Search for Large Extra Dimensions and Compositeness in $\mu^+\mu^-$ and e^+e^- channels in proton-proton collisions at sqrt (s)=13 TeV in CMS

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Fermi Lab

Outline

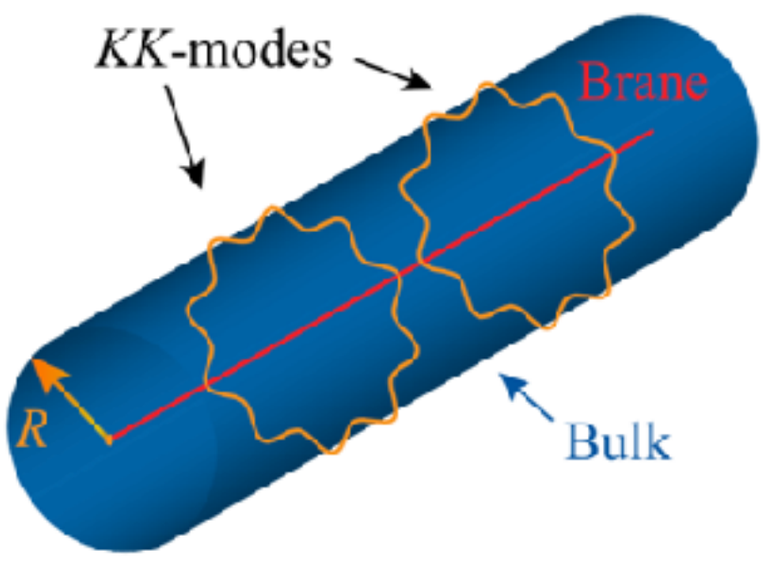
- **Motivation**
- **Large Extra Dimensions**
- **Compositeness**
- **Invariant Mass Distribution**
- **Expected Limits**
- **Summary**

Motivation

- The Standard Model of Particle Physics (SM) does not explain everything such as three generations of quarks and leptons
- Several Beyond the standard model (BSM) theories
- Large Extra Dimensions(LED) or Contact Interactions (Compositeness)
- Non-resonant enhancement of dilepton invariant mass distribution at high mass

Large Extra Dimensions

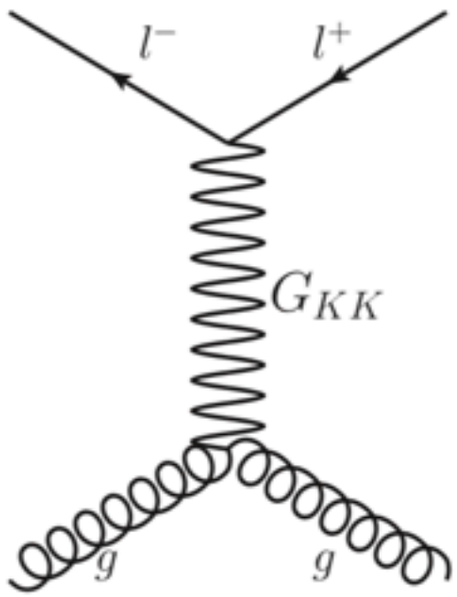
Arkani-Hamed
Dimopoulus
Dvali
MODEL

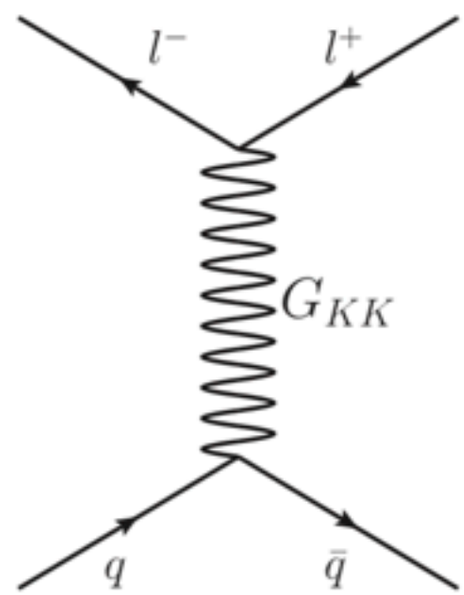


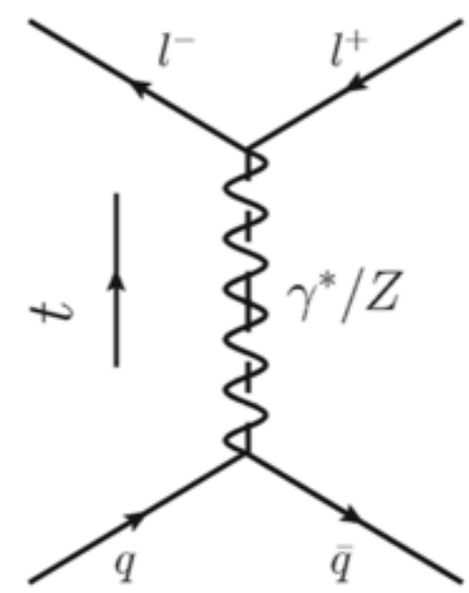
- Space-time is extended by an additional number (n) of compactified dimensions of radius R
- All standard model particles are constrained in a (3+1) space-time dimensions (the brane)
- Gravity propagates to all (n+3) +1 dimensions (the bulk)
- The new reduced (n+3) + 1 dimensional Plank scale M_D and (3 + 1) dimensional Plank scale M_{pl} are related as

$$M_{Pl}^2 = (2\pi R)^n M_D^{n+2}$$

LED Processes



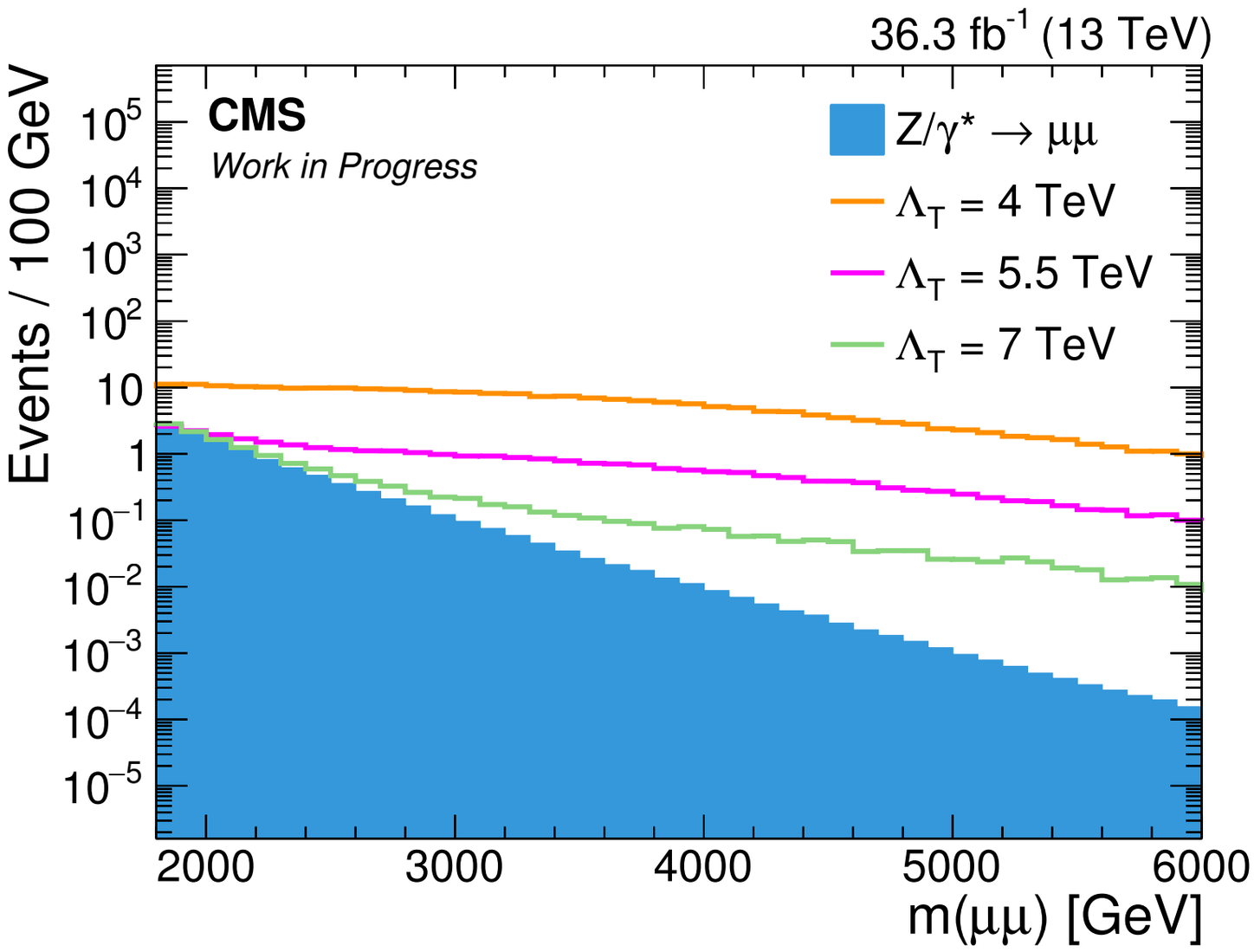




Arkani-Hamed, Dimopoulos, Dvali (ADD) scenario of Large Extra Dimensions:

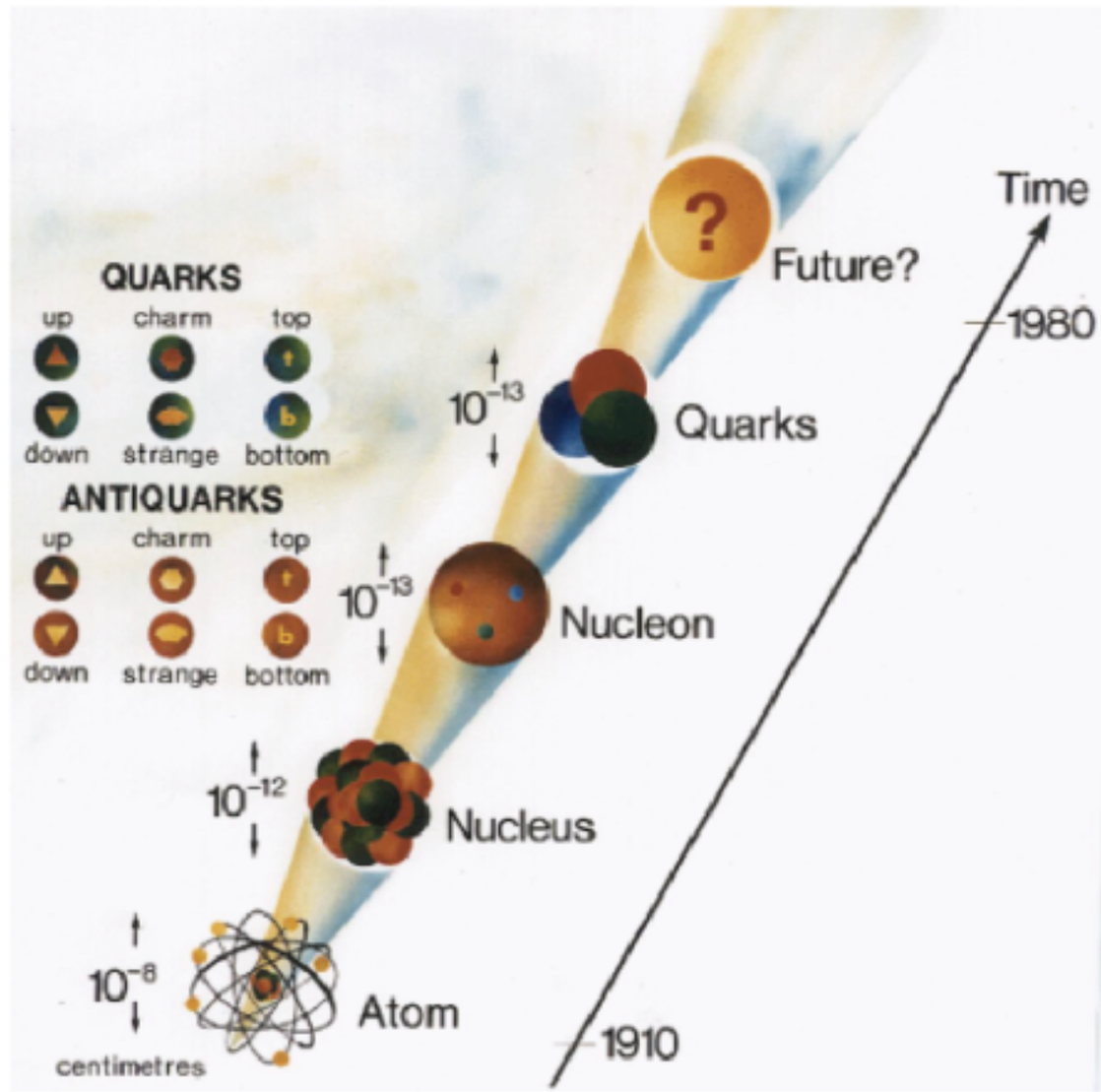
- ADD σ parameterization given by 3 different conventions
  - Guidice,Ratazzi,Wells (GRW): $\sigma_{ADD} \sim \frac{1}{\Lambda_T^8}$
  - Hewett: $M_S = \lambda \frac{\pi}{2} \Lambda_T^8$
  - Han,Lykken,Zhang (HLZ): $n > 2 : M_S^4 = \frac{2}{n-2} \Lambda_T^4$

LED Simulations



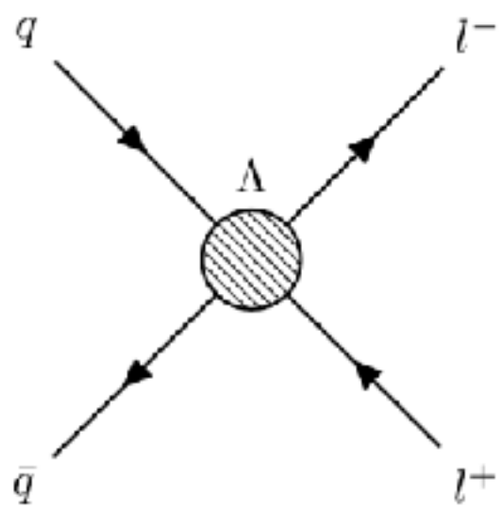
- Simulation of LED background and signal
- Signal deviates more at the higher masses
- At higher the value of Λ_T, signal converges to background

Compositeness/CI



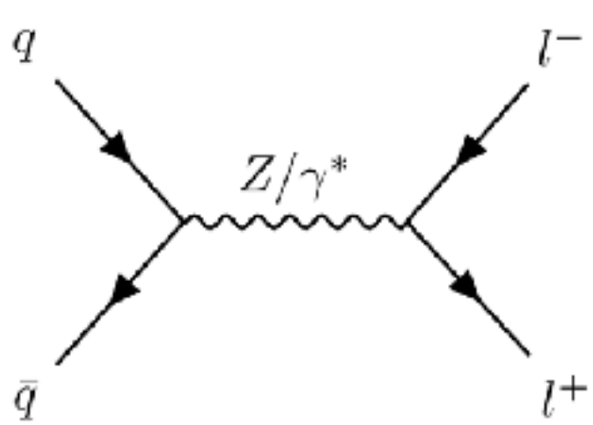
- In compositeness theories, quarks and leptons are composed of “preons”
- The “preons” interacts via a new gauge interaction called “metacolor”
- Below the interaction energy scale Λ, “preons” bind to a composite state like the quarks and leptons.

CI Processes



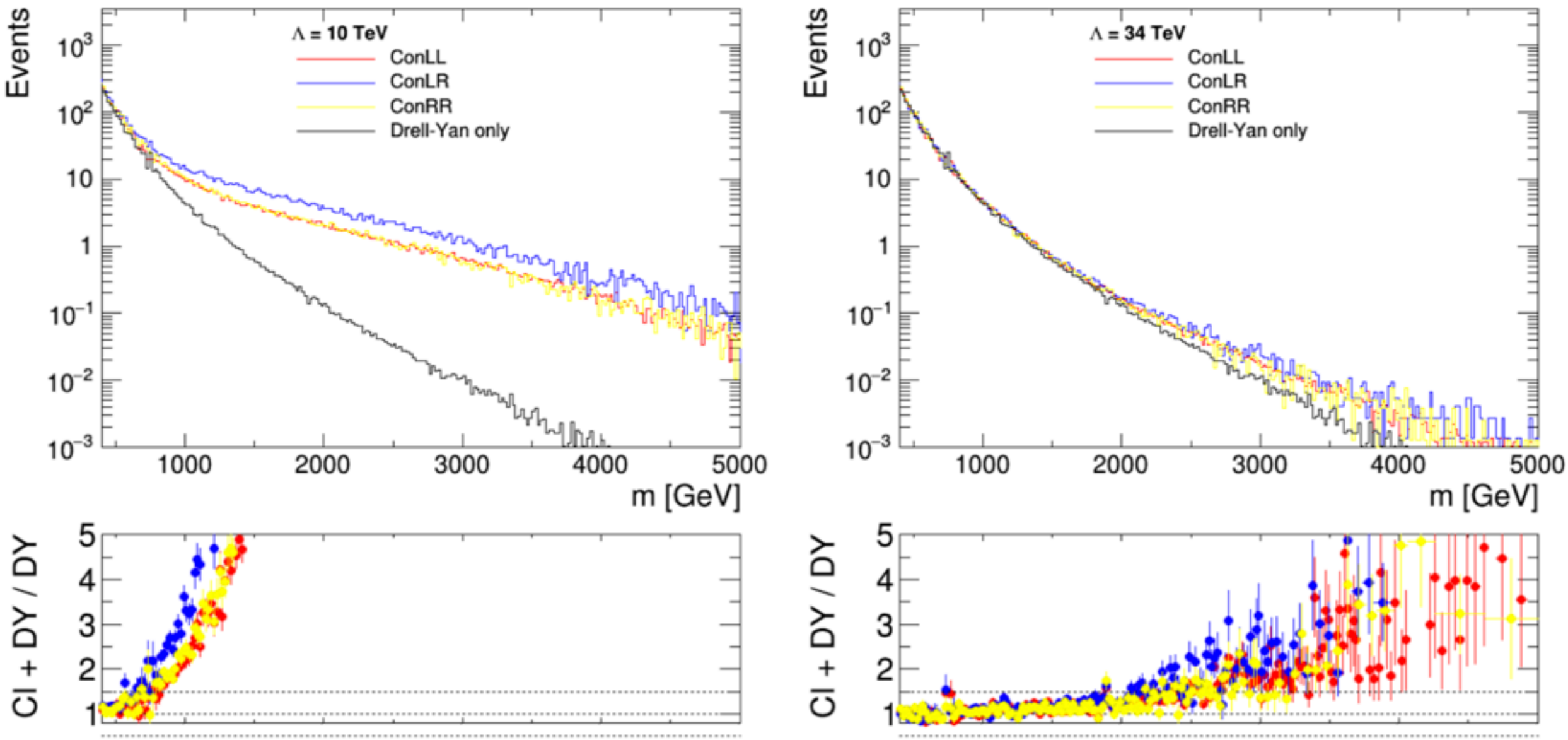
- At the energy scale, effect of Compositeness can be visible as a four-fermion contact interaction(CI).

$$\mathcal{L}_{q\ell} = \frac{g^2_{\text{contact}}}{\Lambda^2}\left[\eta_{LL}(\bar{q}_L\gamma^\mu q_L)(\bar{\ell}_L\gamma_\mu\ell_L) + \eta_{RR}(\bar{q}_R\gamma^\mu q_R)(\bar{\ell}_R\gamma_\mu\ell_R)\right.$$
$$\left.+\eta_{LR}(\bar{q}_L\gamma^\mu q_L)(\bar{\ell}_R\gamma_\mu\ell_R) + \eta_{RL}(\bar{q}_R\gamma^\mu q_R)(\bar{\ell}_L\gamma_\mu\ell_L)\right]$$



$$\frac{d\sigma}{dm} = \frac{d\sigma}{dm}(\text{DY}) - \eta_{LL}\frac{I}{\Lambda^2_{LL}} + \eta^2_{LL}\frac{C}{\Lambda^4_{LL}} \quad \rightarrow \quad \begin{cases} \eta_{LL} = -1 & \text{constructive} \\ \eta_{LL} = +1 & \text{destructive} \end{cases}$$

CI Simulations



- PYTHIA 8 implementation of contact interactions defines $LR := LR + RL$

Lepton Selection

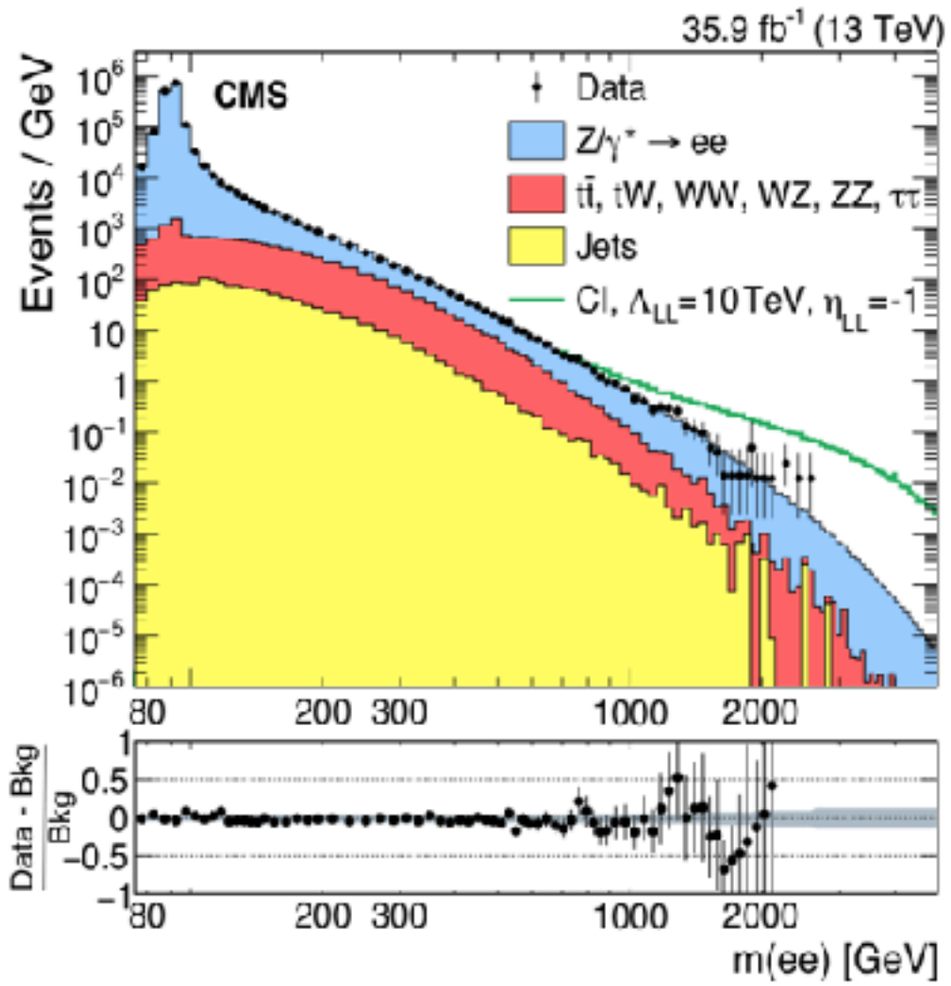
Muon selection:

Variable	Expression
Acceptance	
Muon Momentum	$p_T > 53\,\text{GeV}$
Pseudo Rapidity	$\lvert\eta\rvert < 2.4$

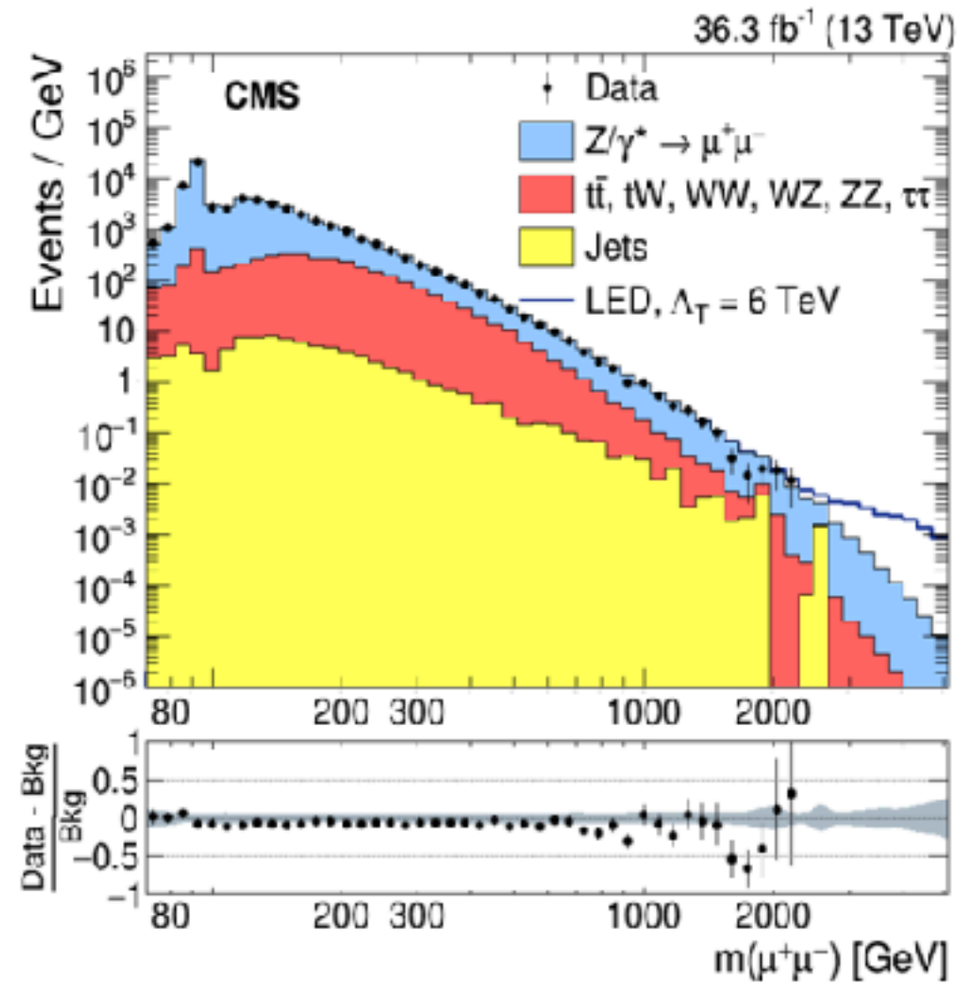
Electron Selection:

Variable	Barrel	Endcap
Acceptance selections		
E_T	$E_T > 35\,\text{GeV}$	$E_T > 35\,\text{GeV}$
η	$\lvert\eta_{SC}\rvert < 1.4442$	$1.566 < \lvert\eta_{SC}\rvert < 2.5$

Observed Mass Spectra



CI Electron pair mass spectra



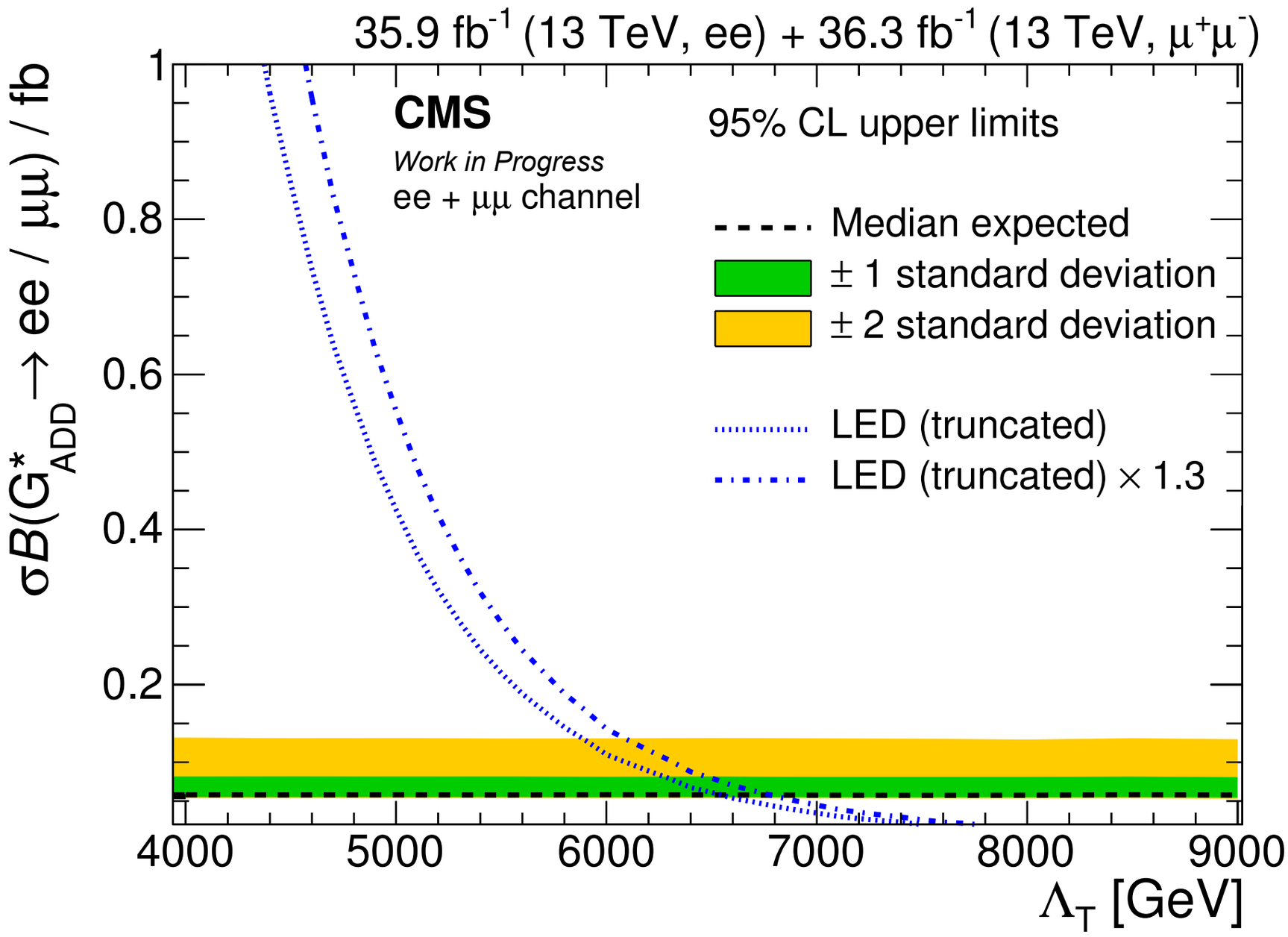
LED Muon pair mass spectra

There is good agreement between data and MC background in both dielectron and dimuon mass spectra

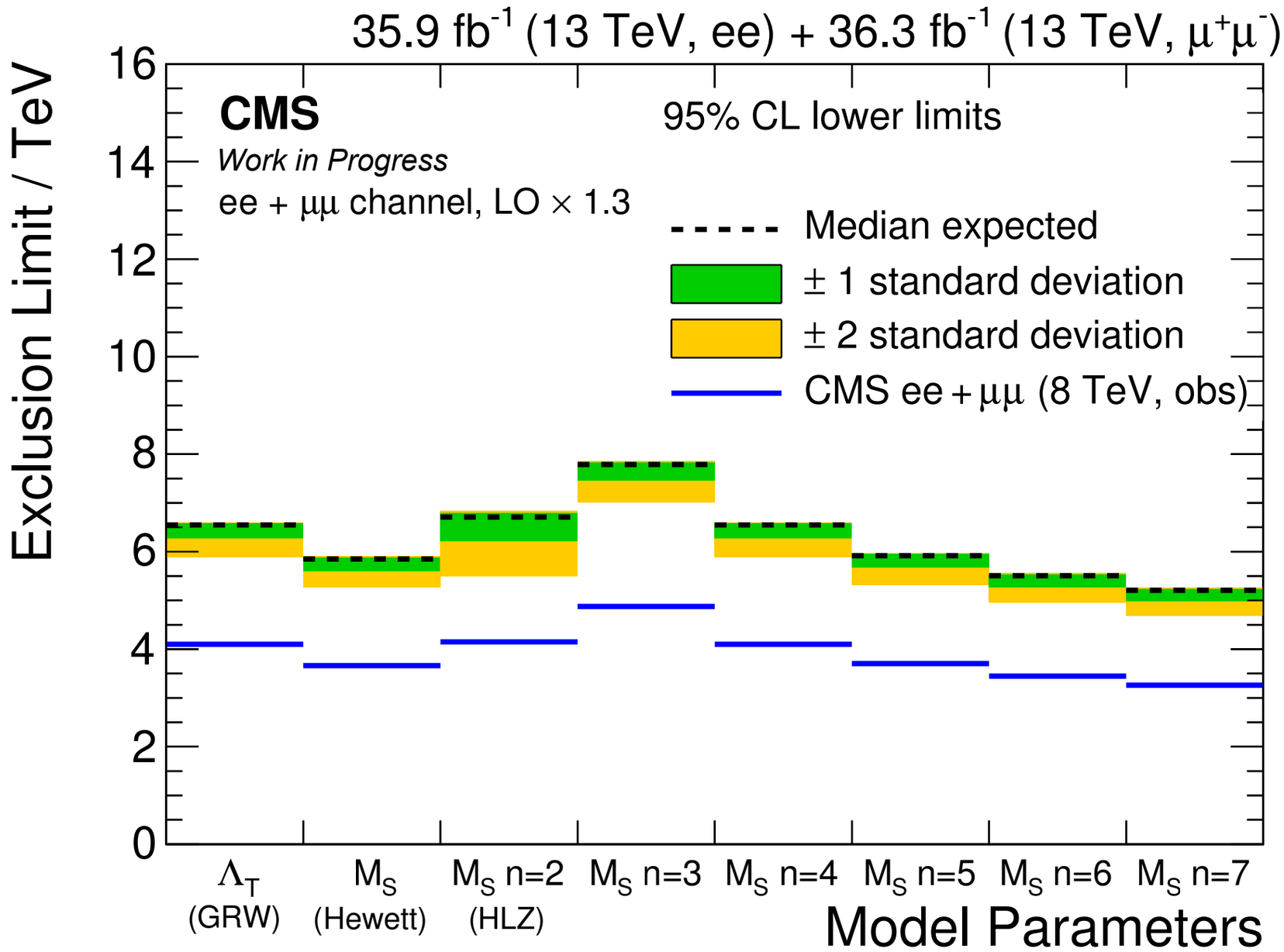
Limits Setting

- All limits are calculated using Bayesian approach
- LED limits use single bin approach
- CI limits use multi-bin limits for constructive interference
- CI limit use single-bin limit for destructive interference

LED Expected GRW Limits

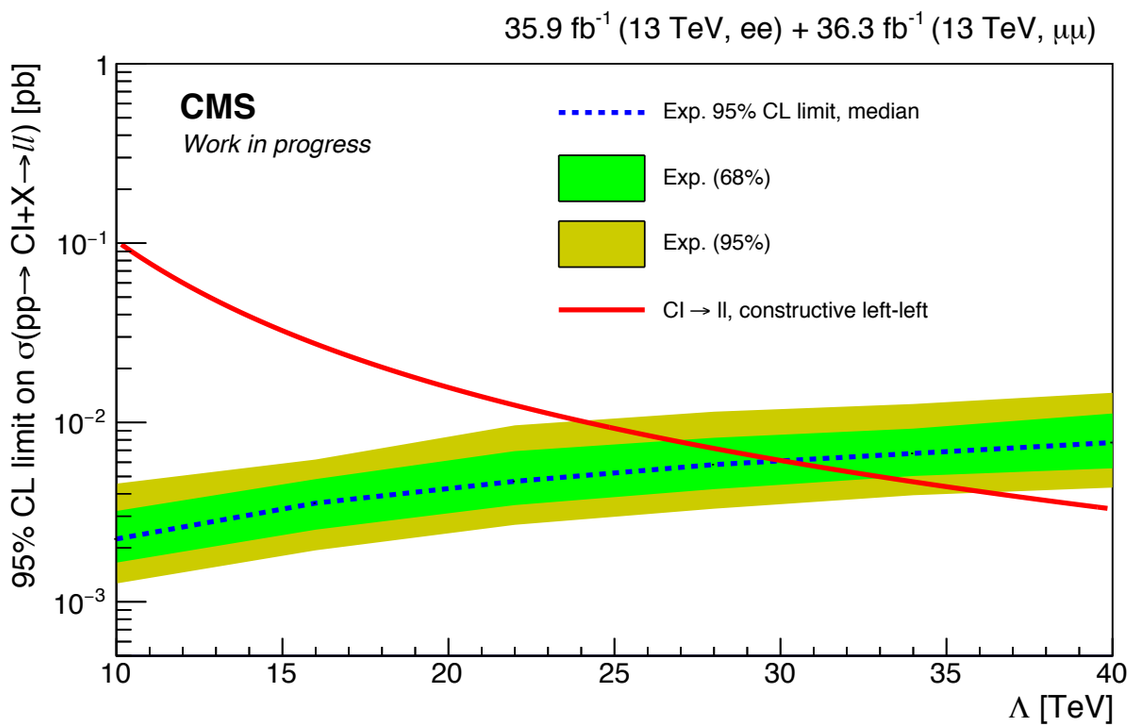


Summary: LED Expected Limits

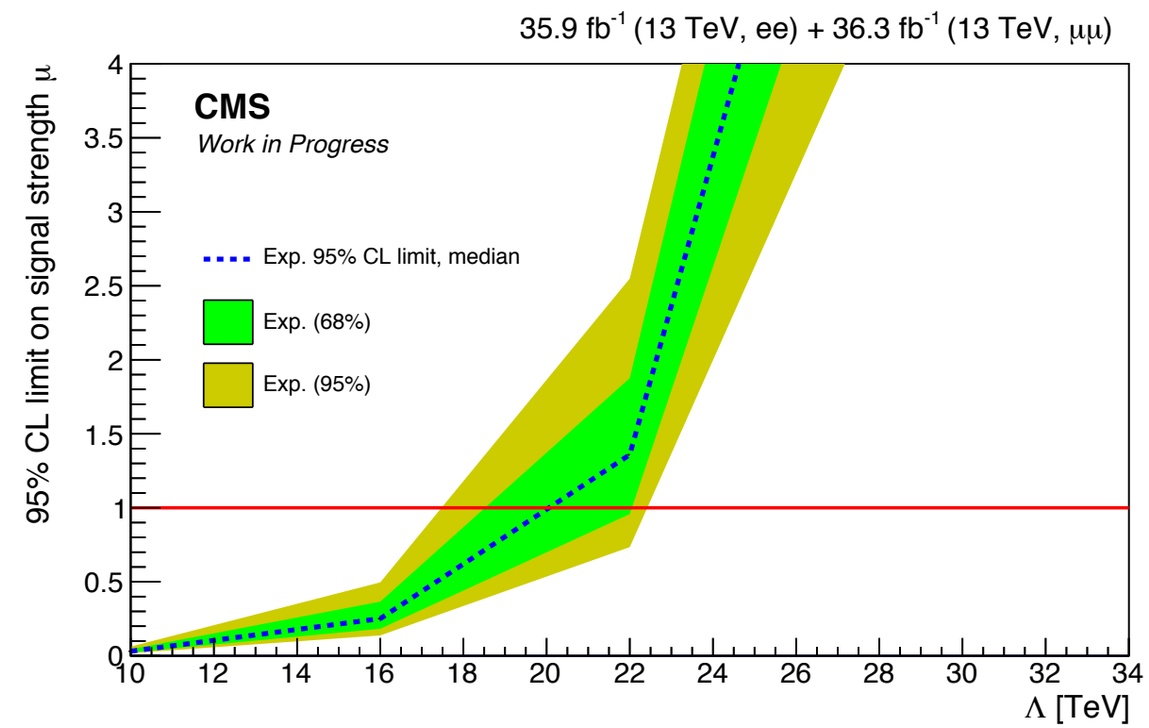


The expected limits for 13 TeV collision energy are much better than the published limits at 8 TeV collision

CI Expected Limits

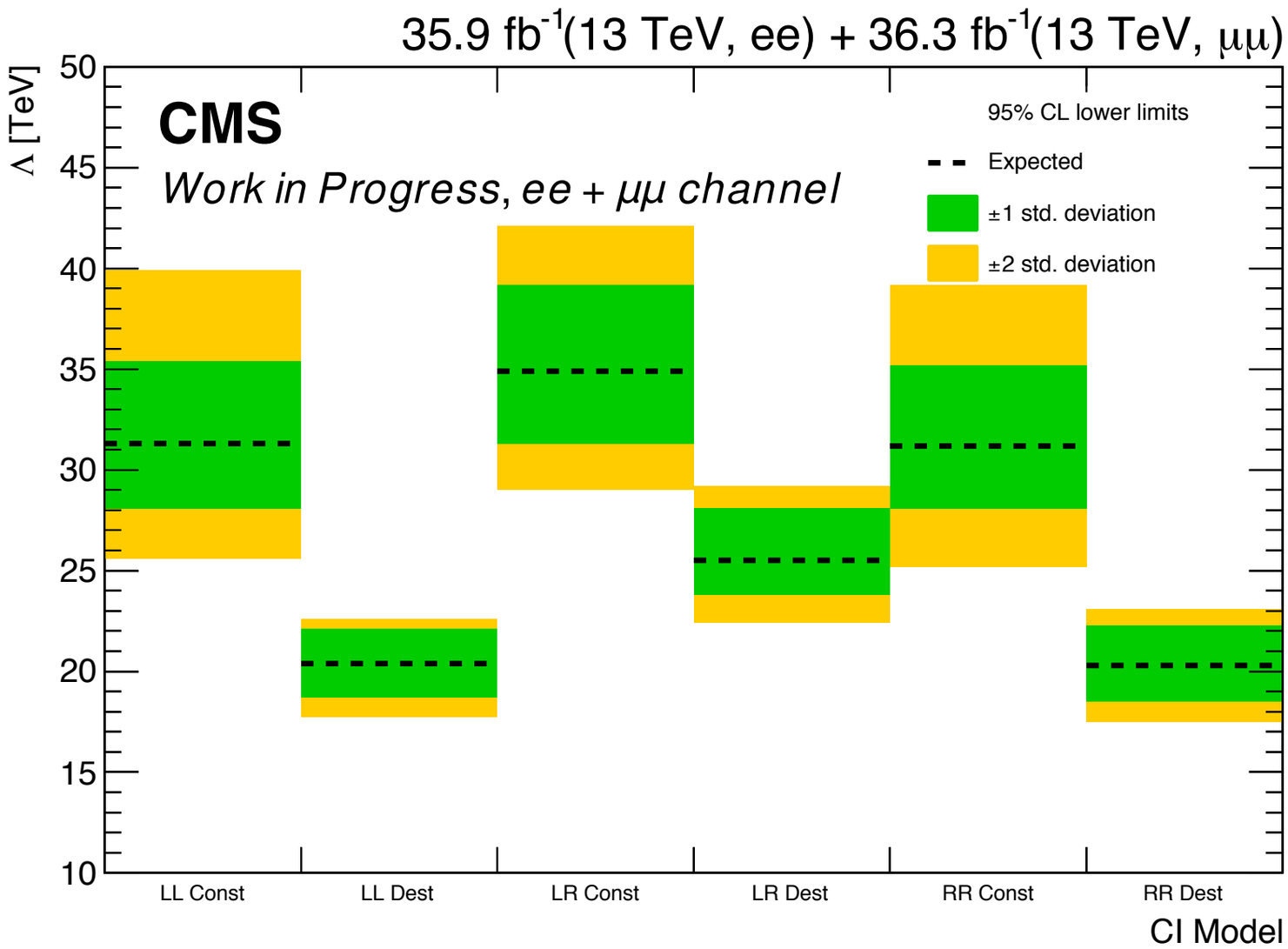


LL constructive interference



LL Destructive interference

Summary: CI Expected Limits



Limit on CI is much improved compared to Run I

Lower expected limit on Λ ranges from 20 to 35 TeV

Summary

- A good agreement between Data and SM background for electron and muon mass spectra
- Expected limit on CI ranges from 20 to 35 TeV
- Expected limit on LED is around 8 TeV
- Analysis is waiting for approval
- In the future, we will include Collins-Soper distributions and separate LR and RL models

Thank you

Back-Ups

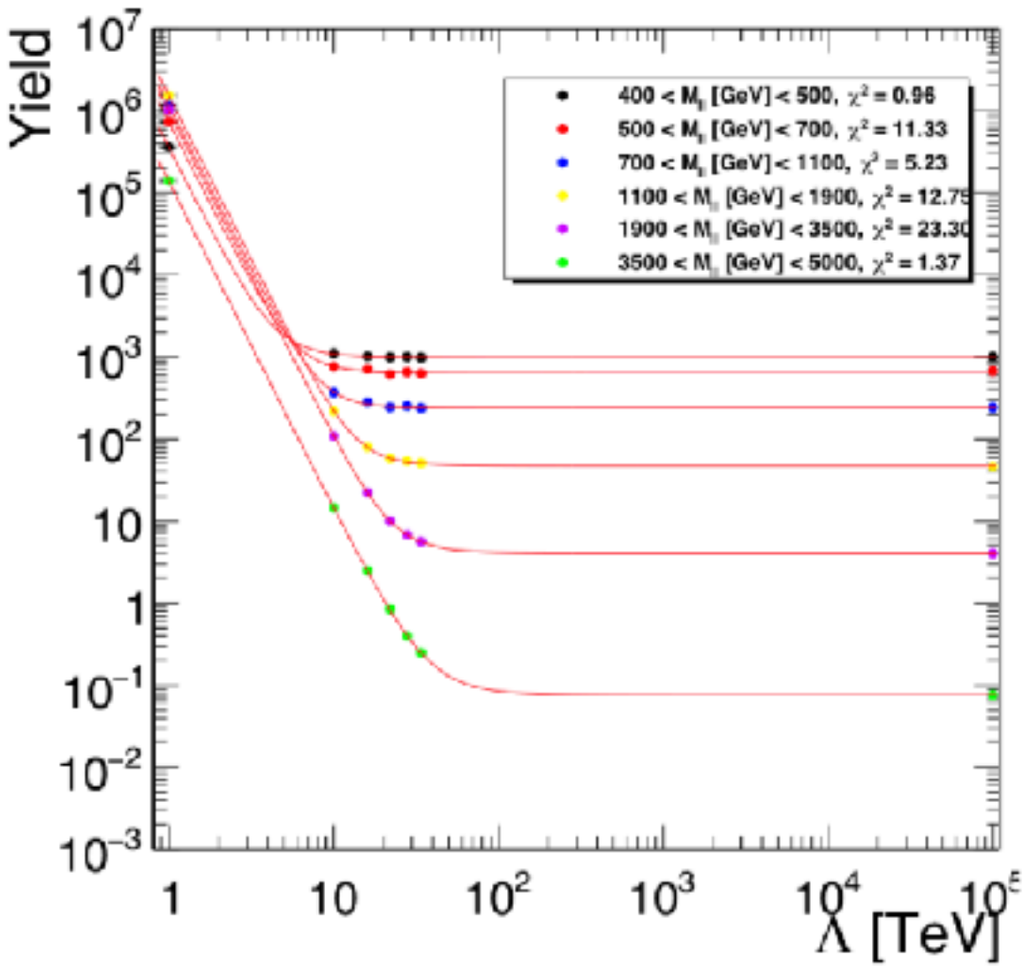
Electron Selection

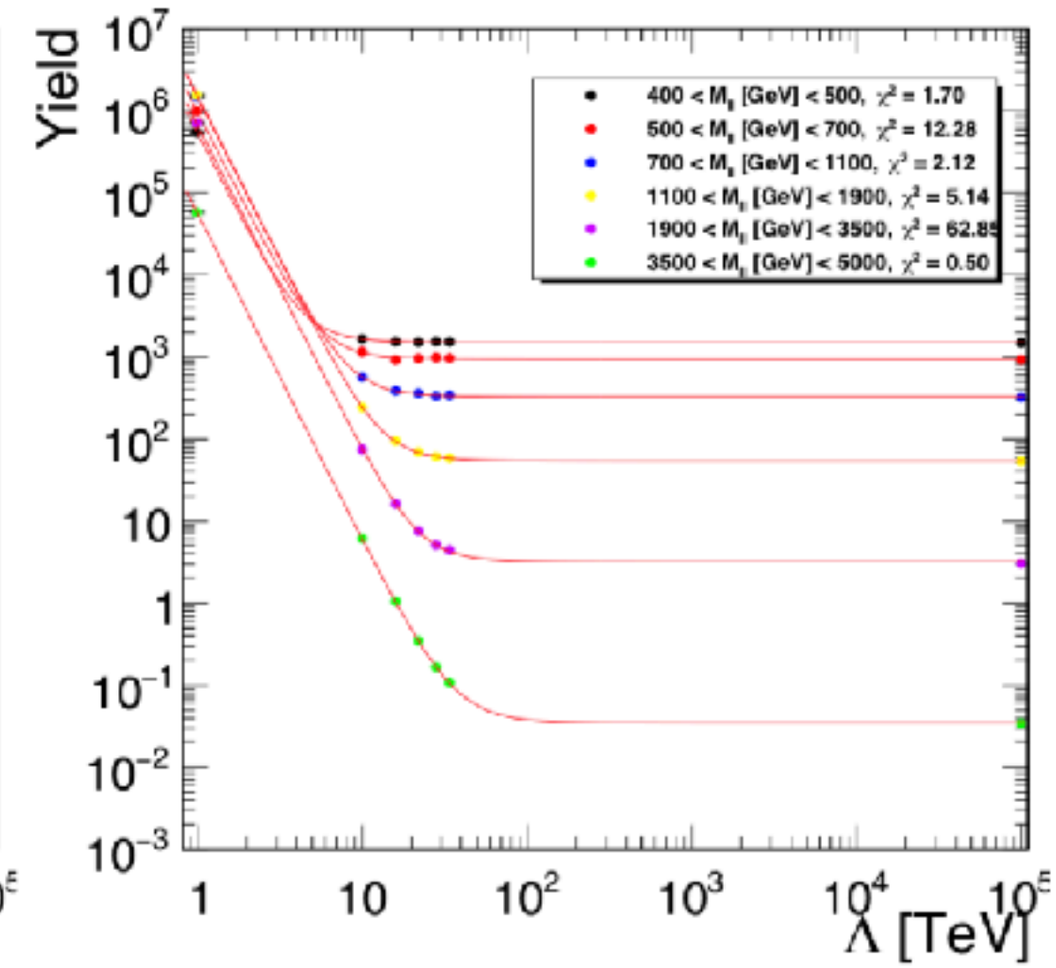
Variable	Barrel	Endcap
	Acceptance selections	
E_T	$E_T > 35\,\text{GeV}$	$E_T > 35\,\text{GeV}$
η	$\lvert\eta_{SC}\rvert < 1.4442$	$1.566 < \lvert\eta_{SC}\rvert < 2.5$
	Identification selections	
`isEcalDriven`	true	true
$\Delta\eta_{in}^{seed}$	$\lvert\Delta\eta_{in}^{seed}\rvert < 0.004$	$\lvert\Delta\eta_{in}^{seed}\rvert < 0.006$
$\Delta\phi_{in}$	$\lvert\Delta\phi_{in}\rvert < 0.06$	$\lvert\Delta\phi_{in}\rvert < 0.06$
H/E	$H/E < 1/E + 0.05$	$H/E < 5/E + 0.05$
$\sigma_{i\eta i\eta}$	-	$\sigma_{i\eta i\eta} < 0.03$
$\frac{E_{1\times5}}{E_{5\times5}}, \frac{E_{2\times5}}{E_{5\times5}}$	$\frac{E_{1\times5}}{E_{5\times5}} > 0.83$ or $\frac{E_{2\times5}}{E_{5\times5}} > 0.94$	-
Inner lost layer hits	lost hits ≤ 1	lost hits ≤ 1
Impact parameter, d_{xy}	$\lvert d_{xy}\rvert < 0.02$	$\lvert d_{xy}\rvert < 0.05$
	Isolation selections	
EM + had depth 1 isolation, *iso*	$iso < 2 + 0.03E_T + 0.28\rho$	$iso < 2.5 + 0.28\rho$ ($E_T < 50$, GeV) else $iso < 2.5 + 0.03(E_T - 50\,\text{GeV}) + 0.28\rho$
p_T isolation (V7), *isopt*	$isopt < 5\,\text{GeV}$	$isopt < 5\,\text{GeV}$

Muon Selection

Variable	Expression
Acceptance	
Muon Momentum	$p_T > 53\,\text{GeV}$
Pseudo Rapidity	$\lvert\eta\rvert < 2.4$
Track Reconstruction	
Global Muon	True
Tracker Muon	True
Track Quality	
Relative Momentum Error	$\Delta p_T / p_T < 0.3$
Hits in Muon System	$N_{\text{Hits in Muon System}} > 0$
Hits in Tracker	$N_{\text{Hits in Pixel}} > 0$
Tracker Layers	$N_{\text{Tracker Layers with Meas.}} > 5$
Matched Stations	$N_{\text{Matched Stations}} > 1$ OR $N_{\text{Matched Stations}} = 1 \wedge$ *No* hit in first layer OR $N_{\text{Matched Stations}} = 1 \wedge$ Hit in first layer $\wedge\ N_{\text{Matched RPC Layers}} > 2$
Transverse impact parameter	$d_{xy} < 0.2\,\text{cm}$
Isolation	
Relative Tracker Isolation	$I_{\Delta R<0.3,\,\text{rel.}} < 0.1$

CI Event Yield





Functional form for CI event yield

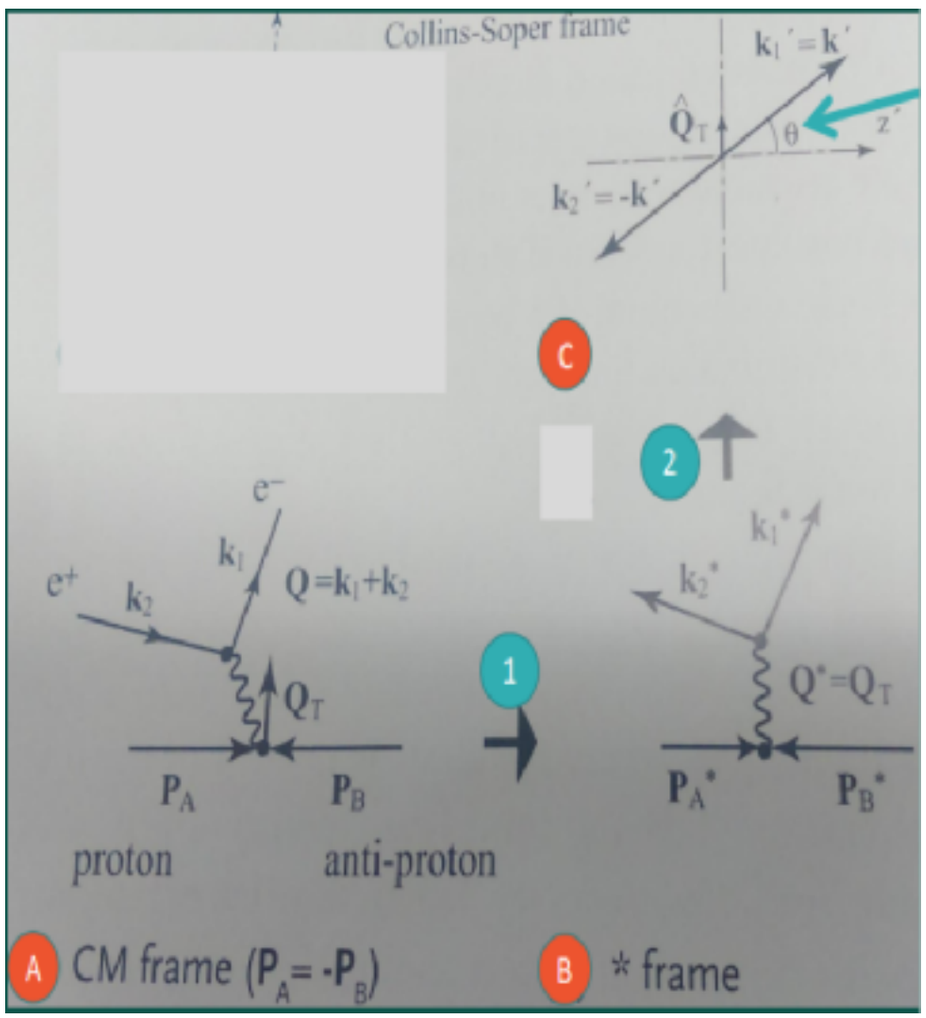
$$\text{yield} = a + \frac{b}{\Lambda^2} + \frac{c}{\Lambda^4}$$

- Event yields in each of the 6 mass bins for dimuon
- LL constructive interference model
- Barrel-Barrel (left), and Barrel-Endcap (right)

Collins Soper Angle

In 2017 Analysis, we are going to repeat the same procedures

Include RL helicity model and Collins Soper angle information



Nagasima, Elementary Particle Physics

Collins-Soper (CS) frame is the rest frame of dilepton system of interest

To get to CS frame, from CM frame boost along longitudinal direction, then boost along transverse direction

The distribution for LR Model is much more symmetric than LL and RR which are similar to DY process only for CS distribution

$$\cos\theta^* = \frac{p_z(\ell^+\ell^-)}{|p_z(\ell^+\ell^-)|} \frac{2(p_1^+ p_2^- - p_1^- p_2^+)}{m(\ell^+\ell^-)\sqrt{m(\ell^+\ell^-)^2 + p_T(\ell^+\ell^-)^2}}$$

$p_n^\pm$ denotes $\frac{1}{\sqrt{2}}(E \pm p_z)$

RL Model in CI

RL model is the RL+LR model in PYHIA event generator

Two methods to extract the information of true LR and RL model

- Modify PYTHIA event generator
- OR **Reweighing the LR model**

CMS Run I Limit

Dileptons	Λ_c (TeV)	Λ_d (TeV)
e^+e^-	18.3	13.5
$\mu^+\mu^-$	15.2	12.0

Lower limits on Λ from Run 1:
CMS collaboration, Search for physics beyond the standard model in dilepton mass spectra in proton-proton collisions at $\sqrt{s} = 8$ TeV, arXiv:1412.6302v2.

LED Parameters

Parameter Conversions

Hewett, $\lambda = +1$	HLZ, $n = 2$	HLZ, $n > 2$
$M_S = \sqrt[4]{\frac{\pi}{2}}\Lambda_T$	$M_S^4 = \log\left(\frac{M_S^2}{M^2}\right)\Lambda_T^4$	$M_S^4 = \frac{2}{n-2}\Lambda_T^4$