Searches for New Phenomena with Long-lived Particles at ATLAS

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on behalf of the ATLAS collaboration

Aspen 2017 Winter Conference
"From the LHC to Dark Matter and Beyond"

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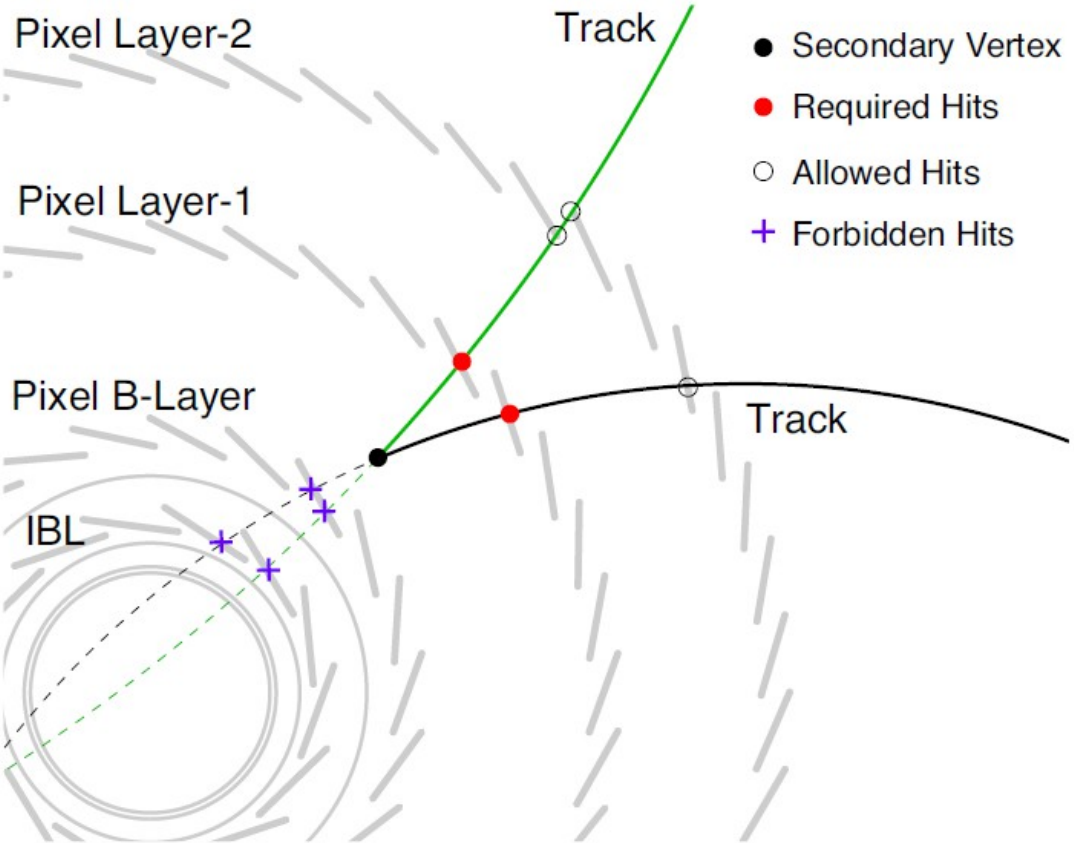
https://indico.cern.ch/event/550030/



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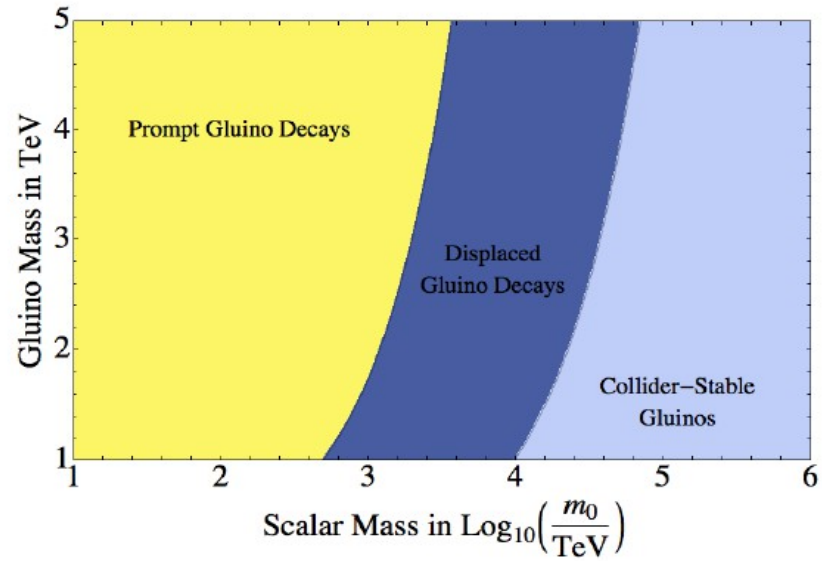
Introduction

- New particles will either be
  - Prompt decays
  - *Semi-stable, decay in detector*
  - *Detector-stable, decay outside detector*
    (or get stopped in the detector and decay later)
- **Must ensure sensitivity to semi-stable and detector-stable cases!**



- Focus on these well-motivated scenarios:
  - **"Higgs-like decays to LLP" (scalar production)**
    - Hidden-valley scenarios
  - **"Long-lived gluino" (strong production)**
    - Split / mini-split SUSY
    - mH=125 GeV $\rightarrow$ 10-10^4 TeV squarks $\rightarrow$ off-shell gluino decay
  - **"Long-lived chargino" (weak production)**
    - NLSP $\rightarrow$ LSP with small Δm
    - AMSB Wino/Higgsino

Scalar decays to LL neutrals decaying in the H-Cal

- Dedicated p_T=60 GeV R=0.2 jet cal-ratio trigger
- Specialized cuts against beam-induced muons
- BDT selects signal, based on jet $\log(E_H/E_{EM})$, p_T, width, cluster moments, and track variables
- Require 2 cal-ratio jets passing BDT per event
- Multijet background estimated with ABCD

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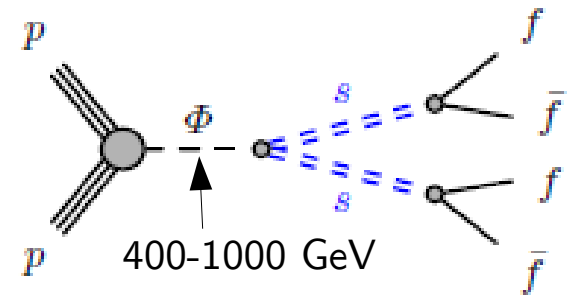
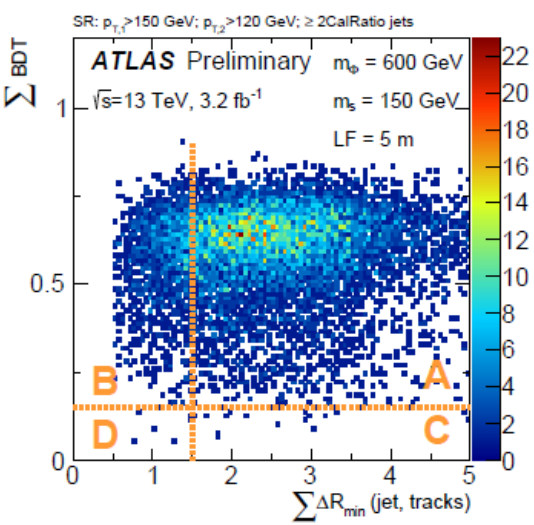
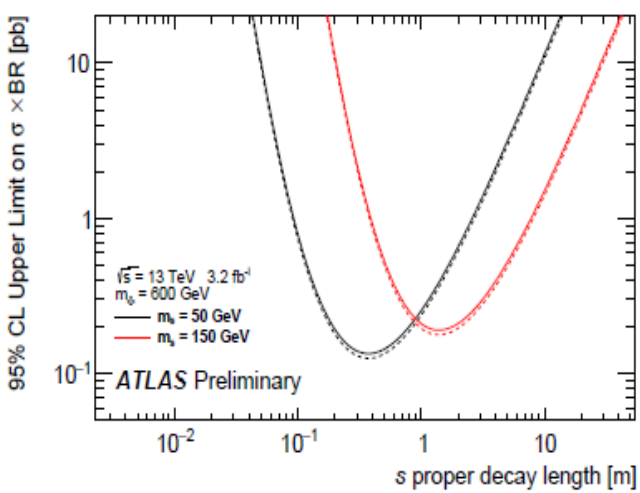
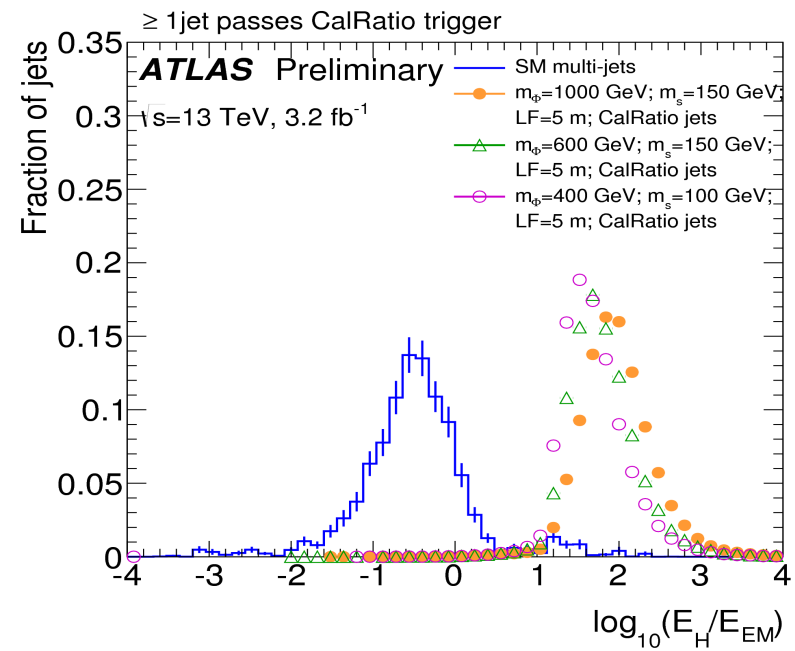


88% to $b\bar{b}$, 8% to $c\bar{c}$, and 4% to $\tau^+\tau^-$

Region	A	B	C	D	Estimated A = BC/D
SR : $p_{T,1} > 150$ GeV; $p_{T,2} > 120$ GeV :					
$\sum$ BDT boundary = 0.15	24	16	39	34	18.0 ± 6.3
VR : $p_{T,1} > 140$ GeV; 80 GeV $< p_{T,2} <$ 120 GeV:					
$\sum$ BDT boundary = 0.2	15	14	84	77	15.3 ± 4.7
$\sum$ BDT boundary = 0.15	42	38	57	53	40 ± 10
$\sum$ BDT boundary = 0.1	72	64	27	27	60 ± 19







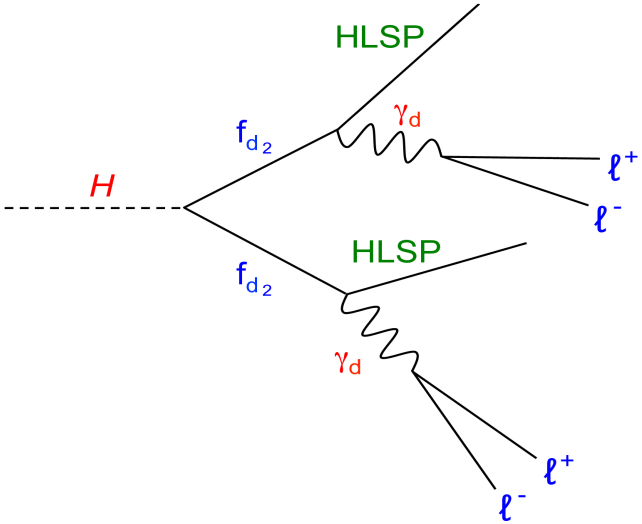
Nearly all hadronic energy

Also narrower and trackless...

Higgs-like decays to LL neutrals decaying to lepton-jets

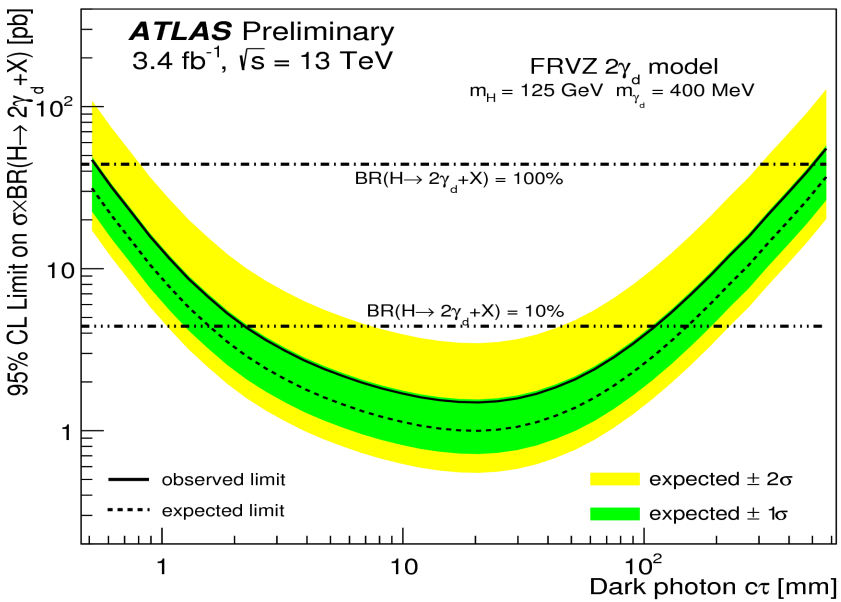
ATLAS-CONF-2016-042

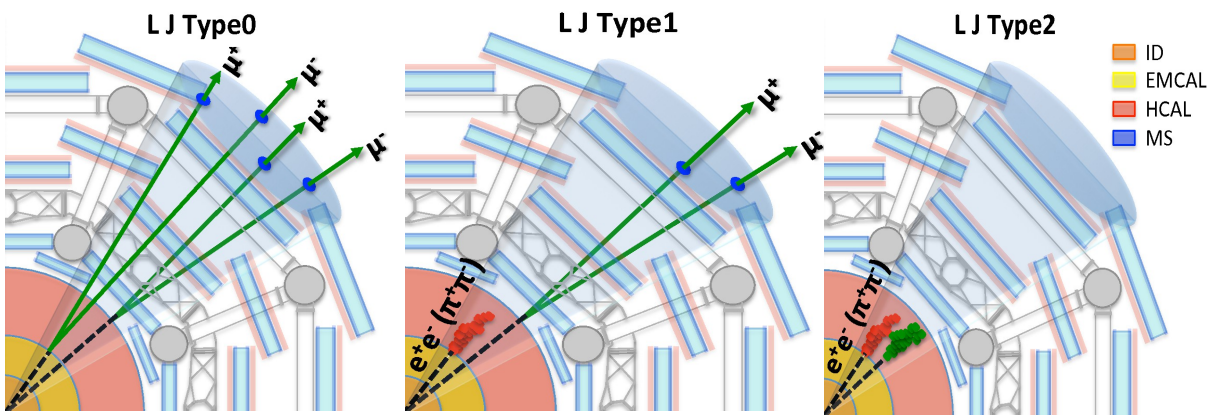
- Long-lived, light, dark photon decays back to SM
- Specialized HLT trigger based off L1 muons
- Various combinations of EM/had/muon object requirements to reject multijet, cosmics, and beam-muon backgrounds



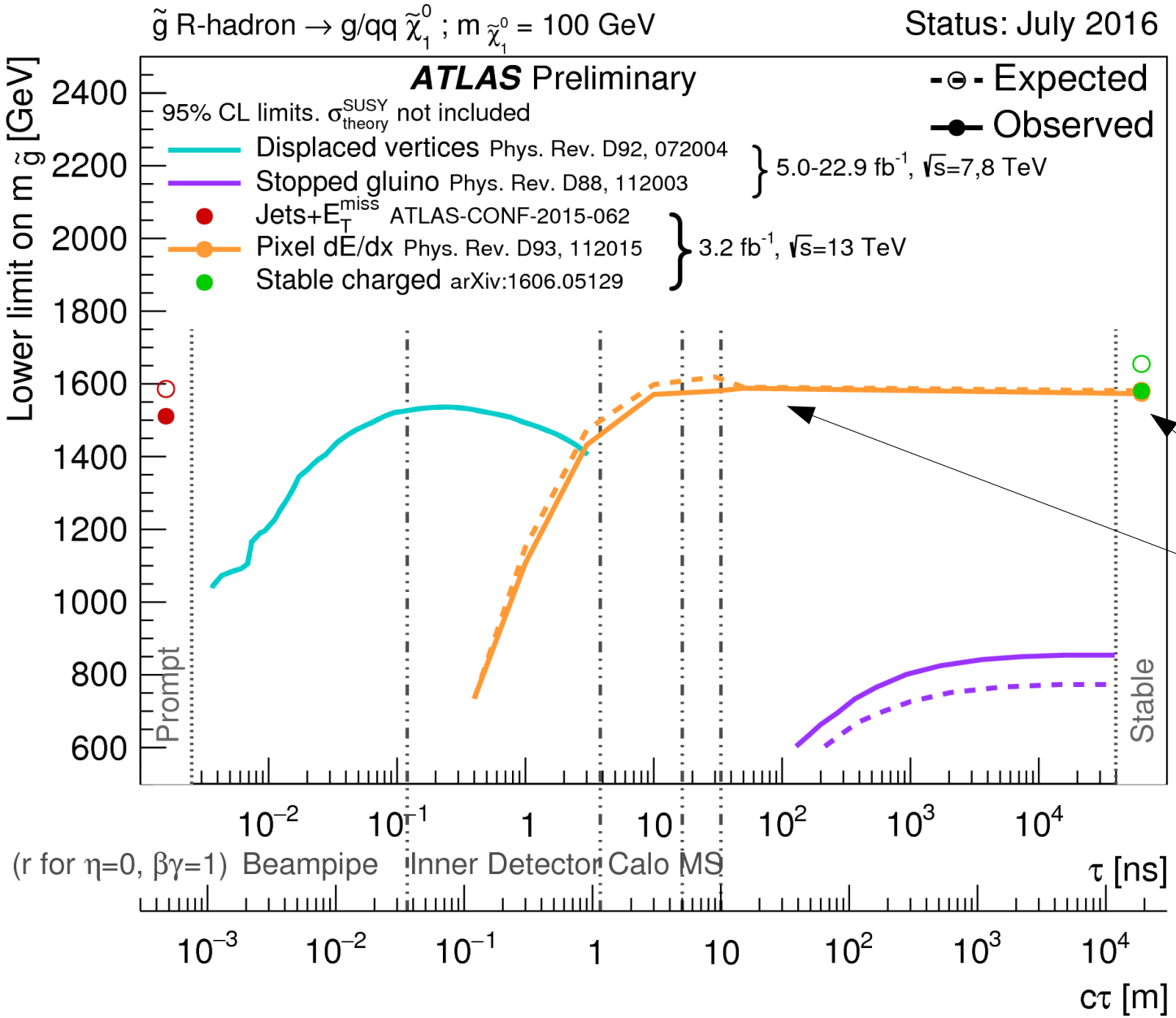
45% e^+e^-, 45% $\mu^+\mu^-$, 10% $\pi^+\pi^-$

Category	Observed events	Expected background
All events	285	231 ± 12 (stat) ± 62 (syst)
Type2–Type2 excluded	46	31.8 ± 3.8 (stat) ± 8.6 (syst)
Type2–Type2 only	239	241 ± 41(stat) ± 65(syst)





Long-lived gluino searches



Updated SMP

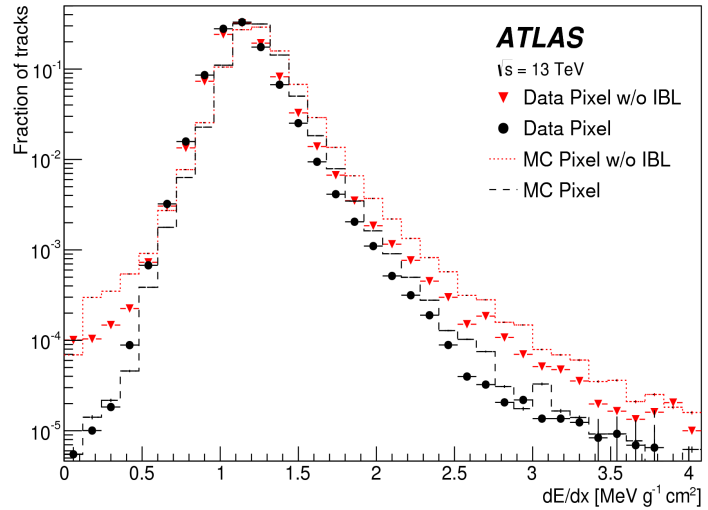
Updated pixel dE/dx

(Also updated prompt gluino jets+MET search)

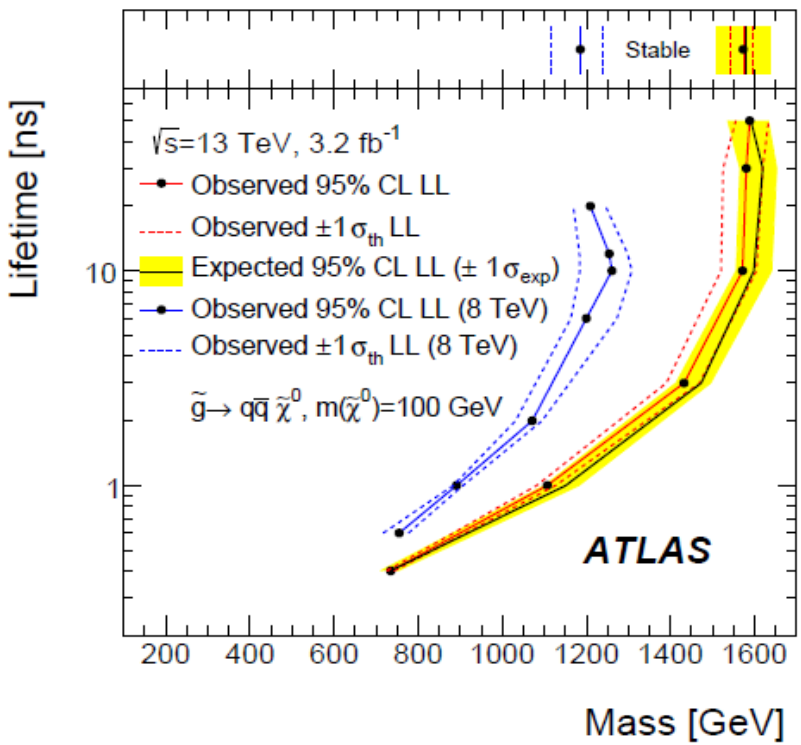
Meta-stable heavy charged particles with large dE/dx

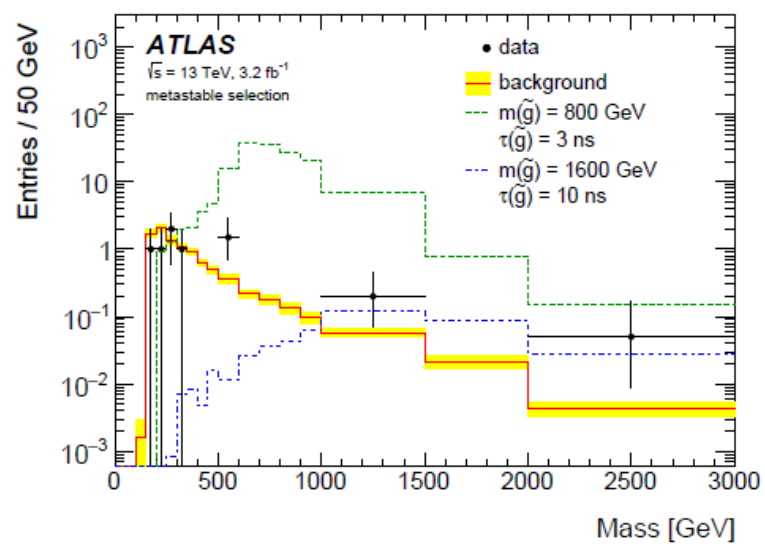
- Use dE/dx (ionization left in silicon) to infer particle mass
  - Invert Bethe-Block, knowing momentum of charged track
  - Make use of new IBL layer in Run2 to narrow dE/dx distribution
- No excess, extend Run1 limits

Phys. Rev. D 93, 112015 (2016)



$$(\mathrm{d}E/\mathrm{d}x)_{\mathrm{MPV}}(\beta\gamma) = \frac{p_1}{\beta^{p_3}}\ln(1 + [p_2\beta\gamma]^{p_5}) - p_4$$

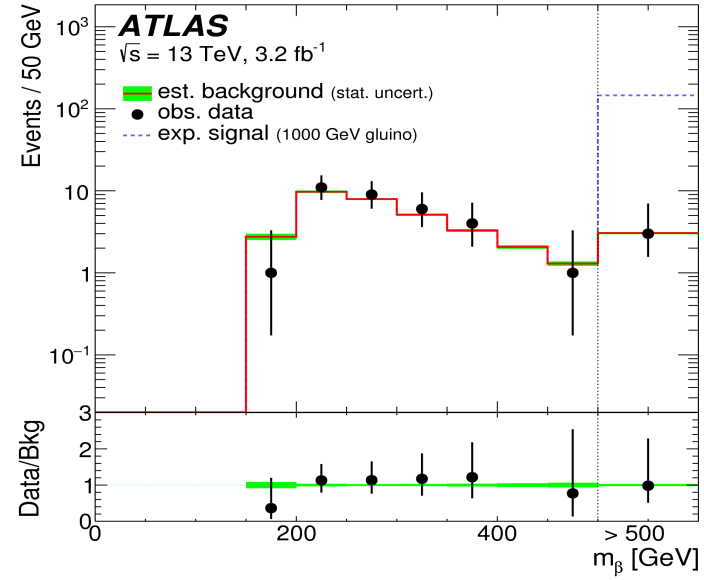




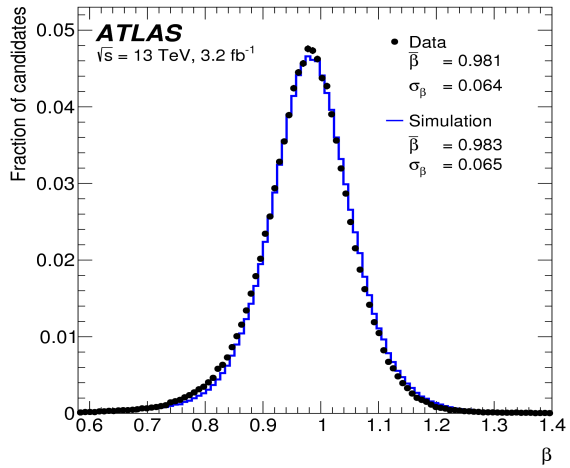
Heavy slow escaping particle search

Physics Letters B (2016), pp. 647-665

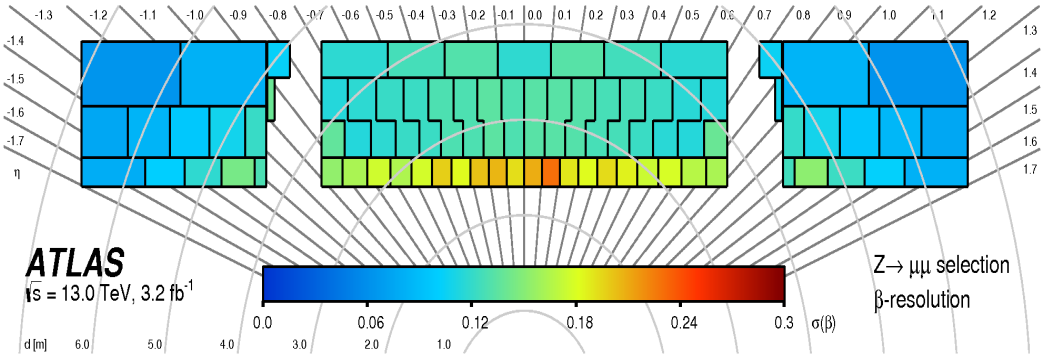
- Use good timing resolution of Tile Calorimeter to directly measure speed of isolated tracks
- Does not rely on muon system for this version, in case Rhadron becomes neutral after going through dense material

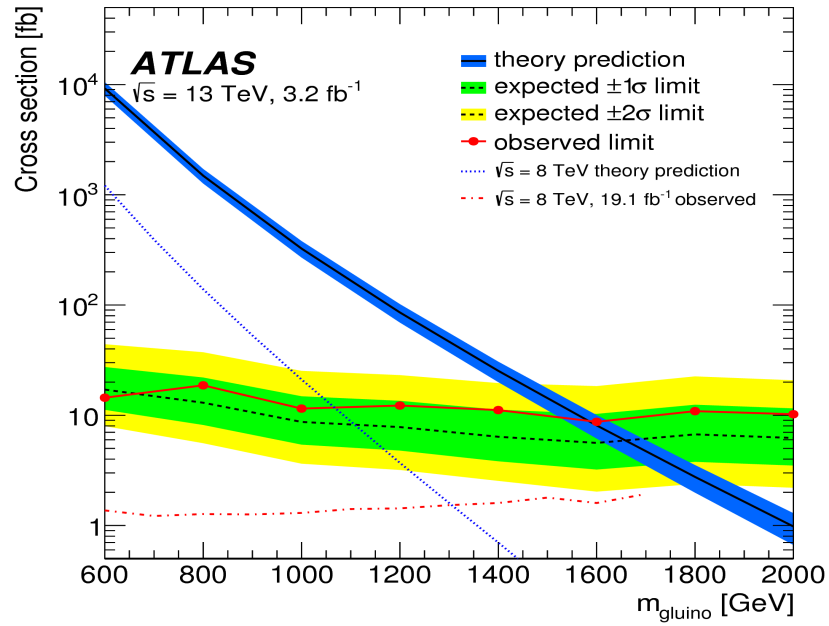


- Calibrate timing using Z→μμ
- Still no excess, limits improve beyond Run1



Going a longer distance improves speed measurement...

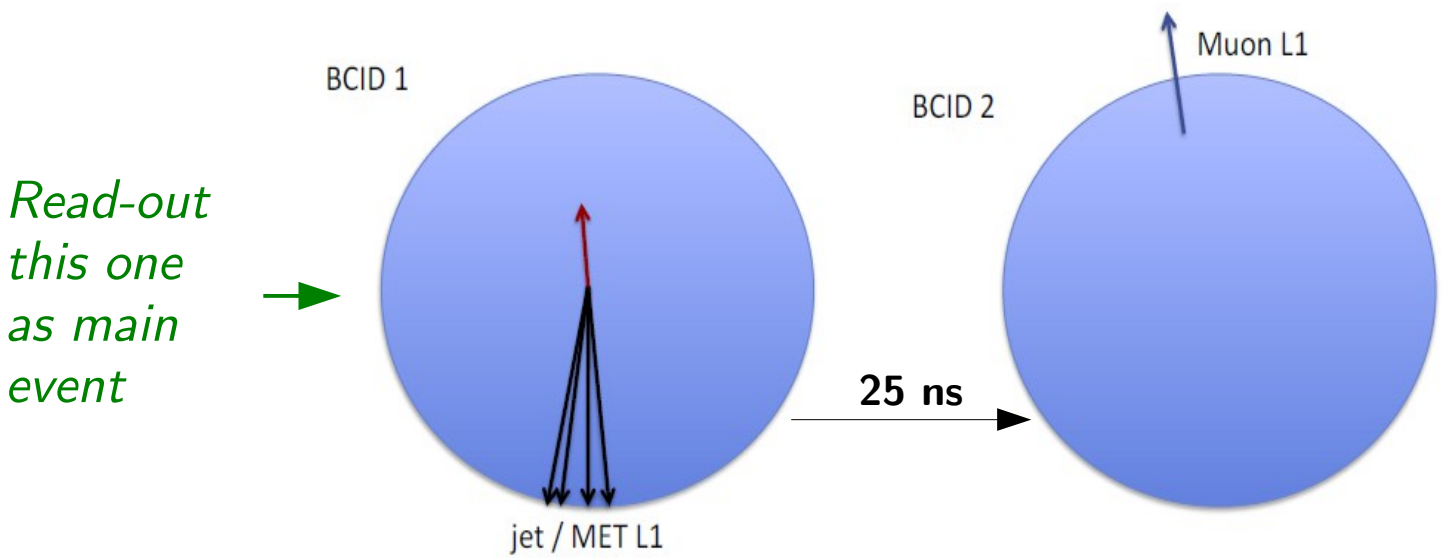




"Late" triggers

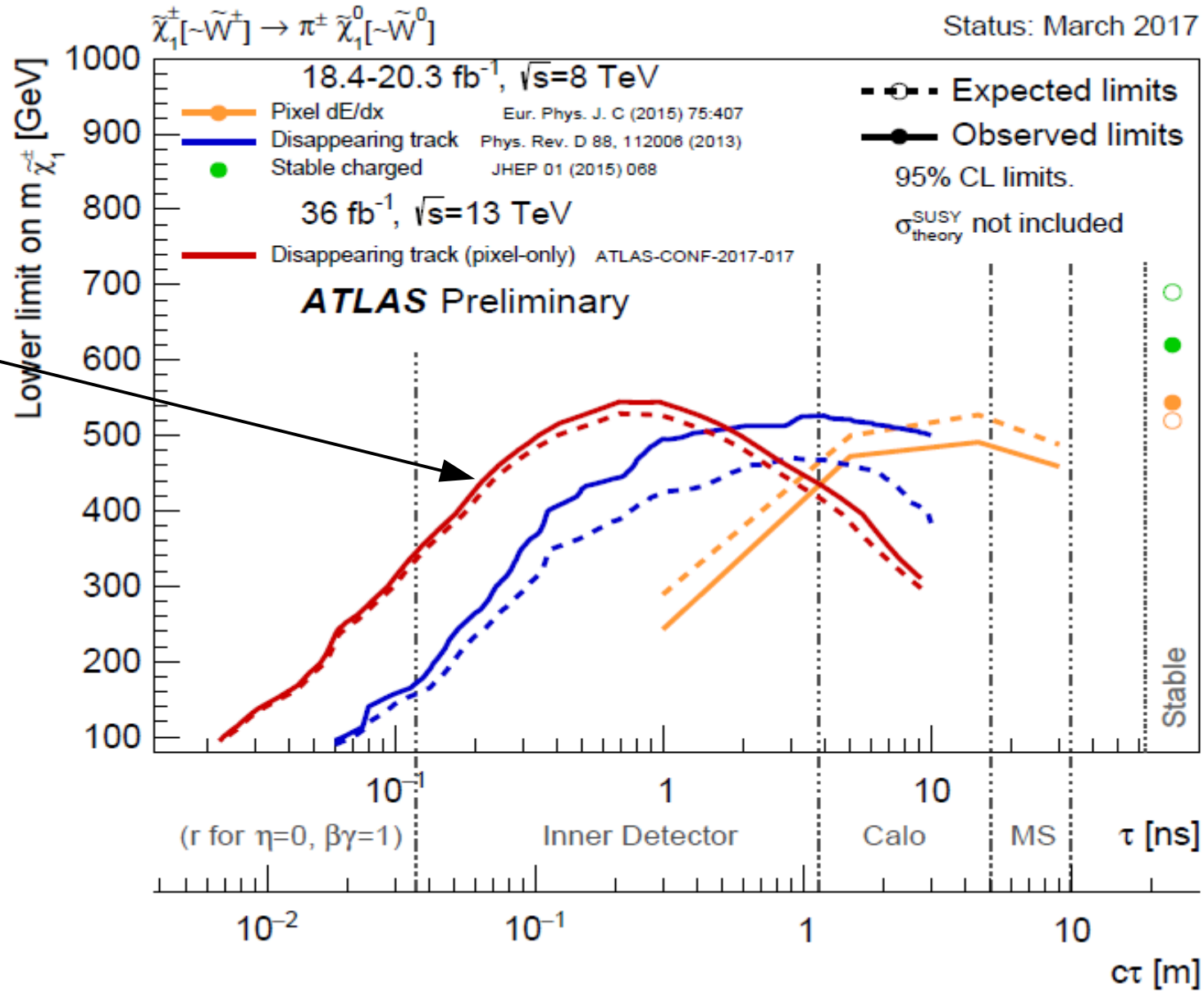
- Combine info from *multiple bunch crossings* in ATLAS Run2 trigger
  - Recall, bunch spacing is just 25 ns in Run2 (was 50 ns in Run1)

- Heavy, slow ($\beta <\sim 0.8$), charged long-lived particle
  - Too slow to reach muon trigger in bunch 1 (production crossing)
  - Reaches muon trigger in next bunch crossing
  - Would not fire muon trigger by itself
  - *Combine with jet/MET in <u>previous</u> bunch crossing*



Long-lived chargino searches

Updated disappearing track search



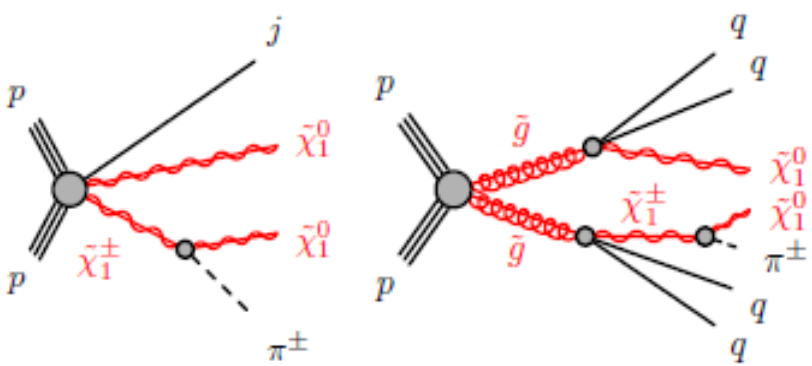
Updated disappearing track search

ATLAS-CONF-???

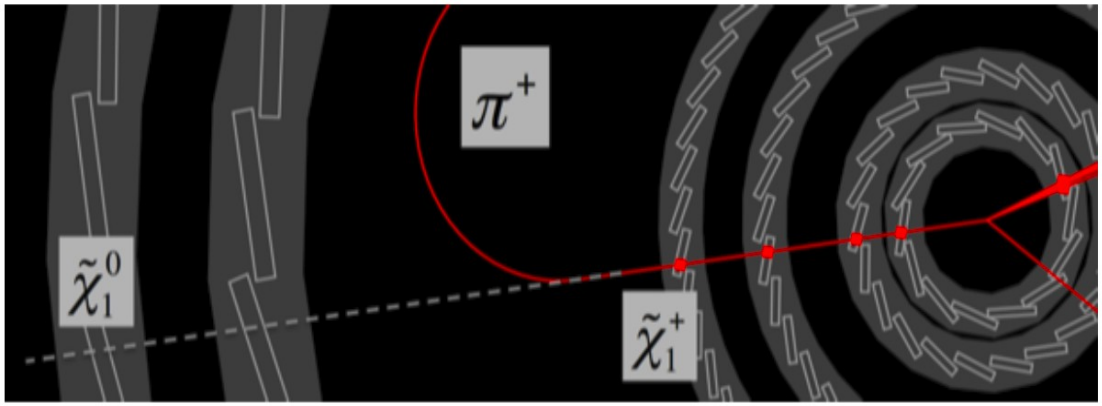
36.1/fb
13 TeV

- AMSB model (or in mini-split SUSY)
  - Squarks heavy (10-100 TeV), consistent with mH
  - Wino-like LSP, good DM candidate
- Chargino and neutralino nearly degenerate
  - Lifetime of chargino ~0.2 ns → ~6 cm
- Chargino track "disappears" when it decays, into MET
  - Low-momentum (~0.1 GeV) pion track is lost

- Now consider both weak (direct) and strong (gluino) production in Run2
- Challenge to reconstruct short tracks, with decent momentum resolution



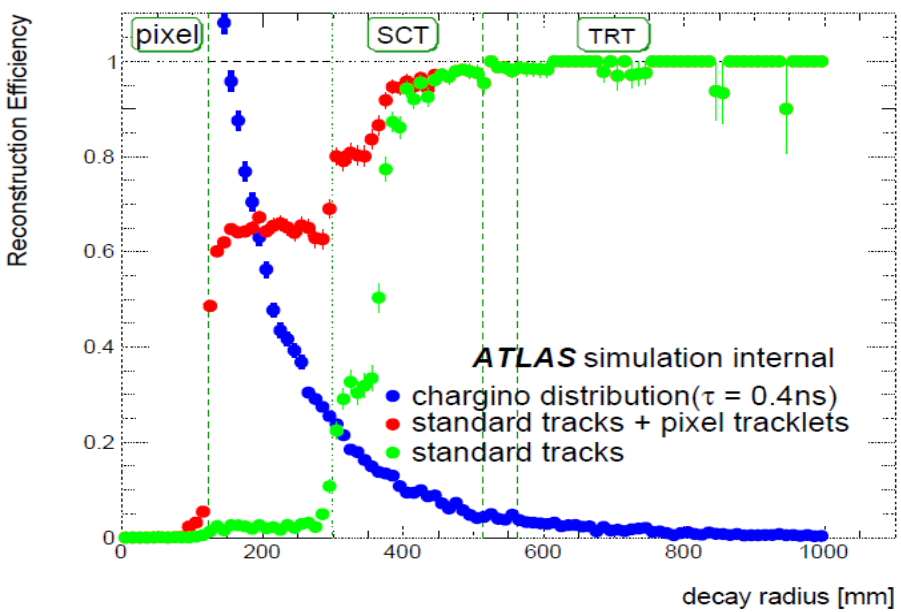
Direct, weak Gluino, strong

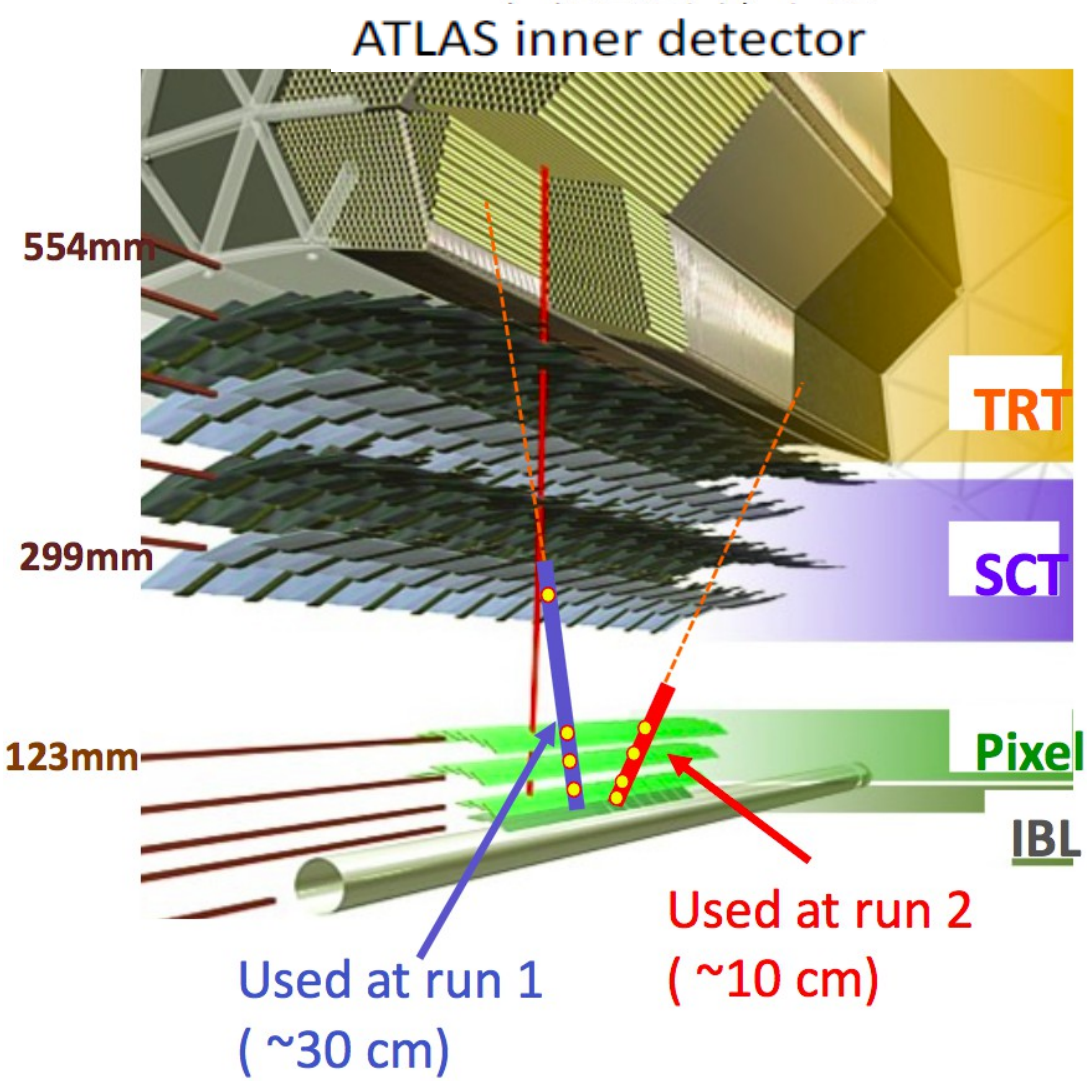


Updated disappearing track search

- New technique for Run2: pixel-only tracks, using IBL and existing layers!
  - Reconstruct ~10cm tracks, SCT veto, p_T>5 GeV
  - **~10x larger acceptance for 400 GeV AMSB chargino**

- Challenge to reject fakes, tracks with poor momentum resolution, and model backgrounds





Updated disappearing track search

- MET trigger (>~120 GeV), calibrated in W data
- Lepton veto, remove W's

- Tight requirements on track pointing to PV
- Tight track calorimeter isolation

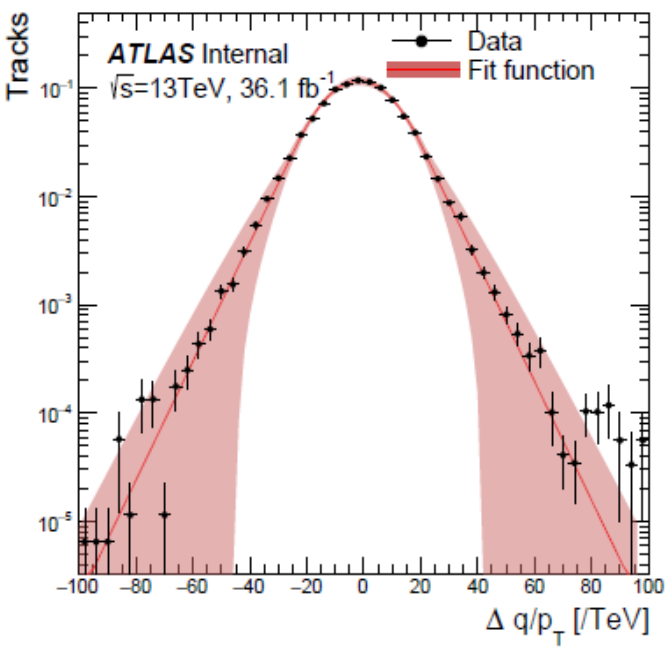
- Special procedure for modeling track p_T resolution

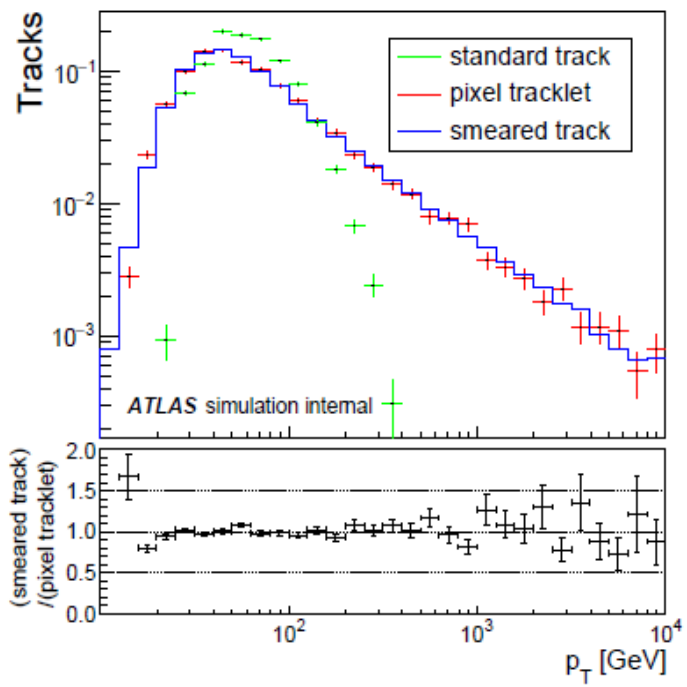
EW channel

- Leading Jet $p_T > 140$ GeV
- $E_T^{missing} > 140$ GeV
- $\Delta\phi_{min}(Jet_{1,2,3,4}, E_T^{missing}) > 1.0$

Strong channel

- Leading Jet $p_T > 100$ GeV
- 2nd Jet $p_T > 50$ GeV
- 3rd Jet $p_T > 50$ GeV
- $E_T^{missing} > 150$ GeV
- $\Delta\phi_{min}(Jet_{1,2,3,4}, E_T^{missing}) > 0.4$

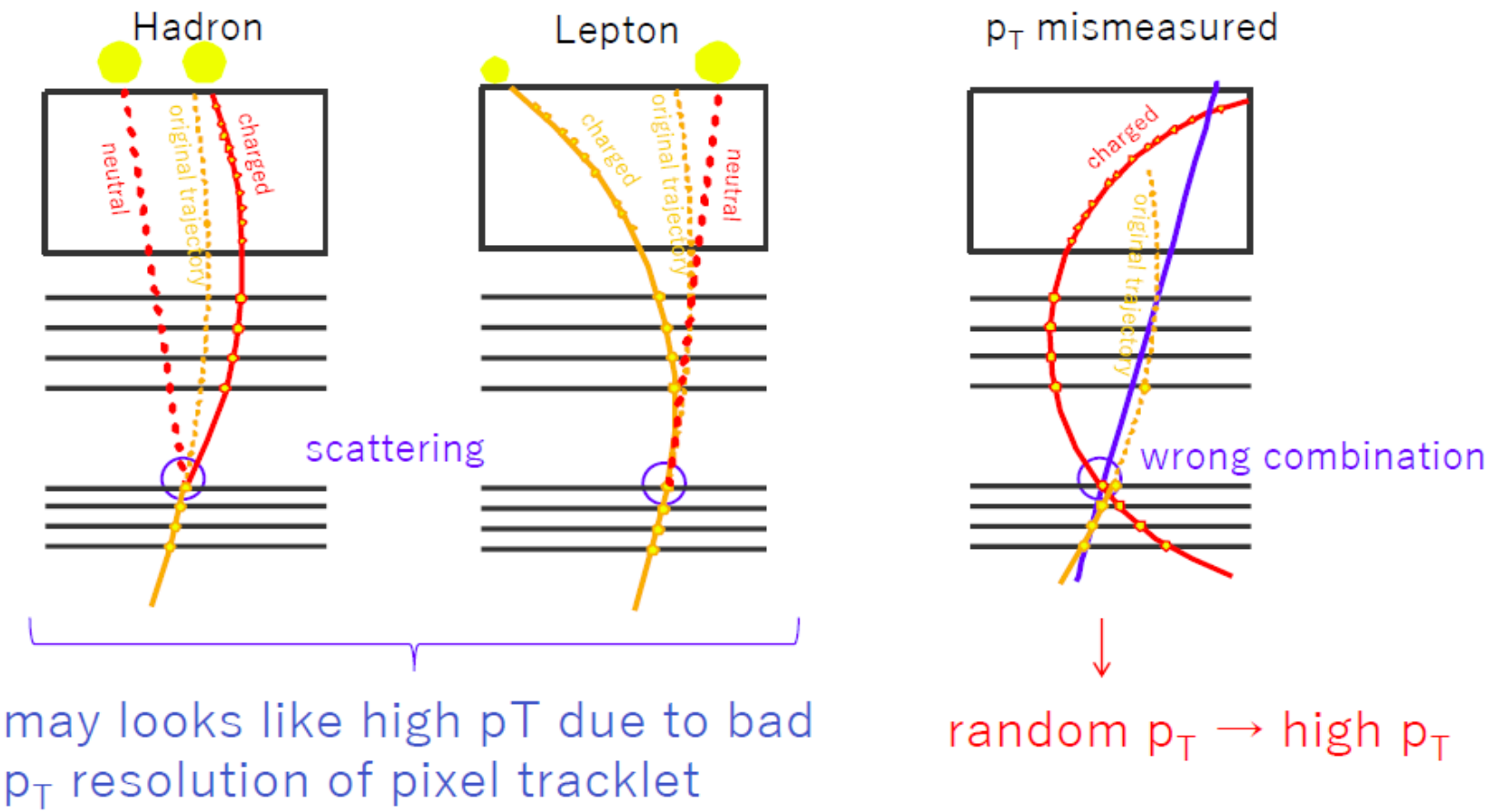




Updated disappearing track search

- Main background is W+jets, where e or π scatters
- Random background dominates at very high p_T

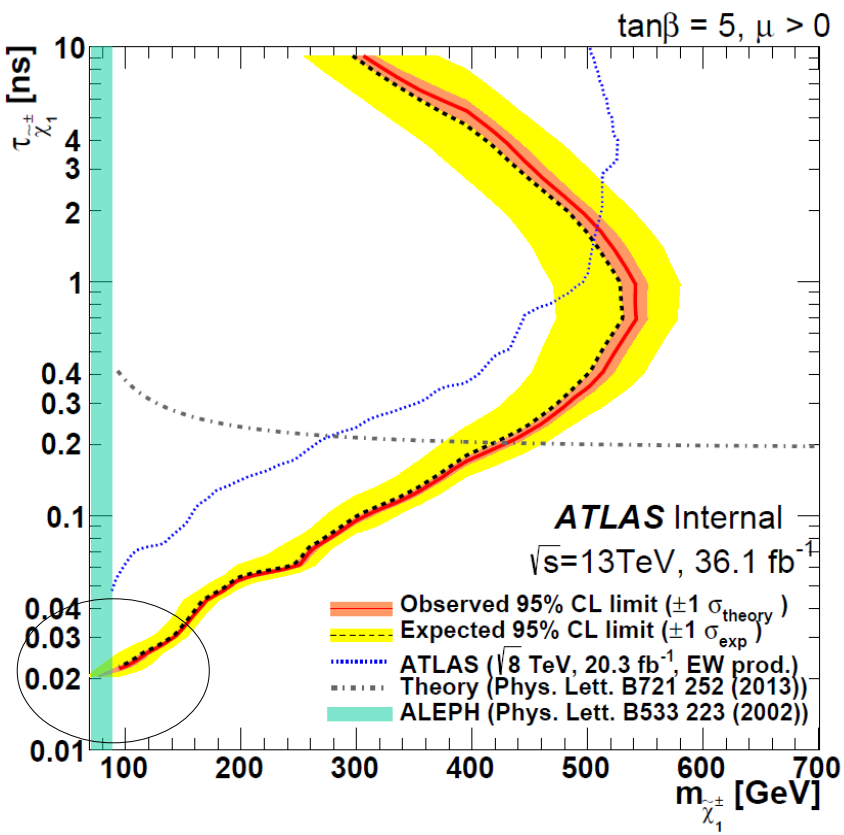
- Background types:

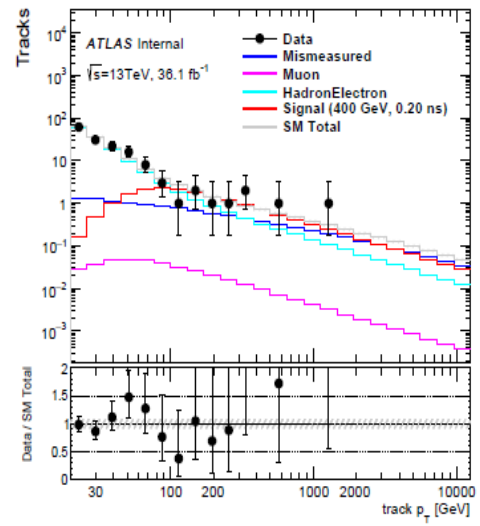


Updated disappearing track search

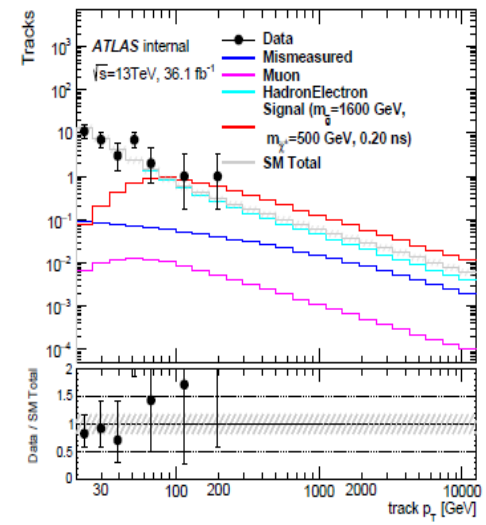
No excess seen...

(high-E_T^{miss}, p_T > 100 GeV)	Electroweak channel	Strong channel
Observed events	9	2
Expected background	11.5 ± 3.1	2.3 ± 0.5
Signal	10.4 ± 1.7	4.1 ± 0.5
CL_b	0.403	0.647
Observed $\sigma_{vis}^{95\%}$ [fb]	0.24	0.12
Expected $\sigma_{vis}^{95\%}$ [fb]	$0.30^{+0.13}_{-0.14}$	$0.11^{+1.53}_{-0.04}$





Weak production channel

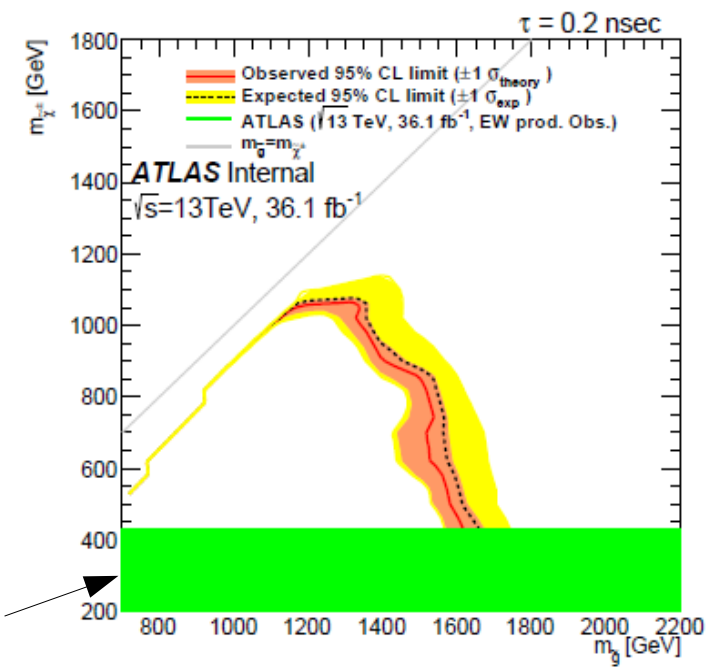


Strong production channel

Good reach extends to very small lifetimes!

Starting to attack Higgsino territory...

Weaker than 8 TeV result for long-lifetimes



Direct, weak limits

Summary

- Have started exploiting large Run2 dataset in search of LLP's

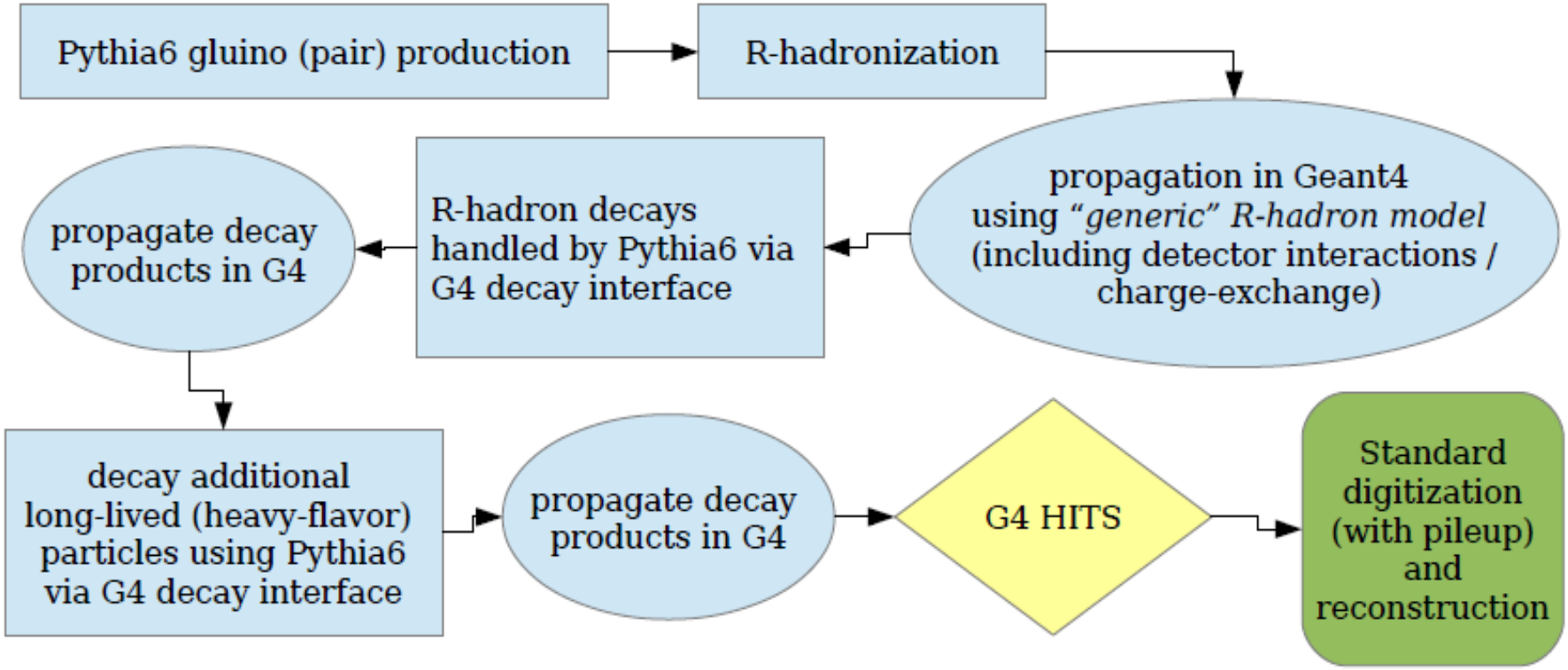
- Making use of new detector capabilities as well
  - IBL (new inner pixel layer)
    - Better dE/dx measurement
    - Pixel-only tracks
  - Trigger flexibility at L1 and HLT

- An exciting and busy time ahead for Run2 and Run3 and beyond
- We'll keep working hard, and hope for some surprises!

Backup

Prompt search reinterpretations

- *First explicit limits on gluinos with intermediate lifetimes from reinterpretation of prompt SUSY searches*
  - 7-10 jets and 0,1,2 b-jets and MET
  - 2-6 jets and MET
  - *3 b-jet and SS/3L searches also considered but don't add sensitivity*
- Generated fullly-simulated MC of decaying Rhadrons at ATLAS



Prompt search reinterpretations

- Limits on gluino mass vs. lifetime
  - Also scan neutralino mass

ATLAS-CONF-2014-037

- Gluino with lifetime of 1 ns excluded up to ~900 GeV, for $m(x_1^0)$=100 GeV