Search for contact interactions in the dimuon final states at CMS

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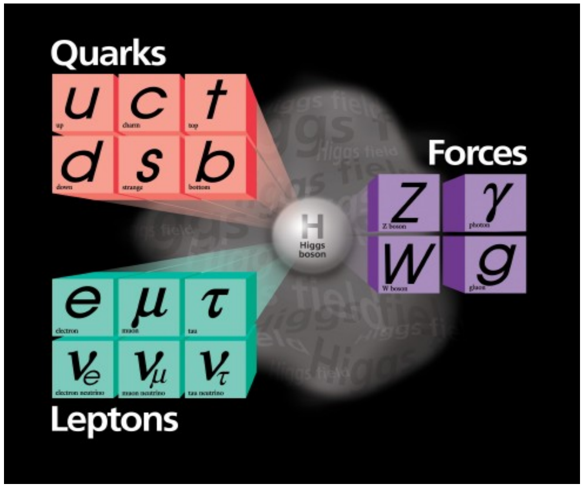
Why look beyond the SM ?

→ Standard model (SM) successfully predicts many fundamental processes,

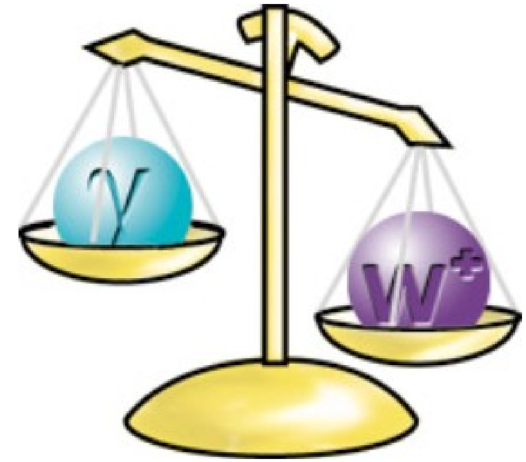


BUT...

Why ONLY 3 generations?

What about masses?

Where is the Higgs boson?
The hierarchy problem?



WHERE DO WE FIT IN ?

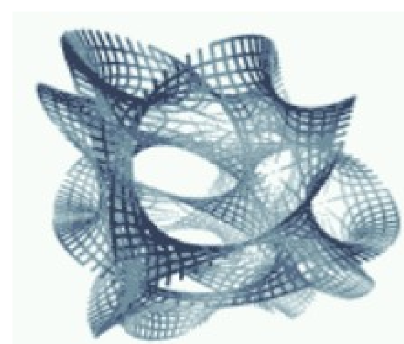
Massive neutrinos!

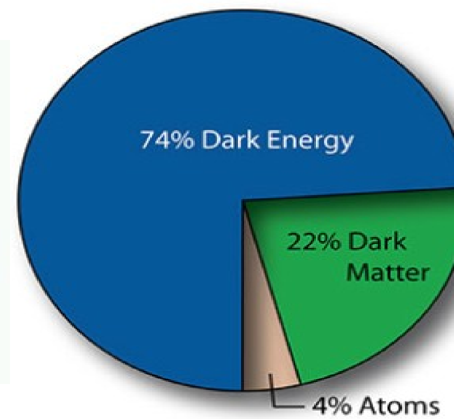
Gravity?

Dark matter?

Dark energy?

Extra dimensions? etc...



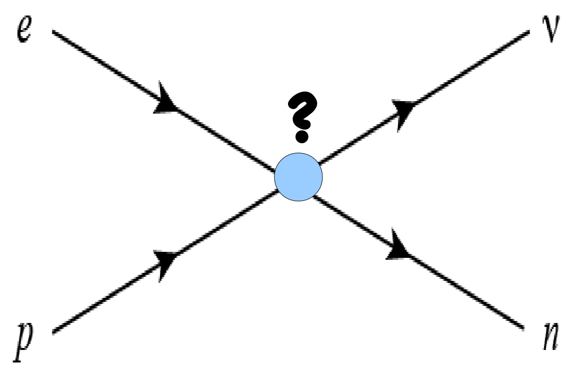


New Physics Contact Interactions → Quark compositeness

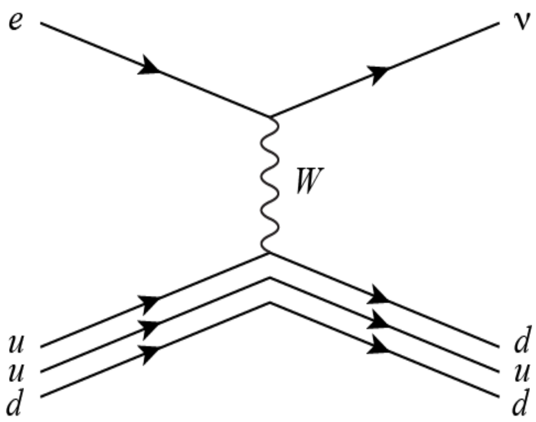
Contact Interactions (CI)

- New physics via CI has long history: In 1930's, Fermi's Beta decay

Lagrangian describing a new vector interaction without knowing the intermediate process.



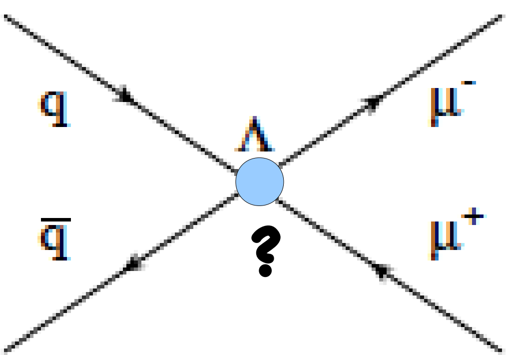
4-point Fermi CI-beta decay



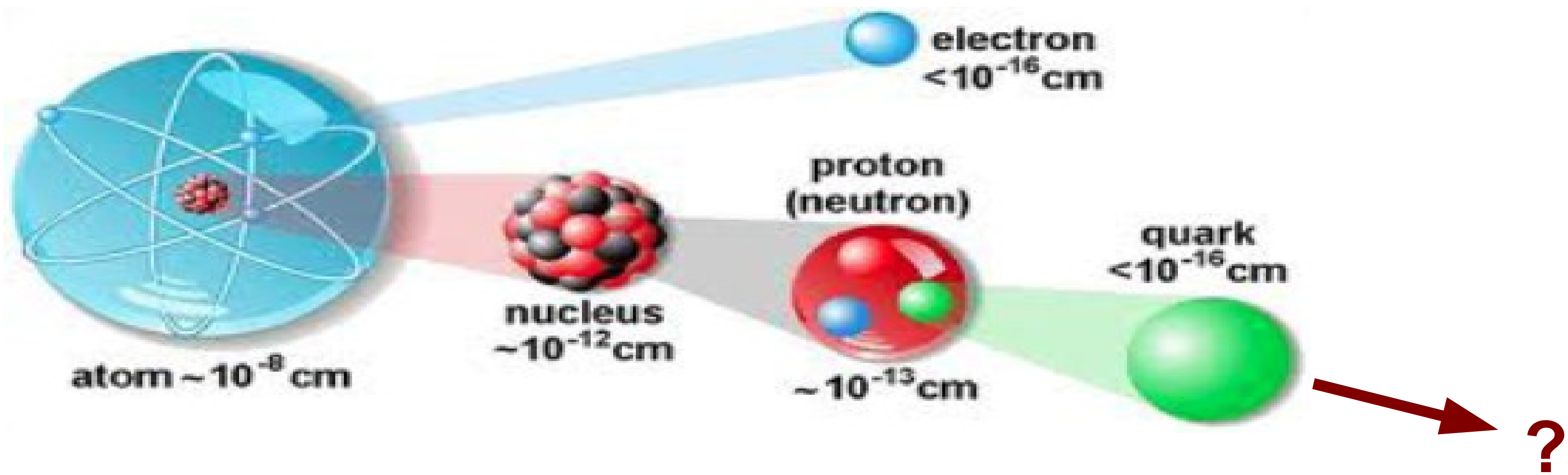
Beta decay (now)

Similarly, new physics may exist at an energy scale Λ

- Λ can be much higher than the achievable COM energy at the LHC
- But, its effects can be detected at energies < Λ at the LHC



Compositeness of Quarks and Leptons



→ Introducing quarks and leptons as composite objects

- the more fundamental constituents popularly called *preons*

→ Visible only above a characteristic energy scale Λ

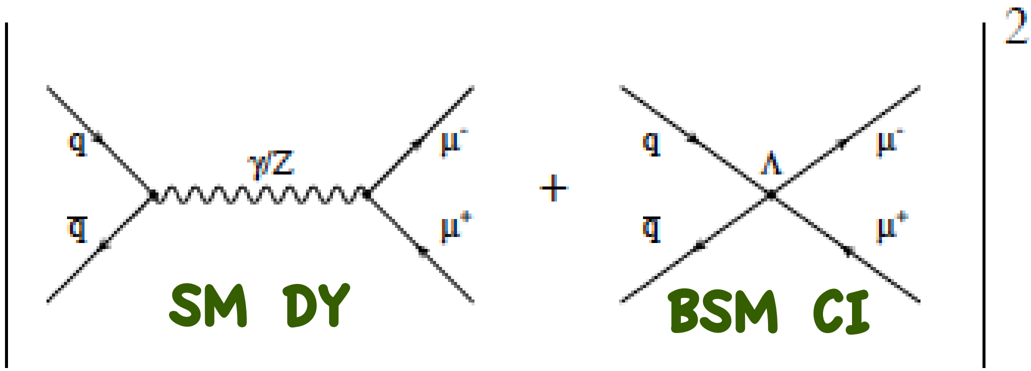
→ Below Λ, preon interactions become strong and quarks appear point-like

→ Λ characterizes both

- strength of the preon coupling
- physical size of compositeness scale

Manifestation of Compositeness dimuon channel

Production mechanism (same final states → scattering amplitudes add)



$$\frac{d\sigma}{dm} = \frac{d\sigma}{dm}(DY) - \eta\frac{I}{\Lambda^2} + \eta^2\frac{C}{\Lambda^4}$$

I - Interference term
C - Pure contact term

As $\Lambda \rightarrow \infty$, distribution → SM

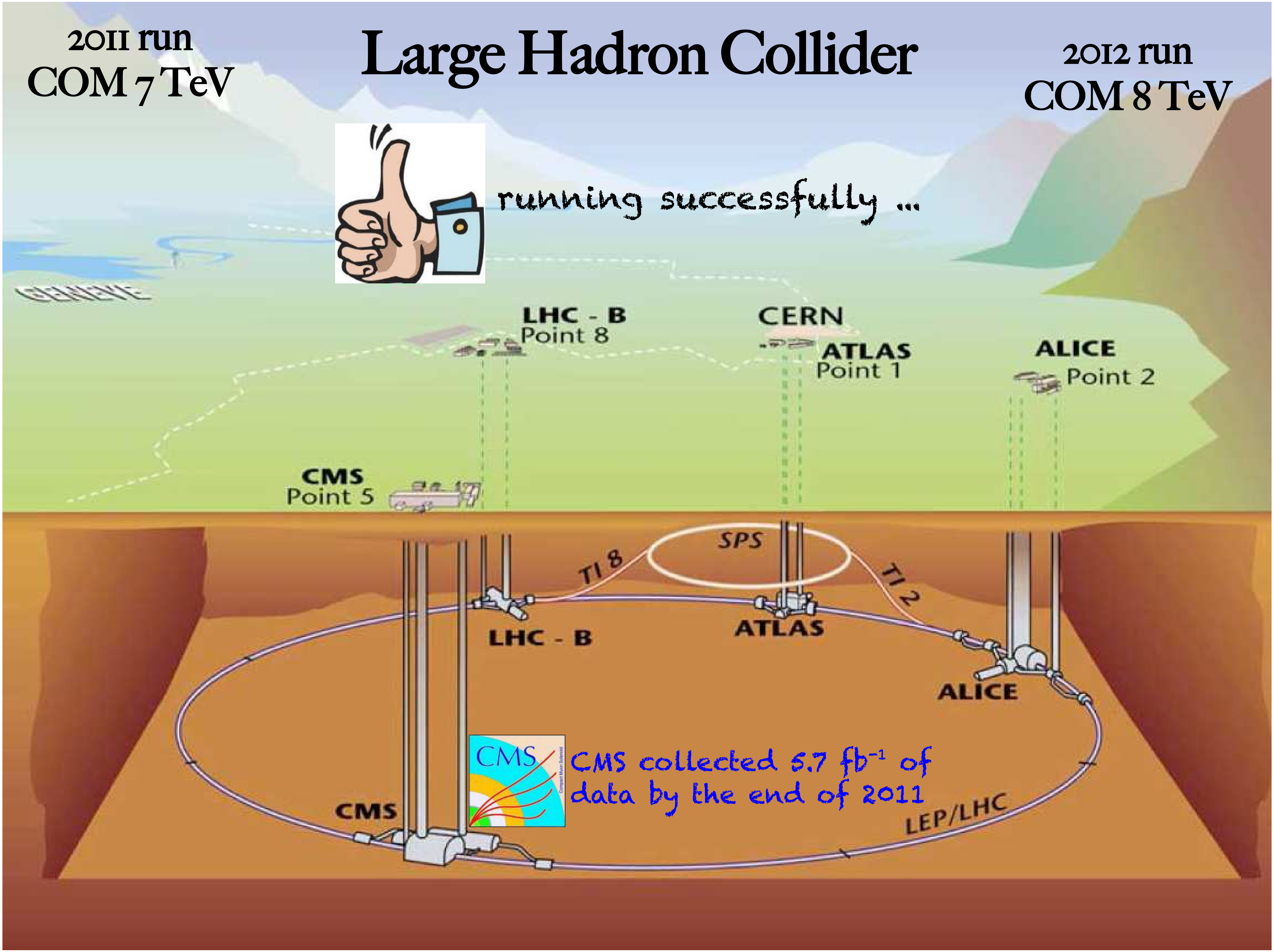
Experimentally,

- Observe excess of events in the tail of the dimuon invariant mass distribution

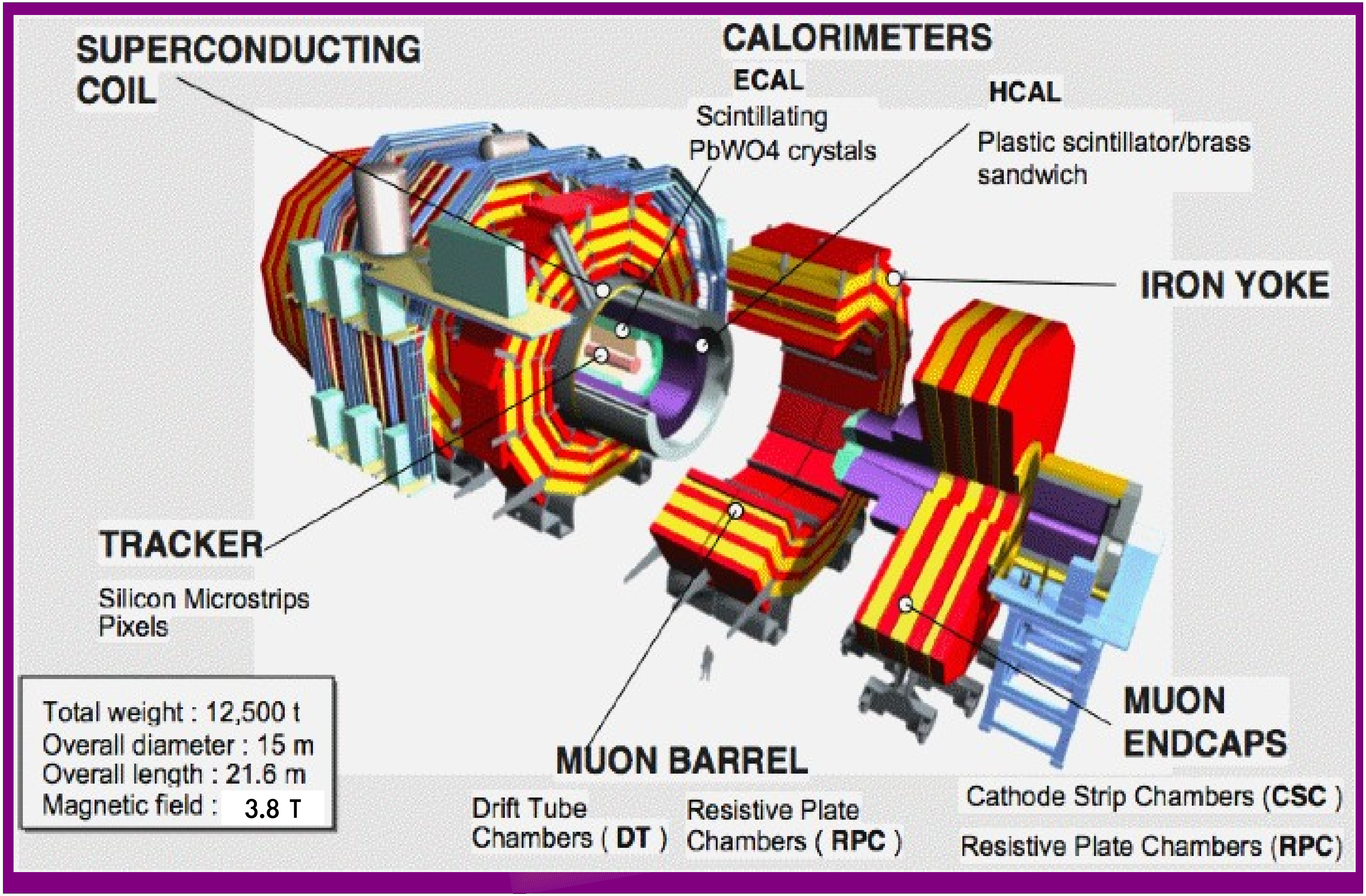
Lagrangian for contact interactions with dimuon final states

$$\begin{aligned} L_{ql} = (g_0^2/\Lambda^2)\{&\eta_{LL}(\bar{q}_L\gamma^\mu q_L)(\bar{\mu}_L\gamma_\mu\mu_L) + \eta_{LR}(\bar{q}_L\gamma^\mu q_L)(\bar{\mu}_R\gamma_\mu\mu_R) \\ &+\eta_{RL}(\bar{u}_R\gamma^\mu u_R)(\bar{\mu}_L\gamma_\mu\mu_L) + \eta_{RL}(\bar{d}_R\gamma^\mu d_R)(\bar{\mu}_L\gamma_\mu\mu_L) \\ &+\eta_{RR}(\bar{u}_R\gamma^\mu u_R)(\bar{\mu}_R\gamma_\mu\mu_R) + \eta_{RR}(\bar{d}_R\gamma^\mu d_R)(\bar{\mu}_R\gamma_\mu\mu_R)\} \end{aligned}$$

- η = sign of the interference of new physics with the DY process (η = -1 constructive; η = +1 destructive)
- Different η_{lm} values correspond to different compositeness models with distinct Λ


2011 run
COM 7 TeV
Large Hadron Collider
2012 run
COM 8 TeV
running successfully ...
GENEVE
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
SPS
TI 8
TI 2
LHC - B
ATLAS
ALICE
CMS
CMS collected 5.7 fb⁻¹ of
data by the end of 2011
CMS
LEP/LHC

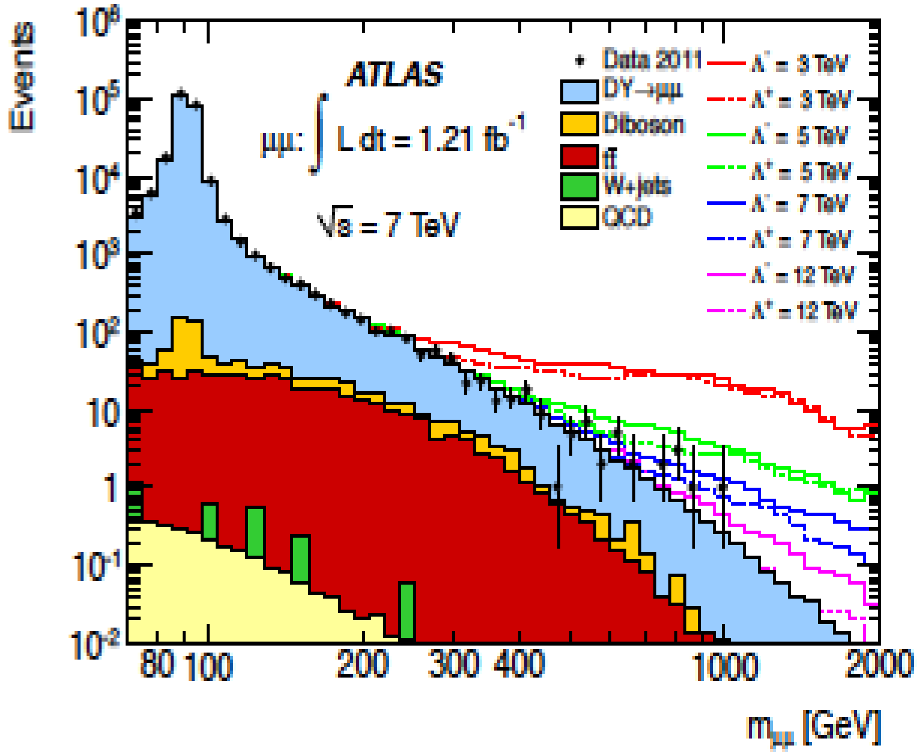
The Compact Muon Solenoid (CMS) Experiment



Exploded view of the CMS detector

Previous results on Λ

Ref: arXiv:1112.4462v1 [hep-ex]



$$L_{ql} = (g_0^2/\Lambda^2)\{\eta_{LL}(\bar{q}_L\gamma^\mu q_L)(\bar{\mu}_L\gamma_\mu\mu_L) + \eta_{LR}(\bar{q}_L\gamma^\mu q_L)(\bar{\mu}_R\gamma_\mu\mu_R)$$
$$+\eta_{RL}(\bar{u}_R\gamma^\mu u_R)(\bar{\mu}_L\gamma_\mu\mu_L) + \eta_{RL}(\bar{d}_R\gamma^\mu d_R)(\bar{\mu}_L\gamma_\mu\mu_L)$$
$$+\eta_{RR}(\bar{u}_R\gamma^\mu u_R)(\bar{\mu}_R\gamma_\mu\mu_R) + \eta_{RR}(\bar{d}_R\gamma^\mu d_R)(\bar{\mu}_R\gamma_\mu\mu_R)\}$$

Compositeness model: Left-left Iso-scalar
Channel: dimuon

95% C.L. Exclusion lower limits

Λ > 7.0 TeV (Destructive)
Λ > 8.0 TeV (Constructive)

For this analysis,

→ **Limits are set on the η_{LL} term in the Lagrangian –**

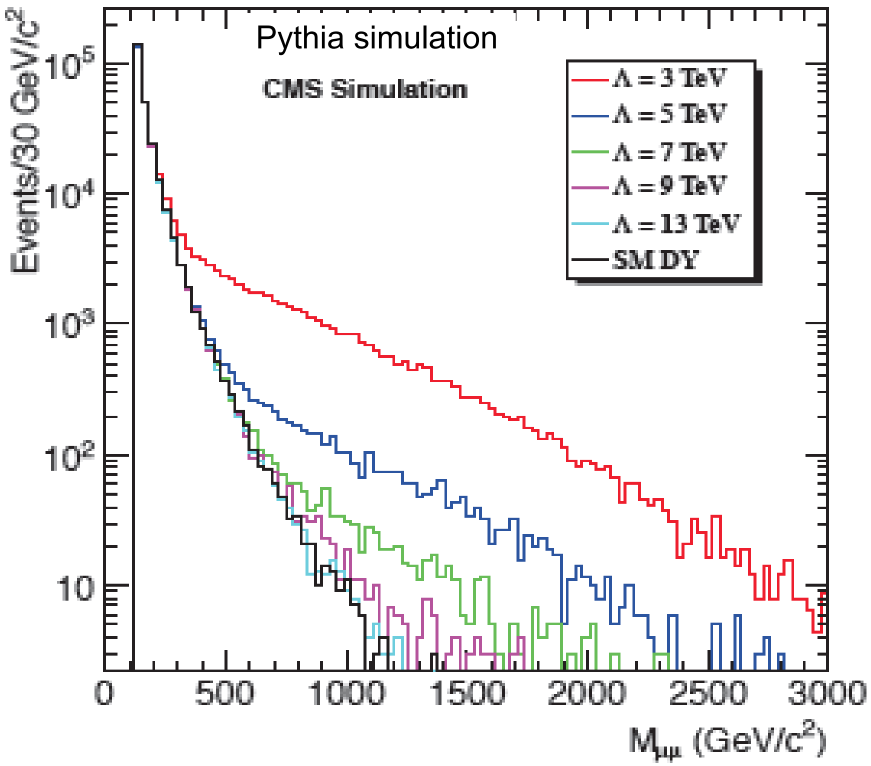
→ **Left-Left is one of the two models implemented in the Pythia monte carlo**

→ **PDG limits are exclusively given for LL model**

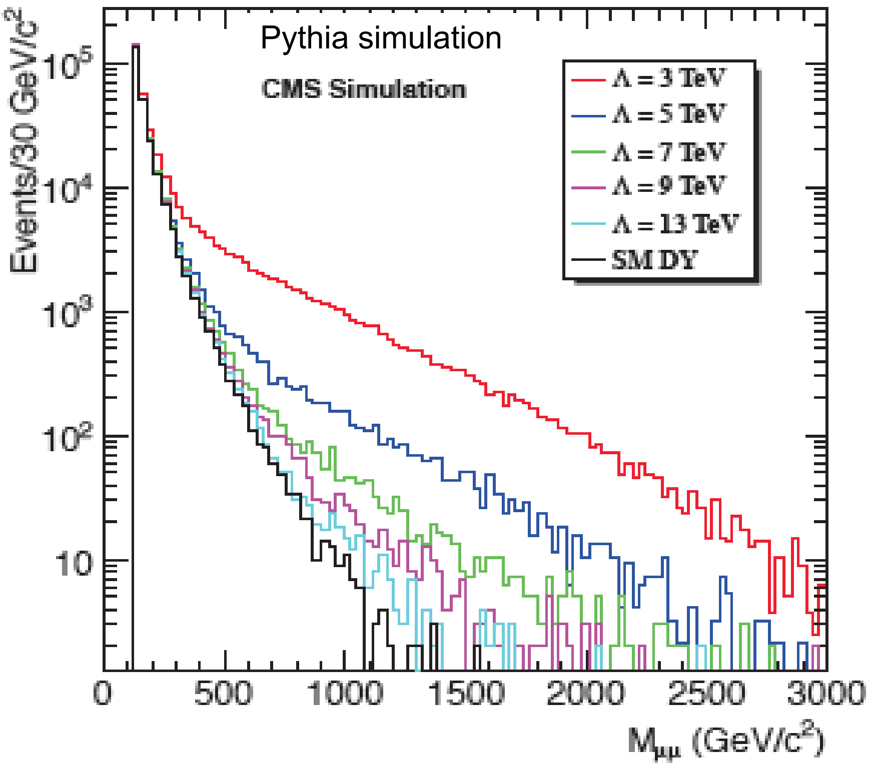
Pythia Left-Left Iso-scalar model

Compositeness scale Λ

As $\Lambda \rightarrow \infty$, distribution → SM



η = +1 destructive



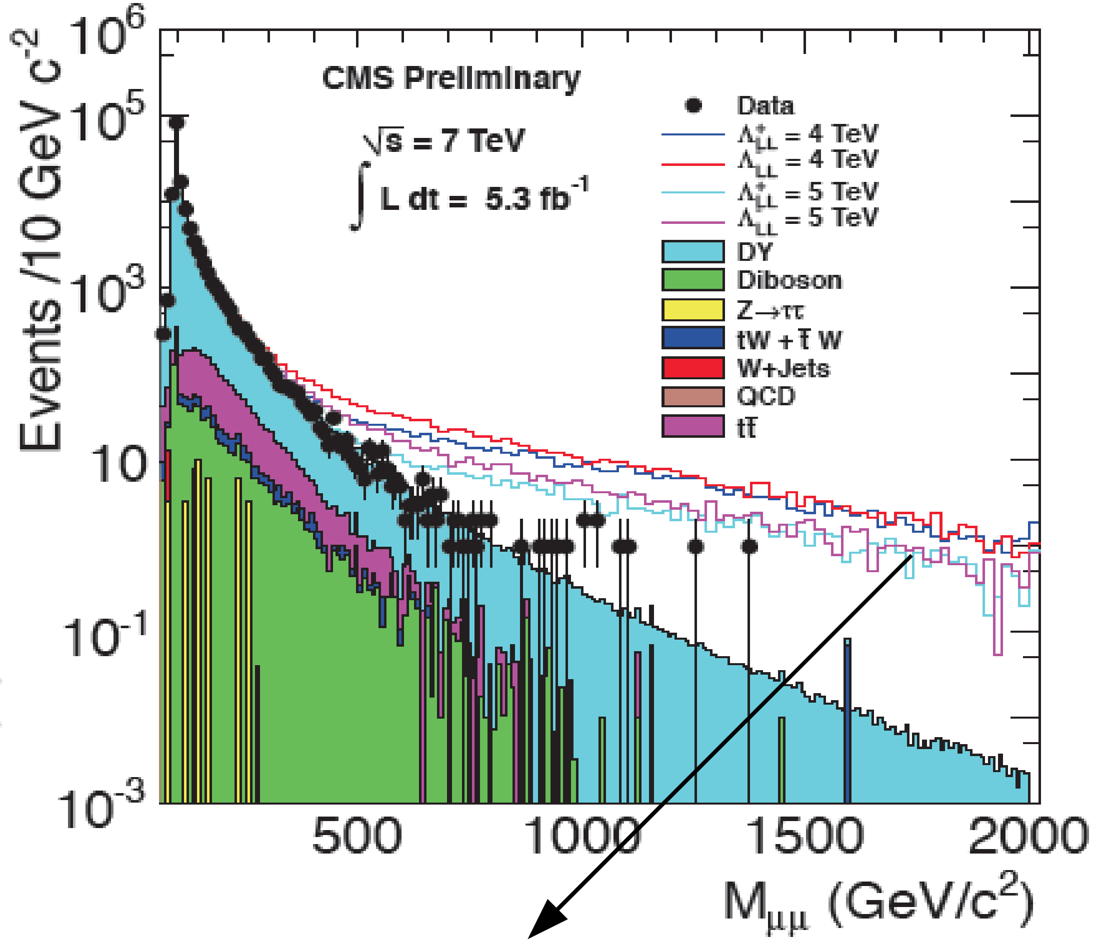
η = -1 constructive

$$\frac{d\sigma}{dm} = \frac{d\sigma}{dm}(DY) - \eta \frac{I}{\Lambda^2} + \eta^2 \frac{C}{\Lambda^4}$$

Dimuon mass spectrum

Dimuon Selection

- pT > 45 GeV
- Oppositely charged
- Well isolated from muons arising from hadron decays
- Have a common vertex
- Must have tracks reconstructed both in silicon tracker and muon detector
- 3D dimuon opening angle cut to suppress cosmic-ray muons



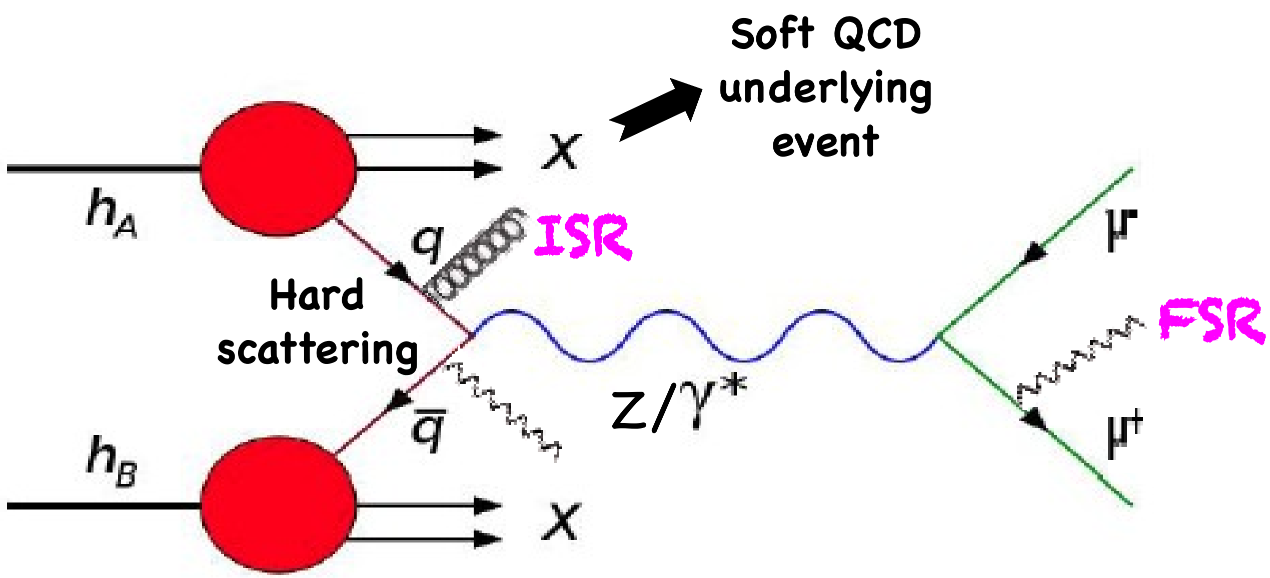
Expected signal = (CI * Acc * QCD K * QED K) + BKG

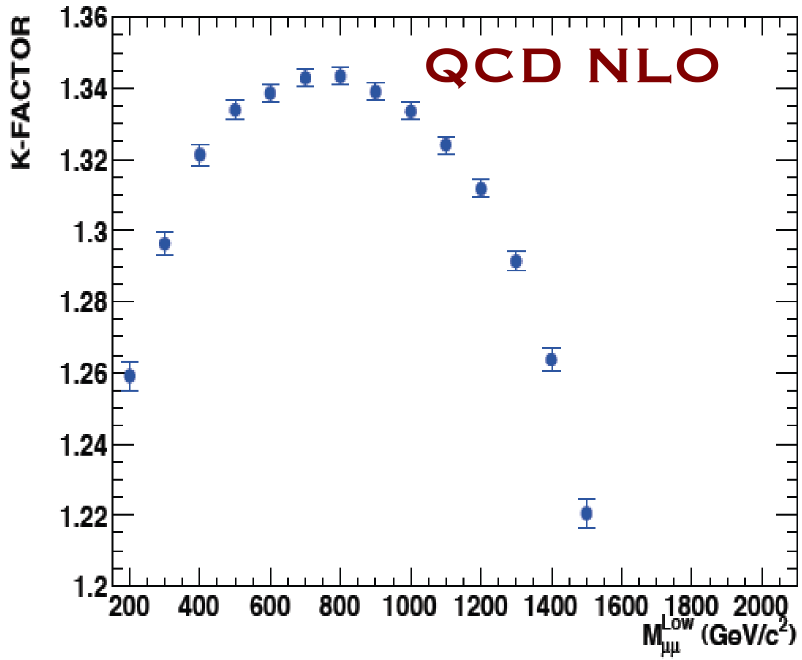
Where	E	-	expected signal
	CI	-	generator level contact signal
	Acc	-	acceptance*migration
	BKG	-	background estimation
	QCD K	-	QCD K-factor for NLO corrections
	QED K	-	EW K-factor for NLO corrections

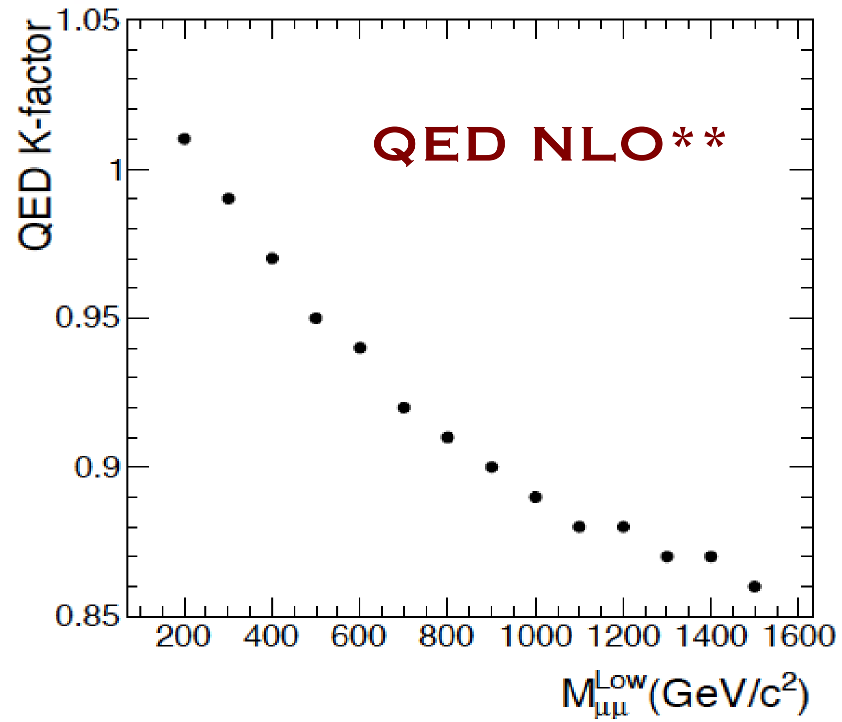
NLO corrections

K-factor

- Ratio of MC@NLO (NLO generator) to Pythia (LO generator) dimuon events
- is mass-dependent







** J. High Energy Physics 10 (2007)109-130

Limit setting procedure

- Based on Modified frequentist technique (CLs technique)
  (A. Read, J. Phys. G: Nucl. Part. Phys. 28 (2002).)

- profile likelihood ratio as a test statistic

- Expected mean for signal events = total events (finite Λ) – total events (DY)

- Expected mean for background events = total events (DY)

- Observed number of events → CMS data

- Limits includes systematics coming from
  - integrated luminosity
  - acceptance
  - expected background (DY).

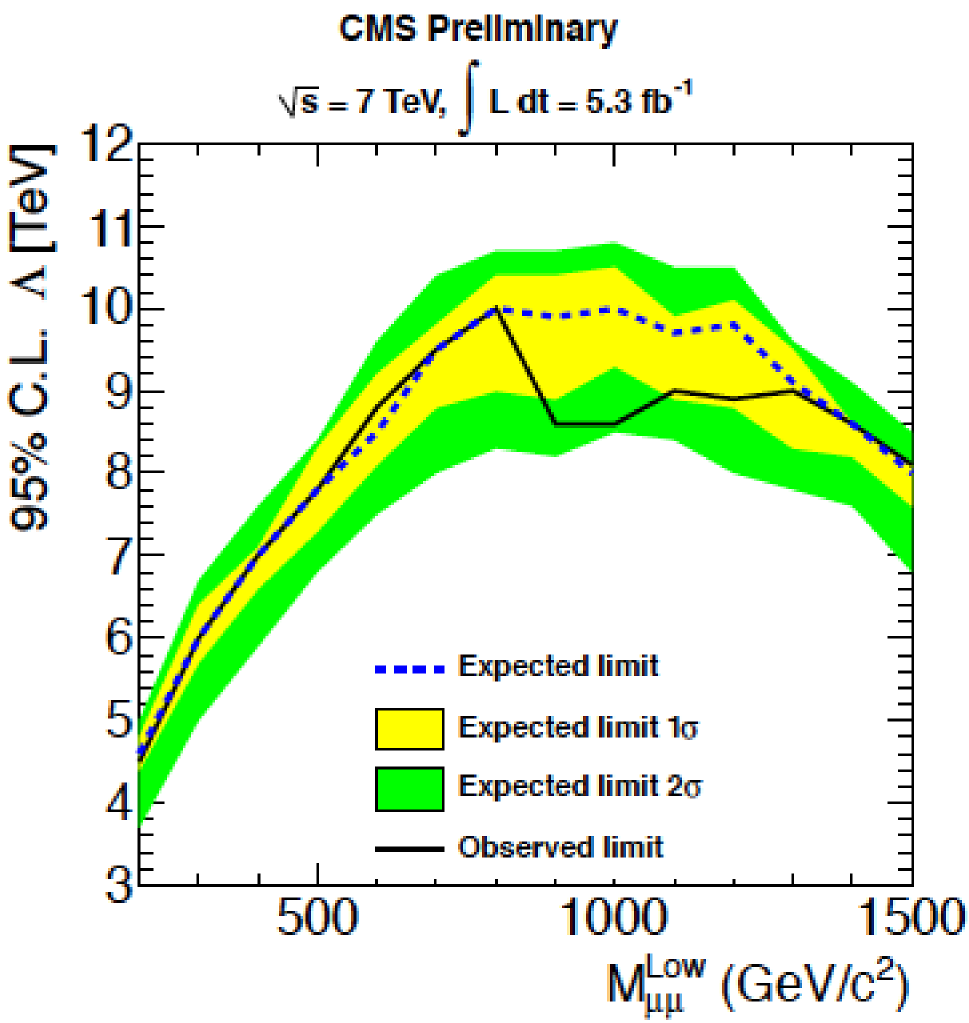
Systematics

Values quoted at $M_{\mu\mu} > 700$ GeV; $\Lambda = 13$ TeV; constructive interference

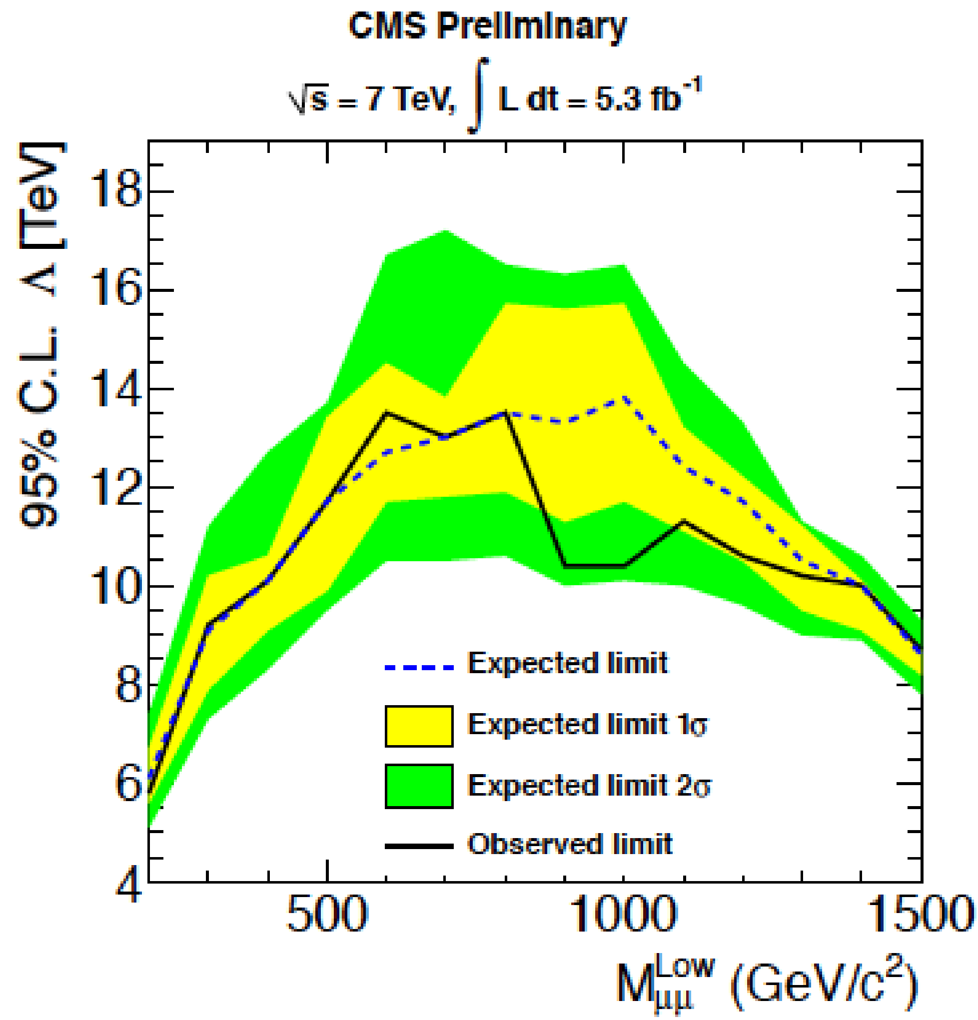
Source	Uncertainty (%)
Integrated luminosity	2.2
Acceptance	3.0
Background estimate	14.7
PDF set variation (+)	12.3
PDF set variation (-)	9.9
DY event yield	0.8
non-DY event yield	15.0
QCD k-factor	0.2

- PDFs has the largest effect on the limits
- All other sources have negligible effect on limits

95% CL Lower limits on Λ



Destructive



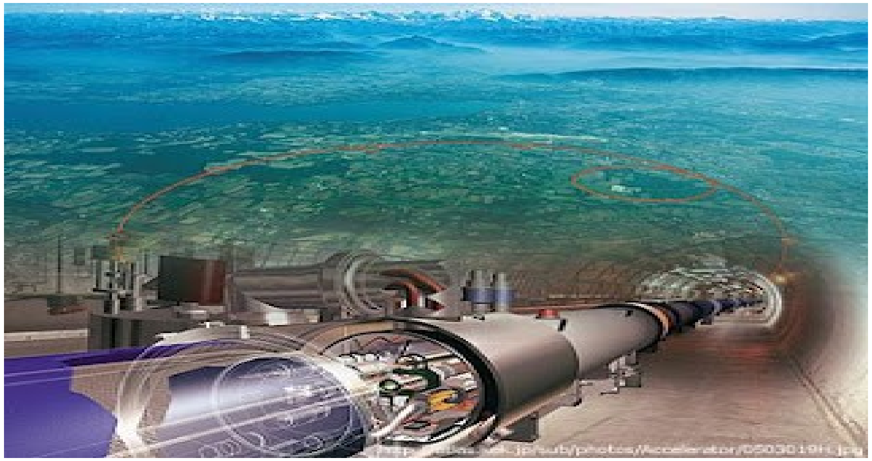
Constructive

Summary & Conclusions

Comparison with other results

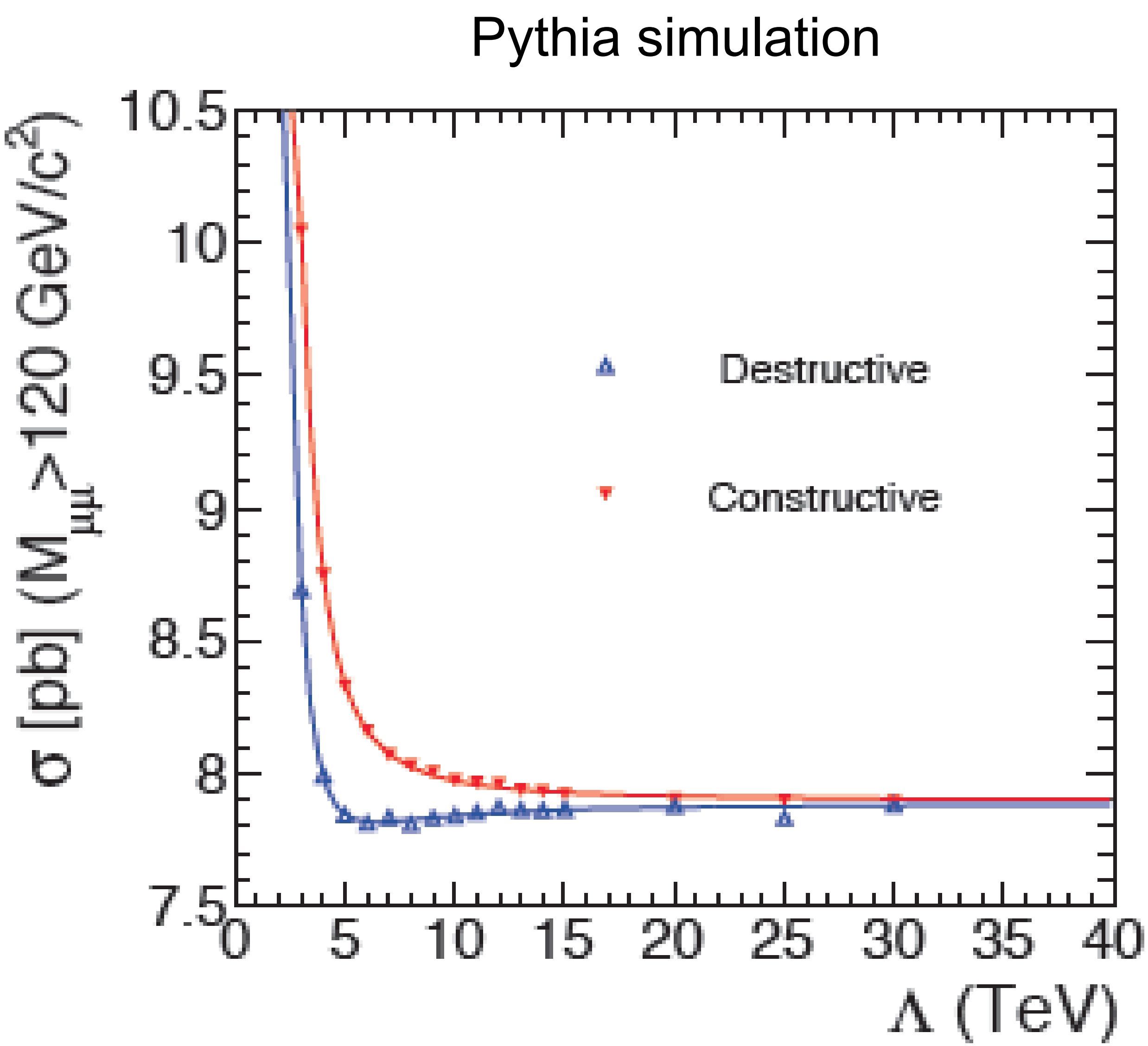
Source	COM (TeV)	L (fb^{-1})	Λ (Dest.) TeV	Λ (Const.) TeV
CDF	1.8	0.11	2.9	4.2
ATLAS	7	1.21	7.0	8.0
This analysis	7	5.28	9.5	13.0

- Limits significantly better than the current published limits
- With increased Collision energy (8 TeV) in 2012 at the LHC, search for this exciting possibility continues ....

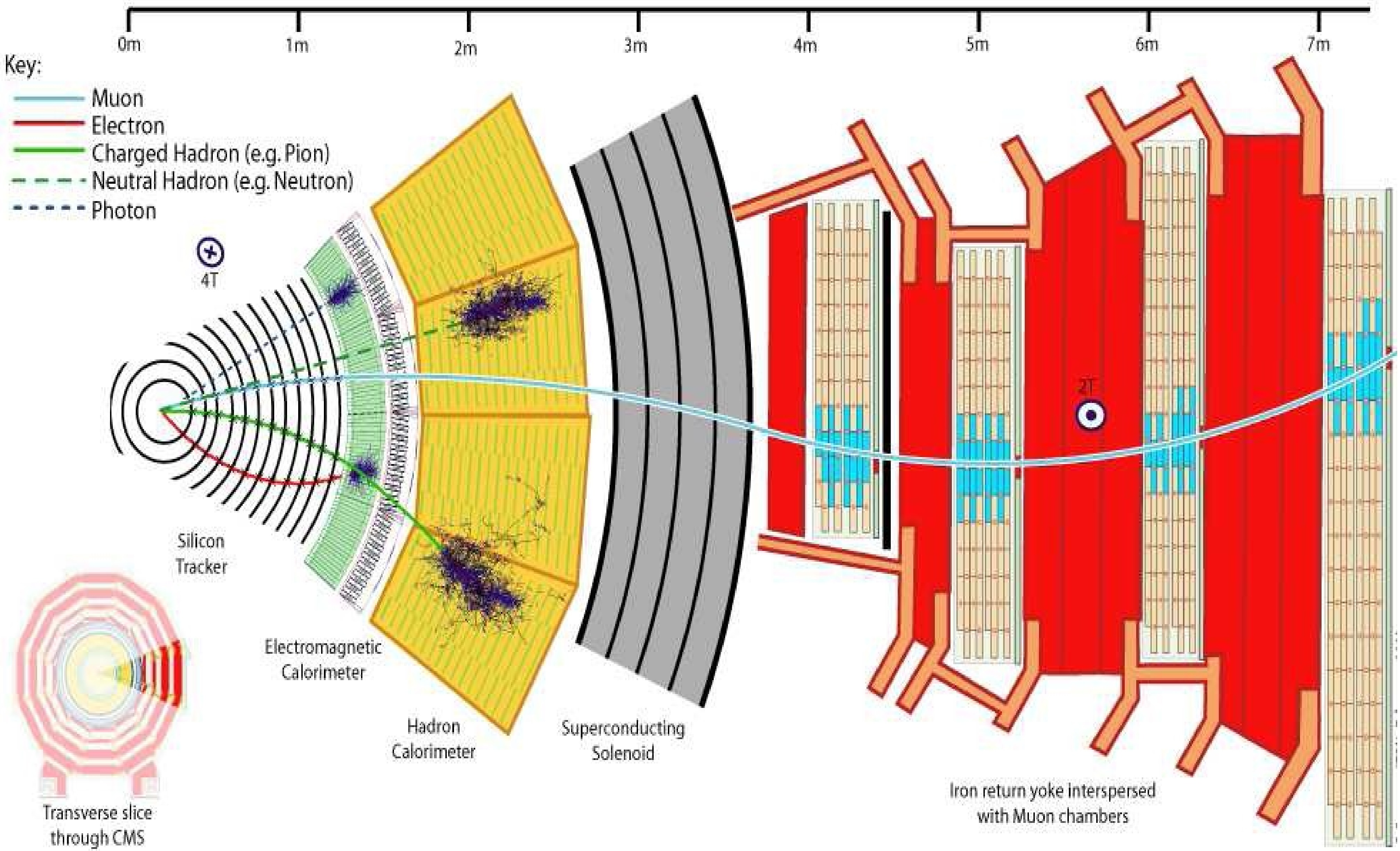


BACK UP

Pythia Left-Left model cross-sections



Particle detection at CMS



Dimuon backgrounds I

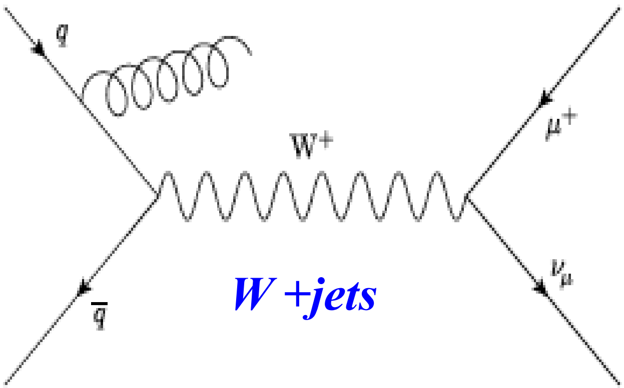
QCD PROCESSES

- Heavy flavor decay
  - $t\,\bar{t}\,,b\,\bar{b}\,,c\,\bar{c}$
- $tW+\bar{t}\,W$ production

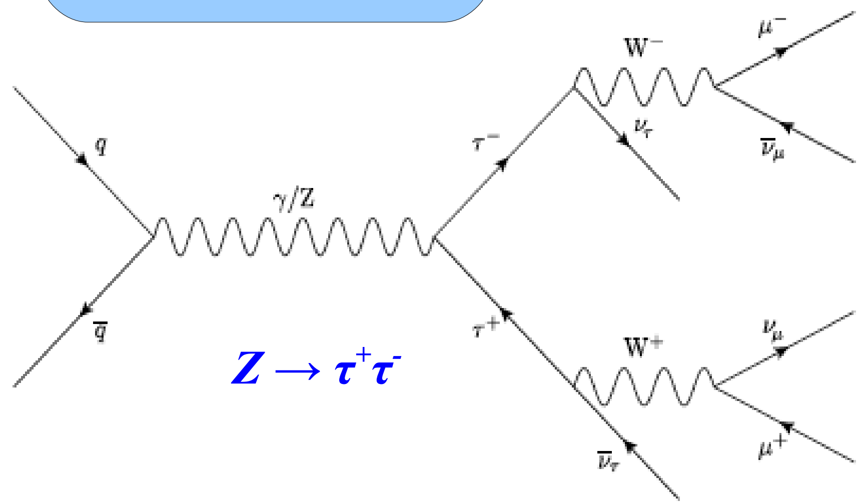
EWK PROCESSES

- $Z\rightarrow\mu^{+}\mu^{-}$, $Z\rightarrow\tau^{+}\tau^{-}$
- W +jets
- Diboson
  - $W^{\pm}Z$, ZZ, $W^{+}W^{-}$

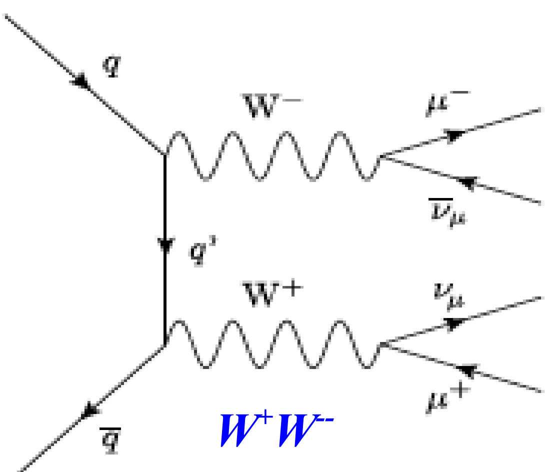
Irreducible background



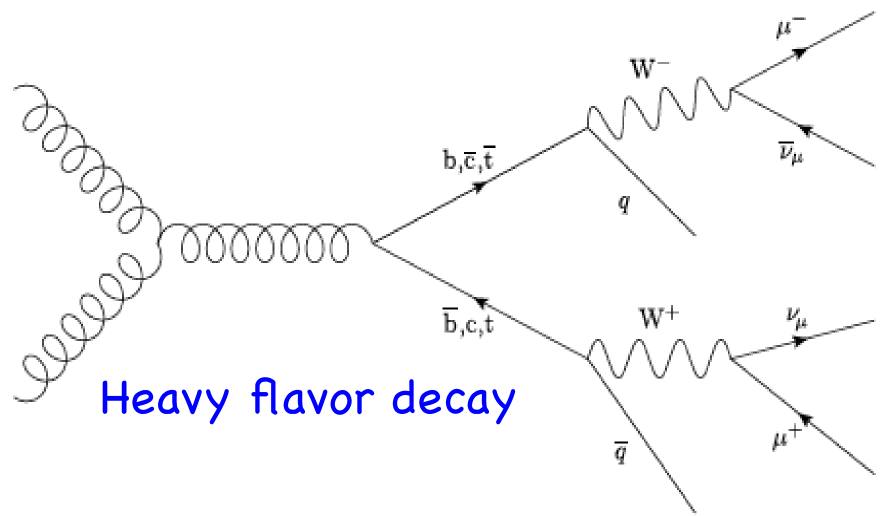
W +jets



$Z\rightarrow\tau^{+}\tau^{-}$



$W^{+}W^{-}$

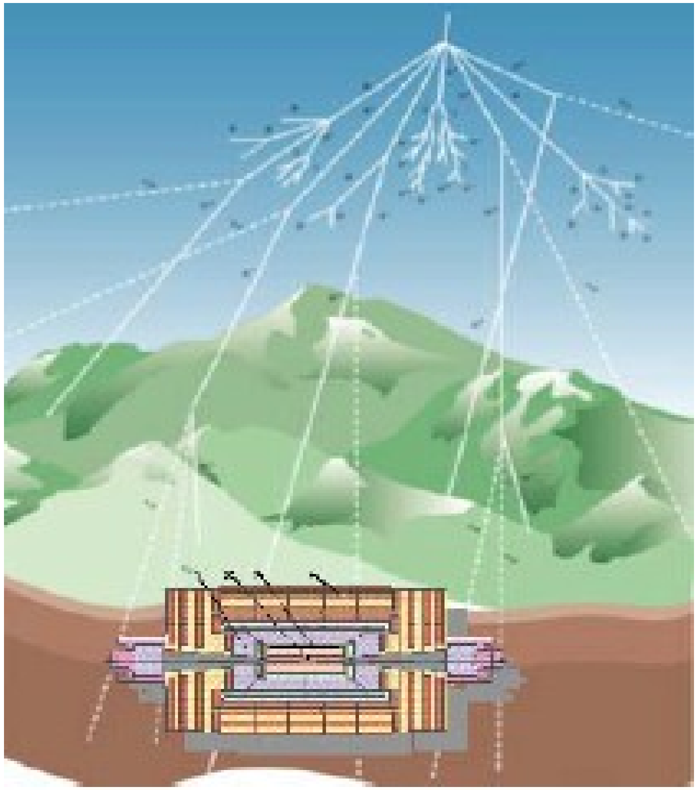


Heavy flavor decay

Dimuon backgrounds II

COSMIC RAY MUONS

- Atmospheric cosmic ray muons penetrating into the detector
  - CMS well-shielded deep underground (~100m deep) (only ~1% of rate on surface of earth reach the detector)
  - But, increased acceptance through the 3 access shafts of CMS



- A cosmic ray muon passing close to the detector interaction point can appear as two muons back-to-back in η, faking a dimuon event
- To suppress, select events with
  - atleast one primary vertex
  - 3D dimuon opening angle < 0.02 rad

Acceptance and Mass resolution

- Reconstructed events to generated events above a mass threshold
- Includes mass resolution effects (generator masses below threshold are included in the relative yield)
- Boost due to resolution smearing significant for masses > 600 GeV/c
- Resolution smearing sensitive to the shape of cross-section for CI and DY
- 3% systematic assigned to account for differences in acceptance between CI and DY