# Extreme high vacuum system of high brightness electron source for ERL

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CERN

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# Outline

- Compact ERL (cERL) and DC gun test facility

- DC-gun using GaAs photocathode
  - Low intrinsic emittance beam generation
  - Cathode lifetime problem

- 2nd 500kV DC gun R&D
  - Outline of design
  - Measurement of outgassing rate
    - > Titanium chamber
    - > Ceramic chamber
  - XHV pump & gauges
  - Preparation system

- Summary

# Teams for high brightness DC-gun development

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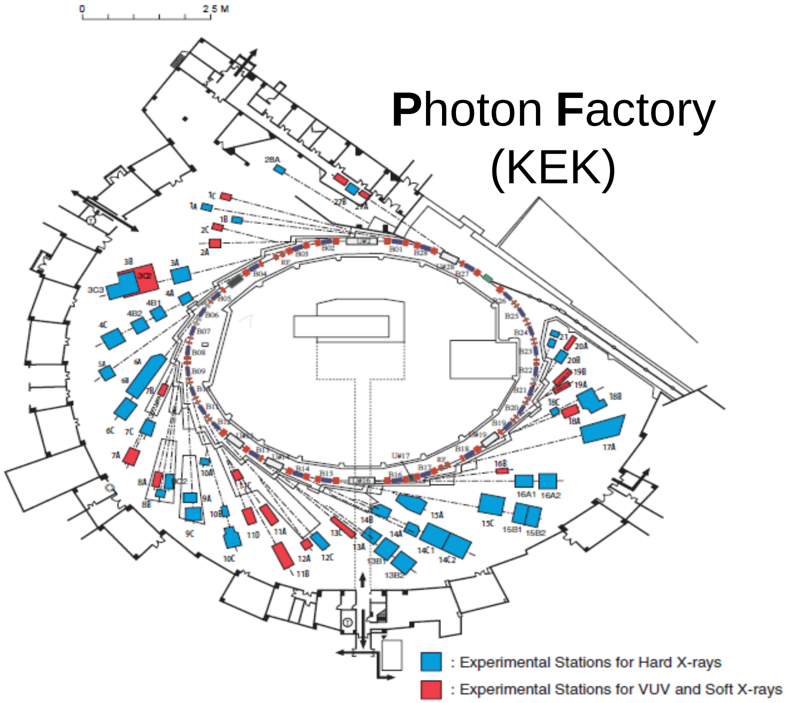
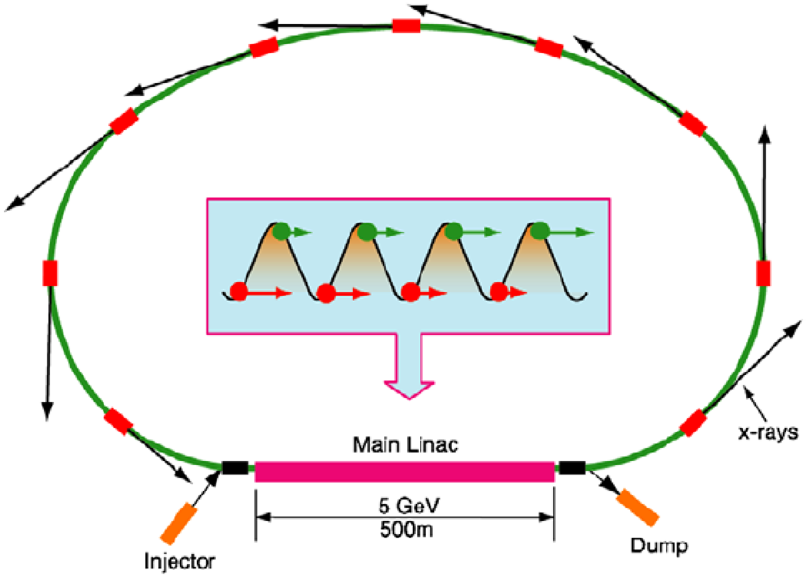
# Comparison PF & ERL



**P**hoton **F**actory
(KEK)



C=186.6 m, $\varepsilon$ = 36 nmrad
E=2.5GeV,I = 450 mA,
$\tau$ = ~ 60 hrs

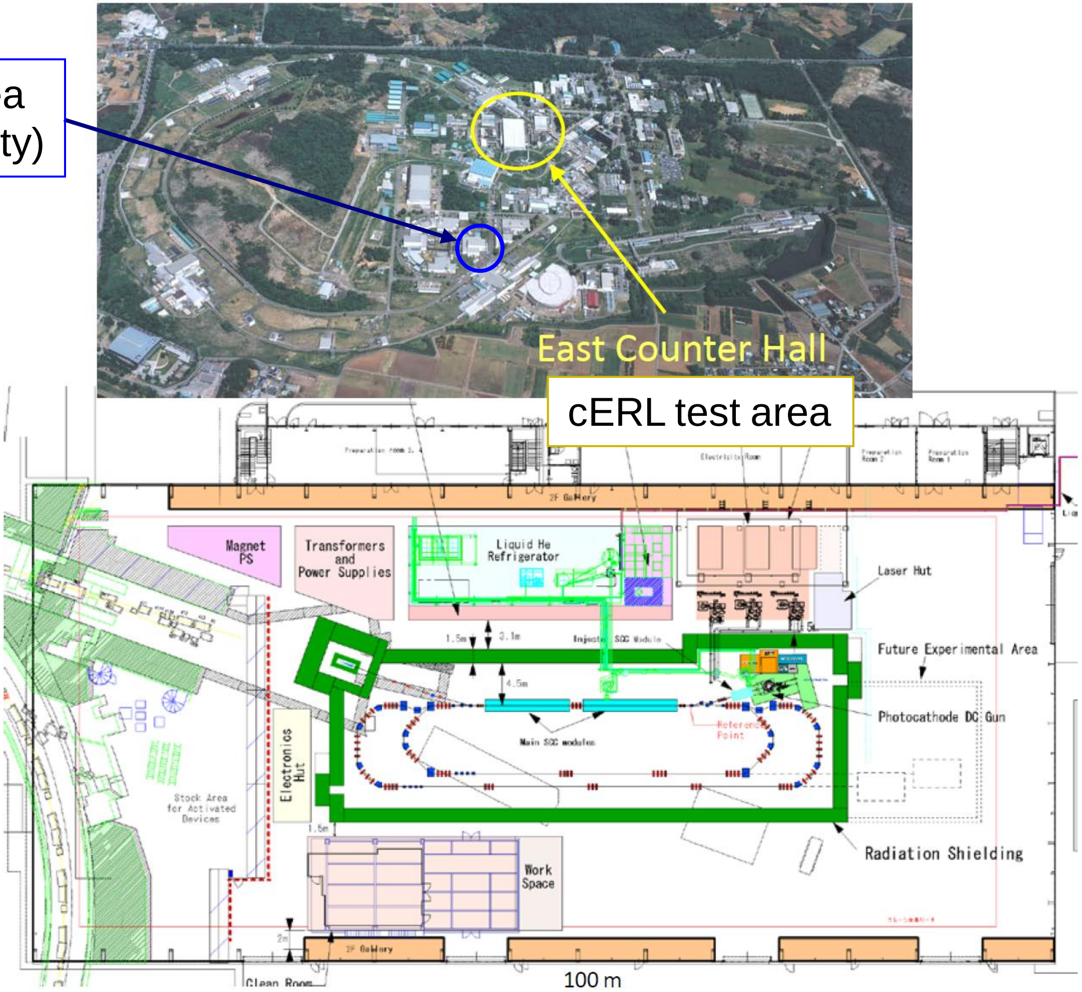
- Bunch length: Order of ~10ps
- Normalized emittance:
  $\gamma\beta\varepsilon$ ~ 180 mm.mrad

E=5GeV, I=100mA,
$\gamma\beta\varepsilon$ <1mm.mrad
Bunch length: 0.1~1 ps
Average brilliance ~ 10^23
( >$10^2$ times larger than PF )
Peak brilliance ~10^26 ( > $10^4$ times)
(Unit : photons/mm$^2$/mrad$^2$/0.1%/s)

# Compact ERL (test facility)

**Parameters of the Compact ERL**

| | Parameters |
|---|---|
| Beam energy | 35 - 245 MeV |
| Injection energy | 5 MeV |
| Average current | 10 - 100 mA |
| Acc. gradient (main linac) | 15 MV/m |
| Normalized emittance | 0.1 - 1 mm·mrad |
| Bunch length (rms) | 1 - 3 ps (usual)<br>~ 100 fs (with B.C.) |
| RF frequency | 1.3 GHz |



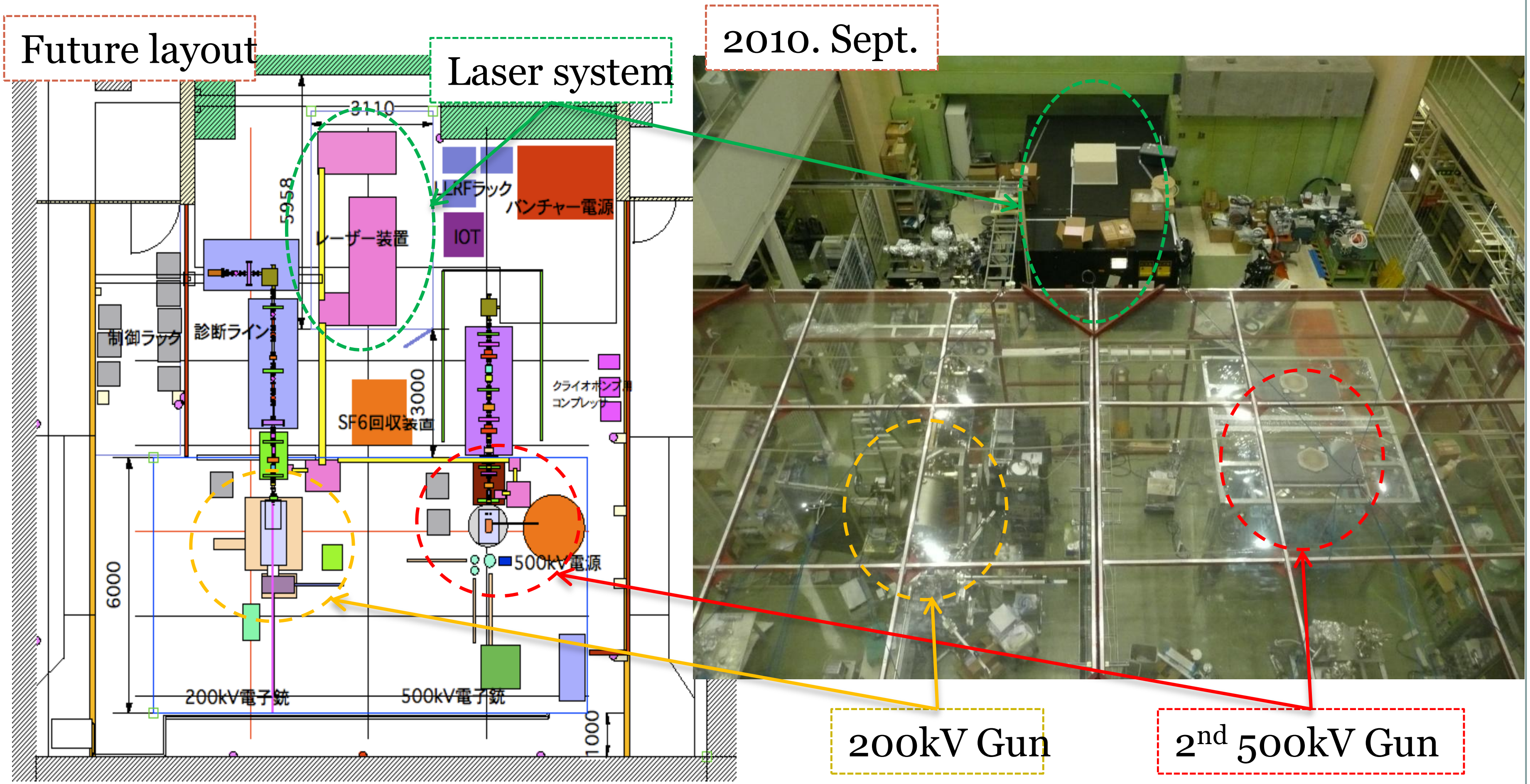
PF-AR south area (DC gun test facility)

cERL test area

Commissioning will be started at end of 2012 FY.

# Photocathode DC Gun Test Facility at KEK

PF-AR south experiment area



Future layout

Laser system

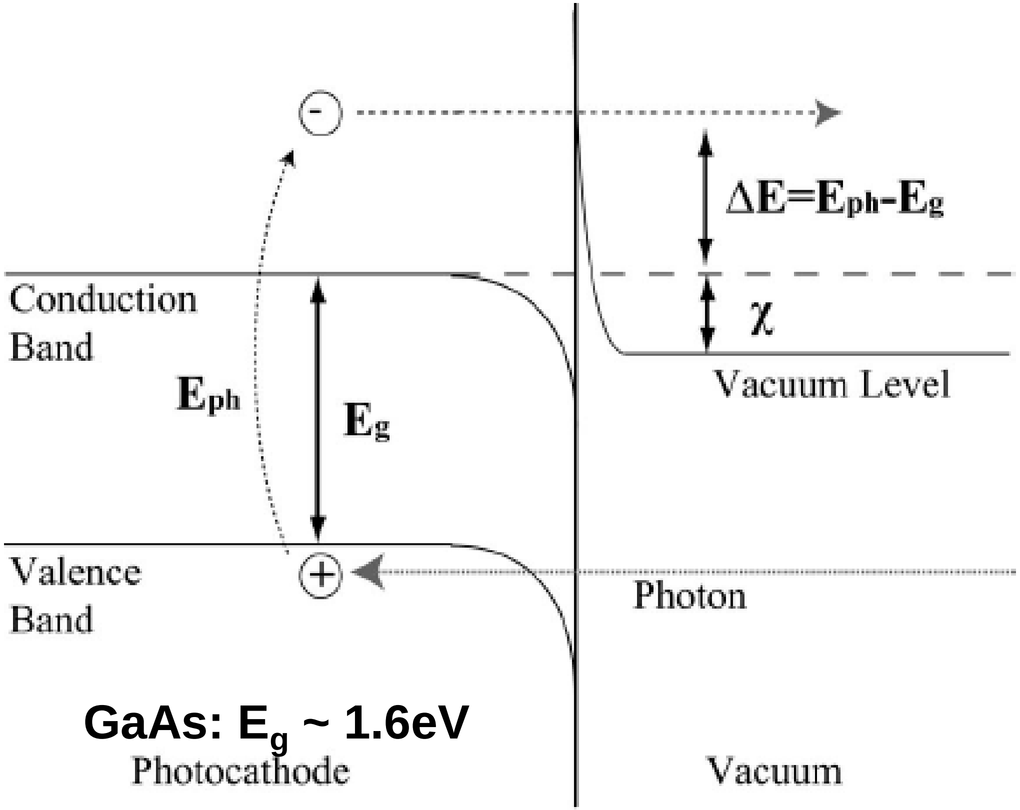
2010. Sept.

200kV Gun

2nd 500kV Gun

# DC-gun using GaAs photocathode

# Low emittance beam generation from GaAs cathode



**GaAs: $E_g$ ~ 1.6eV**

$$\epsilon_n = \sigma_0 \sqrt{\frac{kT_\perp}{mc^2}}$$

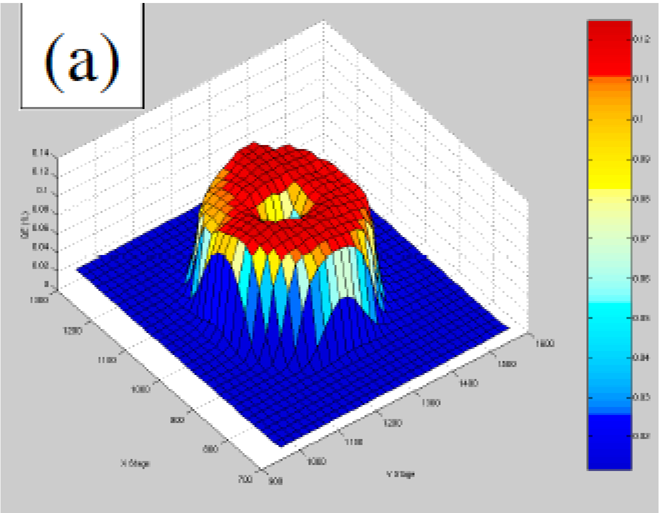
$\Delta E+\chi$ ~ 100 meV ~ kT,
Laser diameter ~ 1mm

**$\varepsilon_{n.rms}$ ~ 0.1 mm.mrad**

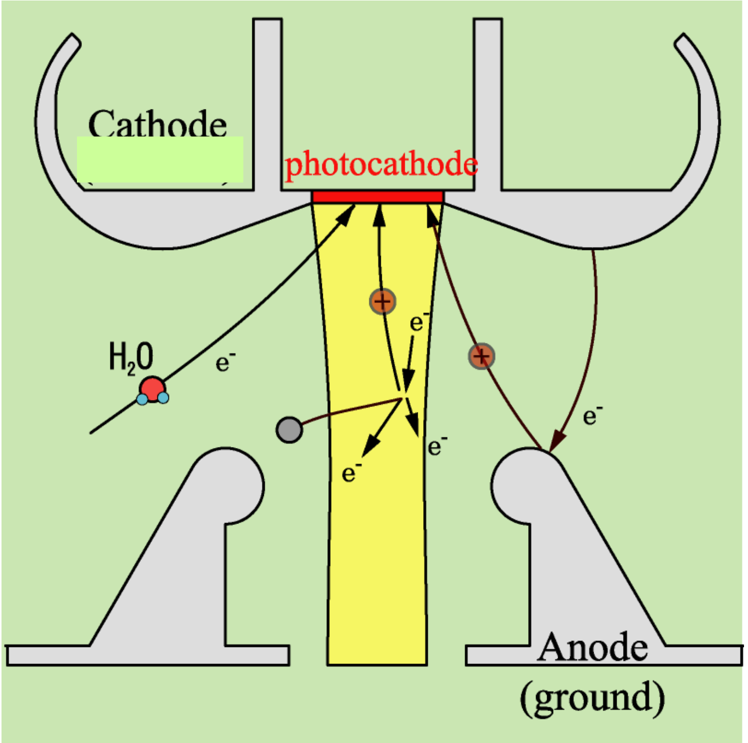
Negative electron affinity surface is essential to generate ultra-low emittance beam.

# Cathode lifetime problem

QE decay of NEA GaAs photocathode in ultra/extreme high vacuum ($\lesssim 10^{-9}$Pa) is dominant by ion back bombardment. The only way to eliminate ion back bombardment is improving base pressure.



Charge density 1/e lifetime was estimated $2\text{x}10^5$ Coulomb/cm$^2$ (~E-9 Pa) by JLAB group.



$$\frac{1}{\tau} = \frac{1}{\tau_{gas}} + \frac{1}{\tau_{DC}} + \frac{1}{\tau_{ion}}$$

C.K.Sinclair et.al., Phys. Rev. ST Accel. Beams **10,** 023501 (2007)

# Ultimate vacuum

Ultimate vacuum : ~1E-9 Pa
Charge density 1/e lifetime:
$2\times10^{5}$ Coulomb/cm$^{2}$
Laser diameter : 1mm

Charge lifetime:
1570 Coulomb
If gun operate 100mA,
QE 1/e lifetime is calculated
**~ 4.3 hours.**

**Need good vacuum as much as possible !**

$$P = \frac{Q}{F}$$

P: Ultimate pressure (Pa)
Q: Total outgassing (Pa.m$^{3}$/s)
F: total pumping speed (m$^{3}$/s = $10^{3}$ L/s)

Large pumping speed in XHV

The ability of Ion pump was strongly decreased in XHV.

NEG may still keep of its pumping speed in XHV. Is the limit of the pumping speed decided by its hydrogen equilibrium pressure?

Low outgassing surface

Outgassing rate < $10^{-11}$ Pa.m/s

- Material choice
- Surface treatment
- …

# Low outgassing material & treatment

- Air-baked stainless steel (SUS316L)

  400 C air-bake in ~100 hours

  150 C in situ baking

  Outgassing rate ~ $2x10^{-11}$ Pa· m/s (*~1.6mm thickness)

  C.D. Park et. al., J.Vac.Sci.Technol. A26 1166-1171

- Pure titanium & titanium alloy （ KS100 ）

  CP treatment (San-titan)

  Outgassing rate <$10^{-12}$ Pa· m/s (150C in situ baking)

  H.Kurisu et. al., J.Vac.Sci.Technol. A21 L10-12

- 0.2% BeCu

  400 C vacuum fire in 3 days

  Outgassing rate < $10^{-12}$ Pa· m/s

  F.Watanabe. J.Vac.Soc.Jpn Vol.49, No6 349-356

# 2nd 500kV gun development

# Strategy to generate extreme high vacuum

$$P = \sum_{\mathrm{i}} P_{\mathrm{i}} \qquad P_{\mathrm{i}} = \frac{\left(\sum_{\mathrm{j}} Q_{\mathrm{j}}\right)_{\mathrm{i}}}{\boxed{\left(\sum_{\mathrm{k}} S_{\mathrm{k}}(P)\right)_{\mathrm{i}}}}$$

Pumping speed depends on the pressure.

$$Q_{\mathrm{i}} = \left(\boxed{Q_{\mathrm{chamber}}} + Q_{\mathrm{ceramic}} + \boxed{\cdots}\right)_{\mathrm{i}}$$

Titanium is excellent to suppress outgassing.

$$P_{\mathrm{H_2}} = \frac{\left(\sum_{\mathrm{j}} Q_{\mathrm{j}}\right)_{\mathrm{H_2}}}{\boxed{\left(S_{\mathrm{NEG}}(P, x_{\mathrm{H_2}})\right)_{\mathrm{H_2}}} + \left(S_{\mathrm{cryo}}(P, x_{\mathrm{H_2}})\right)_{\mathrm{H_2}}}$$

NEG has large pumping speed for $H_2$

Concentrations of molecules in getter material.

$$P_{\mathrm{CO}} = \frac{\left(\sum_{\mathrm{j}} Q_{\mathrm{j}}\right)_{\mathrm{CO}}}{\left(S_{\mathrm{NEG}}(P, x_{\mathrm{CO}})\right)_{\mathrm{CO}} + \boxed{\left(S_{\mathrm{cryo}}(P, x_{\mathrm{CO}})\right)_{\mathrm{CO}}}}$$

Cryopump (< 20 K operation) has large pumping speed except for $H_2$ and He.

# 2nd 500kV gun system design

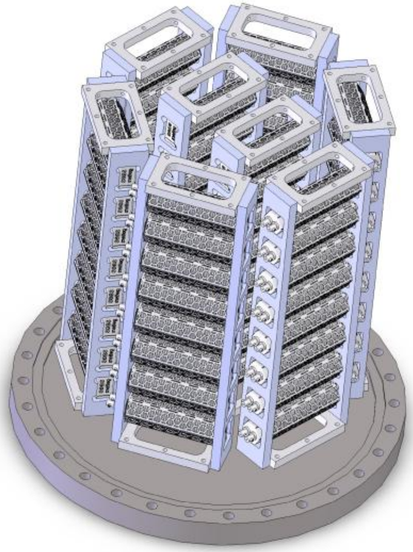
- Using titanium as a base material of the chamber and flanges to decrease outgassing rate.

  H. Kurisu et al.,“Titanium alloy material with very low outgassing”, J. Vac. Sci. Technol. A21 (2003) L10

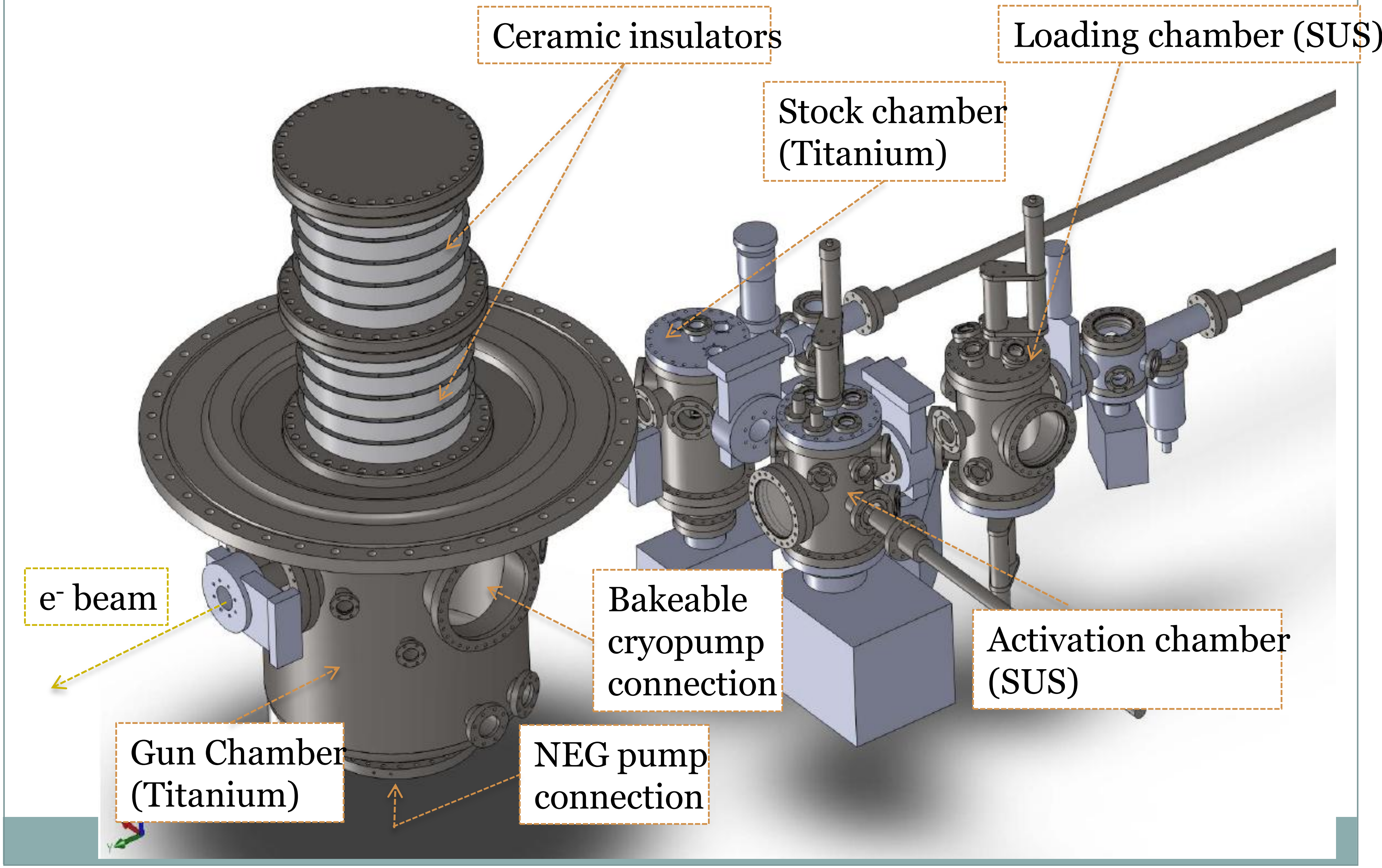
- Using a specialized pumping system for extreme high vacuum.

  \- Combination of NEG pumps and a bake-able cryopump.

  H. Yamakawa , “Development and performance of bakeable cryopumps for extreme high vacuum”, Vacuum 44 (1993) 675.



# The 2nd 500kV Gun



Ceramic insulators

Loading chamber (SUS)

Stock chamber
(Titanium)

e- beam

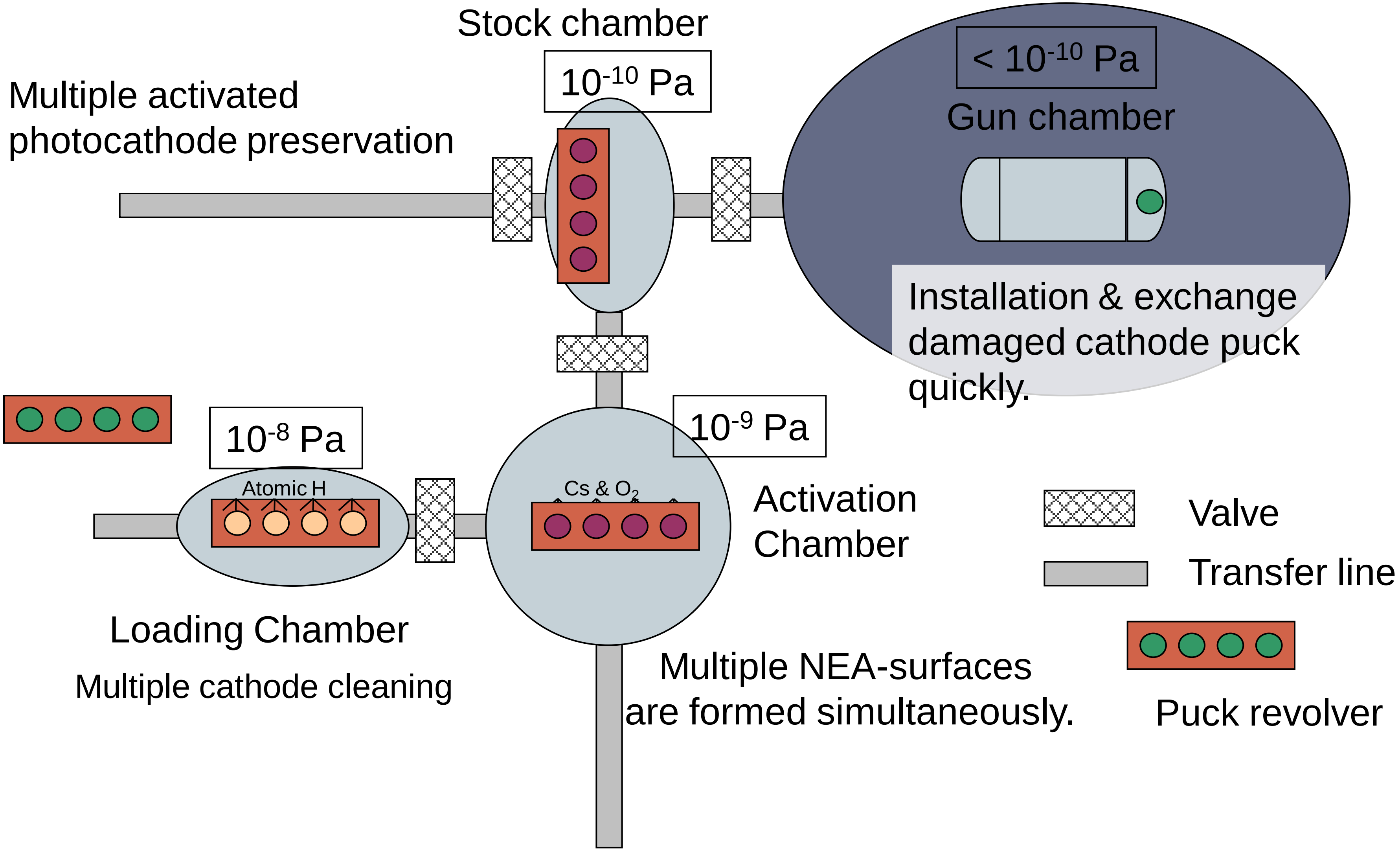
Bakeable
cryopump
connection

Activation chamber
(SUS)

Gun Chamber
(Titanium)

NEG pump
connection

# Outline of 2nd 500kV Gun Operation



Stock chamber

Multiple activated photocathode preservation

Gun chamber

Installation & exchange damaged cathode puck quickly.

Activation Chamber

Loading Chamber

Multiple cathode cleaning

Multiple NEA-surfaces are formed simultaneously.

▨ Valve

▭ Transfer line

Puck revolver

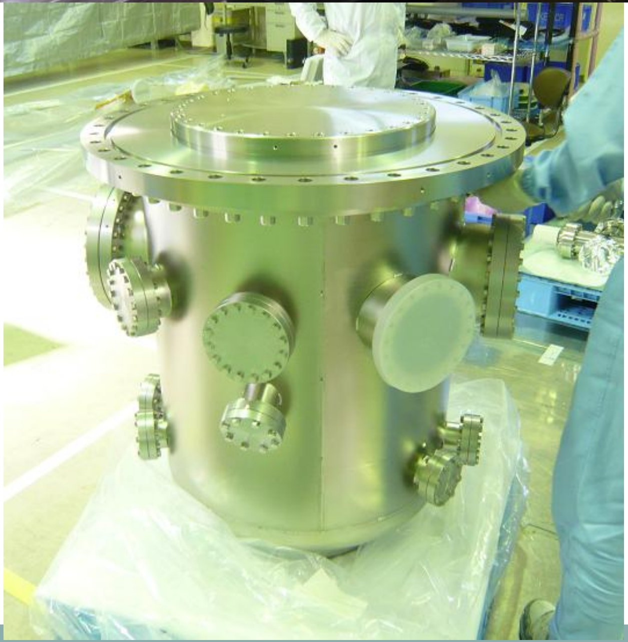
# Fabrication of Titanium Gun Chamber

<u>Material</u>

Chamber body : JIS-2 pure Ti
Flanges : JIS-3 pure Ti (Hv>180 )
6Al4V-Ti alloy (Hv>330)

All base materials for flanges are forged.

The titanium chamber was made by Komiyama Electron Inc.



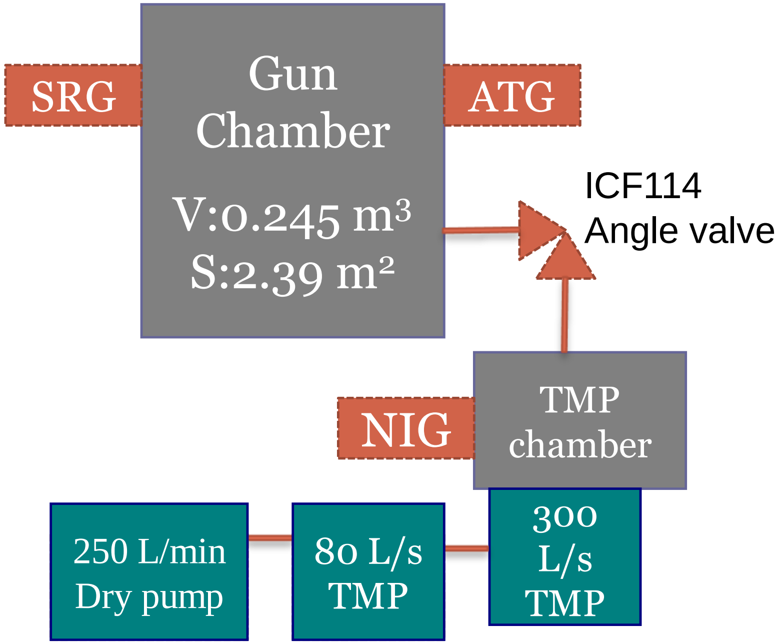
<u>Polishing & Cleaning process</u>

1.Chemical polishing
2.Water rinse
3.Nitric acid treatment
4.Water rinse & wiping
5.Ultra pure water rinse (clean room)
6.Dry by $N_2$ blowing & package (clean room)

The polishing and cleaning process was done at Sanai plant industrial Inc.

# Construction of the gun chamber

# Vacuum Test of Titanium Gun Chamber


SRG

Gun Chamber

V:0.245 m³

S:2.39 m²

ATG

ICF114

Angle valve

NIG

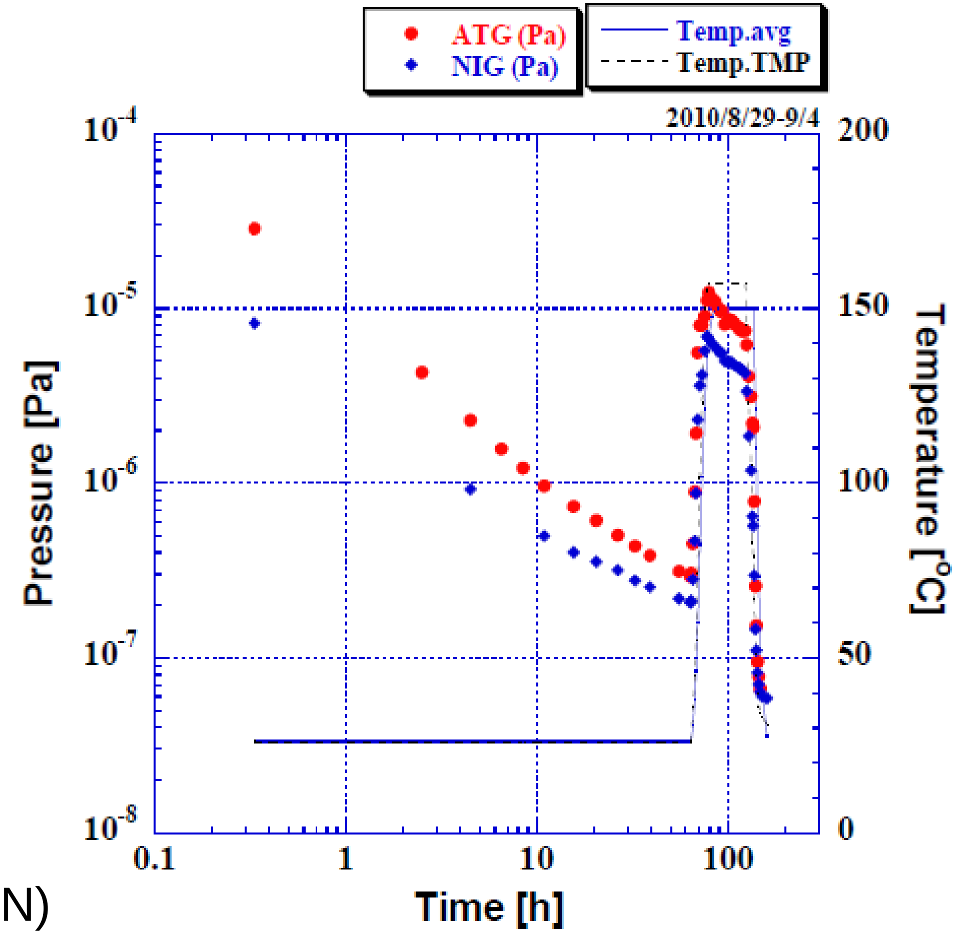
TMP chamber

250 L/min Dry pump

80 L/s TMP

300 L/s TMP

ATG: Axial Transmission Gauge
made by ULVAC Inc.

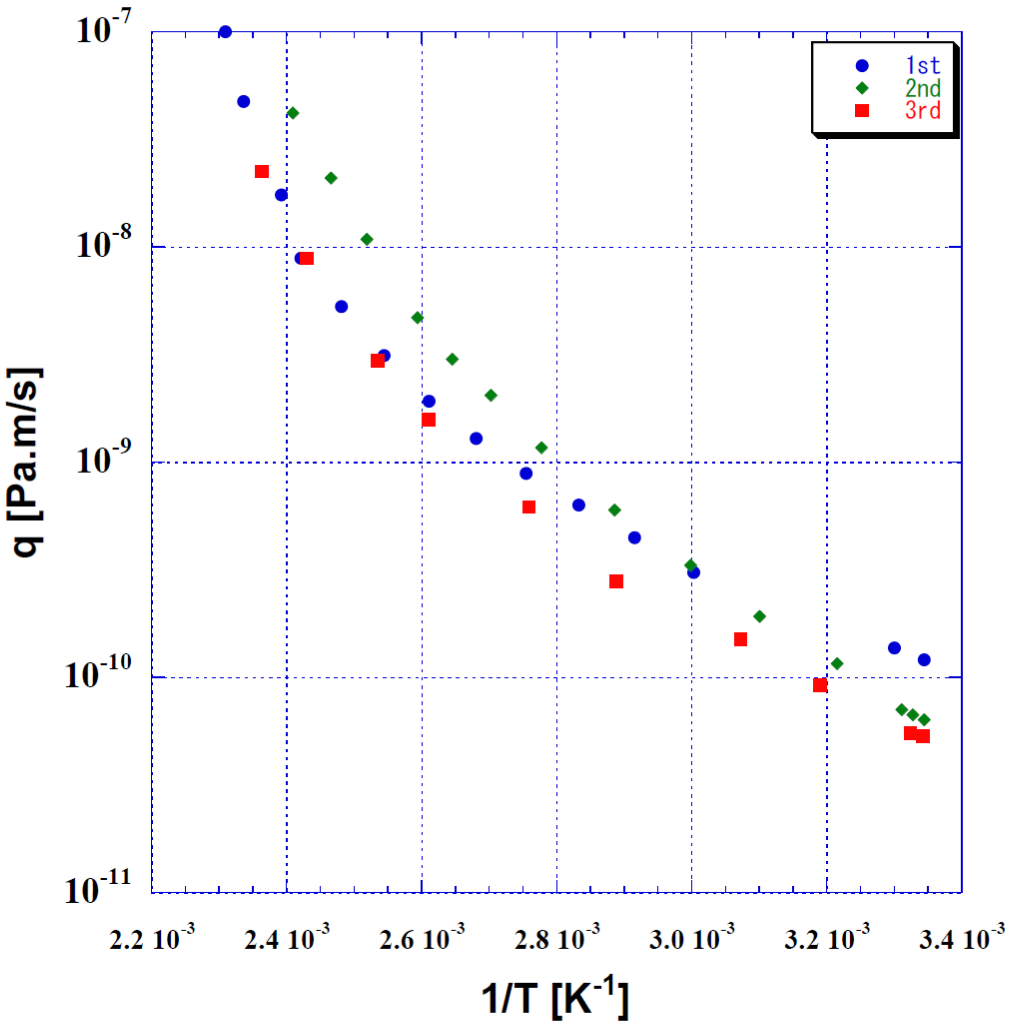


<u>Baking condition (3rd baking)</u>

The chamber was purged by dry $N_2$ (>5N) after 2nd baking and kept over 30 min before restart evacuation.

baking temperature: 150 °C, period: 50 hrs

# Vacuum Test of Titanium Gun Chamber



Measurement of outgassing rate

Method: Accumulation method

$$\Delta P / \Delta t = Q / V$$

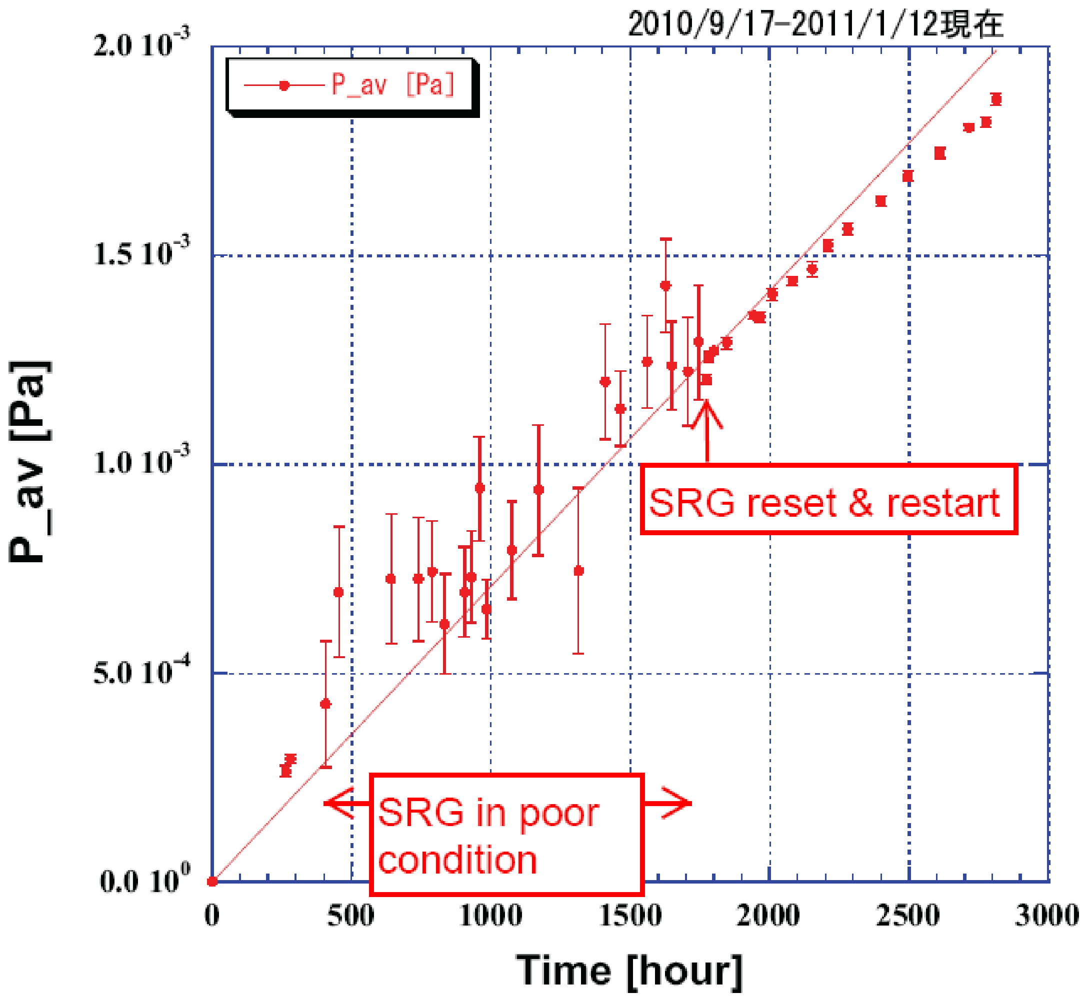
Gauge: Axial transmission gauge (yttrium oxide coated filament)

Duration of accumulation
: ~ 600 sec.

The measurements were done 10~20 $^{o}$C step during cool down process in the baking.

Outgassing rate @R.T.
5.3E-11 Pa.m/s

# Vacuum Test of Titanium Gun Chamber



Method: Accumulation method

Gauge: Spinning rotor gauge

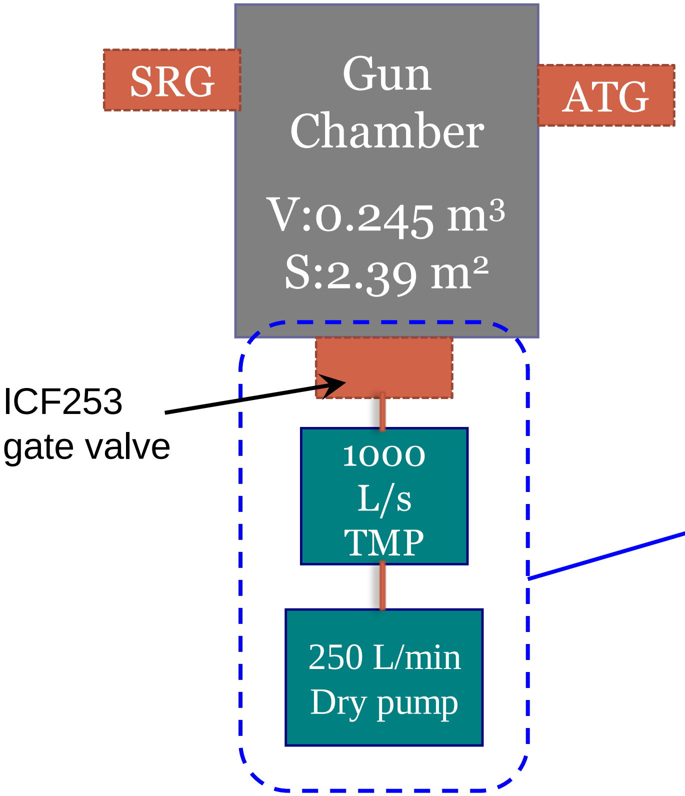
Duration: ~ 2800 hours.

The pressure rose almost linearly by ~1.9E-10 Pa/s.

.

Outgassing rate @R.T.
1.9E-11 Pa.m/s

# Outgassing from a large gate valve



SRG

Gun Chamber

V:0.245 $m^3$

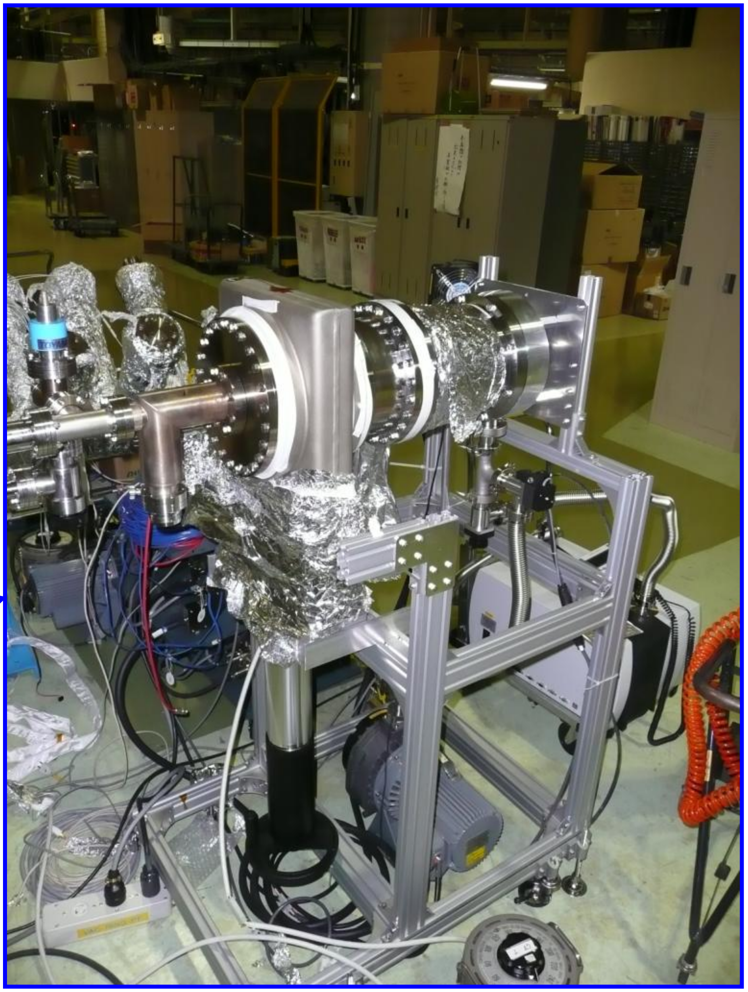
S:2.39 $m^2$

ATG

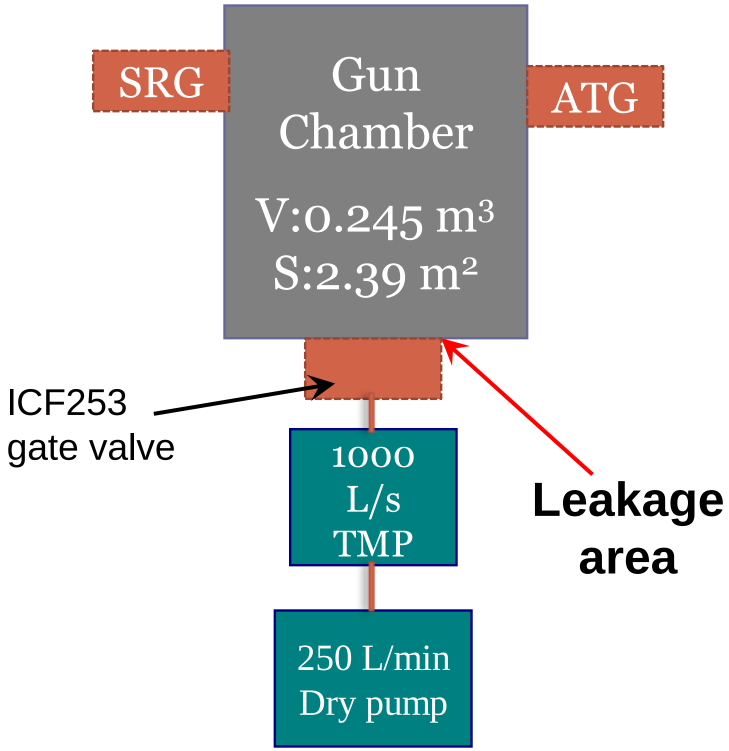
ICF253 gate valve

1000 L/s TMP

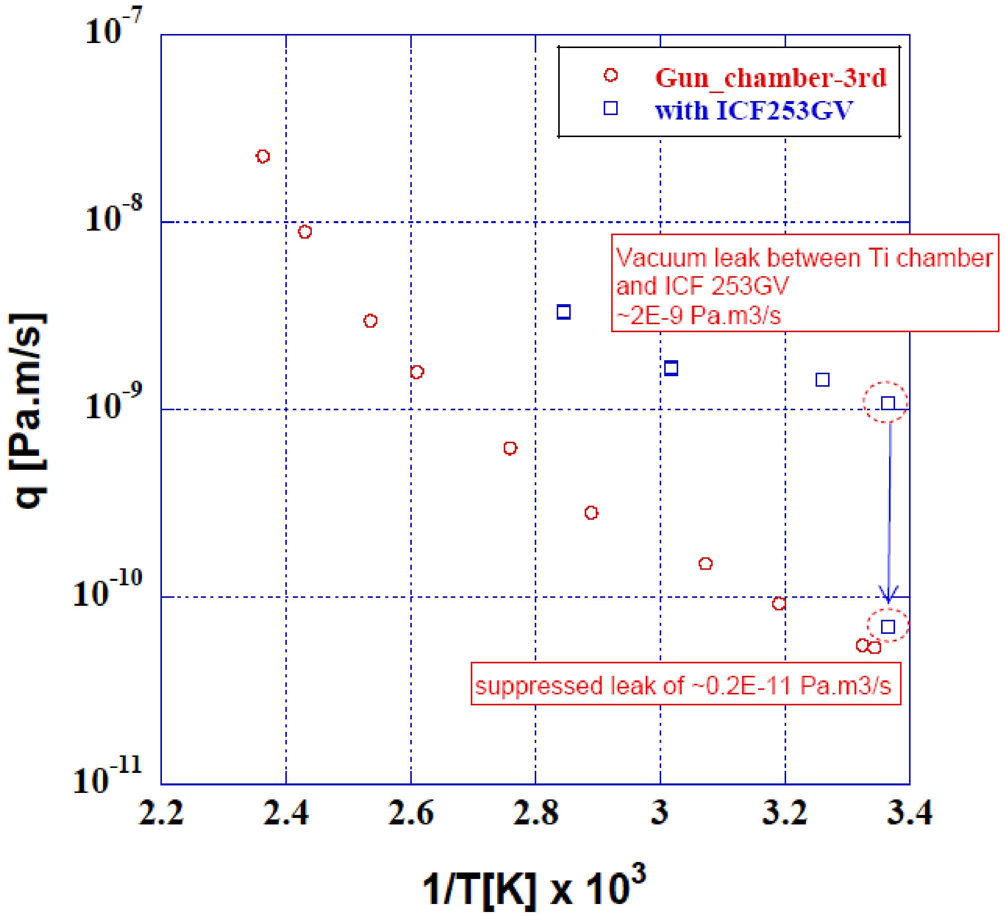
250 L/min Dry pump



# Outgassing from a large gate valve



**Leakage area**

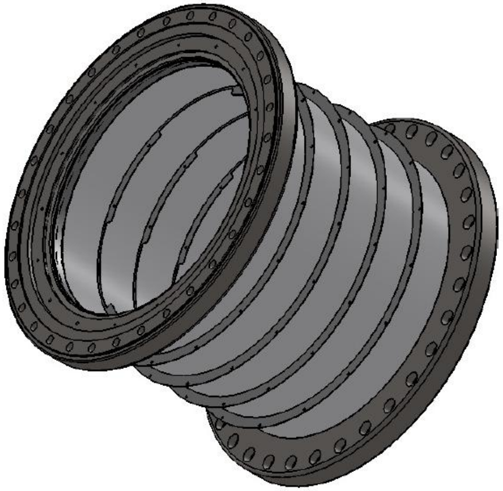


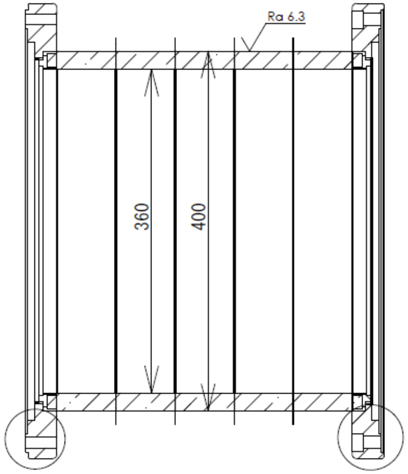
Vacuum leak between Ti chamber and ICF 253GV ~2E-9 Pa.m3/s

suppressed leak of ~0.2E-11 Pa.m3/s

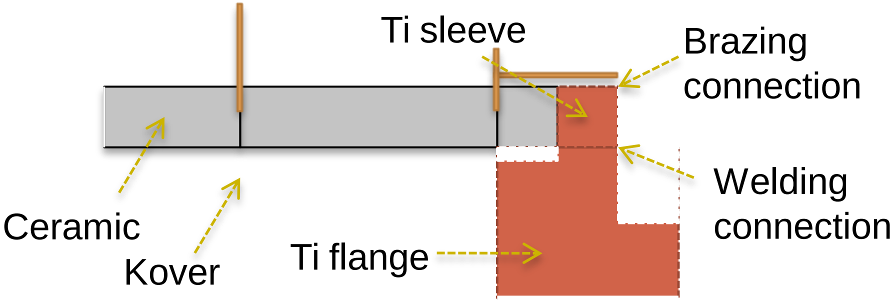
Total outgassing rate @R.T. was increased ~4E-10 Pa.m3/s

# Segmented Ceramic Chamber





Base ceramic: TA010 (Kyocera)
Metalize: Active-metal soldering
Segmented metal: Kover
Flange material: Titanium (JIS-3)

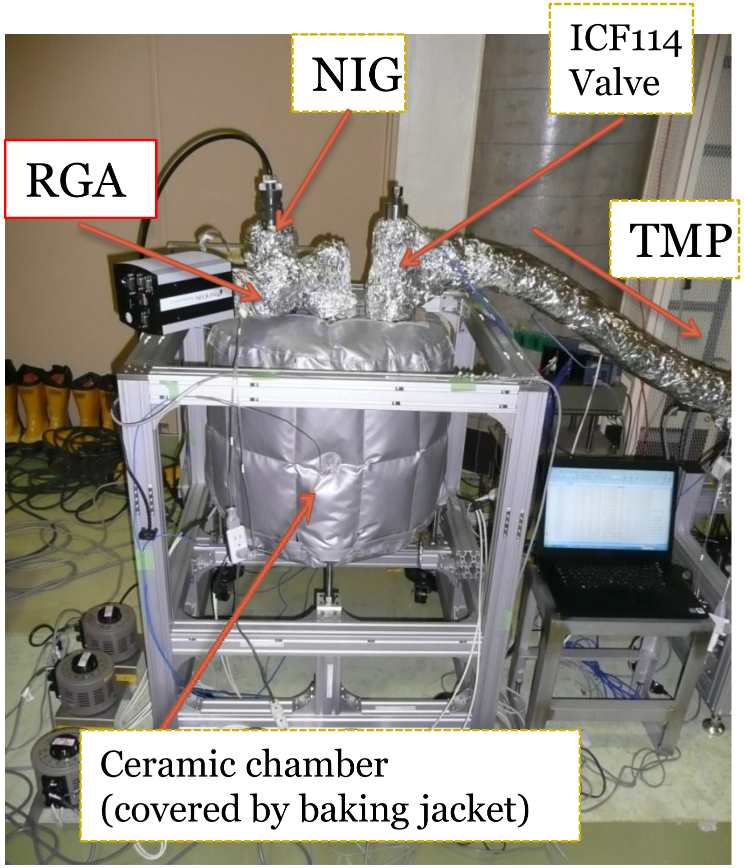


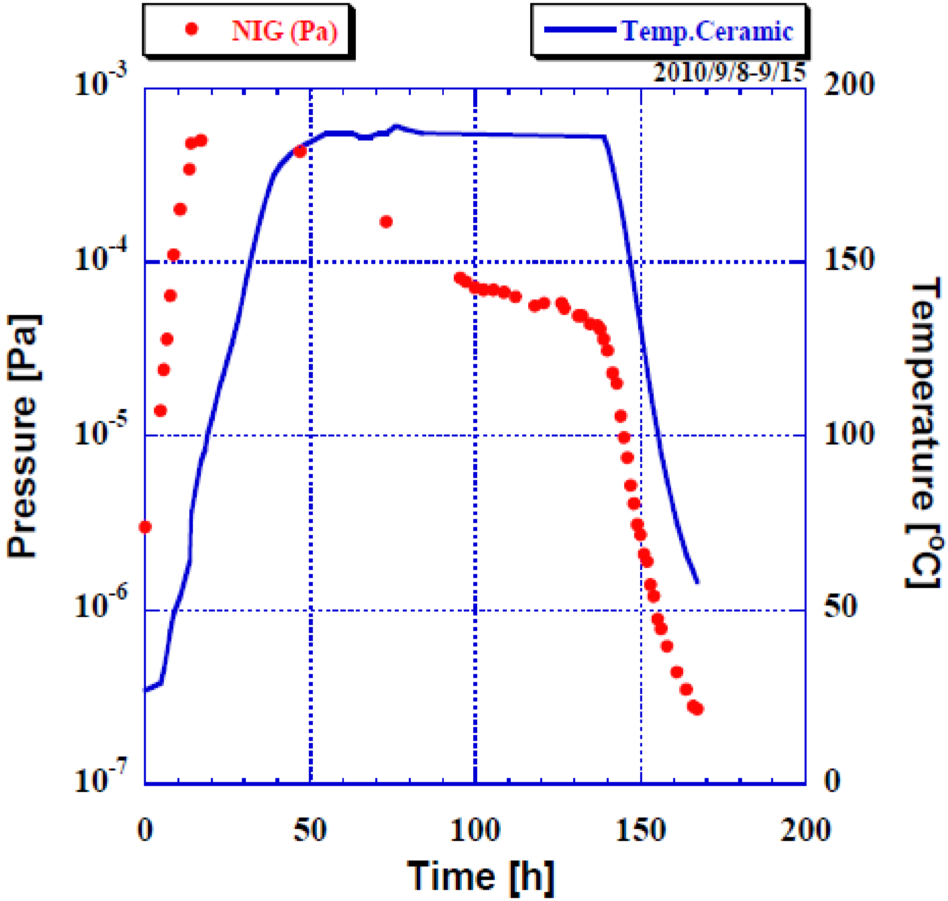
Resistance of ceramics for each segments. (x$10^{10}$ $\Omega$)

| Seg. No | No.1 (*1) | No.2 (*2) |
|---|---|---|
| 1 | 200 | 9.8 |
| 2 | 150 | 8.1 |
| 3 | 250 | 8.1 |
| 4 | 100 | 6.0 |
| 5 | 100 | 8.0 |

Condition of humidity, *1:38%, *2:50%
Measured by K. Iwamoto (Kyocera Inc.)

# Vacuum Test of Ceramic Chamber

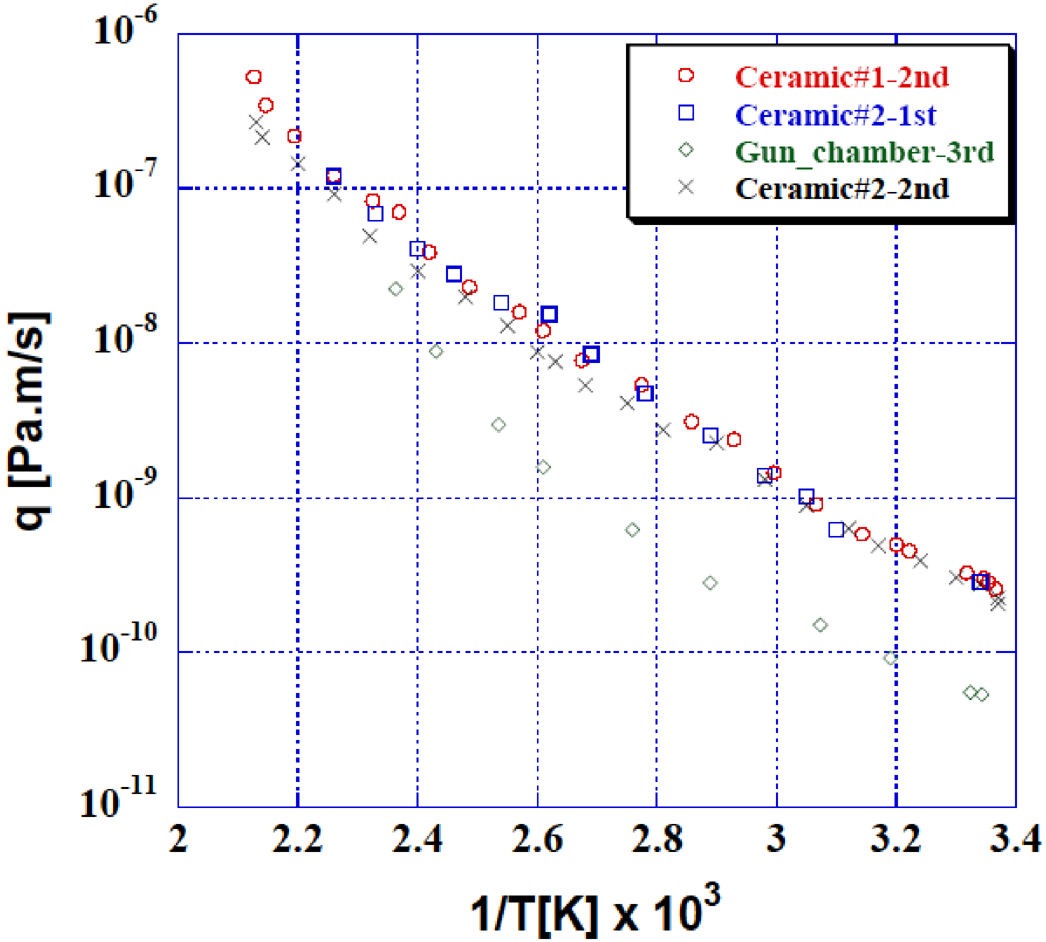




Baking condition: 190 °C for 100 hours

Maximum temperature gradient: 7 °C/h

# Vacuum Test of Ceramic Chamber



<u>Outgassing rate measurement</u>

Method: accumulation method

Gauge: B-A gauge (yttrium oxide coated filament)

Duration: 30 ~ 300 sec.

Outgassing rate was improved about two order of magnitude after 190 °C , 100 hrs baking.

Outgassing rate @R.T.
~<u>2.5E-10 Pa.m/s</u>

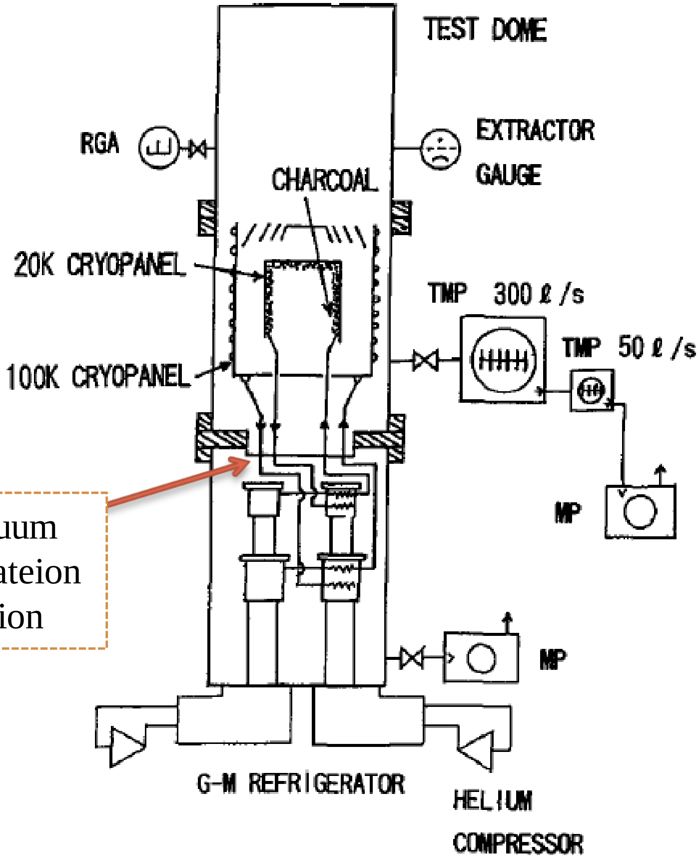
(Included titanium flanges surface)

# Estimation of total outgassing rate

| | outgassing rate<br>*q* [Pa・ m/s] | surface area<br>*A* [$m^2$] | total outgassing<br>*Q* [Pa・ $m^3$/s] |
|---|---|---|---|
| Gun chamber body | **5.0E-11** | 2.4 | **1.2E-10** |
| Ceramic chamber | **2.5E-10** | 1.6 | **4.0E-10** |
| Guard ring electrode | 5.0E-11 | ~3 | ~1.5E-10 |
| Cathode electrode & Support rod | 1.0E-10 | ~1.5 | ~1.5E-10 |
| Anode electrode | 1.0E-10 | ~0.3 | ~3.0E-11 |
| NEG cartriges support | 5.0E-11 | ~0.5 | ~2.5E-11 |
| Cryopump chamber | 5.0E-11 | ~0.5 | ~2.5E-11 |
| Gate valves & View ports | 1.0E-09 (?) | ~0.3 | **> 3.0E-10 (?)** |

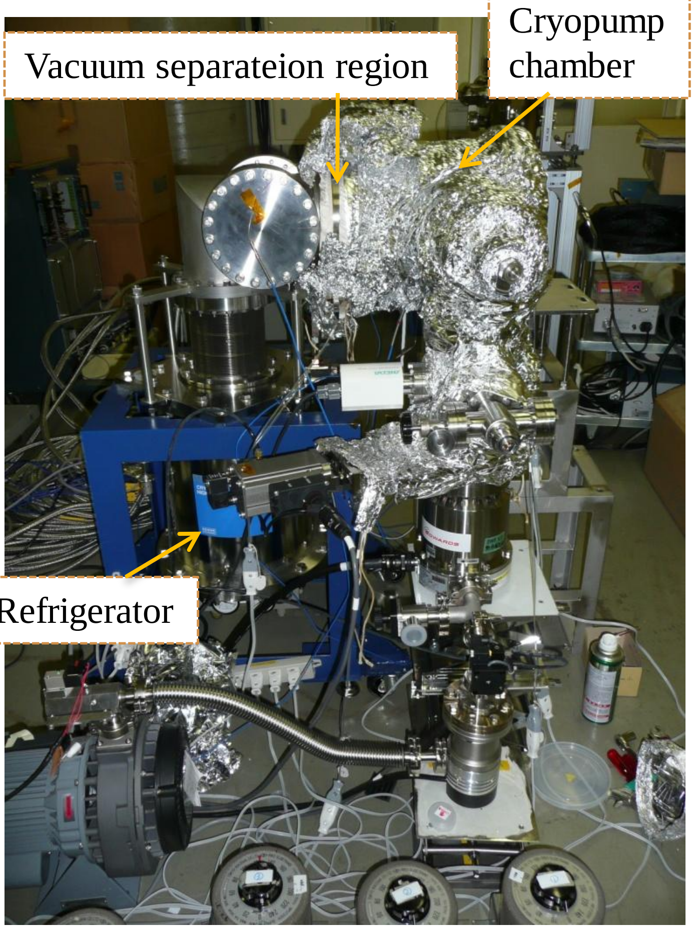
| Total Q of the Gun | **> 1.2E-09** |
|---|---|

# Bakeable Cryopump System



Vacuum separateion region

H. Yamakawa, Vacuum 44, p675 (1993)



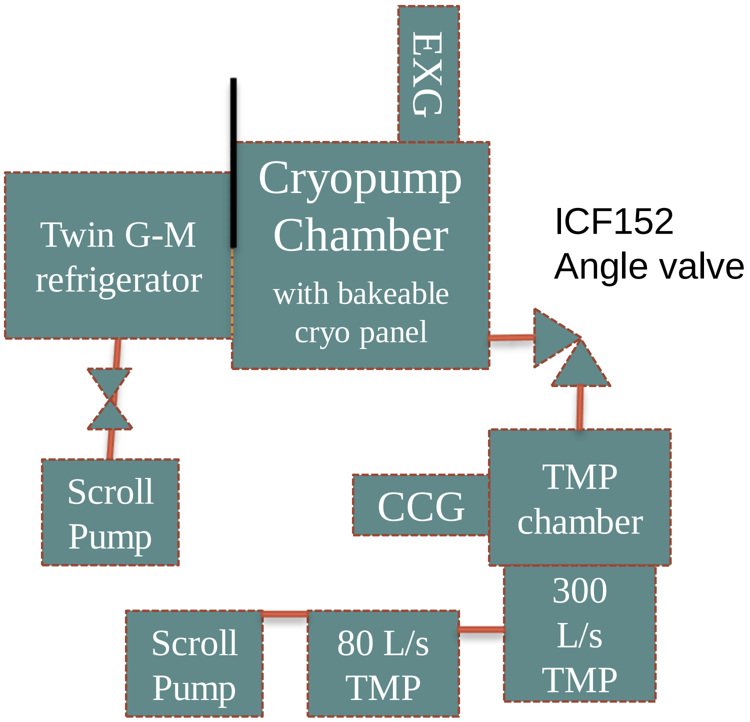
Cryopump chamber

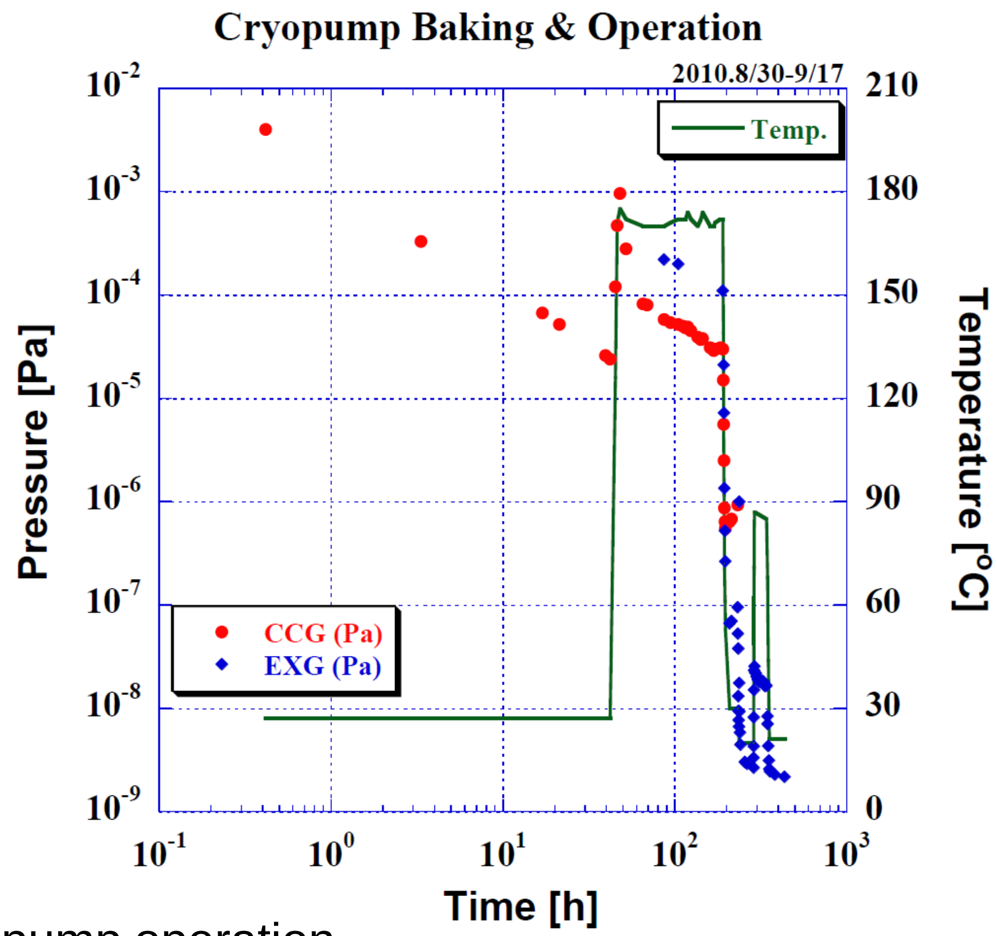
Vacuum separateion region

Refrigerator

- Cryo-panel is separated from refrigerator.
- Absorbent (Charcoal) is brazed on the base panel to improve heat-resistant in baking.

# Vacuum Test of bakeable Cryopump





Baking & operation condition

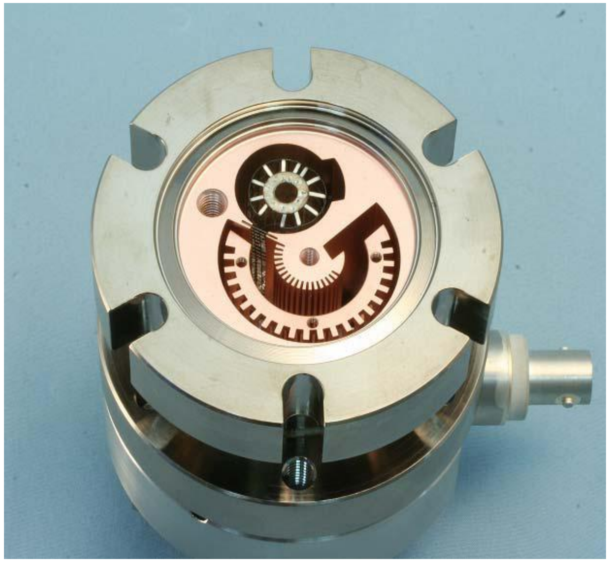
1. 170℃ baking for 140 hours w/o cryopump operation.
2. Cool down for two days.
3. Cryopump operation & closed valve
4. 80℃ baking for 50 hours with cryopump operation.

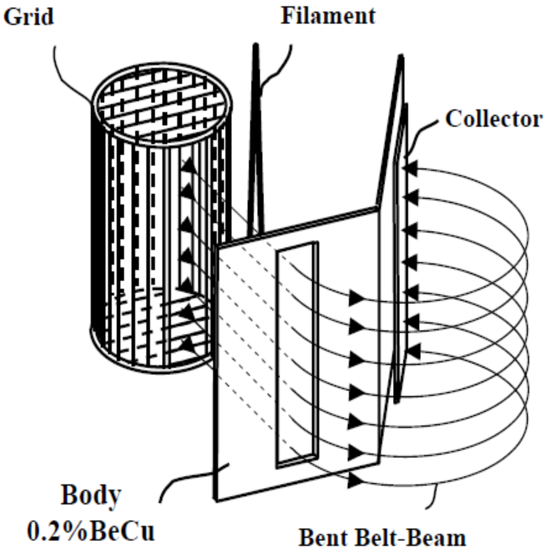
Preliminary ultimate pressure

2.2E-9 Pa

# XHV gauge to measure vacuum of $10^{-10}$ Pa or less

## Bent Belt Beam (3B) Gauge



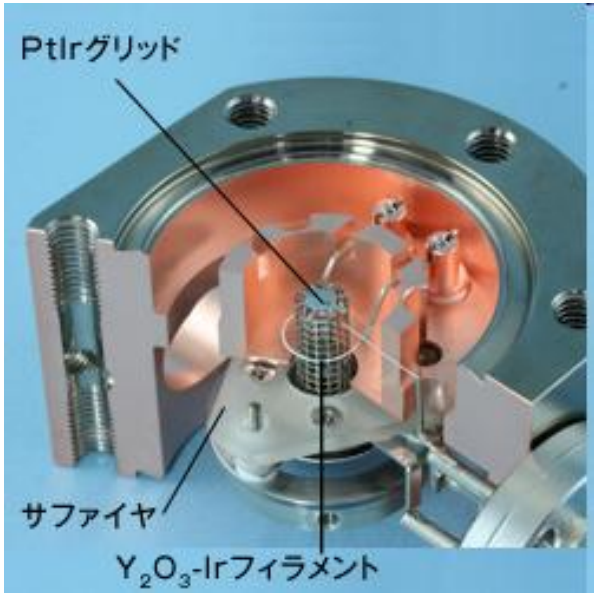


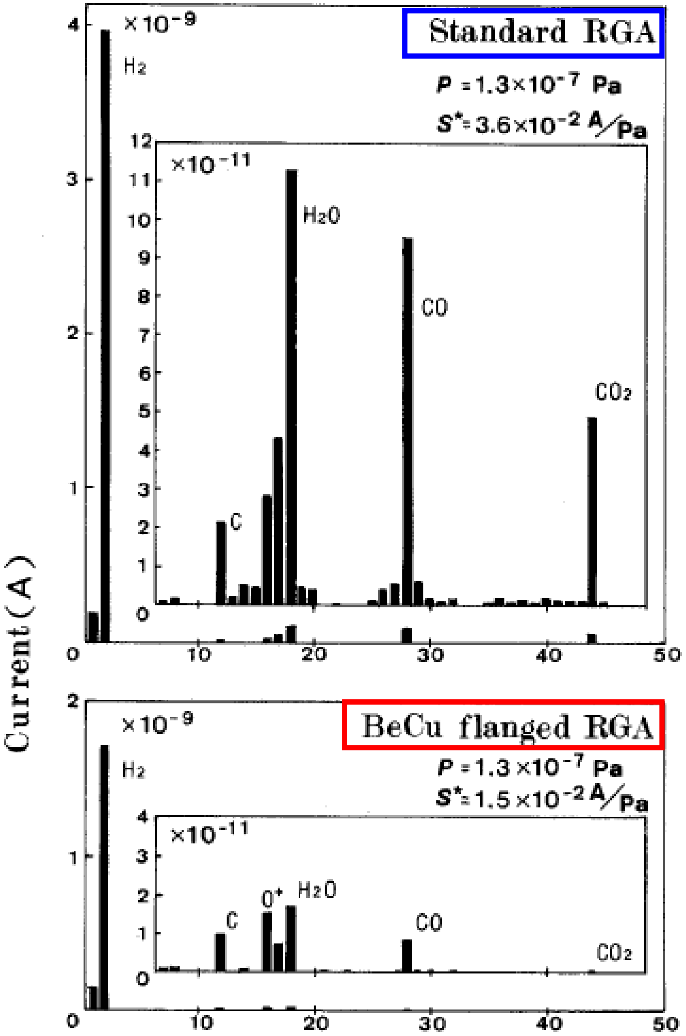
Prevent soft x-ray and ESD ions.
Ultra low outgassing.

Dr. F. Watanabe has developed new type vacuum gauge.(http://www.vaclab.co.jp)
It can use the same controller of extractor gage (IM540). (It is possible to measure the range of E-12 Pa by using 1E-16A accuracy electro-meter.)
The detail report has been published in J. Vac. Sci. and Technol. A 28, (2010) 486

# Special RGA to evaluate vacuum better than $10^{-8}$ Pa

## Ultra low outgassing RGA (WATMASS)

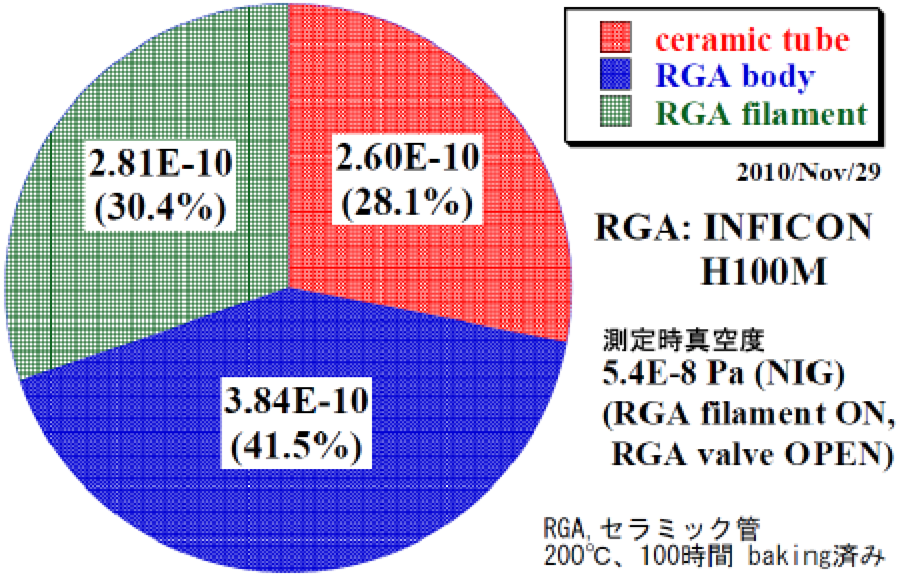




**http://www.vaclab.co.jp/product04.html**

Dr. F. Watanabe has developed ultra low outgassing RGA based on BeCu technology. The RGA is reconstructed from a RGA made by INFICON Inc. It can use the same controller of INFICON RGA. The detail report has been published in J. Vac. Sci. and Technol. A 13, (1995)

# Special RGA to evaluate vacuum better than $10^{-8}$ Pa



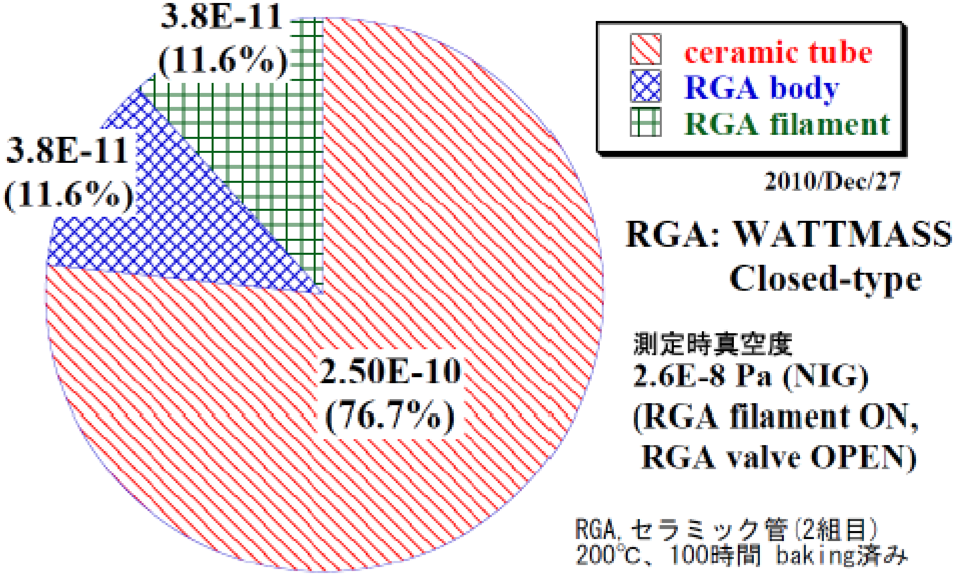
2010/Nov/29

**RGA: INFICON H100M**

測定時真空度
5.4E-8 Pa (NIG)
(RGA filament ON,
RGA valve OPEN)

RGA, セラミック管
200°C、100時間 baking済み

全ガス放出速度： 9.25E-10 [$Pa.m^3/s$]



2010/Dec/27

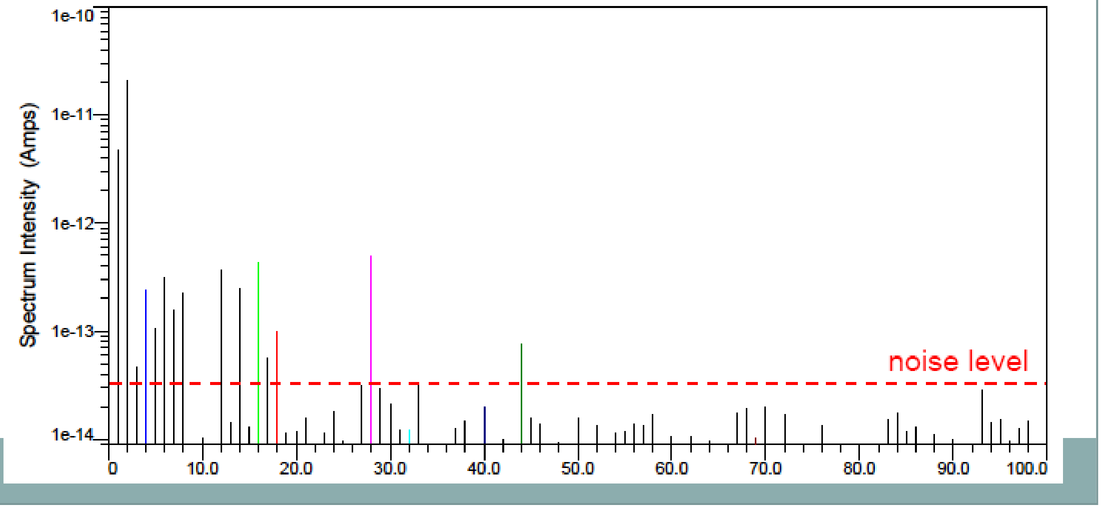
**RGA: WATTMASS Closed-type**

測定時真空度
2.6E-8 Pa (NIG)
(RGA filament ON,
RGA valve OPEN)

RGA, セラミック管 (2組目)
200°C、100時間 baking済み

全ガス放出速度： 3.26E-10 [$Pa.m^3/s$]

Total outgassing rate from RGA was improved about one order of magnitude by using WATMASS.
These results include outgassing from a ICF70 angle valve (bellows side).



# Summary

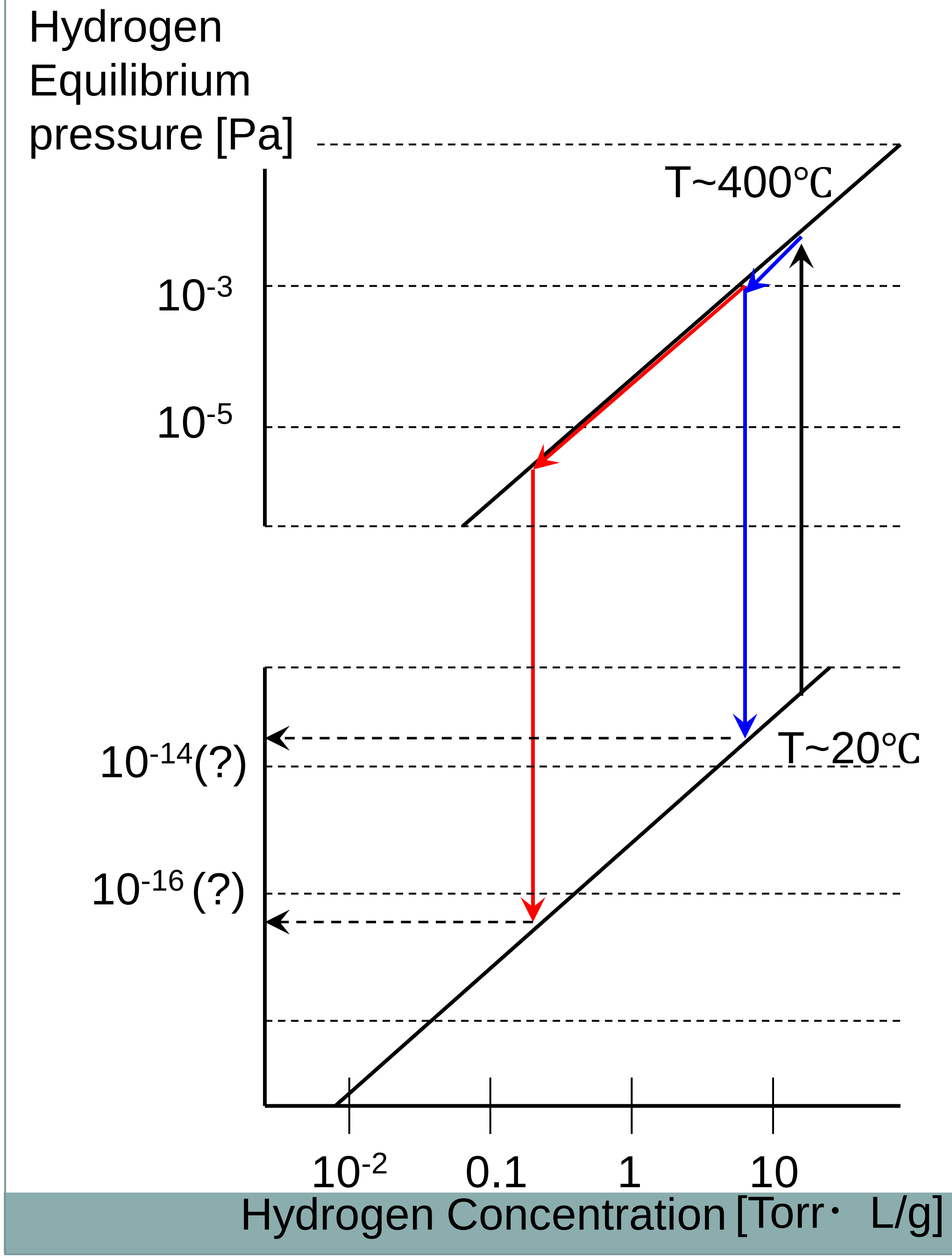
- Commissioning of cERL will be started at the end of 2012 FY.

- DC gun test facility has been constructed at PF-AR south area in KEK.

- Development of the 500 kV 2nd DC gun has been started at KEK since 2009.
  - Vacuum test of the components are progressed.
  - Outgassing rate of Titanium and ceramic chambers were measured 1.9E-11 Pa.m/s, 2.5E-10 Pa.m/s respectively.
  - Total outgassing rate is estimated >1.2E-10 Pa.m3/s.

- Special gauges were employed to accurate measurement.
  - Belt Bent Beam gauge
  - Ultra low outgassing RGA (WATMASS)

Back up Slide



Hydrogen equilibrium pressure

$$\log P = A - \frac{B}{T} + 2\log q$$

Sievelts' low indicate very low equilibrium pressure in low temperature even the getter hydrogen concentration is high.

← Usual activation

Recommended activation procedure ~450 C, 1 hour for St707.
Vacuum was reduced little or nothing during activation.

← Sufficient activation

Evacuating with a large pumping speed TMP for several hours can decrease hydrogen concentration.

# 排気速度測定の準備状況について（１）

圧力が高い状況においても、その時の
平均自由行程よりも十分に短い径をもつ
微小な孔を通過するガスは、分子流として
考える事ができる。

**産総研：圧力真空標準研究室　吉田肇氏らが開発**

**今回使用する焼結フィルタの特性**

コンダクタンス：
$C = 3.03E\text{-}10\ m^3/s$
精度：6%
校正条件
温度：27.5度
校正ガス：窒素

流量：$Q_A = P_F \cdot C_F \sqrt{\frac{28}{M_A}} \sqrt{\frac{T_0}{T}}$

$P_F$:焼結フィルタ上流部圧力
$C_F$：焼結フィルタのコンダクタンス
$T_0$：校正時の温度

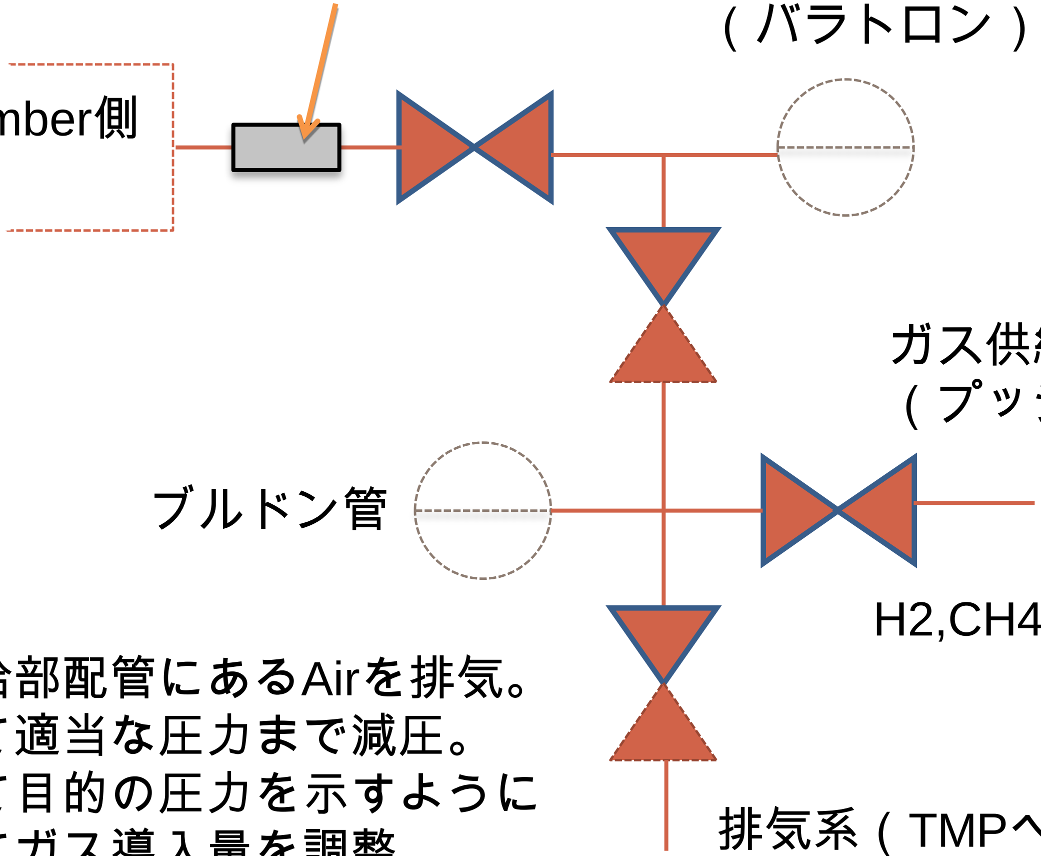
$$S = \frac{Q}{P}$$

左の式より計算された流量と、計測されたChamber内の真空度（圧力変化量）より、導入したガス種の排気速度が求められる。

排気Chamberへ設置済み。1月下旬頃にガス導入操作の試験を予定。

# 排気速度測定の準備状況について（２）

## ガス導入系の概略図



焼結フィルタ
（ICF34,両面フランジ）

隔膜真空計
（バラトロン）

測定系Chamber側
（ICF70）

ガス供給部
（プッシュ缶、ボンベより

ブルドン管

H2,CH4,N2,O2,Ar,CO2

排気系（TMPへ）

・ 初期にガス供給部配管にあるAirを排気。
・ ブルドン管にて適当な圧力まで減圧。
・ バラトロンにて目的の圧力を示すようにバルブを調整してガス導入量を調整。
・ ICF34で各所接続。

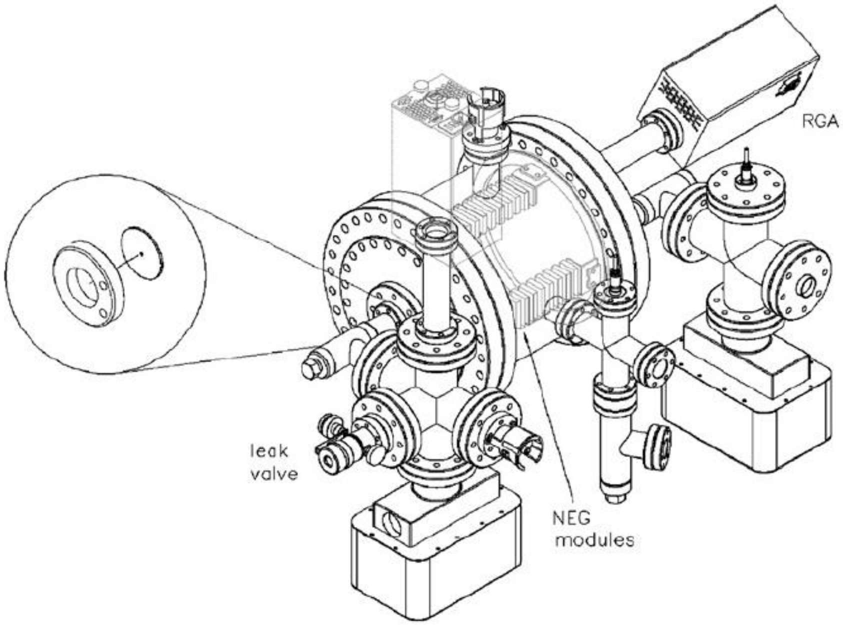
# 2. Limiting mechanisms for a NEG

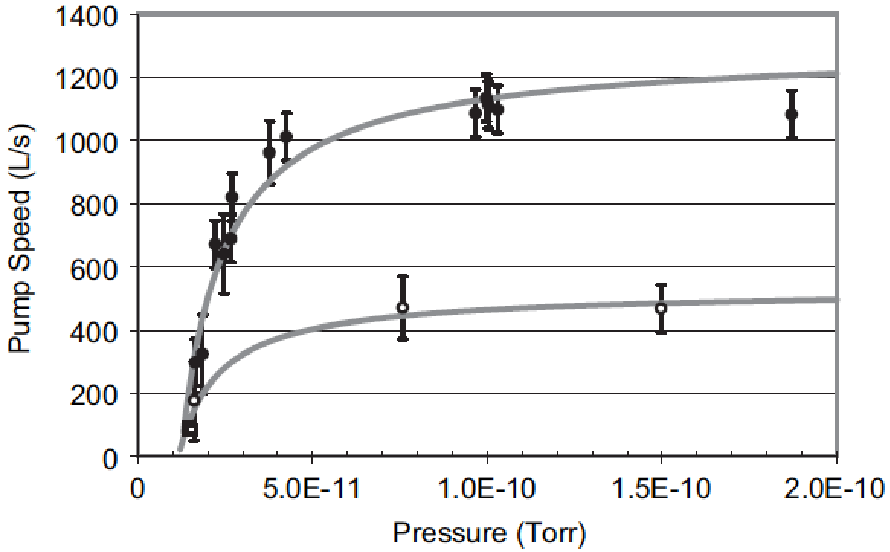
- Sievert's law may limit ultimate achievable pressure (St 707, $PH_2$ ~ $2x10^{-16}$ Torr @ 25° C and 1 Torr/g $H_2$).

- No $H_2$ equilibrium data available <$10^{-10}$ Torr to provide insight on the actual $H_2$ sorption mechanisms at XHV

- Various getter alloys with lower equilibrium pressure than St 707 are being considered by SAES for NEG pumps in XHV

# NEG pumping speed measurement in UHV (JLAB)





M.L.Stutzman et al., NIM-A (2007)

- Throughput method
- Passive activation (280C, 30 hours) and additional full activation (400C, 1hour).
- Pumping speeds are difference but ultimate vacuum are the same ?

# Cathode Preparation System