Performance Evolution and Expectations Management: Lessons from Tevatron and Other Colliders

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Fermilab

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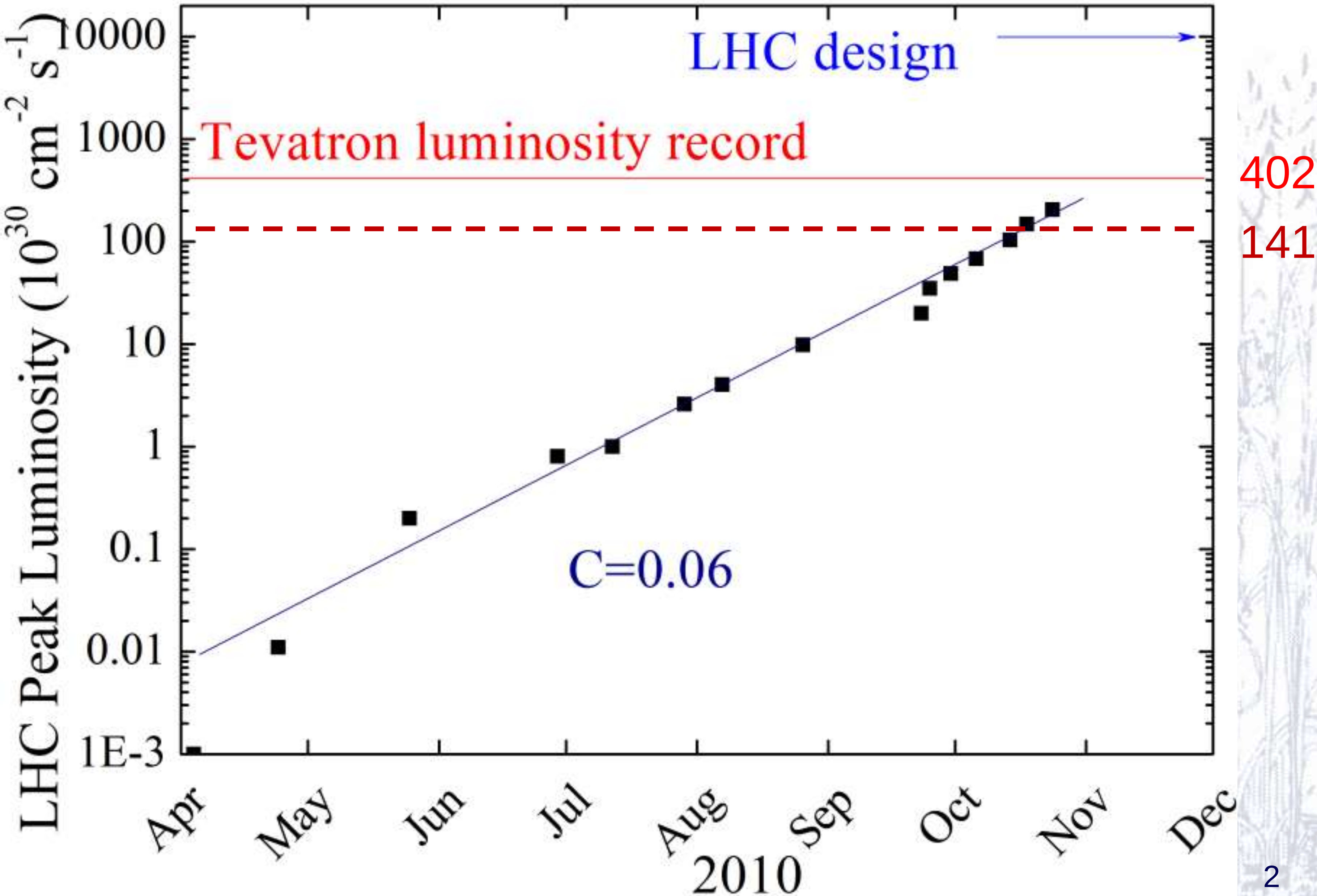
LHC 2010 Success in Numbers



What will LHC luminosity be in 2011-12? Later on.. in, say 2015? 2020? Can one learn anything from other machines?

- … Lucio asked me to present *"… a global comparison (thermodynamic view).."* on the subject
- Of course, that might make sense only if machines are not totally unique and comparable in some sense…

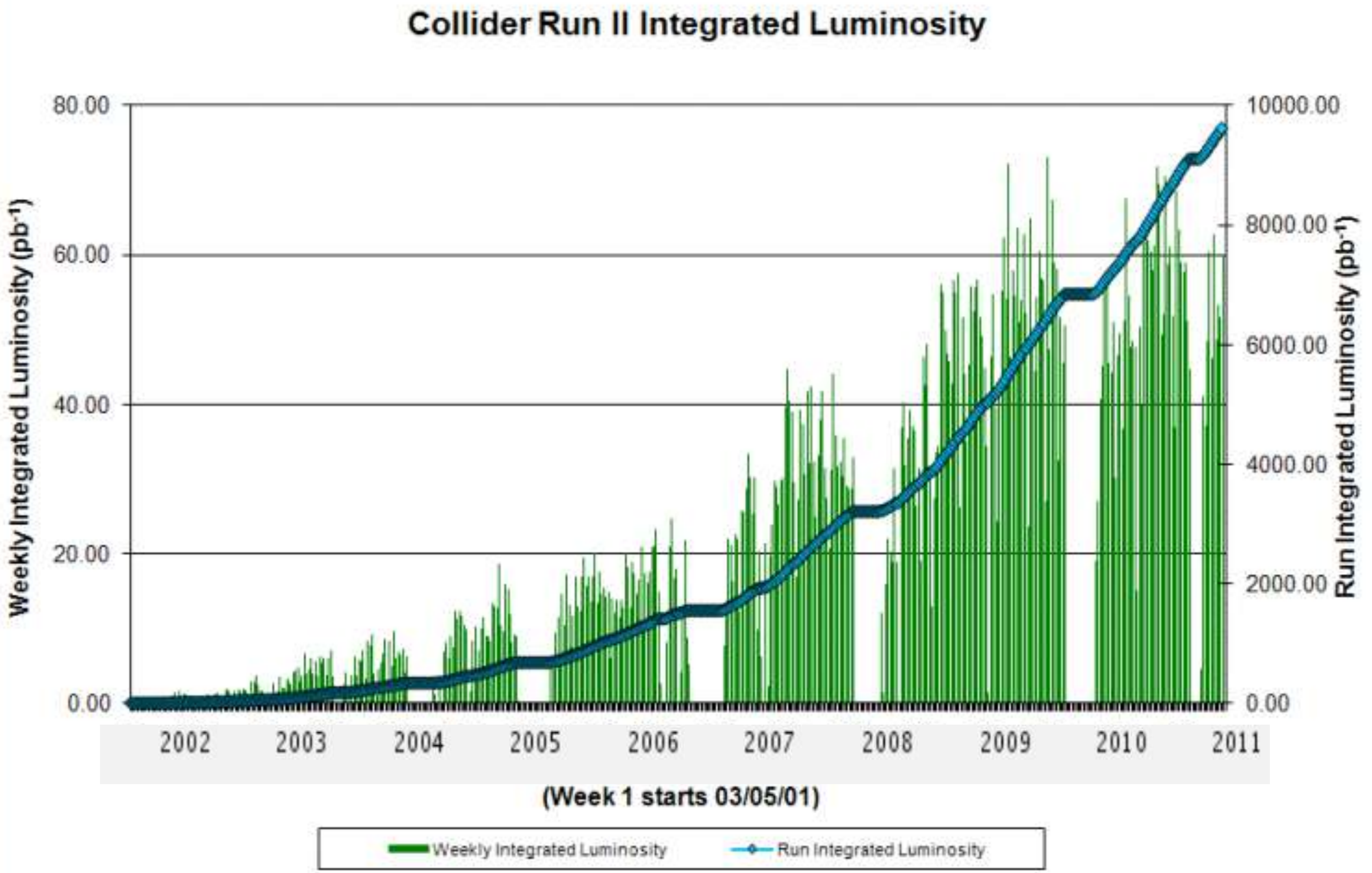
e.g. "apples and apples" or even "apples and oranges" are ~comparable while "apples and elephants" are not

High Luminosity Hadron Colliders: Side-by-Side Comparison

	TEV p-pbar	LHC p-p
State-of-the-art SC magnets	yes ~800	yes ~1800
(Old) Sophisticated injector chain	yes 6	yes 4
Antiproton production/storage/cooling	yes	no
Beam-beam effects limiting performance	yes	not yet?
Critical importance of collimation	~no	yes
Electron-cloud effects matter	no	yes
Space-Charge effects at low energies	yes	yes

Tevatron Performance

As of Jan'2011: >10 fb^{-1} total; about 2.4 fb^{-1} /year; 60+ pb^{-1} /week



Run II Luminosity Progress

Some **30** steps, no "silver bullet"

Improvement		Luminosity Increase
Pbar injection line AA → MI optics	12/2001	25%
Tevatron quenches on abort stopped by TEL-1	02/2002	0%, reliability
Pbar loss at Tevatron squeeze step 13 fixed	04/2002	40%
New Tevatron injection helix	05/2002	15%
New AA lattice reduces IBS, emittances	07/2002	40%
Tevatron injection lines tuned up (BLT)	09/2002	10%
Pbar coalescing improved in MI	10/2002	5%
Tevatron C0 Lambertson magnets removed	02/2003	15%
Tevatron sextupoles tuned/ SEMs taken out of pbar lines	06/2003	10%
New Tevatron helix on ramp, losses reduced	08/2003	2%
Tevatron magnets reshimming & realignment	12/2003	10%
MI dampers operations/ store length increased	02/2004	30%
2.5MHz AA → MI transfer improved/Cool shots	04/2004	8%
Reduction of β* to 35 cm	05/2004	20%
Antiprotons shots from both RR and AA	07/2004	8%
RR e-cooling operational	01-07/2005	~25%
Slip Stacking in MI	03/2005	~20%
Tevatron octupoles optimized at 150 GeV	04/2005	~5%
Reduction of of β* to 28 cm	09/2005	~10 %
"Pbar production task force"	02/2006	~10 %
Tevatron 150 GeV heliximproved, more protons	06/2006	~10 %
Tev collision helix improved, better lifetime	07/2006	~15 %
New RR WP, smaller pbar emittances	07/2006	~25 %
Fast transfers AA→RR (60→15min)	12/2006	~15%
New Pbar target/higher gradient	01/2007	~10%
Tevatron sextupoles for new WP	(2007?)	~10(?)%
Tevatron zero 2nd order chromaticity	2008	~5%?
Shot-setup time reduction/multi-bunch proton injection	2008-09	~5%?
Scraping protons in MI	2008	~10%?
Pbar size dilution at collisions/B0 aperture increased	2008	5%?
Booster proton emittances reduced /P,A1lines tuneup	Apr 2010	10%?

Overall factor of **30** luminosity increase

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Tevatron Exponential Progress

….that makes an average ~12.5% increase per step

$$Gain\ after\ 8\ steps\ (1+0.125)^8 \approx e$$

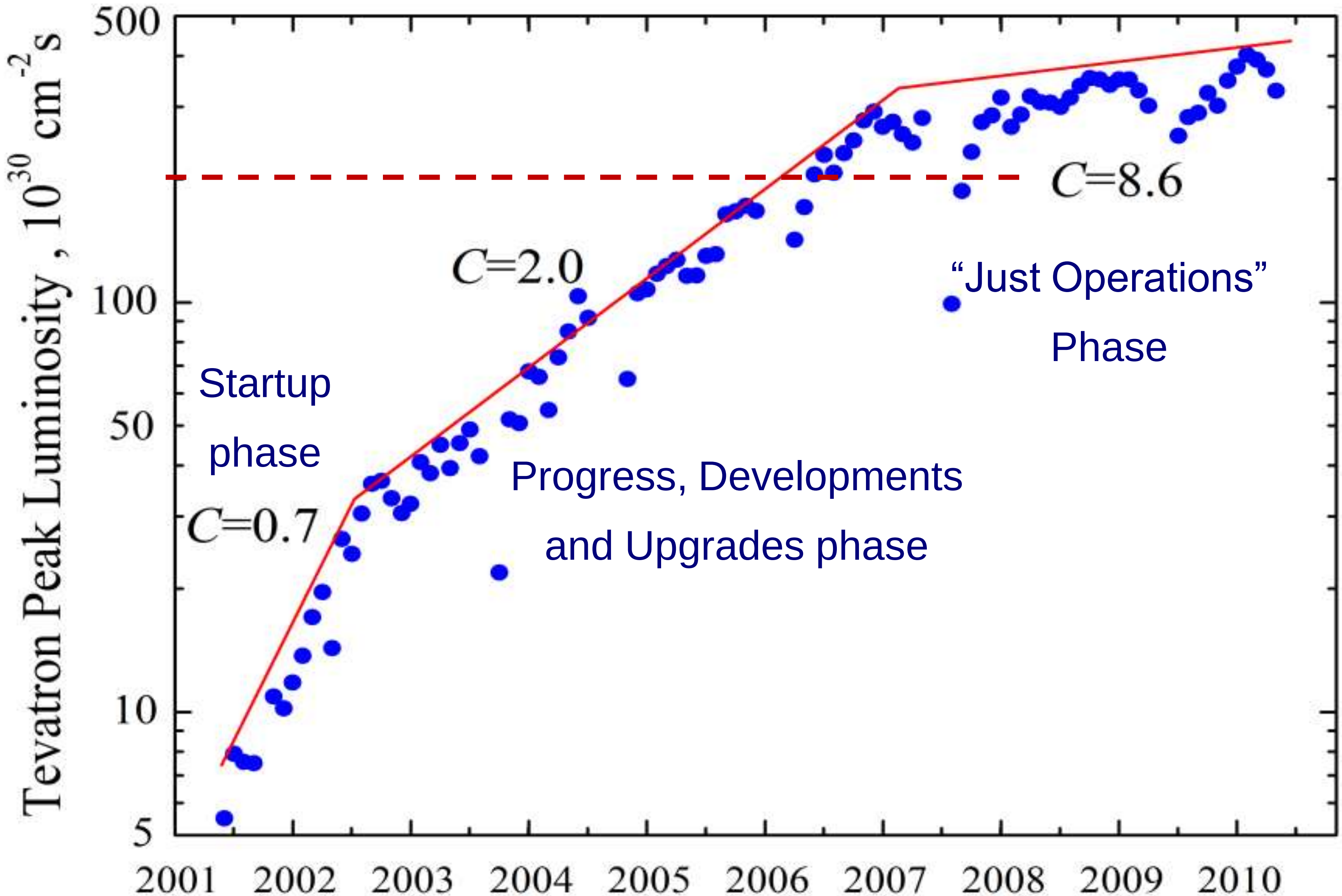
$$after\ 16\ steps\ (1+0.125)^{16} \approx e^2, \text{etc.}$$

So, due to regular improvements the evolution was

$$L(after\ \ time\ T) = L_0 \times \exp(T/C)$$

C (Complexity) = time [years] to **e**-fold

Tevatron Run II "Complexity"



"CPT Theorem for Accelerators"

$$C \times P = T$$

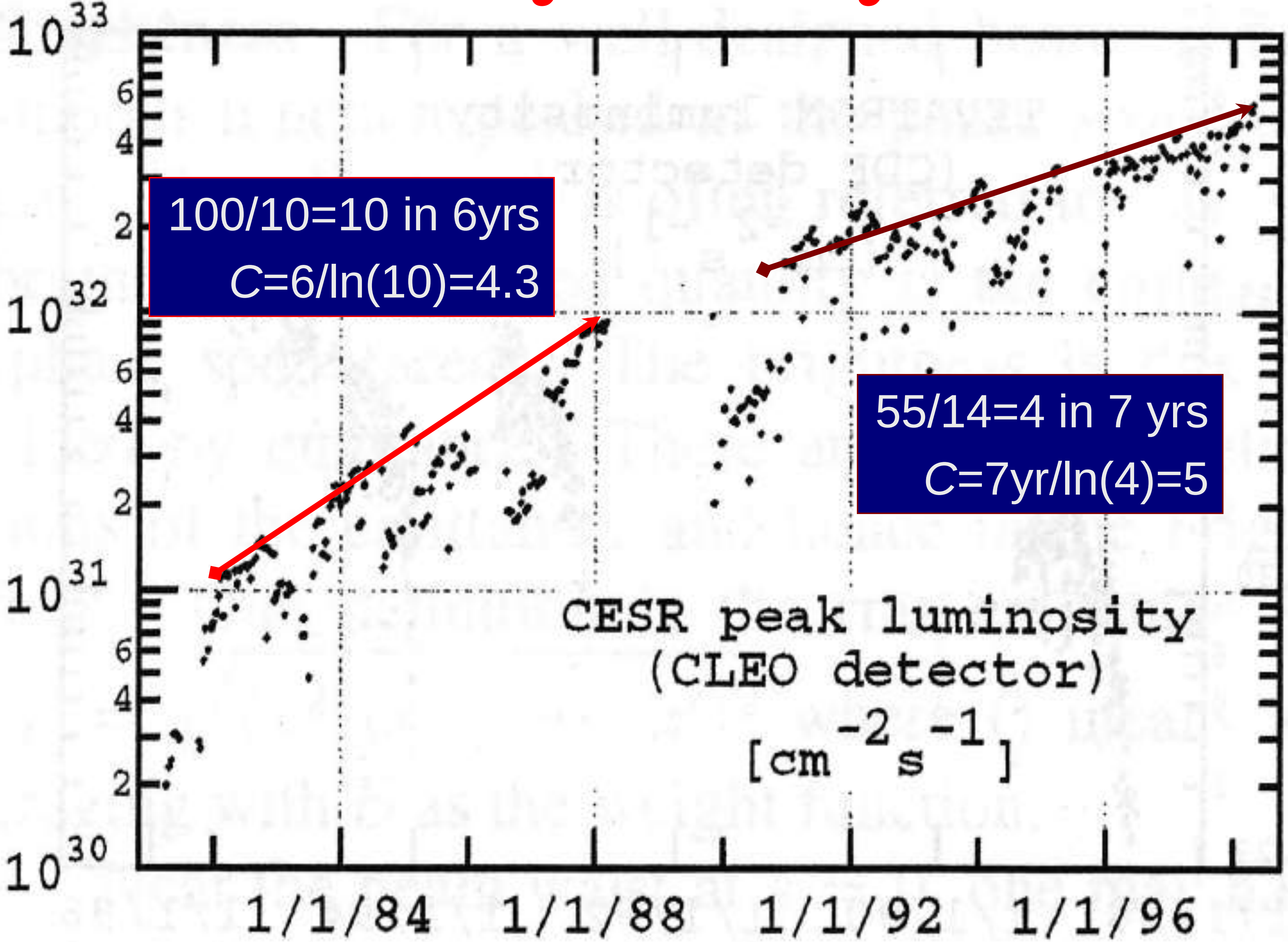
C = Complexity of the machine

P = Performance (or Challenge)

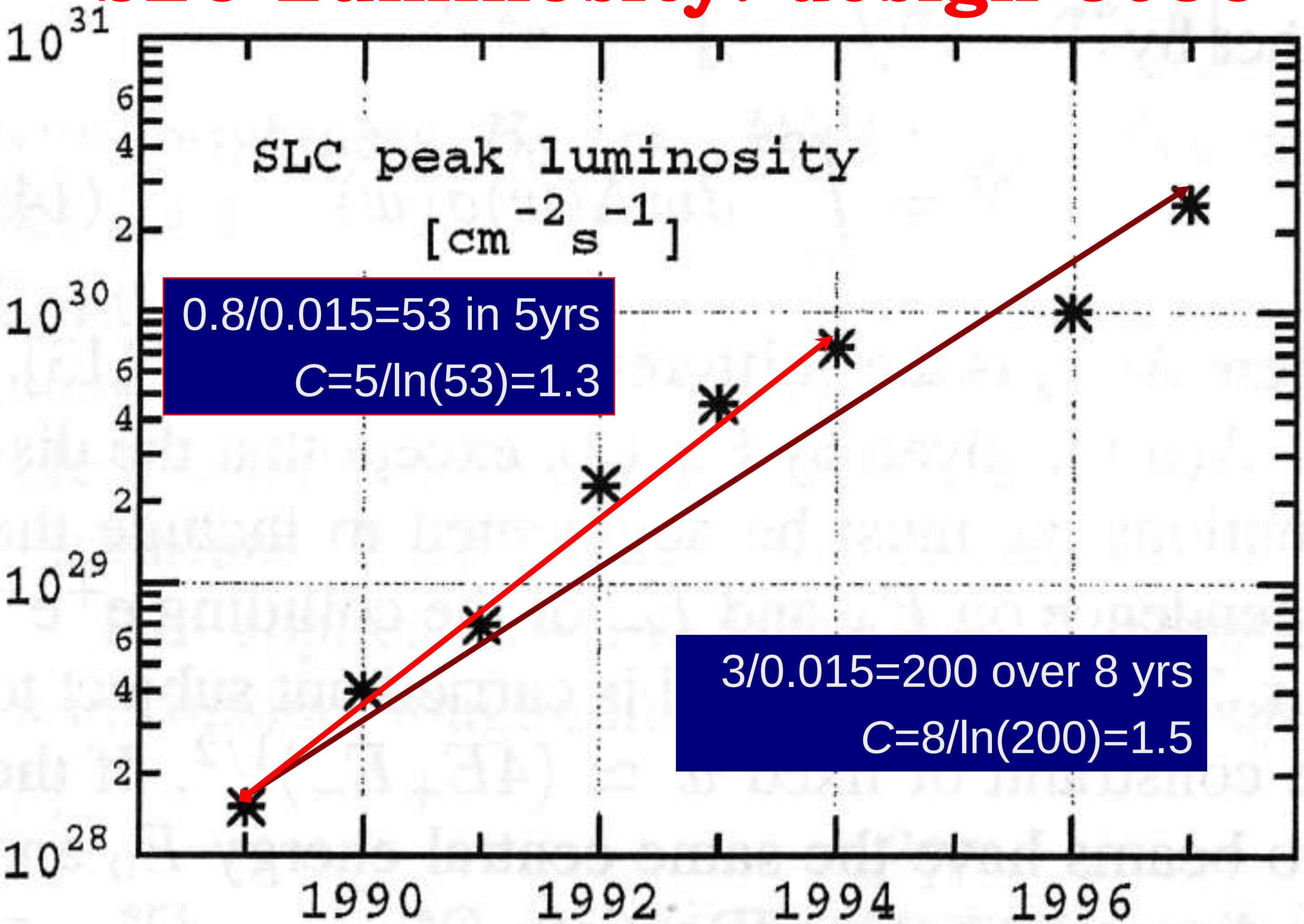
= ***ln*** (Luminosity Increase)

T = Time to reach ***P***

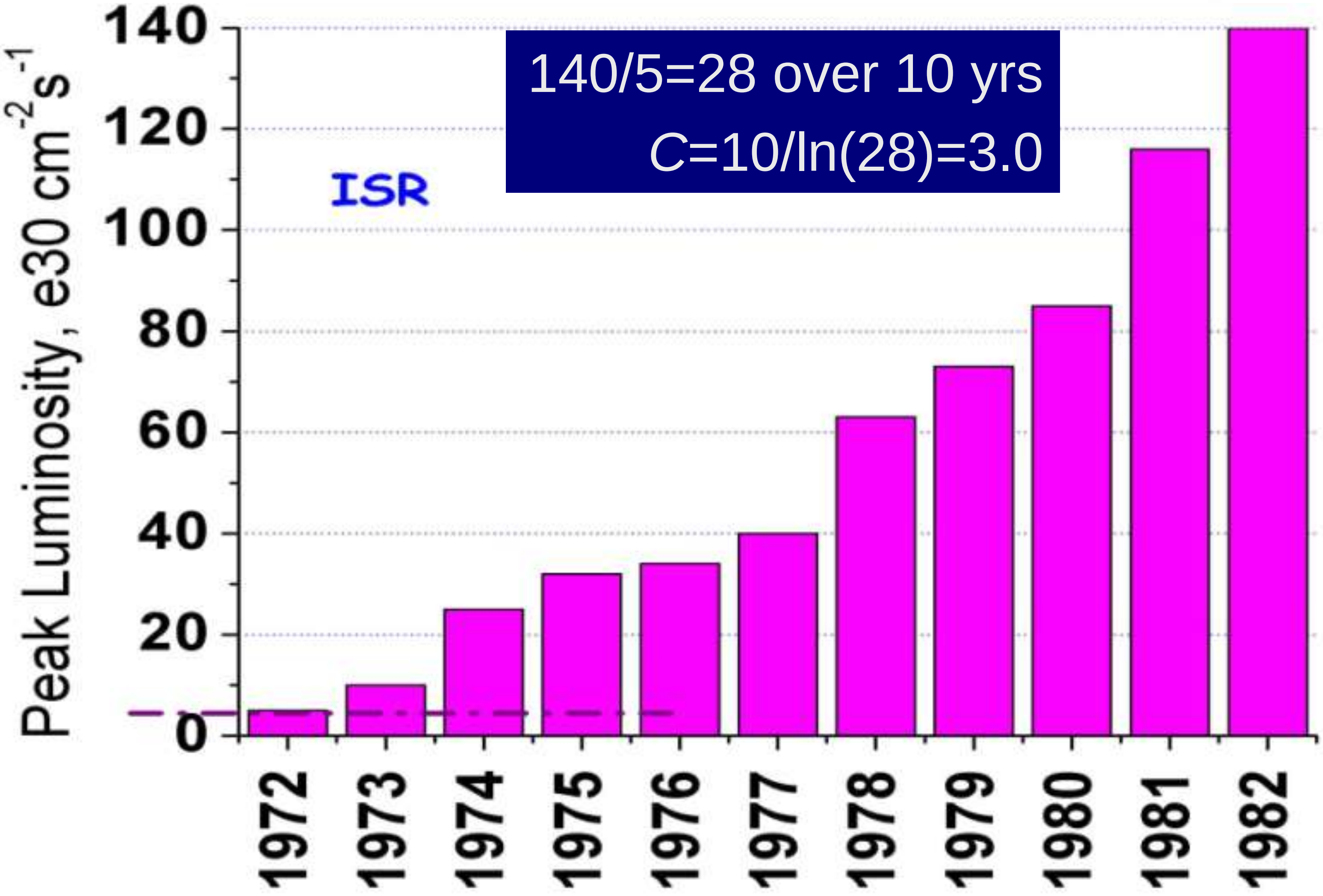
Luminosity History - CESR



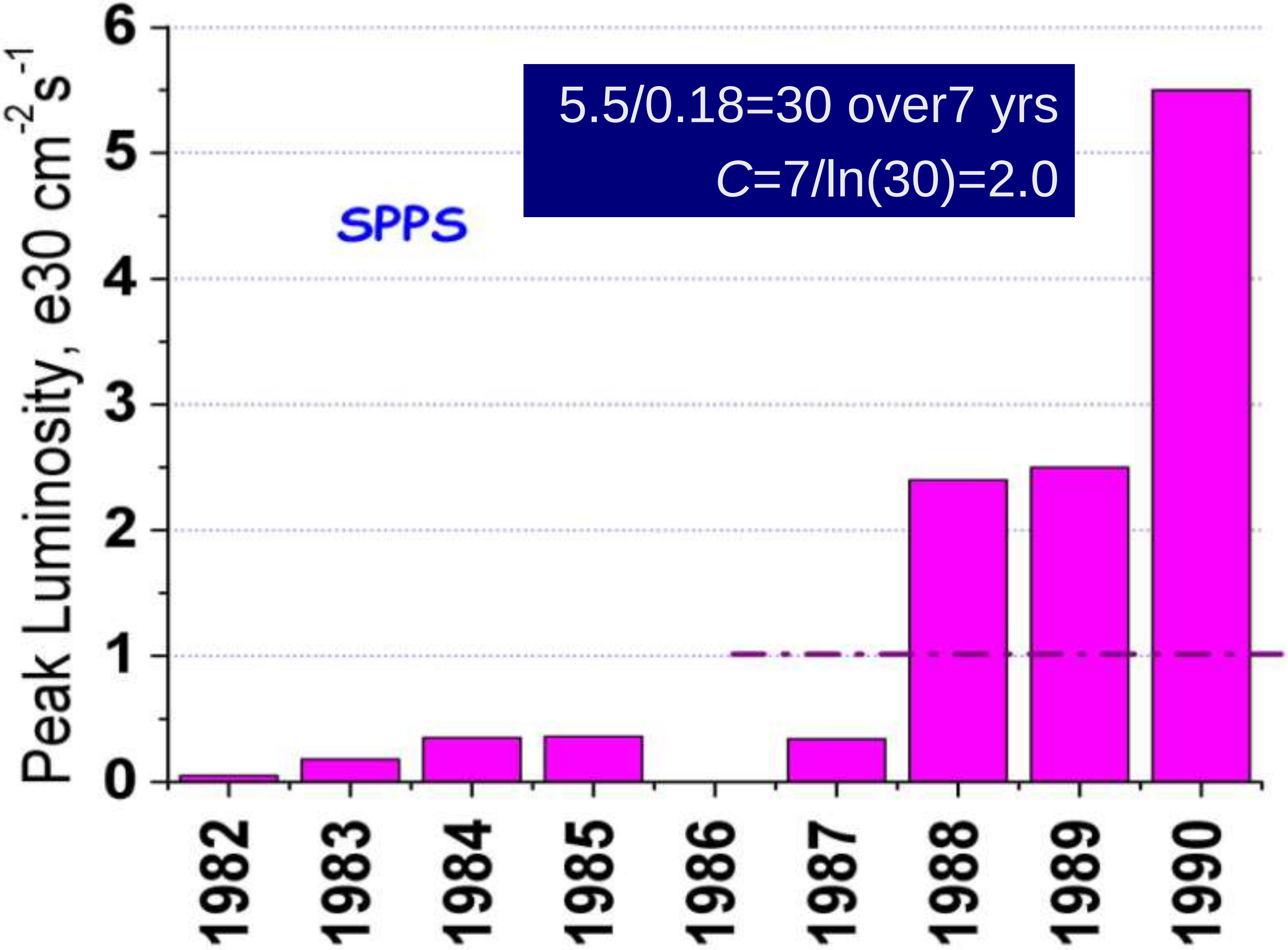
SLC Luminosity: design 6e30



Luminosity – ISR: design 5e30

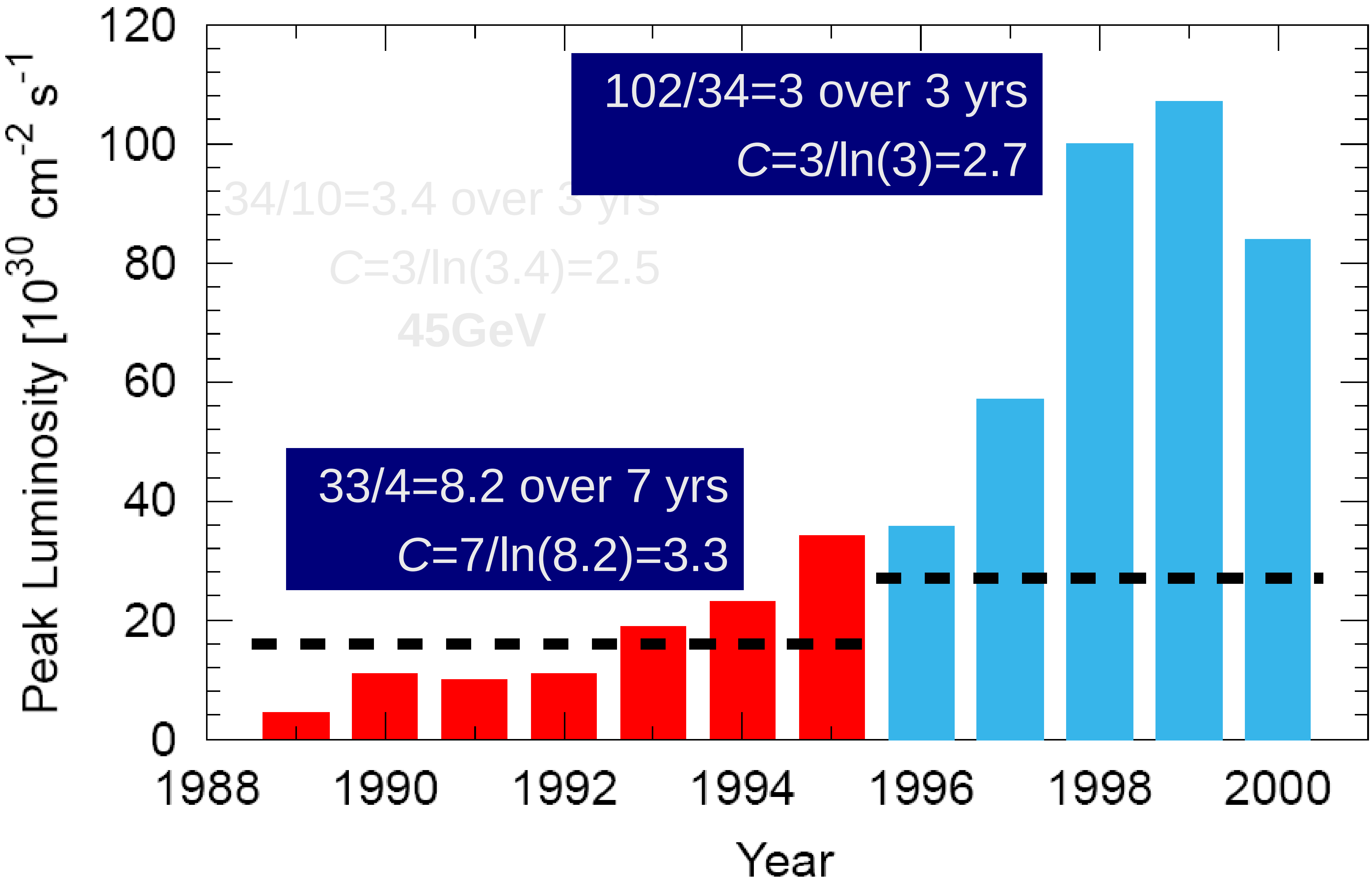


Luminosity – SppS: design 1e30

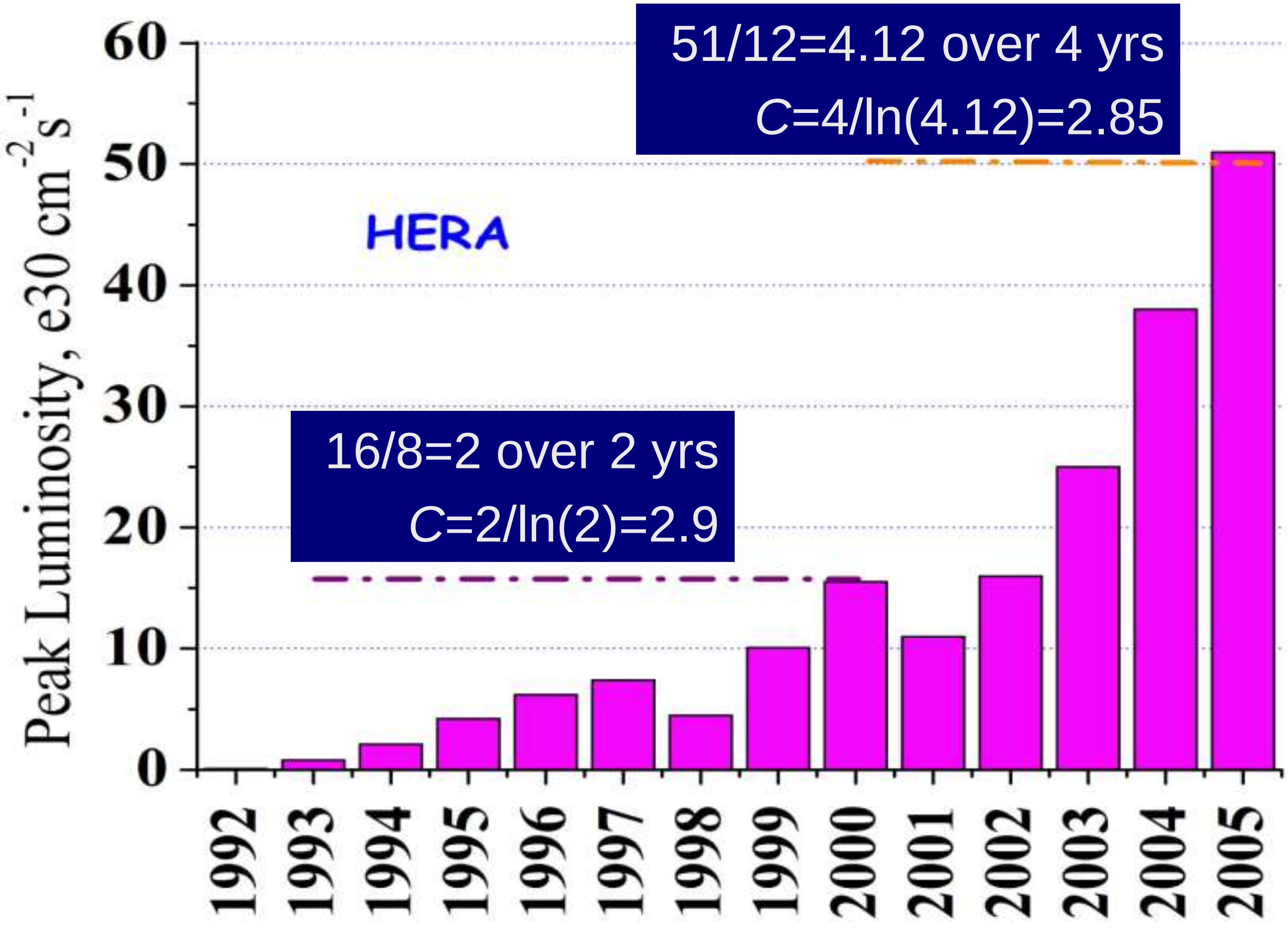


Luminosity LEP:design 16/27e30

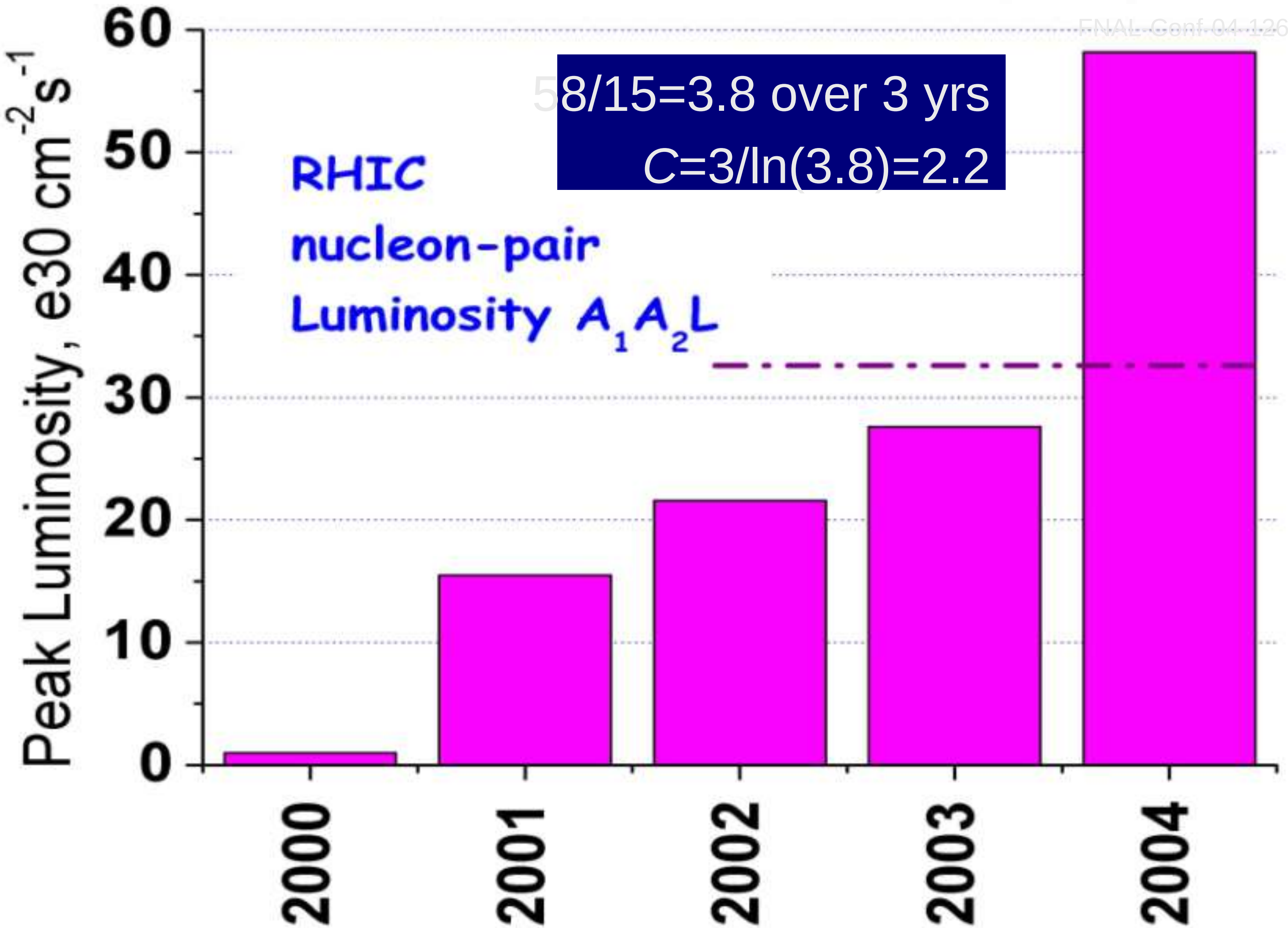
R.Assmann, APAC'2001



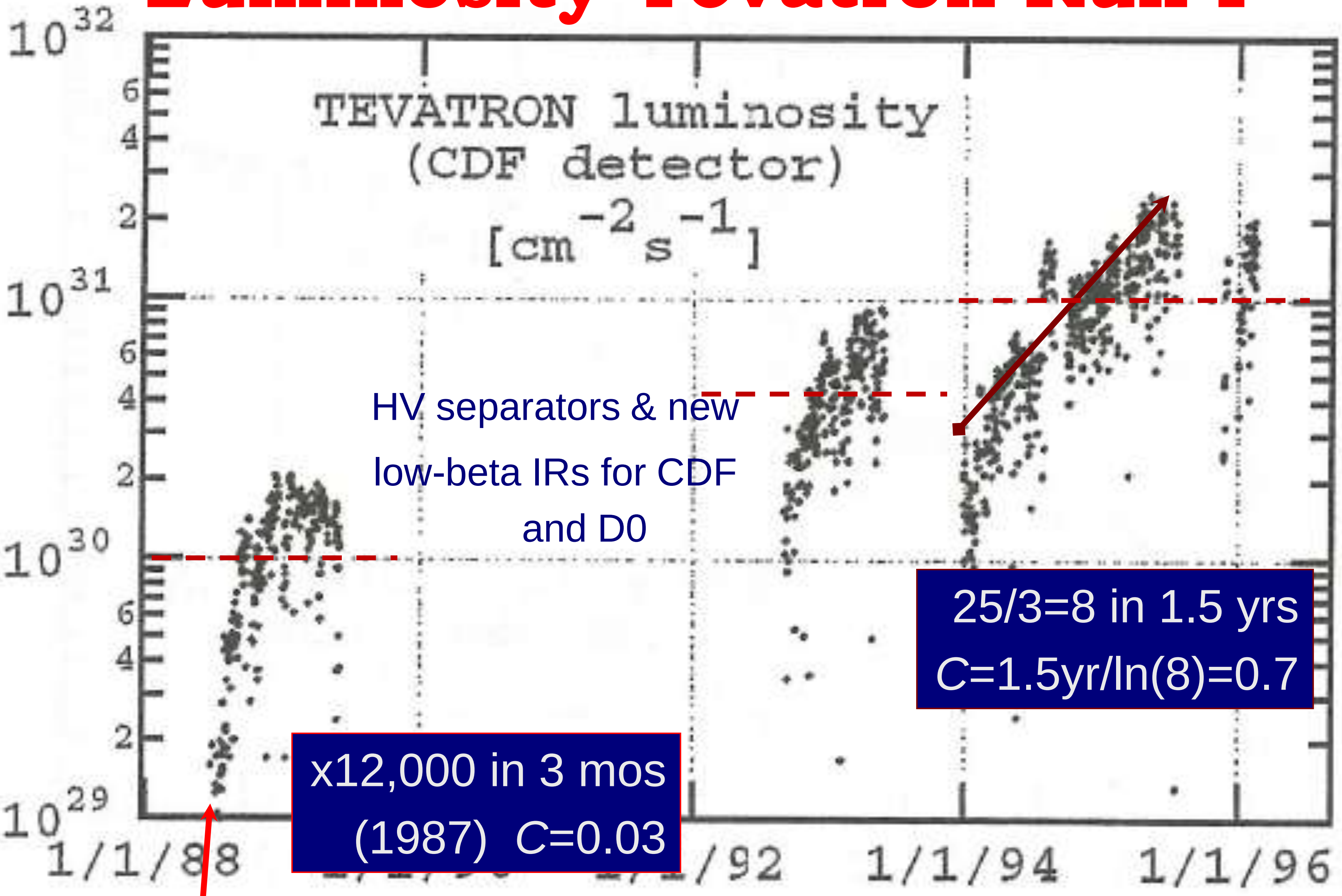
e-p HERA: design 15e30 →50



Luminosity RHIC: design 33e30



Luminosity Tevatron Run I

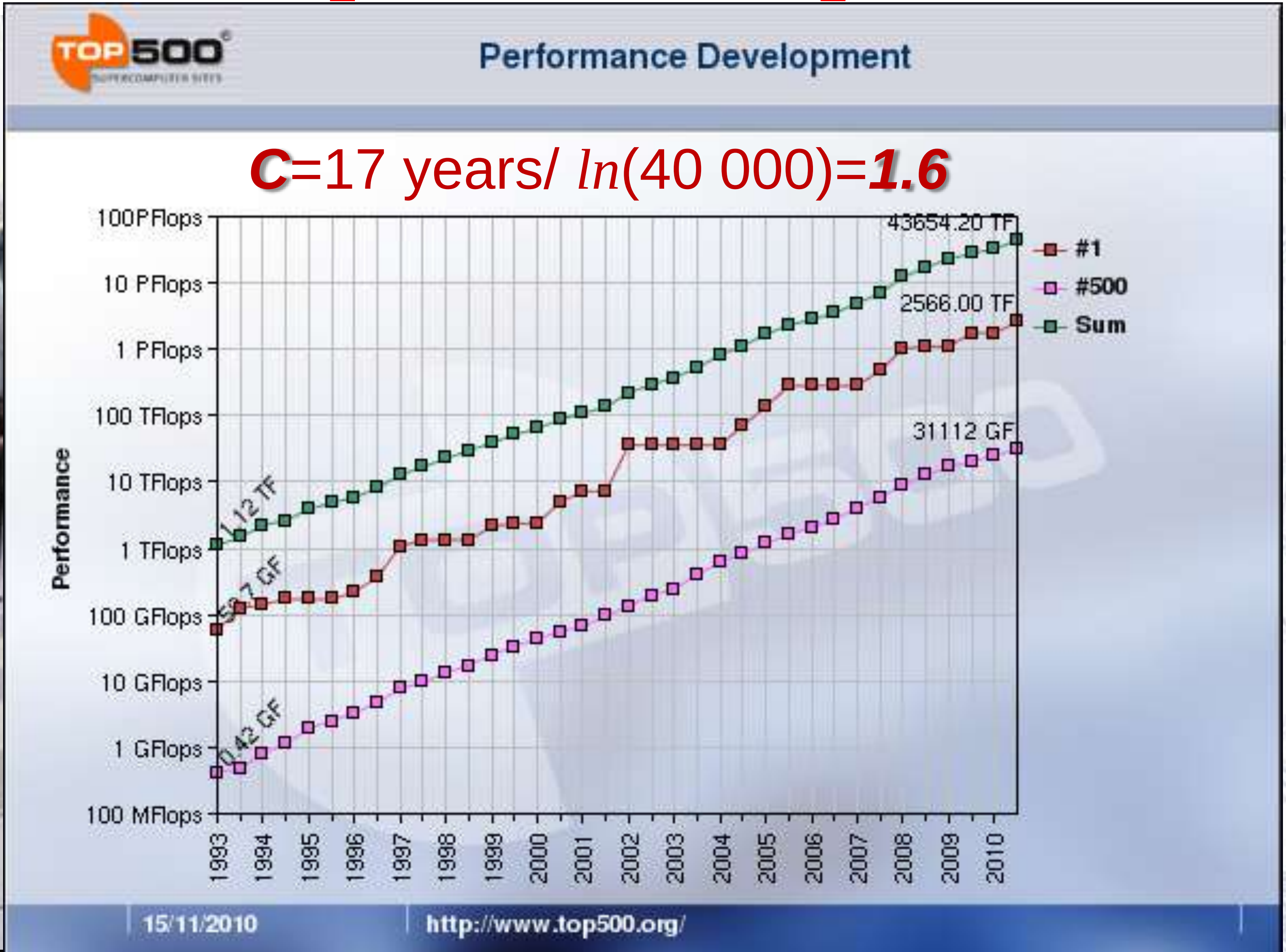


Colliders "Complexity" Table

	C	years
CESR *e+e-*	***4.3***	1883-1988
LEP I *e+e-*	***3.3***	1989-1995
SLC *e+e-*	***1.5***	1989-1997
HERA I, II *p-e*	***2.9***	1992-00-2005
ISR *p-p*	***3.0***	1972-1982
SppS *p-pbar*	***2.0***	1982-1990
Tevatron Run II *p-pbar*	***2.0***	2002-2007
RHIC *p-p*	***2.2***	2000-2004
Tevatron startup	***0.03***	1987
LHC startup	***0.06***	2010

Computations Speed

C=17 years/ ln(40 000)=**1.6**

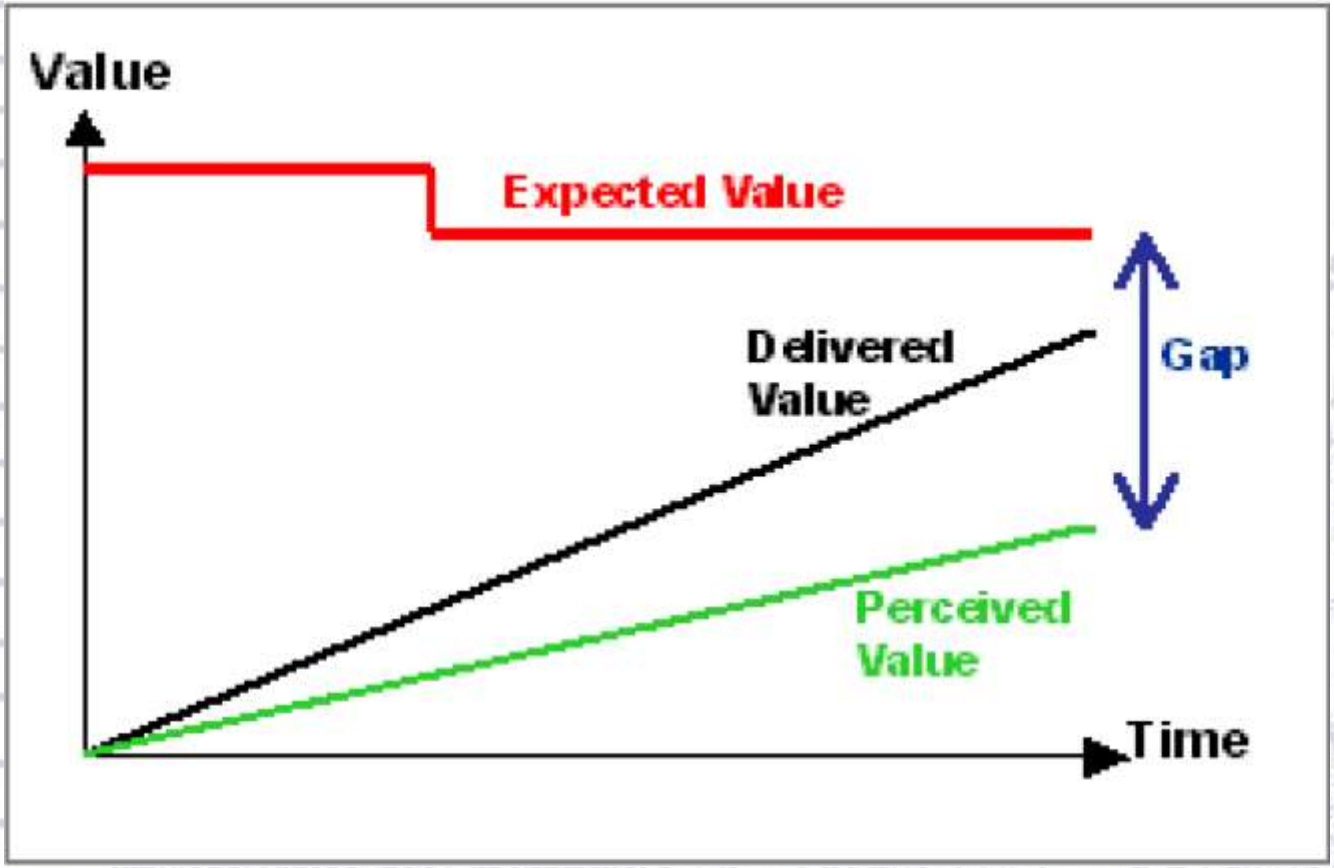


Conclusions (1)

- One should not expect that the period of incredibly fast growth of luminosity as in 2010 will last long
- At some point the progress will most probably turn to the rate corresponding to complexity of C=1.5-2.5
- Such a period of exploration and fight for ultimate performance with $C\approx2$ might take as short as 3-4 years and as long as 6-10 years
- It will be followed by relative stabilization of performance (either running out of ideas or preparing for a major upgrade)
- *A numerical example*: progress from L=3e33 to L=5e34 might take 6-9 years if C=2-3

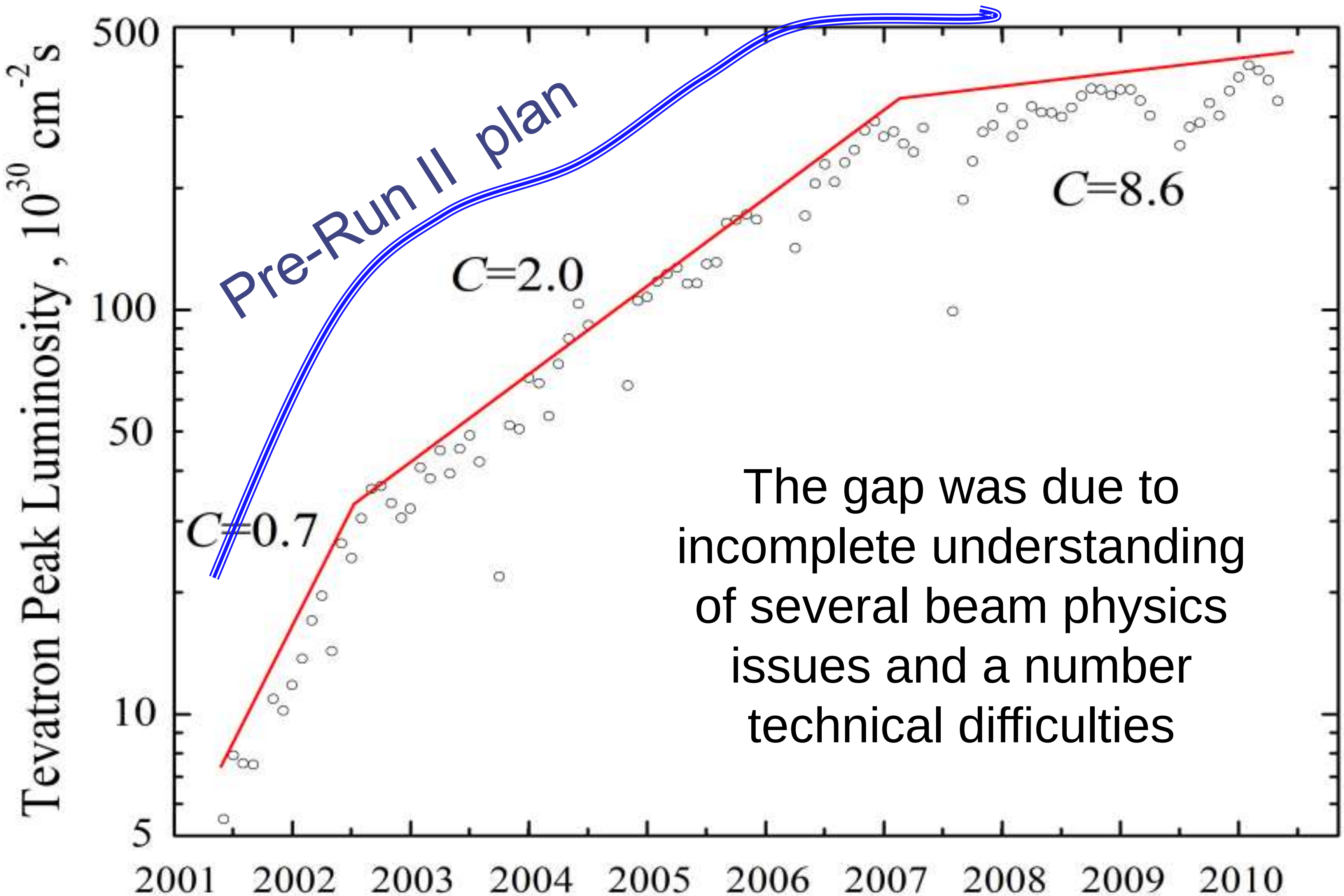
Expectation Management

Another lesson from the Tevatron Run II : the road to superb Collider performance was not smooth: during the first 2 years of Run II we were way below the 2001 plan



" Expectations are a primary measure of your success"

Run II Luminosity Progress



The gap was due to incomplete understanding of several beam physics issues and a number technical difficulties

2003 : New Methodolgy of Setting Up the Goals

The goals were expressed in terms of "base" goals that we believe have high degree of certainty of being achieved and "stretched" goals that represent our "best estimate" of the limit of performance to which the facility can be pushed (with the most likely outcome somewhere in between)

	Run IIB handbook (fb^{-1})	Review Base goal (fb^{-1})	Review Stretch goal (fb^{-1})
FY 2002	0.32	0.08*	0.08
FY 2003	0.83	0.20	0.32
FY 2004	1.30	0.40	0.60
FY 2005	1.80	1.00	1.50
FY 2006	3.40	1.50	2.50
FY 2007	3.90	1.50	3.00
FY 2008	3.90	1.80	3.00
Total	15.00	6.50	11.00

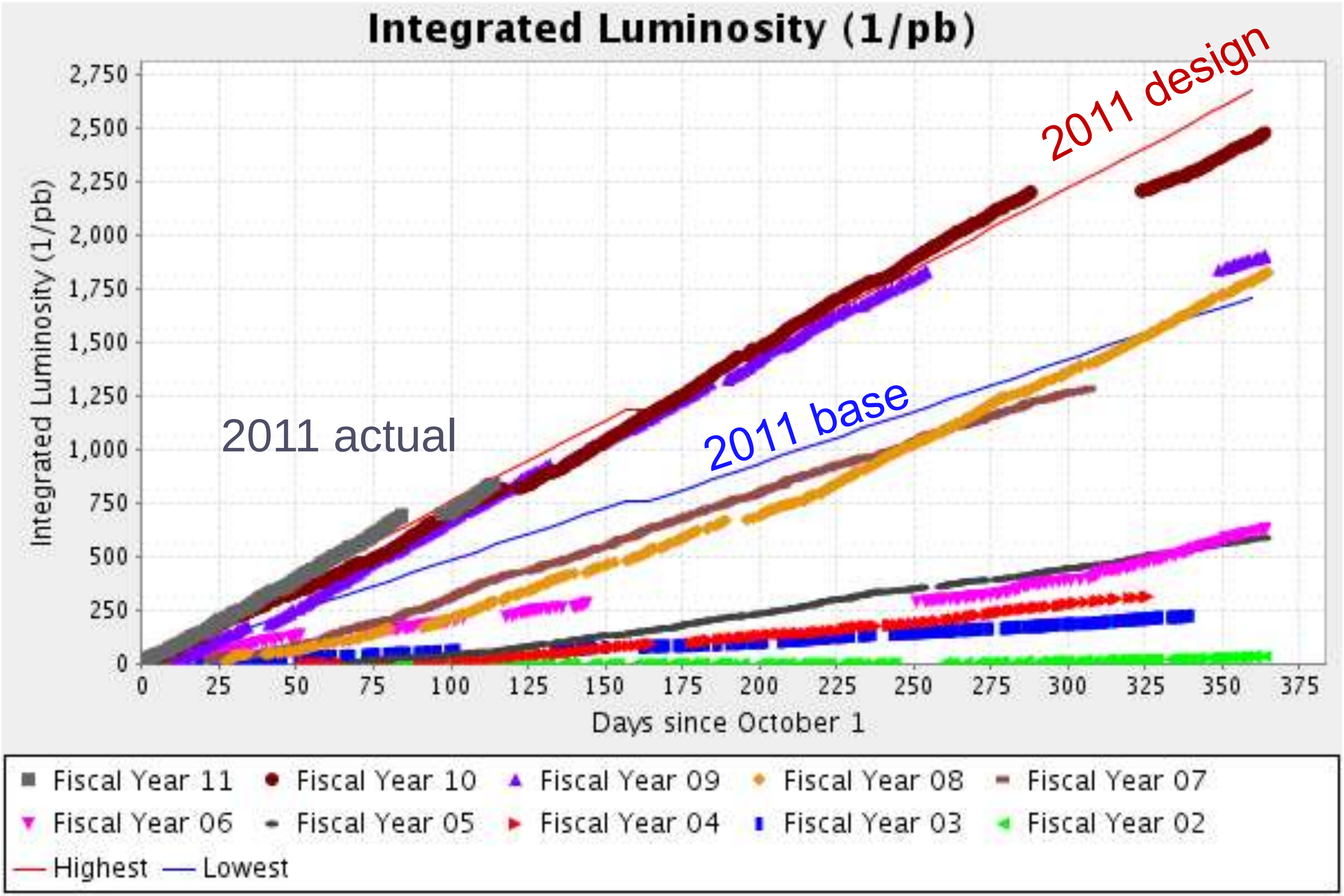
*Already achieved.

…later, the word "stretched" → "design"

How did it look in 2006

Run II Goals: FY06-09

How does it look now (FY2011)



Conclusions (2)

- Expectations management is crucial
- As in the case of the Tevatron, the LHC goals may need to be expressed in terms of two goals:
  - "base" goal – that you believe has very high degree of certainty of being achieved
  - "design" or "stretched" goal that represents your "best estimate" of the limit of performance to which the facility can be pushed
  - with the most likely outcome somewhere in between
- The goals and ratio of "base" to "design" goals depend on the level of understanding of the machine
  - E.g. the ratio might change from larger to smaller to reflect lower level of uncertainty in later years