Requirements from the LHC Experiments

1) "The nominal stuff"

   - the detectors and their aims
   - their location in the LHC
   - direct impact on the machine

2) "The immediate future"

   - The grand plan for 2009-2010
   - The experiment desiderata and our targets

The nominal stuff

The LHC Experiments

Vertical crossing

IP1: ATLAS high lumi
- "general purpose detector"
- roman pots + ZDC

LHCf low lumi
- fwd detector

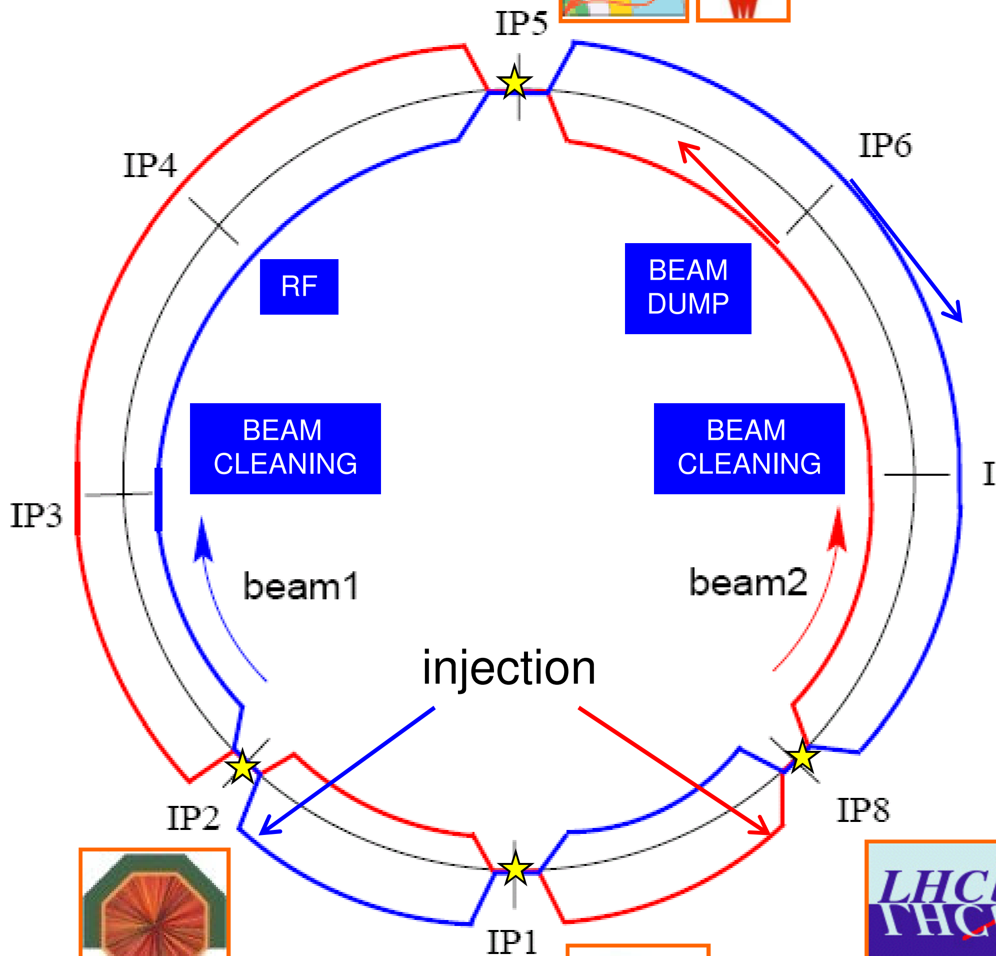
IP2: ALICE low lumi
- HI expt, but also pp
- ZDC

Horizontal crossing

IP5: CMS high lumi
- "general purpose detector"
- ZDC

TOTEM low lumi
- fwd det., roman pots

IP8: LHCb medium lumi
- B physics
- displaced IP, movable vertex detector

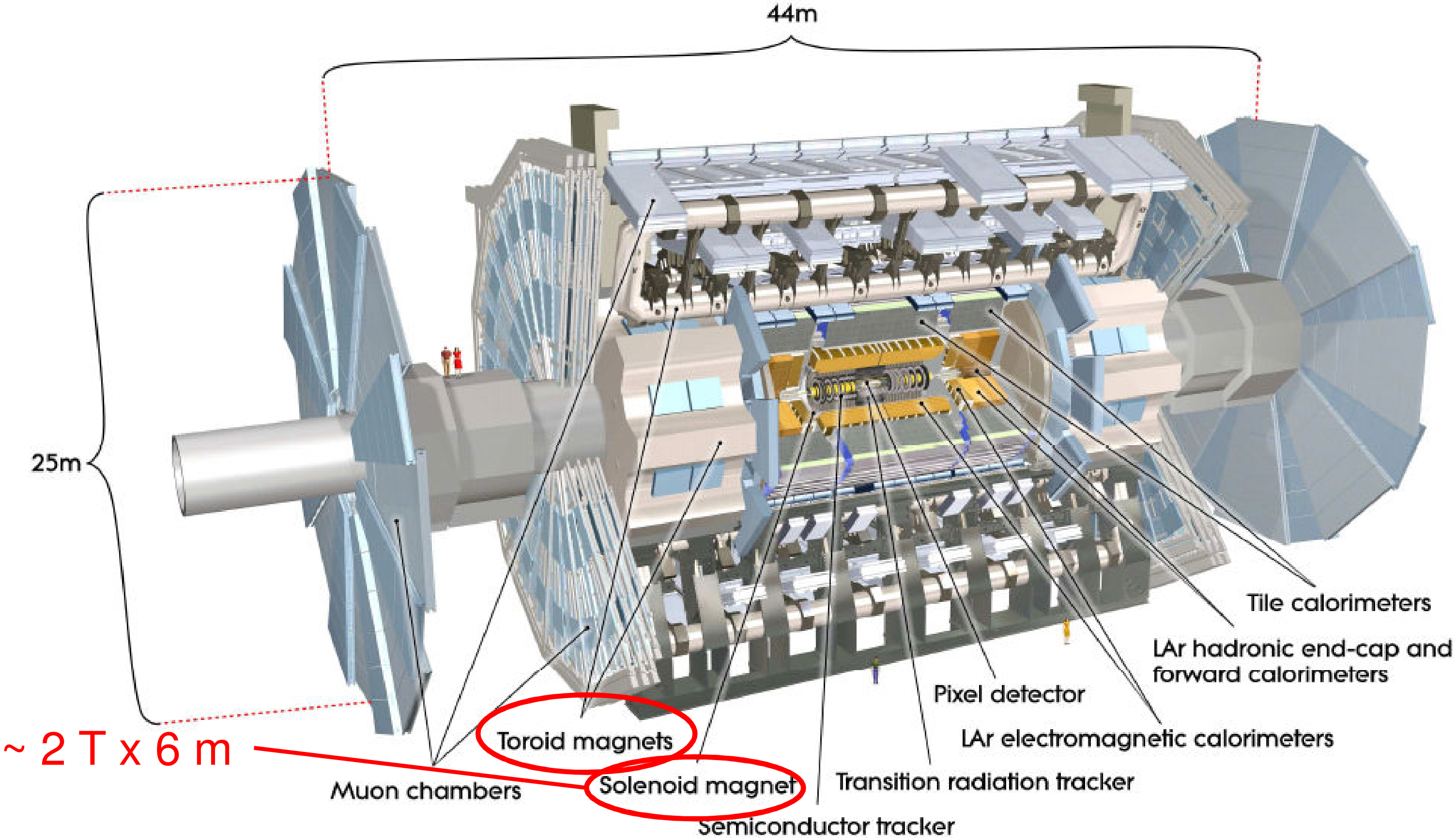


ATLAS

The ATLAS Experiment at the CERN Large Hadron Collider
The ATLAS Collaboration, G Aad *et al* 2008 JINST 3 S08003 link

IP1

symmetric



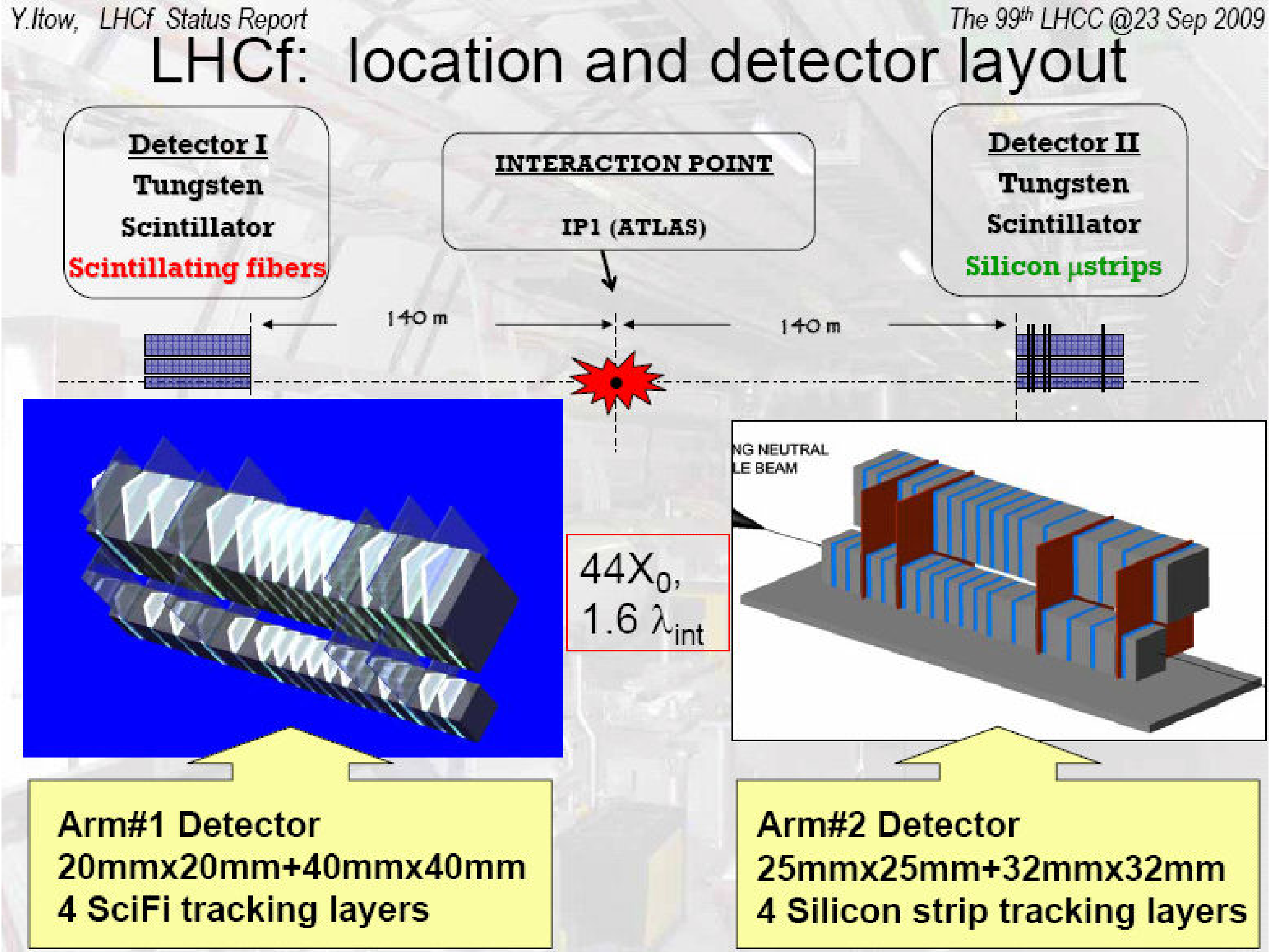
~ 2 T x 6 m

- "Frontier" physics at high energies and high lumi, direct search of new particles (Higgs, SUSY, ...), high p_T, high missing E_T
  - L~ 1e34 $cm^{-2}s^{-1}$, "pile-up" μ ~26 , bunch spacing 25 ns
- But also fwd physics (Roman Pots , 2011) and HI physics

The LHCf detector at the CERN Large Hadron Collider

The LHCf Collaboration, O Adriani *et al* 2008 JINST 3 S08006 link

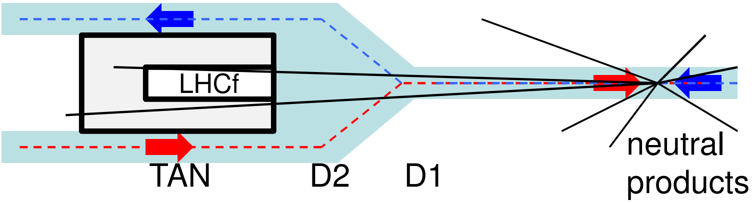
IP1



- neutral particles in very fwd direction, calibration of cosmic-ray shower models
- L~ 1e29-1e30 $cm^{-2}s^{-1}$, fill scheme 43x43, $\alpha = 0$ and $\alpha \neq 0$
- run time O(hours)

- Located in TAN of IR1
- Movable vertically

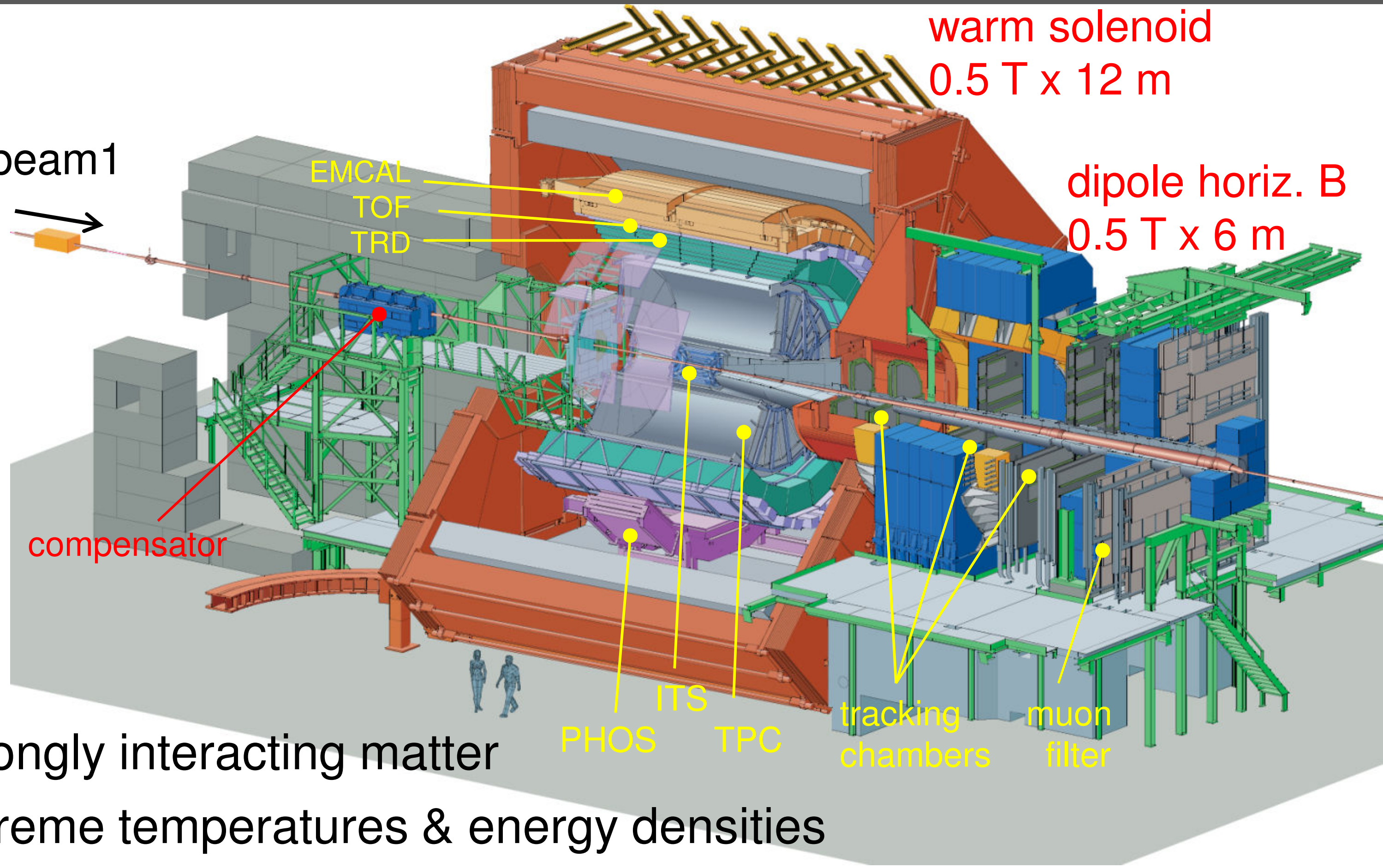
- interference with BRAN and ATLAS ZDC
- Must go out after ~1 kGy (2 pb^{-1} @3.5TeV/beam)



The ALICE experiment at the CERN LHC

The ALICE Collaboration, K Aamodt *et al* 2008 JINST 3 S08002 link

IP2



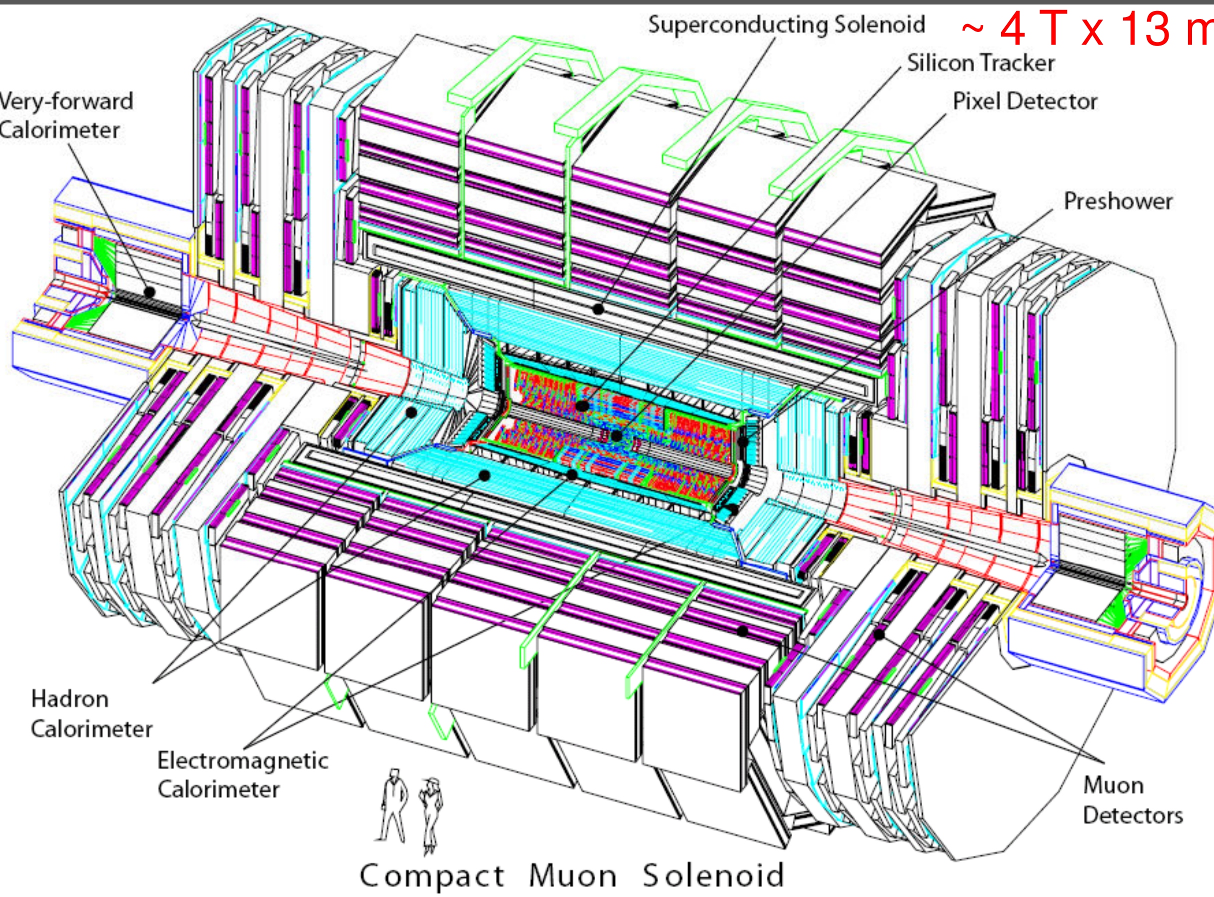
- Physics of strongly interacting matter and QGP, extreme temperatures & energy densities
- Mostly HI: (~1 month per nominal year)
  - L~ 1e27 $cm^{-2}s^{-1}$, 100 ns bunch spacing > 100 ns , 7 TeV/beam (5.5 TeV NN)
- But also pp (reference data)
  - L~ 1e29-1e30 $cm^{-2}s^{-1}$, $\mu <$ ~0.15 , bunch spacing > 100 ns

The CMS experiment at the CERN LHC

The CMS Collaboration, S Chatrchyan *et al* 2008 JINST 3 S08004 link

IP5

symmetric



- "Frontier" physics at high energies and high lumi, direct search of new particles (Higgs, SUSY, ...), high p_T, high missing E_T
  - L~ 1e34 $cm^{-2}s^{-1}$, μ ~26 , bunch spacing 25 ns
- But also fwd physics with TOTEM and HI physics

The TOTEM Experiment at the CERN Large Hadron Collider

The TOTEM Collaboration, G Anelli *et al* 2008 JINST 3 S08007 link

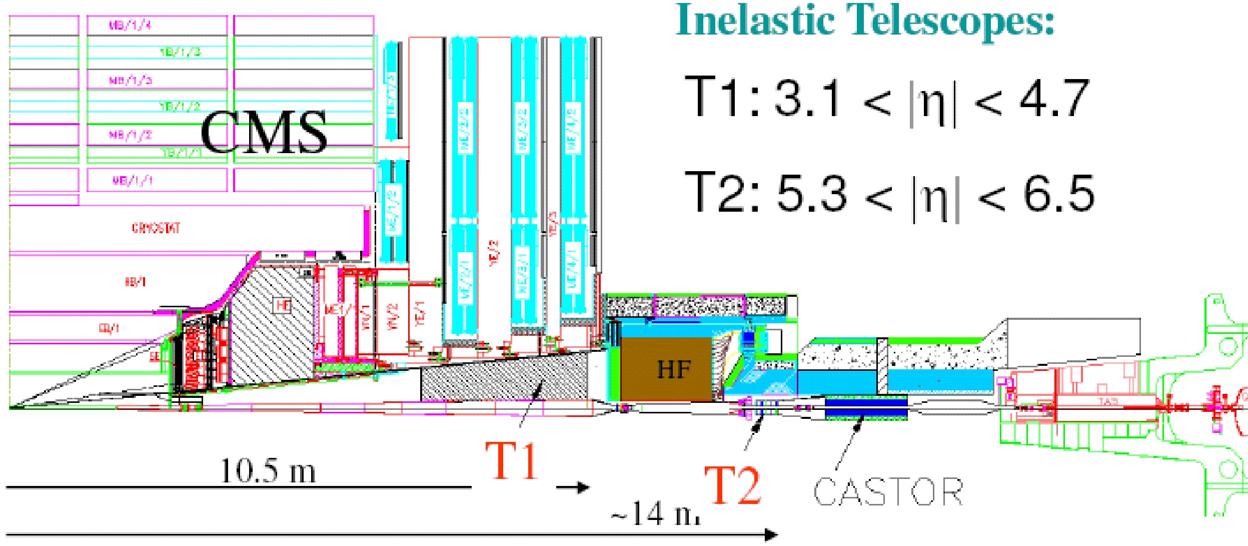
IP5

symmetric

Inelastic Telescopes:

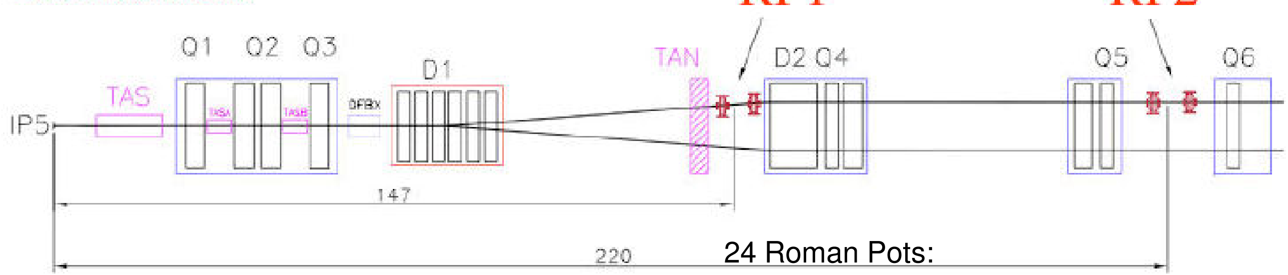
T1: 3.1 < |η| < 4.7

T2: 5.3 < |η| < 6.5



- elastic and diffractive physics, optical theorem, total cross section

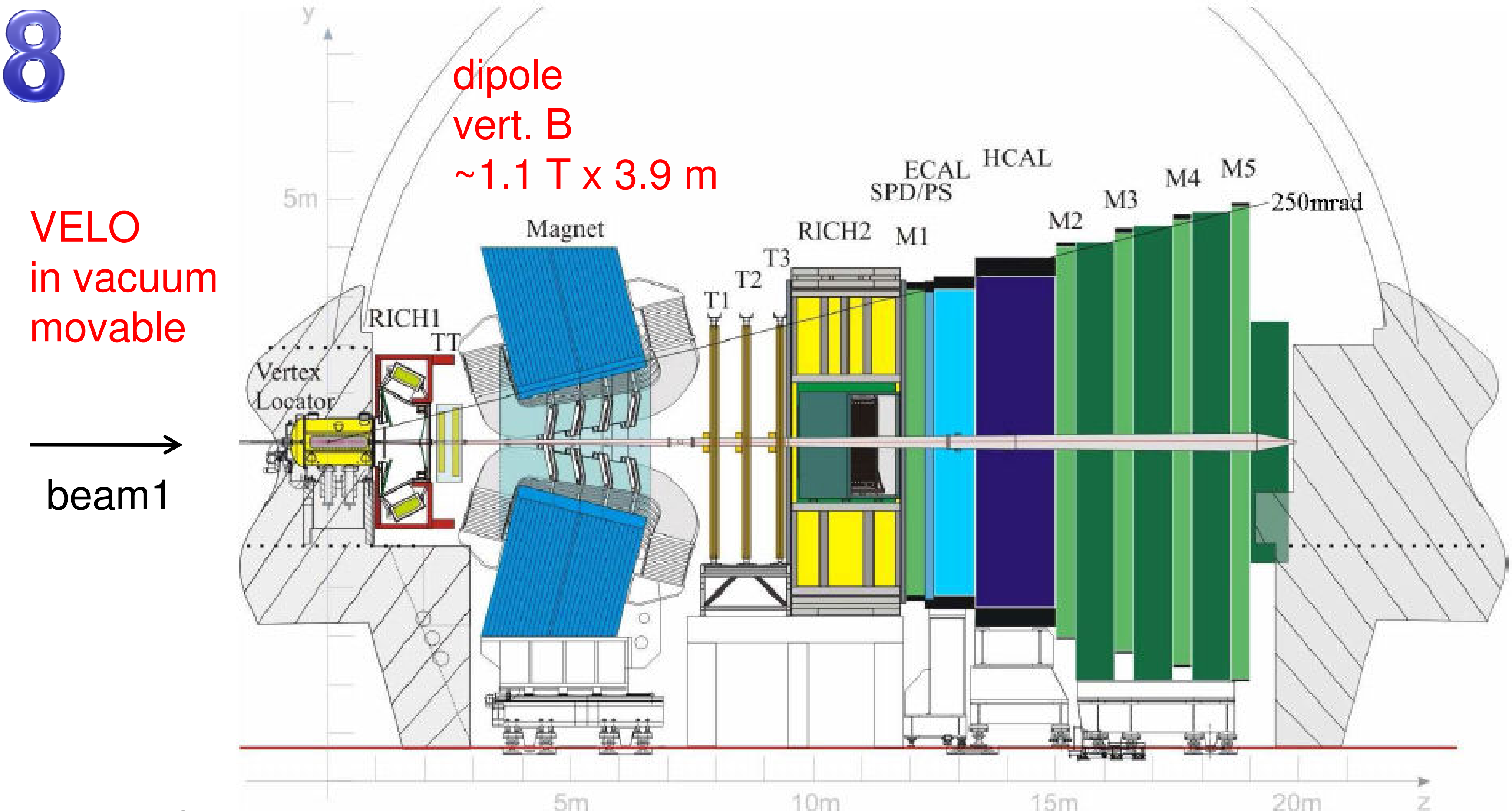
Roman Pots:



24 Roman Pots:
2V pots + 1H pot per station
2 RP1 stations + 2 RP2 stations per side
Move to 10 sigma from beams

- high β* (90 m, then 1.5 km): dedicated!
  - Focus: low-t elastic, σ_{tot}, minbias, soft diffraction
  - L~ 1e29-1e30 $cm^{-2}s^{-1}$, fill scheme 156x156, $\alpha = 0$, run time O(days)
- low β* (0.5 - 11 m => CMS):
  - Focus: large-t elastic, hard diffraction

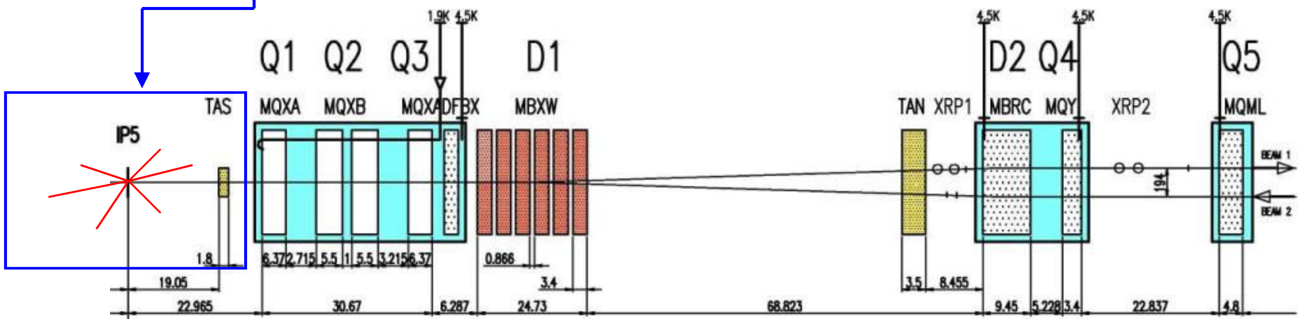
IP8



- B physics, CP violation, rare decays
  - L~ 2e32 $cm^{-2}s^{-1}$, μ ~1, bunch spacing 25 ns
  - IP displaced by 11.25 m , breaks "8-fold" symmetry
- No HI programme

Typical Insertion Region (Region Around Experiment)

- Here is CMS (same for ATLAS), symmetric at IP:



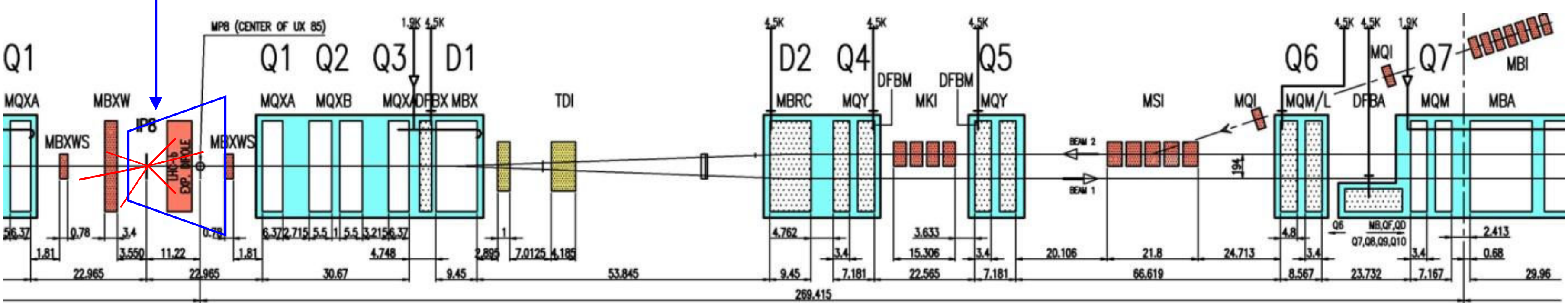
- sc magnet
- warm magnet
- absorber/ collimator

TAS = absorber to protect triplet from IP primaries

Tertiary collimators not shown here

- Here is LHCb (similar for ALICE):

injection from SPS !



- No TAS
- presence of dipole magnet + compensators MBXW...

The immediate future

“New” 2009-2010 run strategy (Aug 09)

- “*The LHC will run at 3.5 TeV per beam until a significant data sample has been collected and the operations team has gained experience in running the machine. Thereafter, with the benefit of that experience, we'll take the energy up towards 5 TeV per beam. At the end of 2010, we'll run the LHC with lead-ions*”

- Main effect of energy reduction on luminosity reach: larger beams, but higher expected intensity limit

- Some expts expressed interest in taking a minimum amount of data at 3.5 TeV (~10-100/pb)
  - Transition from 3.5 TeV and 5 TeV to be rediscussed later on (early 2010?), based on experience

The experiments

"Experiments desiderata "
Chamonix workshop 2009
http://cdsweb.cern.ch/record/1172831?ln=en

- ... are ready to take data!
- Very keen to see first collisions
- With >100 pb^{-1} good data at E≥3.5 TeV/beam ⇒ LHC experiments can start competing at the physics frontier
  - new limits set on hypothetical particles, or even discoveries possible!
  - Higgs masses around 160 GeV, B-physics, top physics...
- With 1 fb^{-1} g.d. at 5 TeV/beam ⇒ find Higgs if around 160 GeV mass
- Of course, the higher the energy, the faster it should go

What peak luminosity do we need ?

in order to well exceed 100 pb^{-1} integrated luminosity

and assuming:

- run length = 10 months
- overall effficiency ~0.1
  (including lumi decay)

we need a

- luminosity of at least ~ 10^{32} s^{-1} cm^{-2}

$$L = \frac{f \; k_b \; N^2}{4\pi \; (\varepsilon_n/\gamma) \; \beta^*}$$

f = revolution frequency = 11245 Hz
k_b = number of colliding bunch pairs
N = bunch population
ε_n = normalised transverse emittance
γ = Lorentz factor
β^* = optics function at IP
negligible geometric factor for 2009-2010

A few initial fill patterns

- 43x43
  - ΔT = 2us
  - α=0 possible
  - IP8 max 21 collisions

displaced	0	4 (asym)	4 (sym)	11 (sym)	19 (sym)
IP1	43	39	43	43	43
IP2	42	38	34	21	4
IP5	43	39	43	43	43
IP8	0	4	4	11	19

Table 3: Number of collisions for 43 bunches in the four collision points.

- 156x156
  - ΔT = 0.5us
  - α=0 possible
  - IP8 max 72 collisions

	no bunches displaced	option 1	option 2
collisions in IP1	156	156	156
collisions in IP2	152	76	16
collisions in IP5	156	156	156
collisions in IP8	0	36	68

Table 4: Number of collisions for 156 bunches in the four collision points.

- 50ns
  - ΔT = 50ns
  - α=0 not possible

	a	b	c	d	e
IP1	1404	1404	1404	1404	1333
IP2	1368	684	0	72	2
IP5	1404	1404	1404	1404	1333
DELPHI	1368	684	0	72	2
IP8	0	655	1311	1242	1173

Table 5: Number of collisions with 50 ns spacing in the four collision points.

Input from the LHC expts...

... on lumi strategy

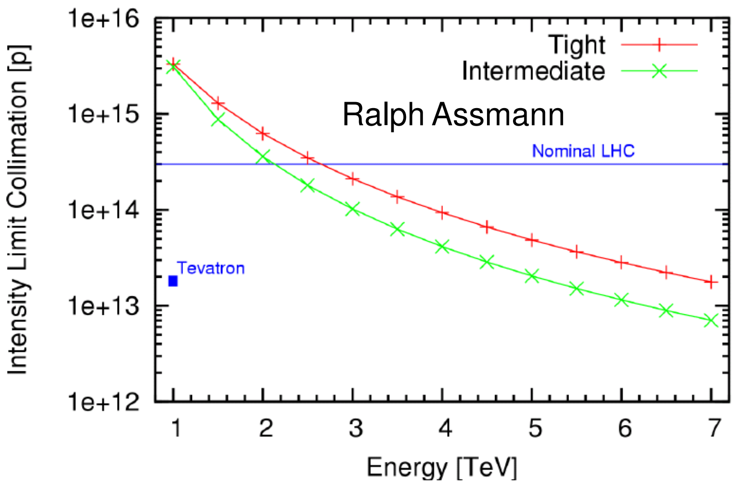
- **ATLAS and CMS**: highest possible lumi, even if average number of inelastic interactions of μ = 7 (which we very probably never exceed in 2010)
- **ALICE**: two different running modes with typically very low lumi (2 to 10e28 and 1 to 5e30) and low pile-up per crossing (μ ~ 0.1 or smaller), for example
  - in equidistant schemes: L = 2...10e28 , $\mu < 0.15$
    - k_b=1-4, N~5e10, β^*=10m (largest possible bunch spacing)
  - in 50ns trains: L = 1...5e29 , $\mu < 0.05$
    - k_b=24, N~1.5e10, β^*=3m , bunch spacing 150ns
- **LHCb**: "medium lumi" ~ few e32 => as much as ATLAS and CMS for this run, but keep pile-up at reasonable level (nominally μ ~ 1, but may try working with higher pile-up)
  - large benefit from going to 50ns trains asap
- **TOTEM and LHCf**: special short runs (typ. of order few days/hours)

Optimal number of bunches for peak lumi at 3.5 TeV

- I_{max} = 6e13 … 15e13 protons/beam
- N_{max} = 5e10 … 10e10 protons/bunch

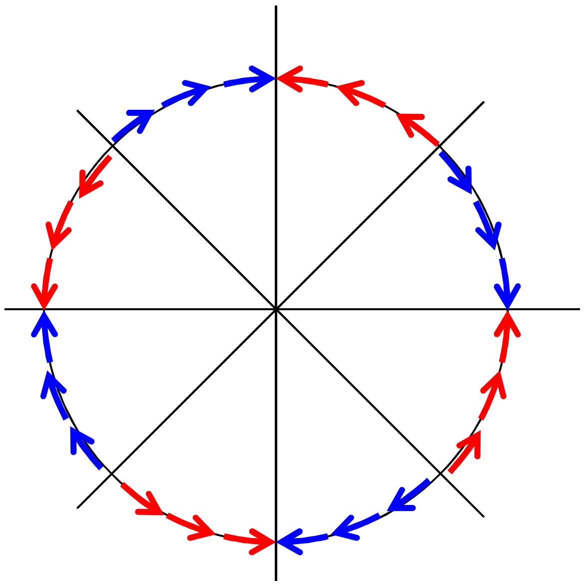
- K_{opt} = I_{max} / N_{max}
  = ~ 3000 … 600 bunches > 156

==> crossing angle should pay off quickly !!

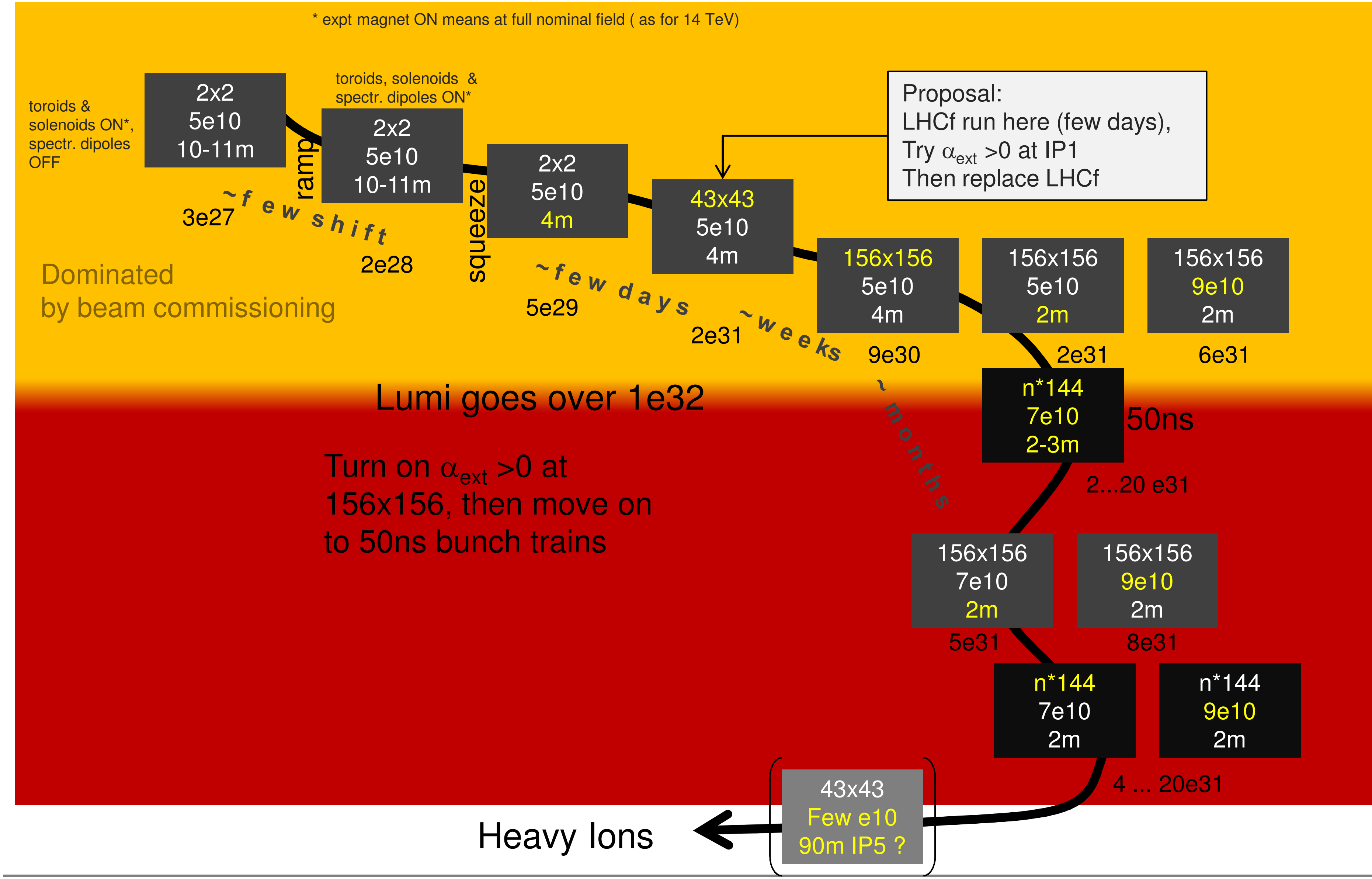


Baseline for crossing angle: Truncated 50 ns

- Allows nicely sharing number of colliding pairs between all Expts
  - Add special ALICE bunches (150ns ?)
    - Tailored lumi w/o defocusing & separation ?
- Start with one 36-bunch train per quadrant
- All bunches see immediately the maximum number of long-range collisions
- Then add more trains to increase intensity without increasing beam-beam effects

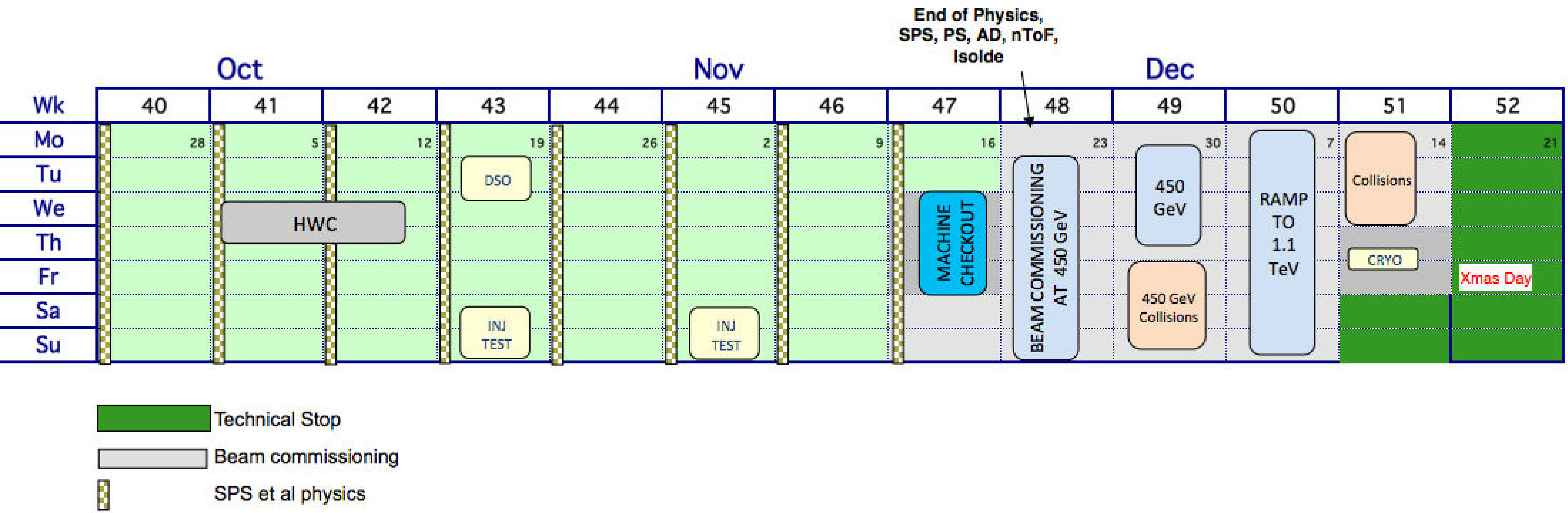


Grand plan


* expt magnet ON means at full nominal field (as for 14 TeV)
toroids & solenoids ON*, spectr. dipoles OFF
2x2 5e10 10-11m
ramp
toroids, solenoids & spectr. dipoles ON*
2x2 5e10 10-11m
squeeze
2x2 5e10 4m
43x43 5e10 4m
Proposal:
LHCf run here (few days),
Try α_{ext} >0 at IP1
Then replace LHCf
156x156 5e10 4m
156x156 5e10 2m
156x156 9e10 2m
~few shift
3e27
2e28
Dominated
by beam commissioning
~few days
5e29
2e31
~weeks
9e30
2e31
6e31
Lumi goes over 1e32
~months
n*144 7e10 2-3m
50ns
2...20 e31
Turn on α_{ext} >0 at
156x156, then move on
to 50ns bunch trains
156x156 7e10 2m
156x156 9e10 2m
5e31
8e31
n*144 7e10 2m
n*144 9e10 2m
4 ... 20e31
43x43 Few e10 90m IP5 ?
Heavy Ions

Up to date schedule till end of 2009

- complete HW cmg to 2 kA (1.1 TeV) by ~16 Nov and make beams
- 450 GeV collisions, study ramp (E<1.1 TeV), possibly collisions at 1.1 TeV/beam



- 2010: complete HW cmg to 6 kA and move on to 3.5 TeV

Filling schemes

- "**Standard Filling Schemes for Various LHC Operation Modes**"
  http://cdsweb.cern.ch/record/691782
  - equidistant 43x43, 156x156
  - 75 ns , 25 ns
  - ions: equidistant 62x62, 100 ns

  nominal

- "**LHC bunch filling schemes for commissioning and initial luminosity optimization**"
  http://cdsweb.cern.ch/record/1114612
  - revisited 43x43 and 156x156
  - 50 ns

  new sharing of collisions between IP2/IP8
  - IP2: no defocusing/displacement required while keeping luminosity and pile-up acceptable
  - IP8: more collisions

- "**Options and preferences for proton running**"
  http://cdsweb.cern.ch/record/1172832?ln=en
  - truncated 50ns

  increase intensity while keeping long-range beam-beam effects unchanged

thank you

Experimental magnets (see also https://cern.ch/lpc)

- **"The Effects of Solenoids and Dipole Magnets of LHC Experiments"**
  http://cdsweb.cern.ch/record/974594?ln=en

- **"How do we have to operate the LHCb spectrometer magnet?"**
  http://cdsweb.cern.ch/record/1159131?ln=en