MICHIGAN STATE UNIVERSITY

Hunting for Beyond-Standard-Model physics with the ATLAS detector at the HL-LHC

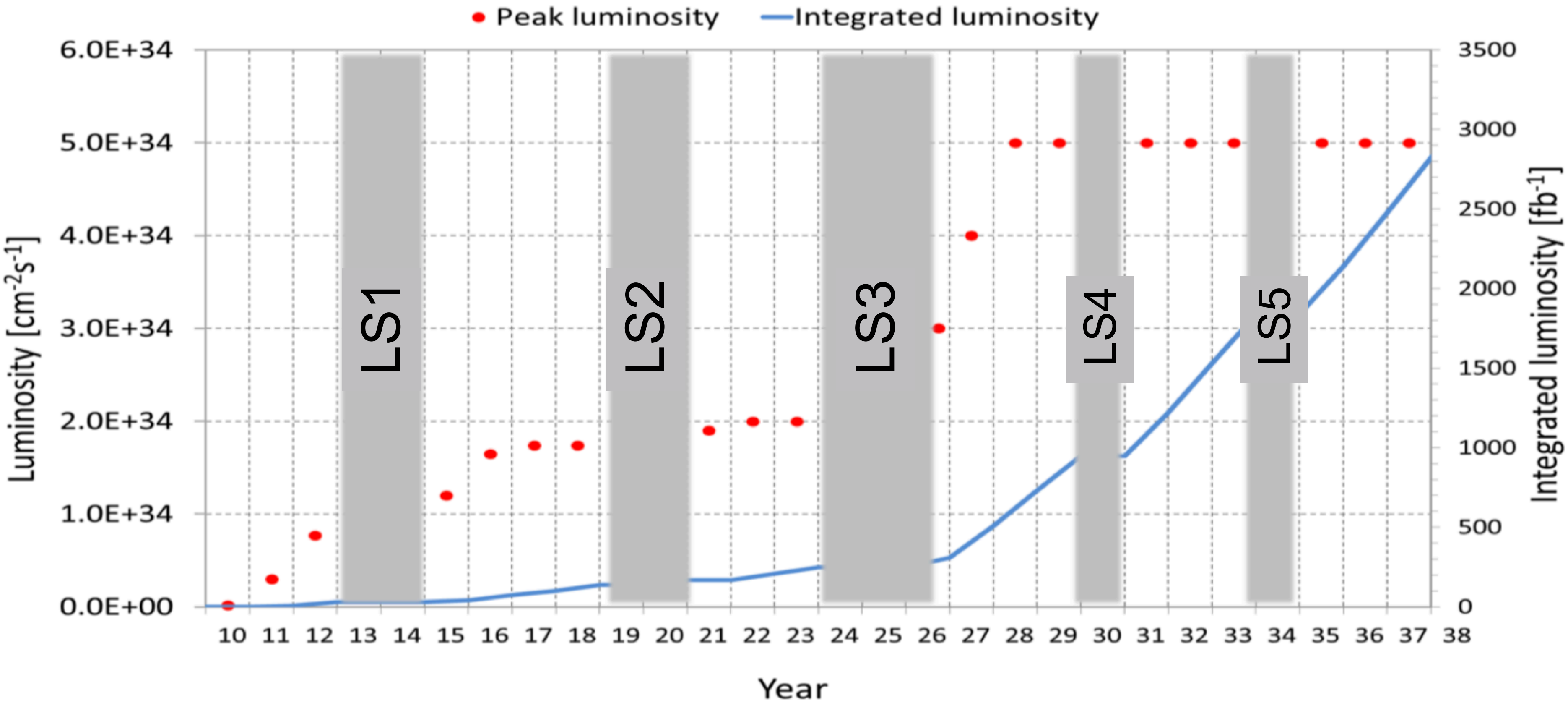
On behalf of the ATLAS Collaboration

EPS Conference
12th of July 2019

Daniel Hayden
daniel.hayden@cern.ch

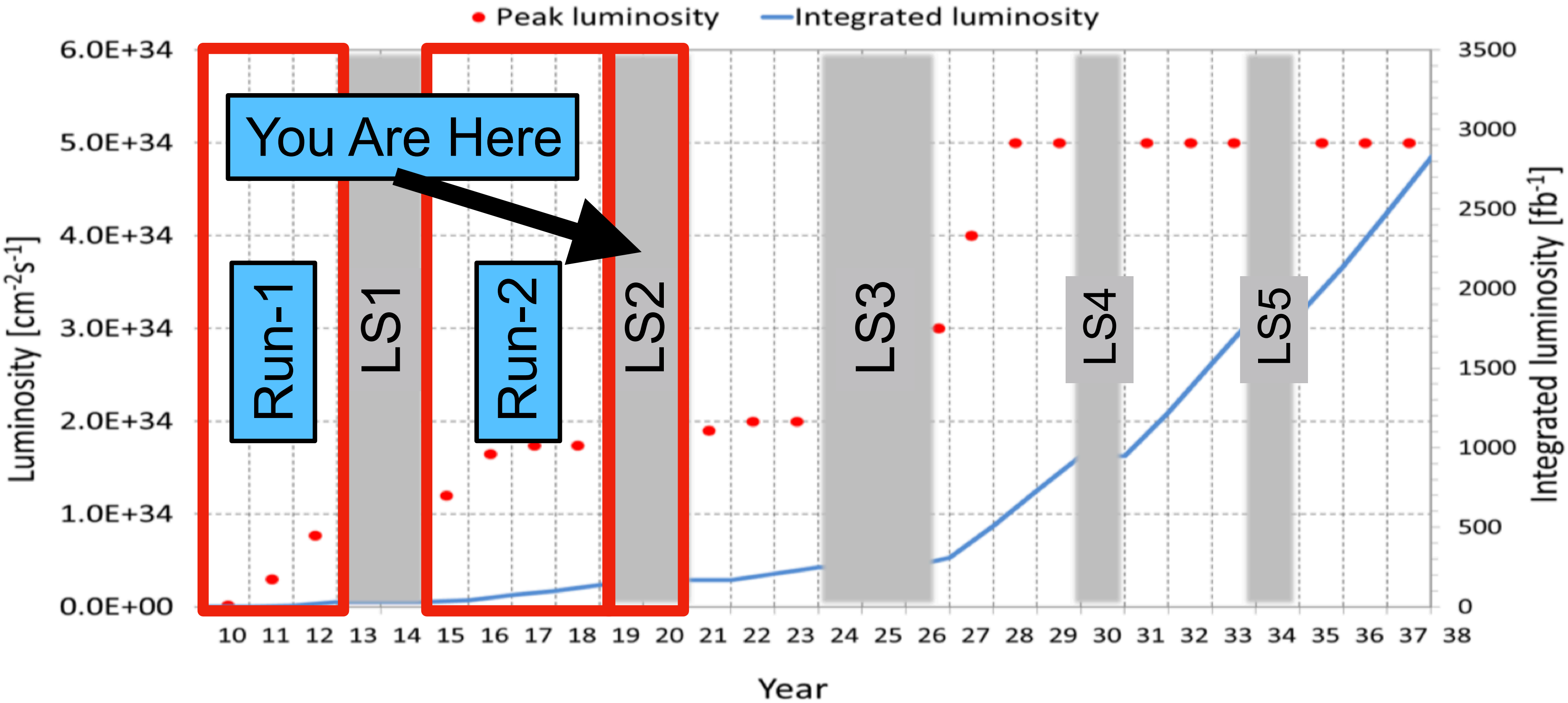
HL-LHC TDR

What is the HL-LHC?



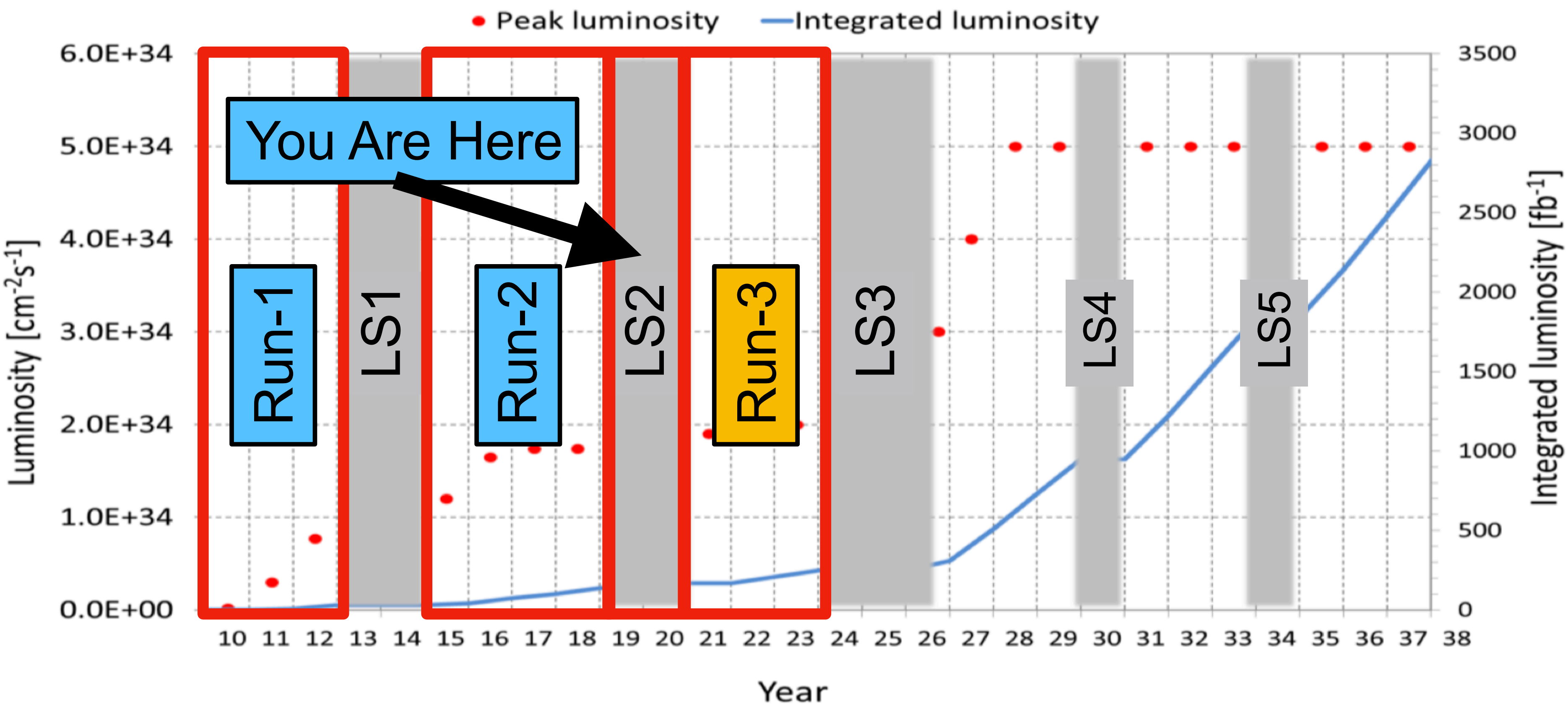
What is the HL-LHC?

HL-LHC TDR



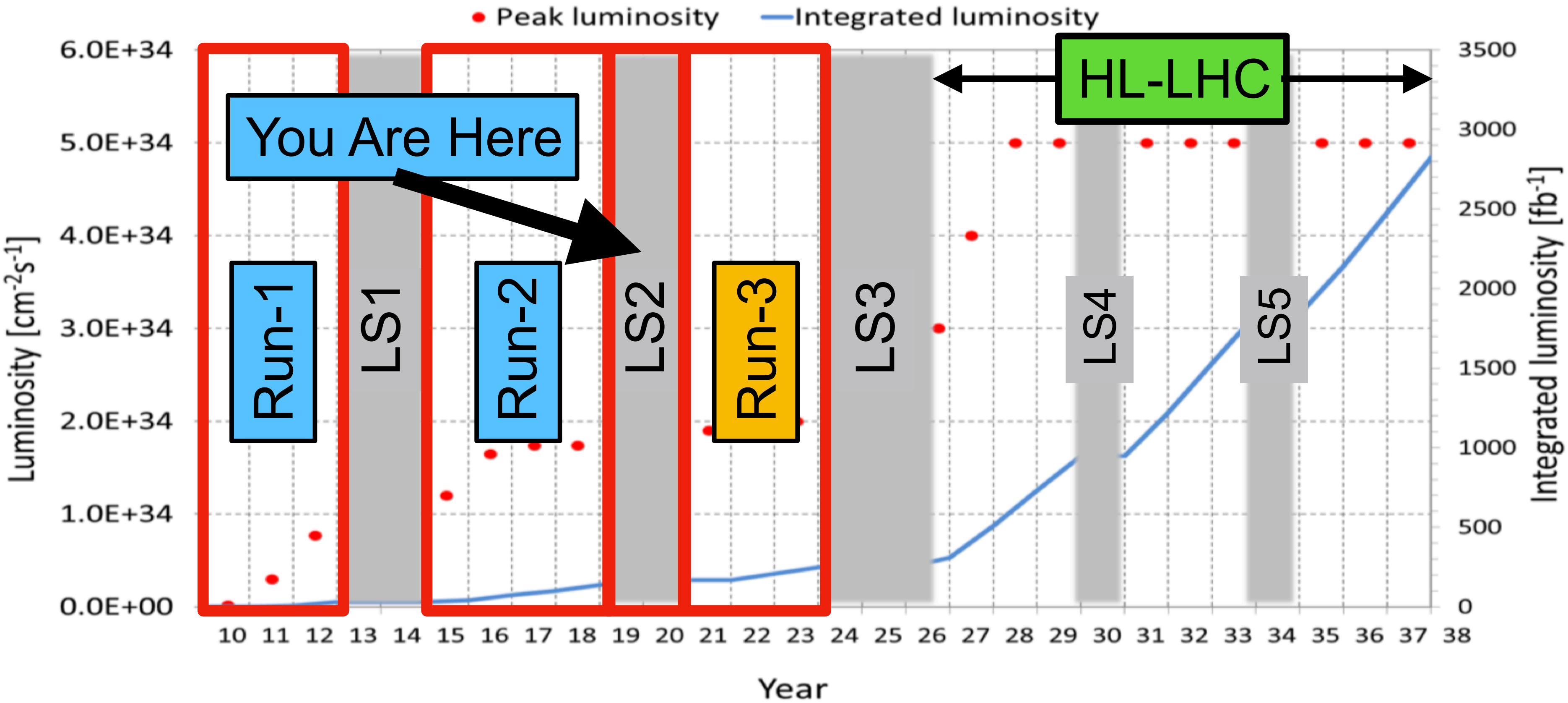
HL-LHC TDR

What is the HL-LHC?



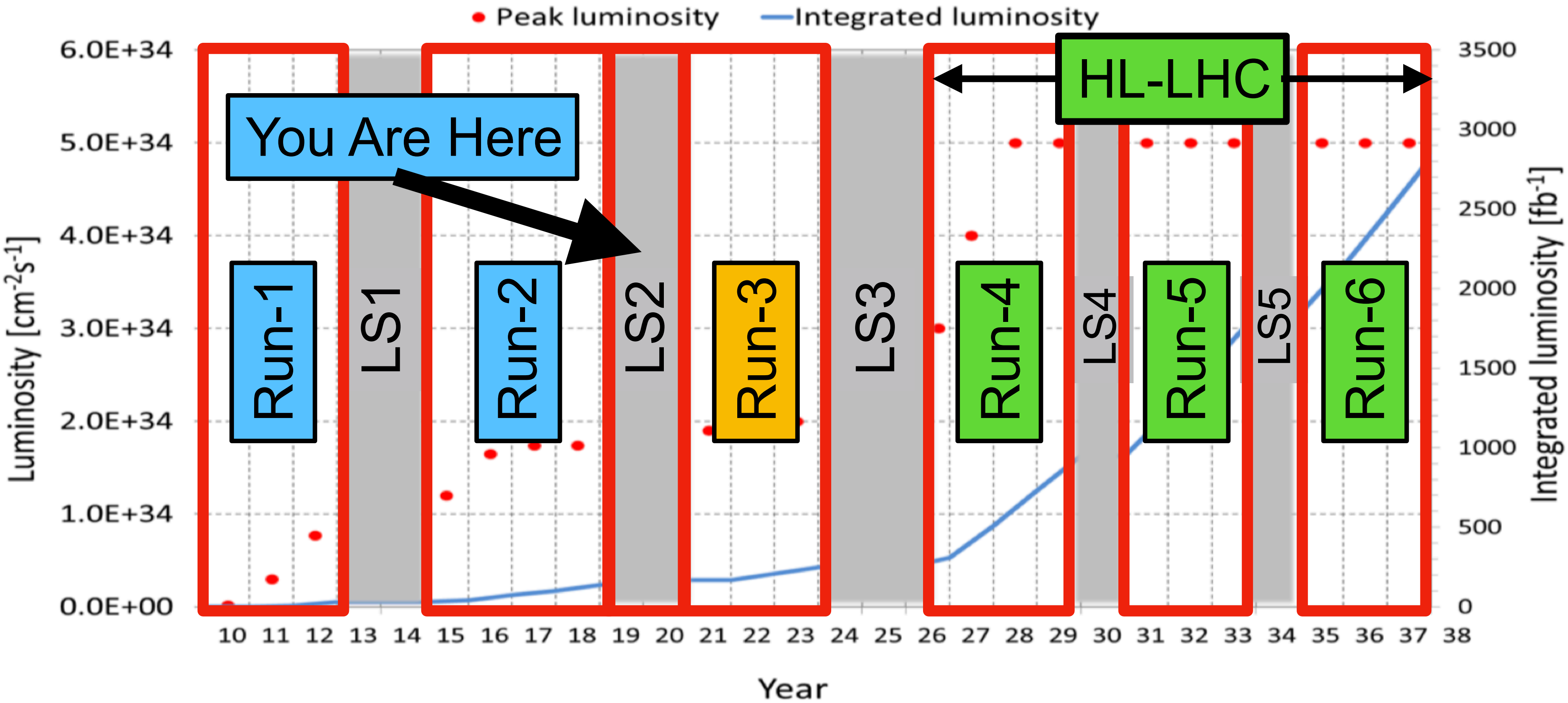
What is the HL-LHC?

HL-LHC TDR



HL-LHC TDR

What is the HL-LHC?



- Only collected 5% of the LHC lifetime dataset!
- Need to upgrade both LHC, and ATLAS.

ATLAS Phase-II Scoping Document

Many Challenges for ATLAS…

Higher Instantaneous Luminosity:

$1.8 \times 10^{34}\ cm^{-2}s^{-1} \rightarrow 5 \times 10^{34}\ cm^{-2}s^{-1}$.

Higher Integrated Luminosity:

$300\ fb^{-1} \rightarrow 3000\ fb^{-1}$. ($4\ ab^{-1}$?).

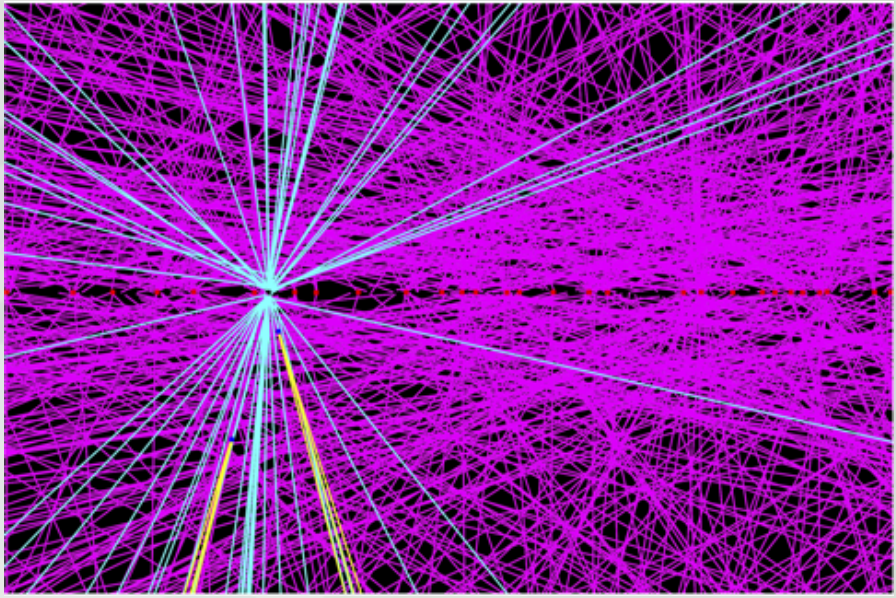
Many Challenges for ATLAS…

ATLAS Phase-II Scoping Document

Higher Instantaneous Luminosity:
1.8 x 10^{34} $cm^{-2}s^{-1}$ → 5 x 10^{34} $cm^{-2}s^{-1}$.

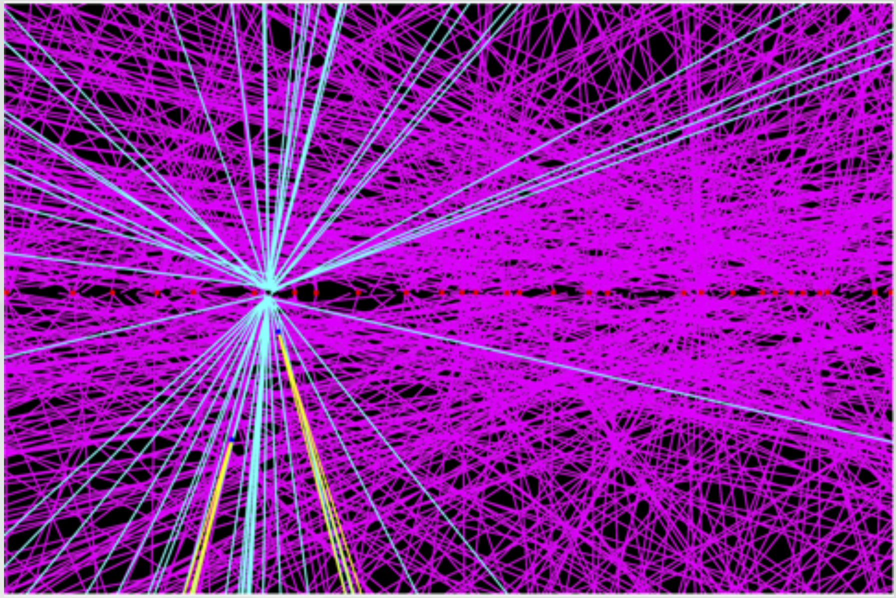
Higher Integrated Luminosity:
300 fb^{-1} → 3000 fb^{-1}. (4 ab^{-1}?).

Higher Pile-Up:
$\langle\mu\rangle = 60$ → $\langle\mu\rangle = 140$. (200?).



ATLAS Phase-II Scoping Document

Many Challenges for ATLAS…



Higher Instantaneous Luminosity:
1.8×10^{34} cm^{-2}s^{-1} → 5×10^{34} cm^{-2}s^{-1}.

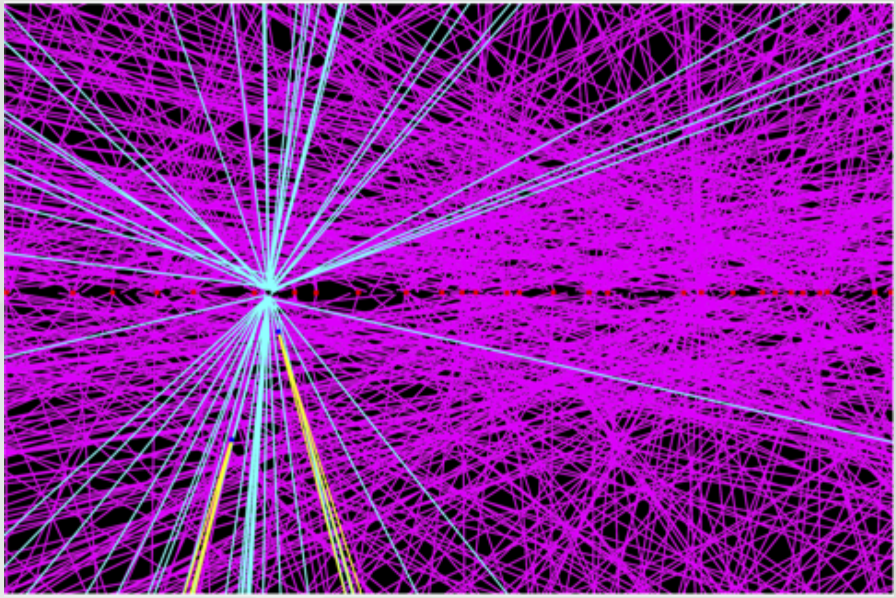
Higher Integrated Luminosity:
300 fb^{-1} → 3000 fb^{-1}. (4 ab^{-1}?).

Higher Pile-Up:
$\langle\mu\rangle = 60$ → $\langle\mu\rangle = 140$. (200?).

Higher Radiation Doses:
Up to factor 10 increase.

ATLAS Phase-II Scoping Document

Many Challenges for ATLAS…



Higher Instantaneous Luminosity:
$1.8 \times 10^{34}\ cm^{-2}s^{-1} \rightarrow 5 \times 10^{34}\ cm^{-2}s^{-1}$.

Higher Integrated Luminosity:
300 fb^{-1} → 3000 fb^{-1}. (4 ab^{-1}?).

Higher Pile-Up:
$\langle\mu\rangle = 60 \rightarrow \langle\mu\rangle = 140$. (200?).

Higher Radiation Doses:
Up to factor 10 increase.

Higher Trigger Rates, L1 (Final):
100 kHz (1 kHz) → 1 MHz (10 kHz).

Many Challenges for ATLAS…

[ATLAS Phase-II Scoping Document]

Higher Instantaneous Luminosity:
$1.8 \times 10^{34}\ cm^{-2}s^{-1} \rightarrow 5 \times 10^{34}\ cm^{-2}s^{-1}$.

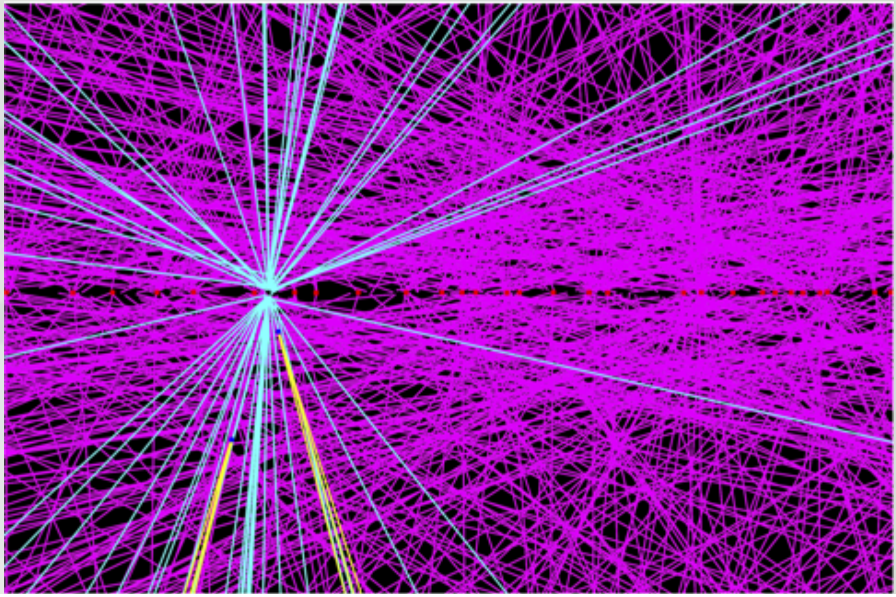
Higher Integrated Luminosity:
300 fb^{-1} → 3000 fb^{-1}. (4 ab^{-1}?).

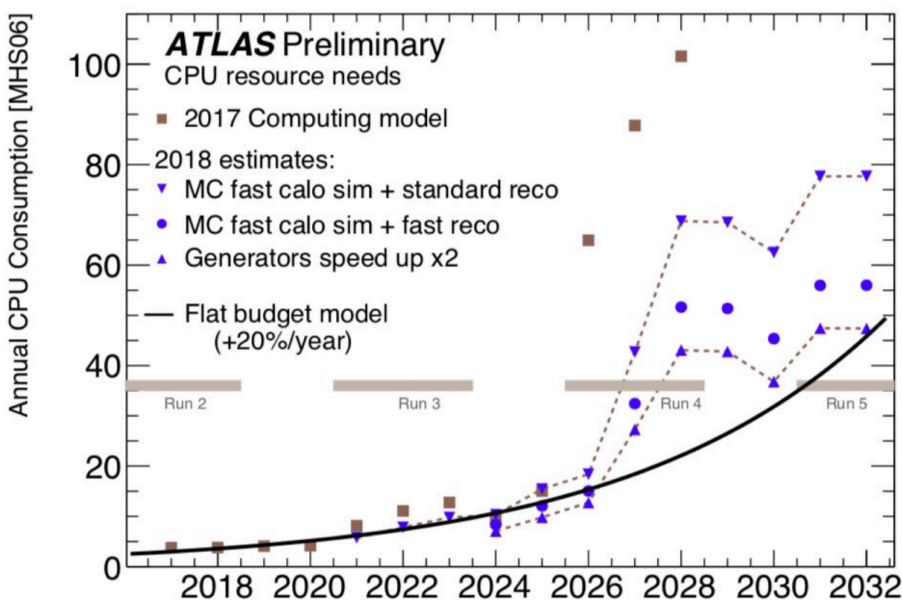
Higher Pile-Up:
$\langle\mu\rangle = 60 \rightarrow \langle\mu\rangle = 140$. (200?).

Higher Radiation Doses:
Up to factor 10 increase.

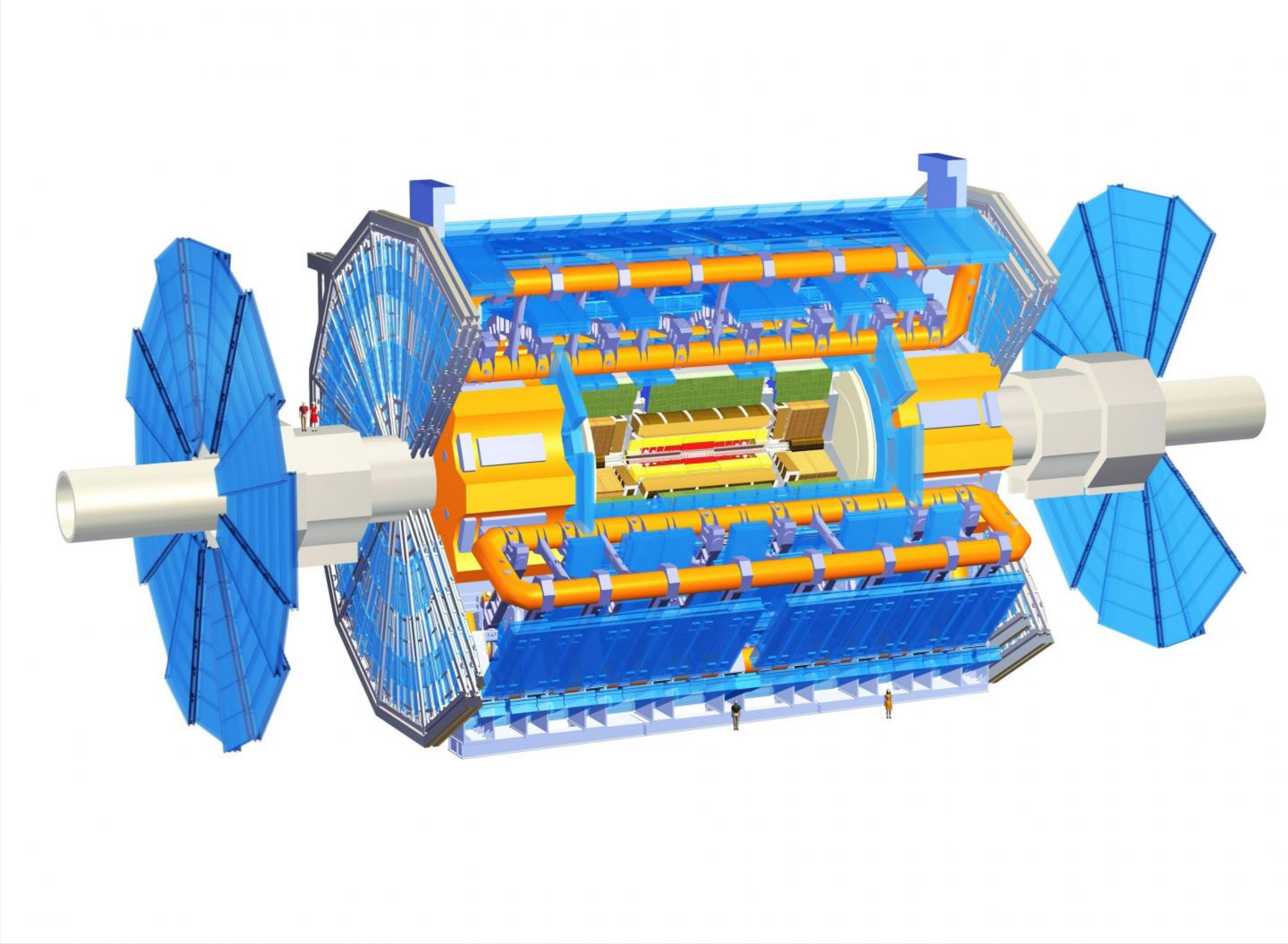
Higher Trigger Rates, L1 (Final):
100 kHz (1 kHz) → 1 MHz (10 kHz).

Higher Computing Resource Needs.



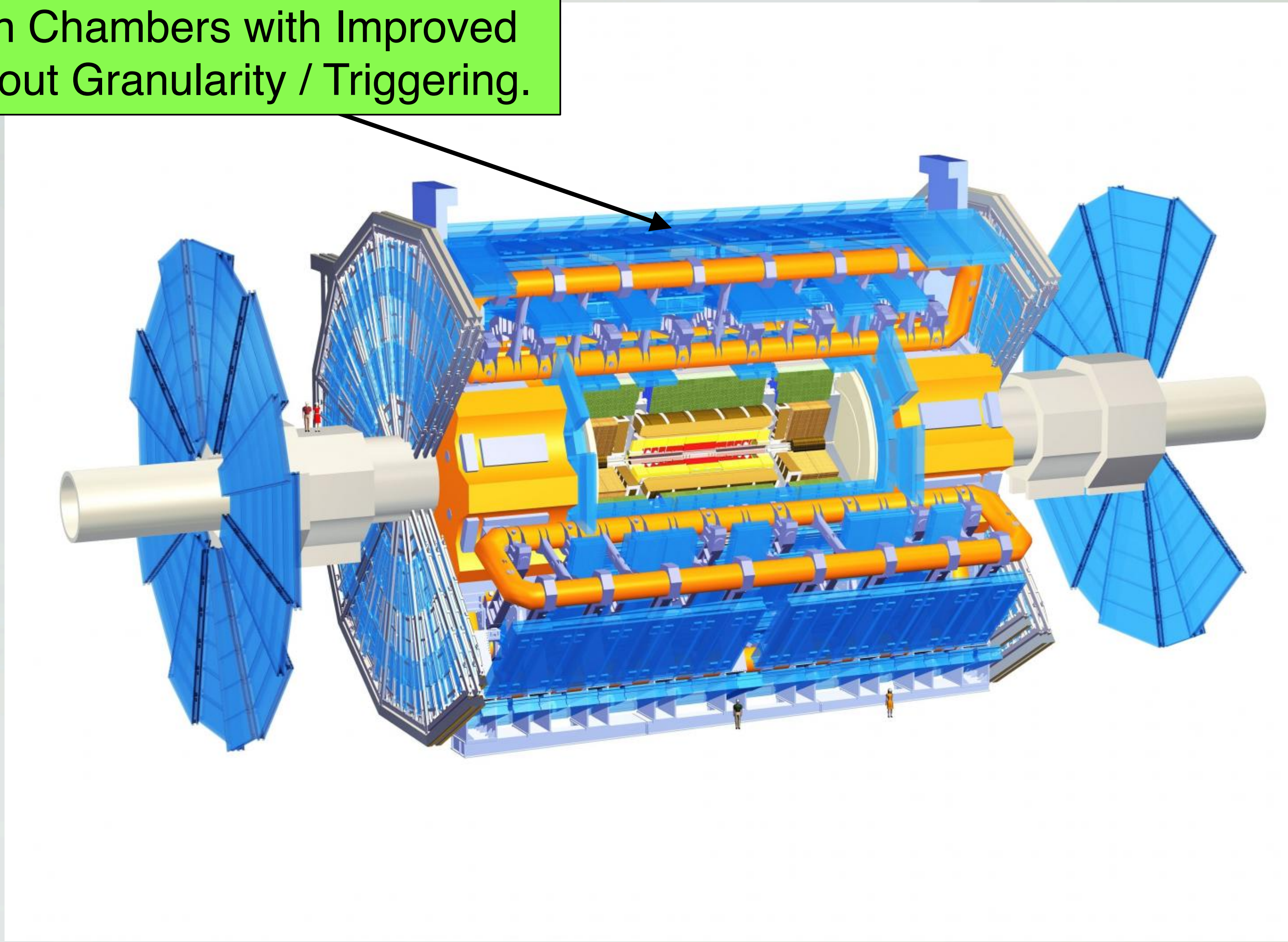


…And Upgrades to Meet Them!



…And Upgrades to Meet Them!

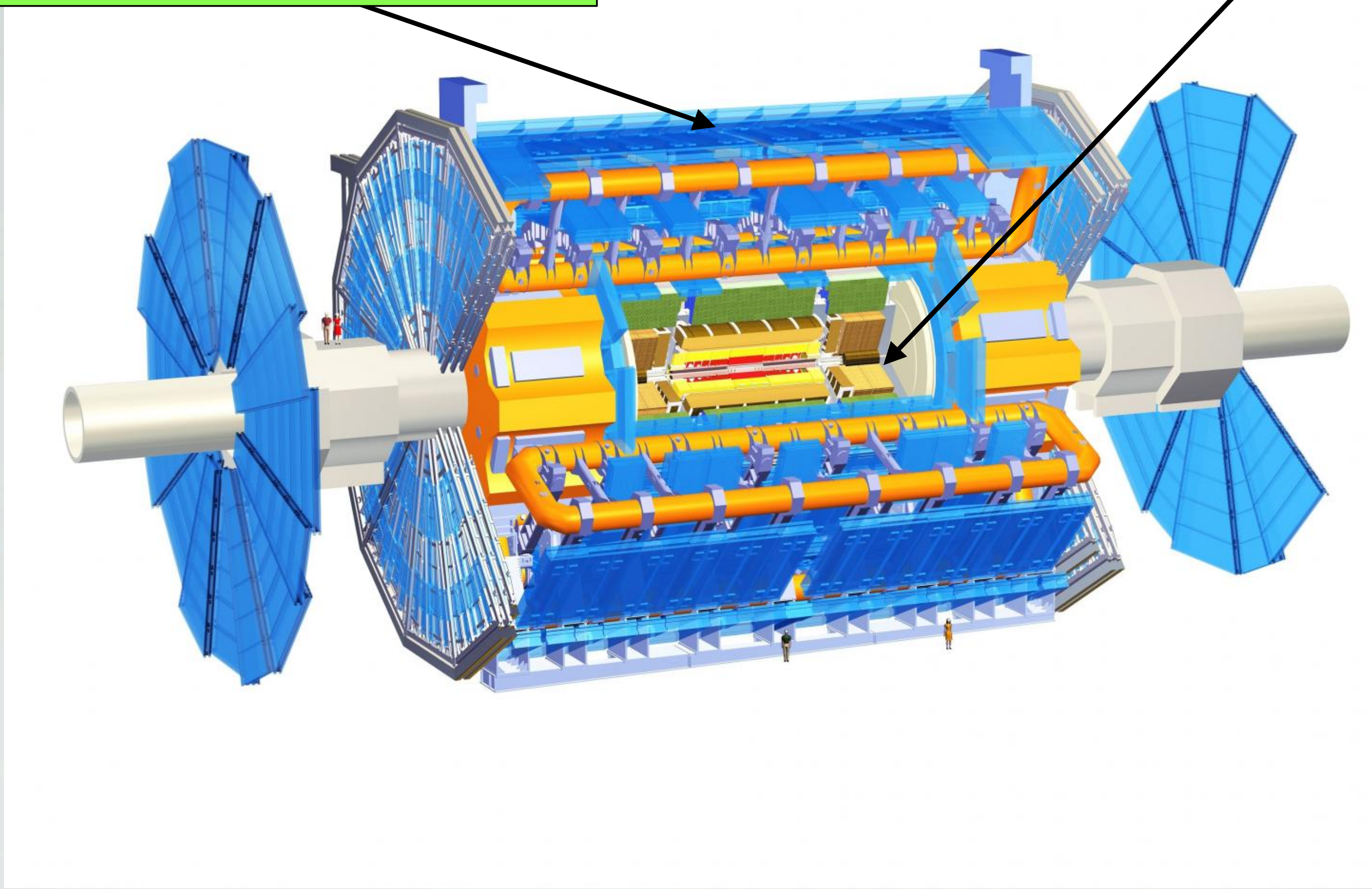
Muon Chambers with Improved Readout Granularity / Triggering.



…And Upgrades to Meet Them!

Muon Chambers with Improved Readout Granularity / Triggering.

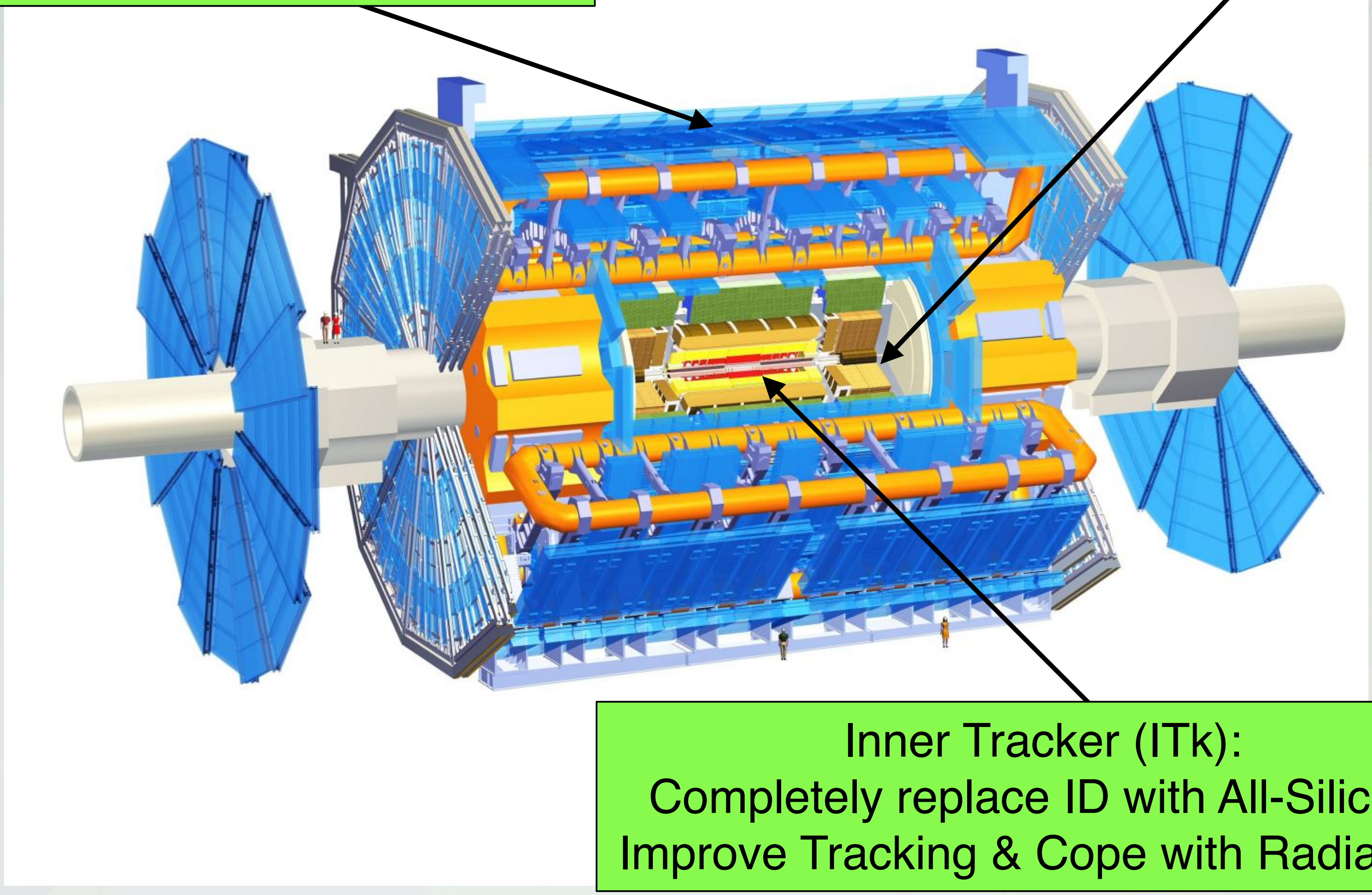
High Granularity Timing Detector (HGTD): $2.4 < |\eta| < 4.3$ (5.0?)



…And Upgrades to Meet Them!

Muon Chambers with Improved Readout Granularity / Triggering.

High Granularity Timing Detector (HGTD): $2.4 < |\eta| < 4.3$ (5.0?)

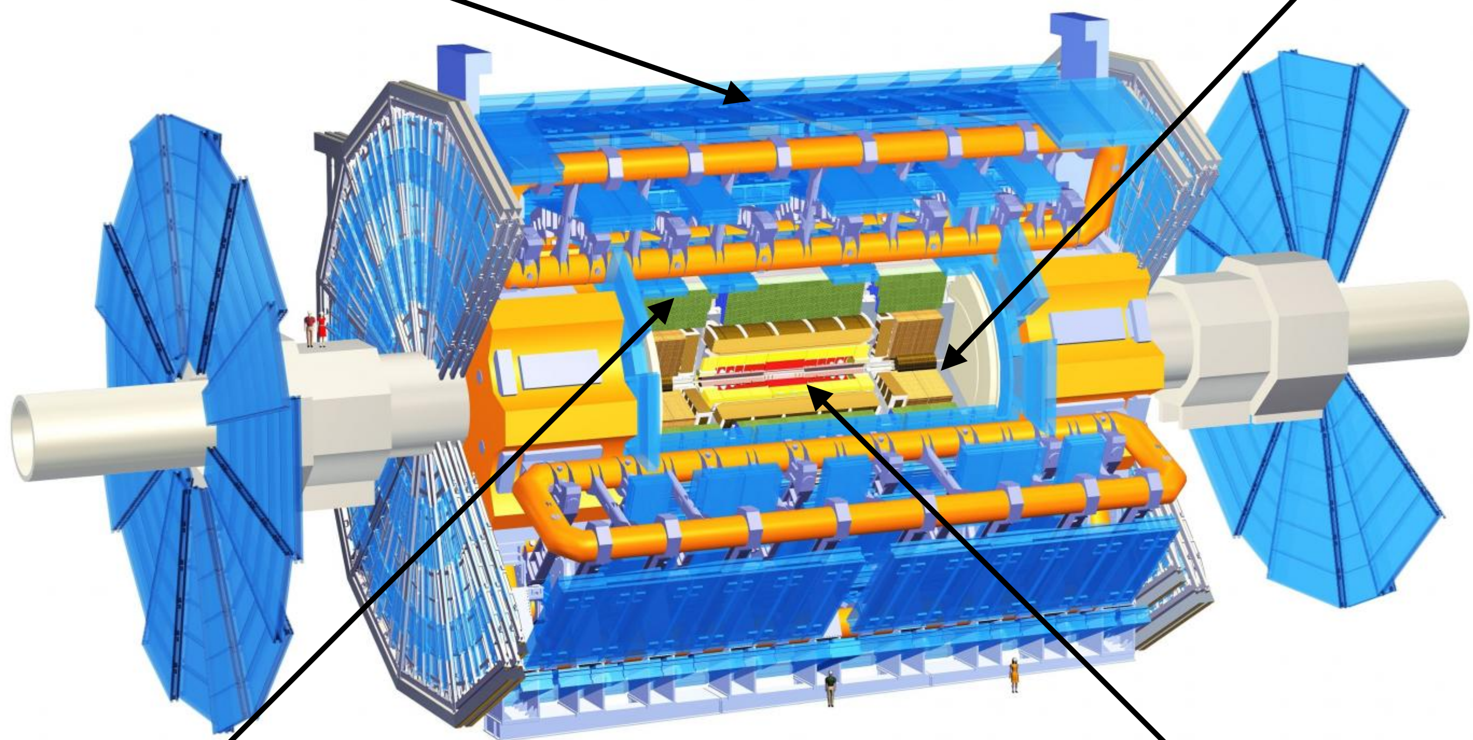


Inner Tracker (ITk):
Completely replace ID with All-Silicon.
Improve Tracking & Cope with Radiation.

…And Upgrades to Meet Them!

Muon Chambers with Improved Readout Granularity / Triggering.

High Granularity Timing Detector (HGTD): $2.4 < |\eta| < 4.3$ (5.0?)



LAr & Tile Readout/Power using Radiation Tolerant Technology.

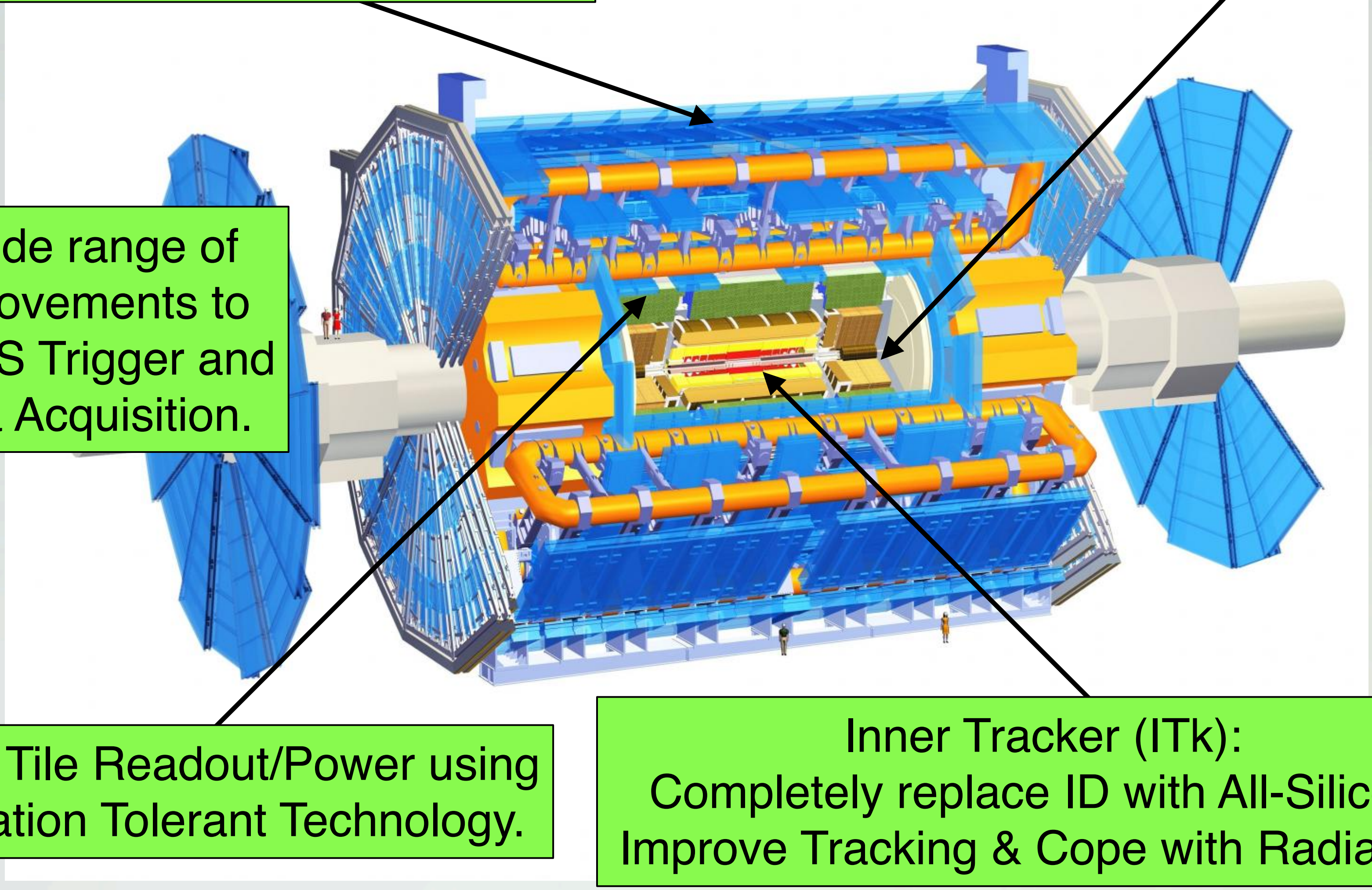
Inner Tracker (ITk):
Completely replace ID with All-Silicon.
Improve Tracking & Cope with Radiation.

…And Upgrades to Meet Them!

High Granularity Timing Detector (HGTD):
$2.4 < |\eta| < 4.3$ (5.0?)

Muon Chambers with Improved Readout Granularity / Triggering.

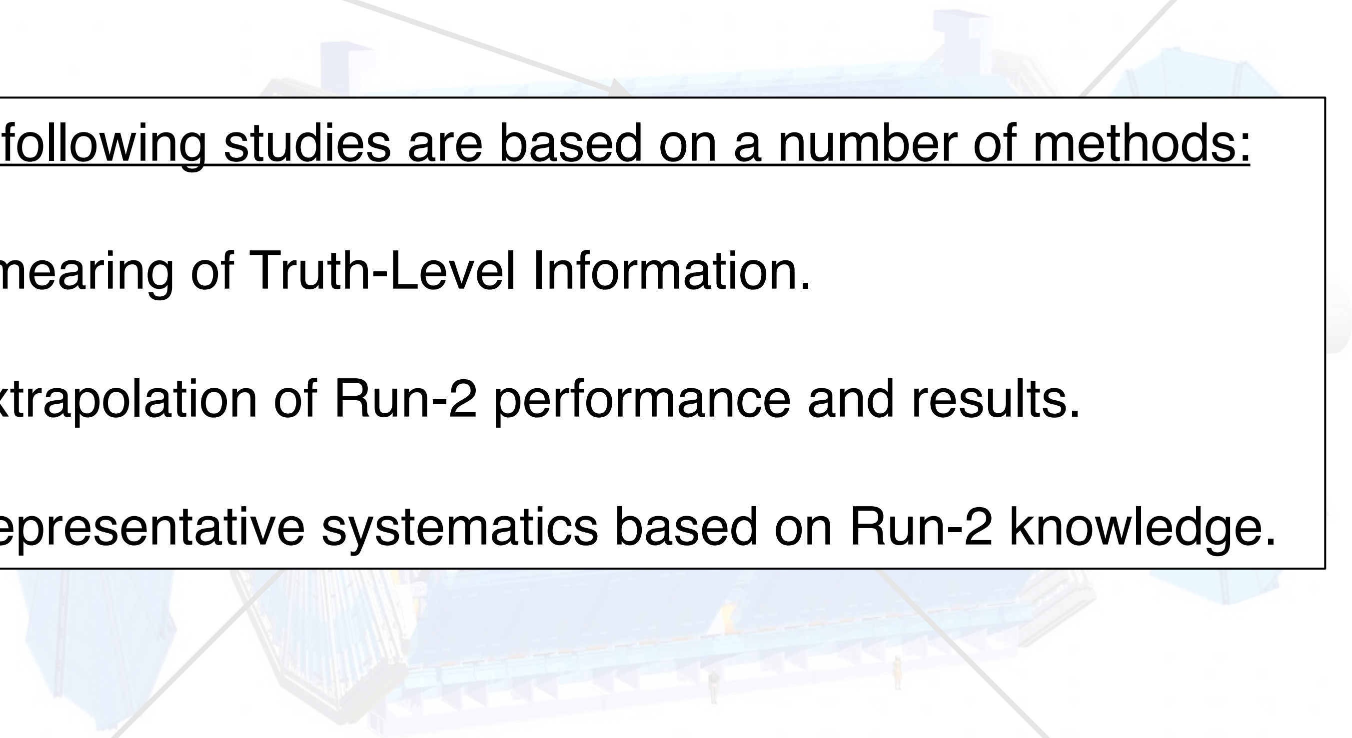
A wide range of improvements to ATLAS Trigger and Data Acquisition.



LAr & Tile Readout/Power using Radiation Tolerant Technology.

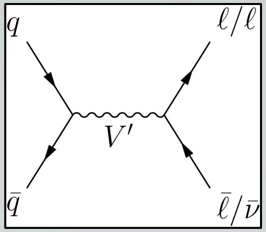
Inner Tracker (ITk):
Completely replace ID with All-Silicon.
Improve Tracking & Cope with Radiation.

…And Upgrades to Meet Them!



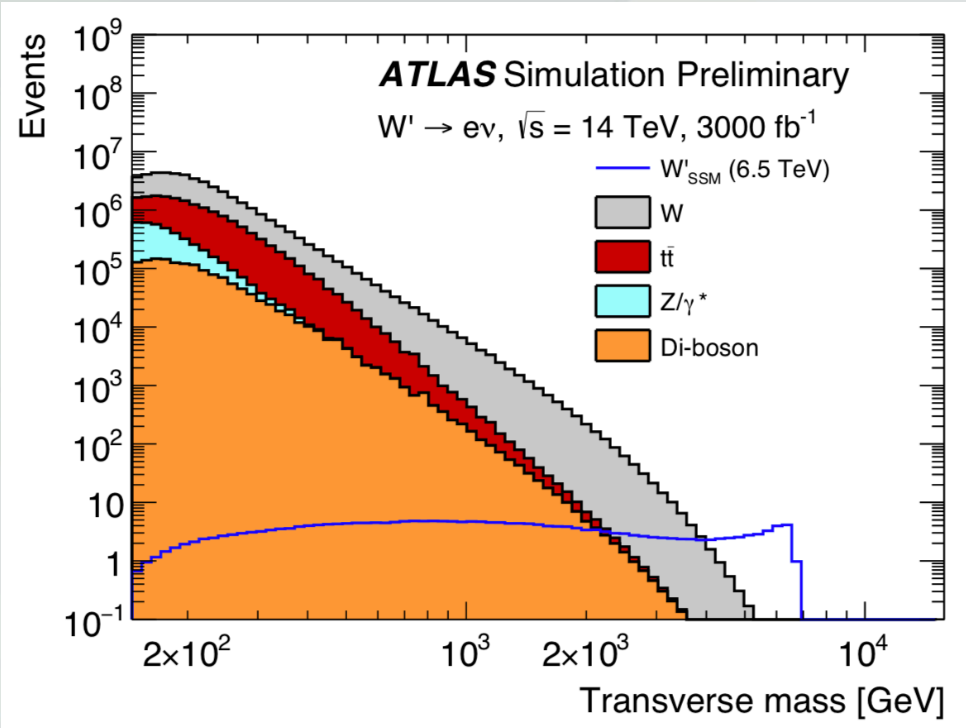
<u>The following studies are based on a number of methods:</u>

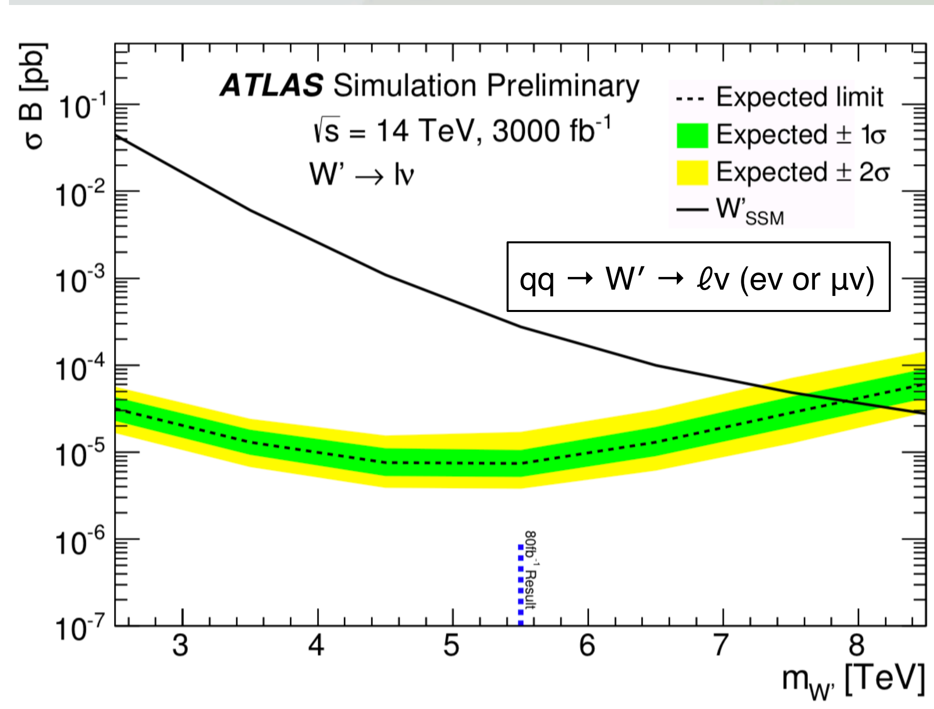
- Smearing of Truth-Level Information.
- Extrapolation of Run-2 performance and results.
- Representative systematics based on Run-2 knowledge.



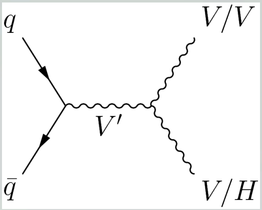
Searching for Resonances at the HL-LHC: Leptonic Searches

ATLAS HL-LHC Prospects



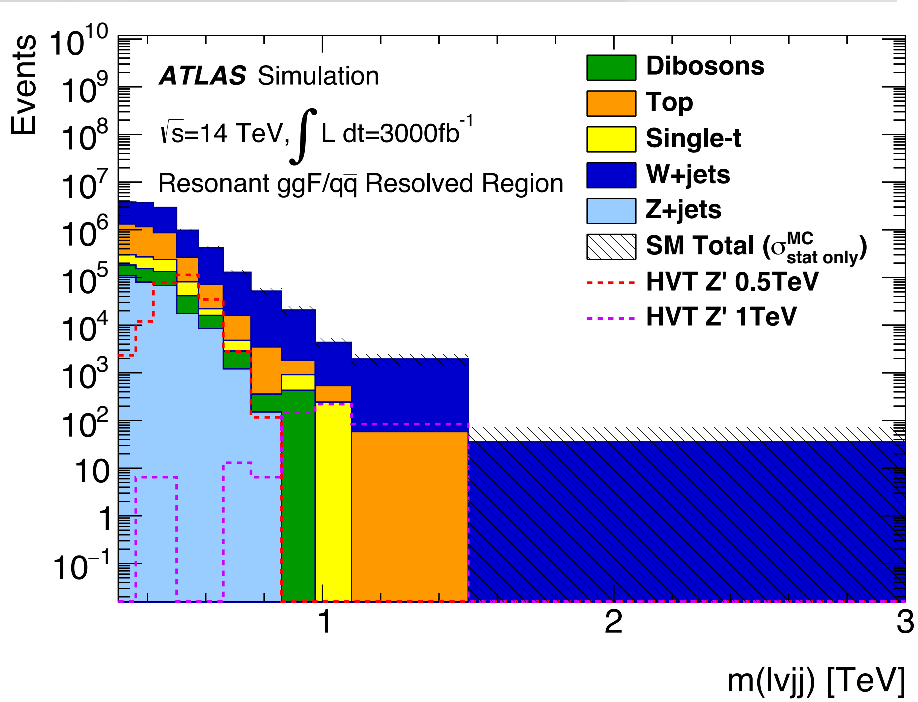


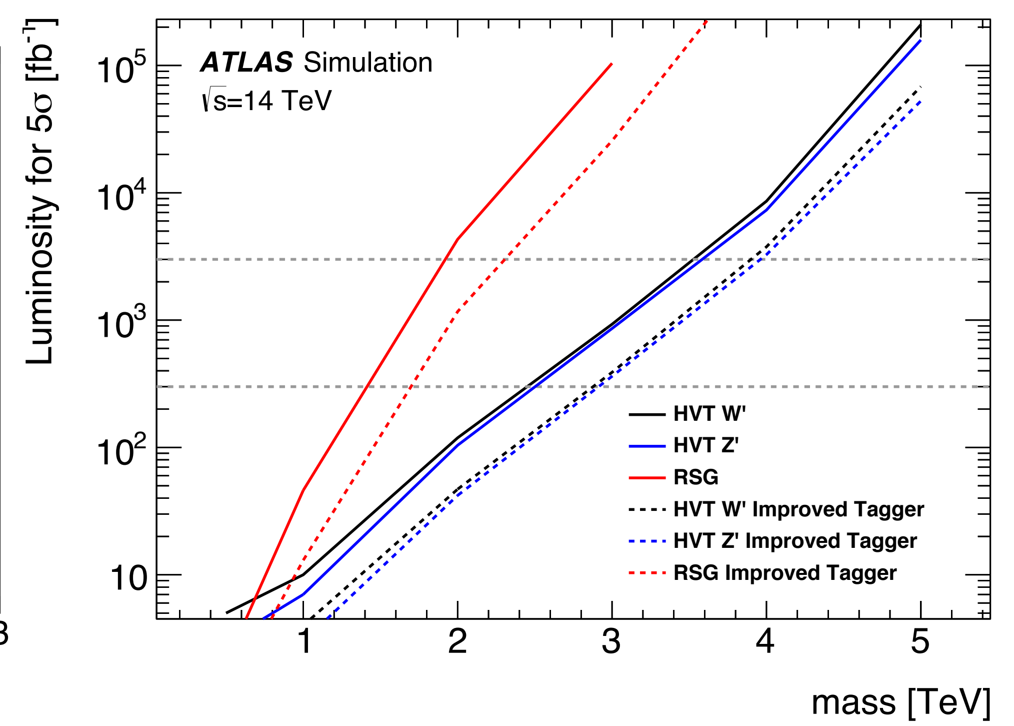
- Improved tracking and calorimetry leads to similar analysis performance despite harsher environment conditions.
- Run 2 → HL-LHC Improvement in Mass(~40%), σB(Factor 10).



Searching for Resonances at the HL-LHC: Diboson Searches

ATLAS HL-LHC Prospects



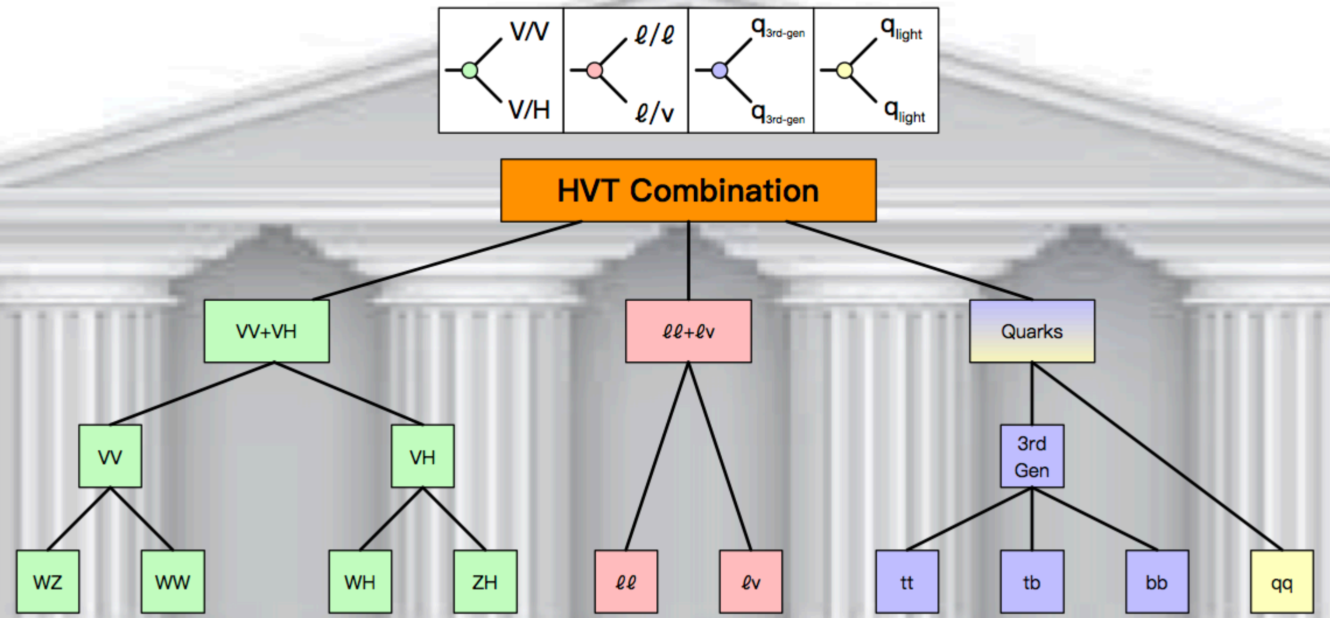


- Search with WW/WZ decaying to ℓvqq (resolved/merged).
- Compared current W/Z tagger efficiency to future tagger with +50% signal efficiency and +factor 2 background rejection.
  - Topologically-clustered calo-jets → track-calocluster jets.

Searching for Resonances at the HL-LHC:

Heavy Resonance Combinations

- To continue getting the most out of our data, we also combine results!
- At the HL-LHC this will be even more important, to catch small excesses across multiple searches with good statistical precision.



HVT $\mathcal{W}^a_\mu[g_\ell(\bar{\ell}_L\gamma^\mu\tau_a\ell_L) + g_q(\bar{q}_L\gamma^\mu\tau_a q_L) + g_{q_3}(\bar{q}^3_L\gamma^\mu\tau_a q^3_L) + g_\phi(\phi^\dagger\tau_a iD^\mu\phi + h.c.)]$

Picture Credit: D.Hayden, G.Halladjian, H.Torre, T.Farooque, W.Fisher.

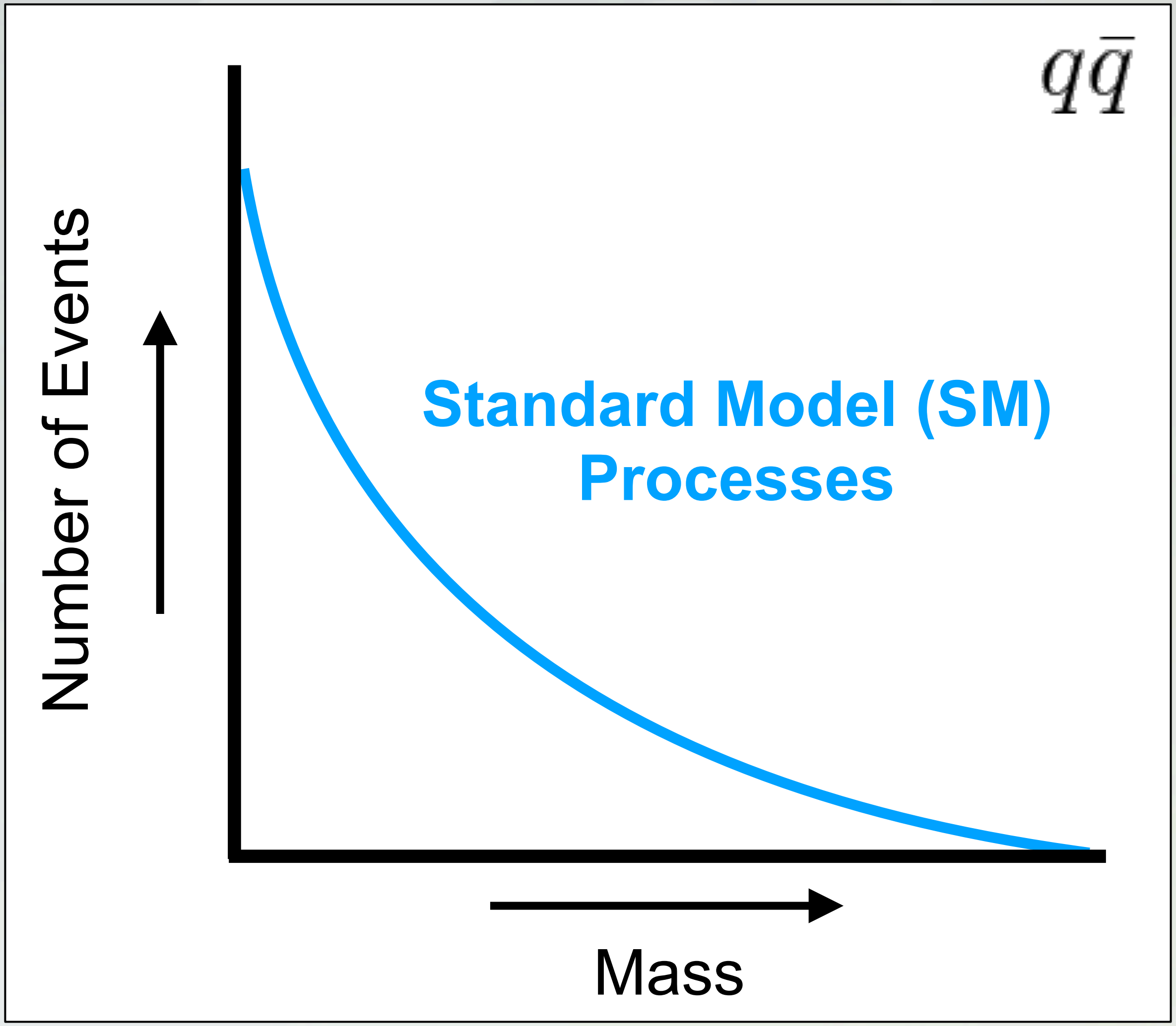
Searching for Resonances at the HL-LHC:

The Issue of PDF Uncertainties

- How can we trust our background estimation at extreme mass?

Searching for New Physics at the HL-LHC:
The Issue of PDF Uncertainties

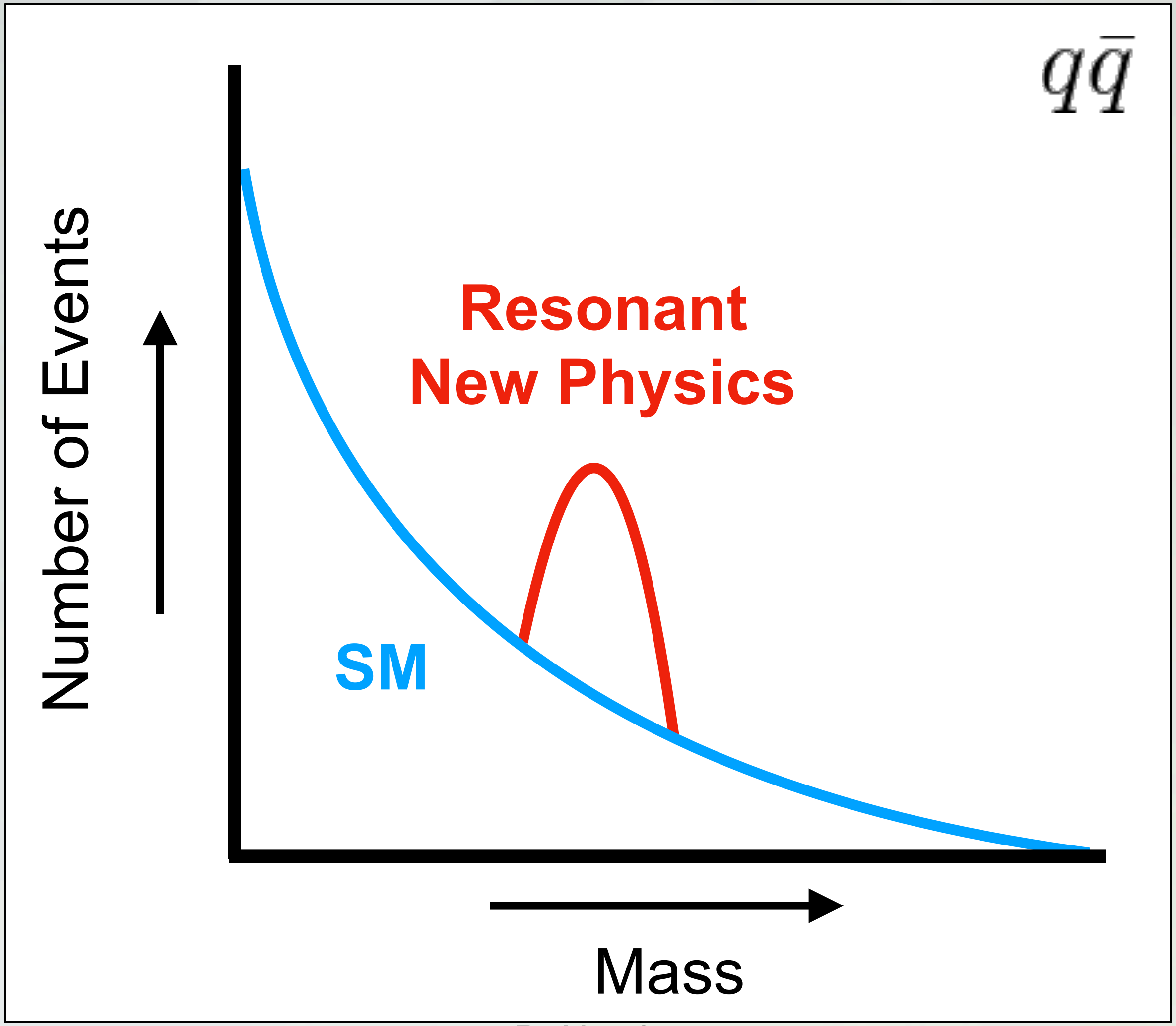
- How can we trust our background estimation at extreme mass?



Searching for New Physics at the HL-LHC:

The Issue of PDF Uncertainties

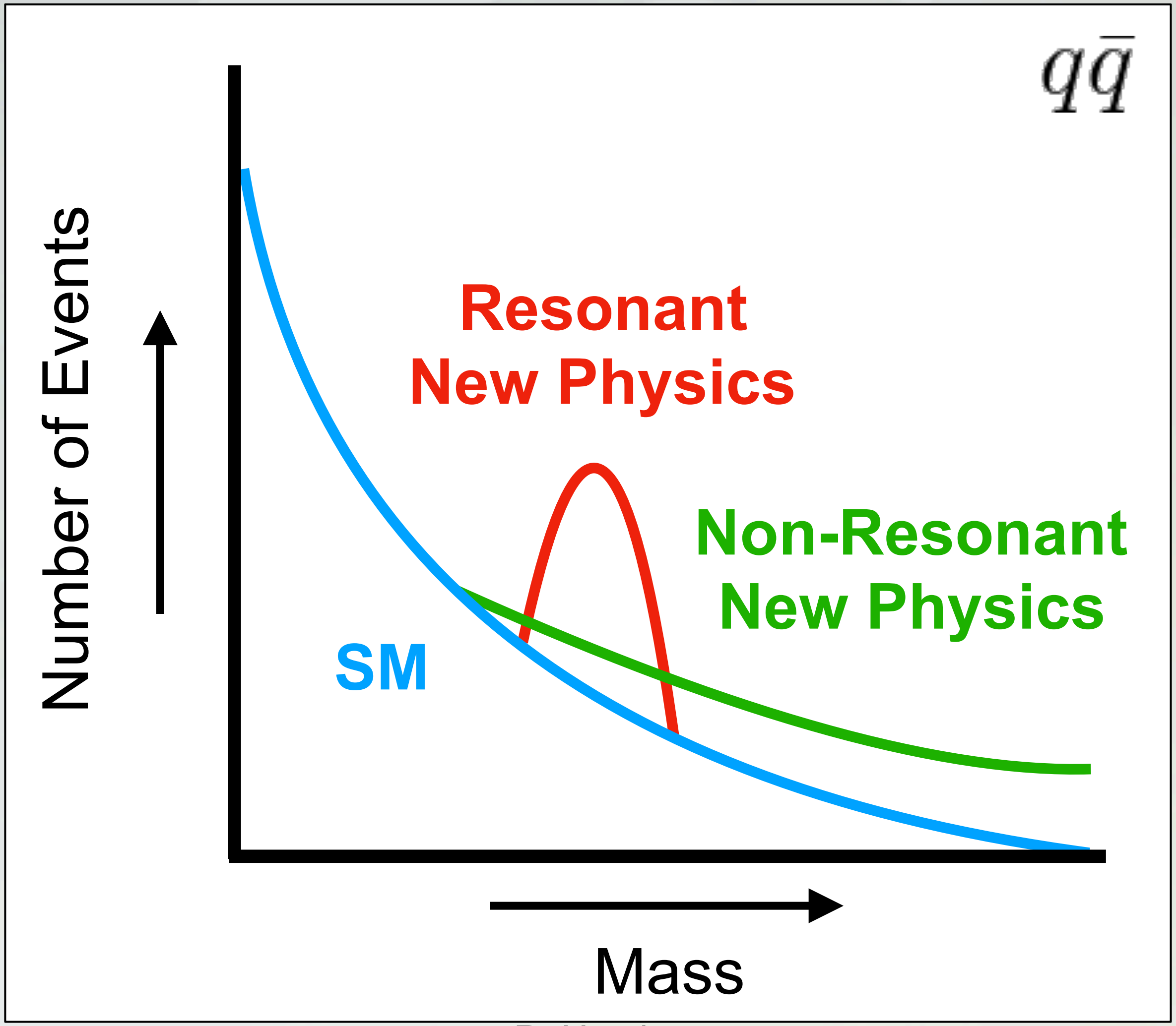
- How can we trust our background estimation at extreme mass?



Searching for New Physics at the HL-LHC:

The Issue of PDF Uncertainties

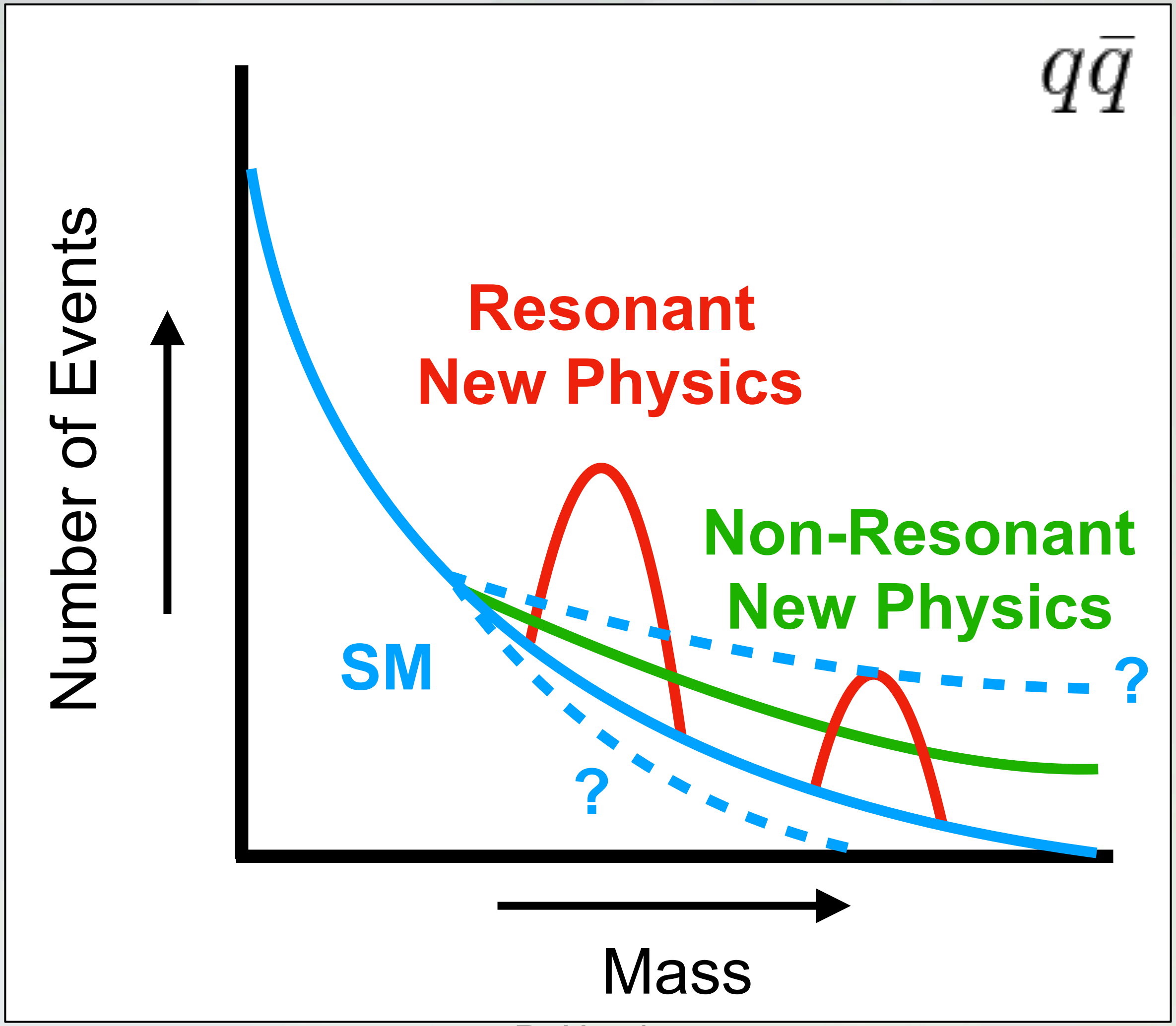
- How can we trust our background estimation at extreme mass?



Searching for New Physics at the HL-LHC:

The Issue of PDF Uncertainties

- How can we trust our background estimation at extreme mass?



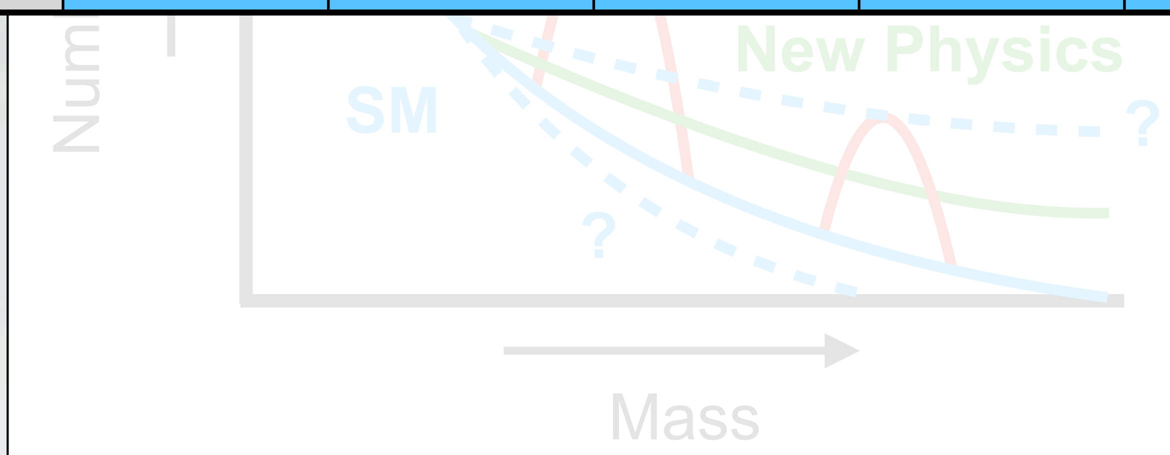
Searching for New Physics at the HL-LHC:

The Issue of PDF Uncertainties

- How can we trust our background estimation at extreme mass?

- Especially when looking for non-resonant new physics this becomes by far the largest limiting factor.

PDF (M(ℓℓ)) Uncertainty	@ 3 TeV	@ 4 TeV	@ 5 TeV	@ 6 TeV	@ 7 TeV
CT14	10%	20%	26%	40%	52%
NNPDF	10%	20%	40%	100%	250%



Searching for New Physics at the HL-LHC:

The Issue of PDF Uncertainties

- How can we trust our background estimation at extreme mass?

- Especially when looking for non-resonant new physics this becomes by far the largest limiting factor.

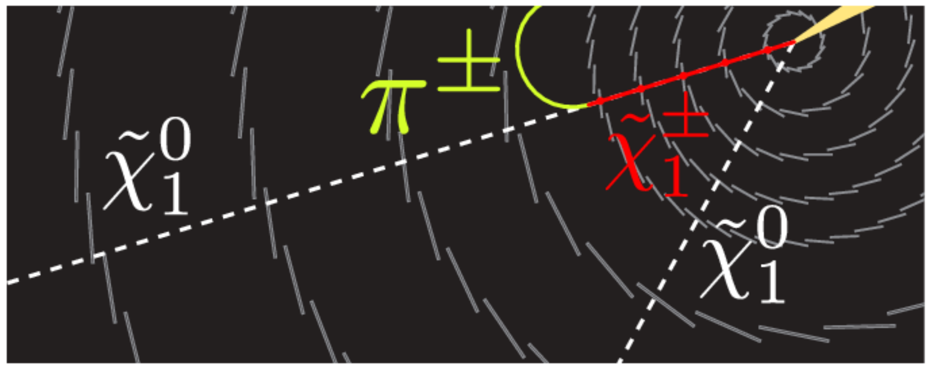
PDF (M(ℓℓ)) Uncertainty	@ 3 TeV	@ 4 TeV	@ 5 TeV	@ 6 TeV	@ 7 TeV
CT14	10%	20%	26%	40%	52%
NNPDF	10%	20%	40%	100%	250%

- Need PDF description / uncertainty to keep up with experiment!
- Lines between Precision Measurements and Searches blur.
- Prospects for improvement from HL-LHC data studied.
- Also bootstrapping techniques to reduce these kind of uncertainties in real time → Provide greater feedback.

Searching for SUSY at the HL-LHC:

ATLAS HL-LHC Prospects

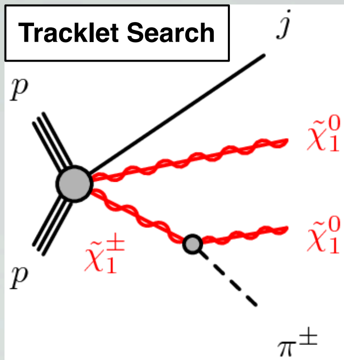
- R-Parity conserving model, with LSP being stable DM candidate.
- Chargino ($\chi^{\pm}$) → Neutralino (χ^0) which exits detector leaving "tracklet"

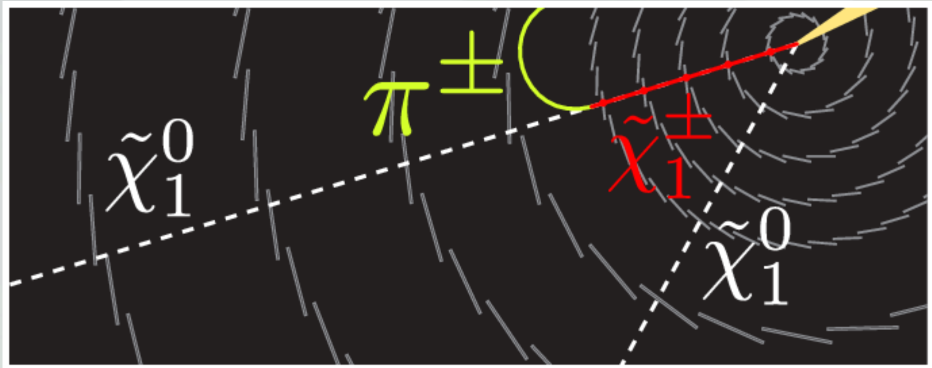


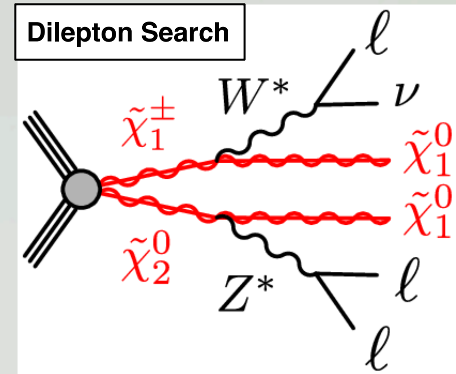
Searching for SUSY at the HL-LHC:

ATLAS HL-LHC Prospects

- R-Parity conserving model, with LSP being stable DM candidate.
- Chargino ($\chi^{\pm}$) → Neutralino (χ^{0}) which exits detector leaving "tracklet"



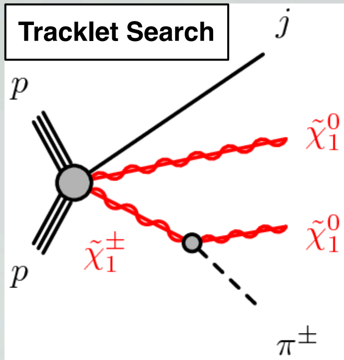


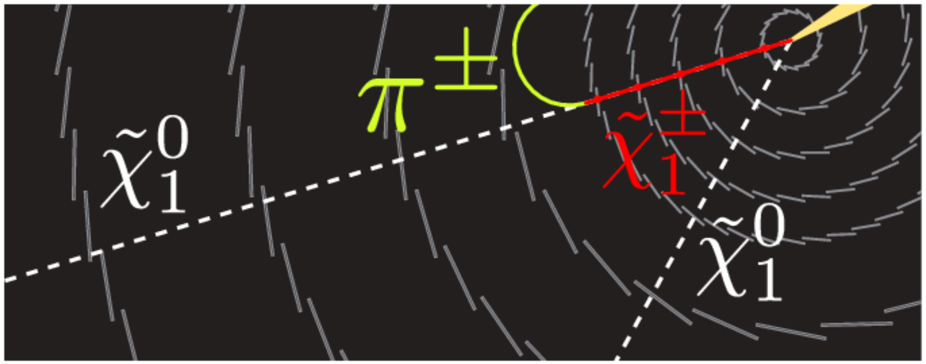


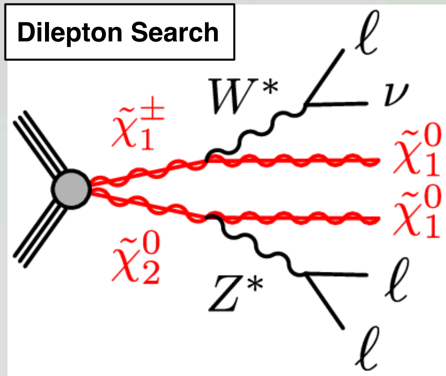
Searching for SUSY at the HL-LHC:

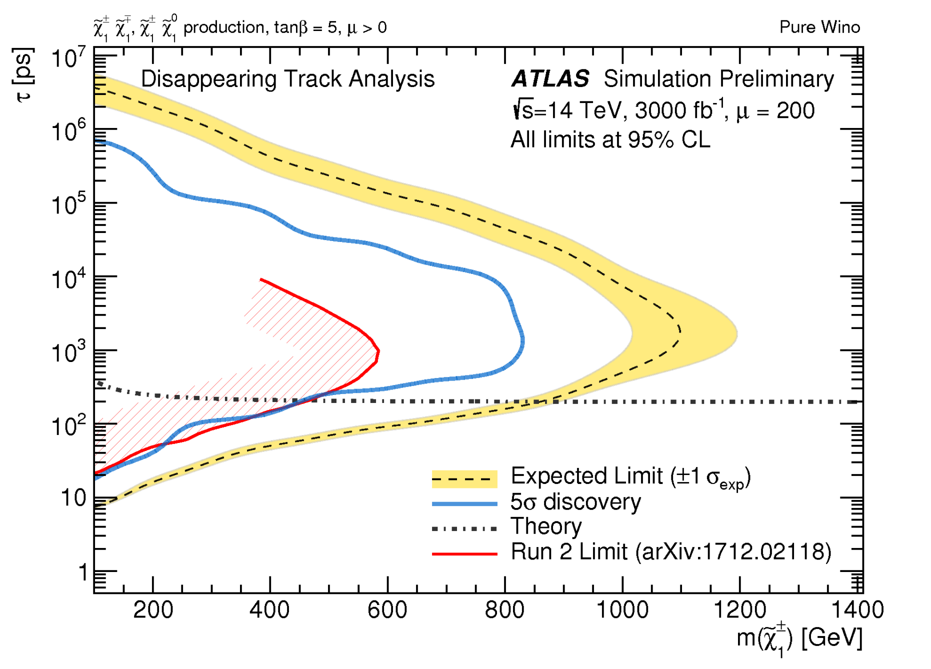
ATLAS HL-LHC Prospects

- R-Parity conserving model, with LSP being stable DM candidate.
- Chargino ($\chi^{\pm}$) → Neutralino (χ^0) which exits detector leaving "tracklet"





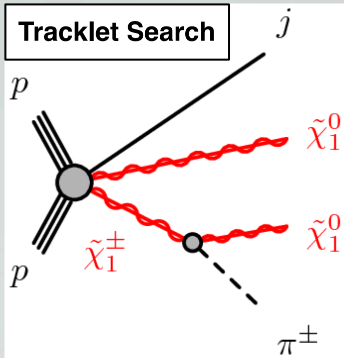


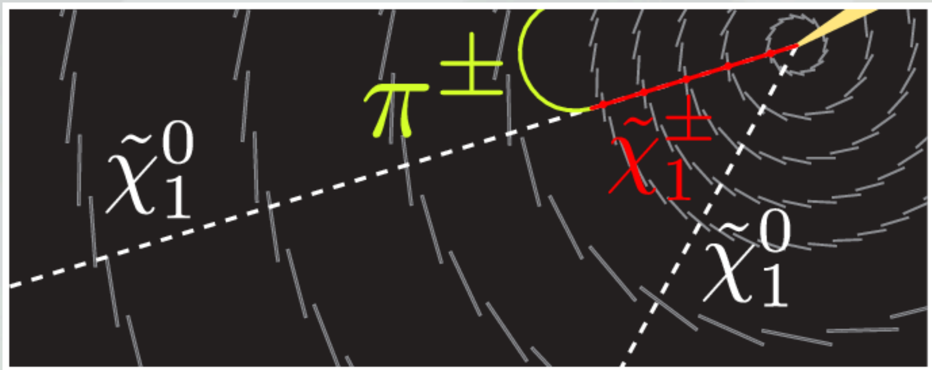


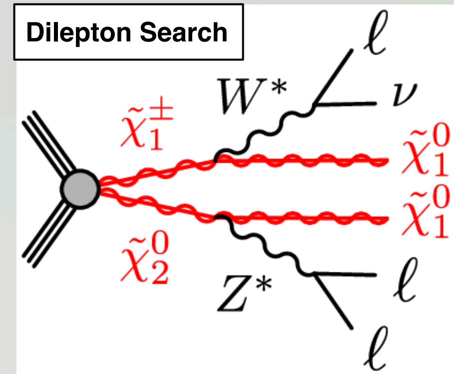
Searching for SUSY at the HL-LHC:

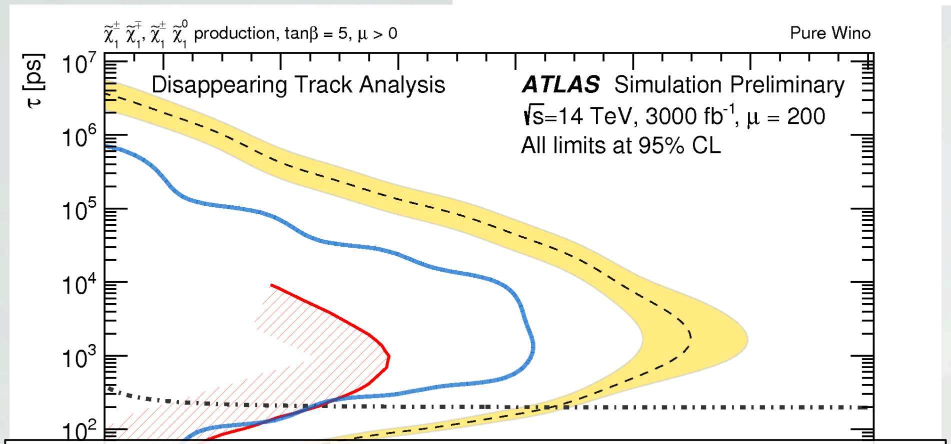
ATLAS HL-LHC Prospects

- R-Parity conserving model, with LSP being stable DM candidate.
- Chargino ($\chi^{\pm}$) → Neutralino (χ^0) which exits detector leaving "tracklet"







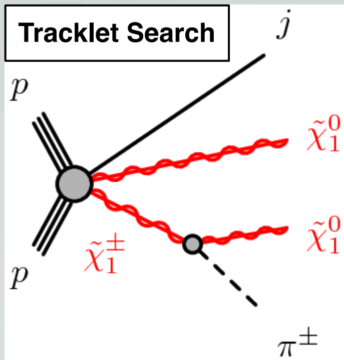


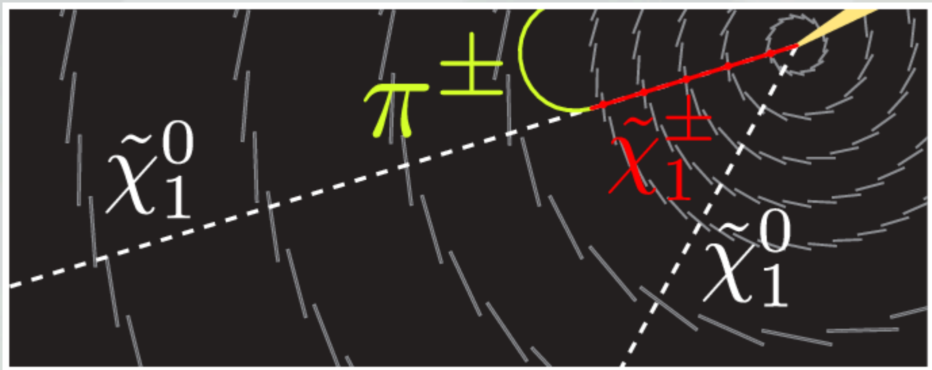
Large tracking improvements:
- Better quality / shorter tracklets.
- Better fake tracklet rejection.

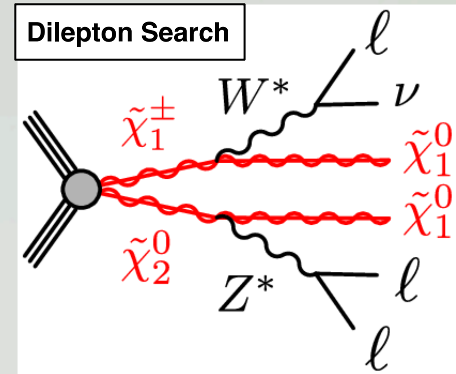
Searching for SUSY at the HL-LHC:

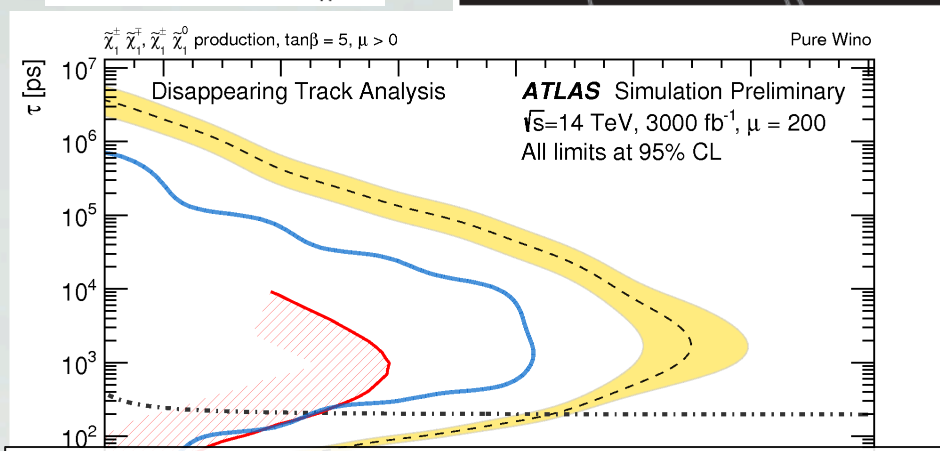
ATLAS HL-LHC Prospects

- R-Parity conserving model, with LSP being stable DM candidate.
- Chargino ($\chi^{\pm}$) → Neutralino (χ^{0}) which exits detector leaving "tracklet"

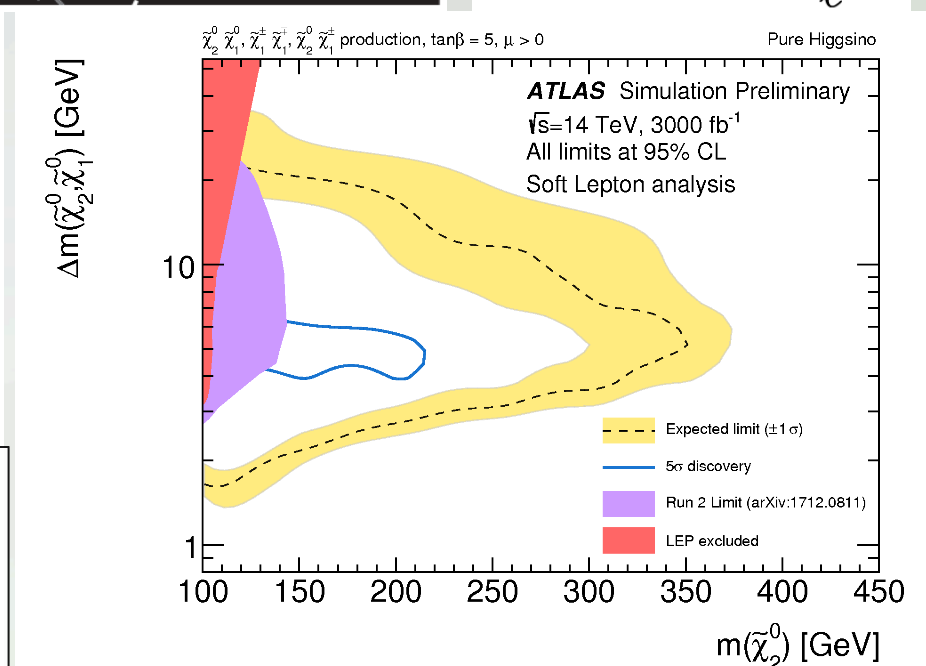








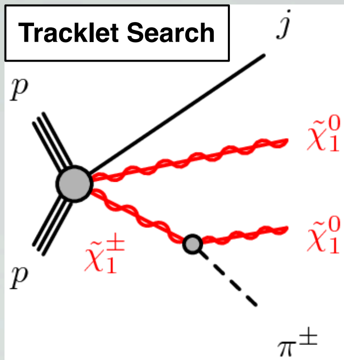
Large tracking improvements:
- Better quality / shorter tracklets.
- Better fake tracklet rejection.

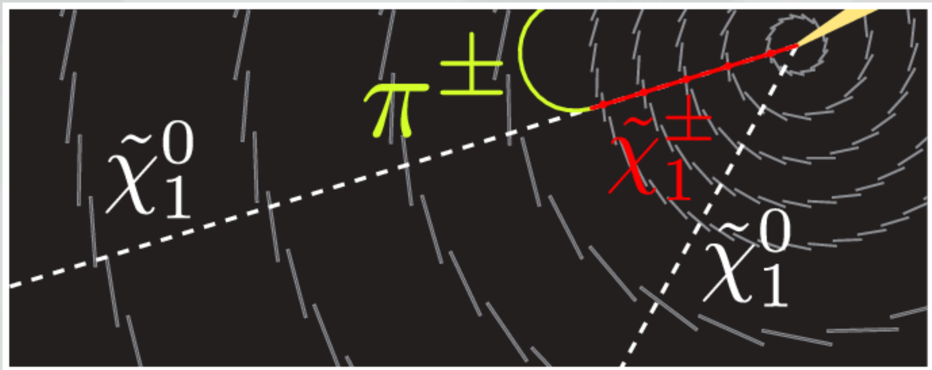


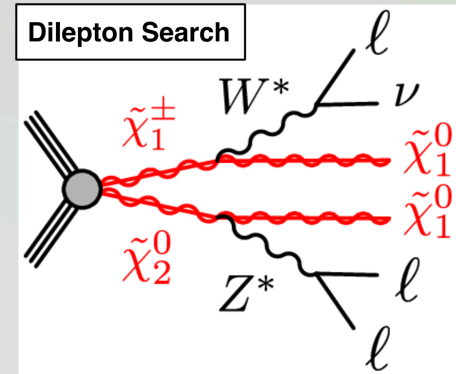
Searching for SUSY at the HL-LHC:

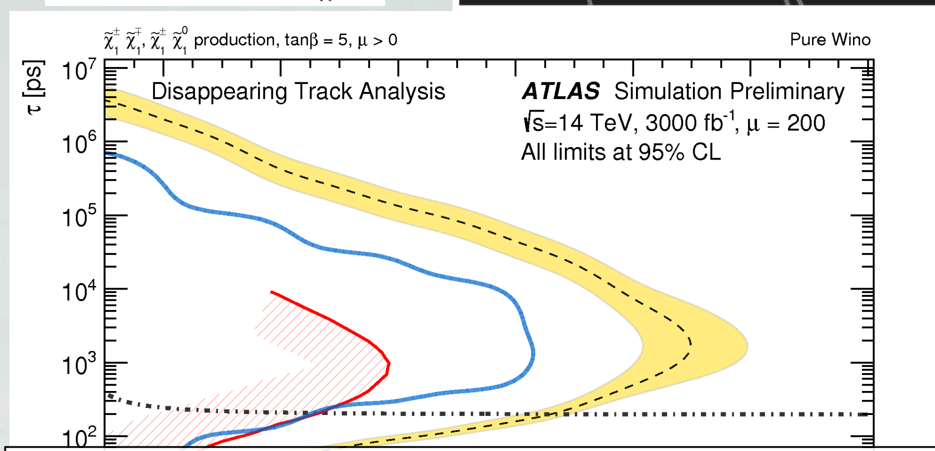
[ATLAS HL-LHC Prospects]

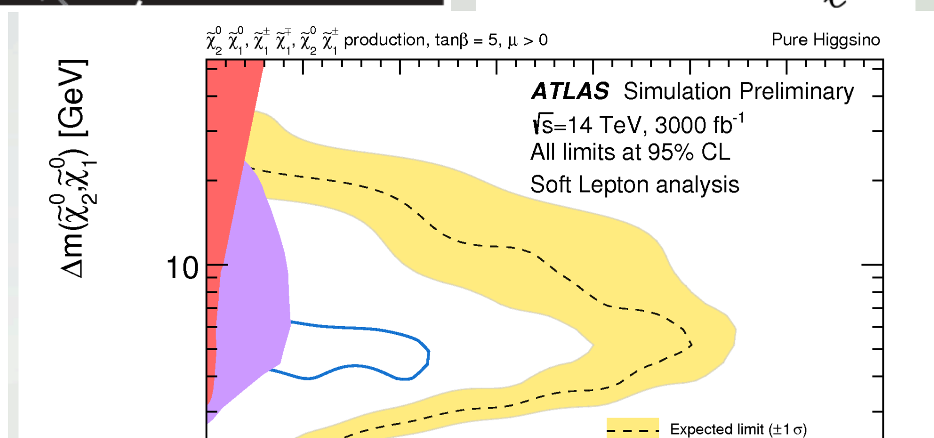
- R-Parity conserving model, with LSP being stable DM candidate.
- Chargino ($\chi^{\pm}$) → Neutralino (χ^0) which exits detector leaving "tracklet"





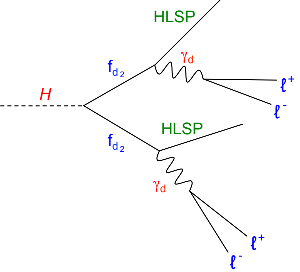






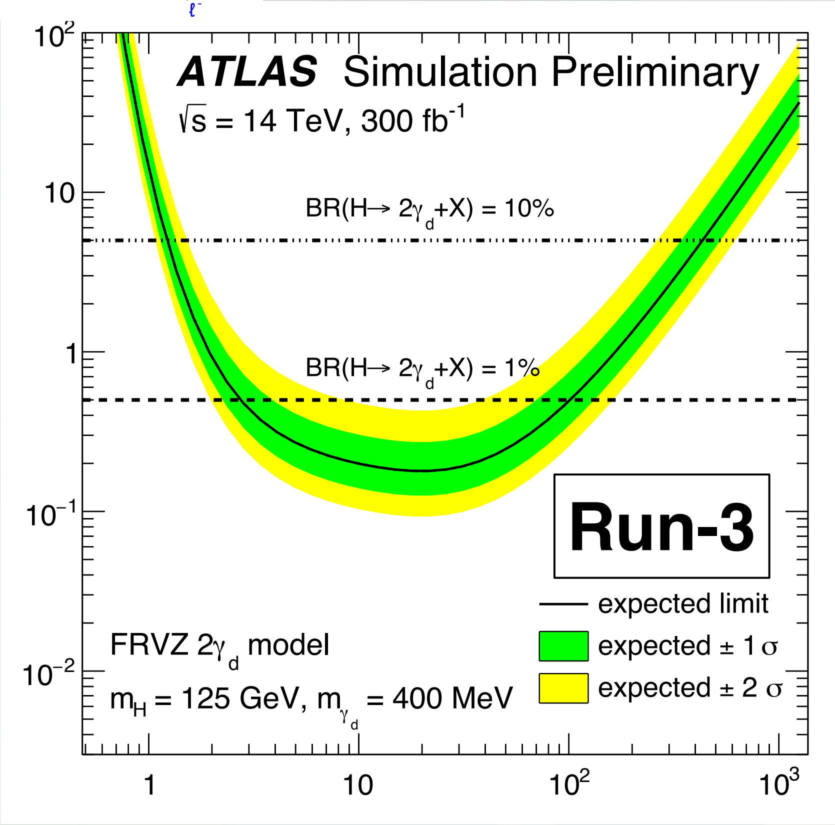
Large tracking improvements:
- Better quality / shorter tracklets.
- Better fake tracklet rejection.

Improvements also from tracking:
- Increased reconstruction efficiency for low pT leptons.

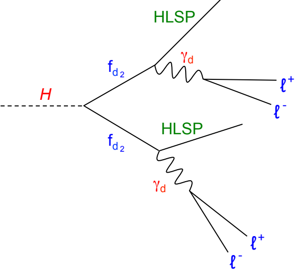


Long-Lived Particles at the HL-LHC: Dark Photon Search

ATLAS HL-LHC Prospects



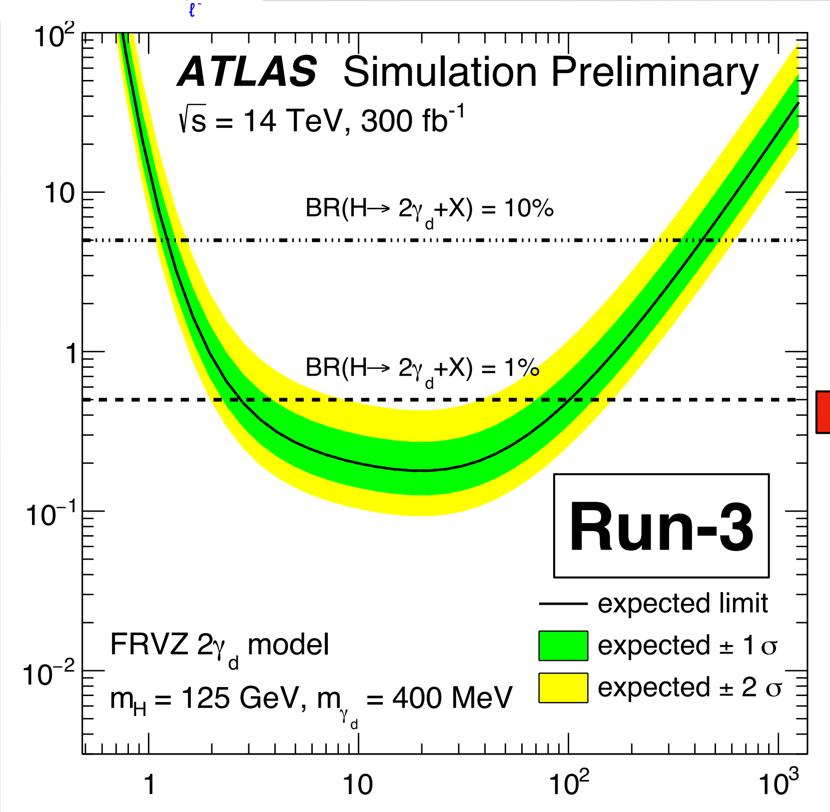
- Big issue from collimated muons causing single μ trigger loss.

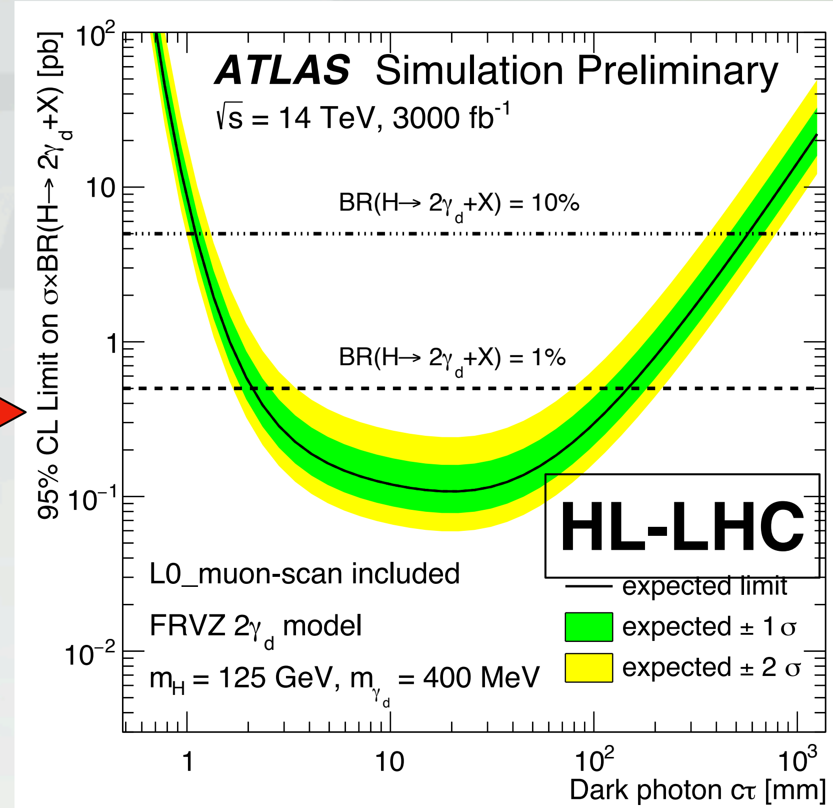


Long-Lived Particles at the HL-LHC:

Dark Photon Search

ATLAS HL-LHC Prospects

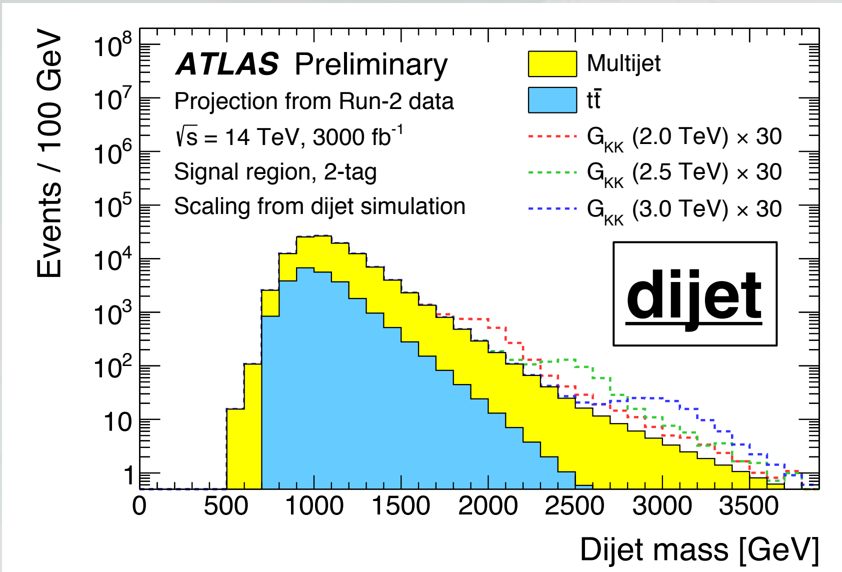


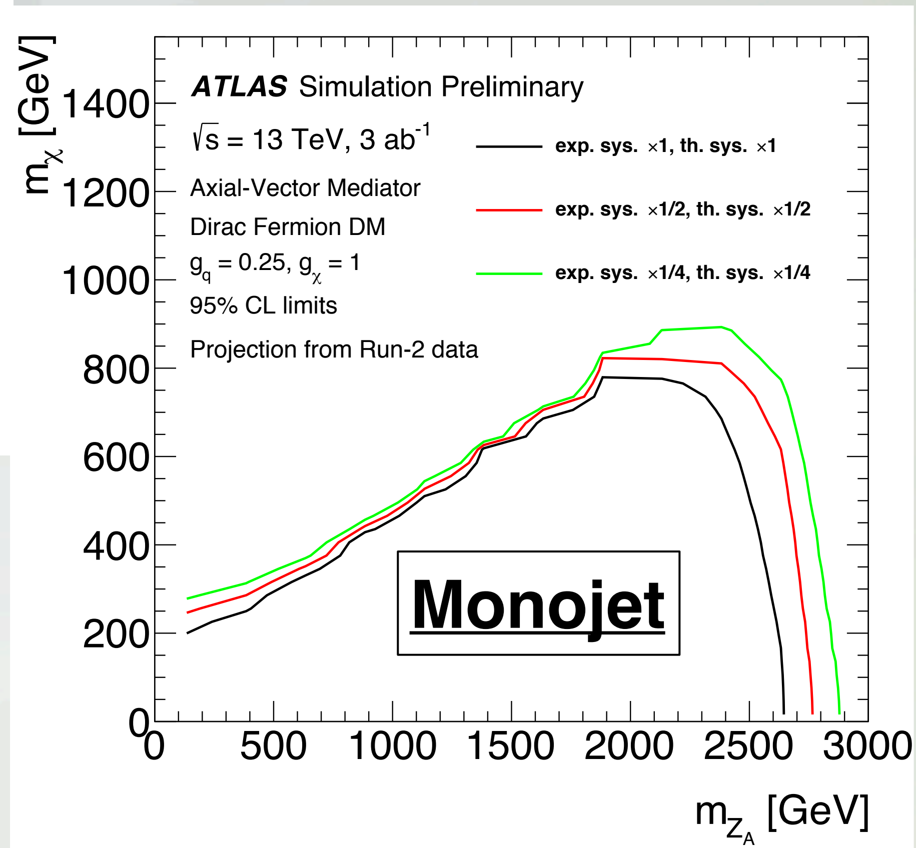


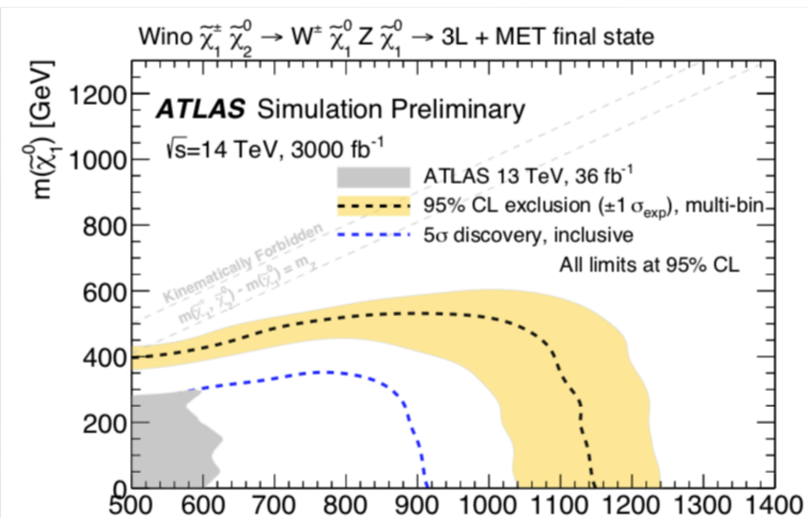
- Big issue from collimated muons causing single μ trigger loss.
- New trigger designed to analyse MS hit patterns for multiple-μ.
- Allows analysis to use a lower pT threshold with reasonable rate.

Searching for New Physics at the HL-LHC:

Many Other Search Prospects Studied



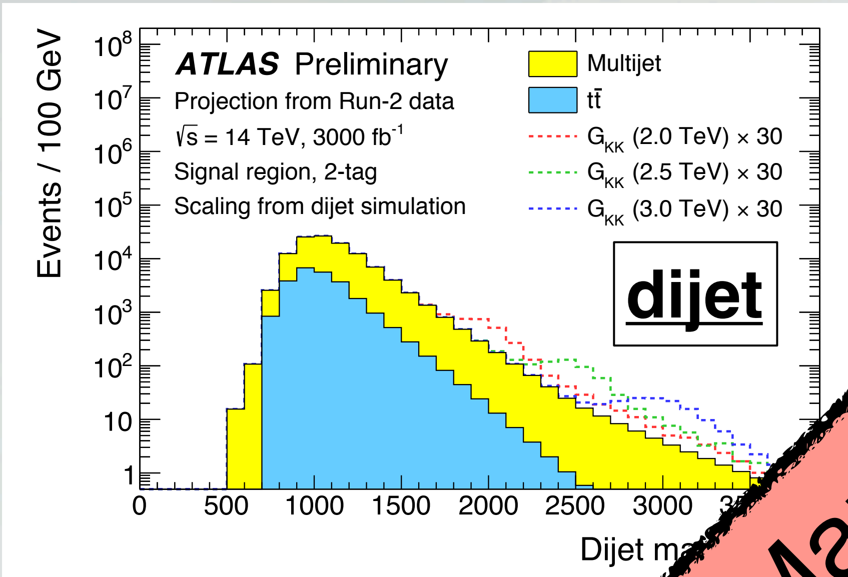


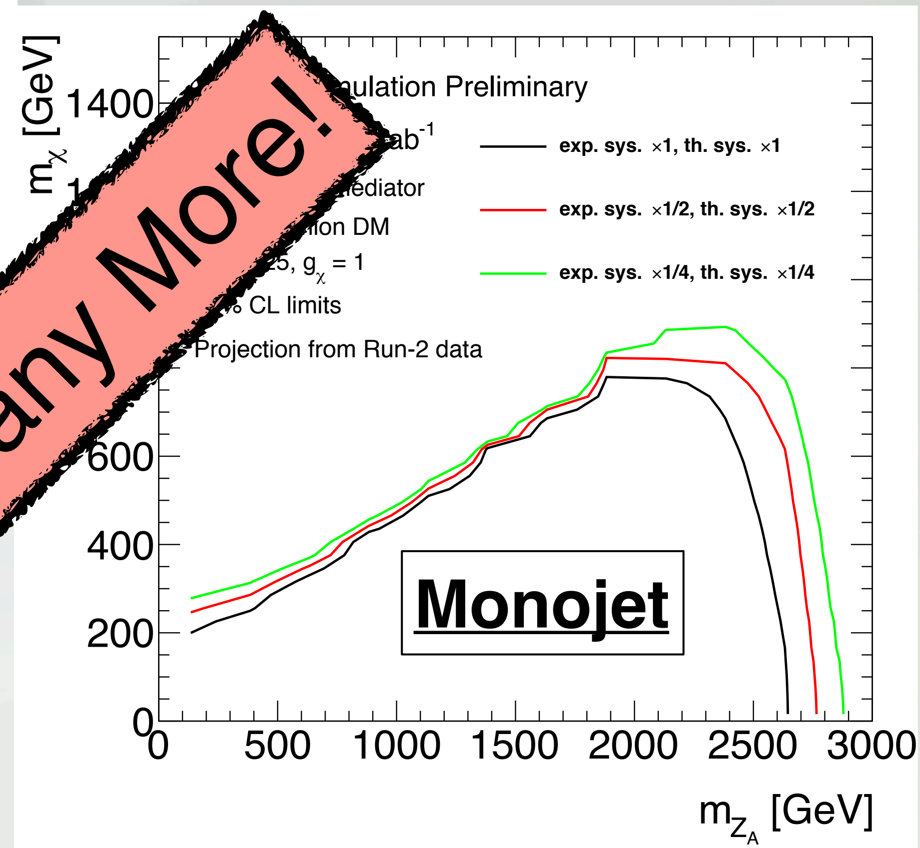


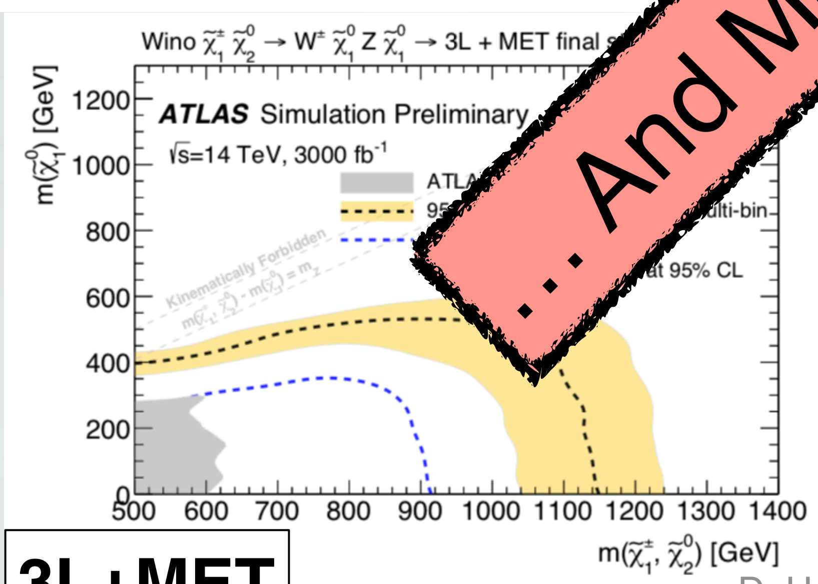
3L+MET

Searching for New Physics at the HL-LHC:

Many Other Search Prospects Studied







… And Many More!

Conclusions

- The HL-LHC sometimes **feels** like the distant future - **but it’s not!**
  - Understand BSM searches in this regime and prepare.
  - Prospect studies show great potential for increased sensitivity.

Conclusions

- The HL-LHC sometimes **feels** like the distant future - **but it's not!**
  - Understand BSM searches in this regime and prepare.
  - Prospect studies show great potential for increased sensitivity.

- We also need to keep thinking about the bigger picture.
  - Combinations of results can boost sensitivity even further.
  - Eventually cross-collaboration, cross-HEP combinations?

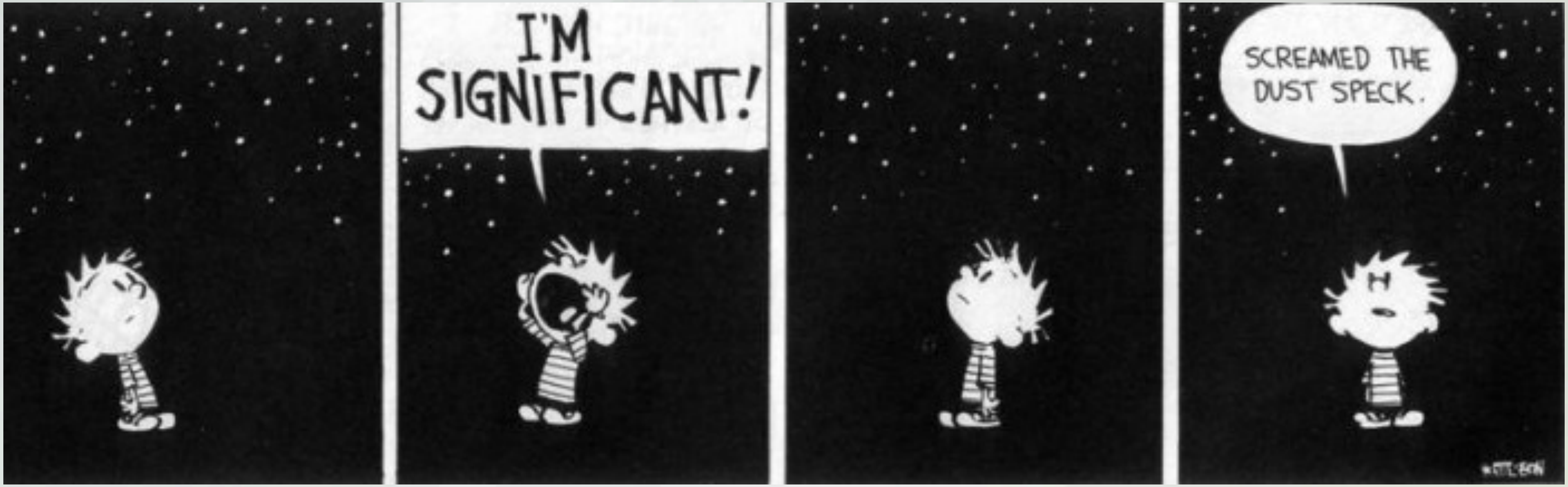
Conclusions

- The HL-LHC sometimes **feels** like the distant future - **but it's not!**
  - Understand BSM searches in this regime and prepare.
  - Prospect studies show great potential for increased sensitivity.

- We also need to keep thinking about the bigger picture.
  - Combinations of results can boost sensitivity even further.
  - Eventually cross-collaboration, cross-HEP combinations?

- Be wary of potential pit falls.
  - What would a discovery at the HL-LHC look like?
  - Need to work closely with the theory community.

Thank you for listening!



Questions?