LHC Physics Center

LHC PHYSICS CENTER

Fermilab
50 Years of Discovery

Research Activities as CMS LPC Distinguished Researcher

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PURDUE UNIVERSITY

Abid Patwa's visit to the LPC, July 27 – 28, 2017, FNAL

Outline

- Searches for new Physics using di-leptons
- HLT tracking with the Phase-I pixel detector
- LPC community service

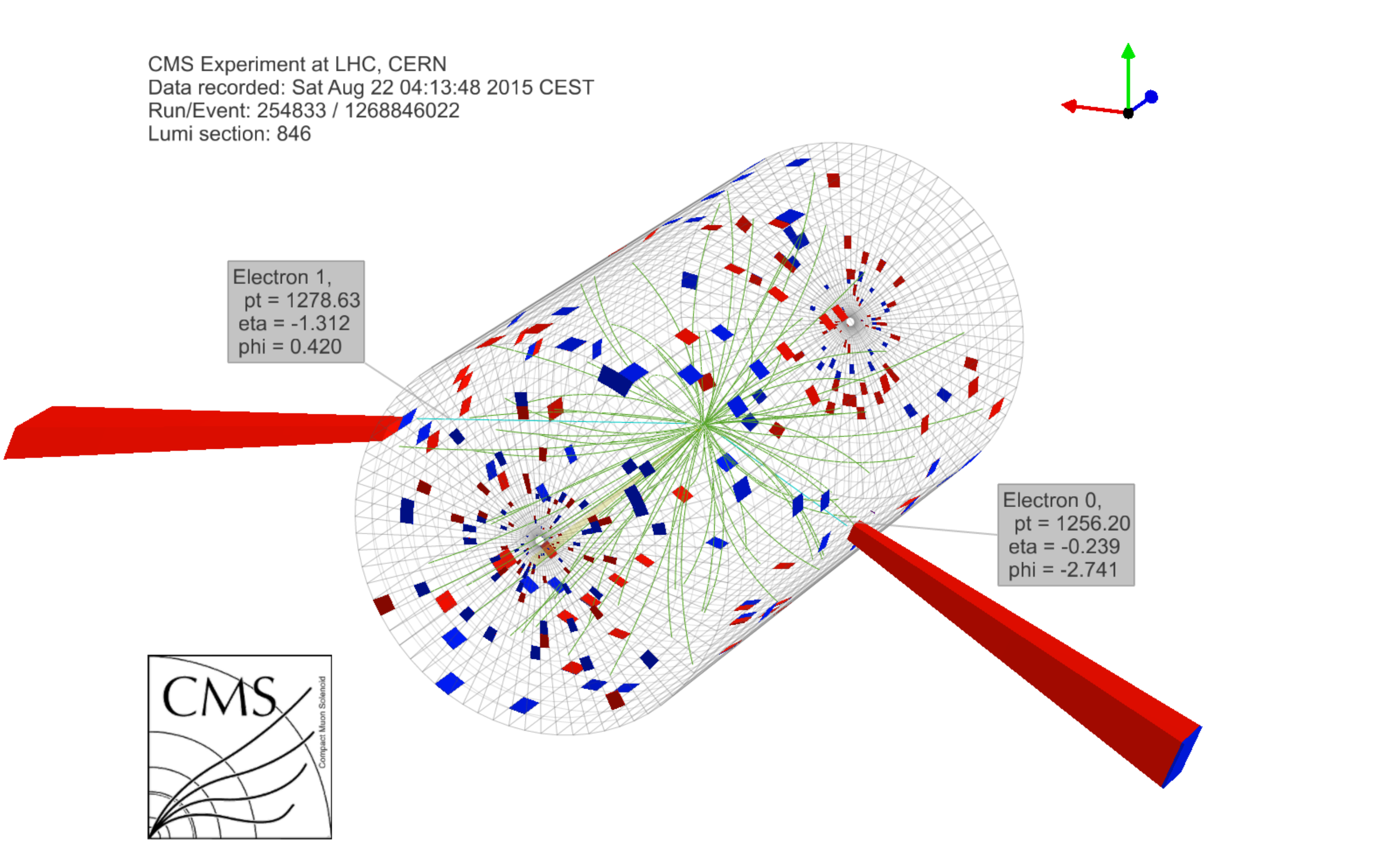
Di-Lepton Analysis

- A multitude of searches target anomalous production of resonant/ non-resonant di-leptons, motivated by a wide range of theoretical models
  - Distinct signature with low SM backgrounds
  - Simple signatures allow for largely model-independent searches
- High energy and large integrated luminosity give sensitivity for searches in unexplored phase space
  - High energy: Particularly important for searches for high mass resonances
  - Large statistics: 2016 data crucial for these searches
- The di-lepton mass spectrum has been a fruitful place for discoveries in the past
  - Studying it at the highest energies at the LHC opens up great sensitivity to new phenomena

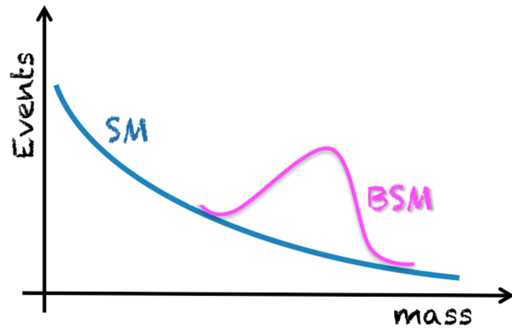
Extended Gauge Symmetries

- New gauge bosons predicted by many extensions of the Standard Model with extended gauge symmetries
  - Sequential Standard Model Z_{SSM} with same coupling as in Standard Model
  - Z'_ψ , Z'_χ , Z'_η models from E6 and SO(10) GUT groups
  - Left-Right symmetry model (LRM) and Alternative LRM (ALRM)
  - The Kaluza-Klein model (KK) from Extra Dimensions
  - Some Dark Matter models
- No precise prediction for mass scale of gauge bosons
- Other models predict the non-resonant production of new physics at high mass
  - Contact Interaction (CI) models
  - Large extra dimensions (ADD)
- Discrimination of different models requires measurement of
  - Cross section, mass, width, angular distributions

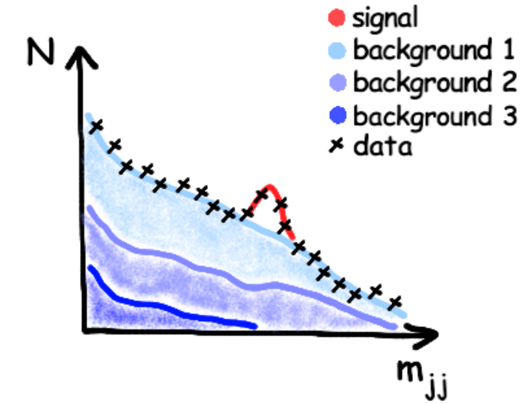
Di-Leptons


CMS Experiment at LHC, CERN
Data recorded: Sat Aug 22 04:13:48 2015 CEST
Run/Event: 254833 / 1268846022
Lumi section: 846
Electron 1,
pt = 1278.63
eta = -1.312
phi = 0.420
Electron 0,
pt = 1256.20
eta = -0.239
phi = -2.741
CMS
Compact Muon Solenoid

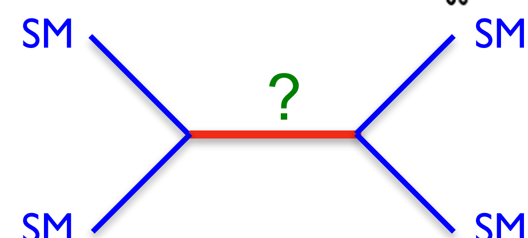
Resonance Searches

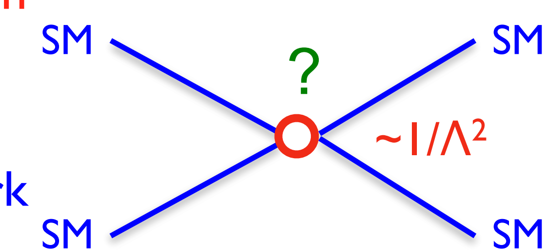


- Search for new resonances in the tails of the SM distributions
- Backgrounds
  - relatively clean with good S/B
  - most SM backgrounds can be modeled from data



- Experimental challenges
  - understanding detector resolution is key
  - 1.3% − 2.4% for electrons and 7% for muons at 1 TeV
- Also look for modifications in angular and mass distributions arising from new contact interactions
  - New mediating particle with a mass much higher than the energy exchange modeled as contact interaction with new physics at energy scale Λ
- Resonance searches can also be interpreted in terms of Dark Matter models



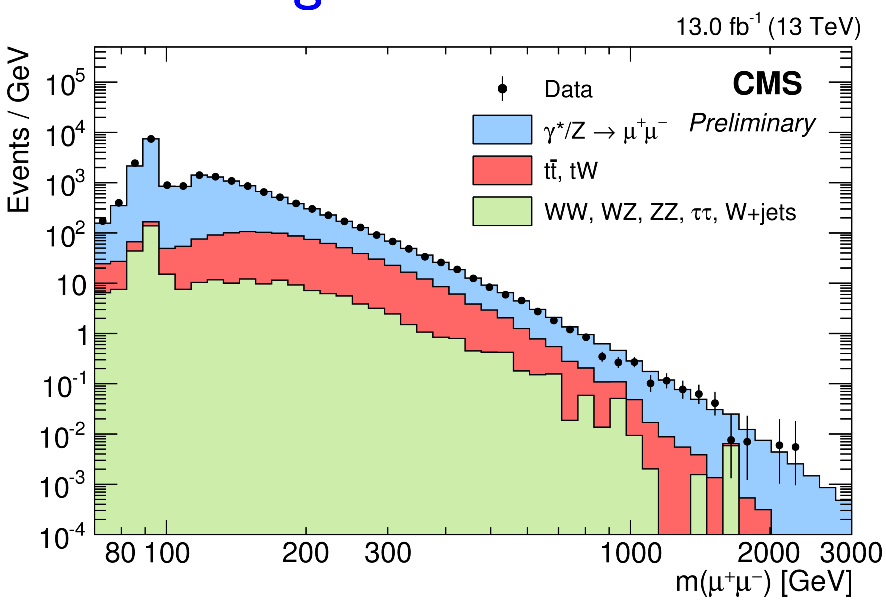


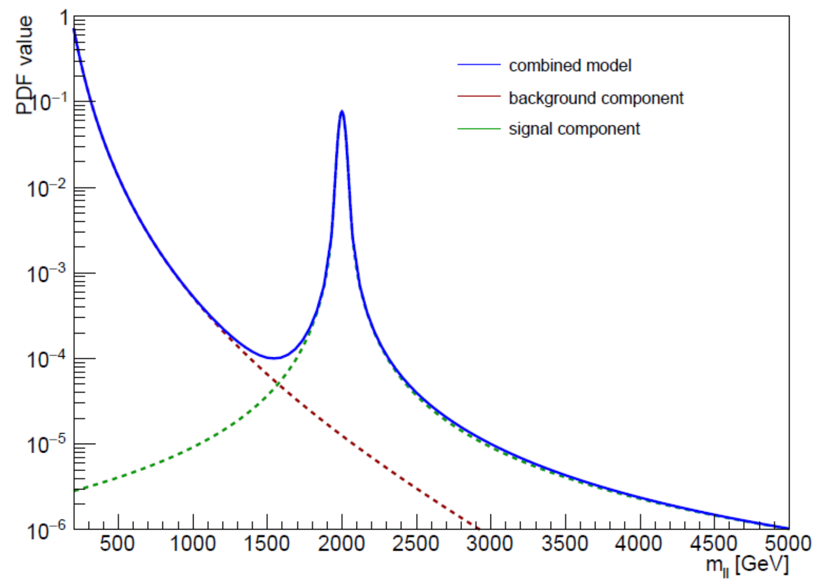
Di-Lepton Analysis @LPC

- My group has been involved in the di-lepton analysis for many years
  - Collaboration with UCLA, U. Florida, RAL, Bologna, JINR, etc.
- Current focus:
  - Measurement of the di-muon mass resolution
  - Statistical analysis of the search results and interpretation in terms of new physics
- As LPC DR I started a collaboration with the FNAL group (L.Spiegel, P. Bhat), Wayne State (P. Karchin, S. Zaleski, S. Jared) and Aachen (M. Radziej, A. Meyer, T. Pook) to unify the various di-lepton analyses
  - Common framework for di-lepton searches and interpretation
- The LPC has become a hub for the interpretation of di-lepton searches!

$Z' \rightarrow \ell^+\ell^-$ Searches

- Expected narrow resonance on top of steeply falling background
- Perform maximum likelihood fit to test for presence of a signal
- Analysis principle: Select di-lepton pairs, compute the invariant mass distribution, and compare to theory
- The main challenge is to accurately reconstruct and identify leptons with very high momenta
- Main background: Drell-Yan

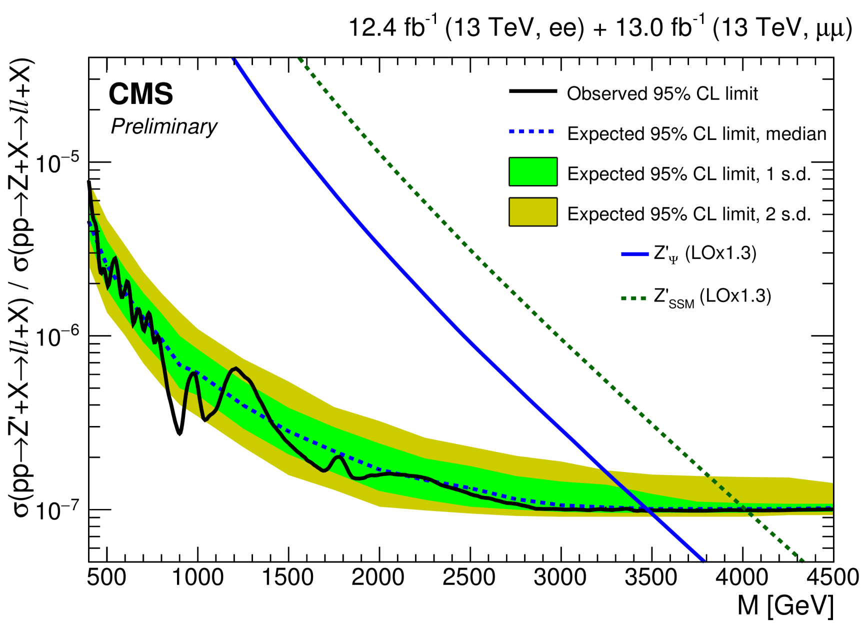




Z'→$\ell^+\ell^-$ Searches

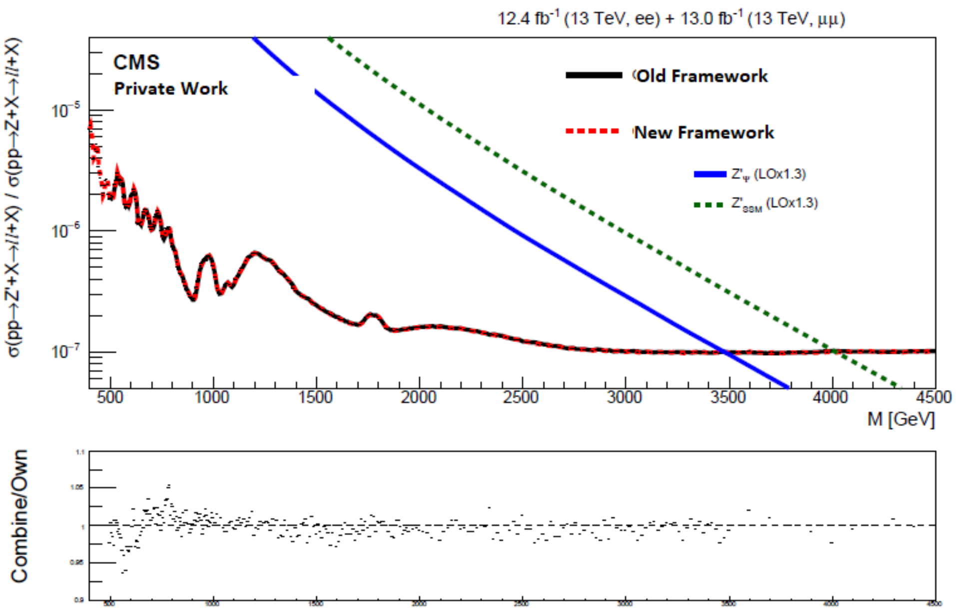
- To quantify the result of the analysis, 95% Confidence Level upper limits are set on the cross section ratio between the Z' and the Standard Model Z boson.
- Exclusion limits are set on the ratio σ(Z')/σ(Z) using an unbinned maximum likelihood fit to the data.
- Limits on Z' : 3.5 – 4.5 TeV
  - Limits weaken above 3.5 TeV: Rapidly falling signal x-sections and off-shell low mass signal tail

$$R_\sigma = \frac{\sigma(Z' + X \to \mu^+\mu^- + X)}{\sigma(Z + X \to \mu^+\mu^- + X)}$$



Interpretation

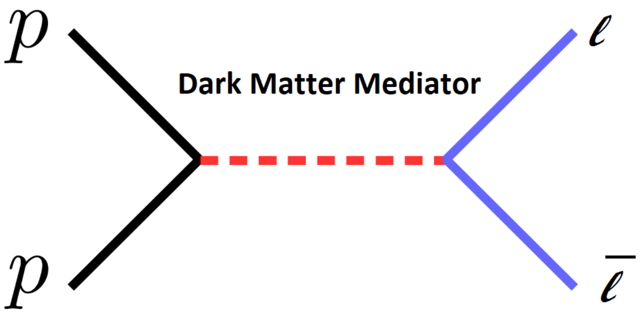
- The scope of the statistical interpretation is to be expanded to include more models.
- My group developed a new software framework to perform the necessary calculations, based on tools developed by the CMS Higgs group.
- The new software has several advantages over the existing tools
  - Uses tools widely used in CMS and extensively validated
  - Faster performance allows for more extensive interpretations
  - Modular construction allows for easy extension, for example to models with non-resonant signatures



- New framework reproduces previous results very well.

Dark Matter

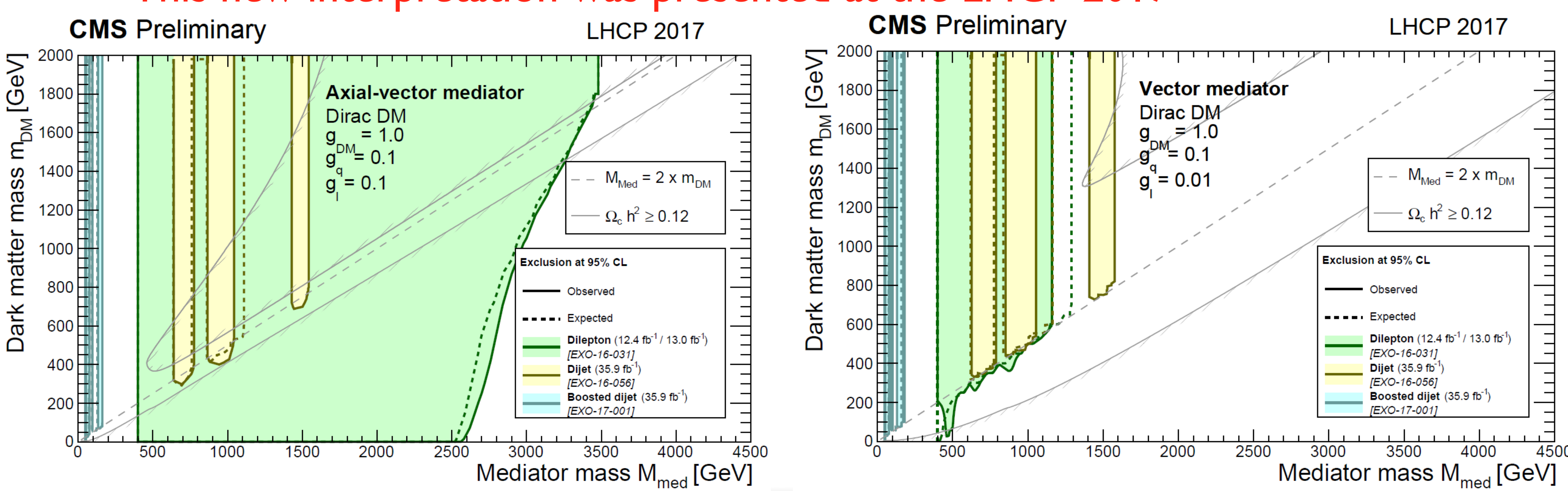
- The identity of Dark Matter is one of the biggest unsolved puzzles in modern physics.
- Complementary to the extensive program of direct and indirect detection experiments on earth and in space, searches for Dark Matter at the LHC have become a hot topic.
- The "classic" approach is to look for pair production of Dark Matter particles via a Mediator particle. The DM particles are not detected, leading to large missing energy. The events are then tagged by the presence of ISR photons or jets.



- However, if this mediator particle couples not only to quarks but also to leptons, the di-lepton final state has a great potential for a direct observation of the Mediator.
- Expanded the analysis interpretation to cover these models, in collaboration with A. Albert (Aachen).

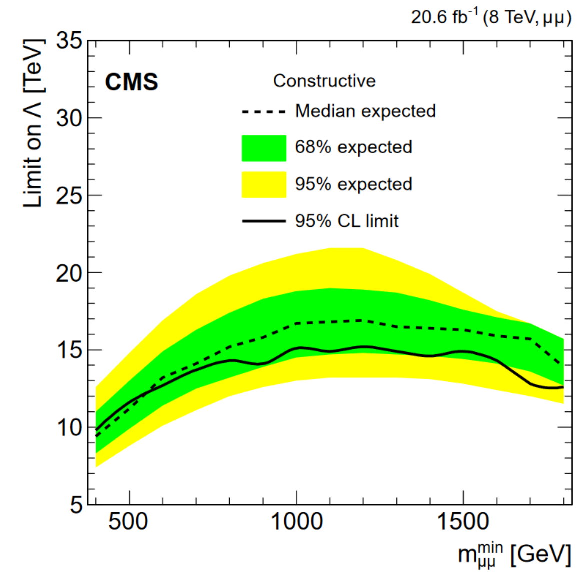
Dark Matter

- Limits using the ICHEP 2016 dataset are translated into the Mediator-Dark Matter mass plane.
- In case of large lepton couplings, the di-lepton analysis excludes large portions of the parameter space. Mediator masses below 2.5 − 3.4 TeV are excluded, depending on the Dark Matter mass.
- For small lepton couplings, the di-lepton analysis has a more moderate impact and sets limits up to 1.2 TeV.
  - This new interpretation was presented at the LHCP 2017



Contact Interactions

- One of the models leading to a non-resonant signature in the di-lepton mass spectrum is a four-fermion contact interaction.
- The defining model parameters are the energy scale of the contact interaction Λ and the couplings to left- and right-handed fermions, governing the interference with the Standard Model Drell-Yan process.
- My group is collaborating with L. Spiegel and S. Zaleski to update the existing CMS result on 8 TeV data with the 2016 dataset.
- This interpretation is being integrated into the Z' statistics framework to allow direct access to results from the resonance search for easy exchange of information.
- The use of angular information to improve the sensitivity of the search to the contact interaction signal is being studied.



Outlook and Plans

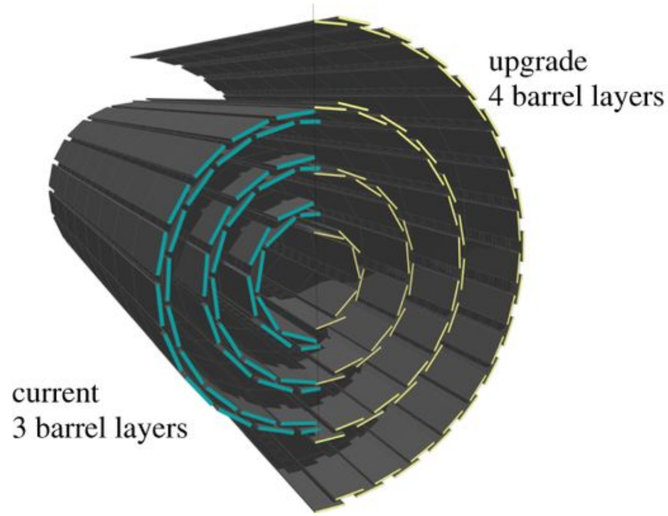
- The Z' analysis of the 2016 dataset will be finalized in the near future and a publication of these results, including the new interpretations, is targeted for the fall 2017.
- In the coming months, we will further explore additional signals and interpretations to maximize the use we make of the existing data.
- This includes studying the feasibility of extending the simple search in the di-lepton invariant mass spectrum by making use of the angular distributions of the leptons for certain models.
- These new developments will take into account not only the existing 2016 dataset but also the newly recorded 2017 data, to the analysis of which we will be contributing.
- The LPC has become a key place for the interpretation of di-lepton searches!

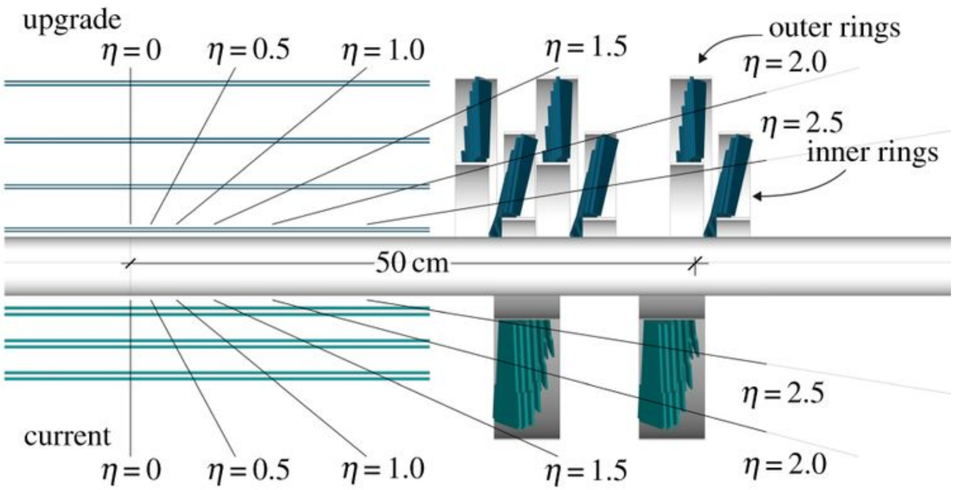
HLT Tracking

- The Purdue group made major contributions to the production and testing of the Phase-I pixel detector.
- A large group of people from FNAL has been working on various aspects of the Phase-I pixel detector.
- Add a new component to the ongoing LPC activities: High-Level Trigger (HLT) tracking with new pixel detector
  - In the context of the LPC Run 2 lepton and trigger discussion group
- The HLT uses a fast version of the offline reconstruction software in order to utilize more complicated physical objects.
- To speed up reconstruction one can request sub-detector data from regions of the detector which are of interest.
  - E.g.: a specific window in the silicon detector where there may be a muon may have interacted.
  - Strip clustering: OnDemand

Phase-I Pixel Detector

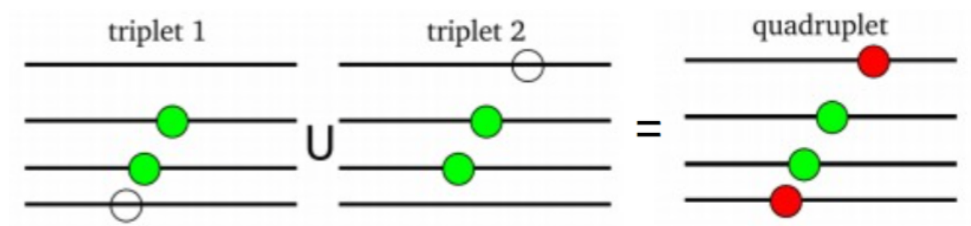
- A new pixel detector has been installed during this EYETS
  - Innermost layer closer to the beam pipe
  - New readout chips to cope with high rates
  - Large impact on tracking performance, both offline and at HLT
  - Additional fourth layer in the barrel and third FPIX layer helps to increase efficiency and suppress fakes at the same time
- Tracking setup at HLT needs to be adjusted
  - Good opportunity to apply new ideas and techniques





HLT Tracking

- The tracking algorithm in the CMS High-Level Trigger (HLT) had to be adapted to make use of the improved detector.
- Changes were made mostly to the track seeding, following the example of offline tracking.
  - New seed finding algorithm (Cellular Automaton), is faster and reduces fake rate
  - Switch from pixel hit triplets and doublets to pixel hit quadruplets and triplets as track seeds



iterative tracking in run2

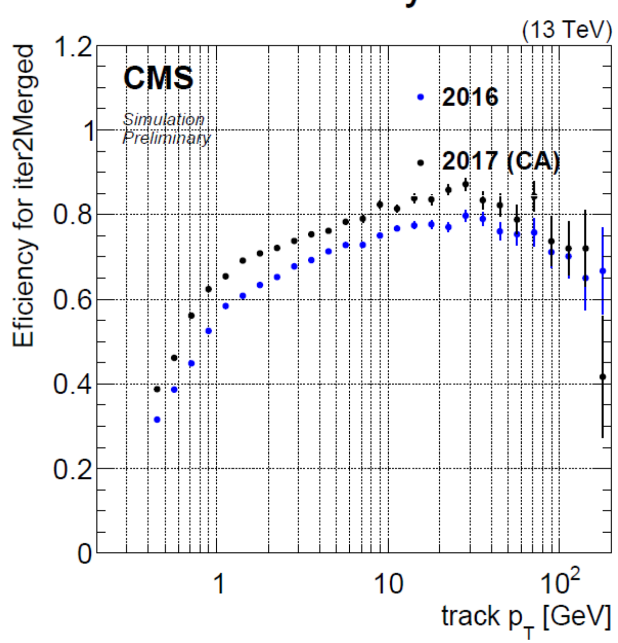
N	Step Name	Seeding	Target Track
0	iter0	pixel tracks	prompt, high p_T
1	iter1	pixel triplets	prompt, low p_T
2	iter2	pixel pairs	high p_T recovery

N	Step name	Seeding	Target Track
1	iter0	pixel tracks (from Quadruplets)	prompt, high pT
	iter1	pixel quadruplets	prompt, low pT
3	iter2	pixel triplets	hight pT recovery

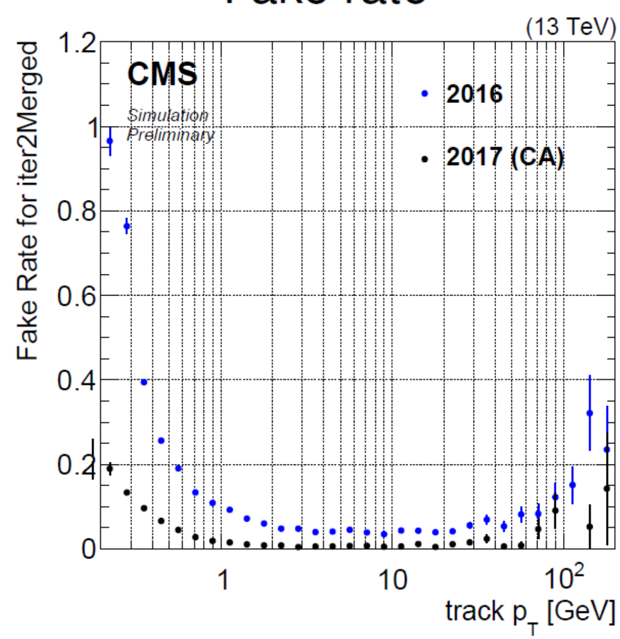
Performance with ideal Detector

- Algorithm tuned for best performance, in collaboration with the Tracking POG (M. Tosi, M. Kortelainen, V. Innocente, M. Rovere and F. Pantaleo).
- Significant improvement in efficiency compared to 2016 performance – with an ideal detector simulation!
- Fake rate drastically reduced due to the additional hits used in the track seeding.

Efficiency

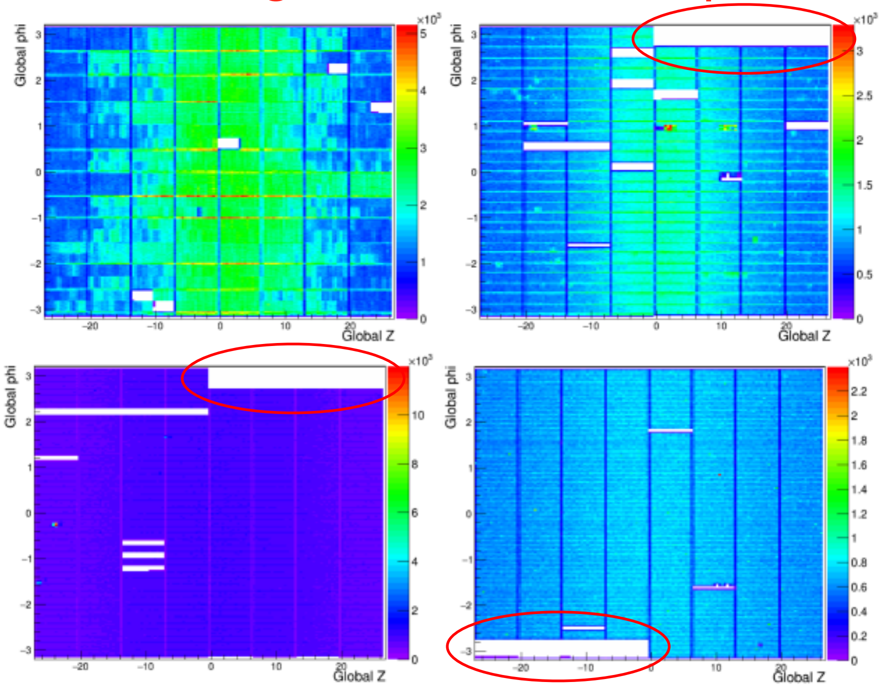


Fake rate

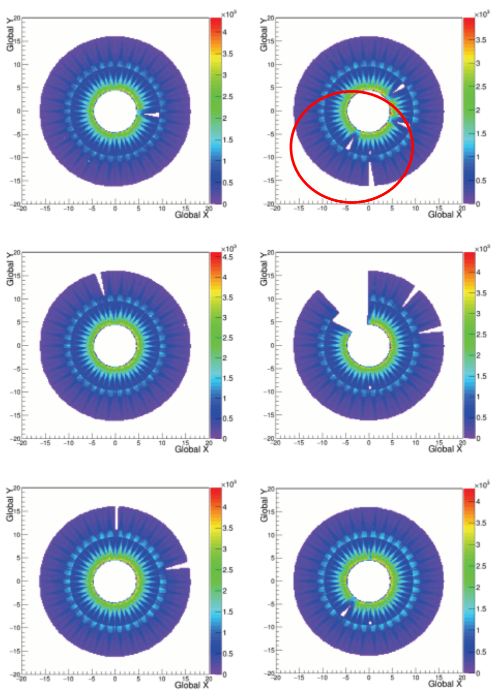


Performance of the new Pixel Detector

- Commissioning of the new detector is ongoing. A lot of work is going into understanding all its features under real world conditions
  - The new detector is by now well aligned
  - Timing, Gain and other calibrations are being finalized
  - Mitigation for observed problems is in progress

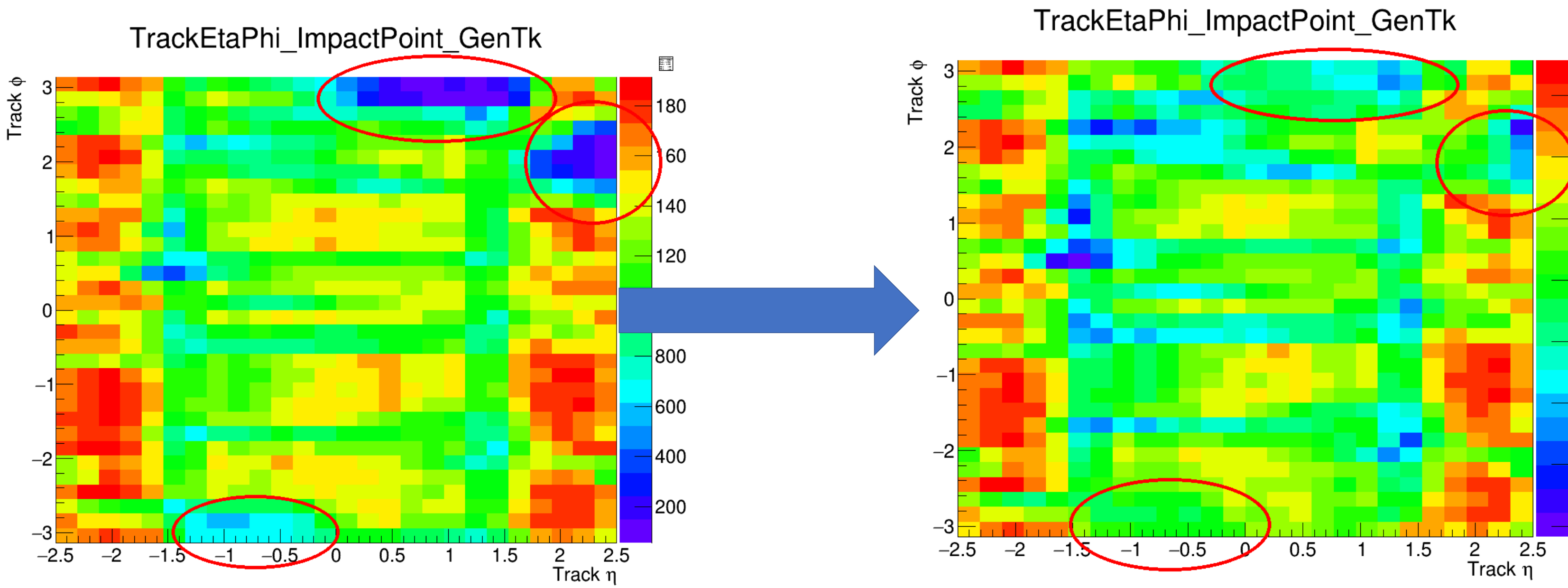


- Final detector has 95.08% active channels in the barrel and 96.16% in the endcap region.
- 4 larger regions of non-functioning modules due to powering or read-out failures → have noticeable impact on tracking performance.

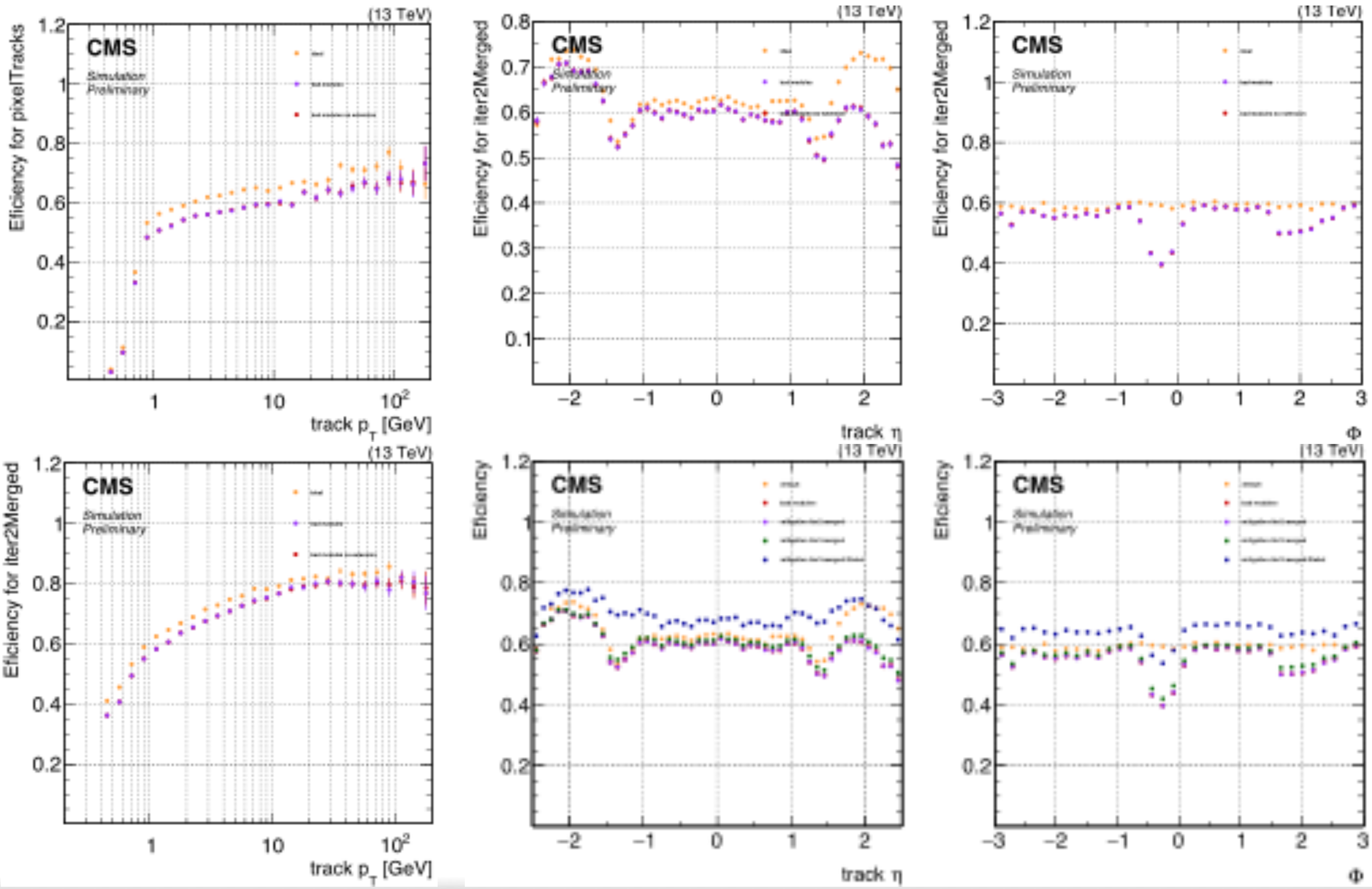


Mitigation for non-working modules

- Larger regions of non-working modules, in one case correlated in two consecutive layers, degrades tracking performance.
- Visible in track occupancy maps.
- Introduce dedicated tracking in this regions allowing for less hits in the track seeds. Recovers most of the lost efficiency.
- Configuration prepared on simulation and then adapted for effects observed in the real detector.



Performance



New Level-3 Muon Trigger

- A new L3 muon reconstruction (Iterative Muon L3) has been implemented, aiming to:
  - Improve the performance (efficiency vs time).
  - Needs to be robust against the challenging Run2 conditions.
    - Allowing it to be used also for special signatures such as close-by muons or displaced signatures.
  - Simplify the code to make it easier to debug any problem.
  - Reduce the amount of unnecessary code duplication: as we make full use of the iterative tracking code.
    - Tracking code has improved since Cascade was created and this has not translated to the L3
- This new development is mandatory due to the installation of the new Pixel detector (new geometry).
- Strategy: New L3 reco = OI + IO algorithm

LPC Service

- Help the LPC community with the following contributions:

- Facilitator for short (Muon) and long (Mono Higgs) exercise at the CMSDAS, January 2017
- Muon Hands-on Advanced Tutorial Session (HATS), June 2017
- Leadership in Run 2 discussion group on Trigger/Lepton

- Help to keep the LPC a vibrant place to do physics.

Summary

- I started a collaboration with the FNAL group (L.Spiegel, P. Bhat), Wayne State (P. Karchin, S. Zaleski, S. Jared) and Aachen (M. Radziej, A. Meyer, T. Pook) to unify the various di-lepton analyses.
- My group developed a new software framework for the interpretation of di-lepton searches.
- The LPC has become a hub for the interpretation of di-lepton searches.
- I added a new component to the ongoing LPC activities: High-Level Trigger (HLT) tracking with new pixel detector.
- I help the LPC community with CMSDAS, HATS, Run 2 discussion group on Trigger/Lepton, etc.