DE LA RECHERCHE À L'INDUSTRIE

Status of the IPM for cold linac NPMs

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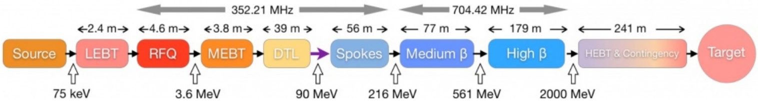
Proton beam profile monitor @ ESS



MOTIVATIONS:

Perfect beam alignment in order to:

- Maximize protons on target
- Prevent beam losses ☢

⇓

REQUIREMENTS:

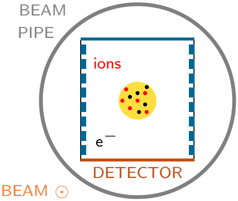
- Must stand high proton beam intensity
- Minimum impact on proton beam

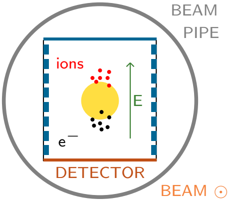
⇓

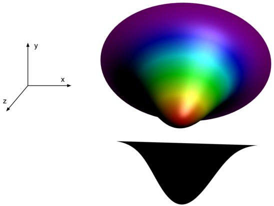
IONIZATION PROFILE MONITORS
(1 in Spokes, 3 in Medium β, 1 in High β)

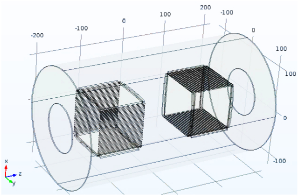
Ionization Profile Monitors (IPMs)

PRINCIPLE OF OPERATION









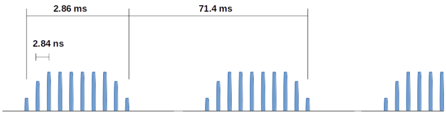
FEASIBILITY STUDIES (F.S.):

- ➢ Nb of ion/pairs per pulse?
- ➢ Electric field uniformity (A. Vnuchenko)
- ➢ Space charge effect

F.S. (1/10): ion/electrons pairs expected

ESS PROTON BEAM PARAMETERS:

- Energy : [90,2000] MeV
- Current peak: 62.5 mA
- Pulse length: 2.86 ms
- Pulse frequency: 14 Hz (duty cycle 4%)
- Bunch frequency: 352.21 MHz and 754.42 MHz

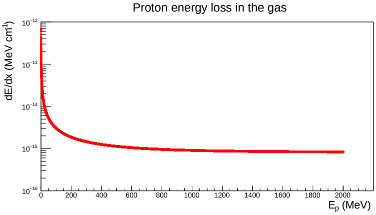


IPM GAS PARAMETERS:

- Composition : H_2 (79%), CO (10%), CO_2 (10%), N_2 (1%)
- Pressure: 10^{-9} mbar
- Mean Ion. Pot.: 35.65 eV

$$-\left\langle \frac{dE}{dx} \right\rangle = .\, T_{\max} = \frac{2m_e c^2\, \beta^2\gamma^2}{1+2\gamma m_e/M + (m_e/M)^2}\beta^2 - \frac{\delta(\beta\gamma)}{2} \Big]$$

$$T_{\max} = \frac{2m_e c^2\, \beta^2\gamma^2}{1+2\gamma m_e/M + (m_e/M)^2}$$

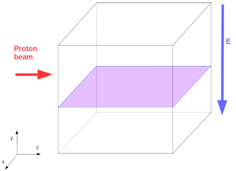


Proton energy (Mev)	Pairs /cm/s
90	103235
216	55531
561	33769
2000	26150

F.S. (2/10): electric field uniformity

ELECTRIC FIELD INTENSITY CONSTRAINTS:

- Below spark threshold
- Avoid proton beam deviation
- Avoid emittance growth
- Uniformity needed on planes perpendicular to the electric field
- "Identity" needed among planes perpendicular to proton beam

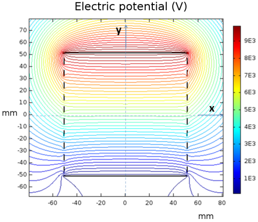


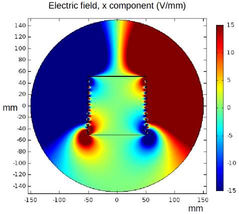
SIMULATIONS OF THE ELECTRIC FIELD UNIFORMITY MADE BY A. VNUCHENKO WITH COMSOL:

COMSOL Multiphysics is a platform for physics-based modelling and simulation tools for electrical, mechanical, fluid flow, chemical and other applications.
A numerical technique (finite element method) is used to find approximate solutions to boundary value problems for partial differential equations. FEM solvers generate an optimized mesh and calculate the potential value on it.

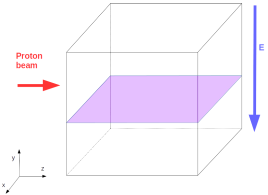
a. 2D MODEL OF A SINGLE IPM:

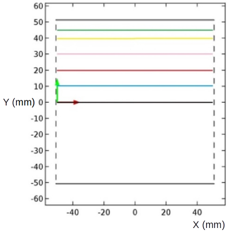
- $E = 10$ kV/10 cm
- Dimensions = 10 cm x 10 cm
- Equally spaced field degrader
- Beam tube radius = 250 mm

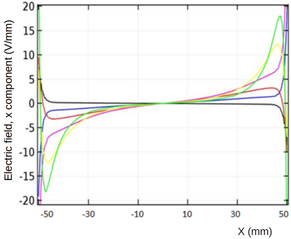


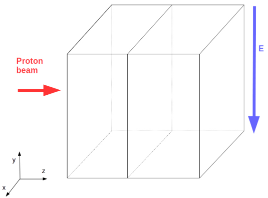


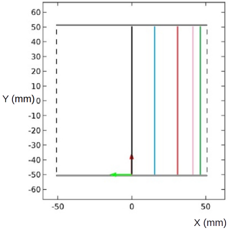
F.S. (3/10): electric field uniformity

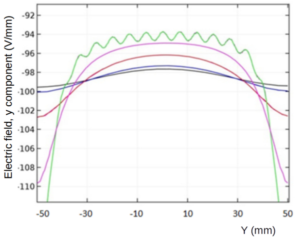








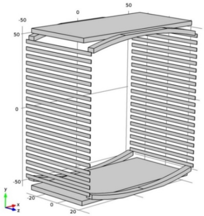




F.S. (4/10): electric field uniformity

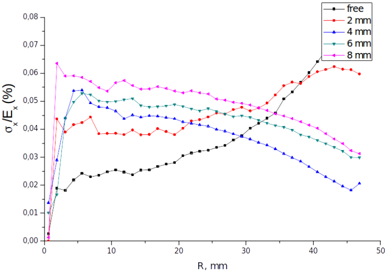
b. 3D MODEL OF A SINGLE IPM:

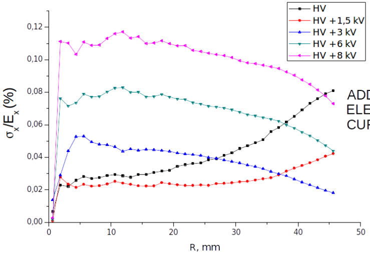
- E = 30 kV/10 cm
- Dimensions = 10 cm x 10 cm x 4 cm
- 40 Equally spaced field degraders
- y dimension of field degrader = inter field degraders space
- **Additional curved electrodes**



VARIABLE TO CHECK ELECTRIC FIELD UNIFORMITY:
(Electric field imposed along the y axis)

$$\sigma_x = \frac{\sqrt{\Sigma(E_x)^2)}}{N}$$

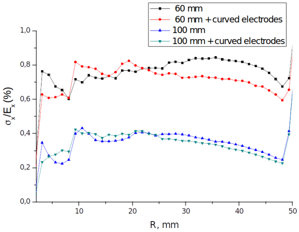




ADDITIONAL ELECTRODE CURVATURE 2mm

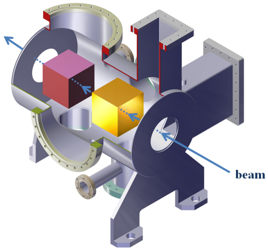
c. 3D MODEL OF A SINGLE IPM:

- $E \geq 30$ kV/10 cm
- Dimensions = 10 cm x 10 cm x **10 cm**
- 40 Equally spaced field degraders
- y dimension of field degrader = inter field degraders
- Additional curved electrodes
- Beam pipe radius = 15 cm



For detectors with larger z the additional curved electrode is not necessary

d. 3D MODEL OF 2 IPMs:

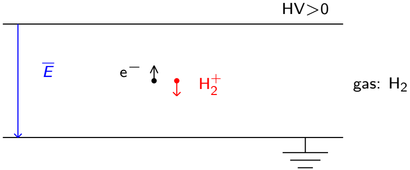


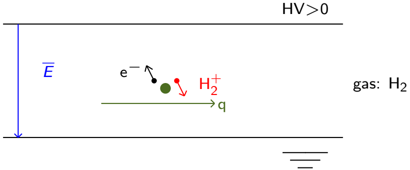
OUTCOME

- E = 30 kV/10 cm
- Cages dimensions = 10 cm x 10.2 cm x 10.2 cm
- 40 Equally spaced field degraders
- y dimension of field degrader = inter field degraders space
- No curved electrodes
- Vaccum chamber length = 42.8 cm
- Beam pipe radius = 12.2 cm
- Distance between cages = 9 cm
- Distance between chamber wall and first IPM = 12.6 cm
- Distance between chamber wall and first IPM should be increased to avoid spatks →Flange should be moved (Unfortunately the VC PDR refused)

F.S. (6/10): Space charge

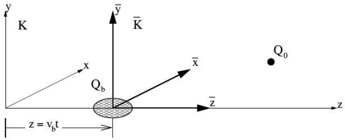
REMINDER:





POSSIBLE CORRECTION METHODS

- High electric field ✓ ✗
- Add magnetic field ✗
- Software correction ✓



SOFTWARE CORRECTION

R. Wanzenberg, Nonlinear Motion of a Point Charge in the 3D Space Charge Field of a Gaussian Bunch.

A Gaussian bunch with total charge $\mathbf{Q}_b$ is moving with the velocity $\mathbf{v}_b$ along the z-axis of the laboratory frame K.
The electric field of the bunch is calculated in the comoving frame and transformed into an electric and magnetic field in the laboratory frame K where the Lorentz-Force on a point charge $\mathbf{Q}_0$ is calculated.

F.S. (7/10): Space charge

CODES:

- MATLAB (**C. Thomas**)
- C++ (translation of the MATLAB code)

SIMULATION STEPS:

- **a single electron (or ion)** is created in the center of the IPM: x= Gaus(0,σ_x)
  y= Gaus(0,σ_y)
  z = Unif(-2.5 mm, 2.5 mm)
- A proton bunch of total charge q = 1.1 e^{+9} and kinetic energy E_p is considered
- A time step *dt* is chosen by the program
- the displacement *dx* of the electron (or ion) is calculated by solving the motion equation (adaptive Runge Kutta Fehlberg method)
- at every *dt* passed, the following variable values are saved: t, x, y, z, v_x, v_y, v_z, a_x, a_y, a_z, fields info (lab and comoving frame)
- when the y position of the electron (or ion) is larger than **5 cm**, the simulation stops
- t and y are plotted and fitted with a spline to find the time $\mathbf{t}_{stop}$ when the electrode was reached
- t and x are plotted and fitted with a spline. x(t_{stop}) is extracted
- the procedure is iterated N times, to reach a statistical uncertainty of (100 $\frac{\sqrt{N}}{N}$) %

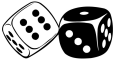
F.S. (8/10): Space charge

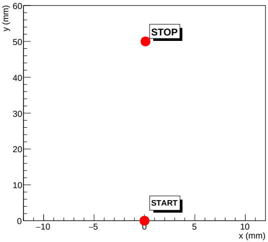
EXAMPLE:

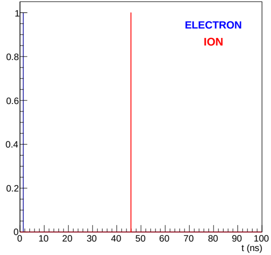
- Particle: e^-
- Initial particle speed: 0 m/s
- Proton beam energy: 90 MeV
- Proton beam direction: Z
- |Electric field|: 300 kV/m
- Electric field direction: -Y
- $\sigma_x = \sigma_y = 0.5$ mm
- $\sigma_z = 0.75$ mm

- Particle: H_2^+
- Initial particle speed: 0 m/s
- Proton beam energ: 90 MeV
- Direction of the proton beam: Z
- |Electric field|: 300 kV/m
- Electric field direction: -Y
- $\sigma_x = \sigma_y = 0.5$ mm
- $\sigma_z = 0.75$ mm

SIMULATION OF A SINGLE PARTICLE IN THE CHAMBER

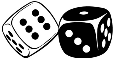


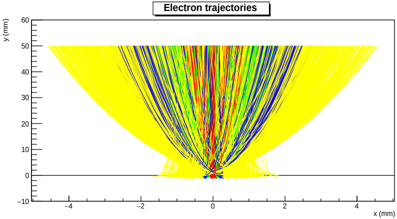


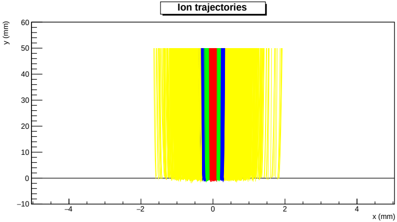


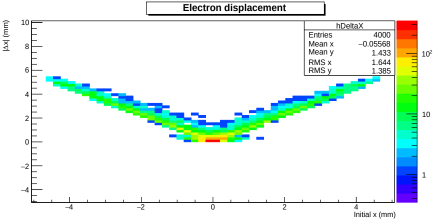
F.S. (9/10): Space charge

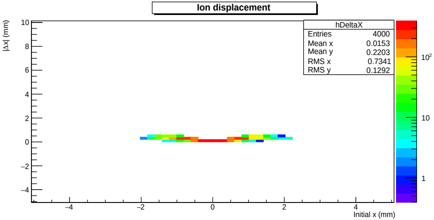
SIMULATION OF 4000 PARTICLE INS THE CHAMBER



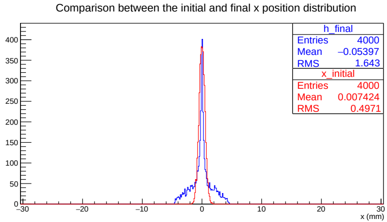


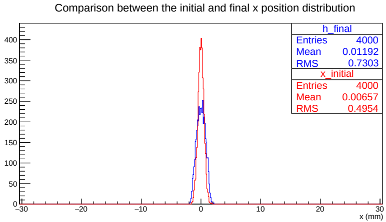






F.S. (10): Space charge





OUTCOME:

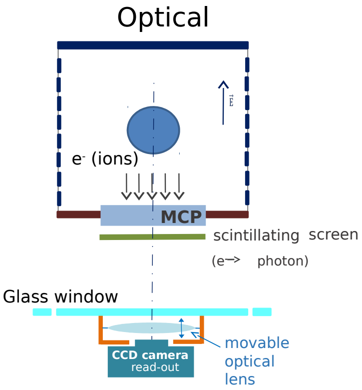
- We are running 1260 simulations
- For ions no space charge issues
- For electrons:
  if $|E_y|$ gets higher, no space charge problems
  if $|E_y| \leq 300000$ V/m, no space charge problems if $\sigma_x \geq 3$ mm
  (for $|E_y| < 300000$ V/m and $\sigma_x < 3$ mm ,
  data still to be analysed...)

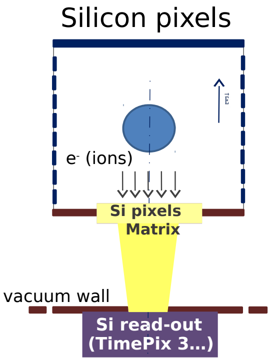
ISSUE:
Storage place

STILL TO DO (for space charge):

- Finish running simulations and analyse results
- Check impact of initial electron speed and, in case, re-run sim

Two directions are investigated





Read Out

Optical

- sensitive parts to radiations
  - MCP
  - Scintillating screen
    - → Can be overcome with gain calibration by injecting light through an optical fiber
    - → Once not usable, throw and change it: maintenance?
- contact with Photonis

Silicon pixel matrix

- radiation hard (100 MGy)
- electronic cooling down
- pixel auto calibration (current injection)
- contact taken at Cern
  - no beam test before Feb. 2017
  - collaboration…

Ability to get profile for each pulse (2.86 ms) : it should be ok for both techniques

Idea: test beam with 2 IPMs equipped with both read-out systems

Florian Benedetti, new PhD student starts his position yesterday. He will investigate the read-out purposes.