Report from the “Low mass hidden sector” working group

Contributions from:

Roni Harnik, David “the young one” Kaplan, Henry Lubatti, Tim Nelson, Antonio Policicchio, Maxim Pospelov, Matt Reece, Pierre Savard, Matt Strassler, Dan Ventura, Neil Weiner

Pauline Gagnon, Indiana University

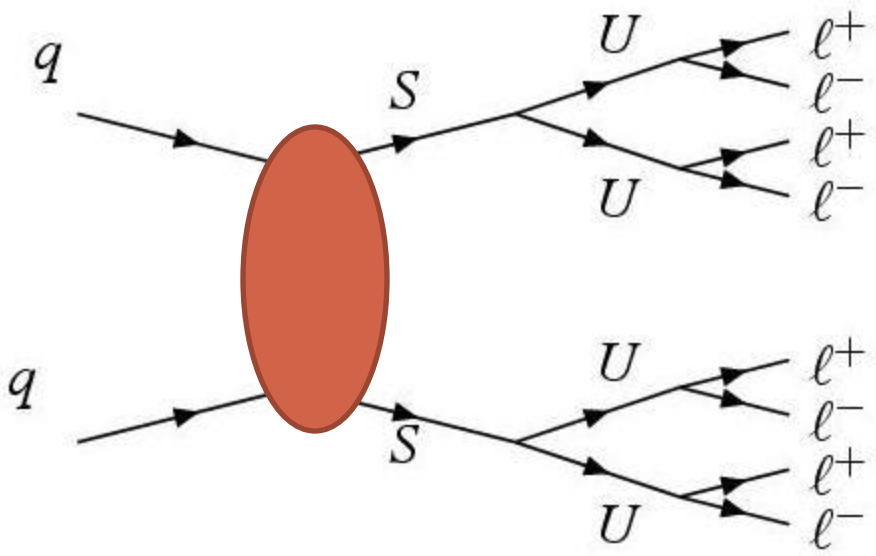
Two broad categories of models

- Neal Weiner suggested to regroup all models into <u>two broad categories</u>:
  1. Models where σ depends on ε^2
     - No SUSY involved
     - A new light gauge boson emitted at a cost of small coupling
       → better suited for high luminosity e^+e^- experiments
  2. Models where Standard Model and Dark Matter sectors are related by some parity
     - We decided to concentrate on this class of models since these have a better chance of discovery at LHC
- Both lead to "lepton jets": one or more pairs of highly boosted leptons closely related in space

Top priority for LHC studies:

- Get a generic MC generator that will provide a "lepton jet" gun to study how experimental triggers will react
- Study a broad range of new gauge boson masses to evaluate effect on trigger efficiencies
  - the higher the boost, the more collimated the leptons
  - allow the light bosons to also decay into pions and see the effect on trigger efficiency
  - vary the lepton multiplicity in a jet

Generic MC simulation for a Hidden Valley model involving some parity
(suggested by Maxim Pospelov and Matt Reece)



U can decay to leptons or pions:
- 1/3 e+e-
- 1/3 μ+μ-
- 1/3 ππ

Experiments only trigger on leptons

S	**Scalar from dark sector, pair produced for parity conservation**	**m_S = [50 GeV, 1 TeV]**
U	**Light gauge boson U-boson (aka, ϕ, Z', γ_{dark}, γ')**	**$m_{U\text{-boson}}$ < 1 GeV Adjust BR to leptons or pions**

Suggestion from Matt Strassler: Use Pythia for generic MC production

- Use production mode 300: $qq \rightarrow H^0A^0$
- Set all parameters in pyupda file:
  - p_T transfer in this event sets the boost factor
  - can add long lifetimes to U-boson if desired
  - set $m_{H0} = m_{A0}$ = a few 100's GeV
  - set $H^0 \rightarrow UU$ and $A^0 \rightarrow UU$
  - set $U \rightarrow l^+l^-$ or $U \rightarrow \pi^+\pi^-$ (about 33% each)
  - Matt Reece pointed out the BR depends on m_U
- Matt Strassler is writing/checking data card

Matt Strassler developed three different implementations in Pythia

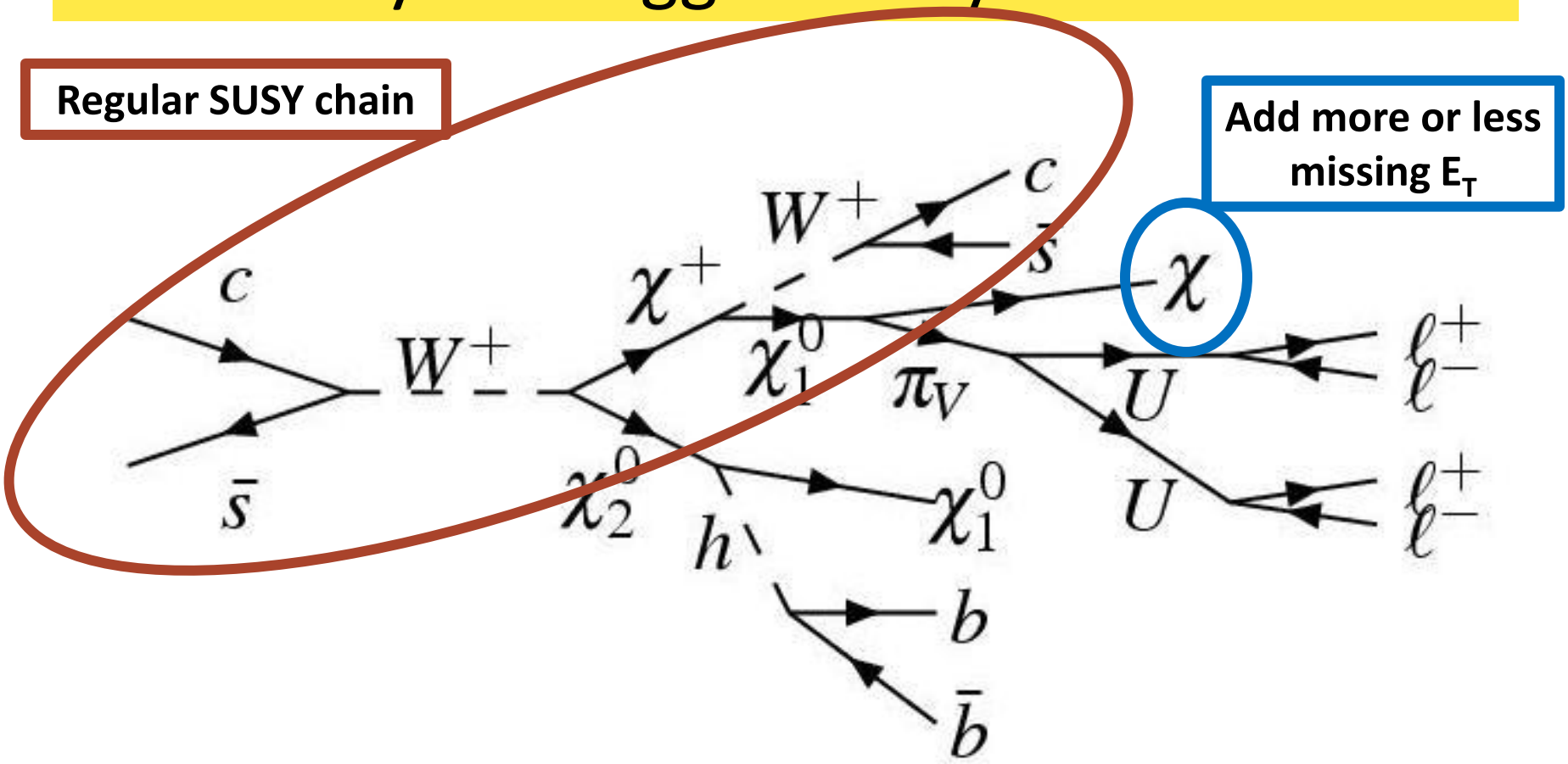
1. $gg \rightarrow h \rightarrow \pi_v \pi_v \rightarrow UU\ UU \rightarrow l^+l^-\ l^+l^-\ l^+l^-\ l^+l^-$
   - With a low π_v mass, force 4 leptons into one jet
2. $qq \rightarrow SS \rightarrow UU\ UU \rightarrow l^+l^-\ l^+l^-\ l^+l^-\ l^+l^-$
   - Get 4 jets with 2 leptons each
3. Produce the light gauge boson through SUSY
   - To study effect of all extra particles in the event

All these can be tuned to study the trigger or made to look like one specific model

Generic MC generator imbedded in SUSY within Pythia suggested by Matt Strassler

Regular SUSY chain

Add more or less missing E_T

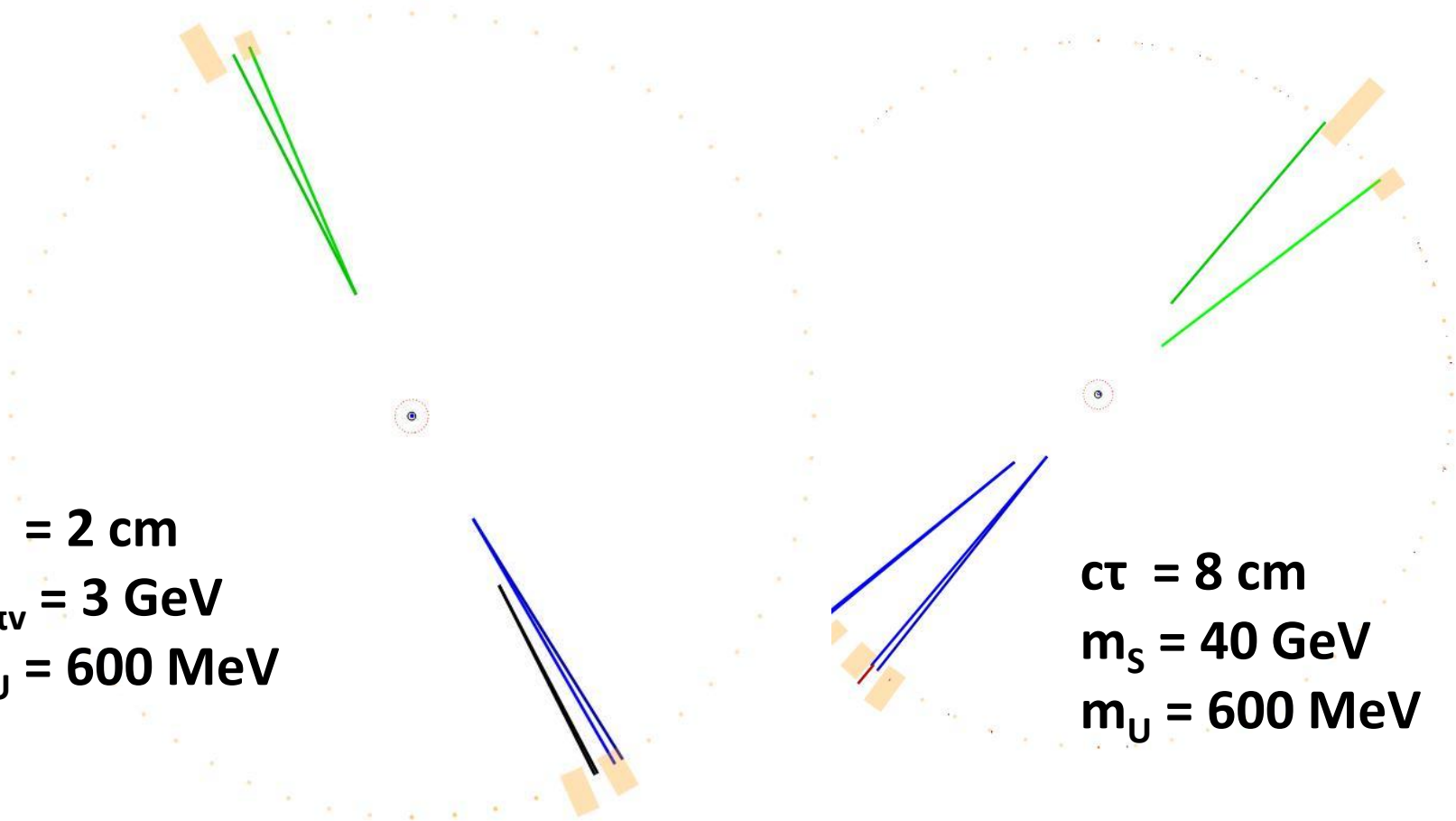


Modify the pyupda file to change final states decays

from Matt Strassler

$gg \rightarrow h \rightarrow \pi_v \pi_v \rightarrow UU\ UU \rightarrow l^+l^-\ l^+l^-\ l^+l^-\ l^+l^-$

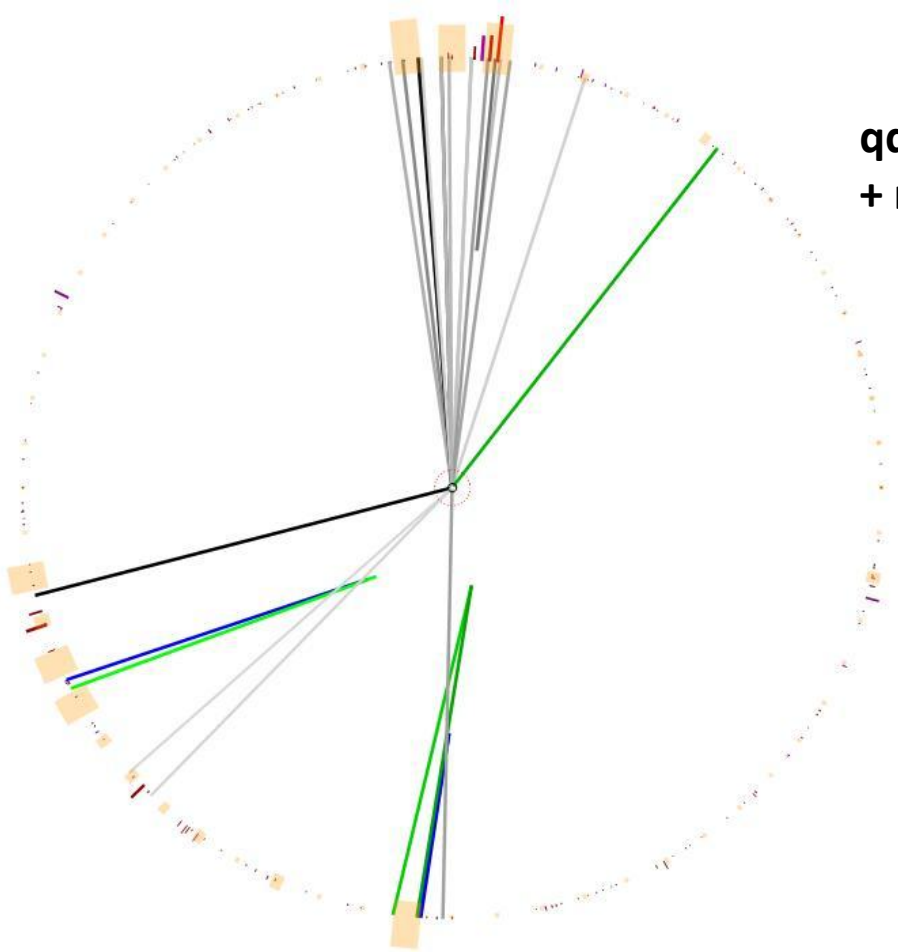
$qq \rightarrow SS \rightarrow UU\ UU \rightarrow l^+l^-\ l^+l^-\ l^+l^-\ l^+l^-$



$c\tau = 2$ cm
$m_{\pi v} = 3$ GeV
$m_U = 600$ MeV

$c\tau = 8$ cm
$m_S = 40$ GeV
$m_U = 600$ MeV

SUSY decay from Matt Strassler



$qq \rightarrow \chi_1^+ \chi 20 \rightarrow$ 2jets + $\mu\upsilon$ + neutralino $l^+l^- l^+l^- l^+l^- l^+l^-$

Benchmarks

Matt Strassler and Neal Weiner will work with Itay Yavin to provide benchmarks for those models

Second step: design level-2 trigger algorithms for all possible decays (prompt or not)

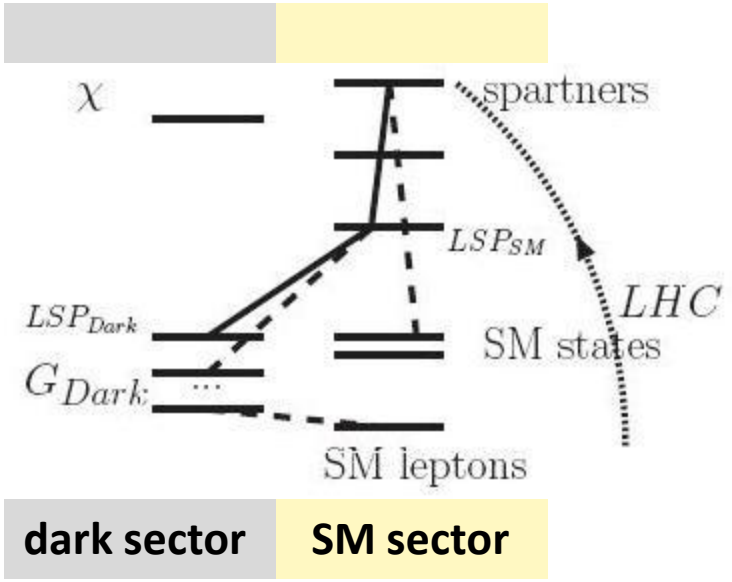
- First studies of lepton jets show that events pass the level-1 triggers in ATLAS which are hardware-based and not modifiable at this point
  - Preliminary studies indicate that ~90% muons pass L1 trigger using events from various model
- Work is now in progress at level-2 to develop new software trigger algorithms
  - Standard ATLAS muon triggers require association of muon segment to track segment (only 10% survived for long-lived light bosons decays)
  - But new isolated muon triggers bypass that (implemented by Stefano Giagu; tested by Antonio Policicchio: ~90% efficiency w.r.t. L1)
  - Could also adapt J/ψ triggers for prompt decays by modifying the mass window
  - For decays in the hadronic calorimeter, the new long-lived triggers will probably work
  - We need to look at electrons

Last step: design specific analyses for each particular model

- Study various models and see that they are still satisfying the new trigger algorithms developed with broad studies based on generic model
- Many different models exist and most already have a MC implementation (or will soon have one)

Picture presented by Neal Weiner and Nima Arkani-Hamed in arXiv:0810.0713v2

- Two parallel sectors:
  - SM sector with SUSY
  - Dark sector also with $SUSY_{dark}$
- At LHC, we can produce the highest SUSY states in SM sector
- These will cascade down to LSP_{SM} but this is not the real LSP
- The LSP_{SM} is a messenger that can cross-over to the dark sector then decay into the true LSP, the LSP_{dark}
- These can annihilate into ϕ, a new light dark sector gauge boson, will decay into SM particles (leptons and pions)
- $m_{\phi} \sim 600$ MeV



Only the LHC can produce the highest SUSY states, giving us an entry point to the dark sector through cascading and crossing-over

Neal Weiner, Itay Yavin and Matt Strassler will implement this model

Neal Weiner et al.,

Can produce ϕ through dark matter annihilation

$\chi\chi \rightarrow \phi\phi$

$\phi \rightarrow e^+e^-$ or $\mu^+\mu^-$

- **$m_\chi \sim 500\text{-}800$ GeV**
- **$m_\phi \sim 100$ MeV - 1 GeV**
  - **Fermi data favors 600 MeV**

- **$\phi \rightarrow e^+e^-$ or $\phi \rightarrow \mu^+\mu^-$**
- **So ϕ has a large boost:**
  - **Very collimated or superimposed leptons**
- **Will there be other objects we can trigger on in these events?**

Lepton jets from modified π_v decays

From Matt Strassler:

$gg \rightarrow h \rightarrow \pi_v \pi_v$

$\pi_v \rightarrow e^+e^-$ or $\pi_v \rightarrow \mu^+\mu^-$

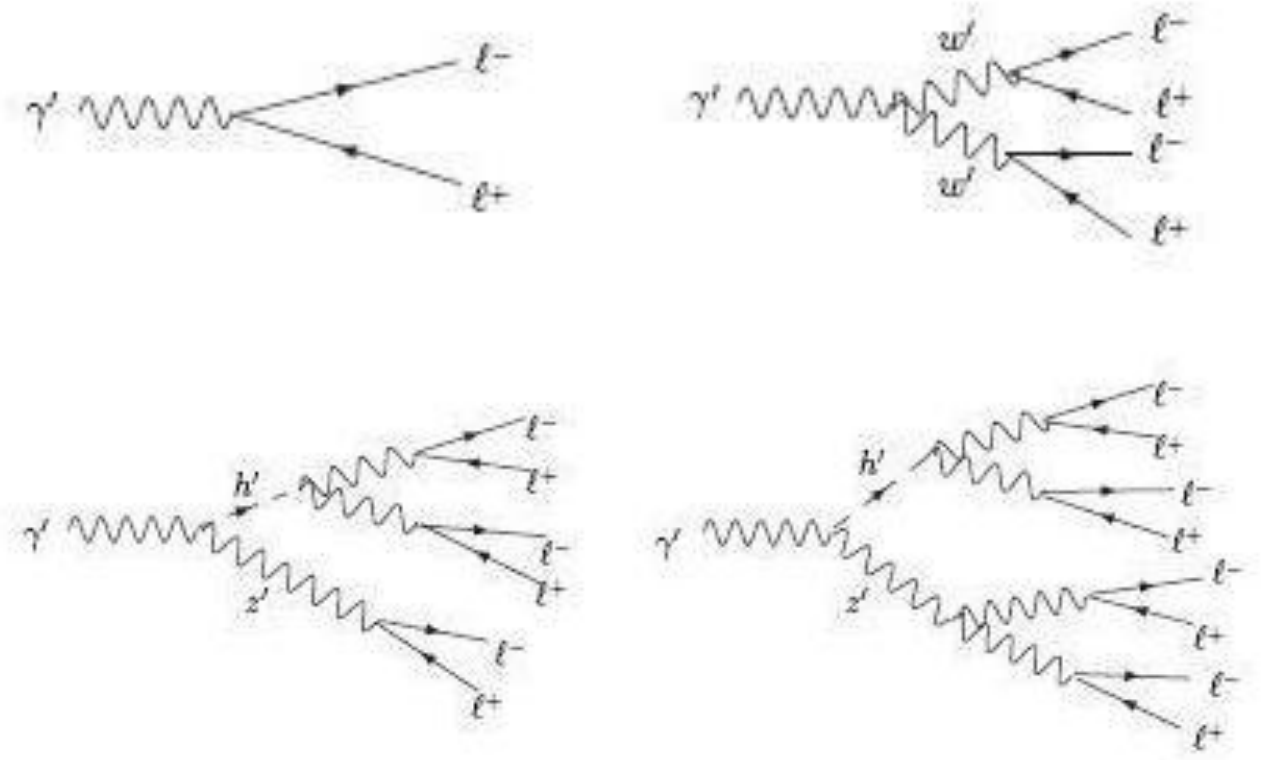
In ATLAS, we have implemented a modified version to produce highly boosted lepton jets $\pi_v \rightarrow e^+e^-$ or $\mu^+\mu^-$

- $m_H \sim 140$ GeV
- $m_{\pi_v} \sim 1$ GeV

- **So π_v has a large boost:**
  - **Very collimated or superimposed leptons**
- **But the 2 muons could be reconstructed**
- **The new, isolated muon trigger retained ~90% of these events**

Model without SUSY

Lian-Tao Wang, Itay Yavin et al. arXiv:0901.0283v1



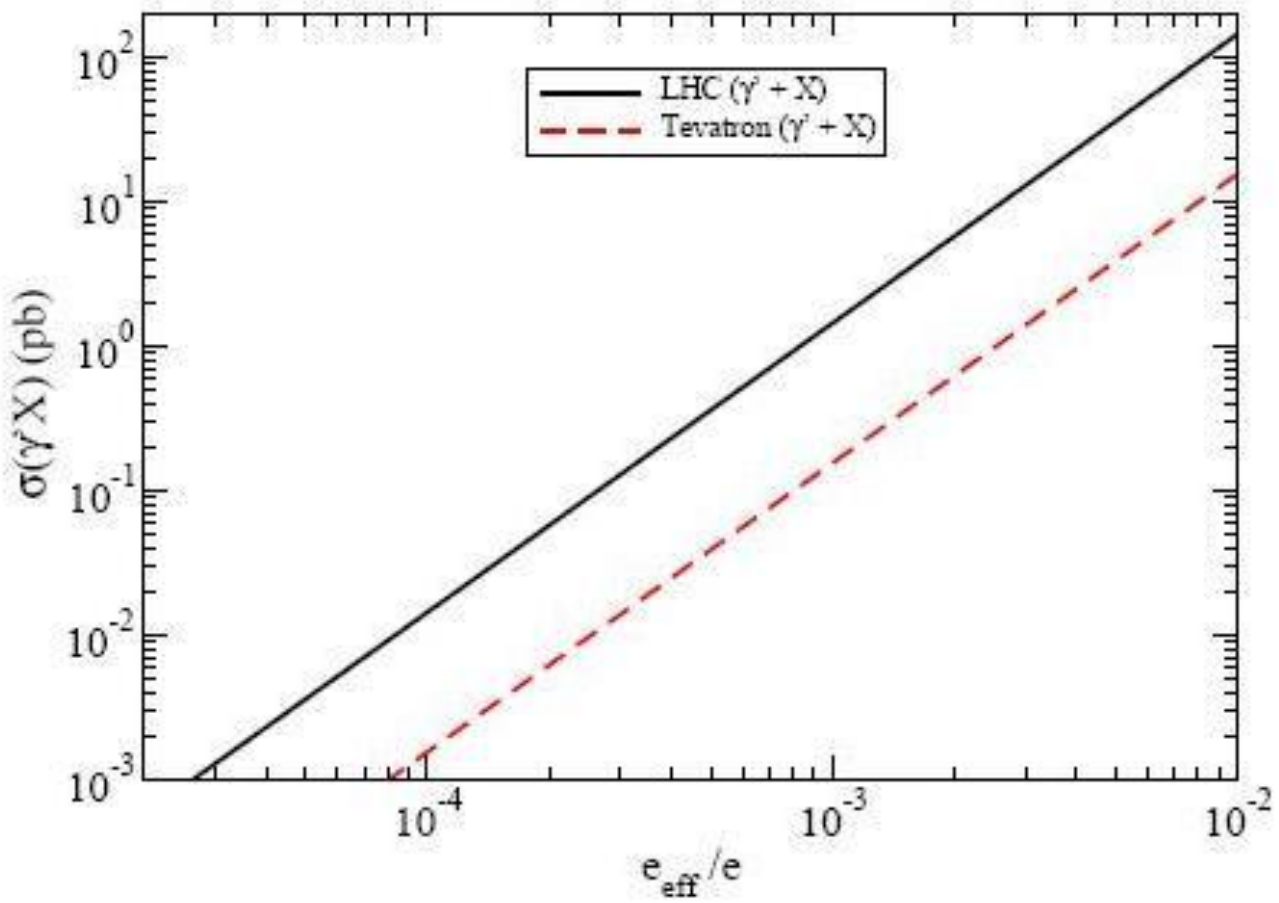
- **γ'**: dark sector light gauge boson
- Can decay directly into lepton pairs or into other dark gauge bosons **w', z', h'**
- Gives rise to "leptons jets" containing 2-8 leptons

Cross-section in hadron collider: could be of order 1 pb for $\varepsilon \sim 10^{-3}$

We expect ~100-200 pb of data for the first year at LHC

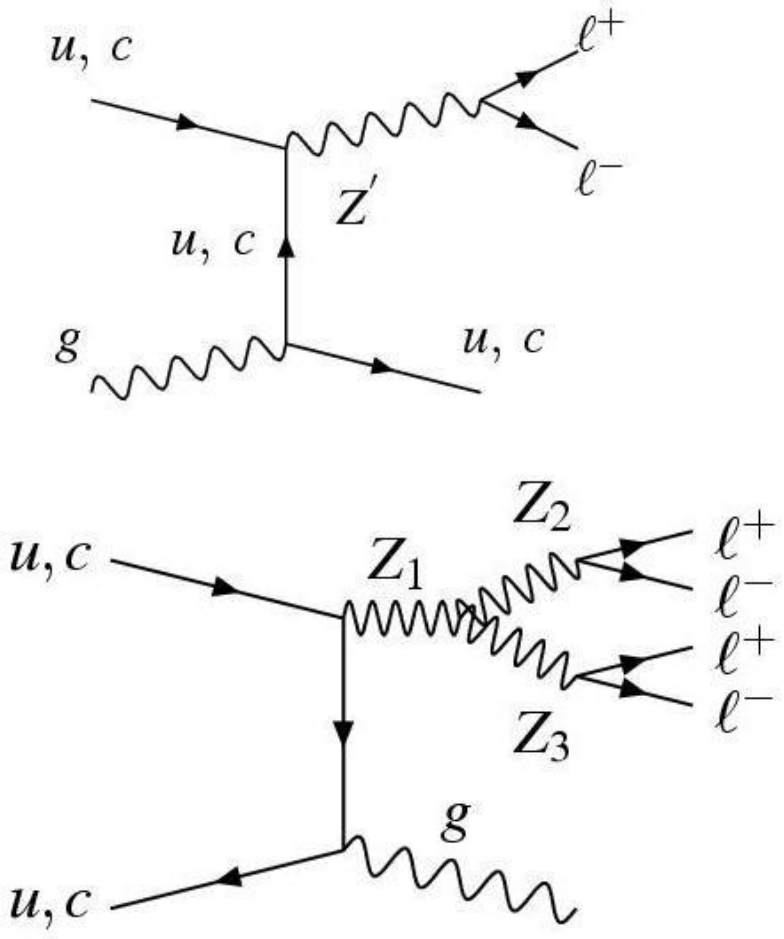
Would be visible for $\varepsilon > 10^{-3}$ but only high pT events will be detectable as Pierre Savard pointed out

→ Not for first data



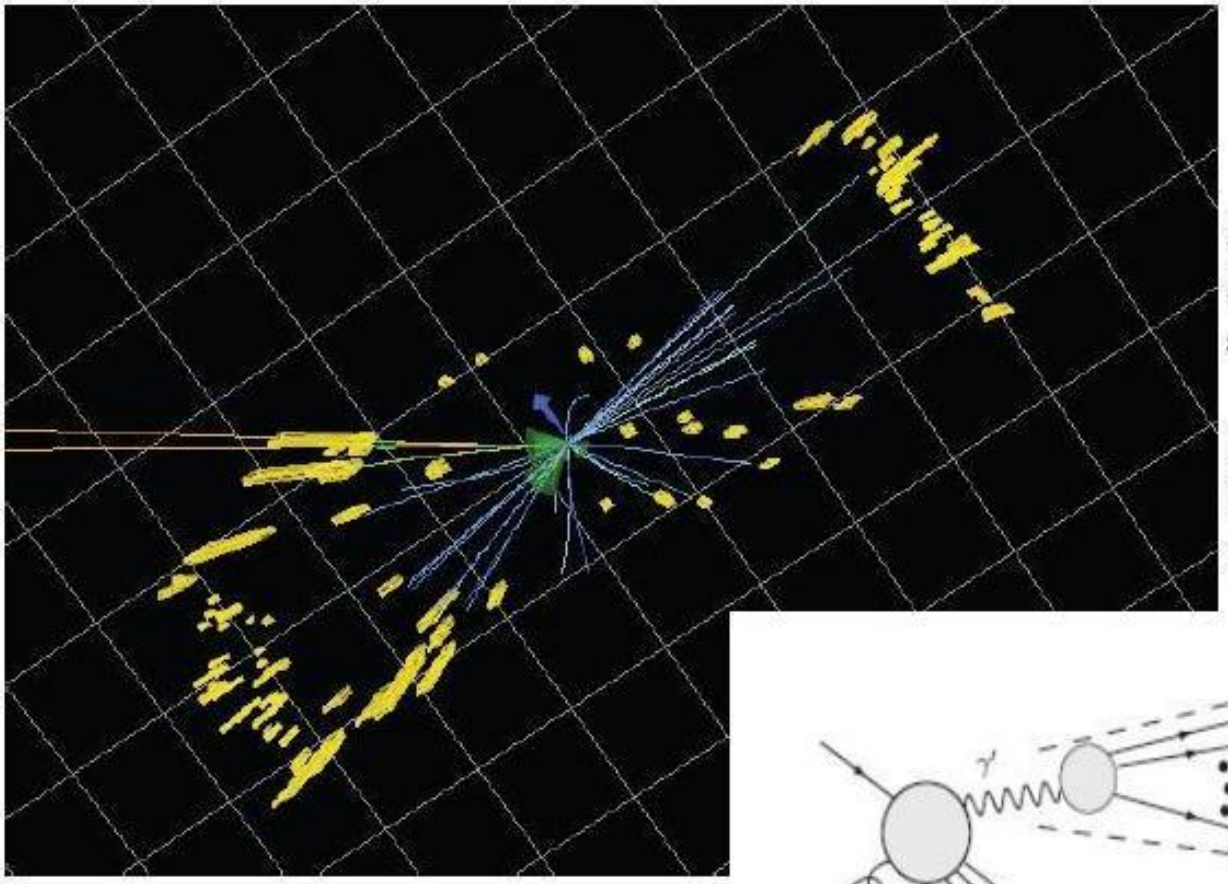
Lian-Tao Wang et al, arXiv:0901.0283v1

MC production with MadGraph from Lian-Tao Wang now implemented within ATLAS code



- Matt Reece volunteered to add some pions to this diagram in the right proportions
- Other diagrams can produce more lepton jets
- Having Z' → pions will give a more realistic picture by affecting trigger efficiencies

Itay Yavin provided a simulation to Bilge Demirkoz from ATLAS

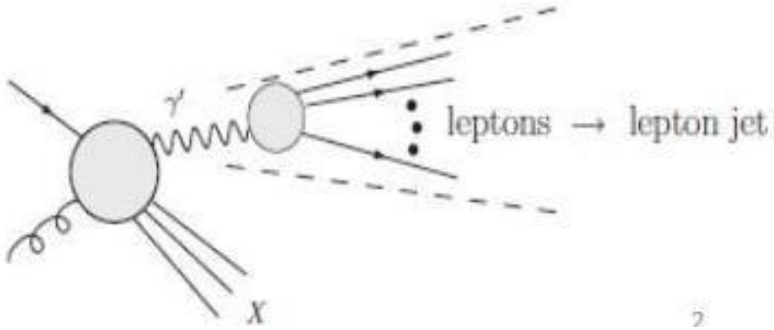


2 jets in event found (green cones):
1 leptonjet + 1 jet

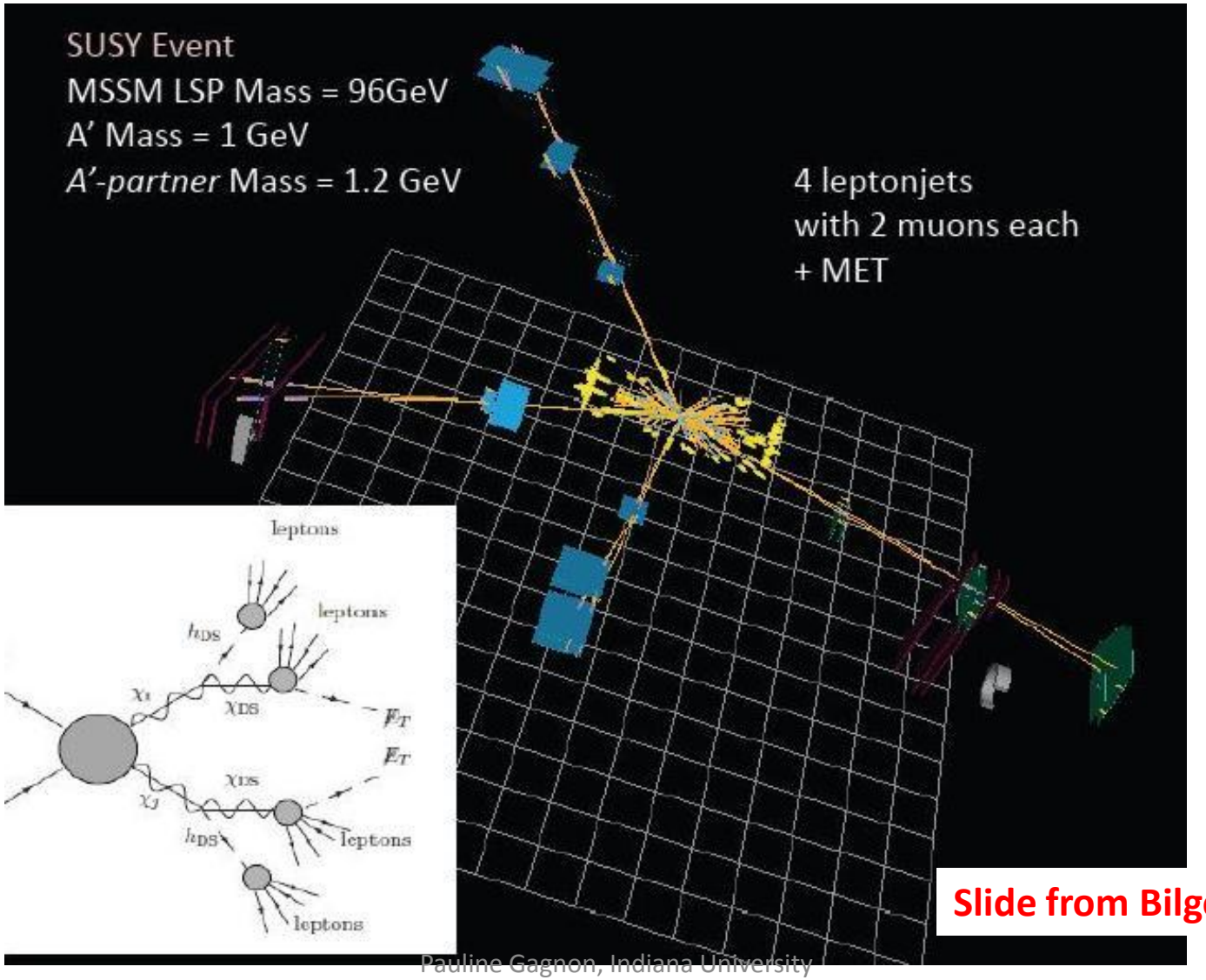
Slide from Bilge Demirkoz

2 electrons and 2 muons in the same cone.

No SUSY here. Prompt dark sector photon production:



Itay also have simulations within SUSY – Bilge Demirkoz from ATLAS is working on this



Slide from Bilge Demirkoz

Homework questions

With new MC simulations, we can now address the two first questions:

1. Think of at least one signature that current trigger strategies miss
2. Think of at least one signature that current analyses can't deal with

3. At least one idea for a new trigger
   - Isolated muon triggers
   - J/psi like triggers
4. At least one new signature: **the "Seattle model"**
   - The "generic MC simulation" with pure lepton jets and nothing else in it
5. How to present experimental results in most useful form:
   - Matt Reece suggests stating results for relatively inclusive signatures such as "lepton jet + hard isolated muon + X", "two lepton jets + missing Et + X", etc.
6. To-do list for the next year
   - **by theorists:** benchmarks, realistic MC simulations and Seattle model
   - **by experimentalists:** trigger studies, analysis strategies and refine the answer to point 5.

Thanks to the organisers

Many thanks to the organisers and the whole team here at University of Washington for providing us with excellent opportunities to move forward with this work.