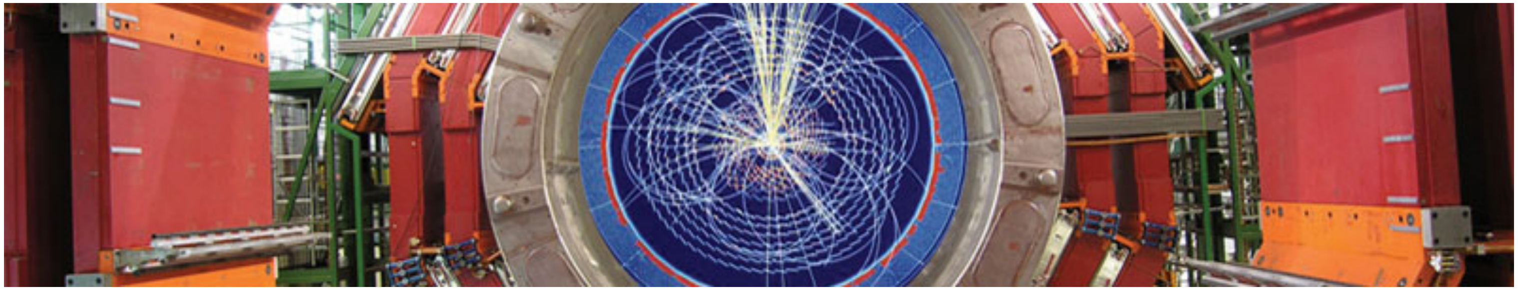
Boosted Signature



Hwidong Yoo
Seoul National University

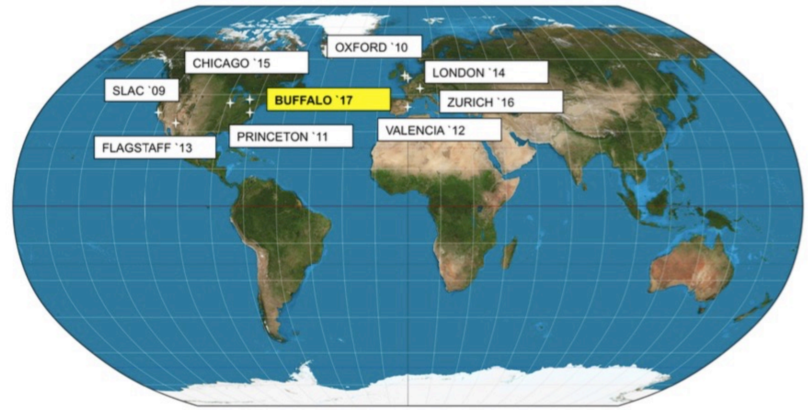
Diboson physics at LHC, September 14th 2017

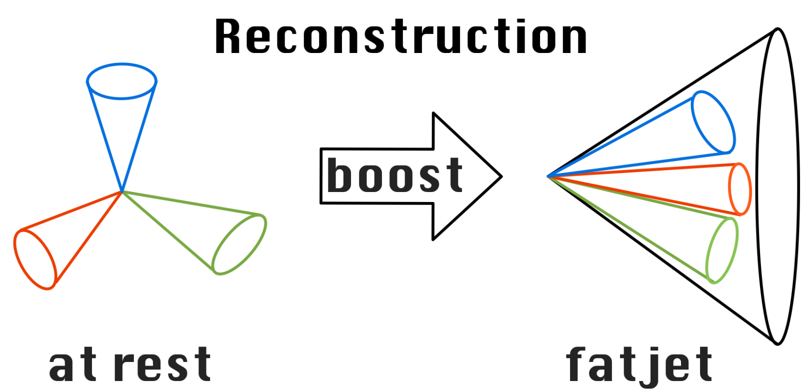
Introduction

- Boosted objects are being discussed popularly because
  - At LHC, we search a new particle with various senarios, mostly related to high mass
  - With the high mass scenarios, a boosted signature in the final state may occur
- In the boosted case, our standard object identification may not work properly and the collimated objects by the boost can be merged in reconstruction process
  - This merged case will result in significant inefficiency for our selection
  - We need a different treatment for the boosted objects

Efforts for the Boosted Signature

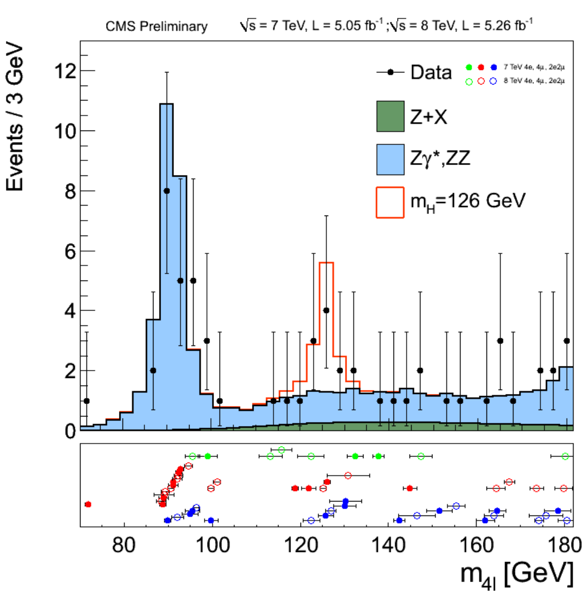
- There is dedicated workshop to discuss the boosted signature for both theory and experiment
  - A lot of efforts are on-going to discuss the treatment of the boosted signature
- Most of efforts are based on jets
  - Jet substructure, fat-jet
  - t/b-tagging
  - W/Z-tagging
  - H-tagging
  - Etc.
- But don't we need special treatment for boosted leptons?

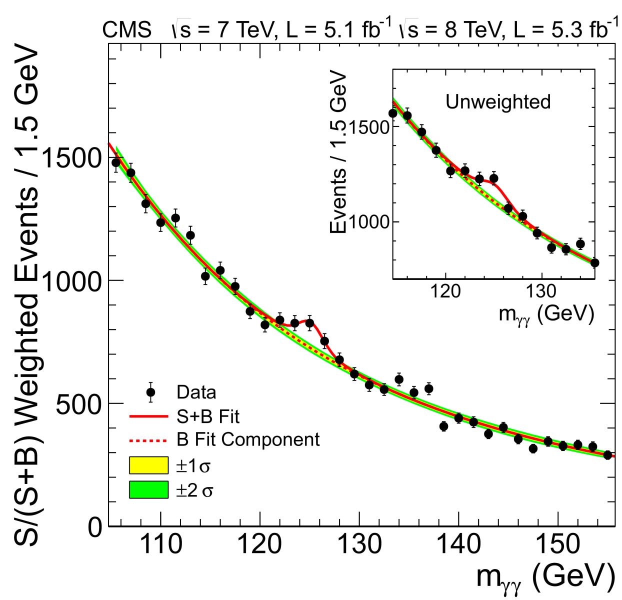


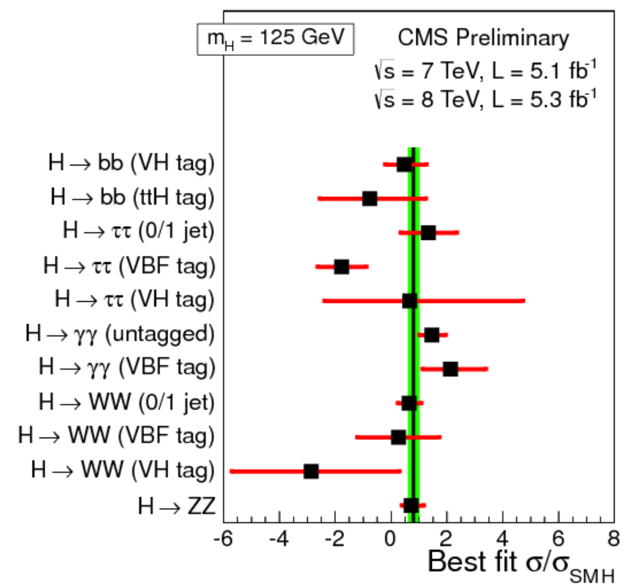


Why Leptonic Channel?

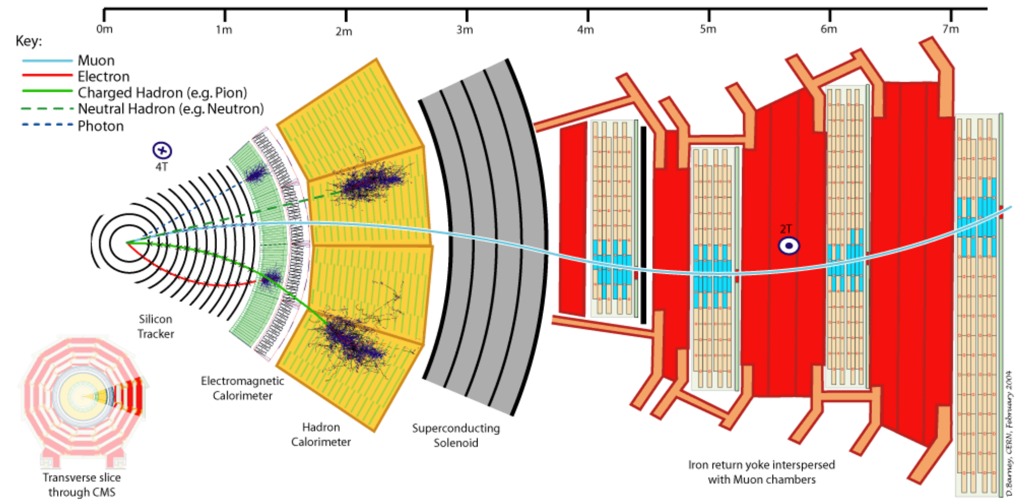
- Provide relatively clean signal
  - Suppress backgrounds from QCD process
  - Misidentification rate is low
  - Provide good resolution
  - Less significant impact from high pile-up
- Uncertainty of lepton reconstruction and identification is significantly lower than other physics





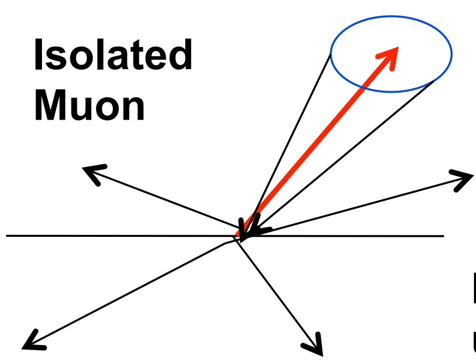


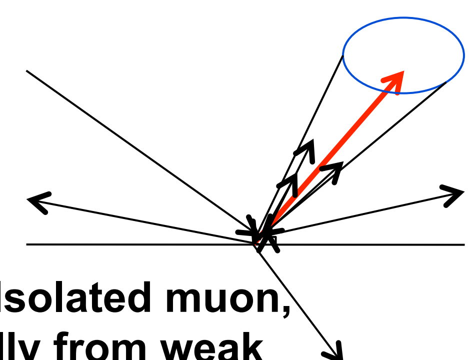
Muons in Boosted Signature



- Muon is reconstructed using silicon tracker and muon chamber
- Silicon tracker provides sufficient power to distinguish two collimated muons with narrow angle
- One problem can happen on isolation
  - We can easily identify 2nd muon and remove the activity in isolation definition

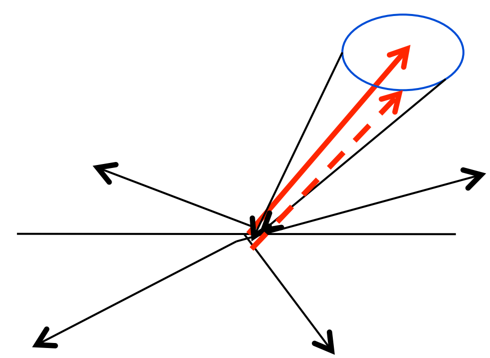
Isolated Muon





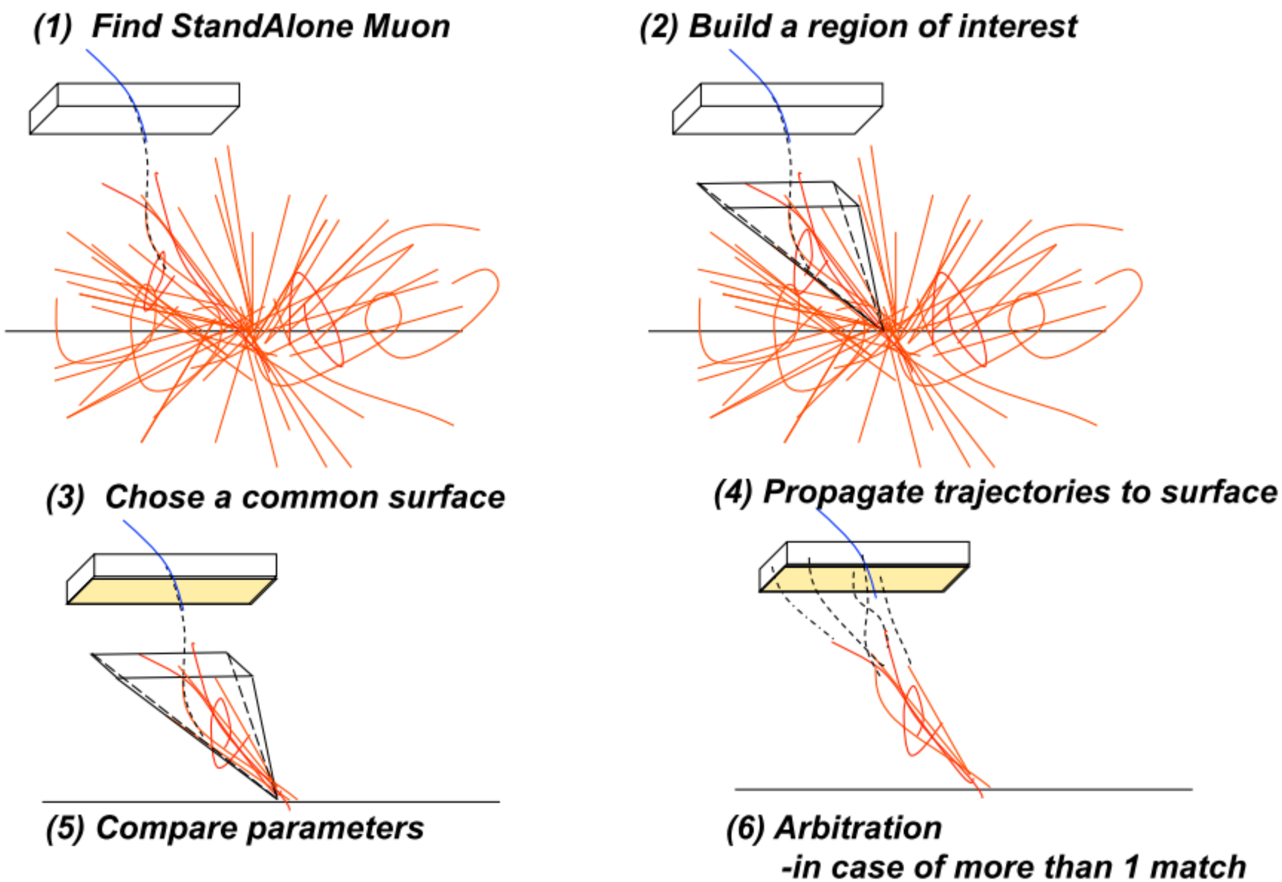
Non-Isolated muon, usually from weak decay inside a jet

Boosted muons



Muons in Boosted Signature

- Another problem is that we can have only one STA muon
  - We can accept one global muon and one tracker muon



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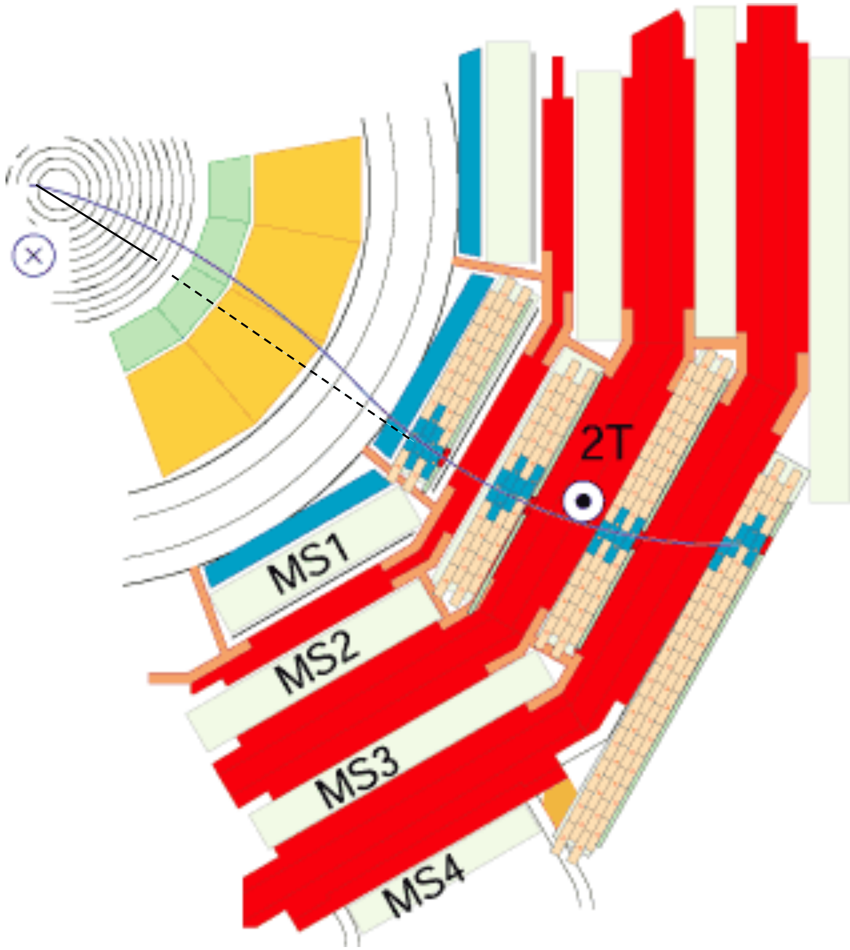
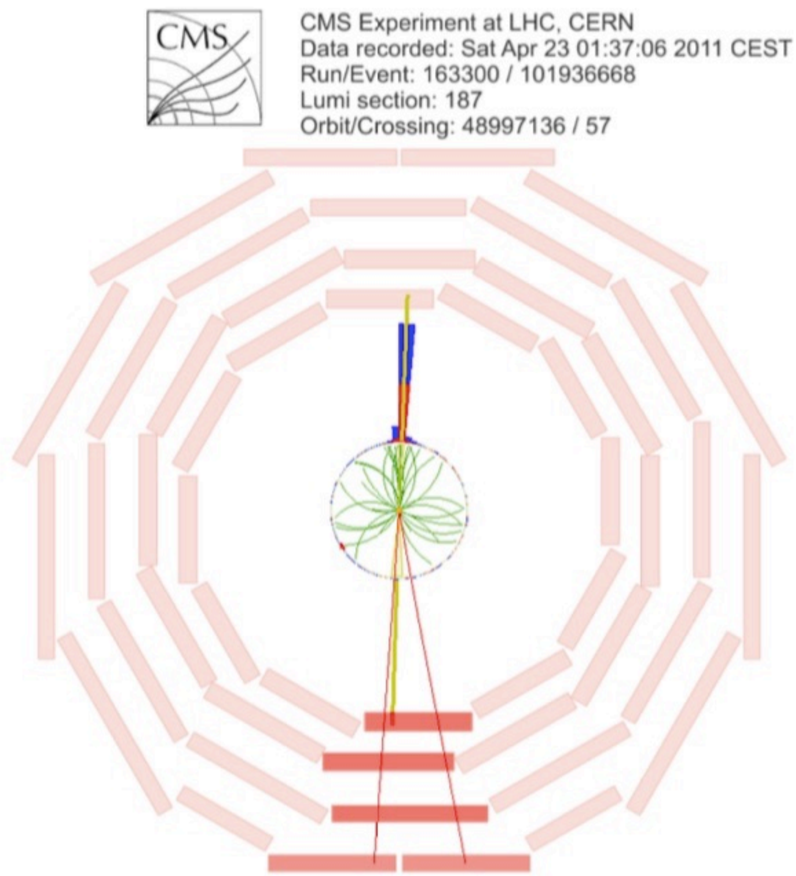
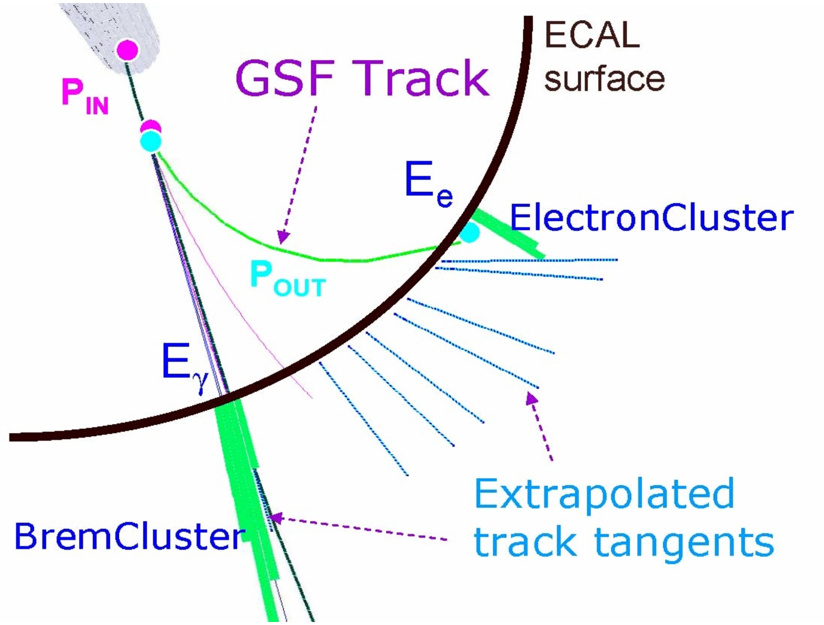
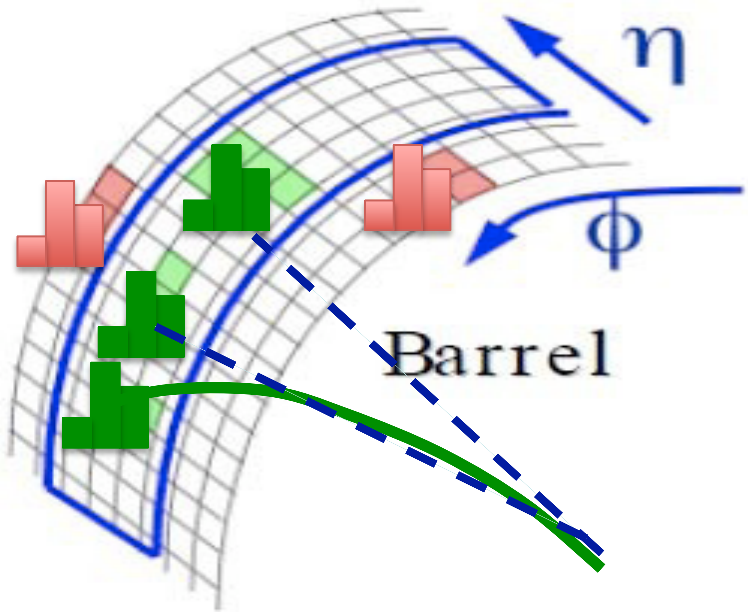




Electrons in Boosted Signature

- Feature is much more complicated than muons
- Clustering is necessary to reconstruct electrons (photons are same situation)
  - Collimated electrons (photons) by boosted signature can be merged in the clustering procedure!

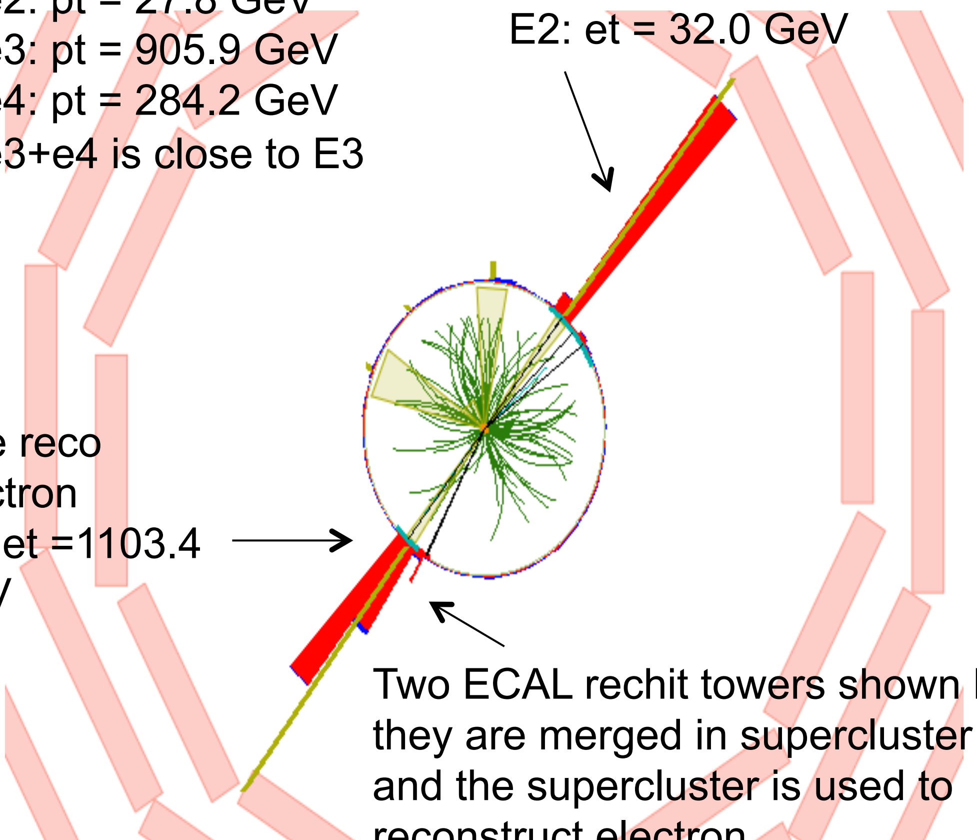




Example of Merged Electron

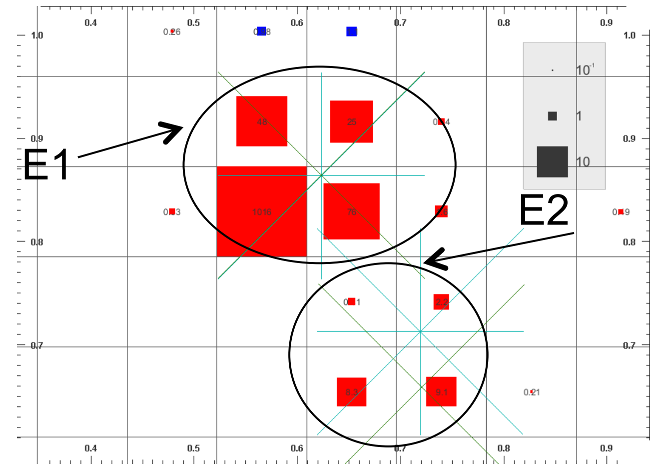
MC truth tracks
e1: pt = 1162.0 GeV
e2: pt = 27.8 GeV
e3: pt = 905.9 GeV
e4: pt = 284.2 GeV
e3+e4 is close to E3

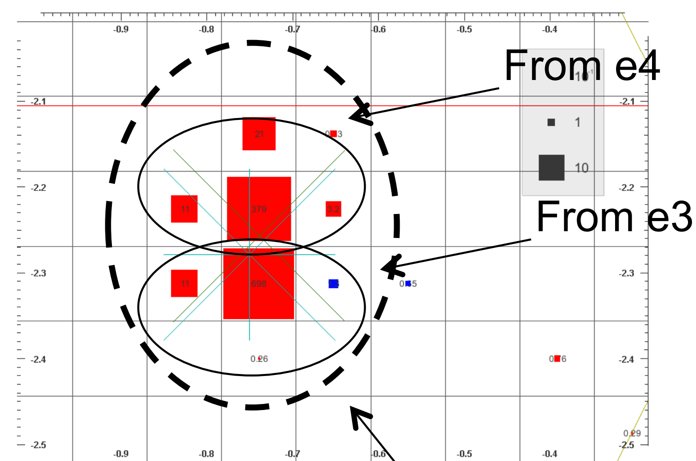
Two reco electrons
E1: et =1146.2 GeV
E2: et = 32.0 GeV



One reco electron
E3: et =1103.4 GeV

Two ECAL rechit towers shown but they are merged in supercluster and the supercluster is used to reconstruct electron

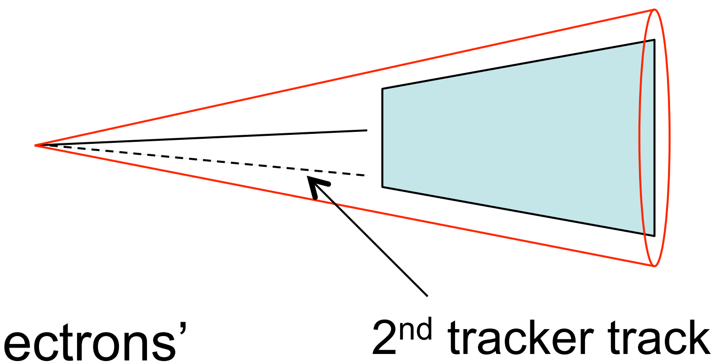




Reconstructed E3

Treatment for Merged Electron

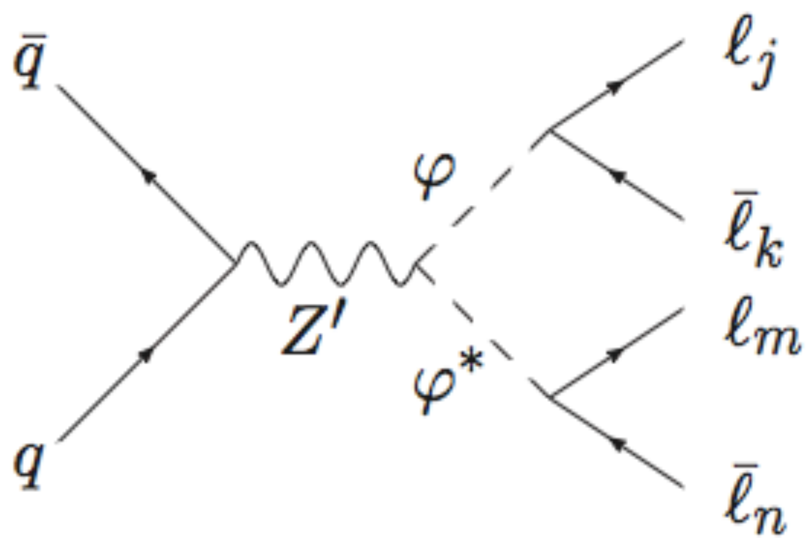
- How to resolve this problem?
  - Simplest way is to find 2^{nd} tracker track (called gsf track) nearby the electron
  - Another useful information is E/p of electron because E includes both electrons' activity but p contains only one electron's



- At 8 TeV, for search for leptophobic Z' decaying into four leptons, we use this treatment
  - CMS-PAS-EXO-14-006, accepted by PLB
- At 13 TeV, we are trying to apply advanced MVA technique (BDT, ANN) to improve the performance on the merged electron identification
  - Talk ("Merged Electron Identification") by Kyoungpil Lee, Friday 14:20
  - Talk ("Search for H/Z'→4l at 13 TeV") by Joon Bin Lee, Friday 14:40

Search for Z' → 4l

- A baryonic Z´ resonance model
  - *V. Barger, H.S. Lee, Phys. Rev. D 85, 055030 (2012)*
  - Z´ decays into two new scalar particles and they decay into leptons
  - This model allows a 4-lepton Z´ resonance without having a corresponding dilepton signal
- Use as benchmark signal model in this analysis

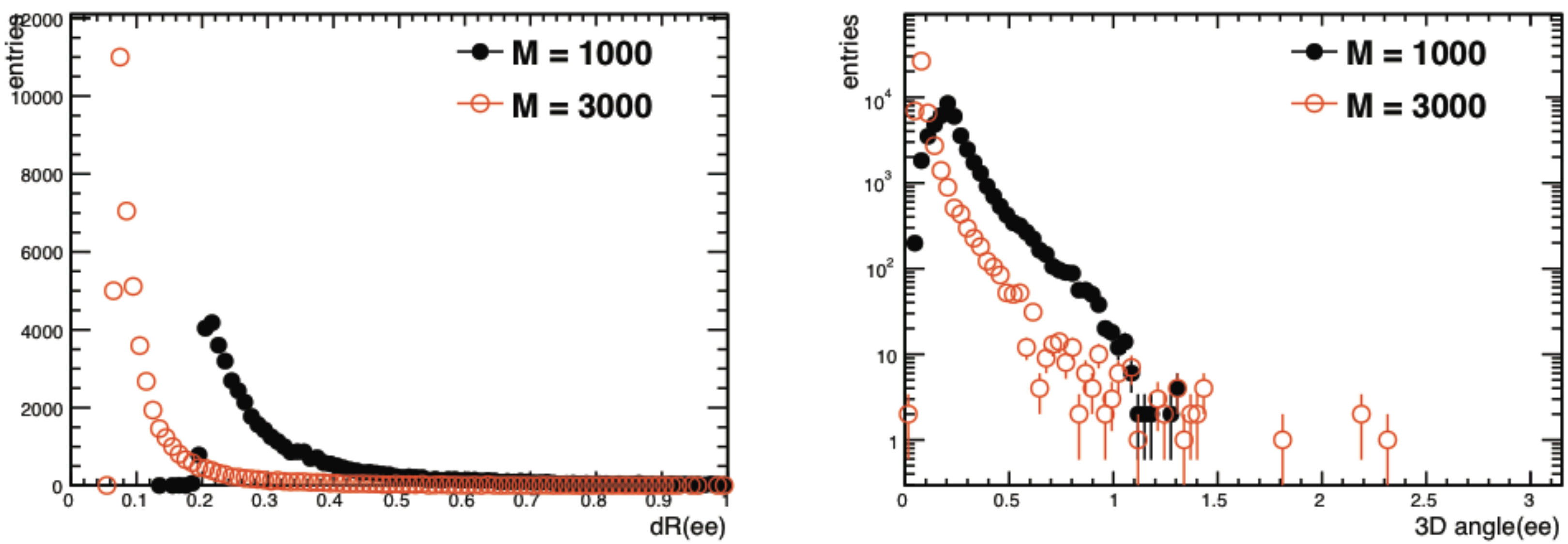


Analysis Strategy

- Classifiy five different channels: μμμμ, μμμe, μμee, μeee, eeee
- Dataset
  - 2012 full 8 TeV dataset: 19.7/fb
  - Benchmark signal MC is produced
    - Model files provided by authors of theory paper
    - Use for event selection and efficiency studies
- Recover inefficiency of detector performance caused by boosted signature
  - Merged electron identification
- Background estimation
  - Negligible SM backgrounds are expected in high mass region
  - Study with both data-driven approach and MC prediction
- Limit calculation
  - Results on individual channel and the combination of all channels

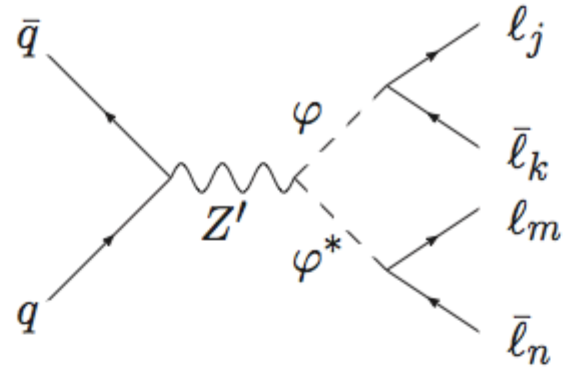
Benchmark Signal Modeling

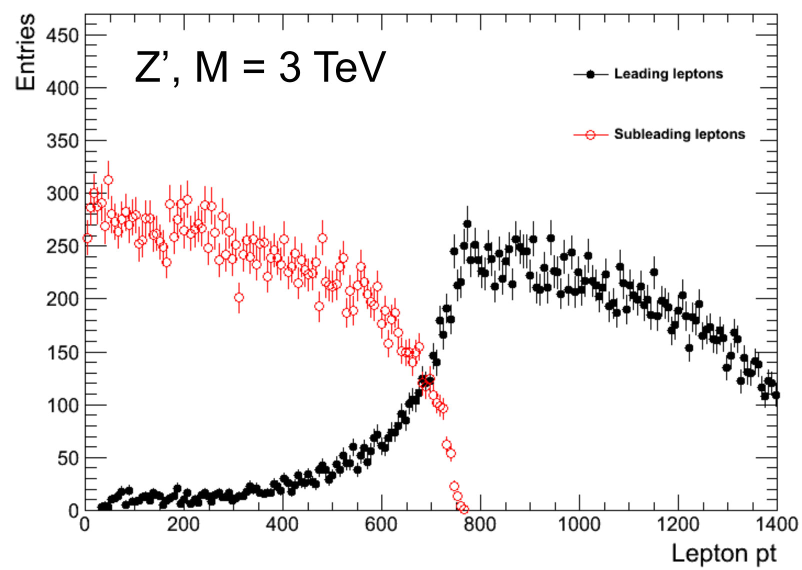
- Generate 12 mass bins (12000 events each) for expected limit calculations: M = 250-3000 GeV with 250 GeV bin size
  - Generator: CalcHep 3.4.1 + PYTHIA
  - Use Full-Sim in CMSSW environment
- Assumptions on the intermediate particle (Φ)
  - Mass: M(ϕ)=50 GeV sample is used as a default (intro. Boost sig.)
    - 5%/10%/20%/30%/40% of M(Z') ➔ 5 more M(ϕ) scenarios



Event Signature

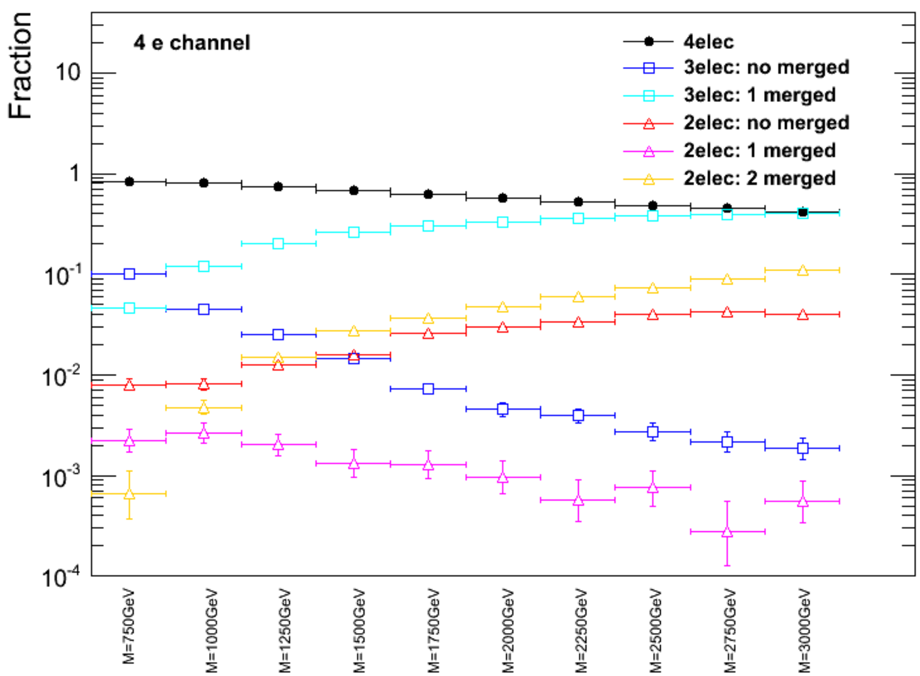
- Similar kinematics across all five channels
  - Two leptons from same parent are boosted in the same direction
  - It depends on the M(ϕ) in comparison of M(Z´)
- Two leading leptons with high p_T
  - Subleading leptons with relatively low p_T
- Apply different p_T cuts on leading and subleading leptons to maximize the acceptance
  - Leading leptons: p_T > 45 GeV
  - Subleading leptons: p_T > 30 GeV
    - Suppress fake leptons from low p_T leptons
  - |eta| < 2.4





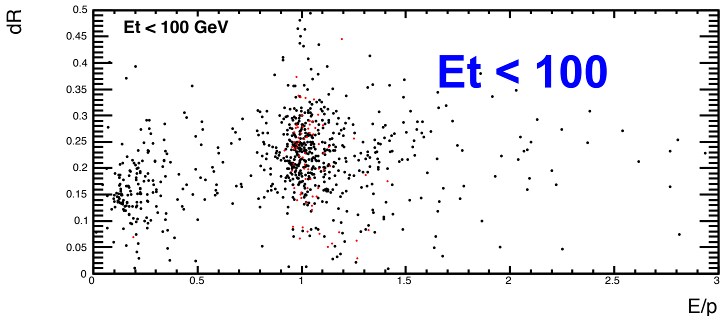
Probability of Merged Electrons

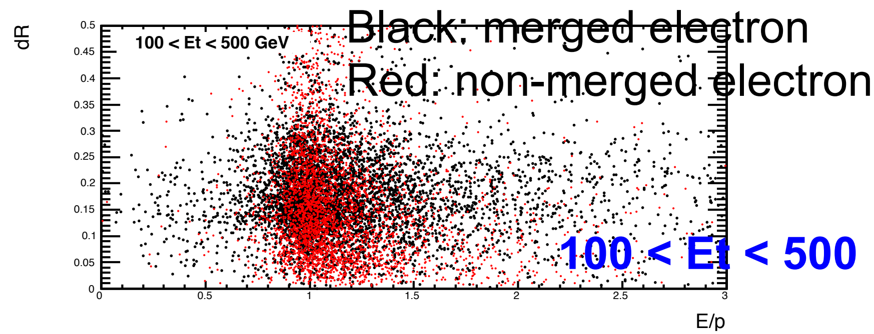
- Calculate the fraction of merged electrons
  - Fraction = events with # of merged electrons / events passing acceptance
- In most cases, the merged electron only occurs for one pair
  - The probability for two merged electrons (both pairs) will increase with mass
  - Therefore the treatment of merged electrons is important in signal region

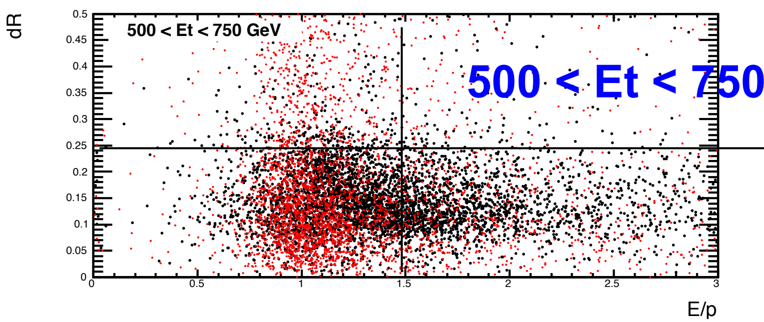


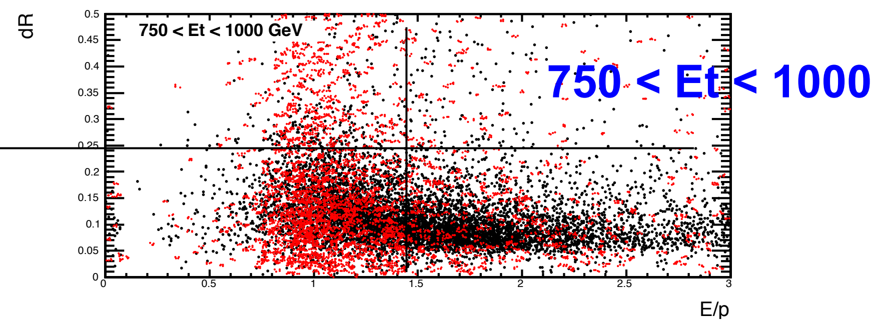
Merged Electron ID

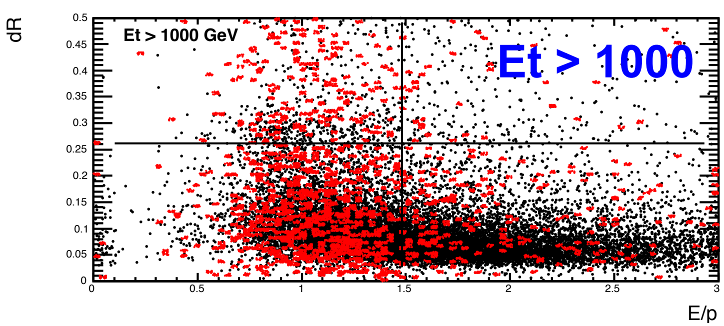
- Selection: one additional gsf track (pt > 30 GeV) in ΔR < 0.25 and E/p > 1.5 for electron E_T > 500 GeV





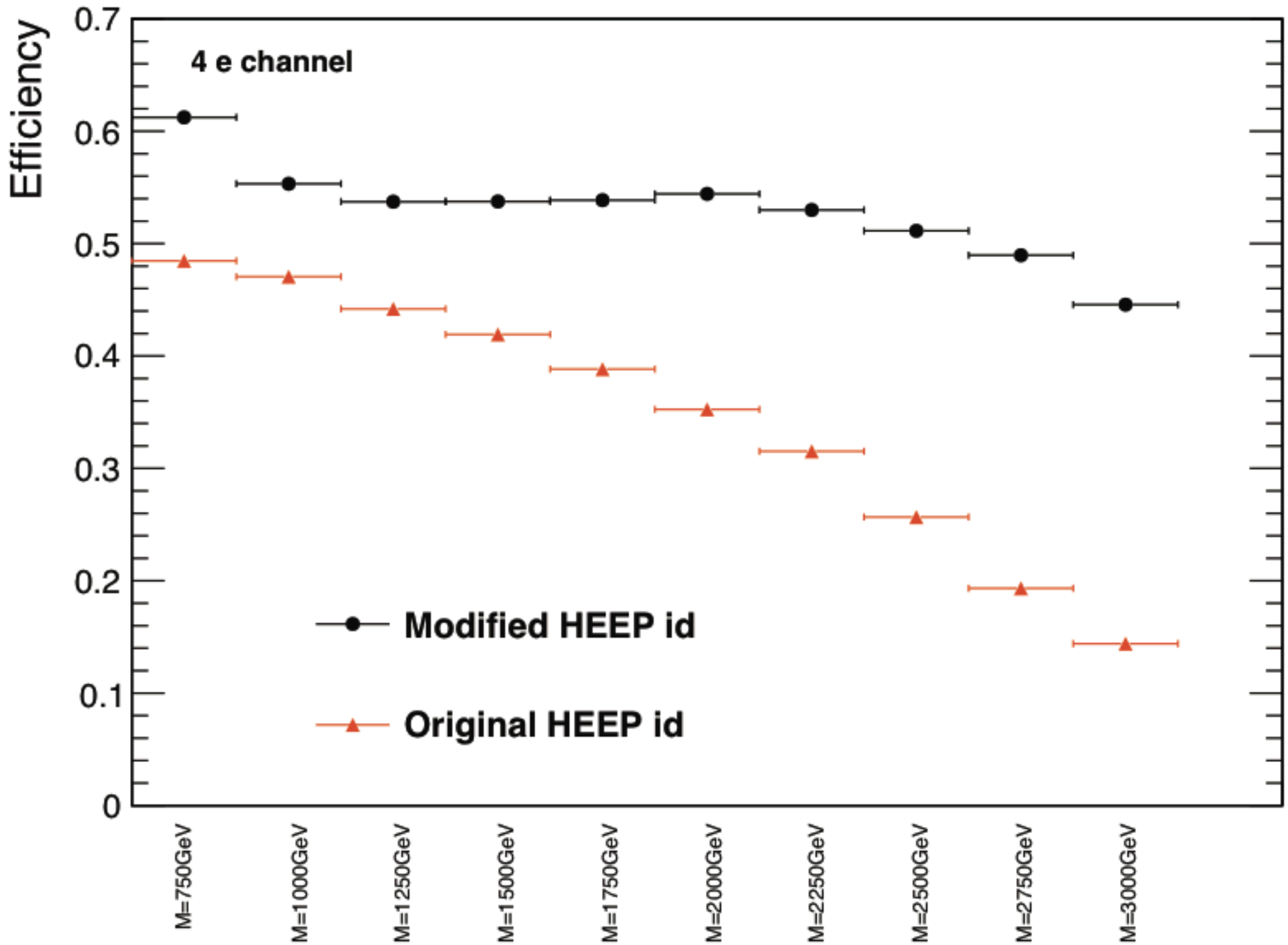




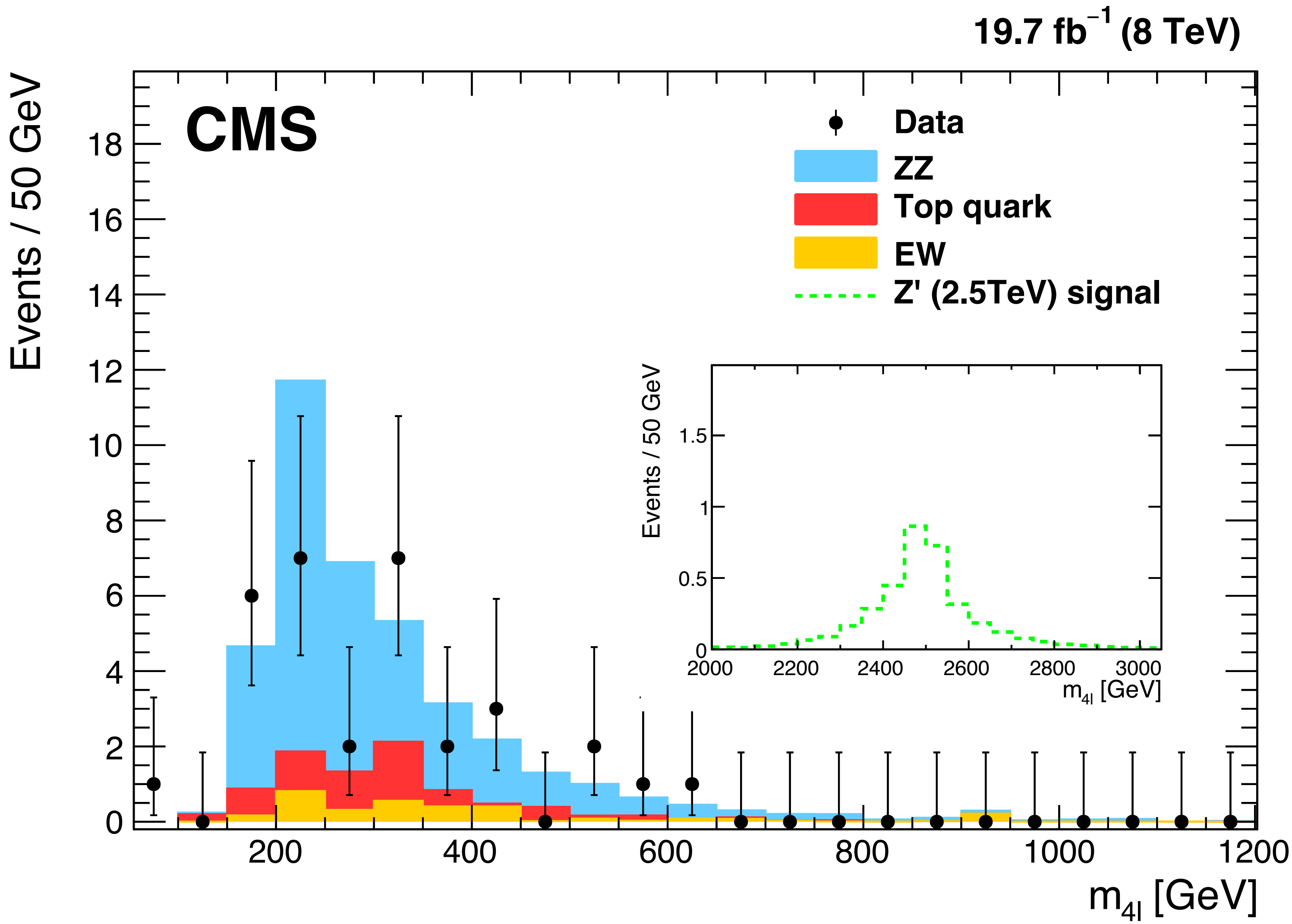


Not major contribution from the merged electron in E_T< 500 GeV
Significant contribution from non-merged electron up to E/p 1.5

Improvement by Merged Electron



Four Lepton Invariant Mass



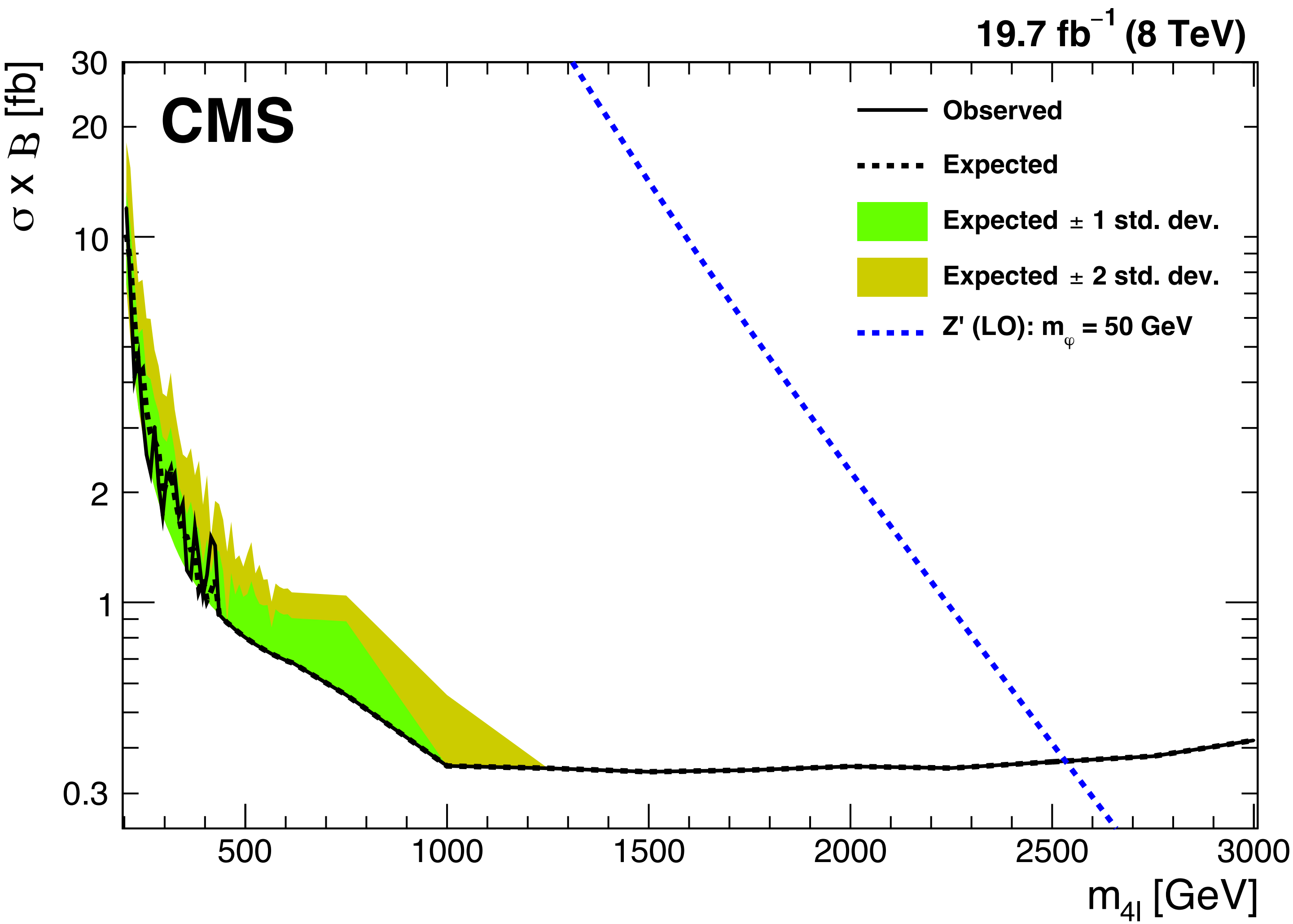
Systematic Uncertainties (1)

- Selection efficiency based on high pT muon id and HEEP id from Z' search in dilepton channel
  - Muon channel: 0.5% (id) and 0.2% (isolation)
  - Electron channel: EB (EE)
    - Below 100 GeV: 0.7% (0.6%)
    - Above 100 GeV: 1.4% (0.4%)
  - Varied 2.2% - 2.7% w.r.t. mass range and channel
  - Assign 10% for all channels to take into account the boosted effect
- Electron energy scale: 1% on the electron E_T
  - Signal: 1% for M(Z') < 1 TeV and negligible for M(Z') > 1 TeV
  - Background: 0.5% for all mass range
- Muon momentum scale: 0.2% (5%) for muon pT < 200 GeV (> 200 GeV)
  - Impact on the event yield is small (< 0.1%)

Systematic Uncertainties (2)

- Mass resolution
  - Muon channel: muon pT smearing of 0.6%
  - Electron channel: electron E_T smearing of 1%
  - Impact on the event yield is small for both channels (< 0.1%)
- Background cross section: 15% (ZZ NLO) and 3.5% (ttbar NNLO)
  - Backgrounds are very small and the limit calculation is completely dominated by statistics, we assign 30% for backgrounds.
- Luminosity: 2.6%
- Test the sensitivity of the obtained limits by assigning two times larger uncertainties and obseve a negligible change in the limits

Limit for Benchmark Model



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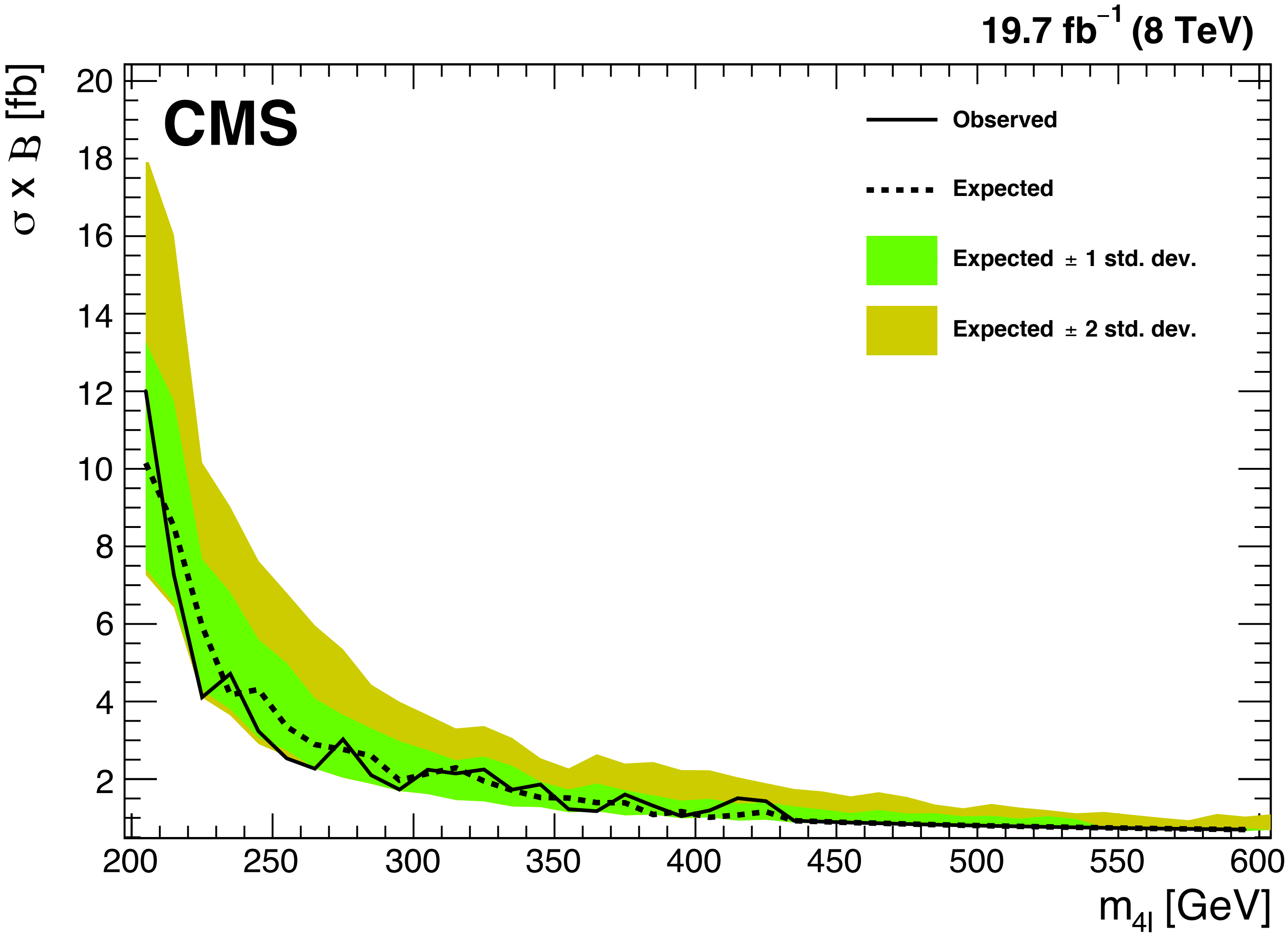

Limit: M(Z') vs. M(ϕ)

- Calculate limit using the various M(ϕ) samples

Table 2: The 95% CL lower limits (in TeV) on $m_{Z'}$ for the five separate channels and for their combination. Results are presented for the benchmark assumption $m_\varphi = 50\,\mathrm{GeV}$, and for the five different values of the ratio $m_\varphi / m_{Z'}$.

m_φ	50 GeV	$0.05 m_{Z'}$	$0.1 m_{Z'}$	$0.2 m_{Z'}$	$0.3 m_{Z'}$	$0.4 m_{Z'}$
$\mu\mu\mu\mu$	1.7	1.6	1.7	1.7	1.7	1.7
$\mu\mu\mu$e	2.0	2.0	2.1	2.1	2.1	2.1
$\mu\mu$ee	2.4	2.4	2.5	2.5	2.5	2.5
μeee	2.0	2.0	2.1	2.1	2.1	2.1
eeee	1.7	1.7	1.7	1.7	1.7	1.7
Combined	2.5	2.6	2.6	2.6	2.6	2.6

Summary

- Boosted signature is popular topic at LHC
  - But the discussion is mostly based on jets
- Boosted signature is also significant for muon and electron reconstruction and identification
  - Treatment for collimated muons is relatively easy
  - Two collimated electrons can be merged in clustering and we need a special treatment for the merged electron
- Perform a search for Z' decaying into four leptons in five channels
  - http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/EXO-14-006/index.html
  - Improve the selection for the boosted event signature
- Advanced tool for merged electrons is on-going at 13 TeV analysis