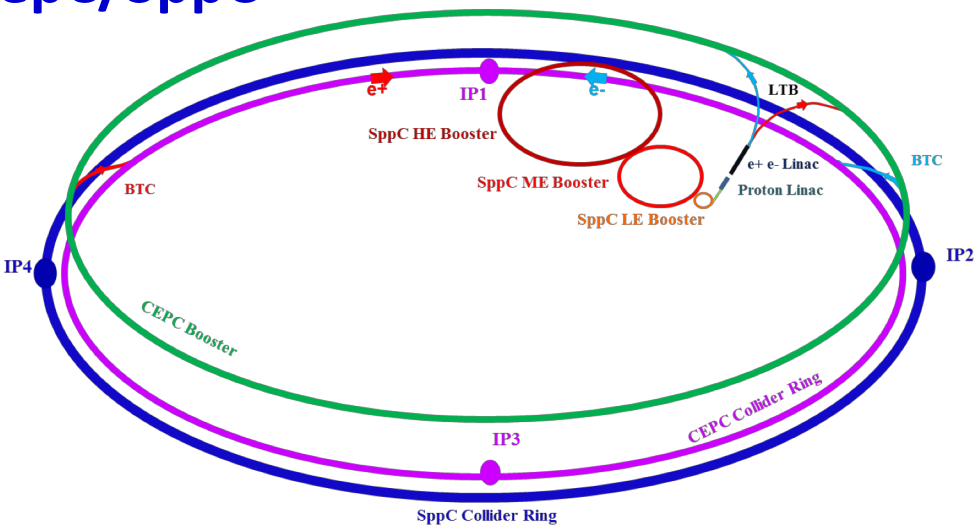




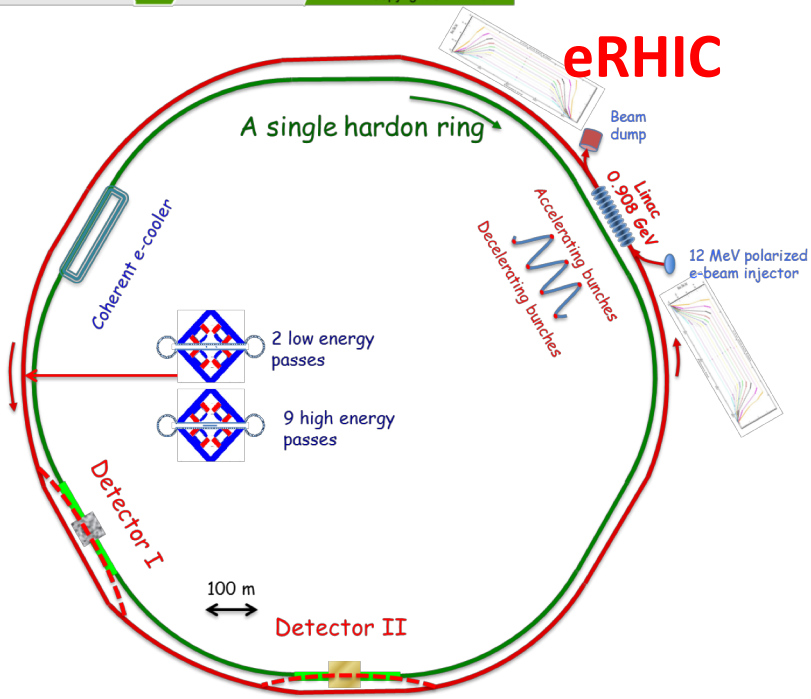
FCC

- FCC-hh
- FCC-ee
- FCC-he

CepC/SppC



eRHIC



future currents & beams

	HL-LHC	FCC-ee (*Z*)	CepC (*Z*)	FCC-hh		SppC	LHeC	eRHIC	
***I* [A]**	**1.0**	**1.45**	**?**	**0.5**		**1.0**	**0.15**	**0.4**	**1.1**
N_b [10^{11}]	2.2	1.8	?	1	0.2	2.0	0.01	0.3	0.3
bunch spacing [ns]	25	20	?	25	5	25	~4	~10	
rms bunch length [mm]	75.5	2.6	?	80		~80?	≤1	50	4
f_{RF} [MHz]	200	400	650	400?		400	400 /800	28& 197	412
V_{RF} [GV]	0.02	2.5[11]	[6.9]	~0.03		~0.03	20	?	0.9
pwr/cav [kW]		**180**	**260**						**400**

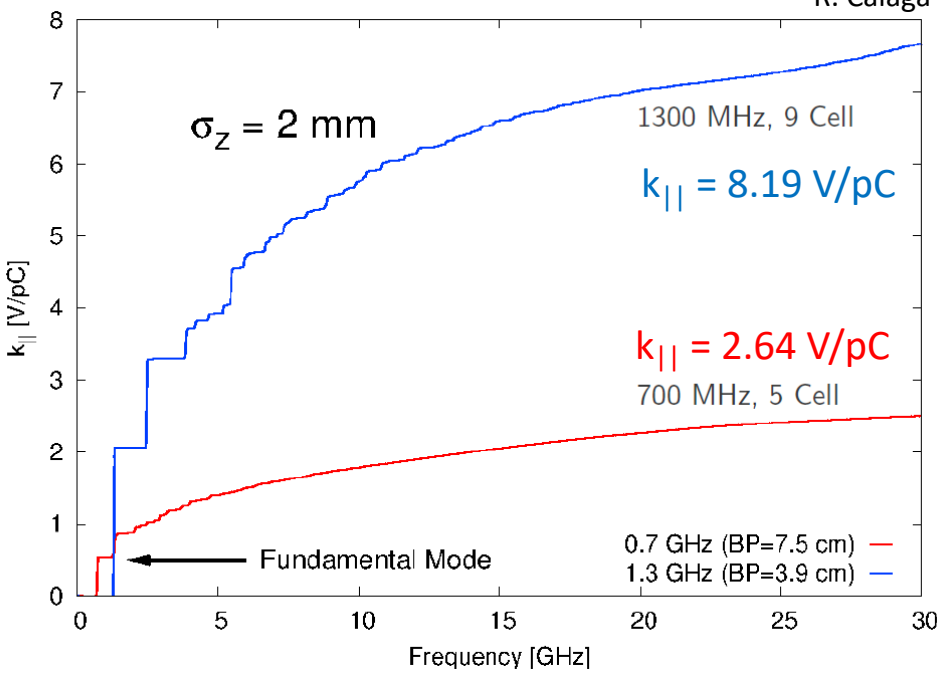
input power per cavity ~several 100 kW (→ coupler R&D)

future HOM power levels

A. Butterworth

loss factor

R. Calaga



average $P_{HOM} = k_{||}.Q_{bunch}.I_{beam}$

	FCC-ee-Z	FCC-hh-H
Beam current [mA]	48.6	10.8
Num. bunches	160	24
Bunch charge [nC]	41	60
HOM power (704 MHz cavities) [kW]	**110**	**0.6**
HOM power (1.3 GHz cavities) [kW]	342	1.8

project	Beam current [mA]	HOM power / cav [W]
CEBAF upgrade	0.10	0.05
XFEL	5	1
BerlinPRO	100	150
eRHIC	**300**	**7,500**
FCC-ee-Z	**1450**	**110,000**

Challenge: HOM powers in the kW range to remove from the cavity at 2 K

examples of other beam tests for future projects

orbit wake field effects (A. Chao, Na Wang)

- Beam tilt due to the transverse wake fields
  - When a beam passes through a impedance with a transverse offset, the tail particles will receive transverse kicks

$$\Delta y'(z) = \frac{Ne^2}{E}\int_0^\infty dz'\rho(z'+z)W_\perp(y_b,z')$$

  - This will lead to a transverse displacement of the bunch tail at IP

$$\Delta y = \sqrt{0.5\beta_y^*\beta_y}\,\Delta y'$$

  - CEPC case:
    - Pretzel orbit of 5mm in horizontal
    - Closed orbit of 1mm in vertical

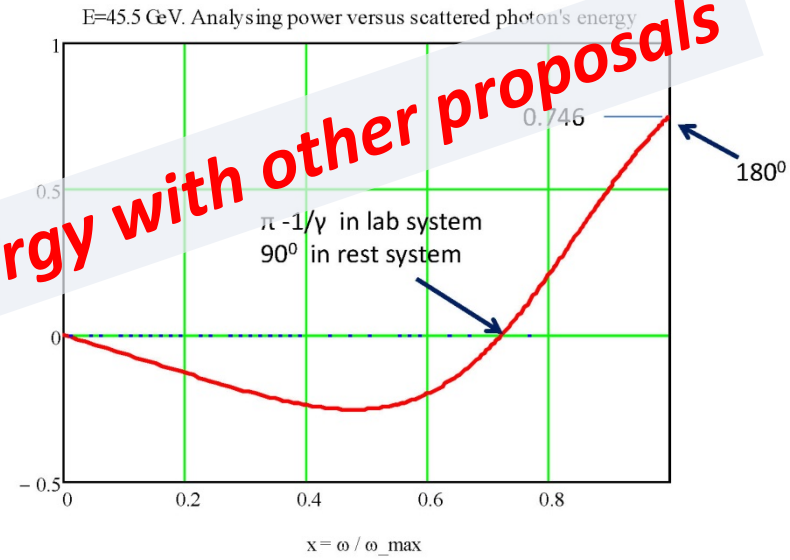
SR effects on vacuum for *ee* and *pp* colliders (R. Cimino et al.)

techniques & photon beam lines available:

- IR for micro imaging and FEL spectroscopy
- DXR2 (2–10 eV) for reflection, absorption, scatt., det. calibration
- XUV-LEB (30–200 eV) for photoemission, PY, photon reflectivity
- XUV-HEB (60–1000 eV) for photoemission and SR-XPS and PY
- DXR1 (900–3100 eV) for soft X ray absorption spectroscopy

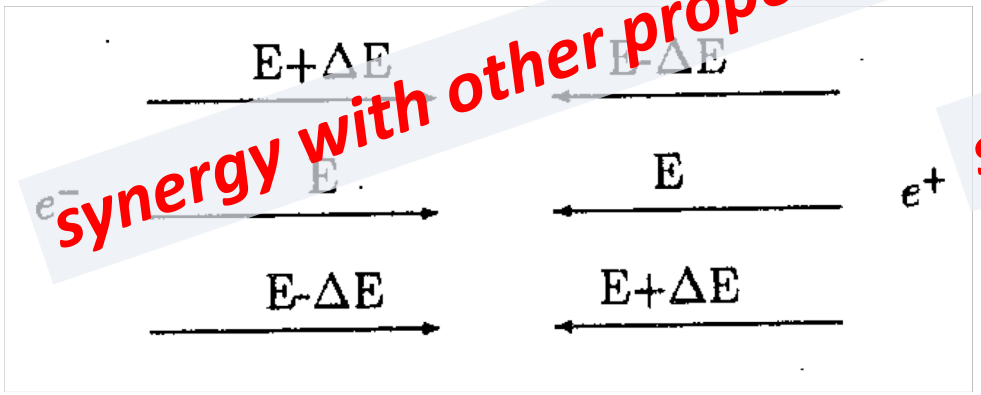
synergy with other proposals

energy calibration, e.g. by Compton scattering & selection (A. Muchnoi)



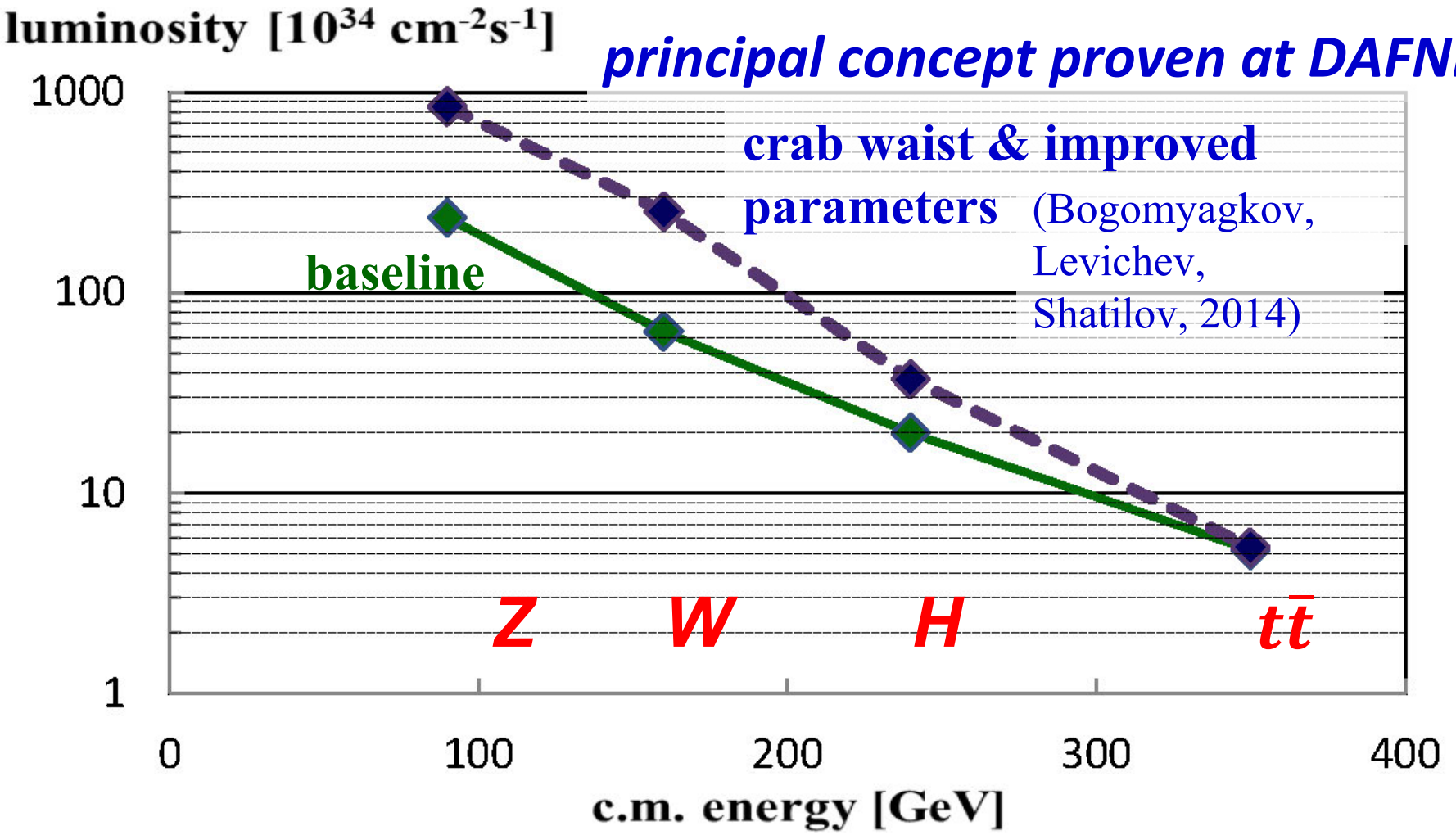
synergy with other proposals

monochromatization (A. Faus-Golfe)



synergy with other proposals?

FCC-ee luminosity vs energy



benchmarking of off-momentum dynamic aperture?!

possible next steps

discussions with potentially interested partners,

in particular

- Italian SRF community (C. Pagani, E. Palmieri, …)
- CERN (DIR, RF group, HL-LHC, FCC, LHeC, beam dynamics, vacuum)
- BNL (I. Ben-Zvi, S. Belomestnykh),
- JLAB, UK RF experts (e.g. from Daresbury, Sheffield)
- BINP
- CEA & CNRS
- CepC/SppC SRF & beam dynamics groups, …

preparation of proposals for EU/H2020 funding,

e.g. as transnational access facility

summary

"… an SRF and high-current test facility [in Frascati] could nicely complement CERN's SRF development program and could be also relevant for testing any high-current related effects (impedances, vacuum, beam heating, etc.) while making efficient use of an existing infrastructure and supporting in this case strongly the Italian accelerator community"

Michael Benedikt, FCC Study Leader,
10 November 2014

An Exercise for Crab Waist at DAΦNE-TF

17 Dec. 2018 @ DAFNE-TF Workshop, Frascati
K. Oide (CERN)

Many thanks to M. Biagini, C. Milardi, F. Zimmermann

Motivation

PRL **104,** 174801 (2010) PHYSICAL REVIEW LETTERS week ending 30 APRIL 2010

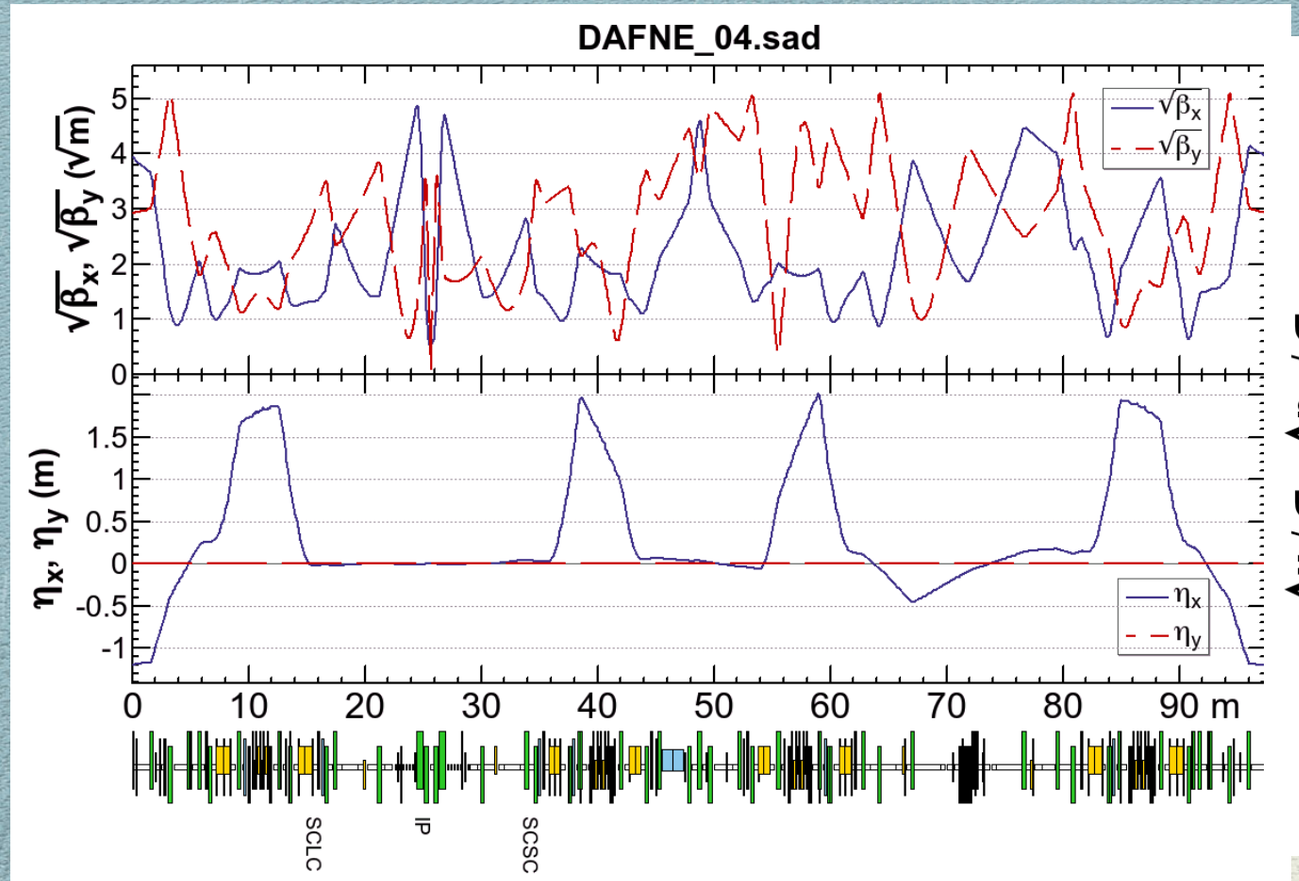
Test of "Crab-Waist" Collisions at the DAΦNE Φ Factory

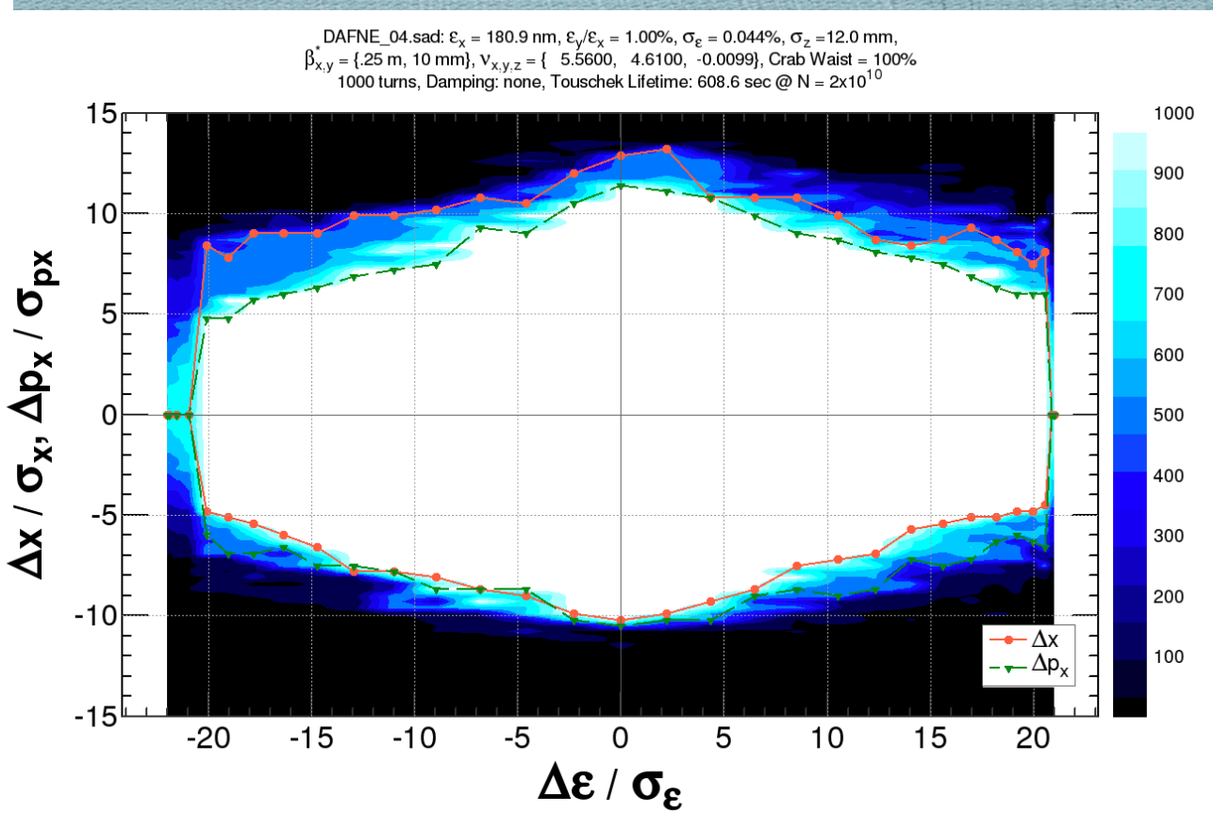
M. Zobov,[1] D. Alesini,[1] M. E. Biagini,[1] C. Biscari,[1] A. Bocci,[1] R. Boni,[1] M. Boscolo,[1] F. Bossi,[1] B. Buonomo,[1] A. Clozza,[1] G. O. Delle Monache,[1] T. Demma,[1] E. Di Pasquale,[1] G. Di Pirro,[1] A. Drago,[1] A. Gallo,[1] A. Ghigo,[1] S. Guiducci,[1] C. Ligi,[1] F. Marcellini,[1] G. Mazzitelli,[1] C. Milardi,[1] F. Murtas,[1] L. Pellegrino,[1] M. A. Preger,[1] L. Quintieri,[1] P. Raimondi,[1] R. Ricci,[1] U. Rotundo,[1] C. Sanelli,[1] M. Serio,[1] F. Sgamma,[1] B. Spataro,[1] A. Stecchi,[1] A. Stella,[1] S. Tomassini,[1] C. Vaccarezza,[1] M. Schioppa,[2] M. Esposito,[3] P. Branchini,[4] F. Iacoangeli,[5] P. Valente,[5] E. Levichev,[6] P. Piminov,[6] D. Shatilov,[6] V. Smaluk,[6] N. Arnaud,[7] D. Breton,[7] L. Burmistrov,[7] A. Stocchi,[7] A. Variola,[7] B. F. Viaud,[7] S. Bettoni,[8] K. Ohmi,[9] and D. Teytelman[10]

	SHIDDDARTA 2010	FCC-ee tubar	DAFNE-TF in this exercise [with beam-beam]
E_{Beam} (GeV)	0.51	182.5	0.51
$\varepsilon_{x,y}$ (nm)	250 / -	1.5 / 0.0029	230 / 1 [350 / 2.9]
$\beta^*_{x,y}$ (mm)	250 / 9.3	1000 / 1.6	150 / 10 [100 / 9]
$\sigma^*_{x,y}$ (μm)	250 / -	38 / 0.068	180 / 3.2 [185 / 5.1]
σ_z (mm)	15	2.5	12
half crossing angle (mrad)	25	15	15
Piwinski angle	1.5	1.0	1.0 [1.0]
Particles / bunch (10^{10})	2.0	23.0	2.0
Beam-beam $\xi_{x,y}$	- / 0.044	0.099 / 0.126	[0.02 / ?]

- How ξ_y can be increased under simplified optics for DAFNE-TF with no detector, no solenoids, etc.?

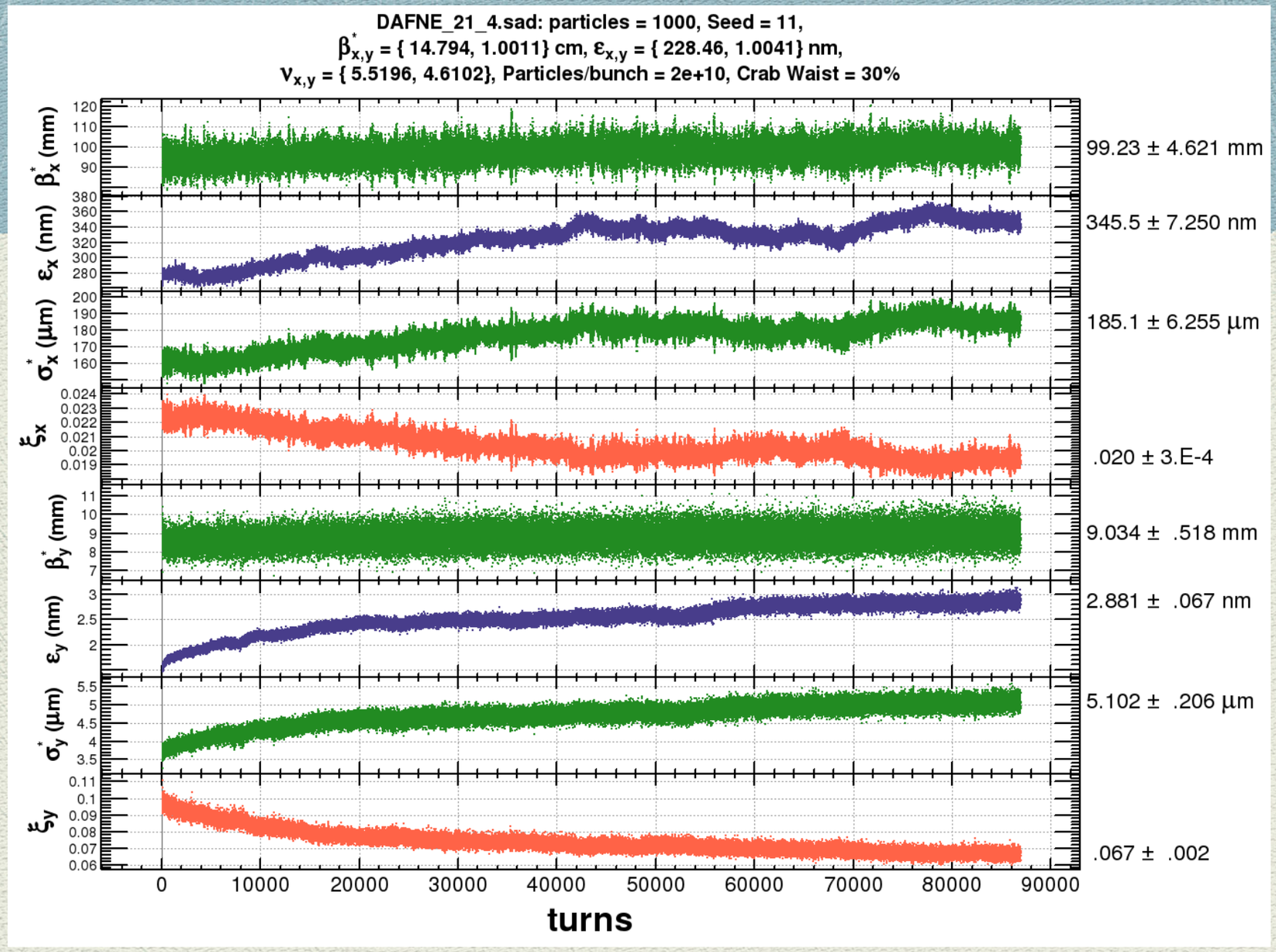
Collider Optics





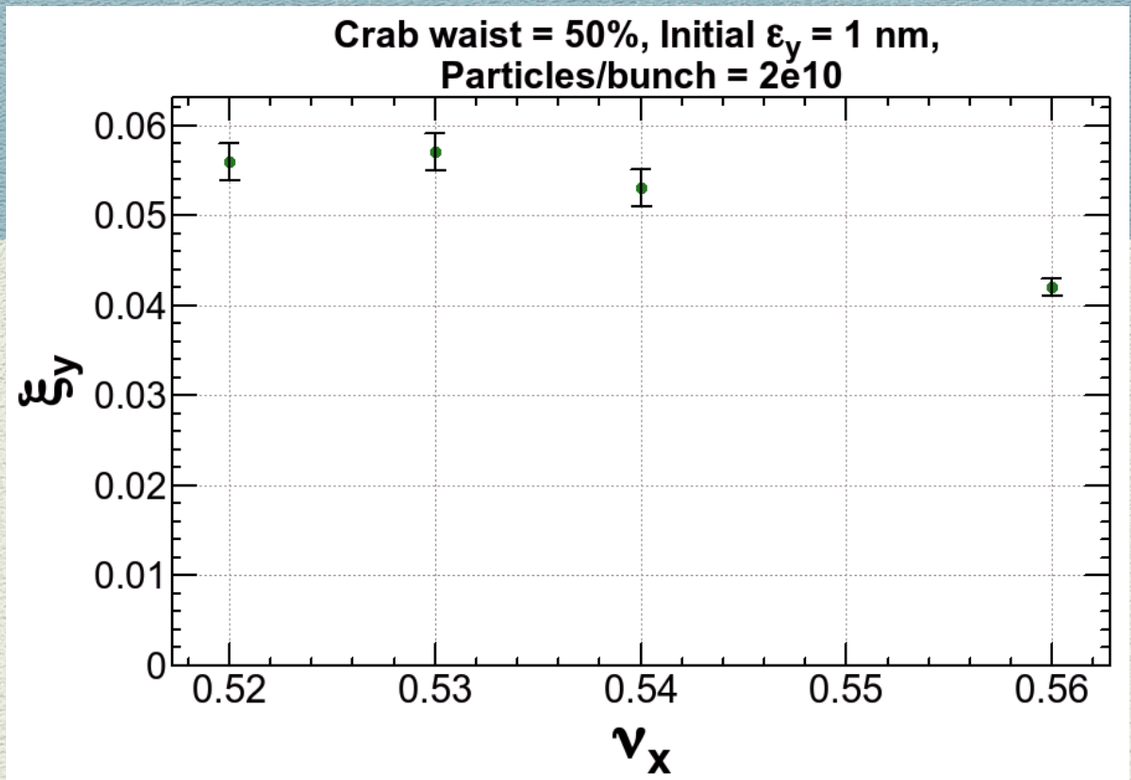
- The beam optics was provided by M. Biagini, converted by Y. Ohnishi into SAD.
- Dipoles are tweaked to make the ring close.
- Removed all solenoids and skew components.
- $\beta^*_{x,y}$ and the ring tunes are adjusted.
- X/y phases between crab sextuples (SCL, SCS) and the IP are adjusted to $1.0\pi/1.5\pi$.
- Several mismatches remain in the arc.
- The dynamic aperture with crab-waist after optimizing the arc sexts looks OK. The momentum acceptance is limited by the RF bucket.

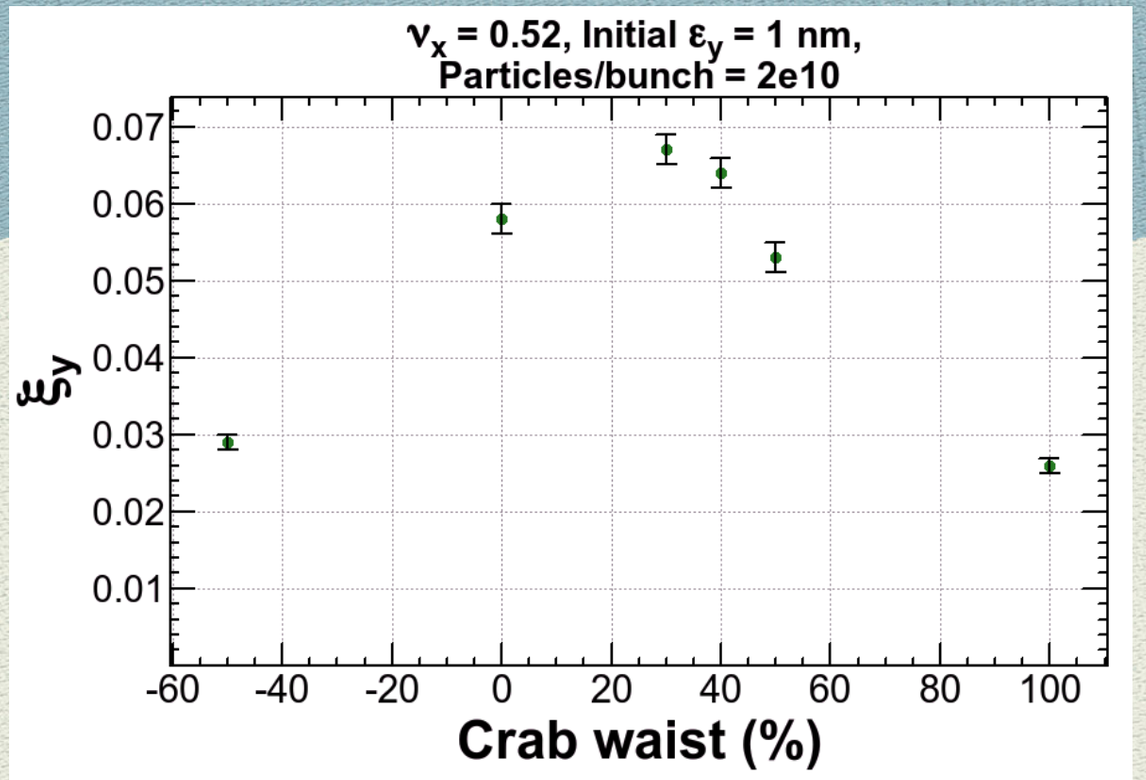
Beam-beam simulation with the lattice

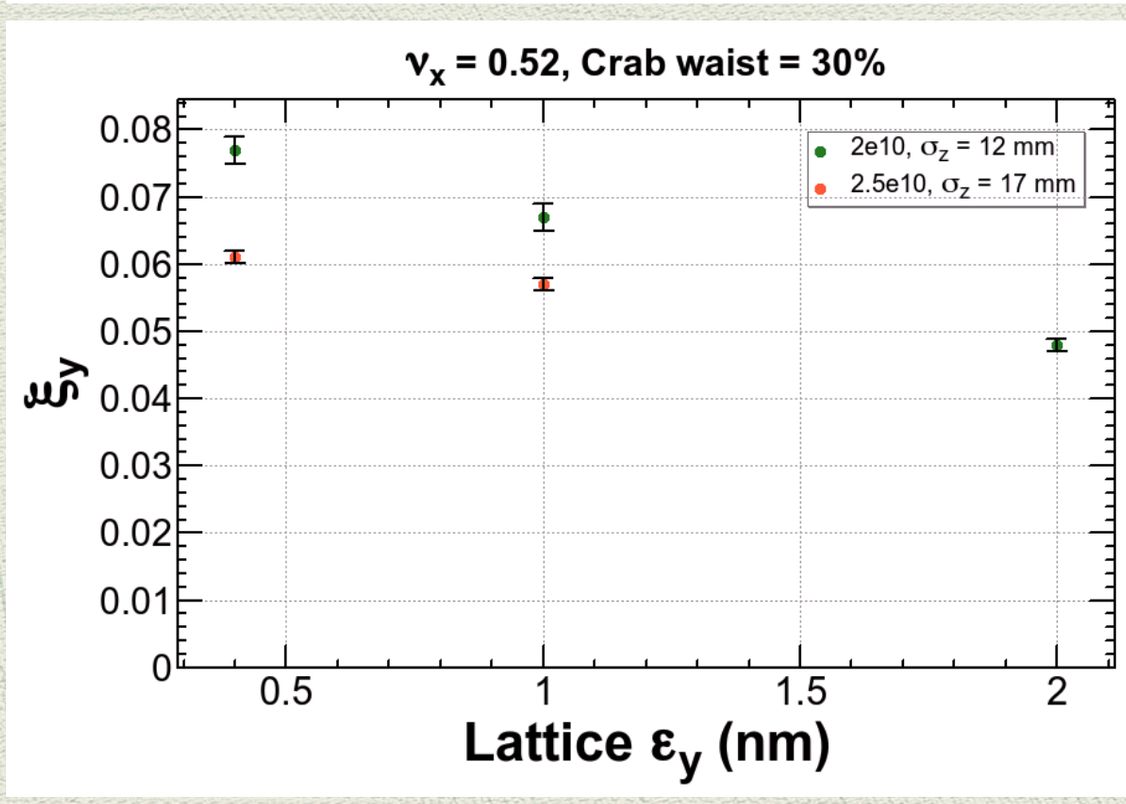


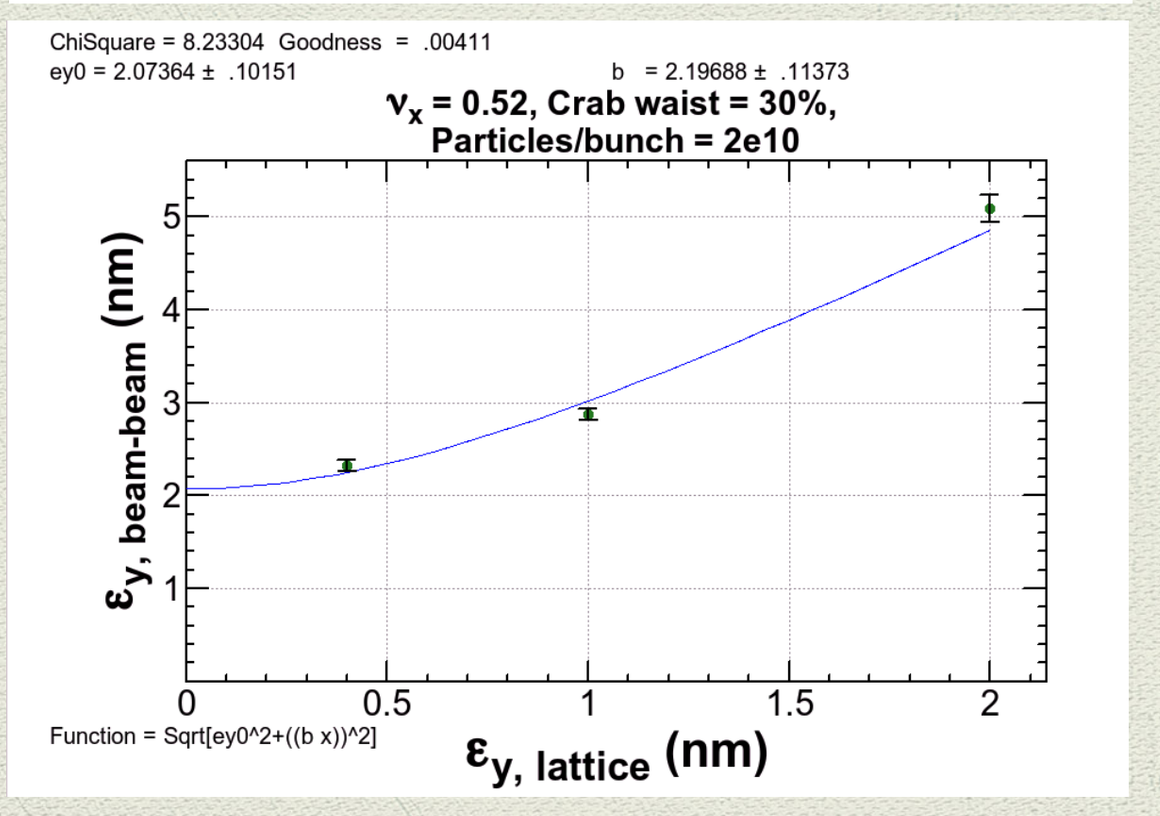
- A weak-strong beam-beam (BBWS by K. Ohmi, embedded in SAD) tracking simulation with lattice has been performed.
- The vertical emittance is generated by random vertical misalignment of sextupoles (only one seed has been tried so far).
- Assumed a perfect dispersion/coupling/orbit correction at the IP in the first order.
- The parameter of the strong beam is matched to the weak beam every turn, with an exponential decay of 100 turns.
- 1000 particles, 87000 turns (≈ long. damping time).
- Beam sizes and emittance are obtained by Gaussian fit.
- "All" effects are included in the tracking.

Parameter dependences on ξ_y









Summary

- Beam-beam simulation has been tried with a lattice for crab-waist at DAFNE-TF.
- The beam-beam parameter depends on the horizontal tune, lattice emittance, and the crab-waist ratio.
- The maximum value $\xi y = 0.077$ is obtained at $\nu x = 0.52$, εy, lattice = 0.4 nm, and crab-waist = 30%. The low crab-waist ratio is due to the small Piwinski angle.
- Significant blowup of the vertical emittance has been observed in all cases. The reason should be identified.

a few references

References for multi-cell cavities:

W. Xu et al, Progress on the High-Current 704 MHz Superconducting RF Cavity at BNL, IPAC'12
http://accelconf.web.cern.ch/AccelConf/IPAC2012/papers/weppc113.pdf

P. Jain, S.A. Belmonestnykh et al, "Development of a Fundamental Power Coupler for High-Current Superconducting RF Cavity," IPAC'12,
http://accelconf.web.cern.ch/AccelConf/IPAC2012/papers/weppc112.pdf

S. A. Belomestnykh et al,, "Superconducting RF Systems for eRHIC", IPAC'12
http://accelconf.web.cern.ch/AccelConf/IPAC2012/papers/weppc112.pdf

In 2005 a 7-cell 1.3 GHz cavity was designed for DAFNE (~1 A beam currents) -

D. Alesini et al, Proc. PAC 2005, Knoxville, TPPT060