HERA Performance and Prospects

DIS 2004,

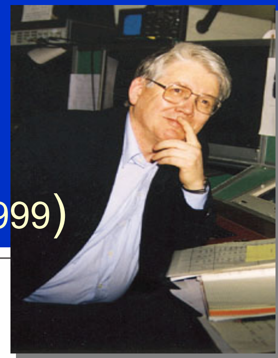
April 17 2004 , Strbske Pleso

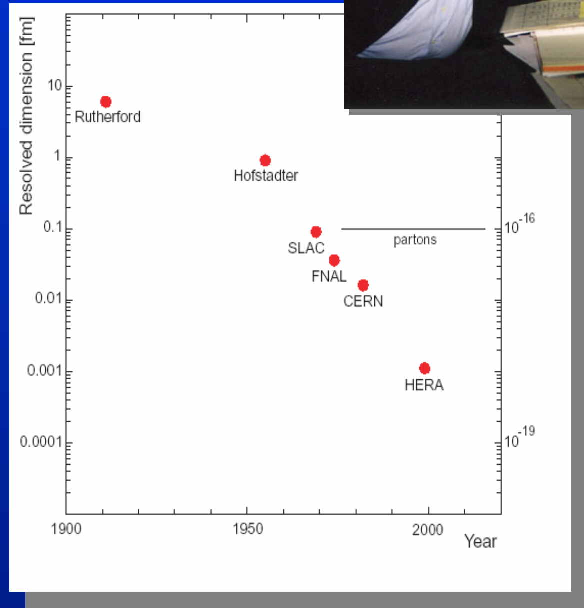
F. Willeke, DESY

- HERA overview
- HERA challenges and issues
- HERA present performance
- Luminosity prospects
- HERA beyond 2007

The HERA Double Ring Collider a Lepton-Proton collider with 320 GeV center of mass energy

Björn Wiik (1937-1999)

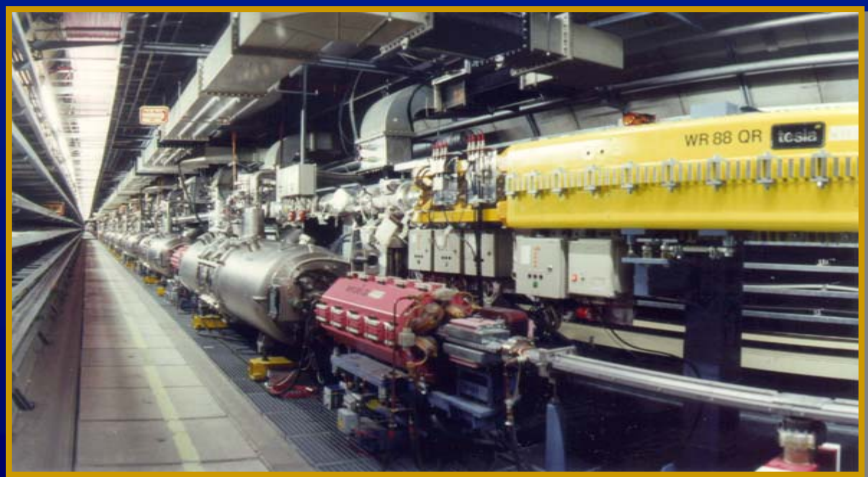




820 GeV Protons (actual **920 GeV**)

30 GeV Leptons e^+ or e^- (actual **27.5 GeV**)

@ Spatial resolution 10^{-18}m



Building an Accelerator in Collaboration

HERA was made possible by generous contributions from outside Germany:
half of the superconducting magnets, proton RF system, injection systems, human resources, cryogenic installations:

➔ **1/3 of the investments contributed from outside (excluding buildings)**

➔ **HERA model**: In kind contributions of accelerator components and contributions of human resources during construction

<u>Lessons learned for future collaborations</u>:

- HERA model worked, all the contributions from outside have been useful
- Human resources were integrated into the project despite large cultural differences
- In some of the critical systems, support beyond the construction phase would have been desirable

HERA Main Parameters

	leptons	protons
Beam Energies	27.5 GeV	920 GeV
Beam Intensities	60 mA	180×10^{11}
Magnetic Field	0.15 T	1.5 T
Acc. Voltage	130 MV	2 MV

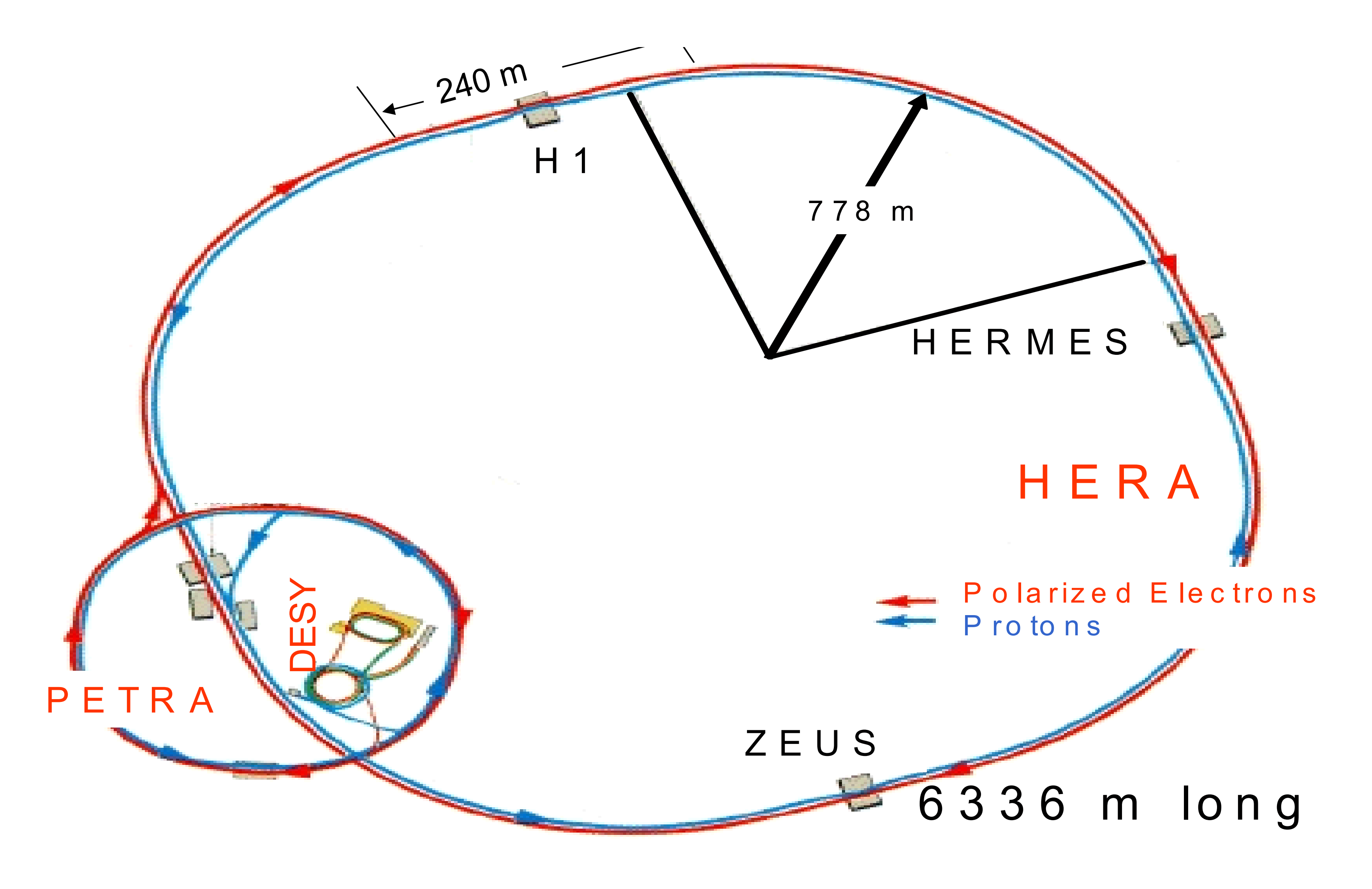
Circumference 6355 m

Luminosity $(1.5 \rightarrow 7)\ 10^{31}\ cm^{-2}\ sec^{-1}$

@ $(70 \rightarrow 300)\ pb^{-1} y^{-1}$

e-Spin Polarization (50-70)%

Overview



240 m
H 1
7 7 8 m
H E R M E S
H E R A
P o l a r i z e d E l e c t r o n s
P r o to n s
DESY
P E T R A
Z E U S
6 3 3 6 m l o n g

Milestones

1981	Proposal
1984	Start Building
1991	Commissioning, first Collisions
1992	Start Operations for H1 and ZEUS, **1st Exiting Results with low Luminosity**
1994	Install East spin Rotators ➔ longitudinal polarized leptons for HERMES
1996	Install 4th Interaction region for HERA-B
1998	Install NEG pumps against dust problem, Reliability Upgrade
1999	High Luminosity Run with electrons
2000	High efficient Luminosity production rate:100$pb^{-1}y^{-1}$
	180pb^{-1} $e^{+}p$ ➔ Precision Measurement on proton structure
2001	Install HERA Luminosity Upgrade, Spin Rotators for H1 and ZEUS
2001/2	Recommissioning, severe background problems, HERA-B physics Run
2003	1st longitudinal polarization in high energy ep collisions

Critical Choices

Use PETRA as Injector
Concern : Proton Injection Energy in HERA 40GeV=$^{1}/_{20}$·Emax
Dynamic Aperture Problems due to static & time dependent eddy currents of s.c. magnets
Mitigated by beam pipe wound sextupole corrections and reference magnets
HERA Dynamic Aperture is sufficient (though not comfortably large) ☺
Concern: PETRA is a slow proton injector ☹ mitigated by automated HERA injection set up ☺

Rebuilt DESYI as Proton Injector DESYIII
Concern: Space charge limited proton beam brightness: DESYIII exceeded design performance ☺

Avoid transition crossing by appropriate choice of DESYIII top and PETRA injection energy
Concern: Non-ideal optics at PETRA, poor lifetime at injection ☹

Use PETRA RF System
Concern: non-optimum RF cavities (designed for high gradient, but not to transfer large energy)
Concern: RF Controls
Concern: Large distance between RF PS and Klystrons ☹

Tight Apertures in the HERA Injection Lines
➔ Injection efficiency critical and not very reproducible ☹

Carry over PETRA Control System
Concern: Inadequate ☹ needed new control system, control system replaced ☺

1997/1998 Improvement Program

Success of 1999/2000 Operation based on major investments:

Replace ion pumps by NEG pumps in e-Ring arcs

And get e-beam dust problem under control

New 1.5MW 500MHz RF station provides margins needed for >50mA beam operation

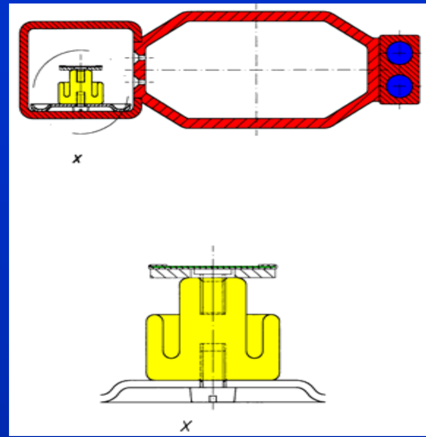
New 8kA, 3MW PS for p-Ring eliminates a frequent source of failure

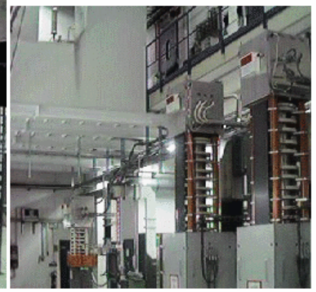
Bias voltage at couplers of 500MHz S.C. Cavities allows reliable operation with 30MV and high beam currents

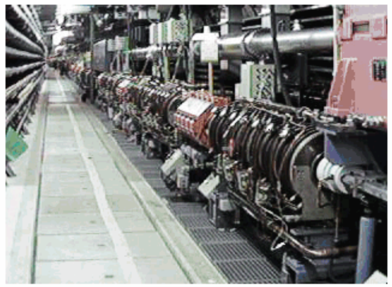
Replace all coils of GM type p-low b quads

New control system replaces inadequate Norsk-data system and allows for adequate handling of the complex collider

Additional optical elements in p-injection line provides more aperture for the incoming p-beam







HERA I

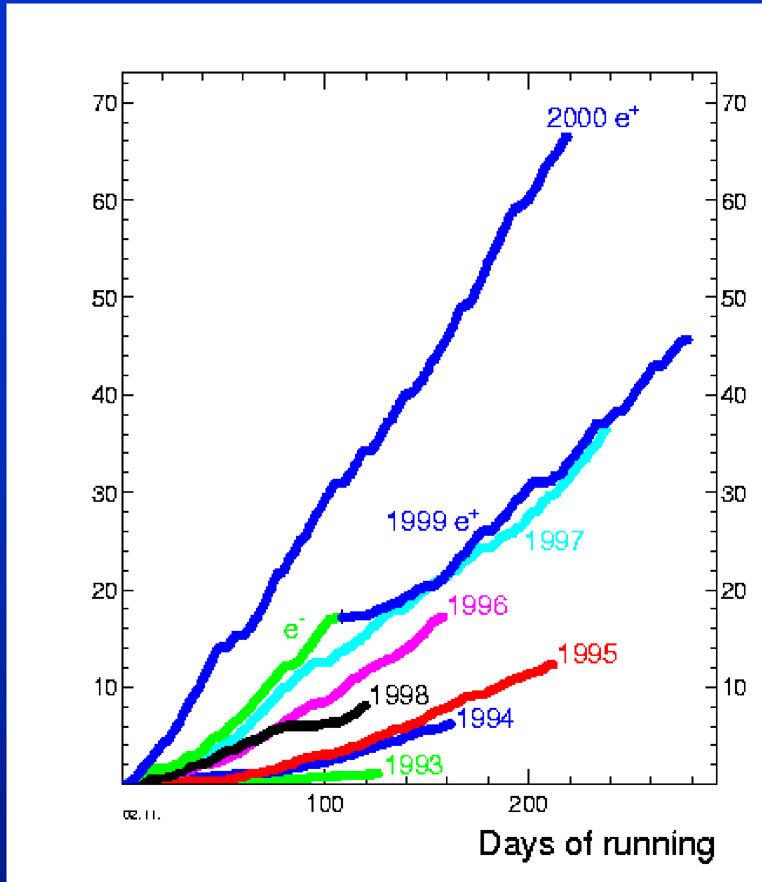
The building, commissioning and efficient operation of the complex HERA accelerator represented a major challenge for DESY, which required a large and continuous effort

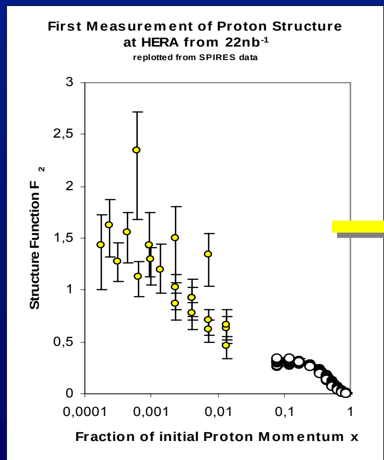
This effort allowed eventually to exceed the planned peak performance with a peak luminosity

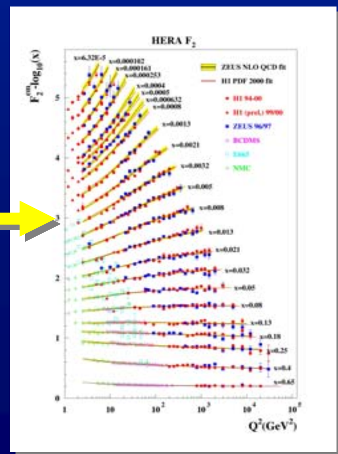
$L_{peak} = 2 \cdot 10^{31}\ cm^{-2}\ s^{-1}$

and a Production of $67 pb^{-1}$ in the 200 days of running in 2000.

For more luminosity, a upgrade was performed in 2000-2001 for an increase of a factor of three in peak performance







HERA Luminosity Constraints & Limitations

$$L = \frac{N_p \cdot I_e \cdot \gamma_p}{2\pi e \cdot \varepsilon_N \sqrt{\beta^*_{yp} \cdot \beta^*_{xp}}}$$

Constraints:

$\theta < 1$ mr

$\sigma_{x,yp} \approx \sigma_{x,ye}$

$\Delta\nu_{ey} < 0.045$

Limitations:

N_p / ε_N p-beam brightness = $1 \times 10^{11} / 4\mu m$ (injector, ibs, bb-e)

I_e total lepton beam current = 60mA (rf power, bb-p)

$\beta_{x,y\,p}$ Beta functions at the IP limited by IR layout and σ_p

UPGRADE → β_x^*: 7m → 2.45m β_y^*: 50cm → 18cm

HERA 2002 Luminosity Parameters

$$L = \frac{N_p \cdot I_e}{4\pi e \cdot \varepsilon_N \cdot \sqrt{\beta_{xp}\beta_{yp}}}$$

UPGRADE

number of protons per bunch	N_p	$= 1 \times 10^{11}$
normalized emittance	ε_N	$= 20\ \mu m$
Proton beta functions	$\beta^*_{y,x}$	**= 18cm , 2.45m**
leptons current	I_e	= 58mA
lepton emittance	ε_e	**= 20nm**
number of coll. bunches	n_b	= 174
lepton vert. b.-b. tune shift par.	$\Delta\nu_{y,x\ e}$	**= 0.045, 0.025**
hor./vert. beam size at IP	$\sigma_{x,y,p,e}$	$= 114\mu m / 30\mu m$
luminosity		$L = 7 \times 10^{31} cm^{-2} sec^{-1}$

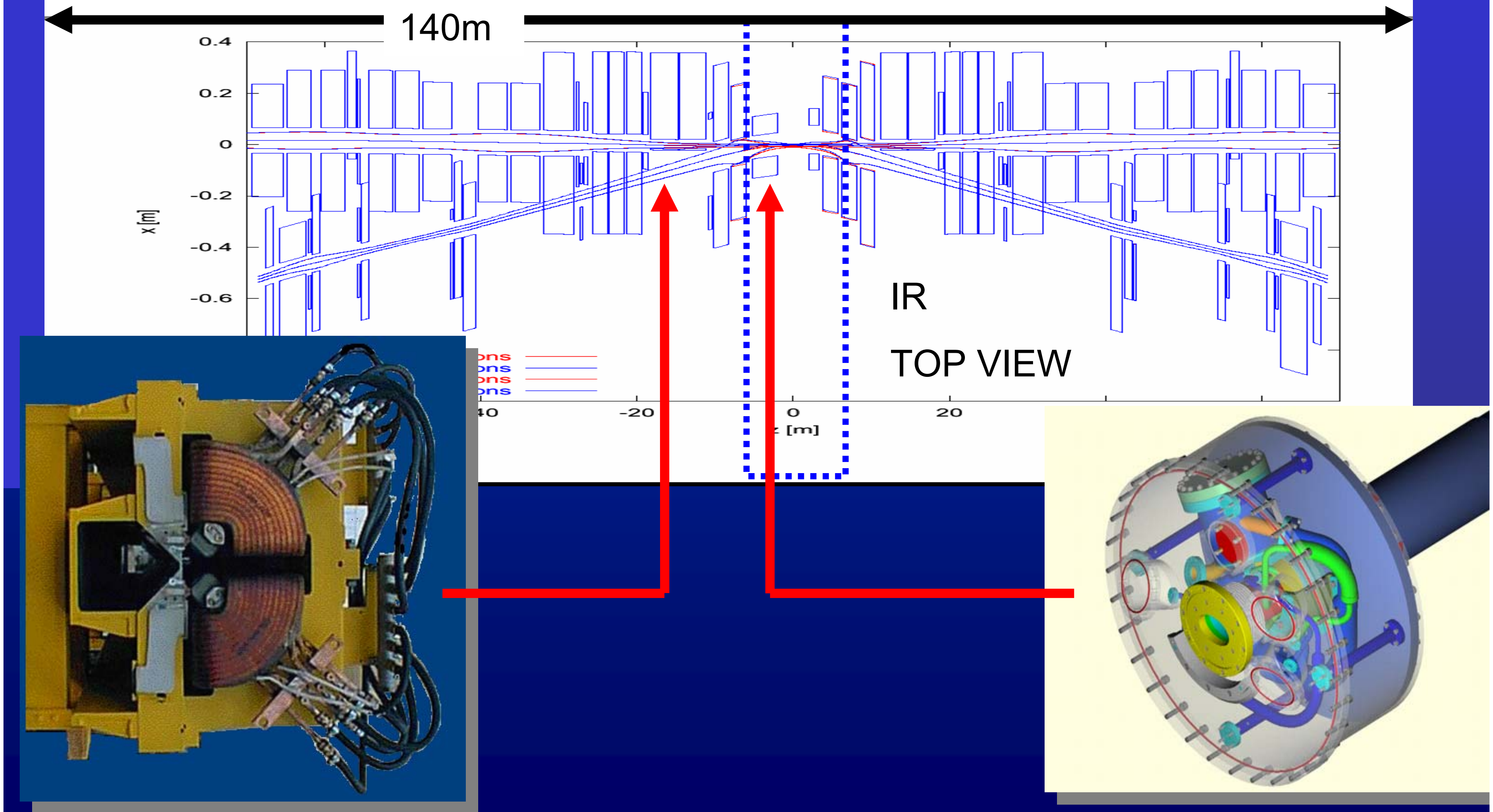
VERY AMBITIOUS & CHALLENGING !!

Factor of ≈3

Basic Concept: low β Quadrupole Magnets closer to the Interaction Point, using novel magnet technology

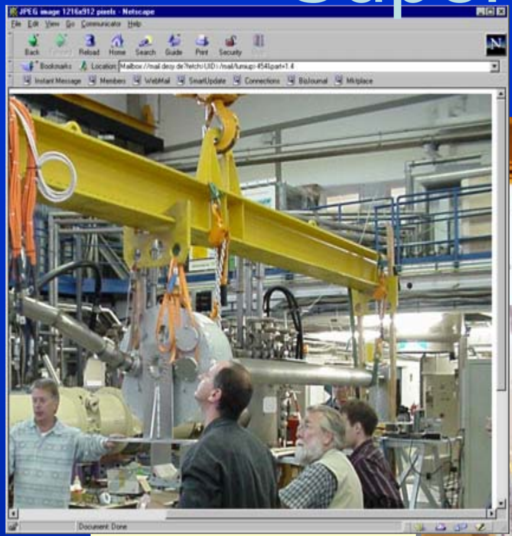
Half Quadrupoles for p-focusing

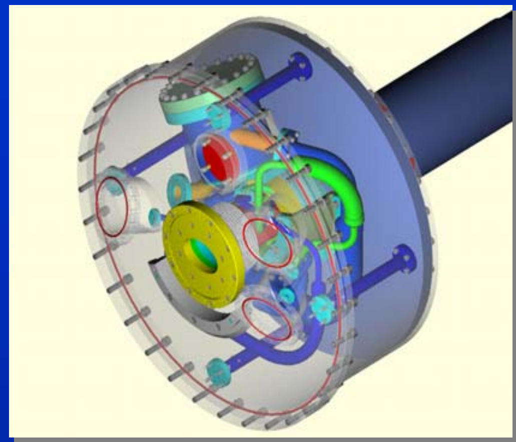
Superconducting Separator/Quads

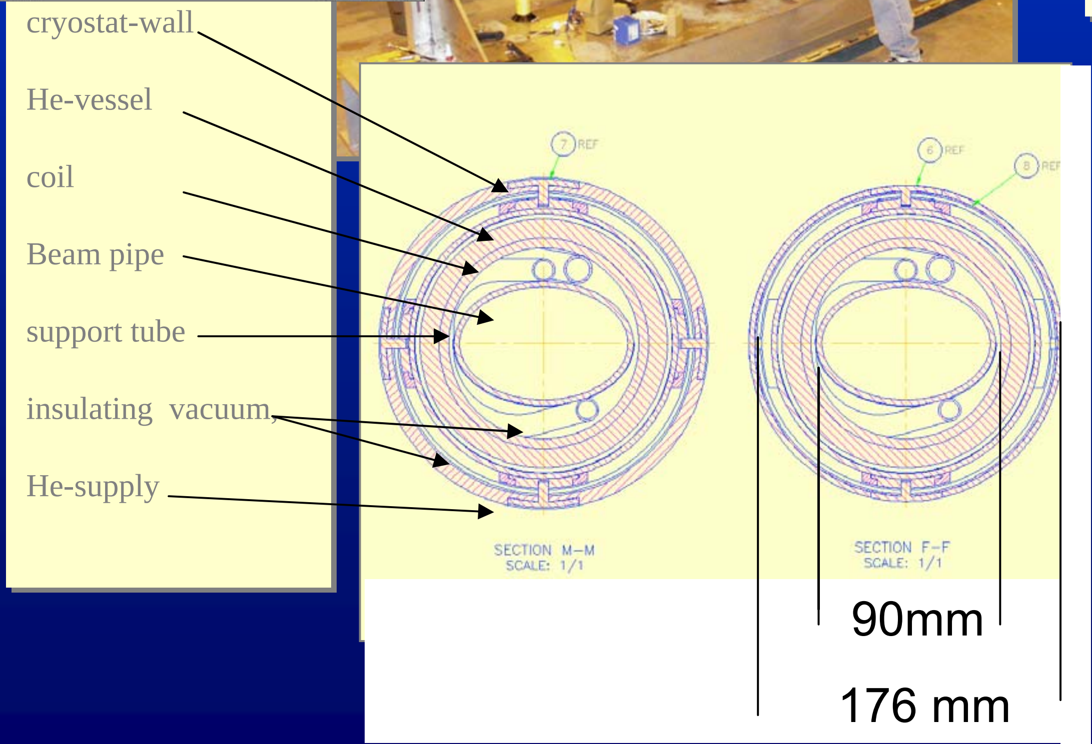


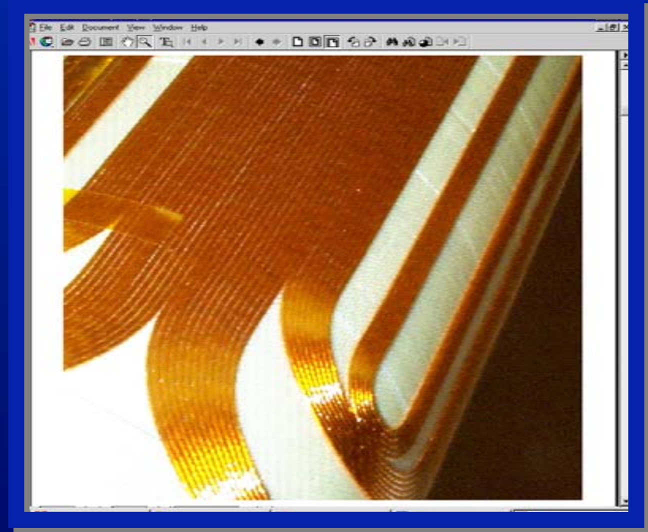
Superconducting Magnets GO/GG

Designed + built in collaboration with BNL

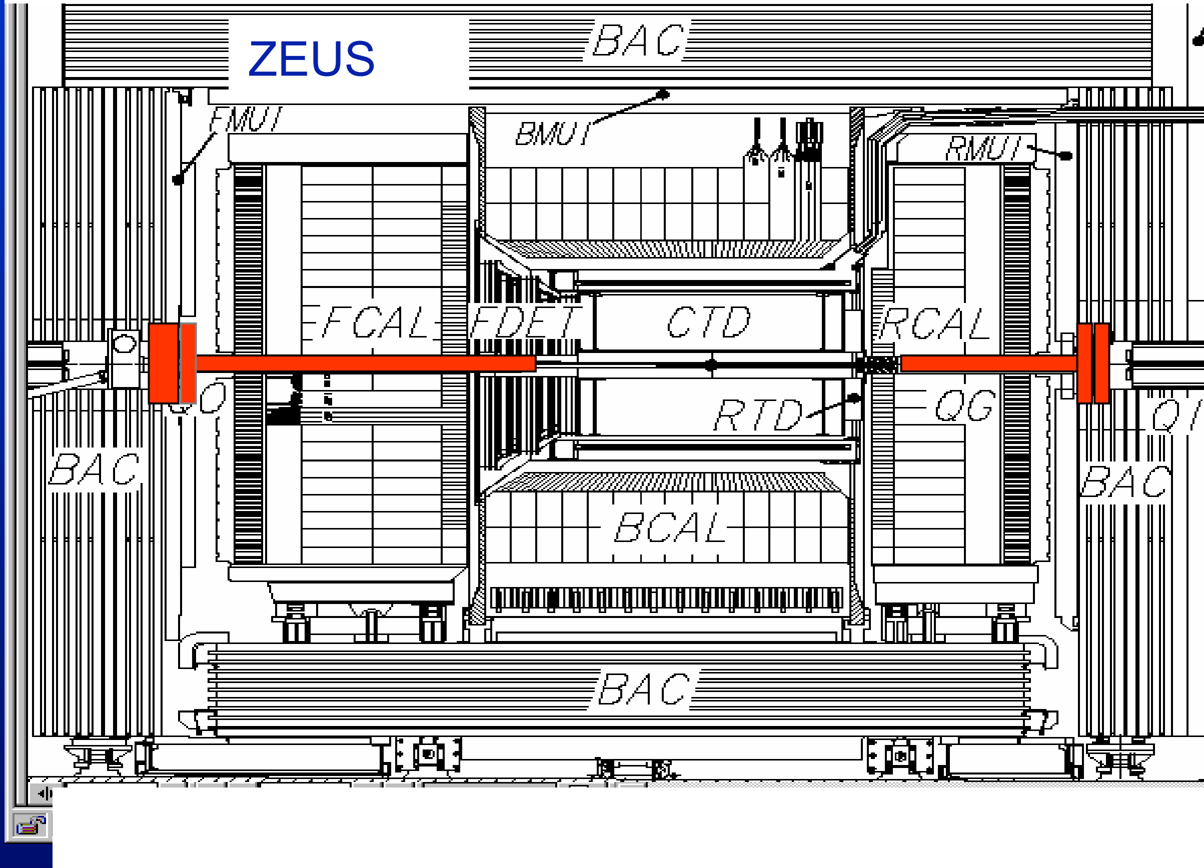








Superconducting Magnets in the Detectors



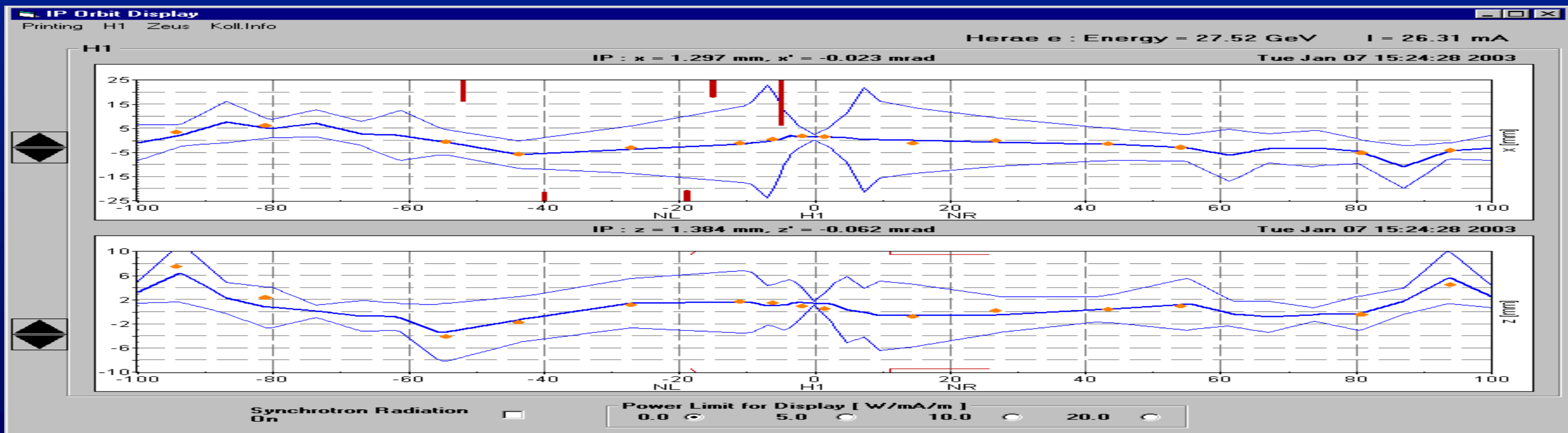
HERA II Operations

Accelerator after Luminosity upgrade is much more complicated

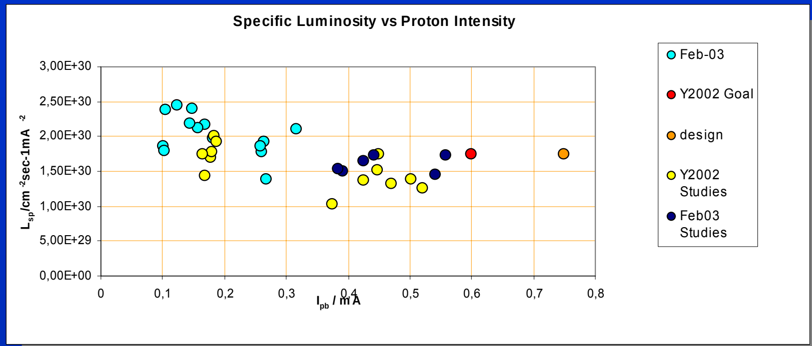
➔ Sophisticated operational procedures introduced:
- Beam Orbit feedback (dx < 1mm)
- automatic beam optics corrections
- beam based alignment
- Advanced Orbit manipulations
- faster magnet cycling, ramping and β-squeezing procedures
- more sophisticated machine data management

➔ Routine operation procedures could be quickly re-established and are continuously improving

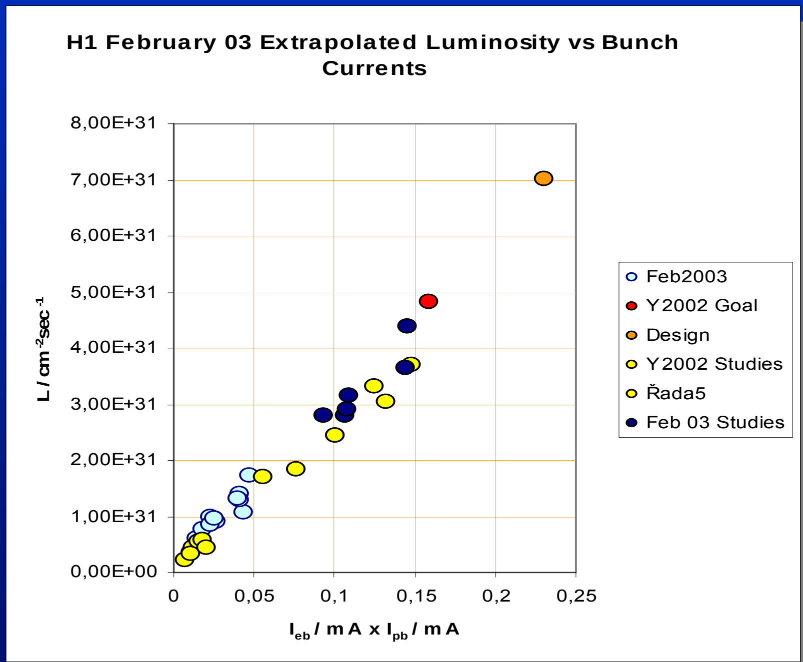
Desired specific Luminosity (for low intensity beam) could be verified early on

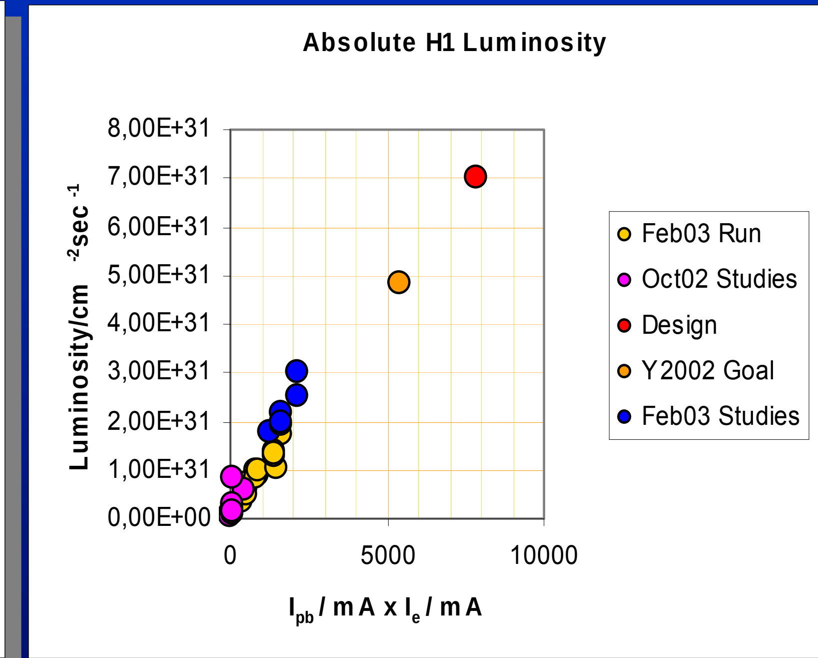


Recommissioning: High Luminosity Demonstrated



Record Luminosity
120 Bunches
I_p < 70 mA
I_e < 35 mA
L_{peak} > 2.7 x 10^{31} $cm^{-2}s^{-1}$

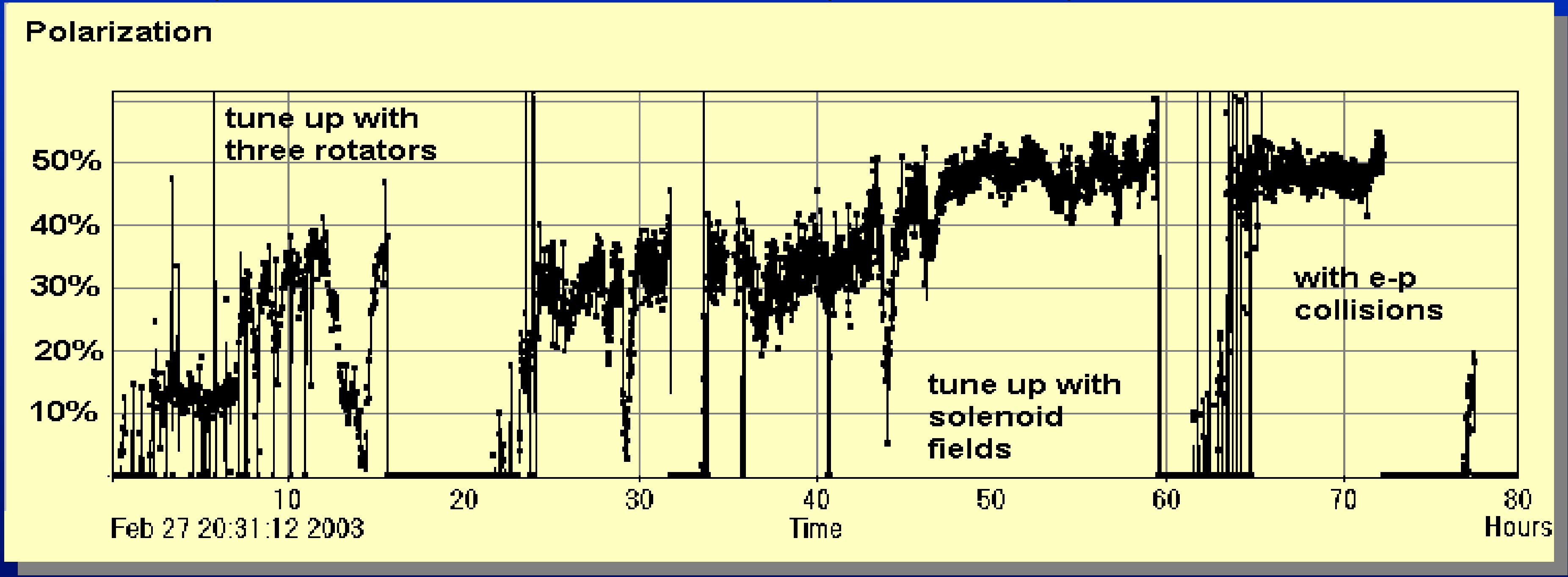




Conclusion: HERA is able to deliver luminosity as advertised

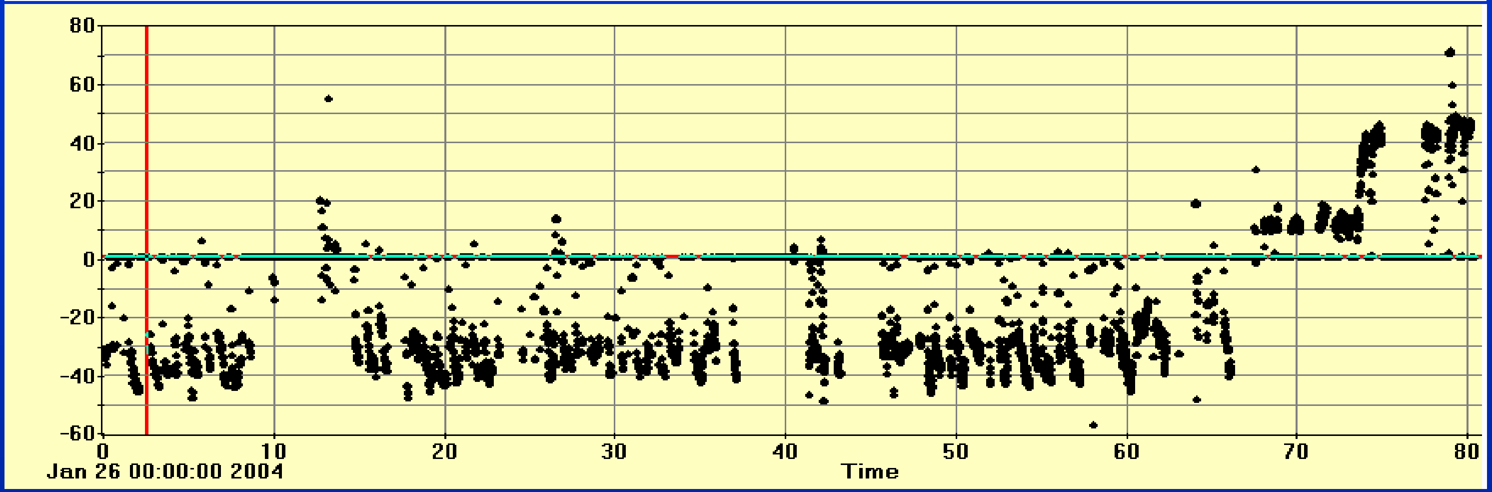
Important feature of HERA : Spin polarized Lepton Beams with (50-60)% longitudinal polarization at the HERMES IP achieved between 1995-2000

February 2003: a World First:
Helically polarized Positrons colliding with a high energy proton beam with three pairs of spin rotators



➔ This opened up an exciting part of the HERA physics program starting in 2003

HERA Longitudinal Polarization



Polarization in collisions: 30-40%
Polarization without collisions up to 50%

Further improvement plans:

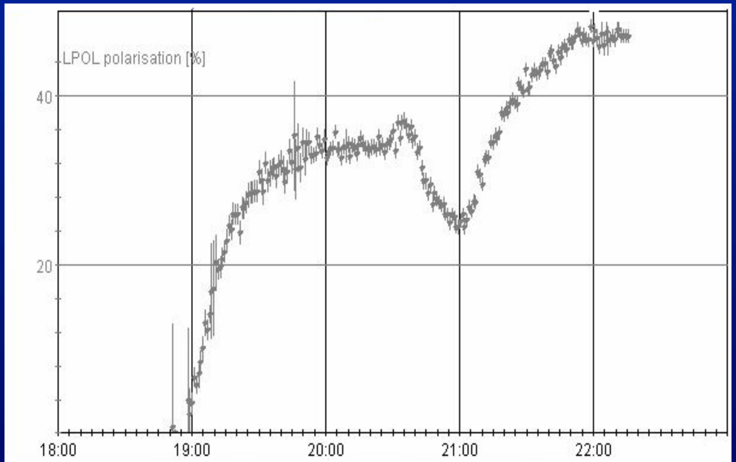
Dedicated 2 Polarization Studies

Beam Based alignment
(suffers from lack of resources)

Need better polarization measurement for fast tuning!!

Regular Rotator Flip

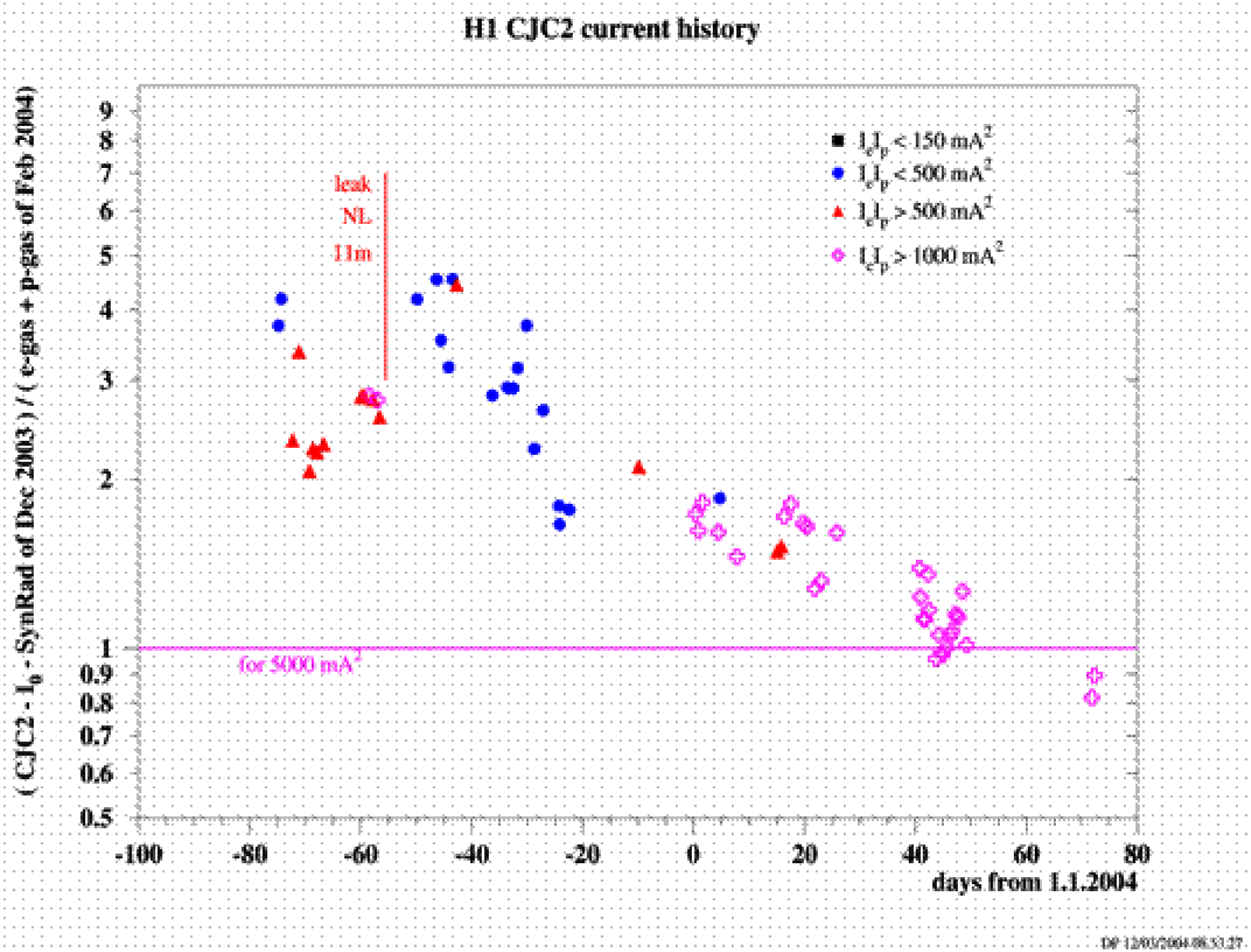
Polarization after p-Beam Loss on Feb. 12, 2004



Backgrounds after Luminosity upgrade:

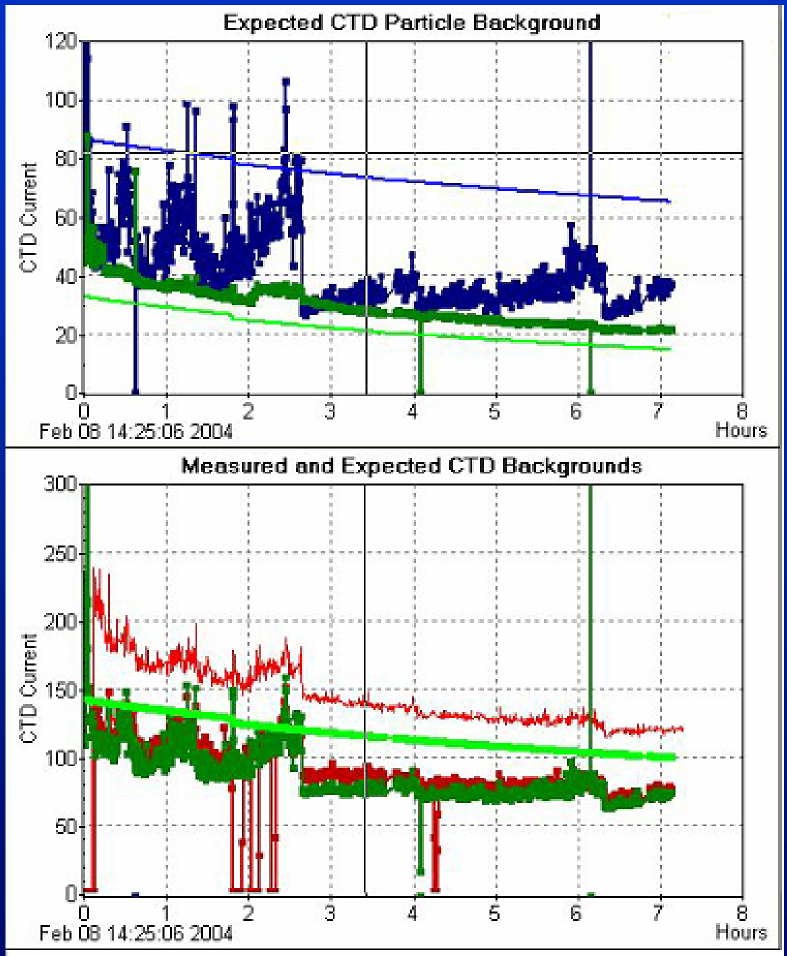
This looked very serious in the beginning and required time to gain understanding and implement counter measures

- Direct Synchrotron Radiation: solved by IR design, SR collimation and sophisticated beam steering procedures
- Indirect (backscattered) synchrotron radiation required improved masking in ZEUS
- e+ particle backgrounds improved with improving vacuum (beam conditioning) and the addition of a pump in a critical location
- proton backgrounds improved with regular beam operation and we are at the point, were this is no issues for ZEUS anymore and almost no issue for H1 anymore

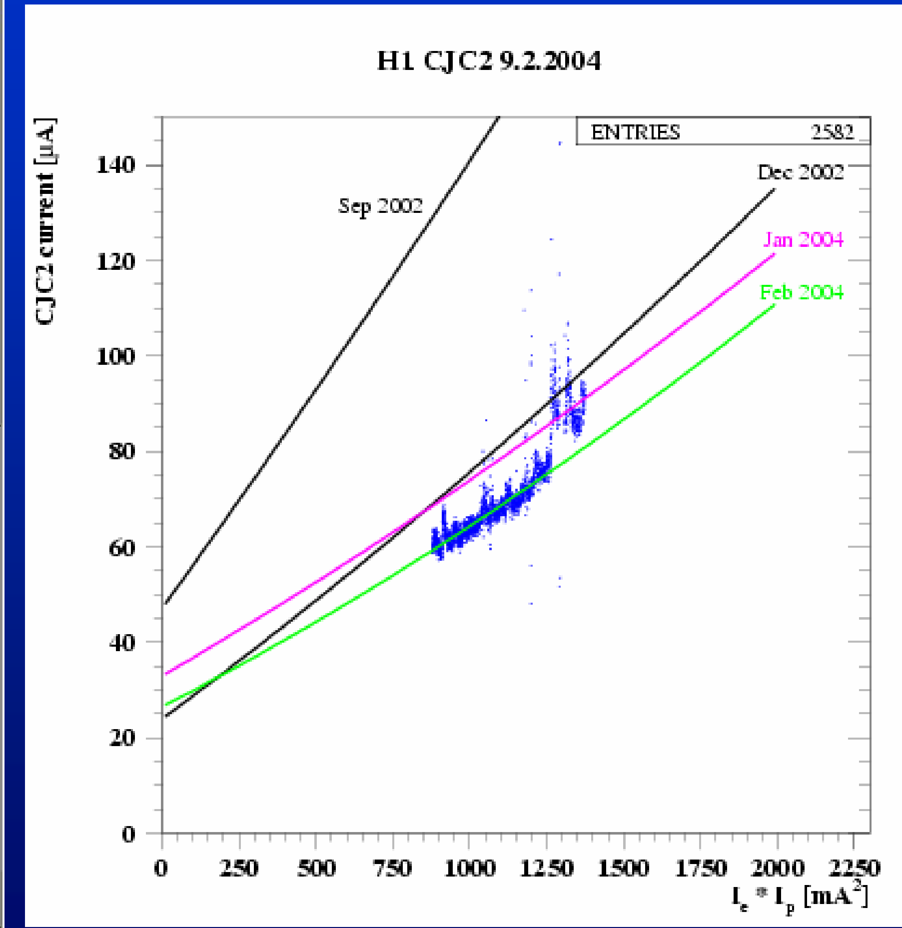

H1 CJC2 current history
(CJC2 - I0 - SynRad of Dec 2003) / (e-gas + p-gas of Feb 2004)
days from 1.1.2004
IeIp < 150 mA²
IeIp < 500 mA²
IeIp > 500 mA²
IeIp > 1000 mA²
leak
NL
11m
for 5000 mA²
DP 12/03/2004 08.53.27

Backgrounds

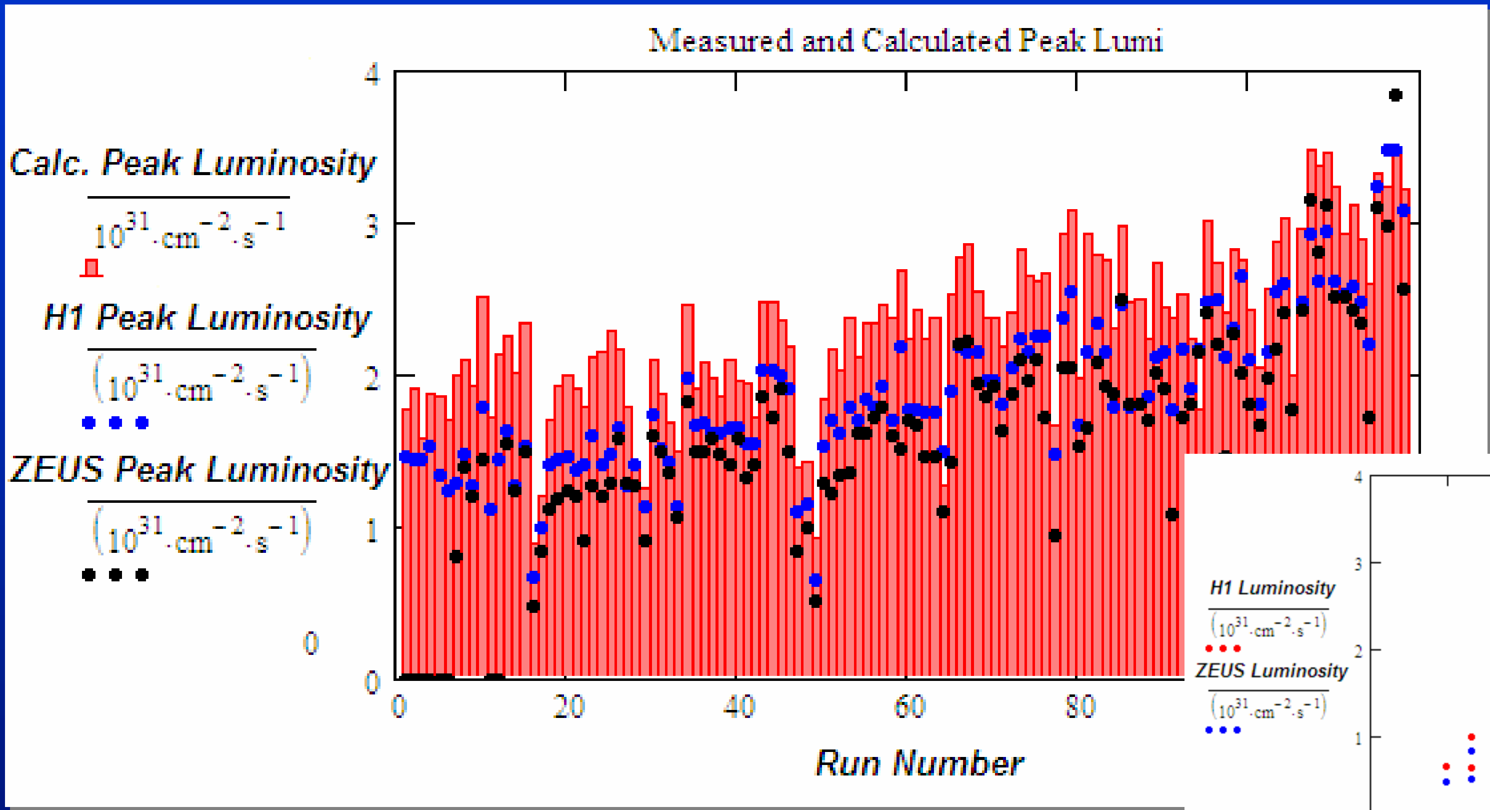
ZEUS Background Monitor

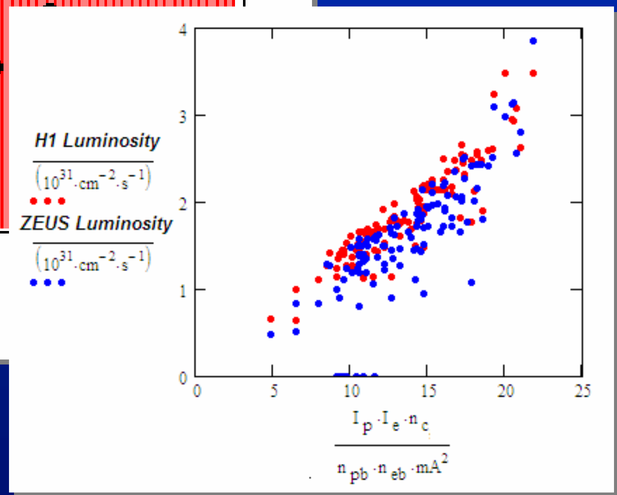


H1 Backgrounds do not limit HERA Performance any more!



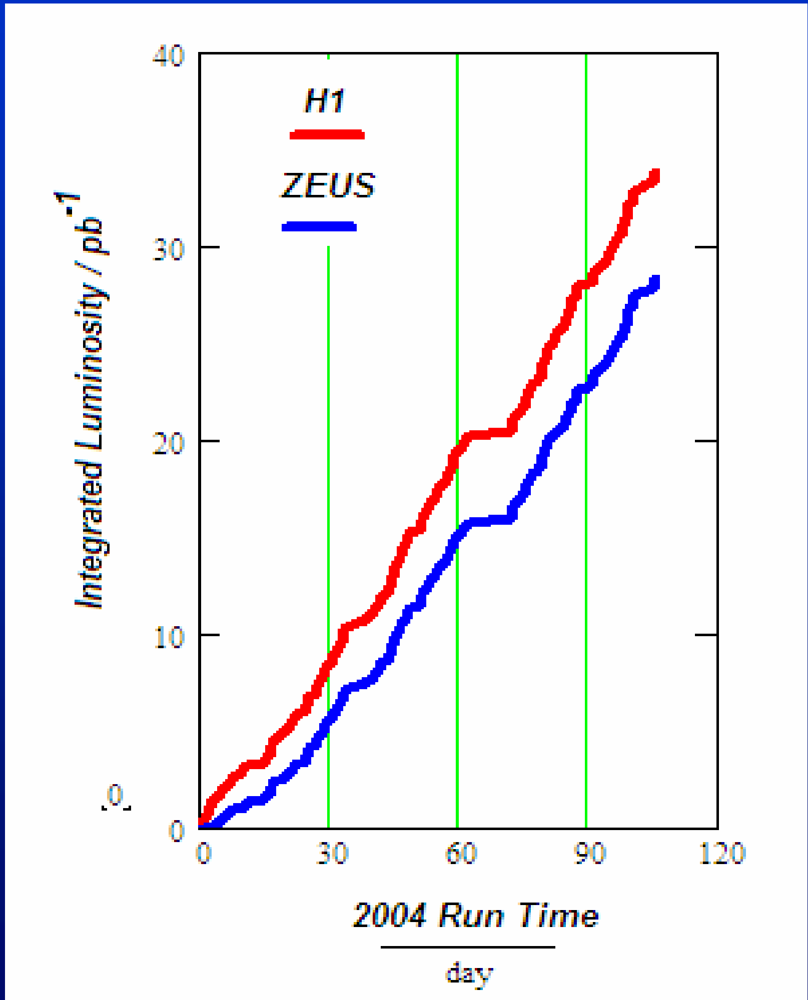
HERA Luminosity 2004: Steady increase of of Luminosity with increasing lepton beam currents





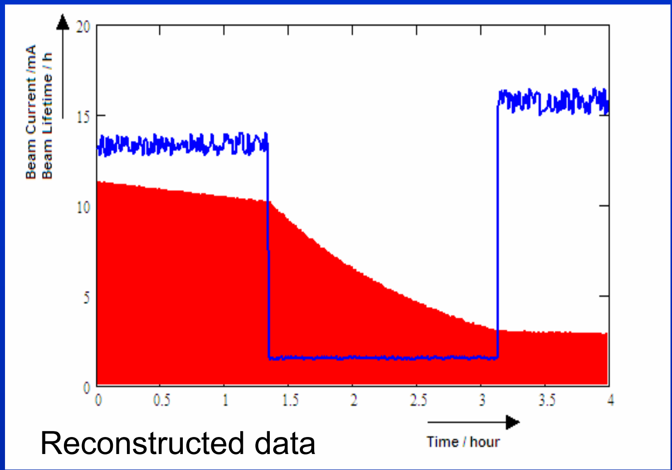
Expect to approach HERA II peak Luminosity goal of $4.5 \cdot 10^{31}$ $cm^{-2}s^{-1}$ within the next few months as soon as 50mA of positrons can be stored

Integrated Luminosity Jan-April suffered from technical failures



Improvement of overall Accelerator availability is the largest challenge

Problems with Electrons due to "Dust"



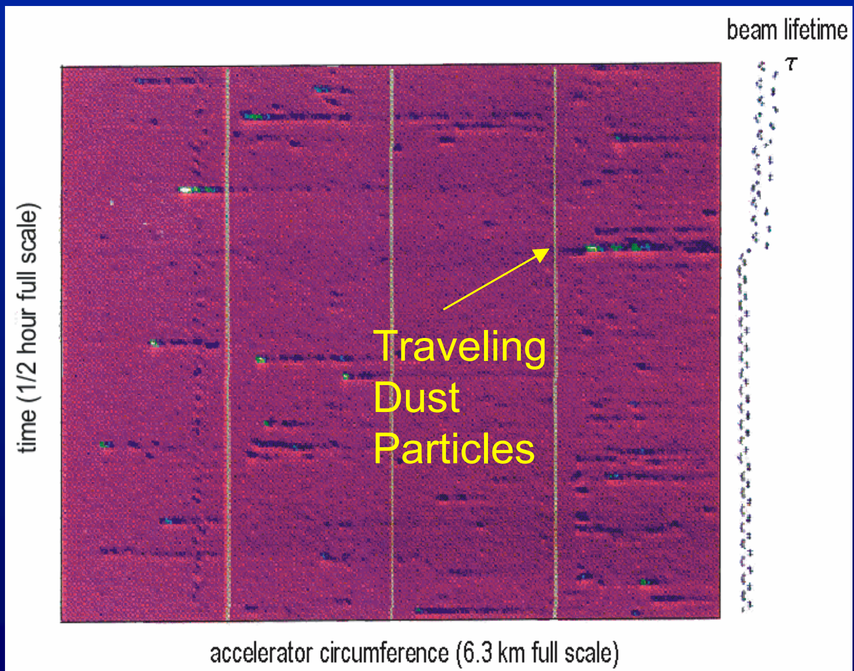
Sudden breakdown of the beam lifetime due to dust a ~1μm size dust particle above ~10mA beam current

Emitted by the integrated ion pumps

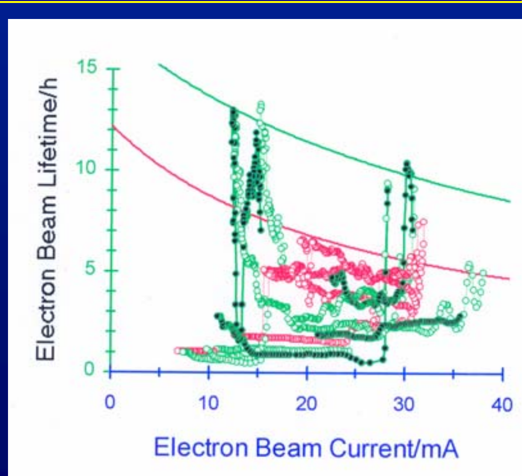
Replace all integrated ion pumps by NEG pumps in 1997/8

➔ **Operate with e^+ 1994-1997**

HERA electron losses in space and time

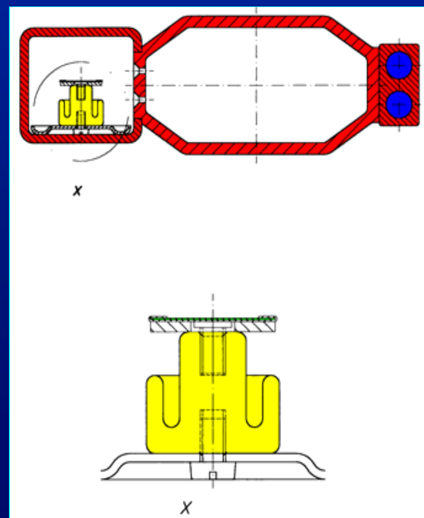


Experiments confirms the ion pumps as major source



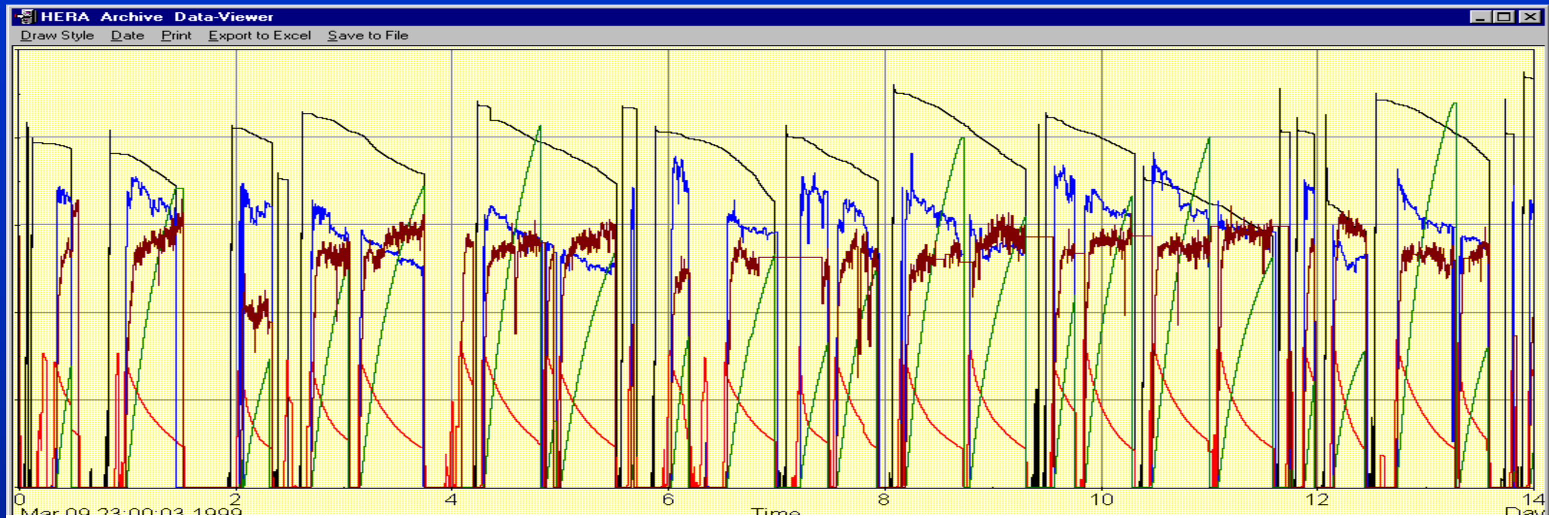
Replace Ion Pumps by NEG Pumps

WS 1997/1998



Successful operation with electrons in 1999

2 Weeks of HERA Luminosity Operation with e^- in March 1999



- Proton currents 80-90mA; e- currents 30-35mA; e-beam lifetime (8-14) h
- two e-fills per p-Fill
- Polarization ok, backgrounds tolerable
- Up to 400/nb /day, up zu 2/pb pro week
- short Fill time close to Minimum
- Good reliability

➔ HERA II Running with Electrons

- Expect average beam currents of 35mA
- Beam lifetime expected to be somewhat shorter (11h ➔ 8h) ➔ shorter runs
- Particle backgrounds due to tails in transverse e- distribution expected to increase
- One has to expect more frequent background "spikes"

➔ e- Luminosity production somewhat less effective compared to e+

Accelerator Physics Issues

Coherent Beam-Beam Effects

Beam-Beam Footprint accommodation

Proton Beam Longitudinal Stability

First order linear Beam Parameters and low intensity specific luminosity

Working Point

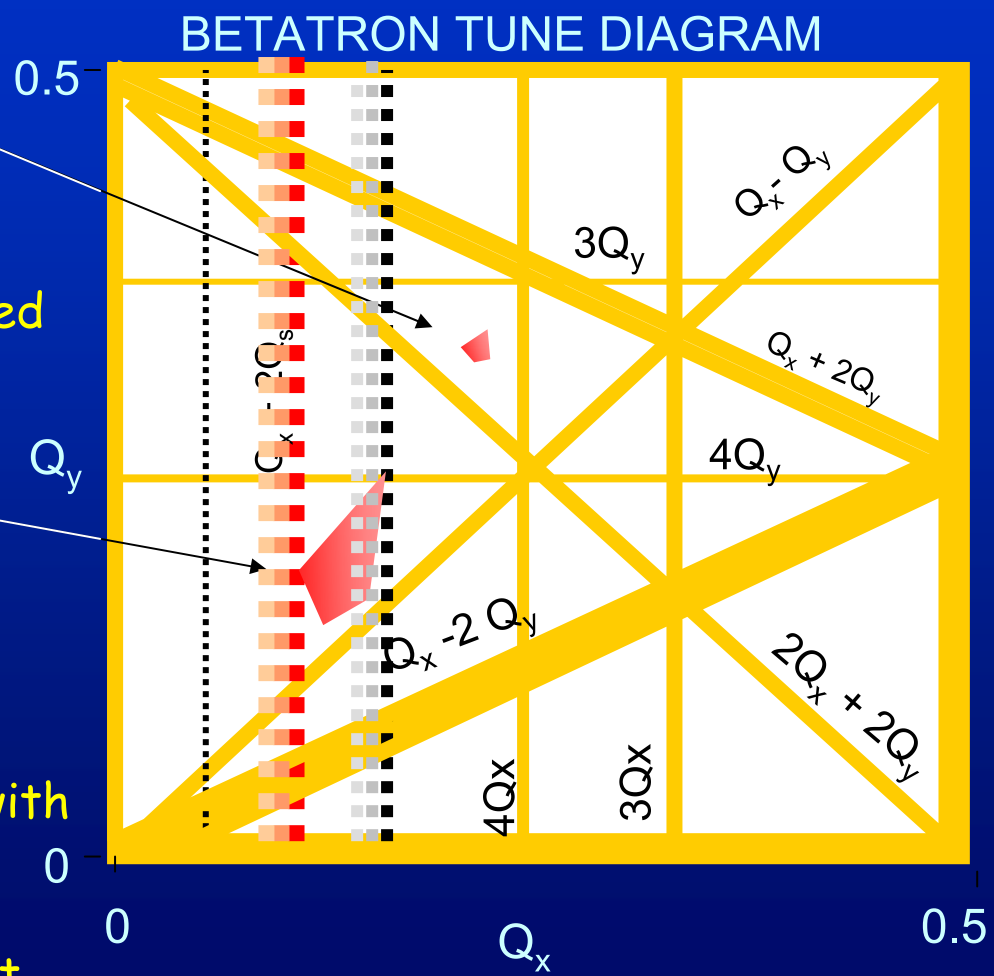
$\Delta Q^{x}_{bb} = 0.036$ $\Delta Q^{y}_{bb} = 0.072$

Injection Tune:

Dynamic Aperture Sufficient
High specific Luminosity
But in Collisions Tune footprint limited by strong resonances
Poor Polarization

Collision Tunes:

Dynamic Aperture small (6-7)s
Frequent sudden lifetime breakdown
non-reproducible orbit effects
reduced specific luminosity (10%)
good polarization (50% in collisions with 3 rotators)
Frequent beam loss when switching tunes Squeeze with C.T very difficult



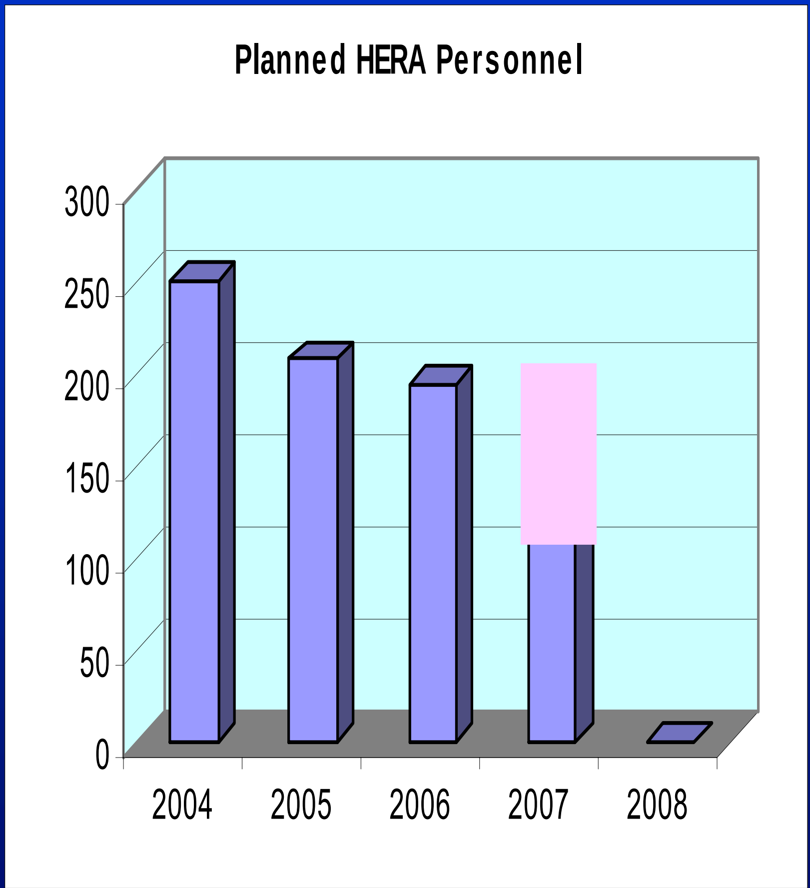
HERA Improvement Program:

rich program with 70 items, the most important ones being:

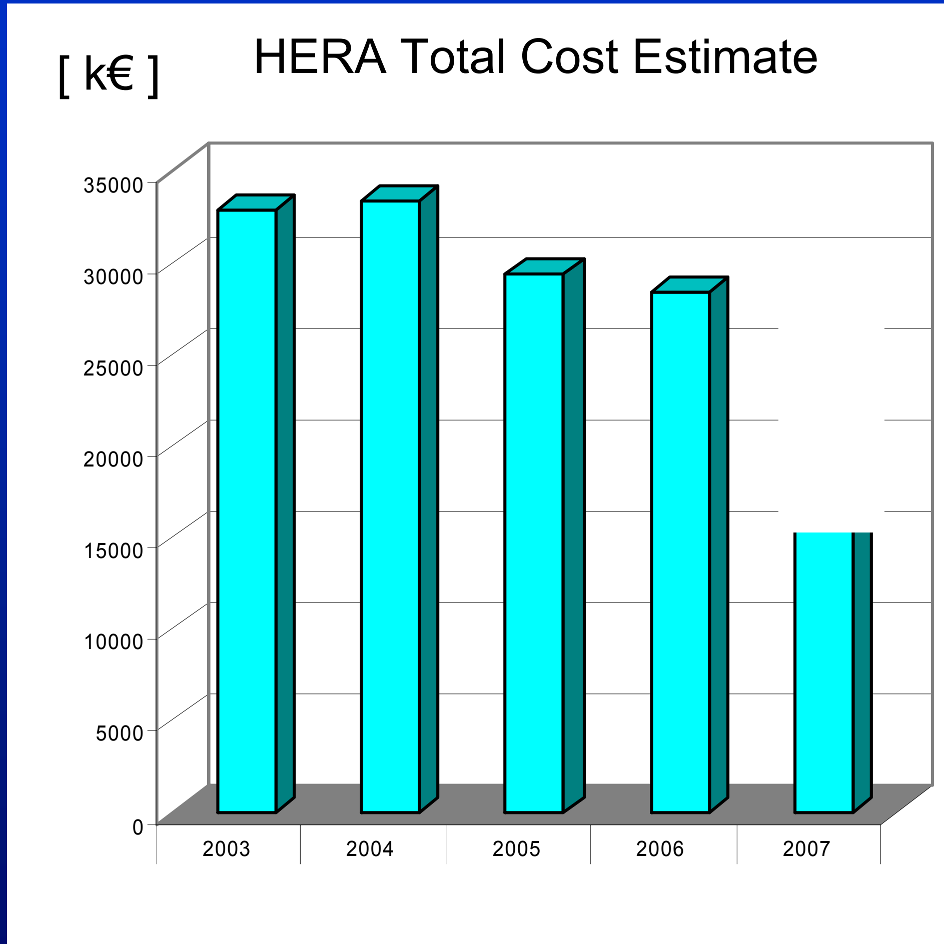
Proton RF Systems	Improved low-level controls Suppression of long. Instability	2/2/.5 PJ	0.55 M€
Injection Systems	Improved monitoring vertical excitation kicker	0/0.2/0.2 PJ	0.09 M€
Collimation Systems	increased reliability	0/0.25/0.2 PJ	0.10M€
Diagnostics Systems	improved monitors (BPM, SR)	1./0.3/0.1 PJ	0.15 M€
RF-Controls	p-RF freq. control, etc	1/0.25/0.25 PJ	0.04 M€
Vacuum System	better pumping in RF sections	0/0.5/1.0PJ	0.5 M€
Power Supply Systems	add'l Ps for spin matching	0 /0.3/0.2 PJ	0.2 M€
e-RF Systems	RF Modulator	0/0.5/.95 PJ	0.13 M€
Cryogenic Systems	compressor and controls upgr.	0 /0.5/1.5 PJ	0.45 M€

Summe: **14.6 PJ @ 0.605 M€** (add'l only) **2.26 M€**

HERA is the highest priority project at DESY which will be adequately supported

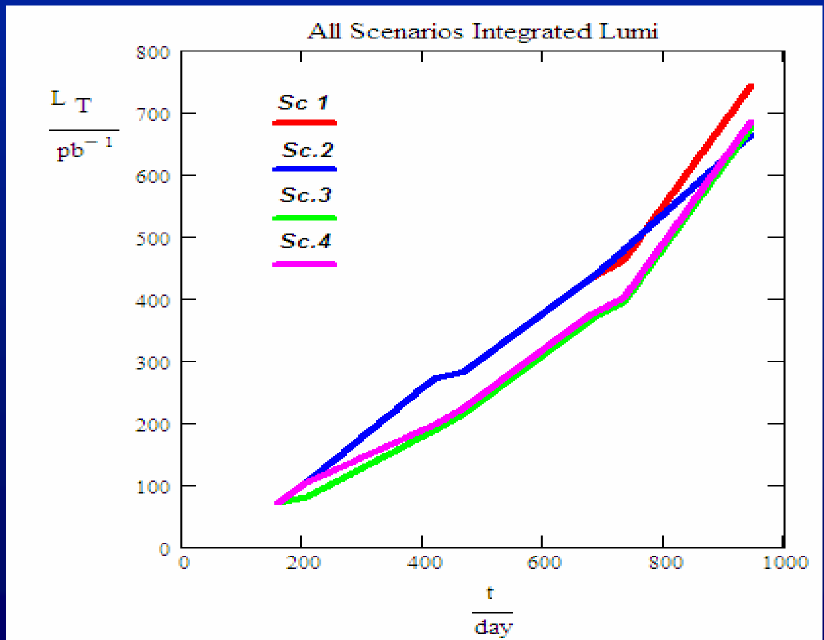


HERA+Accelerator Chain

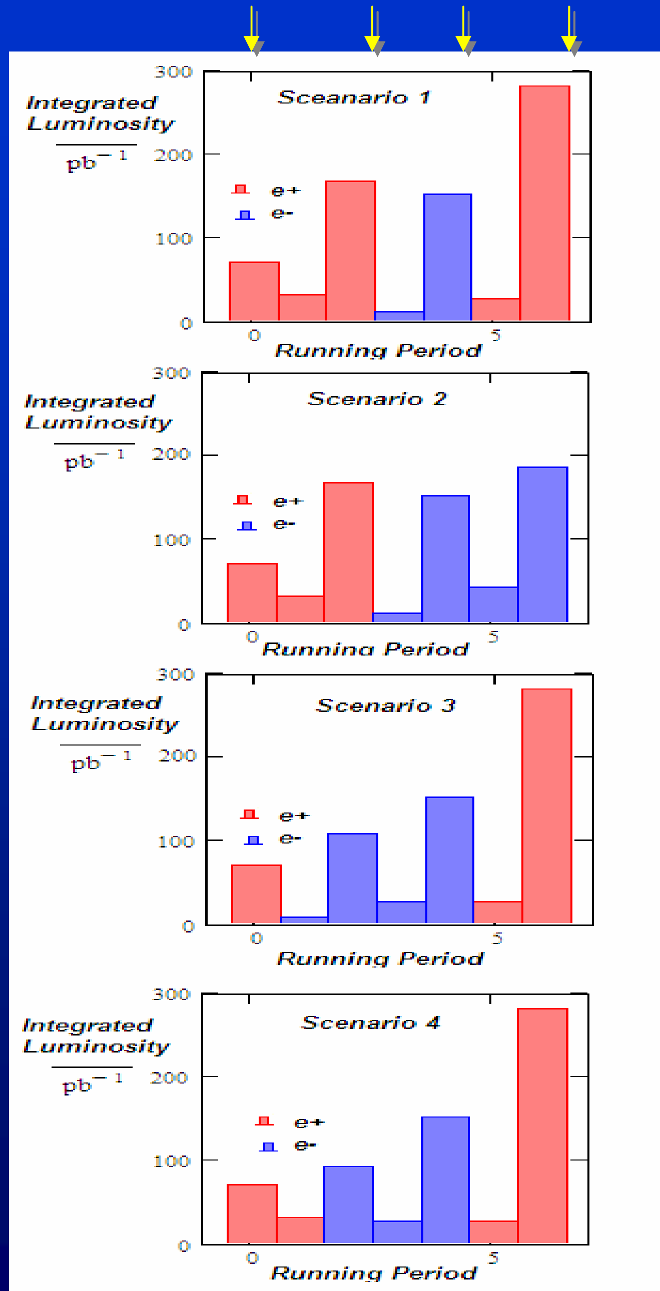


Projected Performance

Scenario	1	2	3	4
1-8 2004	p	p	p	p
10-12 2004	p	p	e	p
1-8 2005	p	p	e	e
10-12 2005	e	e	e	e
1-8 2006	e	e	e	e
10-12 2006	p	e	p	p
1-8 2007	p	e	p	p



Summer 2004/2005/2006/2007



HERA beyond 2007

HERA II running will end in June 2007 ☹
and the upgrade of the PETRA ring into the
3rd generation Light source PETRA III will start

However

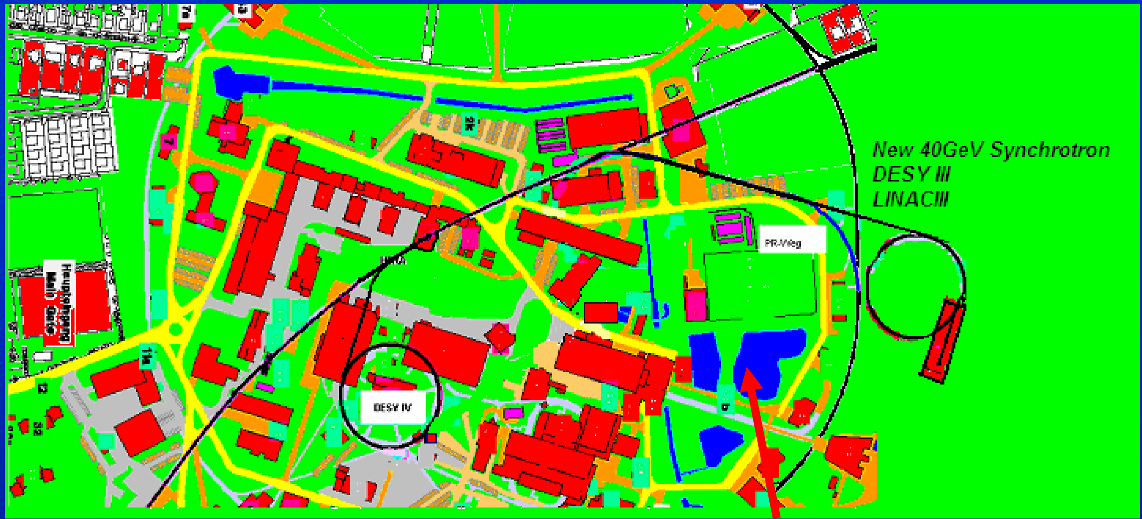
Two interesting letters of intend for a continuation of the HERA program have been submitted:

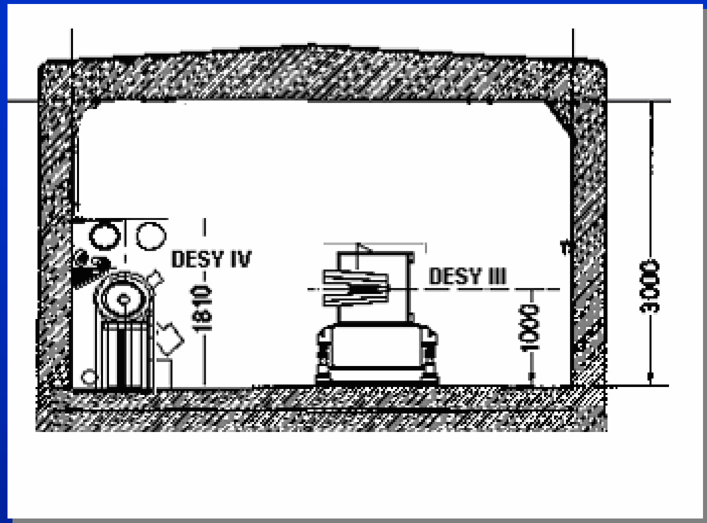
- Lepton Deuteron Scattering proposing
- Specialized detector for low-x physics

These have been received very well and the excellent physics case has been unanimously acknowledged by the review committees

➔ Activities in the user committee have been initiated to look into the possibilities for a new HERA injector

HERA Beyond 2007
possible new injectors





Possible site for a new HERA p-injector

<u>Preliminary ideas</u>:

• Direct injection from DESY II into HERA-e (alternatively via a damping ring in the DESY tunnel)

• New tunnel for DESY III and a new superconducting 40GeV Proton Booster

➔ Needs more study to assure feasibility & determine costs

Design study carried out by HERA III users envisioned

Conclusions

- The background problems which occurred with the luminosity upgrade are now solved
- HERA made rapid progress towards operating with twice the Y2000k peak luminosity and with longitudinally polarized positrons at the 3 IPs
- The challenge is now to achieve the Y99/2000 operating efficiencies
- And to improve on the "usual" backgrounds
- There is a good chance to deliver a decent amount of luminosity until the end of the HERA II running period
- There are exciting ideas for a continuation of the HERA physics program
- There appear to be technical solutions to overcome the HERA injector problem which need some serious study, these however are not part of the present planning of DESY high energy physics program