



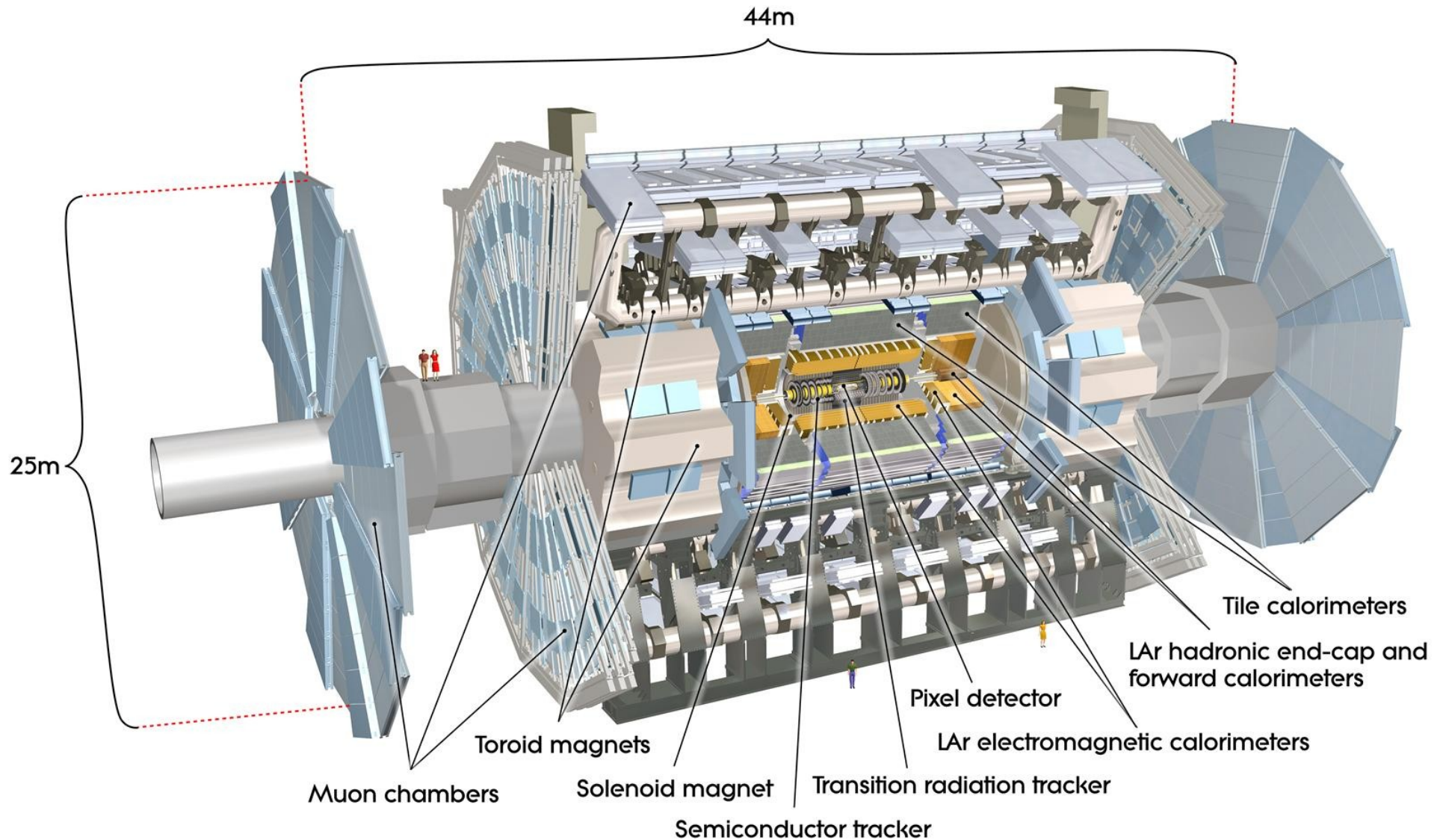
Search for supersymmetry with displaced dileptons at the ATLAS experiment

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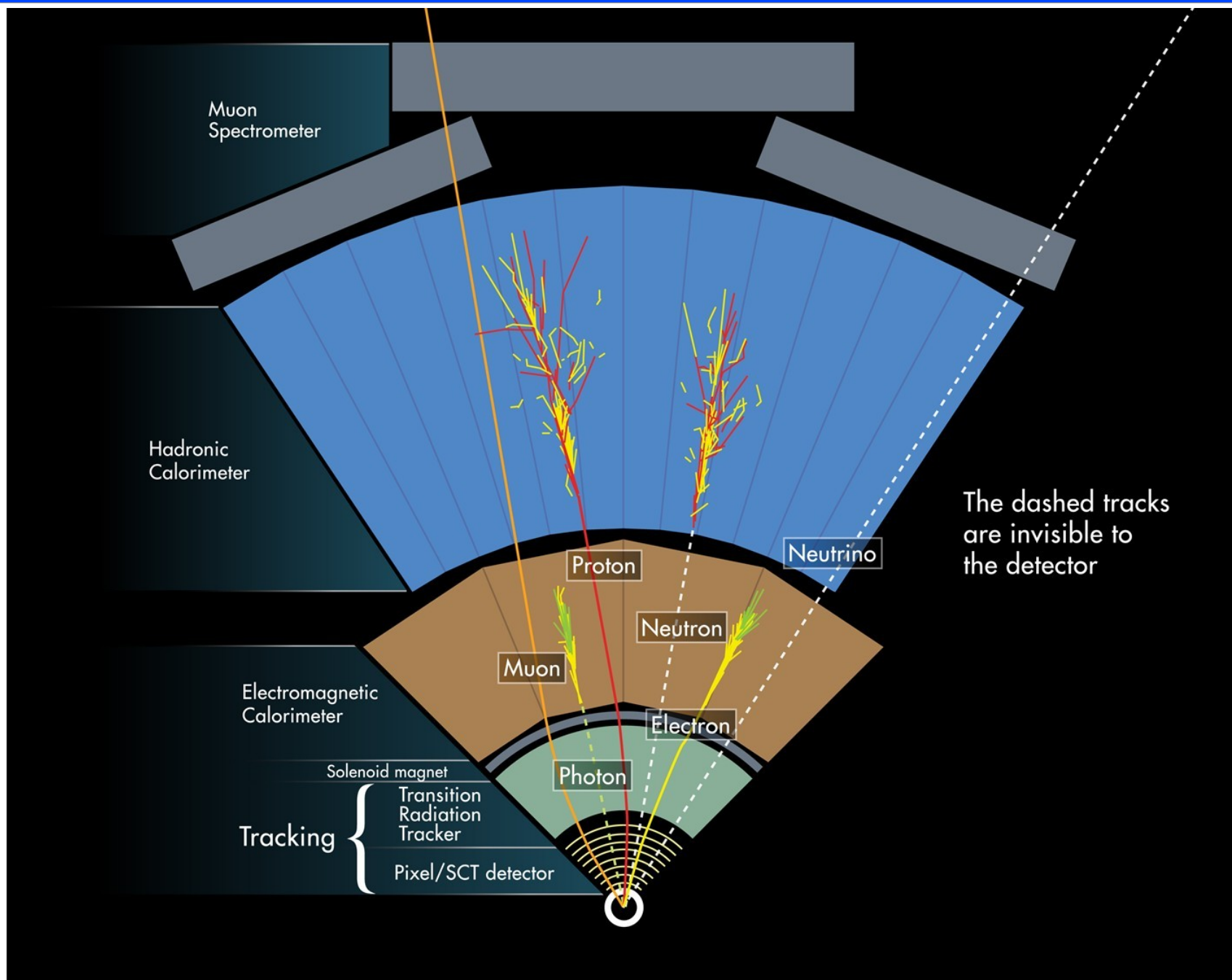


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(Werner-Heisenberg-Institut)

ATLAS Detector



Particle Identification and Reconstruction



Supersymmetry (SUSY)

- Symmetry between fermions and bosons
- Every Standard Model (SM) particle gets superpartner
- Spin differs by $\frac{1}{2}$
- Minimal supersymmetric Standard Model (MSSM):

Quarks	Gauge Bosons	Higgs Bosons
u c t	γ	h^0
d s b	Z^0	H^0
Leptons	W^\pm	H^\pm
e^\pm μ^\pm τ^\pm	g	A^0
ν_e ν_μ ν_τ		

Gauginos	Squarks
$\tilde{\chi}_1^0$ $\tilde{\chi}_1^\pm$	\tilde{u} \tilde{c} \tilde{t}
$\tilde{\chi}_2^0$ $\tilde{\chi}_2^\pm$	\tilde{d} \tilde{s} \tilde{b}
$\tilde{\chi}_3^0$	Sleptons
$\tilde{\chi}_4^0$ \tilde{g}	\tilde{e}^\pm $\tilde{\mu}^\pm$ $\tilde{\tau}^\pm$
	$\tilde{\nu}_e$ $\tilde{\nu}_\mu$ $\tilde{\nu}_\tau$

R-Parity Violation

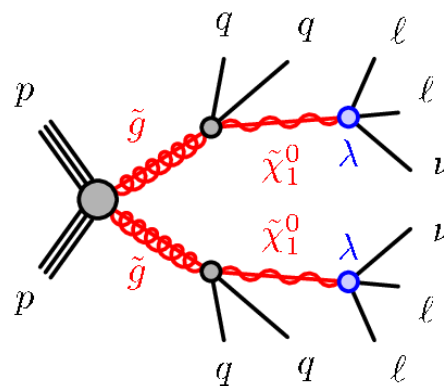
- R-parity: +1 (SM) and -1 (SUSY)
- Conserved in the MSSM to avoid fast proton decay
- R-Parity violated:
 - Lightest supersymmetric particle (LSP) unstable
 - LSP decay described by the following superpotential terms:

$$W_{RPV} = \frac{1}{2} \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \frac{1}{2} \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k + u_i H_u L_i$$

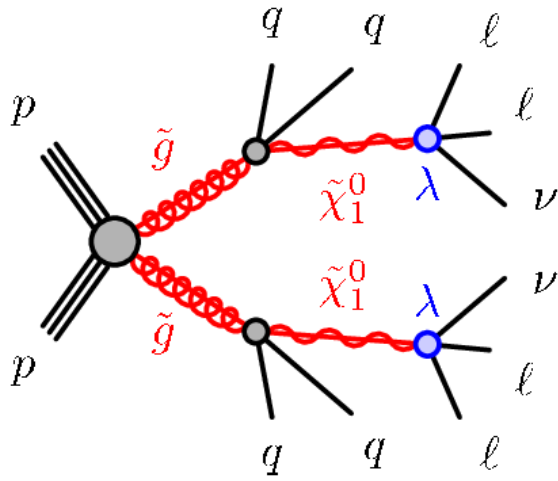
L, E: (s)leptons
 Q, U, D: (s)quarks
 H: Higgs(ino)

- Lepton and baryon number violation
- Avoid proton decay: Allow only one violation
- This presentation: $\lambda_{ijk} \neq 0$

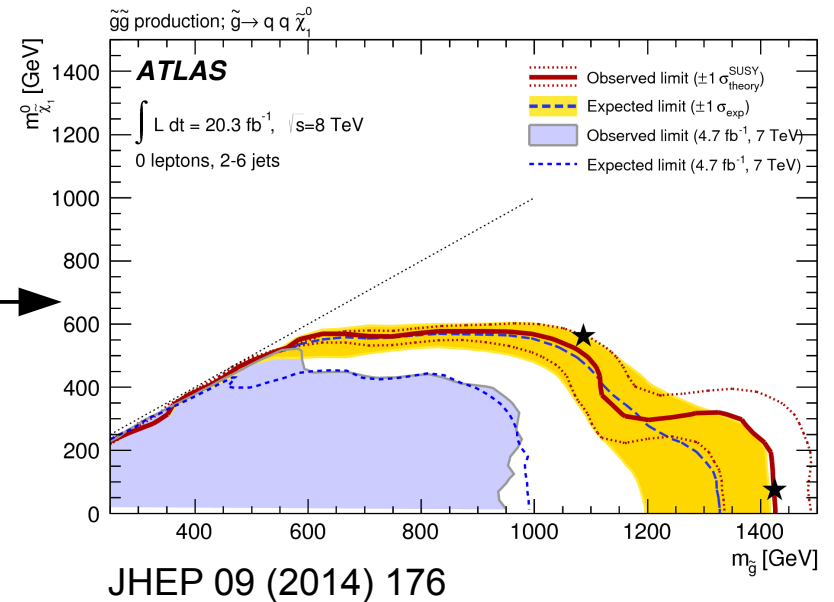
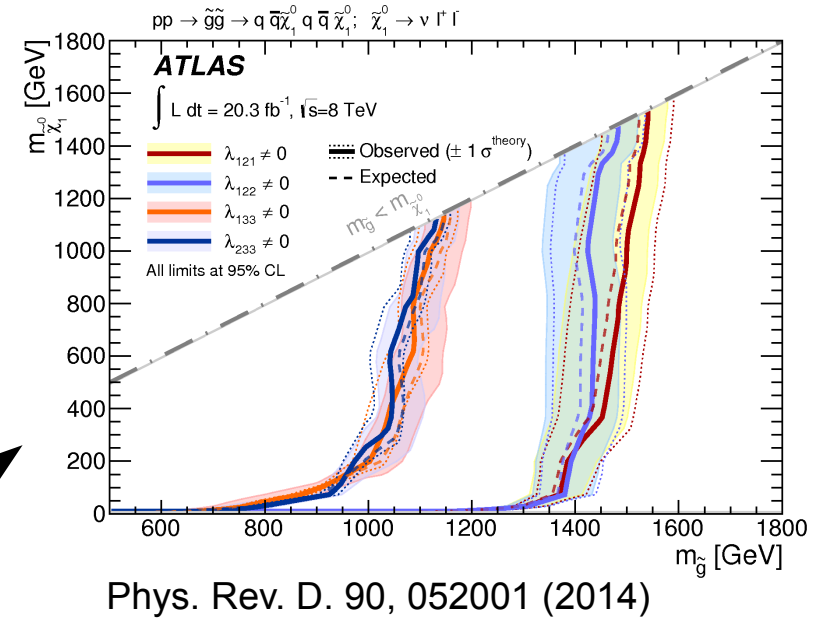
Left- and right-handed



Limiting Cases of the LSP Lifetime

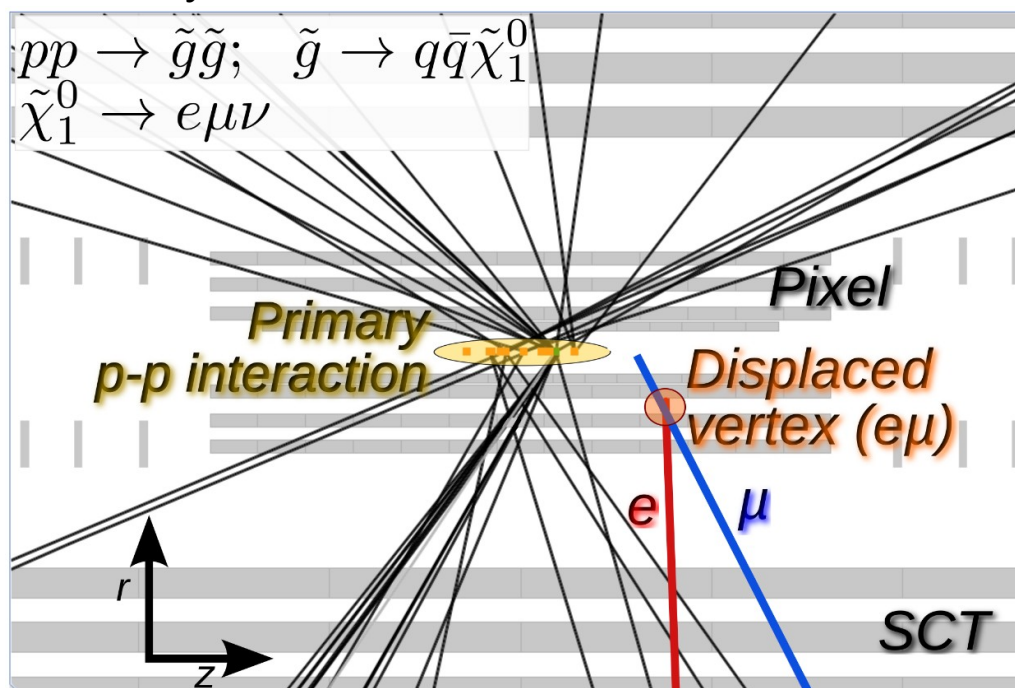
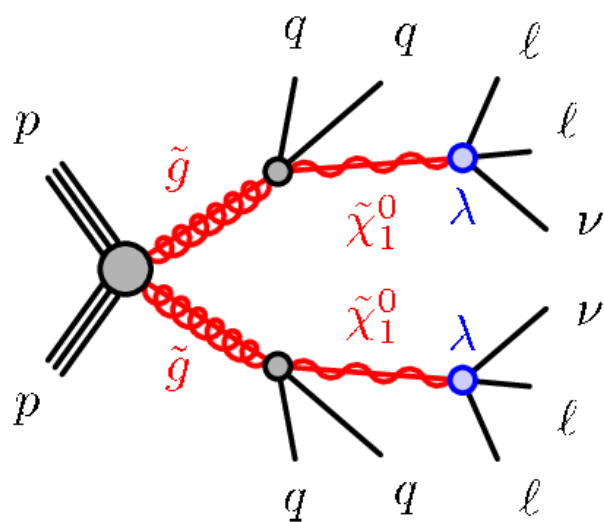


- Values of λ_{ijk} unknown
=> LSP lifetime τ unknown
- Prompt LSP decay ($c\tau \leq 0.1\text{mm}$)
 - Four leptons at primary vertex
- LSP decays outside of detector ($c\tau > 10\text{m}$)
 - LSP escapes undetected
=> Large missing transverse energy
 - Same signature like R-parity conservation



Medium LSP Lifetimes

- Signatures in the calorimeter/muon spectrometer: $1 \text{ m} < c\tau < 10 \text{ m}$
- **Displaced vertex:** $1 \text{ mm} < c\tau < 1 \text{ m}$
 - LSP decay displaced from primary vertex inside inner detector
=> Secondary vertex with two lepton tracks
 - Searches optimized for prompt decays:
Low sensitivity due to cuts on impact parameter of particle tracks
=> Dedicated searches necessary



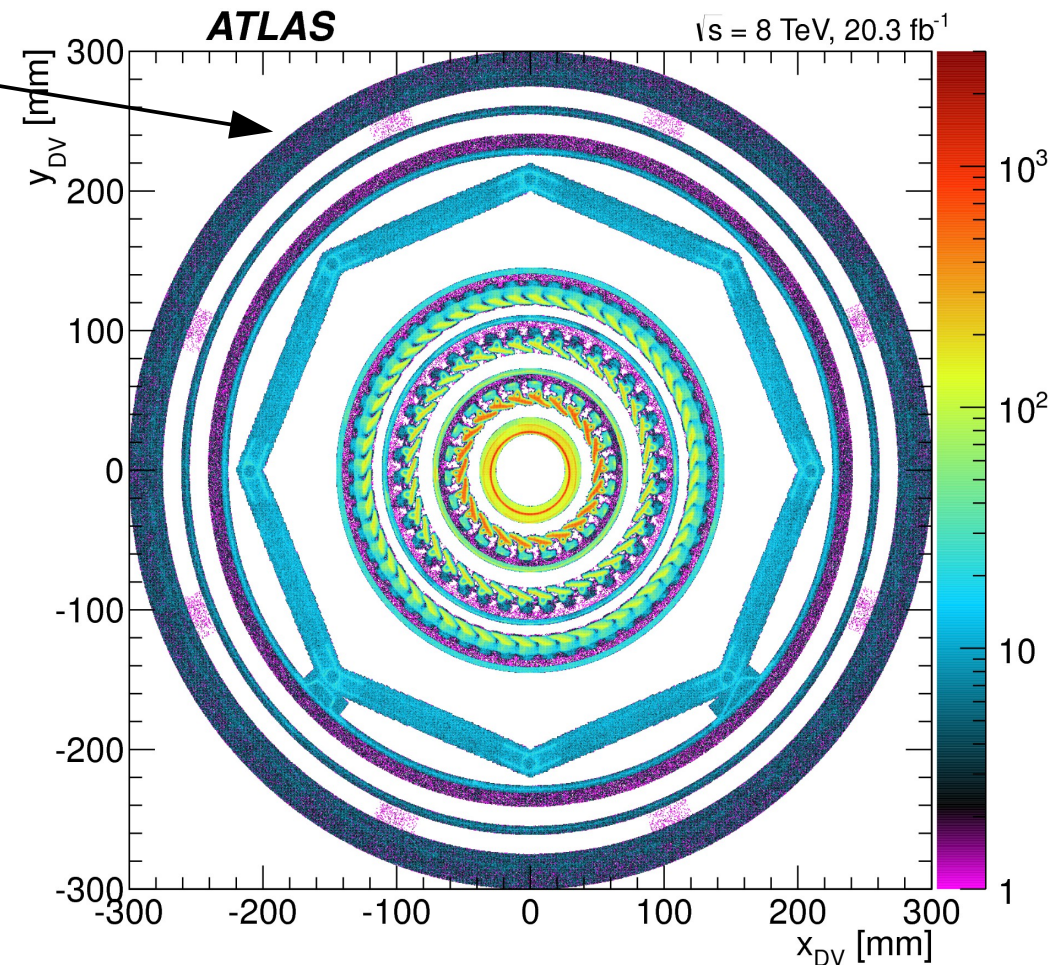
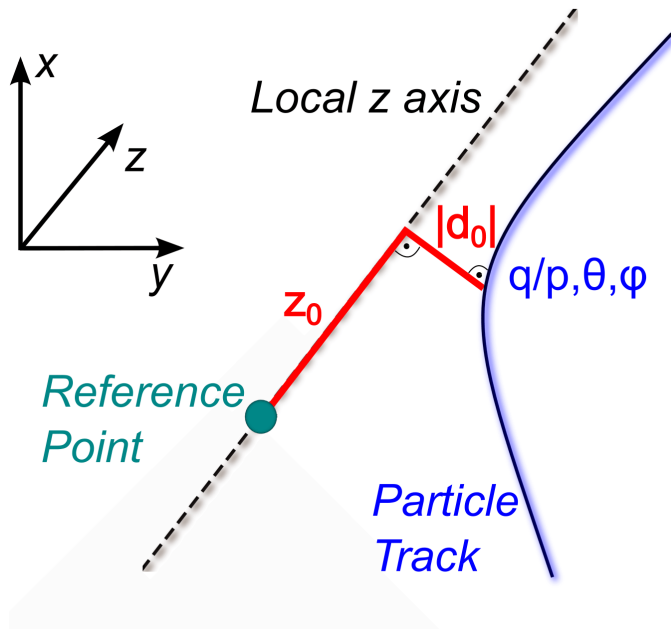
Simulation from Max Goblirsch (CERN-THESIS-2015-095)

Run 1 analysis

Phys. Rev. D 92, 072004 (2015)

Signal Selection

- Displaced vertex (DV) with 2 lepton tracks: $p_T > 10$ GeV and $|d_0| > 2$ mm
- Distance to primary vertex in transverse plane: > 4 mm
- $|r_{DV}| < 300$ mm, $|z_{DV}| < 300$ mm
- Veto against dense detector regions
- Oppositely charged leptons
- Invariant mass $m_{DV} > 10$ GeV

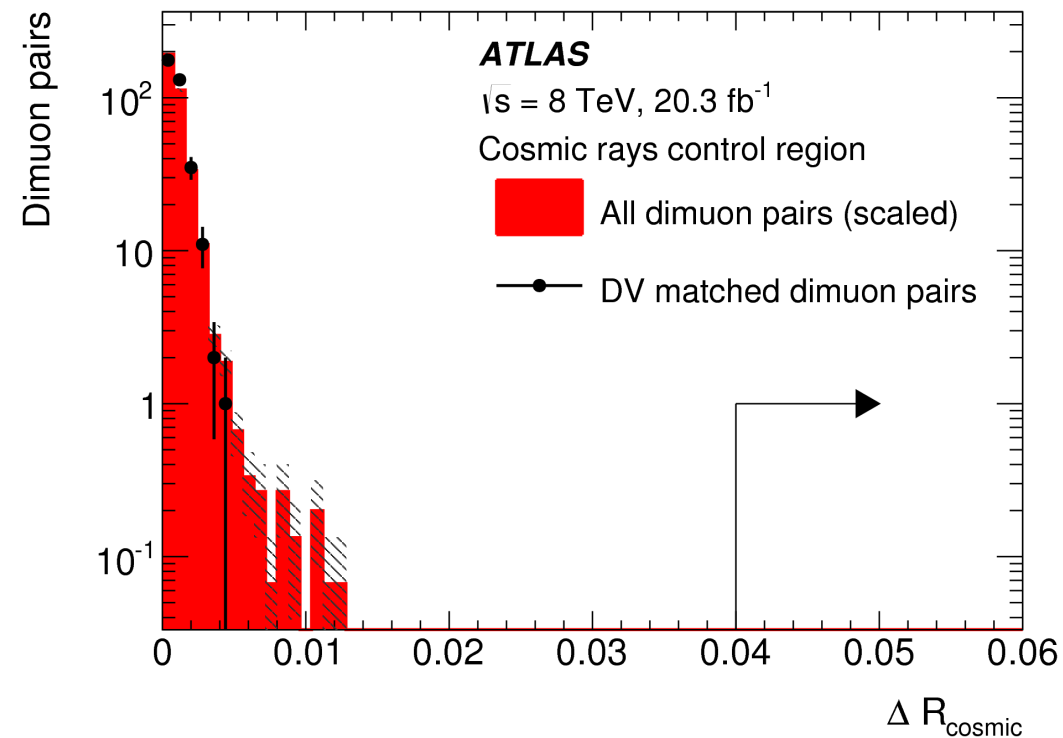


Background Components

- Cosmic muons
 - Reconstructed as a back-to-back muon pair

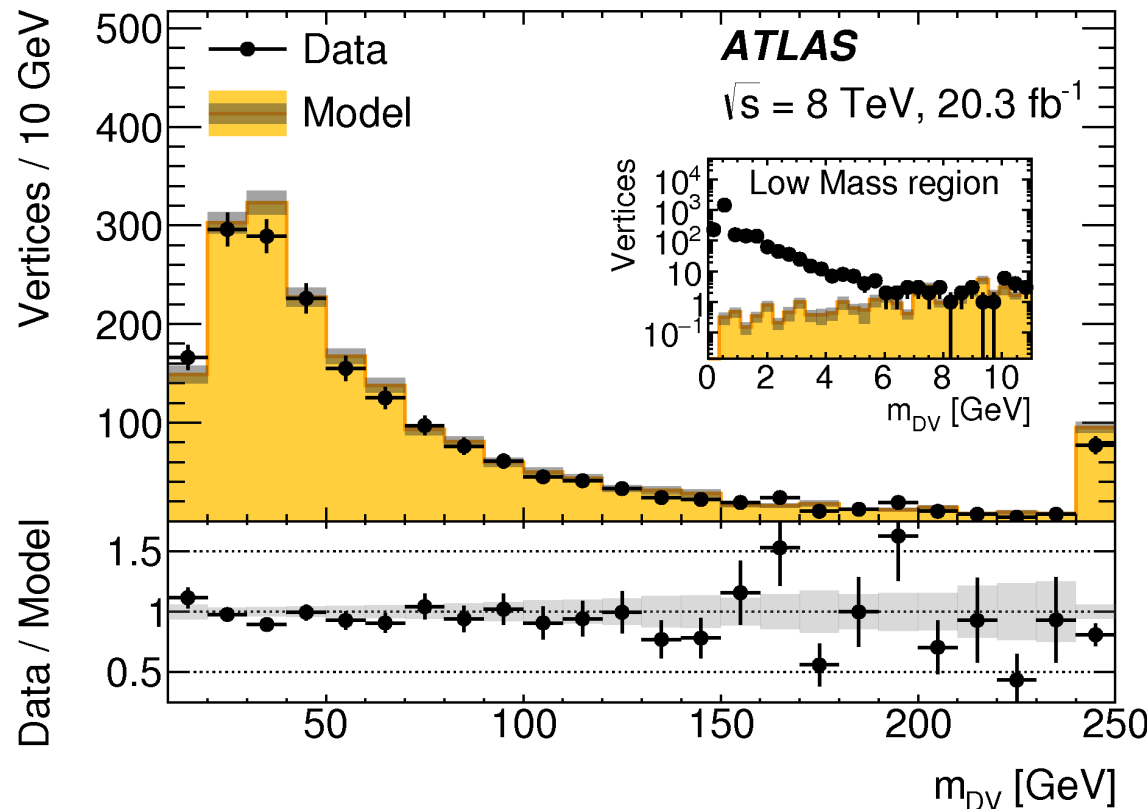
- Introduce new variable for muon pairs: $\Delta R_{Cosmic} = \sqrt{(\pi - \Delta\varphi)^2 + (\eta_1 + \eta_2)^2} > 0.04$

- Decays of long-lived hadrons (especially B-hadrons)
=> Suppressed by: $m_{DV} > 10 \text{ GeV}$
- Misreconstruction of $Z/\gamma \rightarrow ll$ events
=> Suppressed by:
 - $r_T(DV) > 4\text{mm}$
 - $|d_0|$ cut of lepton tracks
- Run 1: All three components negligible



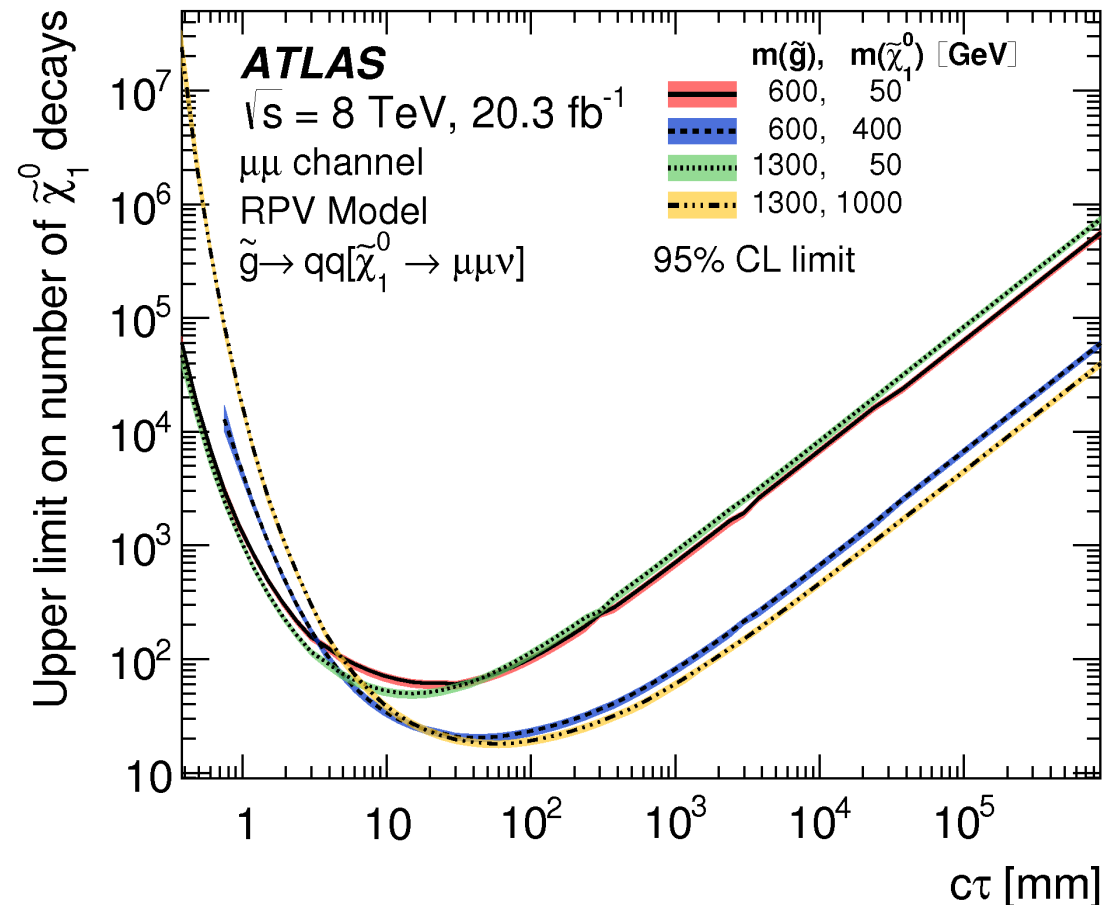
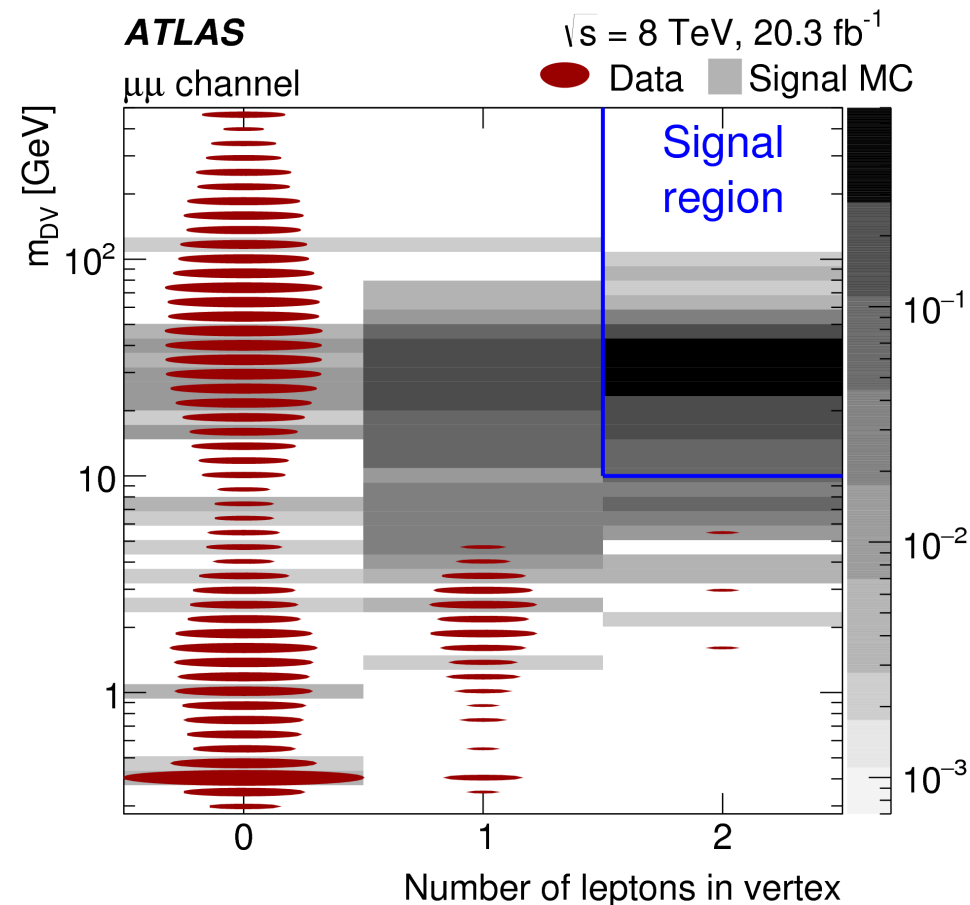
Background: Random Crossing of Tracks

- Two **uncorrelated** tracks cross in the inner detector => displaced vertex
- Estimate by a data-driven method:
 - Combination of all lepton tracks from data to pairs
=> Number of lepton pairs N satisfying signal selection
 - Vertex fits for a random selection of these pairs
=> Probability p for a track crossing forming a vertex
 - Expected background = Np
- Expected background for Run 1:
 10^3 vertices in signal region
=> “zero background analysis”
- Background validation: \longrightarrow
 - Same procedure
 - Two non-leptonic tracks



Run 1 Results

- No signal vertices found
- Model independent 95% CL limits on visible cross section:
0.14 fb (ee, $\mu\mu$), 0.15 fb (e μ)
- $\mu\mu$ channel:

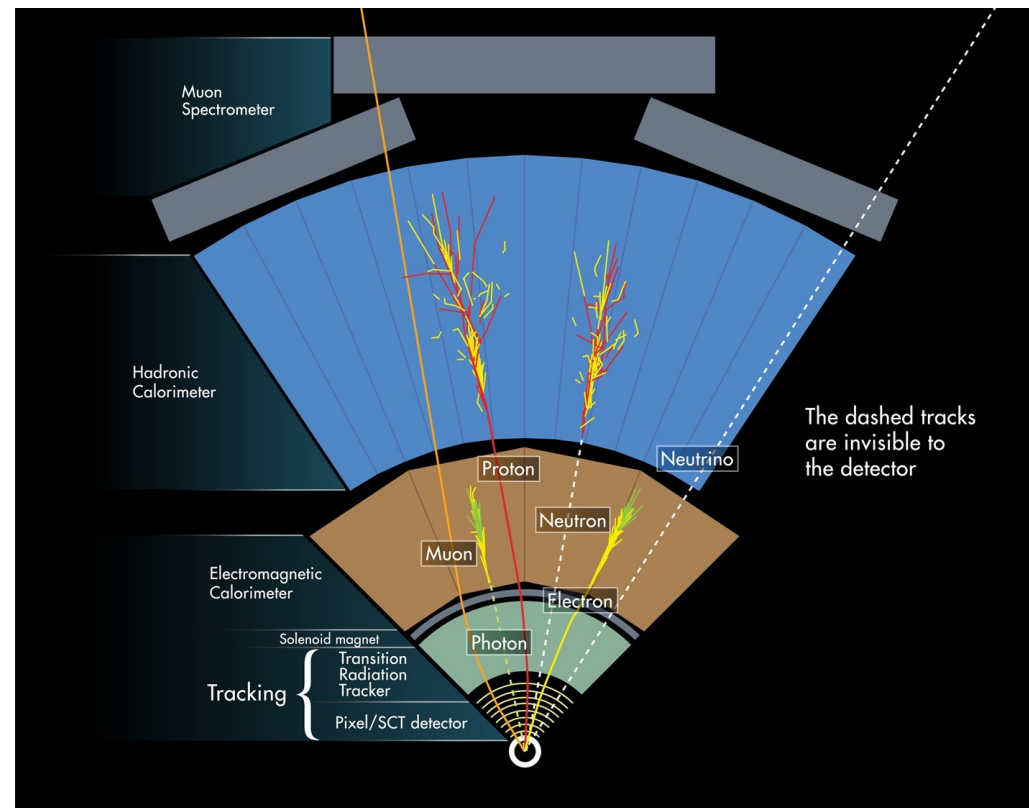


Run 2 Analysis

Reconstruction of High- d_0 Tracks

- Problem: Standard reconstruction of tracks optimized for low $|d_0| < 1$ mm
- Renewed track reconstruction for higher impact parameter necessary
- Very resource consuming => Preselection of data events via filters:
 - No triggers on displaced vertices available in ATLAS
 - Triggering on lepton candidates without inner detector information
 - e: Energy depositions in calorimeters => Photon triggers
 - μ : Tracks in muon spectrometer (MS) => MS only triggers
 - 0.1% of 2015 data selected

Same problem and strategy as in Run 1




Preselection Filters

- Filters had to be adapted for 13 TeV and increased luminosity
- Main challenge: Significantly increased rates of photon triggers wrt Run 1
- Overview of filters:

μ	$p_T > 60 \text{ GeV}, \eta < 1.07$
e	$p_T > 140 \text{ GeV}$
γ	$p_T > 150 \text{ GeV}$ + electron/photon/muon: $p_T > 10 \text{ GeV}$
ee e γ $\gamma\gamma$	$p_T > 50 \text{ GeV}$

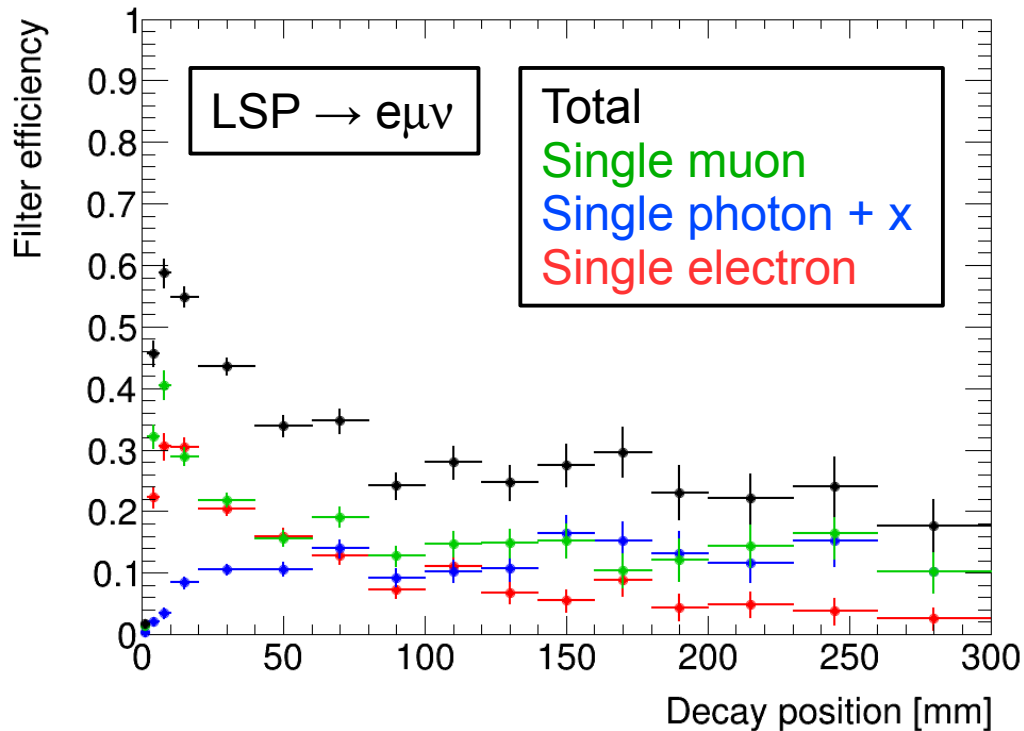
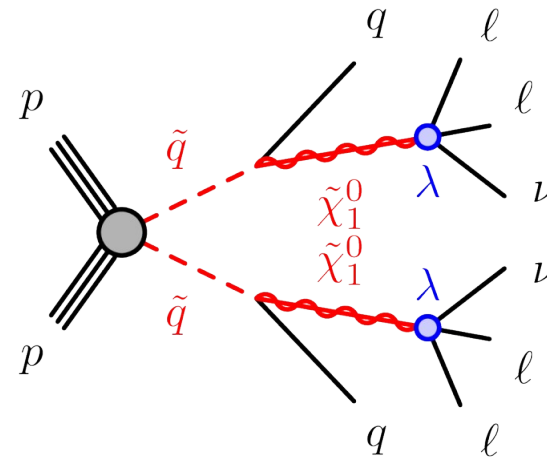
Trigger rate for $1.07 < |\eta| < 2.5$
not manageable



- Muon: $|\eta| < 2.5$, standalone or combined ($|d_0| > 2 \text{ mm}$)
- Electron: $|\eta| < 2.5$, $|d_0| > 2 \text{ mm}$
- Photon: $|\eta| < 2.5$, identification: “loose”

Signal efficiency of Preselection Filters

- Monte Carlo simulation (MadGraph+Pythia8)
- Full detector simulation
- $m(\text{squark}) = 700 \text{ GeV}$, $m(\text{LSP}) = 500 \text{ GeV}$
- $c\tau = 100 \text{ mm}$
- Efficiencies per decay:



Conclusions

- Search for long-lived supersymmetric particles with displaced dileptons
- Background: Random crossing of lepton tracks
- Run 1 analysis published in mid of April
 - No signal vertex found
 - 95% CL model independent limits: $\sigma_{\text{vis}} < 0.15 \text{ fb}$
- Run 2 analysis with good progress
 - 2015 data preselected
 - 13 TeV MC samples for signal models available
 - Software framework ready
 - Publication planned for 2016