Testing NSI at colliders

NTN Workshop 05.29.2019

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Motivation

$$\mathcal{L}_{\rm NSI} = -2\sqrt{2}\, G_F \varepsilon^{fP}_{\alpha\beta} \left(\overline{\nu}_\alpha \gamma_\rho \nu_\beta\right) \left(\overline{f}\gamma^\rho P f\right)$$

Collider Physics

Solar neutrino exp.

Atmospheric neutrino exp.

NSI

Reactor neutrino exp.

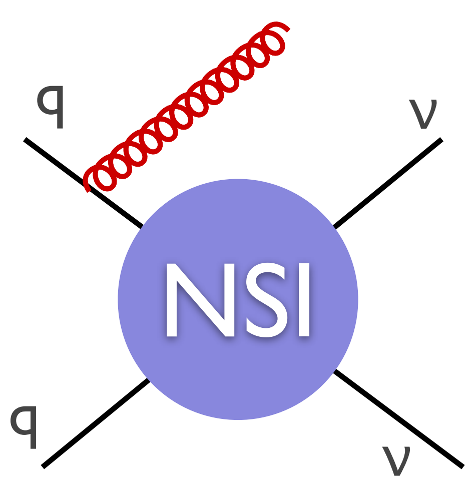
Beam neutrino exp.

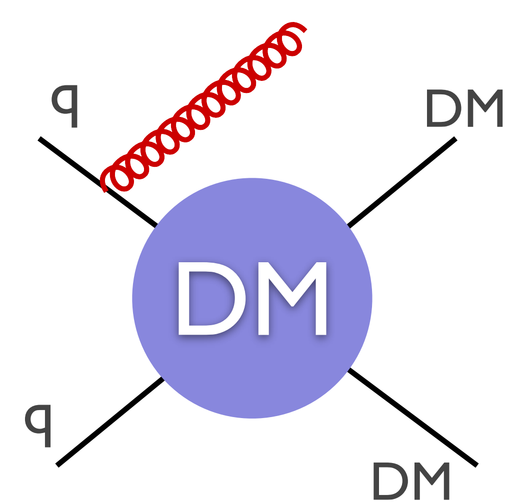
see Ivan's talk for global constraints on NSI

Motivation

$$\mathcal{L}_{\rm NSI} = -2\sqrt{2}\, G_F \varepsilon^{fP}_{\alpha\beta} \left(\overline{\nu}_\alpha \gamma_\rho \nu_\beta\right) \left(\overline{f} \gamma^\rho P f\right)$$

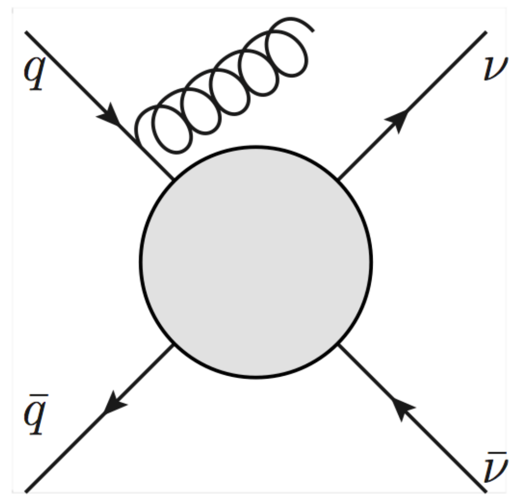
- In general, NSI contains both flavor-changing and flavor-diagonal interactions.
  Flavor-changing - No SM analog
  Flavor-diagonal - Interfere with SM background (can display non-trivial differences to DM scenario)

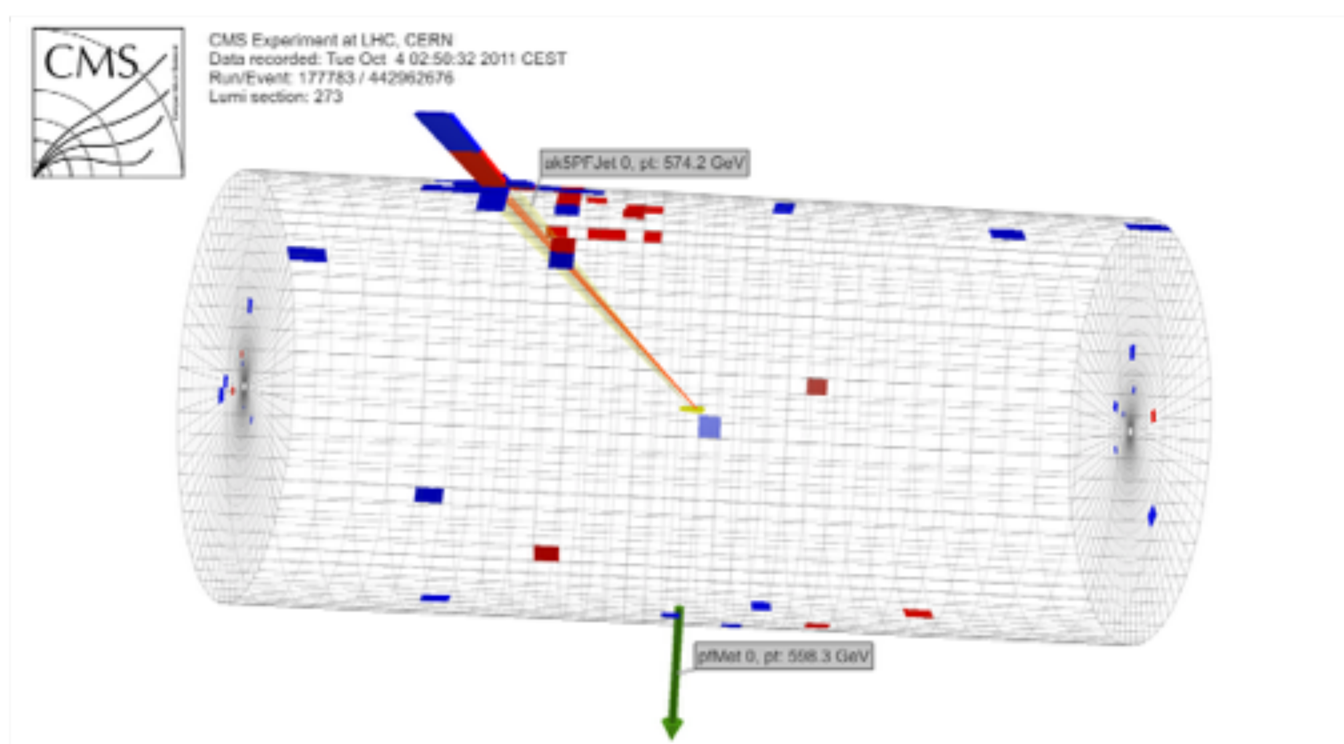




NSI at colliders

$$\mathcal{L}_{\text{NSI}} = -2\sqrt{2}\, G_F \varepsilon^{fP}_{\alpha\beta} \left(\overline{\nu}_\alpha \gamma_\rho \nu_\beta\right) \left(\overline{f}\gamma^\rho P f\right)$$





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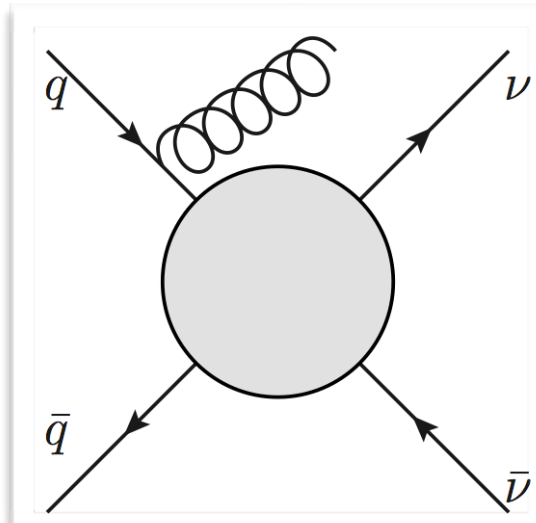
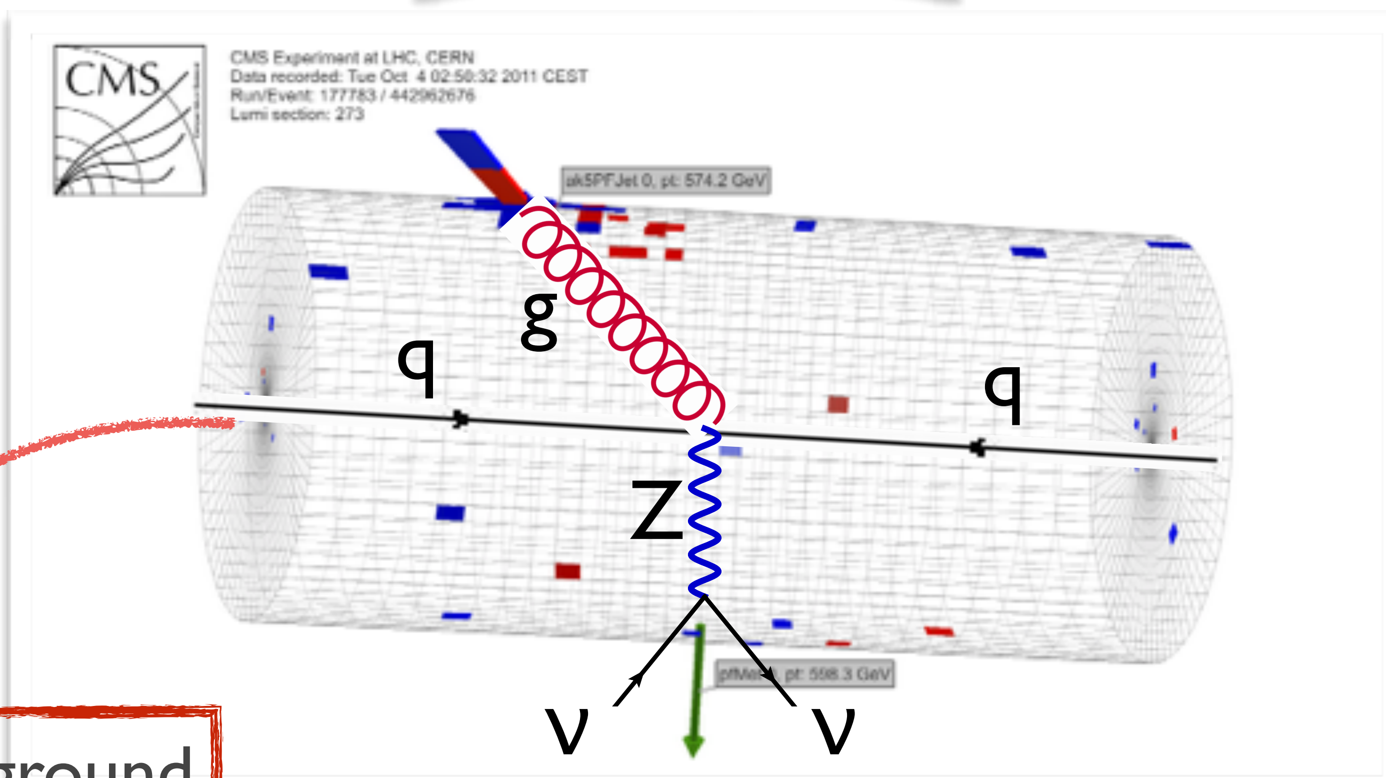
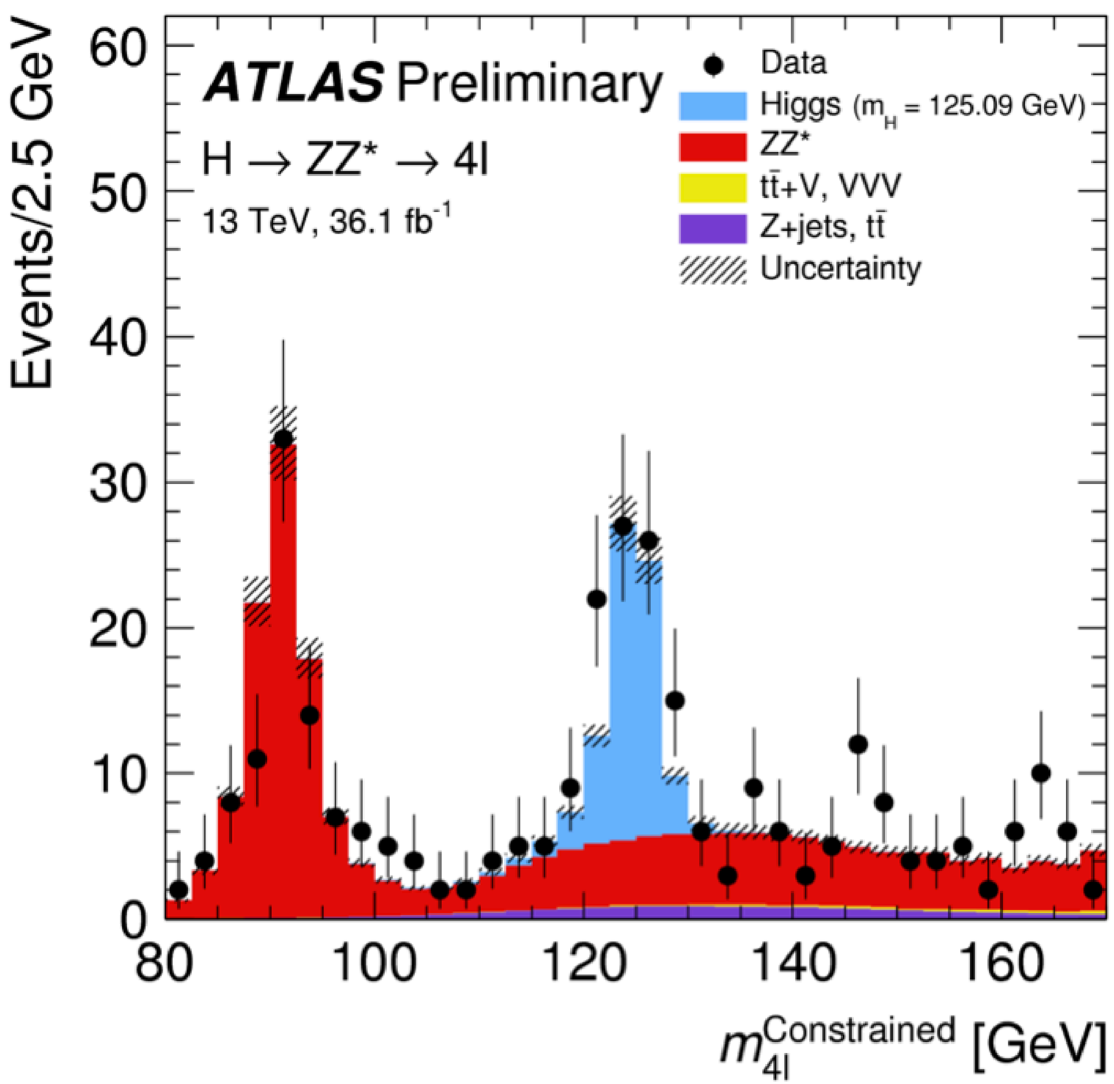


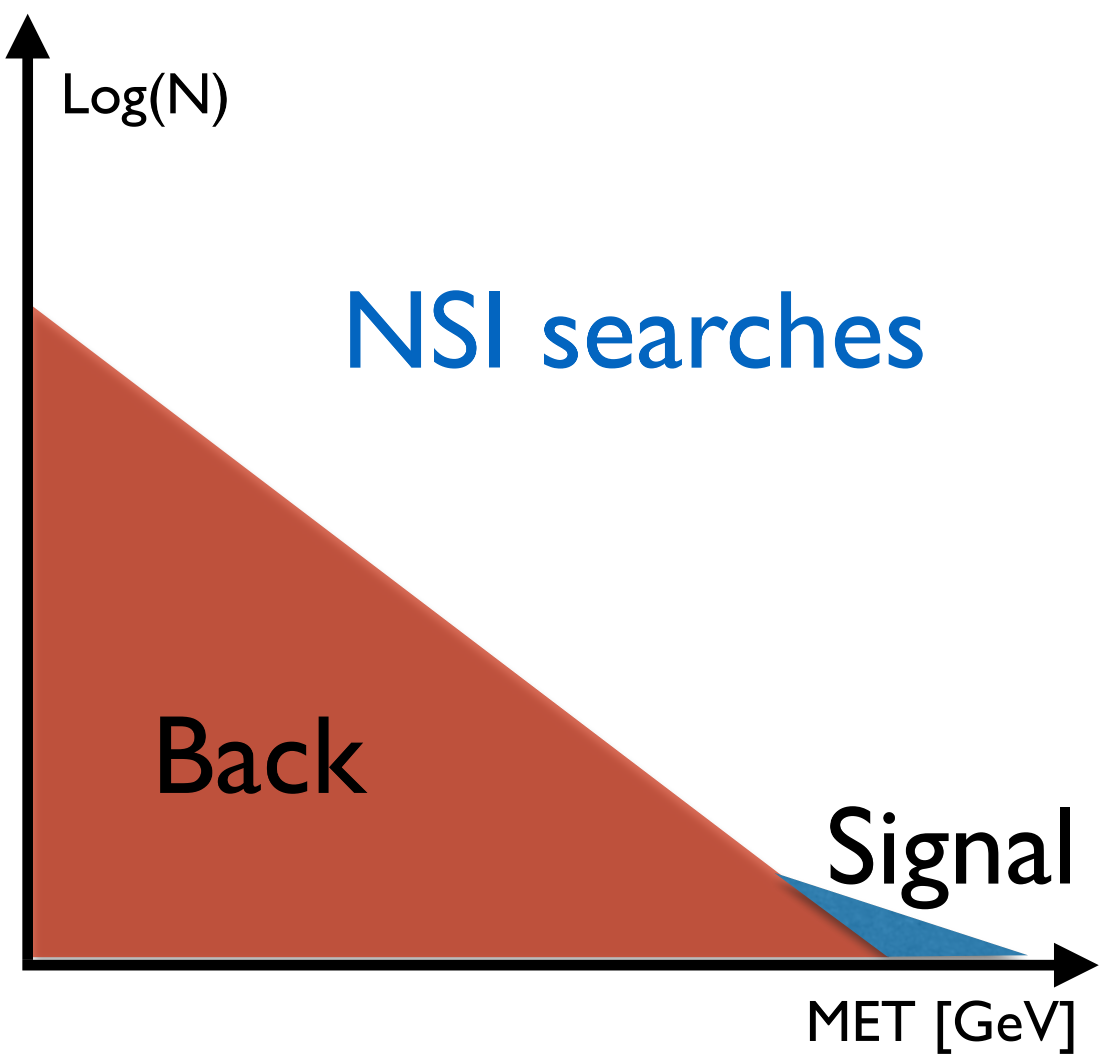


Irreducible SM background

NSI at colliders



vs.

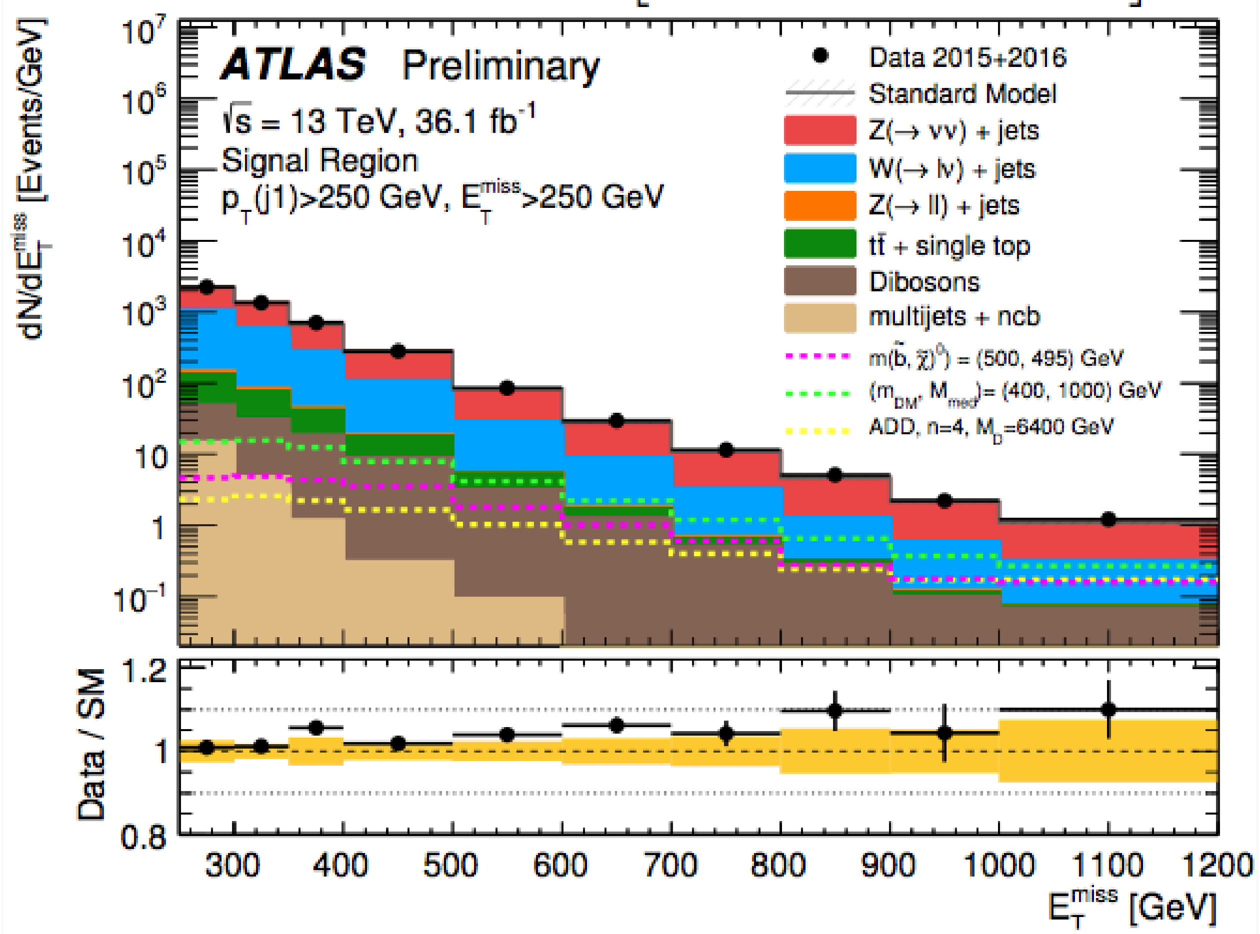


- Overwhelming SM background
- Signal: small enhancement in the tail of MET distribution

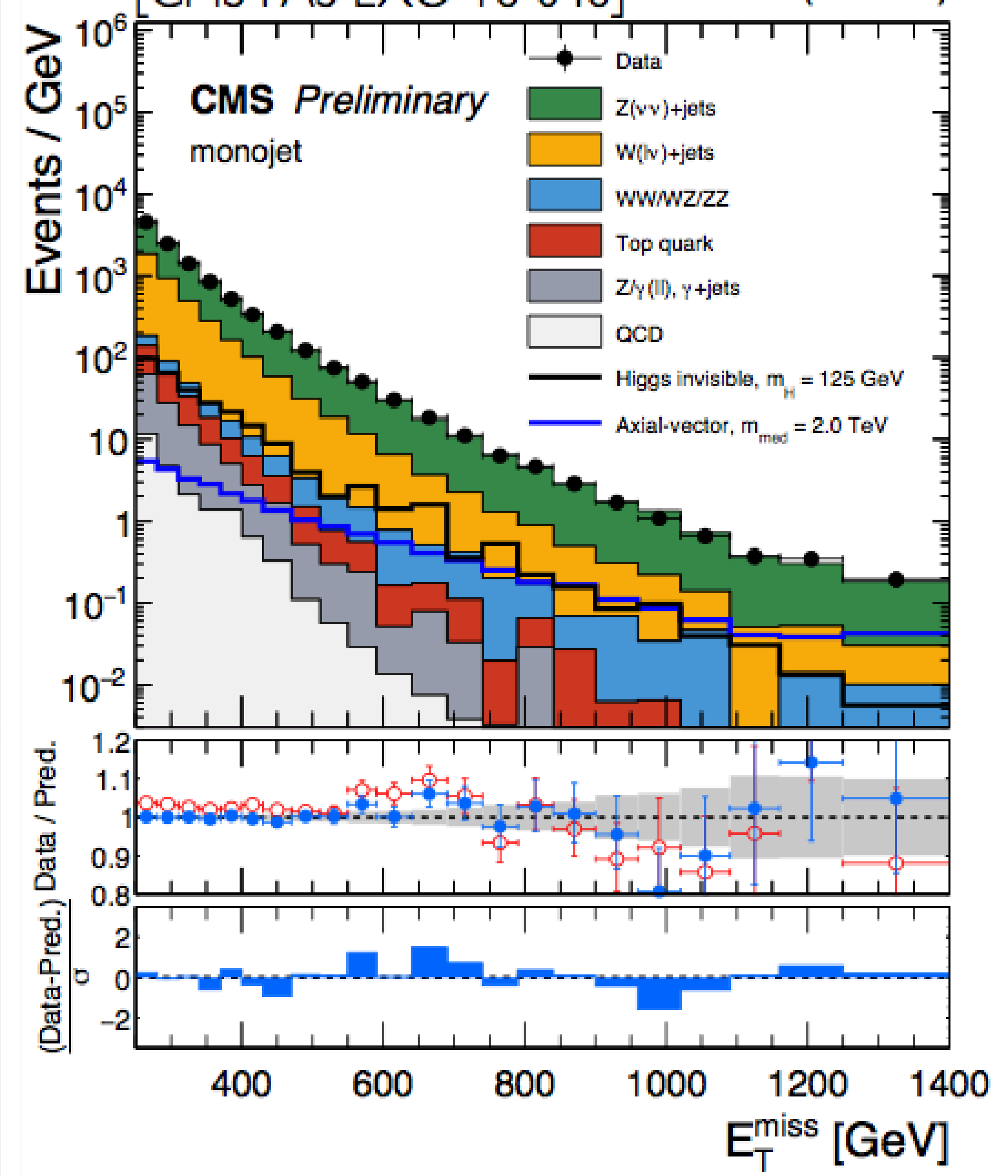
➡ Big challenge: requires precise estimation of background

Background composition

[ATLAS-CONF-2017-060]



[CMS PAS EXO-16-048]



- Dominant backgrounds:

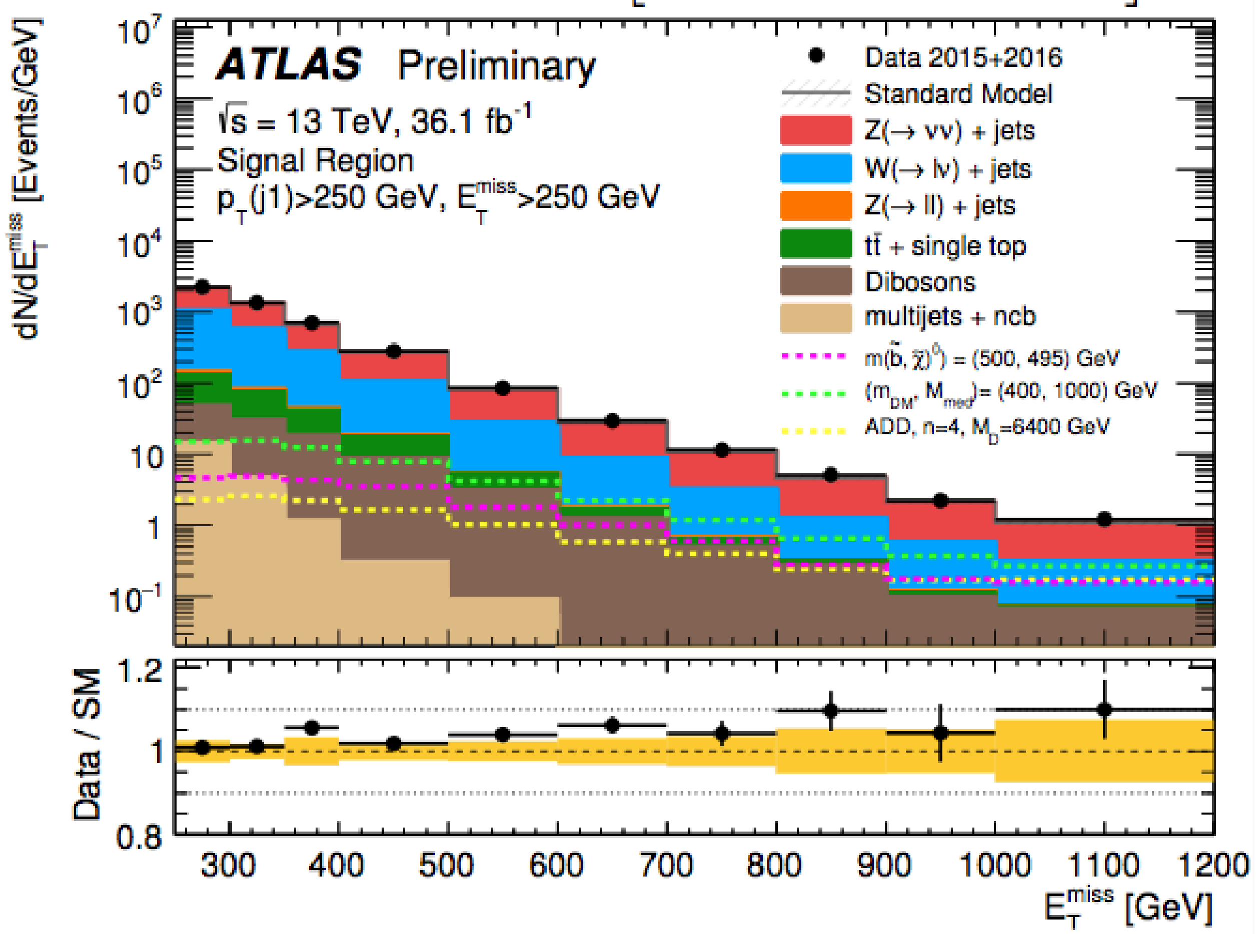
$pp \to Z(\to \nu\bar{\nu})+\text{jets} \;\Rightarrow\; \text{MET} + \text{jets}$

$pp \to W(\to l\nu)+\text{jets} \;\Rightarrow\; \text{MET} + \text{jets}$ (lost lepton or hadronic taus)

→ Major limitation for NSI bounds: large and uncertain backgrounds. Background syst. ~5%

Background composition

[ATLAS-CONF-2017-060]



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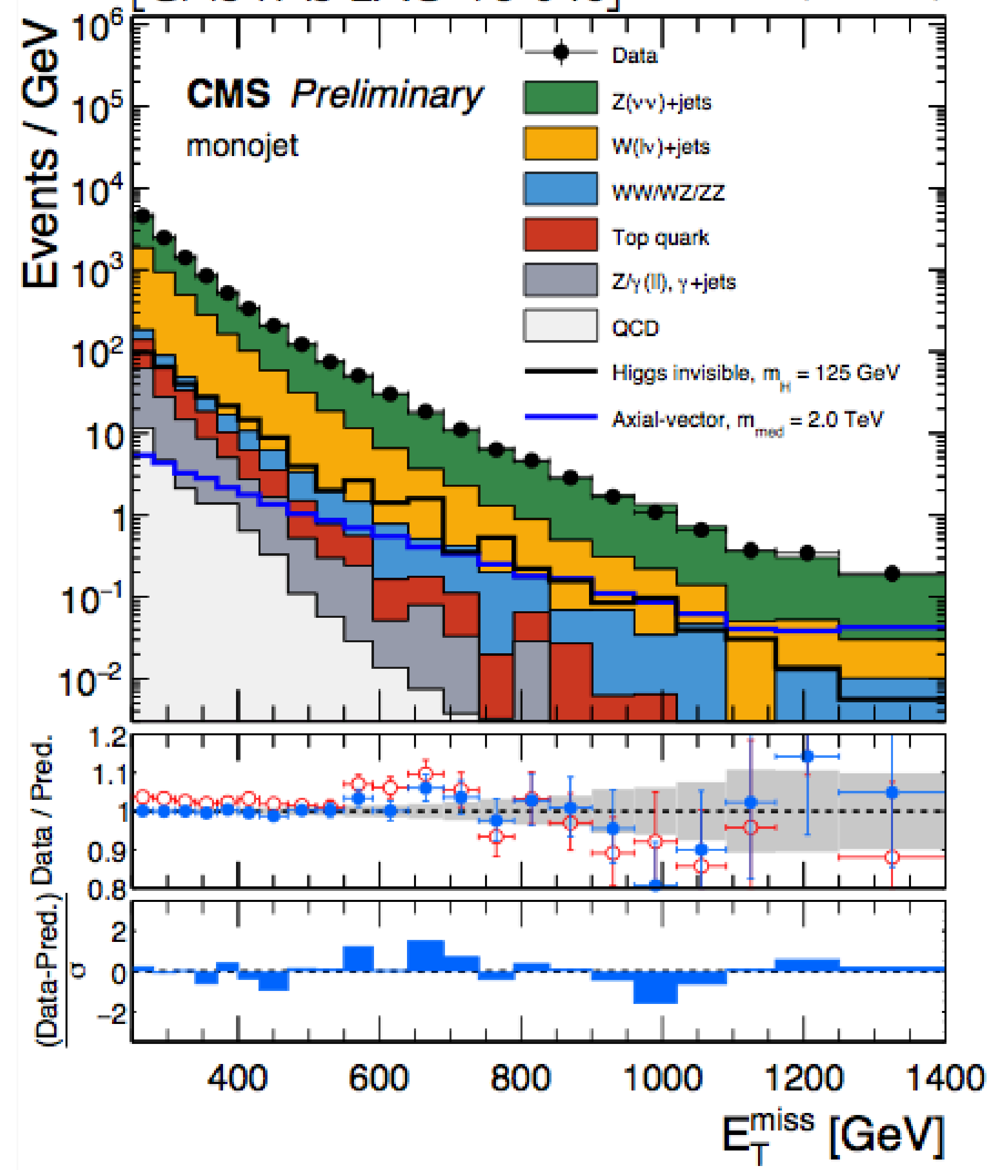

- Dominant backgrounds:

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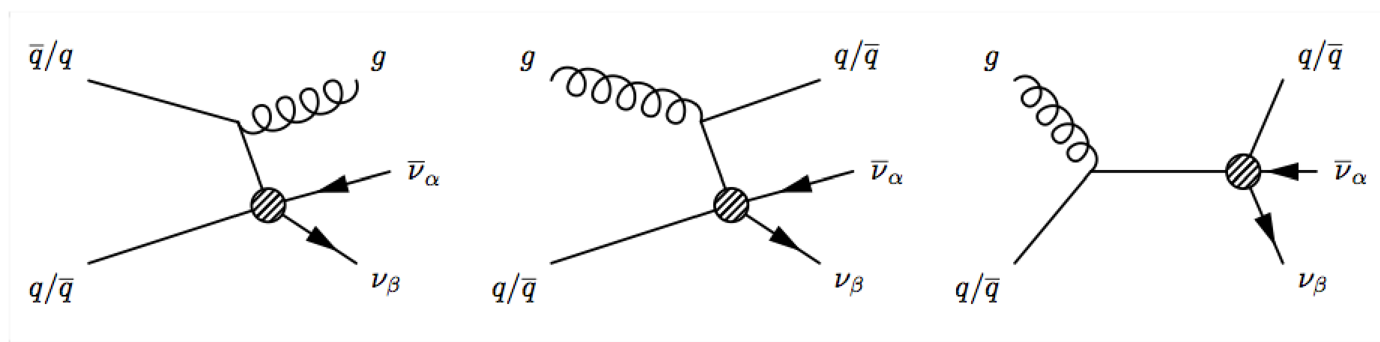
$pp \to W(\to l\nu)+\text{jets} \implies \text{MET} + \text{jets}$ (lost lepton or hadronic taus)

→ New theoretical and experimental efforts are significantly suppressing this syst. constraint

Contact NSI

- Monojet signature: $\mathcal{L}_{NSI} = -2\sqrt{2}\, G_F\, \epsilon^{qX}_{\alpha\beta}\, (\bar{q}\gamma_\mu P_X q)\,(\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta) + H.c.$



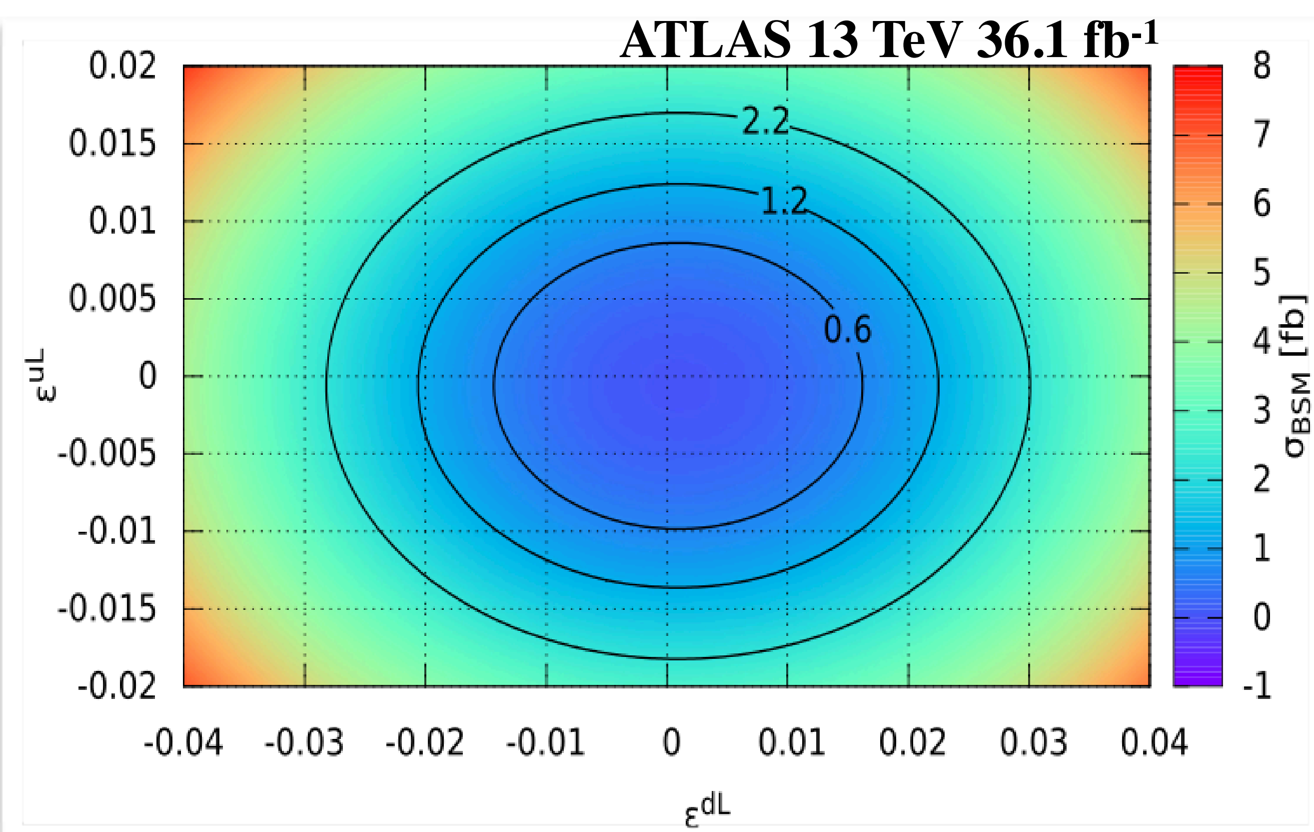
$$\sigma(pp \to j\bar{\nu}_\alpha \nu_\beta) = \sigma_{\rm SM} + \varepsilon\sigma_{\rm int} + \varepsilon^2 \sigma_{\rm NSI}$$

→ Different choices of (α,β) lead to same observables: indistinguishable from each other

- Limiting single pair of op. at a time

→ $a_u < a_d$ larger densities for u-quark in the proton

→ $\sigma_{int}/\sigma_{BSM}$ can be as significant as 50%



Choudhury, Ghosh, Niyogi '18; see also Friedland, Graesser, Shoemaker, Vecchi '12; Davidson, Sanz '11

Contact NSI

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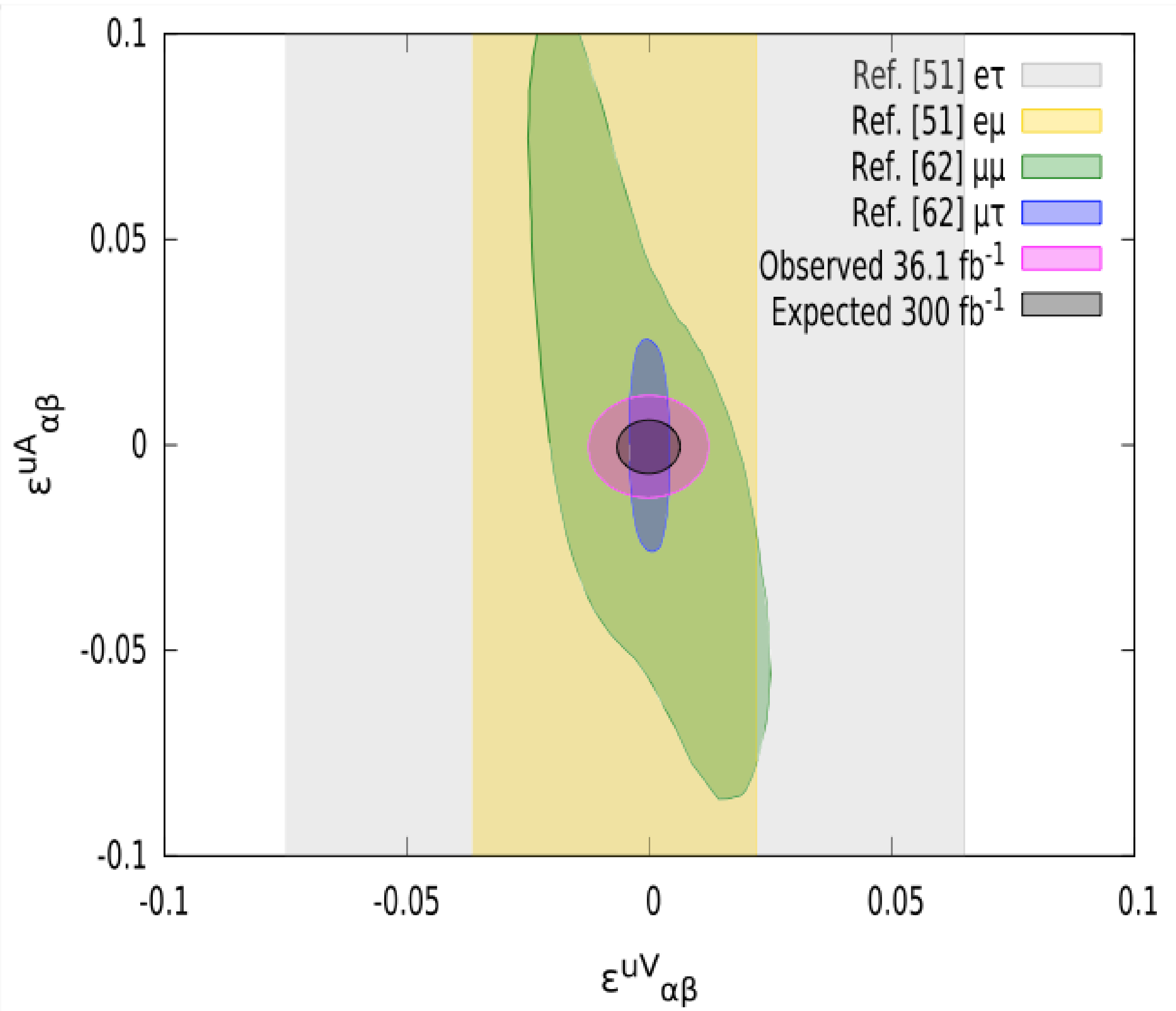

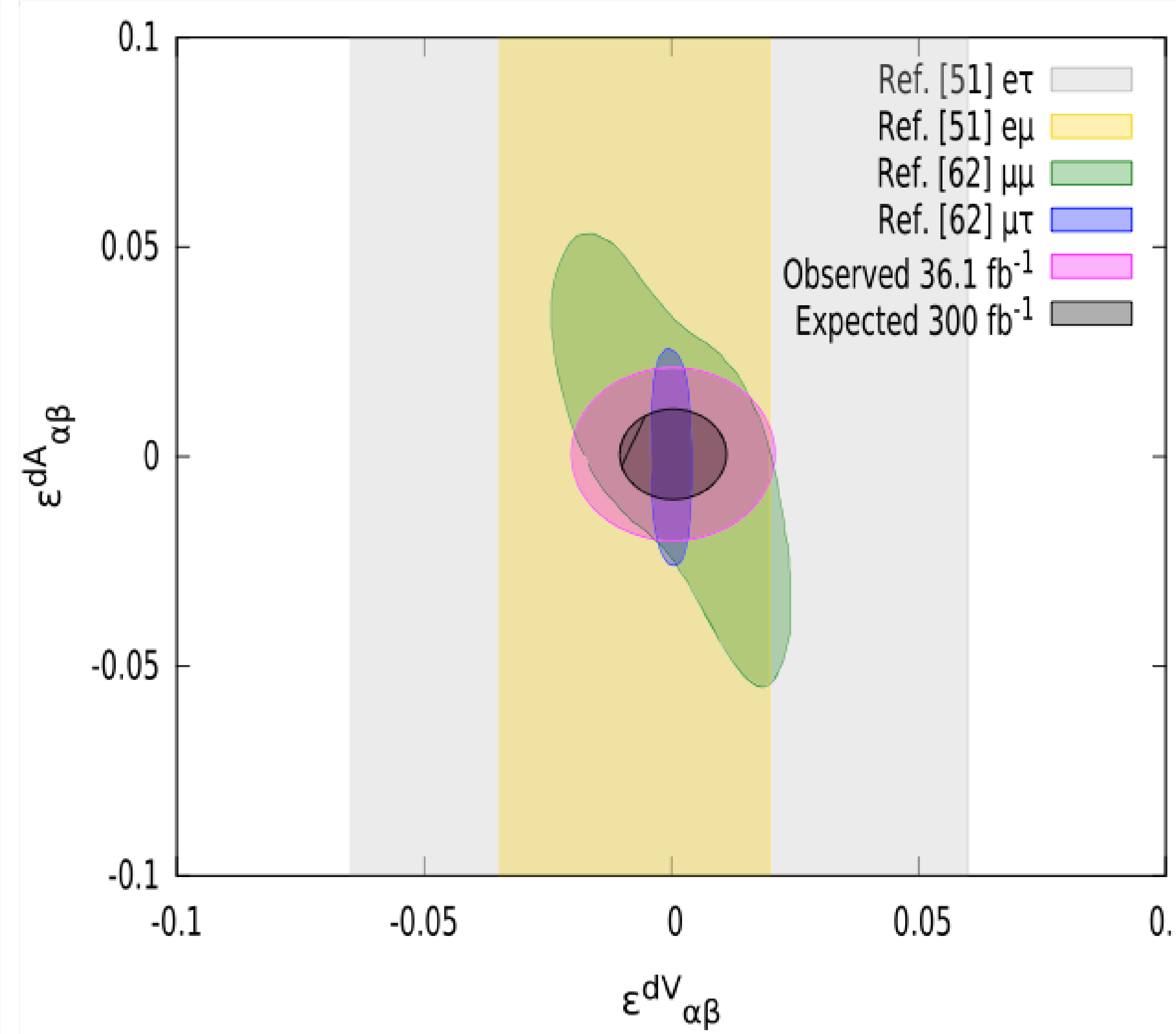

Choudhury, Ghosh, Niyogi '18

- Ref. [51] neutrino oscillation bounds Coloma, Gonzalez-Garcia, Maltoni, Schwetz '17;
- Ref. [62] global fit atmospheric with accelerator neutrino data Escrihuela, Miranda, Tórtola, Valle '11

→ LHC u-quark currents results are significantly stronger than neutrino exp. d-quark currents are very competitive

Caveat: LHC bounds hold for the contact interaction limit. Light mediator can completely change the picture

Effective Field Theory Description

- Model independent approach to NSI searches
- NSI bounds with few parameters
- Valid in the presence of an energy gap: $M_* \gg E$

M_*: New physics effective scale

E: Relevant process energy scale

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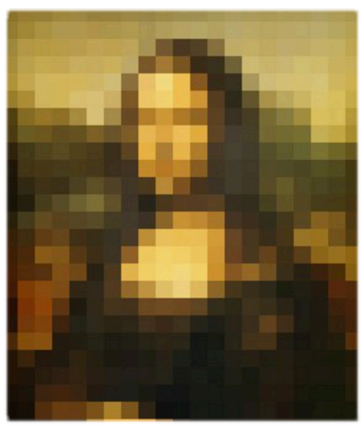


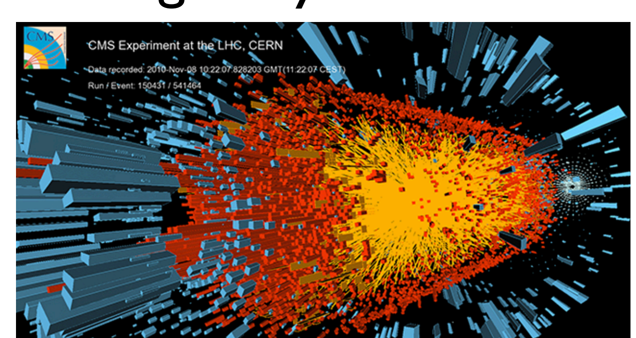
DUNE, CHARM, NuTeV…

M_W ~ 1 TeV **New States** say/hope ~ 10 TeV E

—— EFT ~OK ——→

Integrate out UV physics associated to NSI & describe interactions with eff ops.

LHC can go beyond EFT validity



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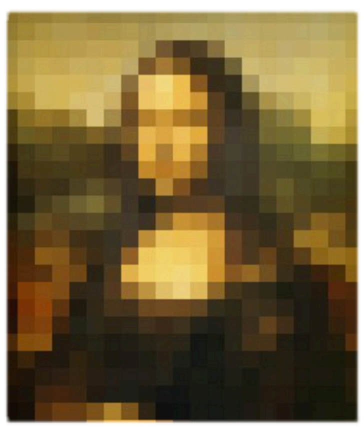

DUNE, CHARM, NuTeV…

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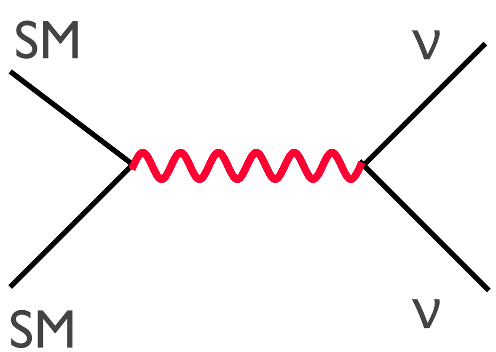
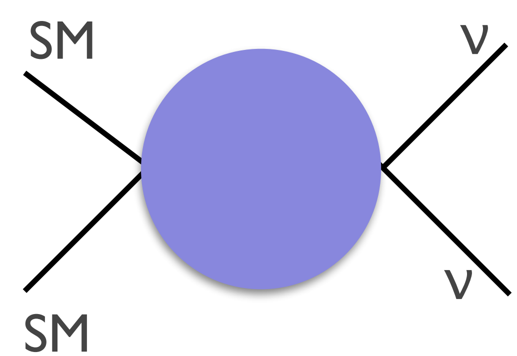
Babu, Friedland, Machado, Mocioiu '17

Pospelov '11



$$\frac{g_q g_\chi}{M_{med}^2 - Q_{tr}^2} \sim \frac{g_q g_\chi}{M_{med}^2} = \frac{1}{M_*^2}$$



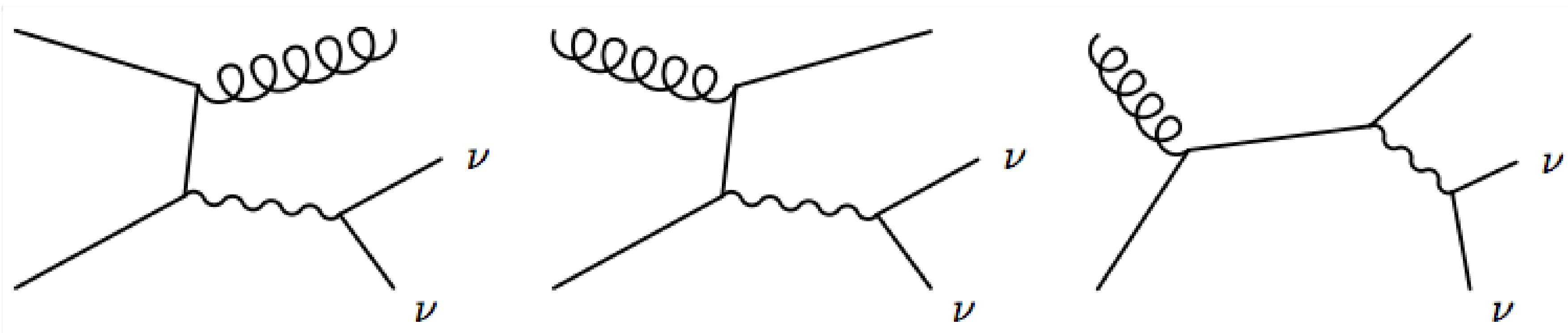
- For a given choice of $\sqrt{g_q g_\chi}$, use only events that satisfy $Q_{tr} < M_{med} = \sqrt{g_q g_\chi} M_*$

Simplified Model for NSI

$$\mathscr{L}_{NSI} = -2\sqrt{2} G_F \varepsilon^{fP}_{\alpha\beta} (\overline{\nu}_\alpha \gamma_\rho \nu_\beta) (\overline{f} \gamma^\rho P f)$$

$$\mathscr{L}_{\rm NSI} = g_\nu (\overline{\nu} P_L \gamma_\mu \nu) R^\mu + (\overline{q} \gamma_\mu (g_q^V + g_q^A \gamma^5) q) R^\mu$$

Leptophobic Z' model



Diogo, Frandsen, Shoemaker '15; Friedland, Graesser, Shoemaker, Vecchi '12

Simplified Model for NSI

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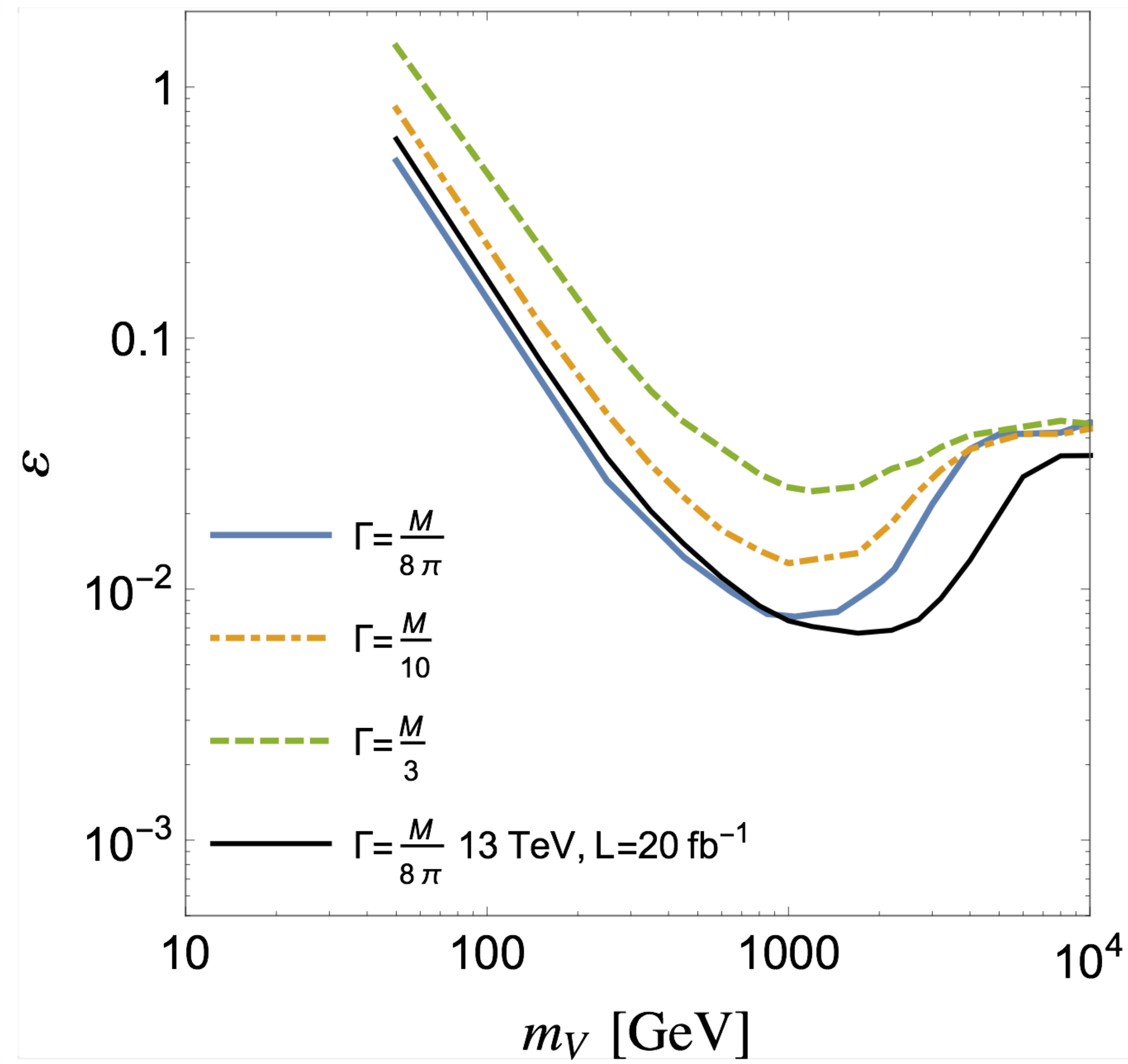
- Notice that the bounds saturate for m_V<1TeV. Bounds assume syst. unc. of 5% on background

→ Systematic uncertainties saturate the bounds already at the very low luminosity.

CMS 8 TeV 19.5 fb-1



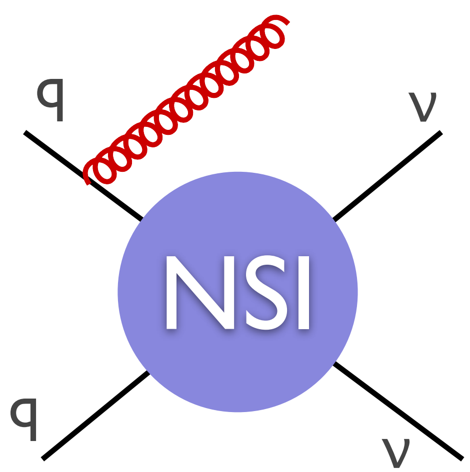
Diogo, Frandsen, Shoemaker '15

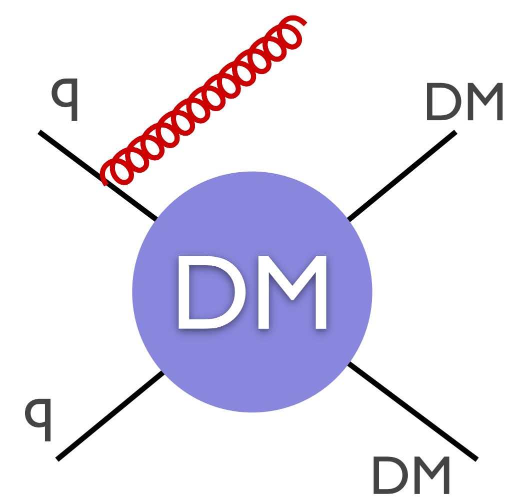
Discriminating NSI signature from DM

$$\mathscr{L}_{\text{NSI}} \;=\; g_\nu \, (\overline{\nu} P_L \gamma_\mu \nu)\, R^\mu + \left(\overline{q}\gamma_\mu (g_q^V + g_q^A \gamma^5) q\right) R^\mu$$

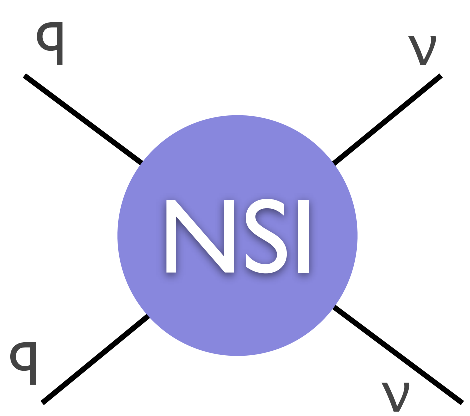
vs.

$$\mathscr{L}_{\text{DM}} \;=\; g_X \, (\overline{X}\gamma_\mu X)\, R^\mu + \left(\overline{q}\gamma_\mu (g_q^V + g_q^A \gamma^5) q\right) R^\mu + m_X \overline{X} X$$

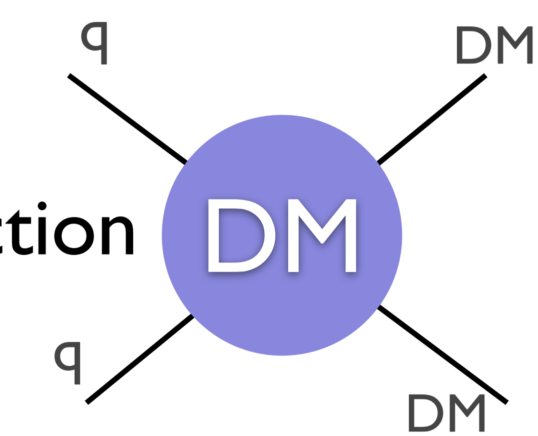




Osc. exp.



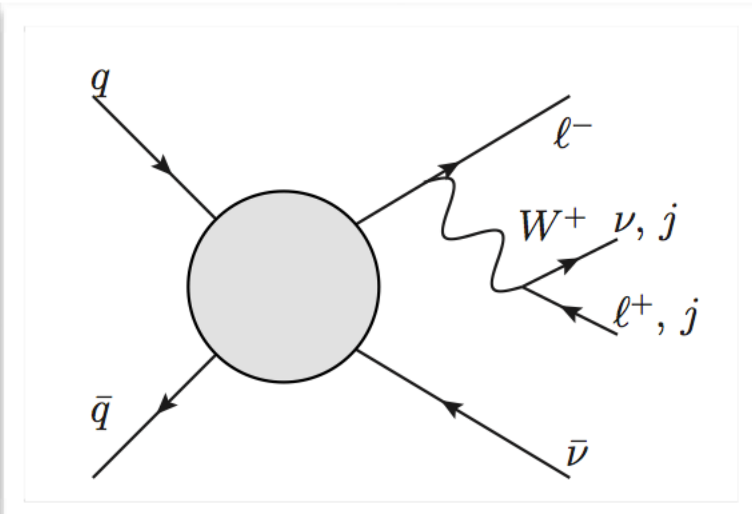
Direct detection

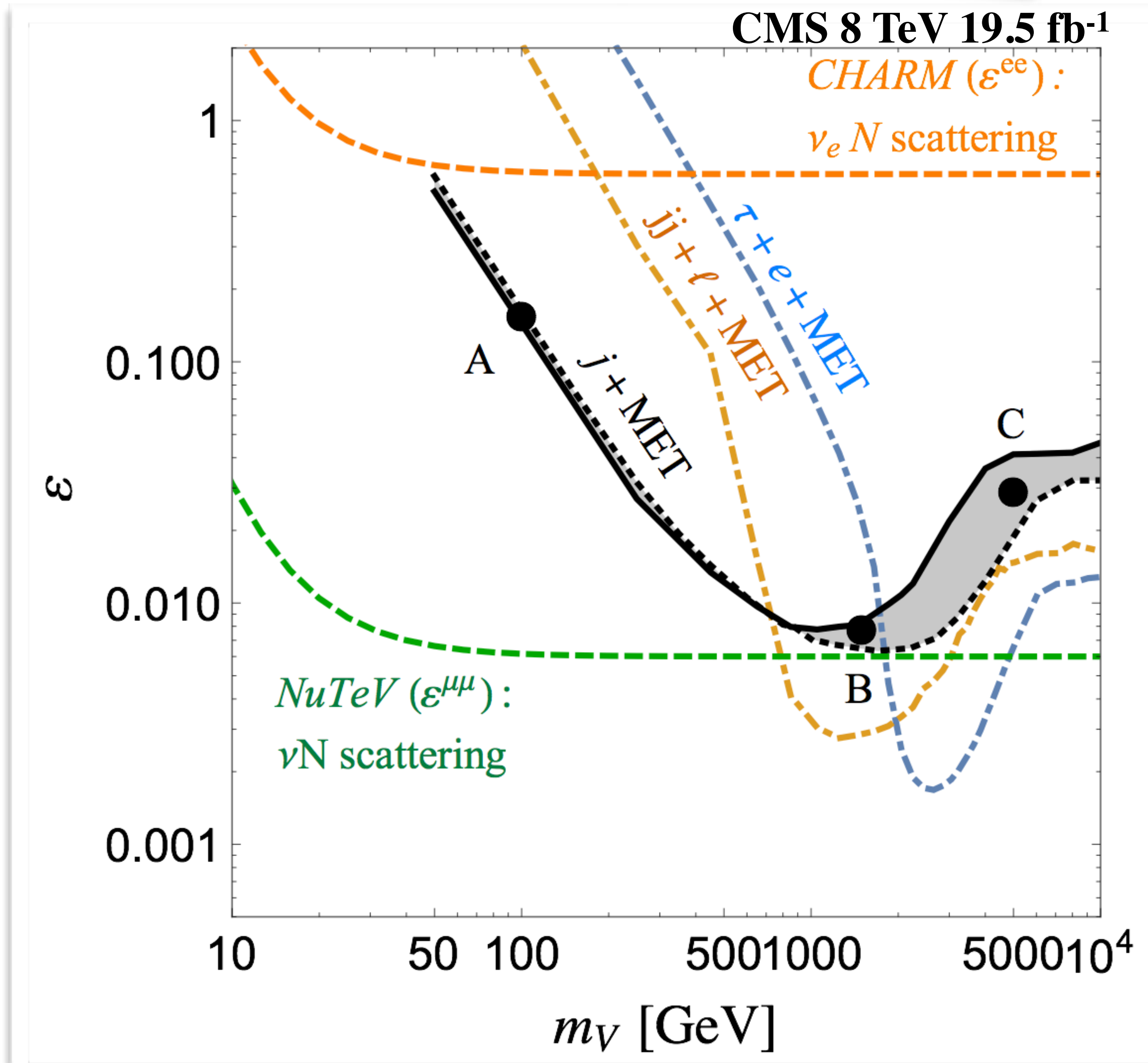


Diogo, Frandsen, Shoemaker '15

Discriminating NSI signature from DM

- Multilepton searches



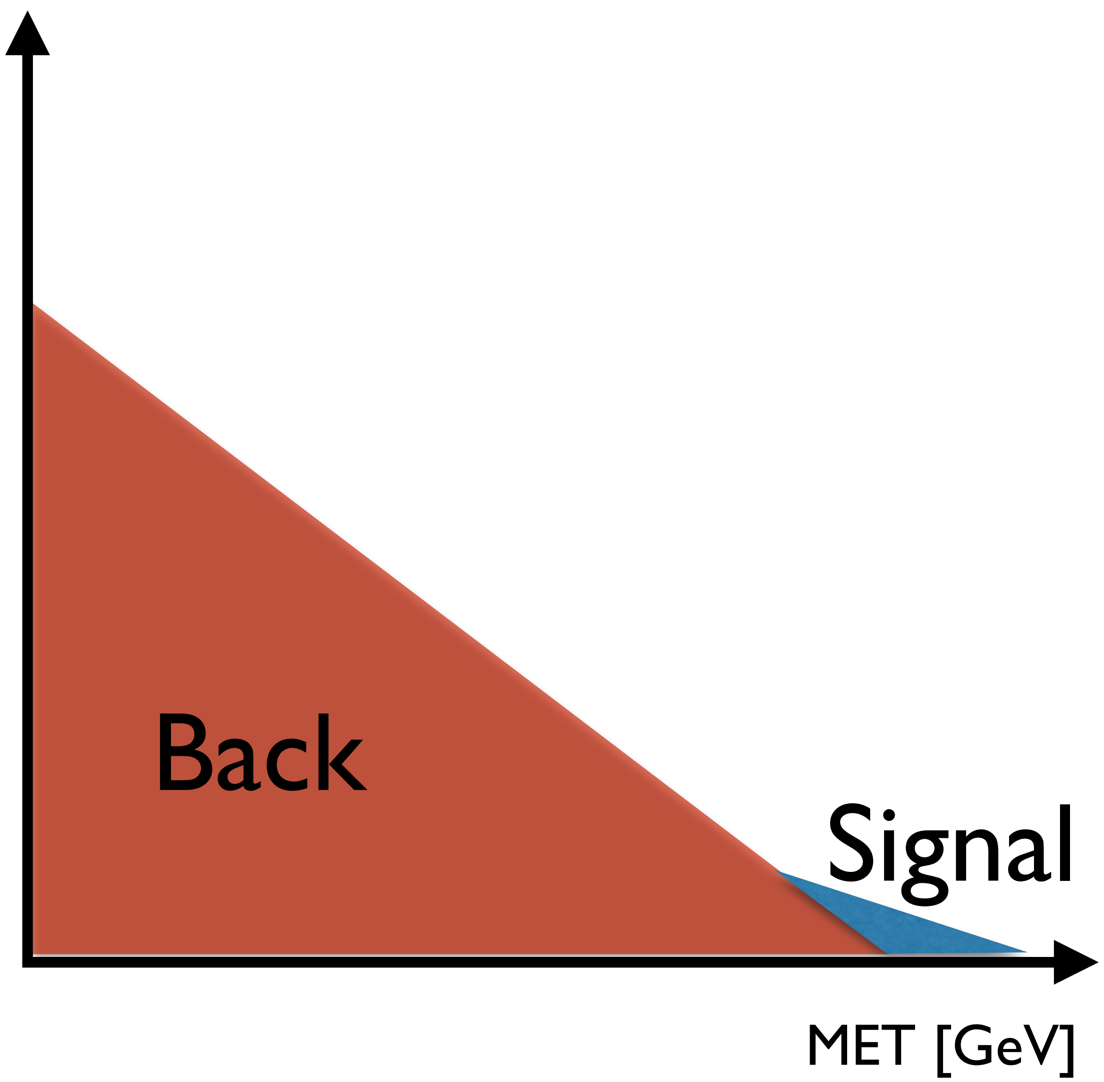


Diogo, Frandsen, Shoemaker ‘15

- **Complementarity:**
  Heavy mediators are strongly constrained by LHC data
  Low mediators constrained by low-energy experiments. Bounds from nu-N scattering measurements
- If DM itself transforms non-trivially under SU(2) the situation is more complex

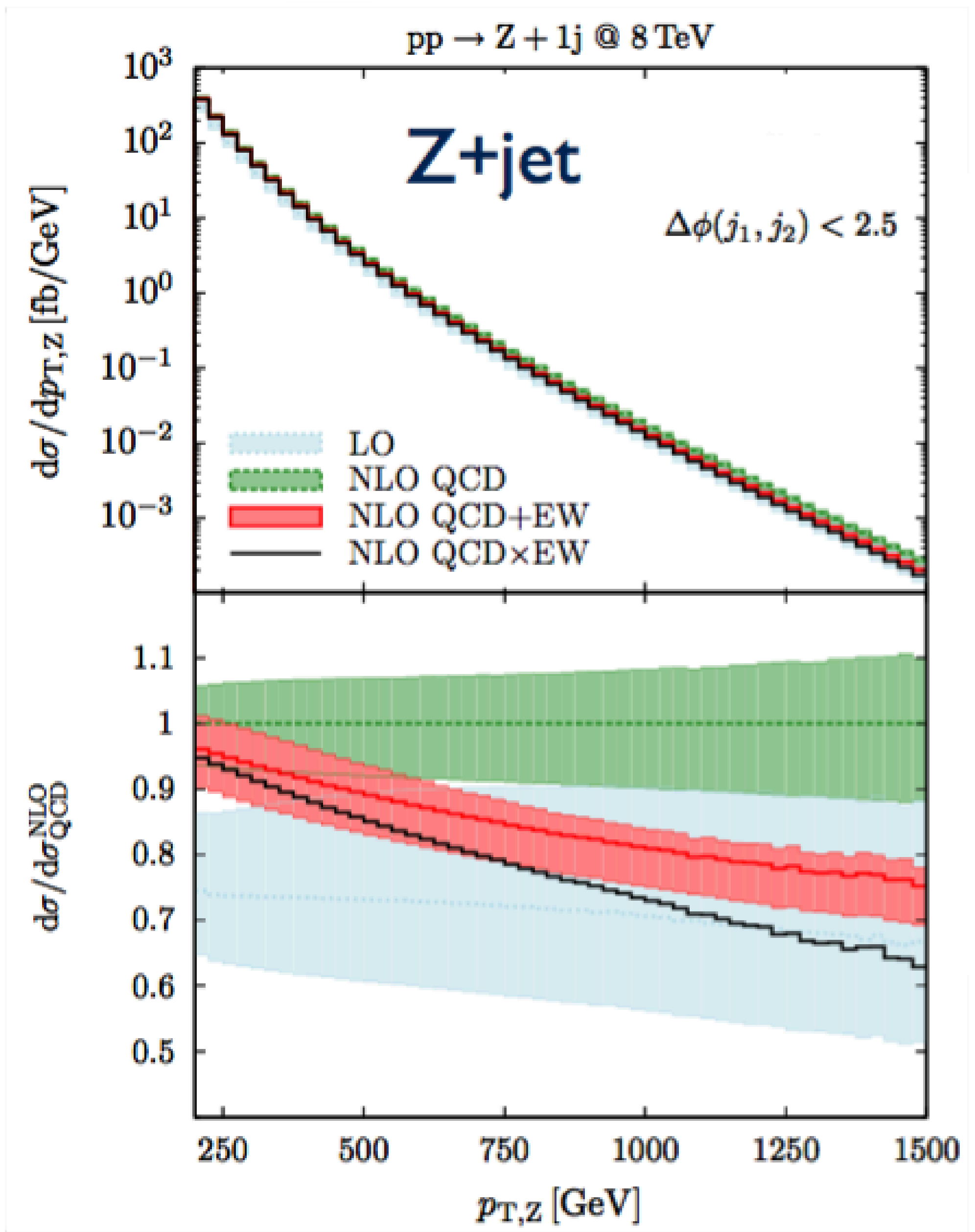
Monojets: systematic uncertainties

- Major limitation for NSI (DM) bounds:
  Overwhelming SM backgrounds and syst. ~5%
  Signal is a small enhancement in the tail of MET distribution



➡ Requires precise estimation of background

Monojets: systematic uncertainties



Lindert, Pozzorini, et al '17

- QCD corrections:

  Moderate and stable

  NLO uncert. 5-10%

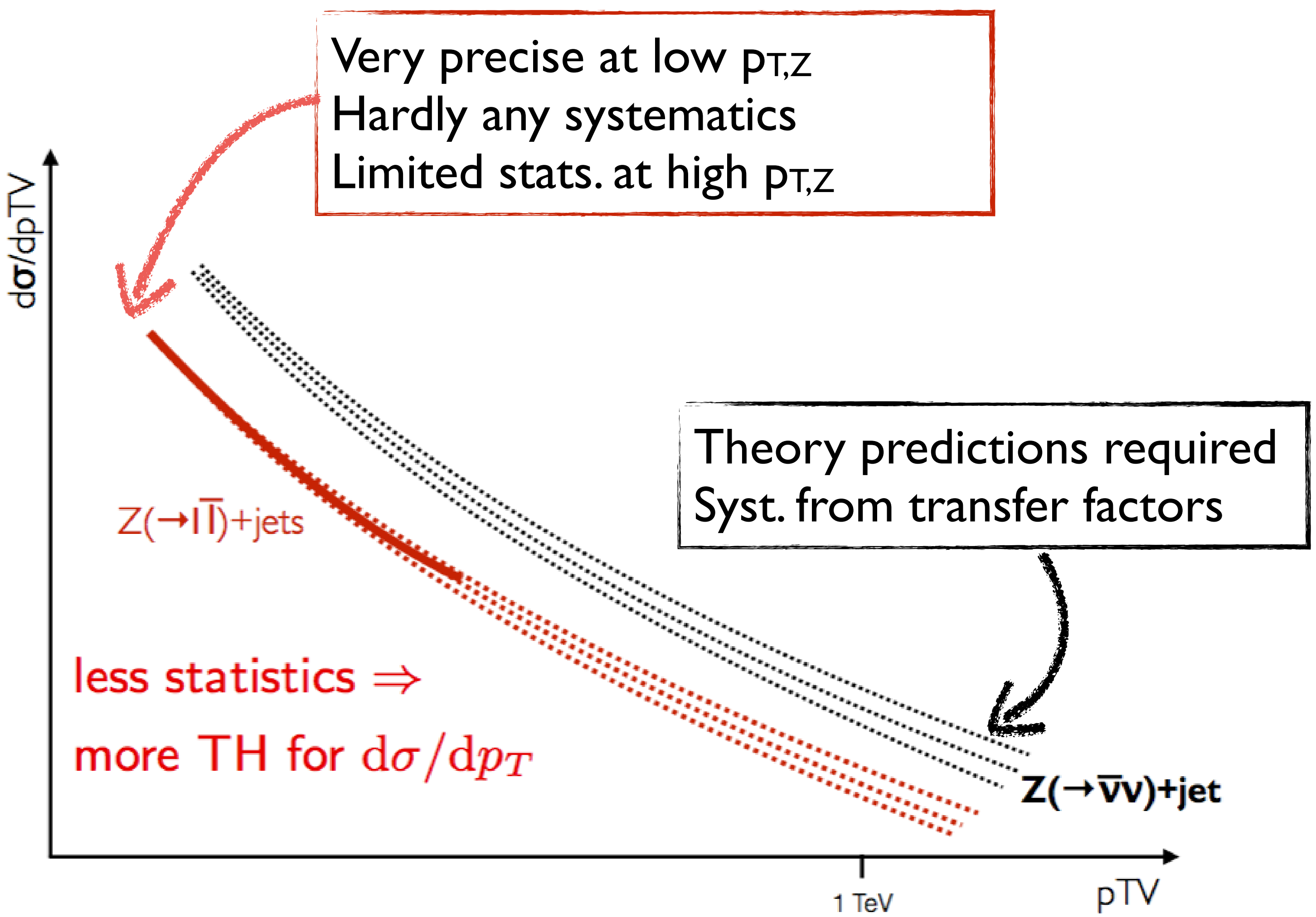
- EW corrections:

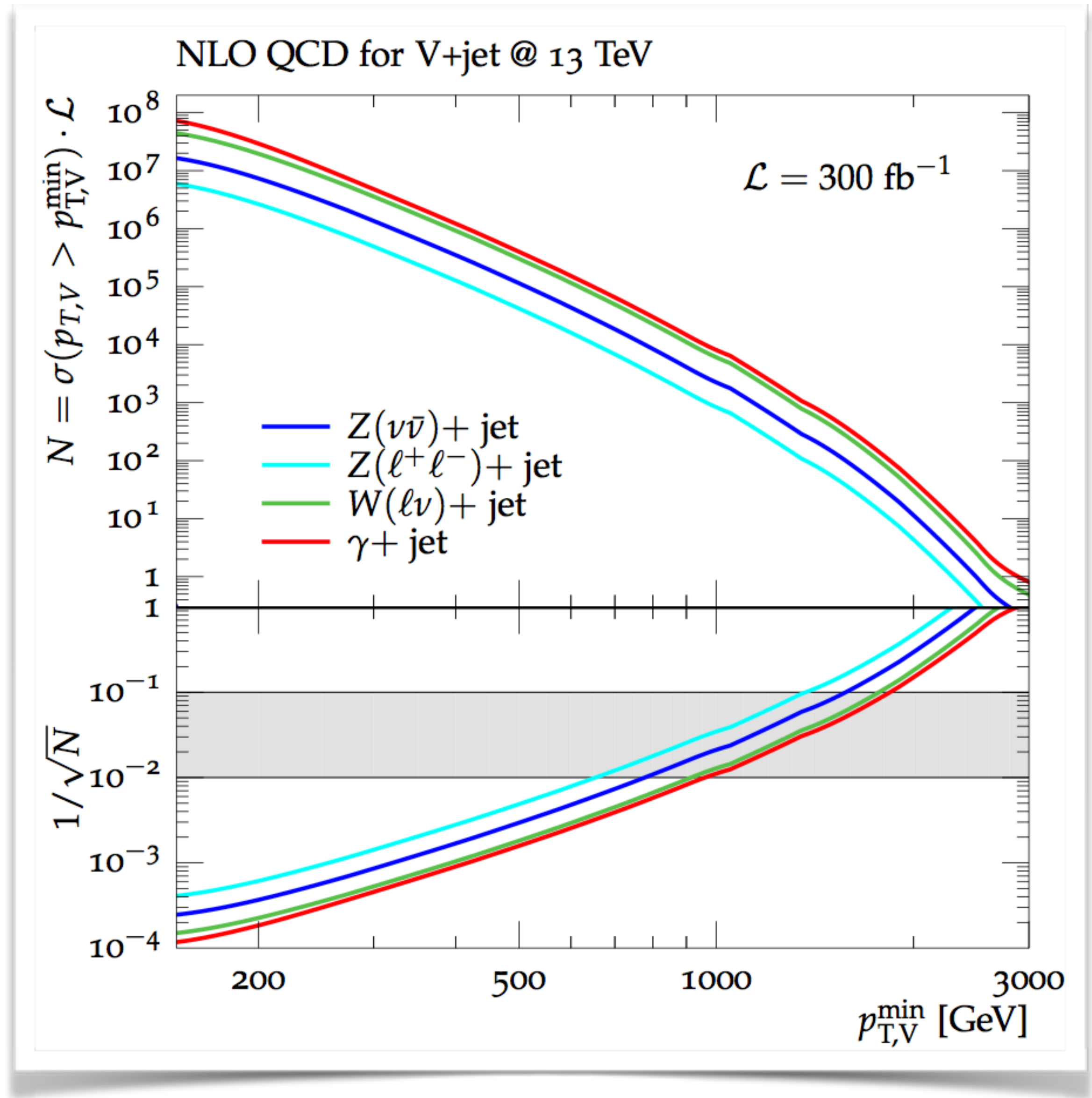
  EW corrections> QCD corrections for $p_{T,Z}$>350 GeV

→ Given that QCD and EW corrections are large, mixed QCD-EW corrections have to be considered

- State of the art of MC simulation: NNLO QCD + NLO EW
  "Simply" accounting for higher orders is not enough. Uncertainties O(5%)
  We need new ingredients to control the errors!

Monojets: systematic uncertainties





Lindert, Pozzorini, et al '17

Summary

- Collider studies result in strong constraints to NSI and are relevant to the global picture
- Monojet and multilepton searches display stronger limits to heavy mediator masses.
  They also offer a probe to discriminate NSI from DM (in the case of discovery).
- New theoretical and experimental efforts are significantly improving the background estimation

→ Theory and experimental efforts are transforming the LHC into a precision machine

Thank you for your attention!