Hector :

A fast multi-purpose simulator for particle propagation

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- Validation : cross-checks
- RP scenario
  - acceptance, irr. dose, chromaticity
  - E reconstruction, misalignment
- Perspectives

Introduction

Matrix representation of the transport :

$$X(s) = X(0) \underbrace{M_1 M_2 ... M_n}_{M_{\mathrm{beamline}}}$$

Where :

X is the phase-space vector of the particle

M_i are the matrices associated to the magnets

Rem : here energy losses NOT negligible => energy dependence of M_i as a correction to linearity

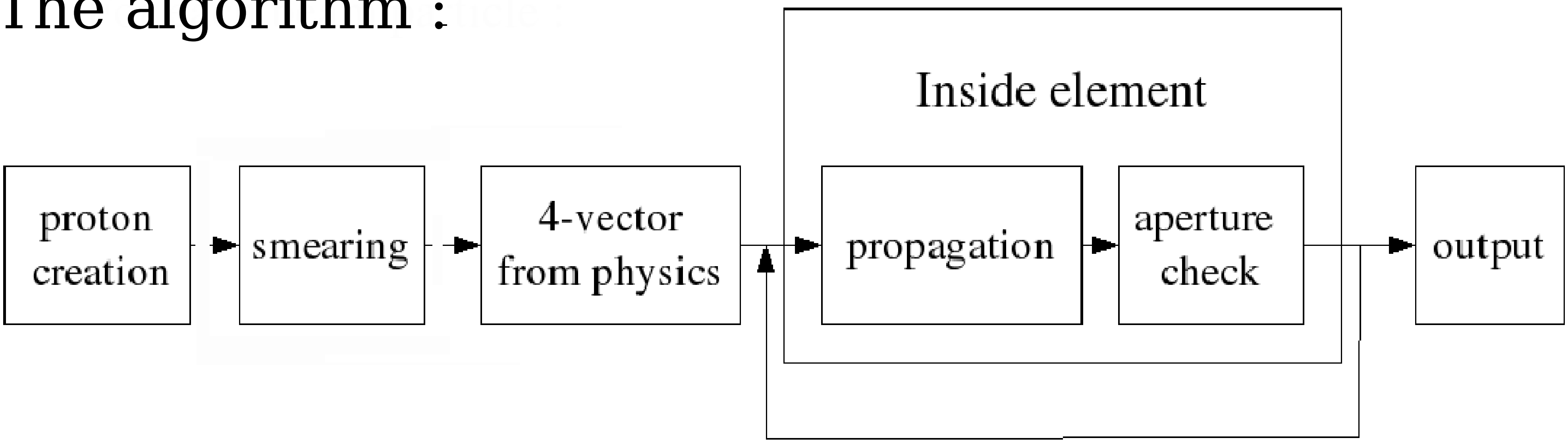
Input Needed :

- effective field strength / length
- magnet position / aperture

Direct interface with the LHC optics tables, but Hector is also compatible with any beamline (multi-purpose library)

Implementation

The algorithm :



The 4-vector can be specified :

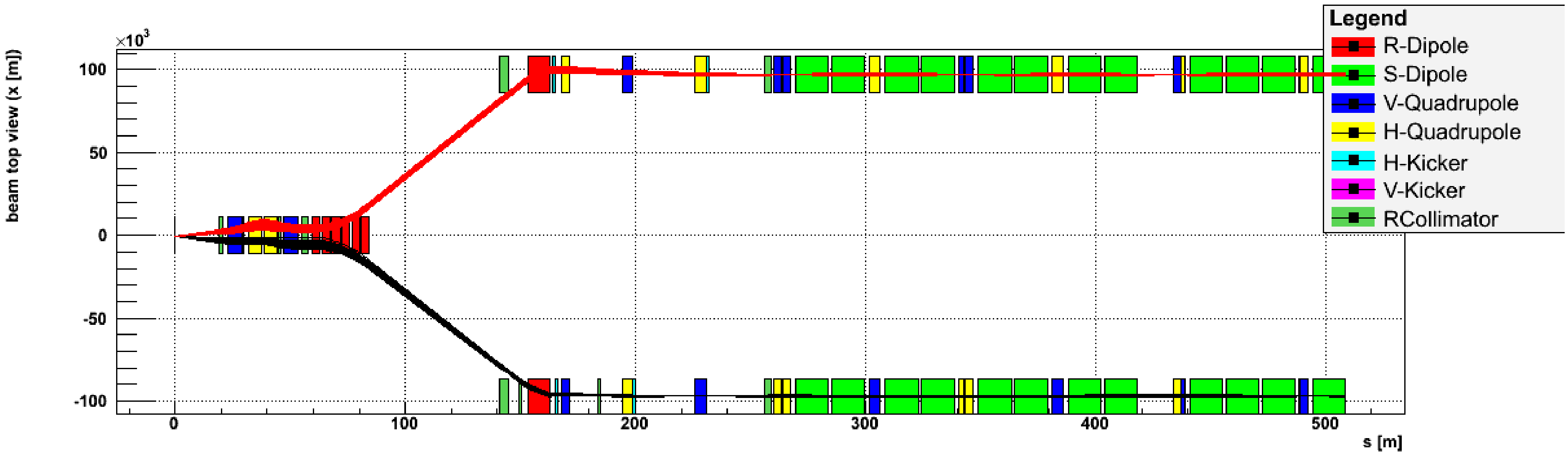
- completely (from generator)

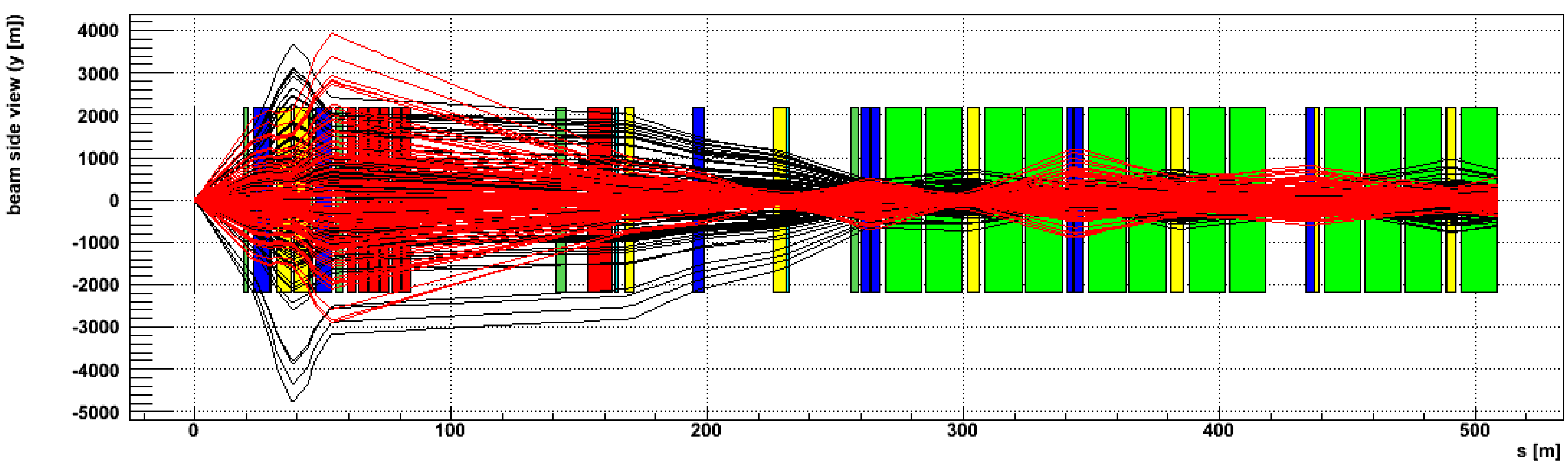
- by choosing energy loss and Q^2 of emitted object

Implementation : C++/ROOT + support (CVS, doxygen, make)

Implementation

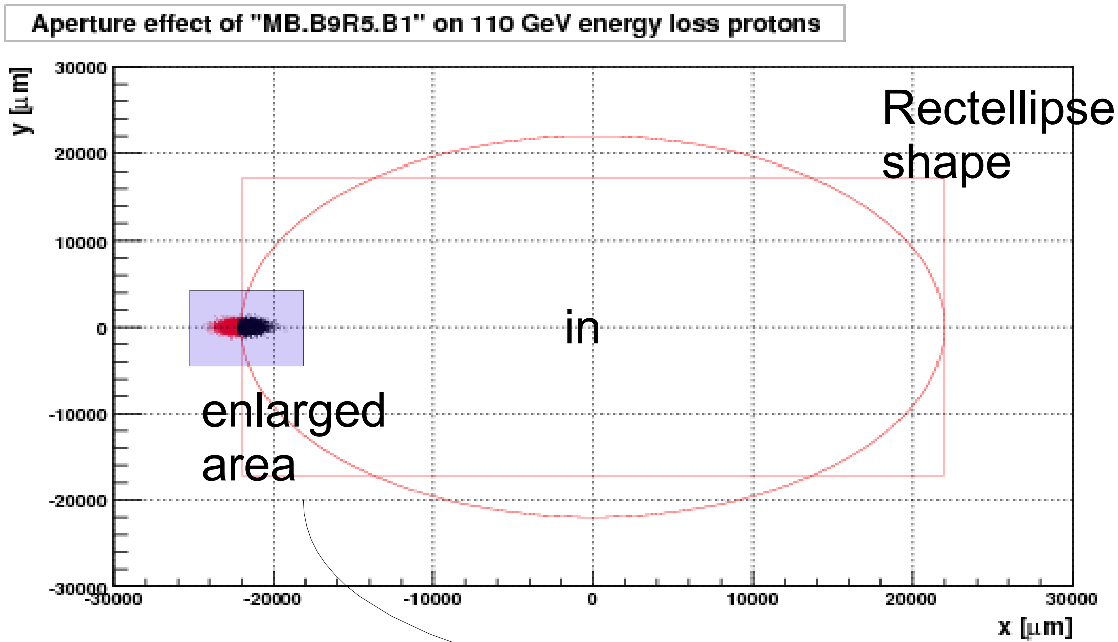
The LHC beams (right of CMS) :

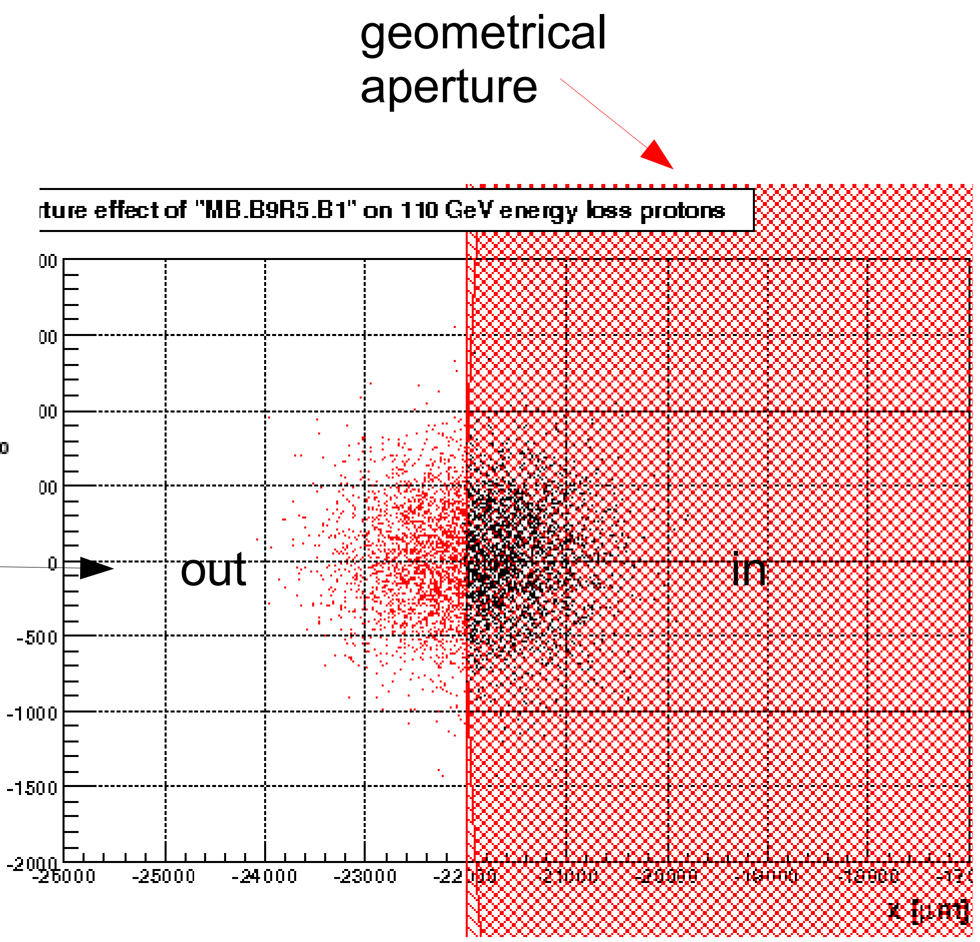




Implementation

Aperture :

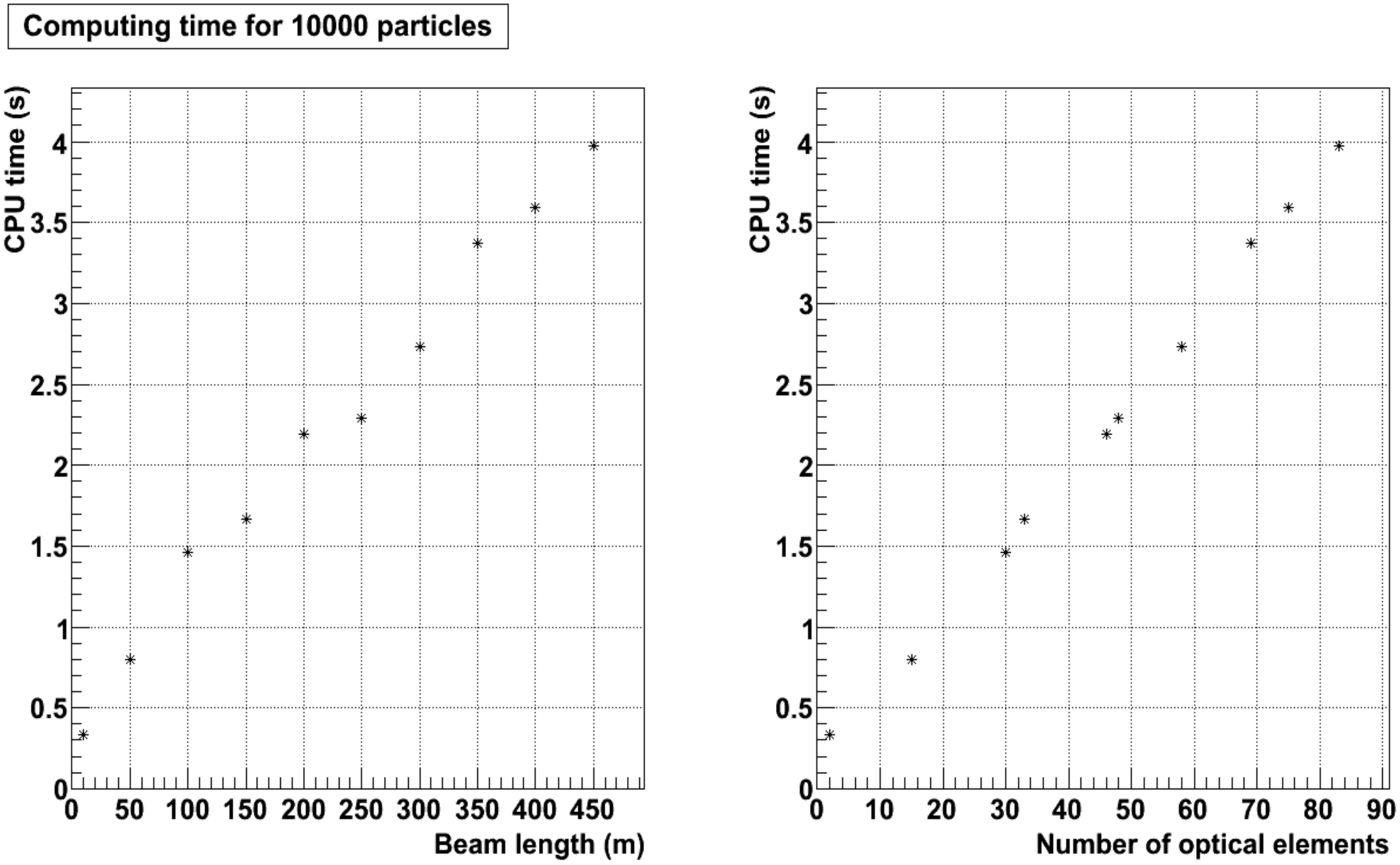




Tests whether the particles hit the physical border of the vacuum tube

Introduction

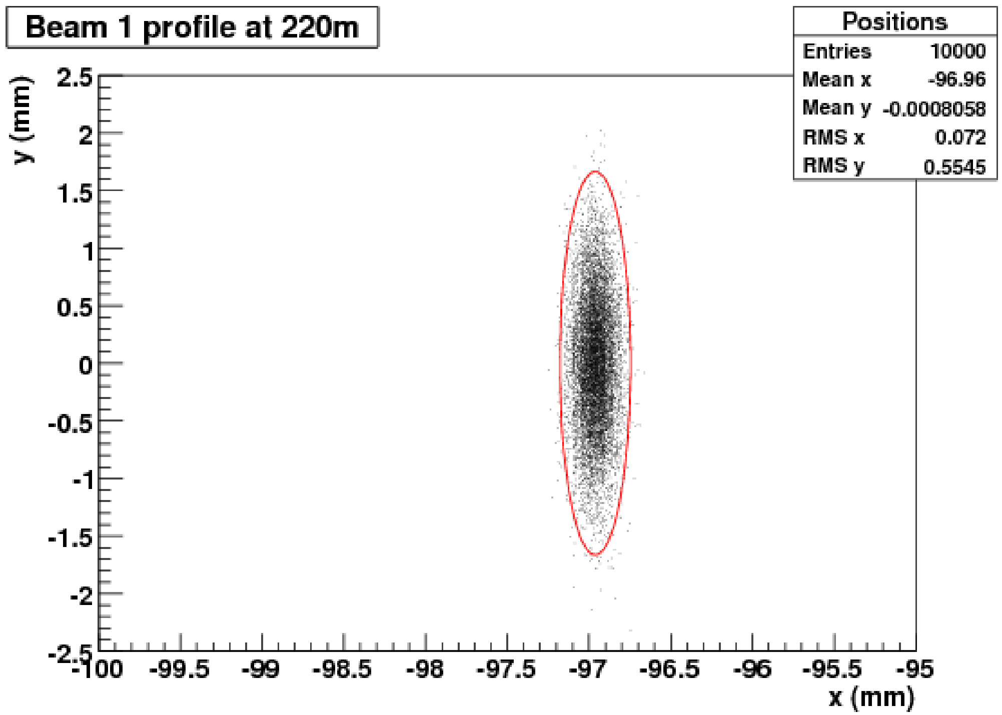
Performances :

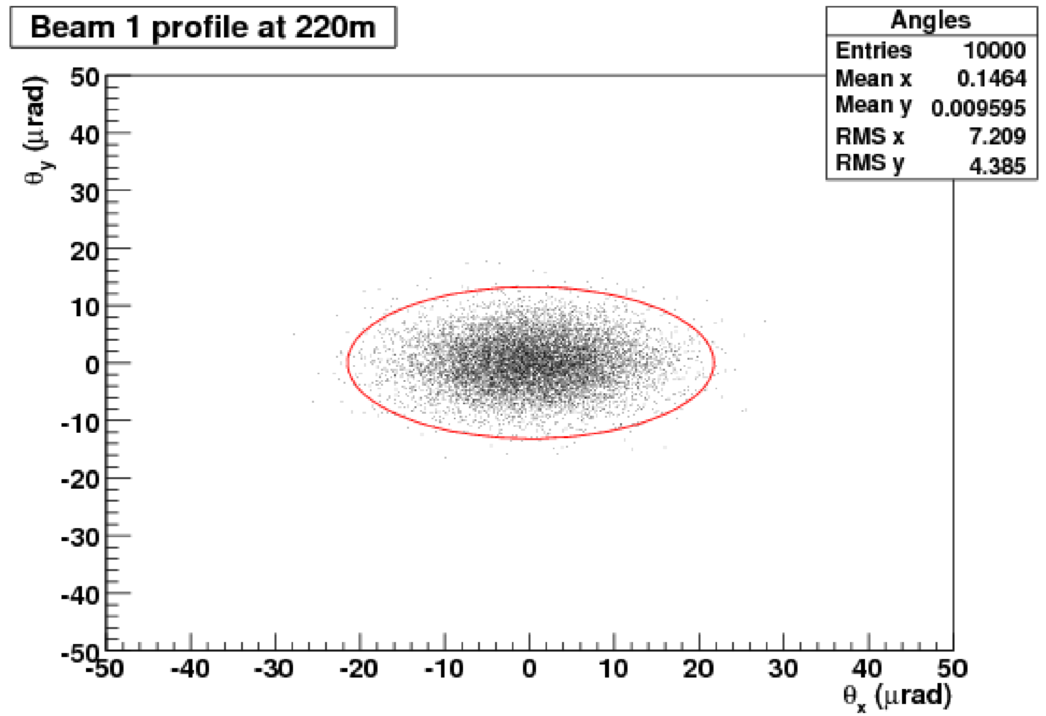


~ 3.5 µs $particle^{-1}$ $magnet^{-1}$

-> ~10^{-3} s / CMS event

Output

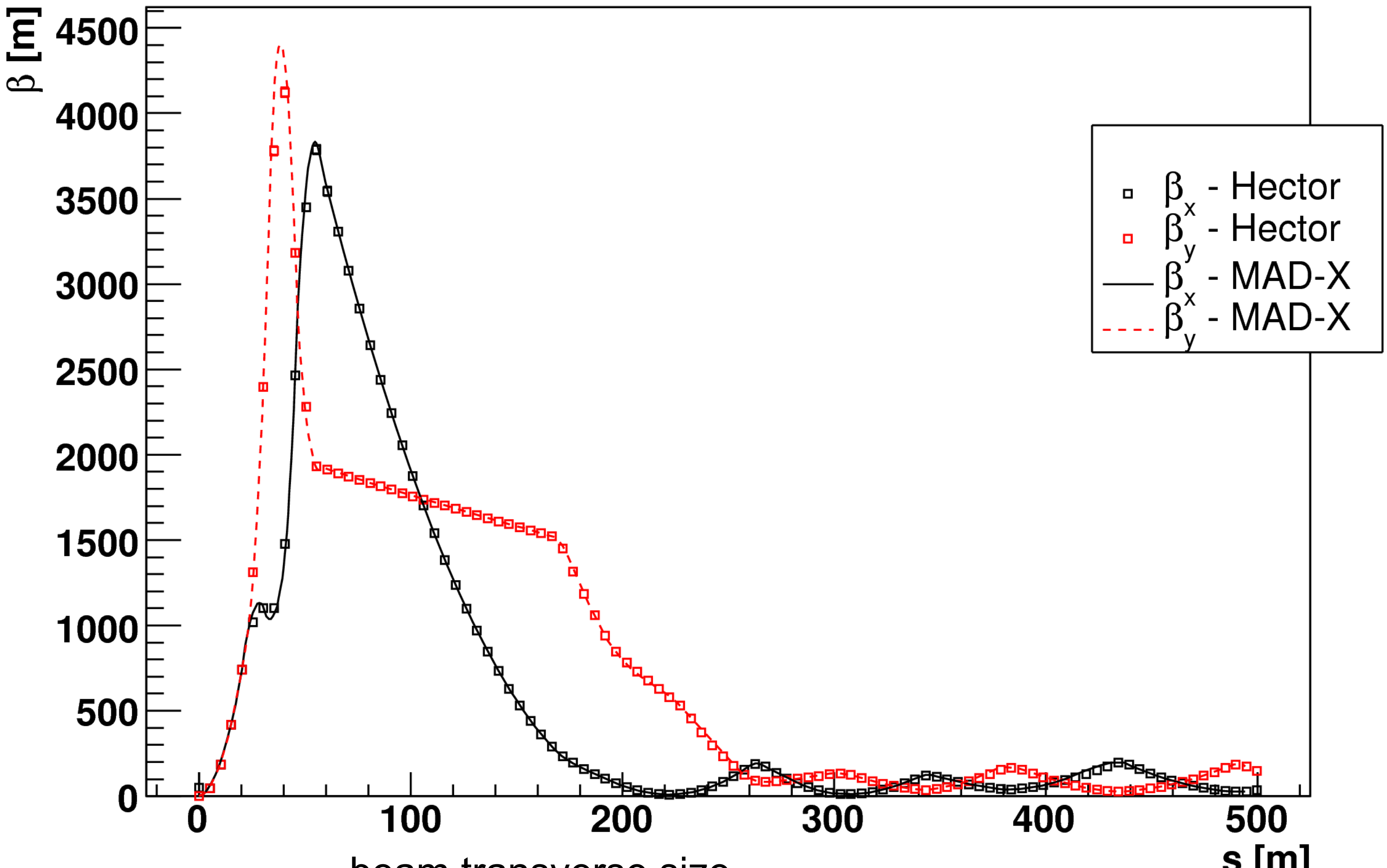




- Just take some protons, from LHC beam 1
- Propagate them to your favourite Roman pot detector
- Plot the x,y,x',y' in the transverse plane

Validation

β functions - beam 1, forward



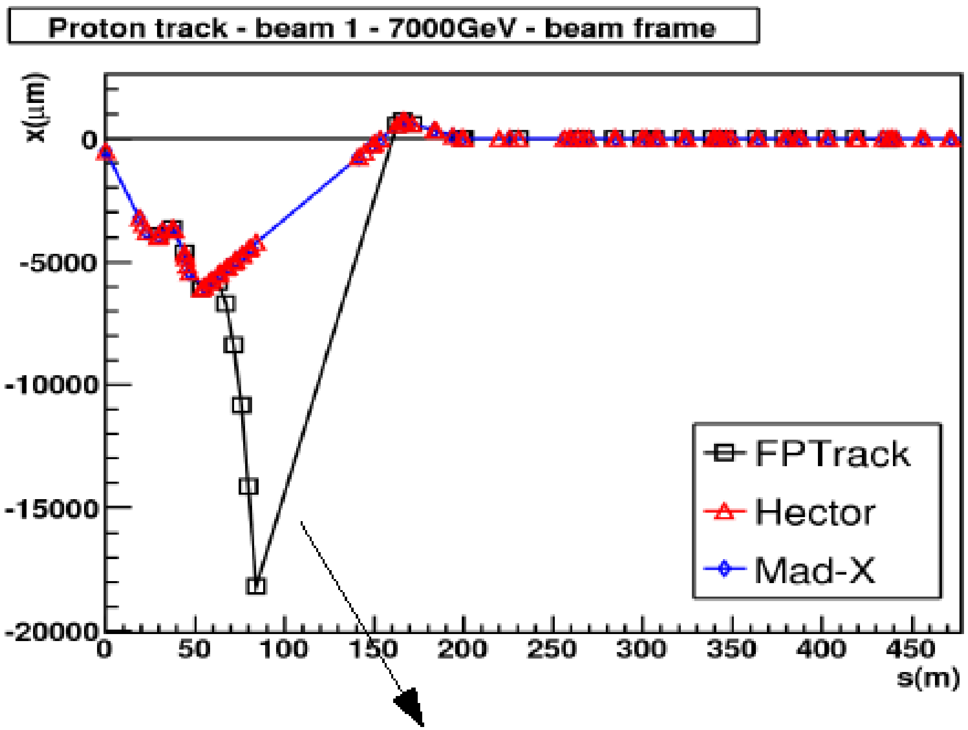
~ beam transverse size

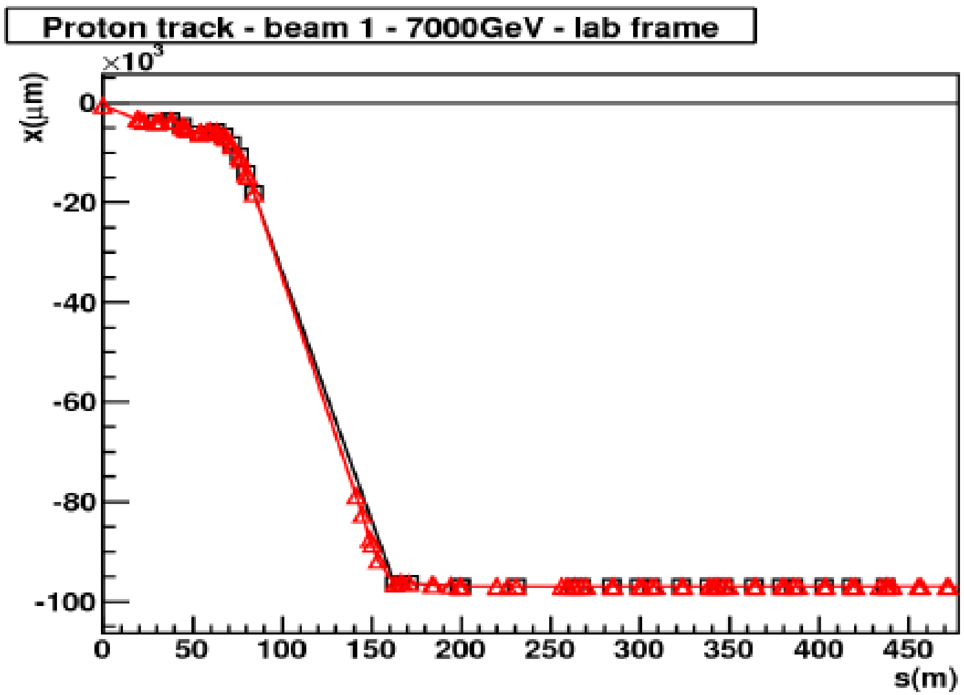
Validation

Comparing to MAD-X and FPTrack

Beam Frame

Absolute Frame



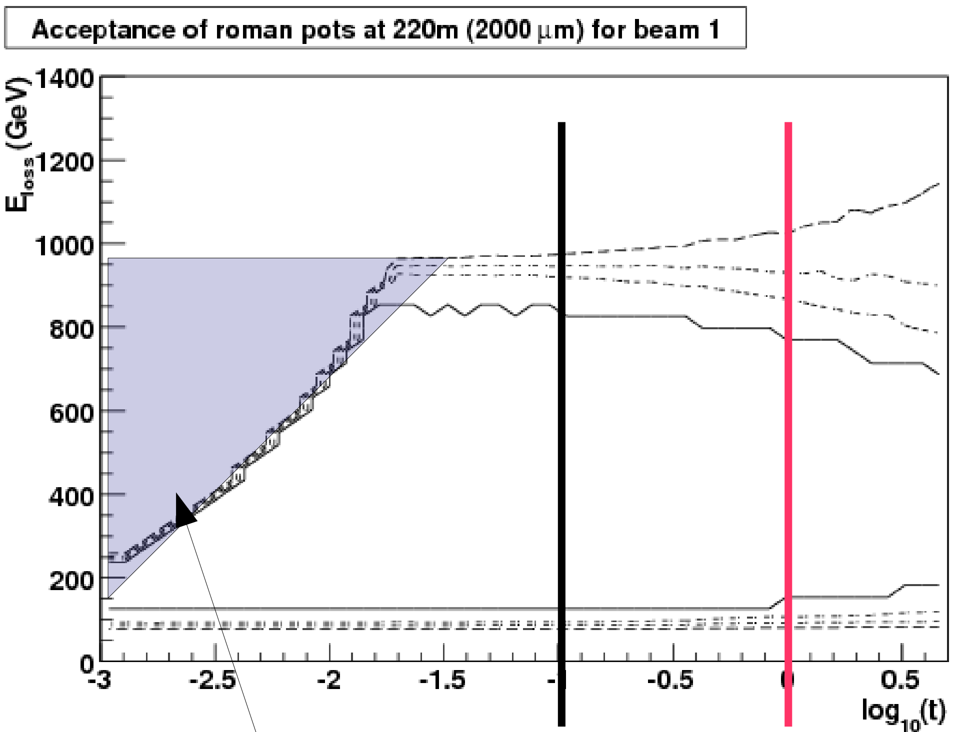


Only from frame definition

Very good agreement everywhere :
FPTrack vs Mad : < 5 μm
Hector vs Mad : < 0.5 μm

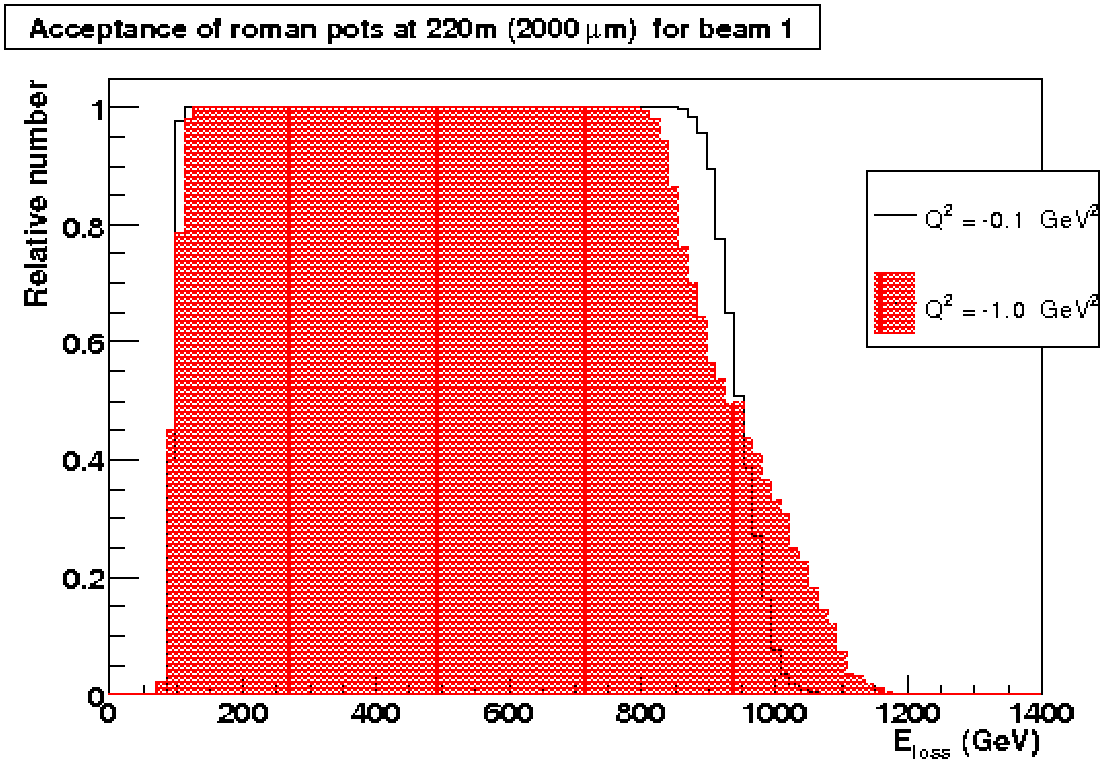
Direct physics output

RP acceptances (220m) :

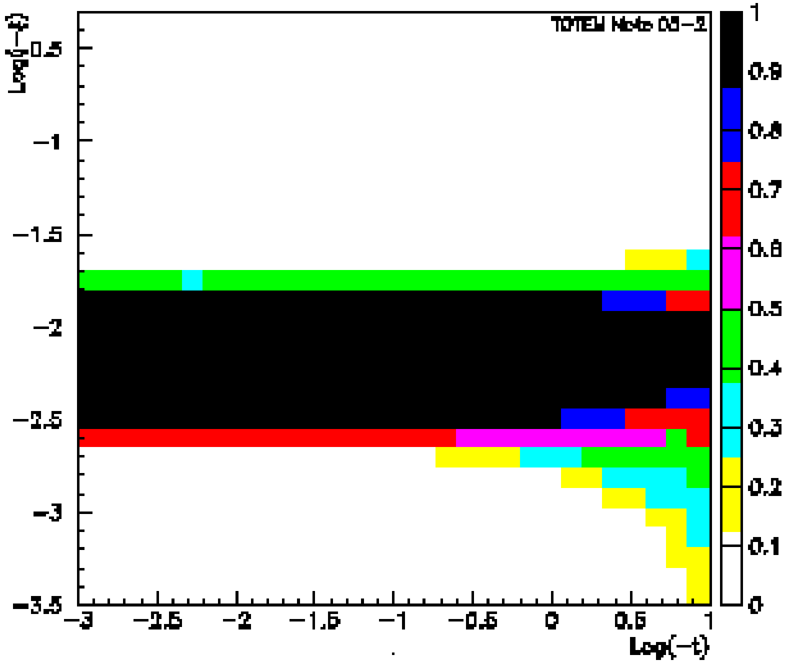


Forbidden by kinematics

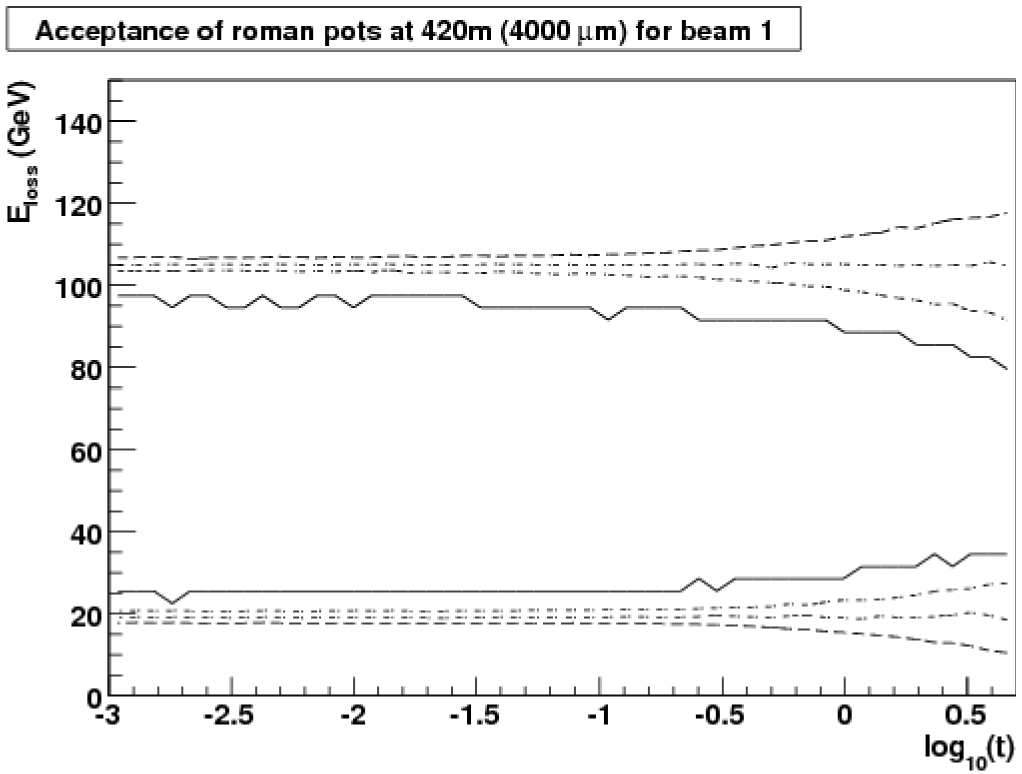
Which protons are detected ?



Comparison to MAD-X



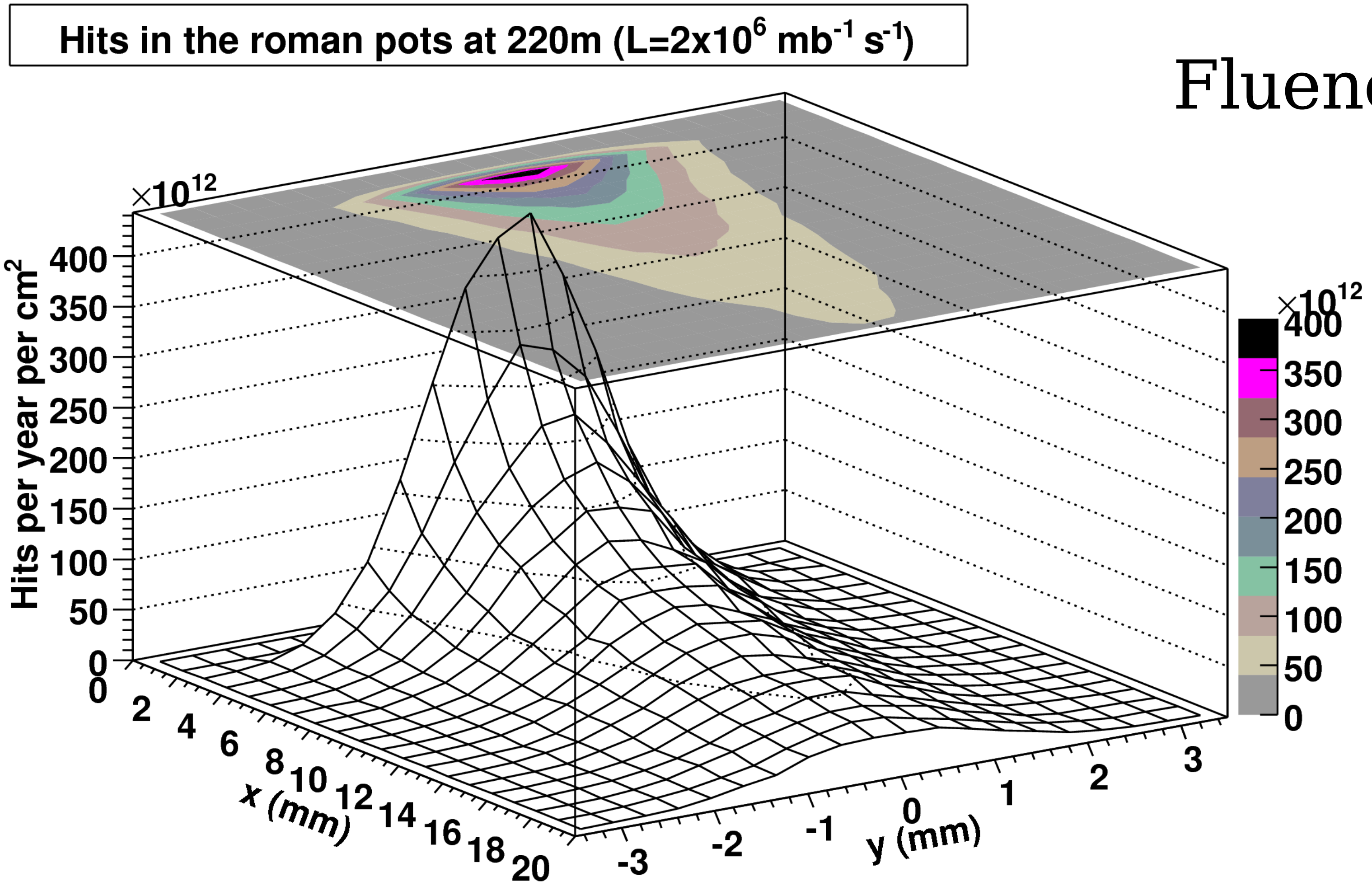
MAD-X (from TOTEM Note 05-2)



Hector

Direct physics output

Fluencies :

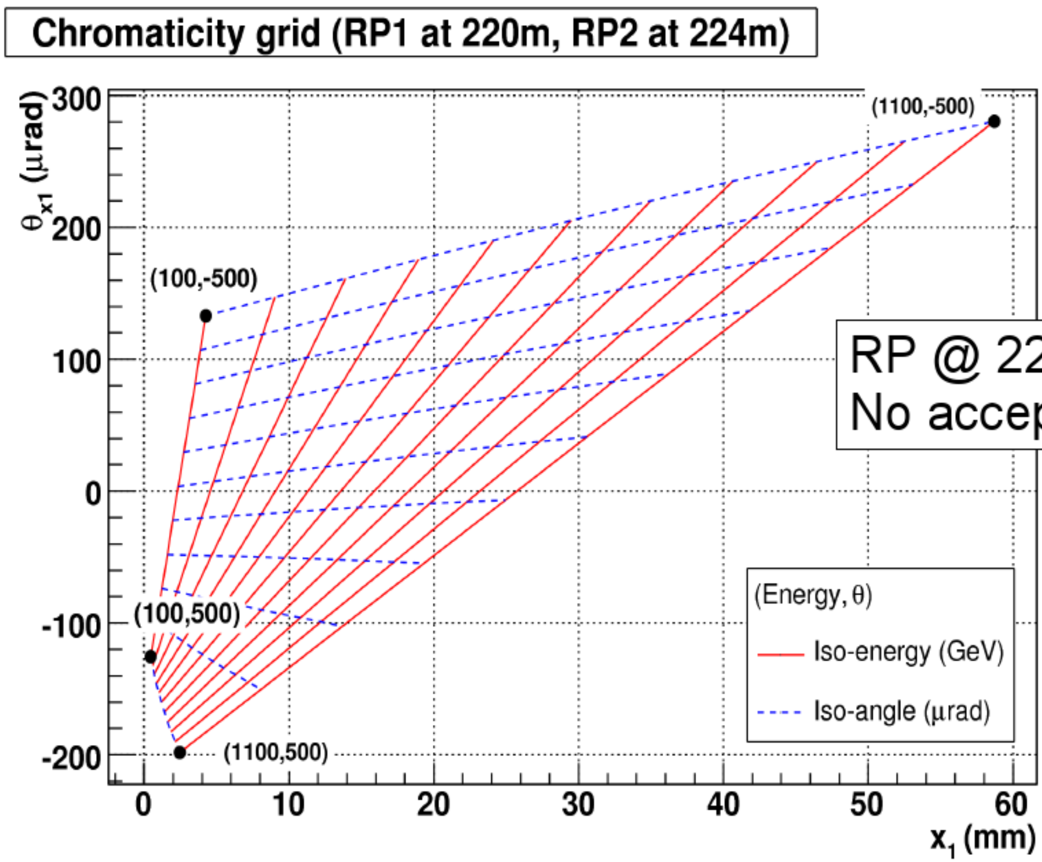


Diffractive physics : pp → pX
(PYTHIA inside)

Direct physics output

Chromaticity grid :

where is your proton given its energy/angle ?



RP @ 220 m
No acceptance effects

- •Choose a proton, with a given energy loss and initial angle
- •Propagate it to your 2 roman pots.
- •Measure x,x'

- Comparisons with FPTrack ok

[100 ; 1000] GeV ◄—— Remember the acceptances !

Reconstruction

By linearity :

$$x_s = a_s x_0 + b_s x_0' + d_s E$$
$$x_s' = \alpha_s x_0 + \beta_s x_0' + \gamma_s E$$

We should solve for x_0, x_0', E (with only 2 equations)

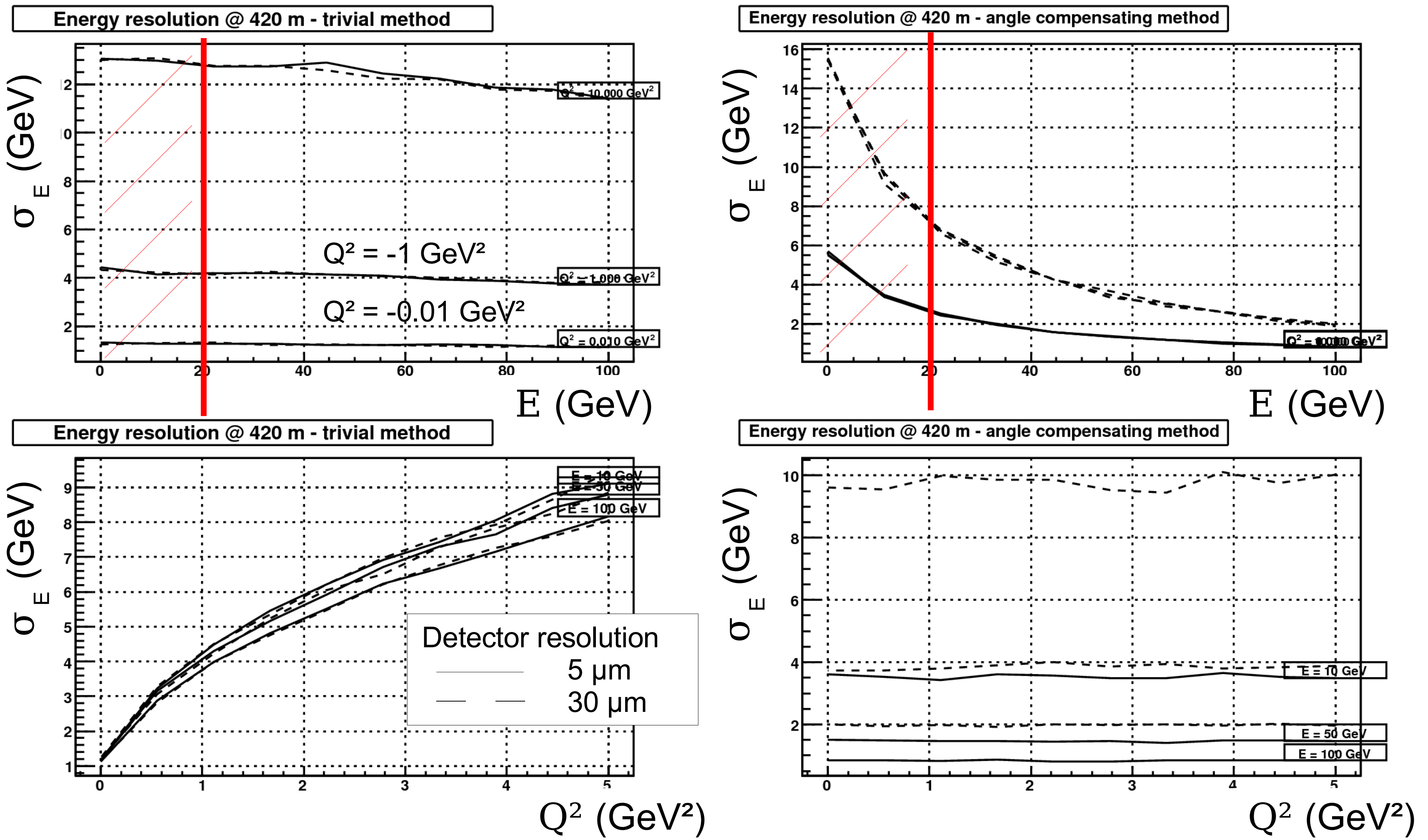
As physics won't change x_0, we choose to neglect a_s and α_s. This method leads to :

$$E = \frac{b_2 x_1 - b_1 x_2}{b_2 d_1 - b_1 d_2}$$ *Angle compensation method*

where b_1 and b_2 are the b parameters for the two detectors.

Reconstruction

Reconstructed variables : energy loss (σ_E vs Q^2 and E)



Misalignment

Using Hector, one can estimate the effect of the misalignment of quadrupoles on the center-of-mass energy reconstruction :

Example 2 :

Higgs mass = 115 GeV

Quadrupole : MQXA.1R5 (B1

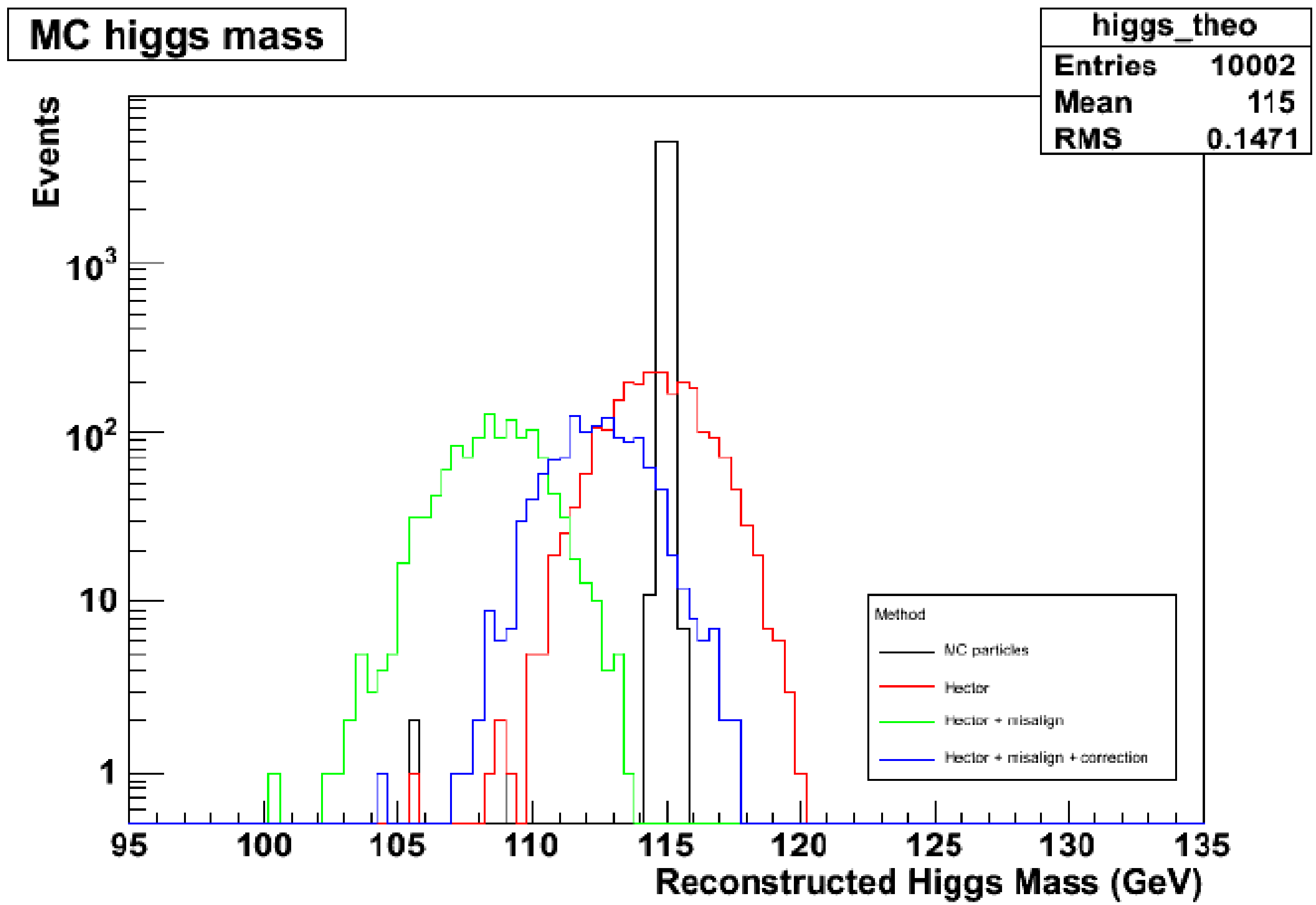
Location : 23m from IP

Displacement : 500 µm

tag in both 420m detectors

legend :

- hector reconstruction
- misalignement effect
- correction by beam position



Work-in-progress

In progress :

• Integration into CMS software framework, as a routine for MC production

• Validation with true electromagnetism

• Beam optics misalignment effects

• using Hector for fwd physics

•...

http://www.fynu.ucl.ac.be/hector.html

new : https://twiki.cern.ch/twiki/bin/view/CMS/HECTOR

Back-up slides

Implementation (III)

Matrix structure :

$$\mathbf{M_{units}} = \begin{pmatrix} \mathcal{A} & \mathcal{A} & 0 & 0 & 0 & 0 \\ \mathcal{A} & \mathcal{A} & 0 & 0 & 0 & 0 \\ 0 & 0 & \mathcal{B} & \mathcal{B} & 0 & 0 \\ 0 & 0 & \mathcal{B} & \mathcal{B} & 0 & 0 \\ \mathcal{D} & \mathcal{D} & 0 & 0 & 1 & 0 \\ 0 & K & 0 & K & 0 & 1 \end{pmatrix}$$

► (de)focusing

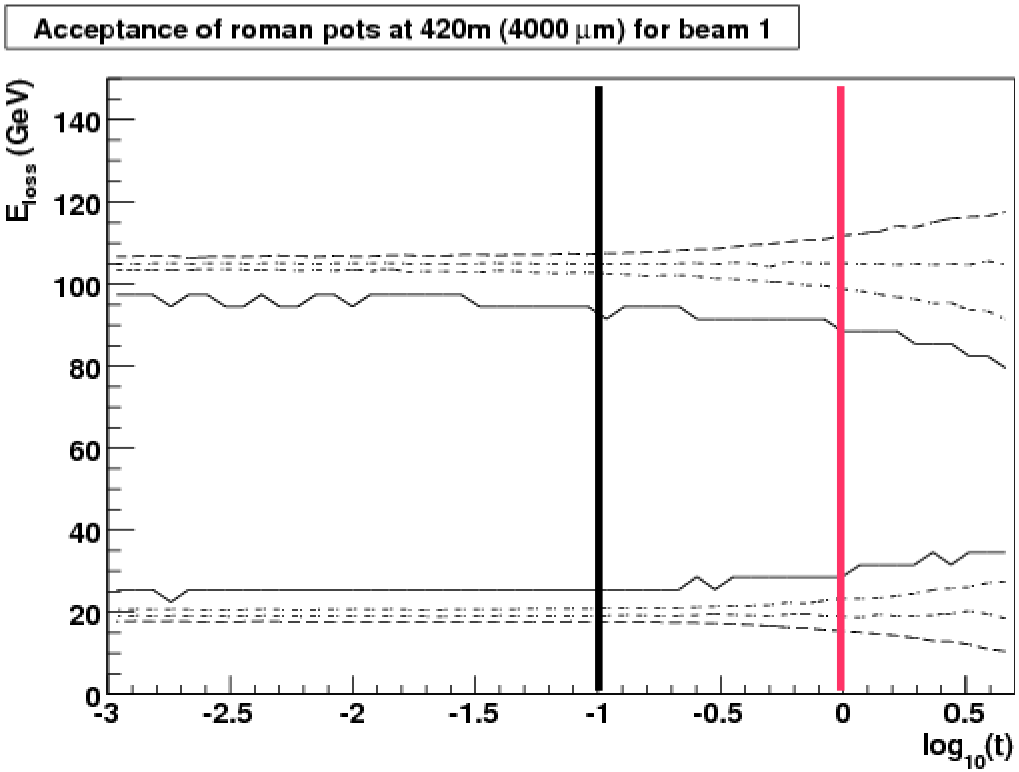
► bending

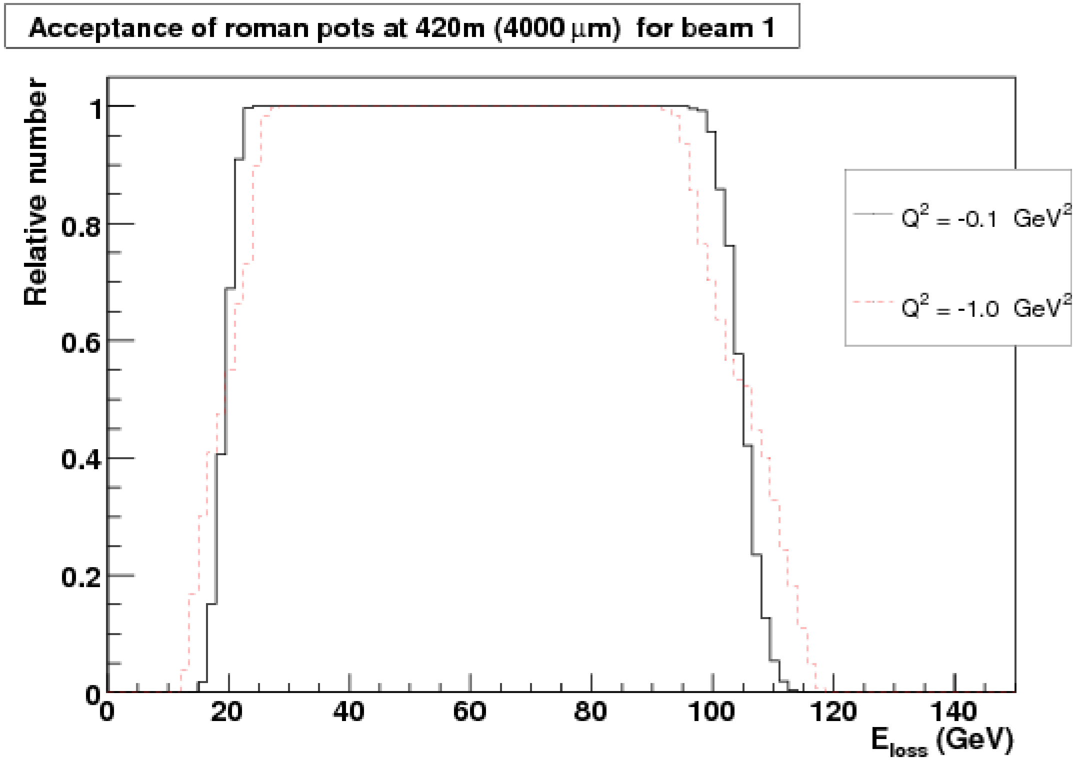
Matrix example : Quadrupole

$$\mathbf{M_{vertical-quadrupole}} = \begin{pmatrix} \cosh(\omega) & \sqrt{k}\sinh(\omega) & 0 & 0 & 0 & 0 \\ (1/\sqrt{k})sinh(\omega) & \cosh(\omega) & 0 & 0 & 0 & 0 \\ 0 & 0 & \cos(\omega) & -\sqrt{k}sin(\omega) & 0 & 0 \\ 0 & 0 & (1/\sqrt{k}) * sin(\omega) & \cos(\omega) & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

Direct physics output (III)

RP acceptances (420m)





Reconstruction (III)

Reconstructed variables : Q^2