Journées Accélérateurs, Roscoff 2021

DYVACS (DYnamic VACuum Simulation) code

Calculation of gas density profiles in presence of Electron Cloud

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MAVERICS team at IJCLab

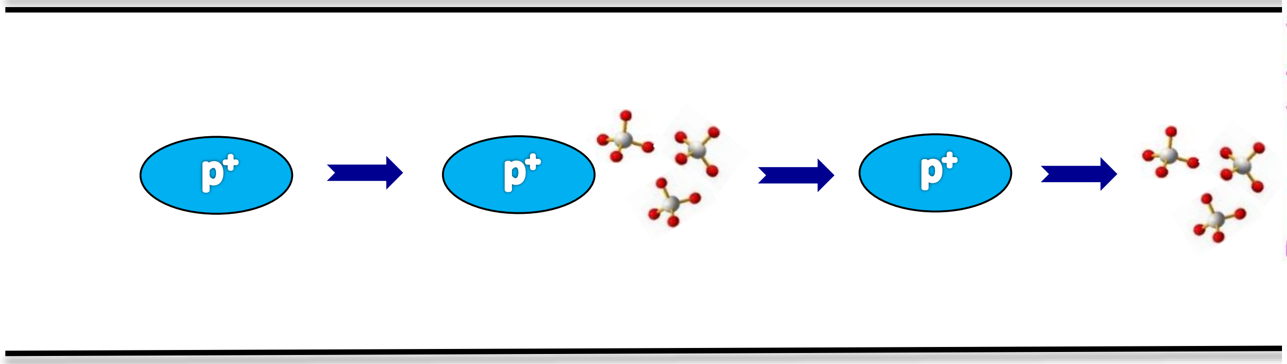
October 15, 2021

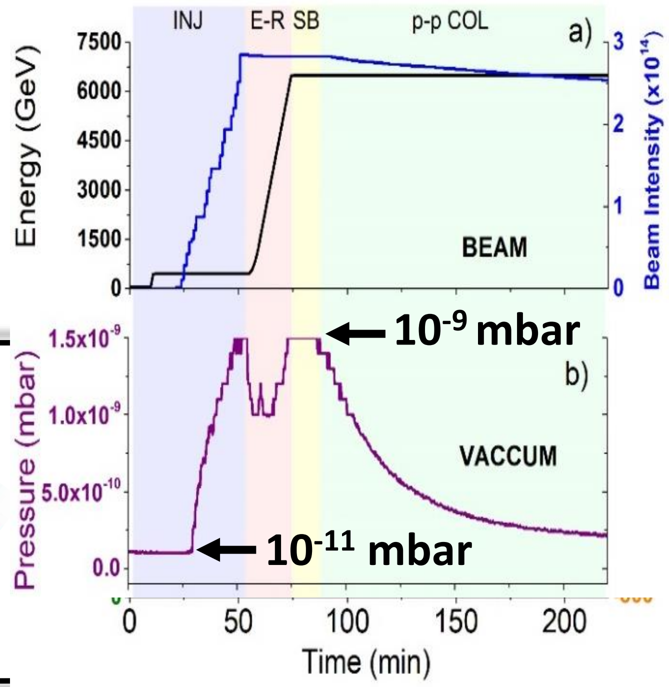
Gas density in presence of E-Cloud

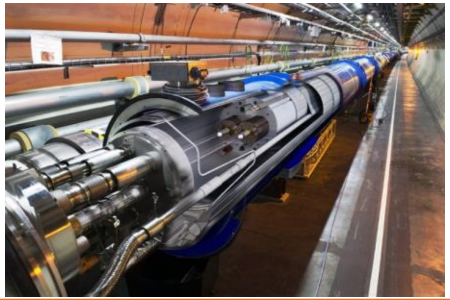
Matériaux pour les accélérateurs

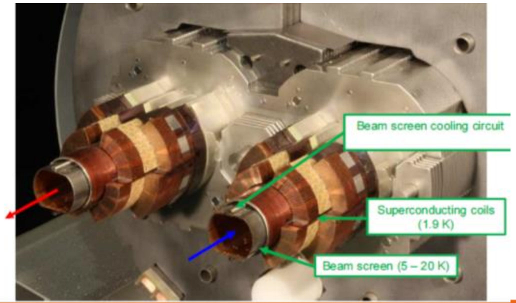
Etude du vide dynamique

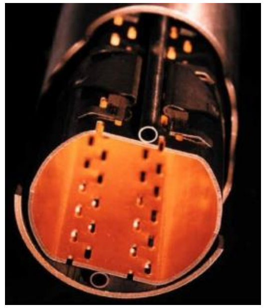
Exemple du LHC











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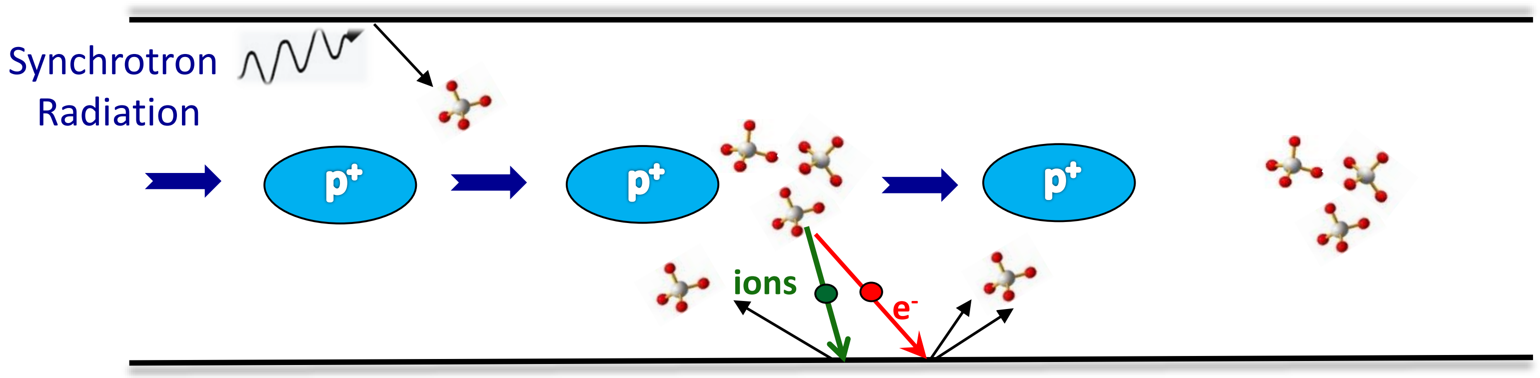
Materials for accelerators

Dynamic vacuum study

Stimulated Desorption

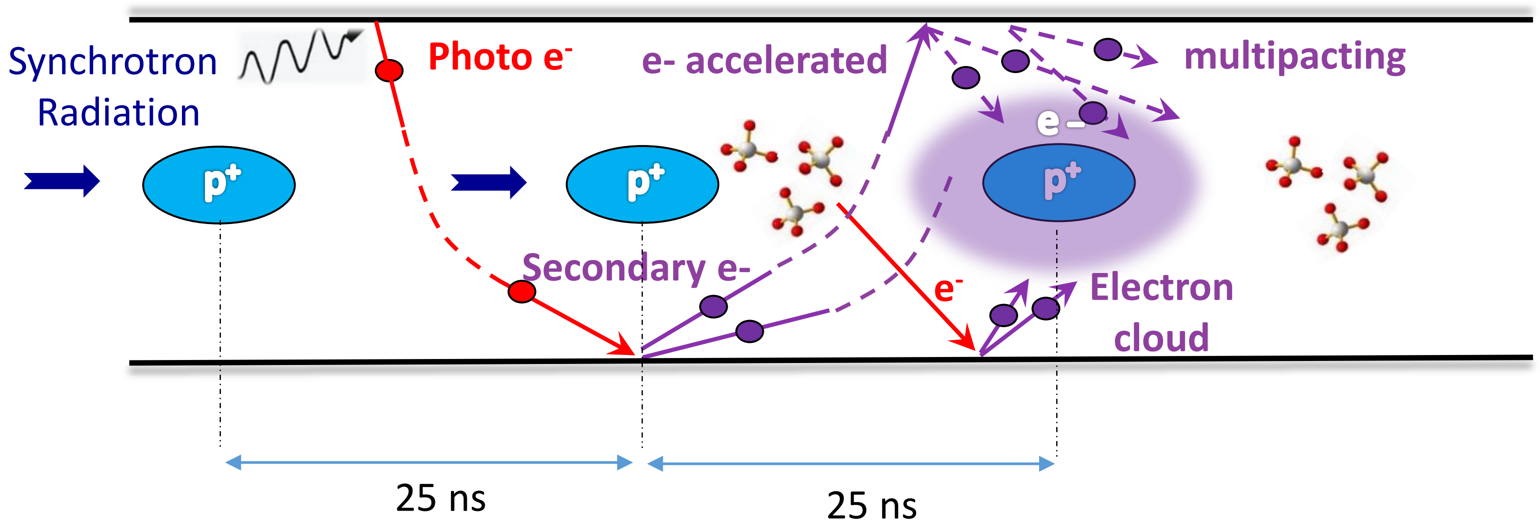


Gas density in presence of E-Cloud

Materials for accelerators

Dynamic vacuum study

Secondary particles creation

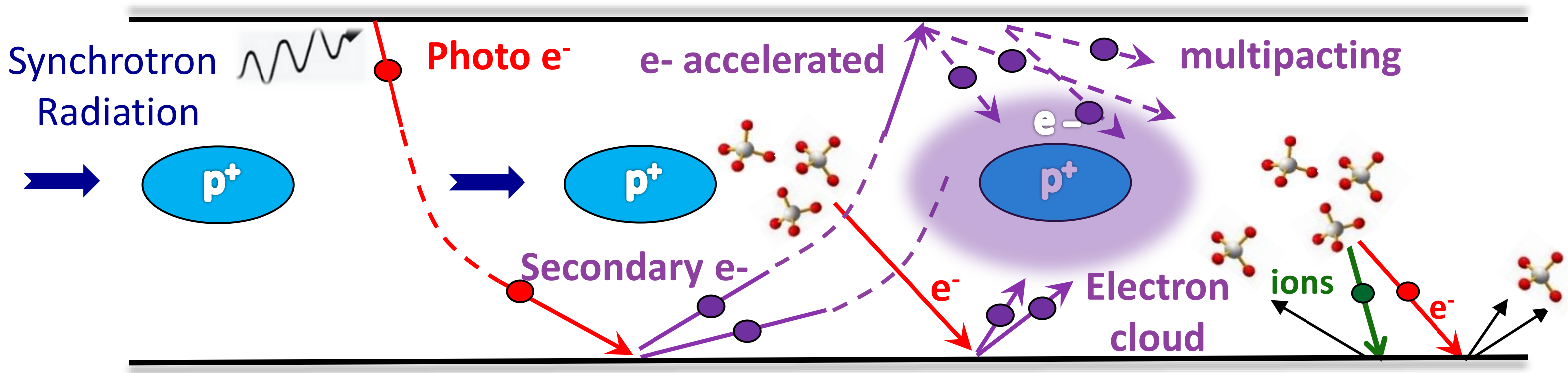


Gas density in presence of E-Cloud

Materials for accelerators

Dynamic vacuum study

Limitation of accelerator performance

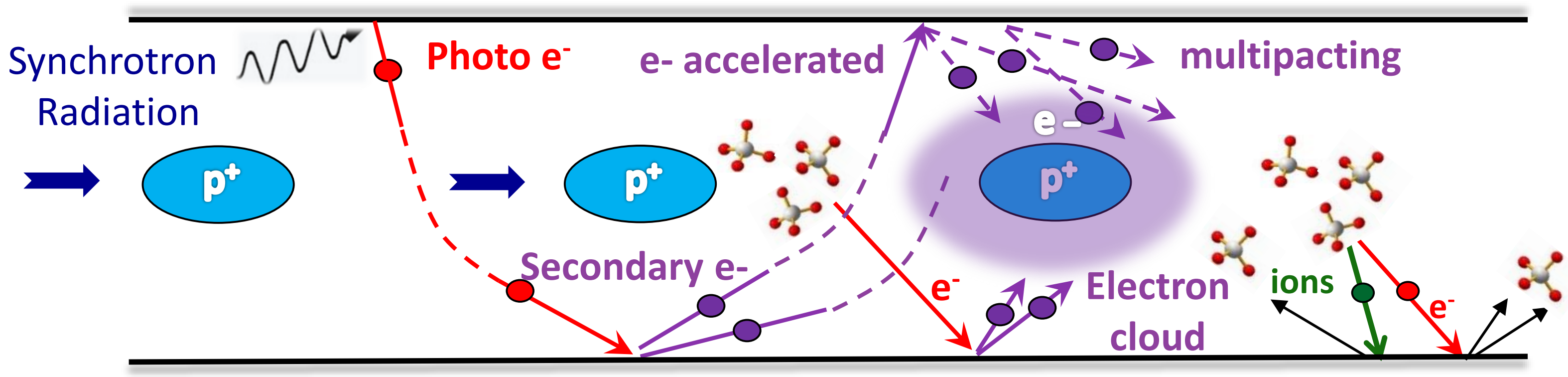


Gas density in presence of E-Cloud

Materials for accelerators

Dynamic vacuum study

Goals: → Limitation of unwanted collective effects inside the beamlines (materials)

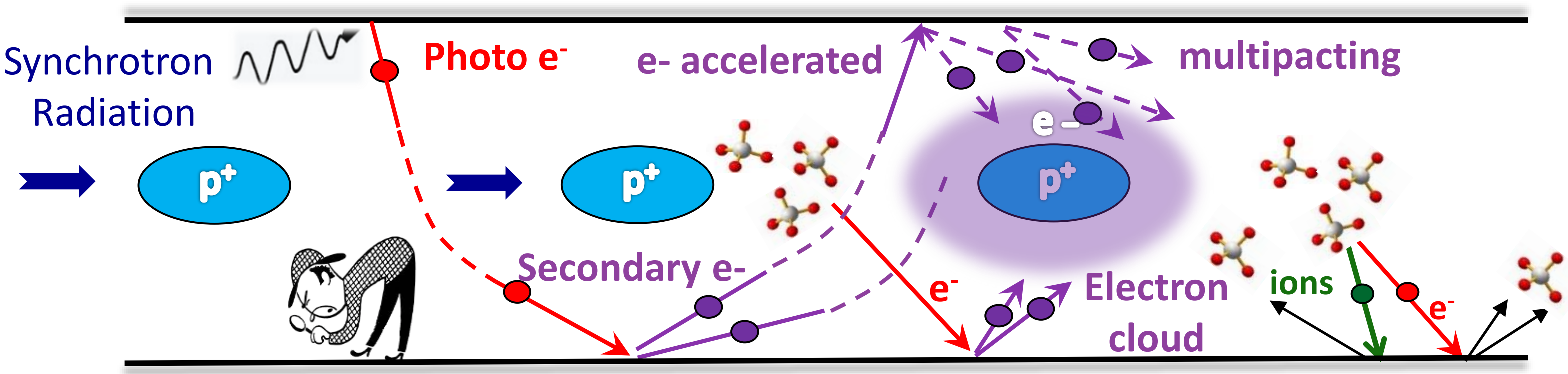


Gas density in presence of E-Cloud

Materials for accelerators

Dynamic vacuum study | **Material characterization**

Goals:
→ Limitation of unwanted collective effects inside the beamlines (materials)
→ The study of the surface chemistry modification under irradiation



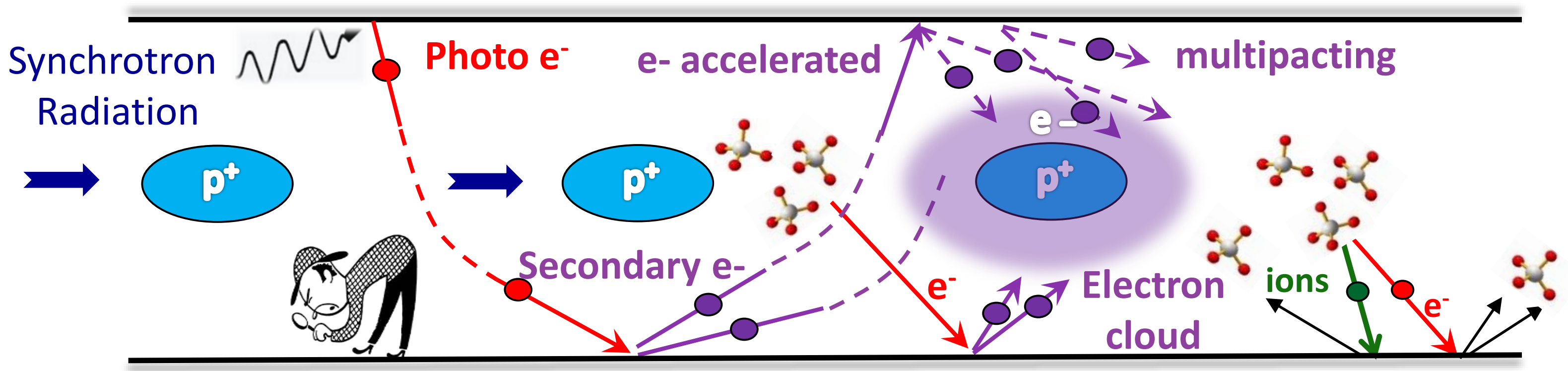
Gas density in presence of E-Cloud

Materials for accelerators

Dynamic vacuum study | **Material characterization**

<u>Goals</u>:
→ Limitation of unwanted collective effects inside the beamlines (materials)
→ The study of the surface chemistry modification under irradiation

Gaël Sattonnay
Rôle de la chimie de surface sur les propriétés des matéiaux pour accélérateur



Materials for accelerators

Dynamic vacuum study | **Material characterization**

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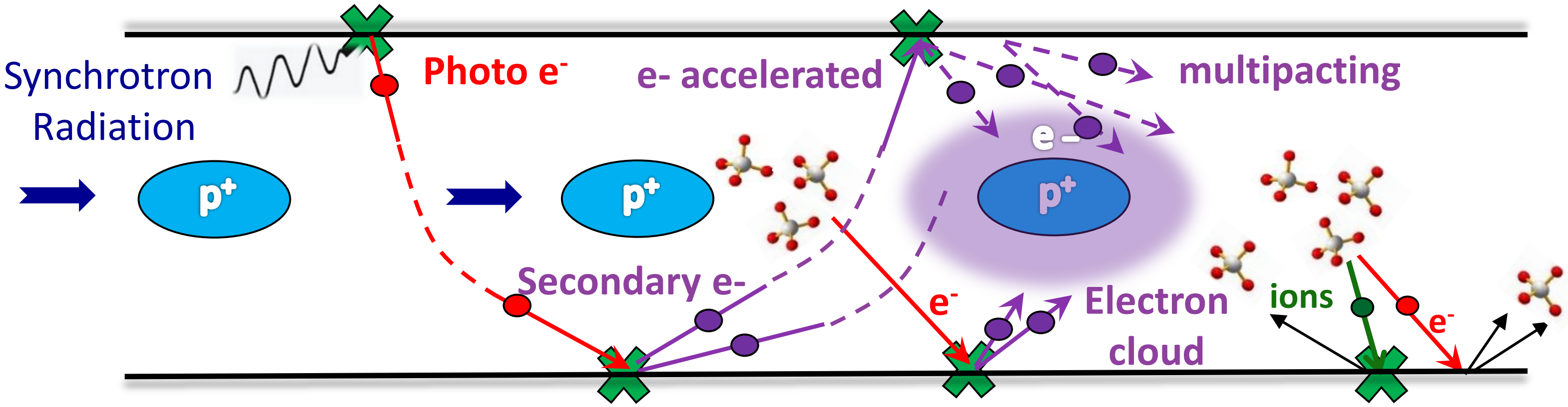


Materials for accelerators

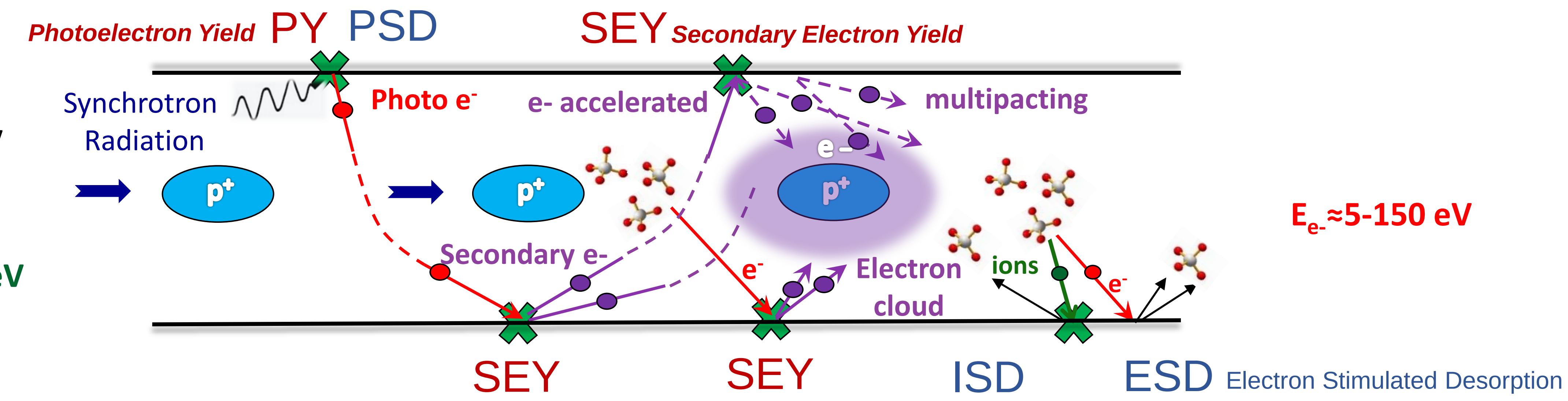
Dynamic vacuum study | **Material characterization**

Goals: → Limitation of unwanted collective effects inside the beamlines (materials)
→ The study of the surface chemistry modification under irradiation

For the LHC

$EC_{photon} \approx 35$ eV

$E_{ion} \approx 200\text{-}400$ eV



$E_{e-} \approx 5\text{-}150$ eV

DYVACS - Gas density profiles

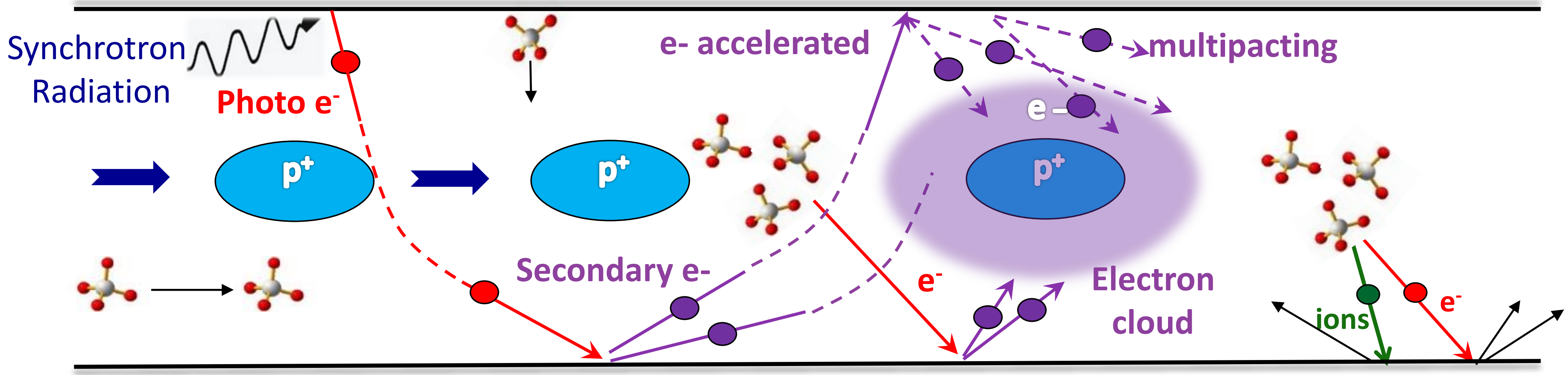
Analytical model of the dynamic pressure – DYVACS – DYnamic VACuum Simulation code

$$C_j \frac{\partial^2 n_j}{\partial x^2} + D_{ion-j} + D_{e-j} + D_{ph-j} + D_{th-j} - S \cdot n_j = 0$$

DYVACS is based on the gas balance differential equation (VASCO)
It is used to compute the gas density n_j

for j= H_2, CH_4, CO, CO_2

Boundary conditions: continuity of flux and pressure between each segment



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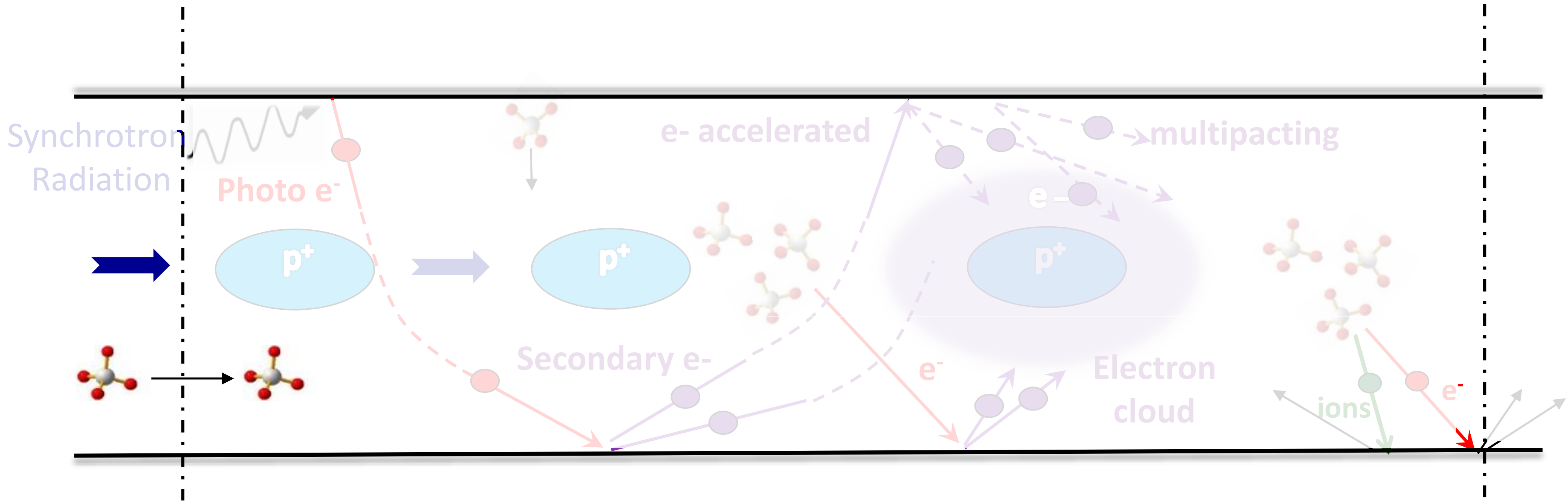
C_j is the specific conductance for j gas species



Inputs: C_j,,

DYVACS - Gas density profiles

Analytical model of the dynamic pressure – DYVACS – Dynamic VACuum Simulation code

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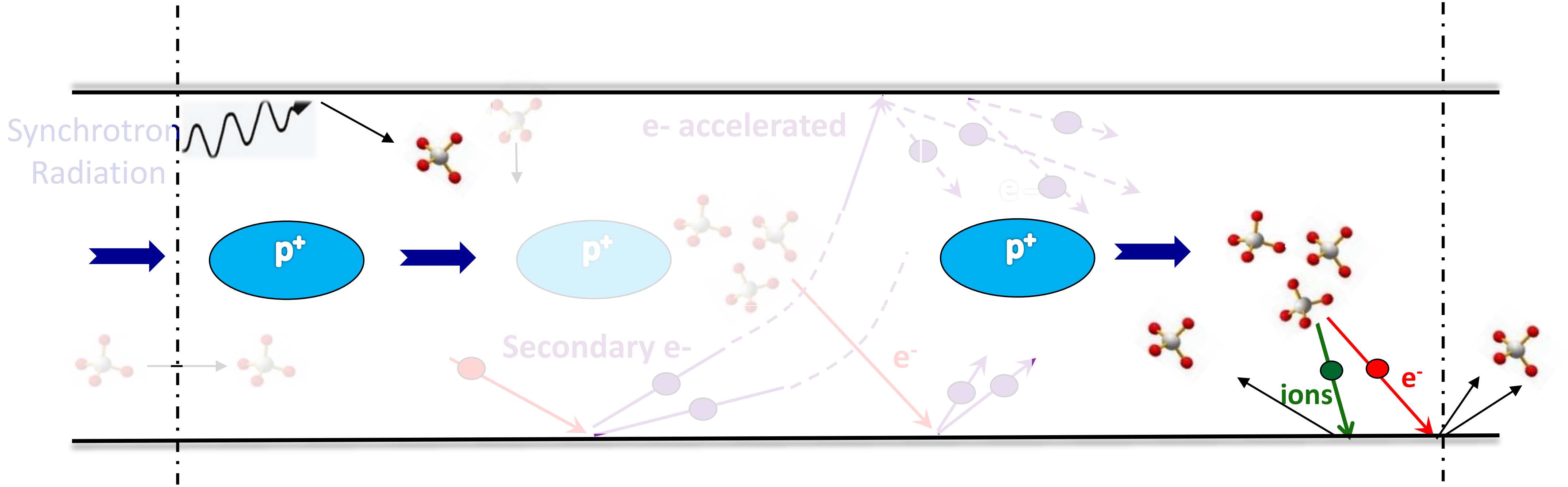

Inputs: C_j, $\eta_{i,j}$, $\eta_{e,j}$, $\eta_{ph,j}$, Γ_i, Γ_e, Γ_{ph},

Analytical model of the dynamic pressure – DYVACS – Dynamic VACuum Simulation code

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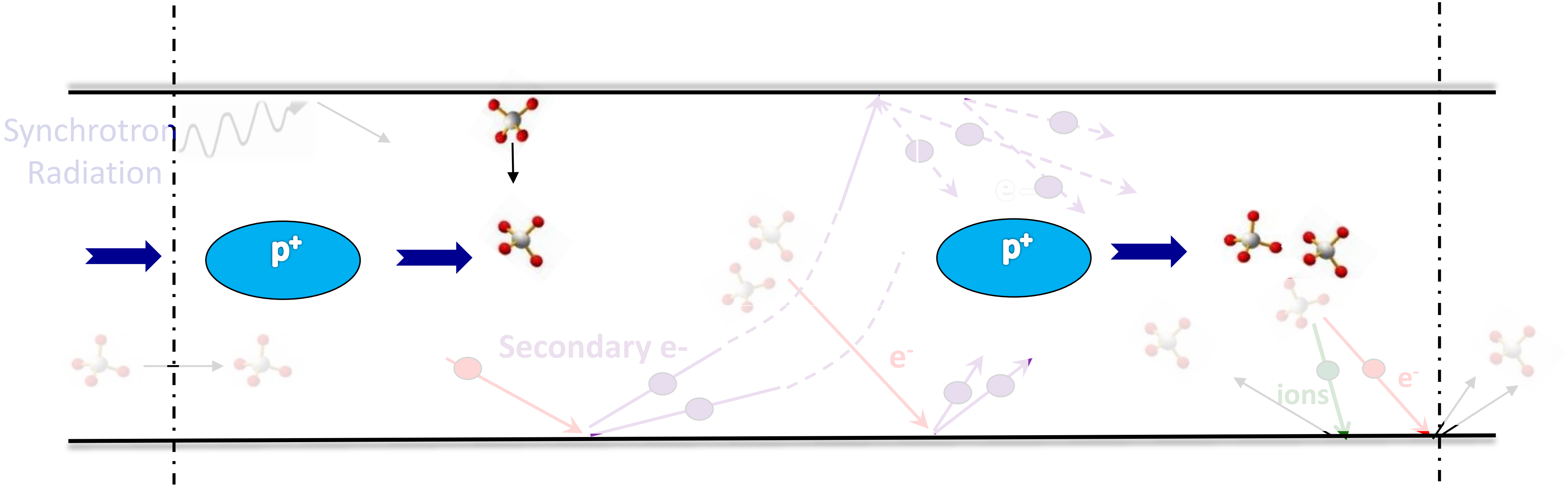
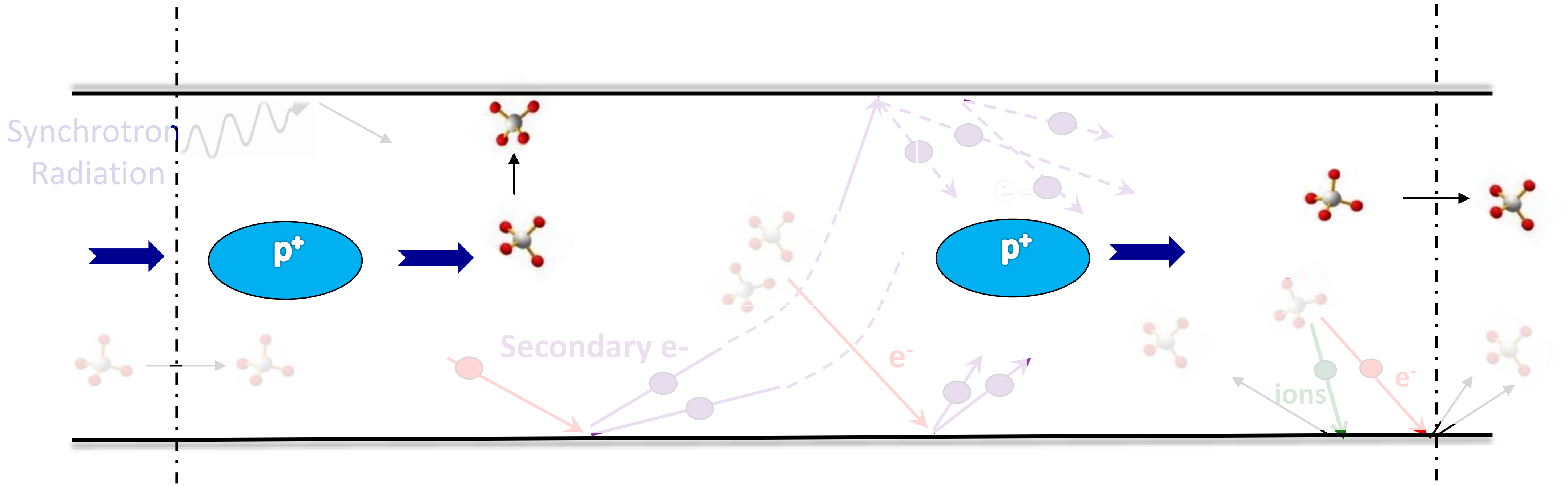


Inputs: C_j, $\eta_{i,j}$, $\eta_{e,j}$, $\eta_{ph,j}$, Γ_i, Γ_e, Γ_{ph}, $q_{th,j}$,

Analytical model of the dynamic pressure – DYVACS – Dynamic VACuum Simulation code

$$C_j \frac{\partial^2 n_j}{\partial x^2} + D_{ion-j} + D_{e-j} + D_{ph-j} + D_{th-j} - S \cdot n_j = 0$$

S is the wall distributed pumping speed for each gas.



Inputs: C_j, $\eta_{i,j}$, $\eta_{e,j}$, $\eta_{ph,j}$, Γ_i, Γ_e, Γ_{ph}, $q_{th,j}$, S_j ,

Analytical model of the dynamic pressure – DYVACS – Dynamic VACuum Simulation code

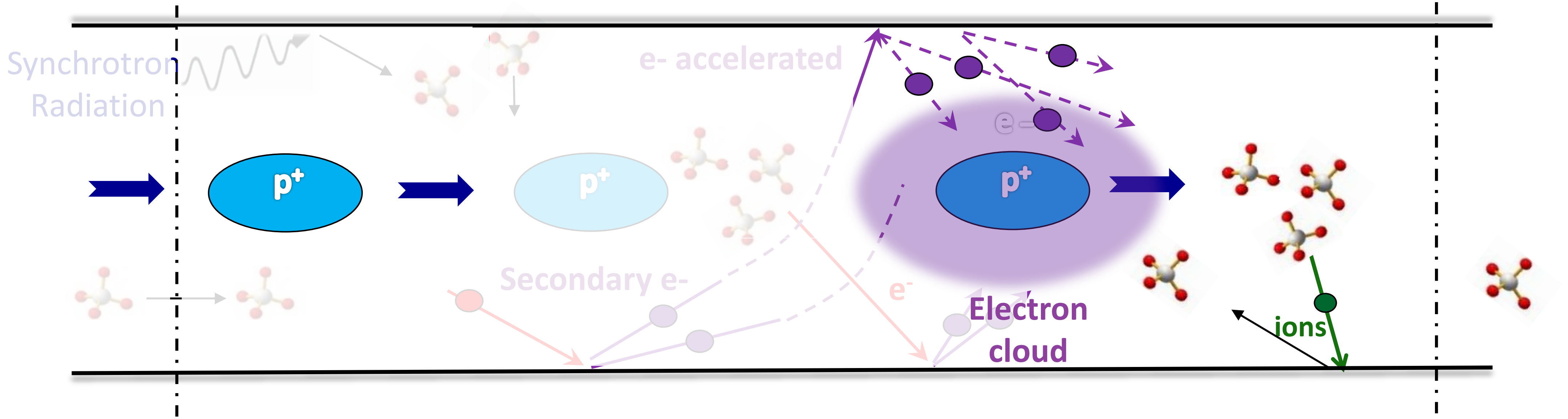
$$C_j \frac{\partial^2 n_j}{\partial x^2} + D_{ion-j} + D_{e-j} + D_{ph-j} + D_{th-j} - S \cdot n_j = 0$$

Residual gas ionization

by the p beam — by the EC

$$D_{ion-j} = \sum_{i=1}^{4} \eta_{ion-i\to j} \left(\sigma_{p\to i} \cdot \frac{I_{beam}}{e} + \sigma_{e\to i} \cdot \rho_e \cdot v_e \right) n_i$$

for i= H_2, CH_4, CO, CO_2



Inputs: C_j, $\eta_{i,j}$, $\eta_{e,j}$, $\eta_{ph,j}$, Γ_i, Γ_e, Γ_{ph}, $q_{th,j}$, S_j, $\sigma_{p\to i}$, $\sigma_{e\to i}$, I_{beam}, ρ_e, v_e,

DYVACS - Gas density profiles

Analytical model of the dynamic pressure – DYVACS – Dynamic VACuum Simulation code

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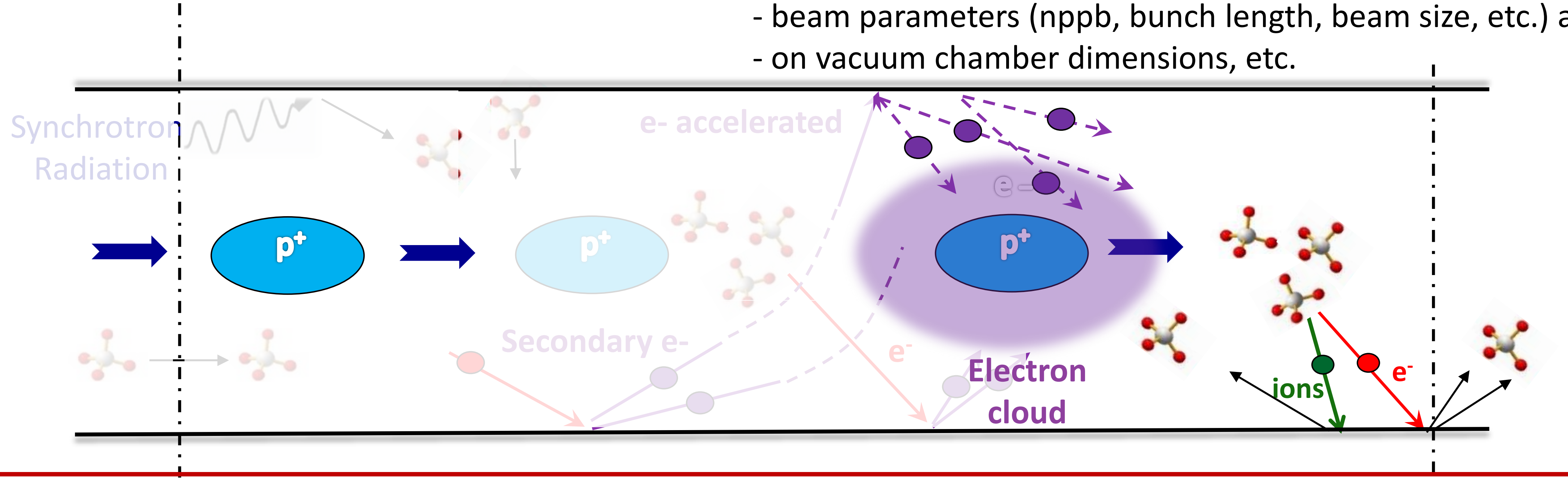
$D_{e,j} = \eta_{e,j}\Gamma_e \longrightarrow$ * Γ_e EC density computed with « the map model »

T. Demma *et al.* Model

Γ_e depends on : - SEY (surface properties) ,
- beam parameters (nppb, bunch length, beam size, etc.) and
- on vacuum chamber dimensions, etc.



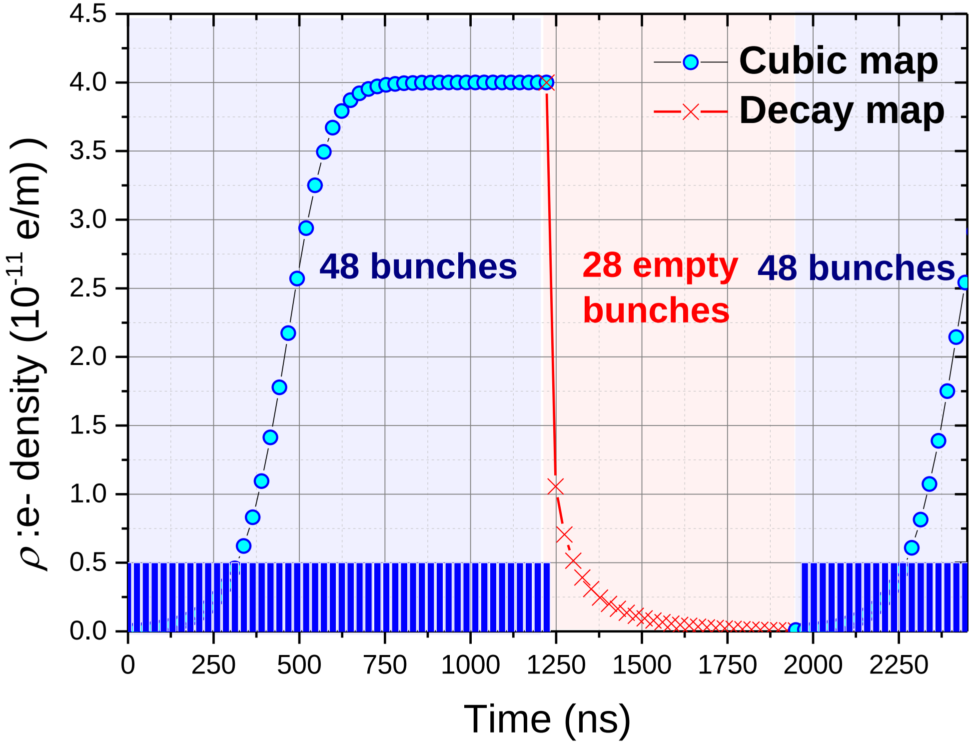
Inputs: C_j, $\eta_{i,j}$, $\eta_{e,j}$, $\eta_{ph,j}$, Γ_i, Γ_e, Γ_{ph}, $q_{th,j}$, S_j, $\sigma_{p\rightarrow i}$, $\sigma_{e\rightarrow i}$, I_{beam}, ρ_e, v_e, a, b, c, size of the segment, radius BP, E_{beam}, time of one turn, etc.

Electronic density build up of the EC computed using the map model

$$\rho_{m+1} = a\rho_m + b{\rho_m}^2 + c{\rho_m}^3$$

T. Demma *et al.* Model

→ ρ_m (10^{11} e-/m): EC density/meter after the m^{th} passage of bunch



Electron density for a nominal LHC fill using 48 bunches followed by 28 empty bunches for the decay

DYVACS - Gas density profiles

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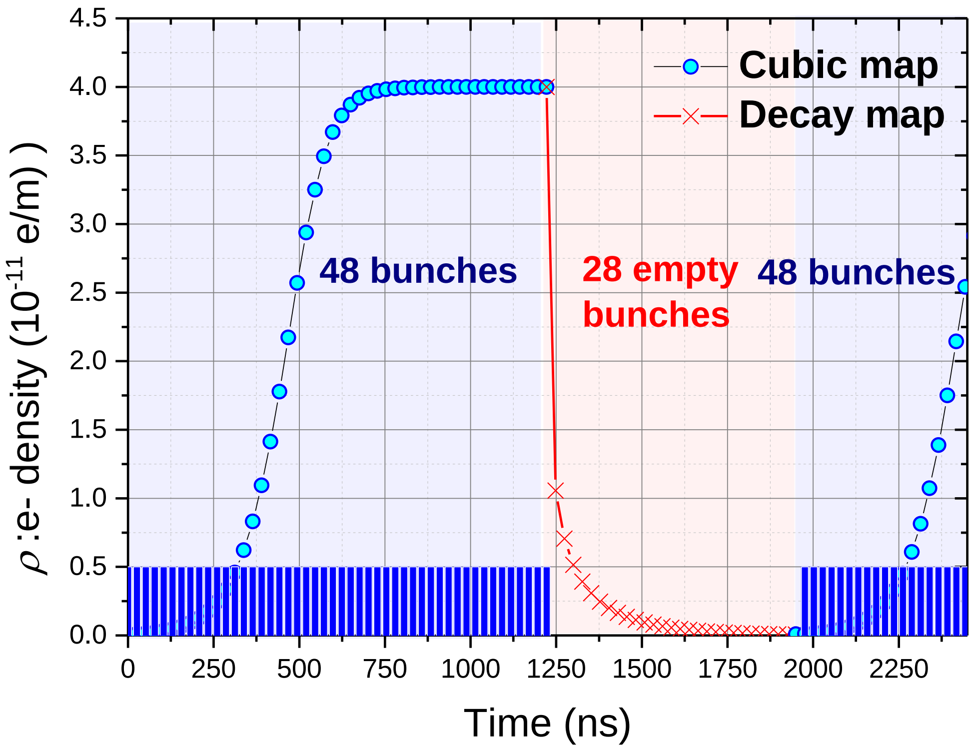

Electron density for a nominal LHC fill using 48 bunches followed by 28 empty bunches for the decay

a: linear coefficient

- used to determine the e- gain from one bunch to another.
- a depends strongly on the SEY.

DYVACS - Gas density profiles

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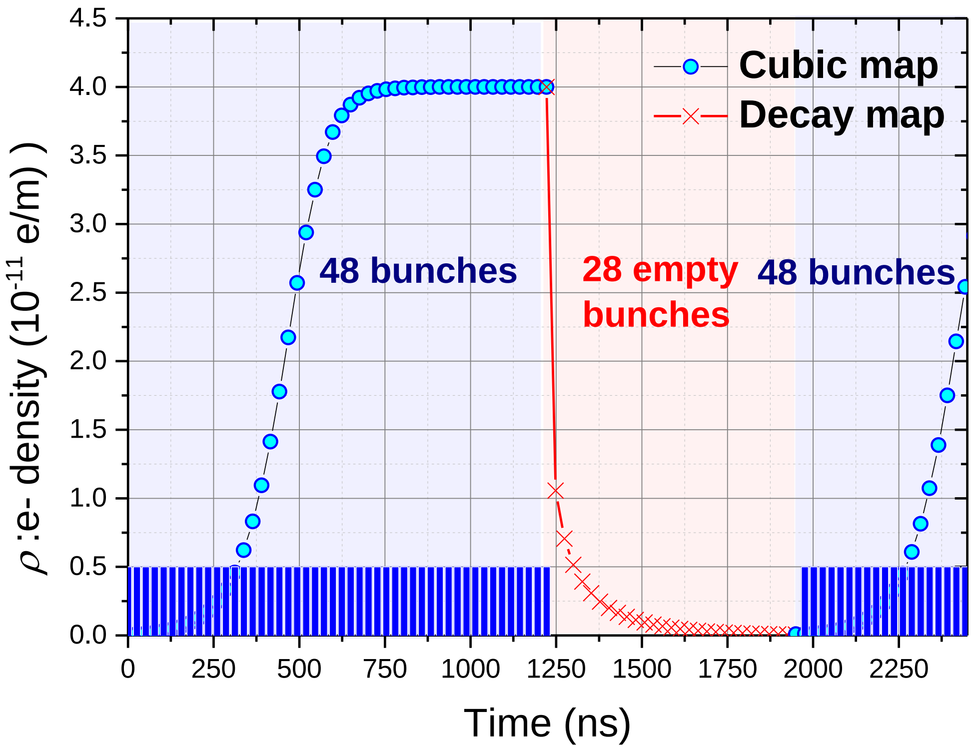


Electron density for a nominal LHC fill using 48 bunches followed by 28 empty bunches for the decay

a: linear coefficient

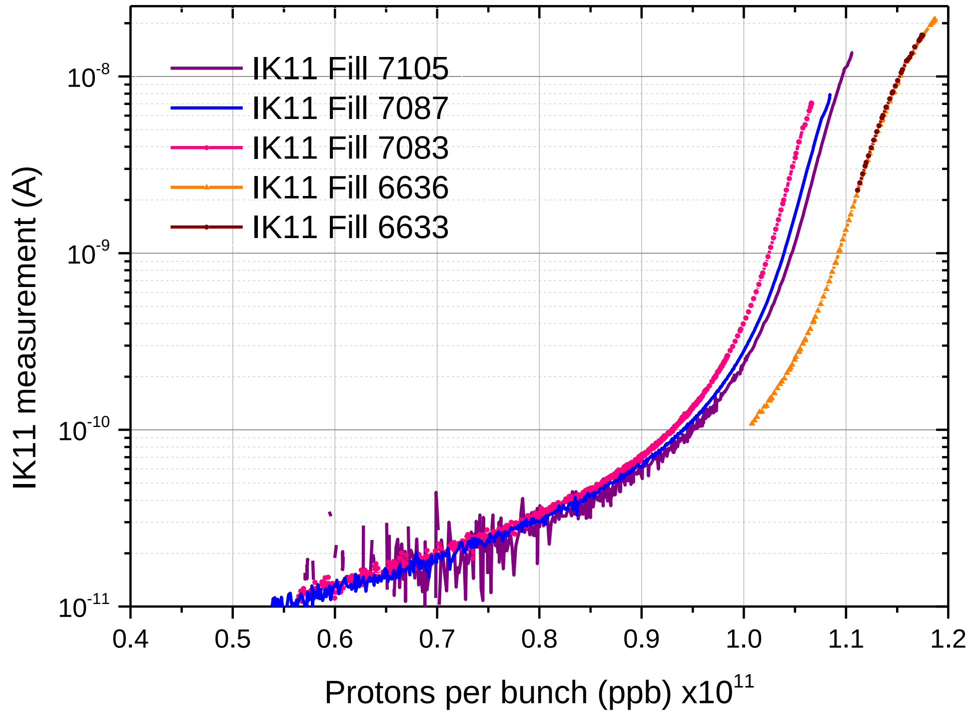
- used to determine the e- gain from one bunch to another.
- a depends strongly on the SEY.

b: quadratic term

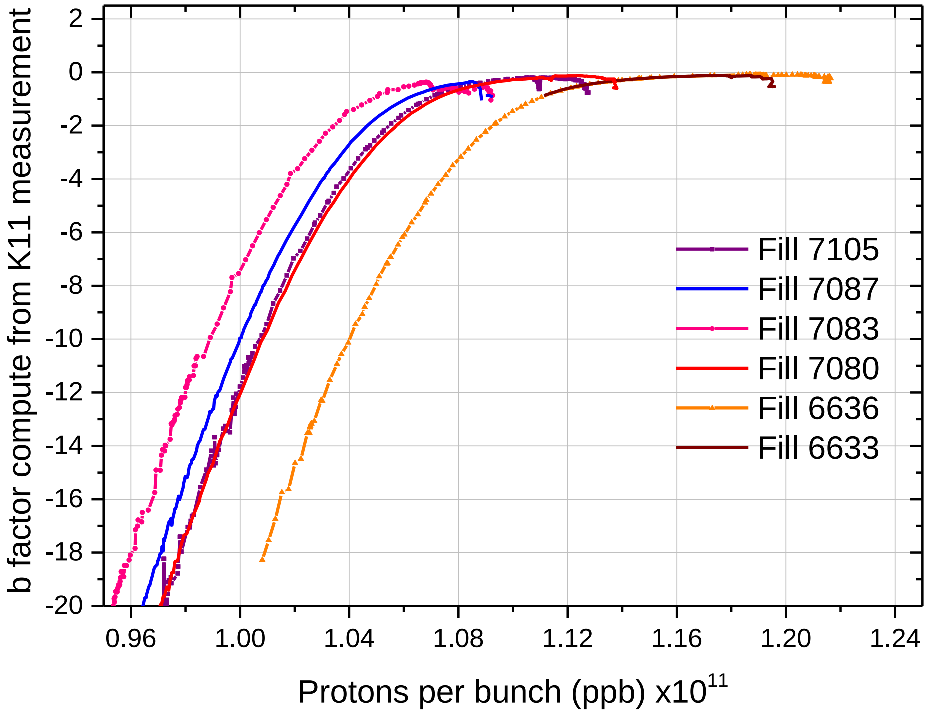
- considers the equilibrium density (plateau) of the EC.
- b depends on beam parameters (nppb, bunch length, beam size, etc.) and on vacuum chamber dimensions.

variation of the b factor computed from in situ measurement of e- current

Experimental electron current
as a fonction of nppb



b factor computed from electrical current
measurements as a fonction of nppb



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DYVACS - Gas density profiles

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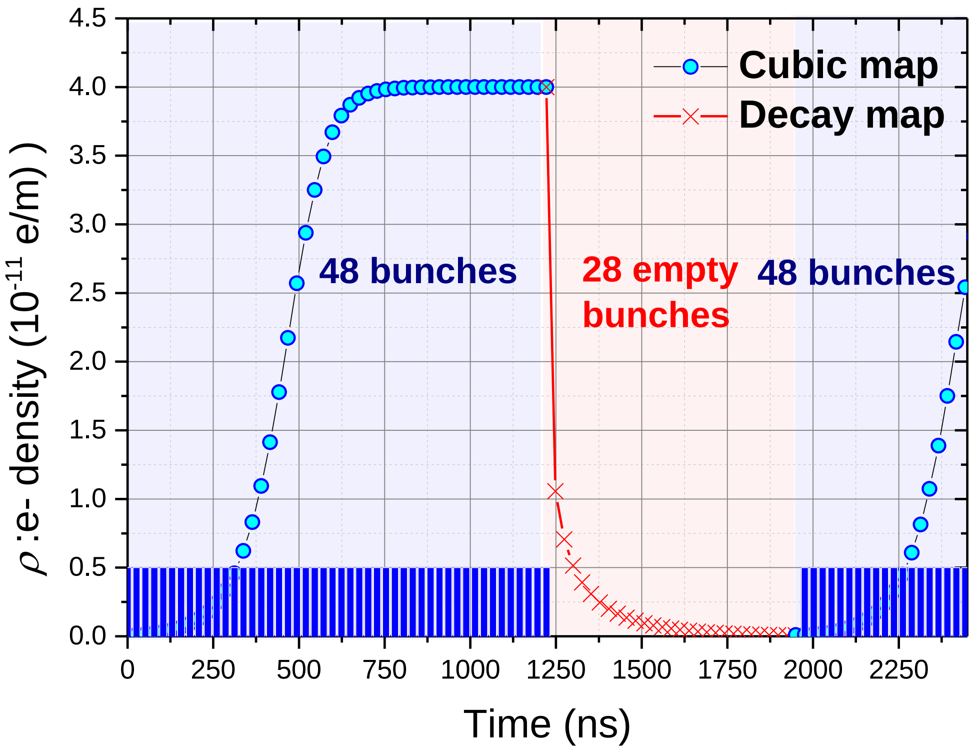

Electron density for a nominal LHC fill using 48 bunches followed by 28 empty bunches for the decay

a: linear coefficient

- used to determine the e- gain from one bunch to another.
- a depends strongly on the SEY.

b: quadratic term

- considers the equilibrium density (plateau) of the EC.
- b depends on beam parameters (nppb, bunch length, beam size, etc.) and on vacuum chamber dimensions.

c: cubic term

- corresponds to a minor correction factor and C=0 for our simulations.

DYVACS - Gas density profiles

Analytical model of the dynamic pressure – DYVACS – Dynamic VACuum Simulation code

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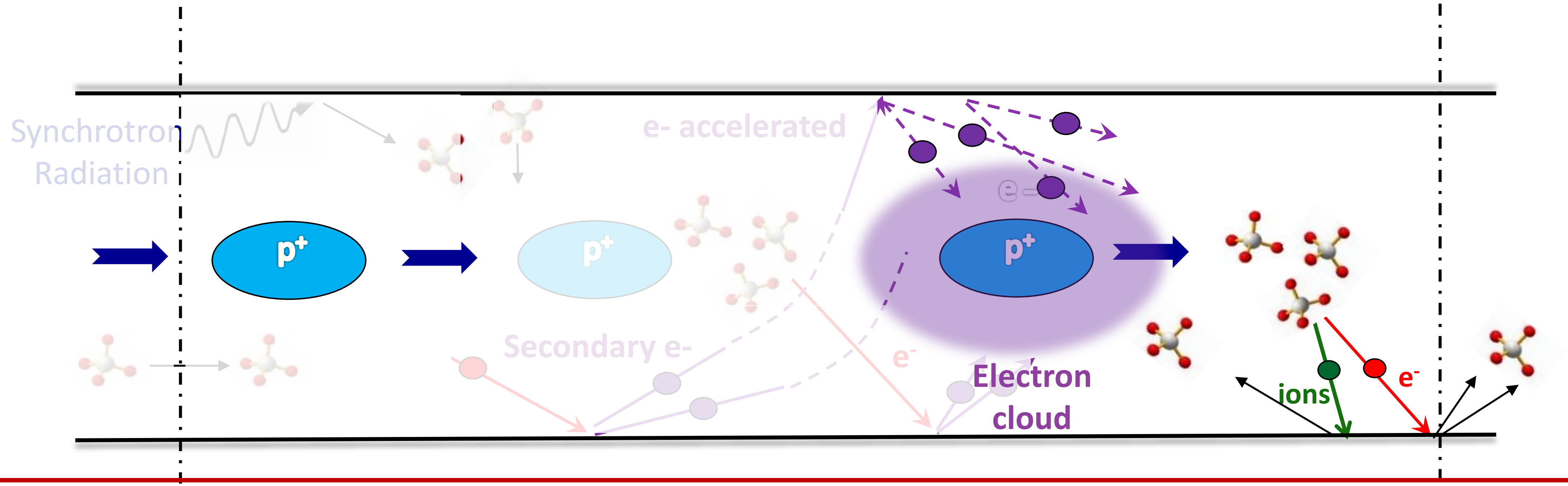
Many inputs are necessary → measurements in laboratory are needed!

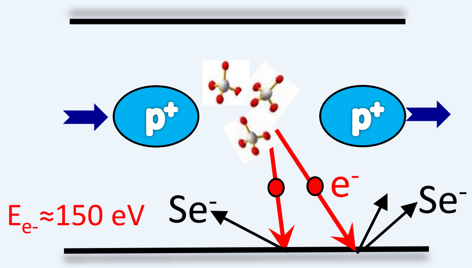


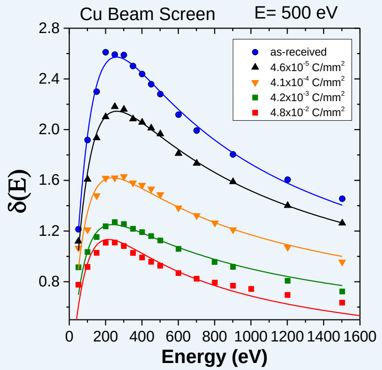
Inputs: C_j, $\eta_{i,j}$, $\eta_{e,j}$, $\eta_{ph,j}$, Γ_i, Γ_e, Γ_{ph}, $q_{th,j}$, S_j, $\sigma_{p\to i}$, $\sigma_{e\to i}$, I_{beam}, ρ_e, v_e, a, b, c, size of the segment, radius BP, E_{beam}, time of one turn, etc.

DYVACS - Gas density profiles

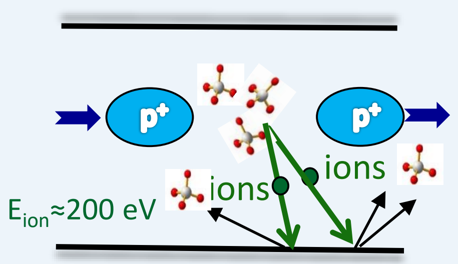
Experimental measurements in lab

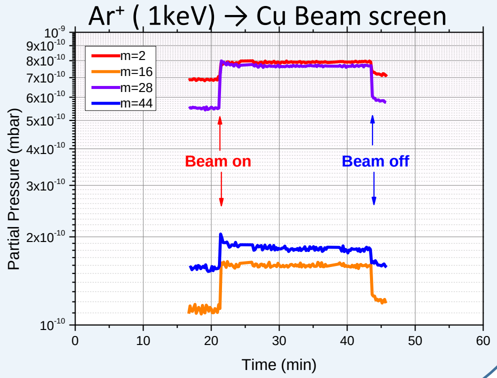
SEY *Secondary Electron Yield (IJCLab)*





ISD *Ion Stimulated Desorption (CERN)*





S. Bilgen Thèse Université Paris Saclay 2020

PY, SEY

$$yield = \frac{number\ of\ electrons\ emitted\ from\ the\ surface}{incident\ particle\ (ph\ or\ e-)}$$

ESD, ISD, PSD

$$yield = \frac{number\ of\ gas\ molecule\ desorbed}{incident\ particle\ (e-, ion\ or\ ph)}$$

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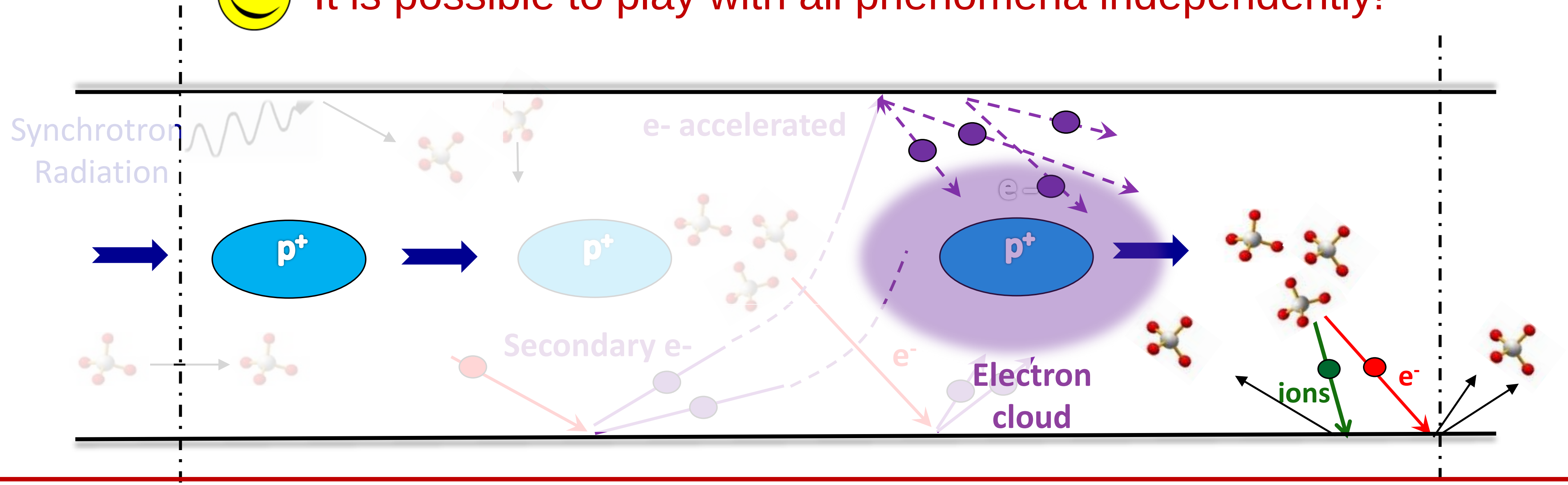
Many inputs are necessary → measurements in laboratory are needed!

It is possible to play with all phenomena independently!



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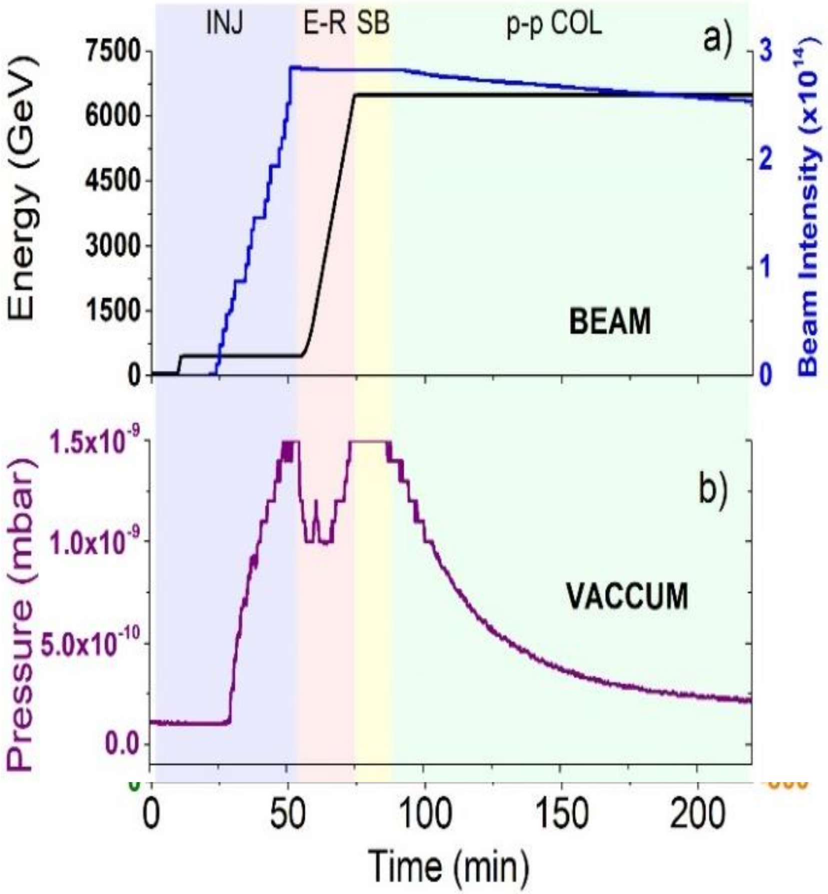
DYVACS - Gas density profiles

Comparison between *in situ* measurements in the LHC and the DYVACS simulation



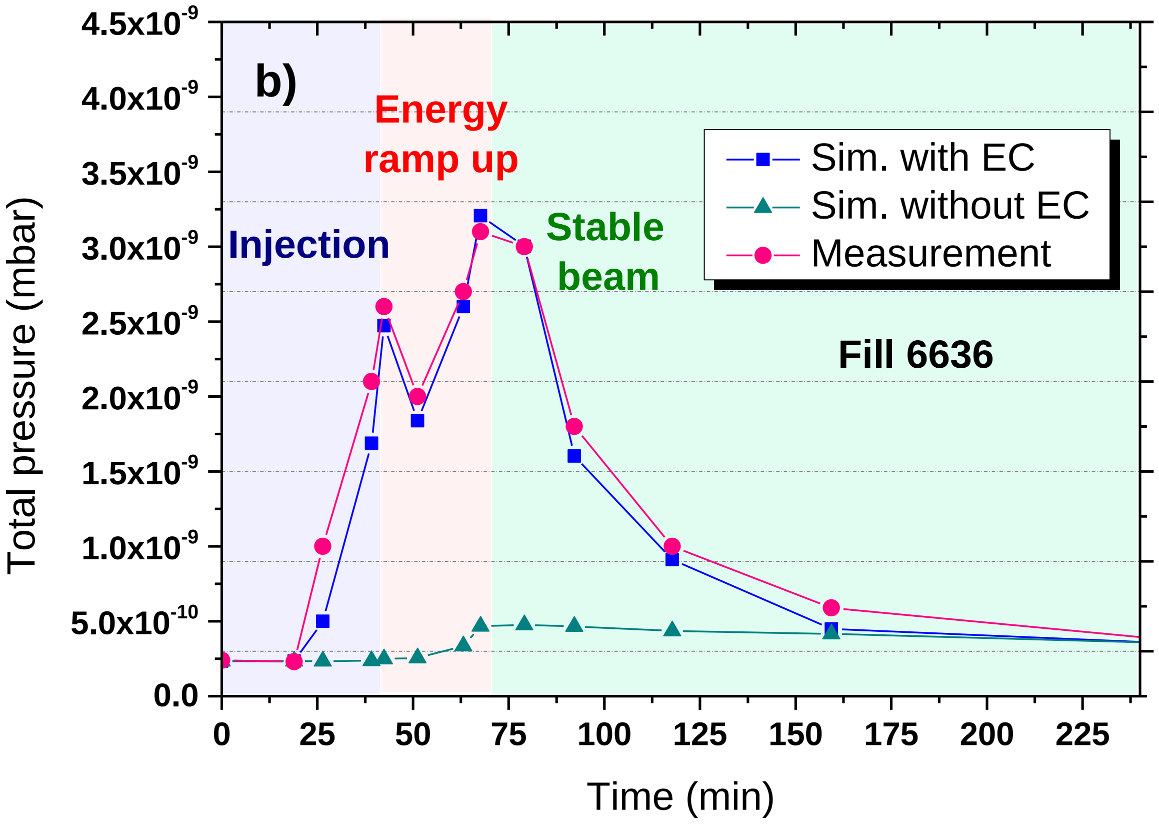
In situ beam intensity and energy evolution

In situ pressure measurement (VPS Station N°4)

DYVACS - Gas density profiles

Comparison between *in situ* measurements in the LHC and the DYVACS simulation

For a=1,4 (SEY=1,6); b=[0; -5] variation of the b factor by DYVACS; c=0

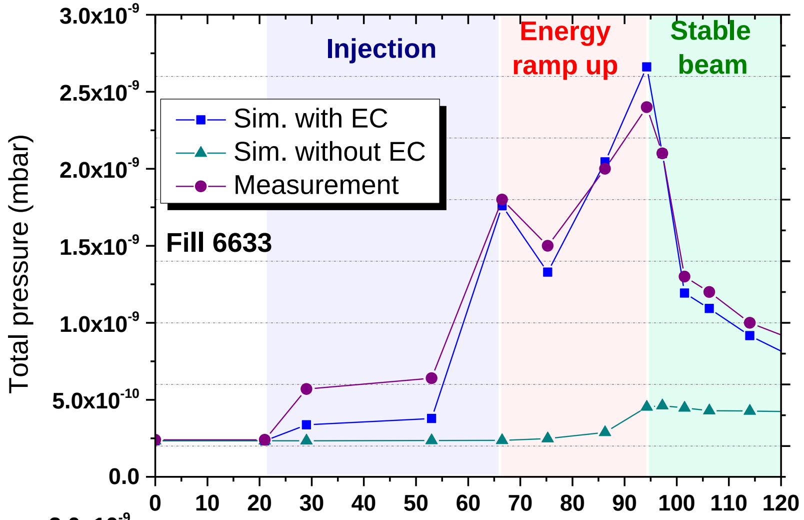


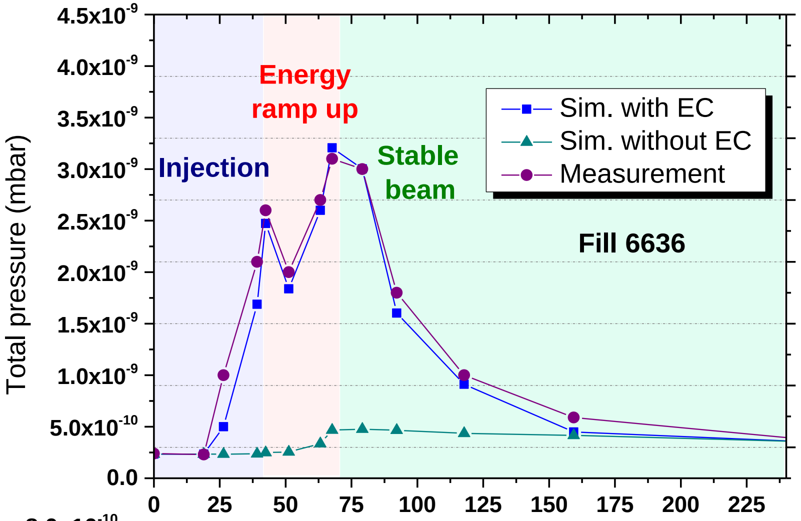
- Experimental pressure (pink line)
- computed pressure using DYVACS with EC (blue line)
- and without EC (green line)

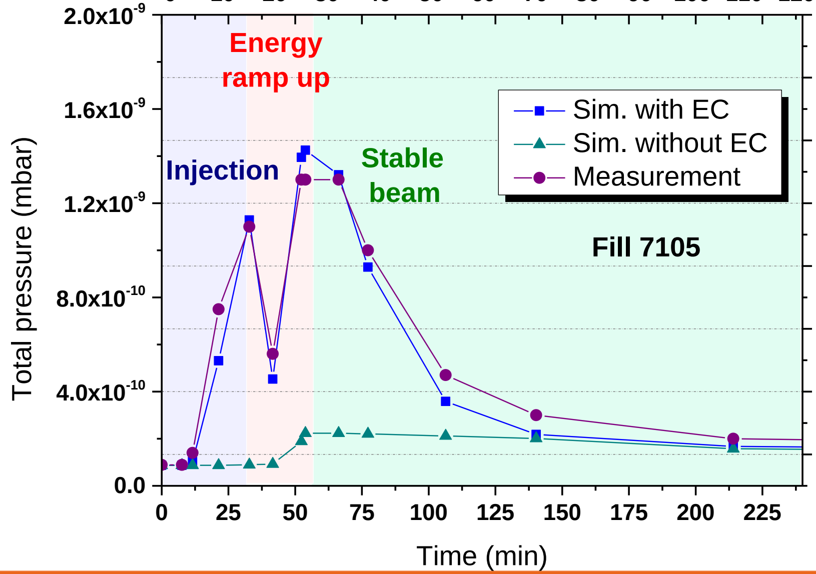
A **good agreement** was observed in a short computation time, between the *in situ* pressure measurements and DYVACS simulation

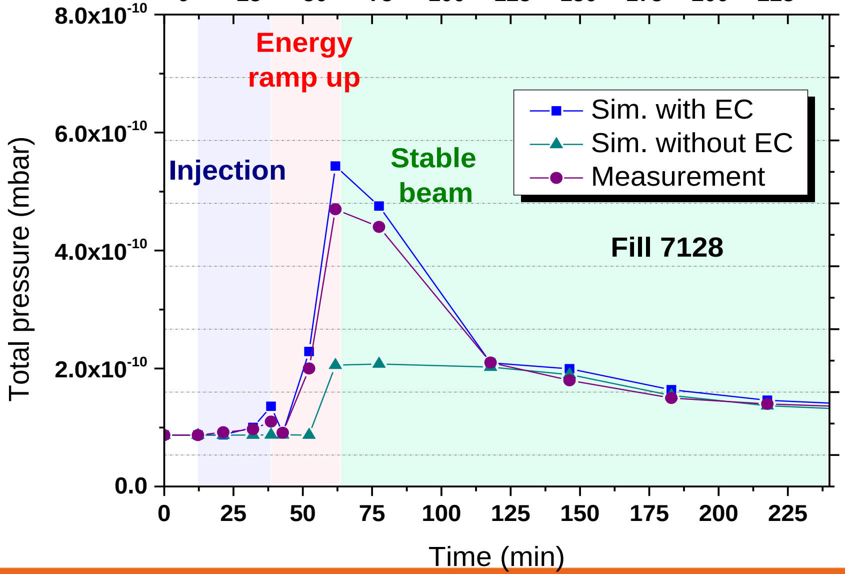
DYVACS - Gas density profiles

Pressure time evolution measurements vs DYVACS simulations







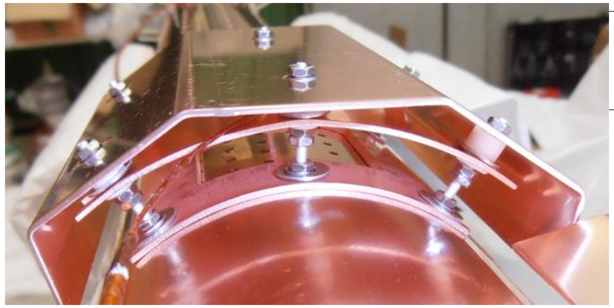


inputs:

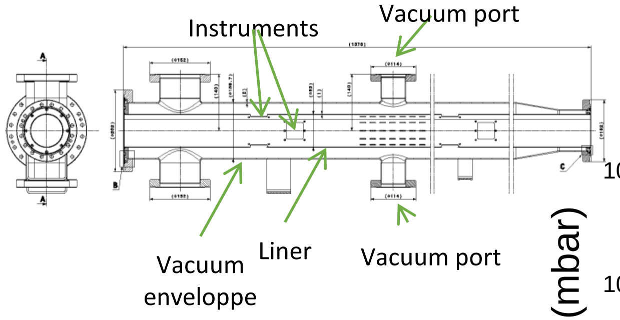
Same ESD,PSD and ISD used.
a fixed for a constant SEY
b is computed as a function of nppb.

All calculations reproduce with a good agreement the in situ pressure evolution measured in station 4 (unbaked copper) of VPS in the LHC.

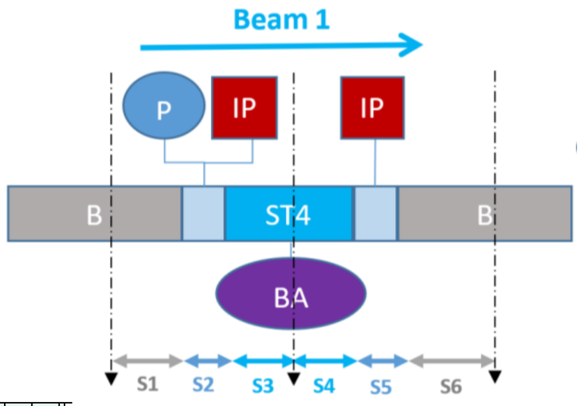
V. BAGLIN, meeting, CERN, 5th Dec. 2017

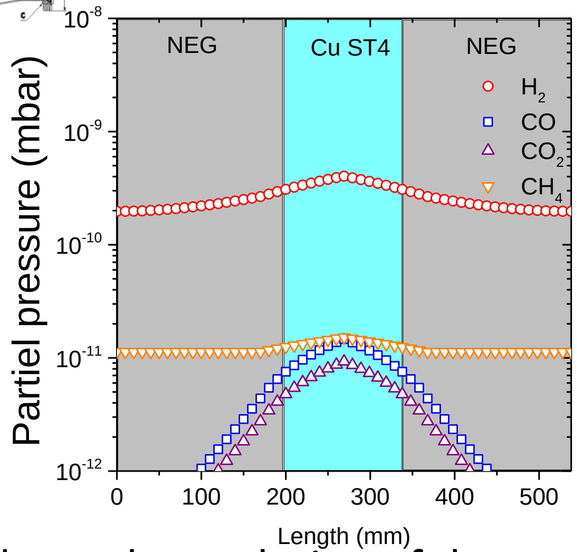


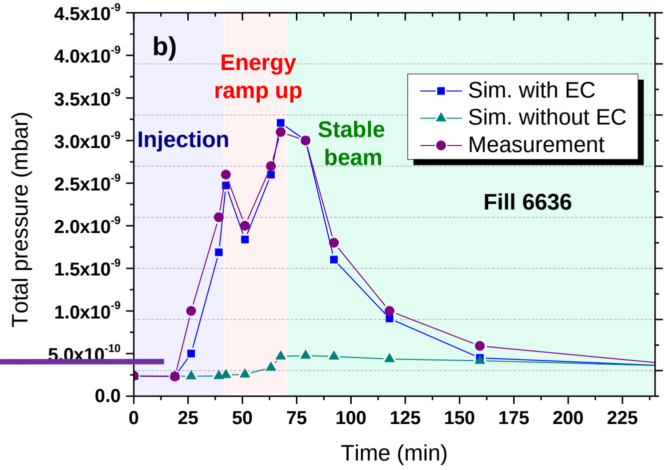
Distribution of partial pressures along the pipe



Distribution of partial pressures for H_2, CO_2, CO and CH_4 along the Cu station 4



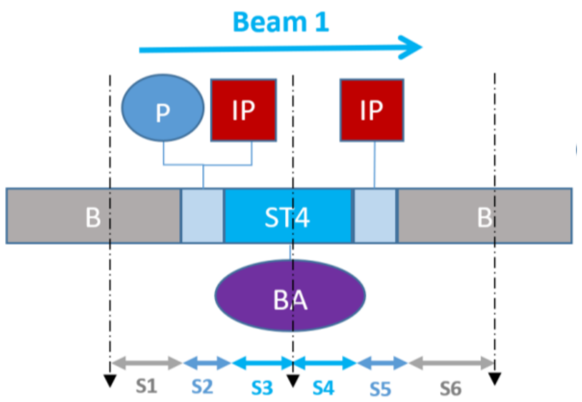


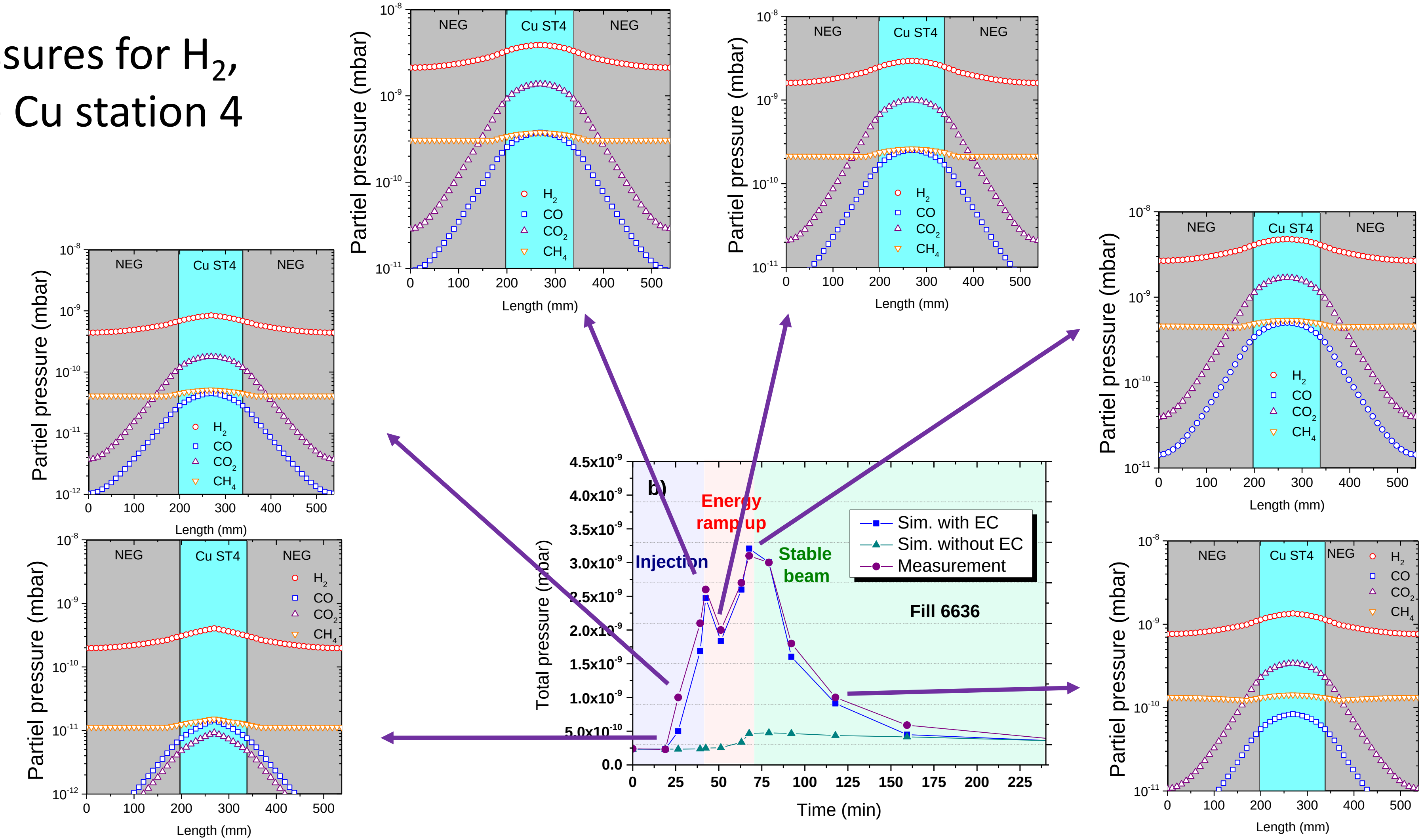


DYVACS reproduces the evolution of the partial pressures for H_2, CO_2, CO and CH_4 during beam operation

H_2 has the highest partial pressure

Distribution of partial pressures for H_2, CO_2, CO and CH_4 along the Cu station 4





DYVACS reproduces the evolution of the partial pressures for H_2, CO_2, CO and CH_4 during beam operation

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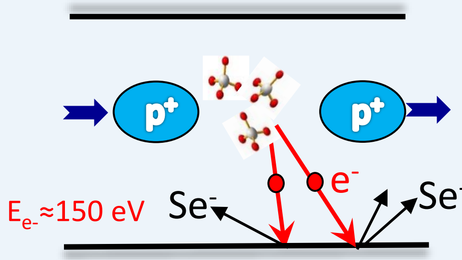
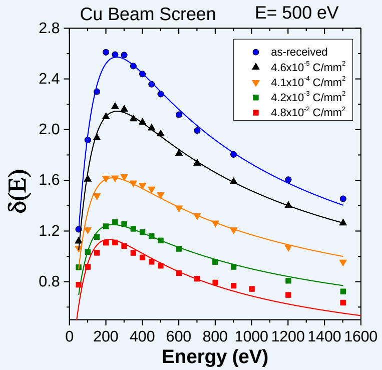
Conclusion

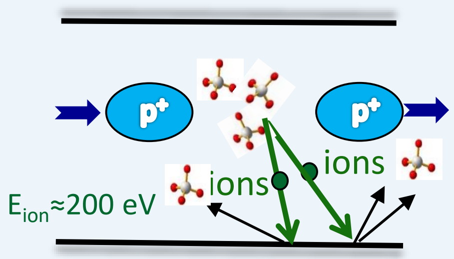
Experimental measurements in lab

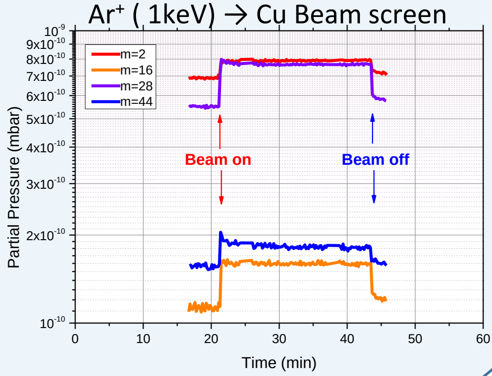
SEY *Secondary Electron Yield (IJCLab)*



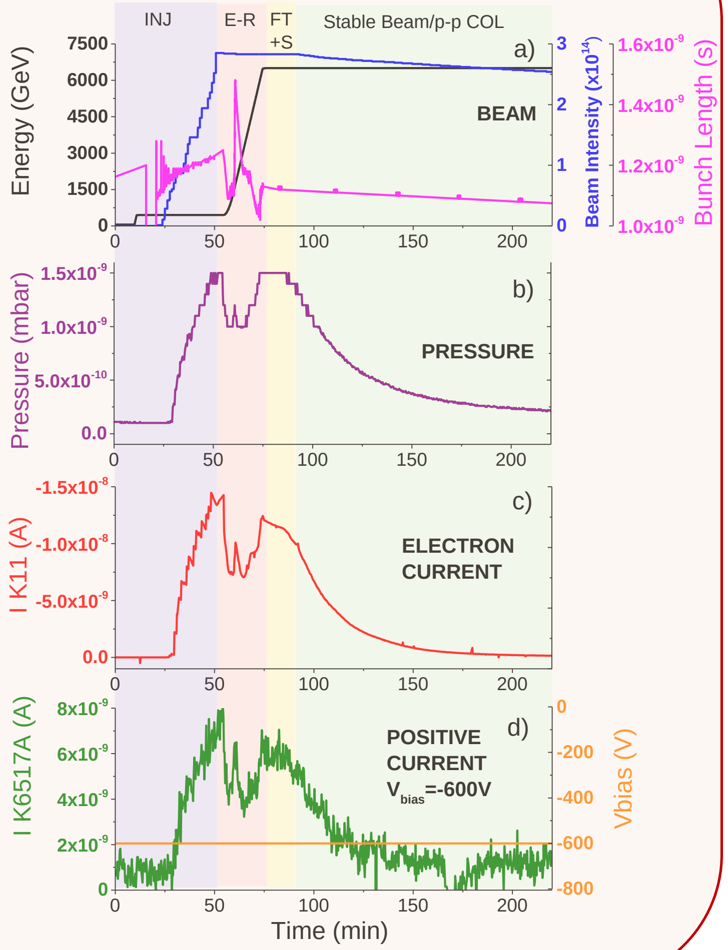


ISD *Ion Stimulated Desorption (CERN)*



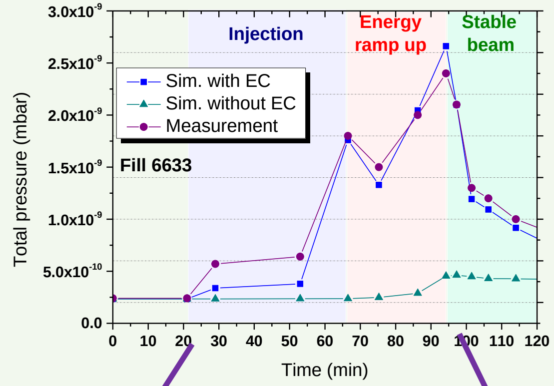


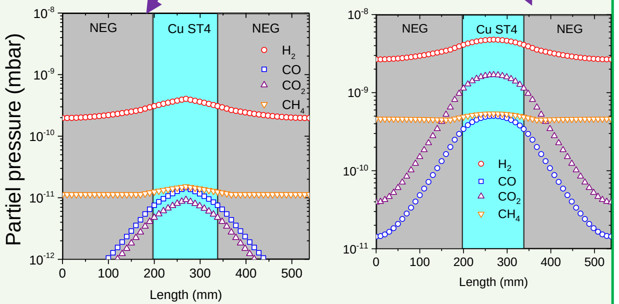
In situ measurements in the LHC

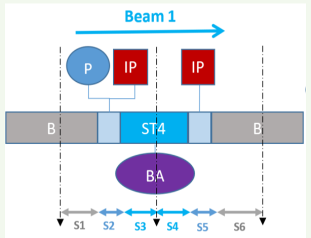


Simulations

DYVACS simulation







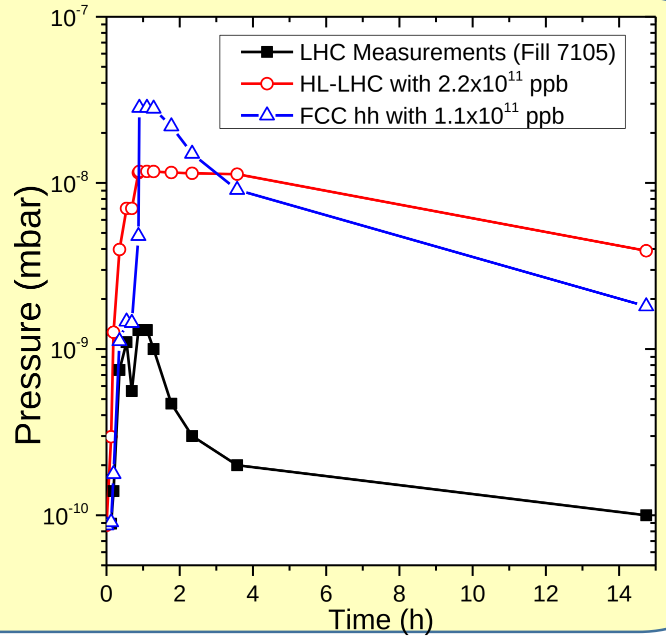
S. Bilgen Thèse Université Paris Saclay 2020

Perspectives

- **Laboratory measurements :**
  - Consolidate **ISD yield measurements**;
  - Study the **relationship between conditioning effects and surface chemistry** of materials **(in particular the NEG coating due to the high SR in FCC-ee)**;
  - Accumulate experimental data on the desorption yields and conditioning effects;
  - Investigate the effect of cryogenic temperatures.

- **In situ measurements in the LHC**
  - Confirm the measurements of the ion current in the **next LHC RUN (2022)**

- **Simulation of the dynamic pressure**
  - **Improve and optimize** the DYVACS code;
  - Use the DYVACS code as a predictive tool for future machines such as **HL-LHC and FCC-hh** (nppb, ESD, PSD etc.);
  - **Very preliminary results,** Further calculations must be performed **:**



Vacuum studies constitute an essential issue for all accelerator community and high energy physics field.

Thank you for your attention !

Journées Accélérateurs 2021 de la SFP

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BACK SLIDES

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DYVACS inputs

DYVACS DATA

DEBUT SEGMENT	2			
FIN SEGMENT	3	Station 4 (1)		
LONGUEUR (cm)	69			
DIAMETRE (cm)	8			
DISTANCE REF (cm)	200			
TEMPERATURE (K)	300			
surface degaz				
	H2	**CH4**	**CO**	**CO2**
POMPE EXT debut segment, (l/s)	0	0	0	0
POMPAGE REPARTI UNIFORMEMENT				
coefficient de collage	0,00E+00	0,00E+00	0,00E+00	0,00E+00
DEGAZE PONCTUEL EXT (x=0)	0,00E+00	0,00E+00	0,00E+00	0,00E+00
TAUX DEGAZ THERMAL (mbar,l/s/cm2)	5,00E-13	5,00E-15	1,00E-14	5,00E-15
ISD DEGAZ IONIQUE				
section efficace ionisation (m2)	4,50E-23	0,00E+00	0,00E+00	0,00E+00
	0,00E+00	3,20E-22	0,00E+00	0,00E+00
	0,00E+00	0,00E+00	2,70E-22	0,00E+00
	0,00E+00	0,00E+00	0,00E+00	4,30E-22
désorption H2 impact ionique (molé/ion)	5,40E-01	5,40E-01	5,40E-01	5,40E-01
desorption ch4	0,04	0,05	0,07	0,11
desorption CO	0,25	0,29	0,29	0,33
desorption CO2	0,14	0,14	0,14	0,14
PSD DEGAZ PHOTON				
coeff suivant distance	1,00E-02			
rendement mol/ph à 6,5TeV Ec=35,5 ev	1,50E-04	1,40E-05	1,00E-05	2,00E-05
ESD DEGAZ ELECTRON				
flux electrons (e-/m/s)	1,00E-10			
désorption H2 impact e- (molé/e-)	0,005	1,00E-04	2,00E-04	1,00E-03
PY rendement e/ph	0,1			
Paramètre map E cloud a, b et c	1,4	-0,1	0	
ISD DEGAZ IONIQUE ecloud				
section efficace ionisation (m2)	8,00E-21	0,00E+00	0,00E+00	0,00E+00
	0,00E+00	3,04E-20	0,00E+00	0,00E+00
	0,00E+00	0,00E+00	2,48E-20	0,00E+00
	0,00E+00	0,00E+00	0,00E+00	3,60E-20
désorption H2 impact ionique (molé/ion)	5,40E-01	5,40E-01	5,40E-01	5,40E-01
ch4/H2+ ch4/Ch4+ ch4/Co+ ch4/Co2+	0,04	0,05	0,07	0,11
co/H2+ co/Ch4+ co/Co+ co/Co2+	0,25	0,29	0,29	0,33
	0,14	0,14	0,14	0,14

FILL INPUT

Nbre bunch vide	Nbre bunch
2,80E+01	4,80E+01

Nbre de mesure	durée entre bunch (s)
1,40E+01	2,50E-08

Rayon courbure (m)	LHC circonférence (m)
2784,302	2,70E+04

Nbre total Bunch	temps (heures)	charge totale	Pression (mbar)ST4	Energie (Gev)	I K11 (A)
0,00E+00	1,11E-04	0,00E+00	8,90E-11	4,50E+02	0,00E+00
1,09E+02	1,26E-01	1,21E+13	8,90E-11	4,50E+02	2,75E-12
5,40E+02	1,93E-01	6,10E+13	1,40E-10	4,50E+02	9,02E-10
1,60E+03	3,56E-01	1,79E+14	7,50E-10	4,50E+02	9,28E-09
2,56E+03	5,47E-01	2,84E+14	1,10E-09	4,50E+02	1,35E-08
2,56E+03	6,93E-01	2,84E+14	5,60E-10	2,41E+03	4,37E-09
2,56E+03	8,72E-01	2,83E+14	1,30E-09	6,14E+03	1,32E-08
2,56E+03	8,97E-01	2,82E+14	1,30E-09	6,50E+03	1,32E-08
2,56E+03	1,10E+00	2,82E+14	1,30E-09	6,50E+03	1,21E-08
2,56E+03	1,29E+00	2,79E+14	1,00E-09	6,50E+03	7,96E-09
2,56E+03	1,77E+00	2,71E+14	4,70E-10	6,50E+03	1,98E-09
2,56E+03	2,34E+00	2,64E+14	3,00E-10	6,50E+03	5,73E-10
2,56E+03	3,57E+00	2,49E+14	2,00E-10	6,50E+03	1,33E-10
2,56E+03	1,47E+01	1,43E+14	1,00E-10	6,50E+03	1,00E-11

PSD vs Ec

$PSD = c\ Ec^{\alpha}$	α
pour H2	7,40E-01
Pour Ch4	9,40E-01
pour Co	1,01E+00
Pour Co2	1,12E+00

PY vs Ec

$PY = A.E_c^2 + B. .E_c + C$	
A	-9,0E-07
B	6, 0E-04
C	1,0E-02

PSD vs Dose

$PSD = PSD_0\ (D/D_0)^{\beta}$	
D_0 (ph/m)	5,0E+18
β	-9,0E-01

Ecloud map (a,b)

Par calcul a=1,4 b_0 =-0,1 pour nppb=$1,2.10^{11}$ → I_0= -1,98.10^8 A

Evolution of b parameter $b = b_0 \frac{I_0}{I}$ → $I = I_{k11}<0$ measurement

Variation du facteur B de la map Ecloud

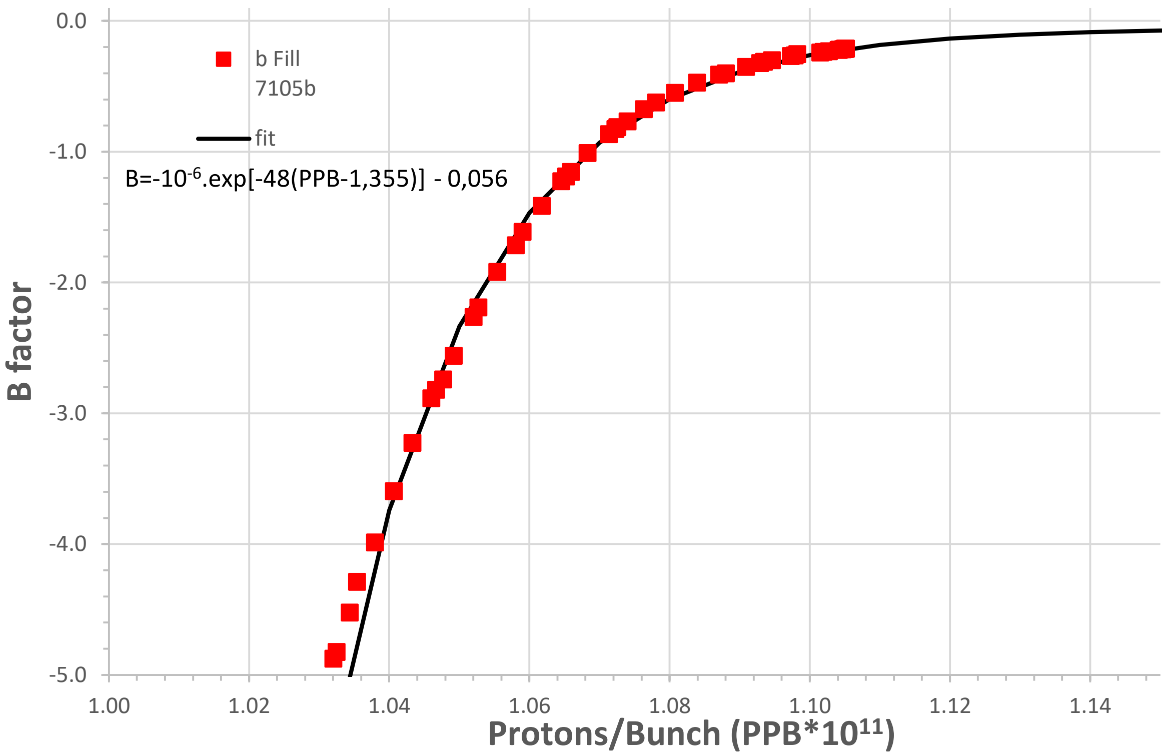
LHC station4

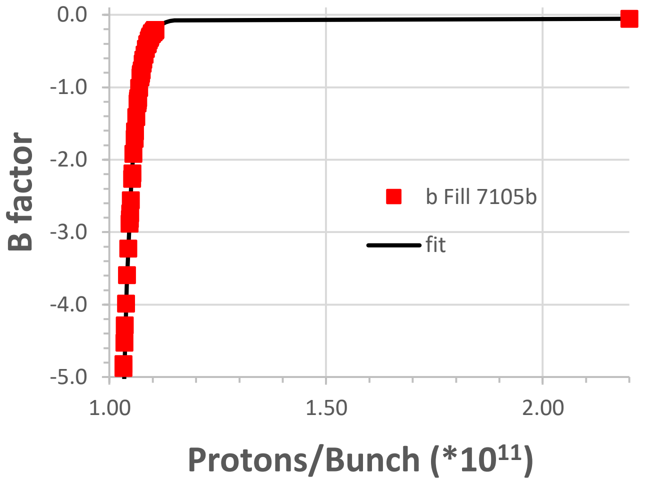
PPB $1.2.10^{11}$ <ρsat> = $3.8.10^{11}\ e/m$

HI-LHC station4

PPB $2.2.10^{11}$ <ρsat> = $7.10^{11}\ e/m$

SEY=1,6 a=1,4 b= -0,057





DYVACS   FCC-hh

Parameter	LHC	FCC-hh
Energy [TeV]	7	50
Current [mA]	580	500
Photon flux [ph/(m·s)]	$1 \cdot 10^{17}$	$1.7 \cdot 10^{17}$
SR power in BM [W/m]	0.22	35.4
Critical energy [eV]	43.8	4286
Cold bore aperture [mm]	50	44
Circumference [km]	26.7	97.75
Number of bunches	2808	10400
Bunch charge (10^{11})	1,15	1
Bunch distance (ns)	25	25
RMS bunch length (cm)	7,55	8
Train (number [bunch / bunch empty])	72/28	80/17
Attenuation RS station4	0,01	0,01
Sey (station 4)	1,6	1,6

Ionisation cross-sections for 50 TeV protons

σ ***(m2)*** H_2 $5.00 \cdot 10^{-23}$ CH_4 $3.64 \cdot 10^{-22}$ CO $3.15 \cdot 10^{-22}$ CO_2 $4.93 \cdot 10^{-22}$

Section efficace pour des électrons de 150 ev

σ ***(m2)*** H_2 $1.00 \cdot 10^{-20}$ CH_4 $3.8 \cdot 10^{-19}$ CO $2.75 \cdot 10^{-19}$ CO_2 $4.20 \cdot 10^{-19}$

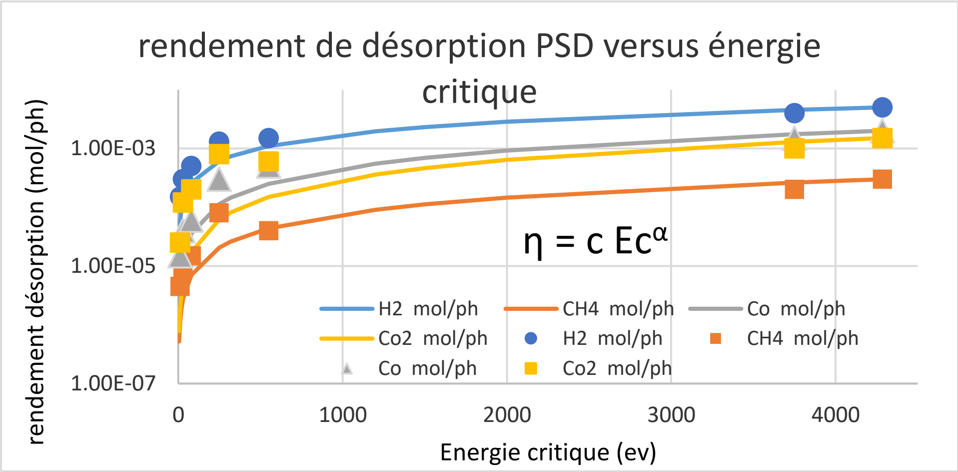
Rendement de désorption ionique (idem LHC simulation station4)

Rendement de désorption électronique (idem LHC simulation station4)

Rendement de désorption photonique

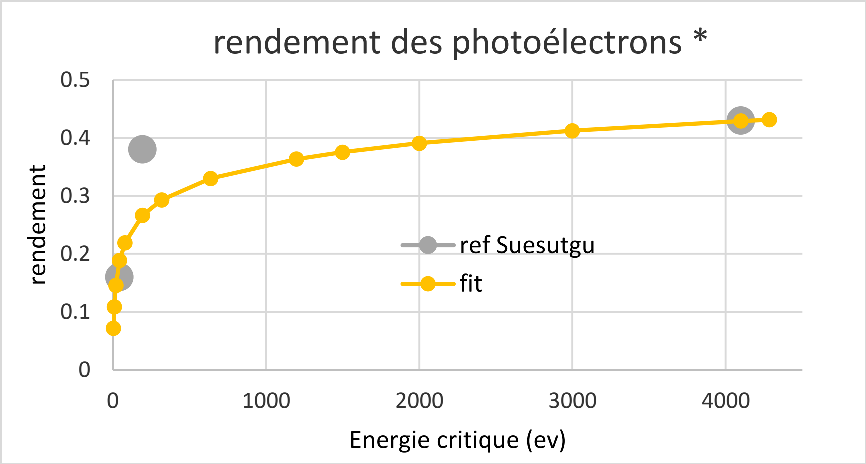
PSD (cuivre étuvé et non conditionné) Ec=4,3 Kev	
H2	5*10-3
C0	2*10-3
co2	1,5*10^-3
ch4	3*10^-4

ref Gomez Goni	**α**
pour H2	7,40E-01
Pour Ch4	9,40E-01
pour Co	1,01E+00
Pour Co2	1,12E+00



Rendement de photo électrons

Critical Energy	4.1 keV		
Incident Angle	52 mrad		
	η	R [%]	η*
Saw-Tooth	0.016	0.18	0.016
Machining	0.04	1.1	0.04
Smooth	0.29	33.2	0.434



Determination of Ecloud map factors: $\rho_{m+1} = \mathbf{a}\rho_m + b{\rho_m}^2 + c{\rho_m}^3$

$$a = \frac{\rho_{m+1}}{\rho_m} \quad \Rightarrow \quad a = \delta_{BSE}^{n}(E_g) + \delta_{SE}(E_g)\delta_T^{n\varepsilon}(E_{SE})\frac{1-\delta_T^{-n\varepsilon}(E_{SE})\delta_{BSE}^{n}(E_g)}{1-\delta_T^{-\varepsilon}(E_{SE})\delta_{BSE}(E_g)}$$

a depends mainly on : **SEY (δ_{SE}), ε and n**

ε depends on : -E_{SE} (energy of SE = cste ≈5eV)
-Eg = electron energy gain produced by the bunch passage

n = number of elastic collisions with energy Eg performed between two bunches
n depends on the bunch spacing + Eg

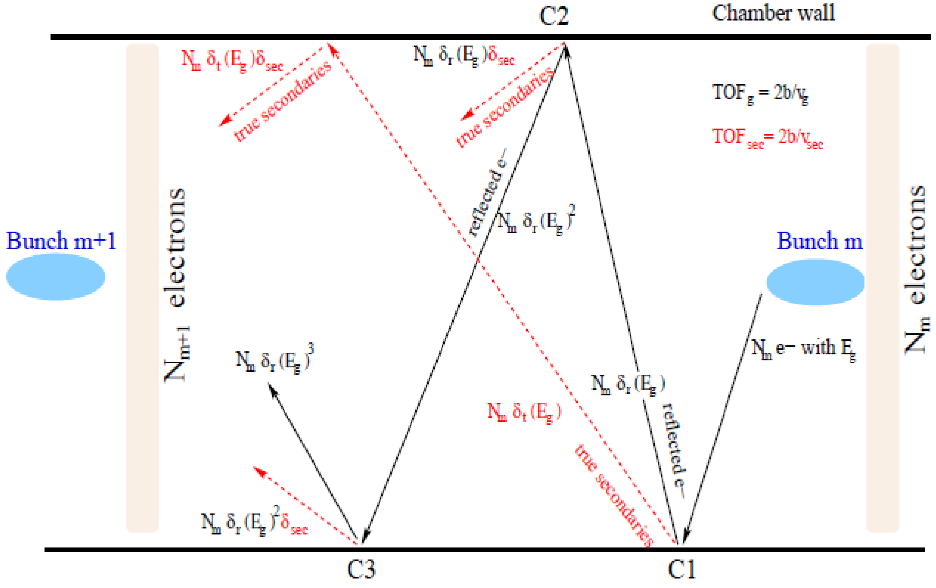
→ **SEYmax ≈ 1.6 = constant** (no conditioning between May and October)

→ **E_{SE} ≈ 5eV = constant**
Eg is given by the experimental energy spectra of electrons recorded by Elena Buratin in the VPS
Same different experimental spectra were recorded by Elena Buratin in different conditions, no significant influence of the nppb is noticed on the electron energy spectrum

→ **Eg = 150 eV = constant**

a = 1.4 = constant in these conditions

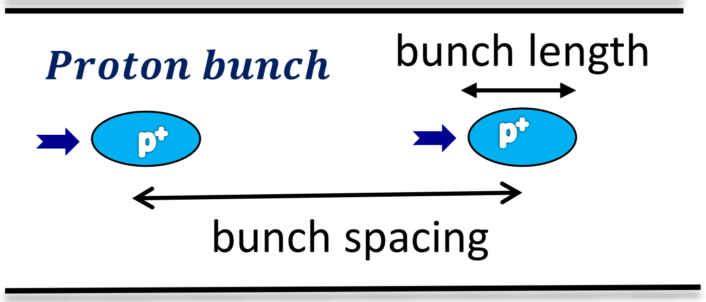
Iriso and Peggs (EPAC 2006)



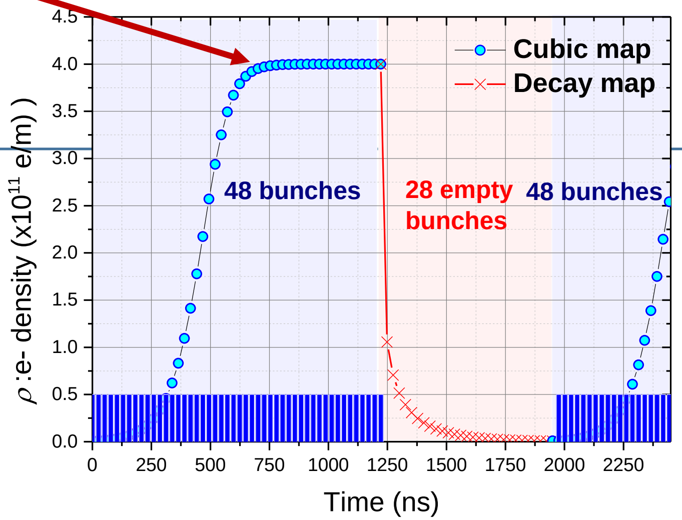
Determination of Ecloud map factors: $\rho_{m+1} = a\rho_m + \mathbf{b}\rho_m{}^2 + c\rho_m{}^3$

$$b_0 \approx \frac{1-a}{\rho_{sat0}} \qquad \rho_{sat0} = \frac{nppb}{cT}\ (e-/m)$$

with c*T= **bunch length**



the electron density at the equilibrium state calculated by DYVACS is ≈an **instantaneous value (calculated for the bunch length)**



Other calculation in the literature:

$$< n > = \frac{N_b}{\pi s_b b^2}. \quad (e-/m3)$$

s_b = bunch spacing

Electron cloud at high beam currents*
S. Heifets, Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309, USA

in this calculation the electr. density is averaged on the **bunch spacing** → It is thus lower than the one calculated by DYVACS

if the bunch spacing is used for calculation rather than bunch length, our ρ_{sat} is divided per 25
In this case, the calculated pressure evolution is not in good agreement with the exp. measurements, unless the ESD yields are increased to unrealistic values.

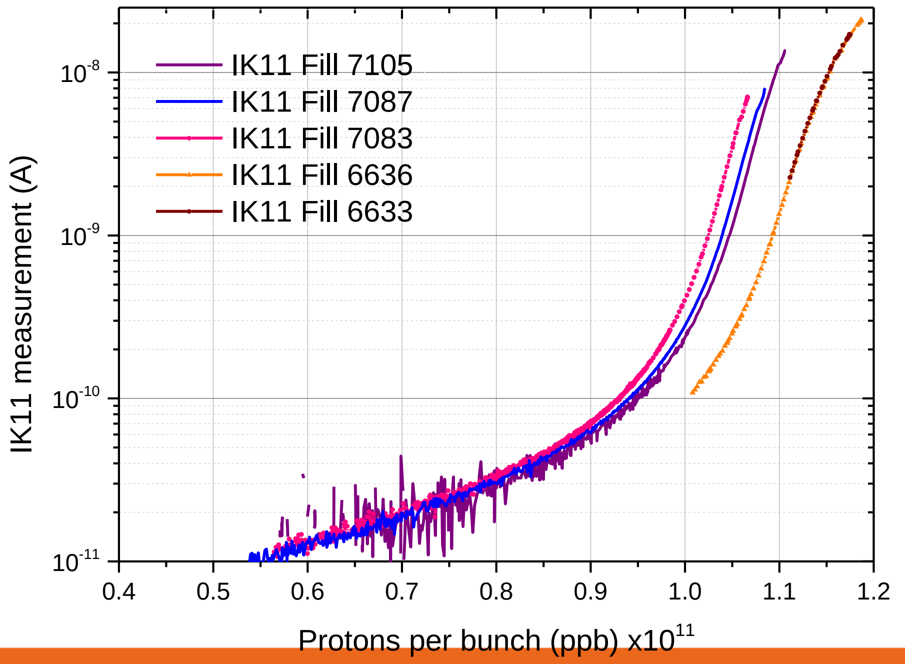
Determination of Ecloud map factors: $\rho_{m+1} = a\rho_m + \mathbf{b}\rho_m^{\ 2} + c\rho_m^{\ 3}$

$$b_0 \approx \frac{1-a}{\rho_{sat0}} \qquad \rho_{sat0} = \frac{nppb}{cT}\ (e-/m)$$

with c*T= **bunch length**

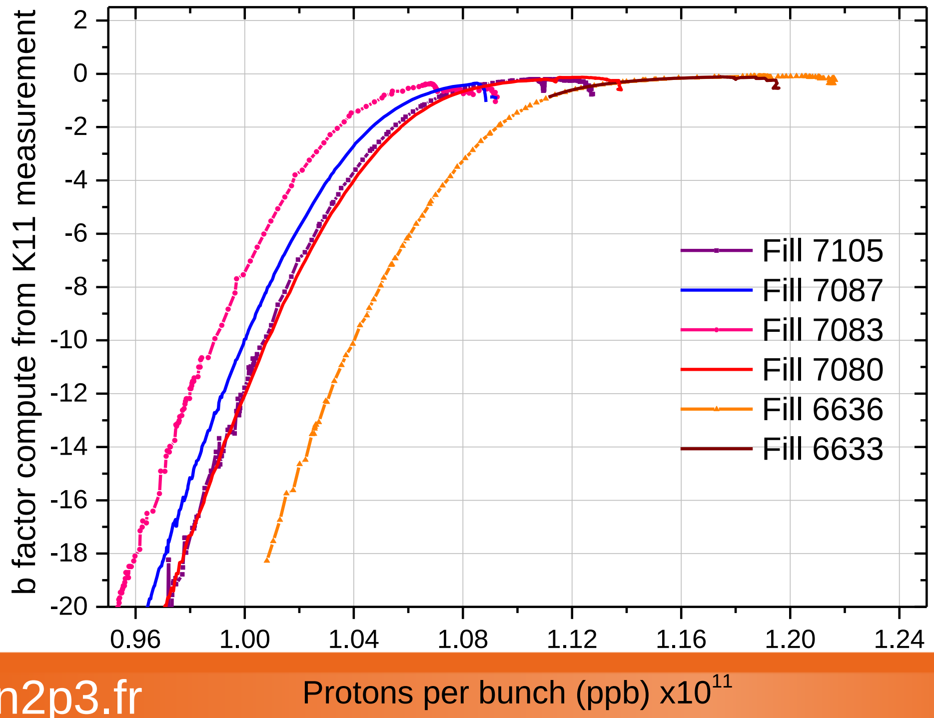
ρ_{sat} is proportional to the electron current measured in the VPS

Experimental electron current as a fonction of nppb



$$b = b_0 \frac{\rho_{sat0}}{\rho_{sat}} \approx b_0 \frac{I_0}{I}$$

b factor computed from electrical current measurements as a fonction of nppb



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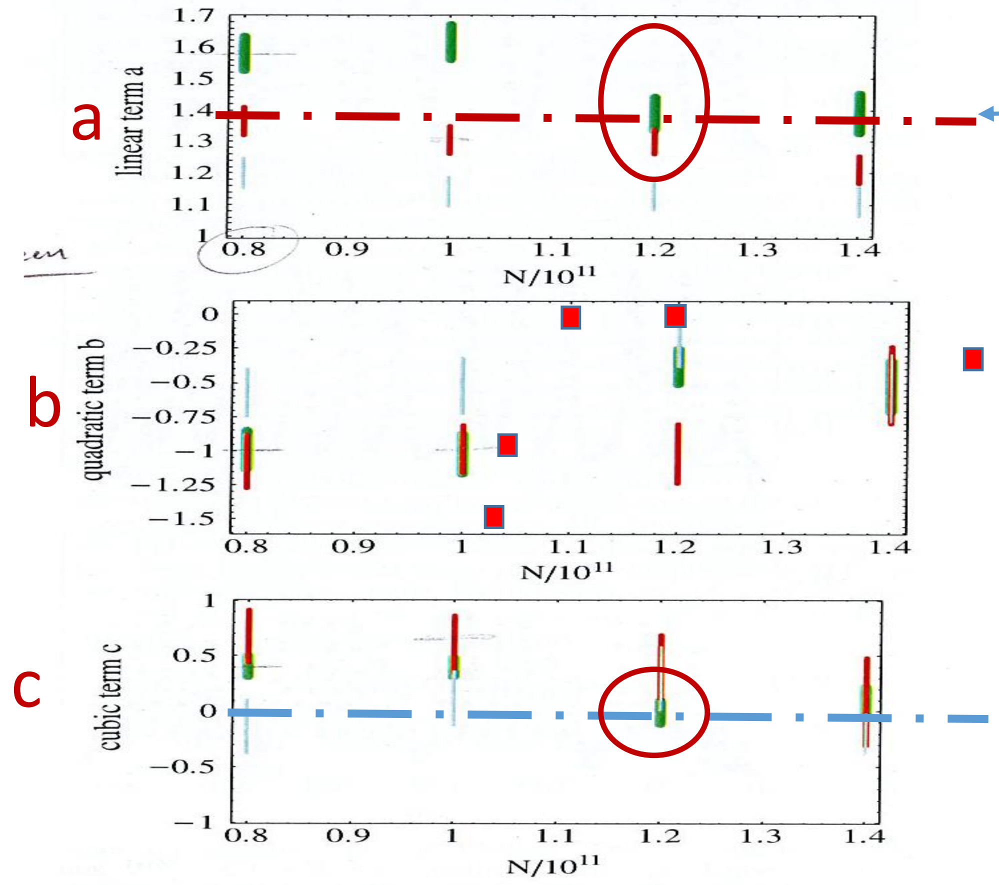
Comparaison of Ecloud map parameters : our results *vs* T. Demma article

$$\rho_{m+1} = a\rho_m + b{\rho_m}^2 + c{\rho_m}^3, \qquad (1)$$

which are seen to reproduce the data quite well. The map idea introduced in [4] with reference to RHIC thus works also for LHC.



factor a=1.4 for a SEYmax=1.6

Variation of the b factor by Dyvacs

FIG. 3. (Color) The a, b, c coefficients obtained by fitting the map (1) to the density buildup regime, for several N. The bars represent the 95% confidence intervals for $\delta_{max} = 1.3$ (cyan), $\delta_{max} = 1.5$ (red), and $\delta_{max} = 1.7$ (green). All other parameters as in Table I.

simulation for the LHC with a magnetic field in the article

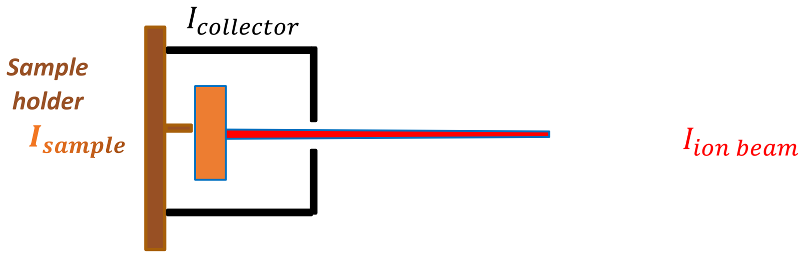
TABLE I. Input parameters for ECLOUD simulations.

Parameter	Units	Value
Beam particle energy	GeV	7000
Bunch spacing	m	7.48
Bunch length	m	0.075
Number of bunches N_b		72
Number of particles per bunch N		8×10^{10} to 1.4×10^{11}
Bending field B	T	8.4
Length of bending magnet	m	1
Vacuum screen half height	m	0.018
Vacuum screen half width	m	0.022
Circumference	m	27 000
Primary photoemission yield		8×10^{-4}
Maximum SEY, δ_{max}		1.3 to 1.7
Energy for maximum SEY, E_{max}	eV	237
Energy width of secondary e^-	eV	1.8

Our a, b and c factors are in good agreement with those calculated by T. Demma

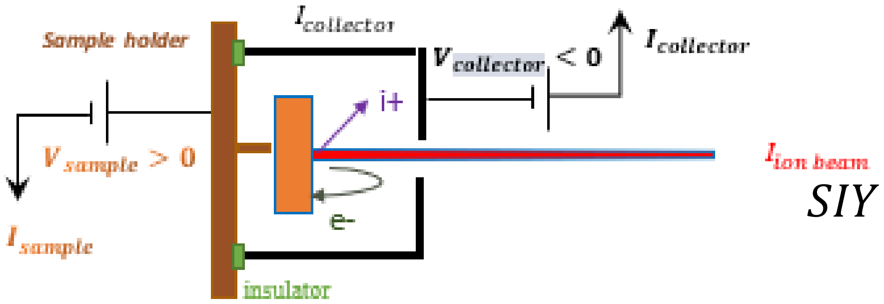
Surface property measurements in laboratory

ISD



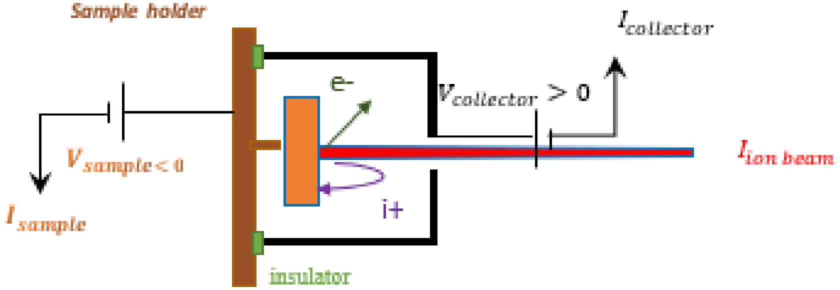
$$\eta_i = \frac{\Delta I(RGA)_i . S_i . e}{K(RGA)_i . k_B . T . I_{beam}}$$

SIY

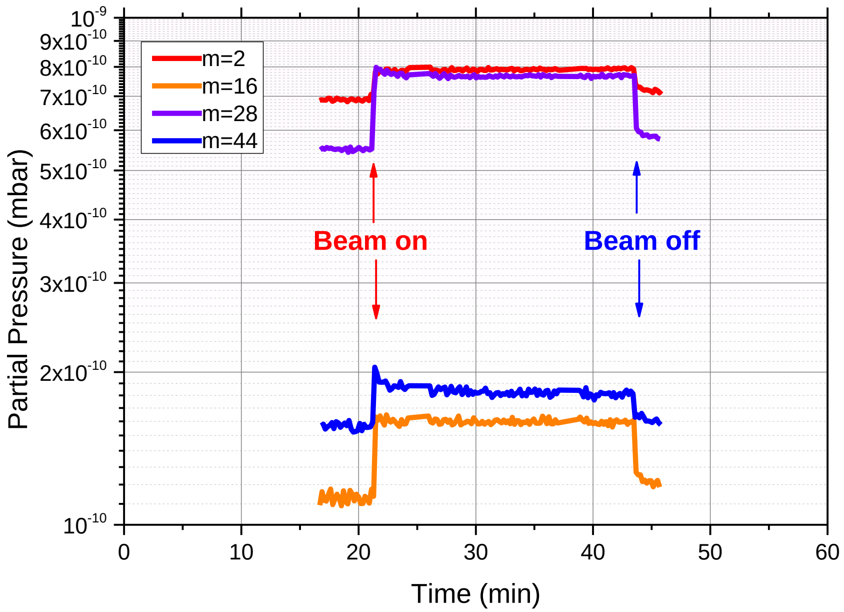


$$SIY = \frac{I_{i+}}{I_{ion\ beam}} = \frac{I_{collector}}{I_{sample} + I_{collector}}$$

IISEY



$$IISEY = \frac{I_{e-}}{I_{ion\ beam}} = \frac{I_{collector}}{I_{sample} + I_{collector}}$$



- base pressure: $5x10^{-10}$ mbar
- Gases used: Ar, H2, CO
- Continuous beam
- Beam current: pA up to 300 nA
- Beam energy: 200 eV to 5keV