On the trail of dark matter by use of simplified models at CMS

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Kai Schmidt-Hoberg,
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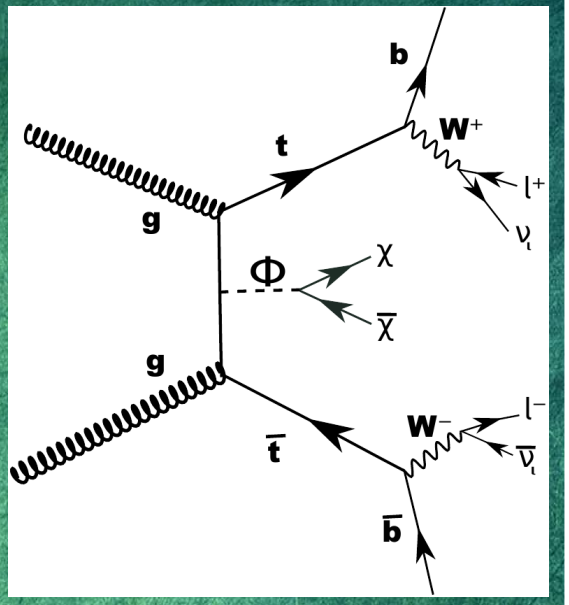
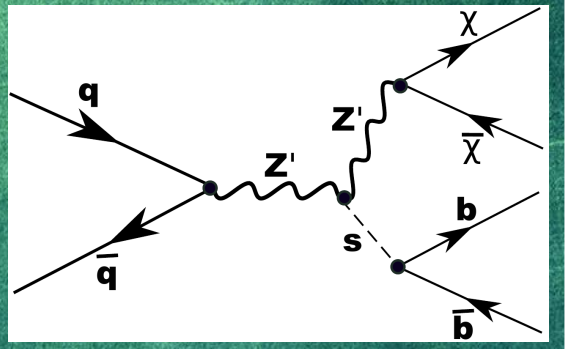
Nicole Stefanov

DPG-Frühjahrstagung Würzburg,
20th March 2018





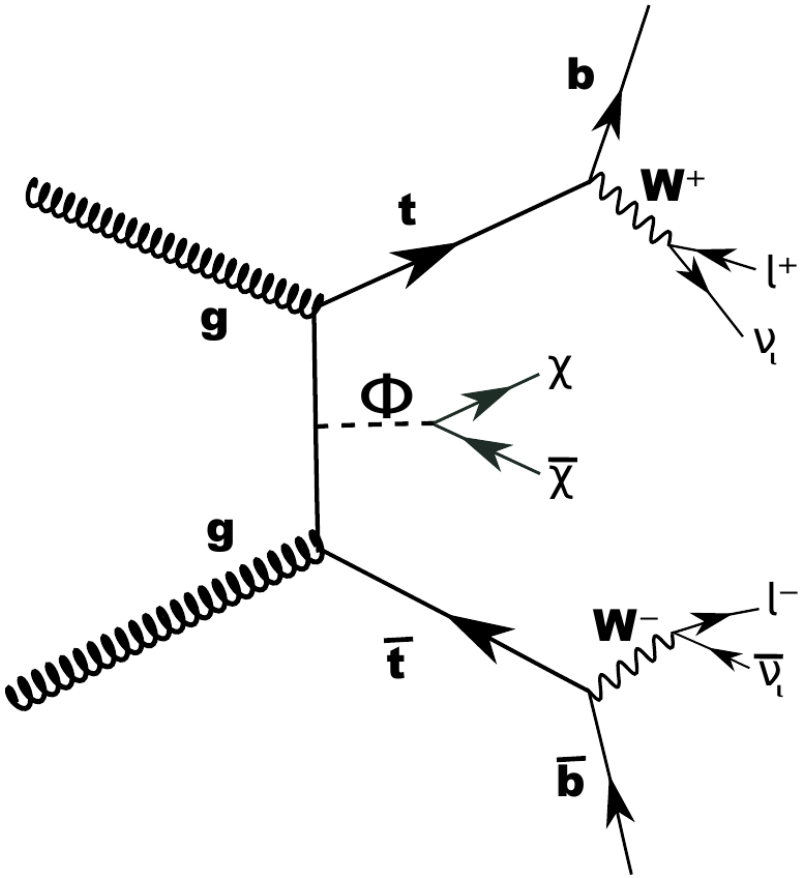
DESY

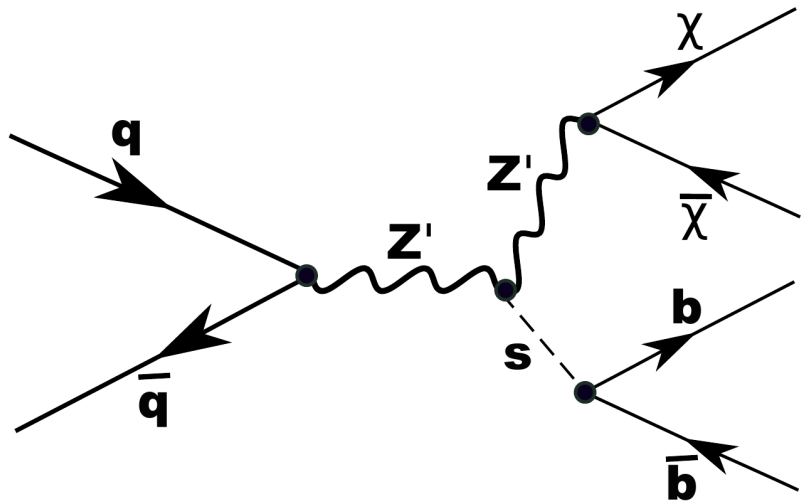
HELMHOLTZ ASSOCIATION

CMS

Outline

- **W**eakly **I**nteracting **M**assive **P**article hypothesis
- Search at LHC possible





with Spin-0 mediator

with Spin-0 and Spin-1 mediator

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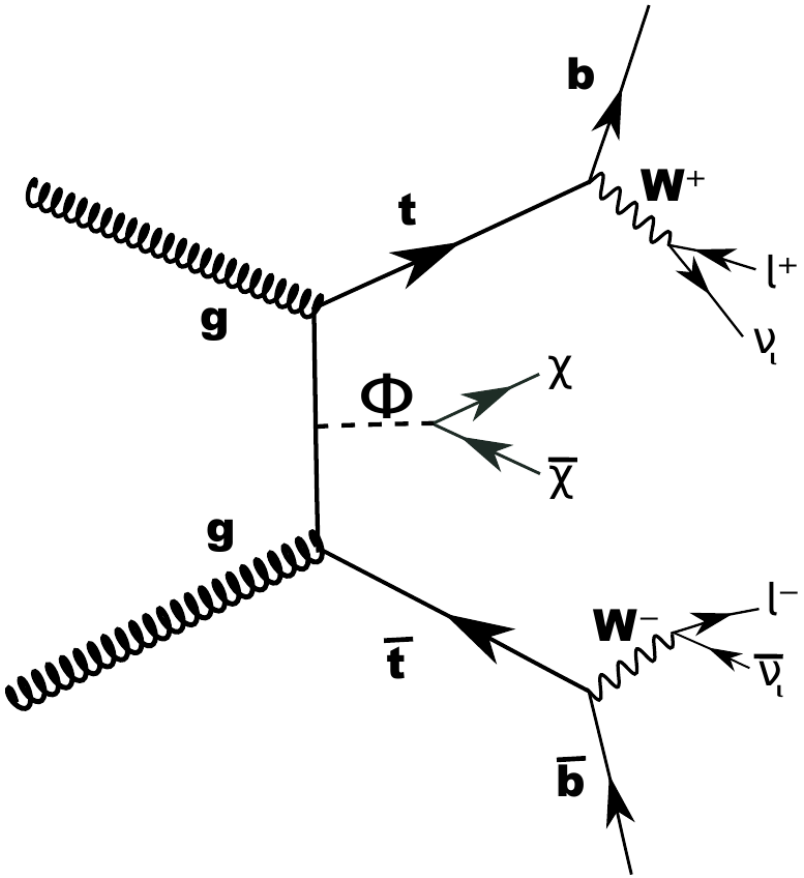
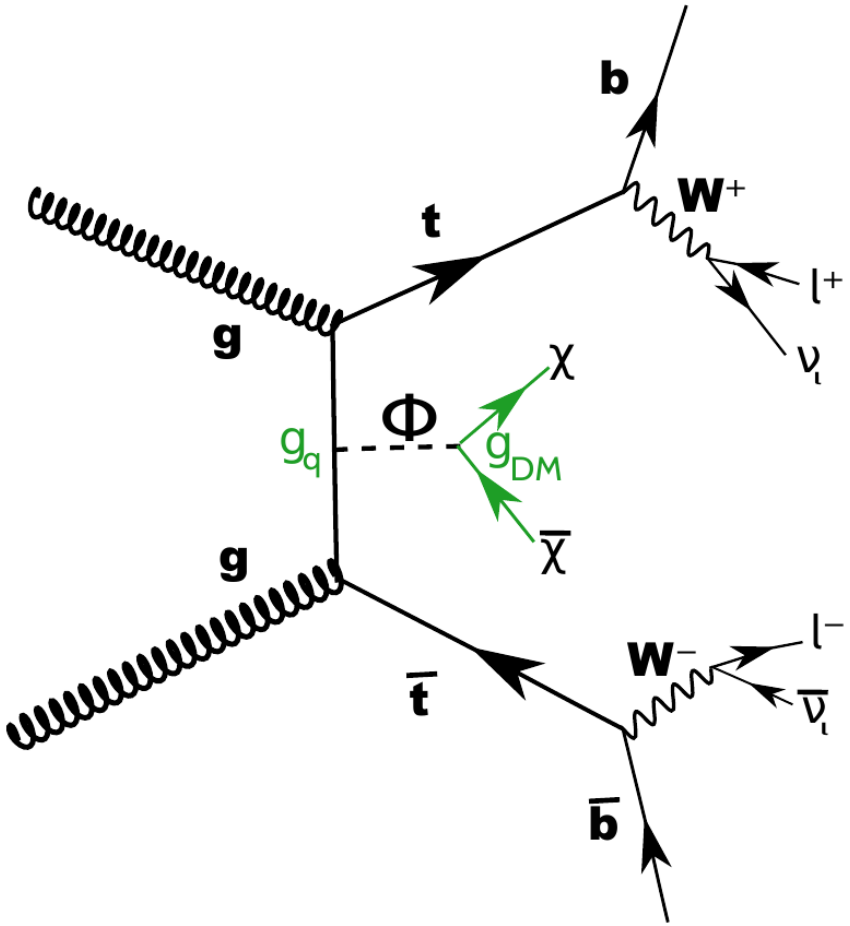
- Search at LHC possible



with Spin-0 mediator

Search by use of simplified DM models



Framework

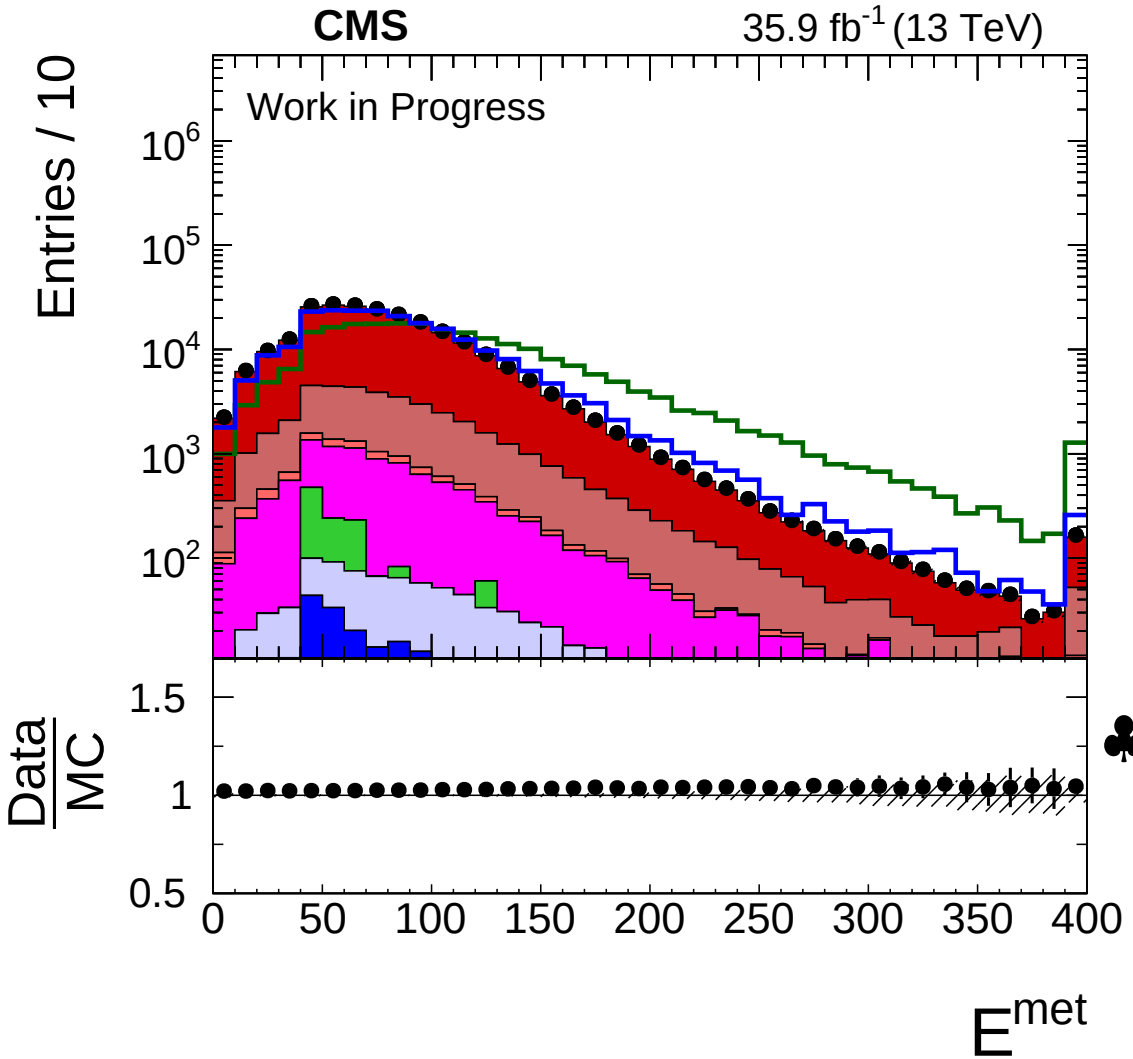
- DM Dirac fermions
- (pseudo-) scalar Φ
- Four parameters for description needed: $g_q, g_{DM}, m_\chi, m_\Phi$

Direct recoil of DM against SM particles

Motivation

- Yukawa-like coupling
  $\Rightarrow$ strongest coupling to heaviest quark (= top quark)
- test nature of mediator

Search by use of simplified DM models



Challenges in this search:
- large $t\bar{t}$- background
- $t\bar{t}$Z-events with Z $\rightarrow \nu\bar{\nu}$

♣ *correct* kinematic reconstruction of signal event needed

Kinematic reconstruction

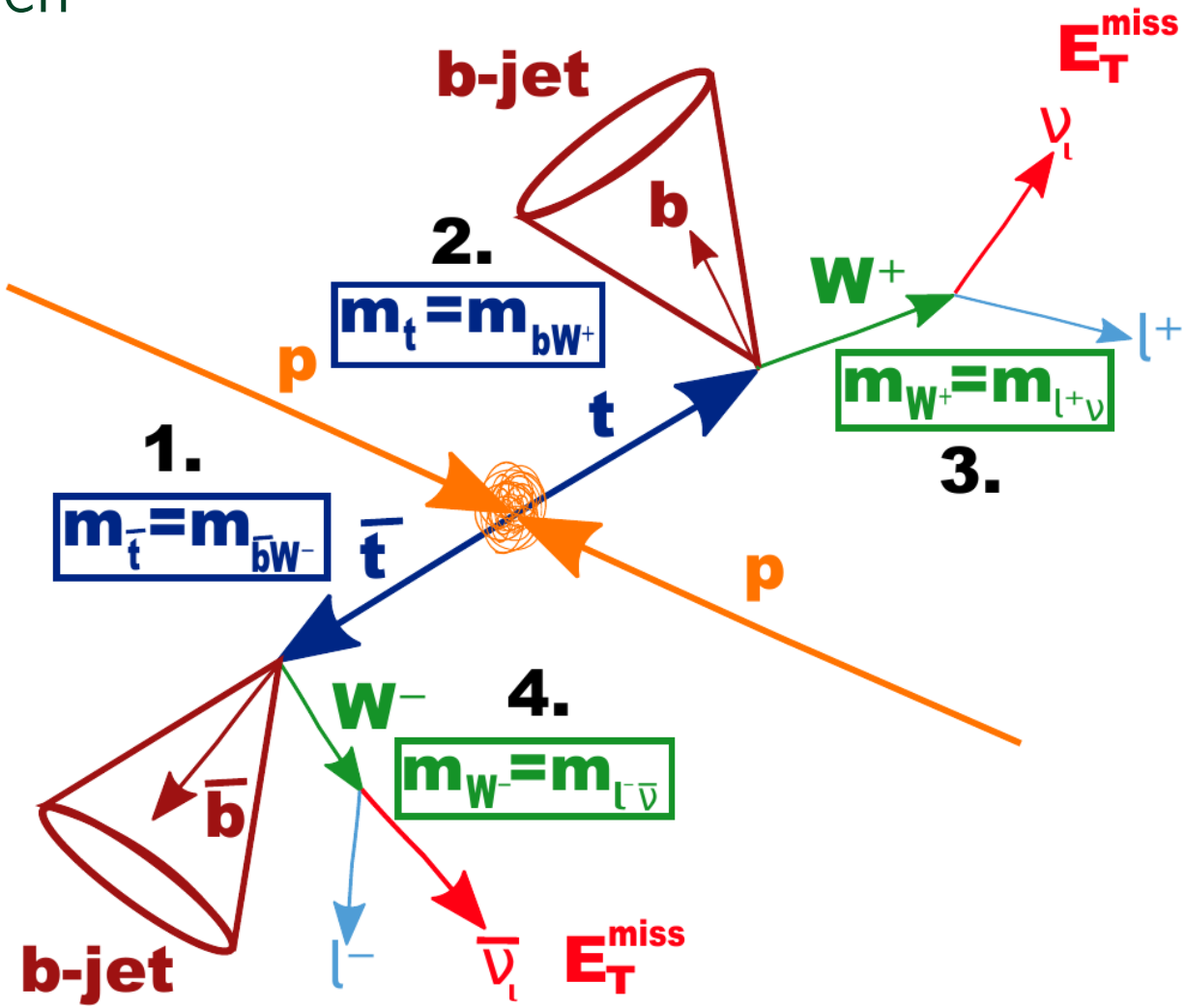
Sonnenschein's approach

Unknown:
neutrinos' 4-momentum

$\Rightarrow$ 6 unknown variables
$\Rightarrow$ 6 constraints needed

5. $E_{T,x}^{miss} = p_{\nu_x} + p_{\bar{\nu}_x}$ &
6. $E_{T,y}^{miss} = p_{\nu_y} + p_{\bar{\nu}_y}$

arXiv:0603011v3



$\Rightarrow$ results in a polynomial of $p_{\nu_x} \rightarrow$ in total max. 4 solutions

Kinematic reconstruction

Betchart's approach, arXiv:1305.1878v2

$\Rightarrow$ Splitting decay chain of top quark event into two steps
t $\rightarrow$ W b and W $\rightarrow$ l ν

$$E_t = \underbrace{E_b + E_W}_{step1} = E_b + \underbrace{E_l + E_\nu}_{step2} \quad \& \quad \vec{p}_t = \vec{p}_b + \vec{p}_W = \vec{p}_b + \vec{p}_l + \vec{p}_\nu$$

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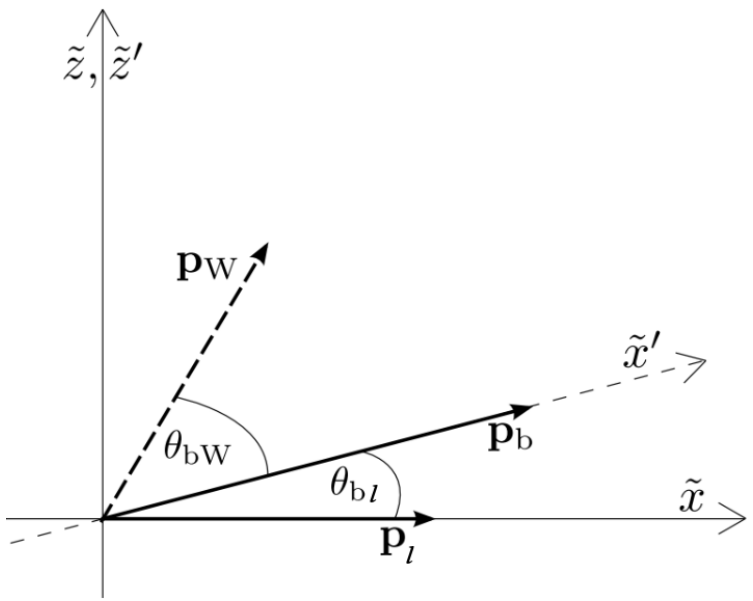
$$m_t^2 = E_t^2 - \vec{p}_t^{\,2} = (E_b + E_W)^2 - (\vec{p}_b + \vec{p}_W)^2$$
$$= m_b^2 + m_W^2 + 2E_b \cdot E_W - 2p_b \cdot p_W \cos\theta_{bW}$$

- $\vec{p}_W$ restricted to ellipsoid's surface



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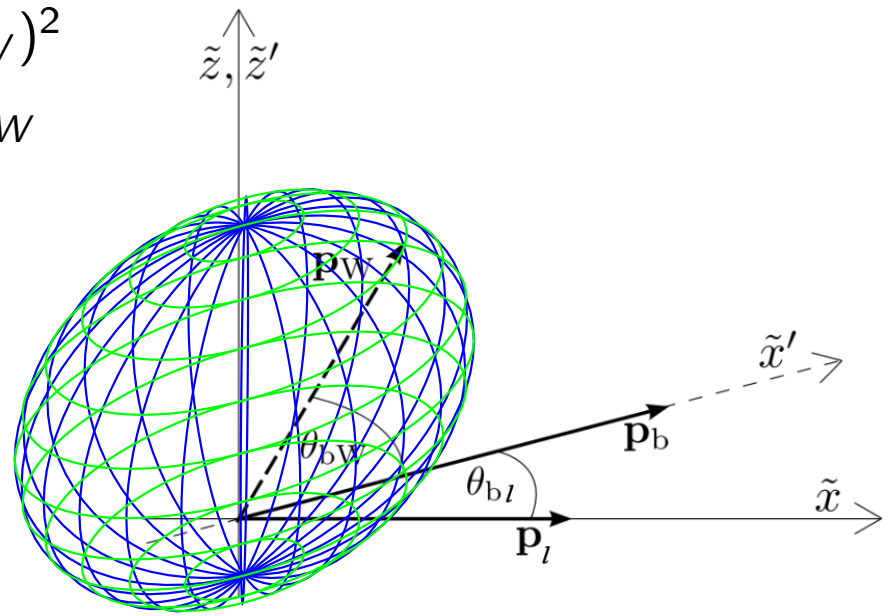

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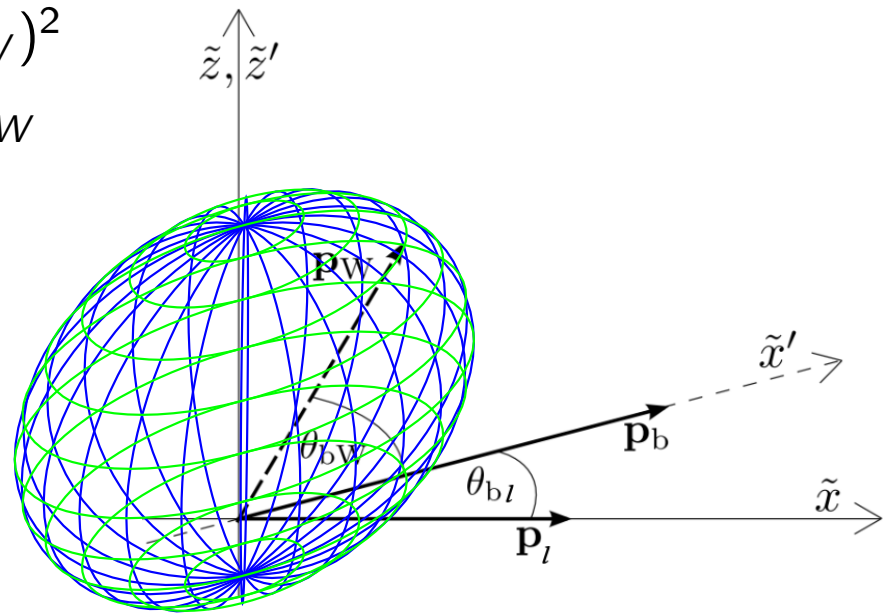
- $\vec{p}_W$ restricted to ellipsoid's surface
- Solve step 2 for $\vec{p}_\nu$ analogously

+ shift by $\vec{p}_l$ to get 2. ellipsoid for $\vec{p}_W$

- intersect ellipsoids



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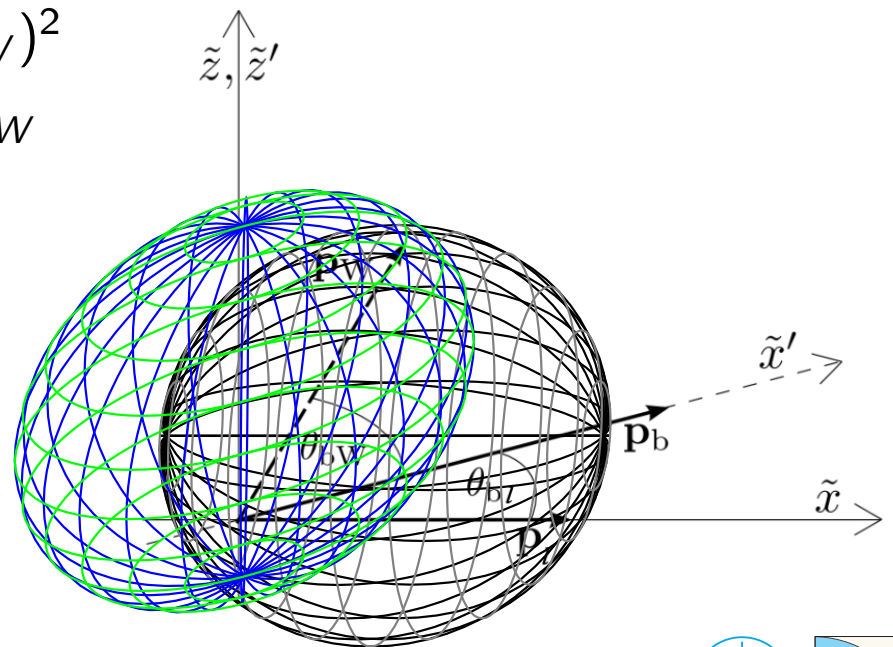

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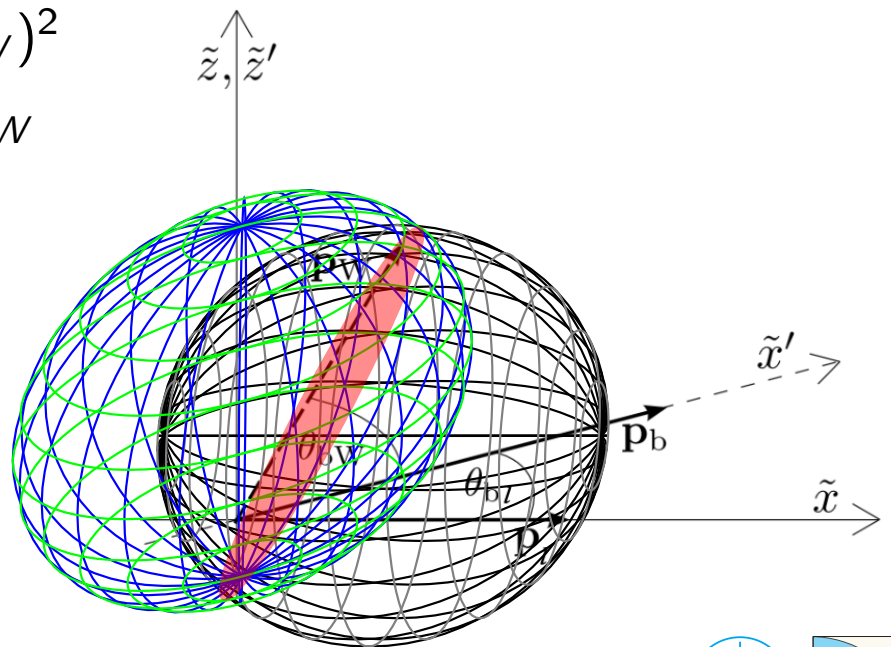
⇒ ellipse with ∞ solution points ≡ ES



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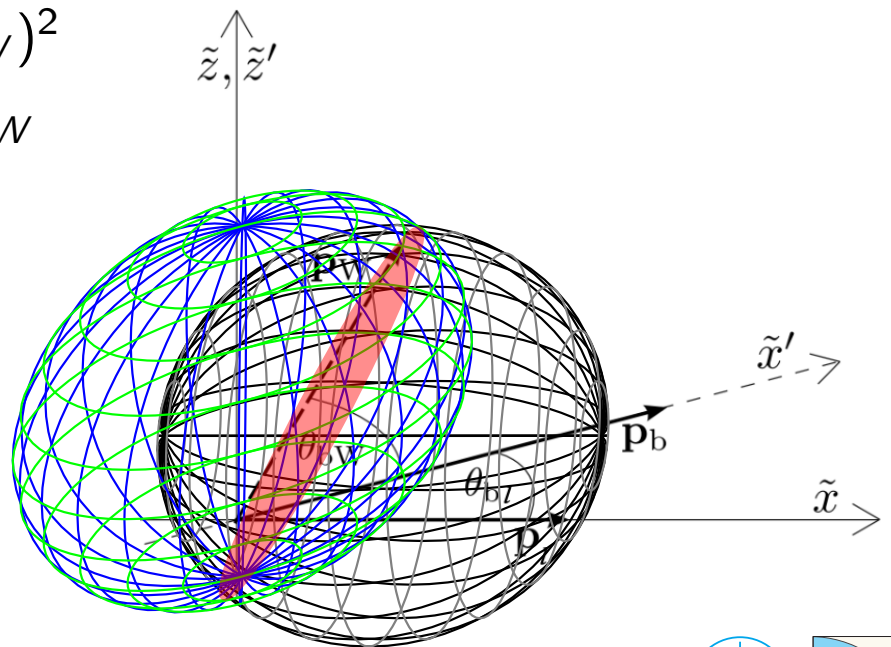
- intersect ellipsoids

⇒ ellipse with ∞ solution points ≡ ES

- analogously for antitop quark

→ intersect ES of $\vec{p}_\nu$ with MET ellipse
→ in total max. 8 solutions



Kinematic reconstruction

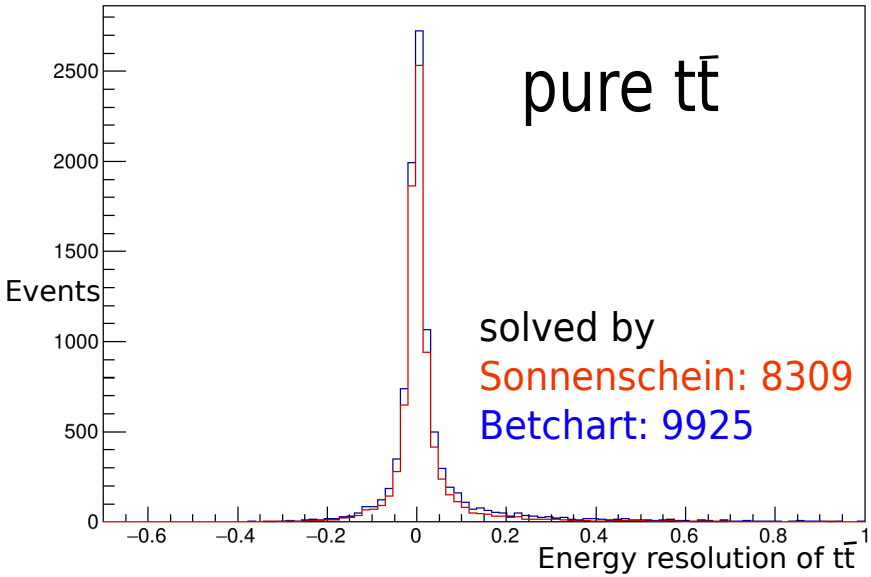
Signal events used for
Betchart vs. Sonnenschein comparison

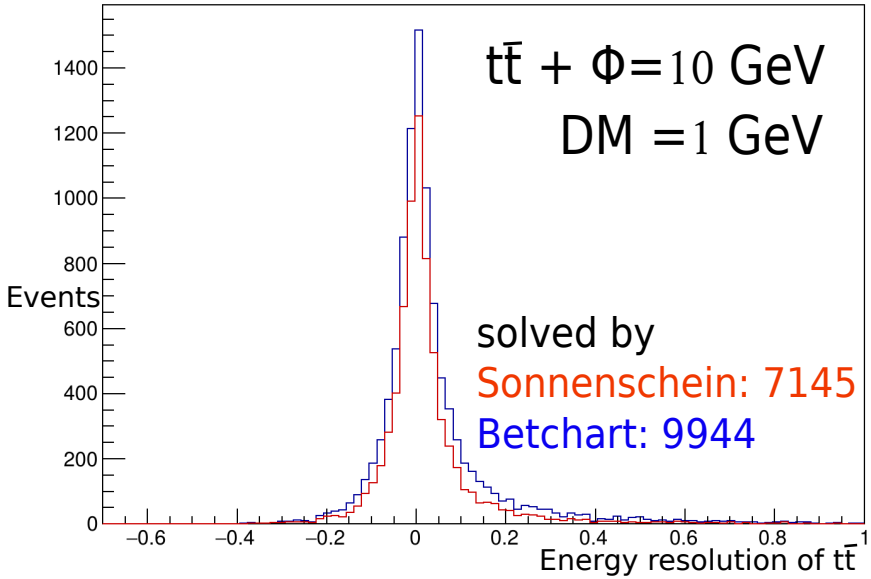
Test on

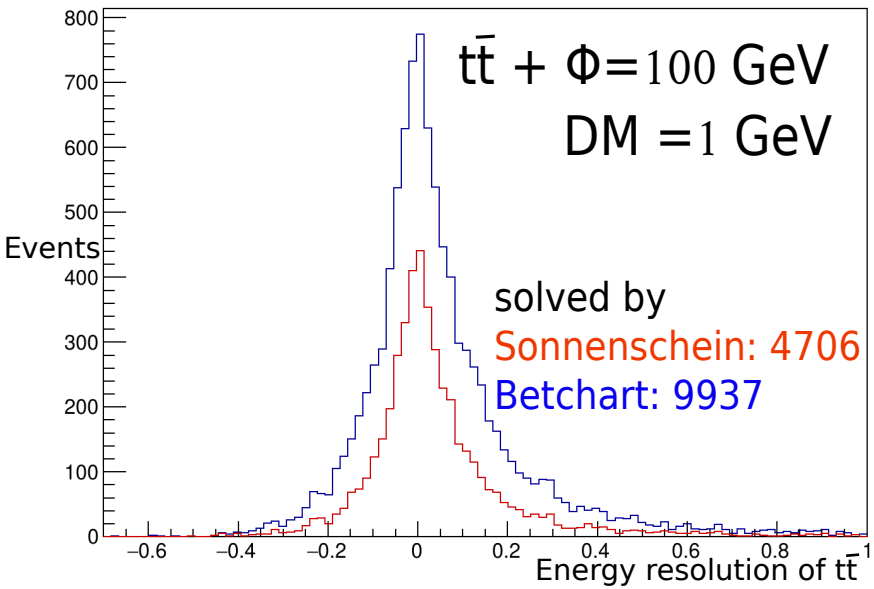
- Monte Carlo samples on parton level
- With 10000 events, respectively
- Betchart and Sonnenschein algorithm provided

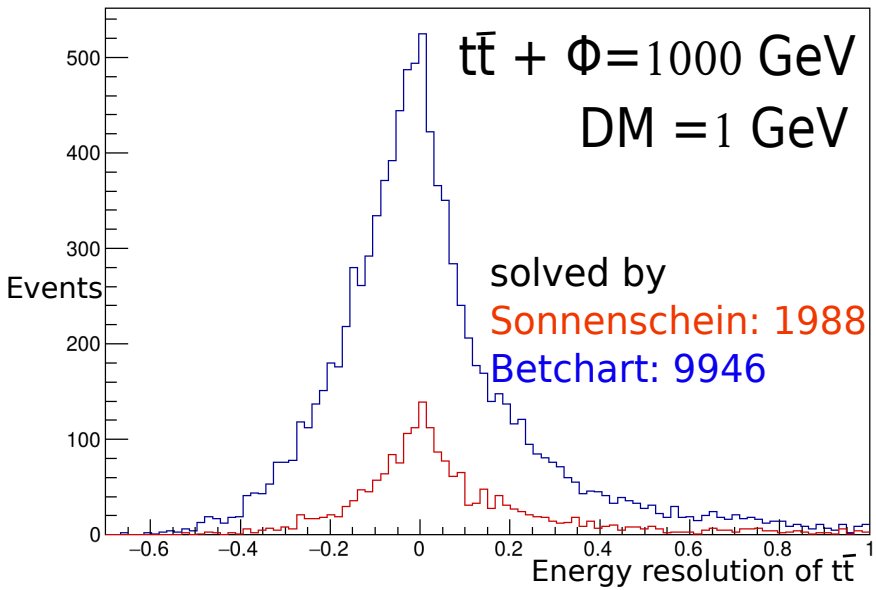
  $\rightarrow$ with fixed values for $m_t, m_{\bar{t}}, m_{W^{-/+}}$
  $\rightarrow$ and correct b-jet matching
- NLO model files of
  `http://feynrules.irmp.ucl.ac.be/wiki/DMsimp`
  used for generation of $t\bar{t}$DM samples

Kinematic reconstruction Betchart vs. Sonnenschein



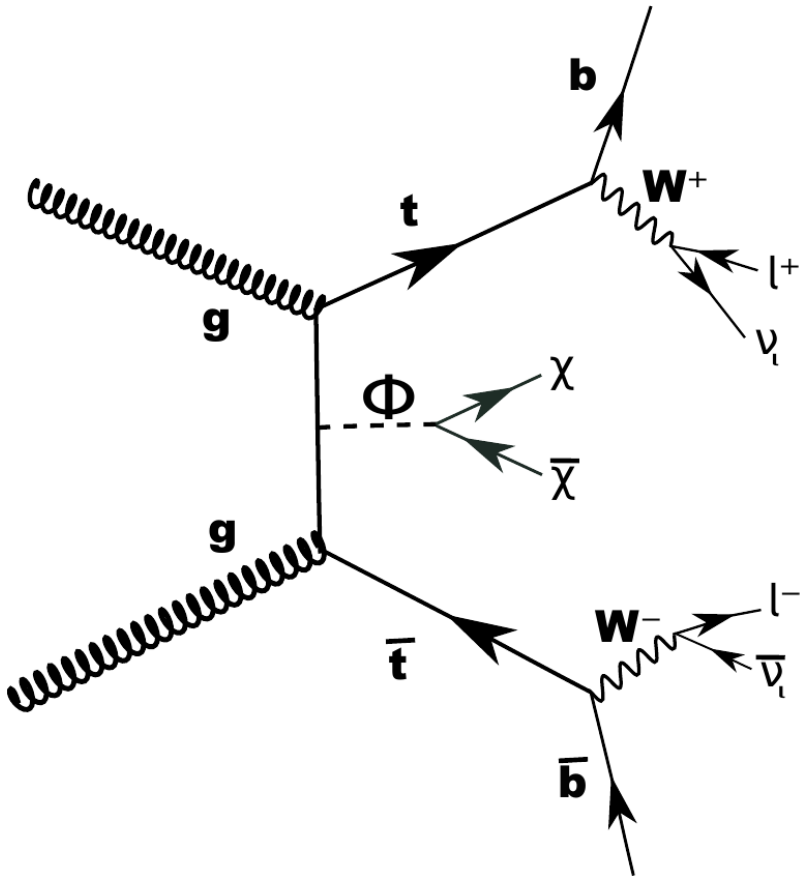






♣ *With higher Φ mass, Sonnenschein fails increasingly, Betchart still stable*

What's next?



with 1 Spin-0 mediator

♣ *Continuing with Betchart's approach*

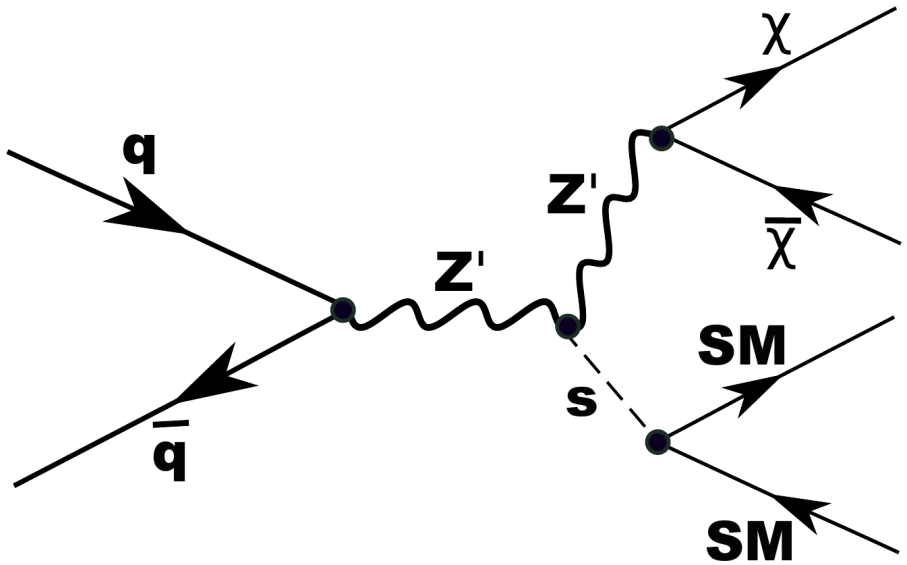
- Ellipse of solution = ES gotten without MET

→ more robust for higher Φ masses

- Finding condition without using MET for determining the correct solution on ellipse

→ Search gets more sensitive for higher mediator masses (>100 GeV) where Sonnenschein breaks down

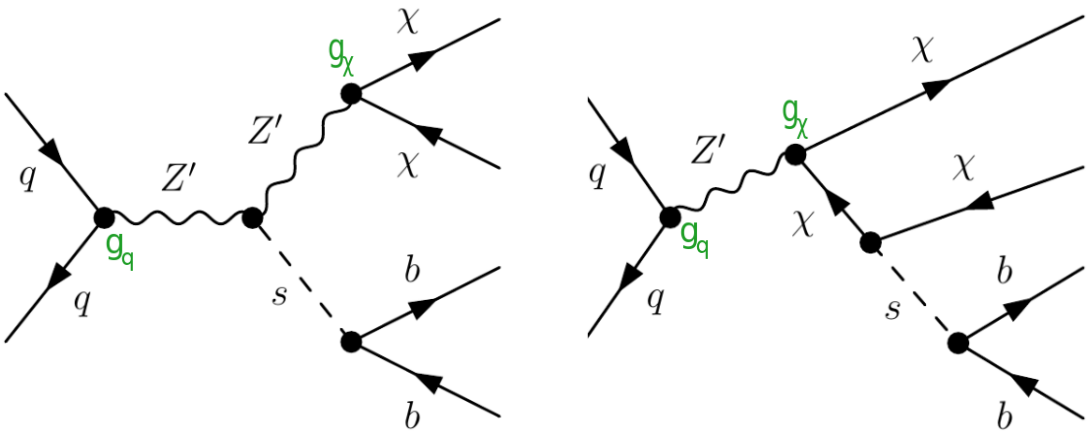
Extended simplified DM models



with 1 Spin-0 and 1 Spin-1 mediator

Extended simplified DM models

with Spin-0 mediator s and Spin-1 mediator Z'



Motivation *DM mass generation needed + relaxing experimental constraints from DM relic abundance*

$\rightarrow$ new $U(1)'$ gauge group for dark sector $\rightarrow$ symmetry breaking

$\rightarrow$ gives rise to Z' and DM masses

DM Majorana fermions

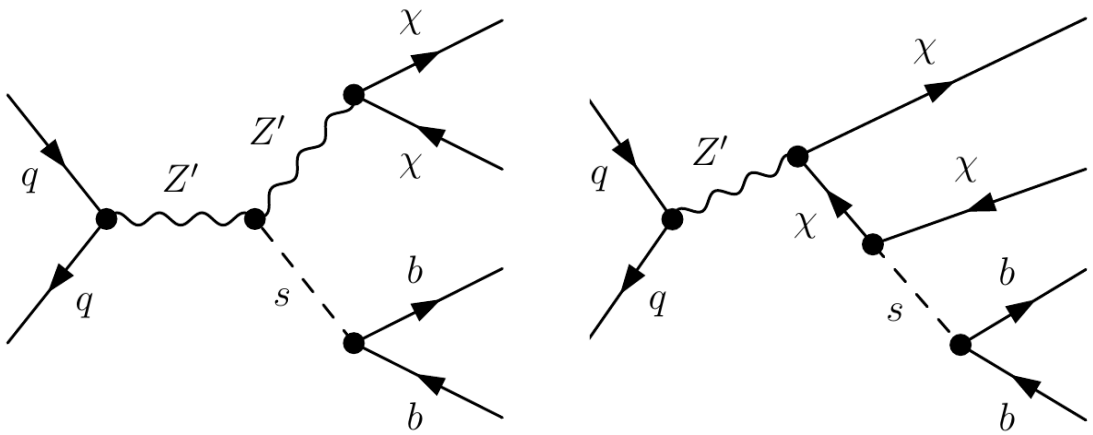
Six parameters for description needed: $g_q, g_\chi, m_\chi, m_{Z'}, m_s, \theta$

with θ= mixing angle between dark and SM Higgs

arXiv: 1510.02110, 1606.07609, 1701.08780

Extended simplified DM models

with Spin-0 mediator s and Spin-1 mediator Z'



⇑ *Recoil of DM particles* ⇑
against visibly decaying dark Higgs

♣ For $m_s < m_\chi$, annhiliation channel $\chi\chi \to ss$ facilitates reaching the correct DM relic abundance

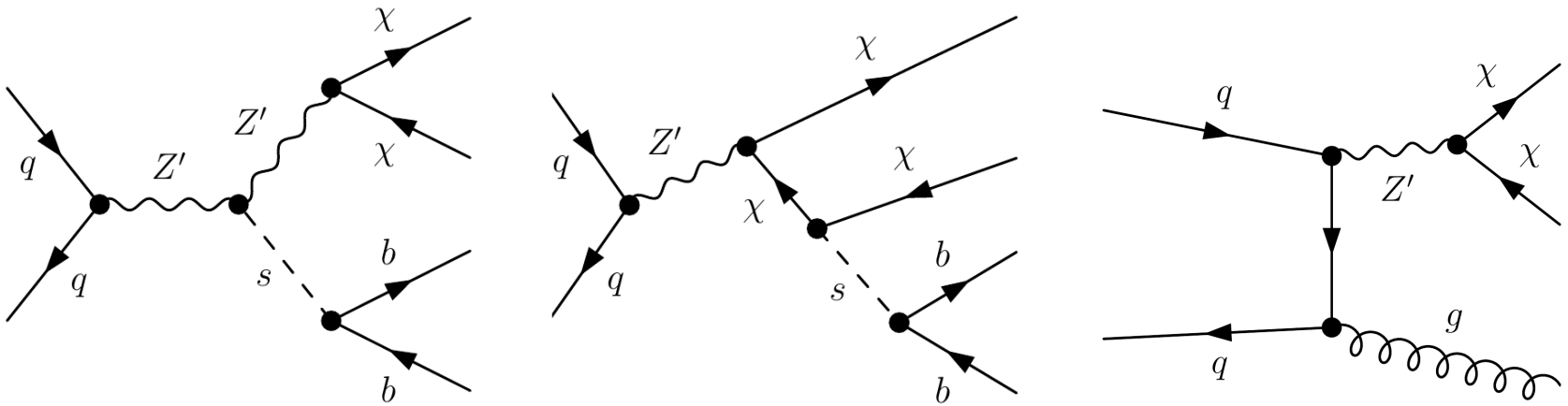
⇒ Experimental constraints relaxed

♣ DM production via additional Z' mediator gives rise to dark-Higgs strahlung

arXiv: 1510.02110, 1606.07609, 1701.08780

Extended simplified DM models

with Spin-0 mediator s and Spin-1 mediator Z'



⇑ *Recoil of DM particles* ⇑ *against visibly decaying dark Higgs*

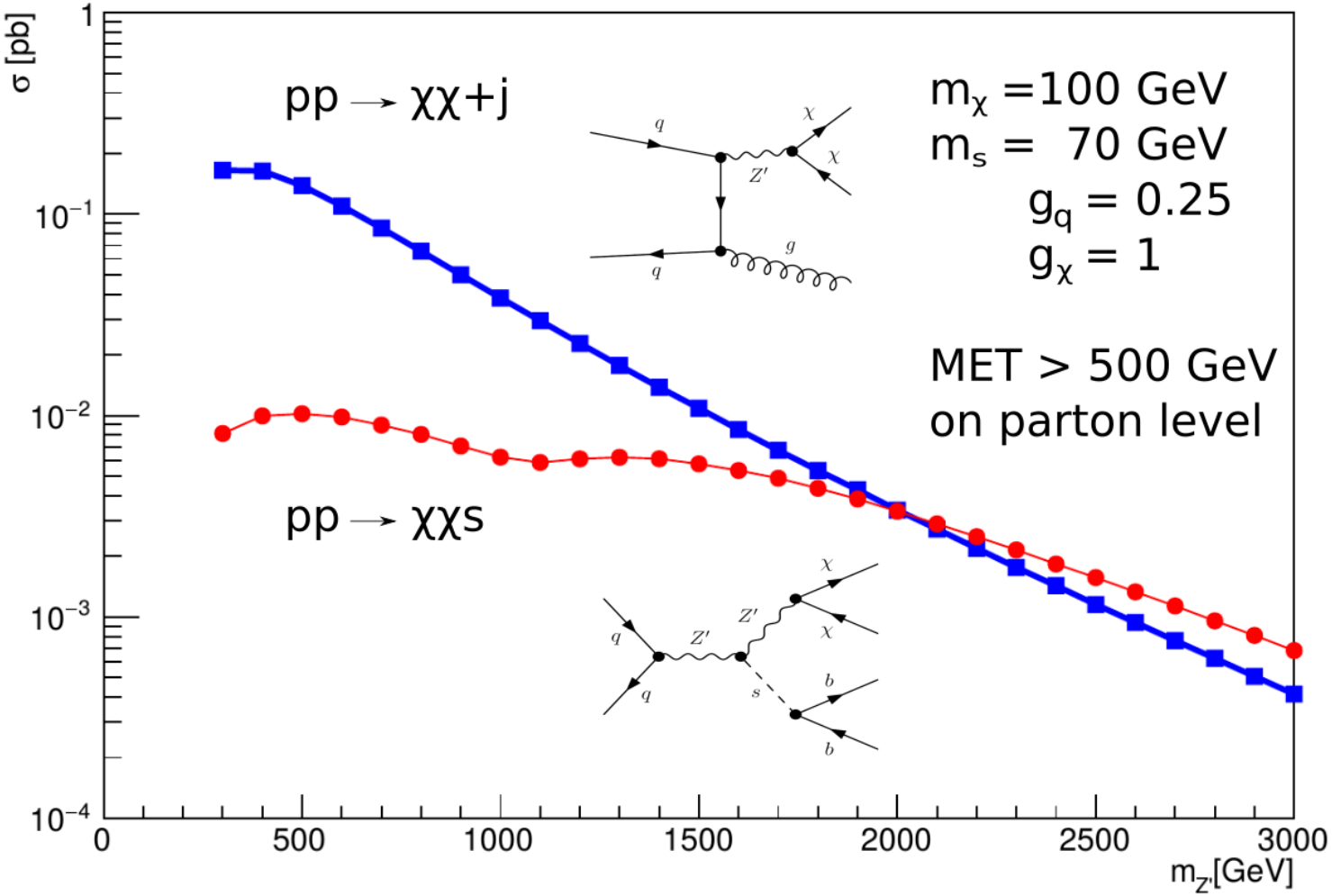
⇑ *Recoil of DM against SM particles*

How does it compare to the mono-jet search?

arXiv: 1510.02110, 1606.07609, 1701.08780

Dark Higgs: New search possibilities

$pp \to \chi\chi + j$ vs. $pp \to \chi\chi s$



⇒ signature of decaying dark higgs channel gains in importance

♣ With higer Z' mass, especially ⇑ at $m_{Z'} \approx 1500$ GeV when

$$2 \cdot \sigma(pp \to \chi\chi s) \approx \sigma(\chi\chi + j)$$

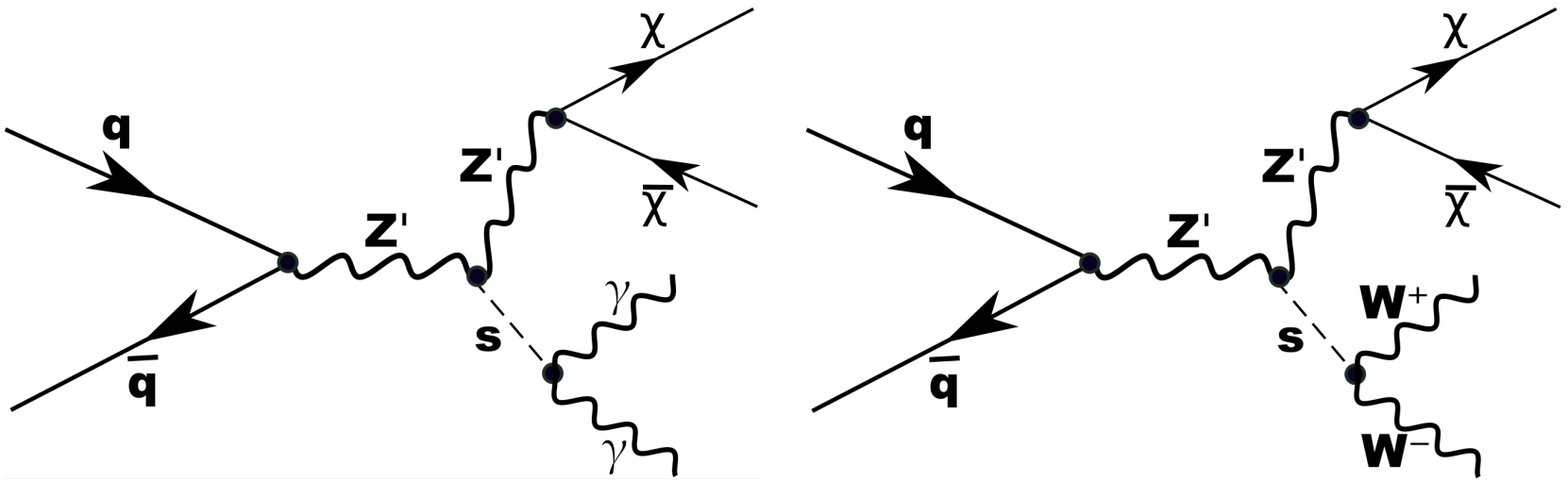
What's next?

$s \to b\bar{b}$ covered in arXiv: 1701.08780

$\Rightarrow$ see talk T 77.8 on Thursday, 22nd March, at 18.30
„*Hunting the Dark Higgs at CMS*“ by Samuel Baxter

But other decay modes also possible:

$\Rightarrow$ Study expected LHC sensitivity for various Z' masses for different decay modes:



Conclusion.

- **Simplified model with Spin-0 mediator**

Kinematic reconstruction by Betchart will increase sensitivity in search for $t\bar{t}$DM considerably

- **Simplified model with Spin-0 and Spin-1 mediators**

Search for p p $\rightarrow \chi\chi s$ production will be extended by including further s decay modes

Thanks for your attention!

Any Questions?