

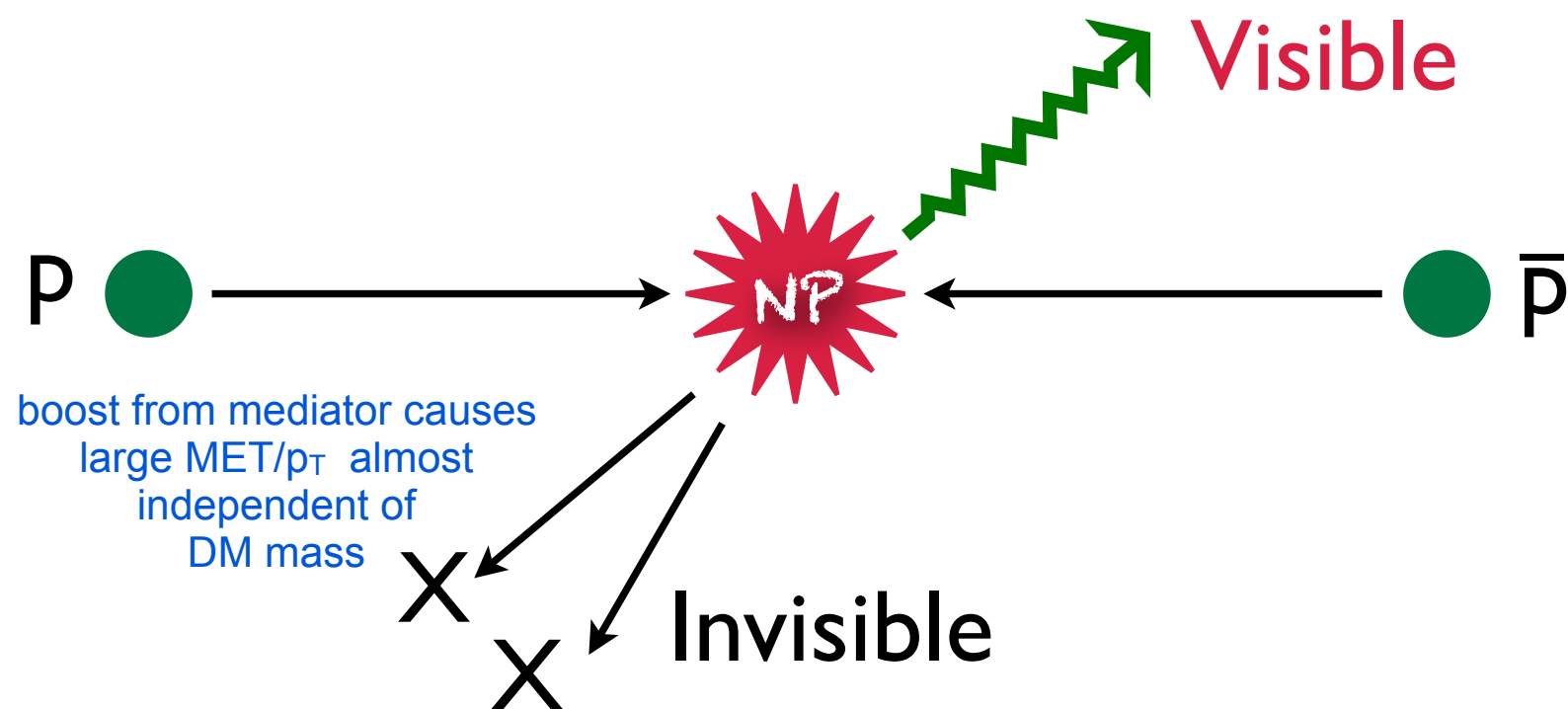


Heavy Quark Dark Matter Searches at the LHC



Giacomo Artoni, Gabriella Sciolla, Alessio Venturini (Brandeis)
Tongyan Lin, Yangyang Cheng (UChicago)
Björn Penning (UChicago/Fermilab)

- Properties of DM ~ 10 GeV
 - Pair produced (stable)
 - Mediating particle (M^*) not directly observed \rightarrow Effective Field Theory (EFT)

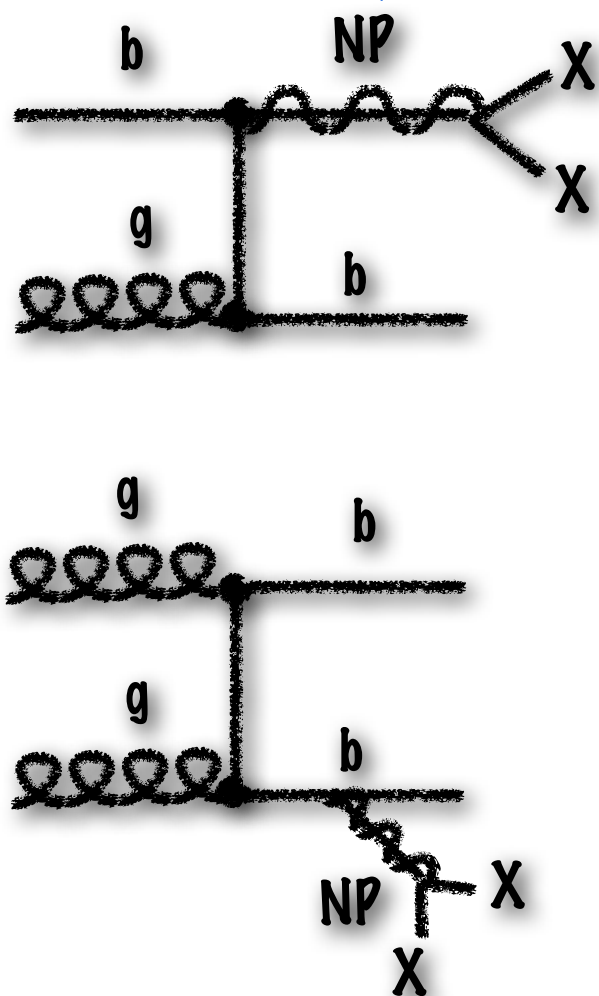


- Collider signature: **mono-'X'** (sort of a misnomer)
- Sensitive to **spin-dependent** and **independent dark matter** and for **low masses**

$$\frac{m_q}{M_\star^3} \bar{\chi} \chi \bar{q} q$$

$$\bar{\chi} \gamma^\mu \gamma^5 \chi \bar{q} \gamma_\mu \gamma^5 q$$

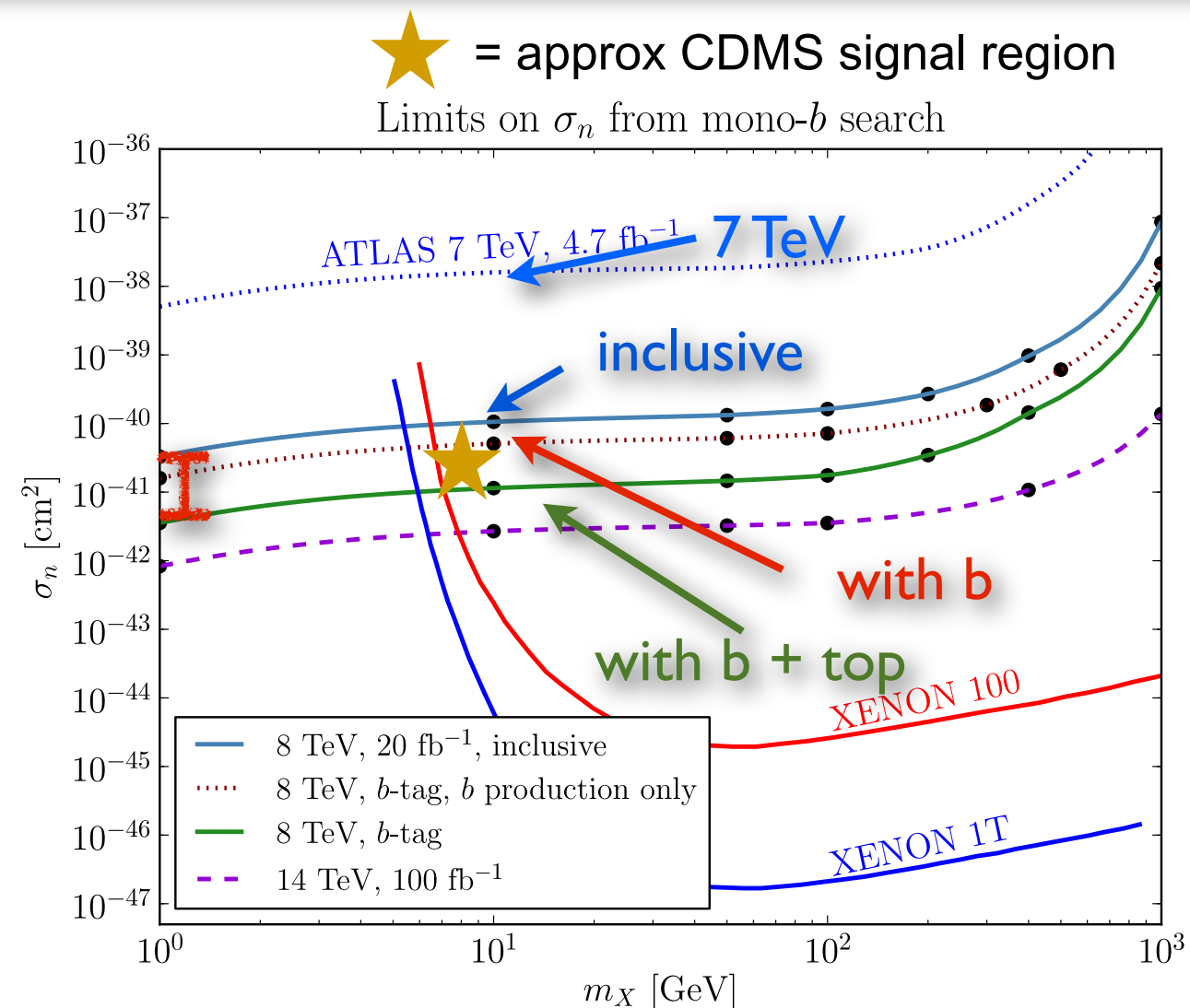
New processes:



$$bg \rightarrow \chi\bar{\chi} + b$$

$$gg \rightarrow \chi\bar{\chi} + b\bar{b}$$

$$gg \rightarrow \chi\bar{\chi} + t\bar{t}$$



- Extended mono- X approach to complex topology with focus on interesting region
- New signal processes and higher order calculations ([arxiv:1303.6638](https://arxiv.org/abs/1303.6638), [arxiv:1211.6390](https://arxiv.org/abs/1211.6390))
- DM + b very powerful for quark mass dependent operators
- Focus here of items of general interest for collider DM analysis

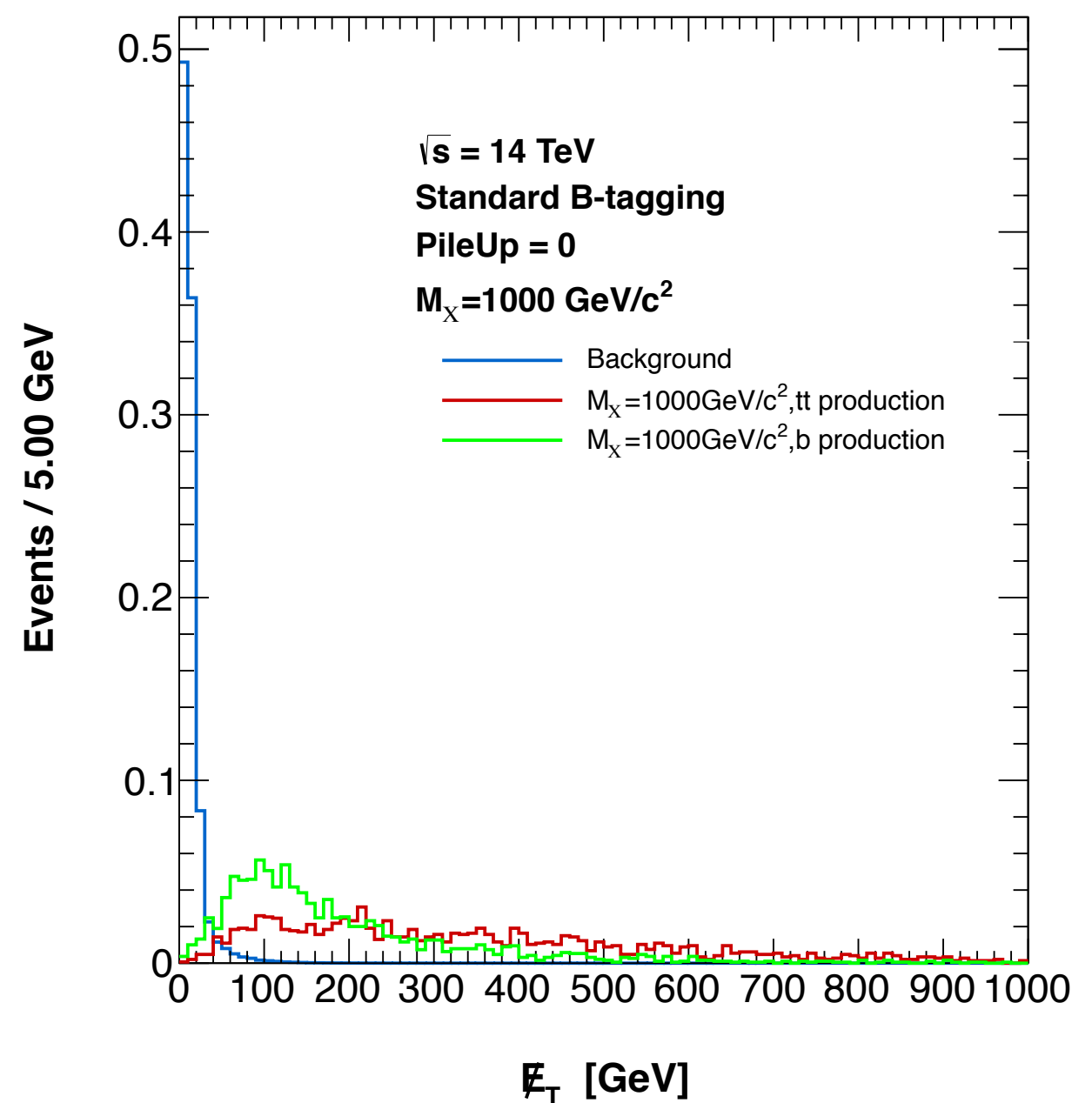
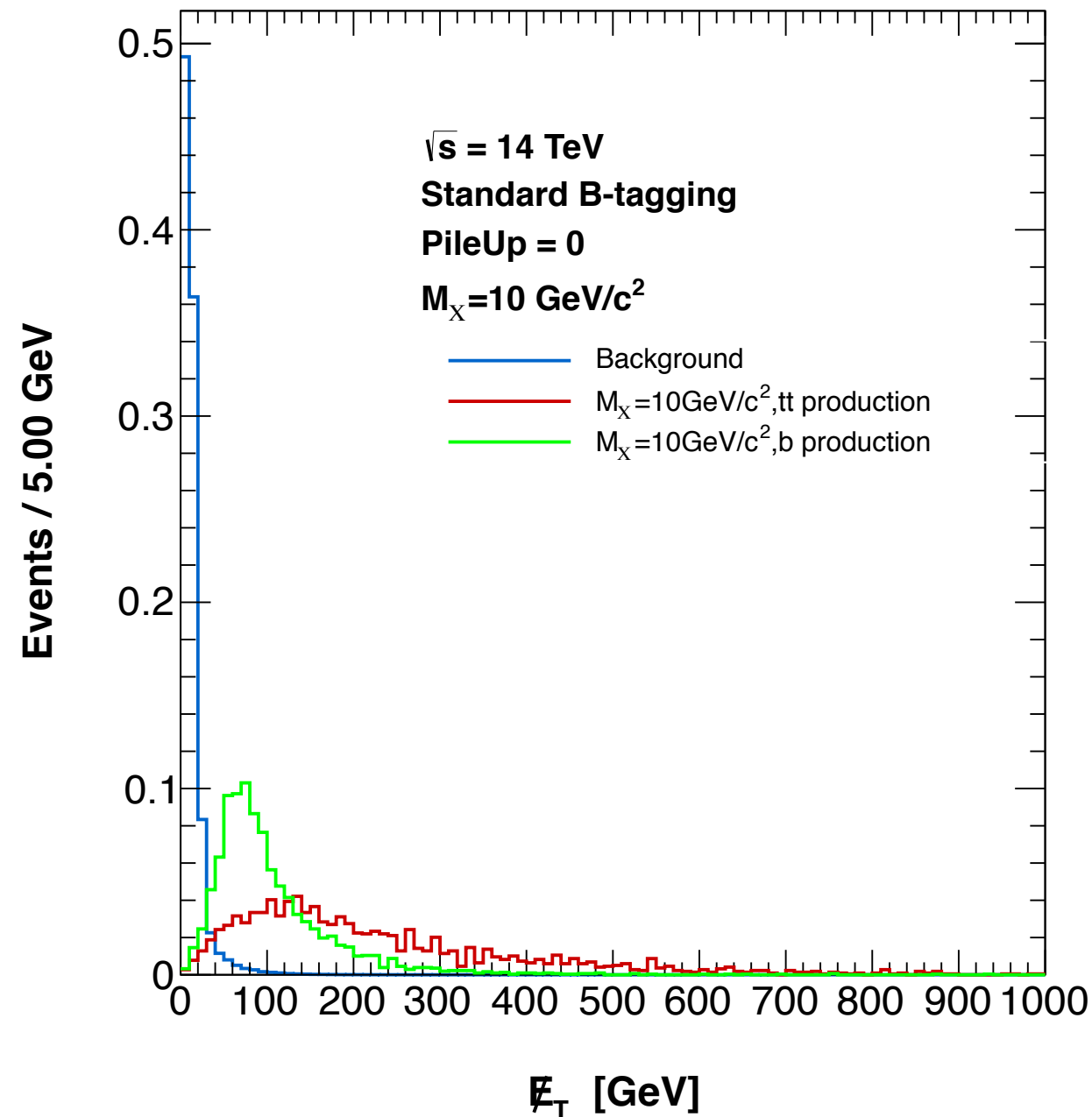
- Generated **two signal models**:
 - Common selection: **0 lepton + jets + MET**
 - '**mono-b**': Requesting b-quark in final state, otherwise consistent with existing mono-jet signals (jet mult. ≤ 2)
 - '**ttbar+xx**': Quite different topology to mono-'X' but great sensitivity
- Model signal regions differ in **jet multiplicity**
- Particularly interested in **quark mass dependent operators**
- Signal samples according to Snowmass recommendations:
 - LHC 14 TeV, 300/fb** , spacing: 25 ns, **pileup: 50** events/crossing
 - LHC 14 TeV, 3000/fb** (HL-LHC) , spacing: 25 ns, **pileup: 140** events/crossing
 - HELHC 33 TeV, 3000/fb** samples, **pileup: 250** events/crossing

Coupling Group	Operator	Operator Structure	Coefficient
Scalar quark	D1	$\bar{\chi}\chi\bar{q}q$	m_q/M_*^3
Vector quark	D5	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
Tensor quark	D9	$\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$	$1/M_*^2$
Gluon	D11	$\bar{\chi}\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^3$

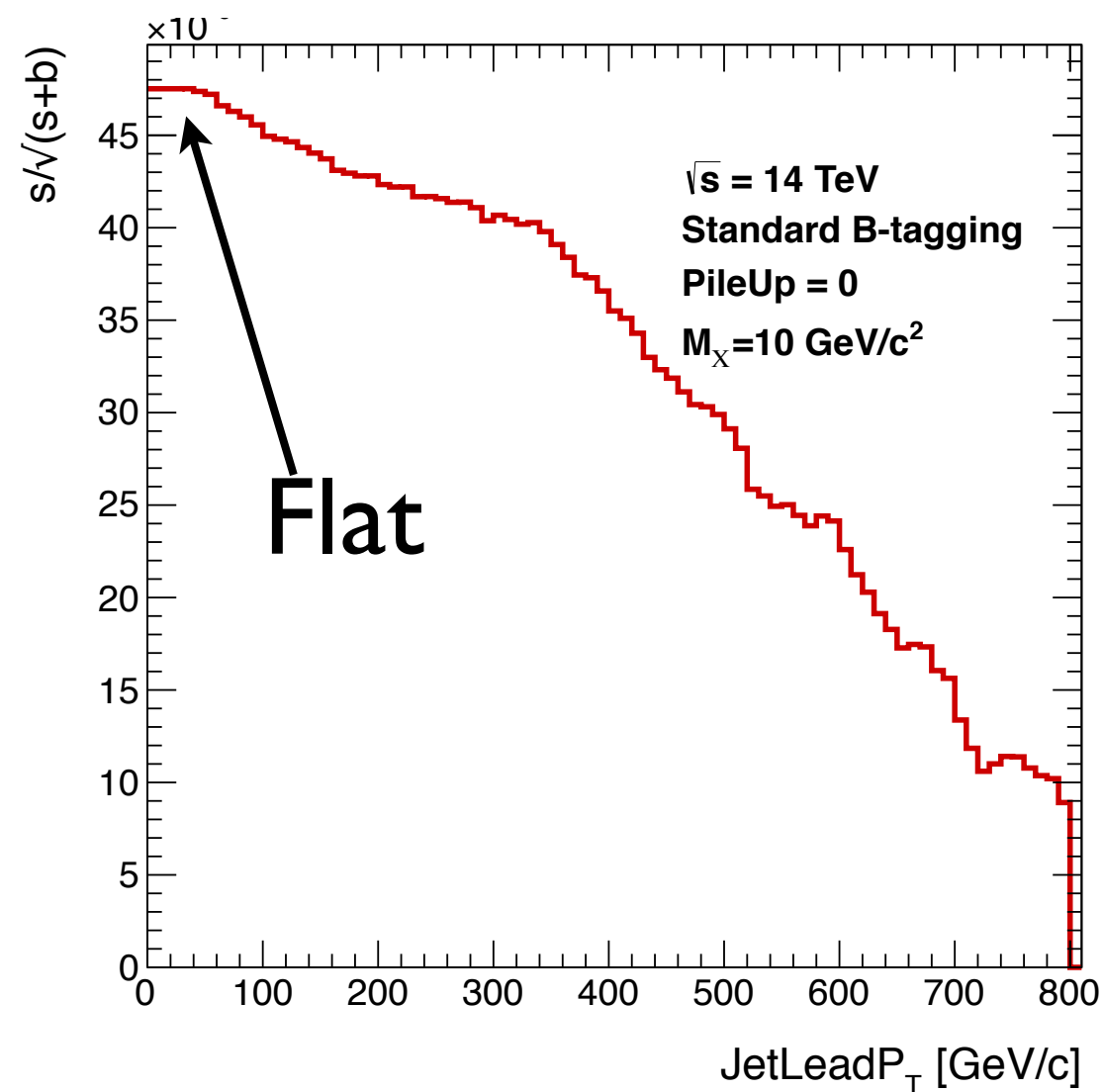
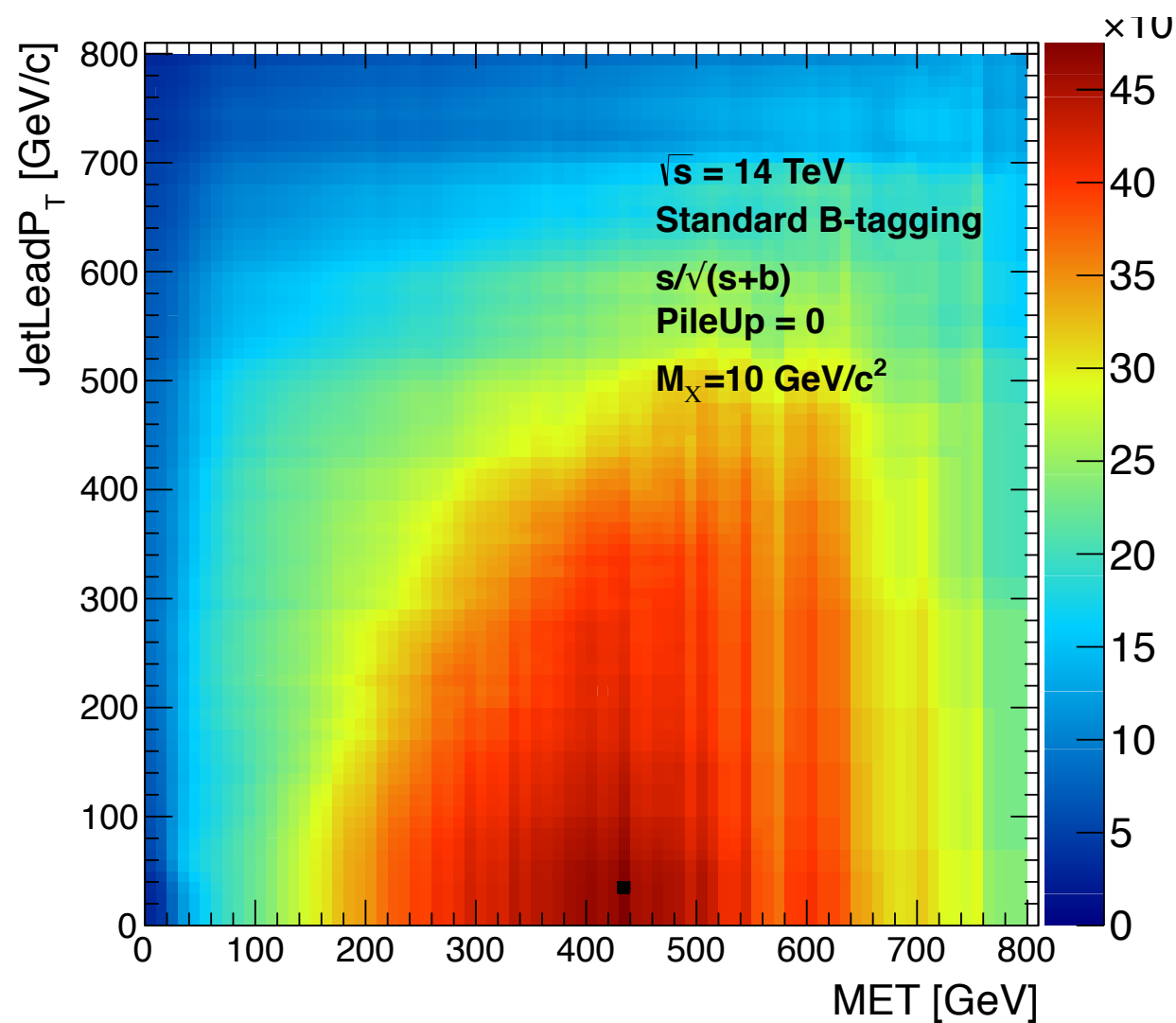
Fermion DM

Coupling Group	Operator	Operator Structure	Coefficient
Scalar quark	C1	$\chi^\dagger\chi\bar{q}q$	m_q/M_*^2
Vector quark	C3	$\chi^\dagger\partial_\mu\chi\bar{q}\gamma^\mu q$	$1/M_*^2$
Gluon	C5	$\chi^\dagger\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^2$

Complex scalar DM



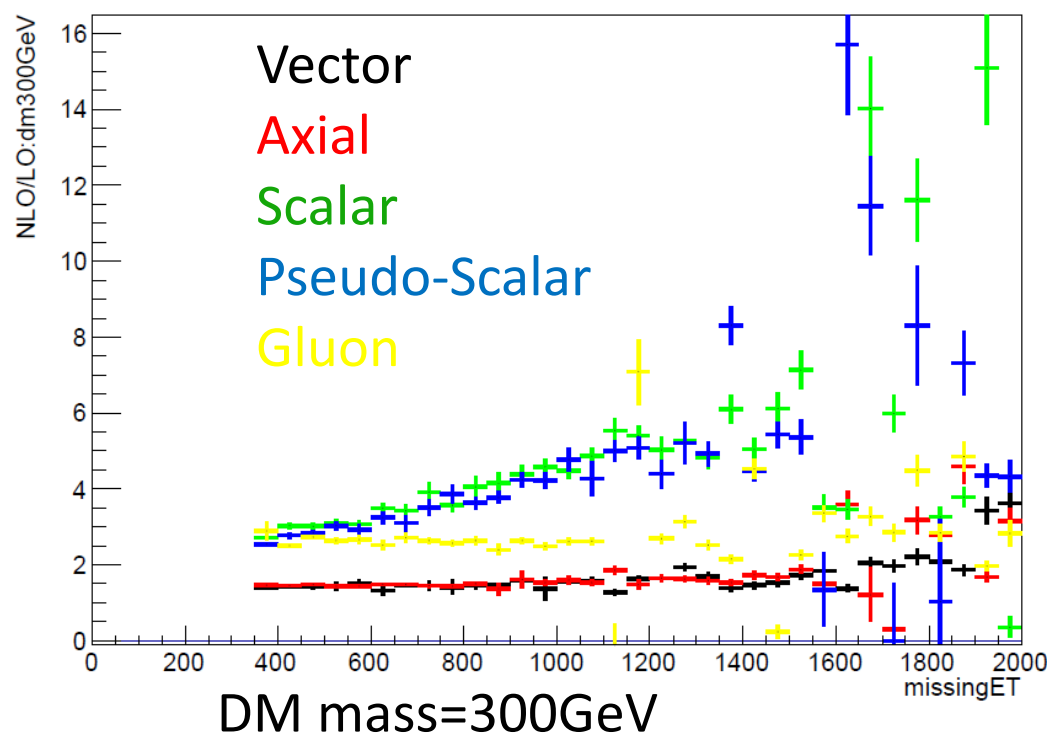
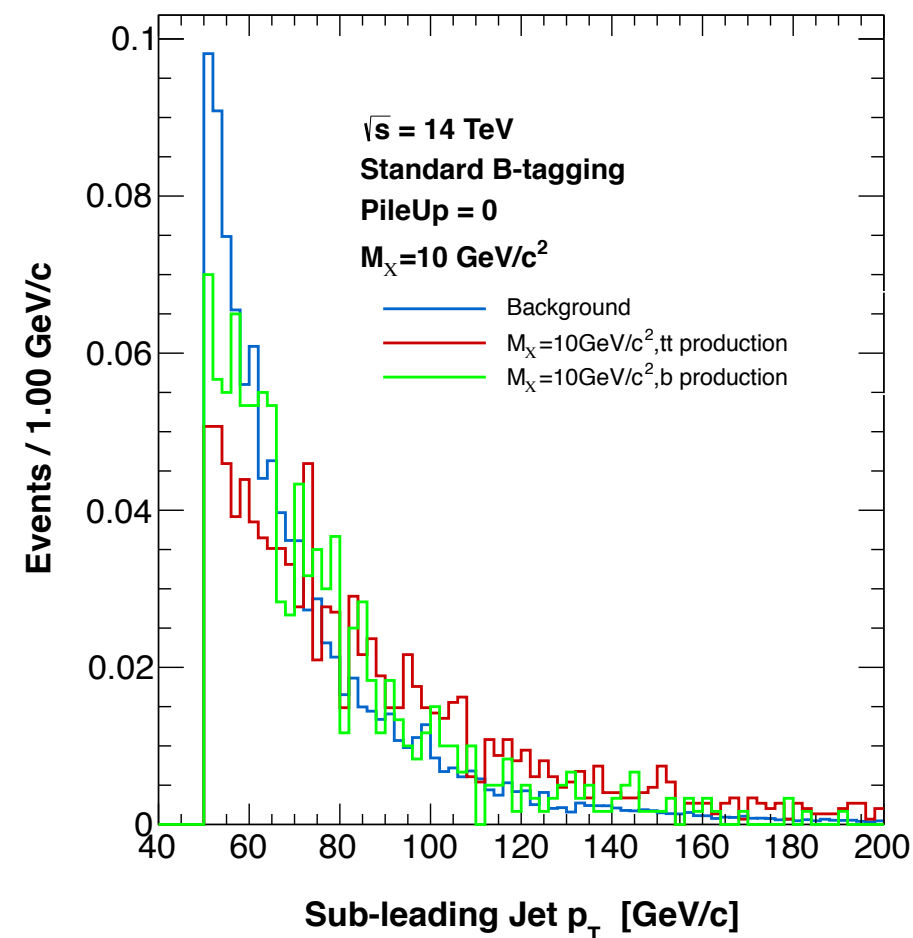
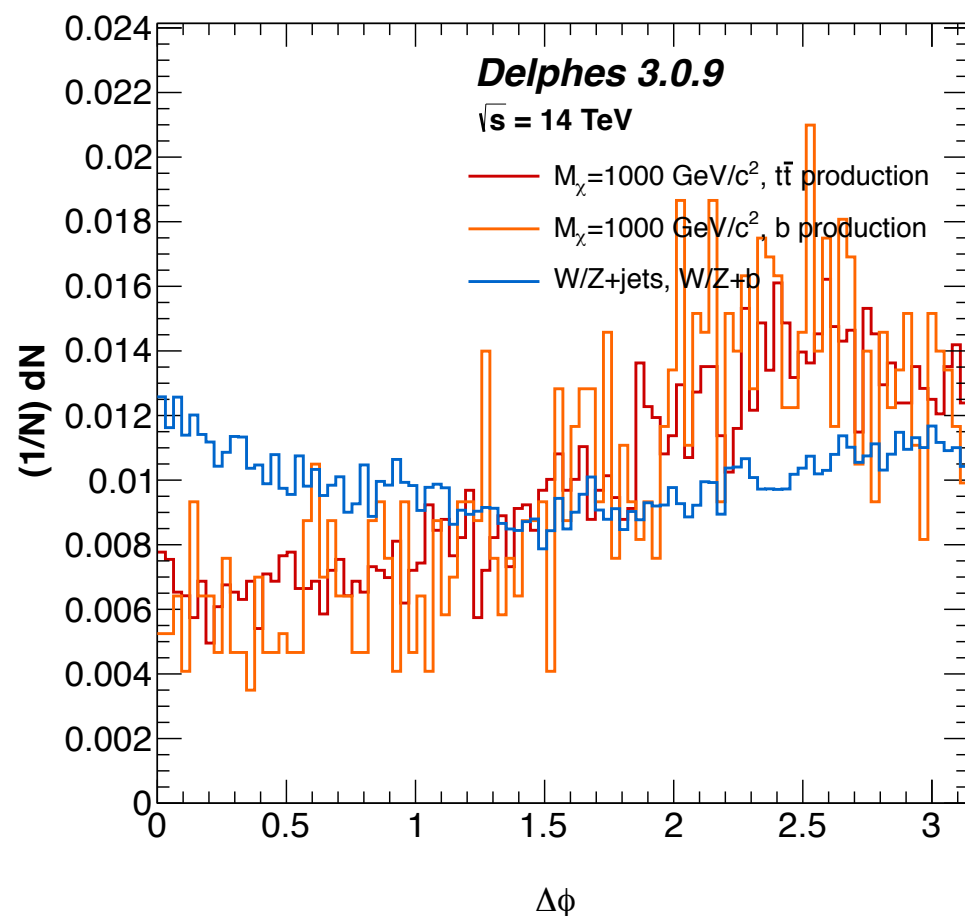
- Kinematic dependencies for various dark matter masses



- Possibility to apply significantly looser kinematic cuts than in monojet final state



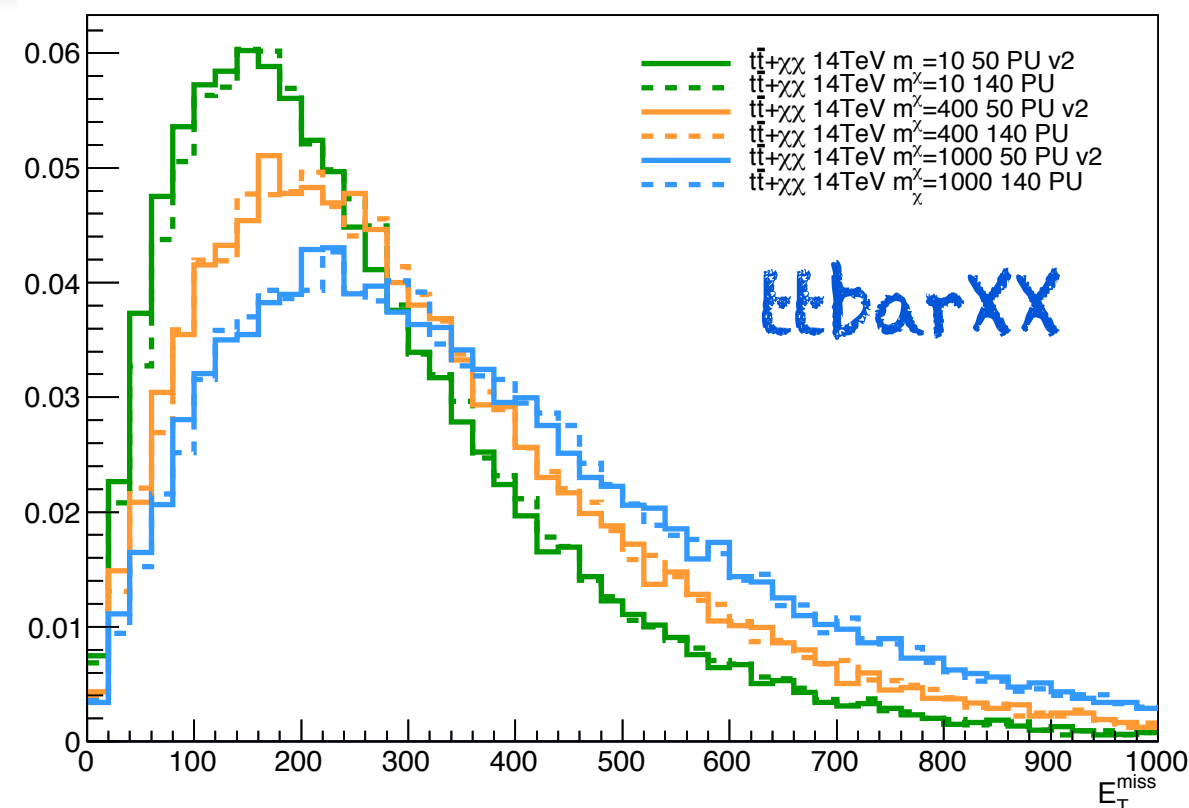
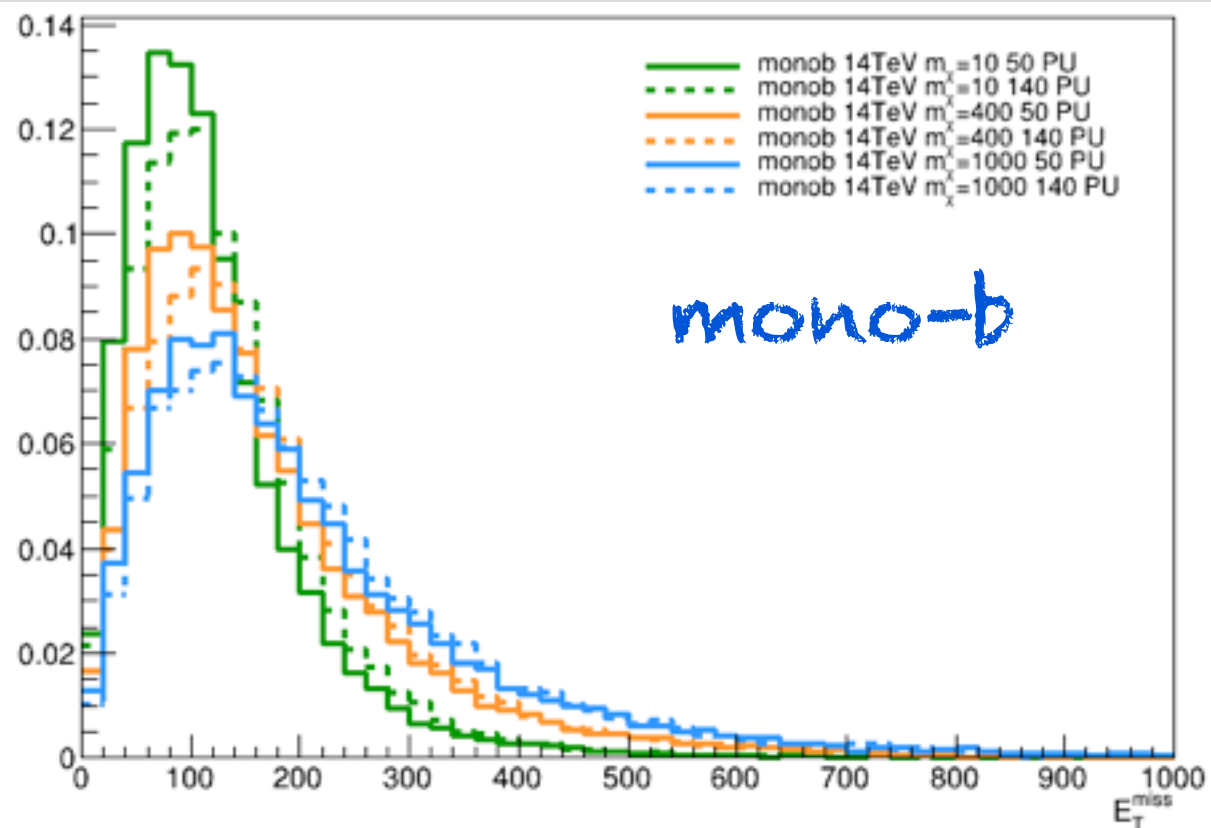
Signal Discrimination



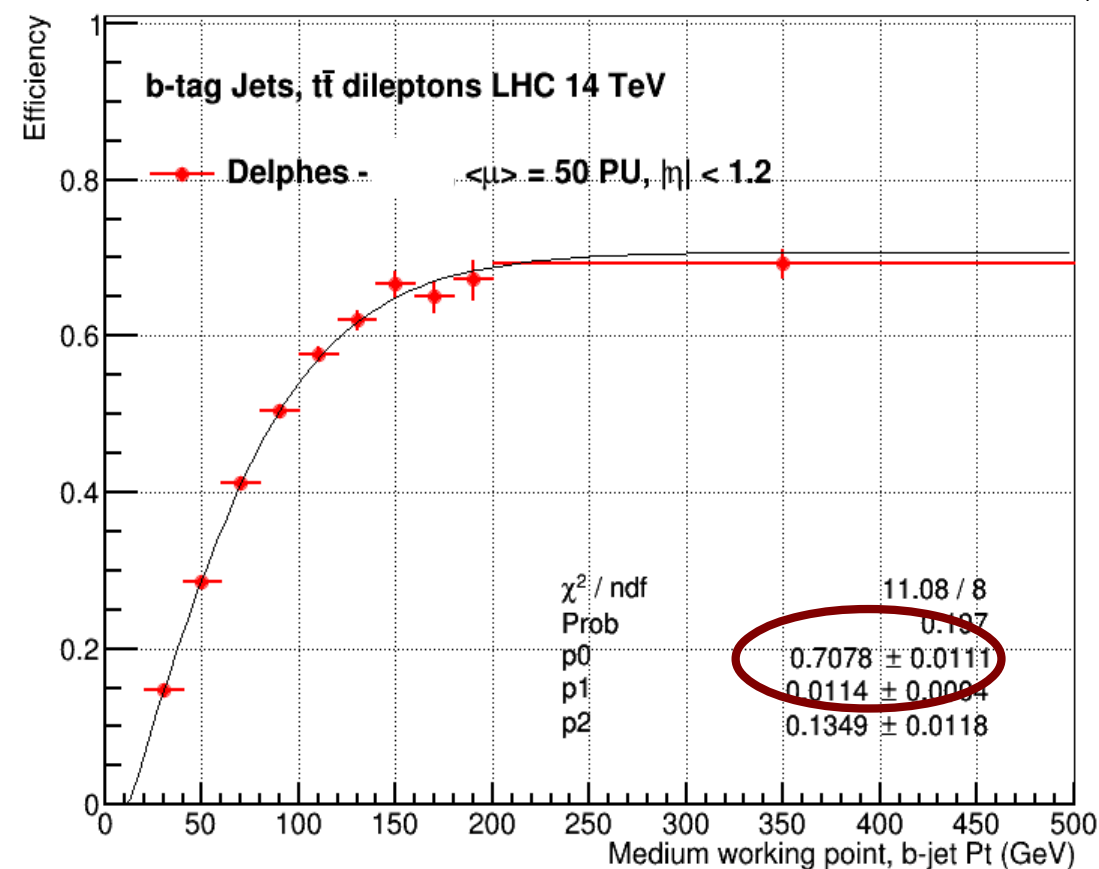
- Limited set of discriminating variables, still looking into improvements
- NLO signal calculations:
 - stronger and more accurate/robust analysis
- Predictive in terms of kinematic information
- Thanks to Paddy Fox and Ciaran Williams (FNAL) for providing MCFMdark



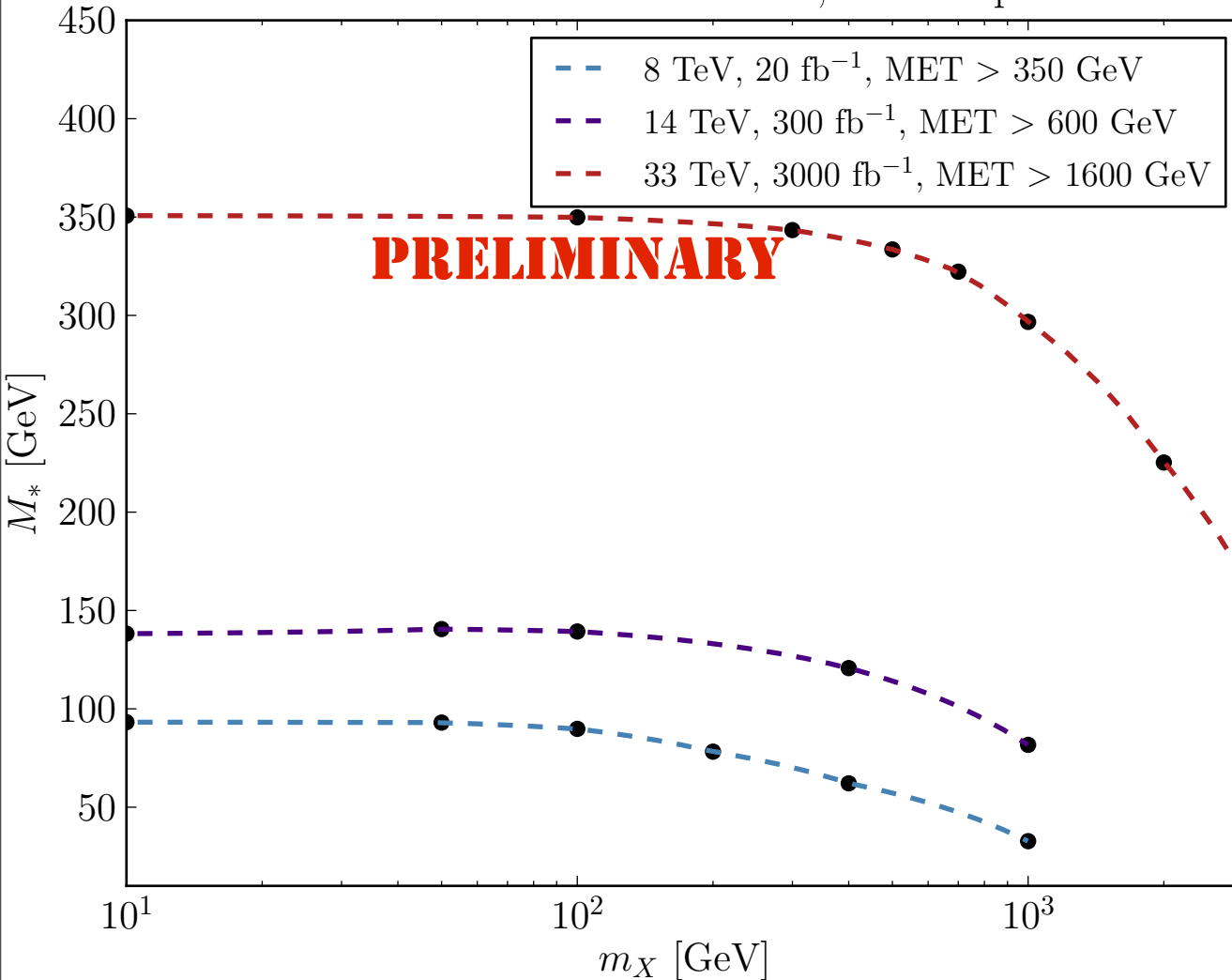
Effect of Pileup and Systematic



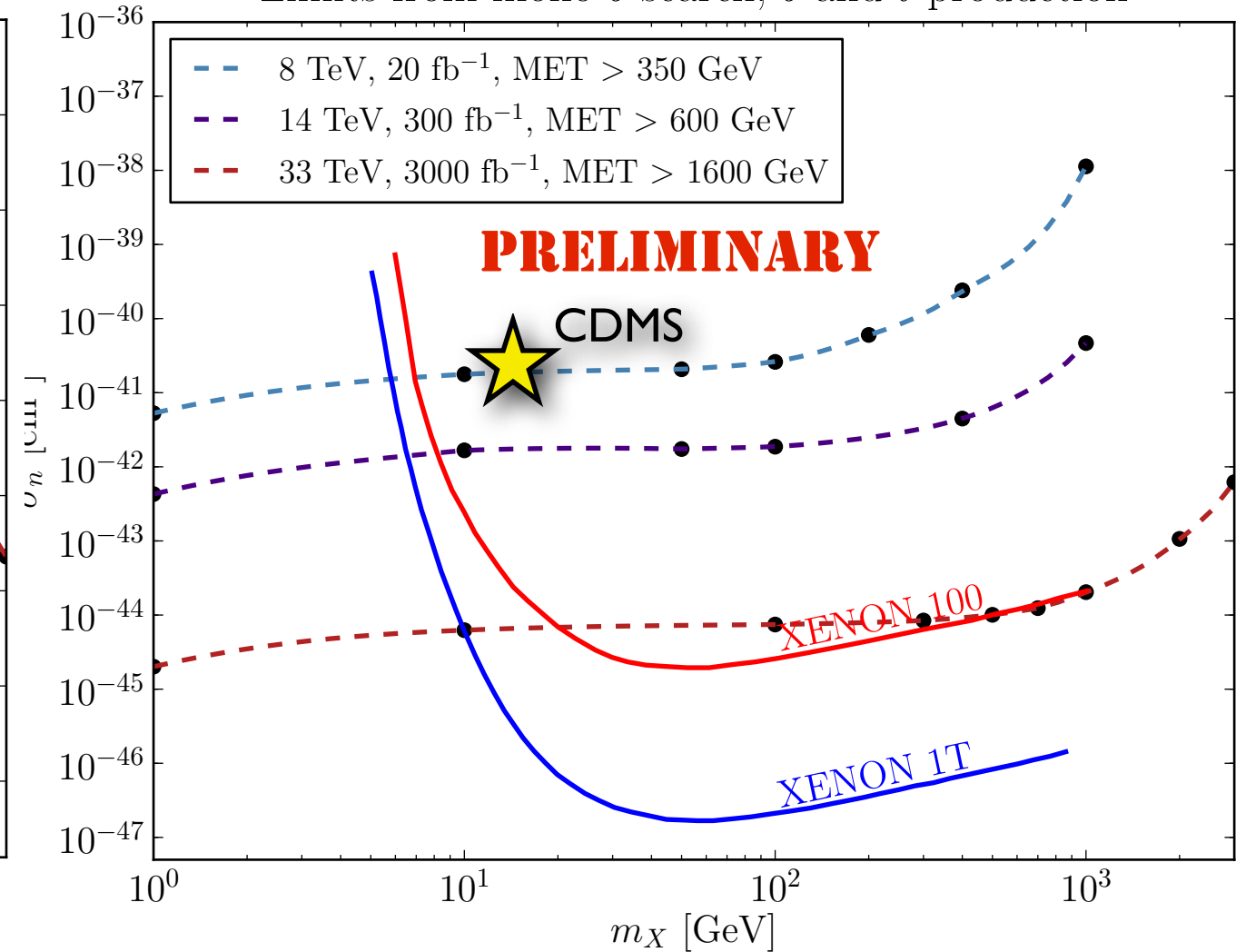
- Pile up seems not to be a major effect
- Delphes b-tagging flat in p_T
 - probably realistic what we will be able to do



Constraints from mono- b searches, b and t production



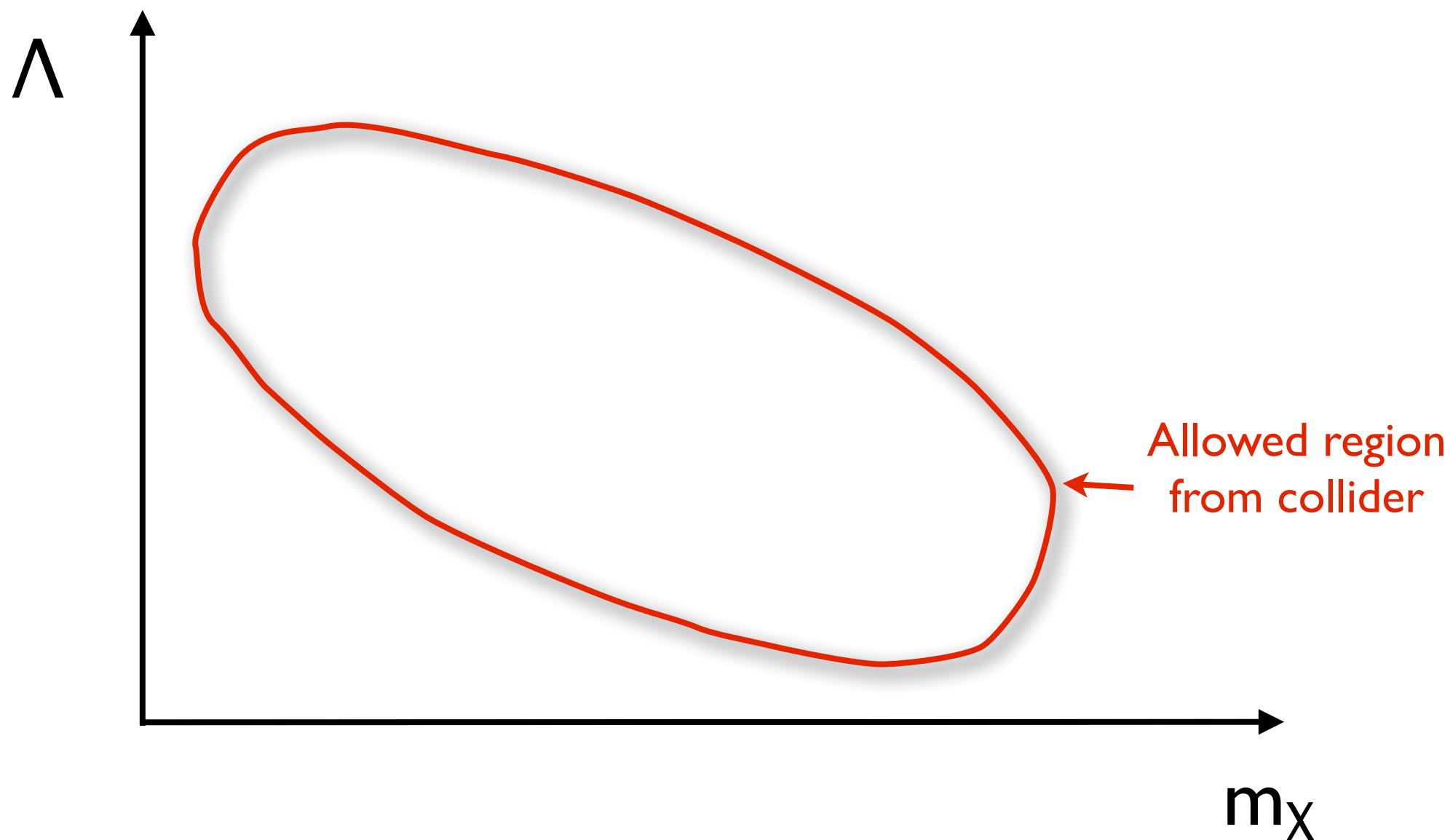
Limits from mono- b search, b and t production



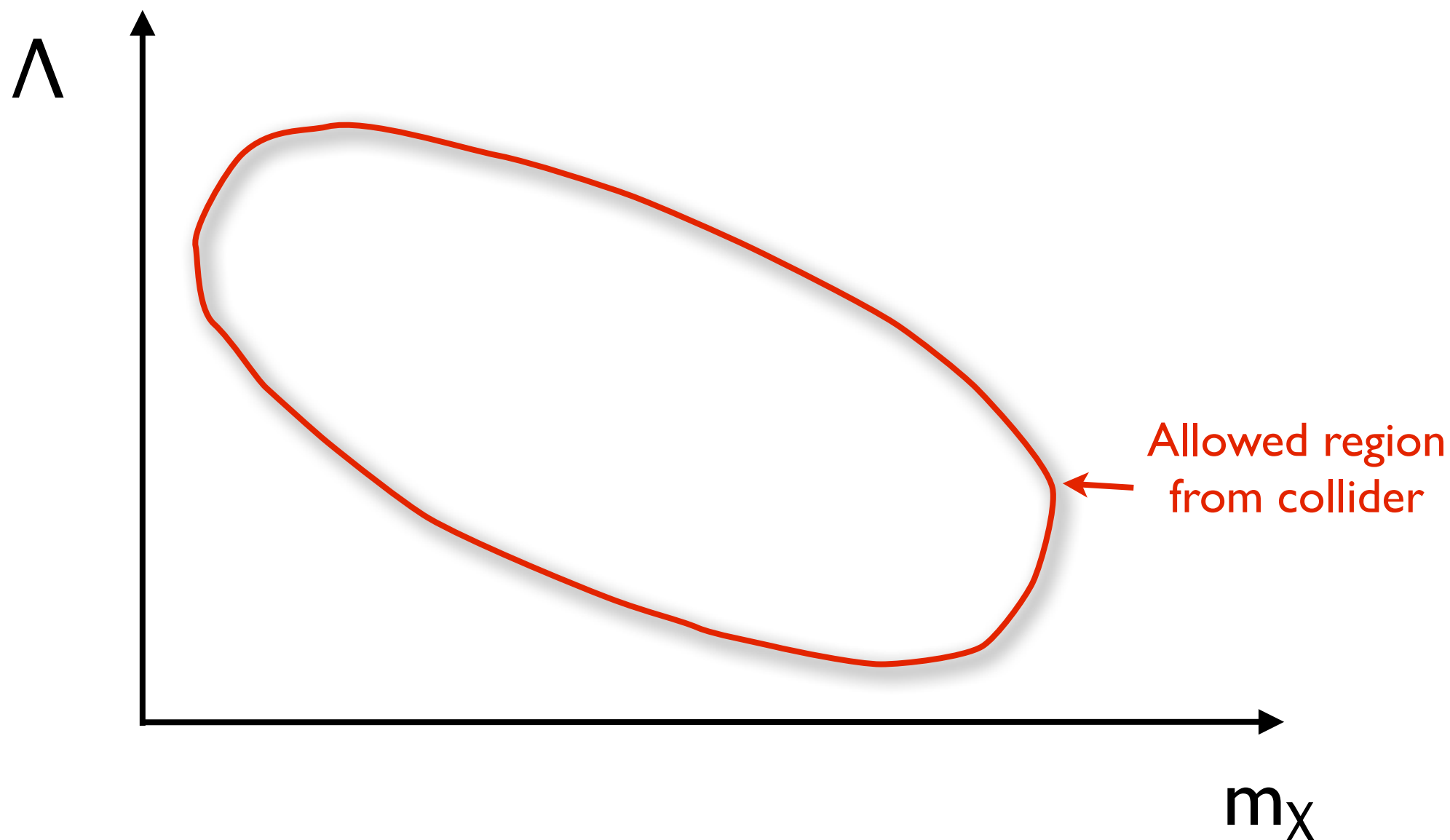
- Sensitivity projections (not yet fully optimized) for various scenarios
- Great sensitivity for selected operators



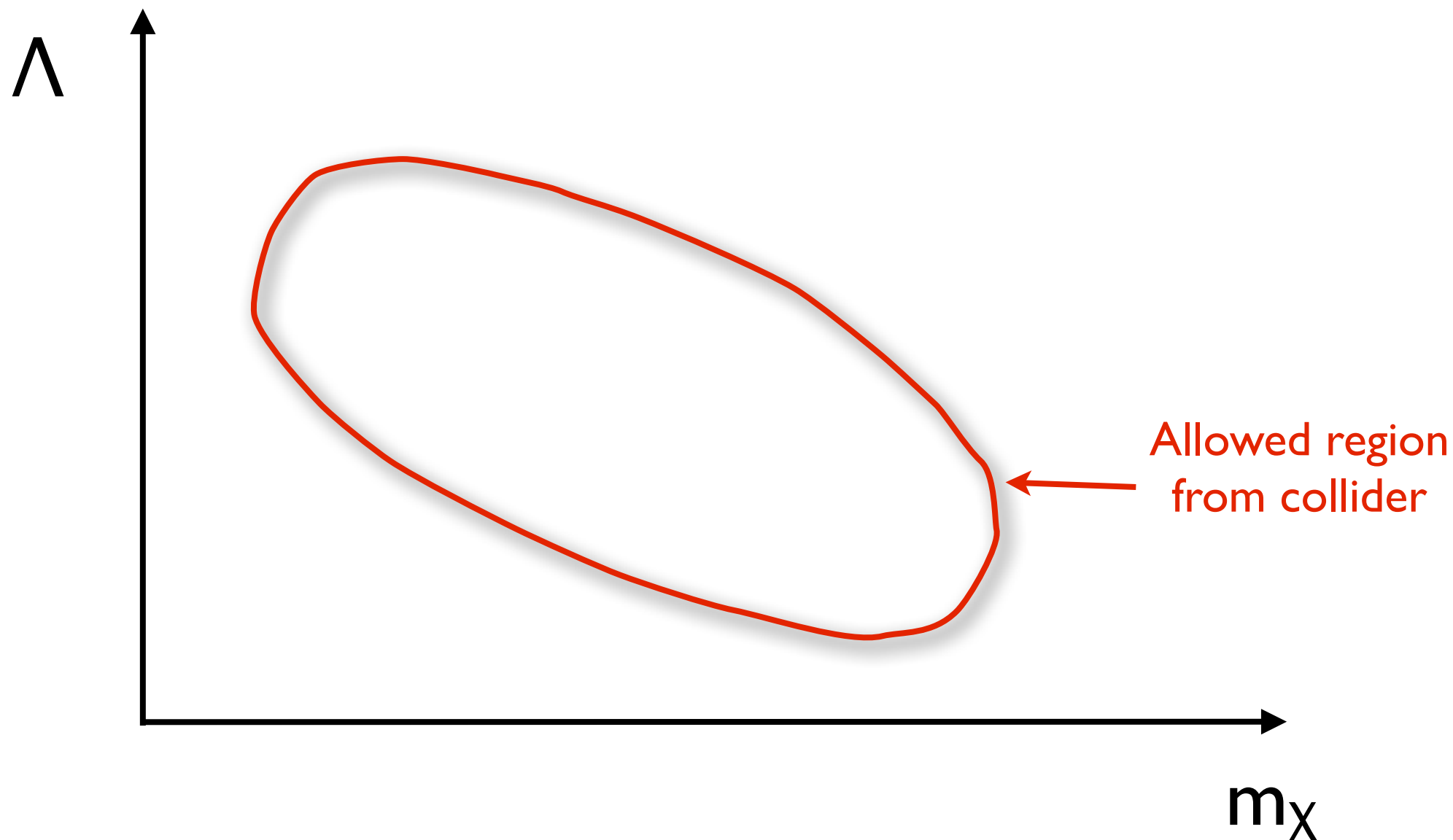
- As requested: [Discovery Scenario](#)
- Suppose we observe an excess, what to do next?



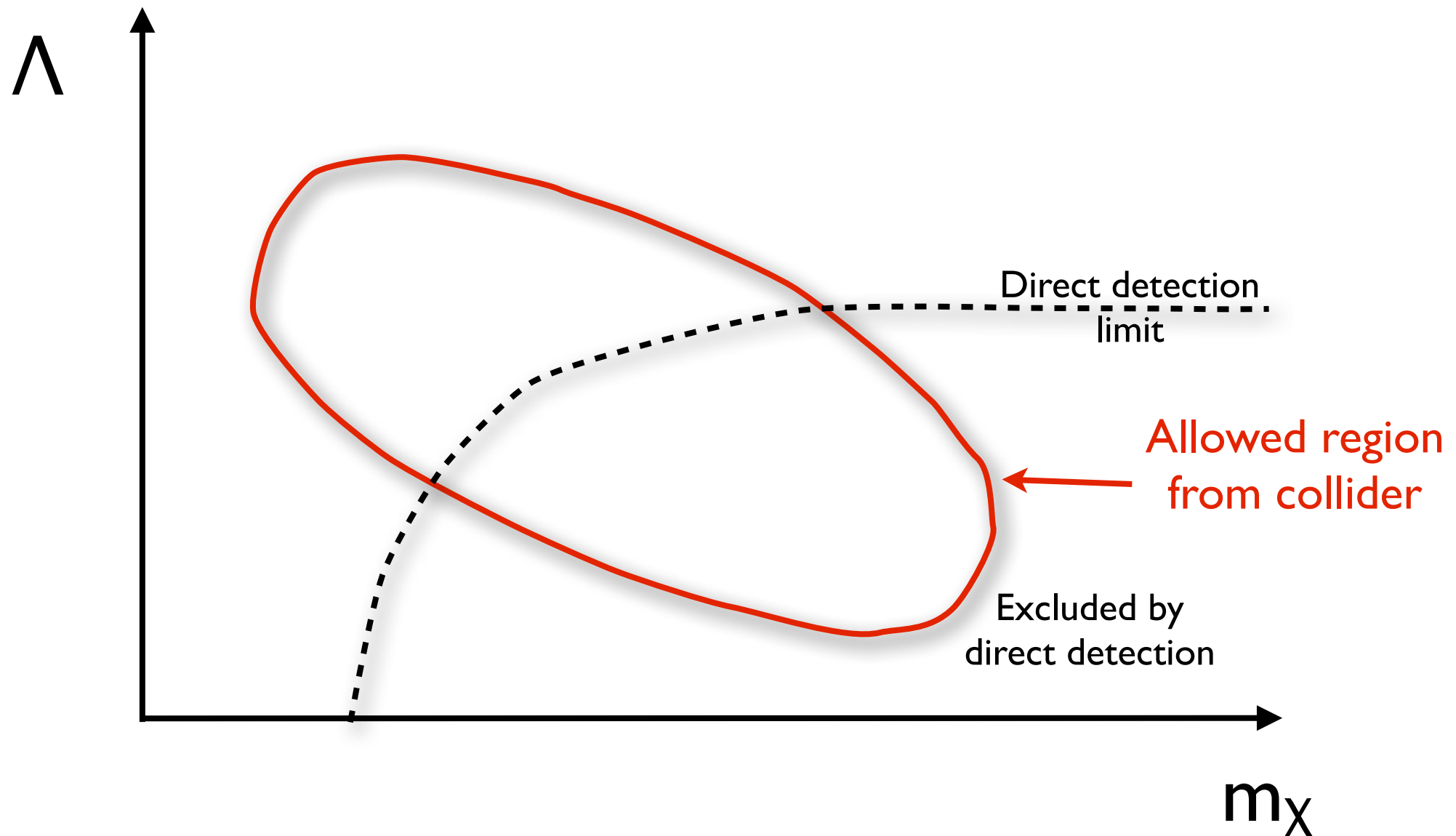
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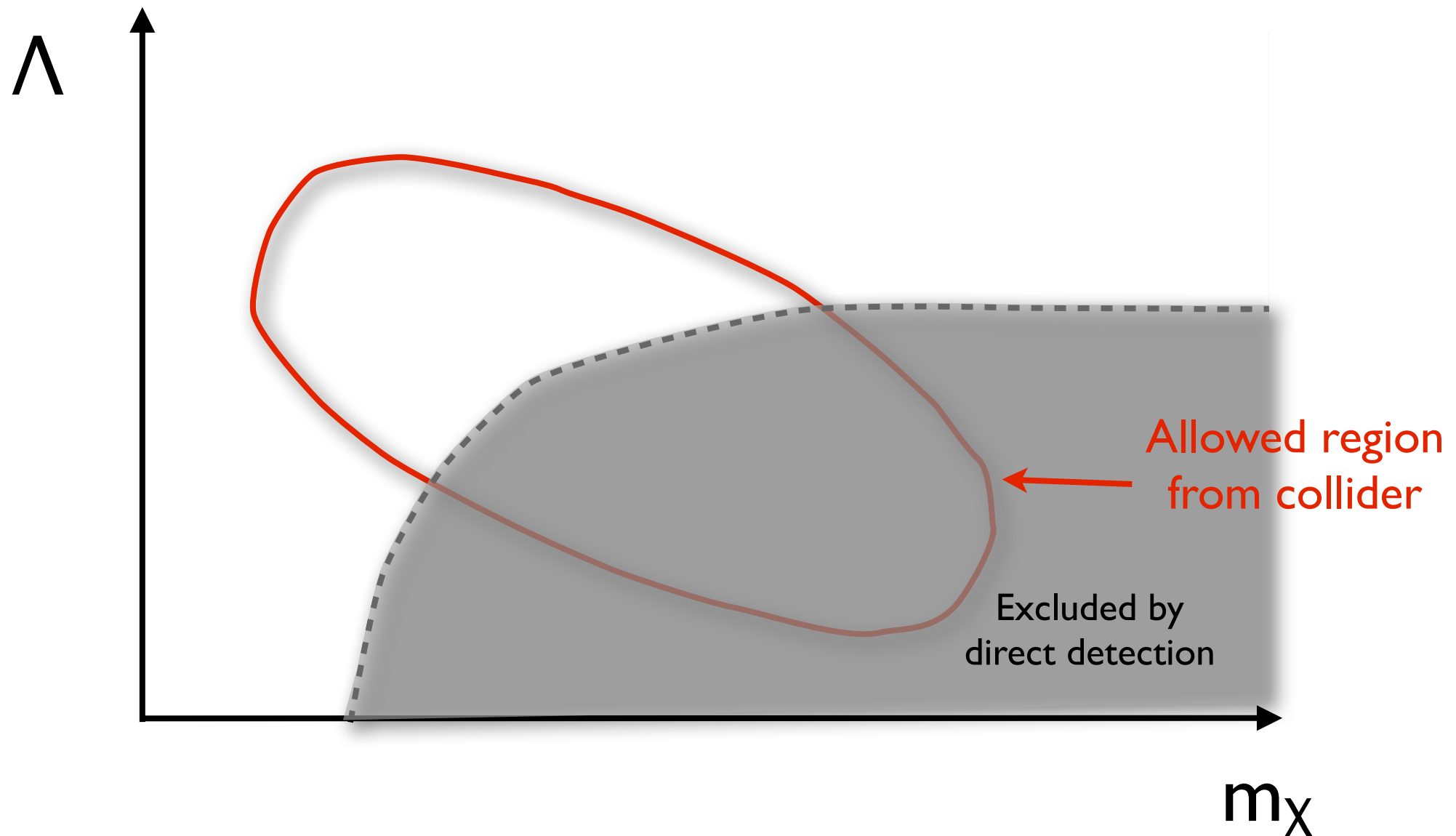
- Improve measurements and additional channels
- Identify potentially responsible operators



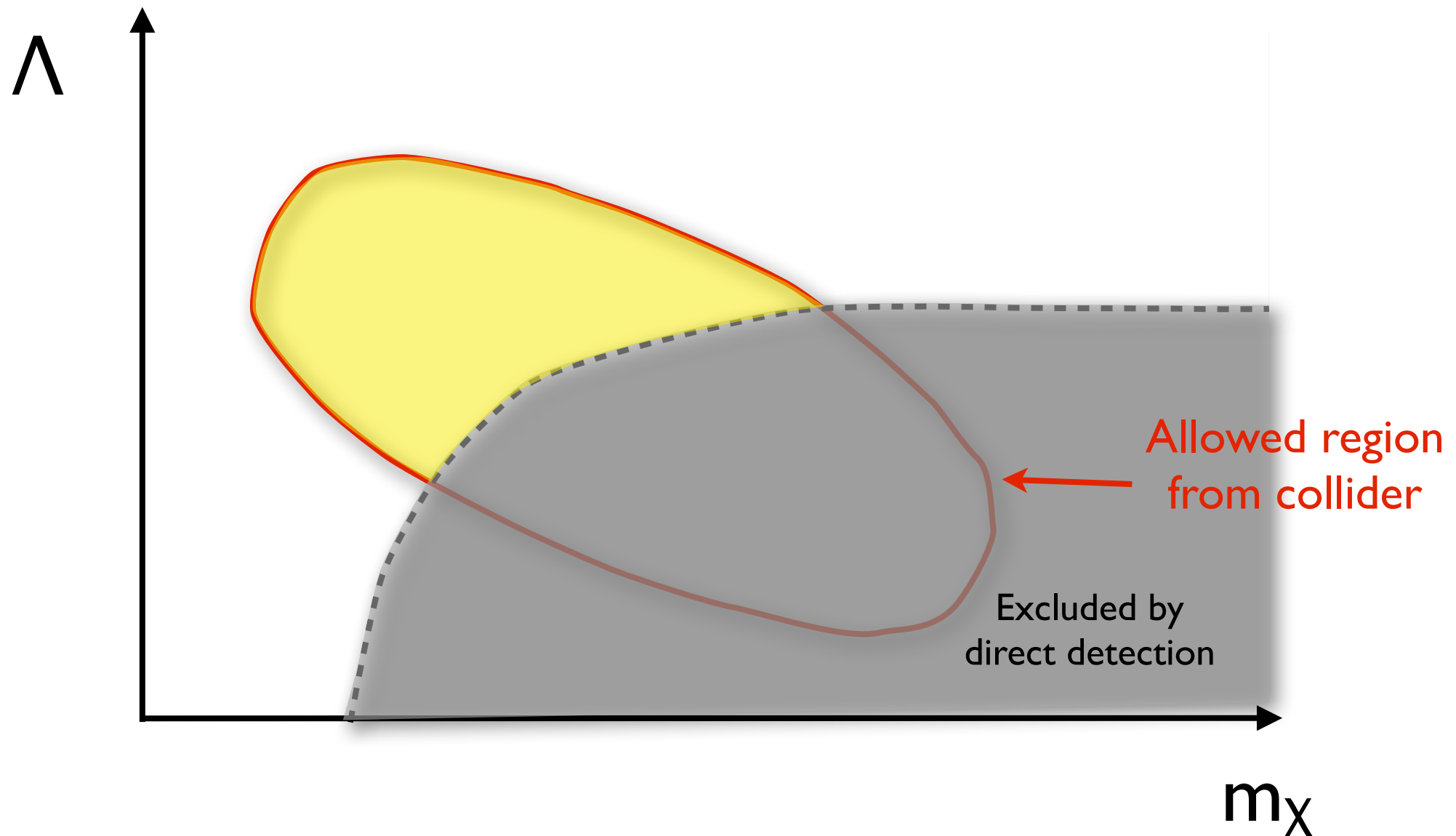
- Infer order of [mass/rate](#) by fits to kinematic variables, e.g:
 - Study operators by comparing rates of mono-b plus tops+MET final stat
 - Information about couplings to up and down type quarks



- **Correlate** with other measurements and experiments (LEP/LHC/direct detection/relic density etc), e.g:
- **Different sensitivities between direct and collider detection**
Dirac vs. Majorana DM
Scalar vs Fermion DM
- Does 'discovery region' agree with relic density calculations?

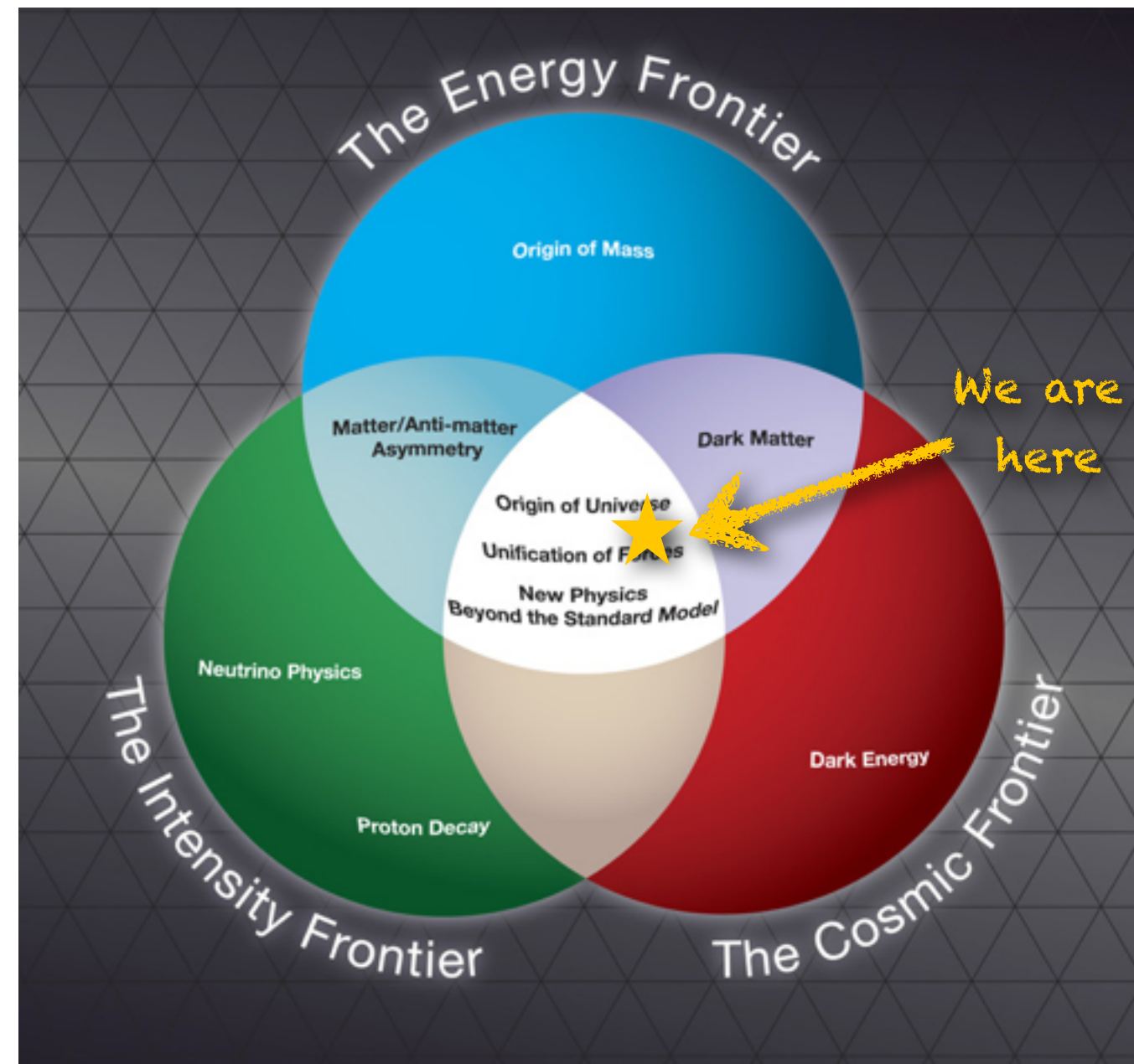


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- Frontier crossing effort could lead to significant information for a Dark Matter candidate
- Thanks to Paddy Fox and Dan Hooper for help guiding my thoughts

- Tantalizing excesses for low mass DM
- ‘Mono-jet’ and more complex EFT signatures have great physics reach
- Truly ‘first’ analysis and more channels not yet explored: (leptonic, VBF, mono-top, etc)
- Affecting several frontiers simultaneously
- Complementary to direct searches
- Pile up no primary issue
- Still evaluating high- p_T effects, selections and systematics
- <http://kicp-workshops.uchicago.edu/DM-LHC2013/>



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KICP Dark Matter Hub Workshop
Chicago, IL
September 19-21, 2013



<http://kicp-workshops.uchicago.edu/darkmatterlhc2013>

Organizing Committee:
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 Rocky Kolb (Chicago/KICP)
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 Björn Penning (Fermilab/Chicago)
 Lian-Tao Wang (Chicago/KICP)
 Steve Worm (Rutherford/CERN)

Topics Include:
 Monojets, Mono-photon, Mono-b
 Effective Field Theory approach
 Theoretical improvements in calculations

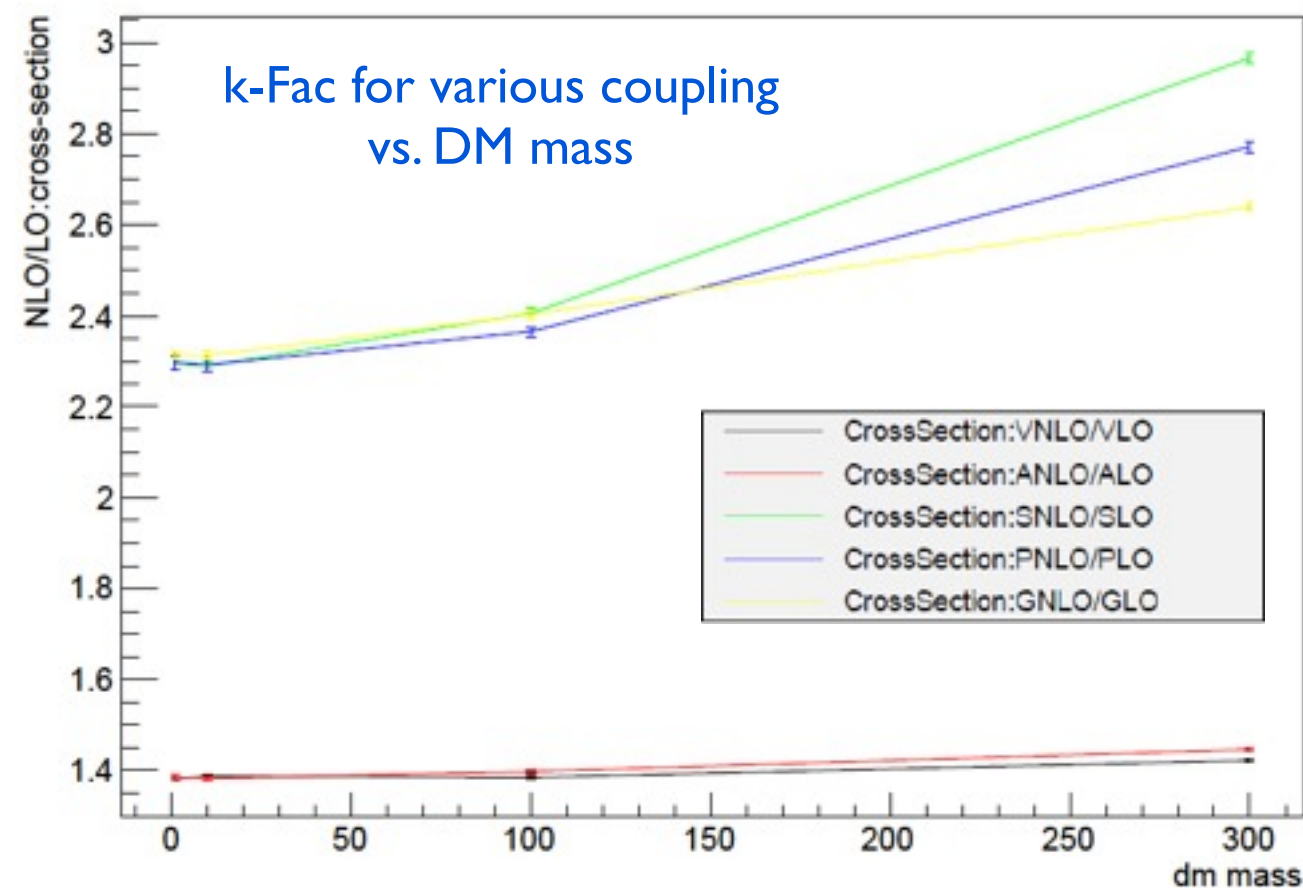
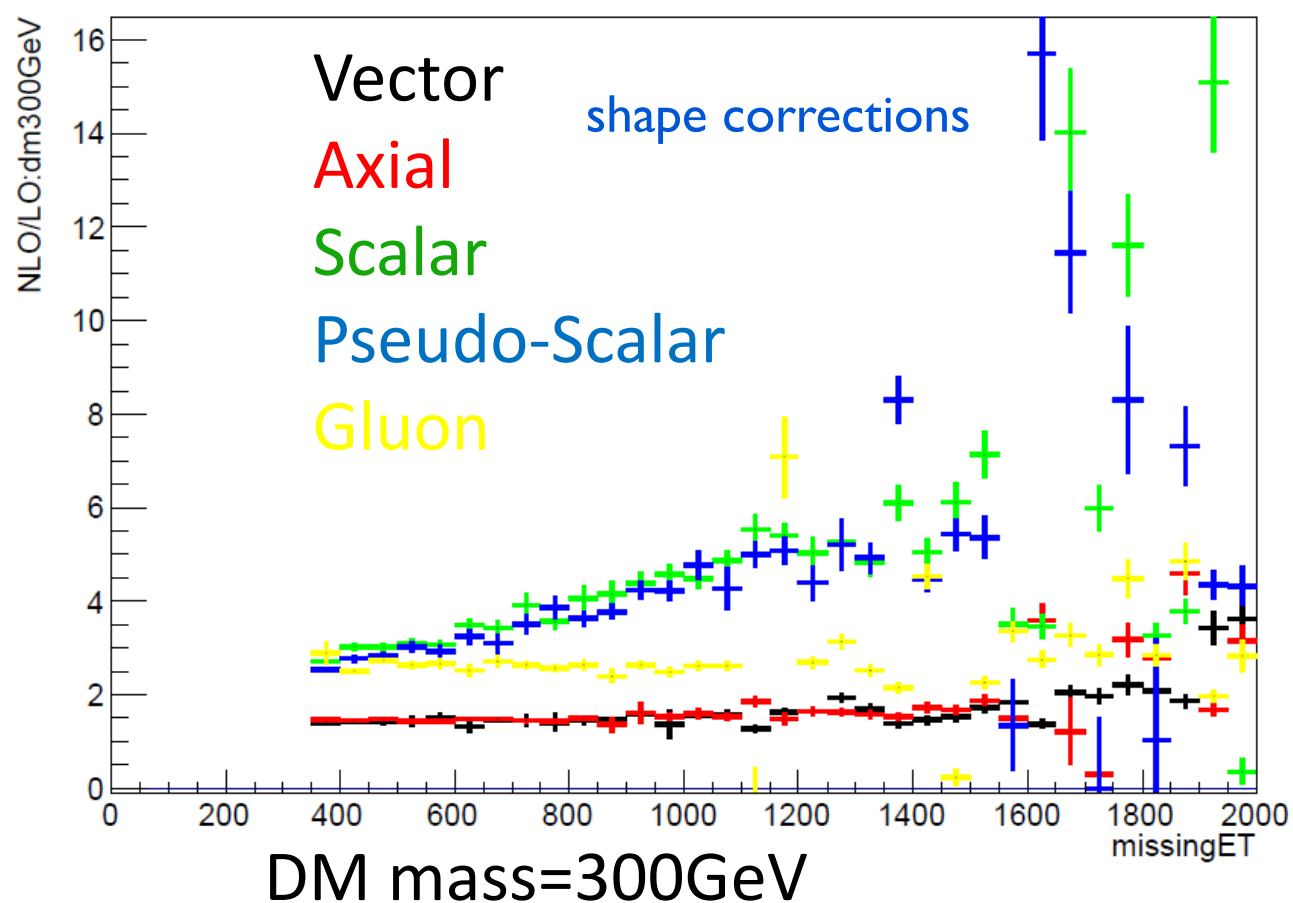
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Backup

- NLO signal calculations:
 - stronger and more accurate/robust analysis
 - derive 'theory safe' selections
- Predictive in terms of kinematic information
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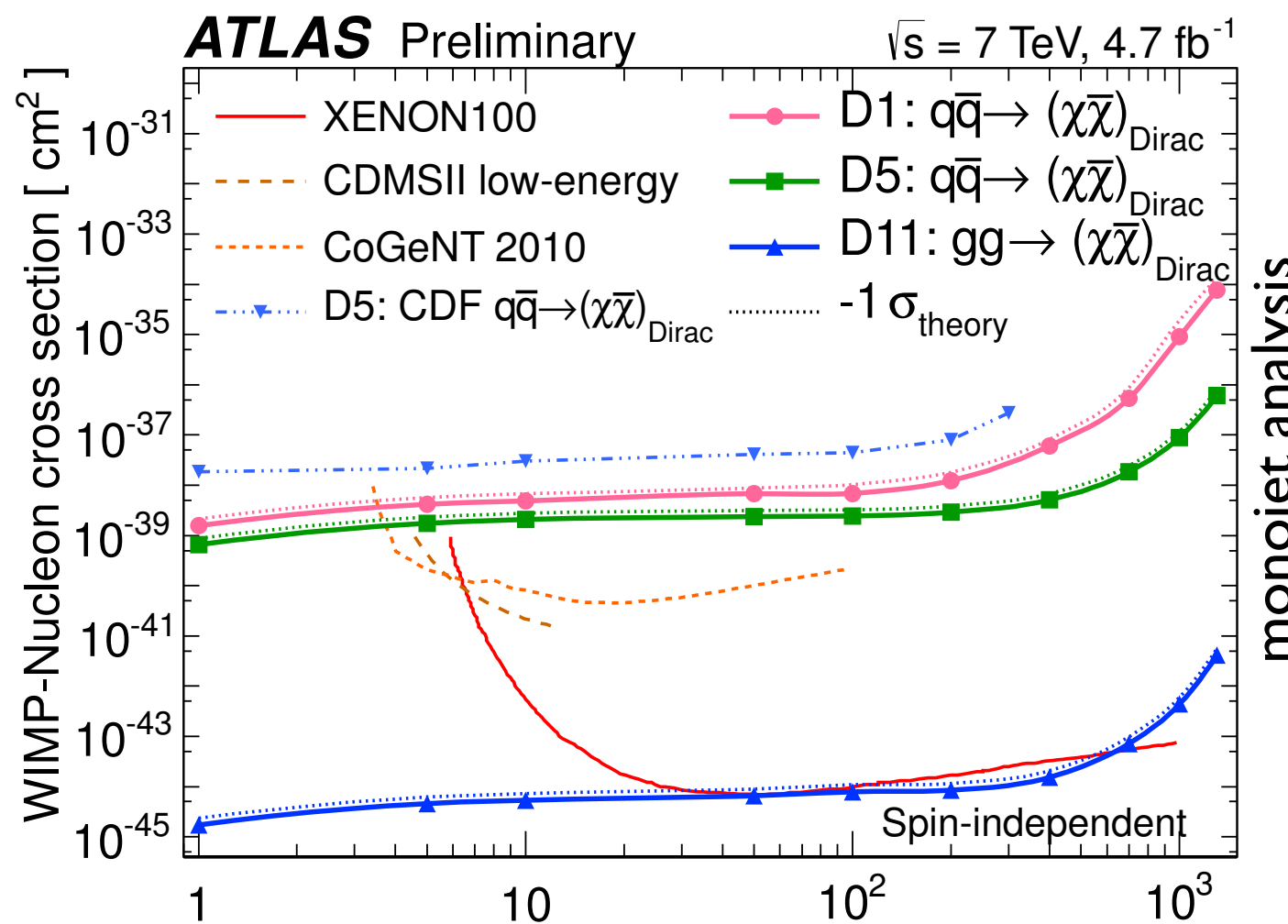
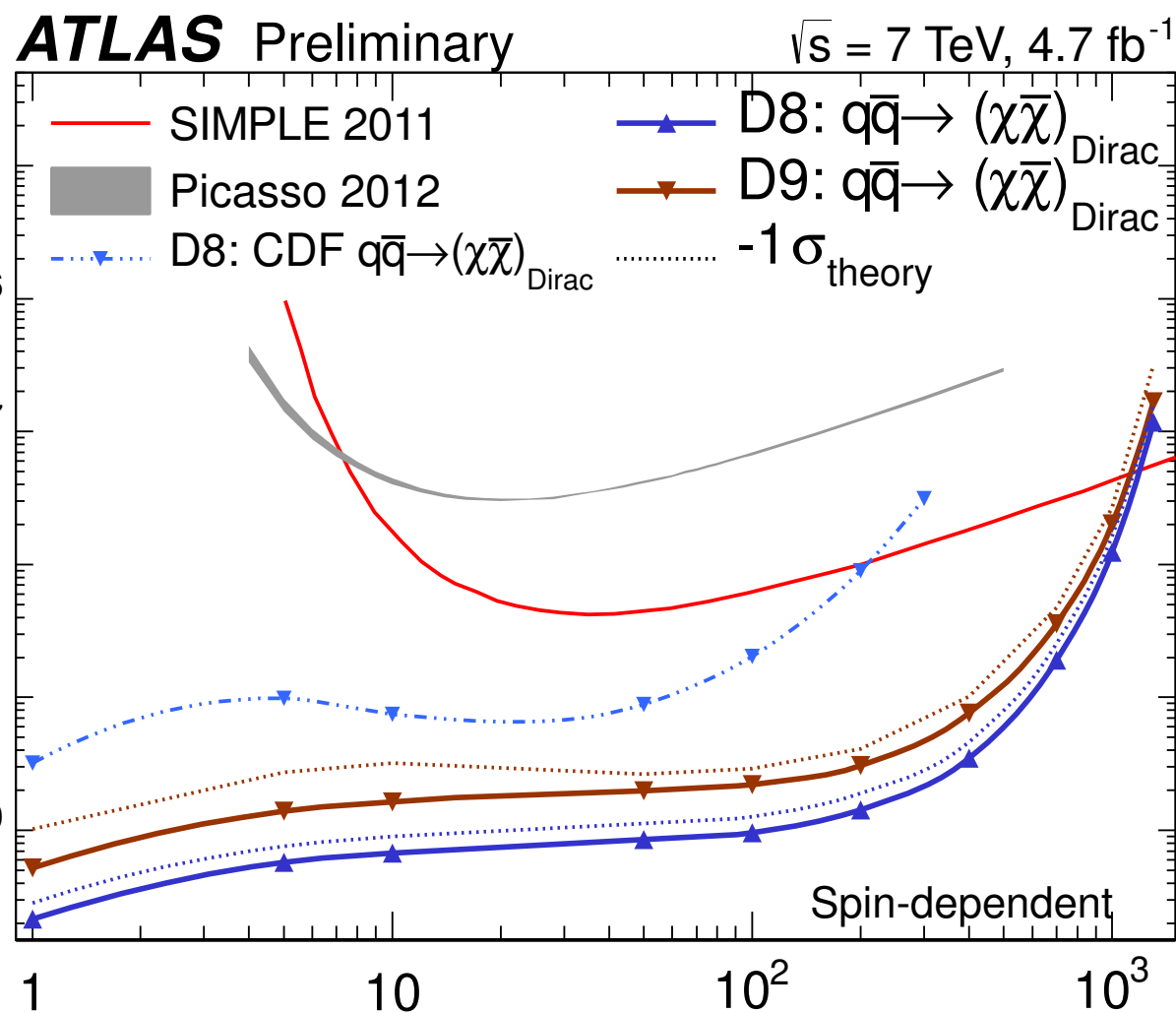
- Optimized selections (shape?)
- New discriminating variables
- May reduce systematic effects
- Not yet used in current limits!



- Comparison with direct detection experiments

(see arXiv:1109.4398v1, Fox et al.)

- **Spin-Dependent** (SIMPLE, Picasso)
Atlas limits stronger for axial vector (D8) and tensor (D9) couplings
- **Spin-Independent** (XENON100, CDMSII, CoGent)
Atlas limits stronger for scalar (D1) and vector (D5) at low m_χ



- Limits on vector and axial-vector interactions as cross section upper limits on **WIMP annihilations** into light quarks, interactions flavor neutral
- Comparing to annihilations to $b\bar{b}$ from **Galactic high energy gamma ray** observations by FERMI LAT

above relic density
line need add.
operations

