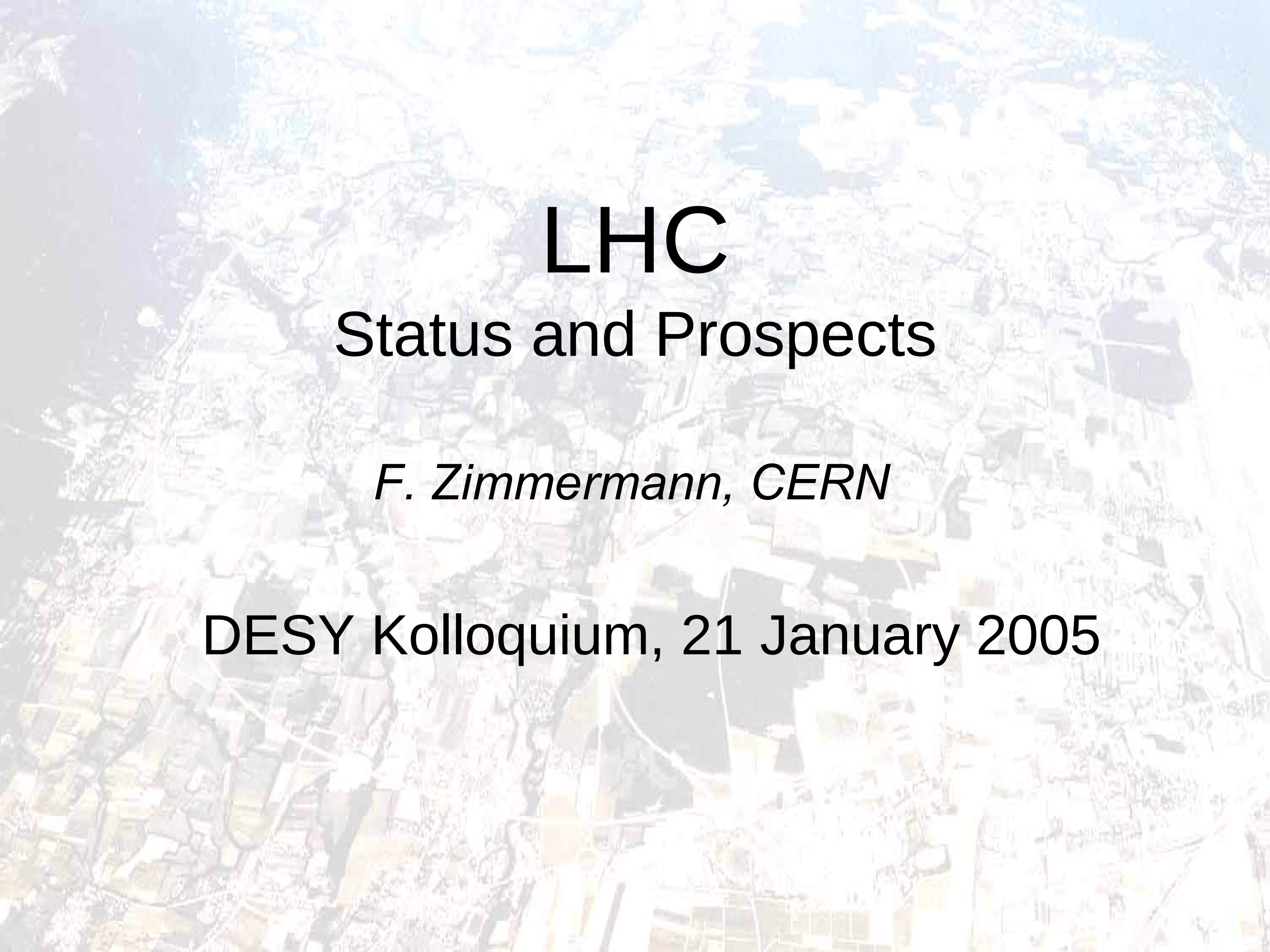
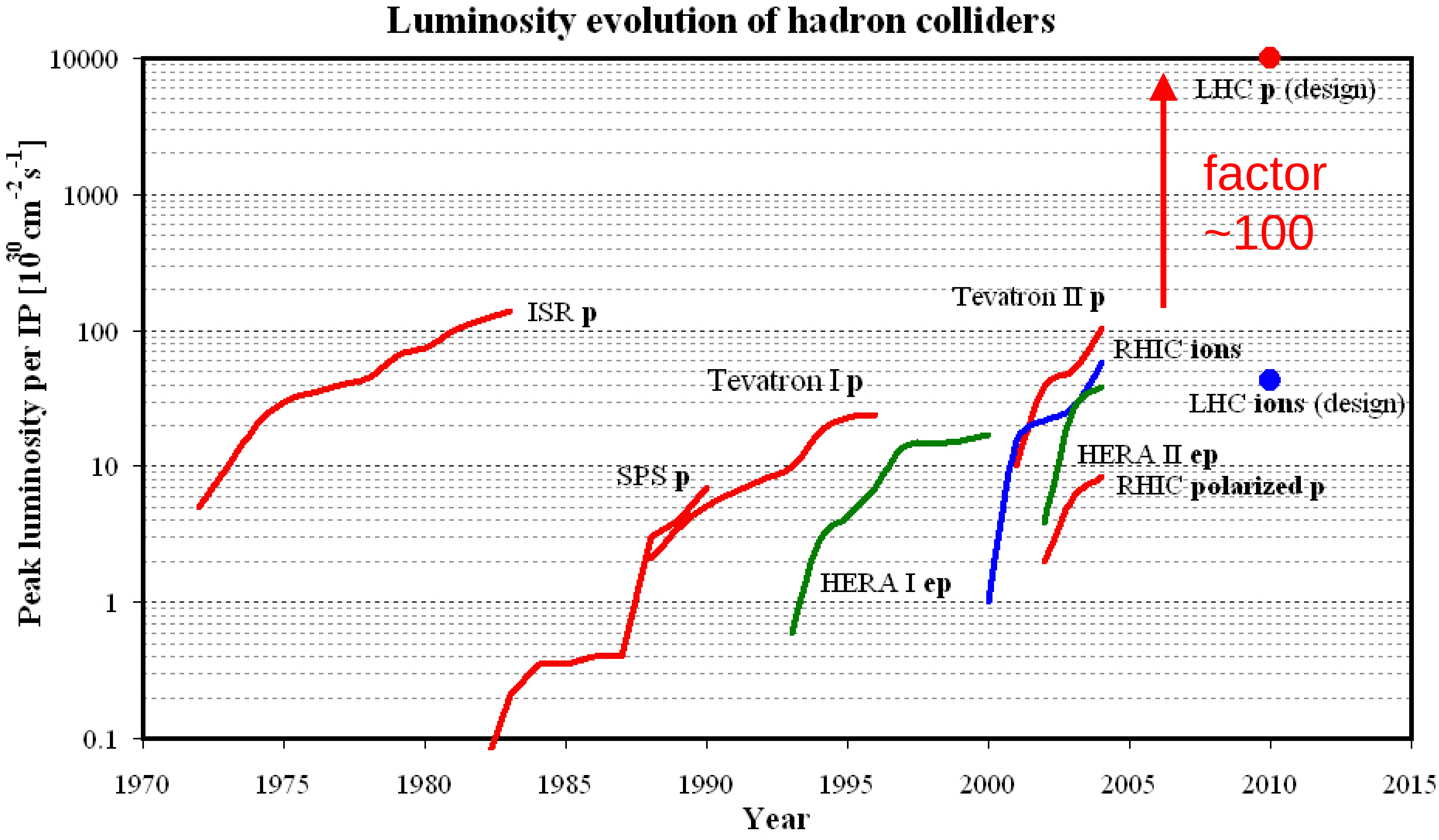


LHC

Status and Prospects

F. Zimmermann, CERN

DESY Kolloquium, 21 January 2005

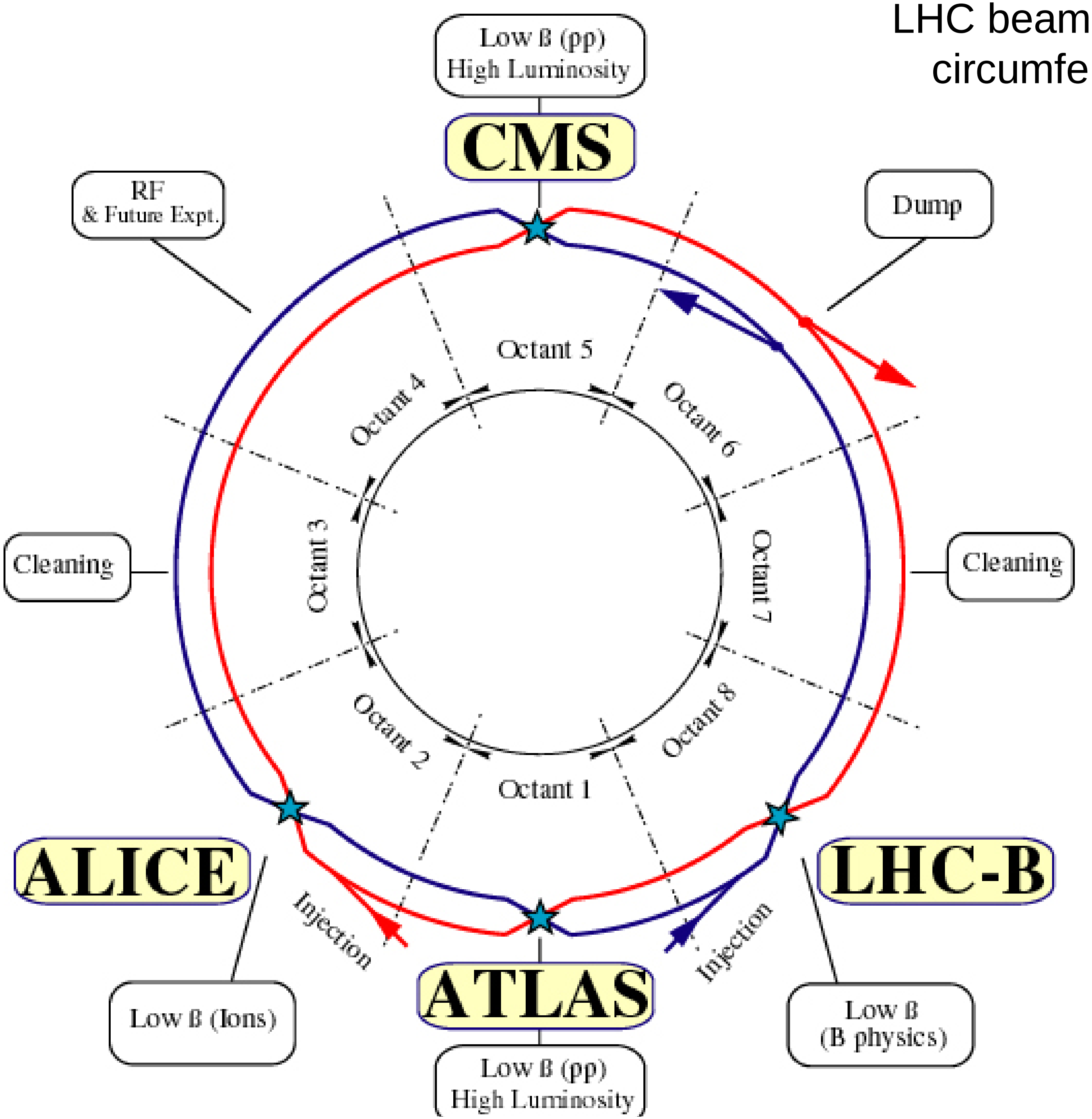


factor ~100

W. Fischer

LHC beam energy 7 TeV
circumference 26.7 km

(Tevatron:
0.98 TeV,
6.3 km)



parameter		nominal	‘ultimate’ LHC
#bunches	n_b	2808	2808
protons/bunch	N_b	$1.15\mathrm{x}10^{11}$	$1.7\mathrm{x}10^{11}$
bunch spacing	Δt_{sep}	25 ns	25 ns
average current	I	0.58 A	0.86 A
n. transv. emit.	ε_N	3.75 μm	3.75 μm
rms bunch length	σ_z	7.55 cm	7.55 cm
beta at IP1 & 5	β^*	0.55 m	0.55 m
crossing angle	θ_c	285 μrad	315 μrad
Piwinski angle		0.64	0.75
length lum. region	σ_{lum}	44.9 mm	42.8 mm
events/crossing		19	44
luminosity	L	$10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$	$2.3\mathrm{x}10^{34}\ \mathrm{cm}^{2}\mathrm{s}^{-1}$

outline

- hardware & commissioning status
- expected performance limitations
  - machine protection, beam dump, collimation
  - beam-beam & beam-beam compensation
  - electron cloud
  - commissioning plans
- upgrade
  - physics motivation, scenarios, IR layout, options

hardware & commissioning status

experiments

ATLAS

Atlas cavern

installation in cavern has started:

barrel tile calorimeter *complete*

barrel toroid magnet system

barrel LAr calorimeter cryostat

CMS

assembly on surface (wheels)

4th coil module since Dec04

5th module leaves Genova Jan05

cool down Sept.05

Q4 2005 magnet test (4 T, 12x6 m, 2.7 GJ, largest solenoid ever)

CMS cavern

excavation will finish 01/05

L. Evans, S. Tapprogge, CERN photolab

SPS-LHC transfer test 6/7.11.04

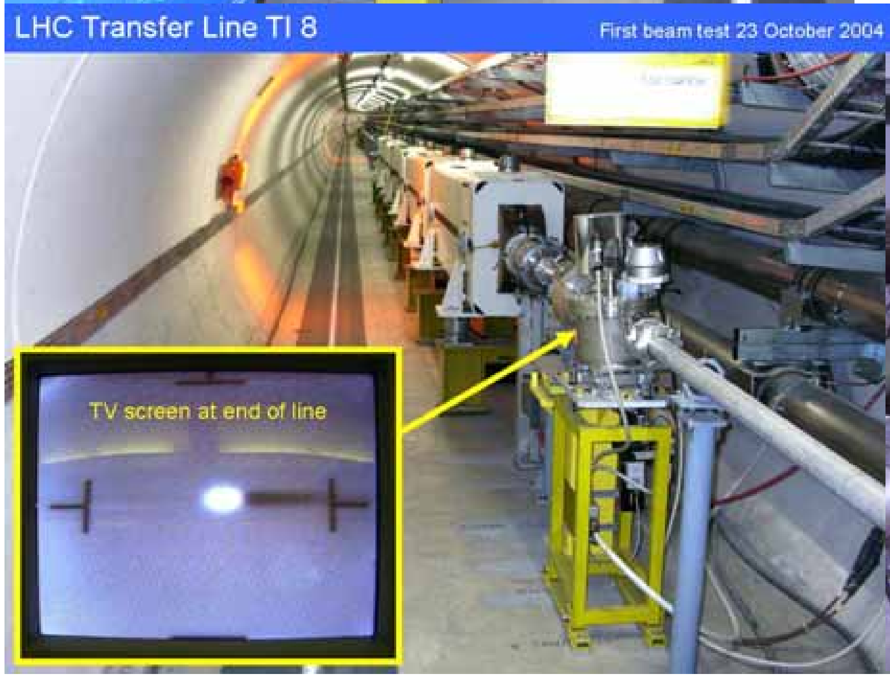
LHC Transfer Lines Overview

- combined length 5.6 km
- over 700 room-temperature magnets (74 recup'd)

beam tests
23./24.10.04
6./7.11.04

beam tests
8.9.03

TI 2 upstream part commissioning (w/o beam) possible as of Q2/2005



LHC Transfer Line TI 8

First beam test 23 October 2004

TV screen at end of line

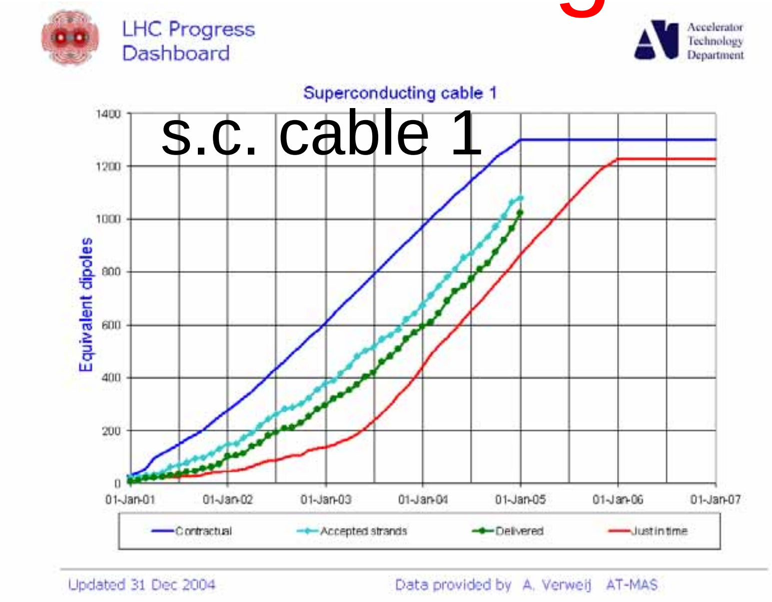
LHC Transfer Line TI 8

First beam test 23 October 2004

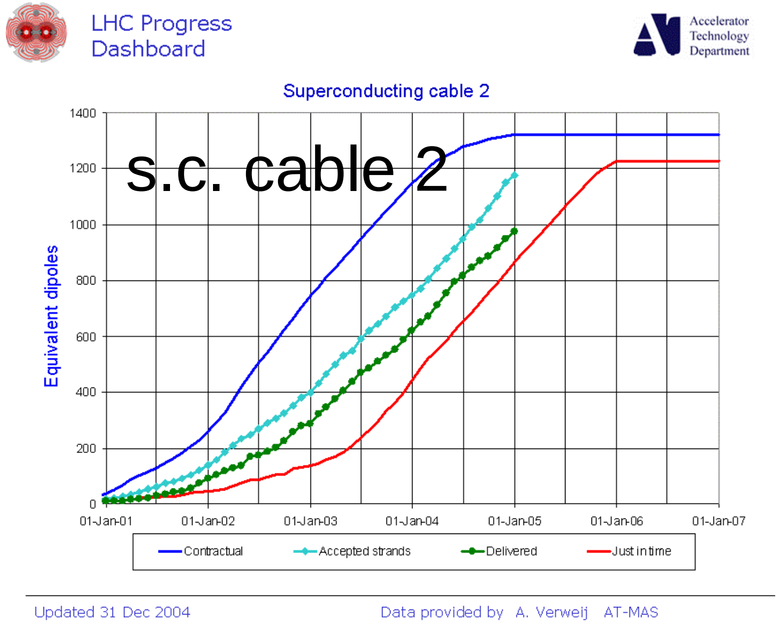
Beam dump at end of line

L. Evans

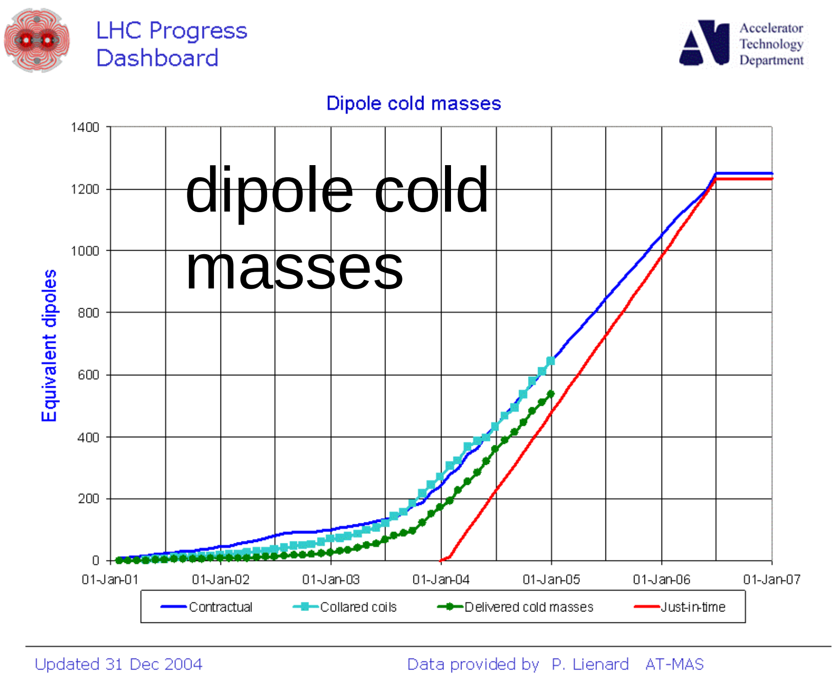
cable & magnet production at full rate


s.c. cable 1

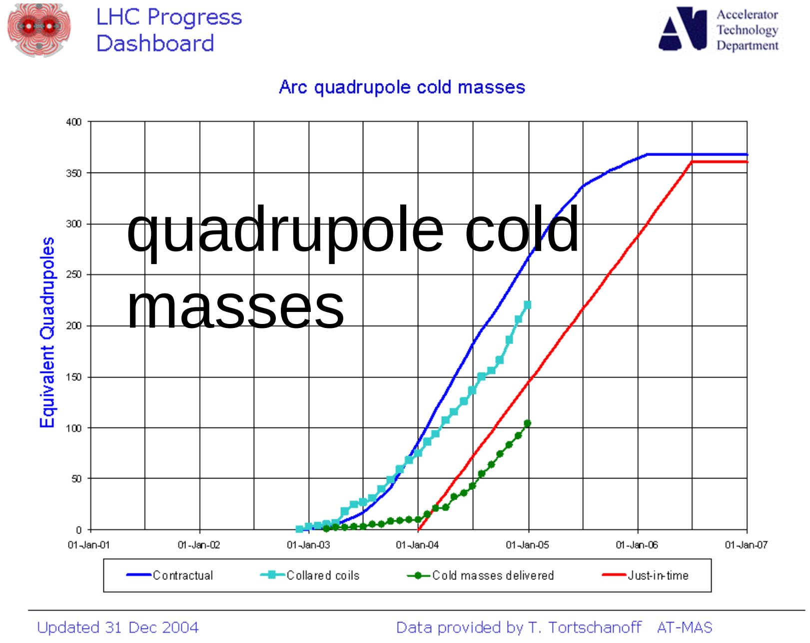
Updated 31 Dec 2004 Data provided by A. Verweij AT-MAS


s.c. cable 2

Updated 31 Dec 2004 Data provided by A. Verweij AT-MAS


dipole cold masses

Updated 31 Dec 2004 Data provided by P. Lienard AT-MAS

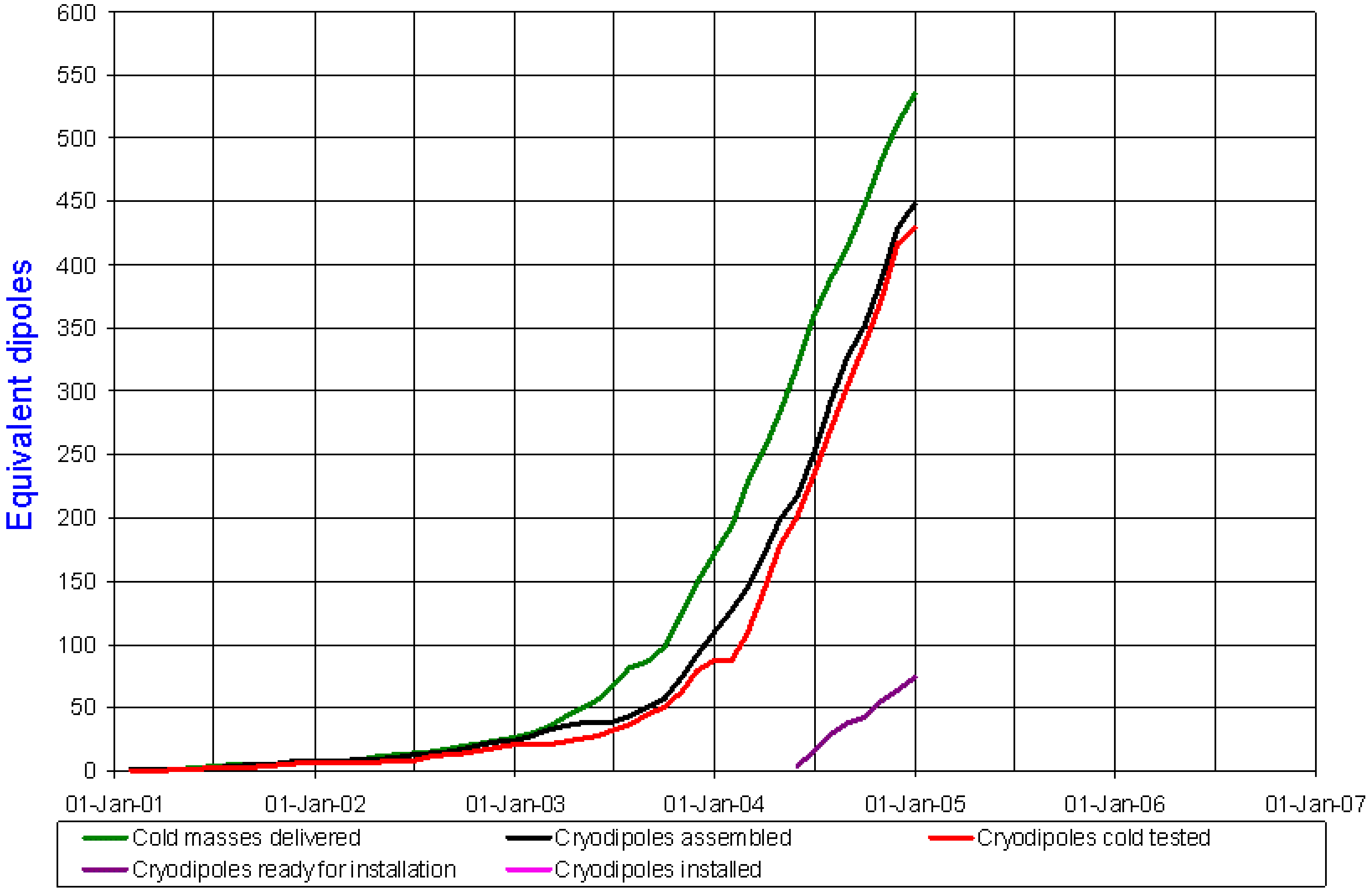

quadrupole cold masses

Updated 31 Dec 2004 Data provided by T. Tortschanoff AT-MAS

LHC Progress Dashboard

Accelerator
Technology
Department

Cryodipole overview



Updated 31 Dec 2004

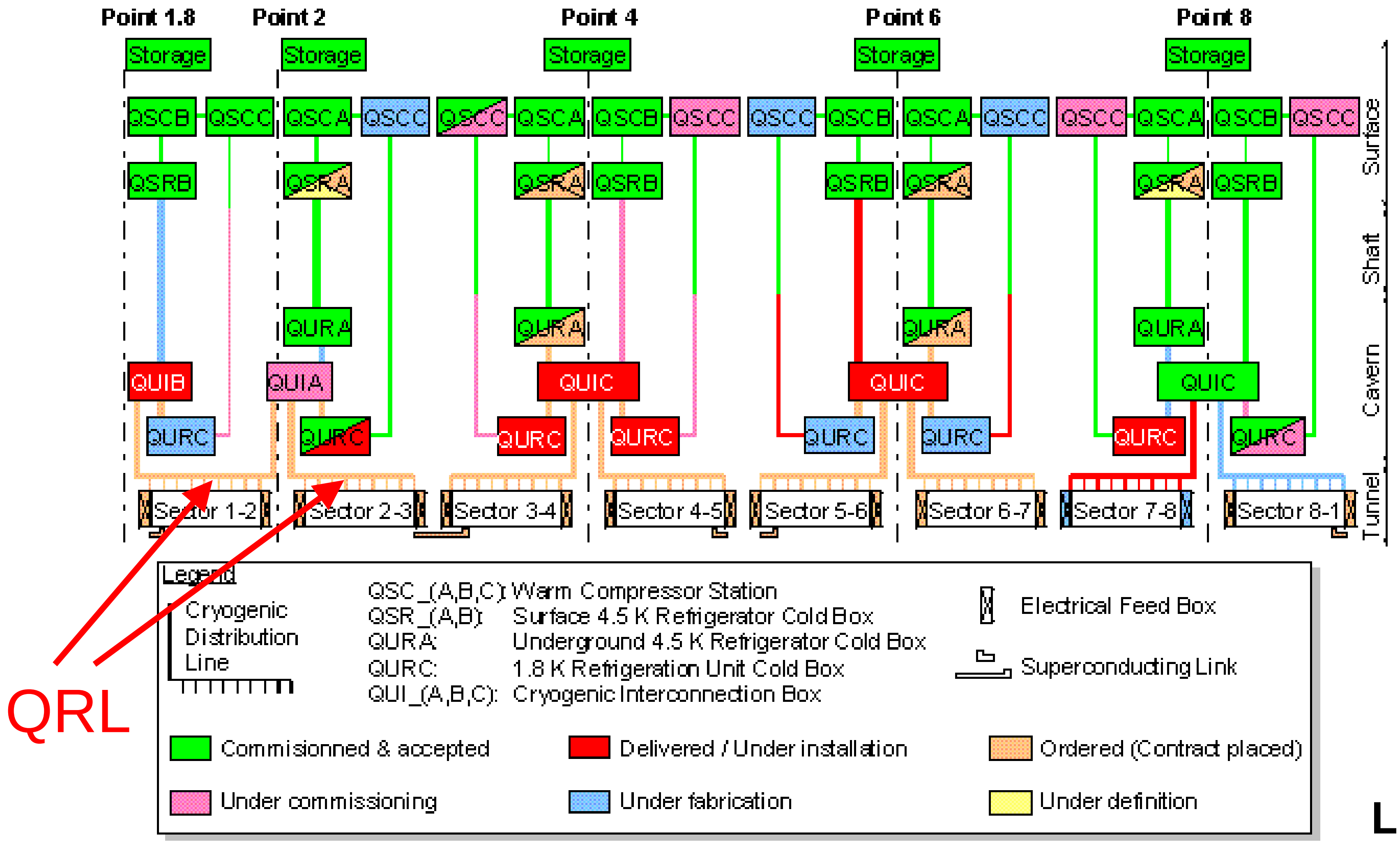
Data provided by D. Tommasini AT-MAS

LHC Progress Dashboard

cryogenics

Accelerator Technology Department

Cryogenics overview

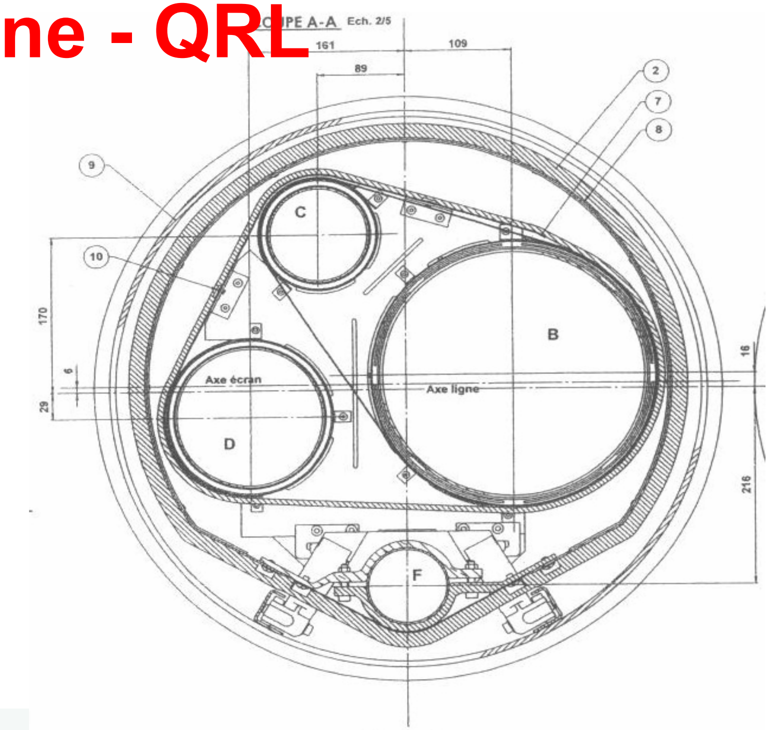


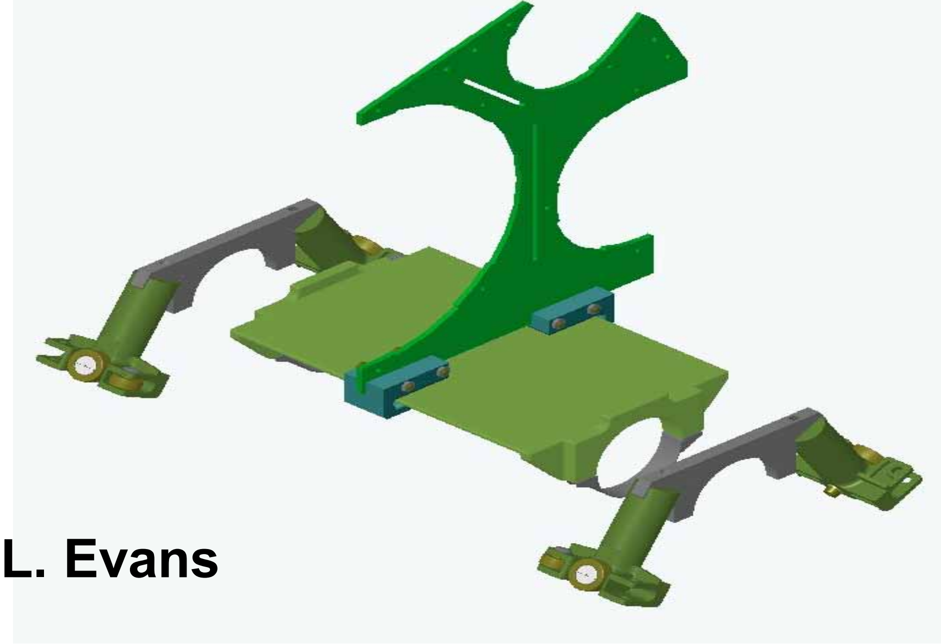
L. Evans

Updated 30 Sep 2004 Data provided by L. Tavian AT-ACR

Via the QRL helium at different temperatures and pressures feeds the local cooling loops. With an overall length of 25.8 km the QRL has a very critical cost-to-performance ratio.

cryogenic distribution line - QRL





L. Evans

cracked support tables discovered -improper material used by company

- QRL repair crash programme (incl. Christmas shutdown)
- Fabrication in Air Liquide subcontractors restarted with increased controls
- Installation restarted in November; plan to install 2 (or 3) sectors in parallel
- QRL should be finished before Q3 in 2006; and last tested magnet available end 2006
- First collisions in 2007

from R. Aymar, January 2005

expected performance limitations (1)

- machine protection
- beam dump
- collimation

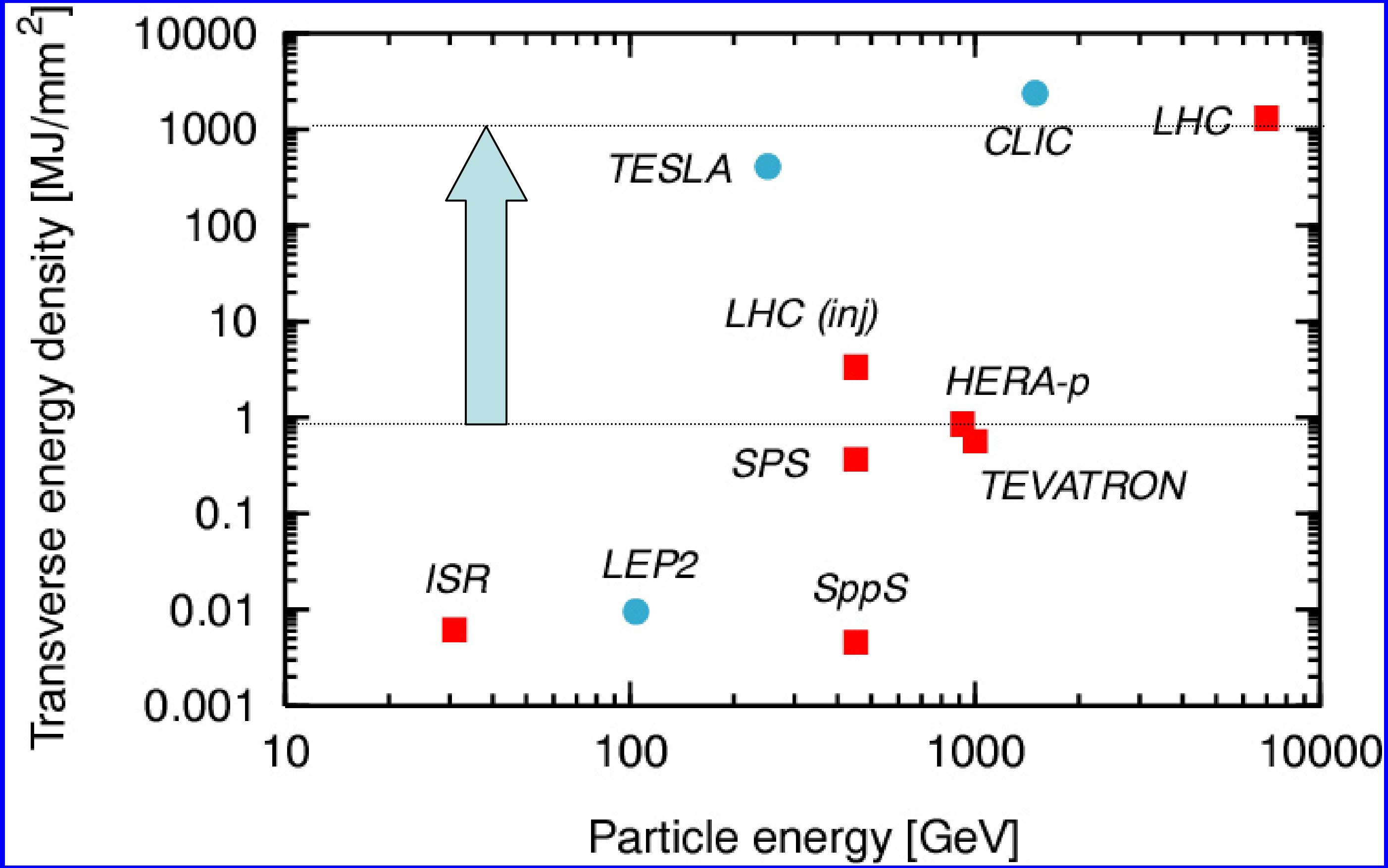
why protection? total stored energy = 11 GJ

total beam energy ~ 1 GJ

Comparing damage potential

Transverse energy density is a measure of damage potential …

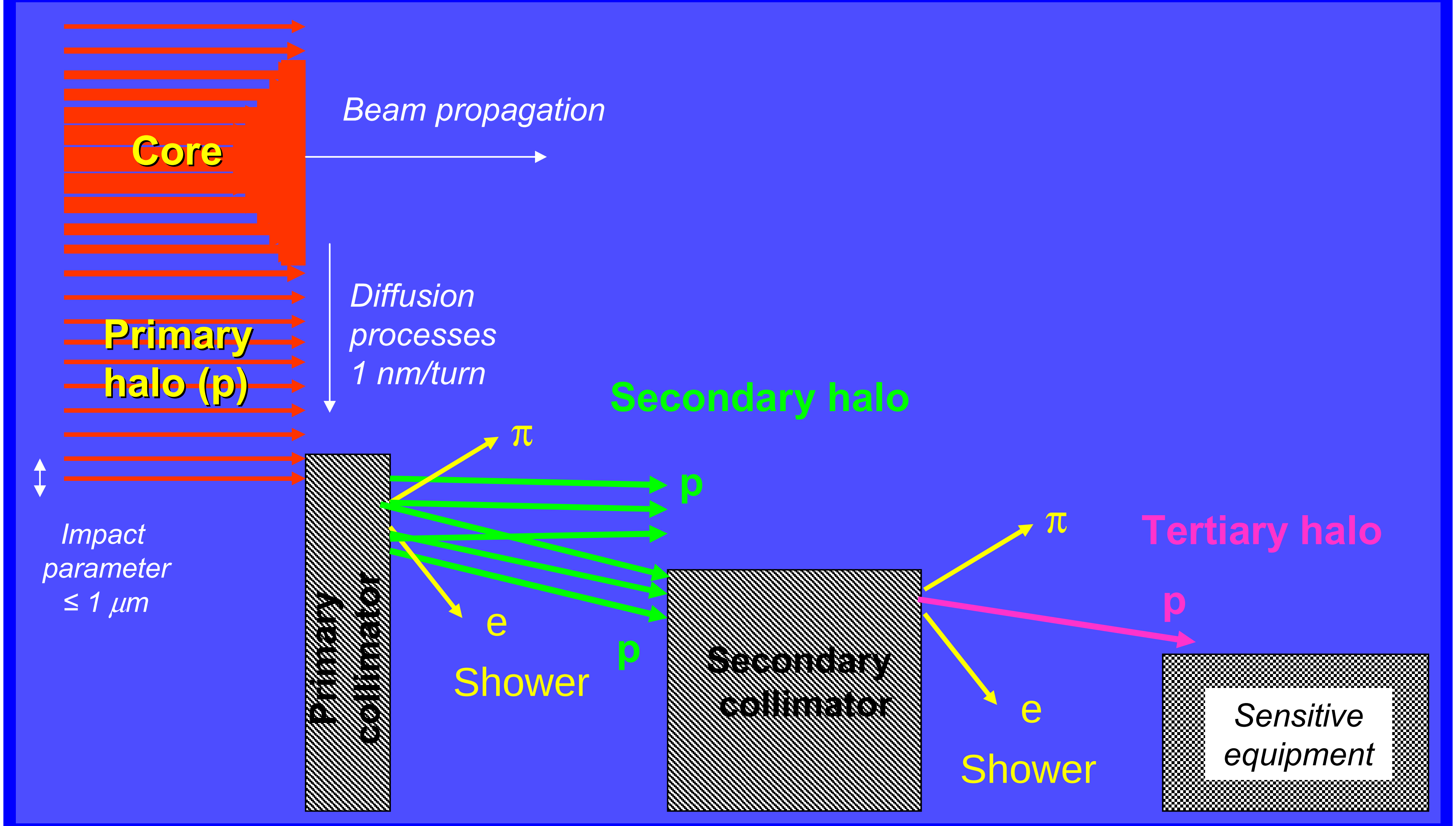
… AND proportional to luminosity!



In terms of damage potential, LHC advances the state of the art by 3 orders of magnitude!

R. Assmann

Principle of Beam Collimation



... two stage cleaning ...

R. Assmann

Scope of the LHC collimation

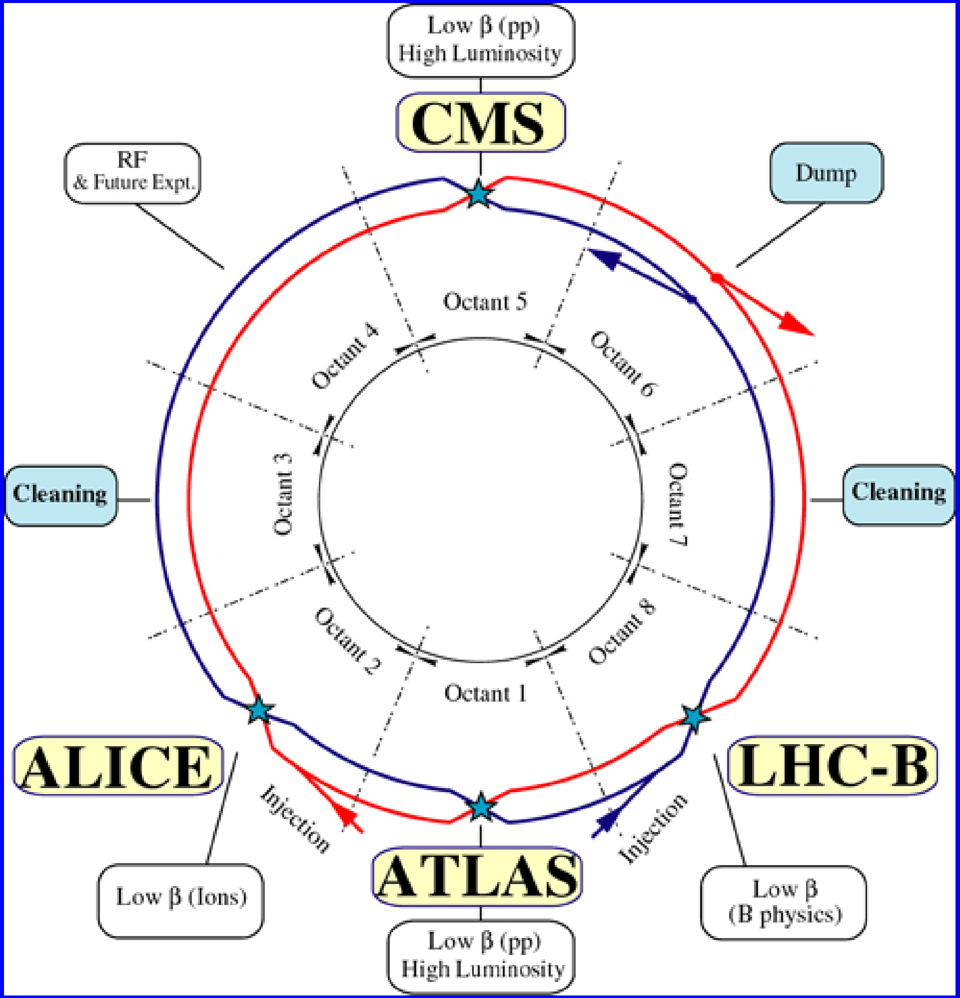
Two warm LHC insertions dedicated to cleaning:

IR3 ➔ Momentum cleaning

IR7 ➔ Betatron cleaning

Building on collimation system design that started in 1992!

Various collimators in experimental insertions IR1, IR2, IR5, IR8.



➔ Four collimation systems: Momentum and betatron for two beams!

R. Assmann

Super-Conducting LHC Environment

Proton losses into cold aperture

⇩

Local heat deposition

⇩

Magnet can quench

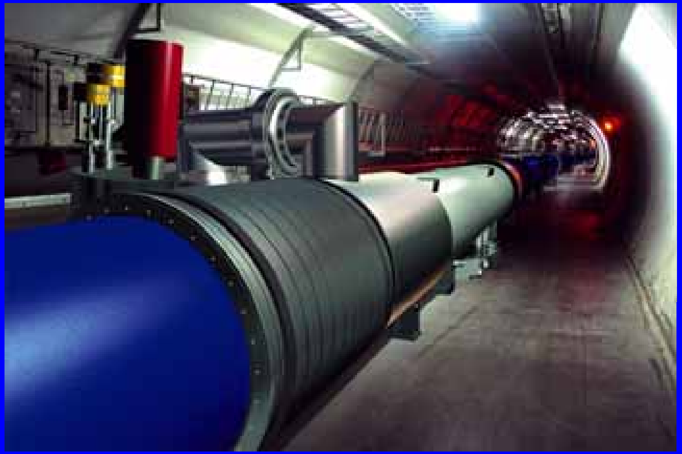


Illustration of LHC dipole in tunnel

Energy [GeV]	Loss rate (10 h lifetime)	Quench limit [p/s/m] (**steady losses**)	Cleaning requirement
450	8.4e9 p/s	7.0e8 p/s/m	92.6 %
7000	**8.4e9 p/s**	**7.6e6 p/s/m**	**99.91 %**

Control transient losses (10 turns) to ~1e-9 of nominal intensity (top)!

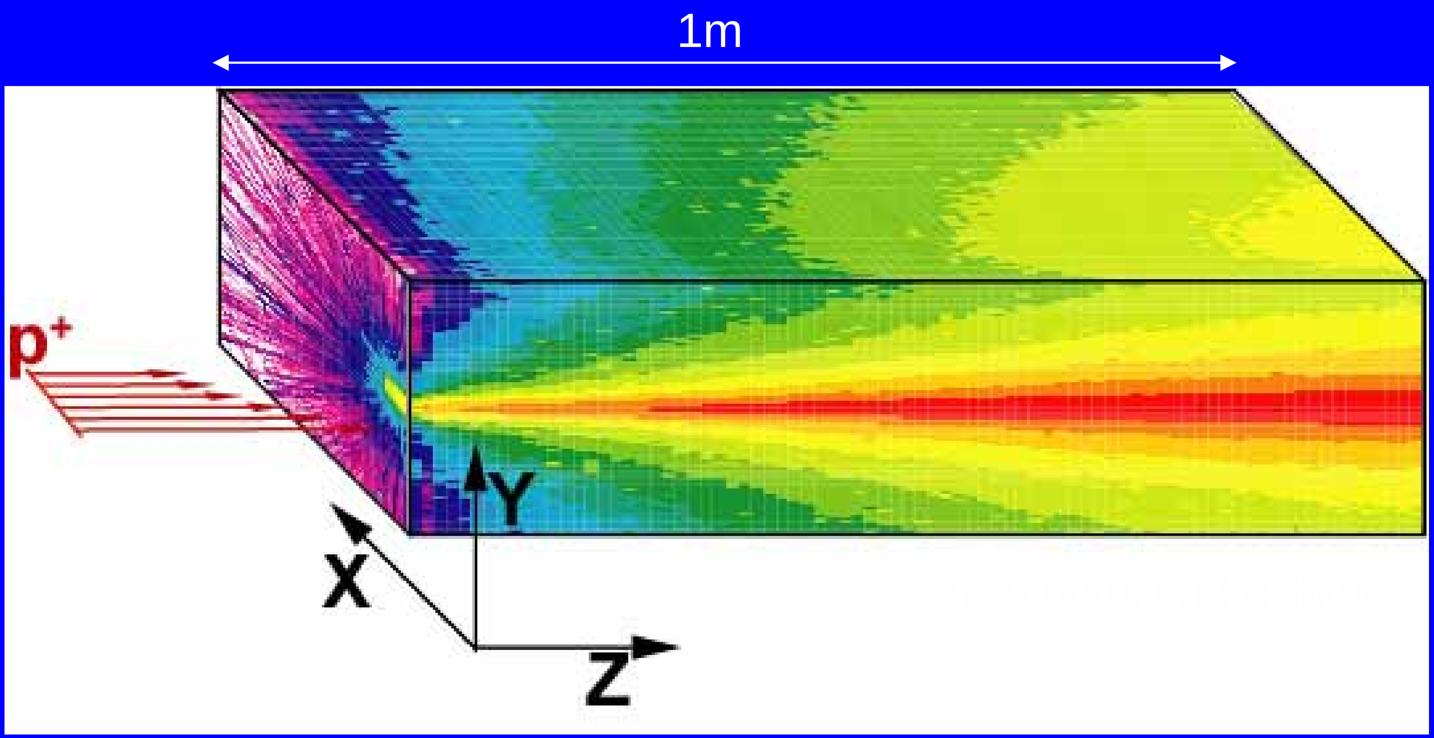
Capture (clean) lost protons before they reach cold aperture!

Required efficiency: **~ 99.9 %** *(assuming losses distribute over 50 m)*

R. Assmann

Ensuring collimator survival

At 7 TeV about 8 out of 3000 bunches can impact the collimator face (irregular dump):

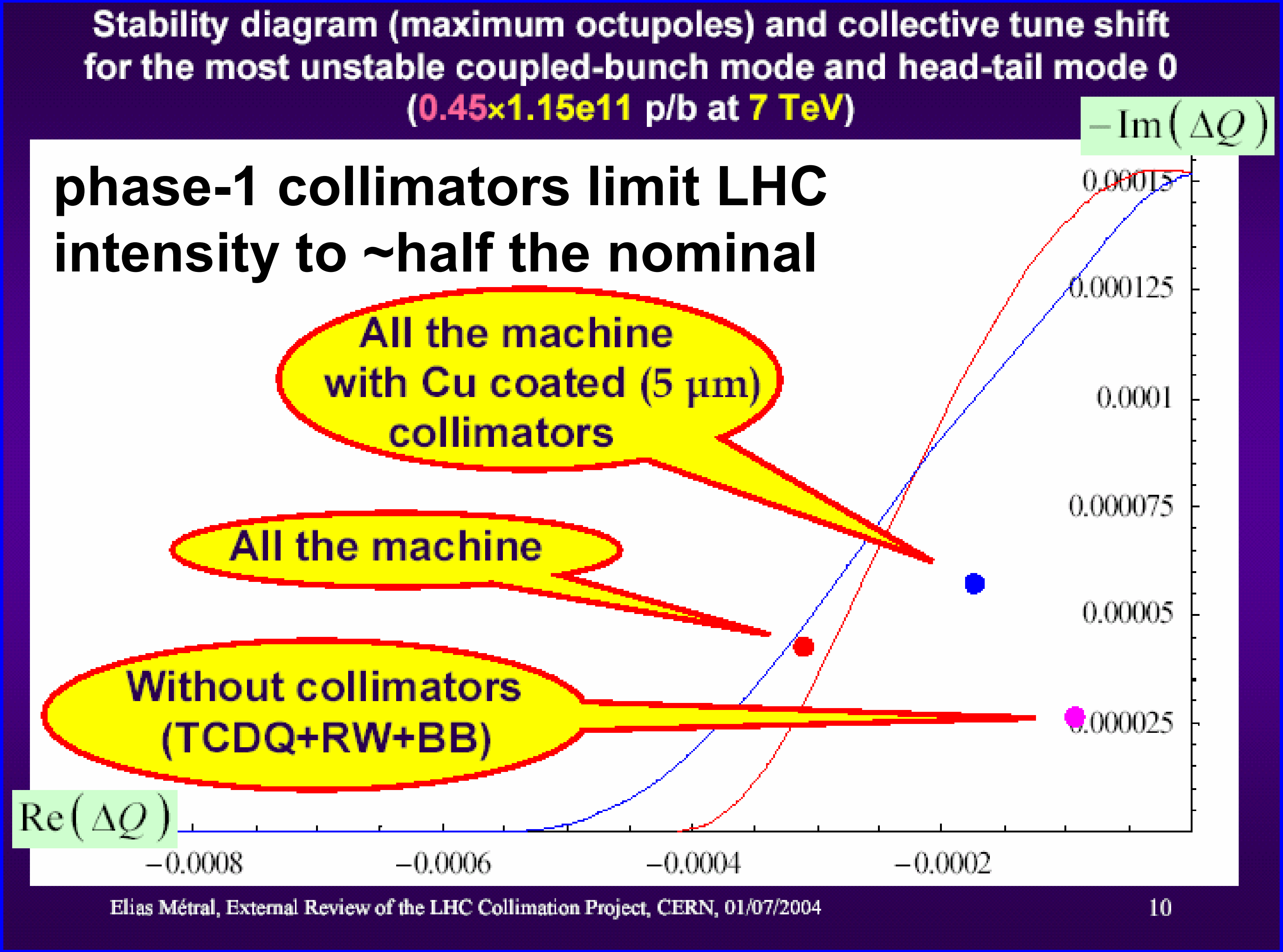


Particle cascade and material heating

Simulations indicate that graphite or fiber-reinforced graphite are the only material choices that would resist!

Search for highest conductivity graphite is ongoing (lowest impedance)…

R. Assmann



Stability diagram (maximum octupoles) and collective tune shift for the most unstable coupled-bunch mode and head-tail mode 0 (0.45×1.15e11 p/b at 7 TeV)

phase-1 collimators limit LHC intensity to ~half the nominal

All the machine with Cu coated (5 µm) collimators

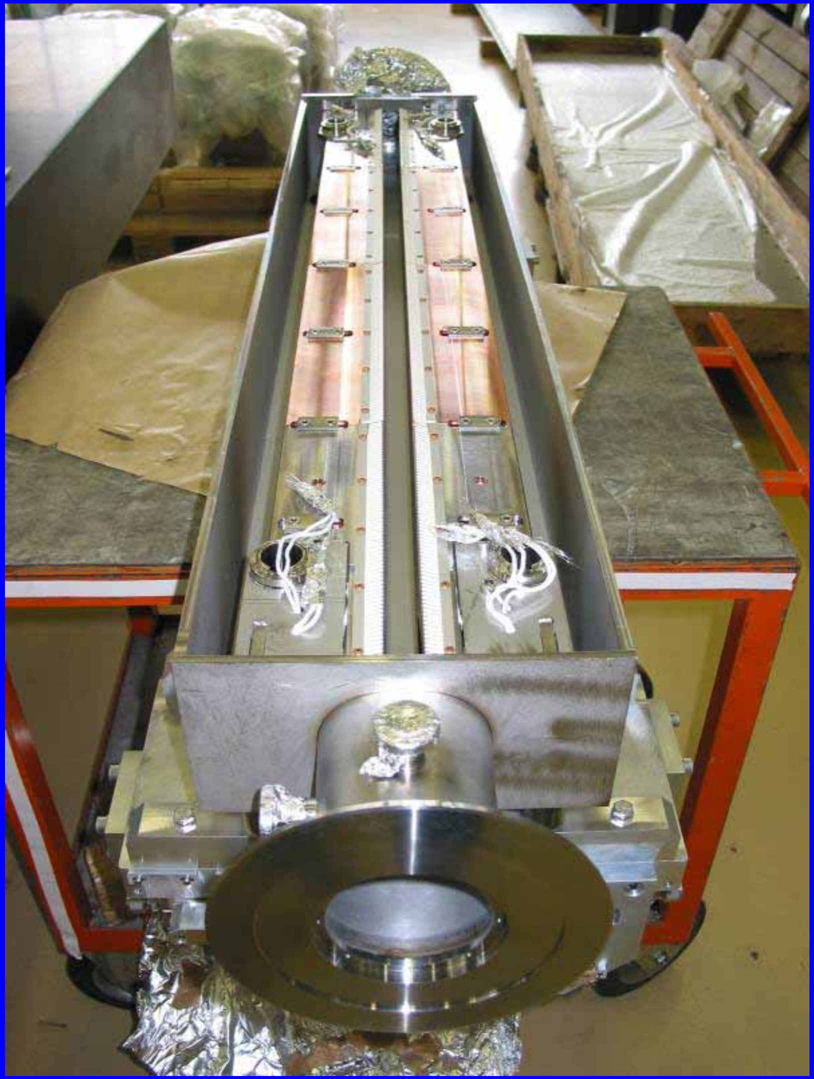
All the machine

Without collimators (TCDQ+RW+BB)

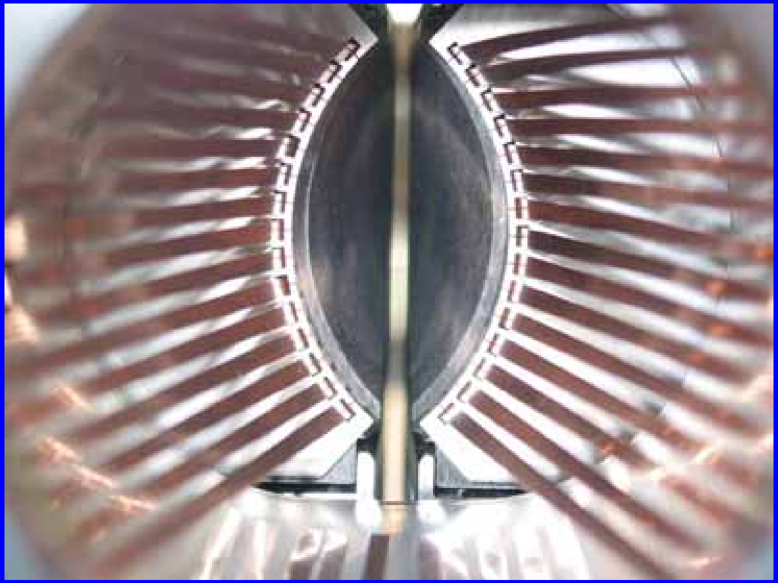
Elias Métral, External Review of the LHC Collimation Project, CERN, 01/07/2004

10

Building an LHC collimator (AB&TS department)



Vacuum tank with two jaws installed

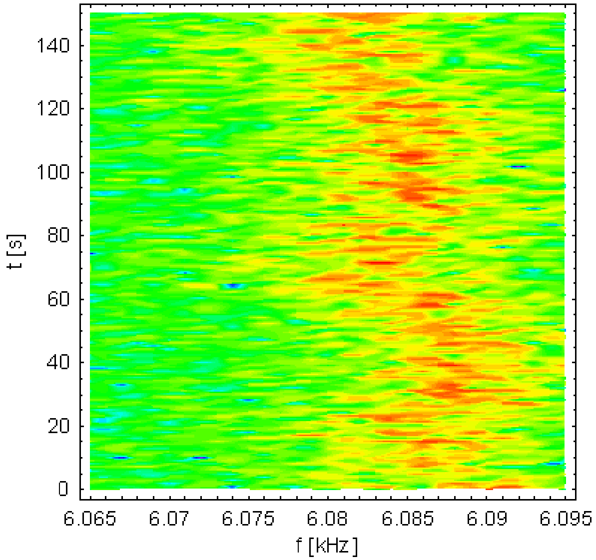


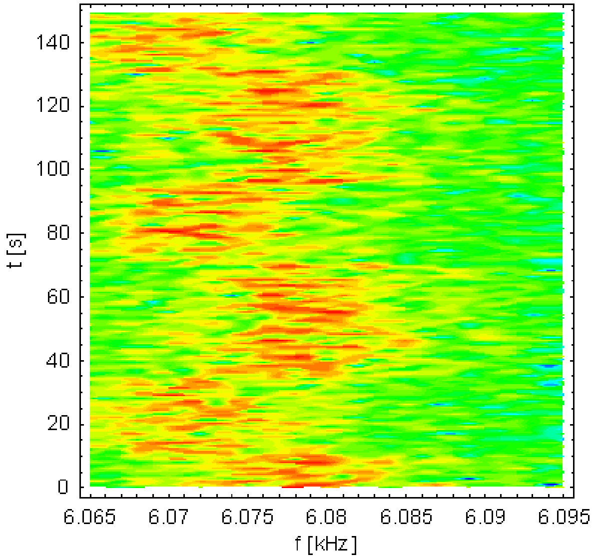
Beam passage for small collimator gap with RF contacts for guiding image currents

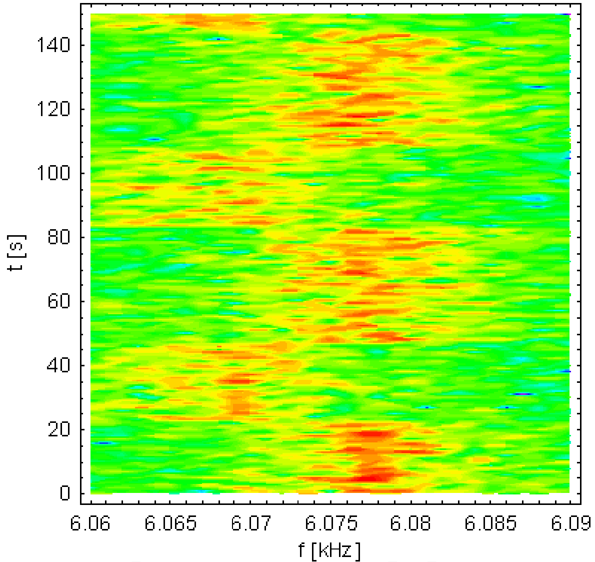
prototype was installed in the SPS

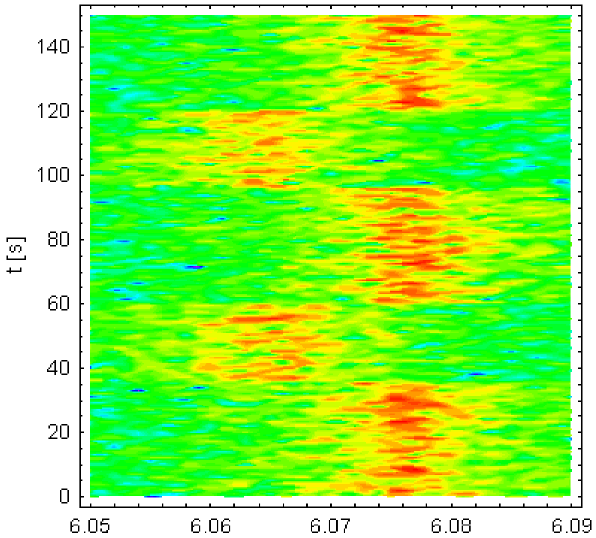
R. Assmann

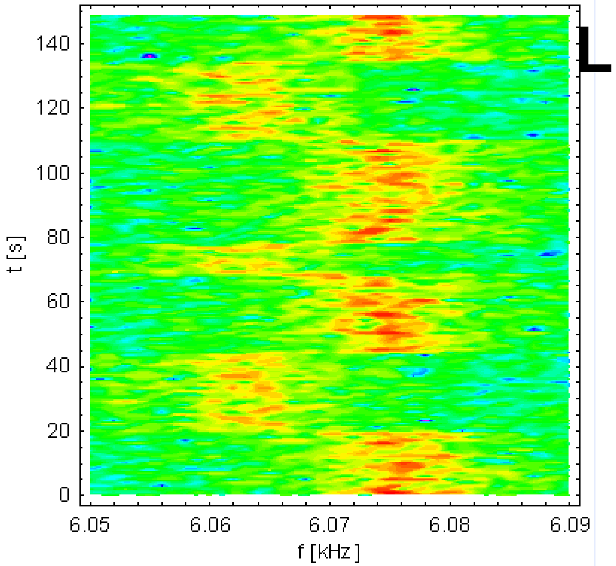
Collimator MDs #2 – (some) BBQ results











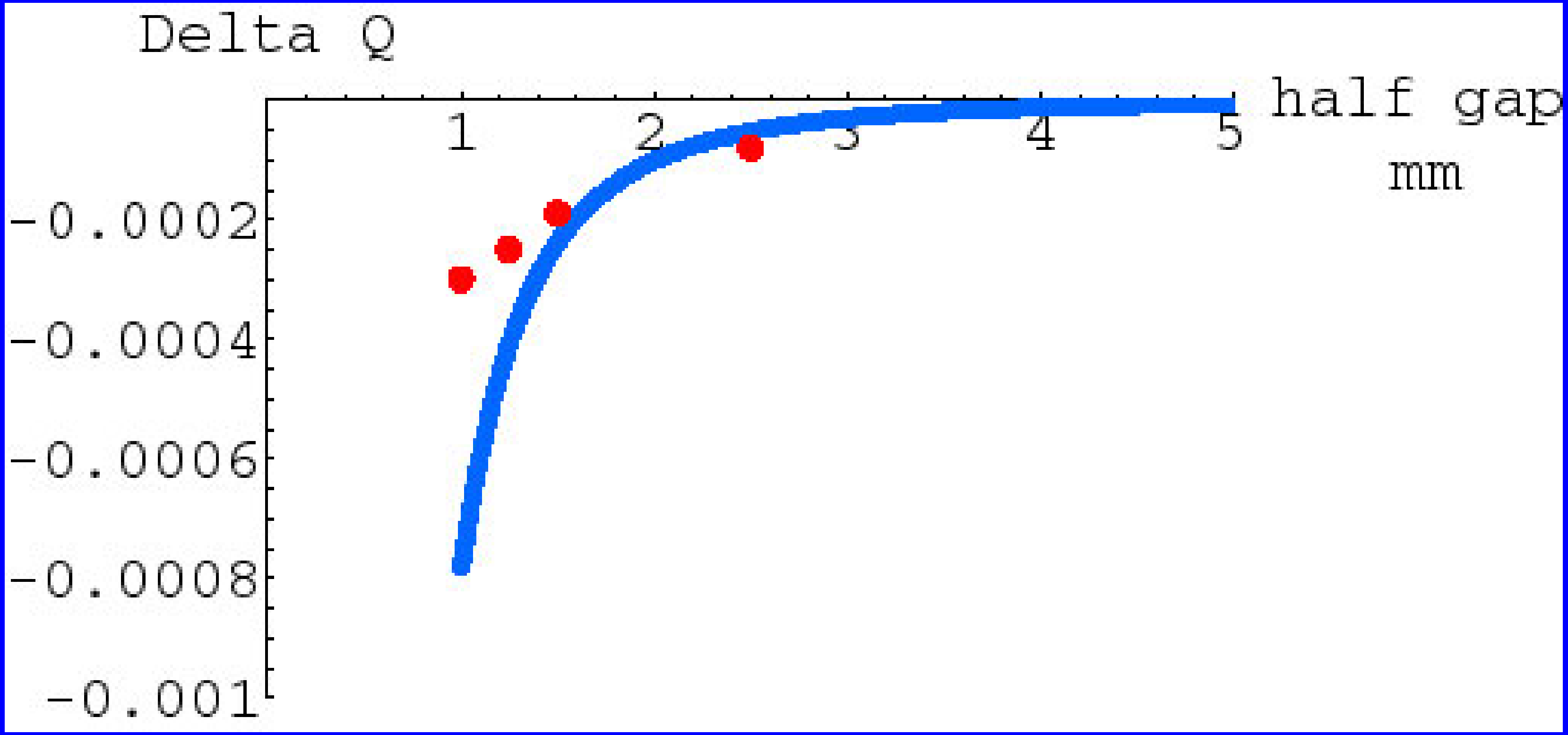
tune change with LHC collimator in/out

Collimator cycled between

- 51 mm and 3.86 mm (5h04)
- 51 mm and 2.86 mm (5h35)
- 51 mm and 2.46 mm (5h43)
- 51 mm and 2.06 mm (5h50)
- 51 mm and 1.86 mm (5h58)

M. Gasior, R. Jones

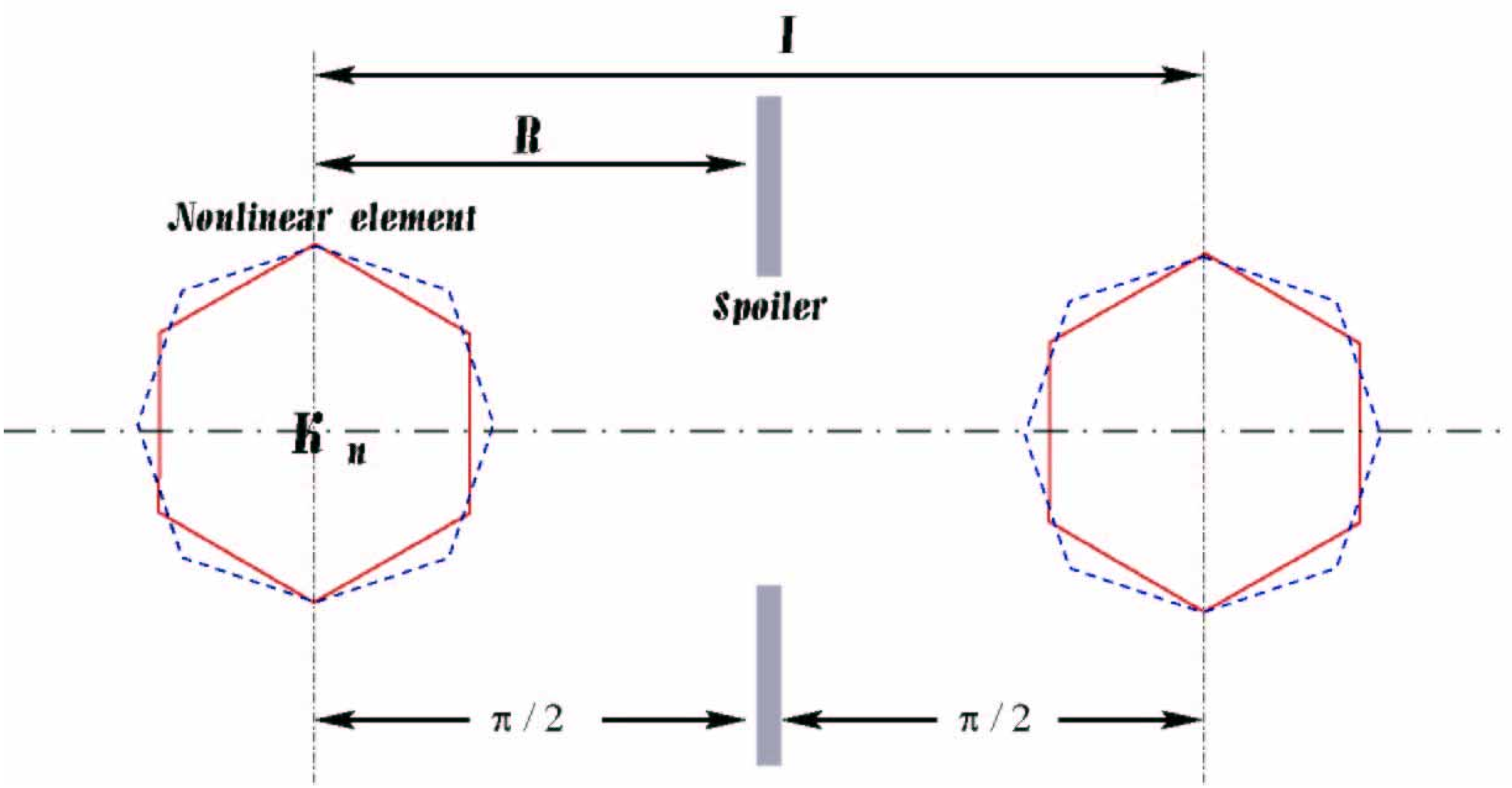
Impedance expectation and measurement in SPS



measured tune shift </= expected
though dependence on gap looks different

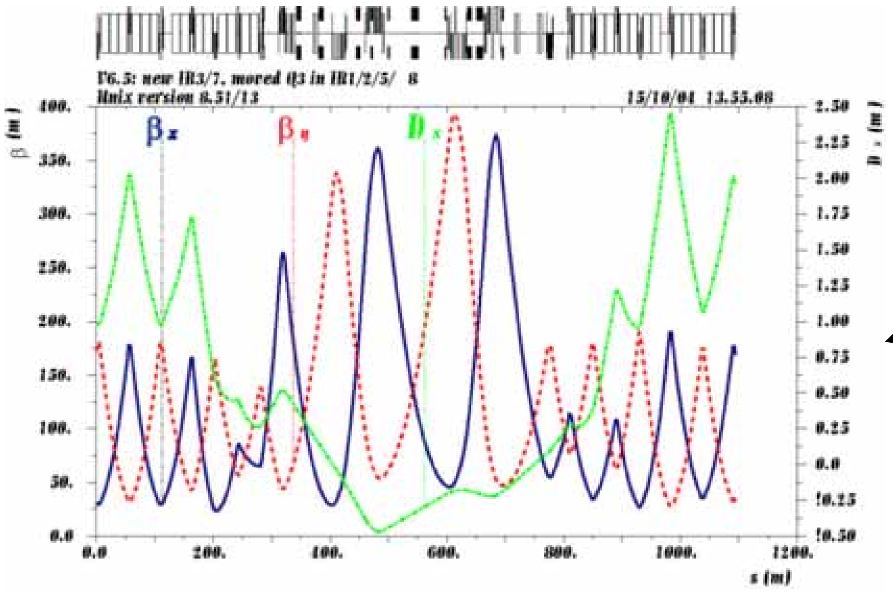
for higher intensity - nonlinear collimation?

based on ideas from LC designs (NLC, TESLA, CLIC)

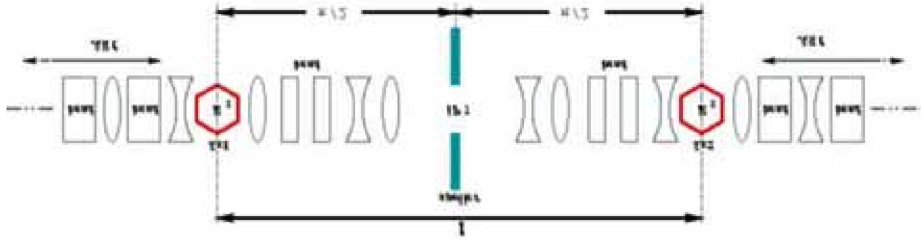


J. Resta Lopez, A. Faus-Golfe, F. Zimmermann, HHH-2004

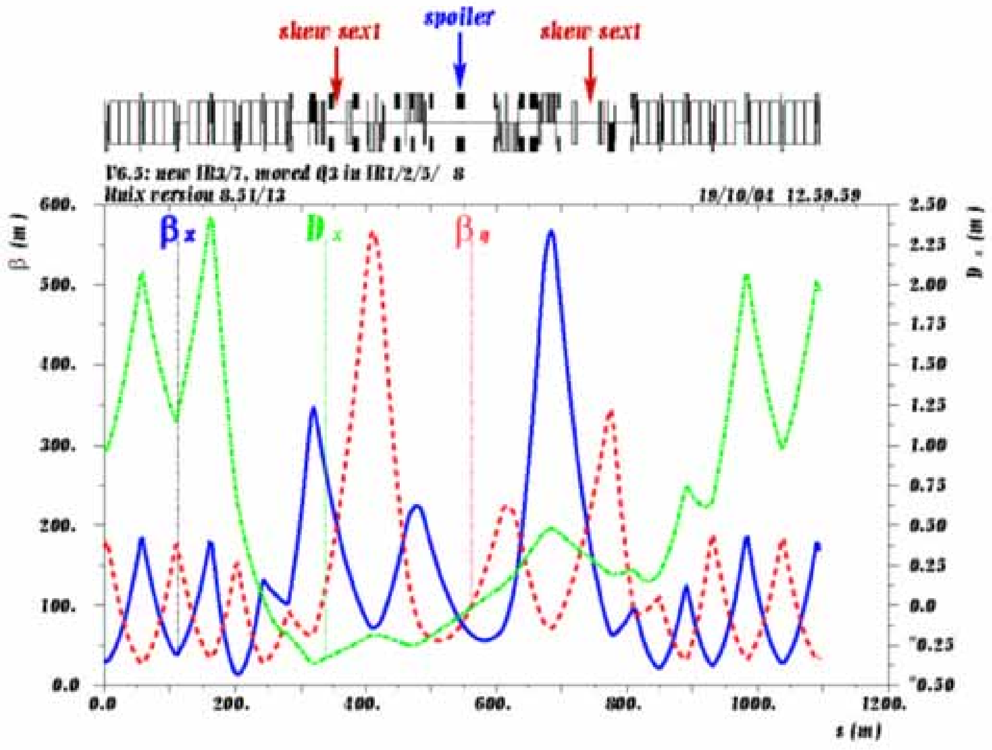
1st draft optics for LHC



present optics of LHC IR7



modified optics of LHC IR7 ***with skew sextupoles for nonlinear collimation***



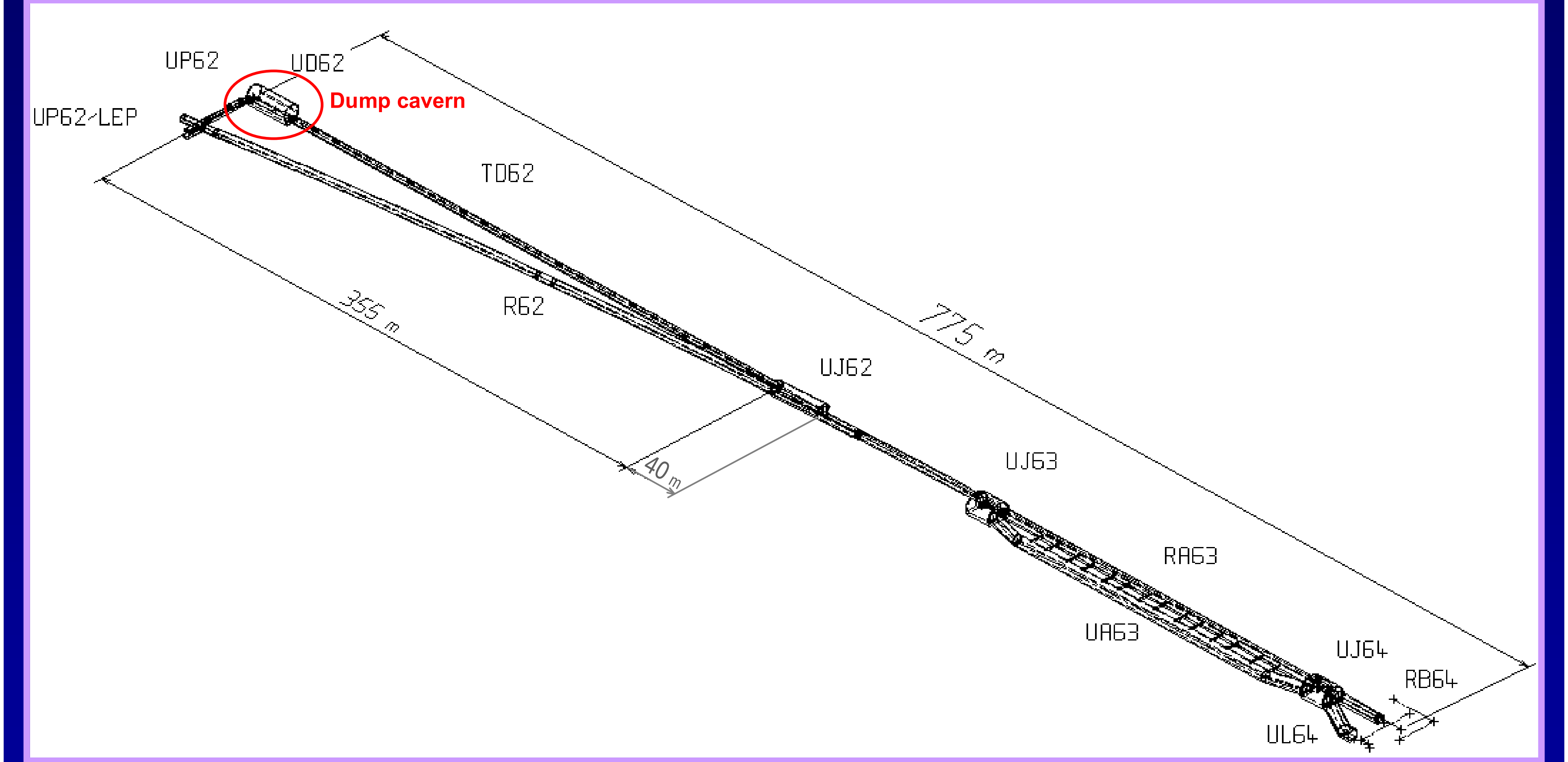
J. Resta Lopez, A. Faus-Golfe, F.Z., HHH-2004

beam dump system - concept

extract ⇒ dilute ⇒ dump

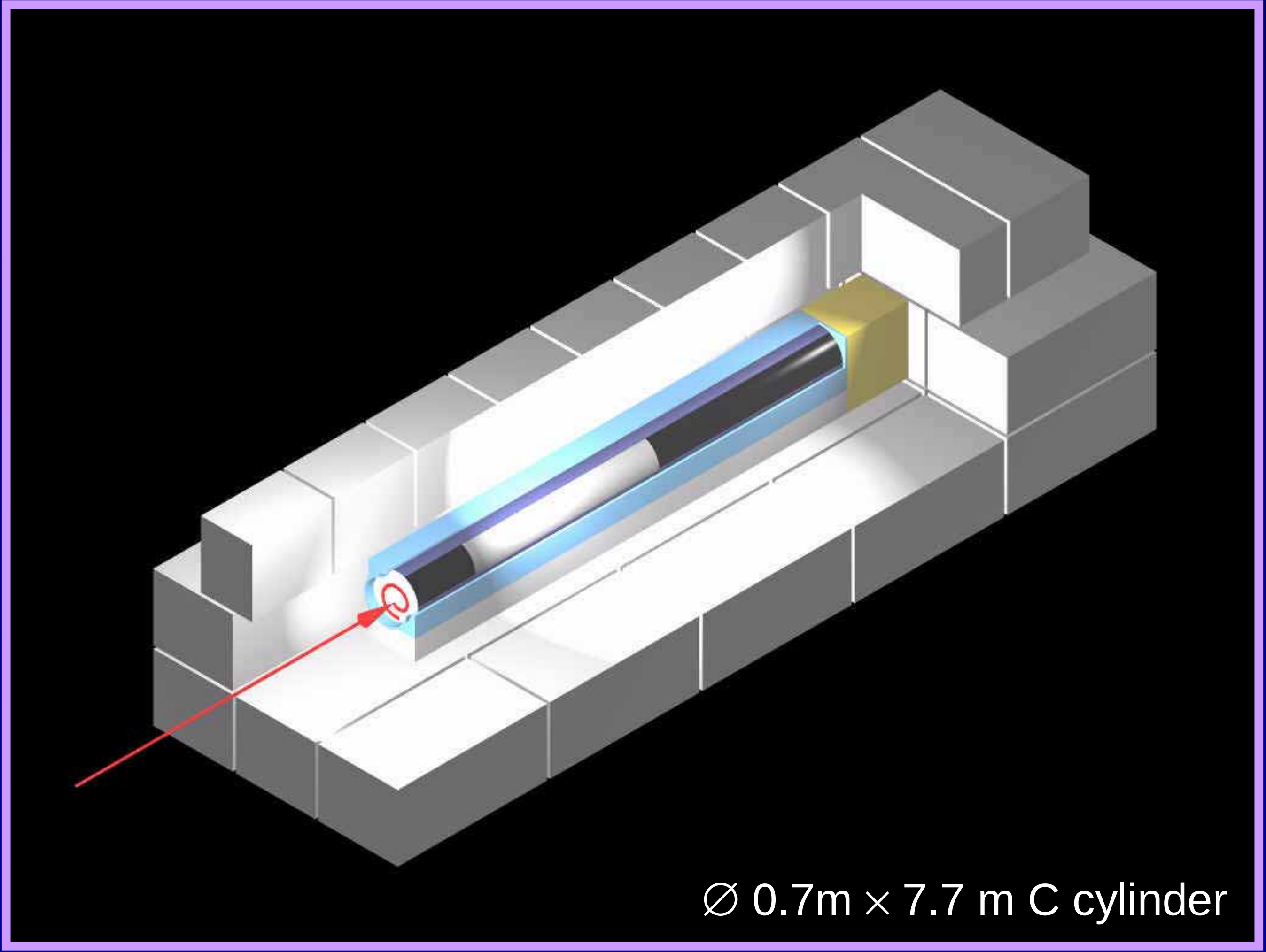
- Loss-free fast extraction system
  - Laminated steel kickers; DC Lambertson septum;
- Dilution system
  - Laminated steel kickers; passive ~650m drift length.
- Beam dump (absorber) block
  - Graphite cylinder, steel and concrete shielding
- Protection devices
  - Graphite protection (dilution) for septum and LHC machine

tunnel layout



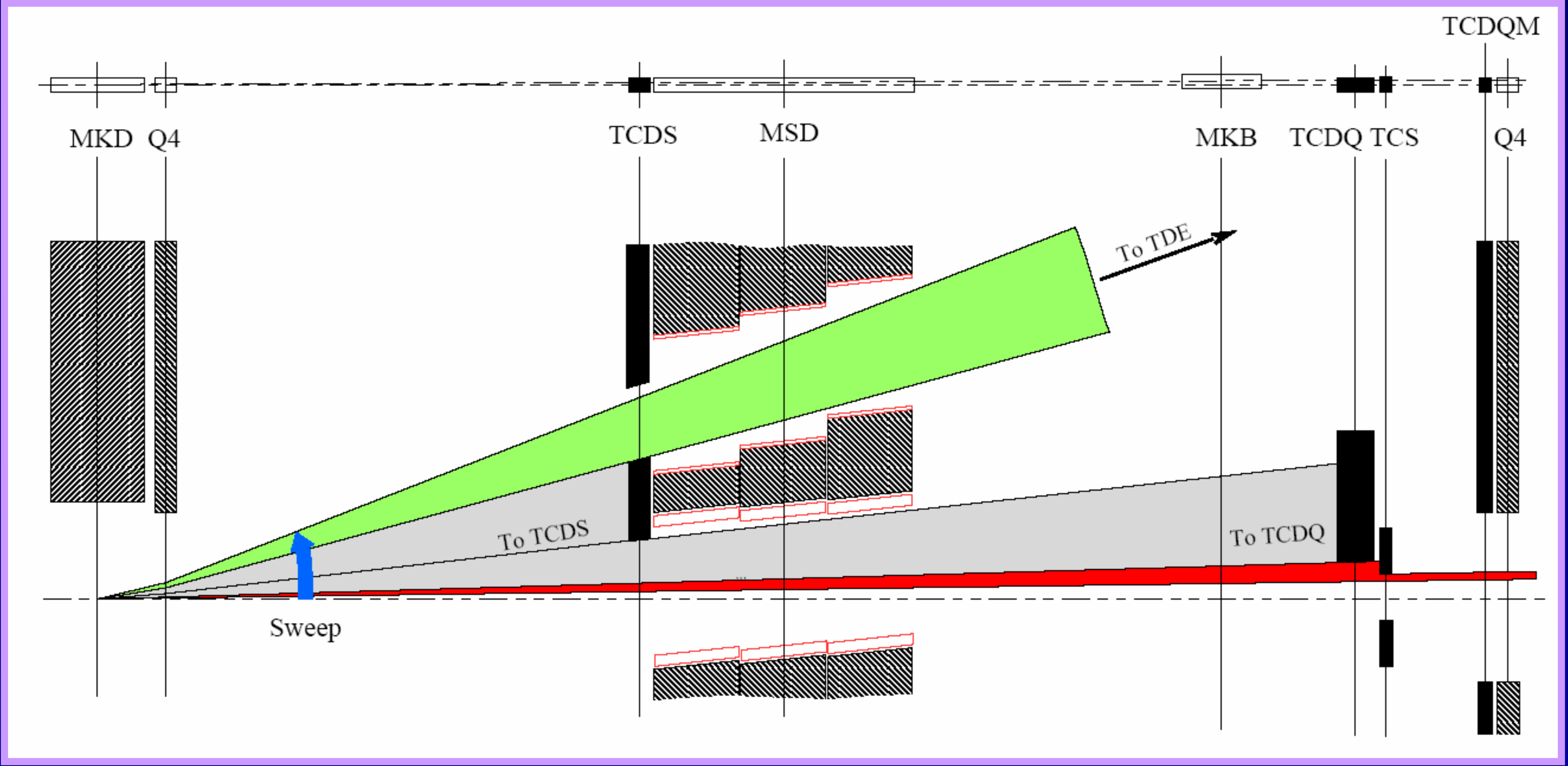
B.Goddard

TDE absorber



∅ 0.7m × 7.7 m C cylinder

protection

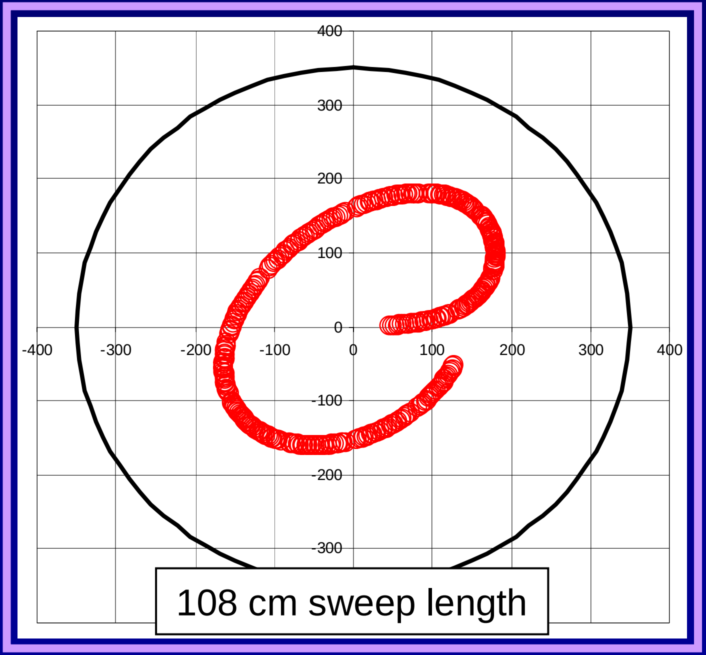


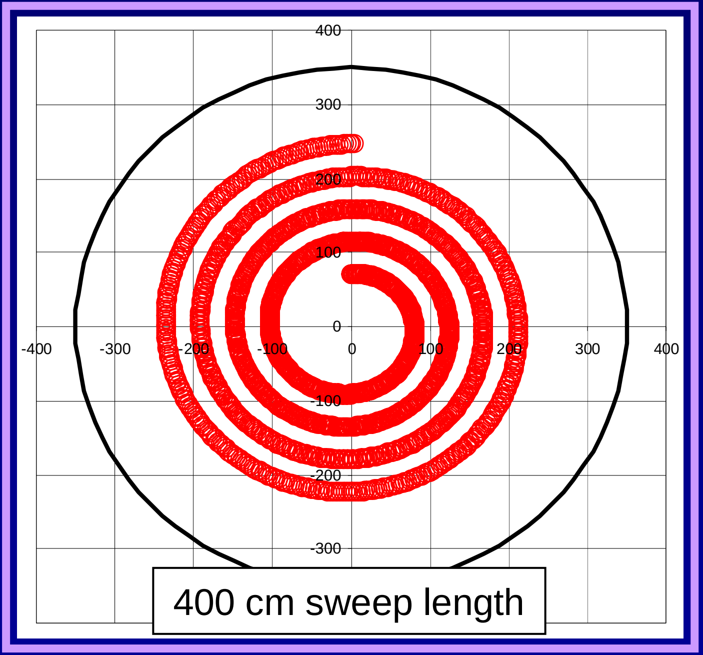
- Unsynchronised dump would destroy septum and downstream elements
- 2 long (6m), low density (carbon) absorbers to intercept undiluted bunches

B.Goddard

Dilution with spiral sweep

- for later upgrade Increase dilution kicker frequency and sweep length
  - 14 to 56 kHz… would require ~4 times more kicker length





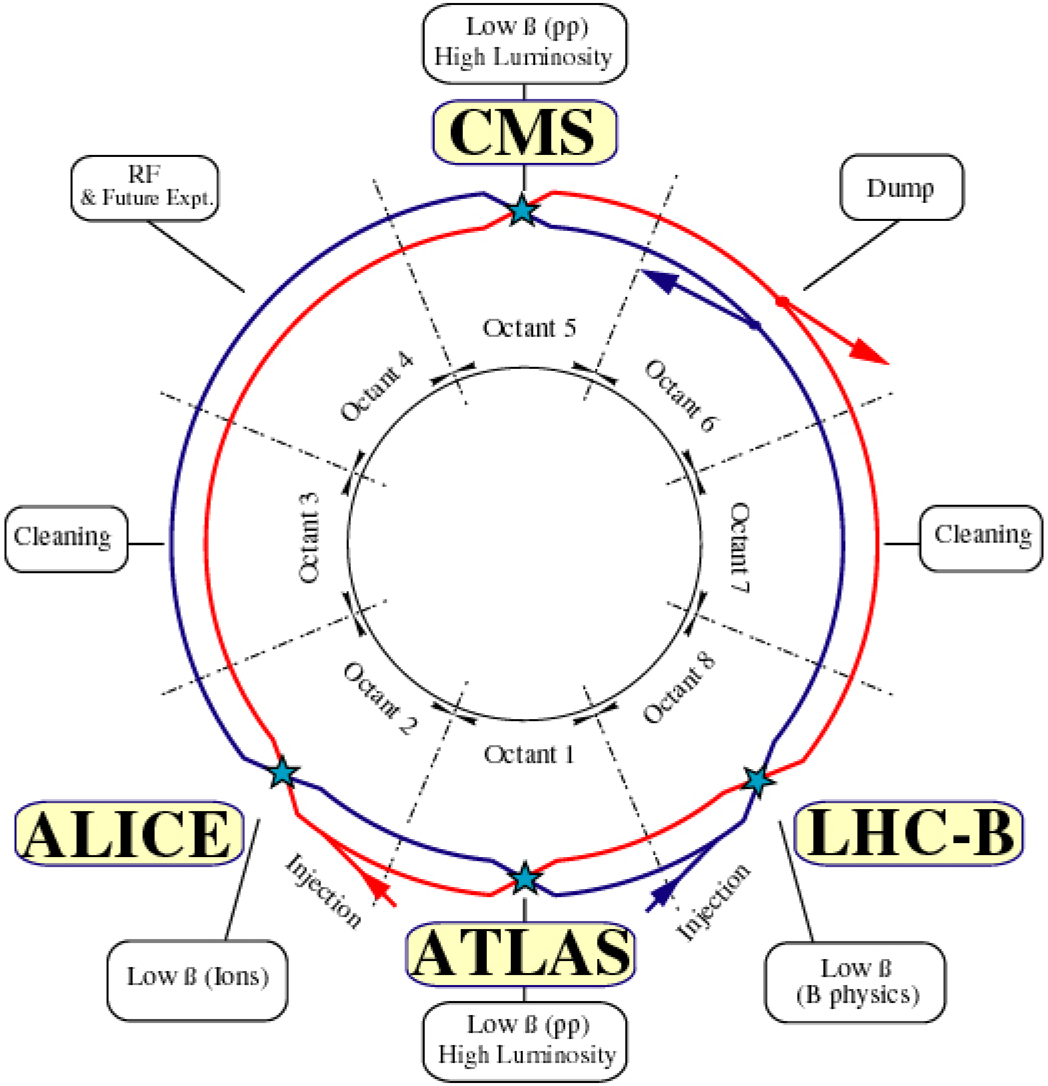
  - At 7 TeV would allow currents of ~3 A in distributed bunches
  - At 14 TeV would allow ~0.8 A in distributed bunches

B.Goddard

expected performance limitations (2)

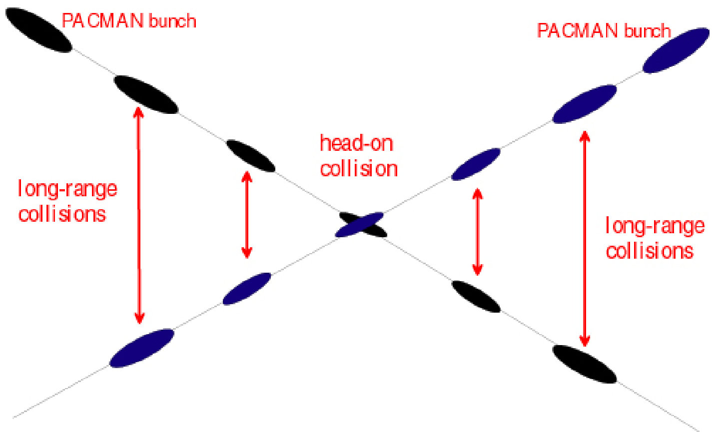
- beam-beam
- beam-beam compensation

LHC: 4 primary IPs



and

30 long-range collisions per IP



120 in total

compensation can act on either head-on or long-range collisions, or on both

beam-beam: tune shift

tune shift from head-on collision (primary IPs)

$$\boxed{\xi_{HO} \equiv \frac{N_b r_p}{4\pi\gamma\varepsilon_{x,y}}}$$

limit on ξ_{HO} restricts $N_b/(\gamma\varepsilon)$

	ξ_{HO} / IP	no. of IPs	ΔQ_{bb} total
SPS	**0.005**	**3**	**0.015**
Tevatron (pbar)	**0.01-0.02**	**2**	**0.02-0.04**
RHIC	**0.002**	**4**	**~0.008**
LHC (nominal)	**0.0034**	**2 (4)**	**~0.01**

what limits the beam-beam tune shift in hadron colliders like the LHC? no reliable prediction so far

conservative value for total tune spread based on SPS collider experience

long-range beam-beam collisions

- perturb motion at large betatron amplitudes, where particles come close to opposing beam
- cause ‘diffusive aperture’ (Irwin), 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

tune spread from long-range collisions

$$\xi_{LR} = 2 n_{par} \frac{\xi_{HO}}{d^2}$$

increases with reduced bunch spacing or crossing angle

d: normalized separation (units of σ), $d \propto \theta_c$

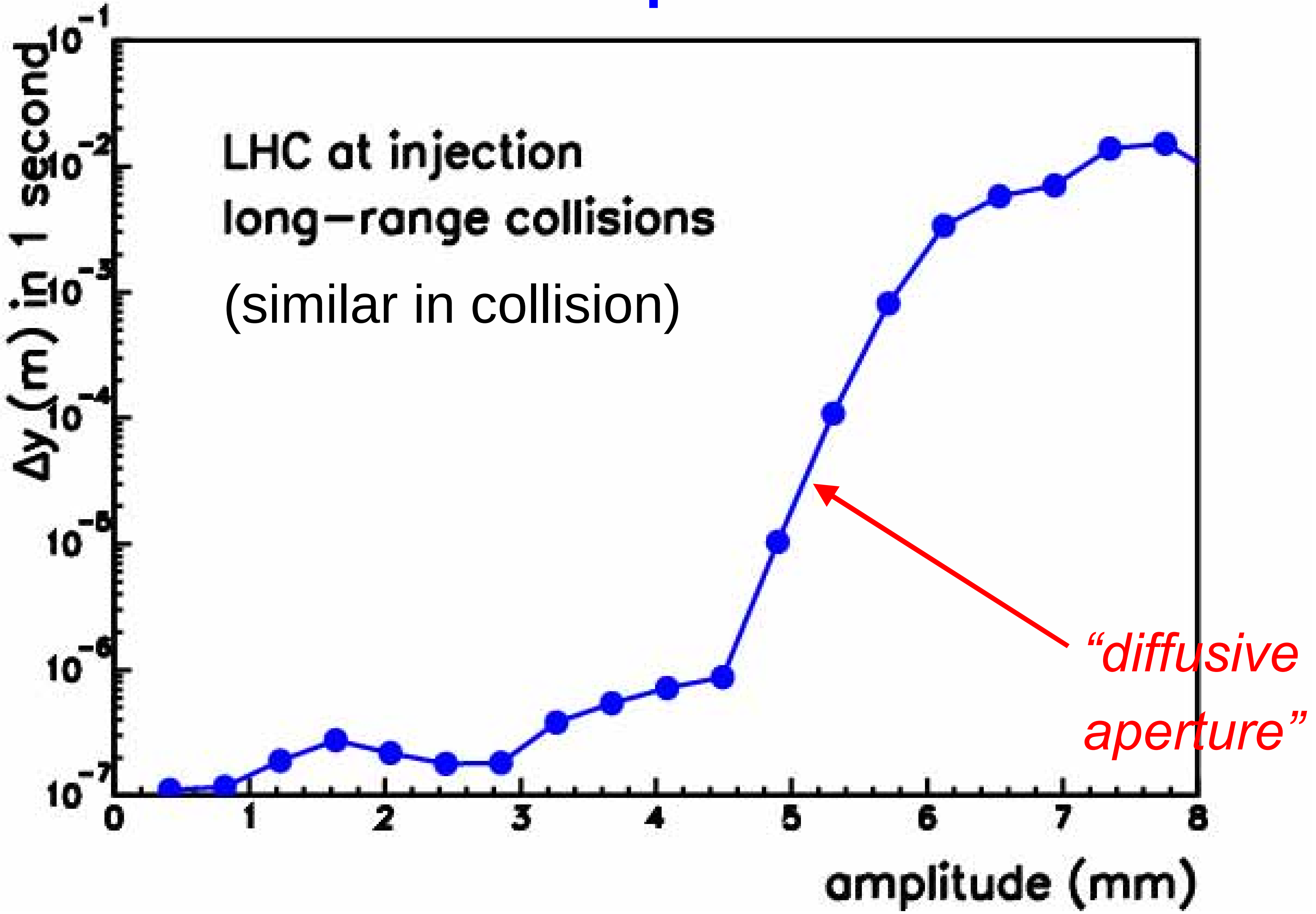
‘diffusive aperture’ due to long-range collisions

$$\frac{d_{da}}{\sigma} \approx \theta_c \sqrt{\frac{\beta^*}{(\gamma\varepsilon)}} - 3\sqrt{\frac{3.75\mu\mathrm{m}}{(\gamma\varepsilon)} \frac{n_{par}}{32} \frac{N_b}{10^{11}}}$$

requires minimum crossing angle

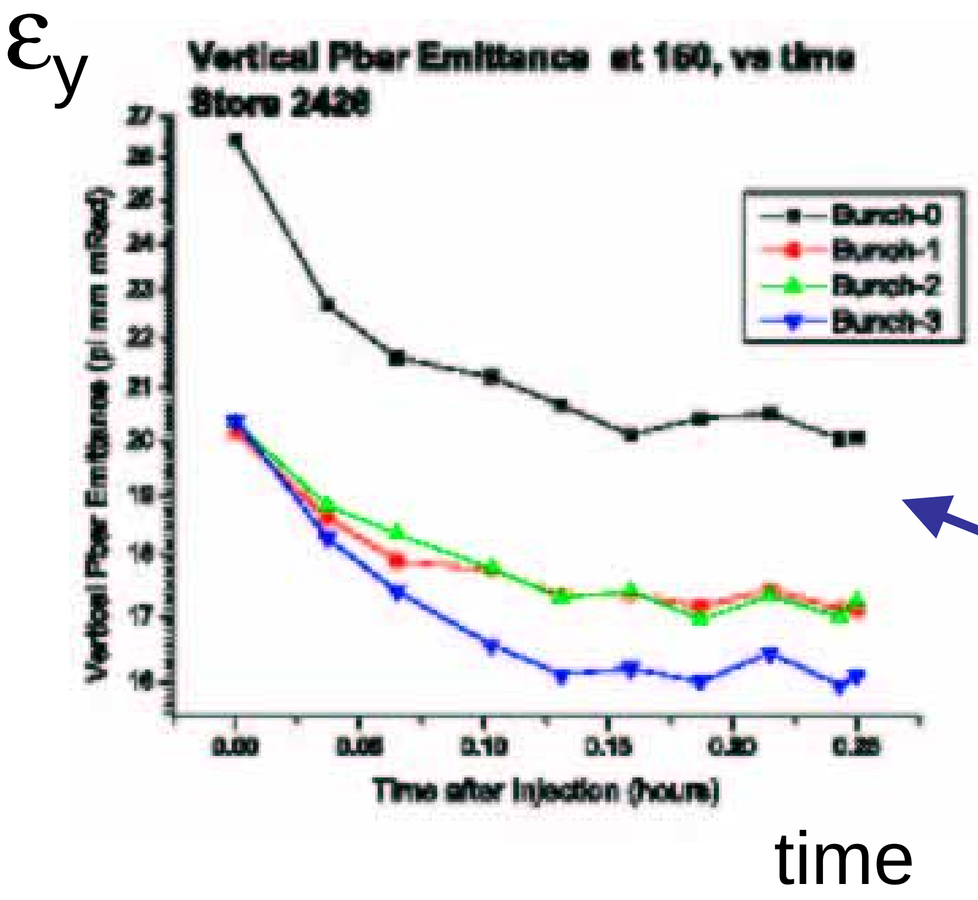
higher bunch charge, more bunches or smaller β* all require larger crossing angle to maintain the same dynamic aperture

diffusion vs. amplitude



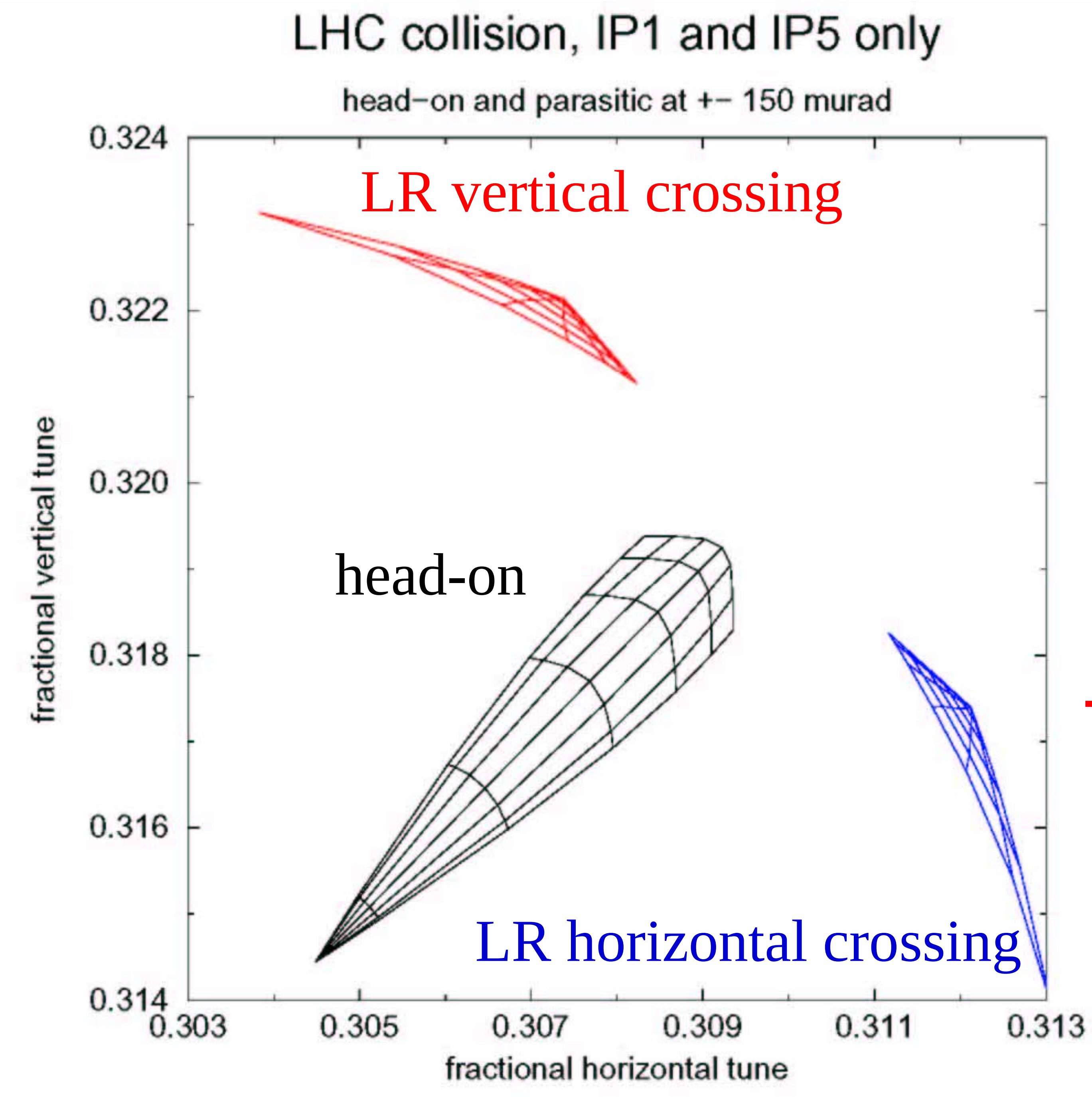
experience from Tevatron Run-II

“long-range beam-beam interactions in Run II at the Tevatron are the dominant sources of beam loss and lifetime limitations of anti-protons …” (T. Sen, PAC2003)



LR collisions reduce the dynamic aperture by about 3σ to a value of 3-4σ; little correlation between tune footprint and dynamic aperture

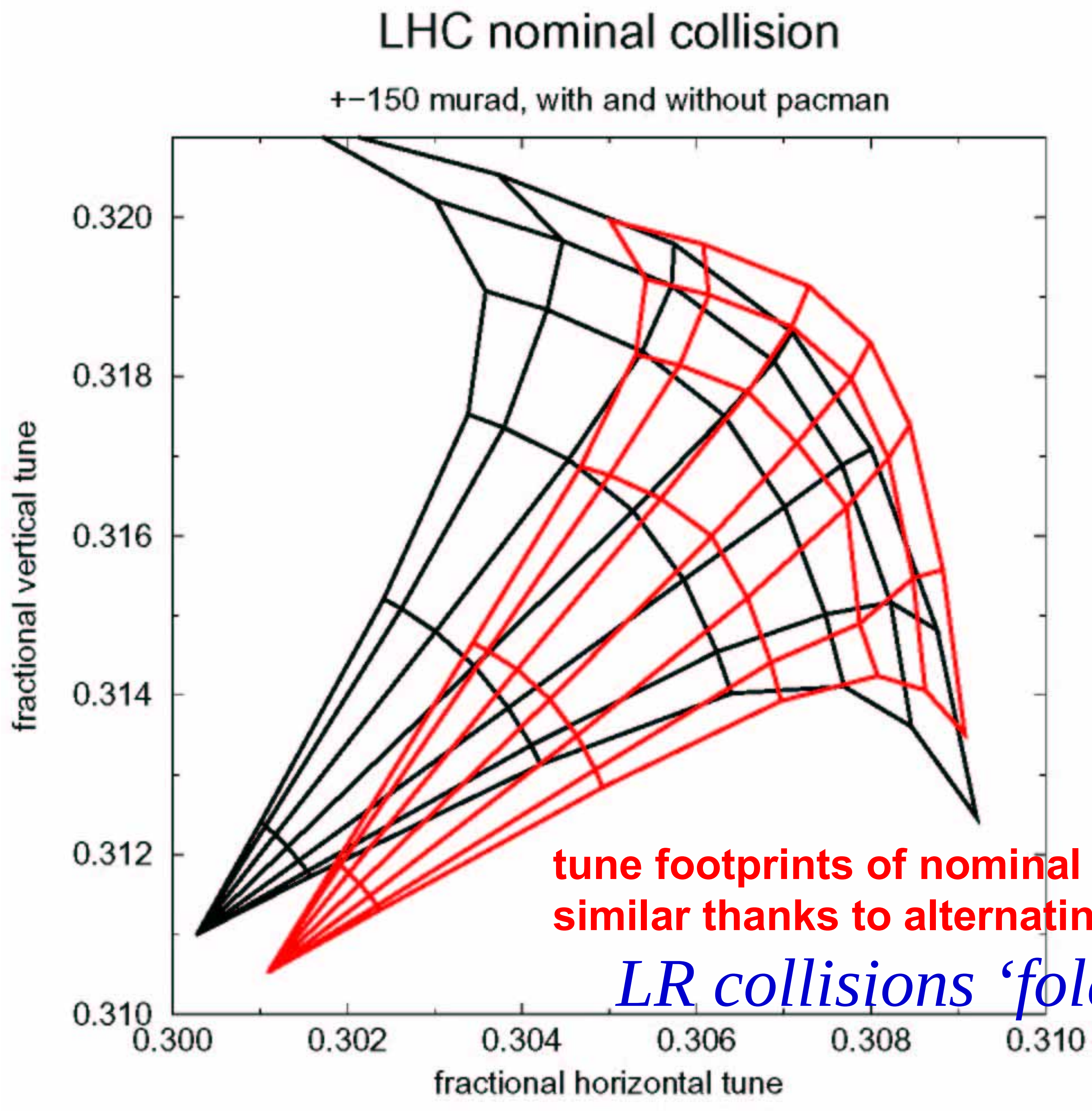
drop in ε_y for first 4 pbar bunches after injection; asymptotic emittance is measure of their dynamic aperture



LHC tune “footprint” due to head-on & long-range collisions in IP1 & IP5 (Courtesy H. Grote)

→

beams **with alternating planes of crossing** have less tune spread

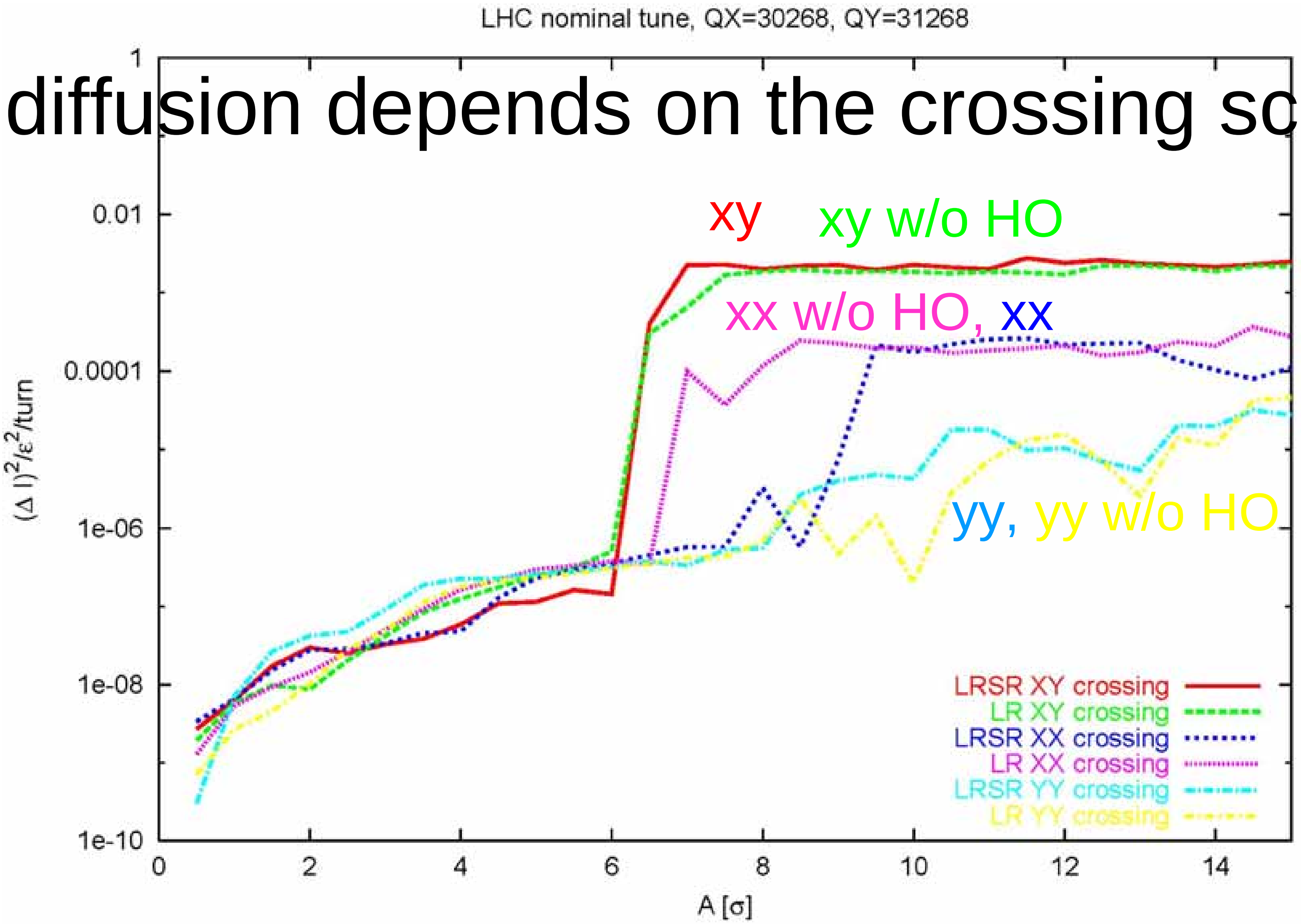


total LHC tune “footprint” for regular and “PACMAN” bunch (Courtesy H. Grote)

tune footprints of nominal & PACMAN bunches similar thanks to alternating crossing

LR collisions ‘fold’ the footprint!

diffusion depends on the crossing scheme



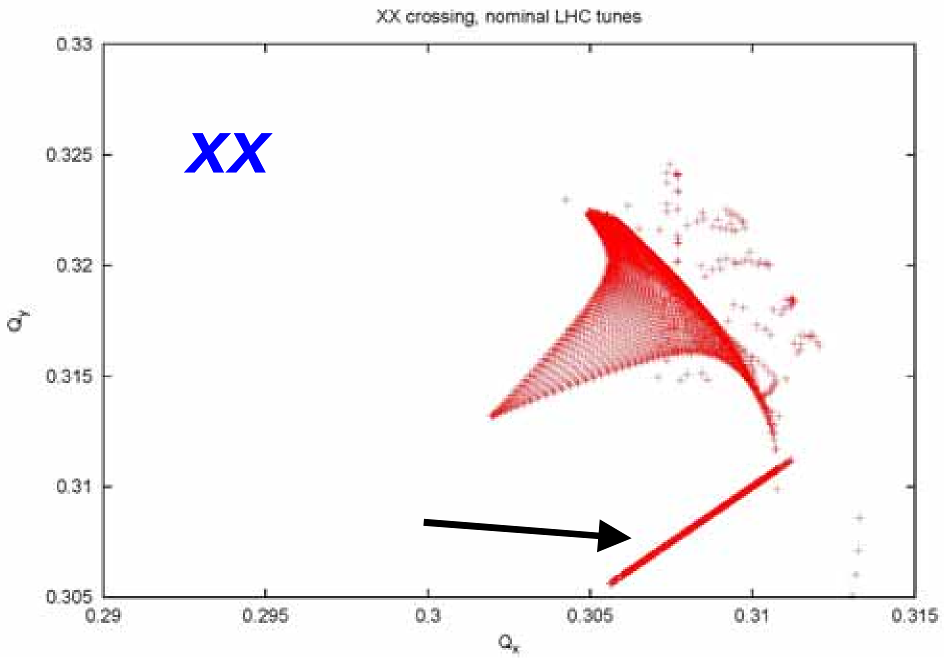
xy

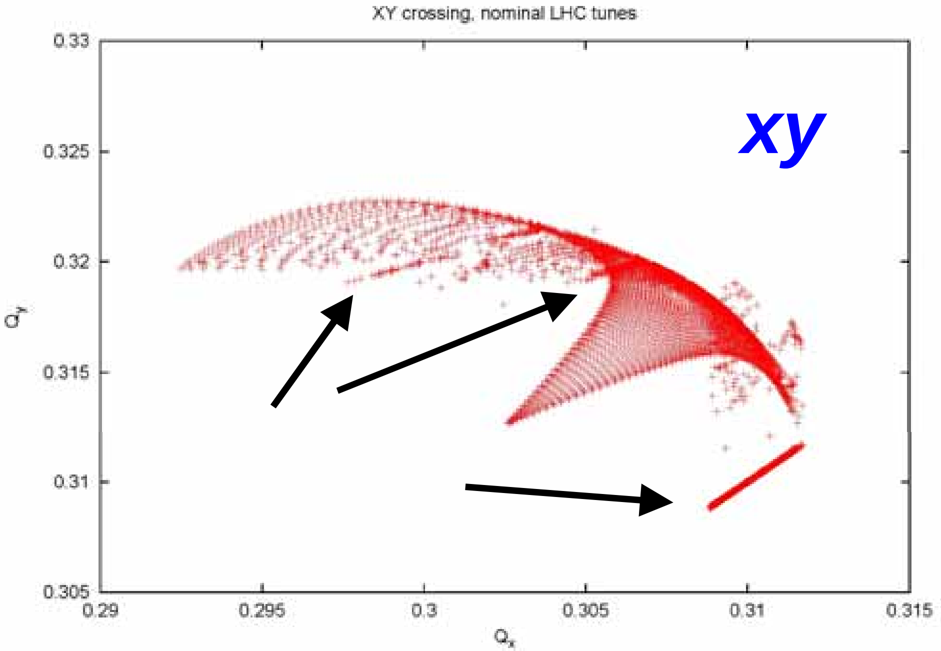
xy w/o HO

xx w/o HO, xx

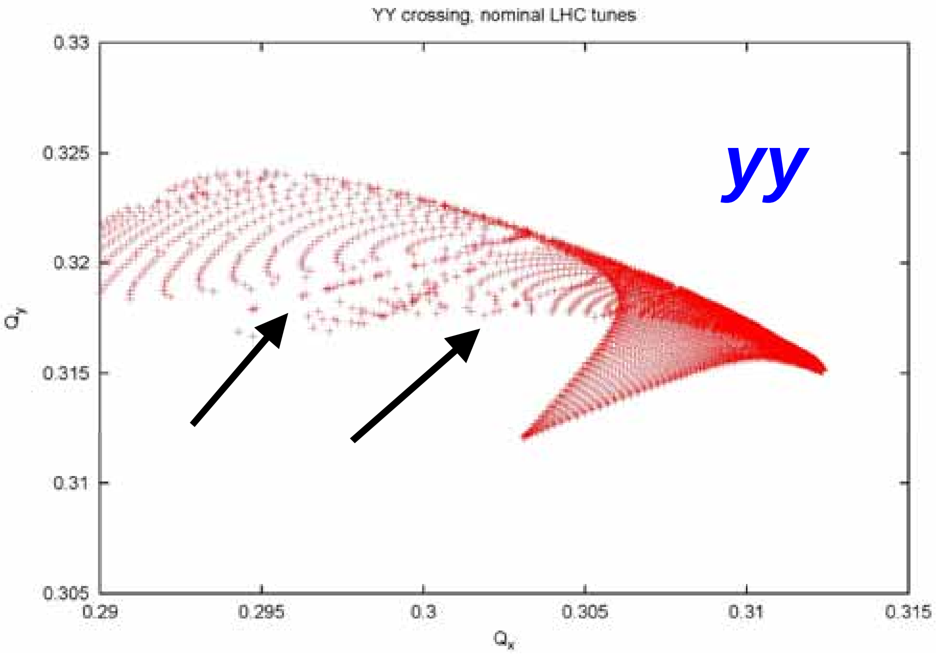
yy, yy w/o HO

Simulated diffusion rate as a function of start amplitude for XX, XY and YY crossing with LR only and with the combined effect of LR and SR collisions, for the *same tunes* 0.30268, 0.31268;





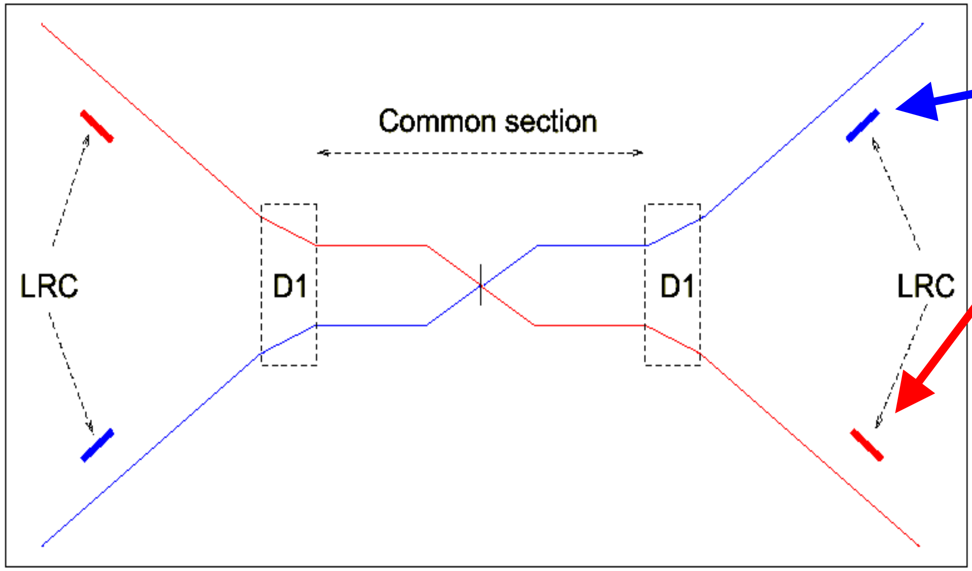
frequency
maps
for
different
crossing
schemes



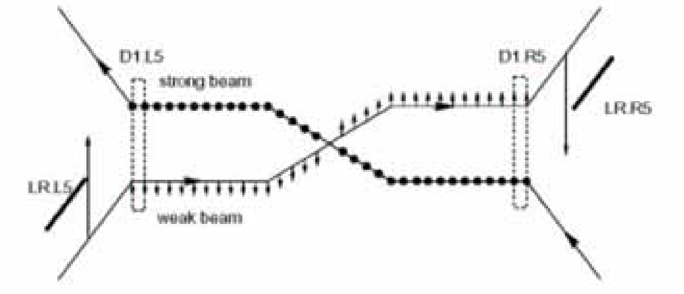
with help from
Y. Papaphilippou

Long-Range Beam-Beam Compensation proposed for LHC

- To correct **all** non-linear effects correction must be **local**
- Layout: 41 m downstream of D2, both sides of IP1/IP5



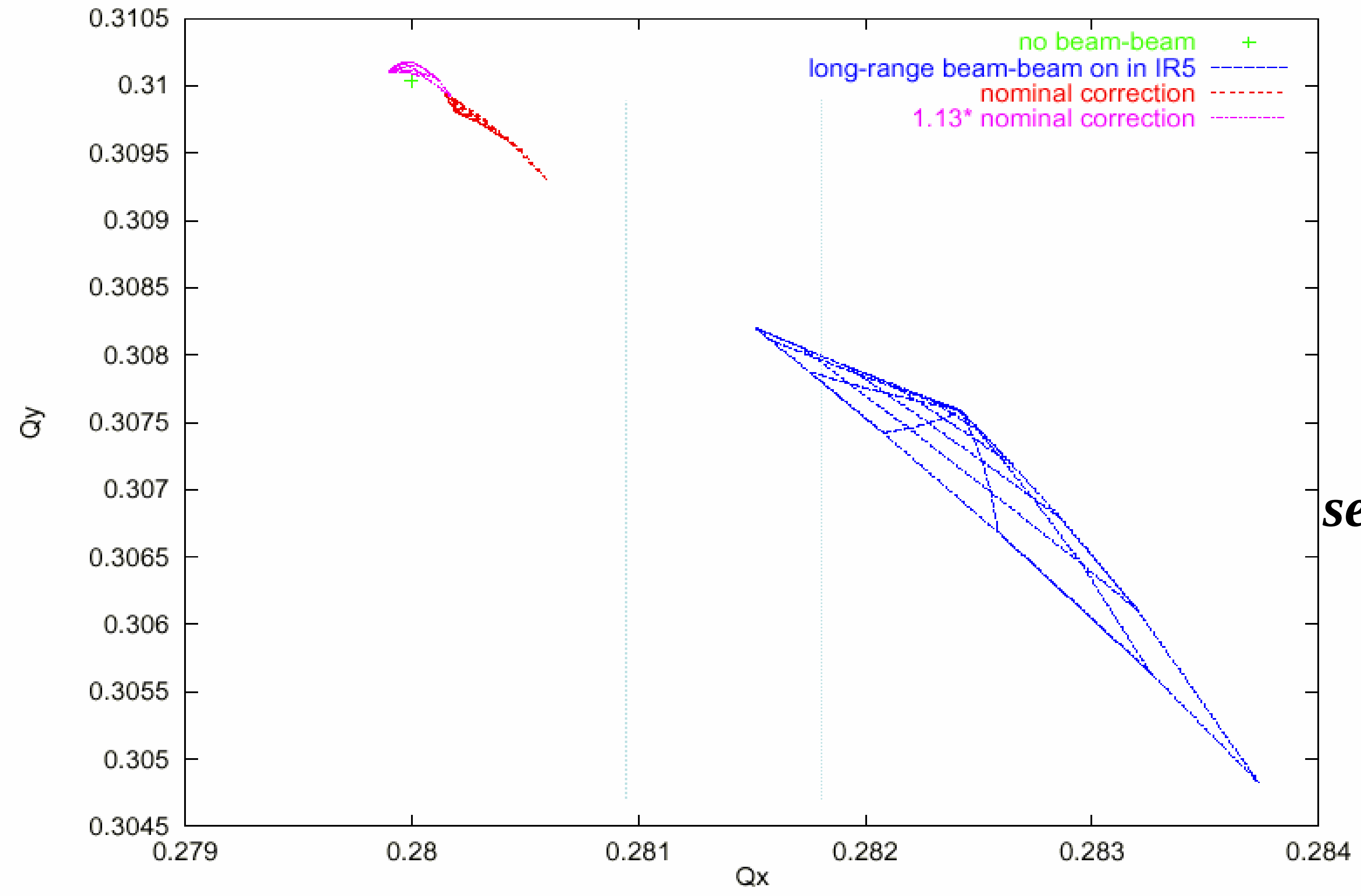
current-carrying wires ‘BBLRs’



Phase difference between BBLRC & average LR collision is 2.6°

(Jean-Pierre Koutchouk)

simulated LHC tune footprint with & w/o wire correction



- .16σ
- .005σ
- .016σ

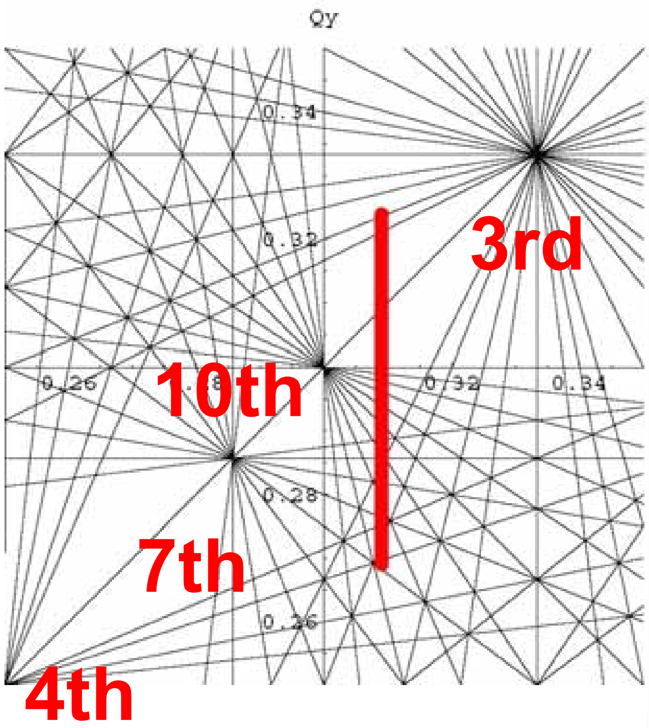
Beam separation at IP

(Jean-Pierre Koutchouk, LHC Project Note 223, 2000)

BBLR prototype installed in the CERN SPS models the effect of long-range collisions & their compensation

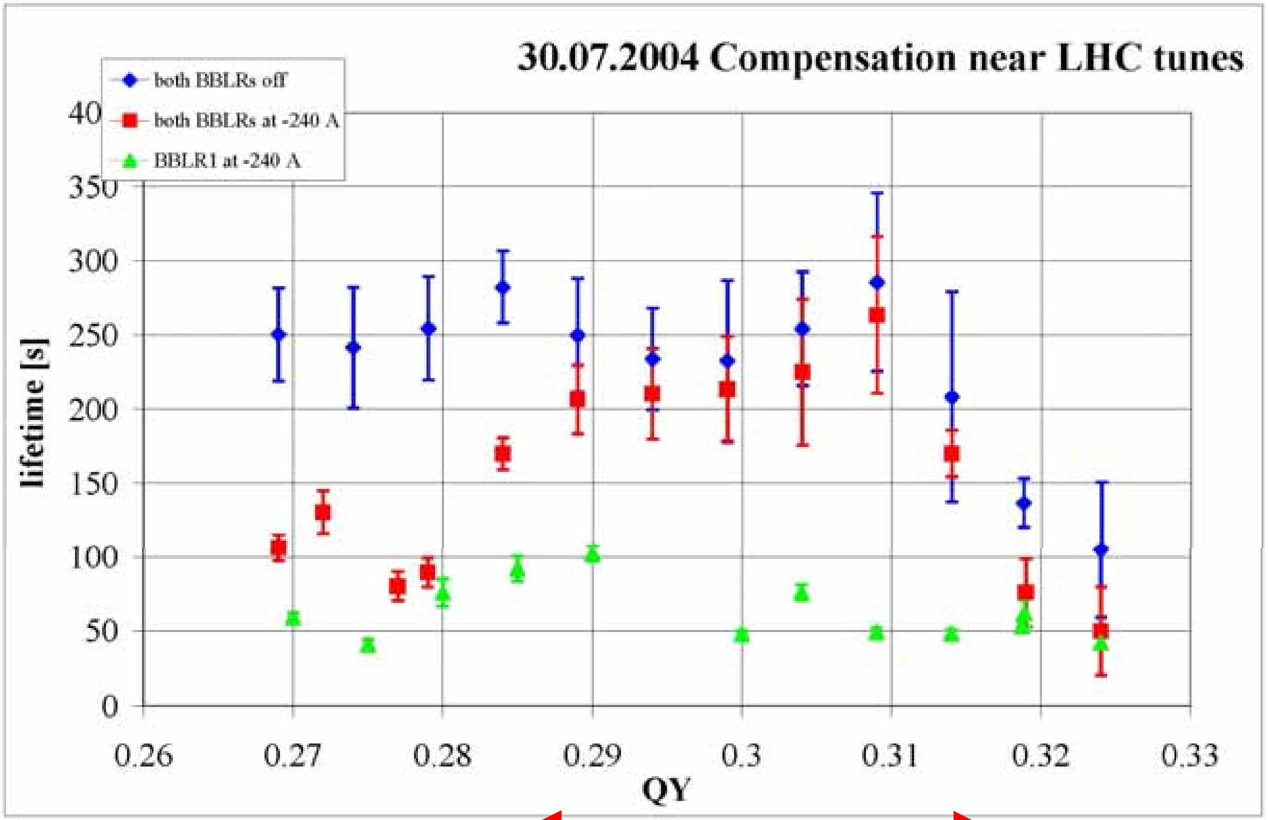
G. Burtin, J. Camas, J.-P. Koutchouk, et al.

measured BBLR compensation efficiency vs. working point - scan around LHC tunes



we scanned QY w/o BBLRs, with BBLR1 only, and with BBLR1 & BBLR2

30.07.04



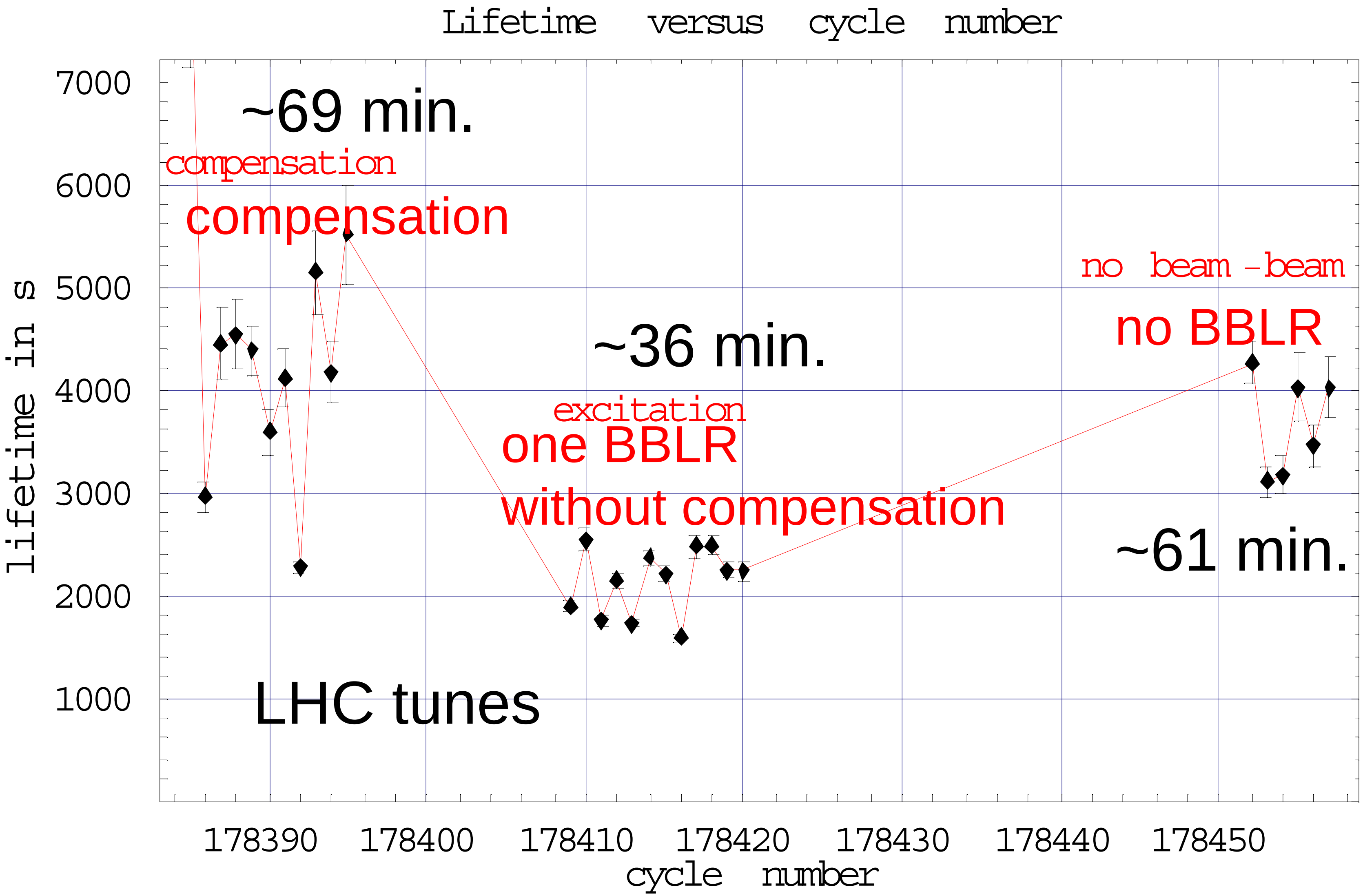
J.-P. Koutchouk,
T. Sen, V. Shiltsev,
J. Wenninger,
F. Zimmermann

what happens here?

nearly perfect compensation

compensate BBLR1 by BBLR2

02.09.04 experiment: measured beam lifetime



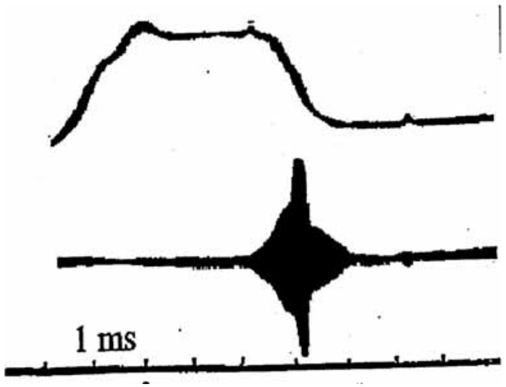
J.-P. Koutchouk

compensation recovers (even improves!) lifetime without LRBB

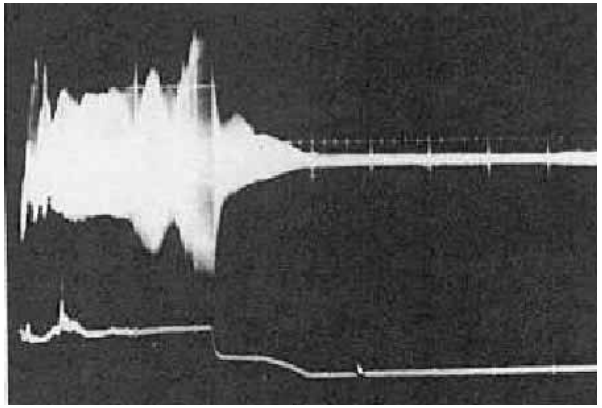
expected performance limitations (3)

- electron cloud

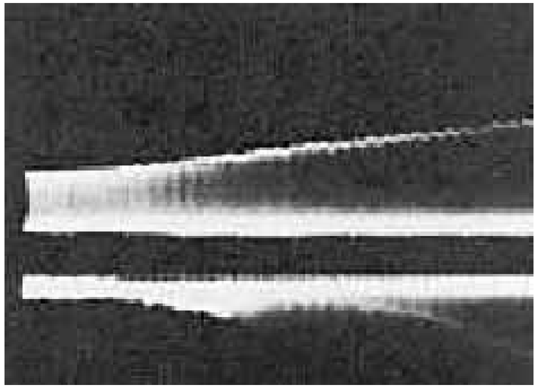
INP Novosibirsk, 1965



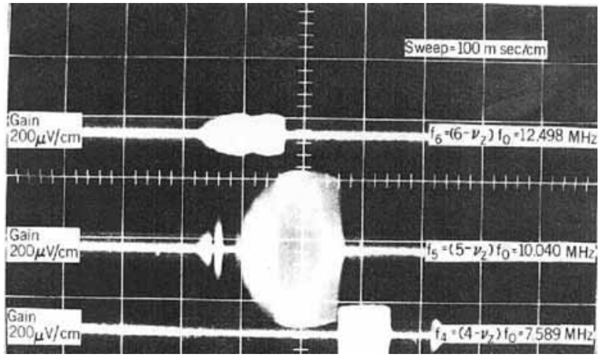
Argonne ZGS,1965



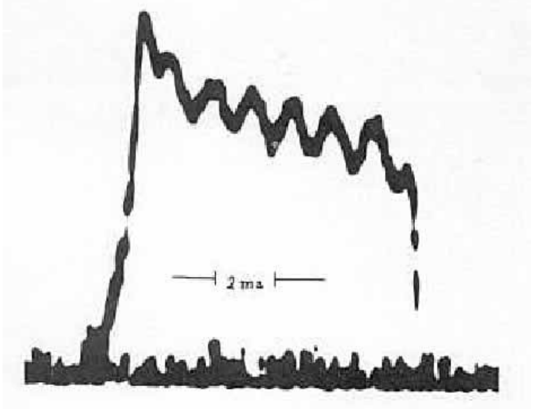
BNL AGS, 1965



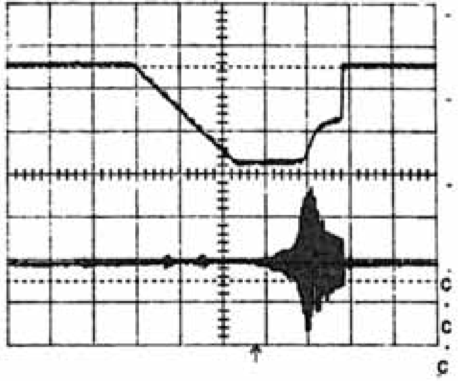
Bevatron, 1971



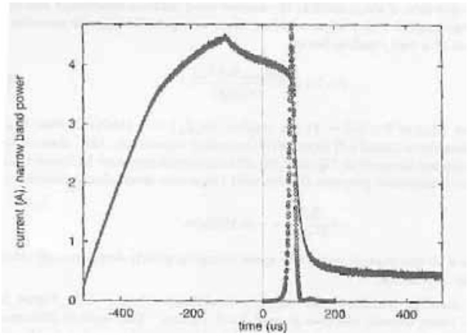
ISR, ~1972



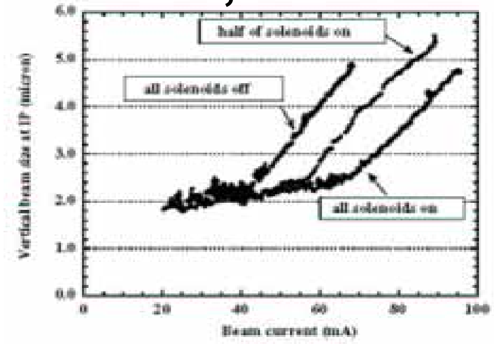
PSR, 1988



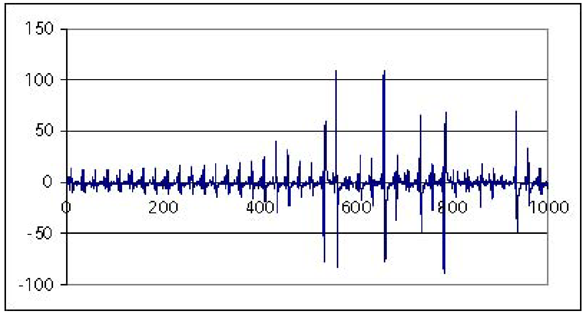
AGS Booster, 1998/99



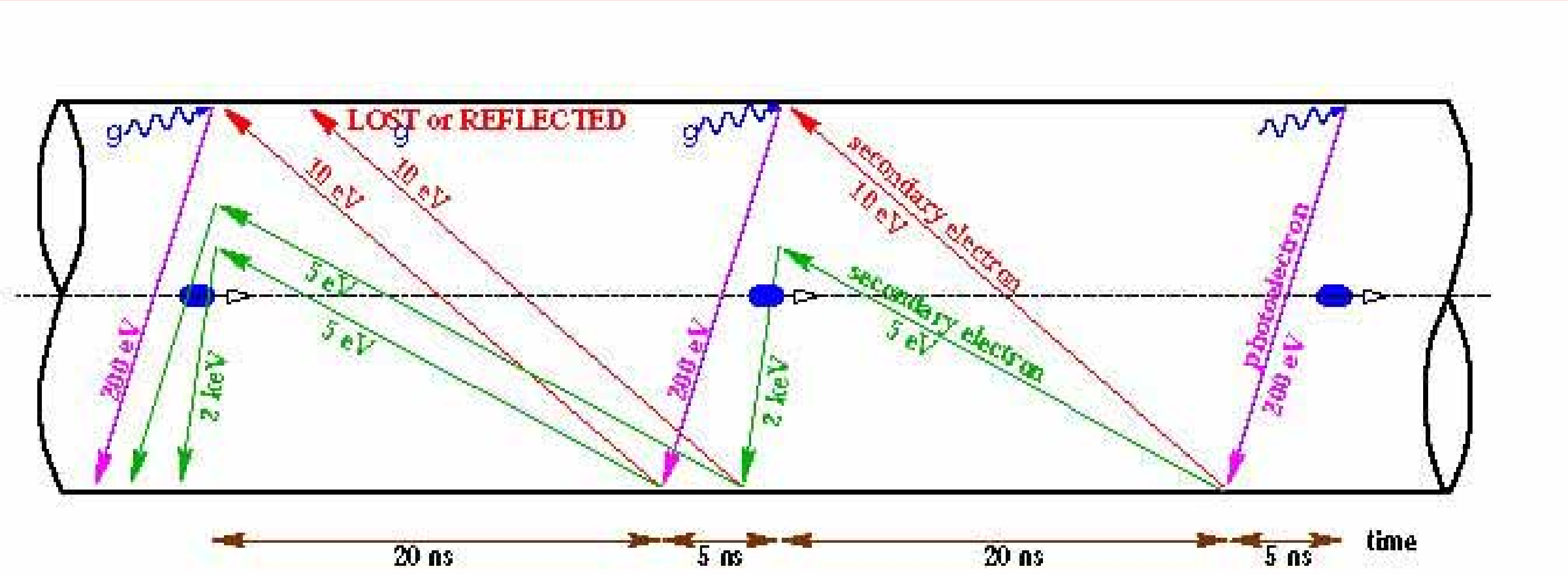
KEKB, 2000



CERN SPS, 2000



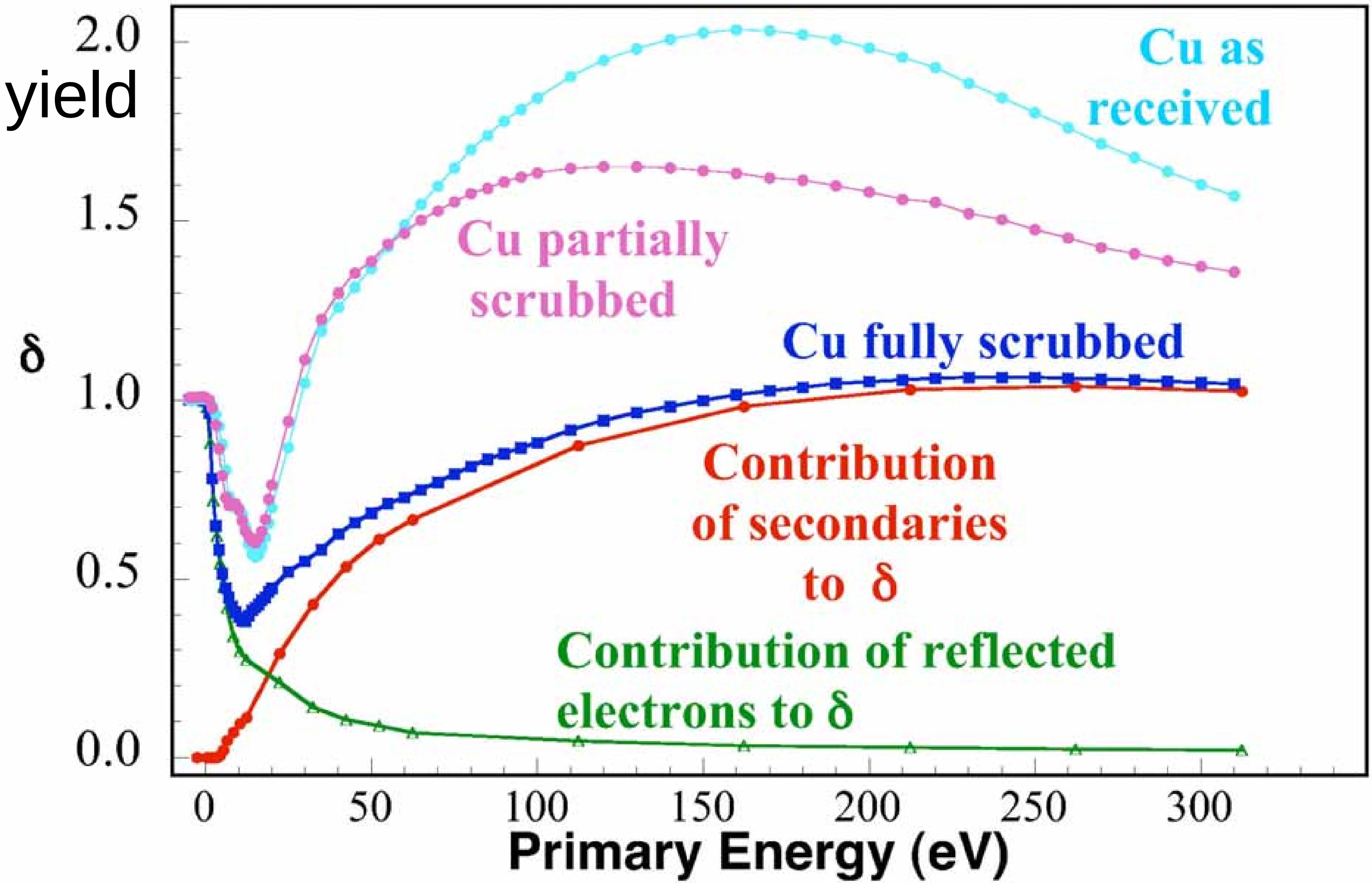
electron cloud in the LHC



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

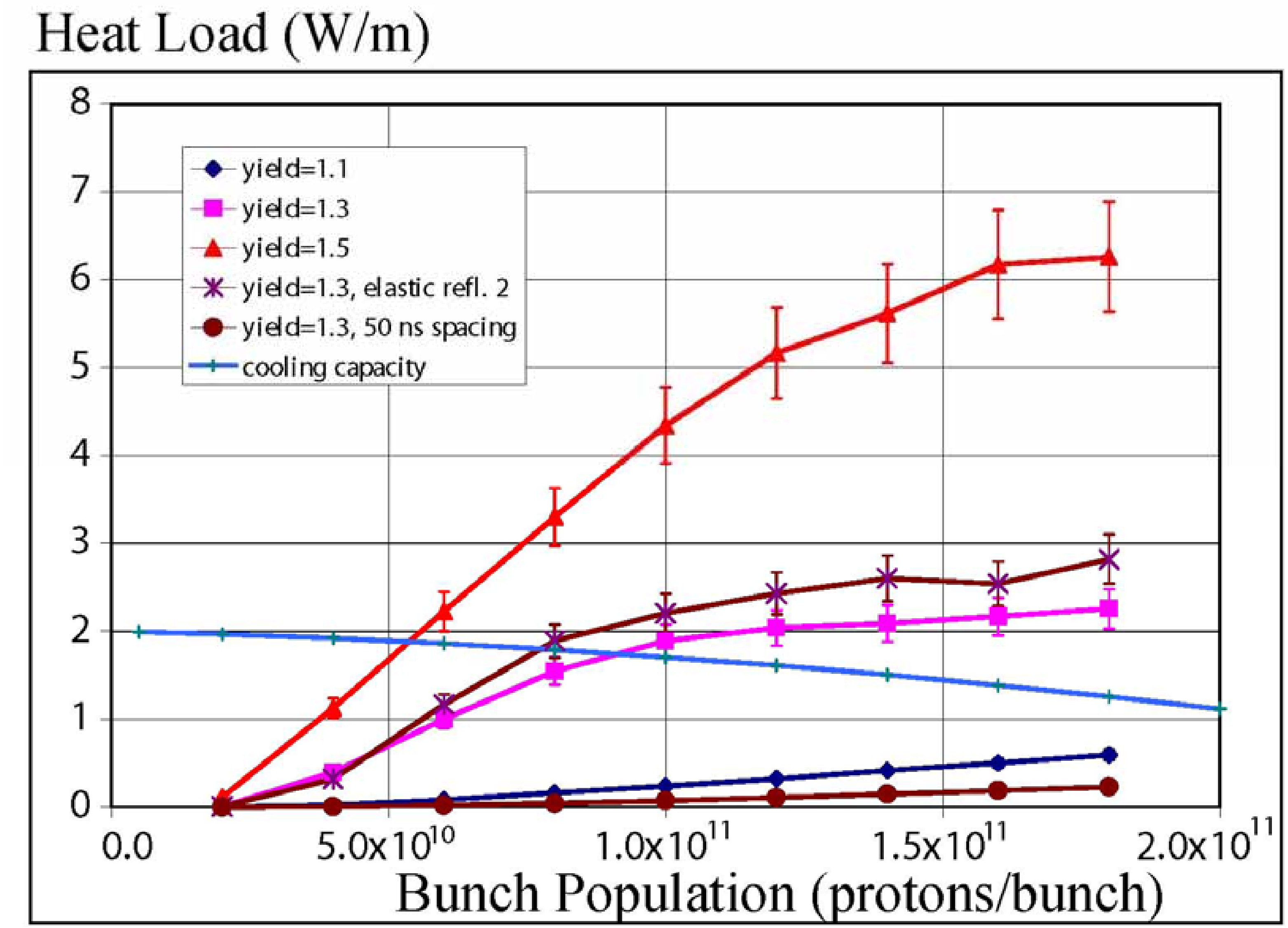
[F. Ruggiero]

in the background: simulation of bunch passing through e- plasma using the



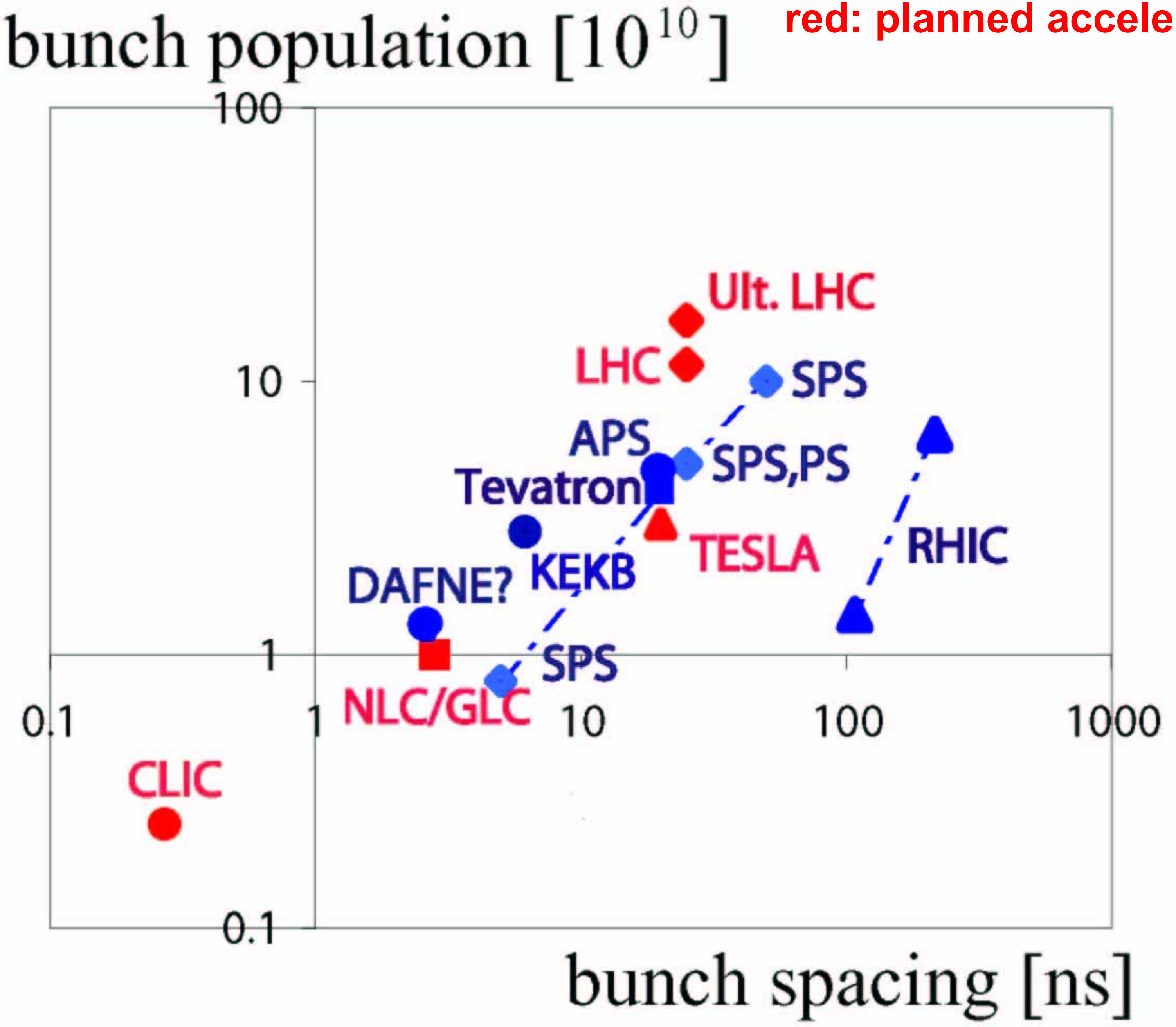
R. Cimino, I. Collins, 2003; CERN-AB-2004-012

probability of elastic electron reflection approaches 1 for zero incident energy and is independent of δ^*_{max}



Simulated average arc heat load due to electron cloud and LHC cooling capacity as a function of bunch population for **different values of the maximum secondary emission yield**. Nominal or ultimate LHC intensity and 25 ns spacing are probably ok for well conditioned surfaces.

blue: e-cloud effect observed
red: planned accelerators



multitude of countermeasures:

- multi-bunch & intrabunch feedback
  (INP PSR, Bevatron, SPS, KEKB)
- clearing electrodes
  (ISR, BEPC, SNS)
- antechamber (PEP-II)
- TiN coating (PEP-II, PSR, SNS)
- high Q’ (SPS)
- octupoles (BEPC)
- solenoids (KEKB, PEP-II, SNS)
- grooved surfaces (NLC)

LHC strategy against electron cloud

1) warm sections (20% of circumference) **coated by <u>TiZrV getter</u>** developed at CERN; low secondary emission; if cloud occurs, ionization by electrons (high cross section ~400 Mbarn) aids in pumping & pressure will even improve

2) outer wall of beam screen (at 4-20 K, inside 1.9-K cold bor will have a **<u>sawtooth surface</u>** (30 μm over 500 μm) to reduce photon reflectivity to ~2% so that photoelectrons are only emitted from outer wall & confined by dipole field

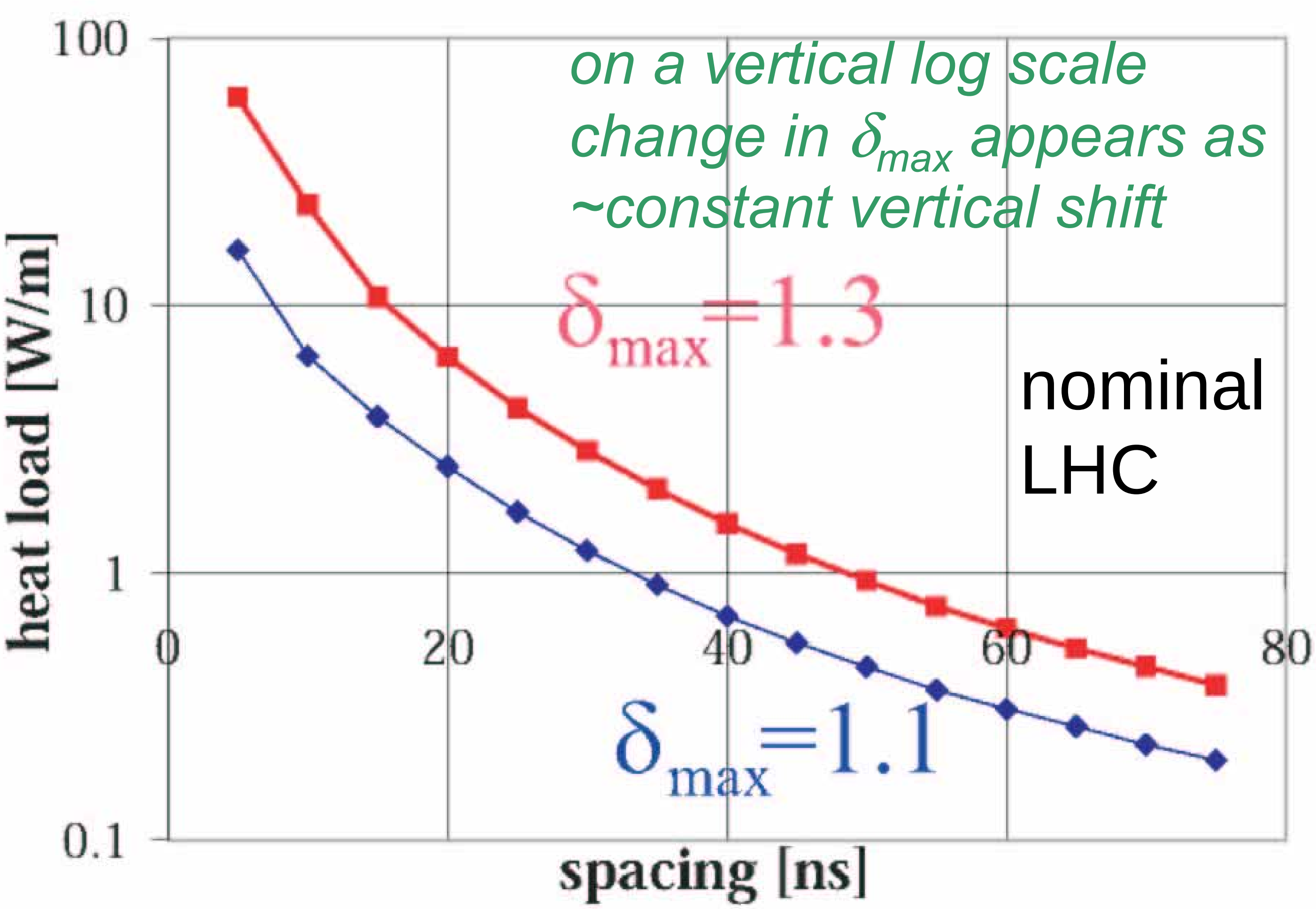
3) pumping slots in beam screen are **<u>shielded</u>** to prevent electron impact on cold magnet bore

4) rely on **<u>surface conditioning</u>** (‘scrubbing’); commissioning strategy; as a last resort doubling or tripling bunch spacing suppresses e-cloud heat load

e- cloud effect may also be reduced by:

- *larger bunch spacing*
- *high bunch intensity*
- *superbunches*

predicted e-cloud heat load vs. bunch spacing



on a vertical log scale change in δ_{max} appears as ~constant vertical shift

nominal LHC

Simulated average arc heat load due to electron cloud for nominal LHC bunch intensity as a function of the bunch spacing, for **two values of the maximum secondary emission yield δ_{max}**. Elastically reflected electrons are included.

saturation of e- build up for high bunch intensities

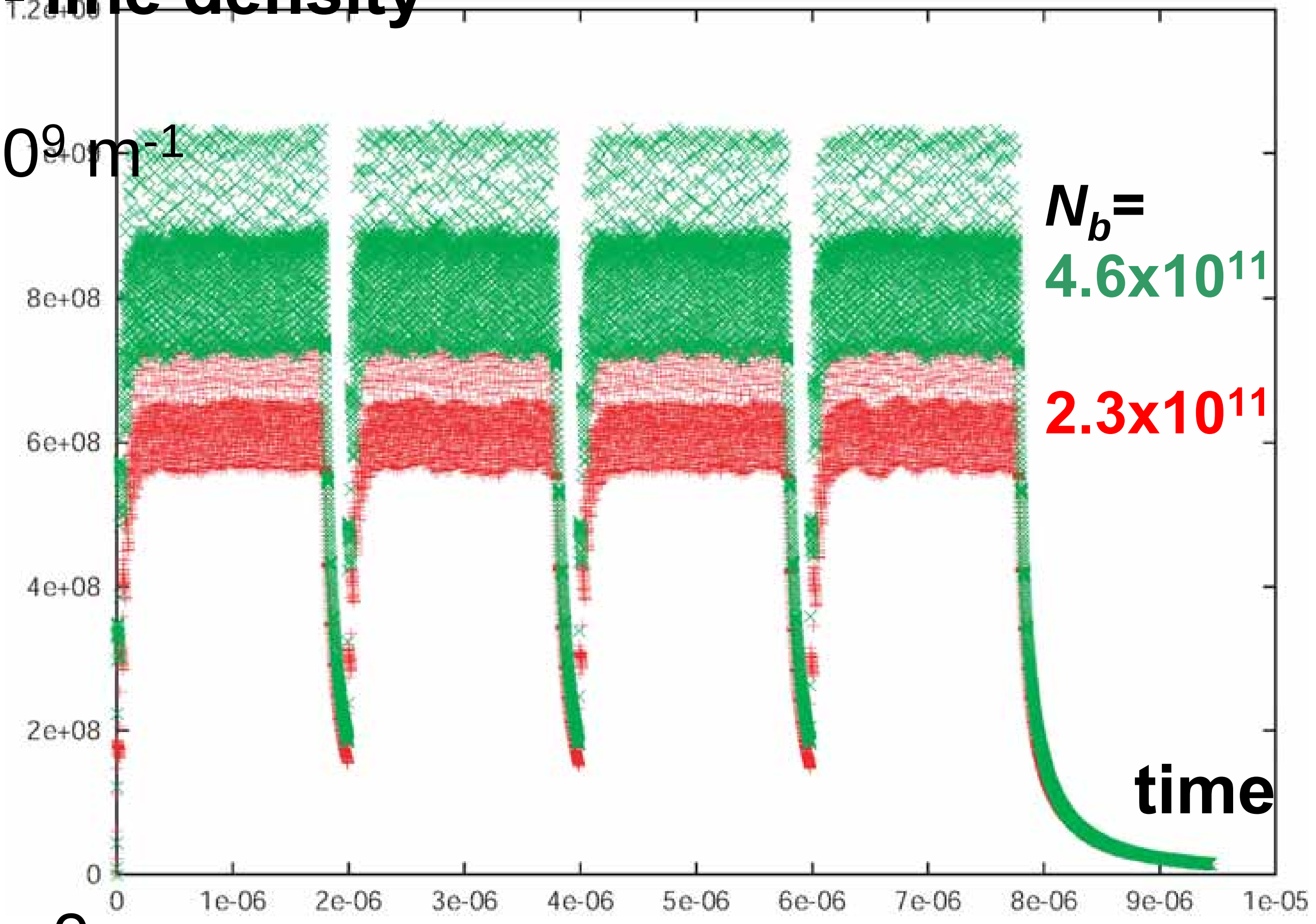
(S. Heifets)

$$\boxed{\lambda_e < \frac{E_0}{r_e m_e c^2} \approx 1.3\times 10^9\,\mathrm{m}^{-1}}$$

$E_0 \approx 1.9\,\mathrm{eV}$

~average energy of secondary electrons

e- line density



$10^9\ \mathrm{m}^{-1}$

N_b=

4.6x10^{11}

2.3x10^{11}

time

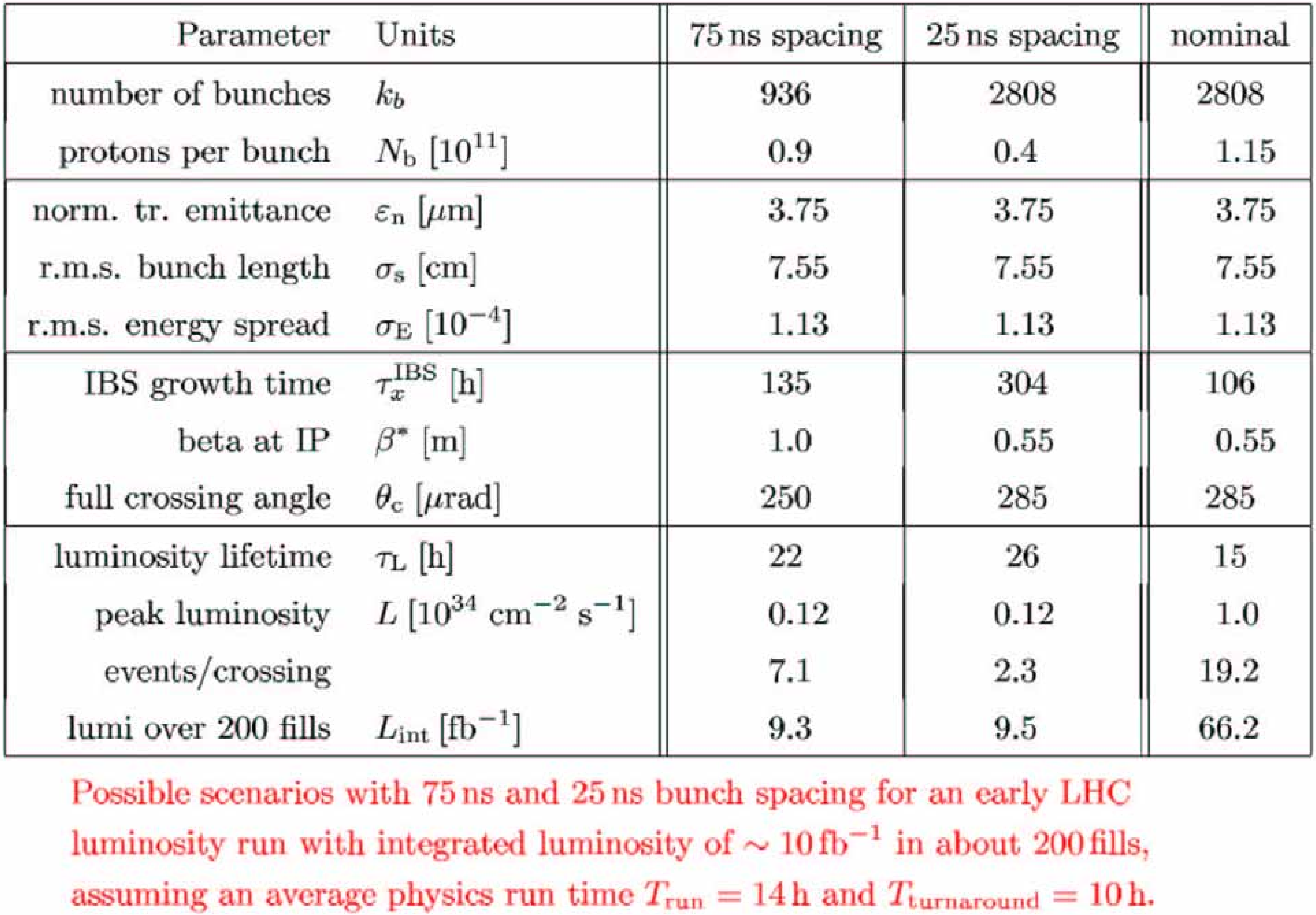
0

10 μs

the electron cloud density saturates and stays almost constant when the bunch intensity is doubled from the beam-beam limit value for two IPs of 2.3x10^{11} to 4.6x10^{11}

expected performance limitations (4)

commissioning plans



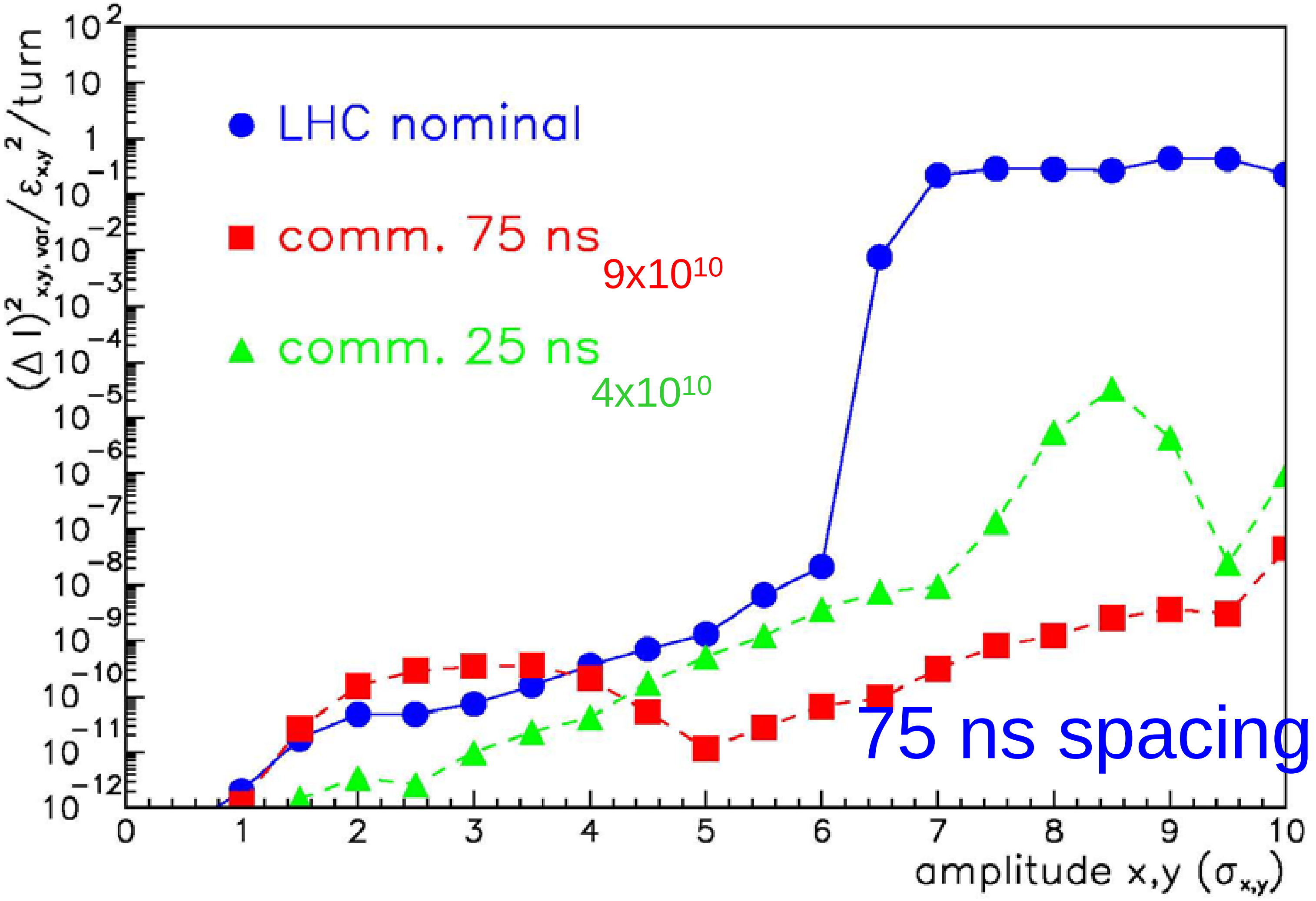
Parameter	Units	75 ns spacing	25 ns spacing	nominal
number of bunches	k_b	936	2808	2808
protons per bunch	N_b $[10^{11}]$	0.9	0.4	1.15
norm. tr. emittance	ε_n $[\mu\mathrm{m}]$	3.75	3.75	3.75
r.m.s. bunch length	σ_s [cm]	7.55	7.55	7.55
r.m.s. energy spread	σ_E $[10^{-4}]$	1.13	1.13	1.13
IBS growth time	τ_x^IBS [h]	135	304	106
beta at IP	β^* [m]	1.0	0.55	0.55
full crossing angle	θ_c $[\mu\mathrm{rad}]$	250	285	285
luminosity lifetime	τ_L [h]	22	26	15
peak luminosity	L $[10^{34}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}]$	0.12	0.12	1.0
events/crossing		7.1	2.3	19.2
lumi over 200 fills	L_int $[\mathrm{fb}^{-1}]$	9.3	9.5	66.2

Possible scenarios with 75 ns and 25 ns bunch spacing for an early LHC luminosity run with integrated luminosity of $\sim 10\,\mathrm{fb}^{-1}$ in about 200 fills, assuming an average physics run time $T_\mathrm{run} = 14\,\mathrm{h}$ and $T_\mathrm{turnaround} = 10\,\mathrm{h}$.

experiments prefer 25 ns with ~2 events/crossing

F. Ruggiero, Chamonix XII

long-range beam-beam effect relaxed

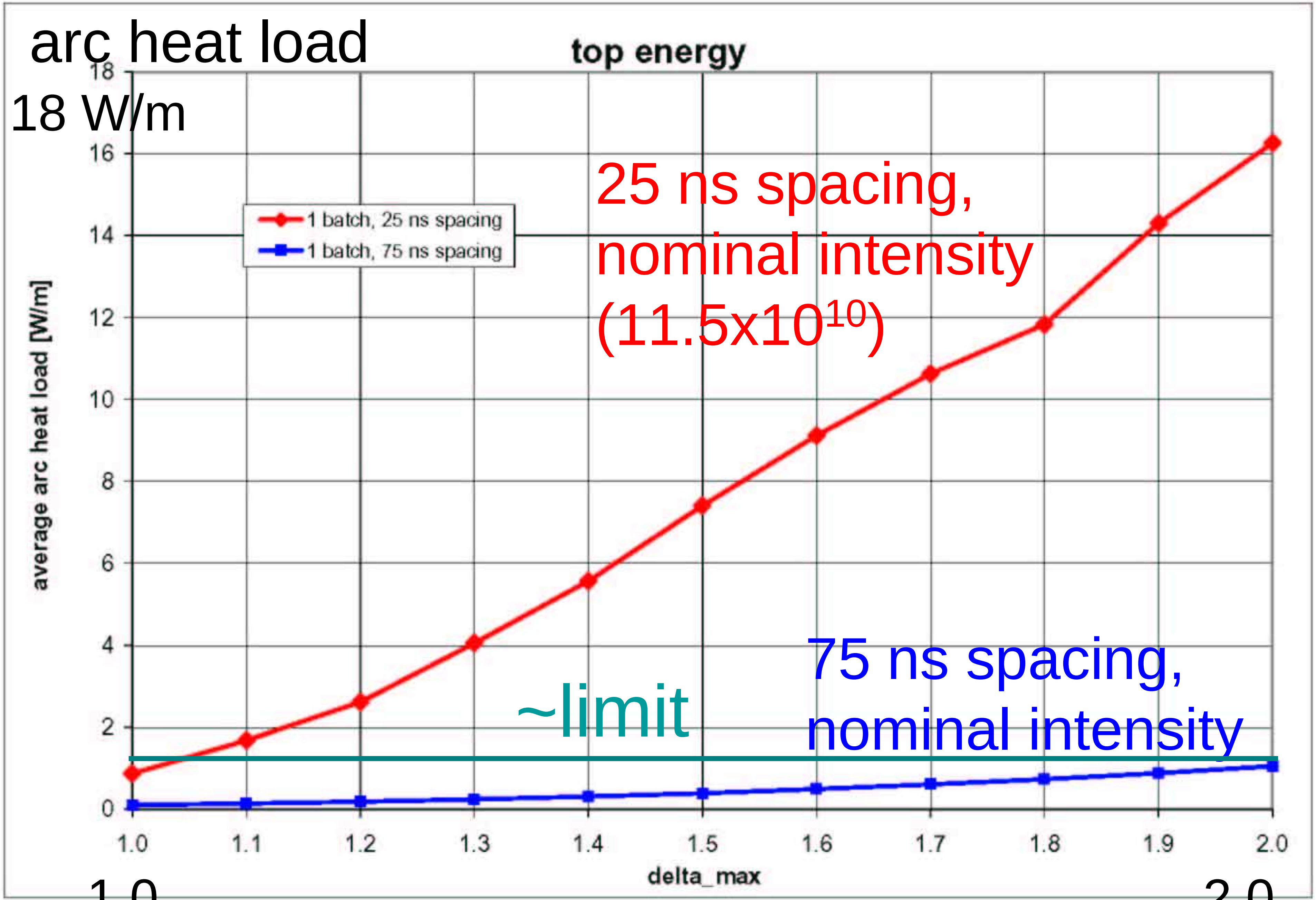


$9\text{x}10^{10}$

$4\text{x}10^{10}$

75 ns spacing

diffusive aperture with nominal and commissioning beams



arc heat load

18 W/m

25 ns spacing, nominal intensity (11.5×10^{10})

~limit

75 ns spacing, nominal intensity

1.0

2.0

δ_{max}

upgrade

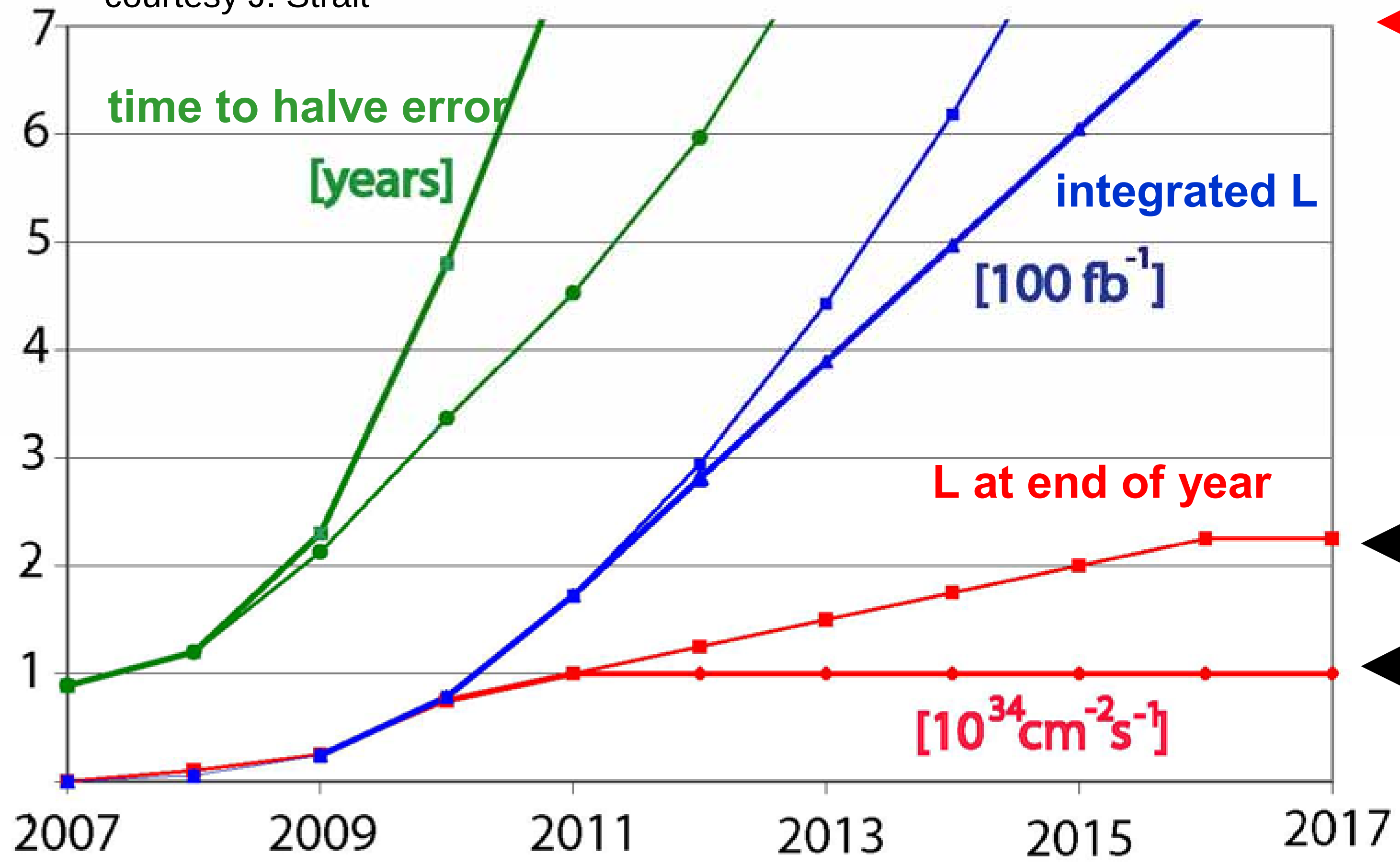
- physics motivation
- scenarios
- IR layout
- options

LHC luminosity upgrade (“SLHC”)
to 10^{35} cm^{-2} s^{-1} at 14 TeV

LHC energy ugrade (“VLHC”)
to 28 TeV c.m. energy

time scale of an LHC upgrade

courtesy J. Strait



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***

Chronology of LHC Upgrade Studies

- **Summer 2001:** two CERN task forces investigate physics potential (CERN-TH-2002-078) and accelerator aspects (LHC Project Report 626) of an LHC upgrade
- **March 2002:** LHC IR Upgrade collaboration meeting
  http://cern.ch/lhc-proj-IR-upgrade
- **October 2002:** ICFA Seminar at CERN on
  "Future Perspectives in High Energy Physics"
- **March 2003:** LHC Performance Workshop, Chamonix
  http://ab-div.web.cern.ch/ab-div/Conferences/Chamonix/2003/
- **2004:** CARE-HHH European Network on
  High Energy
  High Intensity
  Hadron Beams
  http://care-hhh.web.cern.ch/care-hhh/

fundamental luminosity equations

(1) $L \approx \frac{n_b N_b^2 f_{rev}}{4\pi\sigma^{*2}} F\,,\ \text{where}\quad F \approx \left(1+\left(\frac{\theta_c\sigma_z}{2\sigma^*}\right)^2\right)^{-1/2}$

$$\sigma^* = \sqrt{\beta^*\varepsilon}$$

below beam-beam limit, luminosity is reduced for long bunches and large θ_c

HV crossing in 2 IPs ⟶ no linear tune shift due to long-range collisions, total linear tune shift also reduced by a factor F_{bb}~F:

(2) $\Delta Q_{bb} = \xi_{x,HO} + \xi_{y,HO} \approx \frac{N_b r_p}{2\pi\gamma\varepsilon} F$

two schemes:
increase F or 1/F!

combine (1) + (2):

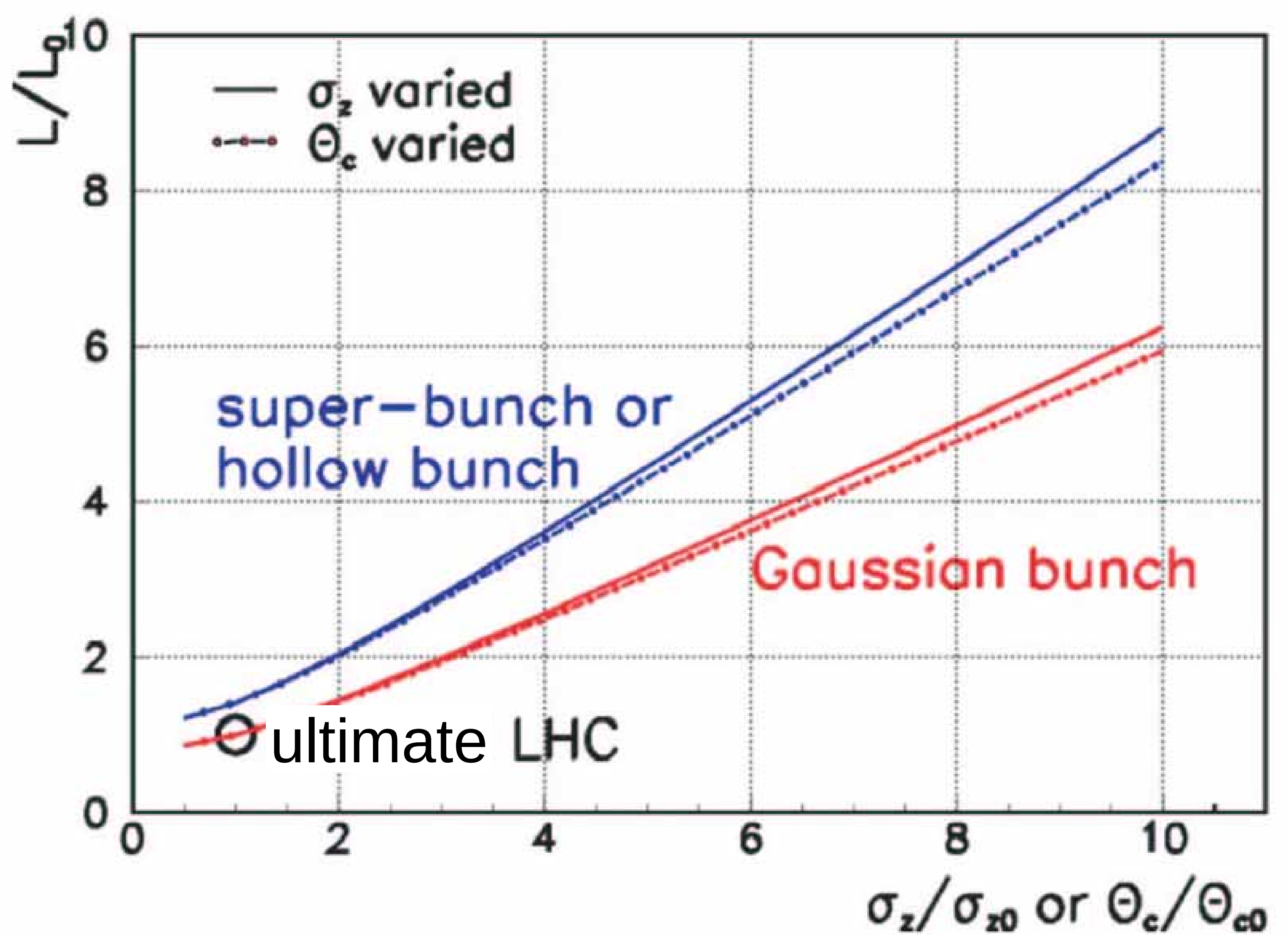
$$\boxed{L \approx \gamma(\Delta Q_{bb})^2 \frac{\pi(\varepsilon\gamma) f_{rep}}{r_p^2\beta^*} \overbrace{\left(1+\left(\frac{\theta_c\sigma_z}{2\sigma^*}\right)^2\right)^{1/2}}^{1/F}}$$

at the beam-beam limit, luminosity can be increased by increasing bunch length or θ_c

*a) **higher injection energy** would allow larger $(\gamma\varepsilon)$ and hence more intensity & luminosity*

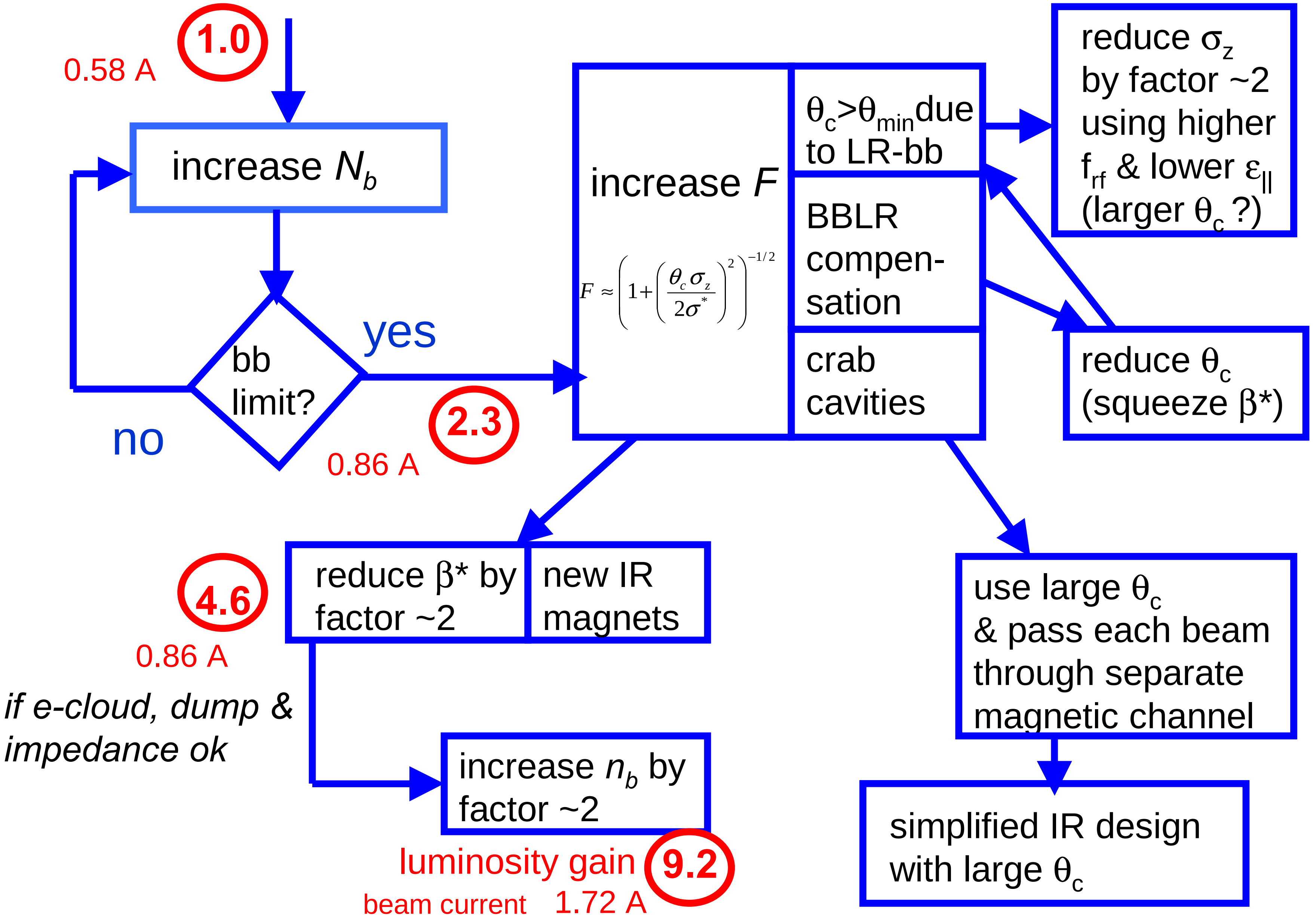
*b) another possibility to achieve higher luminosity is to operate with **large crossing angle** (either 'Piwinski regime' or 'superbunches')*

K. Takayama et al., PRL88, 2002
F. Ruggiero, F. Zimmermann, PRST-AB 5, 2002



Relative increase in LHC luminosity versus bunch length (or crossing angle) for Gaussian and flat (super-)bunches at constant beam-beam tune shift with alternating crossings in IP1 and IP5

luminosity upgrade: baseline scheme



1.0

0.58 A

increase N_b

bb limit?

no

yes

2.3

0.86 A

increase F

$$F \approx \left(1+\left(\frac{\theta_c\sigma_z}{2\sigma^*}\right)^2\right)^{-1/2}$$

$\theta_c > \theta_{min}$ due to LR-bb

BBLR compen-sation

crab cavities

reduce σ_z by factor ~2 using higher f_{rf} & lower $\varepsilon_{||}$ (larger θ_c ?)

reduce θ_c (squeeze β^*)

4.6

0.86 A

reduce β^* by factor ~2

new IR magnets

if e-cloud, dump & impedance ok

increase n_b by factor ~2

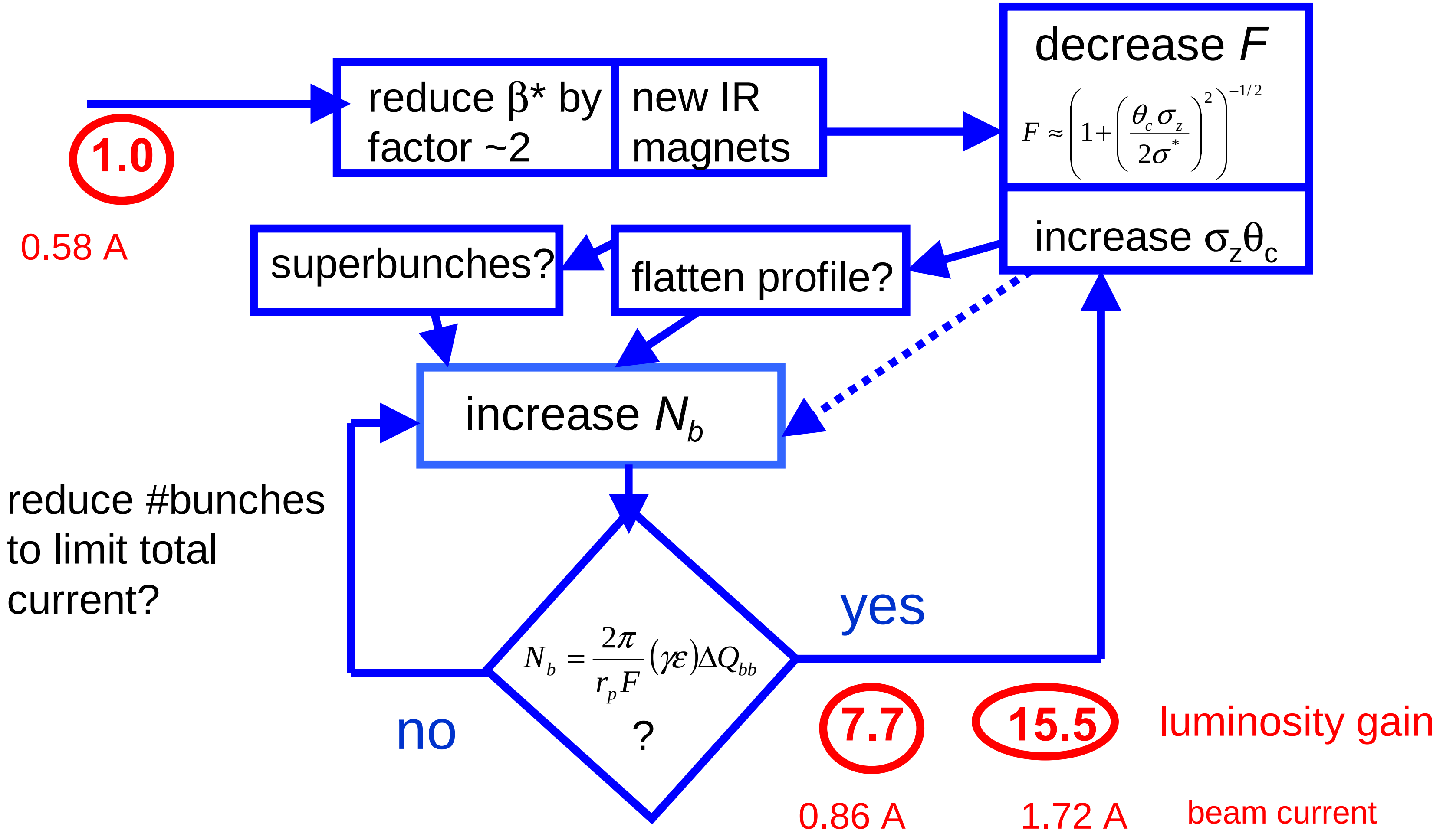
luminosity gain 9.2

beam current 1.72 A

use large θ_c & pass each beam through separate magnetic channel

simplified IR design with large θ_c

luminosity upgrade: Piwinski scheme



1.0

0.58 A

reduce β^* by factor ~2

new IR magnets

decrease F

$$F \approx \left(1 + \left(\frac{\theta_c \sigma_z}{2\sigma^*}\right)^2\right)^{-1/2}$$

increase $\sigma_z\theta_c$

superbunches?

flatten profile?

increase N_b

reduce #bunches to limit total current?

$$N_b = \frac{2\pi}{r_p F}(\gamma\varepsilon)\Delta Q_{bb}$$

?

yes

no

7.7

15.5

luminosity gain

0.86 A

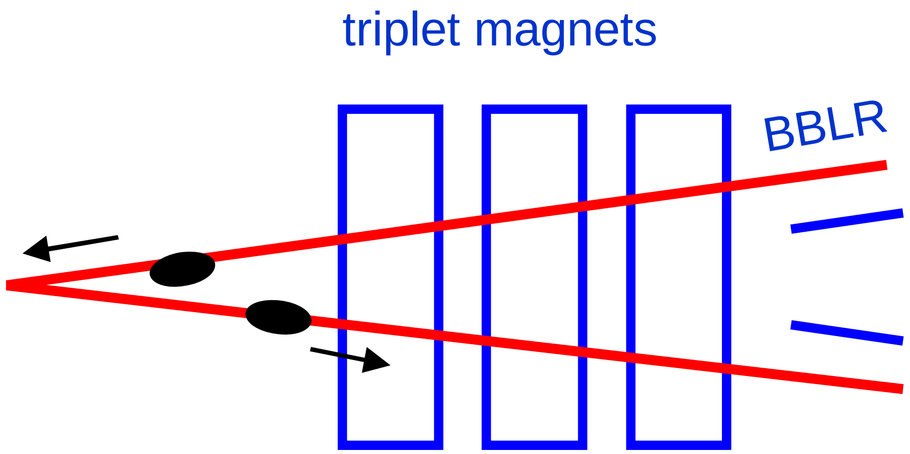
1.72 A

beam current

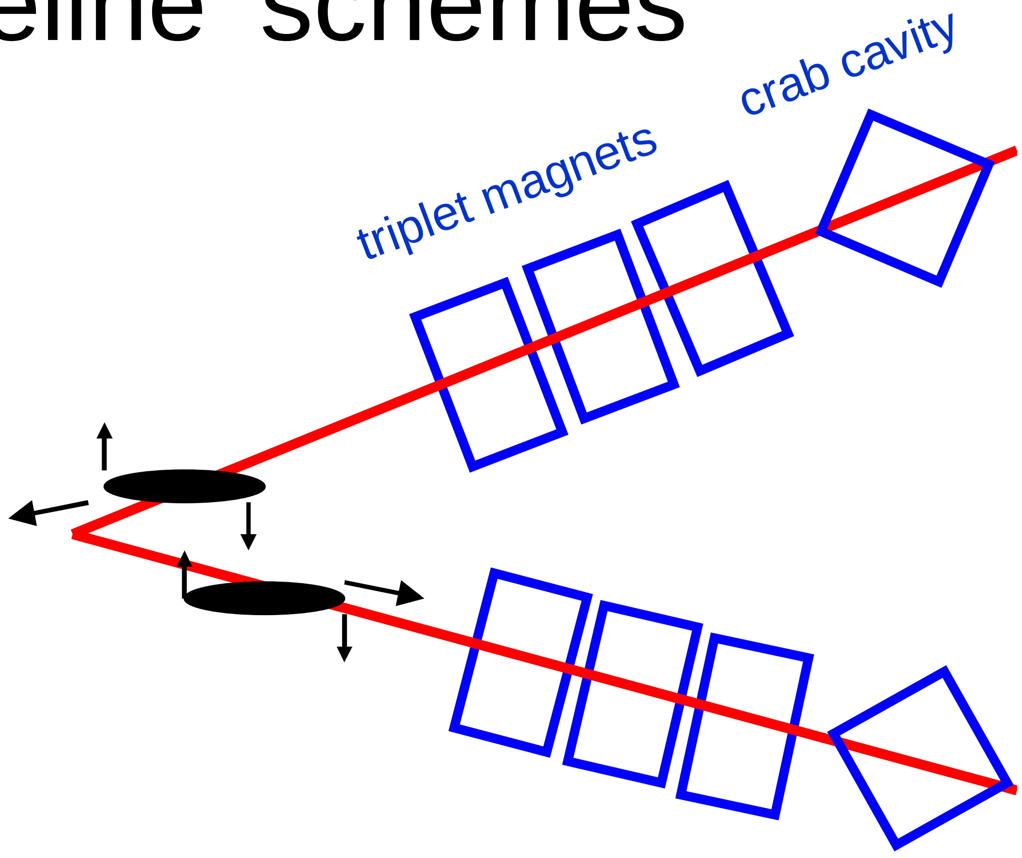
additional considerations

- total current limited? (e.g. by e-cloud, machine protection, dump) ⟶ fewer bunches with more charge give higher luminosity, but also increase the event pile up
- minimum β^*: depends on IR magnets, Q' correction (more critical for larger $\Delta p/p_{rms}$) & collimator settings
- integrated luminosity $\sim T_{bb}/(T_{bb}+T_{turnaround})$: reduce $T_{turnaround}$ by increasing E_{inj} (SuperSPS), which reduces injection time and snapback
- BBLR compensation + "SuperSPS" ⟶ larger intensity at larger ε_n: $L \longrightarrow L{*}2$
- $\approx \sqrt{2}$ more luminosity with flat (long) bunches
- capability of experiments, e.g., bunch structure

IR upgrade ‘baseline’ schemes

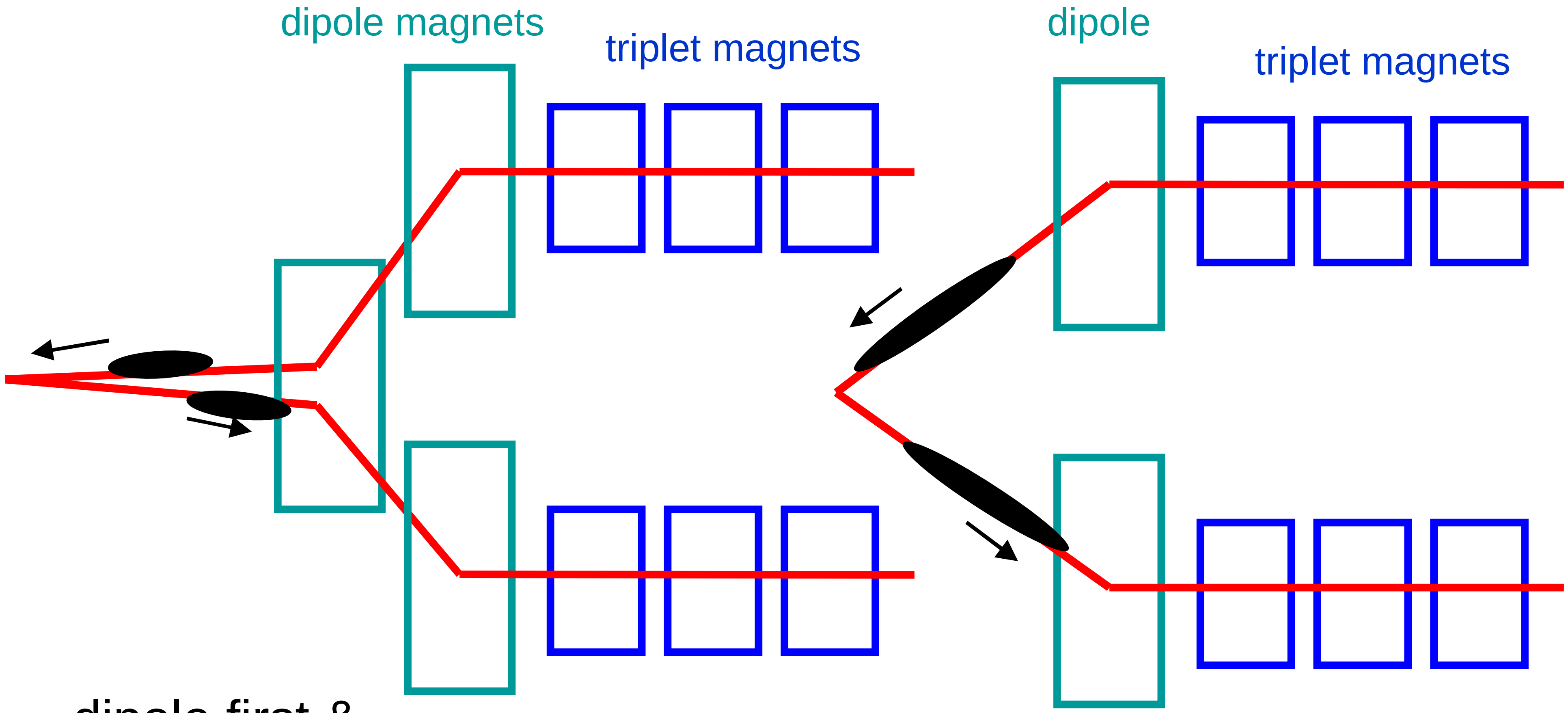


short bunches &
minimum crossing angle &
BBLR



crab cavities &
large crossing angle

alternative IR upgrade schemes



dipole first &
small crossing angle

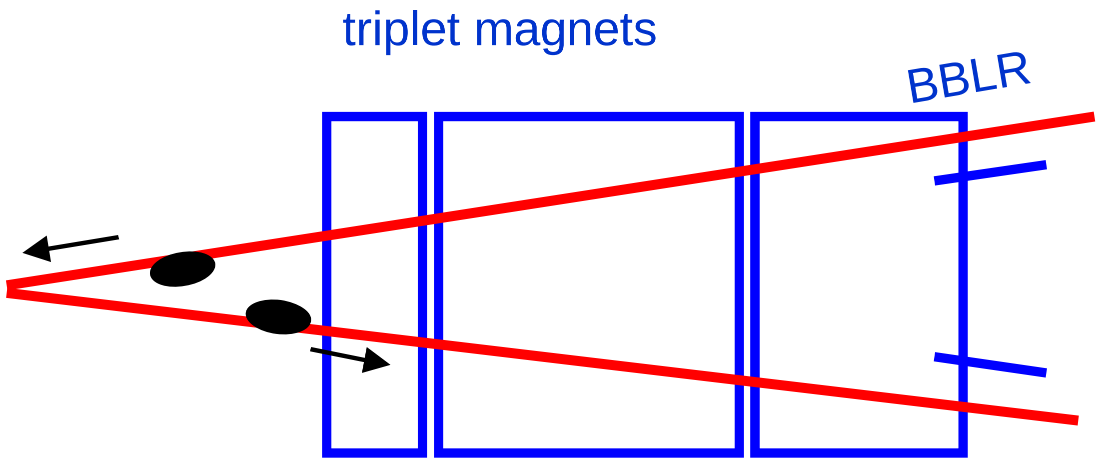
reduced # LR collisions
collision debris hits D1

N. Mokhov et al.,
PAC2003

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

‘cheap’ IR upgrade

in case we need to double LHC luminosity earlier than foreseen



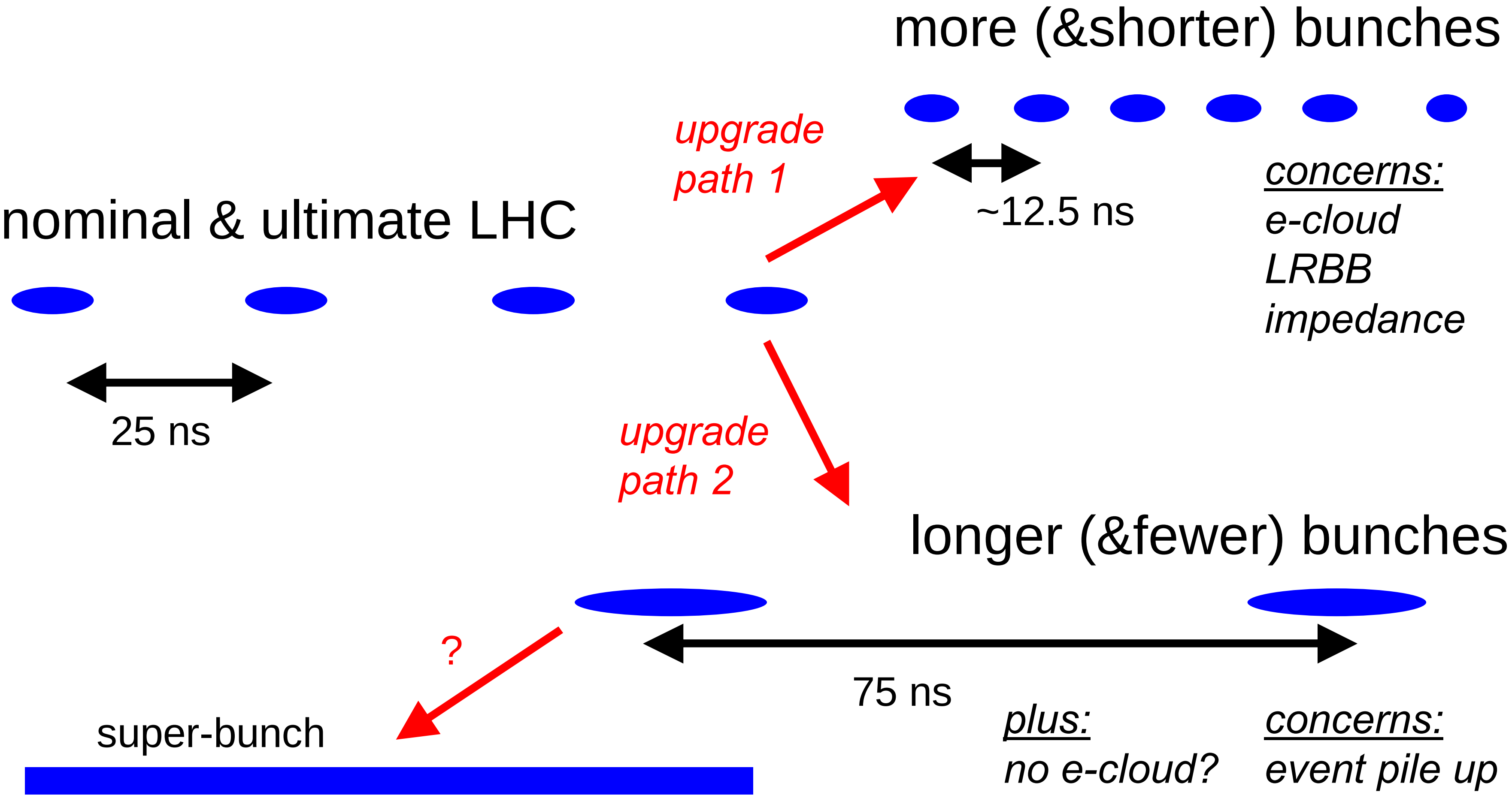
short bunches &
minimum crossing angle &
BBLR

F. Ruggiero et al.,
EPAC2004

each quadrupole individually optimized (length & aperture)
IP-quad distance reduced from 23 to 22 m
NbTi, β^**=0.25 m possible*

bunch structure

plus:
can use crab cavities
event pile up tolerable



more (&shorter) bunches

~12.5 ns

concerns:
e-cloud
LRBB
impedance

upgrade path 1

nominal & ultimate LHC

25 ns

upgrade path 2

longer (&fewer) bunches

75 ns

?

super-bunch

plus:
no e-cloud?
less current

concerns:
event pile up
impedance

concerns:
huge event pile up

plus:
no e-cloud
less current

transitions by bunch merging or splitting;
new rf systems required in all cases

example parameter sets

parameter	symbol	nominal	ultimate	shorter bunches	longer bunches	superbunch
#bunches	n_b	2808	2808	5616	936	1
protons/bunch	N_b [10^{11}]	1.15	1.7	1.7	6.0	5600
bunch spacing	Δt_{sep} [ns]	25	25	12.5	75	89000
average current	I [A]	0.58	0.86	1.72	1.0	1.0
norm. transv. emittance	ε_n [μm]	3.75	3.75	3.75	3.75	3.75
longit. profile		Gaussian	Gaussian	Gaussian	uniform	uniform
rms b. length	σ_z [cm]	7.55	7.55	3.78	14.4	6000
beta at IP1&IP5	β^* [m]	0.55	0.5	0.25	0.25	0.25
crossing angle	θ_c [μrad]	285	315	445	430	1000
Piwinski parameter	$\theta_c\sigma_z/(\sigma^* 2)$	0.64	0.75	0.75	2.8	2700
luminosity	L [10^{34} cm^{-2}s^{-1}]	1.0	2.3	9.2	8.9	9.0
events/ crossing		19	44	88	510	$5\text{x}10^5$
length luminous region (rms)	σ_{lum} [mm]	44.9	42.8	21.8	36.3	16.7

baseline ‘Piwinski’ super-bunch

Crab Cavity for Super LHC?

R. Palmer, 1988
K. Oide, K. Yokoyam 1989

crab voltage

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

phase tolerance

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

challenging parameters & proton-beam emittance growth concern

variable	symbol	KEKB	SuperLHC	
beam energy	E_b	8 GeV	7 TeV	
rf frequency	f_{crab}	508 MHz	0.35	1.3 GHz
crossing angle	Θ_c	11 mrad	8 mrad	
IP β	β*	0.33 m	0.25 m	
cavity β	β_{cav}	100 m	2 km	
kick voltage	V_{crab}	1.44 MV	**171**	**46 MV**
phase tolerance	Δϕ		0.02	0.06 mrad

Physics potential of the LHC at 10^{35} cm^{-2} s^{-1} (SLHC)

What improvements in the physics reach could we expect from operating the LHC at a luminosity of ~ 10^{35} cm^{-2} s^{-1} with an integrated luminosity ~ 1000 fb^{-1} per year at $\sqrt{s} \approx 14$ TeV i.e. retaining present LHC magnets/dipoles - ➡ an upgrade at a relatively modest cost for machine + experiments (< 0.5 GSF) for ~ 2013-15 (much cheaper and before ILC, …..CLIC, VLHC…..)

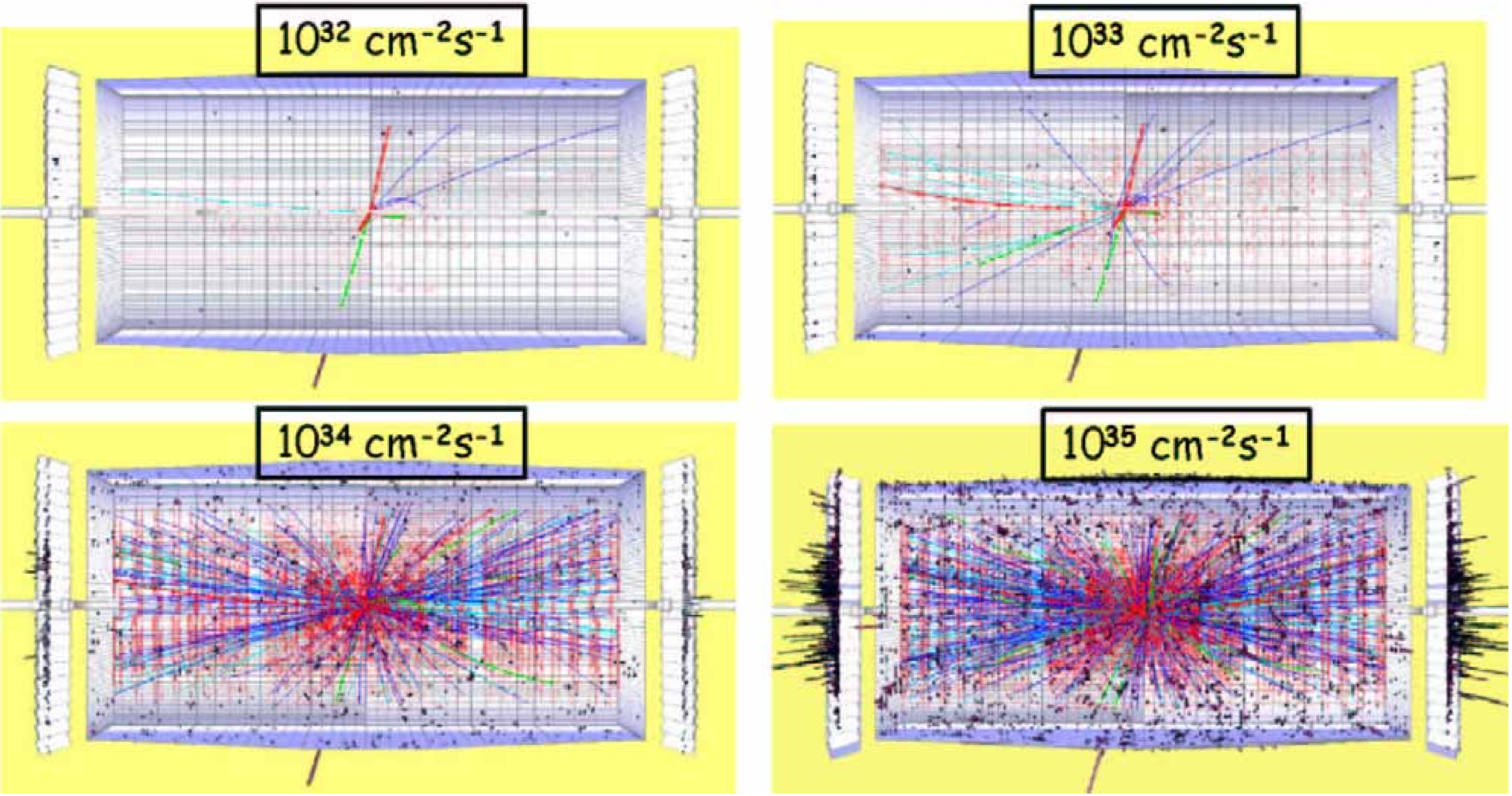
a more ambitious upgrade - at a much higher cost (~ 2 GSF) - would be to go for a $\sqrt{s} \approx 30$ TeV machine changing LHC dipoles (~16T, Nb_3Sn?) - only sporadically mentioned here

Topics addressed:

- some **experimental requirements/desirability**, **expected performances**
- improvements in some basic **SM measurements and in SM/MSSM Higgs reach**
- **improvements in reach at high mass scales**, for ex strongly interacting W,Z,
- **sparticle reach and studies**, possible new gauge bosons, massive states appearing in **extra dimension models**
- **main motivations for an upgrade** i.e.exploit maximally “existing” machine & detectors

D. Denegri, CARE-HHH Workshop, CERN, Nov. 8-11th, 2004

H->ZZ->μμee (m_H=300 GeV)



detector simulation with pile-up noise

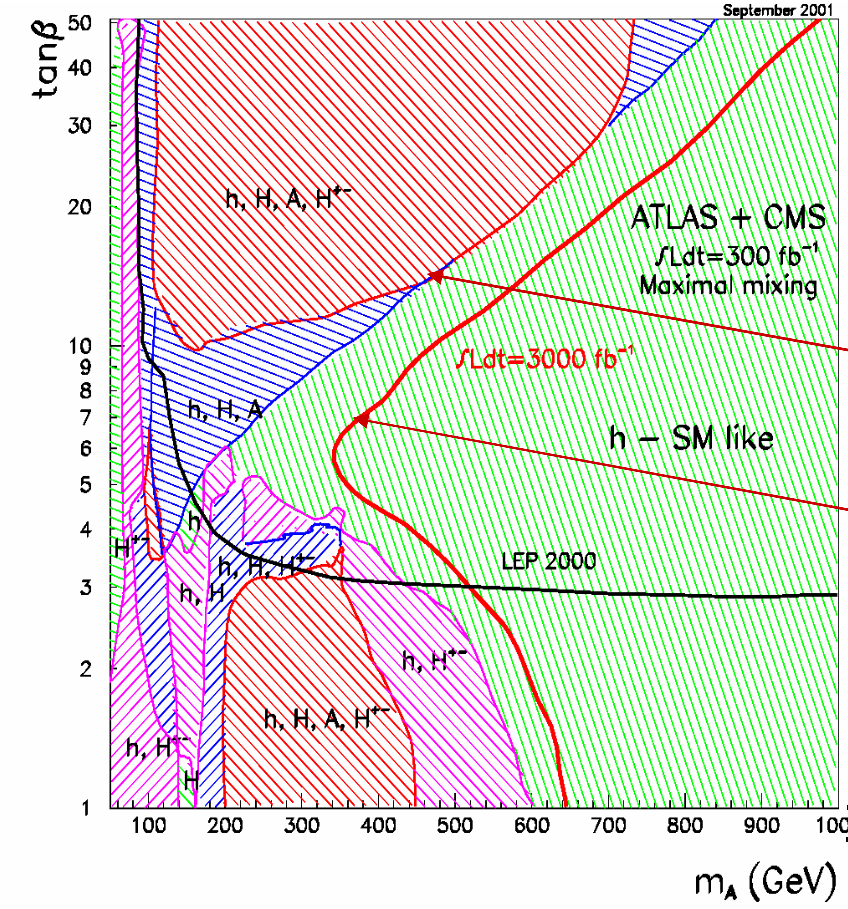
S. Tapprogge, CARE-HHH Workshop, CERN, Nov. 8-11th, 2004

statement from CMS & ATLAS on super-bunches:

‘based on the physics motivation for an upgrade of the LHC luminosity by an order of magnitude, it is not seen how in case of the super-bunch scenario, this increase in luminosity could be exploited by an upgraded ATLAS or CMS detector’

SLHC: improved reach for MSSM Higgs bosons - overview

MSSM parameter space regions for > 5σ discovery for the various Higgs bosons, 300 fb^{-1} (LHC), and expected improvement - at least two discoverable Higgs bosons - with 3000 fb^{-1} (SLHC) per experiment, both experiments combined.



1 TeV

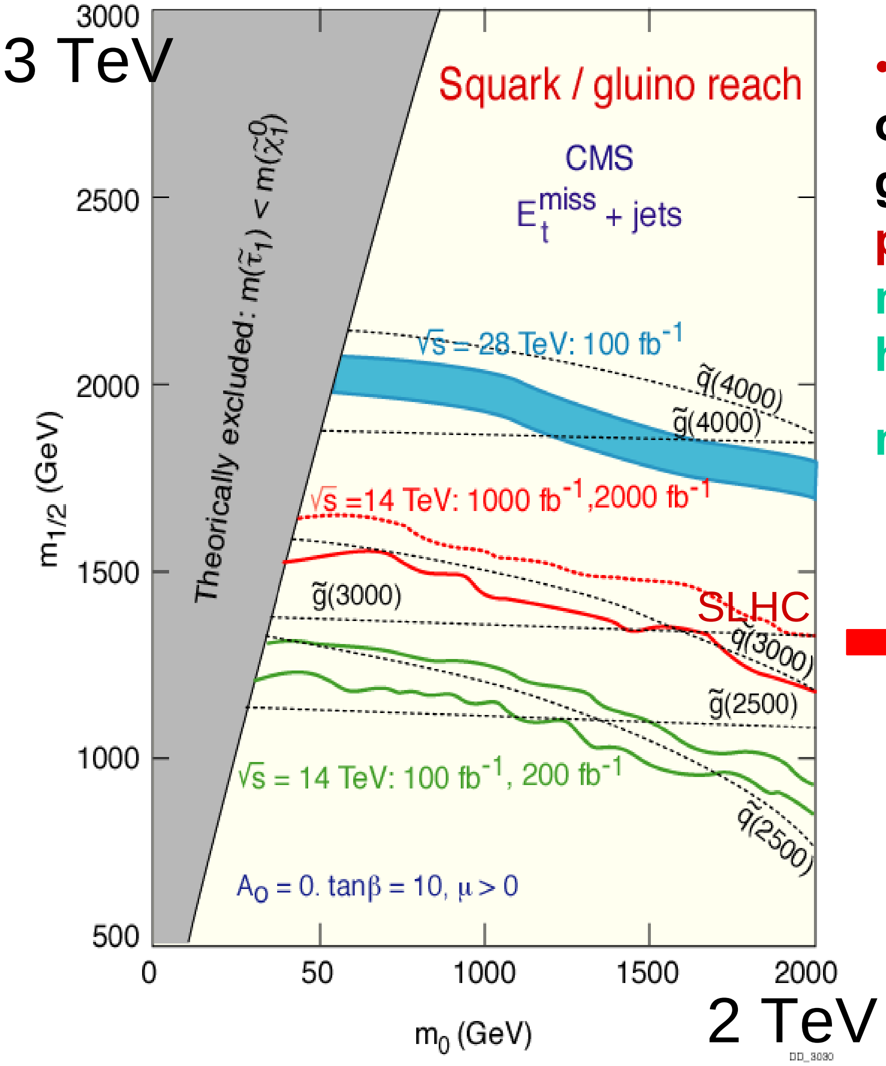
green area: region where only one (the h, ~ SM-like) among the 5 MSSM Higgs bosons can be found in the standard LHC (assuming only SM decay modes)

LHC contour, 300 fb^{-1}

SLHC contour, 3000 fb^{-1}

at least one heavy Higgs discoverable up to here

SUSY at SLHC/VLHC - mass reach



3 TeV

2 TeV

Notice advantage of a 28 TeV machine….

- **Higher integrated luminosity brings an obvious increase in mass reach in squark, gluino searches, i.e. in SUSY discovery potential;**

not too demanding on detectors as very high E_t jets, E_t^{miss} are involved, large pile-up

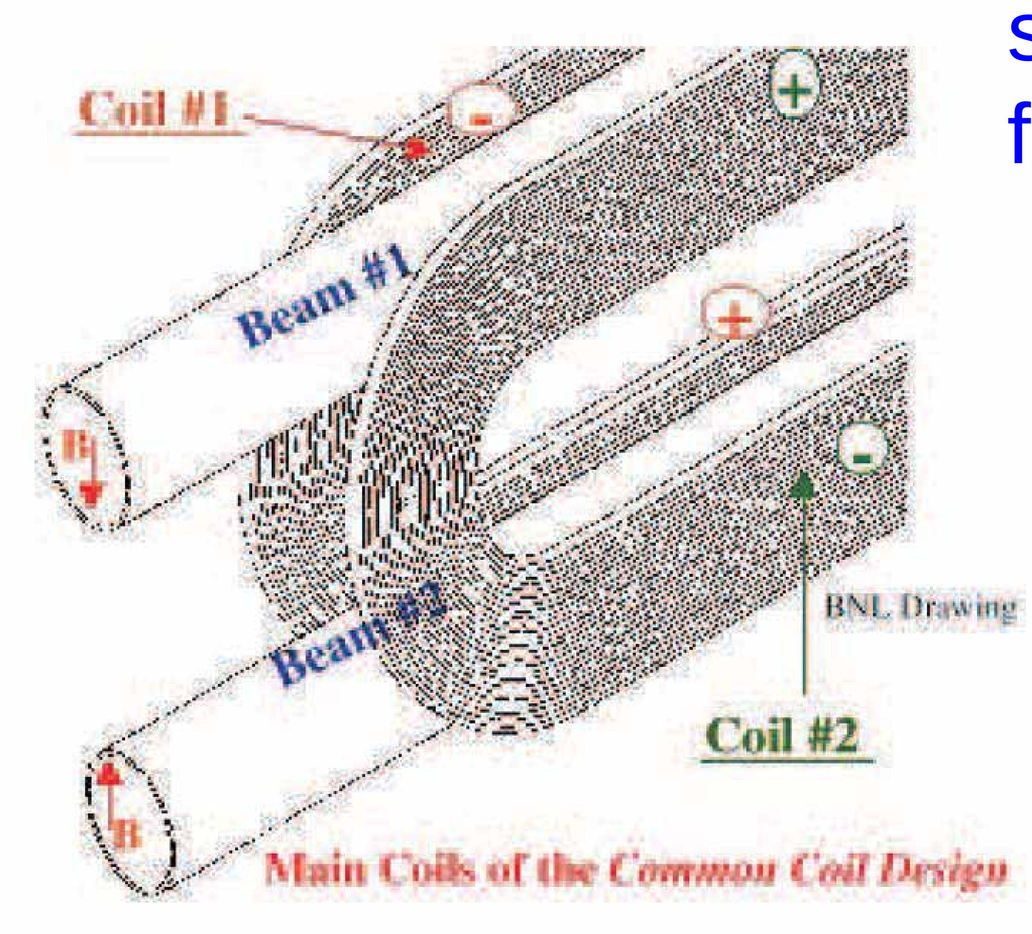
not so detrimental

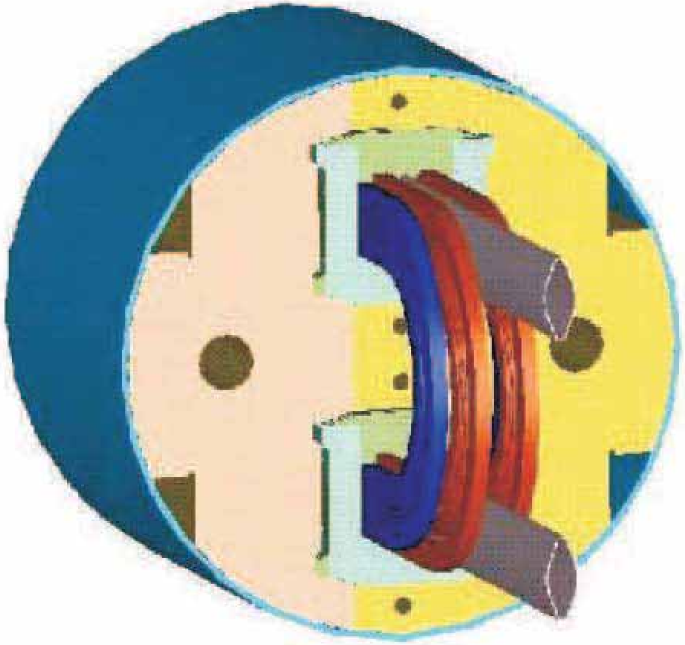
➡ **with SLHC the SUSY reach is increased by ~ 500 GeV, up to ~3 TeV in squark & gluino masses**

(and up to ~4 TeV for VLHC)

D. Denegri, CARE-HHH Workshop, CERN, Nov. 8-11th, 2004

stronger magnets for energy upgrade?





Sketch of the **common coil design** for a double aperture dipole magnet; the coils couple the two apertures and can be flat (no difficult ends). One of the most difficult challenges will be to ***make the magnets at a reasonable cost***, less than 5kEuro/(double)T.m say, including cryogenics, to be compared with 4.5 kEuro/(double)T.m for the present LHC.

BERKELEY LAB
Accelerator and Fusion
Research Division

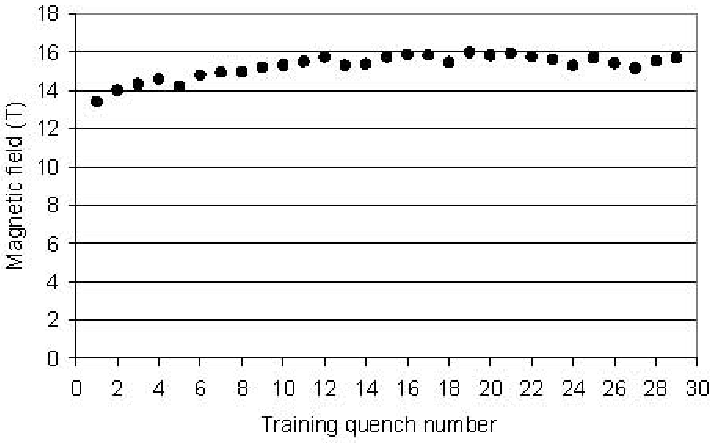
LBNL Superconducting Magnet Program Newsletter

October 2003
Issue No. 2

Nb_3Sn block-coil dipole reached 16 T field

HD-1 Sets New Dipole Field Record

On October 9, 2003, the Nb_3Sn dipole HD-1 achieved its design field of 16 Tesla, surpassing by more than one Tesla the previous field record, set by the RD3b dipole in April 2001. The test started on October 8, 2003, with a first quench at 13.4 Tesla and rapid progress to 14.8 Tesla (above RD3b level) in five more quenches. About 30 training ramps were performed during the first cool-down cycle. After nine quenches, the magnet consistently reached fields above 15.2 T, with five quenches above 15.8 T.



HD-1 training history (first thermal cycle)

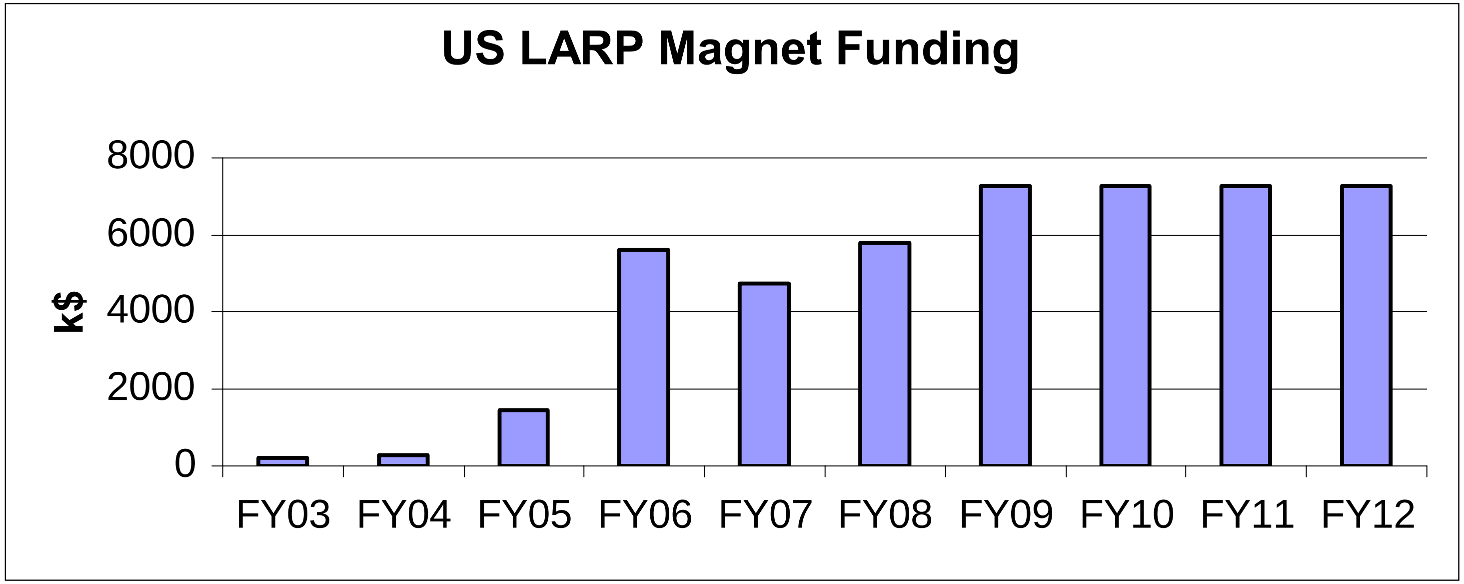
HD-1 is a block-coil dipole designed to push the limits of accelerator magnet technology to unprecedented levels in terms of magnetic field and mechanical stresses. The magnet uses state of the art conductor with a critical current density of 3 kA/mm^2 at 12 T, 4.2 K. This conductor, developed by Oxford Instruments Superconducting Technology, is suitable for generation of very high fields in practical accelerator designs. However, the associated mechanical stresses may cause severe degradation of the conductor properties. Until recent years, this effect was believed to represent a major performance limitation for Nb_3Sn accelerator magnets.

After the D-20 and RD3b dipoles demonstrated successful operation up to a coil stress of 120 MPa, we designed HD-1 to investigate the conductor performance under stress levels above 150 MPa. A single-bore block-coil geometry was selected, marking a return to configurations developed during the early stages of the LBNL Nb_3Sn program. This choice is motivated by the following factors: physical separation between high-field and high-stress points; use of flat cables with minimal degradation; simple winding procedures, end parts, support structures, assembly techniques; modularity of the coil package; potential for high conductor packing and efficient coil grading; compatibility with force bypasses to avoid stress accumulation. Most of these advantages are shared with the common coil

US-LARP

A. Devred

- in June 2003, the DOE has given its backing to the US-LHC Accelerator Research Program (LARP) involving BNL, FNAL, LBNL and SLAC.



(Courtesy S. Gourlay)

- Significant fraction of the Program concerns development of high field-gradient, Nb_3Sn quadrupole magnets aimed at LHC IR upgrade.

EU-FP6 CARE-NED

Next European Dipole

NED is a 3 years Joint Research Activity embedded in the Integrated Activity CARE (Coordinated Accelerator Research in Europe).

objectives:

- ➢ promote high-performance Nb3Sn wire development in collaboration with European industry and produce a number of representative unit lengths of high-performance Rutherford cables, **aiming at a non-copper current density of 1500 A/mm^2 at 15 T and 4.2 K**
- ➢ develop a preliminary design of a **large aperture, high-field Nb3Sn dipole** model magnet that could **push the technology well beyond LHC limits**
- ➢ carry out some investigations on improvement of Nb$_3$Sn conductor insulation and its heat transfer properties

summary

- LHC commissioning scheduled to start 2007 with first physics results foreseen in 2008
- in 1st years learn to protect machine and to overcome limitations from collimation, electron cloud, beam-beam,…
- reach nominal luminosity 10^{34} $cm^{-2}s^{-1}$ after 4-5 years (very challenging! step of 2-3 orders of magnitude beyond present hadron colliders in many parameters!)
- luminosity upgrade up to 10^{35} $cm^{-2}s^{-1}$ (new low-β quadrupoles, higher current, higher-frequency rf?, beam-beam compensation?, crab cavities?) lilkely around 2014/15
- at a later stage energy upgrade to 28 TeV c.m.? (new dipole magnets)