Issues for Future HERA Operation

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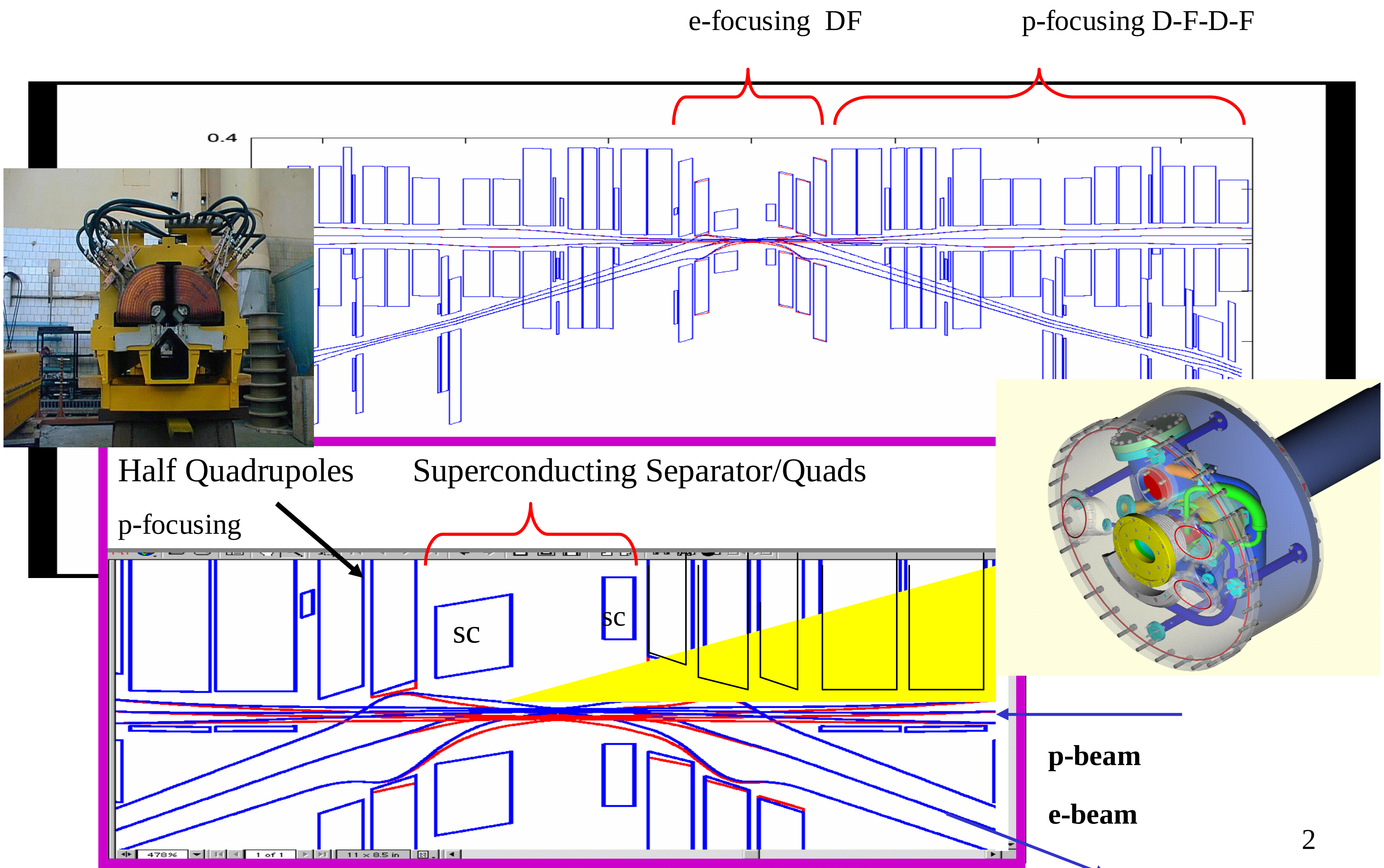
Future Lepton Nucleon Scattering

Workshop at Durham

December 6-7 2001

New HERA Inter Action Region (==>see M. Seidel)

strong magnetic combined function separation



HERA Commissioning Schedule 2001

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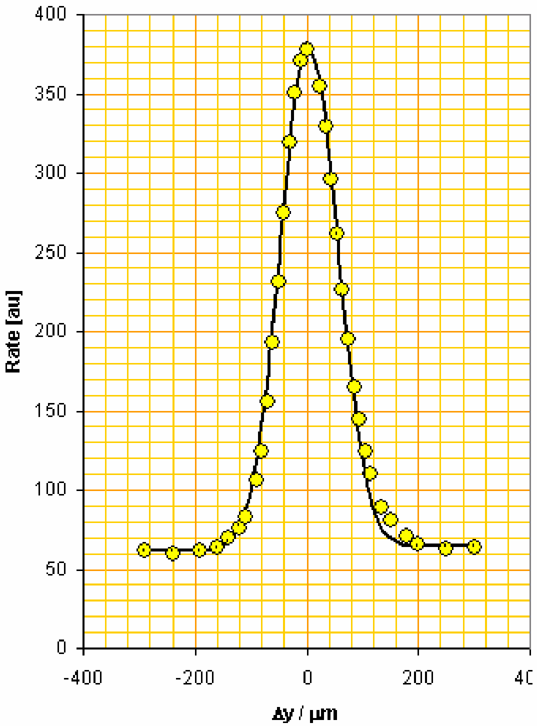
#		Begin	Duration/Days	End
1	Startup 2001	26-Jul-01	1.0	27-Jul-01
2	Establish Beam Operation p	27-Jul-01	17.0	13-Aug-01
3	Maintenance day	13-Aug-01	0.7	13-Aug-01
4	Establish Beam Operation e	13-Aug-01	33.0	15-Sep-01
5	Explore Optics	15-Sep-01	8.7	24-Sep-01
6	Maintenance day	24-Sep-01	0.7	25-Sep-01
7	Explore Optics	25-Sep-01	6.7	1-Oct-01
8	Turn-On Detector Fields	1-Oct-01	17.7	19-Oct-01
9	Set up & Optimize Collisions	19-Oct-01	11.3	30-Oct-01
10	Investigate Synchrotron Radiation	30-Oct-01	20.0	19-Nov-01
11	Break for Experiments	19-Nov-01	3.0	22-Nov-01
12	First Luminosity Runs	22-Nov-01	12.7	5-Dec-01
13	Polarization Tuning	5-Dec-01	7.0	12-Dec-01
14	Turn on North/South rotators	12-Dec-01	10.0	22-Dec-01
15	Maintenance Period	22-Dec-01	25.0	16-Jan-02
16	Startup 2002	16-Jan-02	3.0	19-Jan-02
17	Polarization Tuning	19-Jan-02	11.0	30-Jan-02
18	Start Luminosity Run	30-Jan-02	1.0	31-Jan-02

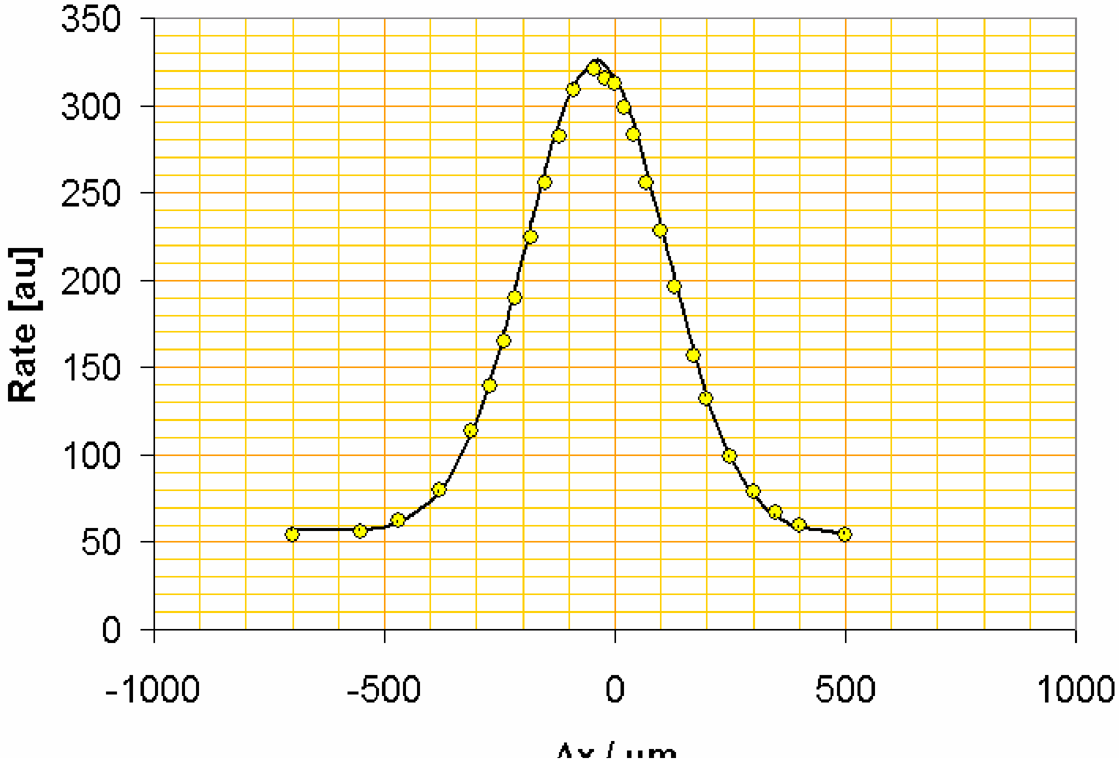
Measured Spec. Luminosity: L_{spec} = **1.68** 10^{30} $mA^{-2}cm^{-2}sec^{-1}$

Design Specific Luminosity: L_{spec} = **1.88** 10^{30} $mA^{-2}cm^{-2}sec^{-1}$

Vertical Lumiscan H1 2.11.01
Fit: Σ_y = 51 µm



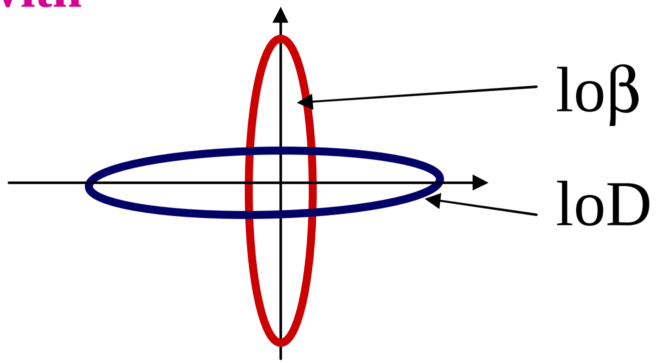
Horizontal Lumiscan ZEUS 2.11.01
Fit: Σ_y = 153 µm



ep Collisions

- get 10 pb^{-1} y^{-1} with Divergence ➔ Divergence/10?

➔ **luminosity decreasing linearly with divergence D_x x D_y**



- Can the magnets GG & GO be moved back to ~5m from IP for loD?

➔ **Yes with some modification to p lattice (doublet focusing)**

- Does moving these magnets affect the luminosity?

➔ **little**

- low D along the proton beam line for detectors l~1m @100m of IP?

➔ **doublet focusing provides sufficient space**

•run at 50% of the nominal p-beam energy?

➔ **Minimum E_p=300GeV (collisions @500GeV done ´91)**

•luminosity drop for low E_p? lower electron energy, luminosity drop

Luminosity Scaling with Beam Energy

Protons

$\varepsilon_p \sim 1/E_p \Rightarrow \beta_{max} \sim E_p \Rightarrow \beta_p^* \sim 1/E_p \Rightarrow \sigma_p^2 \sim 1/E_p^2$

$L \sim E_p^2$

Leptons:

$\varepsilon_e \sim E_e^2 \Rightarrow \beta^*_e \sim 1/E_e^2$; $\Delta\nu_e \sim \beta_e^*/E_e^2 \Rightarrow I_p \sim E_e^4$

mitigatd by larger emittance

HOMLs shorter bunches $\sigma_e \sim E_e^{1/2} \Rightarrow I_e \sim E_e^{1/2}$

$L \sim E_e^{0\text{-}4.5}$

L(12GeV)

Factor 10

Beam Energies:

highest possible energy for searches& larger cross sections &-lowering E_p (and perhaps E_e) for access to large x, lower Q2, FL, FLD, FLc

what is the E_e and E_p energy range of HERA?

- **Ee: 12-27.5GeV, Ep=300-920GeV without investments (10% Ee @ 8Mio Euro)**

could HERA run routinely with 1TeV ?

- **Magnet rearrangement, new Diodes (R&D), better QP**

Larger Luminosity

"only" $1fb^{-1}$ may see indications for new physics

for precision measurements like B production

require $L << 1fb^{-1}$

possibilities to increase

$L > 1fb^{-1}$ or $> 240pb^{-1}/y$ in HERA?

HERA Luminosity Constraints & Limitations

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

L = 7 x 10^{31}cm^{-2}sec^{-1}

Constraints: θ< 1mr (beam-beam tracking Sen'95) =>θ set 0(head on coll.)

$\sigma_{x,yp}$=~ $\sigma_{x,ye}$ (Brinkmann, Willeke PAC'93)

$\Delta\nu_e$ not (yet) limiting

Limitations: N_p / ε_N proton beam brightness = 1 x 10^{11}/ 4μm (injector, ibs, bb-e)

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

γ_p proton relativistic factor = 981 (max field, circumference)

$\beta_{x,y\,p}$ hor.& vert. Betafunctions at the IP = 2.45m/0.18m (ir layout, σ_p)

To what extend are these fundamental?

Limitations to Focussing

•Chromatic effects ➔ Dynamic Aperture Limitations

•Hourglass Effect

•Interaction Region Layout and IR Magnet Design:

Need e & p lenses close to IP

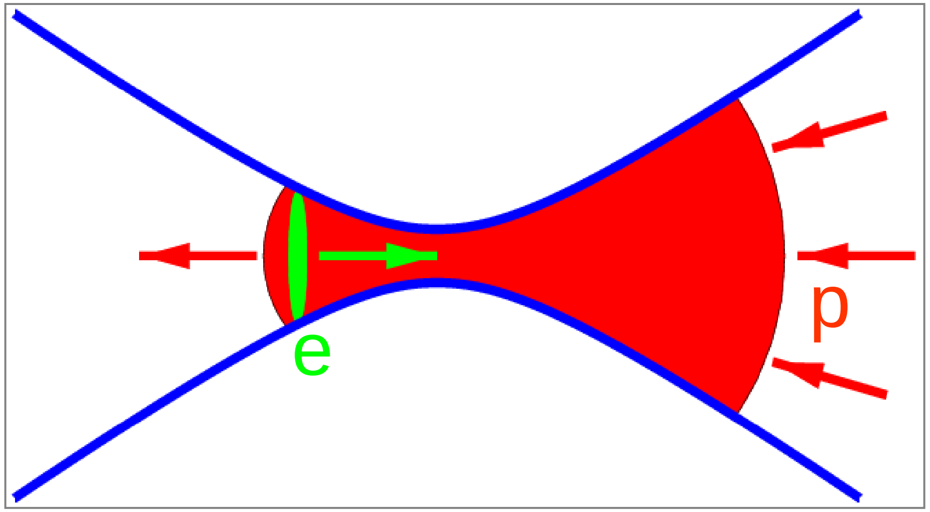
➔separate quickly → Crossing angle

beam dynamics, geometry

→ Magnetic Separation

Concern about SR

Lumi Reduction by Hourglass Effect

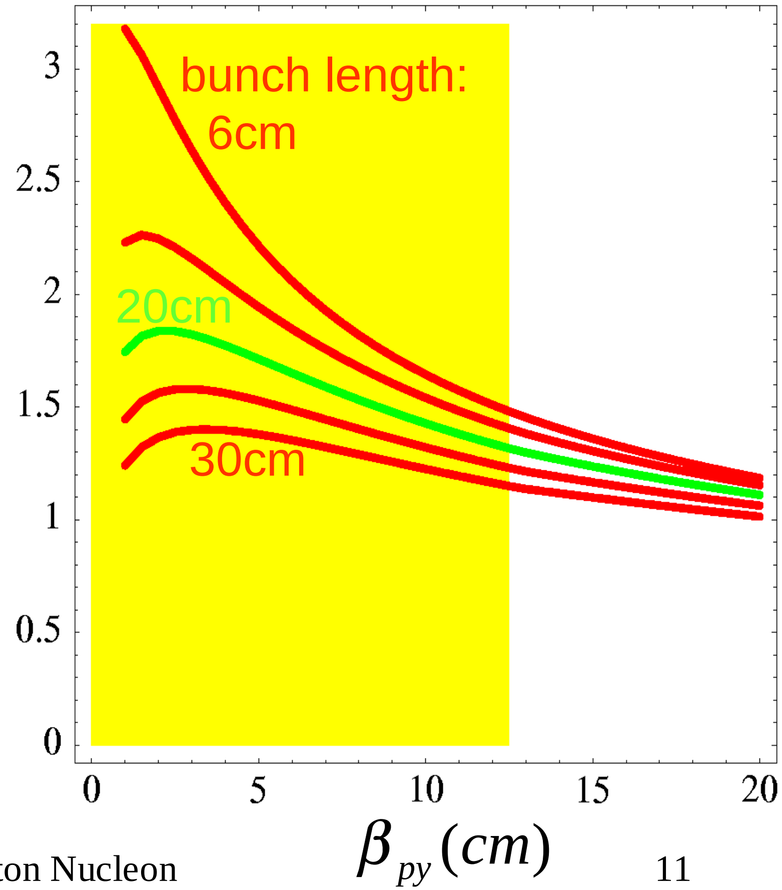


Length

19cm: $\frac{\mathbf{L}(\beta_{py}=12.5cm)}{\mathbf{L}_0}=1.75$

12cm: $\frac{\mathbf{L}(\beta_{py}=12.5cm)}{\mathbf{L}_0}=1.9$

Luminosity (10^{32})



Proton Beam Brightness Limitations

Present design $N_p / \varepsilon_N = 1 \times 10^{11} / 4 \times 10^{-6}$ m

Laslett Tuneshift in DESY III Booster Synchrotron
50MeV (kin.energy) injection

$\Delta\nu_{sc} \sim R\, N_p / (\, \varepsilon_N\, \beta^2 \gamma B\,) = 0.6$ @ $1.3\ 10^{11}$ & $\varepsilon_N = 2\mu m$

Can be overcome by smaller ring are higher injection energy in the booster

No principal limitation \`just´ costs

Example:

DESYIII Inj. Energy from 50MeV→120MeV @ 10M$

Scaling IBS

$\tau_s \sim \varepsilon_N^{1.42} \sim \varepsilon_s^{1.52} \sim U_{RF}^{1/4}$

Increasing N_p/ε_N increases growth time:

➔ larger ε_s ➔ Larger σ_s ➔ larger β^* (hourglass effect)

➔ Luminosity almost independent of N_p/ε_N

Possible Cure: More RF Voltage

$\tau_{ibs} \sim U_{RF}^{0.25}$ however $\sigma_e \sim U_{RF}^{0.25}$

$$\mathbf{L / L0 = (\sigma_e / \sigma_e)^2 = (U_{RF} / U_{RF0})^{1/2}} \text{ (expensive)}$$

HERA Experience: Running with 2x nominal σ_e still ok but effect already noticeable (increased backgrounds)

Proton Beam Brightness Limitations:IBS

Scaling from HERA

$N_p = 1\cdot 10^{11}$ $\quad E = 920\cdot\text{GeV}$ $\quad E\cdot A^{-1} = 920\cdot\text{GeV}$

$\Delta\varepsilon = 3.17\cdot 10^{-4}$ $\quad \varepsilon_s = 0.12\cdot e\cdot\text{volt}\cdot\text{sec}$ $\quad \varepsilon_N = 4\cdot\text{mrad}\cdot\text{mm}$ $\quad \sigma_x = 0.419\cdot\text{mm}$

$\sigma_e = 7.392\cdot 10^{-5}$ $\quad \sigma_s = 168.386\cdot\text{mm}$ $\quad \varepsilon = 4.079\cdot\text{nm}$ $\quad \sigma_y = 0.419\cdot\text{mm}$

$\tau = 0.562\cdot\text{ns}$

longitudinal $\tau_s := \left(\frac{\sigma_h^2}{2\cdot\sigma_e^2}\cdot A_{ib}\cdot F(c_1, c_2, c_3)\right)^{-1}$

$\tau_s = 8.238\cdot\text{hour}$

$$A_{ib} := \frac{1}{64\cdot\pi^2}\cdot r_0^2\cdot\frac{c}{\sigma_s\cdot\sigma_e\cdot\sigma_x\cdot\sigma_y\cdot\sigma_{xp}\cdot\sigma_{yp}\cdot\beta\cdot\gamma^4}\cdot N_p$$

$$F(c1, c2, c3) := 8\cdot\pi\cdot\int_0^1\left[2\cdot\ln\left[\frac{c3}{2}\cdot\left(\frac{1}{\sqrt{p(x,c1)}}+\frac{1}{\sqrt{q(x,c2)}}\right)\right]-0.577\right]\cdot\frac{1-3\cdot x^2}{\sqrt{p(x,c1)\cdot q(x,c2)}}\,dx$$

$$p(x, c1) := c_1^2 + x^2\cdot\left(1 - c_1^2\right) \qquad q(x, c_2) := c_2^2 + x^2\cdot\left(1 - c_2^2\right)$$

$$\sigma_h := \left(\sqrt{\frac{1}{\sigma_e^2}+\frac{D_x^2}{\sigma_x^2}+\frac{D_y^2}{\sigma_y^2}}\right)^{-1} \qquad d := 1\cdot\sigma_x$$

$$c_1 := \frac{\sigma_h}{\gamma\cdot\sigma_{xp}} \quad c_2 := \frac{\sigma_h}{\gamma\cdot\sigma_{yp}} \quad c_3 := 2\cdot\sigma_h\cdot\beta\cdot\sqrt{\frac{d}{r_0}}$$

Cooling

Bunched Beam Stochastic Cooling at High Energy

➔ Not very promising perspective

Bunched e-Beam Cooling:

-May be cost effective way to provide bright beams

-Doesn‘t look promising for high energies

-May work for ions

Electron Beam Current Limitations

RF

RF installation costs, operation costs **Not fundamental**

Now: RF power 12 MW, R_S1.5GW ➔ 60mA @ 27.5GeV

Cost example: prov RF to increase I by factor 1.6 ➔ 5M$

Vacuum costs, not fundamental

SR losses 5.2MW @ 1000W/m (~B-Factories)

Presumably no big current increase factor reasonable! (factor 2-3?) costs!

Feedback System: designed for 60mA, upgrade no technical problem

Proton Beam Beam Effect (stability, background, lifetime concerns)

$$\Delta\nu_{px} = \frac{r_p \cdot I_e \cdot \tau_b}{2\pi e f \cdot \varepsilon_N}$$

f: fill factor

τ_b=96ns, unproblematic

For IR design & paras. Resonances

$\Delta\nu_{px}$=1.4 x 10^{-3} limit?

Conclusions on Luminosity Increase

- Ring-Ring

HERA with present features **$L = \sim 10^{32} cm^{-2} sec^{-1}$**

Collider in the range of HERA Energies:
(Sc rf, new beam pipe, sc. Magn. for p-lo β)
$L = 10^{33} cm^{-2} sec^{-1}$ is an ambitious goal and may be considered as a target for new designs

- Ring-LINAC **$L > 10^{31} cm^{-2} sec^{-1}$** :only feasible with bunched beam cooling

Polarised Protons and Deuterons

- what is the luminosity in ep polarised collisions
- ➔ this is mainly a question of polarized sources
- how would p polarisation be achieved, to which degree? and what are effort and cost?
- how fast could the p polarisation be flipped?
- (how) does the snake system depend on the # of experiments?

➔ For perfect rotators independent

Polarised Protons and Deuterons

Deuteron polarisation at HERA - possible and easier, than for protons?

➨ **d in HERA @ p in PETRA except magnetic field strength**

$a_p/m_p = 25\ a_d/m_d$

what may be the lumi in polarised e-deuteron?

➨ **same as as polarized e-p, but not so much experience with polarized ion sources**

Optically Pumped Polarised H^- Ion Source OPPIS(TRIUMF)

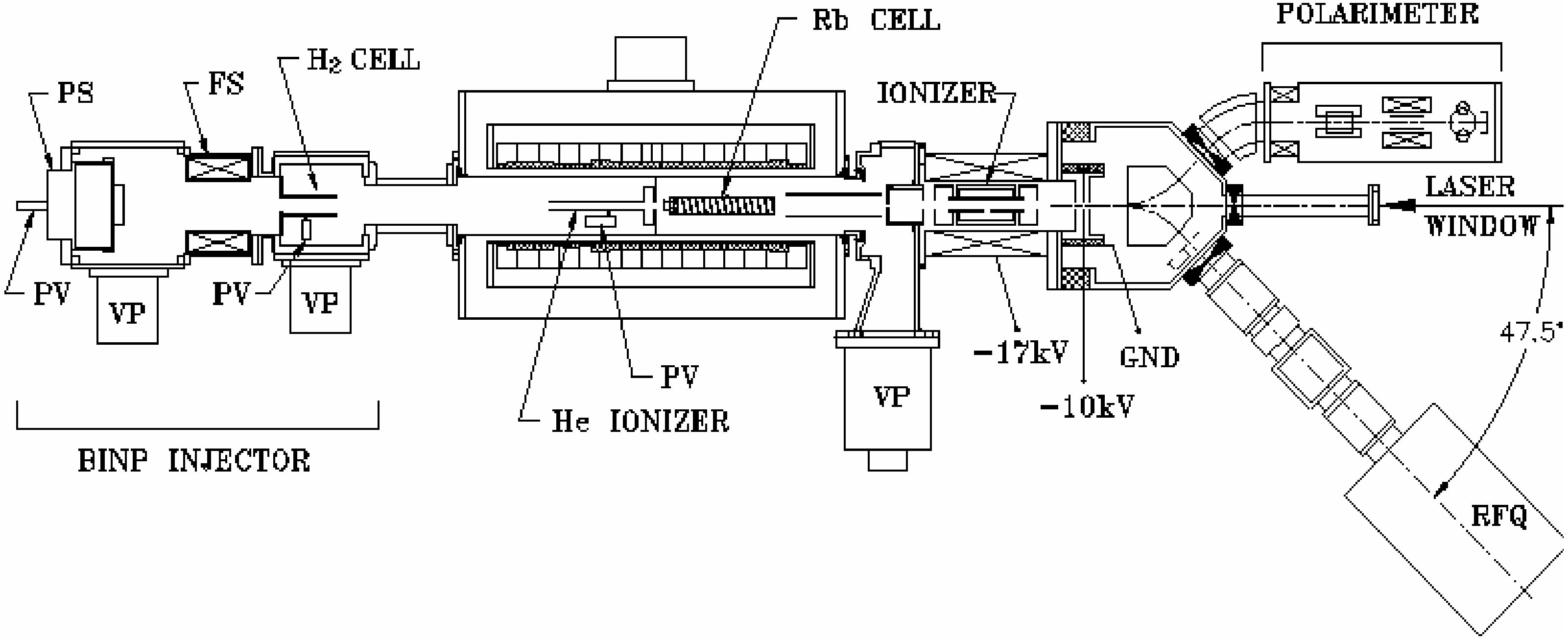
Curtesy of A. Zelensky

Expected : 20 mA @ 200μsec pulse 80% polarized

Achieved ~1.64 mA @ long pulse 80% polarized

28mA unpolarized

28GHz ECR H^+-source



Deuterons information on the low x neutron

deuterons : unfolding quark distribution at high Q^2 (ch. C., need high lumi).

- changes of the machine to accelerate deuterons?

None in HERA, need better linac (IH-structure for example)

- need cooling already for deuterons?

Same as for protons

- eD luminosity?

~1/2 ep Luminosity depending on pre-accelerator

- deuteron beam with minimum divergence? luminosity?

$L \sim D_x D_y$

- diminish the proton beam divergence? luminosity?

Nuclei

not explored eA in the HERA range but may study high parton densities, eA questions are similar as for eD:

- how is it done, what is the effort/cost?
- The effort is in the low energy acceleration luminosity(A) - cooling(A)?
- status of the cooling R&D at DESY?
- how fast change from A to D or p?
- d & A bunches in the machine simultaneously

High Luminosity Linac-e/Ring-N Collisions

feasible to build a E_{e-}Recovery LINAC-Ring at HERA, somehow of the type foreseen at BNL

➔**Energy recovery scheme little benefits for HERA energies**

THERA Ring Linac Collider

Become interesting at Lepton Energies beyond capability of Storage Rings $E_e > 100\text{GeV}$

$$L = 4.8 \times 10^{30}\text{cm}^{-2}\text{sec}^{-1} \frac{N_p}{10^{11}} \frac{10^{-6}\text{m}}{\varepsilon_N} \frac{\gamma_p}{1066} \frac{10\text{cm}}{\beta^*} \frac{P_e}{26.6\text{MW}} \frac{250\text{GeV}}{E_e}$$

High Energy bunched beam Cooling! (→ ε_N)

Energy Recovery (→ P_e)

THERA LINAC-Ring Lattice (proposed)

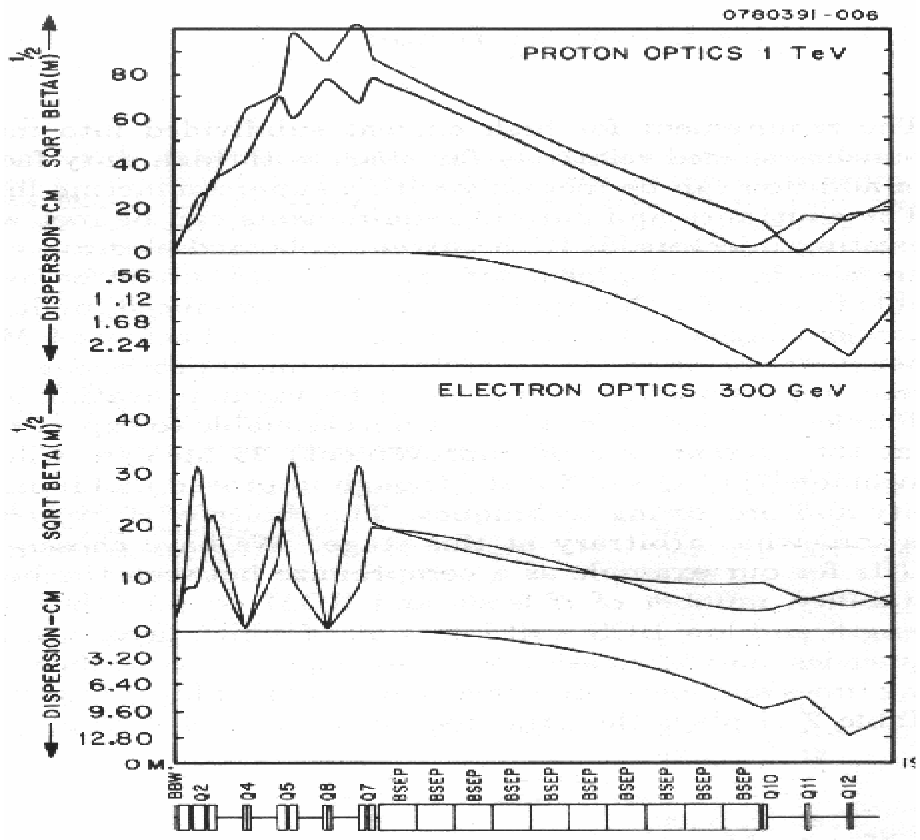
small crossing angle
protons focussed by 2 electron low beta triplets, $\beta^*=10$cm β_{max} 8km
protons deflected from e-orbit by a long off-center quadrupole
electron orbit straight
energy range E_p/E_e: 4/1 - 1/1

Proton Optics →

1TeV

Electron Optics →

250GeV-800GeV



Summary

- Low divergence possible but less luminosity
- Lower lepton and proton energies possible on the cost of luminosity
- Larger proton energy difficult but not impossible
- Larger Luminosity possible but very expensive
- Polarized proton luminosity is a source problem