Exp. High Energy Physics at NCP

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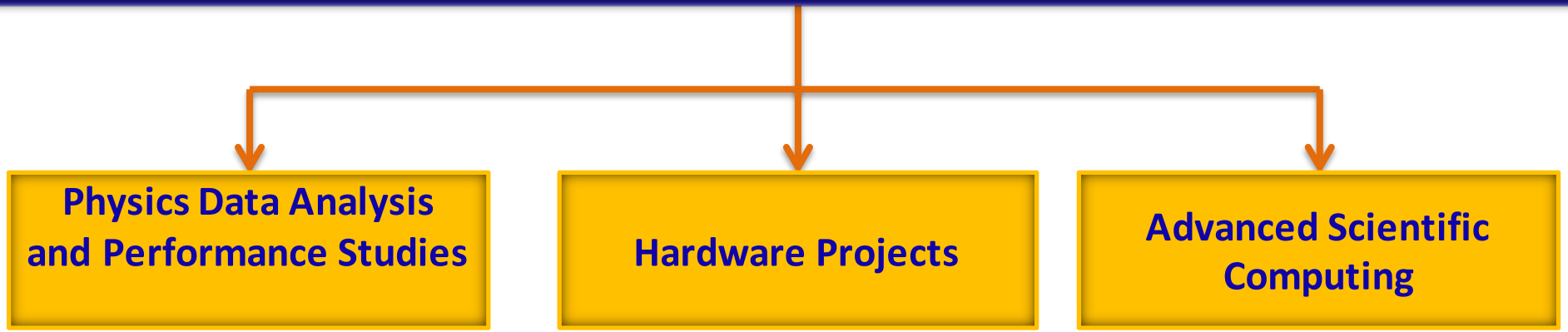
Introduction

- Today: Introduction to Exp. HEP Group activities at NCP
- Lecture 1: Cross section and decay rates
- Lecture 2: Cross section measurement, taking cross section measurement of single top in association Z as example

Projects in Exp. EHEP Department



- NCP has the largest HEP faculty in Pakistan
  - 6 PhD's, experimentalists

- Total thesis on CMS project:
  - Completed 5 PhD and 37 M.Phil theses
    - Students are coming from all over Pakistan, from various Universities such as QAU, IIUI, CHEP Lahore, AWKU …
  - Six PhD and 10 M. Phil theses are currently in progress

EHEP Facilities at NCP

- Gaseous detectors (RPC/GEM) R&D lab with testing setup such as cosmic muon stands, power supply, gas mixing setup, Keithley picoammeter, x-rays source etc
- Plan to develop Silicon Lab at NCP
- Electronics lab with PCB design capabilities
- Tier 2 computing Grid
- Trained manpower

Physics Research Area's

- Top quark Physics:
  - Study of associated production of top quark and Z-boson using CMS data collected in 2012 at 8/13 TeV center-of-mass energy
  - Measurement of Top Mass and ttbar Cross-section at 13 TeV
  - Measurement of the single top t-channel charge asymmetry

- SUSY Searches:
  - SUSY searches in multilepton and Z+MET final states

- Exotica Searches:
  - Search for the Black Holes with the Early Run 2 CMS Data

Recent Important Physics Analysis Finished at NCP

- The cross section measurement of top quark in association with Z boson (Measured for the first time in any HEP experiment)
  - Analysis Note: CMS/AN-14-182 and Paper: CMS/Top-12-039
- Measurement of ttabr cross-section in l+jets channel at 13 TeV
  - Documented in CMS Paper: Top-16-006
- Search for Microscopic Black Holes with the Early Run 2 CMS Data
  - Documented in CMS Paper: EXO-15-007

Physics Data Analysis

- **Analysis of complex data obtained from huge experiments**
  - Searching for rare processes (few events) by analyzing 10's of petabytes of data
    - Modeling/simulation of huge and complex detectors
  - Need skills of advance scientific computing, programming, physics and statistics
  - The skill developed can be used in many areas such modeling and simulation of complex systems, banking, stock exchange, industries etc

Research Area's (Performance Studies)

- Performance studies:
  - Study of coherent noise in Silicon Tracker at CMS
    - Modeling of correlated noise and variation w.r.t conditional parameters
  - Energy Loss measurement in the CMS Silicon Tracker
  - Backplane corrections and Lorentz angle measurement in CMS silicon Tracker
  - Performance of GEM detector at CMS
  - Lepton Efficiency measurement and fake rate estimation

Detector Hardware R&D

❑ Detector R&D:

- ➢ Resistive Plate Chambers(RPC's) Project at NCP
  - ❖ Taking part in GIF++ as well as DAQ related project
- ➢ Gas Electron Multipliers(GEM) Detector R&D
  - ❖ Thin/Thick GEM R&D (Assembly and testing)
  - ❖ GEM DCS developments
- ➢ Silicon Strip Tracker R&D for CMS upgrade
  - ❖ Sensor qualification, module assembly, mechanics
  - ❖ Plan to develop complete Setup at NCP
- ➢ Reverse engineering project for KANUPP
- ➢ Gaseous and Silicon detectors have wide spread applications in HEP, nuclear reactors, medical and security applications

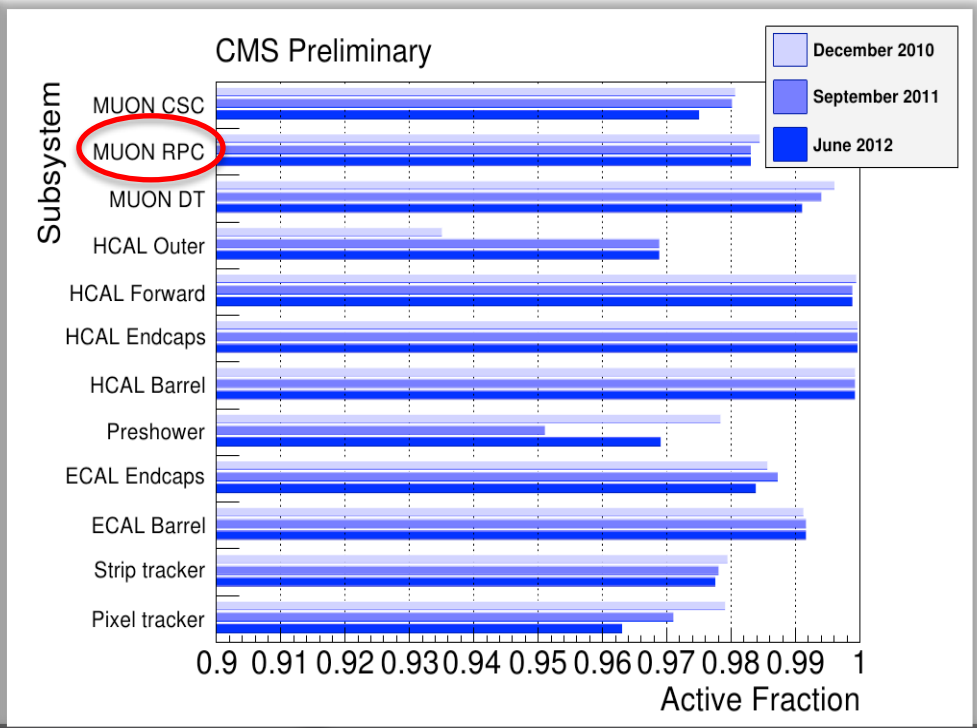
CMS Resistive Plate Chambers(RPC's) Project at NCP

- Built, tested, installed and commissioned (288 + 10% contingency) RPCs

One of the first International Scientific Project from Pakistan

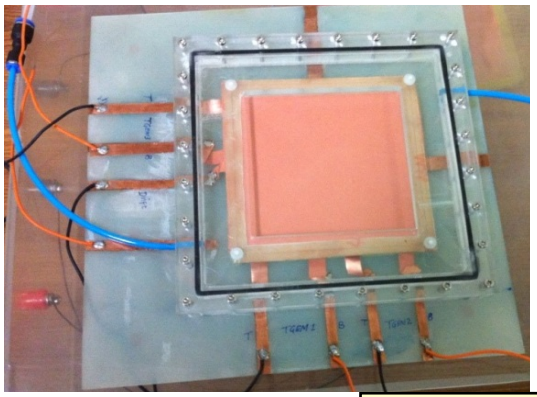
Resulted in Nobel Prize for Peter Higgs and Francois Englert in 2013!

- During data taking RPC's are operational 99.8% of the time with very high efficiency (more than 98%, comparable to any other sub-detector)



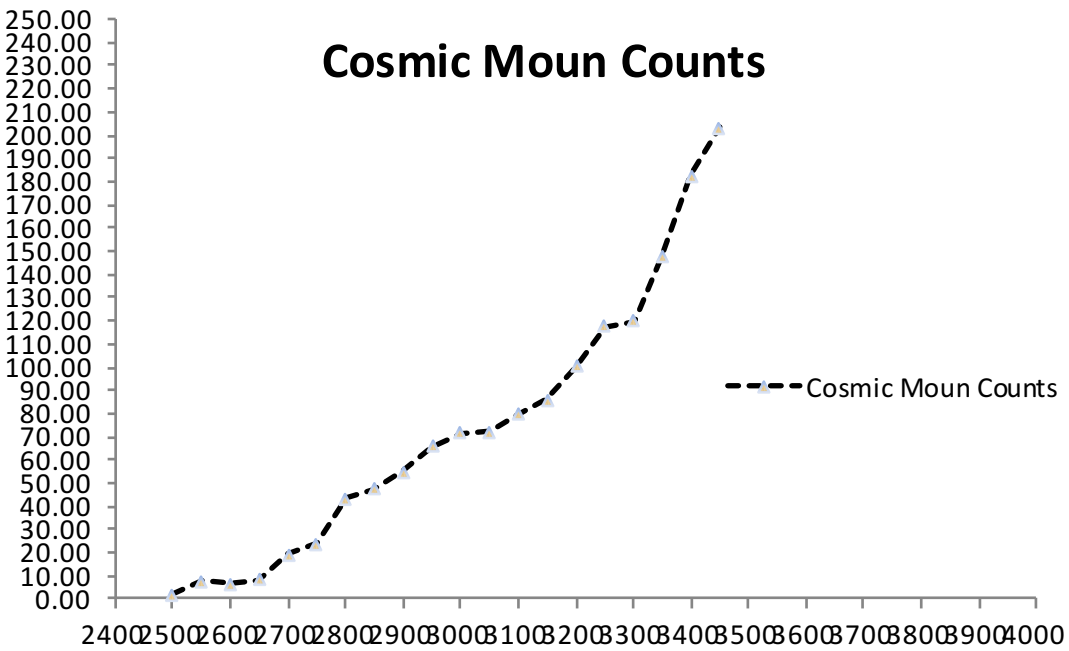
Thick GEM Project at NCP

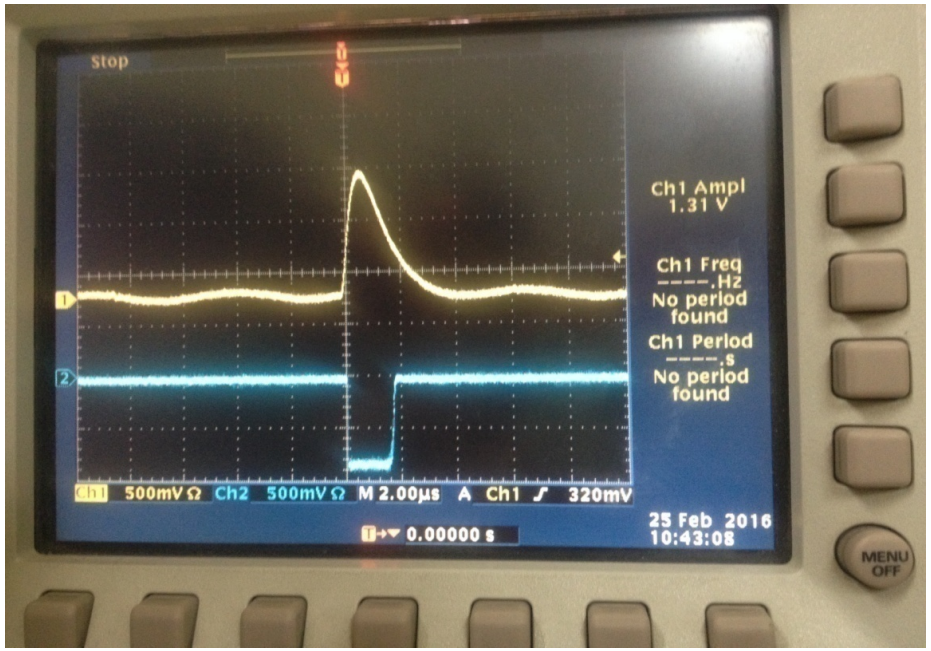
- To overcome GEM foil issues, indigenous R&D on thick GEM has been established in parallel
  - Easy to fabricate locally
  - 6 foils prepared at Smart PCB at the cost of PKR 18000
  - Developed basic readout setup
  - Able to measure cosmic muons
  - Detail studies underway with recently procured x-rays source

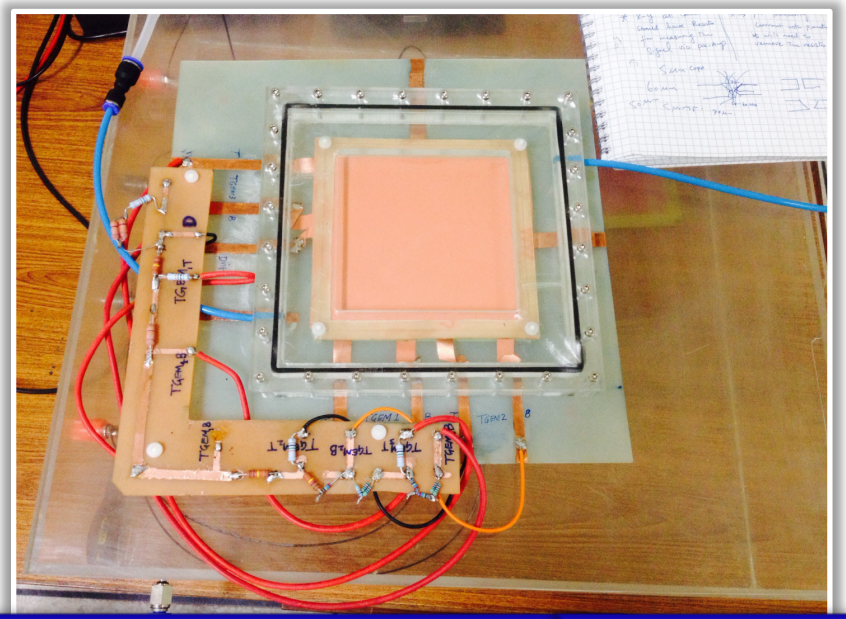


Hole diameter d =0.3–1mm
Distance between holes a = 0.7- 7 mm
Plate thickness t=0.4-3 mm

Performance study of TGEM with Cosmic Mouns







The eventual goal is develop fast , high resolution and cheaper detectors for medical imaging

Visit to the lab will be organized during the next days

Grid Node to access LHC data

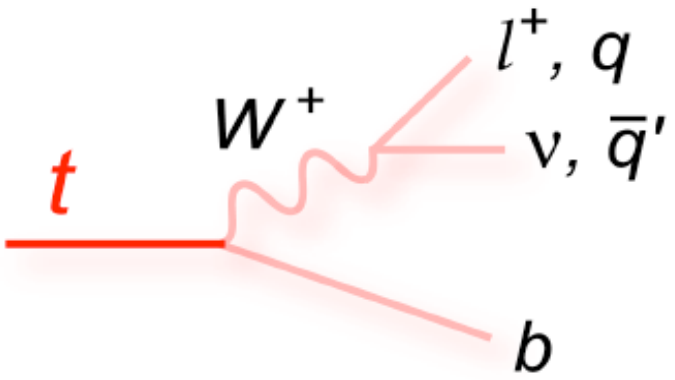
- Processing of huge amount of LHC/CMS data needs a lot of computational power, hence resources
- First Pakistani Tier2 was deployed in June 2004(operational 24/7 even during severe blackout in Pakistan)
- Immediate access to wealth of LHC data with up-to-date CMS software releases

CPU	Storage	Network Connectivity
524	360 TB	1 Gbps (dedicated)

Highlights from Recent Physics Papers finished at NCP

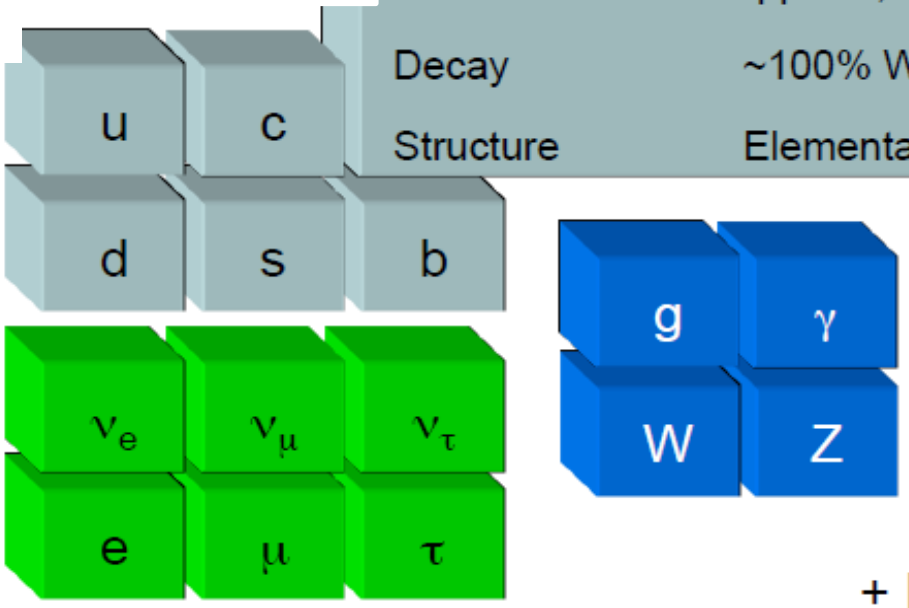
- Top Quark Studies
- Search for Mini-black holes

The Top Quark



Top decays into Ws or Wd are suppressed by the square of the corresponding CKM matrix elements $|V_{ts}|$ and $|V_{td}|$.

up-type quark	3rd generation
Symbol	t
Mass	173.2 ± 0.5 ± 0.7 GeV/c^2
	~186 u
Charge	+2/3
Prod	proton-(anti)proton
Prod mechanism	gg,qq→tt; (qb →qt, qq →bt; bg →Wt)
Decay	~100% Wb
Structure	Elementary?



+ Higgs + …

Importance of Top quark studies (1)

- The heaviest particle in Standard Model

$$m_t = 172.44 \pm 0.13 \pm 0.47\,\text{GeV}$$

  - Strong coupling with Higgs due to it's large mass
- Due to large mass(~EWK scale), play important role in new interactions at high energy
- M_{top} a very important parameter of the Standard Model
- Top quark doesn't form hadrons:

$$\tau_{top} = \frac{1}{\Gamma_{tot}} \approx 10^{-25} < \tau_{had} \approx 10^{-24}\,\text{sec}$$

  - decays before hadronization
  - Access to bare quark properties
  - Decay products keep spin information (spin correlations info is conserved)
    - Very important for polarization studies
  - Sensitive to new physics; can change top quark anomalous couplings

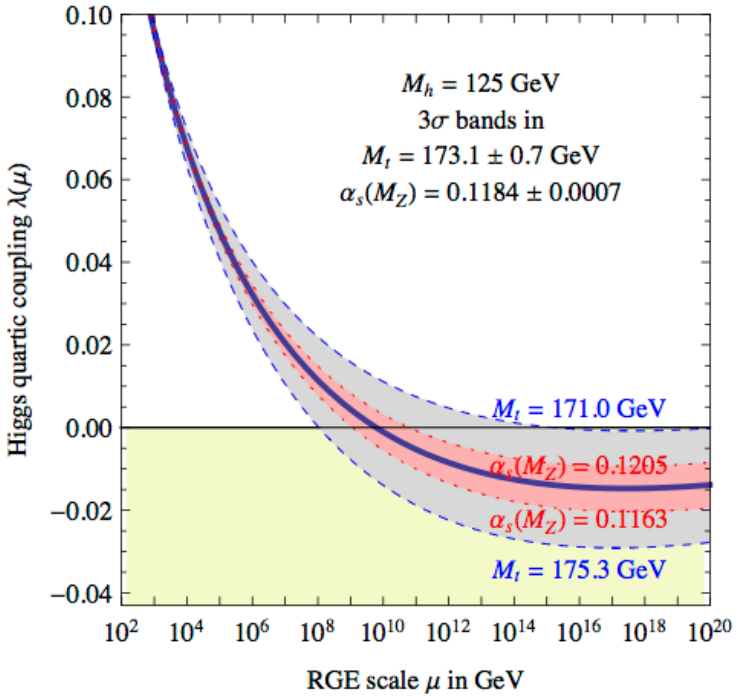
Importance of Top quark studies (2)

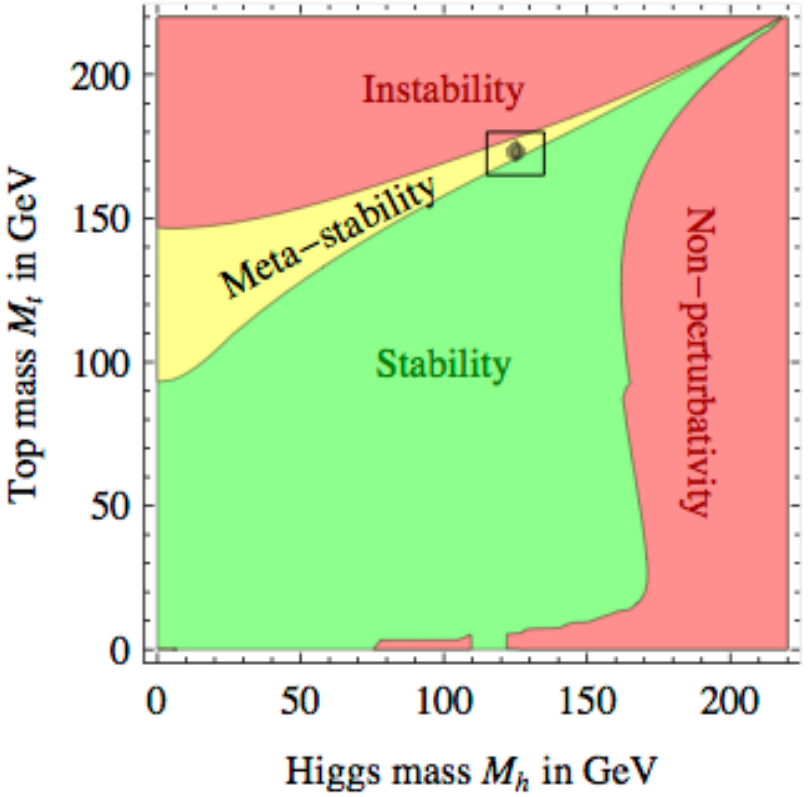
- Important for refinement and tests of different physics aspects of top quark modeling in MC Simulations

- Important for physics searches where top quark is important background

- Implication of Higgs and top masses
  - Renewed interest for precision m_{top} measurements
  - Experimental information on m_H and m_{top} gives us useful hints on the structure of the theory at very short distances
    - Even in the absence of direct evidences for new physics at the LHC

Vacuum Stability





G. Degrassi *et. al., arxiv:1205.6497*

$\lambda = 0.13 \text{for} 125 \text{GeV Higgs}$

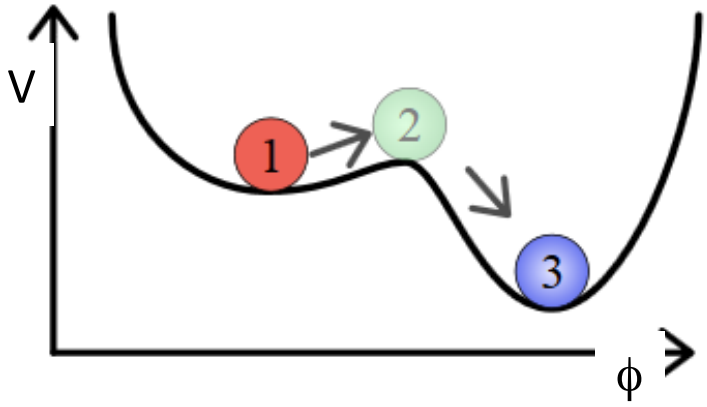
$$V = \frac{1}{2}\mu^2\Phi^2 + \frac{1}{4}\lambda\Phi^4$$

Implication of Higgs and top masses

- Current experimentally measured masses of Higgs and top quark are fascinating from theoretical point of view

- Higgs quartic coupling (λ) could be small, vanish or become negative around Planck scale (~10^{19} GeV)

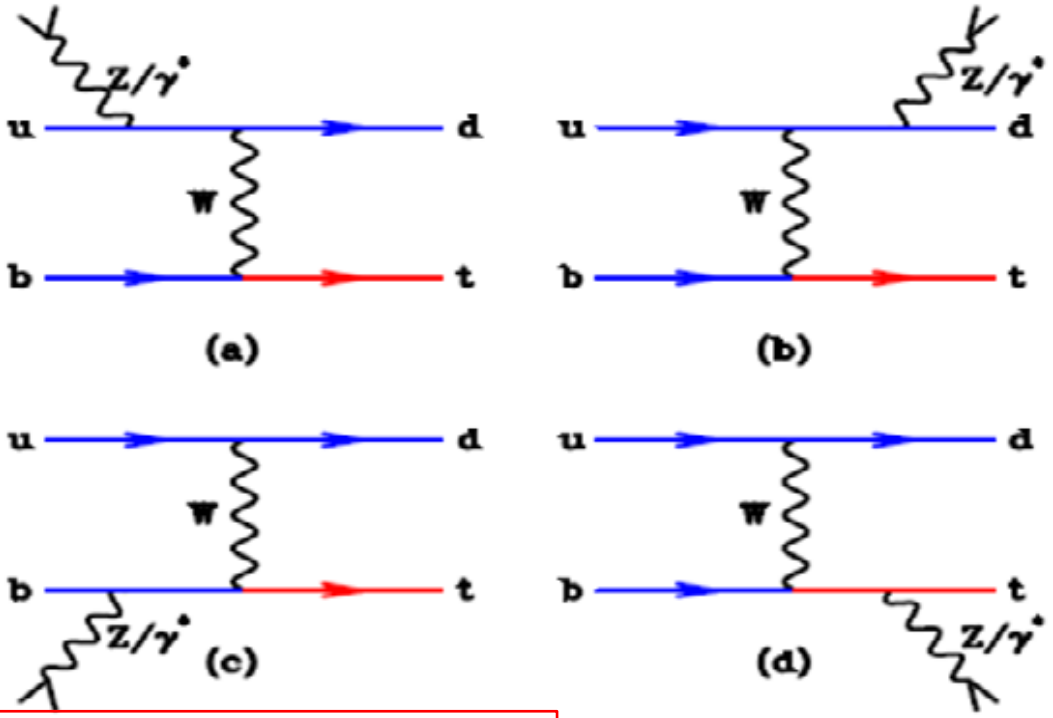
- For $\lambda>0$, the Electroweak vacuum is the global minimum
- For $\lambda<0$, the Electroweak vacuum become meta-stable(doesn't become meta-stable by the age of universe)



Search for associated production of a Z boson with Single Top Quark

- tqZ is an unmeasured rare standard model process.
  - Measurement will confirm a predicted feature of the standard model and allow other analyses(trilepton analysis) to more accurately account for tbZ as a background
  - irreducible background for FCNC t→Zb decay and tH searches
- Analysis techniques can be easily extended to SUSY multilepton analysis

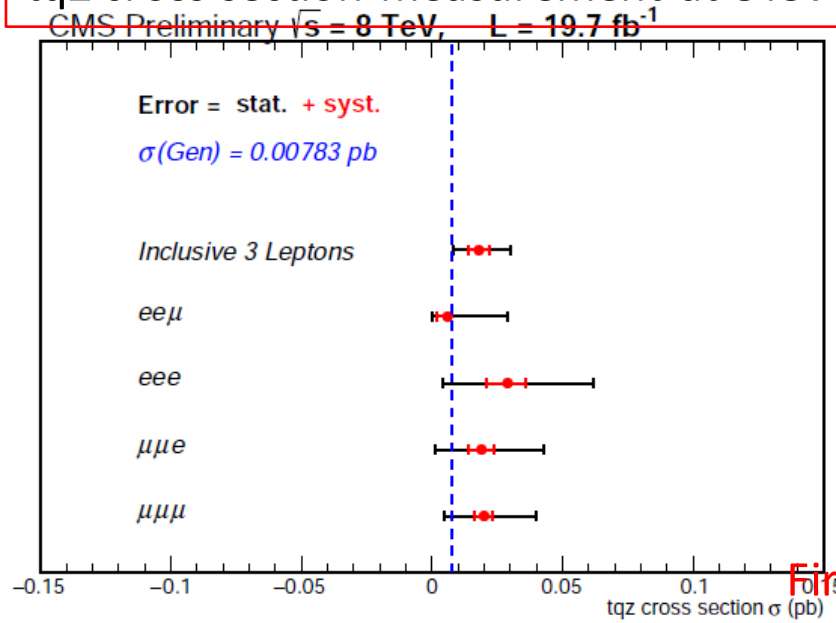
- NLO x-section x BR~ 8 fb
- Finally only 20 three leptons events in 19.7 fb^{-1} at 8 TeV (RUN I data)
- lepton→electron or muon



x-section enhancement w.r.t SM may be a hint of new physics

Measurement of Single Top + Z boson cross section at 8 TeV

tqZ cross section measurement at 8TeV

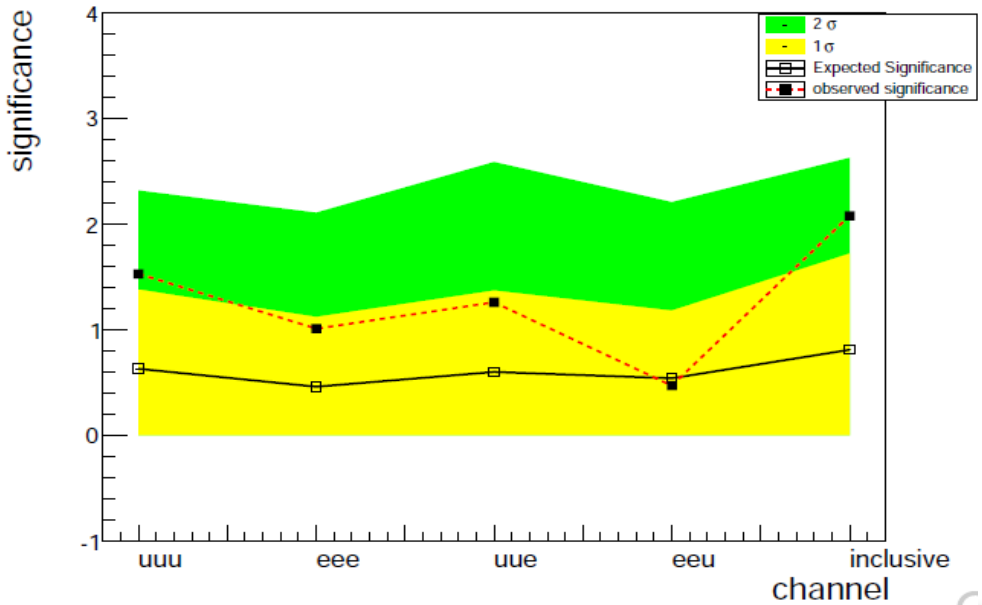


From Paper: CMS/Top-12-039

Channel	cross section (fb)
$\mu\mu\mu$	$20^{+19}_{-15}(stat.)^{+4}_{-3}(syst.)$
eee	$29^{+32}_{-24}(stat.)^{+8}_{-7}(syst.)$
$\mu\mu e$	$19^{+24}_{-18}(stat.)^{+5}_{-5}(syst.)$
$ee\mu$	$6^{+23}_{-6}(stat.)^{+4}_{-0}(syst.)$
inclusive	$18^{+11}_{-9}(stat.)^{+4}_{-4}(syst.)$

First experimental measurement of the tqZ SM process!!

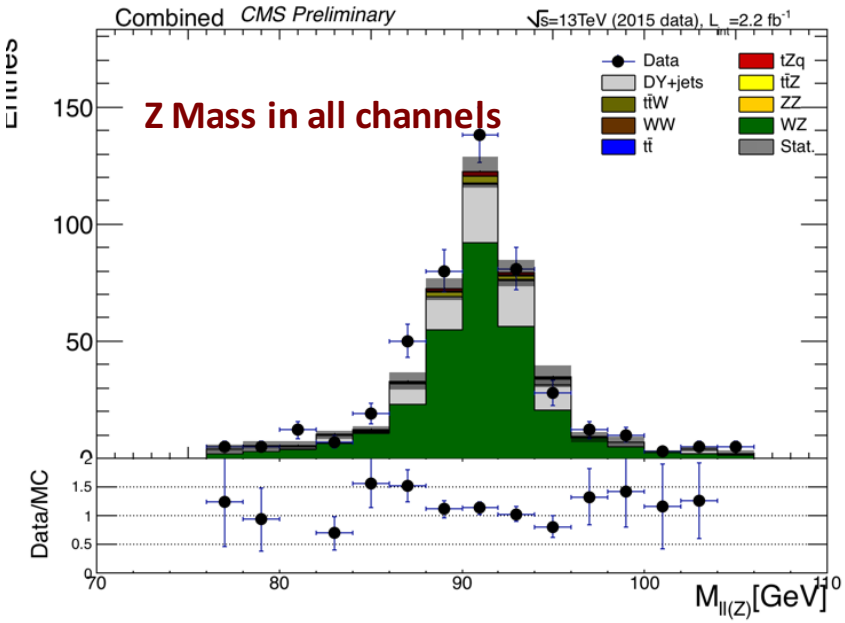
Shown at ICHEP last week for the first time

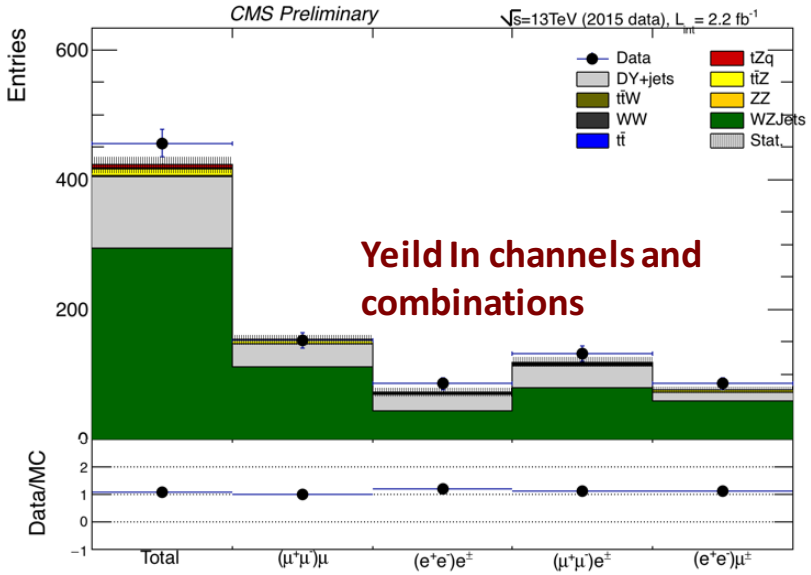


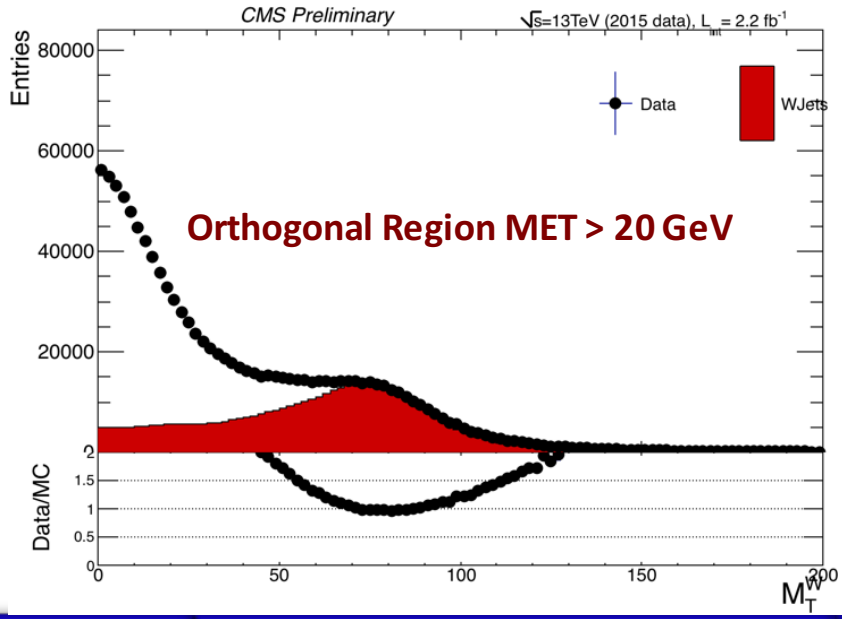
Channel	Expected Significance			Observed Significance
-	Mean	1 σ	2 σ	-
uuu	0.66 ± 0.03	0 - 1.45	0 - 2.48	1.35
eee	0.46 ± 0.03	0 - 1.15	0 - 2.18	1.20
uue	0.61 ± 0.03	0 - 1.35	0 - 2.28	1.04
eeu	0.53 ± 0.02	0 - 1.16	0 - 2.20	0.32
inclusive	0.81 ± 0.04	0 - 1.59	0 - 2.68	1.80

tqZ cross section measurement at 13 TeV (2015/16 data)

Hope to discover the process in 2016 data!



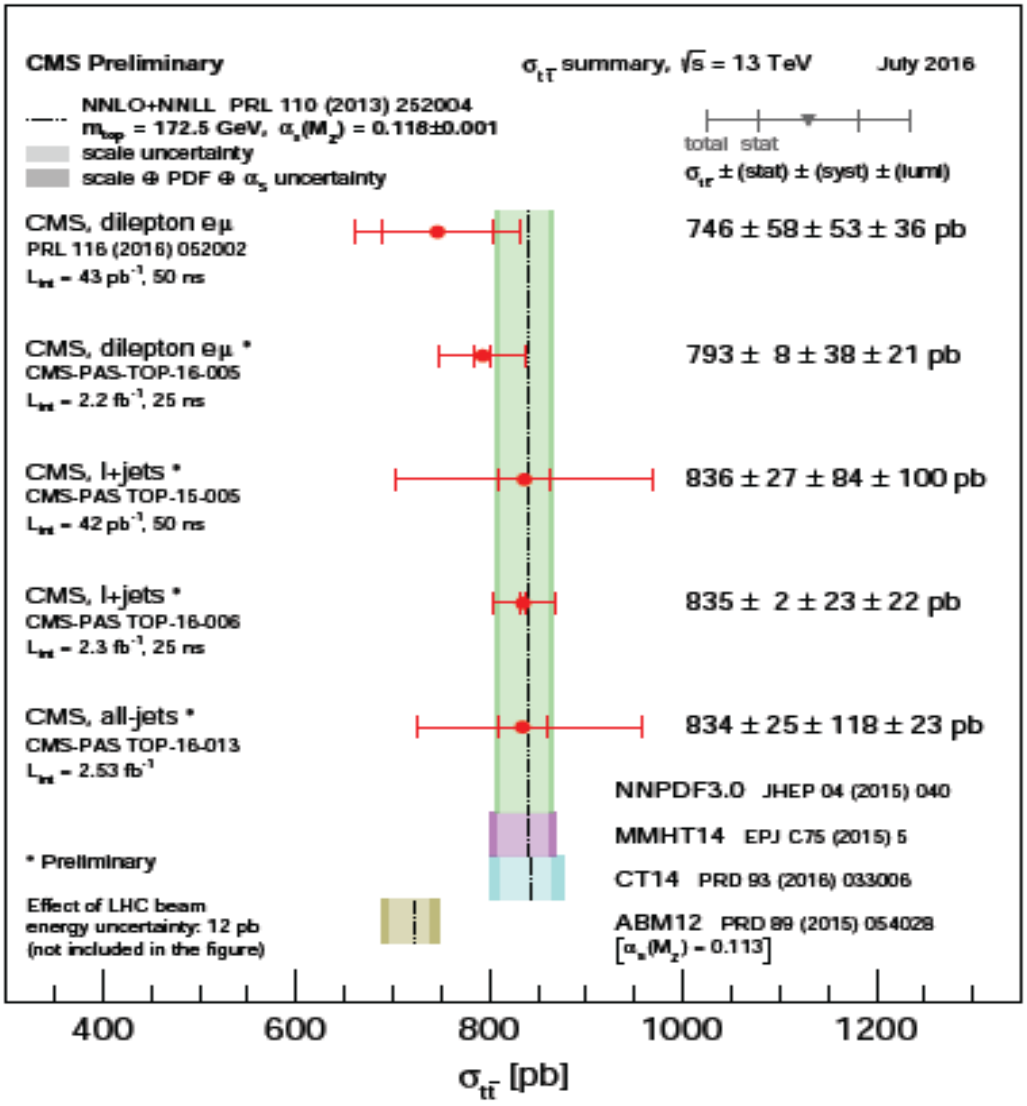


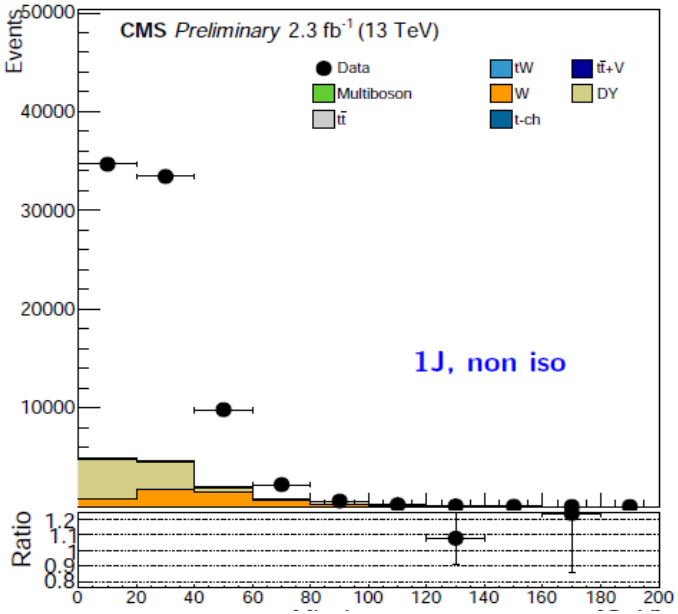


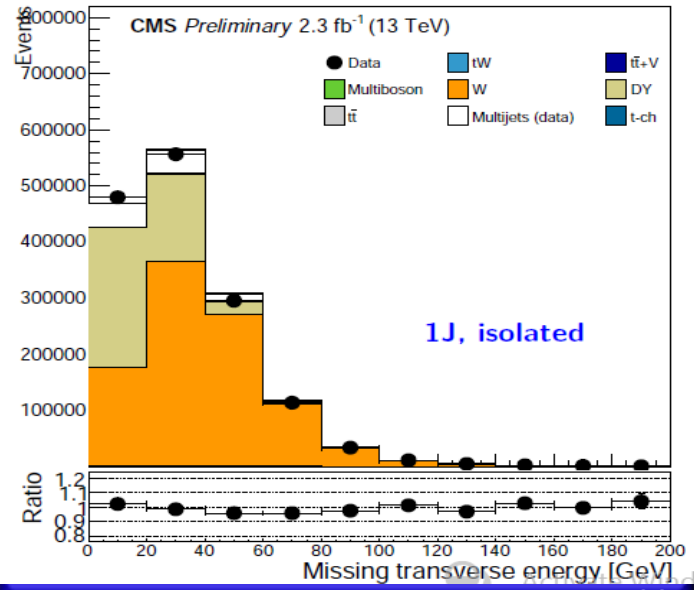
CMS AN /Top-16-285

Measurement of ttabr cross-section in l+jets channel at 13 TeV

- A very precise measurement of ttbar x-section in at 13 TeV
  - High statistics in l+jets channel, moderate backgrc



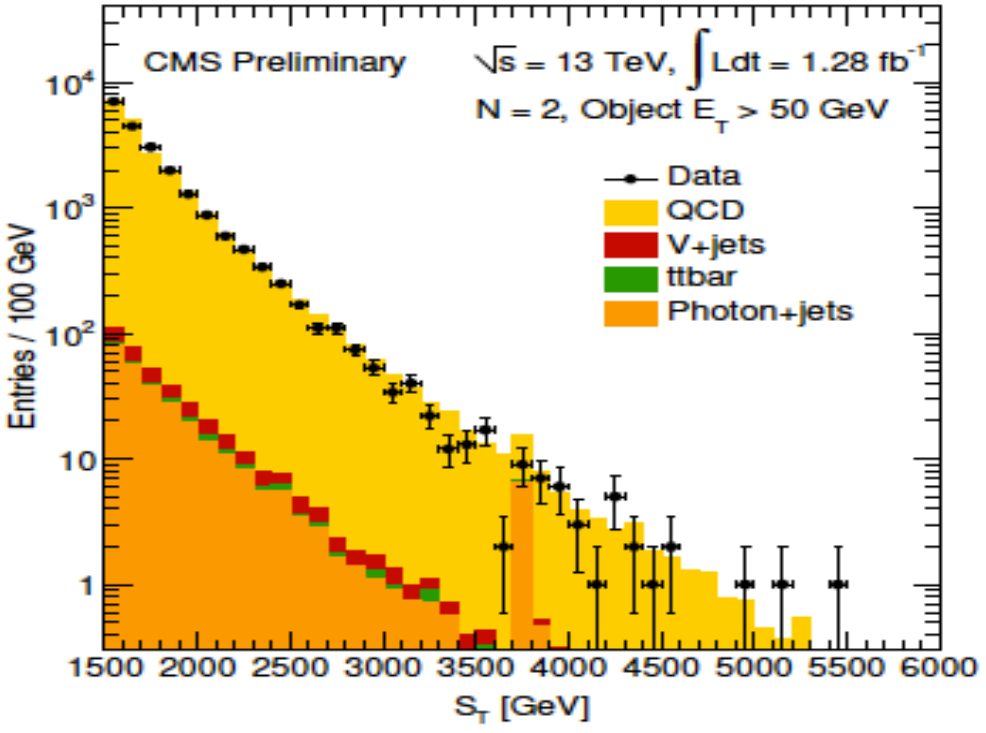




Search for Microscopic Black Holes at 13 TeV

- Models with extra dimension *such as ADD and RS models predict strong gravity*
  - These models predict the production of microscopic black holes in high energy collisions such as at the LHC
- Microscopic black holes can decay to SM particles and high multiplicity jet with large transverse energies

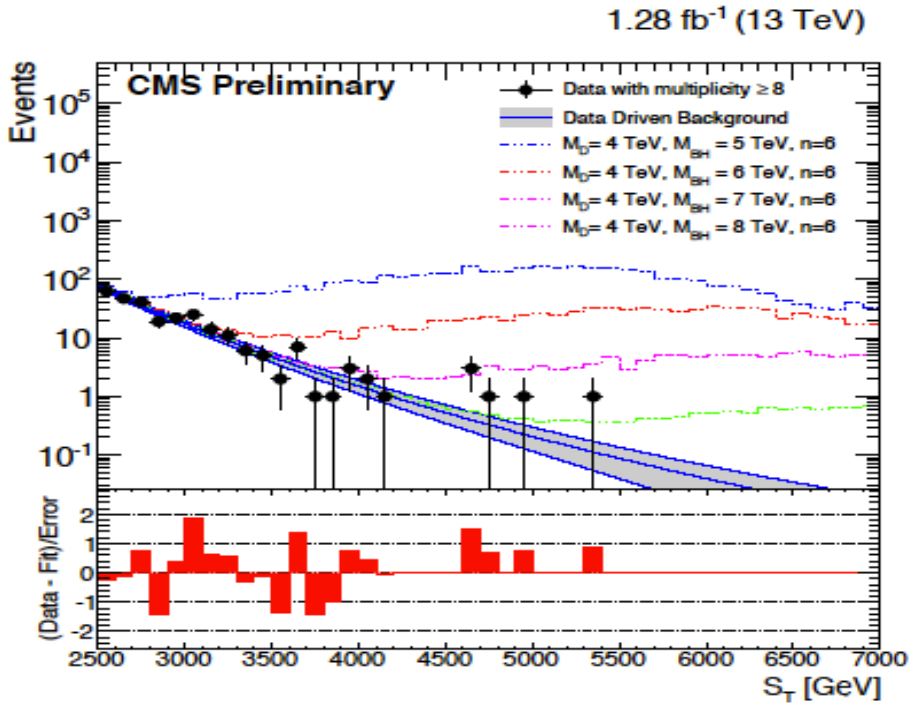
- Data driven background estimation is done in the well understood two jet bins

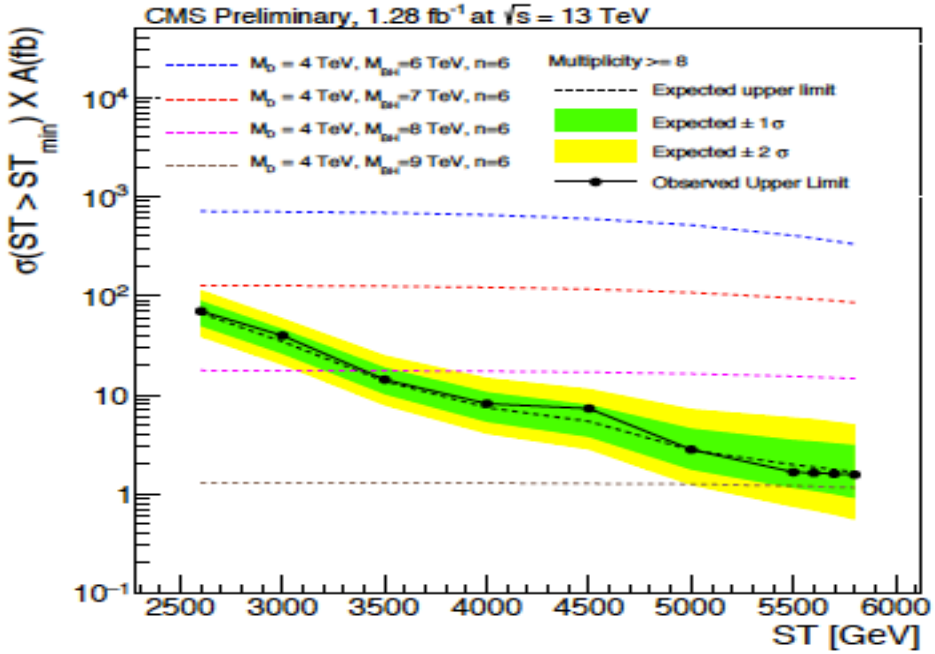


Limits on the production of Microscopic Black Holes

- The data agrees well with the estimated background, so no signal so far
- Limits are derived in model independent (black solid and dotted lines) and model-dependent (colored dotted) way (right) for multiplicity $N \geq 8$.

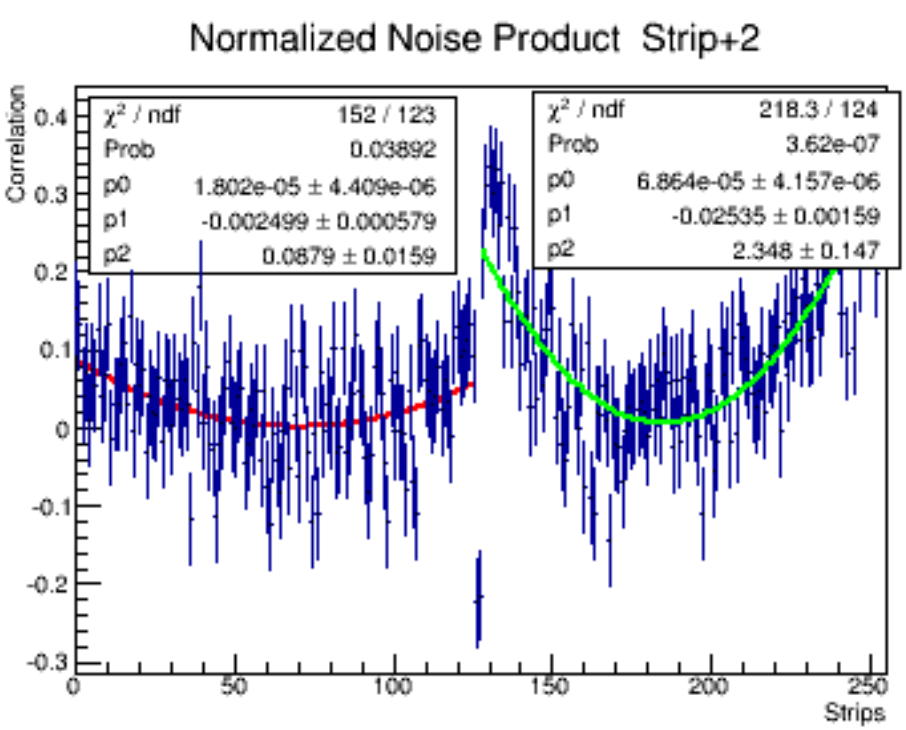
Analysis documented in the CMS paper **EXO-15-007.**

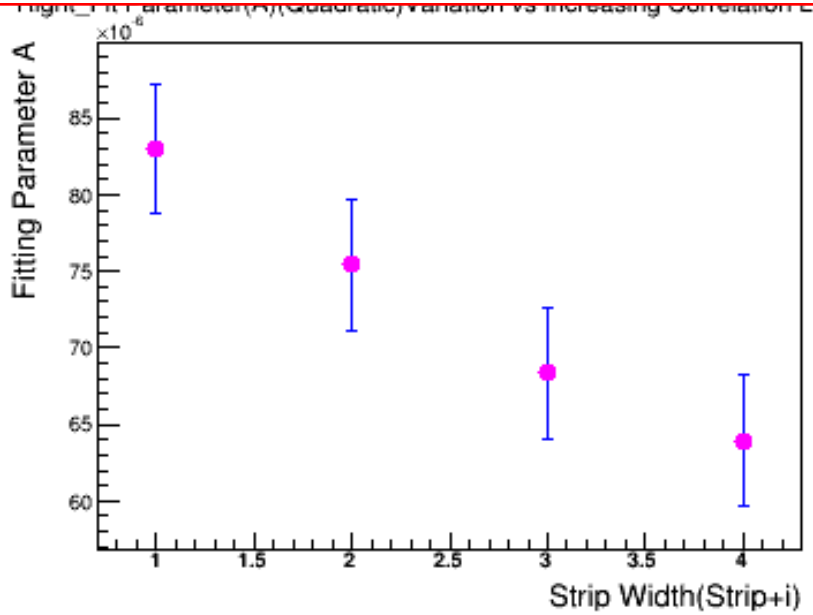


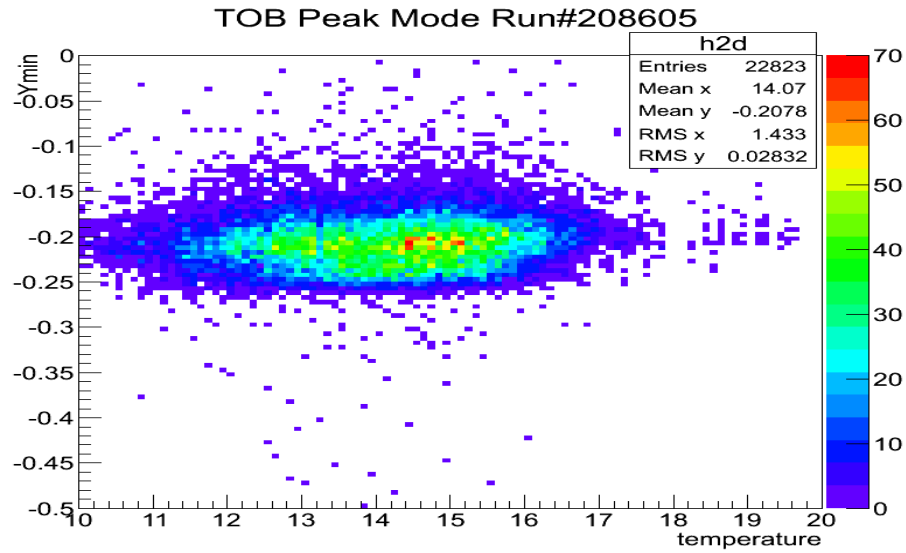


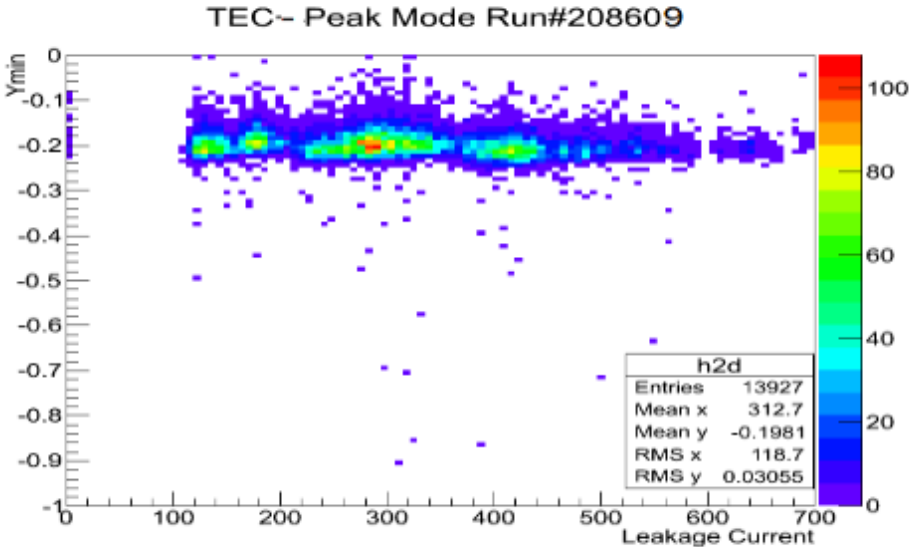
Coherent Noise in Silicon Detector at CMS

Study helps to improve track reconstruction by reducing the chance of noisy clusters





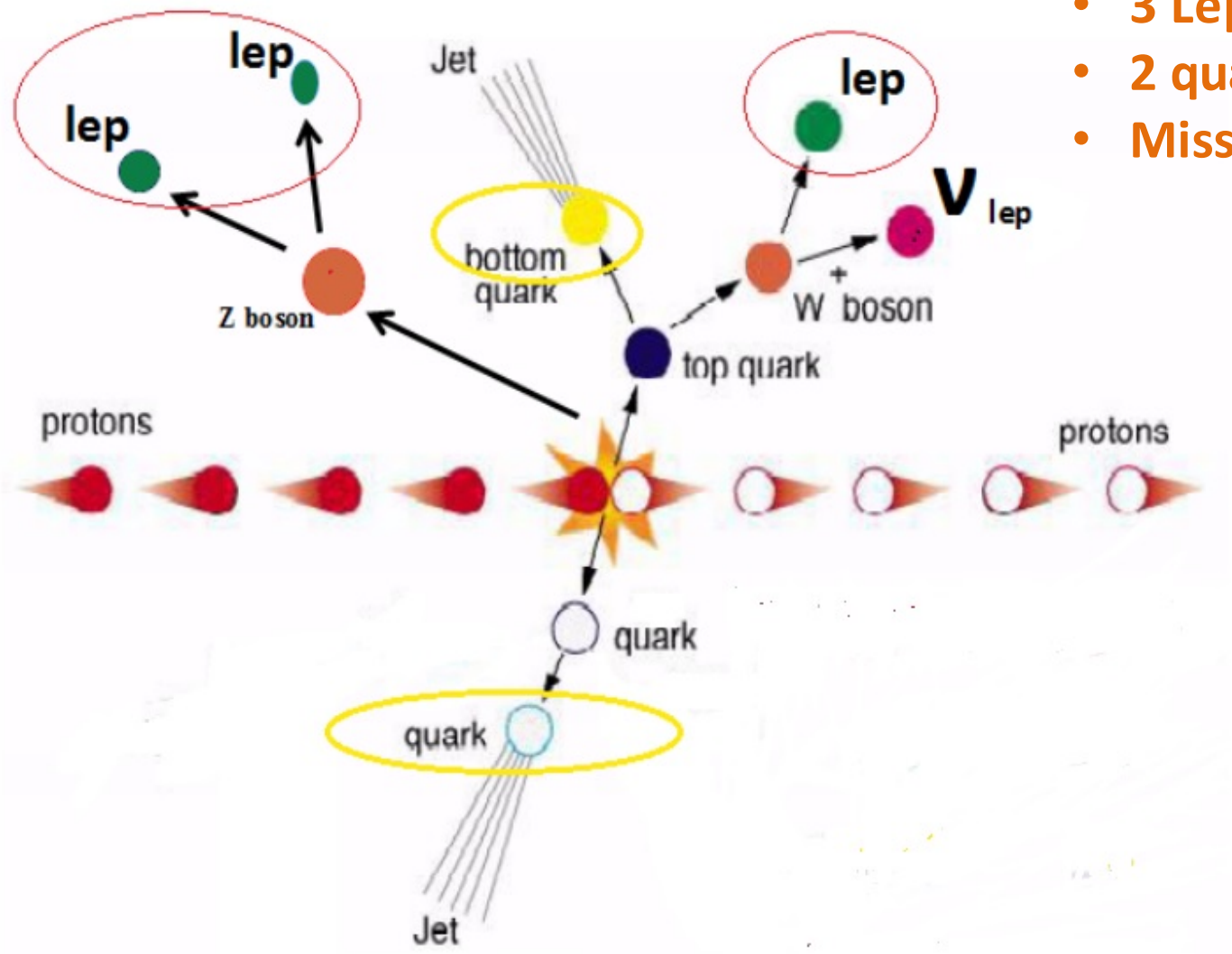




Summary

- Well covered research areas in Exp. HEP group at NCP,
  - Detector development for HEP experiments
  - Performance studies of the CMS sub-detectors
  - Physics analysis of the LHC data
- Good opportunities for new comers to join!

Three leptons final state



tZq Final State:

- **3 Leptons**
- **2 quarks (1 b quark)**
- **Missing energy(neutrino)**