Electron-ion collisions and other options for HERA

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by

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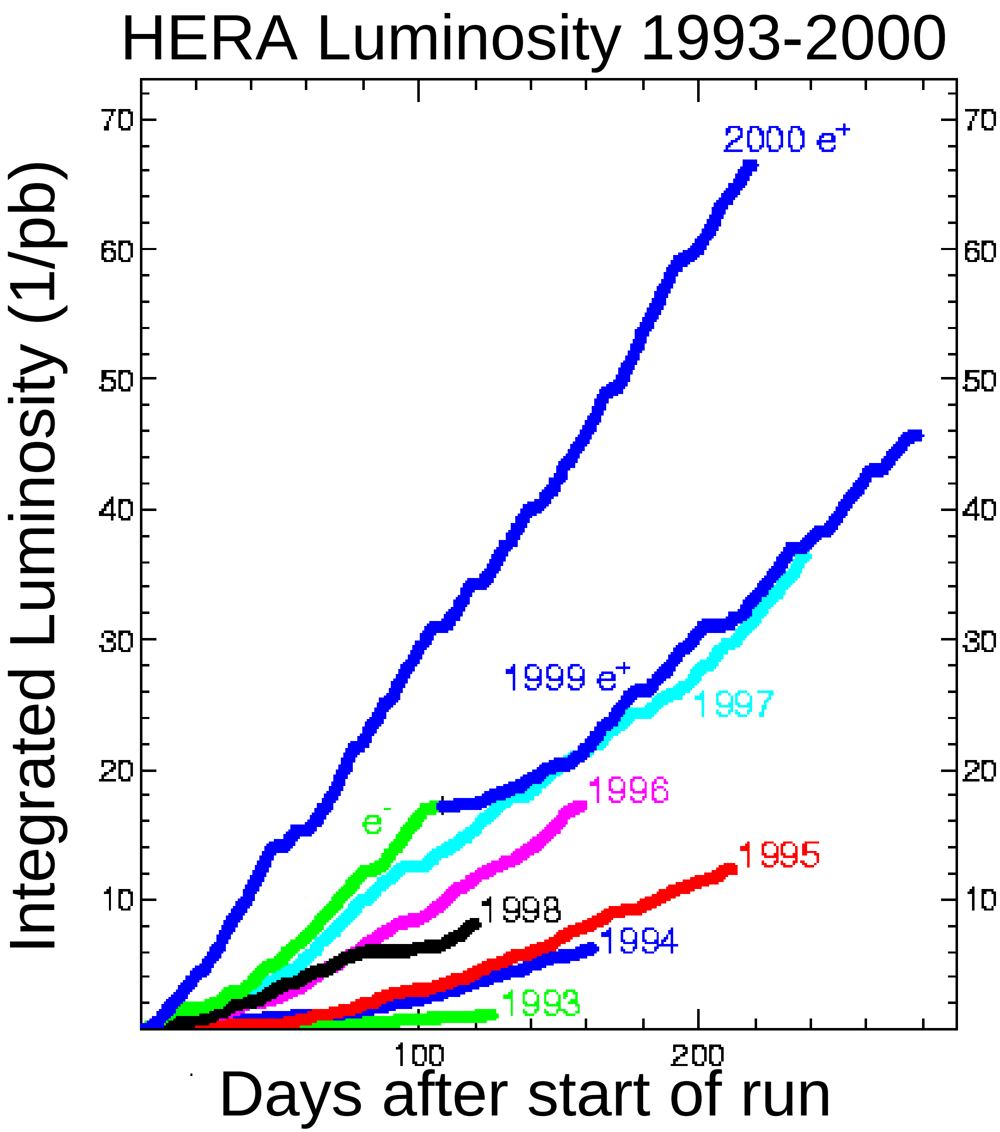
Development of the Luminosity for HERA-I

In 2000, design values have been surpassed for:

- specific luminosity
- peak luminosity
- integrated luminosity per year



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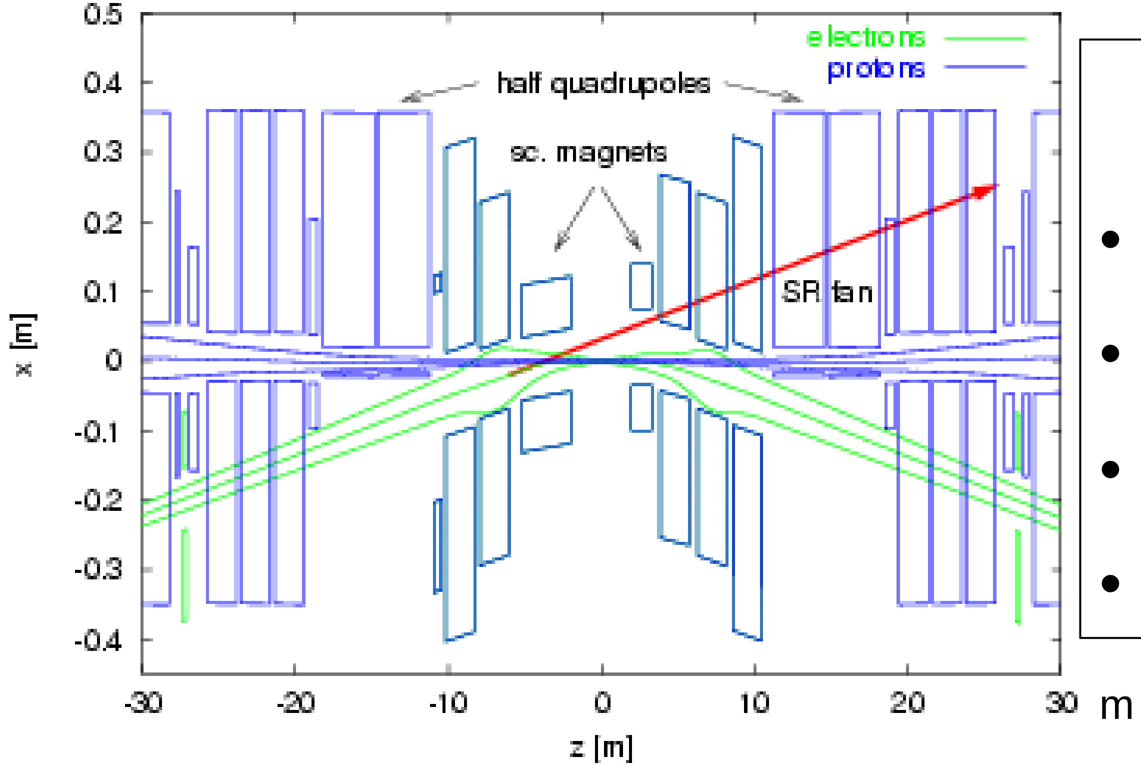
The HERA Luminosity Upgrade



New limitations:

- beam-beam tune shift
- hourglass effect for protons
- dynamic aperture of e-beam
- background due to radiation

- Increase of luminosity from $1.5 \cdot 10^{31}$ to $7 \cdot 10^{31}$
- Beam separation by super-conducting magnets in the detectors
- Focusing to ¼ of the old beam cross-section

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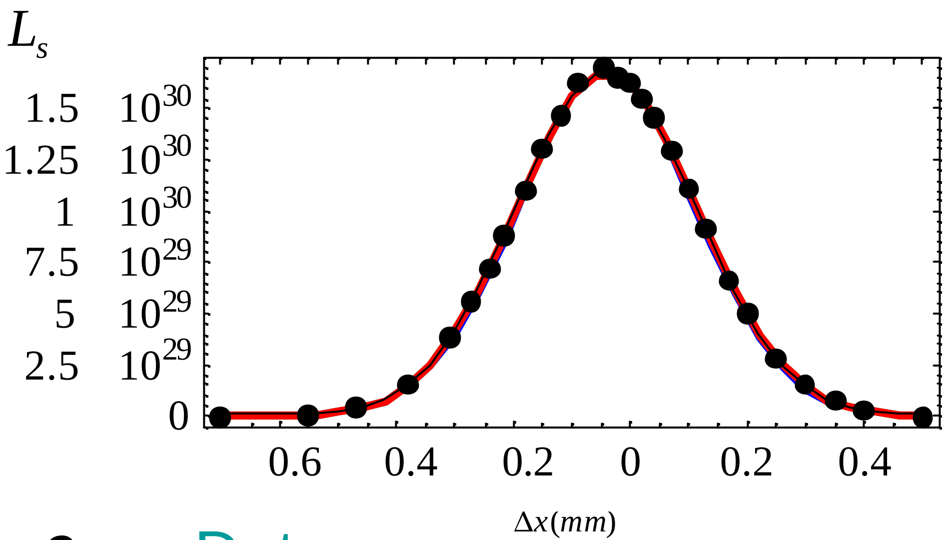
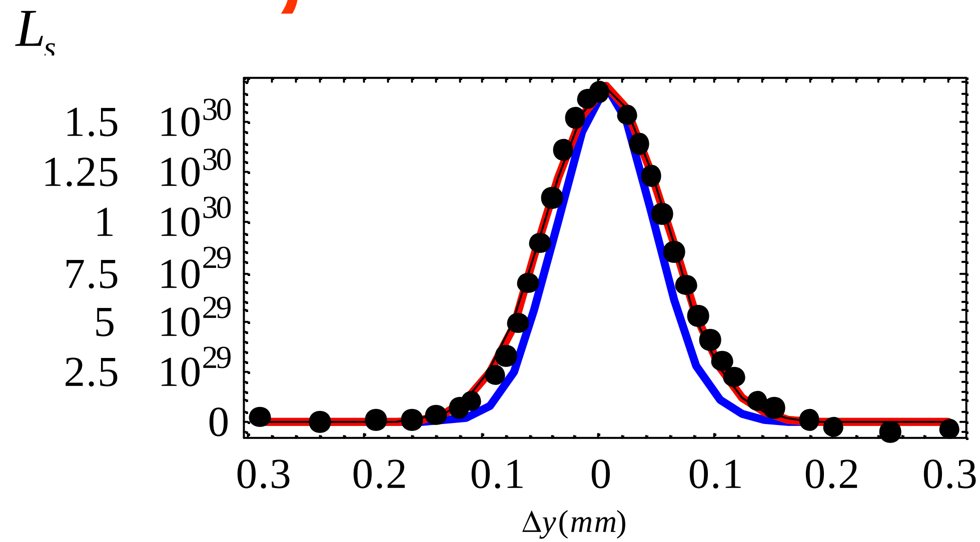
Lumi scan Nov. 2, 2001





- ● Data
- — Gauss fit
- — Gauss for proton emittances 16mum, electron emittances 21nm and 35% coupling
- — Gauss for proton emittances 16mum, electron emittances 21nm and 17% coupling

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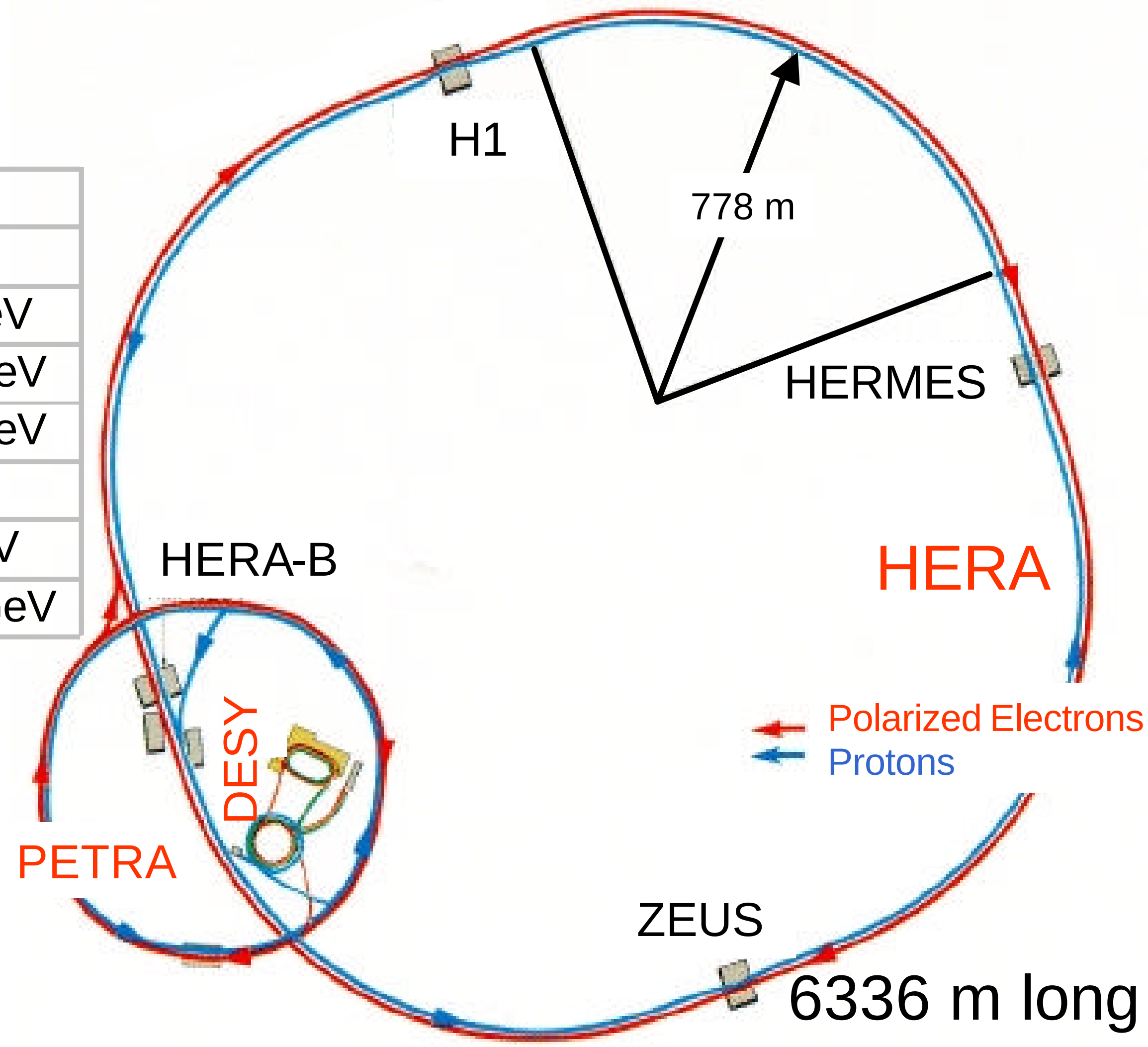
HERA and its Pre-Accelerator Chain

	Protons	Electrons	
20 keV	Source	Source	150 keV
750 keV	RFQ	Linac II	450 MeV
50 MeV	Linac III	Pia	450 MeV
8 GeV	DESY III	DESY II	7 GeV
40 GeV	PETRA	PETRA	12 GeV
920 GeV	HERA-p	HERA-e	27.5 GeV



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Nominal and Ultimate Parameters

	p	e
Energy–p/e	920 GeV	27.5 GeV
Emit. hor/vert	$5/5\pi$ mm mrad	20/3.4 nm
β^* at IP hor/vert	2.45/0.18 m	0.63/0.26 m
Aperture hor/vert	$12/12\,\sigma$	$20/20\,\sigma$
p per bunch and e-cur.	$1.03\cdot10^{11}$	58 mA
Tune shift hor/vert	0.0016/0.0004	0.034/0.051
Bunch Length	191 mm	10.3 mm
Luminosity	$0.74\cdot10^{32}\text{cm}^{-2}\text{s}^{-1}$	

p	e
$3.5/3.5\pi$ mm mrad	20/2.7 nm
1.7/0.125 m	0.42/0.17 m
$10/10\,\sigma$	$12/12\,\sigma$
0.0017/0.0005	0.047/0.069
$1.3\cdot10^{32}\text{cm}^{-2}\text{s}^{-1}$	

- The performance goal of HERA is not unrealistic and should not be too hard to achieve.
- A shortfall of beam intensity in the short term can be compensated.

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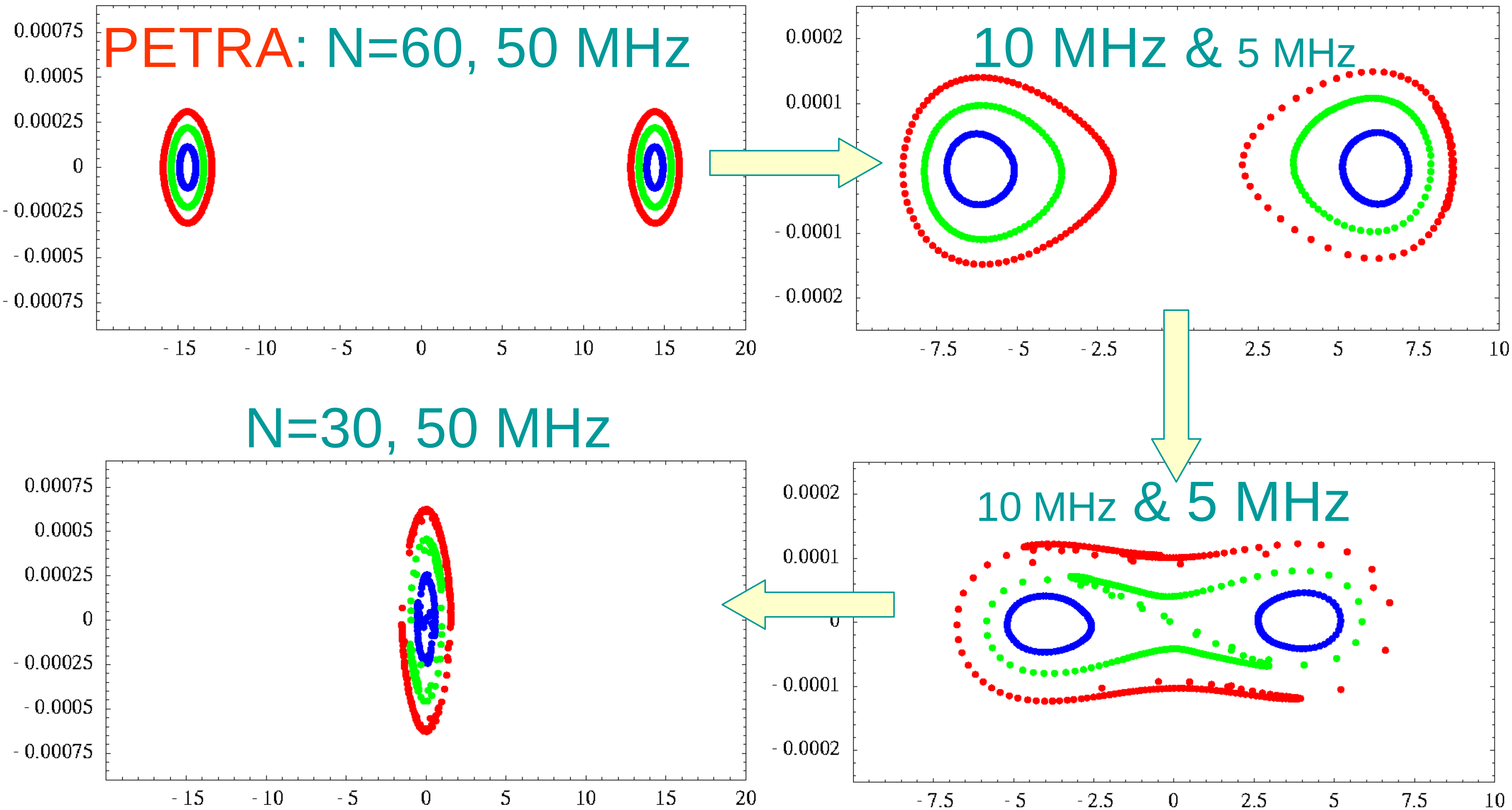
Increasing the Proton Current



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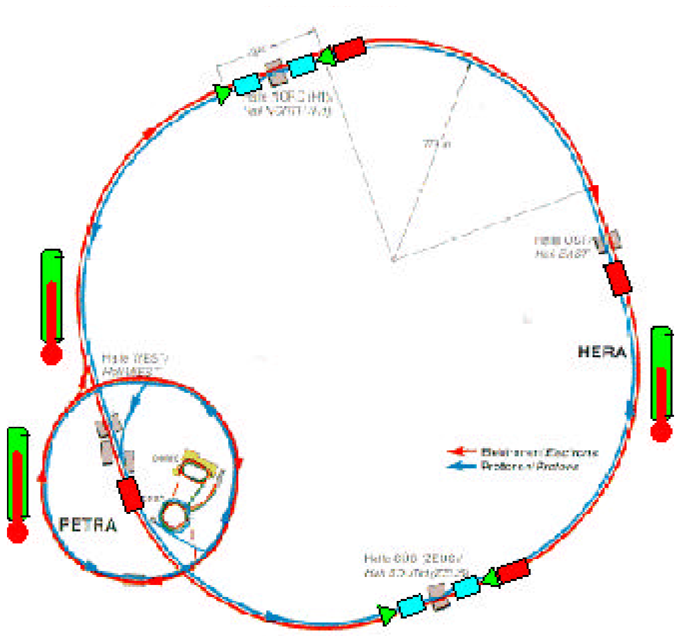
HERA III

Polarized protons in HERA



- Polarimeters
- Flattening Snakes
- Spin rotators
- At least 4 Siberian Snakes

- Polarized protons (30MEuro)
- Polarized deuterons
- Electron precooling and cooling
- Ion acceleration (53MEuro)

$$L_A = L_p \cdot \frac{1}{A} = 7 \cdot 10^{31} \cdot \frac{1}{A}$$

- Pulse stretcher for TESLA
- Collisions with TESLA (120ME.)

$$L_{ep} = 1.6 \cdot 10^{31}$$

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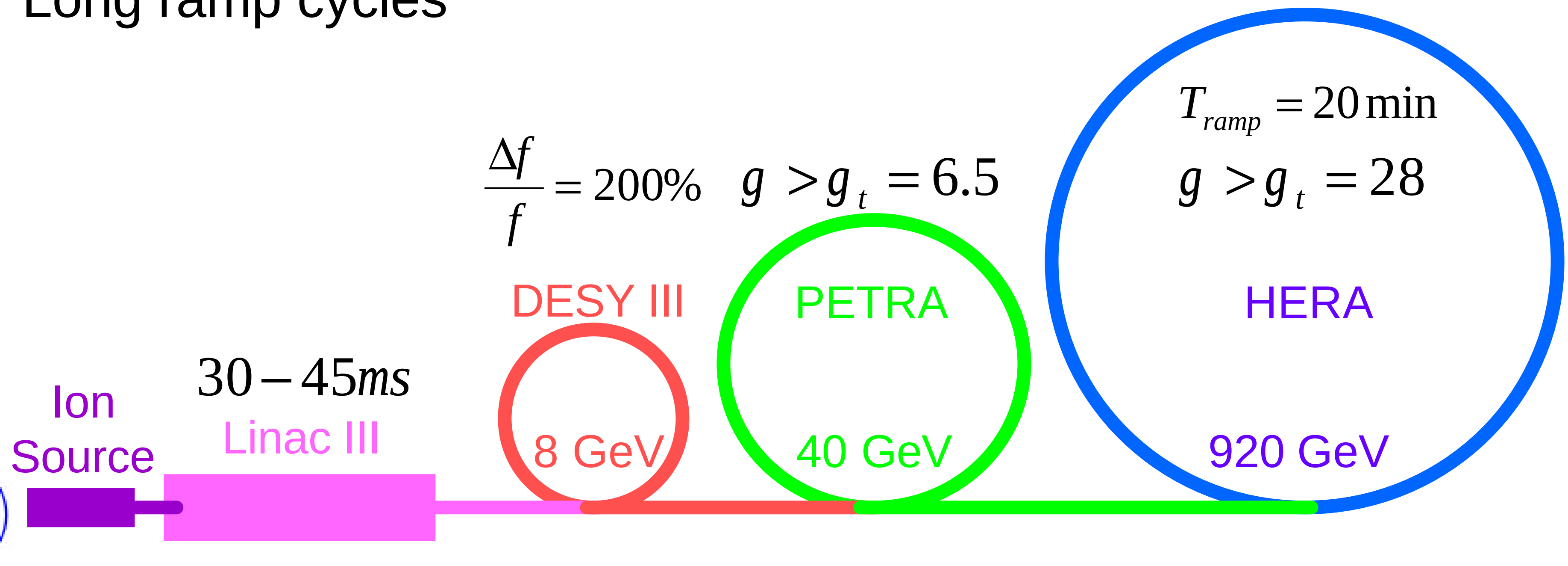
Ions in HERA

Challenges:

- Longer bunch trains needed
- Stronger space charge and IBS
- Strong frequency swing
- Croissing of transition energy needed
- Long ramp cycles



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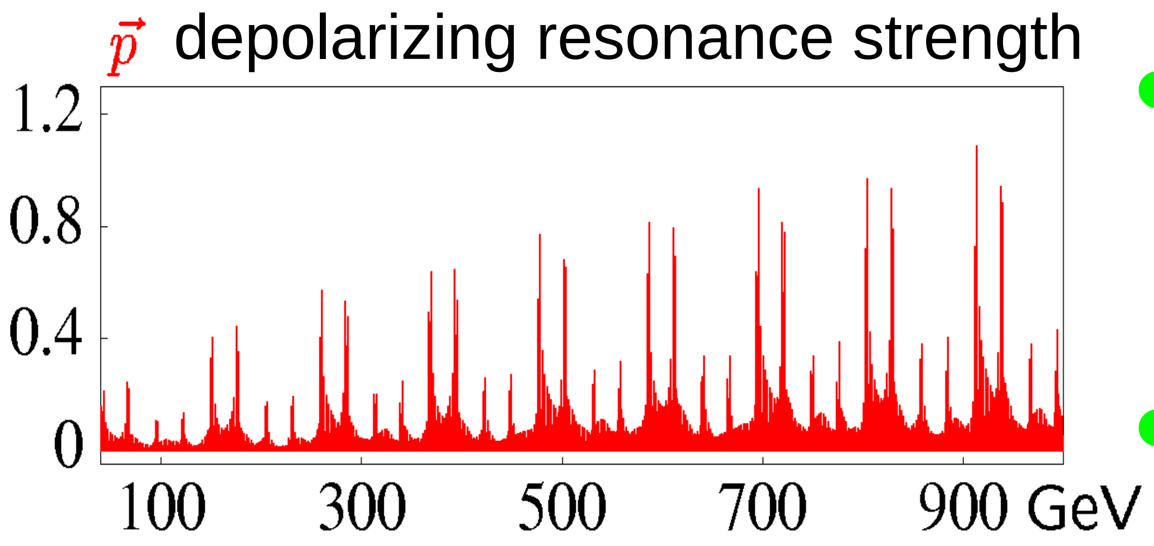
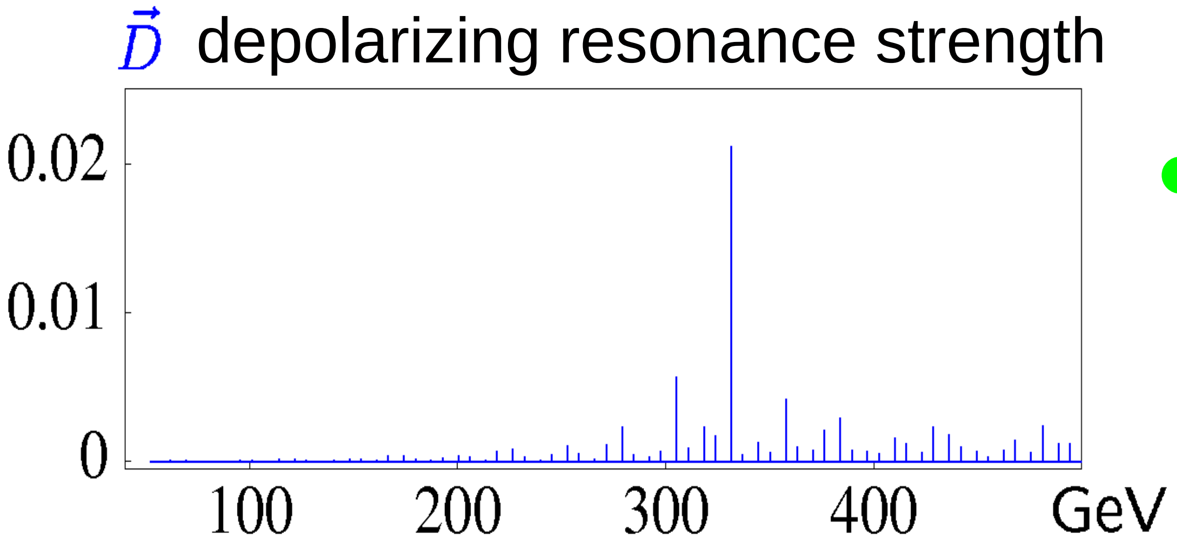
Polarized Deuterons





- Resonances are 25 times weaker and 25 times rarer for D than for p
- Transverse polarization could be achieved without Siberian Snakes
- Transverse RF dipoles could be used to rotate and stabilize longitudinal polarization

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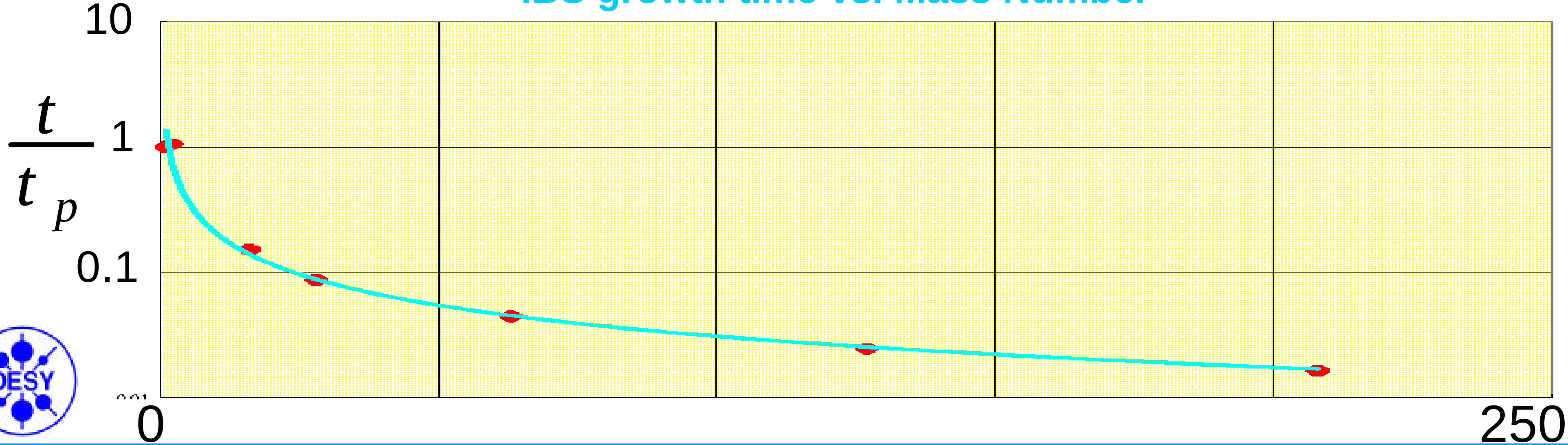
Problem: IBS in HERA

$$\frac{1}{\tau_{IBS}} \propto I_{bunch} \cdot \left(\frac{Z}{A}\right)^2 \cdot \frac{1}{\gamma^3} \cdot Z$$

	Deuteron	$^{16}O^{8+}$	$^{208}Pb^{82+}$
ϵ_N	$2.5\mu m$	$2.5\mu m$	$2.0\mu m$
N_{ppb}	$5.0 \cdot 10^{10}$	$6.0 \cdot 10^{9}$	$4.8 \cdot 10^{8}$
$\mathcal{L}$	$3.5 \cdot 10^{31}$	$4.4 \cdot 10^{30}$	$3.4 \cdot 10^{29}$
$\sum_{xyz} \tau_{IBS}$	140min	20min	2.5min

IBS growth time vs. Mass Number



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Summary on e – Ion collisions

- Deuteron acceleration:

  Technical solutions seem possible

- Heavy ions: $\mathbf{L} \approx \mathbf{L}_p / A$ does not seem possible

- e – cooling counter balances IBS and leads to the required emittances and therefore

$$\mathbf{L} \approx \mathbf{L}_p / A$$

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e – cooling for HERA and PETRA

- e – Ion: balances IBS
- e – protons: doubles luminosity
- e – polarized protons: reduces emittance to a polarizable size

$$\tau_{long} \propto \frac{A}{Z} \cdot \gamma^4 \cdot \sqrt{\epsilon_p}^2 \cdot \frac{1}{Z}$$

$$\tau_{trans} \propto \frac{A}{Z} \cdot \gamma^3 \cdot \sqrt{\epsilon_p}^3 \cdot \frac{1}{Z}$$

- Cooling in PETRA: $(g \approx 19)$
  $e_{px} : 5 \rightarrow 3.3mm$
  $e_{py} : 5 \rightarrow 0.8mm$
- Cooling in HERA: preserve against IBS
  $e_{px} : 3.8mm$
  $e_{py} : 0.9mm$

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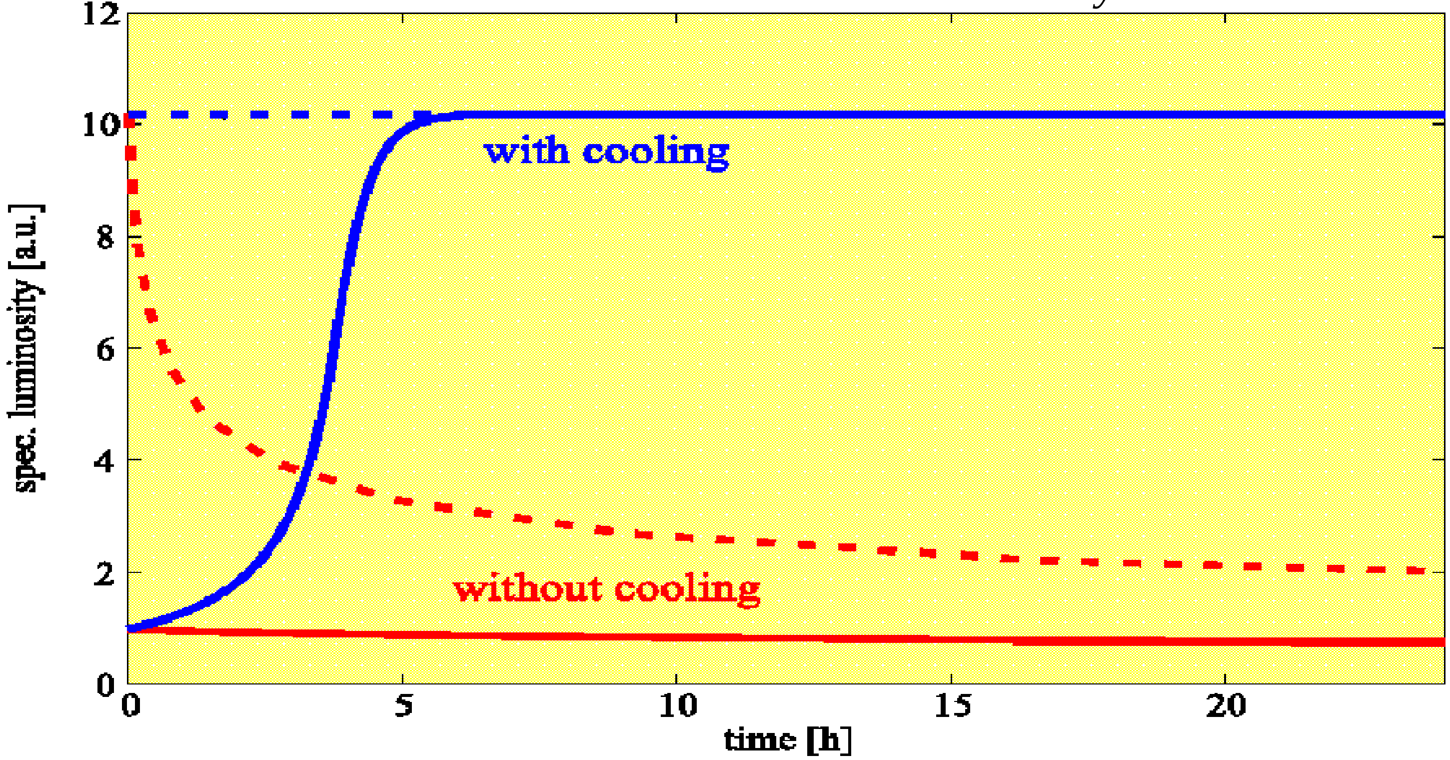
Cooling for e – Ion collisions

$$^{197}A^{79+}: E = 330GeV/u, e_x = 1mm, e_y = 0.25mm$$



$$horizon.: t_{IBS} = t_{cool} = 30\min$$

$$vertical: t_{IBS} = t_{cool} = 18\min$$

$$\mathbf{L}_A = \mathbf{L}_p \frac{1}{A}$$

$$\mathbf{L}_p = \mathbf{0.76 \cdot 10^{32}}\, cm^{-2} s^{-1}$$

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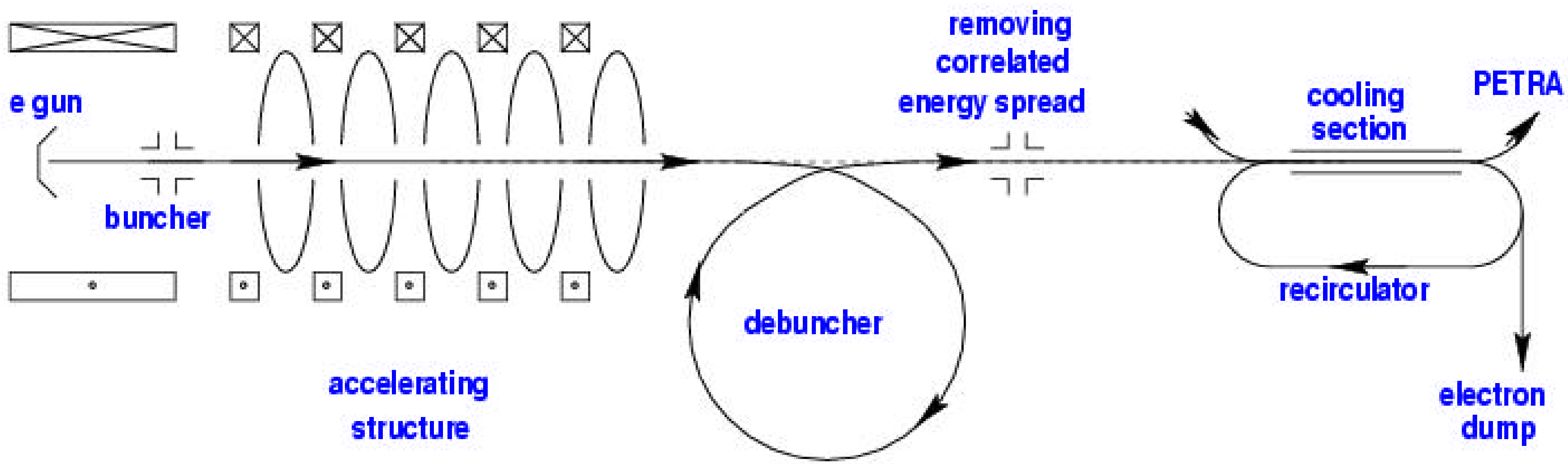
Electron Cooling in PETRA



$$B_z = 0.3\text{T} \qquad N^e_{ppb} = 3 \cdot 10^{10}$$

$$E = 9.8 MeV \qquad \frac{\Delta p}{p} = 30 \cdot 10^{-4} \qquad \sigma_z = 0.017$$

$$B_z = 0.06\text{T} \qquad \frac{\Delta p}{p} = 3 \cdot 10^{-4} \qquad \sigma_z = 0.5$$

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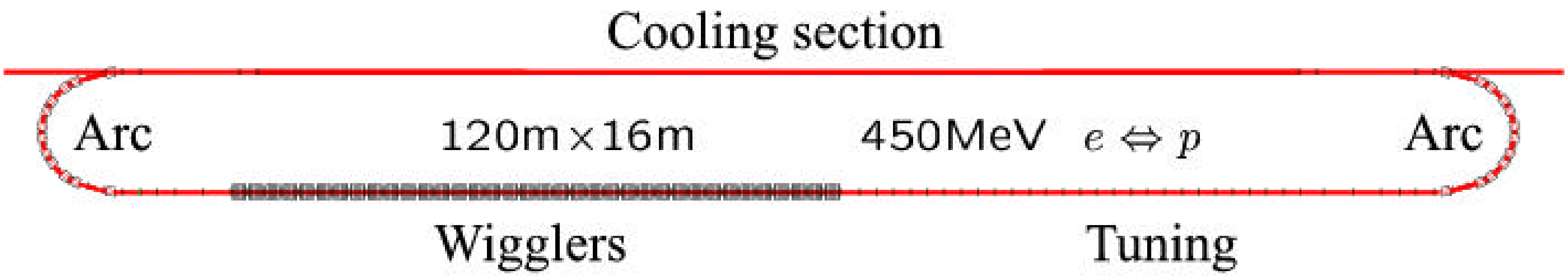
Electron Cooling in HERA



- Width limit: dynamic aperture from sextupoles required due to strong focusing (tunnel has 5.2m)

- 37 wigglers section: $D = 0$, $D' = 0$, $B = 1$T

- Tuning section: tune control, decoupling, RF cavities

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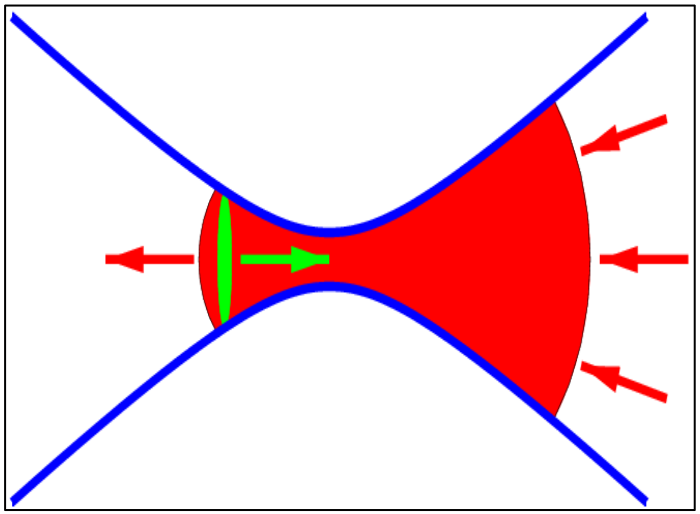
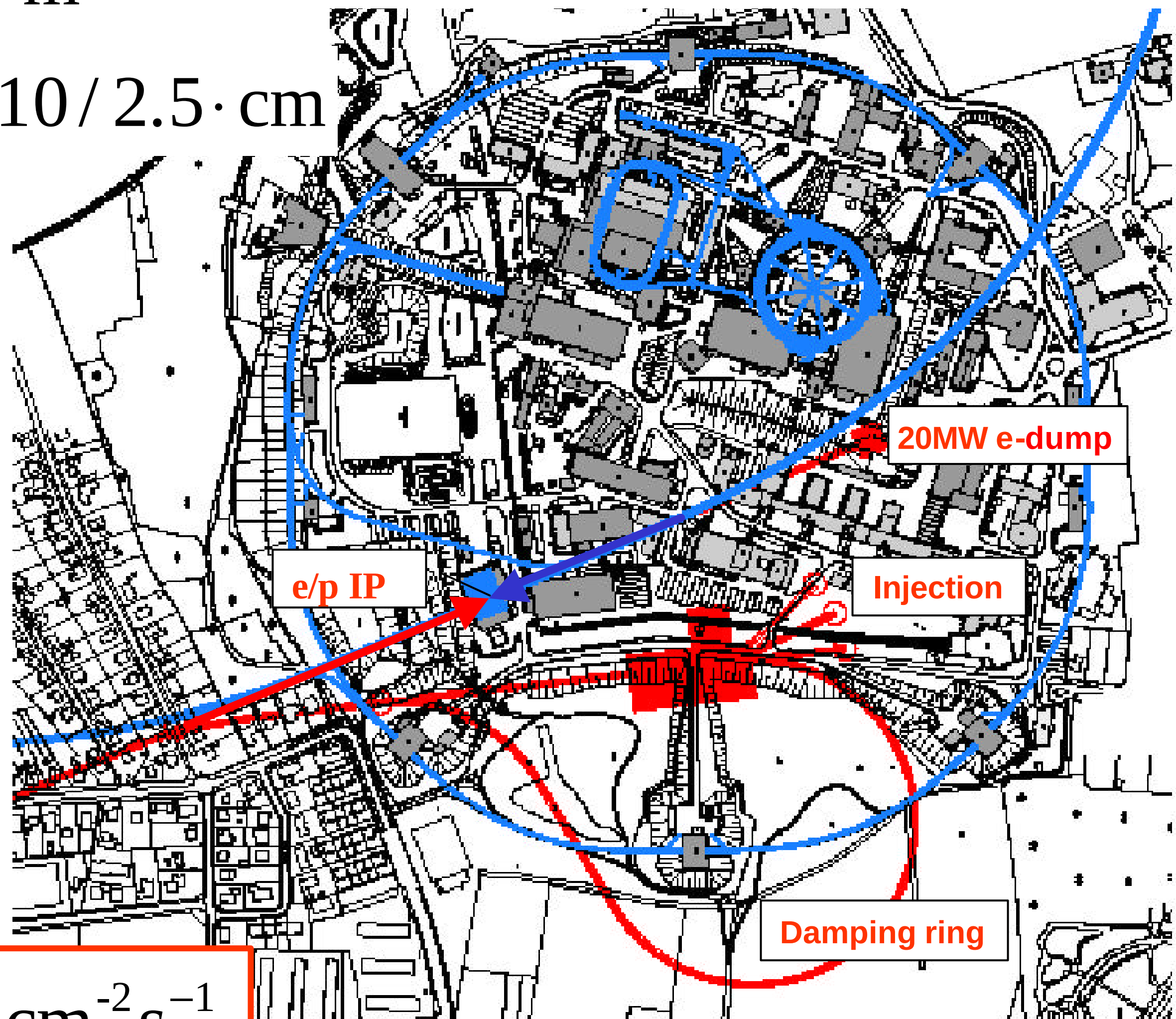
THERA: The TESLA on HERA Collider

- Cooling: $\epsilon_{x/y} = 1/\tfrac{1}{4}\cdot 10^{-6}\,\mathrm{m}$
- Traveling focus $\beta^*_{x/y} = 10/2.5\cdot\mathrm{cm}$





- Variable e-energies
  250-800 GeV

- Luminosity: $L \approx 2\cdot 10^{31}\,\mathrm{cm}^{-2}s^{-1}$

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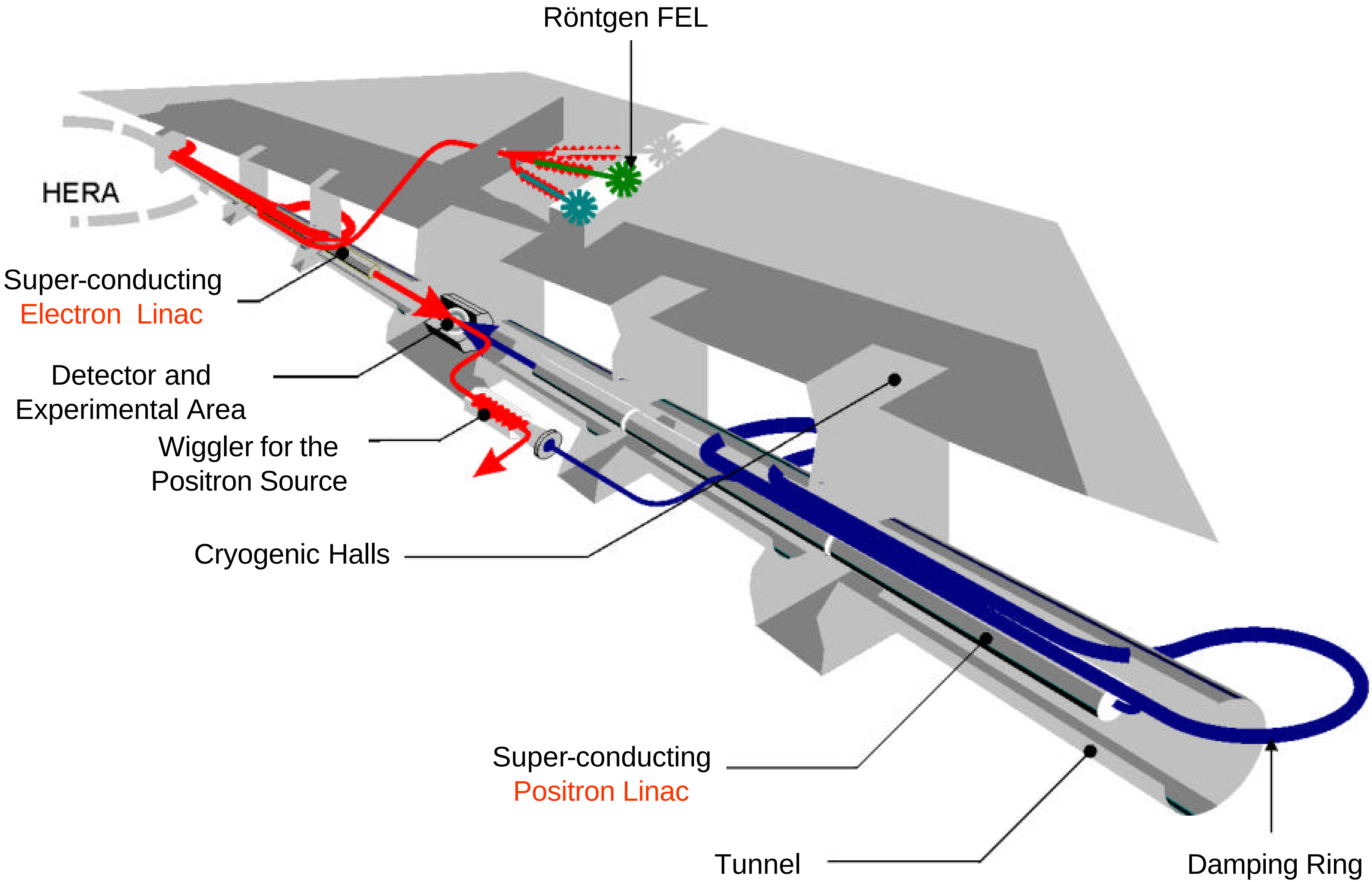
TESLA with Röntgen FEL



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