LHC Phase-II Upgrade Scenarios

Lucio Rossi – CERN/AT

Many slides from HHH woprkshop (Garoby, Scandale and Zimmemann)

CERN-KEK Committee, 3rd meeting, Friday 12 December 2008 - CERN

CERN

outline

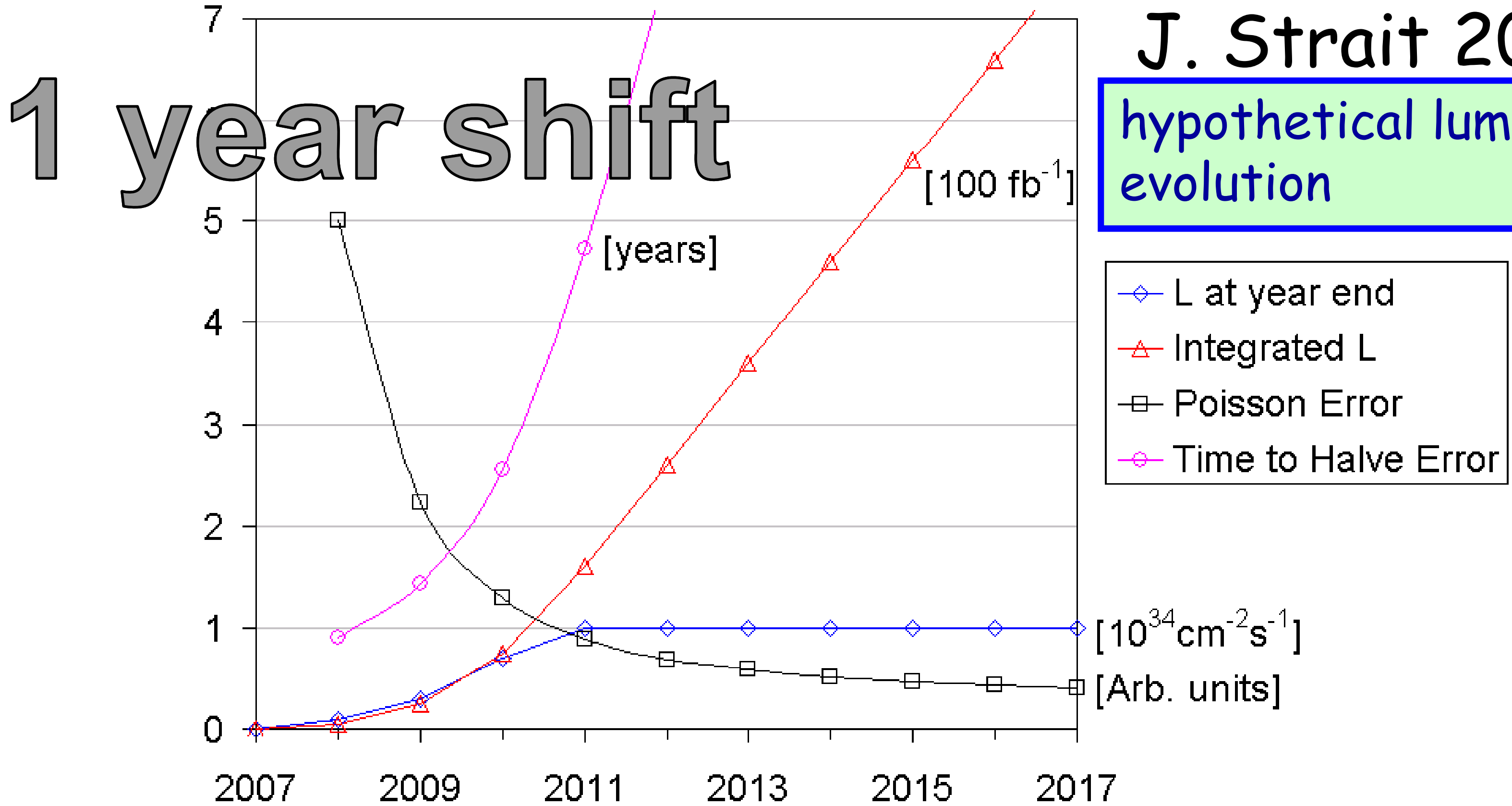
- ✓ motivation & staged approach
- ✓ upgrade scenarios
  & luminosity levelling
- ✓ injector upgrade & schedule
- ✓ complementary advanced schemes
  - *LR + HO beam-beam compensation, e-cloud mitigation, crystal collimation, cooling, crab waists,…*
- ✓ strategy for “phase 2”

motivation & staged approach

Three Strong Reasons for LHC Upgrade

J. Strait 2003

hypothetical luminosity evolution



1) after few years, **statistical error** hardly decreases

2) **radiation damage** limit of **IR quadrupoles** (~700 fb^{-1}) reached by ~2016 =→ time for an upgrade!

3) **extending physics potential**! (A. de Roeck et al)

staged approach to LHC upgrade

"phase 1" 2013: **1 year shift**

new triplets, D1, TAS, β^*=0.25 m in IP1 & 5,
reliable LHC operation at ~2-3x luminosity;
beam from new Linac4

"phase 2" 2017: ***+ injector upgrade***

target luminosity 10x nominal,
possibly Nb_3Sn triplet & β^*~0.15 m

complementary measures 2010-2017:

e.g. long-range beam-beam compensation,
crab cavities, new/upgraded injectors, advanced
collimators, coherent e- cooling??, e- lenses??

phase-2 might be just phase 1 plus complementary measures

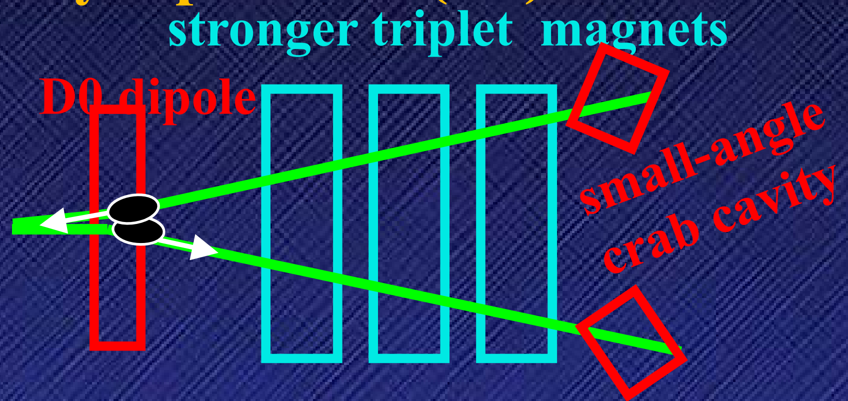
longer term (2020?): energy upgrade, LHeC,…

upgrade scenarios
& luminosity leveling

LHC phase-2 upgrade paths for IP1 & 5

early separation (ES)

J.-P. Koutchouk



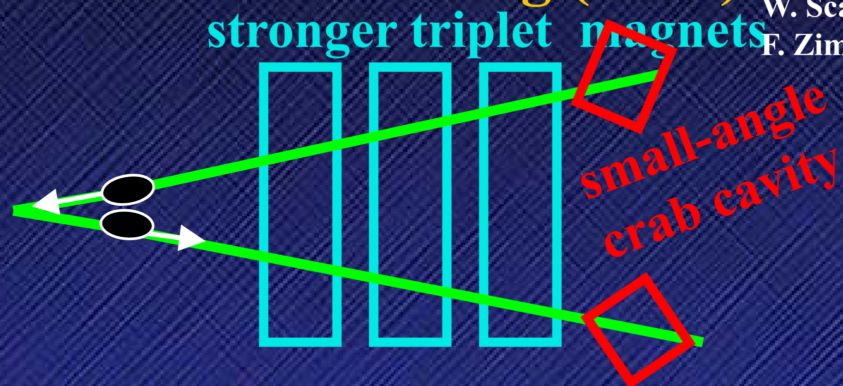
- ultimate beam (1.7x10^{11} p's/bunch, 25 ns spacing), β* ~10 cm
- early-separation dipoles in side detectors , crab cavities

  → hardware inside ATLAS & CMS detectors,

  first hadron crab cavities; off-δ β

full crab crossing (FCC)

L. Evans,
W. Scandale,
F. Zimmermann

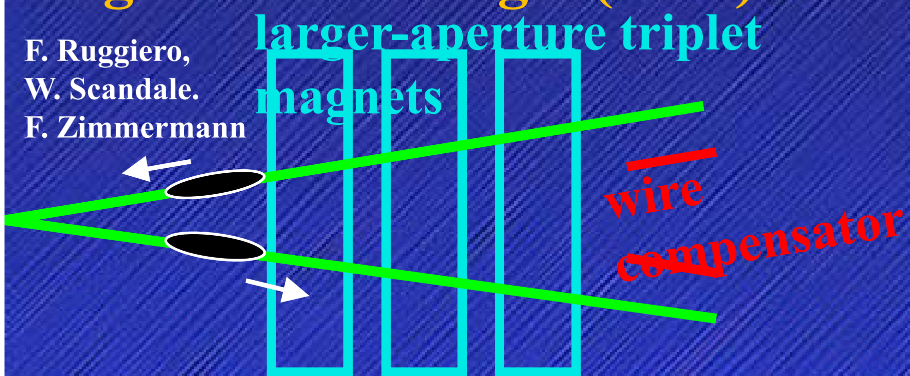


- ultimate LHC beam (1.7x10^{11} p's/bunch, 25 ns spacing)
- β* ~10 cm
- crab cavities with 60% higher voltage

  → first hadron crab cavities, off-δ β-beat

large Piwinski angle (LPA)

F. Ruggiero,
W. Scandale.
F. Zimmermann

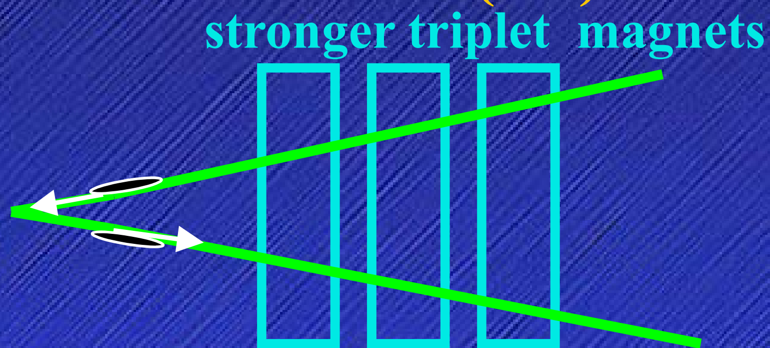


- 50 ns spacing, longer & more intense bunches (5x10^{11} p's/bunch)
- β*~25 cm, no elements inside detectors
- long-range beam-beam wire compensation

  → novel operating regime for hadron colliders, beam generation

low emittance (LE)

R. Garoby

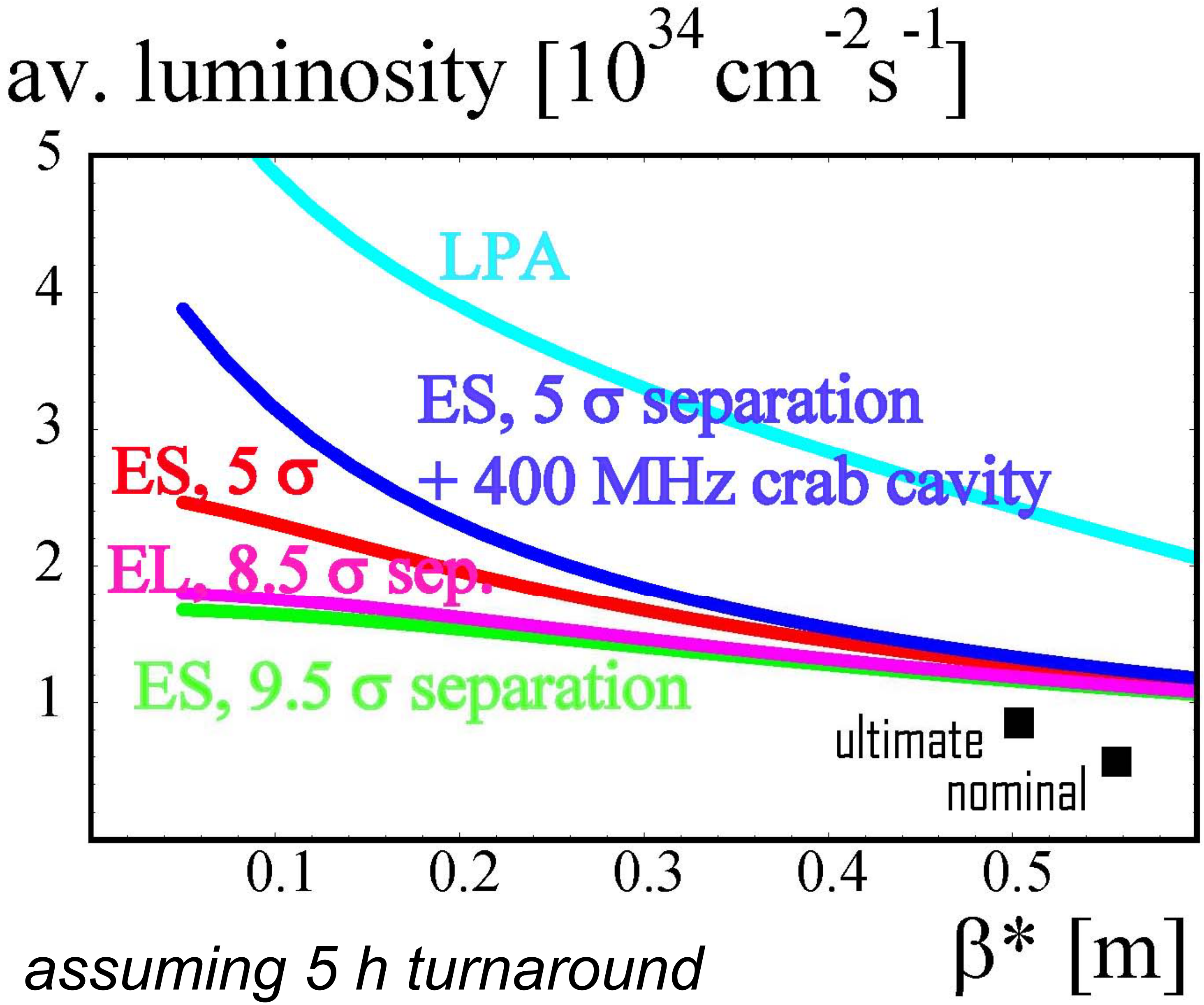


- ultimate LHC beam (1.7x10^{11} p's/bunch, 25 ns spacing)
- β* ~10 cm
- smaller transverse emittance

  → constraint on new injectors, off-δ β-beat

parameter	symbol	nominal	ultimate	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	0.08	0.08	0.1	0.25
full crossing angle	θ_c [μrad]	285	315	0	0	311	381
Piwinski parameter	$\phi=\theta_c\sigma_z/(2*\sigma_x*)$	0.64	0.75	0	0	3.2	2.0
geometric reduction		1.0	1.0	0.86	0.86	0.30	0.99
peak luminosity	L [10^{34} cm^{-2}s^{-1}]	1	2.3	15.5	15.5	16.3	10.7
peak events per #ing		19	44	294	294	309	403
initial lumi lifetime	τ_L [h]	22	14	2.2	2.2	2.0	4.5
effective luminosity ($T_{turnaround}$=10 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	0.46	0.91	2.4	2.4	2.5	2.5
	$T_{run,opt}$ [h]	21.2	17.0	6.6	6.6	6.4	9.5
effective luminosity ($T_{turnaround}$=5 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	0.56	1.15	3.6	3.6	3.7	3.5
	$T_{run,opt}$ [h]	15.0	12.0	4.6	4.6	4.5	6.7
e-c heat SEY=1.4(1.3)	P [W/m]	1.1 (0.4)	1.04(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 (10 h) τ_b	P_{gas} [W/m]	0.04 (0.4)	0.06 (0.6)	0.06 (0.56)	0.06 (0.56)	0.06 (0.56)	0.09 (0.9)
extent luminous region	σ_l [cm]	4.5	4.3	3.7	3.7	1.5	5.3
comment		nominal	ultimate	D0 + crab	crab		wire comp.

average luminosity vs β*



assuming 5 h turnaround

2008 progress with all 4 scenarios

ES: 2008 SPS beam studies;
beam-beam working meeting August 2008;
detailed design & discussion with experiments;
→ *G. Sterbini, J.-P. Koutchouk*

FCC: two mini-workshops, global collaboration,
joint studies with KEKB team; staged
approach
→ *R. Calaga*

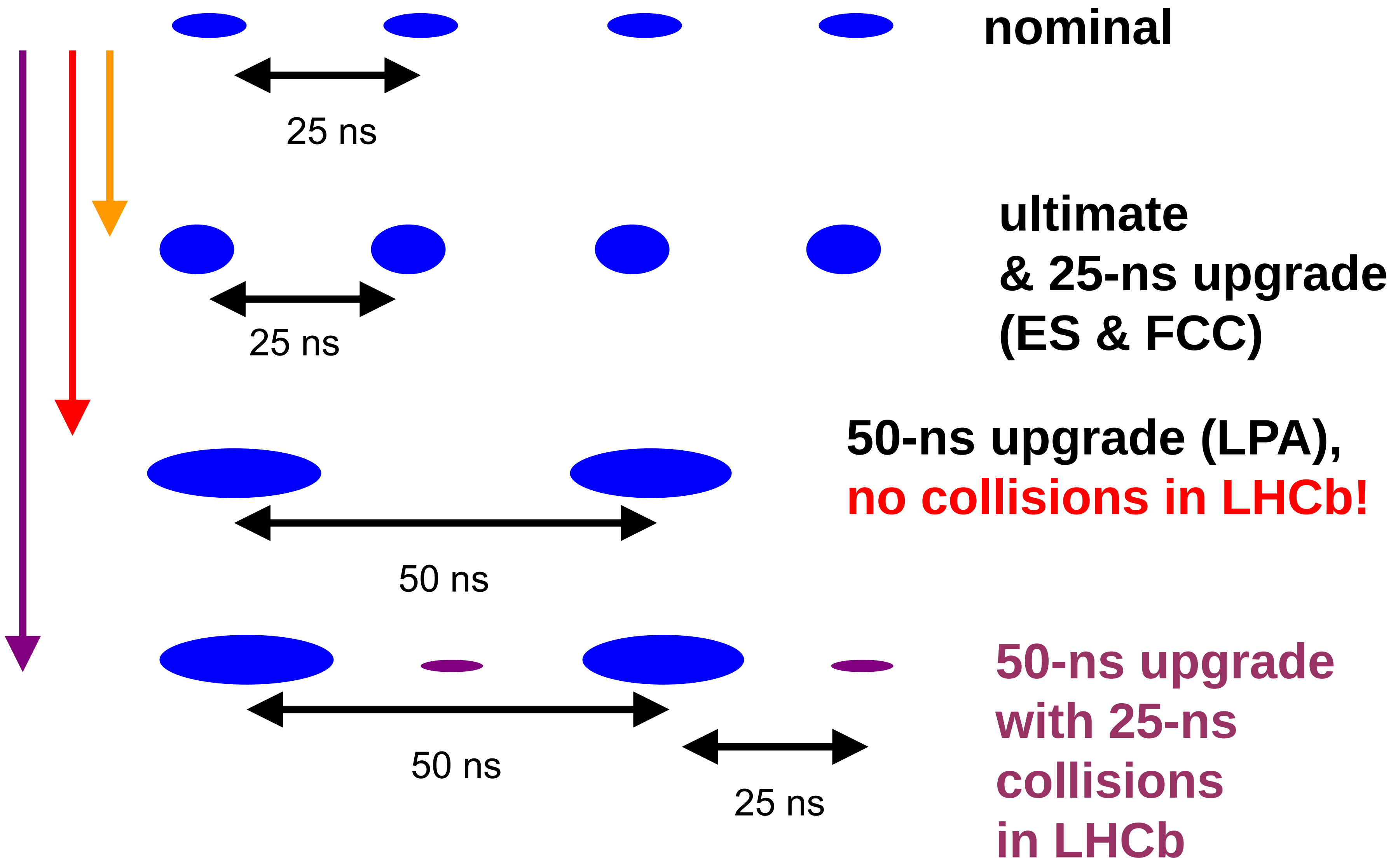
LPA: 2008 simulations & PS beam study
→ *C. Bhat*

LE: 2008 proposal (R. Garoby); parameter study
→ *discussion?!*

examples	ES, low β^*, with leveling	LPA, long bunches, with leveling
events/crossing run time av. luminosity	300 N/A N/A	300 2.5 h $2.6 \times 10^{34} s^{-1} cm^{-2}$
events/crossing run time av. luminosity	150 2.5 h $2.6 \times 10^{34} s^{-1} cm^{-2}$	150 14.8 h $2.9 \times 10^{34} s^{-1} cm^{-2}$
events/crossing run time av. luminosity	75 9.9 h $2.6 \times 10^{34} s^{-1} cm^{-2}$	75 26.4 h $1.7 \times 10^{34} s^{-1} cm^{-2}$

assuming 5 h turn-around time

upgrade bunch structures



injector upgrade & schedule

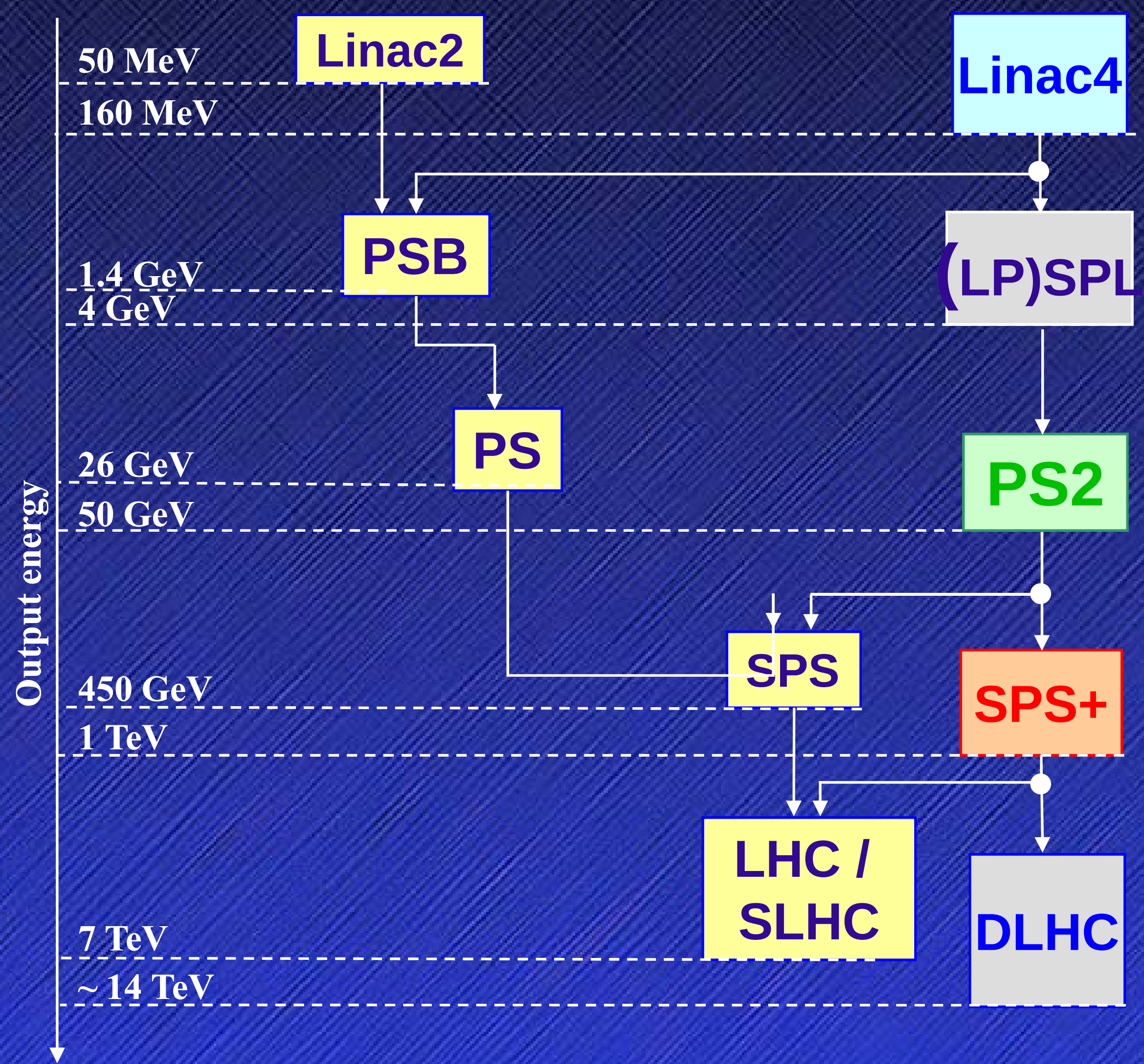
LHC injector upgrade

Reasons:

- **need for reliability:**
  - **accelerators are old [Linac2: 1978, PSB: 1975, PS: 1959, SPS: 1976]**
  - **they operate far from their design parameters and close to hardware limits**
  - **the infrastructure has suffered from the concentration of resources on LHC during the past 10 years**
- **need for better beam characteristics**

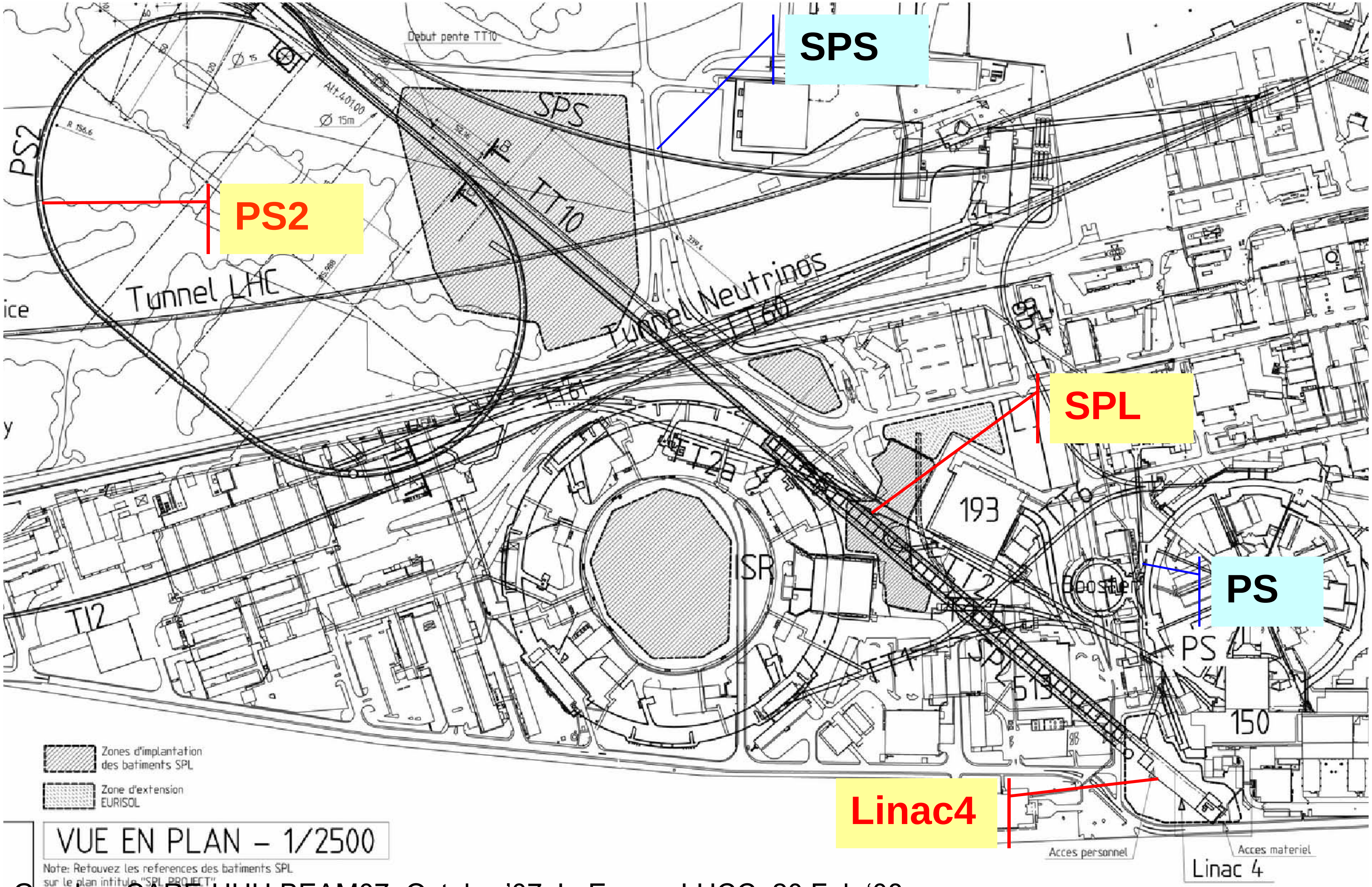
present and future injectors

Proton flux / Beam power



(LP)SPL: (Low Power) Superconducting Proton Linac (4-5 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
SLHC: “Superluminosity” LHC (up to 10^{35} $cm^{-2}s^{-1}$)
DLHC: “Double energy” LHC (1 to ~14 TeV)

layout of the new injectors

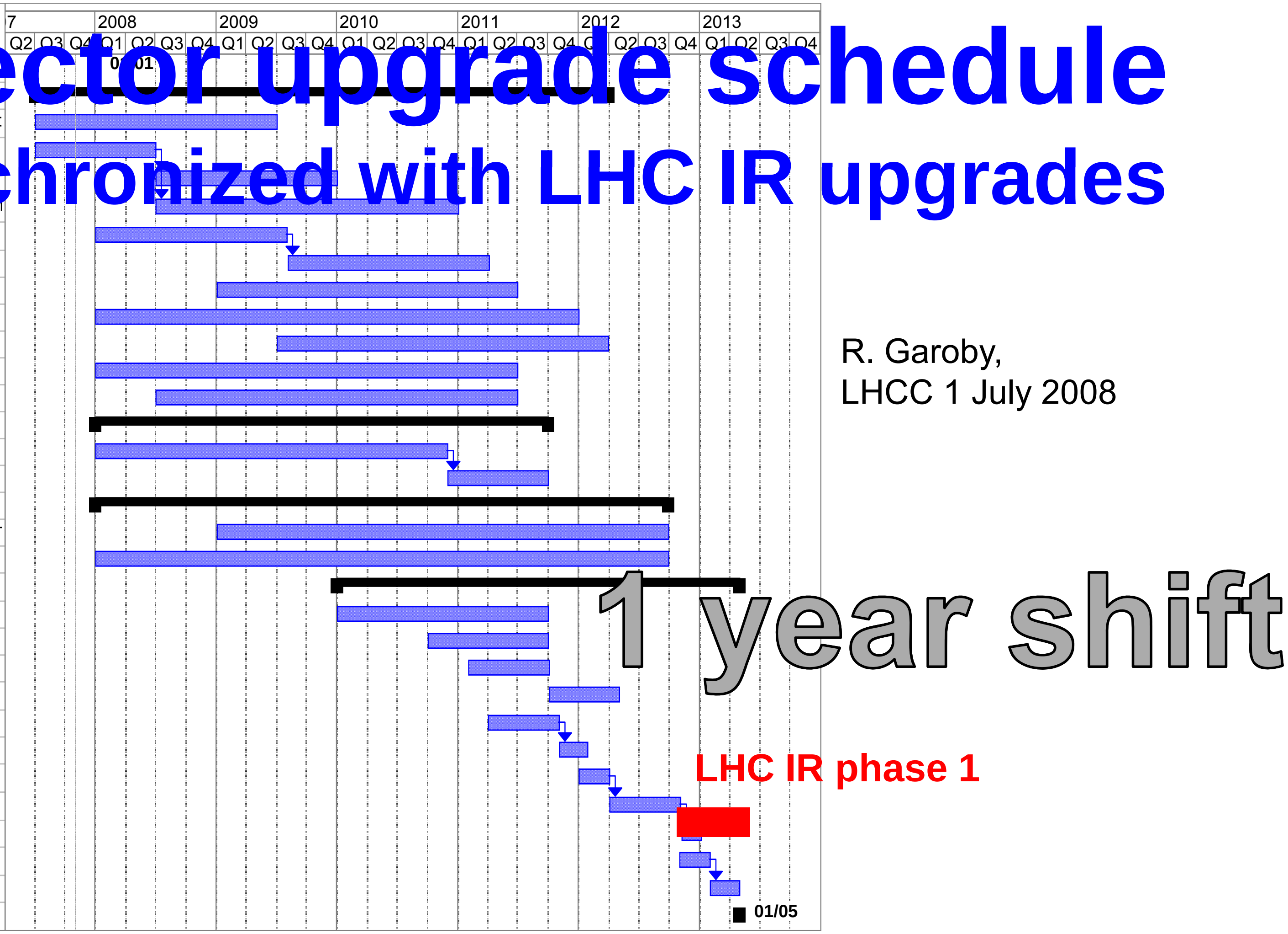


R. Garoby, CARE-HHH BEAM07, October'07; L. Evans, LHCC, 20 Feb '08

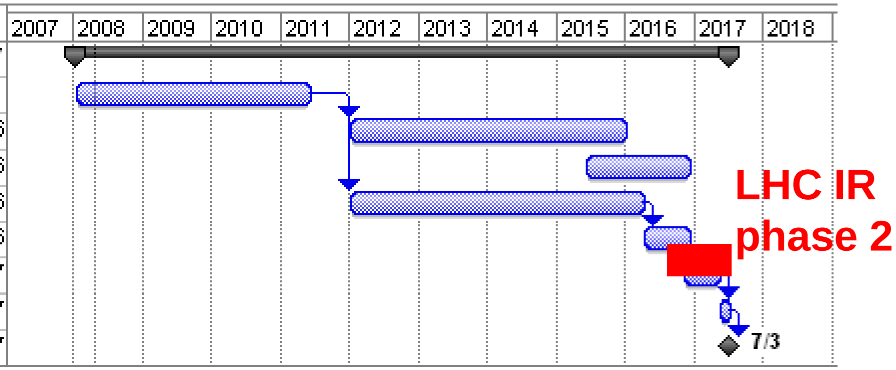
injector upgrade schedule synchronized with LHC IR upgrades

R. Garoby,
LHCC 1 July 2008

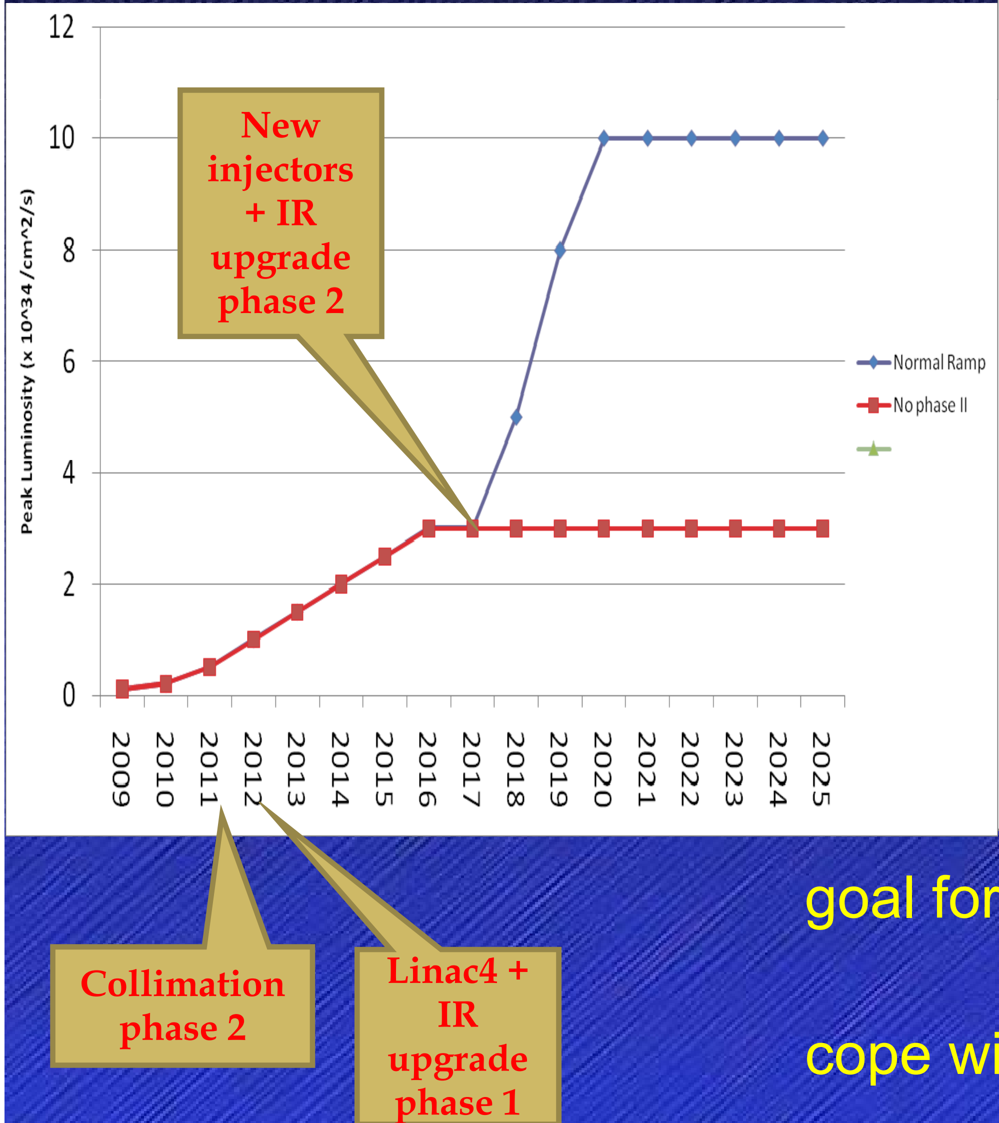
ID	WBS	Task Name
1		**Linac4 project sta**
2	2	**Linac systems**
3	2.1	Source and LEBT constru on, test
4		Drawings, material procurement
5	2.2	RFQ constructi n te t
6	2.4	Accelerating structure construction
7		Klystron prototypying
8	2.6.	Klystrons construction
9	2.6.	LLRF construction
10	2.7	Beam Instrumentation construction
11	2.8	Transfer line construction
12	2.9	Magnets construction
13	2.1(	Power converters construction
14	5	**Building and infrastructure**
15	5.1	Building design and construction
16	5.2,3,	Infrastructure installation
17	3	**PS Booster systems**
18	3.1	PSB injection elements construction
19	3.2	PSB beam dynamics analysis
20	4	**Installation and commissioning**
21	4.1	Test stand operation (3 + 10 MeV)
22	4.2	Cavities testing, conditioning
23		Cabling, waveguides installation
24		Accelerator installation
25		Klystrons, modulators installation
26		Hardware tests
27		Front-end commissioning
28	4.5	Linac accelerator commissioning
29		Transfer line commissioning
30		PSB modifications
31	4.6	PSB commissioning with Linac4
32		**Start physics run with Linac4**

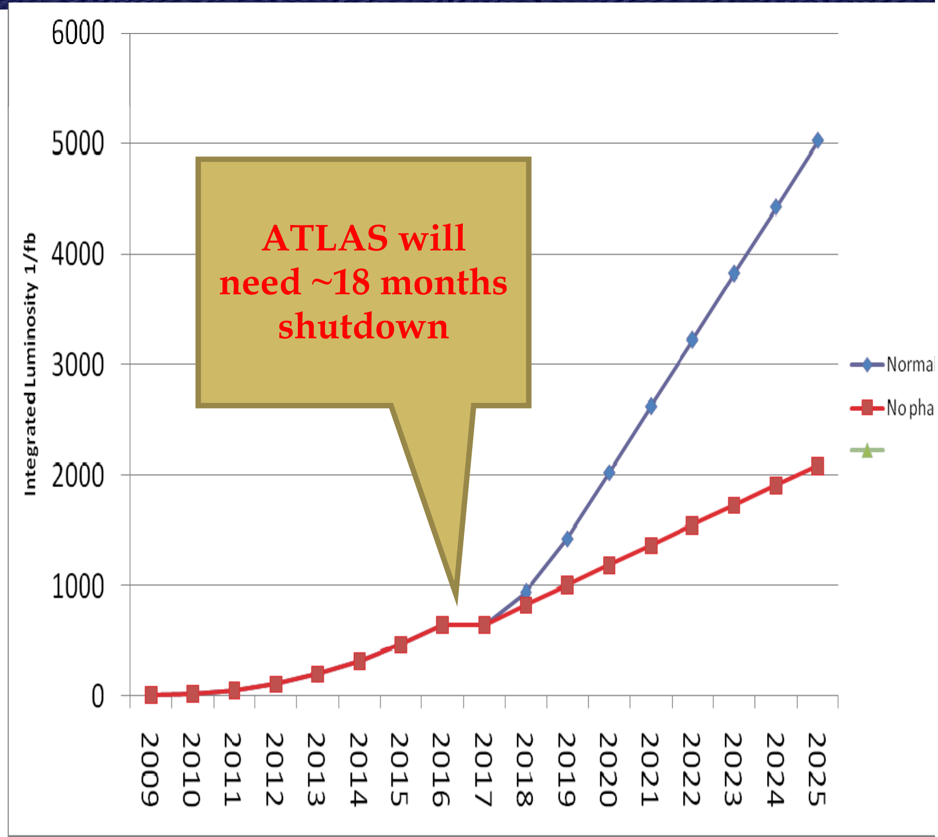


ID	Task Name	Start	Finish
1	**SPL + PS2**	**Mon 1/7/08**	**Mon 7/3/17**
2	Design	Mon 1/7/08	Wed 6/1/11
3	SPL Construction	Mon 1/2/12	Fri 1/1/16
4	SPL beam commissioning	Mon 6/1/15	Fri 12/2/16
5	PS2 construction	Mon 1/2/12	Fri 4/1/16
6	PS2 beam commissioning	Mon 4/4/16	Fri 12/2/16
7	SPS modification	Fri 11/4/16	Fri 5/5/17
8	SPS beam commissioning	Mon 5/8/17	Fri 6/30/17
9	Start operation for physics	Mon 7/3/17	Mon 7/3/17



forecast peak & integrated luminosity evolution





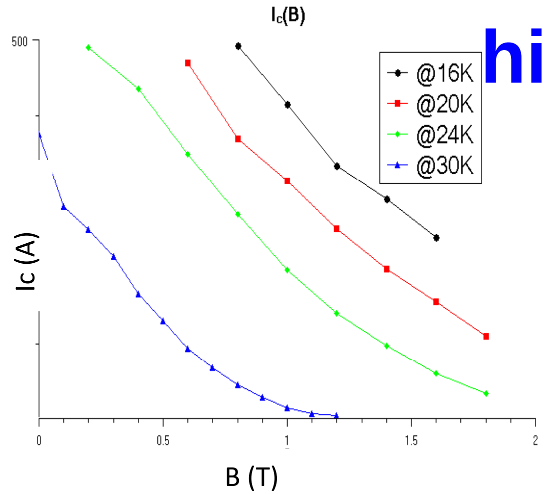
goal for ATLAS Upgrade:
3000 fb^{-1} recorded

cope with ~400 pile-up events each BC

M. Nessi, CARE-HHH LHC crab-cavity validation mini-workshop August 2008, R. Garoby, LHCC July 08

high-Tc s.c. LRBB compensator

A.Ballarino, CARE-HHH
mini-workshop, 28 August 2008

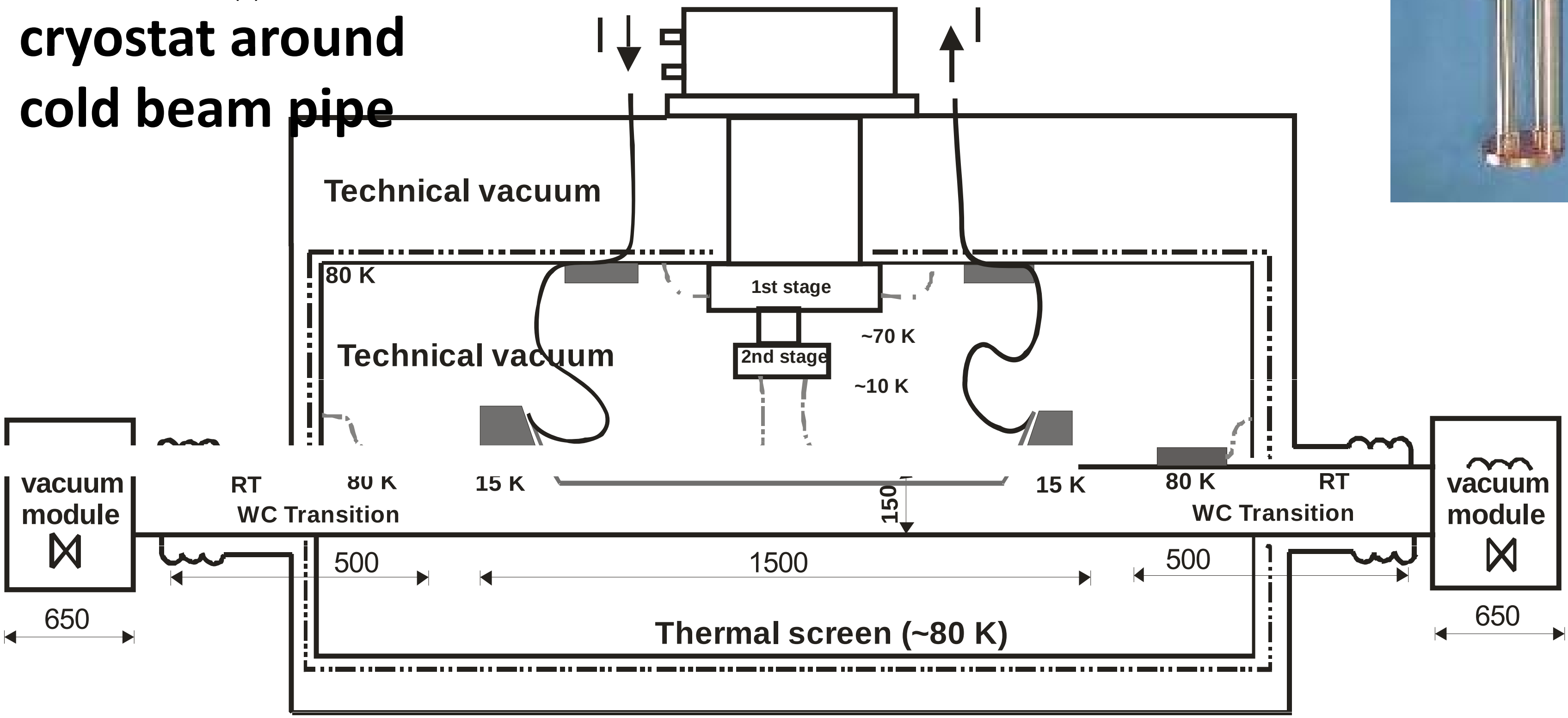


MgB_2 conductor

Ex-situ, 1.1 mm Φ MgB_2 wire (Columbus)

two-stage pulse tube cryocooler

cryostat around cold beam pipe



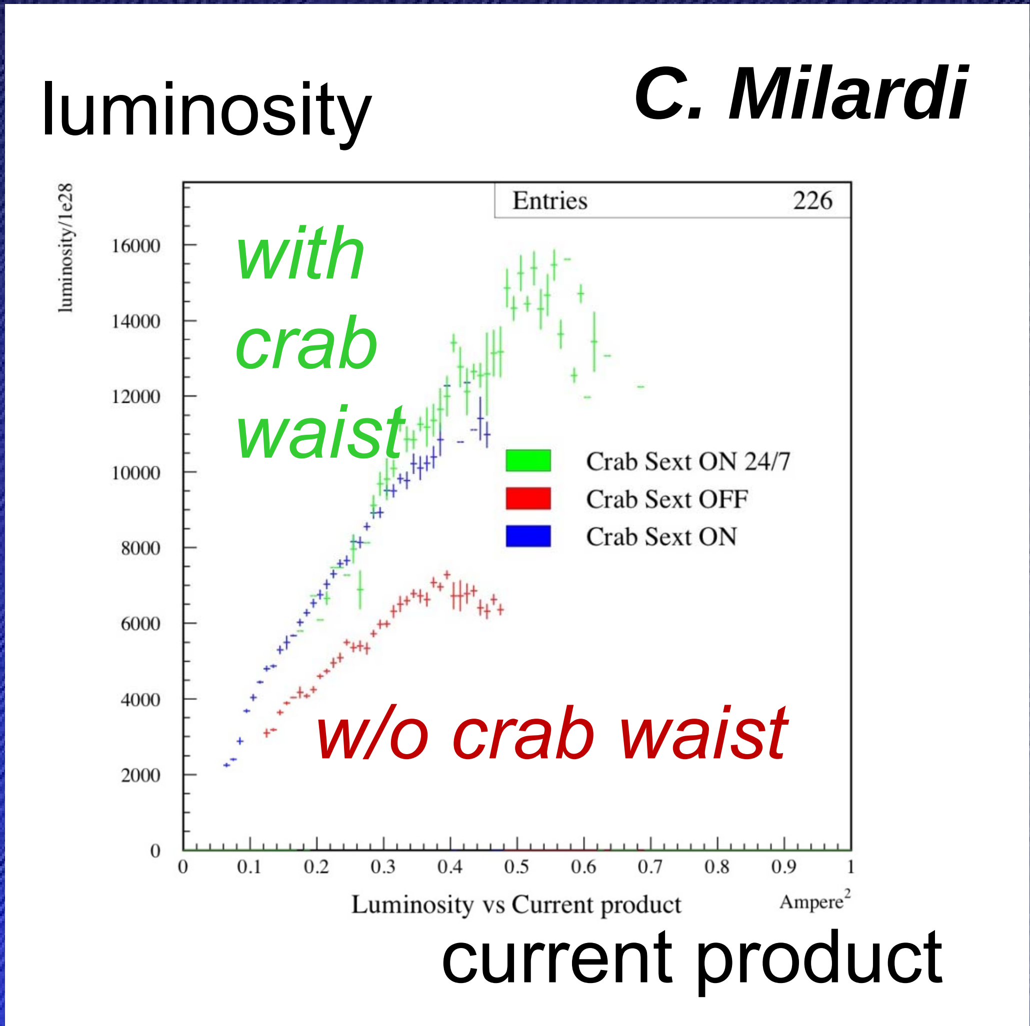
LTOT ~4 m (including vacuum modules)
Lcryostat ~2.5 m
HTOT ~1.2 m

complementary advanced schemes:

- beam-beam compensation
- crab waist collision
- electron-cloud mitigation
- crystal collimation
- cooling

"crab-waist" collisions at DAFNE

(note: no crab cavities but sextupoles!)



can we make use of crab waists at the LHC?

crab waist in LHC?

HHH

K. Ohmi

CARE-HHH
mini-workshop
28 August ‘08

one example:

ϕ=3.5 in LPA option
β_y squeezed to σ_x/ϕ=2.1cm (*extreme!*)

→ L increases $(14/2.1)^{1/2}$=2.6 times
→ ξ_y decreases and ξ_x is small for LPA

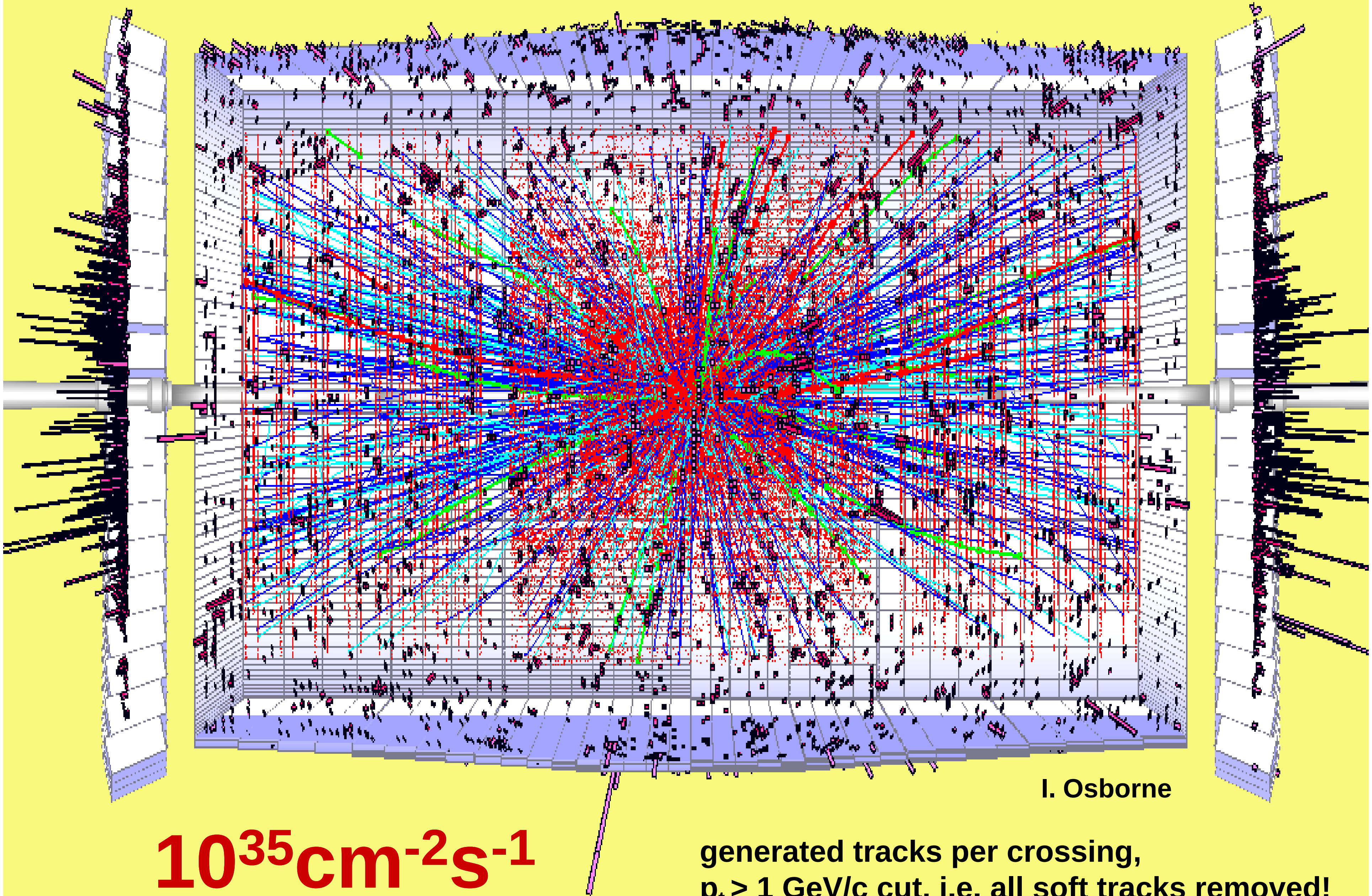
→ “crab waist has a chance to work!”

strategy for "phase 2"

HHH

- ✓ **R&D program for larger-aperture higher-field magnets**
- ✓ in parallel **crab-cavity development and testing**
- ✓ design, production & installation of **wire compensator** already in "phase 0"
- ✓ monitor **complementary schemes**, like crab waist, coherent e-cooling, e-lenses, crystal collimation; integrate them into upgrade plan when they become available
- ✓ validation **generation method for long flat bunches**
- ✓ identify **main limitations of the real LHC**
- ✓ **LHC & injector machine studies** to explore upgrade scenarios, e.g. LPA and LE
- ✓ close coordination with **detector upgrades**

thank you for your attention!



I. Osborne

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

generated tracks per crossing,
p_t > 1 GeV/c cut, i.e. all soft tracks removed!