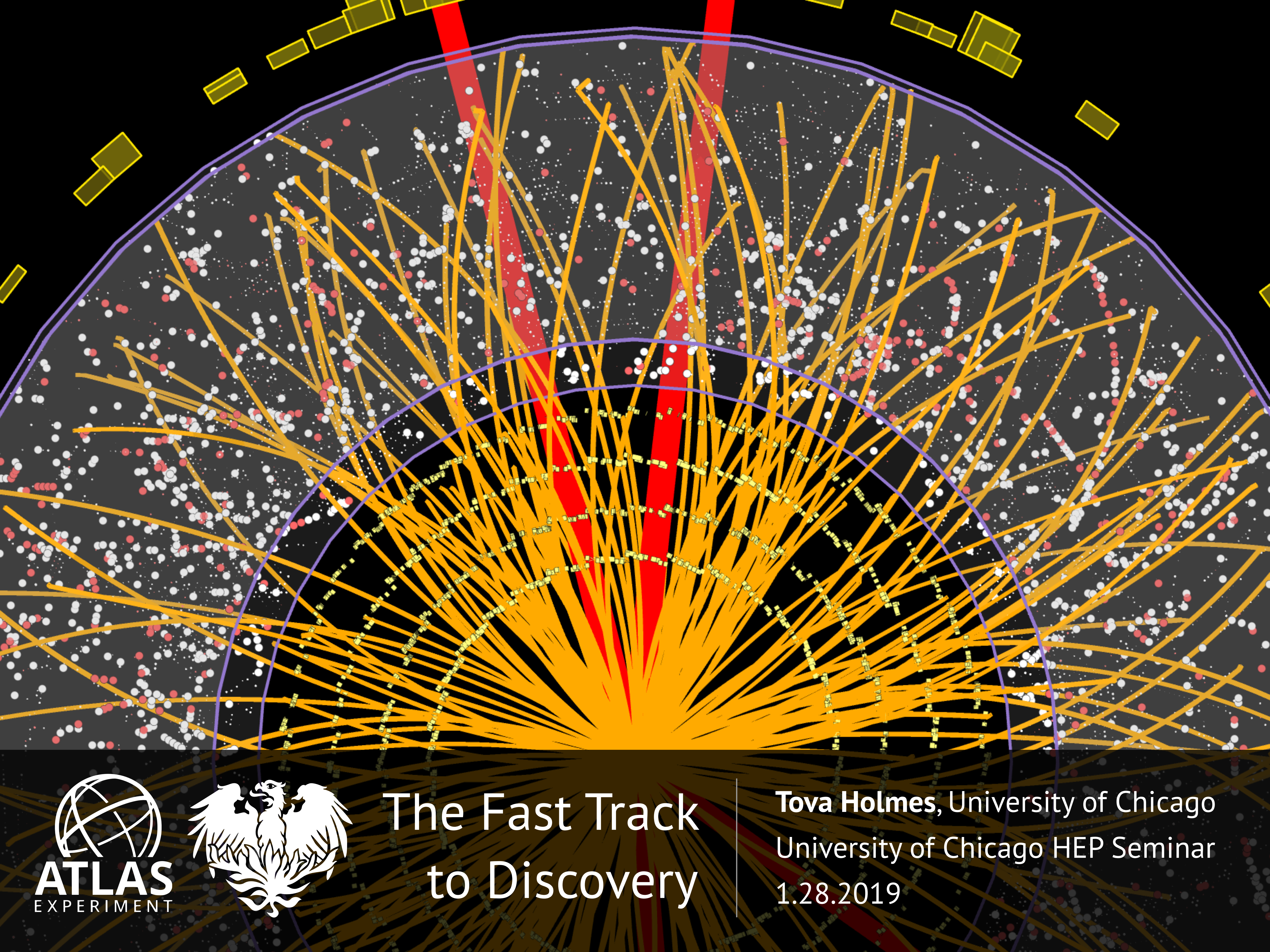


The Fast Track to Discovery

Tova Holmes, University of Chicago

University of Chicago HEP Seminar

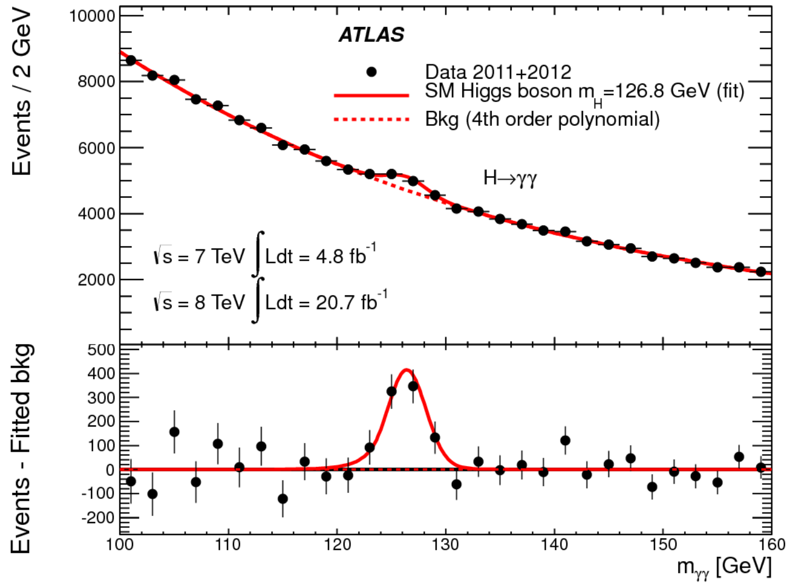
1.28.2019

My goal:

find new fundamental particles

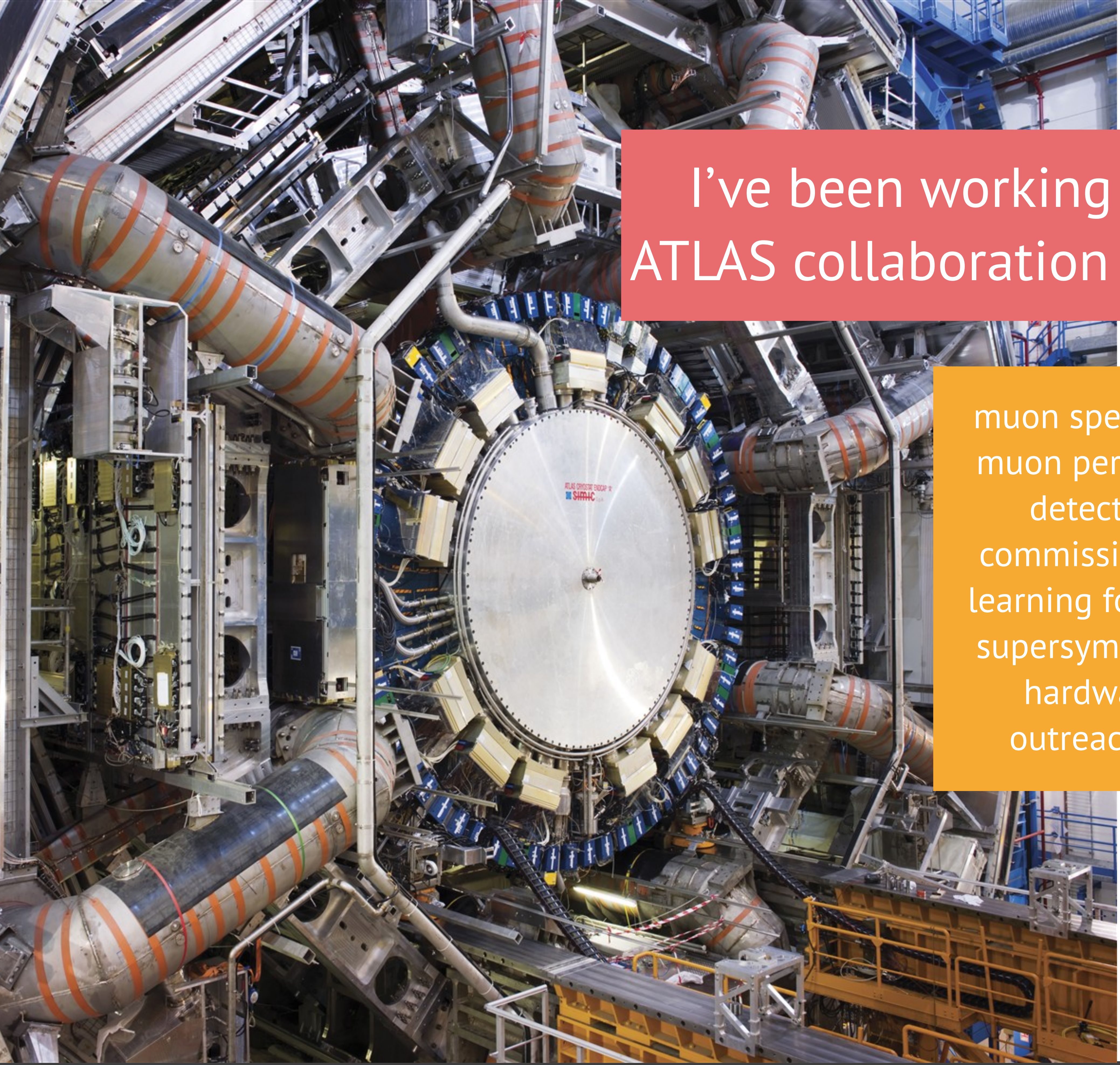

CERN

Higgs discovery, 2012



Most recent machine to accomplish that goal: **the Large Hadron Collider**

CERN, ATLAS Higgs Discovery



I’ve been working with the ATLAS collaboration since 2010

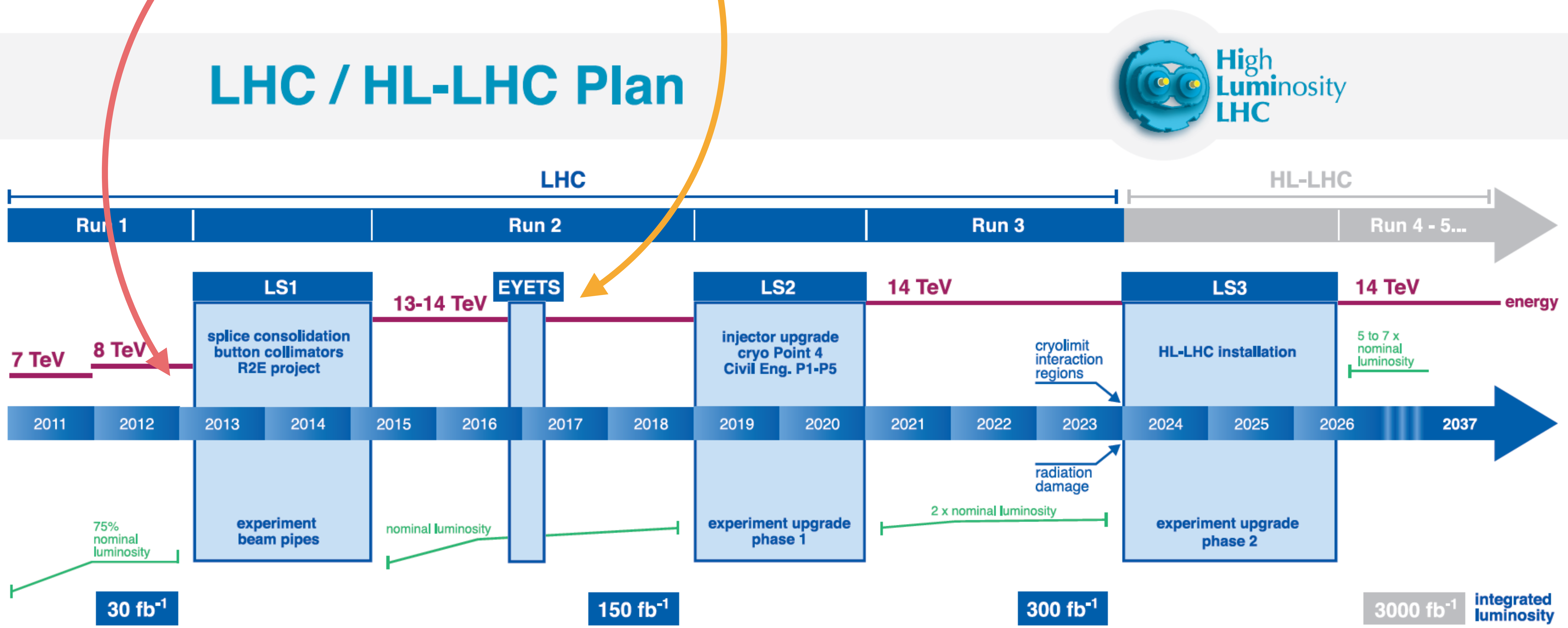
muon spectrometer R&D, muon performance, pixel detector R&D, IBL commissioning, machine learning for hit clustering, supersymmetry searches, hardware tracking, outreach podcasting

CERN

Run 1
We completed the Standard Model

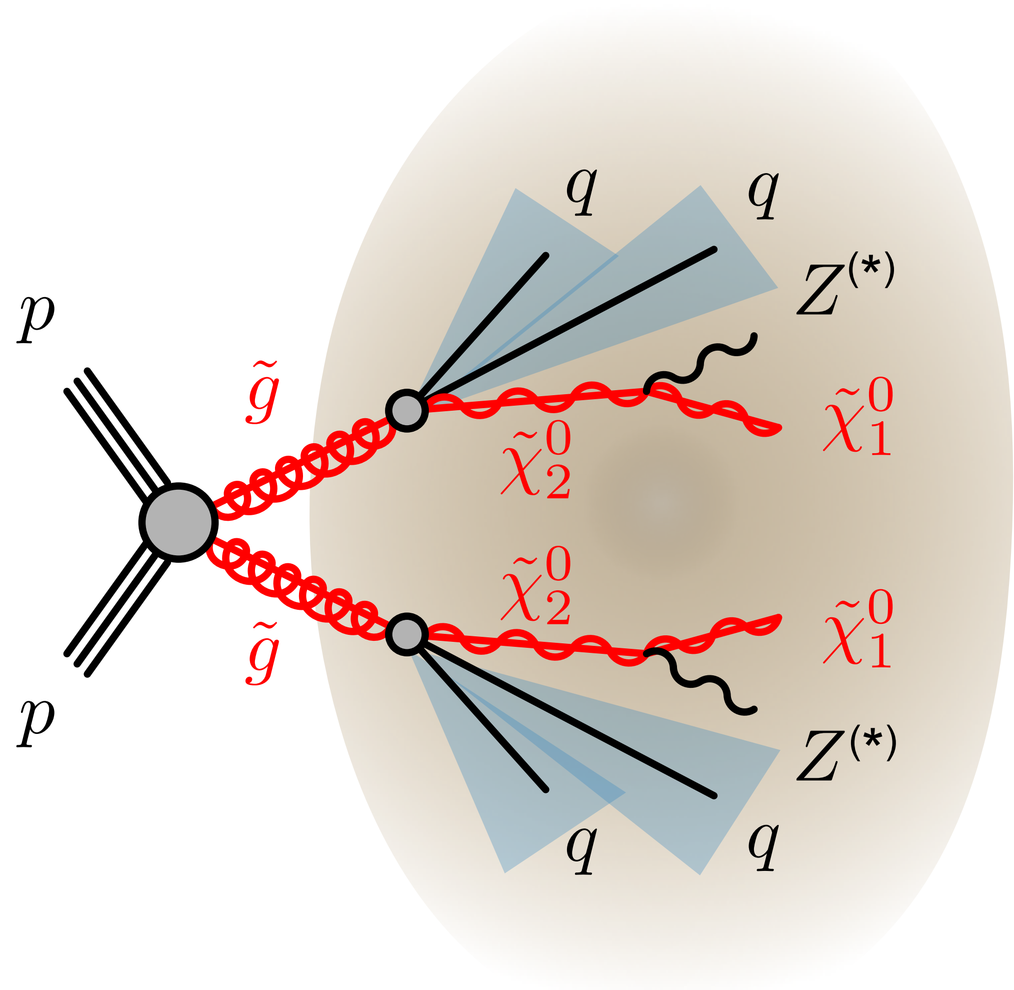
Run 2
We did our best to break it

Luminosity x5
Energy +60%



Looking beyond the Standard Model

Search for jets, missing energy and leptons from Z



Typical Supersymmetry Search

large E_T^{miss} requirements

Lightest supersymmetric particle is stable, and escapes the detector without interacting

large n_{jets}

color-charged SUSY particles emit jets as they go through decay chains

large total energy

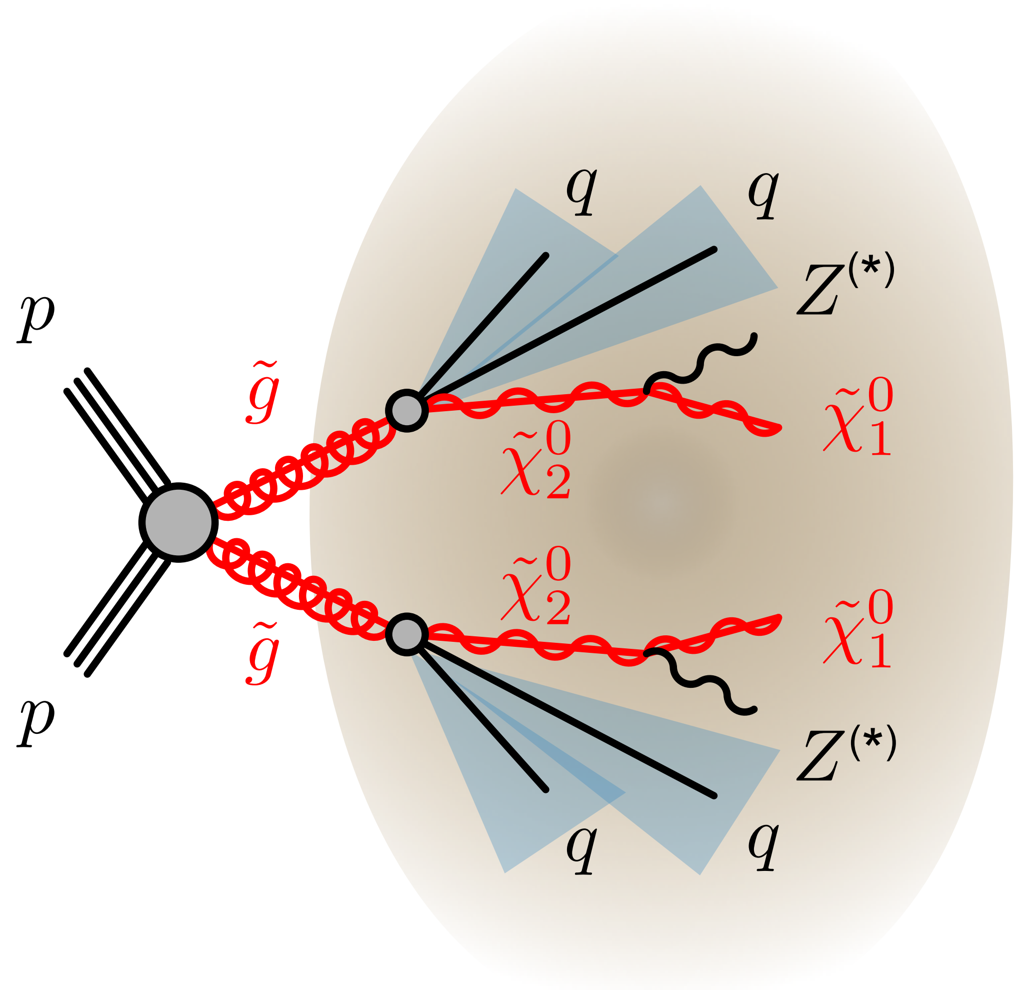
sum the total energy of the event to isolate events that are likely to contain very massive particles

Plus: **two leptons** consistent with the decay of a Z boson

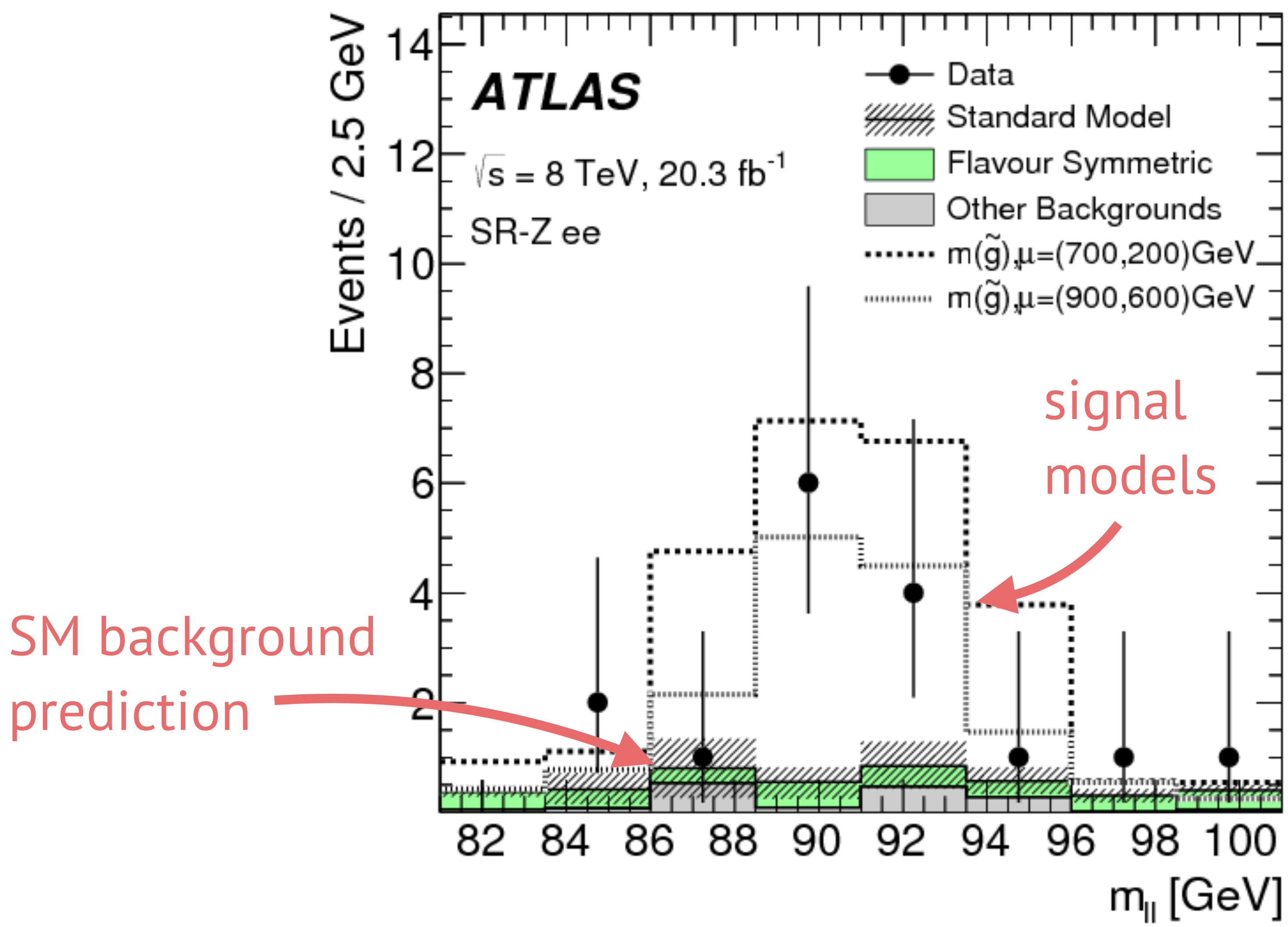
ATLAS-SUSY-2014-10

Looking beyond the Standard Model

Search for jets, missing energy and leptons from Z



Run 1 Signal Region



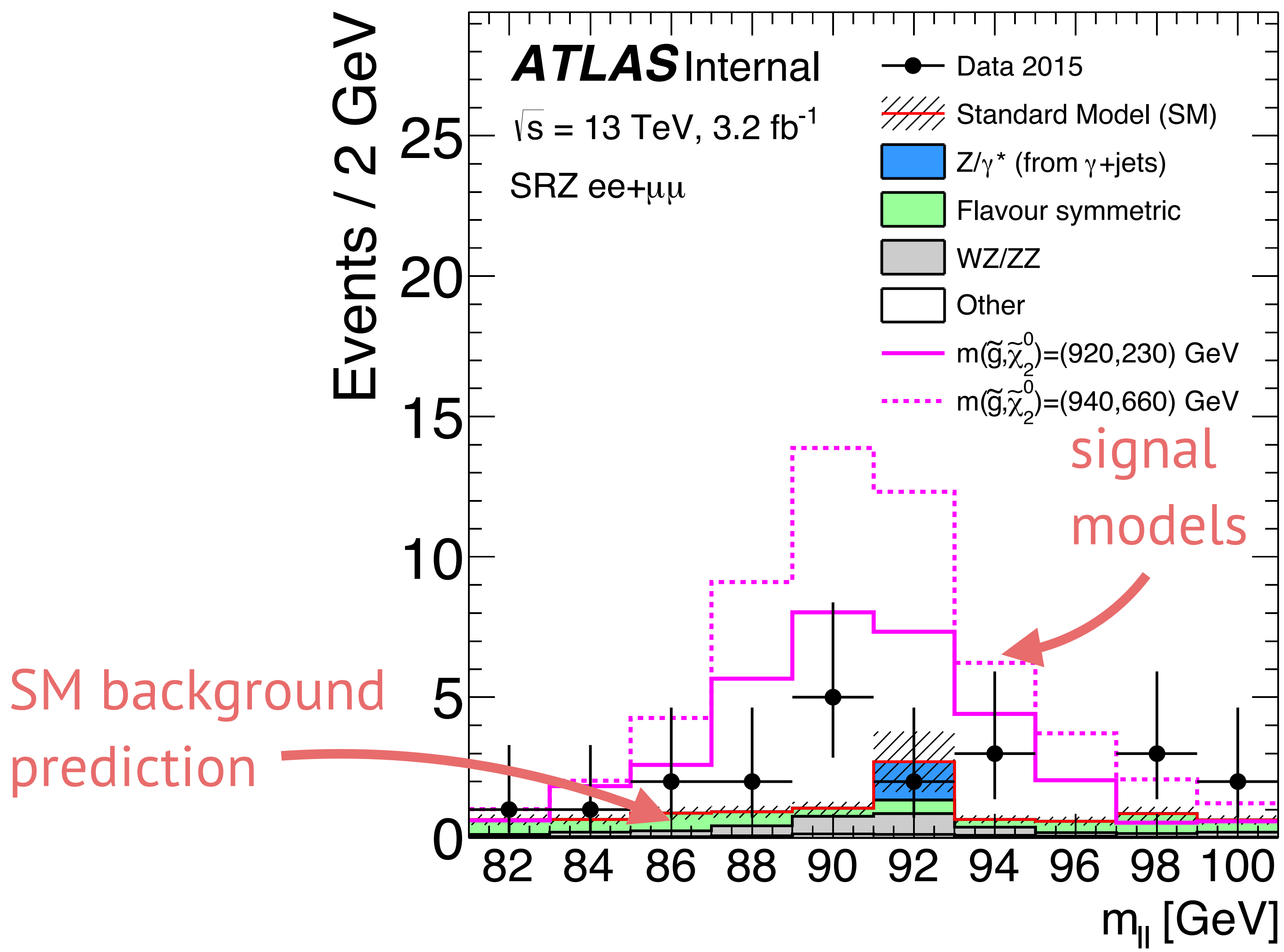
3σ excess

ATLAS-SUSY-2014-10

Looking beyond the Standard Model

First look in Run 2 data

Still ambiguous



2.2.σ excess

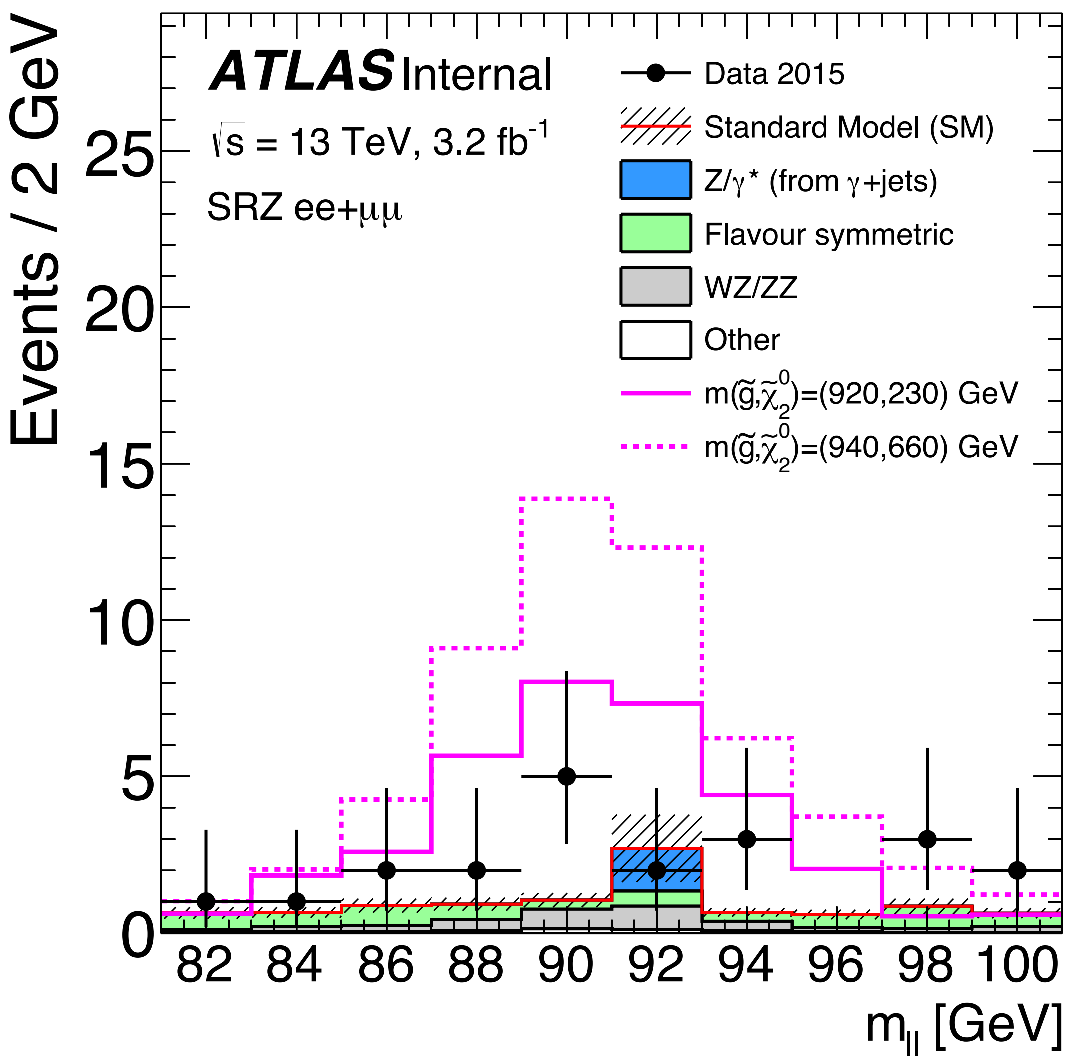
ATLAS-CONF-2015-082

Looking beyond the Standard Model

This is what **exciting** looked like

Hint of **TeV-scale** Supersymmetry
Repeated, consistent **excesses**

Background estimates to improve
Much **more data** coming

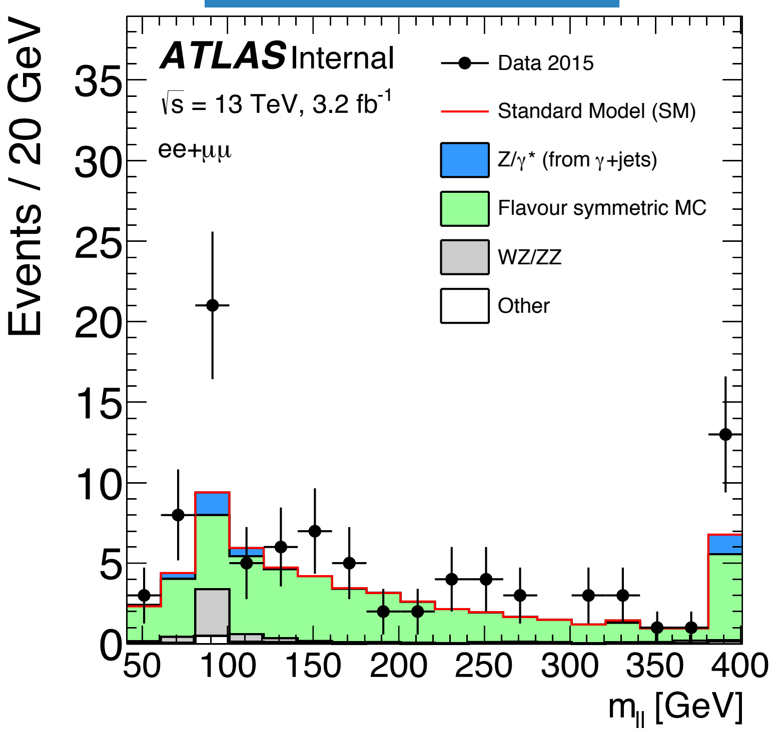


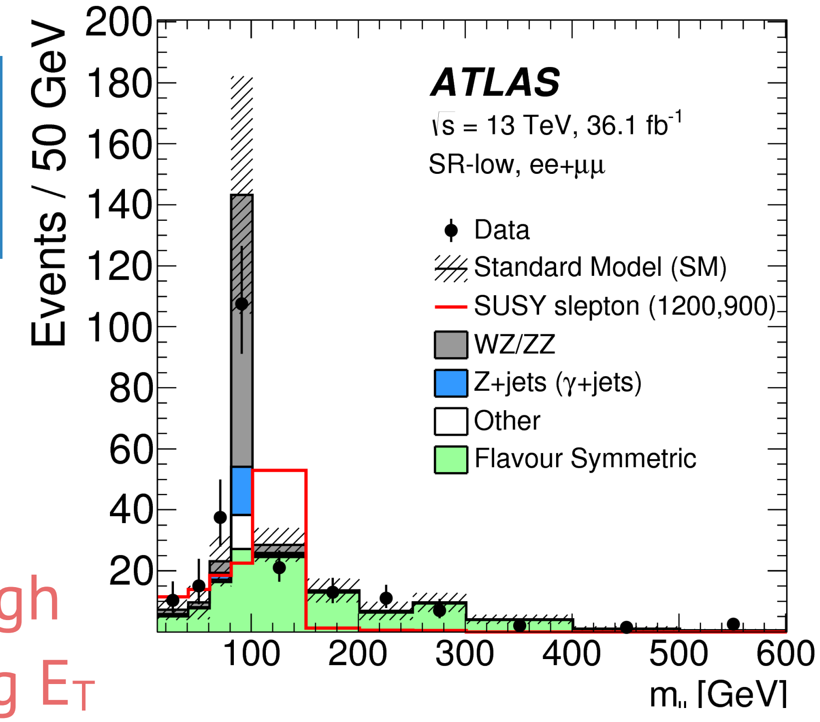
ATLAS-CONF-2015-082

Looking beyond the Standard Model

First Run 2 Data

~10x luminosity

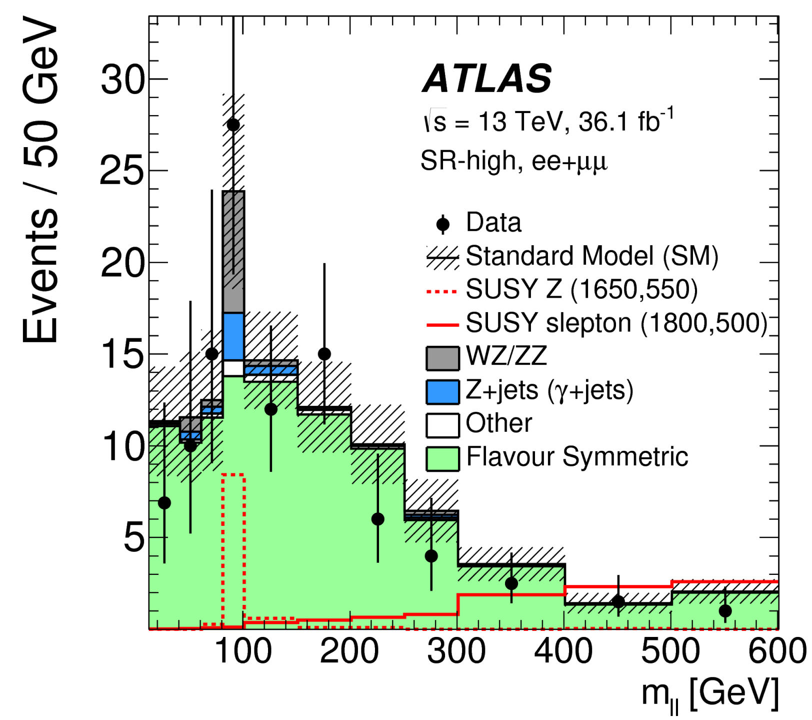


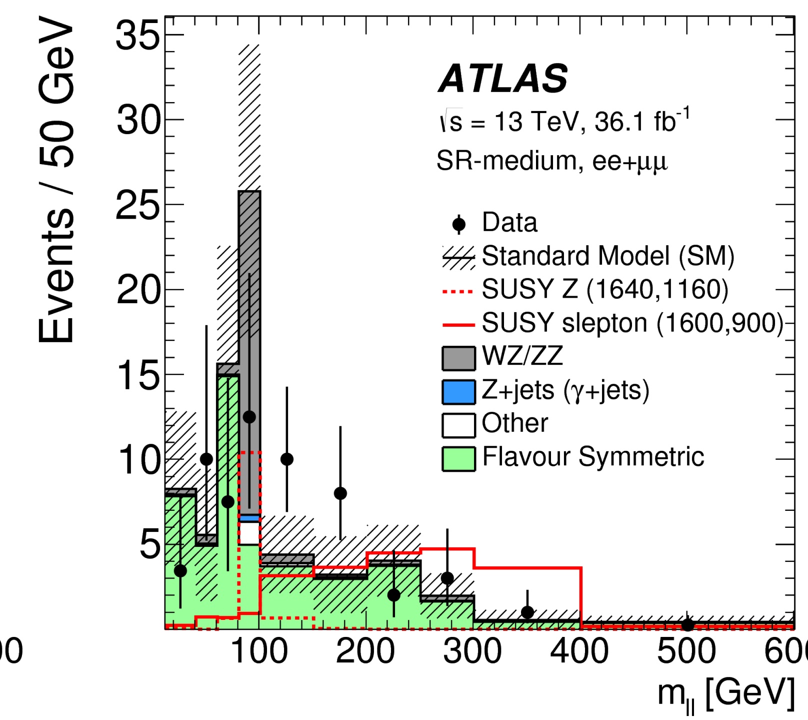


Similar to Run 1 signal region

very high missing E_T

very high total energy





ATLAS-CONF-2015-082

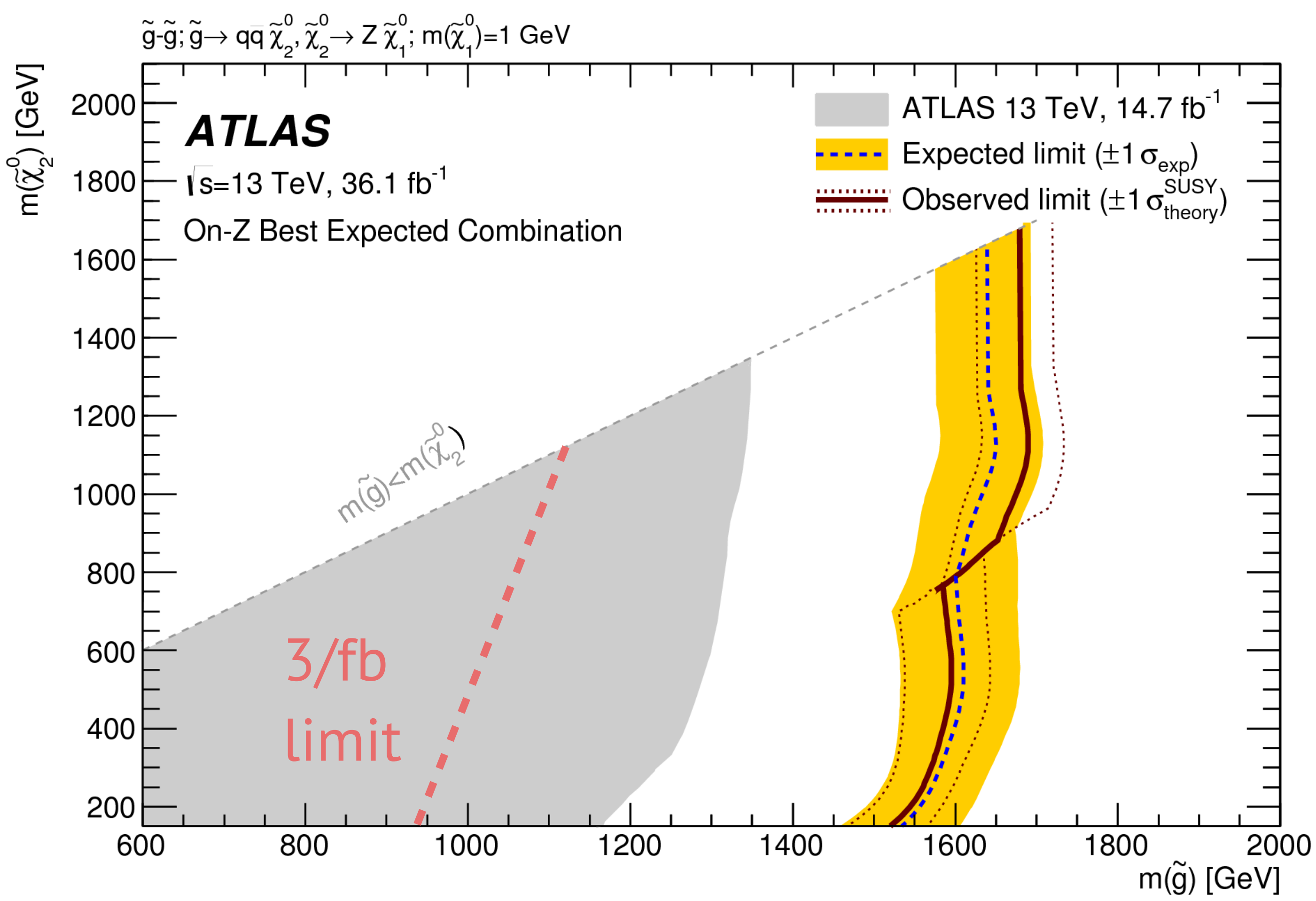
ATLAS-SUSY-2016-33

Looking beyond the Standard Model

No more hints of Supersymmetry
Pushed exclusions past TeV scale

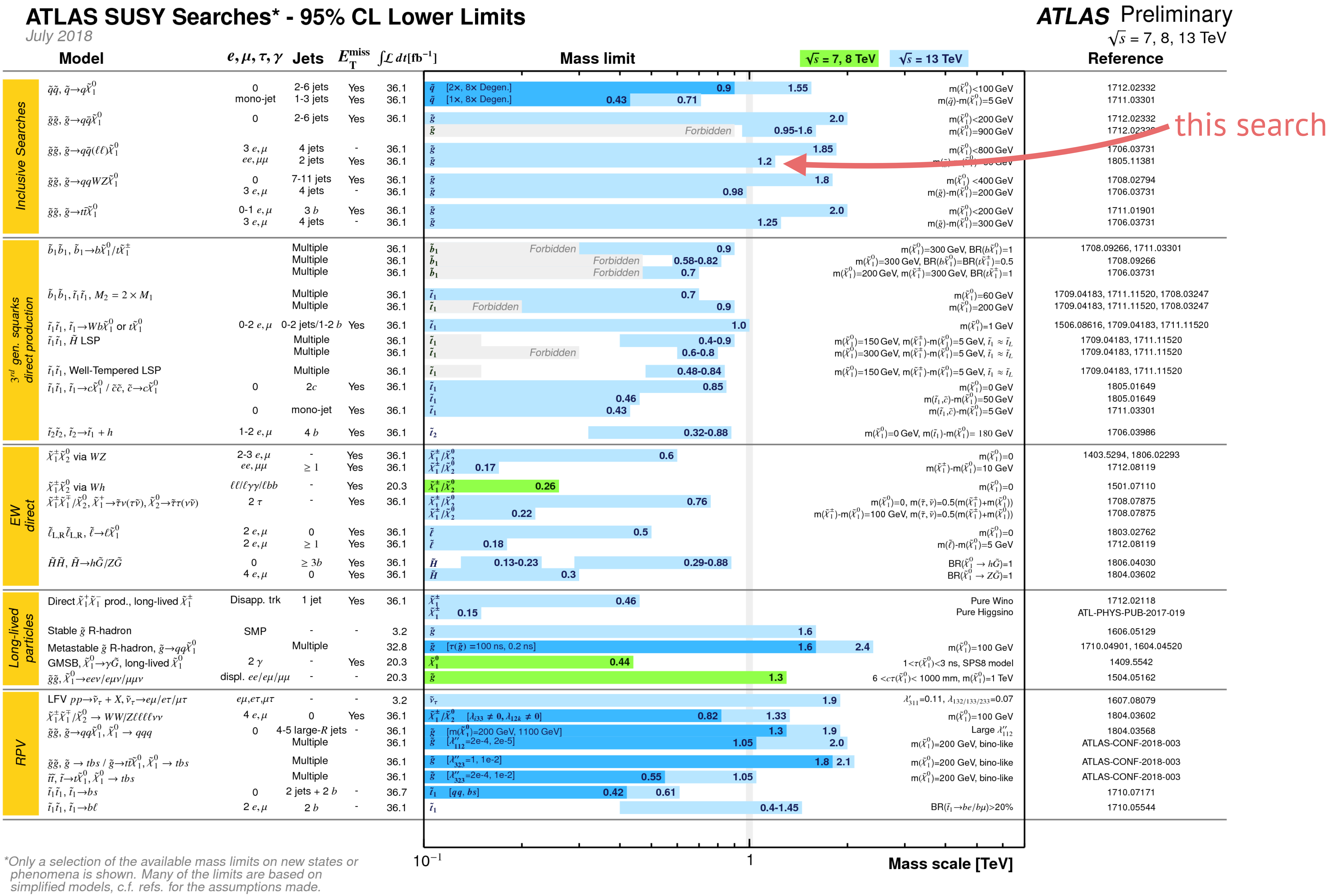
Big gains from re-optimization already achieved

Not as exciting in 2019



ATLAS-SUSY-2016-33

ATLAS Supersymmetry Coverage



ATLAS Supersymmetry Coverage

Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	36.1	$\tilde{\chi}_1^\pm$ 0.46 $\tilde{\chi}_1^\pm$ 0.15
	Stable $\tilde{g}$ R-hadron	SMP	-	-	3.2	$\tilde{g}$ 1.6
	Metastable $\tilde{g}$ R-hadron, $\tilde{g}\to qq\tilde{\chi}_1^0$		Multiple		32.8	$\tilde{g}$ [$\tau(\tilde{g})$ =100 ns, 0.2 ns] 1.6 2.4
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2γ	-	Yes	20.3	$\tilde{\chi}_1^0$ 0.44
	$\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{g}$ 1.3 6 $< c$

Here the usual paradigm falls apart because we add another variable: **lifetime**

Typical analysis workflow:

- Identify a well motivated, simplified model
- Examine the phenomenology of the model and how it changes with SUSY mass spectra
- Figure out how to separate the signal from SM background
- Design an analysis with related signal regions, targeting different points on a mass grid

ATLAS Supersymmetry Coverage

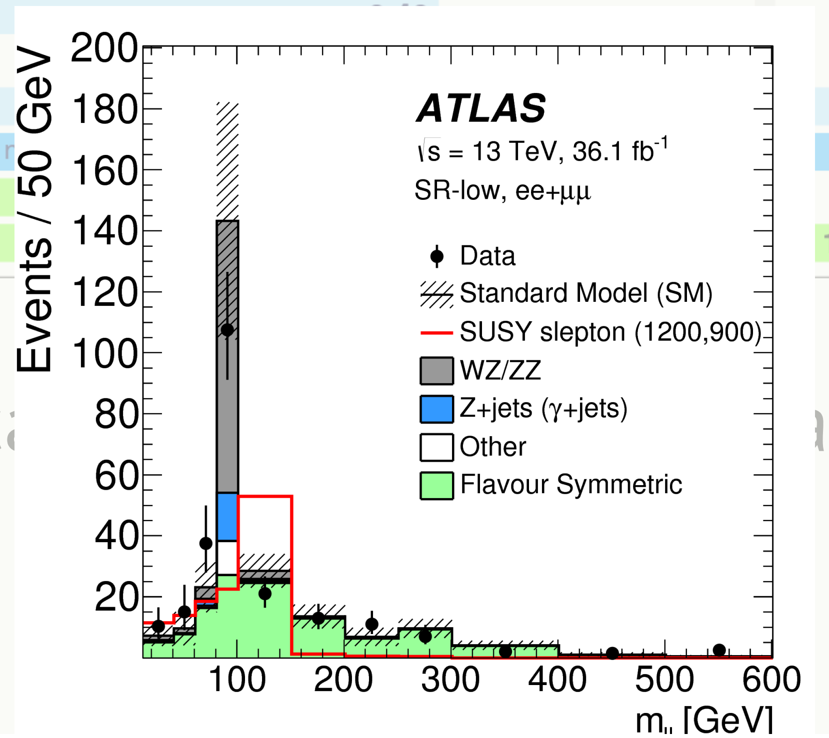
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	36.1	$\tilde{\chi}_1^\pm$ $\tilde{\chi}_1^\pm$ 0.15
	Stable $\tilde{g}$ R-hadron	SMP	-	-	3.2	$\tilde{g}$ 1.6
					8	$\tilde{g}$ [$\tau(\tilde{g})$ =100 r 1.6 2.4
					3	$\tilde{\chi}_1^0$
					3	$\tilde{g}$ 1.3 6 <c

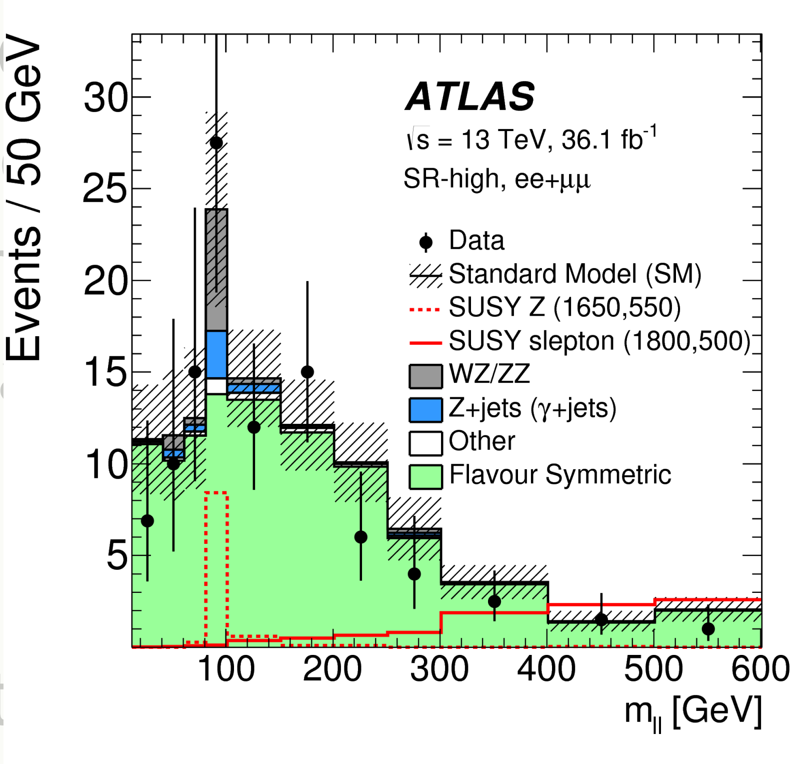
All pairs of leptons, jets, missing energy

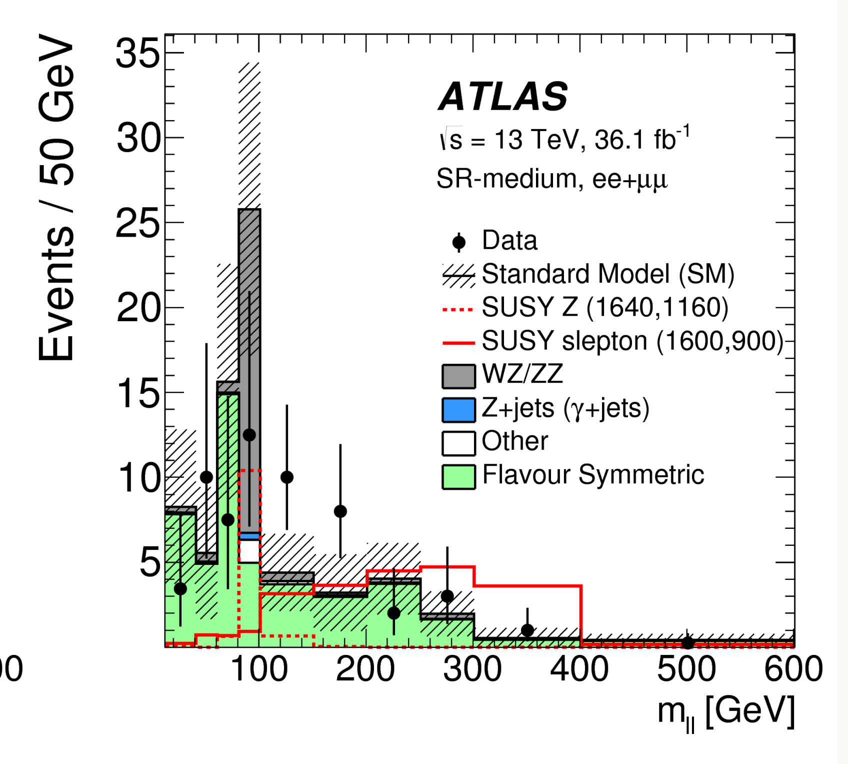
...part beca... ...ariable: **lifetime**

Typical analysis workflow:

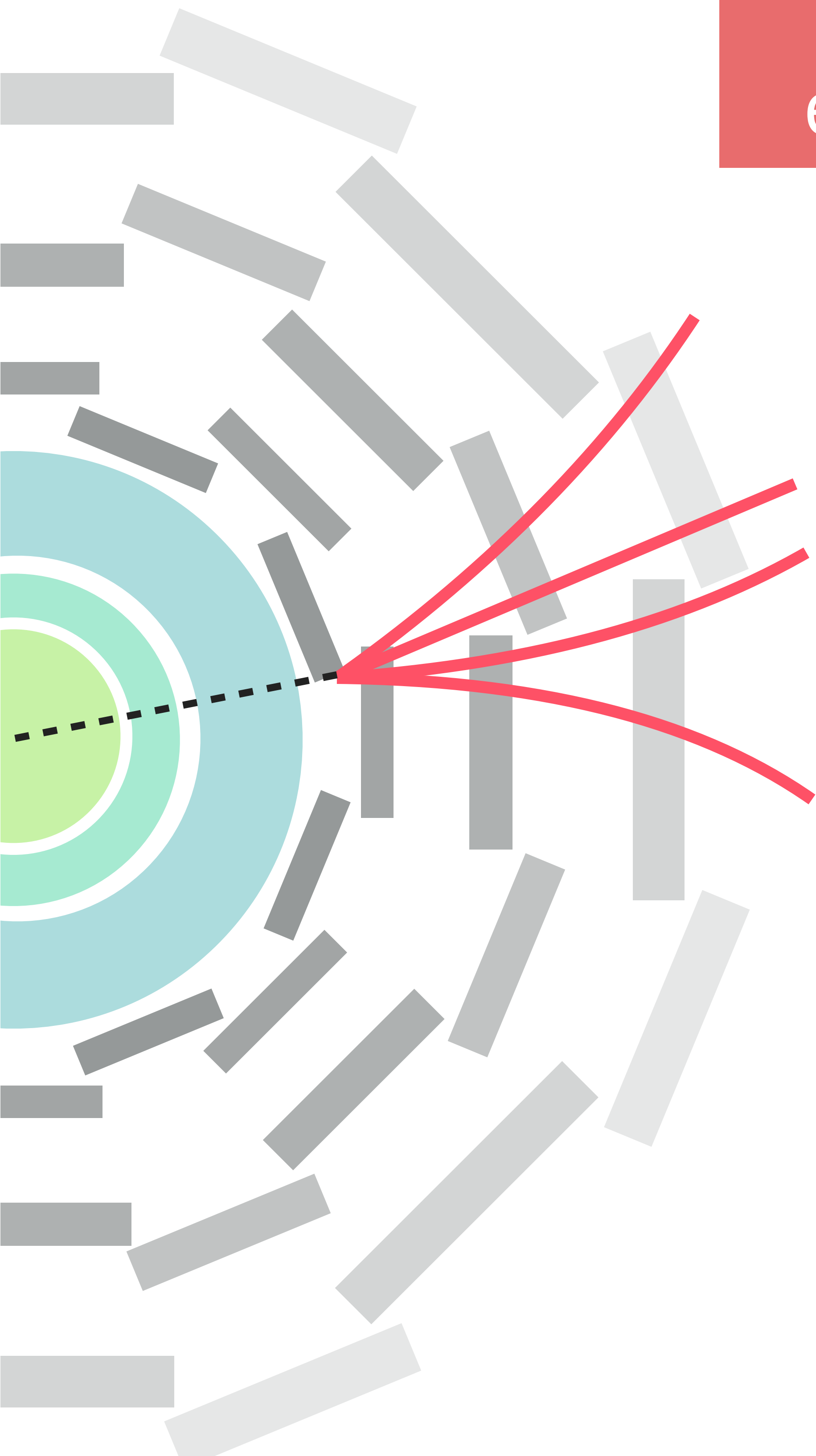
- Identify a well motivate...
- Examine the phenomen... and how it changes with...
- Figure out how to separ... background
- Design an analysis with... targeting different point...





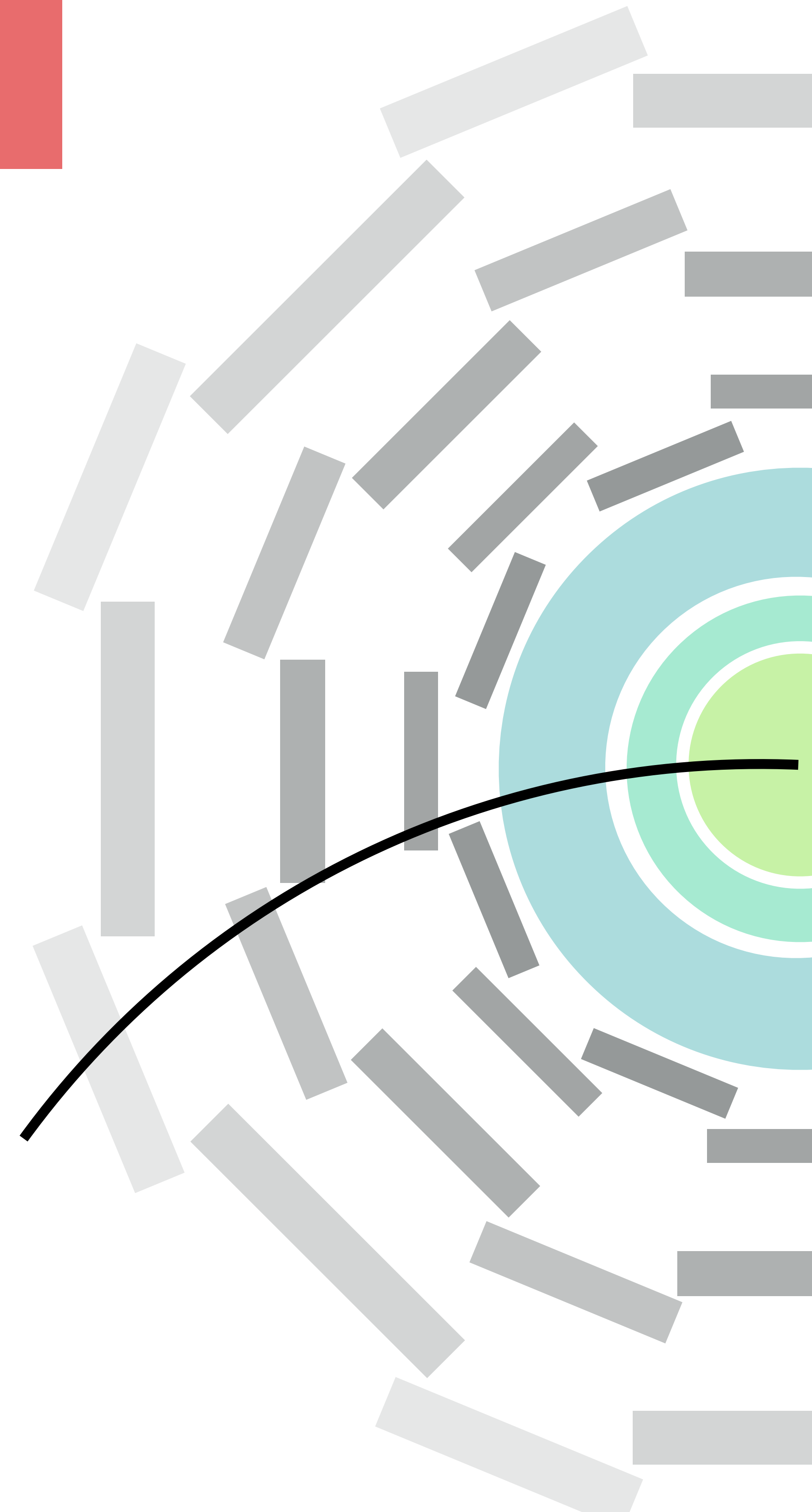


Lifetime changes create fundamentally different experimental signatures



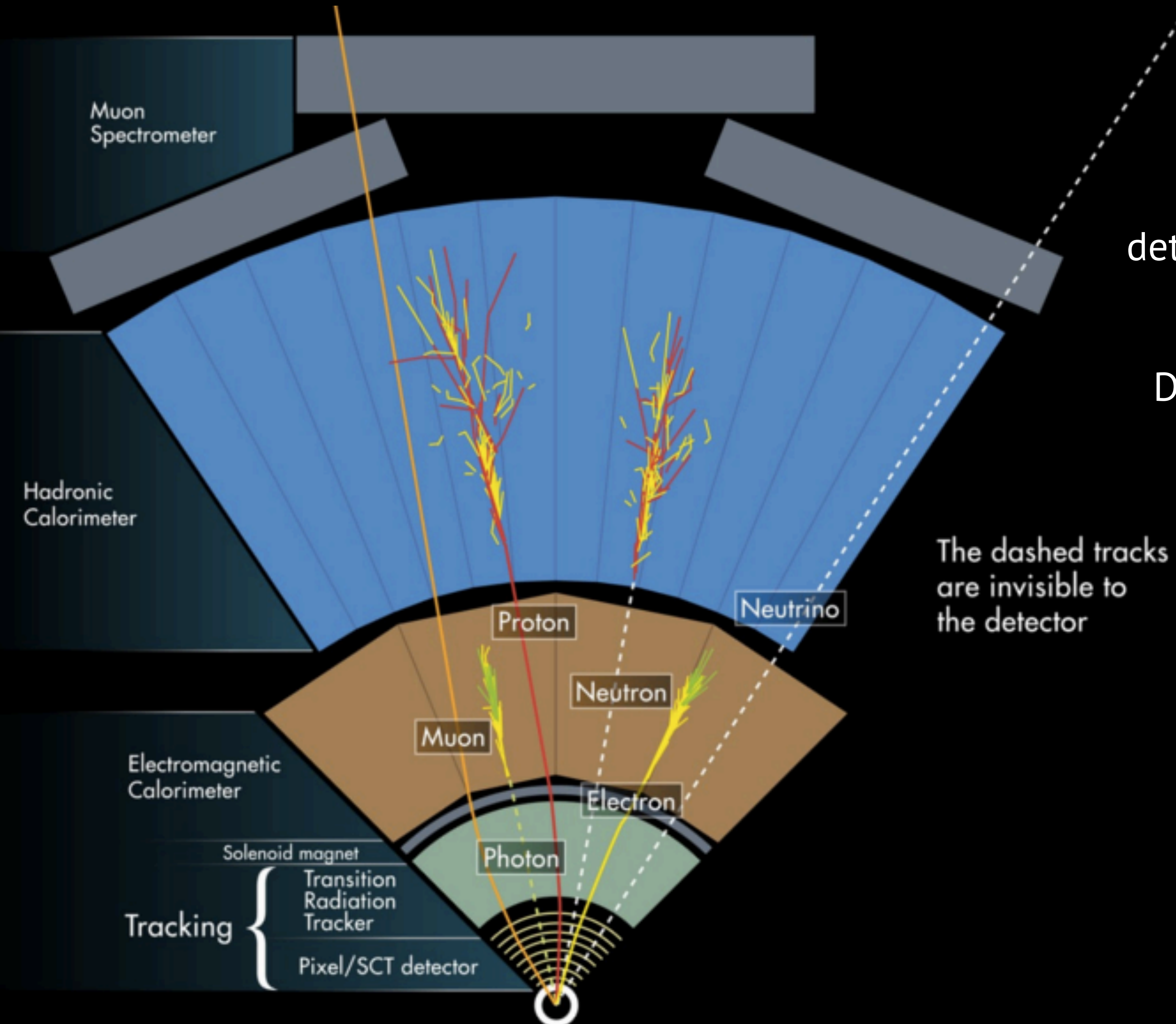
Metastable:
Decays somewhere inside the ATLAS detector

Stable:
Passes through the full detector



LLP signature diagrams adapted from Heather Russell

What ATLAS is designed to do

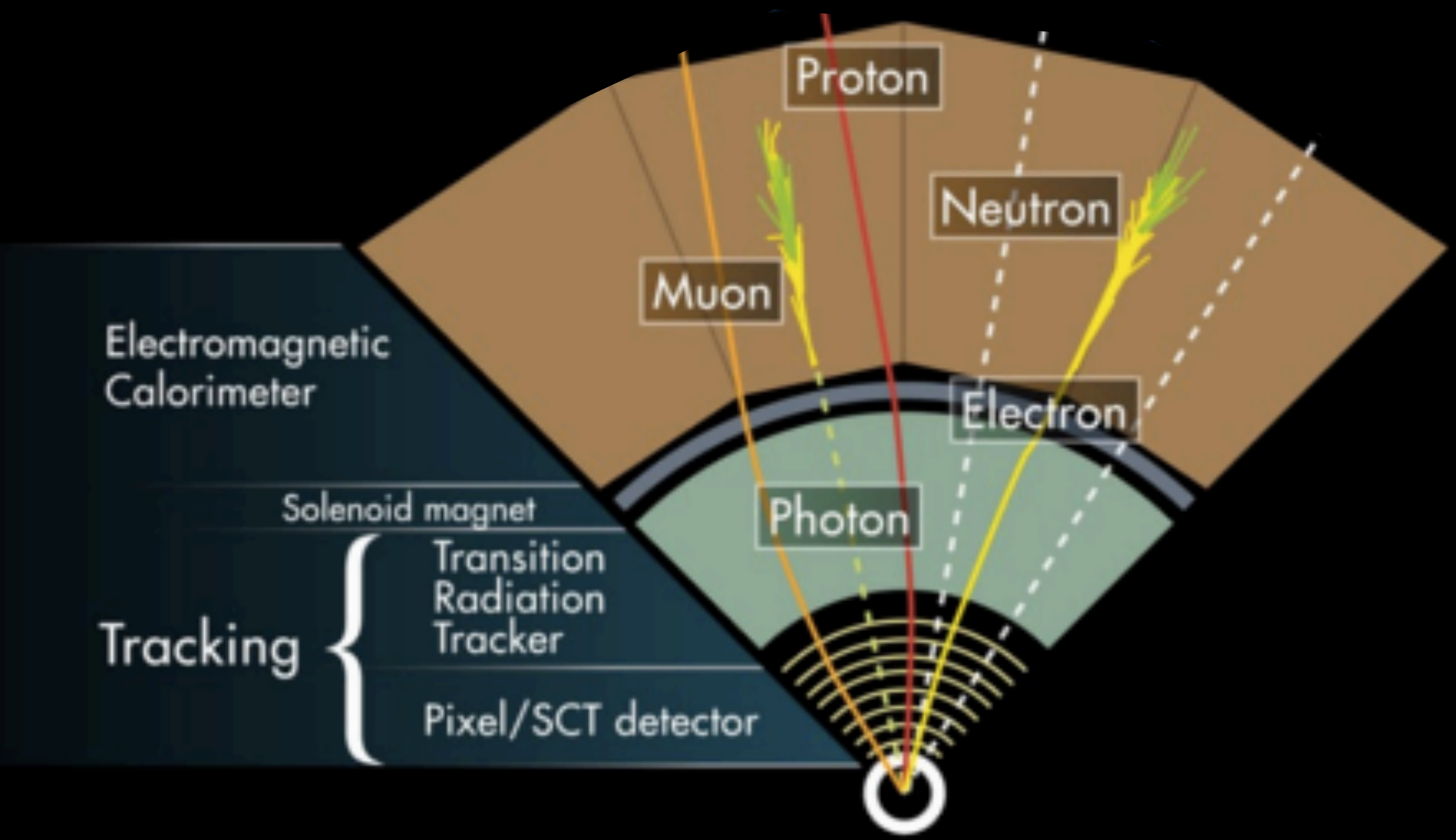


Layers of the ATLAS detector provide complimentary information for particle ID

Designed to look at particles coming from the center

Optimized for known particles

What ATLAS is designed to do

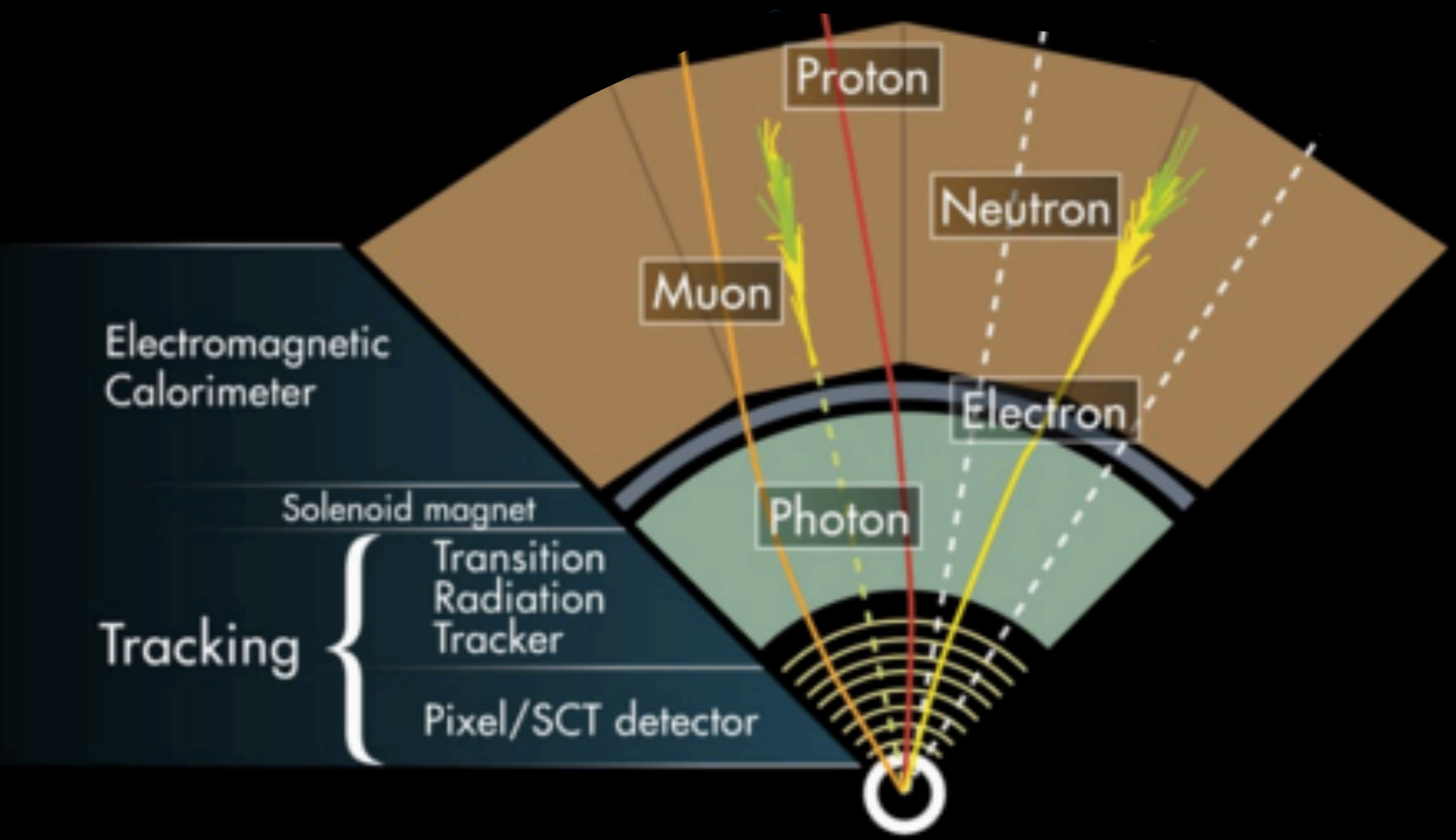


Electron with no prompt track
→ photon

Electron that appears part way through the calorimeter
→ noise?

BSM particle traveling through the detector
→ ???

What ATLAS is designed to do



Electron with no prompt track
→ photon

Electron that appears part way through the calorimeter
→ noise?

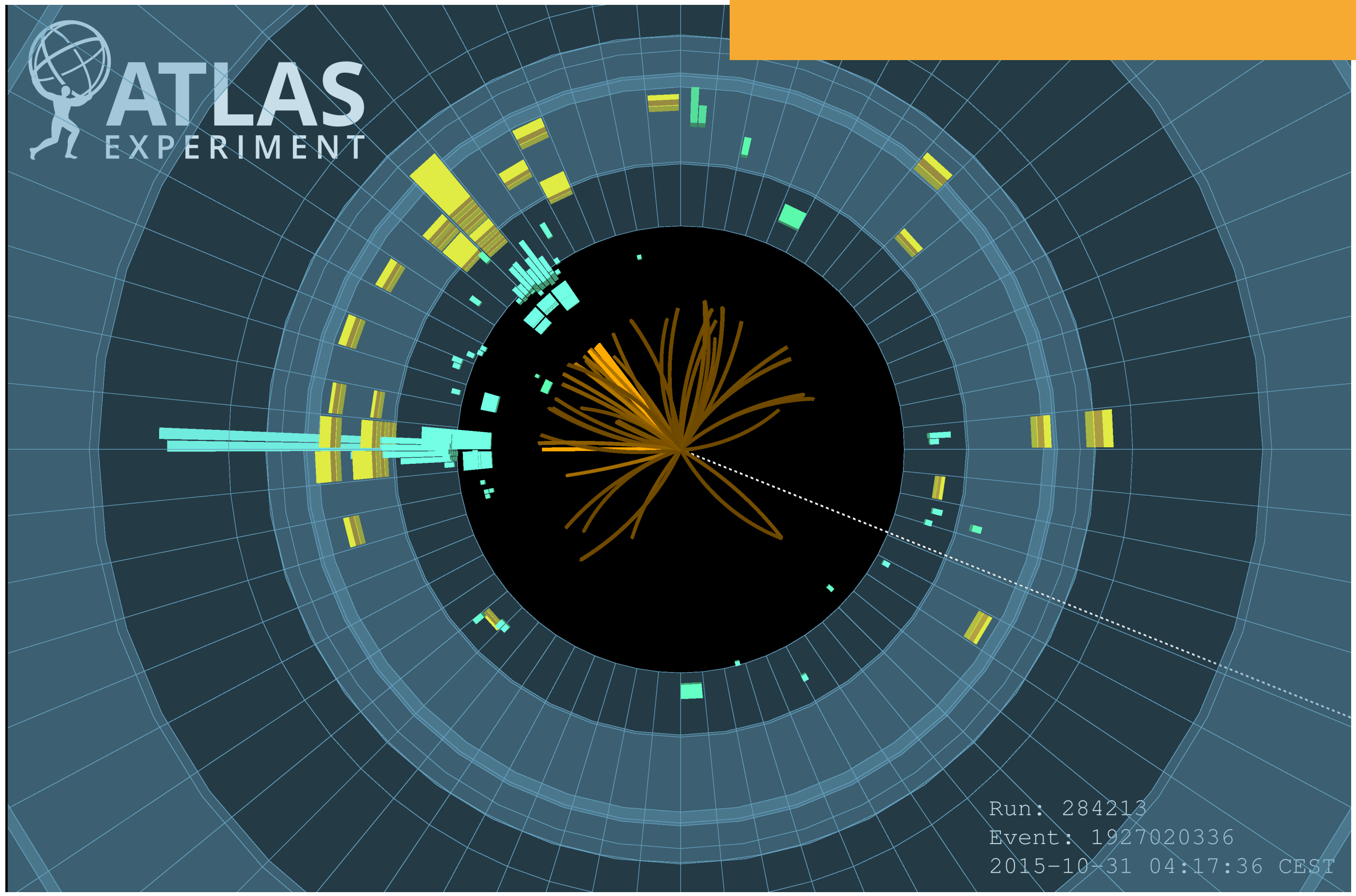
BSM particle traveling through the detector
→ ???

Unusual signatures require dedicated (often time consuming) techniques

Problem:

By the time you can do this special reconstruction, ATLAS has already thrown away more than 99.99% of collisions

The ATLAS Trigger



ATLAS public event displays

Final decision on what to keep is made in around 250 ms

How do we decide if this event is worth keeping?

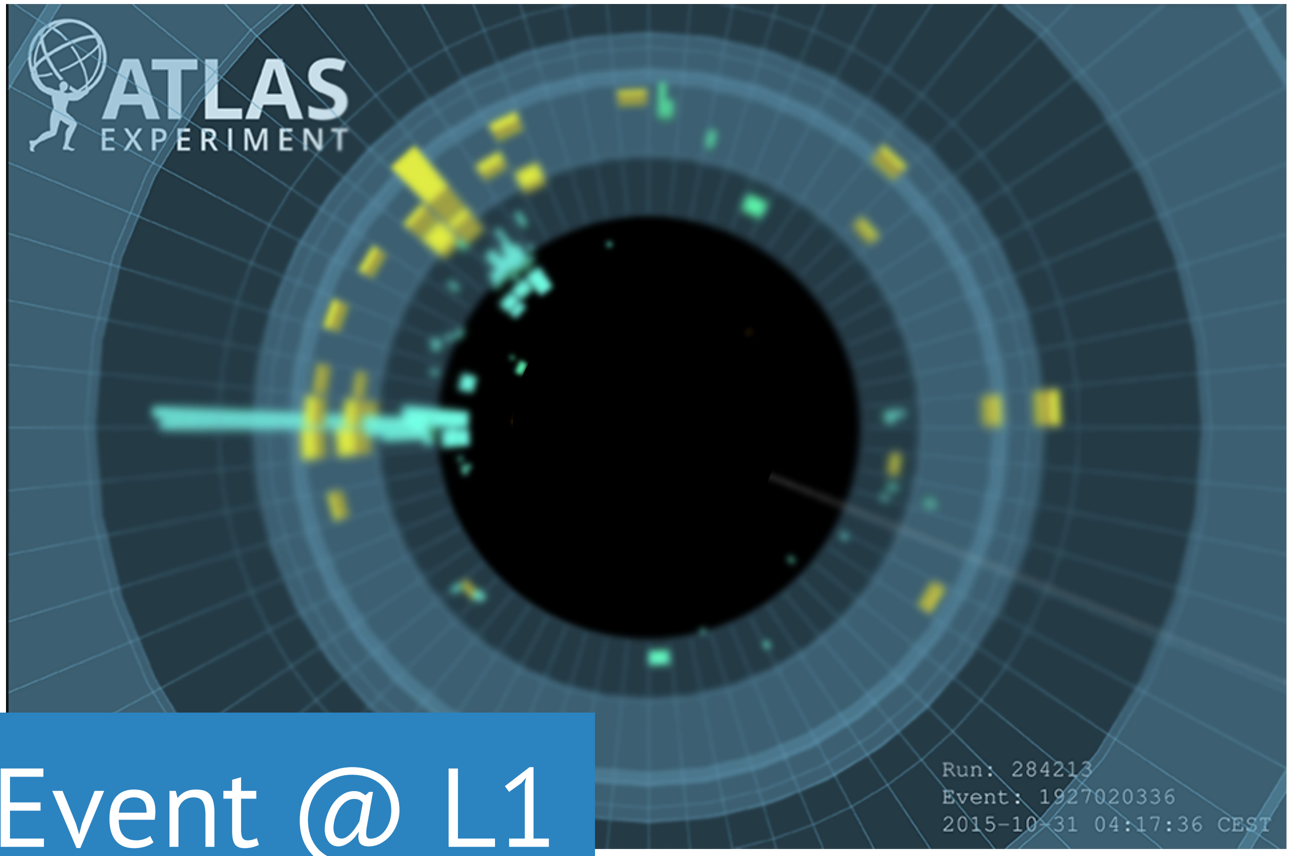
(image of an event with analysis-level "offline" reconstruction)

Level 1 trigger decisions are made with rough **calorimeter** and **muon** information

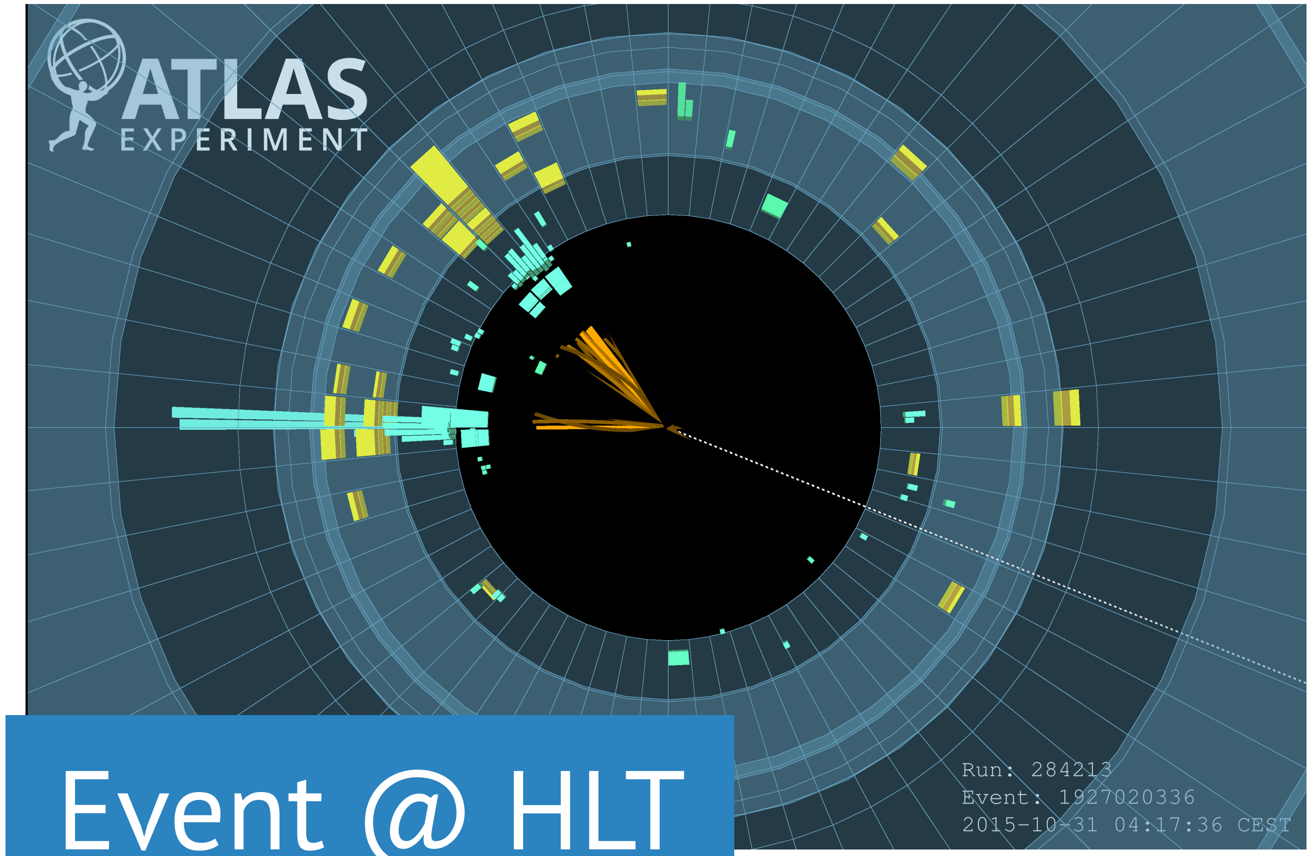
40 MHz → 100 kHz

High Level Trigger uses **full precision** information in **small regions**

100 kHz → 1 kHz



Event @ L1



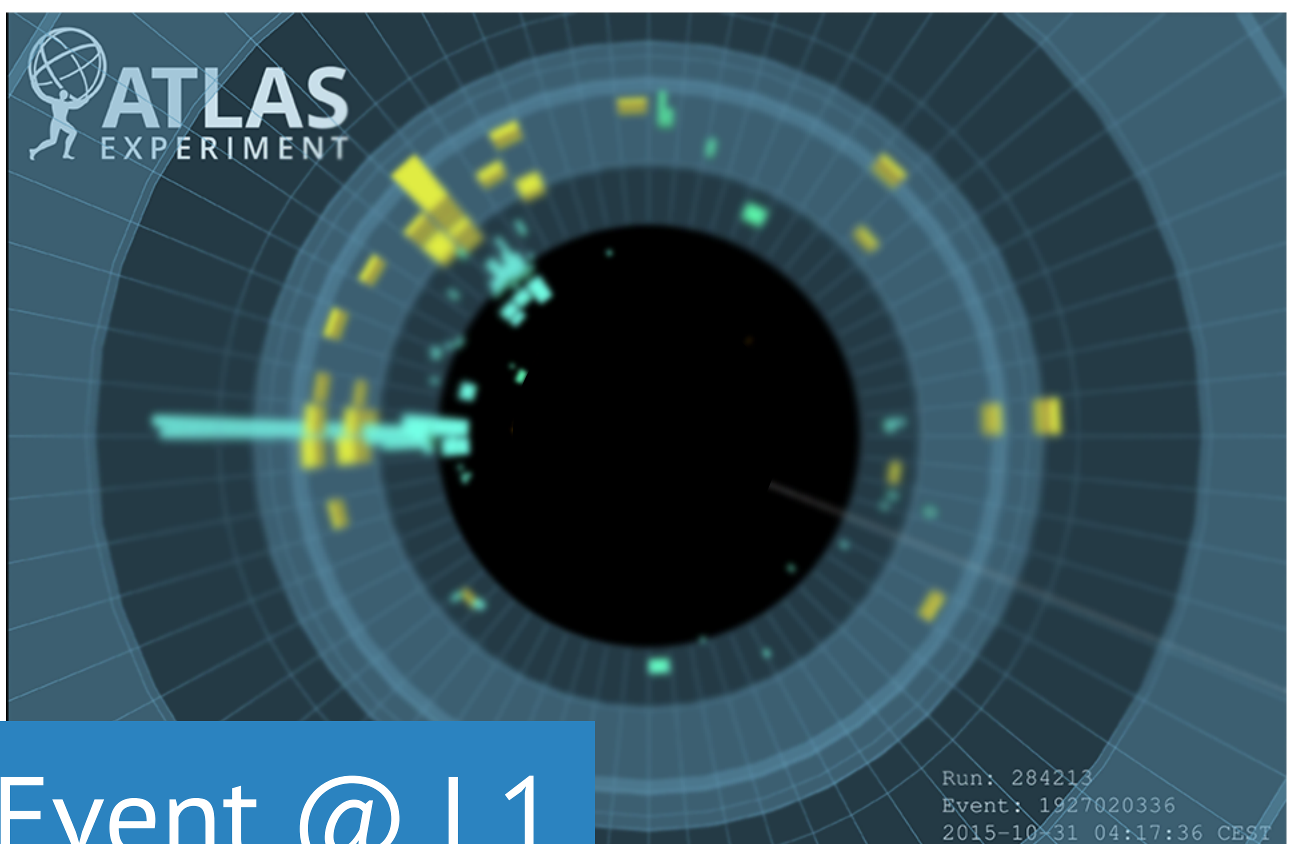
Event @ HLT

Level 1 trigger decisions are made with rough **calorimeter** and **muon** inform

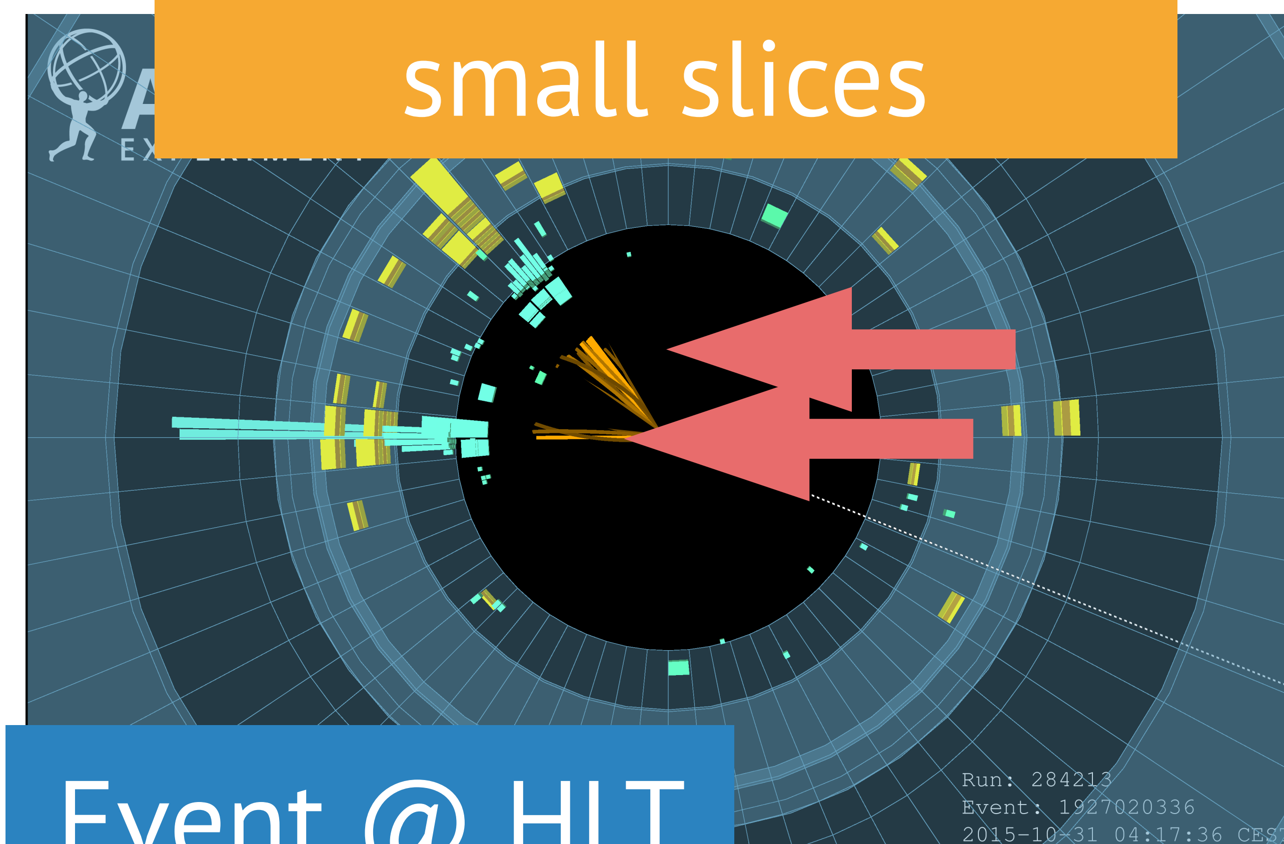
High Level Trigger uses **full pr** information in **small regio**

tracking:
only precise measurement of particle lifetime

only available in small slices



Event @ L1

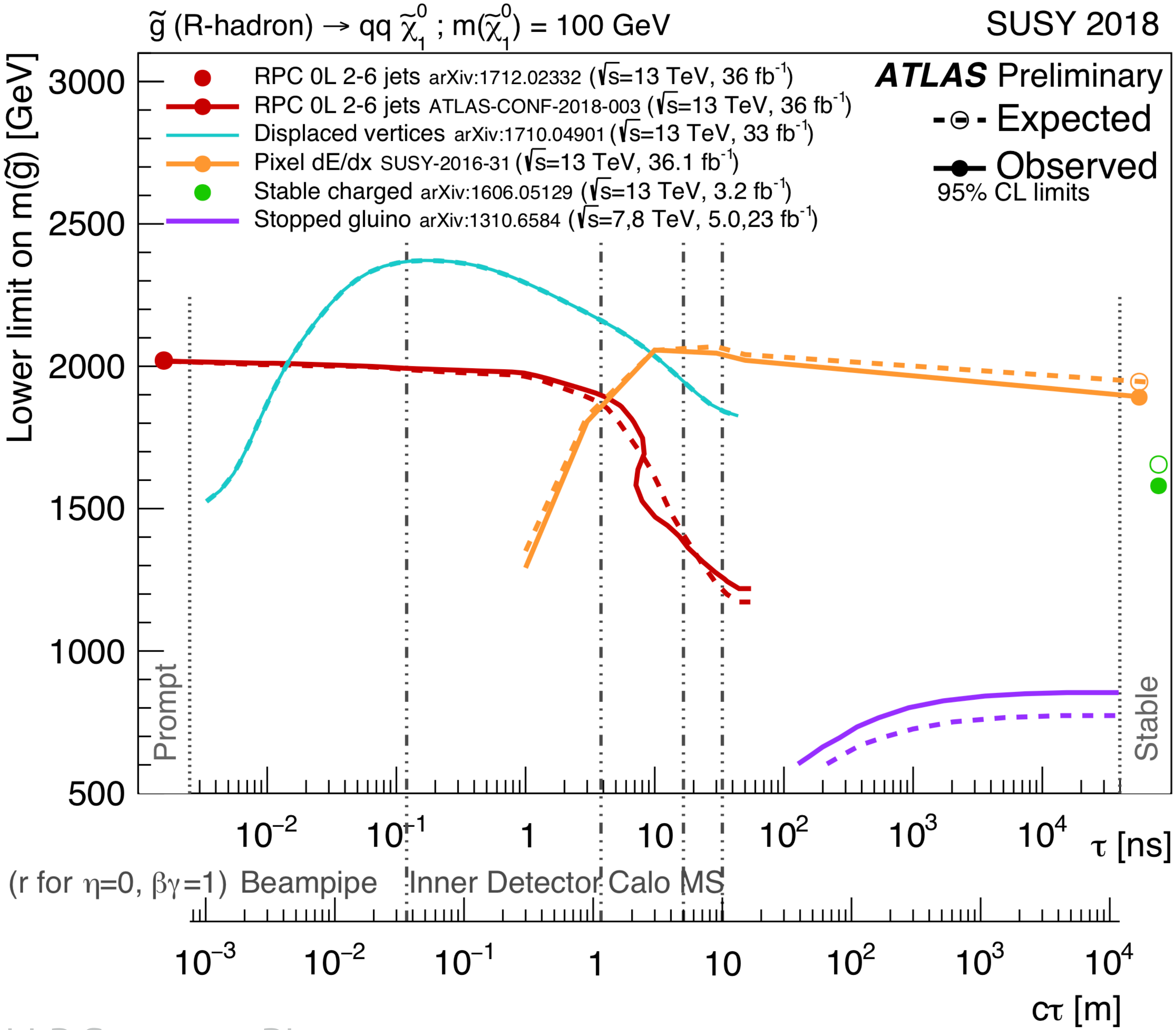


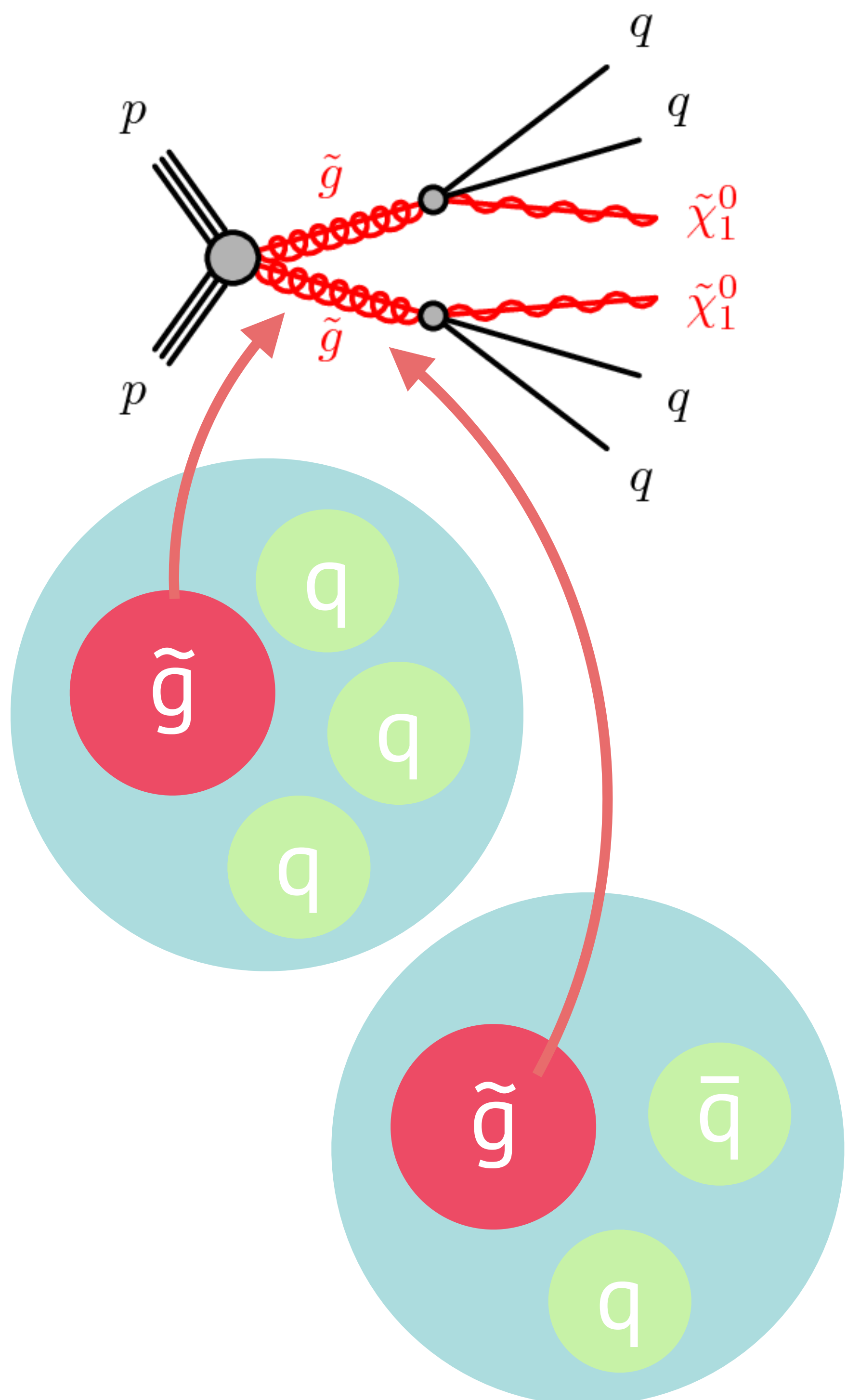
Event @ HLT

ATLAS searches for long-lived particles

an example of success
R-hadrons

hadron formed with a metastable SUSY particle





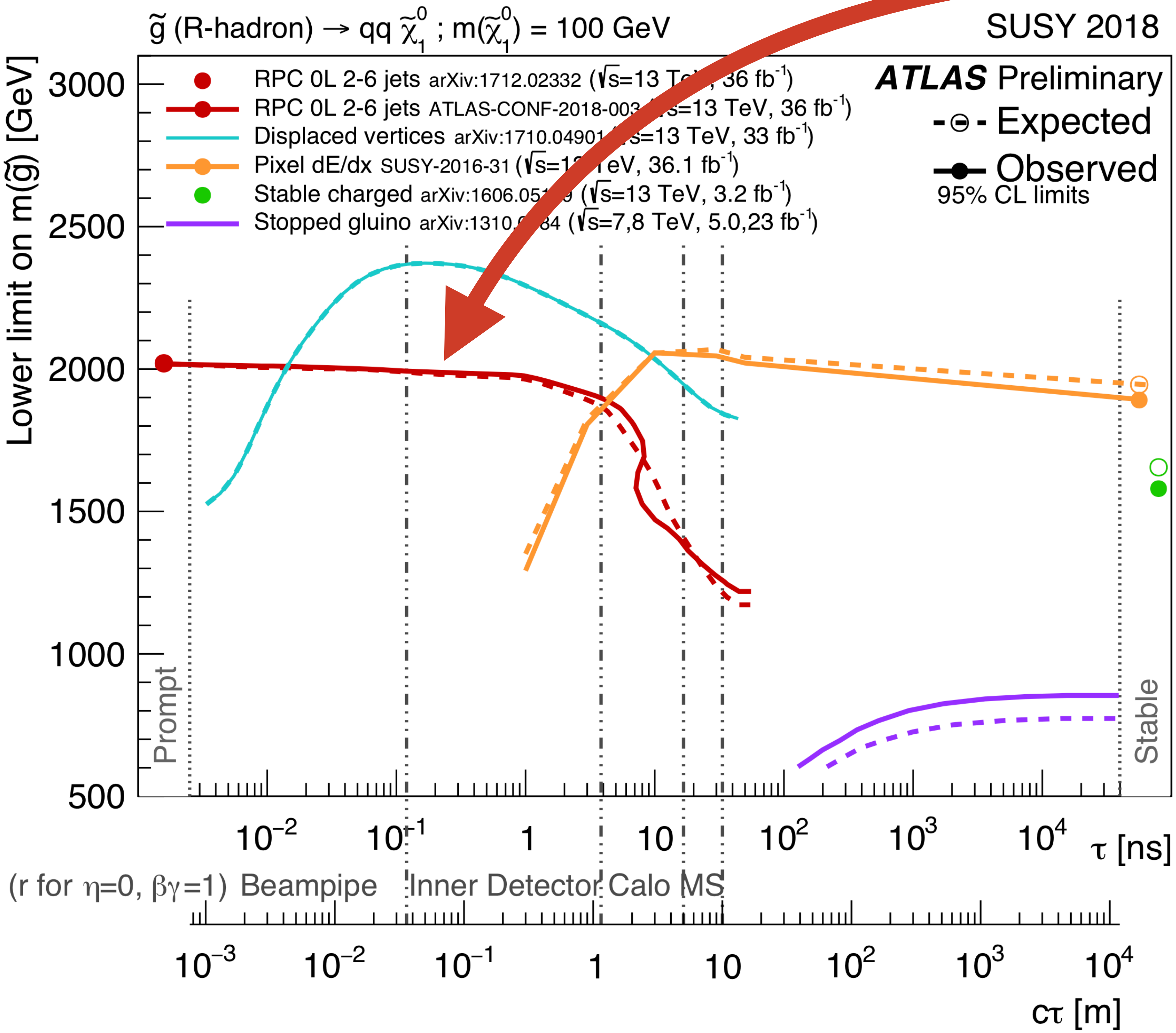
LLP Summary Plots

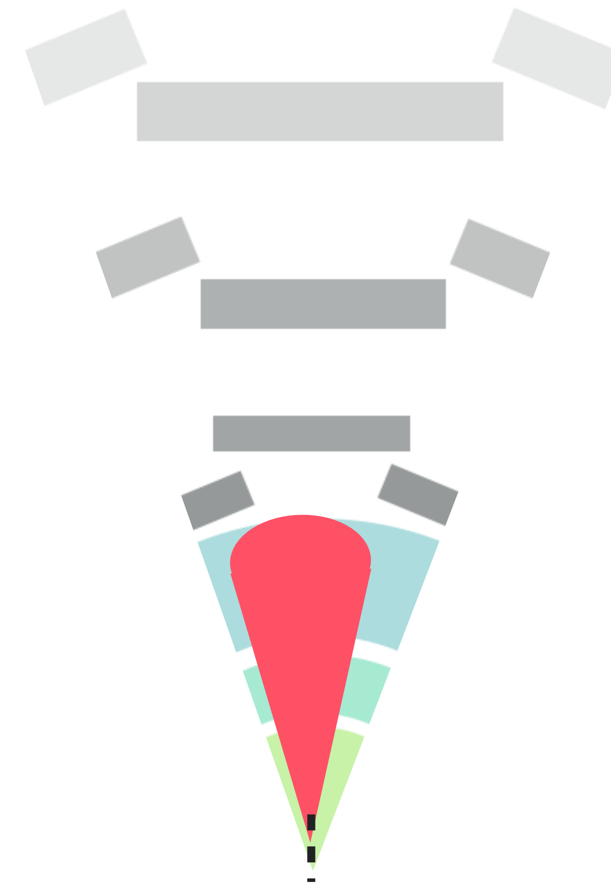
ATLAS searches for long-lived particles

an example of success

R-hadrons

Prompt Search





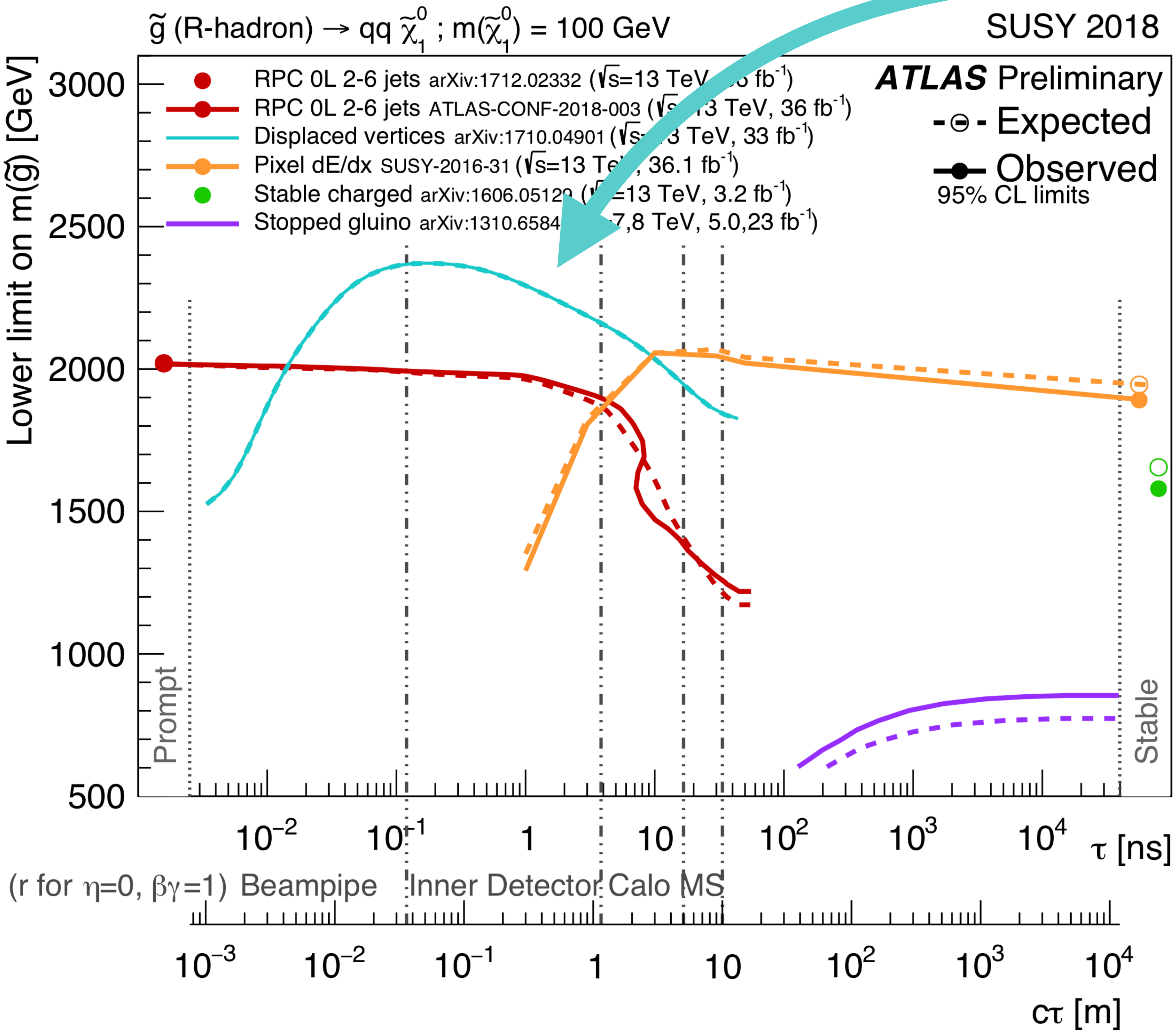
triggers on missing energy from neutralino decay

original search required jets to have associated tracks

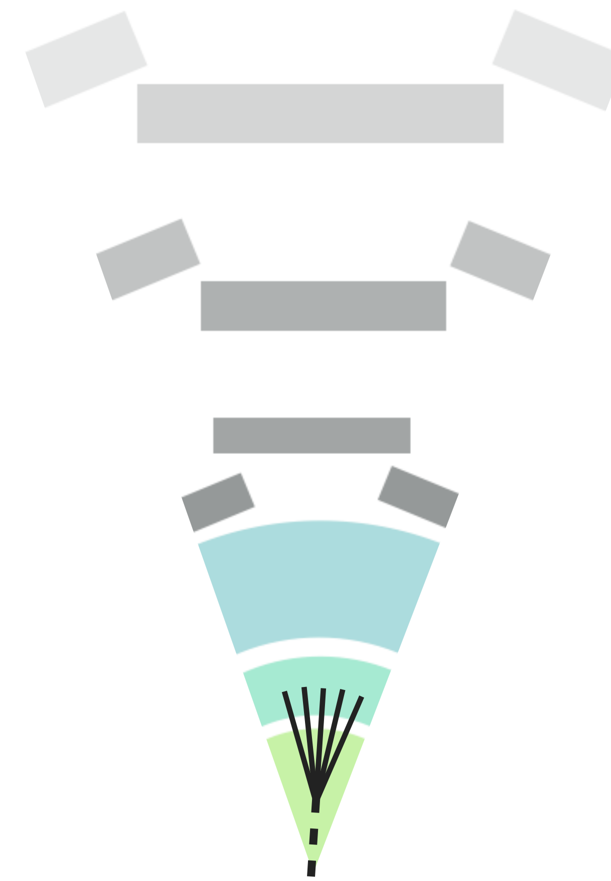
modified to increase acceptance

ATLAS searches for long-lived particles

an example of success
R-hadrons



Displaced Vertices



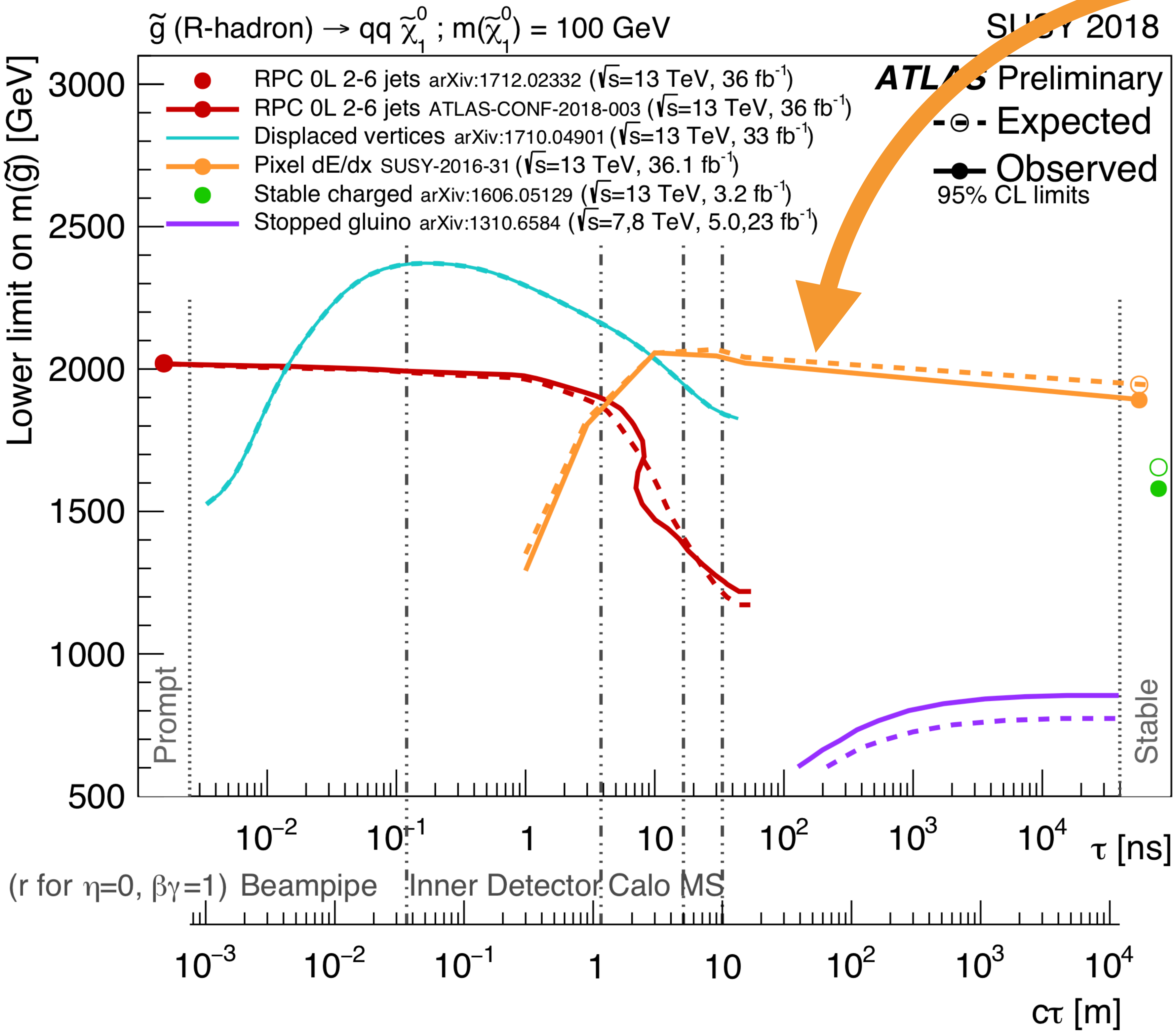
triggers on missing energy from neutralino decay

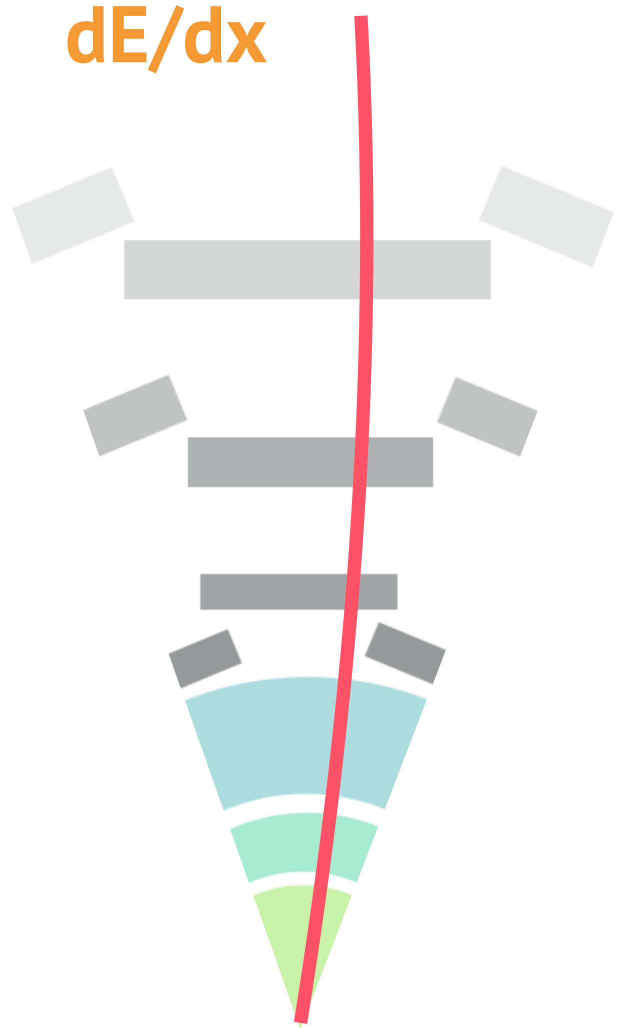
reconstructs displaced vertices with dedicated tracking algorithms

ATLAS searches for long-lived particles

an example of success

R-hadrons





triggers on missing energy from neutralino decay (works less well when stable)

calculate energy deposition in silicon sensors to find high-mass particles

Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	36.1	$\tilde{\chi}_1^\pm$ 0.46; $\tilde{\chi}_1^\pm$ 0.15
	Stable $\tilde{g}$ R-hadron	SMP	-	-	3.2	$\tilde{g}$ 1.6
	Metastable $\tilde{g}$ R-hadron, $\tilde{g}\rightarrow qq\tilde{\chi}_1^0$	Multiple			32.8	$\tilde{g}$ [$\tau(\tilde{g})$ =100 ns, 0.2 ns] 1.6 2.4
	GMSB, $\tilde{\chi}_1^0\rightarrow\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$ 0.44
	$\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\rightarrow eev/e\mu v/\mu\mu v$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{g}$ 1.3 $6 < c$

Many different dedicated searches for R-hadrons

Together they cover the full lifetime range

Each signature has different strategy, specialized techniques

- modified jet cleaning
- specialized track reconstruction
- dE/dx calculation

None use a trigger related to long lifetimes

ATLAS Supersymmetry Coverage

Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	36.1	$\tilde{\chi}_1^\pm$ 0.46 $\tilde{\chi}_1^\pm$ 0.15	
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Many different dedicated searches for R-hadrons

Together they cover the full lifetime range

Each signature has different strategy, specialized techniques

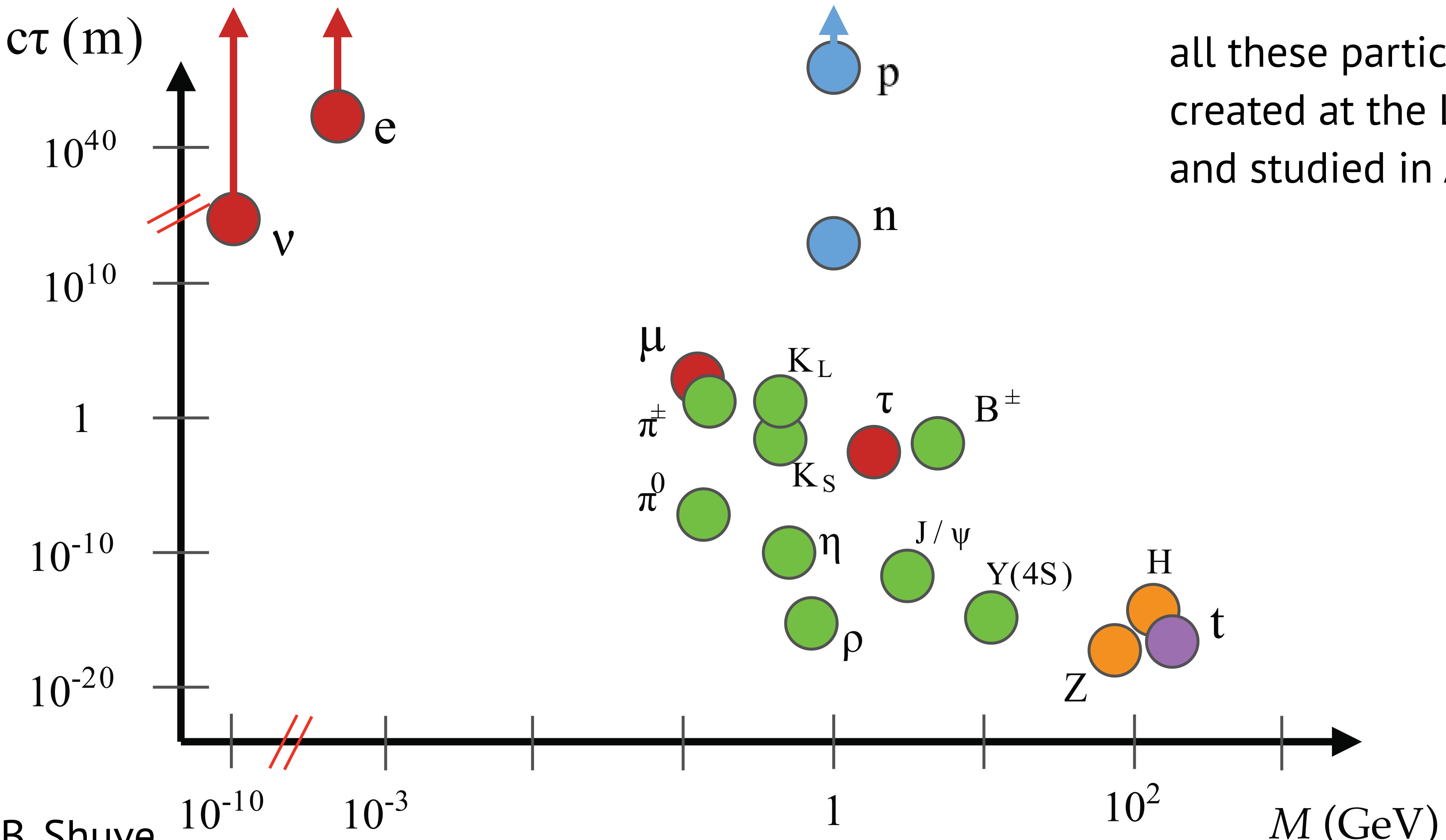
- modified jet cleaning
- spe
- dE/

Is it worth the effort?

Do we really think there are LLPs?

None use a trigger related to long lifetimes

The standard model is full of “long-lived particles”

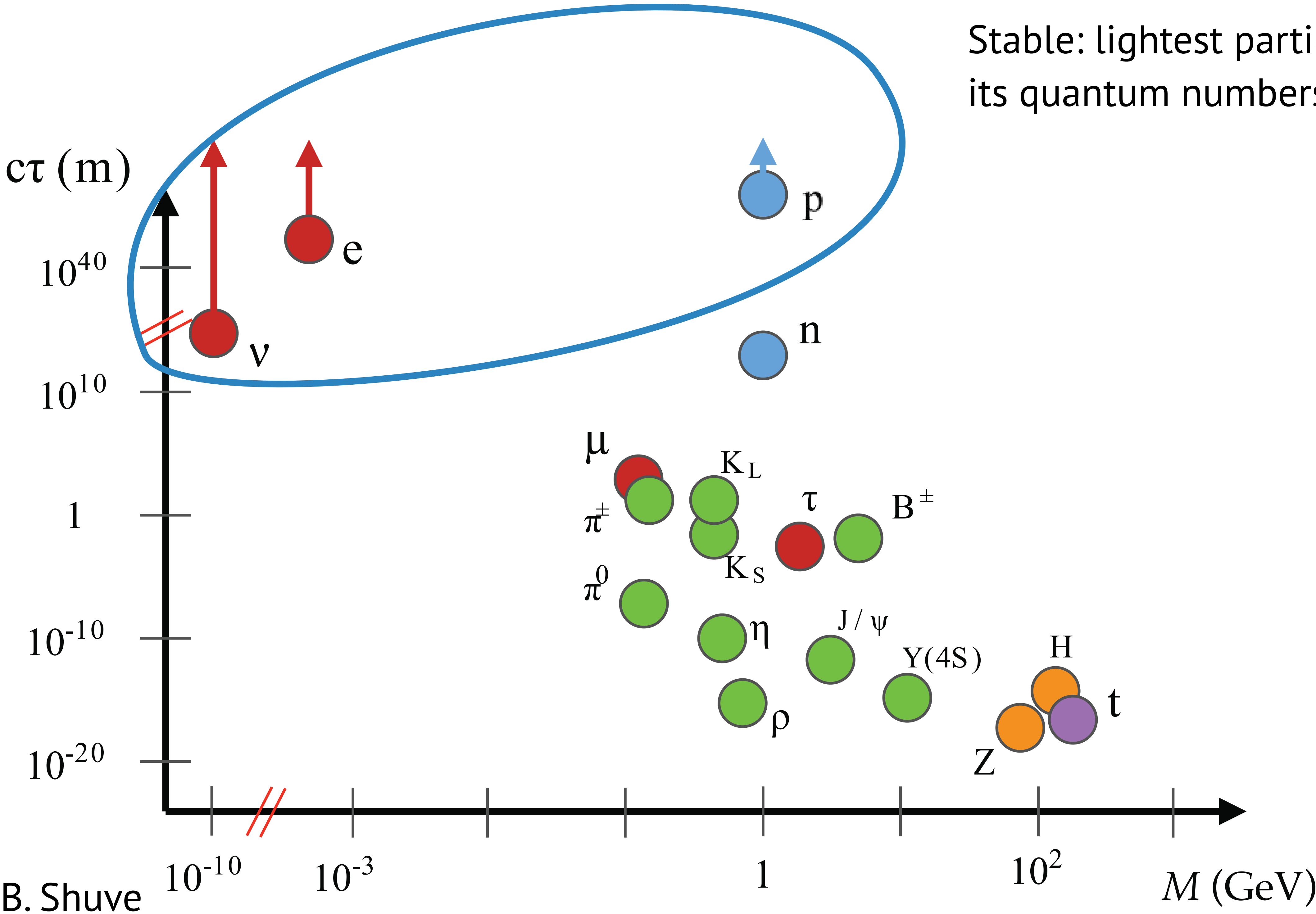


all these particles are created at the LHC and studied in ATLAS

B. Shuve

The standard model is full of "long-lived particles"

Stable: lightest particle with its quantum numbers



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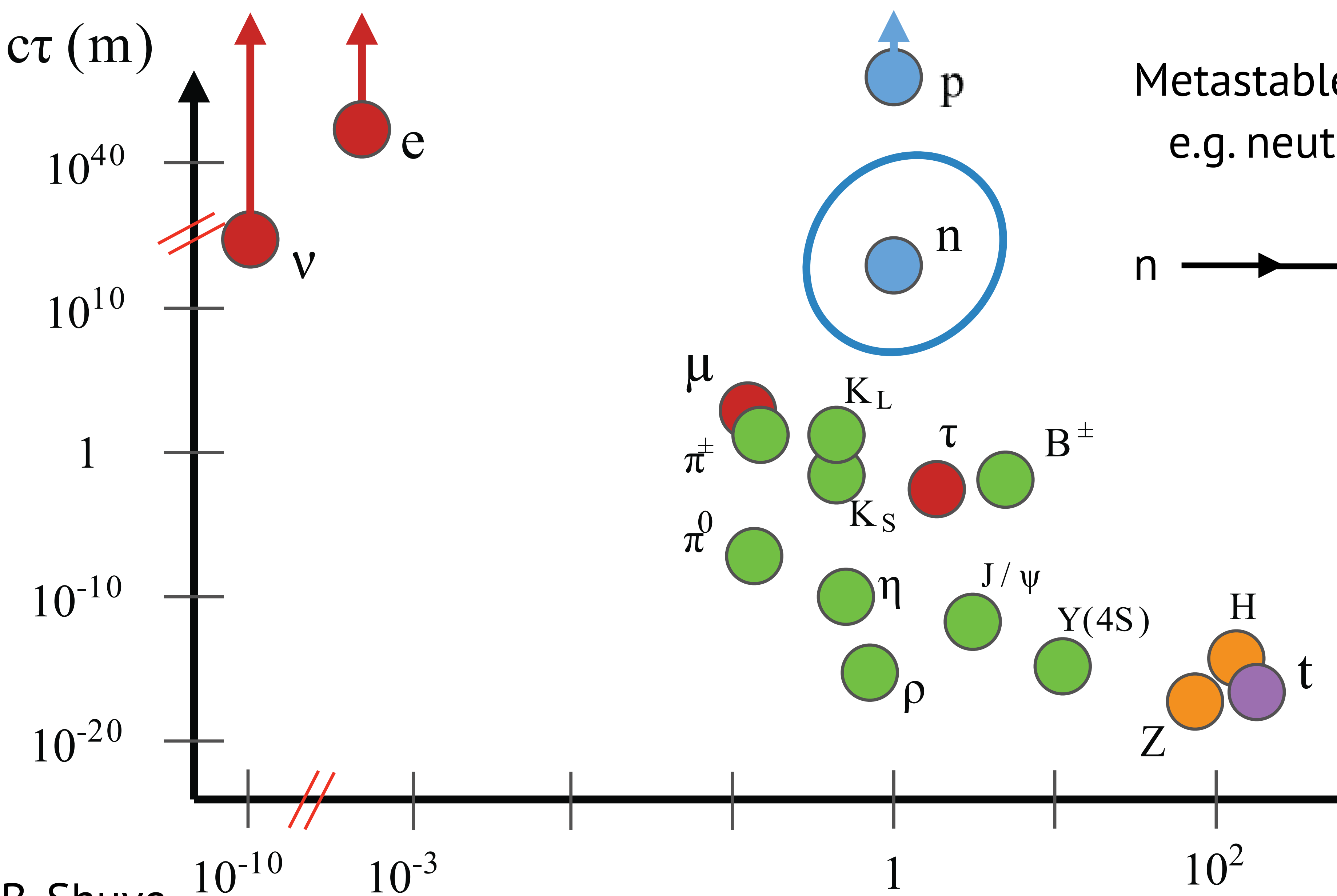
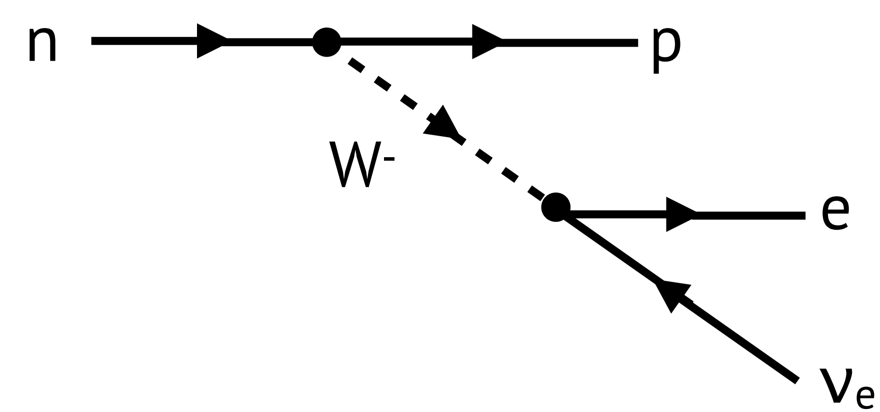
The standard model is full of "long-lived particles"



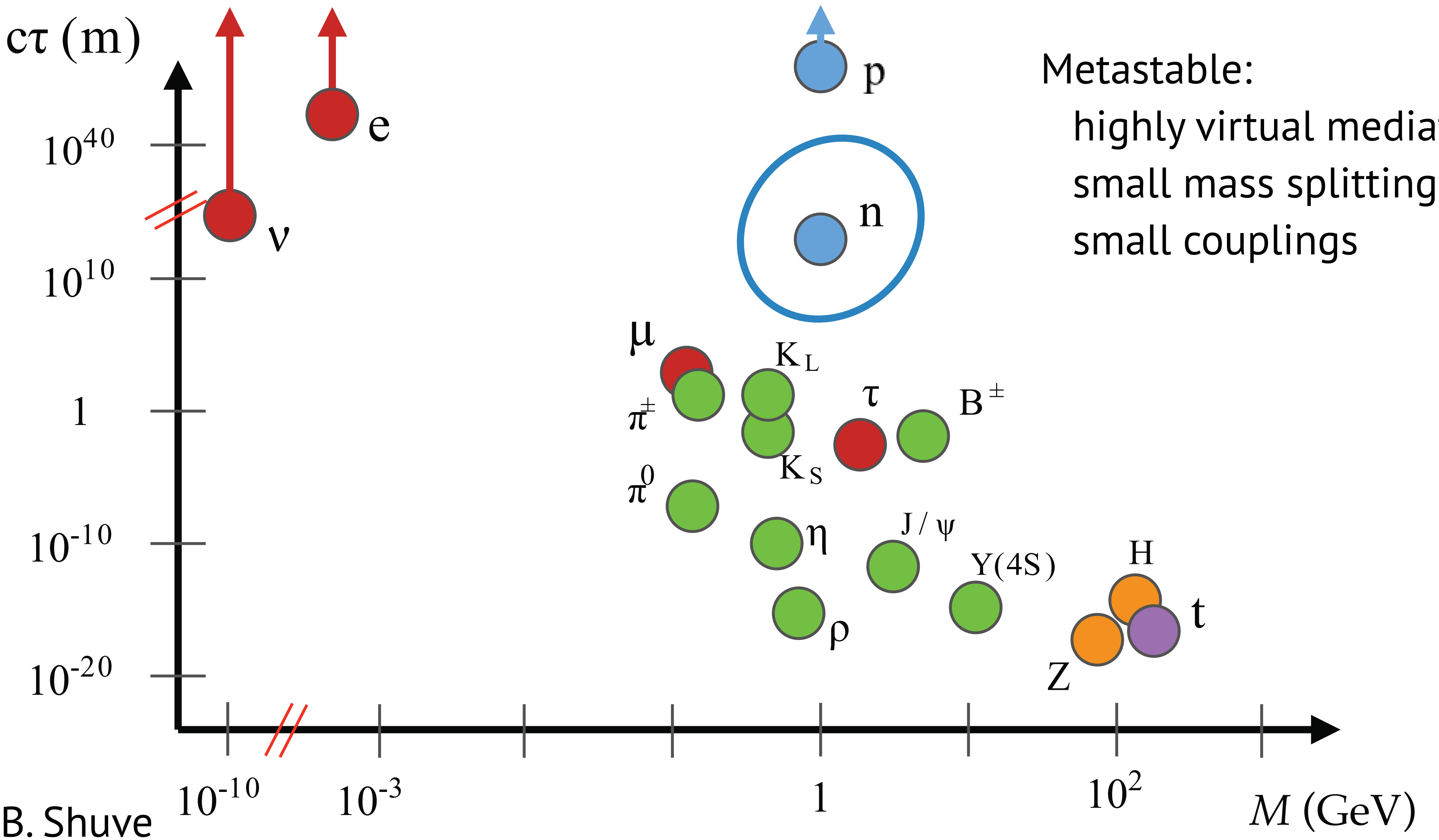
B. Shuve

Stable: lightest particle with its quantum numbers

Metastable:
e.g. neutron



The standard model is full of "long-lived particles"

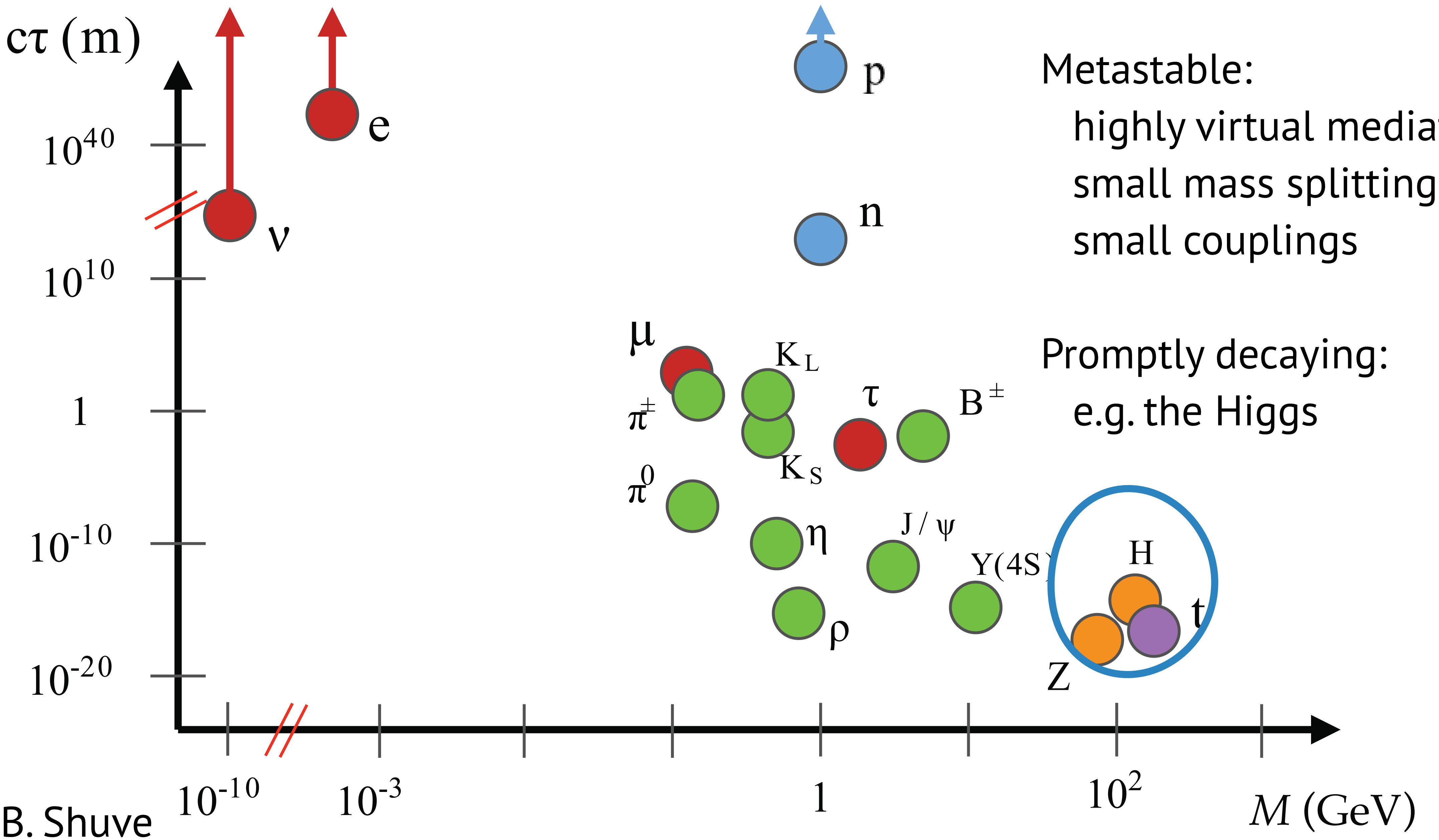


B. Shuve

Stable: lightest particle with its quantum numbers

Metastable:
- highly virtual mediators
- small mass splittings
- small couplings

The standard model is full of "long-lived particles"



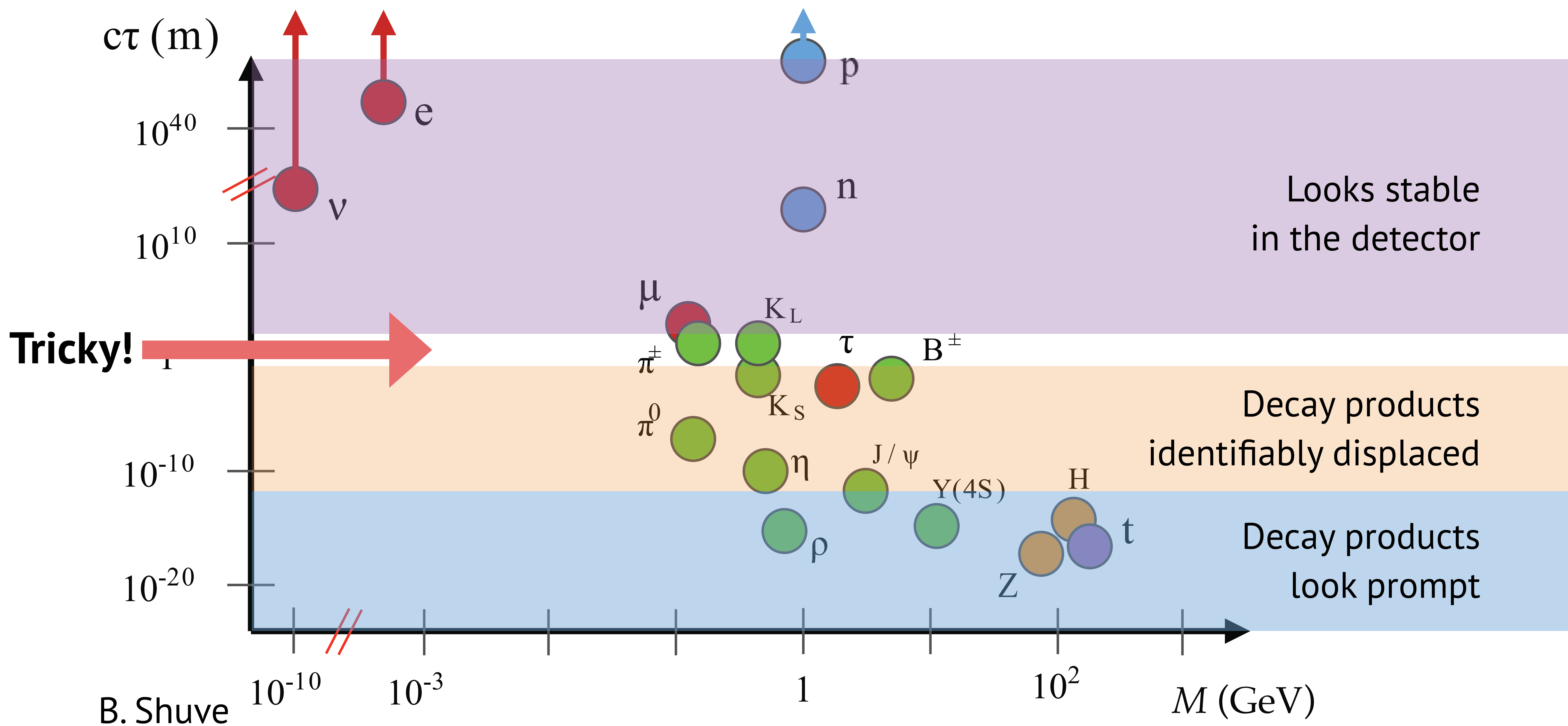
B. Shuve

Stable: lightest particle with its quantum numbers

Metastable:
- highly virtual mediators
- small mass splittings
- small couplings

Promptly decaying:
- e.g. the Higgs

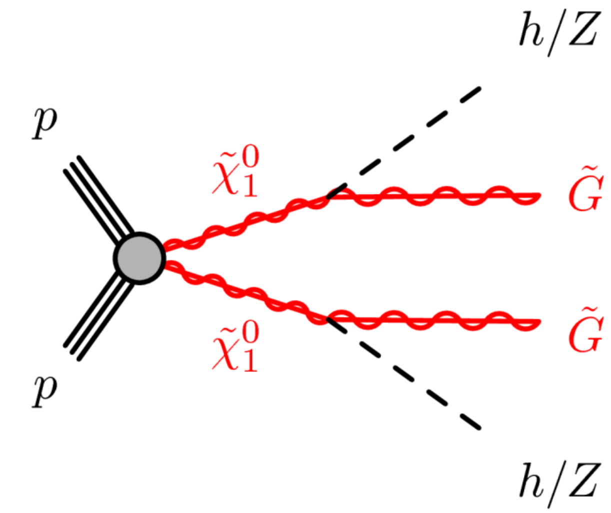
From the experimental point of view…



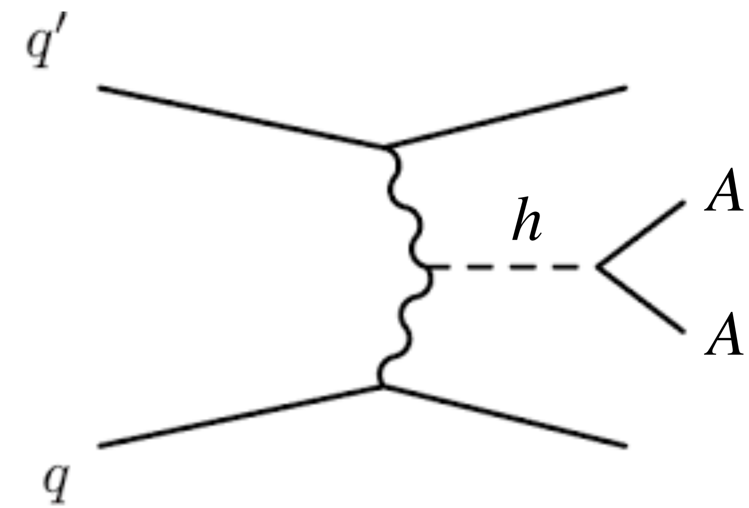
No reason to think there are only Standard Model long-lived particles

Beyond-the-Standard-Model particles can be long-lived for the same reasons (small mass splittings, small couplings, virtual mediators)

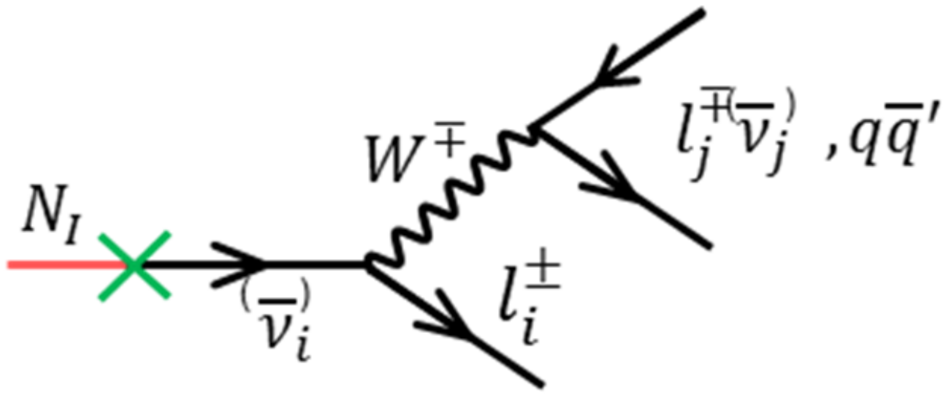
In Supersymmetry…



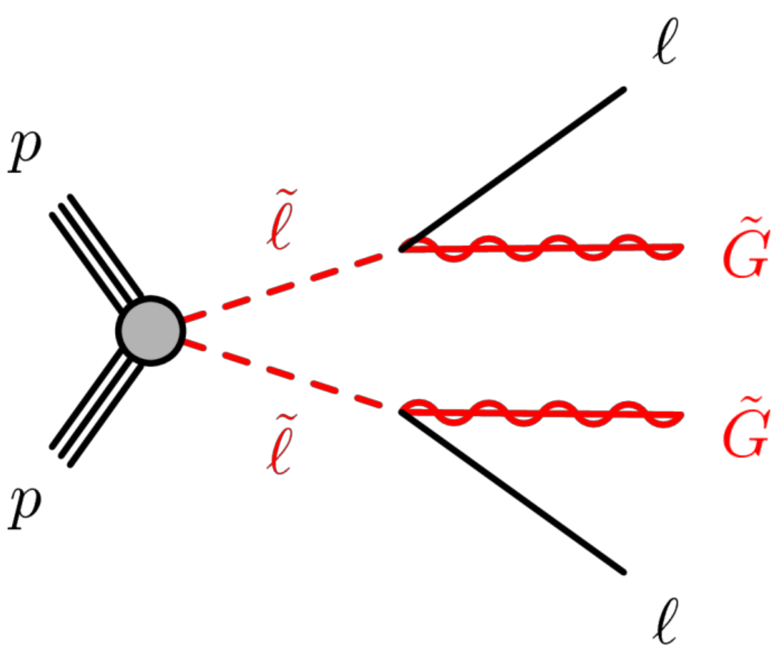
From hidden sectors…



Right-handed neutrinos…



Any **dark matter candidate** has to be metastable or stable!



Uncovered territory

Still many models that haven't been looked at

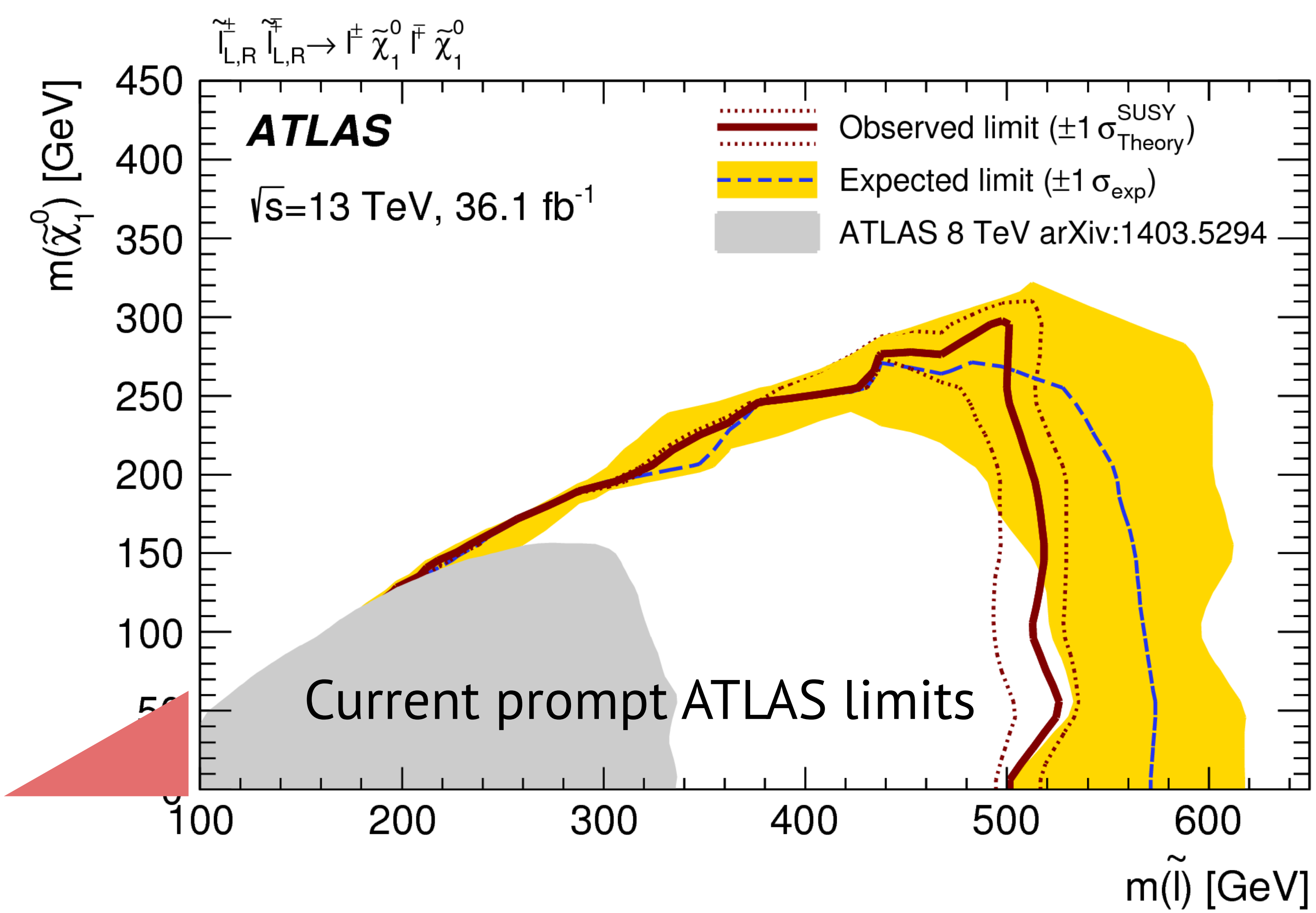
No limit on SUSY decays like this one since OPAL (13 years ago, energies 1/65th of the LHC)

For long-lived sleptons

the limits are at ~100 GeV

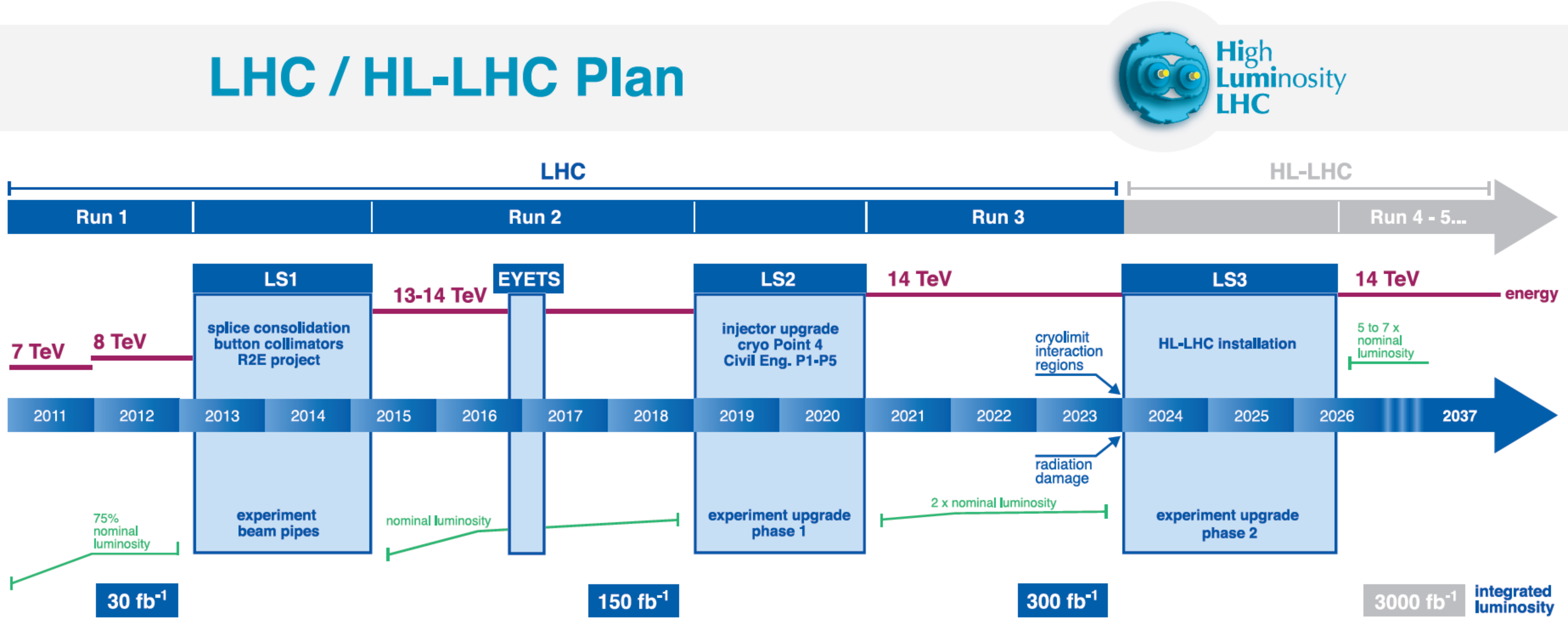
plenty of room to find natural SUSY

(I'm working on this now)



Always interesting but particularly interesting **now**

Run 1 → Run 2	Run 2 → Run 3
Luminosity x5	Luminosity x1
Energy +60%	Energy +8%



Always interesting

but particularly interesting **now**

Run 1 → Run 2

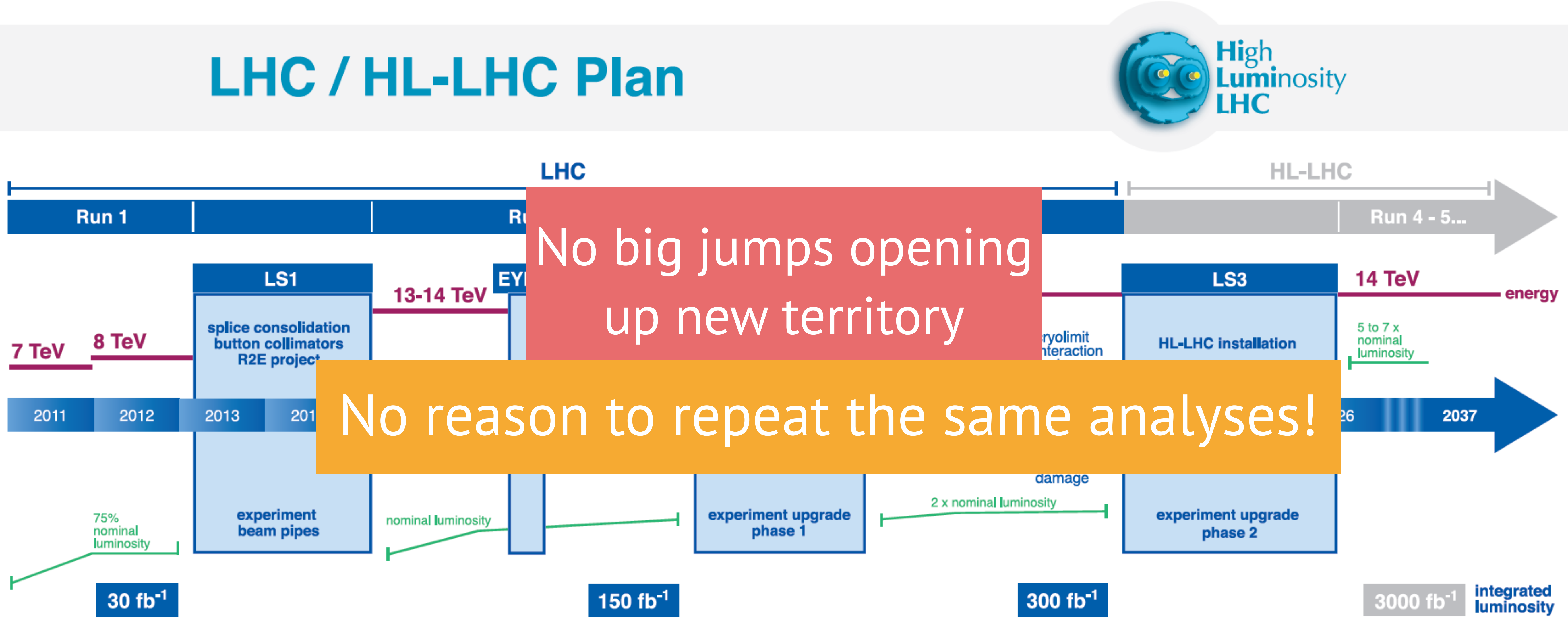
Luminosity x5

Energy +60%

Run 2 → Run 3

Luminosity x1

Energy +8%



No big jumps opening up new territory

No reason to repeat the same analyses!

Run 2 → Run 3

Luminosity x1

Energy +8%

Run 3 is the perfect time to emphasize long-lived particle searches

- New searches that haven't been done before
- Most searches are low-background → larger sensitivity gains with additional luminosity

To improve long-lived searches must improve the **Trigger**

The trigger is a zero sum game.

+ bandwidth and CPU for long-lived particles

- bandwidth and CPU for already existing searches

To improve long-lived searches
must improve the **Trigger**

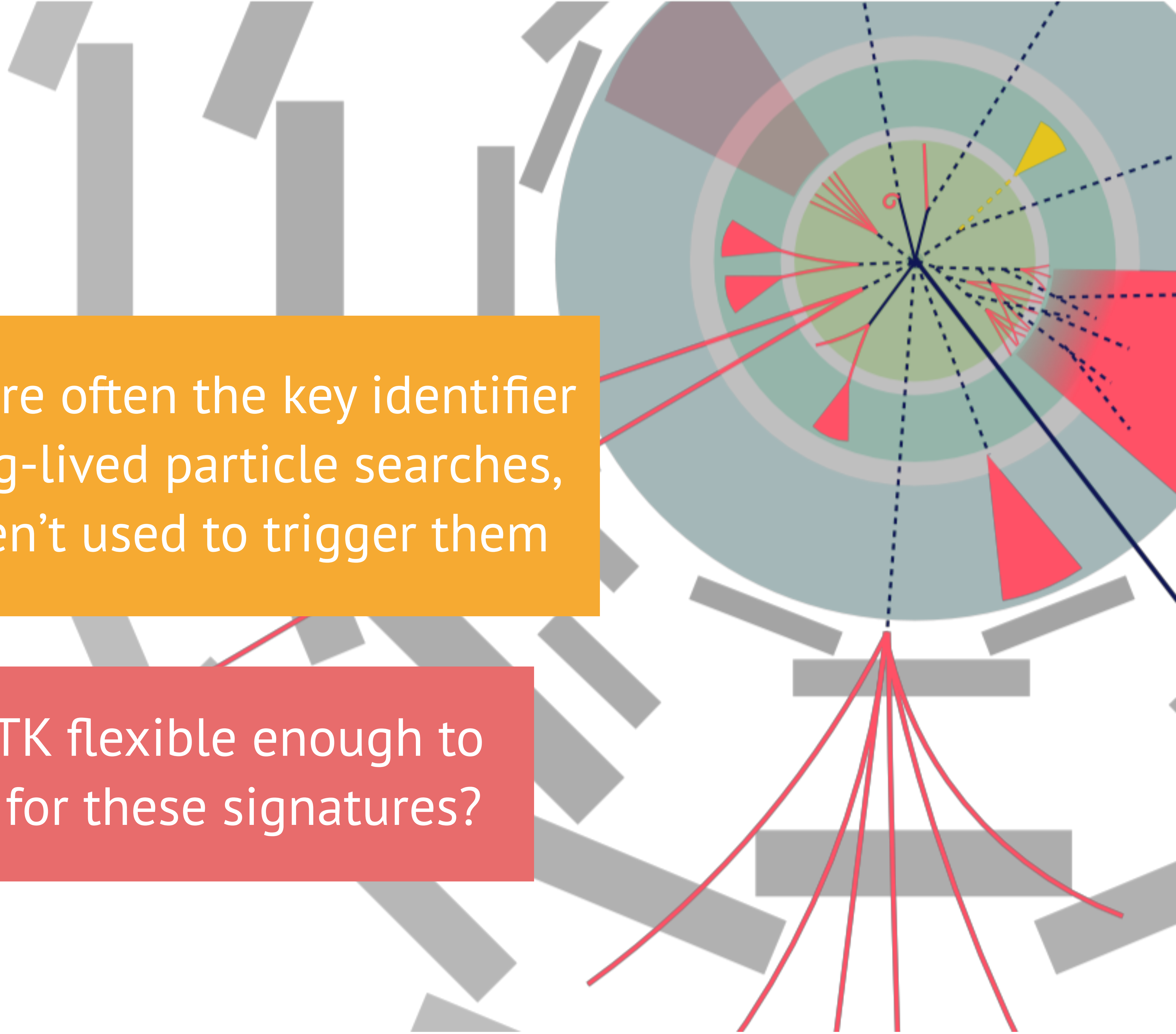
The trigger is a zero sum game.

+ bandwidth and CPU for long-lived particles
- bandwidth and CPU for already existing searches

Or not: make a better trigger

The one thing that *is* changing in Run 3: the **FastTracKer**

- Hardware-based tracker for ATLAS
    - Global tracking: no longer restricted to small regions
    - CPU-based tracking no longer required in many circumstances
- Frees up CPU and rate for new things!



Tracks are often the key identifier for long-lived particle searches, but aren’t used to trigger them

Is FTK flexible enough to use for these signatures?

FTK: A quick explainer

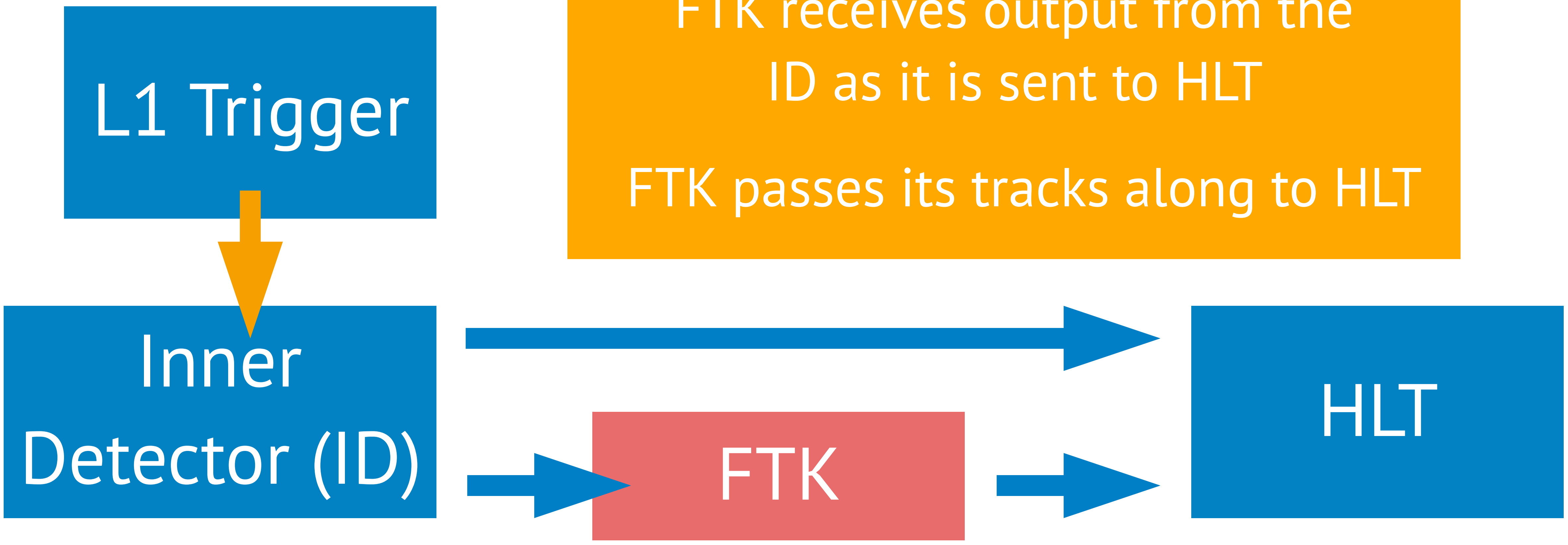
FTK performs **hardware-based** tracking on silicon hits

provides HLT with >1 GeV tracks in ID acceptance ($|\eta|<2.5$)

Data from the ID is read out when a L1 trigger is fired

FTK receives output from the ID as it is sent to HLT

FTK passes its tracks along to HLT



Time constraints

Offline track reconstruction for the full tracking volume requires about 10 s / event

To keep up with L1 rates, FTK must do tracking for the full event in ~.1 ms

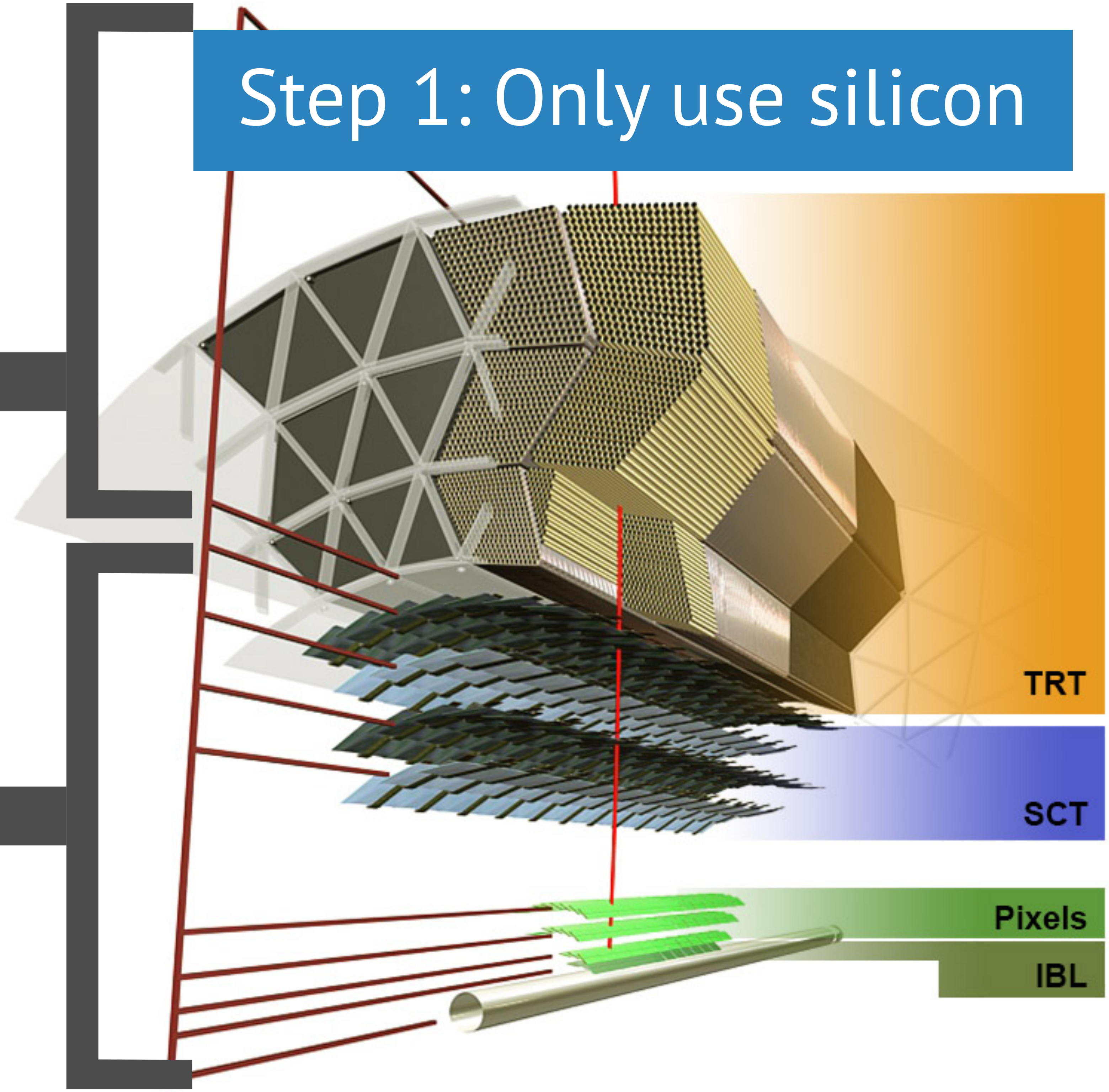
Requires time reduction of ~5 orders of magnitude

How can we track so fast?

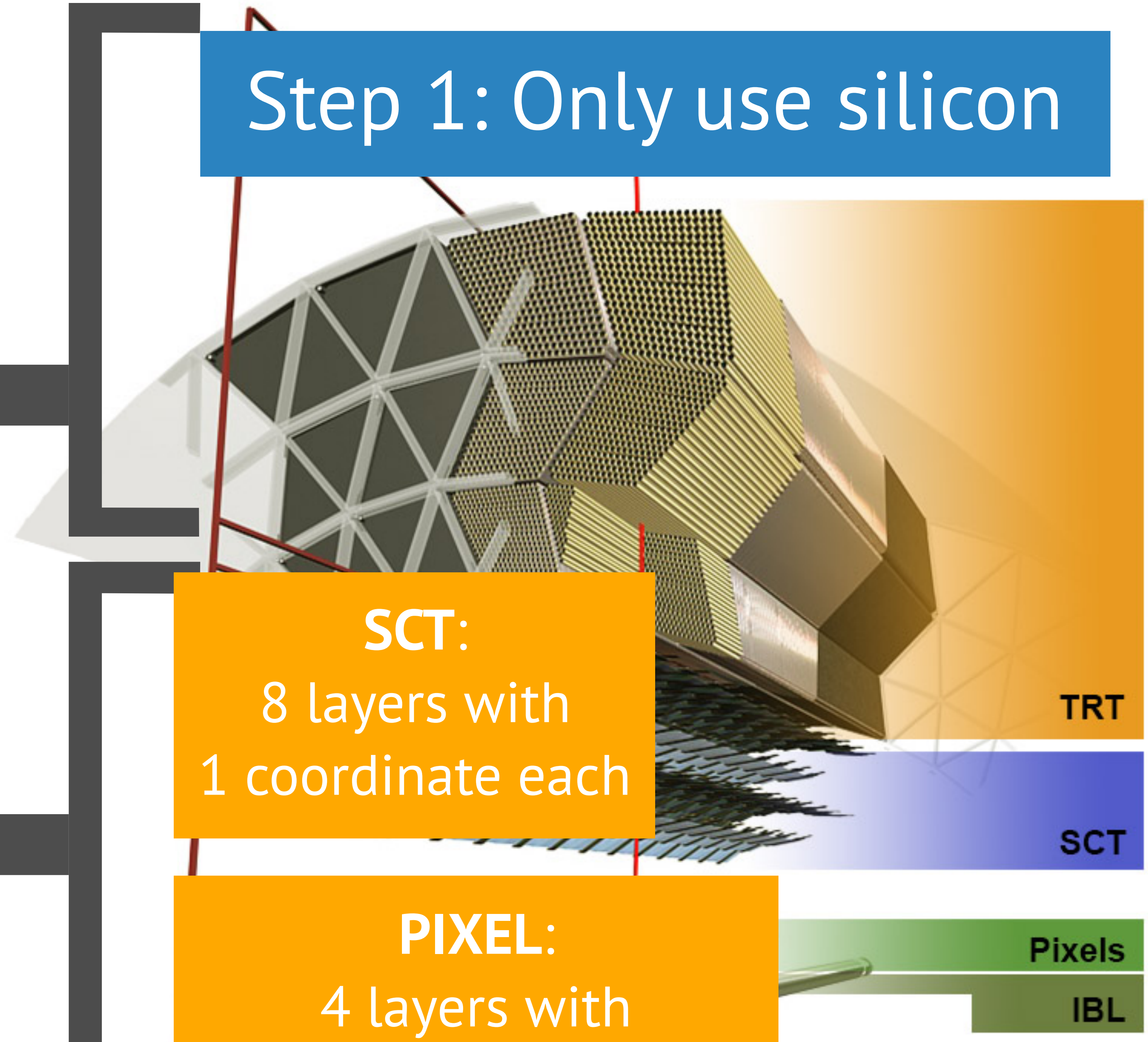
Making tracking a simpler problem

Straight to HLT

Split signals go to HLT and FTK



Making tracking a simpler problem



Step 1: Only use silicon

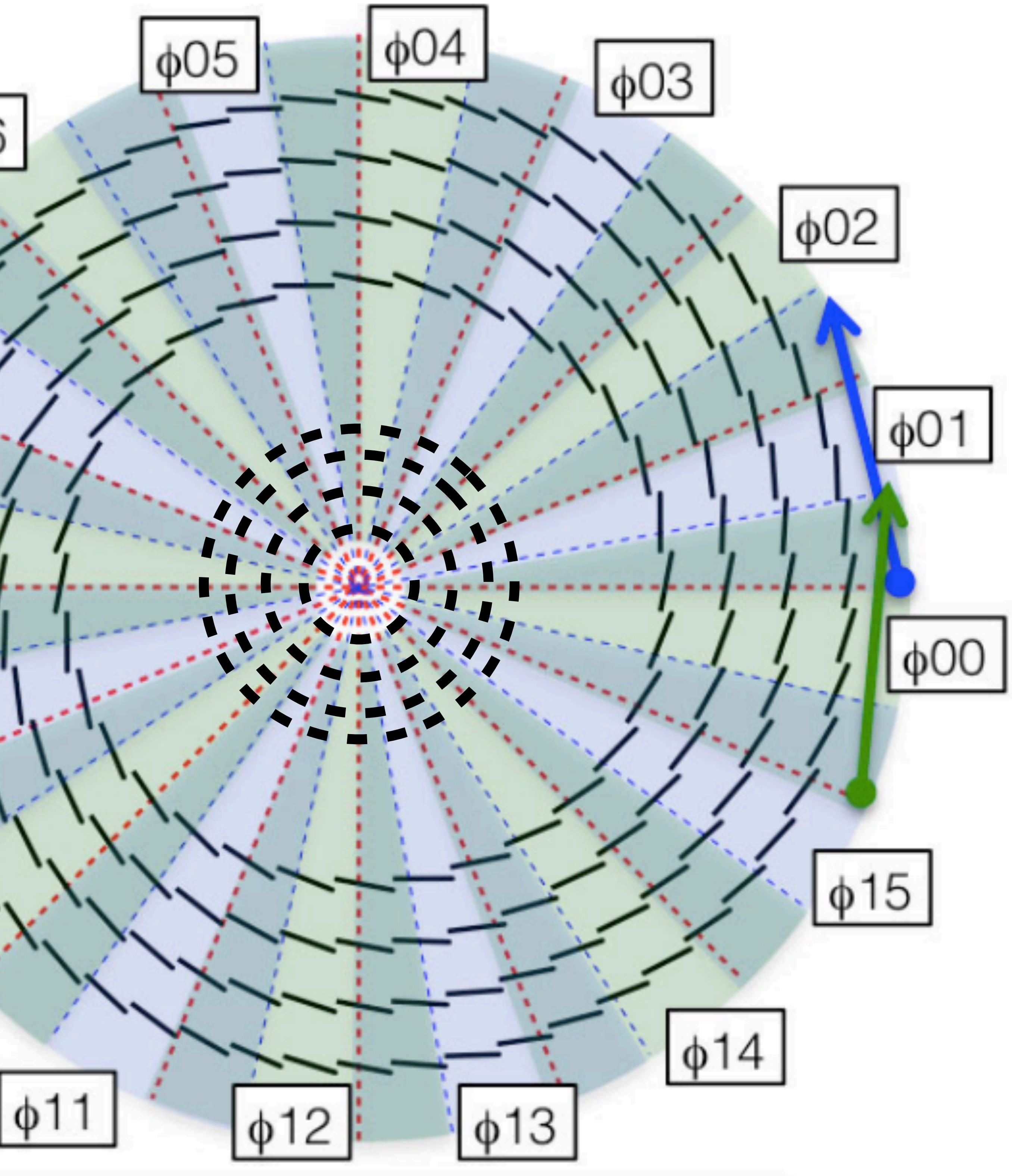
Straight to HLT

Split signals go to HLT and FTK

SCT:
8 layers with
1 coordinate each

PIXEL:
4 layers with
2 coordinates each

Making tracking a simpler problem



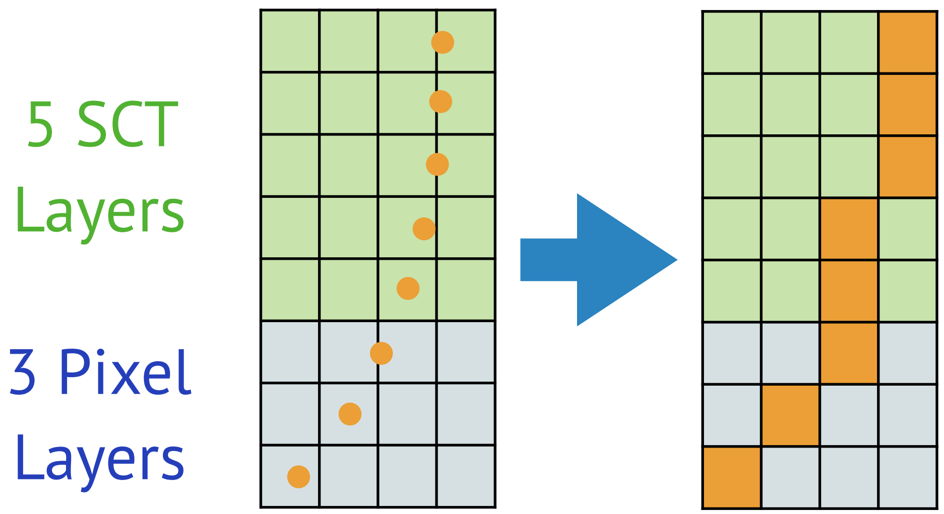
Step 2: Parallelize

Divide the detector into 64 overlapping towers

Send data from each tower to separate processing units

Making tracking a simpler problem

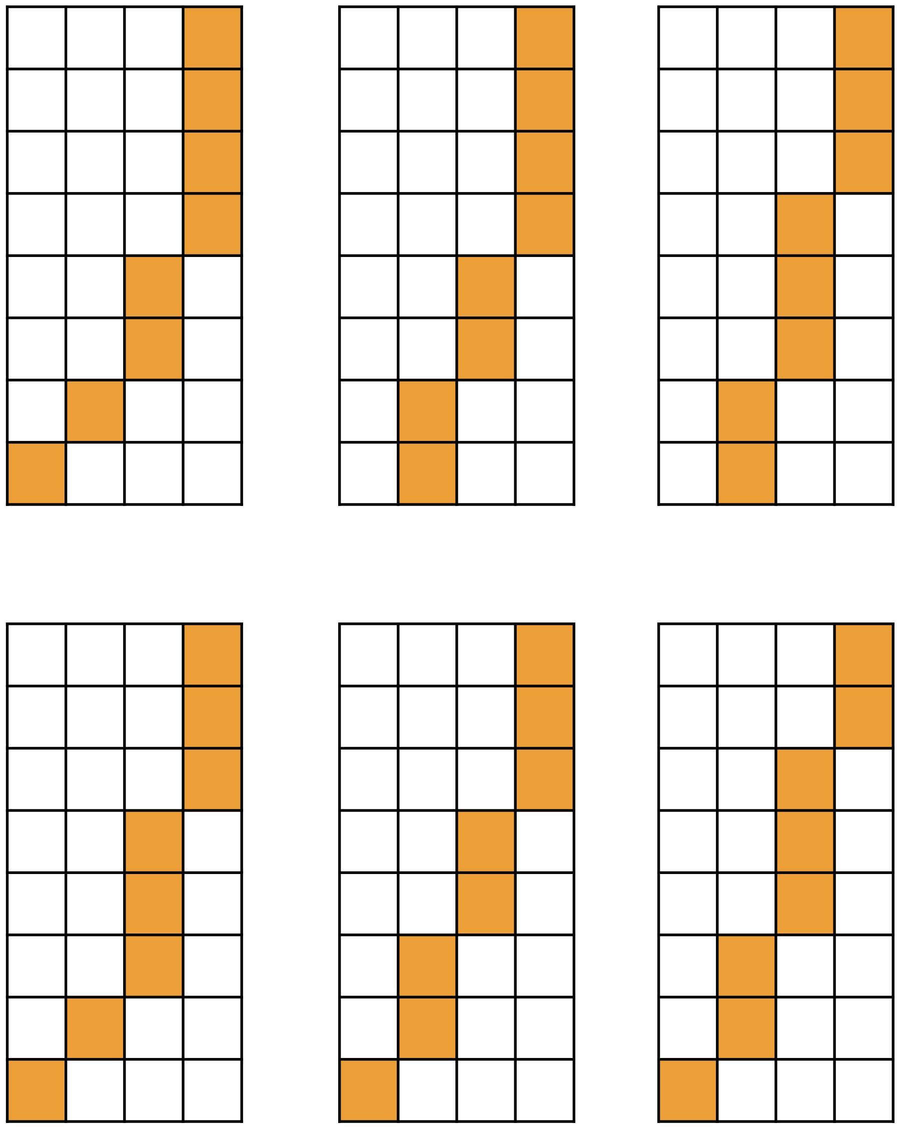
Start with 8/12
silicon layers of ATLAS



Step 3: Pattern Match

Divide each layer into coarse chunks

Making tracking a simpler problem

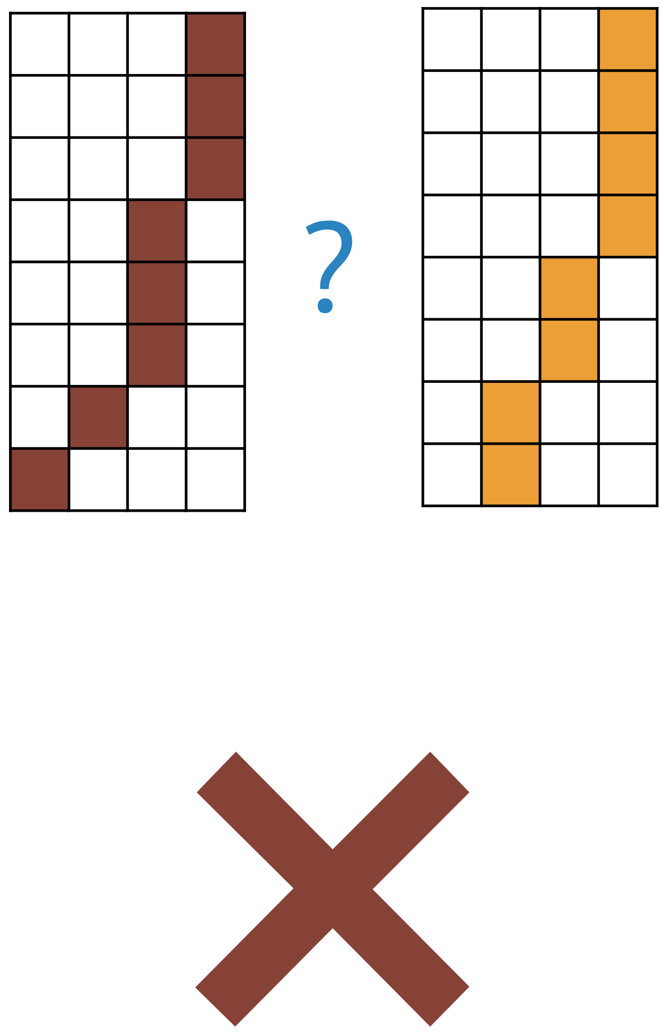


Step 3: Pattern Match

Divide each layer into coarse chunks

Define patterns of these chunks that correspond to tracks

Making tracking a simpler problem



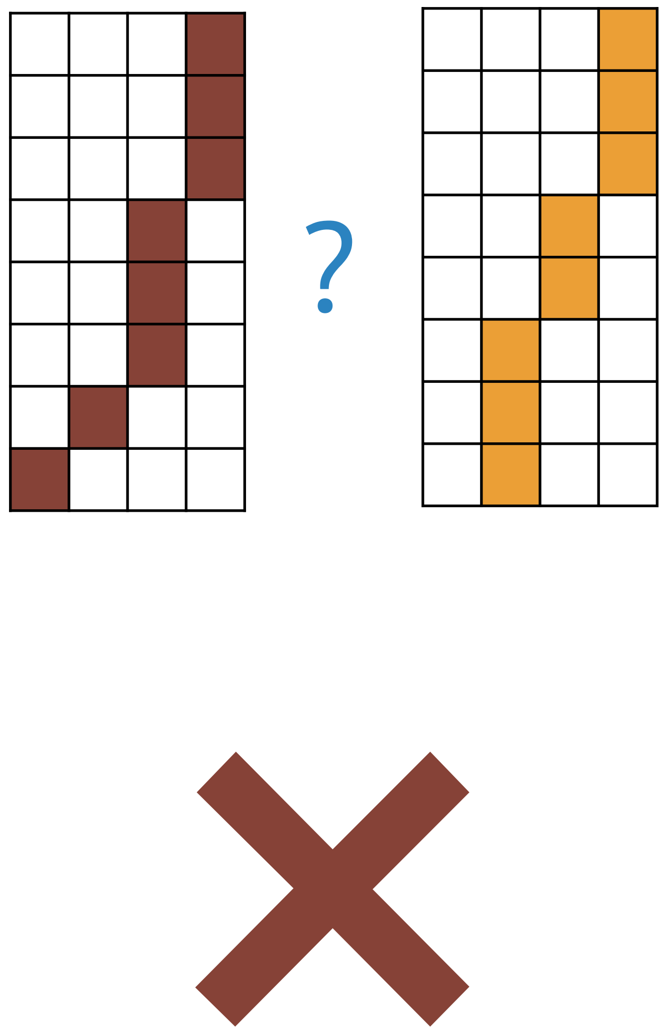
Step 3: Pattern Match

Divide each layer into coarse chunks

Define patterns of these chunks that correspond to tracks

Compare fired patterns to a stored bank of track-like patterns

Making tracking a simpler problem



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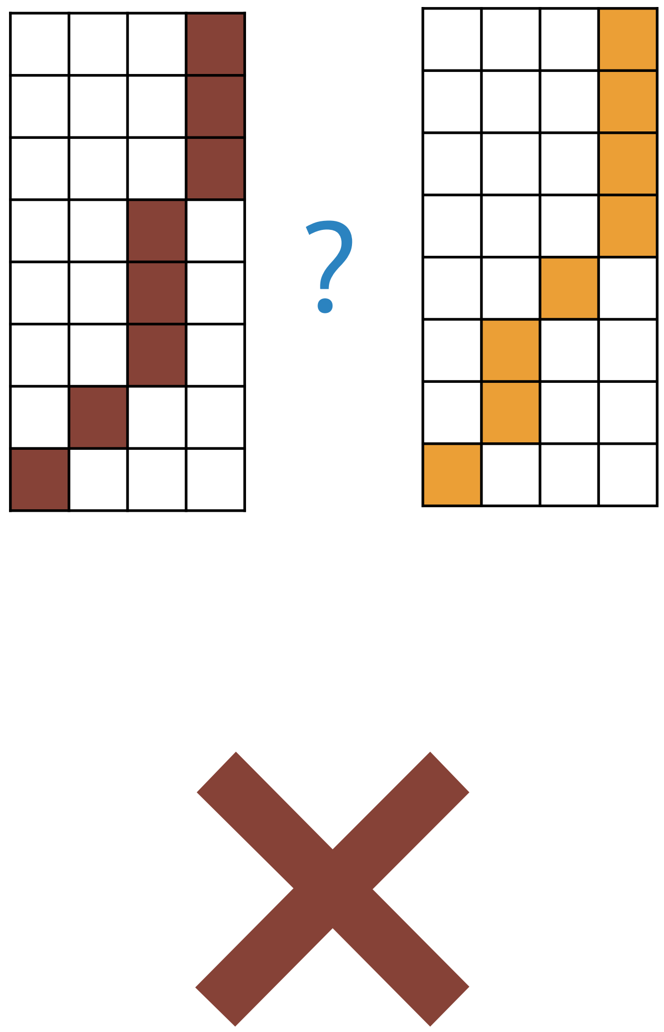
Making tracking a simpler problem



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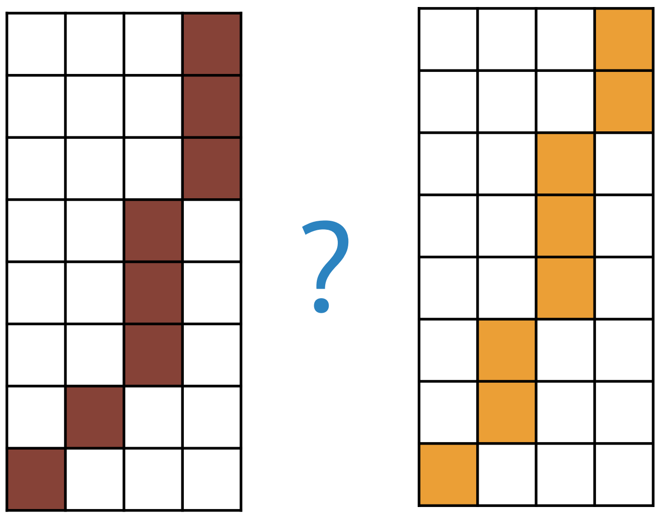
Compare fired patterns to a stored bank of track-like patterns

Making tracking a simpler problem



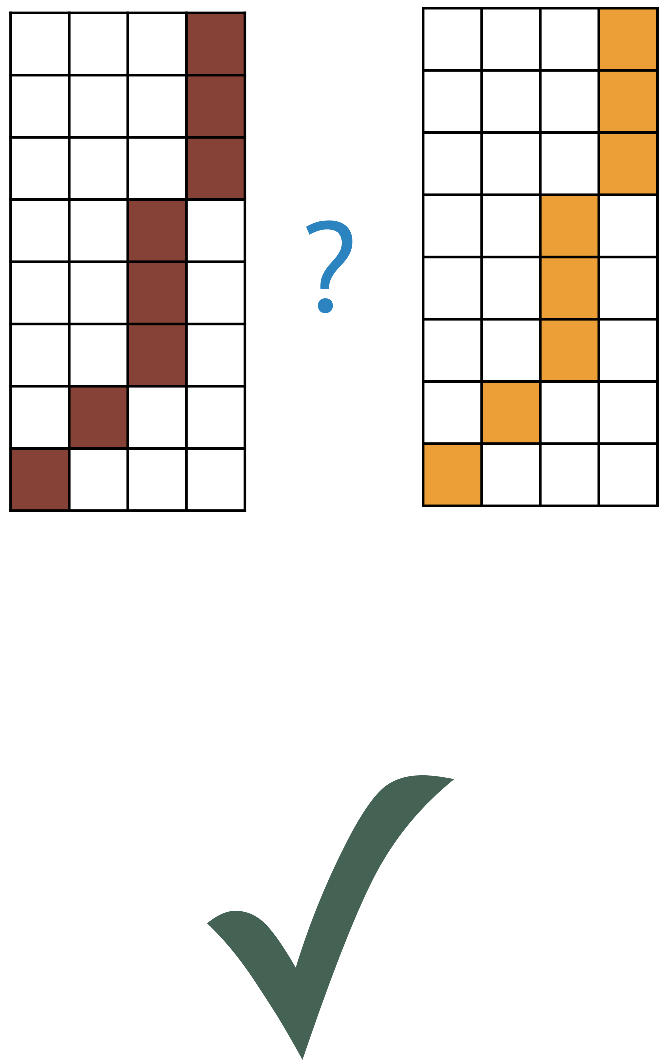
Step 3: Pattern Match

Divide each layer into coarse chunks

Define patterns of these chunks that correspond to tracks

Compare fired patterns to a stored bank of track-like patterns

Making tracking a simpler problem



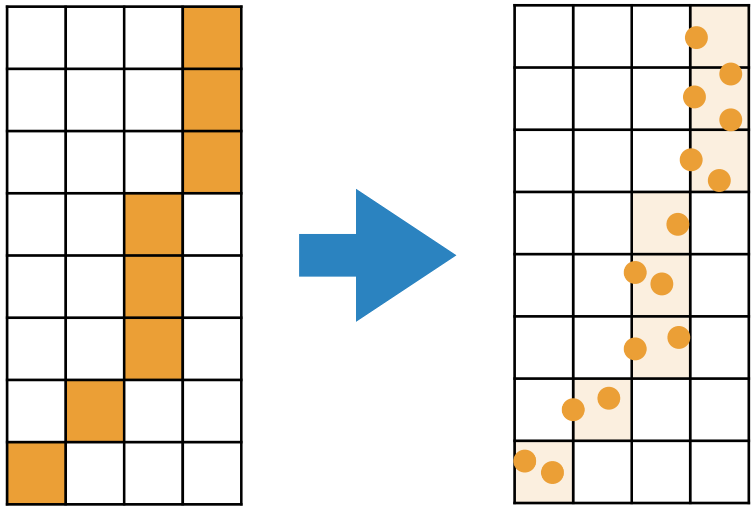
Step 3: Pattern Match

Divide each layer into coarse chunks

Define patterns of these chunks that correspond to tracks

Compare fired patterns to a stored bank of track-like patterns

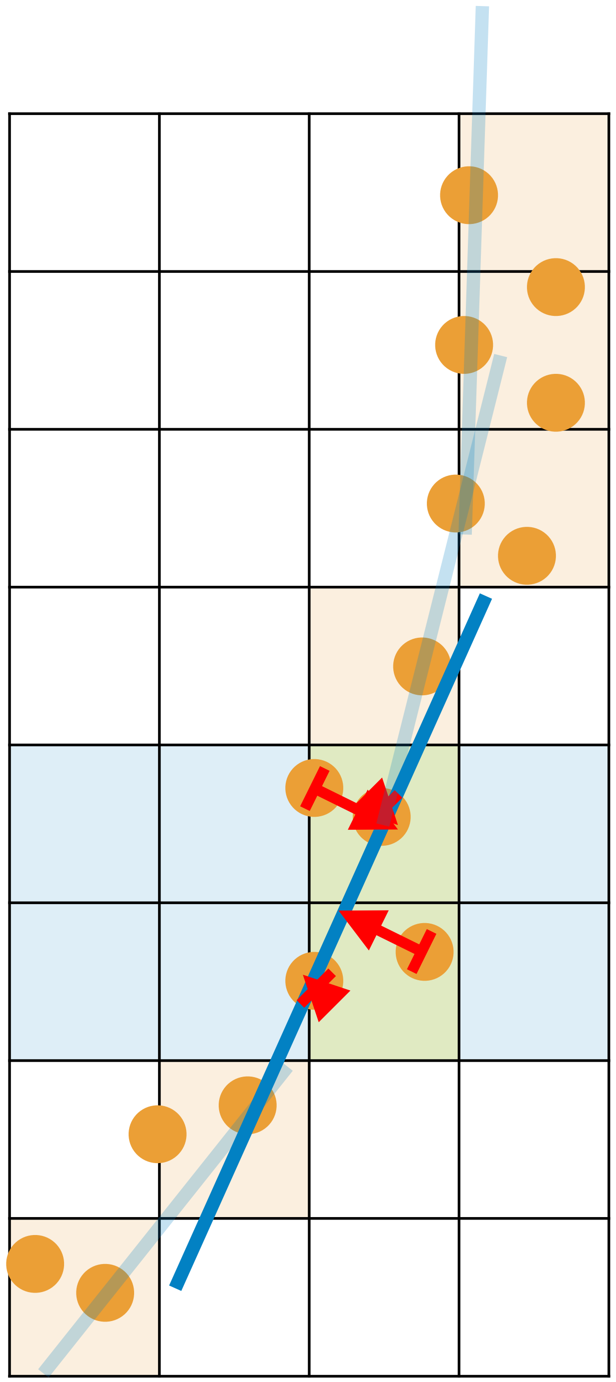
Making tracking a simpler problem



Step 4: Fit a Subset

For matched patterns,
retrieve all full resolution hits

Making tracking a simpler problem



Step 4: Fit a Subset

For matched patterns, retrieve all full resolution hits

Perform a linearized fit on the hits in 8 layers

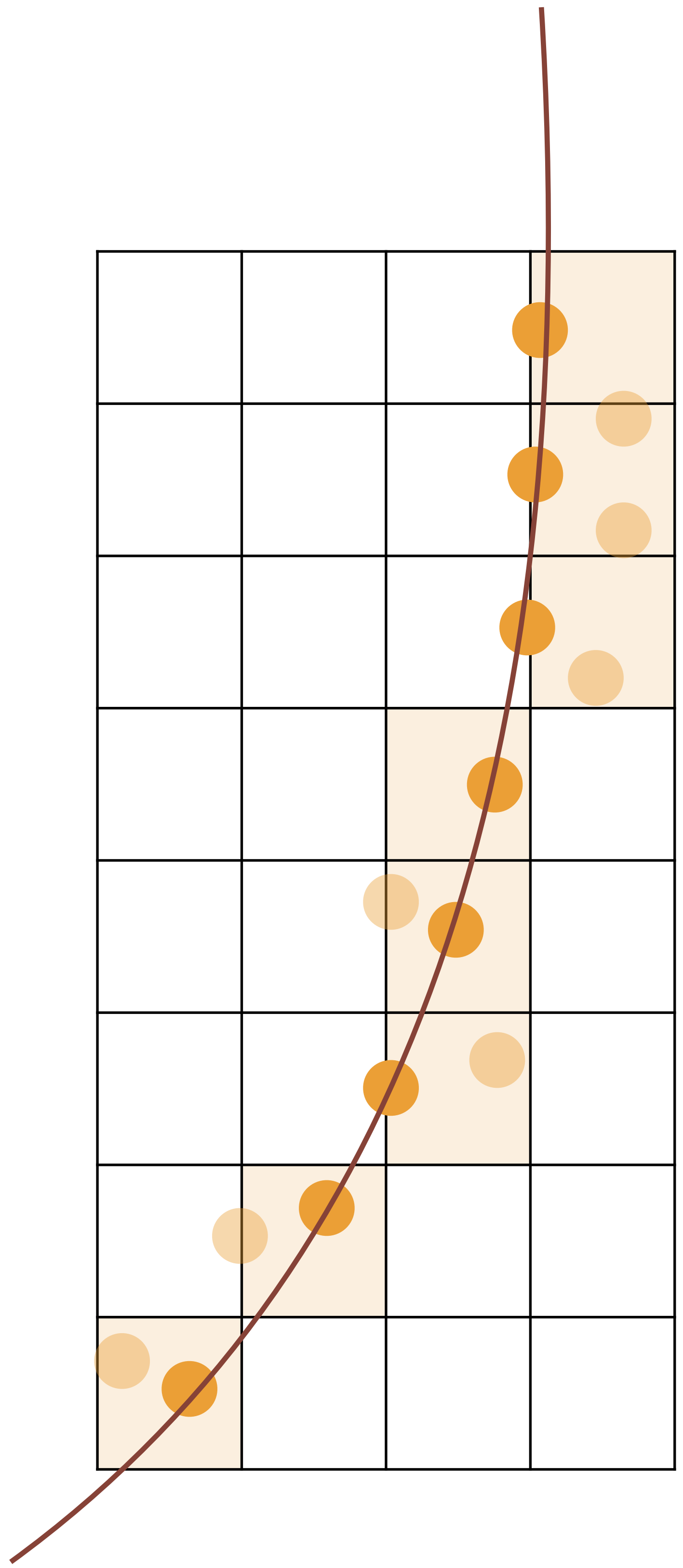
constants pre-defined per detector region

line: $y = mx + b$

each hit has a distance from the line: $\Delta x, \Delta y$

X2 of fit: $\chi^2 = \sum_i^8 \sqrt{\Delta x_i^2 + \Delta y_i^2}$

Making tracking a simpler problem



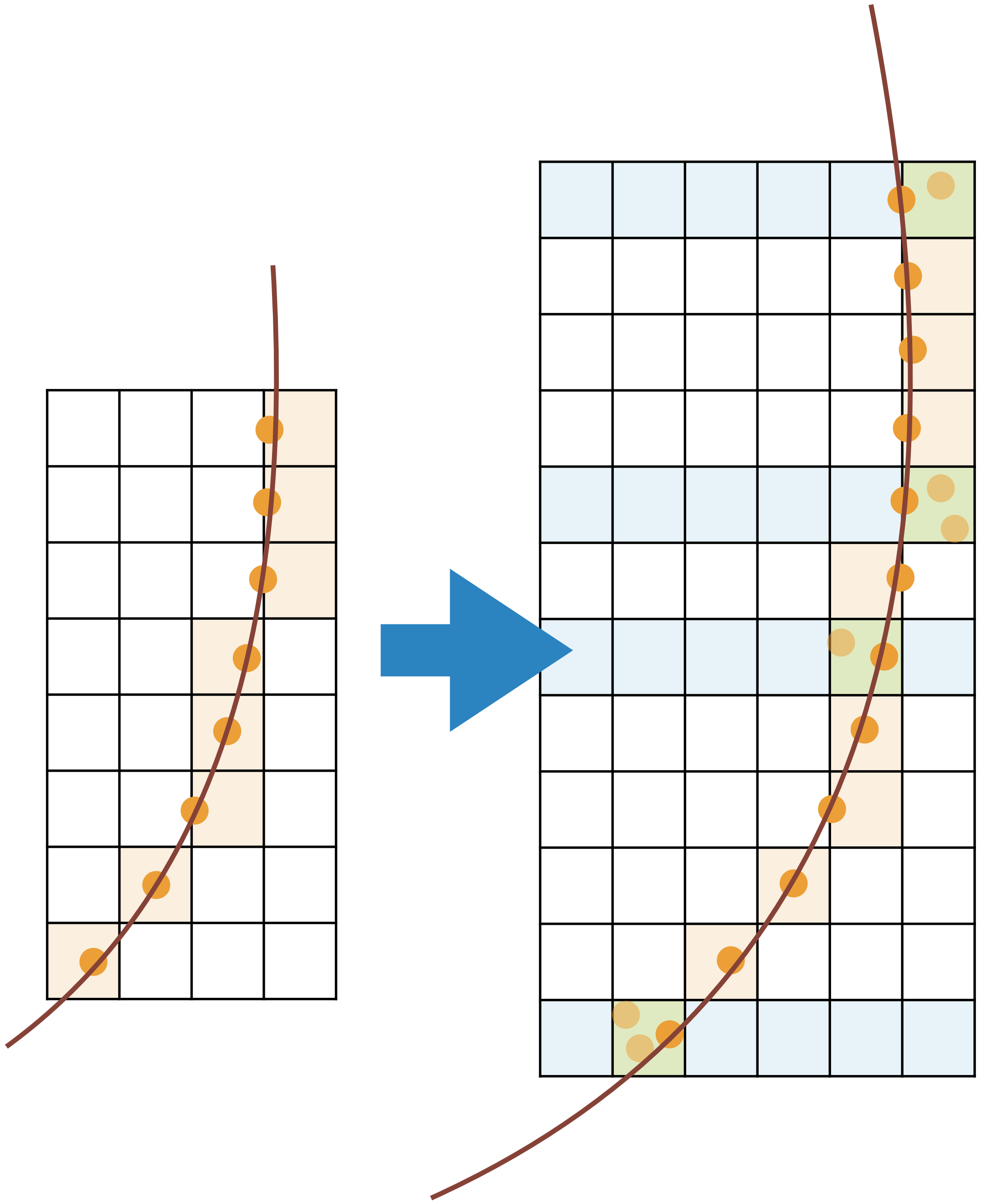
Step 4: Fit a Subset

For matched patterns, retrieve all full resolution hits

Perform a linearized fit on the hits in 8 layers

Keep tracks passing a χ^2 cut

Making tracking a simpler problem



Step 4: Final Fit

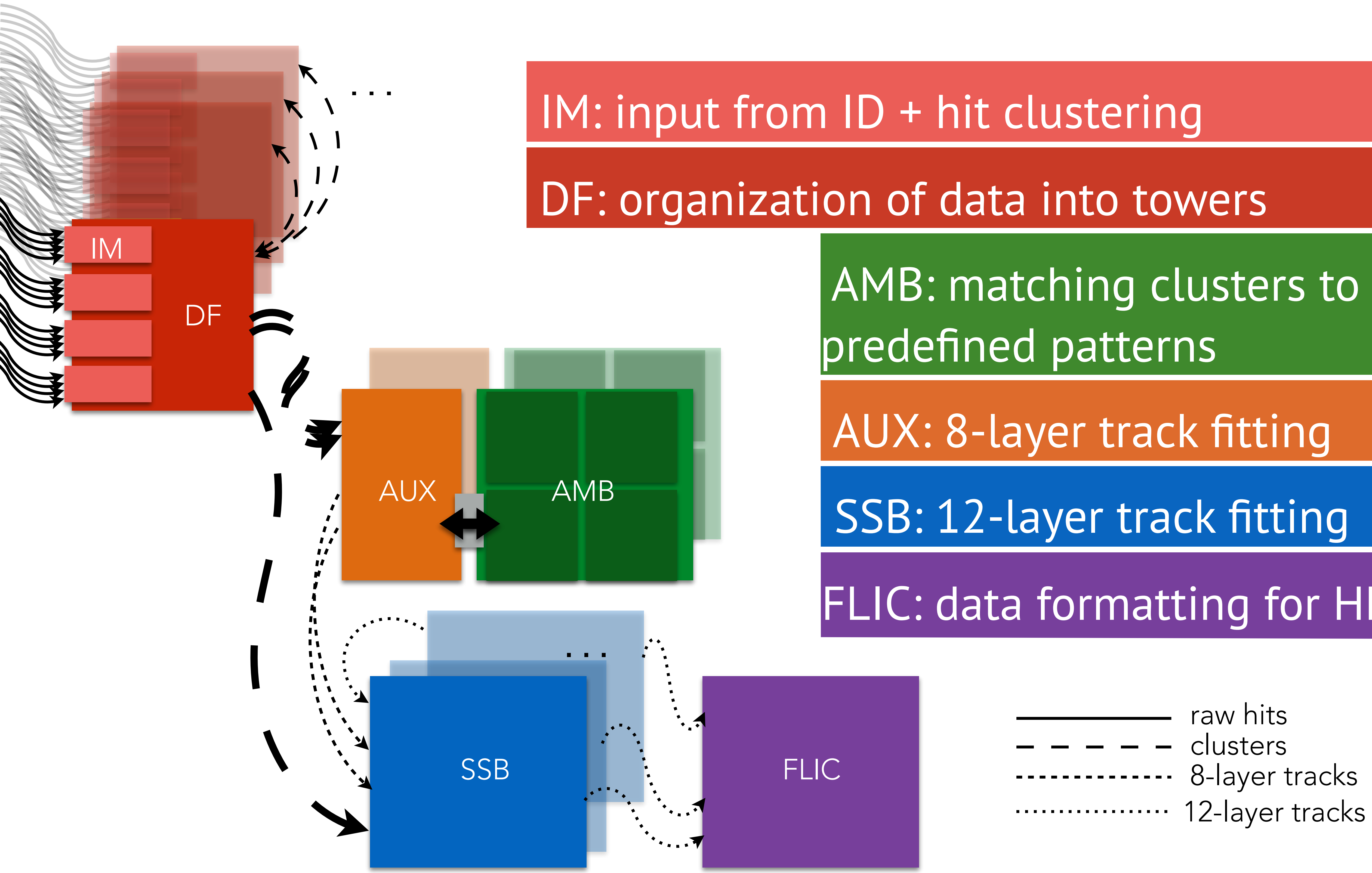
Look for nearby hits in remaining 4 silicon layers

Refit in all 12 layers

Send tracks* passing a χ^2 cut to HLT

*fit parameters also calculated linearly

FTK Boards



IM: input from ID + hit clustering

DF: organization of data into towers

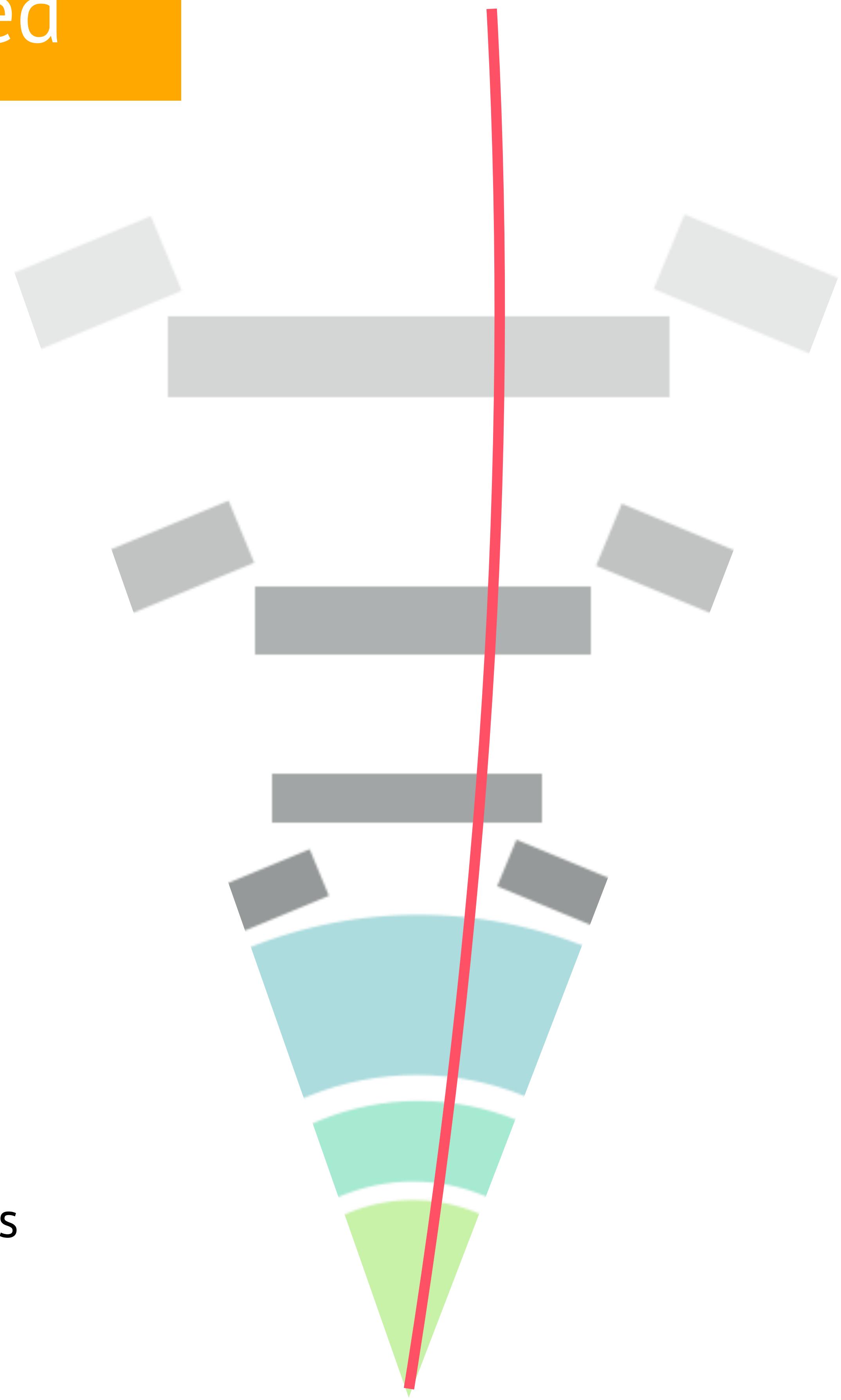
AMB: matching clusters to predefined patterns

AUX: 8-layer track fitting

SSB: 12-layer track fitting

FLIC: data formatting for HLT

FTK as designed

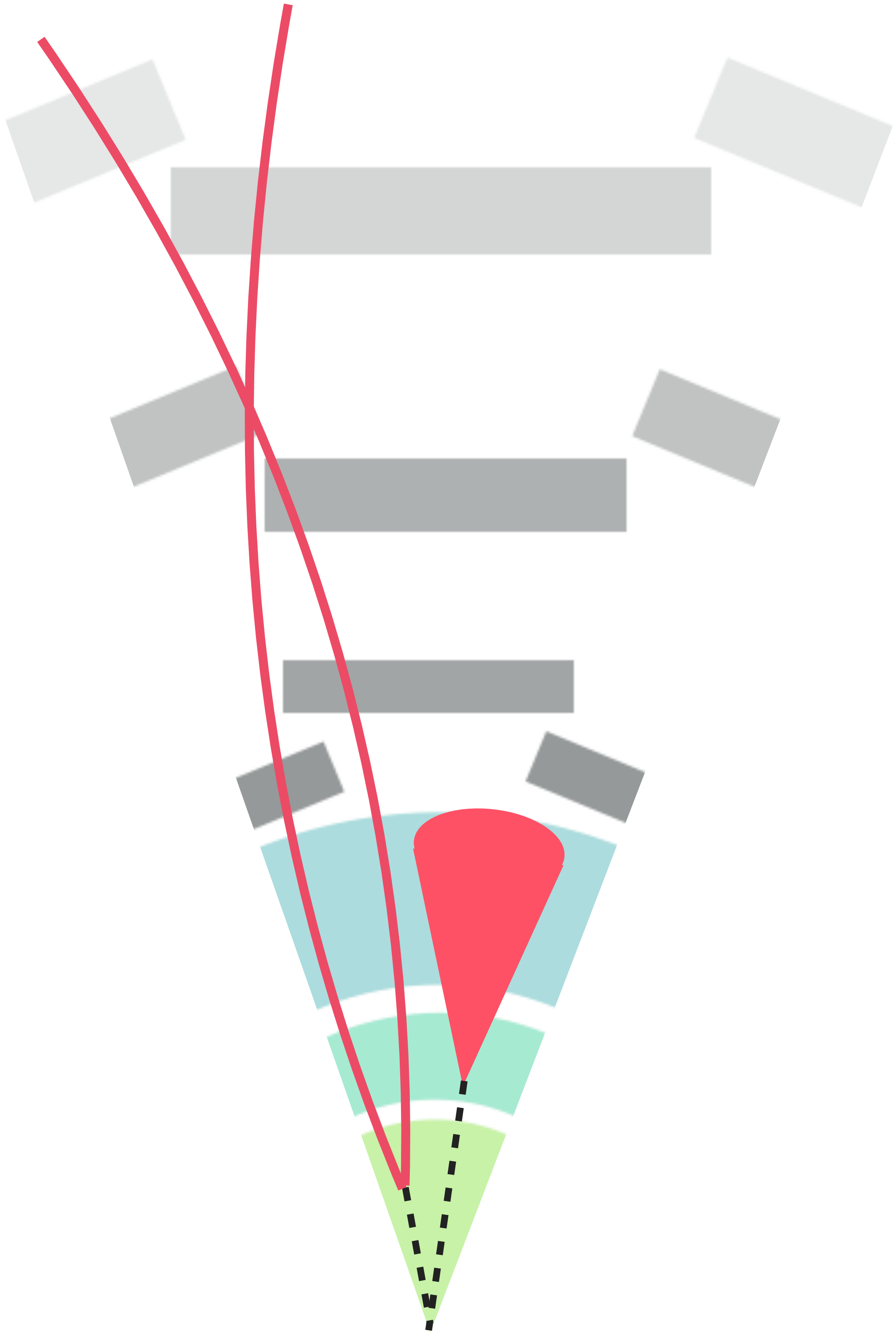


FTK is designed for **near-prompt** tracks (e.g. *b*-jets)

Easiest application is for stable, charged particles (e.g. R-hadrons)

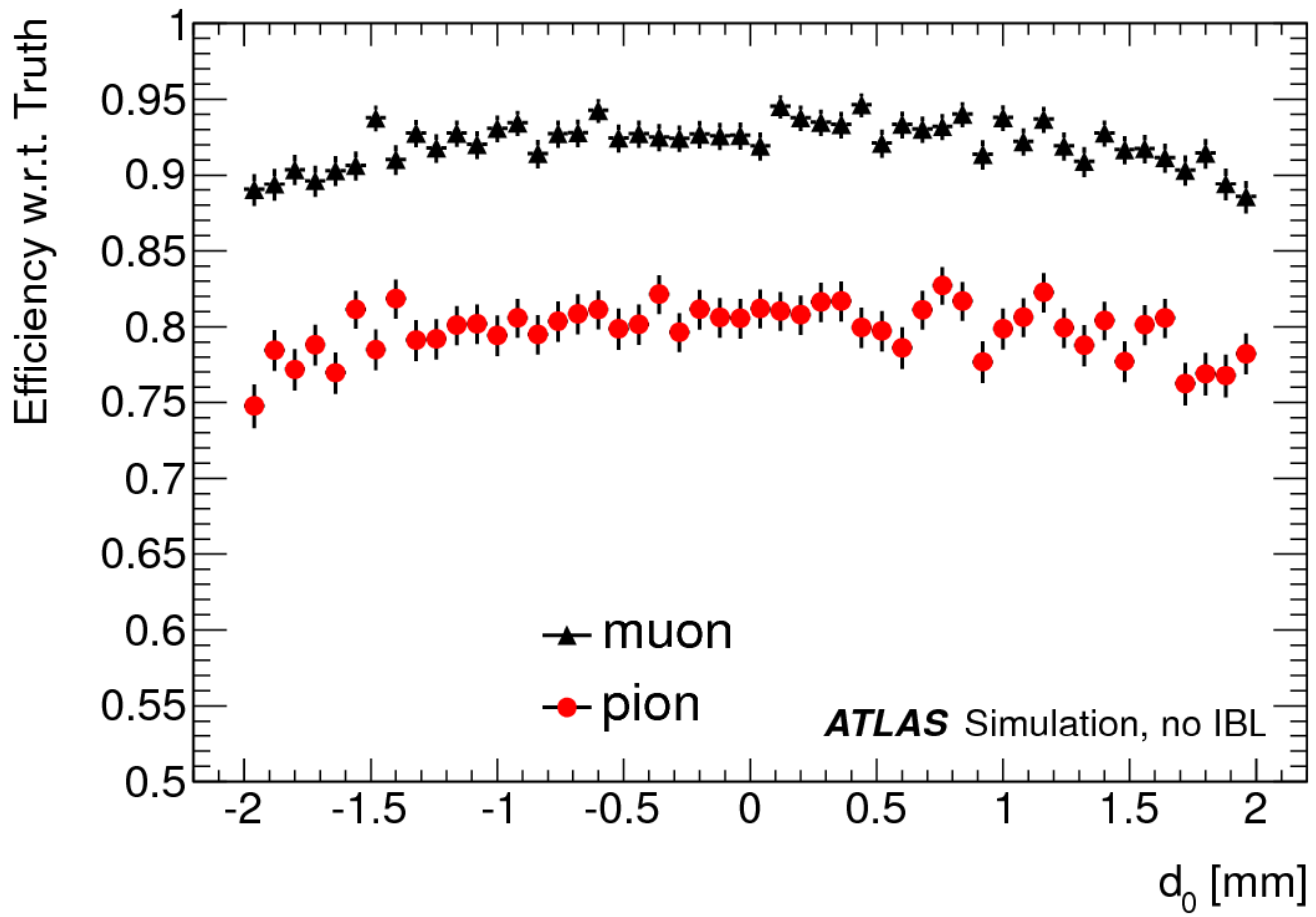
Find isolated, high-p_T tracks, without requiring calorimeter or muon signals

FTK as designed



Alternatively:
Use **FTK as a veto**
and find calorimeter
or muon signals that
don't correspond to
prompt tracks

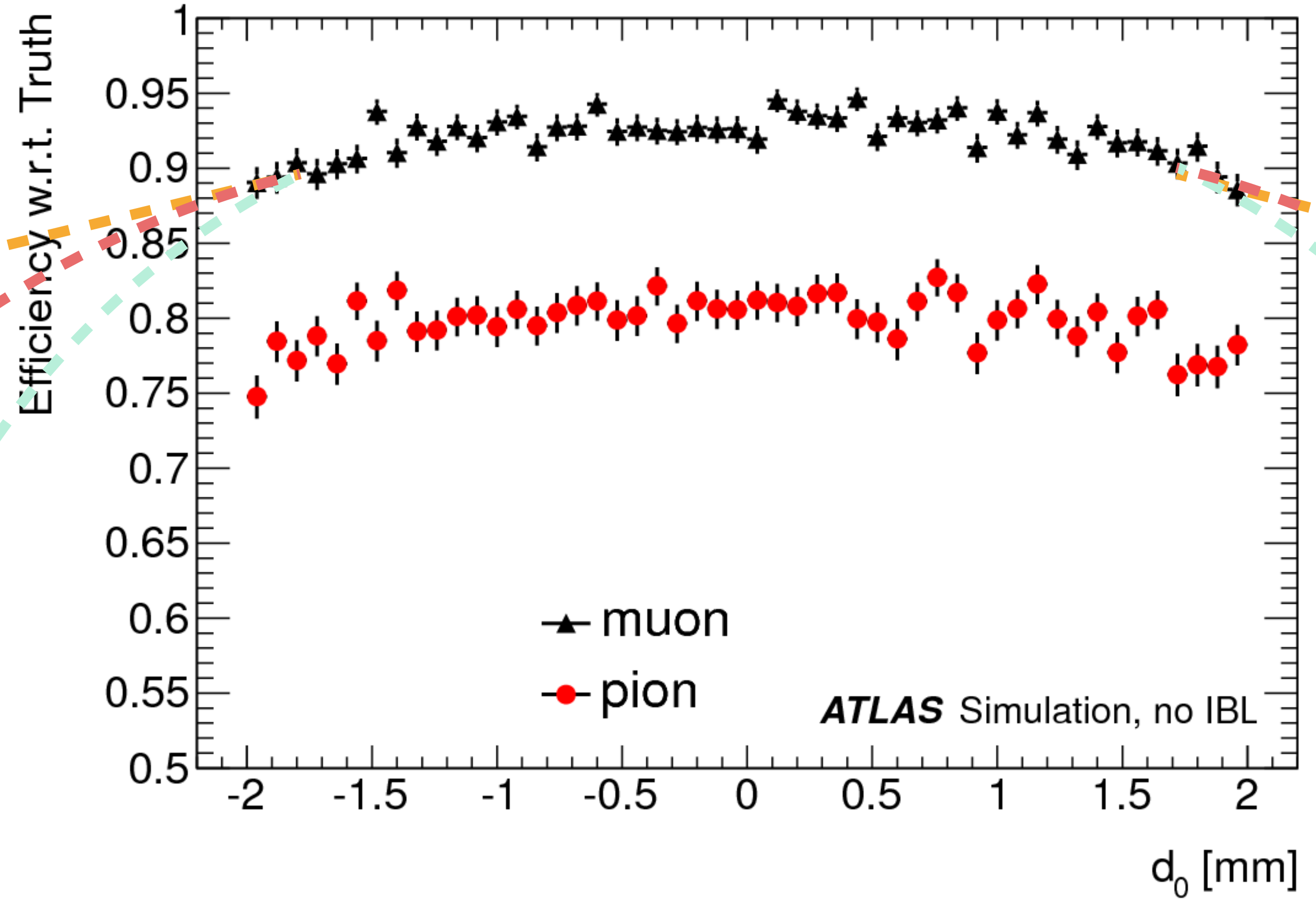
Moving outside the beamspot...



FTK performance is both optimized and studied for **small displacement**

FTK Technical Design Report

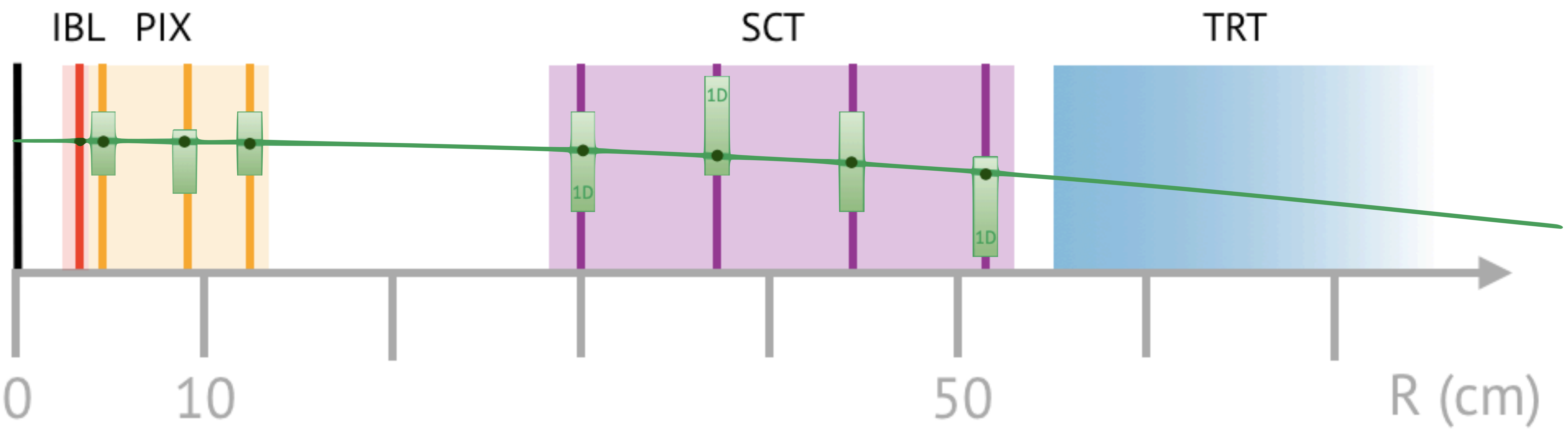
Moving outside the beamspot...



Performance for displaced tracks depends on many factors

- Hit requirements
- Linearized fit performance
- Pattern bank
- Dataflow constraints of FTK

Hit Requirements



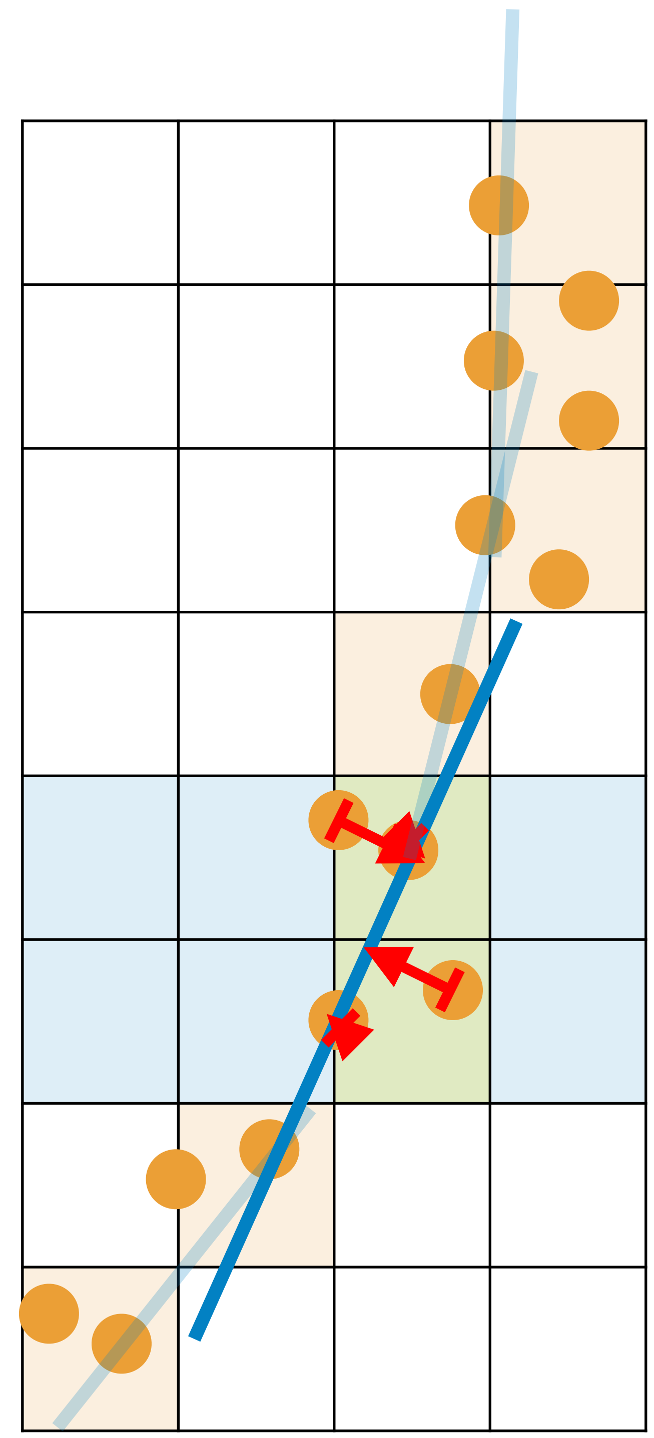
FTK uses silicon layers from ~3 - 50 cm

- Up to two layers can be dropped
- LLPs traveling **> 9 cm** before decaying can't be identified

Linearized fit constraints

Linear constants determined in *sectors*

- Stored in board memory → finite space available
- To add displaced pattern sectors, need to reduce standard sectors



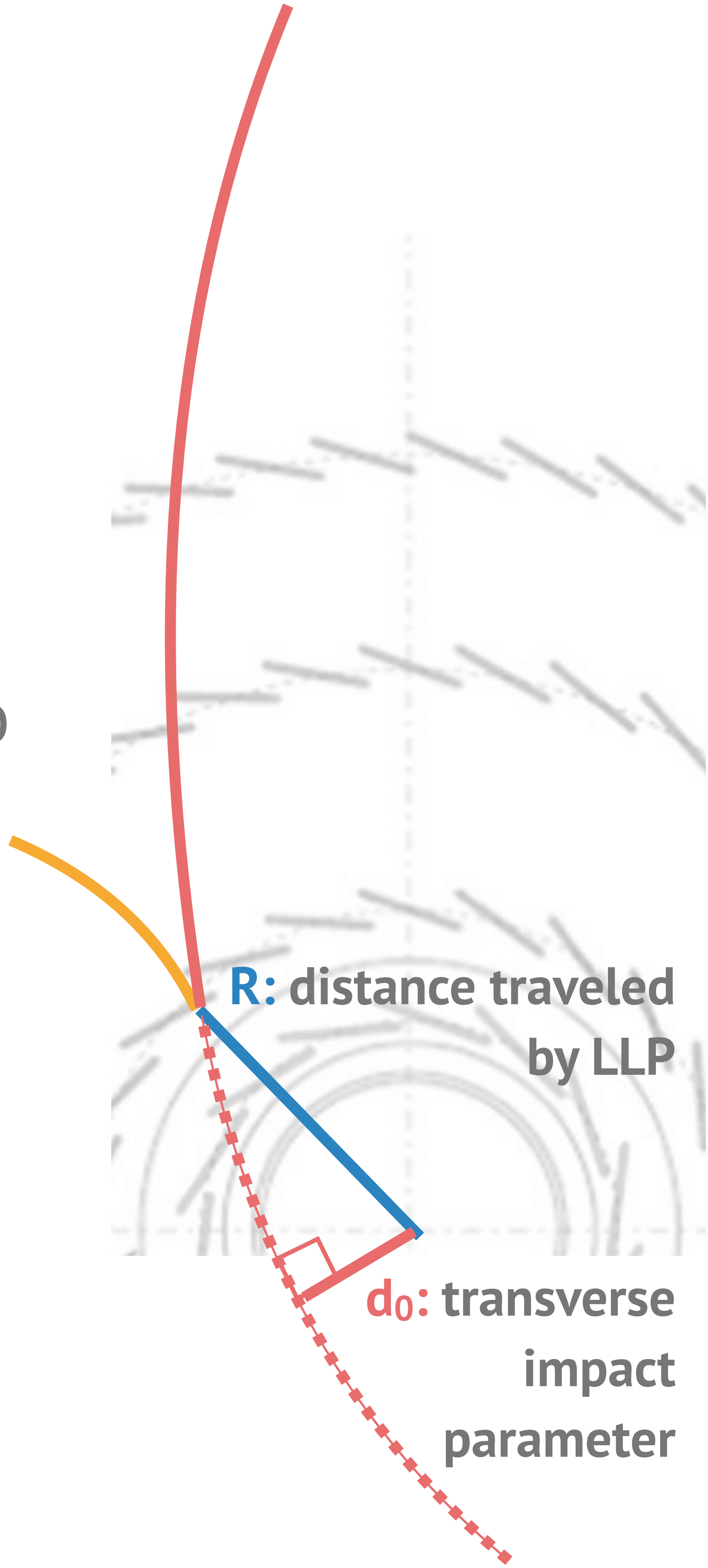
Linearized fit constraints

Linear constants determined in *sectors*

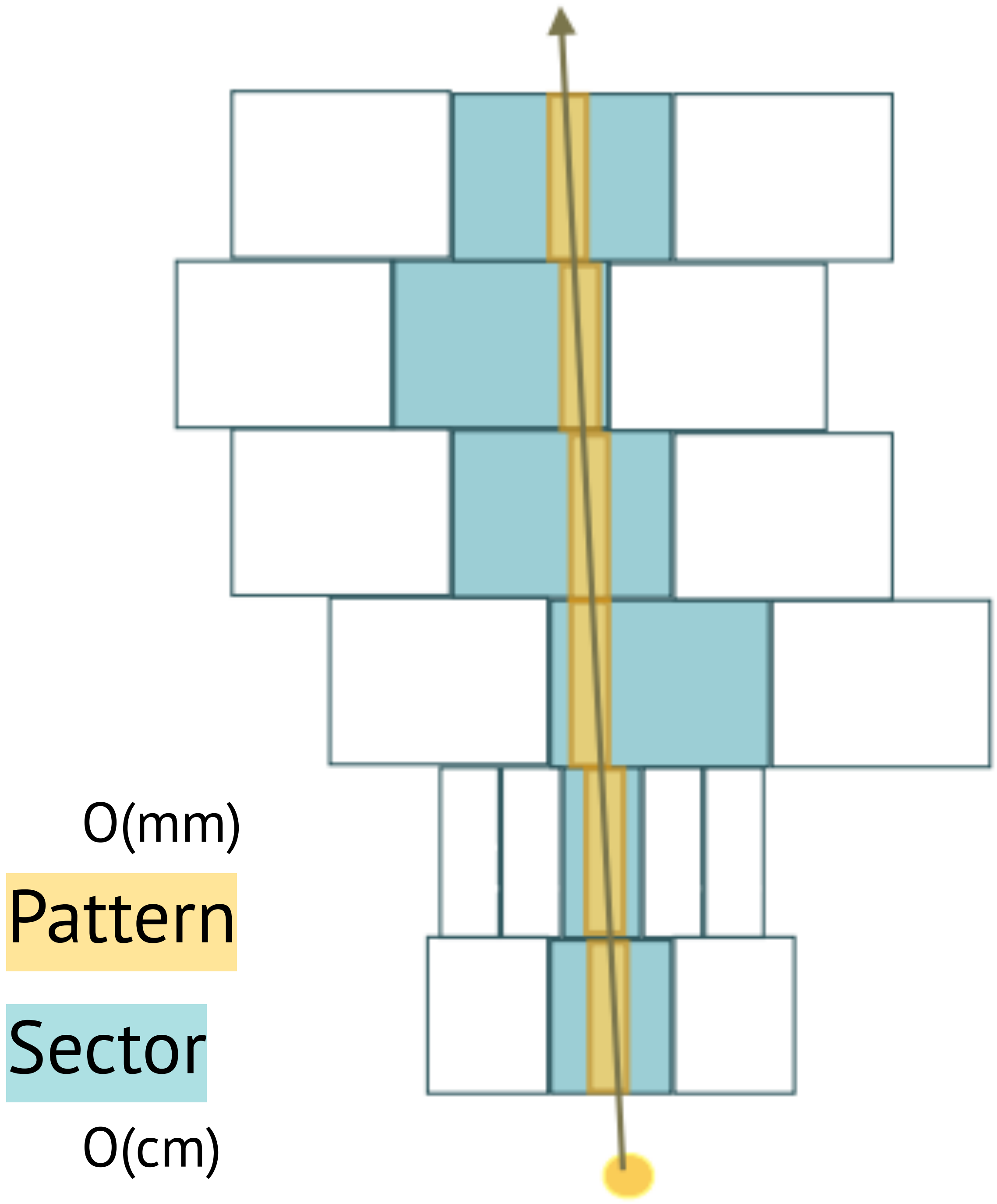
- Stored in board memory → finite space available
- To add displaced track sectors, need to reduce standard sectors

Without changing sectors, looks like we can have some coverage for $\mathbf{d_0 < 20}$ **mm**

(d_0 of 20 mm often means much larger R)

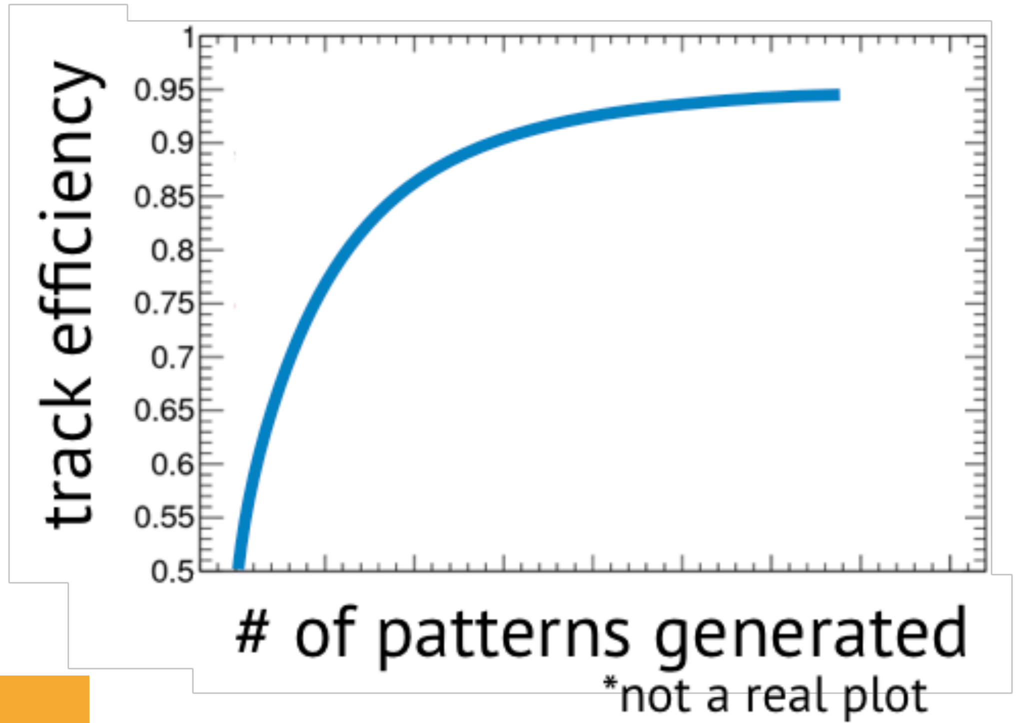


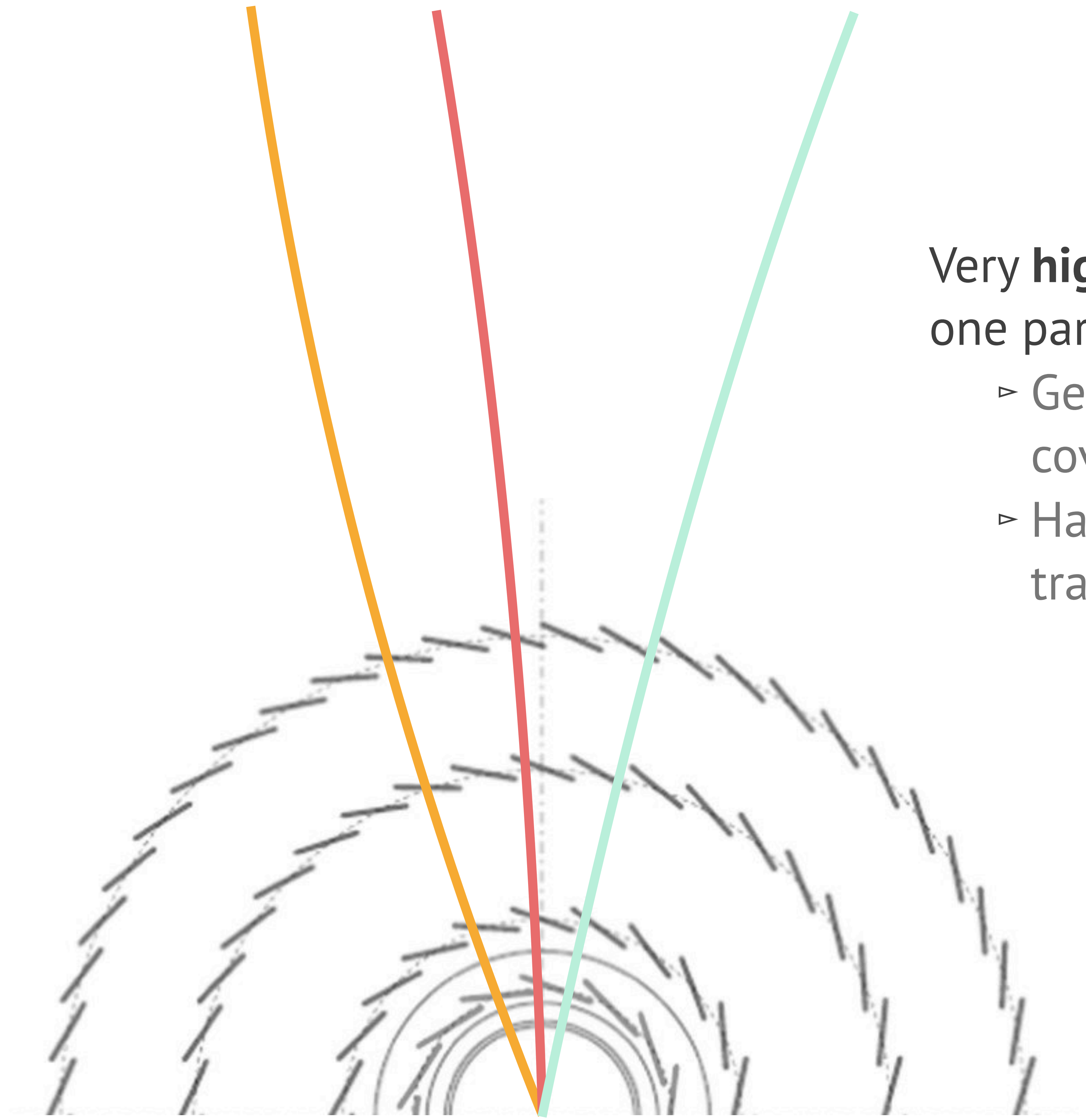
Pattern bank constraints



FTK **patterns** are much smaller than sectors, and need to be trained to include displaced tracks

- Dedicate a portion of the pattern bank to these tracks
- Luckily, most track coverage is due to a small portion of the pattern bank → can reduce prompt tracks with small impact on prompt efficiency



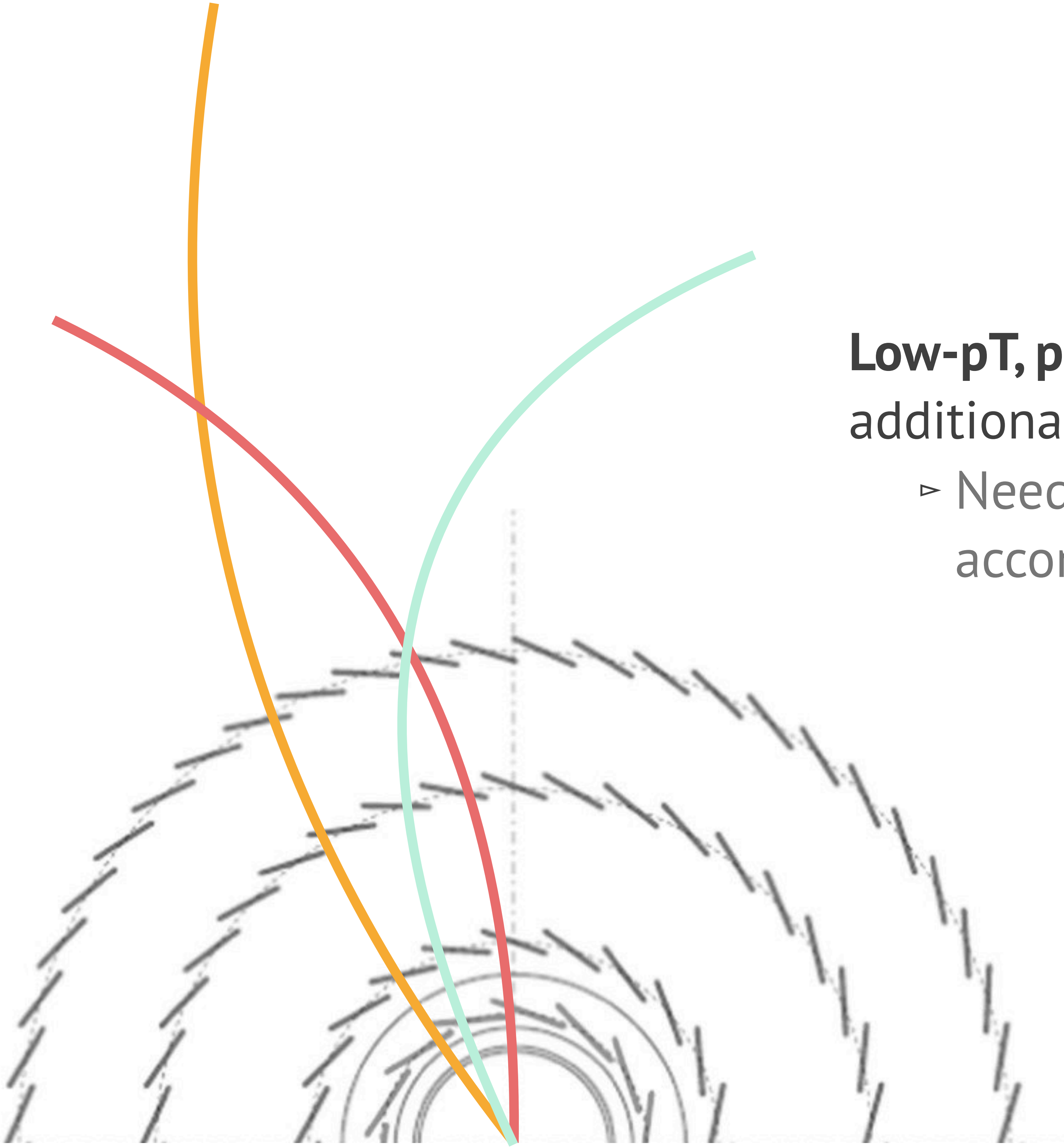


Pattern bank constraints

Very **high-pT, prompt tracks** have only one parameter: **angle**

- Generate enough patterns to cover all angles
- Have complete coverage of these tracks

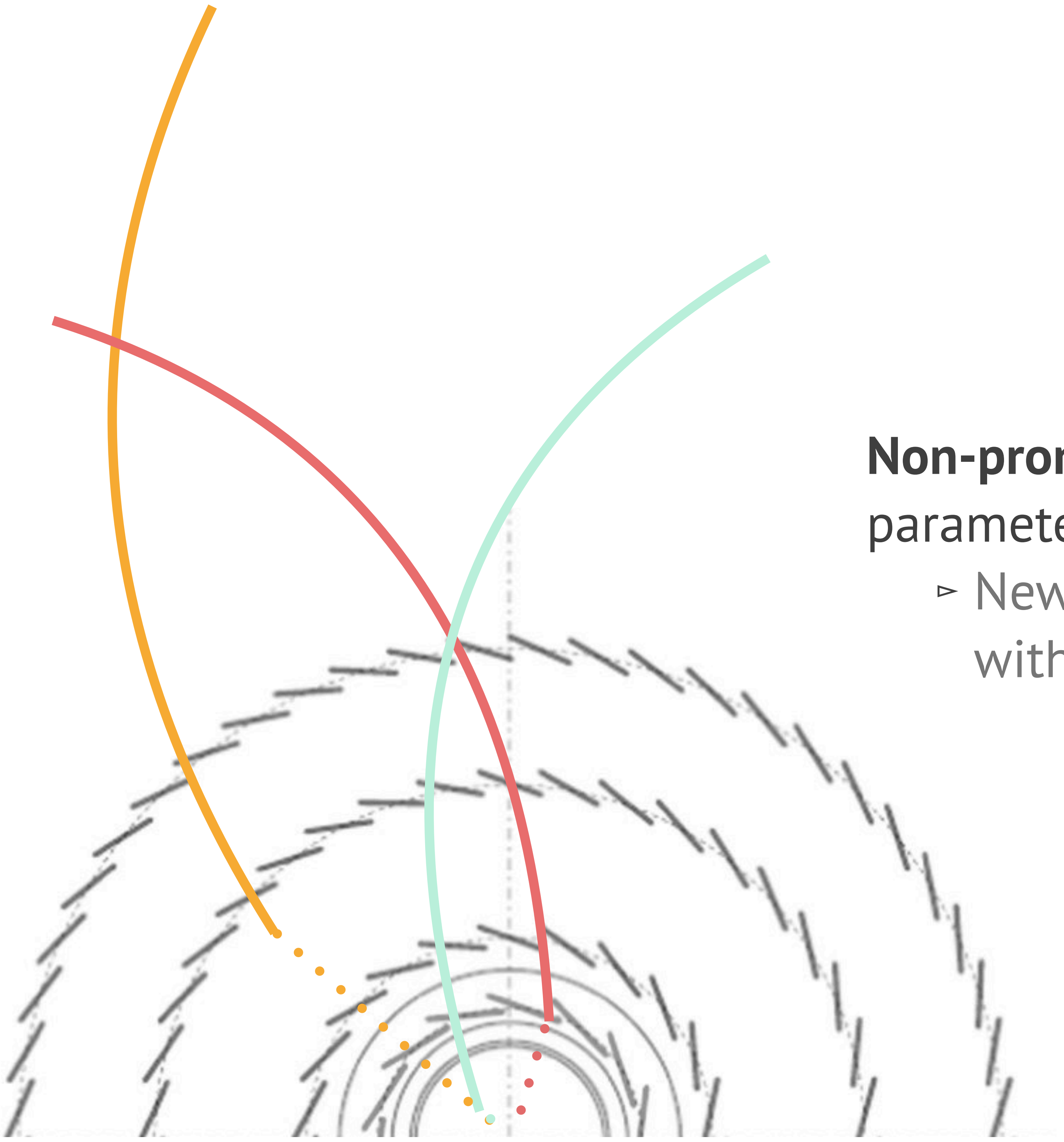
Pixel detector image



Pattern bank constraints

Low-pT, prompt tracks have an additional parameter: **curvature**

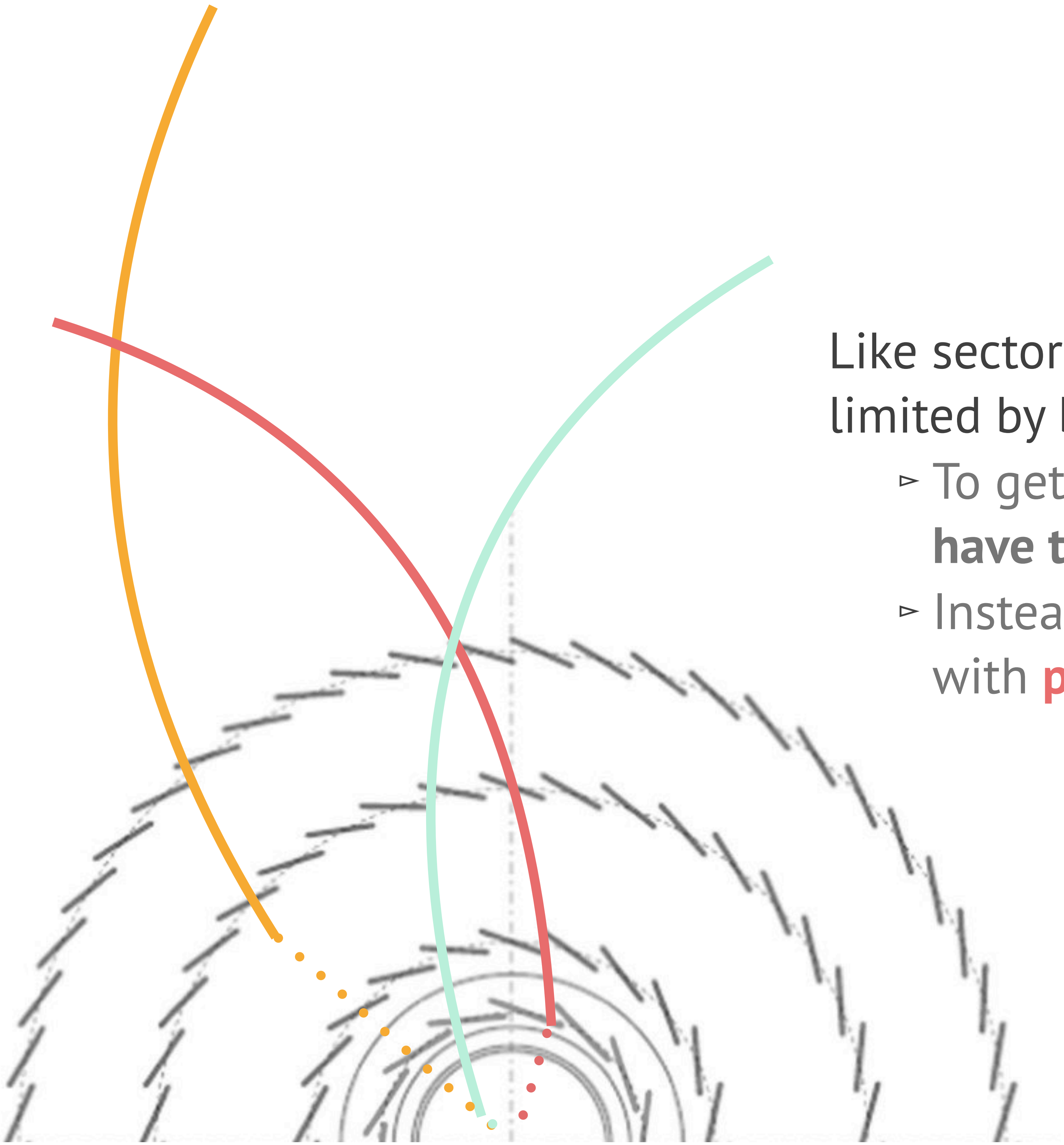
- Need patterns (and sectors!) that accommodate curved trajectory



Non-prompt tracks have one more parameter: **displacement**

- New set of paths not consistent with the center of detector

Pattern bank constraints



Like sectors, number of patterns also limited by board memory

- To get good coverage of displacement, **have to limit p_T range** to compensate
- Instead of p_T > 1 GeV, could get tracks with **p_T > 10 or 20 GeV**

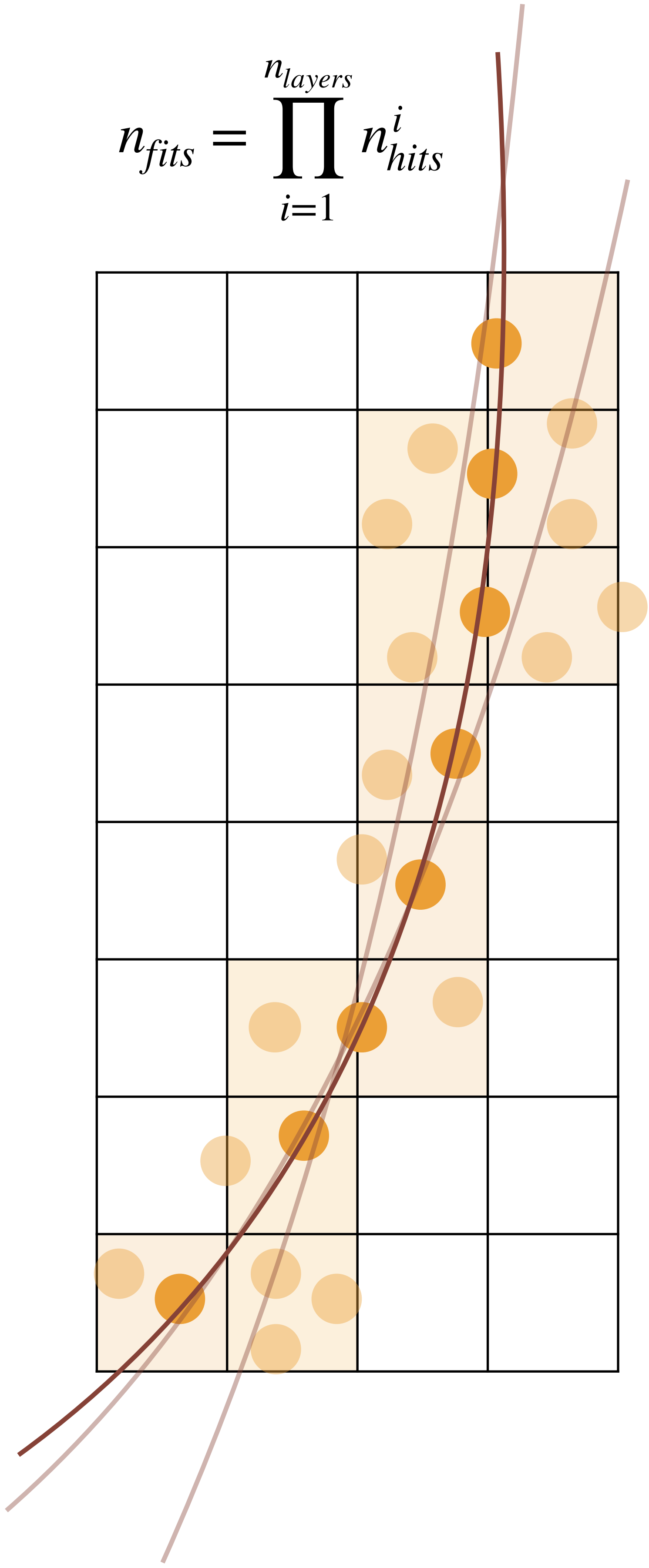
Patterns required goes as $1/p_T$

20 GeV cut ➞ Need ~5% as many patterns as 1 GeV

Pattern bank constraints

Dataflow constraints

$$n_{fits} = \prod_{i=1}^{n_{layers}} n^{i}_{hits}$$



FTK has to keep up with the L1 rate

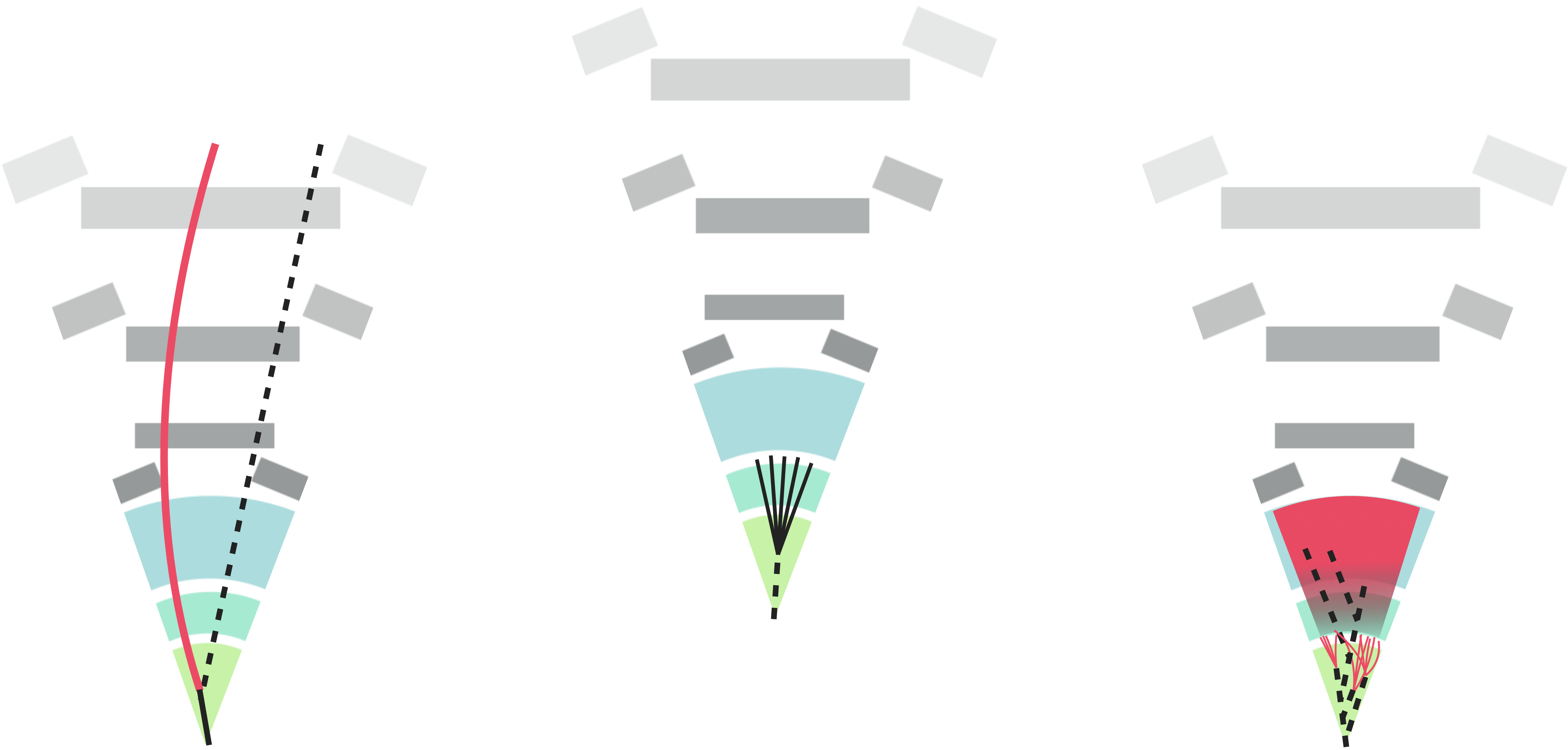
- Increase **number of patterns** → more strain on pattern matching board
- Increase **width of patterns** → more strain on fitting board (more combinations of hits in each pattern)

Freebie: FTK will soon **double** its processing units, so there's room to increase both fits and patterns

Plus: **displaced patterns have fewer fits** (less activity at high displacement)

- Displaced patterns can be wider (need fewer)
- Fewer prompt (high dataflow) patterns means that each can be wider → minimal efficiency impact

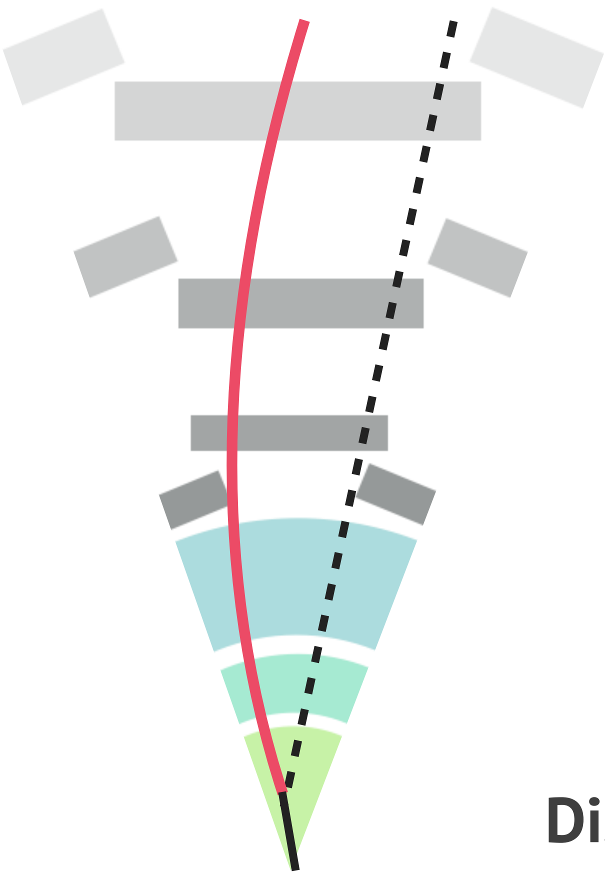
What to use it for?

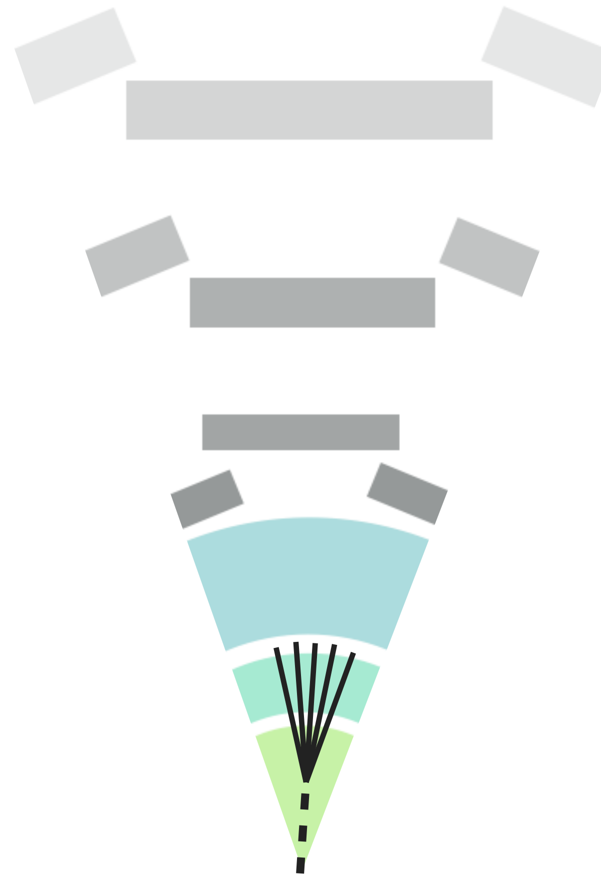


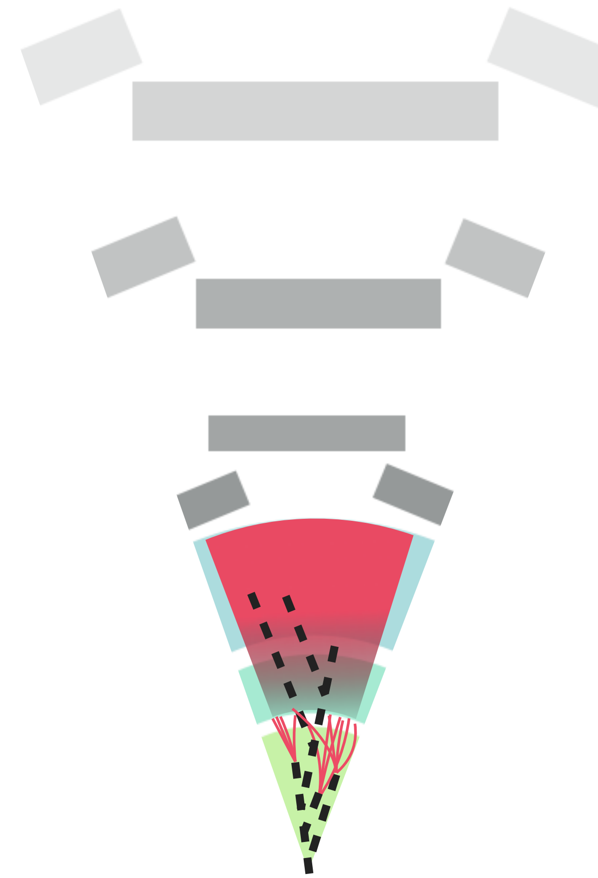
Displaced leptons

- Triggers for leptons without track requirements have high p_T thresholds / angular constraints
- Use displaced track to lower rate and bring down threshold

What to use it for?



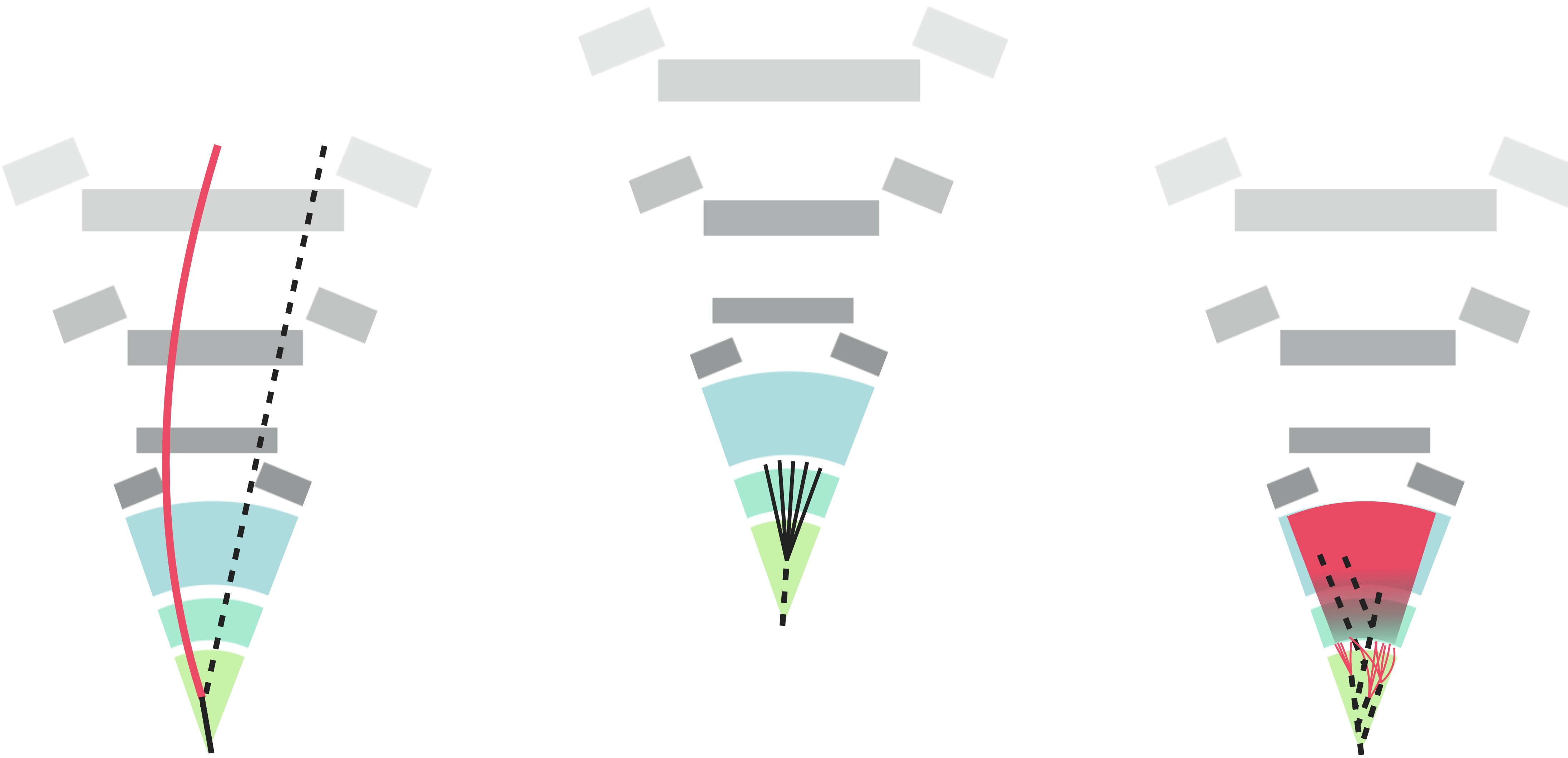




Displaced vertices

- Currently need another feature in the event to trigger on
- Find multiple high-d_0 tracks consistent with a single vertex
- Doesn't need high efficiency for single track

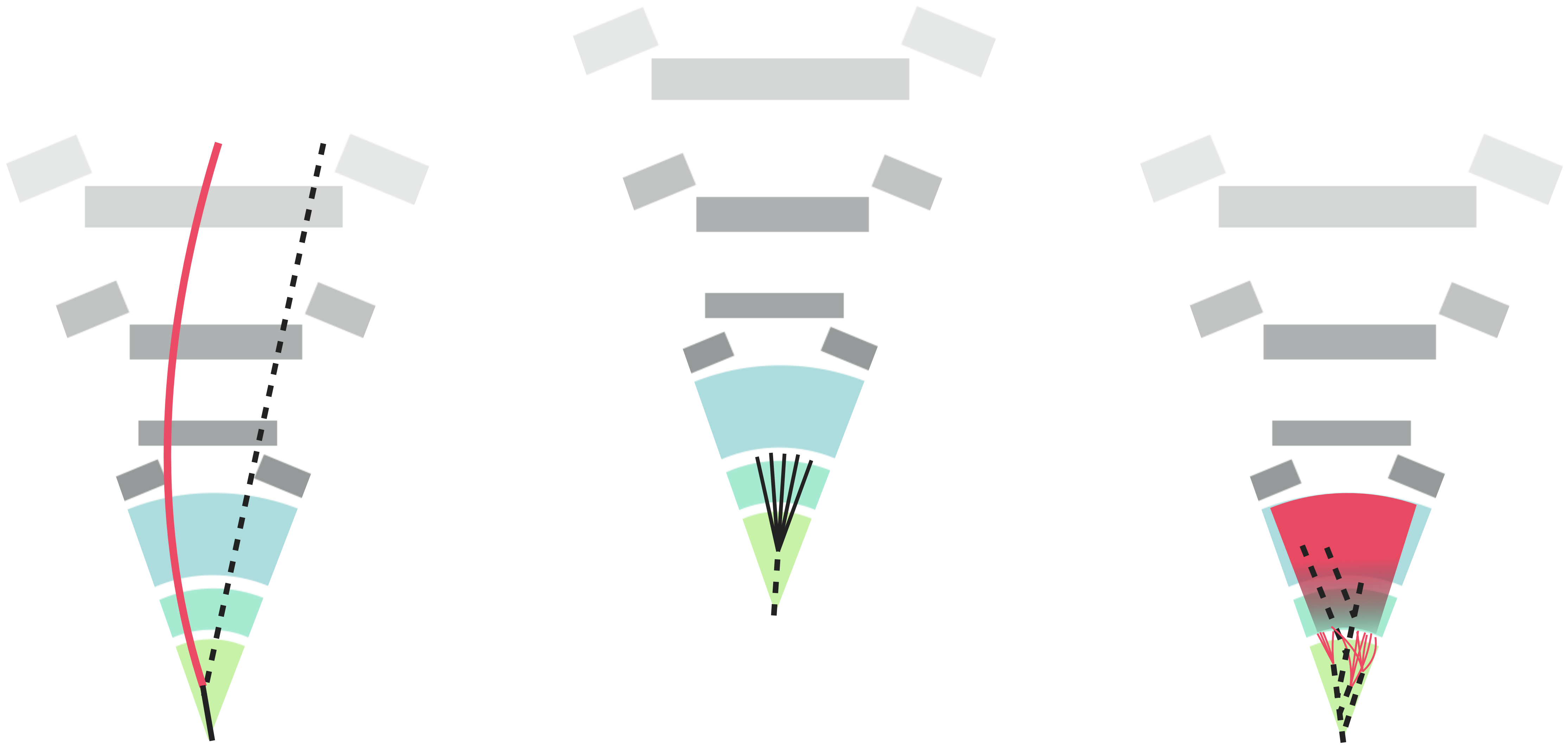
What to use it for?



Emerging jets

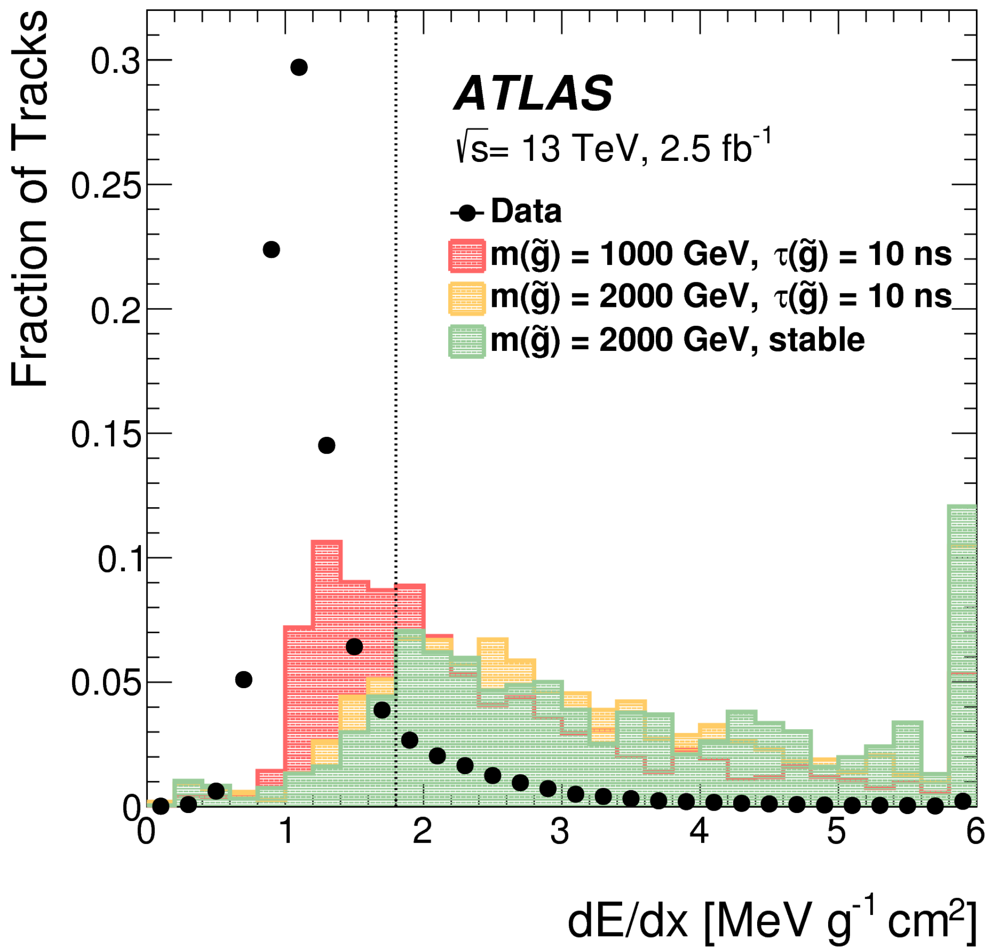
- Jet of dark hadrons decays to visible particles
- Find many high d_0 tracks, not necessarily consistent with one vertex

What to use it for?



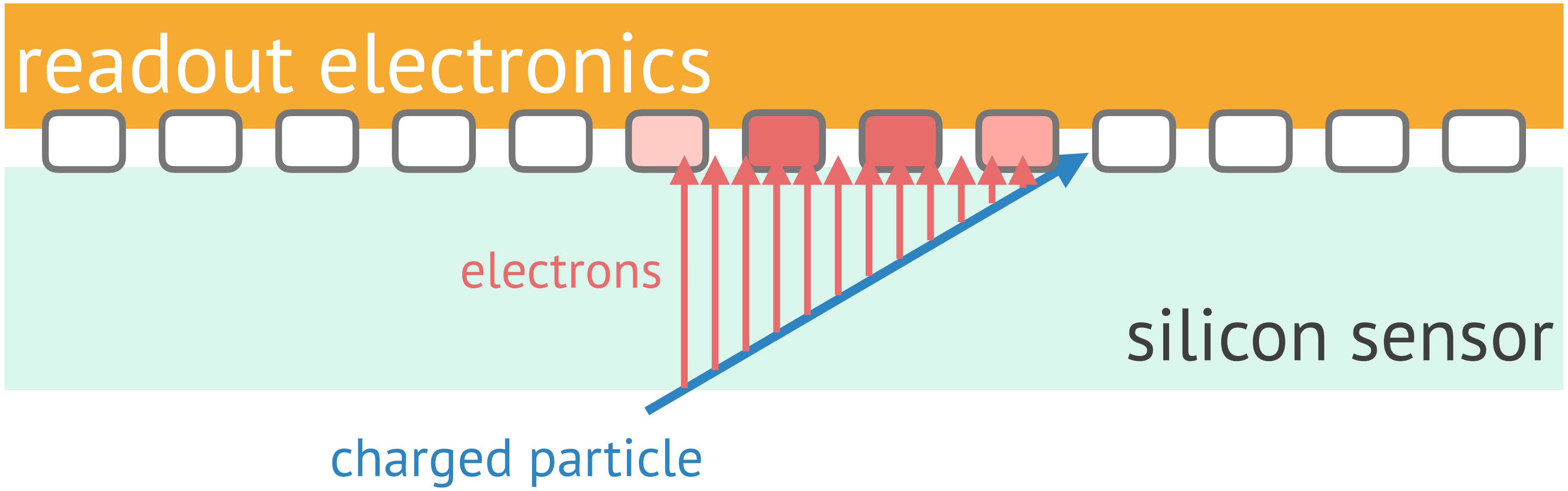
Or any other displaced track signature you can think of!

Clusters in FTK



FTK outputs **cluster sizes** for tracks

- Typically use dE/dx to identify stable high-mass LLPs
- Do dE/dx and cluster size correlate?



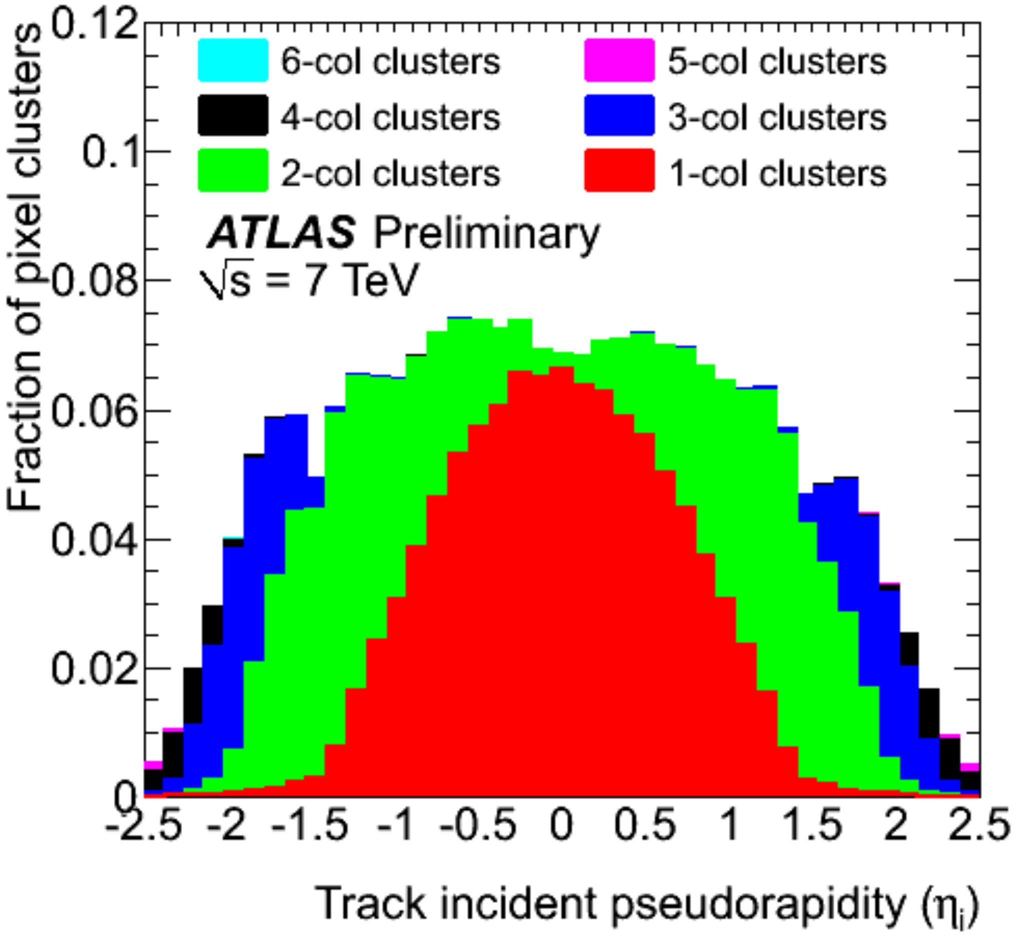
Yes!

Each pixel has a charge threshold

Depending on dE/dx, cluster could be 2, 3, 4 pixels wide

SUSY-2016-31

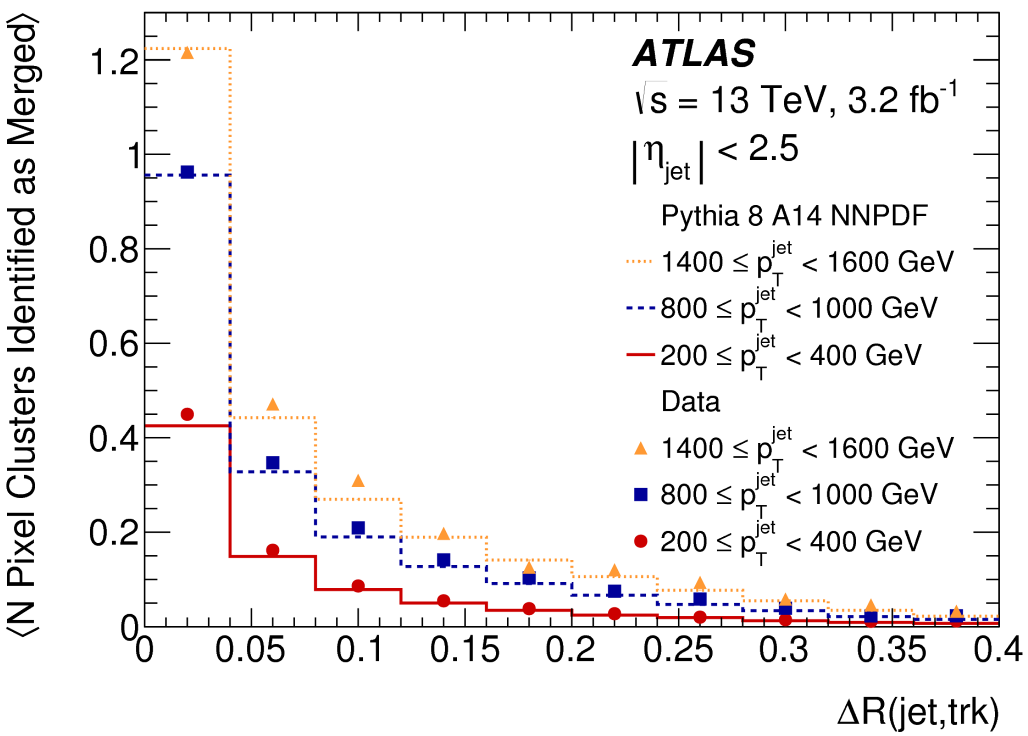
Clusters in FTK



Cluster size is also dependent on **incident angle**

- Can correct for this with the track parameters provided by FTK

Clusters produced by multiple particles



Some **SM backgrounds** remain

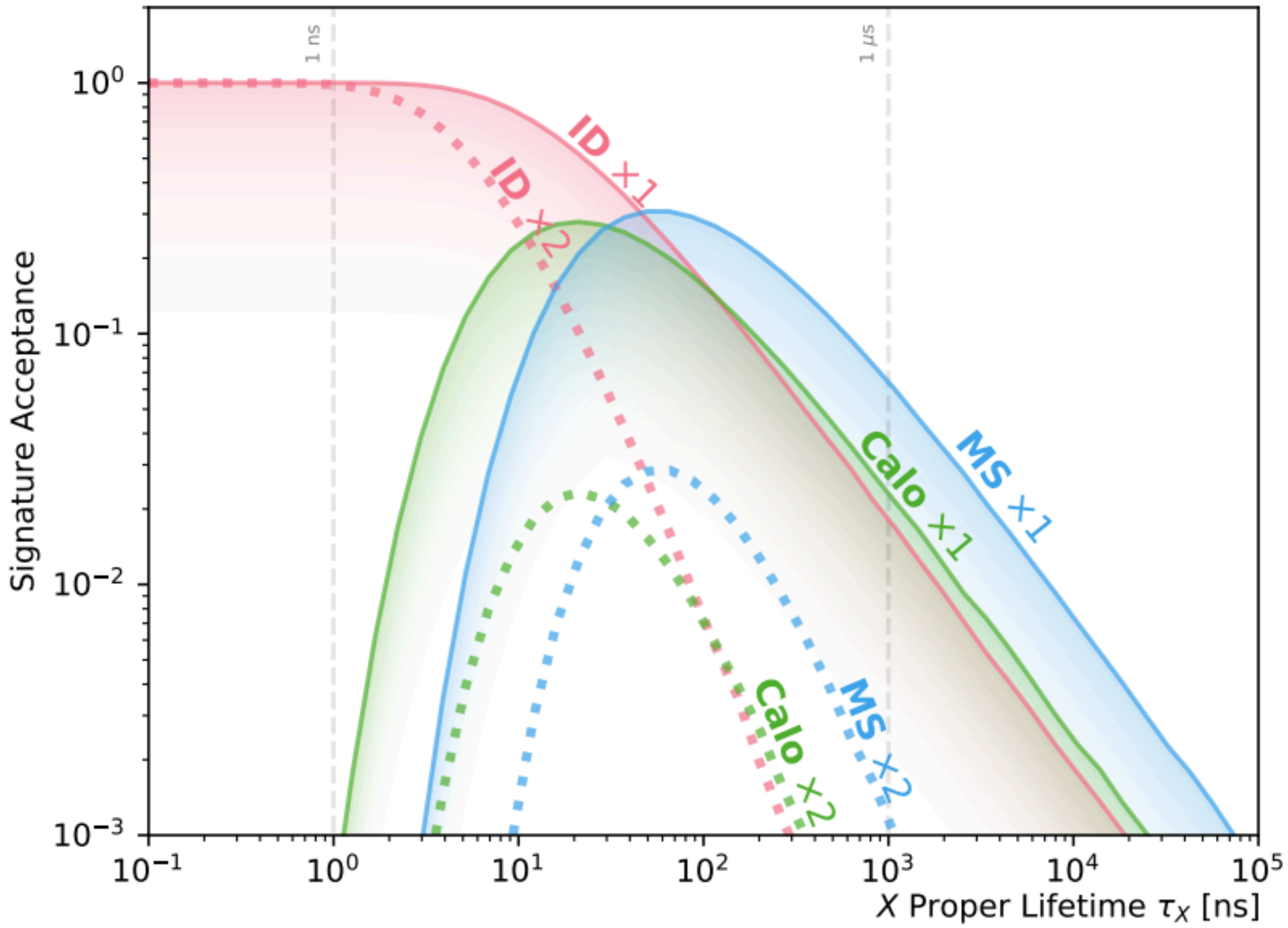
- Dense environments with multiple particles contributing to the same cluster
  - Can reduce this with isolation cuts

Could do even better **if FTK had charge** information

- Would require a modification of FTK data format

Pixel Public Results, Pixel Clustering Neural Net Performance

What about when we can't track?



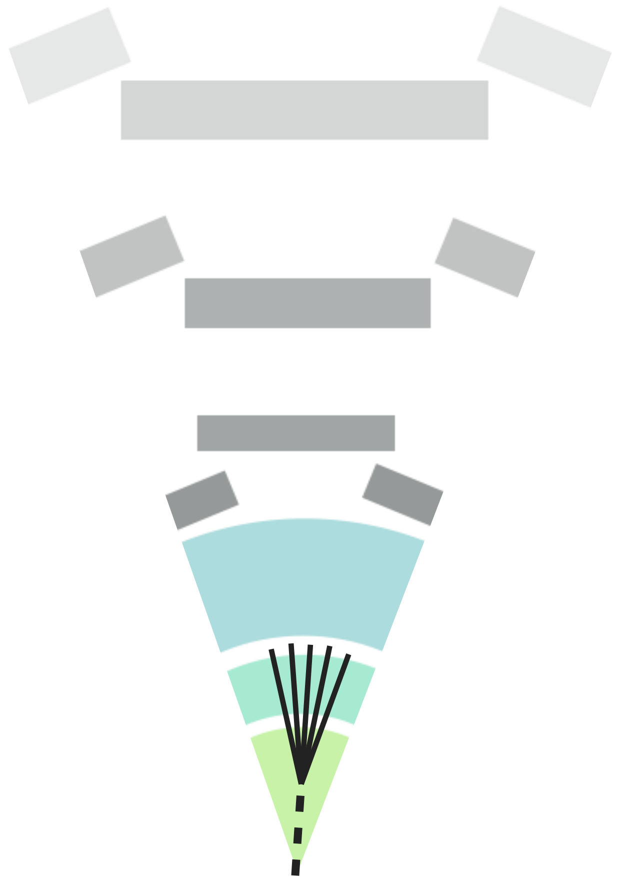
Detector acceptance for
pair-produced 2 TeV gluinos

Inner detector is the most interesting place to look for LLP decays for a large range of lifetimes

- But we can only track particles that decay at < ~1/10 its radius
- Are there other ways to use FTK when we can't track?

L. Lee et al.

Trackless Clusters

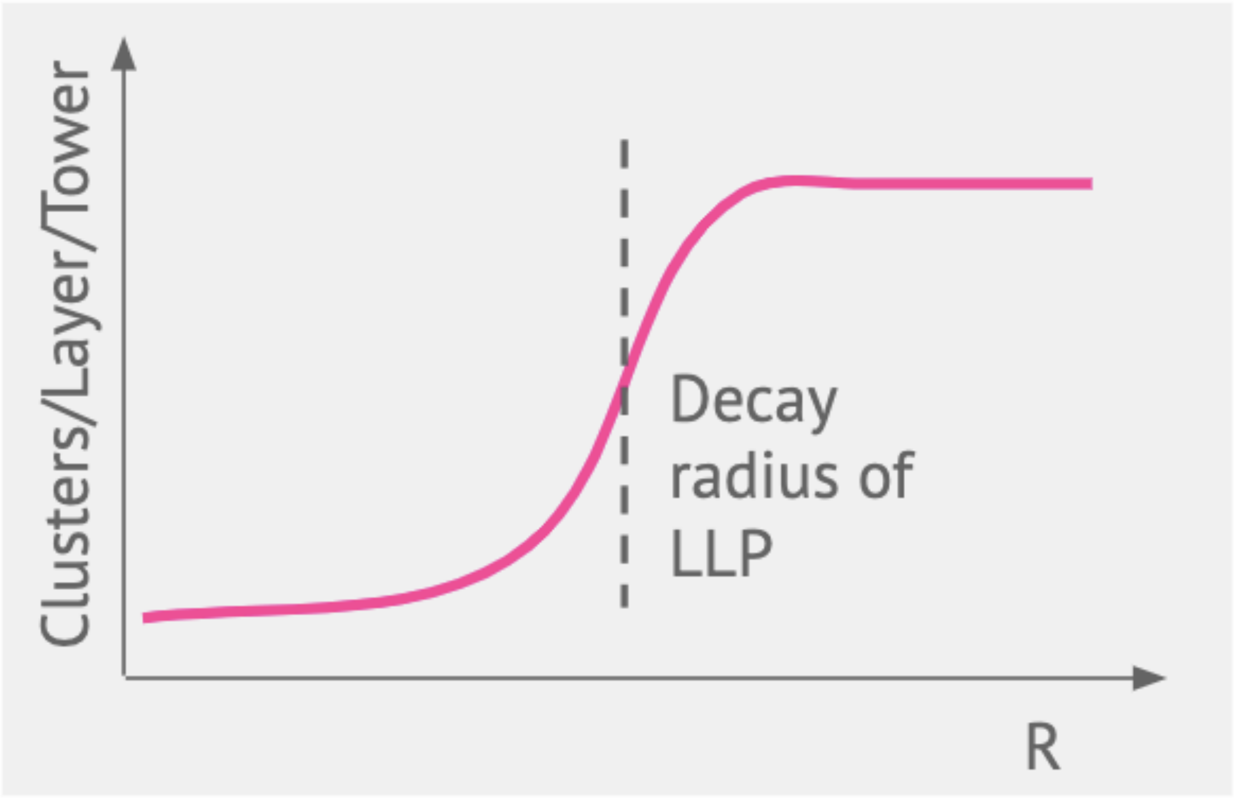


FTK accesses **all hits** in the Inner Detector silicon

- Clusters them and organizes them into towers in η/φ
- For displaced jets, should see a **jump** in number of clusters at decay R

Even better background discrimination by comparing unassociated clusters to number of tracks

- FTK doesn't currently output total number of clusters for each event
  - Could be added to firmware with minimal impact on dataflow



There's a lot that can be done
… but not much time to do it in

FTK is behind schedule: slice functionality demonstrated at the last minute in Run 2, during Heavy Ion run

Uses requiring FW changes can be a hard sell

but there's always Run 4!

Run 4 is interesting for LLP for the same reason as Run 3:

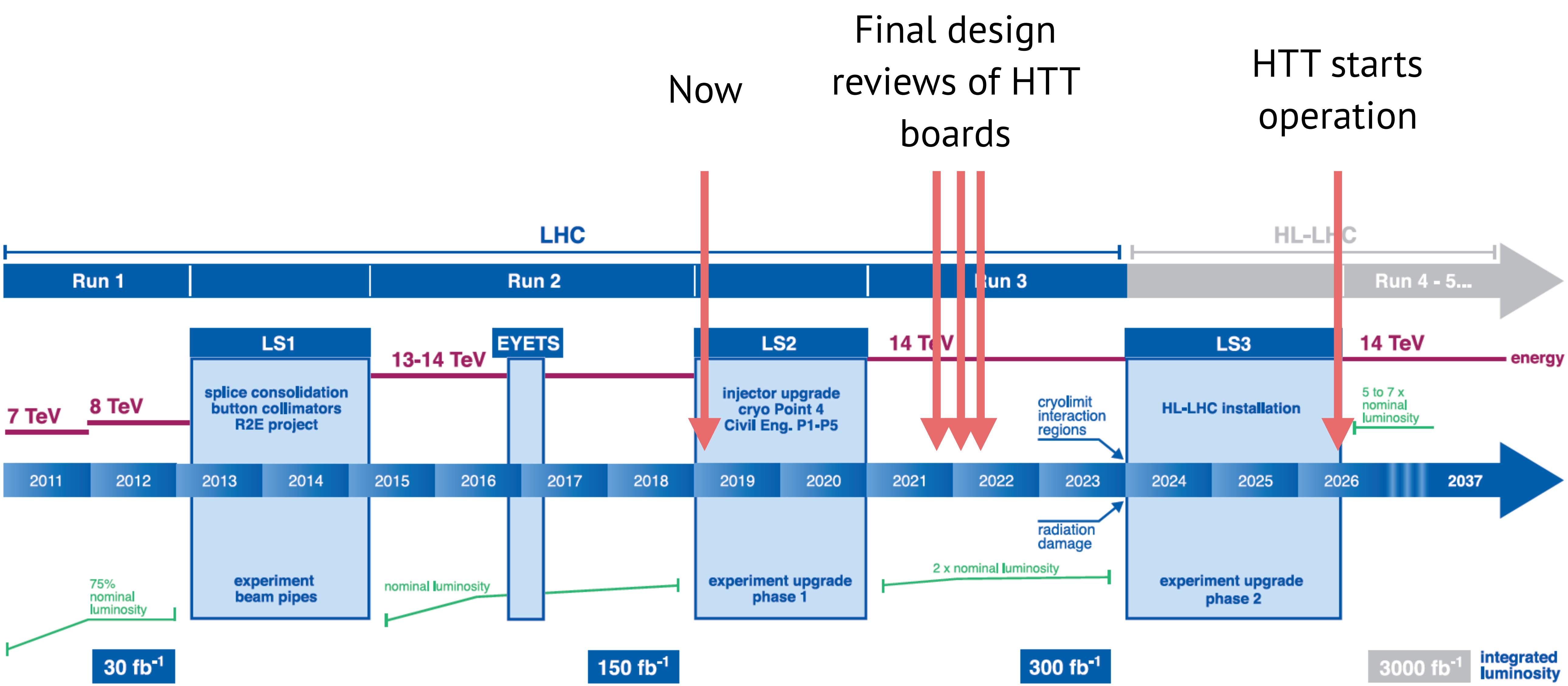
- No more energy jumps, just lots of luminosity ➞ big gains for low background searches
- No more FTK in Run 4: we move on to **HTT**

Hardware Tracker for the Trigger

Currently ID is only read out when L1 trigger is fired

HTT plans currently much more flexible than FTK

- Upgraded, but generally the same principles as FTK
- One big improvement: HTT can do **regional tracking at L1**
- Now is the time to start thinking about utilizing HTT for LLPs



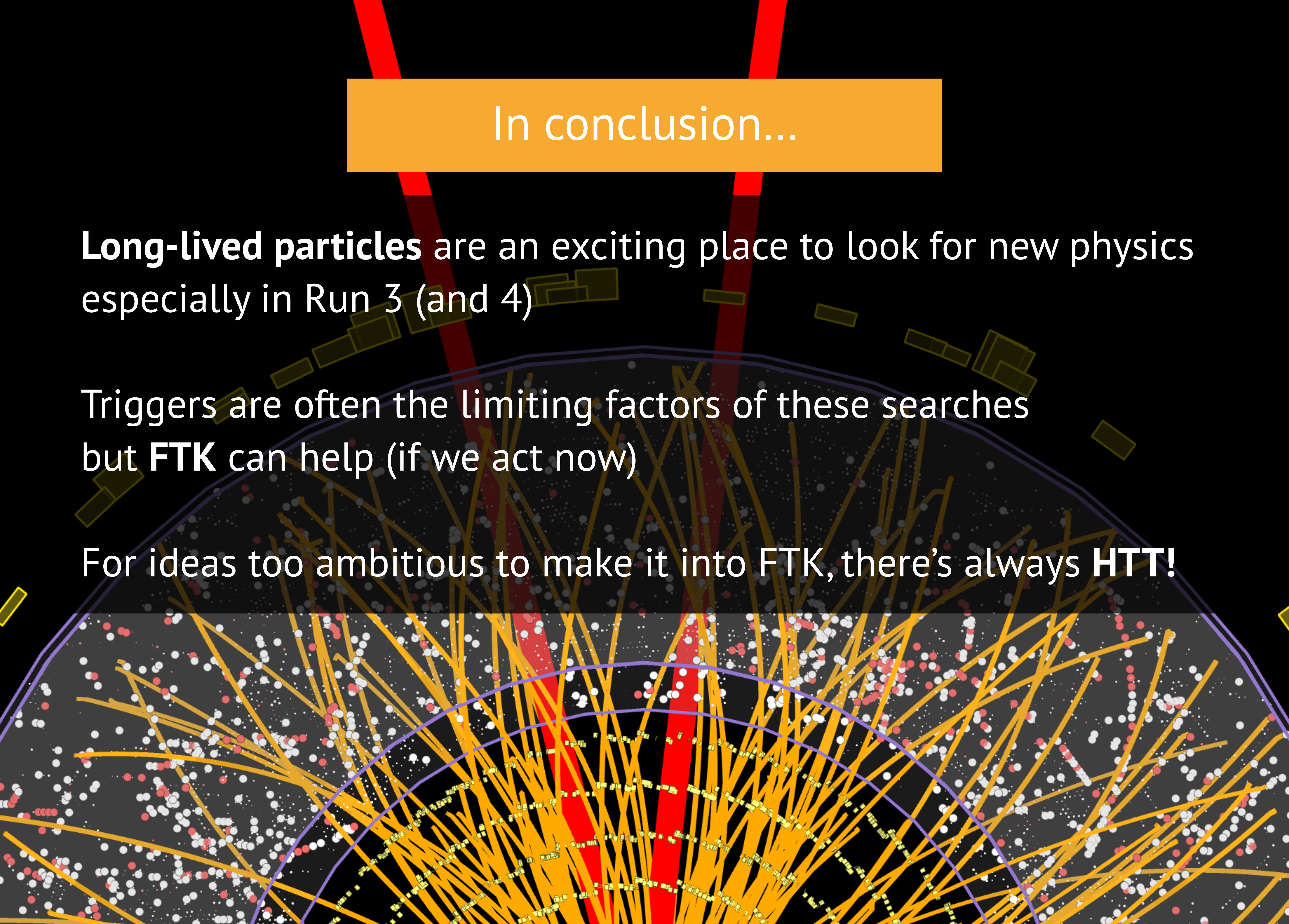
TDAQ TDR

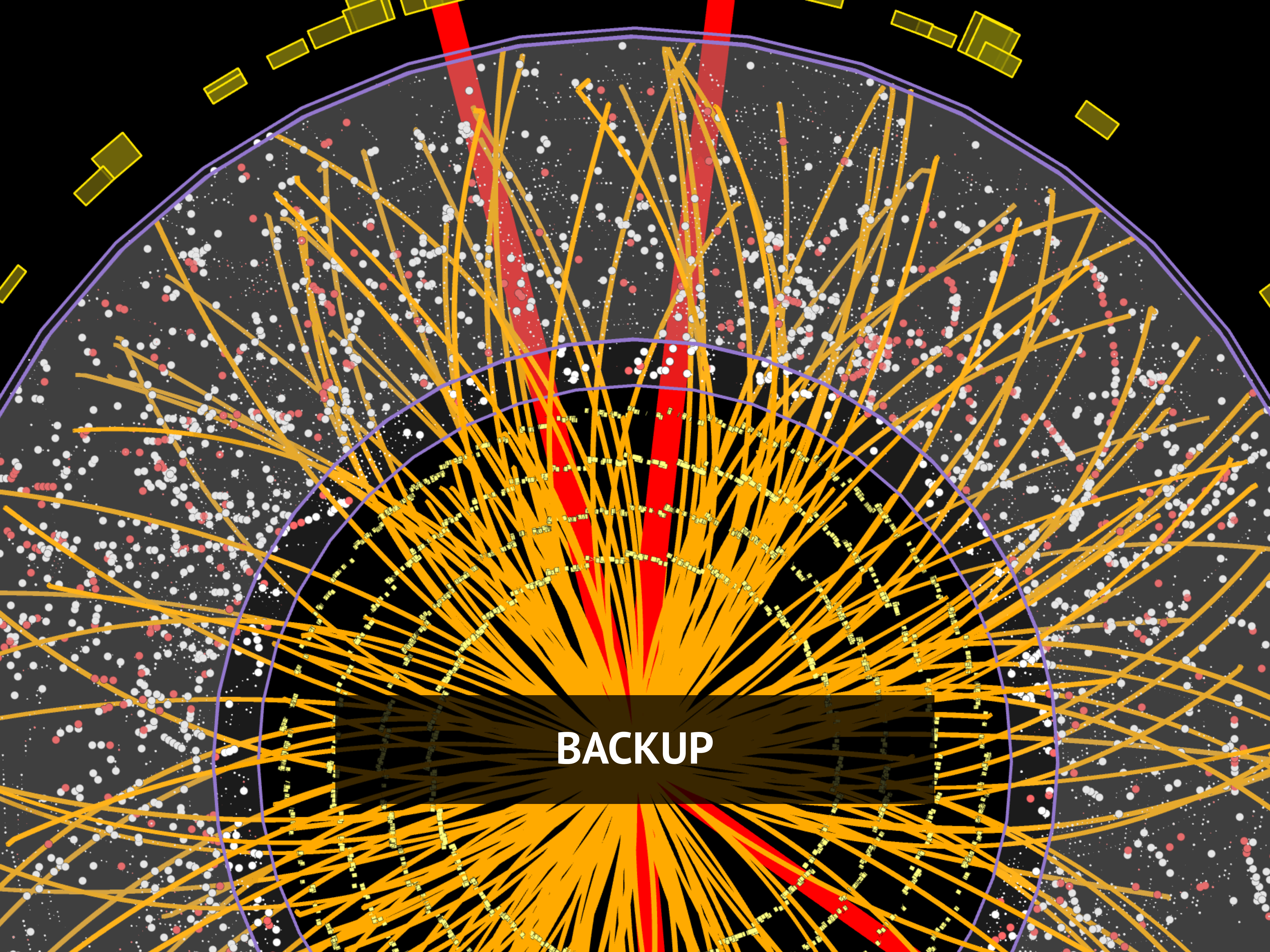
In conclusion…

Long-lived particles are an exciting place to look for new physics especially in Run 3 (and 4)

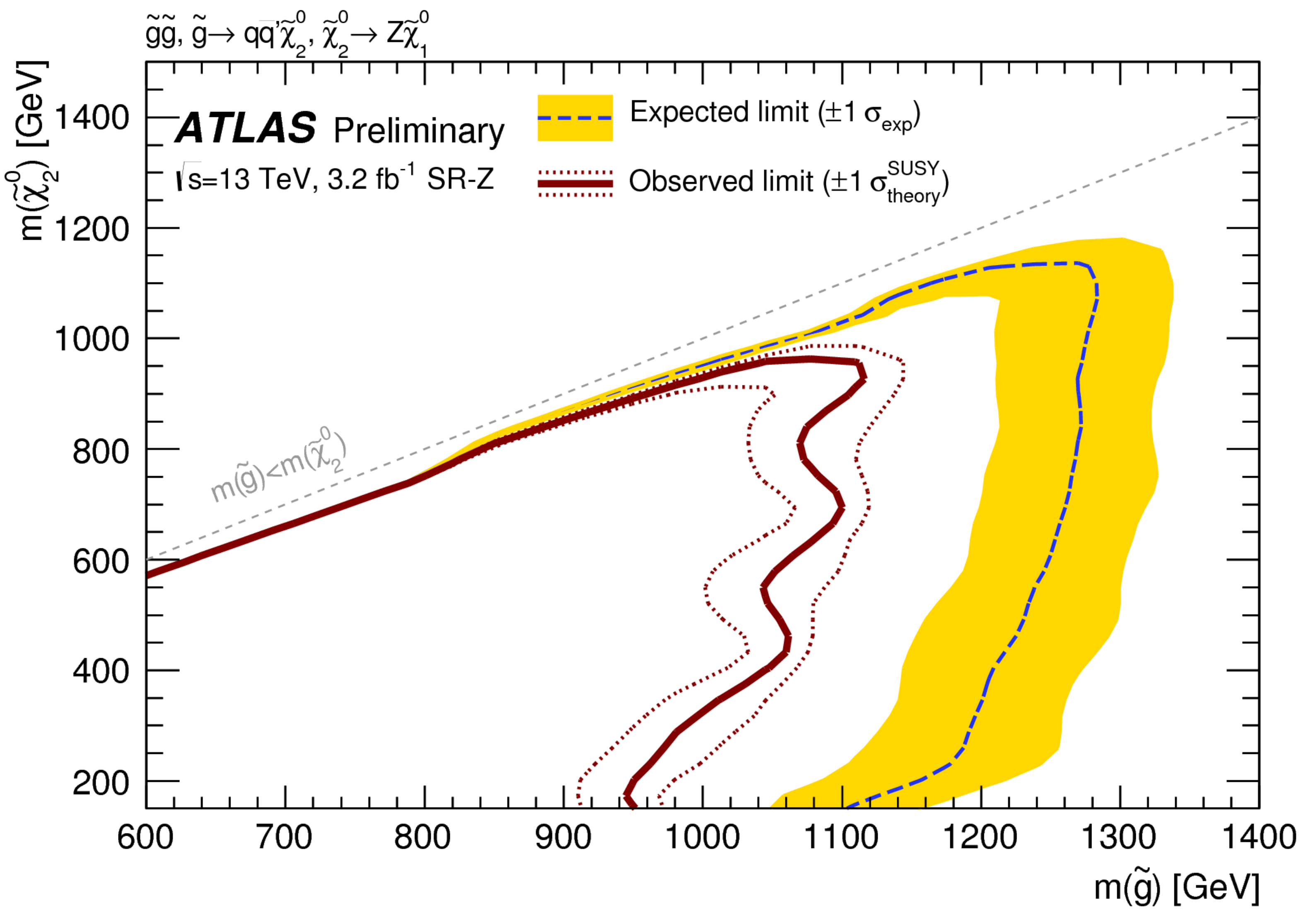
Triggers are often the limiting factors of these searches but **FTK** can help (if we act now)

For ideas too ambitious to make it into FTK, there's always **HTT!**




BACKUP

Z+MET 3.2/fb limit, 36/fb uncertainties



	SR-low	SR-medium	SR-high
Observed events	134	40	72
Total expected background events	144 ± 22	40 ± 10	83 ± 9
Flavour-symmetric ($t\bar{t}$, Wt, WW and $Z \rightarrow \tau\tau$) events	86 ± 12	29 ± 9	75 ± 8
$Z/\gamma^* +$ jets events	9^{+13}_{-9}	$0.2^{+0.8}_{-0.2}$	2.0 ± 1.2
WZ/ZZ events	43 ± 12	9.8 ± 3.2	4.1 ± 1.2
Rare top events	6.7 ± 1.8	1.20 ± 0.35	1.8 ± 0.5

Many more interesting signatures!

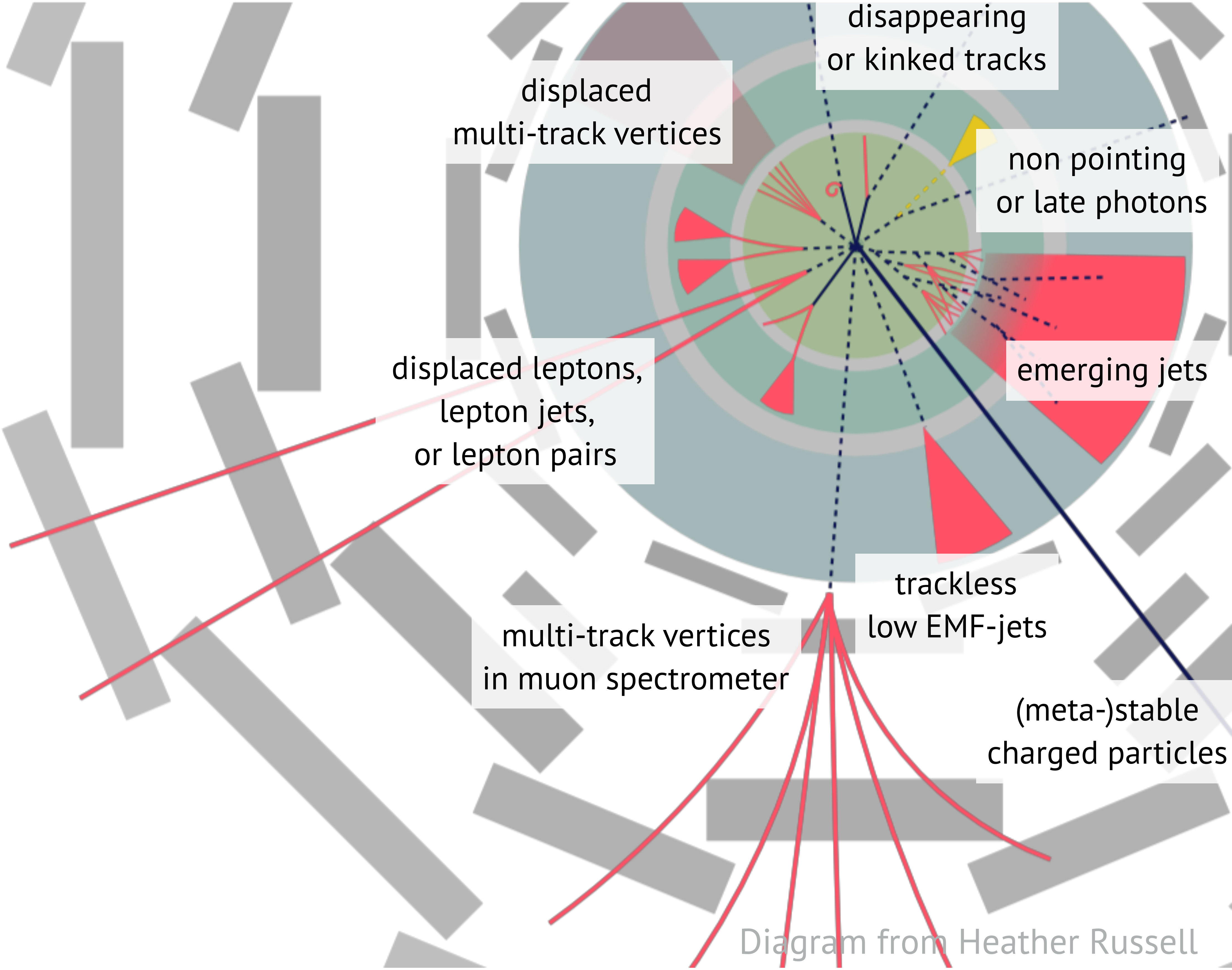
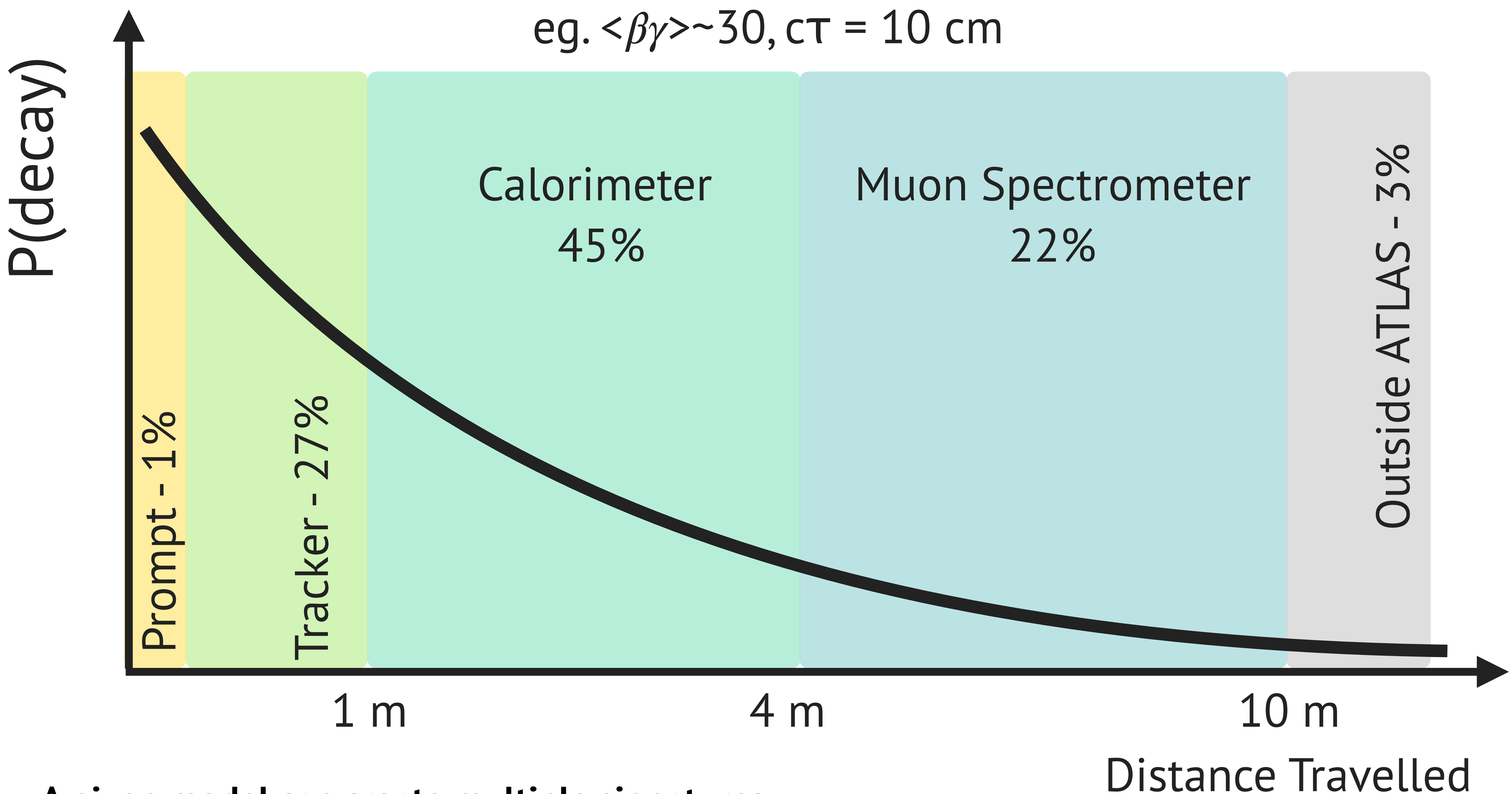


Diagram from Heather Russell

What do these particles look like in ATLAS?



A given model can create multiple signatures

Lifetime gives an exponential

For intermediate lifetimes, particles decay throughout the ATLAS detector

Diagrams from Heather Russell

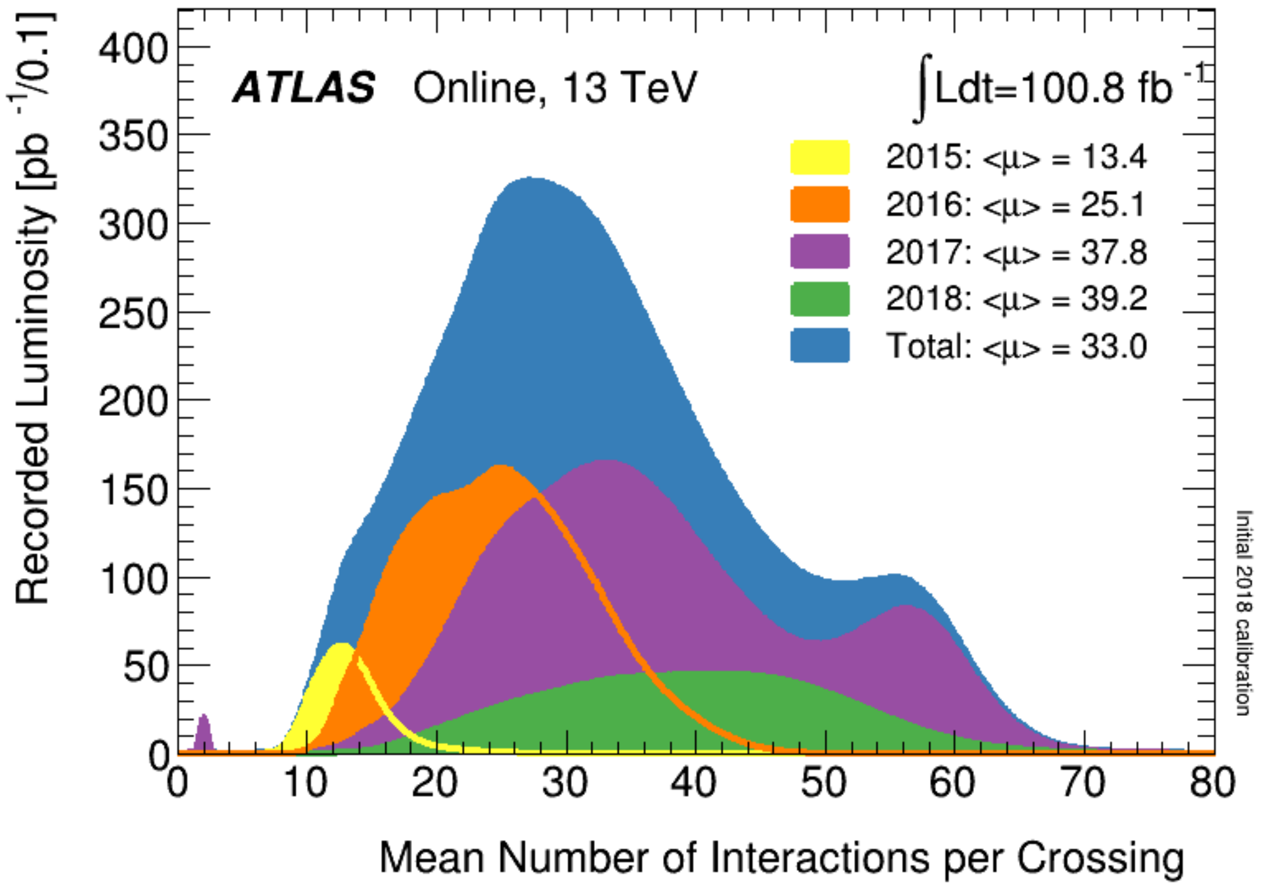
Pileup @ the LHC

~40 simultaneous *pp* interactions per event in 2018

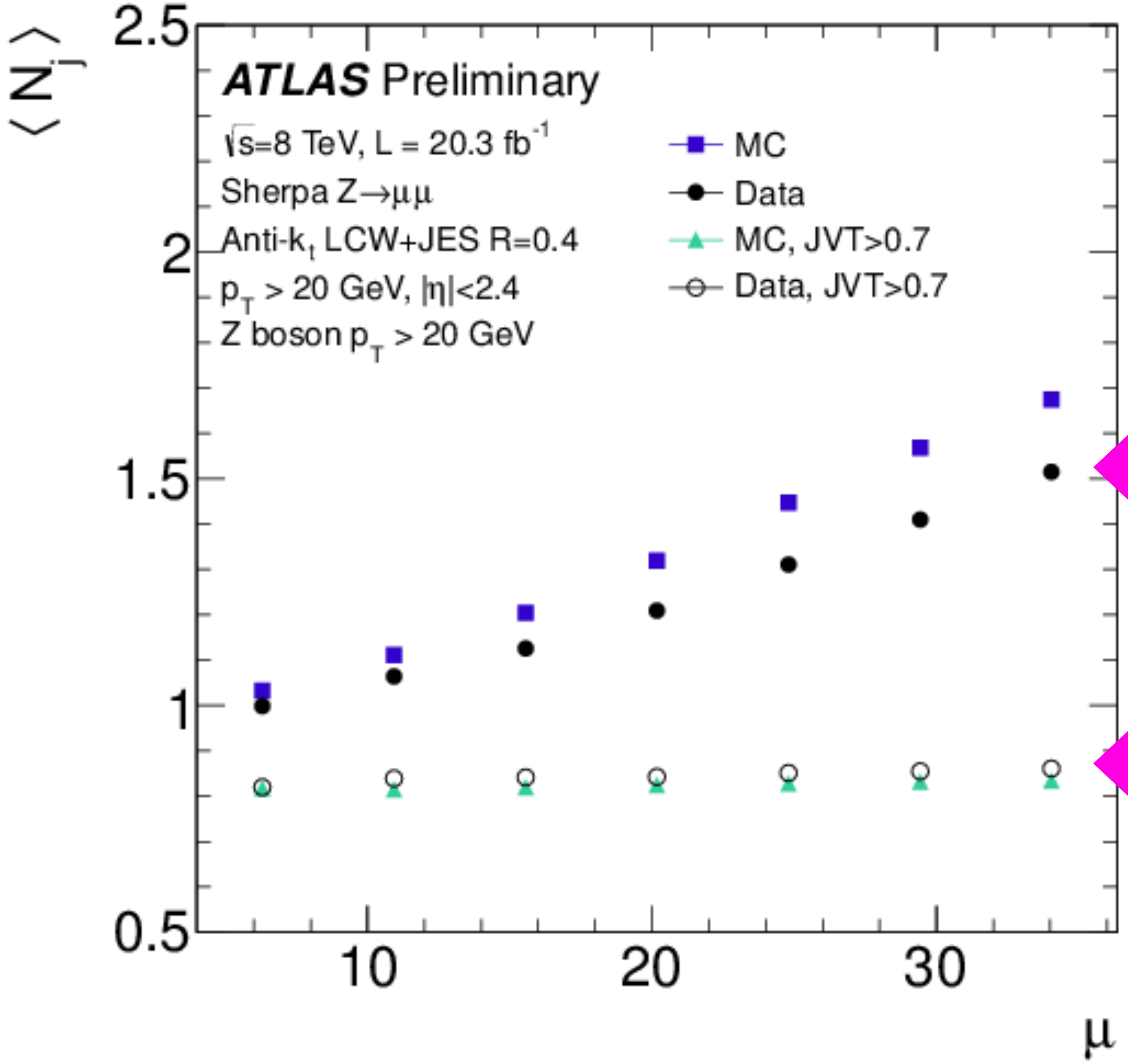
tracks let us identify objects from the primary vertex

(and ignore everything else)

need global tracking to do this for the full event!



Pileup @ the LHC



Tracking at the trigger level is essential to maintaining low trigger thresholds

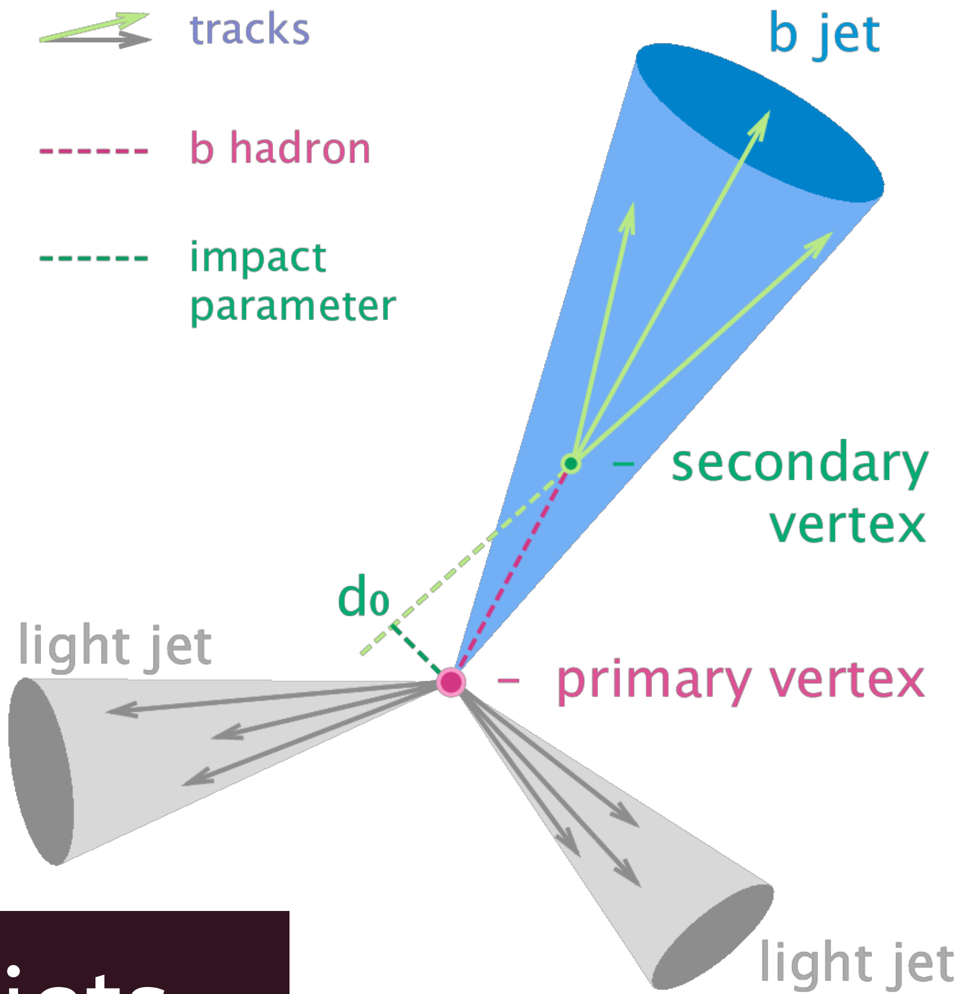
njets selected without tracking

njets selected with tracking

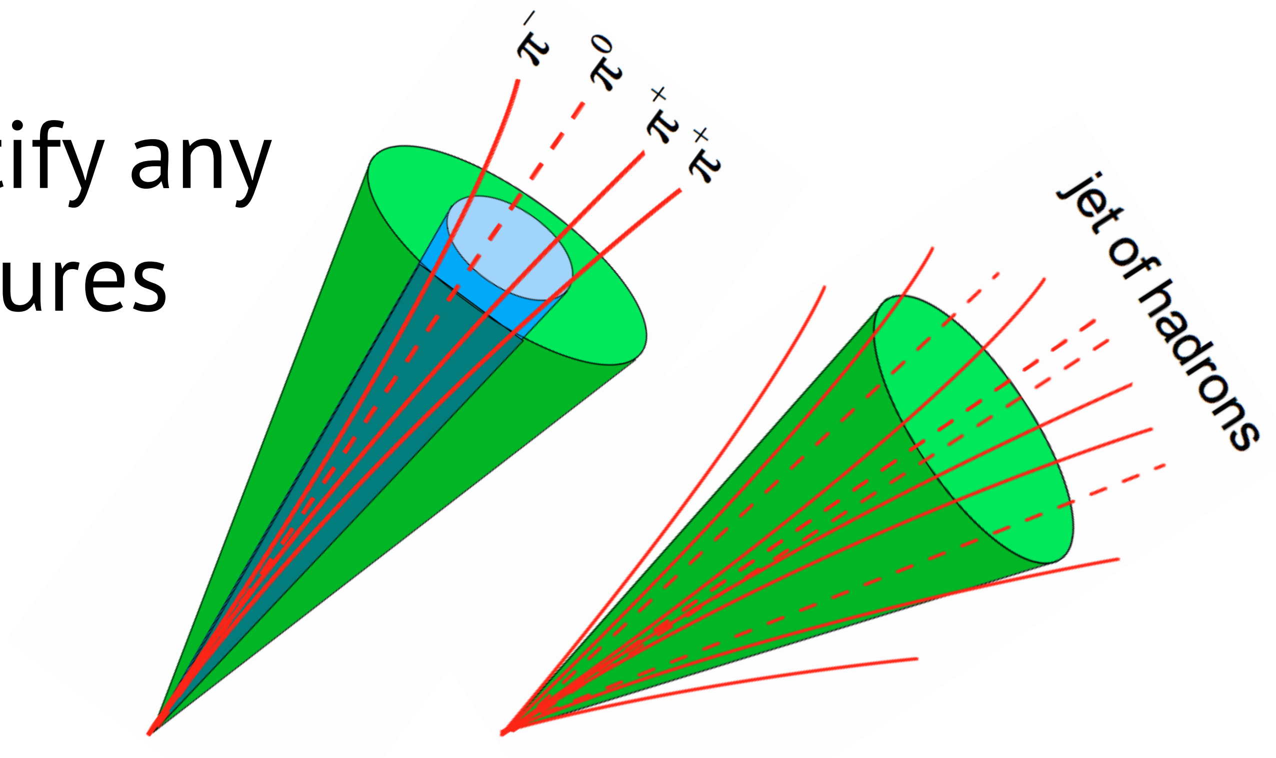
ATLAS-CONF-2014-018

More uses for tracking

Full-scan tracking can help identify any object with track-based signatures



b-jets



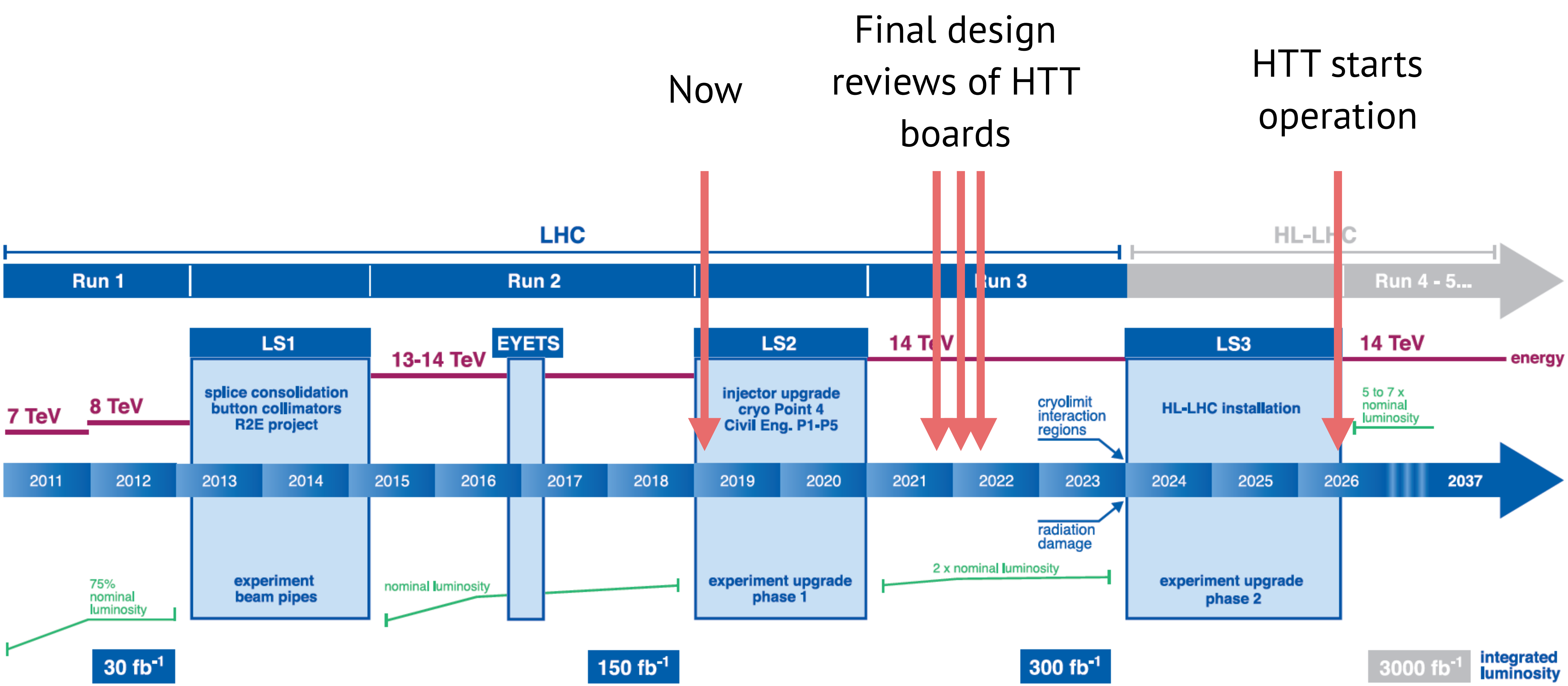
hadronic τs

If tracking is already available, frees up CPU at HLT for other tasks

Hardware Tracker for the Trigger

HTT plans currently much more flexible than FTK

- Upgraded, but generally the same principles as FTK
- One big change: HTT can do **regional tracking at L1**
- Now is the time to start thinking about utilizing HTT for LLPs



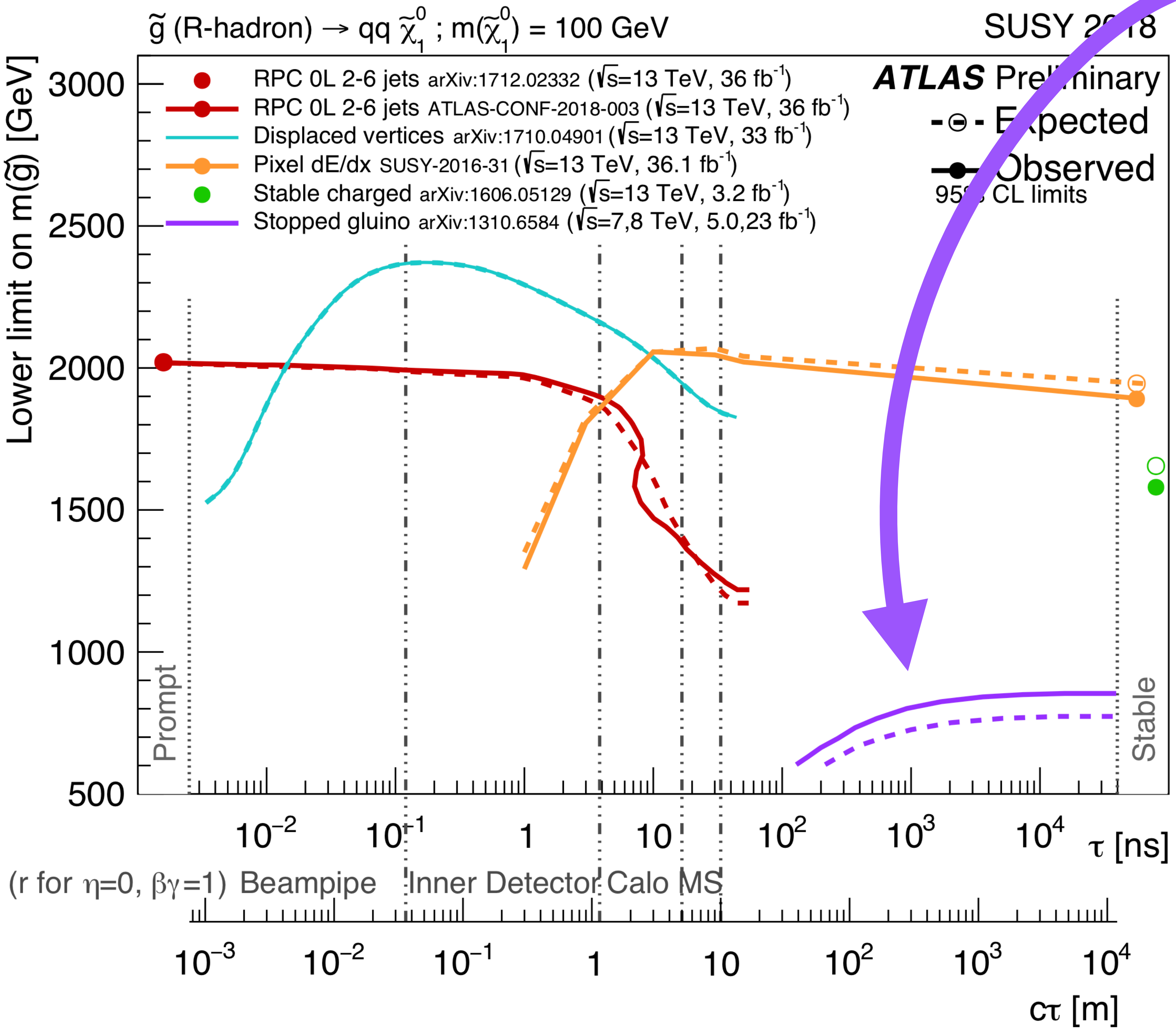
TDAQ TDR

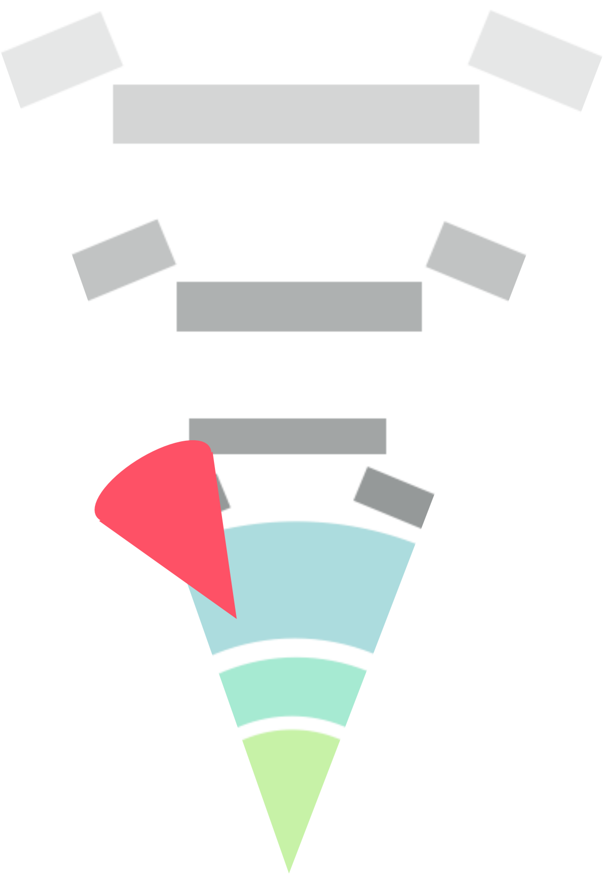
ATLAS searches for long-lived particles

an example of success

R-hadrons

Stopped gluino





Ideas to improve clustering trigger

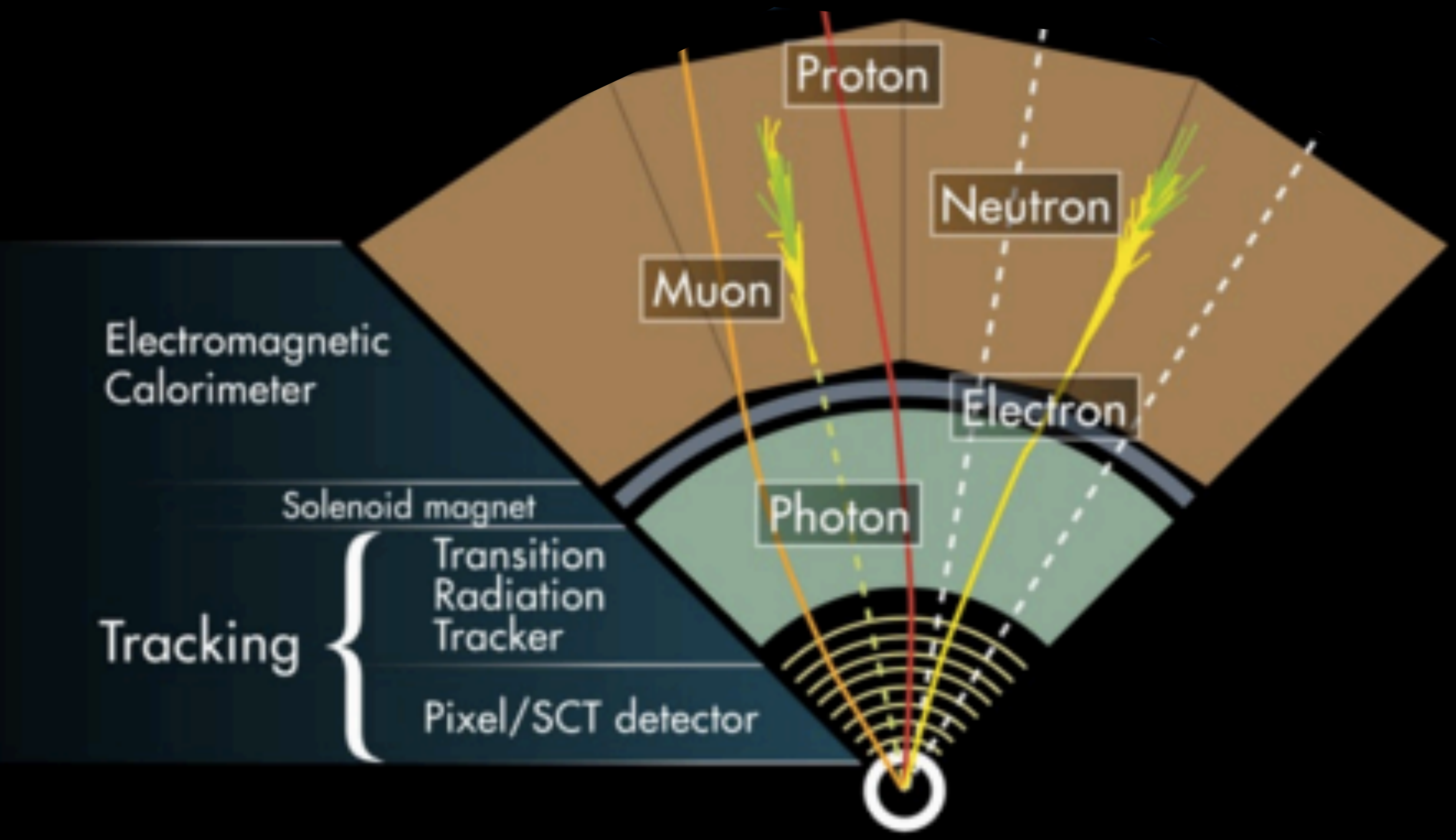
- Look for some kind of consistency between clusters on track
  - Delta rays / merged clusters tend to affect the size and ToT of some but not all of the cluster on track
  - For high dE/dx particles, the deposits should be consistently large in all clusters
- Add isolation
  - Most signals are quite isolated and adding isolation will massively cut down on merged cluster backgrounds

Reminders

- FTK provides input to HLT – need an L1 trigger to use it!
- Most interesting for cases where there's currently a large gap between L1 and HLT
  - MET (because L1 and HLT are so uncorrelated)
  - Photons (because electrons share the same L1)

- Bonus fact:
  - Displaced patterns help with beamspot shifts

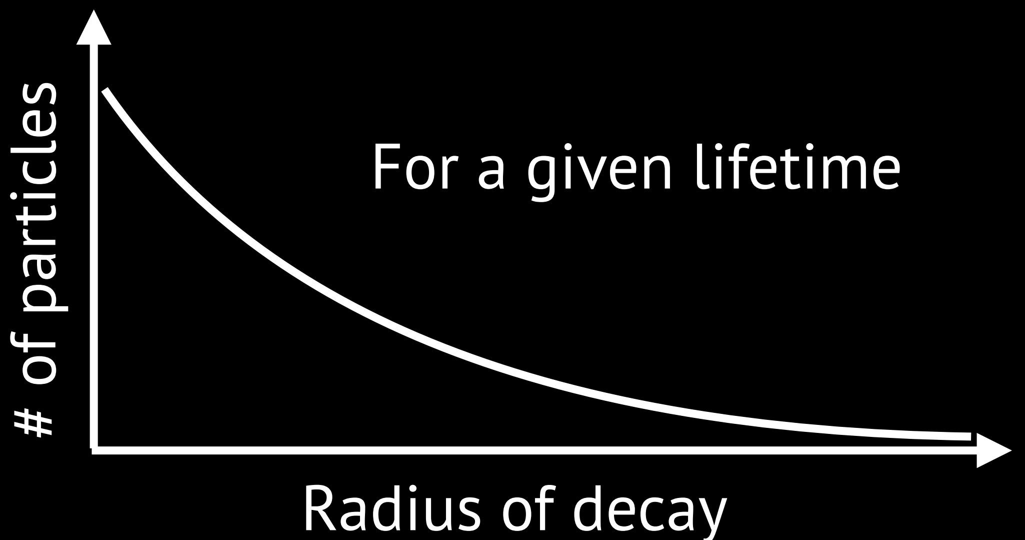
What ATLAS is designed to do



Electron with no prompt track
→ photon

Electron that appears part way through the calorimeter
→ noise?

BSM particle traveling through the detector
→ ???



Luckily, lifetimes represent an exponential
So even for large lifetimes, a big fraction decay early

It's often *possible* to reconstruct them