Vacuum and Aperture Needs for ERL Light Sources

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Acknowledgement

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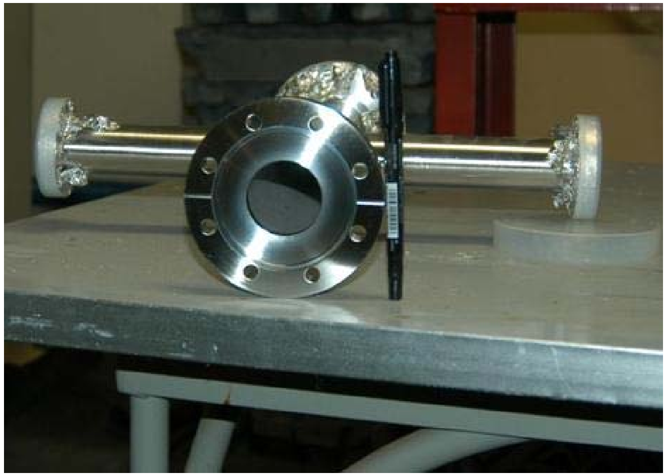
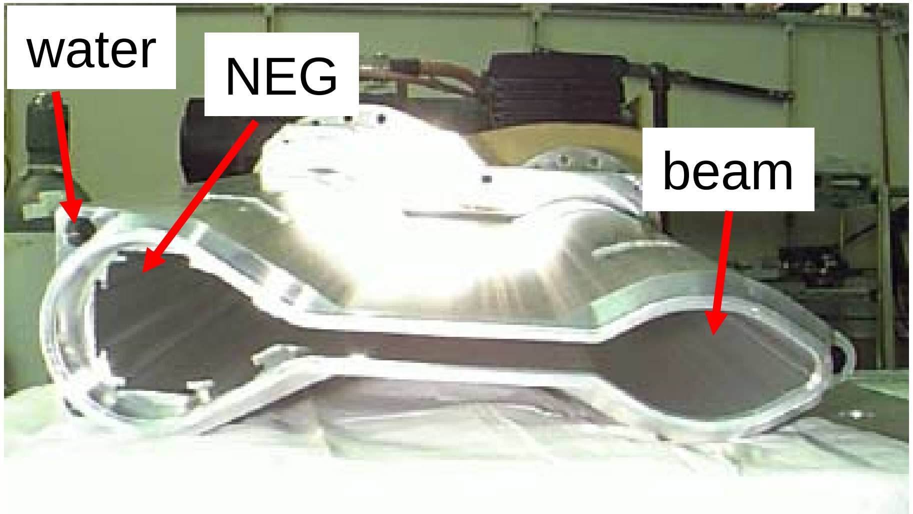
beam pipe



Q-mag. duct of JAEA-ERL
ICF-114 flange,
45 mm inner diameter



Bending magnet duct of APS
equipped with pumping antechamber

JLAB IR-upgrade,
3-inch apertures
from the linac to the wiggler

Light Source

high flux photons = gas desorption

equipped with distributed pump
--- NEG, sputter ion, Ti sublimation

Vacuum and Aperture for ERL LS

- large amount of gas desorption by synchrotron radiation
- scattering of electrons by gas molecules
- beam loss is critical for radiation shielding
- ion trapping may result in instability and additional beam loss

Interaction between electrons and residual gas atoms

- Interaction
  - Inelastic
    - Bremsstrahlung
    - Ionization Energy Loss
    - Electron Capture
    - Electron Loss
    - Nuclear Reactions
  - Elastic
    - Single Coulomb Scattering
    - Multiple Coulomb Scattering

Classification by S.P.Møller, CERN Acc. School (1999)

Beam-loss Tolerance

Storage Ring

beam loss → particle loss → shorten the lifetime

circumstance ~ 1km, lifetime > 10hrs

beam loss < 10^{-10} / turn

ERL

particle-loss is tolerable, if it is well-managed.

energy-loss by synchrotron radiation ~ 10^{-3} / turn

beam loss << 10^{-3} / turn to keep energy recovery

is "beam loss < 10^{-10} / turn" necessary
to keep radiation level same as storage rings ?

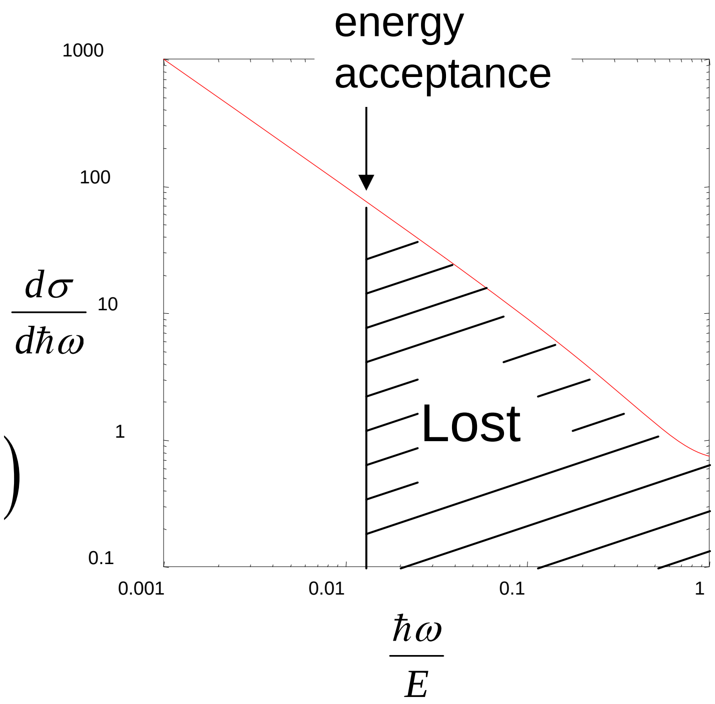
Inelastic Scattering (Bremsstrahlung)

electrons may lose their energy by scattering with residual gas molecules

"Bremssttrahlung"

cross section is a function of energy-loss

energy loss > energy acceptance
-- electrons are lost



$$\sigma_B = 4\alpha r_0^2 Z_i (Z_i + 1)\left(\frac{4}{3}\ln\left(\frac{E}{\Delta E}\right) - \frac{5}{6}\right)\ln\left(183 Z_i^{-1/3}\right)$$

frequency of collision to lose electrons

$$c n_i \sigma_B = \frac{c P_i \sigma_B}{k_B T}\left[\sec^{-1}\right]$$

gas pressure

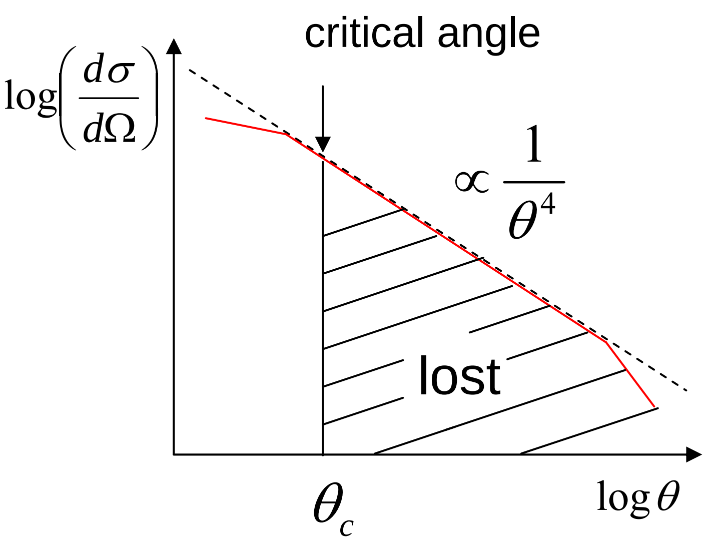
Elastic Coulomb Scattering

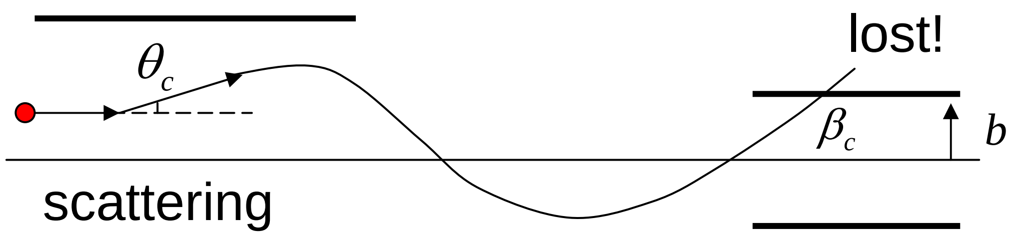
Scattering by nuclei (Rutherford scattering)

$$\sigma_R = 4\pi r_0^2 \left(\frac{Z_i}{\gamma \theta_c} \right)^2$$

Scattering by extranuclear electrons
(Moller scattering)

$$\sigma_M = 4\pi r_0^2 \left(\frac{1}{\gamma \theta_c} \right)^2 Z_i$$

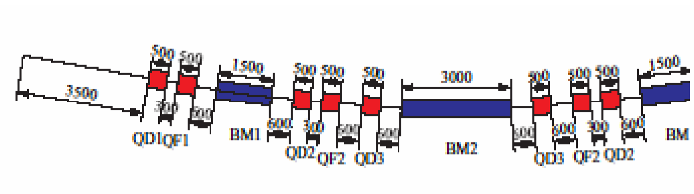


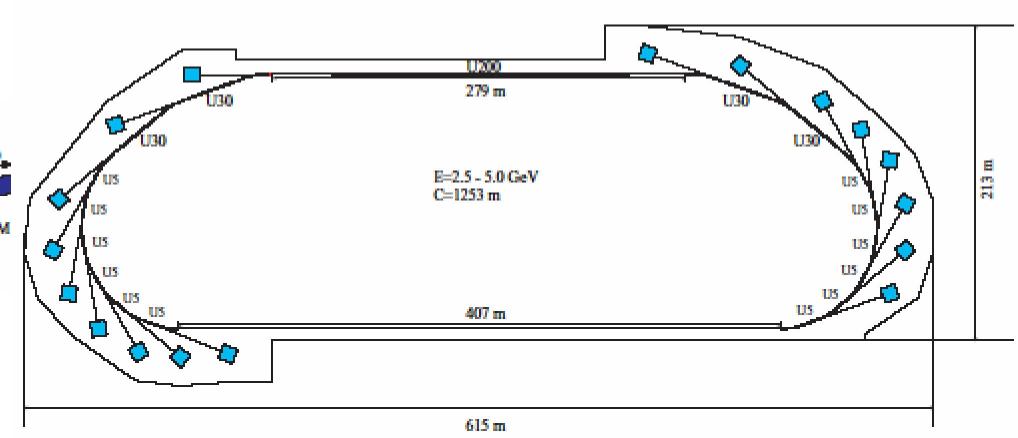


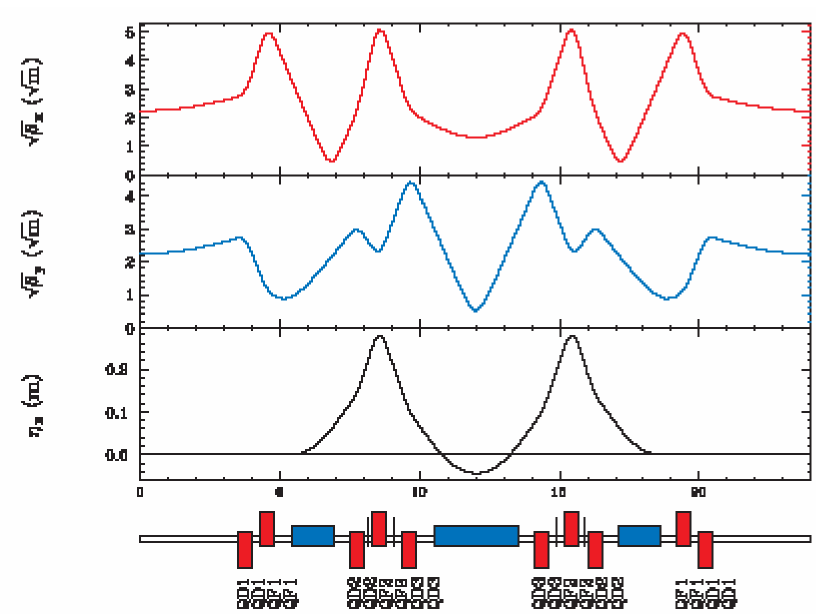
$$\theta_c = \frac{b}{\sqrt{\beta_c \overline{\beta}}}$$

cross section depends on apertures

Example – KEK-ERL (2001 version)



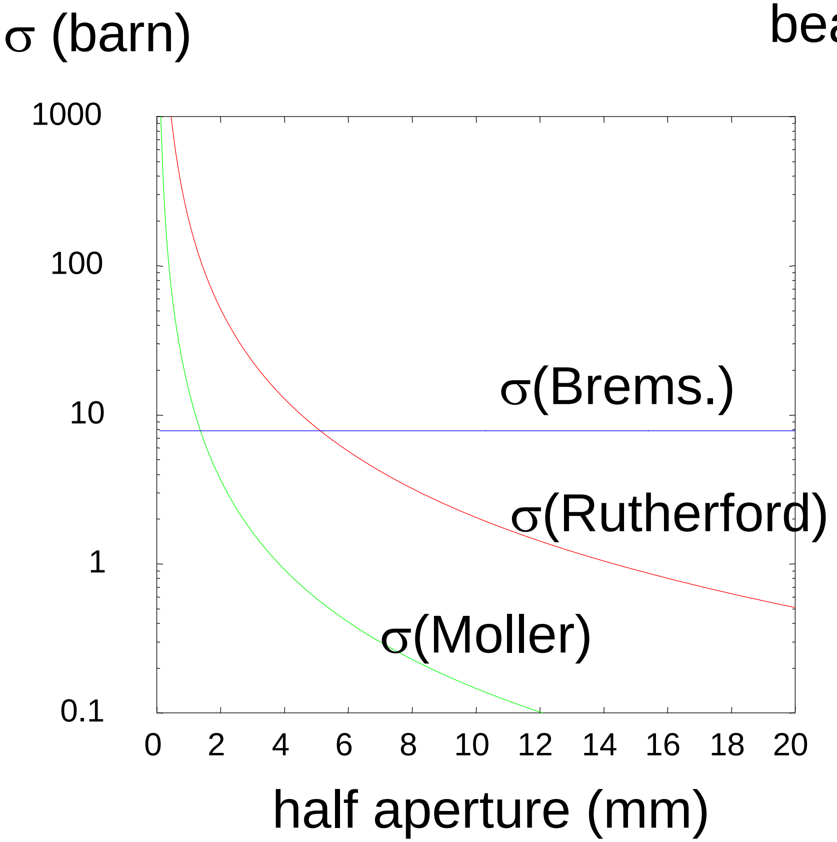


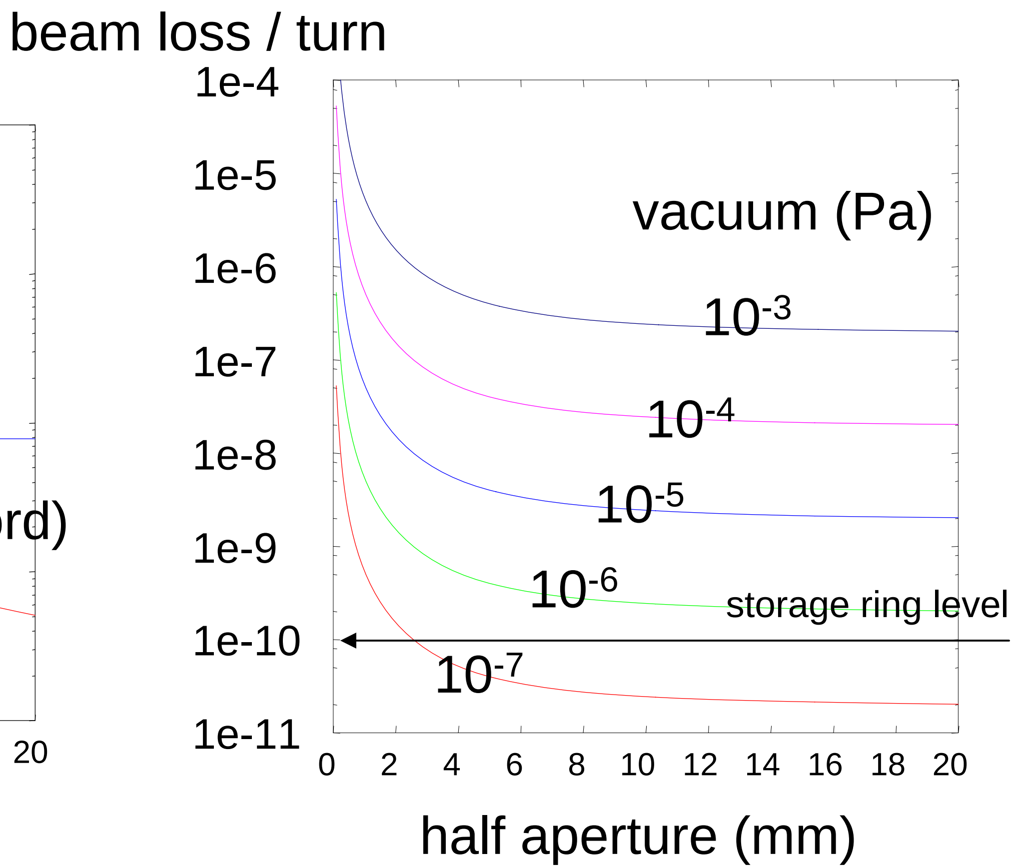


η_x = 0.3m, ϕ20mm
→ 3% Energy-acceptance

β_c ~ 10m
β_{ave} ~ 10m

Cross section of scattering and beam loss

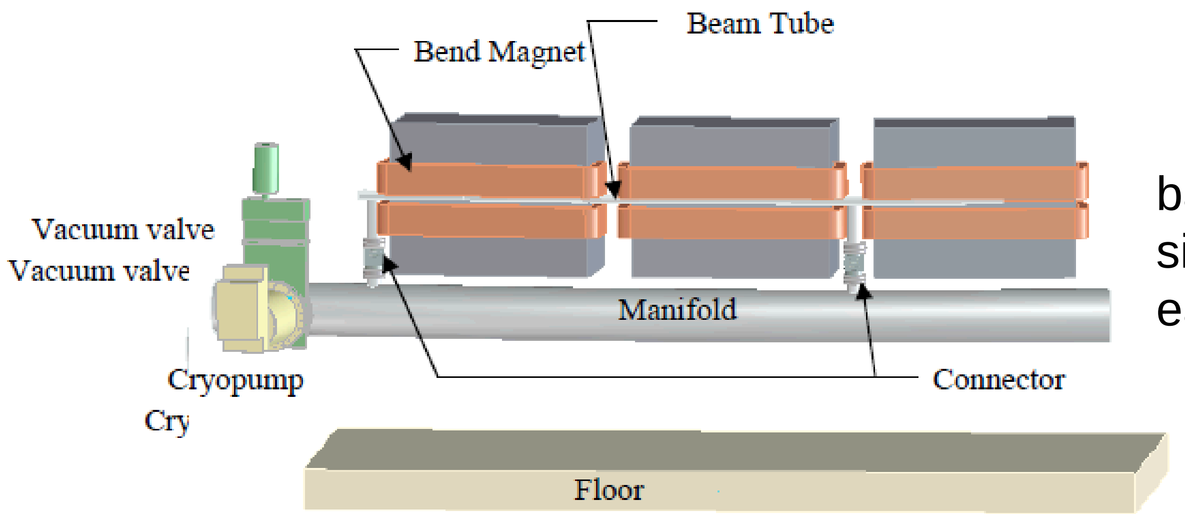




Assuming “CO” only.

10^{-7} Pa = 0.75 x 10^{-9} Torr

Vacuum Pump Configuration – LBL LUX



LBNL-51766 (December 2002)

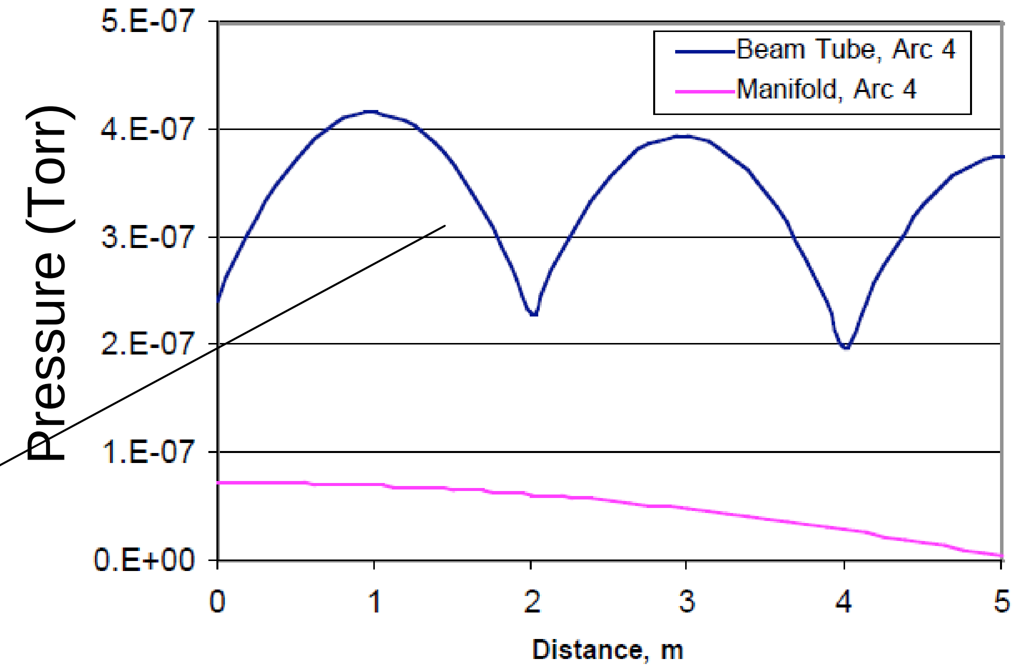
based on commercial products,
simple beam tubes,
easy-replacement of pumps.

small average current ~ 10μA

↓

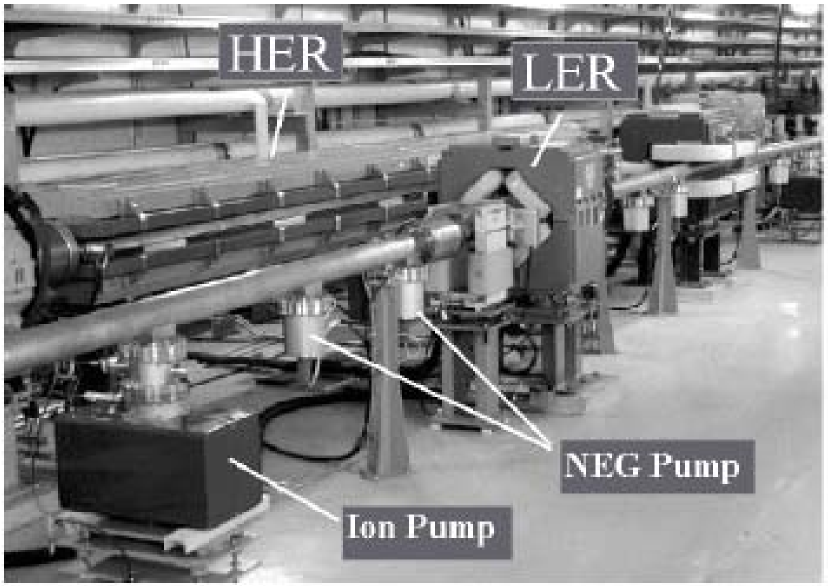
gas desorption and
radiation are not critical

beam loss ~ 10^{-6} at Arc 4



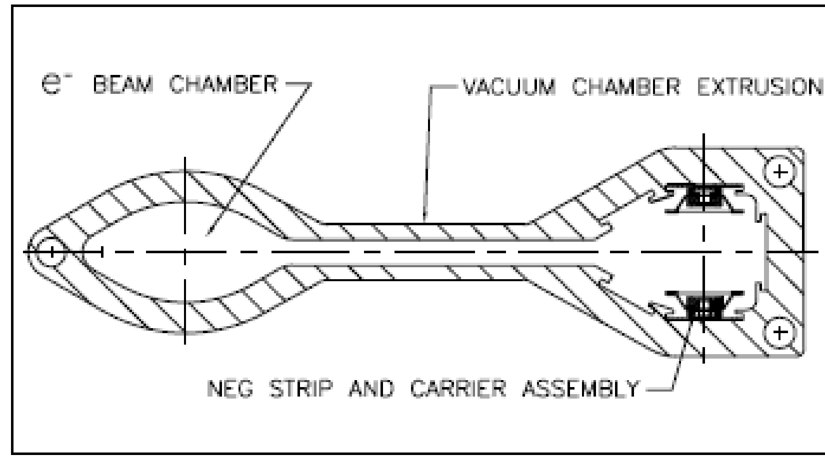
Vacuum System for High-Average Current Machines

KEK-B



H. Hisamatsu et al., EPAC-2000

APS



P. Den Hartog el al., PAC-2001

synchrotron radiation photons

$$N_p = 8.08 \times 10^{17} I_b E_b \text{ photons/s/}2\pi\text{rad}$$

I_b(mA), E_b(GeV)

⇨

distributed pumps are necessary

ion sputter pump
Ti sublimation pump
NEG pump

Photo Stimulated Gas Desorption (PSD)

$$\eta \equiv \frac{\text{gas molecules}}{\text{photon}}$$

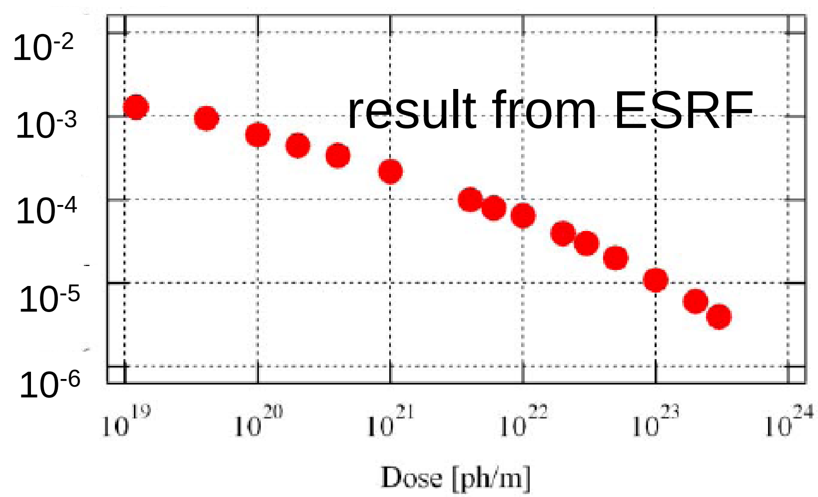
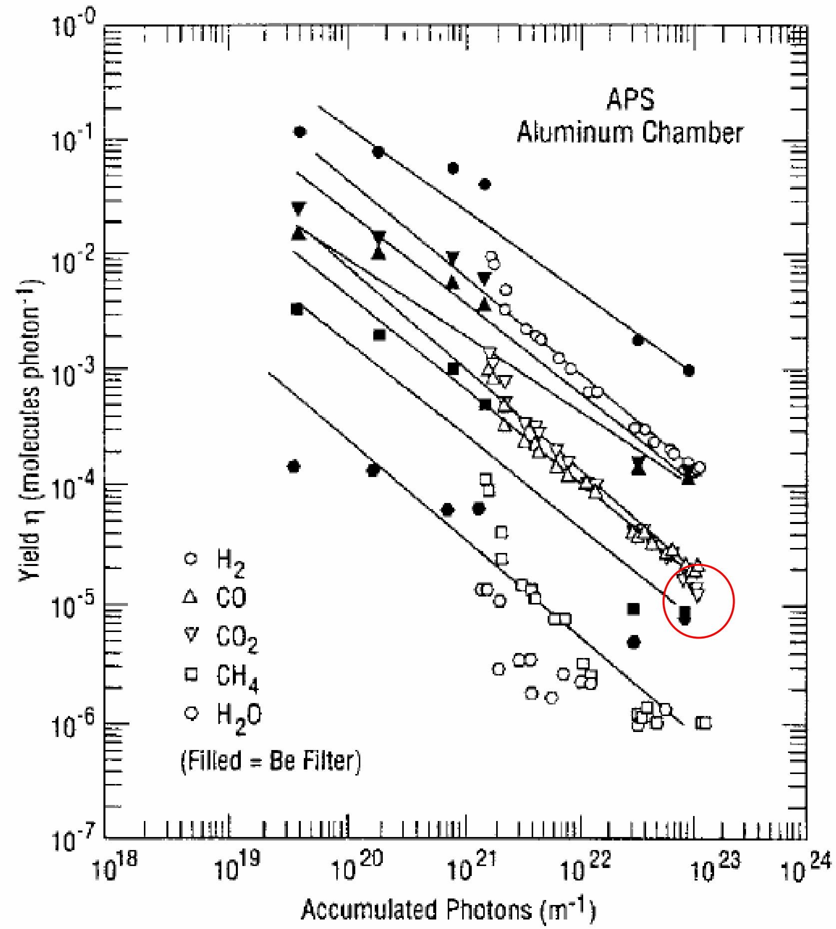


Figure 2 – Desorption yield of the Al + NEG chamber.

F. Mazzolini et al, EPAC-02

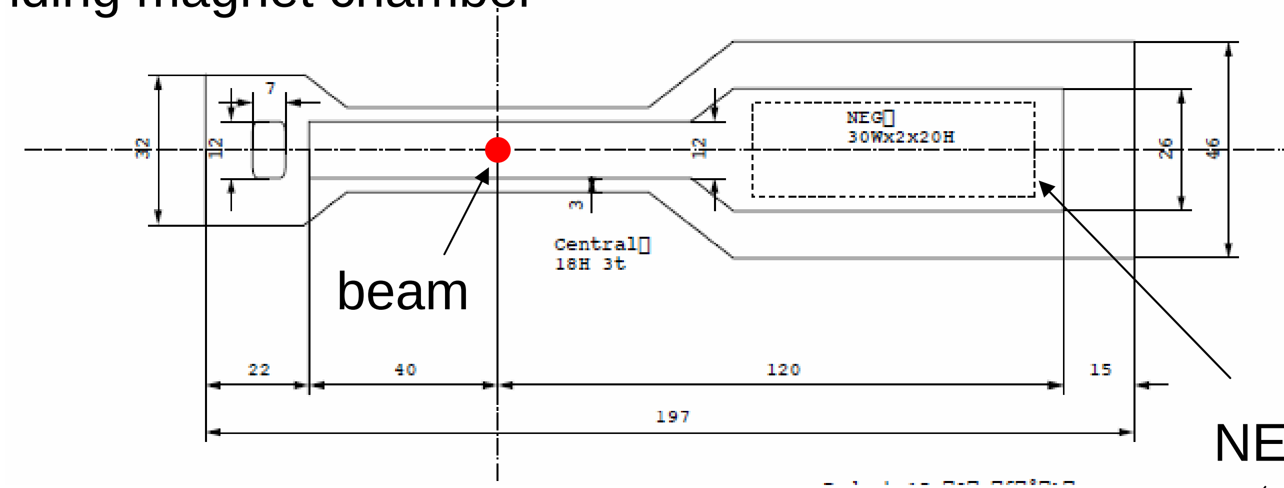


J.R. Noonan et al. PAC-97

10^{23} ph/m (10^3 mA h @ 5GeV ERL) → $\eta \sim 10^{-5}$ for CO, CO_2 is expected

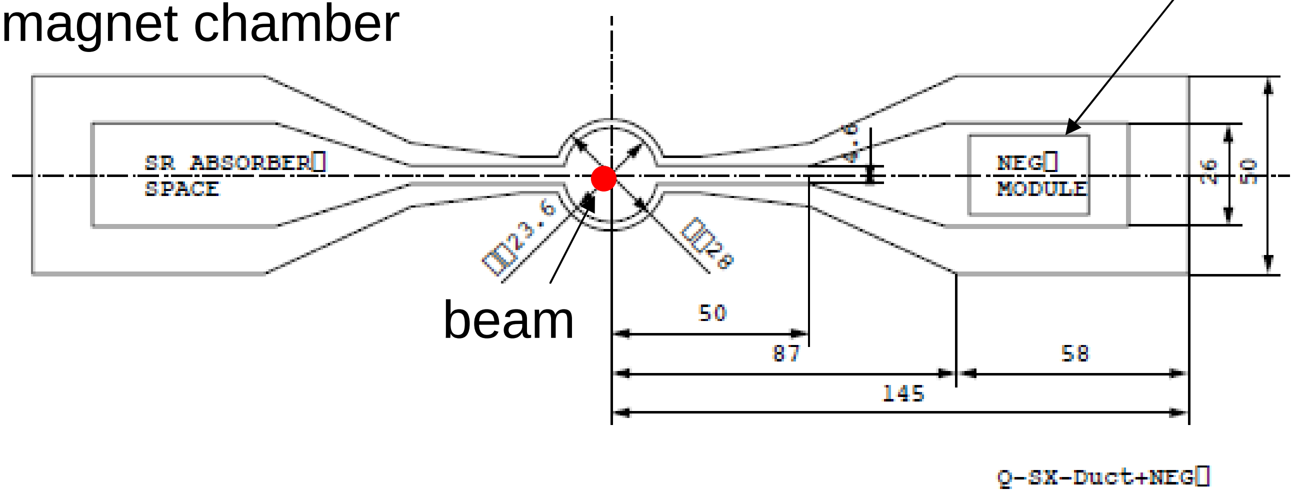
Vacuum Pump Configuration – KEK ERL (2001 version)

bending magnet chamber



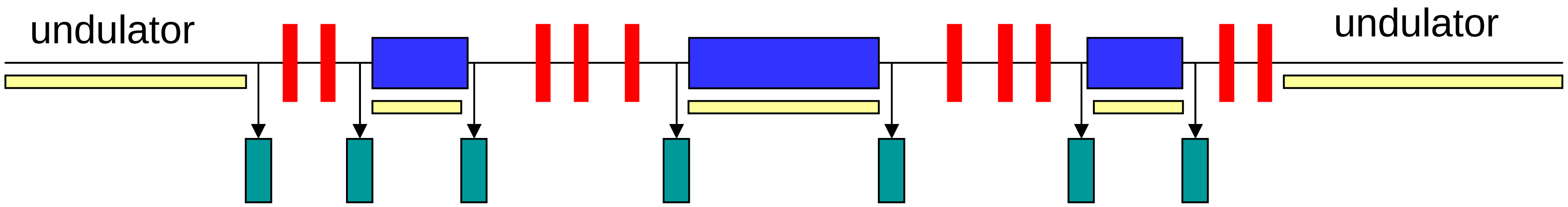
NEG module inside

Q. magnet chamber

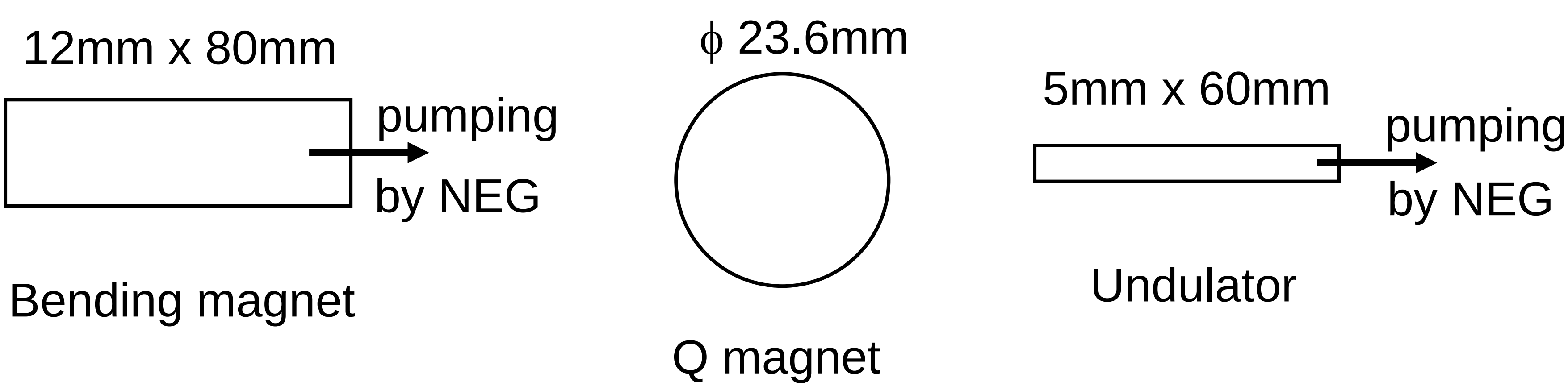


1-D model estimation of vacuum level

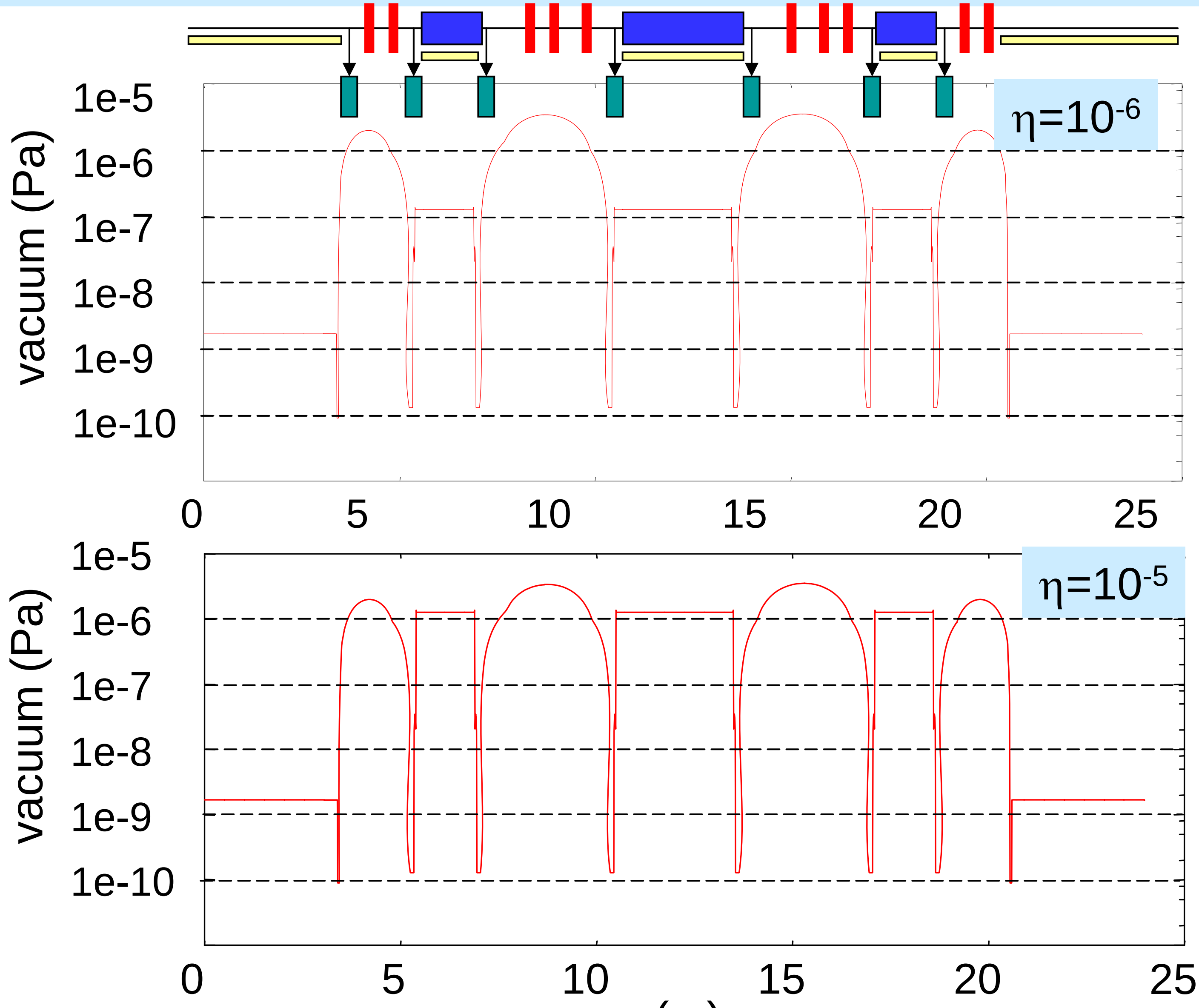
5GeV, 100mA, synchrotron radiation in a bending duct only.
thermal desorption Q_{th}=6x10^{-4} Pa l/s/m^2



NEG pump (100 ℓ /s/m)
ion pump (200 ℓ /s)



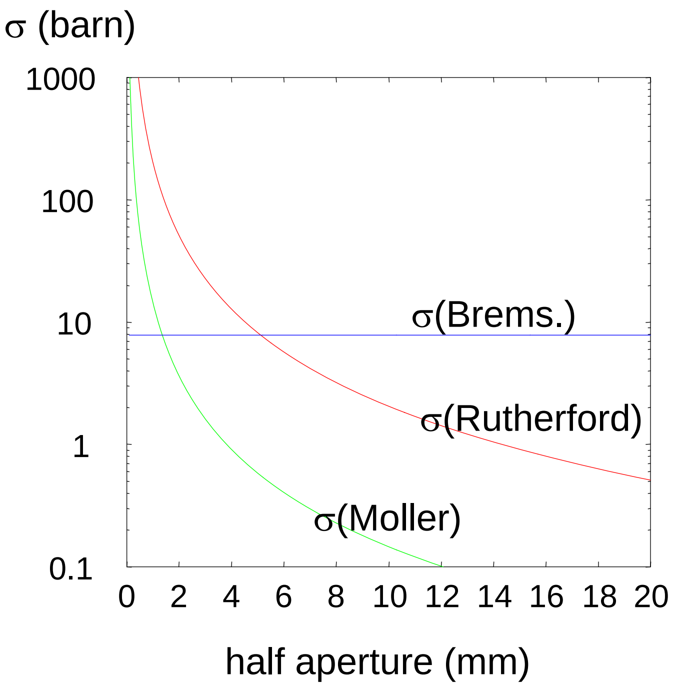
Vacuum level estimation by 1-D model



scraper = beam loss localization

localization of beam loss is helpful
to protect X-ray beam lines from radiation background

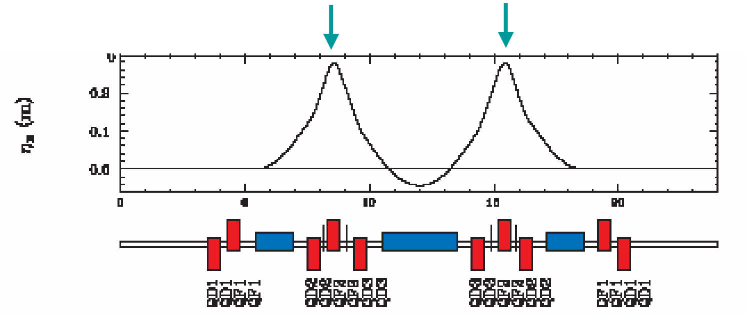
If we allow 10^{-7} loss at specific 20 locations through an ERL loop, each location has beam loss of 2.5W (0.5nA x 5GeV).



When half aperture > 6mm

beam loss occurs mainly by Bremssttrahlung

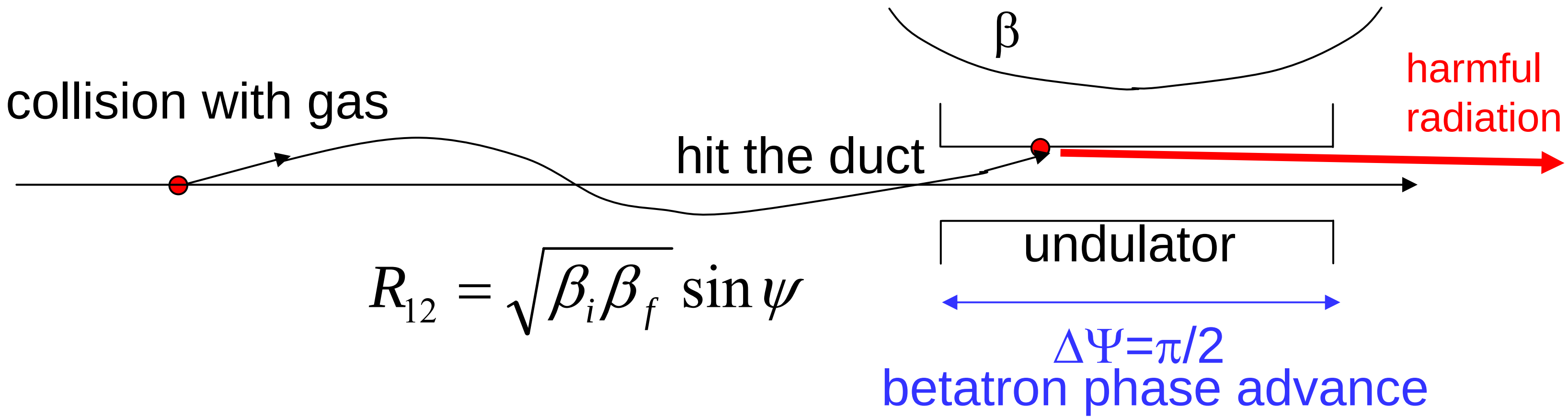
ϕ20mm scraper at η_{max}=0.3m can collects the main part of beam loss.



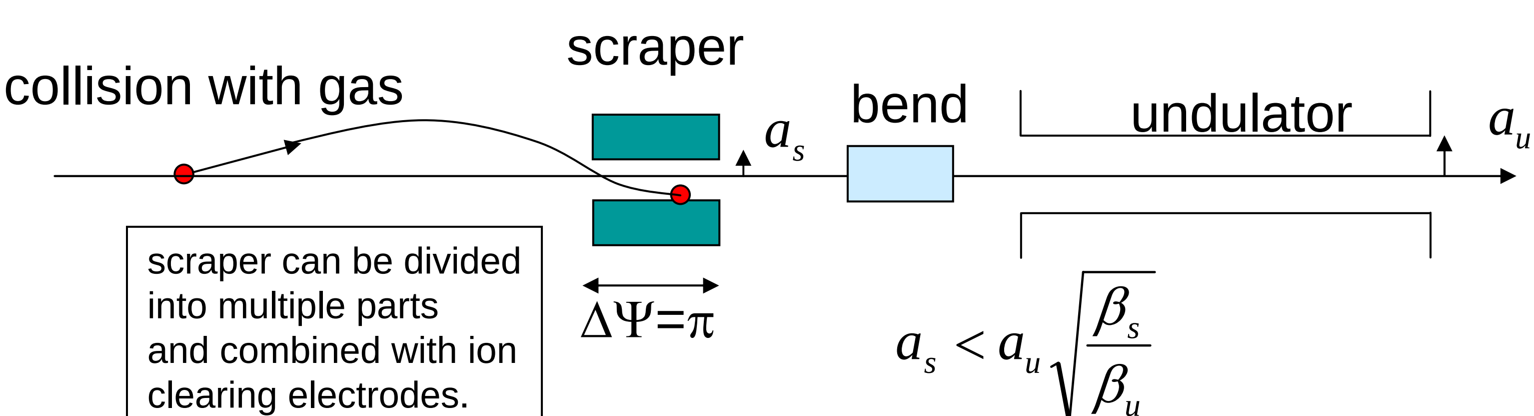
scraper = beam loss localization (cont'd)

half aperture < 6mm ⟶ beam loss occurs inside this small duct.

note that undulator ducts may have such a small aperture.



$$R_{12} = \sqrt{\beta_i \beta_f}\,\sin\psi$$



$$a_s < a_u \sqrt{\frac{\beta_s}{\beta_u}}$$

Vacuum and Aperture Needs for ERL-LS

conservative design

- aperture > 5mm → 10^{-7} Pa vacuum for 10^{-10} loss / turn
- high-flux X-ray = large amount of gas desorption
- vacuum system of ERL-LS will be similar to storage rings
- distributed pumps in bending (and Q) chambers are essential

progressive design

- putting scrapers at appropriate locations
- beam loss of a few watt at each scraper → 10^{-7} loss / turn
- vacuum level of 10^{-4} Pa for 4mm aperture

- keep good vacuum at undulators, ~10^{-7} Pa, in any case
- pay attention to ion effects