CERN Accelerator Projects and Future Plans

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DESY, Hamburg, 30 June 2009

Thanks to: Markus Aicheler, Ralph Assmann, Bernhard Auchmann, Elena Benedetto, Oliver Bruning, Hans Braun, Rama Calaga, Allen Caldwell, Bernd Dehning, Roland Garoby, Frank Gerigk, Massimo Giovannozzi, Alex Herlert, Jena-Pierre Koutchouk, Yannis Papaphilippou, Gersinde Prior, Robert Rossmanith, Walter Scandale, Rüdiger Schmidt, Ralph Steinhagen, Elena Wildner, Guoxing Xia, ...

CERN

- CERN was founded in 1954
- as one of Europe's first joint ventures
- it sits astride Franco-Swiss border near Geneva
- currently 20 European member states (Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, the Netherlands, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland and United Kingdom)
- observer states & organizations (the European Commission, India, Israel, Japan, Russian Federation, Turkey, UNESCO and USA)
- with the participation of the United States, Canada, Japan, Russia, India and others, CERN's main accelerator, the LHC, is the first global project in particle physics

The Twenty Member States of CERN

Member States (Dates of Accession)

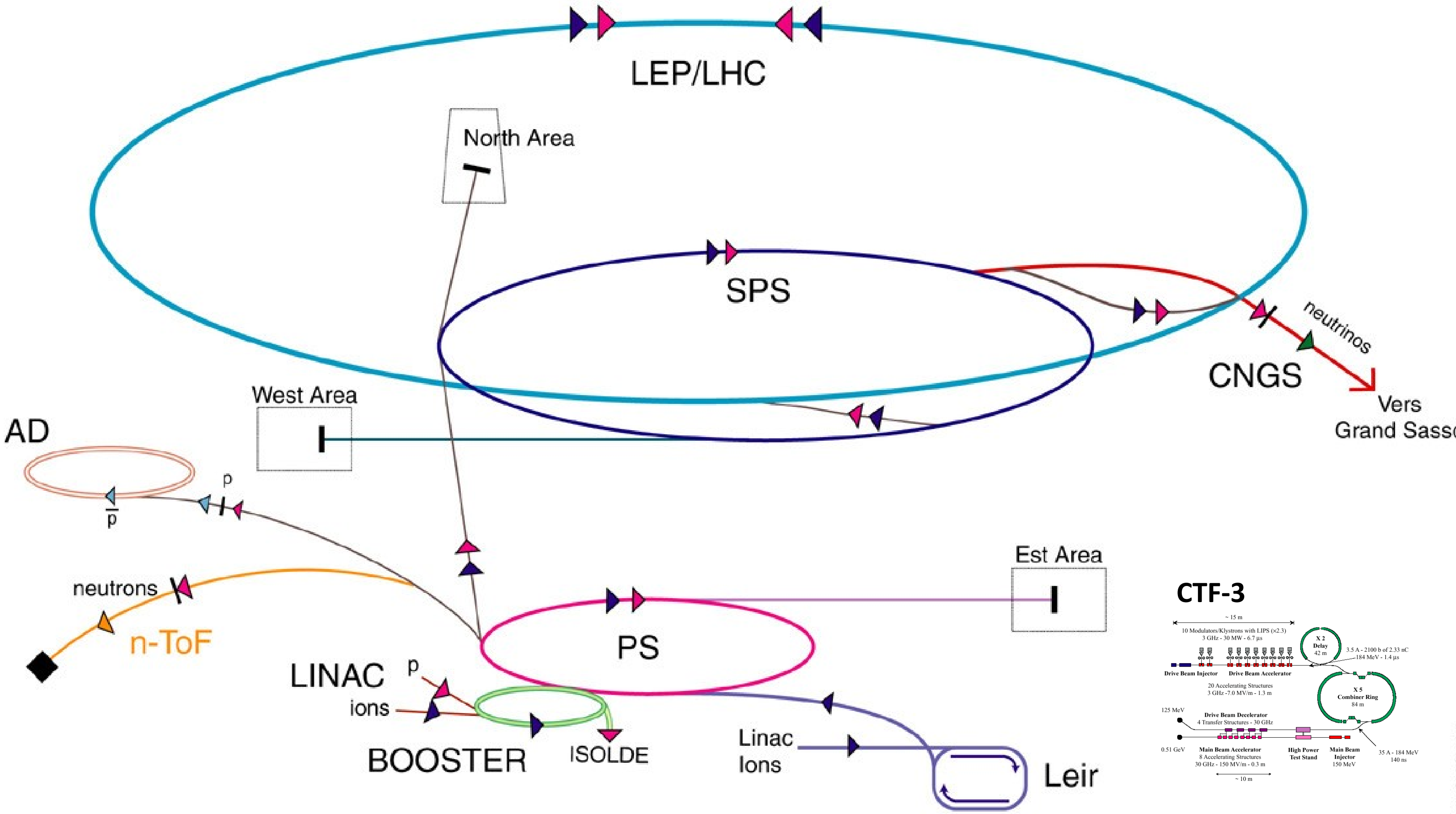
AUSTRIA (1959)	DENMARK (1953)	GREECE (1953)	NORWAY (1953)	SPAIN (1/1961-12/1968-1/1983)
BELGIUM (1953)	FINLAND (1991)	HUNGARY (1992)	POLAND (1991)	SWEDEN (1953)
BULGARIA (1999)	FRANCE (1953)	ITALY (1953)	PORTUGAL (1986)	SWITZERLAND (1953)
CZECH FR (1993)	GERMANY (1953)	NETHERLANDS (1953)	SLOVAK FR (1993)	UNITED KINGDOM (1953)

CERN flagship accelerators

- PS - Proton Synchrotron (1959-)
  first strong-focusing proton ring !
- ISR - Intersecting Storage Rings (1971-1985)
  first hadron collider!
- SPS - Super Proton Synchrotron (1976-)
  first proton-antiproton collider!
- LEP - Large Electron-Positron storage ring (1989-2001) *highest energy e+e- collider!*
- LHC - Large Hadron Collider (2008-)
- SLHC - Super LHC (~2018-) *highest energy proton/ion collider!*
- CLIC - Compact Linear Collider (~2023?-)

colour code: stopped, in operation, planned

Accelerator chain of CERN (operating or approved projects)



p (proton) | $\bar{p}$ (antiproton)
ion | proton/antiproton conversion
neutrons | neutrinos

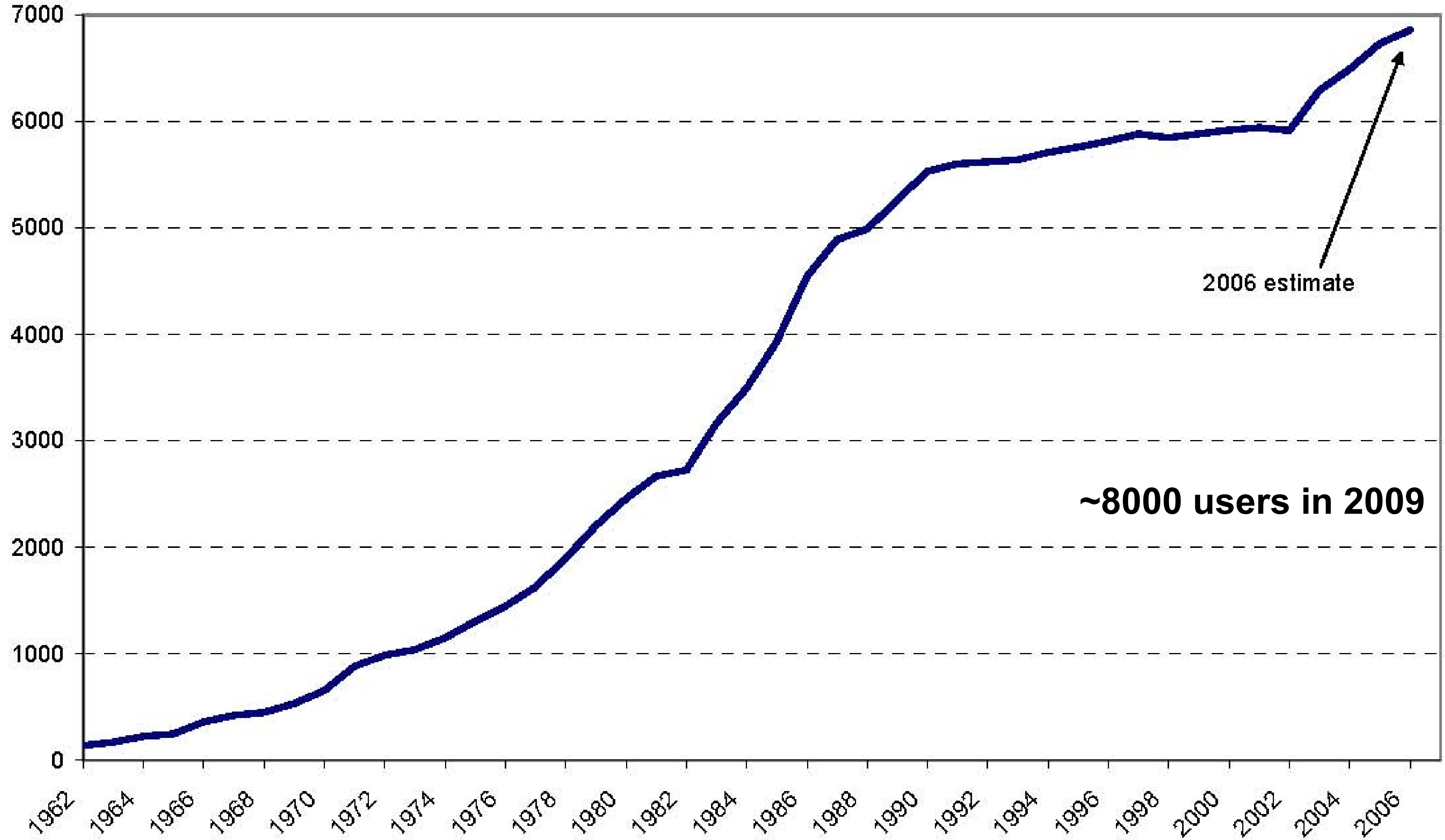
AD Antiproton Decelerator
PS Proton Synchrotron
SPS Super Proton Synchrotron

LHC Large Hadron Collider
n-ToF Neutrons Time of Flight
CNGS Cern Neutrinos Grand Sasso

CERN AC_ HF205_ V05/09/2001

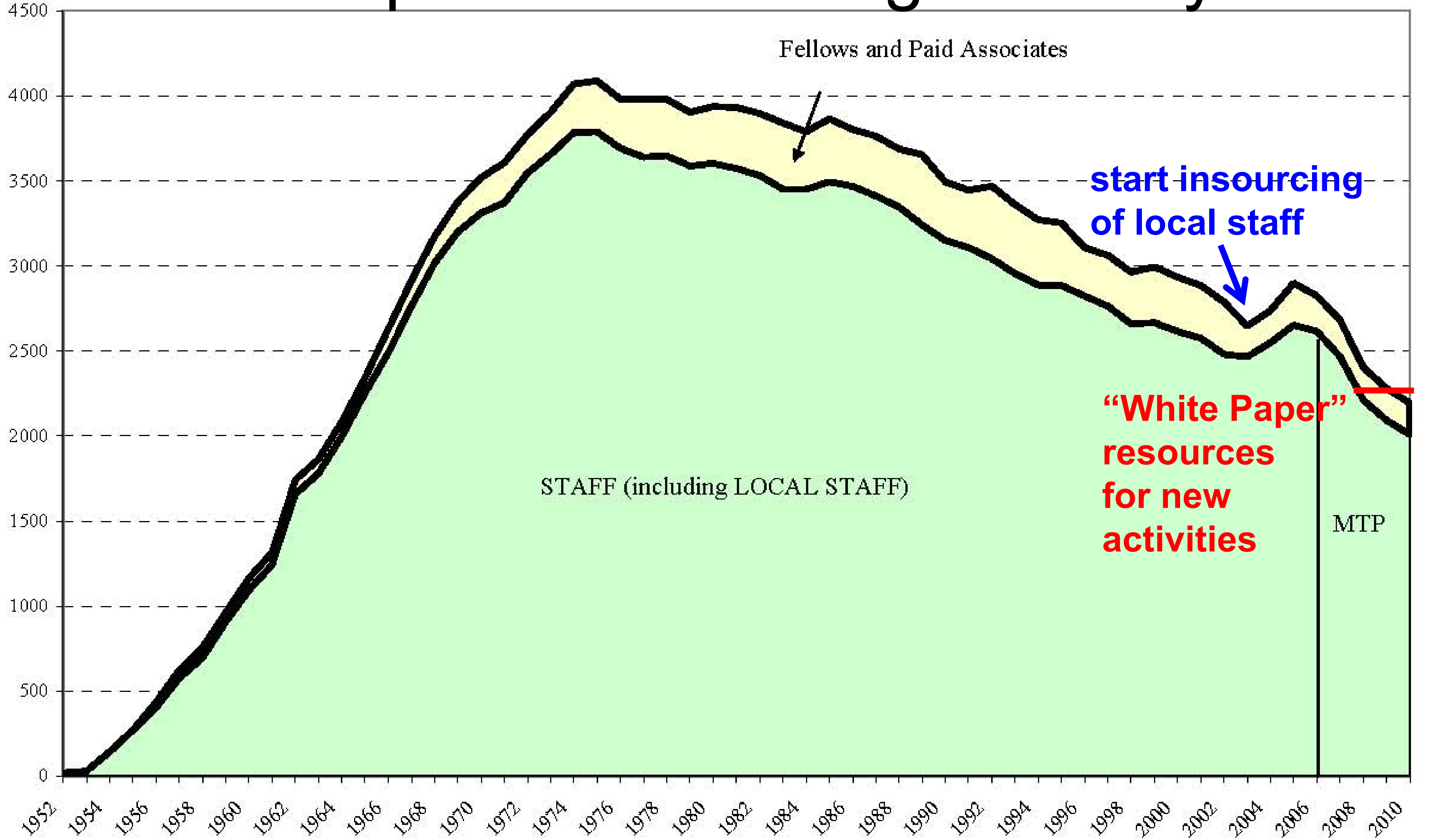
… and there are some German physicists at CERN

CERN users without fellows and associates



Source: DG White Paper. 2006

CERN personnel strength history



Source: DG White Paper. 2006

what to present today?

accelerator projects at CERN

LHC

SLHC

injector upgrade

ESS

CLIC, ILC

fixed-target programme

CTF3

ISOLDE (& EURISOL)

ν's, β beams

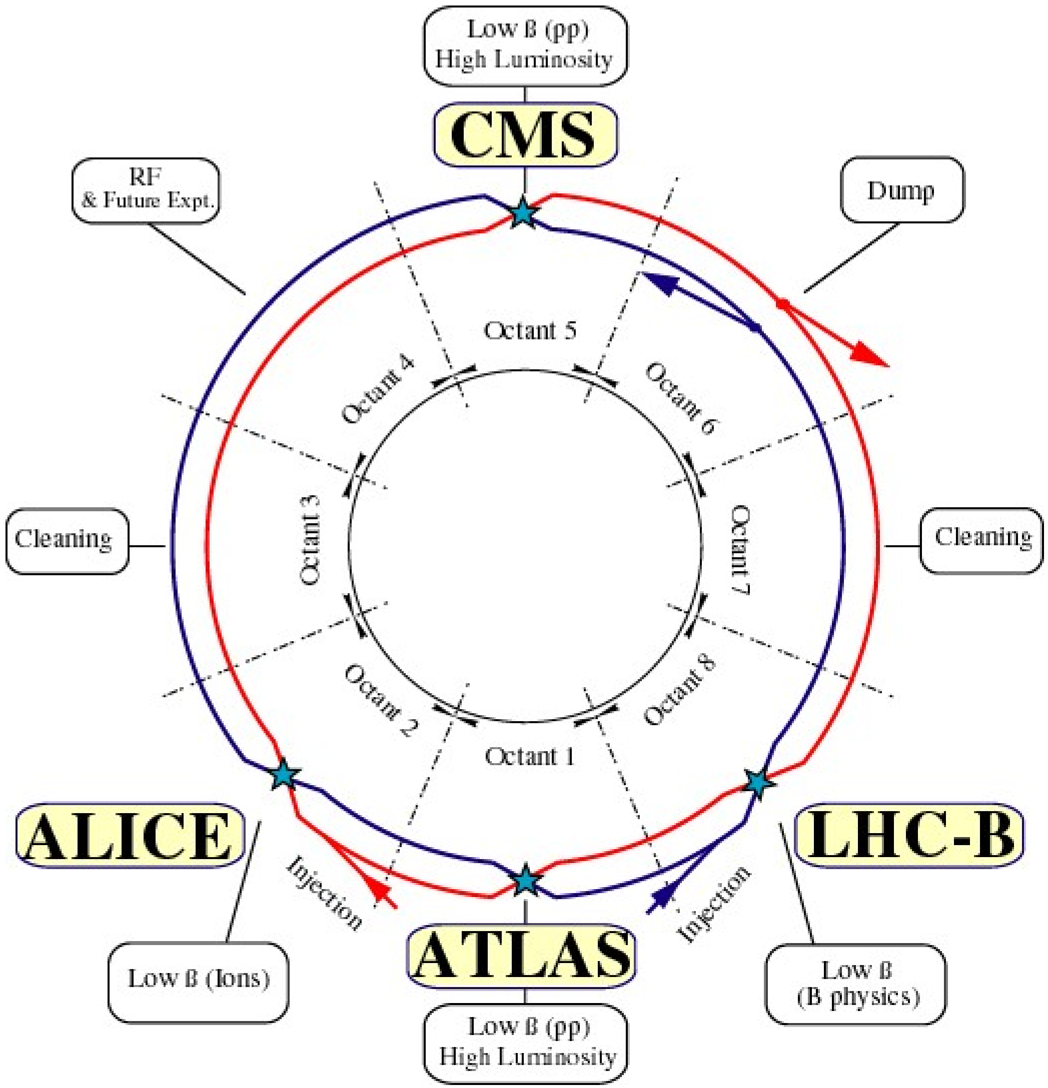
LHeC

med-AUSTRON

advanced concepts

LHC

Large Hadron Collider (LHC)



proton-proton and ion-ion collider

next energy-frontier discovery machine

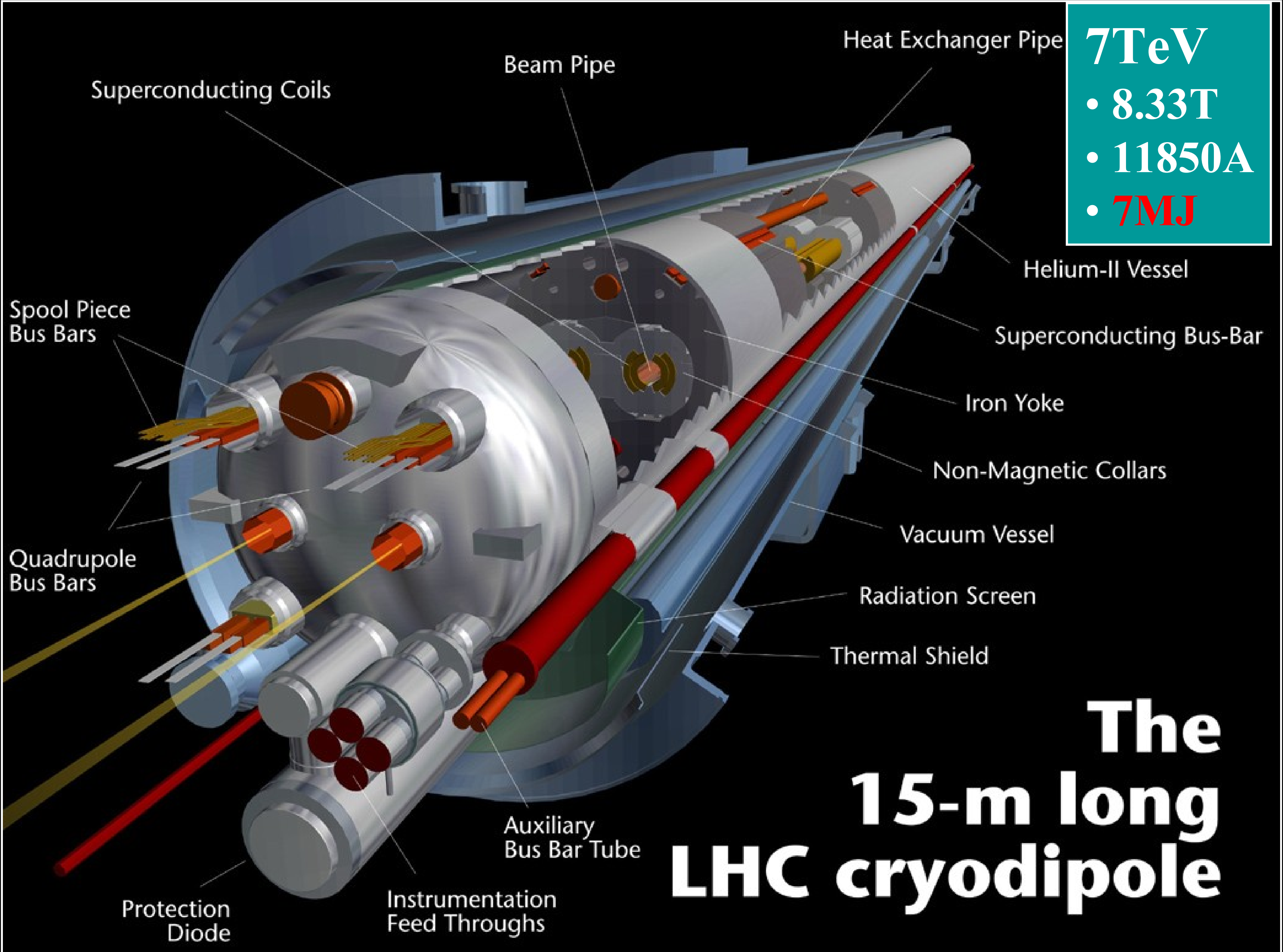
c.m. energy 14 TeV (7x Tevatron)

design pp luminosity 10^{34} $cm^{-2}s^{-1}$ (~30x Tevatron)

LHC baseline was pushed in competition with SSC (†1993)

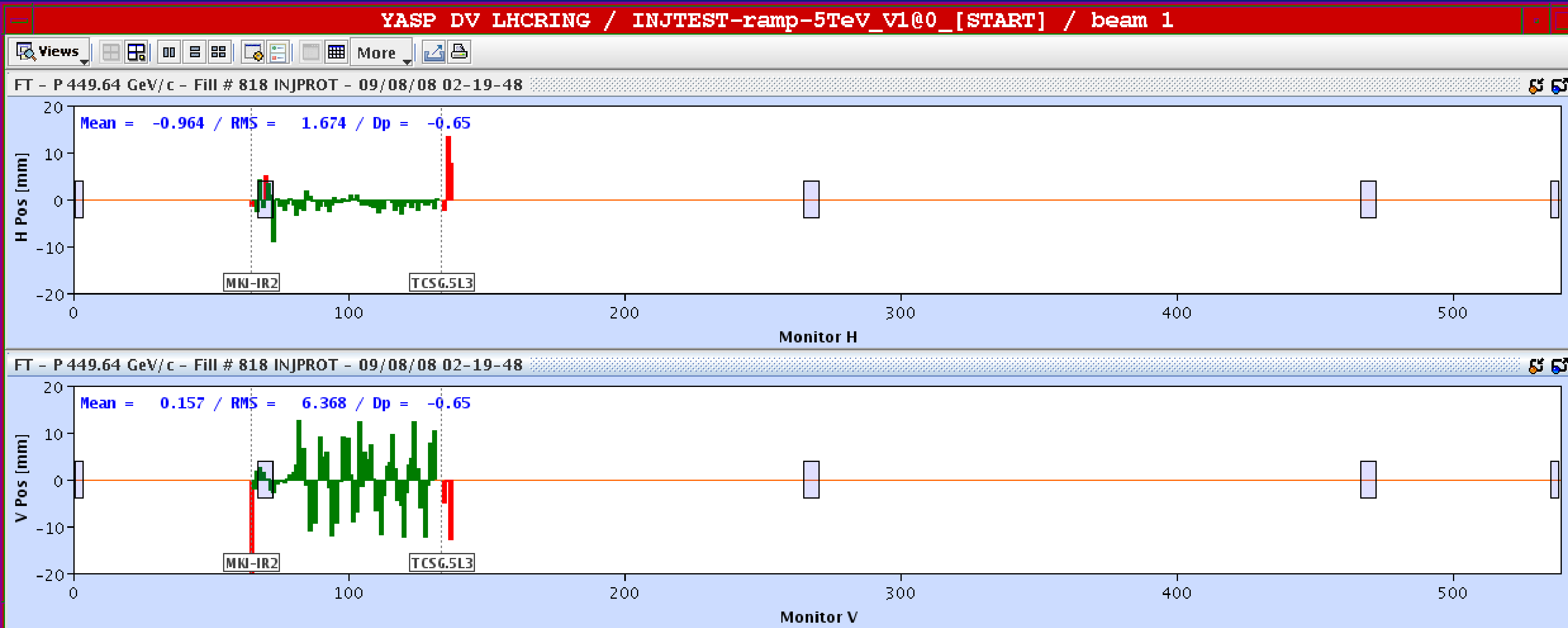
7TeV

- 8.33T
- 11850A
- 7MJ



beam commissioning started 10 September

first beam induced quench at injection with < 4 10^9 protons (~10^{-5} of design intensity)



B. Jeanneret et al, LHC Project Report 44 (1996)

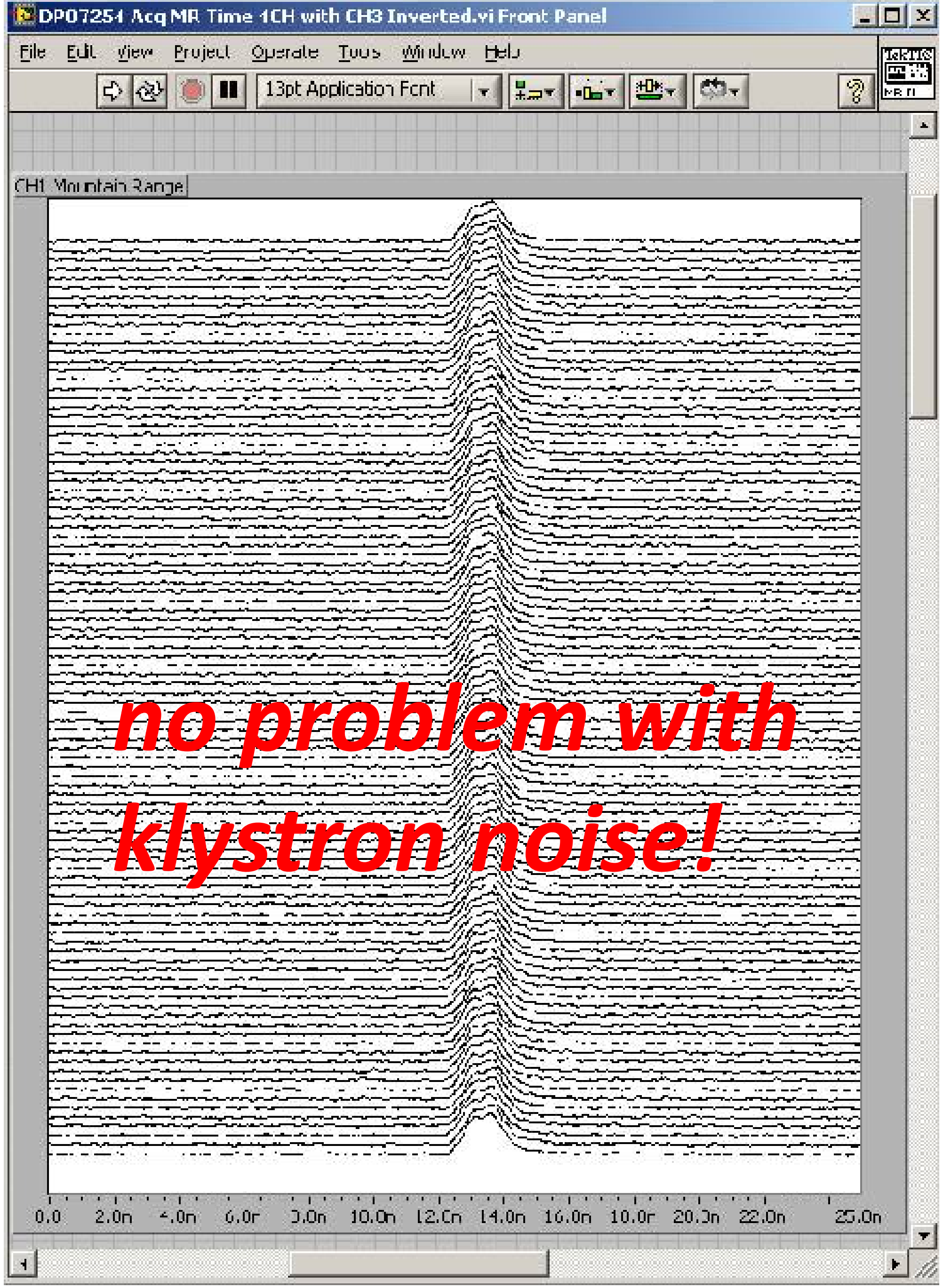
"*The intensity of the bunch shall therefore not be much larger than 3 10^9 protons.*"

at 7 TeV, ~2000 times more sensitive!

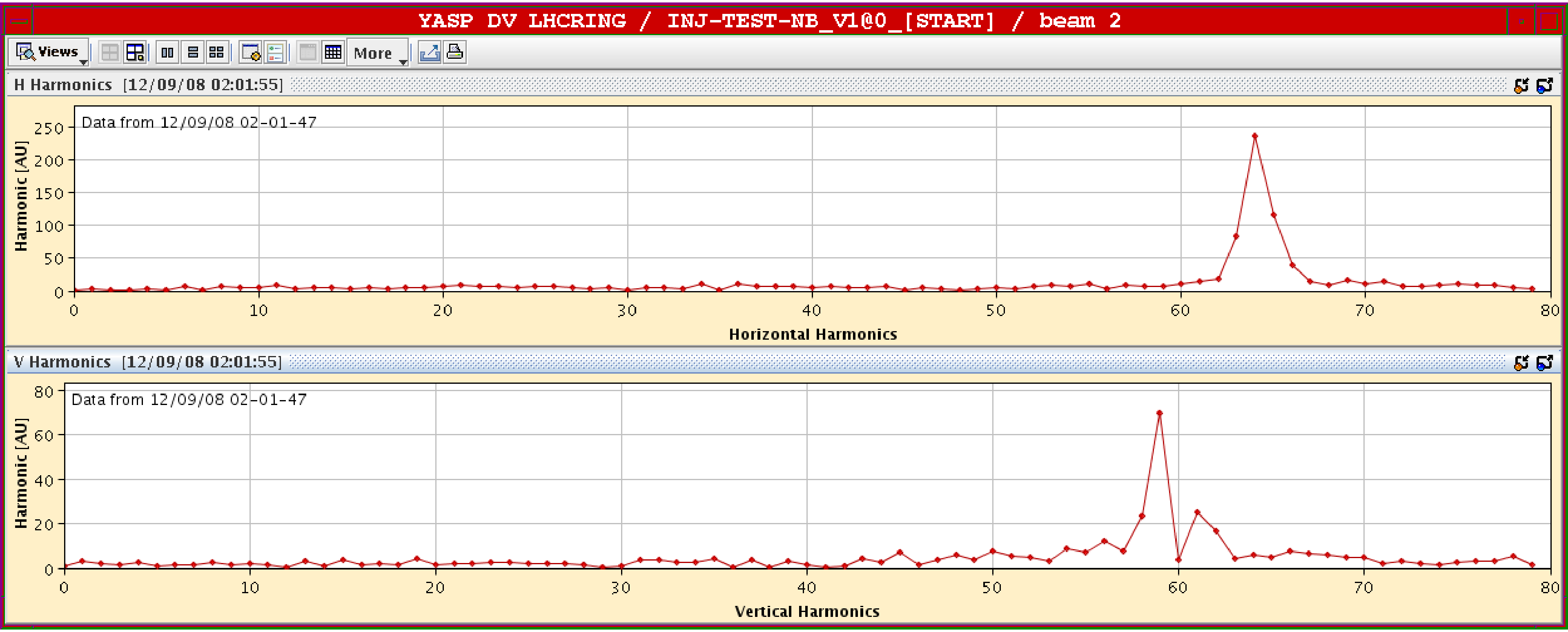
A. Butterworth, RF Group

longitudinal mountain range recorded ~5 minutes after rf capture

beam lifetime ~infinite (too good to be measured; many hours)



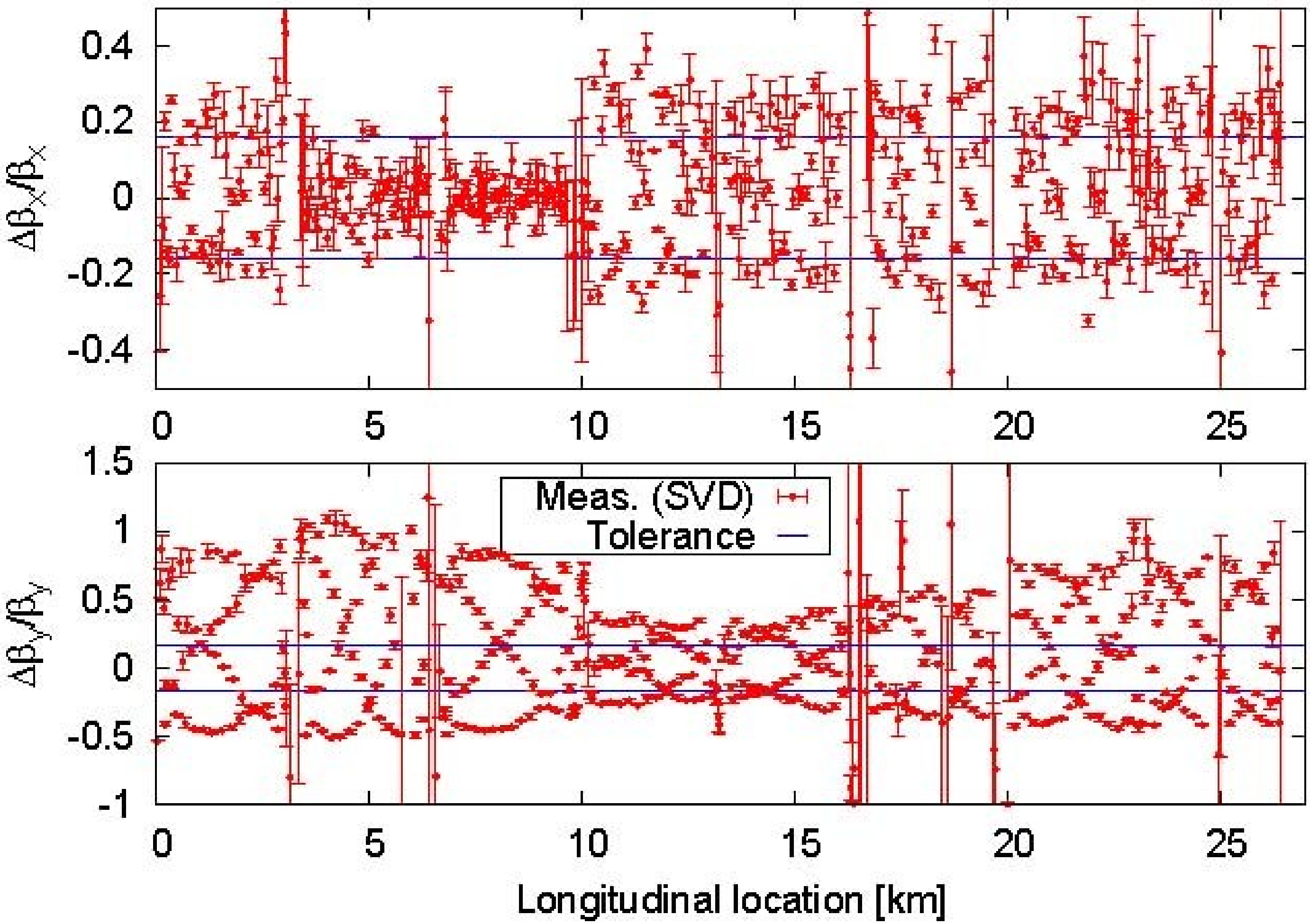
J. Wenninger



tunes 64 and 59 as design (vertical FFT has second peak!?)

very first look at β beating with turn-by-turn BPMs

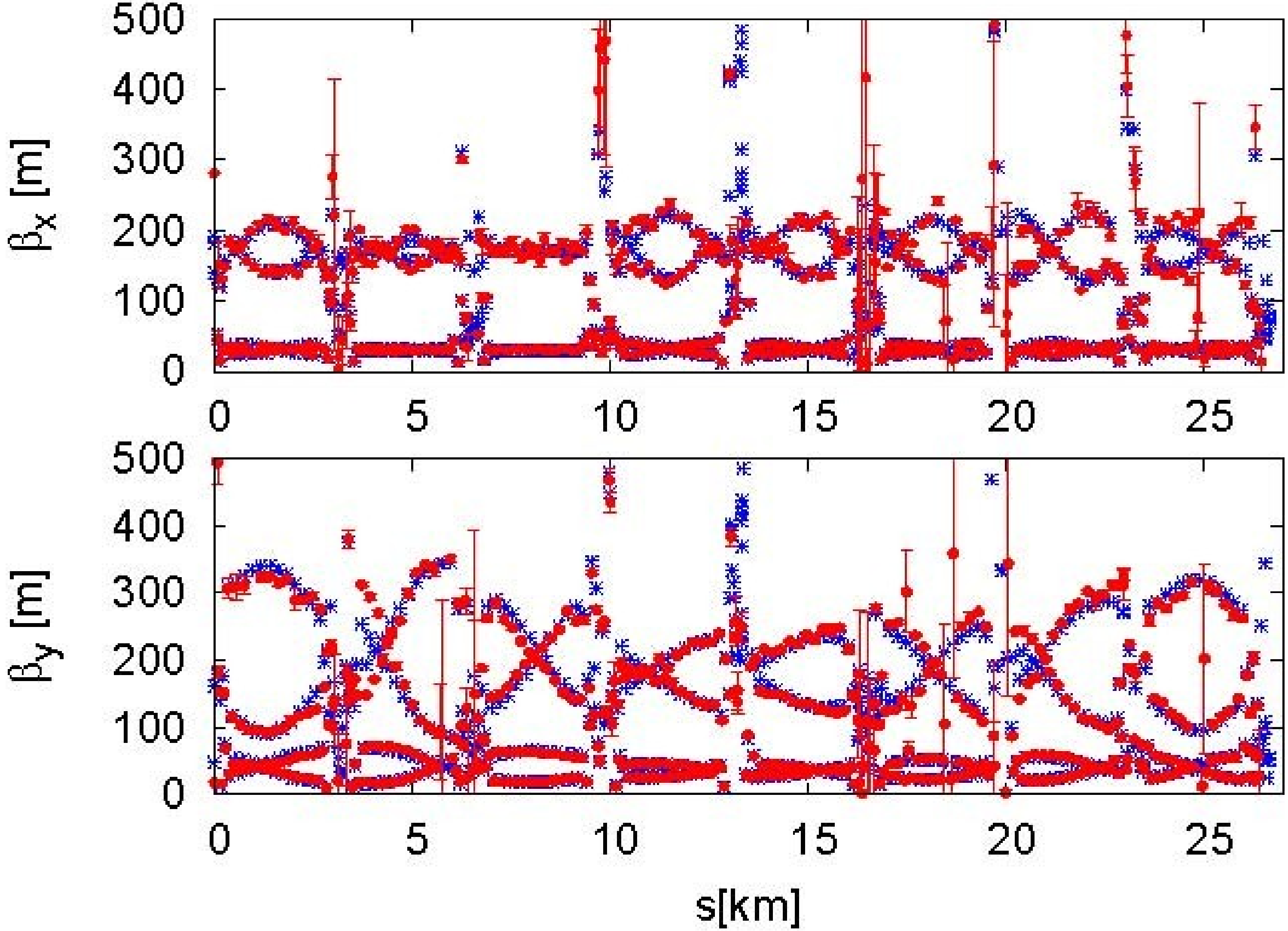
data over 90 turns taken during vertical orbit correc-tion



R. Tomas, M. Aiba

post-analysis of β beating identified a cable swap between two matching quadrupoles for the two beams

R. Tomas, M. Aiba

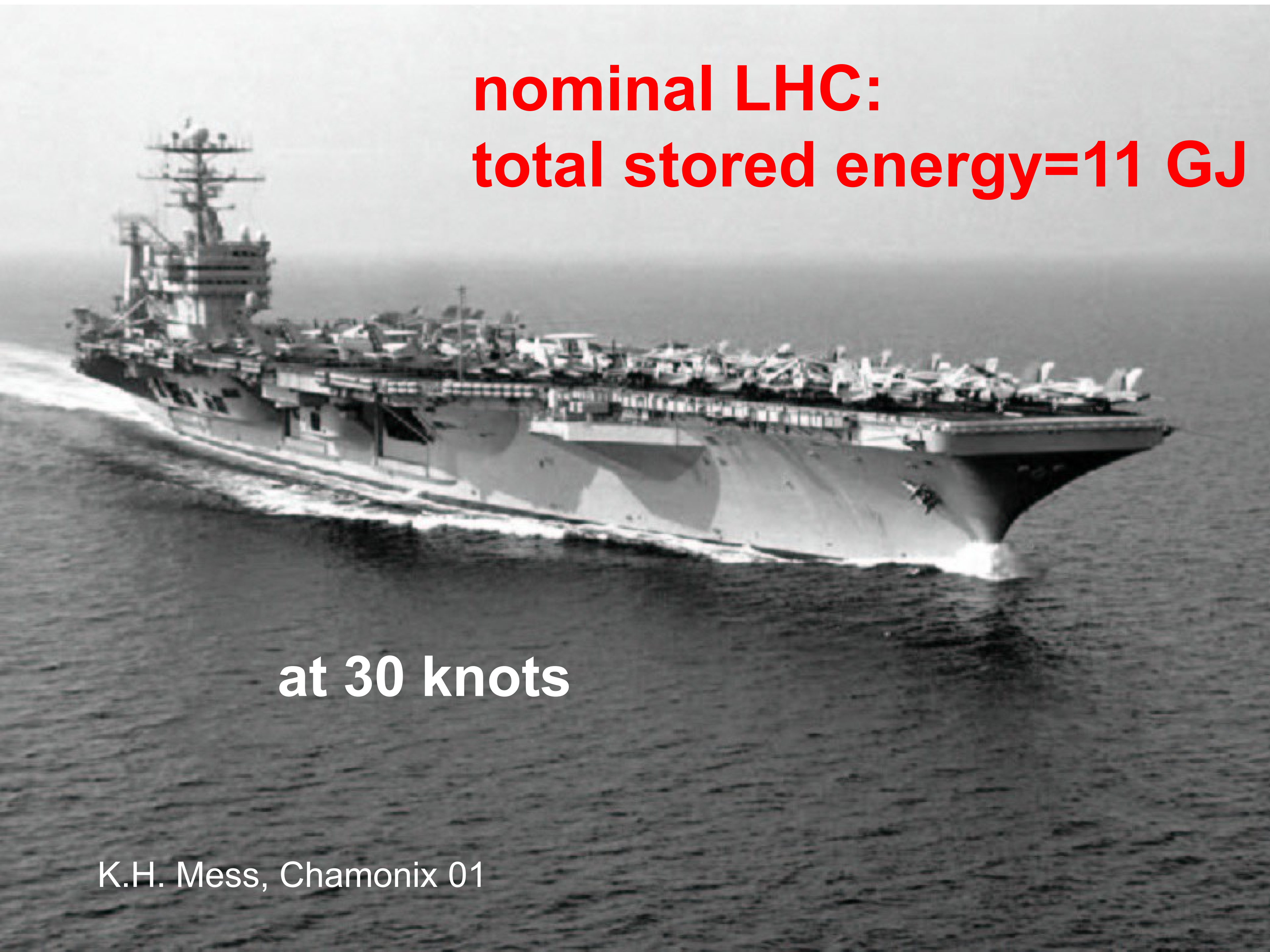


measurement and model prediction with quadrupole errors fitted only in the straight sections


most prominent LHC visitor?
8 June 2009
Mr. Bill Gates
Prof. Rolf Heuer
CERN DG

LHC challenges

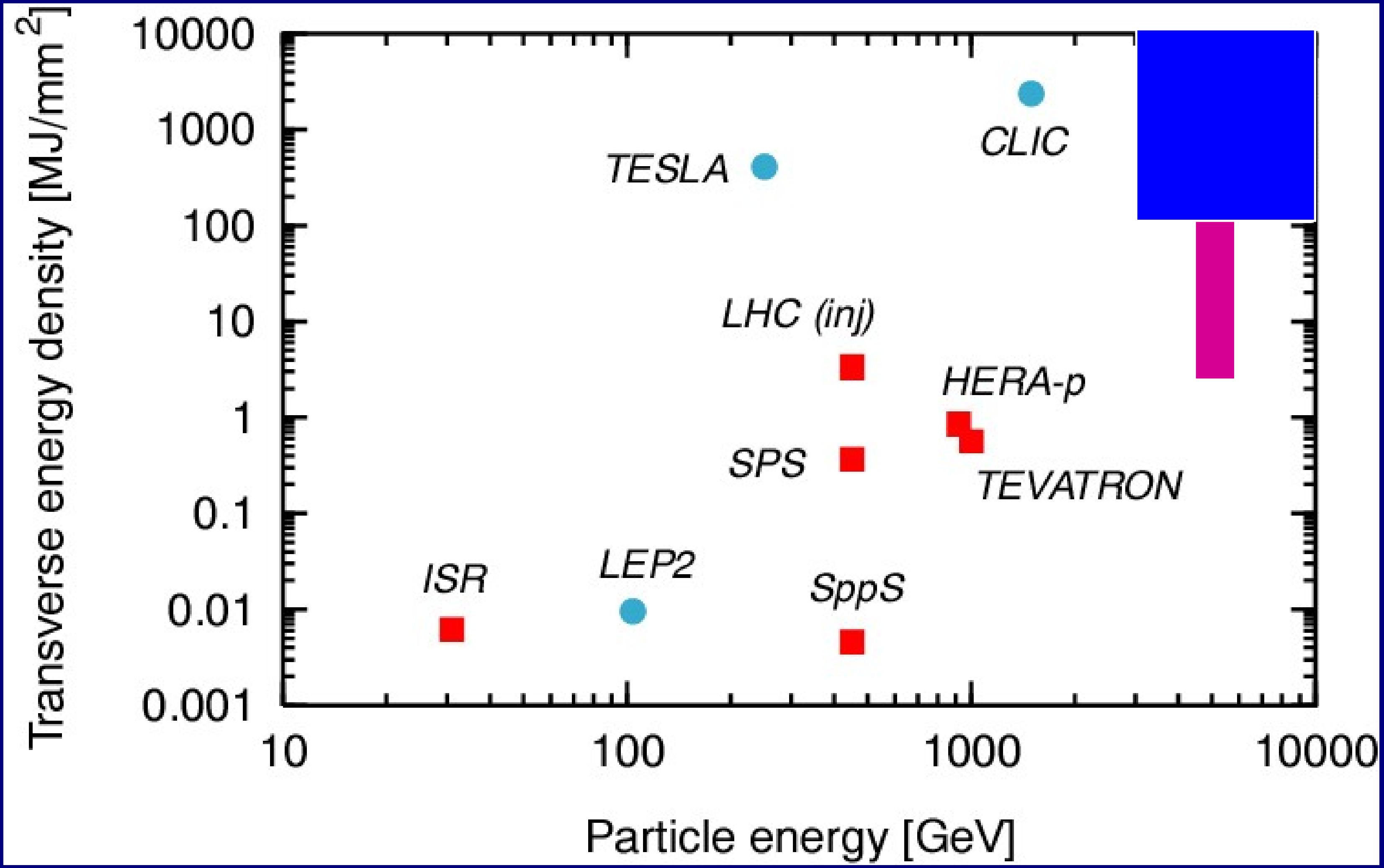
- **extremely high stored beam energy**
  - machine protection
  - collimation
  - radiation damage, magnet quenches & "single-event upsets"
- **many bunches (~3000 / beam)**
  - electron-cloud effects
  - "parasitic collisions," long-range beam-beam interaction, crossing angle



nominal LHC:
total stored energy=11 GJ

at 30 knots

K.H. Mess, Chamonix 01

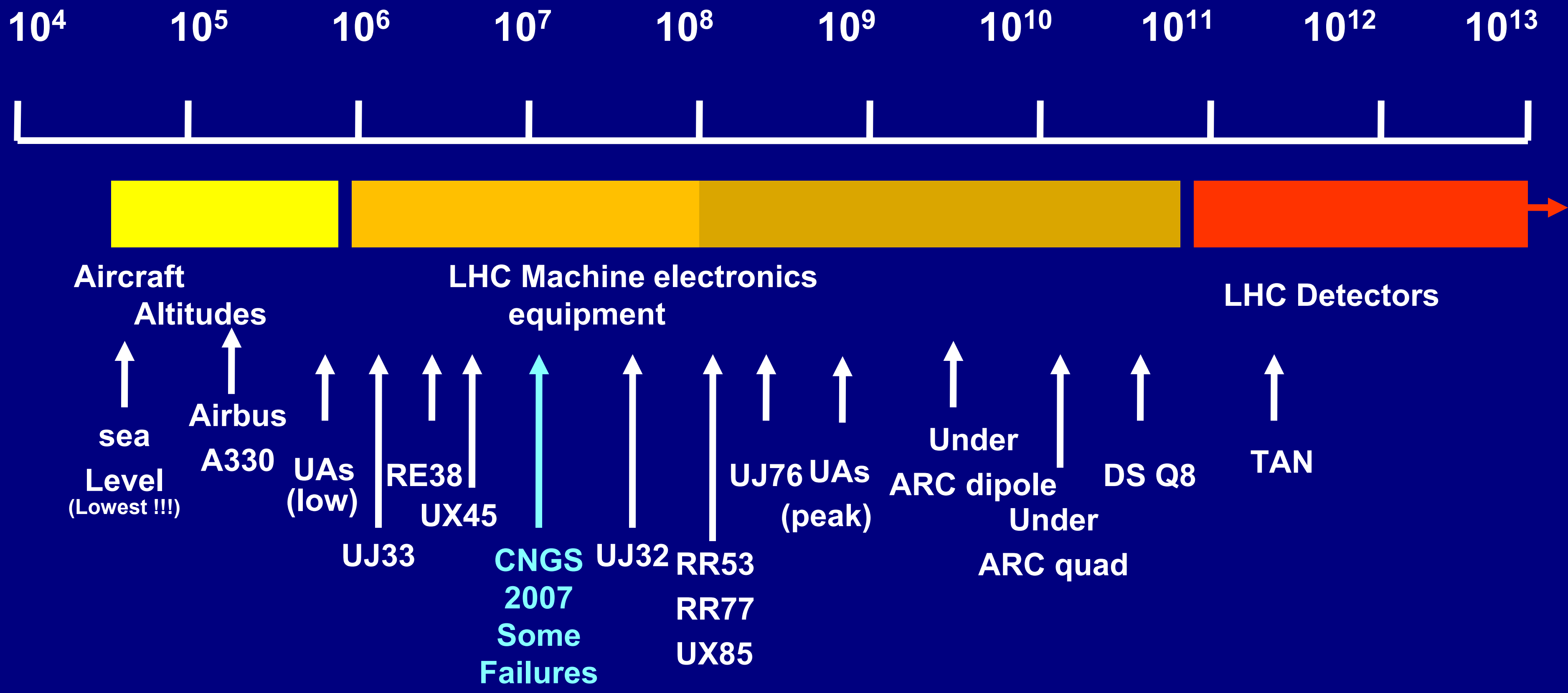


R. Assmann

at <1% of nominal intensity LHC enters new territory

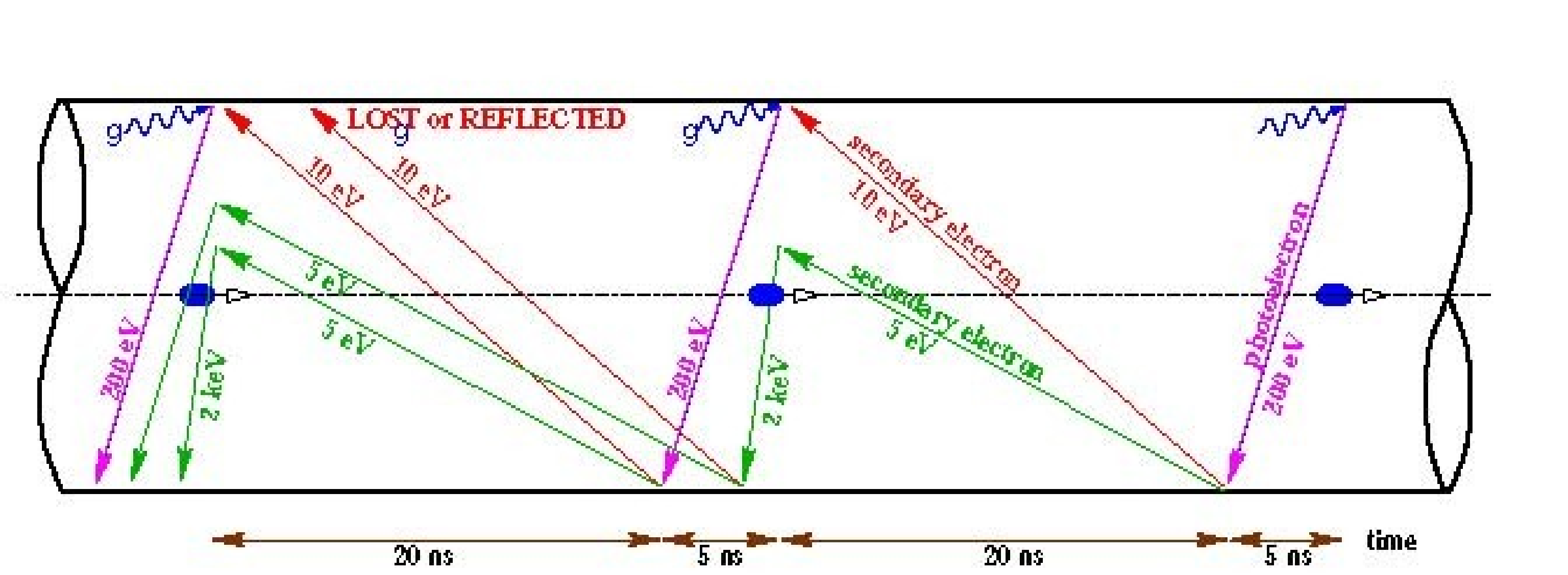
T. Wijnands, M. Brugger

High-Energy Hadron Fluences



e.g., some estimated LHC-levels for hadrons (E > 20 MeV) per cm² <u>per nominal year</u>

electron cloud in the LHC

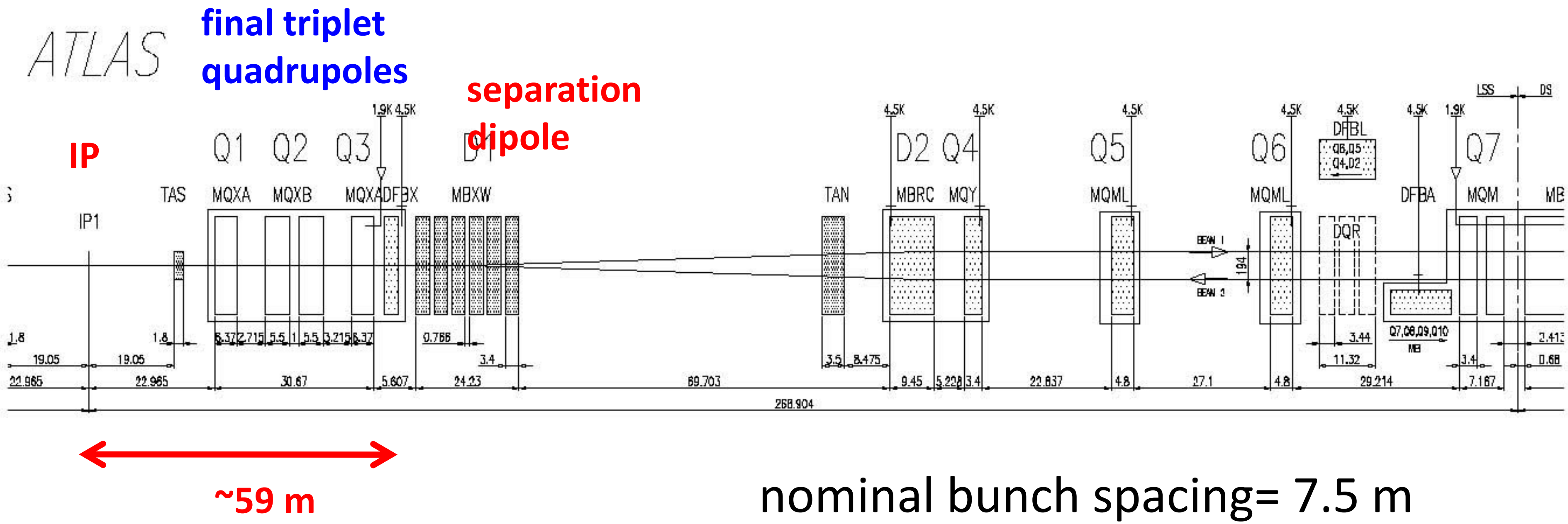


schematic of e- cloud build up in the arc beam pipe, due to **photoemission** and **secondary emission**

[F. Ruggiero]

→ heat load, beam instabilities, poor beam lifetime

LHC interaction-region layout



nominal bunch spacing= 7.5 m

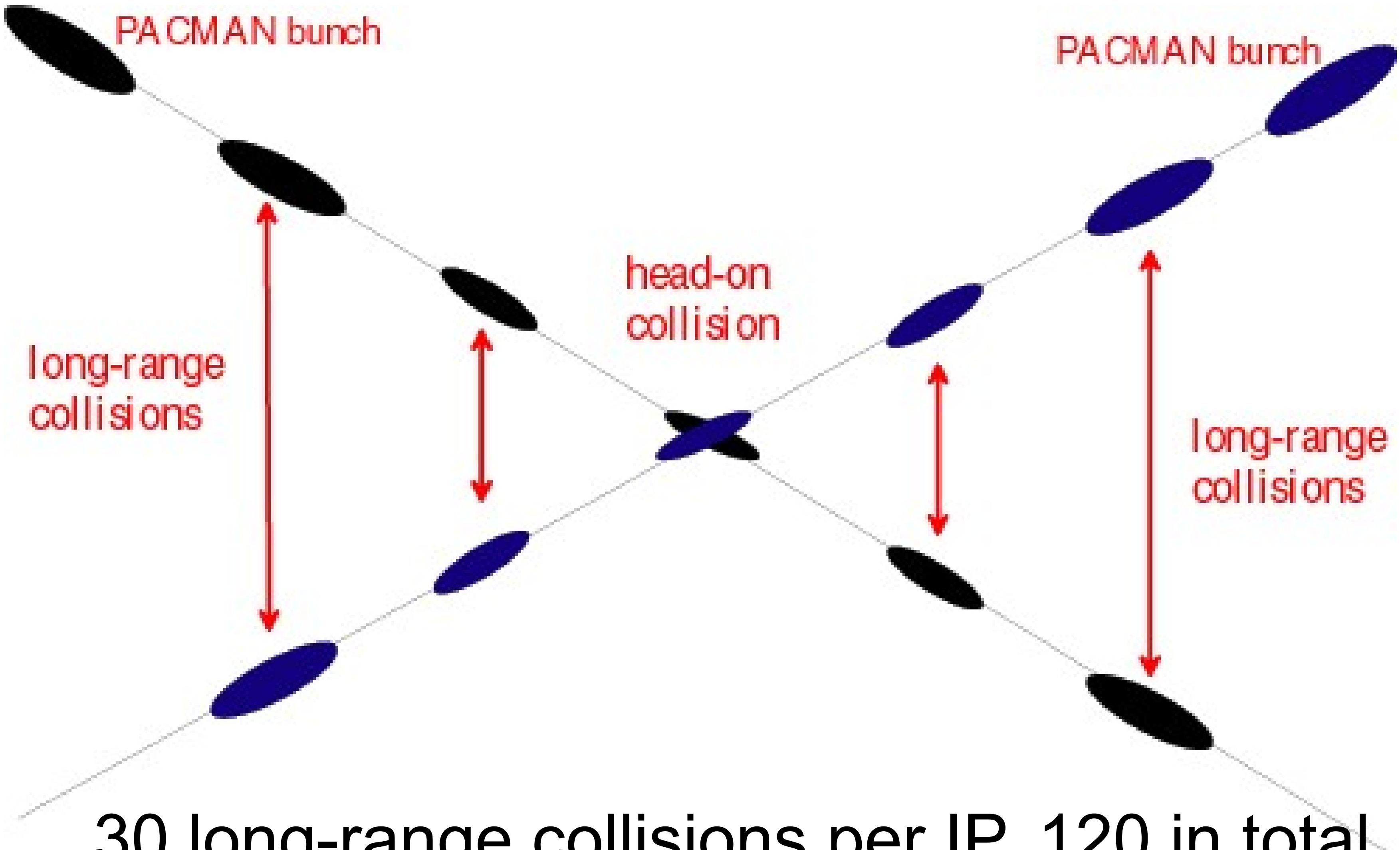
nominal collision spacing = 3.75 m

→ *about 2x15 collisions between*
IP and separation dipole!

tune shift would increase 30 times!

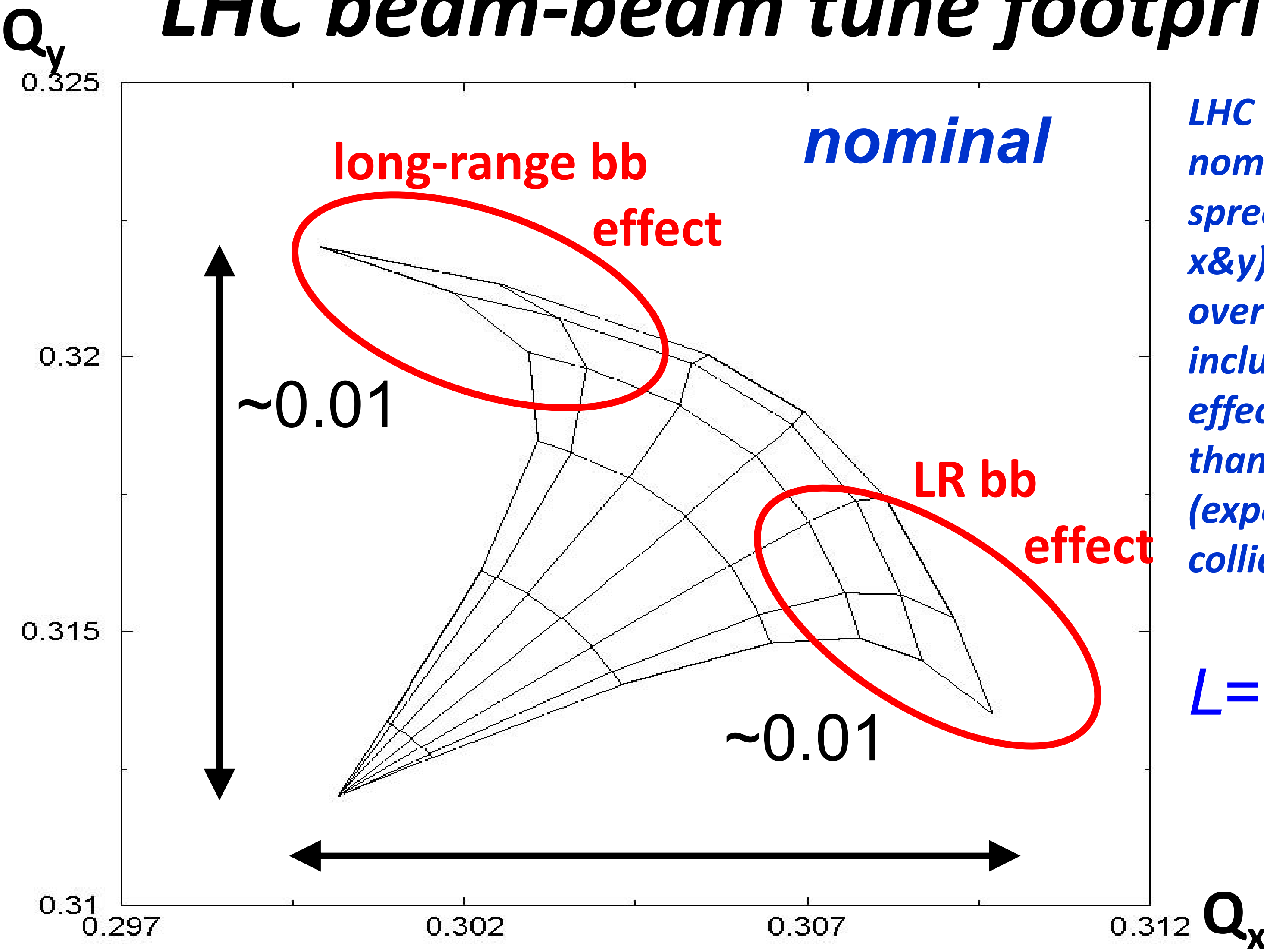
solution: crossing angle

long-range beam-beam



30 long-range collisions per IP, 120 in total

LHC beam-beam tune footprint



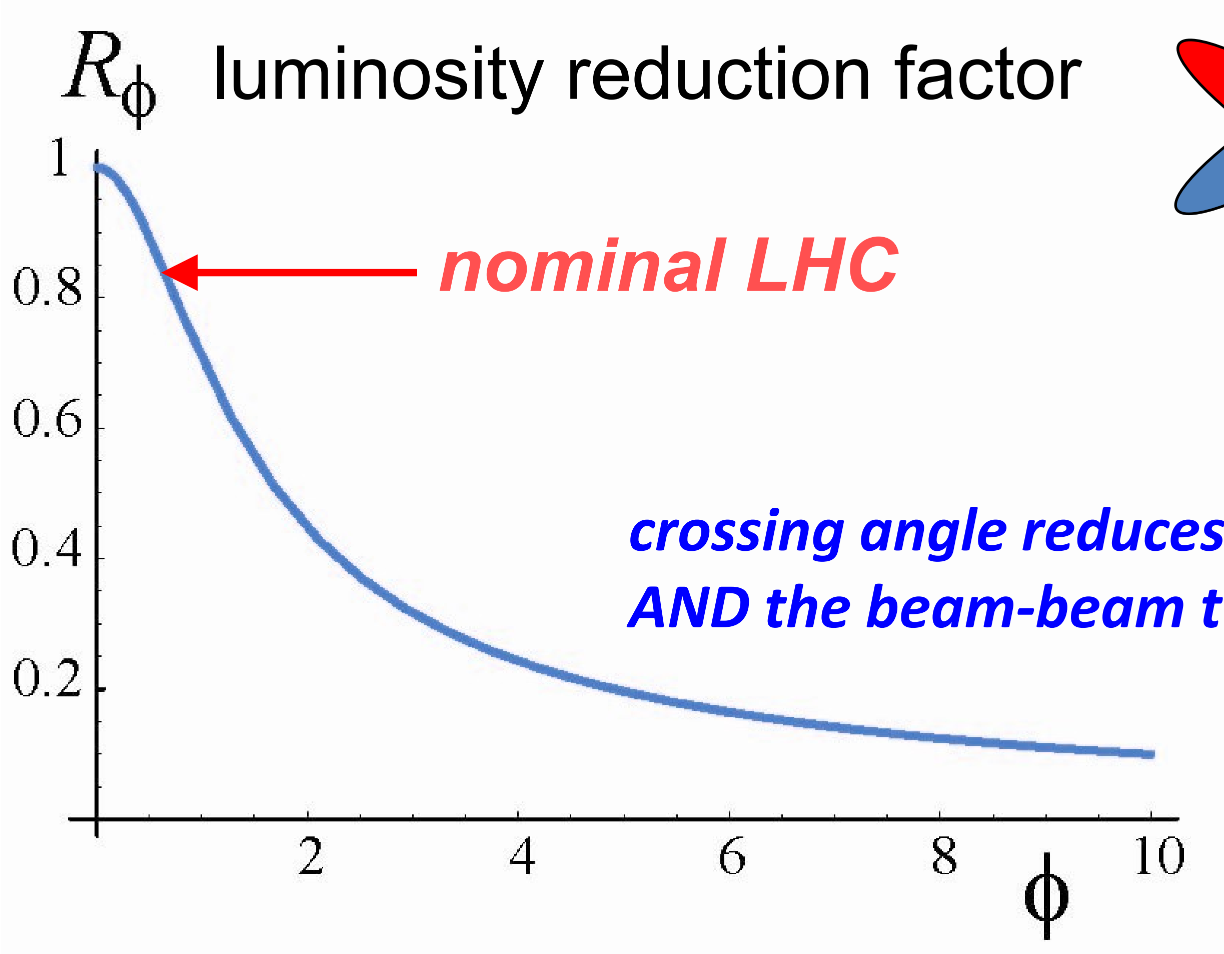
LHC design criterion: nominal total tune spread (up to 6σ in x&y) from all IPs and over all bunches, including long-range effects, should be less than 0.01 (experience at SPS collider)

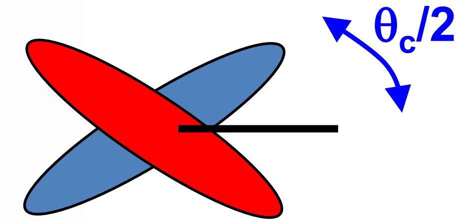
L=10^{34} cm^{-2}s^{-1}

nominal tune footprint up to 6σ with
4 IPs & nom. bunch intensity N_b=1.15x10^{11}

crossing angle

$$R_\phi = \frac{1}{\sqrt{1+\phi^2}}; \quad \phi \equiv \frac{\theta_c \sigma_z}{2\sigma_x}$$ *"Piwinski angle"*





effective beam size $\sigma \rightarrow \sigma / R_\phi$

crossing angle reduces the luminosity AND the beam-beam tune shift

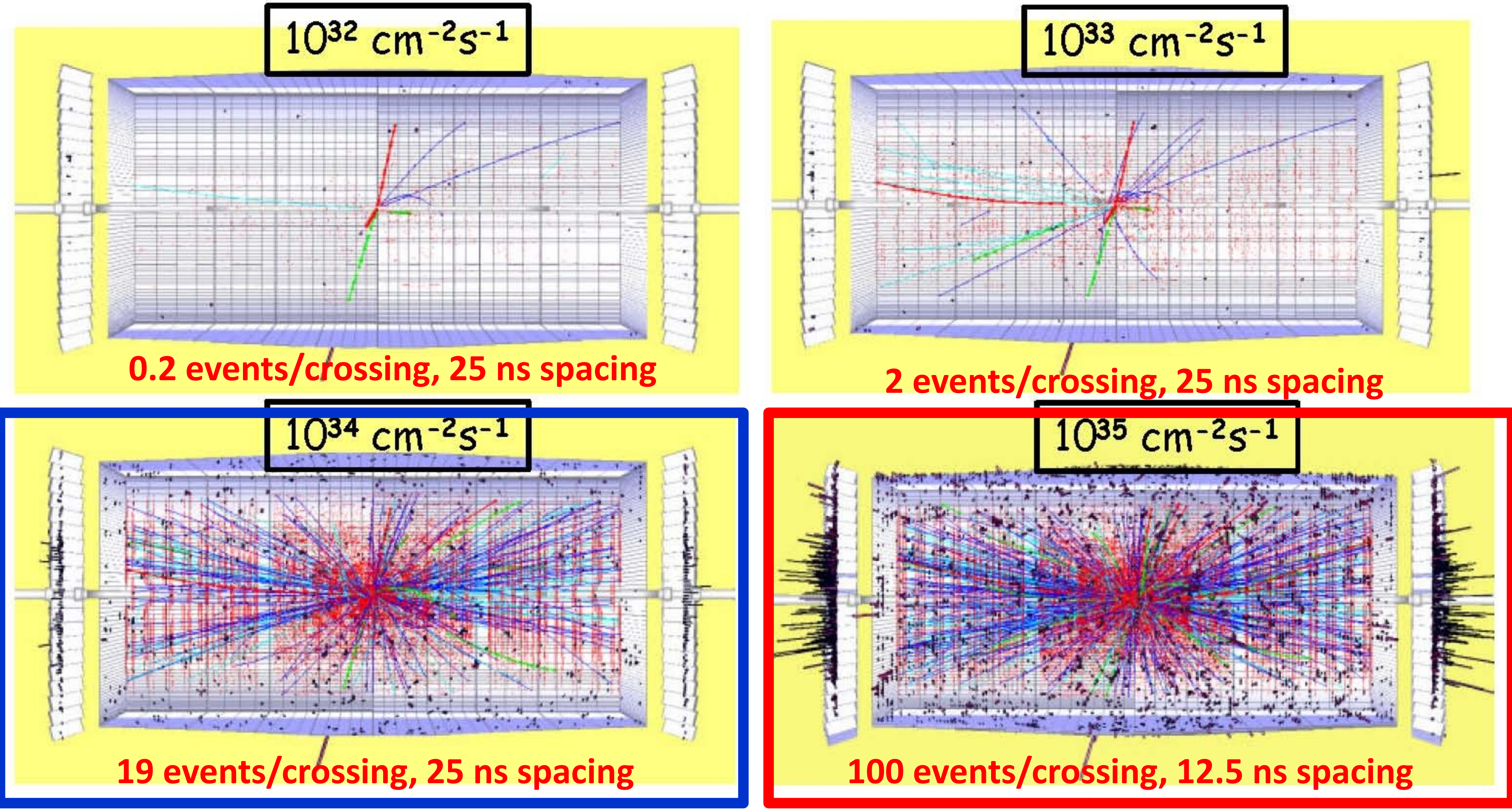
SLHC

LHC with 10x higher luminosity
$= 10^{35}\ cm^{-2}s^{-1}$

some SLHC issues

- event pile up (#events / bunch crossing)
- reducing β^*, new final-focus quadrupoles
- off-momentum optics
- higher beam current
- collimation upgrade
- magnet lifetime & shielding
- low luminosity lifetime ~ 2-5 hours

event pile up in detector



nominal LHC **"SLHC"** I. Osborne

$p_t > 1$ GeV/c cut, i.e. all soft tracks removed

luminosity

beam current

$$L = \left(\frac{\gamma f_{rev}}{4\pi}\right)\frac{n_b N_b}{\beta^*}\left[\left(\frac{N_b}{\varepsilon_N}\right)R_\phi\right]$$

geometric factor

IP beta function

brightness

$$R_\phi = \frac{1}{\sqrt{1+\phi^2}}; \quad \phi \equiv \frac{\theta_c \sigma_z}{2\sigma_x}$$

$$\sigma^* = \sqrt{\beta^* \frac{\varepsilon_N}{\gamma}}$$

rms IP beam size

$$d^* = \sqrt{\frac{1}{\beta^*}\frac{\varepsilon_N}{\gamma}}$$

rms IP divergence

normalized to nominal

$$\theta_c \approx a\, d^* \left(0.7 + 0.3\, b \sqrt{\tilde{n}_b \tilde{N}_b / \tilde{\varepsilon}_N}\right)$$

minimum crossing angle for long-range b-b

total beam-beam tune shift for 2 IPs w x&y crossing

geometric factor

$$\Delta Q_{bb} \approx \frac{r_p}{2\pi}\left[\left(\frac{N_b}{\varepsilon_N}\right)R_\phi\right] < \Delta\hat{Q}_{bb}$$

for Gaussian bunch shape

brightness

b-b tune shift also decreases with crossing angle

SLHC phase I – IR upgrade

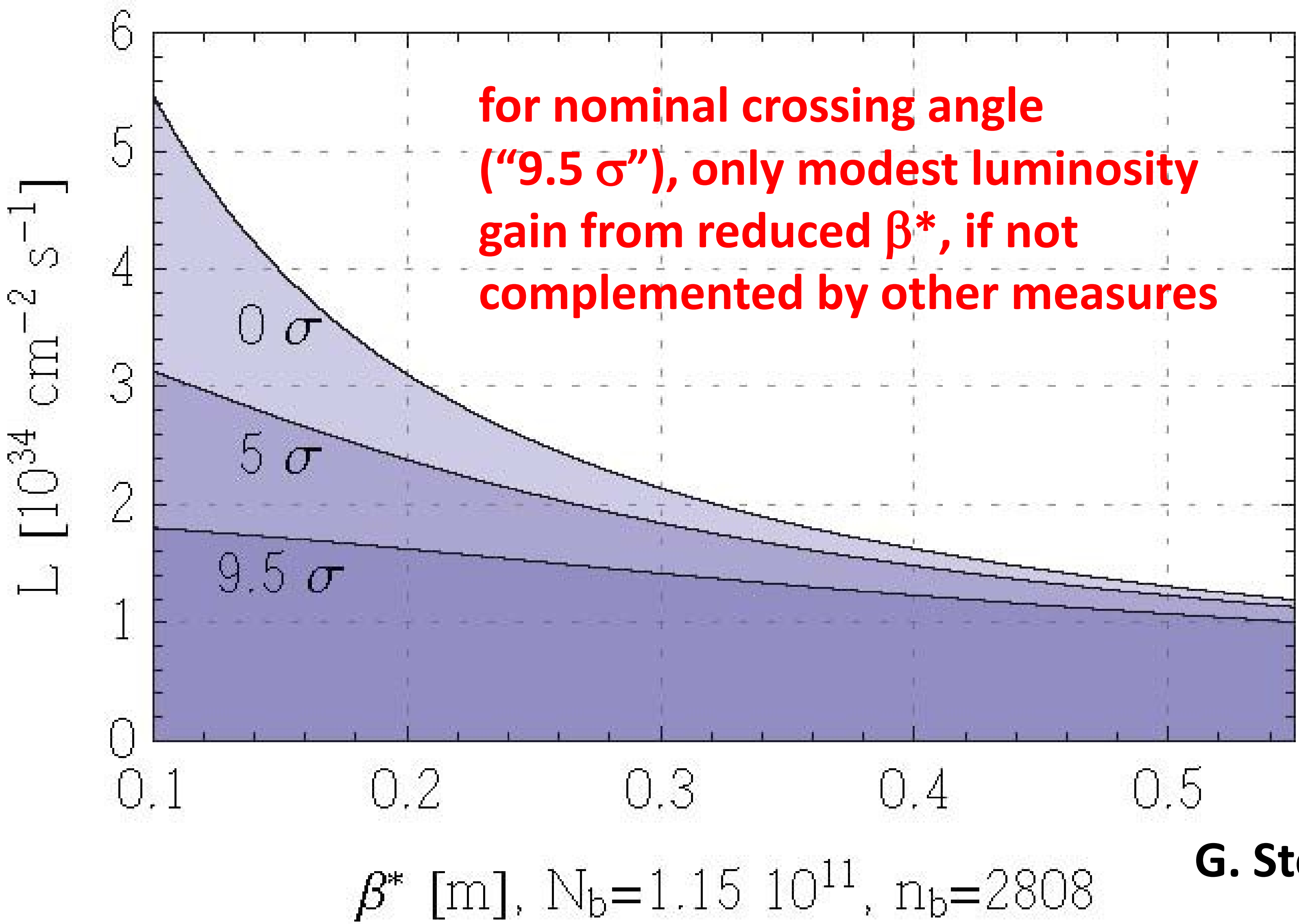
- **new Nb-Ti quadrupole triplets** with larger aperture, new separation dipoles, etc
- may allow reaching **β^* ~ 0.30 m in IP1 and 5**
- should be completed by **2014**

SLHC phase II – IR upgrade

- **Nb_3Sn triplet** with larger aperture providing **β^*~0.10-0.15 m**
- **complementary measures**: long-range beam-beam compensation, crab cavities, etc
- realized around **2018**

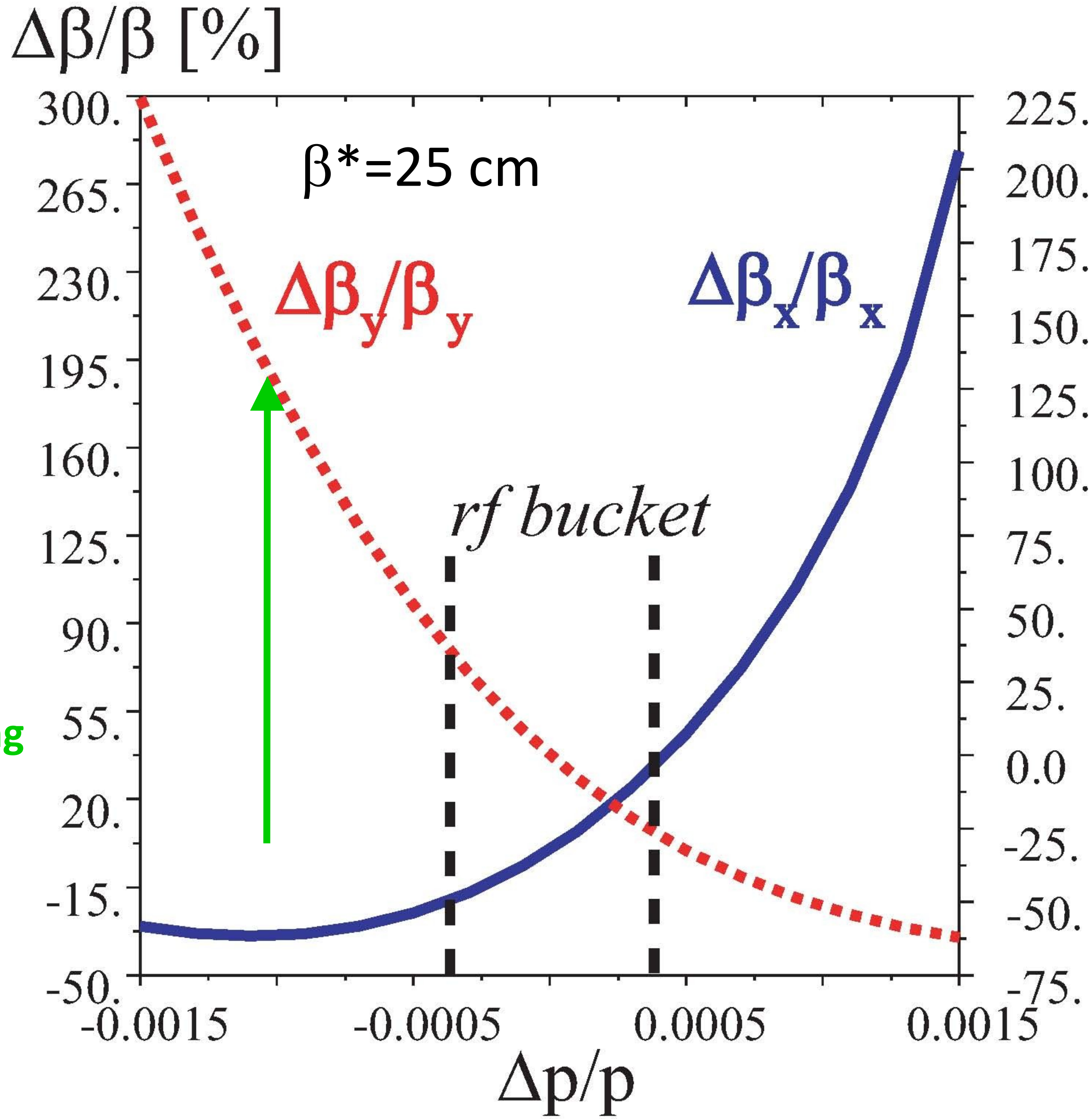
both phases accompanied by extensive injector upgrades

reducing *β* - 1*



G. Sterbini

reducing β* - 2

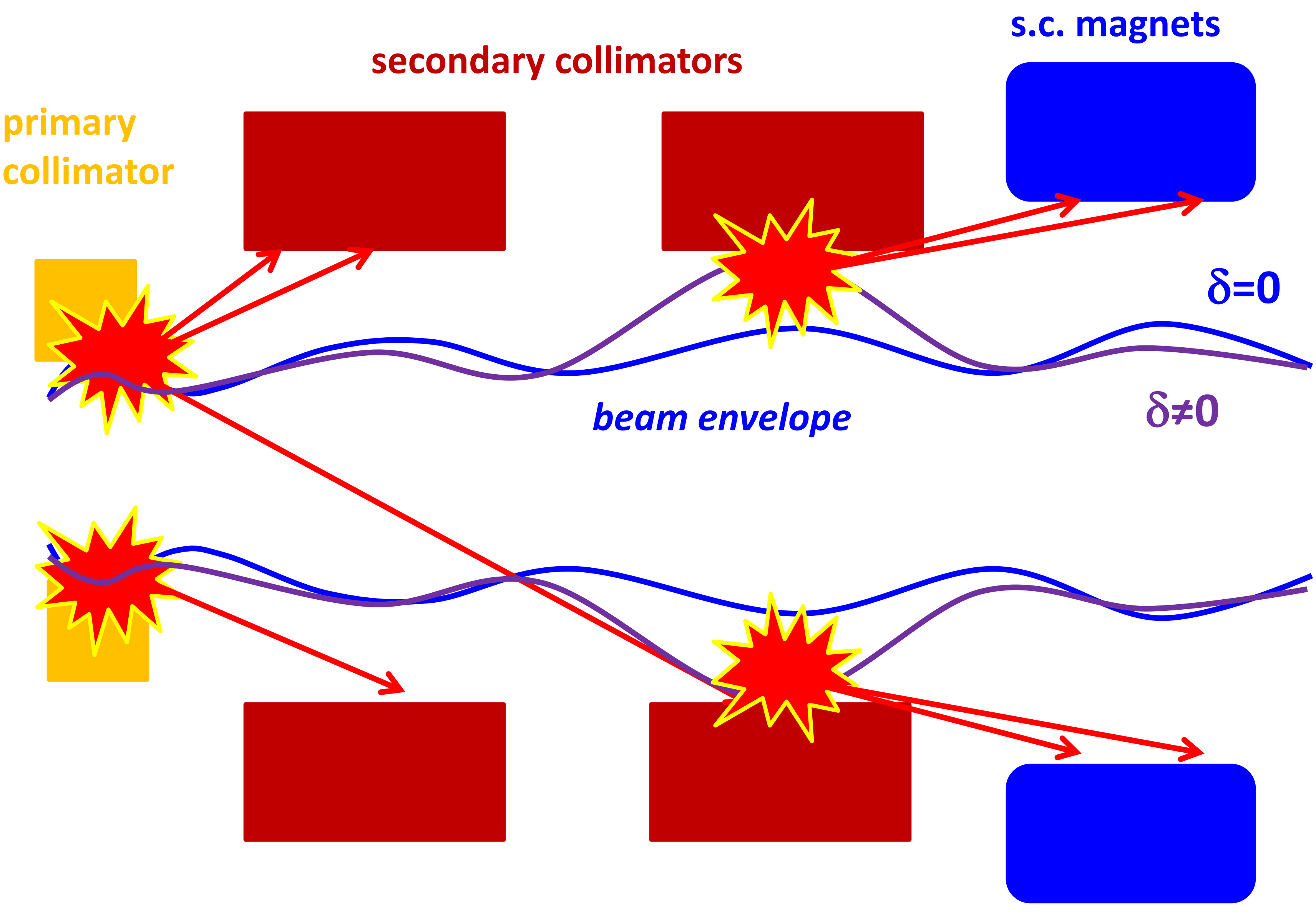


at 9 σ
200%
β beating

higher-order chromatic effects affect momentum collimation, by destroying hierarchy of primary, secondary, and tertiary etc. collimators

S. Fartoukh

effect of off-momentum β beating on collimation



reducing β* - 3

if off-momentum beta beating can be corrected or the collimation be made more robust:

- **β* ~ 30 cm for *l** = +/- 23 m**

with *NbTi* magnet technology
limited by aperture

- **ultimate β* ~ 15 cm for *l** = +/- 23 m**
- **ultimate β* ~ 11 cm for *l** = +/- 13 m**

with *Nb$_3$Sn* magnet technology (higher field, more margin), limited by linear chromaticity correction

tune shift & (peak) luminosity

$$\Delta Q_{bb} = \frac{N_b}{\gamma\varepsilon}\frac{r_p}{2\pi}\frac{1}{\sqrt{1+\phi_{piw}^2}}\frac{1}{F_{profile}} \qquad \phi_{piw} \equiv \frac{\sigma_z \theta_c}{2\sigma_{x,y}^*}$$

Piwinski angle

total beam-beam tune shift at 2 IPs with alternating crossing;

we increase charge N_b until limit ΔQ_{bb} is reached; to go further we must increase ϕ_{piw}, and/or ε and/or $F_{profile}$ (~$2^{1/2}$ for flat bunches)

$$L = \frac{1}{4\pi} f_{rev} n_b \gamma \frac{1}{\beta^*(\gamma\varepsilon)} N_b^2 \frac{1}{\sqrt{1+\phi_{piw}^2}}$$

$$= \frac{1}{2r_p} f_{rev} n_b \gamma \frac{1}{\beta^*} N_b \Delta Q_{bb} F_{profile}$$

$$= \frac{\pi}{r_p^2} f_{rev} n_b \gamma \frac{(\gamma\varepsilon)}{\beta^*} \Delta Q_{bb}^2 F_{profile}^2 \sqrt{1+\phi_{piw}^2}$$

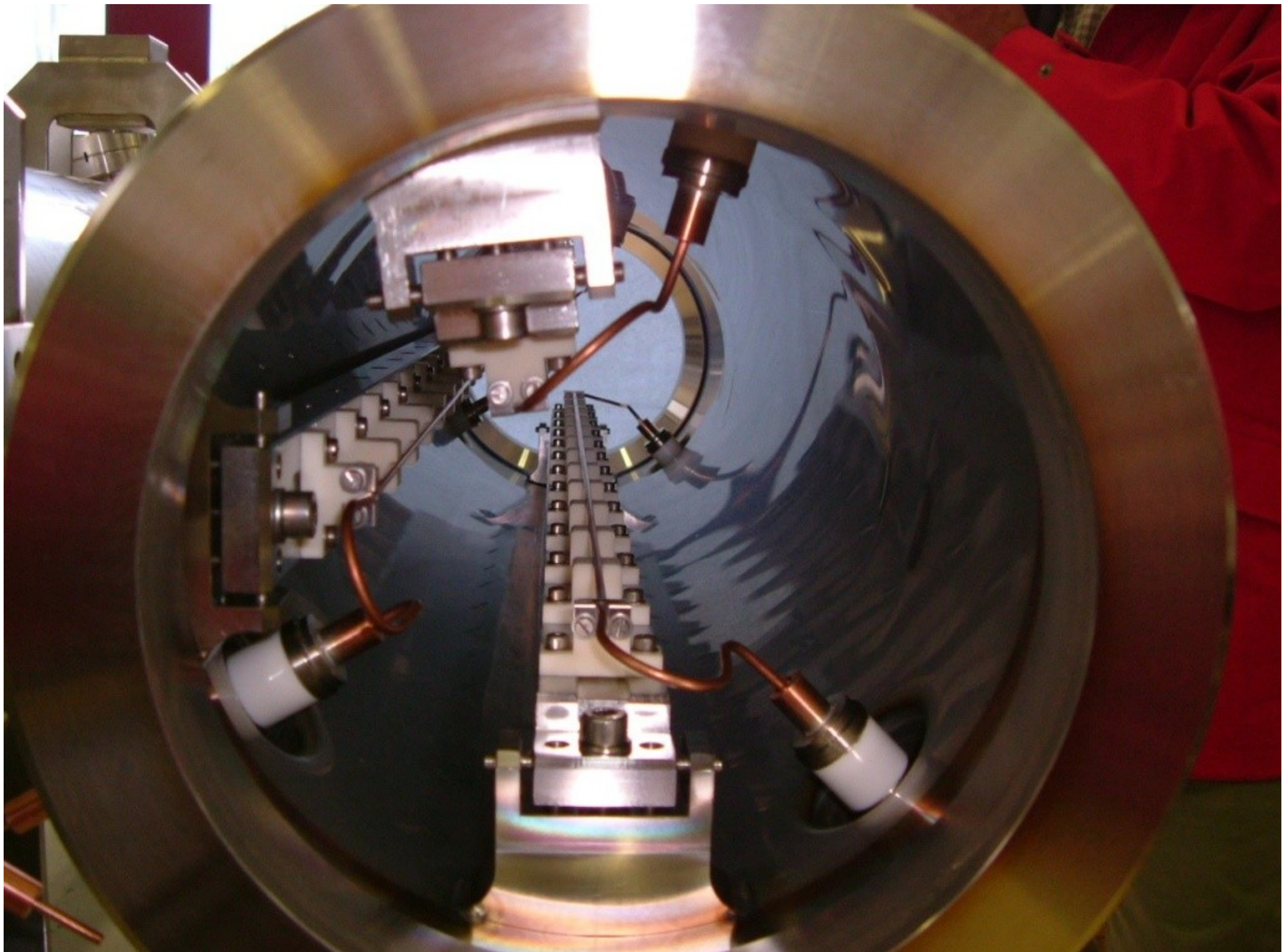
at the b-b limit, larger Piwinski angle &/or larger emittance increase luminosity!

SLHC collision schemes

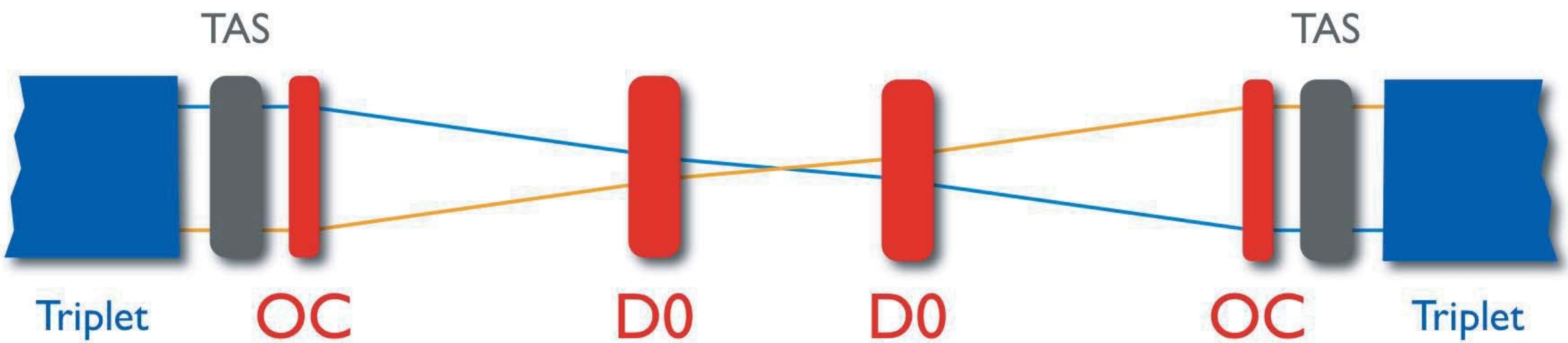
address drop in geometric overlap for smaller β^*

- **long-range beam-beam compensation** increase R_ϕ
  - robust in simulations, effective in SPS beam experiments
  - allows for reduced crossing angle
- **"Early Separation" (ES) scheme** further increase R_ϕ
  - aims at decoupling IP crossing angle from beam-beam separation in common sections by installing dipoles inside the detectors; weak crab cavities further boost luminosity
  - dynamical control of crossing angle → simple leveling
- **Full Crab Crossing** maximum R_ϕ
  - similar effect as ES, no magnets inside detector
  - under test at KEKB
- **"Large Piwinski Angle" (LPA) scheme** exploit $R_\phi \neq 0$
  - exploits concomitant drop in beam-beam tune shift to increase the bunch charge

prototype long-range beam-beam compensator in the SPS



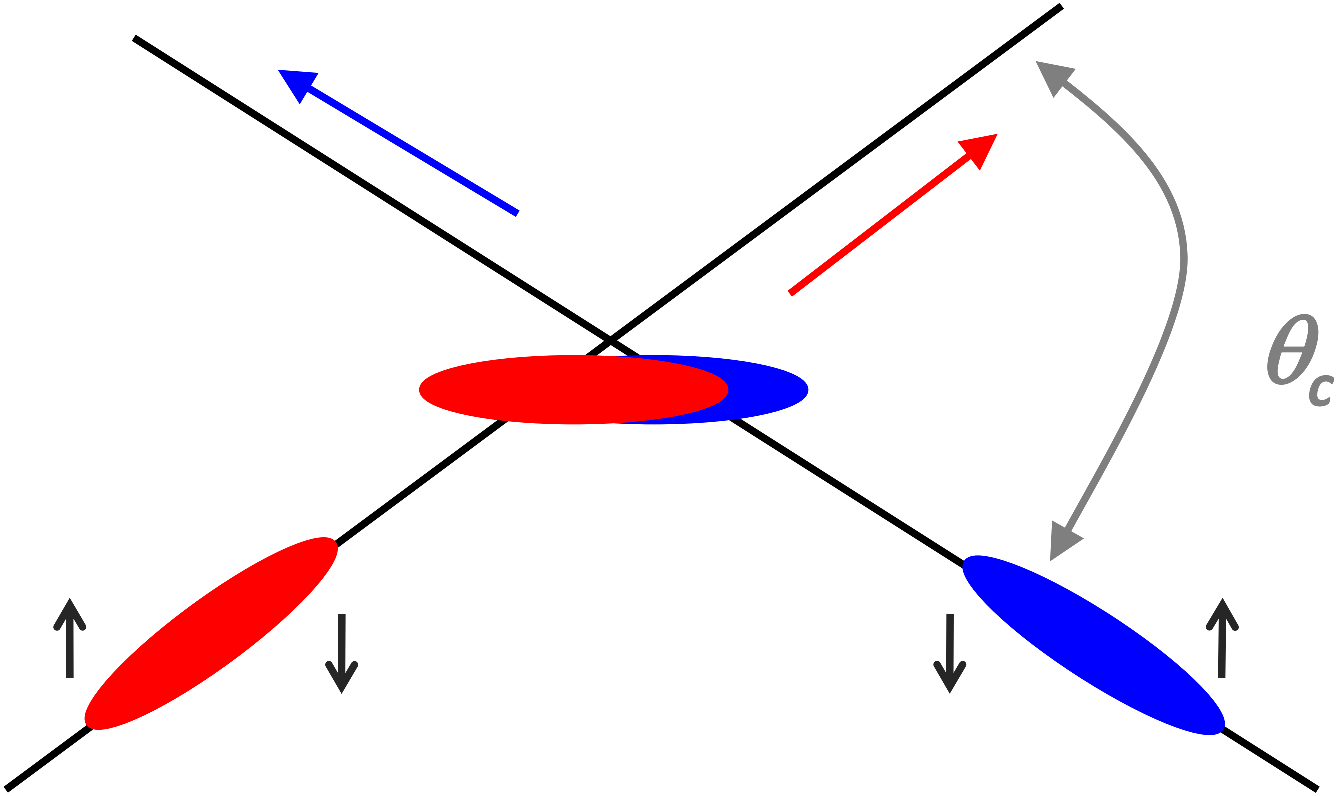
layout of Early Separation scheme



“slim” SC dipoles embedded inside detector

G. Sterbini

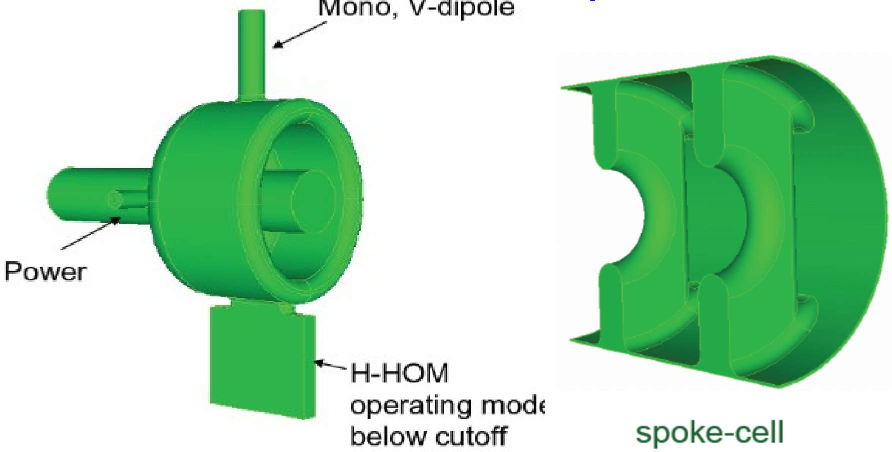
schematic of crab crossing



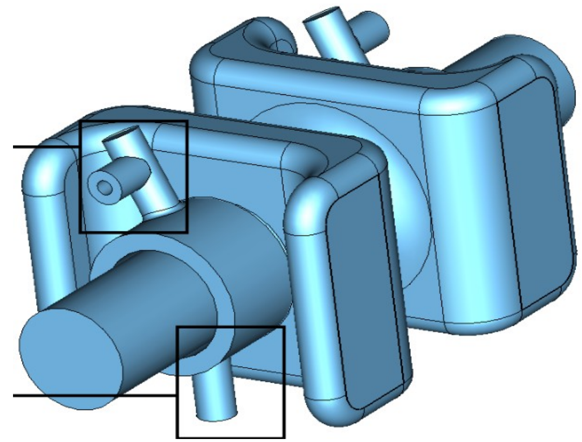
- RF crab cavity deflects head and tail in opposite direction so that collision is effectively "head on" for luminosity and tune shift
- bunch centroids still cross at an angle (easy separation)
- 1st proposed in 1988, in operation at KEKB since 2007

“compact” Crab Cavity candidates for LHC phase II

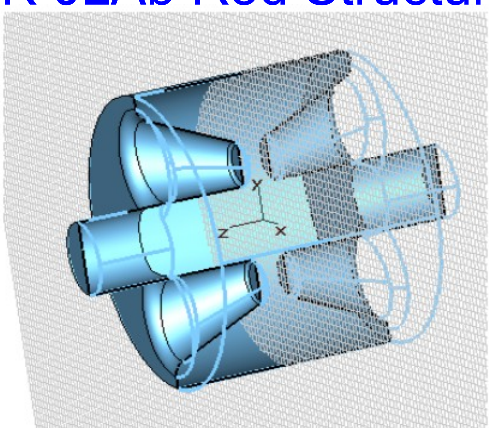
SLAC ½ Wave & Spoke Structures



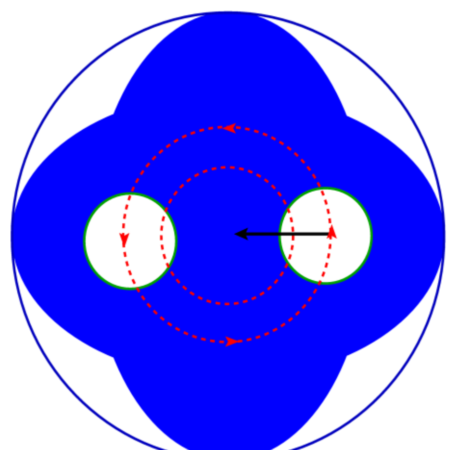
FNAL Mushroom Cavity



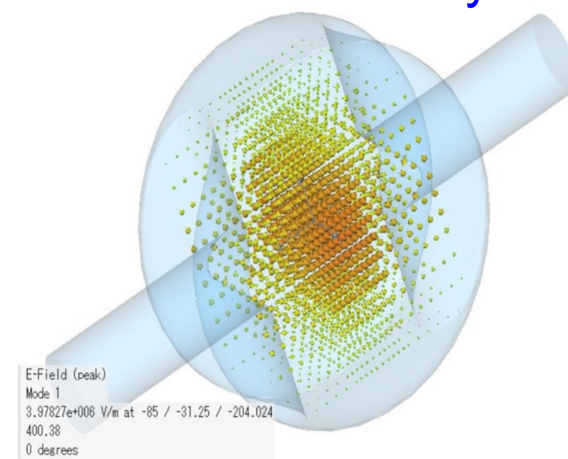
UK-JLAb Rod Structure



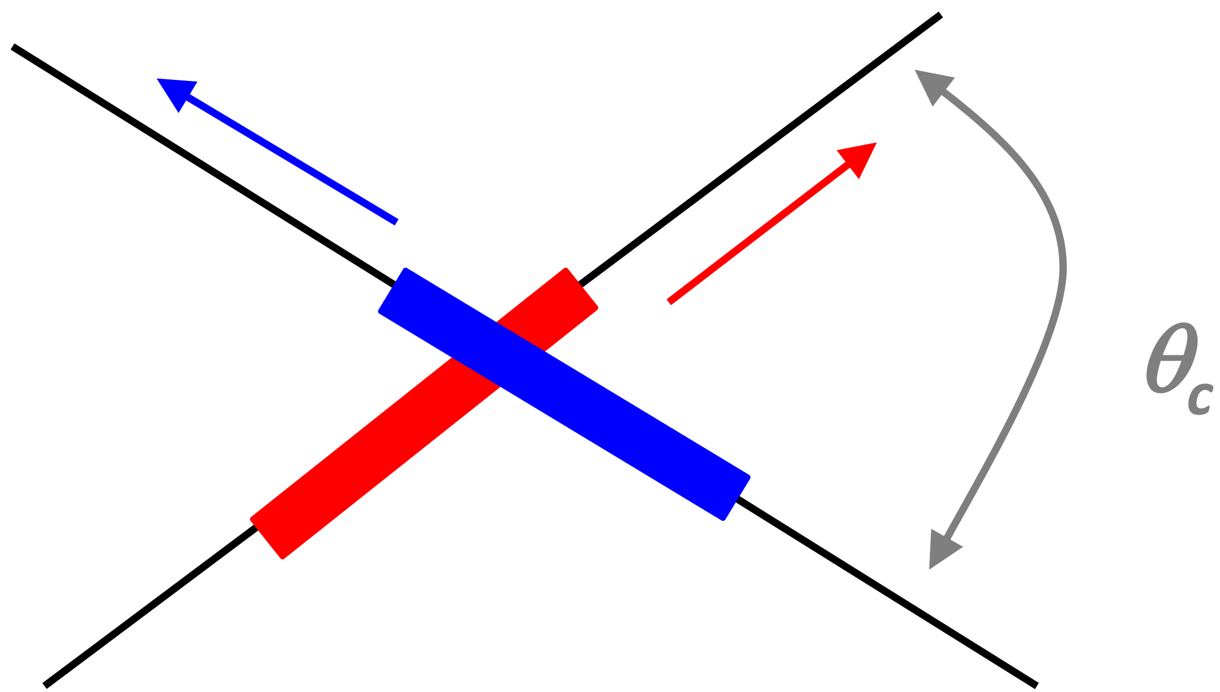
BNL TM010, BP Offset



KEK Kota Cavity



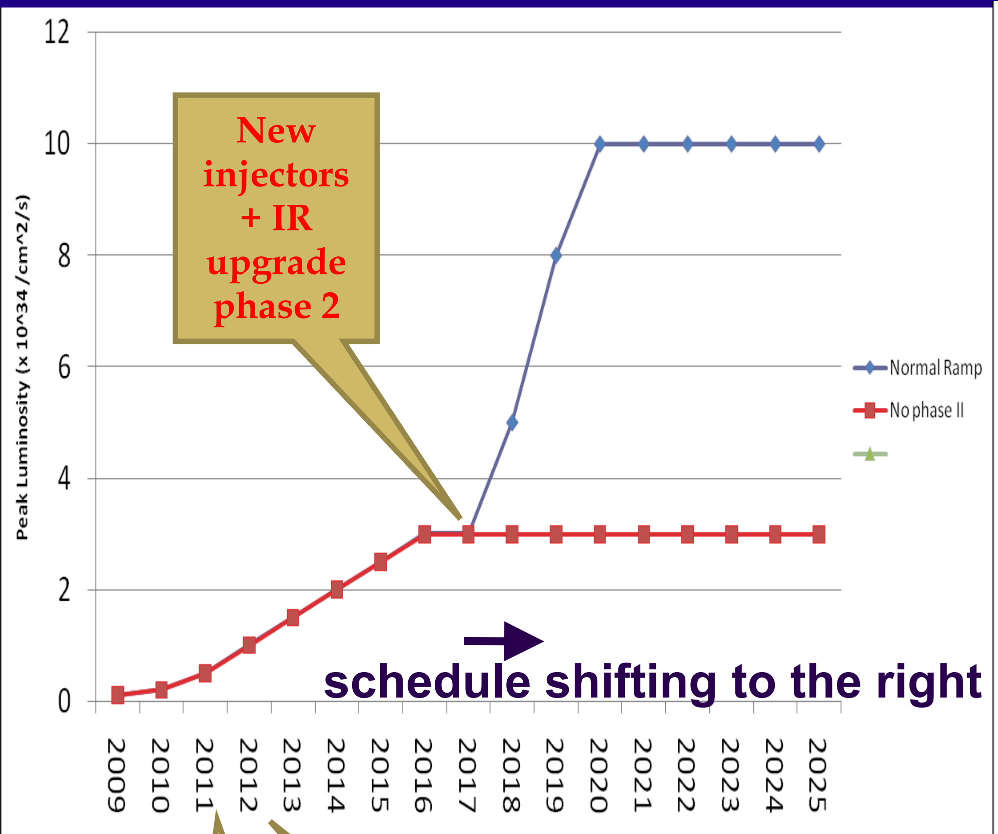
schematic of "LPA" collisions

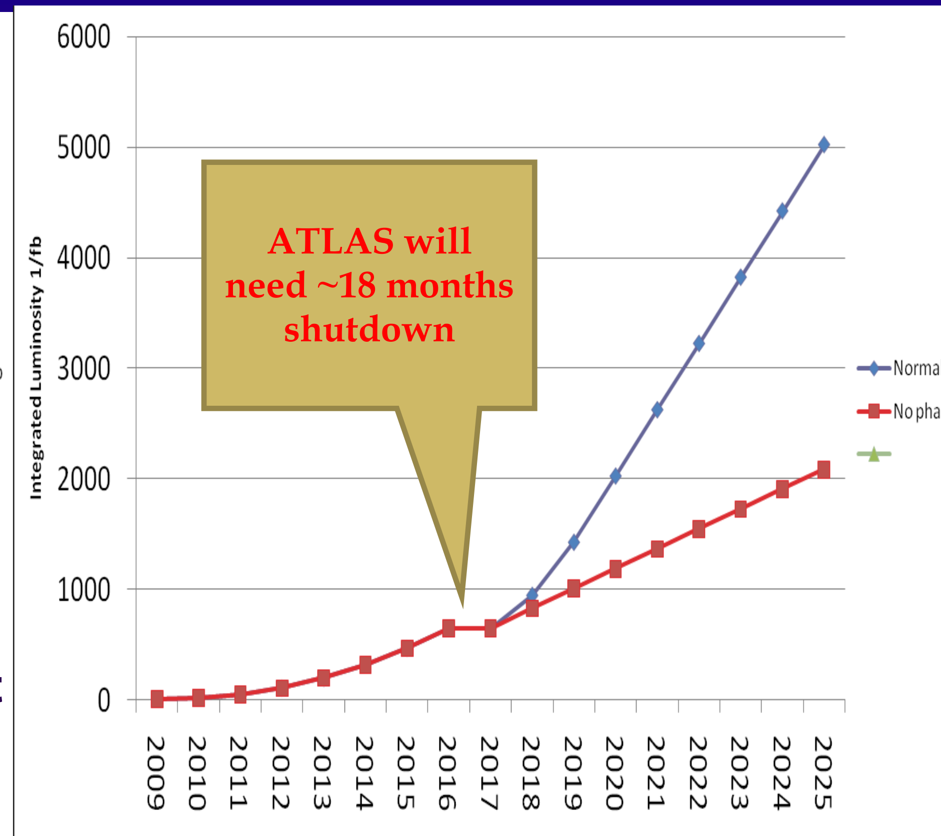


1) large Piwinski angle $\theta_c \sigma_z >> 2 \sigma_x^*$
2) longitudinally flat profile

→ reduced tune shift, higher bunch charge

LHC forecast peak & integrated luminosity evolution





Collimation phase 2

Linac4 + IR upgrade phase 1

goal for ATLAS Upgrade:

3000 fb^{-1} recorded

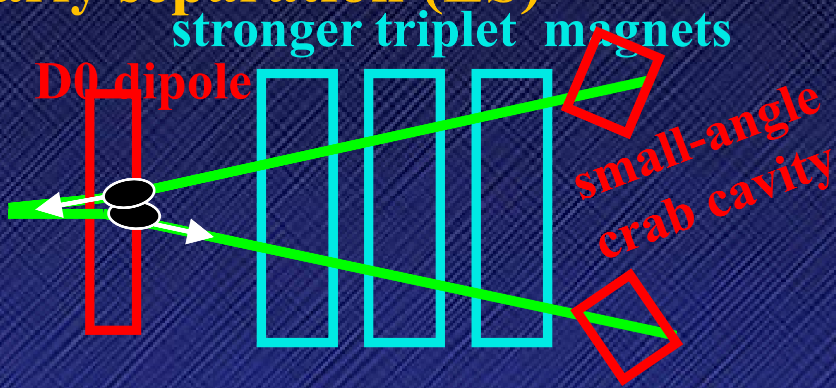
cope with ~400 pile-up events each BC

M. Nessi, R. Garoby

SLHC "phase-2" IR layouts

early separation (ES)

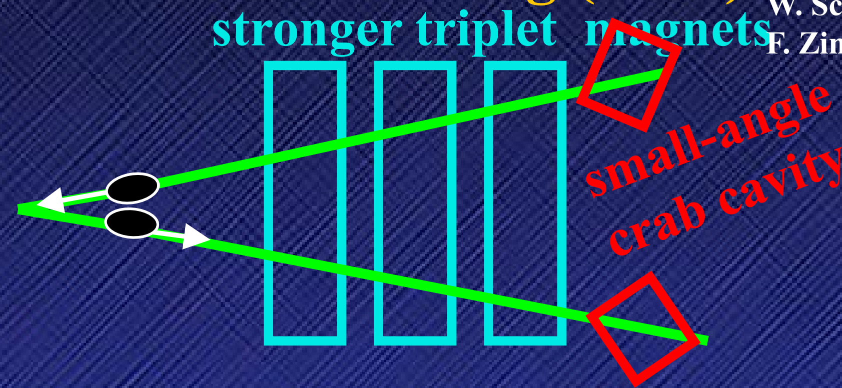
J.-P. Koutchouk



- early-separation dipoles in side detectors , crab cavities
  → hardware inside ATLAS & CMS detectors,
  first hadron crab cavities; off-δ β

full crab crossing (FCC)

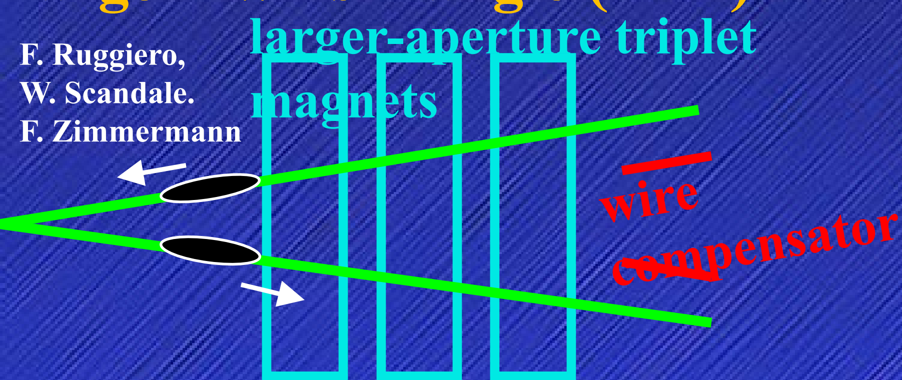
L. Evans,
W. Scandale,
F. Zimmermann



- crab cavities with 60% higher voltage
  → first hadron crab cavities, off-δ β-beat

large Piwinski angle (LPA)

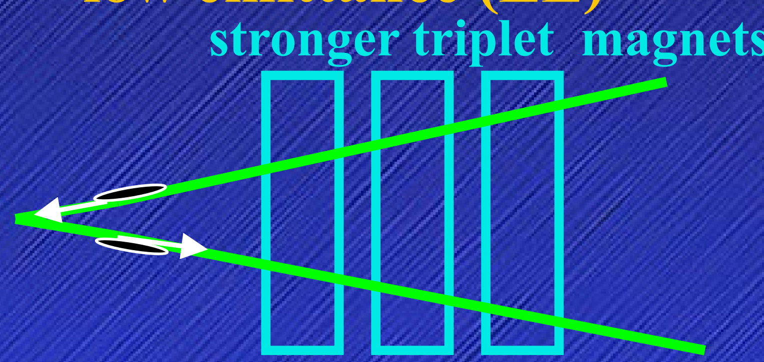
F. Ruggiero,
W. Scandale.
F. Zimmermann



- long-range beam-beam wire compensation
  → novel operating regime for hadron colliders,
  beam generation

low emittance (LE)

R. Garoby



- smaller transverse emittance
  → constraint on new injectors, off-δ β-beat

parameter	symbol	nominal	ultimate	ph. I	ES	FCC	LE	LPA
transverse emittance	ε [μm]	3.75	3.75		3.75	3.75	1.0	3.75
protons per bunch	N_b [10^{11}]	1.15	1.7		1.7	1.7	1.7	4.9
bunch spacing	Δt [ns]	25	25		25	25	25	50
beam current	I [A]	0.58	0.86		0.86	0.86	0.86	1.22
longitudinal profile		Gauss	Gauss		Gauss	Gauss	Gauss	Flat
rms bunch length	σ_z [cm]	7.55	7.55		7.55	7.55	7.55	11.8
beta* at IP1&5	β^* [m]	0.55	0.5	0.3	0.08	0.08	0.1	0.25
full crossing angle	θ_c [μrad]	285	315	410	0	0	311	381
Piwinski parameter	$\phi=\theta_c\sigma_z/(2^*\sigma_x^*)$	0.64	0.75	1.26	0	0	3.2	2.0
geometric reduction		0.84	0.80	0.62	0.77	0.77	0.30	0.48
peak luminosity	L [10^{34} cm^{-2}s^{-1}]	1	2.3	3.0	14.0	14.0	16.3	11.9
peak events per #ing		19	44	57	266	266	310	452
initial lumi lifetime	τ_L [h]	22	14	11	2.2	2.2	2.0	4.0
effective luminosity ($T_{turnaround}$=10 h)	L_{eff}[10^{34} cm^{-2}s^{-1}]	0.46	0.91	1.07	2.3	2.3	2.5	2.7
	$T_{run,opt}$ [h]	21.2	17.0	14.9	6.9	6.9	6.4	9.0
effective luminosity ($T_{turnaround}$=5 h)	L_{eff}[10^{34} cm^{-2}s^{-1}]	0.56	1.15	1.38	3.4	3.4	3.7	3.7
	$T_{run,opt}$ [h]	15.0	12.0	10.5	4.9	4.9	4.5	6.3
e-c heat SEY=1.4(1.3)	P [W/m]	1.1 (0.4)	1.0 (0.6)		1.0 (0.6)	1.0 (0.6)	1.0 (0.6)	0.4 (0.1)
SR heat load 4.6-20 K	P_{SR} [W/m]	0.17	0.25		0.25	0.25	0.25	0.36
image current heat	P_{IC} [W/m]	0.15	0.33		0.33	0.33	0.33	0.78
gas-s. 100 h τ_b	P_{gas} [W/m]	0.04	0.06		0.06	0.06	0.06	0.09
extent luminous region	σ_l [cm]	4.5	4.3	3.3	5.3	5.3	1.6	4.2
comment		nominal	ultimate		D0+CC	crab		wire com.

“luminosity leveling”

expected very fast decay of luminosity (few hours) dominated by proton burn off in collisions

$$L(t) = \frac{\hat{L}}{\left(1 + t/\tau_{eff}\right)^2}$$

$$\boxed{\tau_{eff} = \frac{N_b n_b}{n_{IP} \hat{L} \sigma_{tot}}}$$

luminosity leveling (changing θ_c, β^* or σ_z in store to keep luminosity constant) $\rightarrow$ **reducing maximum event pile up & peak power deposited in IR magnets**

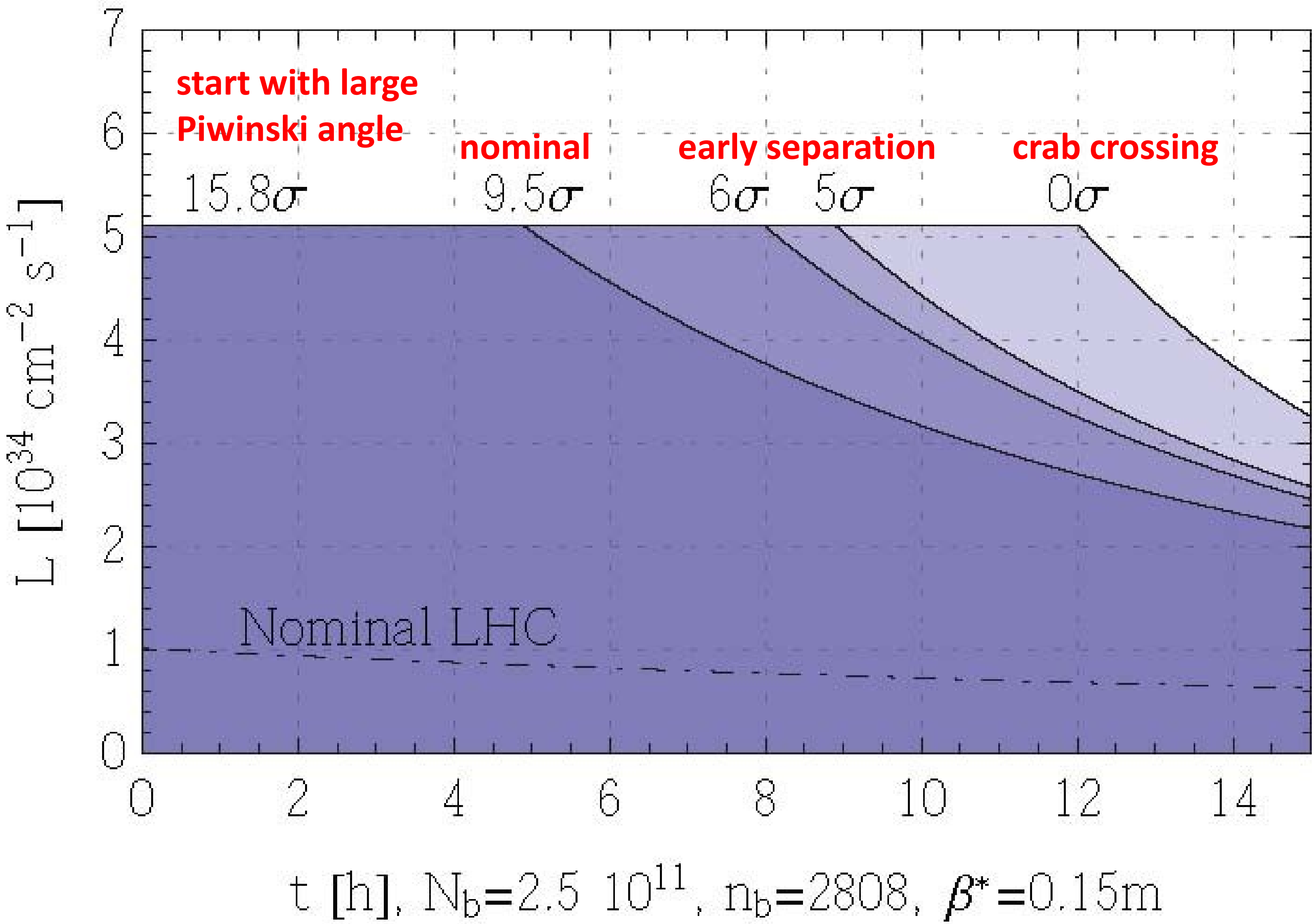
leveling with crossing angle offers distinct advantages:

- increased average luminosity if beam current not limited
- operational simplicity

natural option for early separation or crab cavities

may first be tested in LHC heavy-ion collisions

luminosity leveling with crossing angle



J.-P. Koutchouk, G. Sterbini

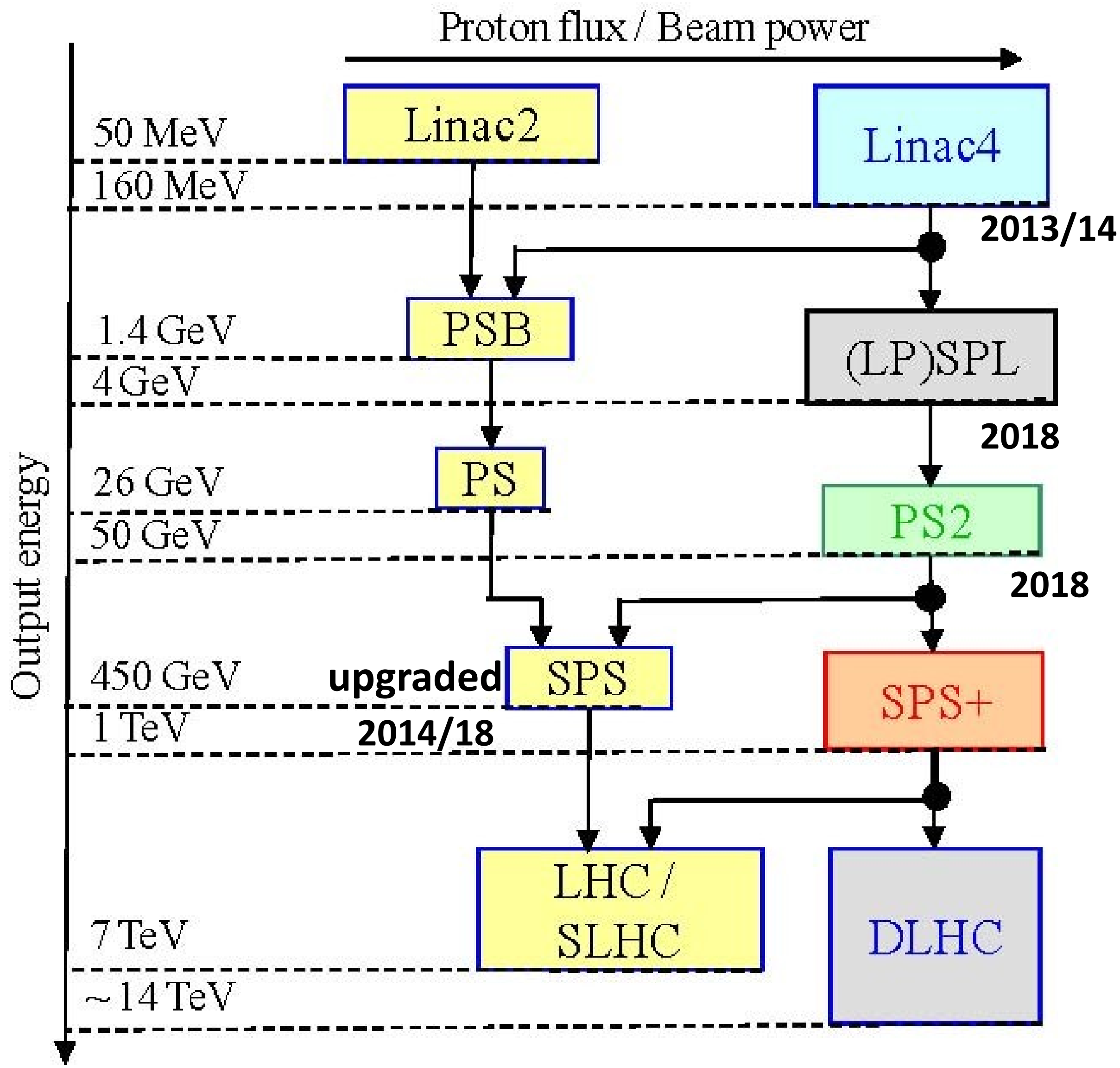
experimenters' choice:

- ✓ no accelerator components inside detector
- ✓ lowest possible event pile up
- ✓ possibility of easy luminosity leveling

→ Full Crab Crossing upgrade,
with Large Piwinski Angle as back up

LHC injector upgrade & high-power *p* beams

CERN complex upgrade strategy



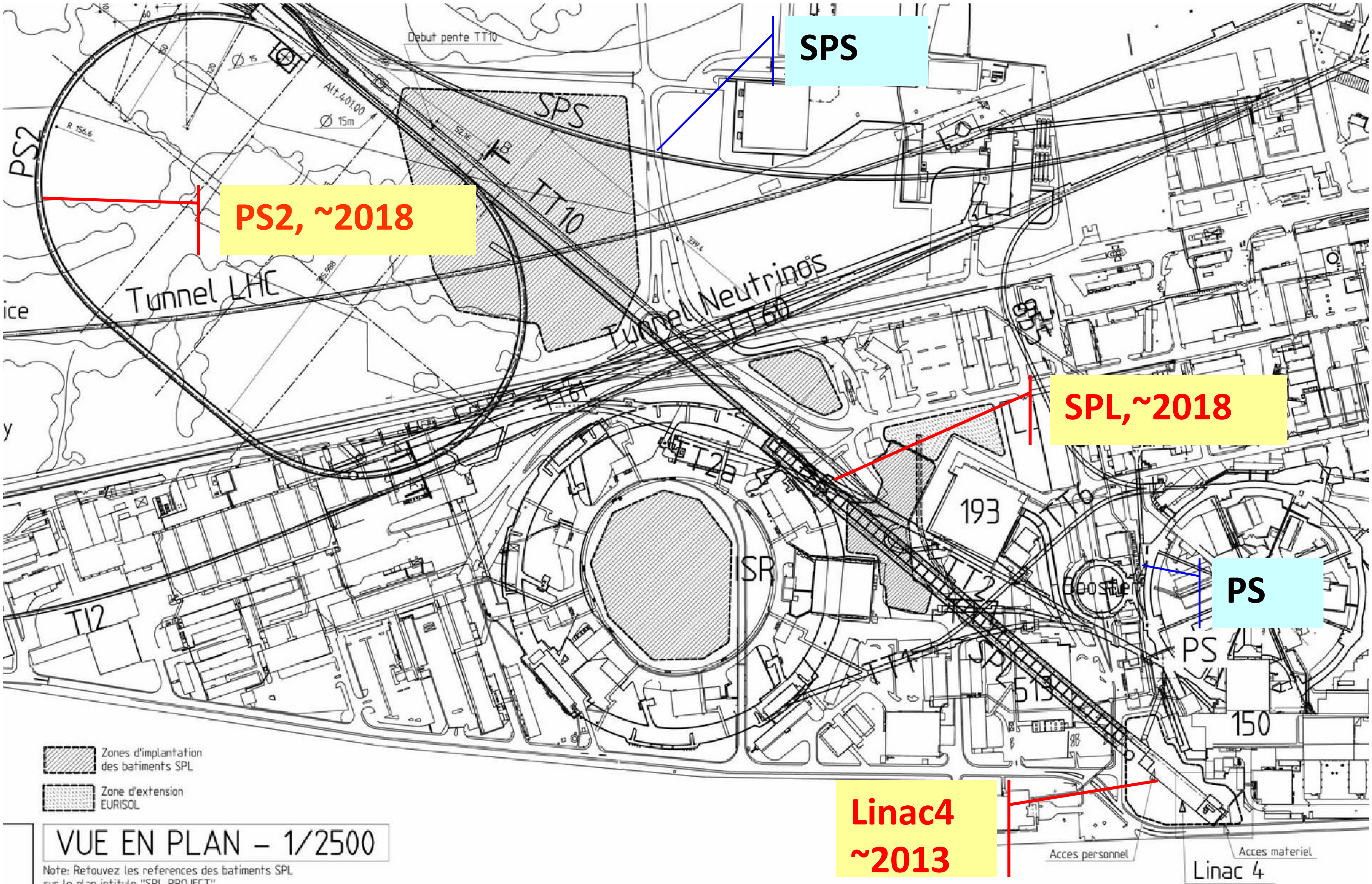
new injectors:
increased
reliability
&
superior beam
parameters

synchronized
with LHC IR
upgrades:

phase I: 2014
phase II: 2018

R. Garoby

layout of new LHC injectors



R. Garoby, CARE-HHH BEAM07, October'07; L. Evans, LHCC, 20 Feb '08

Linac4

Linac4: 80 m, 18 klystrons

45keV 3MeV 3MeV 50MeV 94MeV 160MeV

H-	RFQ	CHOPPER	DTL	CCDTL	PIMS
RF volume source (DESY) 45 kV Extrac.	Radio Frequency Quadrupole 3 m 1 Klystron 550 kW	Chopper & Bunchers 3.6 m 11 EMquad 3 cavities	Drift Tube Linac 18.7 m 3 tanks 3 klystrons 4.7 MW 111 PMQs	Cell-Coupled Drift Tube Linac 25 m 21 tanks 7 klystrons 7 MW 21 EMQuads	Pi-Mode Structure 22 m 12 tanks 8 klystrons ~12 MW 12 EMQuads

Ion current:
40 mA (avg.),
65 mA (peak)

RF accelerating structures: 4 types (RFQ, DTL, CCDTL, PIMS)
Frequency: 352.2 MHz
Duty cycle: 0.1% phase 1 (Linac4), 3-4% phase 2 (SPL), (design: 10%)

<u>Linac4</u> - Civil engineering status

Construction started in fall 2008

Linac4 tunnel (“cut and cover” excavation) seen from high-energy side.

Final concrete works starting at low-energy side, excavation proceeding at high energy side.

Tunnel level -12 m, length 100 m.

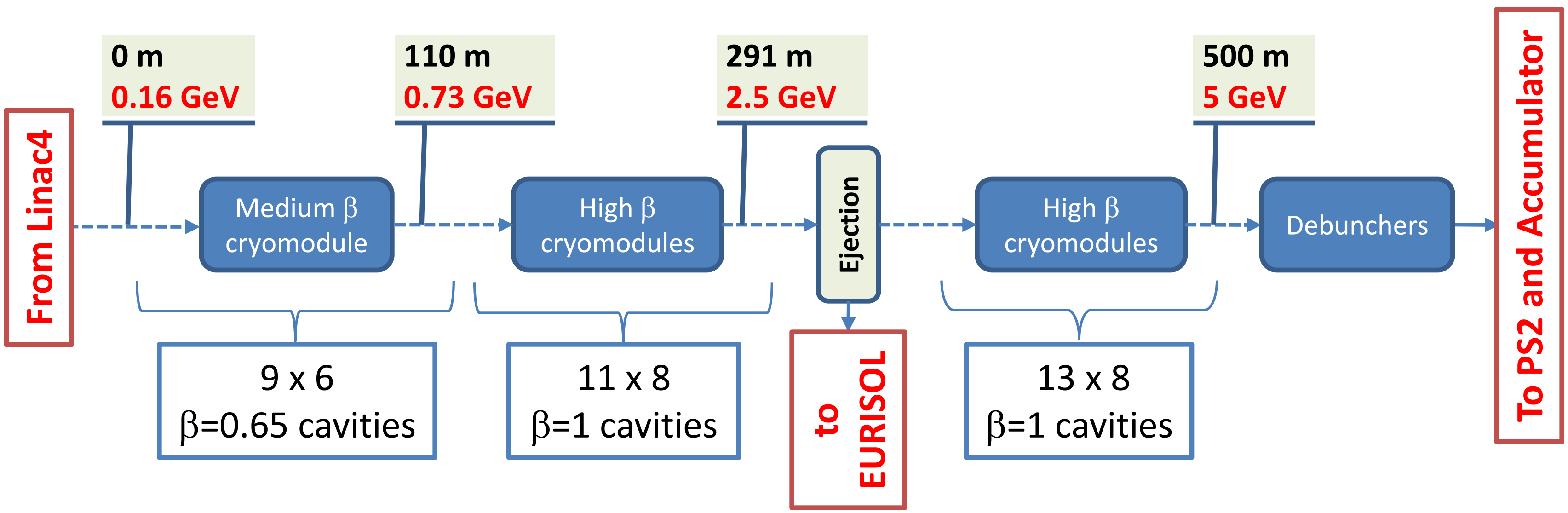
Delivery of tunnel and surface equipment building end of 2010.

Linac4 - Civil engineering status

High-energy side of Linac4 tunnel, with beam dump chamber and connecting tunnel to Linac2 line.

Super Conducting Proton Linac – “SPL” (High Power, 2x4 MW)

SC-linac (160 MeV → 5 GeV) with ejection at intermediate energy



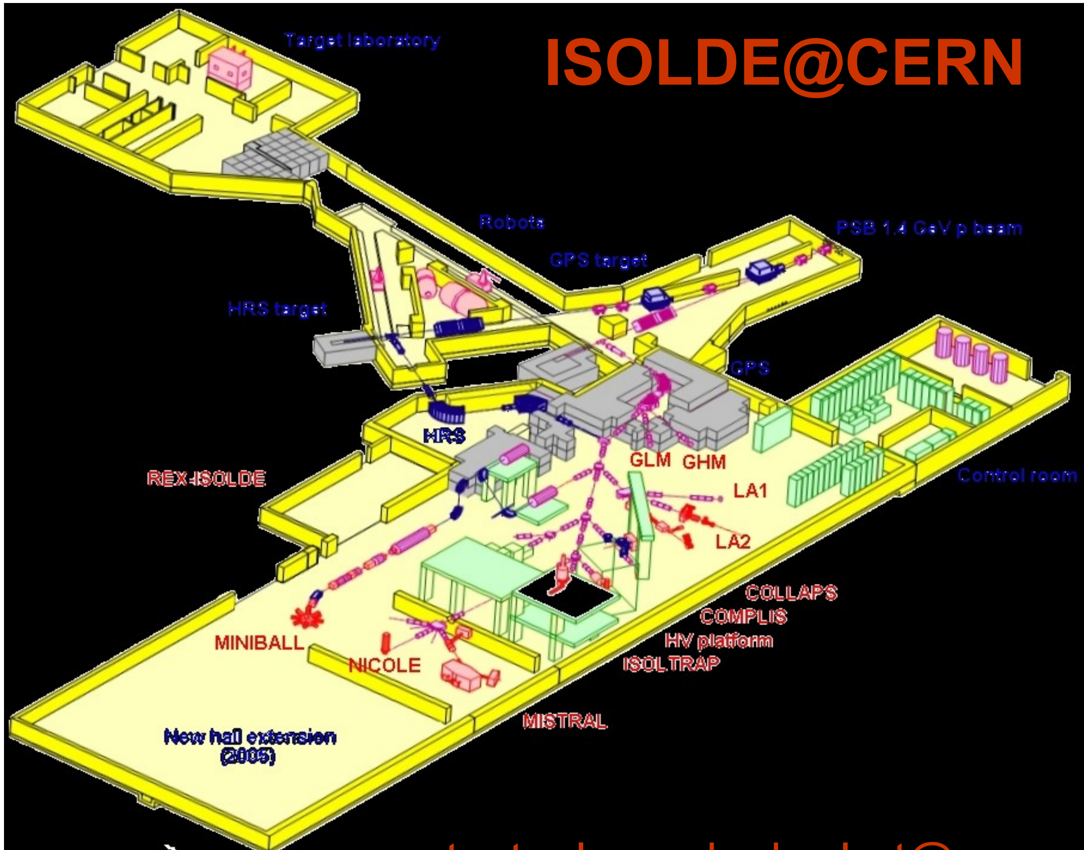
Length: ~500 m

strong synergy and joint R&D with *ESS*

european spallation source

ESS – European Spallation Source

SC proton linac; same RF frequency as SPL (704 MHz), 5 MW (or 2x5 MW) beam power



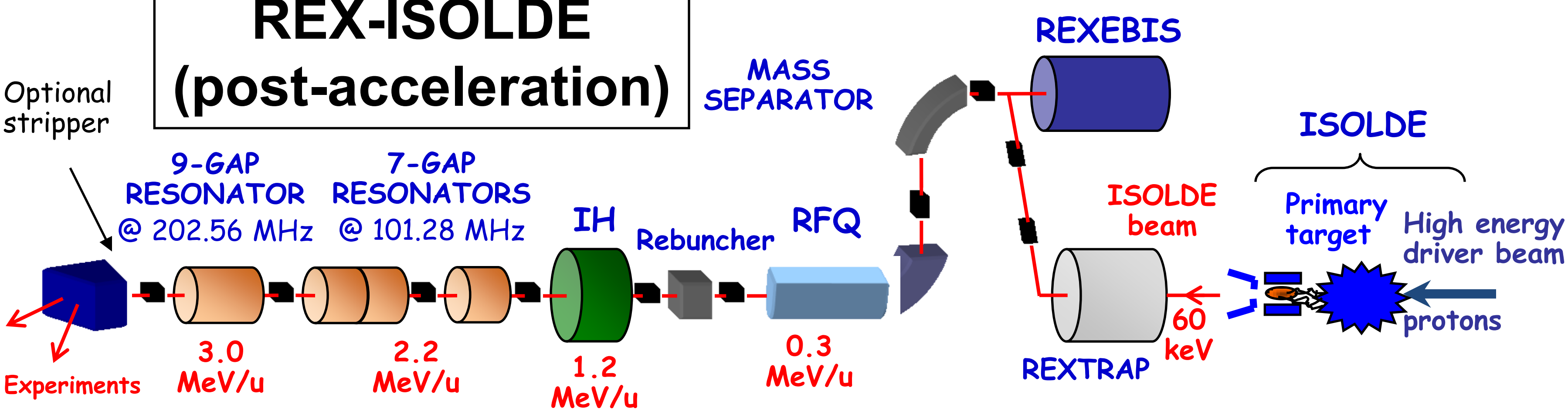
- radioactive ion beam facility
- more than 800 different isotopes of more than 70 different elements
- nuclear physics and solid-state physics research

future projects:

- target development (selectivity and ion beam purity)
- laser application (resonant laser ionization and laser spectroscopy)
- polarized radioactive beams
- HIE-ISOLDE upgrade for higher energy of post-accelerated ions (e.g. superconducting LINAC)

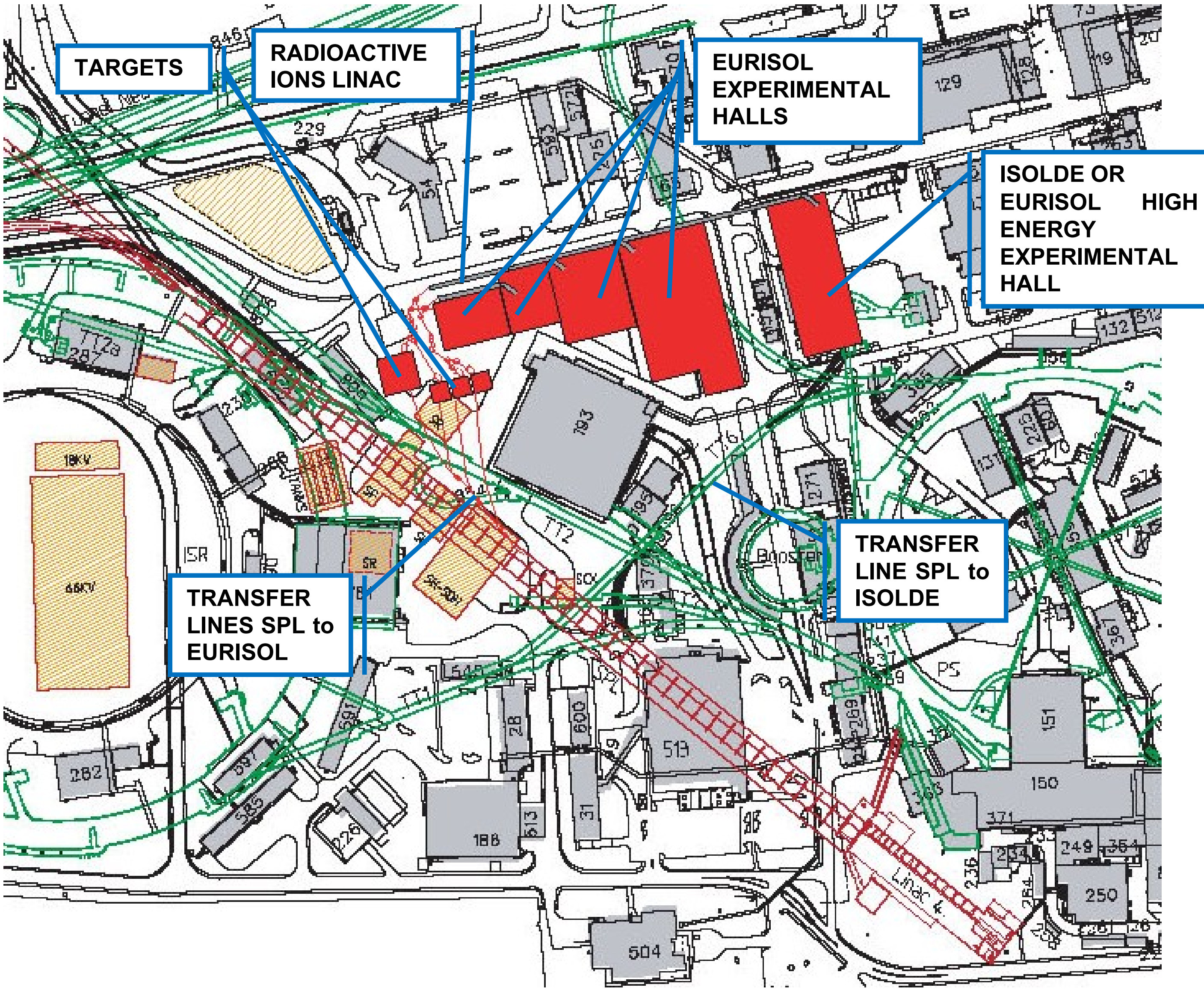
contact: alexander.herlert@cern.ch

REX-ISOLDE (post-acceleration)

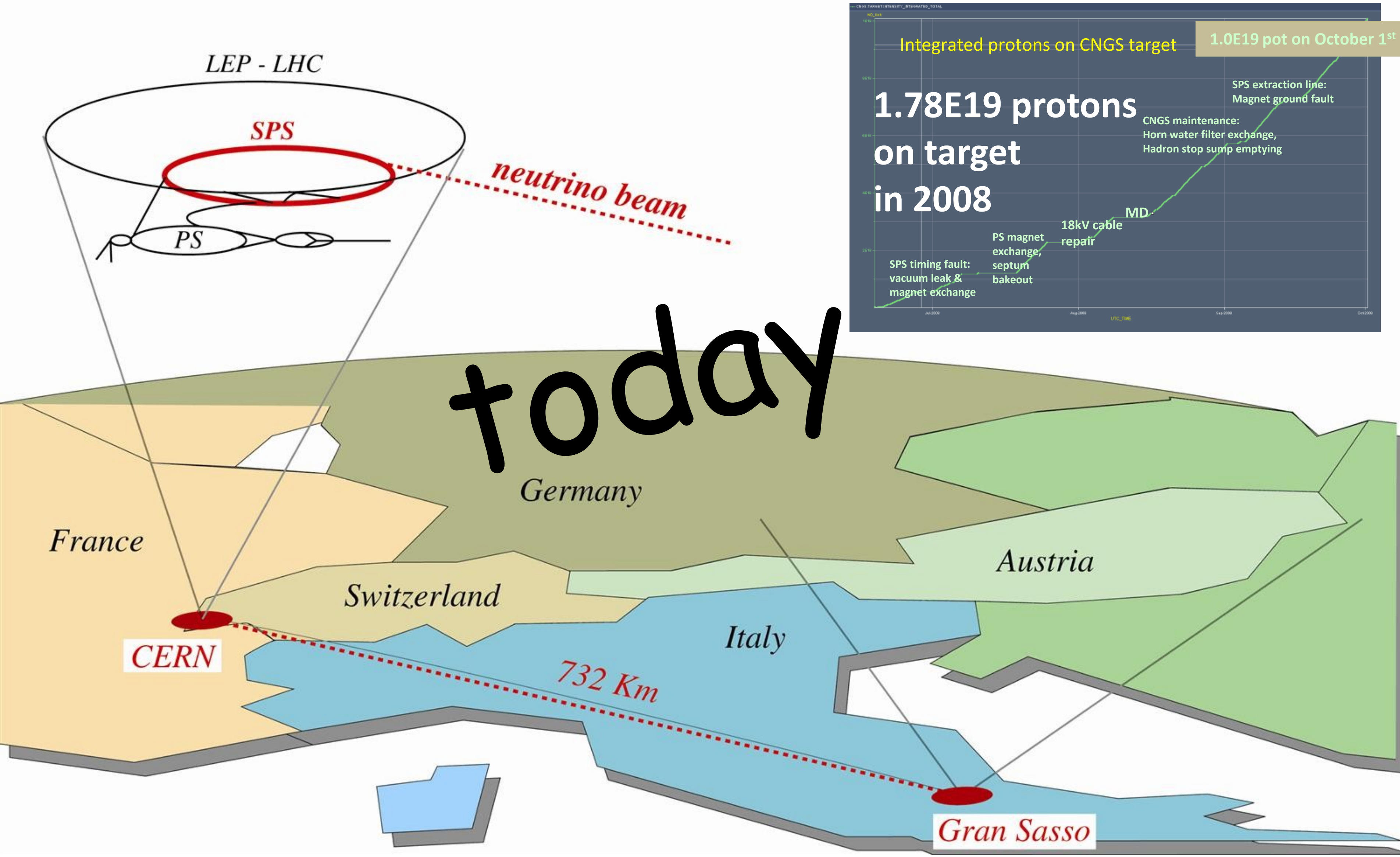


future enhancement by high-power *p* beam?

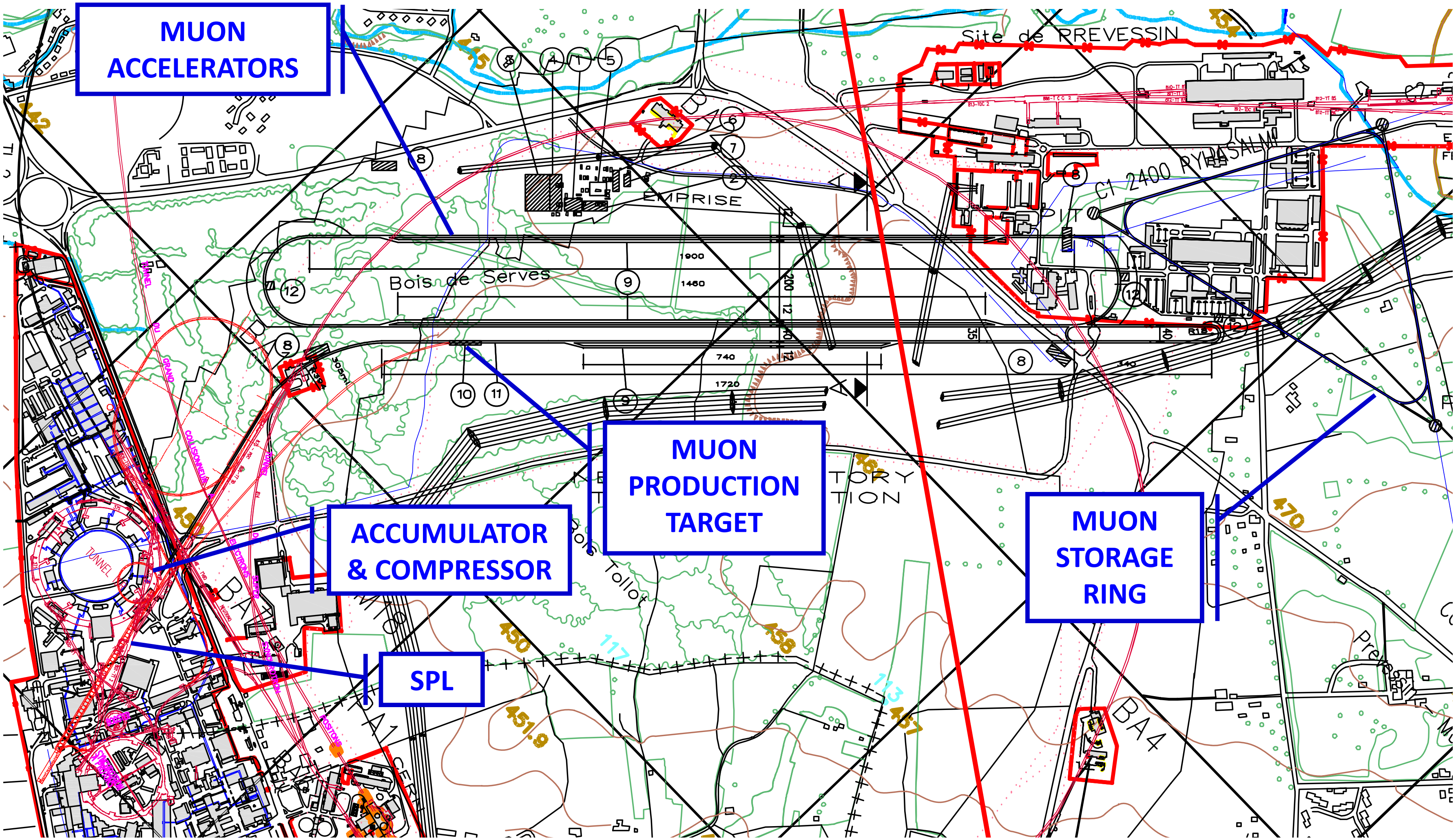
a - <u>ISOLDE & EURISOL driven by SPL</u>



CERN to Gran Sasso Neutrino Beam



future enhancement by high-power *p* beam?
b - <u>neutrino factory with SPL-based *p* driver</u>



PS2

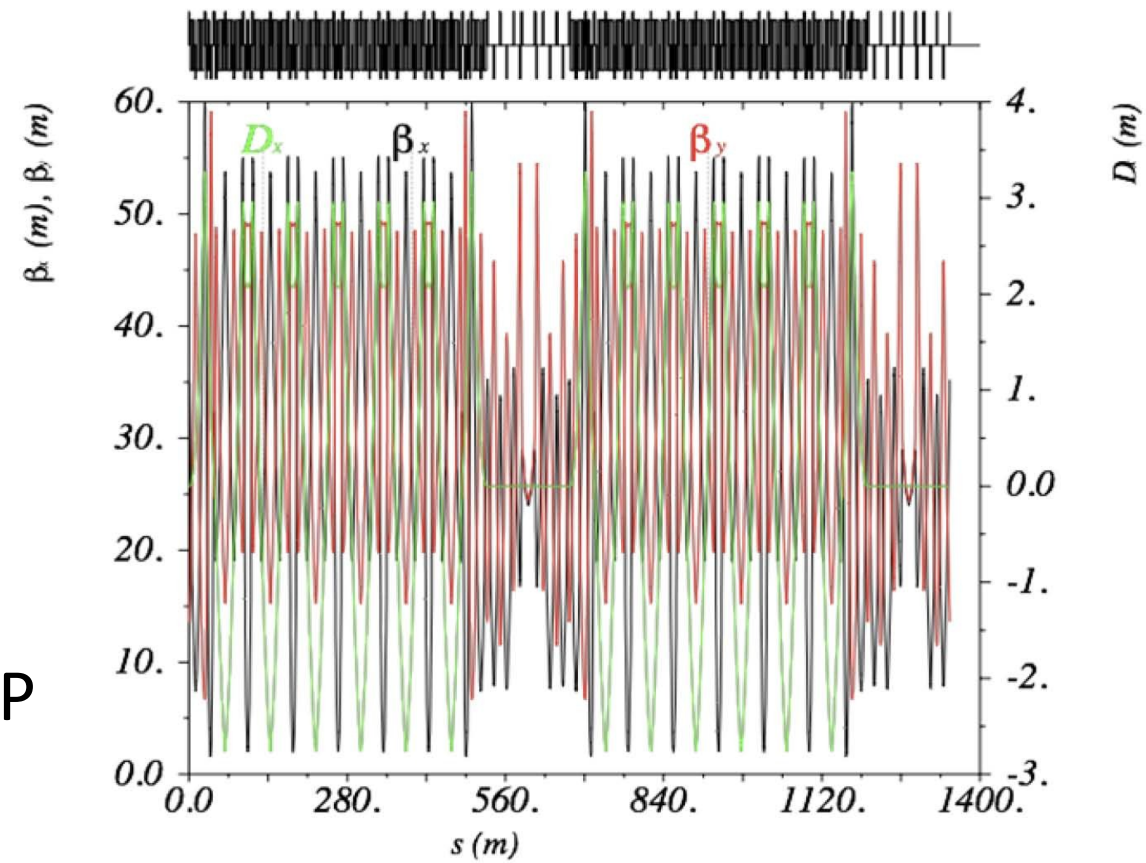
circumference 1346 m

imaginary γ_{tr}

-no transition crossing

-more complicated lattice than regular FODO

collaboration with LARP & US labs



SPS upgrade : e-cloud mitigation

beam-pipe **surface treatment**:

• **in situ**

• **no re-activation**

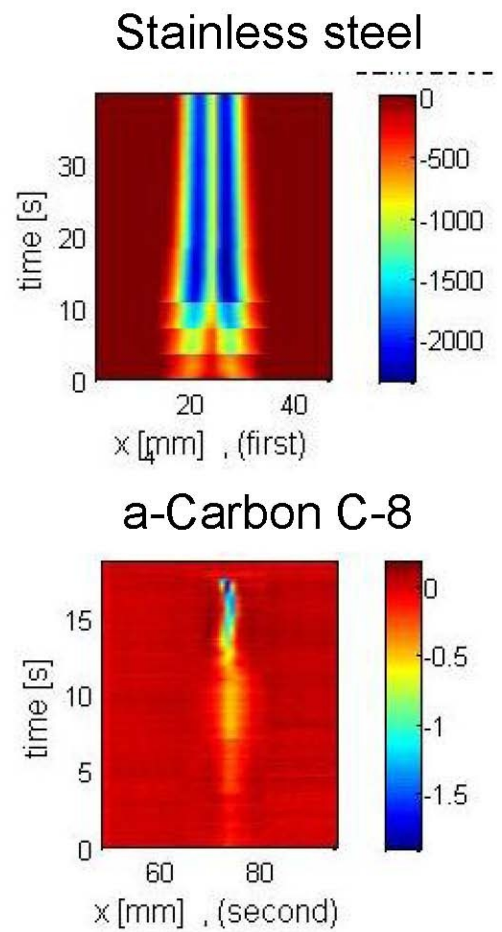
• **no aperture restriction**

carbon-based composites

(amorphous carbon layers,

carbon coated black metals)

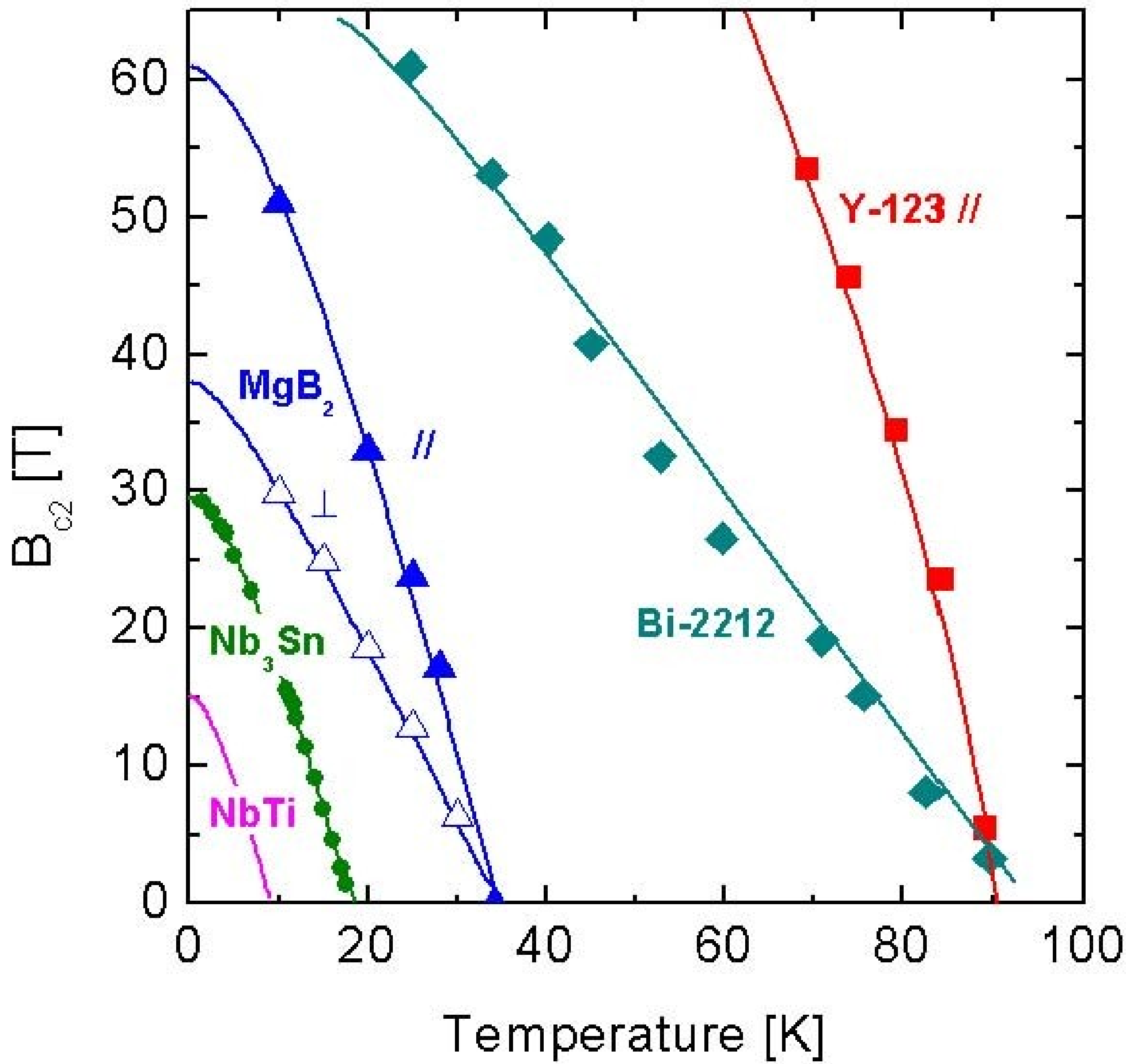
SEY < 1 , even after weeks of air exposure



M. Taborelli et al

high field magnets for SLHC, SPS+, and D/TLHC

critical field B_{c2} vs T for different superconductors

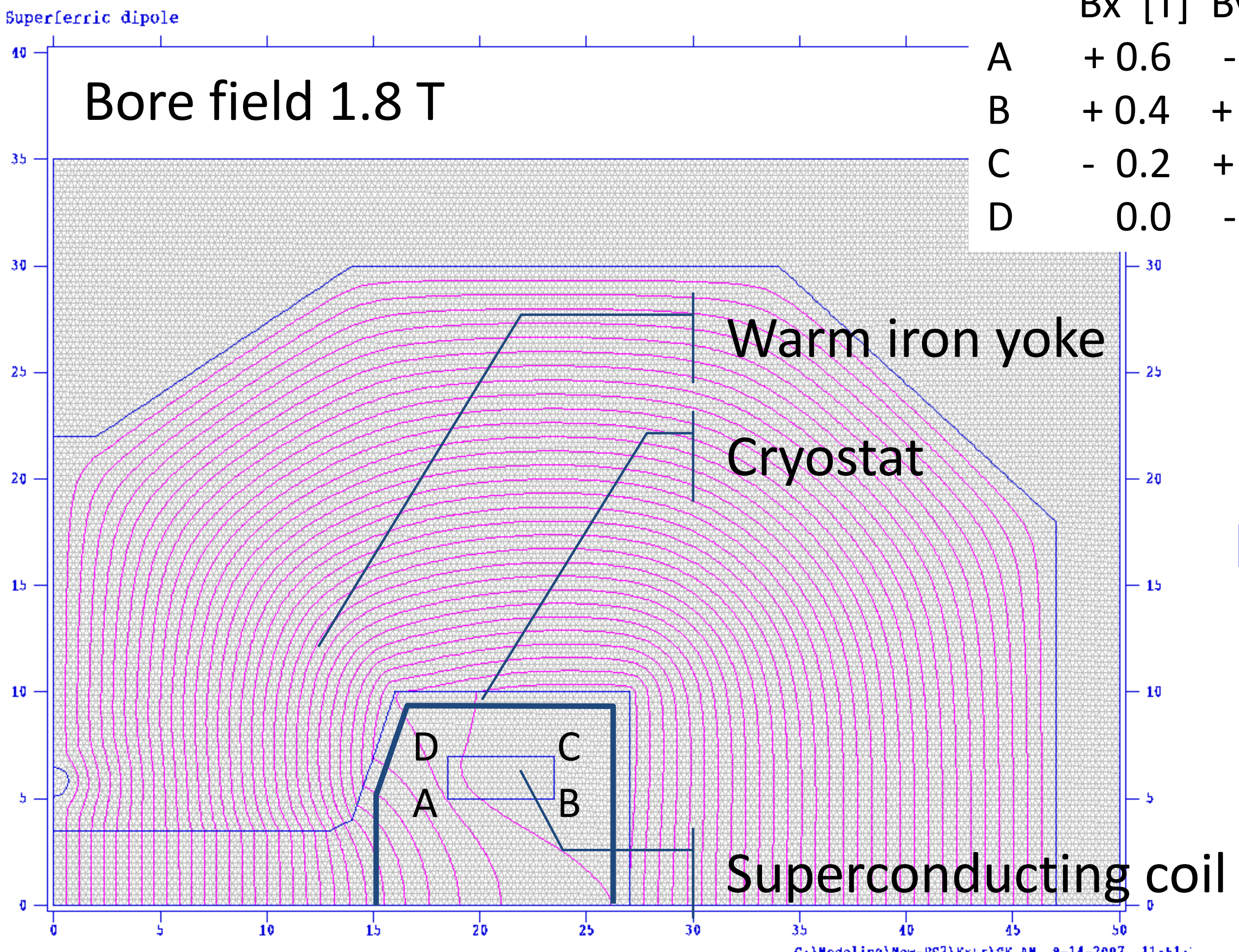


today, fraction of usable B_{c2}:
80% for NbTi
70% for Nb_3Sn
10-15% for HTS & MgB_2

L. Rossi

fast cycling SC magnets for SPS+ (and PS2?)

Iron Dominated SC Dipole



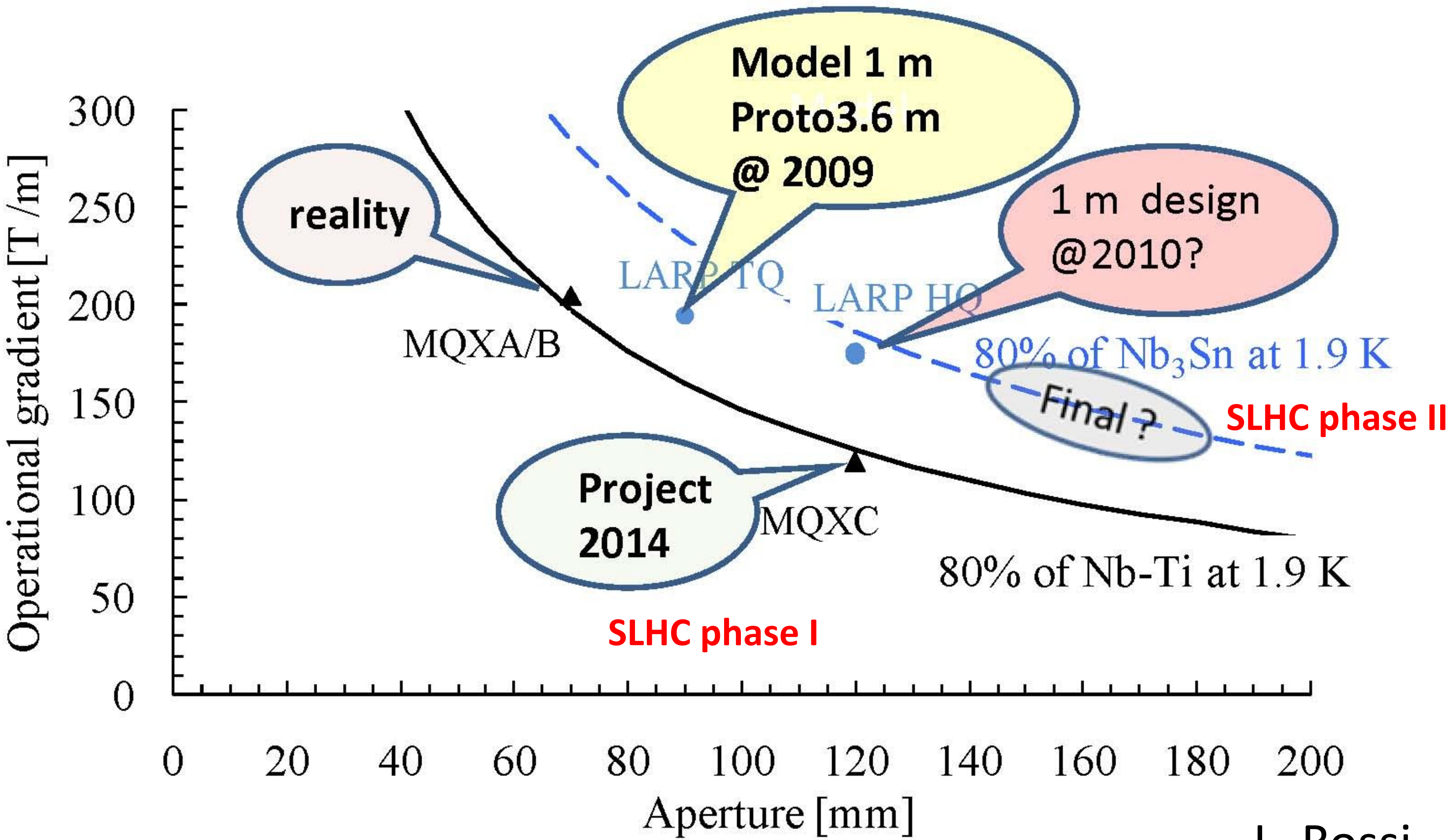
	Bx [T]	By [T]	Bmod [T]
A	+ 0.6	- 0.8	1.0
B	+ 0.4	+ 0.2	0.4
C	- 0.2	+ 0.2	0.3
D	0.0	- 0.7	0.7

Lower field
Higher margin
Lower loss
Coil *hidden*

Magnet design by courtesy of D. Tommasini, CERN

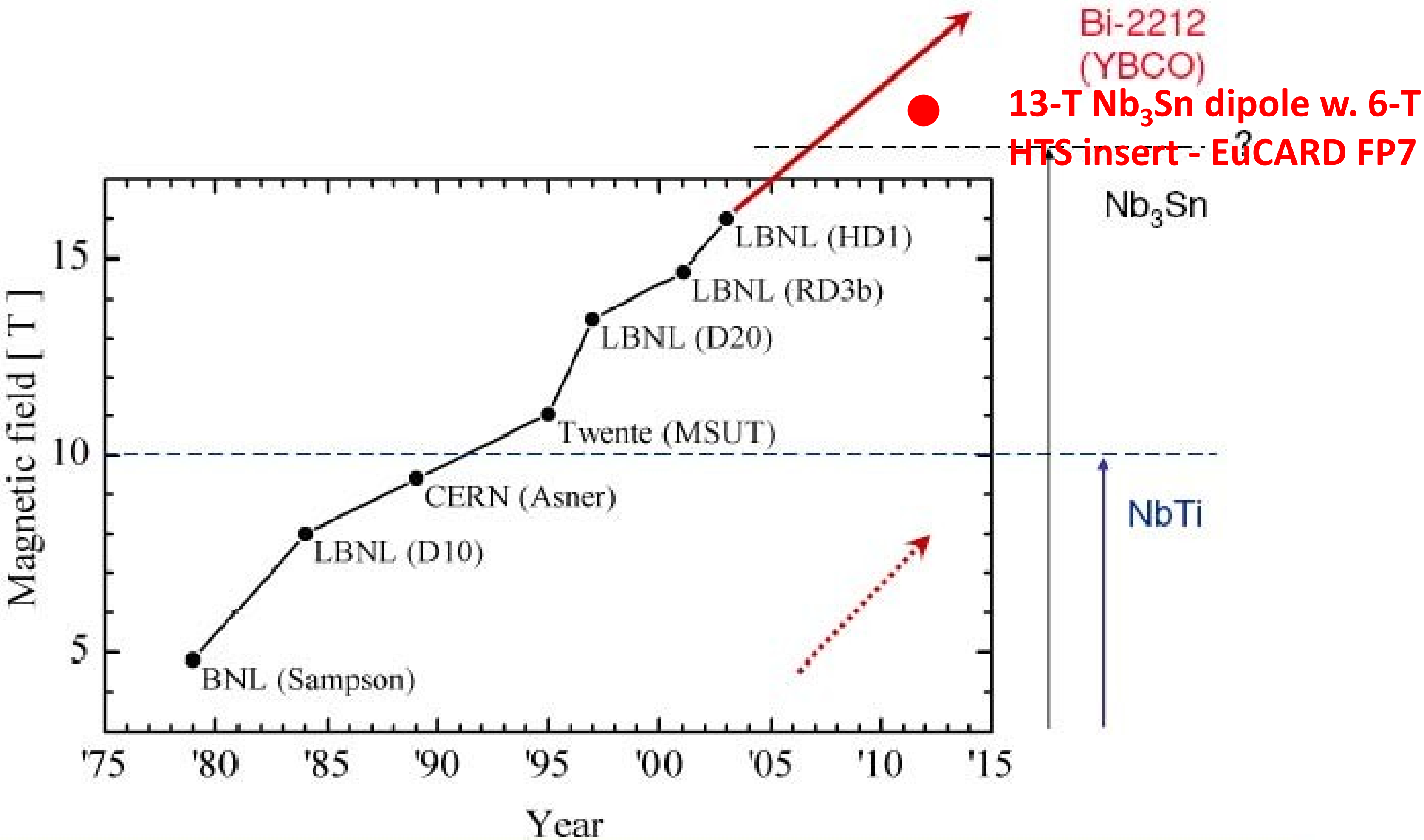
L. Bottura

SC quadrupole gradient vs aperture - scaling laws and real data



L. Rossi

High Field Dipoles



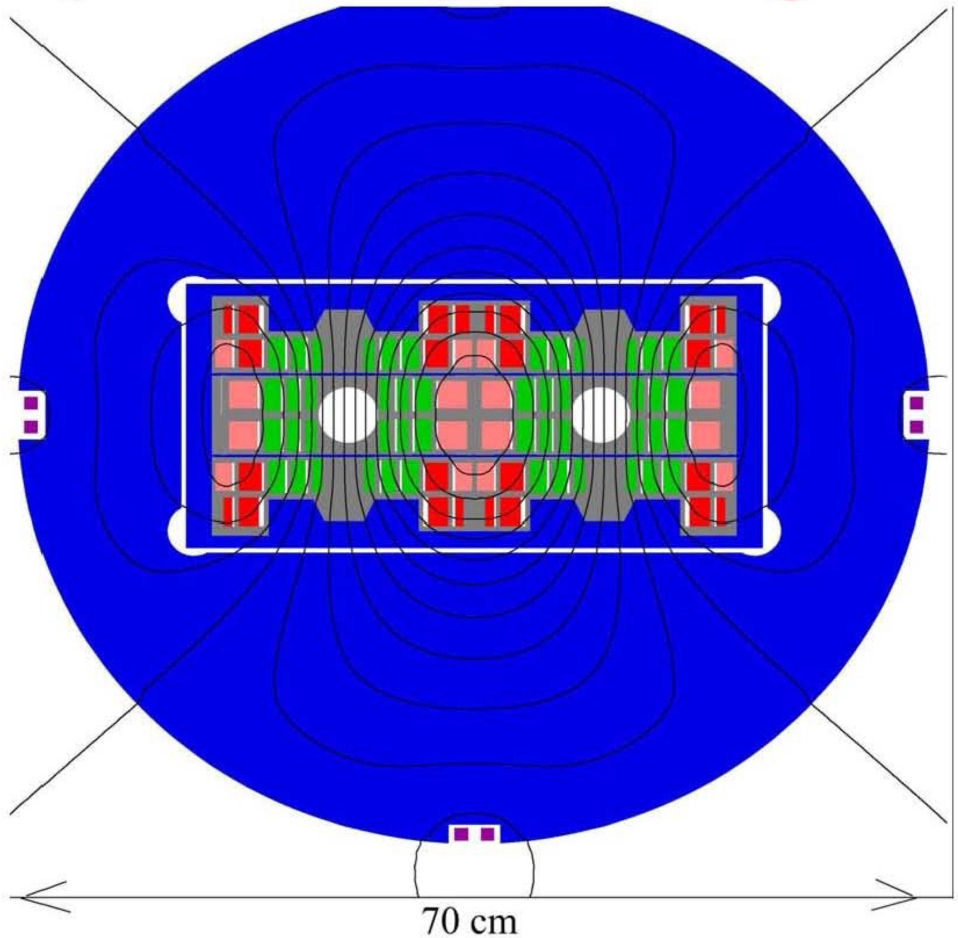
L. Rossi

P. McIntyre

Extend to 24 Tesla: Bi-2212 in inner (high field) windings, Nb_3Sn in outer (low field) windings

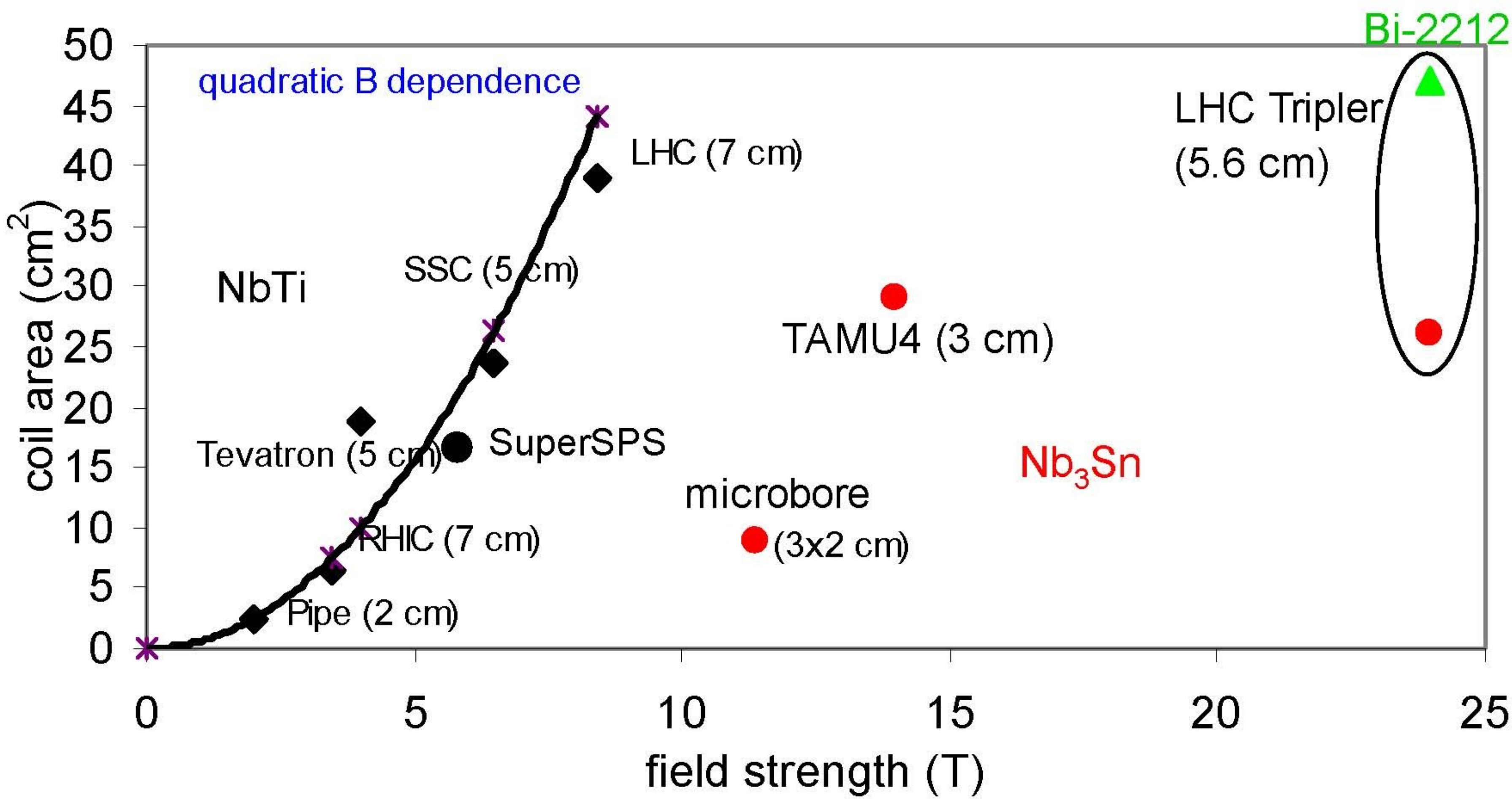
Dual dipole (ala LHC)

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



stress management by block coil geometry

magnets are getting more efficient!

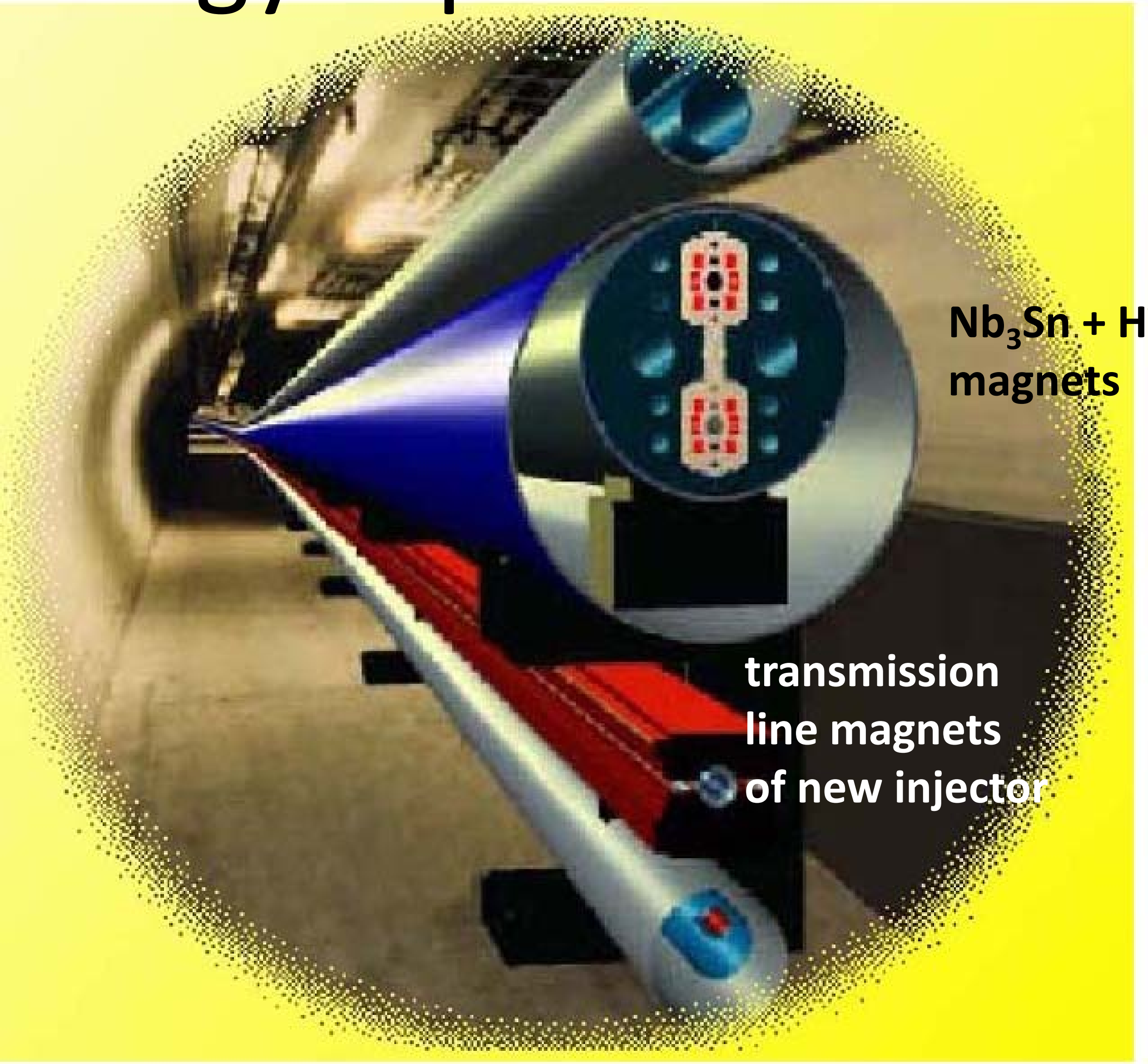


P. McIntyre

LHC energy tripler - TLHC

"LHC luminosity upgrade (SLHC) … is the route that will enable the Farthest Energy Frontier (FEF)"

L. Rossi

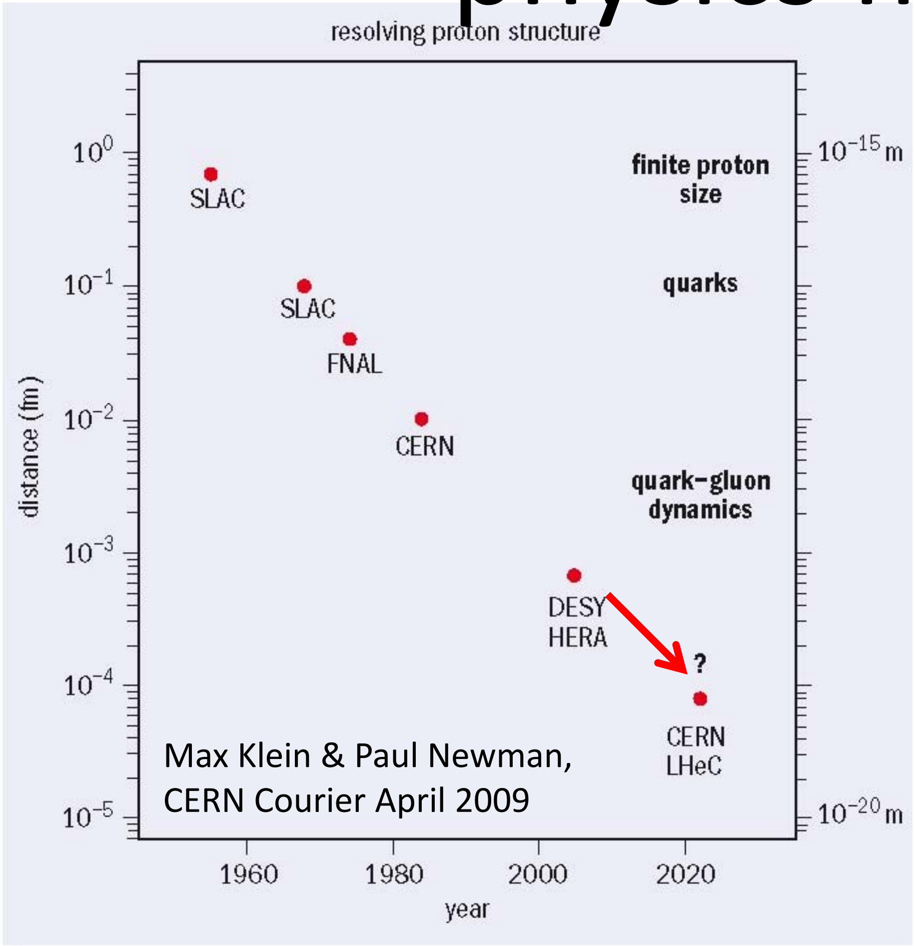


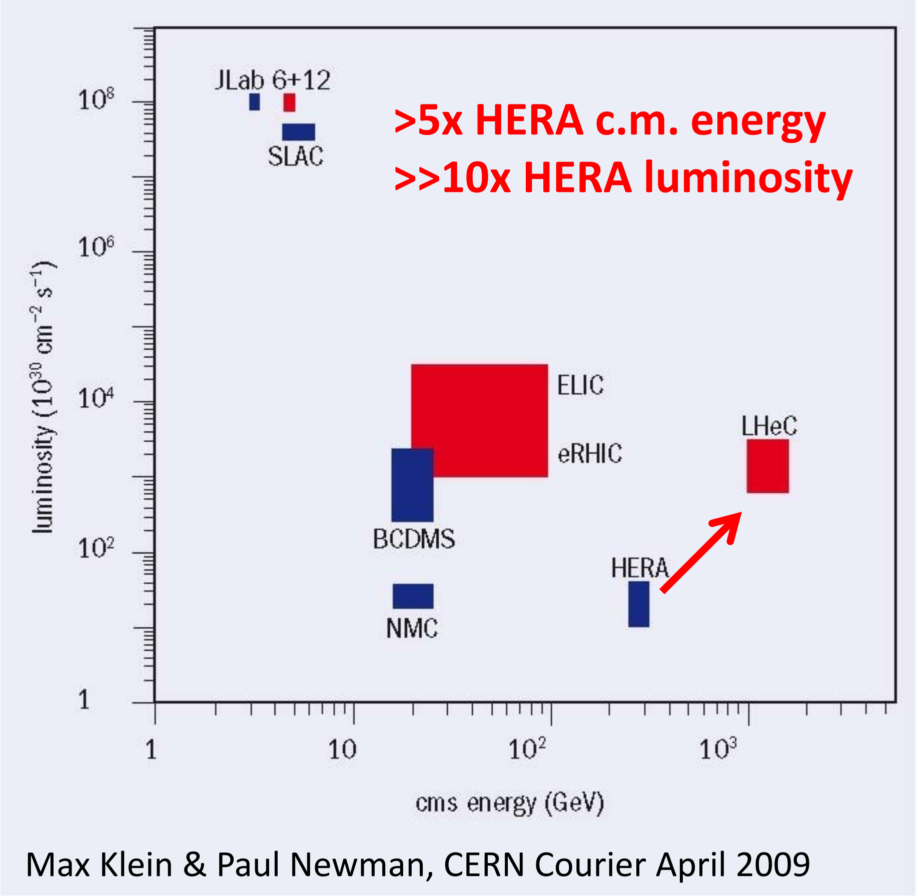
L. Rossi, P. McIntyre

LHeC

high-energy high-luminosity $e^{\pm}p$ & $e^{\pm}A$ collider

physics motivation



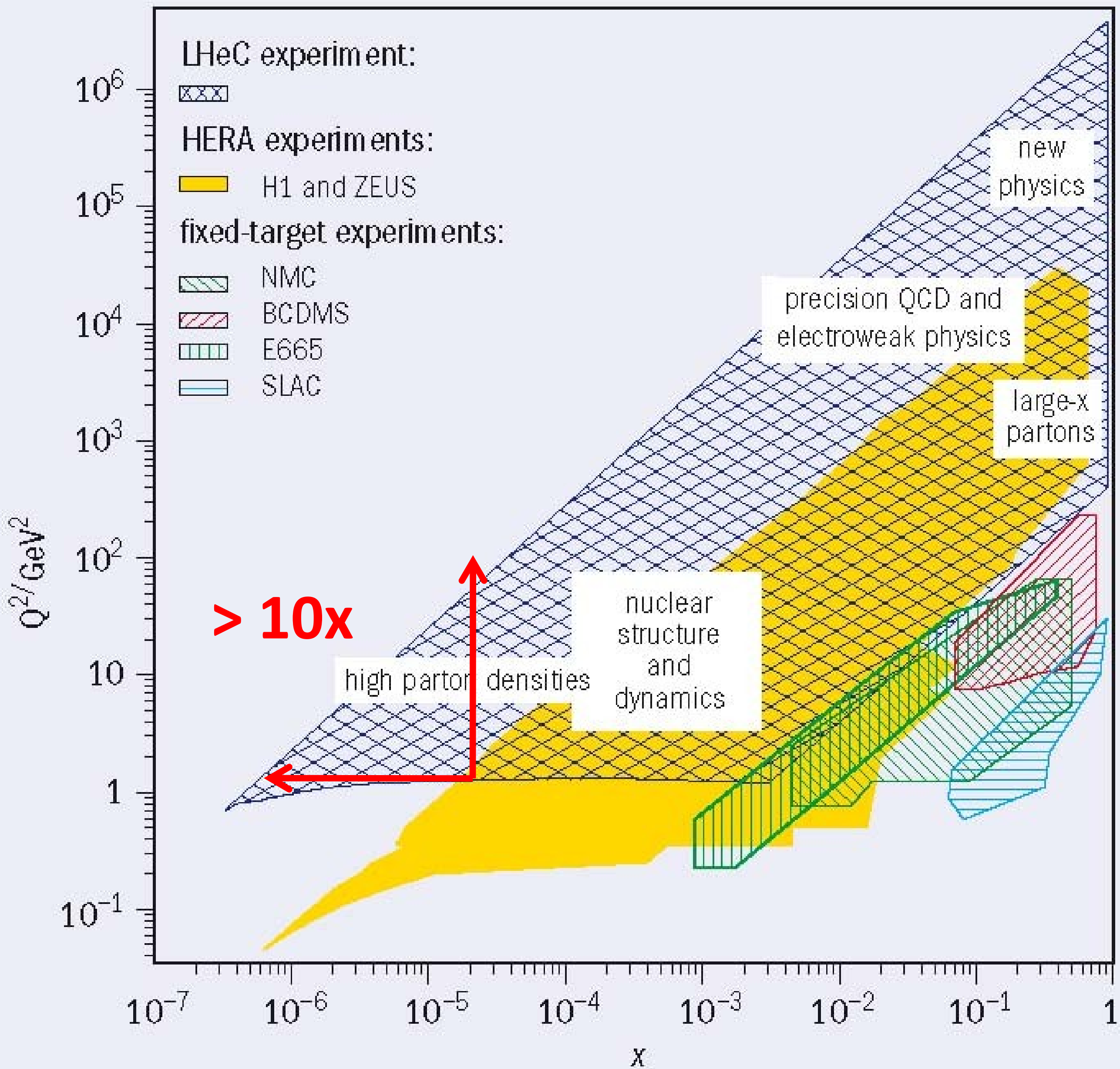


distance scales resolved in lepton-hadron scattering experiments since 1950s, and some of the new physics revealed

energies and luminosities of existing and proposed future lepton-proton scattering facilities

e- energy ~60-140 GeV

luminosity ~10^{33} cm^{-2}s^{-1}



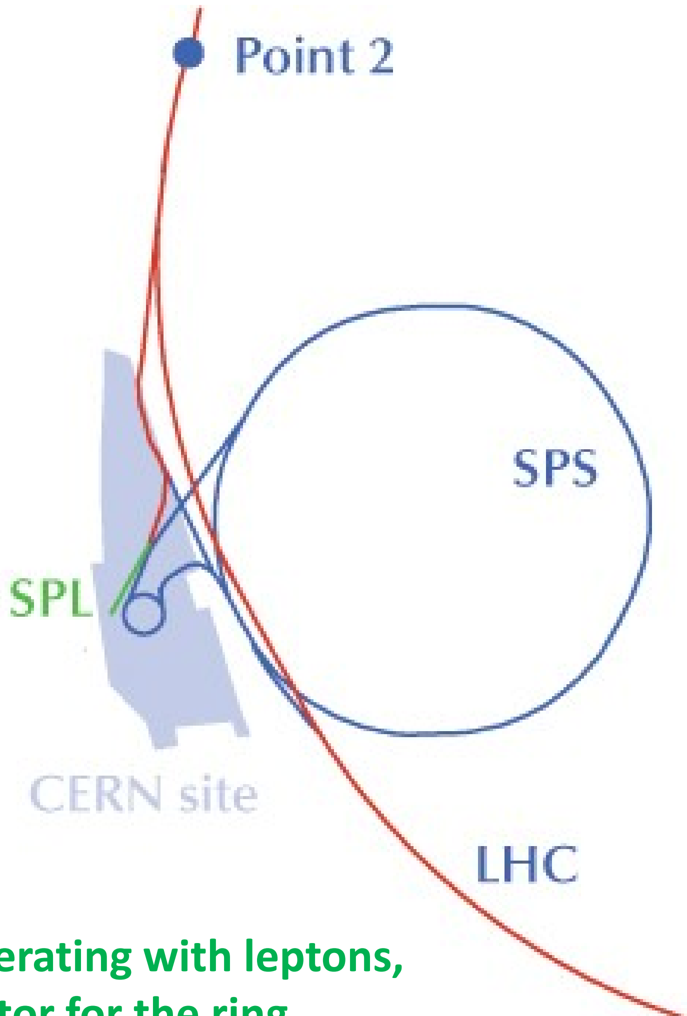
Max Klein & Paul Newman, CERN Courier April 2009

kinematic plane in Bjorken-x and resolving power Q^2, showing the coverage of fixed target experiments, ***HERA*** and ***LHeC***

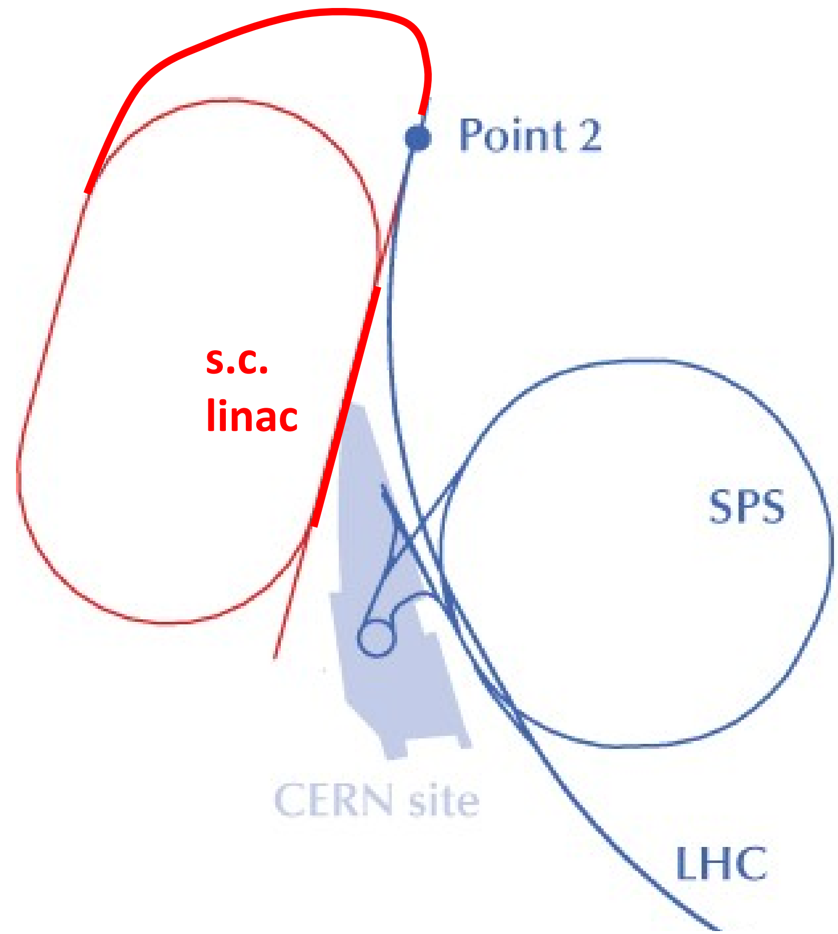
particle physicists request both e^-p & e^+p collisions; lepton polarization is also "very much desired"

option 1: “ring-ring” (RR)
e-/e+ ring in LHC tunnel

option 2: “ring-linac” (RL)



SPL, operating with leptons,
as injector for the ring,
possibly with recirculation



up to 70 GeV: option for cw operation
and recirculation with energy recovery;
> 70 GeV: pulsed operation at higher
gradient ; γ-hadron option

tentative SC linac parameters for RL

LHeC-RL scenario	lumi	baseline	energy
final energy [GeV]	60	100	140
cell length [m]	24	24	24
cavity fill factor	0.7	0.7	0.7
tot. linac length [m]	3000	2712	3024
cav. gradient [MV/m]	13	25	32
operation mode	CW (ERL)	pulsed	pulsed

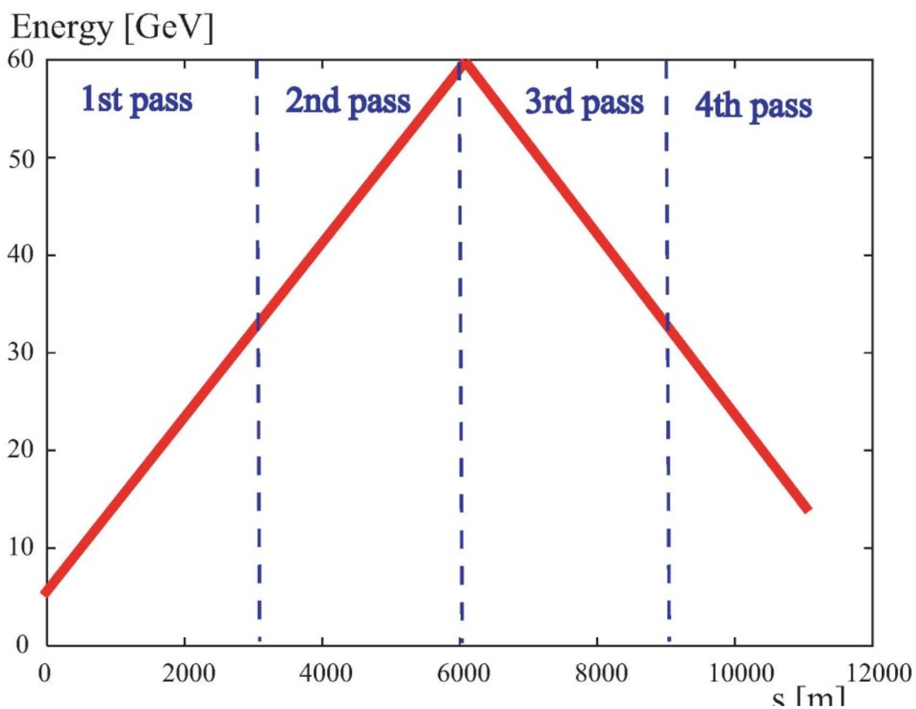
RF frequency: ~700 MHz

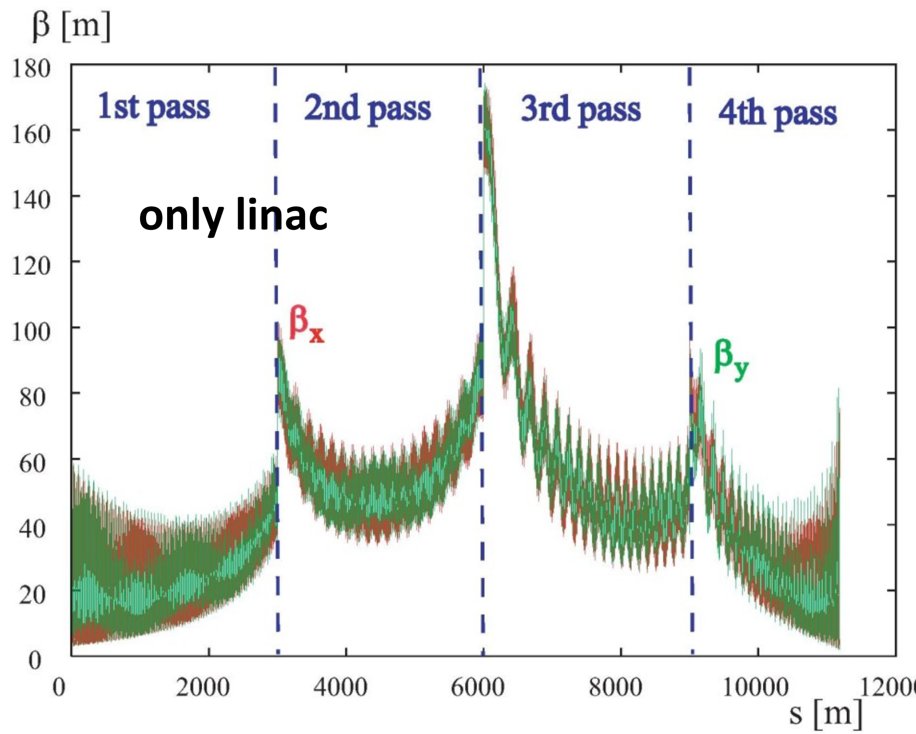
4 passes

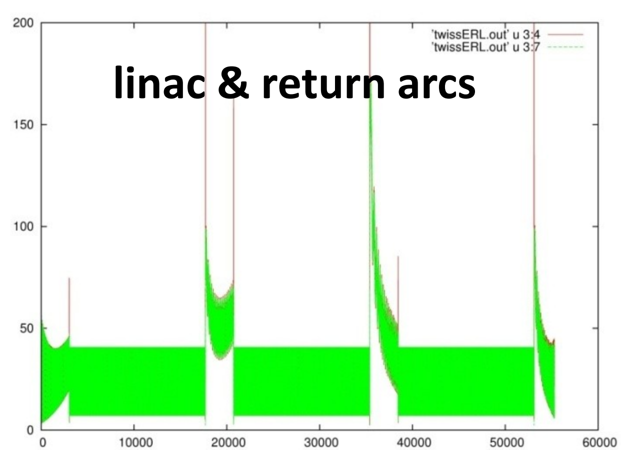
2 passes

Anders Eide

example linac optics for 4-pass ERL option







Anders Eide

luminosity constraints

LHC 7-TeV *p* beam parameters

	$N_{b,p}$	T_{sep}	$\varepsilon_p\gamma_p$	$\beta^*_{p,min}$
LHC phase-I upgrade	**1.7x10^{11}**	**25 ns**	**3.75 μm**	**0.25 m**
LHC phase-II upgrade (“LPA”)	**5x10^{11}**	**50 ns**	**3.75 μm**	**0.10 m**

p and *e* beams matched at collision point

ring emittance >> linac emittance

ring has larger IP beam divergence

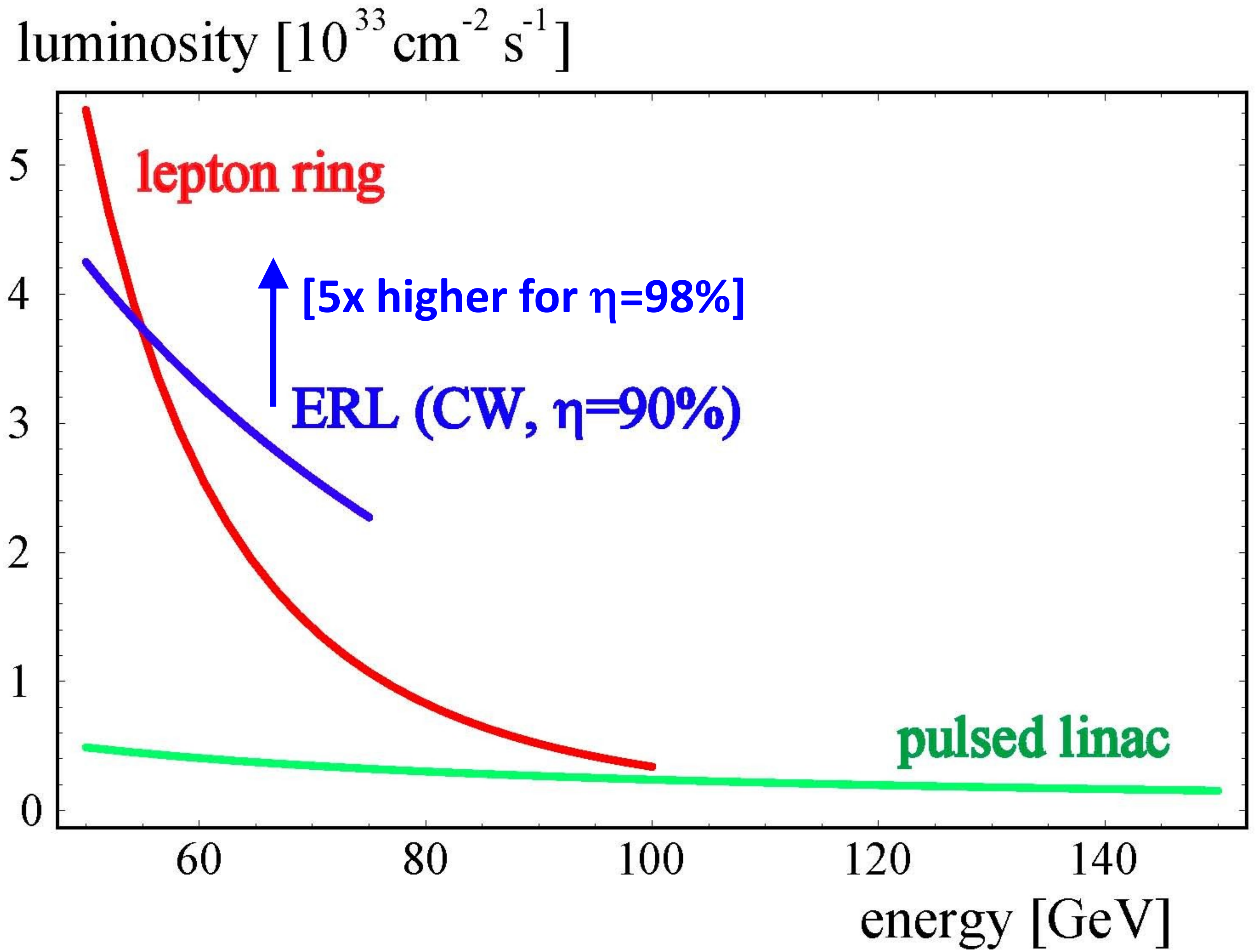
\+ hourglass effect (⟶ **larger β* for ring**)

ring SR power = linac beam power & cryo power

= electrical power set to 100 MW

linac has much lower current

luminosity vs energy



example parameters

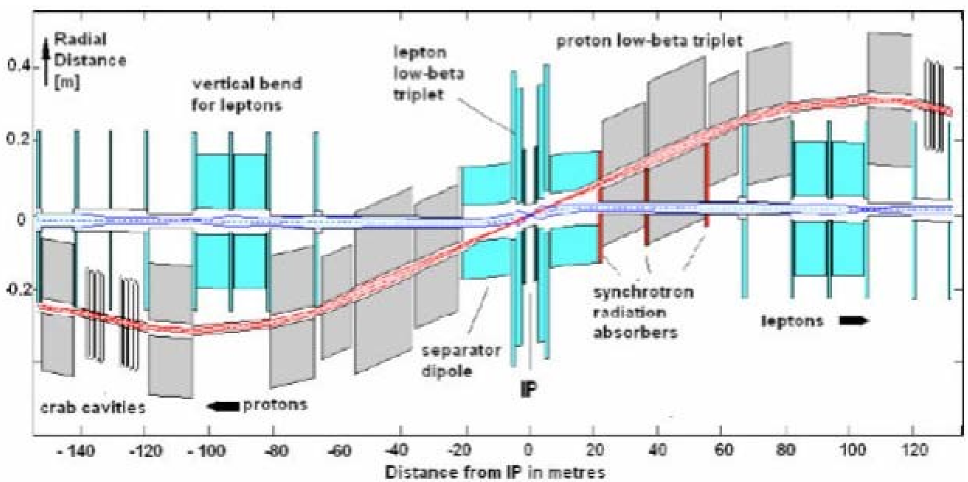
	LHeC-RR	LHeC-RL high lumi	LHeC-RL 100 GeV	LHeC-RL high energy	ILC	XFEL
e^- energy at IP [GeV]	60	60	100	140	(2×)250	20
luminosity [10^{32} cm^{-2}s^{-1}]	29	29† (2.9‡)	2.2	1.5	200	N/A
bunch population [10^{10}]	5.6	0.19† (0.02‡)	0.3 (1.5)	0.2 (1.0)	2	0.6
e^- bunch length [μm]	~10,000	300	300	300	300	24
bunch interval [ns]	50	50	50 (250)	50 (250)	369	200
norm. hor.&vert. emittance [μm]	4000, 2500	50	50	50	10, 0.04	1.4
average current [mA]	135	7† (0.7‡)	0.5	0.5	0.04	0.03
rms IP beam size [μm]	44, 27	7	7	7	0.64, 0.006	N/A
repetition rate [Hz]	CW	CW	10 [5% d.f.]	10 [5% d.f.]	5	10
bunches/pulse	N/A	N/A	71430	14286	2625	3250
pulse current [mA]	N/A	N/A	10	10	9	25
beam pulse length [ms]	N/A	N/A	5	5	1	0.65
cryo power [MW]	0.5	20	4	6	34	3.6
total wall plug power [MW]	100	100	100	100	230	19

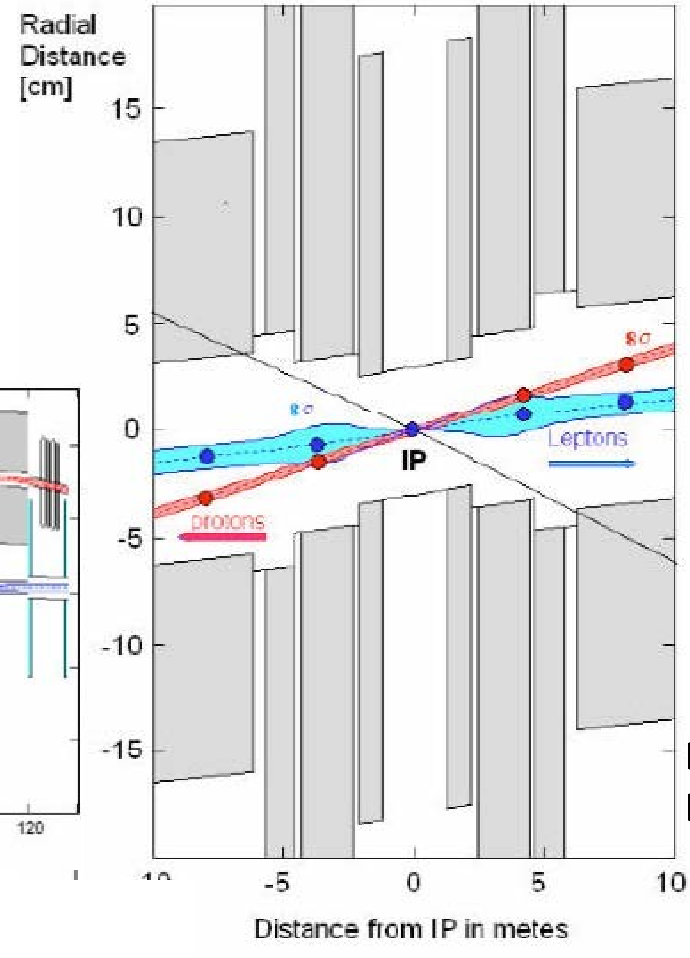
Example LHeC-RR and RL parameters. Numbers for LHeC-RL high-luminosity option marked by `†' assume energy recovery with $\eta_{ER}$=90%; those with `‡' refer to η_{ER}=0%. ILC and XFEL numbers are included for comparison. Note that optimization of the RR luminosity for different LHC beam assumptions leads to similar luminosity values of about 10^{33}cm^{-2}s^{-1}

IR layout & crab crossing (for RR)

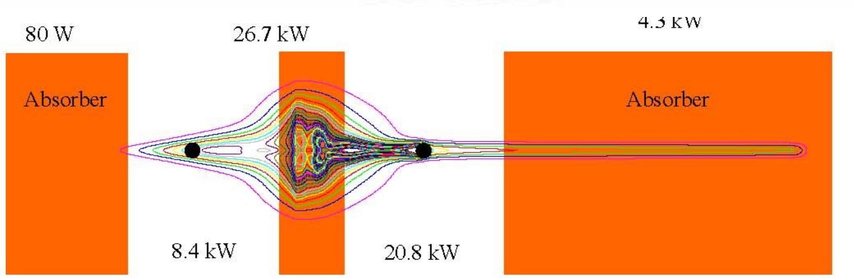
crossing angle to support early separation: 1-2 mrad

proton crab cavities:
15-30 MV at 800 MHz)





Bernhard Holzer



Boris Nagorny

SC half quadrupoles synchrotron radiation

positrons

ring

a rebuilt conventional e^+ source would suffice

linac

true challenge: **10x more e^+ than ILC!**

large # bunches → damping ring difficult

candidate e^+ sources under study (*POSIPOL* coll.):

- **ERL Compton** source for CW operation
  e.g. 100 mA ERL w. 10 optical cavities
- **undulator source using spent e- beam**
- **linac-Compton** source for pulsed operation

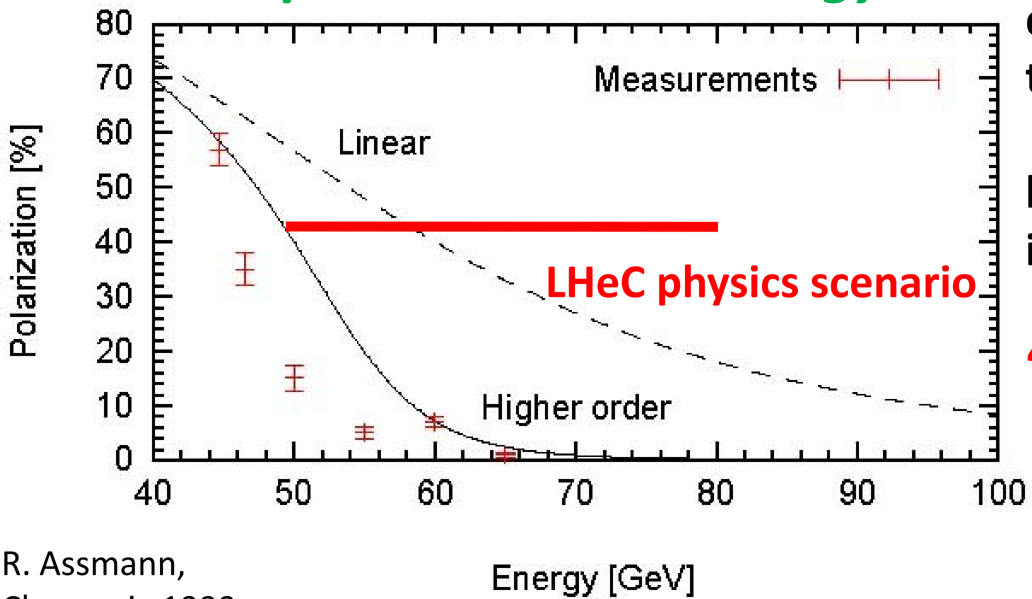
complementary options: collimate to shrink emittance, recycle e+ together with recovering their energy?

T. Omori,
J. Urakawa,
V. Yakimenko

polarization

ring

LEP polarization vs. energy



R. Assmann, Chamonix 1999, & Spin2000

Sokolov-Ternov polarization time decreases from 5 hr at 46 GeV to ½ hr at 70 GeV

but depolarizing rate increases even faster

"very difficult"

(R. Assmann, D. Barber,…)

linac

e- : from polarized dc gun with ~90% polarization, 10-100 μm normalized emittance

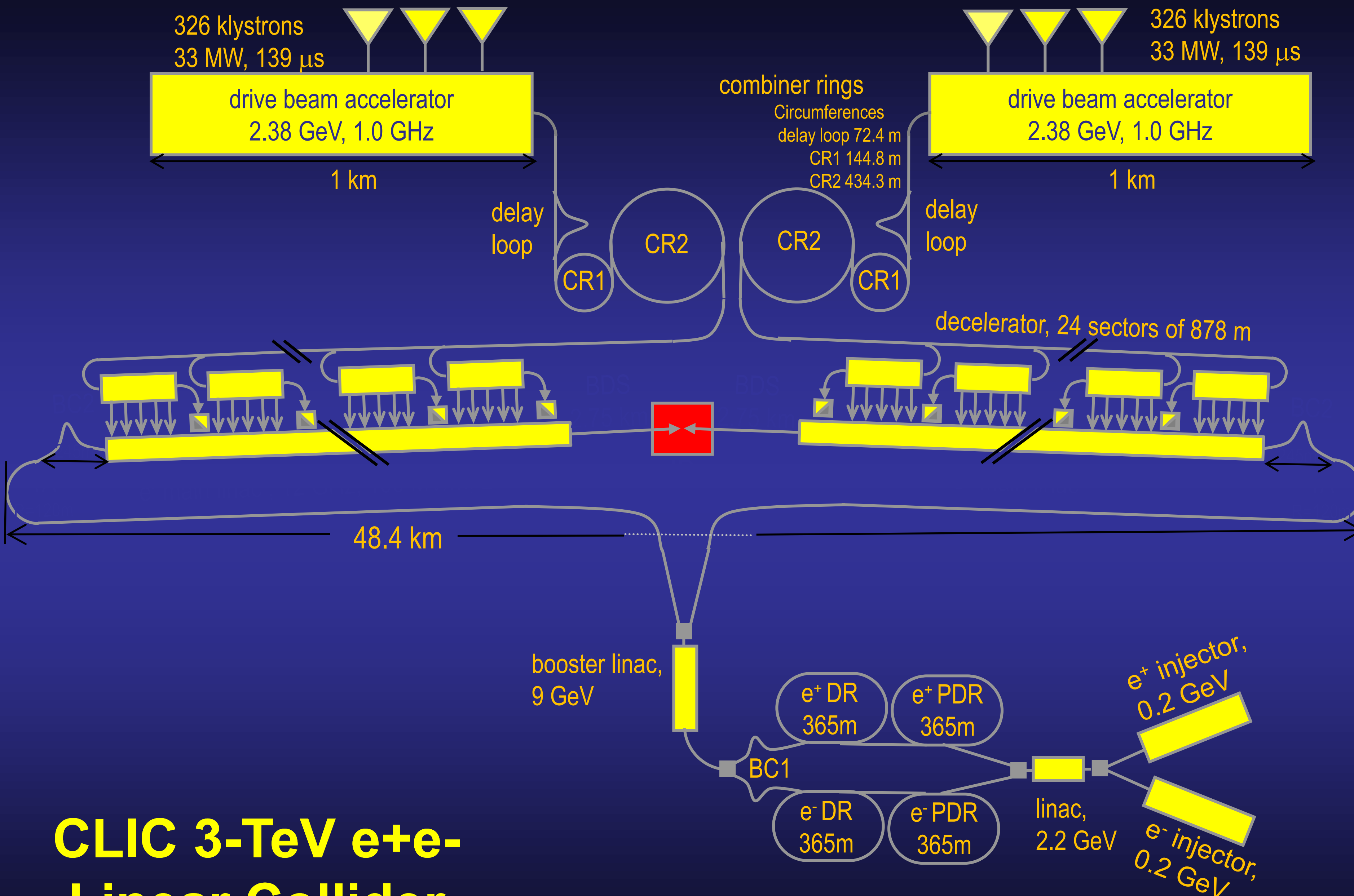
e+: up to ~60% from undulator or Compton-based source

more LHeC information

LHeC web site
www.lhec.org.uk

second ECFA-CERN workshop on the LHeC in September 2009

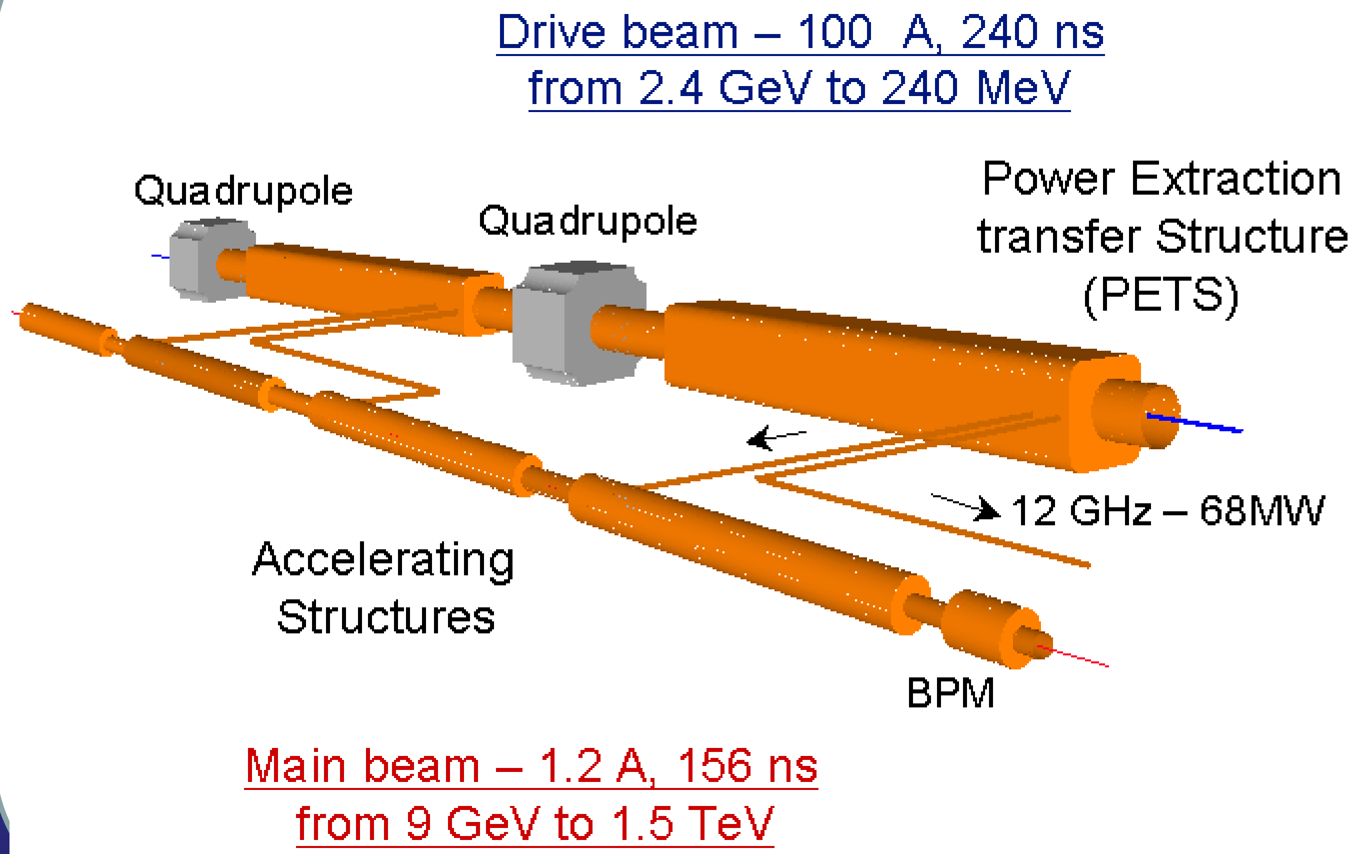
CLIC



CLIC 3-TeV e+e- Linear Collider

H. Braun

Two beam scheme



without drive beam CLIC would need 32000 Klystrons for E_{CMS} =3 TeV

CLIC parameters

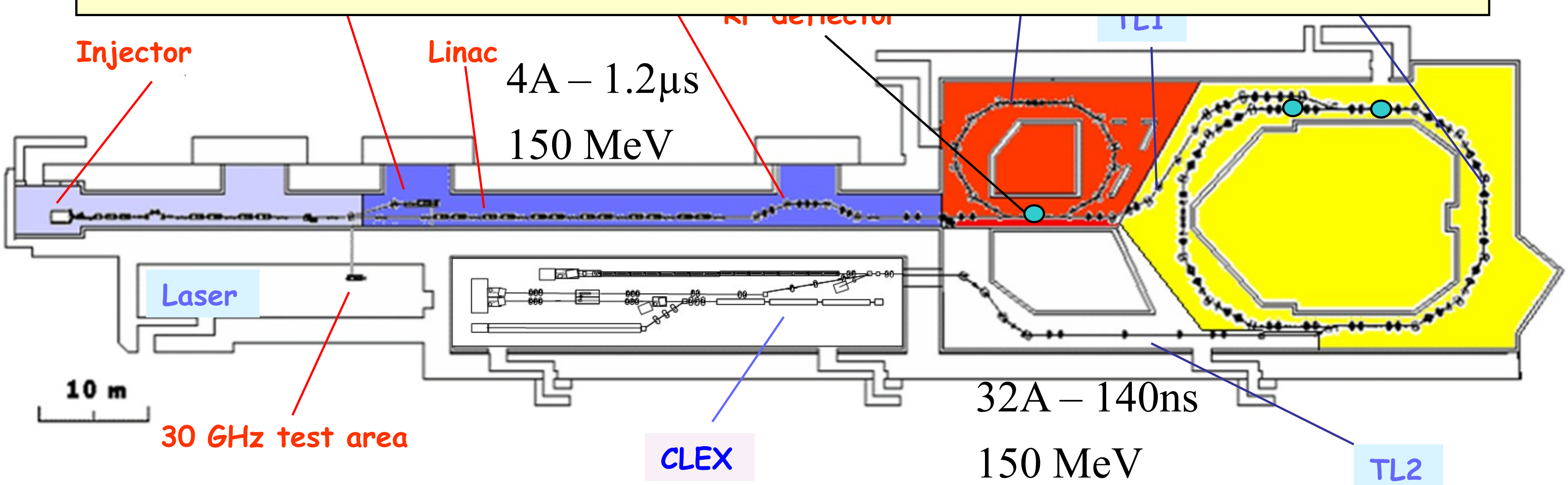
Center-of-mass energy	ILC 500 GeV	CLIC 500 GeV	CLIC 3 TeV
Total (Peak 1%) luminosity [$\cdot 10^{34}$]	2(1.5)	2.3 (1.4)	5.9 (2.0)
Repetition rate (Hz)	5	50	
Loaded accel. gradient MV/m	32	80	100
Main linac RF frequency GHz	1.3	12	
Bunch charge [$\cdot 10^9$]	20	6.8	3.7
Bunch separation (ns)	370	0.5	
Beam pulse duration (ns)	950μs	177	156
Beam power/beam (MWatts)		4.9	14
Hor./vert. IP beam size (nm)	600 / 6	200 / 2.3	40 / 1.0
Hadronic events/crossing at IP	0.12	0.2	2.7
Incoherent pairs at IP	$1 \cdot 10^5$	$1.7 \cdot 10^5$	$3 \cdot 10^5$
BDS length (km)		1.87	2.75
Total site length km	31	13	48
Total power consumption MW	230	130	415

Crossing Angle 20 mrad (ILC 14 mrad)

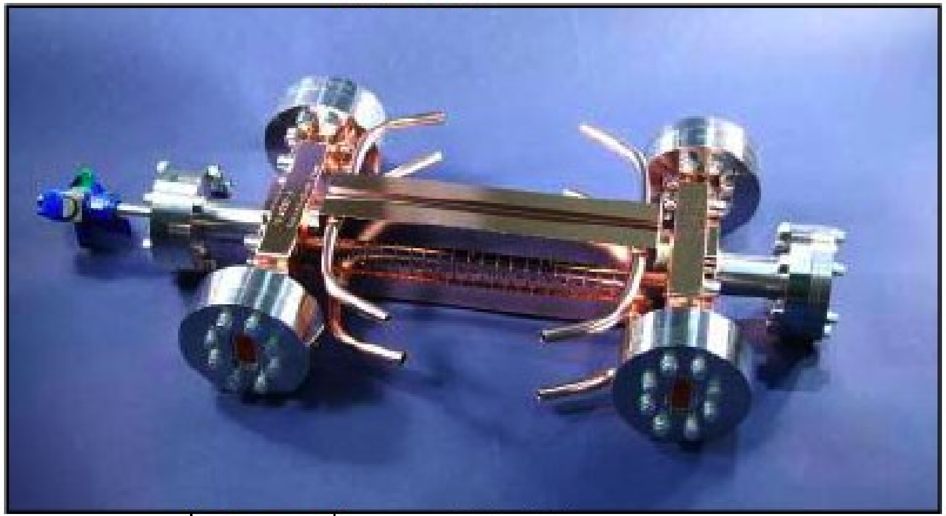
Lucie Linssen

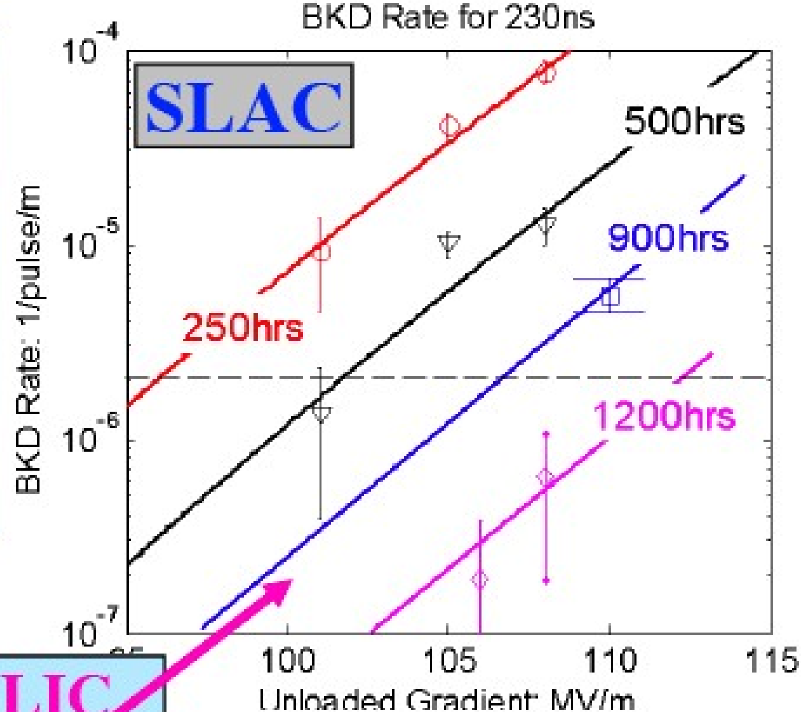
CTF 3

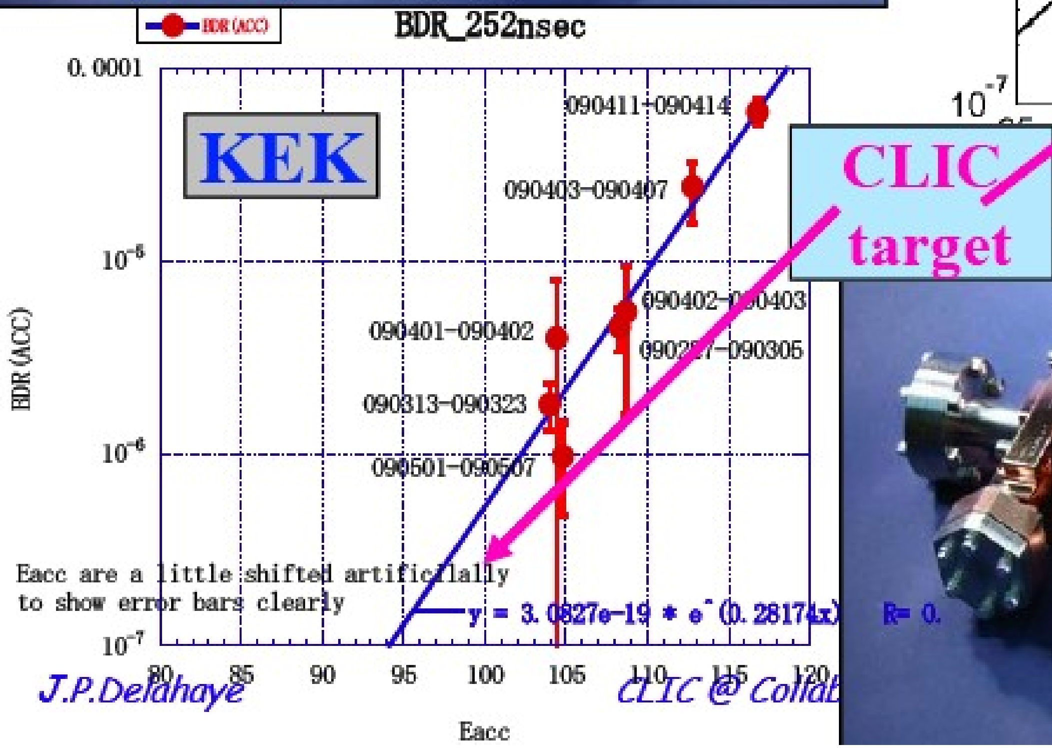
- demonstrate remaining CLIC feasibility issues, in particular:
  - Drive Beam generation (fully loaded acceleration, bunch frequency multiplication)
  - CLIC accelerating structures
  - CLIC power production structures (PETS)

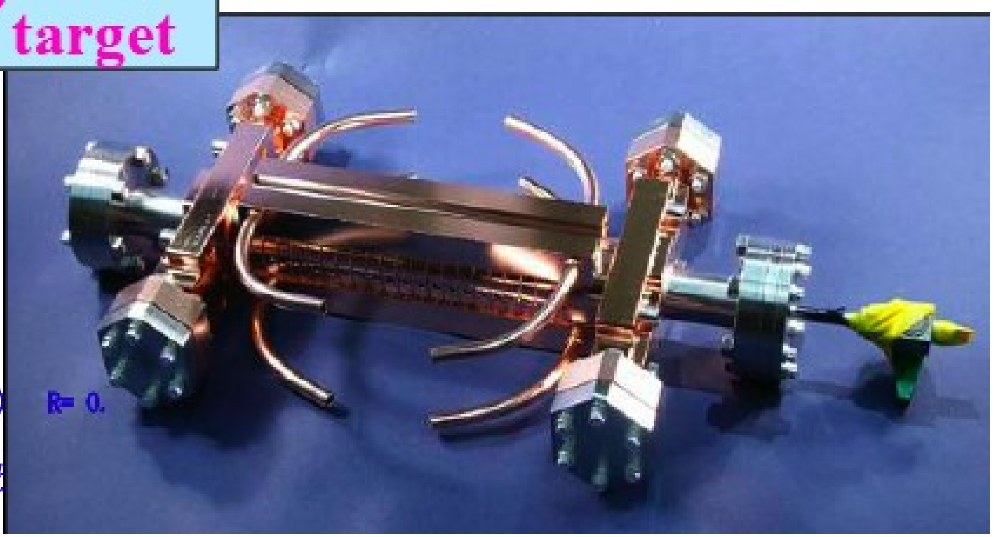


Nominal performance of Accelerating Structures
Design@CERN, Built/Tested @KEK, SLAC



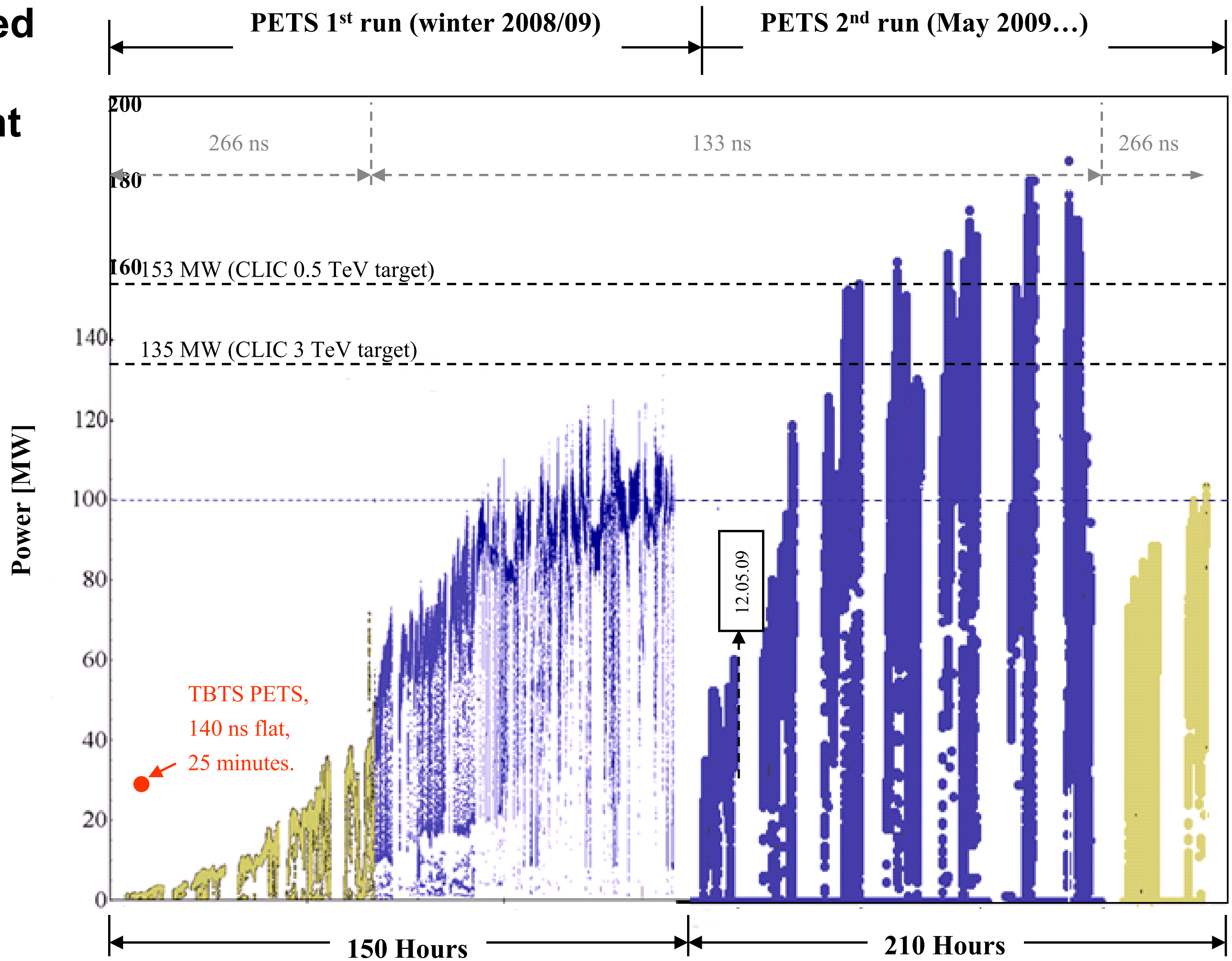






Power Extraction Structures (PETS)

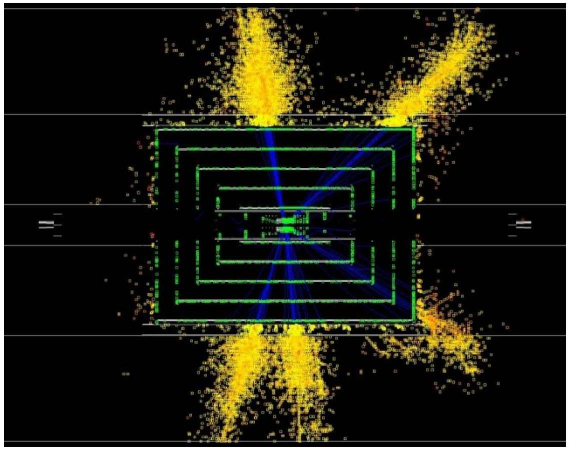
(Previously considered PETS a significant risk)

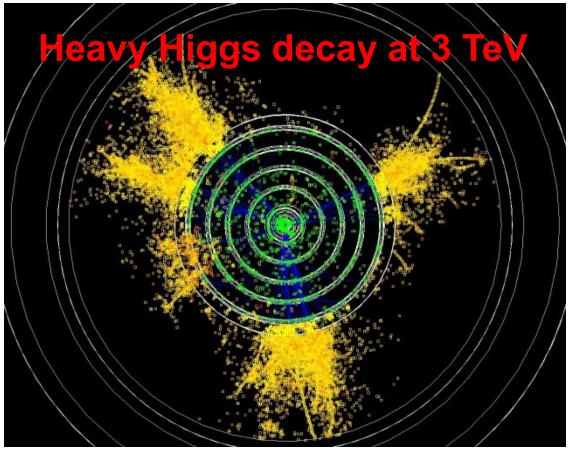


CLIC detector + physics R&D

Two decades of investment in **CLIC accelerator technology now** complemented by in-depth assessment of **detector aspects** and **physics potential**.

Common accelerator/ detector-physics CLIC CDR, end 2010
TDR foreseen for 2015





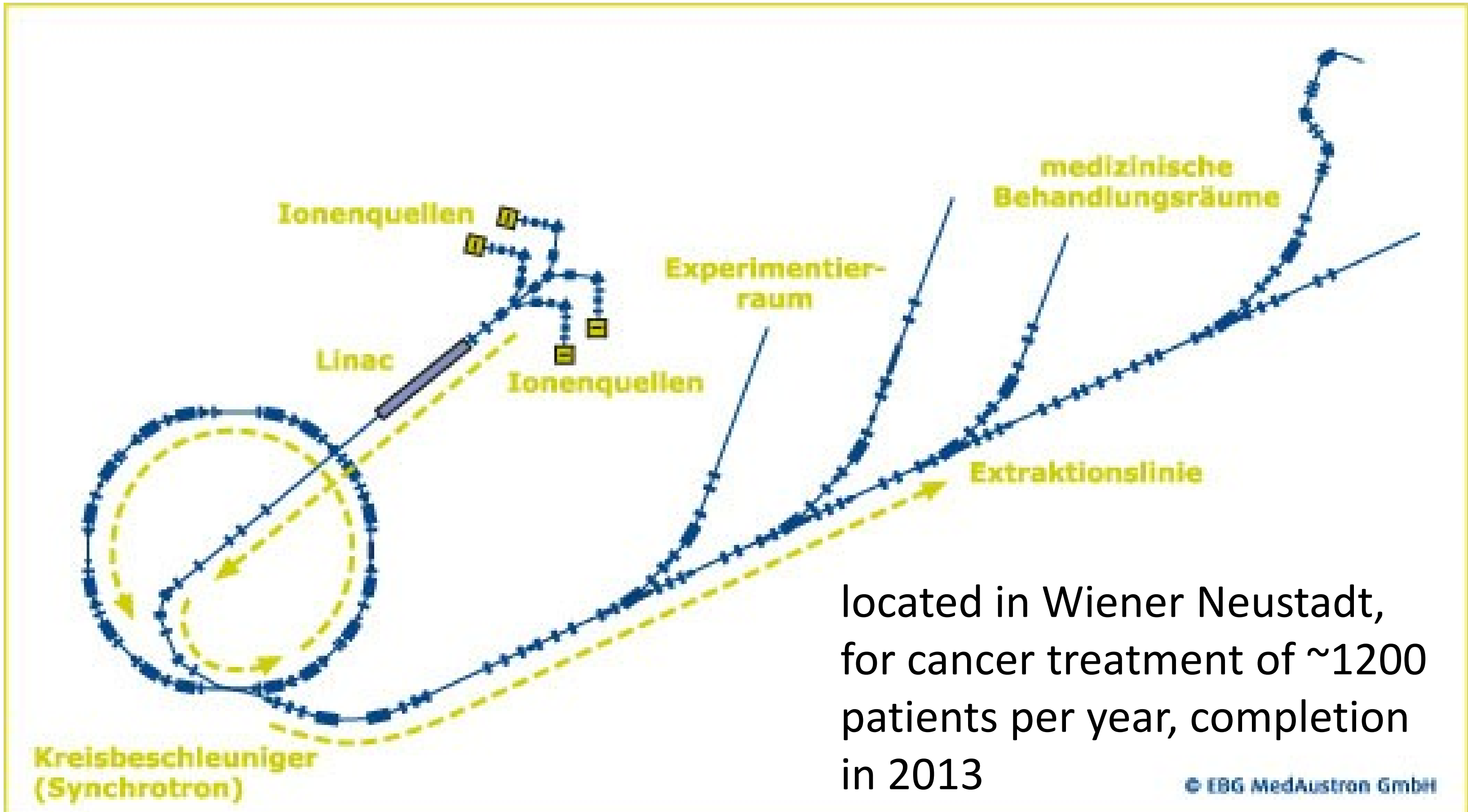
Lucie Linssen,
POSIPOL
June 2009

integrated part of ***ILC-CLIC collaboration***

MedAustron

one of many examples
for technology transfer

CERN technology transfer – *Med*Austron accelerator design



located in Wiener Neustadt, for cancer treatment of ~1200 patients per year, completion in 2013

Strahlparameter

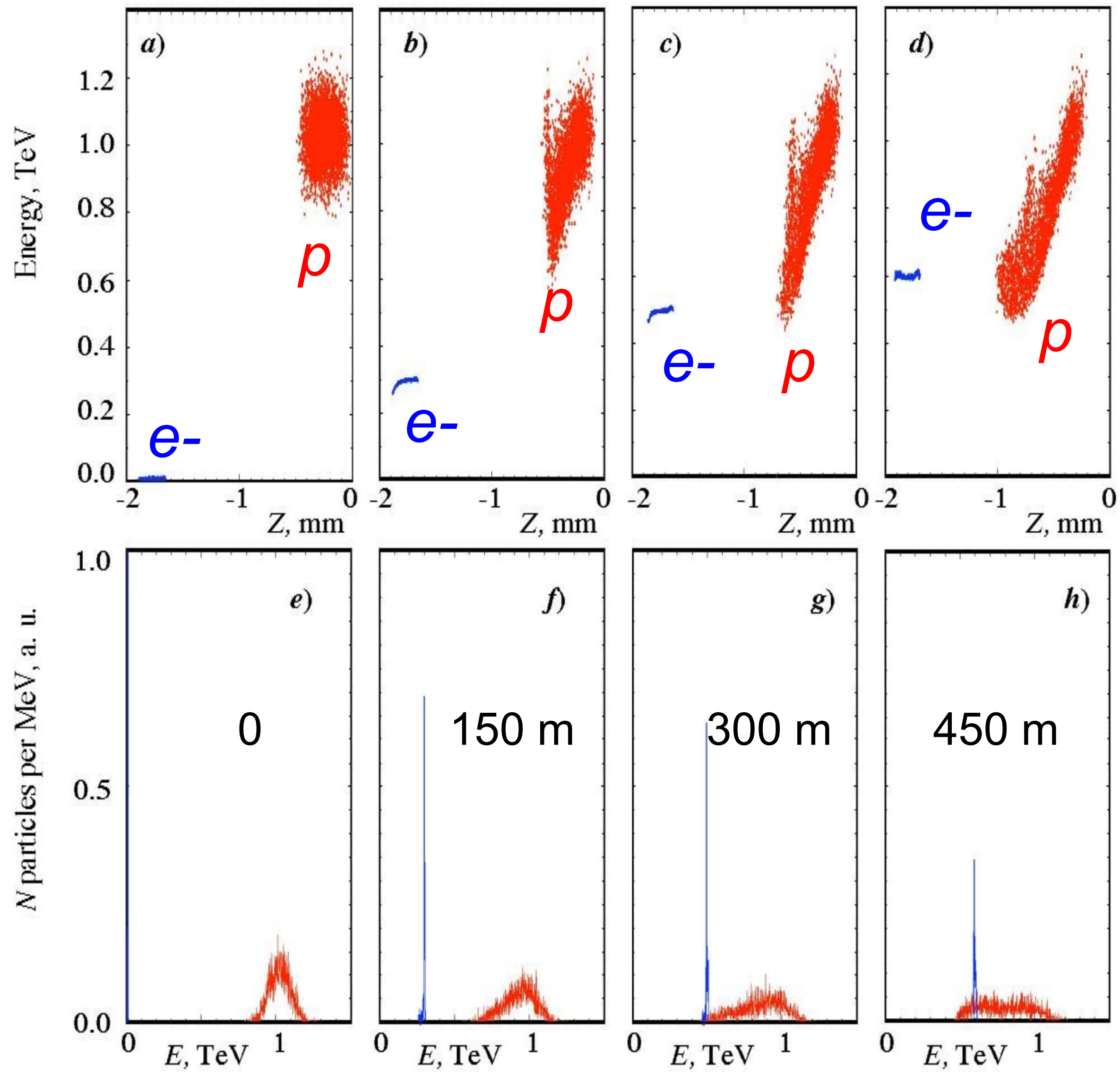
Protonen($^{1}H^{+}$):
Strahlintensität 1 x 10^{10} Prot. pro Puls
Strahlenergie 60-800 MeV
Extraktionsdauer 0.1–1 s

Kohlenstoffionen ($^{12}C^{6+}$):
Strahlintensität ≤ 4×10^{8} Ionen pro Puls
Strahlenergie 120-400 MeV/u
Extraktionsdauer 0.1–1 s

p driven $e^{\pm}$ plasma acceleration

advanced concept:
TeV protons as plasma driver to accelerate electrons to TeV-scale energy

A.Caldwell,
K. Lotov, A.Pukhov,
F.Simon;
MPI-P München,
U. Düsseldorf, &
Novosibirsk



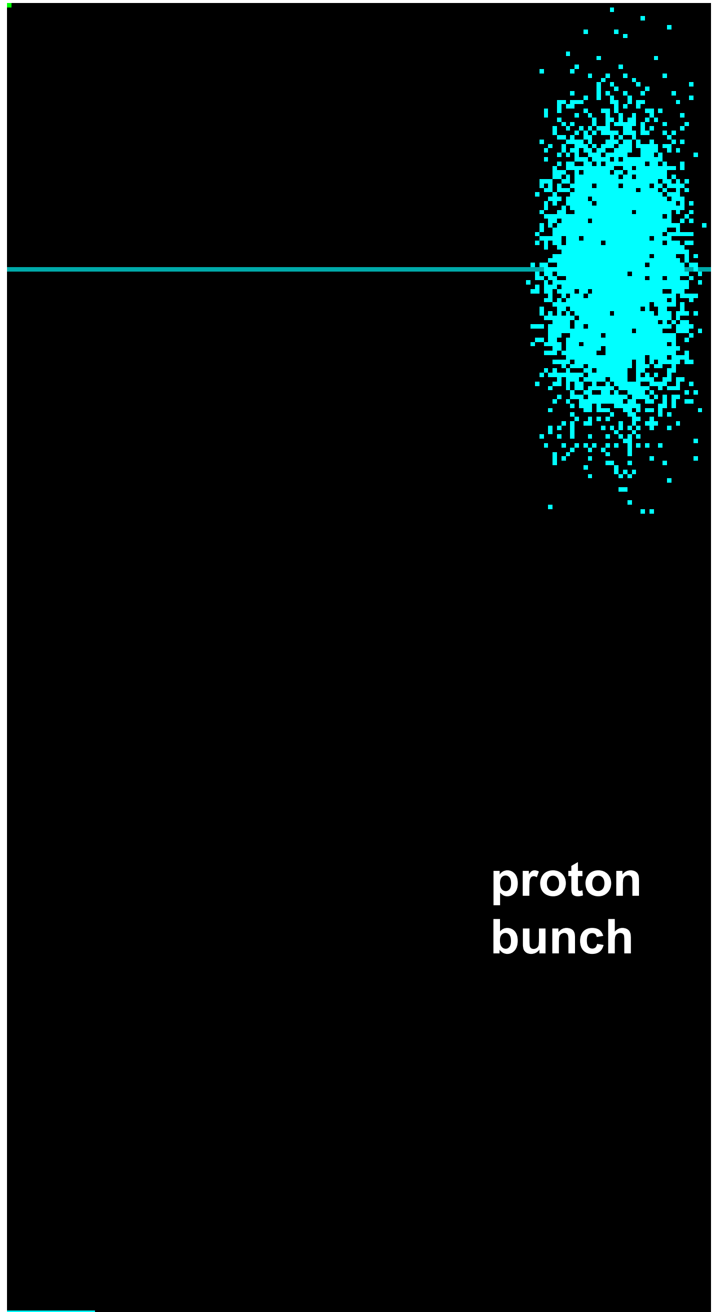
first contacts

Snapshots of the combined longitudinal phase space of the driver and the witness beam (energy vs coordinate), frames (a)-(d) and corresponding energy spectra, frames (e)-(h). The snapshots are taken at acceleration distances $Z = 0,\ 150,\ 300,\ 450$ m. The electrons are shown as blue points, while the protons are depicted as red points.

arXiv:0807.4599v1, July '08

600 GeV
in 450 m!

e- bunch



K. Lotov
et al

upgraded accelerator chain (LHC beam)

	SPL	PS2	SPS	LHC
final momentum [GeV/c]	5	50	450	7000
protons/bunch [10^{11}]	2.5×10^{-4}	4	4	4
rms longitudinal emittance [eVs]	7.3×10^{-7}	0.05	0.06	0.2 (0.08*)
rms bunch length [ns]	1.9×10^{-4}	1	<0.5	0.25 (0.16*)
relative rms energy spread [10^{-3}]	0.18	1	0.3	0.11 (0.07*)
rms transverse emittance [μm]	0.35	3.0	3.5	3.75
bunch spacing [ns]	2.8	25	25	25
# bunches / cycle	200,000	144	288	2808
cycle time	20 ms	2.4 s	~13 s	5-10 h?

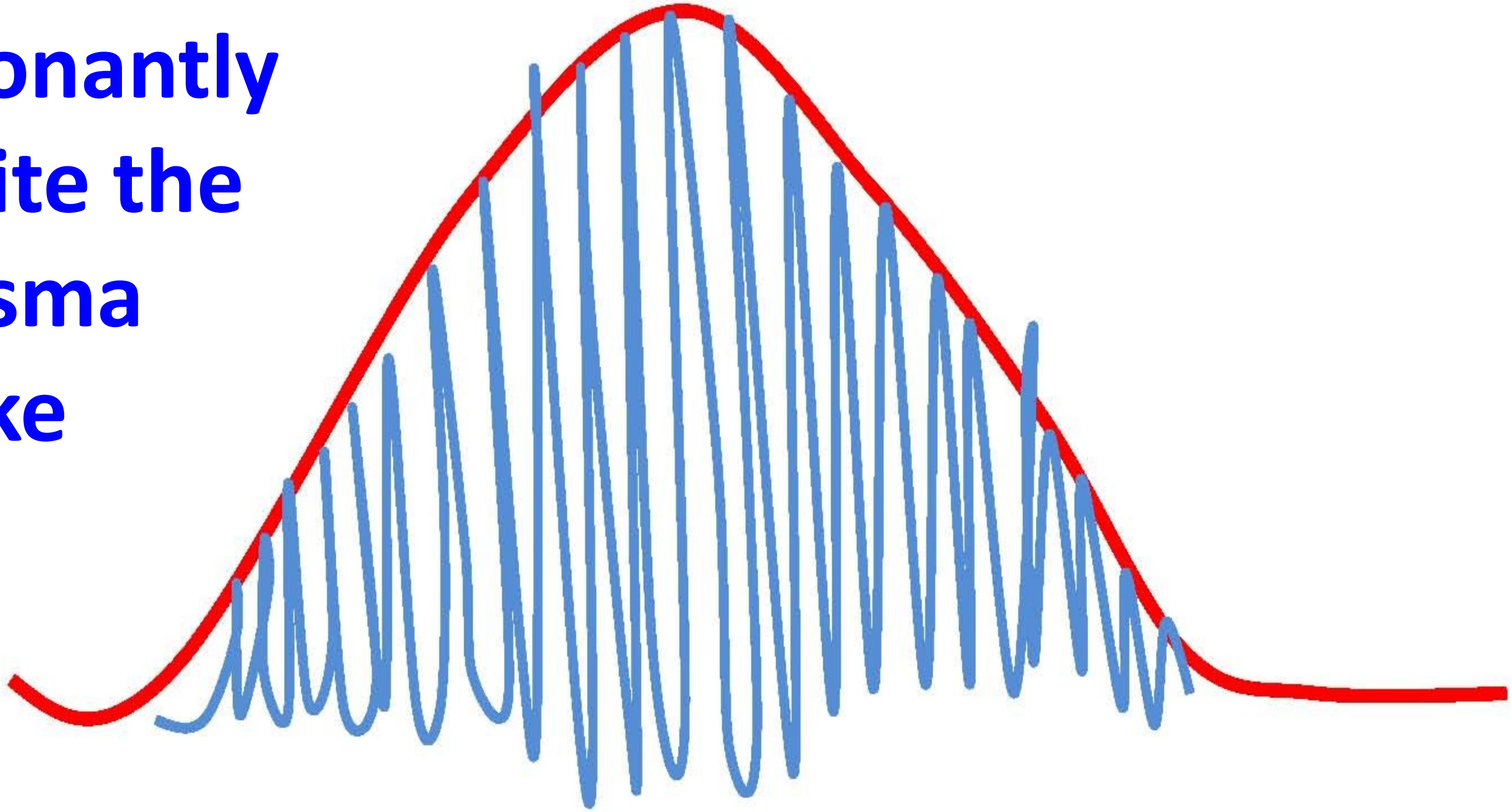
1 ns = 30 cm, 3×10^{-4} ns = 100 μm

* w/o longitudinal blow up in the LHC

to get “high-energy” proton bunch lengths below 1 mm (e.g. for demonstration):

- we can use the **beam from the SPL**, or
- we need strong **cooling**, or **bunch compression**, or an x(y)-z 4/6-D **emittance exchange** transformation or a combination thereof

alternative approach: use moderately compressed bunch length and **create internal "microstructure" at plasma frequency to resonantly excite the plasma wake**



schematic of bunch after applying nano-chopper or with high-frequency microwave instability

summary & outlook

- ✓ decreasing resources & large LHC needs
- ✓ R&D for future accelerators driven
  by collaborations, by postdocs & students
- ✓ **SLHC & new injectors will come**
- ✓ **period of decisions: 2010-2013**
  - ❖ LHC results
  - ❖ CTF3, other LC test results, LC designs
  - ❖ Neutrino-Factory design study
  - ❖ high-field magnet R&D
- ✓ **next project(s) after LHC?**
  - ❖ LHeC, CLIC, ILC, EURISOL, ν factory,
    β beam facility, super-beams,
    LHC energy upgrade, etc etc?


CERN
THANK YOU
FOR YOUR ATTENTION!