About Dorigo's Geometry Optimization study

Giovanni Abbiendi (INFN - Bologna)

MUonE weekly Meeting - 26 February 2020

RECAP: after the CERN workshop

- Thread with Duccio, Mark, Jeoff, Umberto: about the performance of the CMS modules
- Dependency on the spacing of the sensor planes of 2S modules
- Recent beam test at DESY: dependency on the tilt angle
  - Consequences for MUonE design
- Alternative design: staggered sensor layers
- Discussion at the MUonE weekly meeting of 19th February: see <LINK>

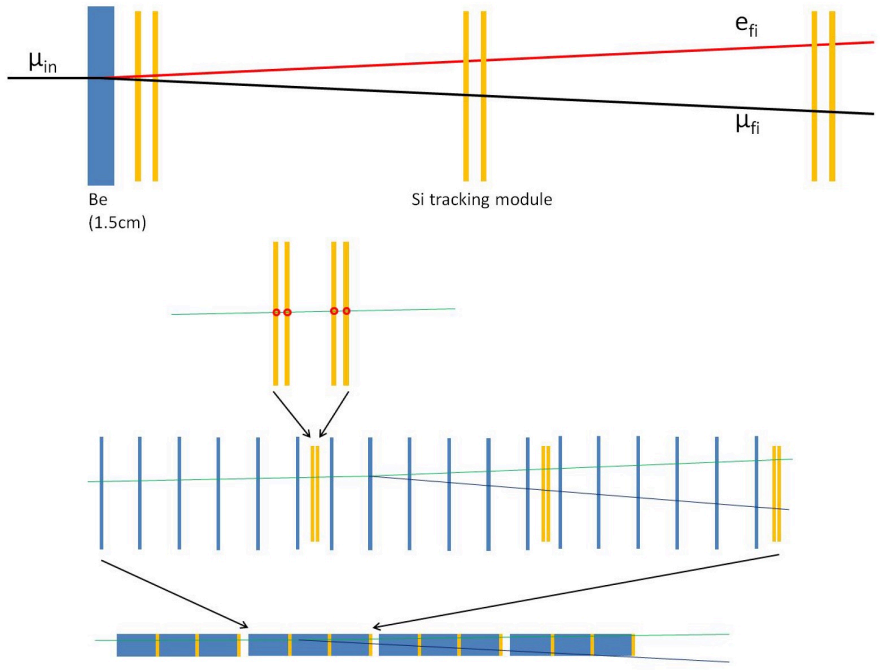
Discussion with Tommaso Dorigo

- Meeting last Friday 21st February in Bologna
- T.D. (from Padova) is an INFN referee for the MUonE project
  - He is also a CMS colleague, former chair of the CMS Statistical Committee (really an expert in statistics)
- Stimulated by the activity as referee he was triggered to a genuine physics interest in our project. Hence came a study (quite detailed!) of possible optimizations to the base geometry design of the MUonE detector.
  - This study is unrelated to his continuing referee activity
  - He will not join MUonE due to many other work/personal commitments
- We discussed with him the main contents of his study, and also its current limitations due to the used assumptions
  - Beyond some limits there are undoubtedly valuable ideas which we should consider carefully
- Soon after the meeting he submitted the study to arXiv (we already asked to correct a few things) :
  - https://arxiv.org/abs/2002.09973
- He gave us «as-is» his simulation code, used for the study (root macro, about 7K lines)

Outline

- I cannot discuss everything here (for lack of time and because I have not still read the latest draft)
- I will just highlight a few notable aspects

Simulation: MUonE layout



Generator: LO μ-e elastic scattering.

Beam spot position, size, divergence, energy spread simulated. E(μ)=150 GeV fixed.

Simulated Four Stations, assuming the scattering was happening in the 2nd ,
Z-scattering position (both in targets and in Si-layers) Simulation of material effects and signal hit formation. Hit Reconstruction.

Baseline Geometry compared to alternative geometries (distributed target, arrangement of detector elements)

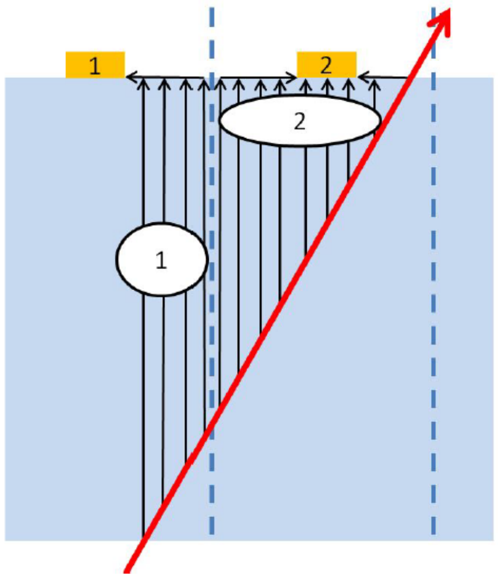
Hit formation

Simple model with uniform ionization along particle trajectories; orthogonal drift to the sensor surface and charge collection in the nearest strip.

Assumed average charge deposition of 660,000 eh pairs per cm, hence total charge as Poisson(N_{signal}|μ=21,120e); Noise simulated as Poisson(N_{noise}|μ=1000e). Readout threshold set at N_{thr}=3000e on every strip.

Clusters made from strips above threshold (but most hits are single-strip hits due to the very low crossing angle)

Si scattering: all three track stubs simulated (but still usually resulting in a single-strip hit)



Event reconstruction

- The full event kinematics is reconstructed in one shot starting from the individual hits to use all the possible physics constraints. In this way the interaction vertex provides a constraint
  - BUT: simplified, no ID / pattern recognition, the hits are correctly assigned to particles
  - BUT: LO, hence perfectly elastic kinematics

Likelihood function

A likelihood function is defined as sum of Gaussian terms, given the expectation values of each particle position at every crossed sensor.

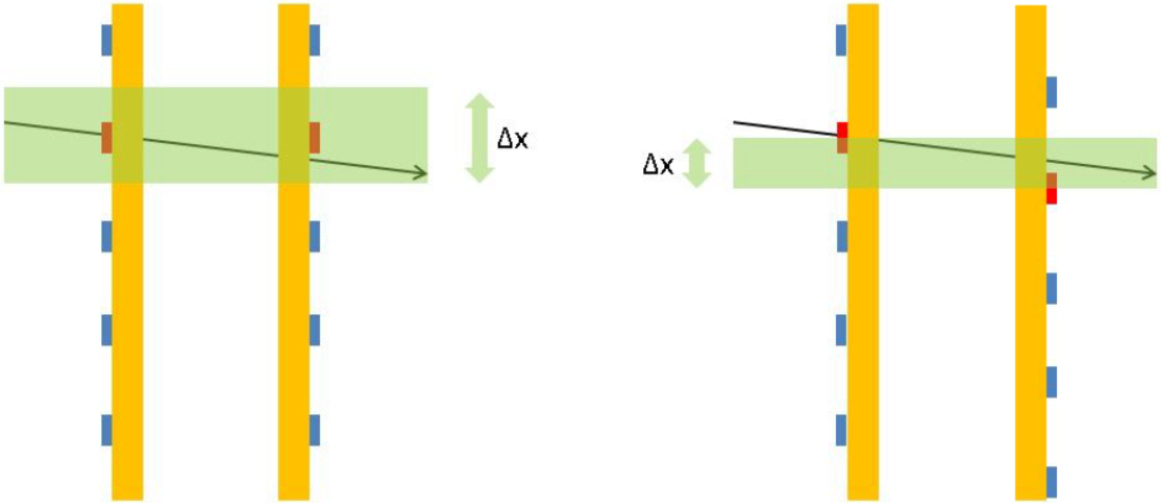
In these simplified conditions there are 7 unknown parameters (including the event q^2) describing the event kinematics.

$$\log L(\vec{p}) = -\sum_{i=1}^{N_{SC}}\Big[\sum_{j=1}^{n_{xhit,in}} 0.5\frac{[x_j^{(')} - x_{in}^{(')}(z_j)]^2}{\sigma^2_{x_j^{(')}}} + \sum_{j=1}^{n_{yhit,in}} 0.5\frac{[y_j^{(')} - y_{in}^{(')}(z_j)]^2}{\sigma^2_{y_j^{(')}}} +$$

$$\sum_{j=1}^{n_{xhit,\mu}} 0.5\frac{[x_j^{(')} - x_{\mu}^{(')}(z_j)]^2}{\sigma^2_{x_j^{(')}}} + \sum_{j=1}^{n_{yhit,\mu}} 0.5\frac{[y_j^{(')} - y_{\mu}^{(')}(z_j)]^2}{\sigma^2_{y_j^{(')}}} +$$

$$\sum_{j=1}^{n_{xhit,e}} 0.5\frac{[x_j^{(')} - x_{e}^{(')}(z_j)]^2}{\sigma^2_{x_j^{(')}}} + \sum_{j=1}^{n_{yhit,e}} 0.5\frac{[y_j^{(')} - y_{e}^{(')}(z_j)]^2}{\sigma^2_{y_j^{(')}}}\Big] + \log P(p_3)$$

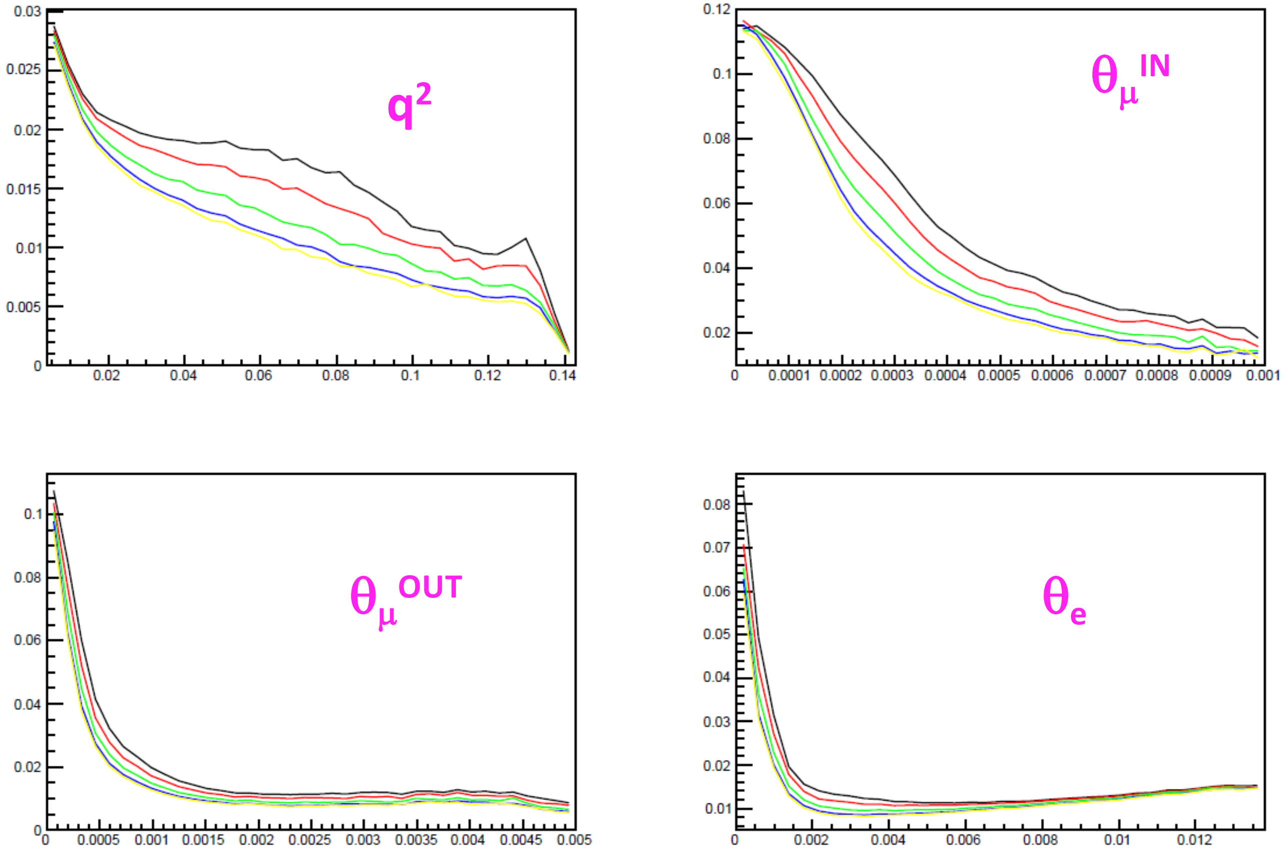
Staggering



The real gain of a half-strip staggering of the 2S sensor layers seem to be clear:
The probability density function for the position measured by a Si-layer for almost orthogonal tracks (giving rise to a 1-strip cluster) is not a Gaussian, but a flat, box distribution with extension equal to the strip pitch. Hence the second Si-layer does not add anything (it is *not* independent at all as the track passes through almost orthogonally)
Staggering by a Half-strip we will constrain the particle position at the middle to the intersection of the two box p.d.f., i.e. within half a strip.
The effective Gaussian $\sigma = \Delta x/\mathrm{sqrt}(12)$ is reduced by a factor 2, from 26 to 13 μm

QUESTION: is the 2S strip geometry really precise (to ~1μm ?), in particular the relative position of the two strip arrays w.r.t. the sensor plane ?

Resolutions as a function of staggering



Plotted curves are for different Staggering:
0 μm (CMS Baseline)
11.25 μm
22.5 μm
33.75 μm
45.0 μm

Big improvement in the angular and q^2 resolution

Effects of spacing between top/bottom sensors are coupled to the staggering geometry: for no staggering better the largest spacing (4mm), for 45μm staggering better the small spacing (1.8mm)

Target design

A segmented target in thin layers can obtain up to 5-10% improvements in the resolutions

However the proposed design breaks up the concept of INDEPENDENT stations. One should correlate informations of one station with the following and the preceding one, making more complex both the reconstruction and analysis and the trigger/DAQ logic.
The improvements are largely due to the effect of z-vertex constraint

Scatterings on Silicon sensors contribute about 40% of the total scattering events: using them also implies to break the independence of stations (each one made by 3 detector layers on X,Y views), unless one changed the station design

The attractive alternative (but maybe only a dream) is a detector design with only active targets (Si planes) and no passive layers. This would imply to increase the number of detector modules to total the necessary luminosity

Alignment / Positioning

- Sensitivity to both transverse and longitudinal positioning of Si layers tested by the same Likelihood technique based on the full event reconstruction
- It is claimed that we could measure everything about alignment (including z-position/tilts/bows of Si-planes) with just elastic scattering data and a precise MC simulation
- I do not think this can be really self-standing :
  - The longitudinal alignment is a weak mode for track-based methods
  - Those parameters affect only in second order the track residuals
  - There is also a circularity in the method: our energy calibration depends on the precise z positioning, so the latter should be a prerequisite to calibrate the beam energy scale.