Integrated luminosity scenarios

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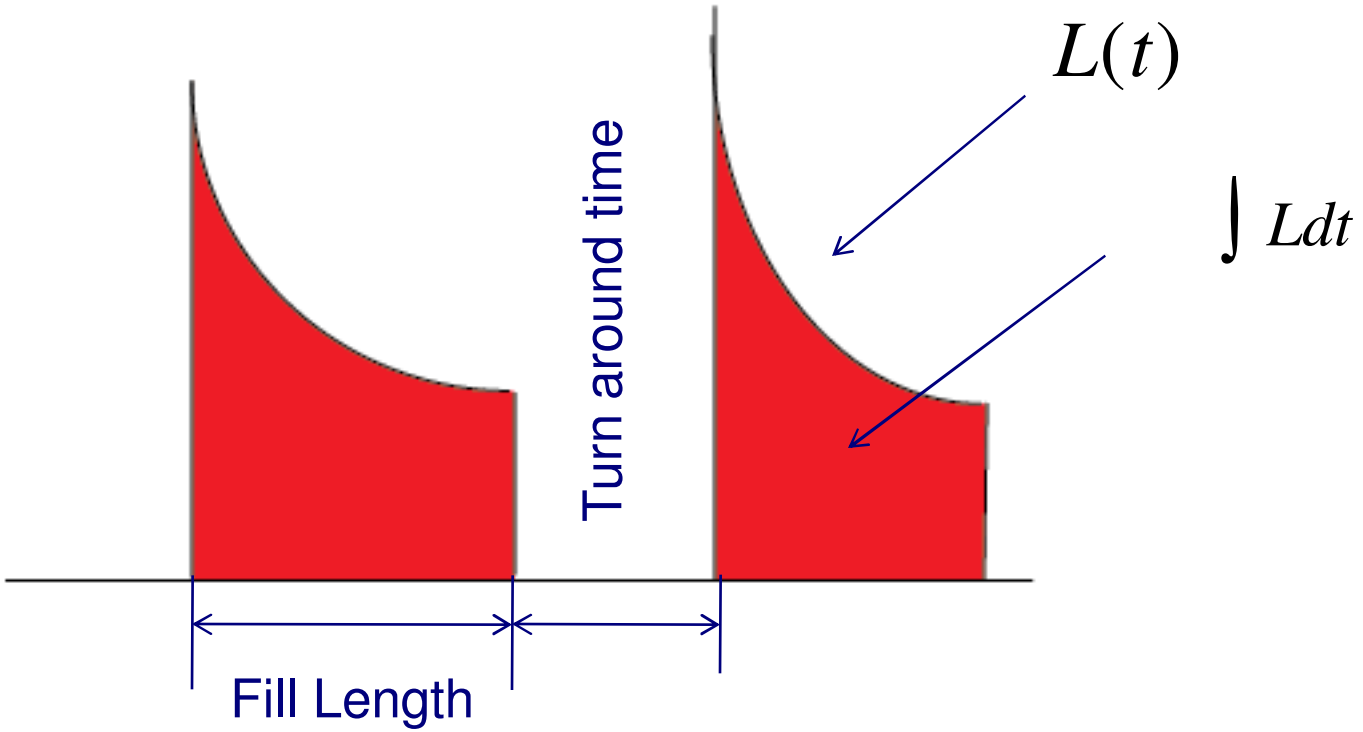
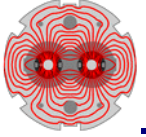
Thanks for discussion: R. Assmann, R. Bailey, M. Ferro-Luzzi, S. Fartoukh, O. Bruning

Luminosity estimates

$$\tau_L = \frac{1}{\frac{1}{2\tau_{IBS}^x} + \frac{2}{\tau_{gas}} + \frac{1.54}{\tau_N}}$$

$$\tau_N = \frac{n_b N_b}{2L\sigma_{TOT}}$$





Luminosity estimates

- Calculate peak luminosity given the usual inputs
  - Bunch current, number of bunches, emittance, beta*, crossing angle
- Calculate luminosity lifetime given
  - Luminosity, cross-section
  - Beam-gas lifetime
  - IBS growth rates
- Optimize fill length given an assumed turnaround time
- Given fill length & luminosity lifetime – calculate integrated luminosity per fill
- Multiply up

Beam in not equal beam into physics

Injection	Losses at injection: injection oscillations, RF capture
Injection plateau	Big beams, lower dynamic aperture, full buckets, un-captured beam, long range beam-beam, crossing angles, persistent current decay. 10 hours lifetime will be good
Start ramp	Un-captured beam lost immediately we start the ramp Snapback: chromaticity, tunes all over the place
Ramp	Things should calm down
Squeeze	Tunes, chromaticity, collimator, TCDQ adjustments – expect some lifetime dips
Collide	Beam finding, background optimization
Physics	Collisions, beam-gas, halo production etc.
Adjust	Squeezing IR8, roman pot adjustment

Turn around time

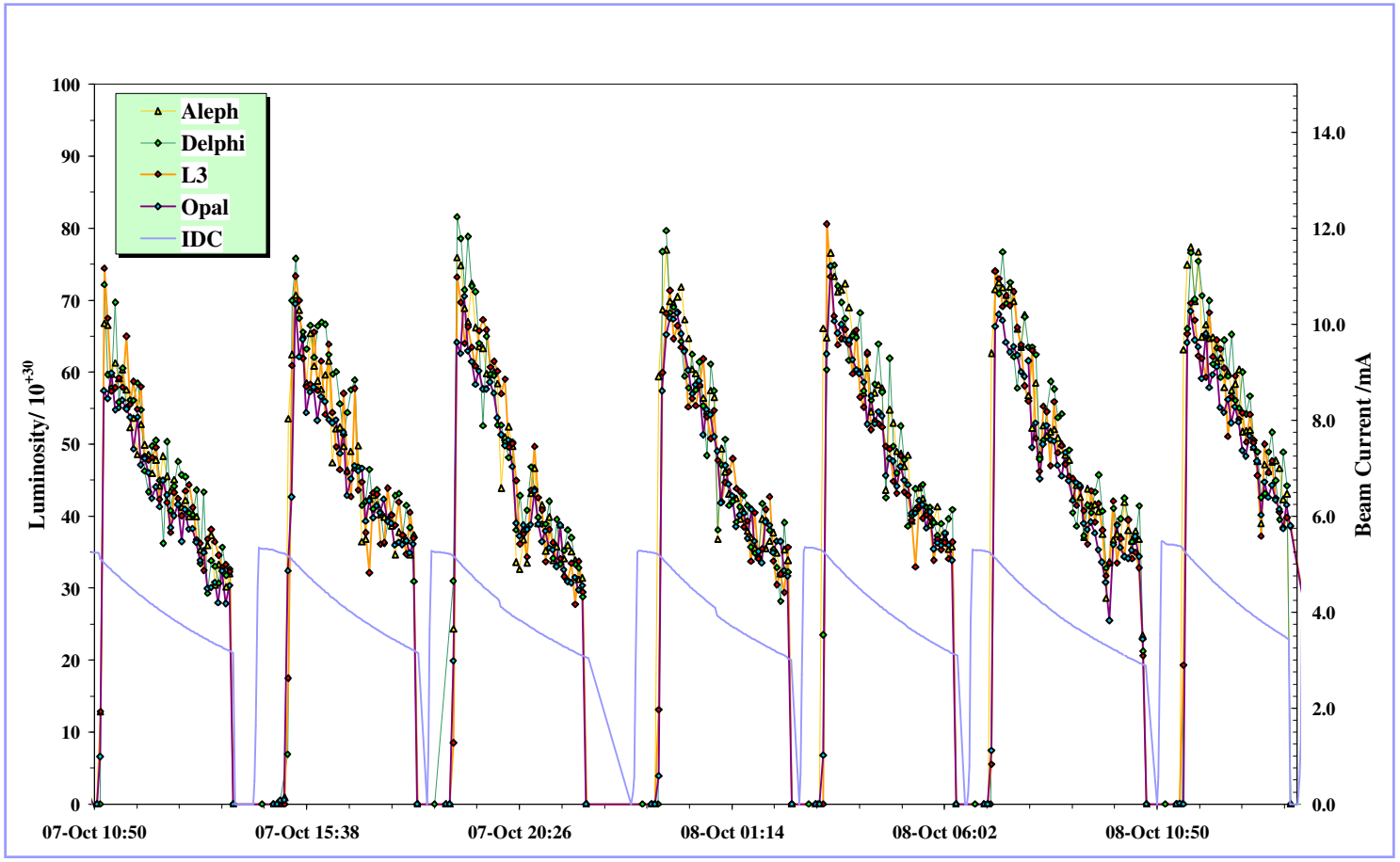
Physics to physics

Phase	Time [mins]
Ramp down and pre-cycle	60
Pre-injection preparation and checks	15
Checks with set-up beam (tunes, orbit etc.)	15
Nominal injection sequence	20
Ramp preparation	5
Ramp	25
Squeeze	30
Adjust	10
TOTAL	180

~ 3 hour minimum. Assume 4 hours here – optimism bias

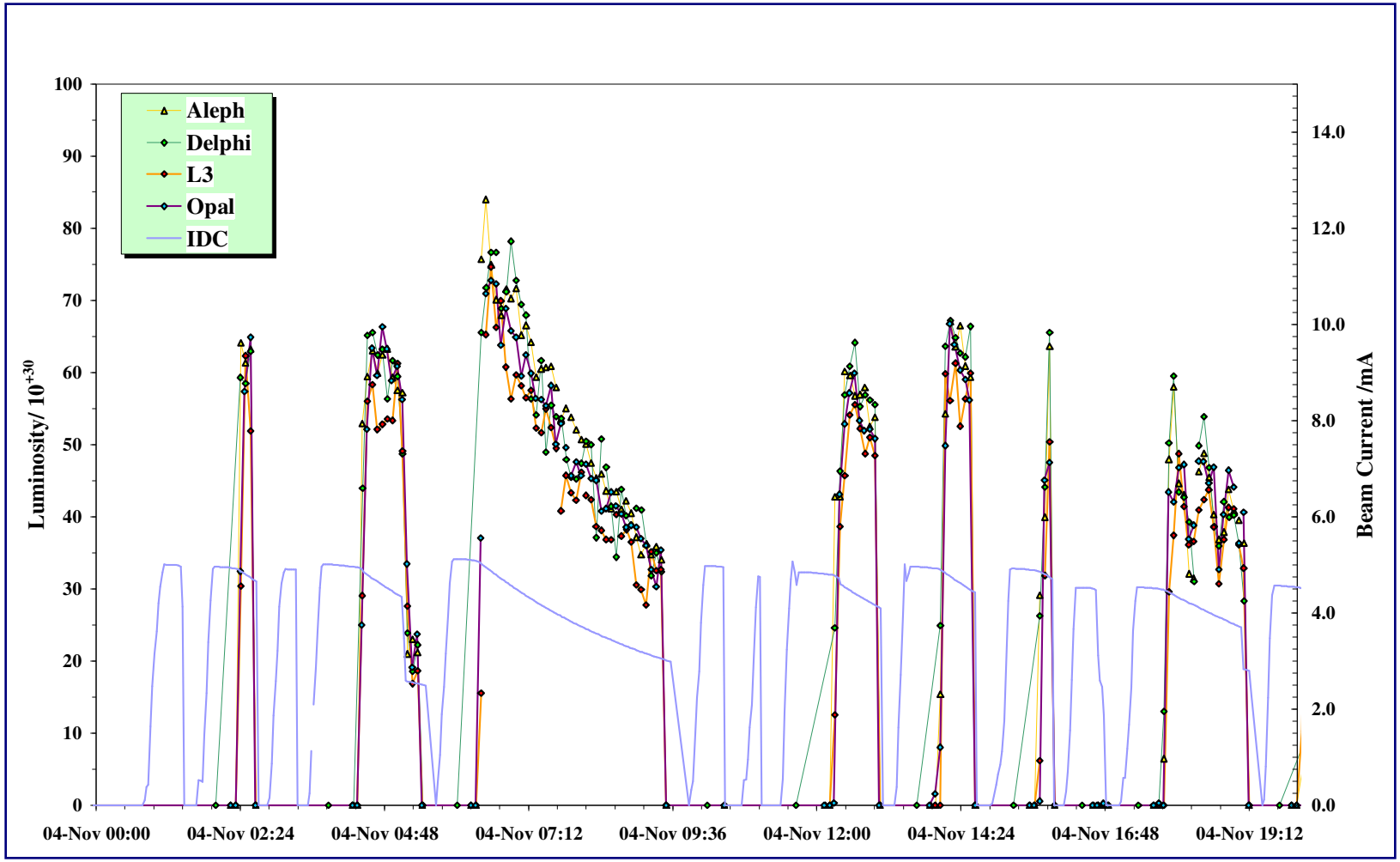
LEP

- No-one ever thought it could be as smooth as:

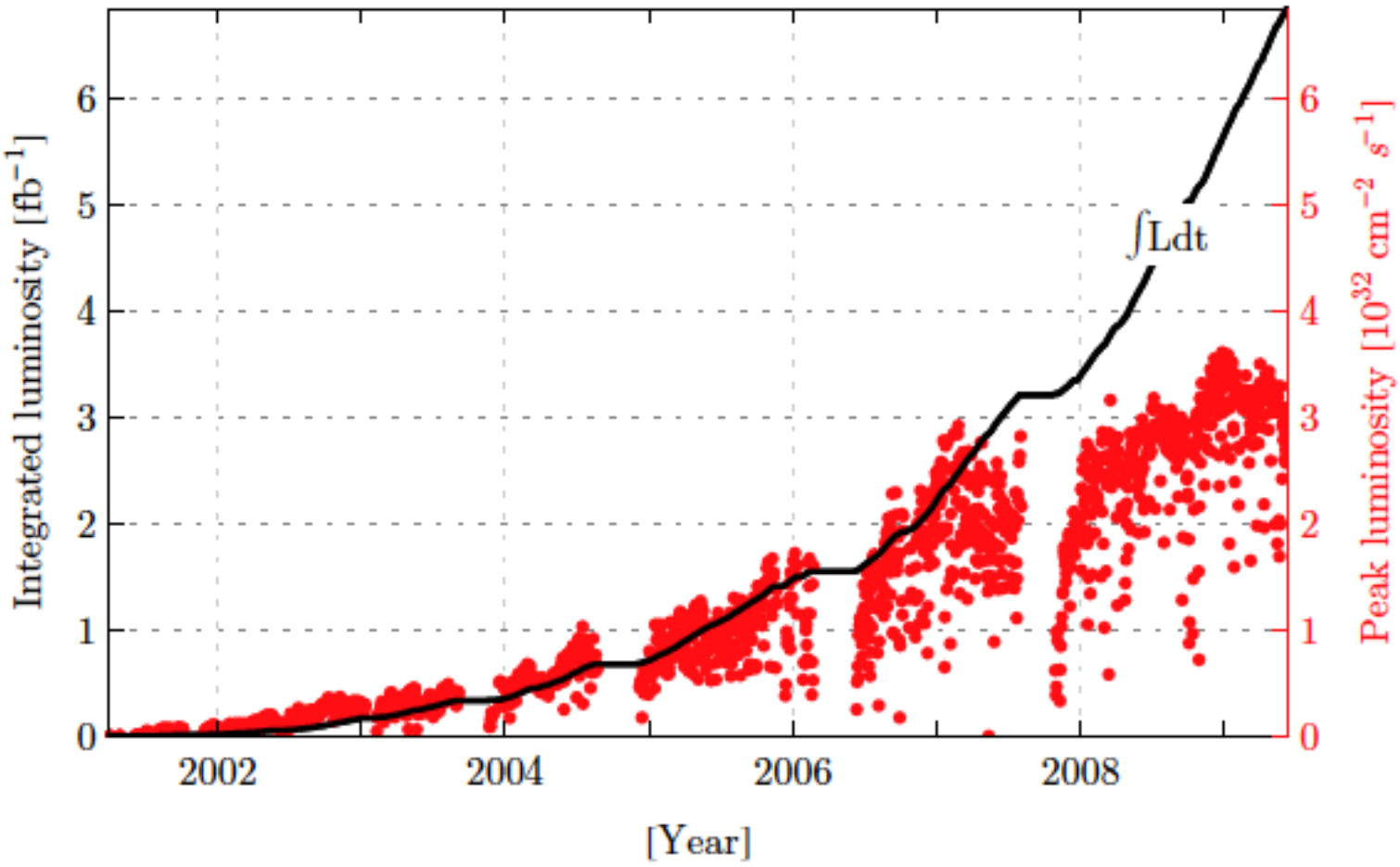


Less than one hour turn around (after 8 years' optimization)

Of course it wasn't always as good as that



Run II


Integrated luminosity [fb^{-1}]
Peak luminosity [10^{32} cm^{-2} s^{-1}]
$\int$Ldt
0
1
2
3
4
5
6
2002
2004
2006
2008
[Year]

Operation month/year

After a year or so…

- 30 days per month
- 3 day technical stop & recovery
- [~2 days machine development]
  - Absorbed into unavailability for this exercise
- 60% machine availability
  - During which time we are dedicated to trying to do physics

- 4 weeks of ions (plus one week setup)
- Other requests e.g. Totem
- Shutdown
  - 3 months
- Assume around 7 months proton physics
  - approx. 200 days

OUT WITH THE CRYSTAL BALL

2010

Step	E [TeV]	Fill scheme	N	β* [m] IP1 / 2 / 5 / 8	Run time (indicative)
1	0.45	2x2	$5x10^{10}$	11 / 10 / 11 / 10	
2	3.5	2x2	2 - $5x10^{10}$	11 / 10 / 11 / 10	Weeks
3	3.5	2x2*	2 - $5x10^{10}$	2 / 10 / 2 / 2	
4	3.5	43x43	$5x10^{10}$	2 / 10 / 2 / 2	Weeks/Months
5	3.5	156x156	$5x10^{10}$	2 / 10 / 2 / 2	
6	3.5	156x156	$9x10^{10}$	2 / 10 / 2 / 2	
7	3.5	50 ns - 144**	$7x10^{10}$	2.5 / 3 / 2.5 / 3	Months
8	3.5	50 ns - 288	$7x10^{10}$	2.5 / 3 / 2.5 / 3	
9	3.5	50 ns - 720	$7x10^{10}$	2.5 / 3 / 2.5 / 3	Months

* Turn on crossing angle at IP1.

**Turn on crossing angle at all IPs.

One month: 720 bunches of 7 e10 at beta* = 2.5 m. gives a peak luminosity of 1.2 e32 $cm^{-2}s^{-1}$ and an integrated of about 105 pb^{-1} per month

[15% nominal – 28 MJ]

2011

Decision made to run through 2010/2011 at 3.5 TeV
Followed by long shutdown (1 year++) to consolidate splices

3.5 TeV: run flat out at ~100 pb^{-1} per month

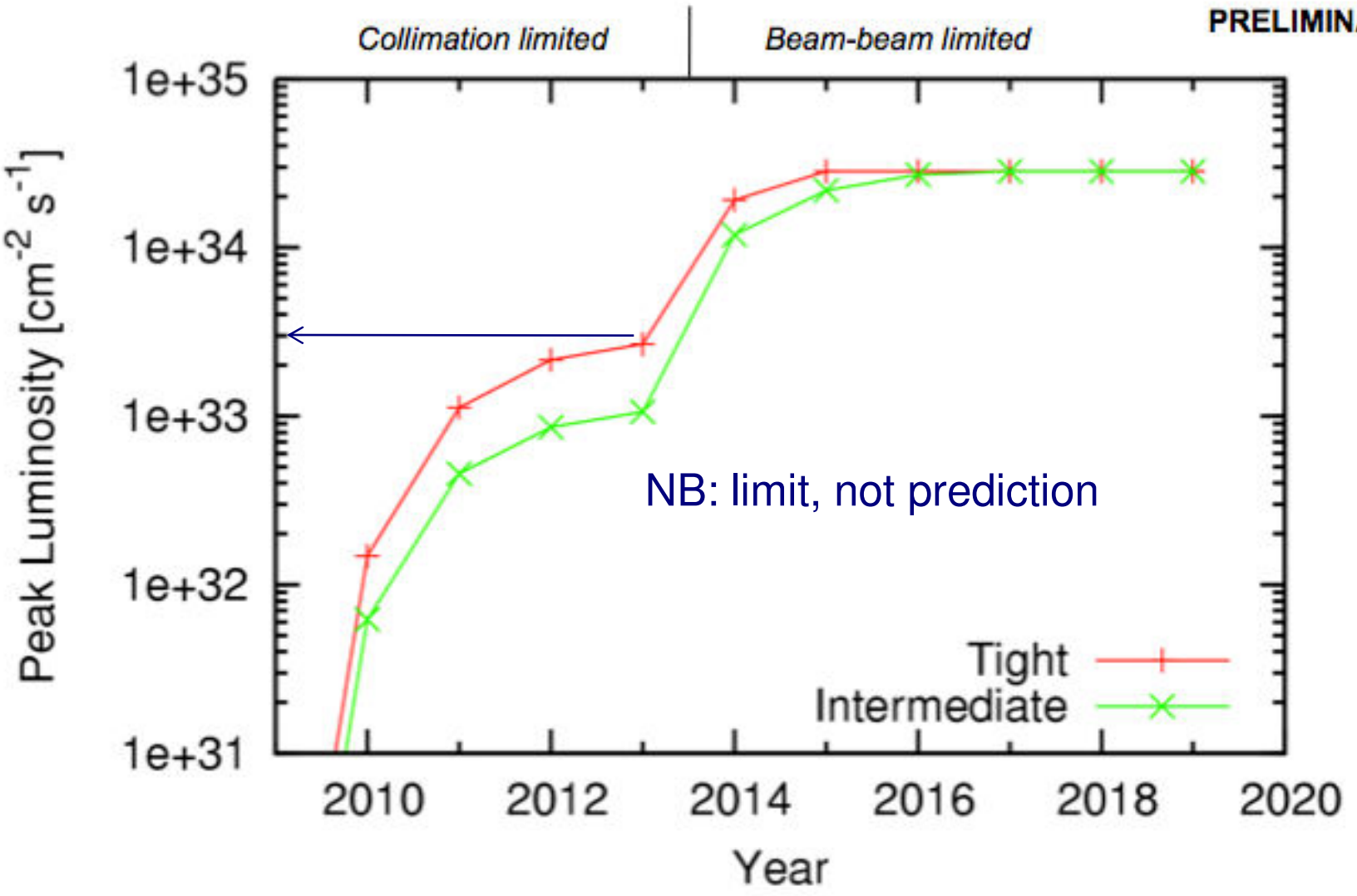
	No. bunches	ppb	Total Intensity	beta*	Peak Lumi	Int Lumi per month [pb^{-1}]
50 ns	432	7 e10	3 e13	2	1.3 e32	~85
Pushing intensity limit	720	7 e10	5.1 e13	2	2.2 e32	~140
Pushing bunch current limit	432	11 e10	4.8 e13	2	3.3 e32	~209

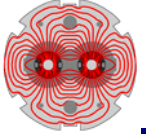
Should be able to deliver around 1 fb^{-1}

Constraints to 2015

- Energy
  - Sort out the splices in one go – takes out 2012+
  - Should open the way to 6.5/7 TeV
- Beam intensity limits from collimation phase 1
  - 40% maximum – less with imperfections
  - 2012 + X: modification of IRs
  - 2012 + X + 1: Cryo collimators buys nominal intensity
  - 2014/2015: Full phase 2 buys nominal and ultimate intensity
- Due respect to destructive power of the beams

Result: Peak Luminosity versus Time (Scenario 1)





To 2014

- Two years at 3.5 TeV
- 2010: should peak at 10^{32} and yield around 0.1 - 0.2 fb^{-1}
- 2011: total 1 fb^{-1} at 3.5 TeV
- 2012: splice consolidation (and cryo collimator prep.)
- 2013: 6.5 TeV - 25% nominal intensity
- 2014: 7 TeV – 50% nominal intensity

} Aggressive

Year	Months	energy	beta	ib	nb	Peak Lumi	Lumi per month	Int Lumi Year	Int Lumi Cul
2010	8	3.5	2.5	7 e10	720	1.2 e32	-	0.2	0.2
2011	8	3.5	2.5	7 e10	720	1.2 e32	0.1	0.8	1.0
2012									
2013	6	6.5	1	1.1 e11	720	1.4 e33	1.1	7	8
2014	7	7	1	1.1 e11	1404	3.0 e33	2.3	16	24

Hubner factor ~ 0.3

Independent estimate

Courtesy of a rather pessimistic but perhaps more realistic Massi Ferro-Luzzi

Year	Months	energy	beta	ib	nb	Peak Lumi	Lumi per month	Int Lumi Year	Int Lumi Cul
2010	6	3.5	2.5	7 e10	720	1.0 e32	-	0.1	0.1
2011	9	3.5	2.5	9 e10	720	2.0 e32	0.1	1	1.1
2012									
2013	6	6.5	1	9 e10	720	9 e32	0.45	2.7	3.8
2014	9	6.5	1	9 e10	1404	1.7 e33	0.6	5.3	9.1

At least in the same ball park

Hubner Factor ~ 0.2

2015 - 2020?

- Arrive at end 2014 (with a bit of luck)
  - 7 TeV
  - 30% nominal performance
  - Between 10 - 30 fb^{-1} in the bag
  - Cryo collimators in – good for nominal
- On the schedule
  - LINAC4 (lose 6 months of proton physics)
  - Collimators phase 2 (shutdown)
  - Phase 1 upgrade (1 year shutdown plus re-commissioning)

2015 - 2020?

- Statistical error halving time
  - Accumulate x fb^{-1} per year
  - A naïve 3 more years at the same rate to halve the error
  - Flat lining soon becomes uninteresting
  - However, we're hardly flat-lining at this stage
  - Clear that having yet to achieve nominal performance, another major shutdown would not be optimal at this stage

2015 – 2016 to nominal

2015: Take a 6 month hit for LINAC4 & collimators phase 2, say,
[leave the phase 1 upgrade for the moment]

Optimist

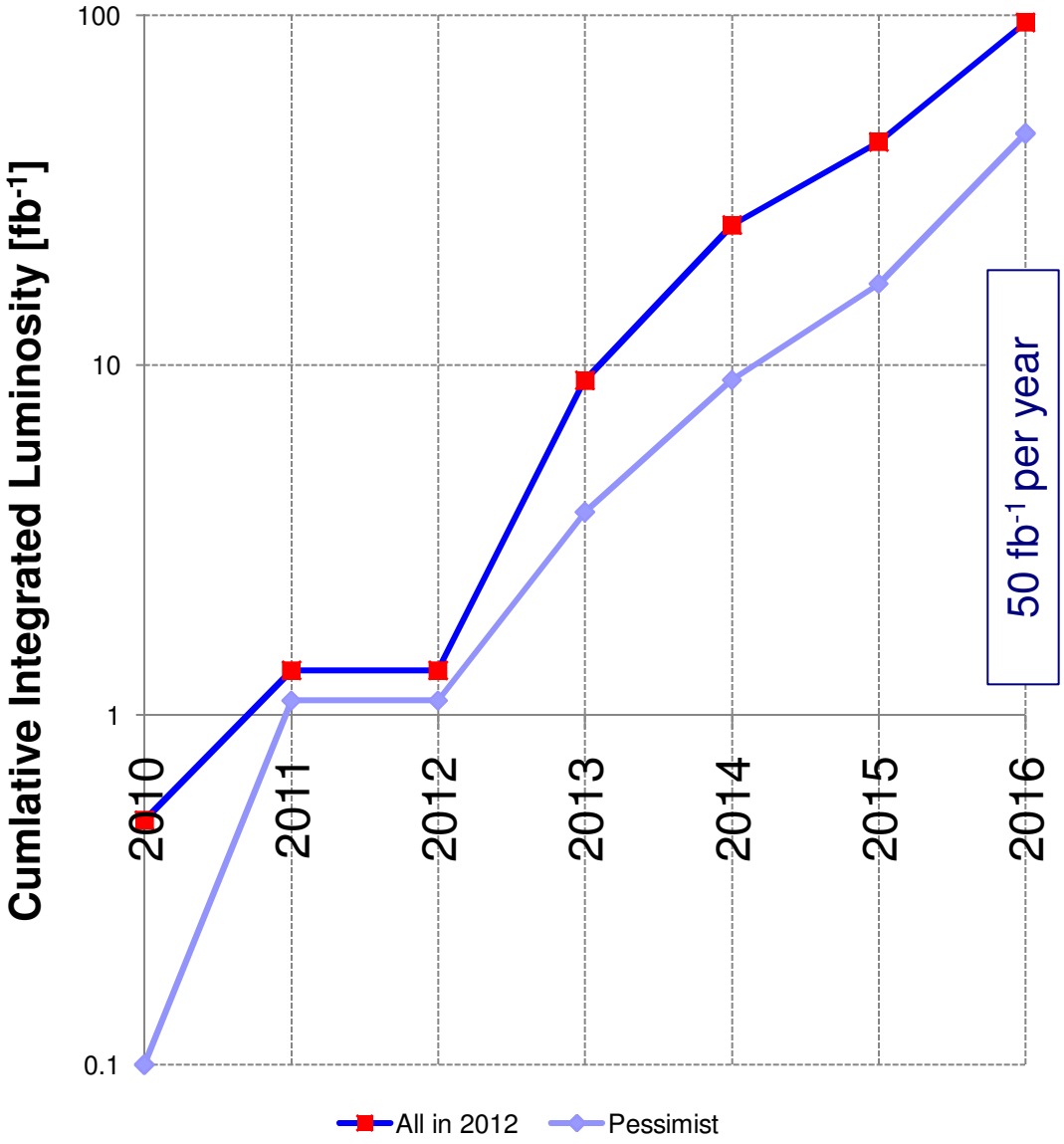
Year	Months	energy	beta	ib	nb	Peak Lumi	Lumi per month	Int Lumi Year	Int Lumi Cul
2015	4	7	1	11 e10	2808	6 e33	4.6	18	43
2016	7	7	0.55	11 e10	2808	1 e34	7.4	52	96

Might hope to hit nominal in 2016

Massi

Year	Months	energy	beta	ib	nb	Peak Lumi	Lumi per month	Int Lumi Year	Int Lumi Cul
2015	4	7	1	9 e10	2808	3.6 e33	2	8	17
2016	9	7	0.55	9 e10	2808	6.2 e33	3.2	29	46

2010 - 2016


Cumlative Integrated Luminosity [fb-1]
100
10
1
0.1
2010
2011
2012
2013
2014
2015
2016
50 fb-1 per year
All in 2012
Pessimist

Beyond 2016

- Assumptions
  - PS at increased injection energy plus LINAC4 are good for ultimate (after a suitable commissioning period)
  - ~1.7 x 10^{11} can be swallowed by the SPS
    - Give or take a long shutdown
  - LHC can swallow ultimate intensity
    - "Ultimate intensity is challenging for the LHC. Many systems at technological limits with little or no margin."

      (R. Assmann – Cham 2010)

Then contemplate

On paper

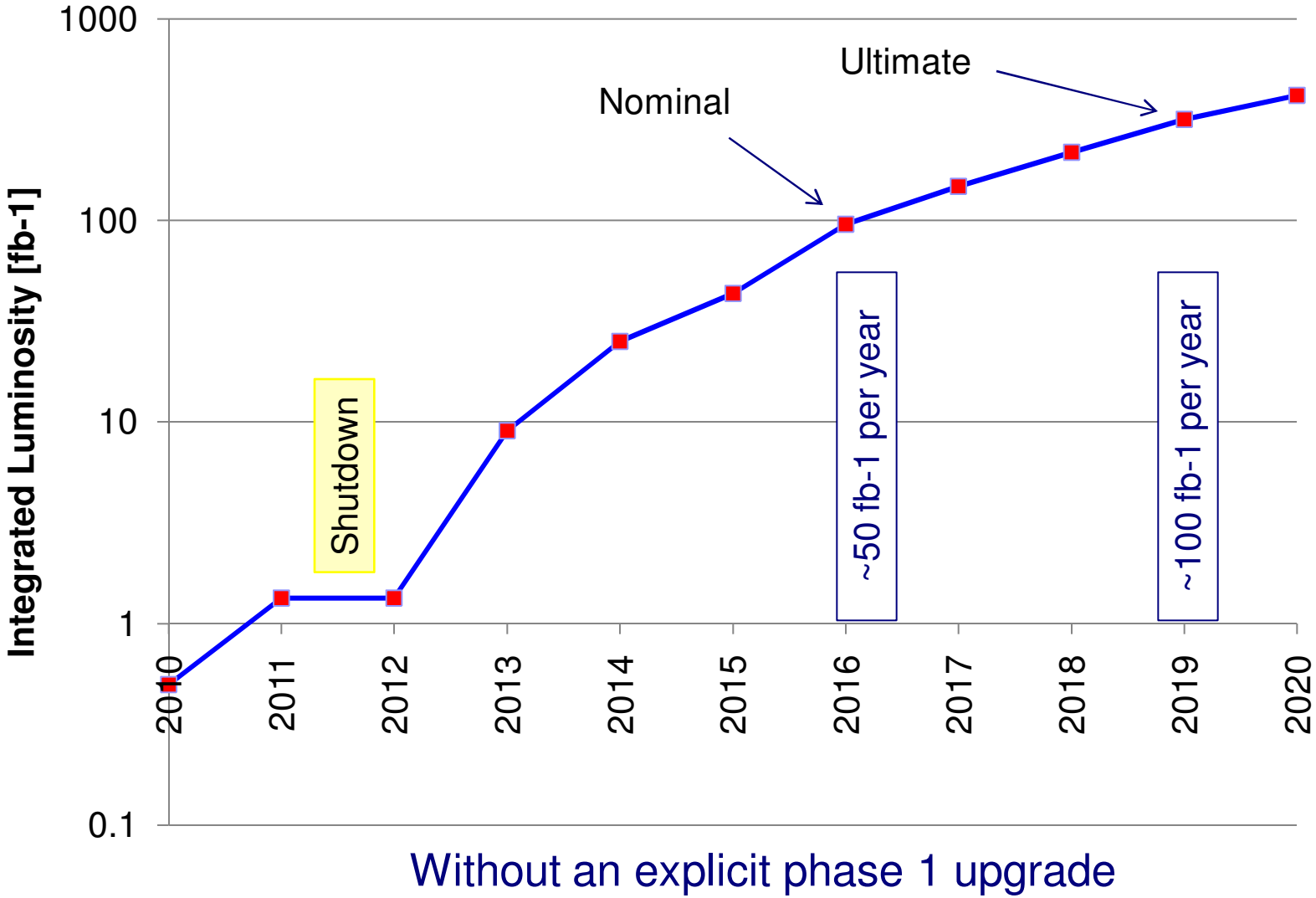
	ppb	beta*	Xing angle	Peak lumi	Int. lumi per month [fb-1]	~per 7 month year [fb-1]
Nominal	1.15 e11	0.5 5	285	1 e34	7.2	50
Ultimate	1.7 e11	0.5 5	315	2.1 e34	14.2	100
Phase 1*	1.15 e11	0.4	410	1.1 e34	7.8	55
Phase 1 Ultimate*	1.7 e11	0.4	560	2.0 e34	14	100

Have to be very careful with these numbers
– read between the lines

* Stephane Fartoukh – "robust"

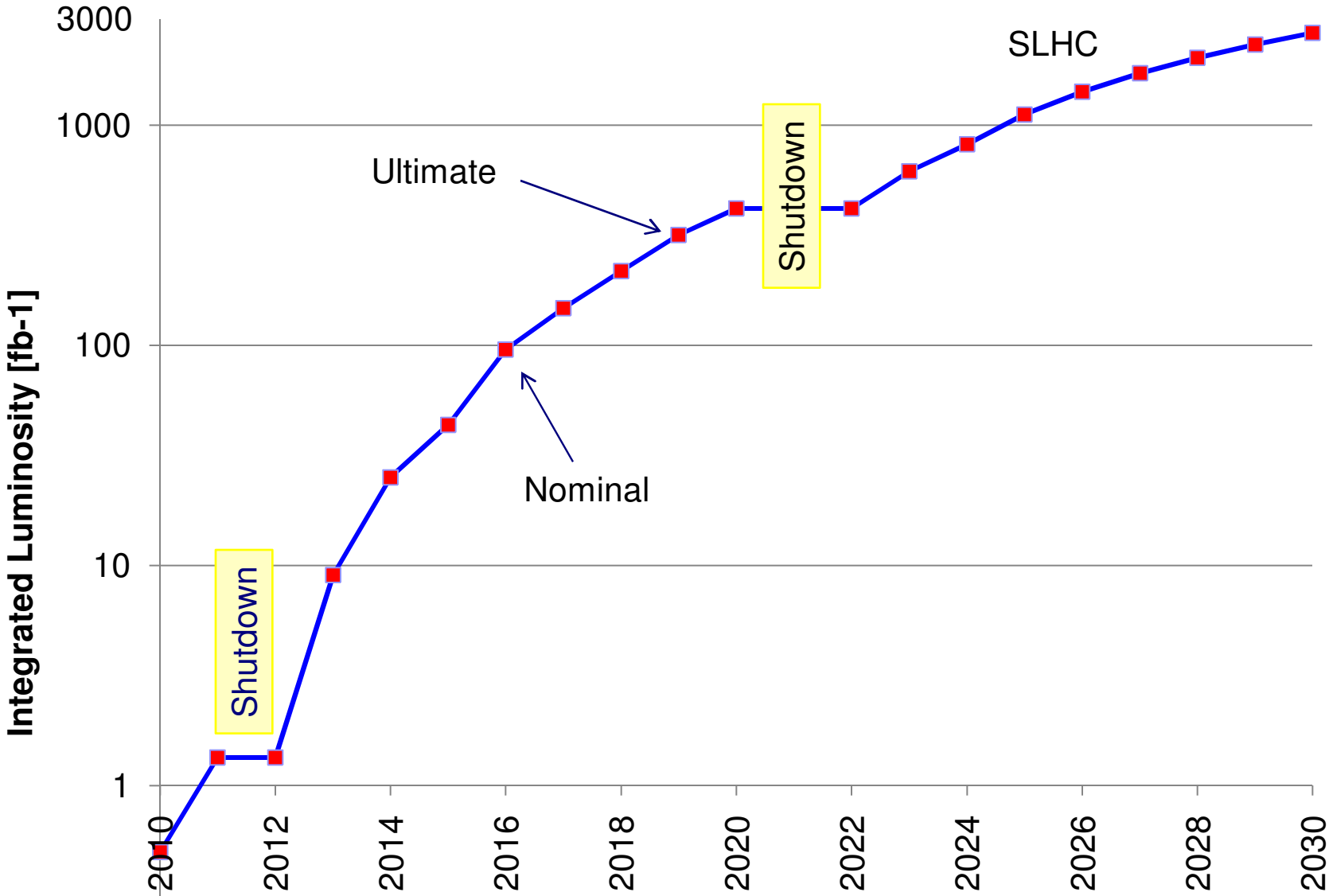
A very optimistic path to 2020

Pushing to nominal in 2016 and taking a couple of years to get to ultimate



Without an explicit phase 1 upgrade

Choose your favourite SLHC option…



Conclusions

- Luminosity estimates for the next ten years presented
- Must note that the LHC has taken a 3 year hit (at least) from 19th September incident
- Biased towards the optimistic side of realistic
  - Nominal performance by 2016
  - 21st century Hubner factors
- Big errors bars and numbers should be treated with care particularly after 2016
- Important to gain some operational experience and gain practical confidence in the numbers.