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**15th International Conference on Supersymmetry
and the Unification of Fundamental Interactions**

Contact Interactions @ the LHC

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on behalf of the ATLAS and CMS Collaborations**

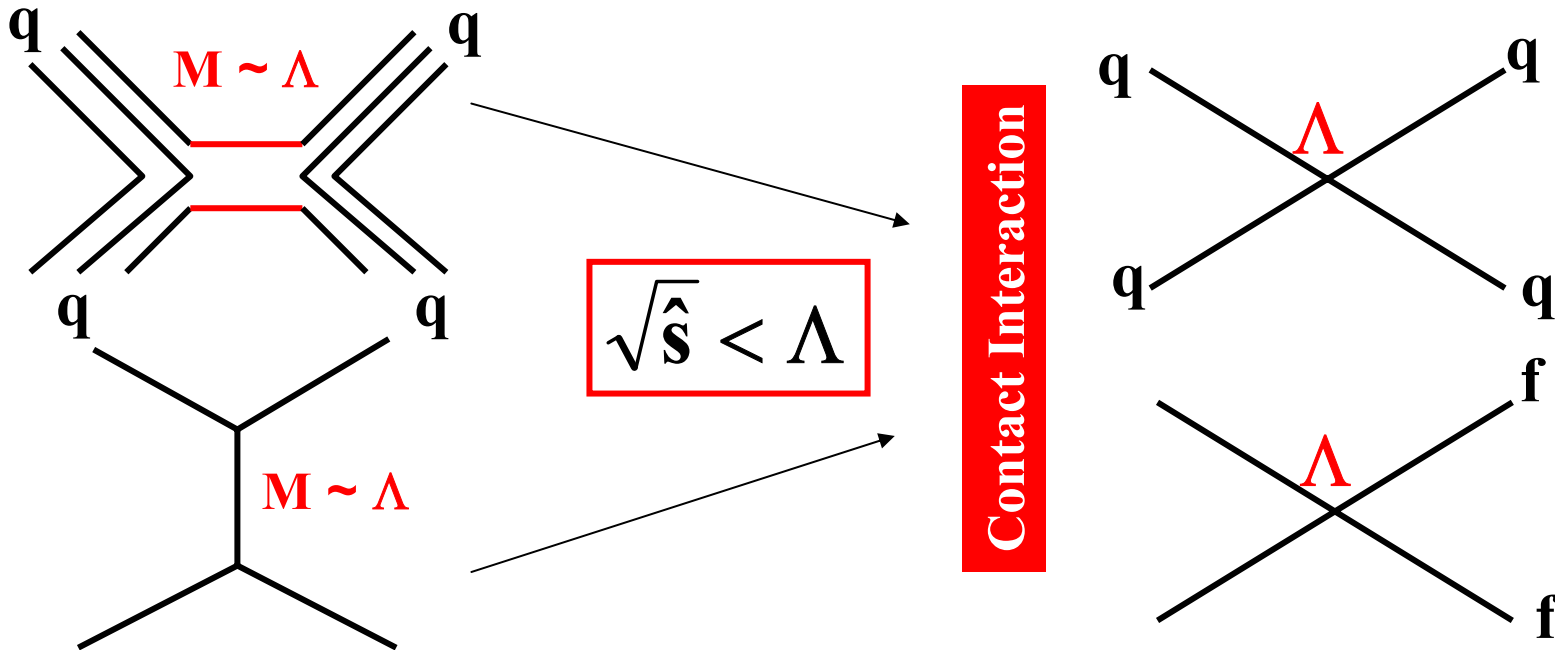
$$\frac{d\sigma}{d\Omega} = \text{SM}(s, t) + \epsilon \cdot C_{\text{Int}}(s, t) + \epsilon^2 \cdot C_{\text{NewPh}}(s, t)$$

$$\mathcal{L} = \frac{2\pi\Lambda}{\Lambda^2} \sum_{i,j=1}^6 (\bar{q}_{iL} \gamma^\mu q_{iL})(\bar{q}_{jL} \gamma^\mu q_{jL})$$

$\Lambda = \pm 1$

New physics at a **scale Λ** above the observed dijet (dilepton) mass is effectively modelled as a contact interaction.

- Quark compositeness
- New interactions from massive particles exchanged

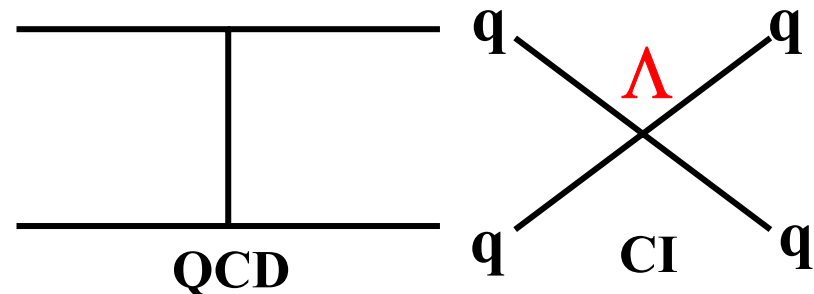
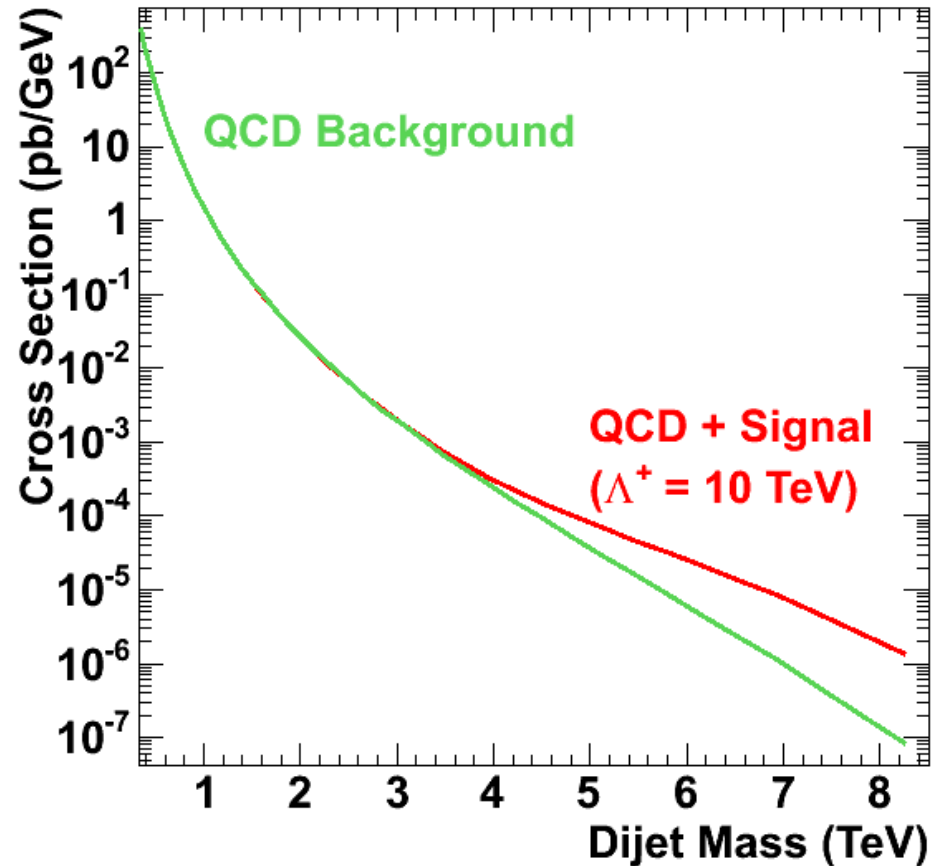


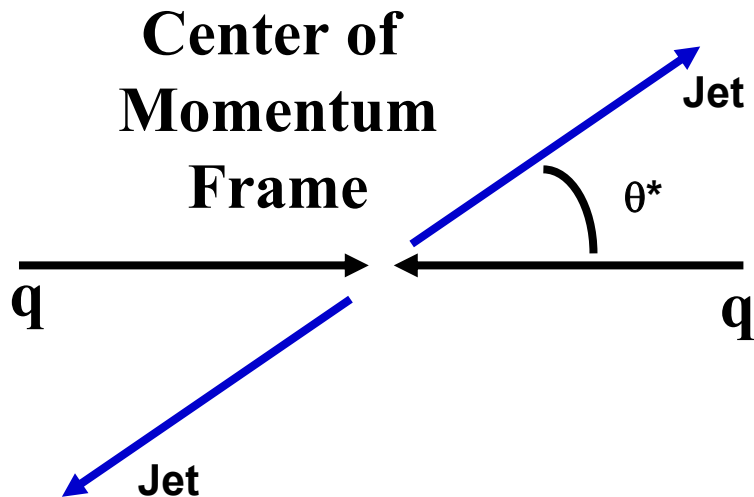
Contact interaction produces **increase in rate relative to QCD** at **high mass**

Observation in mass distribution alone requires **precise understanding of QCD cross section**

Hard to do:

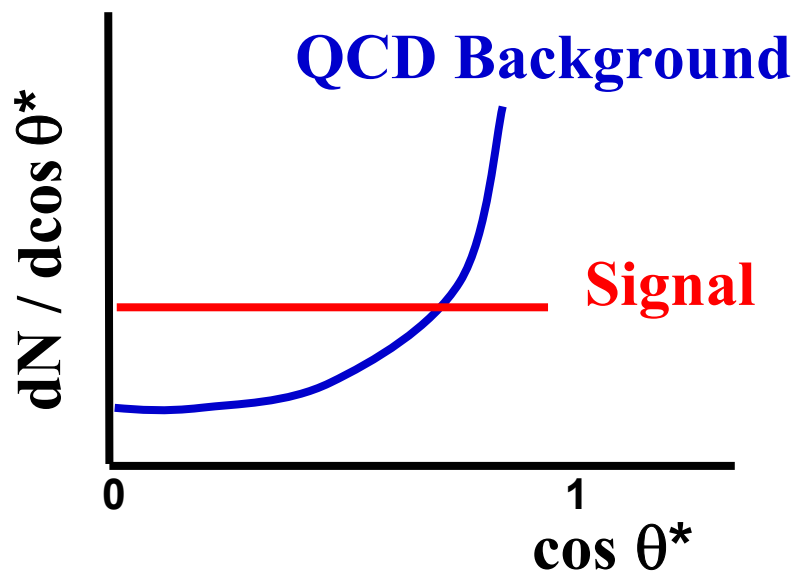
- Jet energy scale uncertainties give **large cross section uncertainties**
- Parton distribution uncertainties are **significant at high mass** = high x and Q^2





Contact interaction is often **more isotropic** than QCD

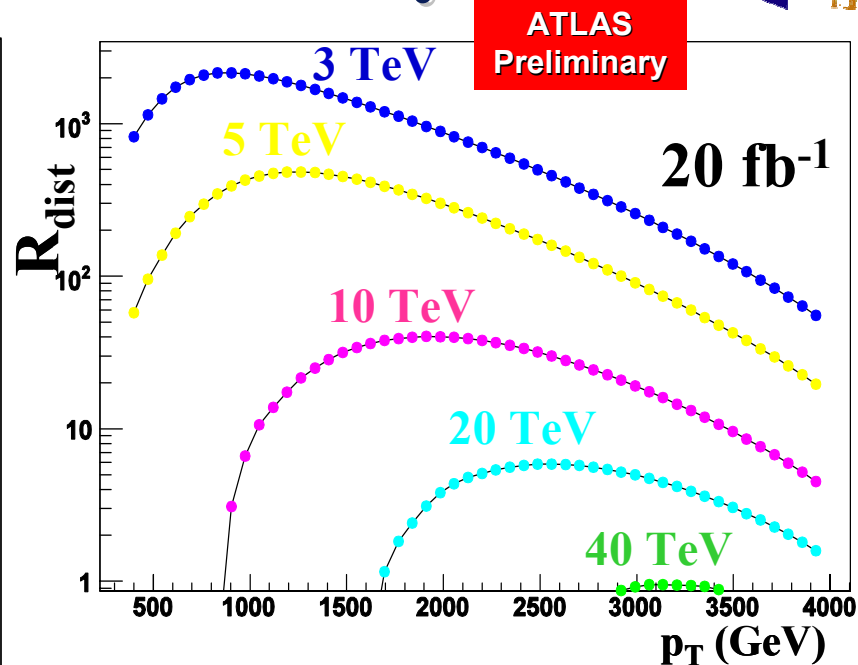
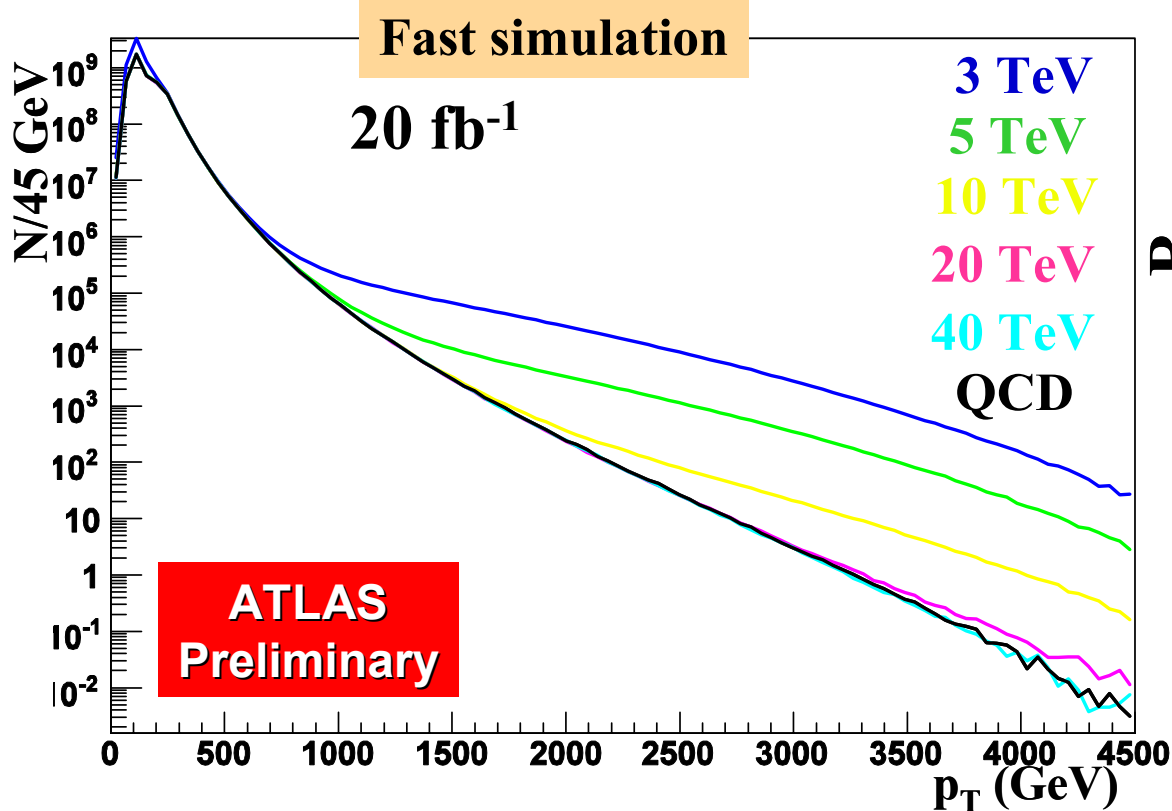
Angular distribution has much **smaller** systematic uncertainties than cross section vs. dijet mass



Effects emerge at **high mass**



ATLAS: Dijet Cross Section Contact Interaction Sensitivity



$$R = \left(\frac{N(E_T > E_T^0)}{N(E_T < E_T^0)} \right)_{\text{CH+QCD}} \left(\frac{N(E_T > E_T^0)}{N(E_T < E_T^0)} \right)_{\text{QCD}}, E_T^0 = 1100 \text{ GeV}$$

Luminosity to achieve sensitivity $R_{\text{dist}} = 3$

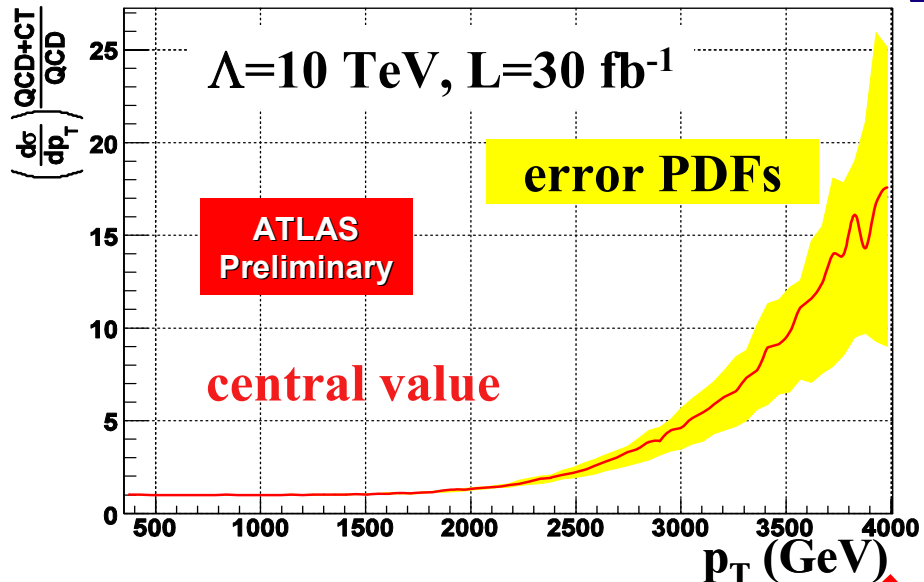
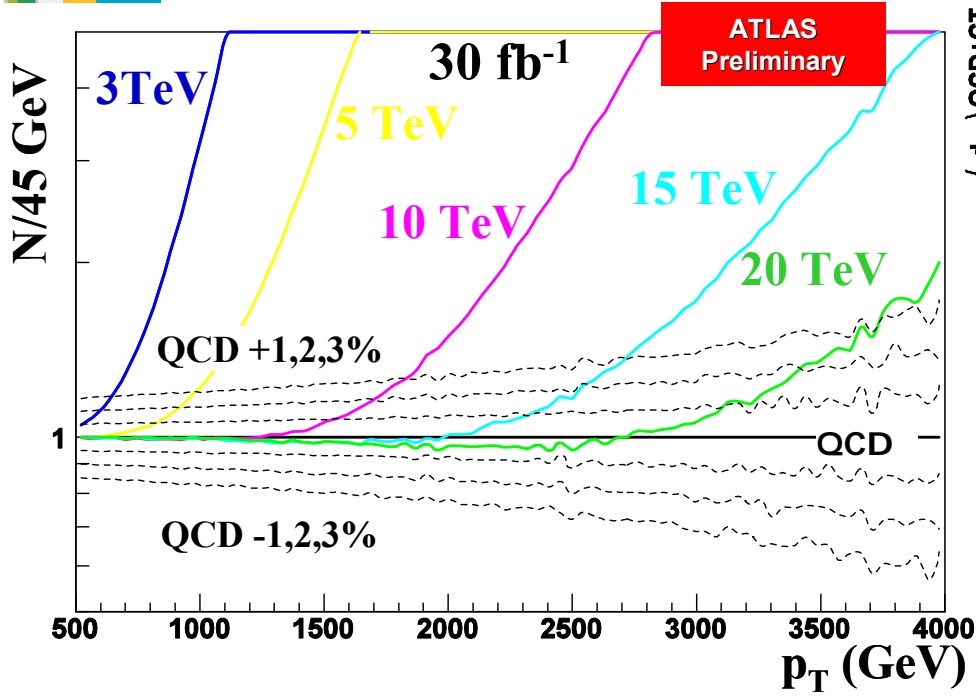
$$R_{\text{dist}} = \frac{R(\Lambda) - R(\text{SM})}{\sigma_{R(\Lambda)}}$$

No systematics

Λ (TeV)	3	5	10	20	40
Lumi	4.3 pb ⁻¹	15 pb ⁻¹	1.4 fb ⁻¹	19 fb ⁻¹	234 fb ⁻¹

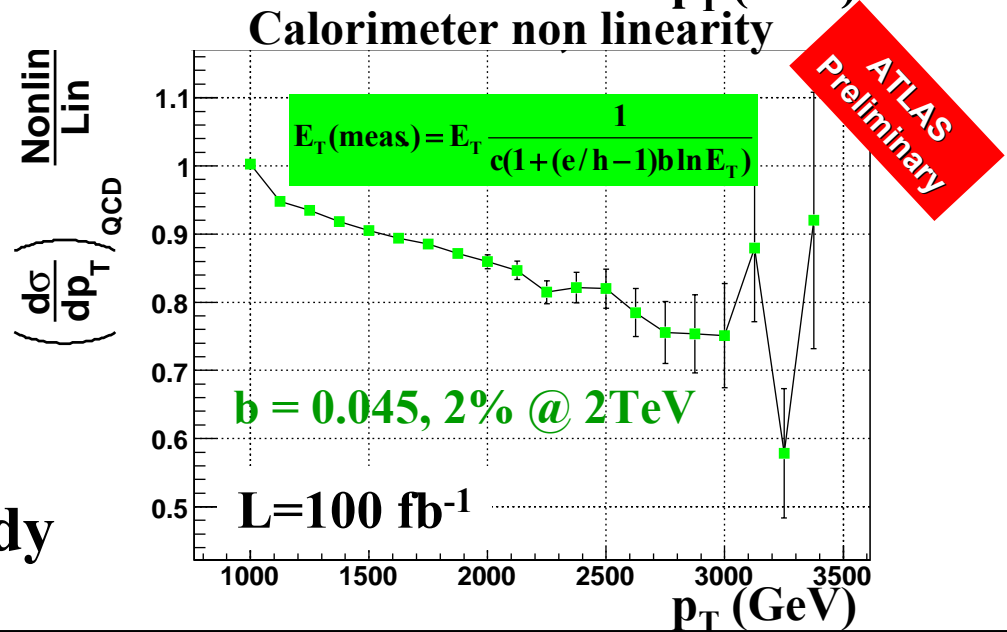


ATLAS: Dijet Cross Section Systematics



1% uncertainty in Energy Scale is enough to hide $\Lambda = 20 \text{ TeV}$

PDF and calorimeter non linearity systematic uncertainties under study



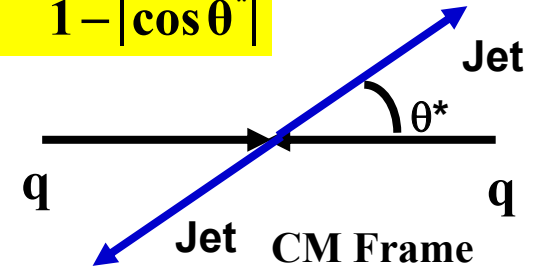


ATLAS: Dijet Angular Distributions



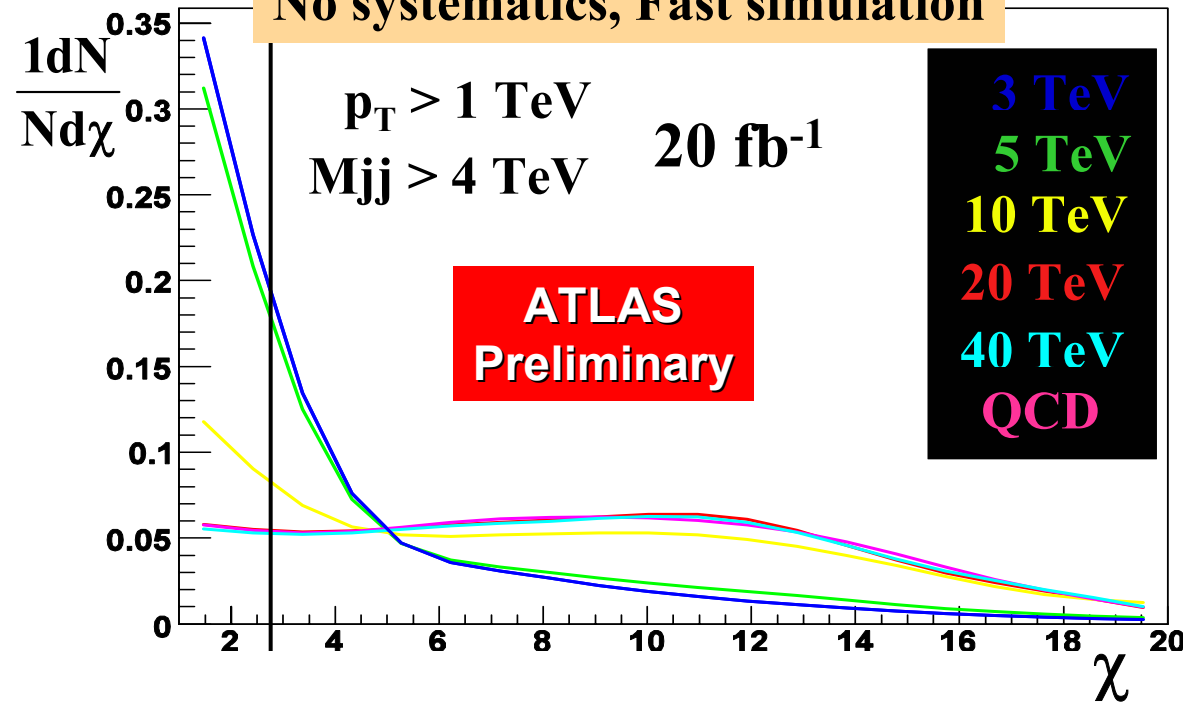
No systematics, Fast simulation

$$\chi = e^{|\eta_1 - \eta_2|} = \frac{1 + |\cos \theta^*|}{1 - |\cos \theta^*|}$$



$$R_\chi = \frac{N(\chi < \chi_{cut})}{N(\chi > \chi_{cut})}, R_1 = \frac{R_\chi(\Lambda) - R_\chi(SM)}{\sqrt{\sigma_\Lambda^2 + \sigma_{SM}^2}}$$

$\chi_{cut} = 2.8$ to maximize sensitivity



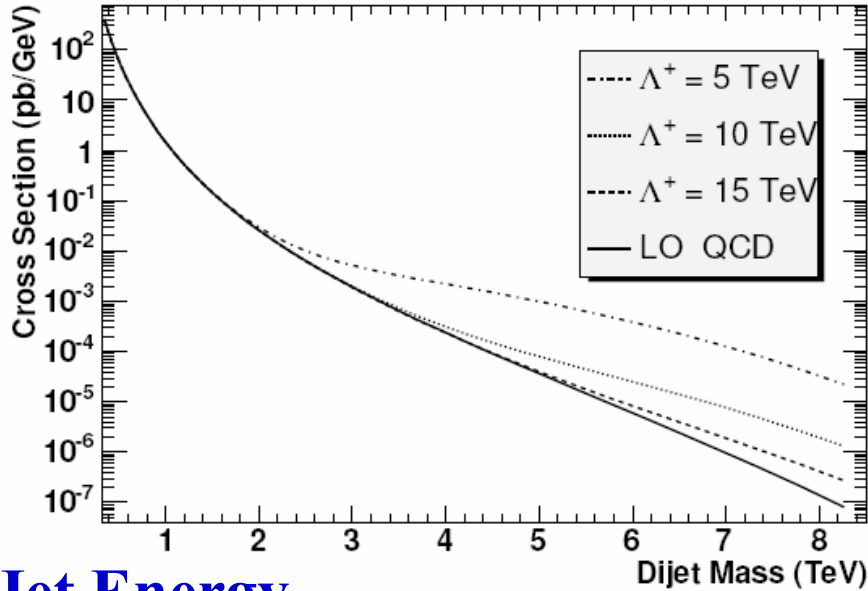
$\Lambda(\text{TeV})$	3	5	10	20	40
Lumi	$< 1 \text{ pb}^{-1}$	6 pb^{-1}	0.7 fb^{-1}	34 fb^{-1}	426 fb^{-1}

Luminosity to achieve sensitivity $R_1=3$

- High-mass dijet angular distributions with **first tens of pb^{-1}** will allow the **discovery of quark compositeness** if the constituent interaction constant is $\Lambda = 3\text{-}5 \text{ TeV}$
- **Systematics** are **expected** to be much **smaller** than for $d\sigma/dp_T$



CMS: Dijet Cross Section Contact Interaction Sensitivity



Systematic uncertainties on the cross section versus dijet mass are large

Jet Energy

CMS estimates $\pm 5\%$ is achievable

Changes dijet mass cross section 30-70%

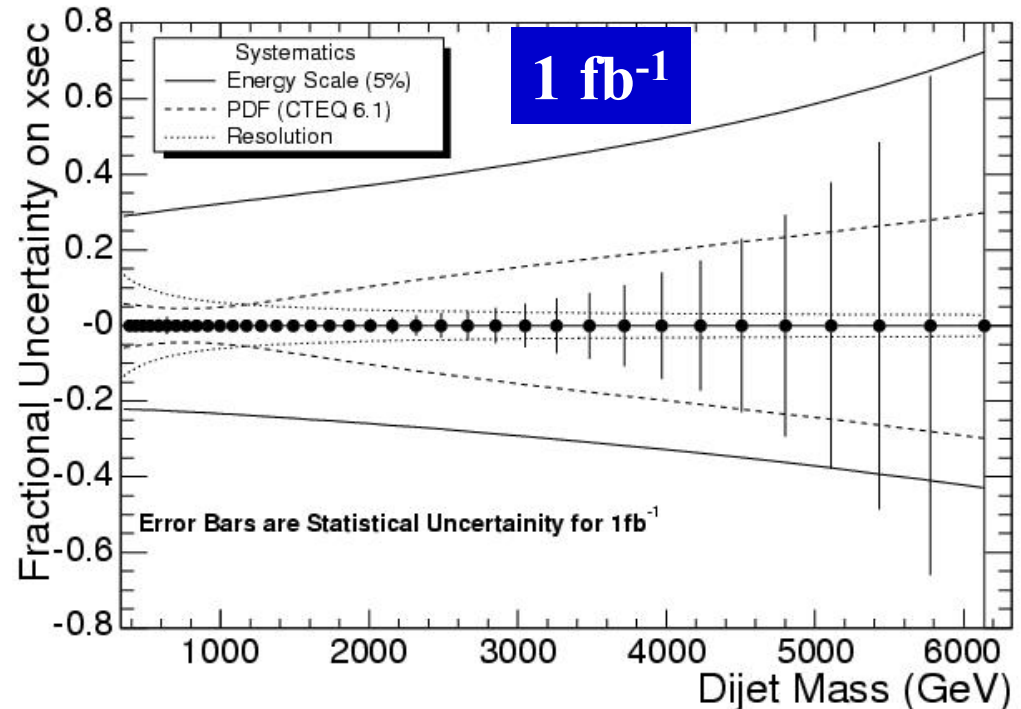
Parton Distributions

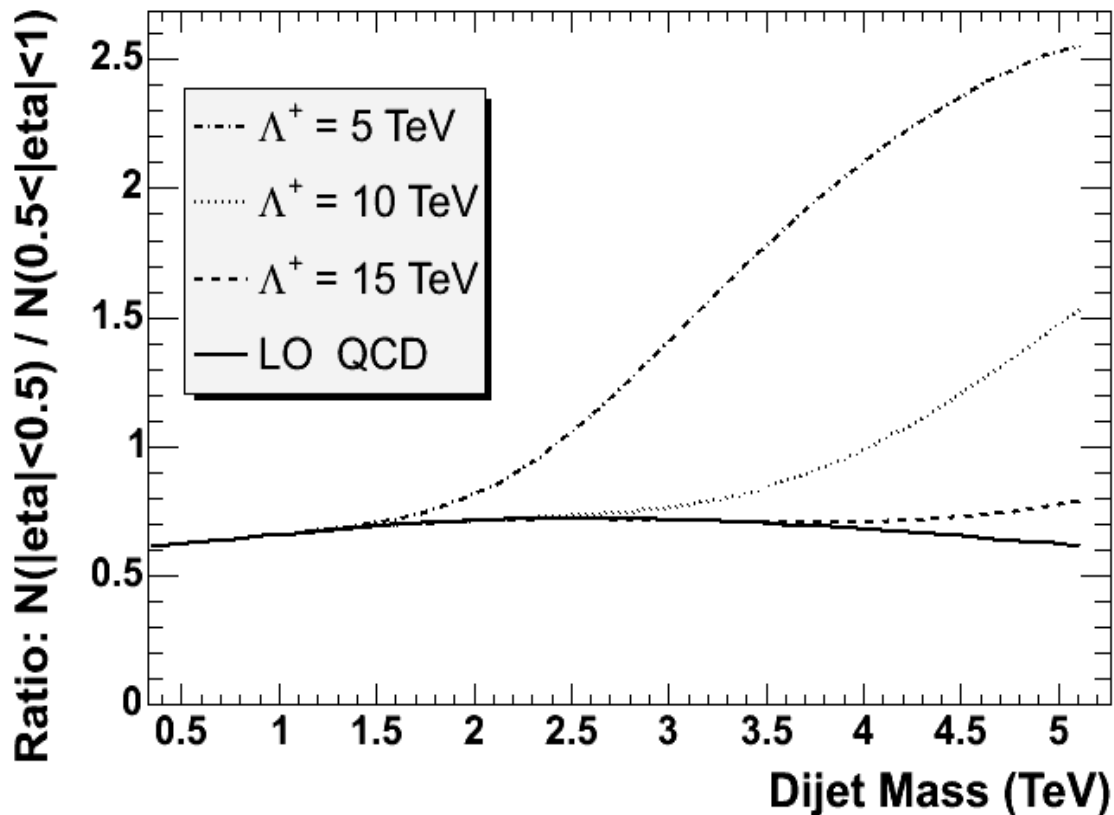
CTEQ6 uncertainty

Resolution

Bounded by difference between

hadron level and detector level jets



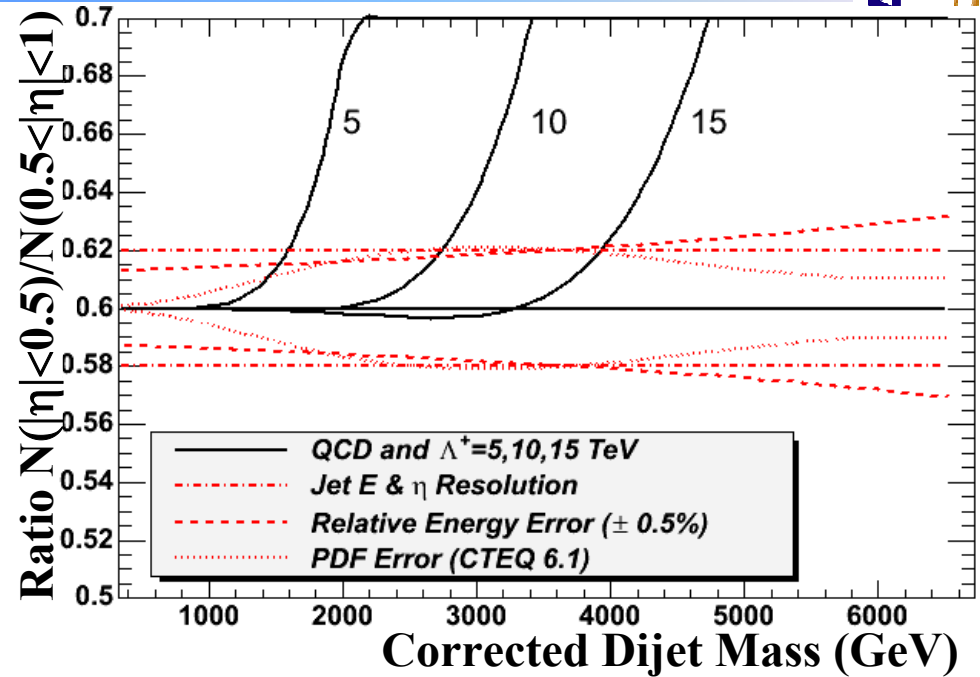
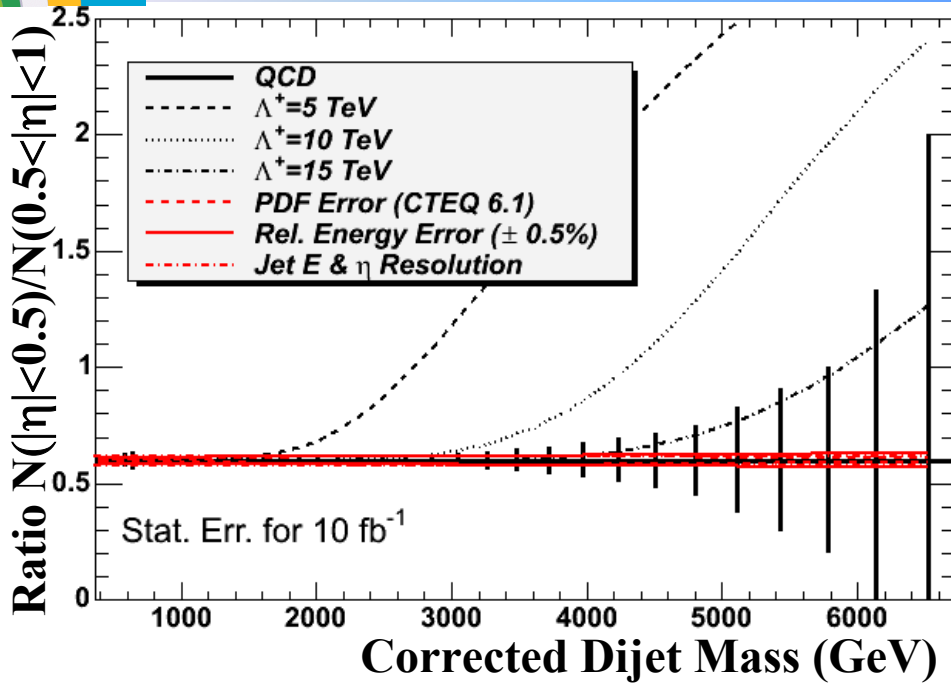


$$\text{Dijet Ratio} = N(|\eta| < 0.5) / N(0.5 < |\eta| < 1)$$

Simple measure of the most sensitive part of the angular distribution

Measure dijet ratio as a function of mass

Systematics on the dijet ratio are small



Absolute Jet Energy Scale

No effect on QCD dijet ratio:

flat vs dijet mass

Causes 5% uncertainty in Λ

Relative Energy Scale

Energy scale in $|\eta| < 0.5$ vs. $0.5 < |\eta| < 1$

Estimate $\pm 0.5\%$ is achievable in Barrel

Changes ratio between $\pm 0.01-0.03$

Resolution

No change to the ratio when changing resolution

Systematics bounded by MC statistics: **0.02**

Parton Distributions

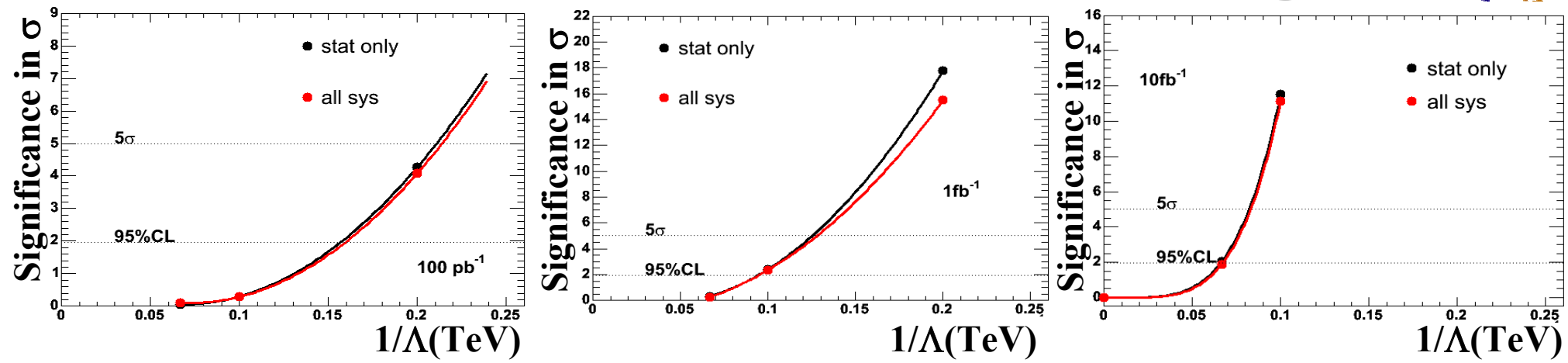
CTEQ6.1 uncertainties, Systematics on ratio **< 0.02**

No testbeam data above 300 GeV. **Discovery range** is in the regime where the **calorimetric response** is **extrapolated**



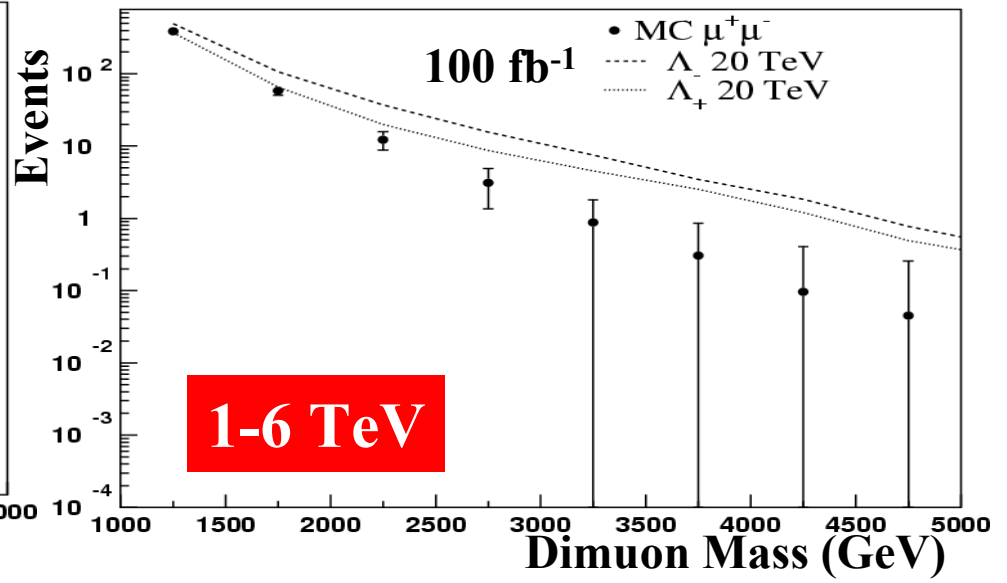
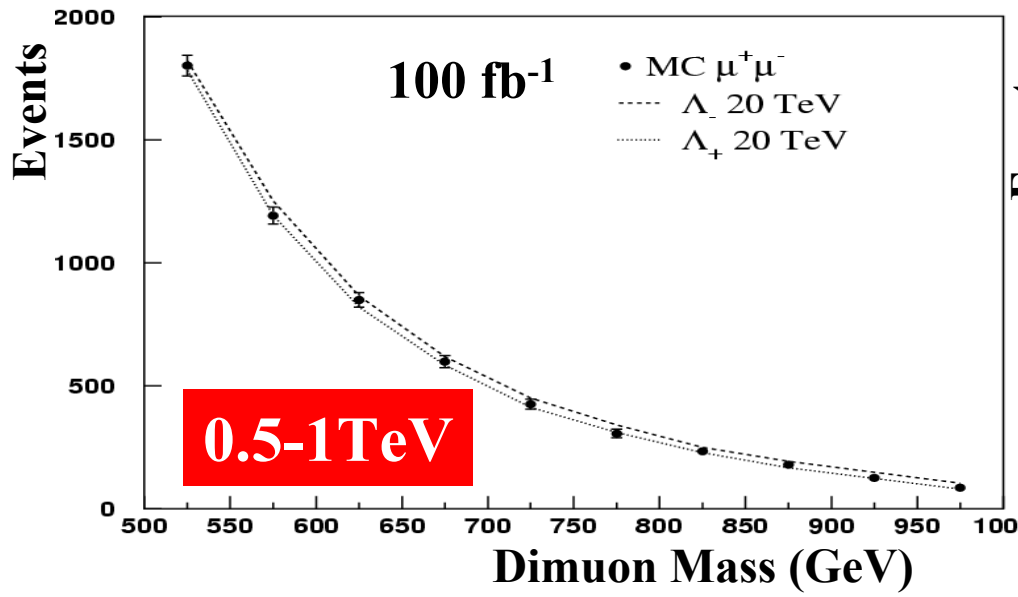
CMS: Dijet Ratio

Significance of Contact Interaction Signal

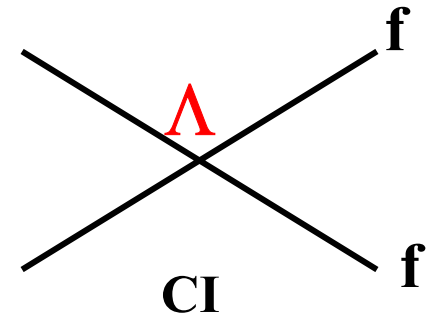
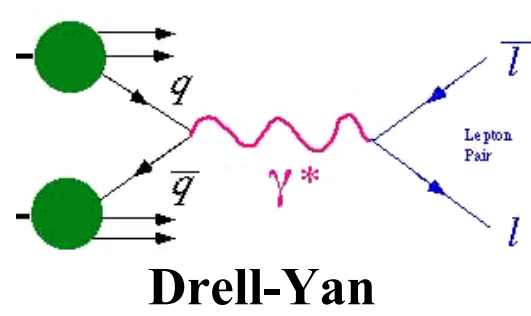


Left-Handed Quark Contact Interaction		Λ^+ for 100 pb^{-1} (TeV)	Λ^+ for 1 fb^{-1} (TeV)	Λ^+ for 10 fb^{-1} (TeV)
95% CL Exclusion	Stat Only	6.4	10.6	15.1
	All Syst	6.2	10.4	14.8
5σ Discovery	Stat Only	4.7	8.0	12.2
	All Syst	4.7	7.8	12.0

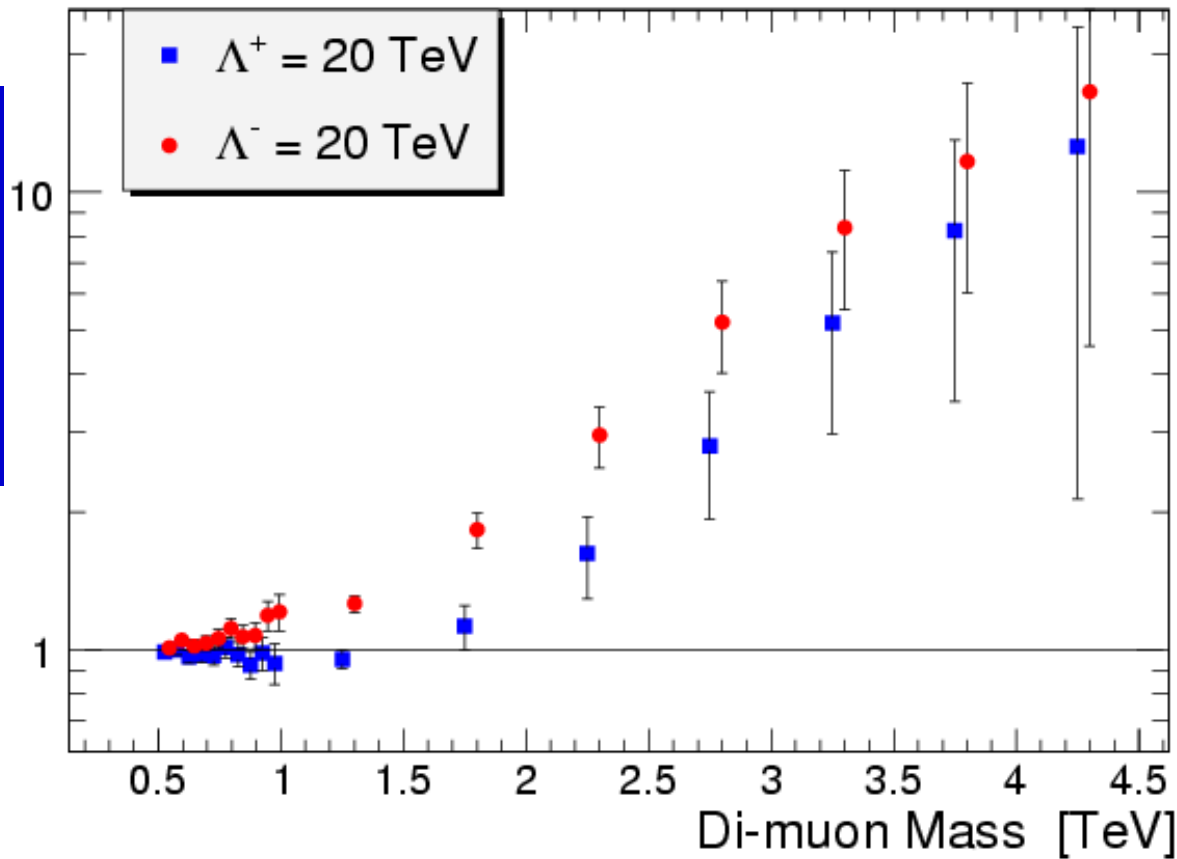
D0 excludes at 95%CL scales of $\Lambda^+ < 2.7 \text{ TeV}$ with 100 pb^{-1} (hep-ex/9807014)



Main sensitivity from cross section @ ~ 1 TeV and higher



Double Ratio



Absolute Efficiency,
EW corrections, ...
cancel out in a ratio

mass bin 250-500 GeV
for **normalization**

- SM valid - Tevatron
- u quark PDF dominant
which has the smallest
uncertainty

$$R_i^{DATA} = N_i^D / N_0^D = \sigma_i^D \cdot \epsilon_i^D / \sigma_0^D \cdot \epsilon_0^D$$

$$R_i^{MC} = N_i^{MC} / N_0^{MC} = \sigma_i^{MC} \cdot \epsilon_i^{MC} / \sigma_0^{MC} \cdot \epsilon_0^{MC}$$

Double ratio: $DR_i = R_i^{DATA} / R_i^{MC}$

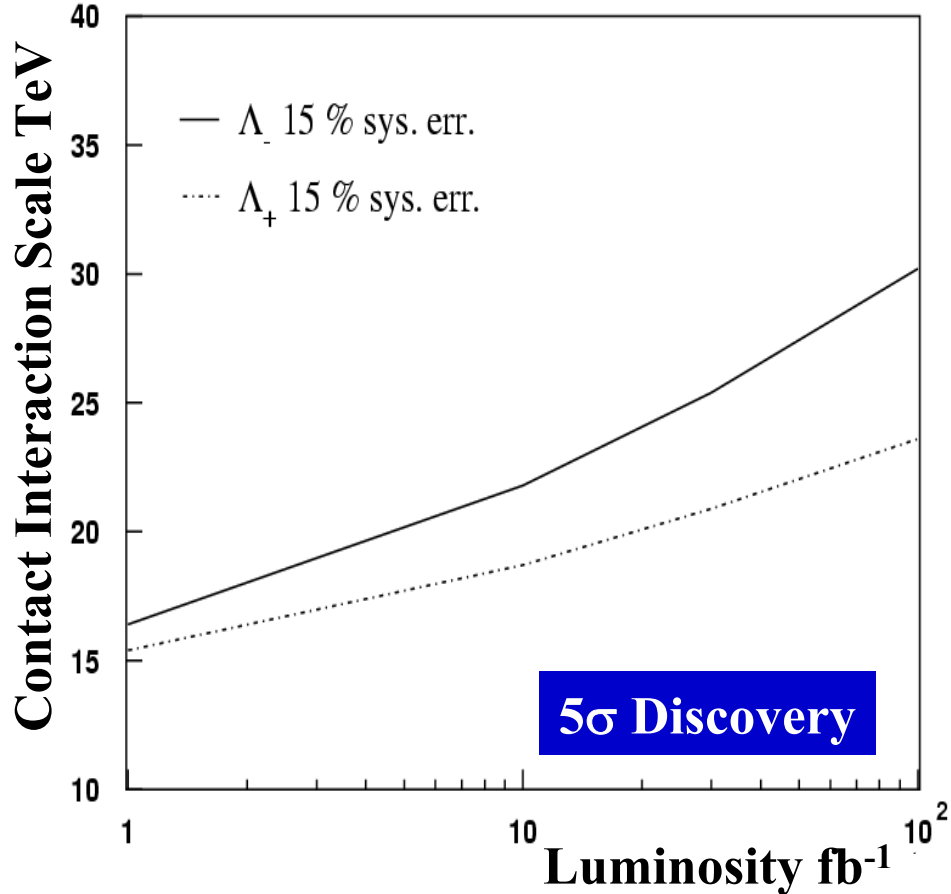
If theory understanding and detector modeling are both perfect $DR_i = 1$



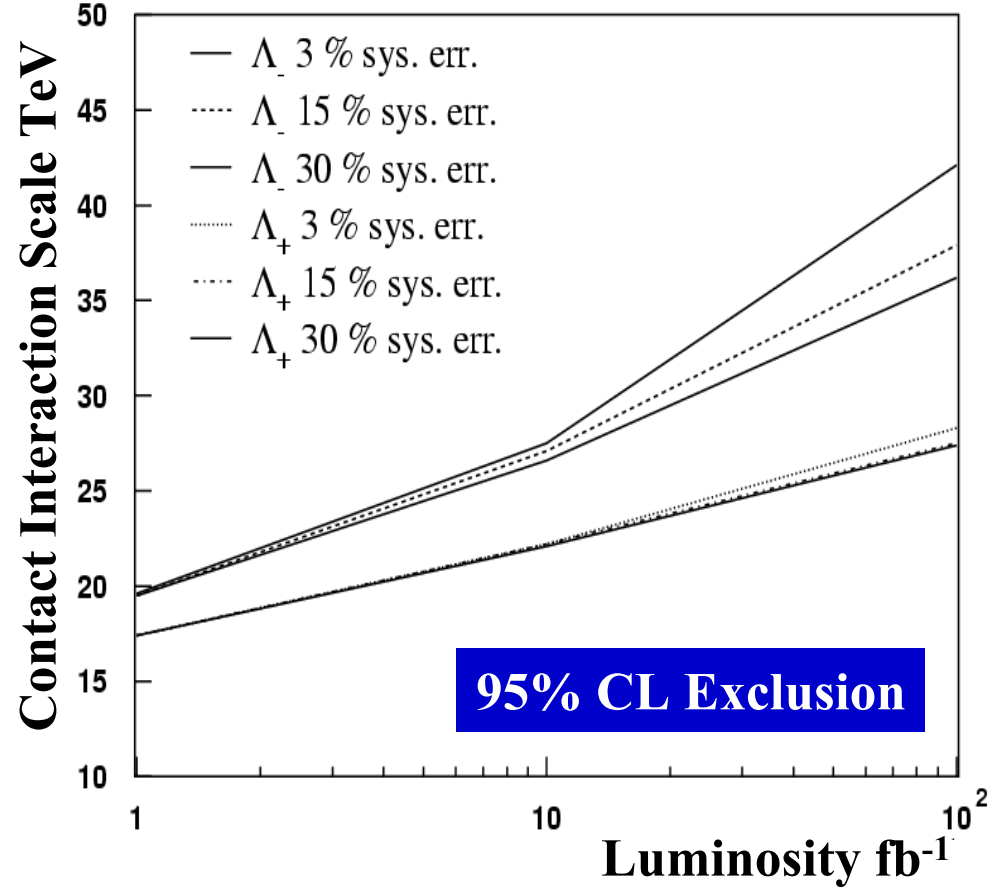
CMS: Dimuon Contact Interactions Discovery Reach



Contact Interactions LL 5σ Discovery in CMS at LHC



Contact Interactions LL 95 % CL Exclusion in CMS at LHC



Up to 10 fb^{-1} (higher for Λ_+) dominated by statistical errors

Even 30 % systematic errors have small impact



Summary



Contact interactions at a scale Λ are generally observed **before any exchanged particle is directly seen**

Many techniques have been developed and show good results with low systematic effects:

- Angular distributions and simple angular ratios (jets)**
- Double ratio (dimuons)**

Sensitivity of the LHC experiments to contact interactions has been investigated

- The **first hundred pb^{-1}** of data will allow the **discovery** of **contact interactions with Λ up to $\sim 5 \text{ TeV}$****
- **100fb^{-1}** of data allows **discovery** of compositeness up to **$\sim 30\text{TeV}$****