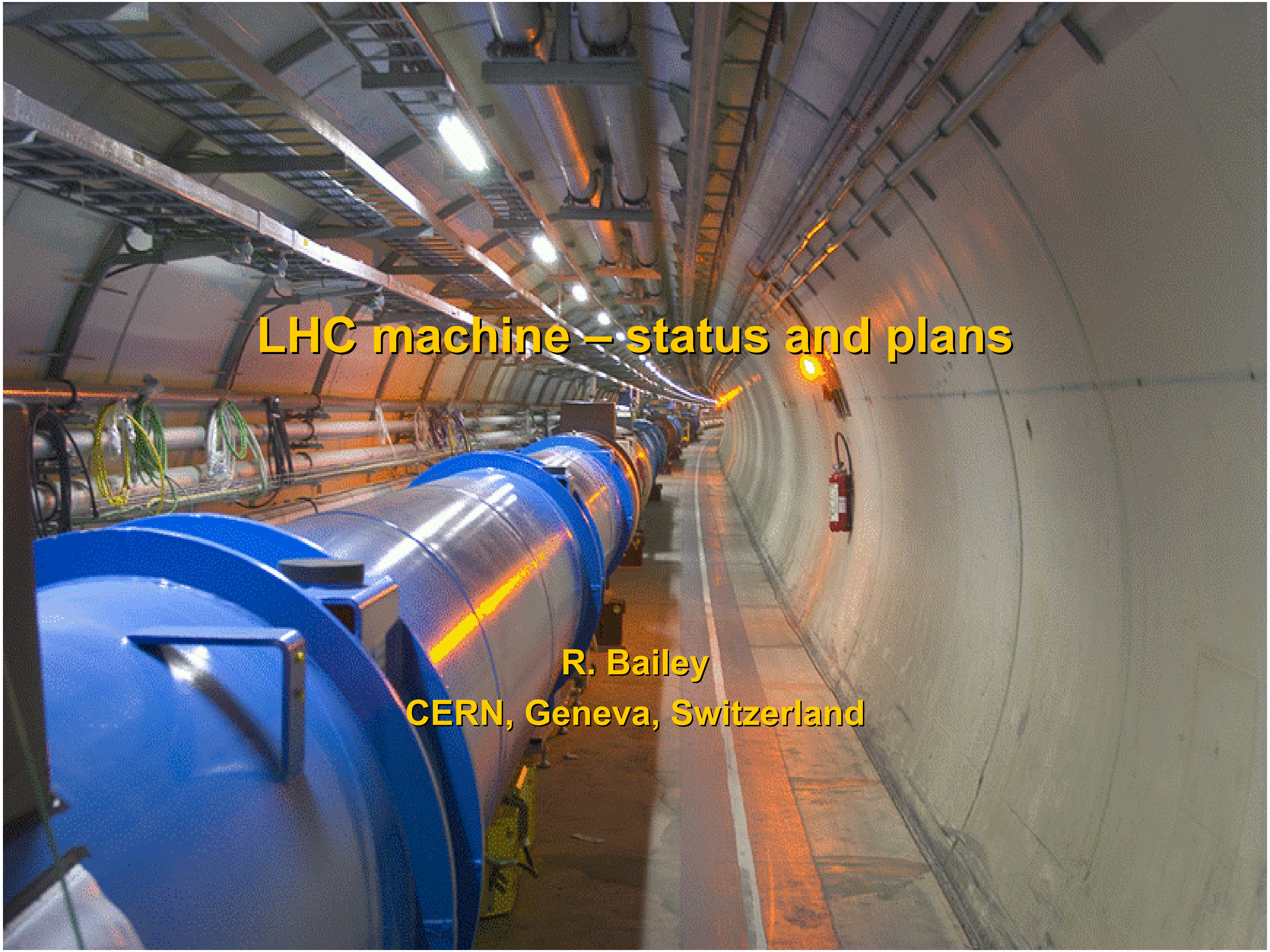


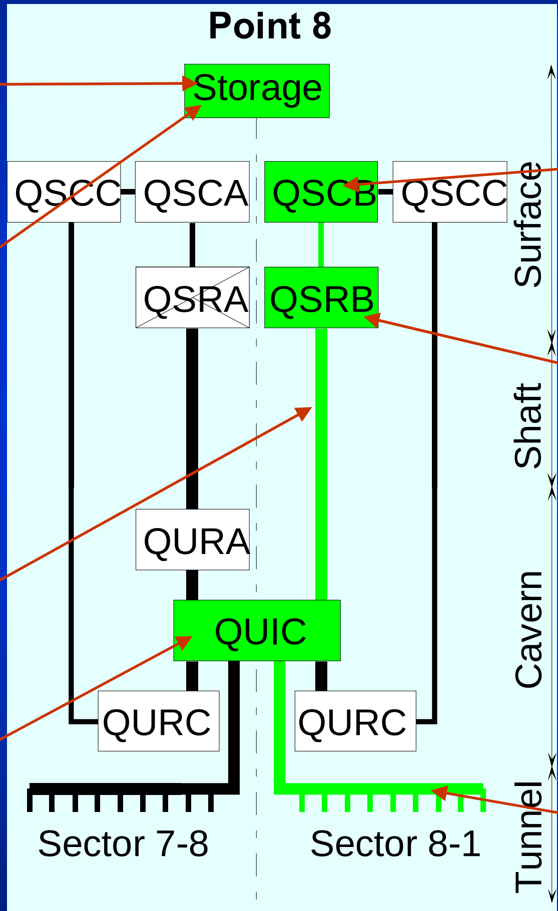
LHC machine – status and plans

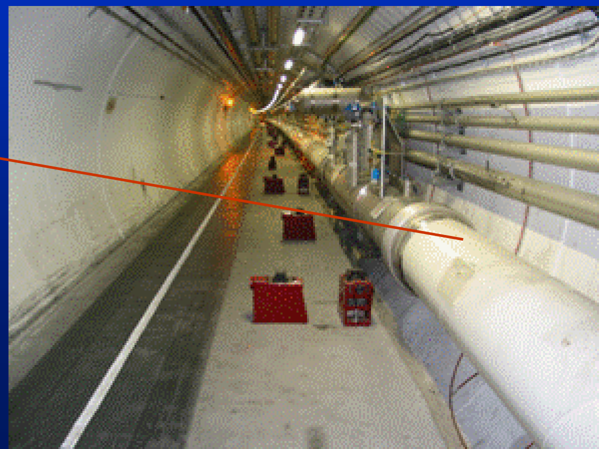
R. Bailey
CERN, Geneva, Switzerland

LHC machine – status and plans

- Progress in 2005/2006
  - Cryogenic distribution line (QRL)
  - Magnet procurement
  - Installation
  - Electrical power tests
- Plans for beam commissioning

Cryogenic system

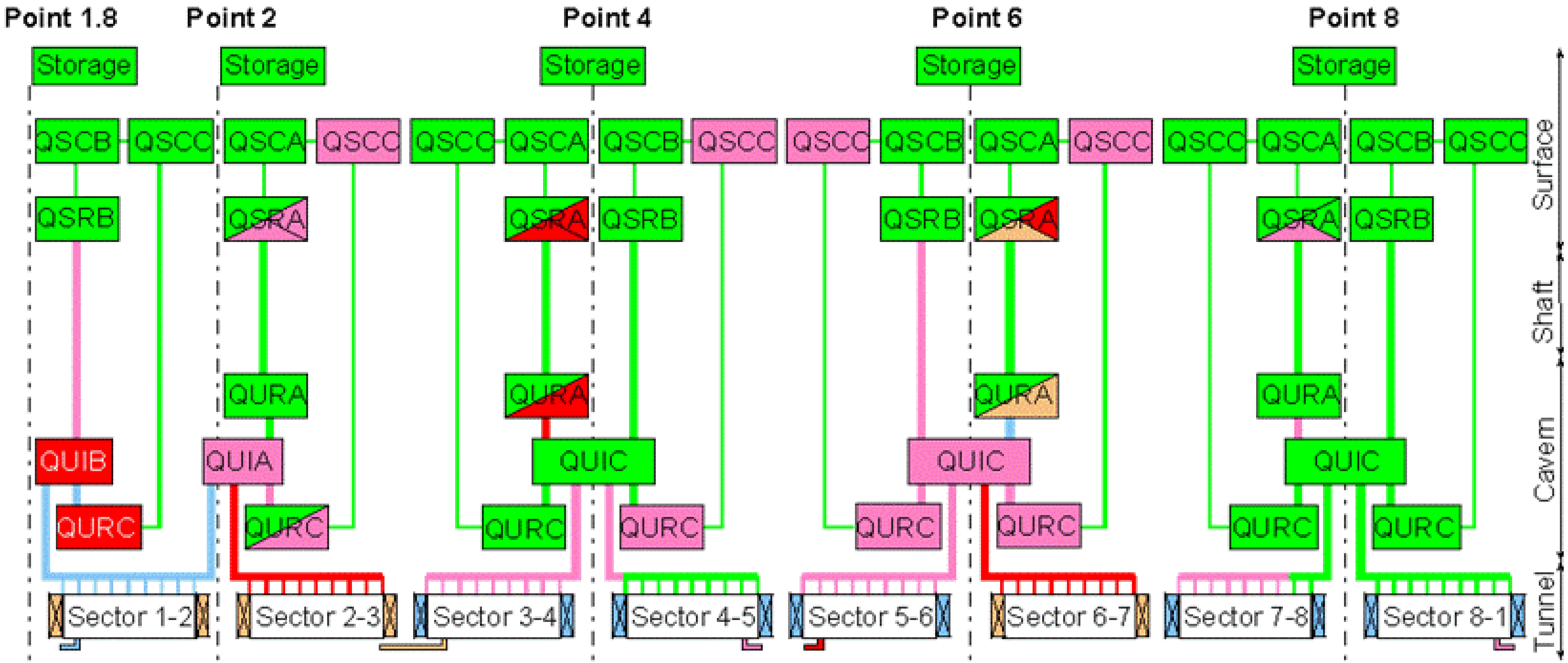




LHC Progress Dashboard

Accelerator Technology Department

Cryogenics overview



Legend

Cryogenic Distribution Line

QSC_(A,B,C): Warm Compressor Station
QSR_(A,B): Surface 4.5 K Refrigerator Cold Box
QURA: Underground 4.5 K Refrigerator Cold Box
QURC: 1.8 K Refrigeration Unit Cold Box
QUI_(A,B,C): Cryogenic Interconnection Box

Electrical Feed Box

Superconducting Link

Commisionned & accepted

Delivered / Under installation

Ordered (Contract placed)

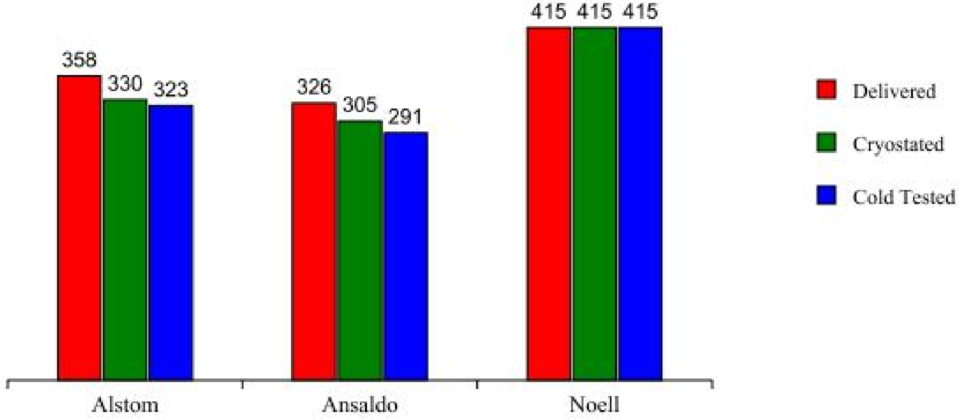
Under commissioning

Under fabrication

Under definition

Magnet procurement

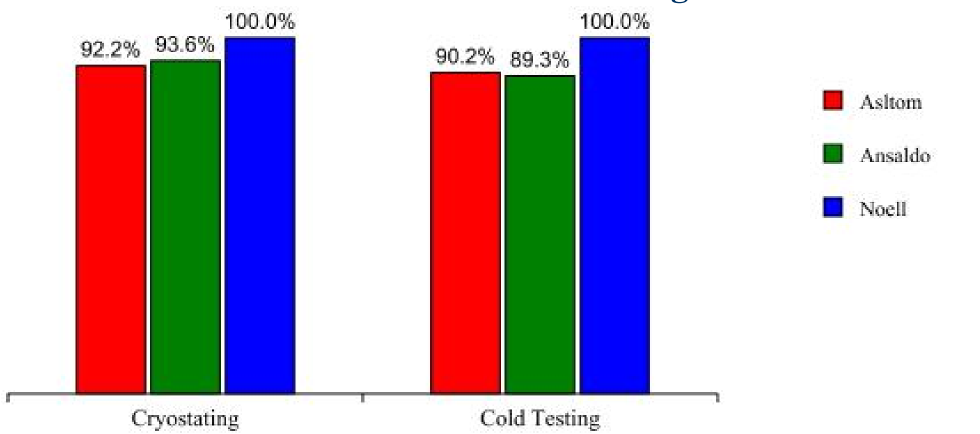
Dipoles



Last magnet from BNN (Nov 2005)

Last Update Wed, 31 May 2006 16:37:35

Treated % of delivered magnets



Dipole sorting

The huge number of stored dipoles allowed matching each individual slot to a specific dipole and opened the opportunity to minimize the effect of field quality differences between individual magnets

Magnet transport

Storage

Storage

SMI2

SMI2

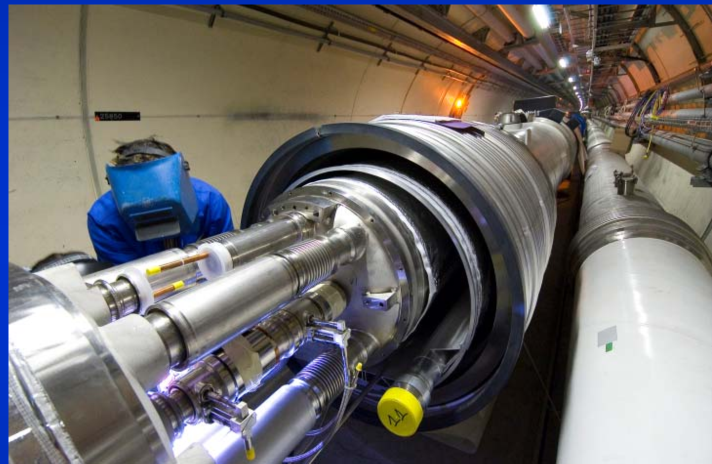
PMI2 &
Final position

Pt18

Final preparation
Final checks

Power tests
Stripping
Fiducialization

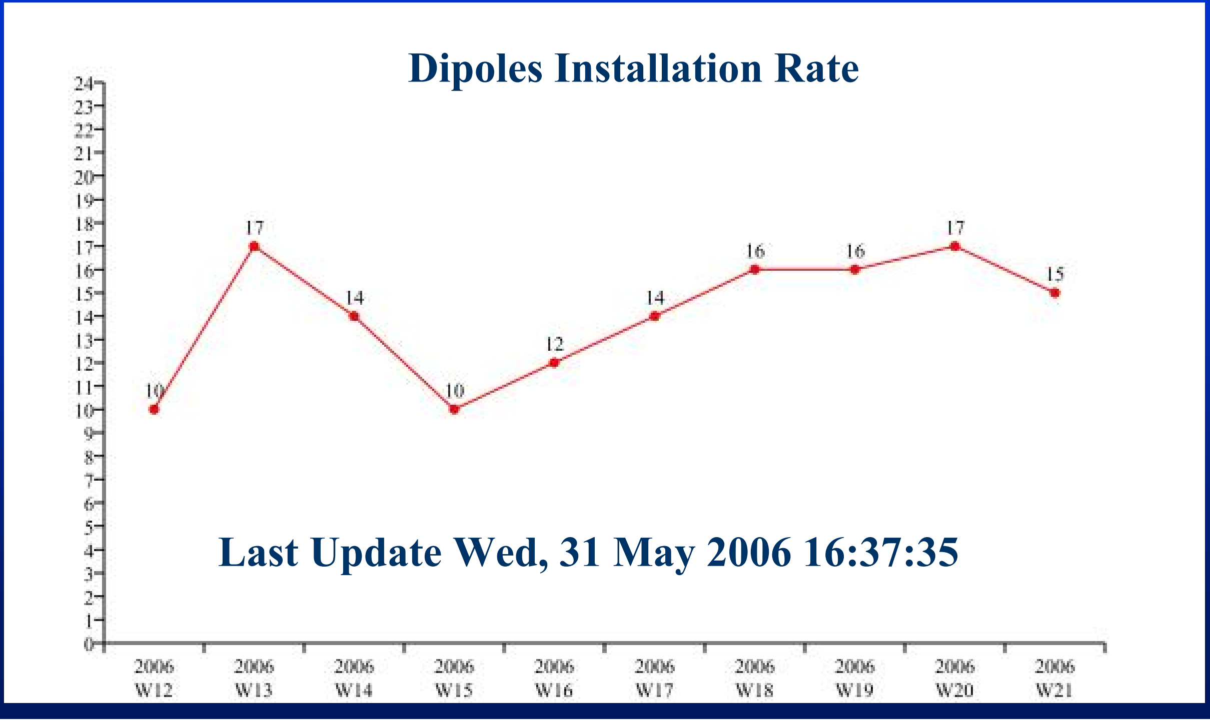
Underground



Magnet installation

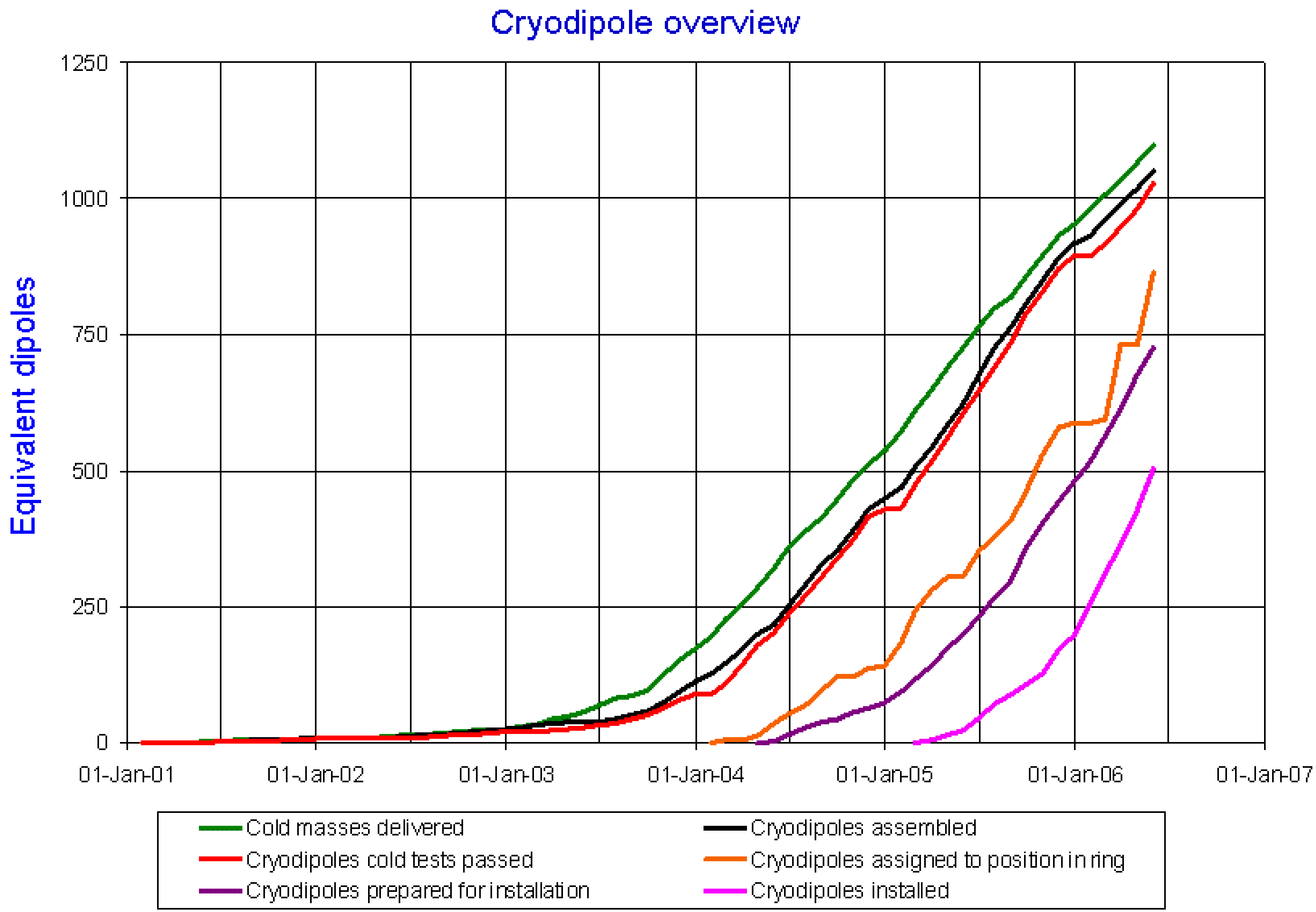
- First magnet lowered down PMI2 on March 7th 2005

- Needed to install a magnet
  - Slot available in the tunnel
  - Magnet available
  - Logistics and associated infrastructure operational



LHC Progress Dashboard

Accelerator Technology Department

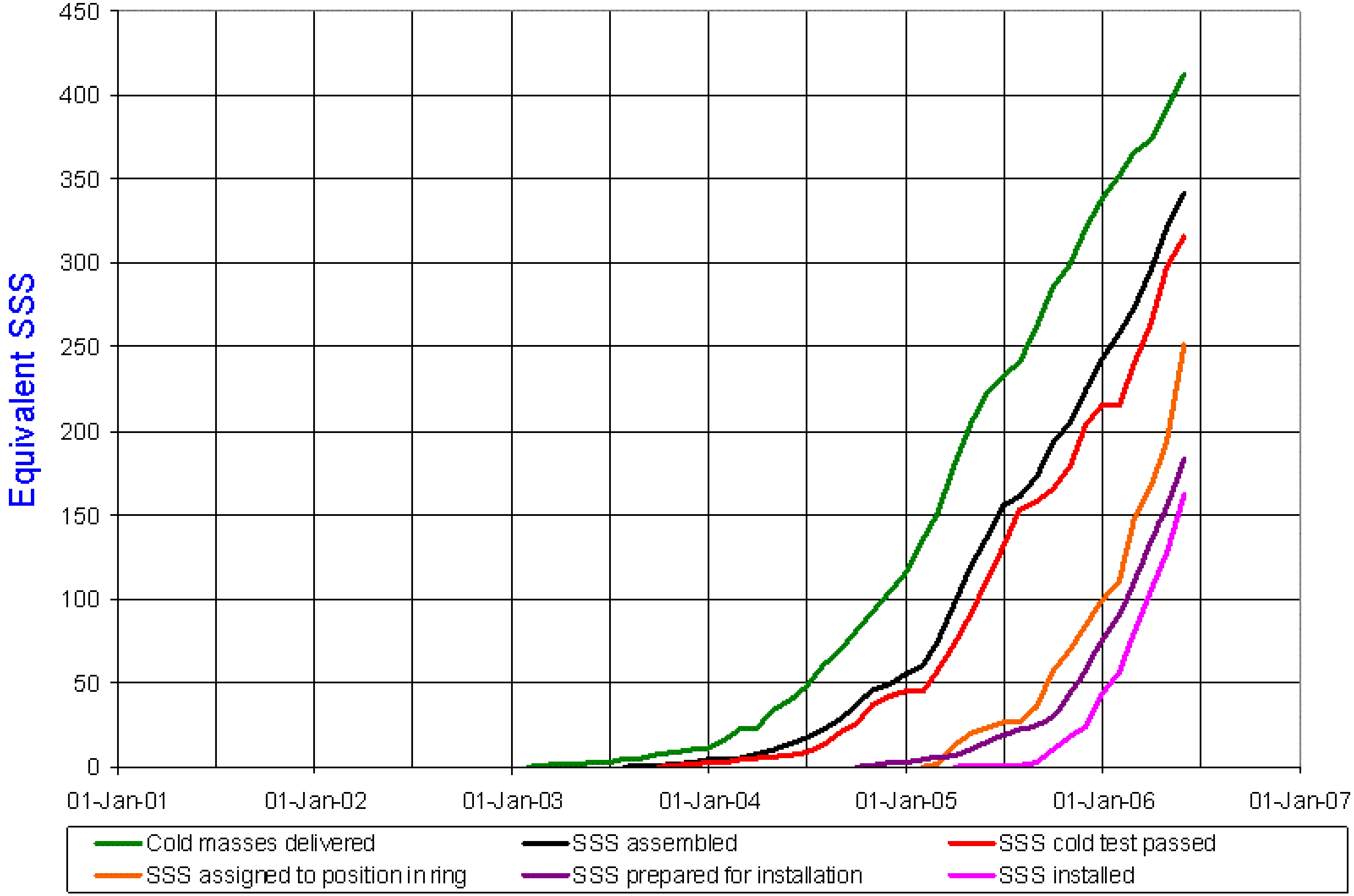


Updated 31 May 2006

Data provided by D. Tommasini AT-MAS, L. Bottura AT-MTM

LHC Progress Dashboard

SSS overview

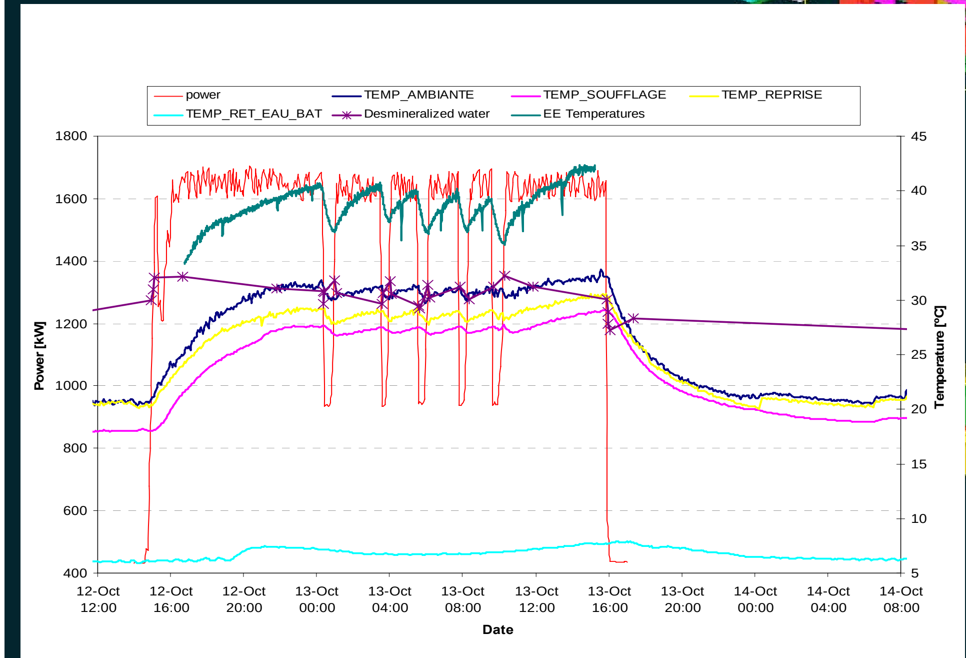


Updated 31 May 2006

Data provided by M. Modena AT-MAS, L. Bottura AT-MTM

24h short circuit heat run (October 2005)

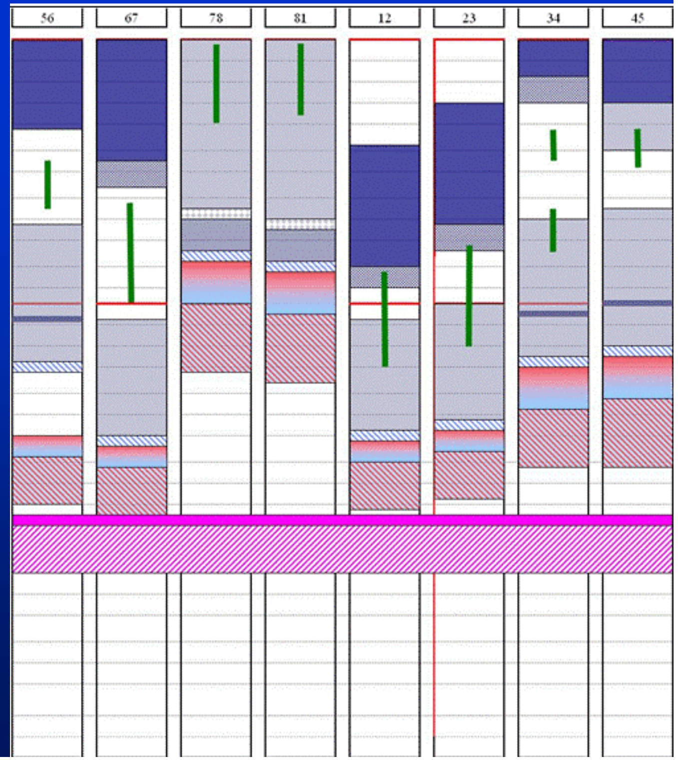
Short-circuit tests are not only power converter tests: energy extraction tests, DC cables tests, AC network conditions, cooling and ventilation, interlocks, control,…



Installation & testing targets

- Complete full installation and tests of QRL in 06
- Complete the cold tests of the 1232 dipoles in 06
- Cool down of sectors 7-8 and 8-1 in 06
- Start hardware commissioning in 06
- Target potential bottlenecks
  - Optimize magnet transport logistics still further
  - Rate of magnet interconnections
  - Procurement of electrical feedboxes (DFBs)
- Last magnet lowered March 2007
- Last interconnect (ring closed) June 2007
- Then
  - Cool down of last sectors
  - Hardware commissioning of last sectors
  - Machine checkout
  - Beam commissioning
- Revised schedule in preparation based on these targets (for approval at the TCC of June 16th)

	Tested	SMI2	Ready	Lowering	Lowered
End-05	979		678		422
Mai	1024	53	731	80	502
June	1062	57	788	85	587
July	1095	53	841	90	677
Aug	1128	53	894	80	757
Sept	1161	57	951	90	847
Oct	1194	57	1008	80	927
Nov	1227	57	1065	80	1007
Dec	1232	25	1090	35	1042
Jan		50	1140	65	1107
Feb		50	1190	65	1172
March		42	1232	60	1232

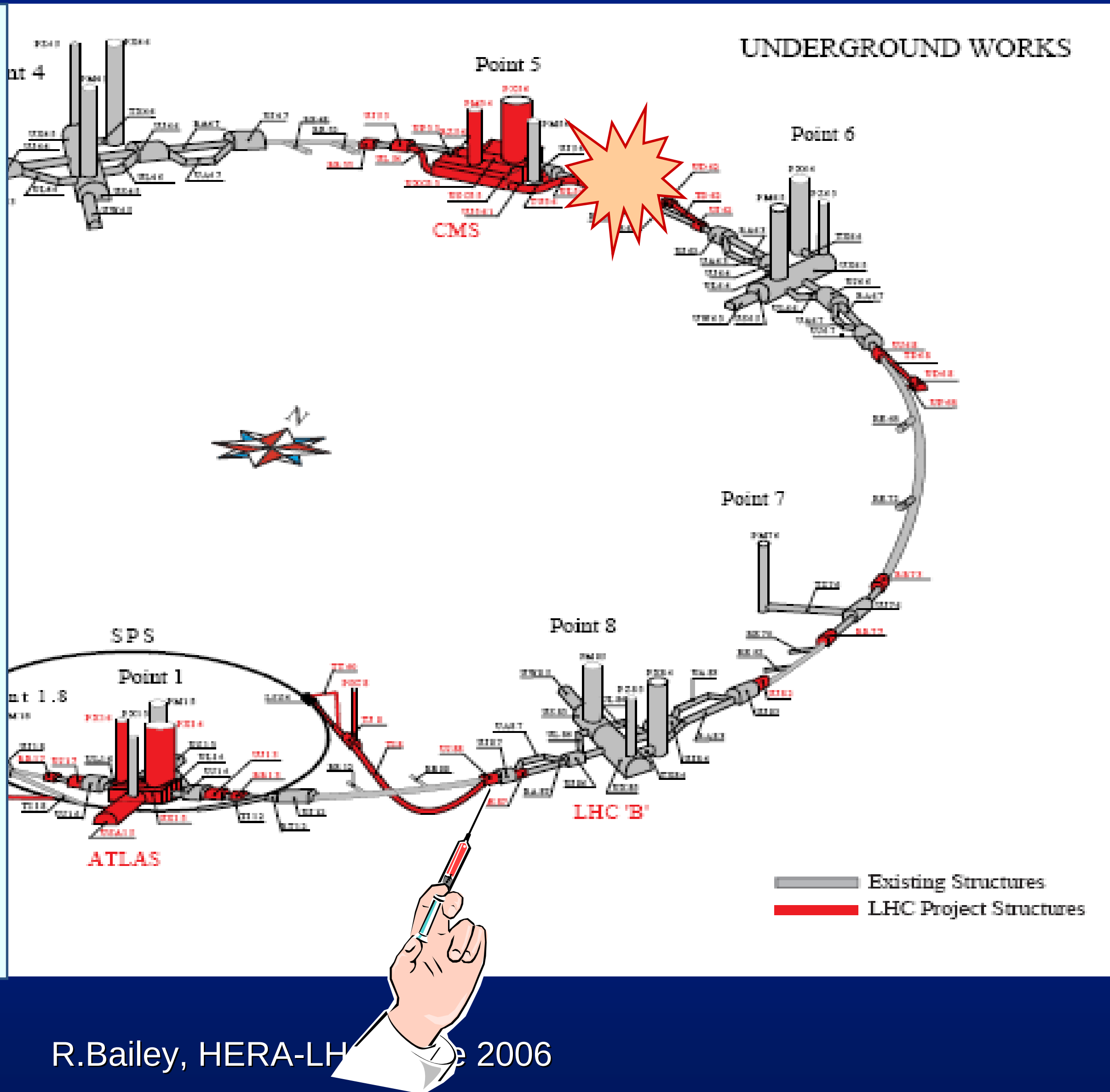


Beam test 8-7-6 in 2007 ?

Aim to send beam

- Out of SPS TT40 ✓
- Down TI8 ✓
- Inject into LHC R8
- Through insertion R8
- Through LHCb
- Through IP8
- Through insertion L8
- Through arc 8-7
- Through point 7
- Through arc 7-6 ?
- To beam dump at L6 ?

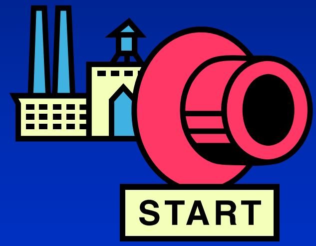
Injection
25% of the ring
Extraction



End of installation in 2007 - then what ?

- **Don't believe what you read**

  "When it is finished, this is what will happen: someone will push a button, and then small bundles ... will be accelerated by powerful magnetic fields ... up to almost the speed of light" UK Daily Mail, May 2006



- **More seriously**

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

"Thus, to achieve high luminosity, all one has to do is make (lots of) high population bunches of low emittance to collide at high frequency at locations where the beam optics provides as low values of the amplitude functions as possible." PDG 2005, chapter 25

- **Nearly all the parameters are variable**
  - **Number of particles per bunch** N
  - **Number of bunches per beam** k_b
  - **Relativistic factor (E/m_0)** γ
  - **Normalised emittance** ε_n
  - **Beta function at the IP** β^*
  - **Crossing angle factor** F
    - **Full crossing angle** θ_c
    - **Bunch length** σ_z
    - **Transverse beam size at the IP** σ^*

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

Global requirements

ATLAS and CMS — **Proton collisions @ highest energy**

- Nominal luminosity 10^{34} cm^{-2} s^{-1} in points 1 and 5
- Minimize event pileup early on (to 2 or 3 cf 20 nominal)
- Go to 25ns as soon as possible
- Will make use of any beam for detector commissioning

LHCb — **Proton collisions @ highest energy**

- Nominal luminosity ~ 5 10^{32} cm^{-2} s^{-1} in point 8
- Tune IP8 to optimize luminosity (1m < β^* > 50m)
- Go to 25ns as soon as possible (optimized for ~ 1 events/crossing)
- Frequent dipole polarity changes (~every fill !)

ALICE — **Proton collisions @ various energies**

- Will use proton beams (intrinsic interest and reference data)
- Nominal luminosity ~ 10^{30} cm^{-2} s^{-1} in point 2
- Tune IP2 to optimize luminosity (0.5m < β^* > 50m)
- Magnet polarities change (+ - 0) a few times per year

Proton luminosity running

IONS — **Collisions @ various energies for ALICE**

- Nominal luminosity ~ 10^{27} cm^{-2} s^{-1} in point 2
- ATLAS and CMS will also take data

Dedicated

TOTEM — **Proton collisions @ various energies**

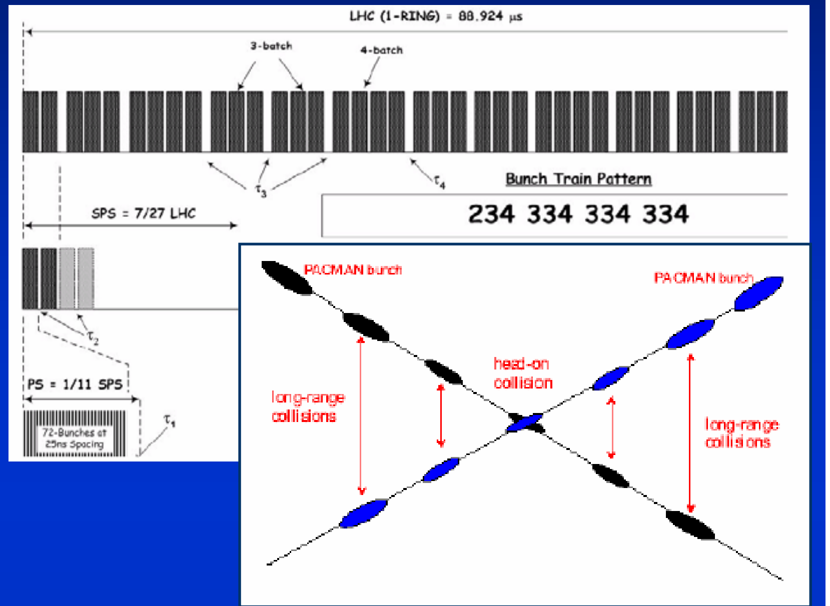
- Special machine conditions (low emittance, high β^*)

Dedicated

(10^6 seconds @ <L> of 10^{33} cm^{-2} s^{-1} → 1 fb^{-1})

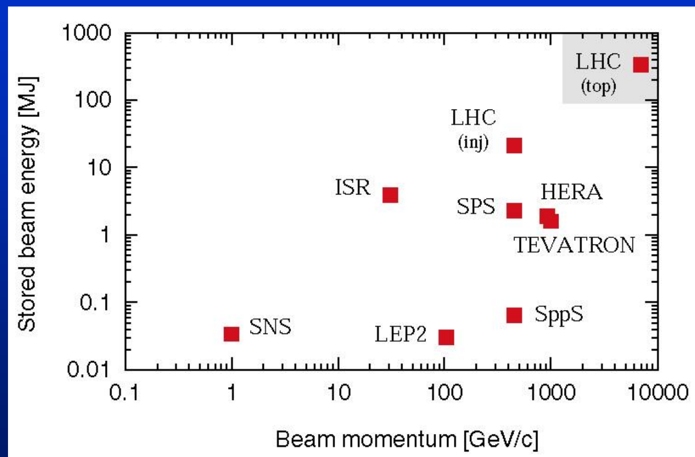
Machine considerations

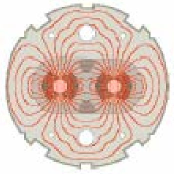
$$L = \frac{N^2 k_b f \gamma}{4\pi \varepsilon_n \beta^*} F$$



Nominal settings	
Beam energy (TeV)	7.0
Number of particles per bunch	1.15 10^{11}
Number of bunches per beam	2808
Crossing angle (μrad)	285
Norm transverse emittance (μm rad)	3.75
Bunch length (cm)	7.55
Beta function at IP 1, 2, 5, 8 (m)	0.55,10,0.55,10

Related parameters	
Luminosity in IP 1 & 5 (cm^{-2} s^{-1})	10^{34}
Luminosity in IP 2 & 8 (cm^{-2} s^{-1})	~5 10^{32}
Transverse beam size at IP 1 & 5 (μm)	16.7
Transverse beam size at IP 2 & 8 (μm)	70.9
Stored energy per beam (MJ)	362



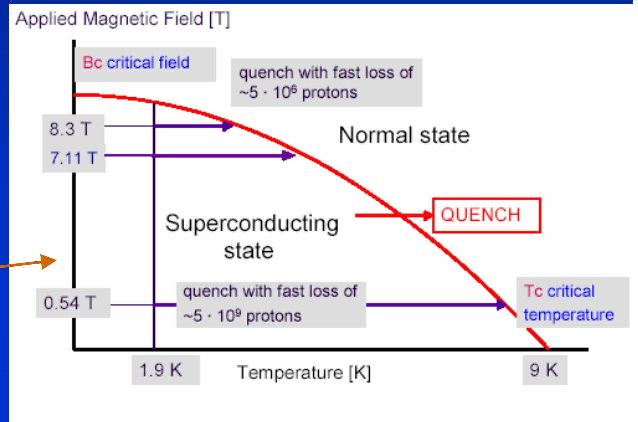


So how to get there ?

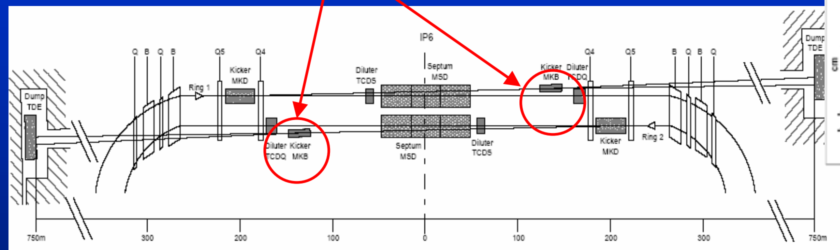
$$Eventrate / Cross = \frac{L\sigma_{TOT}}{k_b f}$$

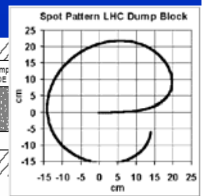
- Find a balance between robust operation and satisfying the experiments
  - Maximize integrated luminosity
  - Minimize event pile-up (to event + 2)

- Avoid quenches (and damage)
  - Higher β^* to avoid problems in the (later part of) the squeeze
  - Reduce total current to reduce stored beam energy
    - Lower i_b
    - Fewer bunches
  - Reduce energy to get more margin ?
    - Against transient beam losses
    - Against magnet operating close to training limit
    - Hardware commissioning will tell us more



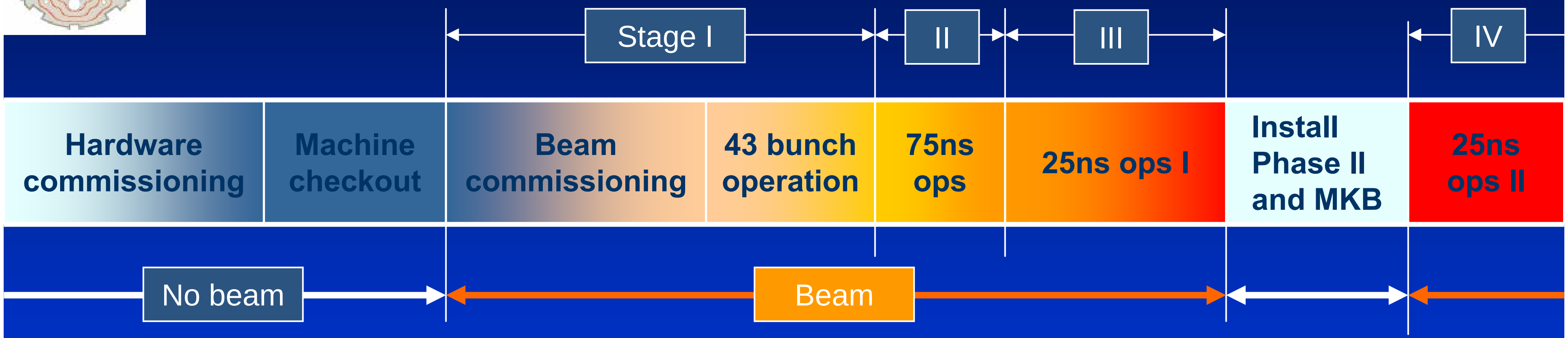
- With lower currents in mind, two machine systems will be staged
  - Only 8 of 20 beam dump dilution kickers initially installed
    - Total beam intensity < 50% nominal
    - Install the rest when needed





  - Collimators (robustness, impedance and other issues)
    - Phased approach
    - Run at the impedance limit during phase I
      - Lower currents
      - Higher β^*

Staged commissioning plan for protons



I. **Pilot physics run**
   - First collisions
   - 43 bunches, no crossing angle, no squeeze, moderate intensities
   - Push performance (156 bunches, partial squeeze in 1 and 5, push intensity)
   - Performance limit 10^{32} cm^{-2} s^{-1} (event pileup)

II. **75ns operation**
   - Establish multi-bunch operation, moderate intensities
   - Relaxed machine parameters (squeeze and crossing angle)
   - Push squeeze and crossing angle
   - Performance limit 10^{33} cm^{-2} s^{-1} (event pileup)

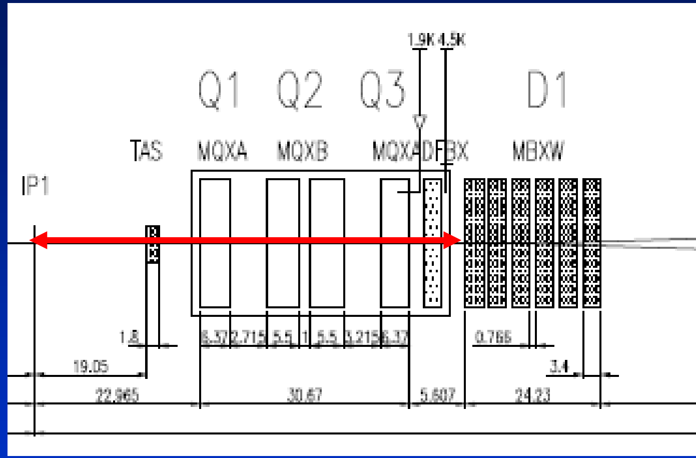
III. **25ns operation I**
   - Nominal crossing angle
   - Push squeeze
   - Increase intensity to 50% nominal
   - Performance limit 2 10^{33} cm^{-2} s^{-1}

IV. **25ns operation II**
   - Push towards nominal performance

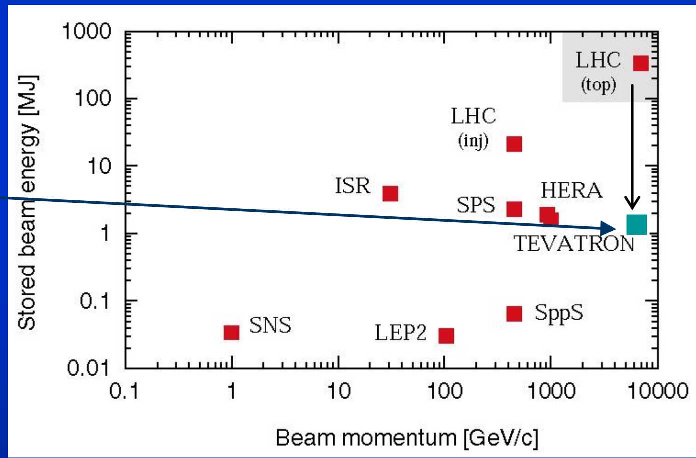
R.Bailey, HERA-LHC, June 2006

Stage I

- Start as simple as possible
  - No squeeze
    - β* = 18m in 1 & 5
    - β* = 10m in 2 & 8
  - Avoid parasitic beam-beam
    - No crossing angle
    - D1L to D1R ~ 116m
    - Minimum bunch spacing 232m, ~ 0.8μs
    - 43 bunches per beam convenient for the injectors, spacing 2.025μs
  - Switch off all unused equipment



- Under these relatively clean, safe conditions
  - Injection of beam from SPS is always safe
  - Stored beam energy comparable to other facilities
  - Commission the nominal cycle
  - Establish reproducible operation
  - Commission machine protection systems
  - Beam measurement campaign
  - Make a few single beam runs at top energy
  - First high energy collisions
  - Increase performance



- Bring on crossing angle
  - Luminosity may well go down (remember SPS collider and LEP)
  - Recover as much as possible without parasitic beam-beam

Stage I physics run

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

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

- Start as simple as possible
- Change 1 parameter (k_b N $\beta^*_{1,5}$) at a time
- All values for
  - nominal emittance
  - 7TeV
  - 10m β* in point 2 (luminosity looks fine)

Protons/beam ≲ 10^{13}
(LEP beam currents)

Stored energy/beam ≲ 10MJ
(SPS fixed target beam)

Parameters			Beam levels		Rates in 1 and 5		Rates in 2	
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
1	10^{10}	18	1 10^{10}	10^{-2}	10^{27}	<< 1	1.8 10^{27}	<< 1
43	10^{10}	18	4.3 10^{11}	0.5	4.2 10^{28}	<< 1	7.7 10^{28}	<< 1
43	4 10^{10}	18	1.7 10^{12}	2	6.8 10^{29}	<< 1	1.2 10^{30}	0.15
43	4 10^{10}	2	1.7 10^{12}	2	6.1 10^{30}	0.76	1.2 10^{30}	0.15
156	4 10^{10}	2	6.2 10^{12}	7	2.2 10^{31}	0.76	4.4 10^{30}	0.15
156	9 10^{10}	2	1.4 10^{13}	16	1.1 10^{32}	3.9	2.2 10^{31}	0.77

LHCb during Stage I

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

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

- Displace bunches in one ring (n on m)
  - 4 per SPS cycle in 43 bunch, 16 per SPS cycle in 156 bunch mode
- Dedicated runs for LHCb (n on n) ?
- Squeeze in point 8 (2m limit for 'bad' LHC dipole polarity)
- All values for
  - nominal emittance
  - 7TeV

Parameters			Rates in 8	
k_b	N	β* 1,5 (m)	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing
1 on 1	10^{10}	10	$1.8\ 10^{27}$	<< 1
4 on 43	10^{10}	10	$7\ 10^{27}$	<< 1
4 on 43	$4\ 10^{10}$	10	$1.1\ 10^{29}$	0.15
4 on 43	$4\ 10^{10}$	2	$5.7\ 10^{29}$	0.76
16 on 156	$4\ 10^{10}$	2	$2.3\ 10^{30}$	0.76
156 on 156	$4\ 10^{10}$	2	$2.2\ 10^{31}$	0.76
156 on 156	$9\ 10^{10}$	2	$1.1\ 10^{32}$	3.9

Stage II physics run

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

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

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

- Relaxed crossing angle (250 μrad)
- Start un-squeezed
- Then go to where we were in stage I
- All values for
  - nominal emittance
  - 7TeV
  - 10m β* in points 2 and 8

Protons/beam ≈ few 10^{13}

Stored energy/beam ≤ 100MJ

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
936	4 10^{10}	18	3.7 10^{13}	42	1.5 10^{31}	<< 1	2.6 10^{31}	0.15
936	4 10^{10}	2	3.7 10^{13}	42	1.3 10^{32}	0.73	2.6 10^{31}	0.15
936	6 10^{10}	2	5.6 10^{13}	63	2.9 10^{32}	1.6	6.0 10^{31}	0.34
936	9 10^{10}	1	8.4 10^{13}	94	1.2 10^{33}	7	1.3 10^{32}	0.76

Stage III physics run

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

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

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

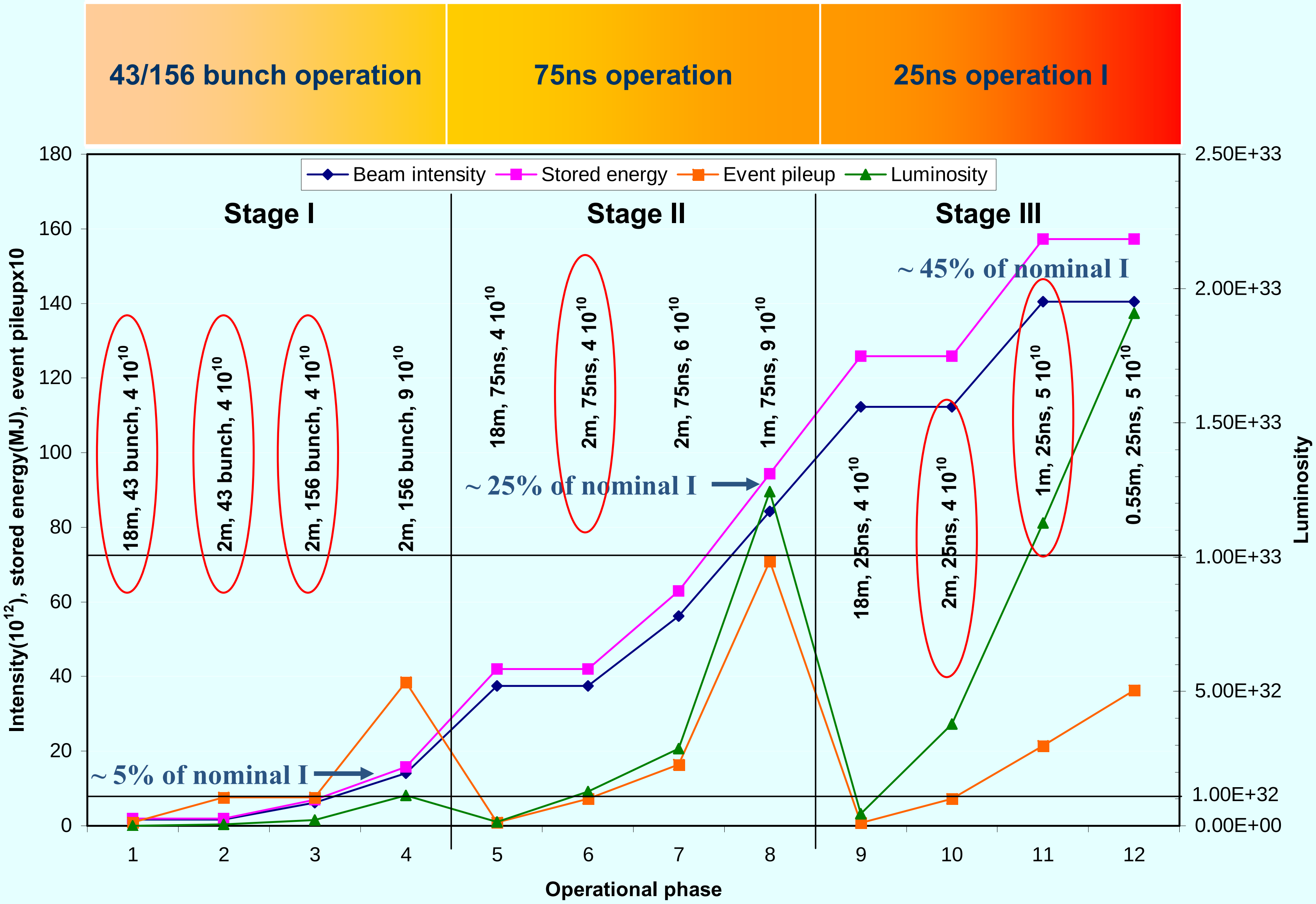
Protons/beam ≈ 10^{14}

- Nominal crossing angle (285 μrad)
- Start un-squeezed
- Then go to where we were in stage II
- All values for
  - nominal emittance
  - 7TeV
  - 10m β* in points 2 and 8

Stored energy/beam ≥ 100MJ

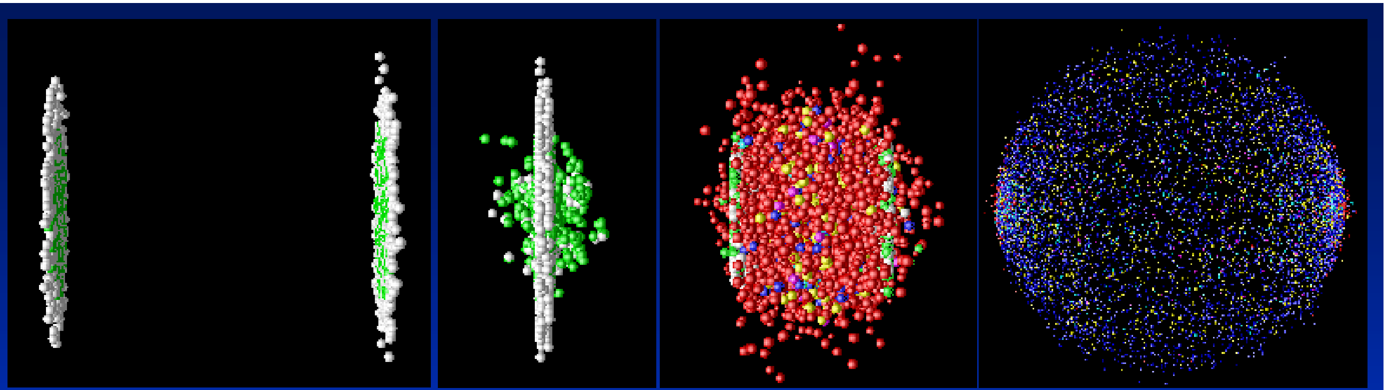
Parameters			Beam levels		Rates in 1 and 5		Rates in 2 and 8	
k_b	N	β* 1,5 (m)	I_{beam} proton	E_{beam} (MJ)	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing
2808	4 10^{10}	18	1.1 10^{14}	126	4.4 10^{31}	<< 1	7.9 10^{31}	0.15
2808	4 10^{10}	2	1.1 10^{14}	126	3.8 10^{32}	0.72	7.9 10^{31}	0.15
2808	5 10^{10}	2	1.4 10^{14}	157	5.9 10^{32}	1.1	1.2 10^{32}	0.24
2808	5 10^{10}	1	1.4 10^{14}	157	1.1 10^{33}	2.1	1.2 10^{32}	0.24
2808	5 10^{10}	0.55	1.4 10^{14}	157	1.9 10^{33}	3.6	1.2 10^{32}	0.24
Nominal			3.2 10^{14}	362	10^{34}	19	6.5 10^{32}	1.2

Evolution of beam levels and luminosity



R.Bailey, June 2006

Ions



Experiment side

- ALICE, ATLAS and CMS will all take Pb-Pb data
- Detectors and machine will be already commissioned with pp
- ALICE requests
  - 4 week ion runs at the end of each year
  - first short run as early as possible

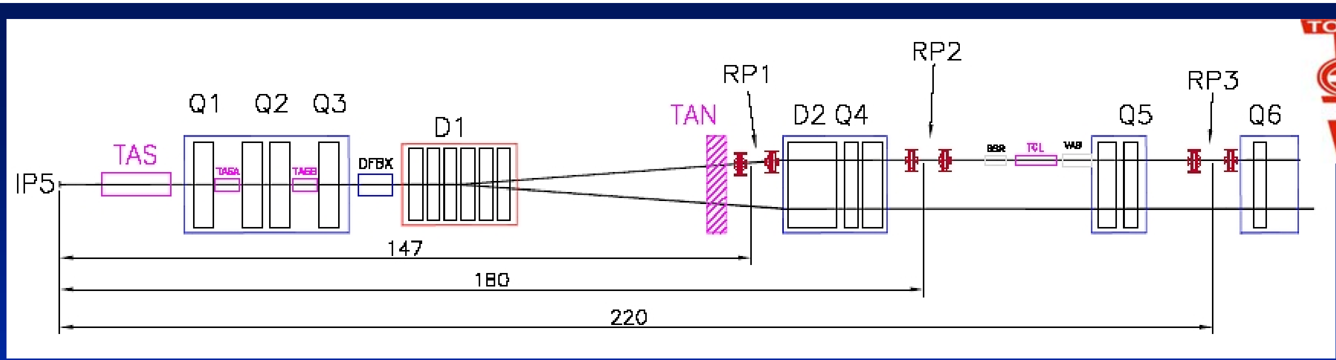
Machine side

- Start with early ion scheme (62 bunches instead of 592, 7 10^7 ions per bunch)
- Will have to
  - Set up RF capture
  - Commission essential instrumentation
  - Commission squeeze in IR2
  - Establish collisions

> Estimate ≥ 1 week for first setup
>
> Followed by physics run

- Could do (some of) this early on if injectors are ready (same optics as for p)
- Ion runs could provide cool down of PS SPS LHC after proton operation
- After early ion scheme run, increase number of bunches
- Move to nominal when possible

TOTEM



A standard TOTEM year would be

- σ_{tot} measurement high priority
- Nominal emittance OK for σ_{tot} , 1 μm needed for elastic scattering
- 3 * 1 day runs at β* of 1540m (90m ?) with 43 or 156 bunches per beam
- 2 * 1 day runs at β* of 18m with 2808 bunches per beam (25ns)

ATLAS requests a period of a few weeks after first years of running

Machine side

- Special machine conditions, similar to polarisation runs at LEP
- Very demanding on beam and optics quality, and for collimation
- Initial setup will take several days (maybe better dispersed)
- Subsequent setups should take a shift or two
- Longer runs may be more efficient if machine reproducibility is an issue

Scheduling

Every year we will need a long shutdown (3-4 months)

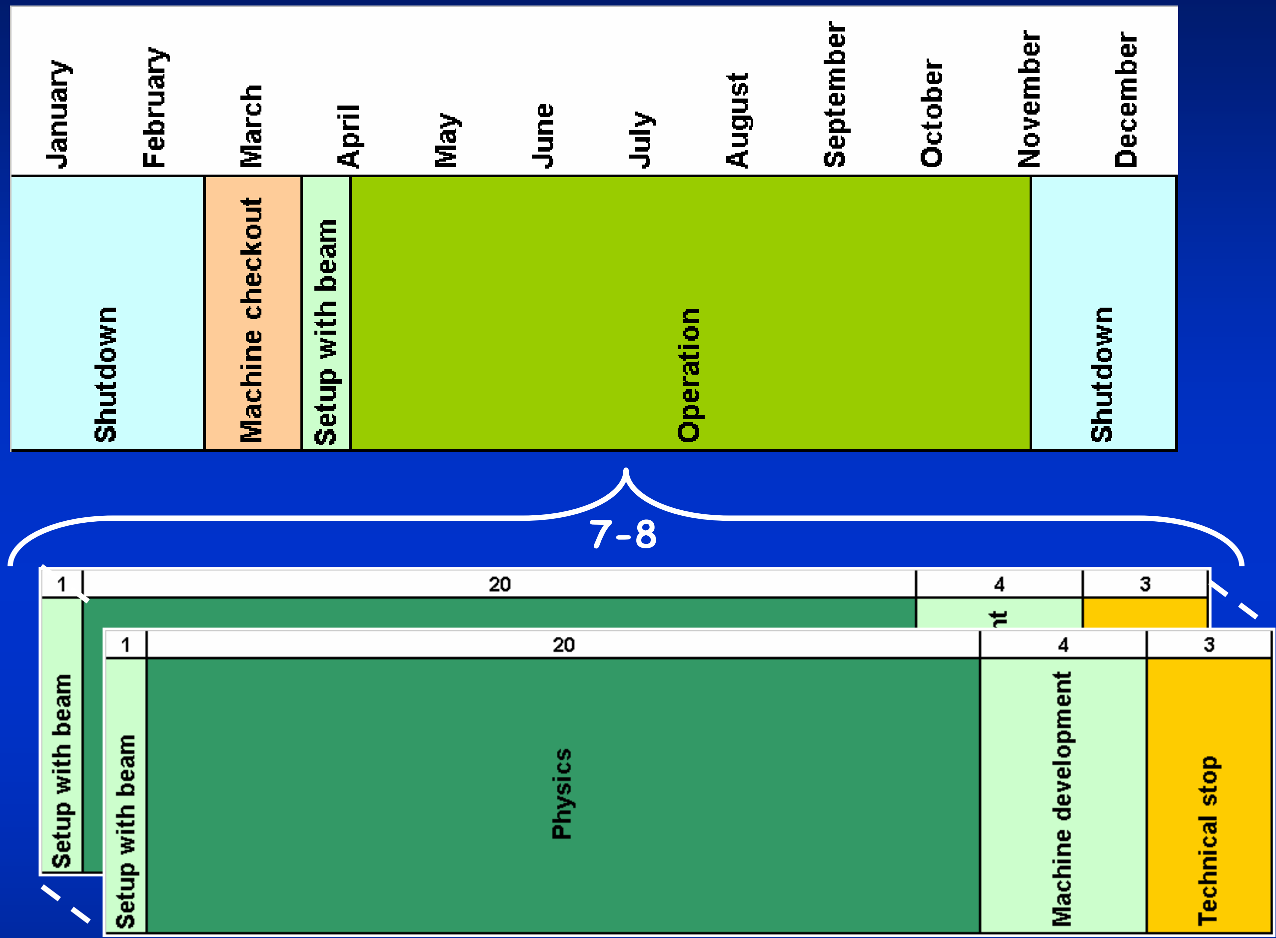
At the end of every shutdown

- Close the machine personnel access system
- Get all equipment ready for beam (machine checkout, ~ 3-4 weeks)
- Get machine ready for operation (setup with beam, 2-3 weeks)

During periods of operation

- Need regular technical stops (3 days every month)
  - Interventions need careful but flexible planning
- Get machine ready for operation (1 day)
- Machine development (around 15% during first years)
- Operations for physics
- Access as required for unscheduled stops

Breakdown of a normal year



~ 140-160 days for physics per year
Not forgetting ion and TOTEM operation
Leaves ~ 100-120 days for proton luminosity running
? Efficiency for physics 50% ?
~ 1200 h or ~ 4 10^6 s of proton luminosity running / year