Progress on investigation of dynamic vacuum (RF structures only)

Sergio Calatroni

With Cedric Garion, Chiara Pasquino, Pedro Costa Pinto, Mauro Taborelli

Outline

- Requirements from beam dynamics
- Static vacuum
- Dynamic vacuum
  - Breakdowns
  - Dark current
- Experimental approach
  - ESD measurements
  - Direct measurement
- Outlook and conclusions

Requirements from beam dynamics

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

H_2 and CO_2 partial pressures < 10^{-9} Torr

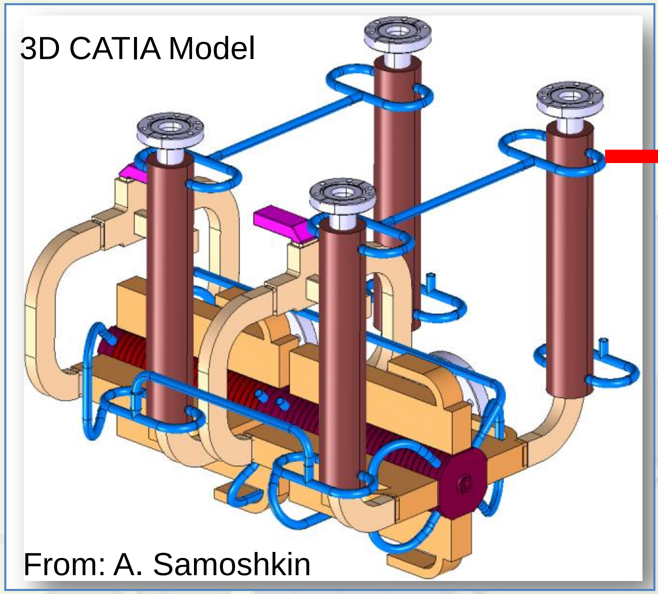
- This happens for practically all the main LINAC length, inside the RF accelerating structures
- For details see G. Rumolo, J-B Jeanneret, D. Schulte and C. Garion (this workshop)

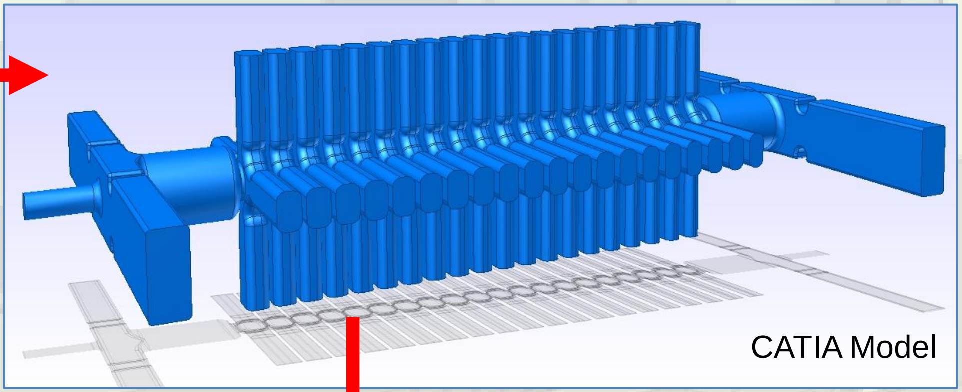
Tools for dynamic vacuum calculations

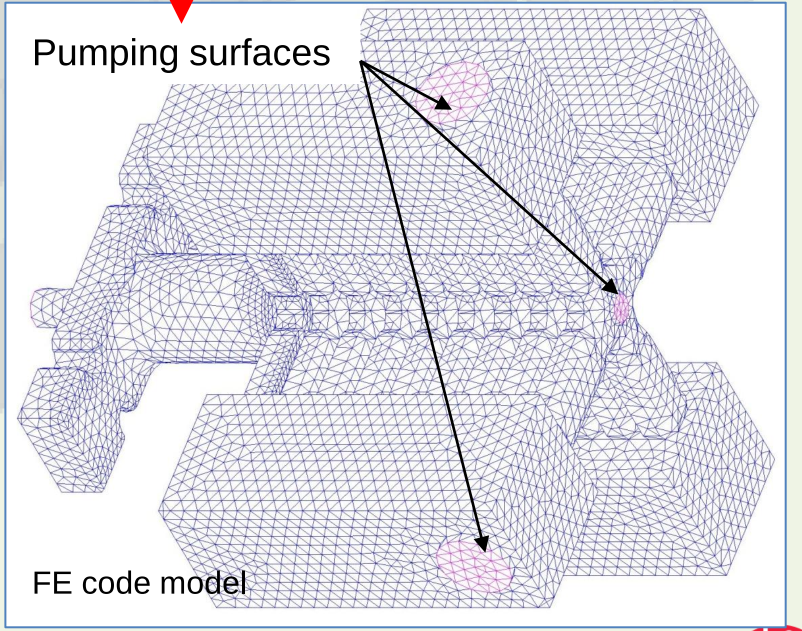
- Several tools have been developed for the calculation of dynamic vacuum:
  - Thermal analogy implemented in FEM by Cedric Garion
  - Monte-Carlo simulations implemented in CASTEM (FEM code) by Cedric Garion (CLIC09 Workshop)
  - Electrical analogy implemented in PSpice, with conductance of single elements calculated by Monte-Carlo by Pedro Costa Pinto (TS Workshop 08)
  - Analytical models by Volker Ziemann (Uppsala University)

- All tools have been crosschecked and agree within 10%

Static vacuum – thermal analogy







Calculations are based on the equivalence of vacuum and thermal conductances, which are evaluated by FE analysis, and using the following outgassing values (H_2O):

10^{-10} mbar.l.sec^{-1}cm^{-2} for 100h pumping

10^{-11} mbar.l.sec^{-1}cm^{-2} for 1000h pumping

Does not take into account re-adsorpion

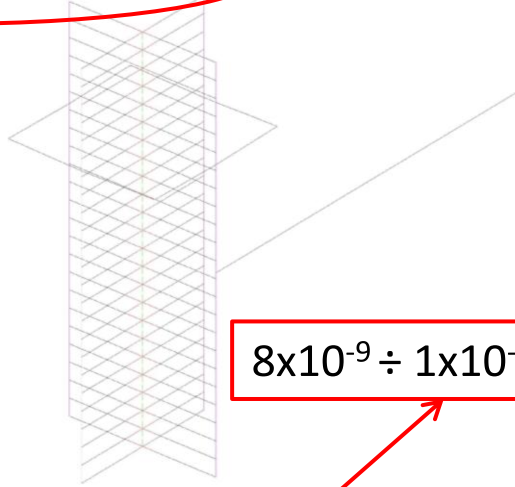
Static vacuum - Results

One word on FE analysis based on thermal/vacuum analogy (1D model)

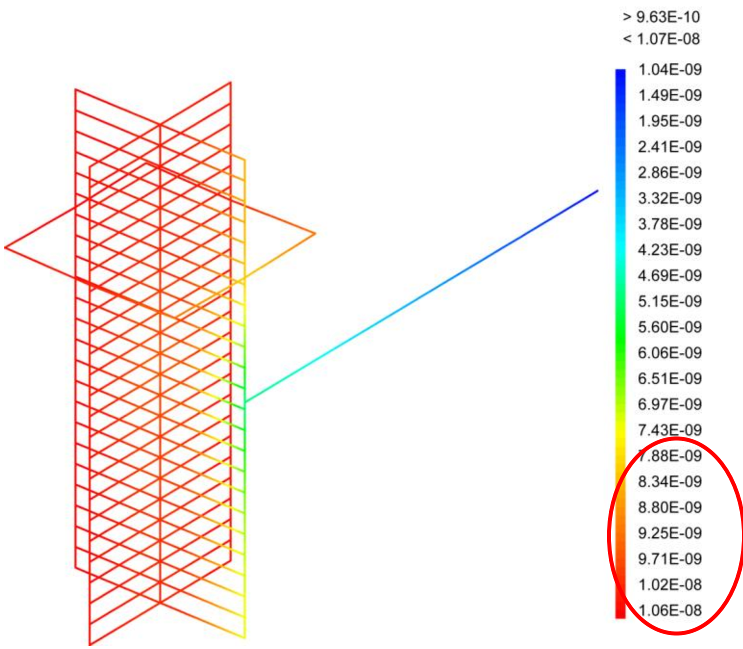
Based on outgassing (H_2O): 10^{-10} mbar.l.sec^{-1}cm^{-2} for 100h pumping

Heat transfer equation: $\rho c_p \frac{\partial T}{\partial t} = q + k\Delta T$

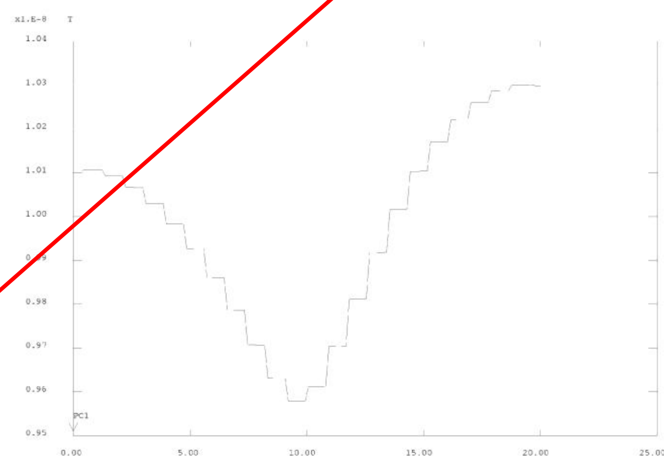
Gas flow equation (1D): $S \frac{\partial P}{\partial t} = a + c \frac{\partial^2 P}{\partial x^2}$



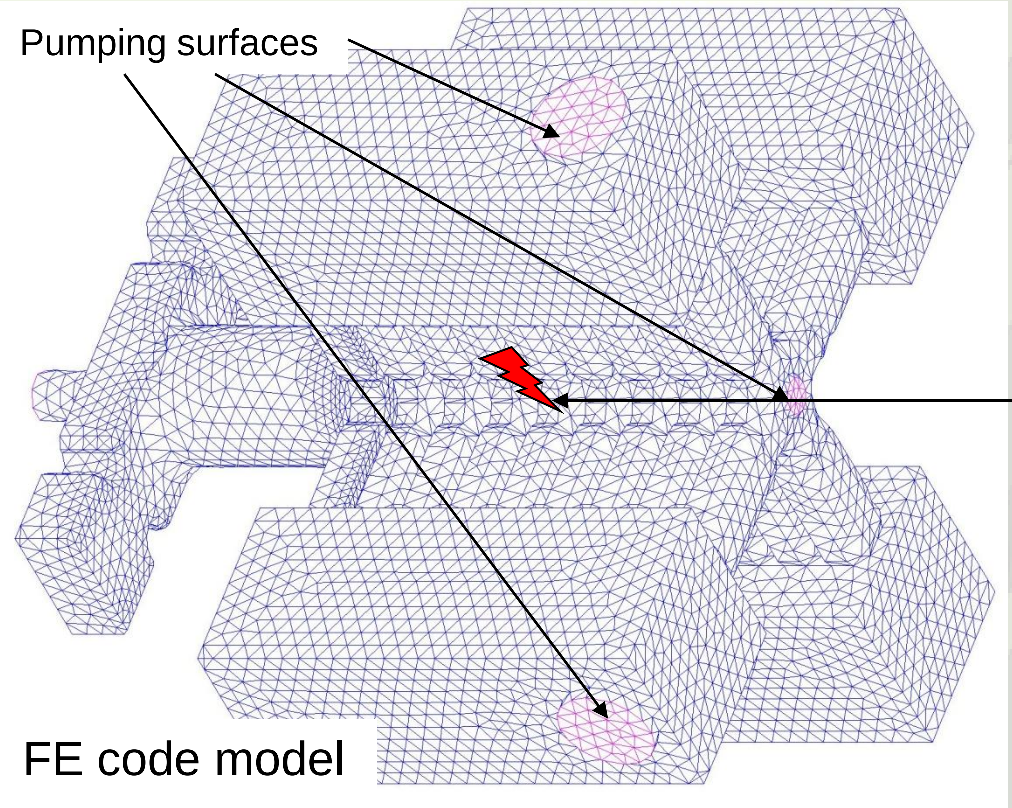
$8\text{x}10^{-9} \div 1\text{x}10^{-8}$ mbar



Static vacuum



Dynamic vacuum I - Breakdown



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 I – Results

Calculated with Monte-Carlo and thermal analogy model

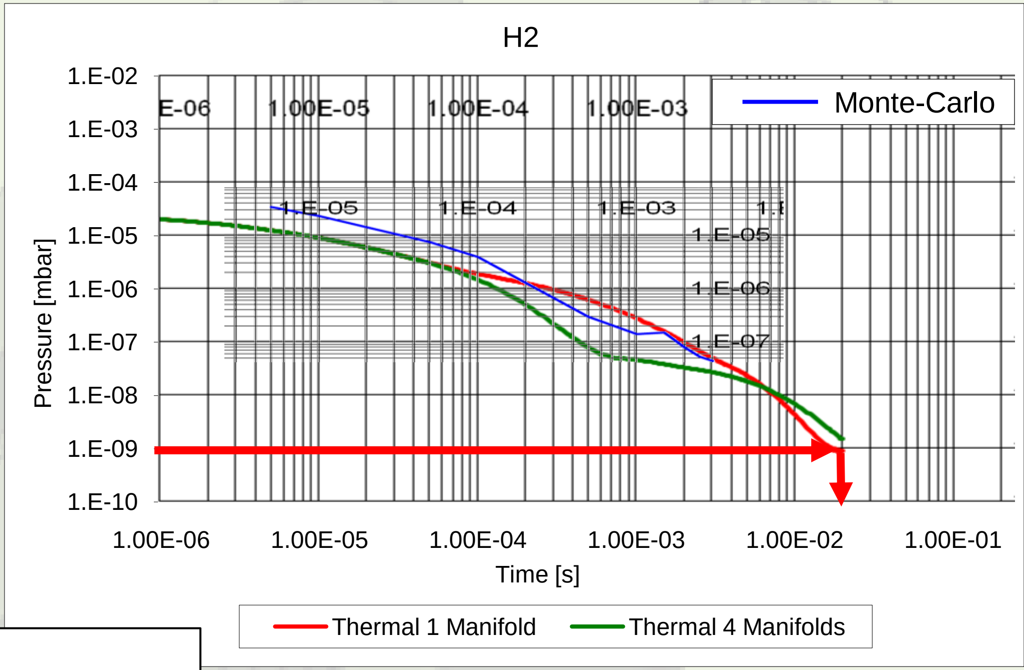
Maximum pressure vs time:

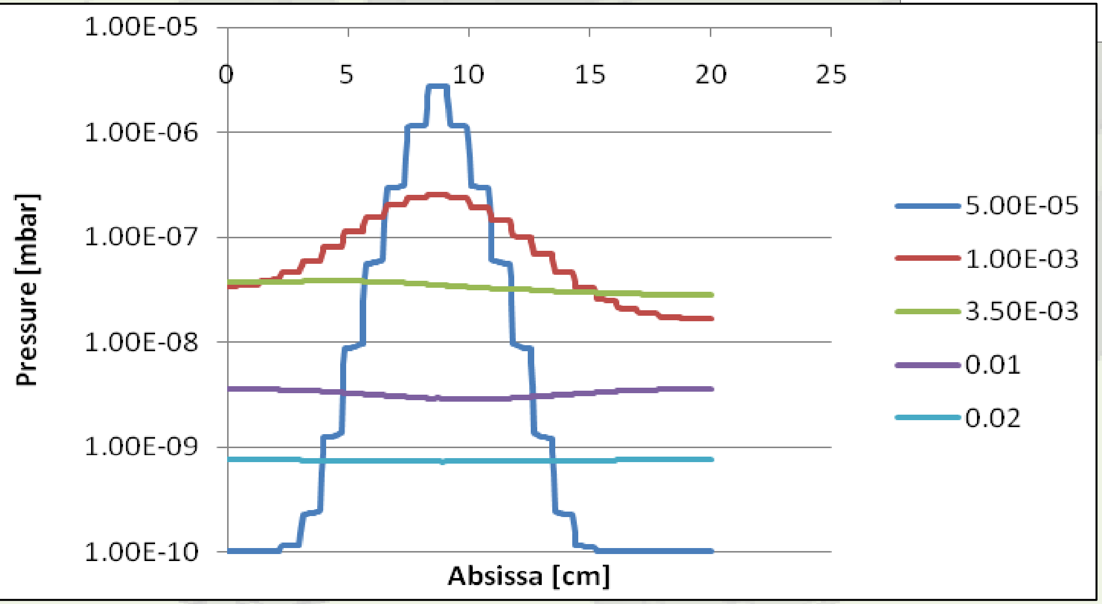
20 ms to reach 10^{-9} mbar for H_2

20 ms to reach $5x10^{-8}$ mbar for CO

(Note: CLIC repetition rate = 50 Hz

Duty cycle = 20 msec)





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

Four manifolds

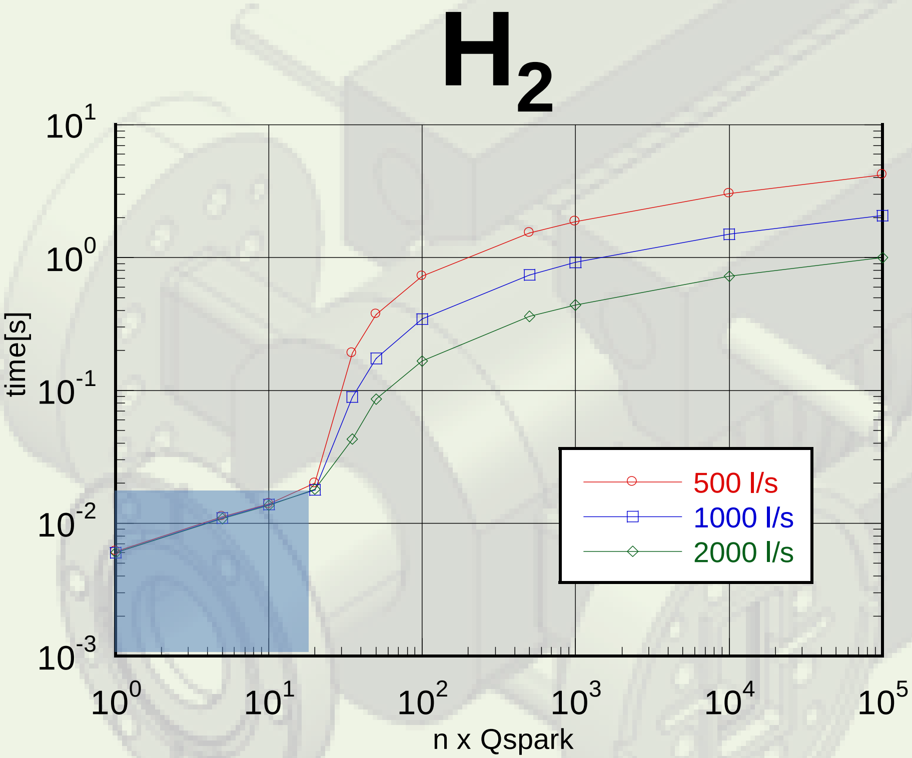
Longitudinal pressure distribution in the cells:

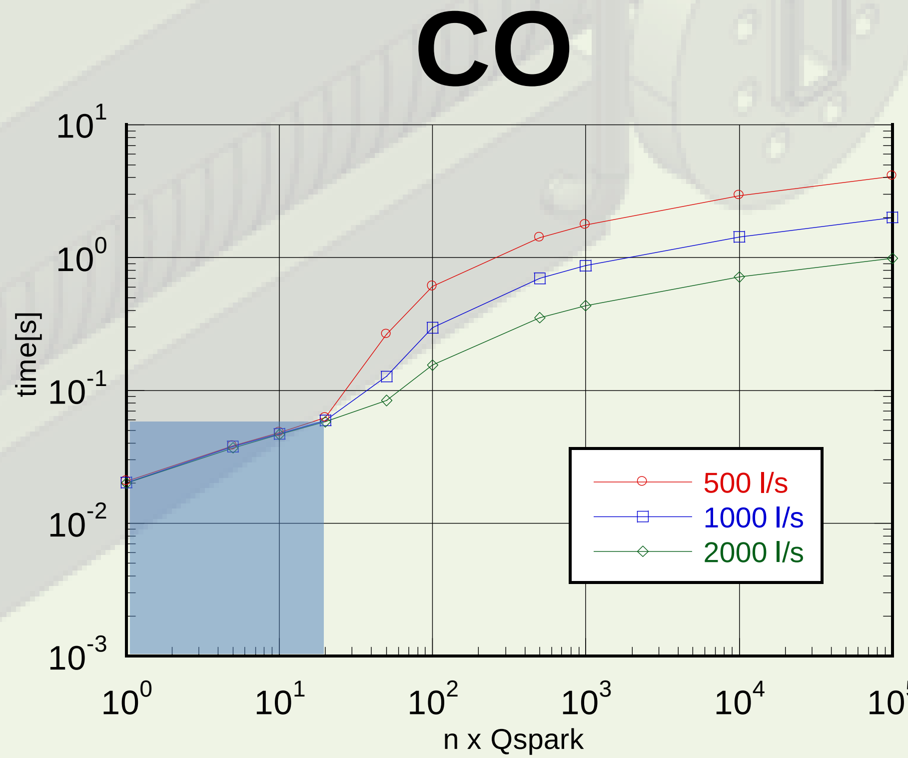
Uniform after ~3 ms

Dynamic vacuum I – Effect of a manifold

- Calculated recovery time to 10^{-8} mbar with PSpice for a quadrant type structure in a CTF2 type tank (**old data**)
- For one sparks outgassing Qspark, or multiples of it equal to n x Qspark

- Two regions: first is determined by the filling time of the cavity + tank volume
- Second is determined by the applied pumping speed



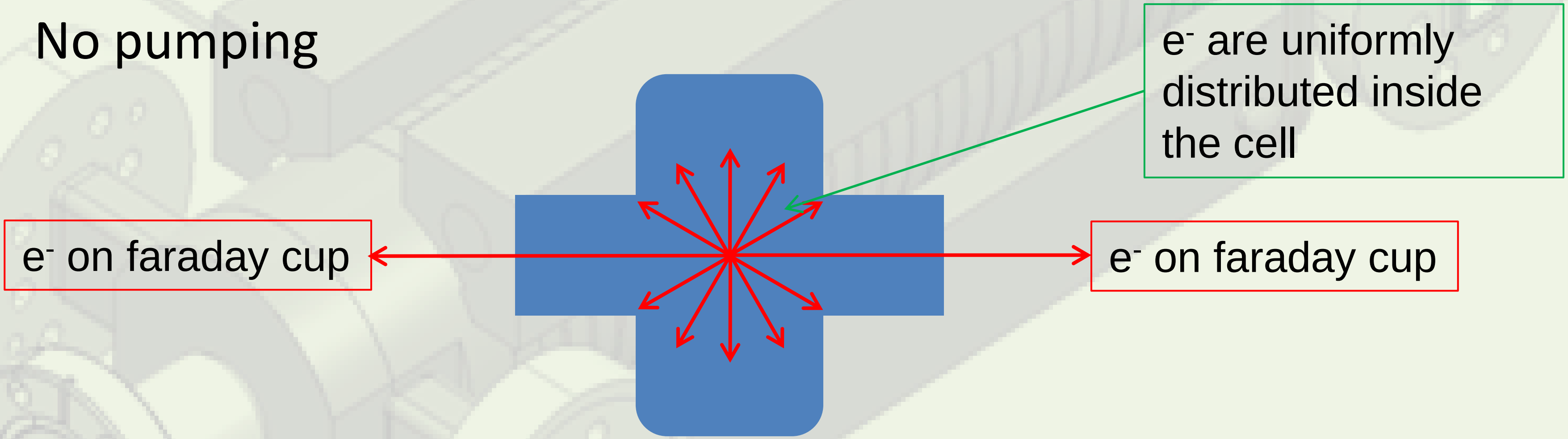


Dynamic vacuum II – Dark currents

- Dynamic vacuum due to field emission: the problem
  - Electrons are field-emitted from high field regions in absence of a breakdown (dark current).
  - They hit the cavity wall releasing gas by Electron Stimulated Desorption (ESD)
  - Outgassed molecules are emitted with eV speeds, but after first collision they are thermalized and then travel <1 mm during the 200 ns RF pulse, thus cannot escape from RF structure.
  - Timescale of the order of the RF pulse duration: outgassing at the beginning of the pulse may affect bunches within the same train.
  - Very difficult to measure: we may have $p>10^{-9}$ mbar locally during the 200 ns RF pulse (in all structures) in a small volume. When this is diluted and pumped through the conductance of the RF structure, it may not be measureble

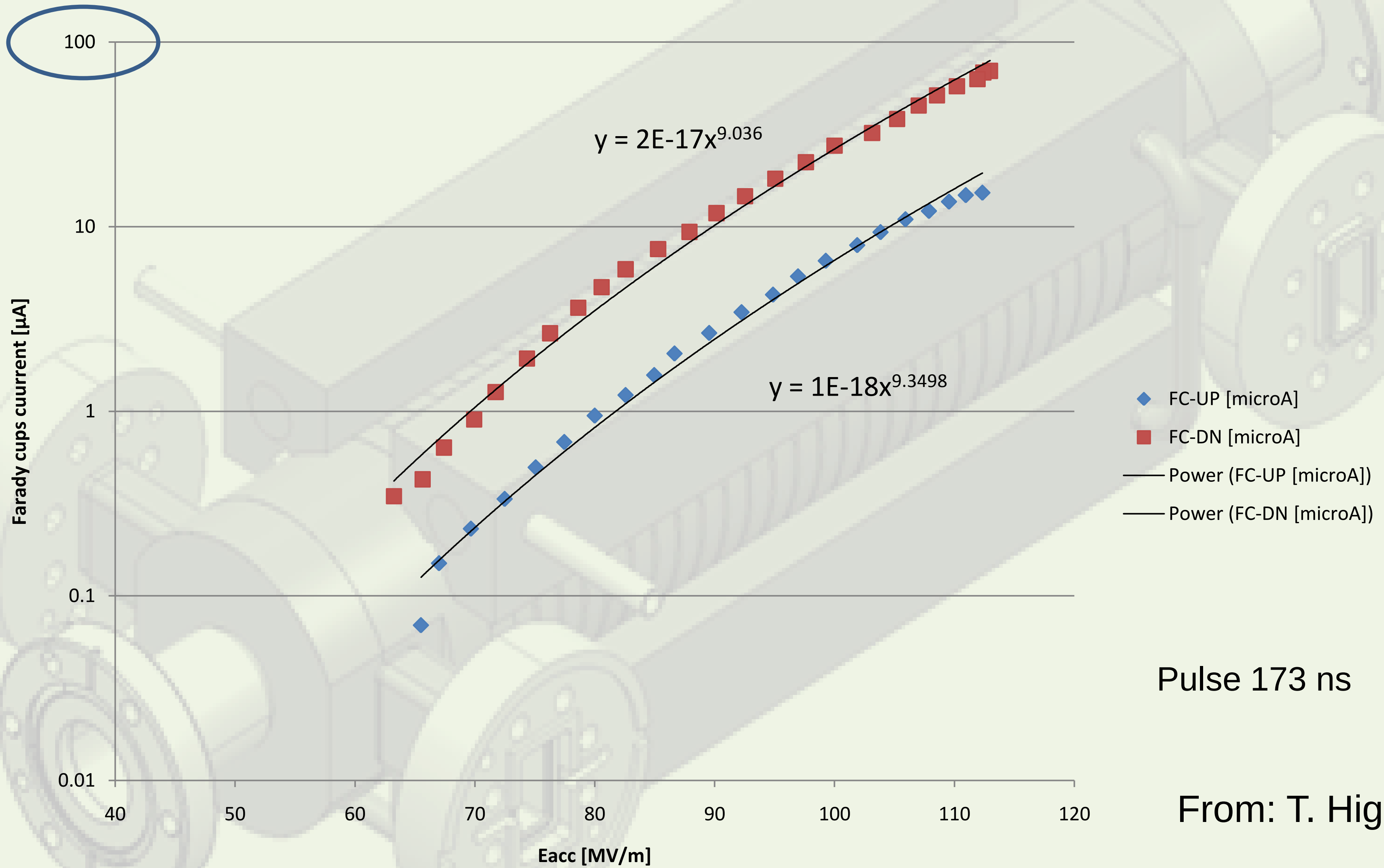
Dynamic vacuum II – (over-)simplified model

- Only one cell is modelled
- Electrons are field-emitted, then accelerated and distributed uniformly in the cell
- Dynamic vacuum by ESD: desorbed molecules fill the whole cell volume
- No pumping



Cell [mm]	dimensions	outer area	beam area	copper area	cell volume [mm3]	beam channel [mm3]
Ext diam	20	1086.99	28.27	1030.44	2293.36	206.40
Iris diam	6				cell volume [liters]	beam channel [liters]
Length	7.3				2.29E-03	2.06E-04

Faraday cup measurements - T18_VG24_Disk_2 - KEK



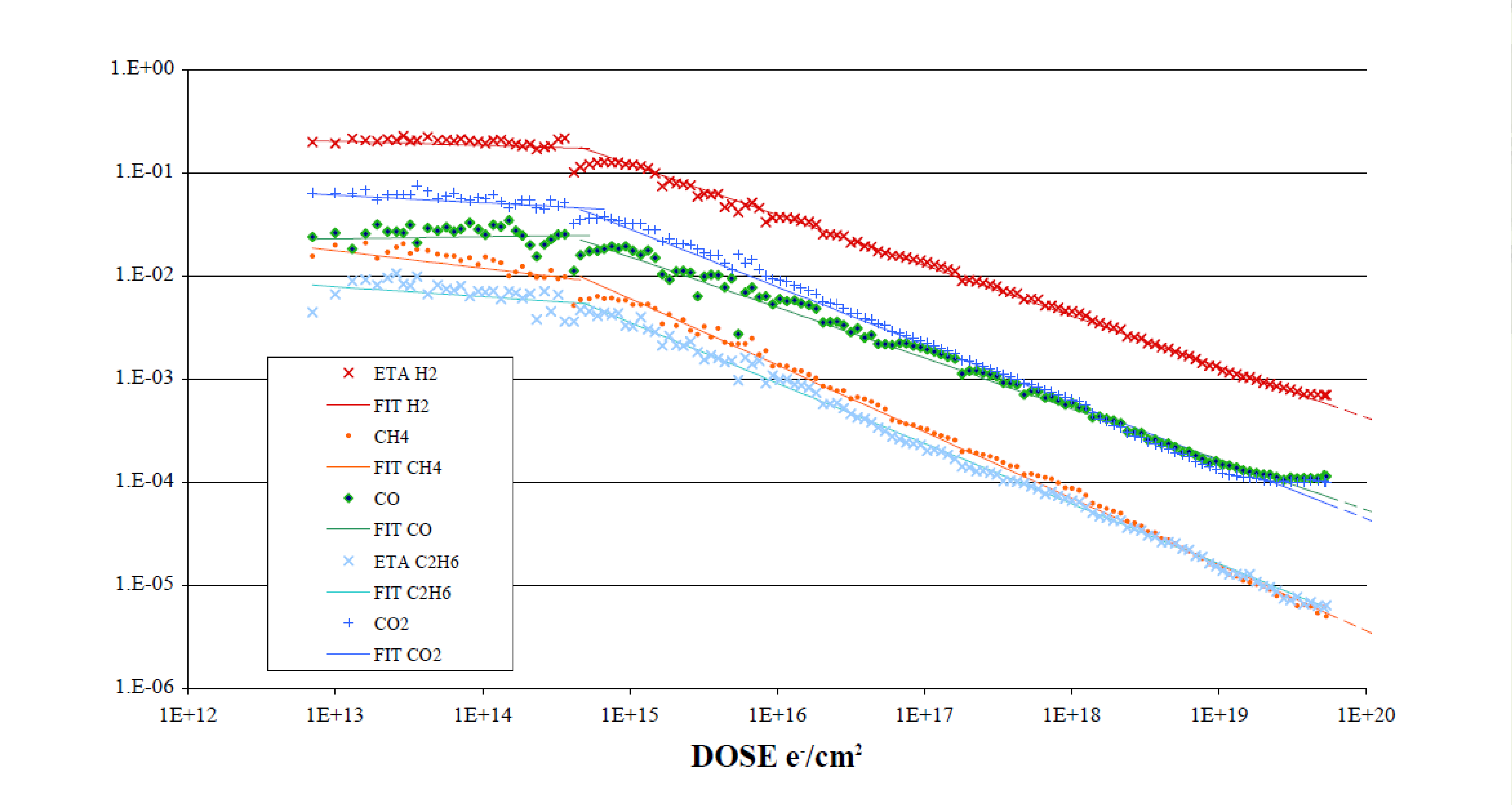
Pulse 173 ns

From: T. Higo

ESD data

- No much data on unbaked copper

(N. Hilleret, CAS Vacuum School 2006 - G. Vorlaufer CERN-Thesis (2002))



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

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)

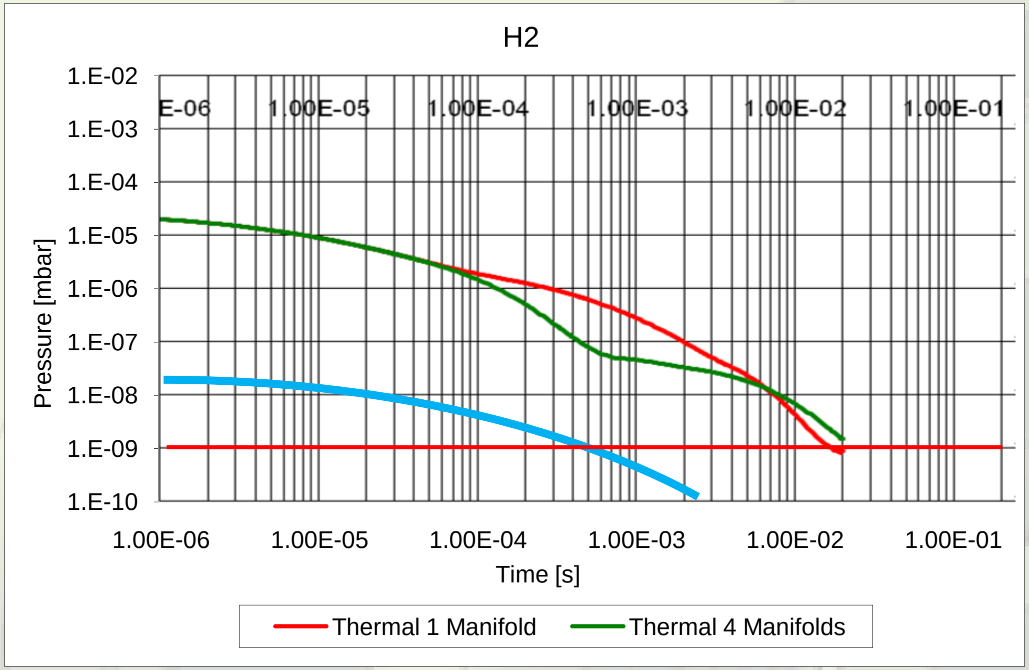
10^9 pulses for ÷10 ESD reduction (200 days at 50 Hz)

10 times maximum allowed

3 times maximum allowed

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

Dynamic vacuum I – Results



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

Same plot as for dynamic vacuum due to breakdowns (2×10^{12} molecules released)

Extrapolating to 1000 less molecules released due to ESD

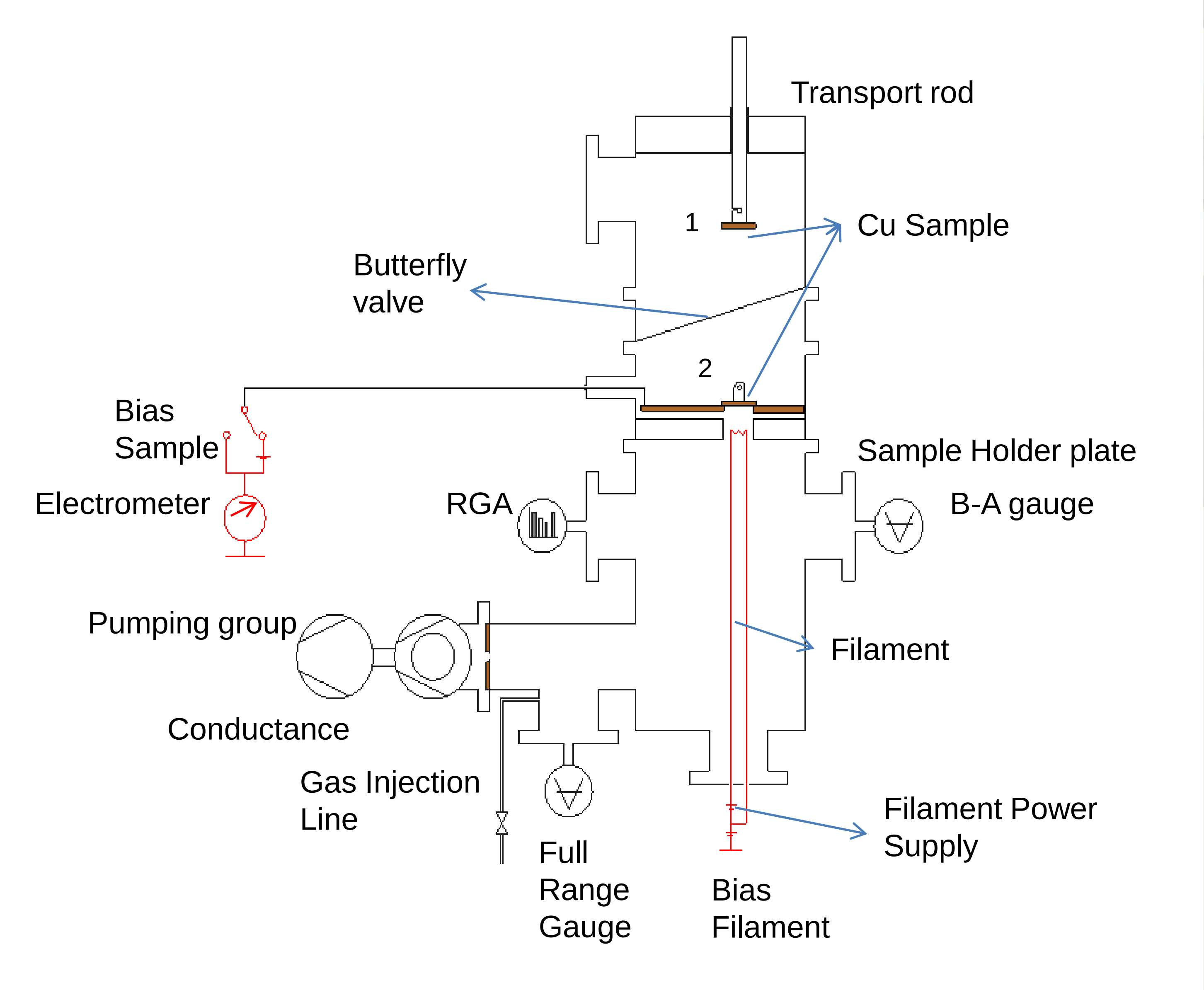
Experimental programme

- Get more precise data on ESD: higher electron energies, effect of surface treatments and of fabrication procedure

- Obtain e^- trajectories maps for reasonable assumptions of distributions of field-emitters, and calibrate the intensities with known Farady-cup dark current measurements.

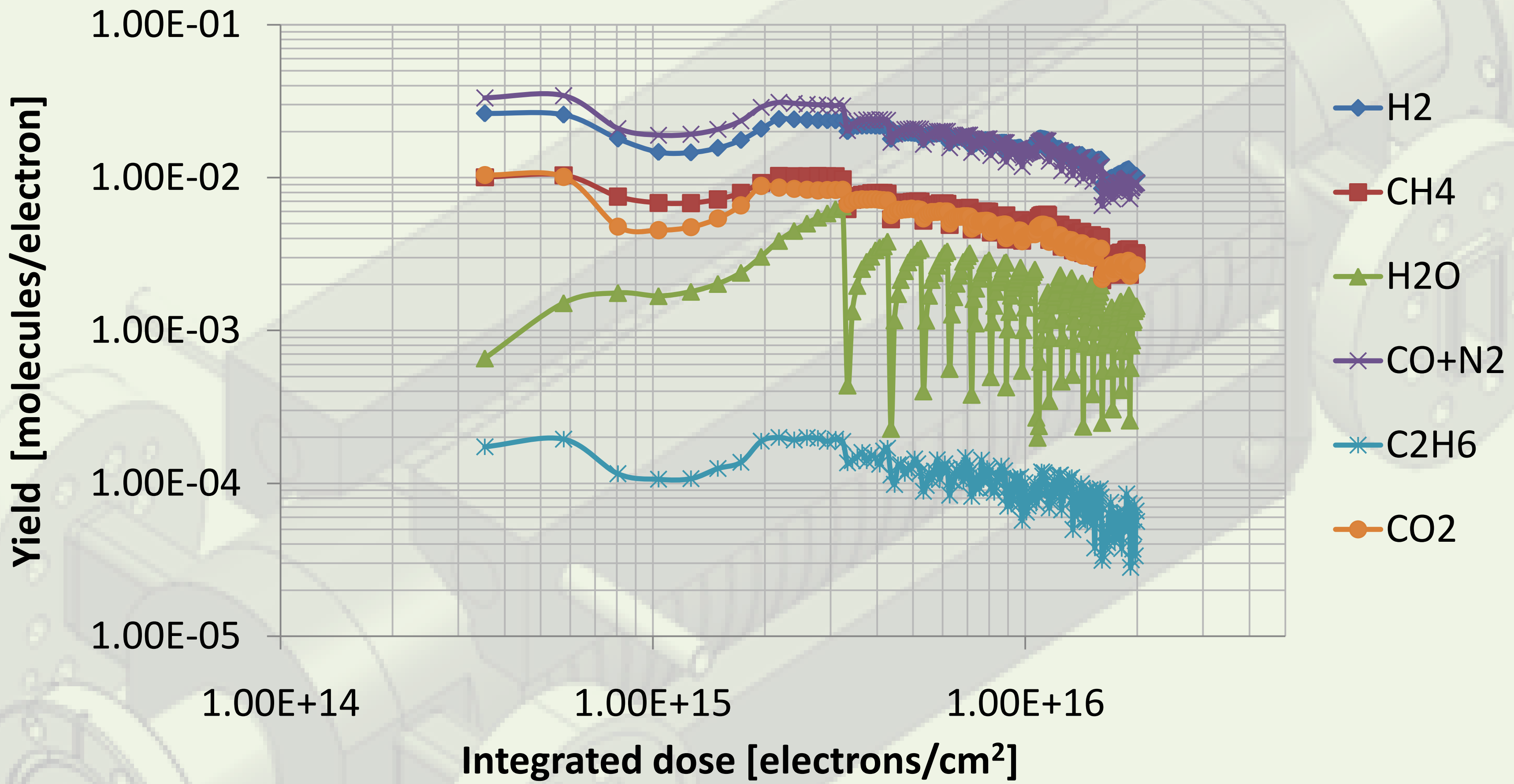
- Couple the above data as input for Monte-Carlo simulations of trajectories and densities of outgassed molecules

ESD measurement system



ESD system pictures

First results (dummy Cu specimen)



The system is operational (Diploma thesis of Chiara Pasquino)

Rationale

- We want to study the effect of surface treatments and fabrication on ESD
- Large number of samples have been prepared (will be tested also by “spark-test”, SEM, XPS)

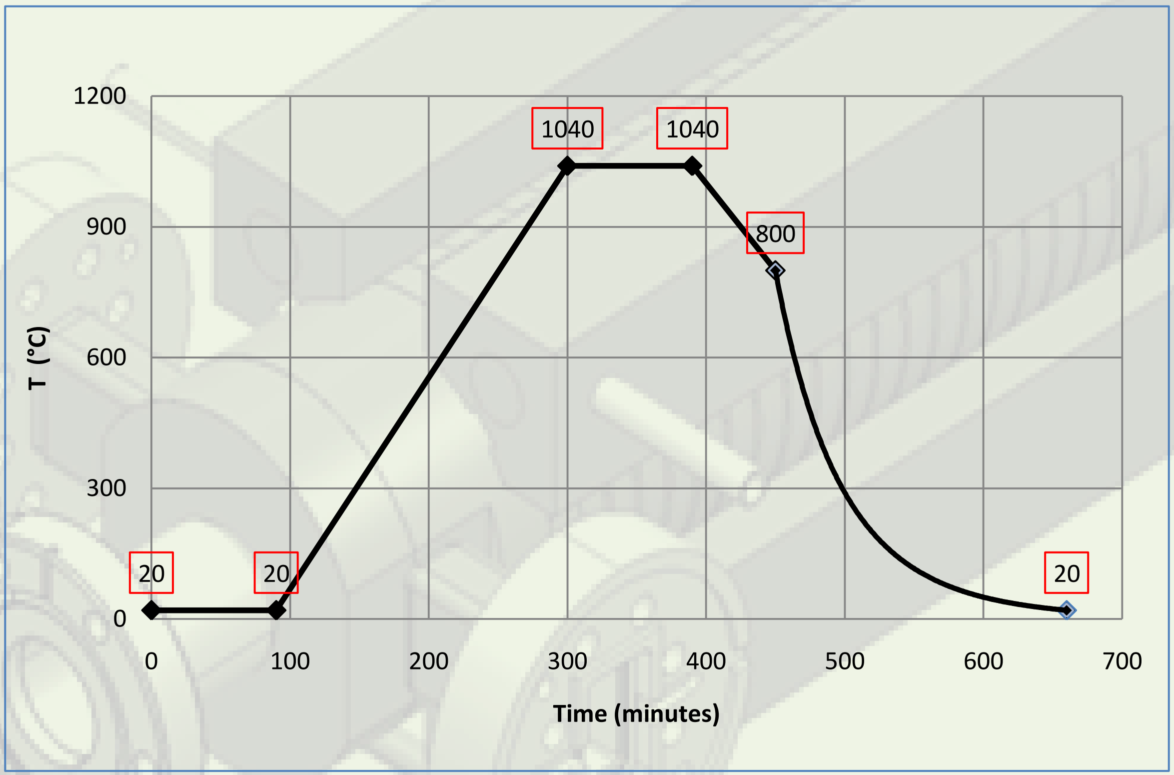
main steps: Machining → Cleaning → Heat treatment → ESD

Vacuum

	REFERENCE			Vacuum			Argon (mbar)			H2 (mbar)			H2 (1 bar)			Vacuum			Argon (mbar)			Hydrogen (mbar)			Hydrogen (1 bar)			
	w/o etch	Passiv ation	SLAC etch	w/o etch	Passiv ation	SLAC etch	w/o etch	Passiv ation	SLAC etch	w/o etch	Passiv ation	SLAC etch	w/o etch	Passiv ation	SLAC etch	w/o etch	Passiv ation	SLAC etch	w/o etch	Passiv ation	SLAC etch	w/o etch	Passiv ation	SLAC etch	w/o etch	Passiv ation	SLAC etch	
CERN	2	2	2	2	2	2										2	2	2	2	2	2							24
Bodycote							2	2	2	2	2	2										2	2	2				18
SLAC													2	2	2										2	2	4	14
	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	**56**
elliptical																												

Heat treatment under hydrogen

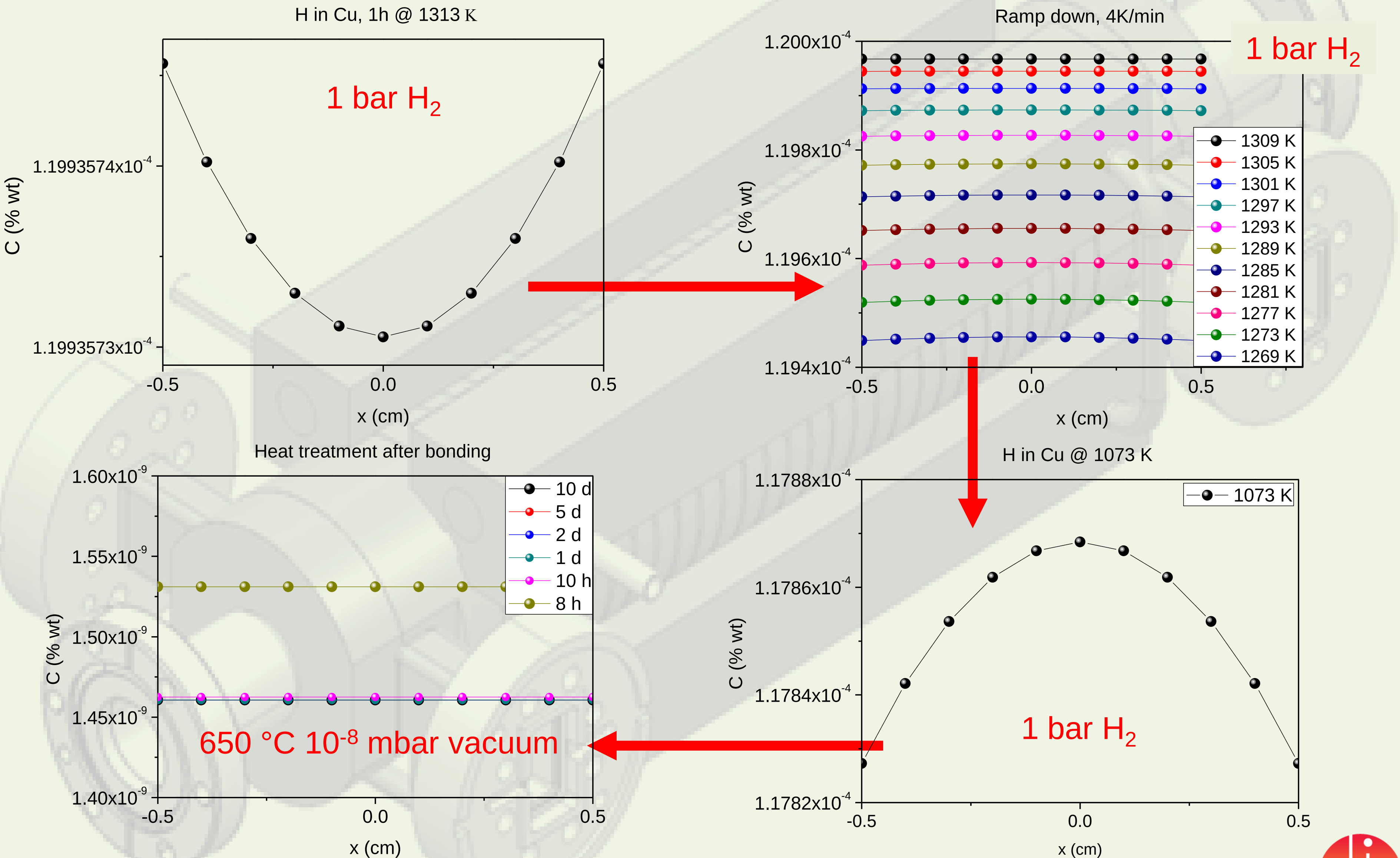
- Rationale for the calculations:
  - H_2 bonding introduces hydrogen in the copper, subsequently outgassed in vacuum annealing.
  - Any H_2 leftover may influence ESD



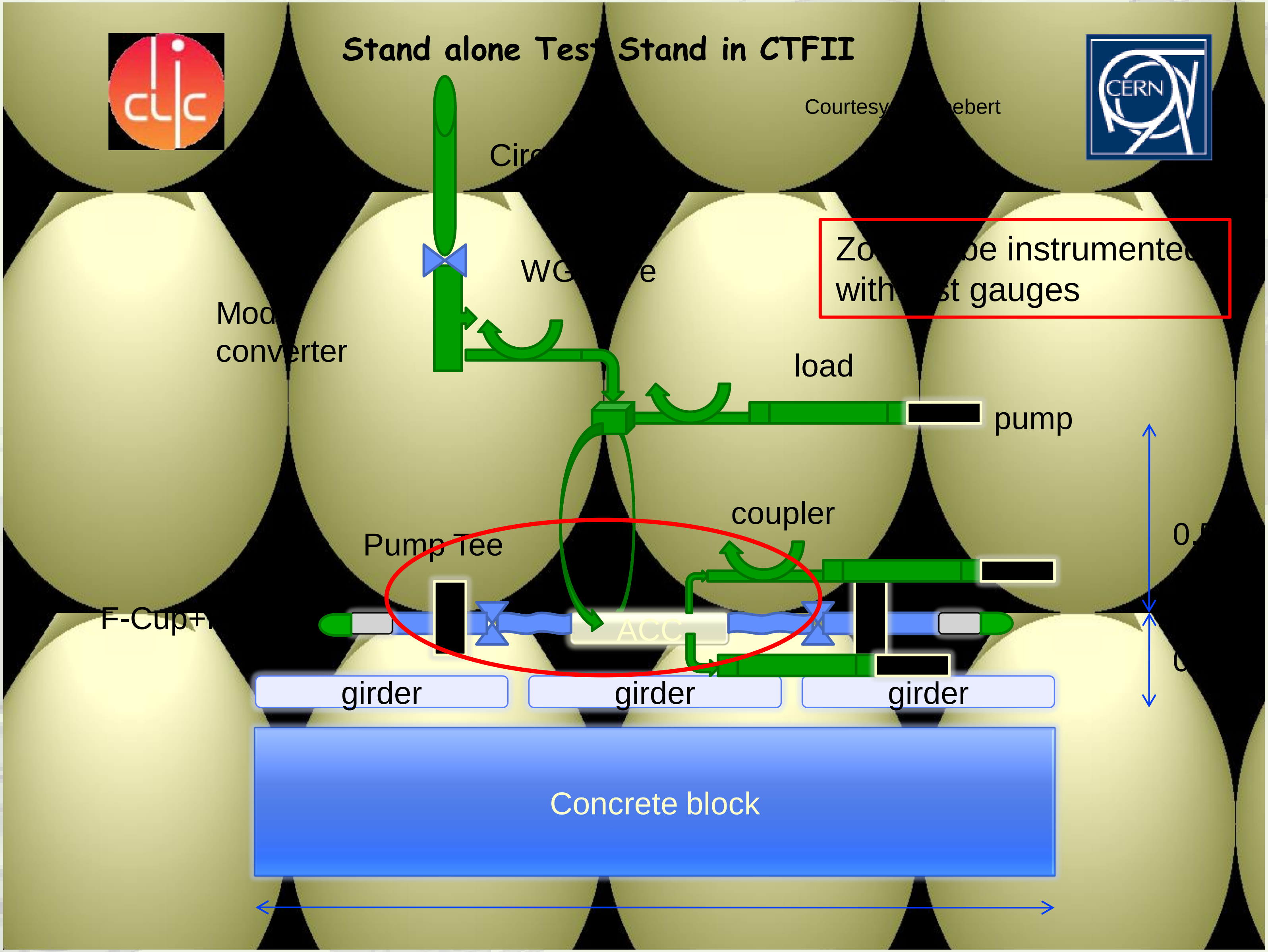
Bonding at 1040 °C with 1 bar of H_2

Annealing at 650 °C for 10 days
$1x10^{-8}$ mbar vacuum

Calculated data (assume Cu sheet 1 cm thick)



Direct measurements, anyway



From: K.M. Schirm

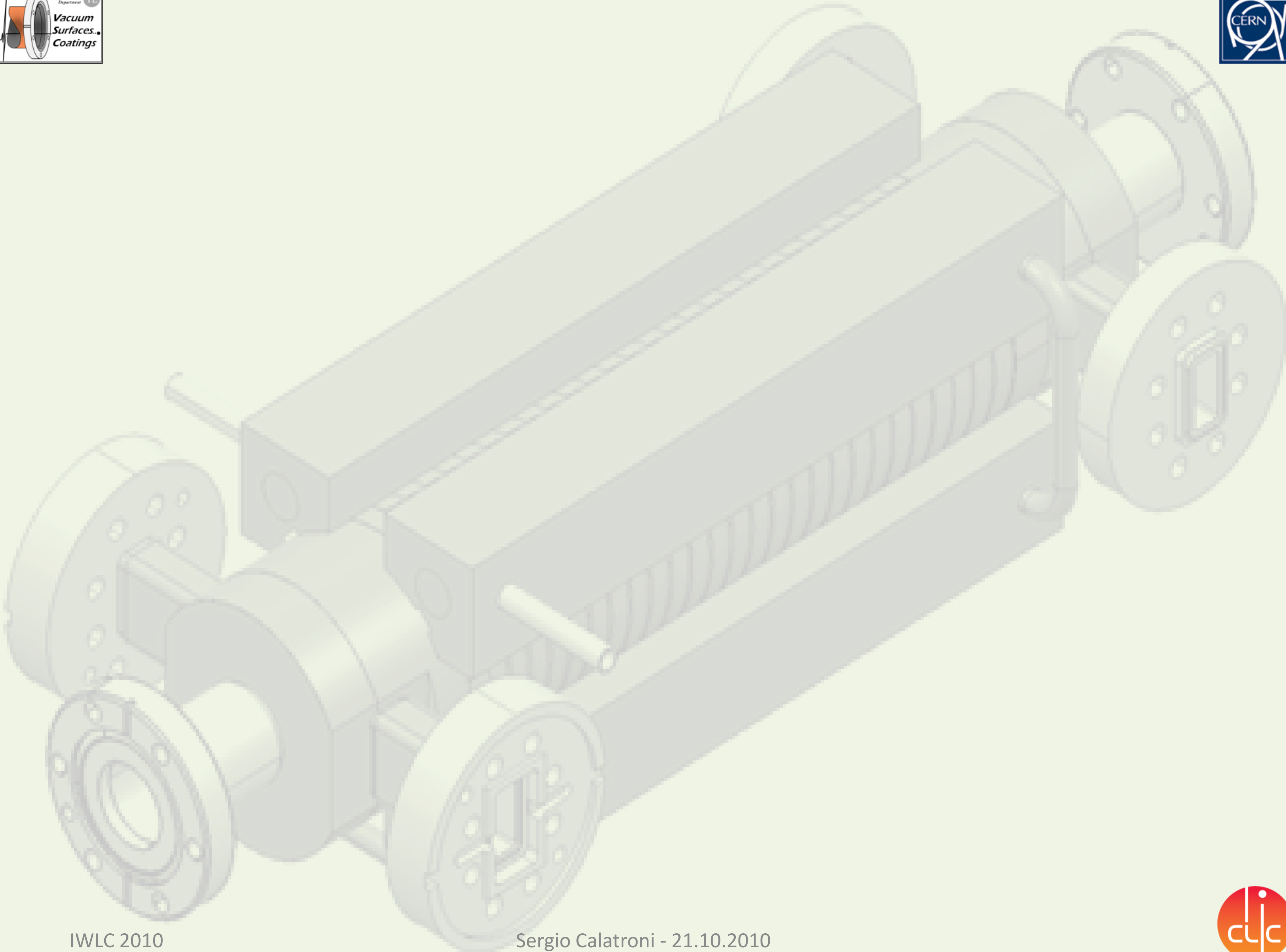
Outlook 1

- Static vacuum seems to be achieved 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 will be attempted in 12 GHz test bench (although feasibility is questionable)



Molecule speed

	Atomic mass	Molecule speed @ 300 K [m/s]	Molecule displacement in RF pulse [mm]
H_2	2	1579	3.16E-01
H_2O	18	526	1.05E-01
CO	28	422	8.44E-02
CO_2	44	336	6.73E-02

Assuming a molecular speed of 300 K = 0.026 eV

Tentatively crosschecked with CTF2 data + Montecarlo simulations