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Design and Studies of μ-strip Stacked Module Prototypes for Tracking at Super-LHC

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Abstract

Experience at high luminosity hadrons collider experiments shows that tracking information enhances the trigger rejection capabilities while retaining high efficiency for interesting physics events. The design of a tracking based trigger for Super LHC (S-LHC), the already envisaged high luminosity upgrade of the LHC collider, is an extremely challenging task, and requires the identification of high-momentum particle tracks as a part of the Level 1 Trigger.
Simulation studies show that this can be achieved by correlating hits on two closely spaced silicon strip sensors. The progresses on the design and development of this micro-strip stacked prototype modules and the performance of few prototype detectors will be presented. The prototypes have been built with the silicon sensors and electronics used to equip the present CMS[1] Tracker.
Preliminary results of a simulated tracker layout equipped with stacked modules are discussed in terms of p_T resolution and triggering capabilities.
The study of real prototypes in terms of signal over noise and tracking performance with cosmic rays and a dedicated beam test experiment will also be shown.

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Keywords: Tracker Trigger, SLHC, Stacked Module, microstrip

1. Introduction

In high luminosity hadrons colliders, track reconstruction represents a big challenge. As the rare events of interest have particles with transverse momentum (p_T) above several GeV/c, a real time discrimination of medium/high transverse momenta can be used to reduce the data rate while quickly transferring the data outside the detector. A proposed solution to this challenge implies a tracking system layout that *uses radiation tolerant sensors* with *local low level trigger capabilities*.

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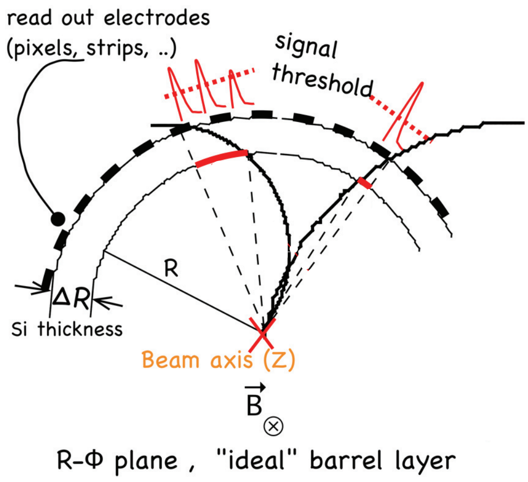

Figure 1: The basic of the track width method[2][4]. Two particles with different momenta cross the cylindrical sensor layer at distance R from the interaction point. The lowest p_T one intersects the layer producing a cluster of larger track intersection width (TW).

This new detector feature should not affect the standard reconstruction for a further good fine tracking. Actually, considering the CMS experiment, $\mu^{\pm}$ trigger is based just on the muon chambers detector which put a p_T trigger threshold of 14 GeV/c, which will be increased in the SLHC phase, so the inclusion of the tracker as additional low level trigger can be useful for physics studies. Using the CMS tracker data, we studied a possible method for the effective local selection in p_T. Then we have built some tracker modules prototypes which were validated with experimental results, and included in the simulation of a new tracker layout.

2. The Basic Idea: measuring p_T/flight direction at single module level

2.1. The Theoretical Model

Tracker detectors in the barrel region are organized in cylindrical layers, with radius R and coaxial with the beam axis (Z), made of μ-strips Si sensors with a given *thickness* (ΔR) and *pitch* (p) between the strips. The magnetic field (B) and Z axis are parallel. Charged particles coming from the interaction point (IP) have helix trajectories with radii depending on p_T and pitchs depending both on p_T and pseudorapidity η. On the $R - \phi$ plane, orthogonal to Z axis (Fig.1), the projections of the intersections (tracks) of charged particles with a sensor layer have widths (TW) that depend on their p_T, on R and on ΔR, as shown in the previous works [2][3]: following Fig.1 and reminding the relation between track helix radius (ρ[m]), magnetic field (B[T]) and p_T[GeV/c] ($p_T = 0.3B\rho$), defining $p_{Tmin} = 0.15BR$ the minimum value of the p_T to reach the tracker layer and considering that relatively high magnetic fields ($\geq 1-2$ T) can be achieved inside the Trackers detector allowing the approximation ($p_T >> p_{Tmin}$), TW satisfy the relations

$$\mathrm{TW} = \frac{\Delta \mathrm{R}}{\sqrt{\left(\frac{p_T}{p_{Tmin}}\right)^2 - 1}} \simeq \frac{0.15\mathrm{BR}}{\mathrm{p_T}}\Delta \mathrm{R} \Longrightarrow \mathrm{p_T[GeV/c]} \simeq 0.15\mathrm{B[T]R[m]}\frac{\Delta \mathrm{R}[\mu\mathrm{m}]}{\mathrm{TW}[\mu\mathrm{m}]} \equiv \frac{0.15\mathrm{B[T]R[m]}}{\mathrm{TW[\#\ \ of\ \ pitches]}} \cdot \mathrm{ToP} \quad (1)$$

Considering sensor placed at R~ $\mathcal{O}$(50 cm) with ΔR ~$\mathcal{O}$(300 μm) inside a magnetic field B ~ $\mathcal{O}$(4 T), charged particles with p_T less than 2 GeV/c have TW~ $\mathcal{O}$(100 μm)[2]: this suggests choosing a suitable value for the sensor pitch so as to measure TWs in pitch units. However, in [2][4] it has been shown that the only sensor pitch is not a critical parameter, but the ratio between thickness ΔR and pitch p ($ToP \equiv \frac{\Delta R[\mu m]}{p[\mu m]}$) is: it has been shown that track selection basing on TW threshold as a function of the ratio $\frac{p_T}{p_{Tmin}}$ [1] increases sensitivity for higher p_T ranges as the ToP

[1] Efficiencies are R-indipendent expressing them as a function of this ratio.

parameter is increased. For this reason, Eq.1 can be arranged to explicit the ToP term[2].

2.2. Deviations from the Ideal Case

Eq.1 is valid for ideal perfect cilyndrical barrel layers. Actually, those are cylindrical assemblies of Si tiles which can be tilted around Z by an angle (α) to partially compensate for the B drift (*Lorentz Angle* θ_L) or simply for a residual misalignment of the mechanics, making the behavior of TW more complex. Those effects have already been well treated in the previous works [2], [3] and [4]; we just limit to summarize how TW obtained by Eq.1 ("TW_0") should be corrected. There are two main corrections that should be applied:

- *in flat sensors TW can be approximated with a linear function of the X local sensor coordinate*, bringing to the correction $TW_0 \rightarrow TW_0 + \text{sign}(charge) \cdot \Delta R \cdot \left(1 + \left(\frac{p_{Tmin}}{p_T}\right)^2\right) \cdot \frac{X}{R}$. The additional term is $\sim O(25 \div 50\ \mu m)$ for a sensor placed at R∼50 cm crossed by a $p_T = 1 \div 3$ GeV/c charged particle, i.e. the correction is of order lower than the pitch size.
- considering $\alpha \neq 0$, *TW has to be corrected for the charge carriers drift inside the sensor thickness* due to a Lorentz Angle $\theta_L \neq 0$, obtaining $TW_0 \rightarrow TW_0 \cdot \cos\alpha + \text{sign}(charge) \cdot \Delta R \cdot \left(1 + \left(\frac{p_{Tmin}}{p_T}\right)^2\right) \cdot \frac{X}{R \cdot \cos\alpha} + \tan\alpha + \frac{D}{\Delta R}\tan\theta_L$, where D is the effective path drift of the carrier inside the sensor. If tilt angle would perfectly compensate Lorentz Angle (i.e. $\alpha \equiv -\theta_L$), $D \equiv \Delta R$ and the correction will be reduced to a multiplied factor $\cos\theta_L$. Considering as reference Lorentz Angle value the CMS Tracker one (∼7°), a correction less than $\sim O(1\%)$ is foreseen.

For the trigger purposes studied in this work both corrections can be neglected.

2.3. Optimized Design of Tracker Modules for p_T and Particle Flight Direction Estimates

In Sec.2.1 we have seen that increasing the ToP value increases the p_T evaluation at the single module level sensitivity. There are two possibilities for this purpose: *Modules based on a single sensor* ($\Delta R \equiv$ Silicon thickness, $TW \equiv$ *Cluster Width* (CW), i.e. the size of strips ensemble interested by the charged particle crossing inside the module, and *Modules based on two stacked sensors, placed with parallel strips along Z direction* ($\Delta R \equiv$ d distance of the two sensors, $TW \equiv$ distance of the centroids of the clusters reconstructed in the two sensors, projected in the R-ϕ plane).

The second case results to be the better choice, not only for the increased ToP ($\Delta R \sim O$(mm) against $\Delta R \sim O(100\ \mu m)$ in the single sensor case), but also because it can give information about the flight direction of the track obtained through the vector defined by the two centroids, achieving a good angular resolution ($\sim O$(15 mrad)) thanks to $\sim O(100\ \mu m)$ of strip pitch over 2 mm of lever arm. So the "stacked" module seems to be particularly useful to retrieve tracks kinematic informations for trigger purposes.

3. Method Validation with Real Data & Results with first prototypes

3.1. Validation with 7 TeV LHC pp collisions

We have considered data samples out of the 35 pb^{-1} pp collisions data collected in 2010 by the CMS experiment[5], corresponding firstly to charged tracks inside hadronic jets, most of them associated to $\pi^\pm$ or $\mu^\pm$. The validation consisted in the p_T estimate capability of the actual CMS tracker[6] μ-strips modules through clusters reconstruction, compared with the p_T measured with the standard track reconstruction. To have a good reference sample, we have considered only charged tracks selected with stringent quality criteria (i.e. 11 crossing points in the whole tracker for the track fit, 1 of them belonging to the Pixel detector; $\overline{\chi}^2 < 2$ (d.o.f. are given by the number of points considered in the track fit minus the number of fitted parameters, i.e. 5); distance from the IP, ±10 cm along Z direction and ±5 cm in the $R - \phi$ plane).

The present CMS tracker is composed by two different kinds of modules: *Single Sided* (SS) modules which consist of one Si μ-strips sensor and *Double Sided* (DS) modules (called also "stereo") built with two Si μ-strips sensors glued at a distance of ∼4 mm used to give position informations also along Z direction, so sensors result to be tilted by a

[2] Furthermore, this formulation contains only terms that can be reconstructed as single sensor local informations.

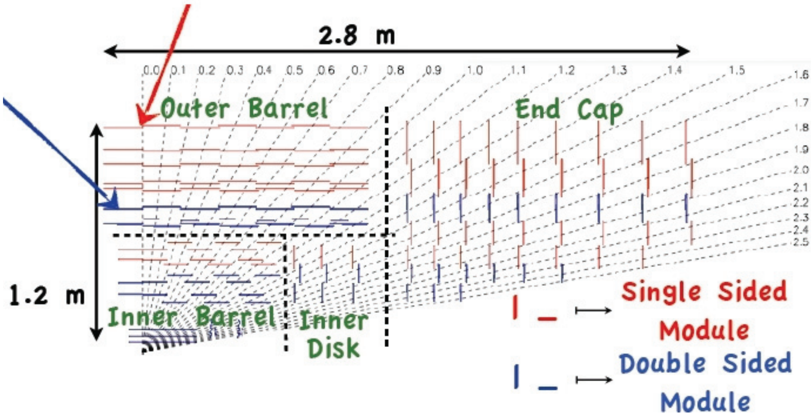

Figure 2: η coverage of a quarter of the present CMS tracker; the arrows indicate the layers considered for the validation.

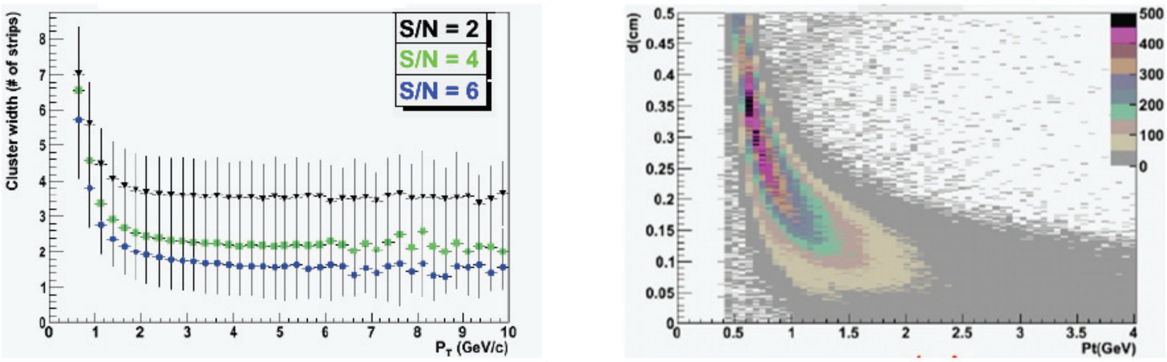

Figure 3: (Left) Correlation between CW and track p_T obtained for various clustering thresholds and considering SS modules placed in the 6th layer of the CMS TOB: errors refer to the spreads on each bin of the profile histogram. (Right) Correlation between TW (in cm) and track p_T obtained for clustering threshold S/N>6 and considering DS modules placed in the 2nd layer of the CMS TOB.

"stereo" angle of ∼100 mrad. In this way, validation for the two cases of modules presented in Sec.2.3 could be done.

We started to consider SS modules placed in the outer layer of the CMS tracker (*TOB layer 6 - R* $\simeq$ 108 *cm, ToP*$\simeq$ 4.2, see as reference Fig.2). Here we are in the case $\Delta R \equiv$Si thickness, and TW is obtained from the reconstructed CW expressed in number of pitches. The clusterizer circuit reads analog signals from each strip and add it into the cluster if a fixed threshold (in term of S/N ratio) above the pedestal is exceeded. In this way, correlation between track p_T and CW of the associated clusters has been studied. Fig.3 shows the obtained results: correlating the CW with the p_T it can be seen that for high values (i.e. >2 GeV/c) CW$\simeq 2 \div 3$ pitches and increases for low p_T (<2 GeV/c) values, as foreseen from theoretical model. A CW mean value of $2 \div 3$ pitches for $p_T > 2$ GeV/c against the $1 \div 2$ pitches foreseen in Sec.2.1 should not be surprising: TW is not a pure geometric quantity. At a higher order it depends on the particle-sensor bulk interaction and on the electrical characteristics of the sensor. Effects such as diffusion, δ rays, strip coupling can affect noise fluctuation and, as a consequence, the actual value of TW: good p_T sensitivities are so achievable just for higher clustering thresholds ($S/N > 6$), due to suppression of capacitive couplings among strips generating false large clusters, as it has been pointed out in our simulations studies (see Sec. 4). Furthermore, it has been shown that the selection CW > 3 preserves just the high p_T range of the events spectrum, with an efficiency higher than 90% for $p_T > 2$ GeV/c tracks, rejecting the big amount of not interesting minimum bias tracks.

DS modules placed in the 2nd layer of the outer part of the CMS tracker (*TOB layer 2 - R* $\simeq$ 70 *cm, ToP*$\simeq$ 21.9, see as reference Fig.2) are used to mimic stacked modules. Now $\Delta R \equiv$sensors distance (∼ 4 mm), and TW is obtained

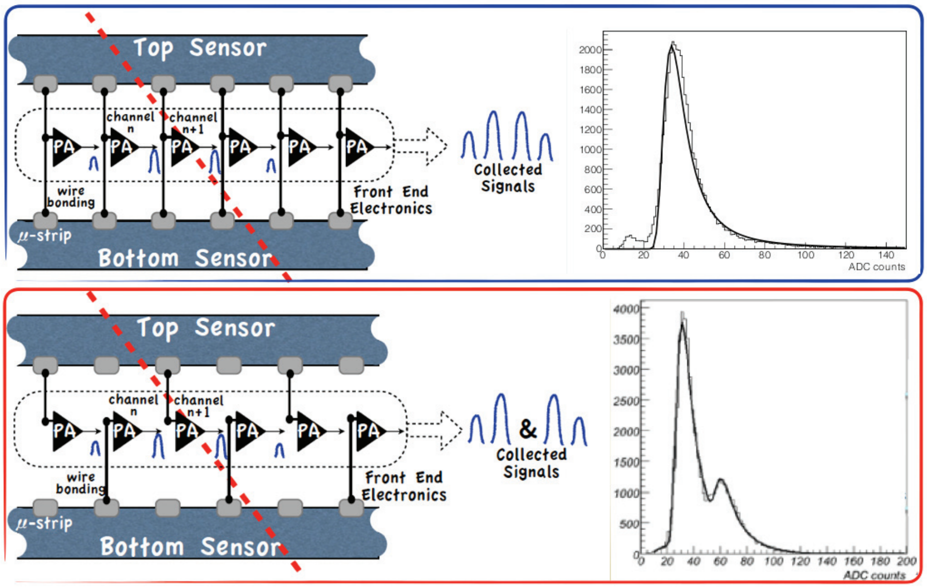

Figure 4: (Blue Box) Module Prototype A wire-bonding and clustering schematization (left), and analytical fit on S/N values (converted in ADC counts) distribution of the clusterized read-out channels (right), obtained during tests with Cosmic Rays - see [8][9] for further details. (Red Box) Same figures for the Module Prototype B.

from the distance of the two clusters centroids projected in the R-ϕ plane, expressed in this case in cm. The important thing is to correct sensors orientation for the stereo angle, to use DS modules as double layer detectors: this has been made rotating the *local* strips coordinates, plotting the correlation between the difference of *local* X variables (along strips direction) of the two sensors and the *global* Y variable of the CMS frame retrieved by reconstructed tracks (more informations were presented in [7]). In Fig.3 results are summarized: high p_T tracks (> 2 GeV/c) have almost overlapping clusters, instead low p_T tracks clusters are each other far $\sim 1 \div 2$ mm. Selecting clusters pairs with TW<1.5 mm (corresponding, for the considered sensors, to ~6 pitches), we obtained efficiencies ≥ 95% for the $p_T > 2$ GeV/c range, higher compared to SS modules beneficing of the higher ToP value.

3.2. *First Prototypes Assembly and Preliminary results*

First stacked modules prototypes have been assembled using CMS tracker spare parts, and tested both with cosmic rays and in beam test experiment. Prototypes were assembled by gluing two μ-strip sensors (with 80 μm of pitch) stacked by a ceramic spacer of 2 mm. Sensors have to be read-out by the same front-end circuitry[3], so two possible solutions can be found, as illustrated in Fig.4: *Module Prototype A* where the two corresponding strips on the two sensors are both (i.e. in parallel) wire-bonded to the same chip read-out channel, and *Module Prototype B* where the wire-bonding to the read-out channel is made on alternating-sensor strip. In both prototypes A and B, charged tracks generate signals in the two sensors closely to the involved strips, but in the module B strips signals are collected indipendently so clusters of bottom and top sensors are reconstructed separately: this could seem an advantage, anyway a dedicated algorithm to correlate clusters pairs is needed. On the other hand, in the module A strips signals are summed by the wire-bonding and from a read-out chip point of view the clusterizer works like in a SS module, presenting the limit case where only one cluster per track is reconstructed if top and bottom clusters are too close (see Fig.4). Higher noise due to higher capacitive load in the wire-bonding to the same readout channel is foreseen, but module A presents the advantage that no correlation algorithm for the clusters pairs is needed: its S/N distribution is well described by a single "clear" Landau distribution, comparable with standard CMS tracker modules performances, so there is no cross-talk between strips. For the module B, S/N distribution is well described by the sum of two Landau

[3]In CMS an opto-hybrid circuit based on four/six APV25s1[10] chips with 128 read-out channels is used.

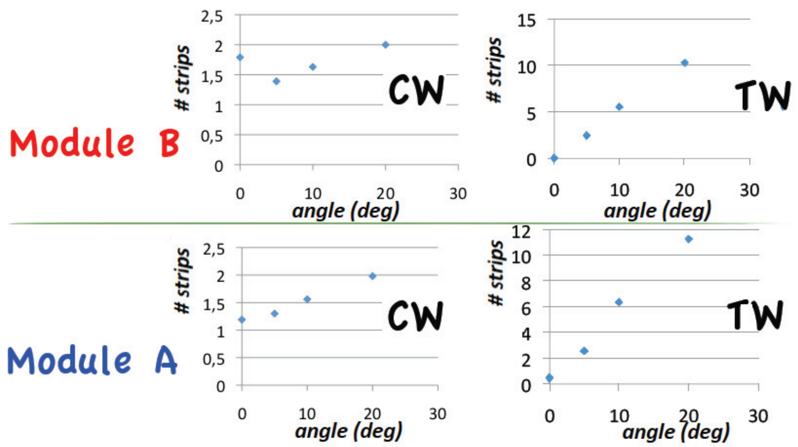

Figure 5: Performances of the two prototypes: CW and TW mean values for incidence angles 0^o, 5^o, 10^o, 20^o, obtained considering the clustering with a threshold S/N>6.

distribution: the peak at lower S/N value (peak "B I") represents the distribution of tracks with spatialy separated clusters, and the comparison with module A peak is understood in terms of the higher noise for module B ($\sigma_{\mathrm{BI}} \sim 12$ and $\sigma_{\mathrm{A}} \sim 17$, so $\sigma_{\mathrm{BI}} \sim \sqrt{2} \cdot \sigma_{\mathrm{A}}$). The peak (peak "B II") at higher S/N value (with a MPV which is the double compared with the first one) collects events where two clusters overlap in one.

Extensive study have been performed using a small telescope for cosmic rays and results are published in [8][9].

Experiment with particle beam test was made at CERN under SPS beams collided on a fixed target. Particles tracks were measured via a multi-layer telescope with 8 reference planes of Si μ-strip sensors with 50 μm of pitch. Prototypes were placed in the middle of the telescope with the possibility to be rotated respect to the axis parallel to the μ-strips, and aligned to the reference frame (for further information see [7]). Good tracks have been identified by the telescope and the incidence angle, defined as the angle between the vector orthogonal to the sensor plane and the track direction, has been measured. Collected data statistical results of both prototypes are summarized in Fig.5: once clusterizer threshold is properly chosen to avoid problems with the higher noise of module B, correlations between mean values of CW/TW and incidence angles show, within the foreseen statistic errors, linear and very similar behaviors, besides values at 0^o: for very small incidence angles, the two prototypes have different behaviors. Two distinct clusters are always reconstructed in module A, with CW depending from the angle of tracks crossing the sensor and from the thickness. In module B, a single cluster is reconstructed even if clusters strips are in different sensors, with a CW which is given by the sum (at the first order[4]) of the CW of each single physical cluster on the sensors: so CW at $\sim 0^o$ for module B could be increased by a factor $\sim O(2)$ respect to the reality. For incidence angles equal or higher than 5^o two distinct clusters are always reconstructed also for the module B, so standard CW behaviors are observed.

4. Study of Stacked Modules Trigger Capabilities through MonteCarlo Simulations

4.1. Simulation Framework

Trigger capabilities of stacked modules were studied through Monte Carlo simulations, based on the analysis software package used in the CMS collaboration (`CMSSW`[11]). Here, the tracker geometry, module topology and material budget description is based on `XML` code architecture, and a simple layout with 3 barrel layers (R=52 cm, 86 cm, 102 cm) 1.2 m long equipped with stacked (ΔR = 1 *mm*) modules mounting two sensors with *active area 9.2*x*9.2 cm*^{2}*, thickness 300* μm*, and segmented μ-strips 4.6 cm long with 98* μm *of pitch* has been considered. For a

[4]This is true only in approximation: the read-out cluster is given by the superposition of the two physical clusters, so the total width is foreseen to be lower than the simple sum.

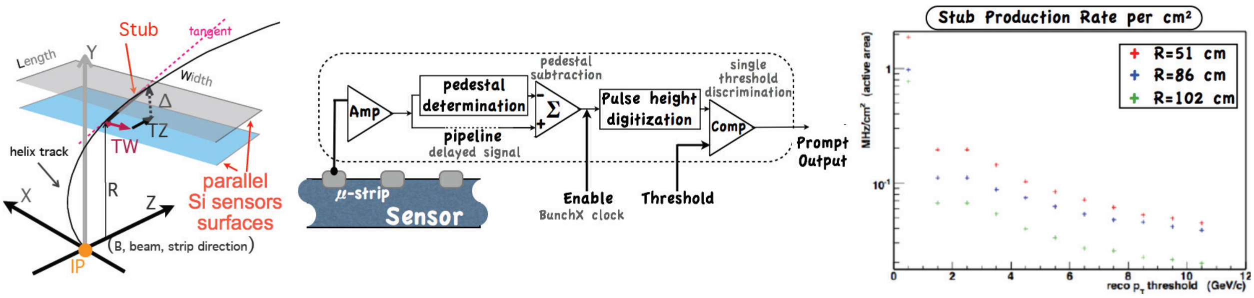

Figure 6: (Left) Stub reconstruction schematization. (Centre) Schematization of the strip digitization and discrimination after the pedestal subtraction. (Right) Stub rate per each layer selected putting a threshold to the estimated p_T; SLHC PhaseII as reference luminosity scenario is considered.

more realistic simulation of the material budget amount, a Si Vertex Pixel detector[5] has been included inside. SLHC collisions simulation were simulated by `Pythia` generator[12], while particles are propagated in the materials using the full detailed CMS detector simulation based on `Geant4`[13]. The CMS software code is finally used to emulate the front-end electronics response: μ-strips are here digitally read-out (as planned for the SLHC upgrade, see Fig.6). After the pedestal subtraction, strips are digitized, their pulse height is compared to a fixed threshold and nearby over-threshold strips are joined to build the cluster. Sensors are read-out independently, so the module A type simulation is considered.

4.2. Conversion of Stacked Module Responses into Trigger Primitives: the "Stubs"

The first step is to correlate cluster pairs in the module, then p_T and flight direction can be estimated as explained in Sec.2.3. Correlation is made via geometric constraints (see Fig.6) between the IP (considering the uncertainties due to the beam collisions spread), and the foreseen bending inside the stacked module: this last is possible through an algorithm which, starting from the bottom sensor (i.e. the closest one to the IP) cluster, extrapolates helices up to the top sensors knowing the detailed B magnetic field lines (solenoidal in the CMS case) map. Only pairs compatible to helices with $p_T \geq 2$ GeV/c were considered, defining a $\Delta\phi(R, \eta)$ window[6] to match top sensor clusters; in case of more matchings, all possible combinations of clusters pairs are kept. Once correlation is made, all information about clusters positions and estimated kinematics (p_T, flight direction) needs to be encoded into a single manageable object. It has to be pointed out that Z information is missing in μ-strip topology, so flight direction is reduced to be a 2-vector in the $R - \phi$ plane: in this sense, the notation $\vec{p}_T$ can be used. Furthermore, the only other informations needed to univocally identify clusters pairs are the (global) position of the module and the (local) cluster position in the sensor plane (strip number, segmentation). A valid trigger primitive is represented by the definition of a "*stub*" as:

$$\text{stub} = 3 - \text{vector}^{(\text{global} \quad \text{position})} + 2 - \text{vector}^{(\vec{p}_T)} + 2 - \text{vector}^{(\text{local} \quad \text{position})} \tag{2}$$

adding eventually also two scalars (CW of each sensor) to keep a quality control information.

Simulations of single $\mu^{\pm}$ events and p-p collisions foreseen for the SLHC PhaseII[14] with ~200 Minimum Bias per p-p bunch crossing were made to study stubs trigger capabilities: single monochromatic muons were used to study the available resolutions with stubs, which can be theoretically obtained starting from Eq.1: estimate of TW (CW for single sensor modules) gives the higher contribution to the error, assuming negligible contributions from B, R and ToP ratio. TW/CW contribution can be evaluated assuming that error on single cluster position is reducible to the one foreseen for uniform distribution between ±1 strips, i.e.

$$\sigma(\mathrm{TW})^2 = 2 \cdot \frac{p^2}{12} \Longrightarrow \sigma\Big(\frac{1}{p_T}\Big) \equiv \frac{\sigma(p_T)}{(p_T)^2} = \frac{1}{0.15\sqrt{6} \cdot B \cdot R \cdot \Delta R \cdot p} \simeq 5\% \tag{3}$$

[5]The one of the CMS detector has been considered.

[6]Depending on the B map, $\Delta\phi$ window results to be a function of layer radius R and pseudorapidity η.

for reference values B = 3.8 T, R = 80 cm, ΔR = 2 mm and p = 98 μm. So resolution decreases as $(p_T)^2$ and is geometrically related to R, ΔR and to the pitch. Statistics on the $1/p_T$ distributions of monochromatic $\mu^\pm$ show resolutions compatible with constant values within $6 \div 7\%$. As a consequence, p_T based selection strongly depends on resolutions, decreasing as $(p_T)^2$; it has been shown that inefficiencies appears starting to require stubs with $p_T \geq 5$ GeV/c: anyway, due to the non-gaussian behavior of evaluated p_T distribution[7], rejection at high p_T is milder.

Selection on measured $p_T \geq 1 \div 2$ GeV/c is enough to reduce the information rate equivalently for all layers to acceptable level for L1 trigger purposes ($\sim\mathcal{O}(100$ kHz$)$), allowing low read-out bandwidths (BW). This is confirmed by further studies on stubs information encoding: it has been shown that 16 bits are enough to encode stub information, and remembering that the active area of a sensor is $9.2\times9.2=84.64$ cm^2, and that CMS tracker is read-out per "rods" of 12 modules, BW $\sim 100\text{kHz/cm}^2 \cdot 84.64\text{cm}^2 \cdot 12 \cdot 16\text{b} \sim 1.66\text{Gb/s}$ can be achieved. This seems to be particularly promising because the obtained result is within the range of data link speeds available with the present technologies.

5. Conclusions

The study of the method based on CW and TW to evaluate charged particle p_T and track direction of flight has shown encouraging results. This method has been validated using CMS p-p collisions data at $\sqrt{s} = 7$ TeV. Stacked modules have been built and used to study method performances with real beam particles. Test on preliminary prototypes, studies with LHC data and based on Monte Carlo simulation of the foreseen SLHC scenario, as well as basic theoretical study on local low-level p_T evaluation, have shown that stacked modules design is a viable solution to provide tracker trigger primitives with a manageable trigger data rate $\sim\mathcal{O}(100$ kHz/cm$^2)$.

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References

[1] CMS Collaboration, `http://cms.web.cern.ch/cms/`.

[2] G. Barbagli, F. Palla and G. Parrini, "*Track Momentum Discrimination Using Cluster Width in Silicon Strip Sensors for SLHC*", proceeding of the 1st Topical Workshop on Electronics for Particle Physics (TWEPP07, September 3-7 2007, Prague, Czech Republic).

[3] G. Parrini et al., "*Guessing the geometric features of a particle trajectory in a magnetic field by measuring one point and its tangent*", proceeding of the 1st Workshop on Intelligent Trackers (WIT2010, February 3-5 2010, Berkeley CA, USA).

[4] F. Palla et al., "*Concepts for a Tracker Trigger based on a multi-layer layout and on-detector data reduction using a cluster size approach*", proceeding of the 1st Workshop on Intelligent Trackers (WIT2010, February 3-5 2010, Berkeley CA, USA).

[5] CMS Collaboration, "*Measurement of CMS Luminosity*", CMS Physics Analysis Summary CMS-PAS-EWK-10-004, (2010). `arXiv:1108.3773`.

[6] CMS Collaboration, "*The CMS Experiment at the CERN LHC*", Journal of Instrumentation Vol. 3 pag. 1-334, 2008.

[7] A. Messineo, Talk given at the 3rd Common ATLAS & CMS Electronics Workshop for LHC upgrades (ACES2011, March 9-11 2011, CERN Geneva, Swissland).

[8] J. Bernardini et al., "*Design and development of micro-strip stacked module prototypes for tracking at S-LHC*", Journal of Instrumentation Vol. 5C pag. 11018-11023, November 2010.

[9] R. Dell'Orso et al., "*Design and Development of micro-strip Stacked Module Prototypes to Measure Flying Particle Directions*", Nuclear Physics Vol. B (Proc. Suppl.) pag. 7275, July 2010.

[10] L. Jones et al., "*The APV25 deep submicron readout chip for CMS detectors*", proceeding of the 5th workshop on electronics for LHC experiments (LHCC99, September 2009, CERN Geneva, Swissland).

[11] The `CMSSW` package Web page: `http://lxr.fnal.gov.us/cmssw/`.

[12] `Pythia` Web page: `http://home.thep.lu.se/~torbjorn/Pythia.html`.

[13] `Geant4` Web page: `http://geant4.cern.ch/`.

[14] A. Dierlamm, "*CMS Tracker Upgrade Issues and Plans*", Nuclear Instruments and Methods in Physics Research Sec. A Vol. 604 pag. 273-276, June 2009.

[7] As foreseen also in standard tracking, $1/p_T$ distribution is symmetric, being related to the bending radius (gaussian distributed). So measured p_T distribution is skewed toward larger values.