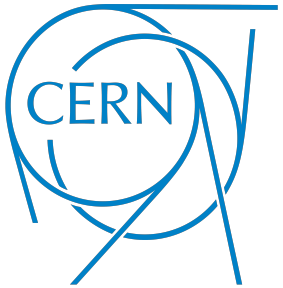


A search for the decays of stopped long-lived particles with the ATLAS detector

E. Cherepanova[1]

[1]JINR

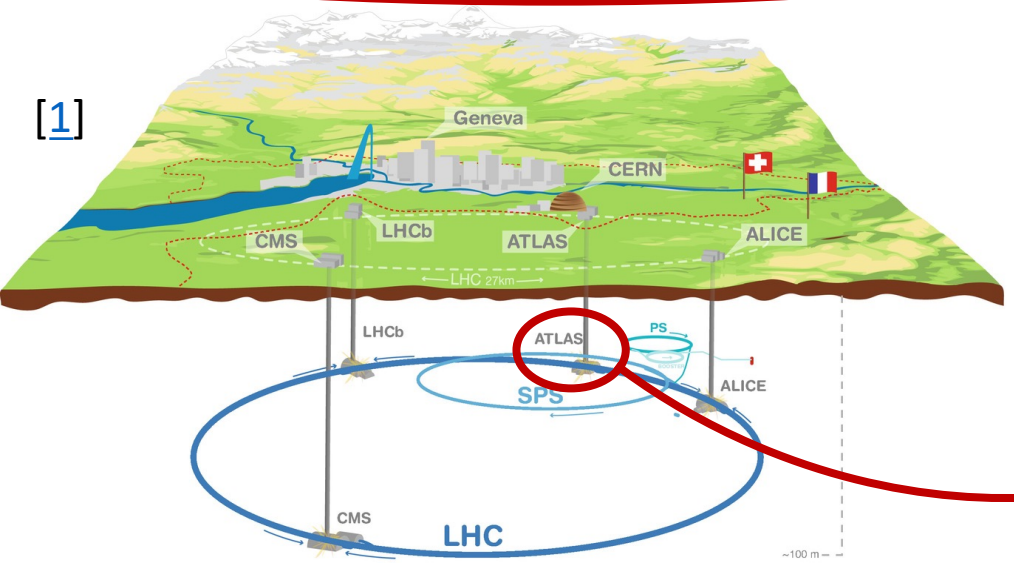
The XXV International Scientific Conference of Young Scientists and Specialists (AYSS-2021)
11-15 October 2021, Almaty

Looking for BSM physics with the ATLAS detector

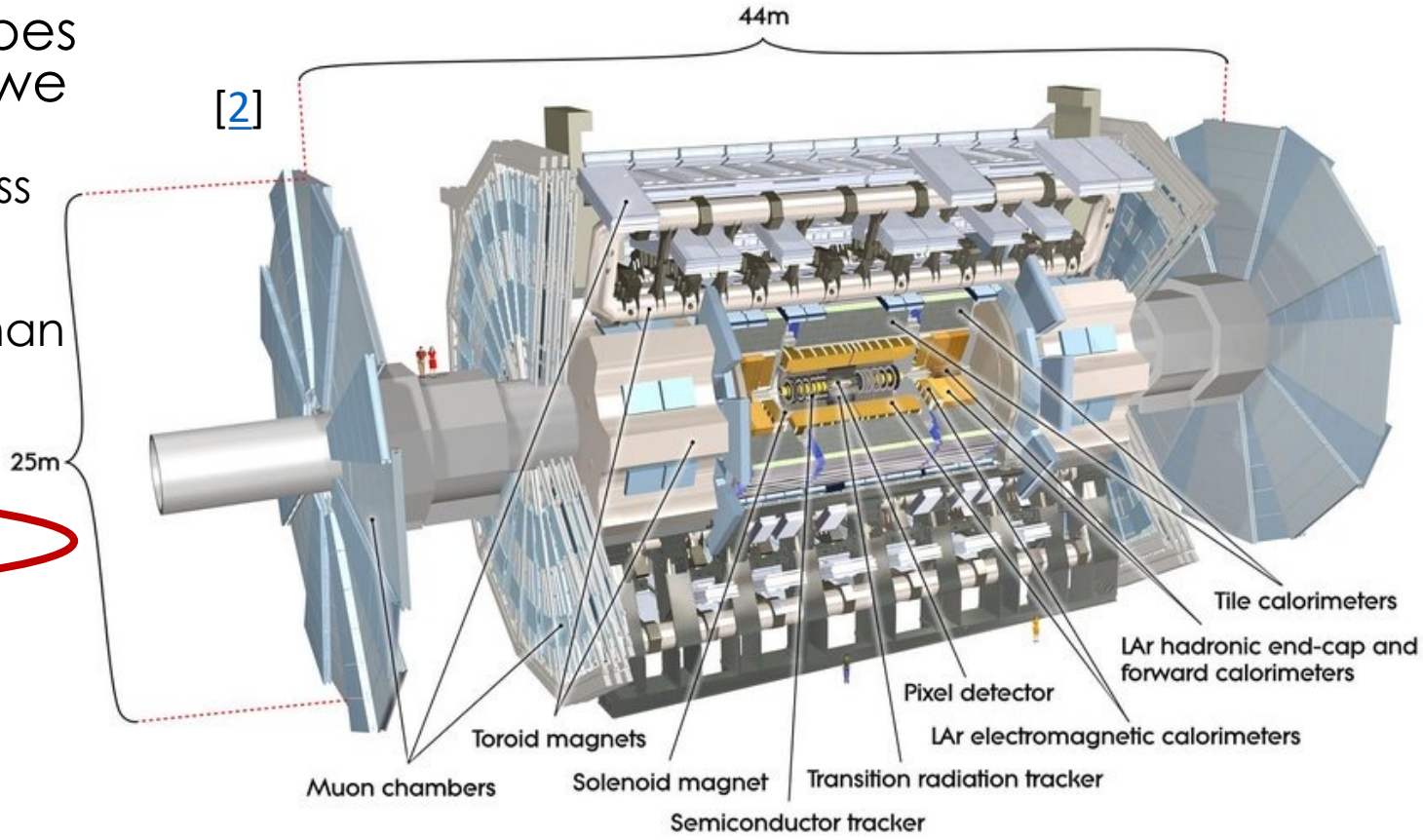
- The Standard Model (SM) describes the most fundamental particles we know and their interactions, but:
  - Why do particles have such a mass hierarchy?
  - What is the dark matter?
  - Why there is much more matter than antimatter?
  - …

Need to go beyond the SM

[1]



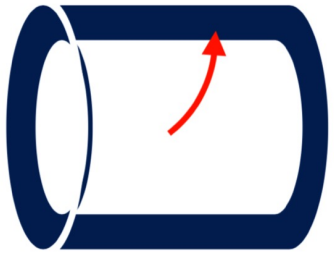
[2]



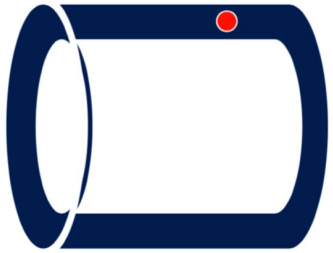
- Mutli-purpose detector at Large Hadron Collider (LHC):
- record the trajectory, momentum, and energy of particles → allows measurement and identification of a single particle

Long-lived stopped particles

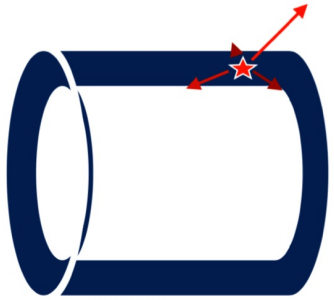
Searching for BSM long-lived particles (LLP) that carry SM charge



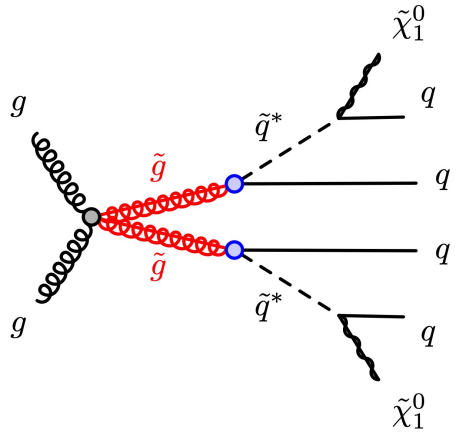
- LLP produced near threshold in *pp* collision, loses energy interacting with the detector material



- if LLP long-lived enough, some will stop inside the detector before decaying



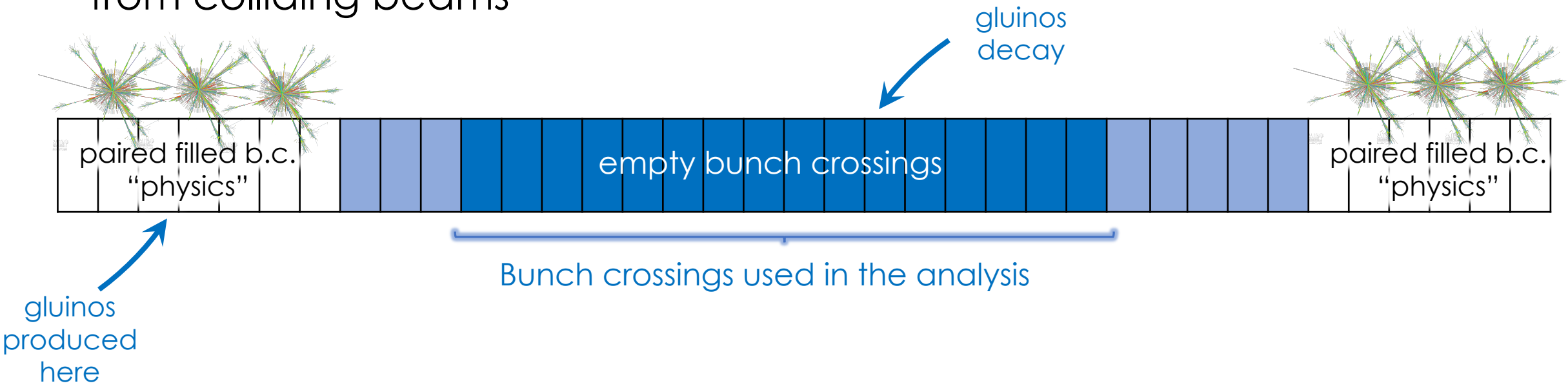
- looking for late decays to hadronic jets → targeting lifetimes from μs to years



Signal model

Search strategy and triggers

- Search strategy:
  - look for late decays to energetic hadronic jets
  - use data in empty bunch crossings (b.c.) → reduce background from colliding beams

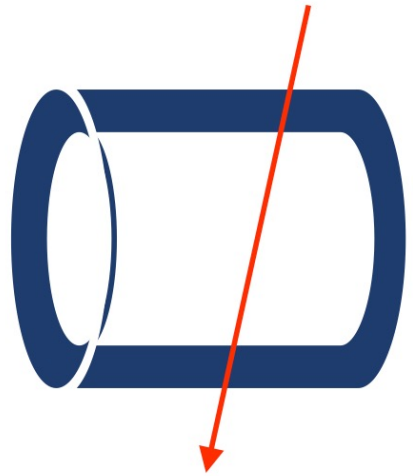


→ Required dedicated reprocessing and non-standard reconstruction

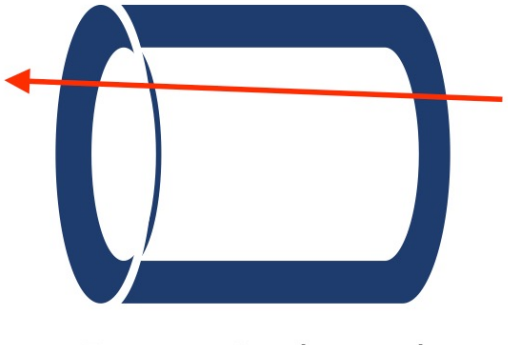
Backgrounds

Anything that can produce an energetic jet in out-of-time b.c.

- **Cosmic rays**
  -dedicated veto + special reconstruction
- **Beam-induced background**
  - dedicated veto
- Calorimeter noise
  - custom jet cleaning
- Cavern background
  - overlay of randomly collected data events

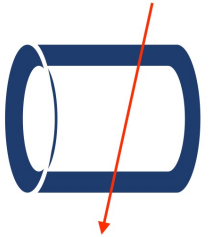


Cosmic rays



Beam-induced background

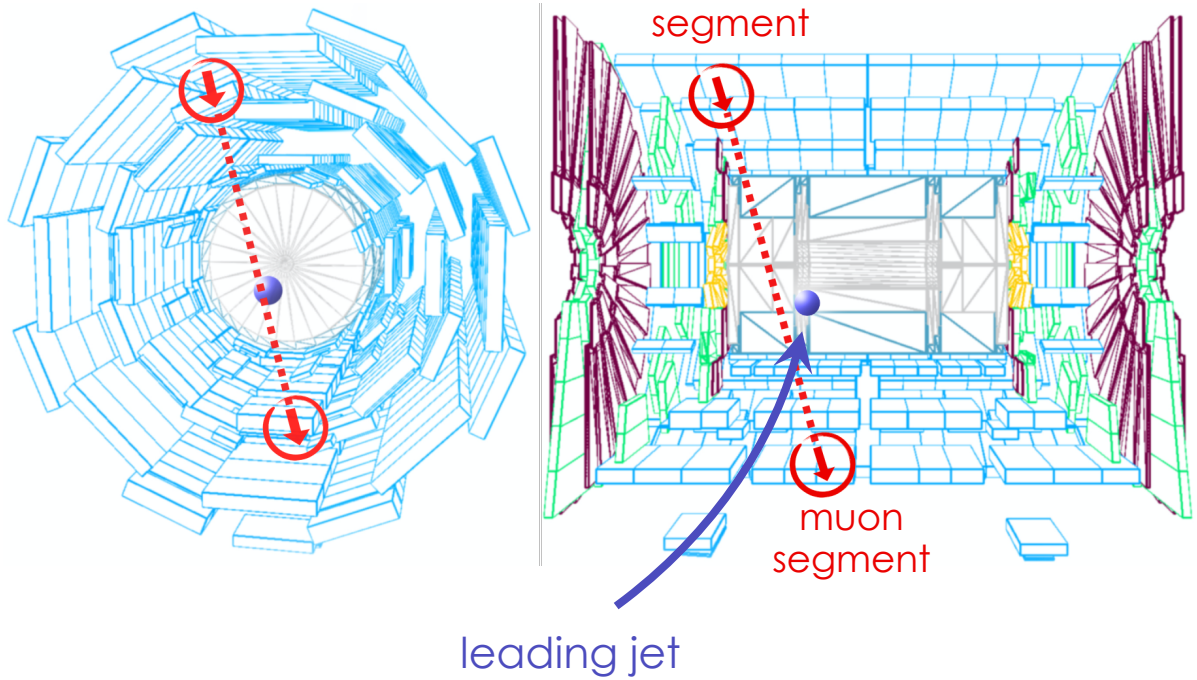
Cosmic-induced background



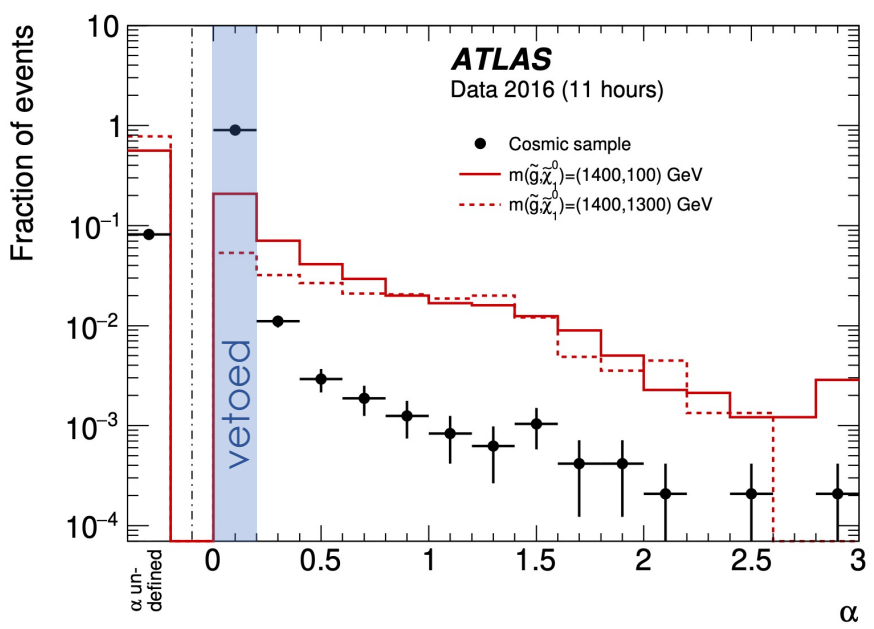
- Only interested in cosmics if they induce an energetic jet
- Construct cosmic veto by exploiting the geometrical relation between the leading jet and muon segments in a cosmic (muon) event:

  1) find top-bottom muon segment pairs
  2) measure distance between jet and curve representing the connection between the segments in a pair
  3) calculate minimum of these spatial distances → **α**

[3]



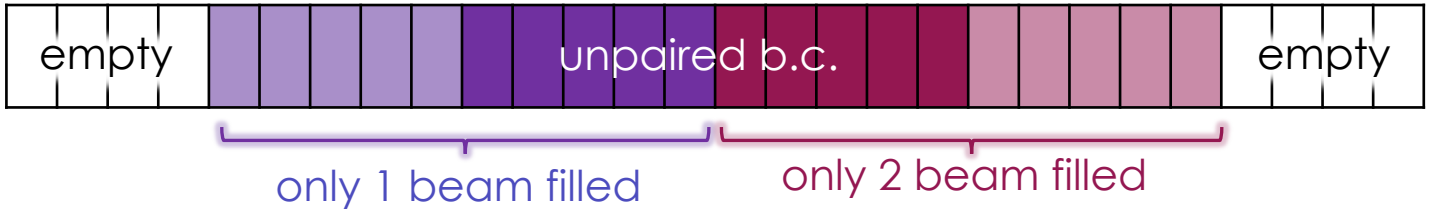
[3]



Veto all events with $|\alpha| < 0.2$

Beam-induced background

- Beam protons interacting with residual beam gas, upstream collimators, or beam pipe resulting in energetic muons traversing the detector parallel to the beam pipe
- Studied in data collected in **unpaired** bunch crossings

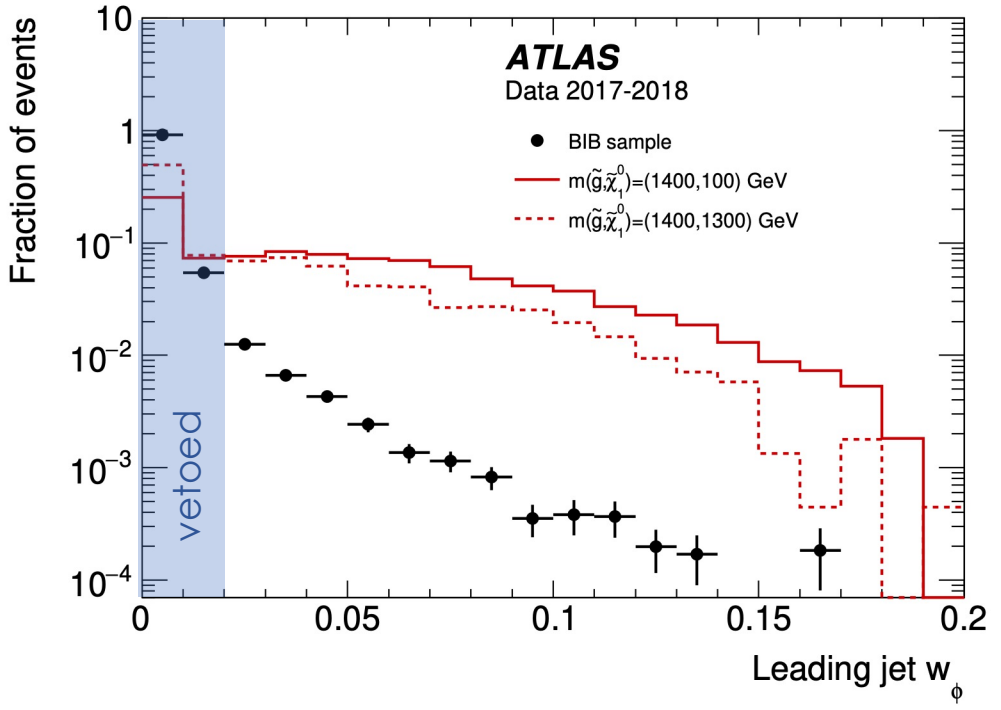


- BIB jets appears mostly in horizontal plane and tend to be narrow in ϕ

$$w_\phi = \frac{\sum_i p_T(i) \cdot |\Delta\phi(\text{jet}, i)|}{\sum_i p_T(i)}$$

Veto all events with w_ϕ <0.02

[3]



Signal regions

- Define Signal Regions binned in leading jet pT

Selection:

- Standard event cleaning
- Strict noise burst cleaning
- Extensive customised jet cleaning
- Collision vertex veto
- BIB veto
- Cosmic veto (additional muon veto)

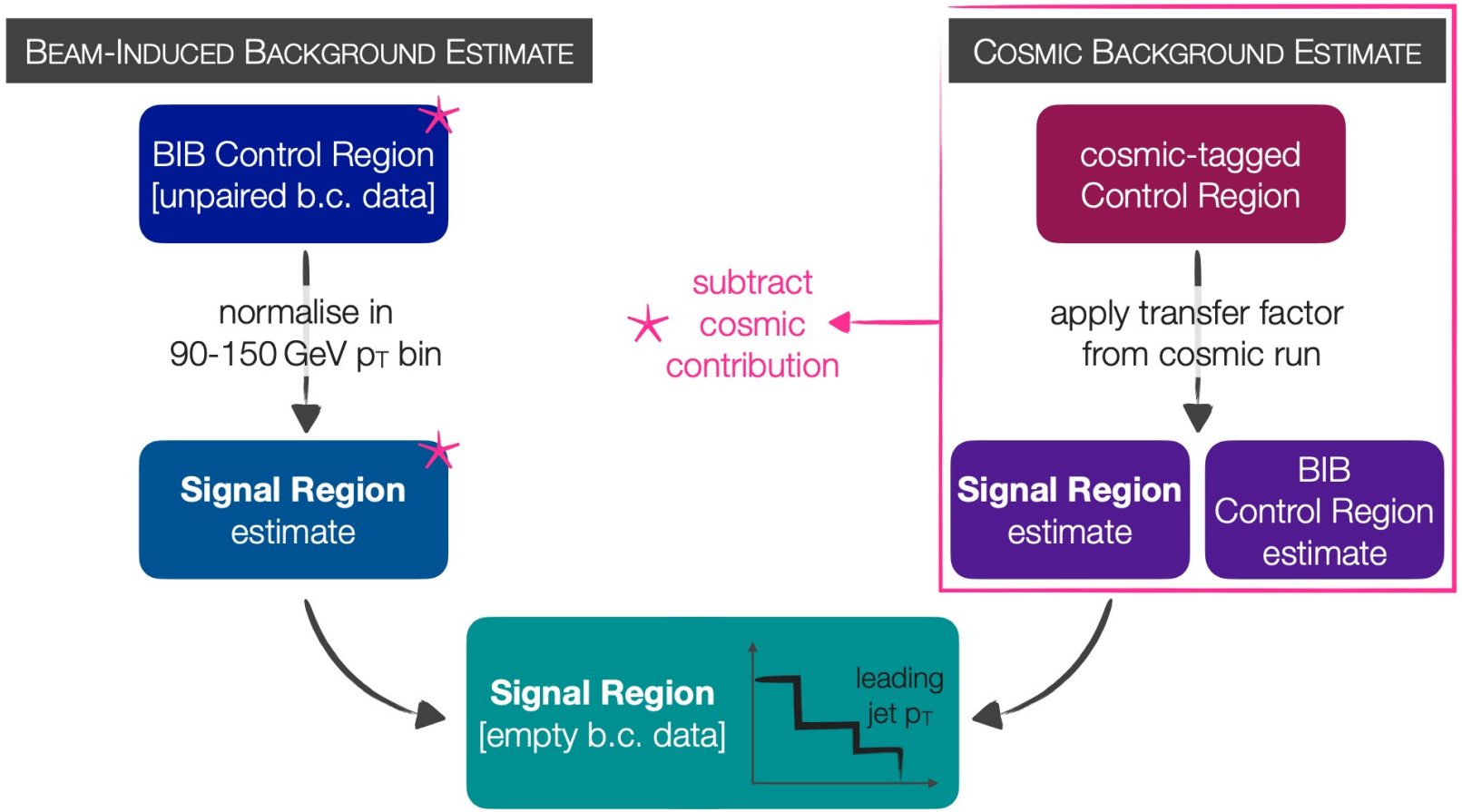
Region	Data sample	Number of muons	Leading jet p_T [GeV]	α	Leading jet w_ϕ	Leading jet $\lvert\eta\rvert$
Central signal region						
SRC	Search sample	0	150–300 300–500 > 500	> 0.2	> 0.02	< 0.8
Inclusive signal region						
SRIncl	Search sample	0	150–300 300–500 > 500	> 0.2	> 0.02	< 2.4

best sensitivity for heavy gluino production

extended coverage for other models

Background Estimate

- Fully data-driven background estimate using leading jet p_T templates
- Validated in dedicated cosmics and BIB enhanced regions



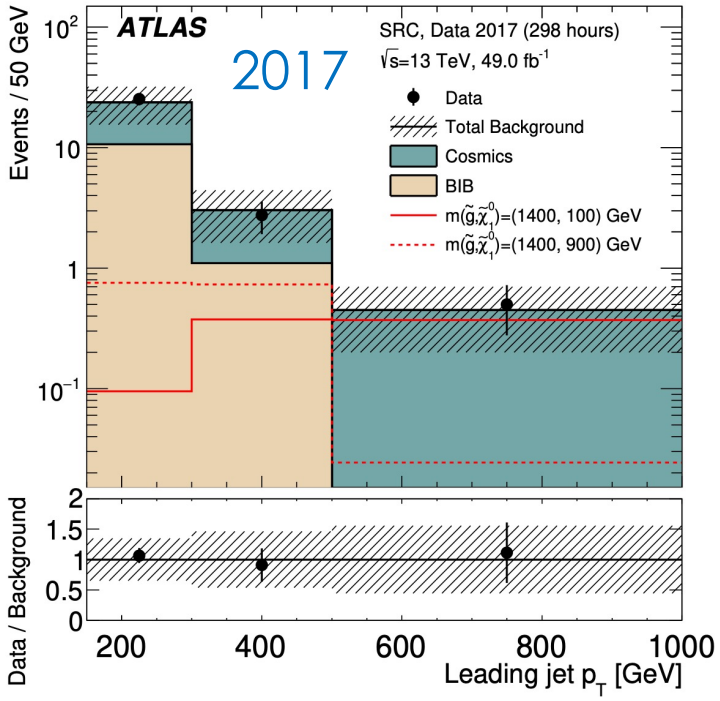
Signal Region results ($|\eta| < 0.8$)

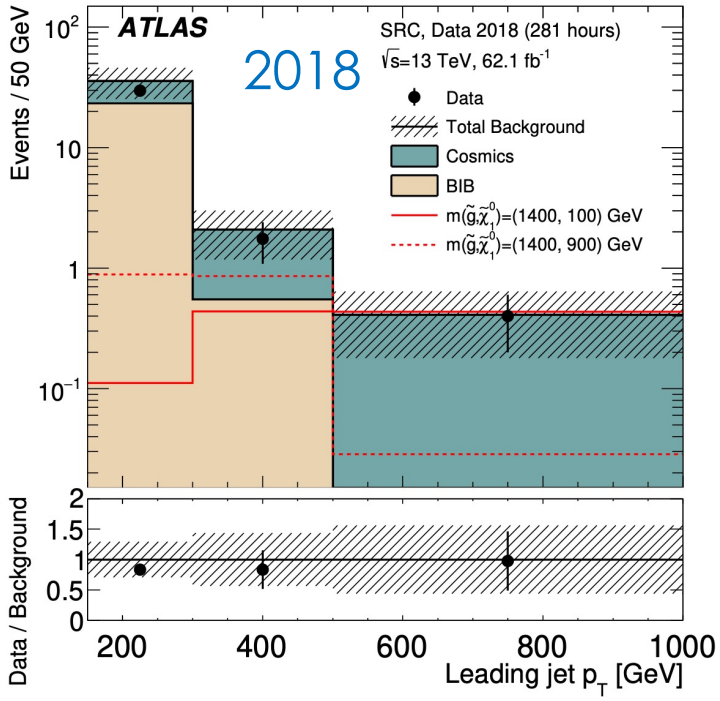
Central signal regions	SRC (2017 data)	SRC (2018 data)
Observed events	92	100
Total expected background events	88 ± 28	119 ± 32
Beam-induced background events	37 ± 23	72 ± 29
Cosmic-ray-induced background events	51 ± 21	47 ± 19

Similar results for the inclusive Signal Regions

- BIB normalized separately in 2017 and 2018
- Cosmic-induced background dominant in highest pT bin
- Data consistent with the background expectation in all bins

[3]





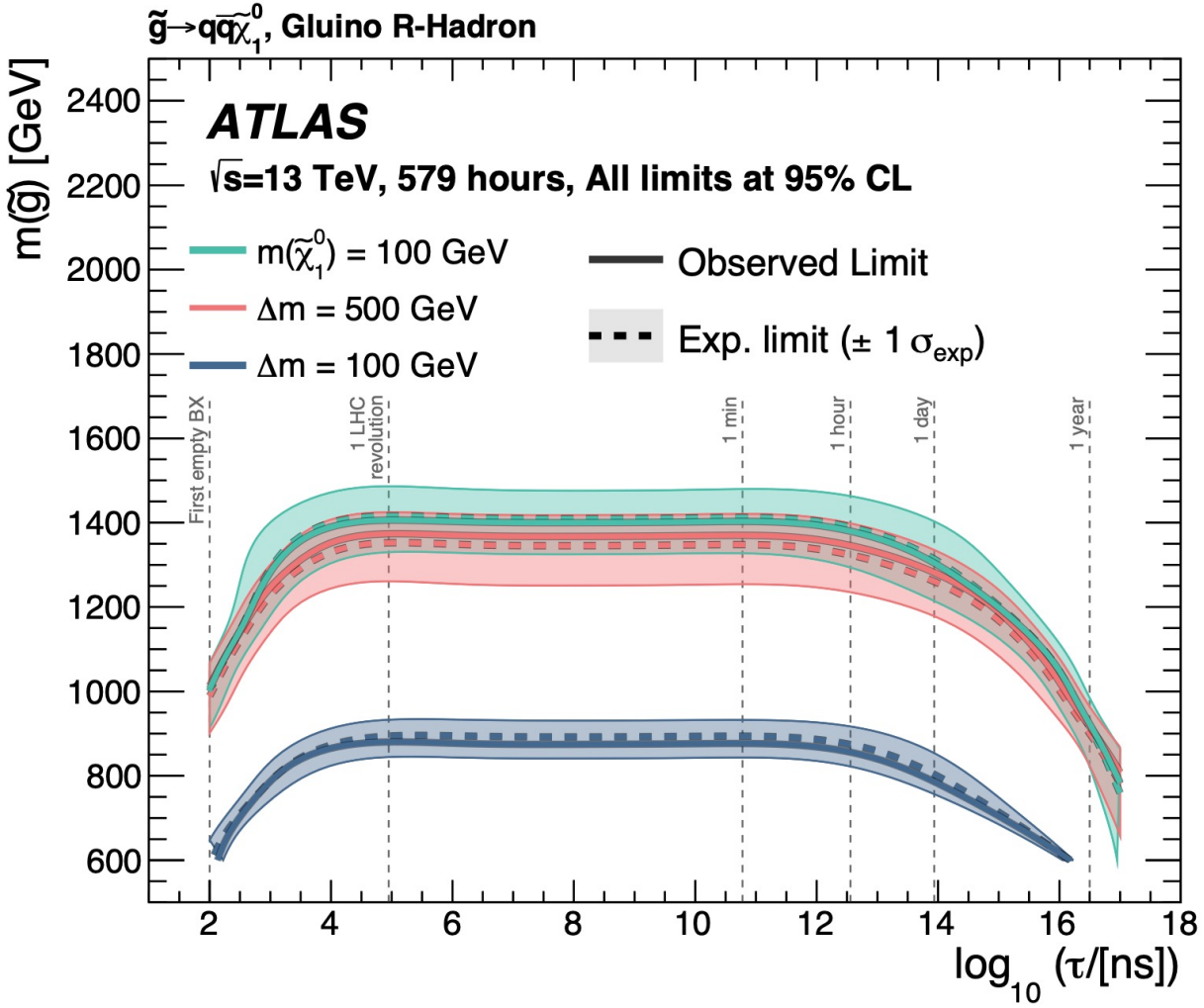
Exclusion Limits

Central ($|\eta| < 0.8$)

- Perform a multi-bin fit to extract limit and fold in live fraction vs lifetime
- With **no significant deviation** from the estimated background yields in the SRs, exclusion limits are set at 95% CL

- Gluinos with a lifetime of 100 ns are excluded up to a mass of 1.0 TeV for a neutralino mass of 100 GeV
- Gluino with masses of up to 1.4 TeV are excluded for lifetimes up to a few hours (10^{-5} – 10^{3} s)
- Gluino masses of 1.0 TeV are excluded for lifetimes of up to 10^{7} s

[3]

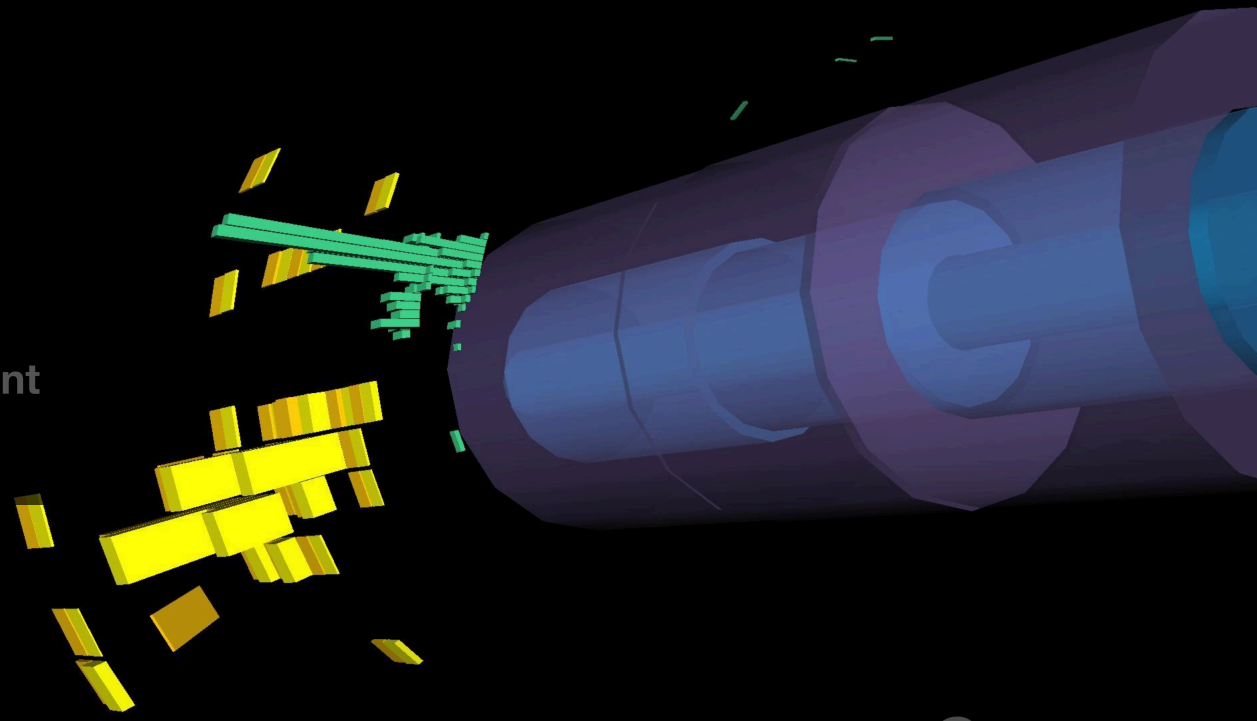


$* \ \Delta m = m(\tilde{g}) - m(\tilde{\chi}_1^0)$

Summary

[3]

- Searching for long-lived stopped particles is performed
- Almost all backgrounds are non-collision in nature → require very special techniques
- Signal Region observations consistent with background expectation
- Exclusion limit on gluino mass vs lifetime → gluino masses up to 1.4 TeV (for lifetimes of ~10^{-5} to 10^{3} s)
- Comprehensive reinterpretation material made available



[Link to the paper]

[Link to the physics briefing]

Thank you for your attention!

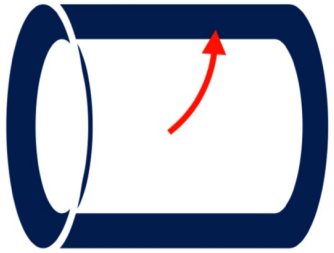
Back up

Signal modelling

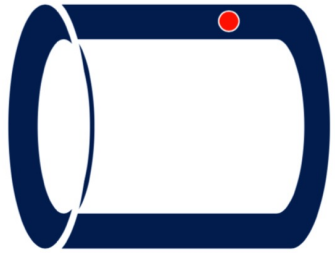
- Gluino R-hadrons serve as benchmark with mini-split SUSY-inspired decays - very high mass squarks induce a large gluino lifetime
  - new setup for signal modelling in Run-2 [ATL-PHYS-PUB-2019-019]*

Three sets of signals:
1) $m(\tilde{\chi}_1^0) = 100\ GeV$
2) $m(\tilde{g}) - m(\tilde{\chi}_1^0) = 100\ GeV$
3) $m(\tilde{g}) - m(\tilde{\chi}_1^0) = 500\ GeV$

Different $\tilde{g}$ masses: 400, 600, 800, 1000, 1200, 1400, 1600, 1800 GeV

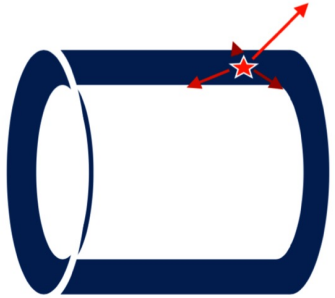


- R-hadronization:
  Custom PYTHIA6 → Official PYTHIA8
  R-hadron spectrum treatment overhaul



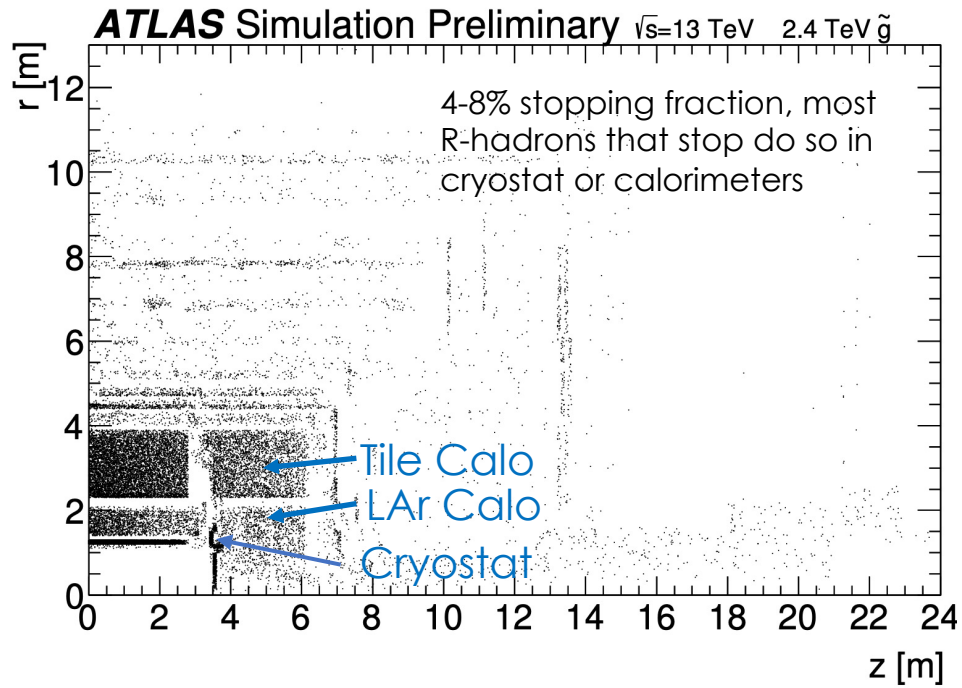
- Interaction model and stopping condition in GEANT simulation

$$v \leq v_{stop} = \frac{v_F}{A^{2/3}}$$



- Decays in separate setup:
  decays placed in sensitive trigger window +offset of propagation time from interaction point (IP)to decay position

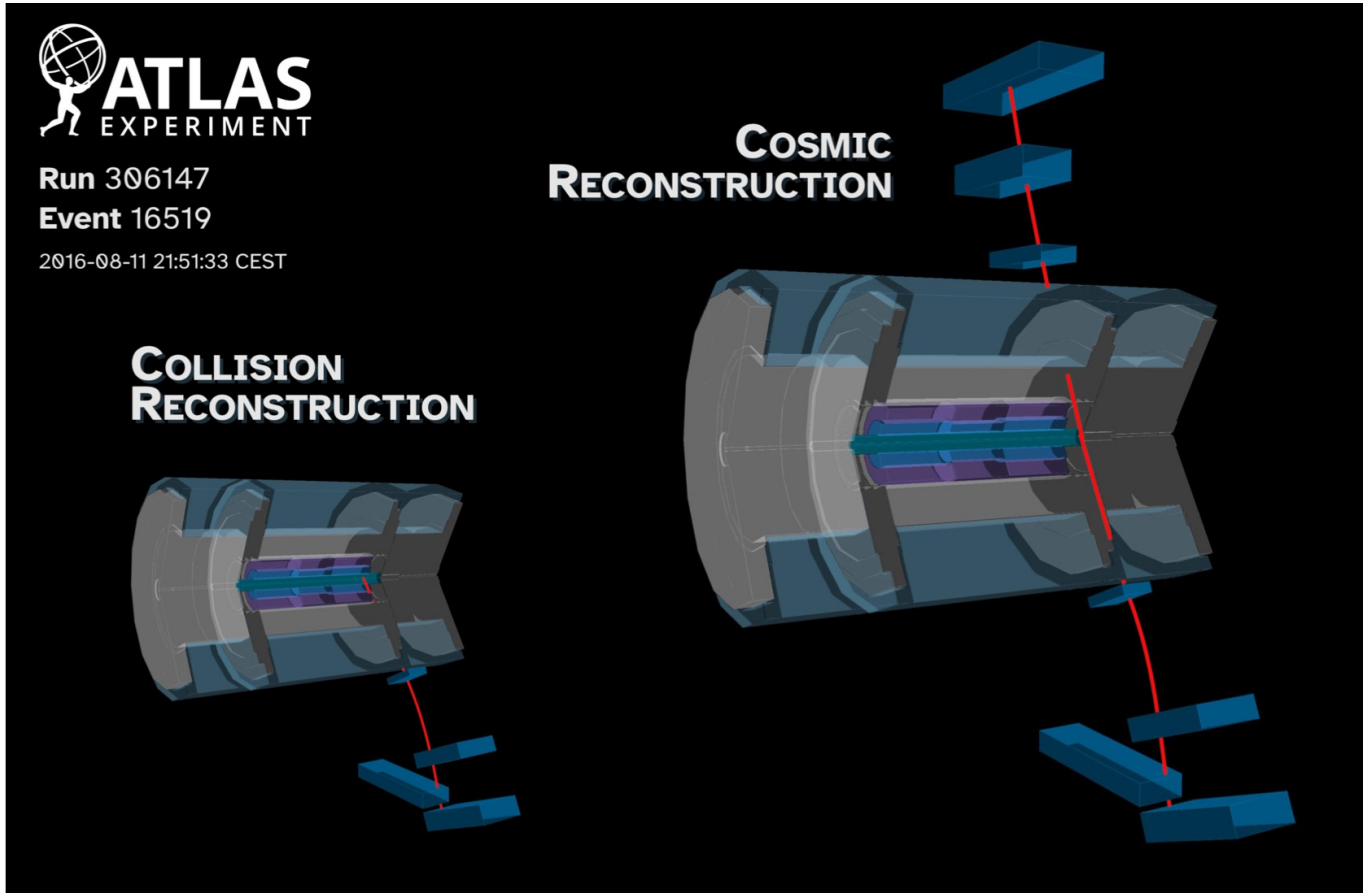
[*]



Reconstruction

- Timing requirements in the muon system reduce efficiency to reconstruct muon system segments from cosmics
- Use cosmic reconstruction settings to increase efficiency of cosmic vetoes
  - no pointing and IP requirement, looser restrictions on hit order and muon segment fits
- Use collisions reconstruction settings only to veto events with reconstructed PVs in empty bunch crossings

[3]

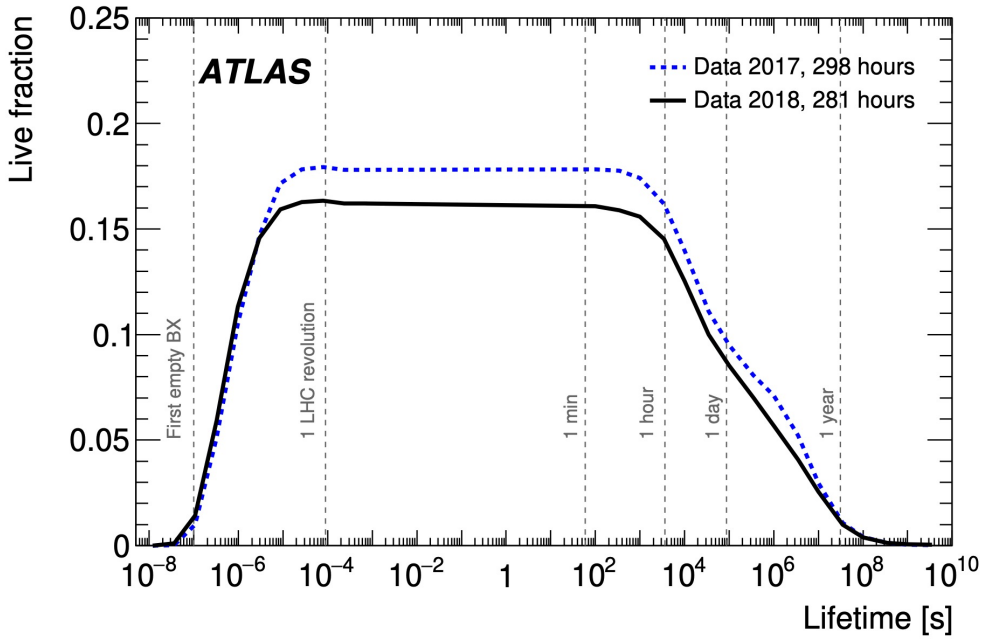


Sensitivity projections [3]

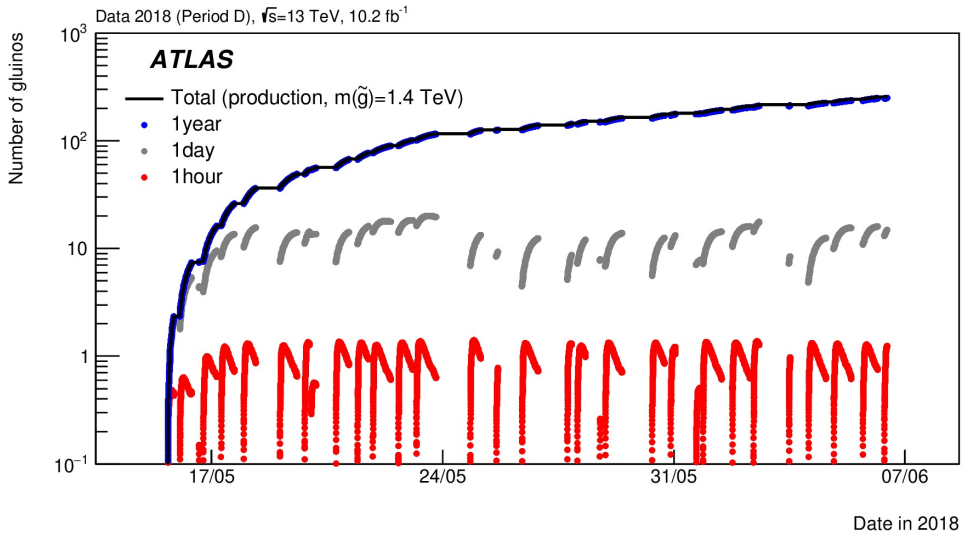
$$N_{\text{events}}^{\text{SR}} = L^{\text{int}} \times \sigma_{\tilde{g}\tilde{g}} \times 2 \times \epsilon^{\text{SR}} \times f_{\text{stopping}} \times (\text{live fraction})$$

L^{int} – integrated Luminocity delivered
$\sigma_{\tilde{g}\tilde{g}}$ – gluino pair-production cross-section
ϵ^{SR} – signal selection efficiency
$f_{stopping}$ – stopping fraction of R-hadrons

- Efficiency from MC samples + random event overlay
- Stopping fraction from GEANT modelling
- Live fraction calculated from:
  - bunch structure for short lifetimes (<1s)
  - run structure for long lifetimes

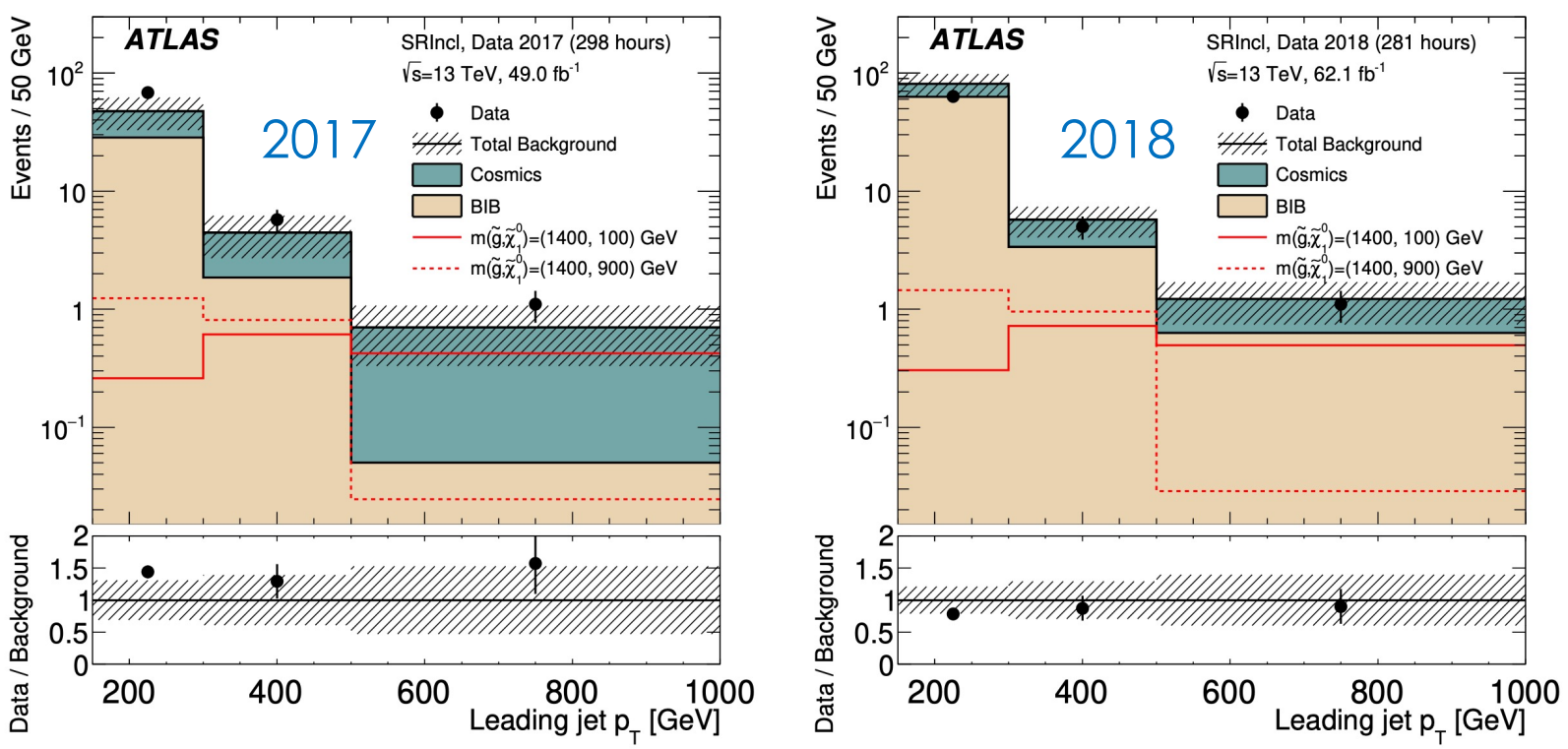


Live fraction for empty b.c. data as a function of particle mean proper lifetime for data collected during 2017 and 2018 [3]



Number of produced gluinos (that are yet to decay) at any given time, taking into account luminosity and bunch configuration information from between May and June 2018 [3]

Inclusive Region results ($|\eta| < 2.4$)

Inclusive signal regions	SRIncl (2017 data)	SRIncl (2018 data)
Observed events	239	221
Total expected background events	167 ± 48	208 ± 50
Beam-induced background events	93 ± 42	139 ± 45
Cosmic-ray-induced background events	74 ± 30	69 ± 28

[3]