Report on PhD activities

Third year

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***Abstract*—In this report I will describe my studies and work during last year. The classes I attended are listed first. Then the research activity is briefly described, mainly focused on data analysis at the CMS experiment at CERN, along with experimental studies on innovative silicon timing detectors.**

I. Classes.

- Collider Physics
- Particle Detectors
- Electronics and Data Aquisition
- Gravitational Waves
- Statistics and Probability (exam in coming weeks)
- *approved school*: CMS Data Analysis School

II. Central Exclusive Production of top-antitop quark pair

The goal of the analysis is to estimate the cross section of the Central Exclusive Production (CEP) of a $t\bar{t}$ pair, as described by the diagram in Fig.1, using data from the Compact Muon Solenoid (CMS) experiment at CERN. The main characteristic of this process is a correlation between the kinematics of the $t\bar{t}$ pair and that of the two protons which survived the collision.

In central exclusive production processes, the incoming beam protons interact without dissociating. As a result of the interaction, a set of particles ($t\bar{t}$ pairs in the case of my thesis) is produced in the final state, and the protons that interacted loose fraction of their momentum and slightly deflected from their original trajectory.

In particular here the focus is on $t\bar{t}$ pairs decaying semileptonically ($b\ell\nu\bar{b}jj$). Because of their more difficult experimental reconstruction, semileptonic $t\bar{t}$ pairs where the charged lepton is a τ are not considered here.

The main background is expected to be the production of $t\bar{t}$ pairs by any other already known process. In order to select the signal and reject the background it is necessary to study the signal characteristics which differentiate it from the background. The distributions of some variables have been already produced and some of them show encouraging differences between signal and background.

Currently the analysis performs both a kinematic fitting and a multivariate analysis (MVA). While the main aim of the kinematic fitter is improving the mass resolution of the reconstructed $t\bar{t}$, a multivariate analysis was developed to further discriminate between inclusive and exclusive $t\bar{t}$ production processes. Even in this case the algorithm will be optimised basing just on the main source of background ($t\bar{t}$ inclusive production). Then, after its optimisation it will be applied to all the background samples. In TMVA (the ROOT class used to perform MVA), several classifiers (like fisher discriminant, likelihood, SVM, BDT, MLP, ...) are implemented.
Some evolving results are shown in the CMS analysis note AN-20-004.

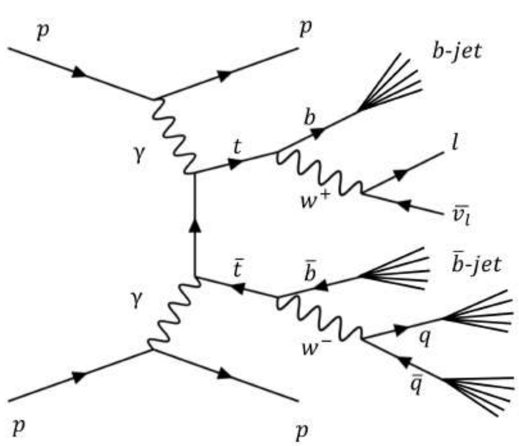

Figure 1: Feynman diagram for the $t\bar{t}$ CEP process

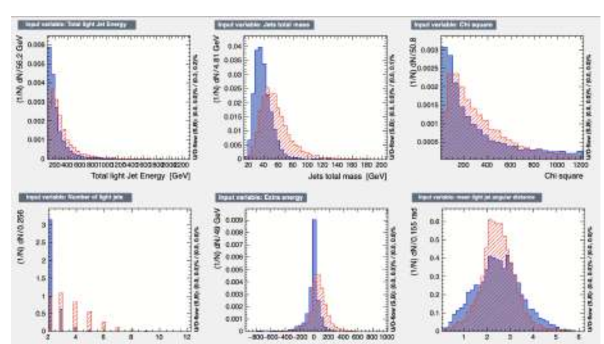

Figure 2: Signal/Background training samples variables.

III. Beam test of innovative sensors for timing measurements.

Future high luminosity particle colliders will pose severe requirements on vertex detectors in terms of space resolution and radiation hardness. The significantly increased pile-up conditions in future high luminosity particle colliders will require unprecedented timing performance with resolutions down to a few tens of picoseconds. The TIMESPOT (TIME and SPace real-time Operating Tracker) project proposes an innovative radiation resistant tracking system able to combine high accuracy time and position measurements. The target is to achieve a time resolution below 50 ps with a pixel size of $55\,\mu\text{m} \times 55\,\mu\text{m}$. Some sensor prototypes were installed on a amplifier board which was designed by the CMS group in Genova and the setup was tested at the Paul Scherrer Institute (PSI) on a π beam in order to measure the timing performance.

A. Sensor

The 3D technology for silicon sensors allows the fabrication of sensors which are characterized by a higher radiation resistance compared to those produced with planar geometry. 3D geometry also allows a complete decoupling of the distance between the collecting electrodes and the bulk thickness, enabling the construction of very close electrodes given a standard wafer thickness, hence enabling a very fast charge collection. Unfortunately the traditional 3D sensors geometry is characterized by column electrodes which produce a highly non uniform electric field and hence a poor timing performance.
The TIMESPOT sensor overcame this limit by using an innovative geometry of trench-shaped electrodes which approximately replicates a parallel plate geometry in a 3D sensor (figure 3).
The necessary technology studies have been finalized at Fondazione Bruno Kessler (FBK), Trento and the first production batch has been completed in summer 2019. It includes a wide variety of sensor geometries with a $150\,\mu\text{m}$ deep active volume, including a pixel sensor whose pixel size is $55\,\mu\text{m} \times 55\,\mu\text{m}$. A second production is expected shortly.

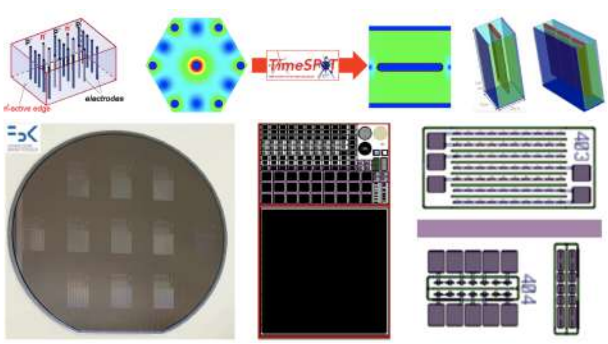

Figure 3: TIMESPOT sensor design and production

B. Test results

Standard electrical tests have initially been performed on the newly produced 3D silicon trench sensors. Measurement of sensor current and capacitance versus bias voltage (IV and CV curves) have been performed using a probe station at room temperature (figure 4).

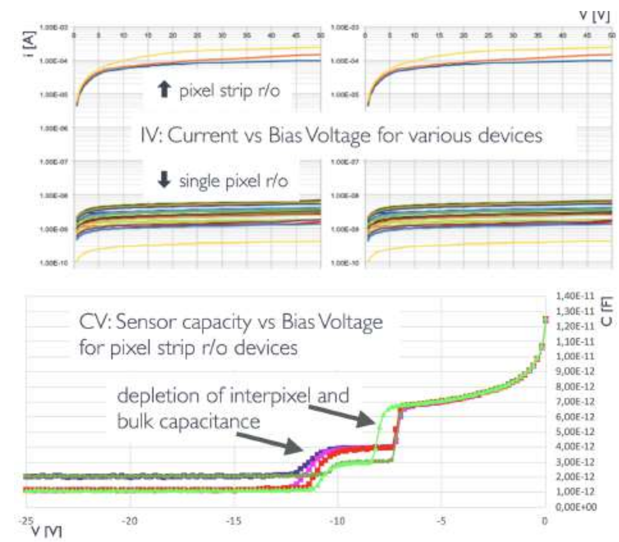

Figure 4: IV and CV curves for 3D trench silicon sensors.

The test setup (figure 5) and the main results (figure 6) are reported. The Genova board performed excellently and the measured time resolution was lower than 30 *ps*. The results have been published in arXiv:2004.10881.

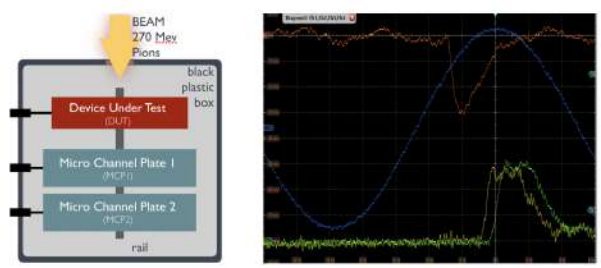

Figure 5: Beam test setup and resulting signals (red: DUT, green and yellow: MCP, blue: beam clock)

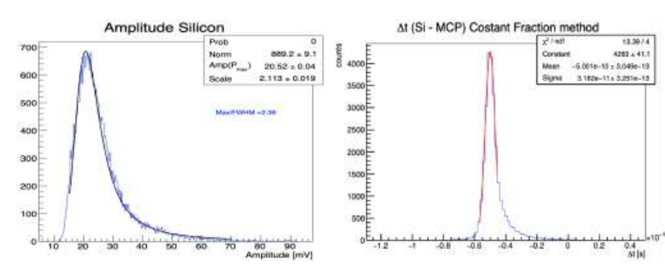

Figure 6: Signal amplitude and time difference distribution