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Research and Development for Future Accelerators

Swapan Chattopadhyay

Presentation at the IoP Particle Physics Conference at Lancaster University
March 31, 2008

Outline

Hadron Colliders (LHC upgrade) *
Electron-Hadron Colliders (LHeC)
Electron-Positron Colliders (B-factories/LC)*
Neutrino Factory & Beta-beams*
Muon Colliders
Advanced Concepts

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Hadron Colliders

Tevatron & RHIC are operating;
LHC starts in 2008

Tevatron (recycler e-cooling!)
RHIC upgrades
LHC upgrades
(luminosity & energy)

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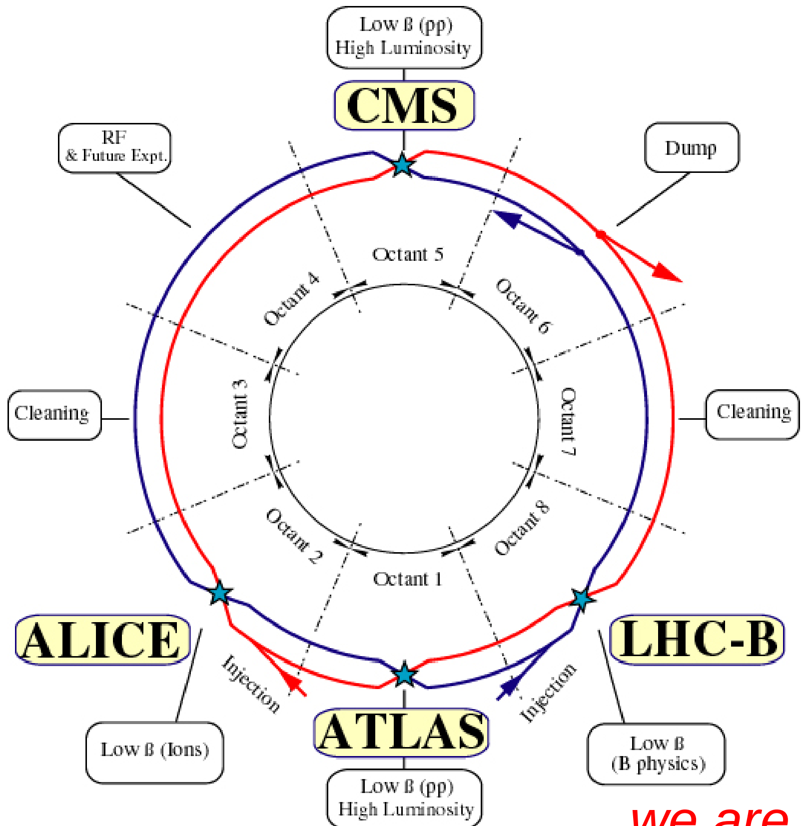
Large Hadron Collider (LHC)



proton-proton collider, ~27 km circumference, next energy-frontier discovery machine

c.m. energy 14 TeV (7x Tevatron), design luminosity 10^{34} cm^{-2}s^{-1} (~100x Tevatron)

450-GeV calibration run end of 2007
1st 7-TeV physics from late spring 2008

we are now studying the upgrade of this facility!

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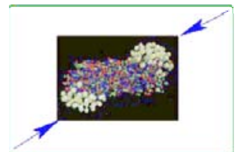
LHC Upgrade
Hadron Luminosity & Energy Frontier

Luminosity $10^{34} \rightarrow \sim 10^{35}$ cm^{-2}s^{-1}

CERN Courier 45, 3 (2005)

LHC upgrade takes shape with CARE and attention



High Energy
High Intensity
Hadron Beams

CARE

European Network

LARP

US LARP

Parameters for various LHC upgrade options compared with nominal and ultimate values

Parameter	Symbol	Nominal	Ultimate	Shorter bunches		Longer bunches
number of bunches	n_b	2808	2808	4680	7020	936
protons per bunch	N_b (10^{11})	1.15	1.7	1.7		6.0
bunch spacing	Δt_{sep} (ns)	25	25	15	10	75
average current	I (A)	0.58	0.86	1.43	2.15	1.0
longitudinal profile	–	Gaussian	Gaussian	Gaussian		uniform
rms bunch length	σ_z (cm)	7.55	7.55	3.78		14.4
beta at IP1 and IP5	β^* (m)	0.55	0.5	0.25		0.25
crossing angle	θ_c (µrad)	285	315	445		430
Piwinski parameter	$\theta_c\sigma_z/(\sigma^*2)$	0.64	0.75	0.75		2.8
luminosity	L (10^{34} cm^{-2} s^{-1})	1.0	2.3	7.7	11.5	8.9
events per crossing	–	19	44	88		510

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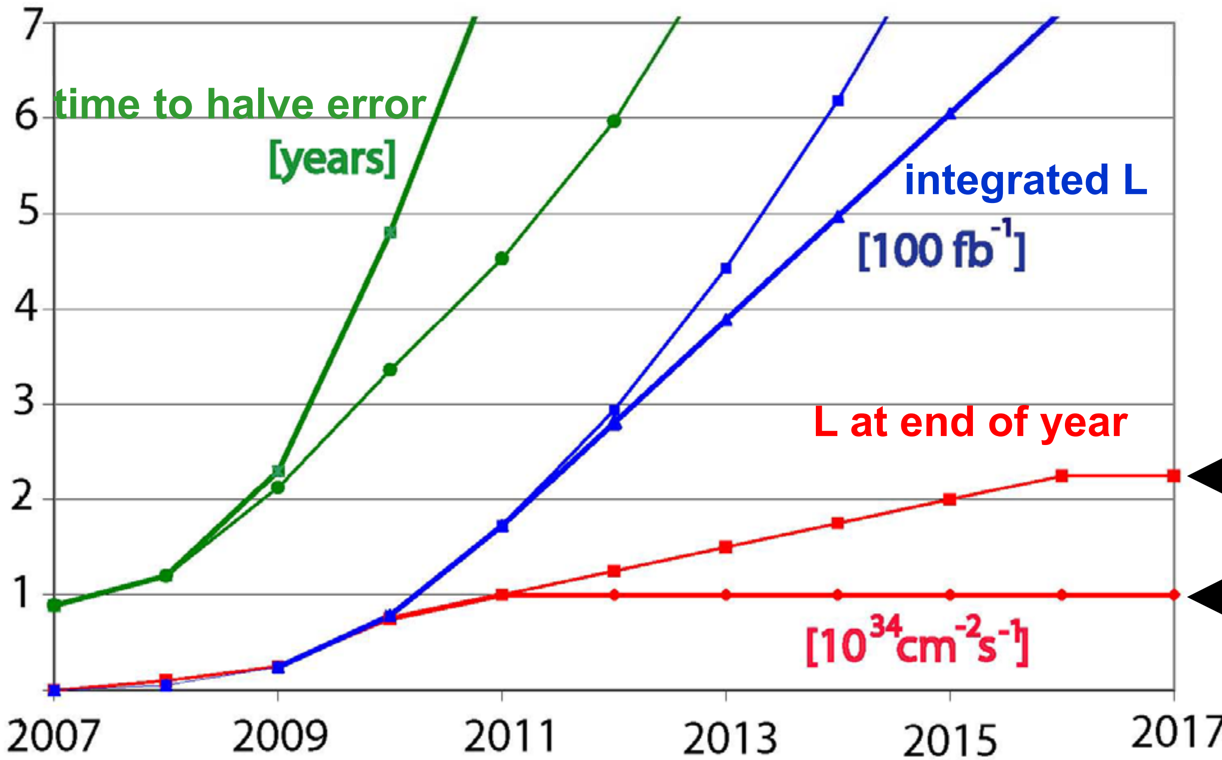
courtesy
J. Strait

Time scale of an LHC upgrade



radiation damage limit ~700 fb-1

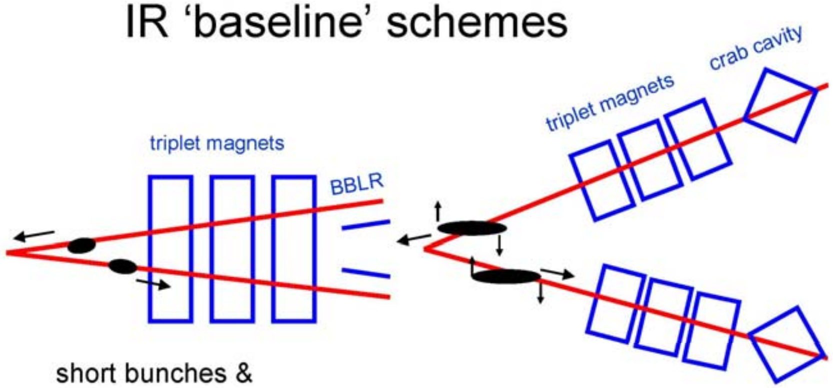
ultimate luminosity

design luminosity

(1) ***life expectancy of LHC IR quadrupole magnets*** is estimated to be <10 years due to high radiation doses
(2) the ***statistical error halving time*** will exceed 5 years by 2011-2012
(3) therefore, it is reasonable to plan a ***machine luminosity upgrade based on new low-β IR magnets before ~2014***

I R U P G R A D E

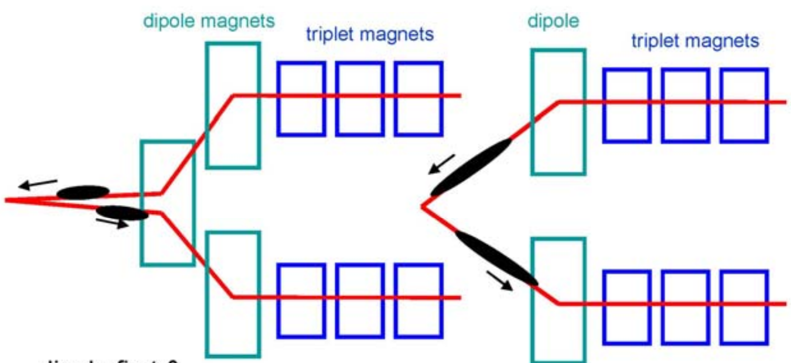
IR 'baseline' schemes



short bunches &
minimum crossing angle &
BBLR

crab cavities &
large crossing angle

alternative IR schemes



dipole first &
small crossing angle

dipole first &
large crossing angle &
long bunches or crab cavities

"quadrupoles first"

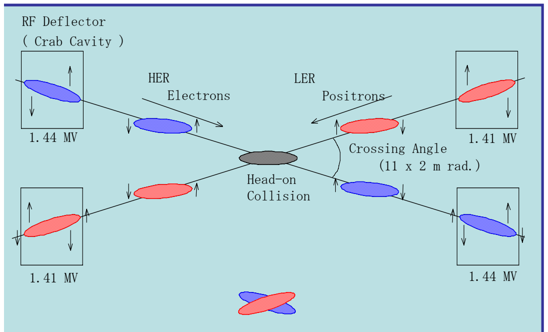
→ minimum chromaticity

→ "dipole first"

reduced # LR collisions;
collision debris hits first dipole

N. Mokhov et al., PAC2003

"open midplane s.c. dipole"
(studied by US LARP)



Crab Cavity combines all advantages of head-on collision and crossing angle

$$V_{crab} = \frac{cE_b \tan(\theta_c / 2)}{e\omega_{rf} \sqrt{\beta^* \beta_{crab}}}$$

$$\Delta\phi_{crab} \leq \frac{\Delta x_{max}}{\lambda_{rf}\theta_c} 2\pi$$

R. Palmer, 1988
K. Oide, K. Yokoya

variable	symbol	KEKB	SuperLHC
beam energy	E_b	8 GeV	7 TeV
rf frequency	f_{crab}	508 MHz	400 MHz
crossing angle	Θ_c	11 mrad	4-5 mrad
IP β	β^*	0.33 m	0.25 m
cavity β	β_{cav}	100 m	3-4 km
kick voltage	V_{crab}	1.44 MV	~110 MV
jitter tolerance	$\Delta t=\Delta\phi/\omega_{rf}$		~2 fs !?

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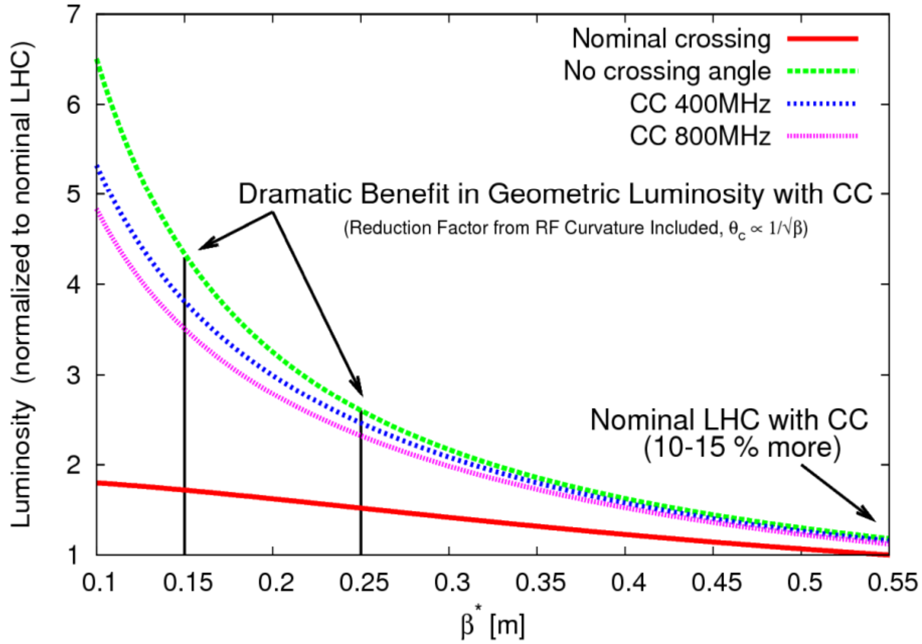
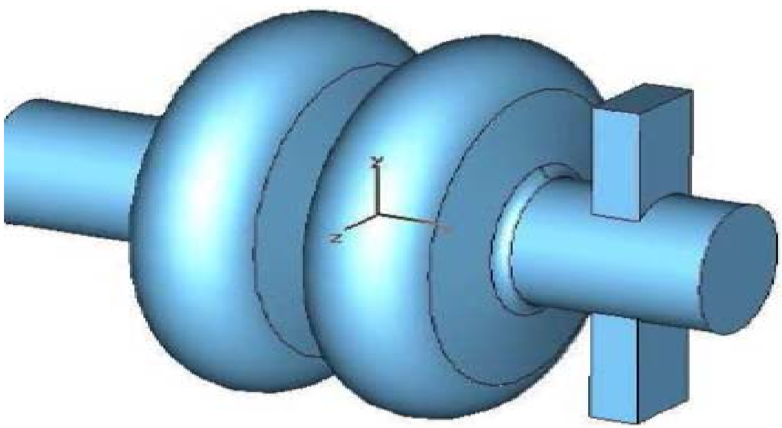
LHC Crab Cavities

LARP / Care / multi-institutional collaboration

Prototype proposed as SBIR by AES with BNL collaboration



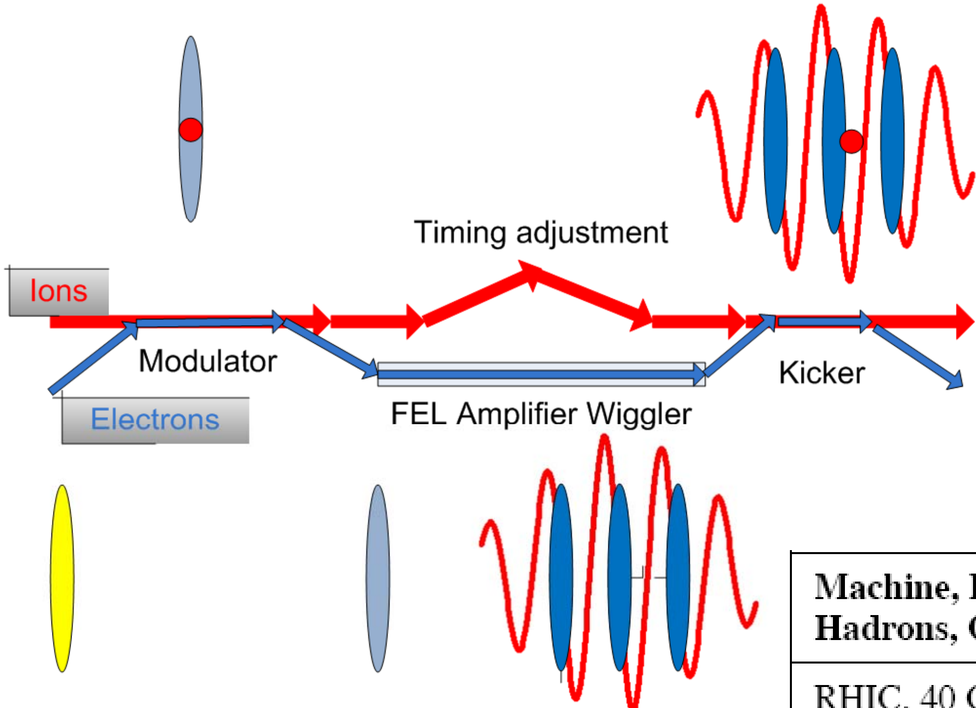


Candidate 800 MHz two-cell LHC crab cavity

University of Liverpool · Lancaster University · The University of Manchester · Science & Technology Facilities Council

Coherent Electron Cooling

Adapted from Derbenev, Litvinenko. Multi-laboratory collaboration

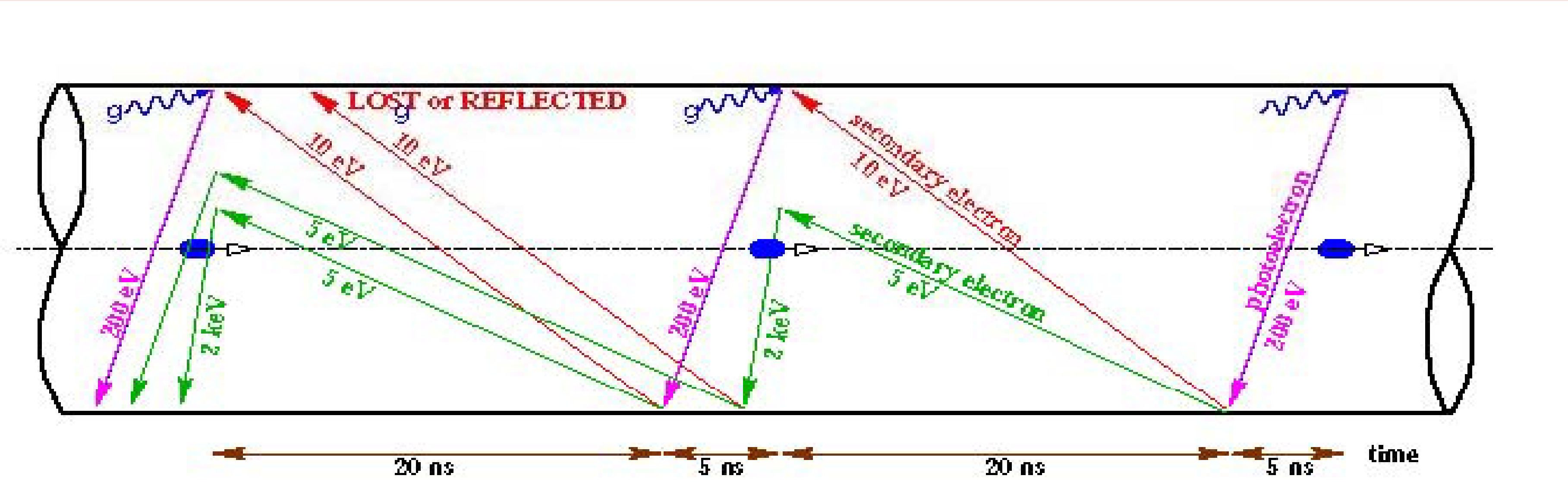


Machine, Energy, Hadrons, GeV/u	λ_o	FEL Length, m	FEL Gain, *amplitude*
RHIC, 40 GeV/n, Au	18 μm	6.5	100
RHIC, 100 GeV, Au, p	3 μm	9	200
RHIC, 250 GeV, p	500 nm	15	100
LHC, 7 TeV, p	10 nm	25	500

Ultimate LHC intensity limitations

- electron cloud
- long-range & head-on beam-beam effects
- collimator impedance & damage
- injectors
- beam dump & damage
- machine protection
- …

electron cloud in the LHC



schematic of e- cloud build up in the arc beam pipe,
due to **photoemission** and **secondary emission**

in the background: simulation of bunch passing through e- plasma using the QUICKPIC code [T. Katsouleas, USC]

[F. Ruggiero]

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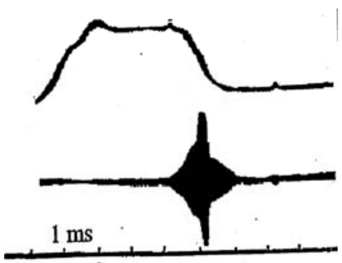
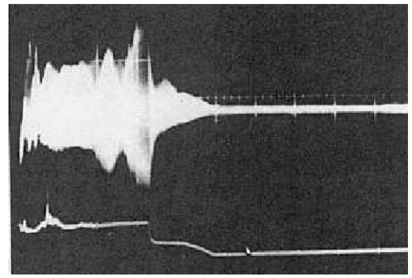
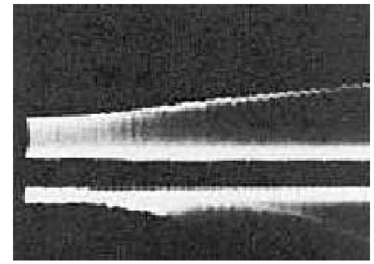
INP Novosibirsk, 1965



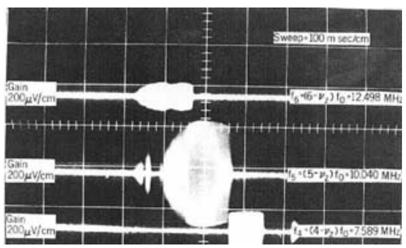
Argonne ZGS,1965



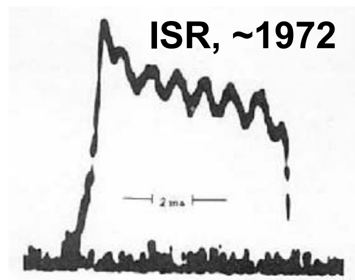
BNL AGS, 1965



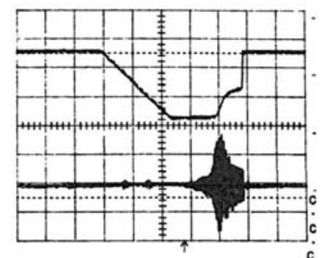
Bevatron, 1971



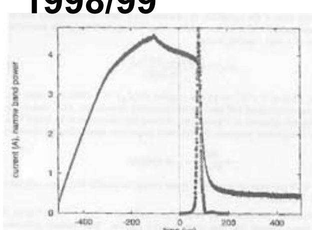
ISR, ~1972



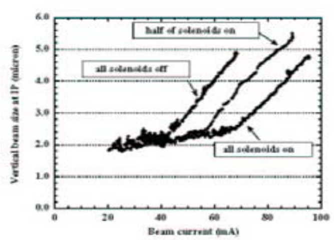
PSR, 1988



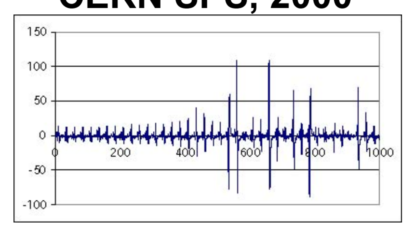
AGS Booster, 1998/99



KEKB, 2000



CERN SPS, 2000



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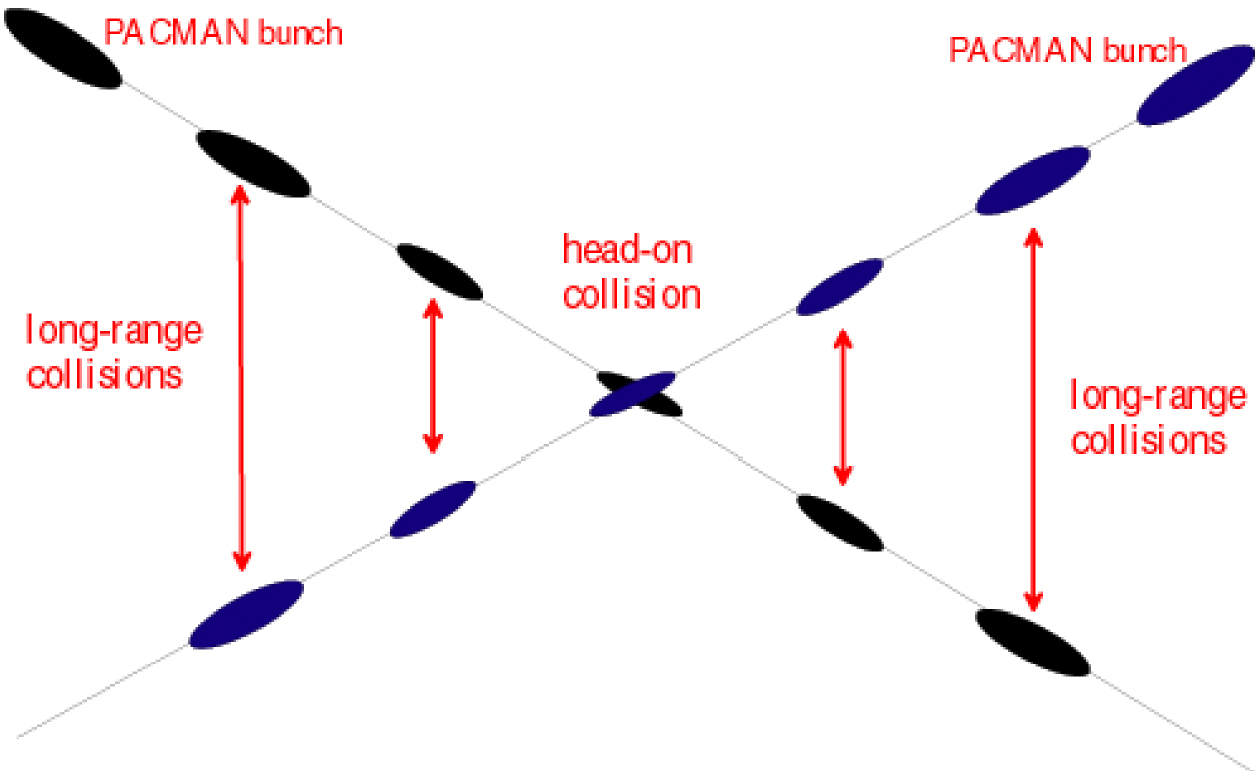
Long-range beam-beam collisions

- perturb motion at large betatron amplitudes, where particles come close to opposing beam
- cause 'diffusive aperture', high background, poor beam lifetime
- increasing problem for SPS, Tevatron, LHC,...

  that is for operation with larger # of bunches

	#LR encounters
SPS	9
Tevatron Run-II	70
LHC	120

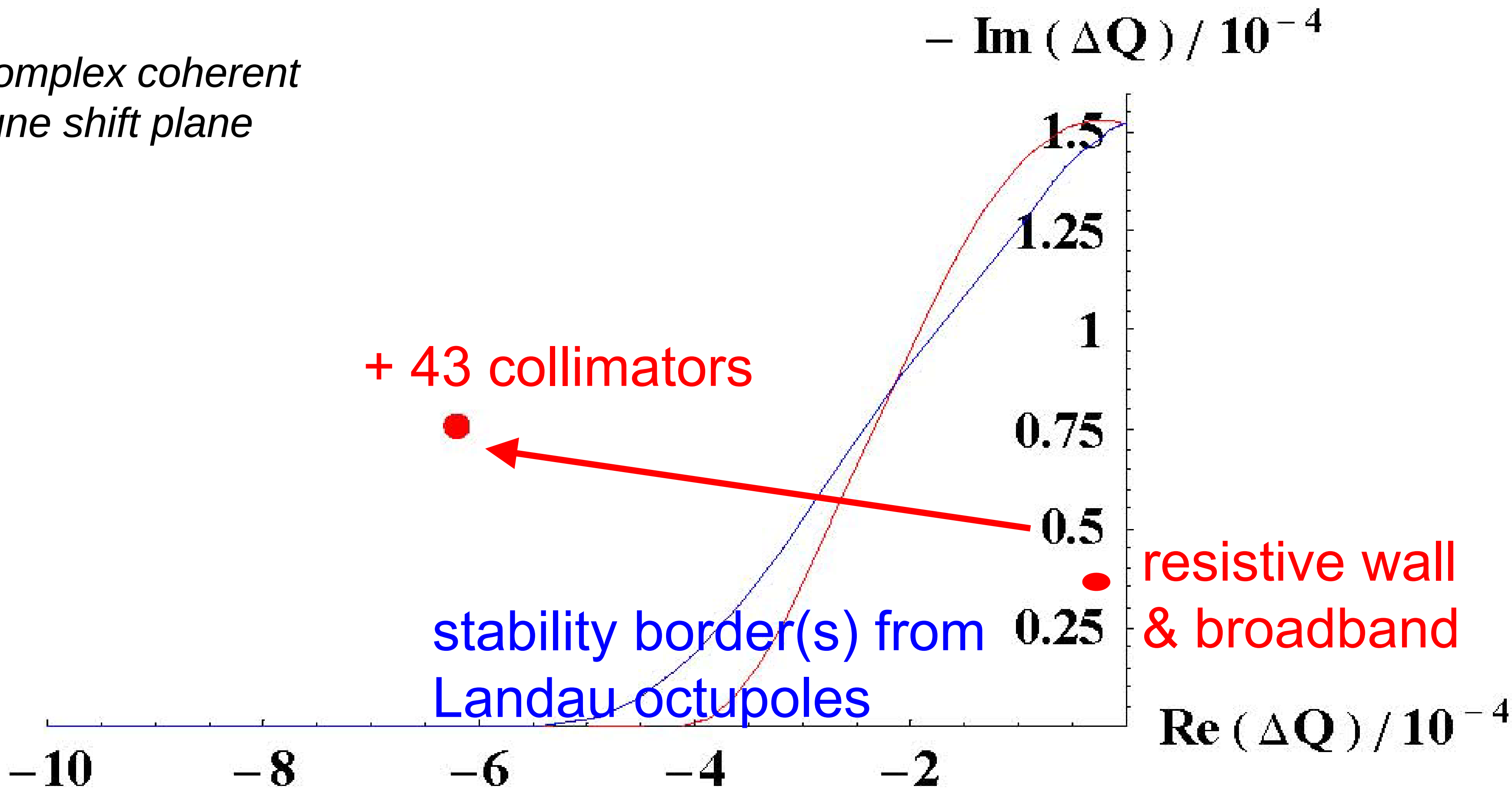
LHC: 4 primary IPs & 30 long-range collisions per IP, 120 in total



partial mitigation by alternating planes of crossing at IP1 & 5 etc.

graphite collimator impedance renders nominal LHC beam unstable

complex coherent tune shift plane



LHC is limited to 40% of nominal intensity until “phase II collimation”

Elias Metral

LHC phase-2 collimation options

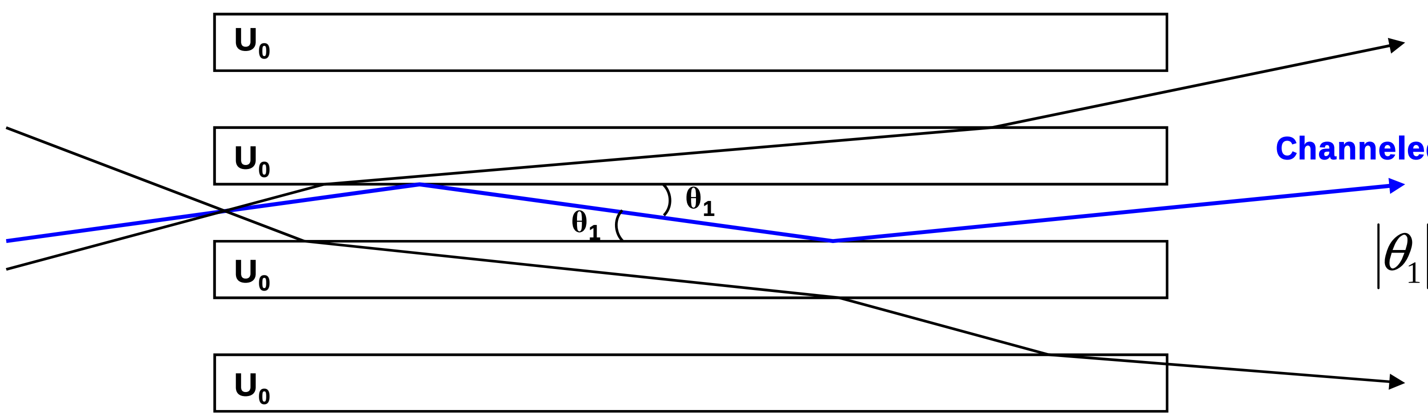
- consumable low-impedance collimators (rotating metal wheels; prototype from US LARP / SLAC to be installed in 2008)
- nonlinear collimation; pairs of sextupoles to deflect halo particles to larger amplitudes & open collimator gaps
- use crystals to bend halo particles to larger amplitudes & open collimator gaps

Channeling in flat crystal

$$\frac{\sin\phi_1}{\sin\phi_2} = \sqrt{1+\frac{2}{mv_1^{\;2}}(U_1 - U_2)} = \sqrt{1-\frac{2U_0}{(pv)_1}}$$

(Landau and Lifshitz, Mechanics)

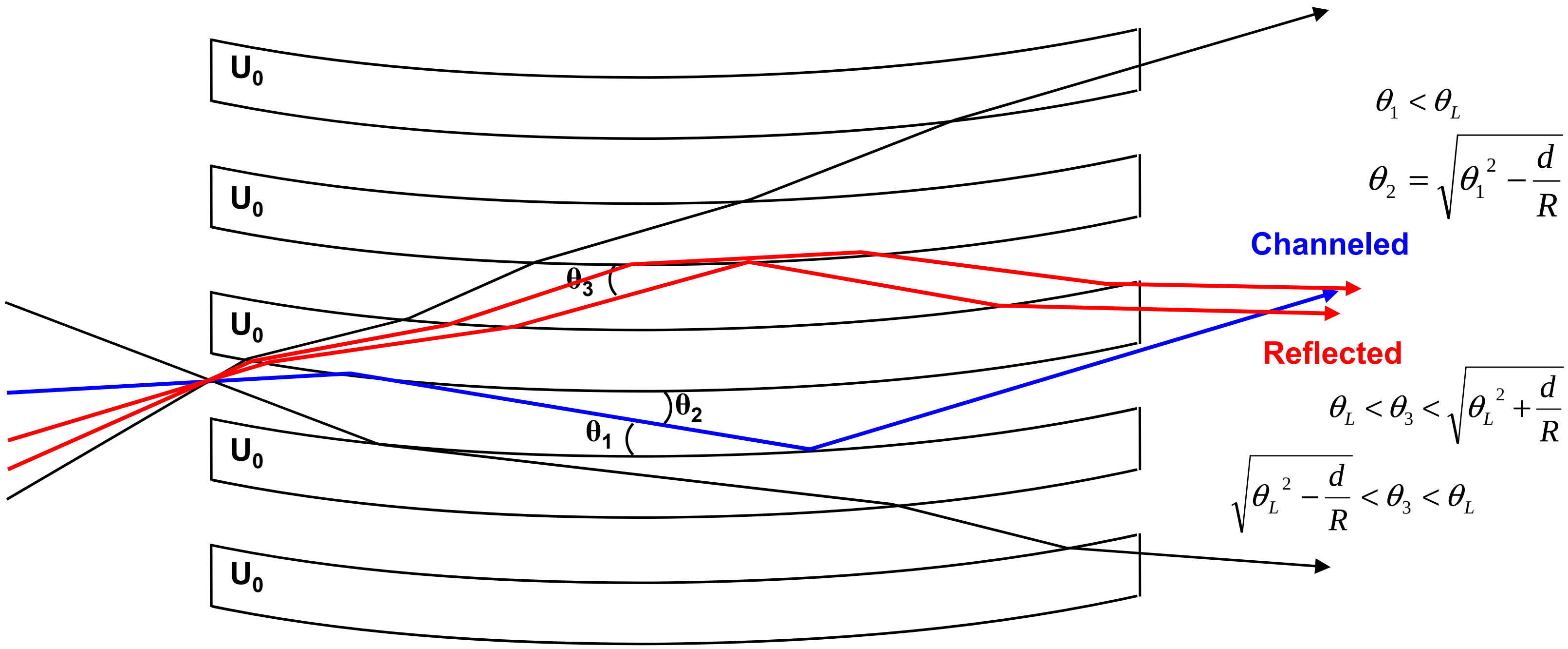
$$\theta_2 \approx \sqrt{\theta_1^{\;2} - \frac{2U_0}{(pv)_1}}$$



$$|\theta_1| \le \theta_L = \sqrt{\frac{2U_0}{(pv)_1}}$$

Y. Ivanov, PNPI

Channeling and reflection in bent crystal



Y. Ivanov, PNPI

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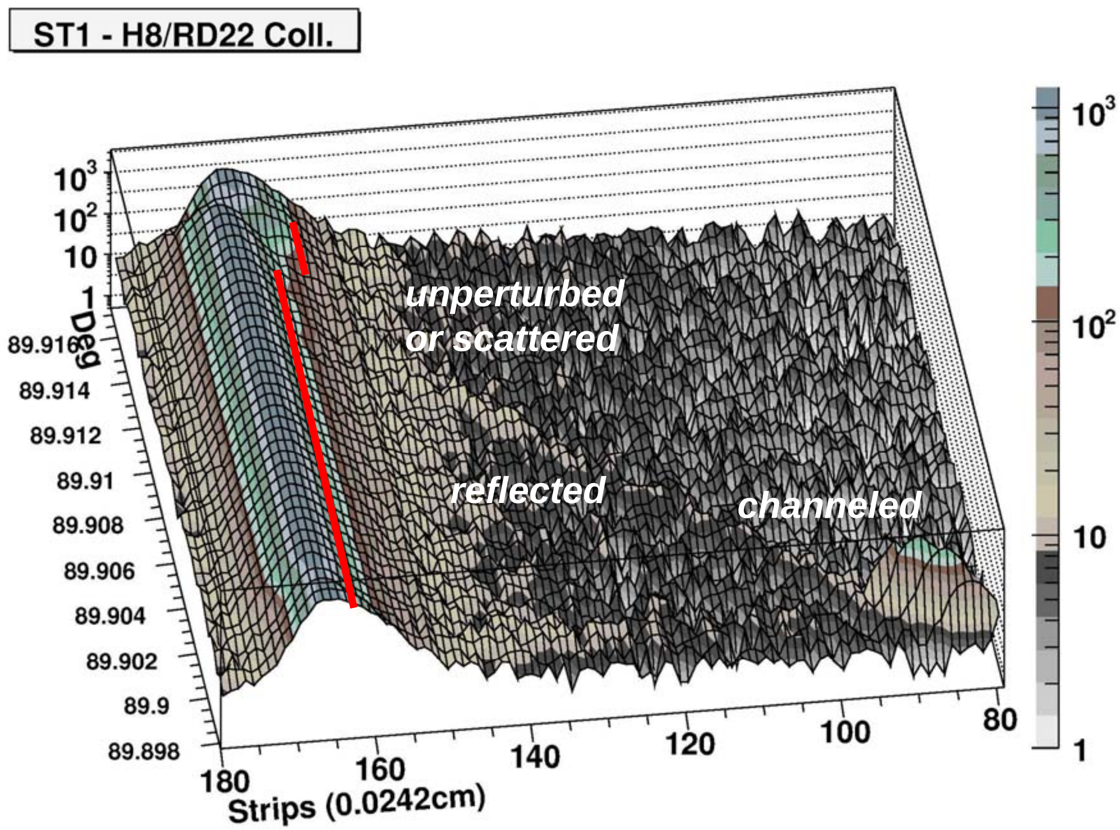
crystal channeling & reflection demonstrated in SPS H8 -12.09.2006!



Si-strip detector 65 m behind Crystal

400 GeV p

10-µrad reflection over 1 µm distance ↔ ~20000 T field!

>99% efficiency

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ultimate LHC “upgrade”: higher beam energy

7 TeV→14 (21) TeV?

R&D on stronger magnets

develop and construct a large-aperture (up to 88 mm), high-field (up to 15 T) dipole magnet model that pushes the technology well beyond present LHC limits.

NED

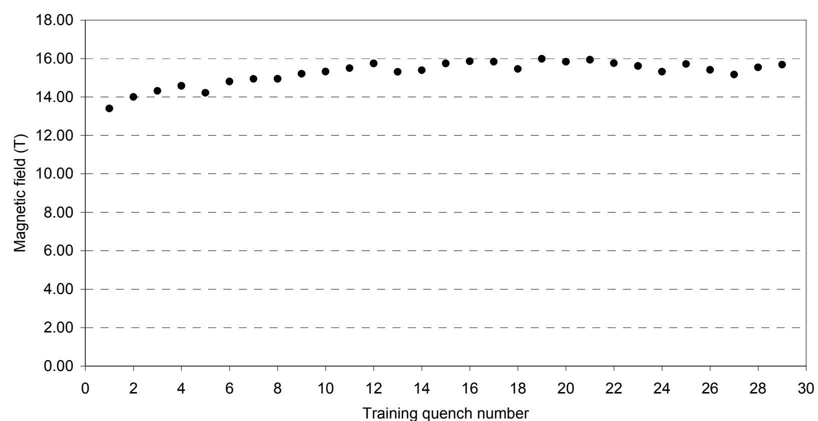
Next European Dipole

European Joint Research Activity

Six institutes: CCLRC/RAL (UK), CEA/DSM/DAPNIA (France), CERN/AT (International), INFN/Milano-LASA & INFN/Genova (Italy), Twente University (the Netherlands), Wroclaw University (Poland).

Three s.c. wire manufacturers (also contributing financially): Alstom/MSA (France), ShapeMetal Innovation (the Netherlands), Vacuumschmelze (now European Advanced Superconductors, Germany)

proof-of principle & world record: 16 T at 4.2 K at LBNL (in 10 mm aperture).



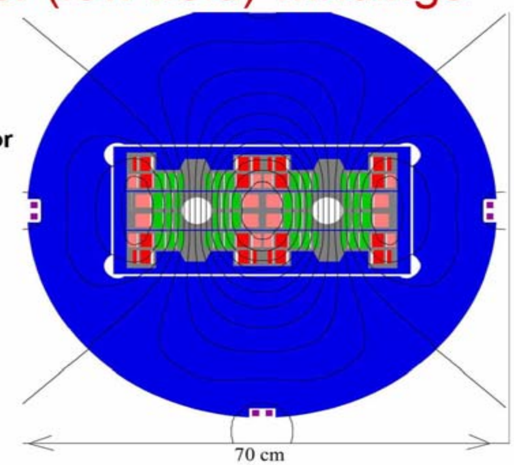
(S. Gourlay, A. Devred)

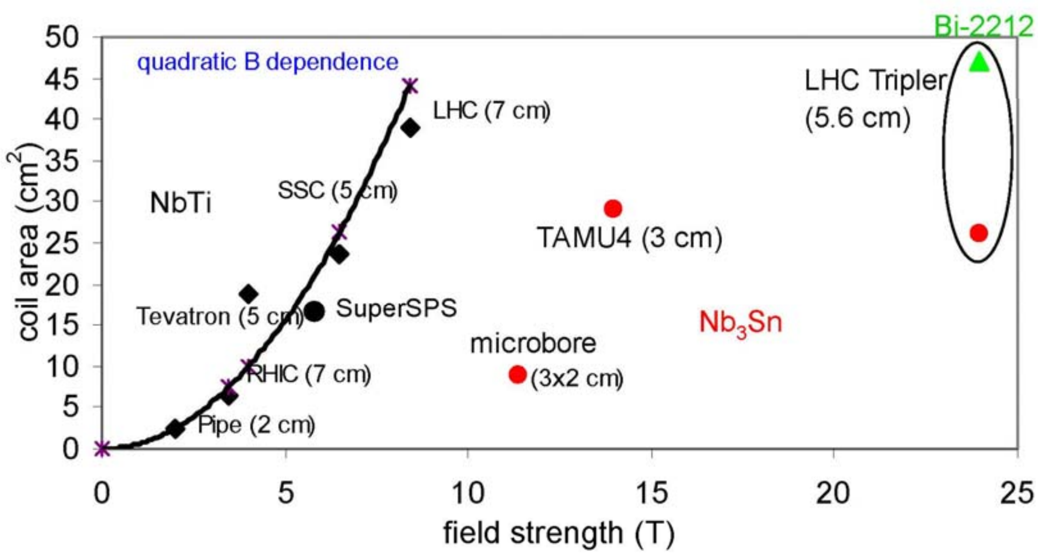
proposed design of 24-T block-coil dipole for LHC energy tripler

P. McIntyre, Texas A&M, PAC'05

Bi-2212 in inner (high field) windings, Nb_3Sn in outer (low field) windings

Dual dipole (ala LHC)
Bore field 24 Tesla
Max stress in superconductor 130 MPa
Superconductor x-section:
Nb_3Sn 26 cm^2
Bi-2212 47 cm^2
Cable current 25 kA
Beam tube dia. 50 mm
Beam separation 194 mm





magnets are getting more efficient!

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Large Hadron-electron Collider

Understanding the fundamental constituents of matter down to sub-atto-metre resolution via probing deep, deeper and ever deeper into the Nucleon…….beyond 10^{-19} meter

100 GeV electrons X 7 TeV protons

@10^{32} -10^{35} $cm^{-2}s^{-1}$

(Attention: DIS 2008 workshop @UCL April 7-11, 2008)

The Large Hadron-electron Collider (LHeC) at CERN LHC…

Emerging initiative!! Fascinating possibilities, among others, with the newly emerging *superconducting linac, energy recovery and advanced electron cooling technologies!!*

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e+e- colliders

- **KEK-B → Super KEK-B, 3.5x8 GeV, ~2010**
- **Super-B, 4x7 GeV, ~2010**
- **ILC, 0.25x0.25 TeV, ~2016?**
- **CLIC, 0.5x0.5 TeV→2.5x2.5 TeV, ~2020?**

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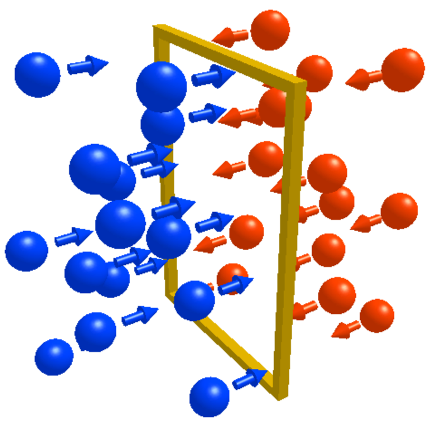
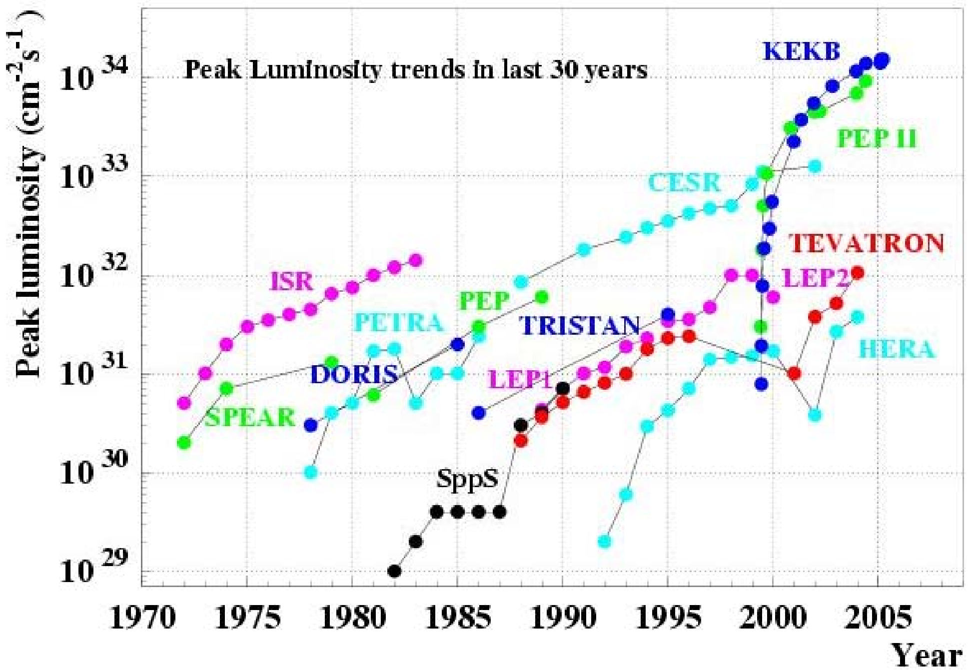
KEKB / SuperKEKB
The Next Luminosity Frontier ?



(number of events/unit time)

= (cross section) X (luminosity)



Super-KEKB: definitive answers on new physics beyond the standard model in the heavy flavor sector

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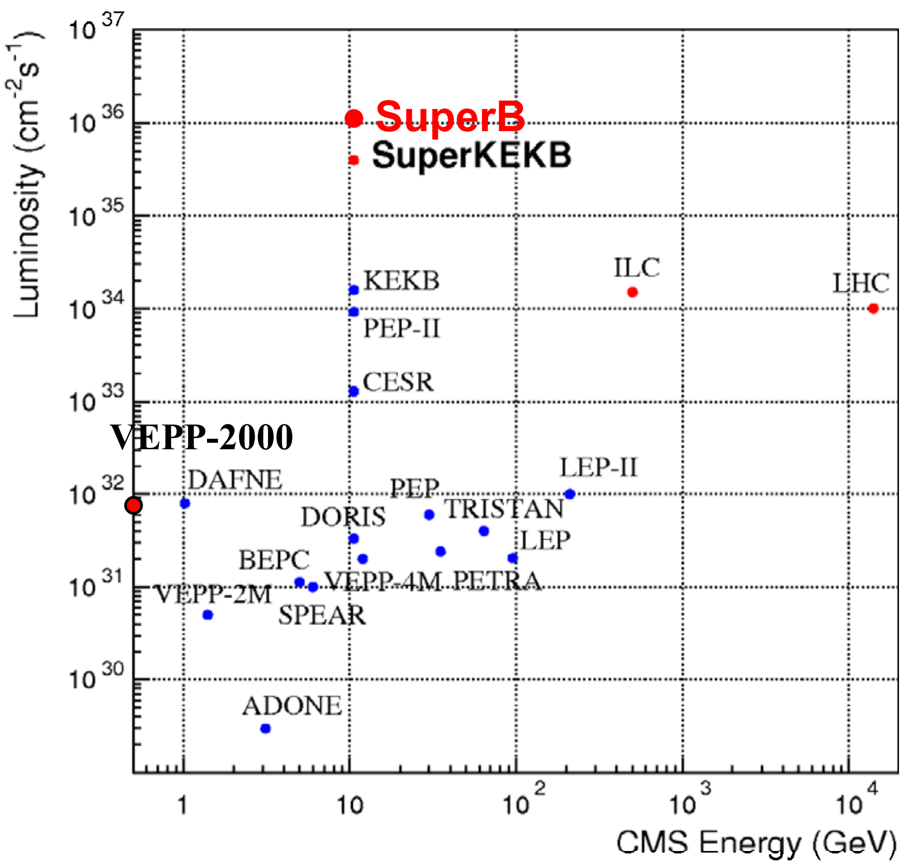
SuperKEKB &/or SuperB



Strategy of SuperKEKB Parameter Choice

$$L = \frac{\gamma_{e\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{e\pm}\xi_y^{e\pm}}{\beta_y^*}\right)\left(\frac{R_L}{R_{\xi_y}}\right)$$

Beam-beam parameter

Beam current

Lorentz factor

Classical electron radius

Beam size ratio@IP
1 ~ 2 % (flat beam)

Vertical beta function@IP

Ratio of luminosity
&
tune shift
reduction
factors: 0.8 ~ 1
(short bunch)

Increase beam currents

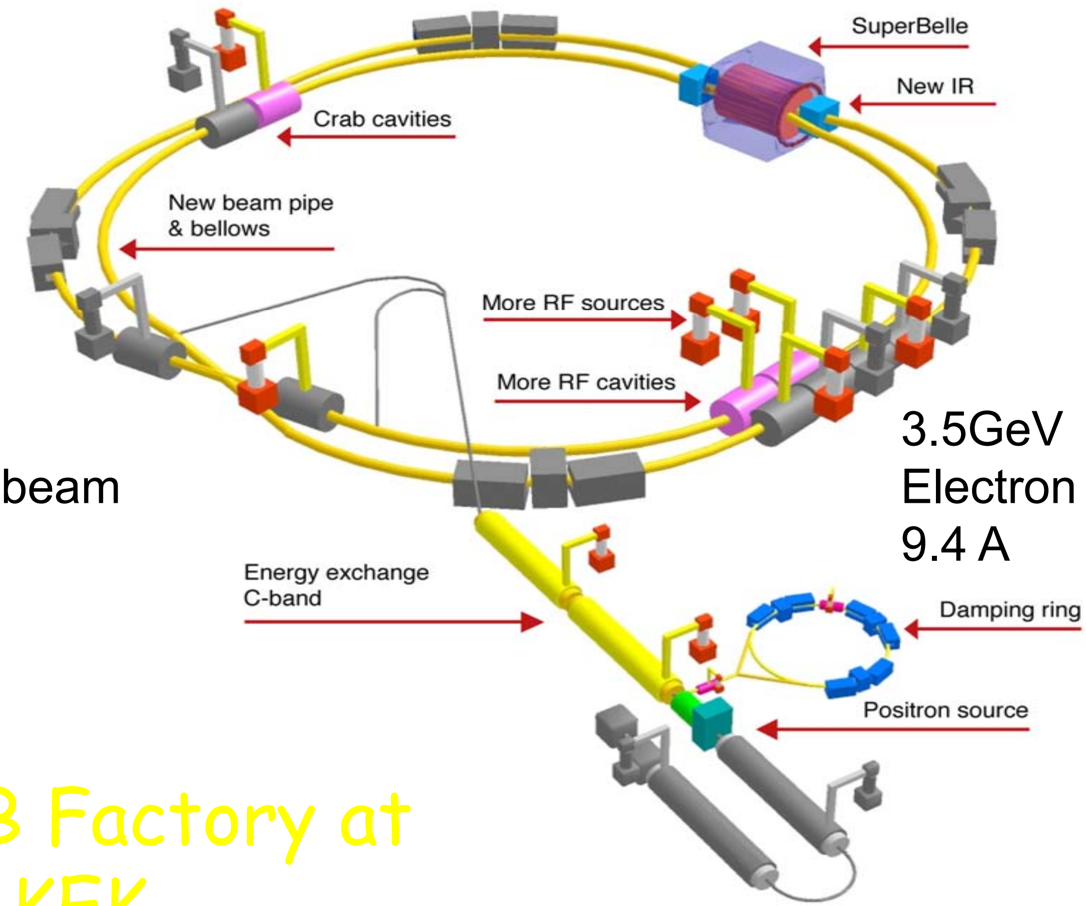
•1.6 A (LER) / 1.2 A (HER) → 9.4 A (LER) / 4.1 A (HER)

Smaller β_y^*/smaller σ_z

•6 mm→3 mm/5 mm→3 mm

Increase ξ_y

•0.05→0.14



8GeV
Positron beam
4.1 A

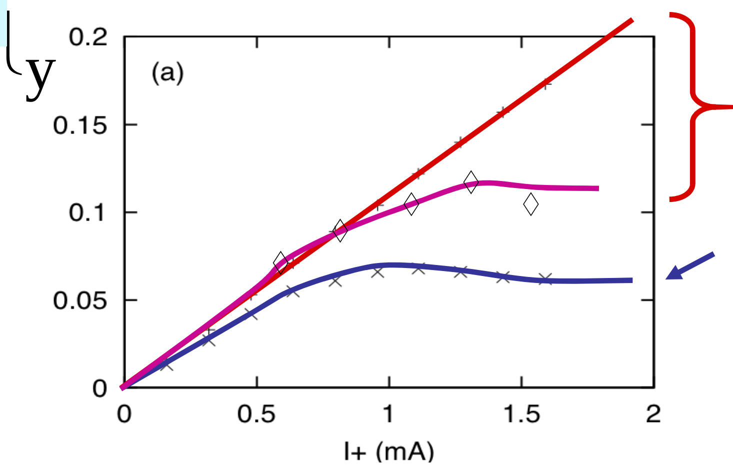
3.5GeV
Electron beam
9.4 A

Super B Factory at KEK

Crab crossing in the near future

- Crab crossing will boost the beam-beam parameter up to 0.19!

K. Ohmi



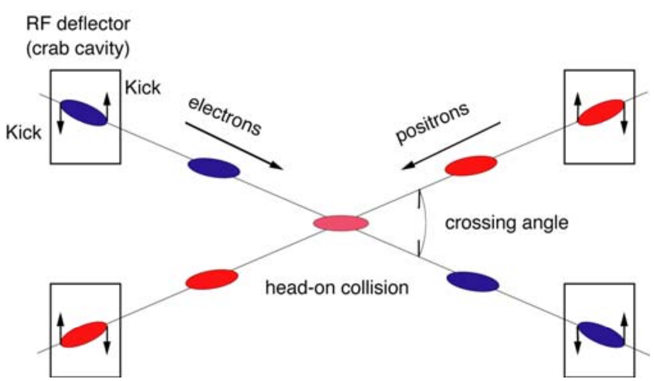
(Strong-weak simulation)

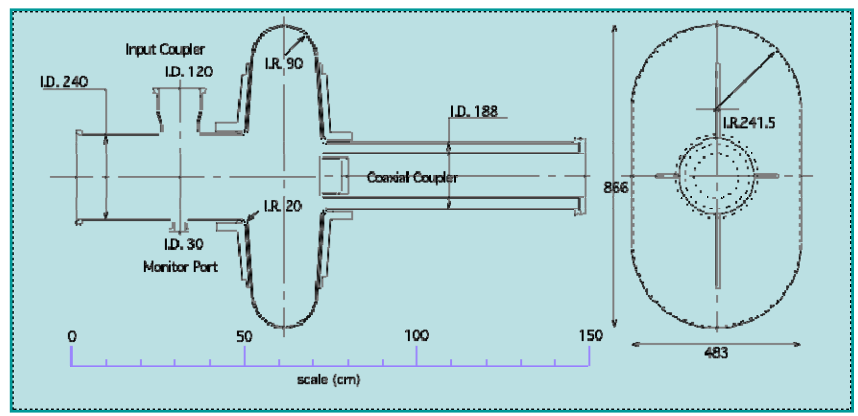
Head-on (crab)

(Strong-strong simulation)

crossing angle 22 mrad

- Superconducting crab cavities are under development, will be installed in KEKB end of 2006.

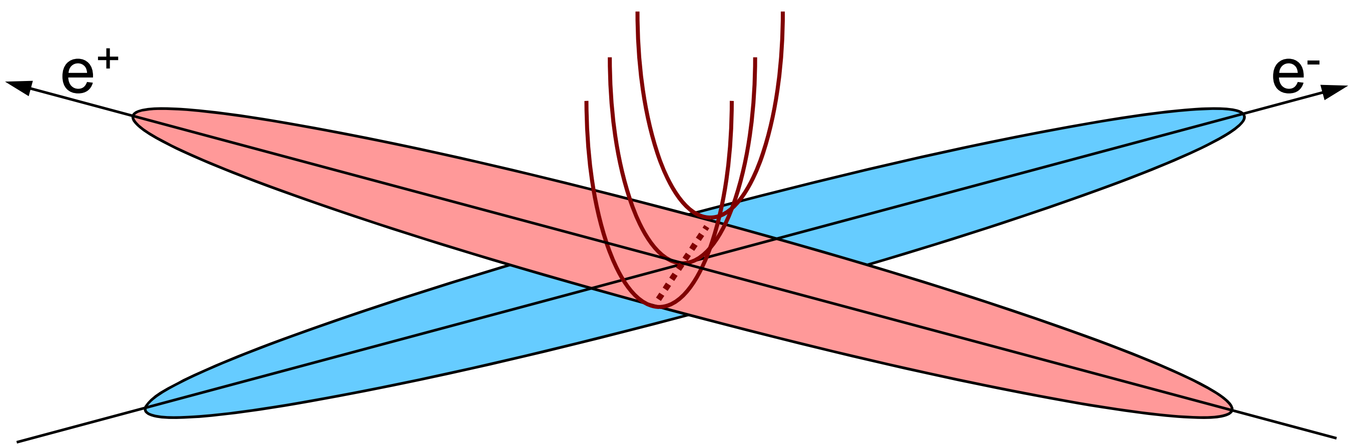




K. Hosoyama, et al

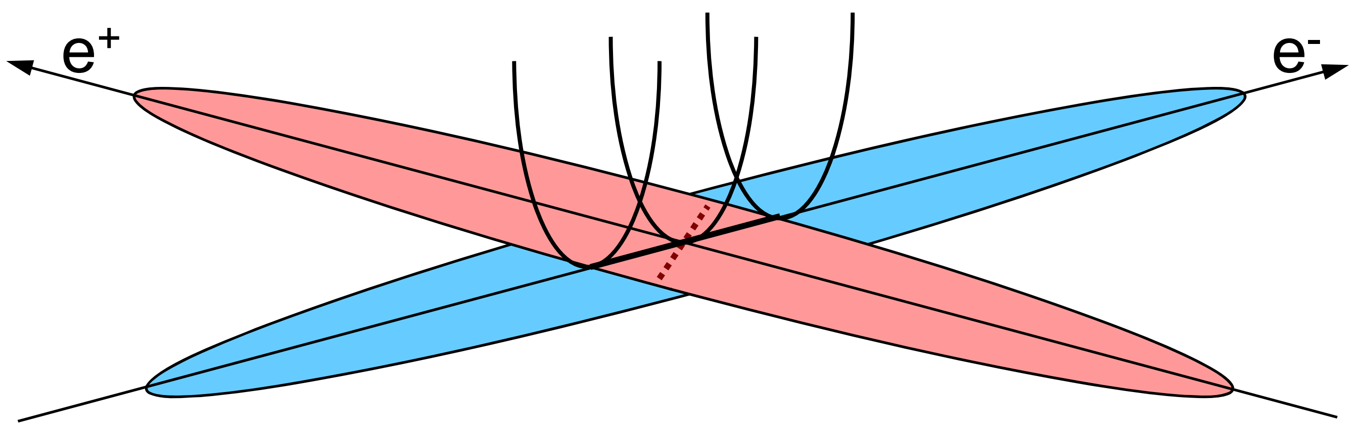
Beam-beam effects: "crabbed waist"

- Normally, at the interaction point of a collider, the longitudinal location of the minimum vertical beam size is independent of the horizontal coordinate.
- When colliding bunches with a crossing angle (which has advantages for design and operation), this results in some loss of luminosity, since the volume of the region where the beams overlap with maximum density is not optimised.



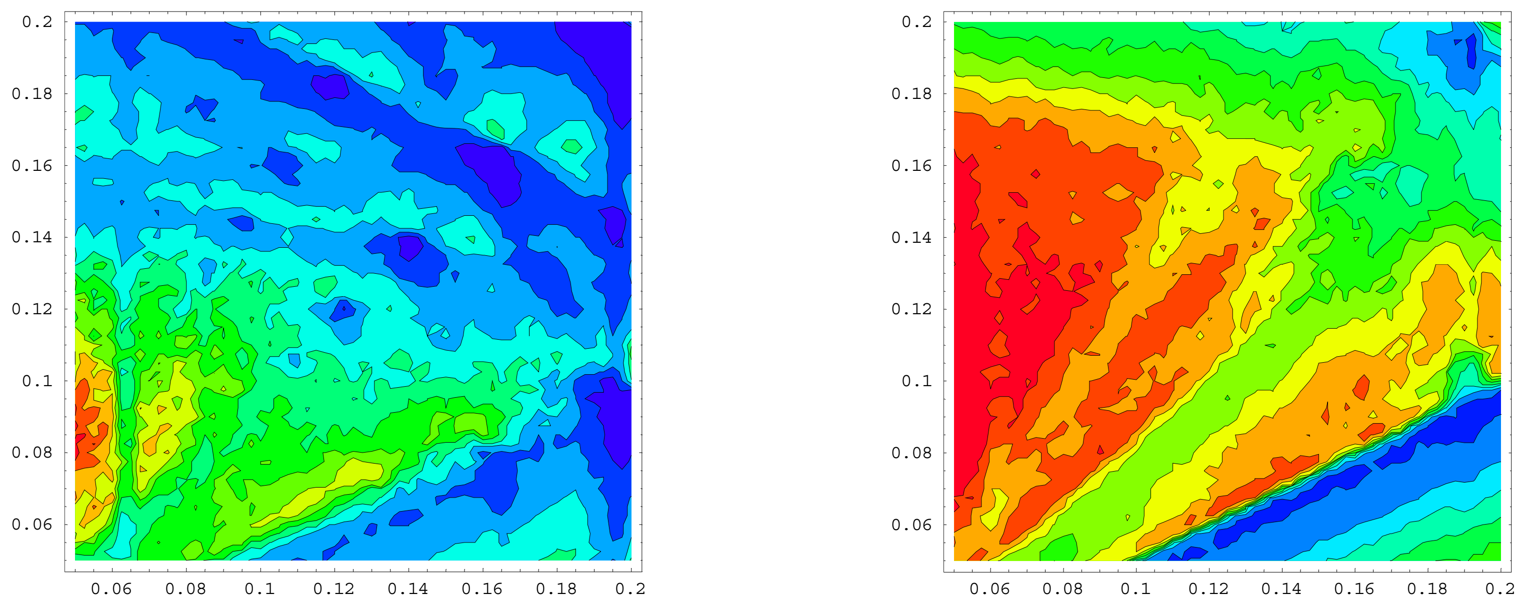
Beam-beam effects: "crabbed waist"

- If the position of the vertical waist is made a function of horizontal position, the volume of the region where the beams overlap with maximum density can be made much larger.
- A "crabbed waist" can be implemented using sextupole magnets near the interaction region. This is a new scheme, which will be tested in DAΦNE later this year.



Super-B Beam-beam effects: “crabbed waist”

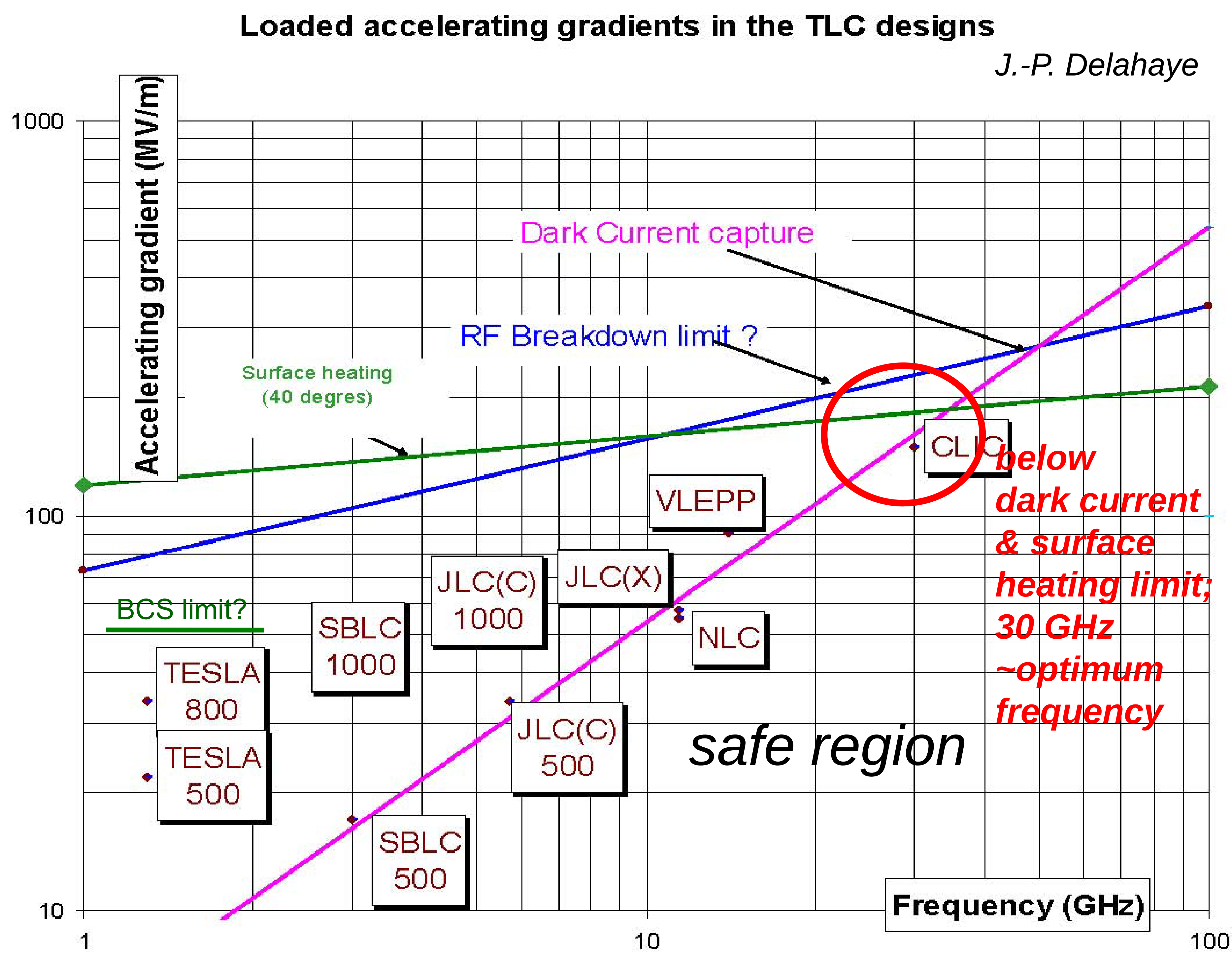
- Using a crabbed waist can (in theory) help overcome some of the limitations from beam-beam effects.



SuperB luminosity as a function of horizontal and vertical tune without (left) and with (right) crabbed waist at the interaction point.
Red areas are regions of high luminosity.

CLIC
Compact Linear Collider

- physics: probing beyond the standard model: origin of mass, unification of forces, origin of flavors
- complementary with LHC
- key features of CLIC:
- ➢ high gradient ~100 MV/m→high frequency ~11.6 GHz
- ➢ two-beam acceleration: energy stored in drive beam, transport over long distances with small losses, rf power generated locally where required
- ➢ drive beam produced in central injector; fully loaded normal conducting linac (~96% efficient) followed by rf multiplication and power compression



Loaded accelerating gradients in the TLC designs
J.-P. Delahaye
Accelerating gradient (MV/m)
1000
100
10
1
10
100
Frequency (GHz)
Dark Current capture
RF Breakdown limit ?
Surface heating
(40 degres)
BCS limit?
TESLA 800
TESLA 500
SBLC 1000
SBLC 500
JLC(C) 1000
JLC(X)
JLC(C) 500
VLEPP
NLC
CLIC
safe region
below
dark current
& surface
heating limit;
30 GHz
~optimum
frequency

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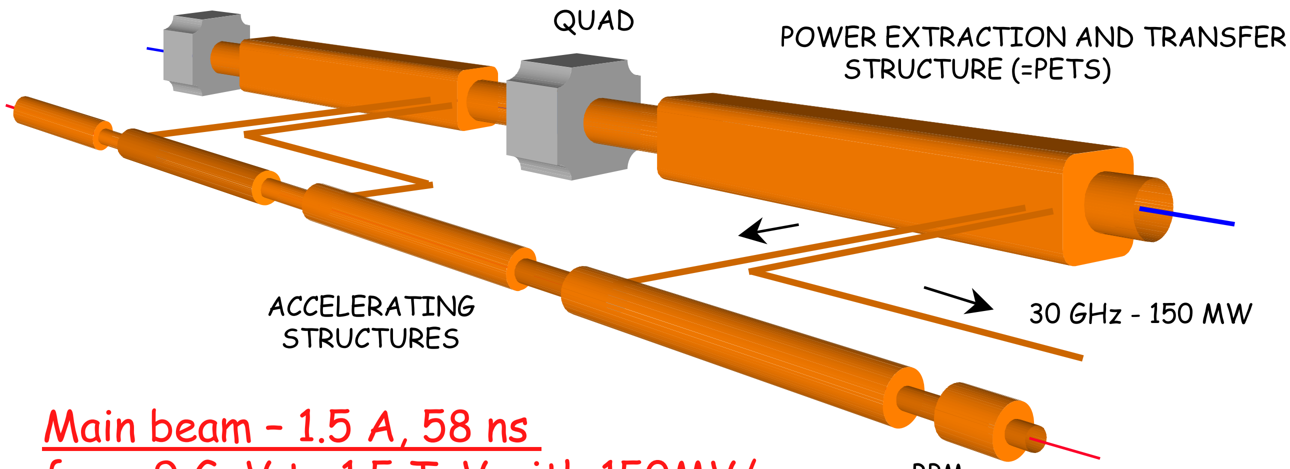
CLIC TWO-BEAM SCHEME

Drive beam - 180 A, 70 ns
from 2.4 GeV to 400 MeV with -9MV/m

A. Sessler 1982,
W. Schnell 1986

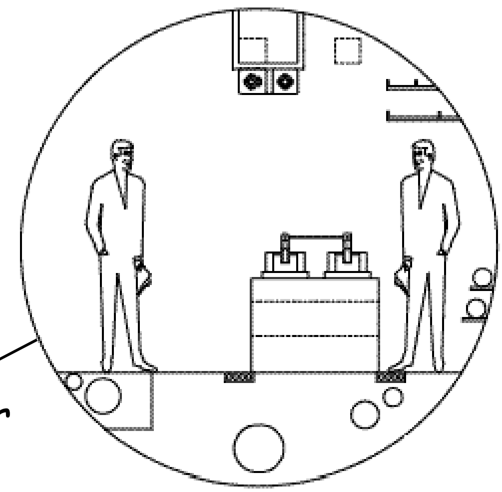


Main beam – 1.5 A, 58 ns
from 9 GeV to 1.5 TeV with 150MV/m

CLIC MODULE

(6000 modules at 3 TeV)

CLIC TUNNEL CROSS-SECTION



3.8 m diameter

CLIC can be built in stages

simple tunnel, no active elements

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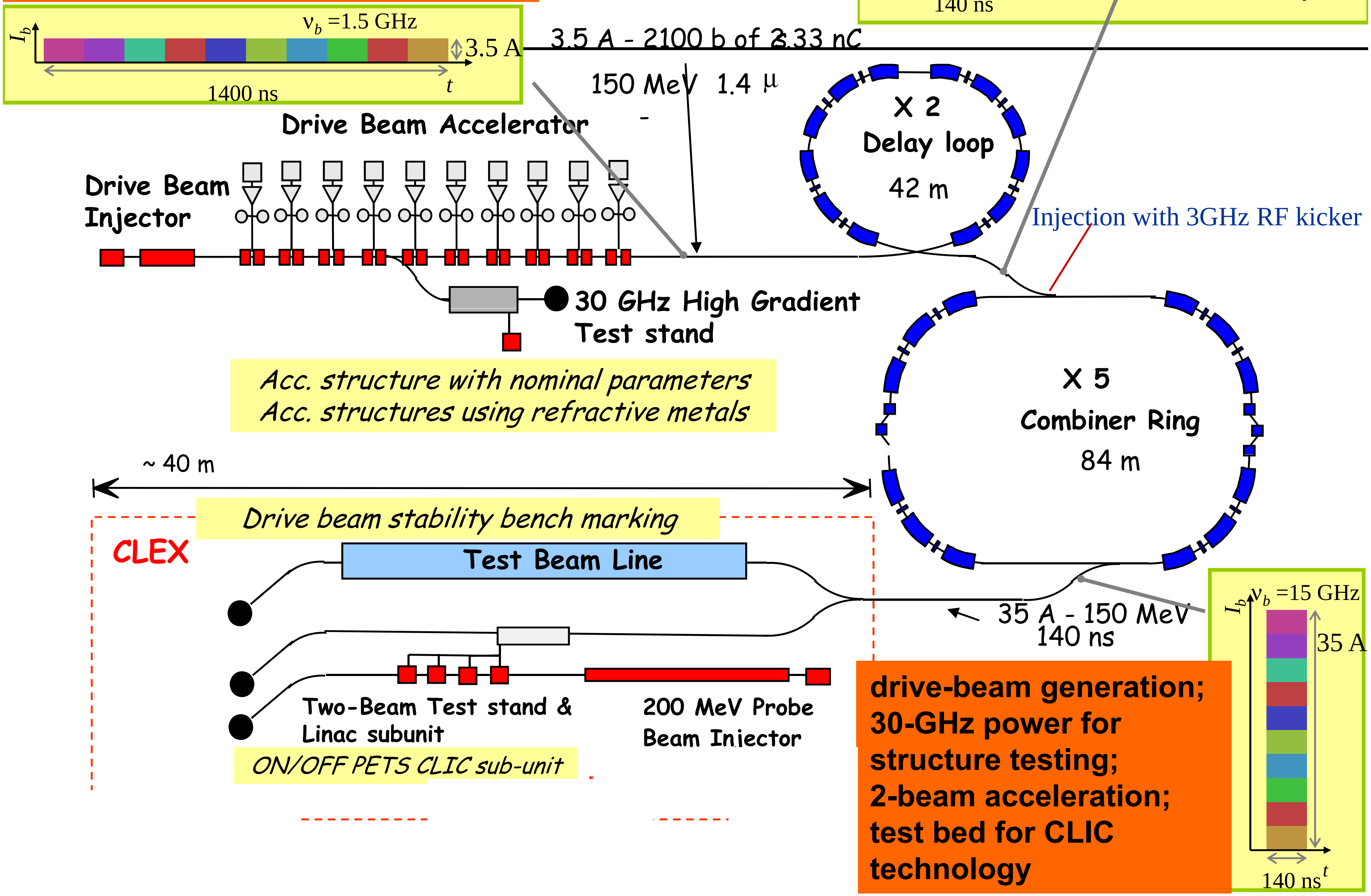
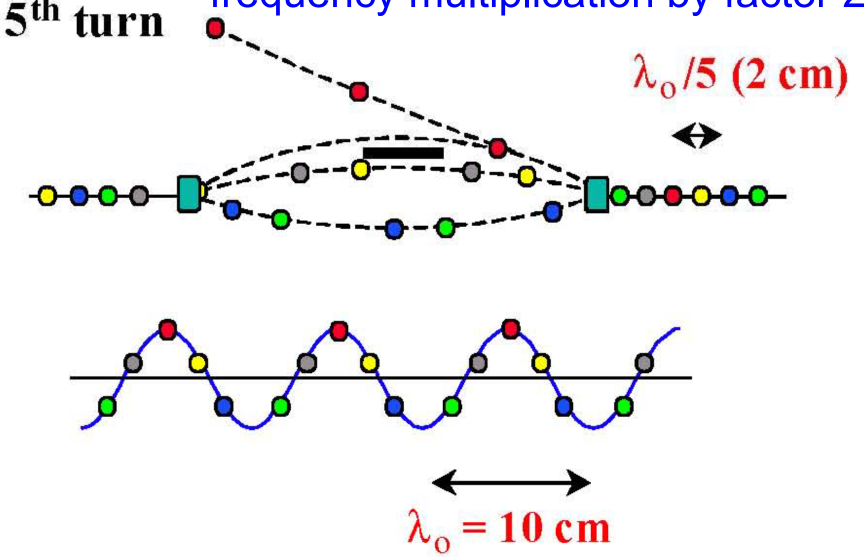
CLIC Test Facility 3 (CTF 3) Layout



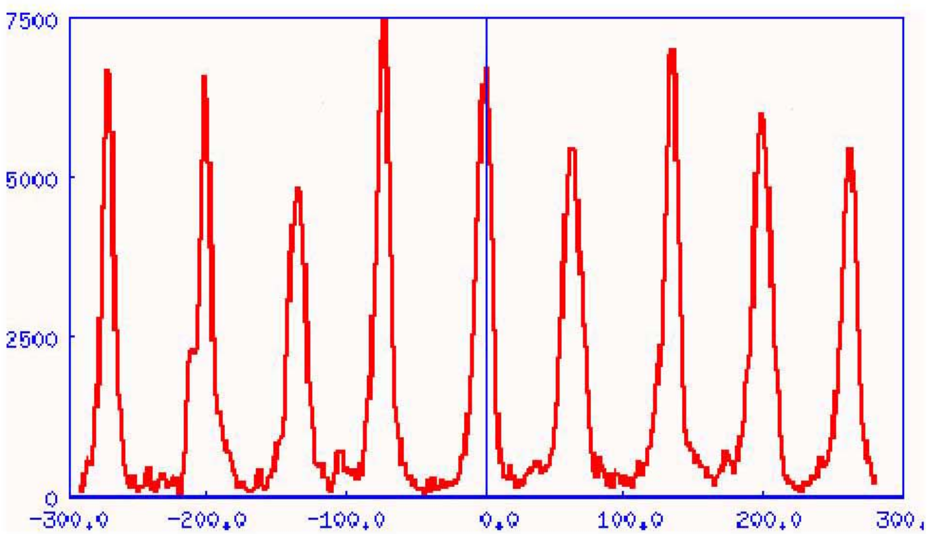
drive-beam generation; 30-GHz power for structure testing; 2-beam acceleration; test bed for CLIC technology

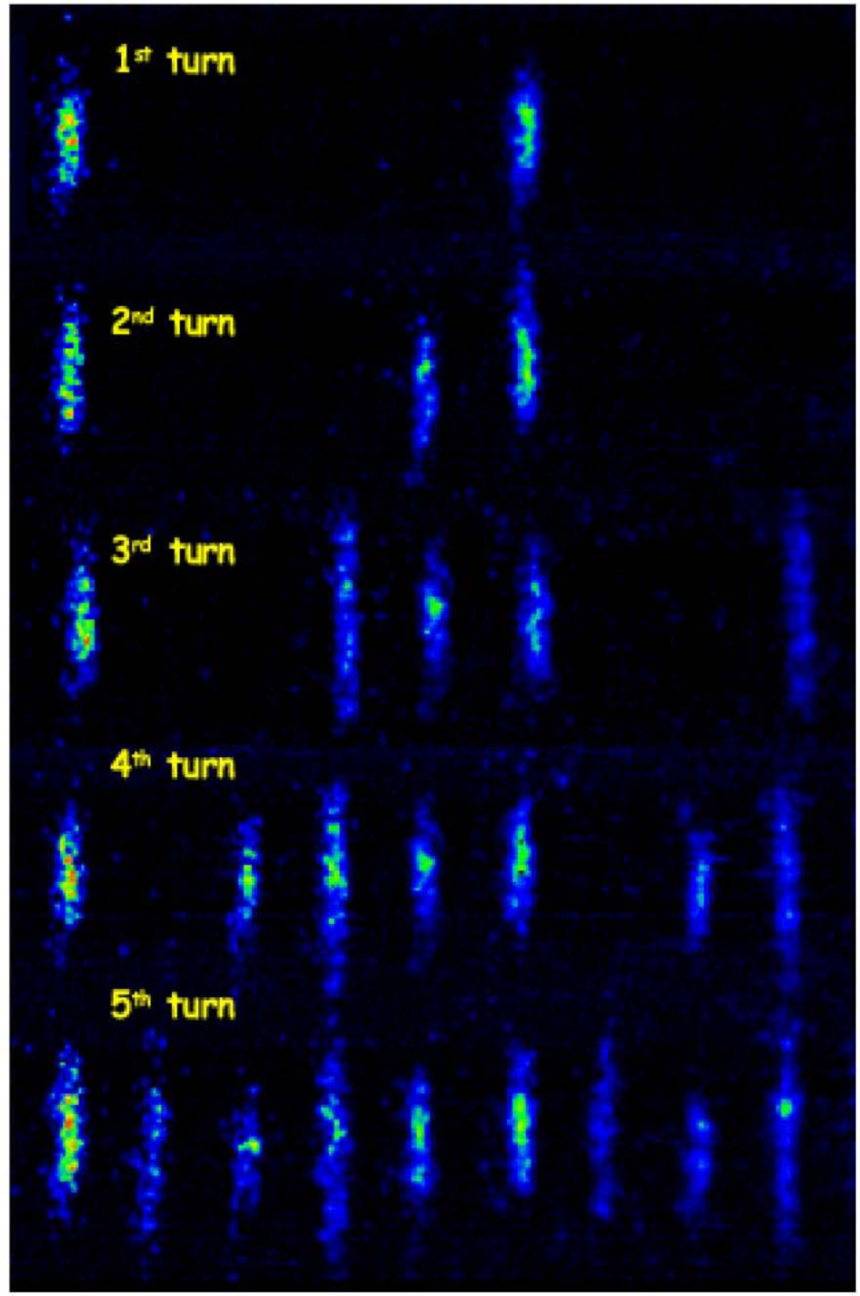
frequency multiplication by factor 2-5 demonstrated in CTF3 preliminary phase

CERN, INFN, SLAC, RAL, LAL, Uppsala



- bunch distance 333 ps → 67 ps
- frequency 3 GHz → 15 GHz





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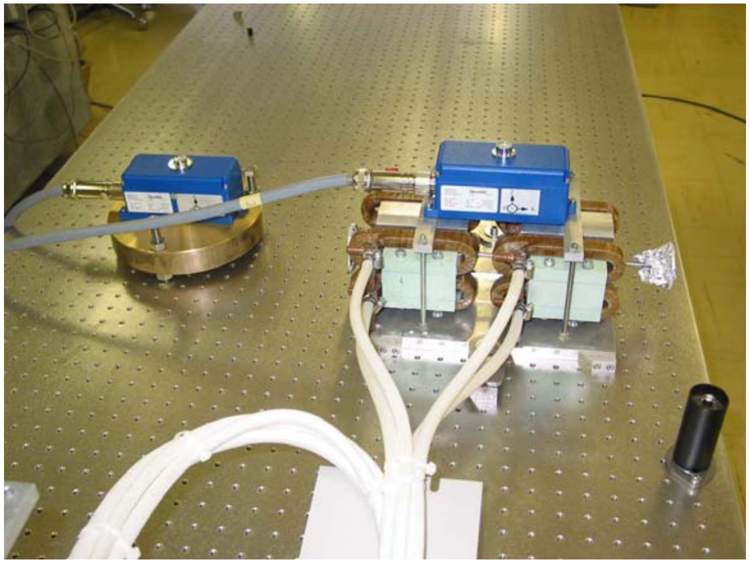
CLIC STABILITY STUDY

R. Assmann, W. Coosemans, G. Guignard, S. Redaelli,
W. Schnell, D. Schulte, I. Wilson, F. Zimmermann

Latest stabilization technology applied to the accelerator field



Stabilizing quadrupoles to the **0.5 nm** level!

(up to 10 times better than supporting ground, above 4 Hz)

CERN has now one of the **most stable places on earth's surface**!

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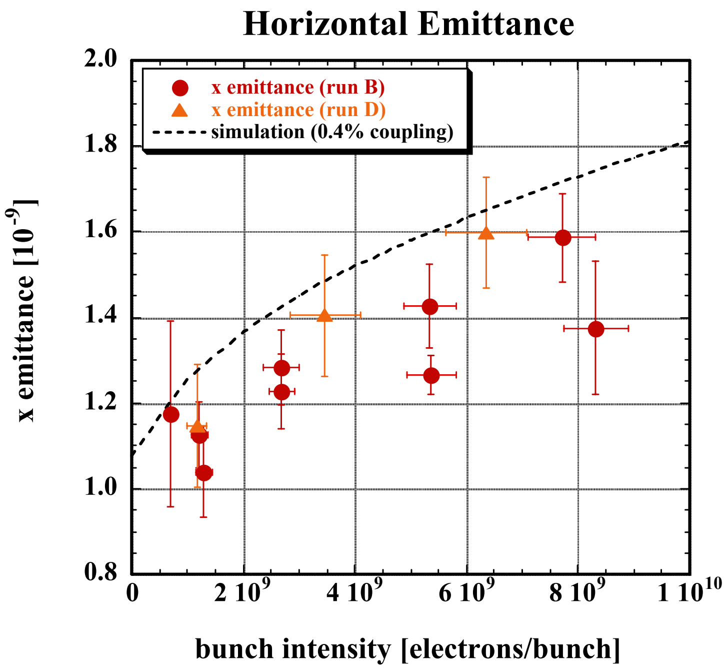
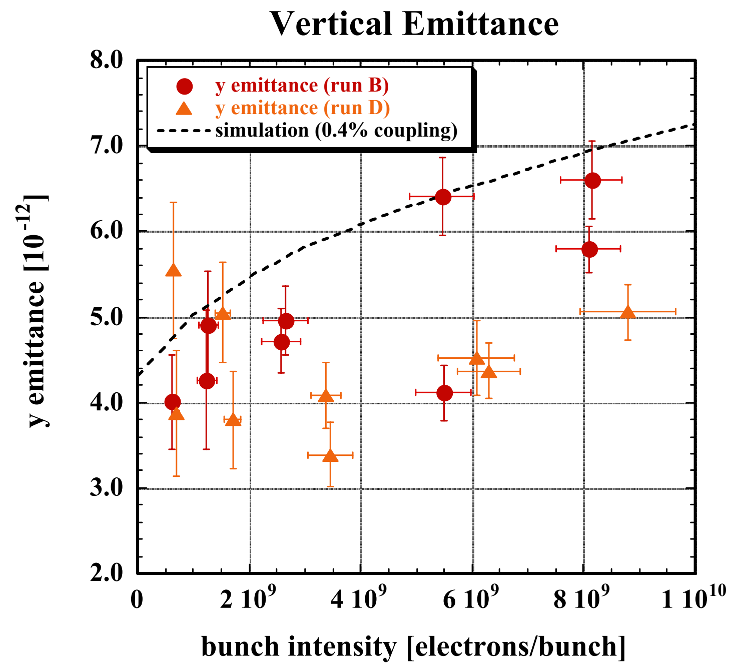
International Linear Collider R&D

- damping-ring prototype
- final focus ATF-2
- polarized e+ source

To date, ILC R&D has helped in a generic way future developments for linear colliders in general such as demonstrating achievement of low emittance, small spot-size, nanometer collisions, etc.

Transverse Emittance by Laser wire





< 0.4% y/x emittance ratio

Y emittance = 4 pm at low intensity

VOLUME 92, NUMBER 5 PHYSICAL REVIEW LETTERS week ending 6 FEBRUARY 2004

Achievement of Ultralow Emittance Beam in the Accelerator Test Facility Damping Ring

Y. Honda,[1] K. Kubo,[2] S. Anderson,[3] S. Araki,[2] K. Bane,[3] A. Brachmann,[3] J. Frisch,[3] M. Fukuda,[6] K. Hasegawa,[14] H. Hayano,[2] L. Hendrickson,[3] Y. Higashi,[2] T. Higo,[2] K. Hirano,[13] T. Hirose,[15] K. Iida,[12] T. Imai,[9] Y. Inoue,[7] P. Karataev,[6] M. Kuriki,[2] R. Kuroda,[8] S. Kuroda,[2] X. Luo,[11] D. McCormick,[3] M. Matsuda,[10] T. Muto,[2] K. Nakajima,[2] Takashi Naito,[2] J. Nelson,[3] M. Nomura,[13] A. Ohashi,[6] T. Omori,[2] T. Okugi,[2] M. Ross,[3] H. Sakai,[12] I. Sakai,[13] N. Sasao,[1] S. Smith,[3] Toshikazu Suzuki,[2] M. Takano,[13] T. Taniguchi,[2] N. Terunuma,[2] J. Turner,[3] N. Toge,[2] J. Urakawa,[2] V. Vogel,[2] M. Woodley,[3] A. Wolski,[4] I. Yamazaki,[8] Yoshio Yamazaki,[2] G. Yocky,[3] A. Young,[3] and F. Zimmermann[5]

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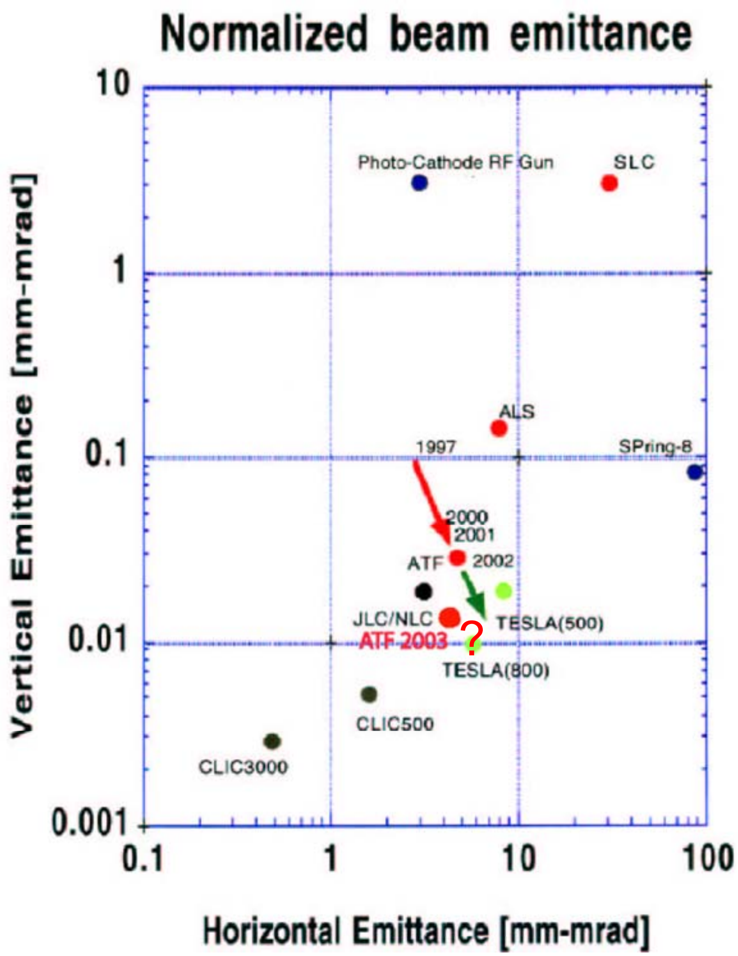

ATF demonstrated
single bunch emittance
$\gamma\varepsilon_x$~3.5-4.3 µm
(1.4-1.7 nm)
$\gamma\varepsilon_y$~13-18 nm
(5-7 pm)
at 8×10^9 e^-/bunch

CLIC target values
$\gamma\varepsilon_x$~0.45 µm
$\gamma\varepsilon_y$~3 nm
at 2.5×10^9 e^-/bunch

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ν factory: Short-Medium Baseline (e.g. Gran Sasso and Long Magic Baseline experiments (e.g. CERN to INO)

- goals: measurement of θ_{13} mixing angle, neutrino mass hierarchy, CP violation δ:

  target intensity: few 10^{20} ν/year

- based on existing sites: CERN (3.5 GeV s.c. p linac), FNAL (6 GeV s.c. p linac), BNL (AGS upgrade), J-PARC (50 GeV RCS), RAL …

- US: 1999-2001 ν-factory feasibility study 1 (FNAL) & 2 (BNL); 2003 APS Study on the Physics of Neutrinos:

  re-optimization & cost reduction (FS2a)

generic ν factory layout

high-power proton source
24-GeV BNL AGS upgraded to
1-4 MW p beam power

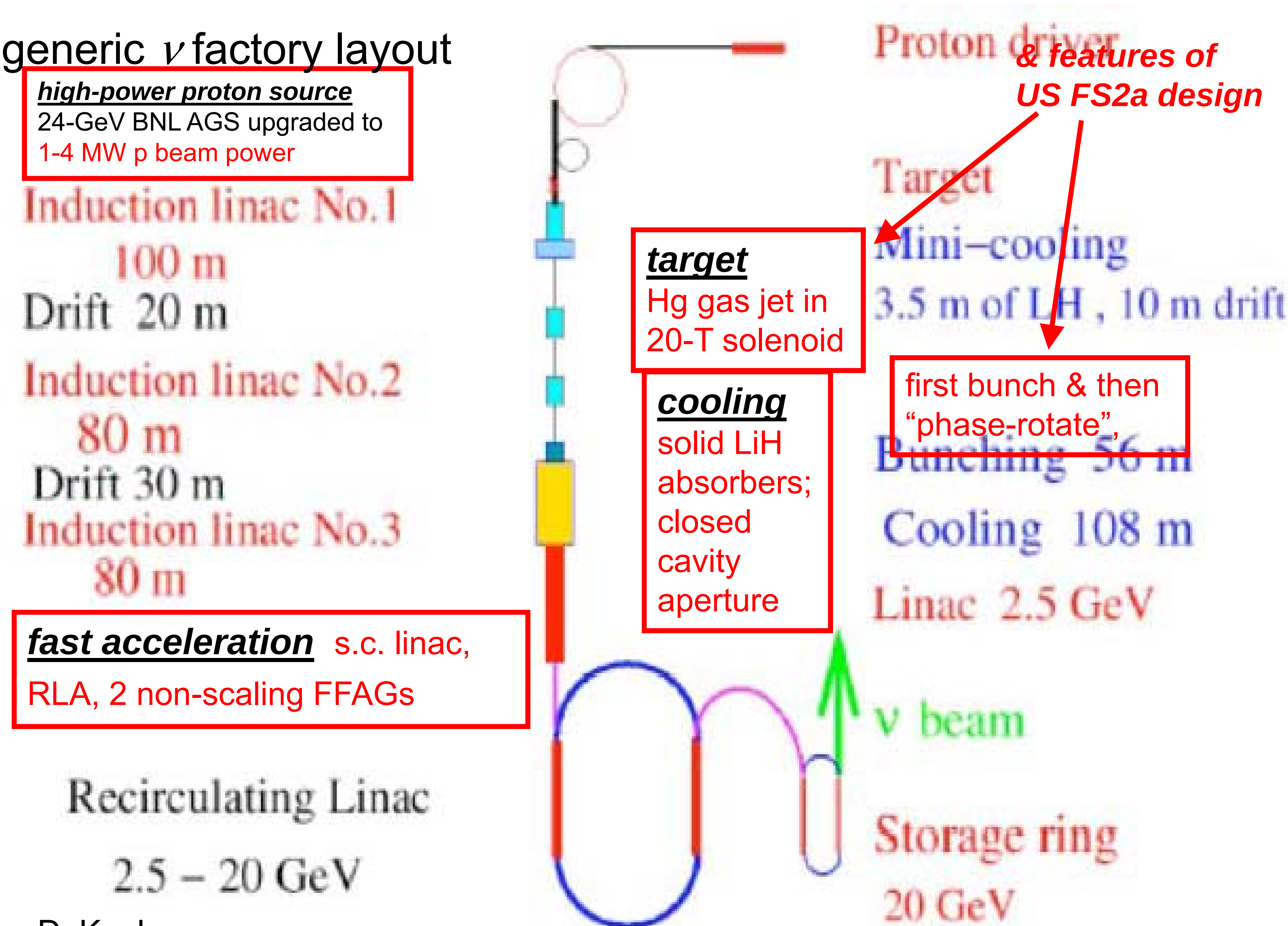
& features of US FS2a design

target
Hg gas jet in
20-T solenoid

cooling
solid LiH
absorbers;
closed
cavity
aperture

first bunch & then
"phase-rotate",

fast acceleration s.c. linac,
RLA, 2 non-scaling FFAGs



decay storage ring

D. Kaplan

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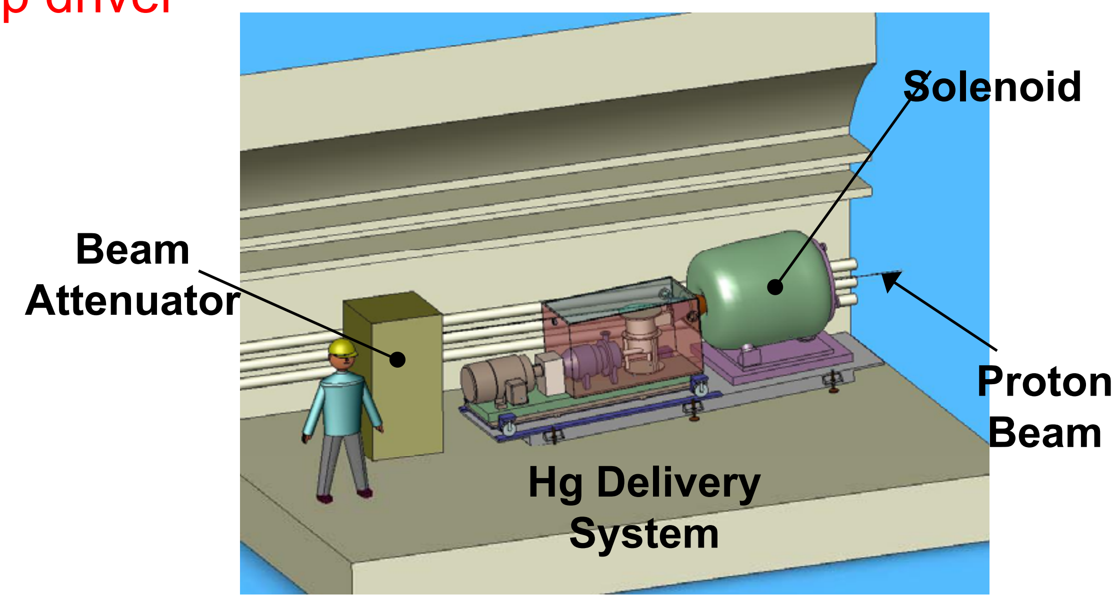
crucial ν-factory demonstration experiments:
(1) targetry: mercury jet with 20 m/s speed will be tested in 15-T solenoid at CERN (nTOF11);
instantaneous power deposition of 180 J/g
~ 4-MW p driver



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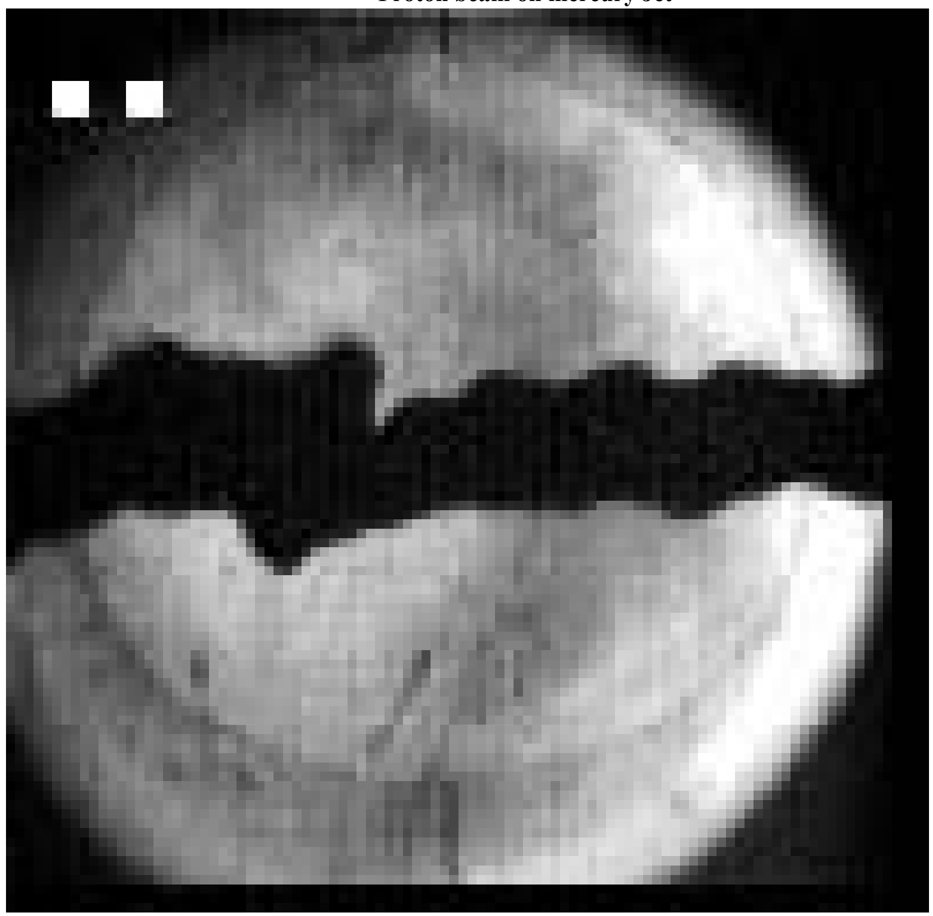
Recorded at
4kHz
Replay at
20 Hz

Proton beam on mercury Jet



1 cm

BNL AGS
Proton beam

Hg jet
v=2 m/s

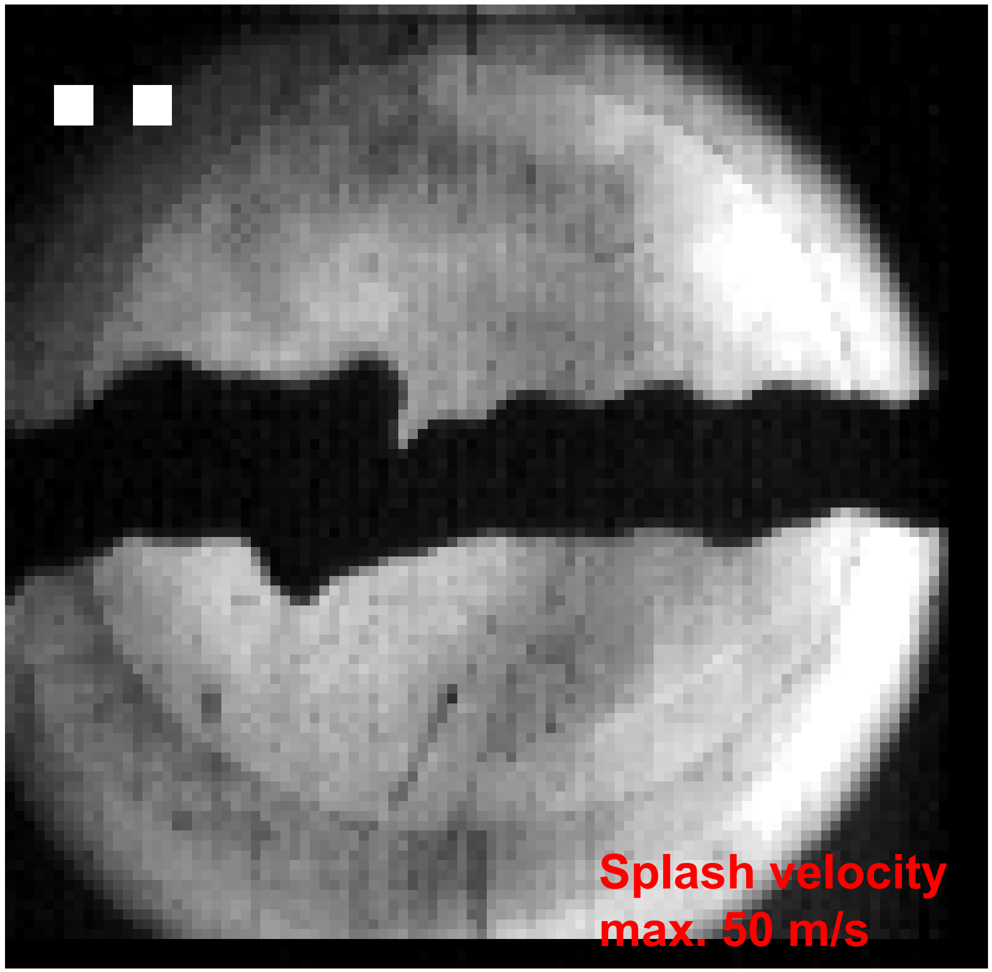
A. Fabich
et al.

Proton beam on mercury Jet

Recorded at 4kHz

Replay at 20 Hz

1 cm



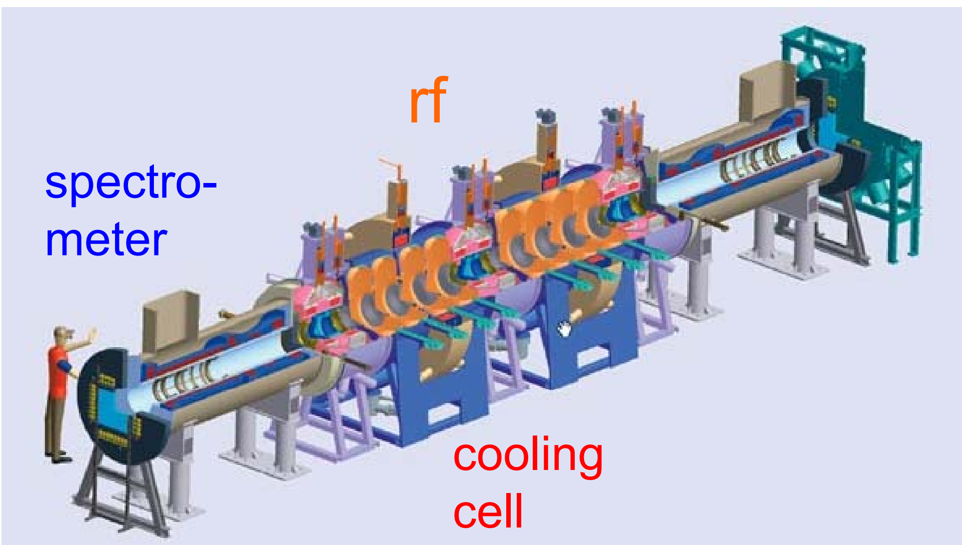
BNL AGS
Proton beam

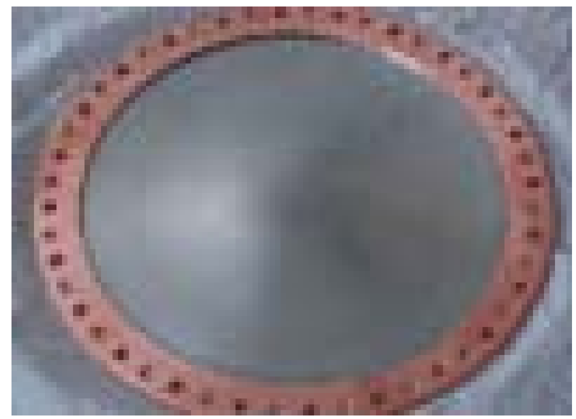
Hg jet
v=2 m/s

A. Fabich et al.

(2) cooling: ionization cooling experiment MICE at RAL;two solenoid tracking spectrometers; 2nd phase: one lattice cell of cooling channel installed between spectrometers; expected emittance reduction ~ 10%; varying absorbers and lattice optics

D. Kaplan



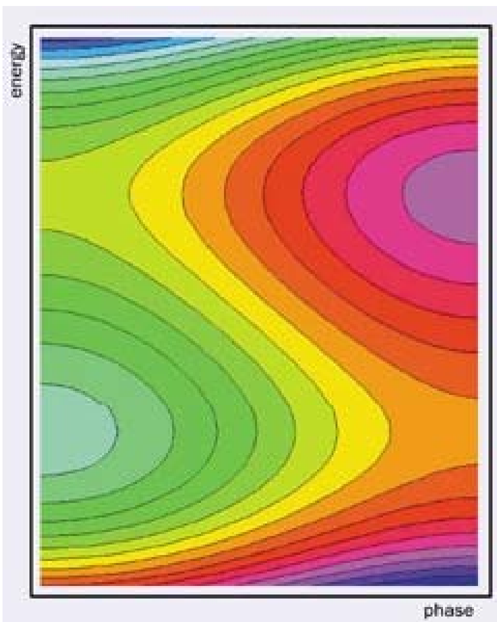


Be window for 200 MHz rf cavity

(3) acceleration:

"non-scaling FFAG" is a new approach, entailing unconventional beam dynamics;

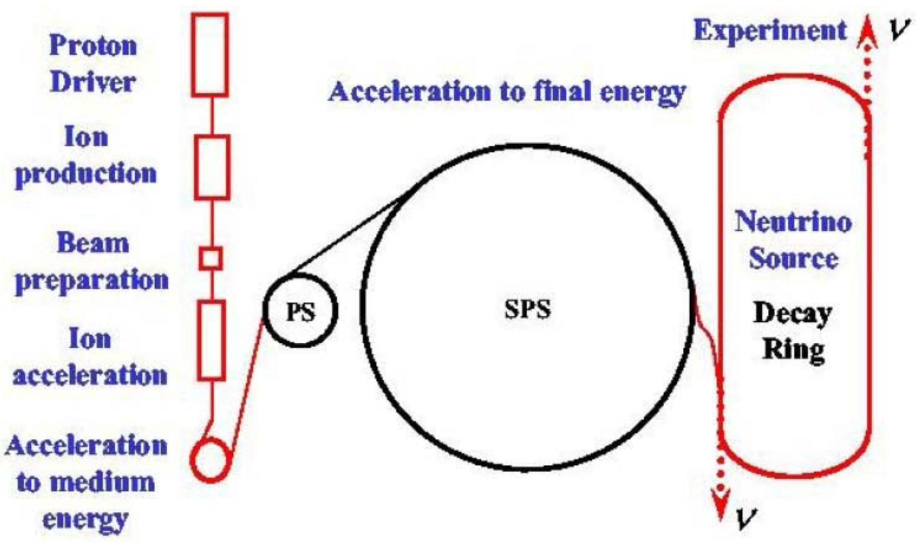
scaled-down model of a non-scaling FFAG using e- beam is under discussion: electron prototype **EMMA** under construction at Daresbury



In the longitudinal phase space of a non-scaling muon FFAG, bunches move from low energy to high energy along the S-shaped yellow band between the "buckets".

β beams

- physics goals similar to ν factory; β decay instead of μ's
- recent discovery of nuclei that decay fast through atomic e- capture (^{150}Dy, ^{146}Gd, etc.)
- → possibility to create mono-energetic ν beams
- neutrino energy is Lorentz boosted: $E=2\gamma E_0$
- it is assumed that 10^{18} ν's per year can be obtained, e.g., at EURISOL - *can profit from LHC injector upgrade!*



schematic of the proposed CERN part of a "CERN to Frejus" (130 km) EC ν beam facility [J. Bernabeu et al.]

alternative to ν factory

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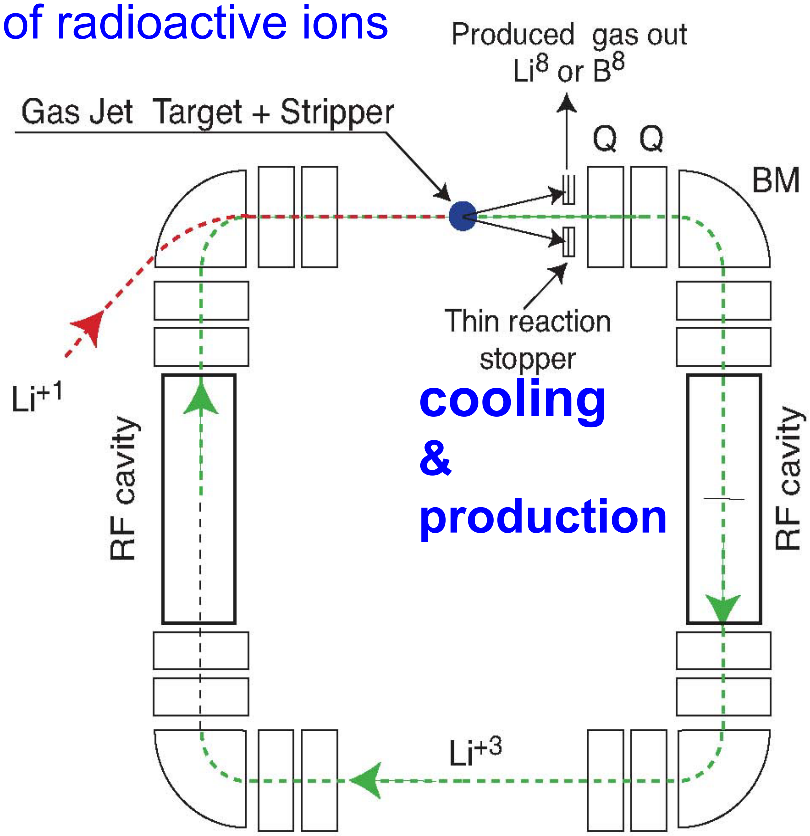
“table top” ion storage ring with ionization cooling

producing intense beam of radioactive ions

e.g., 10^{14} Li-8 ions/s



cooling & production

applications:
β beam
hadron therapy

circumference 4 m,
kinetic energy 27 MeV

rf voltage 300 kV

C.Rubbia
A.Ferrari
Y. Kadi
V.Vlachoudis
February ‘06

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μ collider

"New ideas for producing Bright Beams for High Luminosity Muon Colliders"

Muons, Inc. *IIT, FNAL, JLAB*

H_2-Pressurized RF Cavities

Continuous Absorber for Emittance Exchange

Helical Cooling Channel

Parametric-resonance Ionization Cooling (PIC)

Reverse Emittance Exchange

R. Johnson, Y. Derbenev et al.

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schematic of μ collider

Rol Johnson

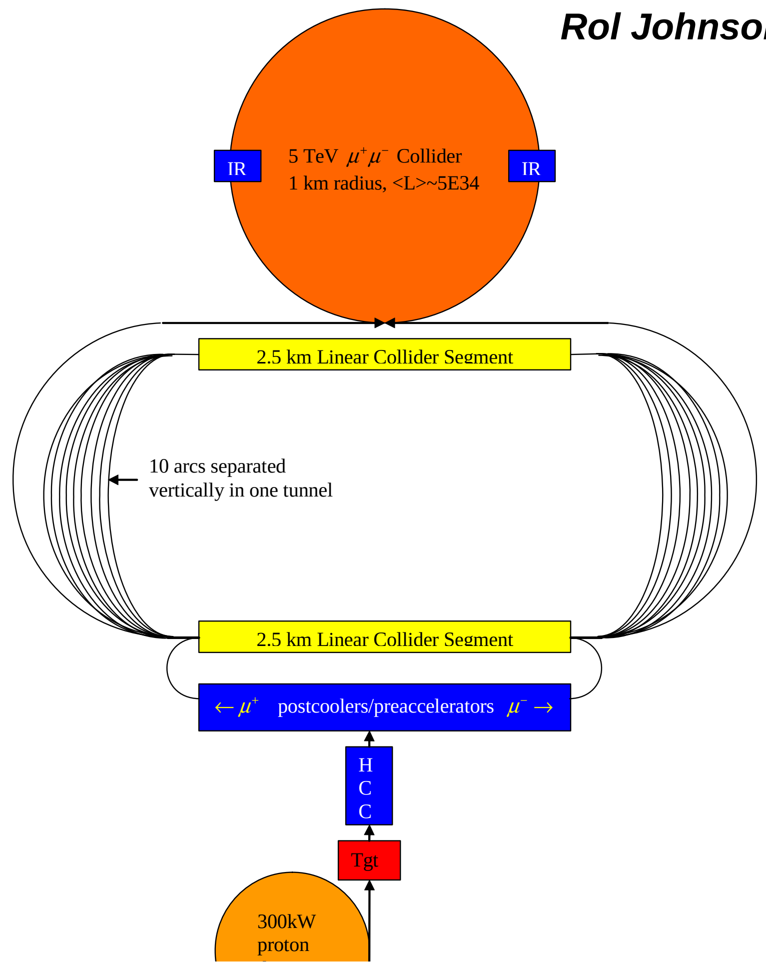
5 TeV

~5 X 2.5 km footprint

5-km total linac length

high L from small emittance!

1/10 fewer muons than originally imagined:
a) easier p driver, targetry b) less detector background c) less site boundary radiation



At 2.5 TeV beam energy

After:	**ε_N tr**	**ε_N long.**
Precooling	**20,000 μm**	**10,000 μm**
Basic HCC 6D	**200 μm**	**100 μm**
Parametric-resonance IC	**25 μm**	**100 μm**
Reverse Emittance Exchange	**2 μm**	**2 cm**

2.5 TeV / beam: $L_{peak} = \frac{N_1 n \Delta\nu}{\beta^* r_\mu} f_0 \gamma = 10^{35} / cm^2 - s$

20 Hz Operation: $\langle L \rangle \approx 4.3 \times 10^{34} / cm^2 - s$

$Power = (26 \times 10^9)(6.6 \times 10^{13})(1.6 \times 10^{-19}) = 0.3 MW$

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plasma acceleration

recent breakthrough in beam quality from laser-plasma acceleration

next step:
1 GeV compact module,
100 TW laser,
& plasma channel;

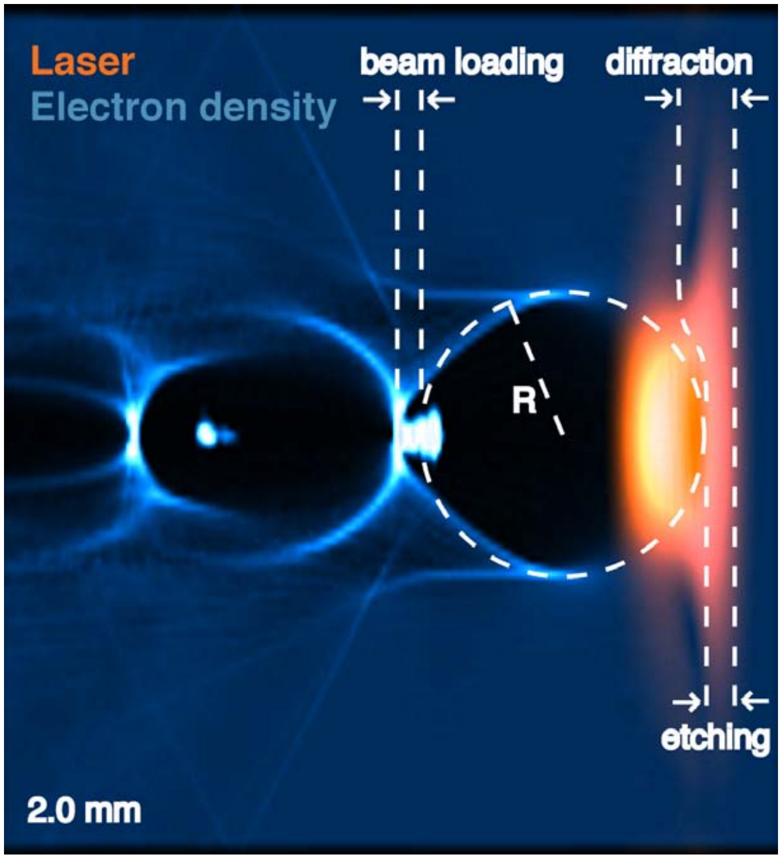
LBNL, Strathclyde,

Oxford, Paris

J. Faure et al., C. Geddes et al., S. Mangles et al. ,
3 articles in Nature 30 September 2004

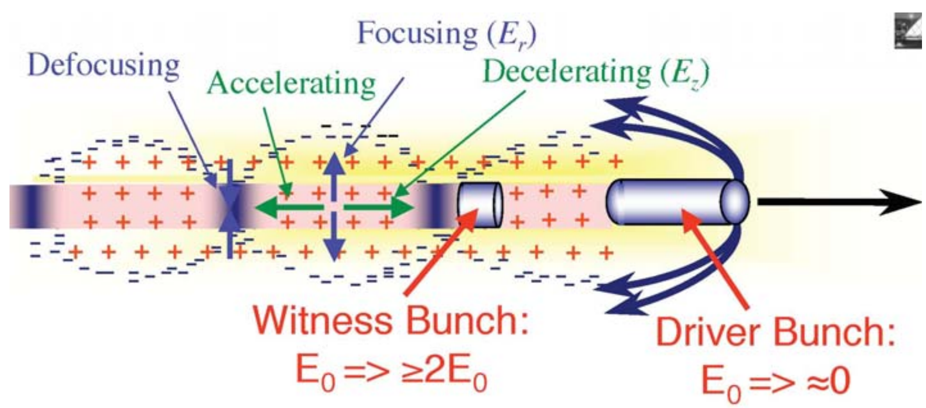
plasma excitation by laser

principle: plasma can sustain high accelerating
gradients ~10-100 GV/m



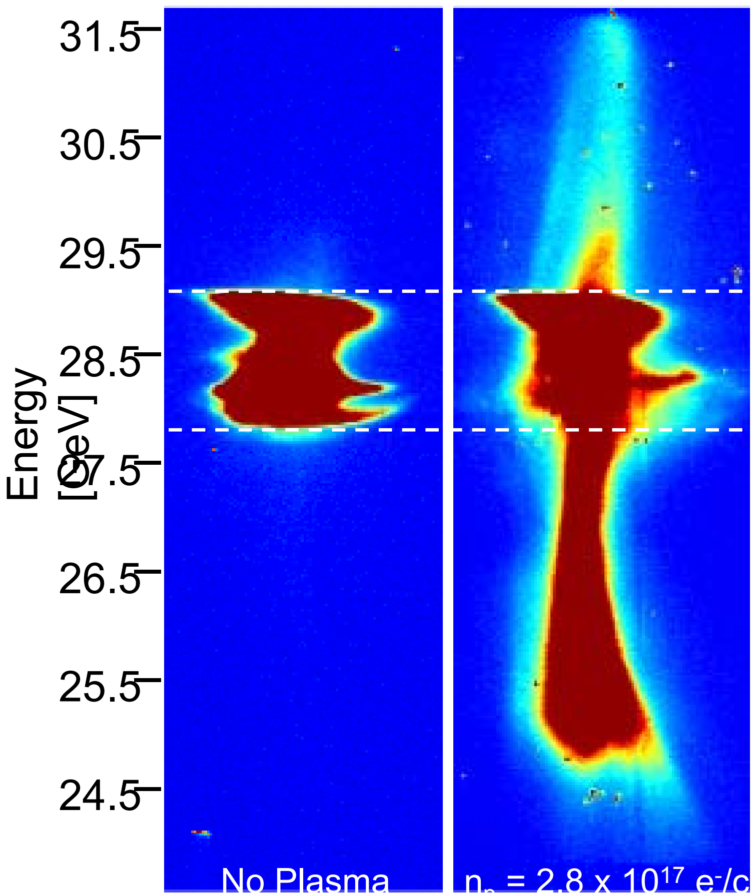
W. Lu, B. Cros

plasma excitation by drive bunch



P. Muggli

Accelerating Gradient > 27 GeV/m! (Sustained Over 10cm)

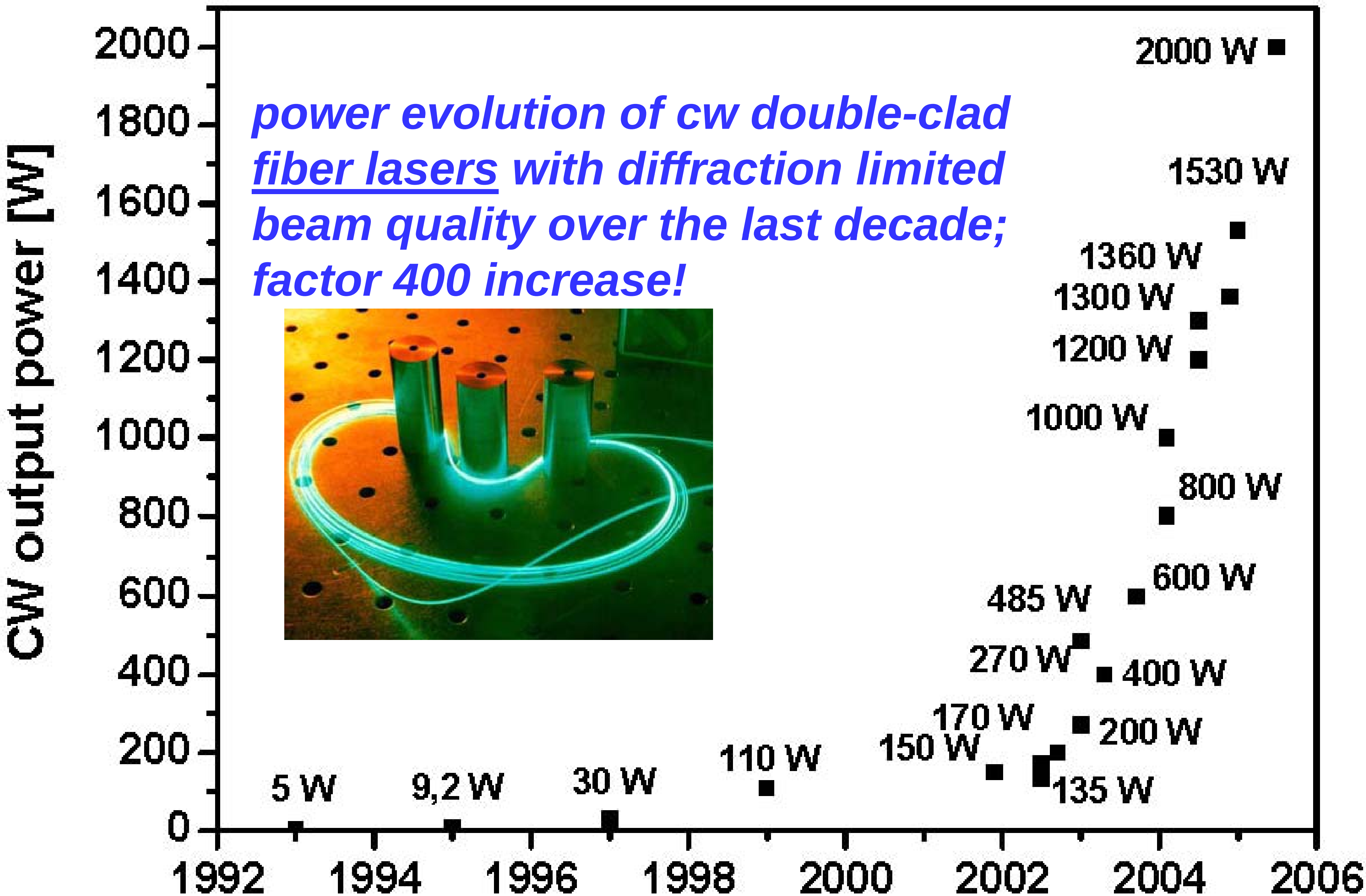


- Large energy spread after plasma is artifact of single bunch experiment
- Electrons have gained > 2.7 GeV over maximum incoming energy in 10cm
- Confirmed the predicted dramatic increase in gradient for short bunches
- First time a PWFA has gained more than 1 GeV
- Two orders of magnitude larger than previous beam-driven results
- Future experiments will accelerate a second “witness” bunch

M. Hogan, P. Muggli, R. Siemann, et al.

Accepted for publication Phys. Rev. Lett. 2005

progress on fiber lasers



Source: Fiber Based High Power Laser Systems,
Jens Limpert, Thomas Schreiber, and Andreas Tünnermann

well suited for plasma acceleration & Compton rings

- we need new technologies and methods to further push the frontiers of energy and luminosity
- luckily there are many novel ideas and great progress everywhere
- we may be heading towards a bright future

Thanks to Hans Braun, Oliver Brunig Helmut Burkhardt, Rolland Johnson, Mats Lindroos, Thomas Roser, Vladimir Shiltsev, Junji Urakawa and Frank Zimmerman for helpful discussions and providing much of the material!