New Measurements with Late Decays at LHC

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Work in progress with
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Motivations

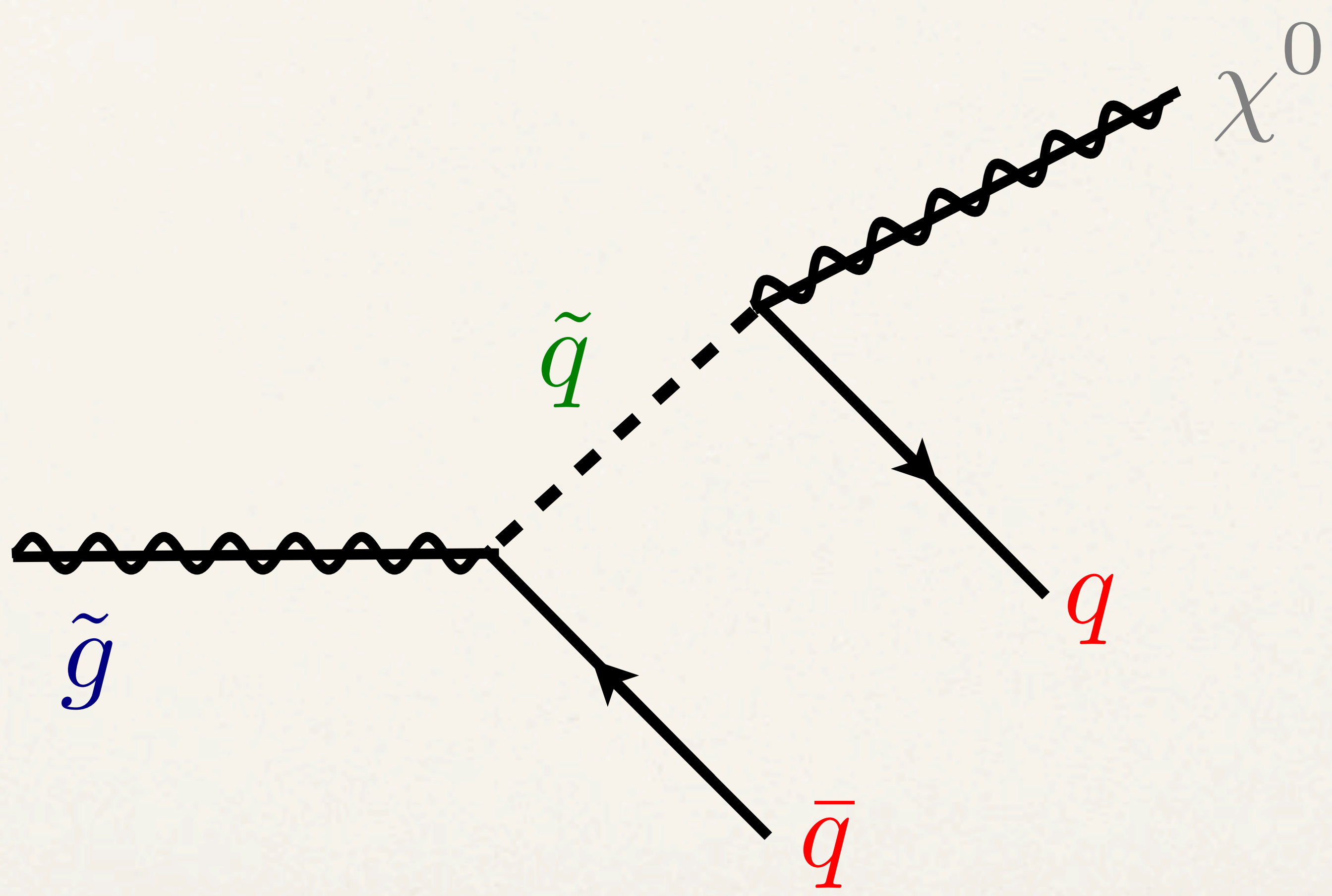
- Long lived (> ns) charged particles (*X*) exist in many models
  Dimopoulos, Dine, Raby, Thomas, 1996. Arkani-Hamed, Dimopolous, 2004...
- Can be electrically charged (CHAMPs) or color charged (SIMPs)
- If new long lived particles exist, what should we do after discovery?
- SM interactions sometimes stop *X* within the detector
  Arvanitaki, Dimopoulos, Pierce, Rajendran, Wacker 2005.

X Decays

- Decay of long lived particle can give access to VERY high energy (proton, muon)
- X often decays to invisible particle
- Can measure mass, coupling, and possibly spin of dark matter candidate

Color Octet (Gluino) Example

- Take **8** under color, neutral under E&M as example



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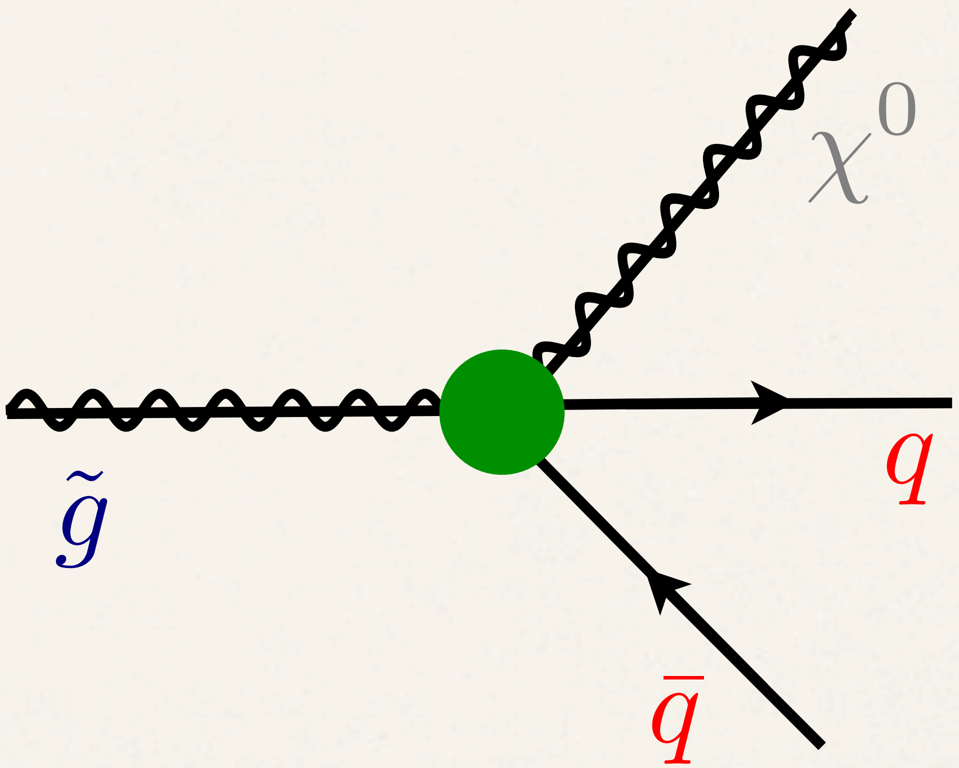
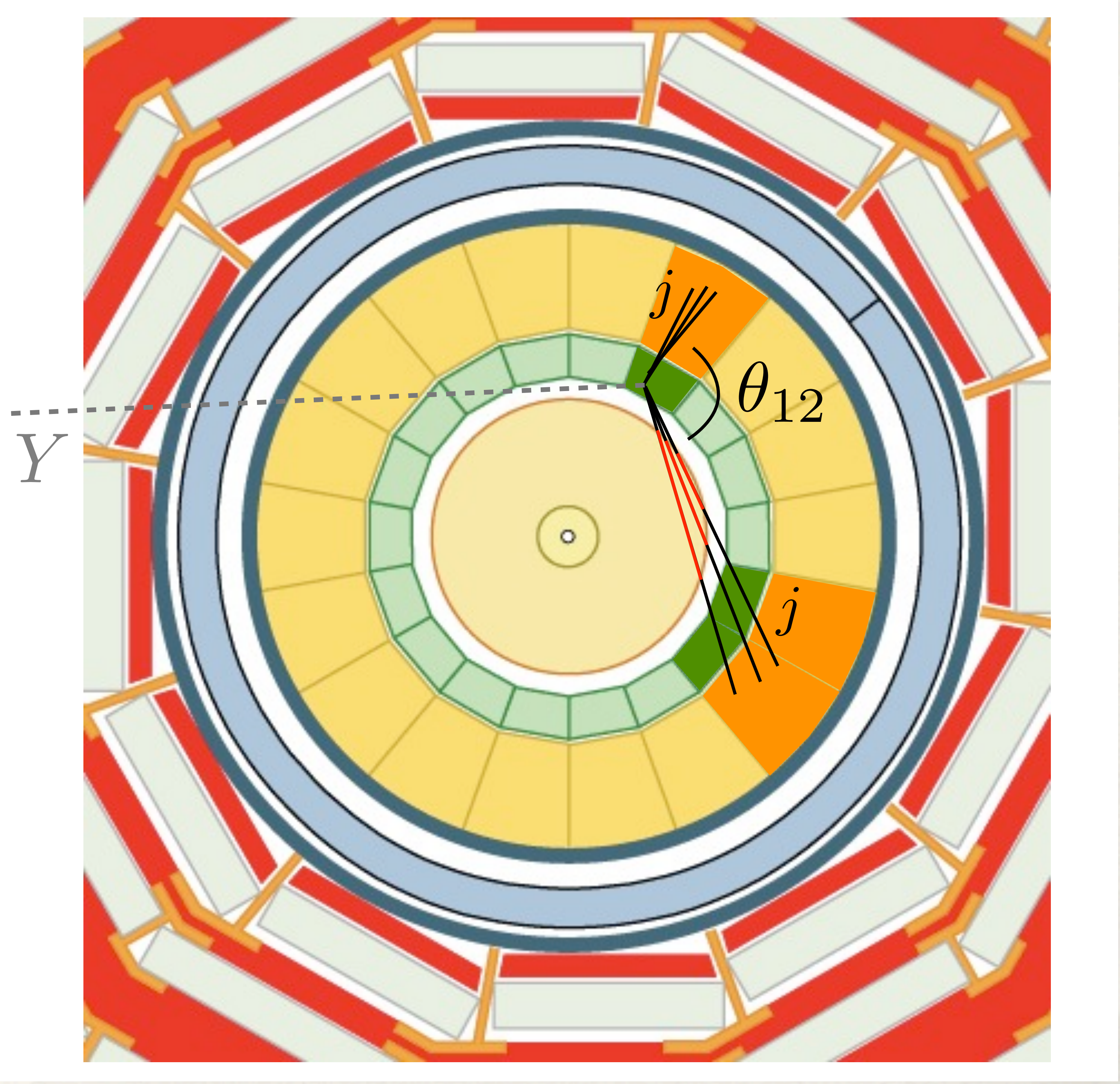


Decays in ECAL

- ECAL does not contain hadronic radiation
- Can measure angles better because multiple detector components are used
- Estimate resolution in ECAL

$$\Delta\theta \sim 30^\circ$$

- Allows you to count jets



Distinguishing Models

Measurements: Counting jets and muons

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Mode	E_j(GeV)	$\Delta\Theta$	1j	2j	3j	$\geq$4j	1μ	2μ
A: $\tilde{g} \to qq'\chi_i^{0,\pm}$	50	30	1	28	27	44	13	2
B: $\tilde{g} \to g\chi_i^0$	50	30	36	28	34	3	3	3
C: $\tilde{t}_1 \to \tilde{a}t$	50	30	32	38	26	0	10	0
D: $\tilde{\tau}_1 \to \tilde{a}\tau$	50	30	79	0	0	0	0	0

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Can distinguish models with O(100) events

Reach of 1 - 1.5 TeV for gluino

Three Body Decay Operators

Three body decays contain more information!

$J_{\text{CHAMP}} \times J_{\text{WIMP}}$	Decay operators	
0×0	O_S^{ss}	$\Lambda^{-1}(\bar{f}_R^2 f_L^1)(\tilde{X}\,\tilde{Y})$
	O_V^{ss}	$\Lambda^{-2}(\bar{f}_L^2 \gamma^\mu f_L^1)(\tilde{X}\partial_\mu \tilde{Y} - \tilde{Y}\partial_\mu \tilde{X})$
$\frac{1}{2} \times \frac{1}{2}$	O_{S1}^{ff}	$\Lambda^{-2}(\bar{f}_R^2 f_L^1)(\bar{Y} X)$
	O_{S2}^{ff}	$\Lambda^{-2}(\bar{f}_R^2 X)(\bar{Y} f_L^1)$
	O_{V1}^{ff}	$\Lambda^{-2}(\bar{f}_L^2 \gamma^\mu f_L^1)(\bar{Y}\gamma_\mu X)$
	O_{T1}^{ff}	$\Lambda^{-2}(\bar{f}_L^2 \sigma^{\mu\nu} f_R^1)(X \sigma_{\mu\nu} Y)$
	O_{T2}^{ff}	$\Lambda^{-2}(\bar{f}_L^2 \sigma^{\mu\nu} X)(\bar{f}_R^1 \sigma_{\mu\nu} Y)$

$J_{\text{CHAMP}} \times J_{\text{WIMP}}$	Decay operators	
1×1	O_S^{vv}	$\Lambda^{-1}(\bar{f}_R^2 f_L^1)(\mathcal{X}_\mu\,\mathcal{Y}^\mu)$
	O_T^{vv}	$\Lambda^{-1}(\bar{f}_R^2 \sigma^{\mu\nu} f_L^1)(\mathcal{X}_\mu\,\mathcal{Y}_\nu)$
	O_{V1}^{vv}	$\Lambda^{-2}(\bar{f}_L^2 \gamma^\mu f_L^1)(\mathcal{Y}_\nu \partial^\nu \mathcal{X}_\mu)$
	O_{V2}^{vv}	$\Lambda^{-2}(\bar{f}_L^2 \gamma^\mu f_L^1)(\mathcal{X}_\nu \partial^\nu \mathcal{Y}_\mu)$
	O_{V3}^{vv}	$\Lambda^{-2}(\bar{f}_L^2 \gamma^\mu f_L^1)(\mathcal{X}_\nu \partial_\mu \mathcal{Y}^\nu - \mathcal{Y}_\nu \partial_\mu \mathcal{X}^\nu)$
1×0	O_S^{vs}	$\Lambda^{-2}(\bar{f}_R^2 f_L^1)(\mathcal{X}^\mu\,\partial_\mu \tilde{Y})$
	O_V^{vs}	$\Lambda^{-1}(\bar{f}_L^2 \gamma^\mu f_L^1)(\mathcal{X}_\mu\,\tilde{Y})$
	O_T^{vs}	$\Lambda^{-2}(\bar{f}_R^2 \sigma^{\mu\nu} f_L^1)(\mathcal{X}_\mu\,\partial_\nu \tilde{Y} - \mathcal{X}_\nu\,\partial_\mu \tilde{Y})$

Three Body Decay Operators

Three body decays contain more information!

$J_{\text{CHAMP}} \times J_{\text{WIMP}}$	Decay operators	
0×0	O_S^{ss}	$\Lambda^{-1}(\bar{f}^2_R f^1_L)(\tilde{X}\,\tilde{Y})$
	O_V^{ss}	$\Lambda^{-2}(\bar{f}^2_L \gamma^\mu f^1_L)(\tilde{X}\partial_\mu \tilde{Y} - \tilde{Y}\partial_\mu \tilde{X})$
$\frac{1}{2} \times \frac{1}{2}$	O_{S1}^{ff}	$\Lambda^{-2}(\bar{f}^2_R f^1_L)(\bar{Y} X)$
	O_{S2}^{ff}	$\Lambda^{-2}(\bar{f}^2_R X)(\bar{Y} f^1_L)$
	O_{V1}^{ff}	$\Lambda^{-2}(\bar{f}^2_L \gamma^\mu f^1_L)(\bar{Y}\gamma_\mu X)$
	O_{T1}^{ff}	$\Lambda^{-2}(\bar{f}^2_L \sigma^{\mu\nu} f^1_R)(X \sigma_{\mu\nu} Y)$
	O_{T2}^{ff}	$\Lambda^{-2}(\bar{f}^2_L \sigma^{\mu\nu} X)(\bar{f}^1_R \sigma_{\mu\nu} Y)$

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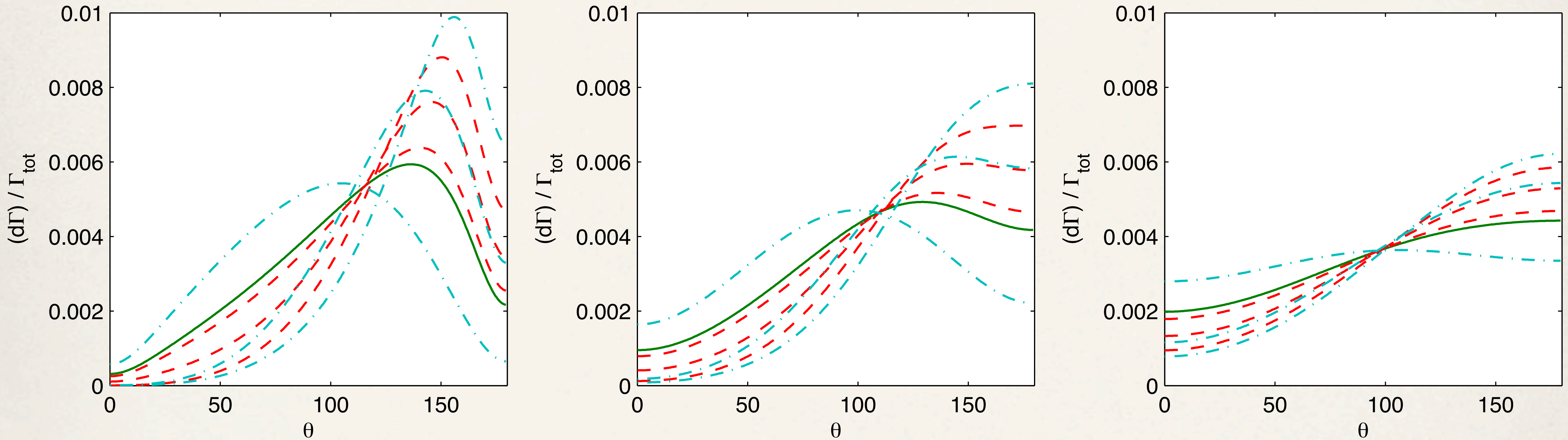
	O_{V1}^{vv}	$\Lambda^{-2}(\bar{f}^2_L \gamma^\mu f^1_L)(\mathcal{Y}_\nu \partial^\nu \mathcal{X}_\mu)$
	O_{V2}^{vv}	$\Lambda^{-2}(\bar{f}^2_L \gamma^\mu f^1_L)(\mathcal{X}_\nu \partial^\nu \mathcal{Y}_\mu)$
	O_{V3}^{vv}	$\Lambda^{-2}(\bar{f}^2_L \gamma^\mu f^1_L)(\mathcal{X}_\nu \partial_\mu \mathcal{Y}^\nu - \mathcal{Y}_\nu \partial_\mu \mathcal{X}^\nu)$
1×0	O_S^{vs}	$\Lambda^{-2}(\bar{f}^2_R f^1_L)(\mathcal{X}^\mu\, \partial_\mu \tilde{Y})$
	O_V^{vs}	$\Lambda^{-1}(\bar{f}^2_L \gamma^\mu f^1_L)(\mathcal{X}_\mu\, \tilde{Y})$
	O_T^{vs}	$\Lambda^{-2}(\bar{f}^2_R \sigma^{\mu\nu} f^1_L)(\mathcal{X}_\mu\, \partial_\nu \tilde{Y} - \mathcal{X}_\nu\, \partial_\mu \tilde{Y})$

Split SUSY operator

Kinematic Distribution



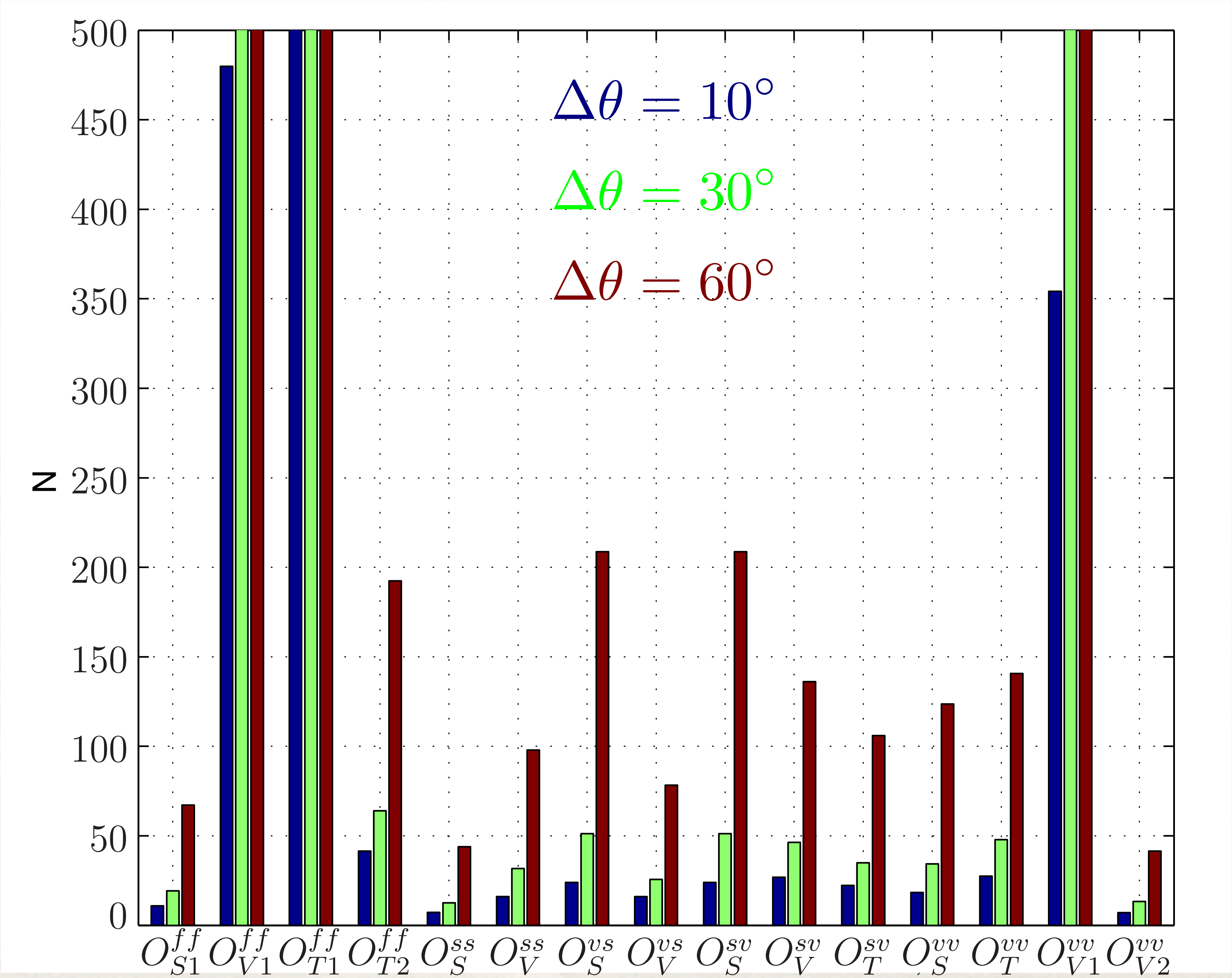
$\Delta\theta = 10^\circ$ $\Delta\theta = 30^\circ$ $\Delta\theta = 60^\circ$

Split SUSY

Operators with same spins

Operators with different spins

Discriminating Operators



Conclusions

- Measurement of decays of long lived charged particles can give insight into very high scale physics and into new sectors
- Measurements are complementary to analyses of X production
- The LHC's detectors can crudely measure angles between jets and muons for decays originating in the ECAL
- Counting jets and muons allows the LHC discriminate different CHAMP and SIMP models with O(100) events
- If there is a three body decay, Lorentz structure and spin can be partially determined with a similar number of events giving insight into UV completion

Thank You