BSM @HL-LHC

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on behalf of the ATLAS & CMS collaborations

23 May 2019

LHCP 2019

The High Luminosity LHC upgrade

This talk will cover a small selection of highlights of BSM searches, from ATLAS and CMS

HL-LHC project approved:

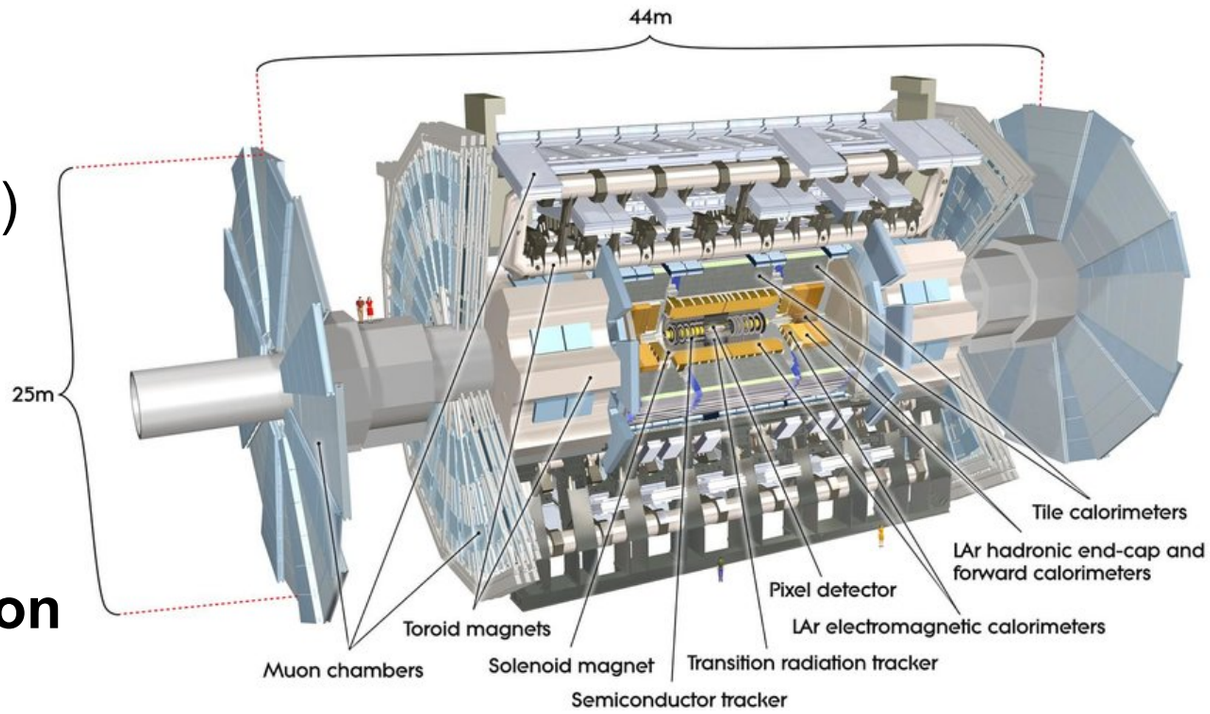
- data taking to start on around 2026
- 3000 fb^{-1} of data
- $\sqrt{s}$ = 14 TeV
- $L = 7.5 \times 10^{34}\ cm^{-2}\ s^{-1}$
- up to 200 interactions/bunch-crossing

A lot of data for EW and QCD precision measurements, Higgs boson properties, flavour physics, BSM searches!

Detectors Upgrade

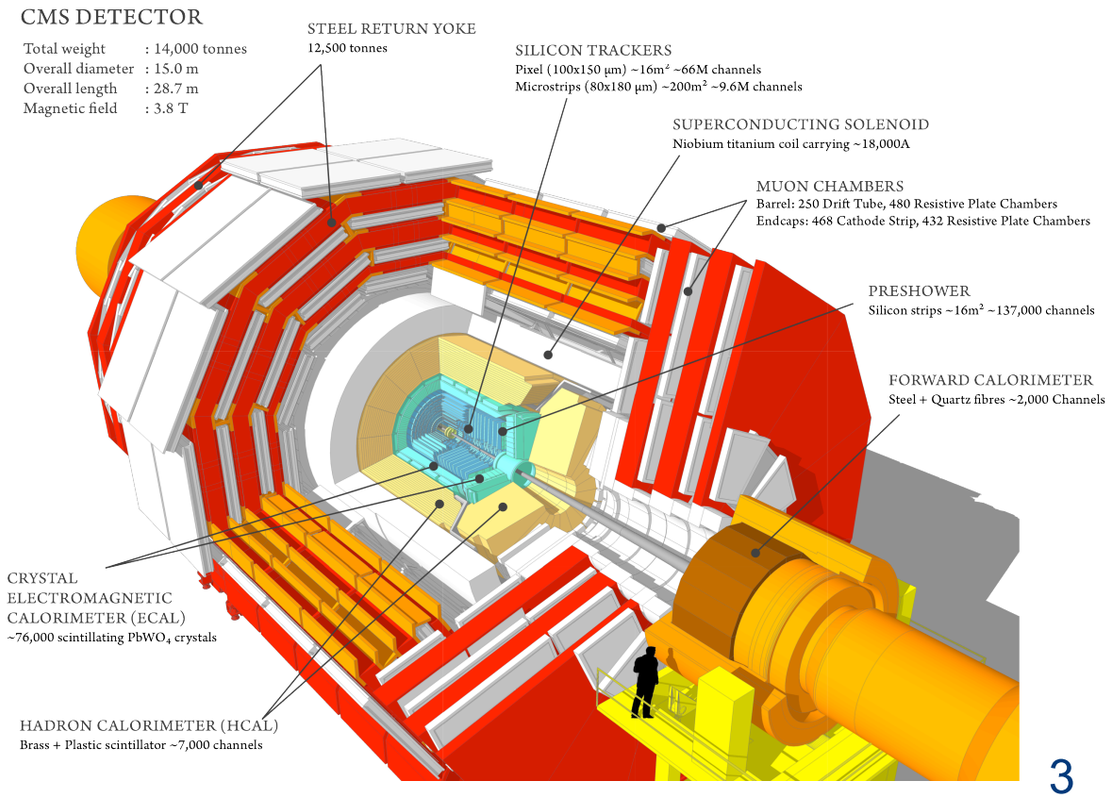
ATLAS upgrades include

- DAQ and trigger systems (L1 and HLT - 10 kHz)
- New **Inner Tracker** up to **$|\eta|<4$**
- **Electronics upgrade** for LAr and Tile calorimeters, muon system
- New **muon chamber** in the **inner endcap region**
- **High granularity timing detector** in endcap



CMS upgrades include

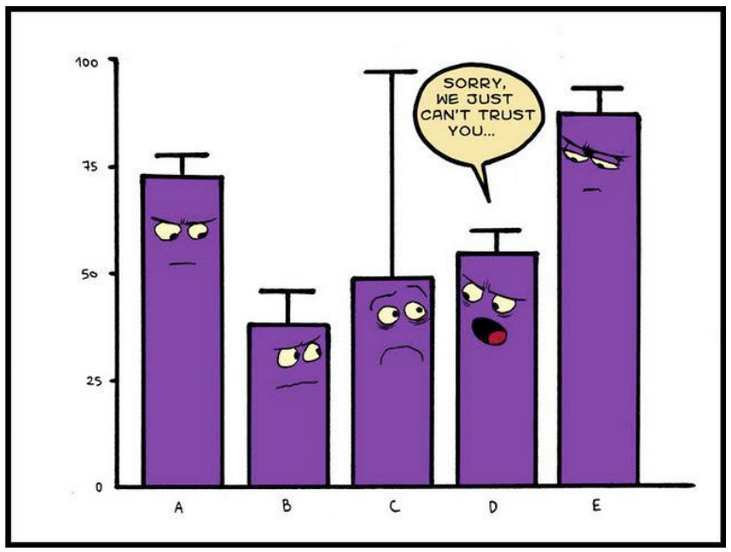
- DAQ and trigger systems (L1 and HLT - 7.5 kHz)
- New **Inner Tracker** up to **$|\eta|<4$**
- Improved **muon system coverage**
- Precise **MIP timing layer** in barrel and endcap
- **High granularity endcap** calorimeter



New openings

Large data sample benefits lower statistical uncertainties

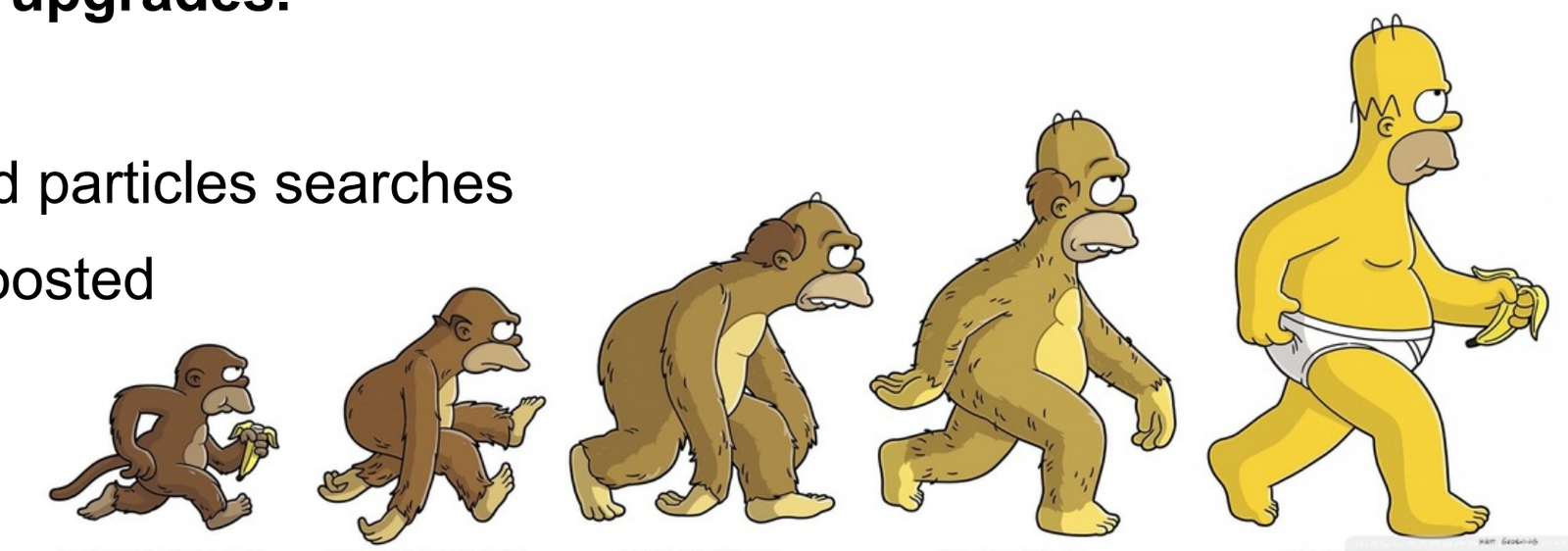
- Lower experimental systematic uncertainties
  (calibrations performed on larger dataset,
  Z counting for luminosity)
- Lower uncertainties on background (& signals) prediction
  (high statistic control samples allows more precise constraints)



Exploit full **potential of detector upgrades.**

New tools for searches:

- timing information for long lived particles searches
- sensitivity to forward events boosted
  by extended tracking
- new trigger strategies
- …



Common effort

Experimental collaborations
(ALICE, ATLAS, CMS, LHCb)
and theorists involved in:

* BSM Yellow Report: arXiv:1812.07831
* Input to European strategy

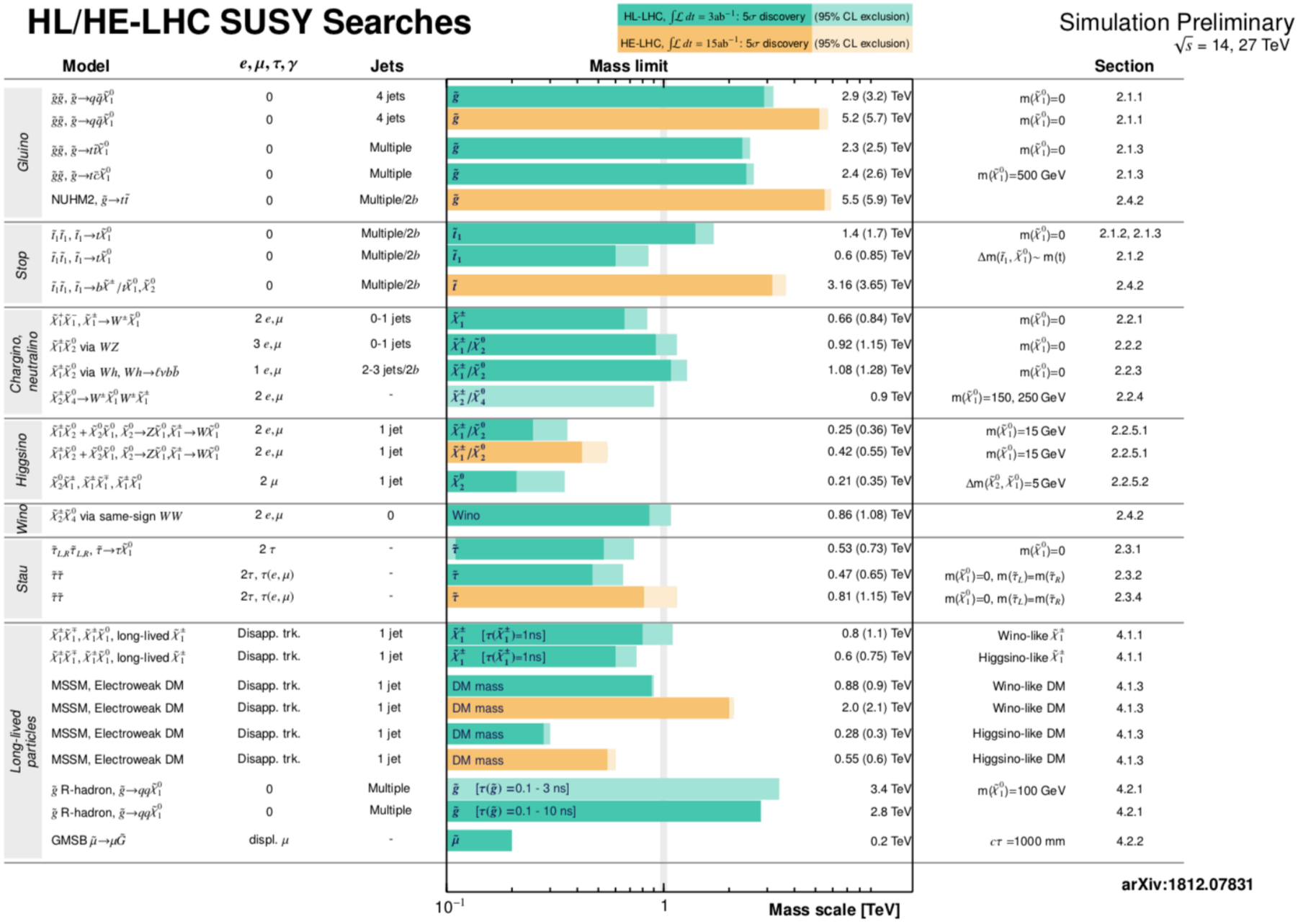
Three main approaches:

* Full simulation in the upgraded detectors
  - CMS: DELPHES with up-to-date phase-2 detector performance
  - ATLAS: Particle-level analysis with energy smearing
* Projections using Run-2 signal and background samples scaled at 14 TeV

Treatment of uncertainties:

* Harmonised treatment of detector and theory uncertainties evolution
  - halved detector and theory/modelling uncertainties
  - neglected MC statistic uncertainties
  - statistical uncertainty decreased by $1/\sqrt{L}$
  - uncertainty on luminosity 1%
  - experimental systematics preserved or reduced by a agreed factors

SUSY



Larger dataset allows to apply stricter selection criteria ➡ phase space corners

In most of these scenarios HL-LHC will increase present mass reach by 20-50% (compared to available Run-2 results).

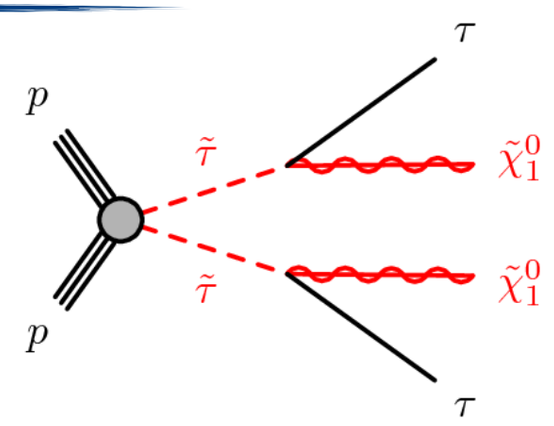
SUSY: staus search

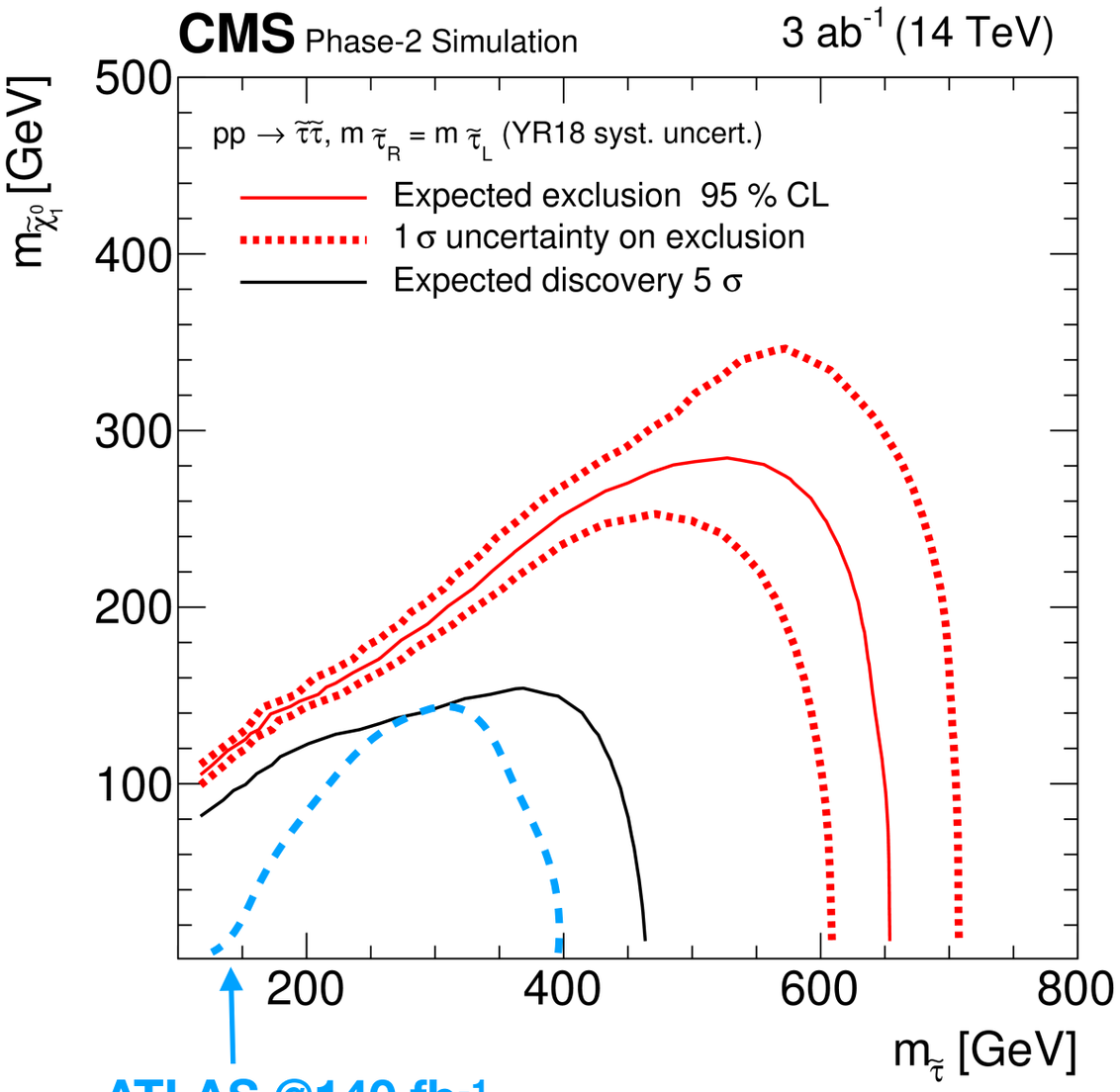
ATL-PHYS-PUB-2018-048

CMS-PAS-FTR-18-010

Direct staus production

Di-tau final state with missing transverse momentum





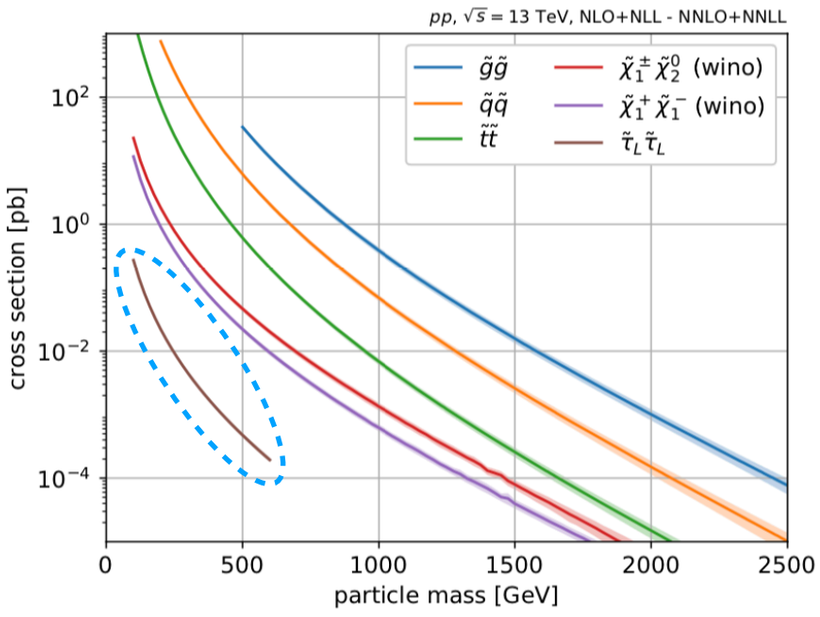
ATLAS @140 fb^{-1}

ATLAS-CONF-2019-018

Only just getting sensitivity @ Run-2!

Limited by production cross-section

(<1 fb^{-1} for m(stau) > 400 GeV @ 14 TeV)



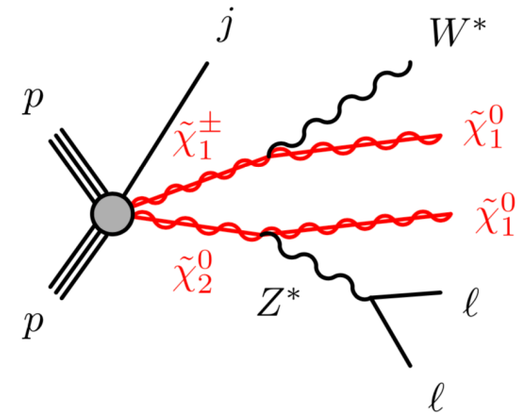
- **Exploit full HL-LHC dataset.**

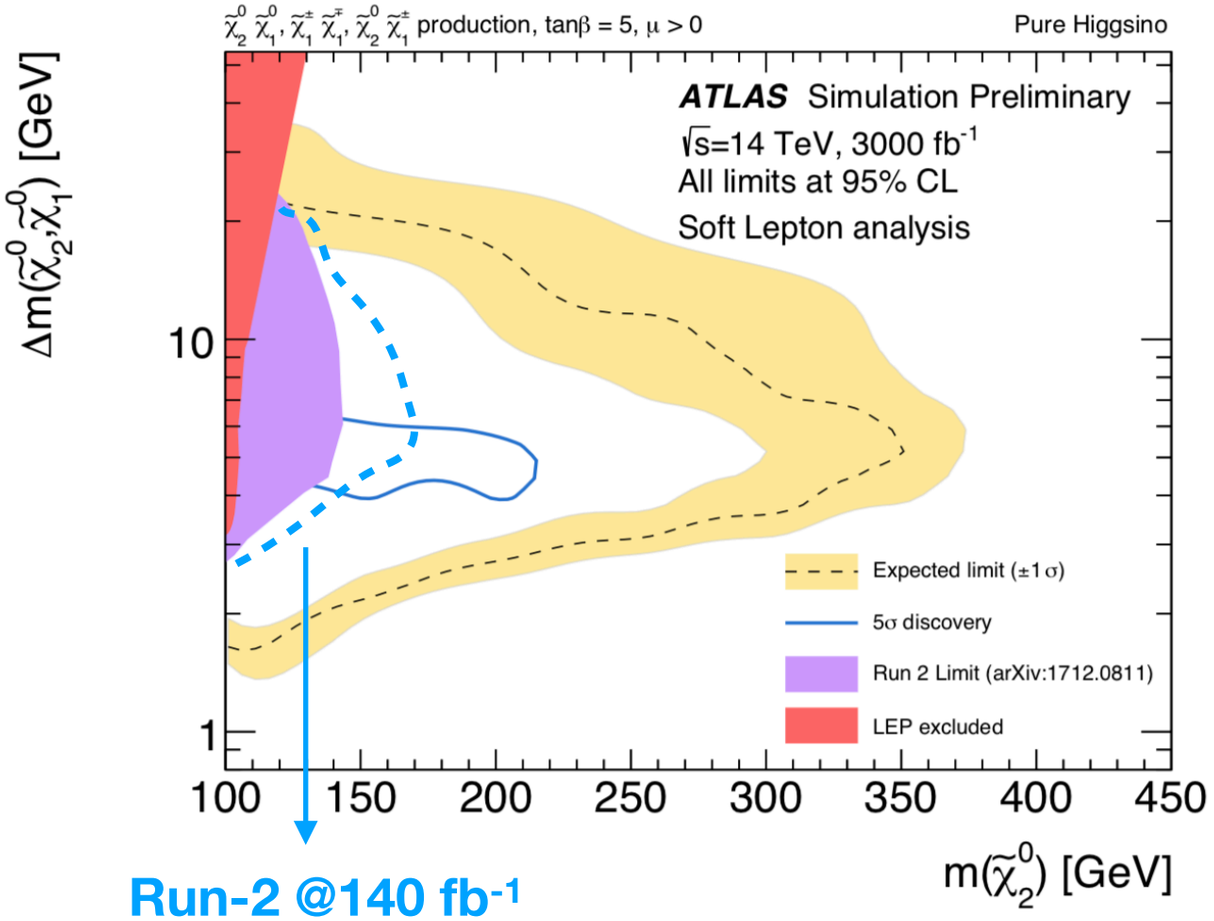
SUSY: compressed signatures

Higgsino-like LSP (naturalness motivated)

challenging topology

Lightest chargino and second neutrino close in mass.
Soft objects in the final state ISR-based selection





Run-2 @140 fb^{-1}
ATLAS-CONF-2019-014

ISR jet + E_T^{miss} + soft leptons

- challenging lepton ID
- triggers upgrades to maintain low lepton thresholds

Large gain expected wrt to
NEW full Run-2 results (W(qq))

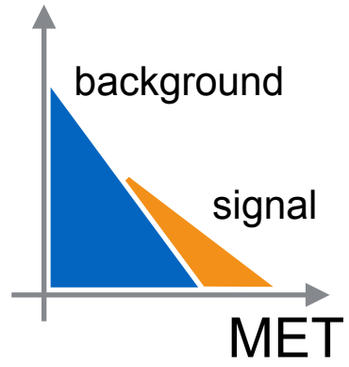
ATL-PHYS-PUB-2018-031

CMS-PAS-FTR-18-001

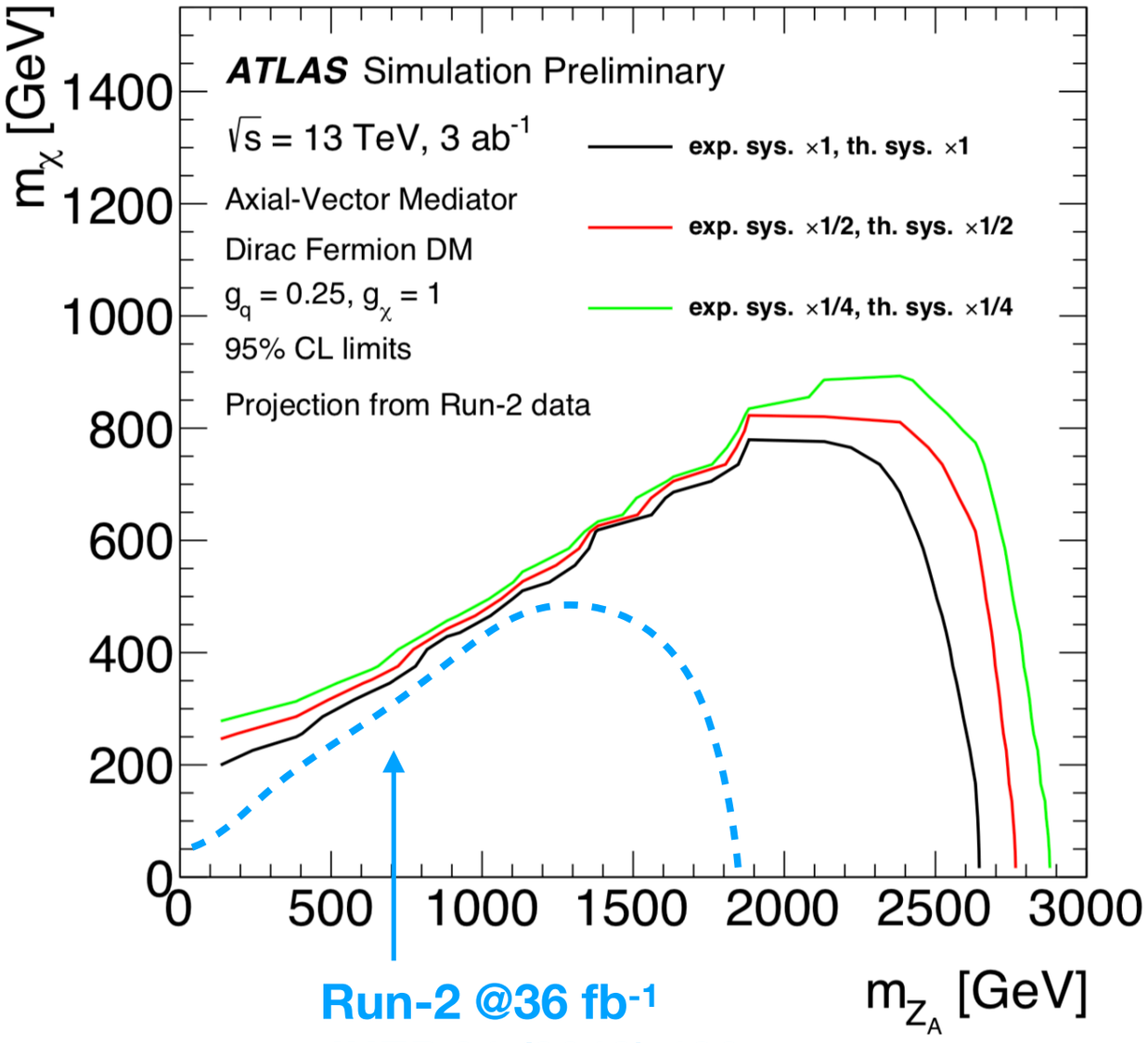
Dark Matter Searches: mono-X

✓ **invisible** DM particles escaping the detector
✓ visible particles from production / ISR

➡ Look for MET tail excess



ATL-PHYS-PUB-2018-043

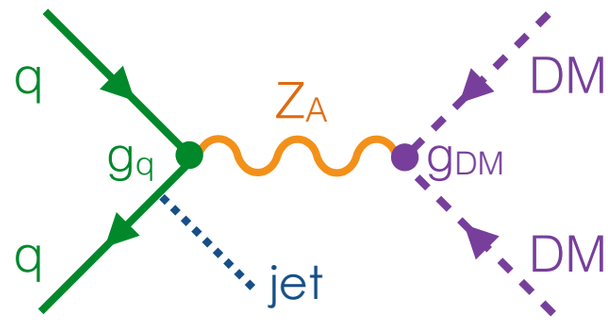


Run-2 @36 fb^{-1}

JHEP 01 (2018) 126
Phys. Rev. D 97 (2018) 092005

Simplified models with few parameters:

* mono-jet domain



Systematics dominated

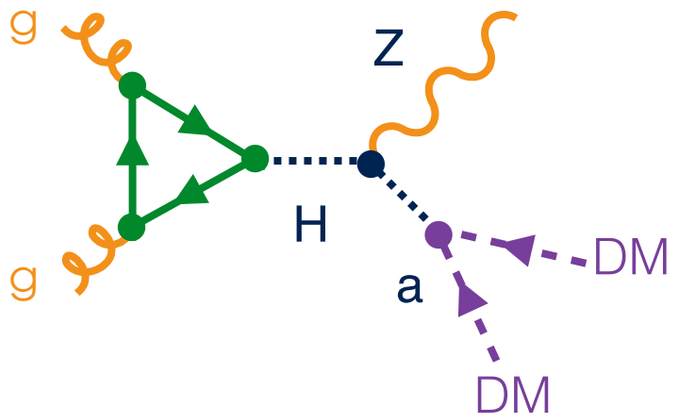
➡ signal, Z/W+jet th. unc.

➡ jet/MET exp. unc.

Dark Matter Searches: mono-X (II)

More refined models (e.g. 2HDM+a) probed by:

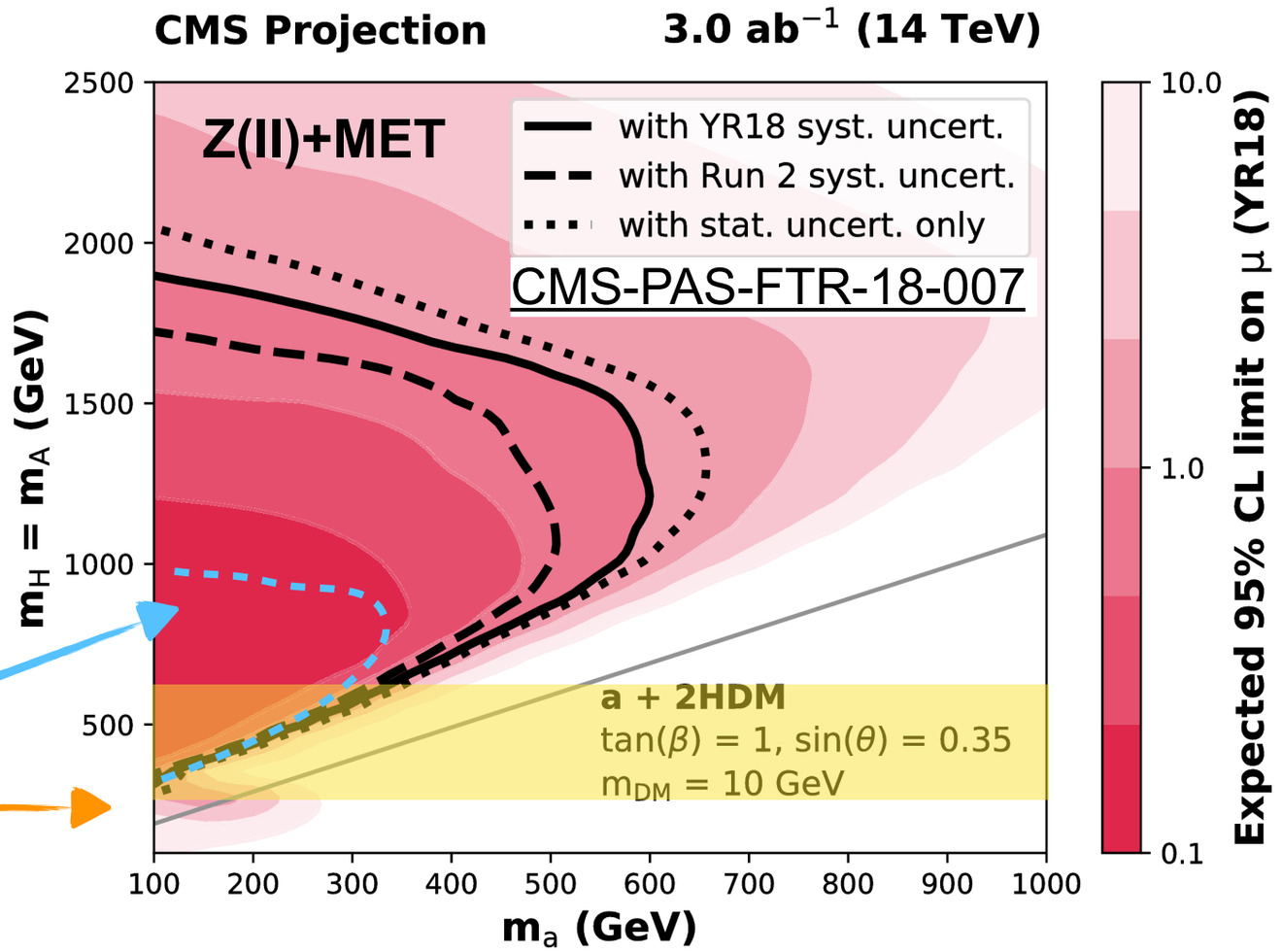
* mono-H/Z/γ, HF+MET, VBF+MET…
  - ATL-PHYS-PUB-2018-024
  - ATL-PHYS-PUB-2018-038



Run-2 @36 fb^{-1} arXiv:1903.01400

constraints from 4t decays

ATL-PHYS-PUB-2018-027



VBF+MET key-channel for h (inv) search → *large sensitivity increase expected by tracker extension $|\eta| < 4$*

BR~5-10% could be reached by reducing syst impacts by a factor 2 (CMS-PAS-FTR-18-016)

Resonance searches

Clear gains from increased lumi and energy

Expansion of the current resonance search program, across a vast variety of channels (tt,tb,lv,ll…)

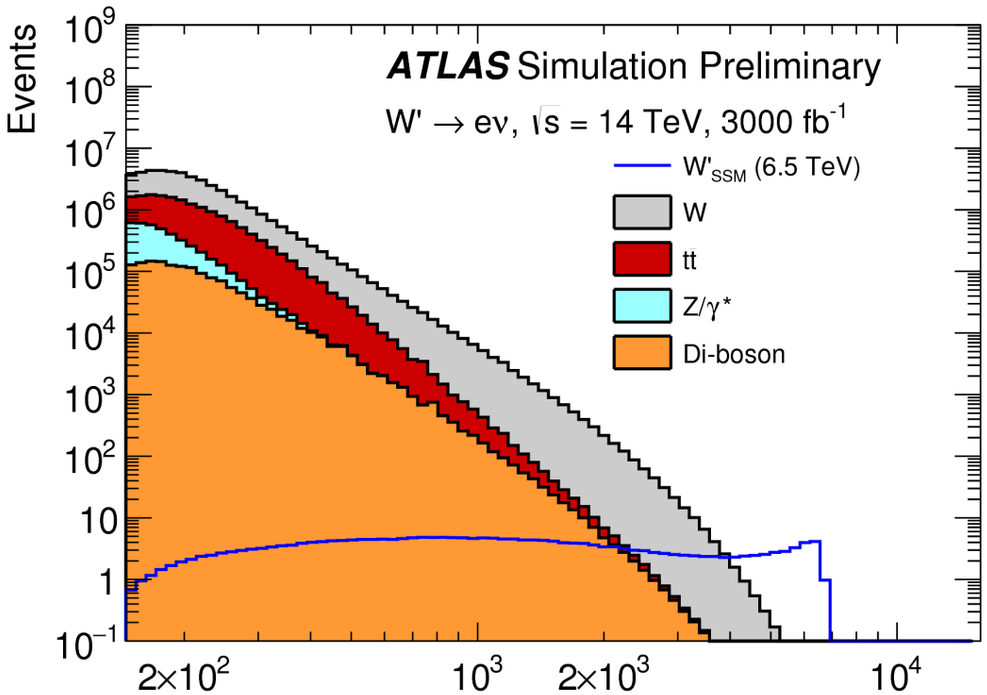
- excellent performance of high pT objects
- high mass sensitivity is dominated by statistics

Reach **6-8 TeV mass** sensitivity in Z'-W' scenarios decaying in leptons:

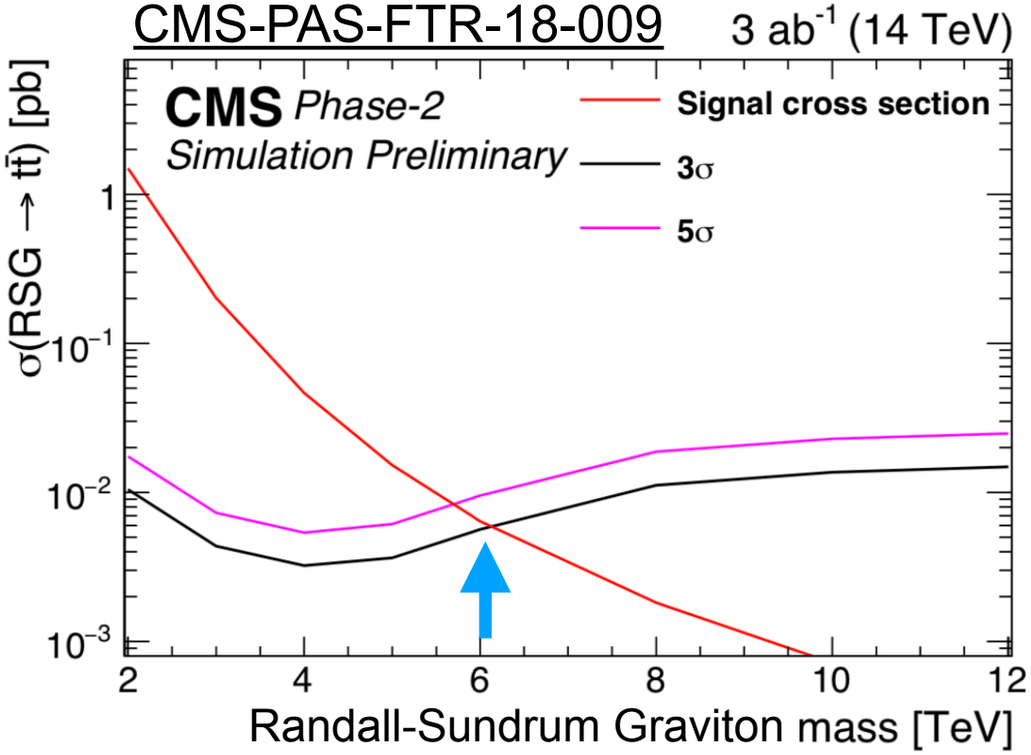
➡ 1-2.5 TeV better than Run-2!

ATL-PHYS-PUB-2018-022

ATL-PHYS-PUB-2018-044



CMS-PAS-FTR-18-009

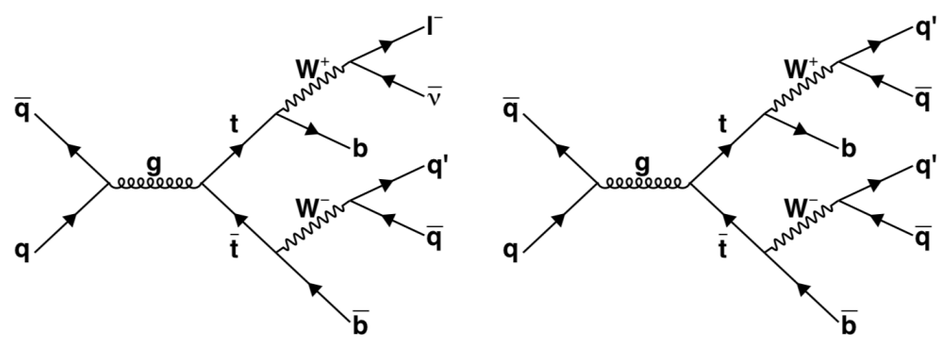


Hadronic decays dominated by top final states

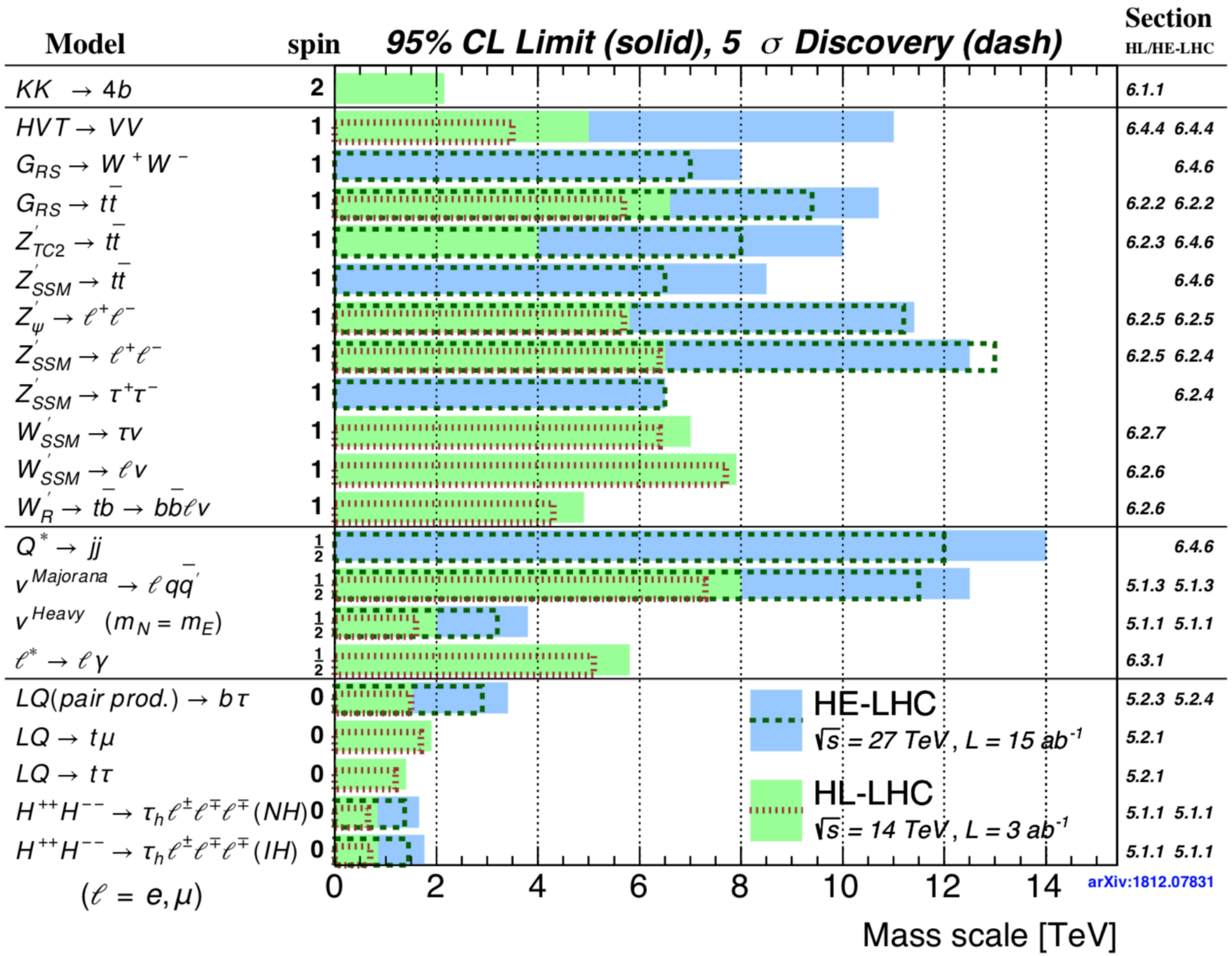
- good b-tagging efficiency
- low mis-ID probability in high pileup regimes

➡ Phase-2 high granularity detector

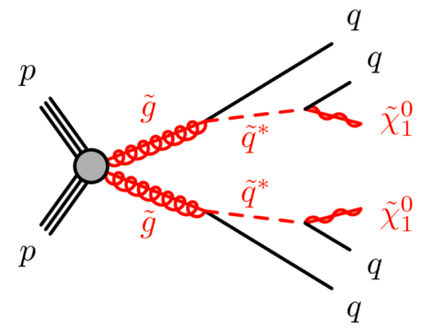
➡ New trigger and DAQ capabilities



Exotics searches reach

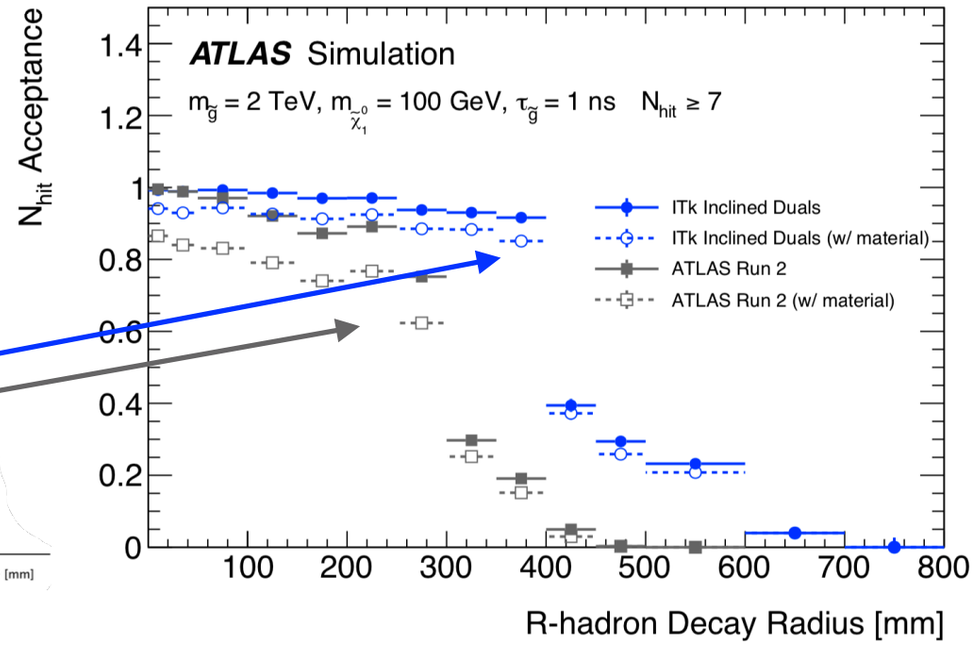


Long Lived particles (ITk)



- Many LLP searches are statistically limited!
- Background-zero searches sensitivity $\propto \mathscr{L}$
- Gain by exploiting new detector technologies

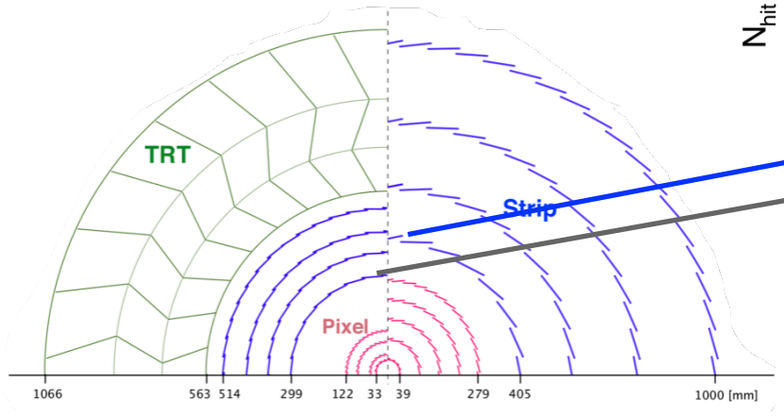
ATL-PHYS-PUB-2018-033



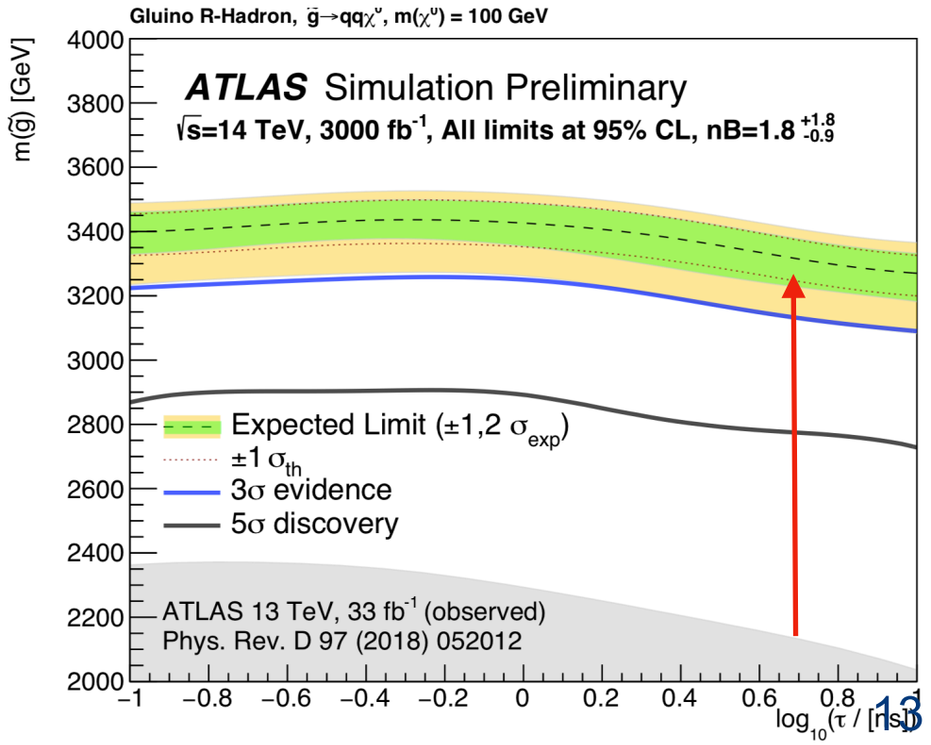
ITk detector

Higher reco efficiency:

- improved geometry
- larger silicon volume
- lower material budget



- More hits-on-track with higher resolution;
- Minimum number of hits after decay to ensure efficient reconstruction and background rejection
- **Tracker-based triggers** could further help to increase sensitivity



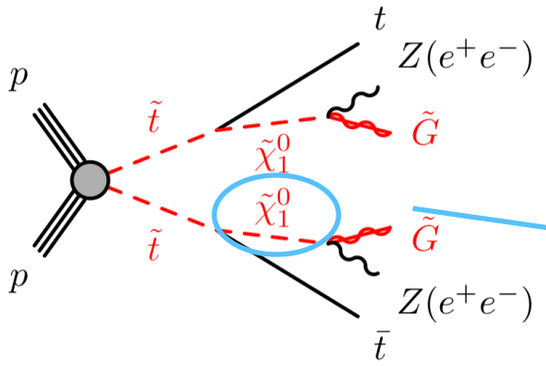
Long Lived particles (MTD)

MIP timing detector (MTD)

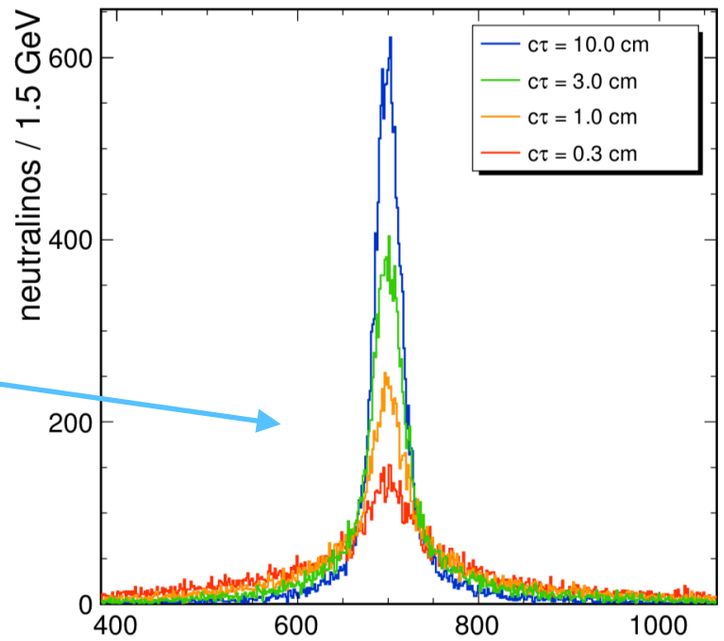
- assigns timing for each vertex (ISR jet)
- measures TOF of LLPs
  - LLP mass measurement.

Precision timing helps to reject

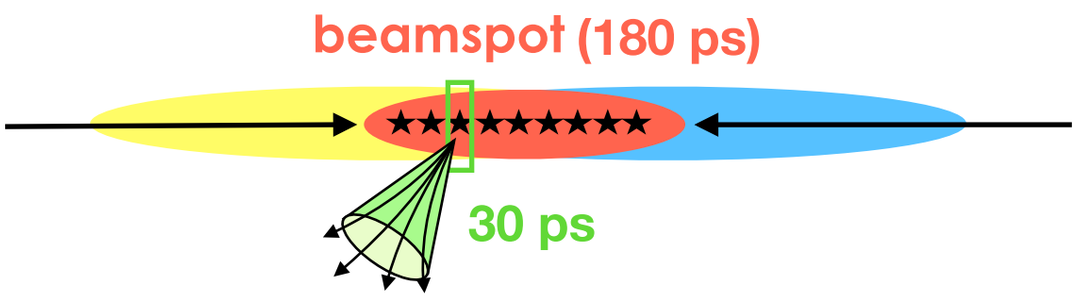
- spurious secondary vertices
- pile-up tracks



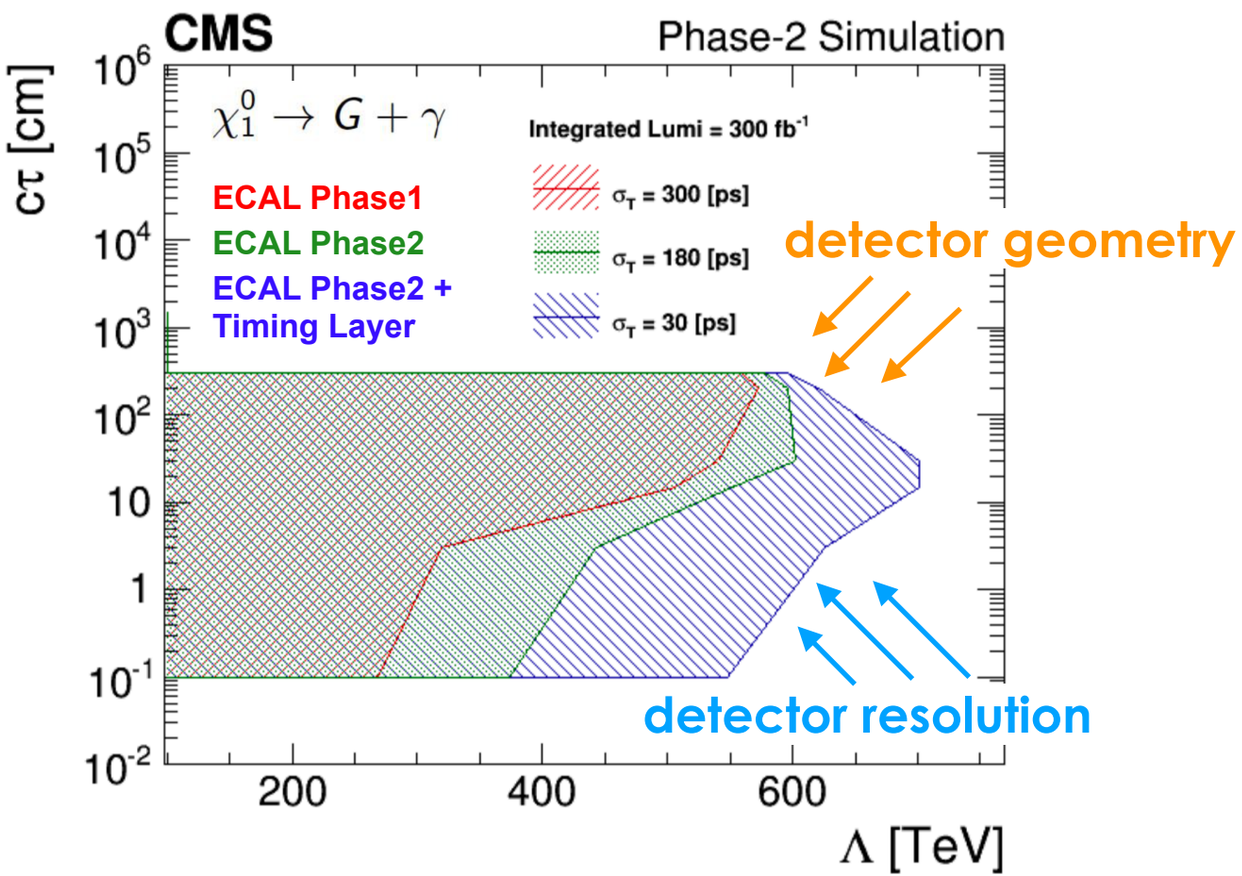
CERN-LHCC-2017-027



- W/o Timing detector:
  time resolution dominated by
  uncertainty from beamspot (~180 ps)



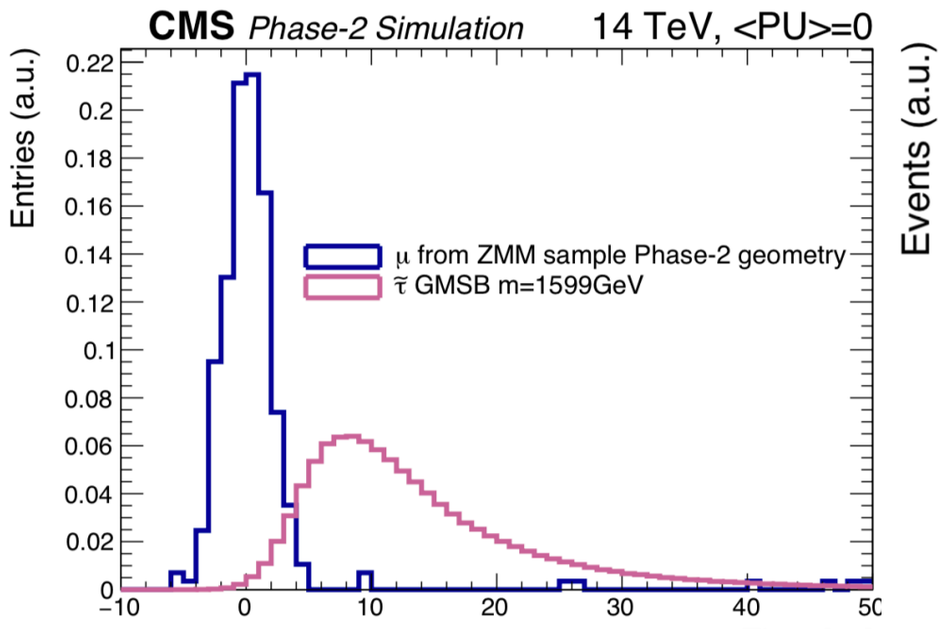
- W/ Timing detector:
  time resolution lowered at 30 ps



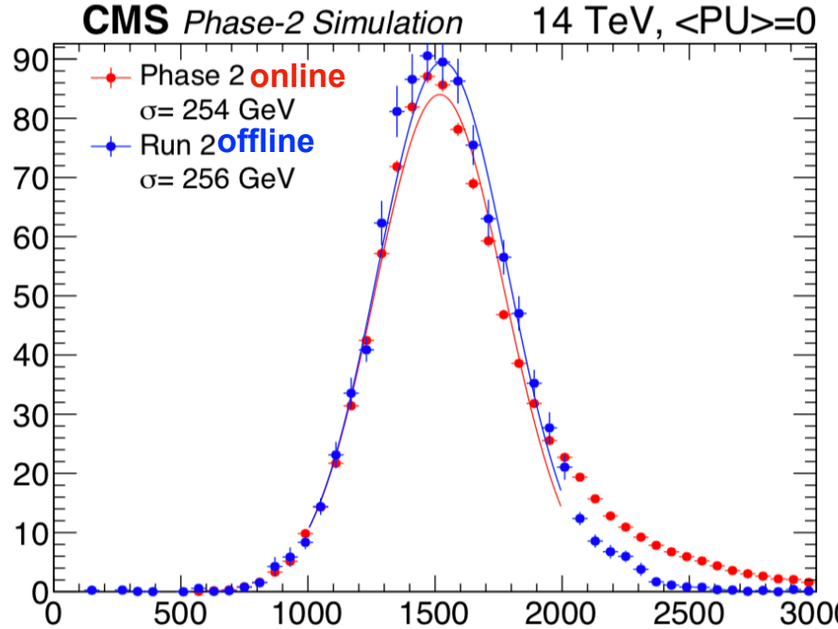
Long Lived particles (RPCs)

TOF measurements: **heavy stable charged particles** similar to muons, but slower.

Use TOF to discriminate! (factor of 25 better time resolutions w/ new CMS link boards)

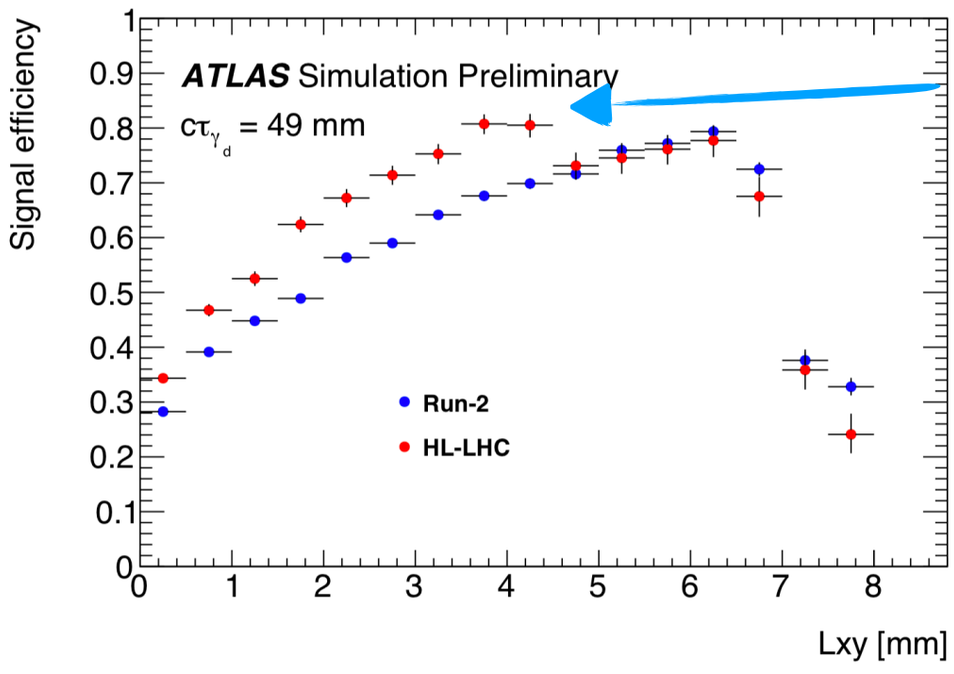


CERN-LHCC-2017-012



Dark-photons are light, decay products boosted: displaced collimated jets of muons at HL-LHC

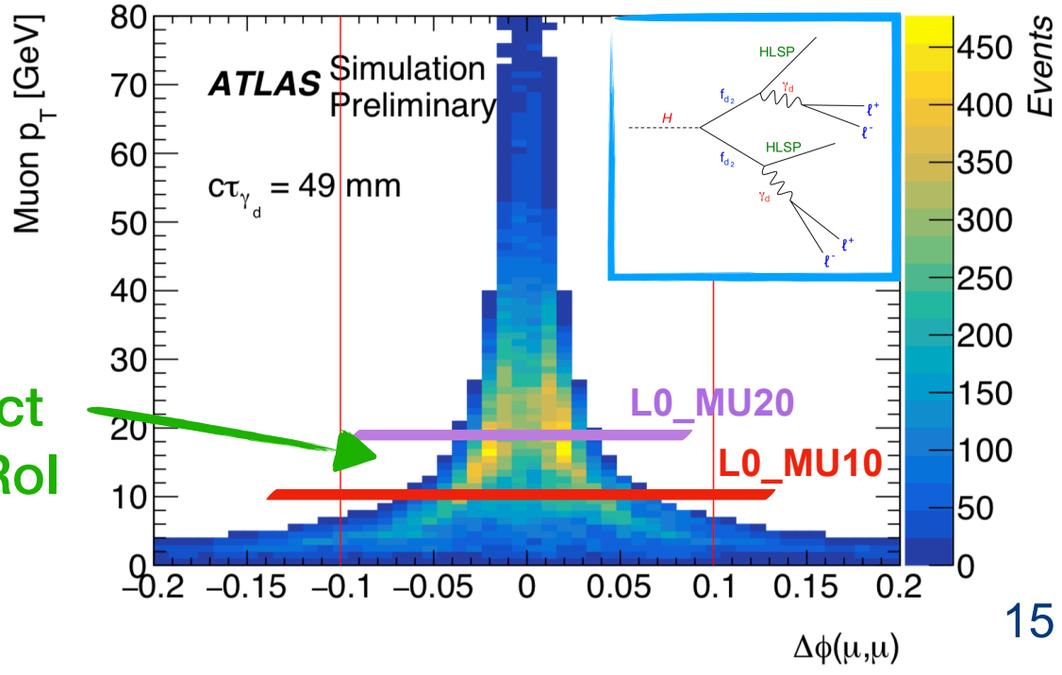
➡ Special L0 triggers designed, using features of upgrade



Additional inner RPC layer

Dedicated algorithm to select multi-μ in single RoI (Δϵ~10%)

ATL-PHYS-PUB-2019-002



Summary

CMS public projected results
ATLAS public projected results

much larger dataset
(e.g.staus production)

upgraded detectors and DAQ systems
(e.g. LLP searches)

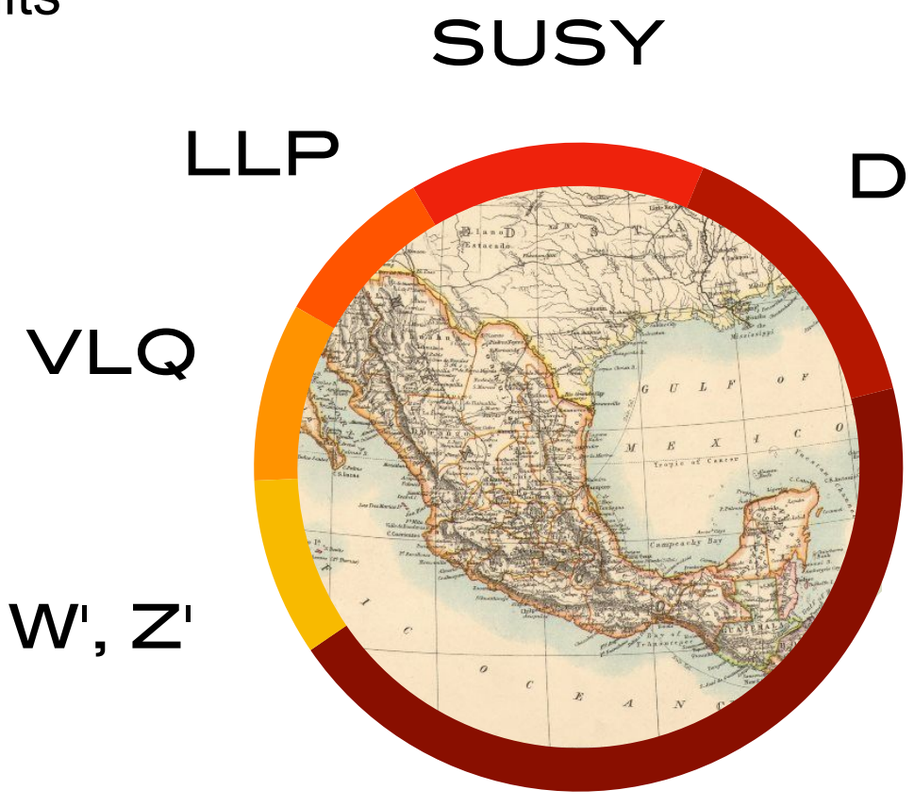
reduce exp & theo. uncertainties
(e.g. monojet)

higher centre-of-mass energy of the collisions
(e.g. resonance searches)

- 20-50% better in most SUSY scenarios
- up to 6-8 TeV high mass resonance exclusion limits
- DM searches reach extended by more than 50%
- even larger gains in more exotic searches!

NEW IDEAS in the next years will allow to probe new physics scenarios or corner cases:

- new trigger strategies?
- deep learning at low and high level physics?
- *THINK OUTSIDE THE BOX!*



HIC SUNT LEONES

G. Gustavino

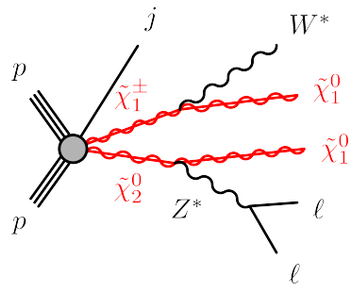
Even if Run-2 will not bring to a new discovery…

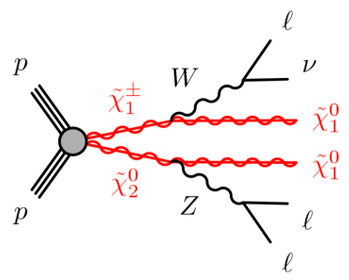
HL-LHC Run-2 New Physics

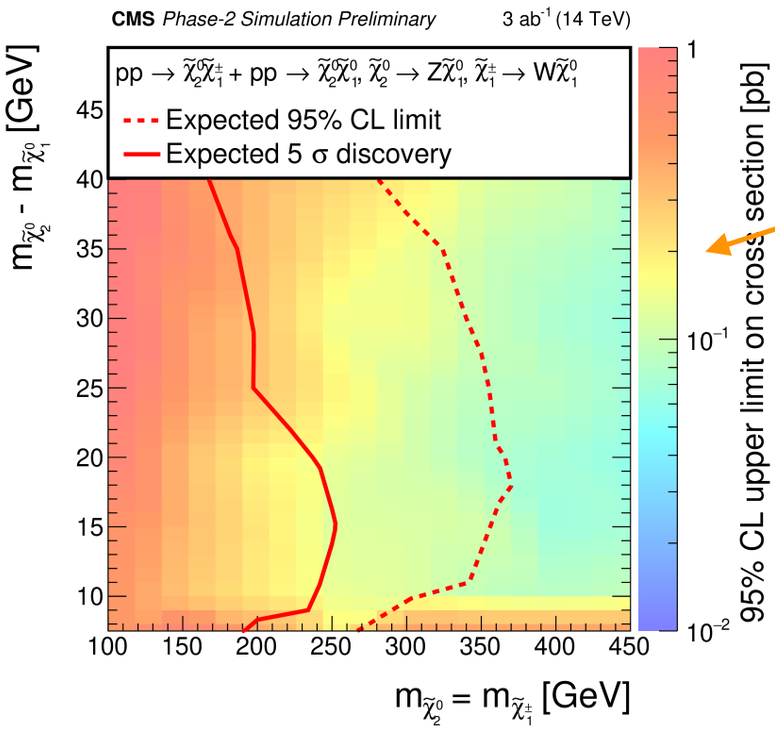
…HL-LHC will get us a new perspective!

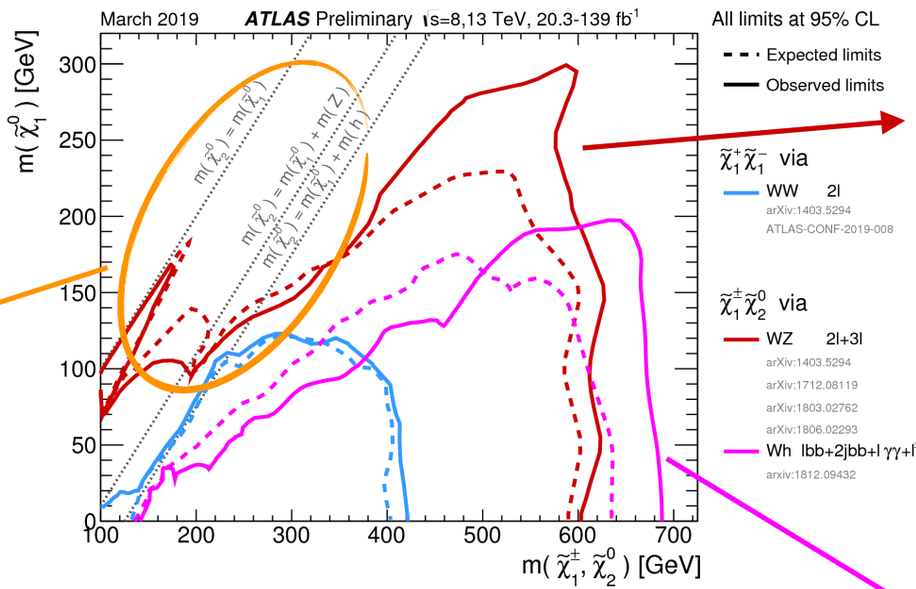
BACK UP

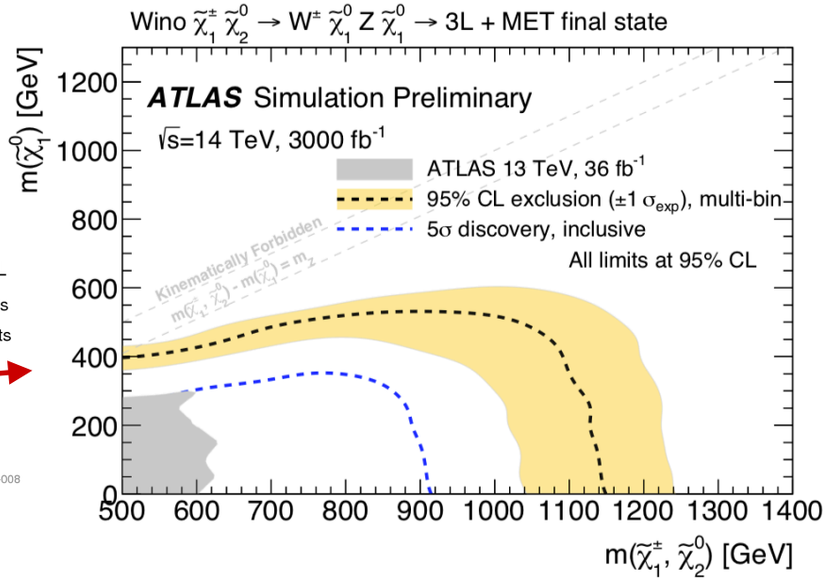
SUSY: EWKinos searches











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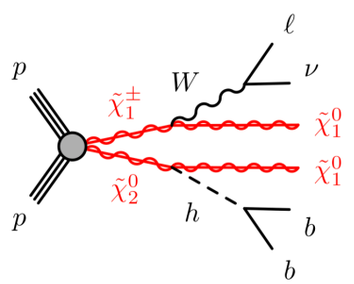
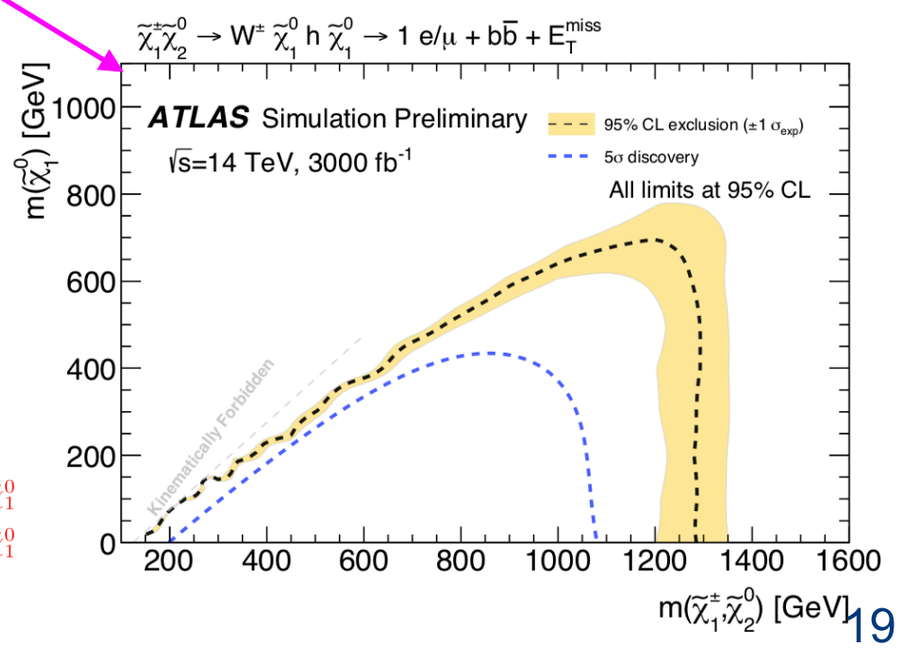
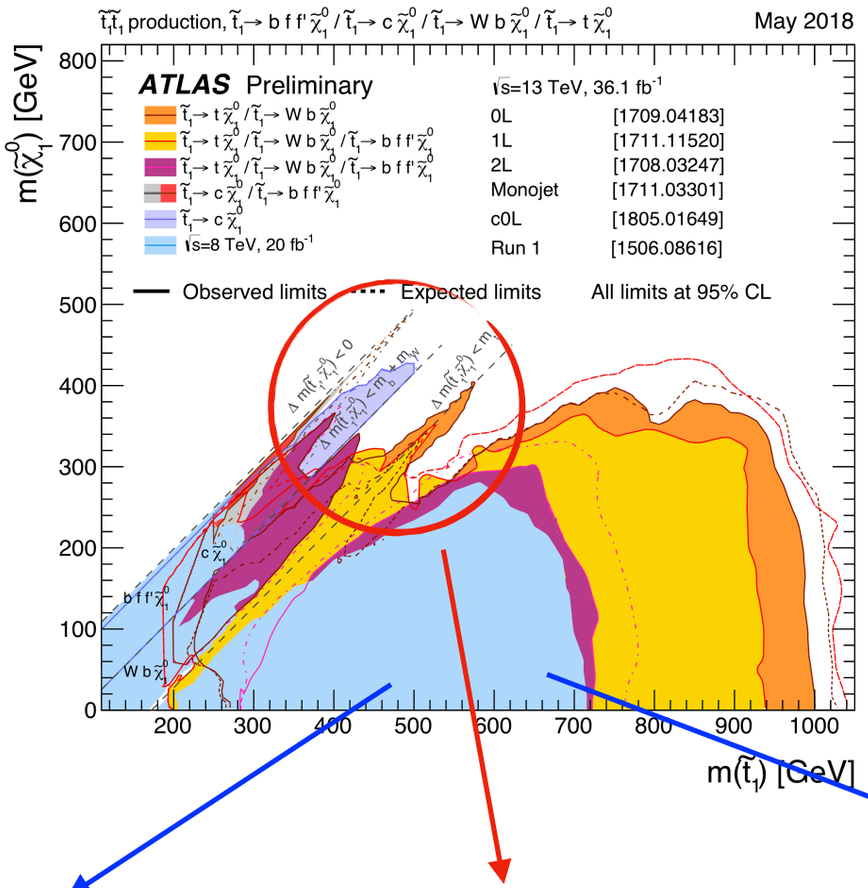
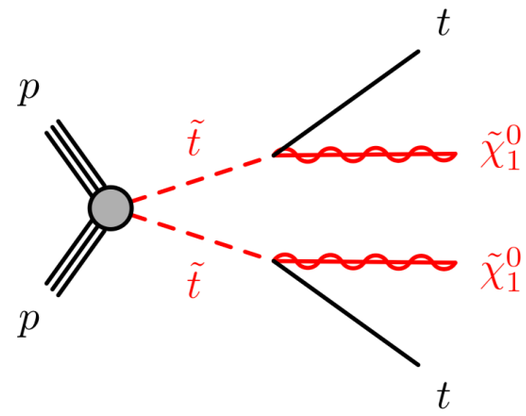




CMS-PAS-FTR-18-001

SUSY: Stop searches





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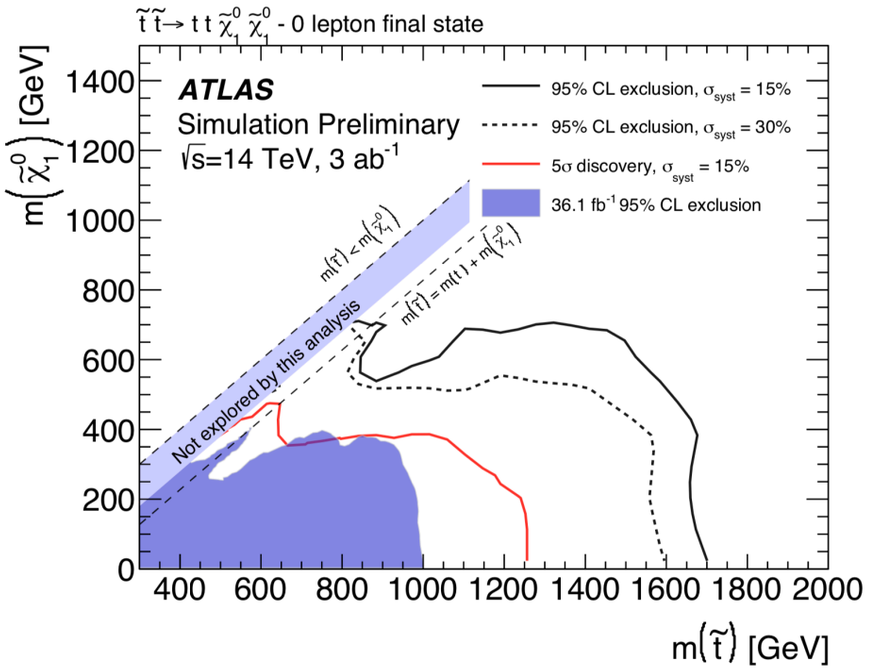

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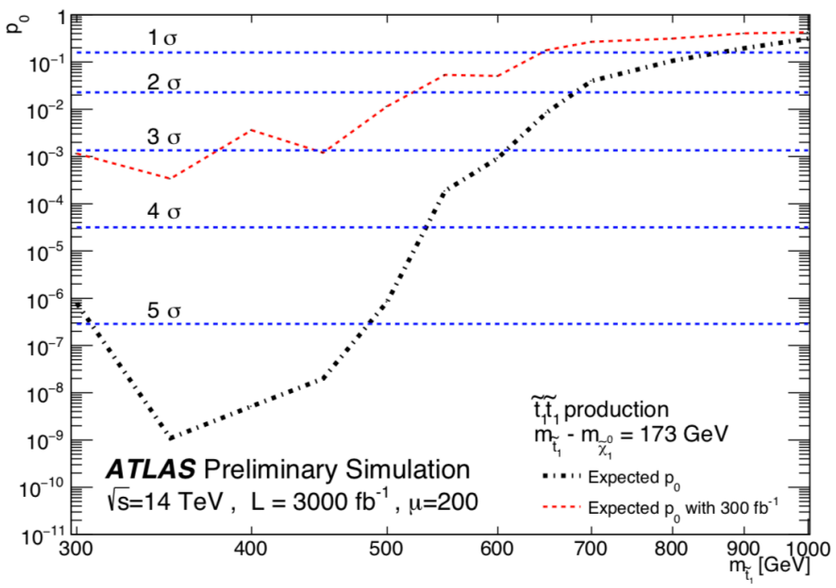
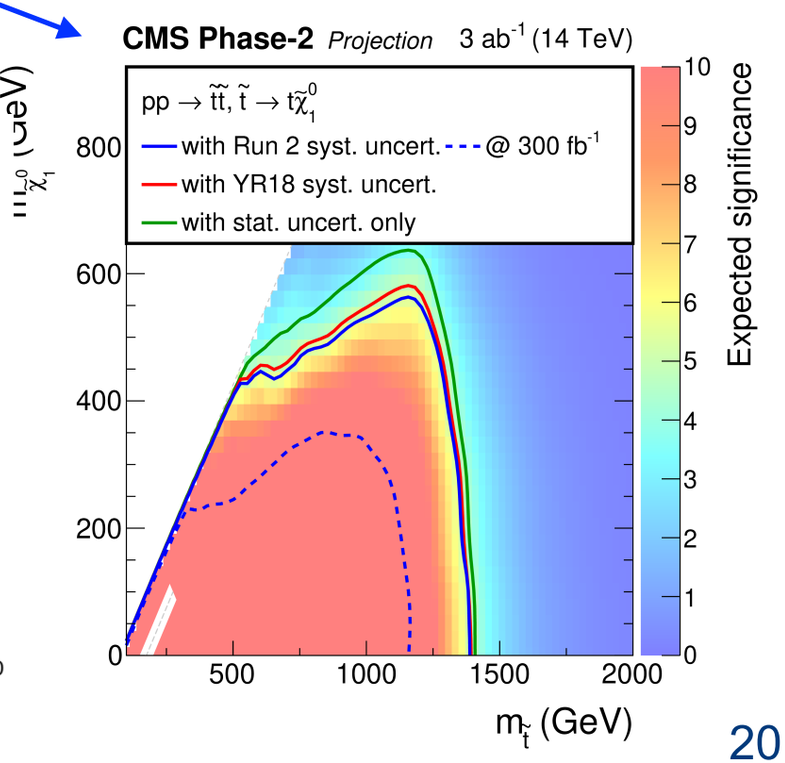


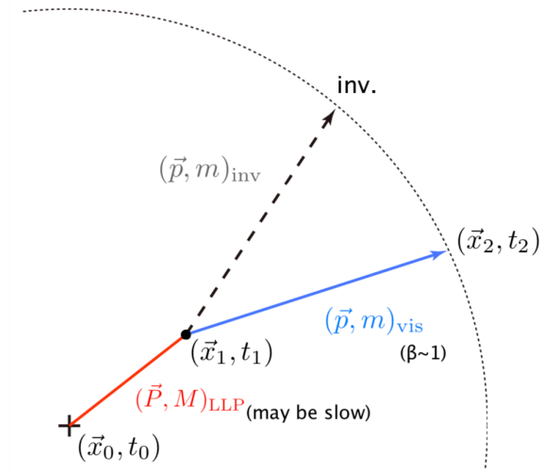
CMS-PAS-FTR-18-037



Timing detector

General feature:

a high granularity segmented timing detector surrounding the tracker.



CMS: MIP timing detector (MTD) will cover |η| < 3 Barrel

- with LYSO+SiPM, endcap with LGAD

ATLAS: LGAD-based technology (low-gain avalanche diode) covering 2.4 < |η| < 4

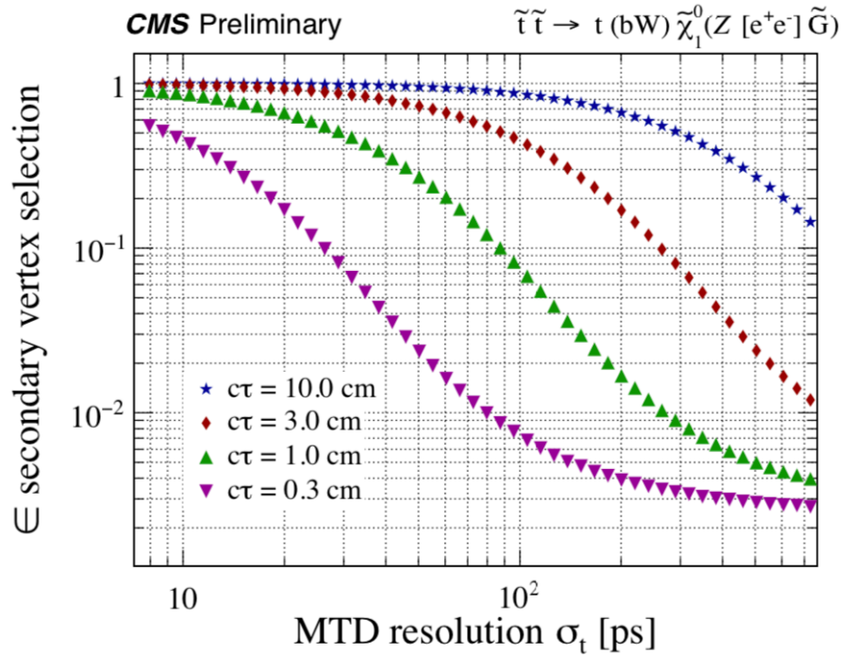
Primary motivation:

- resolving the timing of the primary vertices;
- stronger classification for e.g. jet-to-vertex classification.

Timing detectors would open more kinematic handles for LLP searches.

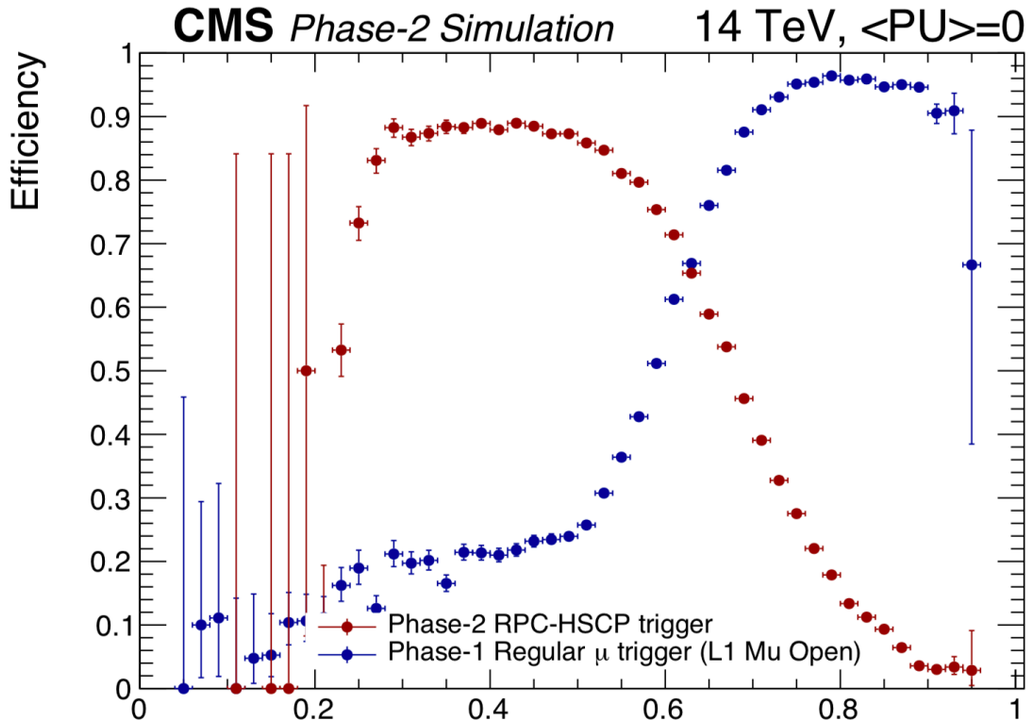
$$E_V^P = \gamma_P \left(E_V^{LAB} - \vec{P}_V^{LAB} \cdot \vec{\beta}_V^{LAB} \right) = \frac{m_P^2 - m_I^2 + m_V^2}{2m_P}$$

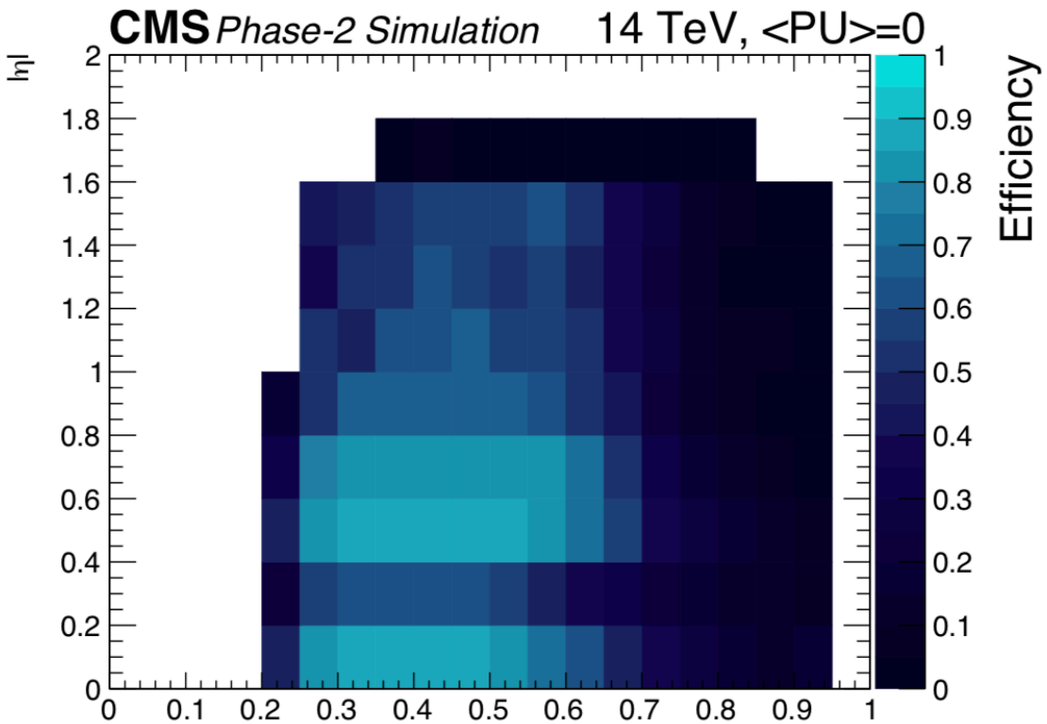
$$m_P = E_V^P + \sqrt{E_V^{P2} + m_I^2 - m_V^2}$$

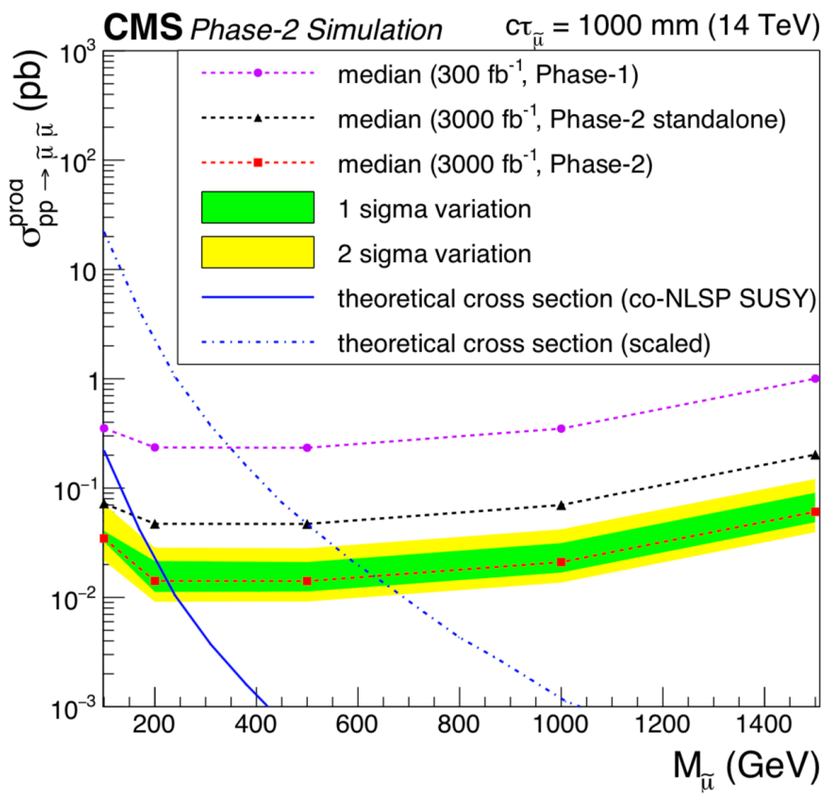


HSCP

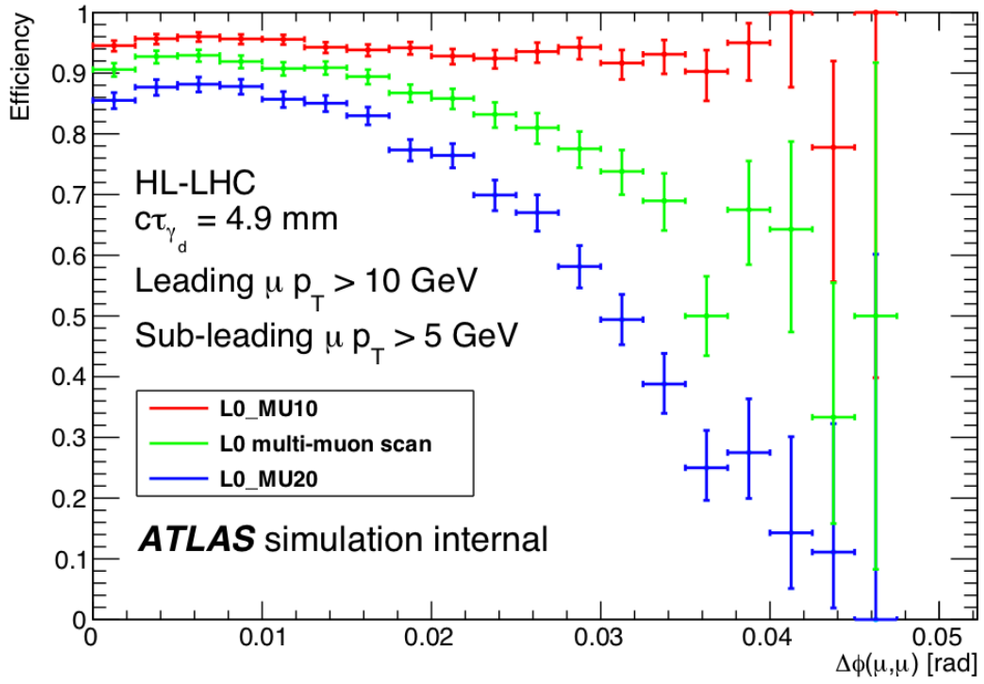
* ϵ~90% for β>0.25
  (in Run-2 ϵ~20% for β<0.5)

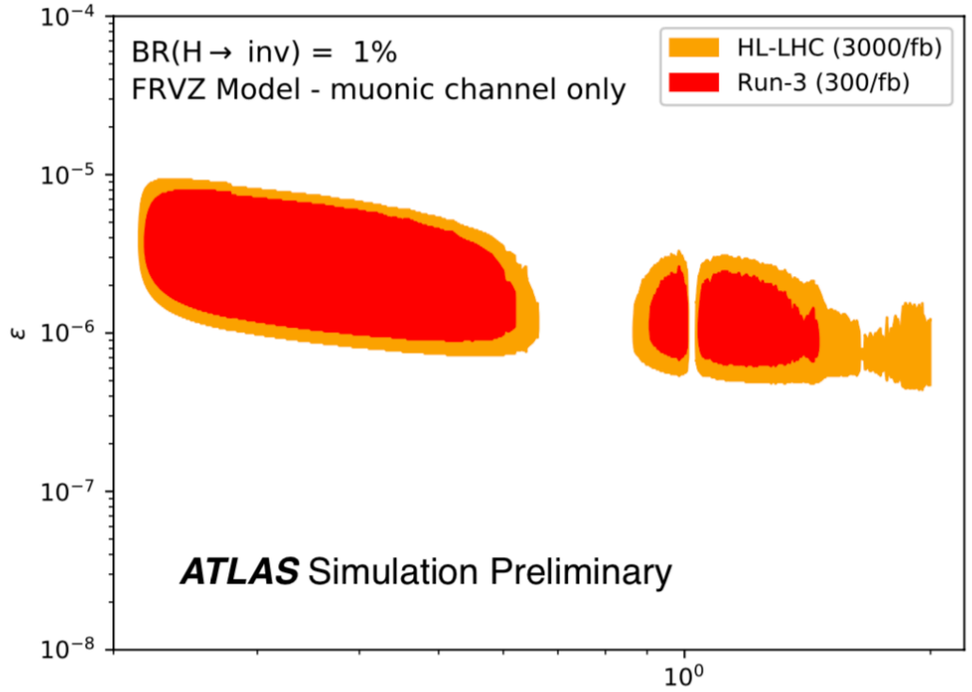


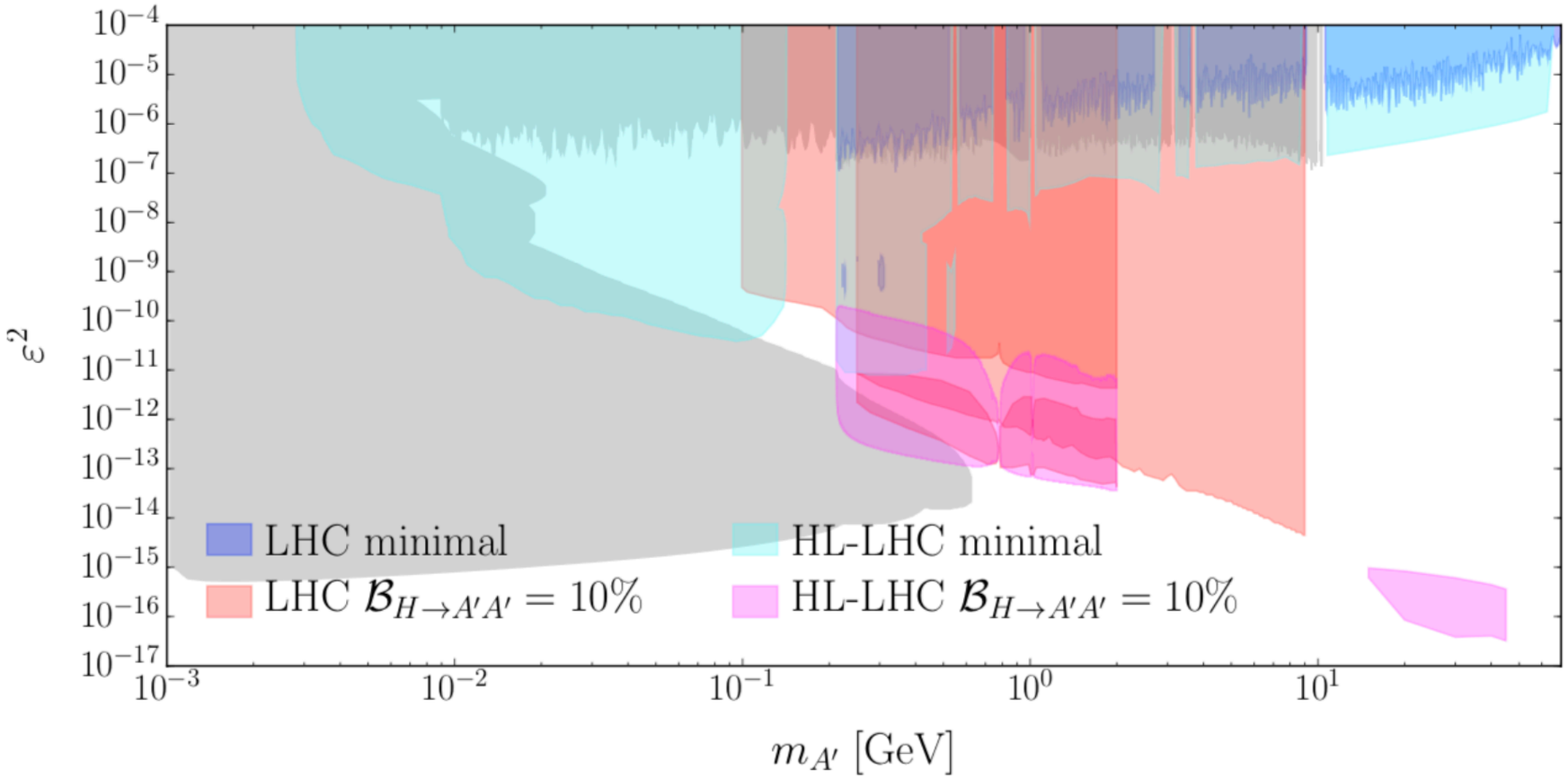




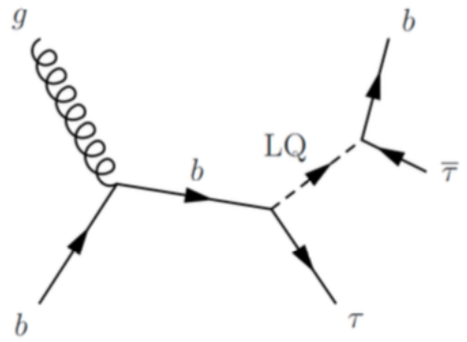
Dark Photons

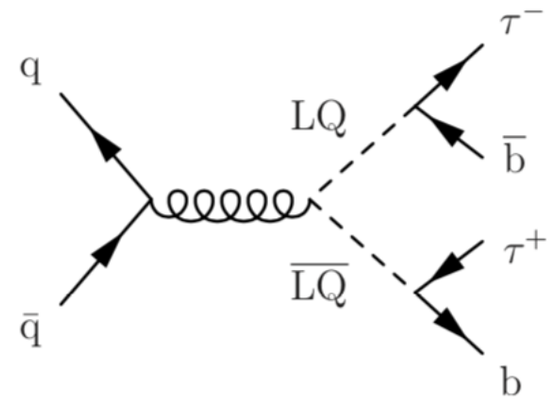






LeptoQuark searches





LQ→τb

discovery up to 1.5 TeV with pair production (stats dominated)

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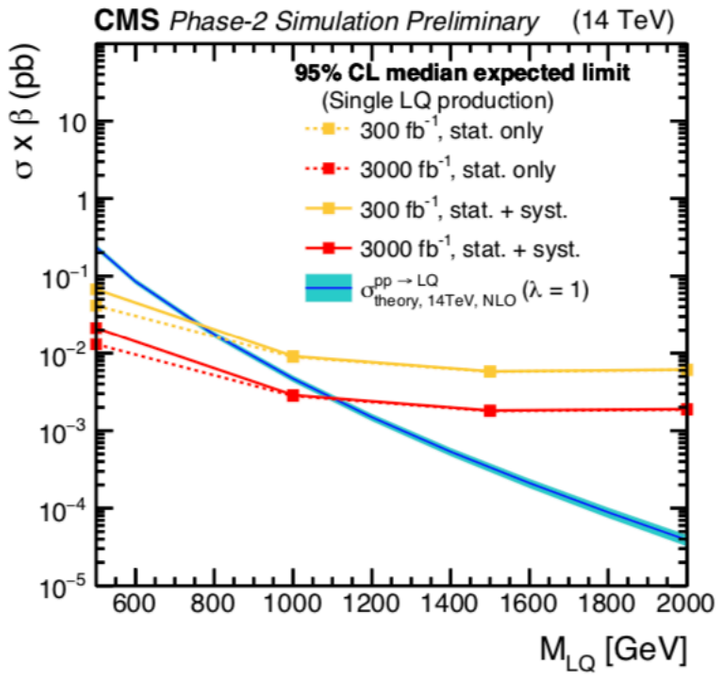

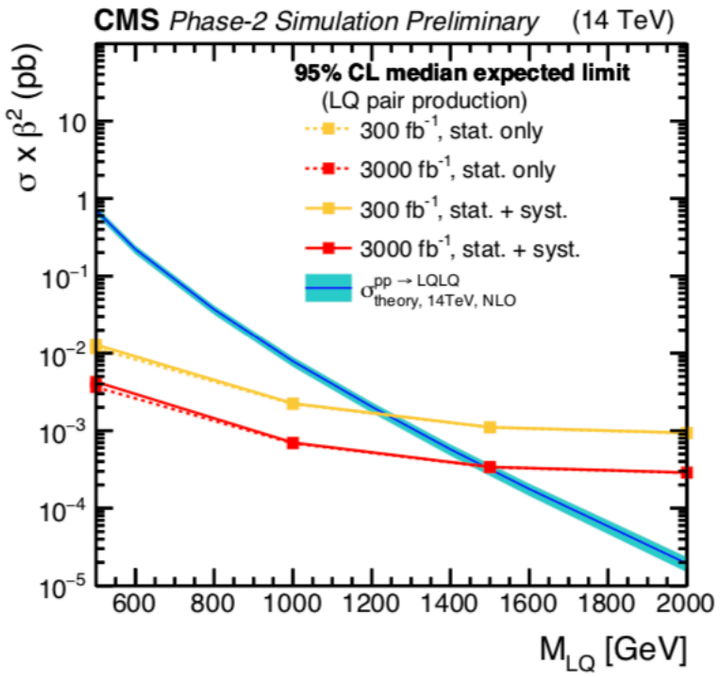

LQ→τμ

>500 GeV
gain wrt 36 fb^{-1}

LQ→τt

~400 GeV gain

wrt 36 fb^{-1}

CMS-PAS-FTR-18-008