ANKA Synchrotron Radiation Facility

Vacuum diagnostics

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Advanced Low Emittance Rings Technology
ALERT 2014

Outline

Karlsruhe Institute of Technology

- Gas sources: static and dynamic pressure
- Effects of vacuum on beam quality
- Vacuum specs for low emittance rings
- Vacuum diagnostics at NSLSII, SIRIUS and MAXIV
- Vacuum diagnostics in cold regions
- Summary

Gas sources

- Thermal outgassing

↓

Static pressure (no beam)

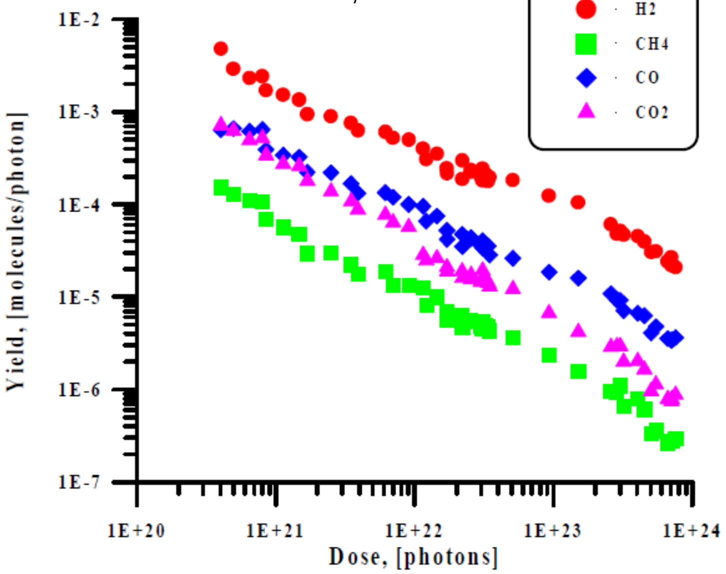
- Photo-desorption,

eventually electron desorption: changes with conditioning or "beam scrubbing"

↓

Dynamic pressure (beam)

Anashin et al, EPAC98



Effects of vacuum on beam quality and operation

- Reduction of beam lifetime
- Increase radiation background
- Increase radiation damage
- Personal safety issues P. Marin in “Snekersten 1999, Vacuum technology”
- Increased emittance W. Hardt, CERN ISR-300/GS/68-11 (1968)
- Effects of trapped ions on the beam include:

increased emittance, betatron tune shifts and broadening, collective instabilities, reduced beam lifetime.

F. Zimmermann in “Handbook of Accelerator Physics and Engineering”, Edited by A. W. Chao and M. Tigner (1998)

Vacuum specs for low emittance rings

- **NSLSII**. The average pressure with beam is designed to be less than 1×10^{-9} Torr. At this pressure level, the beam lifetime due to bremsstrahlung and Coulomb scattering is longer than 10 hours. The stored beam lifetime for 500 mA operation will be limited to 2–3 hours by the Touschek lifetime due to the scattering loss of electrons in the bunch.

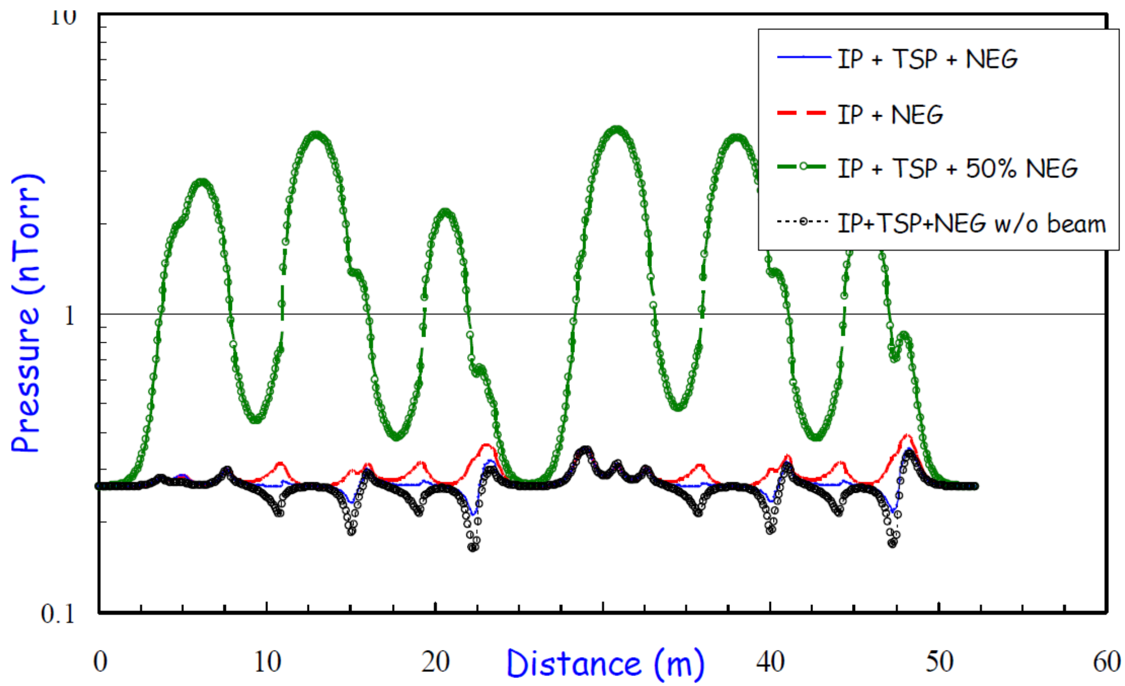


Figure 7.3.7 Pressure distribution inside the electron beam channel in one storage ring super -period without beam (black circles), with 500 mA current (blue line) , without TSP (red line), and with 50% NEG strip coverage (green circle). The average pressure is at ~3×10^{-10} Torr, except when 50% NEG strips are removed, where the average pressure increases five-fold, to 1.5×10^{-9} Torr.

NSLS II CDR

Vacuum specs for low emittance rings

- **SIRIUS**. The vacuum chamber and the system should achieve and maintain a **dynamic pressure smaller than 1 x 10^{-9} mbar** (CO equivalent) in order to guarantee the specified beam lifetime: ~5 h for homogeneous fill at 500 mA.

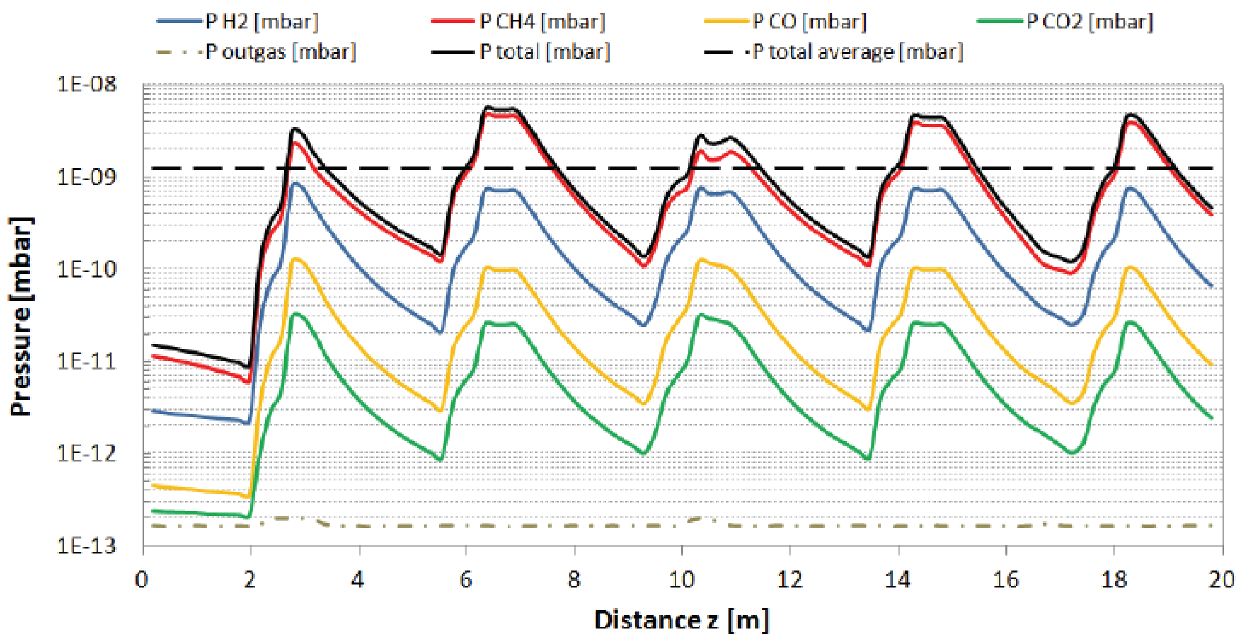


Figure 6.5: Calculated pressure profile along an arc of the Storage Ring (without ID`s) after 0.12 $A \cdot h$ of conditioning. Care must be taken with CH_4, because it will be the prevailing residual gas (not pumped by NEG).

SIRIUS DDR

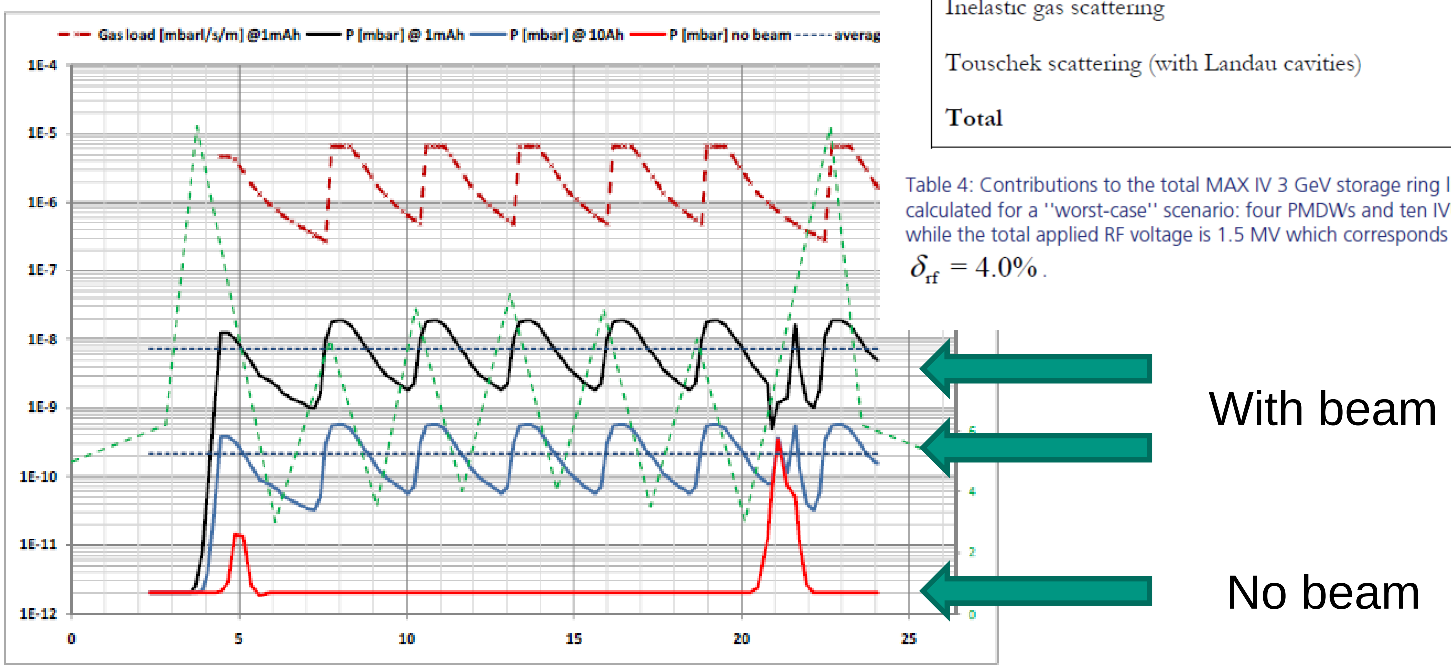
Vacuum specs for low emittance rings

- **MAX IV**. Gas losses should preferably be smaller than the Touschek losses. This requires a partial pressure lower than 10^{-9} mbar for CO-like molecules.

	τ [h]
Elastic gas scattering	25.4
Inelastic gas scattering	53.1
Touschek scattering (with Landau cavities)	25.5
Total	**10.3**

Table 4: Contributions to the total MAX IV 3 GeV storage ring lifetime τ . The results have been calculated for a ''worst-case'' scenario: four PMDWs and ten IVUs are installed in the storage ring while the total applied RF voltage is 1.5 MV which corresponds to an RF acceptance of only $\delta_{rf} = 4.0\%$.

Figure 12: Beam induced pressure.

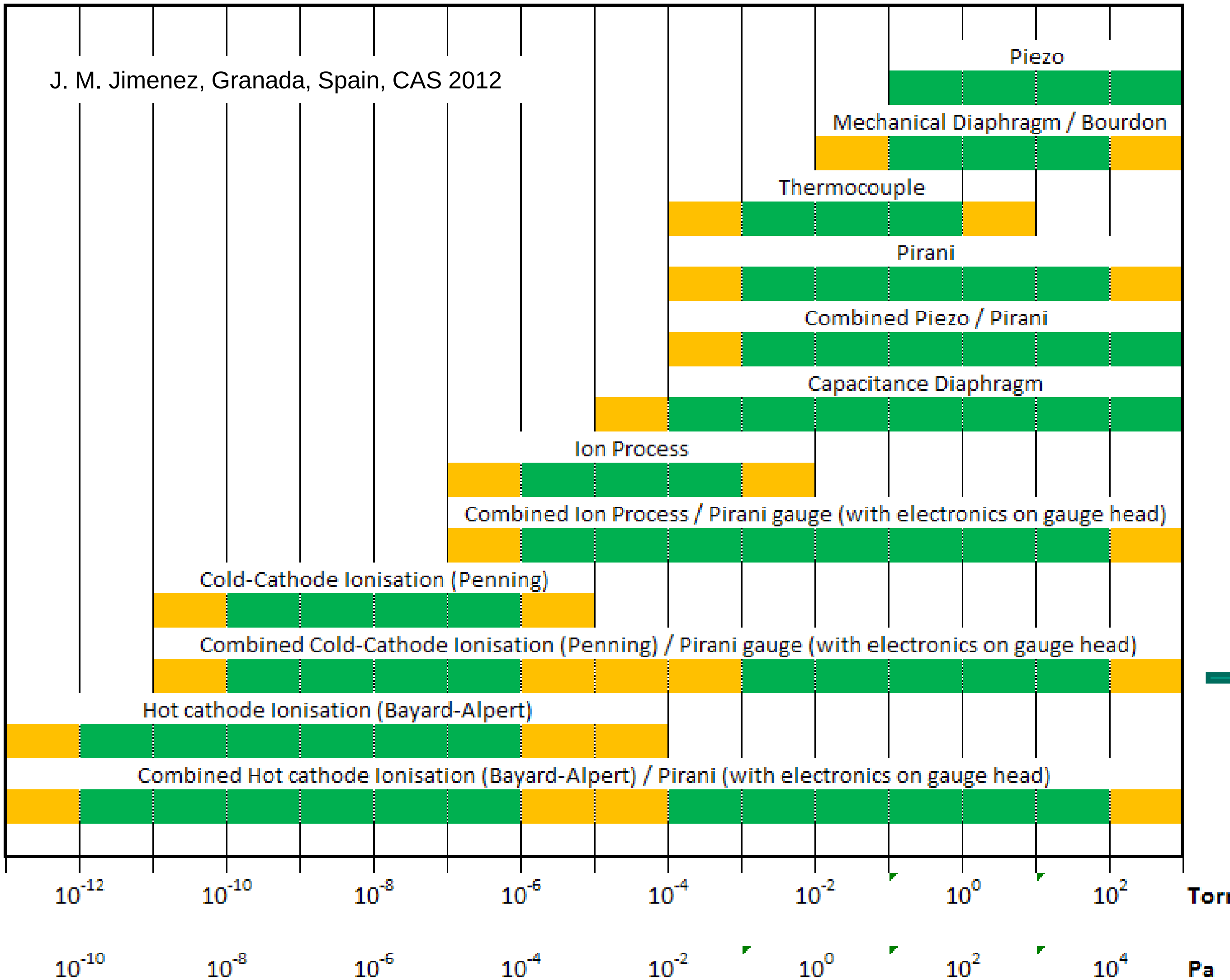


Induced gas load at 1mAh is shown in the diagram.
The pressure should be below 10-9 mbar especially where the βy-function is high.
The beta function is simplified from Figure 3.2. in §2.2. of the DDR.

MAX IV DDR

Pressure gauges

Karlsruhe Institute of Technology



Residual Gas Analyzers are used in the range 10^{-4} -10^{-13} mbar

→ Common choice

Vacuum diagnostics at NSLSII

Table 4.4.5 Number of Gauges and Residual Gas Analyzers in Areas of the Storage Ring.

	TCG*	Ionizing Gauge	Residual Gas Analyzer
SR	30	60	34
Front end	30	60	60
ID	30	60	10
Total	**90**	**180**	**104**

*TCG = convection-enhanced Pirani gauge

+ sputter ion pump currents
+ RGAs

RGA's quadrupole mass filter RF box (contains sensitive electronics) maybe located near the head and needs to be shielded from synchrotron radiation

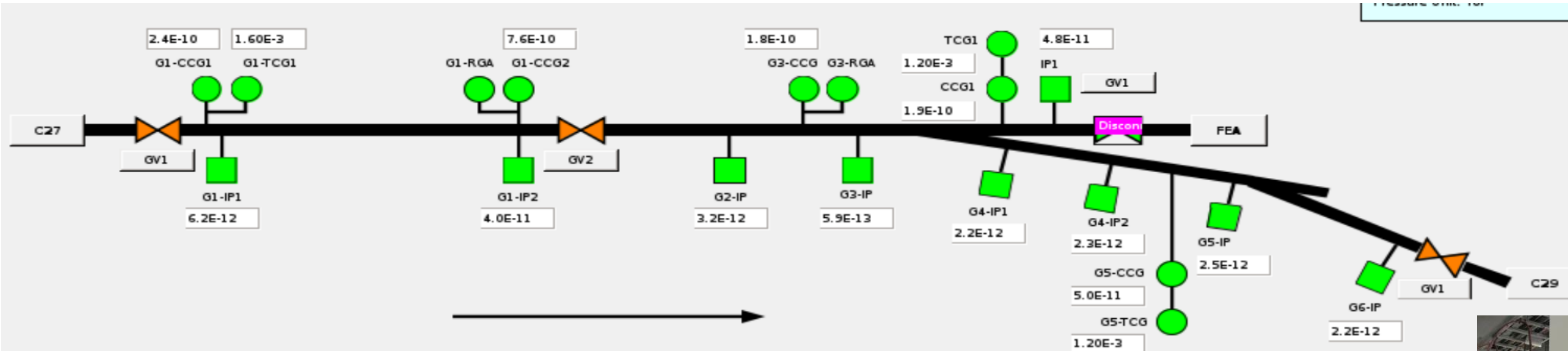
To avoid radiation damage:

- Controllers located at mezzanine above storage ring tunnel
- Radiation resistant cables and appropriate routing

NSLS II CDR

Vacuum diagnostics at NSLSII

Locations of RGA and CCG

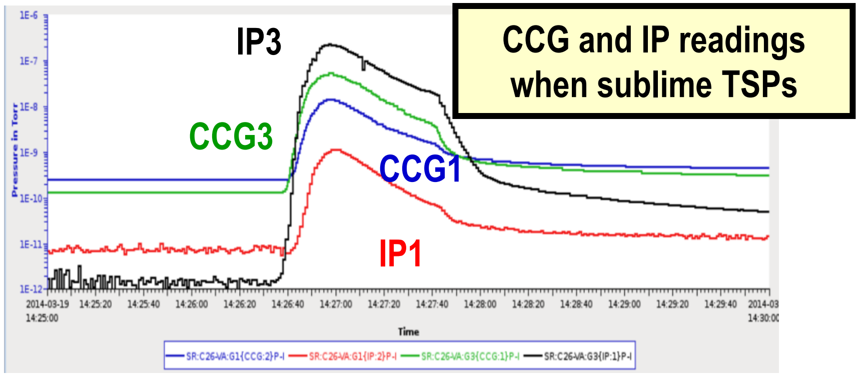


Each cell has

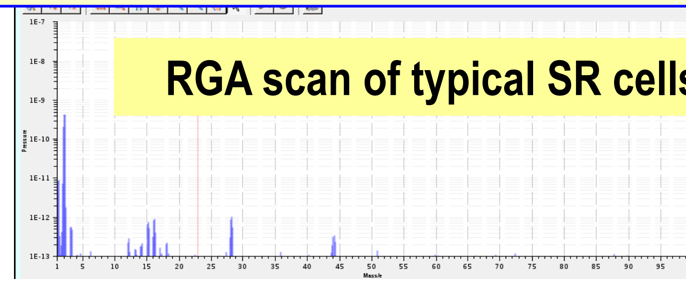
- 2 CCGs and 1 RGA in each straight, each arc and each FE
- CCG/RGA in arc are mounted off dipole ante-chamber
  shielded by custom Cu gasket (~ 50% opening) and RAV
- CCG/RGA in straight are mounted on GV side ports
  shielded by RF fingers and RAV
- RGA RF box is > 40 cm above mid plane
- Limited conductance to beam channel and pumps

Courtesy H. Hseuh

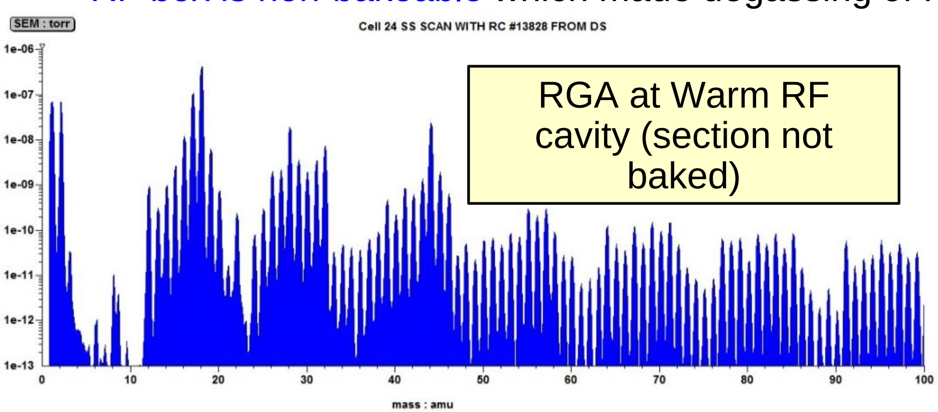
Vacuum diagnostics at NSLSII

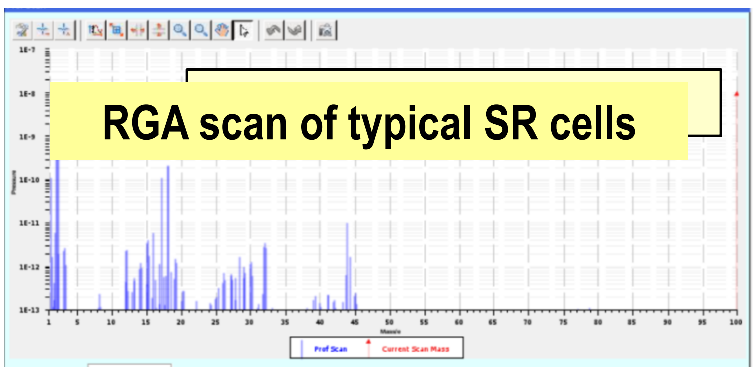


CCG readings are 1-2 decades higher than IP's due to lack of pumping at gauge locations (C = ~ 2 l/s and Q > 10^{-10} Torr.l/sec)
Gauge and pump readings correlate well at higher P
Should provide reliable pressure indication



- **31 of 37** RGA scans are very clean with H_2 > 98%
- 4 scans have 14, 15/16, 18, 28, 32, 40, 44 total to ~ 5% level, no leaks were found
- 2 scans have significant contamination, one was baked and cleaned up a great deal
- RF box is non-bakeable which made degassing of RGA during bake difficult





Courtesy H. Hseuh

Vacuum diagnostics at SIRIUS

Table 6.4: First proposed arrangement of gauges and RGA`s in the storage ring.

Position	PIRANI	IMG	RGA
Post-B1 dipole chamber	1	1	0
Post-2nd B3 dipole chamber	1	1	1
Pre-2nd B1 dipole chamber	1	1	0
ID straight section	1	1	0

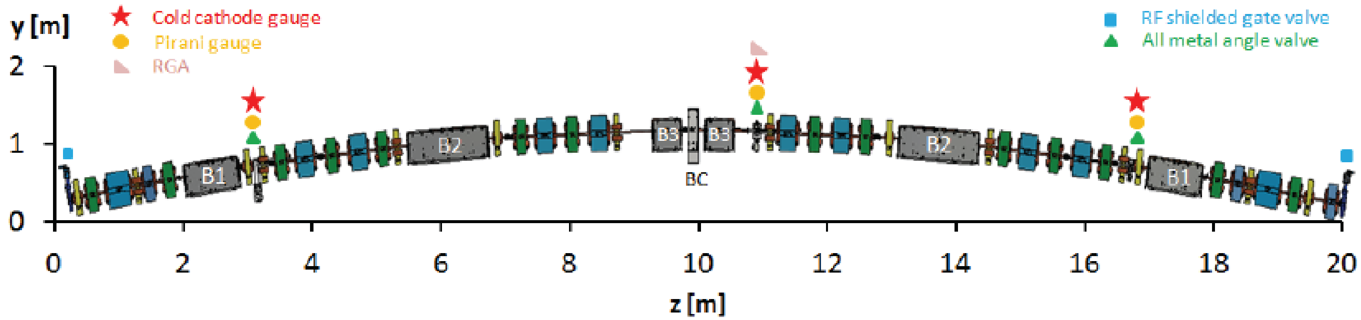


Figure 6.6: Proposed gauges and valves distribution along an arc of the storage ring.

SIRIUS DDR

Coating the vacuum instrumentation, necks and elbows still open.

Vacuum instrumentation baked when activation of NEG coating

Courtesy R. Molena Seraphim

Vacuum diagnostics at SIRIUS

Karlsruhe Institute of Technology

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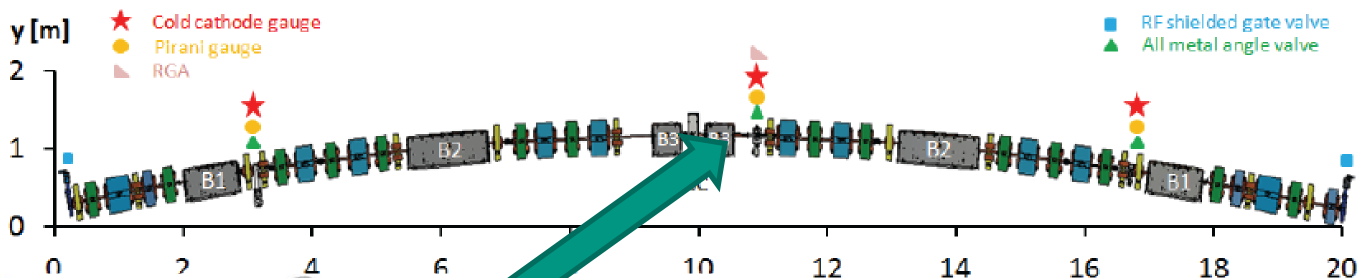

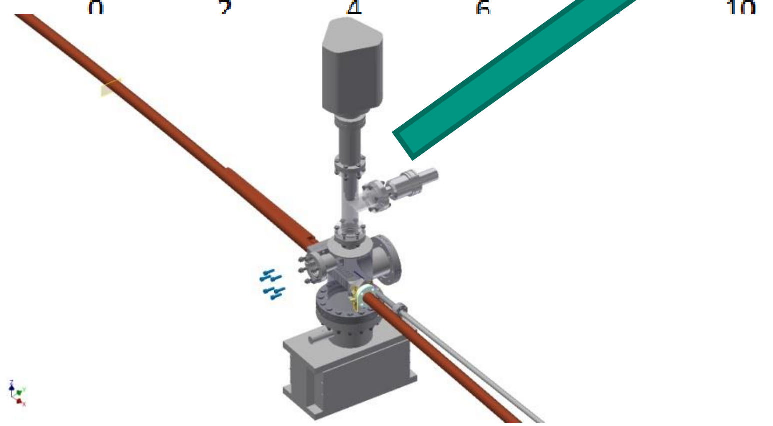

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SIRIUS DDR

d elbows still open.

n of NEG coating

Courtesy R. Molena Seraphim

Vacuum diagnostics at SIRIUS

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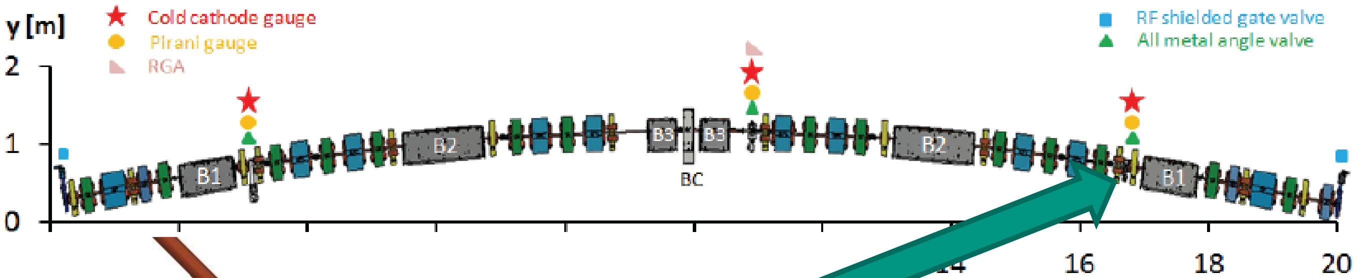
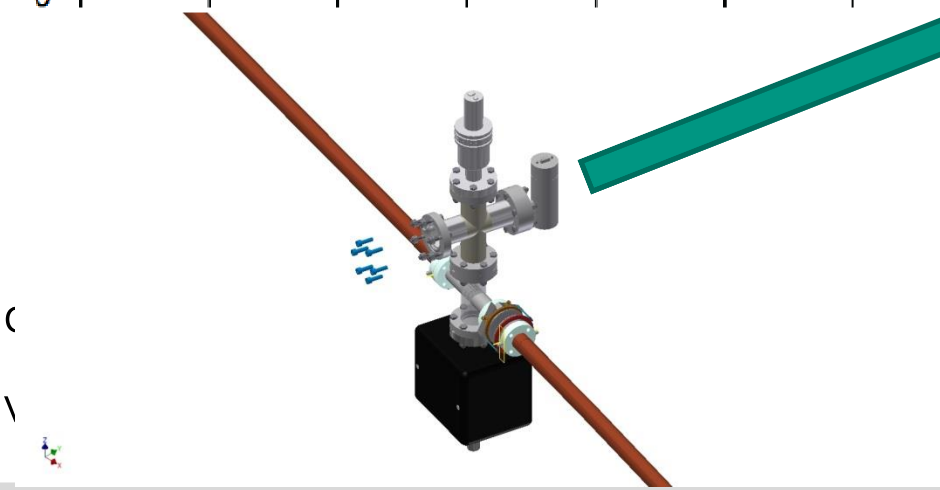




an arc of the storage ring.

SIRIUS DDR

(till open.

\ oating

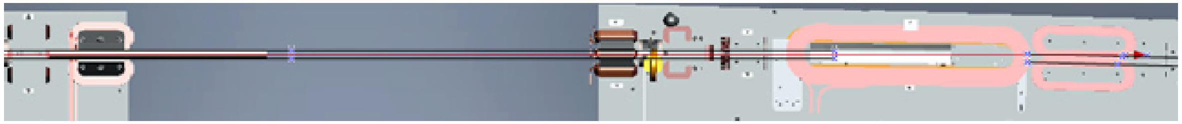
Courtesy R. Molena Seraphim

Vacuum diagnostics at MAXIV

2.8.3. Vacuum Diagnostics

The quality of the vacuum will be read by

- Gamma detection; installed as many as practical. They will serve as the primary tool. A possible position might be at quadrupole after the last matching dipole, where the gammas produced on the last short straight will be detected.



- Ion Sputter pump currents
- Radiation monitors
- RGA; as part of the turbo pump stands.
- Beam loss monitors along the ring as done at DELTA

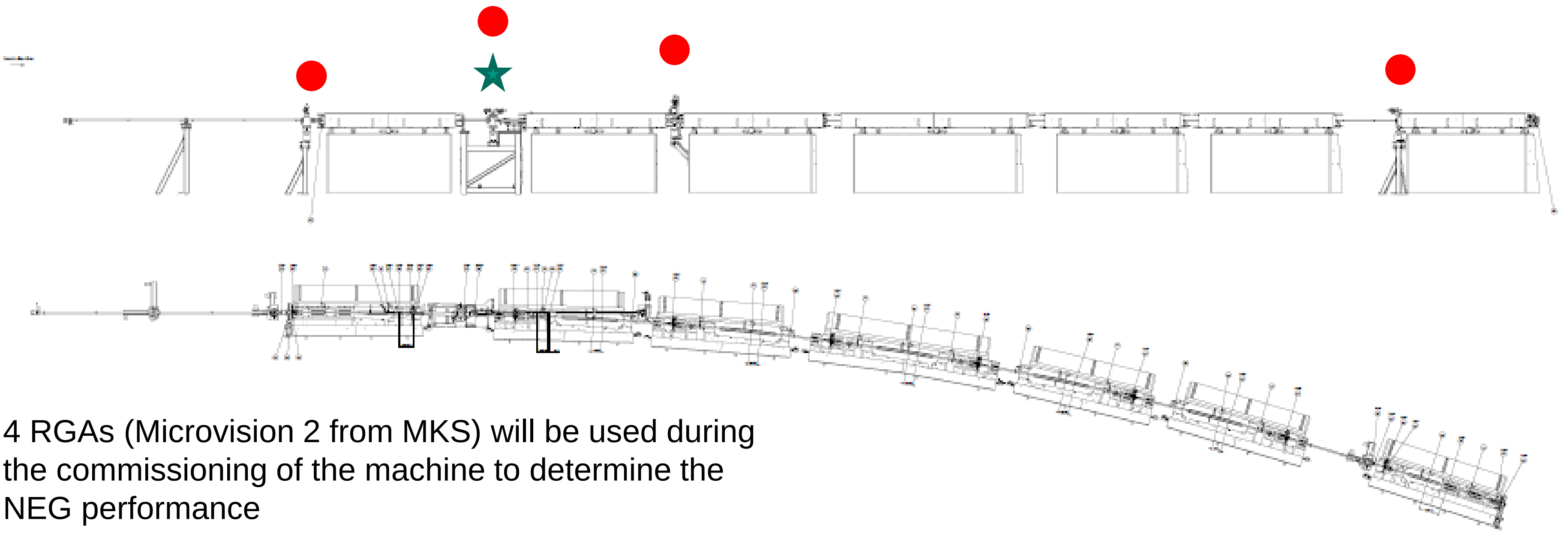
When the NEG coating is activated the RGA and pressure readings will only "see" the local conditions at the measuring point as the distributed pumping speed is quite high for most gases.

The quality of interest is not the total (nitrogen equivalent) pressure as such but the gas induced losses. The loss is a function of the mass of the gas molecule.

MAXIV DDR

Vacuum diagnostics at MAXIV

- ★ Cold cathode gauge (Pfeiffer IKR060)
- ● Current reading from Ion pump (Gamma vacuum)



4 RGAs (Microvision 2 from MKS) will be used during the commissioning of the machine to determine the NEG performance

Bremsstrahlung measurements (as an indication of the pressure inside the chamber) will most probably be used at the start of the commissioning at selected areas. Detectors most probably temporary and movable. Done before at ESRF, Soleil and MAXII and in many other facilities, when they install new coated ID chambers.

Courtesy E. Al Dmour

Bremsstrahlung measurements at MAXII

RGA

NaI scintillation detectors

Vacuum cross section drastically reduced

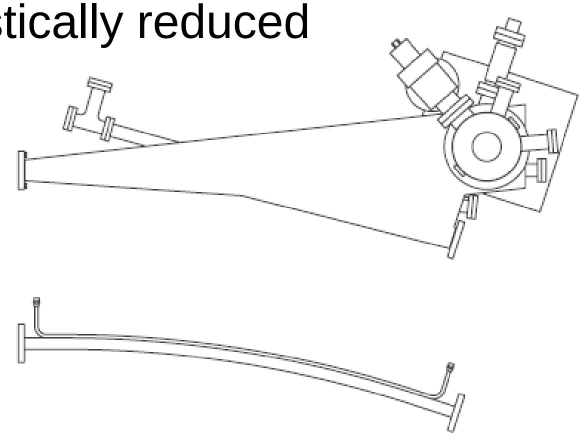


FIG. 2. Drawings of the standard stainless steel dipole vacuum chamber (top) and the new NEG-coated copper dipole vacuum chamber (bottom).

A. Hansson et al., Journal of Vacuum Science & Technology A **28**, 220 (2010)

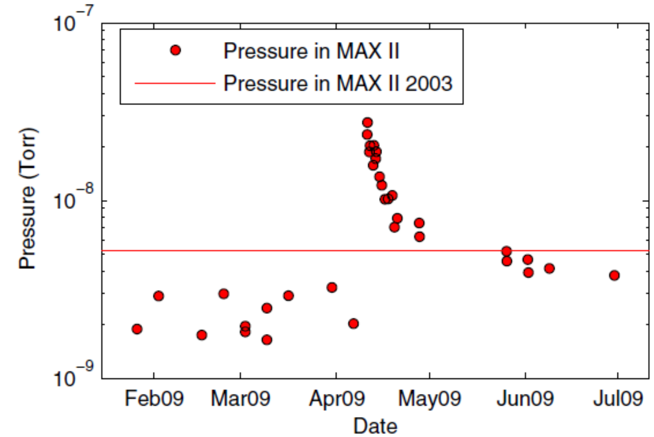


FIG. 3. (Color online) Pressure in the MAX II storage ring from February 2009 to July 2009. The solid line corresponds to the pressure in MAX II in 2003 (Ref. 21).

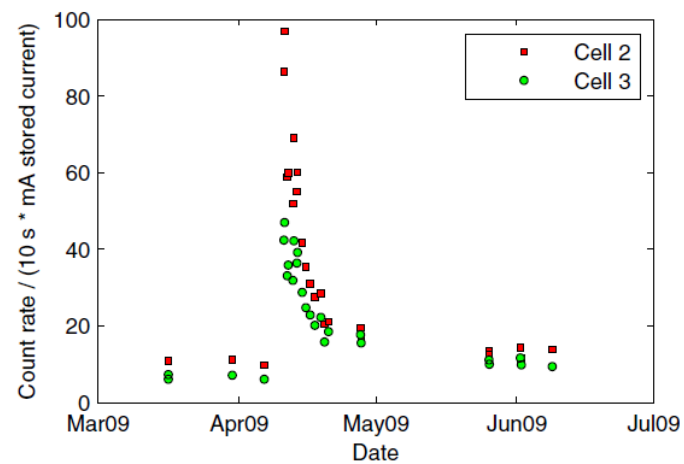


FIG. 5. (Color online) Count rate in the NaI detectors per 10 s and milliamperes stored current in MAX II from March 2009 to June 2009.

Bremsstrahlung measurements at MAXII

NaI crystals
5 cm diameter
5 cm length

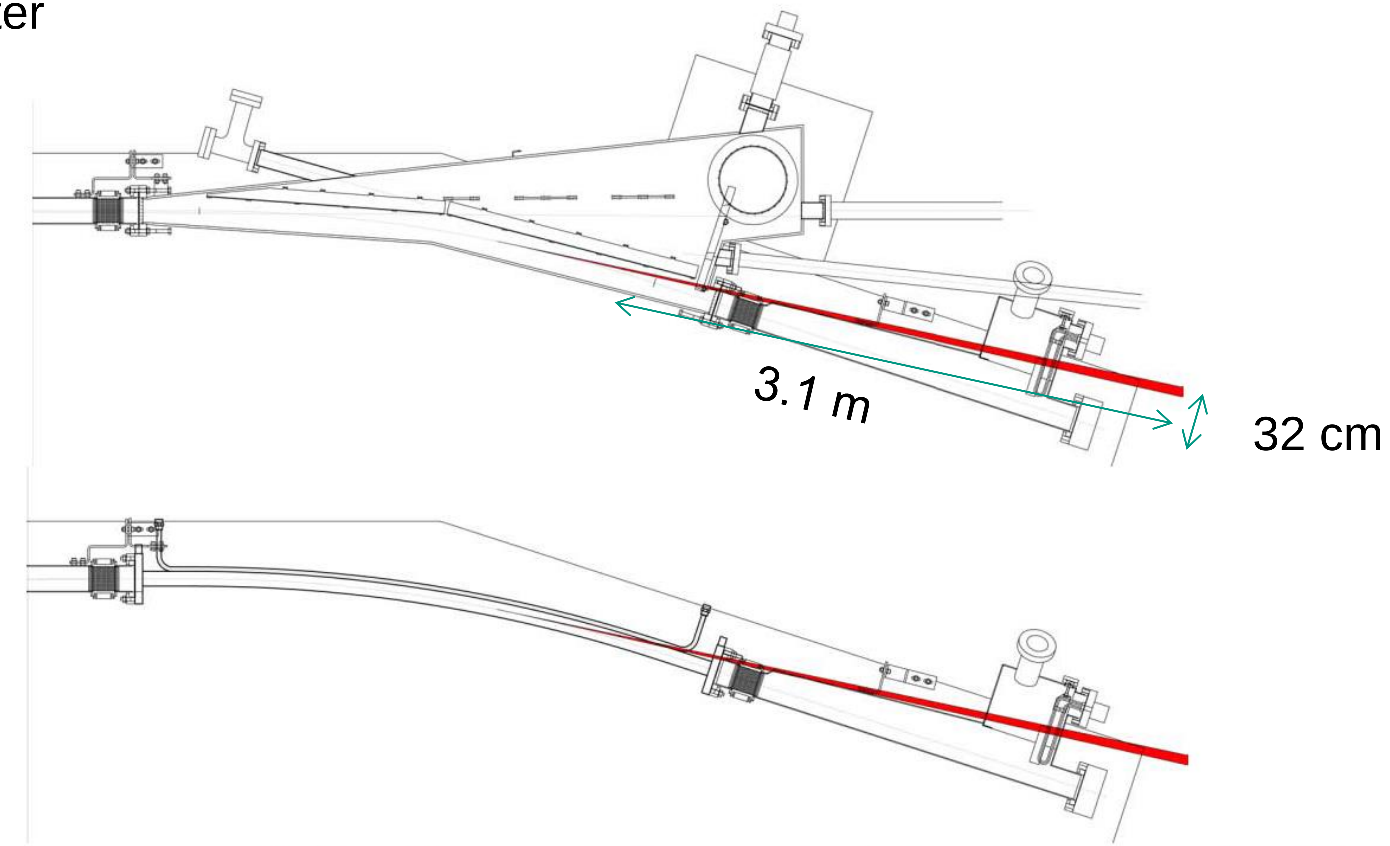
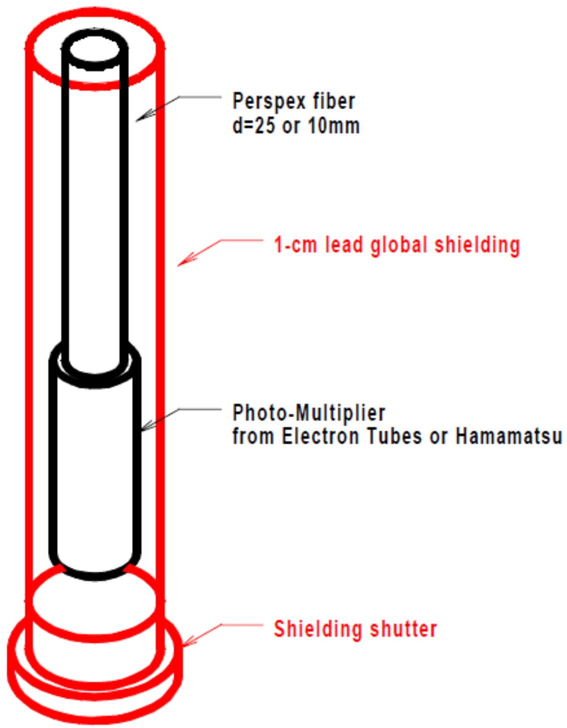


Figure 1: Drawings of the second half of cell 3 (*top*) and cell 2 (*bottom*) in the MAX II storage ring. The added red beam paths show the cone of bremsstrahlung radiation detected by the NaI detectors.

A. Hansson et al., EPAC 208

Beam loss monitors at ESRF



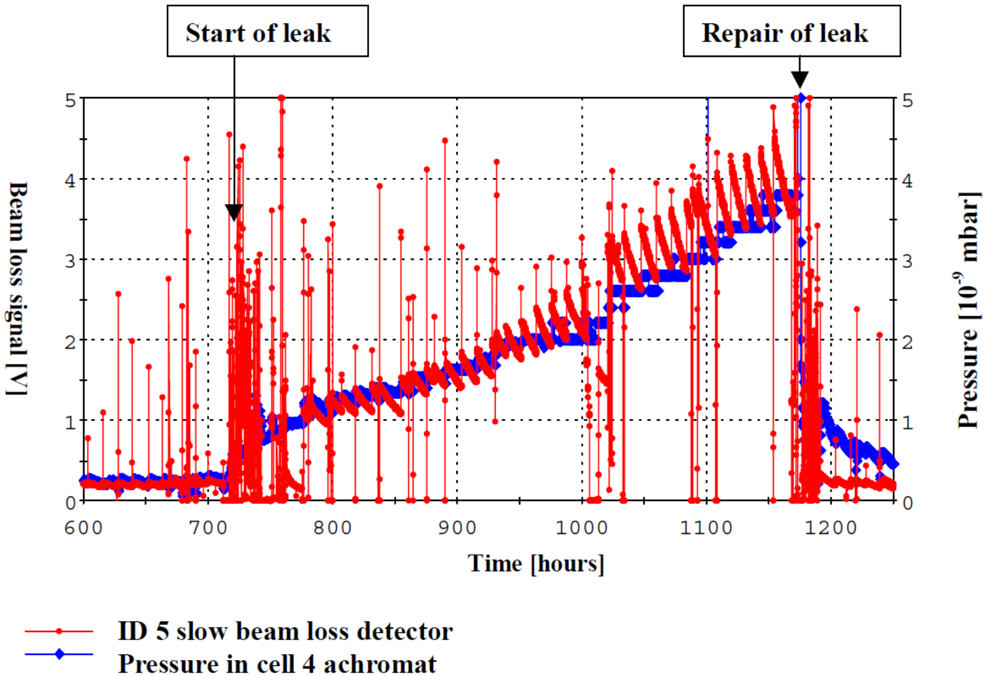
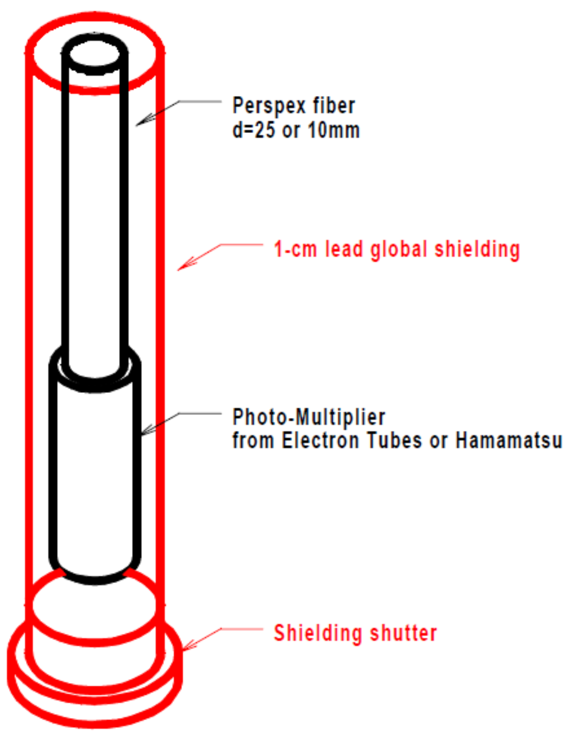


Figure 5-9 detection of a leak in the cell 4 achromat with the ID5 beam loss detector

There is perfect correlation of the beam loss detection signal in the ID5 straight section and the vacuum pressure in the cell 4 achromat during the development of the leak. The saw teeth behaviour of the beam loss detector signal results from the beam intensity variation.

U. Weinrich, PhD Thesis 1999
https://eldorado.tu-dortmund.de/bitstream/2003/2317/1/weinrich.pdf

Beam loss monitors at ESRF



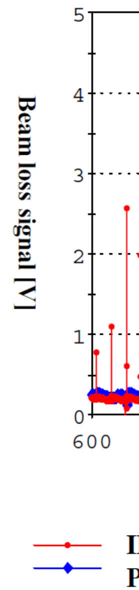


Figure 5-9 de

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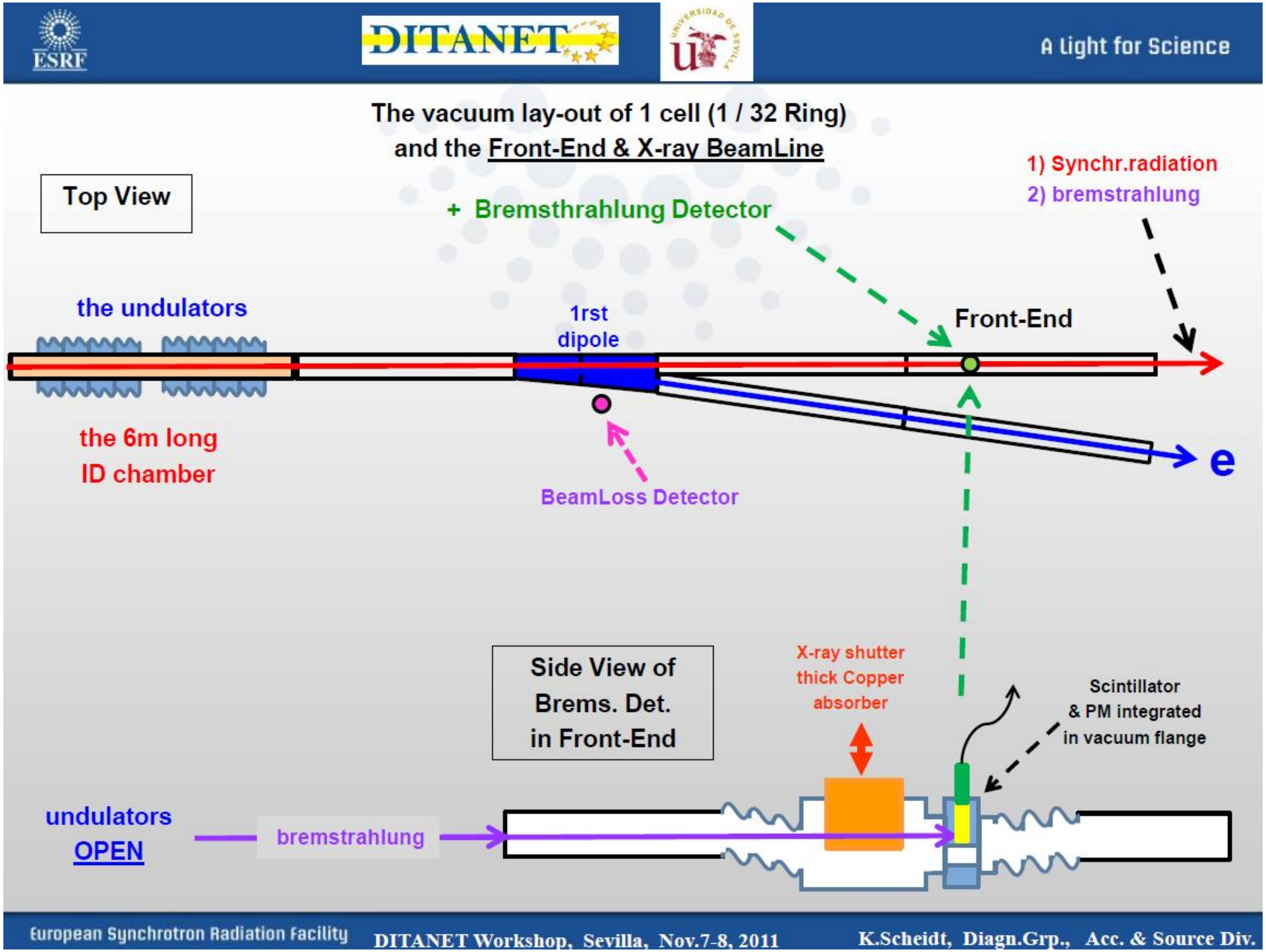
U. Weinrich, PhD Thesis 1999
https://eldorado.tu-dortmund.de/bitstream/2003/2317/1/weinrich.pdf


ESRF
DITANET
A Light for Science
The vacuum lay-out of 1 cell (1 / 32 Ring)
and the Front-End & X-ray BeamLine
Top View
+ Bremsthrahlung Detector
1) Synchr.radiation
2) bremstrahlung
the undulators
1rst
dipole
Front-End
e
the 6m long
ID chamber
BeamLoss Detector
Side View of
Brems. Det.
in Front-End
X-ray shutter
thick Copper
absorber
Scintillator
& PM integrated
in vacuum flange
undulators
OPEN
bremstrahlung
European Synchrotron Radiation Facility
DITANET Workshop, Sevilla, Nov.7-8, 2011
K.Scheidt, Diagn.Grp., Acc. & Source Div.

Distributed beam loss monitor

Fiber optic radiation sensors

- Online monitoring of long accelerator sections (up to some km) with local resolution of few m and response time of some minutes
- Beam loss measurements in narrow gaps
- Insensitive to e.m. disturbances, so they can be operated in regions with strong e.m fields

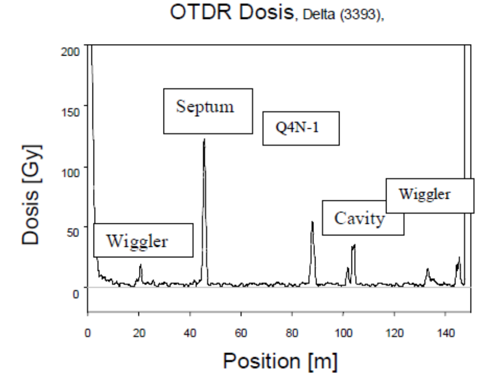


Figure 4: Dose deposited along the optical fibre placed at the outer side of the DELTA storage ring vacuum chamber. The fibre starts and ends at the wiggler. 20 m fibre length are neede to get the fibre out of the shielding wall. G. Schmidt et al., EPAC2002

Optical Time Domain Reflectometer (OTDR)

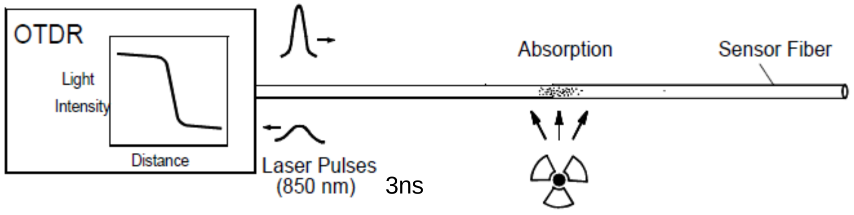
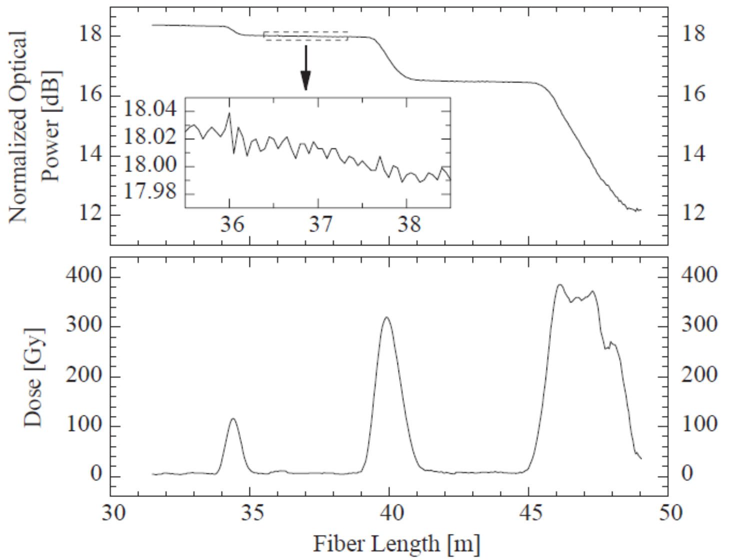


Figure 1: Principle of radiation dose measurement with optical fibres: OTDR-solution (= "distributed" sensor with local resolution). The radiation produces absorbing "colour centers". Propagation time and intensity of the back-scattered laser pulses allow determination of radiation intensity (= dose) and location of the radiation exposure.

H.Henschel, M. Körfer, F. Wulf, DIPAC 2001



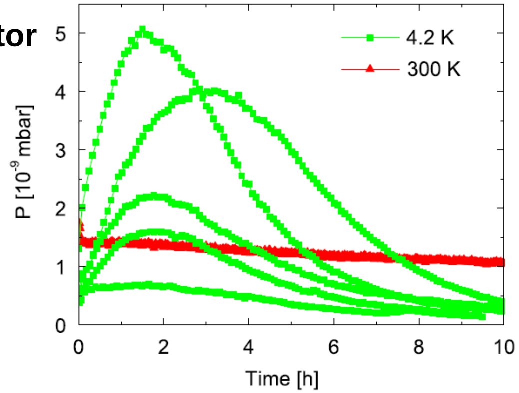
H.Henschel et al., NIMA 526 (2004) 537-550

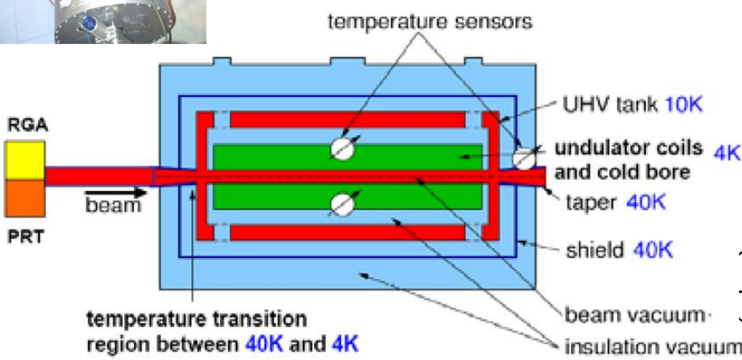
Vacuum diagnostics in cold regions

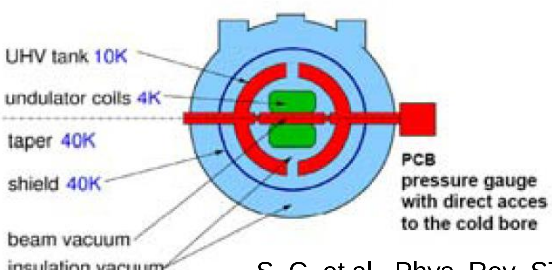
- Superconducting wigglers and undulators

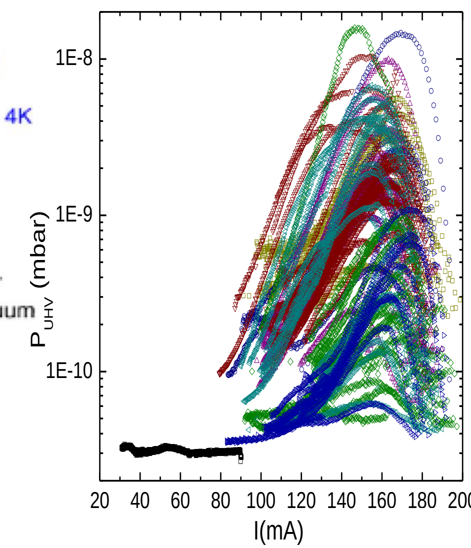
SCU14 demonstrator at ANKA

Pressure rise can be explained by including in eq. of gas dynamic balance electron multipacting.









S. C. et al., Phys. Rev. ST Accel. Beams 10, 093202 (2007)
S. C. et al., Phys. Rev. ST Accel. Beams 13, 073201 (2010)

- Argonne APS superconducting undulator and BINP superconducting wigglers beam pipe with elliptical cross section: no direct access to pressure in cold regions

Possible to use beam loss monitors or perform beam vacuum studies with ad hoc device before installation of superconducting wiggler or undulator

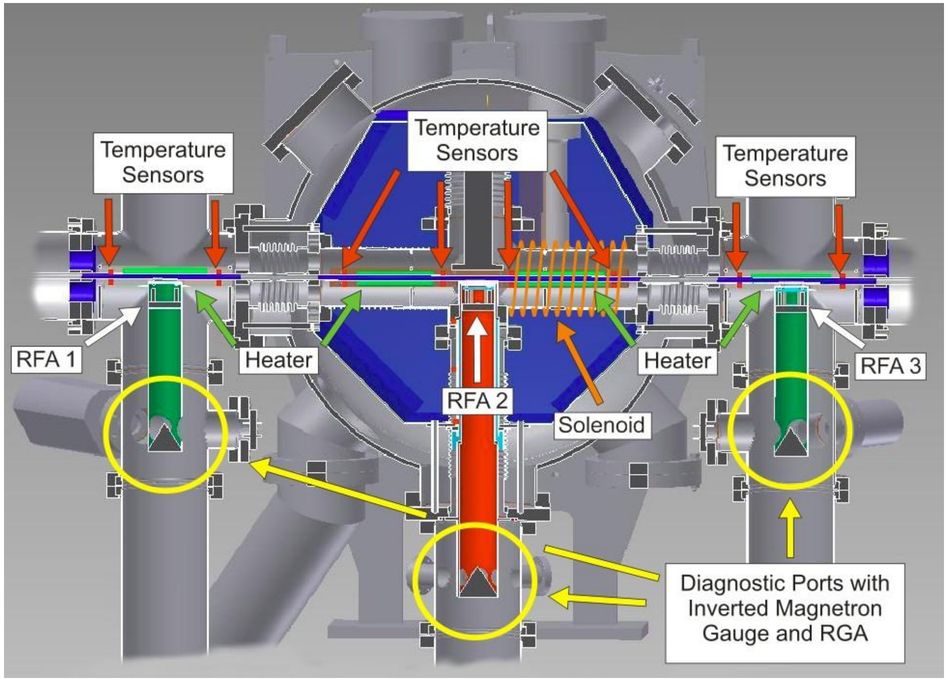
COLDDIAG

Cold vacuum chamber for diagnostics to **measure the beam heat load** to a cold bore in different synchrotron light sources

The beam heat load is needed to specify the cooling power for the cryodesign of superconducting insertion devices

The **diagnostics** includes measurements of the:

- **heat load**
- **pressure**
- **gas composition**
- **electron flux of the electrons bombarding the wall**



Collaboration
ANKA: S.C., S. Gerstl, A. Grau, N. Glamann, T. Holubek, D. Saez de Jauregui, R. Voutta
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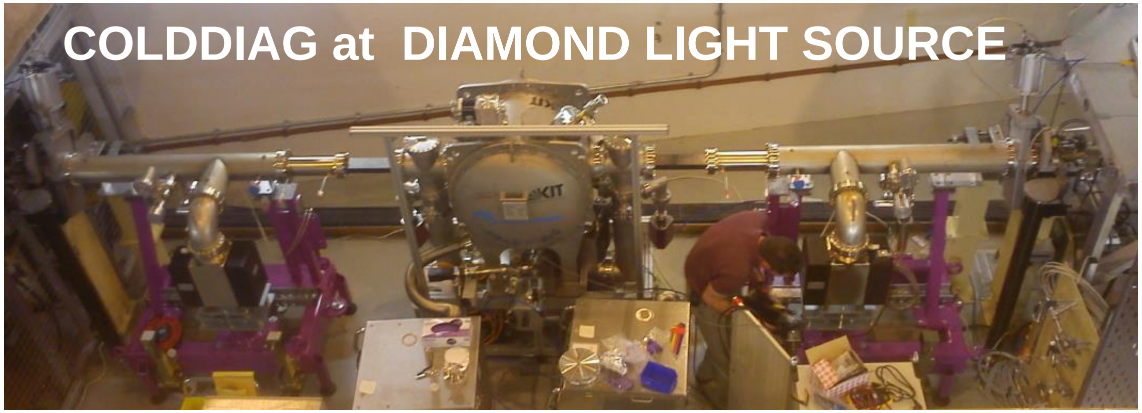
University of Rome ‚La sapienza': M. Migliorati
DLS: R. Bartolini, M. Cox, E. Longhi, G. Rehm, J. Schouten, R. Walker
MAXLAB : E. Wallèn
STFC/DL/ASTeC: J. Clarke
STFC/RAL: T. Bradshaw



S. Gerstl et al. IPAC 2011
S. C. et al., IEEE Trans. on Appl. Supercond. 2300-2303 Vol. 21-3 (2011)

Summary

- Vacuum cross section drastically reduced in low emittance rings

- Vacuum specs do not require development on pressure gauges or RGAs
  - Measurements limited by conductance to beam pipe
  - Ion pumps and ionization gauges readings differ since gauges far from pumps

- In order to be more sensitive to vacuum performance in “critical” regions as magnet chambers where there is no space for “direct” vacuum diagnostics, the tendency (see MAXIV) is to install more beam loss monitors and minimize the “direct” vacuum diagnostics. The disadvantage is that beam loss monitors signal are sensitive to all losses, so difficult to distinguish the reason of the loss (i.e. vacuum problem or losses from Touschek effect)

- Cold regions: possible to use beam loss monitors or perform beam vacuum studies with ad hoc device before installation of superconducting wiggler or undulator