LHC Accelerator
Status and Plans

Frank Zimmermann,
CERN, AB Department

17 September 2008

finally there!

1983 *LEP Note 440* - S. Myers and W. Schnell propose twin-ring pp collider in LEP tunnel with 9-T dipole field; idea stimulated by G. Brianti

> 25 years ago

1991 CERN Council: LHC approval in principle

1992 EoI, LoI of experiments

1993 SSC termination

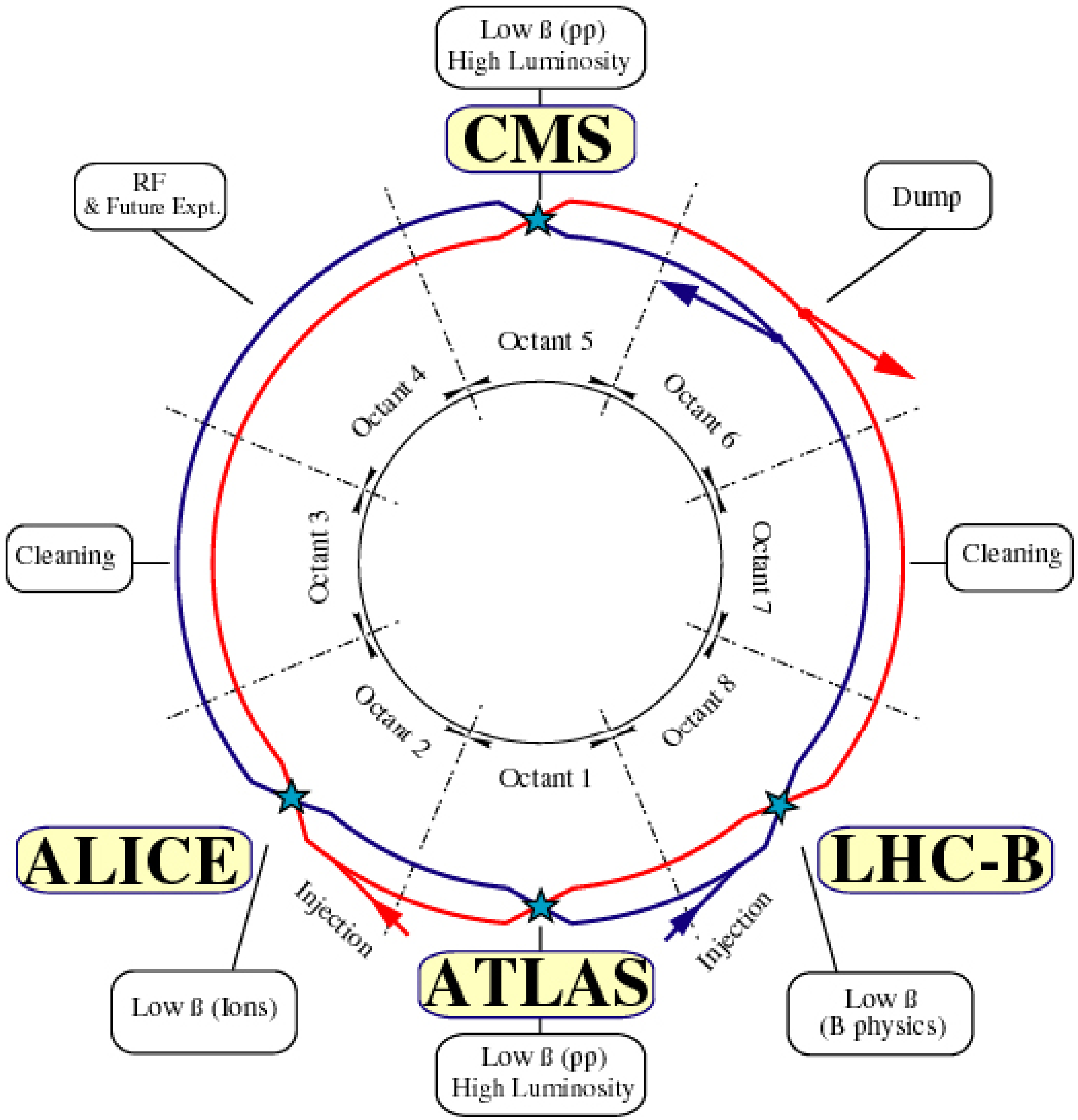
1994 CERN Council: LHC approval

1995-98 cooperation w. Japan, India, Russia, Canada, & US

2000 LEP completion

2006 last s.c. dipole delivered

2008 first beam



design parameters

c.m. energy = 14 TeV
luminosity =10^{34} $cm^{-2}s^{-1}$

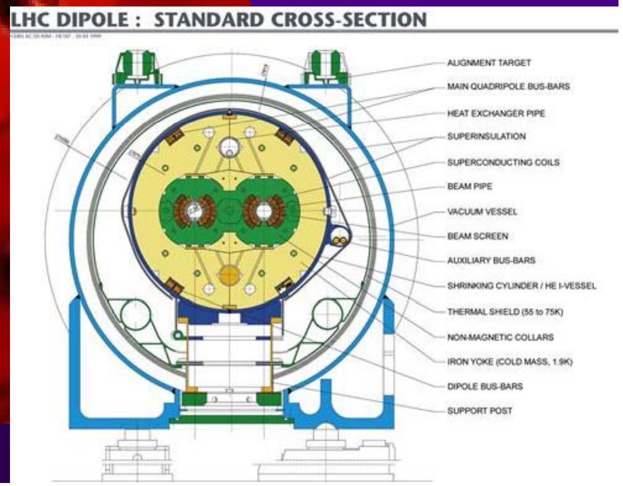
1.15×10^{11} p/bunch
2808 bunches/beam

360 kJ/beam

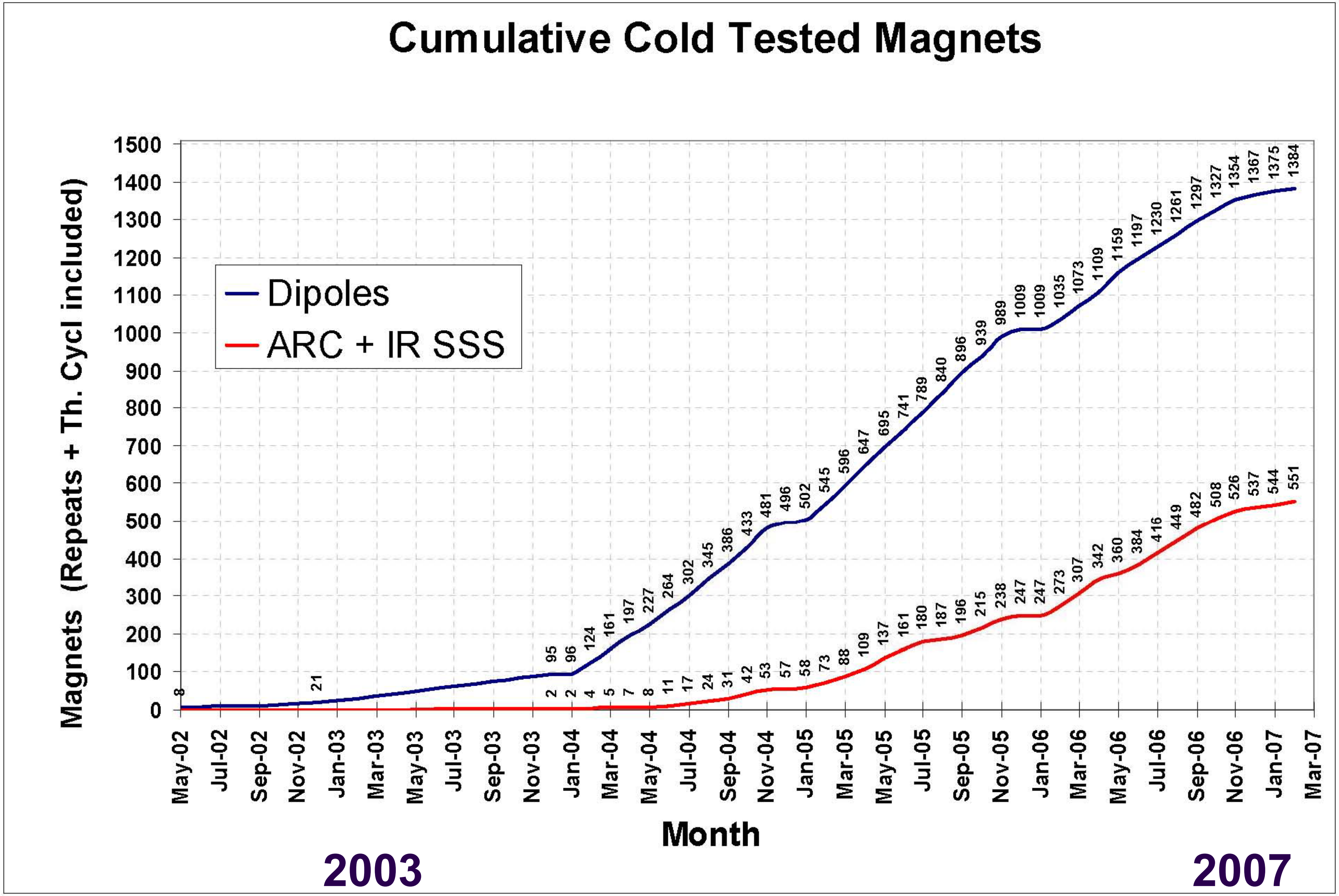
$\gamma\varepsilon$=3.75 μm
β^*=0.55 m
θ_c=285 μrad
σ_z=7.55 cm
σ^*=16 .6μm

Φ=0.64 (Piwinski angle)

LHC s.c. dipole magnet – 8.33 T



all s.c. magnets were tested in “SM18”

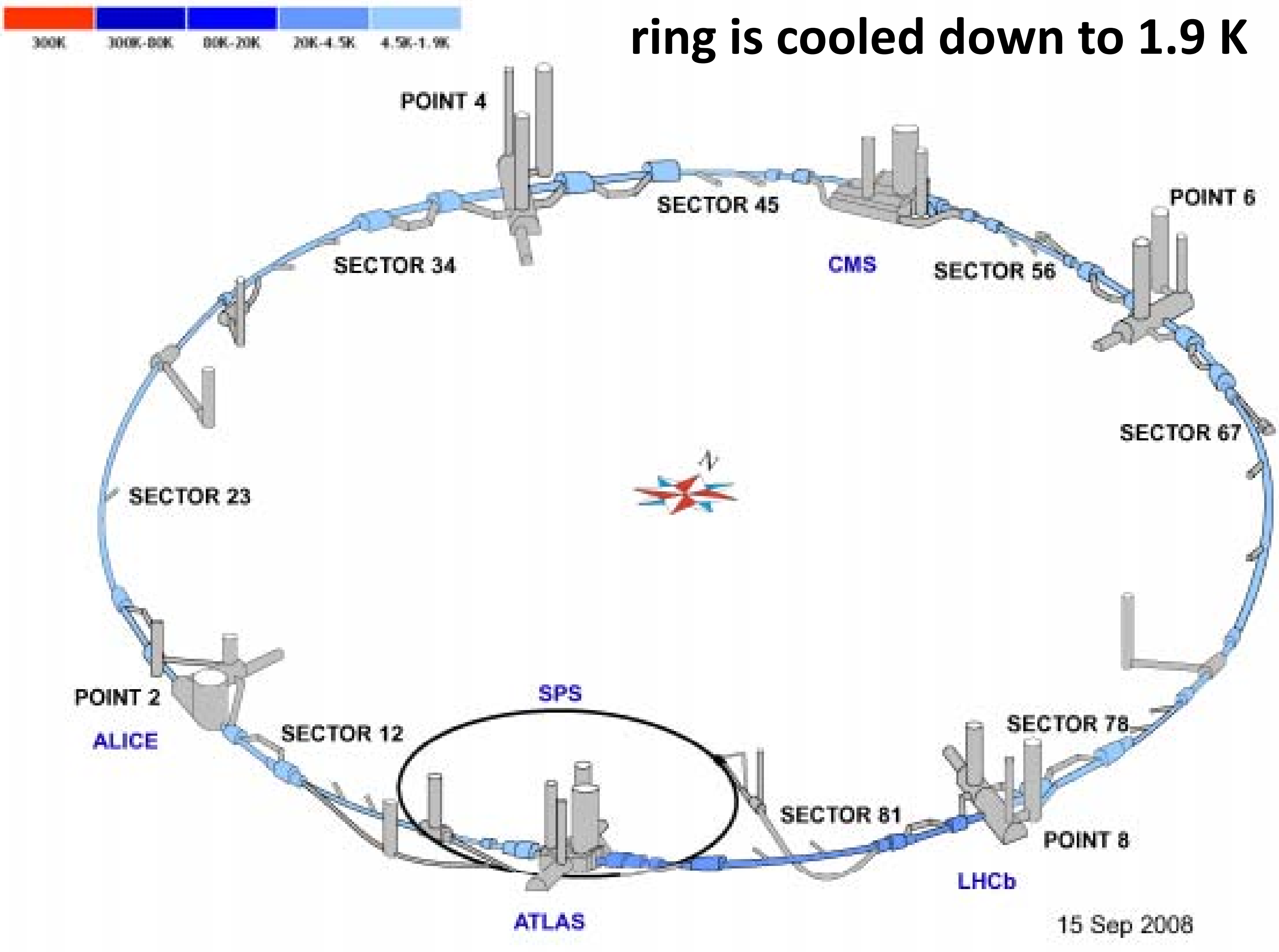

Cumulative Cold Tested Magnets
Magnets (Repeats + Th. Cycl included)
Month
Dipoles
ARC + IR SSS
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
May-02
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Nov-03
Jan-04
Mar-04
May-04
Jul-04
Sep-04
Nov-04
Jan-05
Mar-05
May-05
Jul-05
Sep-05
Nov-05
Jan-06
Mar-06
May-06
Jul-06
Sep-06
Nov-06
Jan-07
Mar-07
2003
2007


27 November 2006
DIPOLE
n° 1232
... THE LAST ONE
L. Evans
L. Rossi

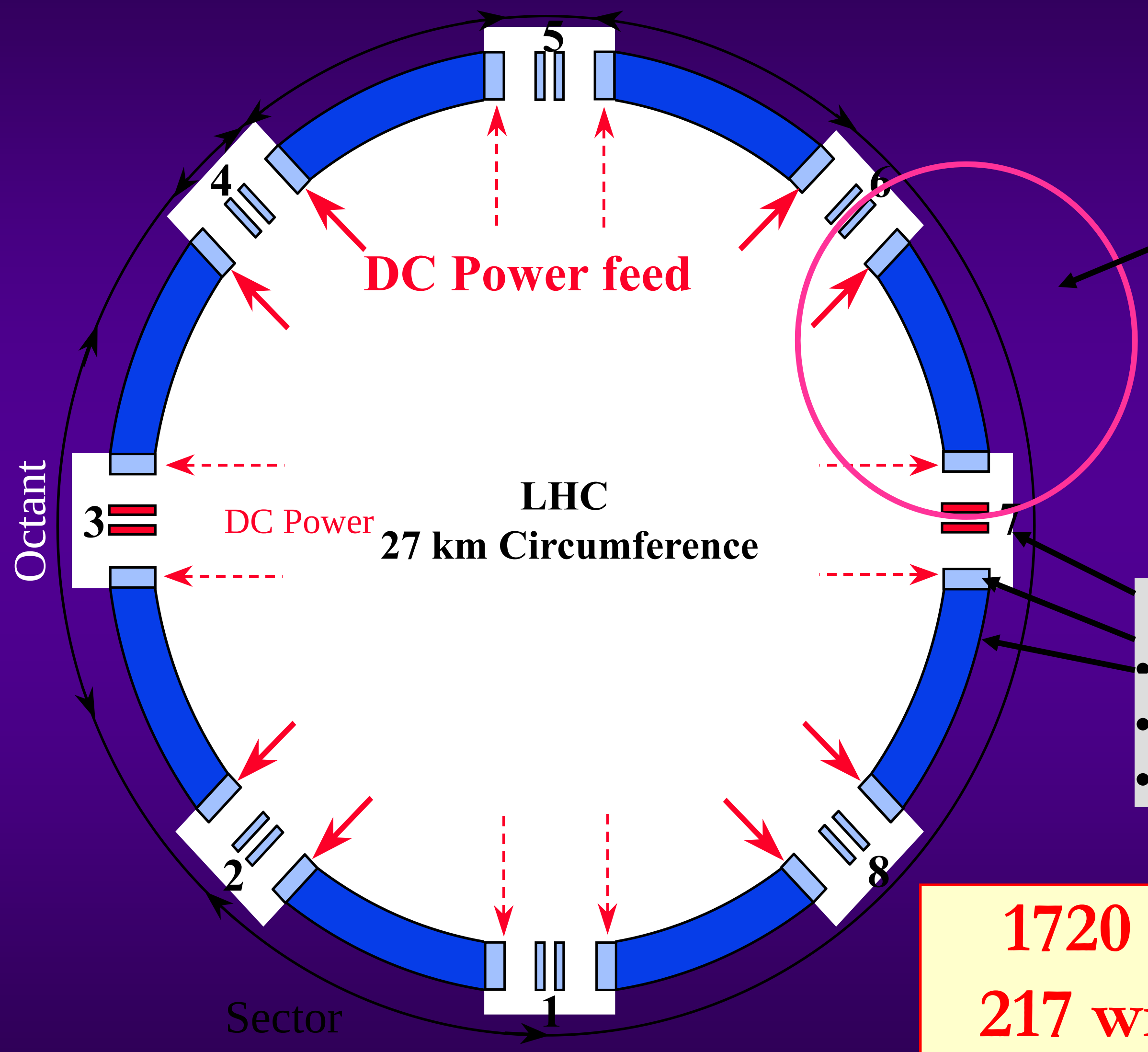

LHC tunnel 2002
L. Rossi


LHC tunnel 2006
L. Rossi

ring is cooled down to 1.9 K



LHC powering in 8 sectors



Powering Sector:
154 dipole magnets
about 50 quadrupoles
total length of 2.9 km

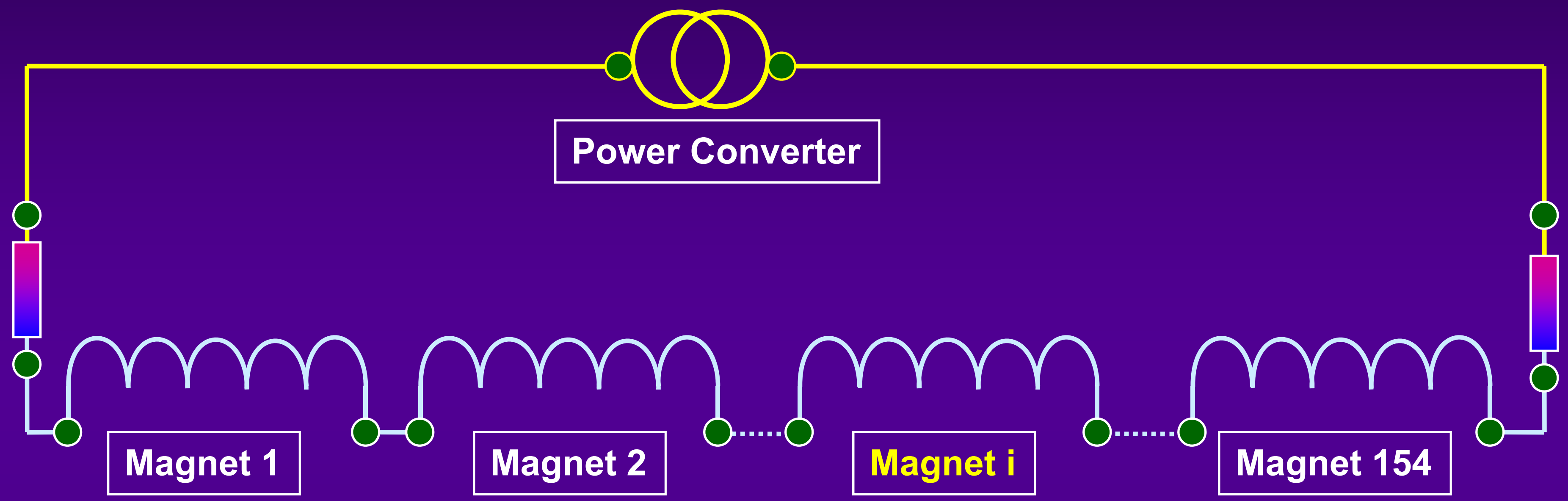
Powering Subsectors:
- long arc cryostats
- triplet cryostats
- cryostats in matching section

1720 circuits (1695 cold, 217 with current >4000A)

for comparison - HERA: 1 main circuit, 90 cold corrector circuits, 20 times "easier"

P.Proudlock, R. Schmidt, K.-H. Mess

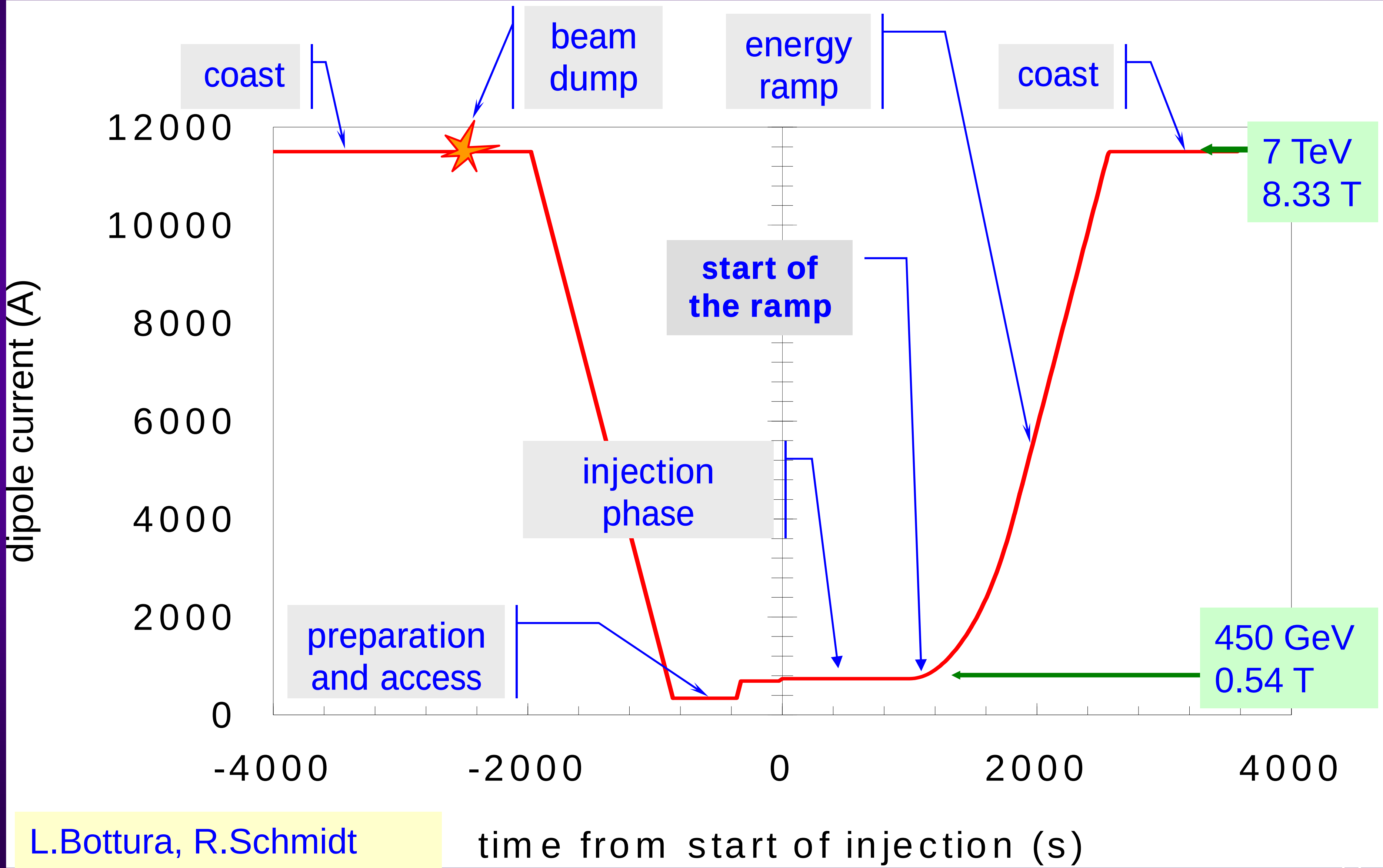
ramping current in string of dipole magnets



- LHC **powered in eight sectors** (154 dipole magnets each)
- Time for energy **ramp**: **~20-30 min** (energy from the grid)
- Time for discharge: **~the same** (energy back to the grid)

R. Schmidt

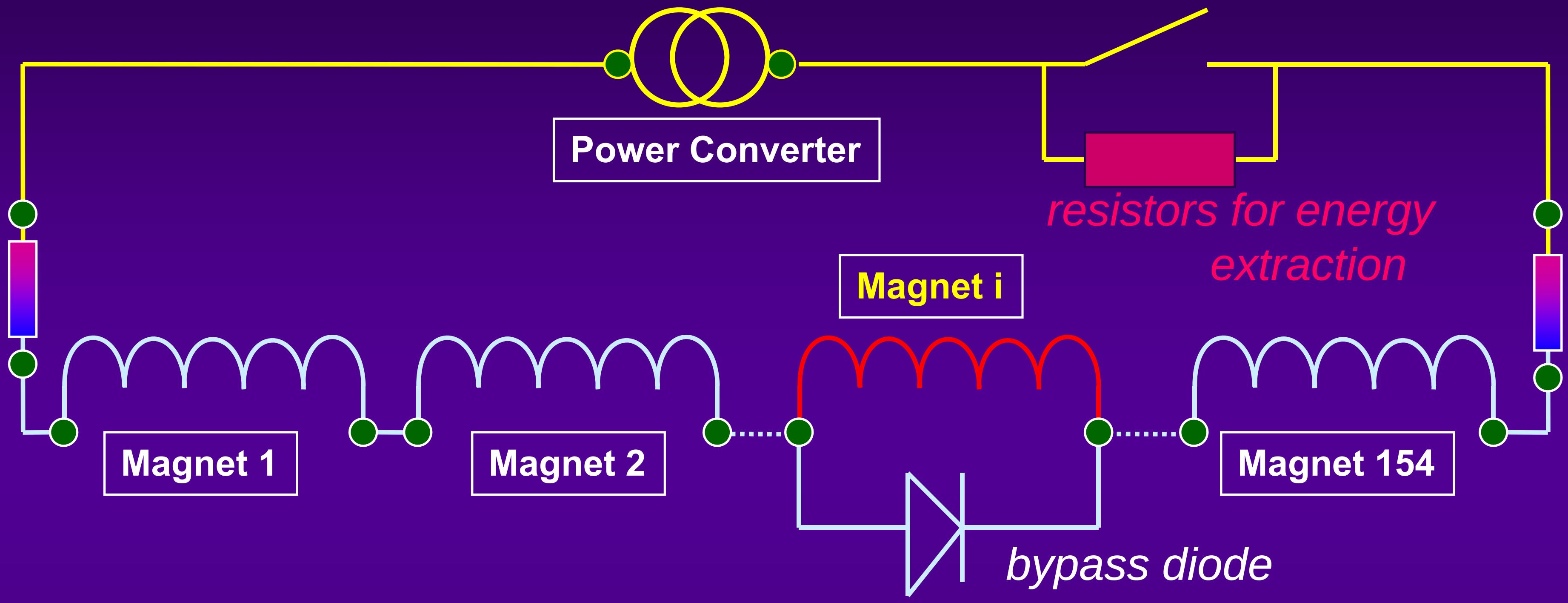
LHC magnetic cycle



L.Bottura, R.Schmidt

LHC quench protection

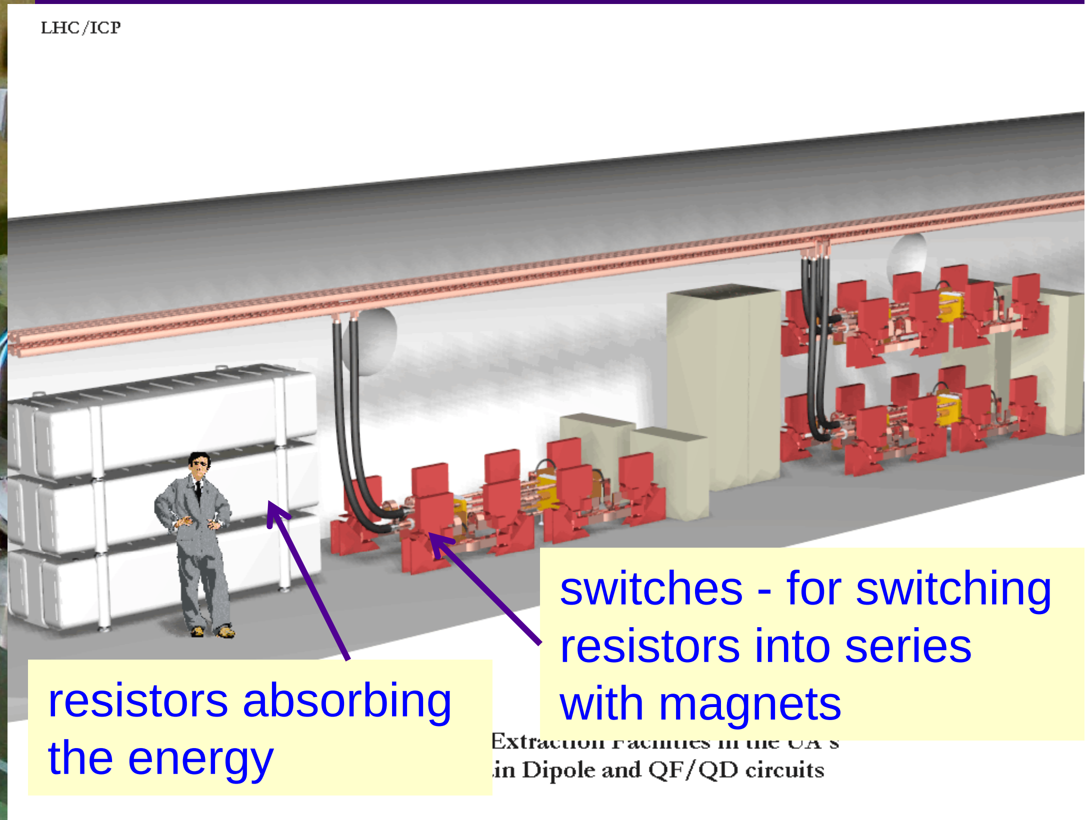
R. Schmidt



- when one magnet quenches, quench heaters are fired for this magnet
- current in quenched magnet decays in about 200 ms
- the current in all other magnets flows through the bypass diode that can stand the current for about 100-200 seconds; resistors are switched in series

bypass diode

energy extraction system in LHC tunnel



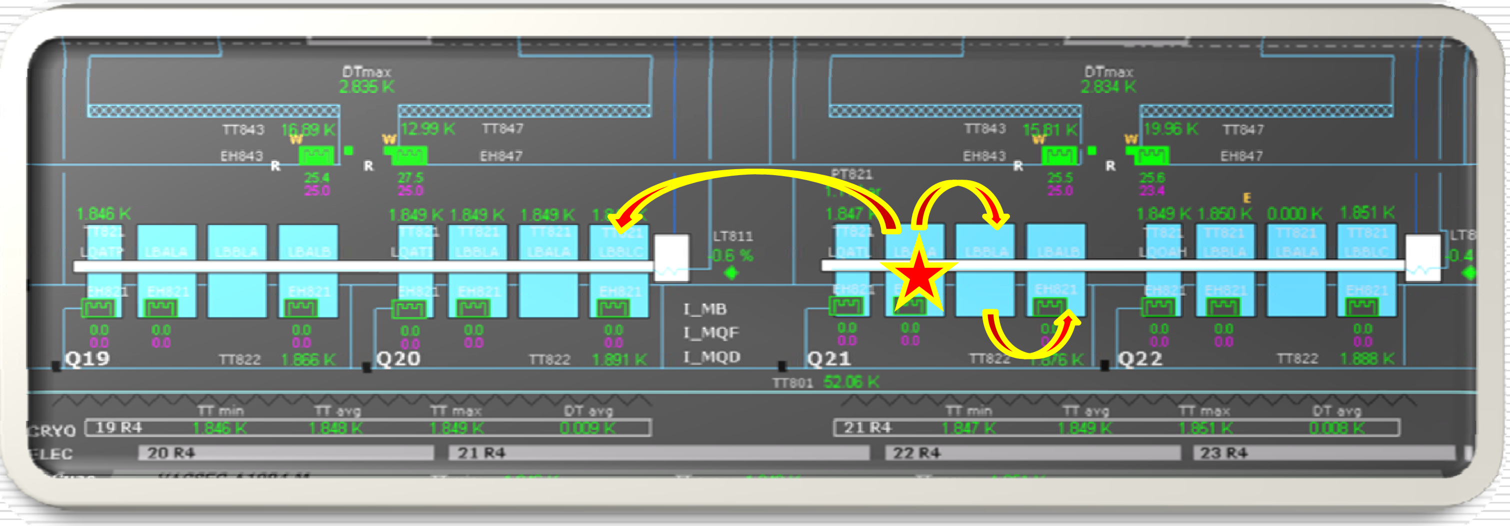
F.Rodriguez-Mateos, K.Dahlerup-Petersen, R. Schmidt

F.Rodriguez-Mateos, D.Hagedorn, R. Schmidt

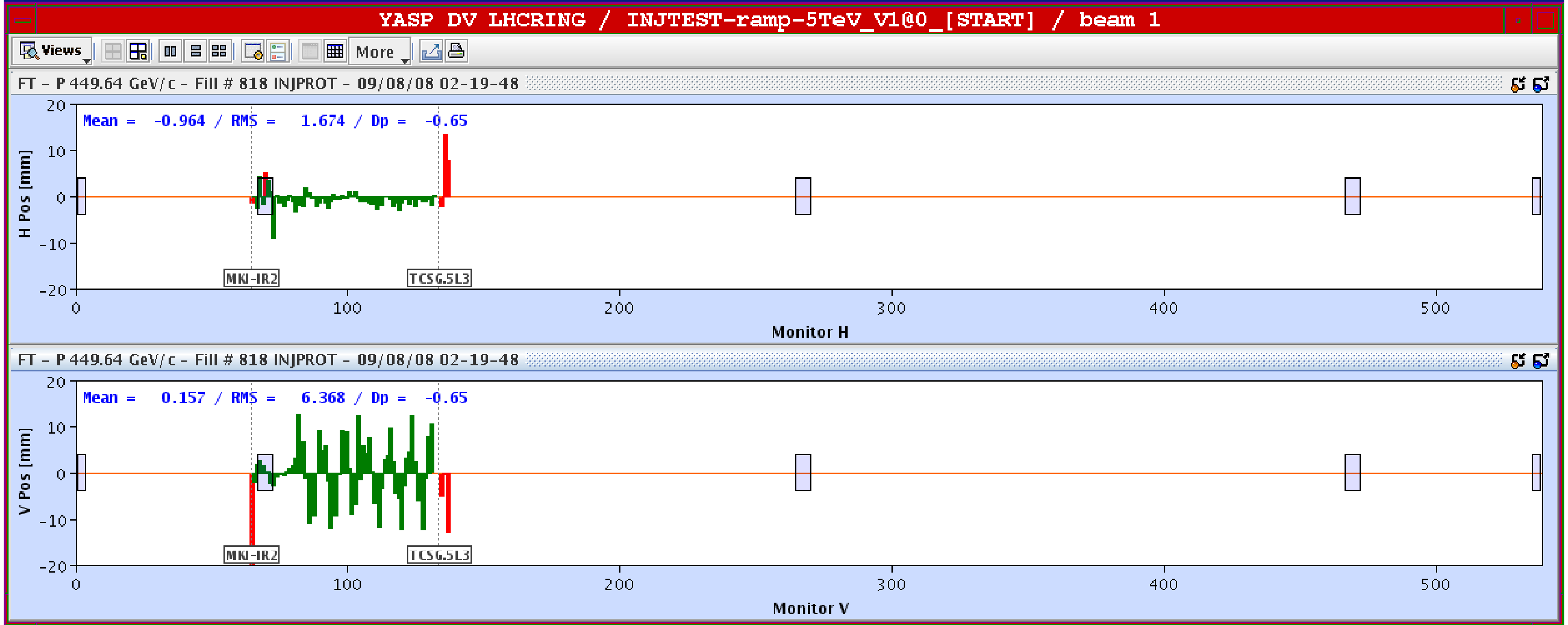
training quench example at 9859 A

- Natural quench in A22R4 (magnet name 3176)
- 4 magnets quenched (3 after quench propagation)
- Sequence of events:

Magnet	Cryogenic cell	Local time	t quench [s]	I quench [kA]	E [MJ]
A22R4	21R4	16:50:34.947	0	**9.859**	4.957
B22R4	21R4	16:51:24.679	49.732	6.011	1.843
C22R4	21R4	16:52:07.532	92.589	3.829	0.748
C21R4	19R4	16:52:41.798	126.855	2.644	0.357
				Total	7.905



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

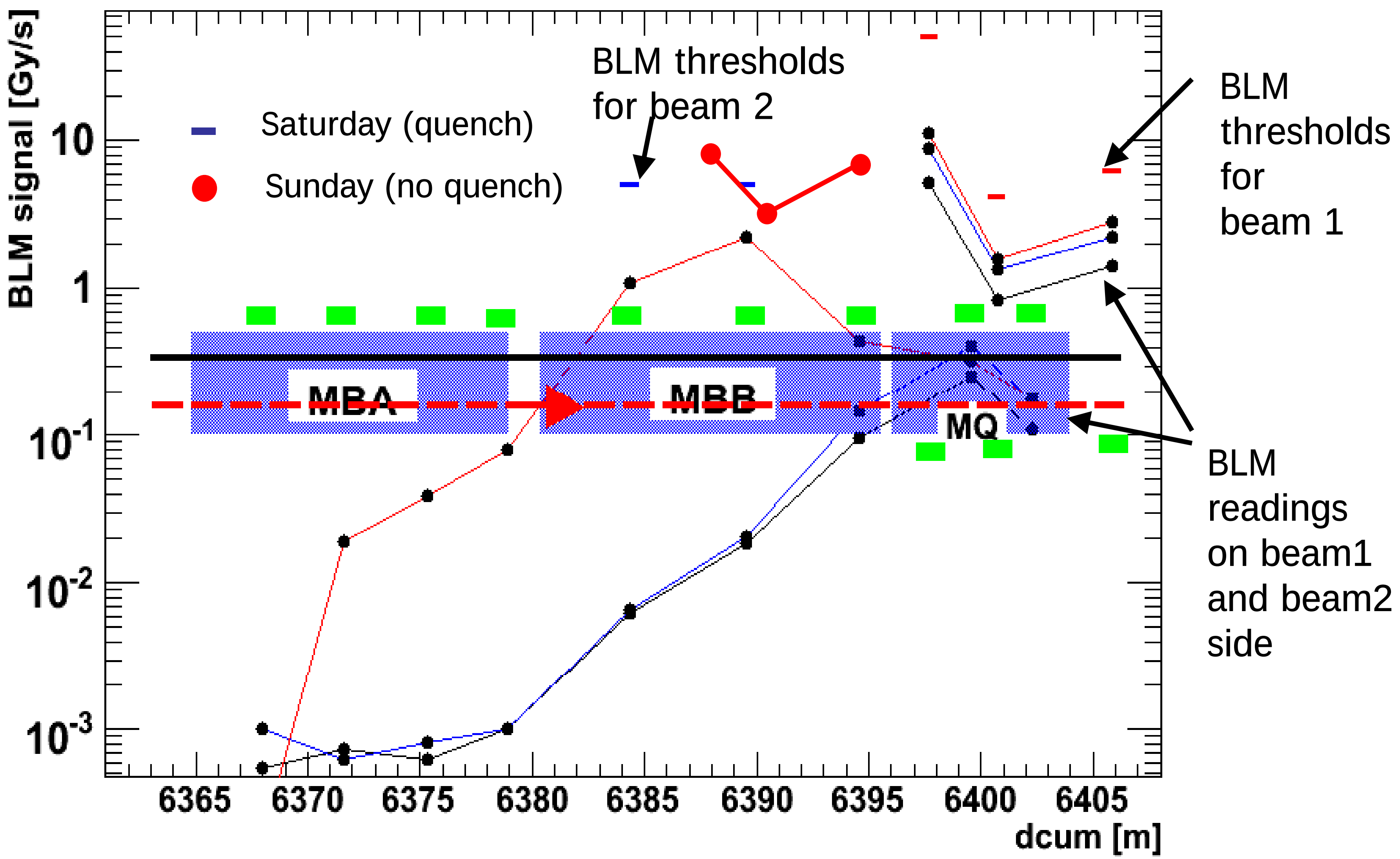


B. Jeanneret et al, LHC Project Report 44 (1996)

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

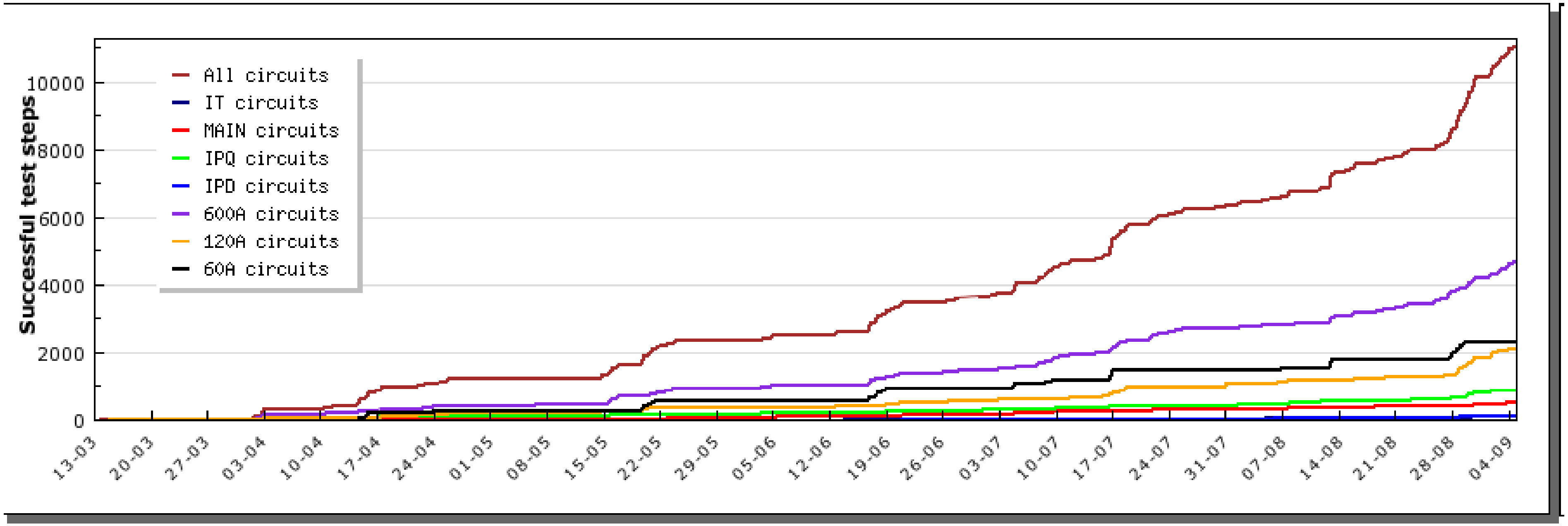
First Beam Induced Quench

B. Dehning



hardware commissioning in 2008

successful test steps (total #tests > 10000)



April May June July August Sept.

M. Lamont

start up 10 September "D-Day"

08.30 Beam to TEDS both lines. Interleaved injection beam 1 & 2.

09.00 Switch to beam 1 only. Kickers executing soft start.

09.30 Beam to TDI. Kickers on.

09.40 TDI out. Beam to collimators point 3.

09.45 Collimators IP3 out. Beam to left of point 5.

09.55 Collimators point 5 out, beam ~to point 6 but not to extr. line.

10.00 Beam to dump block (steered with DC bump). **Half way round!**

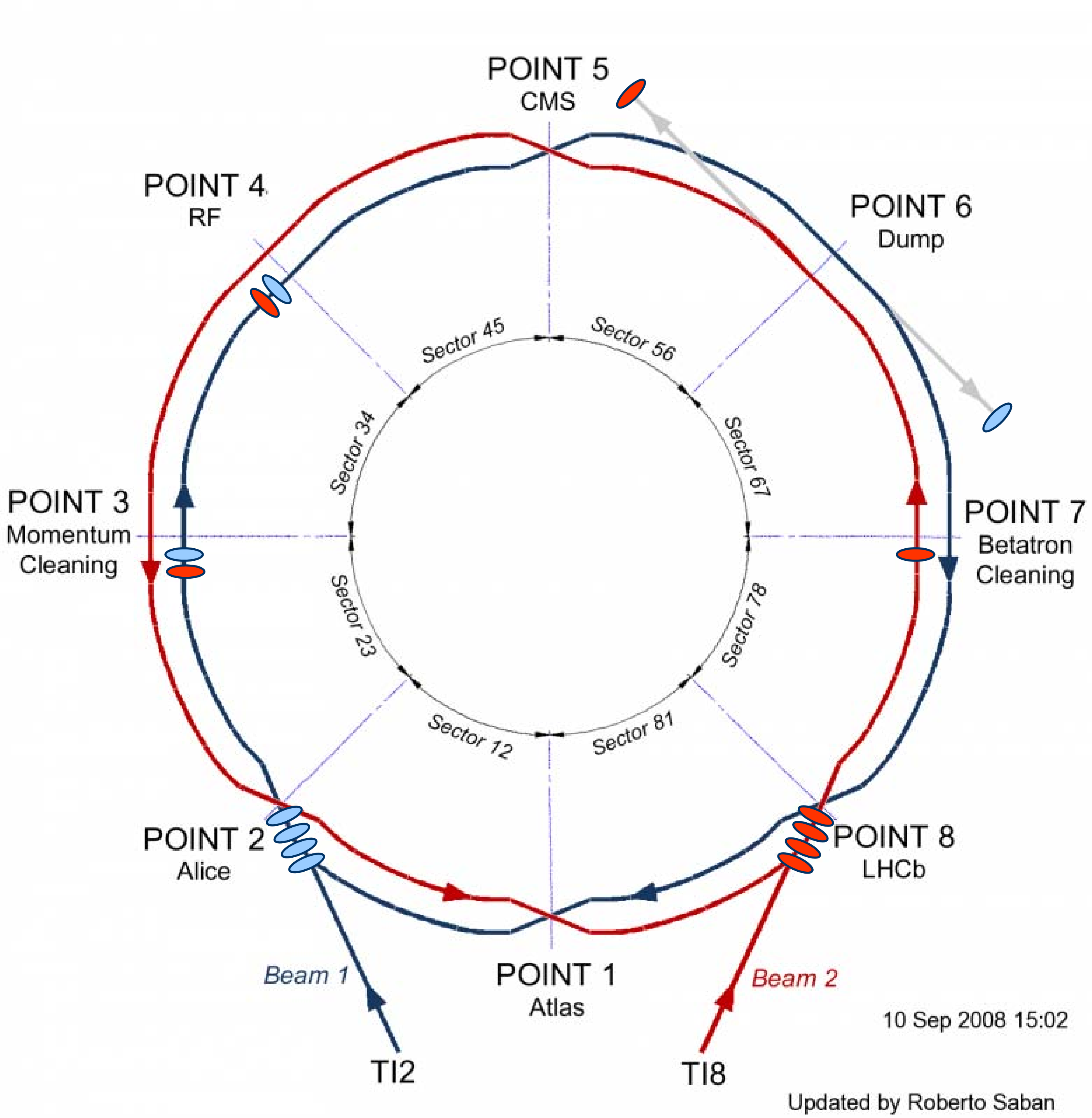
10.08 Beam to collimators in point 7.

10.12 Beam to point 8 collimators.

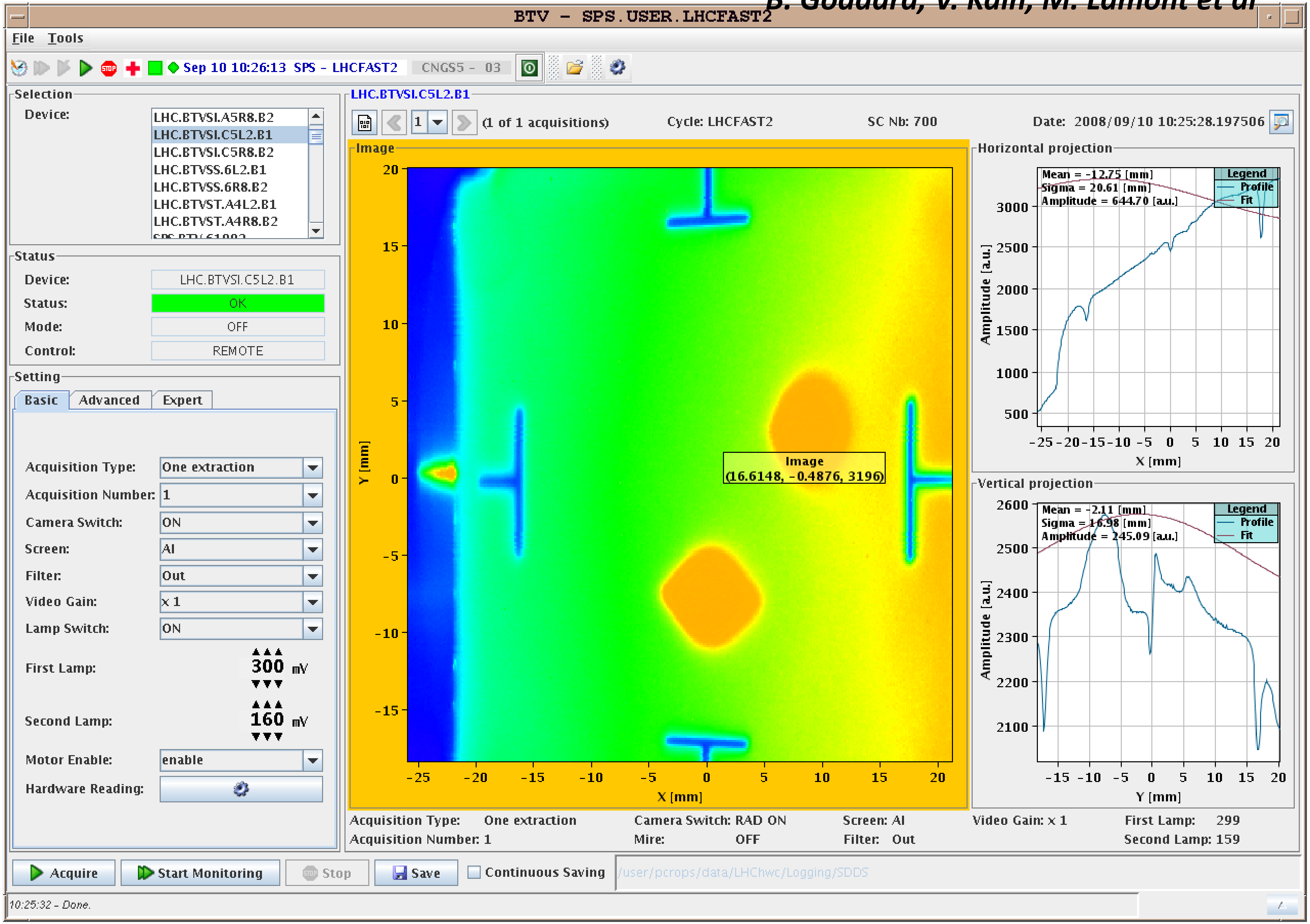
10.30 Beam 1 round > 1 turn (image on screen showing beam on first and second turns, image of trajectory – next slides)

With a bit of correction - beam makes 3 turns (next slides)

beam 1 around ring in less <1 hour (12 h's in LEP!)

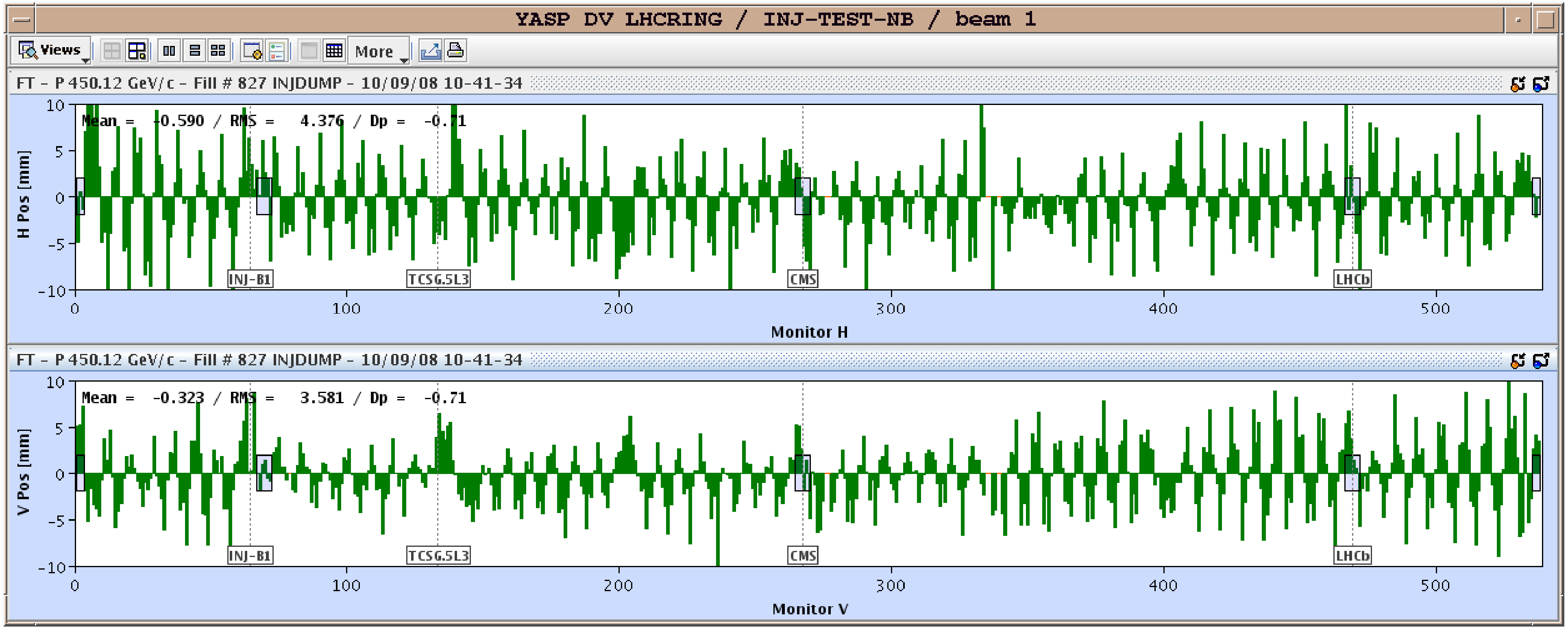

POINT 5
CMS
POINT 4
RF
POINT 6
Dump
Sector 45
Sector 56
Sector 34
Sector 67
POINT 3
Momentum
Cleaning
POINT 7
Betatron
Cleaning
Sector 23
Sector 78
Sector 12
Sector 81
POINT 2
Alice
POINT 8
LHCb
Beam 1
POINT 1
Atlas
Beam 2
10 Sep 2008 15:02
TI2
TI8
Updated by Roberto Saban

B. Goddard, V. Kain, M. Lamont et al

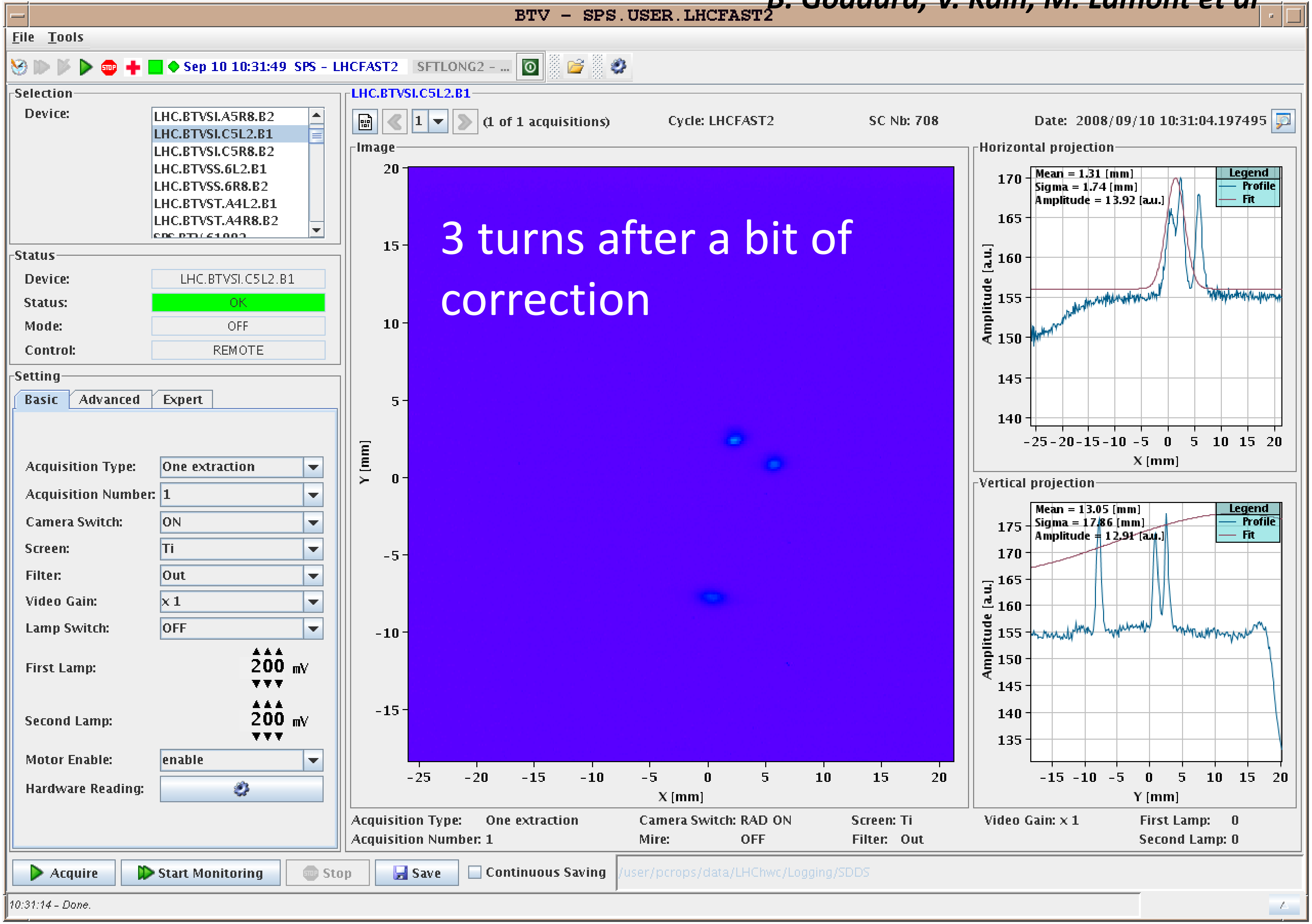


J. Wennninger

1st turn trajectory beam 1

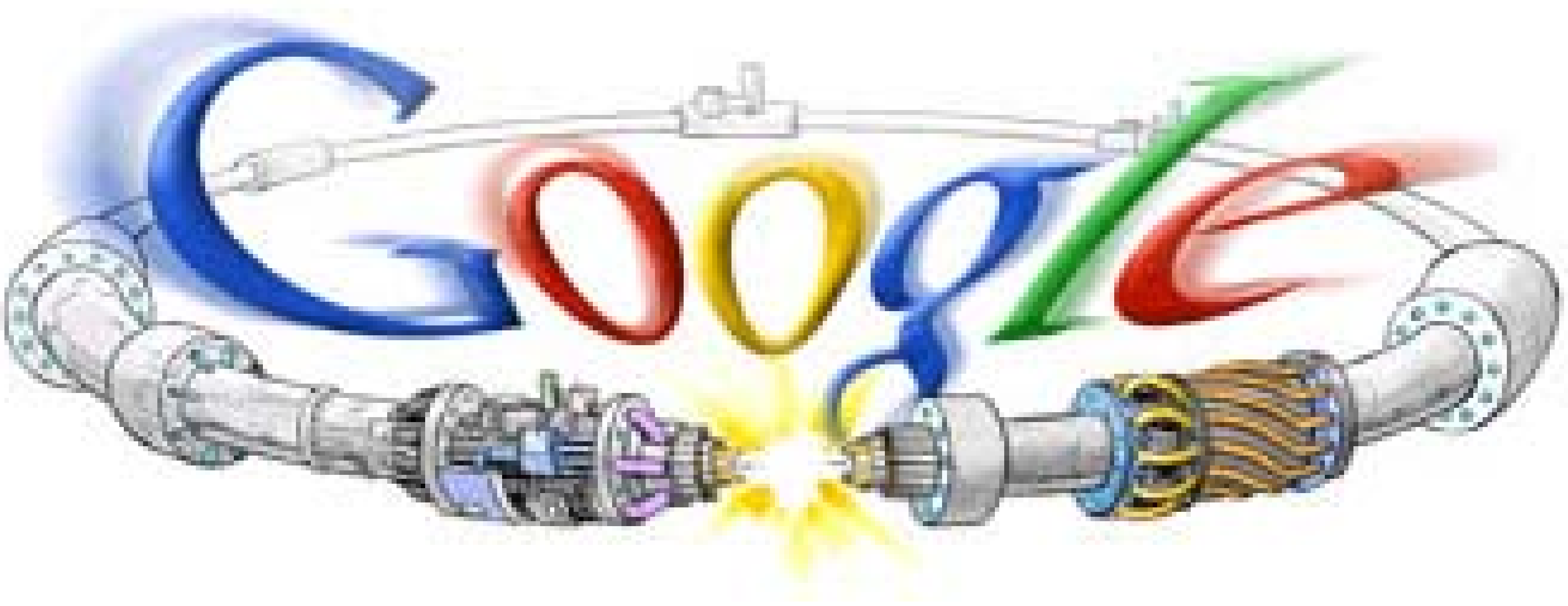


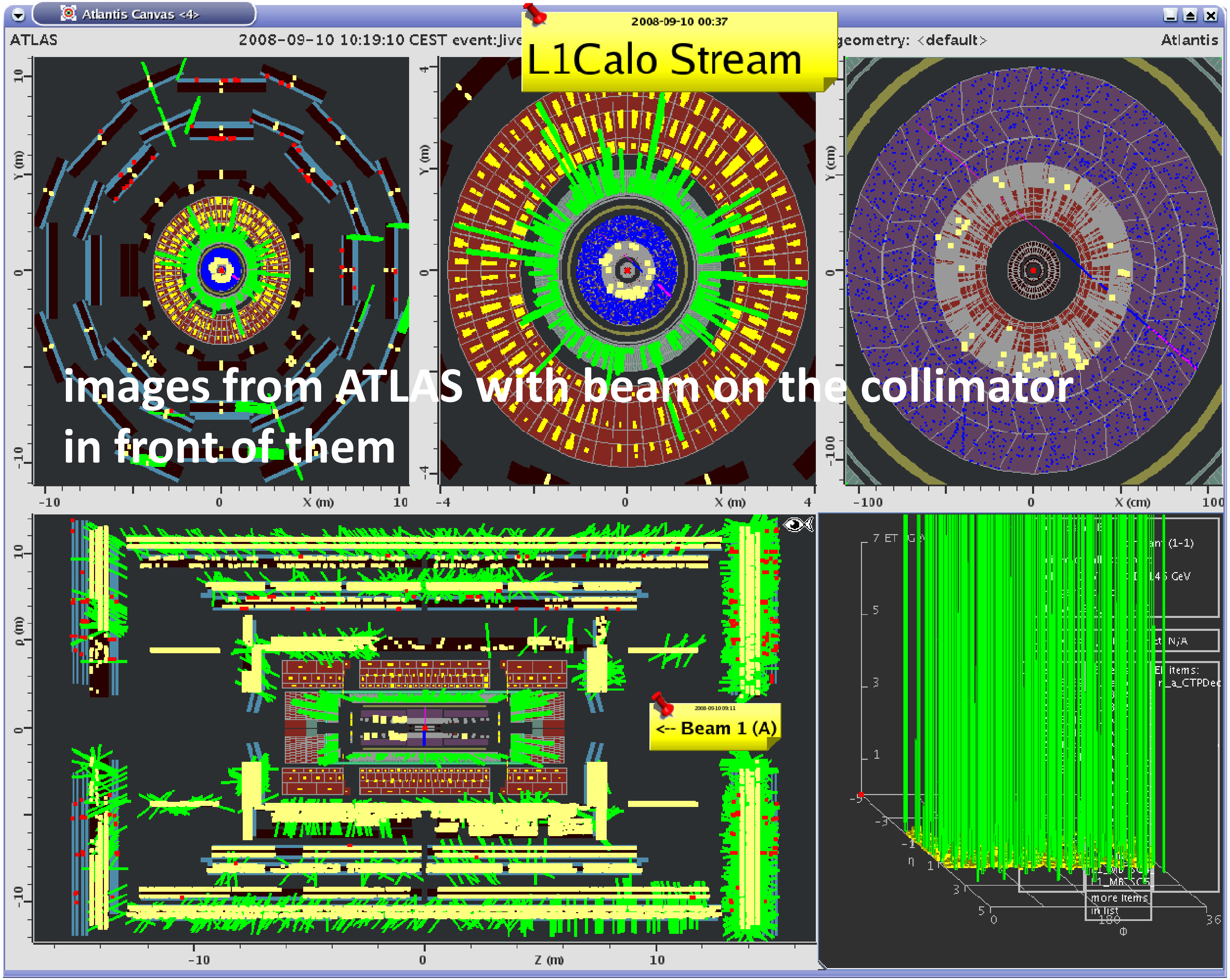
B. Goddard, V. Kain, M. Lamont et al



M. Lamont

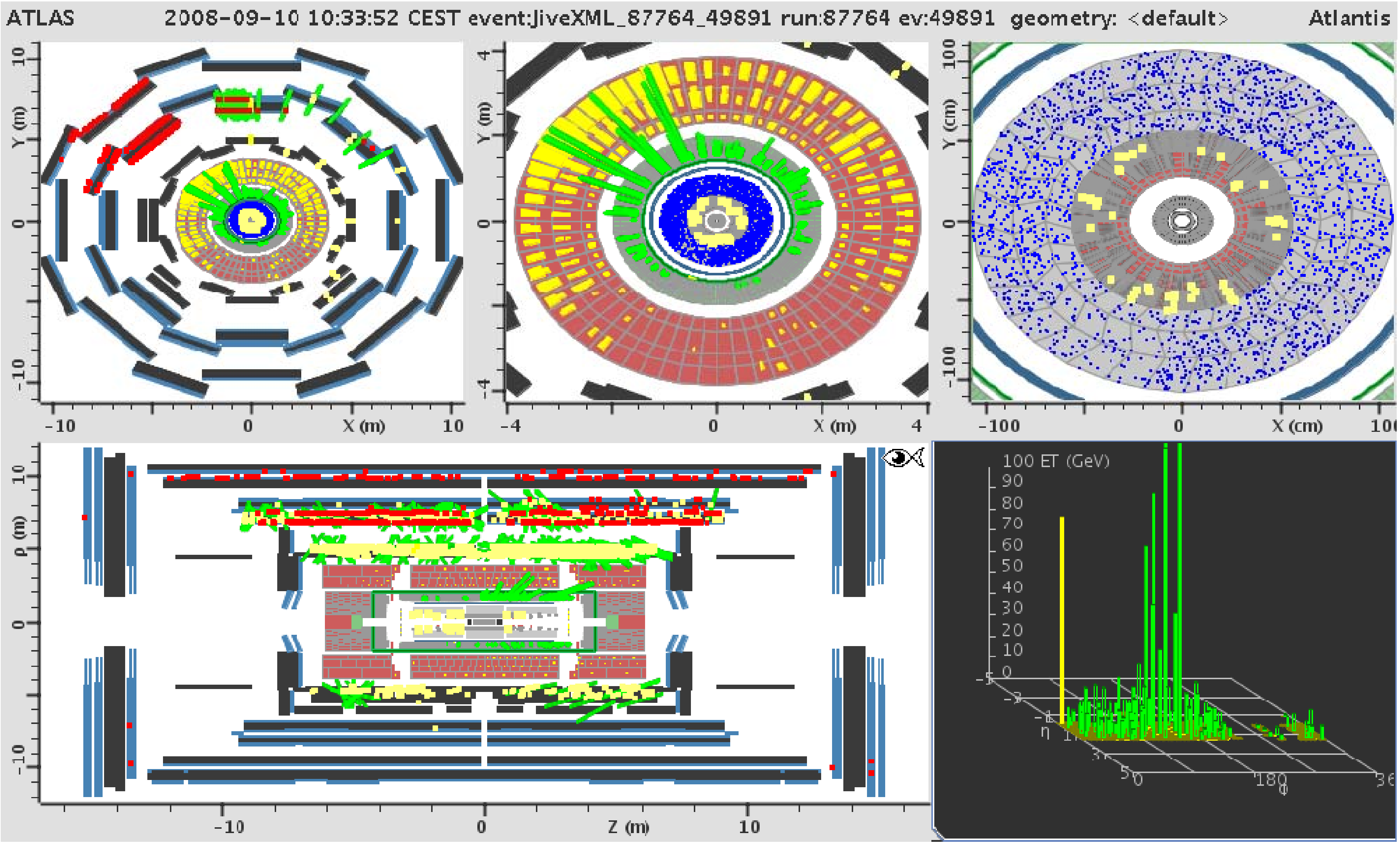
High point of the day was to have made *Google*!





images from ATLAS with beam on the collimator in front of them

images from ATLAS with beam on collimator in front of them



M. Lamont

"D-Day" afternoon – beam 2

non-serious cryogenics problem delays beam 2 inj. until 13:30

Switch to beam 2 only.

13.30 onto the TDI

13.40 TDI out, beam to point 3.

Cryogenic instability needs a little more time

13.55 Beam to 6, steered into start of dump line

14.05 Beam to left of 6. Lost. Investigating.

14.25 Problem understood. Beam to right of 5. 20 shots for CMS.

14.40 Beam round to 3 (after one correction in 4). Few corrections.

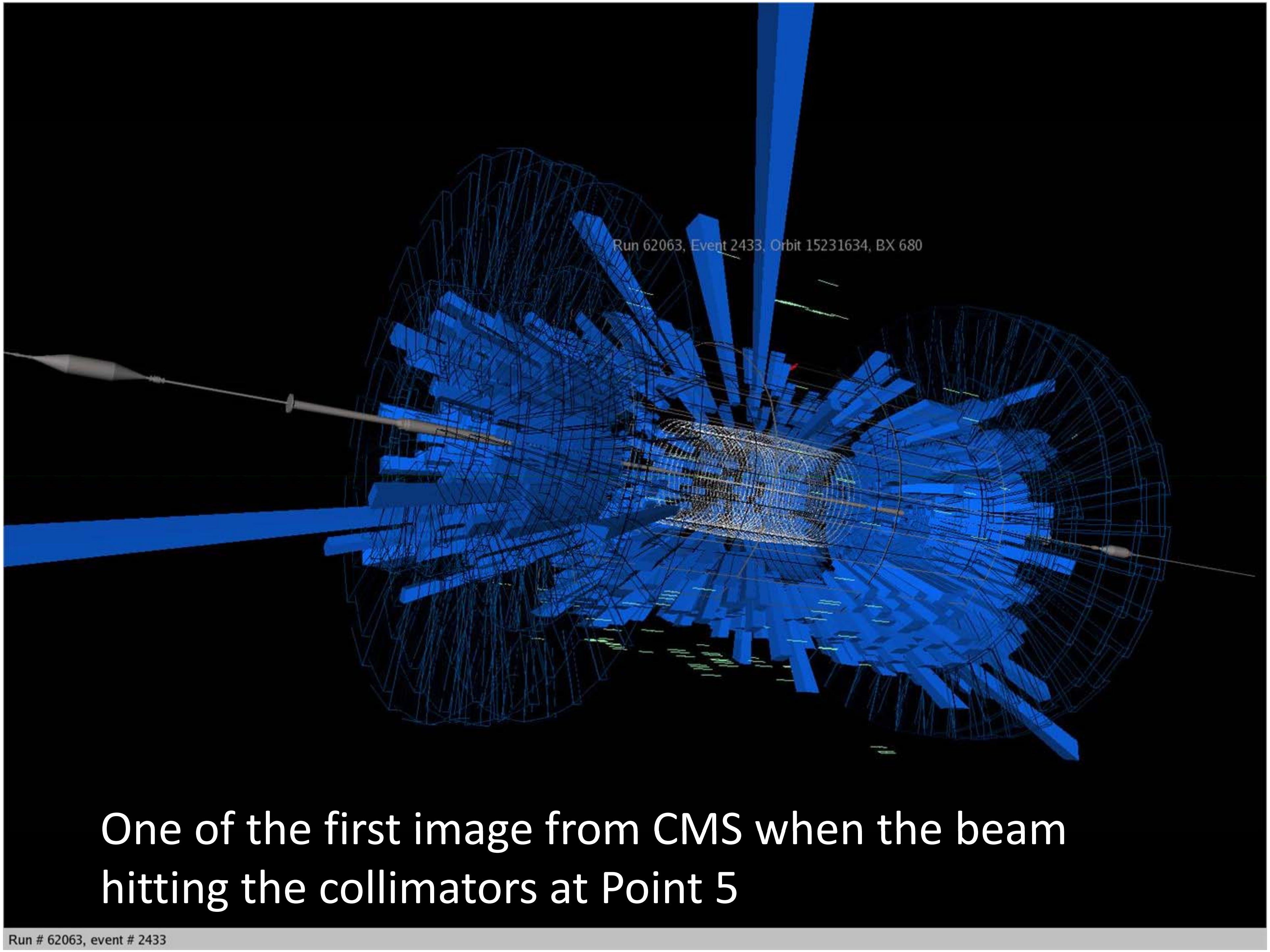
14.45 Beam to ALICE.

14.50 Beam to ATLAS. Few shots for them.

Few minutes no beam. Reboot for screen server.

15.00 Beam > 1 turn

beam 2 around the ring in 1 .5 hours; longer than beam 1
(no beam, corr. problem pt 6, shots for CMS, ALICE & ATLAS)



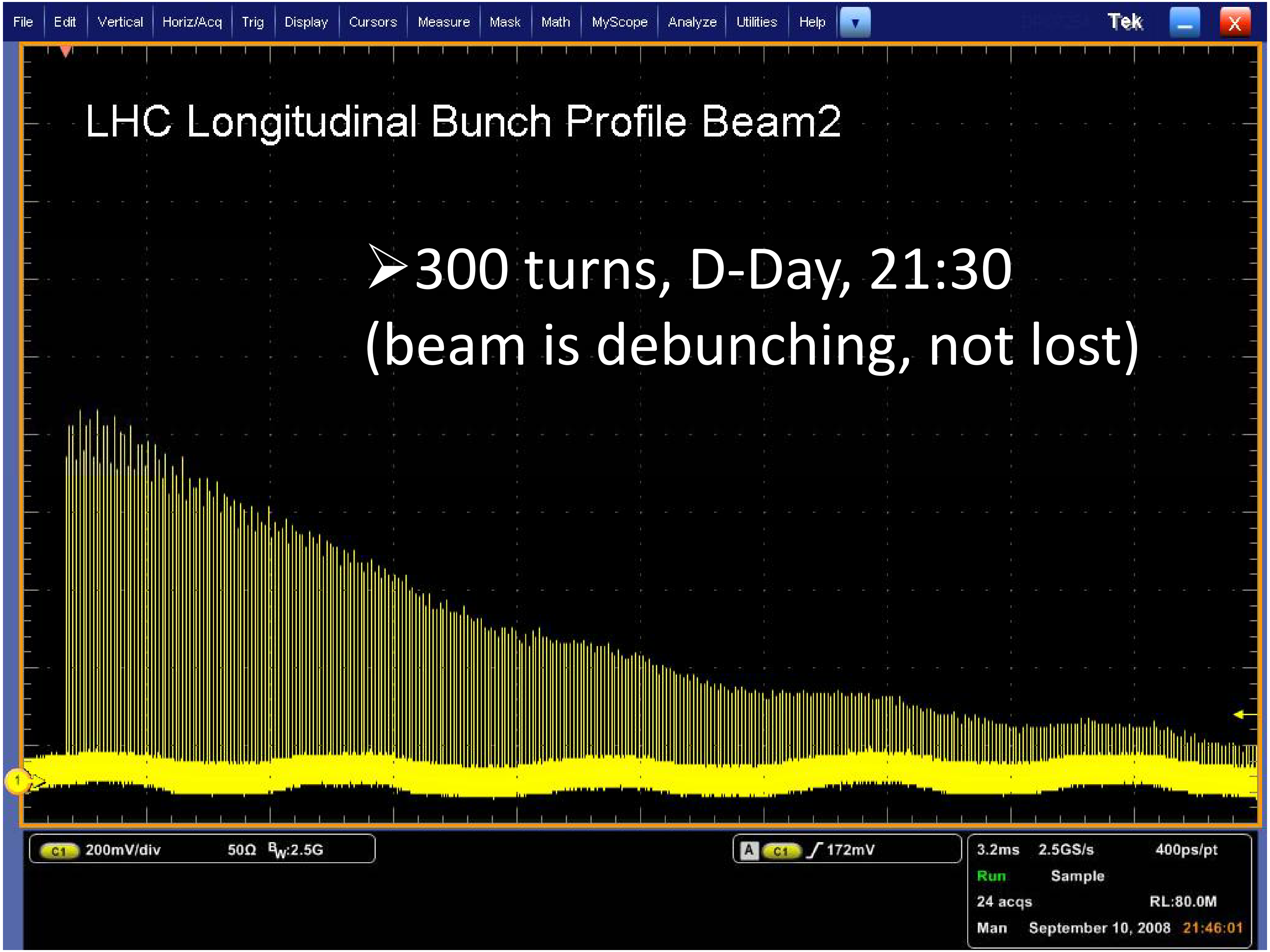
One of the first image from CMS when the beam hitting the collimators at Point 5

M. Lamont

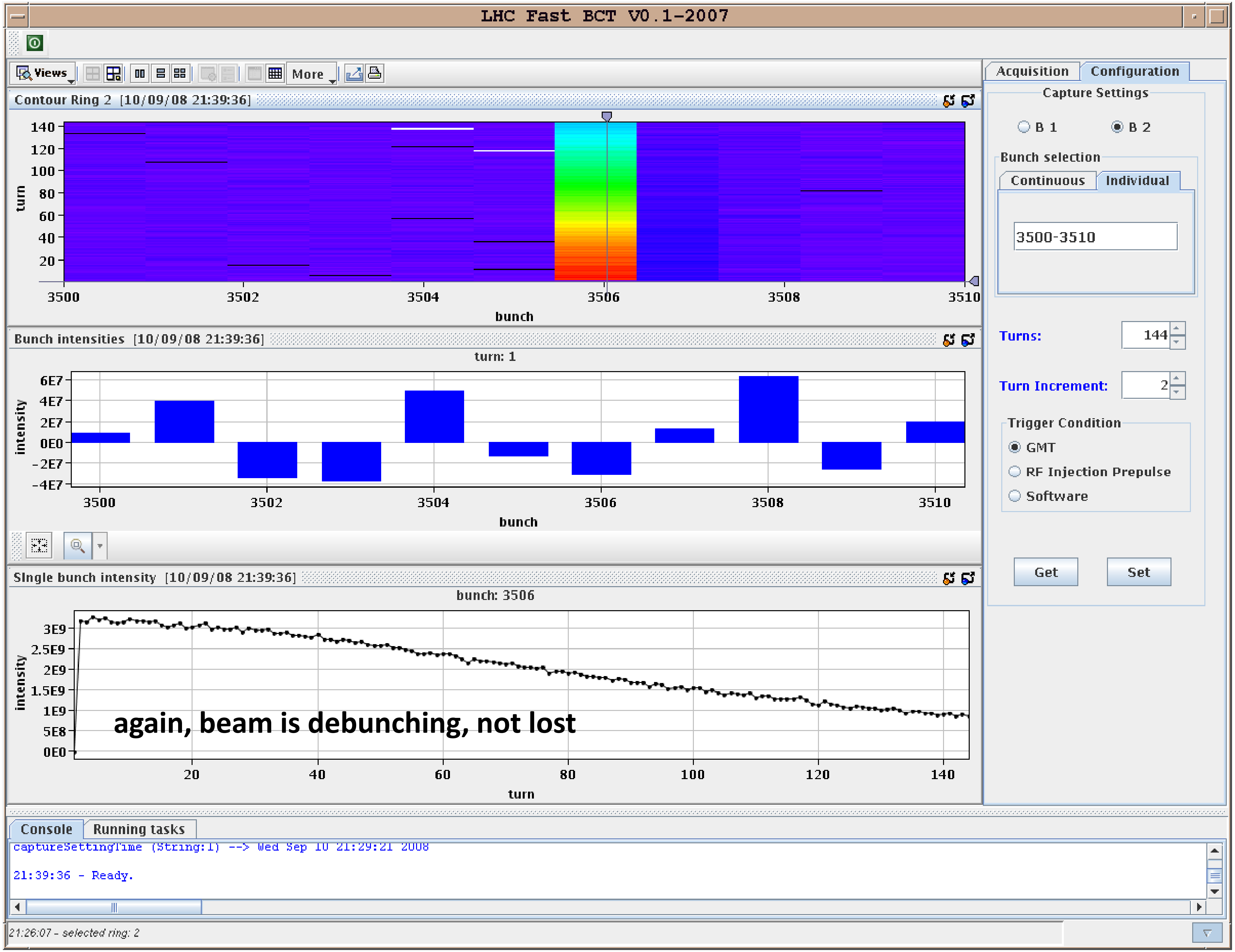
“D-Day” evening

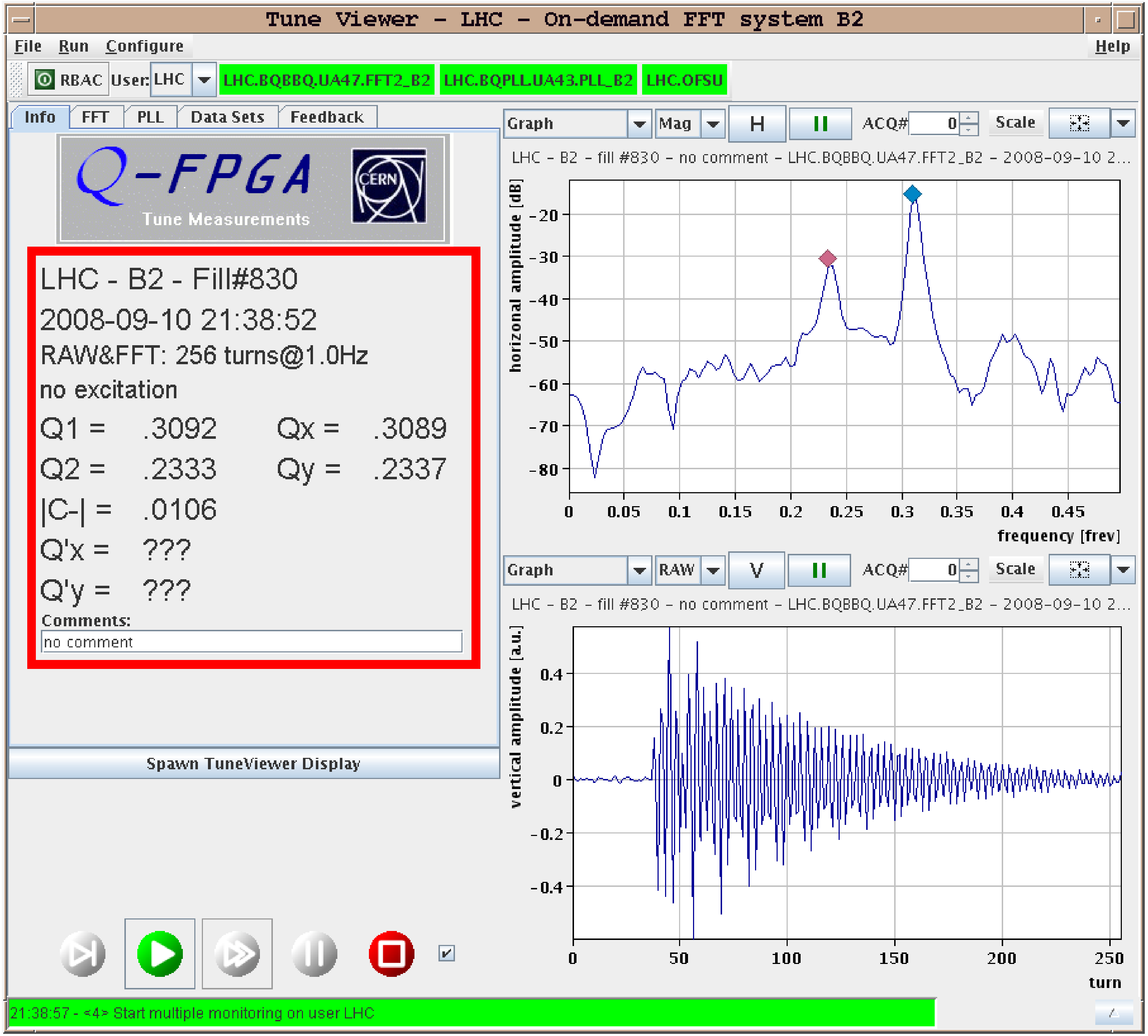
16.00 Beam 2 to collimators ATLAS
Dispersion data
Kick response data
In parallel BI looking at BPM acquisition for >1 turn

18.00 Inject and dump commissioning (all collimators out)
Inject and dump up to 9 turns OK.
20.00 BPM acquisition for multiple turns sorted out
Trimming Qh, Qv, Q'
21.30 Beam 2 makes at least 300 turns!
Fast BCT data and tune measurements - Qh .31 Qv .23
23.00 Start systematic polarity checks of orbit correctors



File
Edit
Vertical
Horiz/Acq
Trig
Display
Cursors
Measure
Mask
Math
MyScope
Analyze
Utilities
Help
Tek
LHC Longitudinal Bunch Profile Beam2
➢300 turns, D-Day, 21:30
(beam is debunching, not lost)
C1 200mV/div
50Ω B_W:2.5G
A C1 172mV
3.2ms 2.5GS/s 400ps/pt
Run Sample
24 acqs RL:80.0M
Man September 10, 2008 21:46:01


LHC Fast BCT V0.1-2007
Views
More
Contour Ring 2 [10/09/08 21:39:36]
turn
bunch
Bunch intensities [10/09/08 21:39:36]
turn: 1
intensity
bunch
SIngle bunch intensity [10/09/08 21:39:36]
bunch: 3506
intensity
turn
again, beam is debunching, not lost
Acquisition
Configuration
Capture Settings
B 1
B 2
Bunch selection
Continuous
Individual
3500-3510
Turns:
144
Turn Increment:
2
Trigger Condition
GMT
RF Injection Prepulse
Software
Get
Set
Console
Running tasks
captureSettingTime (String:1) --> Wed Sep 10 21:29:21 2008
21:39:36 - Ready.
21:26:07 - selected ring: 2



Tune Viewer - LHC - On-demand FFT system B2
File Run Configure
Help
RBAC User: LHC
LHC.BQBBQ.UA47.FFT2_B2
LHC.BQPLL.UA43.PLL_B2
LHC.OFSU
Info FFT PLL Data Sets Feedback
Q-FPGA
Tune Measurements
CERN
LHC - B2 - Fill#830
2008-09-10 21:38:52
RAW&FFT: 256 turns@1.0Hz
no excitation
Q1 = .3092 Qx = .3089
Q2 = .2333 Qy = .2337
|C-| = .0106
Q'x = ???
Q'y = ???
Comments:
no comment
Spawn TuneViewer Display
Graph Mag H ACQ# 0 Scale
LHC - B2 - fill #830 - no comment - LHC.BQBBQ.UA47.FFT2_B2 - 2008-09-10 2...
horizonal amplitude [dB]
frequency [frev]
Graph RAW V ACQ# 0 Scale
LHC - B2 - fill #830 - no comment - LHC.BQBBQ.UA47.FFT2_B2 - 2008-09-10 2...
vertical amplitude [a.u.]
turn
21:38:57 - <4> Start multiple monitoring on user LHC

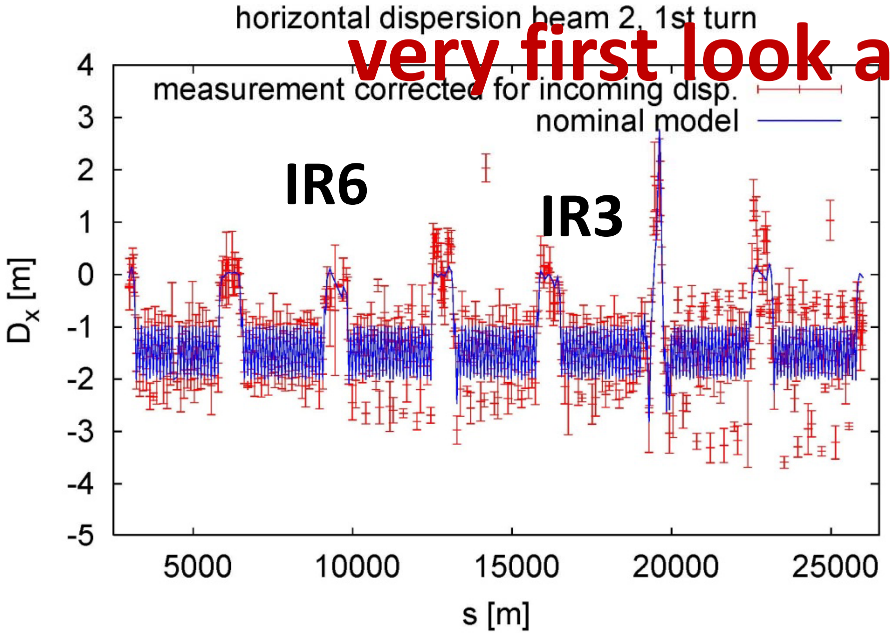
J. Wenninger

other findings from “D-Day”

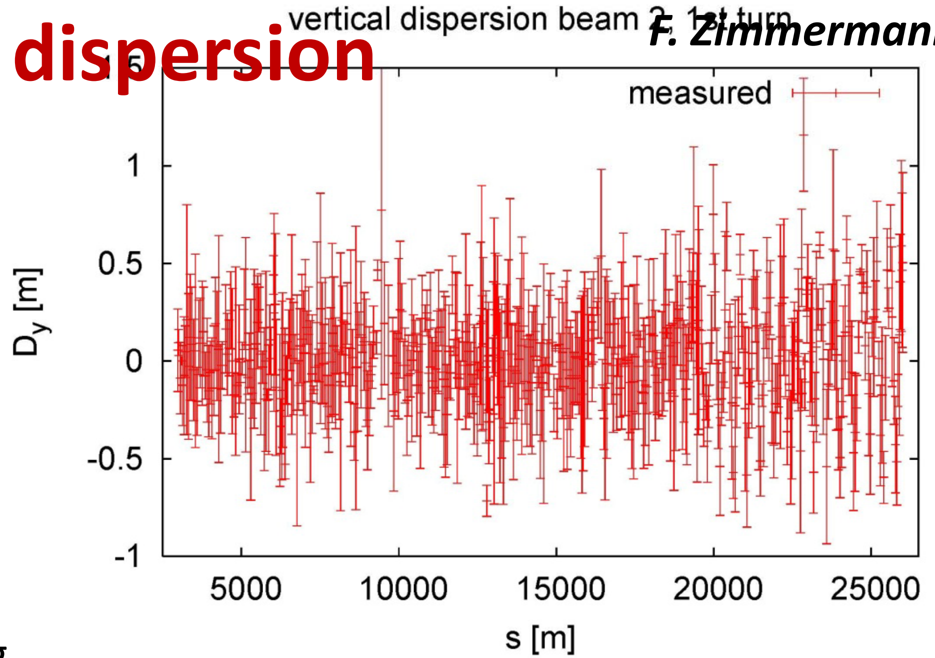
- **rms orbit < 1.5 mm rms**, for beam 2 in both planes
  < 1mm with 2.5 mm peak should easily be possible
  (4 mm peak is LHC design value)
- **250 of 1000 orbit correctors were tested** with beam 2 – **all** responded with **correct sign**, **and within 5%** of expectation
- tunes set to 0.4, 0.2-0.3 in vertical
  tune trims of order 0.4 in vertical, less horizontally
- chromaticity yet to be measured (cannot be too bad; from detuning)
- a little bit of coupling
- BPMs work, FBCT work, screens work, BLMs work,…
- **energy of both beams within 1 per mill of SPS**
- **<15 mm error in circumference w.r.t. design for beam 2**

very first look at dispersion

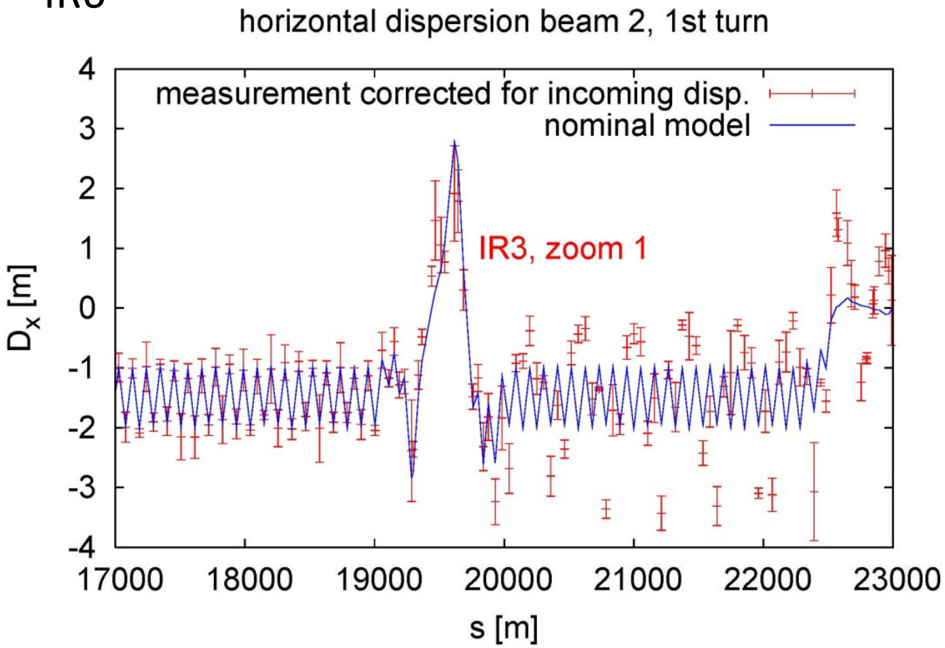
F. Zimmermann

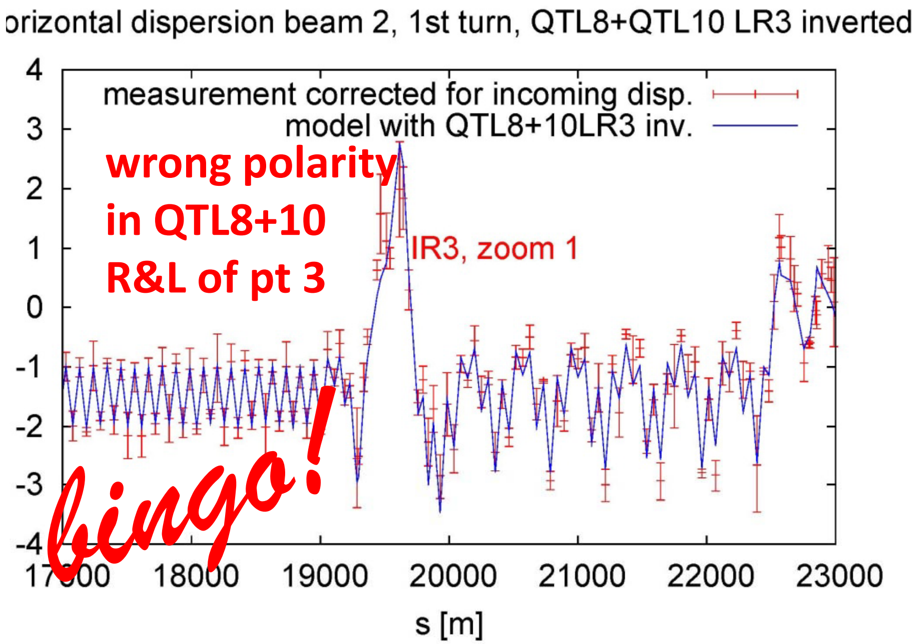


“ring dispersion” after correcting for incoming dispersion oscillation; error in IR3 and perhaps IR6



vertical dispersion ~zero within noise





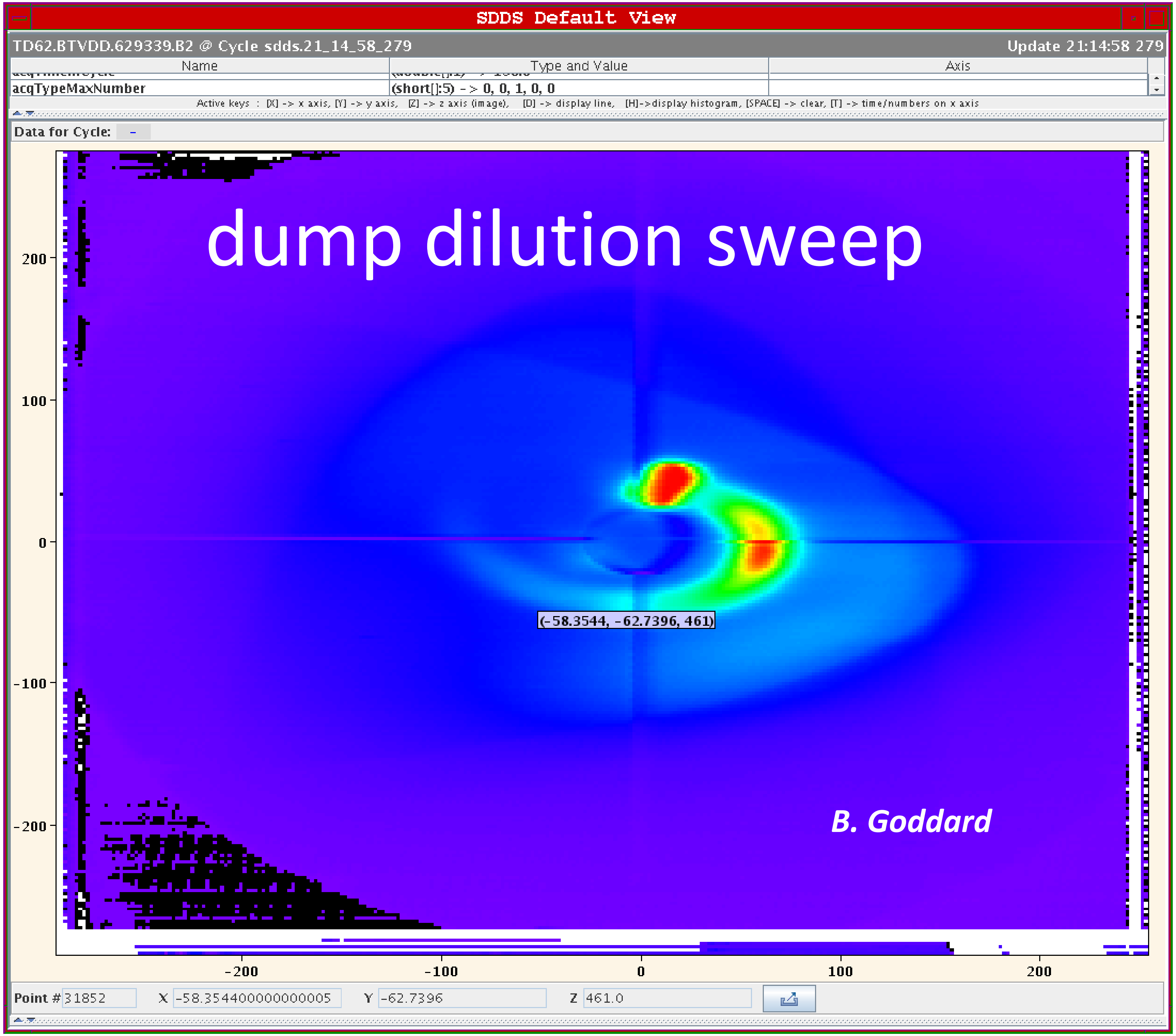
Thursday & Friday, 11-12 Sept.'08

R. Bailey

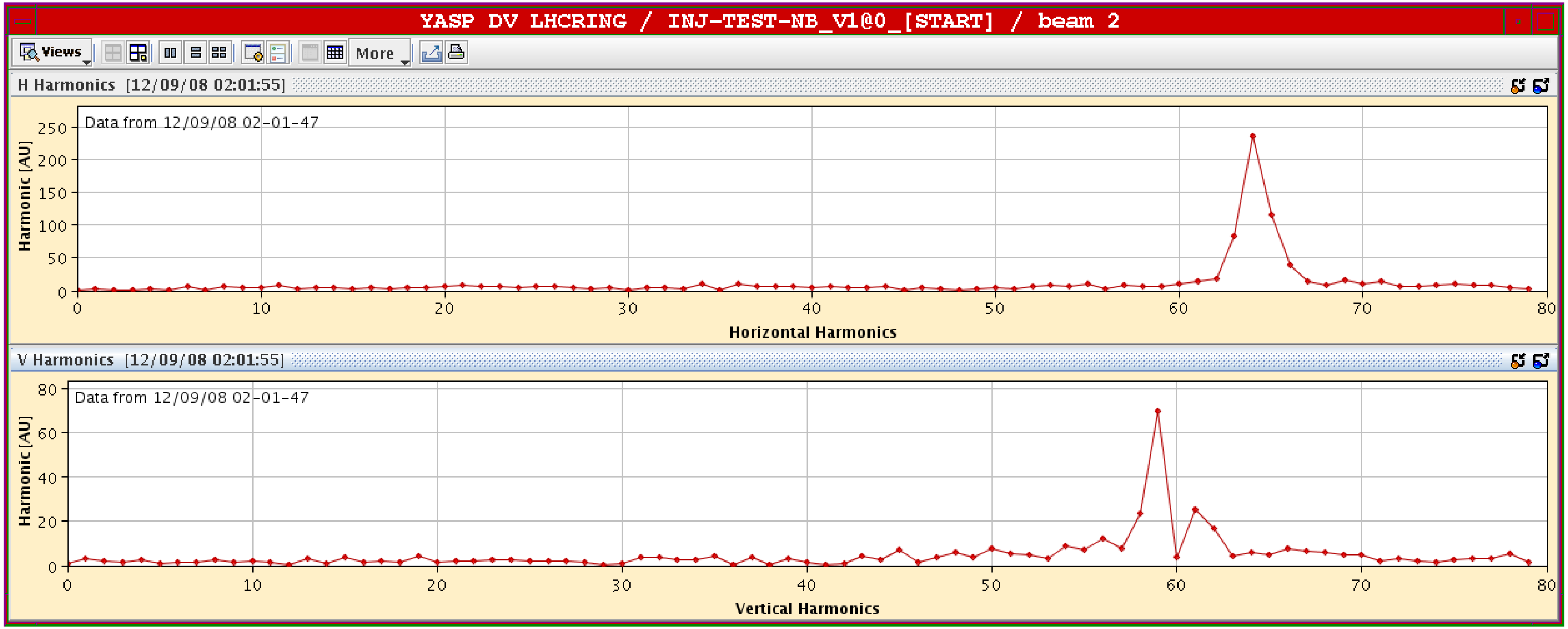
"Inject and dump"
"Circulate and dump after 50 ms"
"Circulate - dump request"
RF capture working – for beam 2 !
Integer tunes OK
Longitudinal pickup & mountain range display working
Systematic polarity checks

Circulating beam
Beta-beat measurement
Wire scan H and V works

Friday ~23:30 high-V transformer fault in pt 8


SDDS Default View
TD62.BTVDD.629339.B2 @ Cycle sdds.21_14_58_279
Update 21:14:58 279
Name
Type and Value
Axis
acqTypeMaxNumber
(short[]:5) -> 0, 0, 1, 0, 0
Active keys : [X] -> x axis, [Y] -> y axis, [Z] -> z axis (image), [D] -> display line, [H]->display histogram, [SPACE] -> clear, [T] -> time/numbers on x axis
Data for Cycle: -
dump dilution sweep
200
100
0
-100
-200
(-58.3544, -62.7396, 461)
B. Goddard
-200
-100
0
100
200
Point # 31852
X -58.354400000000005
Y -62.7396
Z 461.0

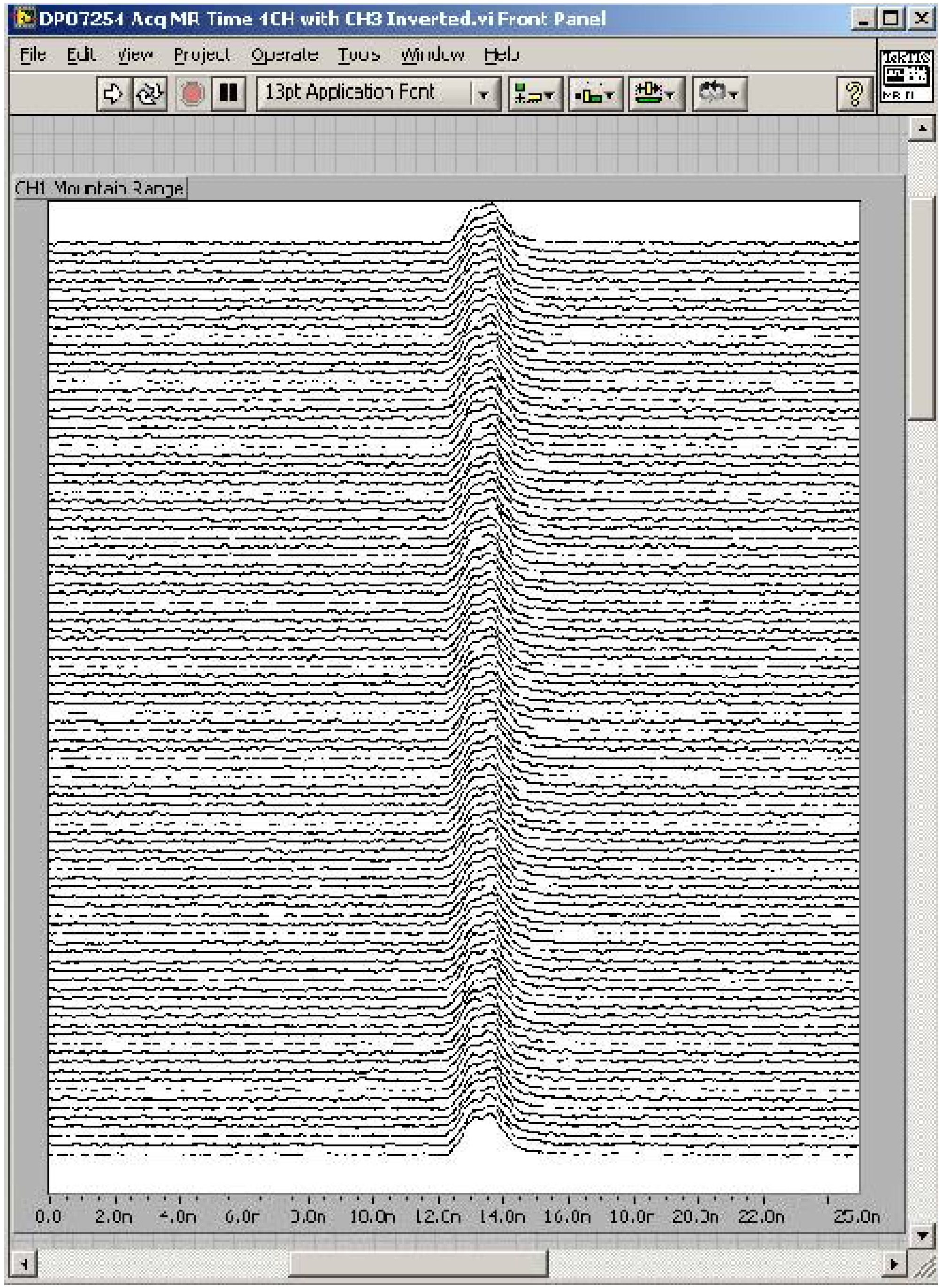
J. Wenninger



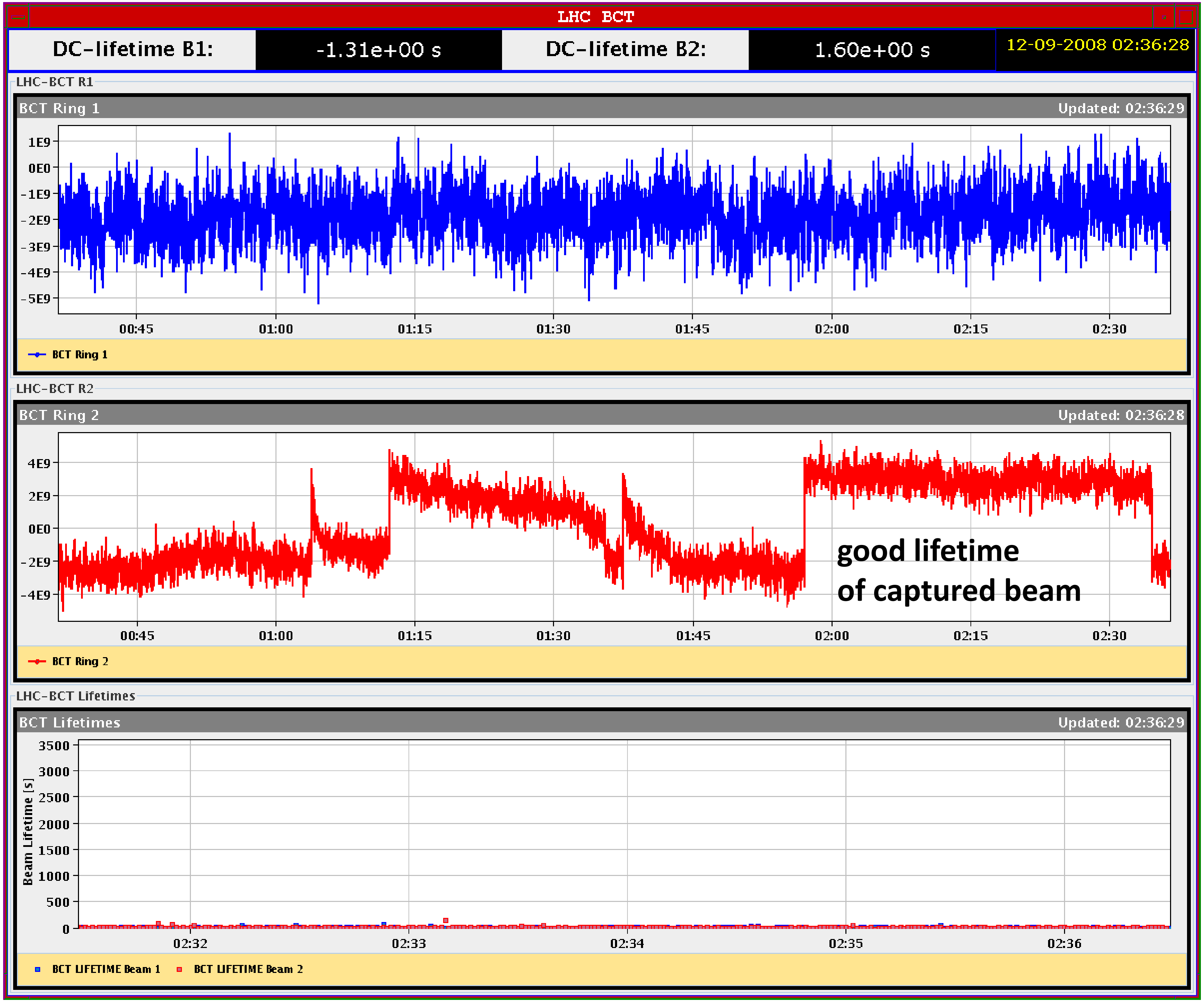
tunes 64 and 59 as design (vertical FFT has second peak!?)

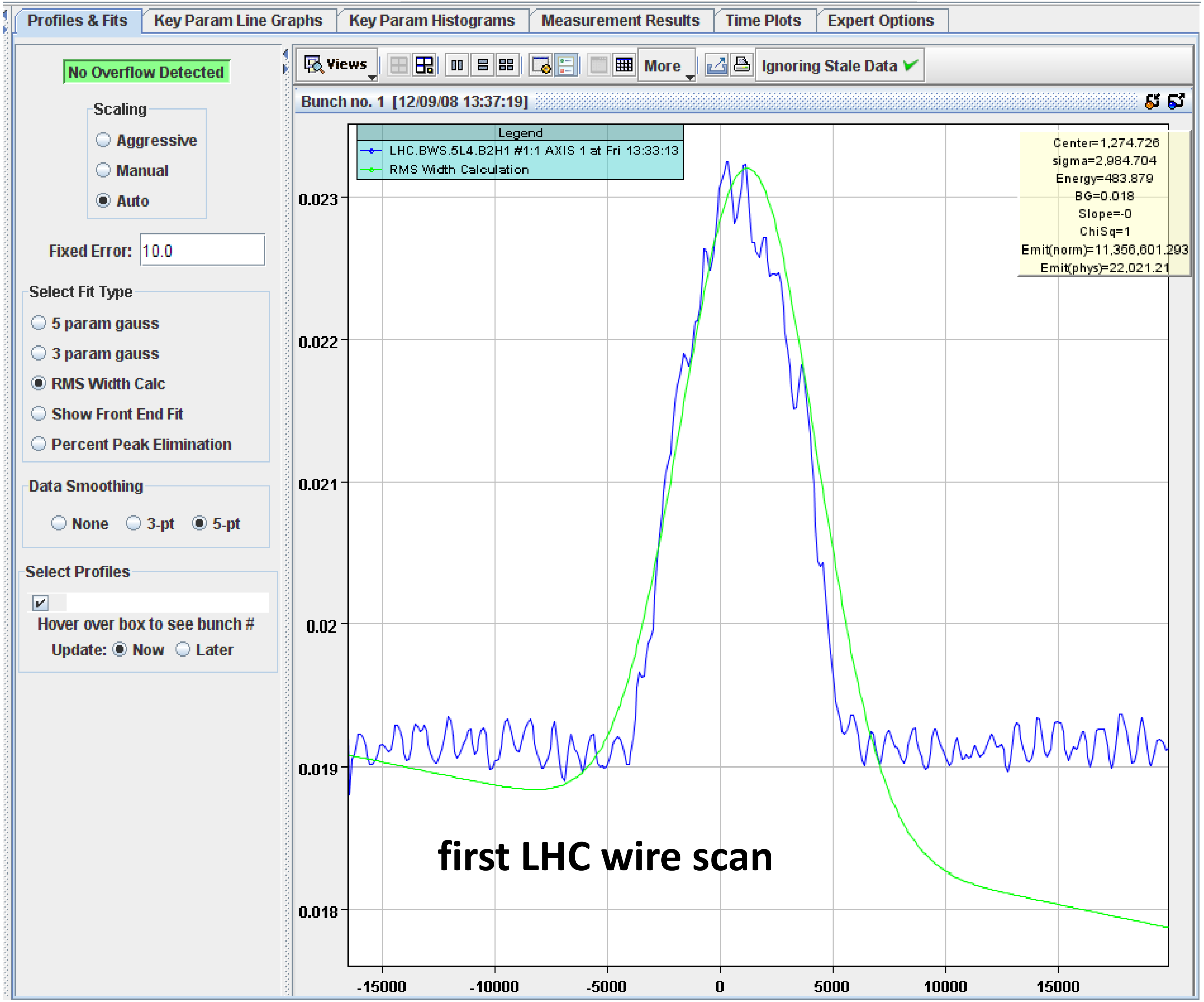
A. Butterworth, RF Group

longitudinal
mountain
range
recorded
~5 minutes
after
rf capture



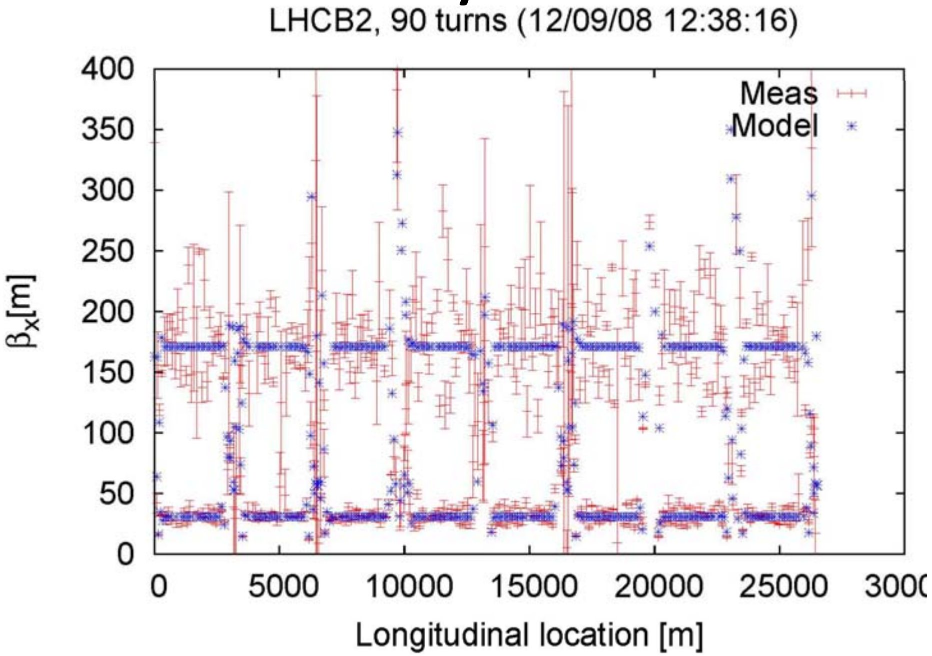
beam lifetime
~infinite
(too good to be
measured;
many hours)

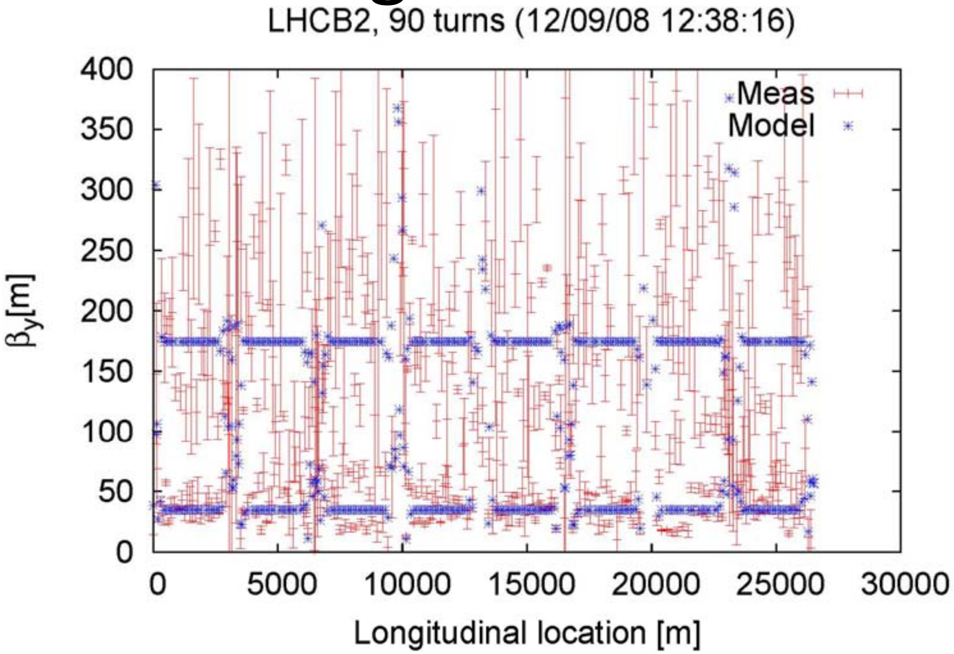

LHC BCT
DC-lifetime B1:
-1.31e+00 s
DC-lifetime B2:
1.60e+00 s
12-09-2008 02:36:28
LHC-BCT R1
BCT Ring 1
Updated: 02:36:29
BCT Ring 1
LHC-BCT R2
BCT Ring 2
Updated: 02:36:28
good lifetime
of captured beam
BCT Ring 2
LHC-BCT Lifetimes
BCT Lifetimes
Updated: 02:36:29
Beam Lifetime [s]
BCT LIFETIME Beam 1
BCT LIFETIME Beam 2



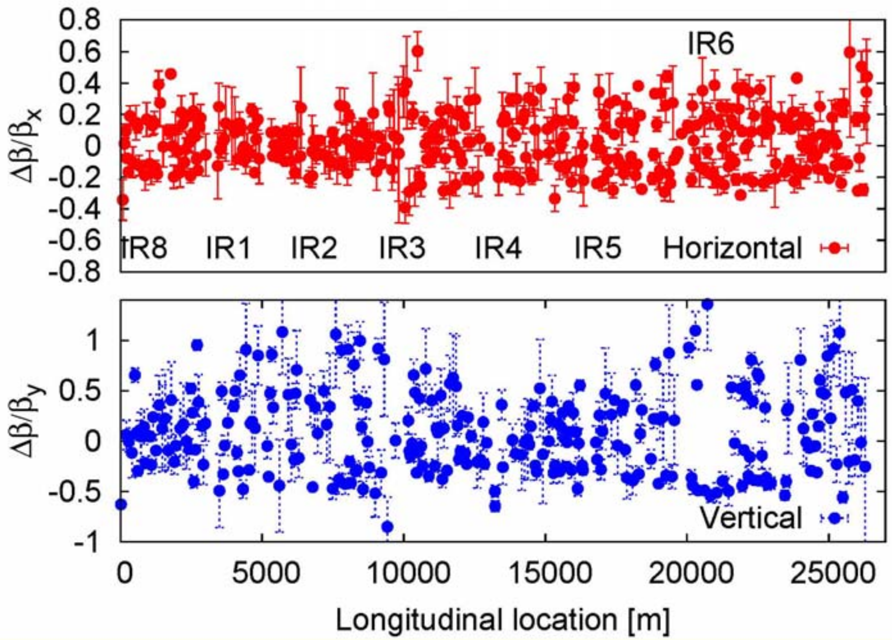
Profiles & Fits
Key Param Line Graphs
Key Param Histograms
Measurement Results
Time Plots
Expert Options
No Overflow Detected
Scaling
Aggressive
Manual
Auto
Fixed Error: 10.0
Select Fit Type
5 param gauss
3 param gauss
RMS Width Calc
Show Front End Fit
Percent Peak Elimination
Data Smoothing
None
3-pt
5-pt
Select Profiles
Hover over box to see bunch #
Update: Now Later
Views
More
Ignoring Stale Data
Bunch no. 1 [12/09/08 13:37:19]
Legend
LHC.BWS.5L4.B2H1 #1:1 AXIS 1 at Fri 13:33:13
RMS Width Calculation
Center=1,274.726
sigma=2,984.704
Energy=483.879
BG=0.018
Slope=-0
ChiSq=1
Emit(norm)=11,356,601.293
Emit(phys)=22,021.21
0.023
0.022
0.021
0.02
0.019
0.018
-15000
-10000
-5000
0
5000
10000
15000
first LHC wire scan

very first look at beat beating





data over 90 turns
taken during
vertical
orbit correction



R. Tomas, M. Aiba

commissioning so far superfast

but challenges ahead:

- ramping in energy (up to 5 TeV)
- higher intensity
- squeeze
- 7 TeV

tentative plan

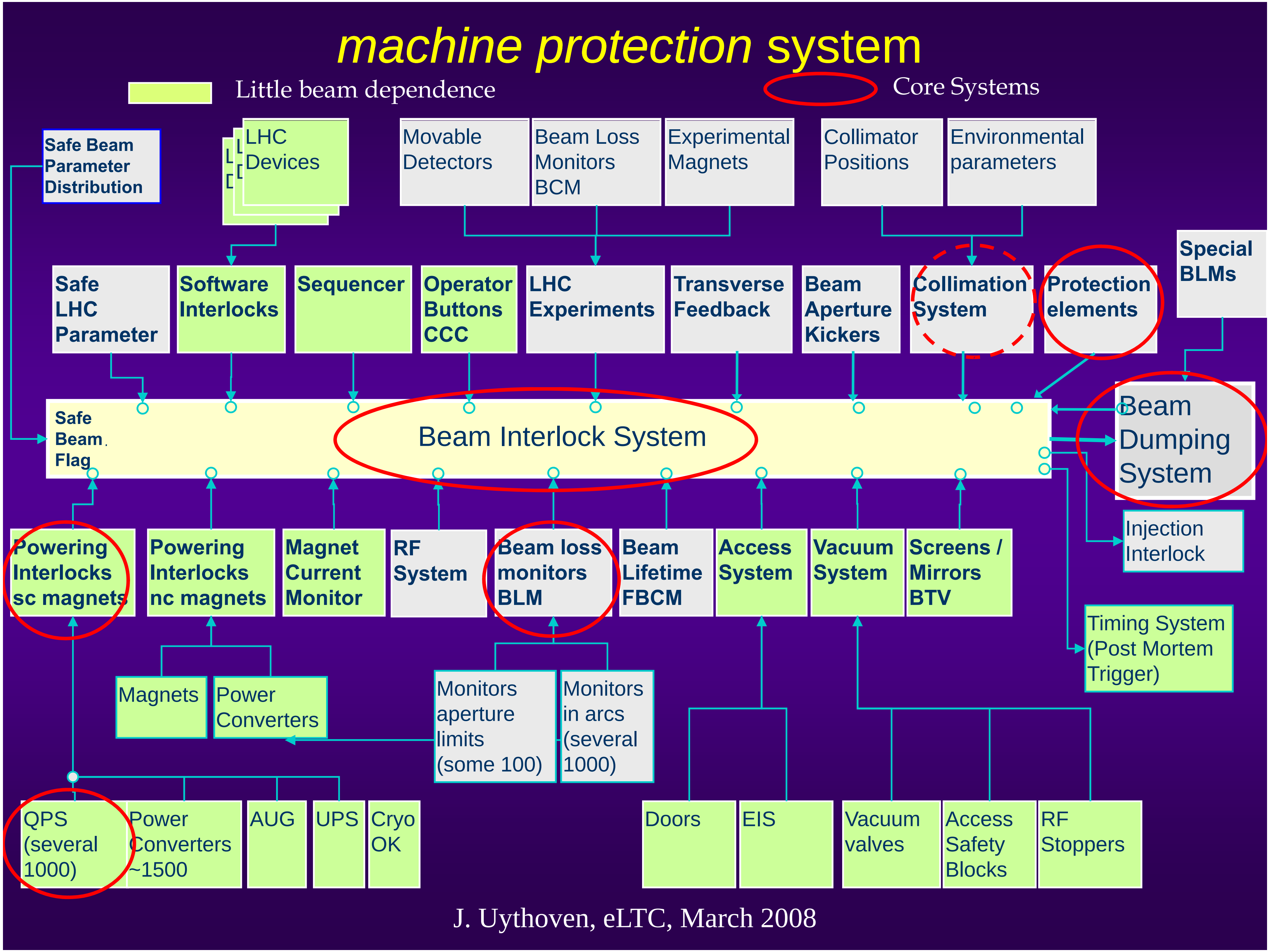
when beam is back (Thursday), continue commissioning: beam 1, rf capture, correct optics, chromaticity etc

first attempts to ramp to ~600 GeV over the weekend or during next week

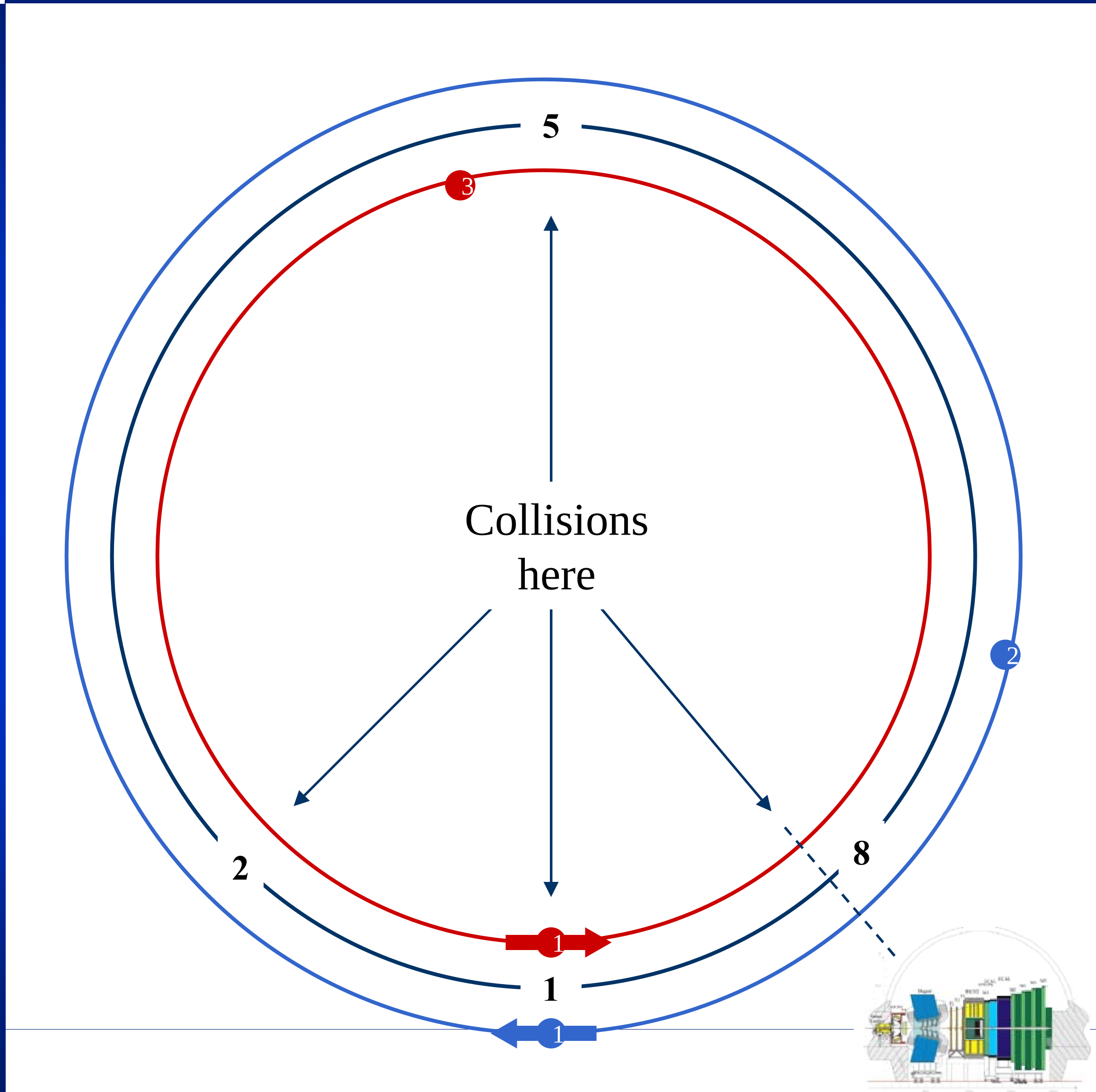
a few shifts with collisions at 450 GeV

~1 week stop to complete hardware commissioning and qualify interlock systems before going to higher intensity and/or higher energy

then ramp to 5 GeV, squeeze, and physics run through end of the year


machine protection system
Little beam dependence
Core Systems
Safe Beam Parameter Distribution
LHC Devices
Movable Detectors
Beam Loss Monitors BCM
Experimental Magnets
Collimator Positions
Environmental parameters
Special BLMs
Safe LHC Parameter
Software Interlocks
Sequencer
Operator Buttons CCC
LHC Experiments
Transverse Feedback
Beam Aperture Kickers
Collimation System
Protection elements
Safe Beam Flag
Beam Interlock System
Beam Dumping System
Injection Interlock
Timing System (Post Mortem Trigger)
Powering Interlocks sc magnets
Powering Interlocks nc magnets
Magnet Current Monitor
RF System
Beam loss monitors BLM
Beam Lifetime FBCM
Access System
Vacuum System
Screens / Mirrors BTV
Magnets
Power Converters
Monitors aperture limits (some 100)
Monitors in arcs (several 1000)
QPS (several 1000)
Power Converters ~1500
AUG
UPS
Cryo OK
Doors
EIS
Vacuum valves
Access Safety Blocks
RF Stoppers
J. Uythoven, eLTC, March 2008

First collisions – 2 on 2, clean collisions everywhere



$$L = \frac{N^2 k_b f \gamma}{4\pi \varepsilon_n \beta^*} F$$

4 10^{10} per bunch
450 GeV 11m
~ 10^{27} cm^{-2} s^{-1}

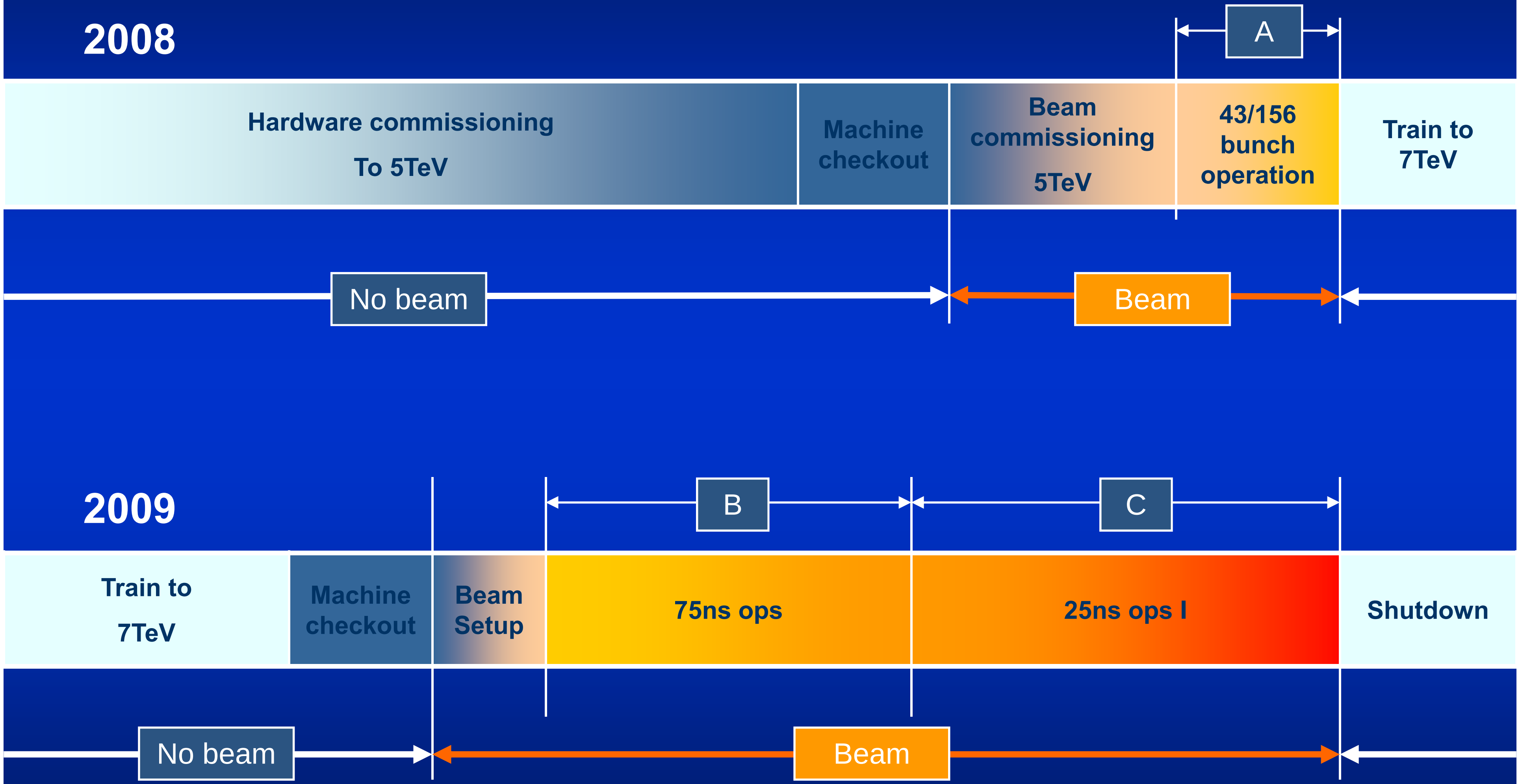
ATLAS sees 11
CMS sees 11
ALICE sees 32
LHCb sees 12

Beam - gas
Both beams

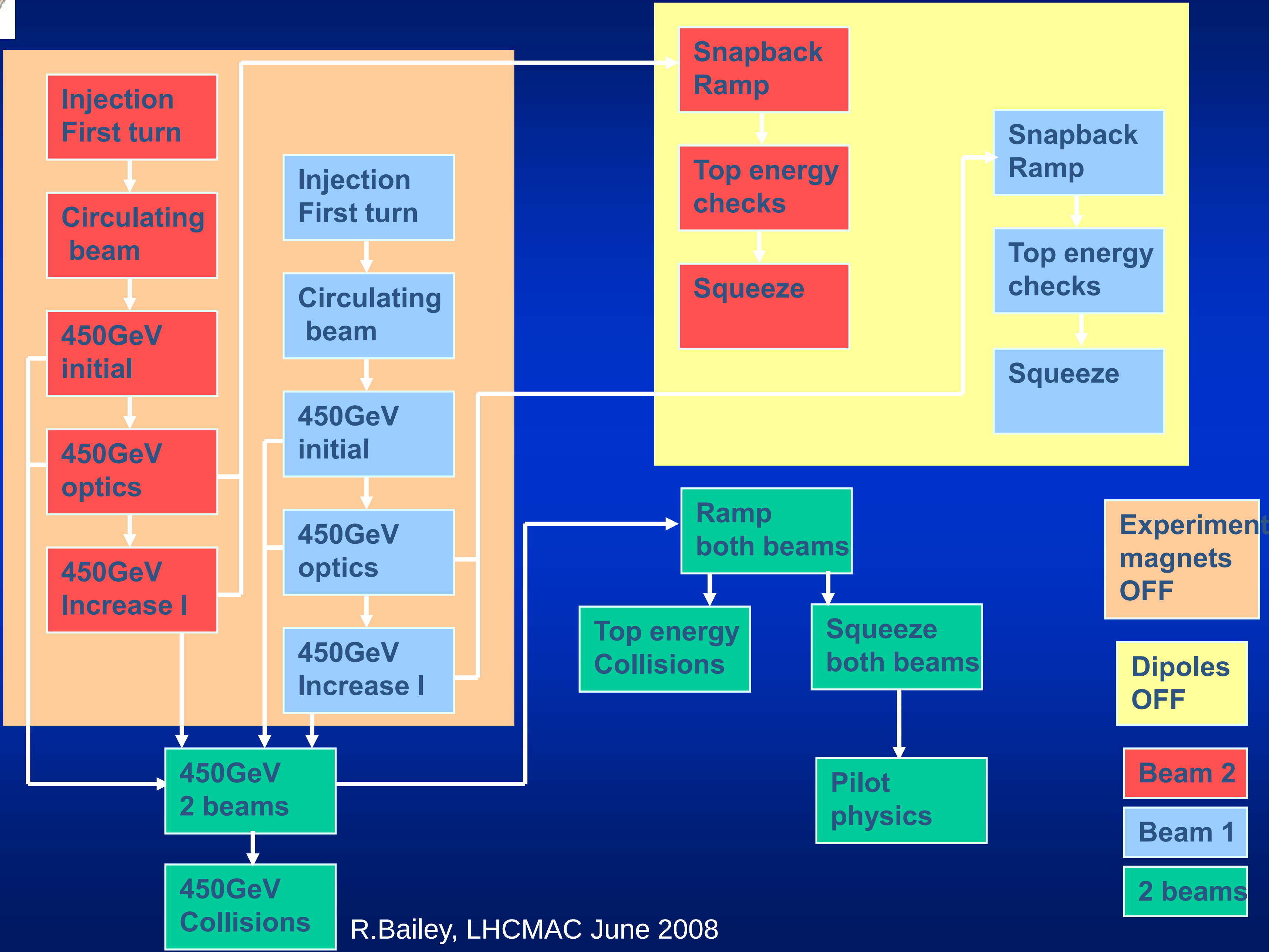
lower commissioning energy ~5 TeV

- no quenches up to 5 TeV (based on SM18 & S45)
- quench recovery much faster below 9 kA (~5 TeV) magnet current
- saving in powering tests (200-300 A sufficient for most 600 A circuits)
- beam operation easier at 5 TeV (magnets much farther away from quench limit)

Strategy for 2008 and 2009



Stage A: routes through the commissioning phases



R.Bailey, LHCMAC June 2008

Stage A: 5TeV collisions

$$L = \frac{N^2 k_b f \gamma}{4\pi \varepsilon_n \beta^*} F$$

$$Eventrate / Cross = \frac{L \sigma_{TOT}}{k_b f}$$

- Approx 30 days of beam to establish first collisions
- Approx 2 months elapsed
  - Given optimistic machine availability
  - Un-squeezed
  - Low intensity
- Continue commissioning thereafter
  - Increased intensity
  - Squeeze

Parameters			Rates in 1 and 5	
k_b	N	β* 1,5 (m)	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing
1 (3)	10^{10}	11	$1.1\ 10^{27}$	<< 1
4	10^{10}	11	$4.5\ 10^{27}$	<< 1
43	10^{10}	11	$5.0\ 10^{28}$	<< 1
43	$4\ 10^{10}$	11	$8.0\ 10^{29}$	<< 1
43	$4\ 10^{10}$	3	$2.9\ 10^{30}$	0.36
156	$4\ 10^{10}$	3	$1.0\ 10^{31}$	0.36
156	$9\ 10^{10}$	3	$5.4\ 10^{31}$	1.8

Parameter evolution and rates

$$L = \frac{N^2 k_b f \gamma}{4\pi \varepsilon_n \beta^*} F$$

$$Eventrate / Cross = \frac{L \sigma_{TOT}}{k_b f}$$

All values for nominal emittance, 10m β* in points 2 and 8

All values for 936 or 2808 bunches colliding in 2 and 8 (not quite right)

	Parameters			Beam levels		Rates in 1 and 5		Rates in 2 and 8	
	k_b	N	β* 1,5 (m)	I_{beam} proton	E_{beam} (MJ)	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing
5 TeV	43	$4\ 10^{10}$	11	$1.7\ 10^{12}$	1.4	$8.0\ 10^{29}$	<< 1	Depend on the configuration of collision pattern	
5 TeV	43	$4\ 10^{10}$	3	$1.7\ 10^{12}$	1.4	$2.9\ 10^{30}$	0.36		
5 TeV	156	$4\ 10^{10}$	3	$6.2\ 10^{12}$	5	$1.0\ 10^{31}$	0.36		
5 TeV	156	$9\ 10^{10}$	3	$1.4\ 10^{13}$	11	$5.4\ 10^{31}$	1.8		
7 TeV	936	$4\ 10^{10}$	11	$3.7\ 10^{13}$	42	$2.4\ 10^{31}$	<< 1	$2.6\ 10^{31}$	0.15
7 TeV	936	$4\ 10^{10}$	2	$3.7\ 10^{13}$	42	$1.3\ 10^{32}$	0.73	$2.6\ 10^{31}$	0.15
7 TeV	936	$6\ 10^{10}$	2	$5.6\ 10^{13}$	63	$2.9\ 10^{32}$	1.6	$6.0\ 10^{31}$	0.34
7 TeV	936	$9\ 10^{10}$	1	$8.4\ 10^{13}$	94	$1.2\ 10^{33}$	7	$1.3\ 10^{32}$	0.76
7 TeV	2808	$4\ 10^{10}$	11	$1.1\ 10^{14}$	126	$7.2\ 10^{31}$	<< 1	$7.9\ 10^{31}$	0.15
7 TeV	2808	$4\ 10^{10}$	2	$1.1\ 10^{14}$	126	$3.8\ 10^{32}$	0.72	$7.9\ 10^{31}$	0.15
7 TeV	2808	$5\ 10^{10}$	1	$1.4\ 10^{14}$	157	$1.1\ 10^{33}$	2.1	$1.2\ 10^{32}$	0.24
7 TeV	2808	$5\ 10^{10}$	0.55	$1.4\ 10^{14}$	157	$1.9\ 10^{33}$	3.6	$1.2\ 10^{32}$	0.24

Configuration of collision pattern

- 25ns and 75ns operation
  - Nothing to do
  - Collisions determined by bunch pattern
- 43 or 156 bunch operation
  - Can optimise according to needs
  - Previously thought to displace bunches in one beam (asym)
  - Can do better (symmetrically displace bunches in both beams)
  - Allows to adjust luminosity sharing between 2 and 8 while keeping maximum number of collisions in 1 and 5

	75ns	25ns
IP 1	936	2808
IP 2	912	2736
IP 5	936	2808
IP 8	874	2622

Displaced	0	4 asym	4 sym	11 sym	19 sym	0	36 sym	68 sym
IP 1	43	39	43	43	43	156	156	156
IP 2	42	38	34	21	4	152	76	16
IP 5	43	39	43	43	43	156	156	156
IP 8	0	4	4	11	19	0	36	68

LHC Upgrade

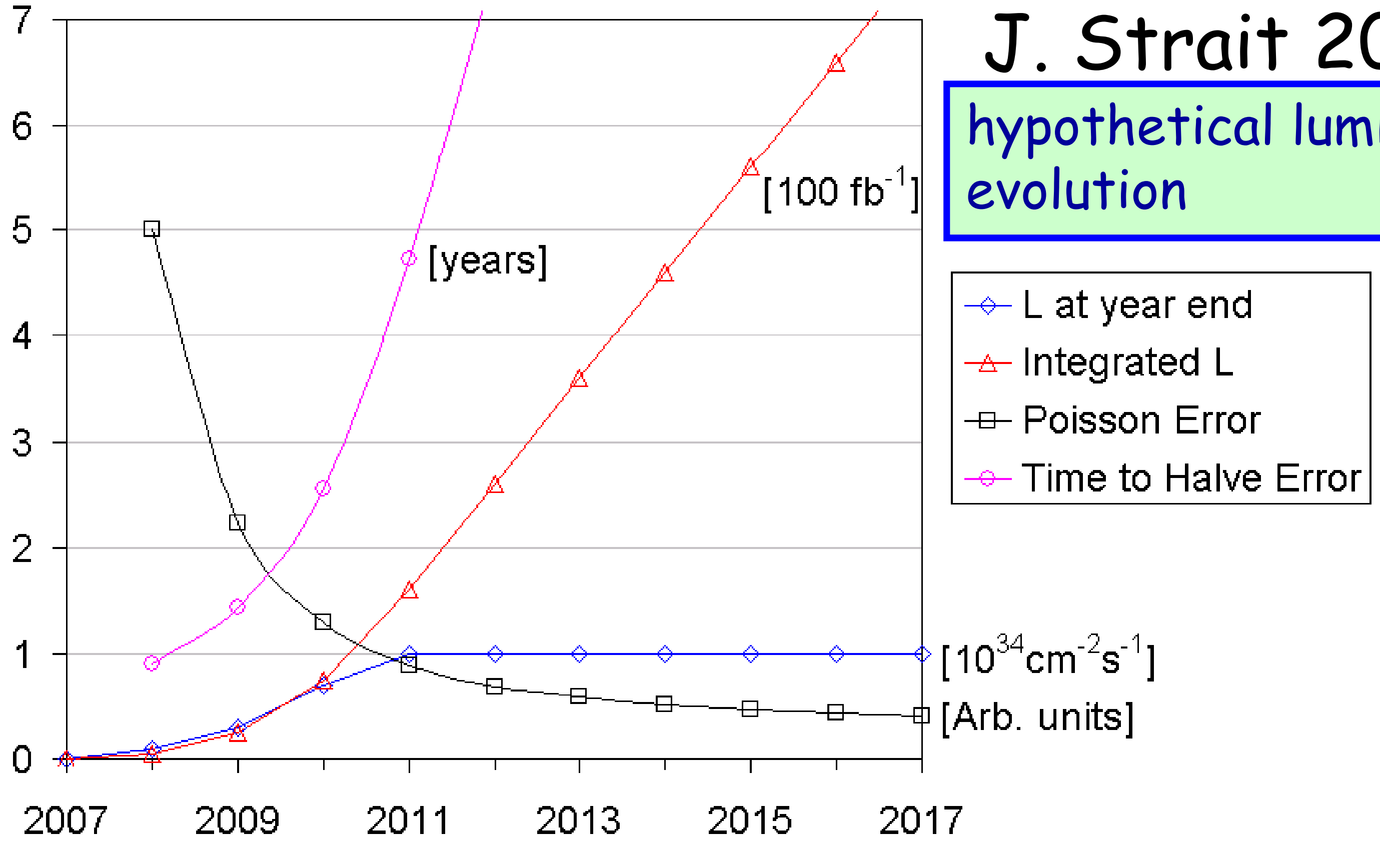
Unlike the Tevatron or LEP, the LHC already has all the attributes to go very quickly to design luminosity .

It is reasonably to assume that the machine will reach 10^{34} cm^{-2} s^{-1} on a 5-year timescale.

It is therefore necessary to plan an upgrade path <u>now</u> in order to be able to open the door to a factor of 4-5 improvement on the same timescale.

Lyn Evans, LHC-MAC, June 2008

Two 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***!

staged approach to LHC upgrade

"phase-1" 2013:

new triplets, D1, TAS, $\beta^*=0.25$ 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 & $\beta^*\sim0.15$ m

complementary measures 2010-2017:

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

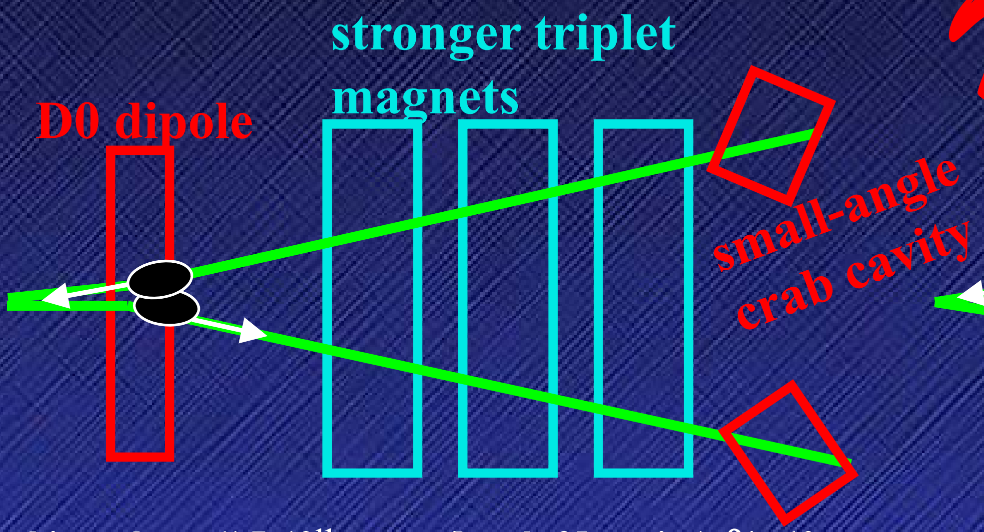
phase-2 might be just phase-1 plus complementary measures

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

LHC upgrade paths for IP1 & 5

early separation (ES)

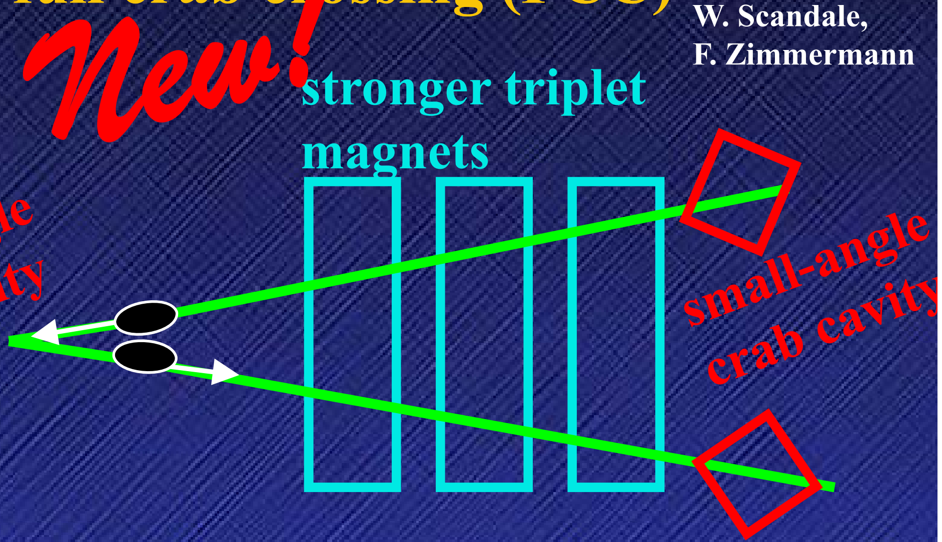
J.-P. Koutchouk



- ultimate beam (1.7x10^{11} protons/bunch, 25 spacing), β* ~10 cm
- early-separation dipoles in side detectors , crab cavities
  → hardware inside ATLAS & CMS detectors,
  first hadron crab cavities; off-δ β

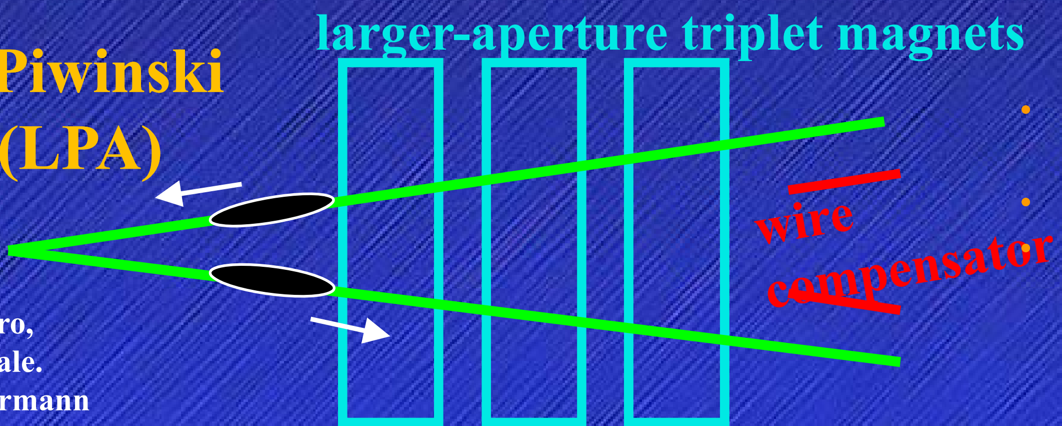
full crab crossing (FCC)

L. Evans,
W. Scandale,
F. Zimmermann



- ultimate LHC beam (1.7x10^{11} protons/bunch, 25 spacing)
- β* ~10 cm
- crab cavities with 60% higher voltage
  → first hadron crab cavities, off-δ β-beat

large Piwinski angle (LPA)



- 50 ns spacing, longer & more intense bunches (5x10^{11} protons/bunch)
- β*~25 cm, no elements inside detectors
- long-range beam-beam wire compensation
  → novel operating regime for hadron colliders, beam generation

F. Ruggiero,
W. Scandale.
F. Zimmermann

parameter	symbol	nominal	ultimate	Early Sep.	Full Crab Xing	L. Piw Angle
transverse emittance	ε [μm]	3.75	3.75	3.75	3.75	3.75
protons per bunch	N_b [10^{11}]	1.15	1.7	1.7	1.7	4.9
bunch spacing	Δt [ns]	25	25	25	25	50
beam current	I [A]	0.58	0.86	0.86	0.86	1.22
longitudinal profile		Gauss	Gauss	Gauss	Gauss	Flat
rms bunch length	σ_z [cm]	7.55	7.55	7.55	7.55	11.8
beta* at IP1&5	β* [m]	0.55	0.5	0.08	0.08	0.25
full crossing angle	θ_c [μrad]	285	315	0	0	381
Piwinski parameter	$\phi=\theta_c\sigma_z/(2*\sigma_x*)$	0.64	0.75	0	0	2.0
hourglass reduction		1.0	1.0	0.86	0.86	0.99
peak luminosity	L [10^{34} $cm^{-2}s^{-1}$]	1	2.3	15.5	15.5	10.7
peak events per #ing		19	44	294	294	403
initial lumi lifetime	τ_L [h]	22	14	2.2	2.2	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
	$T_{run,opt}$ [h]	21.2	17.0	6.6	6.6	9.5
effective luminosity ($T_{turnaround}$=5 h)	L_{eff}[10^{34} $cm^{-2}s^{-1}$]	0.56	1.15	3.6	3.6	3.5
	$T_{run,opt}$ [h]	15.0	12.0	4.6	4.6	6.7
e-c heat SEY=1.4(1.3)	P [W/m]	1.07 (0.44)	1.04 (0.59)	1.04 (0.59)	1.04 (0.59)	0.36 (0.1)
SR heat load 4.6-20 K	P_{SR} [W/m]	0.17	0.25	0.25	0.25	0.36
image current heat	P_{IC} [W/m]	0.15	0.33	0.33	0.33	0.78
gas-s. 100 h (10 h) τ_b	P_{gas} [W/m]	0.04 (0.38)	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	5.3
comment		nominal	ultimate	D0 + crab	crab	wire comp.

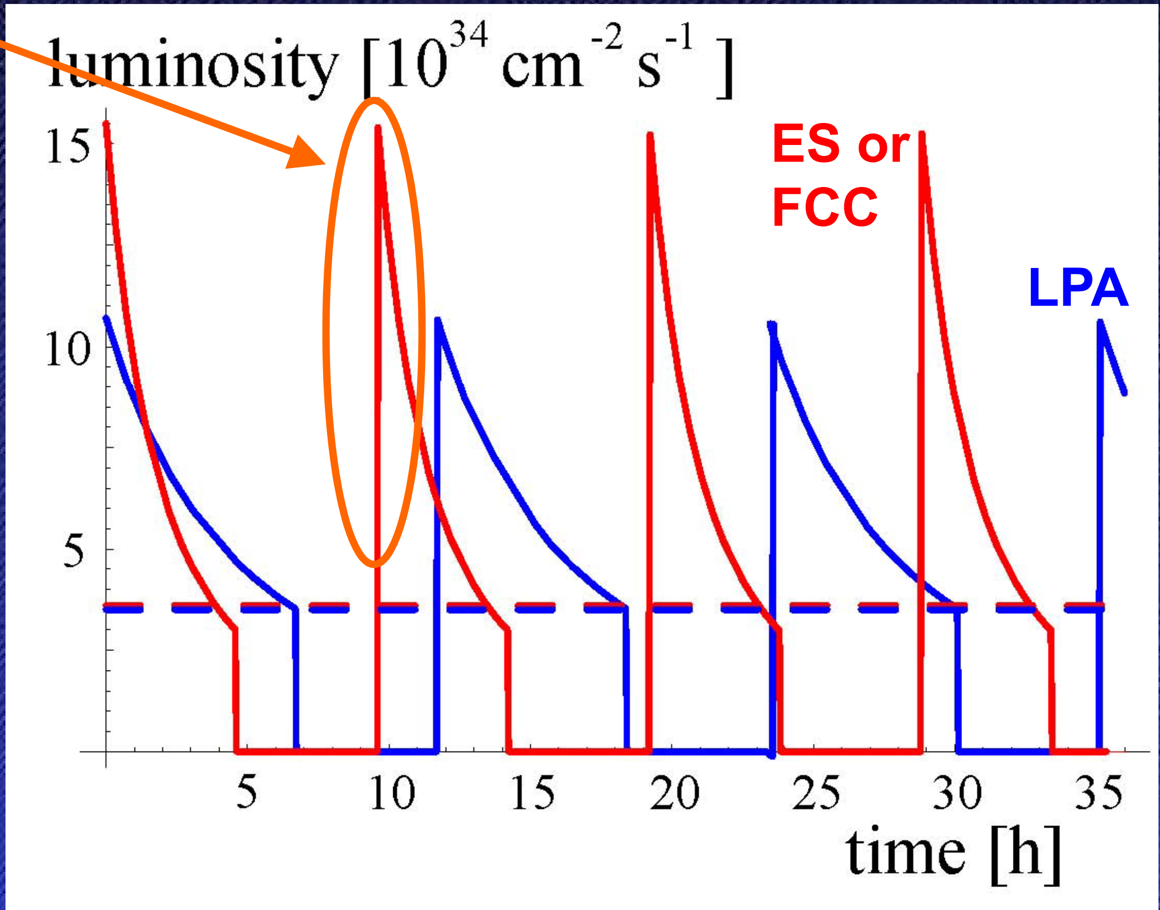
early separation (ES)

full crab crossing (FCC)

large Piwinski angle (LPA)

luminosity leveling

initial luminosity peak may not be useful for physics (set up & tuning?)



average luminosity

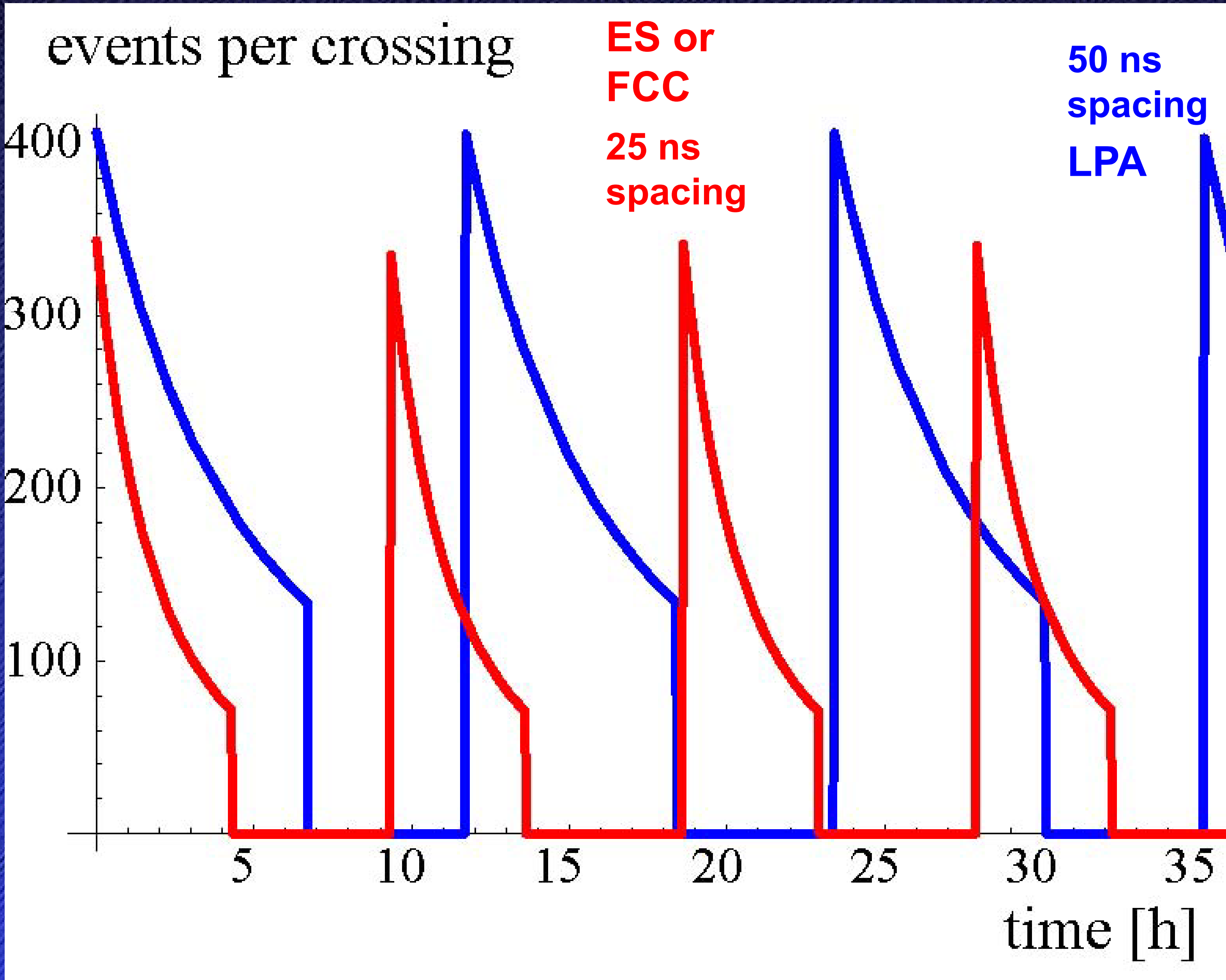
experiments prefer ~constant luminosity, less pile up at start of run, higher luminosity at end

how can we achieve this?

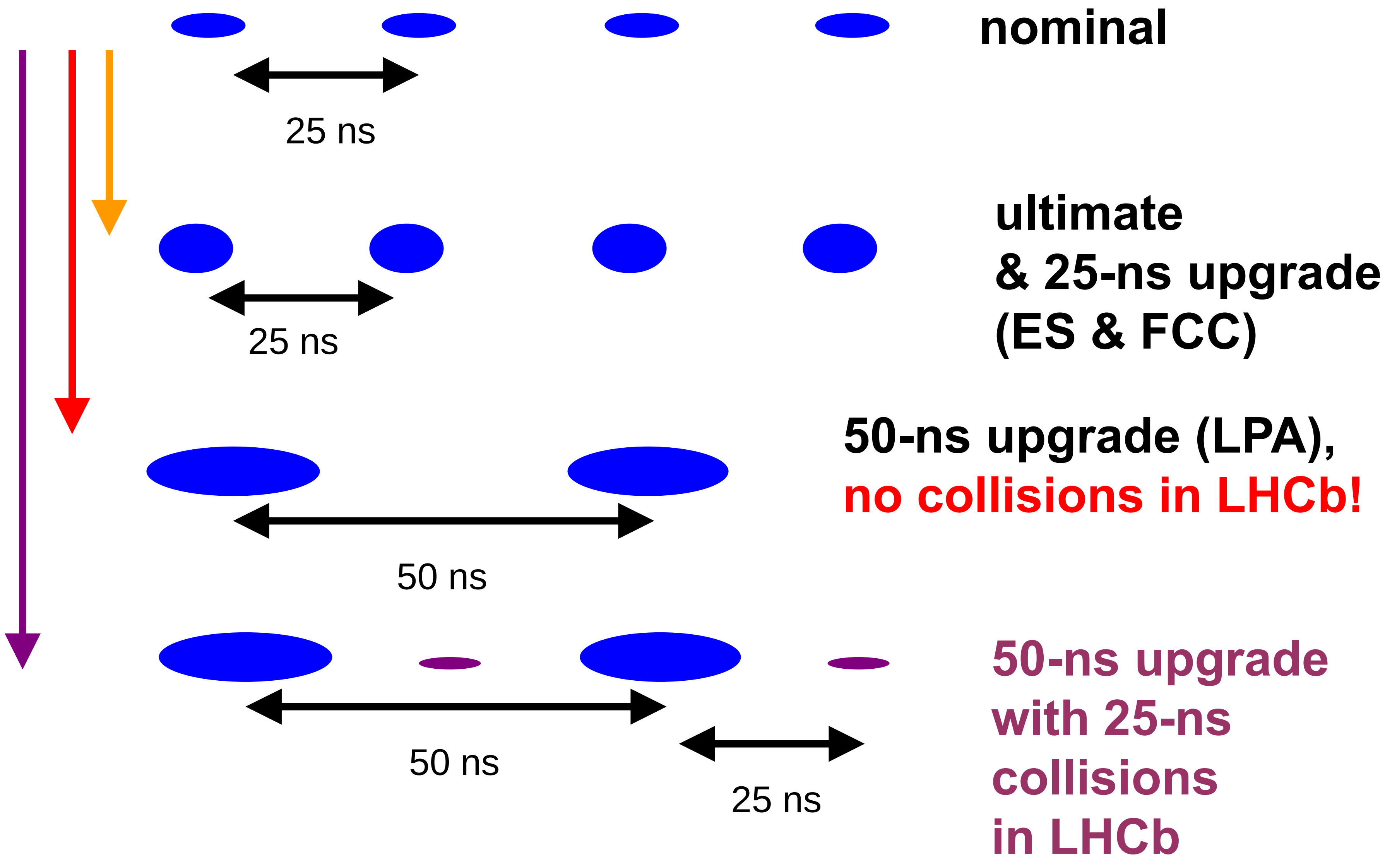
<u>ES or FCC:</u> dynamic β squeeze, or dynamic θ change (either IP angle bumps or <u>varying crab voltage</u>)

<u>LPA:</u> dynamic β squeeze, or dynamic change of bunch length

IP1& 5 event pile up for 25 & 50-ns spacing w/o leveling



upgrade bunch structures



experimenters' choice (LHCC July 2008)

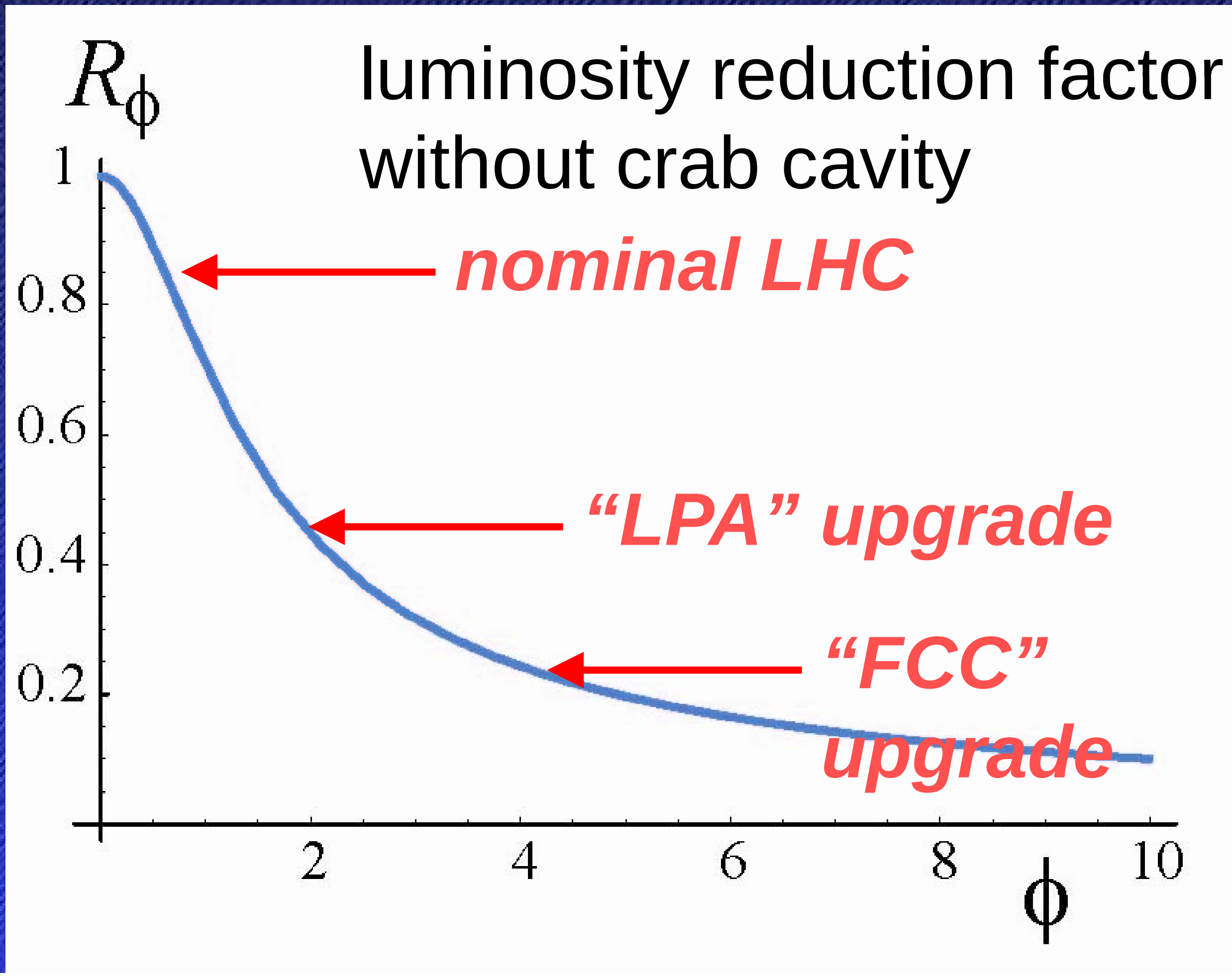
- ✓ no accelerator components inside detector
- ✓ lowest possible event pile up
- ✓ possibility of easy luminosity levelling

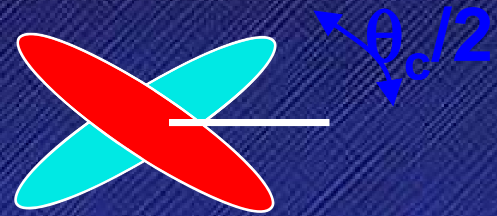
→ **full crab crossing upgrade** *New!*

crab cavity motivation →HHH→

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

"Piwinski angle"





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

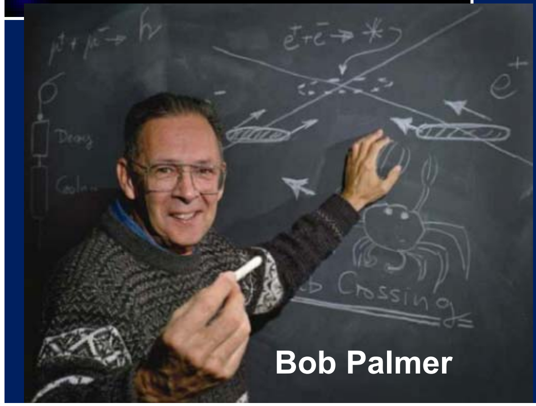
CARE-HHH

LHC Crab Cavity Validation

Mini-Workshop, 21 August 2008

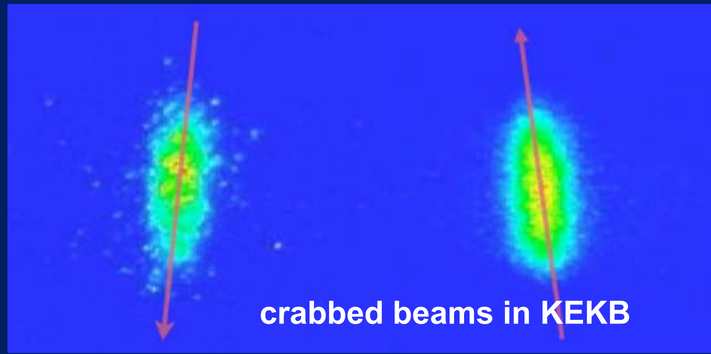
HHH

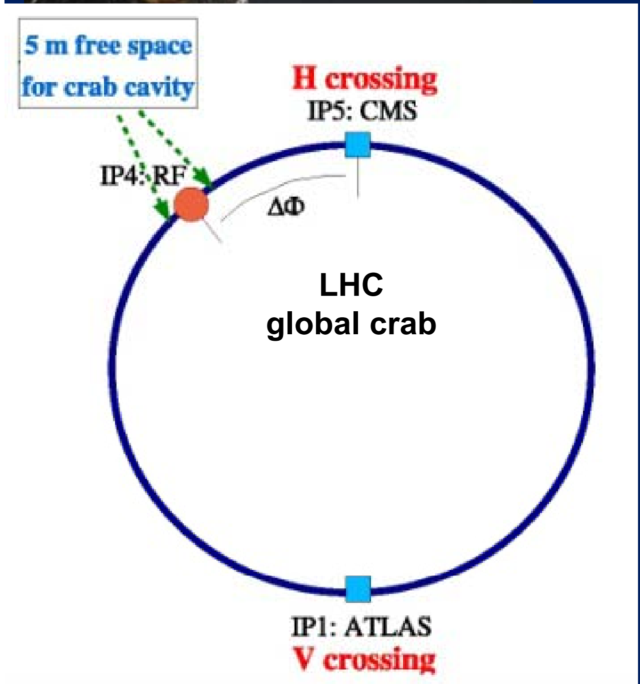
New!

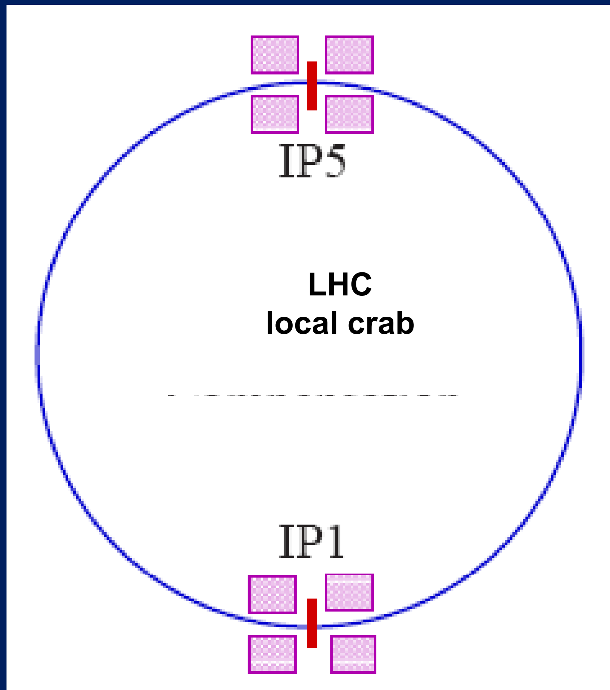


invention 1988

first use in operating ring collider 2007







- KEKB experience
- R&D plan
- phased approach:

(1) prototype

(2) “global” crab cavity test in IR4,

(3) “local” crab cavities in IR1 & 5

- EuCARD, US-LARP & international collaboration

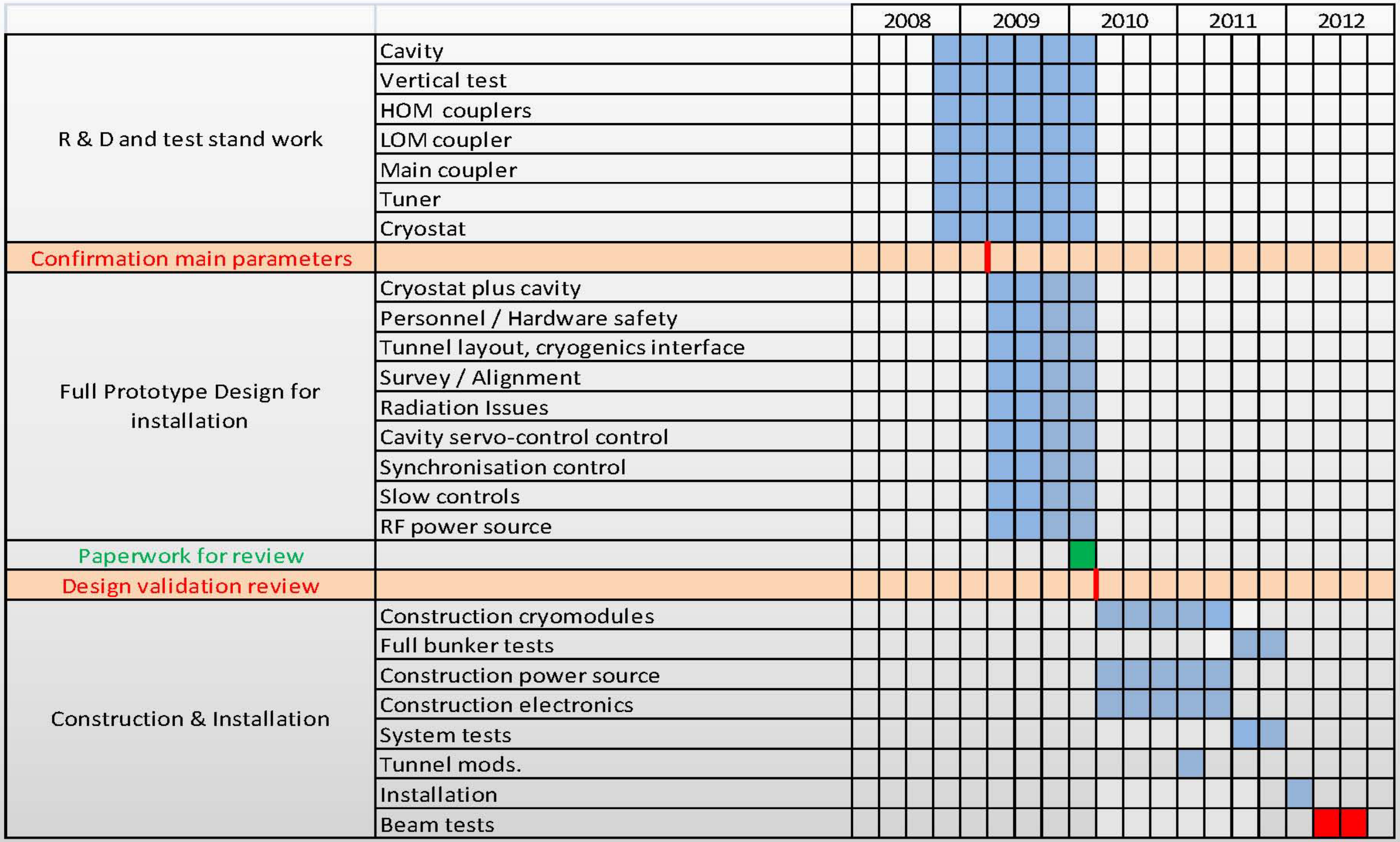
global & local schemes considered for LHC

tentative schedule for crab-cavity prototype & first beam tests

HHH → New!

Schedule

T. Linnecar, HHH Crab-Cavity Validation Workshop August 2008



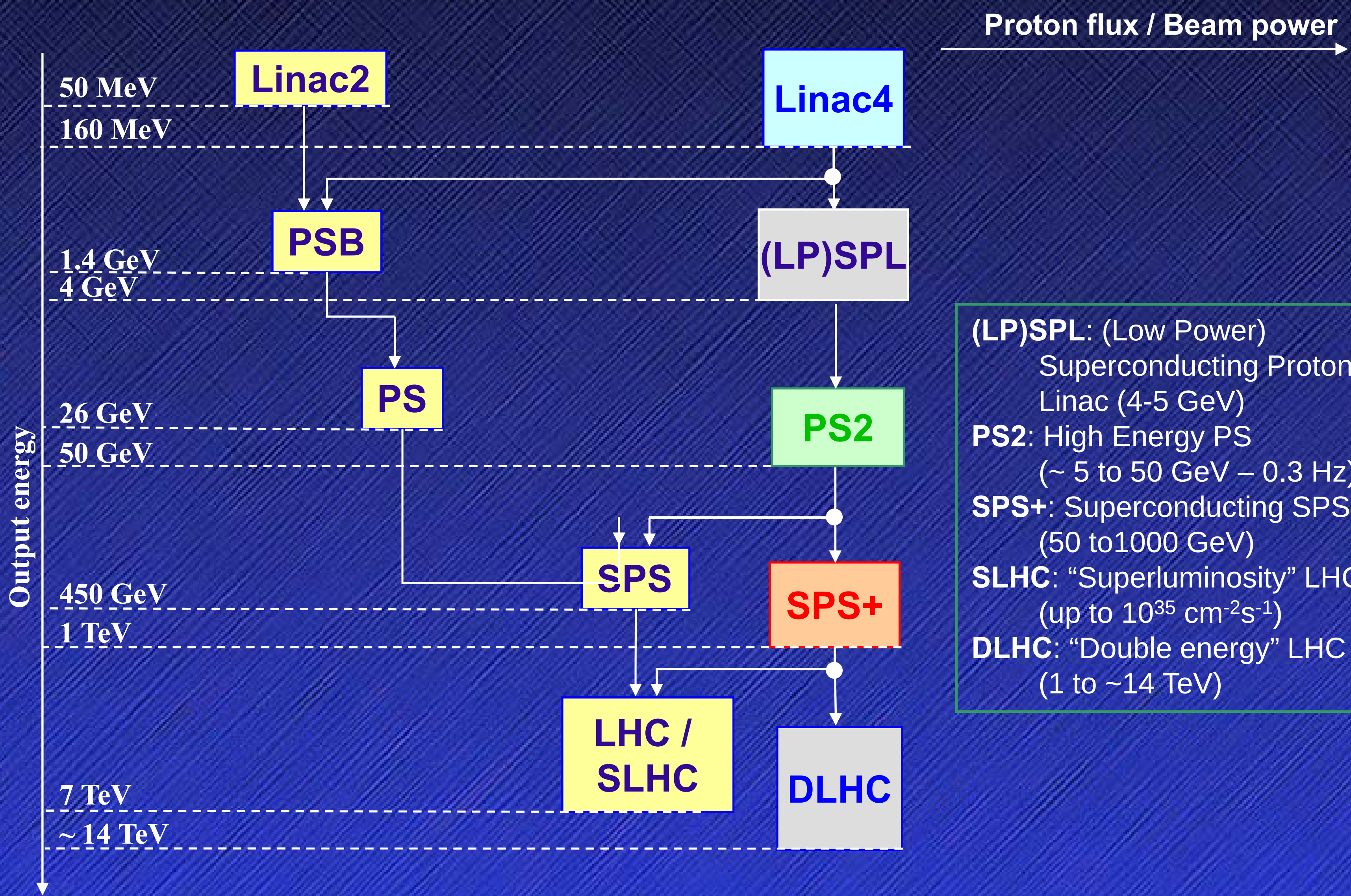
local crab cavities together with IR phase-2 ~2017 ?

LHC injector upgrade

Reasons:

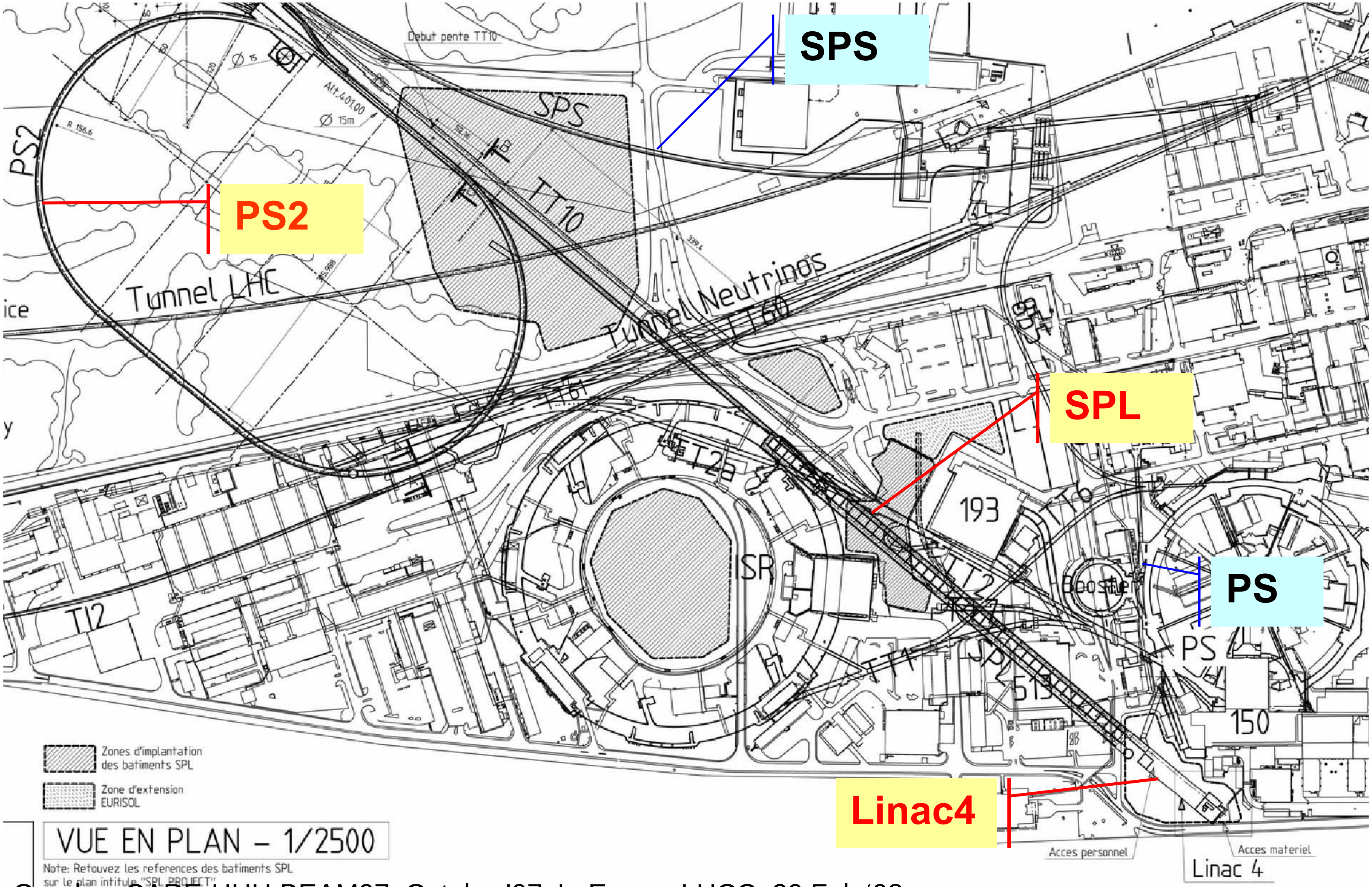
- **need for reliability:**
  - **accelerators are old [Linac2: 1978, PSB: 1975, PS: 1959, SPS: 1976]**
  - **they operate far from their design parameters and close to hardware limits**
  - **the infrastructure has suffered from the concentration of resources on LHC during the past 10 years**
- **need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

present and future injectors



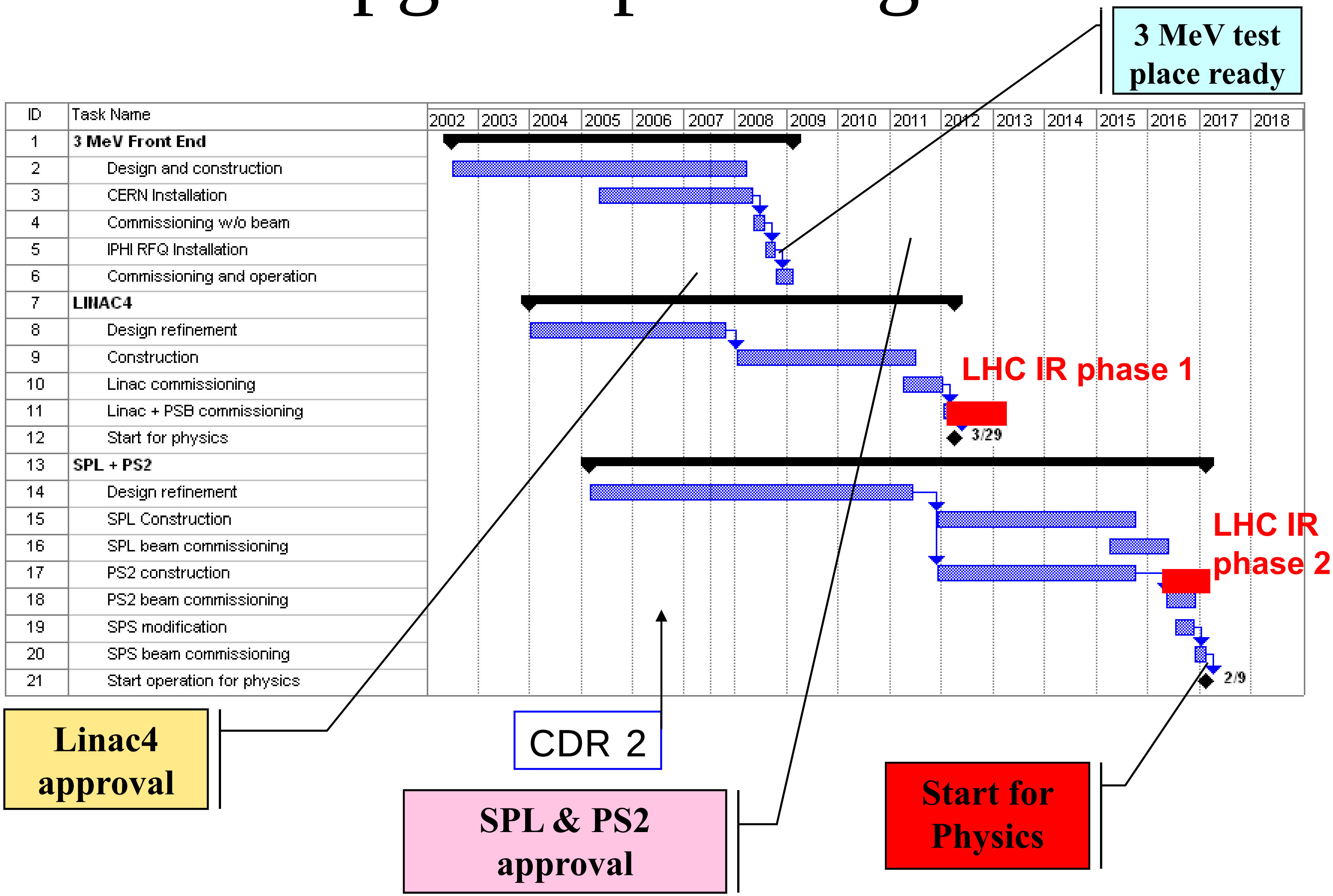
(LP)SPL: (Low Power) Superconducting Proton Linac (4-5 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
SLHC: “Superluminosity” LHC (up to 10^{35} $cm^{-2}s^{-1}$)
DLHC: “Double energy” LHC (1 to ~14 TeV)

layout of the new injectors



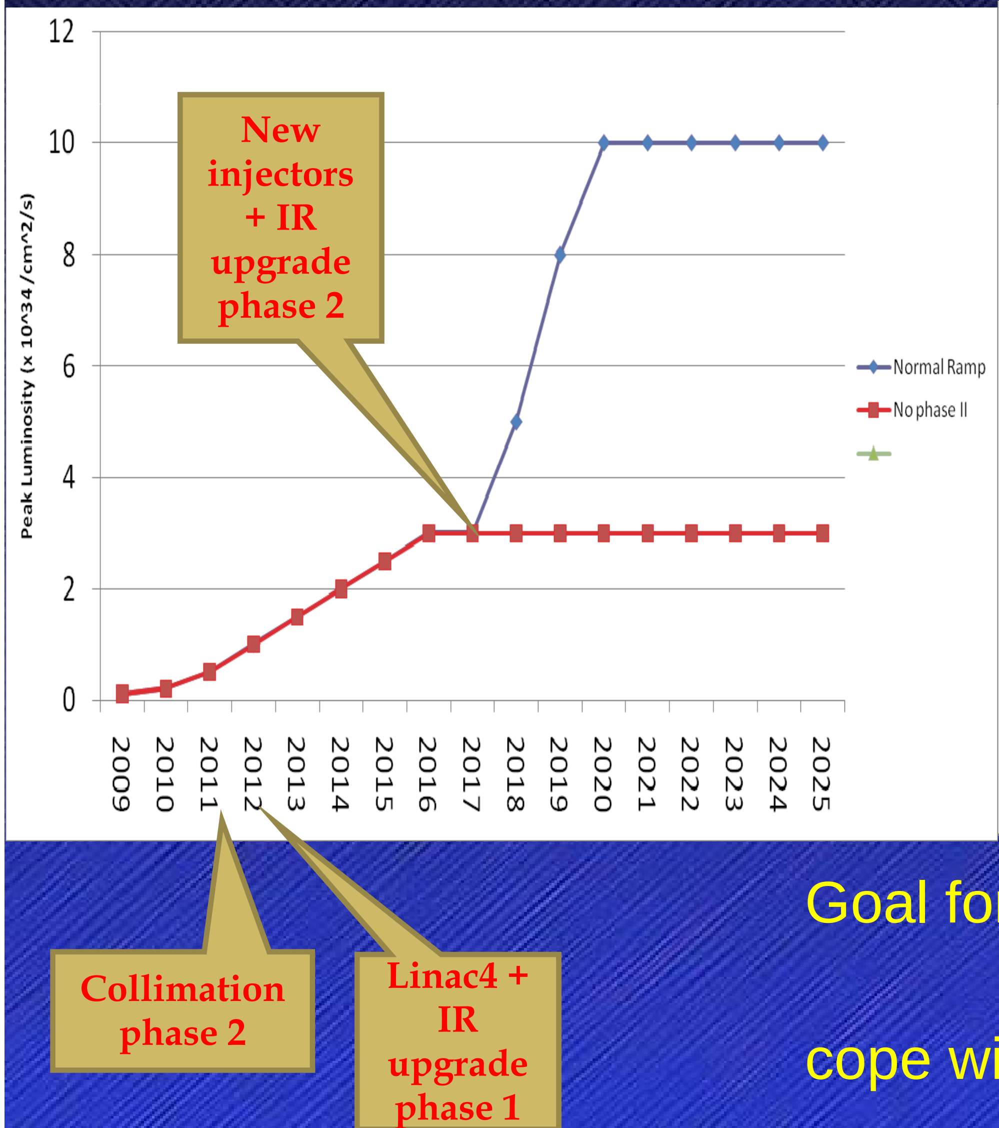
R. Garoby, CARE-HHH BEAM07, October'07; L. Evans, LHCC, 20 Feb '08

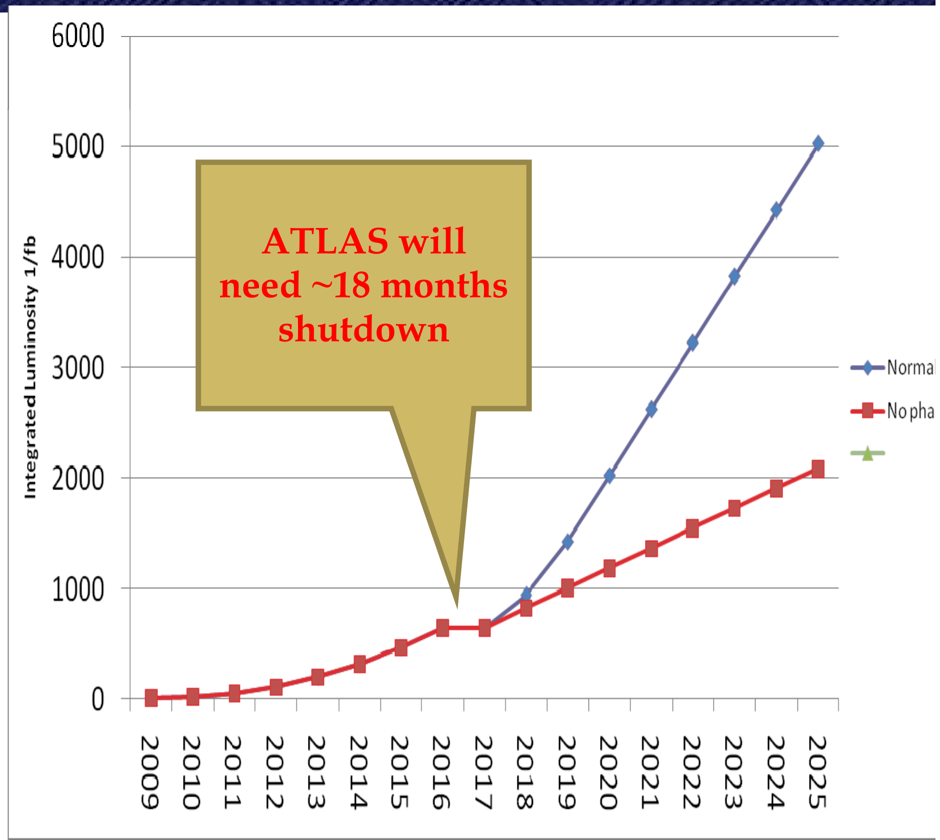
upgrade planning …



Lyn Evans, LHC-MAC, June 2008

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


CERN
Questions?