Searches for long-lived particles at HL-LHC on ATLAS

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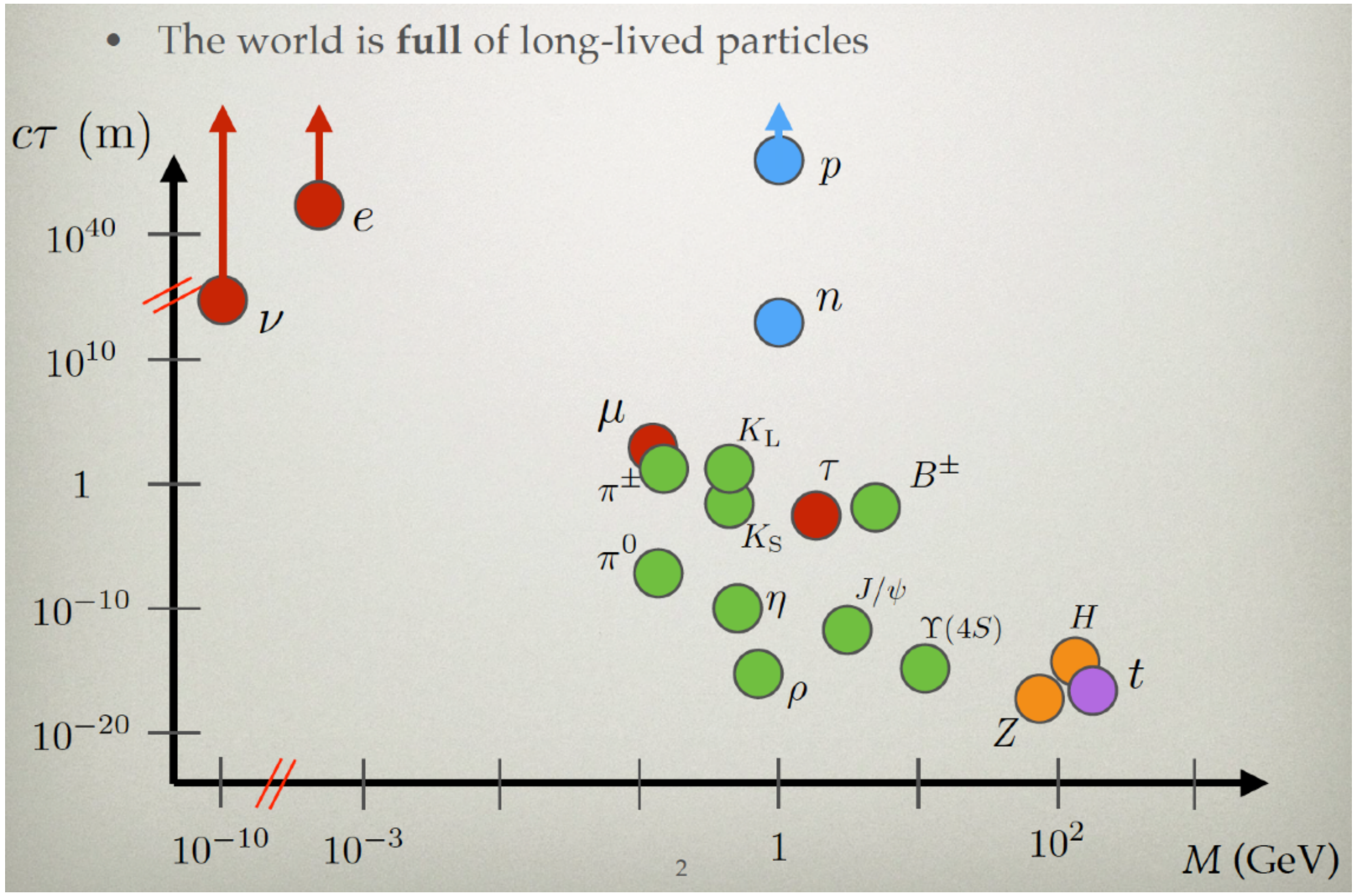
Introduction

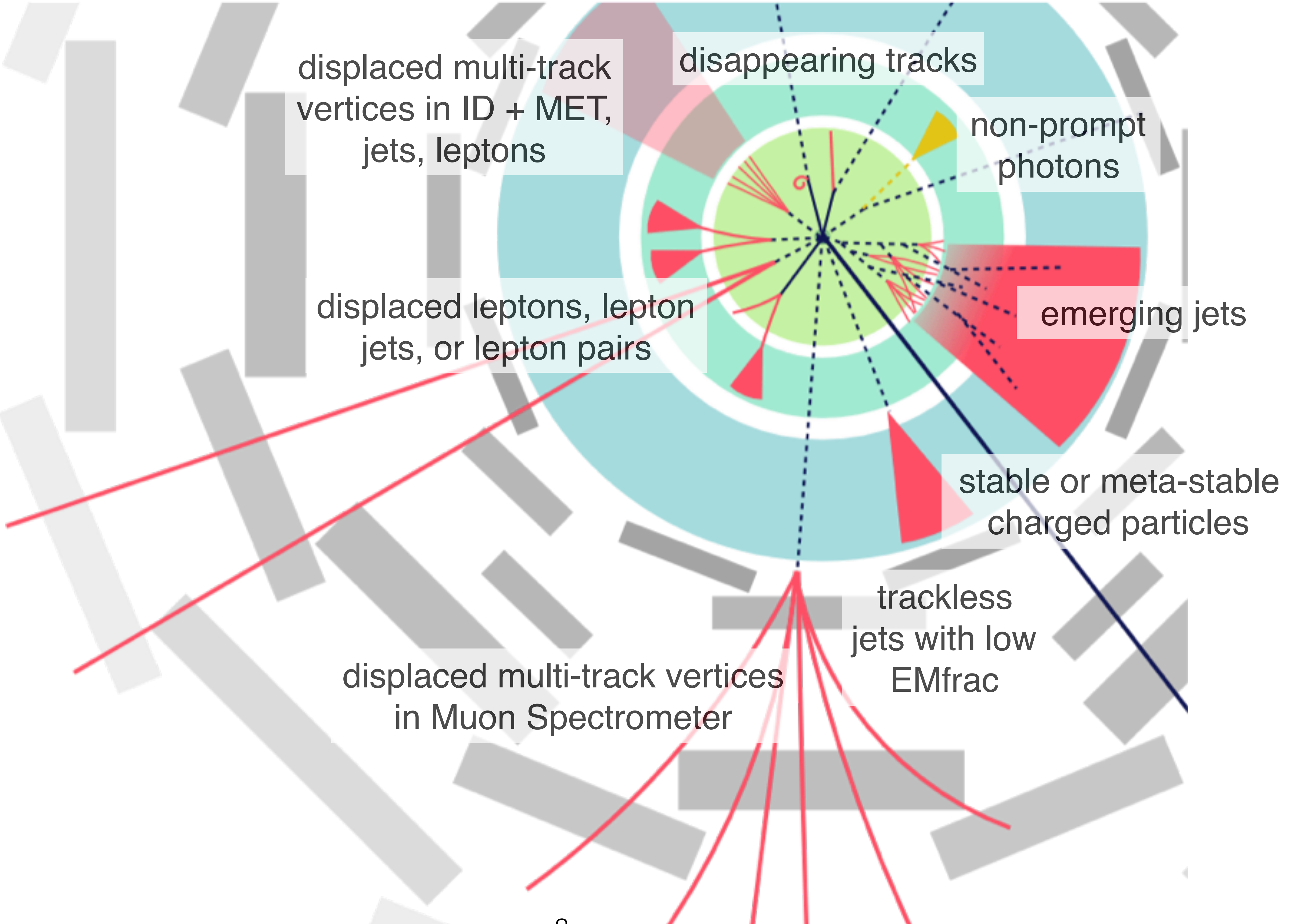
- New long-lived particles are both theoretically and experimentally motivated
  - small couplings
  - phase-space suppression
  - conserved (or nearly conserved) symmetries
- LLP searches are signature-driven, and signatures are a product of
  - electric charge
  - mass
  - lifetime
  - decay products



graphic credit: Brian Shuve

"Prompt particle searches are all alike; every special LLP search is special in its own way" — *few sigma Tolstoy reinterpretation*

Run 2 LLP analyses on ATLAS



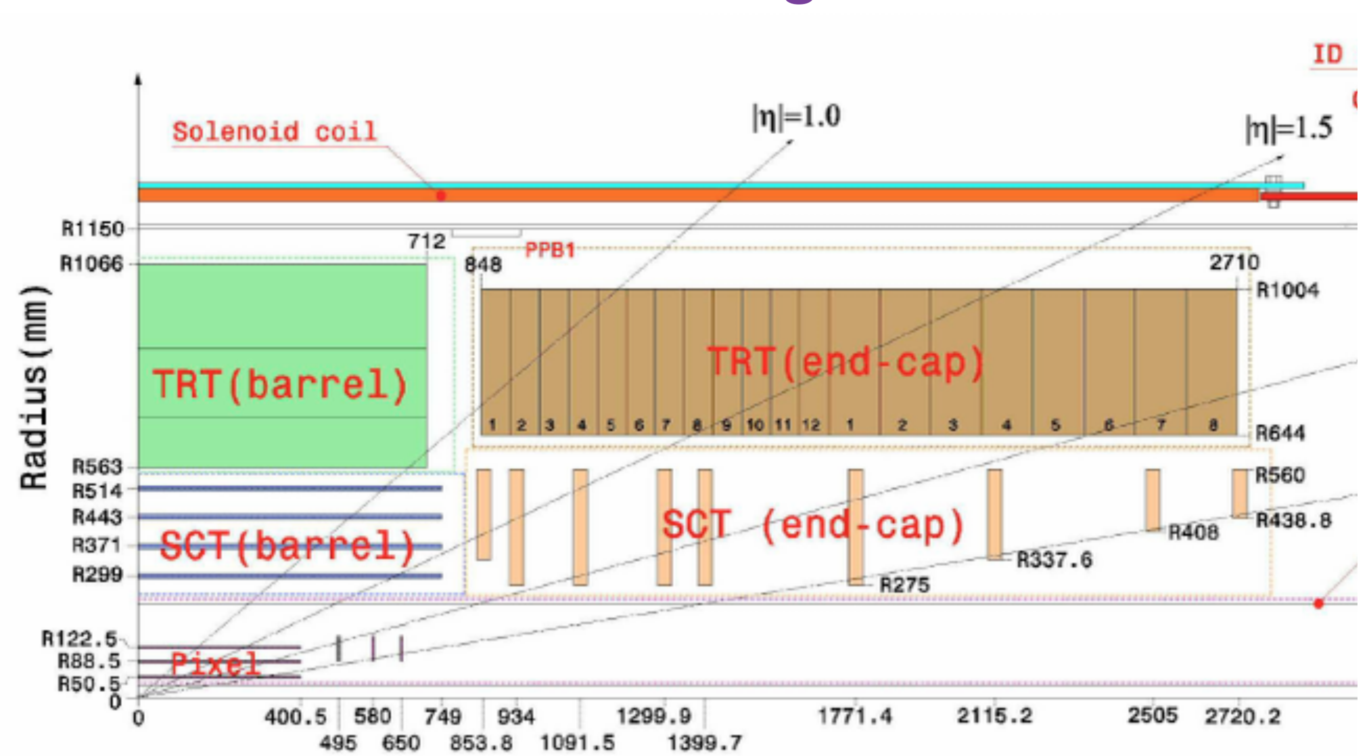
graphic credit: Heather Russell

Focus of HL-HLC LLP studies on ATLAS

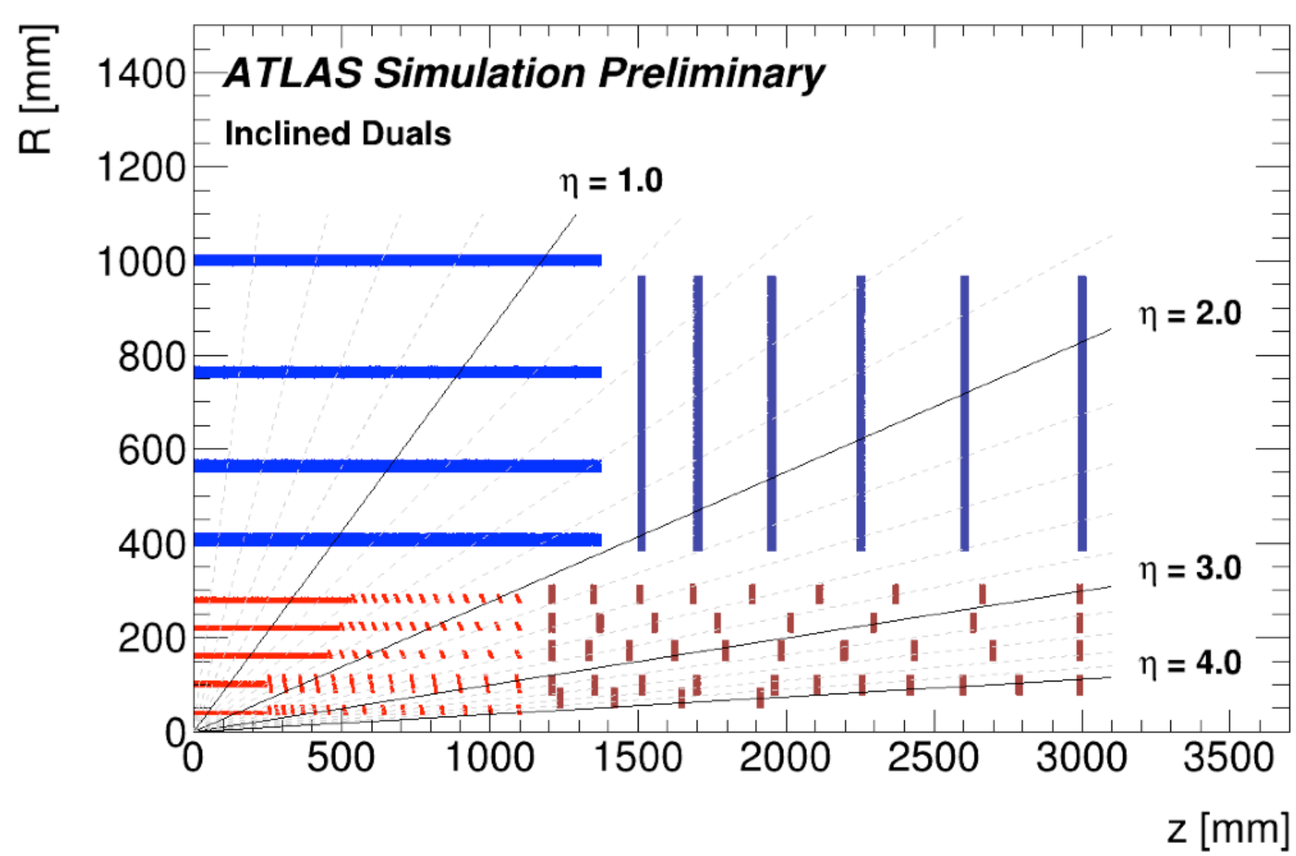
- Focus on interaction between upgraded detector design and search, rather than on analysis improvement or effect of more luminosity or pileup

- Therefore, studies focus on new pieces, including (but not limited to):
    - ITk
    - expanded calo trigger capabilities
    - expanded muon trigger capabilities

Existing ID

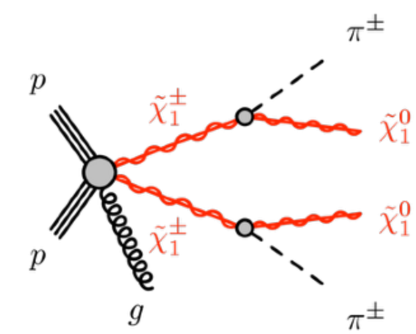


ITk

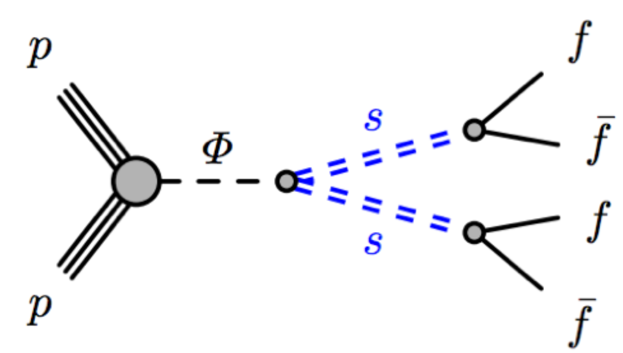


Upgrade studies overview

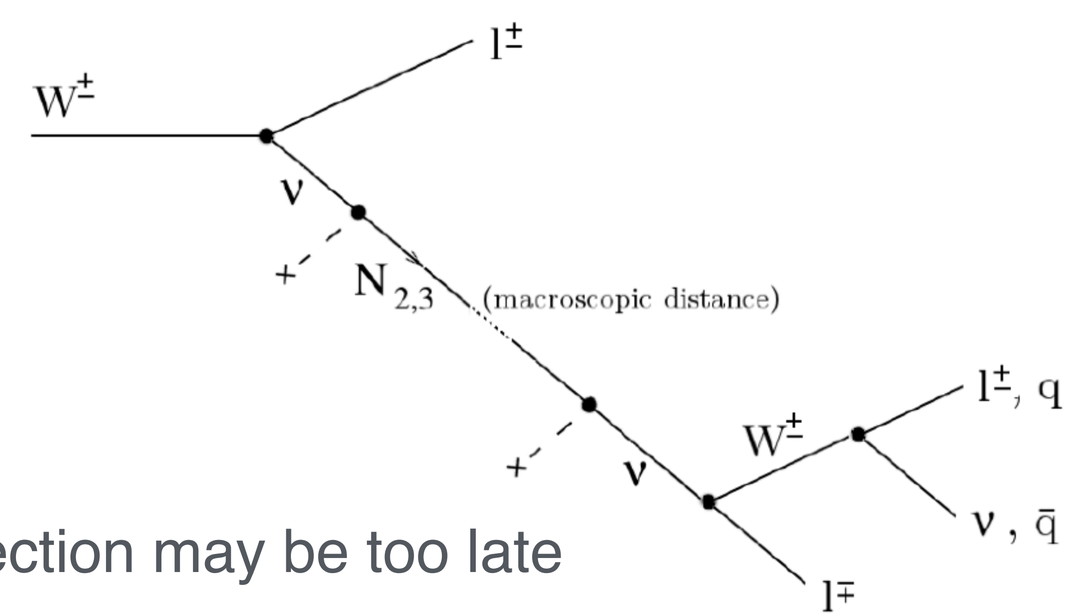
- Disappearing tracks
  - projection in ATLAS Pixel TDR plan for PUB note before yellow report



- Multi-track displaced vertices in ID + MET
  - tracking studies in ATLAS Pixel TDR, plan for PUB note before yellow report
- Lepton jets / displaced vertex in Muon Spectrometer
  - muon trigger studies in ATLAS TDAQ TDR



- Jets in Hadronic calo with low EMfrac
  - calo trigger studies in Tile TDR
- High Granularity Timing Detector
  - work ongoing toward TDR; interest in LLPs

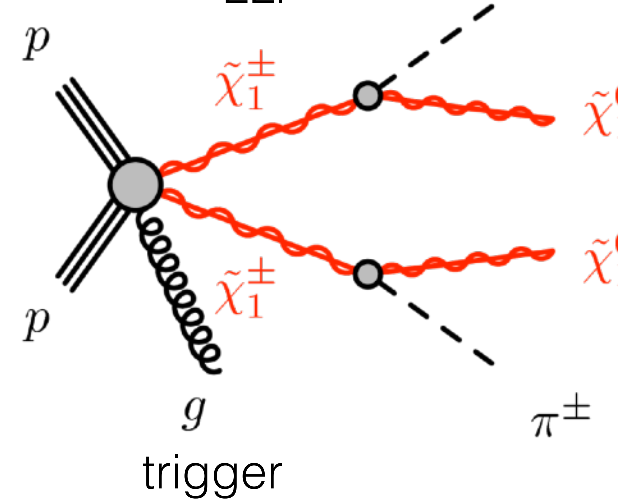


- Displaced DV in ID w/ leptons
  - possible tracking contribution but physics-projection may be too late

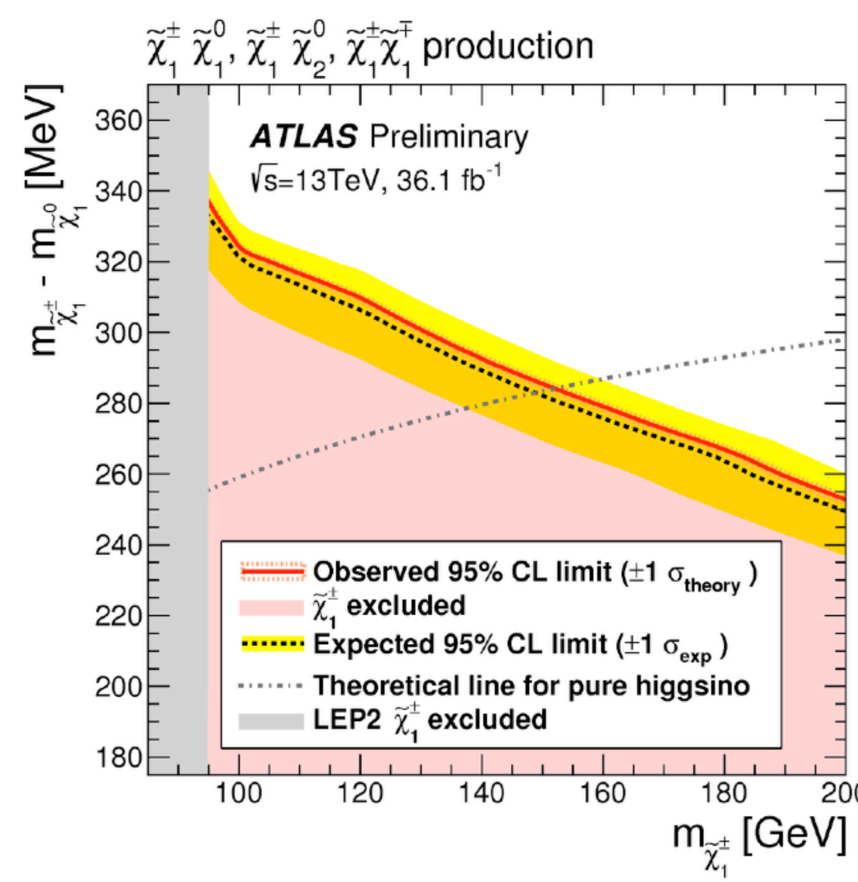
Disappearing tracks

Physics projection study

- Sensitivity
  - charged particle with lifetime ~10 ps - 10 ns which decays to “invisible”
- Favorite models
  - particular sensitive to pure wino or pure higgsino SUSY LSP, in which case the lightest chargino naturally picks up lifetime
    - pure wino: ~0.2 ns
    - pure higgsino: ~0.05 ns
- Event selection (in Pixel TDR) re-optimization underway
  - MET > 450 GeV
  - one jet > 300 GeV
  - tracklet with 4 pixel hits and pT > 250 GeV which disappears in strips
- Background
  - estimated from a combination of upgrade simulation samples and data from Run 2
  - mostly fake tracklets



Run 2 higgsino result

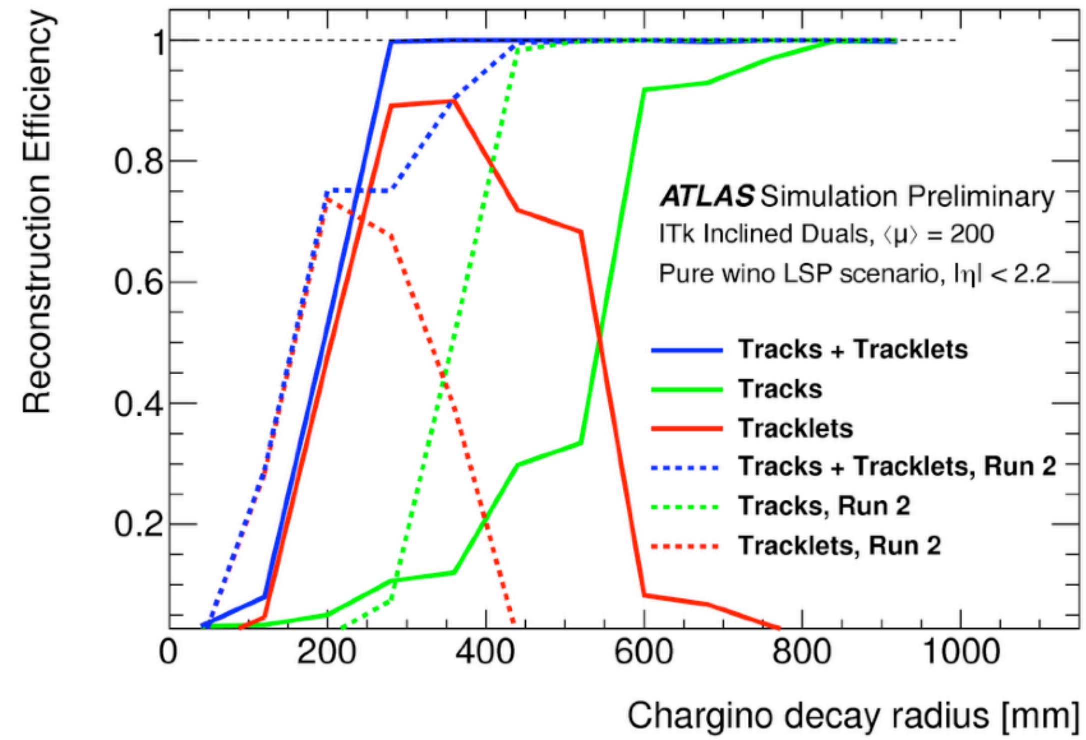


Disappearing Tracks

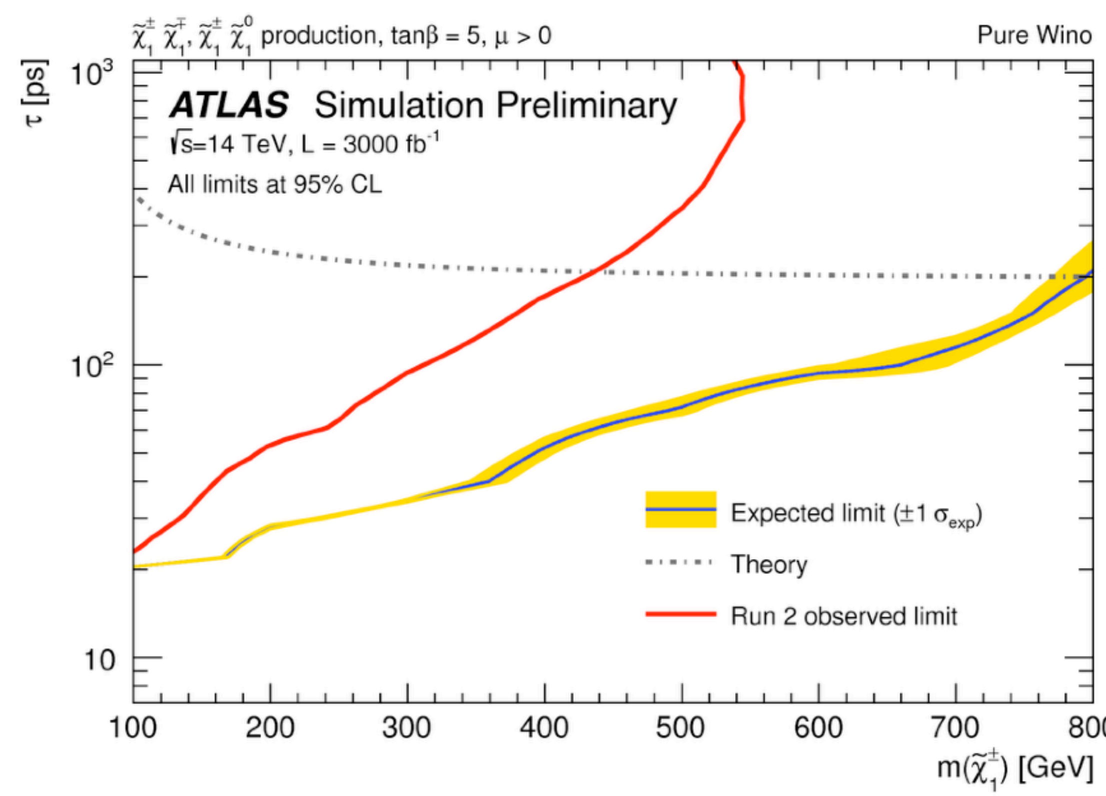
- Results
  - with 3000 fb^{-1}, expect to exclude at least
    - > 800 GeV for pure wino, τ = 0.2 ns
    - > 250 GeV for pure higgsino, τ = 0.05 ns
- Interesting observations
  - fakes significant, can add more signal regions (3,4,5 hits)
  - standard tracking produces more kinked tracks for pions than current ID
  - one of the few analyses that loses efficiency (at low lifetimes) from detector design
- Next steps
  - further optimization of selection to reject fakes
  - some interest in an HE-LHC projection

Question to theorists: how much interest in longer tracklets?

Tracking efficiency versus decay radius



HL-HLC projection for pure wino LSP

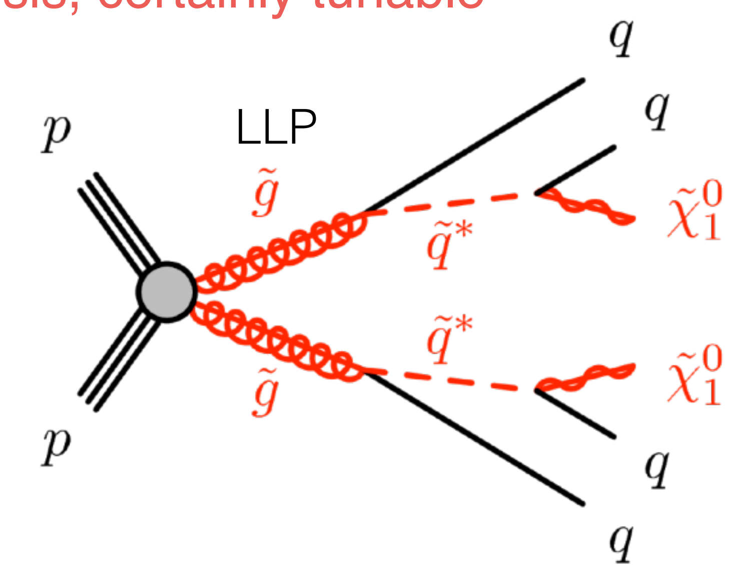


Multi-track displaced vertices in ID + MET

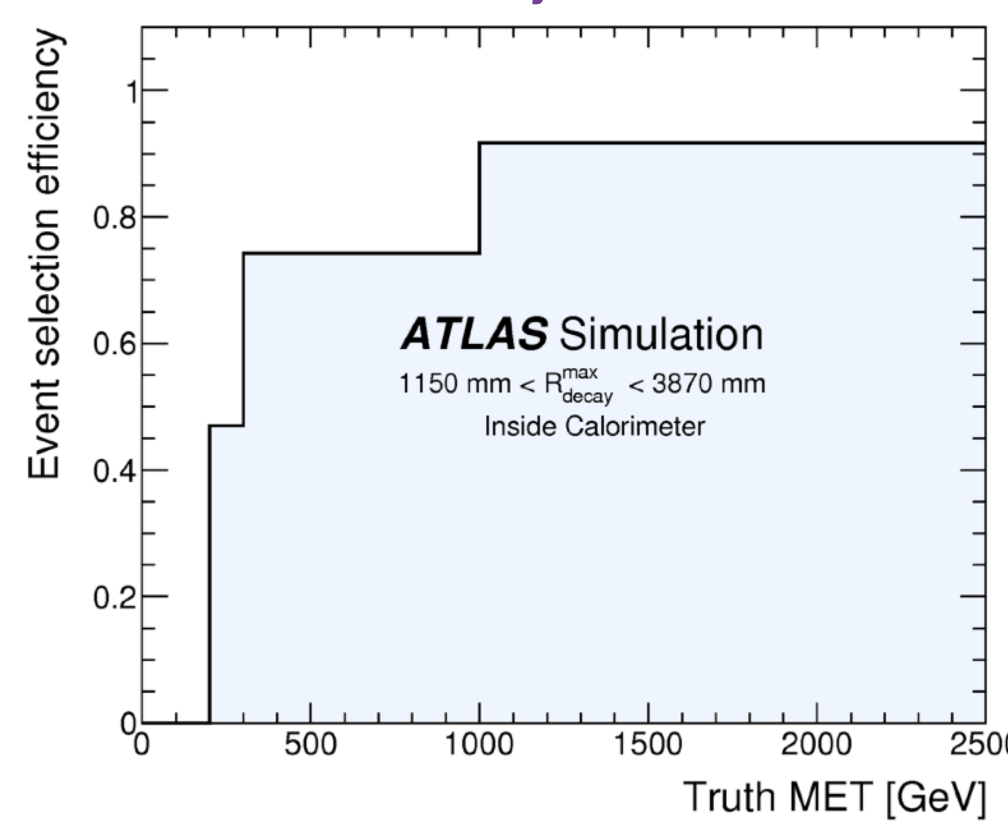
Tracking study, physics projection underway

- Sensitivity
    - neutral or charged LLP which decays within ID to at least one vertex with >= 5 tracks and mDV >= 10 GeV, plus MET
    - τ ~10 ps - 10 ns
- Favorite models
    - gluino R-hadrons, decays to neutralino and jets
- Event selection
    - relies on reconstructing displaced tracks
        - using a dedicated large-radius-tracking setup in current detector
        - using a truth-level projection, extrapolated through geometry and material, for ITk
    - relies on reconstructing displaced vertices from displaced tracks
    - veto of vertices in detector material
    - MET > 200 GeV

selections from Run 2 analysis, certainly tunable

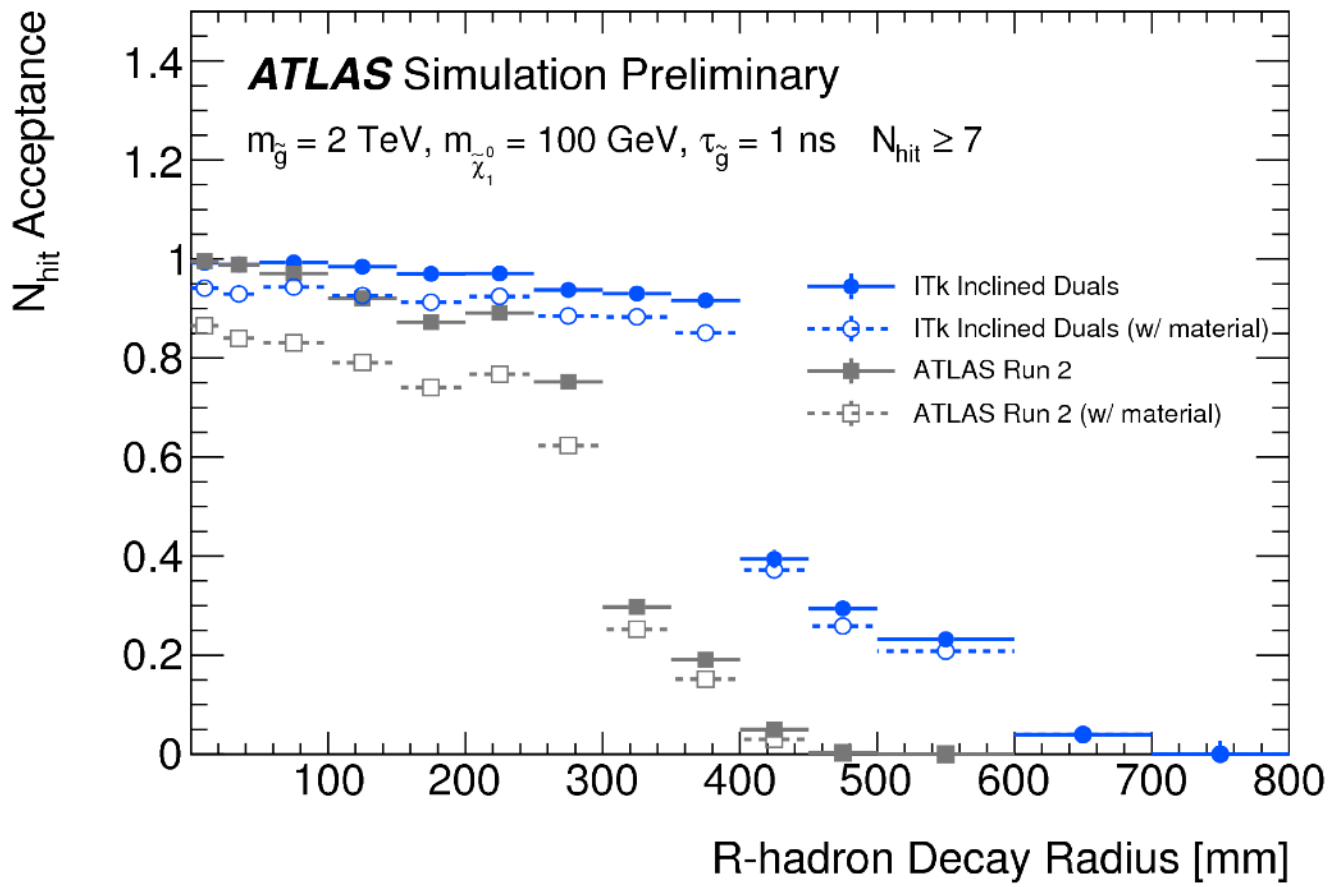


Run 2 Efficiency versus true MET



Multi-track displaced vertices in ID + MET

Tracking efficiency versus decay radius



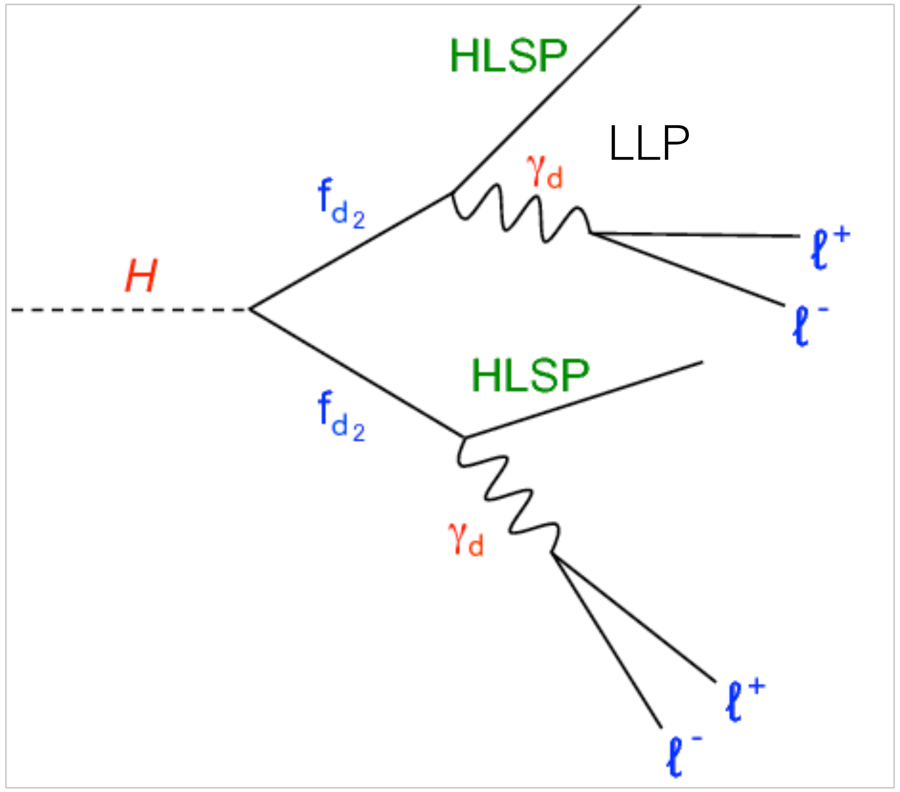
- Results
  - significant increase in efficiency of reconstructing displaced tracks up to 400 mm, and increases reach up to 500 mm
- Next steps
  - calculate efficiency of material veto in ITk for benchmark R-hadron samples
  - use reinterpretation material from public Run 2 result to extrapolate MET and vertexing efficiency
  - scale background to 3000 fb^{-1}
  - estimate physics reach

Question to theorists: strong interest in specific EW or lower x-sec models that we should be targeting here?

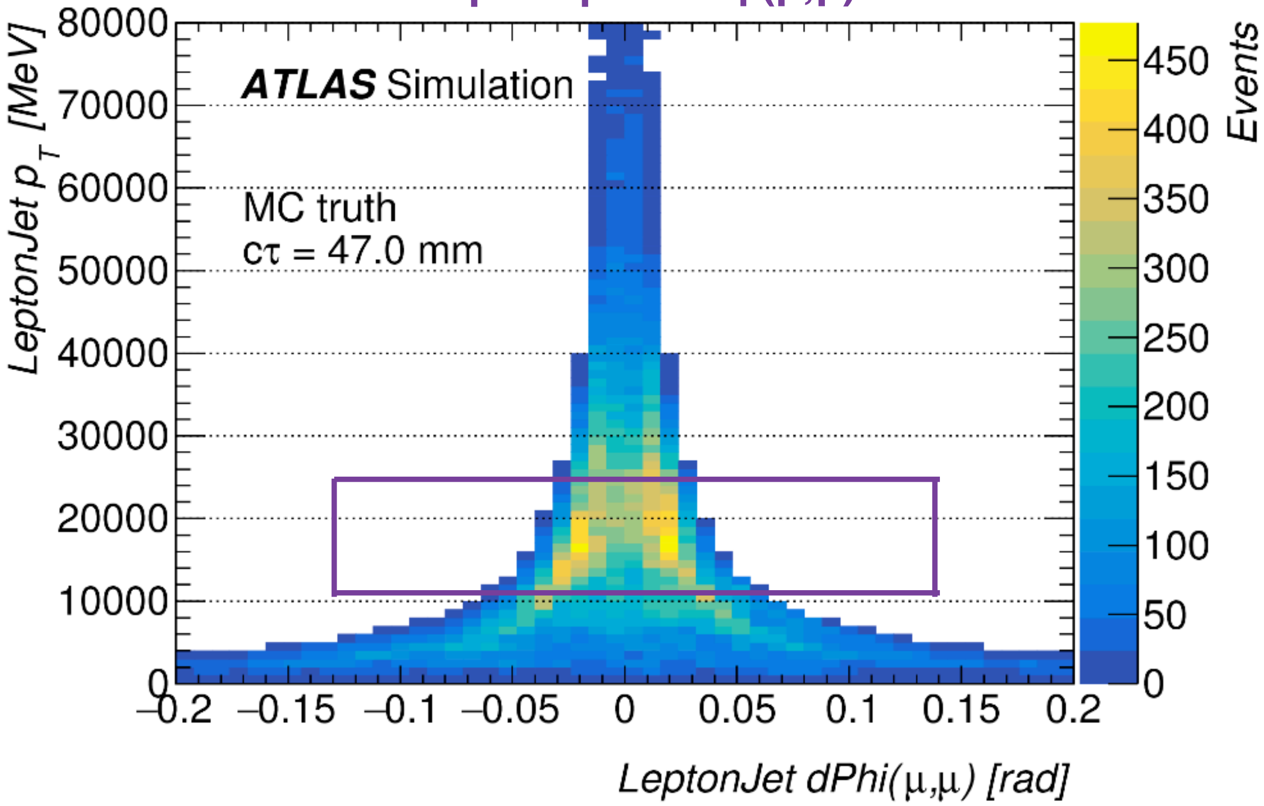
Displaced vertices in Muon Spectrometer

Trigger study

- Sensitivity
  - neutral LLP decays before MS into pairs of multiple pairs of collimated leptons
- Favorite models
  - hidden valley models with dark photon decays to leptons (muons)
- Current trigger
  - two-muon resolution limited to ~0.2 in Δϕ(μ,μ)
  - single muon pT threshold ~ 25 GeV
- Phase II trigger
  - new muon sector logic and NSW and MDT trigger processors allow development of di-muon trigger within Region-of-Interest
  - reduce threshold to ~10 GeV for Δϕ(μ,μ) = 0.01
  - significant gain in trigger eff. for close muons
- Next steps
  - further optimizations in Δϕ(μ,μ) in new alg.
  - studies of efficiency gain v. lifetime

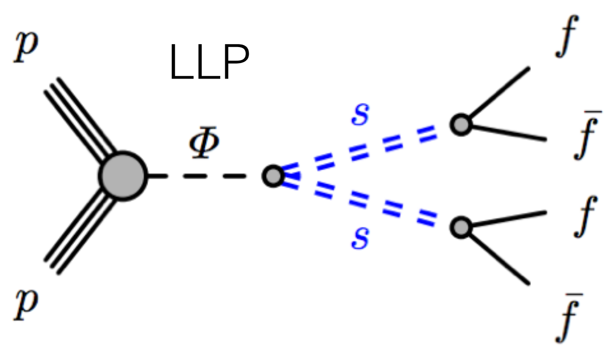


Lepton pT v. Δϕ(μ,μ)



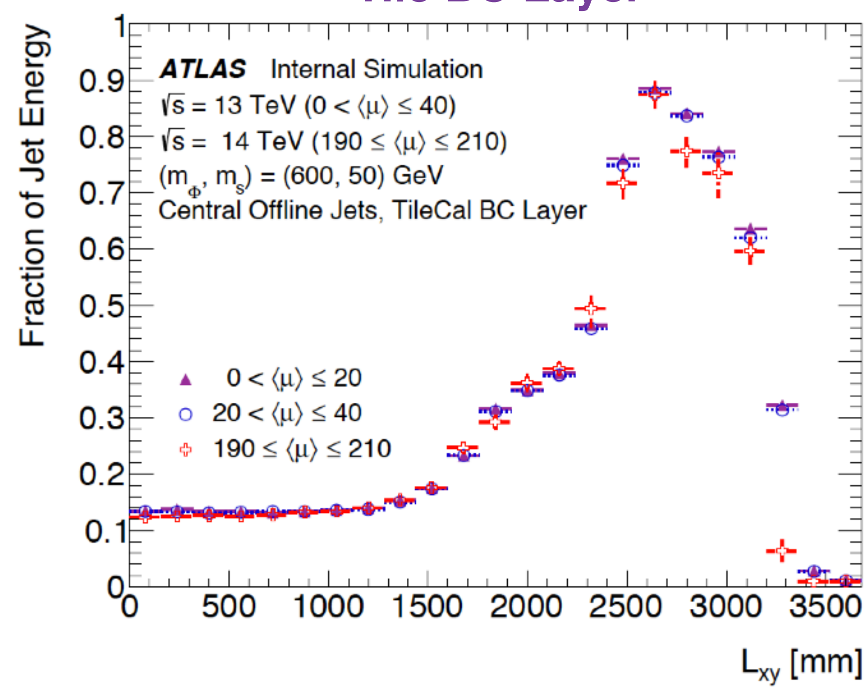
Jets in Hadronic Calo with low EMfrac

Trigger study

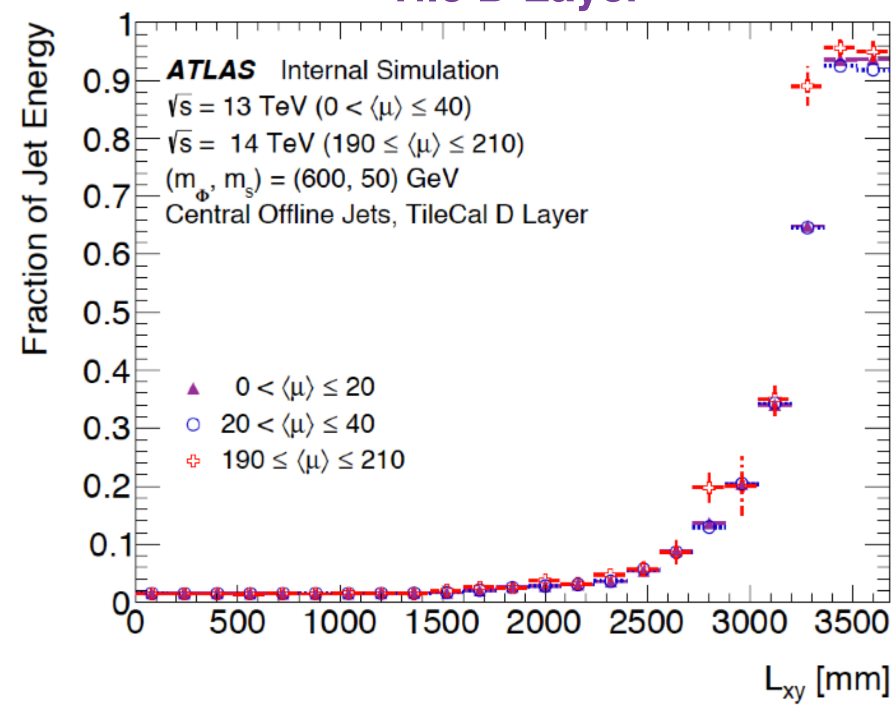


Fraction of energy deposited versus decay radius

Tile BC Layer



Tile D Layer

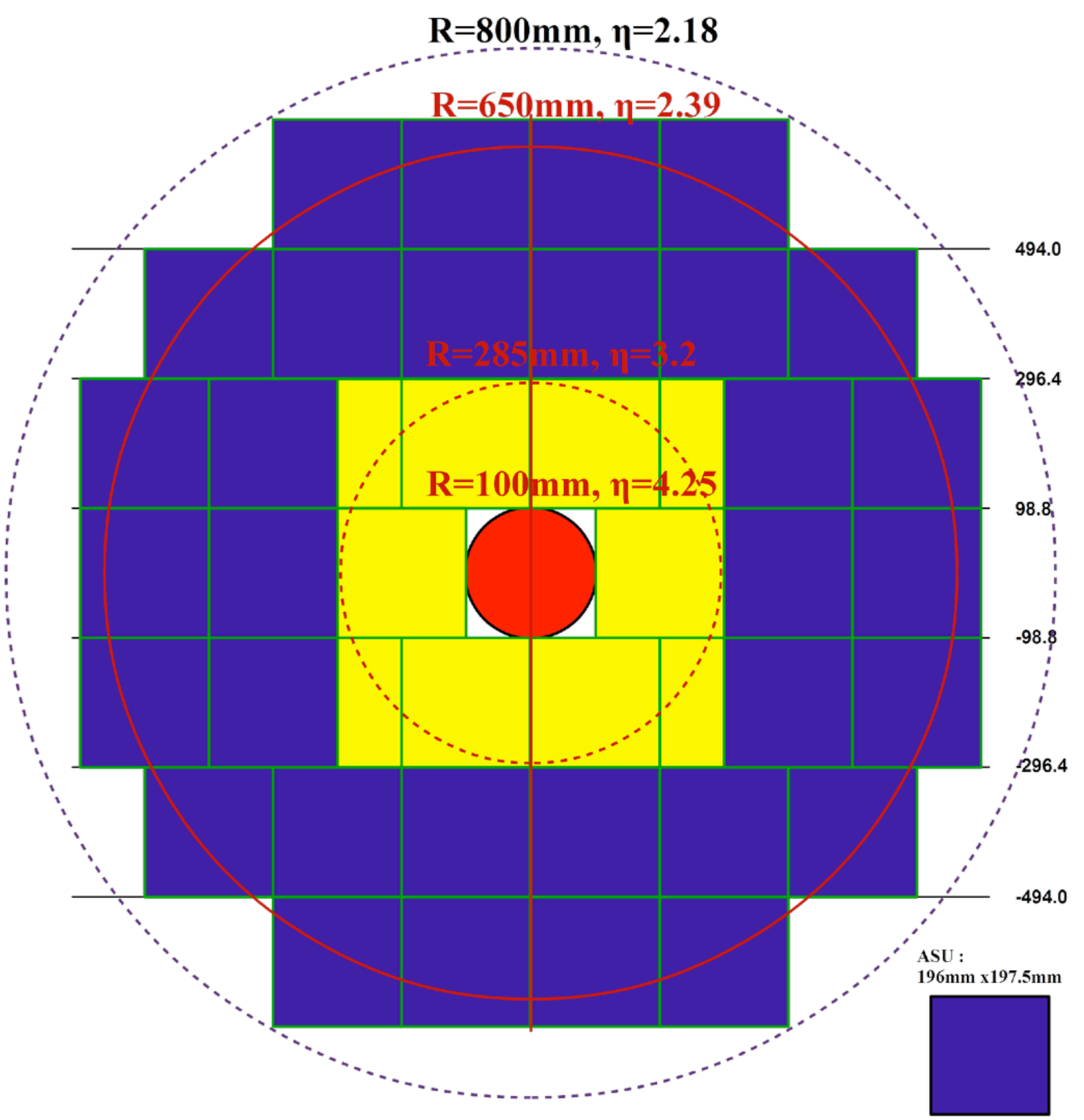


- Sensitivity
  - neutral LLP that decays to jets inside hadronic calorimeter
- Favorite models
  - hidden sector scalar boson decays to more hidden sector particles which decay to (heavy) SM fermions
- Current trigger
  - dedicated level-1 trigger based on tau candidates + low EMfrac
- Phase-II trigger idea
  - low EMfrac will be hurt by pileup activity in EM calo
  - use increased longitudinal Level-1 granularity in Tile to compare energy deposits per layer and reduce sensitivity to pileup while maintaining efficiency for LLPs

High Granularity Timing Detector

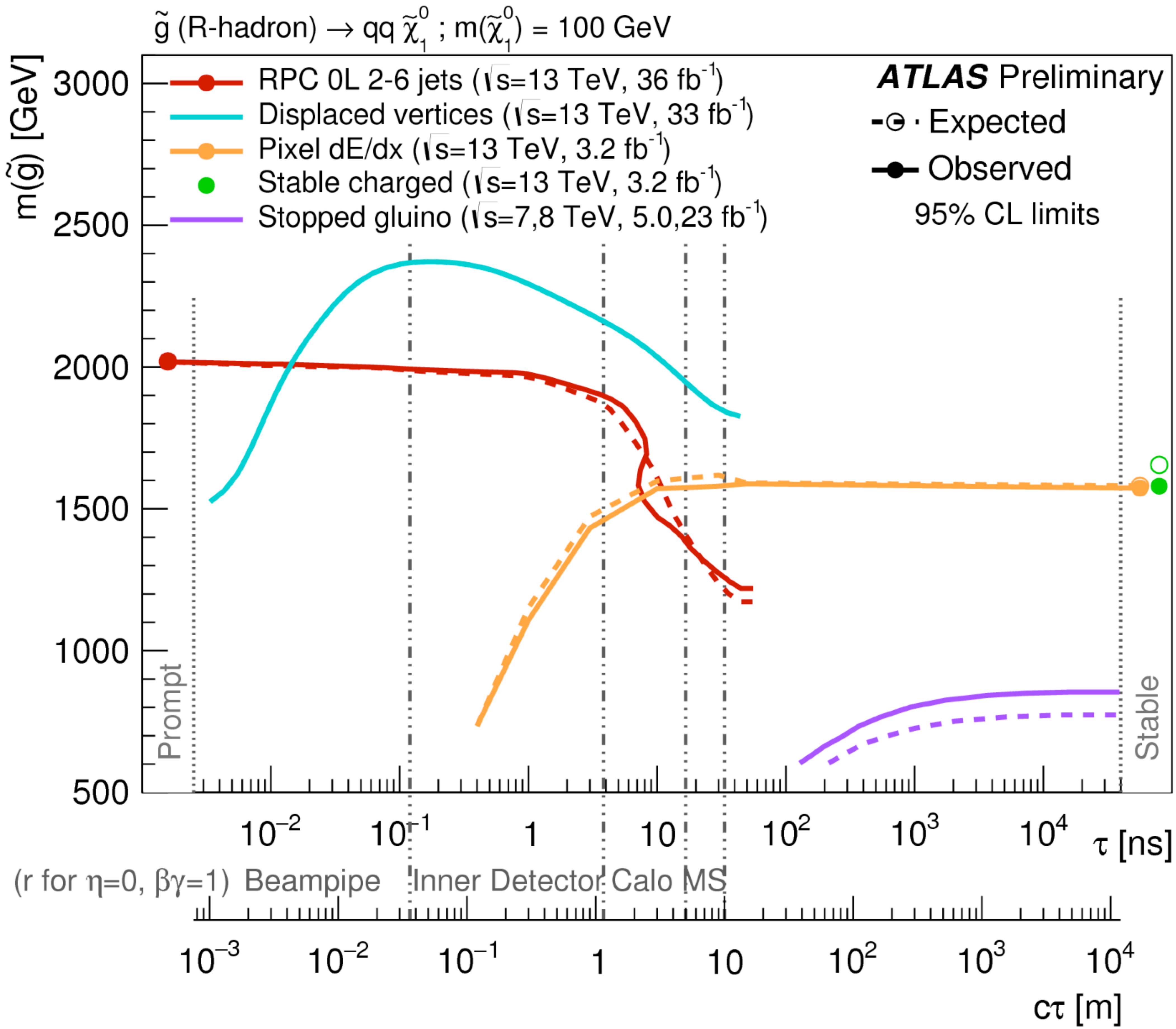
Input welcome

- Detector
  - 2-3 layers of low gain silicon avalanche detectors with pixels of 1.3 x 1.3 mm²
  - located at z = +/- 3.5 m
  - eta coverage from 2.4 to 4.0
  - timing resolution of 30 ps per track
- LLP possibility
  - precision timing may allow to measure — and trigger on — charged particles which arrive late to HGTD
    - if timing window is large enough
  - strong interest in models with slow (or late) *forward* charged LLPs welcome :)



Conclusions and Outlook

- Significant effort went into detector TDRs for various LLP efforts
  - Important to take LLP concerns into account in detector design
- Physics projections underway for a subset of LLP analyses
  - mostly which use the ID / ITk as main detector
- Successful strategy to use Run 2 lessons and upgrade simulation
  - especially useful when Run 2 analyses provide public reinterpretation material
- Aim is to have several PUB notes out in time for the yellow report
  - though only for a subset of LLP analyses
    - no foreseen contribution on longer lifetime meta- or detector-stable charged particle searches
    - no planned effort on interplay between prompt and LLP analysis
  - even for analyses w/ projection, large investments in detector / tracking / performance / analysis optimizations will still remain in order to take full advantage of physics potential ahead!



$\tilde{g}$ (R-hadron) $\rightarrow qq\,\tilde{\chi}_1^0$; $m(\tilde{\chi}_1^0)$ = 100 GeV
RPC 0L 2-6 jets ($\sqrt{s}$=13 TeV, 36 fb^{-1})
Displaced vertices ($\sqrt{s}$=13 TeV, 33 fb^{-1})
Pixel dE/dx ($\sqrt{s}$=13 TeV, 3.2 fb^{-1})
Stable charged ($\sqrt{s}$=13 TeV, 3.2 fb^{-1})
Stopped gluino ($\sqrt{s}$=7,8 TeV, 5.0,23 fb^{-1})
ATLAS Preliminary
Expected
Observed
95% CL limits
$m(\tilde{g})$ [GeV]
Prompt
Stable
τ [ns]
(r for η=0, $\beta\gamma$=1) Beampipe
Inner Detector
Calo
MS
$c\tau$ [m]