Damping ring performance and experimental tests, including potential at CERN

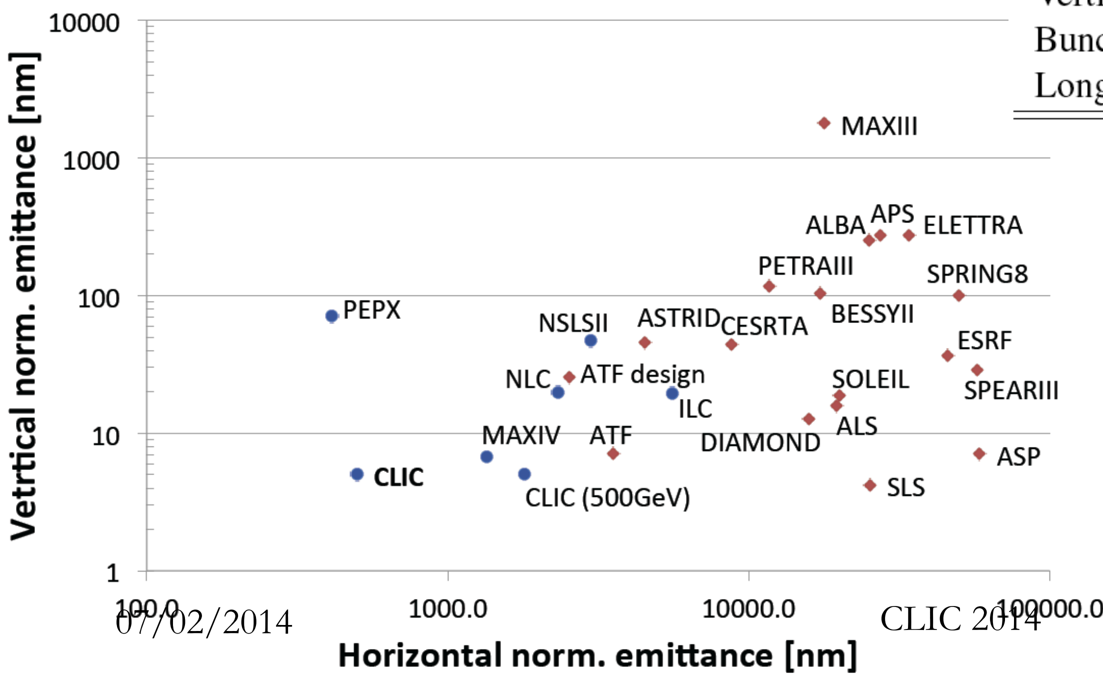
Y. Papaphilippou

With contributions from Low emittance rings collaborators

CLIC DR parameters

- CLIC damping rings target ultra-low emittance in all 3 dimensions for relatively high bunch charge
- Dominated by collective effects (IBS, space-charge, e-cloud, FII, CSR,…)

Parameters	CLIC@3TeV
Energy [GeV]	2.86
Circumference [m]	427.5
Energy loss/turn [MeV]	4.0
RF voltage [MV]	5.1
Stationary phase [°]	51
Momentum compaction factor	1.3e-4
Damping time x/s [ms]	2/1
Number of dipoles/wigglers	100/52
Dipole/wiggler field [T]	1.0/2.5
Bend gradient [1/m^2]	-1.1
Bunch population [10^9]	4.1
Horizontal normalized emittance [nm.rad]	456
Vertical normalized emittance [nm.rad]	4.8
Bunch length [mm]	1.8
Longitudinal normalized emittance [keVm]	6.0



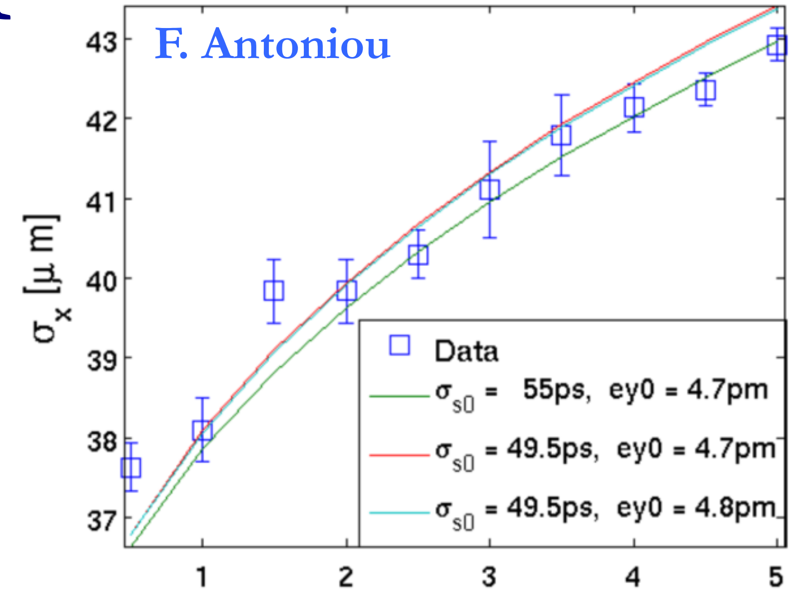
- Challenging technology (SC wigglers, Extraction kickers, RF system, Vacuum, Instrumentation, Feedback)

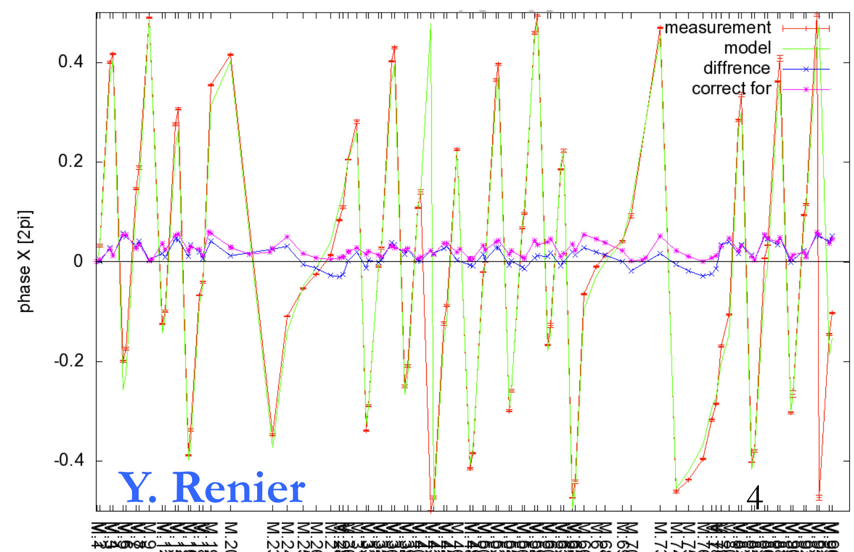
DR R&D

Area	Scope	Institutes	Contract
Optics and non-linear dynamics	Methods and diagnostics for linear and non-linear correction	JAI (DIAMOND), ANKA, SLS, IPM	MOU
Vertical emittance minimization	Beam dynamics and technology (alignment, instrumentation) for reaching sub-pm vertical emittance	SLS, MAXlab, INFN/LNF	**TIARA**
		Australian Synchrotron	MOU
		JAI (DIAMOND)	MOU
Intrabeam Scattering	Experiments for theory/code benchmarking	CESRTA	NSF
		SLS, INFN/LNF	**TIARA**
		SLAC	MOU
E-cloud	Experiments for instability and mitigation (coatings)	CESRTA	NSF
Fast Ion Instability	Experiments for theory/code benchmarking, feedback tests	CESRTA	NSF
Super-conducting Wiggler	Prototype development and beam tests	KIT (ANKA), BINP	**K-contract**
Fast kicker development	Conceptual design, prototyping and beam measurements	IFIC Valencia, ALBA, ATF	**Spanish industry program**
RF design	RF prototype and beam tests	(ALBA)	
Vacuum technology	Desorption tests of coated chambers	MAXIV, Sirius (ALBA)	

CLIC DR beam dynamics experiments

- Low Emittance Tuning
  - **ATF, SLS**, **Australian Synchrotron**
- Optics, non-linear correction
  - **ATF**, **SLS**, ANKA, DIAMOND, SOLEIL
- Intrabeam Scattering
  - **CESRTA**, **SLS,** Australian Synchrotron
- E-cloud
  - **CESRTA**
- Fast Ion Instability
  - **CESRTA,** SOLEIL
- Coherent Synchrotron Radiation
  - ANKA, DIAMOND
- Instabilities
  - **SLS, ALBA**





DR technology and experimental program

- **Super-conducting wigglers**
  - Demanding magnet technology combined with cryogenics and high heat load from synchrotron radiation (absorption)

Prototype built in BINP, to be tested in ANKA (2014-2014)

- **High frequency RF system**
  - 1-2GHz RF system in combination with high power and transient beam loading

Discussions with ALBA (**HELP NEEDED**)

- **Coatings, chamber design and ultra-low vacuum**
  - Electron cloud mitigation, low-impedance, fast-ion instability

Measurements at SPS, CERTA, contract with MAXlab

- **Kicker technology**
  - Extracted beam stability, field homogeneity, low impedance design

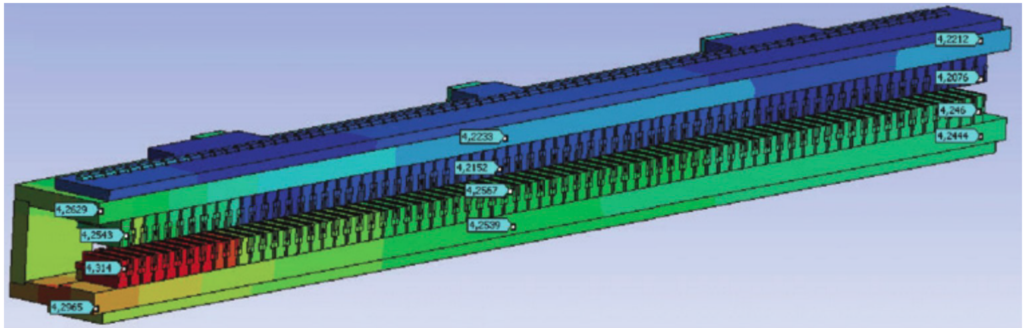
Stripline designed by Spanish industry, to be tested in ALBA, pulser in collaboration with SLAC, Full system test in ALBA and ATF (2014-2015)

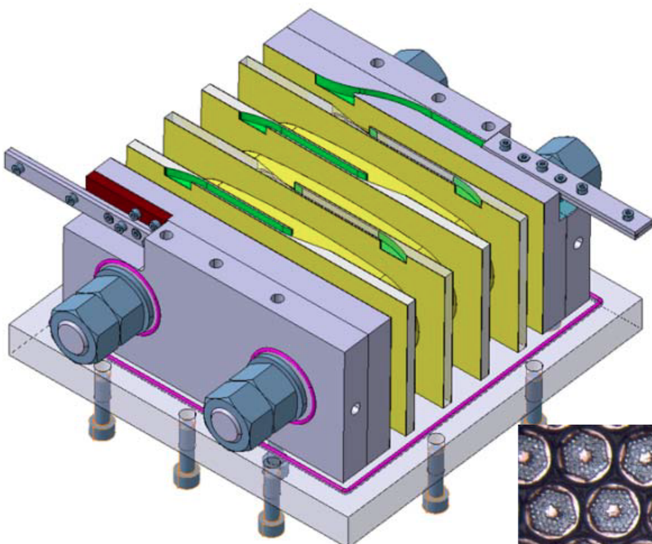
- **Diagnostics for low emittance**
  - Profile monitors, feedback system

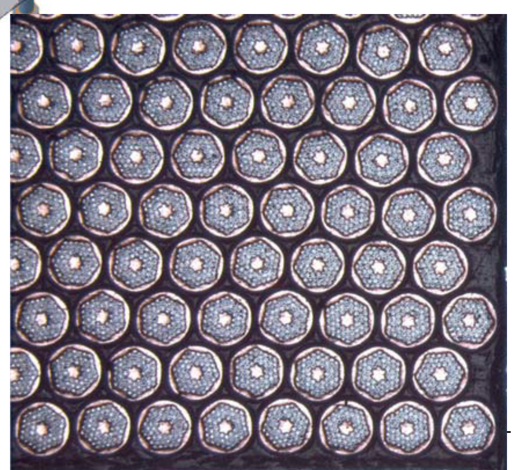
V-UV Profile Monitor (TIARA), initiated collaboration with ALBA

SC wiggler development

A. Bernard, P. Ferracin, N. Mesentsev, S. Hillenbrad, L. Garcia-Fajardo, et al.





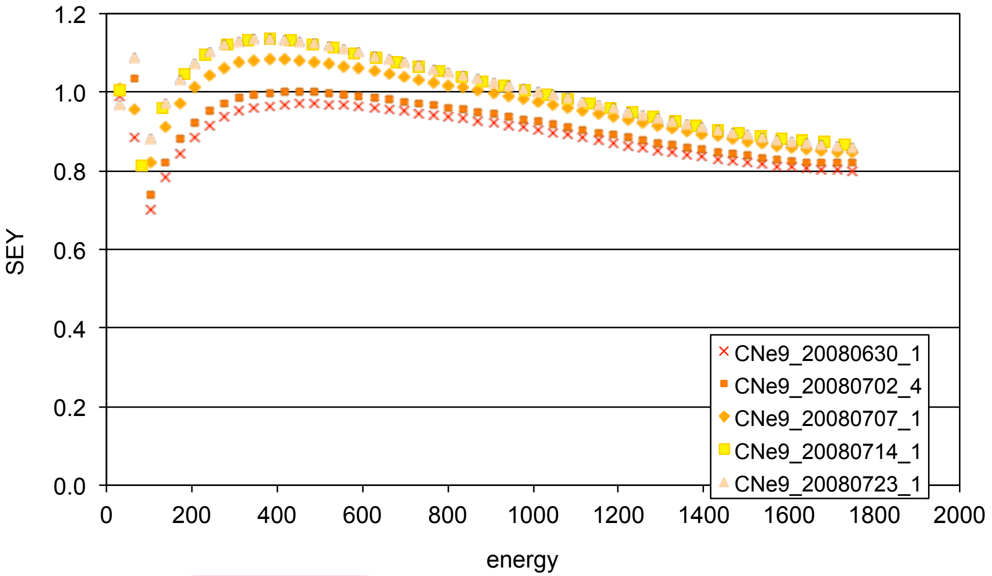


- Two paths of R&D
  - NbTi wire, horizontal racetrack, conduction cooled (BINP/KIT collaboration)
  - Nb_3Sn wire, vertical racetrack, conduction cooled (CERN)
- Full NbTi length prototype
  - Higher than 3T, 5.1cm period, magnetic gap of 18mm
  - Under production by BINP to be installed in (summer 2014) in ANKA for beam tests
  - Operational performance, field quality, cooling concept
- First Nb_3Sn vertical racetrack magnet (3-period) tested in 2011
  - Reached 75% of max. current
  - Limited by short coil-to-structure (insulation)
  - New short model under development (optimised impregnation,

Vacuum technology

S. Calatroni, P. Costa-Pinto, R. Kersevan G. Rumolo, M. Taboreli, et al.

CNe9_top_20080714_3 weeks air



NEG coatting of exotic vacuum chambers, for MAXIV

- Amorphous-C coating shows maximum SEY starting from below 1 and gradually growing to slightly more than 1.1 after 23 days of air exposure
  - Peak of the SEY moves to lower energy
- Experimental tests
  - Huge amount of data at SPS
  - Run with 5 GeV positrons at CESRTA, for different intensities and bunch spacings
  - The total electron current reduced significantly (1 order of magnitude) as compared to Al
  - Continuing collaboration with test facilites for PEY tests in a dedicated beamline (ALBA?)
  - New contract for vacuum design and coatings between CERN and MAXIV

A. Grudiev

RF system

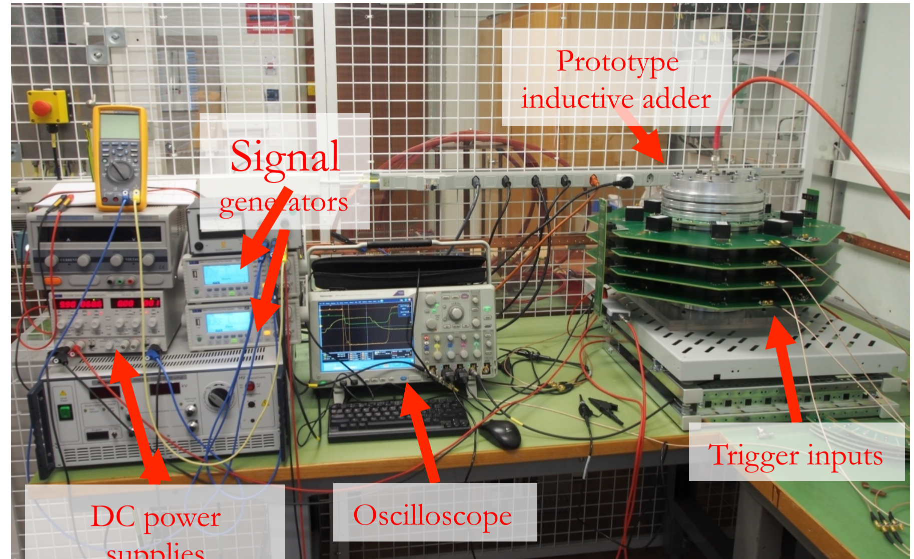
- Single train of 312 bunches spaced at 0.5ns necessitates 2GHz system
  - R&D needed for power source
  - Large average and peak current/power introduces important transient beam loading
- Considered 1GHz system
  - Straight-forward RF design but train recombination in a delay loop is needed
- Need collaborators for taking over full design and experimental tests (ALBA, LBNL?)

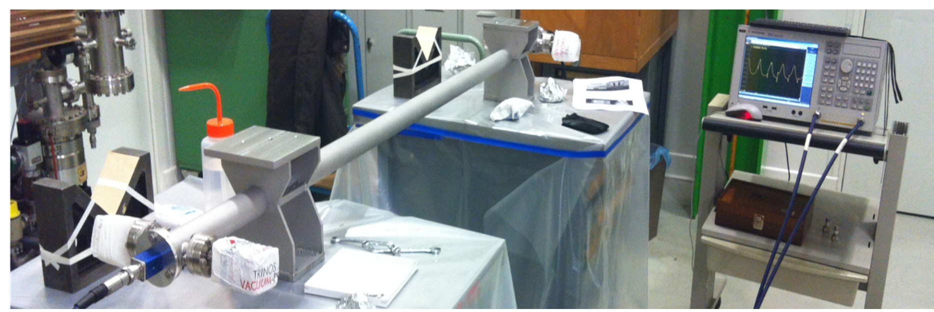
RF design concepts	1 GHz	2 GHz **no train interleaving after DR**
Classical RF system based on the NC ARES-type cavities	Baseline P_{RF} = 3.8 MW; L = 32 m; Cavity design: OK	Alternative 2.0 P_{RF} = 5.9 MW; L = 48 m; Cavity design: ok?
Classical RF system based on the SCC cavities	Alternative 1.1 P_{RF} = **0.6** MW; L = 108 m; Cavity design: **ok?**	Alternative 2.1 P_{RF} = **0.6** MW; L = **800** m; Cavity design: **NOT OK**
RF system with RF frequency mismatch	Alternative 1.2 P_{RF} = **1.3** MW; L = **16** m; Cavity design: **OK**	Alternative 2.2 P_{RF} = 2.1 MW; L = 24 m; Cavity design: OK
"A-la-linac" RF system with strong input power modulations	Alternative 1.3 P_{RF} = 3.3 MW; L = **8** m; Cavity design: **OK**	Alternative 2.3 P_{RF} = 5.8 MW; L = **12** m; Cavity design: **OK**

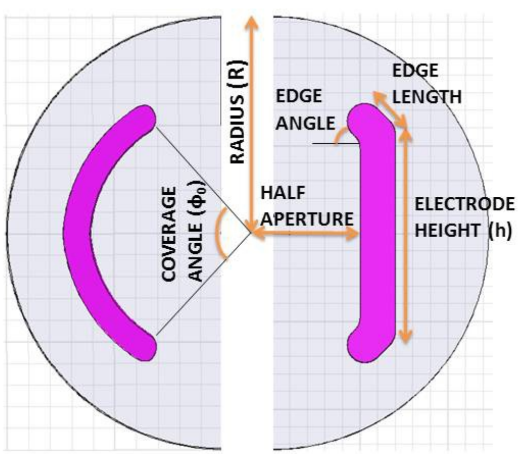
Extraction kicker design

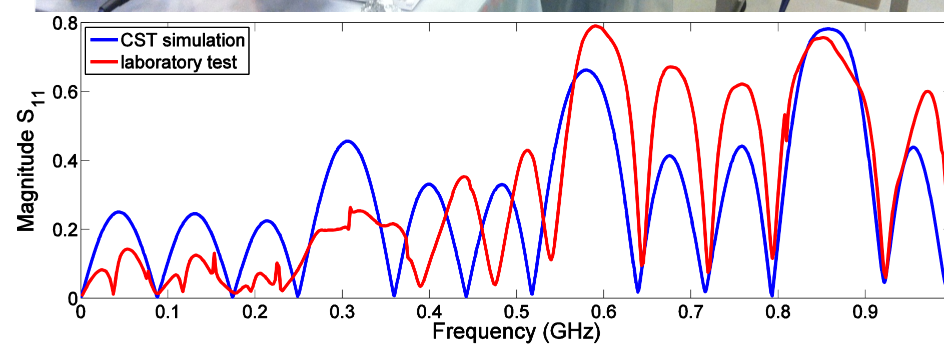
M. Barnes, J. Holma, C. Belver- Aguilar, A. Faus Golfe et al.

- Kicker jitter tolerance ~ few 10^{-4}
- Striplines required for achieving low longitudinal coupling impedance
  - Prototyped under the Spanish Program “Industry for Science”
  - Now, at CERN for laboratory tests (very good
- Significant R&D done for pulser
  - First 5-layer inductive adder prototype under tests at CERN), second one to be assembled during this month
- Collaboration is set-up with ALBA synchrotron and ATF for beam tests

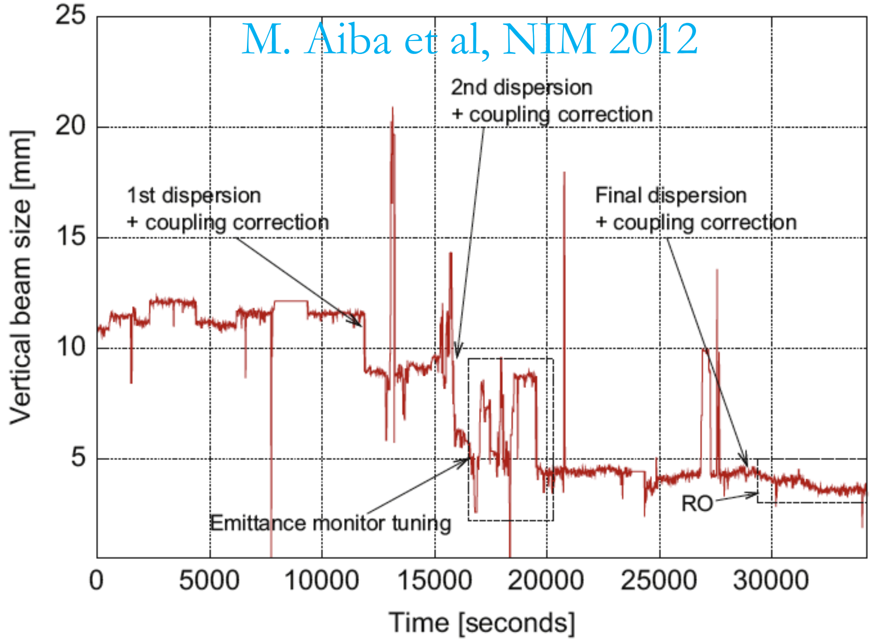








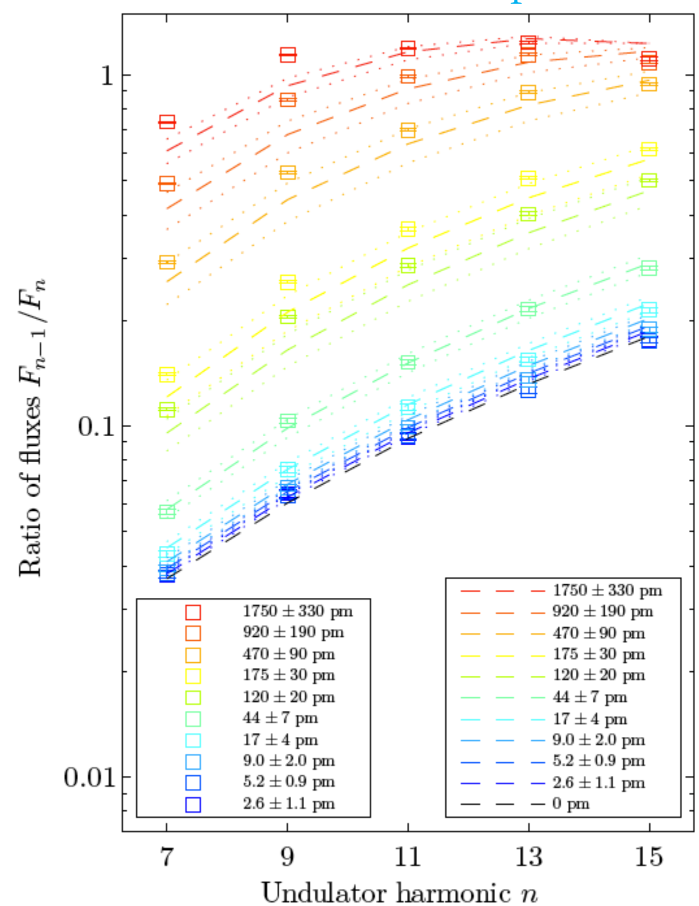
Reaching Quantum L_{imit} O_f $V_{ertical}$ $E_{mittance}$



- EU collaboration between PSI-SLS (Maxlab), INFN-LNF and CERN (TIARA-SVET) for low emittance tuning techniques and instrumentation
  - SLS achieved ε_y record of 0.9 ± 0.4pm (confirmed with different techniques)
  - New emittance monitor for resolutions below 3μm (vertical polarized light) recently installed

- Tousheck lifetime vs. RF voltage in ASLS points to ε_y = 0.5pm!!!
  - New technique for resolving ultra-low beam sizes using vertical undulator

K. Wootton, et al, PRL, accepted



Low Emittance Rings' Collaboration

- Initiated by the ILC-CLIC working group on damping rings and catalyzed by the organization of two workshops (01/2010 @ CERN, 10/2011 @ Heraklion)
  - Common beam dynamics and technology items for synchrotron light sources, linear collider damping rings, b-factories
- Formed a EU network within EUCARD2
  - Coordinated by EU labs
  - Extended collaboration board including colleagues from US and Japan
  - 30 participating institutes world wide
  - First two network workshop with 70-80 participants @ Oxford (07/2013) and Soleil (01/2014)
- Next low emittance rings' technology workshop on 05-06/05/2014 at IFIC/Valencia

Test Facility for DR R&D in the SPS tunnel

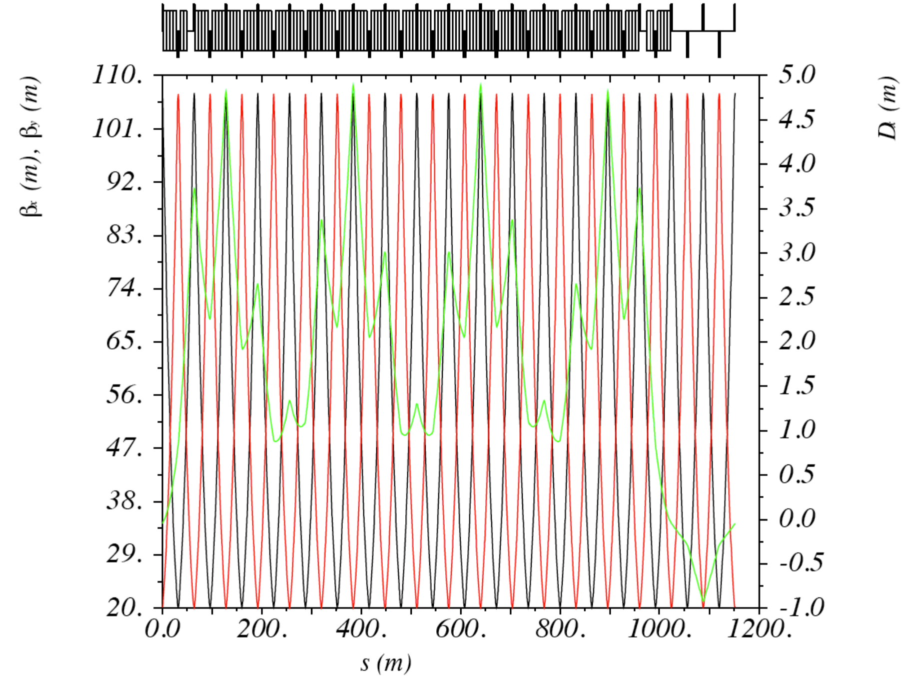
- Ideal future scenario: use existing ring as test facility (TF) for DR R&D, for testing components and interdependencies in similar beam conditions
- Existing or future light source storage rings would be ideal for these tests
- Obvious drawback the beam time availability for experiments
- **Unconventional approach**: use SPS as DR TF
- Reviving old ideas, when SPS was running also as a LEP injector
- More recent ones, serving as e+ DR for LHeC

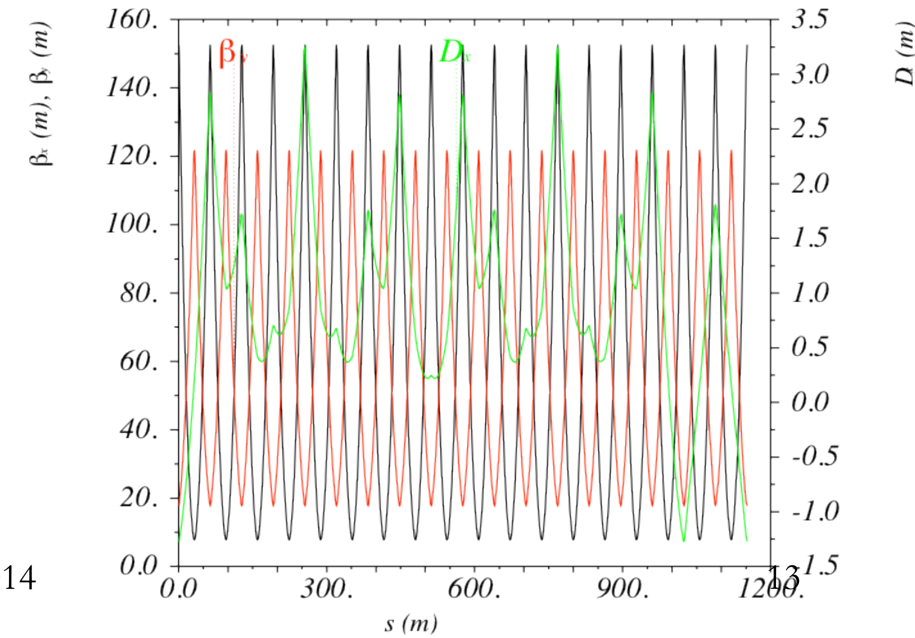
A	B	F	G	H	I
VARIABLES		*WITH WIGGLER*		Intrabeam scattering	
ETA	0.0018	brho	13.3424	ep	0.001637
VOLTS(V)	4.00E+07	wiggler deflection	0.00356	A	3.9E-06
Q VALUE	27	Bending radius	14.04463	k	0.005958
MOMENTUM COMPAC	0.0018	2*pi*rho^2	1239.369	a	0.003439
BETA (V/C)	1	F	0.005544	d	0.997034
ENERGY DPN JE	2	***Parameters With wiggler on***		lnc2a	8.492016
RADIAL DPN JX	1	Energy loss per turn	5.51E+06	Tx(sec)	1.37E+00
ENERGY(EV)	4.00E+09	Energy damping time	1.67E-02	Tz(sec)	1.23E+02
PARTICLES/BUNCH	5.00E+09	Horizontal damping time	3.34E-02		
HORIZONTAL BETA	40	Energy spread	9.11E-04		179.3655
VERTICAL BETA	40	Synchrotron Tune	0.168447		85.4419
HARMONIC NUMBER	10000	Bunch length sigma	1.07E-02		532.8773
BWIGGLER (TESLA)	0.95	Sigmasquared/beta	3.63E-10		27.19585
Pole Length	0.05	Normalised emittance	2.84E-06		179.3655
Total Wiggler Length	300	Norm long emit	7.64E-02		

Evans and Schmidt, 1988

SPS low emittance optics

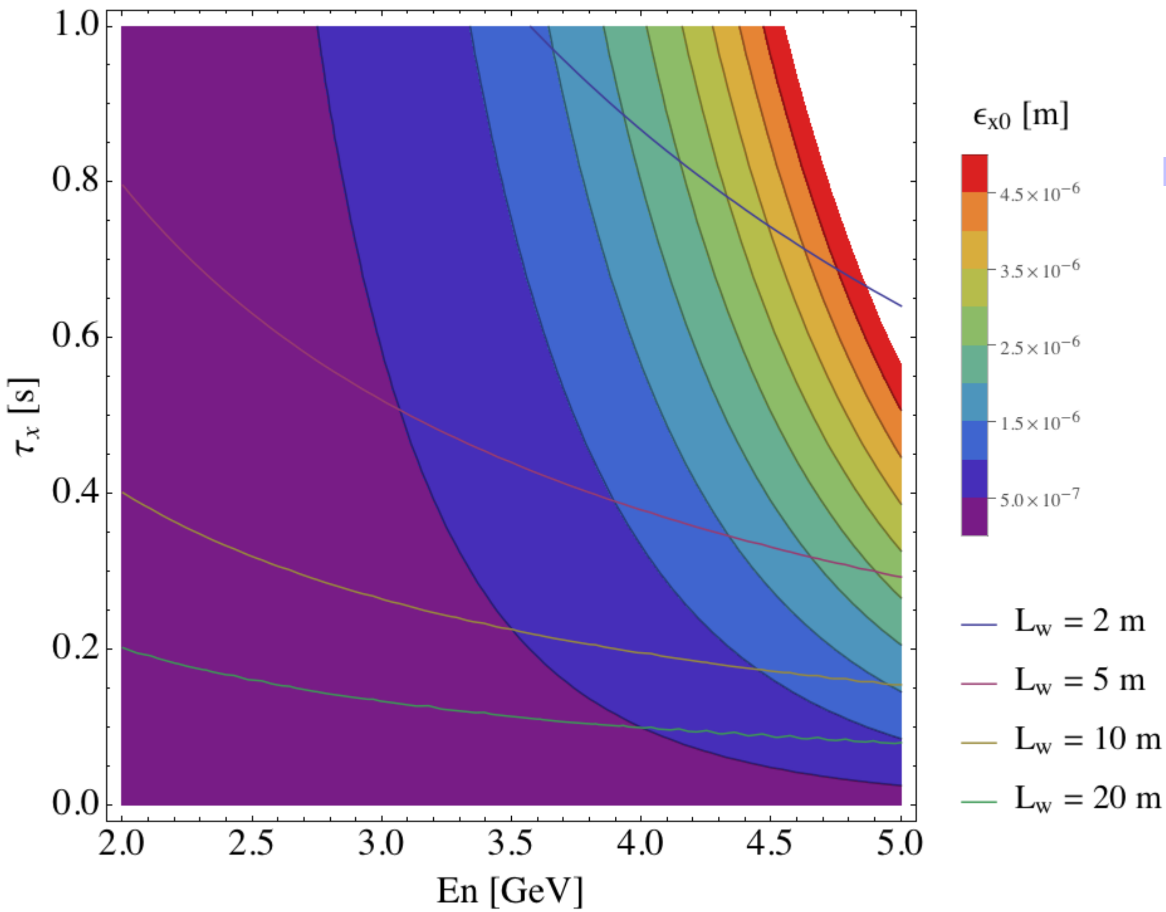
- SPS is an all FODO cell lattice (6 sextants), with missing dipole
- Usually tuned to 90 deg. phase advance for fixed target beams (**Q26**) and since 2012 to 67.5 deg (**Q20**) for LHC beams
- Move horizontal phase advance to 135(3π/4) deg. (**Q40**)
- Normalized emittance with nominal optics @ 3.5GeV of 23.5μm drops to 9μm (1.3nm geometrical)
  - Mainly due to dispersion decrease
  - Almost the normalized emittance of ILC damping rings
- Damping times of 9s
- Natural chromaticities of -71,-39 (from -20,-27)





Emittance

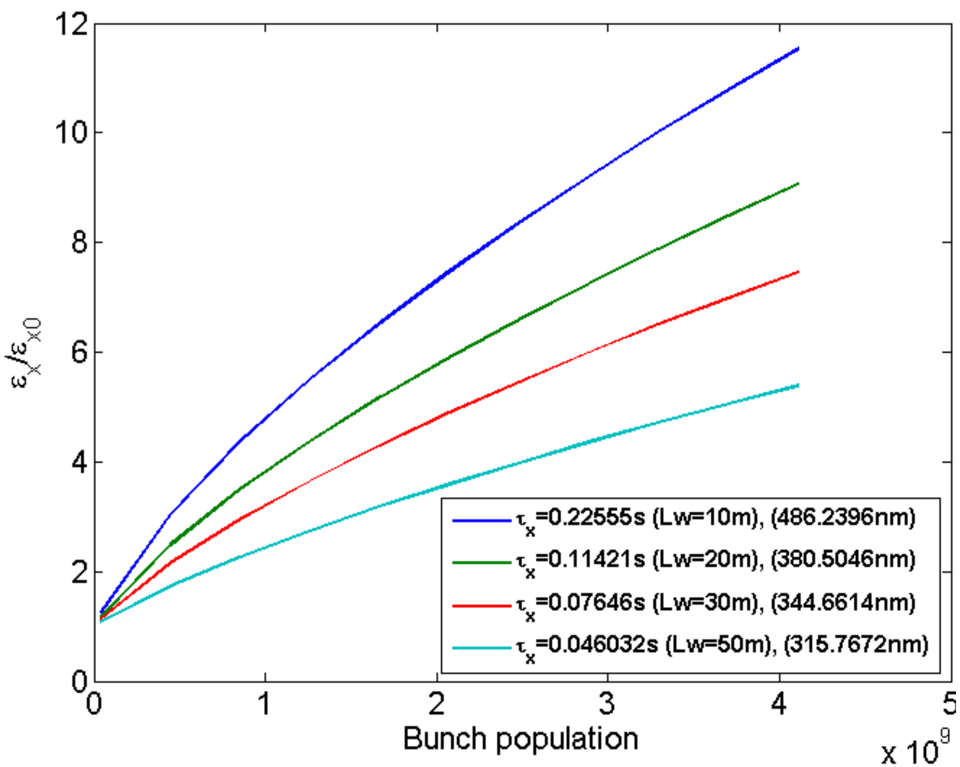
- Energy and damping time can be parameterised with equilibrium emittance, for different wiggler lengths
- Ultra-low emittance achieved in energy range of 2 to 5GeV

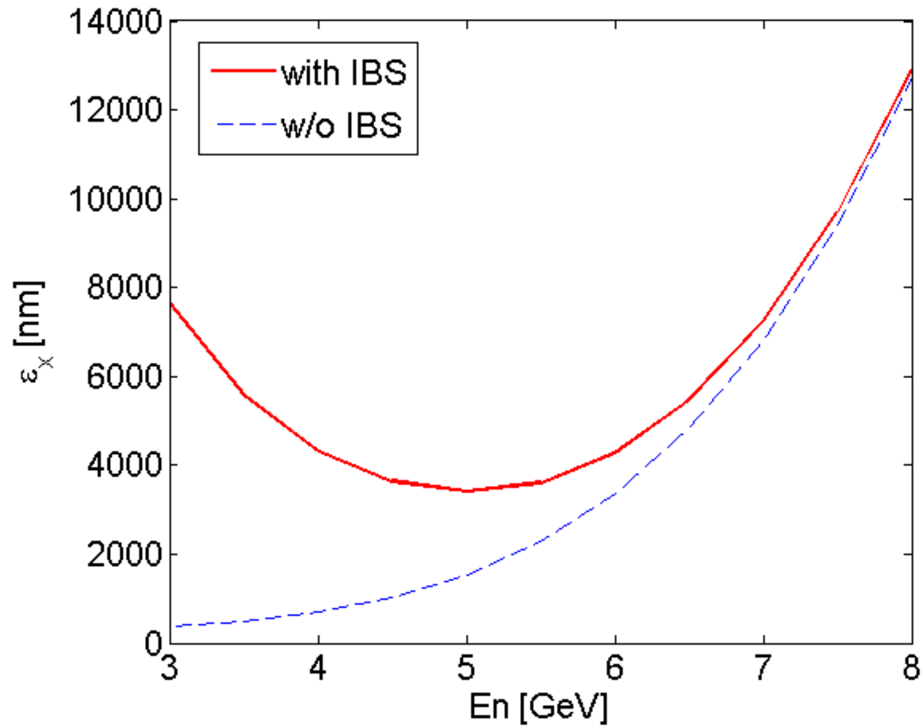


- For reaching emittances below the CLIC target of 500nm (i.e. from 130 to 50pm geometrical in that energy range), a few meters of damping wigglers should be used

Intrabeam Scattering

- Scaling of the blow-up due to IBS in the horizontal plane with the bunch population, @ 3.5GeV for different total wiggler length (thus damping times and zero current emittance)
- For a total wiggler length of 10 m and for the CLIC bunch current Nb=4.07E9
- Minimum at around 5GeV but still a factor of 2 blow up





Tentative e-SPS parameters

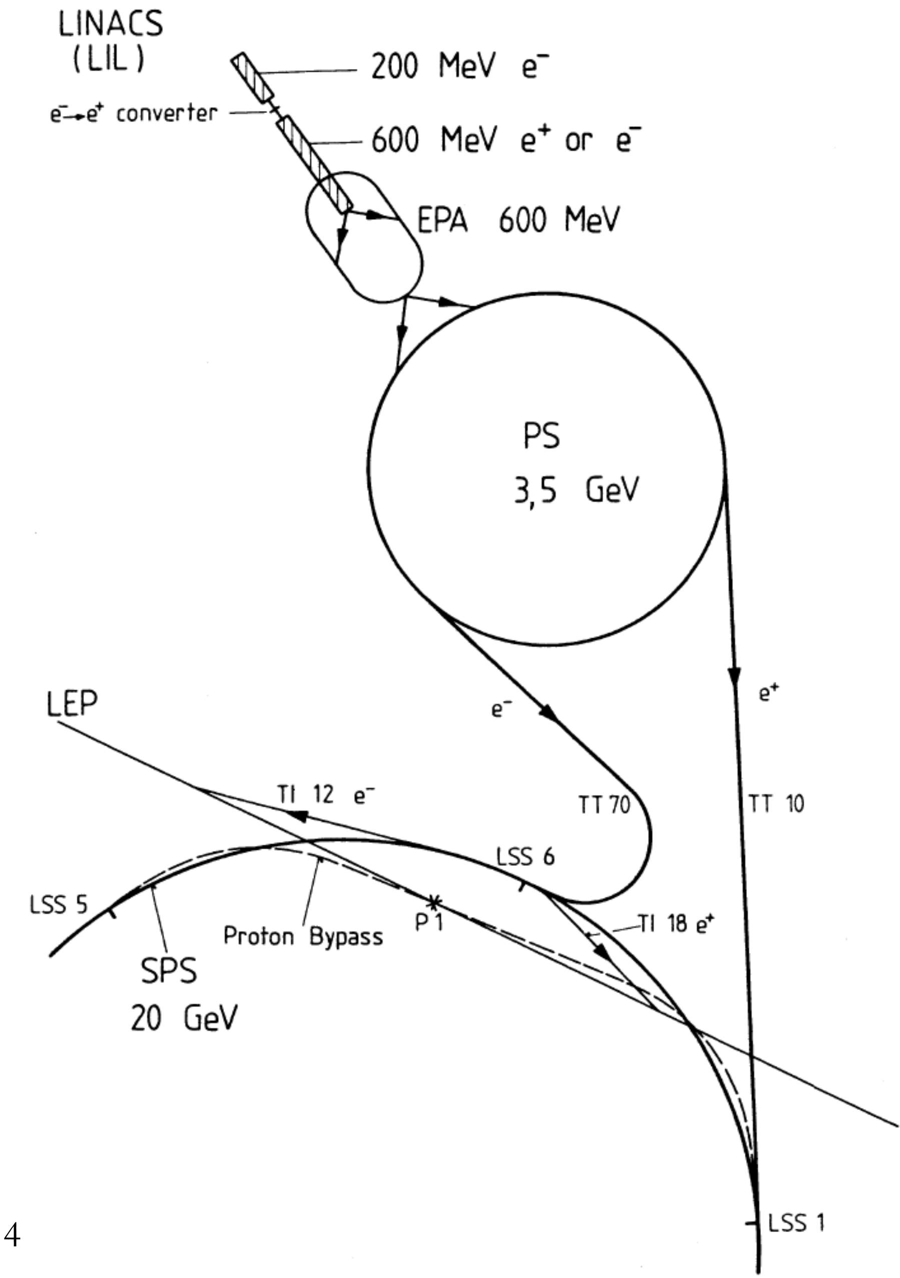
Parameter [Unit]	Lw=0m	Lw=2m	Lw=10m	Lw=2m	Lw=10m
Energy [GeV]	3.5	2.6	3.5	5	6.8
Hor. Norm. emit. [nm]	8800	**480**		5600	
Damping time (x,y) [sec]	9	1.46	**0.22**	0.64	**0.11**
Bunch length [mm]	**3.6**	11.5	16.1	20.5	32.5
Energy spread [%]	0.011	0.13	0.15	0.16	0.20
Energy loss/turn [MeV]	0.02	0.08	0.72	0.36	2.8
Bunches/pulse	<=4620				
Bunch spacing [ns]	5				
Repetition rate [Hz]	0.83				

Potential experimental tests

- Super-conducting wiggler tests
- Kicker tests
- Vaccum tests (coatings)
- Instrumentation
  - Beam profile monitors (synchrotron light), BPMs,
- Feedback
  - Bunch-by-bunch, turn-by-turn (LARP)
- RF system
  - 800MHz cavity (short bunches)
- Beam dynamics experiments
  - Optics, Non-linear dynamics, IBS, instabilities, e-cloud (for e+), ions (for e-)

EP Injector complex

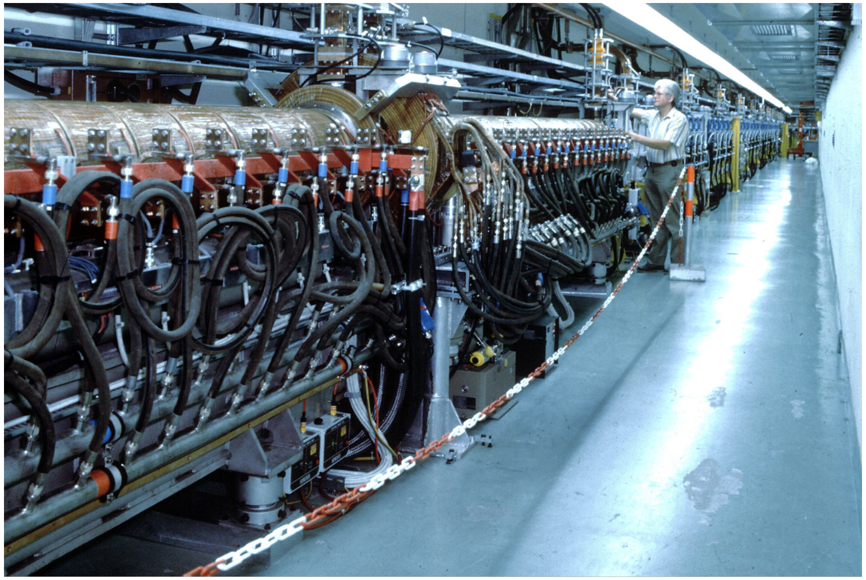
- Need to revive a "LEP-like" injector complex
- Pre-injector includes and e/p linac at a few hundreds MeV (LIL at LEP), and accumulator (EPA for LEP)
- It should be transferred through PS to SPS
- Transfer line for positrons exists (TT10) but for electrons (TT70) completely dismantled

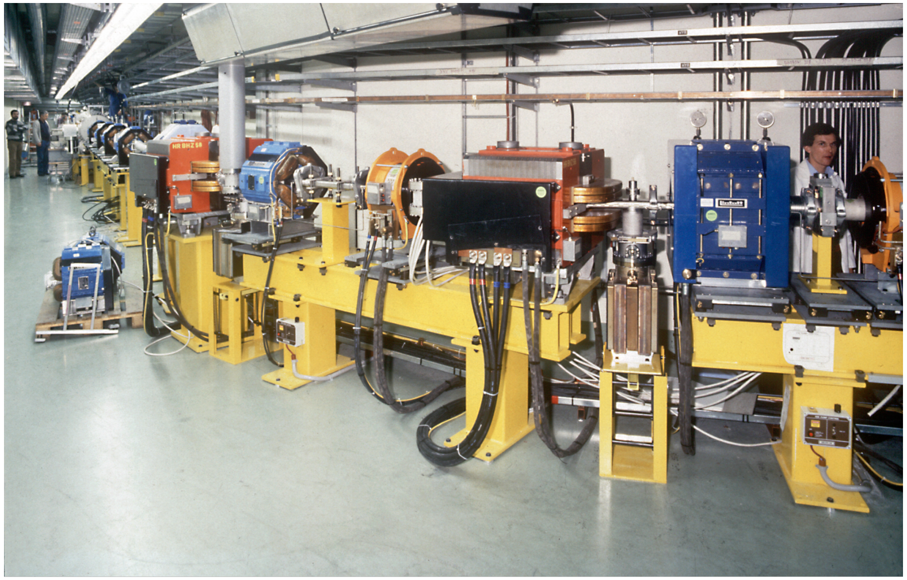


LPI – LEP Pre-Injector

F. Tecker

- 500 MeV e-/e+ into the PS
- EPA storage ring had 1/5 of PS circumference (40π m=125.66m) => multi-bunch transfer to PS
- 19.1 MHz RF system, 50 kW, h=8
- e+ production by 200 MeV linac + W-target

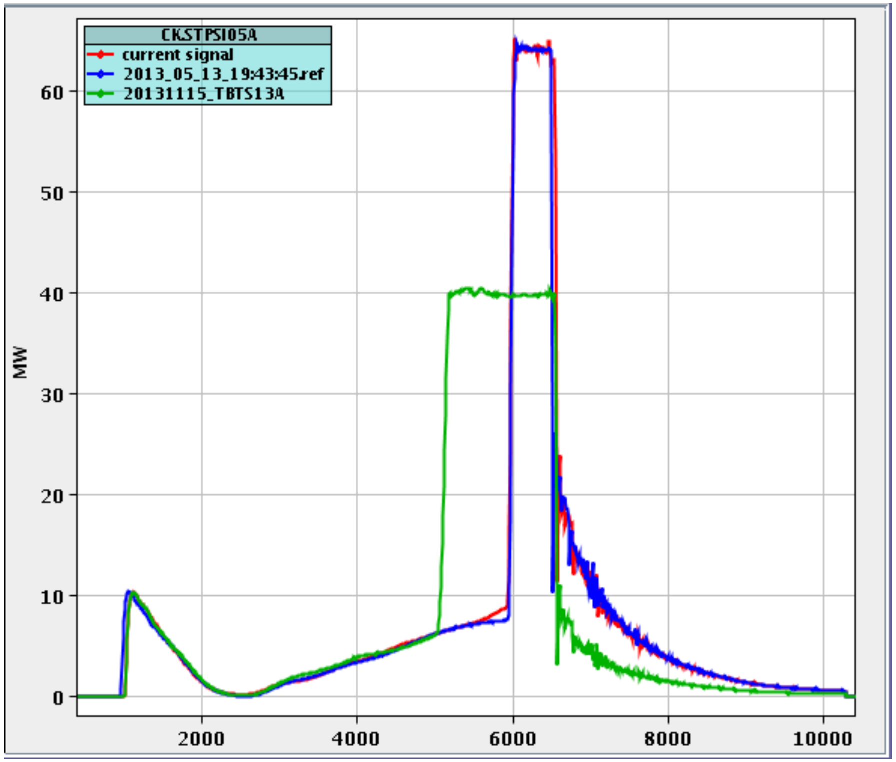




CTF3 Linac Beam Energy

F. Tecker

- present end-of-linac energy ~120 MeV for full beam-loading
- short beam pulse => change RF compression
- length ~ cavity fill time (100ns) + beam
- gain of >2 in power
- √2 in energy => 170 MeV
- short pulse => ~ no loading
- **final energy: ~ 340 MeV**
- +2 structures on girder 14: ~ 370 MeV

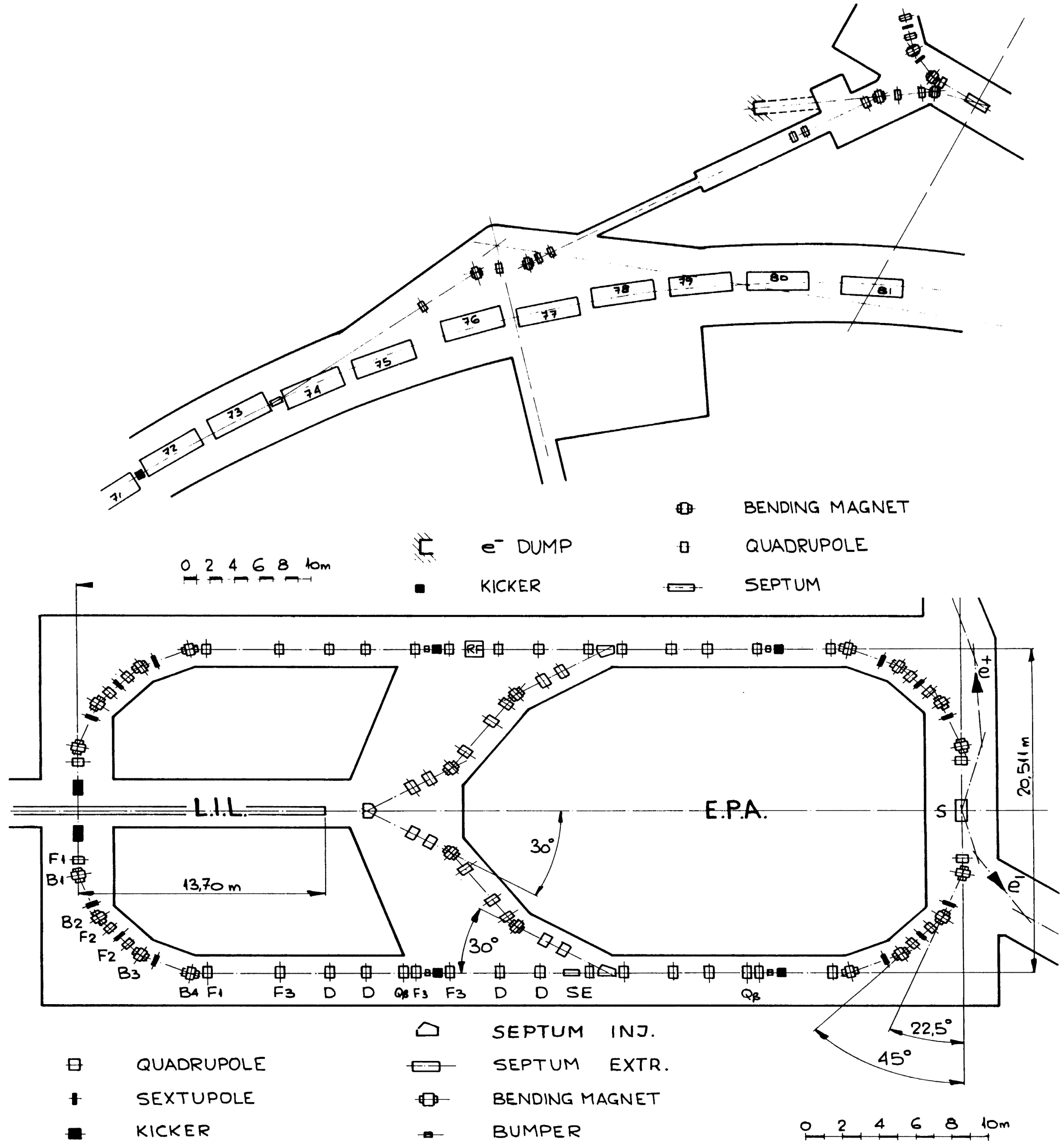


- Magnets and power convertors for TL1 and combiner ring are compatible with this energy

Linac bunch structure and transfer to the PS

F. Tecker

- CTF3 linac:
  - Thermionic gun
  - pulse length < 1.3µs
  - 1.5 GHz sub-harmonic bunching, bunch charge 2.33nC
  - 3 GHz acceleration (333ps period)
- needed for SPS:
  - bunch charge <0.8nC
  - single bunch or bunch spacing 5ns, 25ns (40MHz)
- => use laser RF or DC gun to produce right time structure
- Replace CR wiggler by extraction septum
- Rebuild ~40-50m long extraction line
  was 4 bends and 9 quadrupoles
  (had energy spread acceptance: $0.6\ 10^{-3}$)

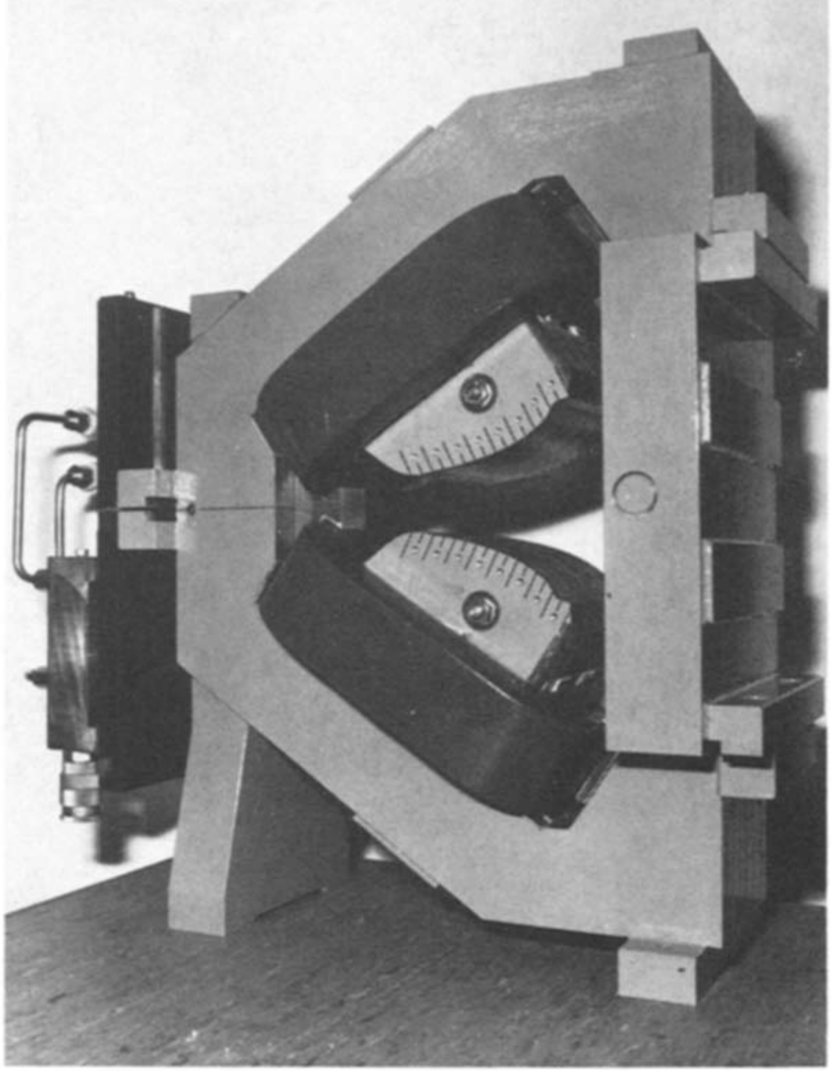


F. Tecker

Leptons through PS to SPS

- PS: from 400 MeV -> 3.5 GeV
  - had 114 MHz RF system (2*500kV, 2*50kW)
    (taken out 2001)
  - had 2 Robinson wigglers controlling damping partition (antidamping in H-plane)
- RF had special 'expansion' of the long. Emittance
- Energy acceptance: E=400 MeV, $\eta = -\alpha = -0.027$
  - Present 200 MHz system, h=420, 8*30kV => $\Delta E/E < 5.7\ 10^{-3}$
  - 40/80 MHz systems have 2*/3*300kV, respectively => $\Delta E/E < 2\% / 1.75\%$
  - 40/80 MHz do not match with the CR rev. frequency
- Filling the PS with CTF3 @50Hz, then ramp @3.5 GeV(2-7 *1.2), fill the SPS in 2-3min
- Full parameter list to be worked out…

Y. Baconnier et al., NIM 1985



Further studies

- Transfer-line and injection/extraction elements
- Issues with positrons
  - Existing transfer line but new production scheme
  - Investigate polarity reversal for accomodating electrons through the existing complex (PS-TT10-SPS)
- Complete parameter set for PS and SPS including DA and coupling simulations, collective effects and synchrotron radiation absorption
- Test the new optics in the SPS with protons at low energy (2015)
- Establish synergies with different projects (LHeC ERL!), FCC-TLEP (top-up!), AWAKE,…)
- Cost estimate…