Lawrence Berkeley National Laboratory

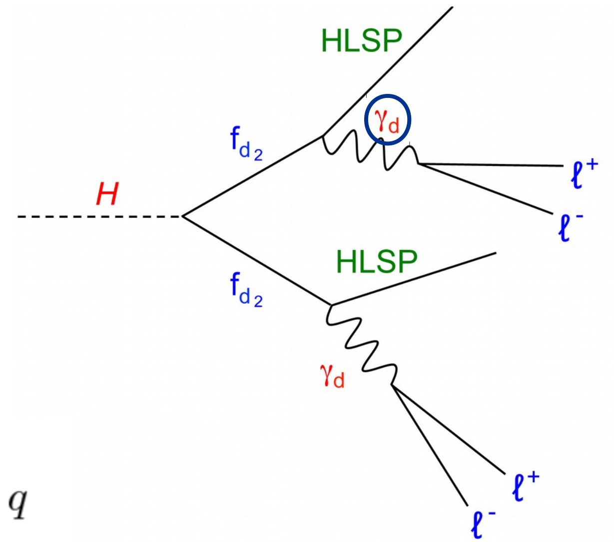
Searches for Long-Lived Particles in ATLAS: challenges and opportunities of HL-LHC

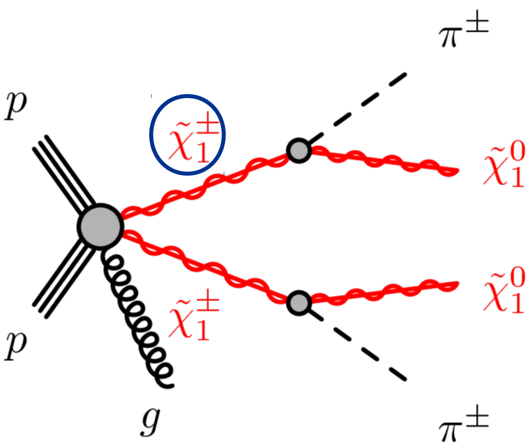
Simone Pagan Griso
Lawrence Berkeley National Lab.
on behalf of the ATLAS Collaboration

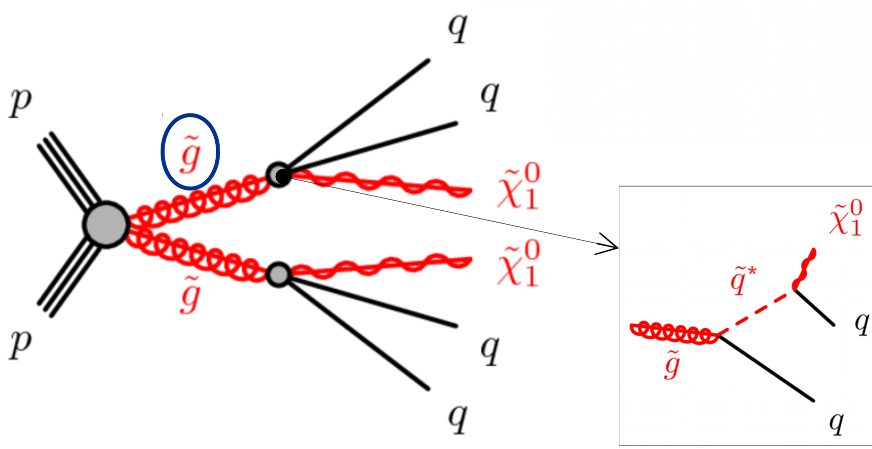
HL(/HE)-LHC Yellow-Report kick-off workshop,
October 31st, 2017

Introduction

- Most common theoretical sources of Long-Lived Particles (LLPs)
  - Approximate symmetries
  - Small couplings
  - Decays through heavy off-shell particles
  - Phase space suppression





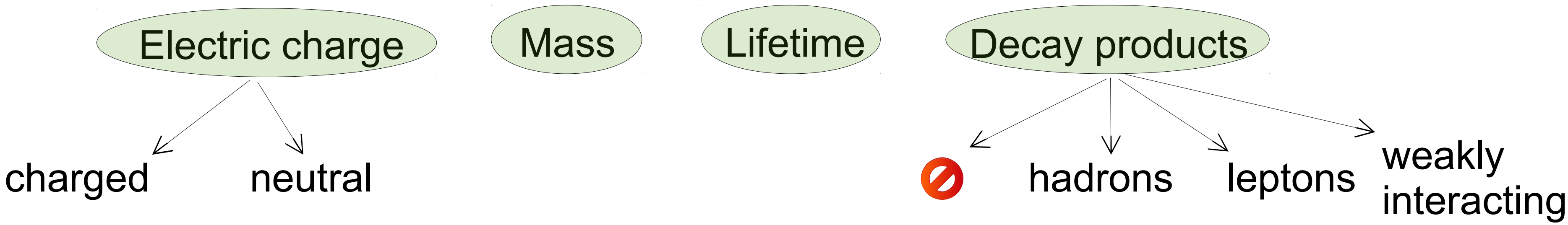


$$m(\chi^\pm) - m(\chi^0) \approx m(\pi)$$
$$c\tau(\chi^\pm) \approx 10 \text{ cm}$$

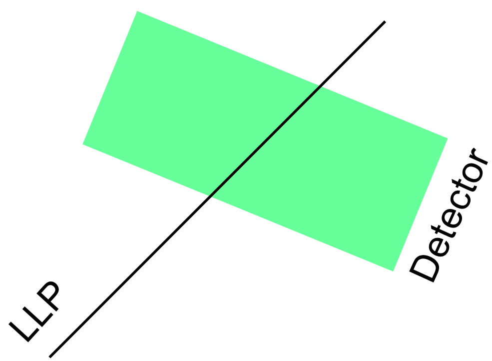
$$c\tau_{GMSB} \approx 0.1mm \left(\frac{m_{\tilde{q}}}{1000\ TeV}\right)^4 \left(\frac{1\ TeV}{m_{\tilde{g}}}\right)^5$$

Experimental strategy

- Best experimental strategy depends on the properties of the particle

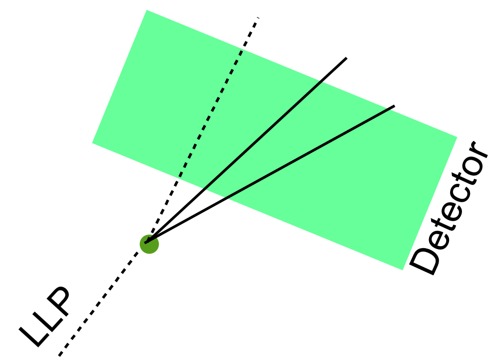


Direct detection



- Direct interaction with detector
- If LLP minimally interacting and escapes detector → $\not{E}_T$

Indirect detection



- SM or invisible decay products
- "Isolated" activity inconsistent with expected prompt or instrumental background

Current analyses

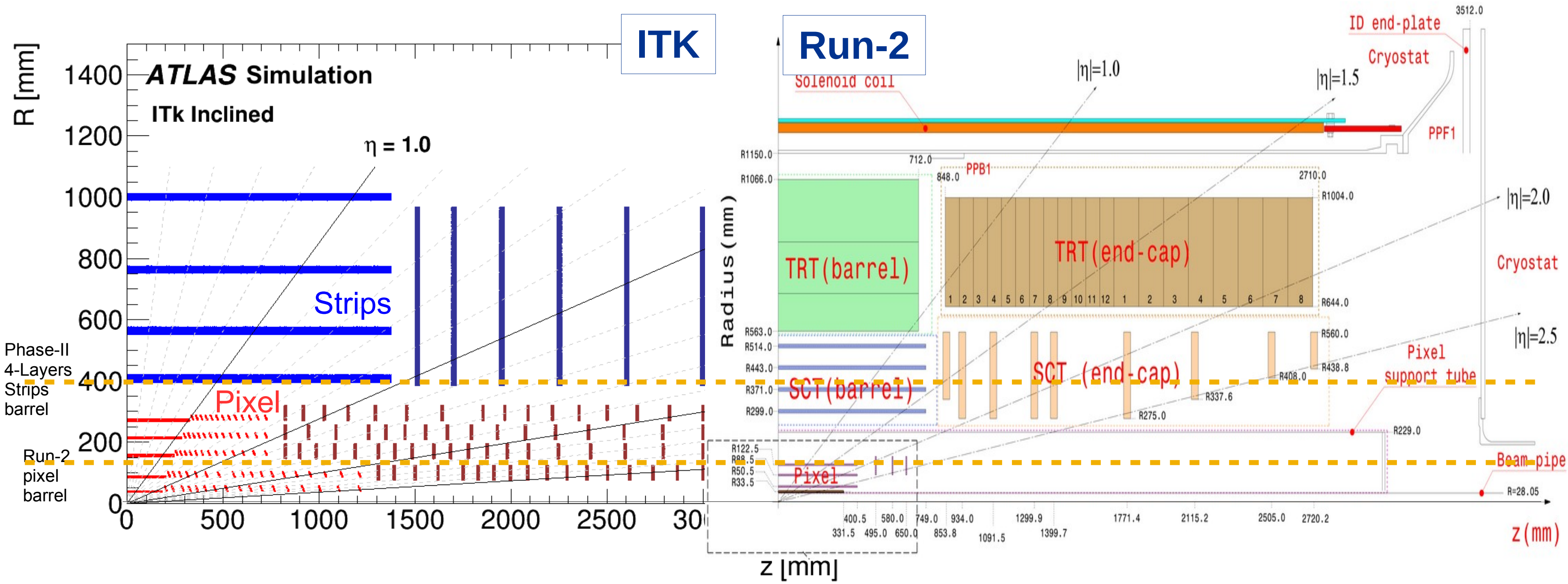
Primary measurement:

Analysis	ID	Calo	Muon	Detection
Prompt analysis (jets+$\not{E}_T$)		✓		Indirect detection
Displaced vertices	✓		✓	Indirect detection
"Isolated" jets		✓		Indirect detection
"Lepton"-jets		✓	✓	Indirect detection
Stopped gluinos		✓		Indirect detection
Delayed photons		✓		
Time-of-flight measurements		✓	✓	Direct detection
Disappearing track	✓			Direct detection
Large ionization deposits	✓			Direct detection

- Dedicated trigger strategies or "collateral" event features (e.g. MET, …)
- Dedicated reconstruction algorithms or calibrations
- Instrumental or "unusual" backgrounds (cosmics, hadronic interactions, …) require data-driven techniques
- Creative use of the ATLAS detector

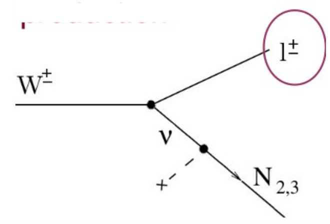
Phase-II ATLAS Inner Tracker

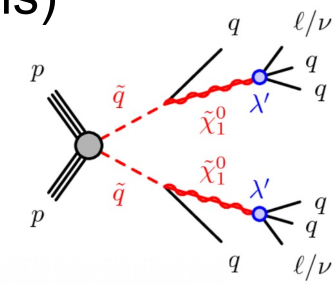
- New all-Silicon tracker (ITk): 5 pixel and 4 strip barrel layers
- ATLAS Phase-II inner tracker has non-trivial implications for LLPs:
  - "Expanded" (in radius) barrel layers
  - Extended coverage $|\eta| < 2.5 \rightarrow 4.0$
  - Reduced material budget
  - Coarser charge measurement in pixels

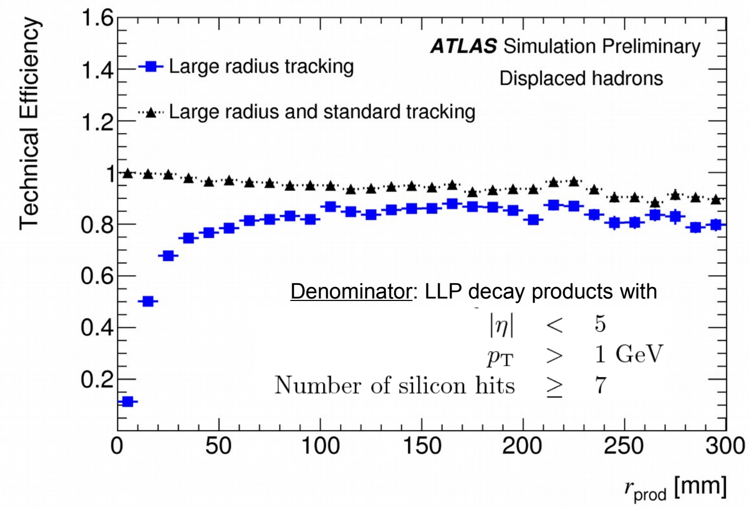


Displaced Vertices in the ID

- Explicit displaced vertex reconstruction (hadrons and/or leptons)
- Tiny background after selections from:
  - hadronic interactions – accidental crossing
- Dedicated tracking and vertexing setup
  - Tacking efficiency driven by geometric acceptance and interactions with material







Opportunities

- Layout design
  - Access to longer lifetime
  - Geometric coverage
- Lower material budget
- Better track parameter resolutions

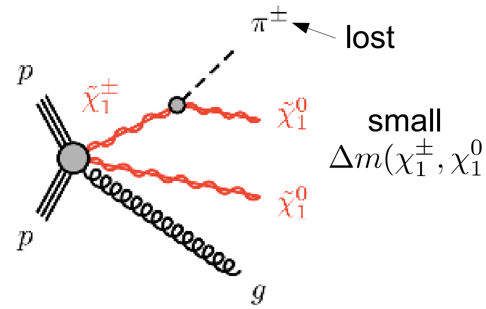
Challenges

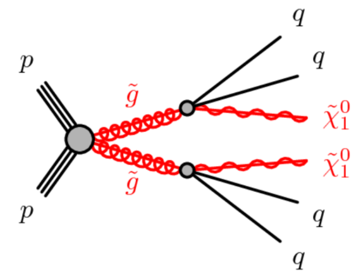
- Keep tracking and vertexing efficiency high with large combinatorics

arXiv:1710.04901, ATL-PHYS-PUB-2017-014

"Short" tracks

- Meta-stable charged LLPs with short lifetime
  - reconstructed as "short" (disappearing) tracks
  - main background from mis-measured and fake tracks
- Can also require large ionization loss if $\beta\gamma < 1$
  - measured using pixel detector



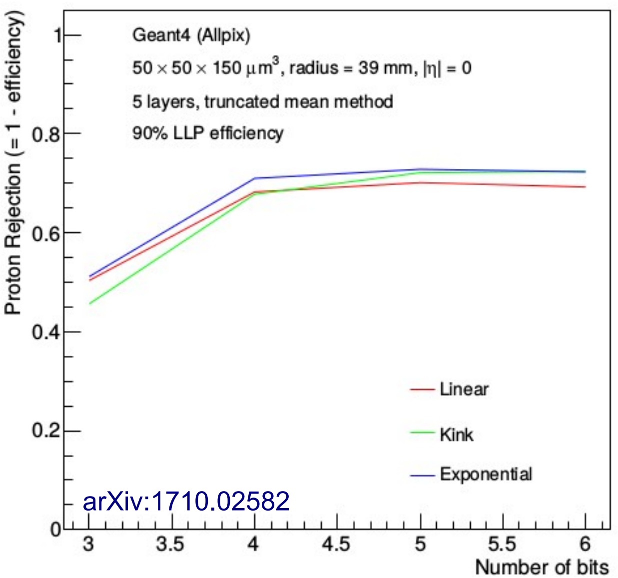


Opportunities

- Lower fake rate and better accuracy
- Low x-section → profit from large luminosity

Challenges

- Only 2-pixel layers in first 12 cm (Run-2: 4!)
  - will need aggressive R&D and creativity
- Impact of coarser pixel charge measurements can be minor



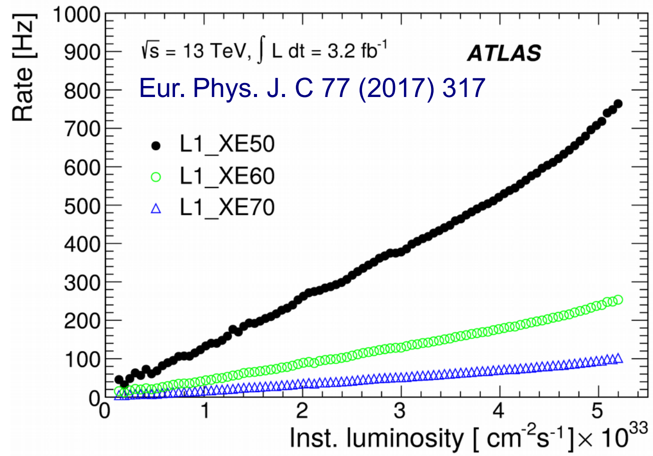
Triggering considerations

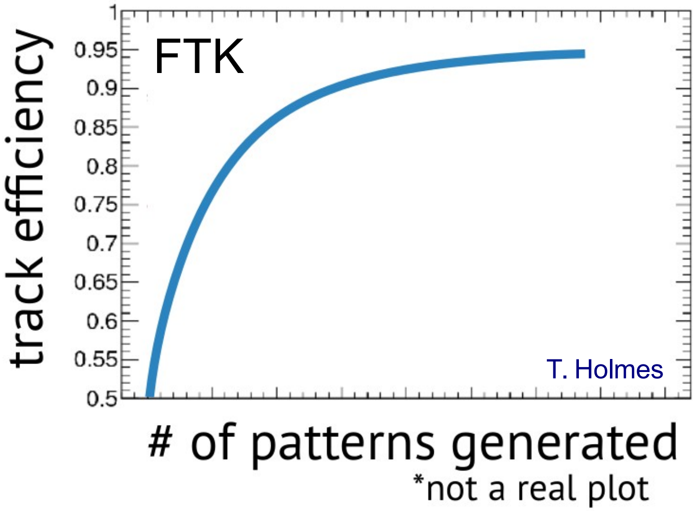
- Ensure we retain high efficiency for triggering non-prompt leptons
  - can easily loose efficiency when fighting against pile-up combinatorics

- MET is a critical trigger, but very sensitive to pile-up
  - need upgraded trigger setup to maintain similar thresholds as now

- Track-based triggers can potentially offer a huge boost in sensitivity
  - but need re-optimization and clever solutions for short / non-prompt tracks!

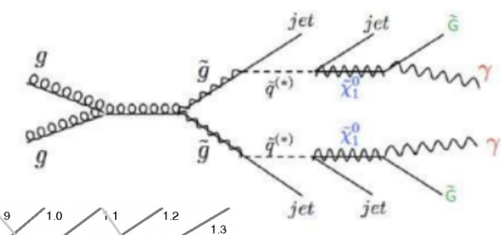
- Flexibility to implement custom triggers for dedicated signatures

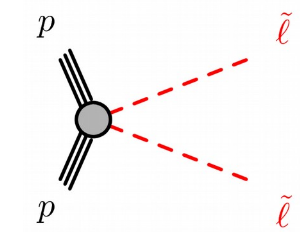




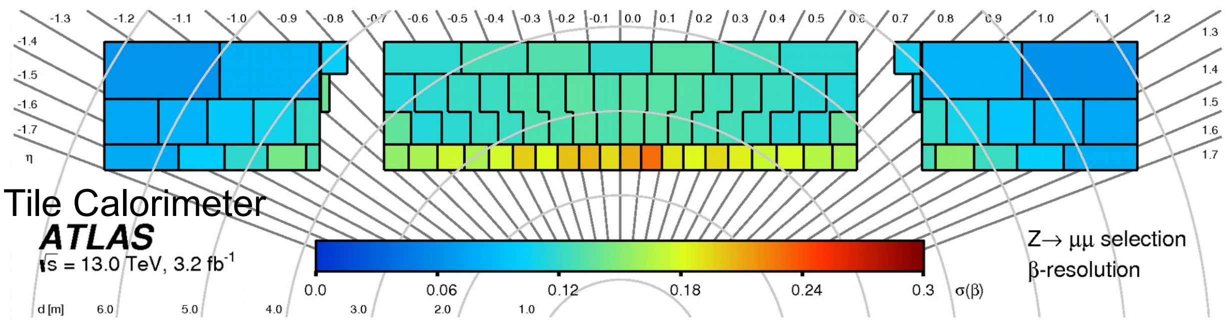
Time of flight measurements

- TOF measurements can reveal massive particles traveling with $\beta << 1$
  - resolution tails as main backgrounds
  - detailed calibration needed





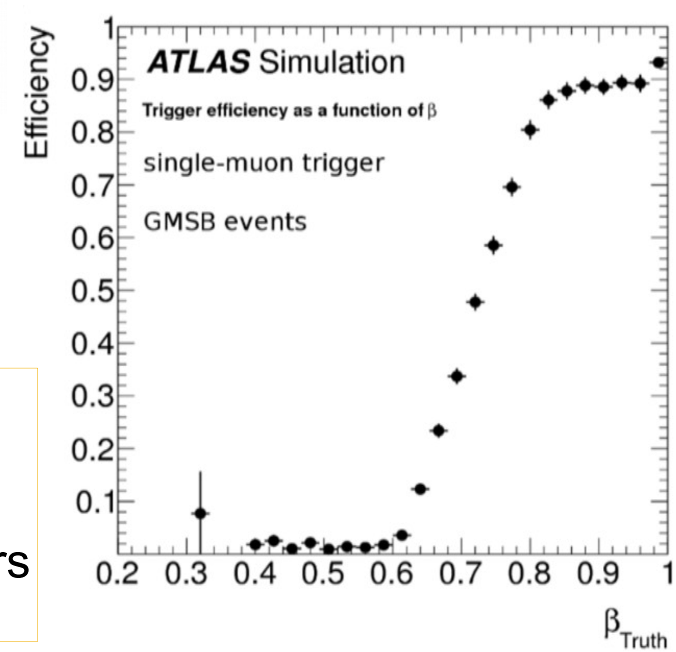
- Calorimeter timing resolution ~ ns



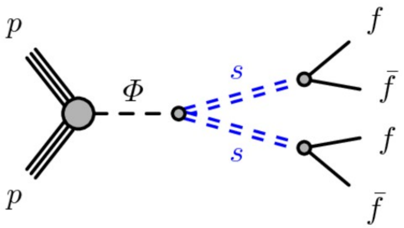
- Proposed High-Granularity Timing Detector ($2.4 < |\eta| < 4.2$) with ~30 ps resolution
  - only sensitive to moderately forward objects

- Trigger strategies that allow objects to be delayed by > 25 ns (1 bunch x-ing)
  - already implemented now w/ L1-Topological triggers using a late muon and MET or Jets

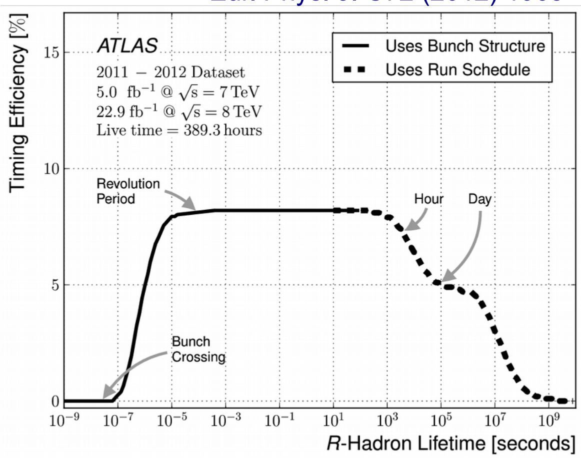
Physics Letters B (2016), pp. 647-665



- Neutral particles decaying in the ATLAS calorimeter



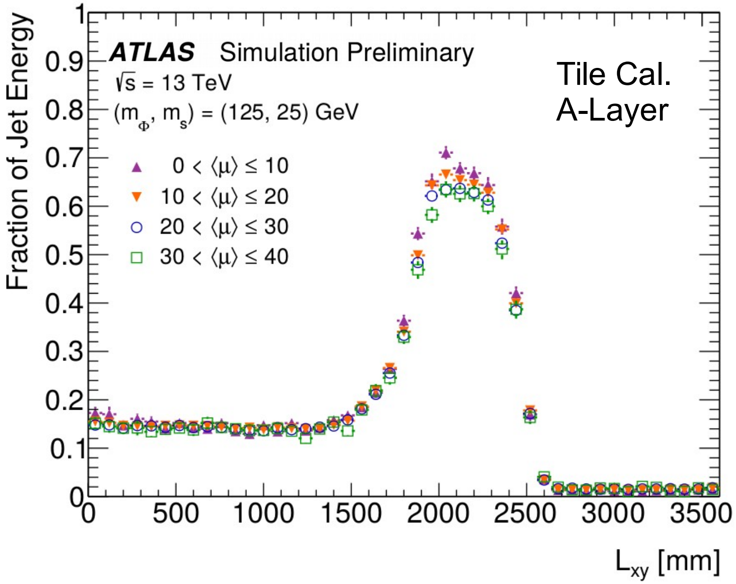
Eur. Phys. J. C72 (2012) 1965



- Dedicated trigger strategies
  - "isolated" and narrow energy deposits in Tile calorimeter vetoing other activity
  - very delayed signature on non-colliding bunch crossings and no-beam periods are sensitive to lifetimes up to ~years

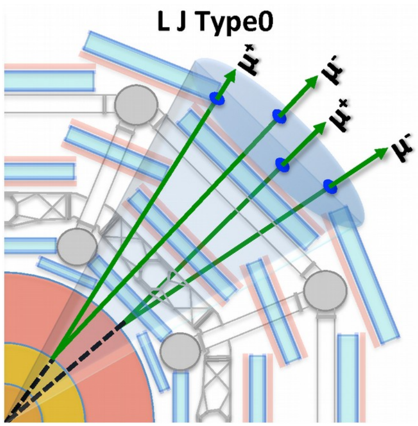
- Need to ensure pile-up robustness and high efficiency in rejecting non-collision backgrounds
  - take advantage of calorimeter segmentation

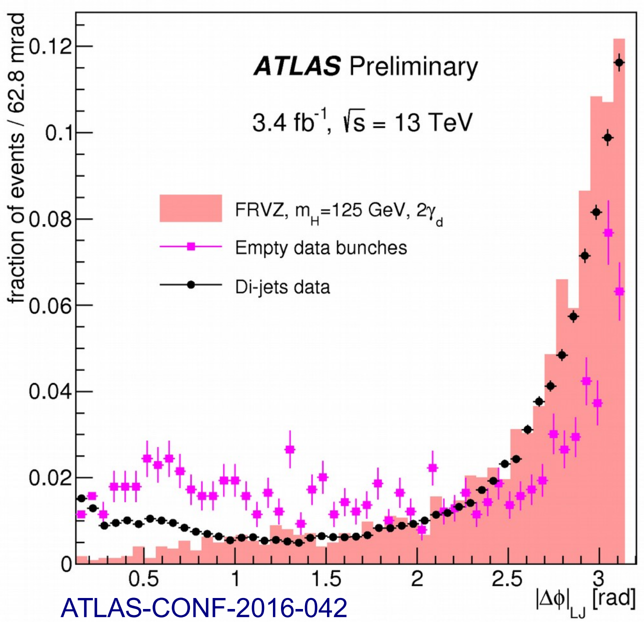
- Upgraded L1 Trigger L1 with increased granularity will help in background rejection



Decays in the Muon system

- Dedicated trigger to select decays of neutral particles in the MS
- Benefit from usage of high-resolution MDT measurement already at L0/L1 trigger
- Main backgrounds for multijets, cosmics and beam-induced backgrounds





ATLAS-CONF-2016-042

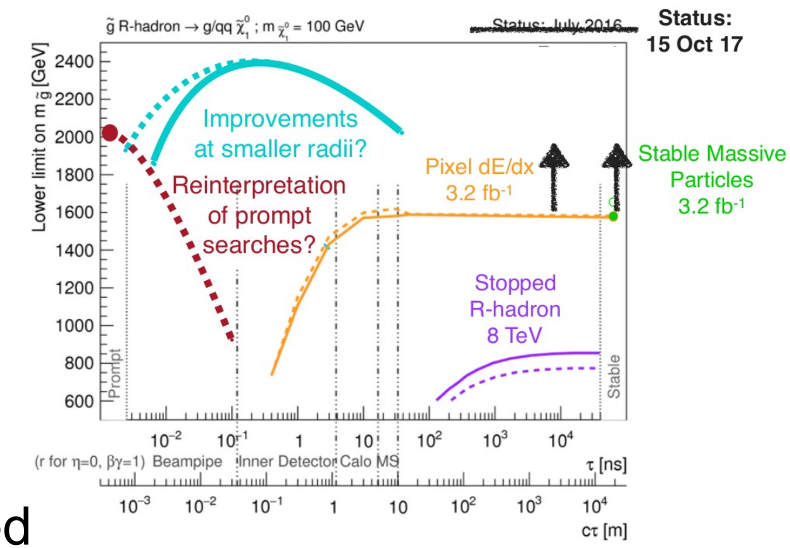
- Unpaired and empty bunches provide unique source for data-driven background estimate
- Dedicated reconstruction of displaced vertices in the Muon Spectrometer may suffer larger combinatorics

Theory benchmarks

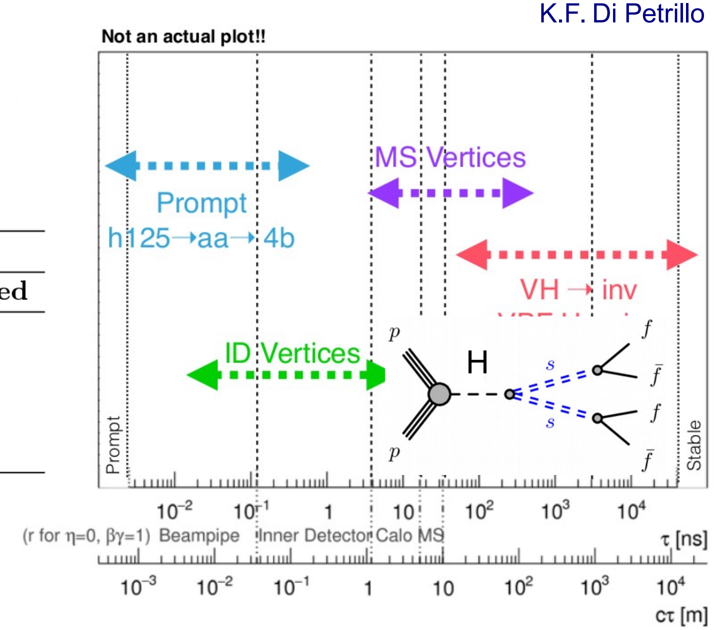
- Common simplified benchmarks
  - identify overlaps and gaps
  - show interplay of various techniques
- More common and comprehensive set of simplified models will help to better characterize our future reach
- Complete models scans including long-lived particles can direct our efforts and help summarizing the full potential of HL-LHC
  - e.g. pMSSM scan performed on 8 TeV results

Long-lived Particle	Bino LSP		Wino LSP		Higgsino LSP	
	Models	Excluded	Models	Excluded	Models	Excluded
$\tilde{g}$	899 (5.2%)	5.1%	58 (3.4%)	3.4%	9 (0.0%)	0.0%
$\tilde{b}_1$	1252 (99.6%)	76.4%	51 (100.0%)	78.4%	67 (100.0%)	80.6%
$\tilde{t}_1$	345 (56.8%)	36.5%	6 (100.0%)	66.7%	17 (82.4%)	47.1%
$\tilde{\tau}_1$	406 (100.0%)	37.4%	2 (100.0%)	0.0%	41 (100.0%)	14.6%

JHEP 10 (2015) 134



K.F. Di Petrillo



Conclusions and Prospects

- Current effort in the context of TDR preparations
  - address challenges posed by HL-LHC conditions
  - exploit the new opportunities of a large detector upgrade
- Not everything will be answered by the TDR, and physics ↔ detector interplay will be crucial in defining the best strategy in this process
- Not yet assessed the full physics potential of HL-LHC for LLP searches
  - common benchmarks and scans of more complete models can provide very useful insights and highlight the complementarity of various approaches
- Leveraging re-interpretation efforts of current analyses, together with dedicated full-simulation studies, can be a key to effectively maximize the output of HL and HE-LHC for long-lived particle searches

BACKUP