Progress on investigation of dynamic vacuum (Talk at CCWM 2012)

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Requirements from beam dynamics

- The vacuum threshold for preventing fast ion beam instability (essentially due to direct field ionization and not the usual impact ionization) :

Main beam linac requirements :
total p ≤ few 10^{-9} Torr each for CO, N_2 and/or H_2O.
H_2 is not harmful (p ≤ few10^{-8})

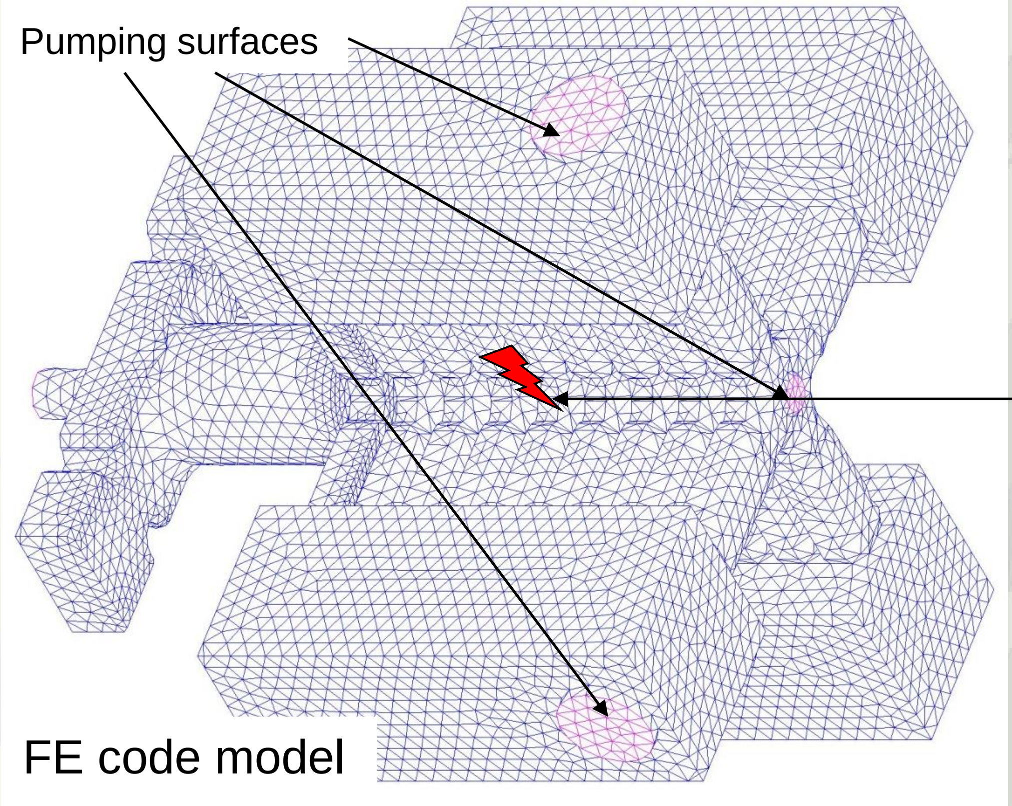
- True for practically all the main LINAC length, also inside the RF accelerating structures
- For details see:
  - G. Rumolo, A Oeftiger http://cdsweb.cern.ch/record/1406050?ln=en
  - C. Garion https://edms.cern.ch/document/1095288/1

The problem

- Static vacuum: not discussed here

- Dynamic vacuum
  - Breakdowns
  - Dark current

Dynamic vacuum – Breakdown I



2.10^{12} H_2 or CO molecules released during breakdown (in a baked system)

Data measured in DC "spark test" reported in PRST-AB12, 092001 (2009)

Dynamic vacuum – Breakdown II

Calculated with Monte-Carlo and thermal analogy model

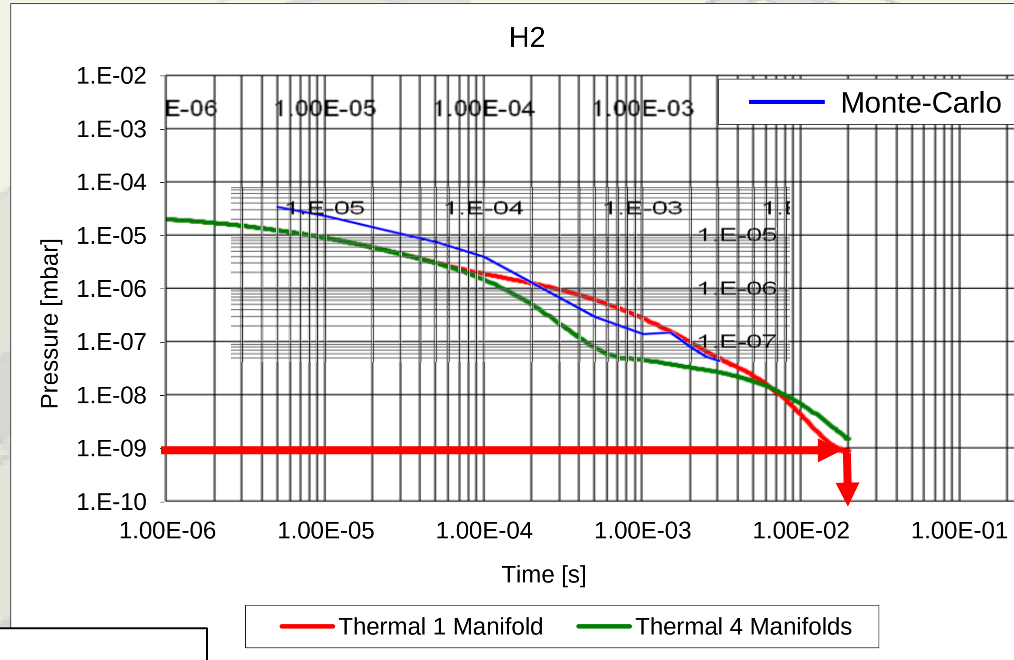
Maximum pressure vs time:

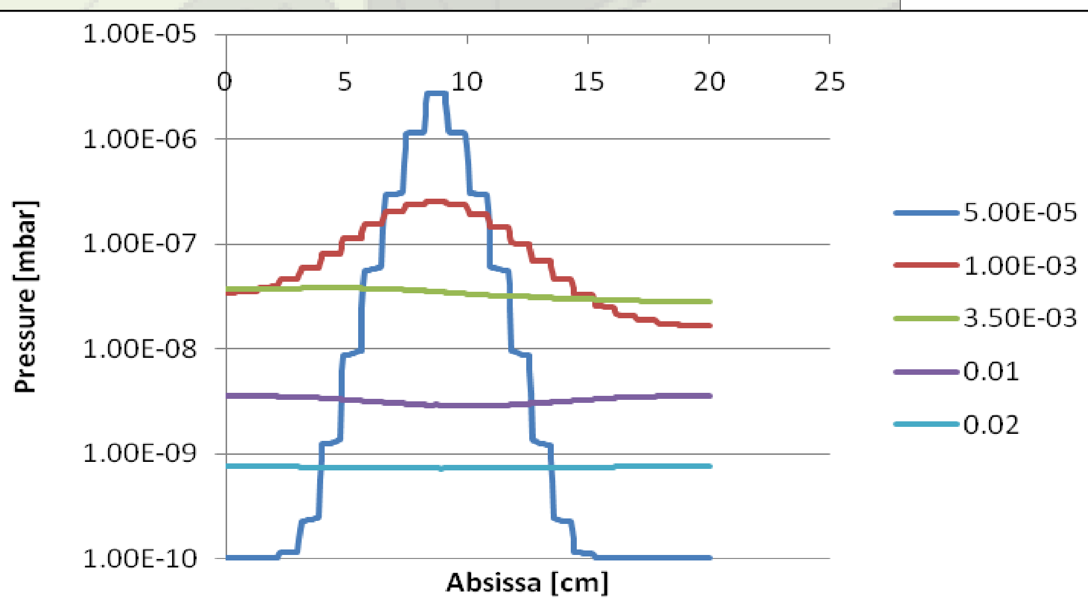
20 ms to reach 10^{-9} mbar for H_2

20 ms to reach 5×10^{-8} mbar for CO

(Note: CLIC repetition rate = 50 Hz

Duty cycle = 20 msec)





Calculated with thermal analogy model (and Monte-Carlo model)

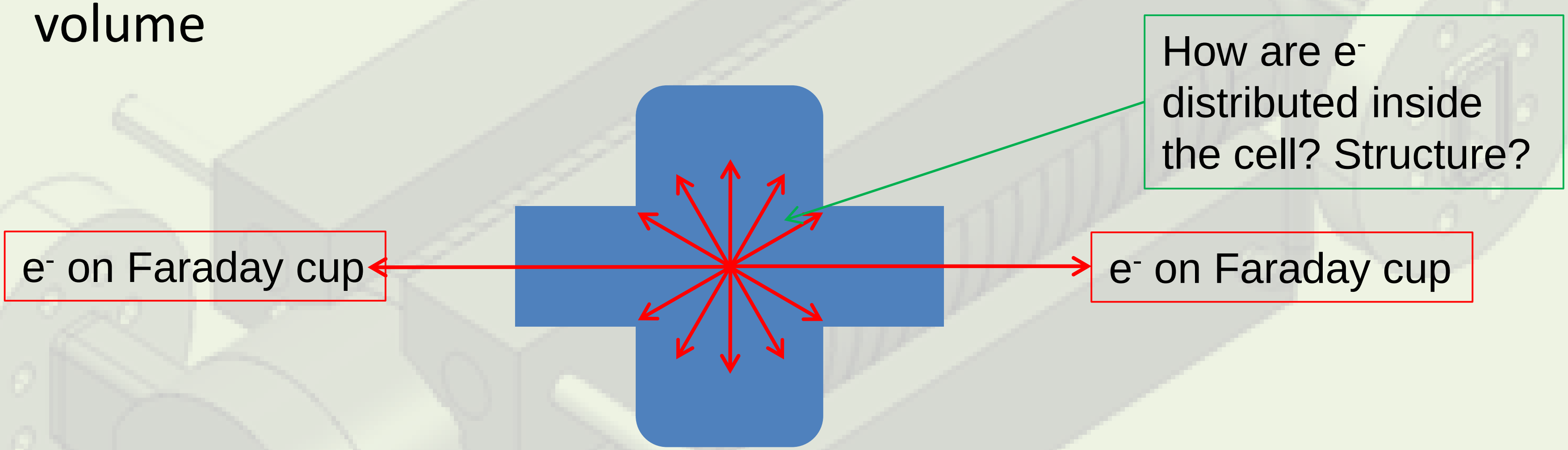
Four manifolds

Longitudinal pressure distribution in the cells:

Uniform after ~3 ms

Dynamic vacuum - Dark currents

- Dark-current electrons are field-emitted, impact on surfaces and desorb gas
- Dynamic vacuum by ESD: desorbed molecules fill the whole cell volume



- e^- current on Faraday cup ~ $10^{-4 \div -3}$ A during pulse
- Need e^- distribution and energy + ESD coefficients at high energy

ESD data unbaked copper – G. Vorlaufer

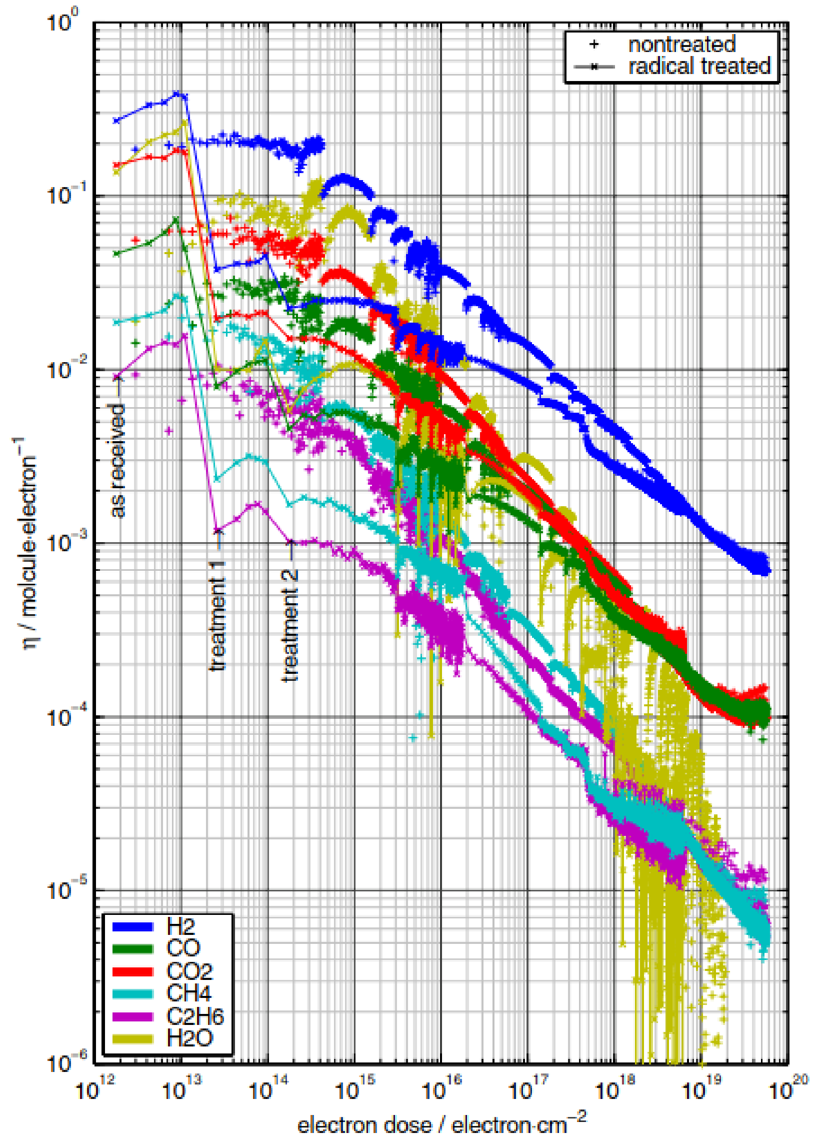


Figure 4.9: The molecular desorption yield as a function of the electron dose – Comparison of an untreated and an oxygen radical treated sample (for further description, see the text)

Data

Total e- current [A]	Pulse duration [ns]	Total charge [C]	Number of electrons	Solid angle (one cell, one side)	Total electrons on copper	Dose per pulse (e- /cm2)
1.00E-04	200	2.00E-11	1.25E+08	0.027439024	4.56E+09	4.42E+08

Source			
G. Vorlaufer CERN-Thesis (2002)	ESD coefficient for H2 (unbaked copper)	Total H2 molecules per RF pulse	Equivalent pressure at RT (total volume)
	2.00E-01	9.11E+08	1.12E-08
	ESD coefficient for CO2 (unbaked copper)	Total CO2 molecules per RF pulse	
	6.00E-02	2.73E+08	3.37E-09
Benvenuti et al LEP2 94-21	ESD coefficient for H2 (copper baked 250 C)	Total H2 molecules per RF pulse	
	1.30E-02	5.92E+07	7.29E-10
	ESD coefficient for CO2 (copper baked 250 C)	Total CO2 molecules per RF pulse	
	6.00E-03	2.73E+07	3.37E-10
Mathewson JVSTA 15 (1997) 3093	ESD coefficient for H2 (copper baked 300 C)	Total H2 molecules per RF pulse	
	3.00E-03	1.37E+07	1.68E-10
	ESD coefficient for CO2 (copper baked 300 C)	Total CO2 molecules per RF pulse	
	1.60E-03	7.29E+06	8.98E-11

10^7 pulses to start conditioning (~2 days at 50 Hz)

10^9 pulses for ÷10 ESD reduction (200 days at 50 Hz)

10 times maximum allowed

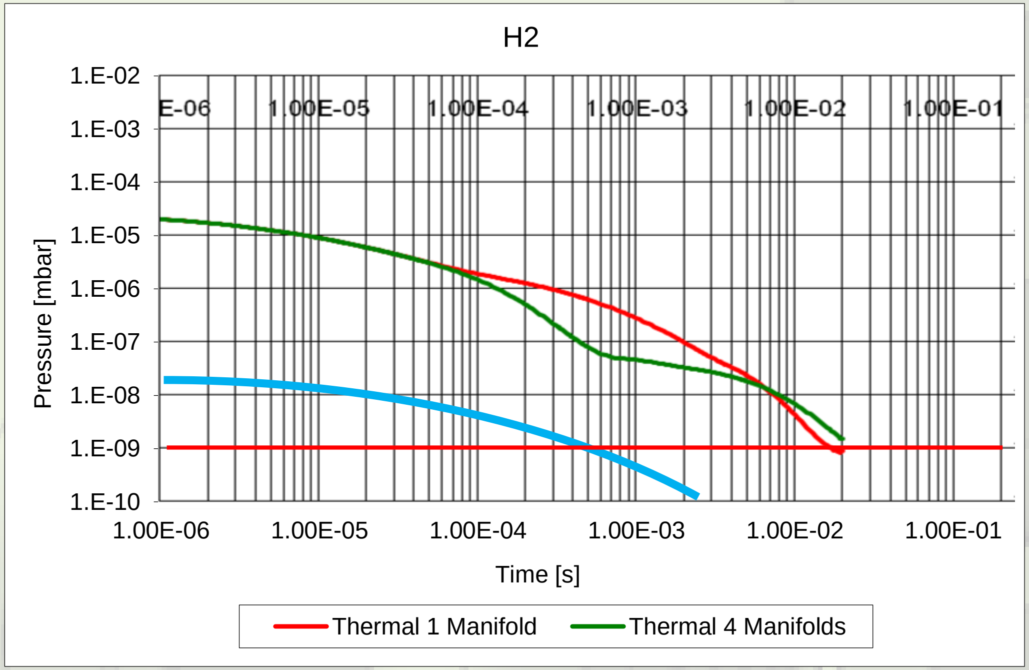
3 times maximum allowed

For the dynamic vacuum of breakdowns we were considering 2×10^{12} molecules.

Need new data on unbaked Cu, at high energies (10s of keV)

Dynamic vacuum I – Results

Molecules released per pulse ~ 10^9 both for H_2 and CO, resulting in pressure bursts of few 10^{-8} mbar locally



Pressure goes to < 10^{-9} mbar in less than 1 msec ! This is faster than the sampling time of common vacuum gauges...

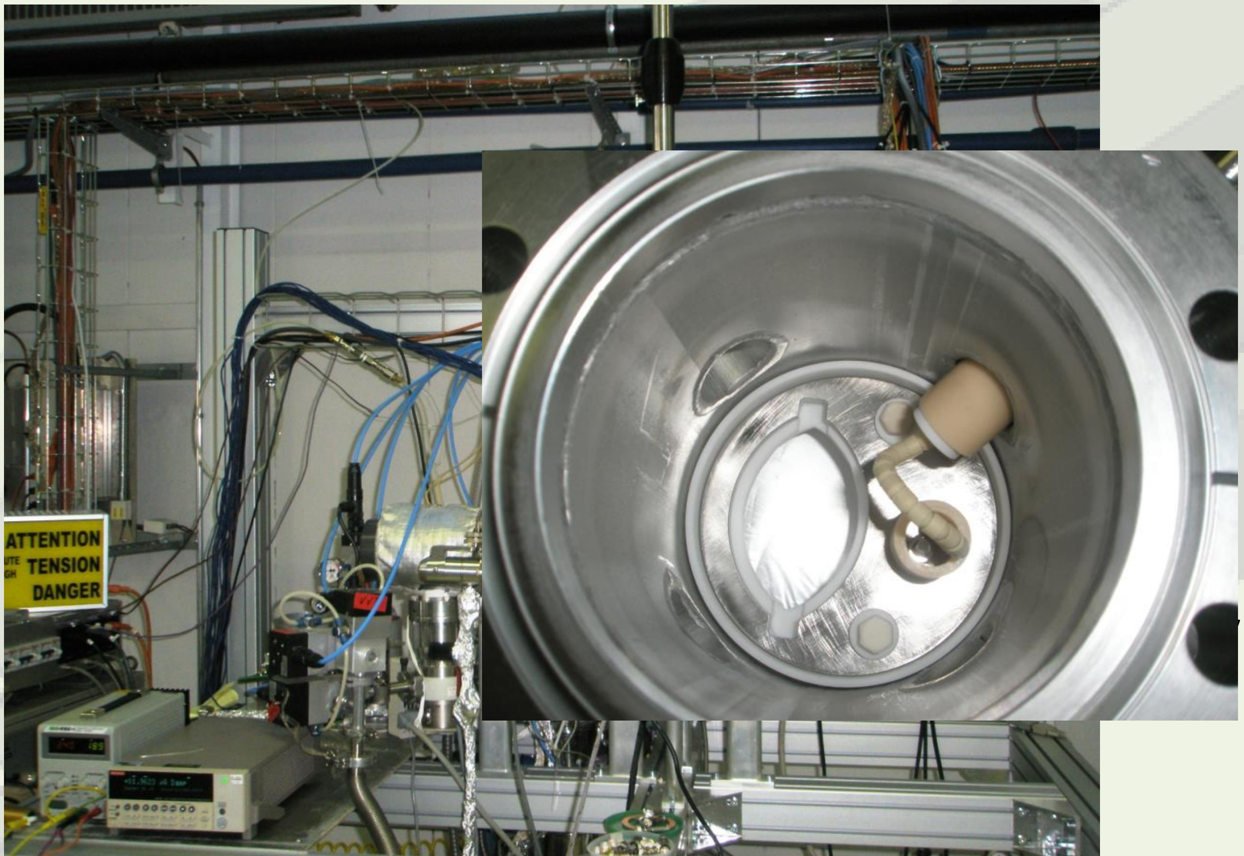
The buildup time and the gas distribution during the RF pulse of 200 ns are unknown

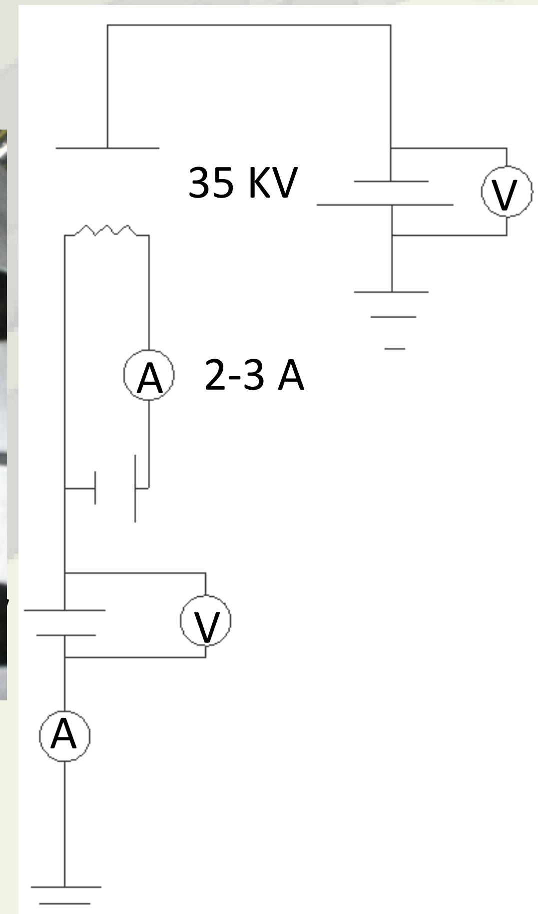
Same plot as for dynamic vacuum due to breakdowns ($2x10^{12}$ molecules released)

Extrapolating to 1000 less molecules released due to ESD

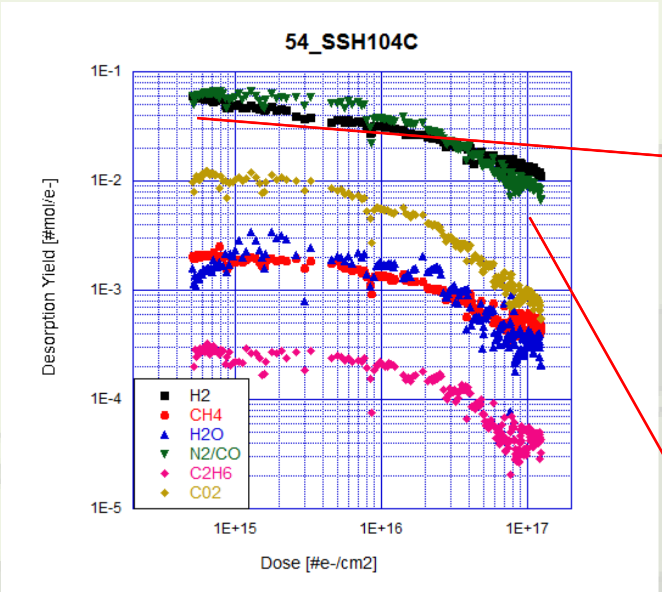
ESD Experimental Set-Up

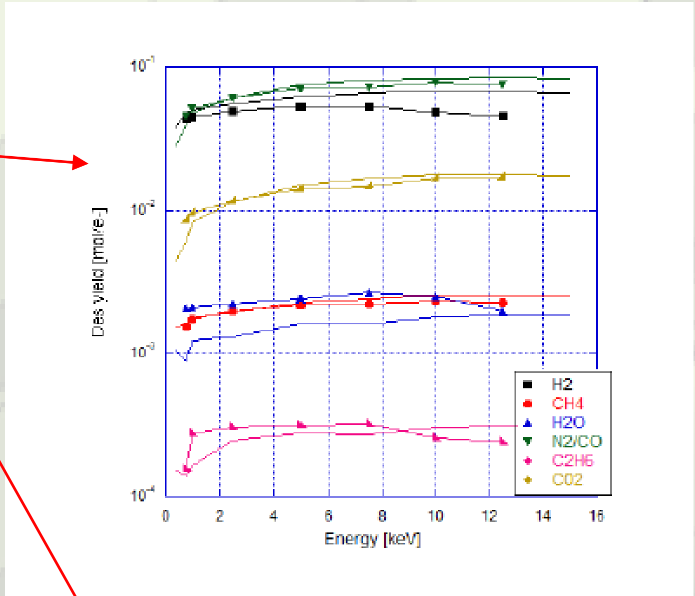
- Work of C. Pasquino & I. Martini for master thesis:
- New ESD measurement system at high-voltage.

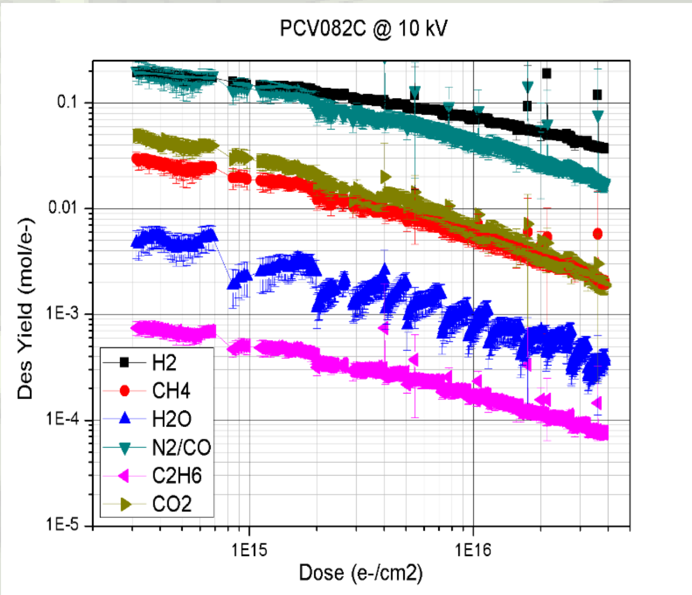


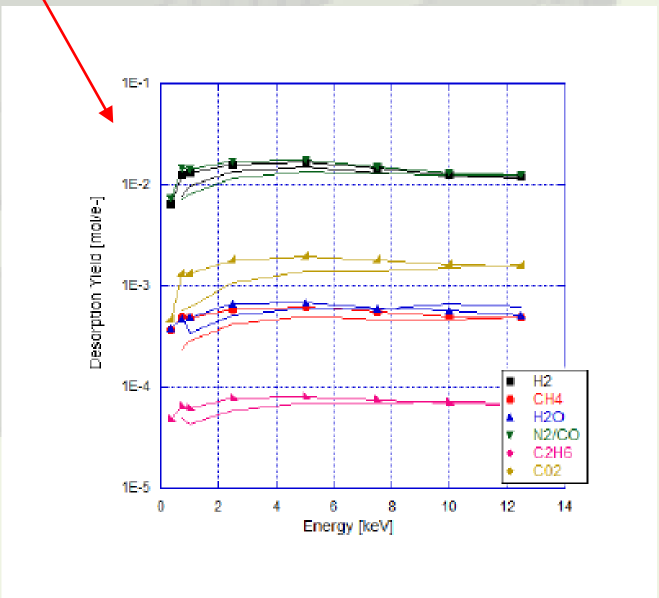


ESD data


54_SSH104C
Desorption Yield [#mol/e-]
1E-1
1E-2
1E-3
1E-4
1E-5
1E+15
1E+16
1E+17
Dose [#e-/cm2]
H2
CH4
H2O
N2/CO
C2H6
C02


Des yield [mol/e-]
Energy [keV]
H2
CH4
H2O
N2/CO
C2H6
C02


PCV082C @ 10 kV
Des Yield (mol/e-)
0.1
0.01
1E-3
1E-4
1E-5
1E15
1E16
Dose (e-/cm2)
H2
CH4
H2O
N2/CO
C2H6
CO2


Desorption Yield [mol/e-]
1E-1
1E-2
1E-3
1E-4
1E-5
Energy [keV]
H2
CH4
H2O
N2/CO
C2H6
C02

Outlook 1

- Static vacuum achieved but only marginally with present design
  - Need more precise data on water re-adsorption (sticking probability depends on coverage)

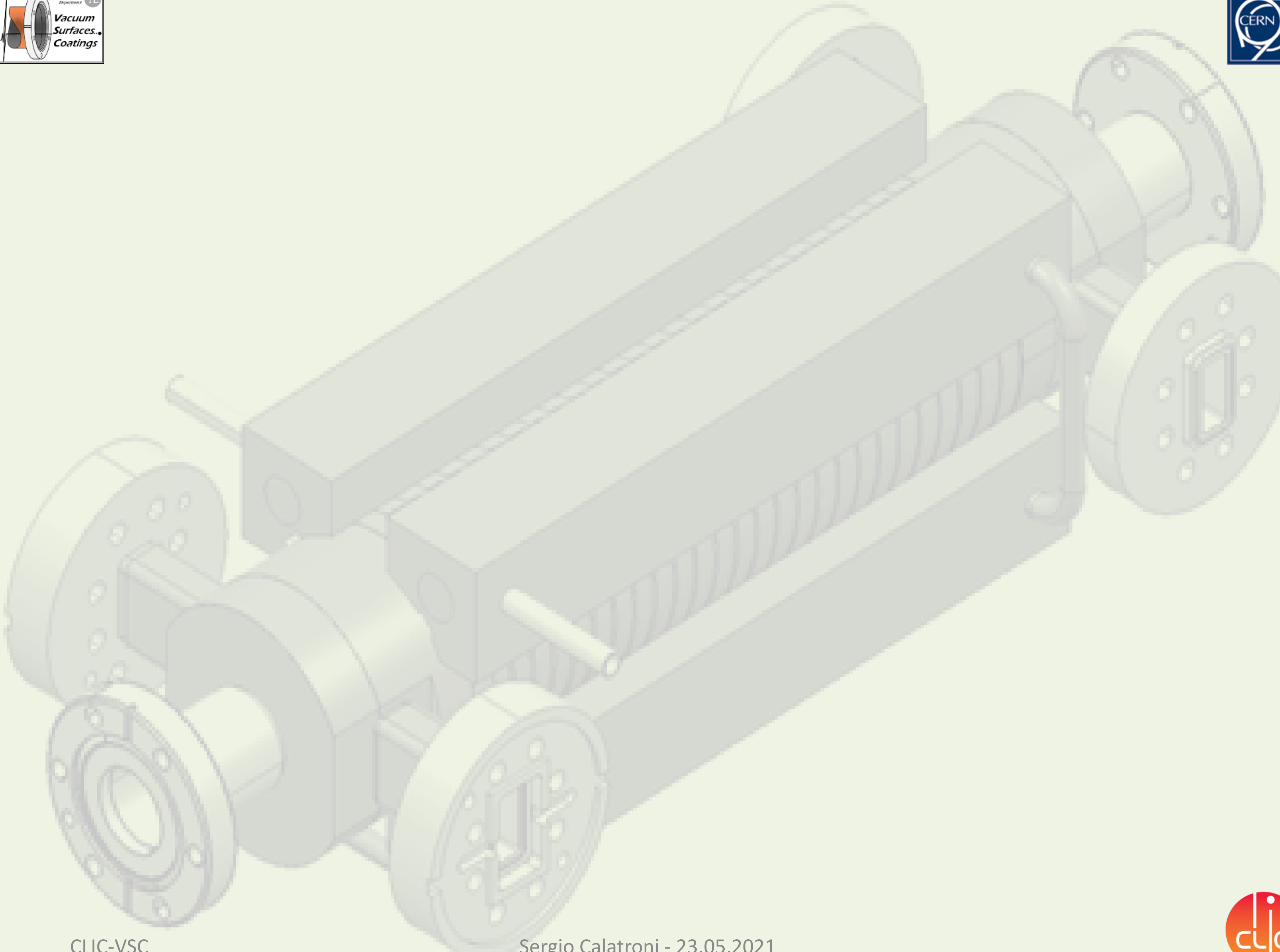
- Dynamic vacuum due to breakdowns seem to be under control (recovery time ≤ pulse repetition)
  - However, data from RF tests are needed for further cross-checking

Outlook 2

- Dynamic vacuum due to dark currents: still open question
- Experimental programme:
  - ESD data on unbaked copper at high e$^-$ energy from CERN √
  - Dark current simulations from SLAC – ACE3P
  - Introduce these into MC+FEM models and get gas distribution
  - Direct measurements should be attempted in 12 GHz test bench
    - Feasibility should be demonstrated
    - Collaborations ?

Outlook 3 - 2021

- Experimental programme, Xbox:
  - Measurement of dynamic pressure, if any
  - Compare these with generic results from Molflow models. Ad minimum, set an upper limit on dynamic vacuum pressure.
  - Simulate dark current distribution
  - Simulate using Molflow and ESD coefficients from HV measurement the gas buildup dynamics
  - Resume ESD measurement campaign at HV
- Experimental programme, LES:
  - Direct measurement of dynamic pressure, if any
  - Compare with Molflow simulations (frame already set in 2020 for pumpdown studies)



Molecule speed

	Atomic mass	Molecule speed @ 300 K [m/s]	Molecule displacement in RF pulse [mm]
H2	2	1579	3.16E-01
H2O	18	526	1.05E-01
CO	28	422	8.44E-02
CO2	44	336	6.73E-02

Assuming a molecular speed of 300 K = 0.026 eV