Vacuum Aspects of Synchrotron Light Sources

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Outline

- What is Synchrotron Radiation?
- Why is it important?
- What are Synchrotron Light Sources?
- What are the vacuum requirements of such sources?

What is Synchrotron Radiation

When a charged particle is accelerated, it emits electromagnetic radiation.

Classically, the radiated power, P, is given by

$$P \propto \frac{2e^2}{3c^3} \cdot a^2$$

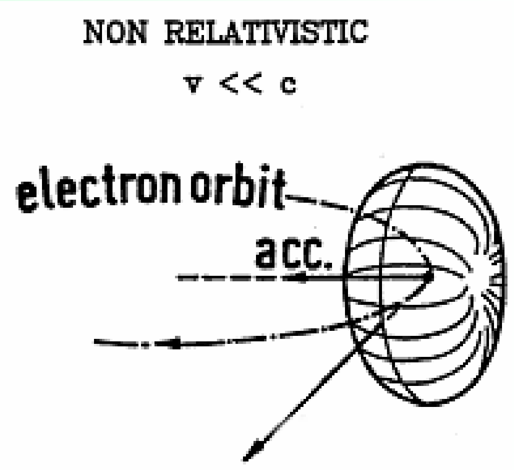
Where e is the charge

a is the acceleration

c is the speed of light

For a circular orbit, the acceleration is the centripetal acceleration $^{v^2}/_r$

This radiation is emitted isotropically

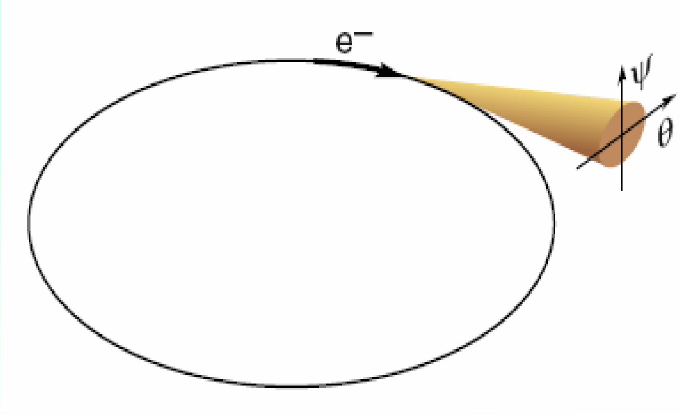


What is Synchrotron Radiation

When the charged particles are travelling at close to the speed of light, as they will be in most accelerators, then the radiation is transformed so that

$$P \propto \frac{2e^2}{3}\frac{\gamma^4 c}{r^2} \qquad \text{Where} \qquad \gamma = \frac{E}{mc^2}$$

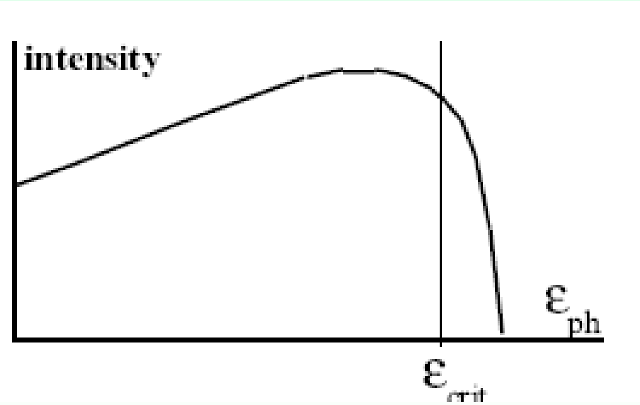
In this case. The radiation is "beamed" forward like a lighthouse beam in the plane of the orbit, with an opening angle of $\frac{1}{\gamma}$



What is Synchrotron Radiation

In practice, this means that the synchrotron radiation sweeps out a fan of radiation in the horizontal plane with a very small vertical dimension. This fan is pulsed and produces very bright pulses of radiation.

The energy spectrum of the emitted radiation depends on the beam energy and the bending radius and can be displayed as a universal curve



Where $$\varepsilon_{crit} \approx \frac{B}{\gamma^2} = 0.665E^2B$$

B is the bending magnetic field (T)

E is the energy in GeV

ε_{crit} is in keV

What is Synchrotron Radiation

Synchrotron radiation is characterized by:

- High brightness and high intensity, many orders of magnitude more than with x-rays produced in conventional x-ray tubes
- High brilliance, exceeding other natural and artificial light sources by many orders of magnitude:
- High collimation, i.e. small angular divergence of the beam
- Low emittance, i.e. the product of source cross section and solid angle of emission is small
- Widely tunable in energy/wavelength by monochromatization (sub eV to tens of keV)
- High level of polarization (linear or elliptical)
- Pulsed emission (pulse durations below one nanosecond);

Why is it important?

- Brightest tuneable sources of light, especially in X-ray region
- Characteristics can be matched to many sorts of experiment
- Huge range of science accessible
- Source is calculable
- Lots of sources around (~50)
- Multi user facilities

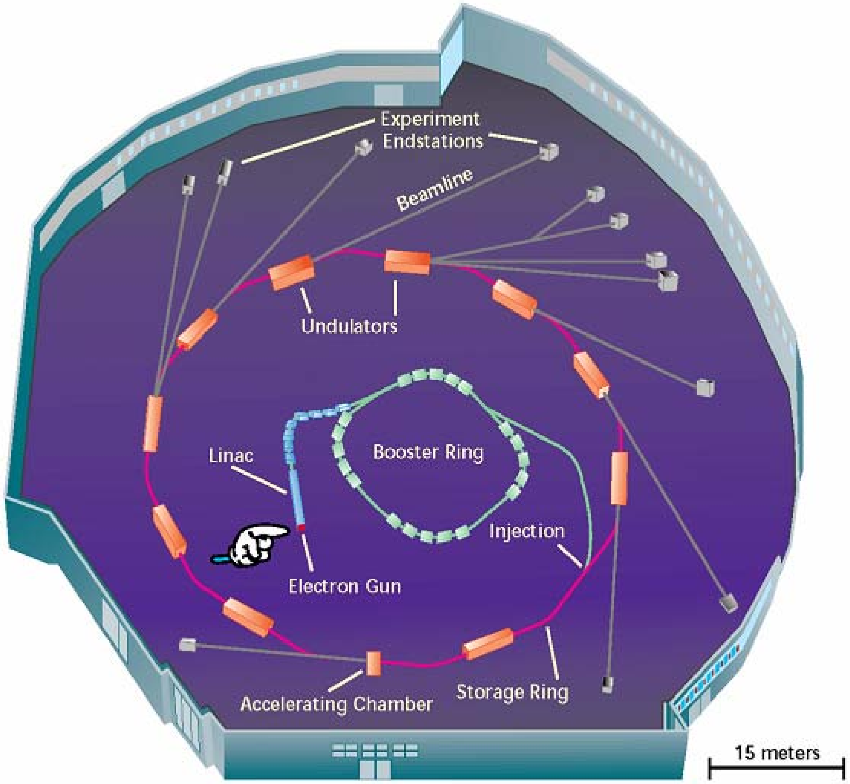
What are Synchrotron Radiation Sources

- Generally now electron storage rings
- First generation
  - Parasitic on particle physics accelerators
    - NBS (1962)
    - Frascati
    - DESY (1964)
    - Tokyo (1965)
    - NINA (1966)

What are Synchrotron Radiation Sources

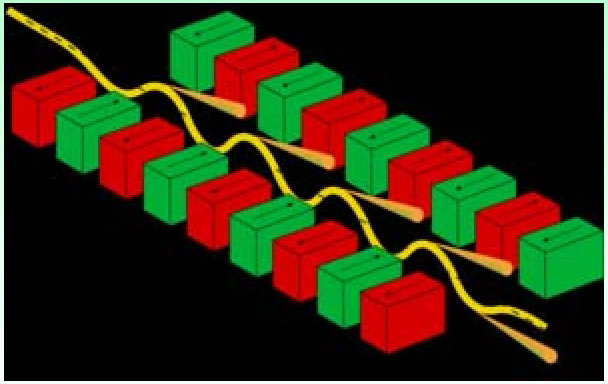
- Second Generation Sources
  - Dedicated, purpose built electron storage rings – optimised for flux
    - SRS (1980)
    - NSLS (1981)
    - Aladdin (1981)
    - Photon Factory (KEK) (1982)
    - Bessy (1982)
    - LURE (1984)
    - ………..

What are Synchrotron Radiation Sources



What are Synchrotron Radiation Sources

- Third generation sources
  - Dedicated electron storage rings with insertion devices – optimised for brightness
    - Higher Energies, large machines
    - Low emittance (typically 3 nm rad horiz)
    - Undulators/wigglers



$$K = \frac{e \cdot B_0 \cdot \lambda_u}{2 \cdot \pi \cdot m \cdot c}$$

B_0 is the magnetic field

λ_u is the period

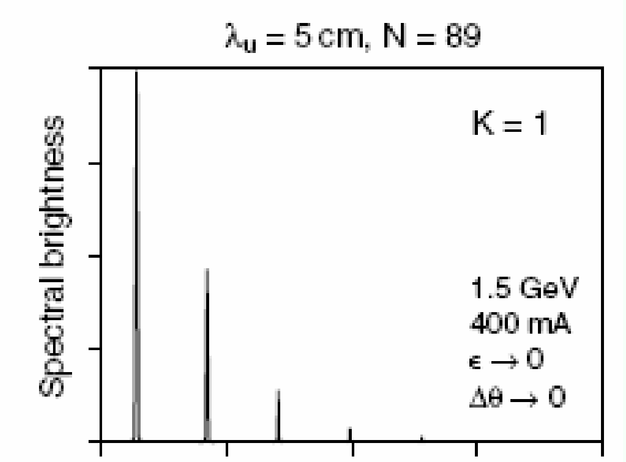
If K<1, the device is an undulator

If K>1, the device is a wiggler

What are Synchrotron Radiation Sources

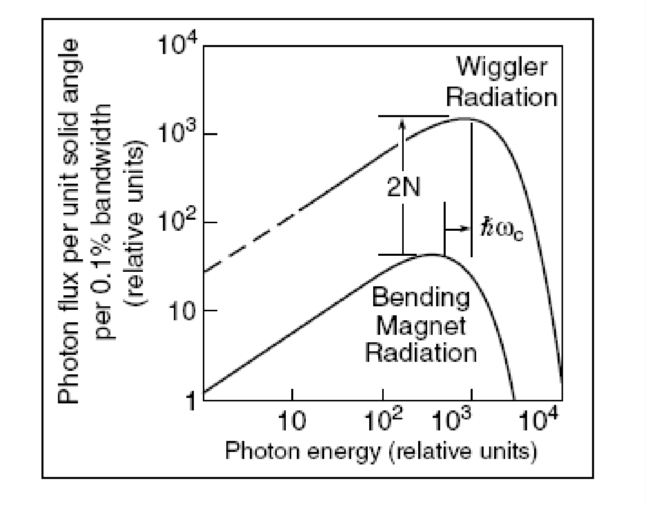
Undulator

- Narrow spectral lines
- High spectral brightness
- Partial coherence



Wiggler

- Higher photon energies
- Spectral continuum
- High flux



What are Synchrotron Radiation Sources

- 3rd Generation Sources
  - ESRF (1994)
  - APS (1996)
  - Spring-8 (1997)
  - Elettra (1994)
  - ……

What are Synchrotron Radiation Sources

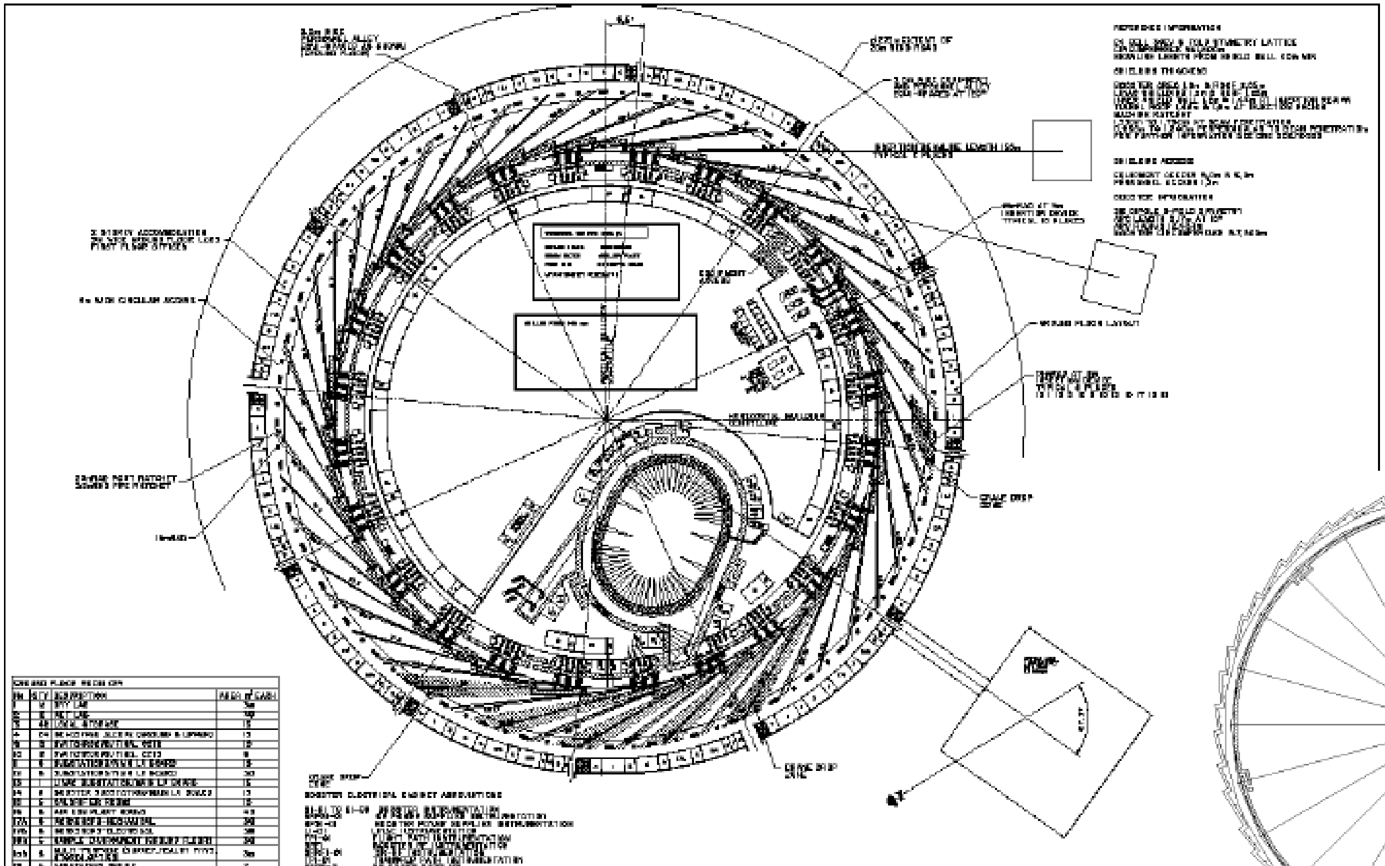
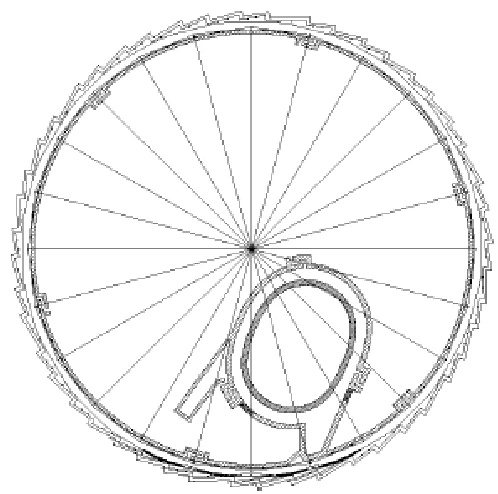


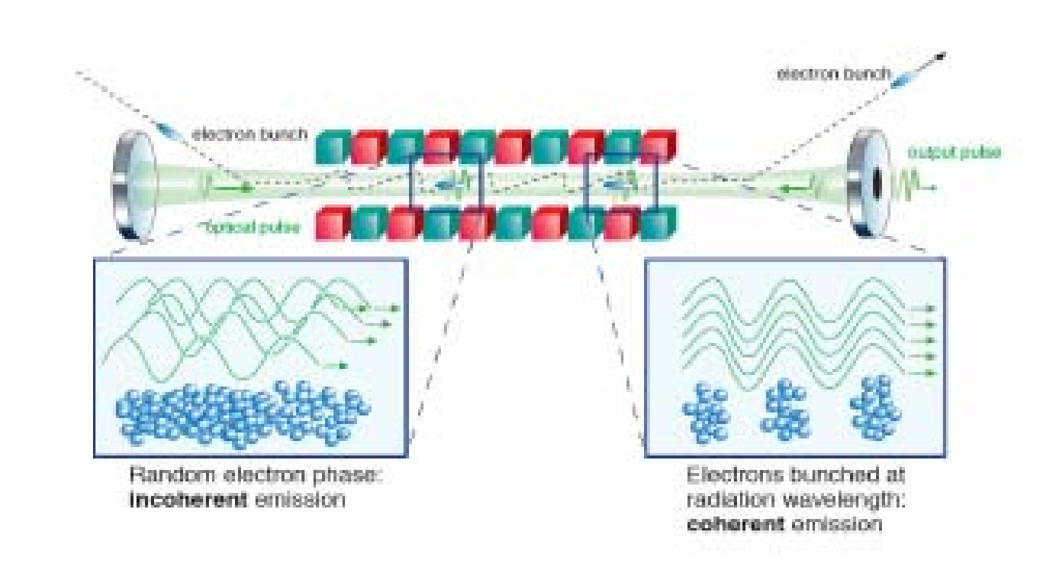
Figure 5.1-4 Overall Plan View of the Experimental Hall



What are Synchrotron Radiation Sources

- Fourth Generation
  - Not based on storage rings
    - Radiation from FEL sources
    - Energy Recovery Linac (Superconducting)
    - Advantages of 4GLS are:
      - Combinations of sources
        - pump-probe and two colour dynamics experiments.
      - intense, tuneable, variable polarisation FEL sources optimized for spectroscopy and imaging in frequency ranges XUV, VUV and IR-THz;
      - energy recovery linac spontaneous light sources available from soft X-ray - THz. This gives short pulse, high repetition rate operation
      - intense broadband source of coherent THz radiation

What are Synchrotron Radiation Sources

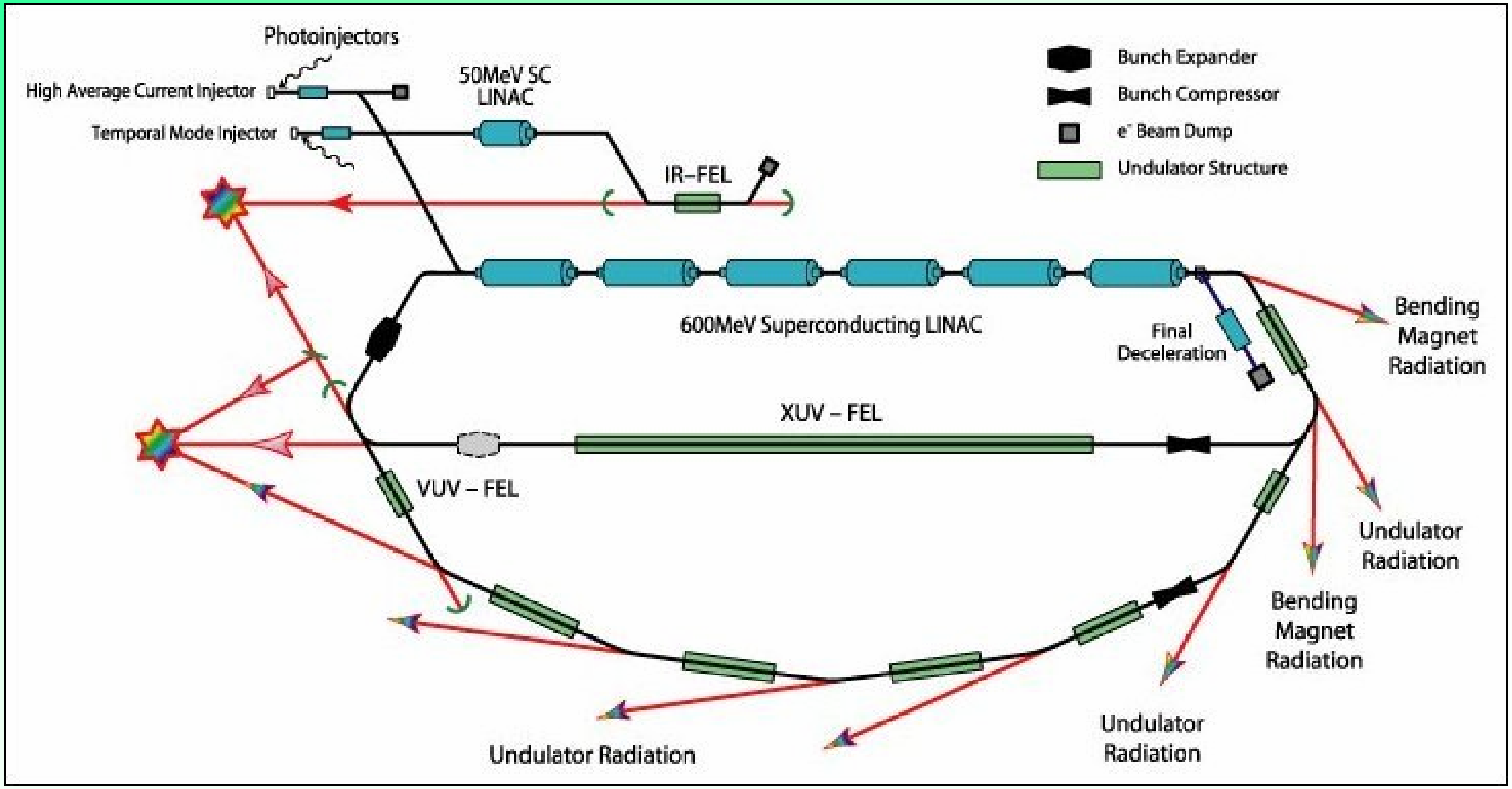


An example of a free electron laser (FEL)

What are Synchrotron Radiation Sources

- Proposed Fourth Generation Sources
  - IR-FEL (J-Lab) (operational)
  - LCLS (SLAC)
  - XFEL (Desy)
  - 4GLS (Daresbury)

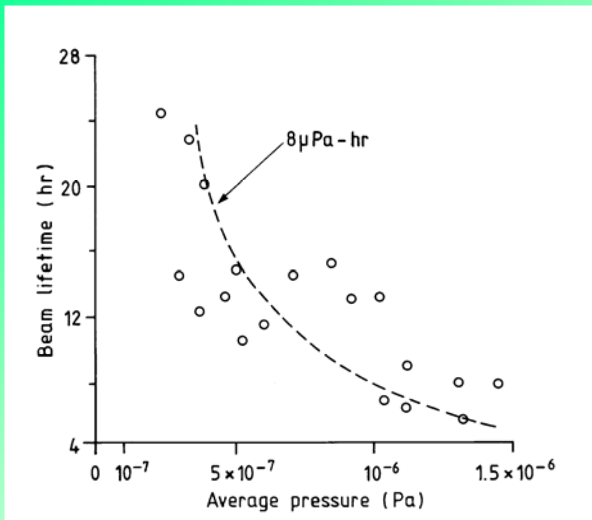
What are Synchrotron Radiation Sources



Vacuum Requirements

- 3rd Generation Sources
  - Beam Lifetime
    - > 12 hours
  - Personnel Safety
    - Radiation
  - Mechanical aspects
    - Stability
- 4th Generation Sources
  - Ion Scattering
  - Cathode or mirror degradation
  - Particulates

Vacuum Requirements (3rd Generation Sources)



An important figure of merit is beam lifetime i.e. the time for the beam current to decay to $^1/_e$ of its initial value

$$\frac{1}{\tau} = \sum_i 15.5\, P_i \left[(W_1 + W_2) Z_i^2 + (W_3 + W_4) Z_i \right] \quad (8)$$

where τ is in seconds

P_i is partial pressure in torr of gas with atomic number Z_i

$$W_1 = 12.5 \times 10^8 \frac{1}{a^2 \gamma^2}$$

$$W_2 = 1.9 \log_e (6 \sqrt{E/V_p})$$

scattering on nuclei

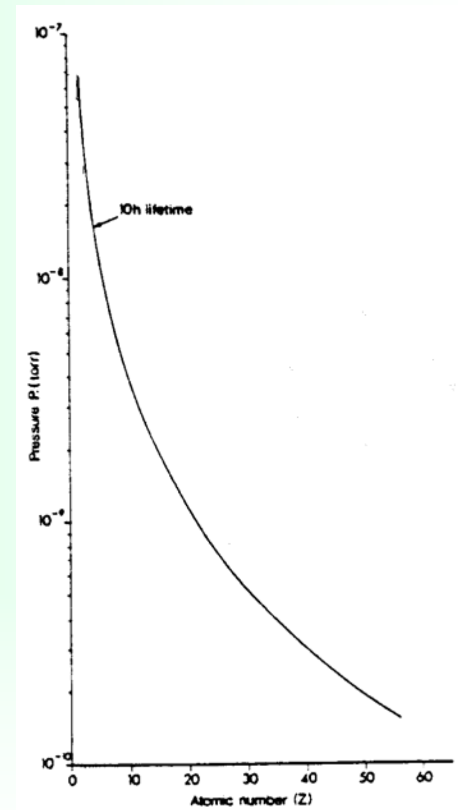
$$W_3 = \frac{765}{\gamma} \sqrt{E/V_p}$$

$$W_4 = 0.42 \log_e (6.85\, \gamma \sqrt{E/V_p}) \times \log_e (6 \sqrt{E/V_p})$$

scattering on peripheral electrons

a is the vertical aperture of the vacuum chamber in mm.

$\gamma = \frac{E}{mc^2}$ is the beam energy referred to the rest mass of the electron.



Beam lifetime is essentially determined by scattering of the electrons from residual gas atoms.

Number density and atomic number of scatterers are the important parameters.

Vacuum Requirements (3rd Generation Sources)

- Beam lifetime is important because
  - It determines the time between refills i.e. the time for an experiment or set of measurements
  - A long lifetime promotes stability – thermal effects such as magnet and mirror movements are slow and minimised
  - It enhances efficiency statistics
  - 3rd Generation Light sources aim for no more than one fill per day

Vacuum Requirements (3rd Generation Sources)

- A long lifetime is obtained by minimising the pressure
  - Typical specification will be < 10^{-9} mbar with beam
  - Reducing contamination e.g. high partial pressures of hydrocarbons and other contaminants
    - Rigorous cleaning and preparation of vacuum vessels
  - Average pressure is in practice determined by beam desorption
- Top-up can, in principle, give effectively infinite lifetimes

Vacuum Requirements (3rd Generation Sources)

- An open question –
  - To bake or not to bake? (in situ)
- Some arguments for –
  - Speeds up conditioning
  - Simple to do
  - It’s always been done
- Some arguments against
  - Beam conditioning equally effective
  - Bakeout of a complex system is dangerous and time consuming
  - It’s expensive

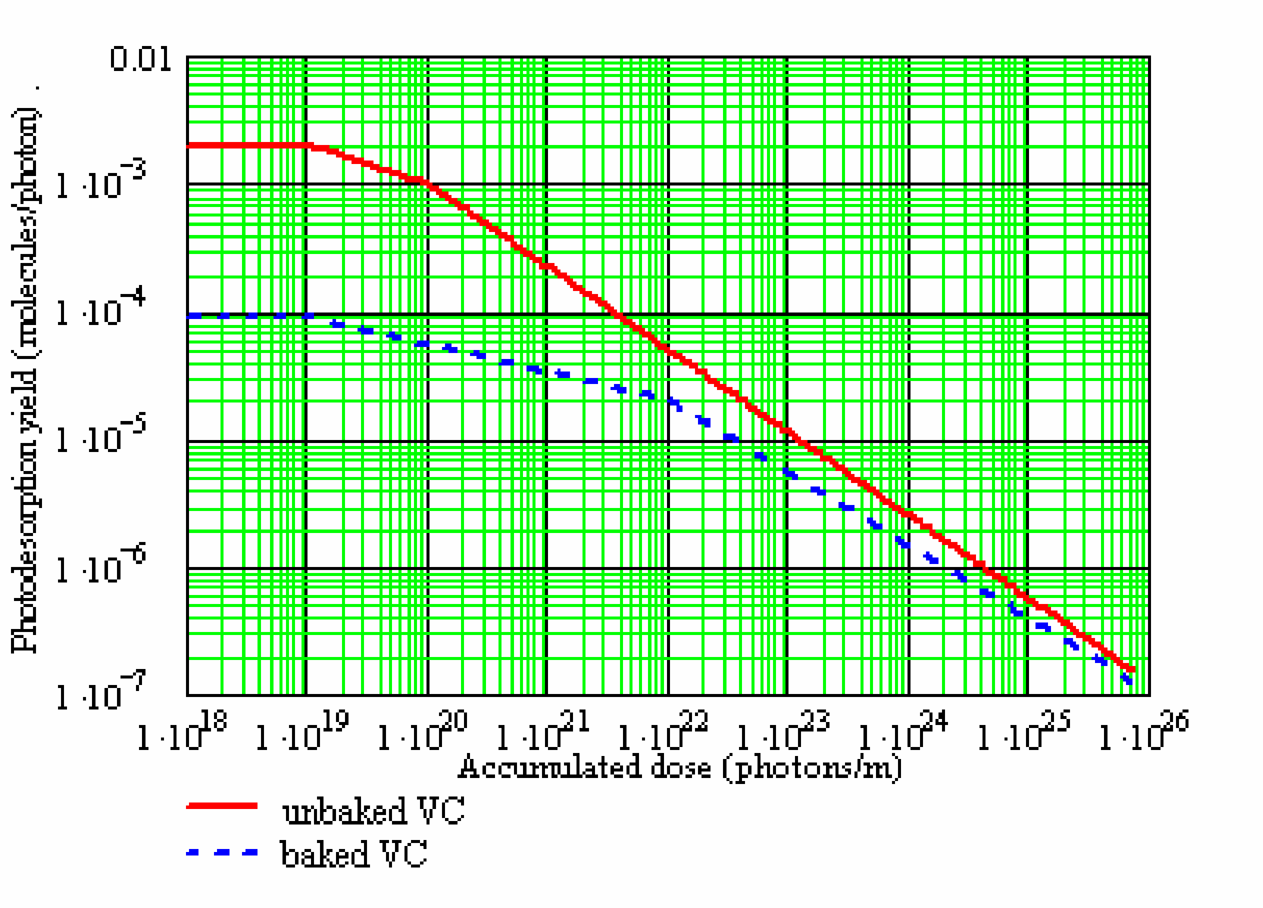
Vacuum Requirements (3^{rd} Generation Sources)

- In each case, all components and sub assemblies must be carefully prepared before installation, including baking
- A system which is not baked in situ should be let up to dry nitrogen (< 1 ppm water; -70C dewpoint)

Vacuum Requirements (3rd Generation Sources)

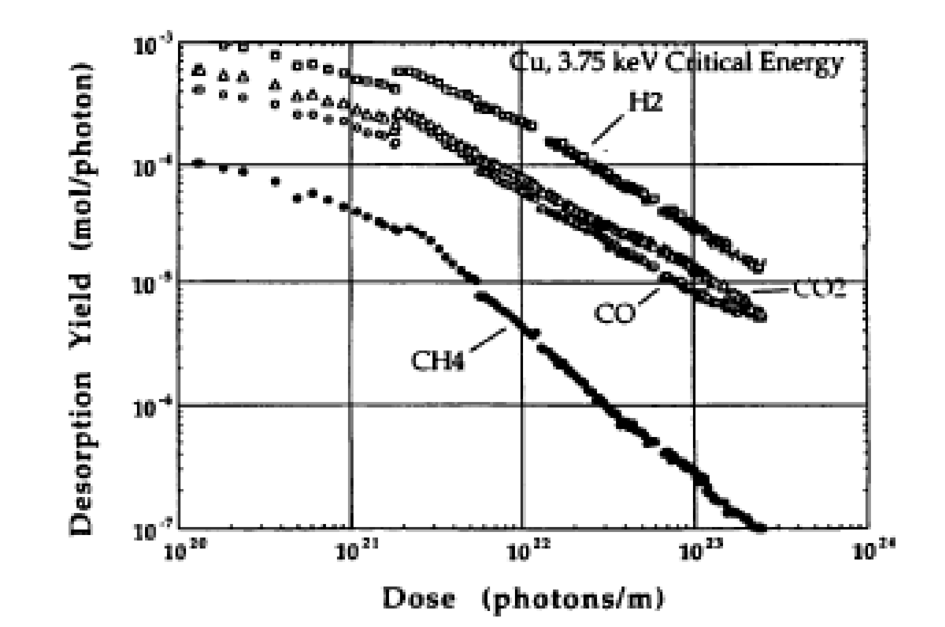
- Beam desorption
  - Otherwise known as photon stimulated desorption (psd)
  - Adsorbed gas is desorbed from surface layers by energy transfer from an incident photon
  - This is not a well understood process
  - Pragmatic (measured, but usually extrapolated) values are used in design work
  - Desorption yields are beam dose dependent

Vacuum Requirements (3rd Generation Sources)



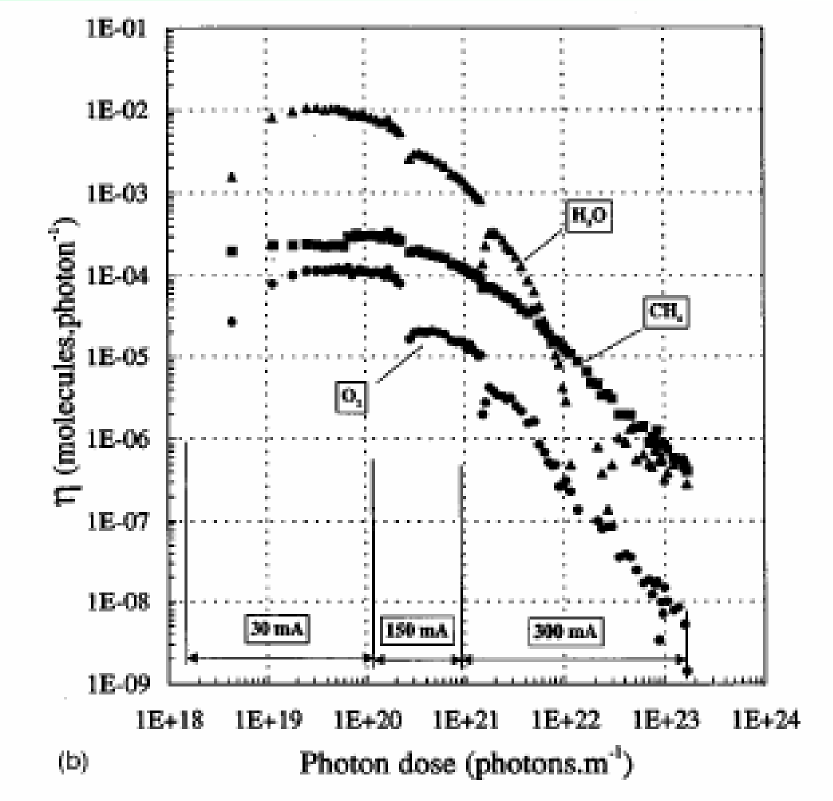
"Idealised" yield curves for baked and unbaked stainless steel

Vacuum Requirements (3rd Generation Sources)



C Foerster, private communication

Desorption yields



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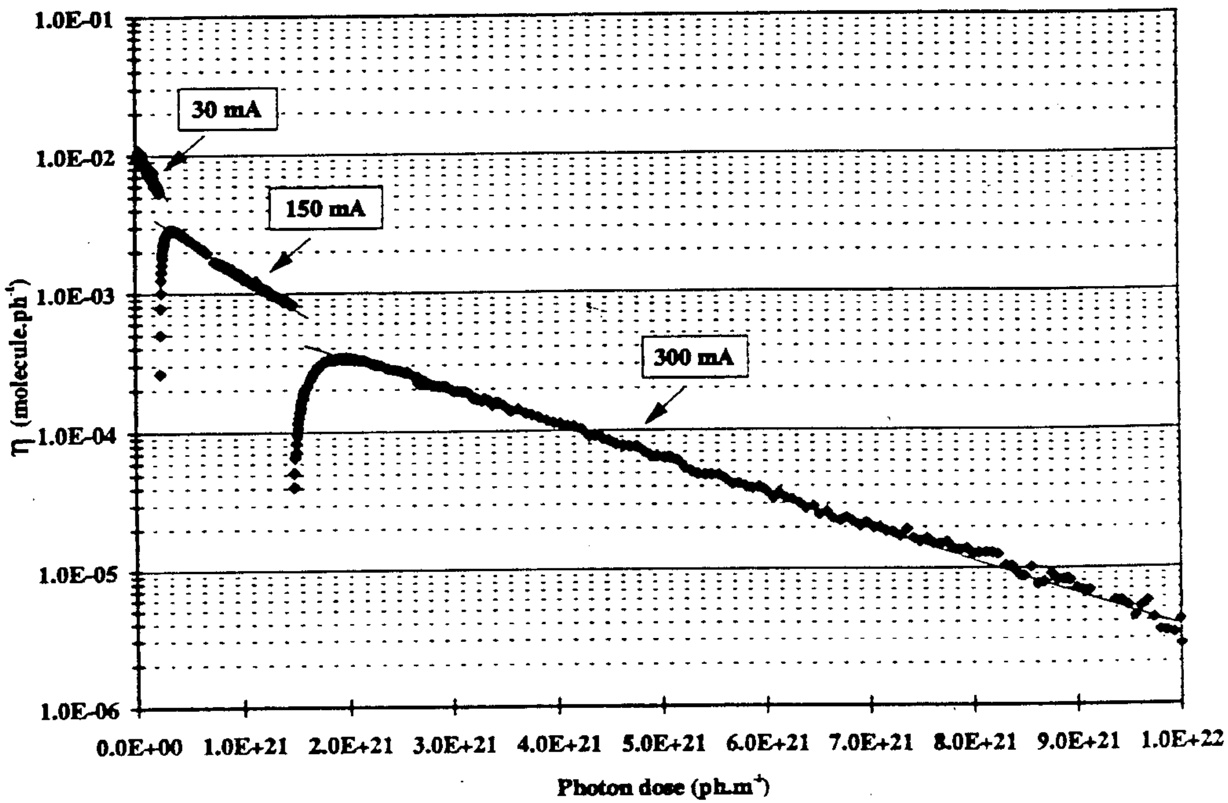
Vacuum Requirements (3rd Generation Sources)



Photon stimulated desorption of H_2O, Showing an exponential variation.

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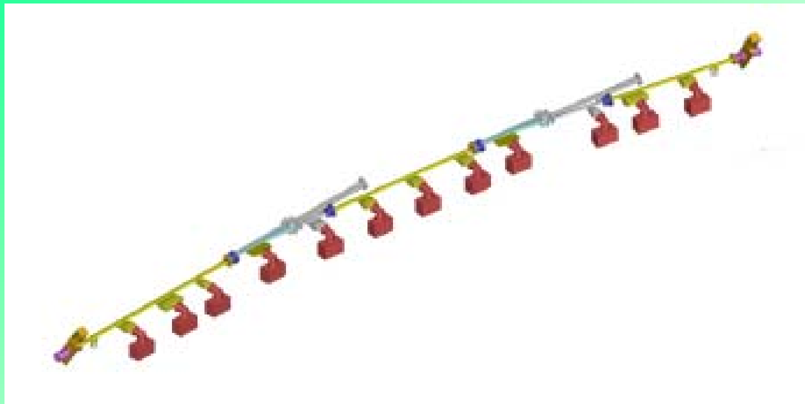
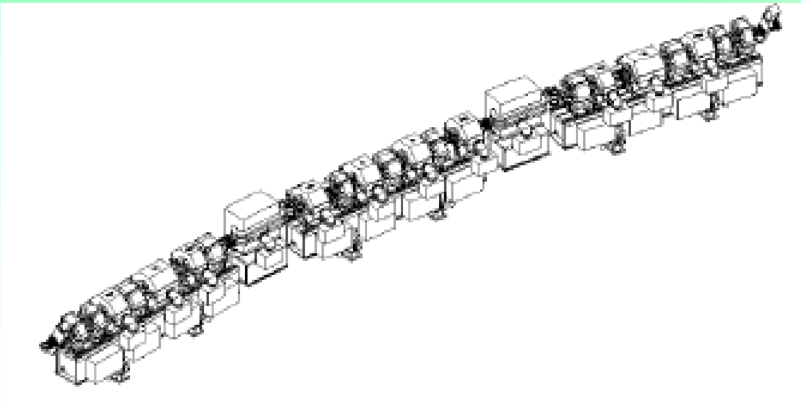
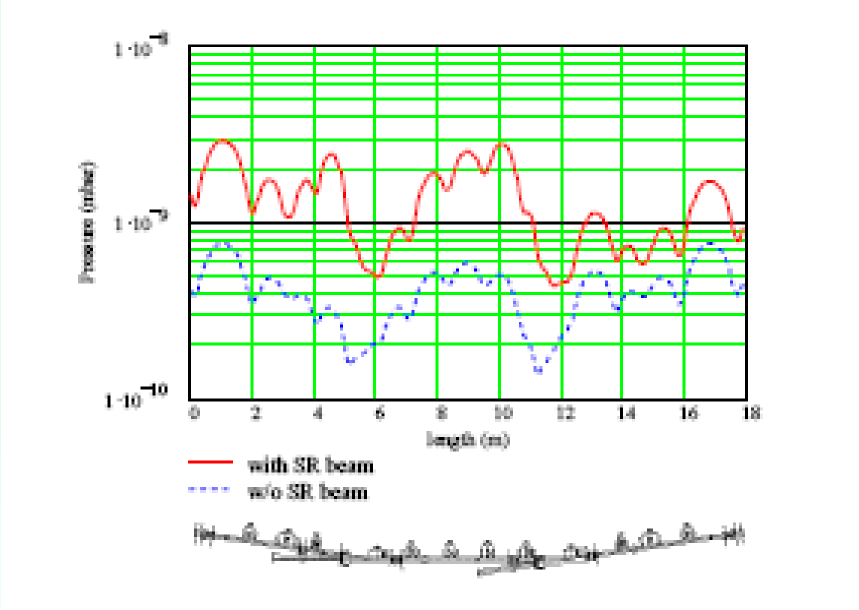
Vacuum Requirements (3rd Generation Sources)

- From a vacuum point of view the main difficulty is getting enough pumping to cope with this gas load
- Needs detailed calculation of pressure profiles
- Eased by being quasi one dimensional
  - Molflow
  - Semi-analytical (e.g. method of angular coefficients)

Vacuum Requirements (3rd Generation Sources)







A "typical" arc of a storage ring

Vacuum Requirements (3rd Generation Sources)

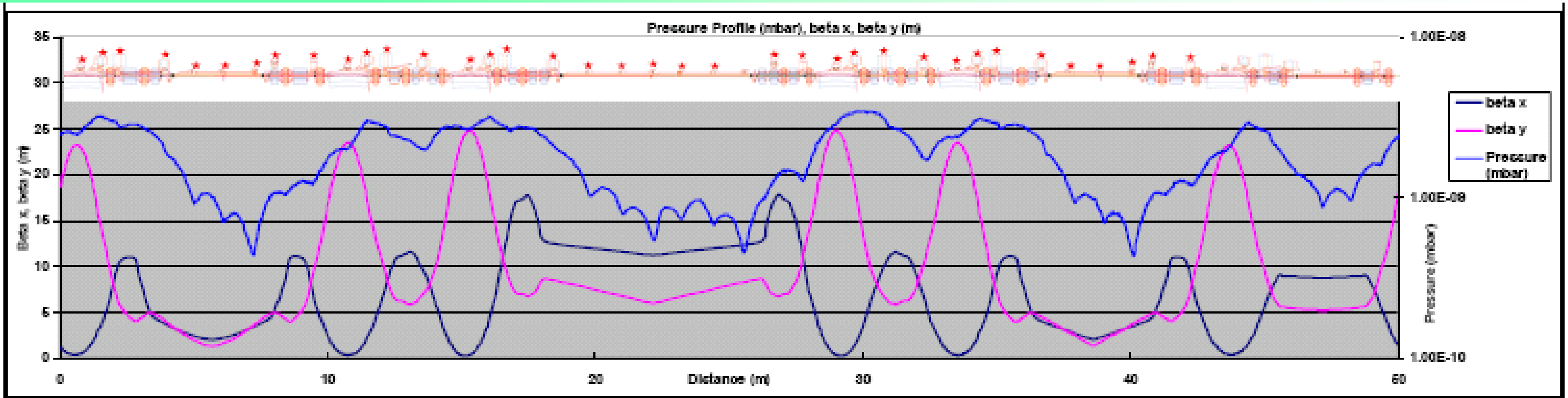
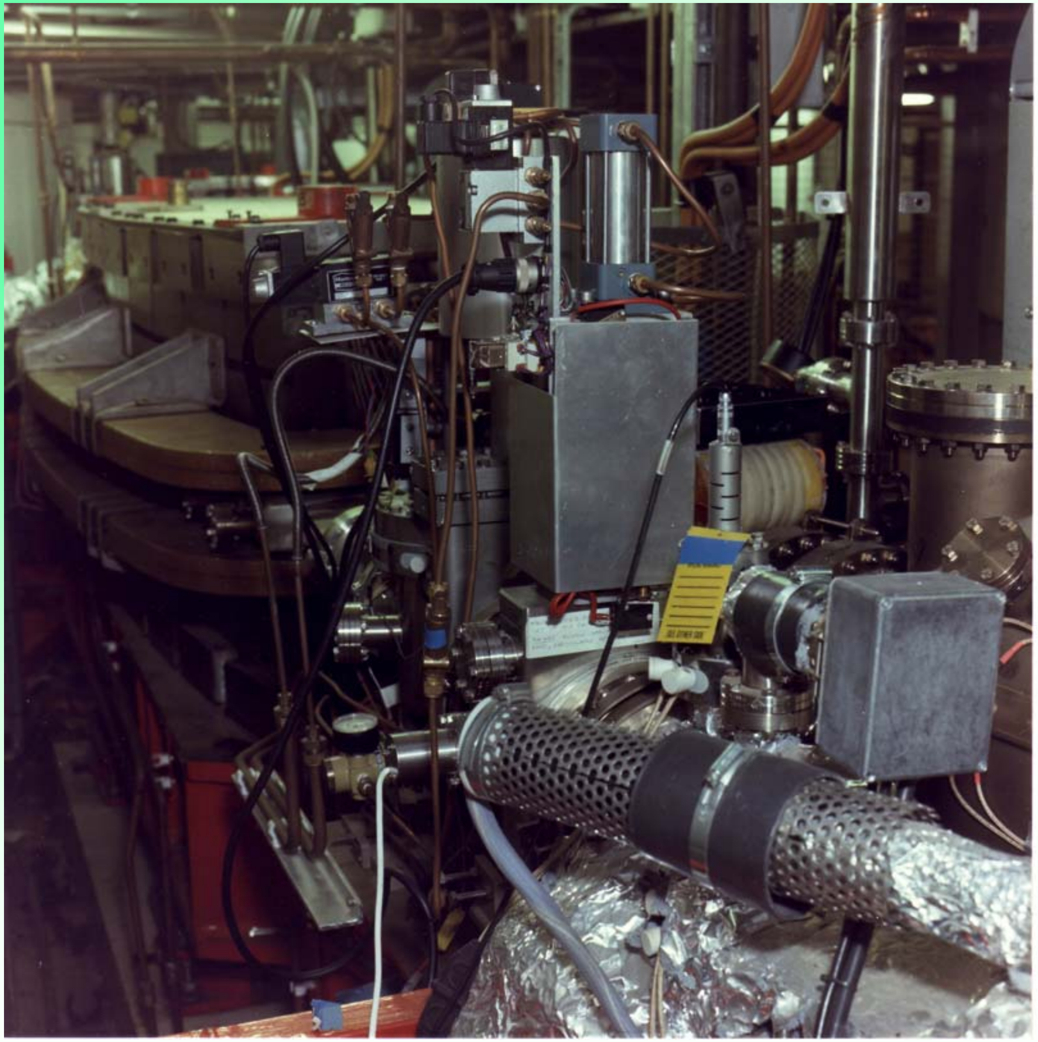


Figure 32 The pressure profile of ALBA for a fully conditioned chamber with the beta x and y.

This is a part of a second generation source (SRS)



Vacuum Requirements (3rd Generation Sources)

- Conventional Technology
  - Turbo Pumps
  - Ion Pumps
  - TSPs
  - NEG cartridges
  - Inverted magnetron gauges (BAGs)
  - RGA

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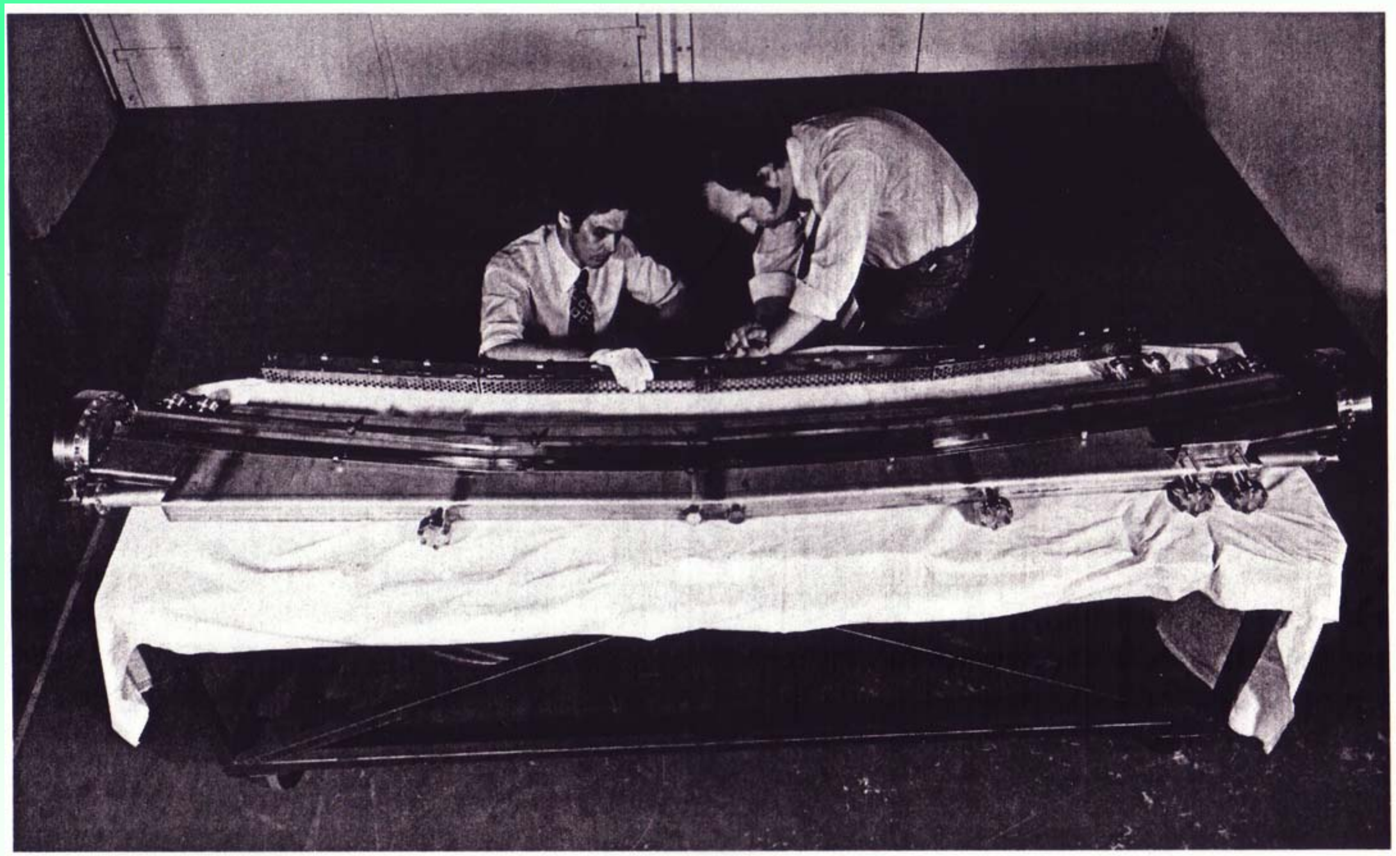
Vacuum Requirements (3rd Generation Sources)

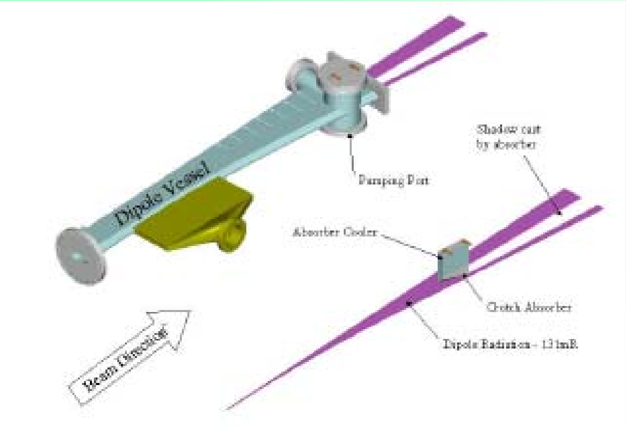


Vacuum Requirements (3rd Generation Sources)

- Personnel safety
  - Radiation along beam lines
  - Bremsstrahlung
  - Dependent on gas pressure
  - Particular problem in ID vessels
    - Tamed by NEG coating

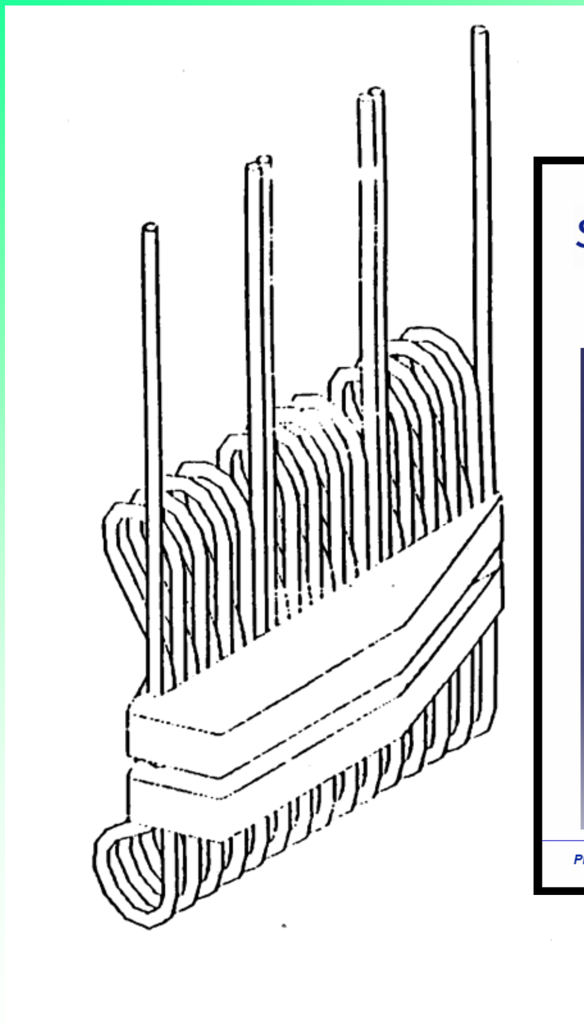
Vacuum Requirements (3rd Generation Sources)

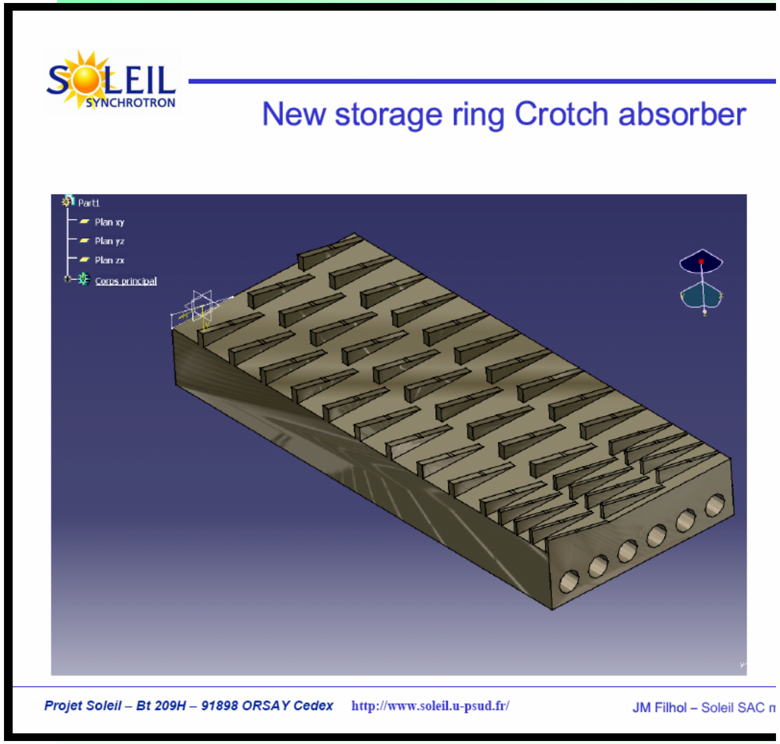
- Mechanical stability
  - Beam stability (<1 micron) important
  - Vessels, magnets must be stable
  - Problem cause by high heat loads, especially on radiation absorbers

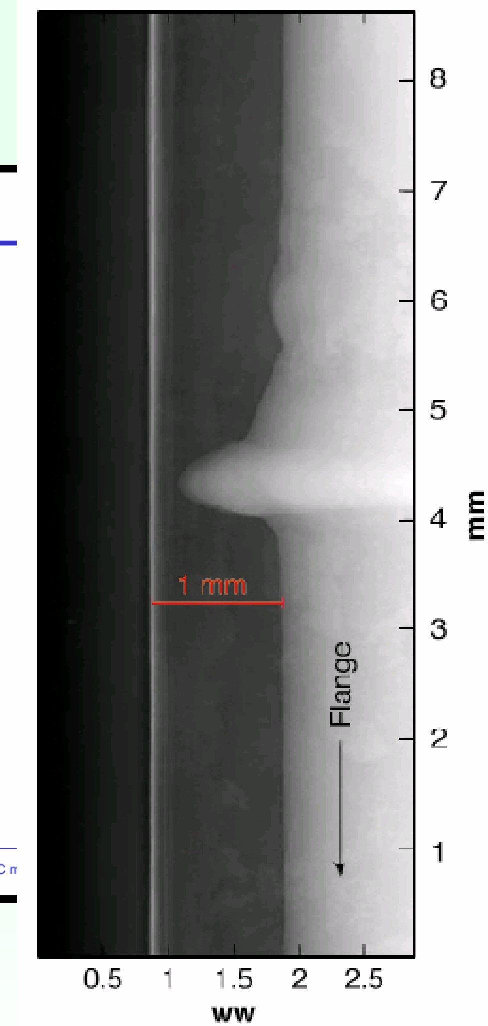


  - Power loads comparable to electron beam welders

Vacuum Requirements (3rd Generation Sources)







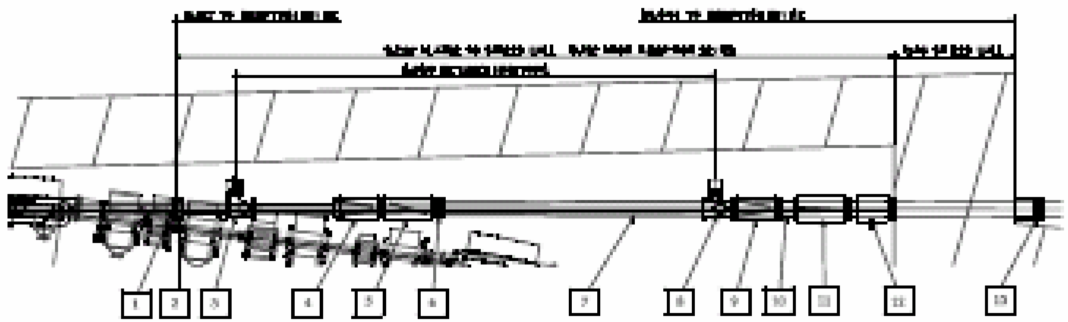
Vacuum Requirements (3^{rd} Generation Sources)

- Other areas requiring detailed attention
  - Bellows
  - Transitions

Vacuum Requirements (3rd Generation Sources)

Beam line front ends are important

Figure 3.1-1 Front-end p



3.6.6 STANDARD ID FRONT-END PARTS LIST

The following table lists the front-end components with their distance to the insertion device (5m straight)

No.	Item	Dist X	No.	Item	Dist X
1.	Front Flange	10.169m	8.	Horiz + Vert PBPM	17m
2.	Isolation Valve	10.2m	9.	Horiz + Vert slits/apertures	17.8m
3.	Horiz + Vert PBPM	11m	10.	Beryllium window (option)	18m
4.	Defining aperture	12.6m	11.	Absorber	18.5m
5.	Absorber	13.2m	12.	Port shutter	19.2m
6.	Isolation valve	13.6m	13.	Isolation valve	21.3m
7.	Conductance pipe	14m			

Vacuum Requirements (4th Generation Sources)

- Pressure requirements
  - Probably not as stringent as 3rd generation
  - Determined by effects of scattering on beam
    - Single pass so lifetime not an issue
  - Superconducting cavity issues
  - Photocathode issues
    - Degradation
  - Particulates
    - Paranoia!
  - But still somewhat of an unknown quantity

Concluding Remarks

- Vacuum systems for synchrotron light sources are reasonably well understood
- Systems have evolved over the years but not dramatically
- Technology solutions are available for third generation sources and probably for fourth generation sources

Thanks for listening