VACUUM PERFORMANCE IN THE MOST RECENT THIRD GENERATION SYNCHROTRON LIGHT SOURCES

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Talk outline

- Introduction.
- New synchrotron facilities and vacuum challenges.
- The design of the vacuum system of the newly commissioned synchrotron light sources.
- The vacuum performance and the commissioning of the new synchrotron radiation sources.
- The vacuum system for the future machines.
- Conclusion.

Introduction

- Nine **Medium energy** Synchrotron light sources were constructed and operated during the last 10 years:

* Siberia II	* SLS	* ANKA
* CLS	* SPEAR III	* Australian Synchrotron
* INDUS II	* Soleil	* Diamond

- The **main objectives** for the design of these machines:
  - The highest brightness by reducing the emittance and/or increasing the beam current.
  - Increase the **stability** of the beam.
  - Largest **space** for Insertion devices.
  - Increase the beam **lifetime** and/or use **top-up injection**.

Among others, the vacuum system performance has an impact on these objectives

Introduction

The main objectives for the vacuum design and operation for the machines:

- The lowest possible thermal and PSD outgassing into the system:
  - optimize the manufacturing process,
  - surface treatment, assembly and vacuum conditioning,
  - the use of non evaporable getter (NEG) coating.
- The highest effective pumping speed for the system:
  - high conductance,
  - distributed pumping.
- Smooth surface facing the beam to have low impact on the impedance:
  - careful design and manufacturing of the flanges, tapers…etc.
- To guarantee the maximum operational time for the users:
  - fast recovery after interventions and accidents,
  - flexibility,
  - reliability and stability.
- Ability to safely absorb the unused part of the radiation.
- Don't occupy too much space …and don't spend a lot of money!

New synchrotron facilities and vacuum challenges

Main vacuum related machine parameters for some 3rd generation medium energy light sources

Parameter	Unit	Diamond	Soleil	ASP	SSRF	ALBA	NSLS-II	TPS
Beam Energy, E	GeV	3	2.75	3	3.5	3	3	3-3.3
Design current, I	mA	300	500	200	300	400	500	400
Storage ring Circumference, C	m	561.6	354.097	216	432	268.8	792	518.4
Horizontal emittance ε	nm.rad	2.7	3.7	7-16	3.9	4.5	2.0, (0.6 with damping wigglers)	1.7
Straight sections (number of straights x length in meters)		6x8m, 18x5m	4x12m, 12x7m, 8x3.8m	14x4.5m	4x12m, 16x6.5m	4x8m, 12x4.2m, 8x2.6m	15x9.3m, 15x6.6m	6x12m, 18x7m
Total power from bending magnets (BM) at the design current, P_T	kW	301	472	187	345	407	144	341
Total PSD outgassing from (BM) at the designed current at the accumulated beam dose of 100 A.h	mbar.l/sec	5.0E-05	3.1E-04	4.0E-05	1.3E-05	7.0E-05	3.0E-04	2.1E-05
Status		Operational				Construction	Design stage	

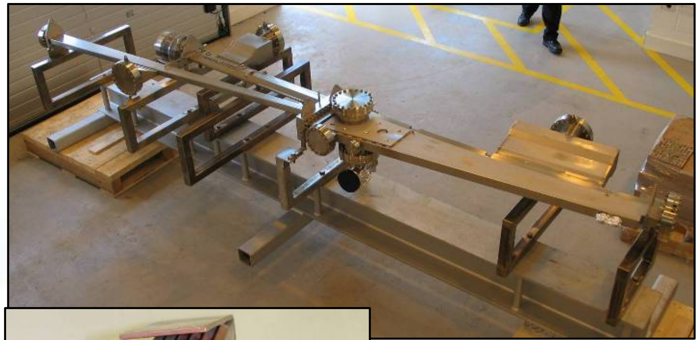
Observations:

- Energy in the range of **3 GeV**.
- **Small emittance**.
- High ratio of **straight sections length** to the machine circumference.
- The **power dissipated** from the bending magnets is up to 472 kW, and the amount of **outgassing** is up to $3x10^{-4}$ mbar.l/sec

The vacuum design of the newly commissioned machines

Diamond

- The storage ring is divided into **48 vacuum sectors**.
- Storage ring chambers are made of **316LN stainless steel**, octagonal profile of **80mm x 38mm (HxV)**, antechamber only in the dipole chamber .
- **7 chambers** (1x5 m and 6x1 m) for the insertion devices (ID) are made of extruded **aluminium** with **NEG coating**.
- **Distributed and lumped absorbers** made of oxygen free high conductivity **(OFHC) copper**.
- Conflat (**CF**) flanges of **spigot type** in order to reduce the effect on the machine impedance.
- **117,000 l/s** nominal pumping speed from conventional pumps (ion pumps, titanium sublimation pumps (TSP) and NEG pumps.
- Wide use of **vacuum instrumentations**.
- **No in-situ bakeout**.



Diamond

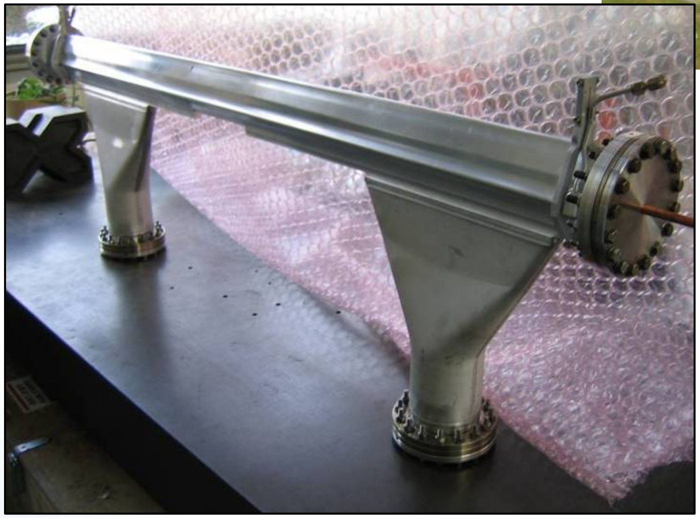
- **Proper and strict vacuum assembly and conditioning.**

- Vessels cleaned and baked to 250°C
- 6 m vacuum "string" assembly and pre-alignment on trolleys
- Pump down and leak test
- Lift into oven
- Bakeout to 200°C
- Lift under vacuum to Girder Assembly area
- Integrate with girders, magnets and services
- Transport up to 16 tonne girders to synchrotron building
- Crane into final position through the SR tunnel roof
- Vent to dry nitrogen, make vacuum interconnections to straights and pump down
- Bake straights *in situ* as needed
- Vacuum conditioning with stored beam

- **COURTESY OF M. COX, EPAC 2006, DIAMOND LIGHT SOURCE VACUUM SYSTEMS COMMISSIONING STATUS.**

Soleil

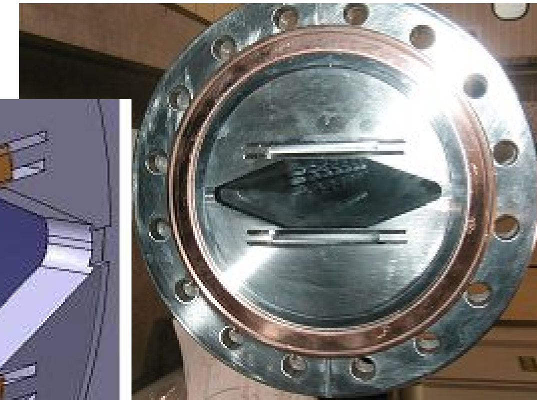
- The storage ring is divided into **48 vacuum sectors** with RF gate valves.
- Broad use of **NEG coating**: **56%** of the chambers are made of **extruded Al** and NEG coated (including 10m chamber of 14mm vertical aperture).
- The dipole is **machined from 316LN stainless steel** (high mechanical tolerances).
- The profile of the Al chambers have **70mm x 25mm (HxV)** aperture with distributed cooling, (antechamber for the dipole chamber only).
- In addition to the NEG coating for pumping down, **55,000 l/s** of nominal pumping speed from conventional pumps.

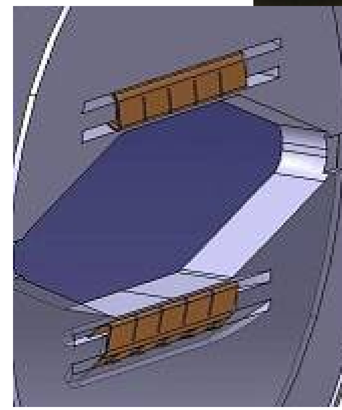


The vacuum design of the newly commissioned machines

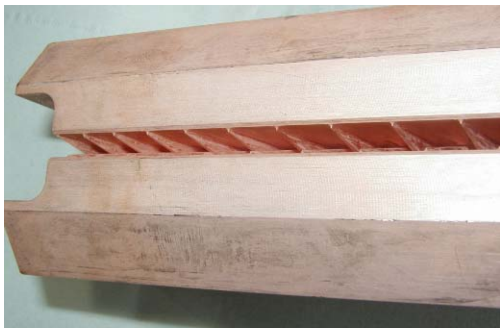
Soleil

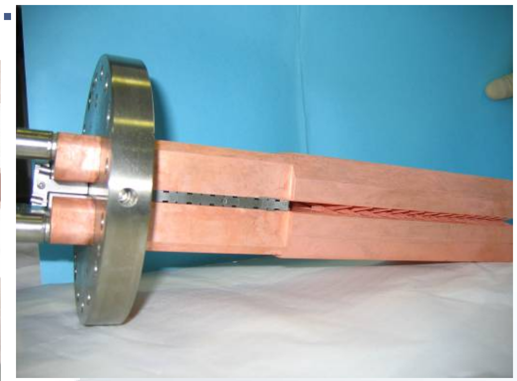
- **CF** flanges with **RF screen** connecting the chambers.



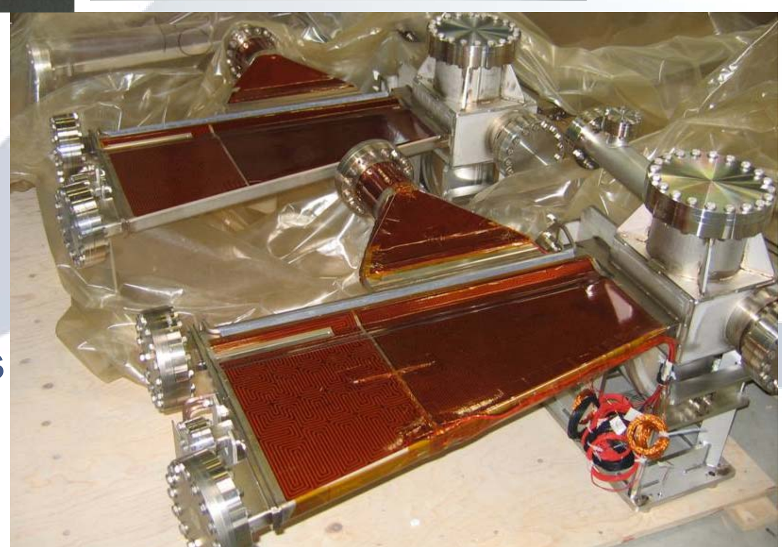


- **Glidcop** copper crotch absorbers (high power densities ~ 256 W/mm²).





- **In-situ bakeout** to activate the NEG at 180°C, kapton foils (thickness <0.4mm) with printed circuits used for the bakeout.



- COURTESY OF: C. HERBEAUX, “Vacuum system design for Soleil synchrotron radiation light source”, ALBA vacuum workshop, 2005.

Australian Synchrotron

- The storage ring is divided into **14 vacuum sectors**.
- Storage ring chambers are made of 3mm thickness **316LN stainless steel**, key hole profile of **70mm x 32mm (HxV)** with **antechamber** for all the chambers.

- **Flat seal** flanges (VATseal®) used to connect the chambers to each other, small gap facing the beam to reduce the effect on the impedance.
- **Lumped absorbers** made of oxygen free high conductivity **(OFHC) copper**.

- **31,000 l/s** nominal pumping speed from conventional pumps (ion pumps and NEG pumps).
- **No in-situ bakeout**.
- The **industry was responsible** for the detailed design, production, installation and achieving the specifications without beam.

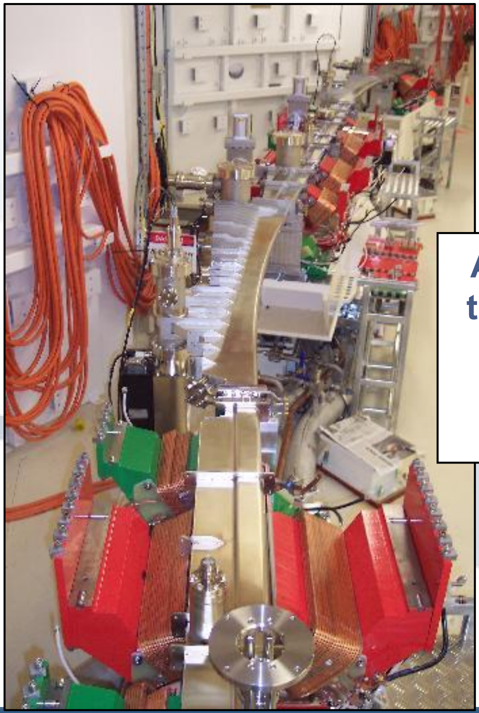
- COURTESY OF B. MOUNTFORD.

Australian Synchrotron

Installation procedure

Assembly of a complete sector (incl. the gate valves), pump and leak test.

Bake out inside an oven



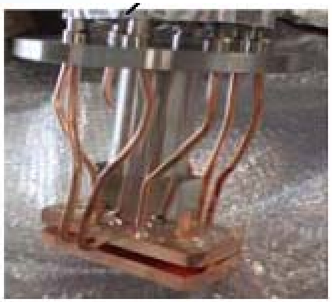
Assembly of the complete sector over the open magnets.

Move it (under vacuum) to the tunnel

SSRF

- The storage ring is divided into **20 vacuum sectors**.

- Storage ring chambers are made of 3mm thickness **316LN stainless steel**, key hole profile of **68mmX35mm (HXV)** with **antechamber** for all the chambers.
- **Flat-seal flanges and CF flanges** were used to connect the chambers to each other.
- **Lumped absorbers** made of oxygen free high conductivity **(OFHC) copper**, also the dipole chamber is equipped with distributed copper absorber.



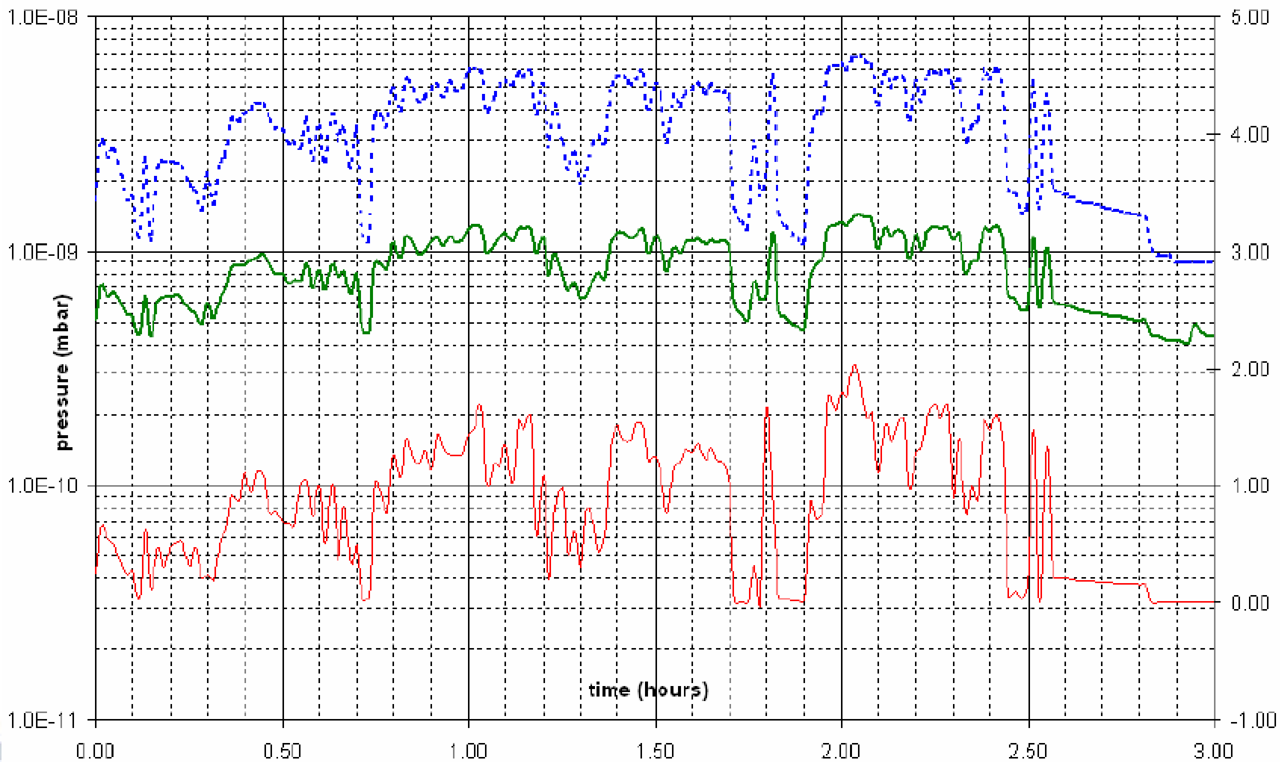
- **300,000 l/s** nominal pumping speed from conventional pumps (ion pumps, TSPs and NEG pumps).
- **Partial in-situ bakeout** (the pumps and the straights are baked in-situ but not the arc vacuum chambers).

▪COURTESY OF D. Jiang, "VACUUM SYSTEM FOR SSRF STORAGE RING", these proceedings.

The vacuum performance and the commissioning of the new synchrotron radiation sources.

Diamond

- The installation of the storage ring was complete on Apr. 2006, operation started on **Sep. 2006**.
- **Static pressure** inside the ring (without beam) was **4.2×10^{-10} mbar**.
- After the first injection (700 MeV, up to 2 mA) the pressure increased into **high 10^{-9} mbar** range (near crotch absorbers) and low 10^{-9} mbar range in the chamber. PSD yield (η) is in the range of **10^{-3} molecules/photon**.



First results of vacuum conditioning

Beam current (mA)

Pressure in the electron beam channel (mbar)

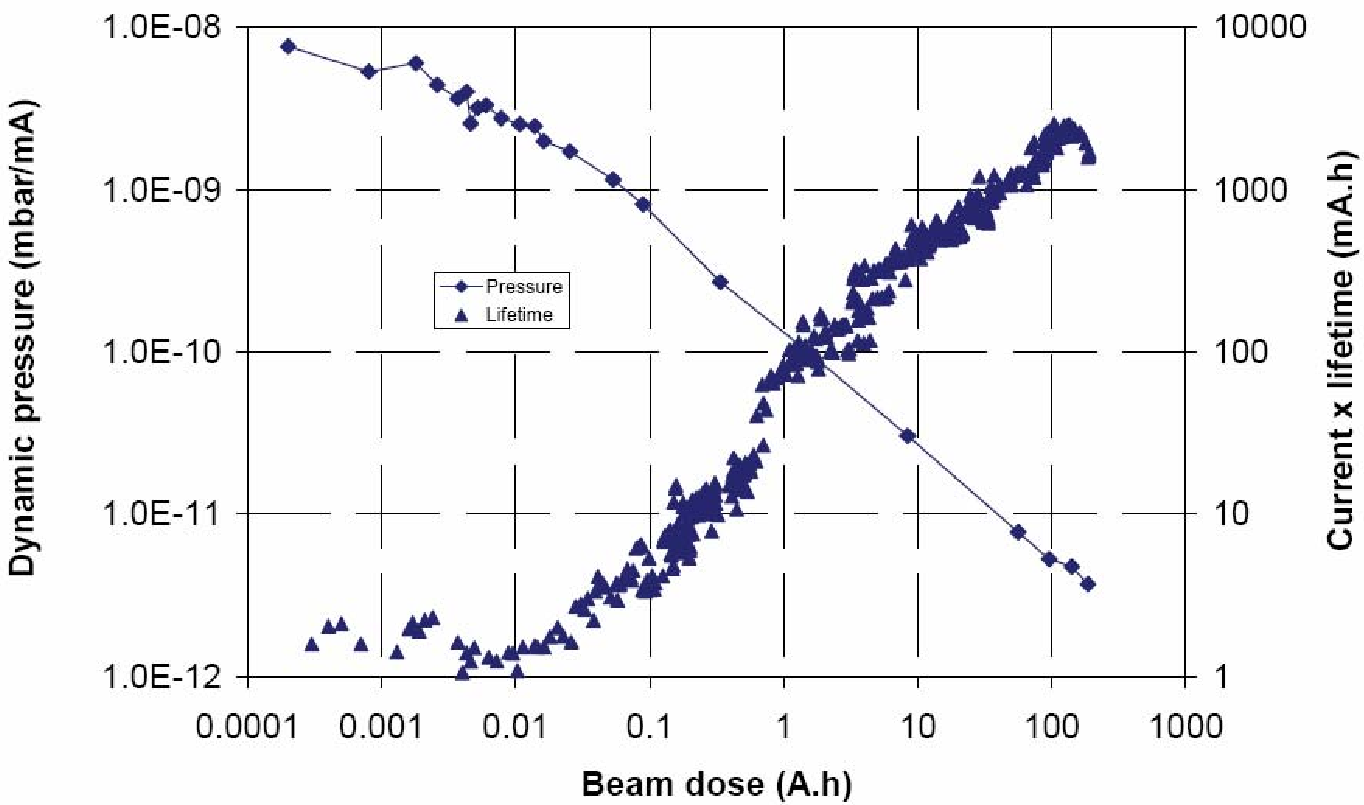
Pressure near the absorber ports (mbar).

- COURTESY OF M. COX, DIAMOND LIGHT SOURCE VACUUM SYSTEMS COMMISSIONING STATUS, EPAC 2006.

Diamond

- With further beam cleaning, the measured dynamic average pressure was **1.5x10^{-9} mbar** with 300 mA beam current and 600 A.h accumulated beam dose (data: Apr. 2008).

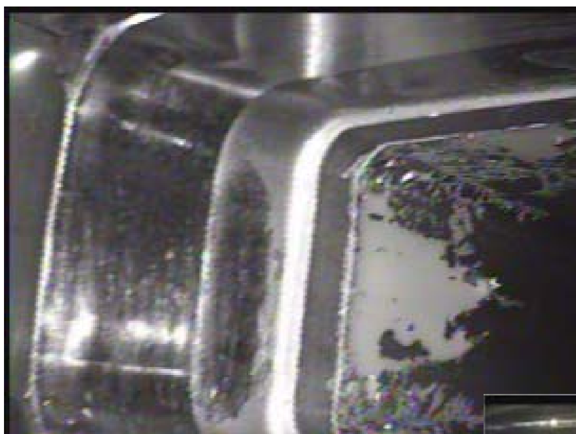
- The beam lifetime is around **20 hours** at 125mA.

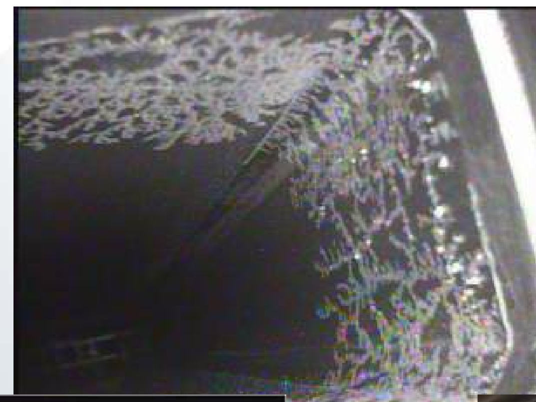


▪COURTESY OF M. COX, "Commissioning of the Diamond Light Source Storage Ring Vacuum System", IVC-17.

Diamond

- **Few failures**: mainly manufacturing issues, e.g.
  - coating adhesion of one kicker,
  - bellows failure of some beam lines shutters,
  - unreliable readings from Pirani gauges and low striking efficiency and visible contamination of cold cathode gauges.
- **Fast recovery after interventions** (e.g. installation of IDs in the straights).

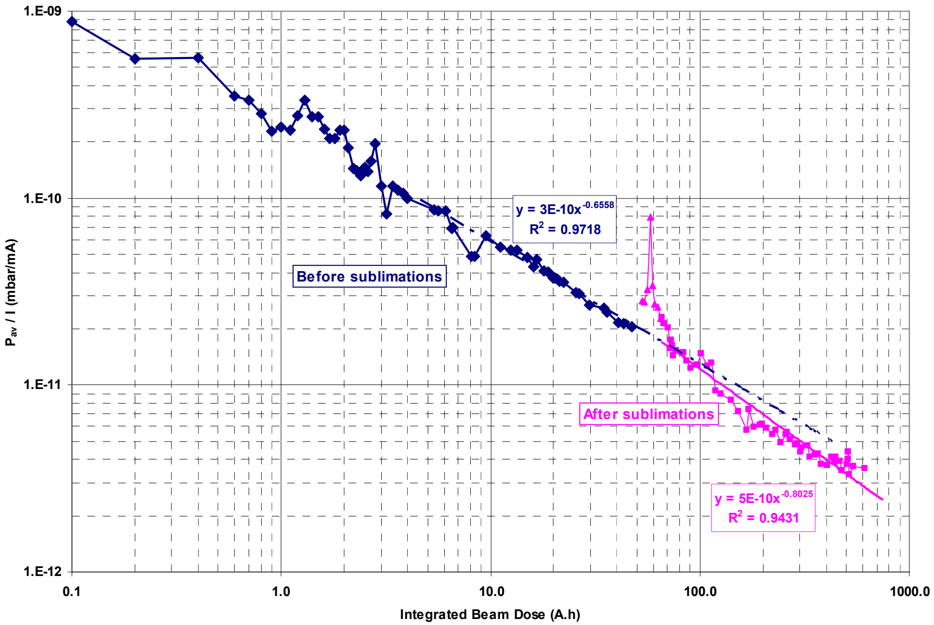


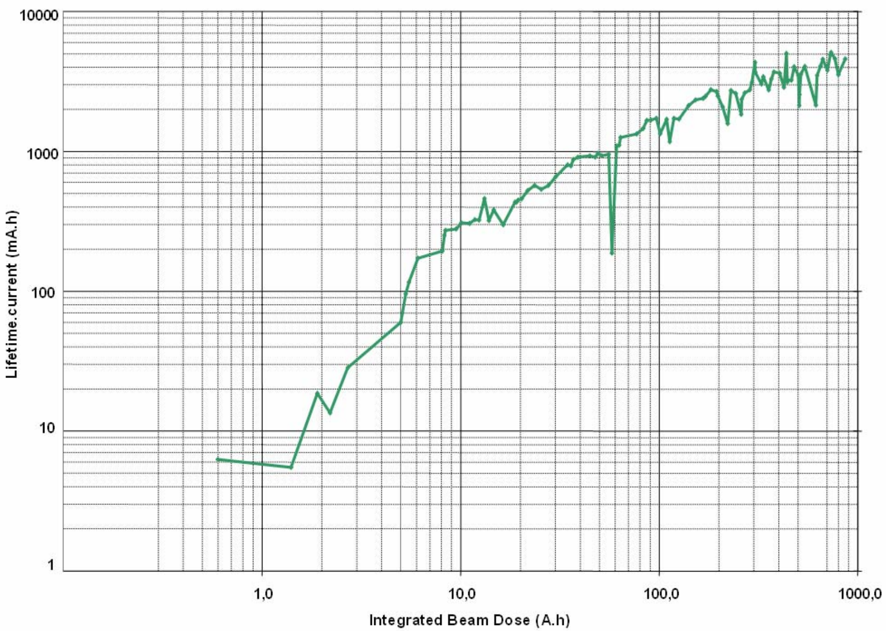


- COURTESY OF M. COX, “The Diamond Light Source Vacuum System: The First Year of Operation”, OLAV II.

Soleil

- The installation of the storage ring was completed and the operation of the machine started on May 2006.
- Static pressure inside the ring (without beam) was $4.0x10^{-10}$ mbar (following the in-situ bakeout and NEG activation).
- After the first injection (up to 0.8 mA) the pressure increased into $2x10^{-8}$ mbar.
- With further beam scraping, the measured dynamic average pressure was $1.9x10^{-9}$ mbar and the beam lifetime is 12 hours with 300 mA beam current and 620 A.h accumulated beam dose (data: Mar. 2008).

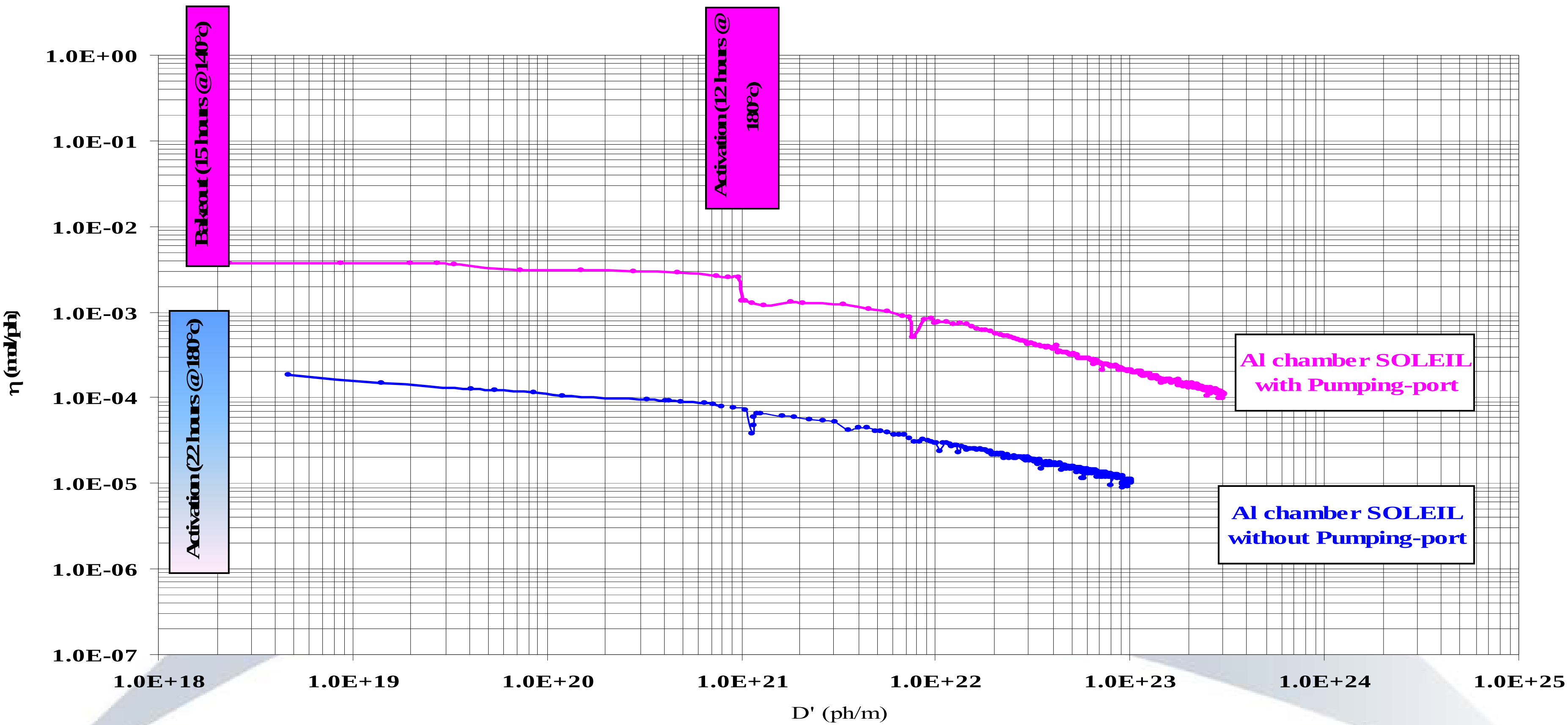




- COURTESY OF C. Herbeaux et al., “VACUUM CONDITIONING OF THE SOLEIL STORAGE RING WITH EXTENSIVE USE OF NEG COATING”, these proceedings.

Soleil

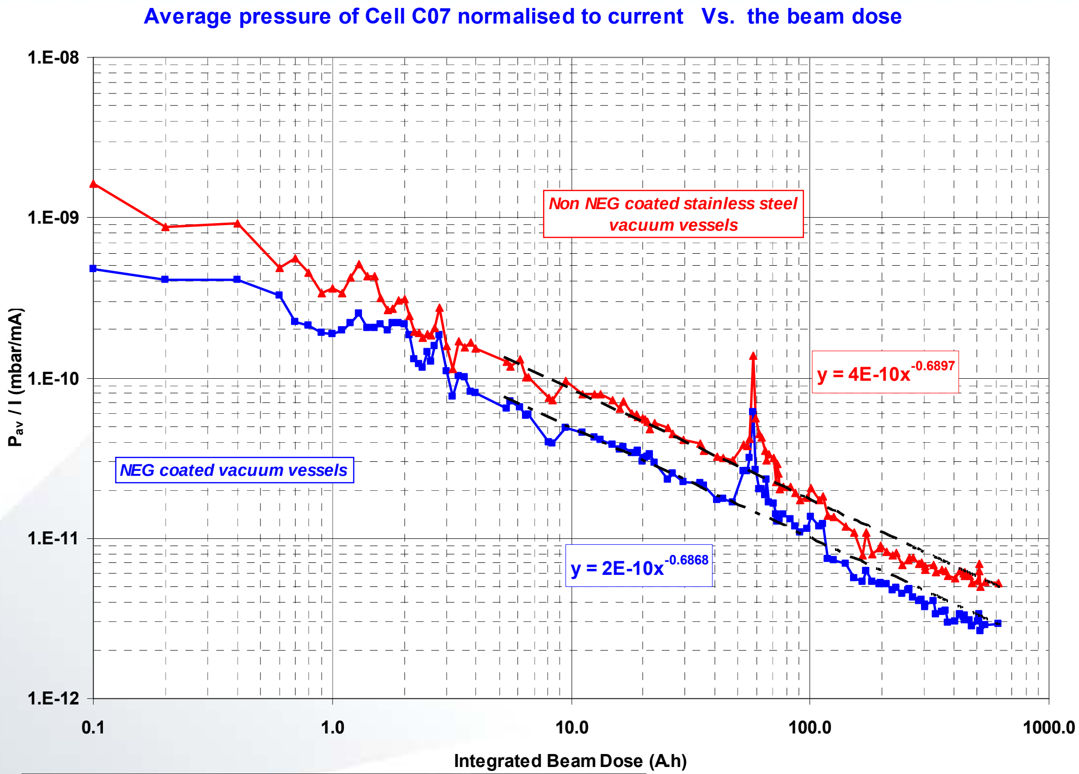
- More investigation being done to measure the performance of the NEG coating.
  - Higher PSD yield (almost 20 times) for the NEG coated chambers with pumping ports (not coated) w.r.t. NEG coated chambers without any ports.



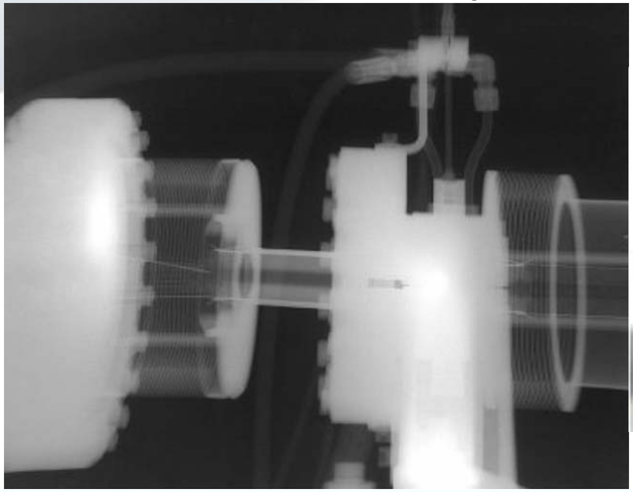
- COURTESY OF R. Kersevan and G. Debut, ESRF, test performed on D31 beamline, C. Herbeaux, "Soleil vacuum system coating and conditioning", OLAV II workshop,

Soleil

- **Higher average dynamic pressure** for the stainless steel non-NEG coated chambers w.r.t. the NEG coated chambers. Expected due to higher PSD yield.

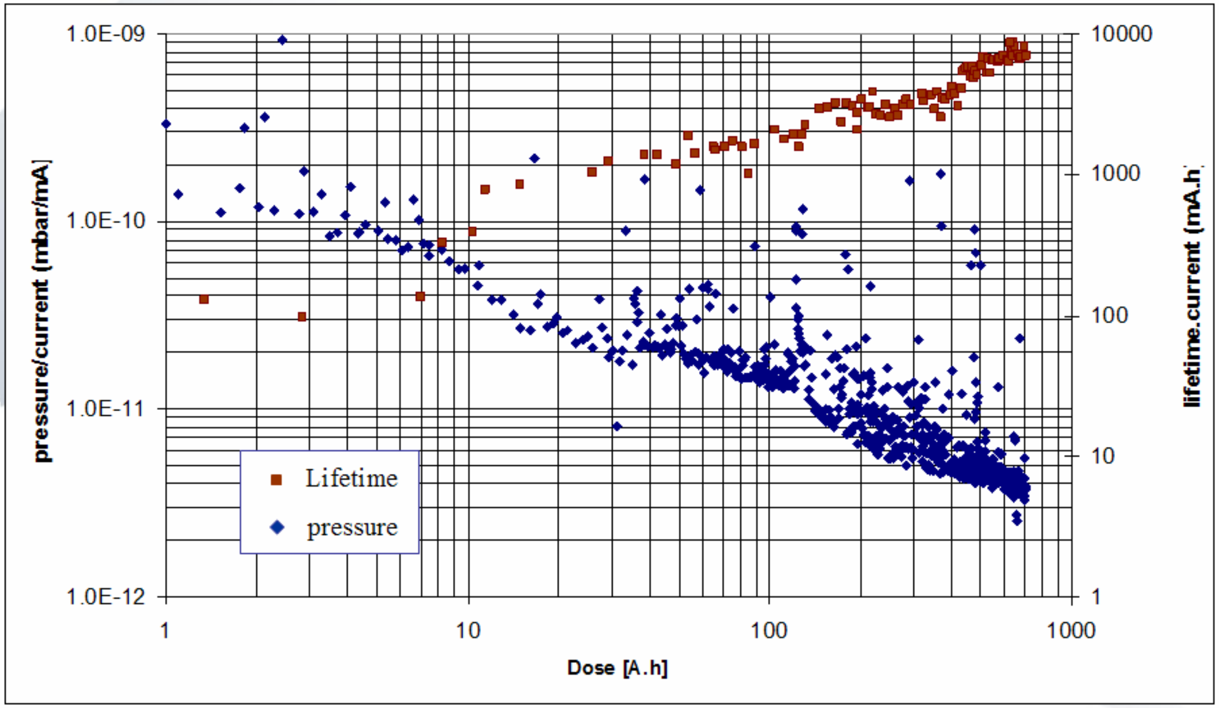


- **Few failures** were faced during the commissioning, they are summarized by some failures to RGAs and ion pumps controllers. Obstacle fell down due to bad mounting of the RF shield of bellows.



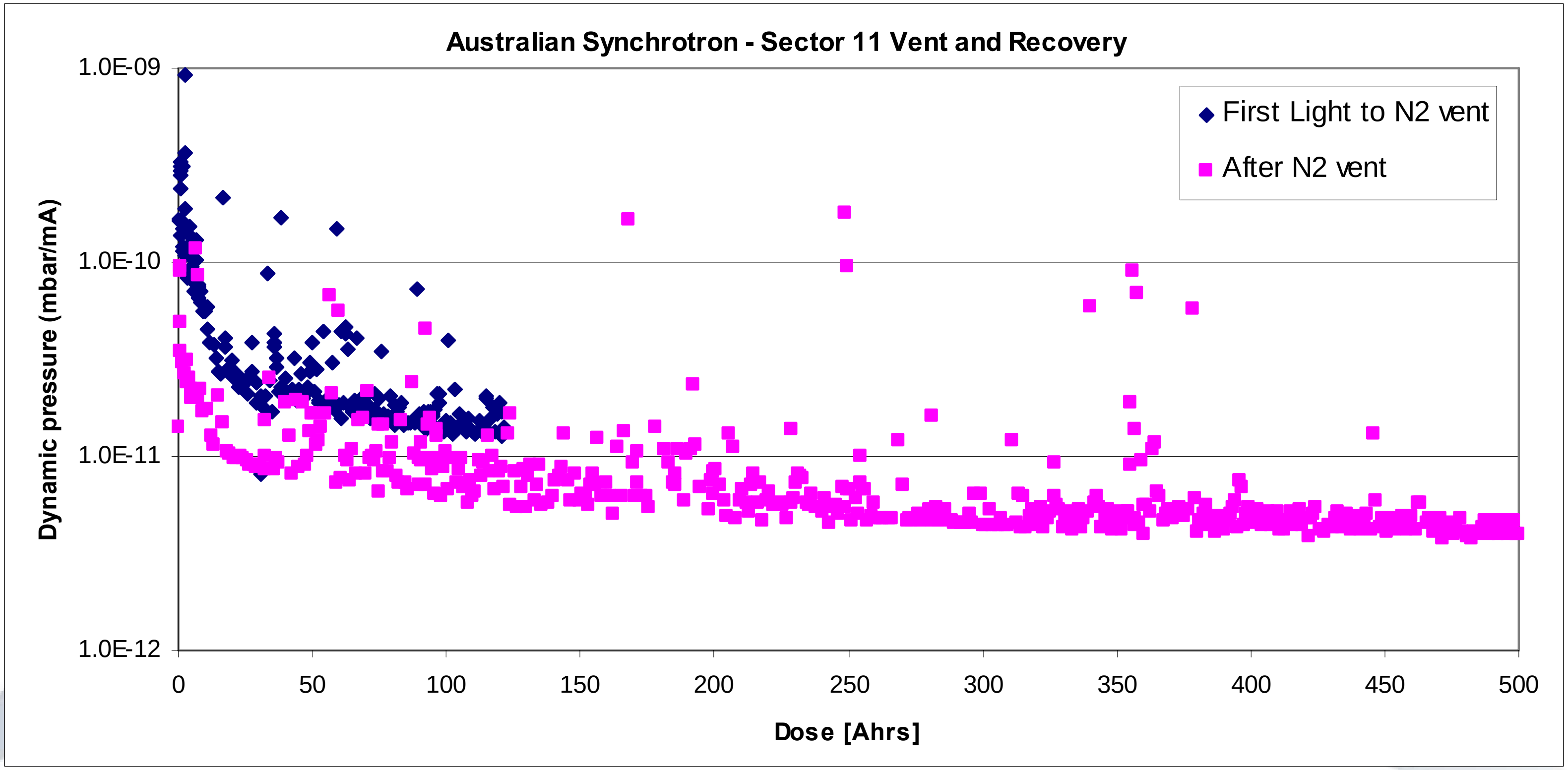
Australian Synchrotron

- The installation of the storage ring was complete on May 2006 and the first beam was delivered to the users on **Apr. 2007**.
- The measured **static pressure** inside the ring (without beam) was **4.0×10^{-10}** mbar.
- **After the first injection** (2 A.h of accumulated dose, up to 1 mA) the pressure increased into **low 10^{-9} mbar range**.
- With beam cleaning process, the average dynamic pressure reduced into **6.4×10^{-10} mbar** (at 172mA and 700A.h of accumulated dose), the measured beam lifetime at these conditions was **41 hours**. (data: May 2008).



Australian Synchrotron

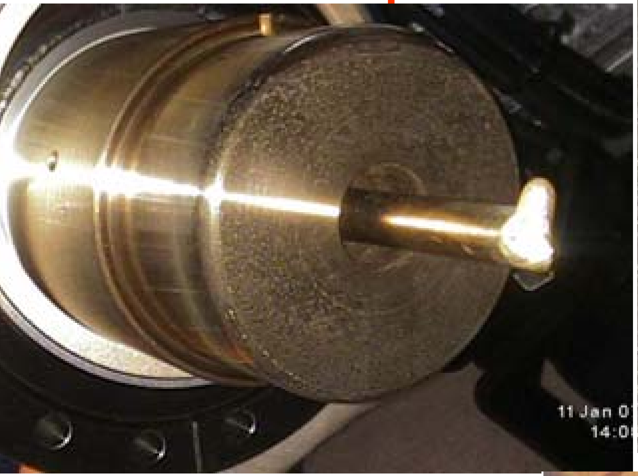
- **Fast recovery** for the dynamic pressure after interventions (10 A.h) to come back to the same pressure.

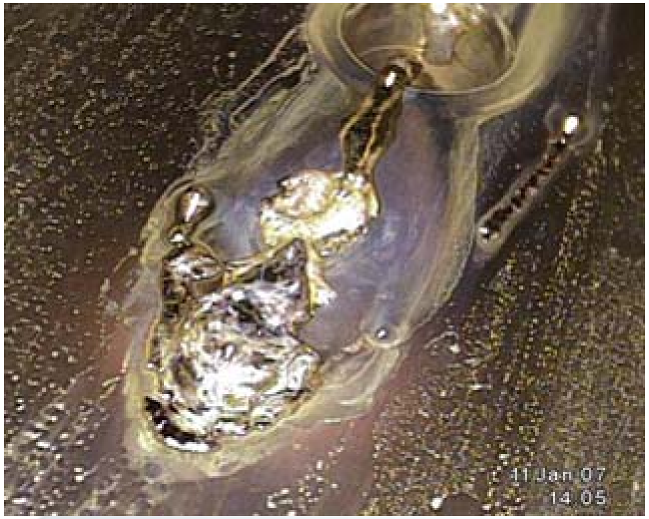


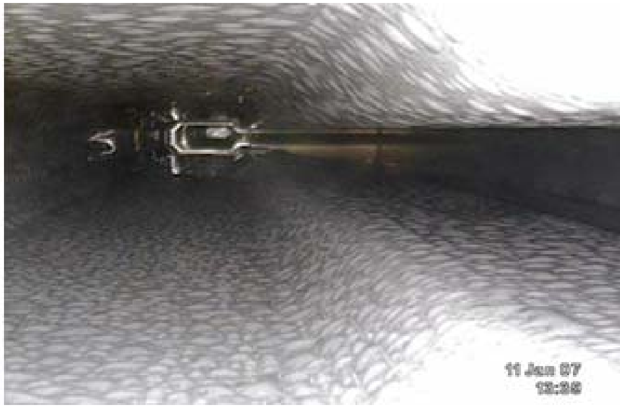
- COURTESY OF B. MOUNTFORD.

Australian Synchrotron

- **Some failures:**
  - **RF HOM Damper failure**





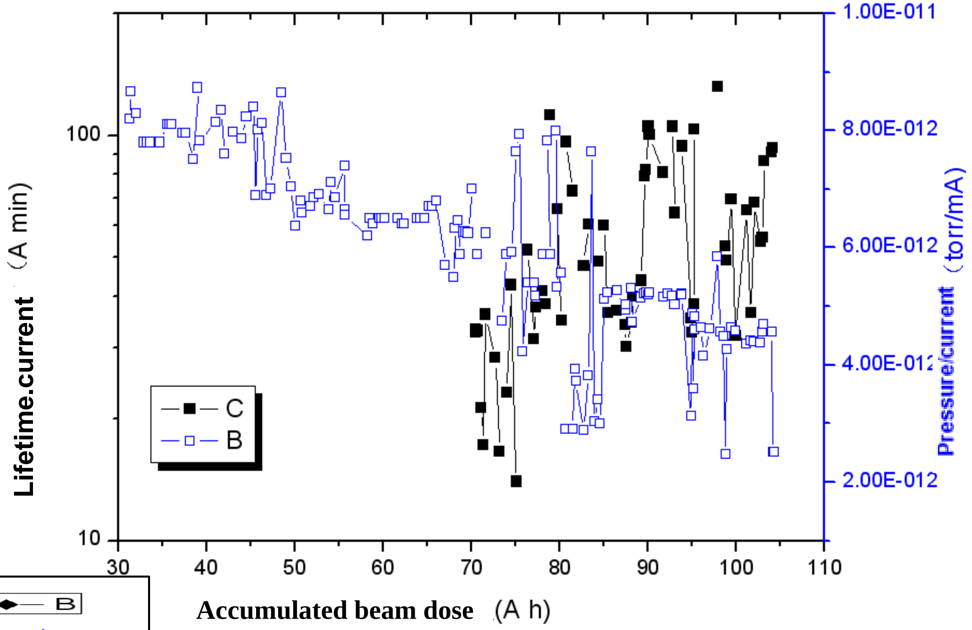


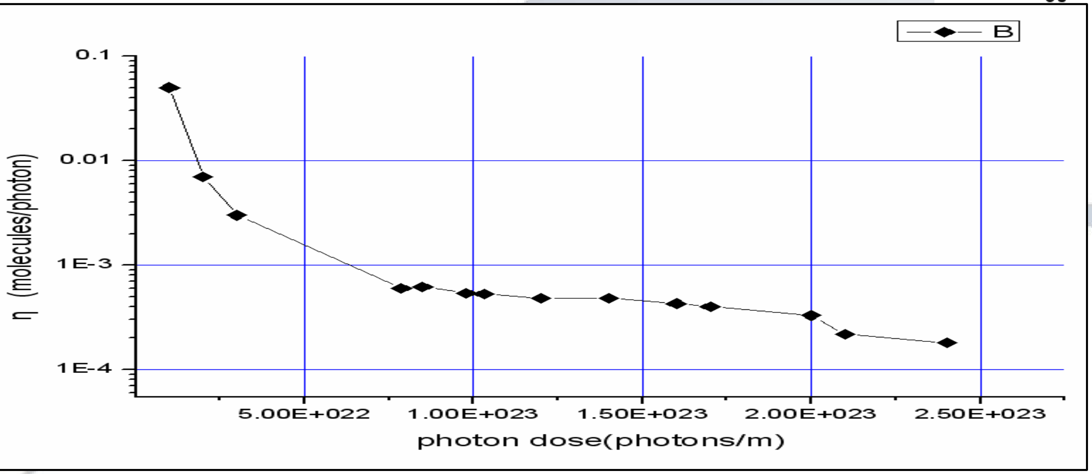
- **IVU Wakefield Shield Damage**

- COURTESY OF B. MOUNTFORD.

SSRF

- SSRF is operating since **Sep. 2006**.
- **Static pressure** inside the ring (without beam) was **2×10^{-10} mbar**.
- The **dynamic pressure** was **5×10^{-10} mbar** and **beam lifetime = 16 hours** (with 110 A.h accumulated beam dose, 2.5 GeV and 100 mA).





- η is **2×10^{-4} mol/ph** for beam does of 110A.h

COURTESY OF D. Jiang, "VACUUM SYSTEM FOR SSRF STORAGE RING", these proceedings.

The vacuum system for the future machines

The vacuum system for the future machines

ALBA

- The vacuum system is in **the manufacturing stage.**
- The storage ring is divided into **16 vacuum sectors.**

- Storage ring chambers are made of **316LN stainless steel**, key hole profile of **72mm x 28mm (HxV)**, **antechamber** everywhere where the crotch absorbers are placed.
- 3 ID chambers, 2.6 m long each, will be made of **extruded aluminium with NEG coating**.

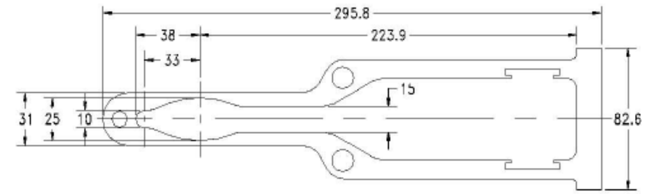
- **OFHC copper and Glidcop lumped absorbers** will be used to remove the unused part of the radiation fan.
- For connecting the chamber together, **flat seal flanges** were chosen, they will reduce the contribution to the machine impedance and correcting possible manufacturing errors.
- Ion pumps and NEG pumps will be used to pump down into UHV, nominal pumping speed from ion pumps is **57,000 l/s**.

- **Ex-situ bakeout**, similar conditioning procedure as for ASP.

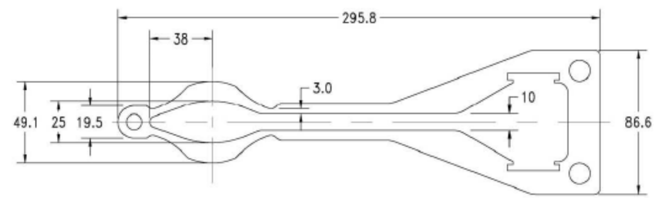
The vacuum system for the future machines

NSLS II

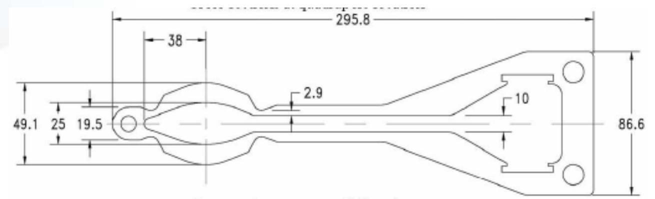
- The vacuum system is in the detailed **design stage.**
- **Very small emittance.**
- The **792 m** storage ring is divided into **30 cells.**
- The storage ring chambers are made of **extruded Al**, cross section of **76mm x 25mm** (HxV), the chambers will be connected to each other with **bimetallic flanges.**
- Two **NEG strips** placed in the antechamber will be used to pump down the system together with **ion pumps and TSPs** near the absorbers.
- **In-situ bakeout** will be performed to condition the vacuum chambers using foil type electrical heaters.



Dipole chamber extruded cross sections



Cross sections at quadrupole location



Cross sections at sextupole location

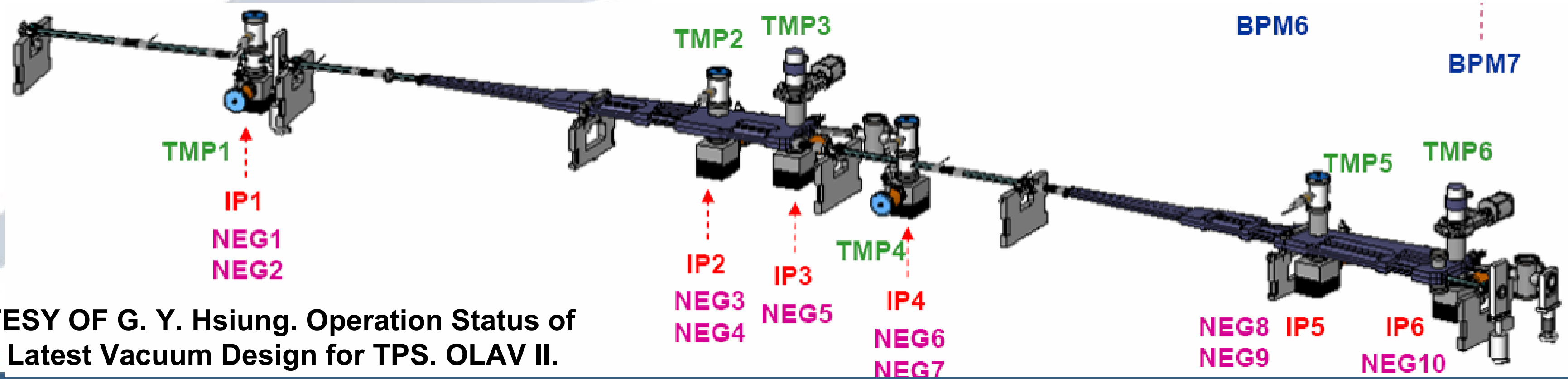
- COURTESY OF H. C. Hseuh.

The vacuum system for the future machines

Taiwan Photon Source (TPS)

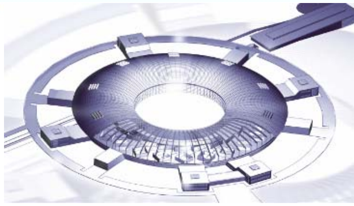
- The design and the prototyping is over and the main components are under manufacturing.
- The 518 m storage ring is divided into 24 cells.
- Chambers with antechamber where lumped absorbers are placed.
- Due to the good experience with TLS vacuum chambers, Al was chosen for the construction of TPS storage ring chamber. The chambers will be manufactured by machining of Al block.
- Studies are going on to optimize all the stages of the manufacturing of the chambers; the machining process, joining techniques and cleaning process.
- For the commissioning, TPS considering the use of turbomolecular pumps for removing the high outgassing for beam cleaning process, Ion pumps together with NEG pumps will be used to after the commissioning.
- Ex-situ bakeout and the installation of the cells will be under vacuum into the machine.

Oil-free CNC machining

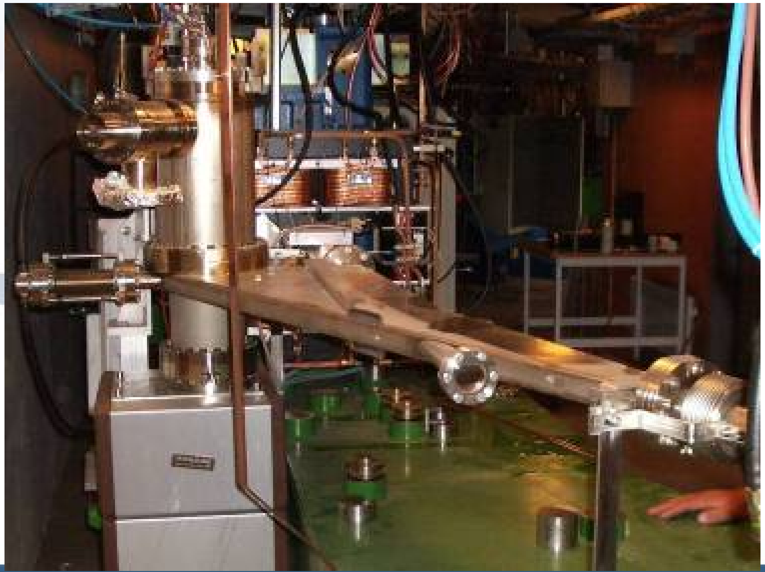


- COURTESY OF G. Y. Hsiung. Operation Status of TLS and Latest Vacuum Design for TPS. OLAV II.

MAX IV



- MAX IV is proposed to be built at MAX-lab, Lund, Sweden.
- **Very small emittance** ~ 0.24 nm.rad (with IDs in operation).
- **520 m** circumference of the storage ring.
- **Very small cross section** of the chamber (very small aperture magnets ~ **15 mm**), this mean very small conductance.
- To get rid of the problems of having small aperture chambers, MAX-lab is planning to use **NEG coating all over the ring**. Experience already exists for the straights but **not yet for the dipole chambers**, one of the design tasks for MAX IV is to investigate this issue.
- Due to the high power from synchrotron radiation in the dipole, **copper NEG coated chambers are planned for MAX IV**, tests are going on at MAX II to guarantee the performance.



- COURTESY OF E. Wallén, Test of a NEG Coated Copper Dipole Vacuum Chamber, these proceedings.

Conclusions

Conclusions

- The designs of the newly commissioned machines are characterized by:
  - The general use of Stainless steel as construction material, with Al for simple geometries (e.g. ID chambers).
  - The use of conventional pumps (SIP, TSP and lumped NEG pumps).
  - More attention is given to the preparation and the conditioning of the system (cleaning, assembly, bakeout…etc).
- The vacuum commissioning and performance of the new machines were presented:
  - Cleaning by photon beam was very efficient.
  - The dynamic pressure improves with the beam dose due to the reduction of the PSD yield and consequently the PSD outgassing.
  - The beam lifetime increased with the increase of the accumulated beam dose as a result of the reduction of the pressure due to the reduction of the beam-gas scattering effect.

Conclusions

- The **designs of the future machines** were presented, they are characterized by:
  - **Conventional design approaches are still dominant**.
  - **Stainless steel** is widely used, however it is clear **that copper and Al alloys are becoming more attractive** for the use for the chamber structure than before.
  - **The NEG coating technique is more used than before**, this can be explained by the confidence being built during the last decade for the performance of this material in several synchrotron light sources.

Acknowledgments

- M. Cox, Diamond.
- B. Mountford, Australian Synchrotron.
- C. Herbeaux, Soleil.
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- H. Hseuh, Brookhaven National Laboratory.
- G. Hsiung, NSRRC.
- J. Dikui, SSRF.
- D. Einfeld, CELLS.

Thanks for your attention