UC SANTA CRUZ

SUSY in the ATLAS Experiment

Dr. Giordon Stark (on behalf of the ATLAS Collaboration)

SUSY2019

May 20th, 2019

giordonstark.com

Run: 300800

Event: 2418777995

2016-06-04 03:47:03

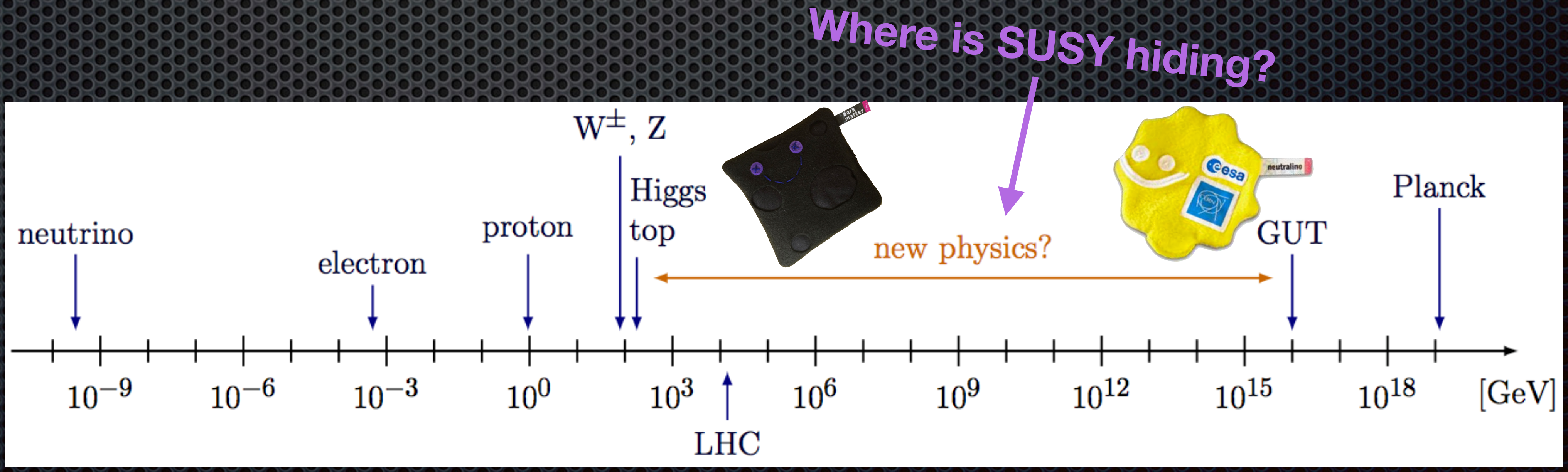
if you can read this, you're too close

> *"SUSY is just around the corner."*
> — Carlos Wagner

https://indico.cern.ch/event/813884/contributions/3394791

Overview of today's talk

- The Large Hadron Collider, **ATLAS**, and you
- A highlight of searches for **new physics inspired by SUSY**
  - Strong,
  - 3rd Generation (**3G**),
  - Electroweak (**EWK**), and
  - Long-Lived Particles (**LL** or **LLP**)
- across R-Parity Conserving (**RPC**) R-Parity Violating (**RPV**) scenarios



LHC ***ATLAS***

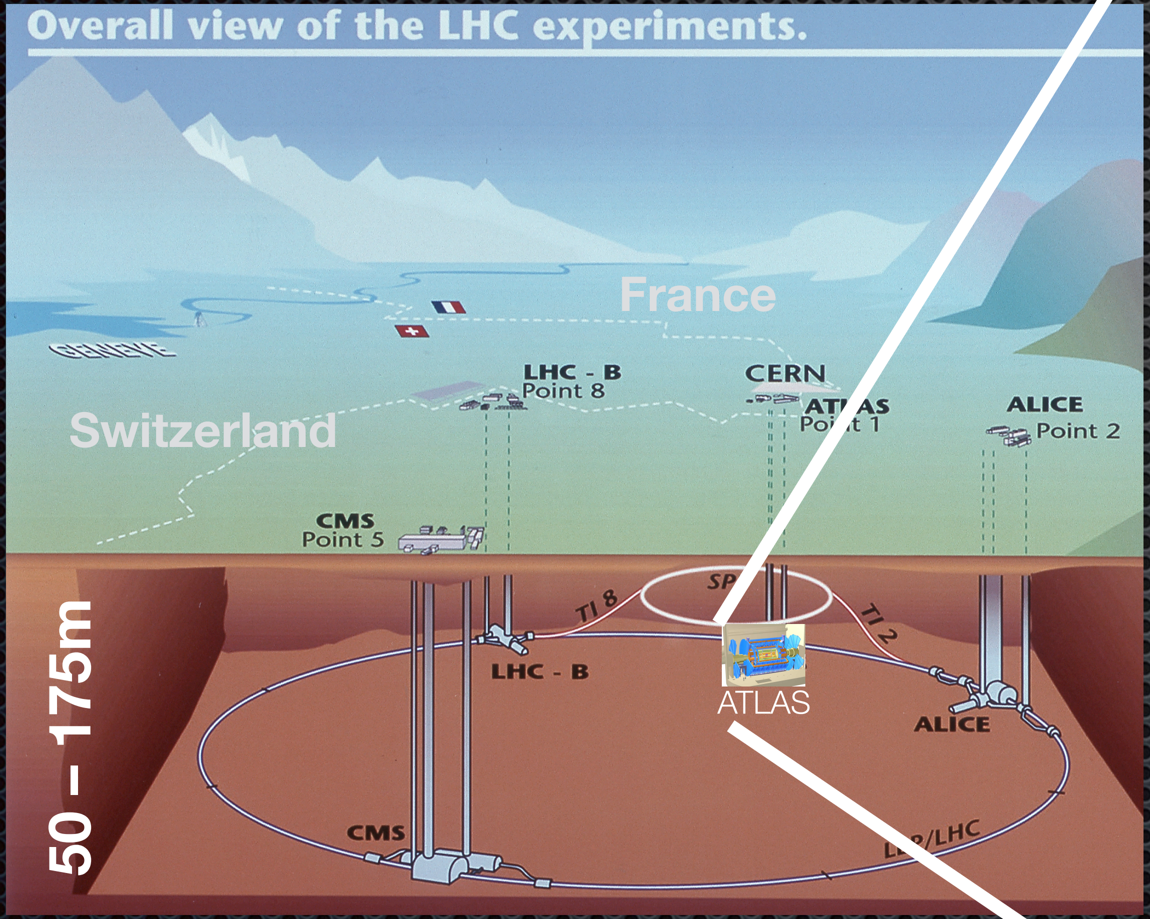
A collider and a detector

The **L**arge **H**adron **C**ollider is a massive, 27 km collider, operational since Sept. 2008

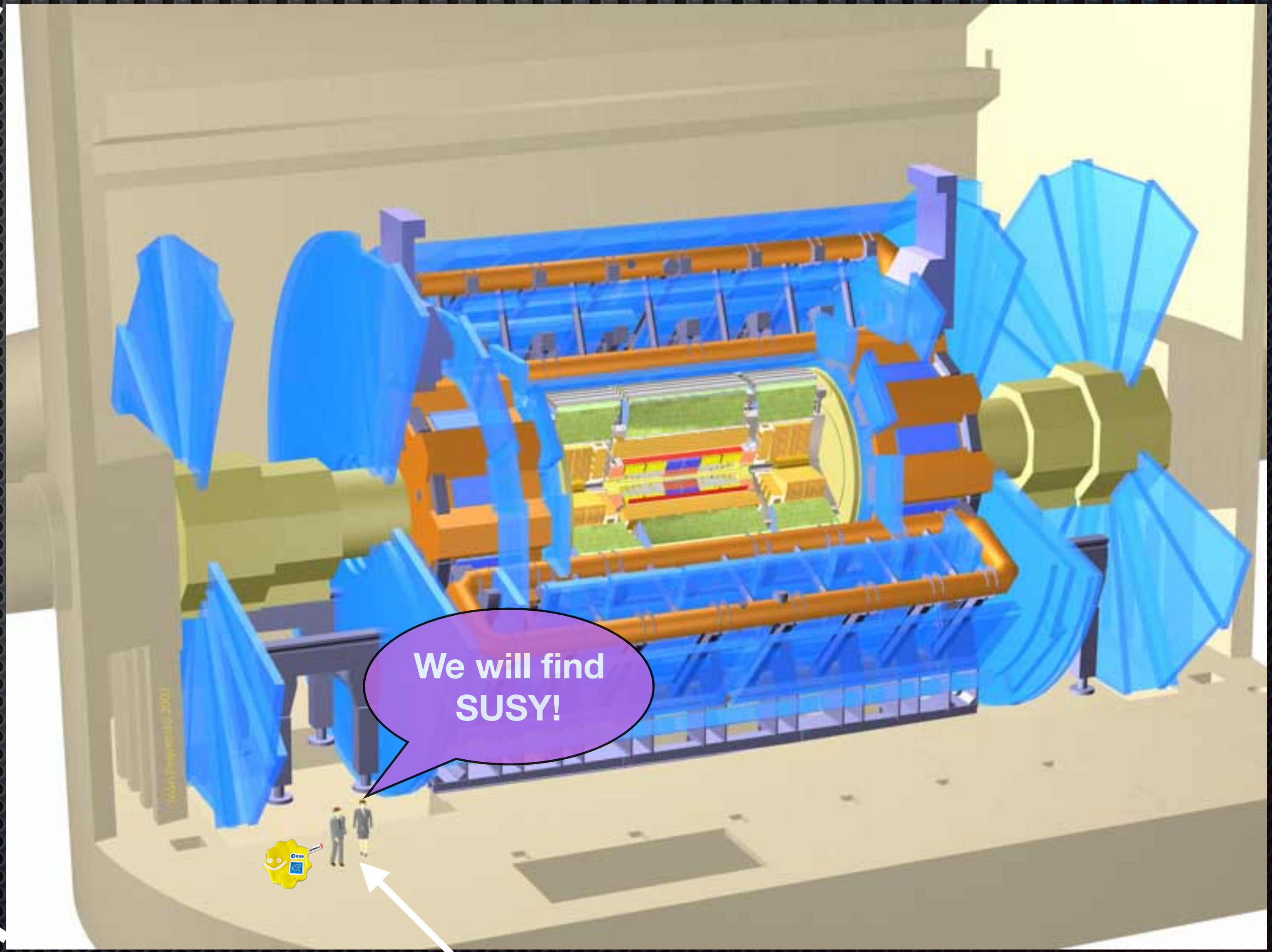
Four points along the ring at which the proton-proton beams cross

ATLAS is a large 7000 ton general purpose detector (46m x 25m)

Located at collision Point 1

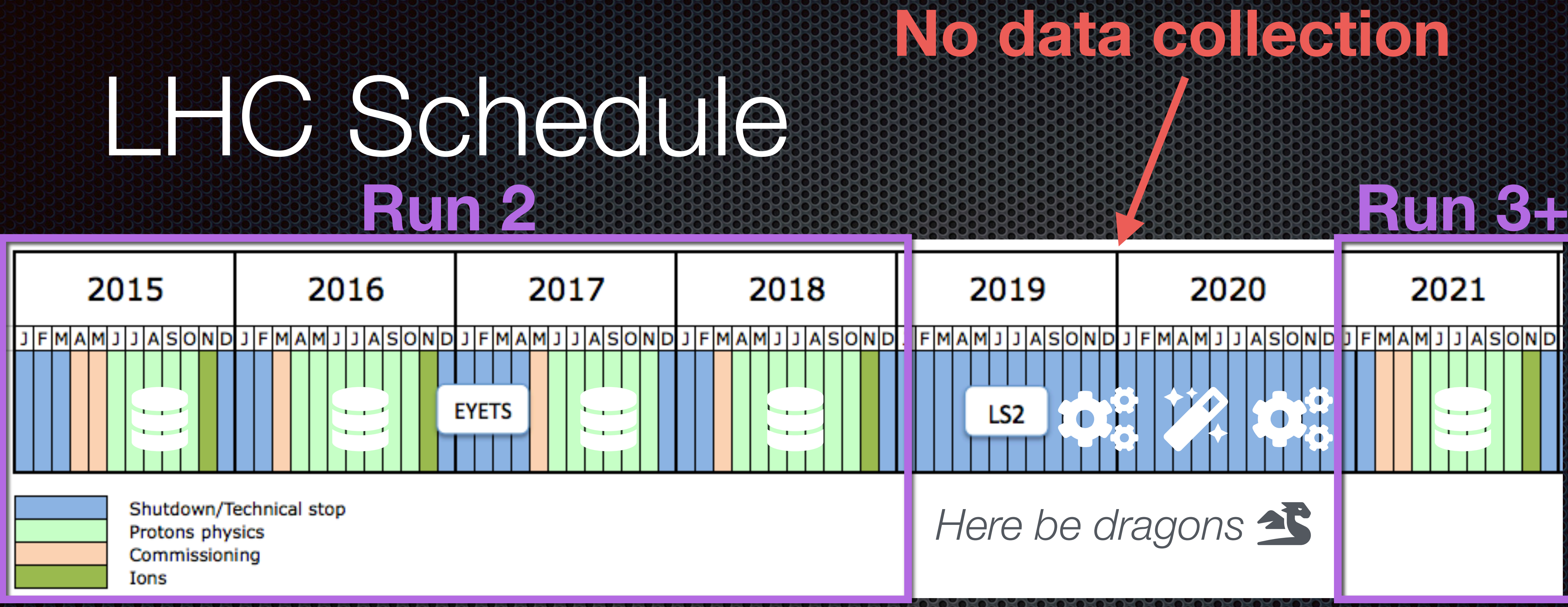


Stable rock at that depth



https://lhc-commissioning.web.cern.ch/lhc-commissioning/schedule/LHC-long-term.htm

LHC Schedule



Experiments currently shutdown, **no new data** expected for 2 years!

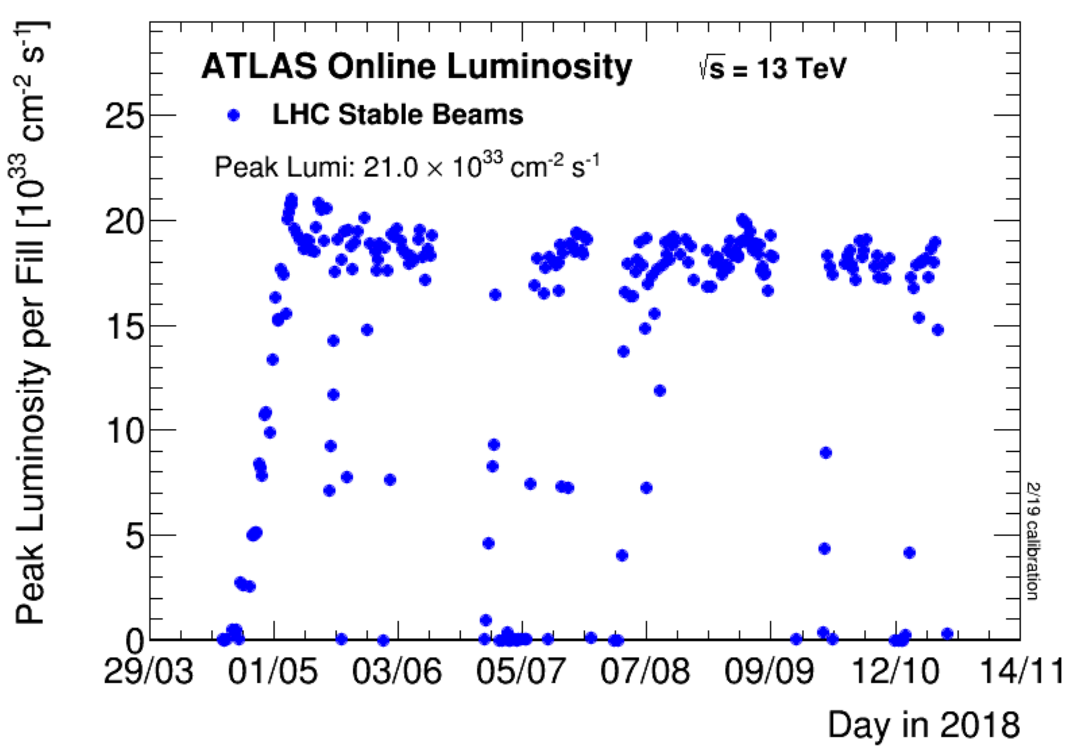
- Focus on doing more with what we have
  - clever techniques to find new physics (SUSY?) in existing data

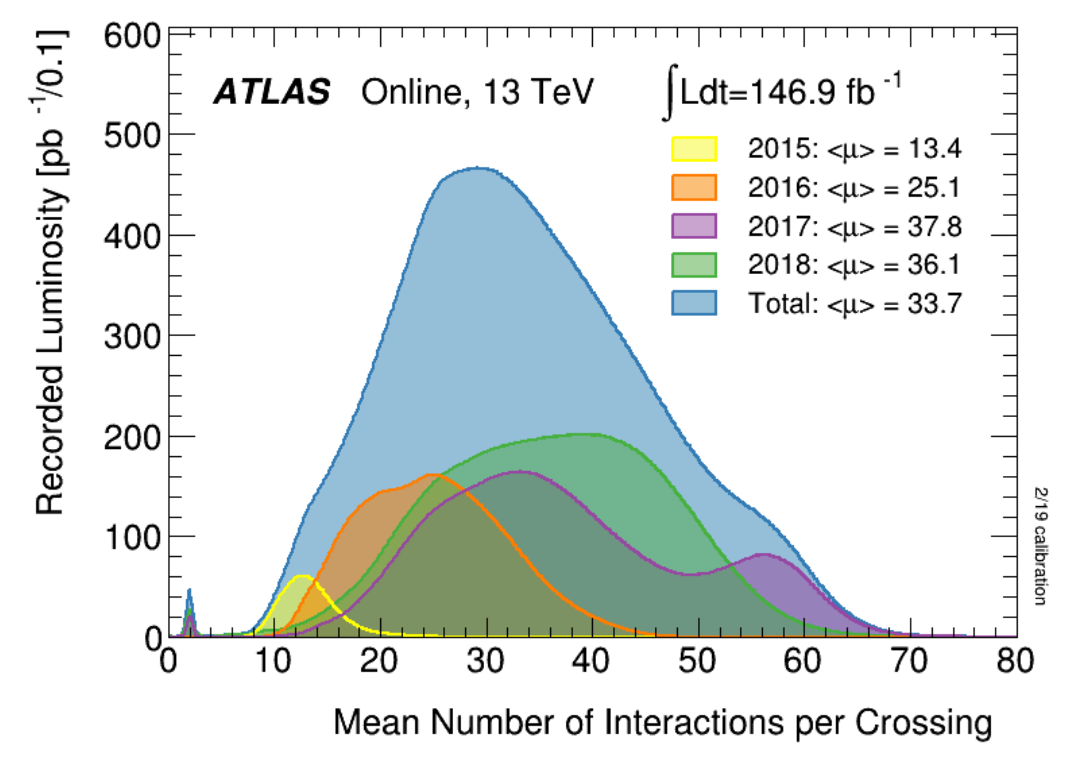
❗ **recursive jigsaw, (variable) jet reclustering, neural networks (DNN, RNN, …)**

- **Finalize calibrations** on physics objects (electrons, muons, jets, photons) and push **object definitions to lower energies**

🔗 https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun2

The Large Hadron Collider





A proton-proton collider at 13 TeV center-of-mass energy

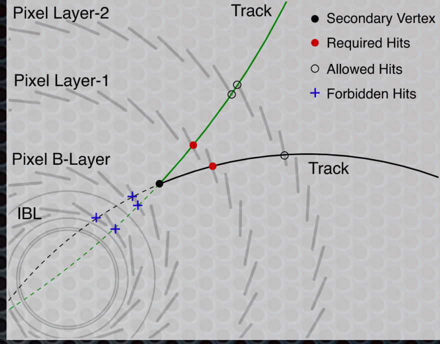
- For 2015-2018 operation:
  - Operating peak luminosity: 21.0 x 10^{33} cm^{-2} s^{-1}
  - Proton bunch spacing: **25 ns** — 40 million crossings per second
  - 2808 bunches colliding in ATLAS
  - **146.9 ifb of data delivered (± 1.7%)**
  - Up to 70 collisions per bunch crossing **(pileup!)** — billions of collisions per second!

❓ ***Why that peak at low <μ>? ATLAS does many special runs. This one was for precision W-physics.***

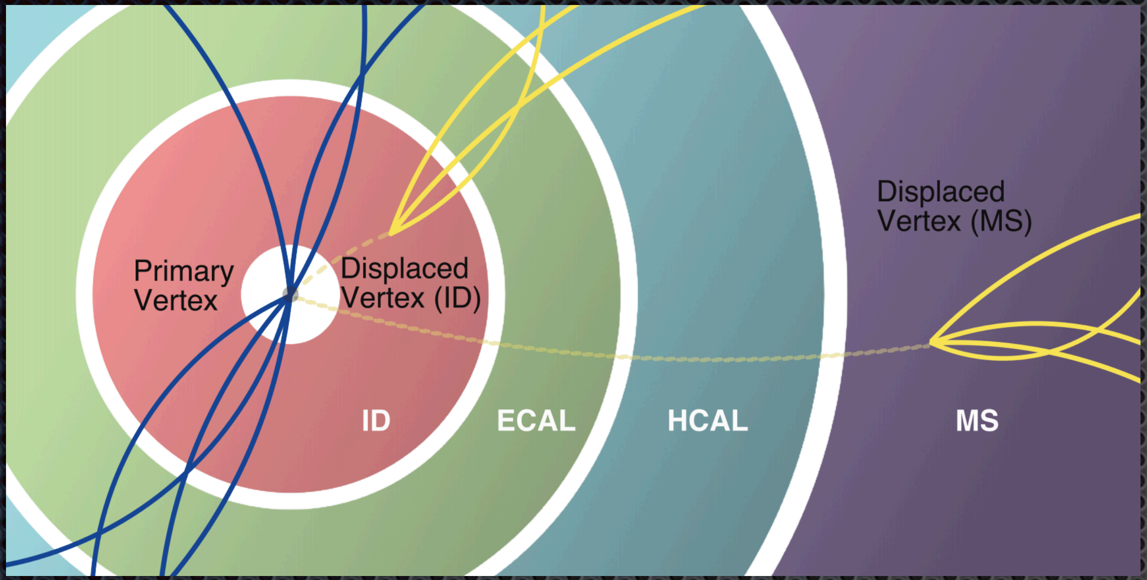
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2019-013/

https://indico.cern.ch/event/742793/contributions/3274366/

https://arxiv.org/abs/1810.12602

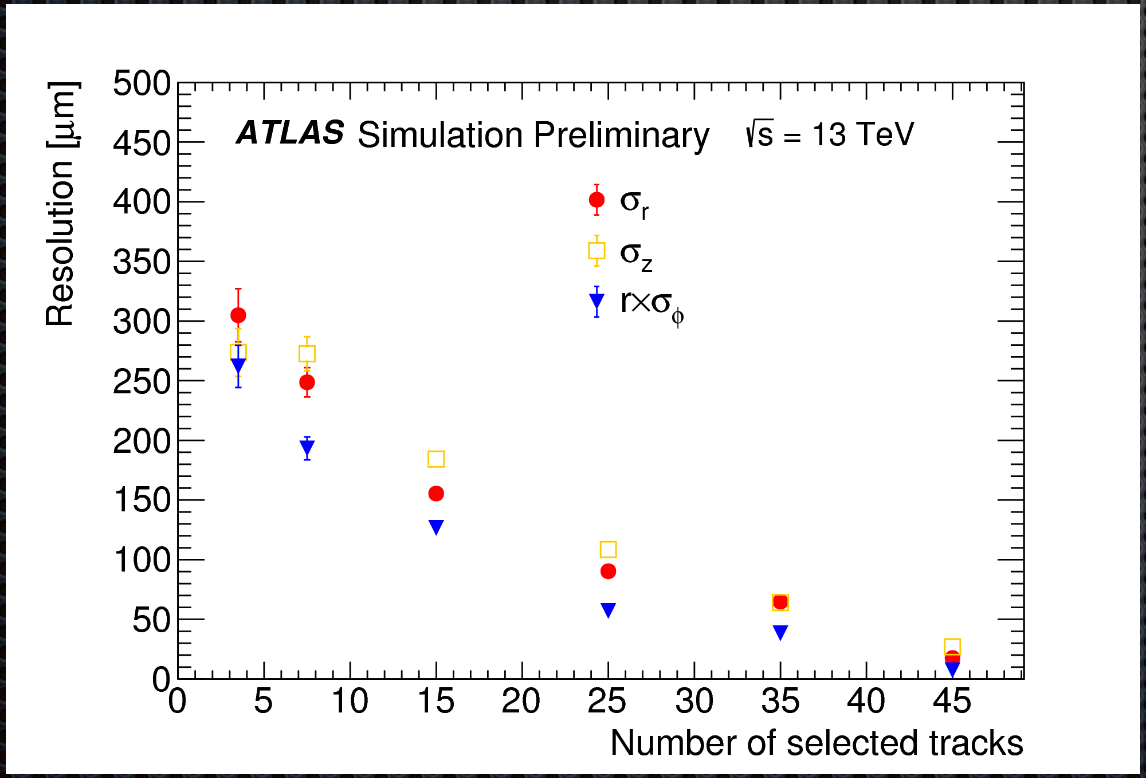


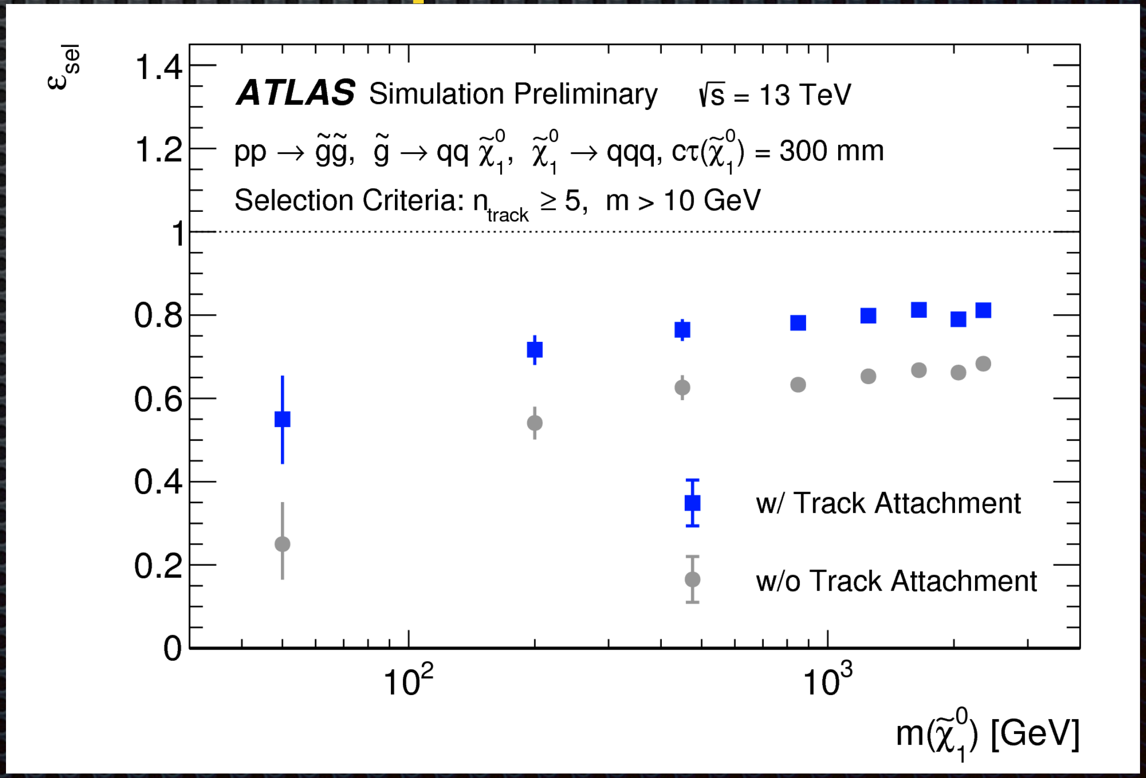
Unconventional Tracking



large radius tracking and secondary-vertexing algorithms
→ reconstruct long-lived particles decaying throughout the inner detector

benefit from new "track attachment" procedure

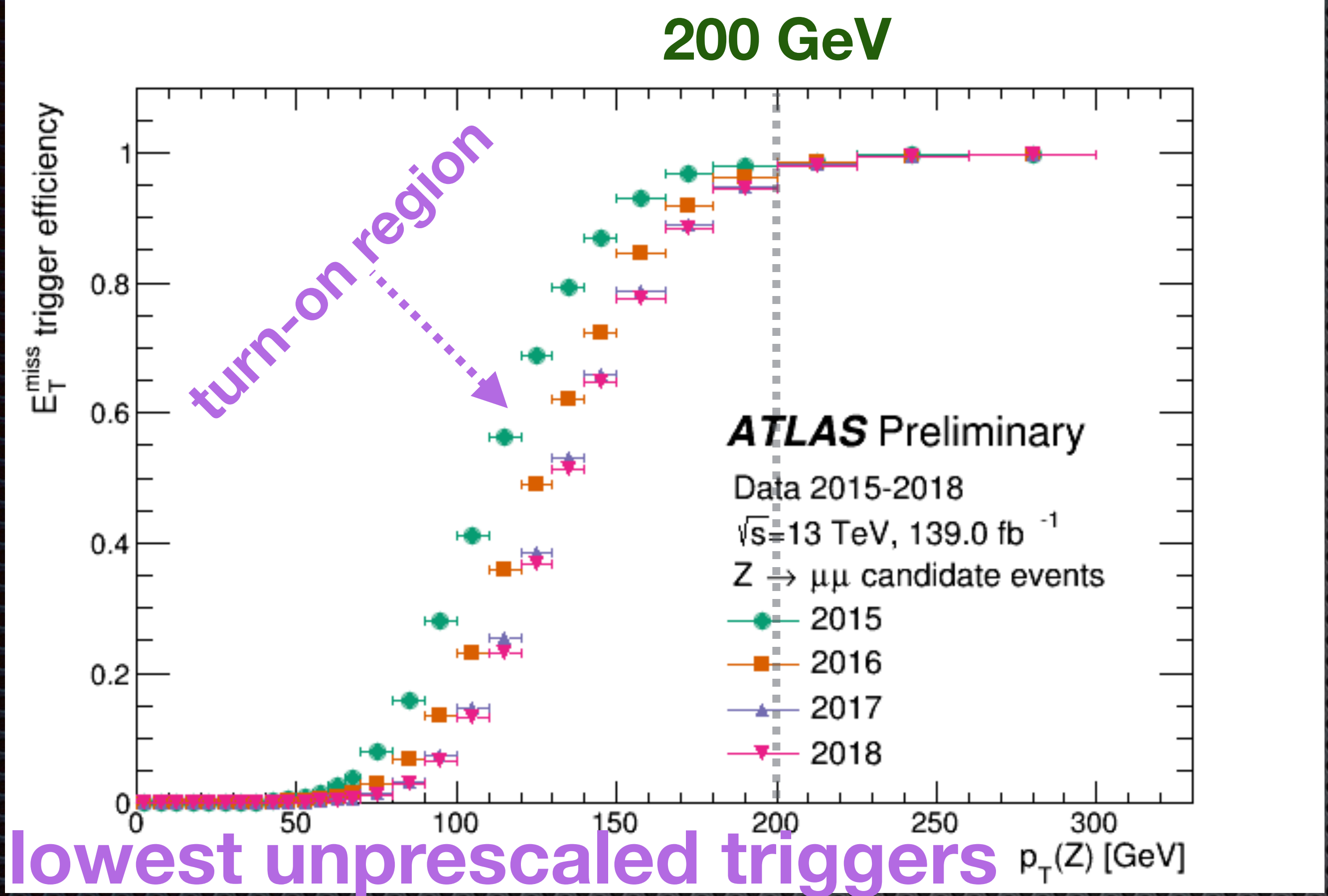


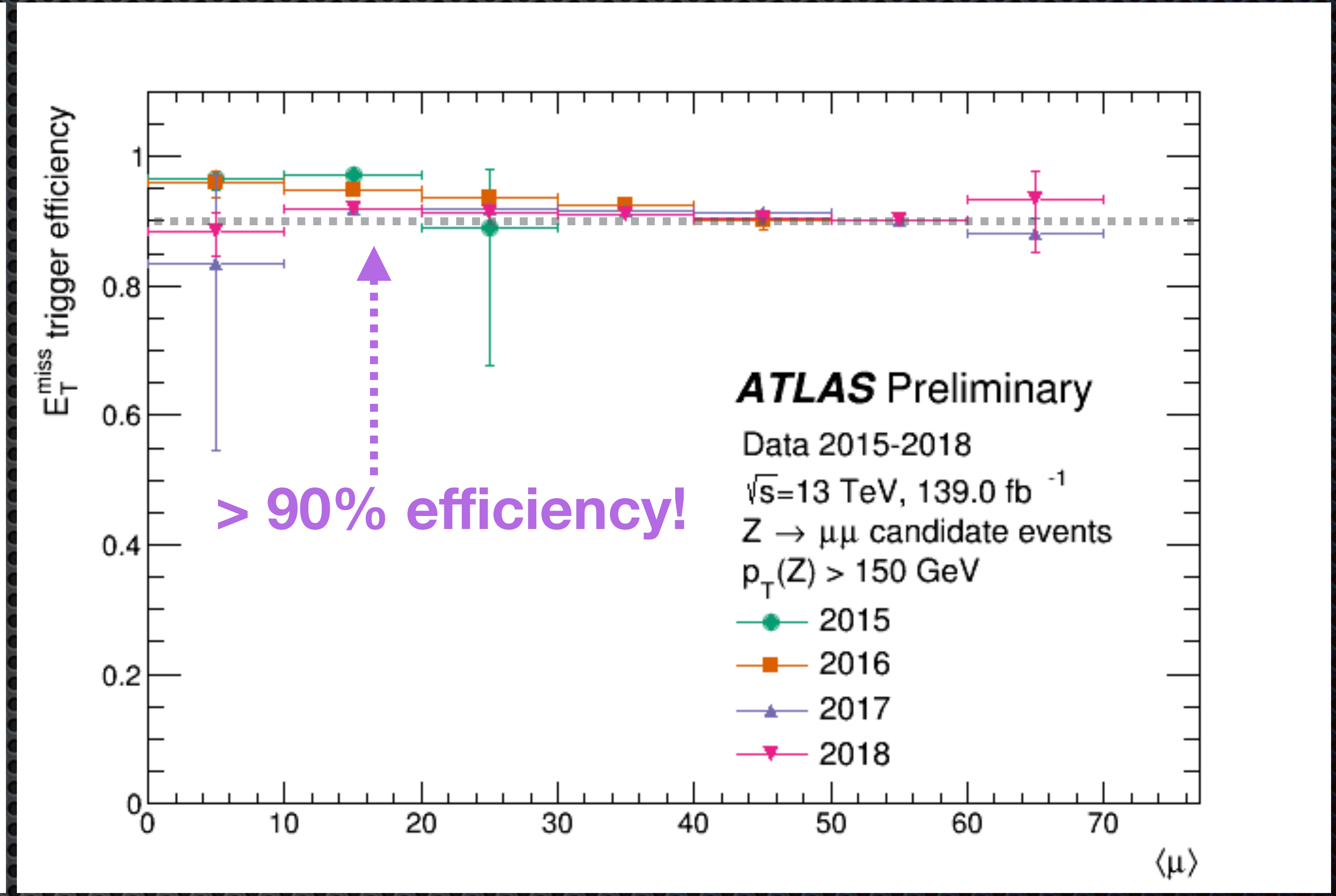


Improved vertex resolution **Higher signal efficiency**

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TriggerPublicResults
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/MissingEtTriggerPublicResults

Triggers in SUSY searches





- **Prescale**: trigger rate is **purposefully decreased** in order to keep the output rate manageable
- Many searches for new physics (excepting RPV-like searches) rely on the amount of missing transverse momentum (MET, E_TMiss)
  - Many use **inclusive MET triggers that require at least 200 GeV** to stay past the turn-on region
  - Want to target lower-MET regions? Rely on other triggers such as b-jets, jet, lepton, and photon triggers.

? ***Why Z→μμ? Trigger system does not get information from muons, so is treated as "invisible" until accounted for in offline reconstruction*** https://indico.cern.ch/event/813884/contributions/3394791

Overview of today's talk

- ~~The Large Hadron Collider, ATLAS, and you~~
- A highlight of searches for **new physics inspired by SUSY**
  - Strong,
  - 3rd Generation (**3G**),
  - Electroweak (**EWK**), and
  - Long-Lived Particles (**LL** or **LLP**)
- across R-Parity Conserving (**RPC**) R-Parity Violating (**RPV**) scenarios

KEY

PRODUCTION

- **Strong** ($\tilde{g}$)
- **3G** ($\tilde{t},\tilde{b}$)
- **EWK** ($\tilde{\ell},\tilde{\nu},\tilde{\chi}_1^{\pm}$)
- **RPVLL** (λ',λ'')

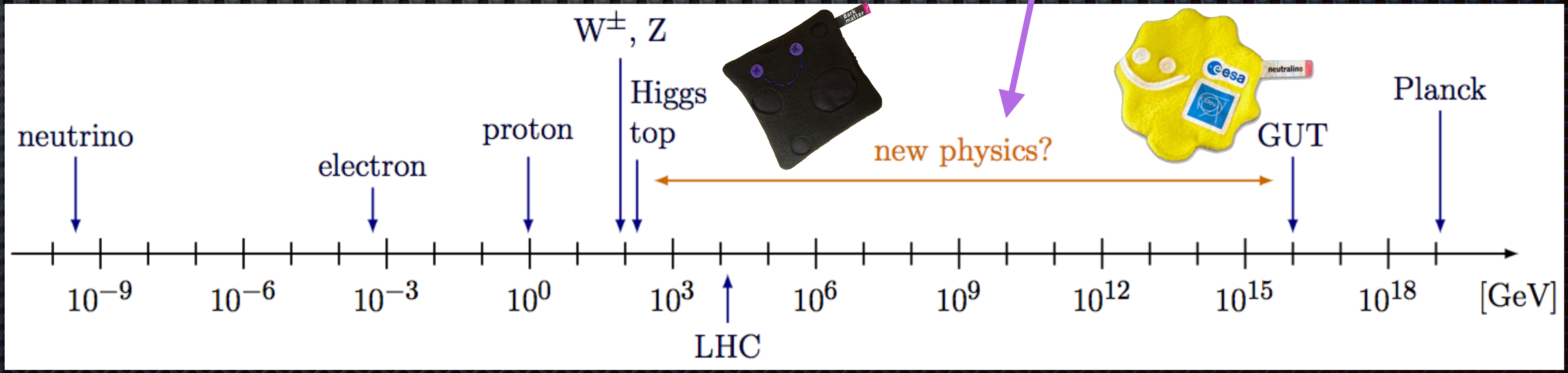
LUMI

- **36 fb^{-1}**
- **80 fb^{-1}**
- **139 fb^{-1}**

FIT

- **cut and count**
- **multi-bin**
- **unbinned**

Where is SUSY hiding?



https://arxiv.org/abs/1605.01416

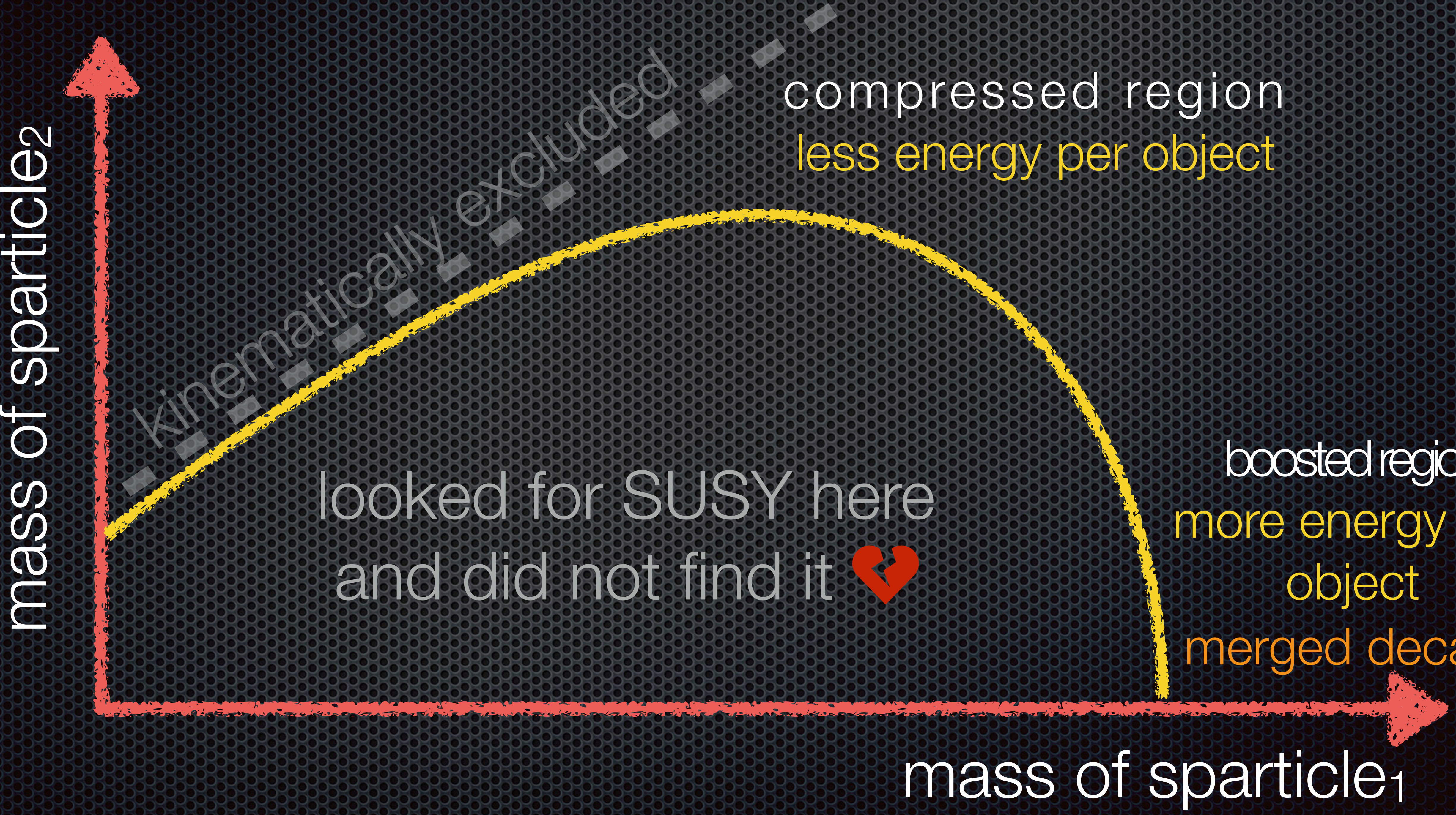
Favorite Discriminating Variables

Event selection observables sensitive to features of supersymmetry models are classified as:

- **Missing momentum-type**: sensitive to the properties of the invisible states
  - ? **how many neutralinos in the event? (*RPC: LSP escapes detection*)**
- **Energy scale-type**: sensitive to the overall energy scale of the event
  - ? **what is the mass of the gluino? (*Strong: can reach high mass scales*)**
- **Energy structure-type**: sensitive to the structure of the visible energy
  - ? **how is the energy of the decay partitioned across the final state visible/invisible objects? *(e.g. decay angle between LSP and jets)***

More details in Christophe Clement talk Wednesday @ 13h40

Parameterizing the model



kinematically excluded

compressed region

less energy per object

looked for SUSY here
and did not find it 💔

boosted region

more energy per object

merged decays

mass of sparticle_2

mass of sparticle_1

https://cds.cern.ch/record/2040684/

RPC-RPV Spectrum

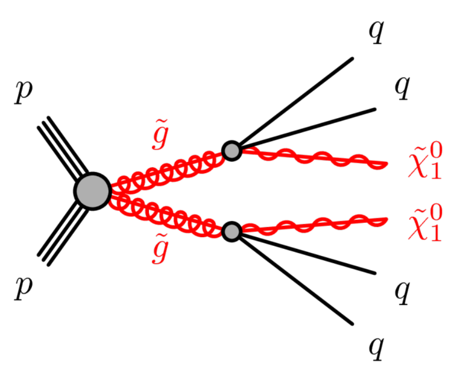
$$\mathcal{W}_{\mathrm{RPV}} = \frac{\lambda_{ijk}}{2}L_iL_j\bar{E}_k + \lambda'_{ijk}L_iQ_j\bar{D}_k + \frac{\lambda''_{ijk}}{2}\bar{U}_i\bar{D}_j\bar{D}_k + \kappa_i L_i H_u,$$

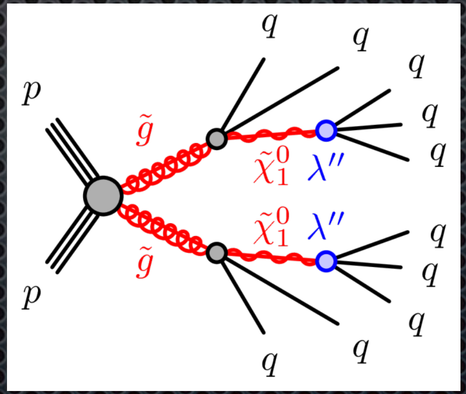
RPV terms in the SUSY superpotential

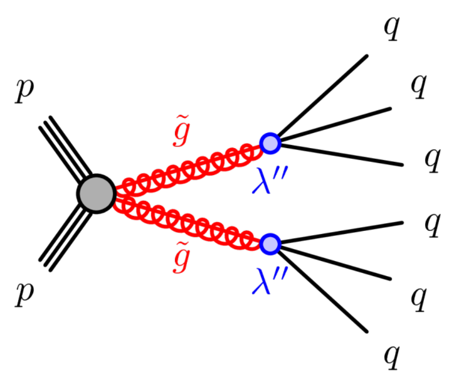
- All simplified models fall somewhere on the RPC-RPV spectrum… either
  - set all terms large or …
  - set all terms to 0 (conserve “SUSYness”, RPC) and require the lightest SUSY particle (LSP) to be stable → dark matter candidates?

prompt decays of LSPs

long-lived LSPs displaced decays?







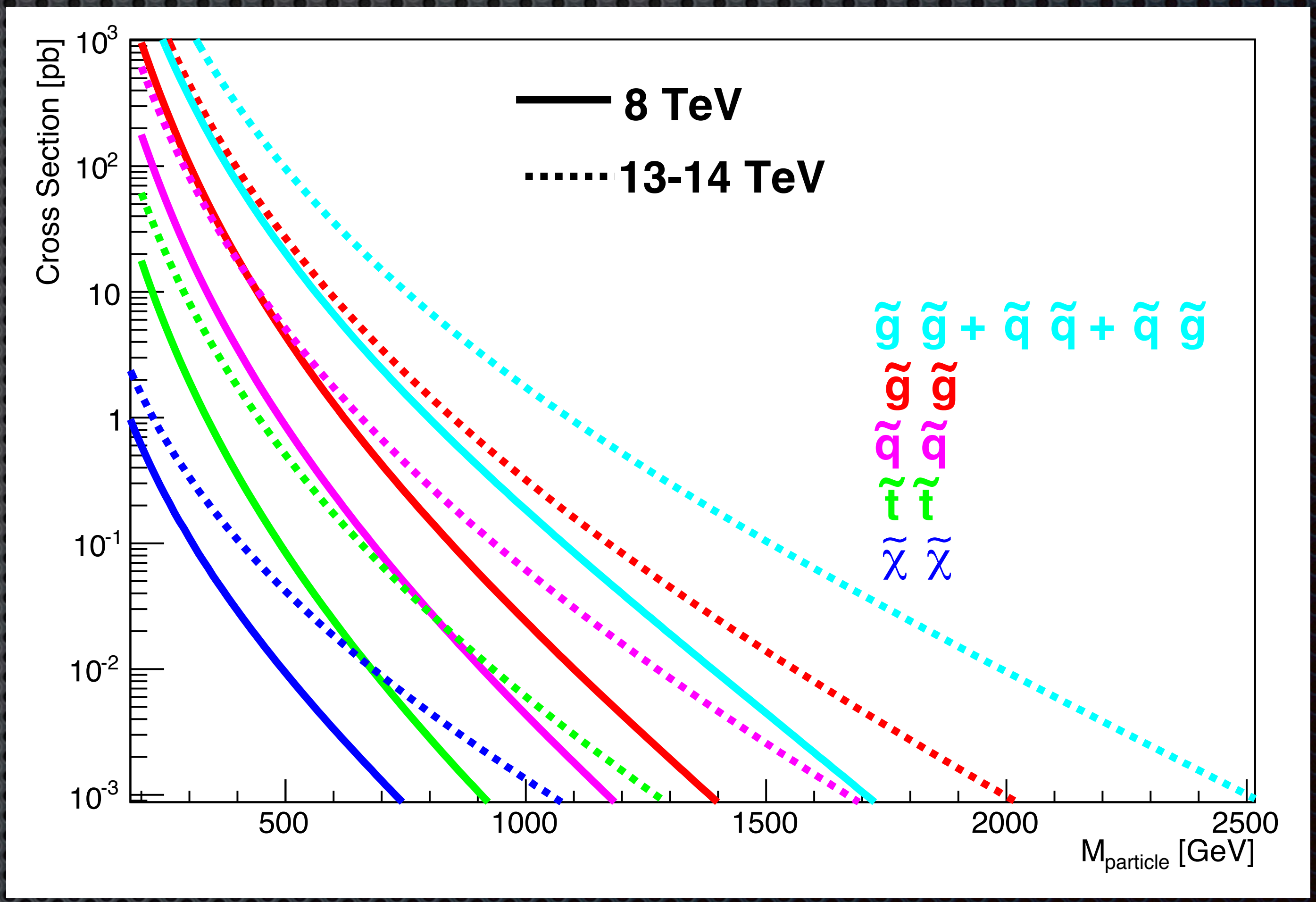
prompt decays of gluinos

increasing λ’' ⟶

❗ Naturalness motivates light gluinos and stops

Searching for SUSY

- **Gluinos**, because of their strong color coupling, have the highest theoretical cross-section of the sparticles found at the LHC
    - The upgrade of LHC from 8 TeV to 13 TeV also provides an order of magnitude increase in the theoretical cross-section
- Theoretical cross-sections are shown for:
    - **total strong production**
    - **gluino production**
    - **total squark production**
    - **heavy squark**
    - **electroweak**



[1407.5066] [1206.2892]

Search for strongly-produced sparticles!

(electroweak states may be first detected if high mass limits on strong production)

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-017/

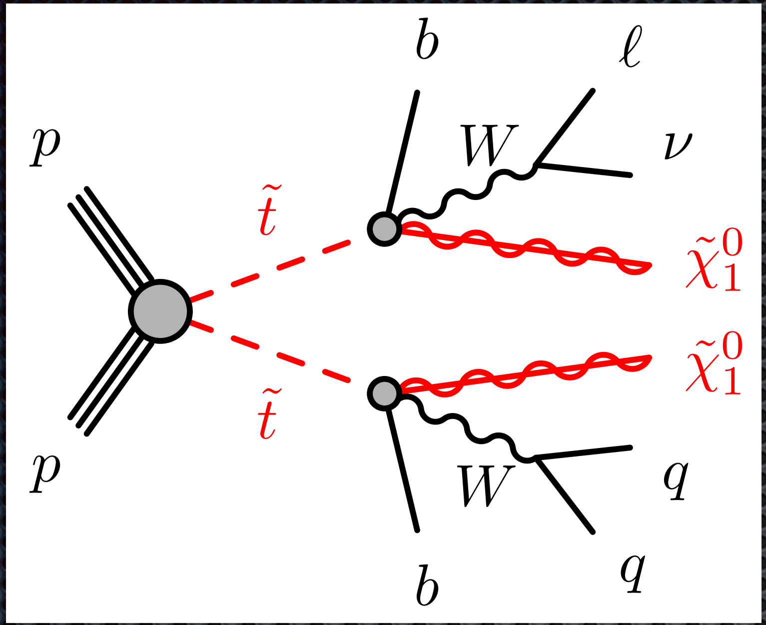
3G $(\tilde{t},\tilde{b})$

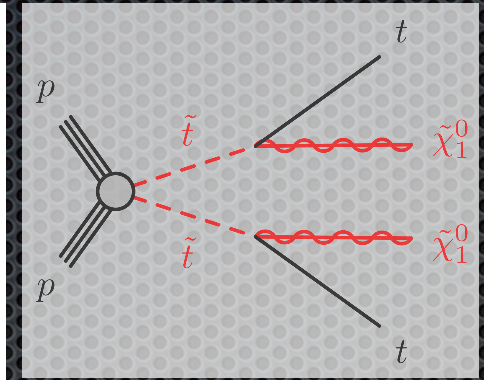
139 fb^{-1}

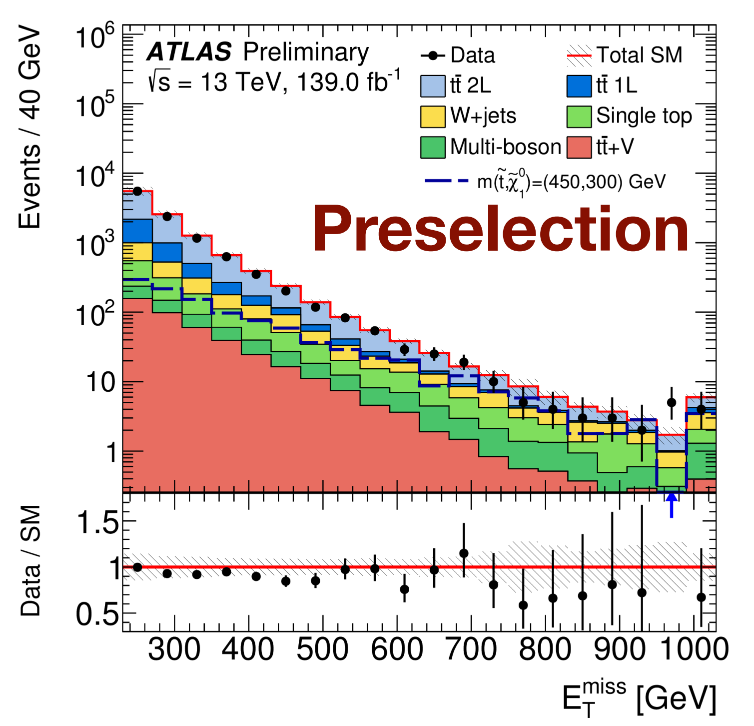
cut and count

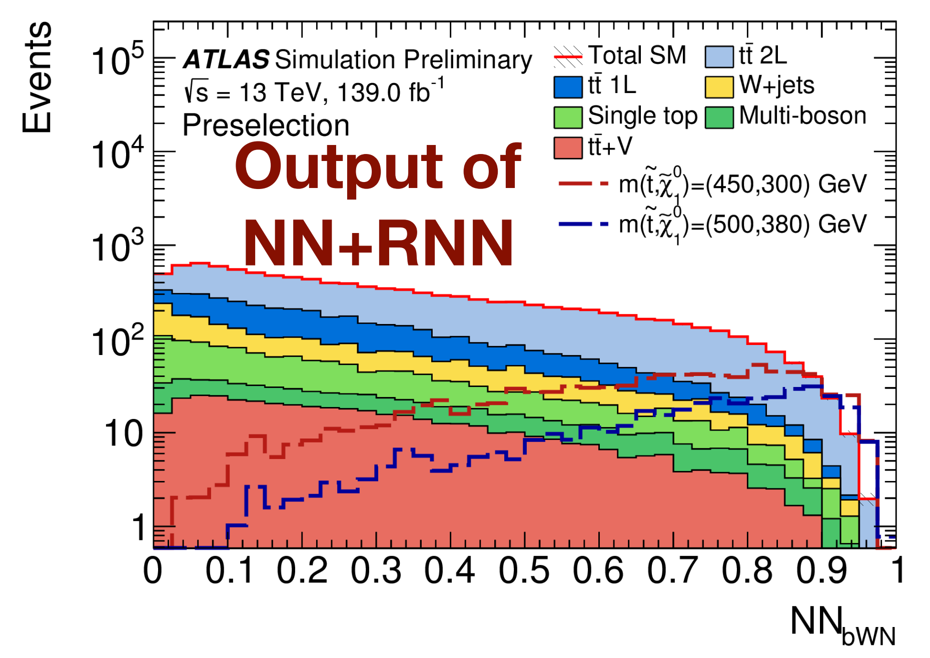
multi-bin

Stop to 1-lepton (3-body)









- MODEL PARAMETERS: $\tilde{t}, \tilde{\chi}_1{}^0$
- FINAL STATE: =1 lepton, ≥ 4 jets, ≥ 1 b-jet
- THREE SIGNAL SCENARIOS:
  - 4-body decay: $\Delta m(\tilde{t}, \tilde{\chi}_1{}^0) \geq m_{top}$
  - **3-body decay: $m_{top} > \Delta m(\tilde{t}, \tilde{\chi}_1{}^0) \geq m_W + m_b$**
  - 2-body decay: $m_W + m_b > \Delta m(\tilde{t}, \tilde{\chi}_1{}^0)$
- DOMINANT BACKGROUNDS: $t\bar{t} \rightarrow \ell^+\ell^-\nu\nu$
- CHALLENGE: large background

More details in John Anders talk today @ 13h40

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-017/

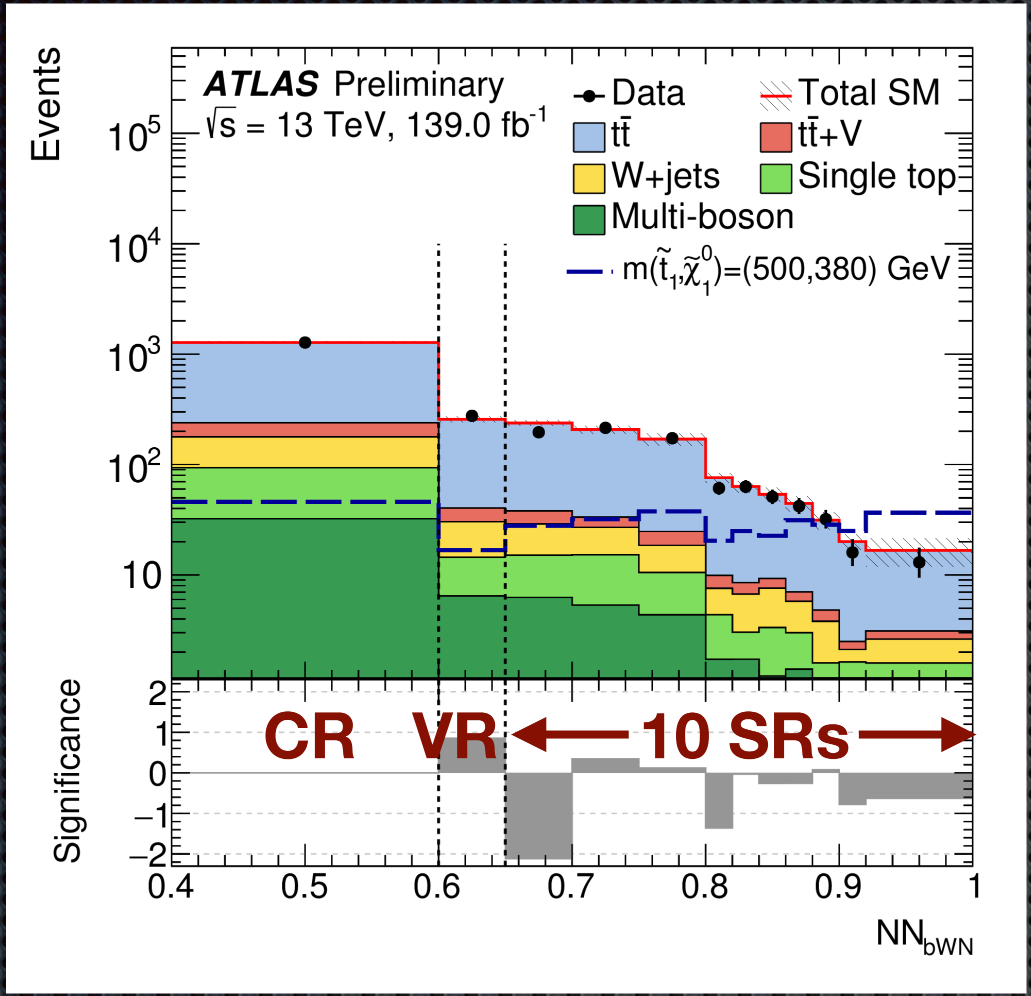
3G $(\tilde{t},\tilde{b})$

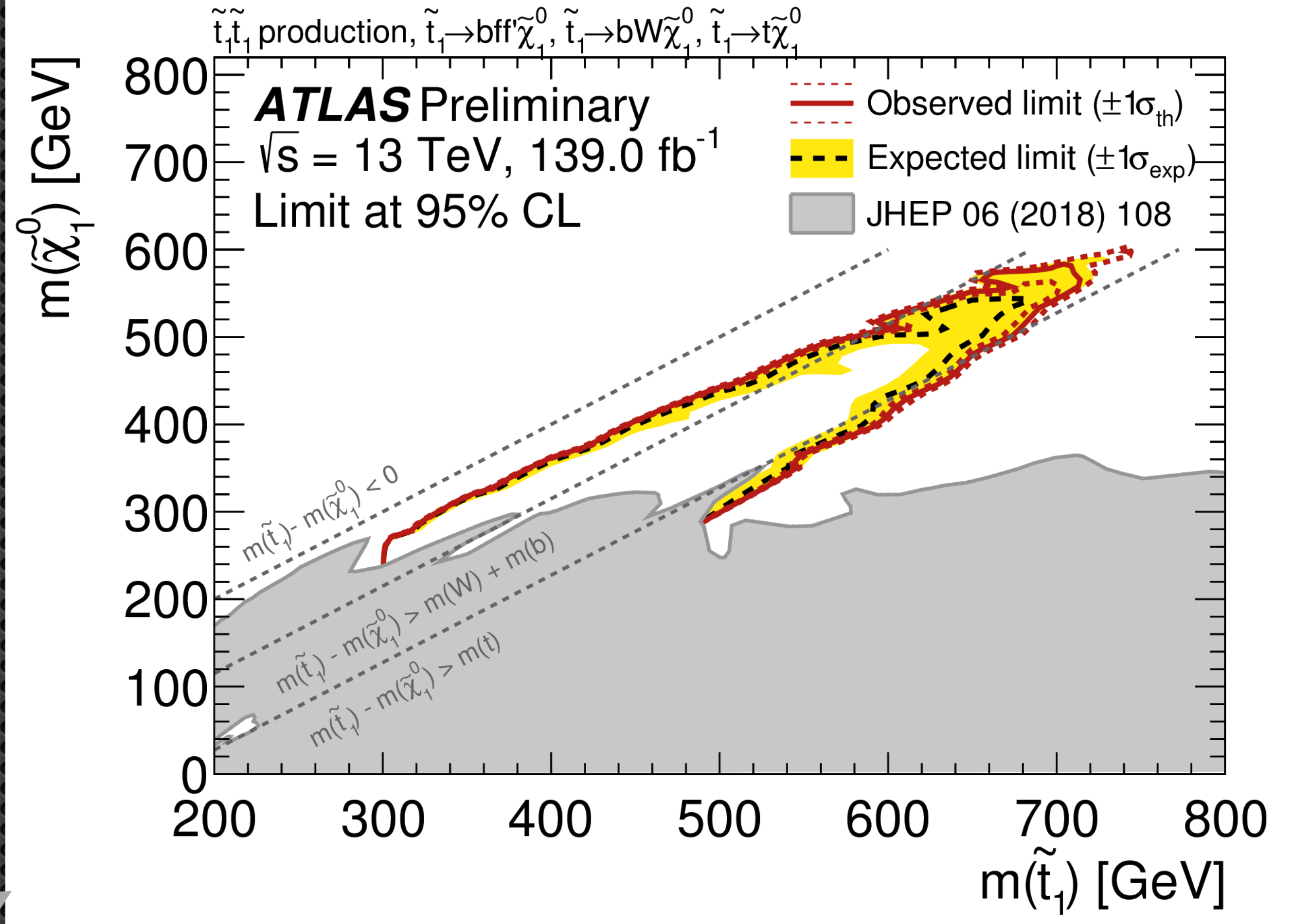
139 fb^{-1}

cut and count

multi-bin

Stop to 1-lepton (3-body)





No excess, set limits with multi-bin fit

Sensitivity increased to 700 GeV

(for neutralino masses up to 580 GeV)

More details in John Anders talk today @ 13h40

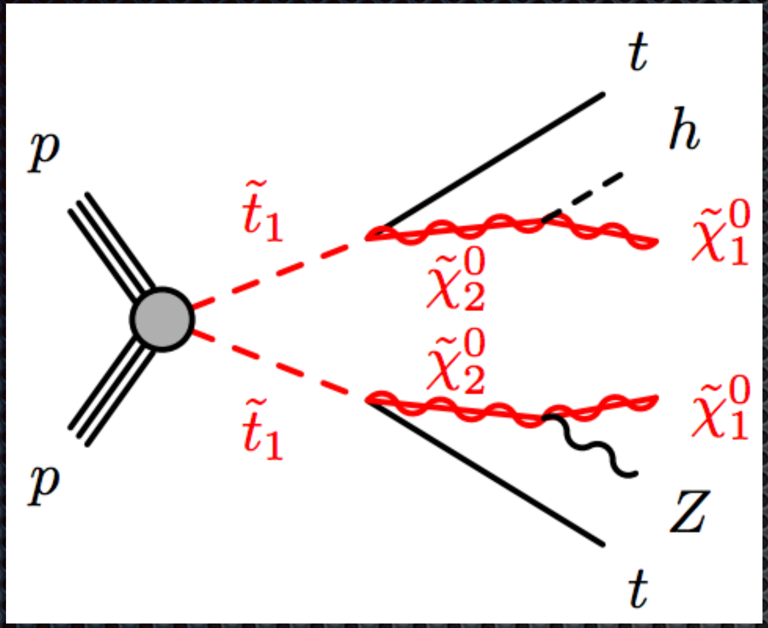
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-016/

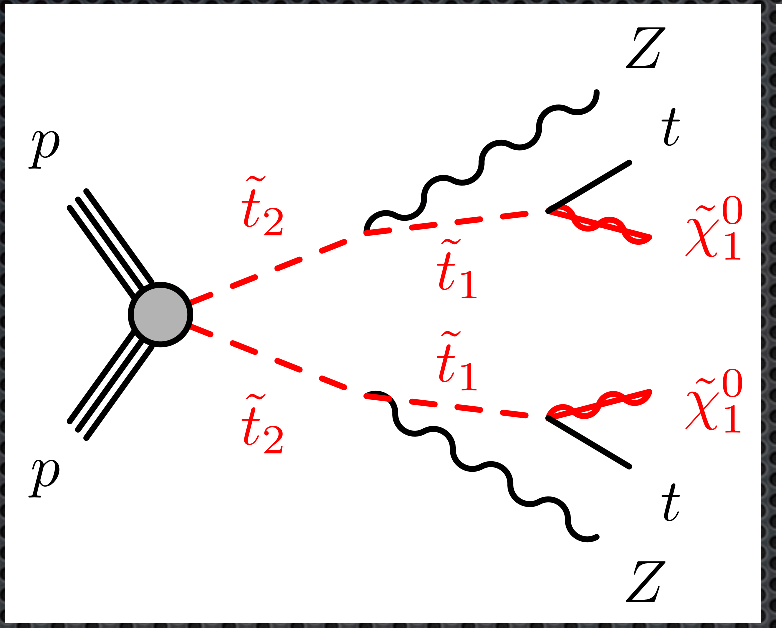
3G $(\tilde{t},\tilde{b})$

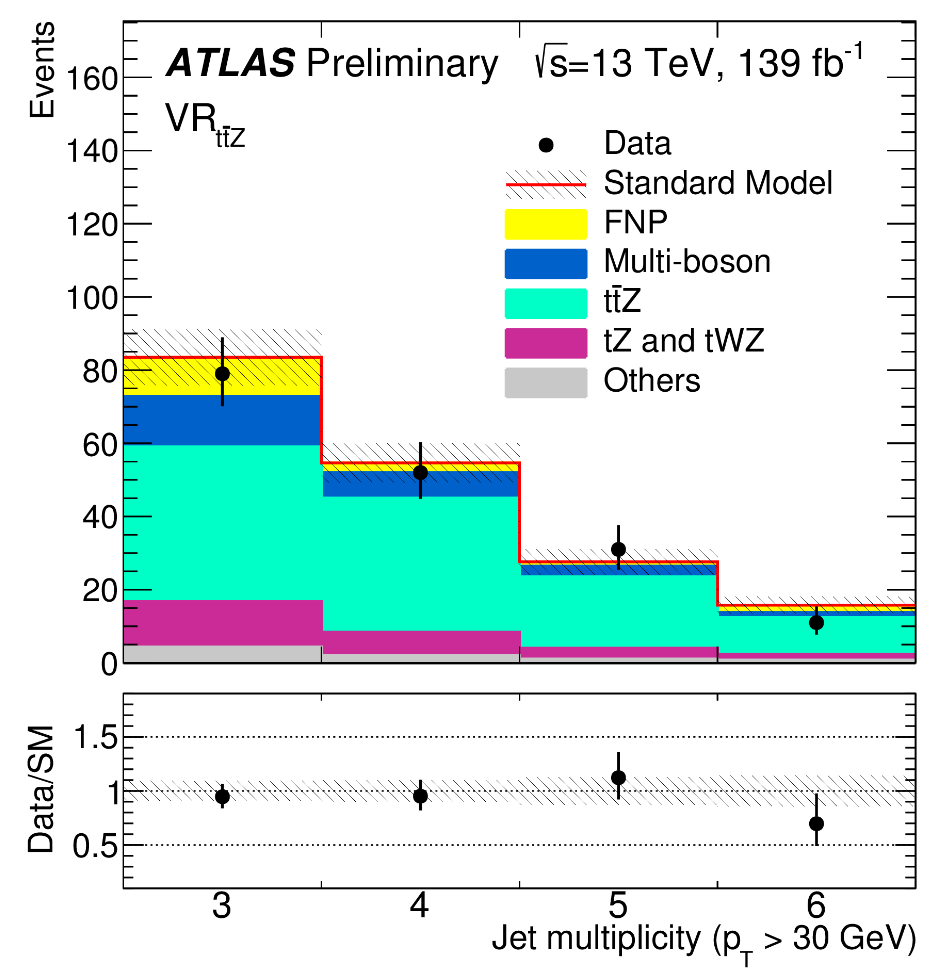
139 fb^{-1}

cut and count

Stop to Z-boson







$t\bar{t}$+Z validation

- MODEL PARAMETERS: $\tilde{\chi}_2{}^0, \tilde{\chi}_1{}^0, \tilde{t}_2$
- FINAL STATE: ≥ 3 leptons (≥ 1 OS-SF), MET
- TWO SIGNAL SCENARIOS (4 signal regions):
  - $\tilde{t}_1 \to t\tilde{\chi}_2{}^0, \tilde{\chi}_2{}^0 \to h/Z\tilde{\chi}_1{}^0$
  - $\tilde{t}_2 \to Z\tilde{t}_1, \tilde{t}_1 \to bff'\tilde{\chi}_1{}^0$
- DOMINANT BACKGROUNDS: $t\bar{t}$+Z, V+jets
- CHALLENGE: jets faking leptons, non-prompt leptons from hadronic decays

More details in John Anders talk today @ 13h40

OS-SF: Opposite-Sign, Same-Flavor

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-016/

https://arxiv.org/abs/1708.03247

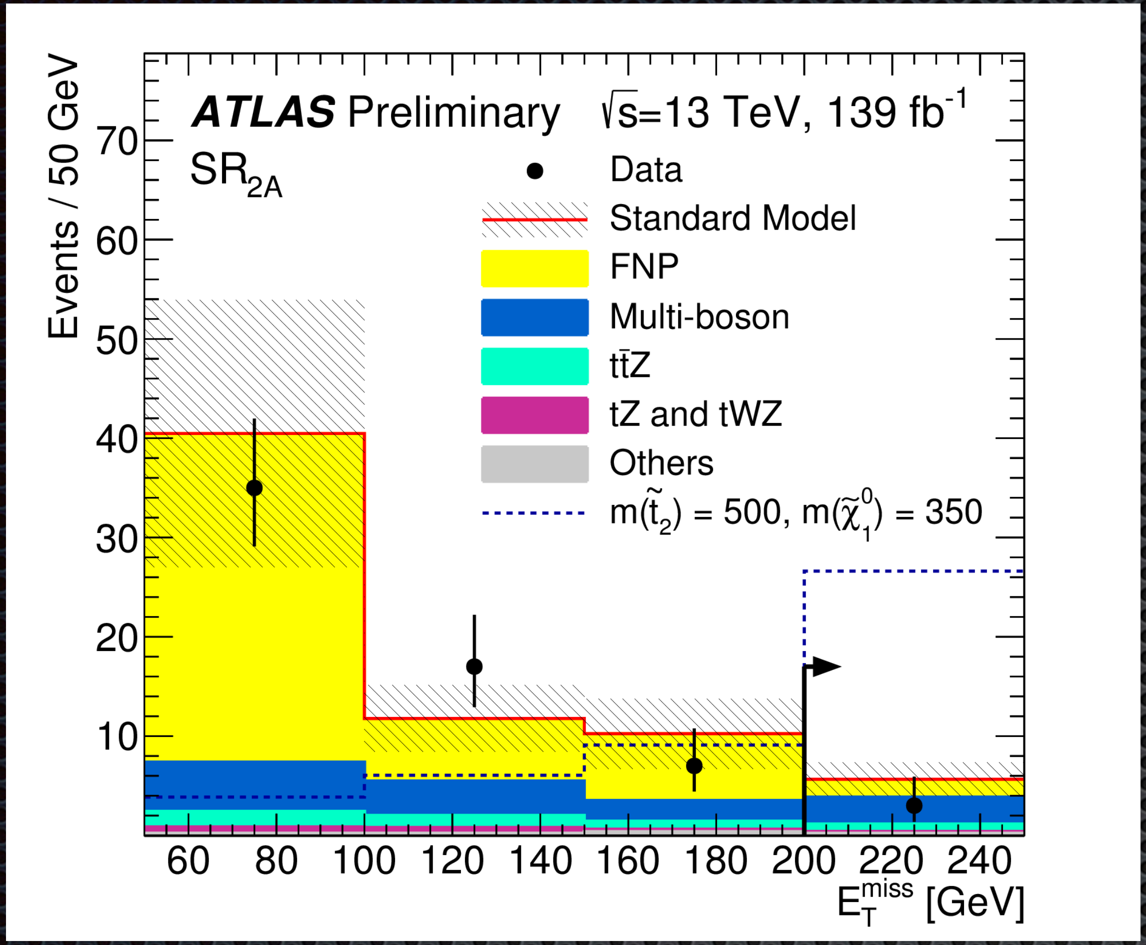
3G $(\tilde{t},\tilde{b})$

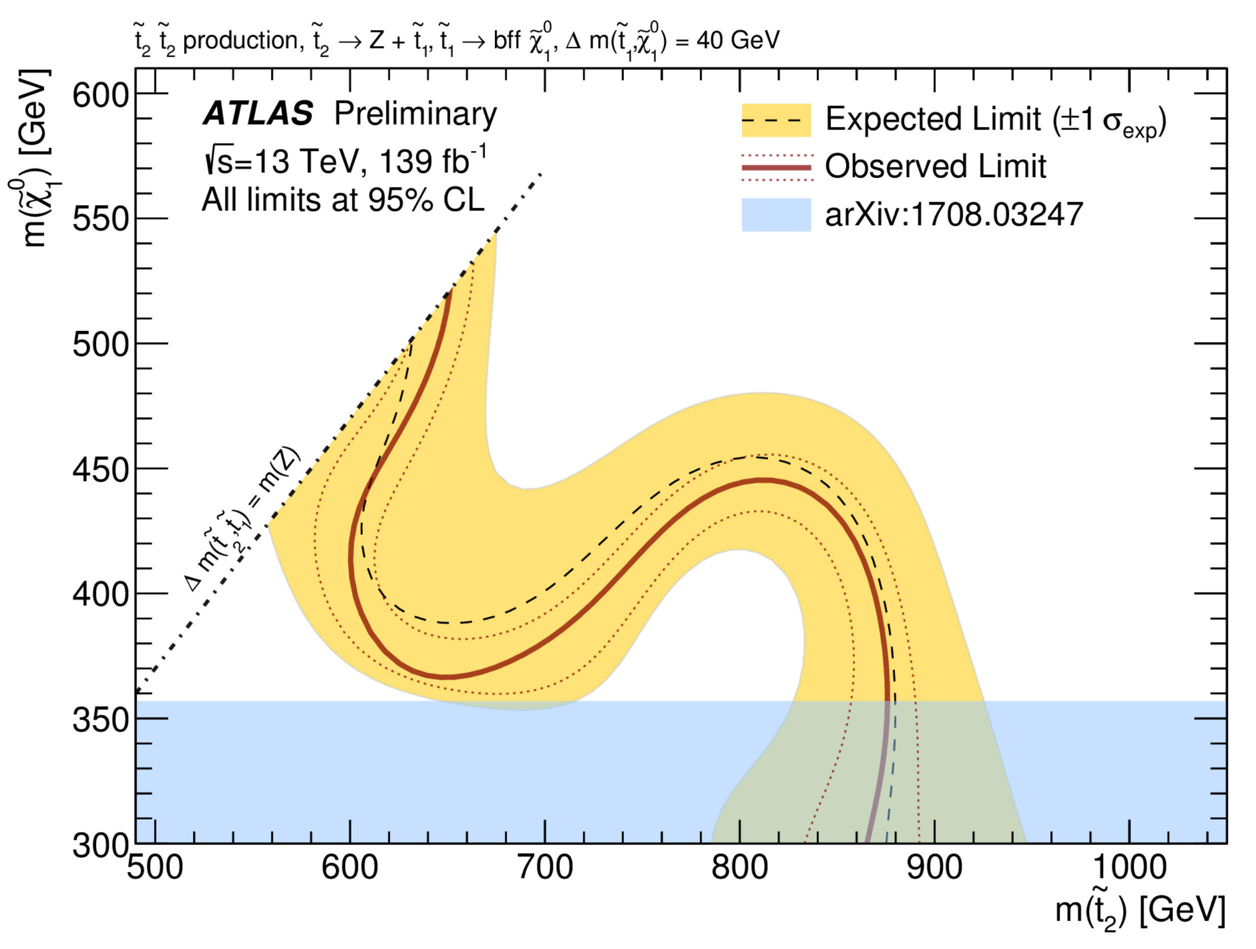
139 fb^{-1}

cut and count

Stop to Z-boson

new in Run 2





$\Delta m(\tilde{t}_2, \tilde{\chi}_1{}^0) \gg 1$

$\Delta m(\tilde{t}_1, \tilde{\chi}_1{}^0) = 40$ GeV

Sensitivity set at 875 GeV

(no signal region targeting between diagonal/bulk)

More details in John Anders talk today @ 13h40

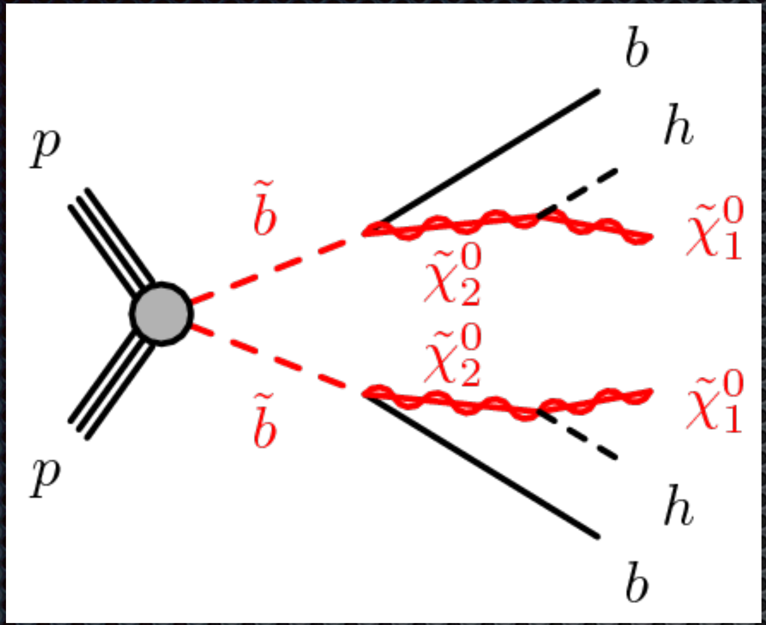
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-011

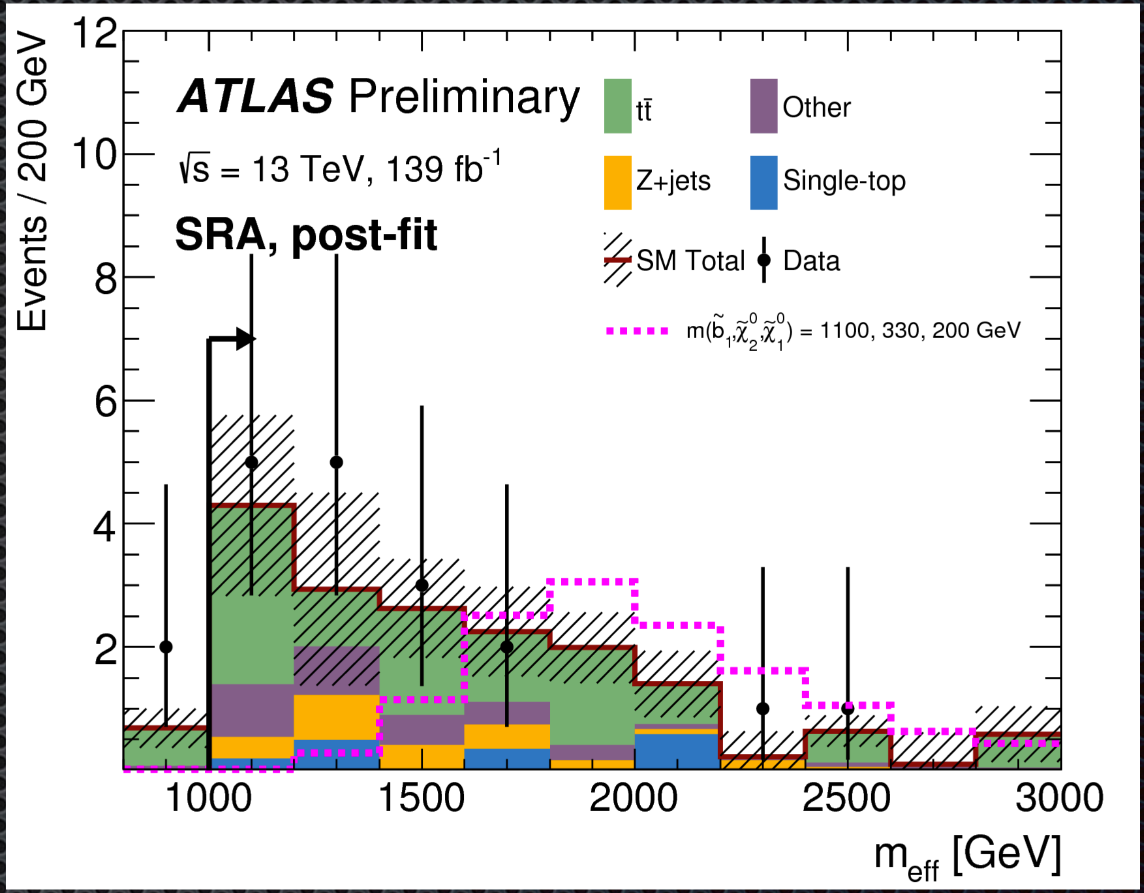
3G $(\tilde{t},\tilde{b})$

139 fb^{-1}

cut and count

sbottom multi-*b*-jets





- MODEL PARAMETERS: $\tilde{\chi}_2^0, \tilde{\chi}_1^0, \tilde{b}$
- FINAL STATE: up to 6 *b*-jets, MET, no leptons
- TWO SIGNAL MASS SCENARIOS:
  - $m(\tilde{\chi}_1^0) = 60$ GeV
  - $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) = 130$ GeV
- DOMINANT BACKGROUNDS: $t\bar{t}$, $Z \rightarrow \nu\bar{\nu}$
- CHALLENGE: reconstructing the Higgs bosons

- Analysis strategy:
  - 3 overlapping single-bin regions targeting (SRA) highly-boosted *b*-jets in "bulk" of both scenarios and (SRB,SRC) compressed with soft *b*-jets from $\tilde{b}$

More details in John Anders talk today @ 13h40

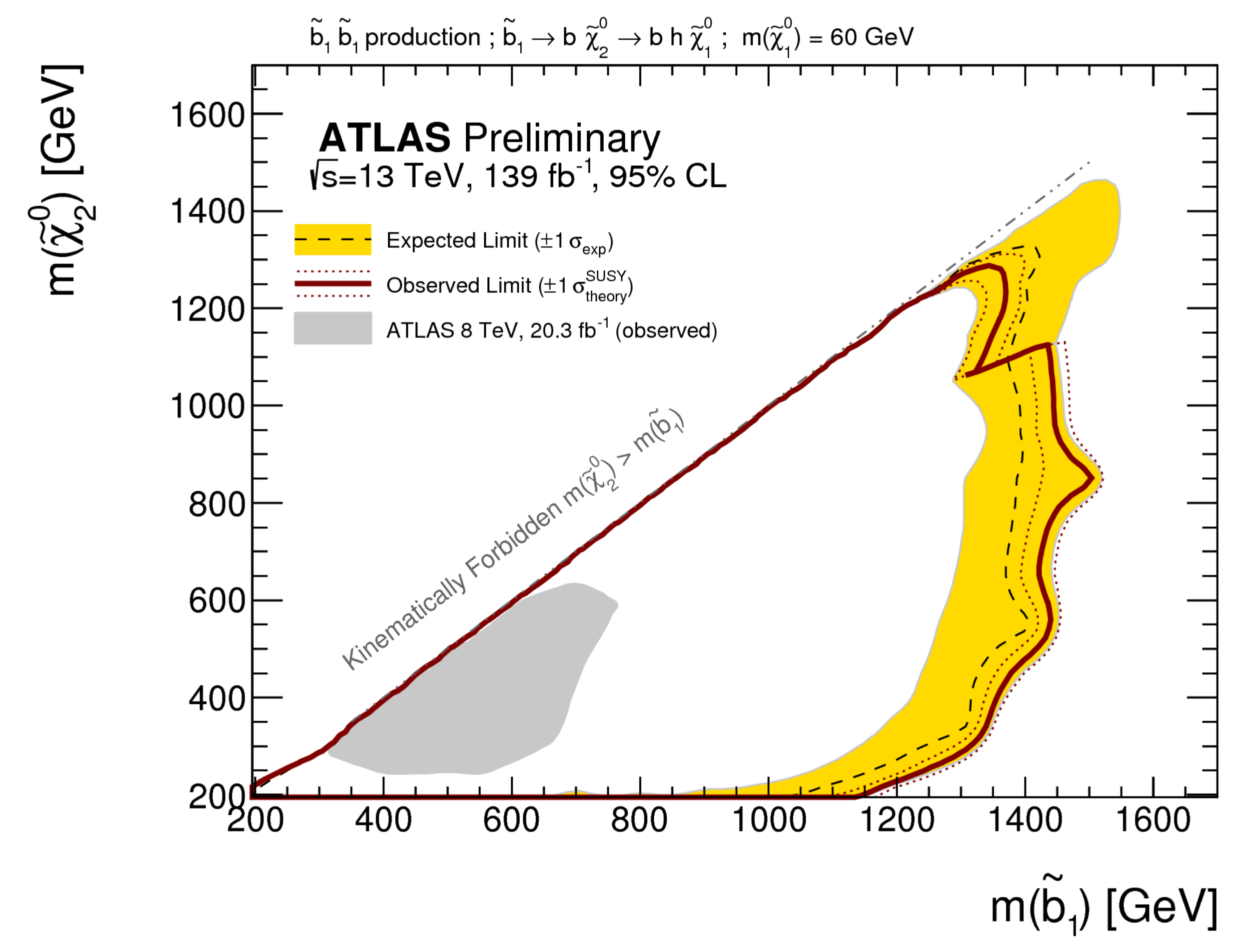
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-011

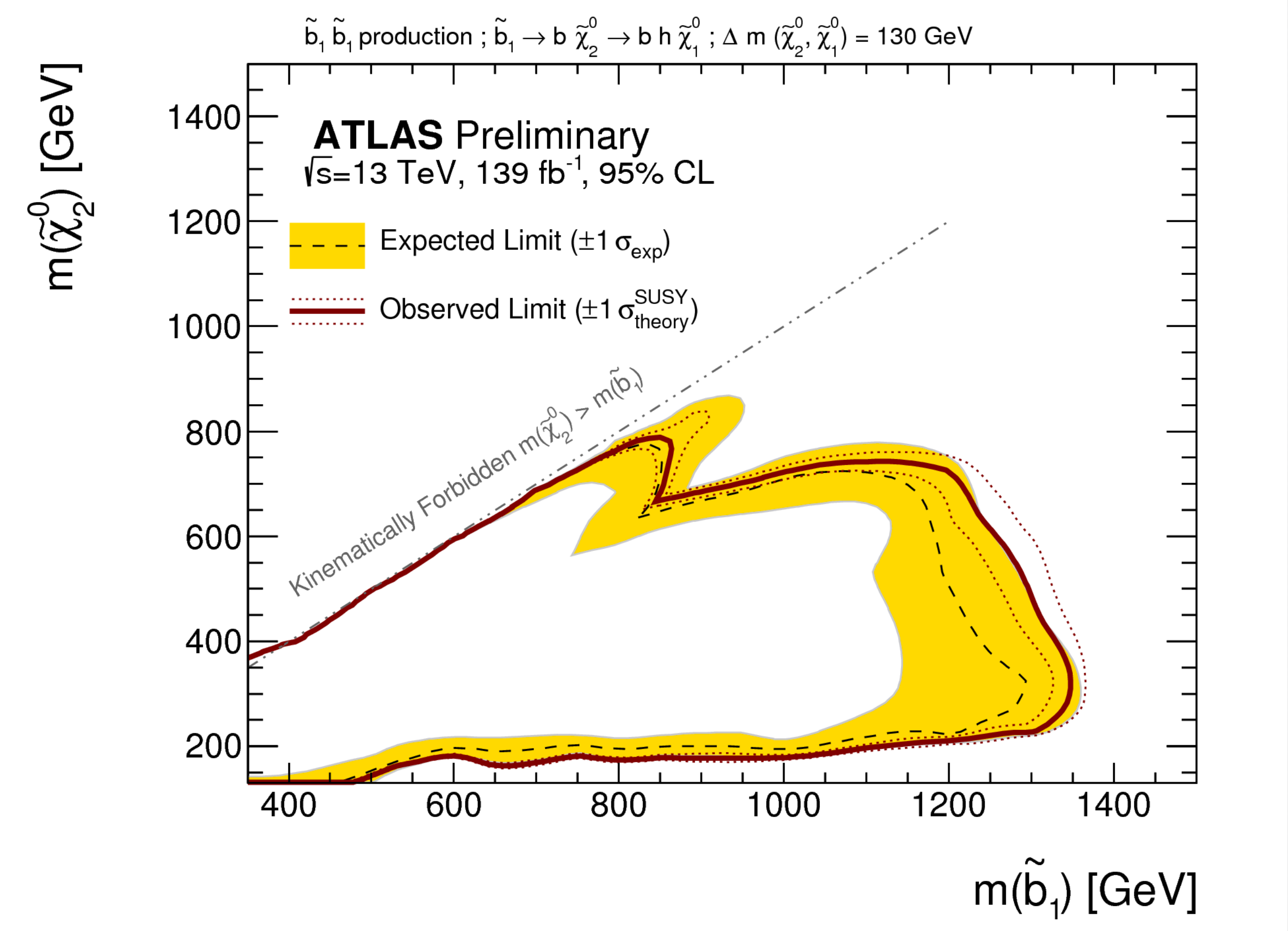
3G ($\tilde{t}$,$\tilde{b}$)

139 fb^{-1}

cut and count

sbottom multi-*b*-jets





$m(\tilde{\chi}_1{}^0)$ = 60 GeV

$\Delta m(\tilde{\chi}_2{}^0, \tilde{\chi}_1{}^0)$ = 130 GeV

★ *new in Run 2*

Sensitivity increased to 1.45 TeV

More details in John Anders talk today @ 13h40

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SUSY/

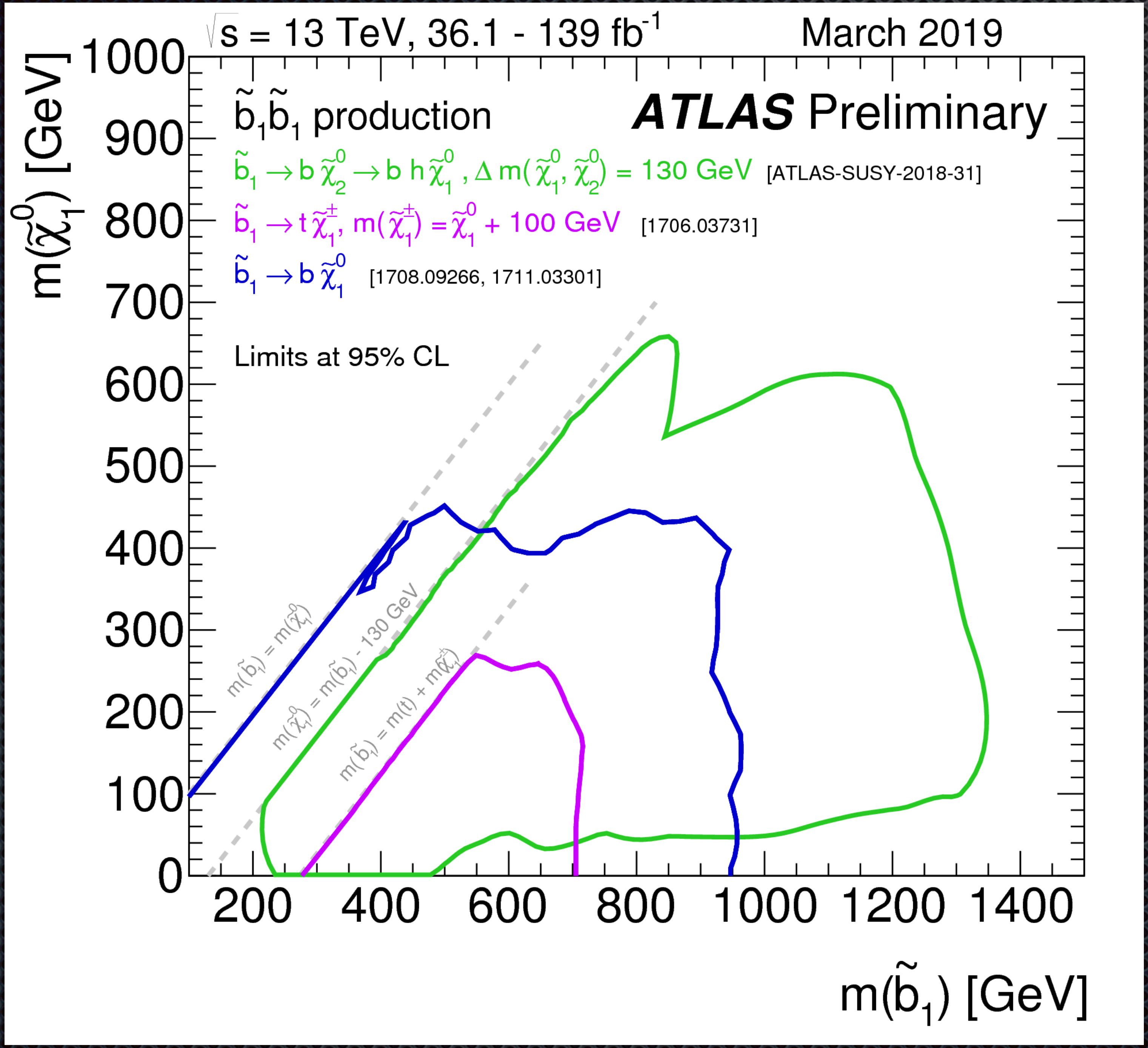
3G $(\tilde{t},\tilde{b})$

139 fb^{-1}

80 fb^{-1}

80 fb^{-1}

Summary of sbottom



- Update of sbottom summary plot with $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) = 130$ GeV from sbottom multi-*b*-jets

More details in John Anders talk today @ 13h40

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2018-041/

sbottom multi-b-jets also had many b-jets

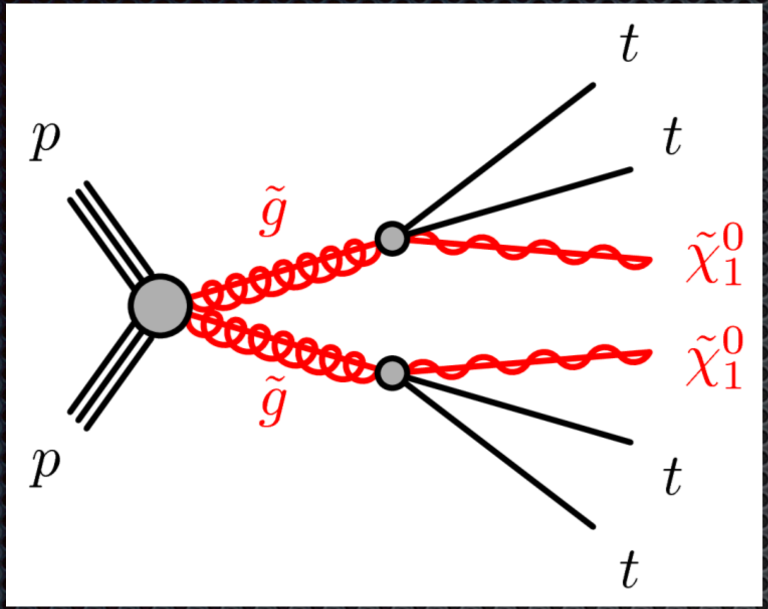
Strong ($\tilde{g}$)

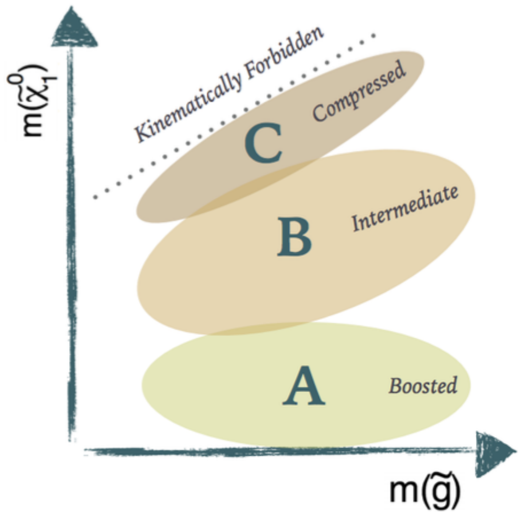
80 fb^{-1}

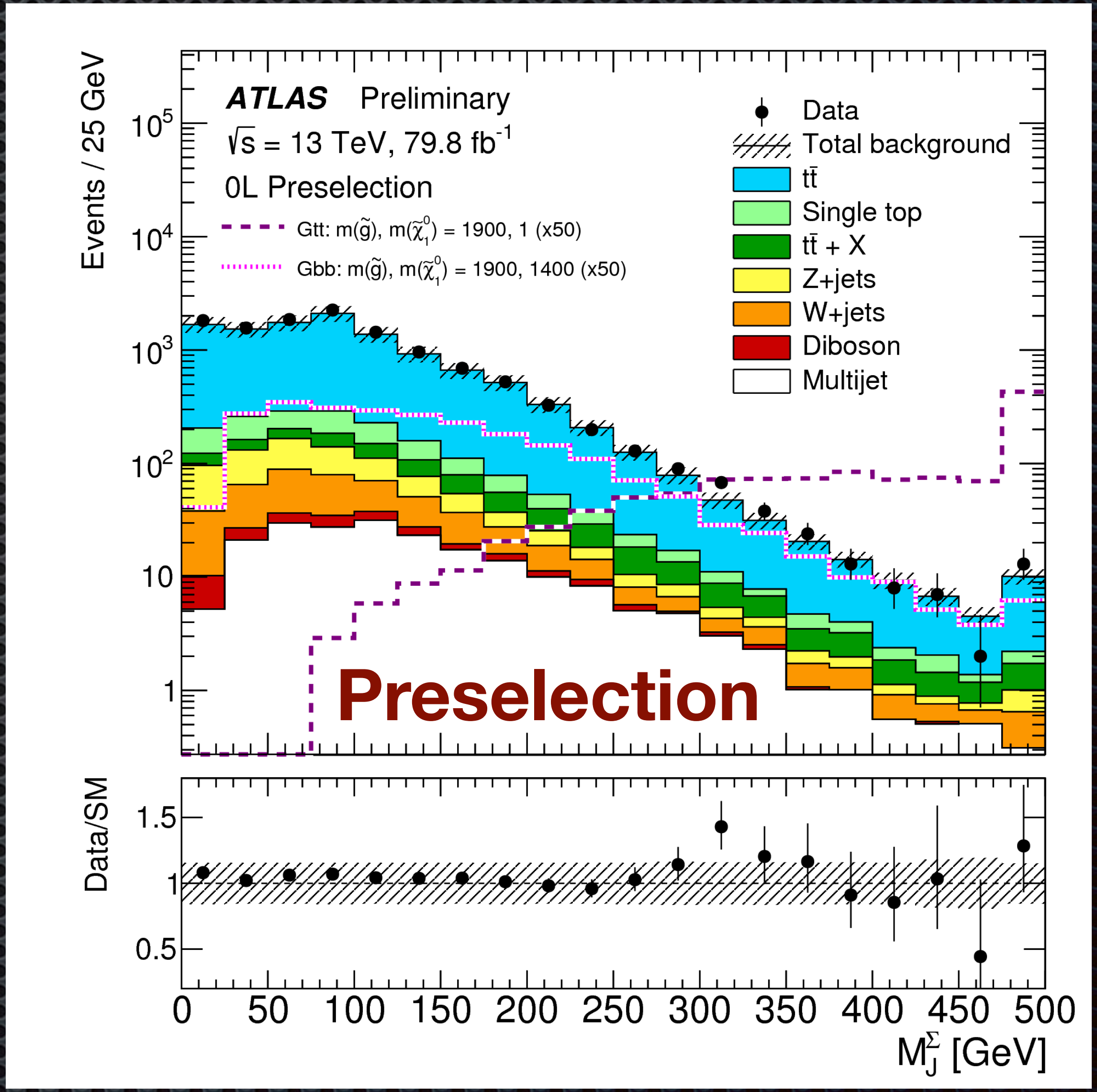
cut and count

multi-bin

Strong multi-*b*-jets







- MODEL PARAMETERS: $\tilde{g}, \tilde{t}, \tilde{\chi}_1^0$
- FINAL STATE: up to 12 jets, 4 *b*-jets, MET
- THREE SIGNAL SCENARIOS (3 discovery regions):
  - $\tilde{g} \rightarrow t\bar{t}+\tilde{\chi}_1^0$ (off-shell/on-shell $\tilde{t}$)
  - $\tilde{g} \rightarrow b\bar{b}+\tilde{\chi}_1^0$ (off-shell/on-shell $\tilde{t}$)
  - $\tilde{g} \rightarrow t\bar{b}+\tilde{\chi}_1^0$ (via chargino)
- DOMINANT BACKGROUNDS: $t\bar{t}$, singletop
- CHALLENGE: busy (hadronic) final state

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-011

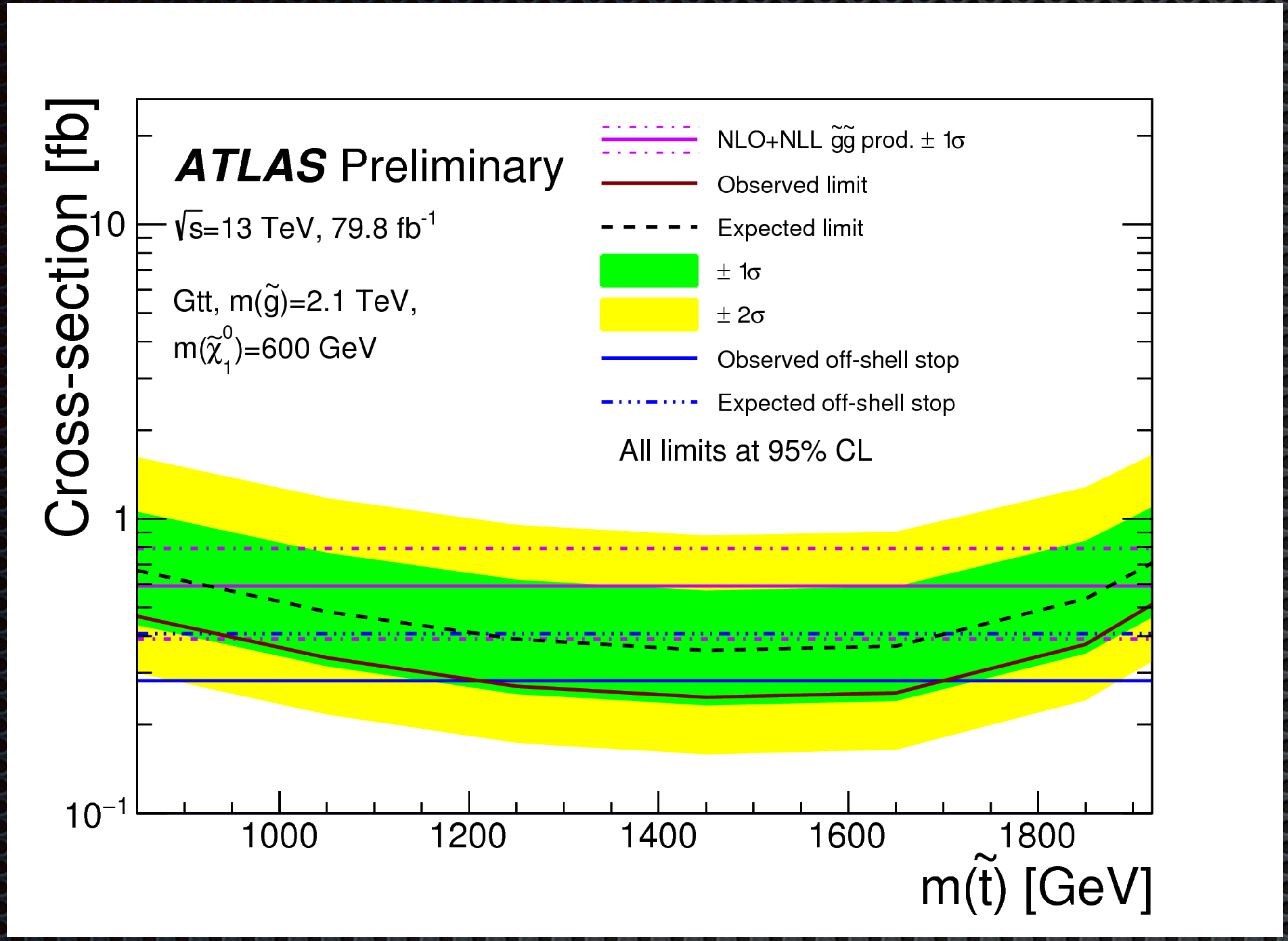
Strong ($\tilde{g}$)

80 fb^{-1}

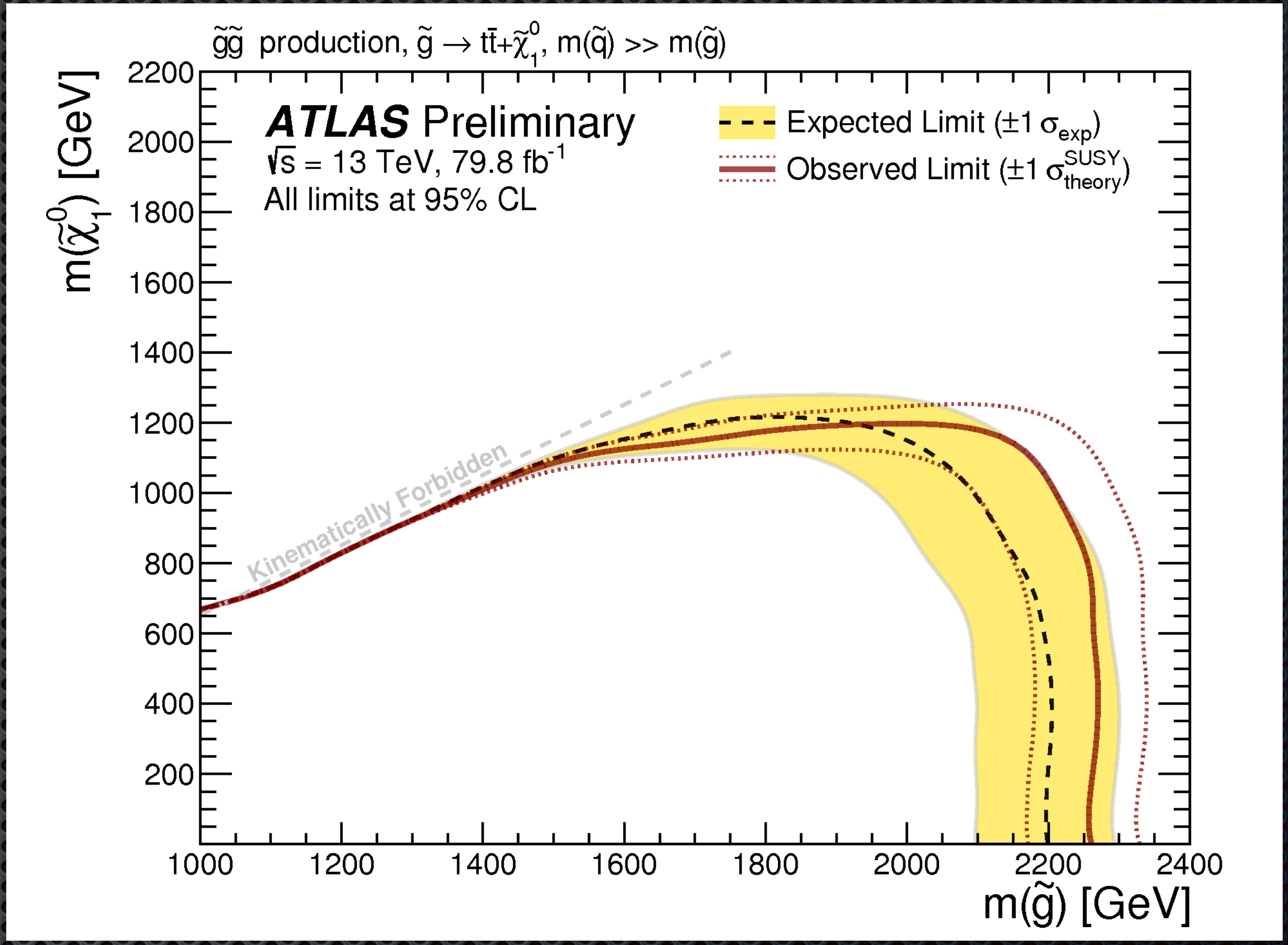
cut and count

multi-bin

Strong multi-*b*-jets



$\tilde{g} \rightarrow t\bar{t}+\tilde{\chi}_1^0$ (**on-shell** $\tilde{t}$)



$\tilde{g} \rightarrow t\bar{t}+\tilde{\chi}_1^0$ (**off-shell** $\tilde{t}$)

Sensitivity increased to 2.25 TeV

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-015/

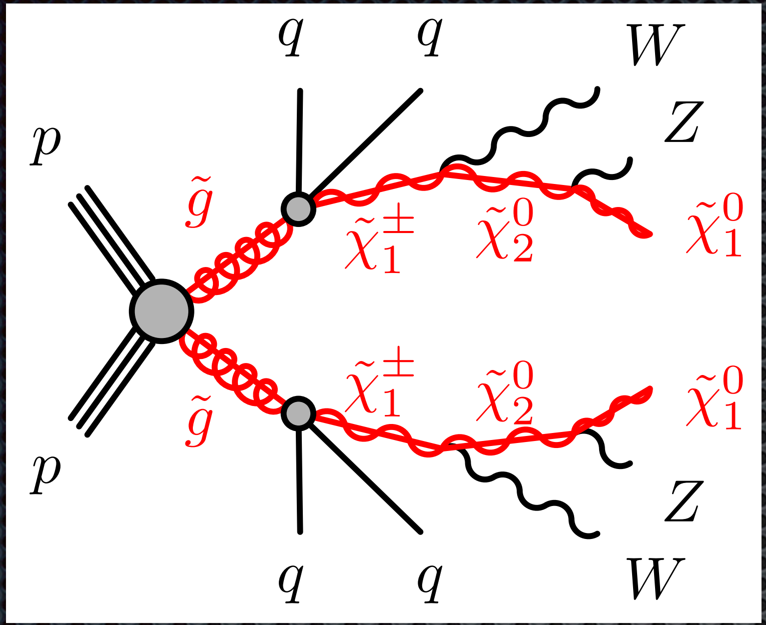
like strong multi-b-jets, also have many jets

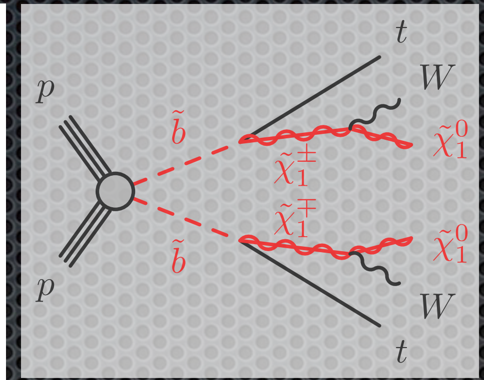
Strong ($\tilde{g}$)

139 fb^{-1}

cut and count

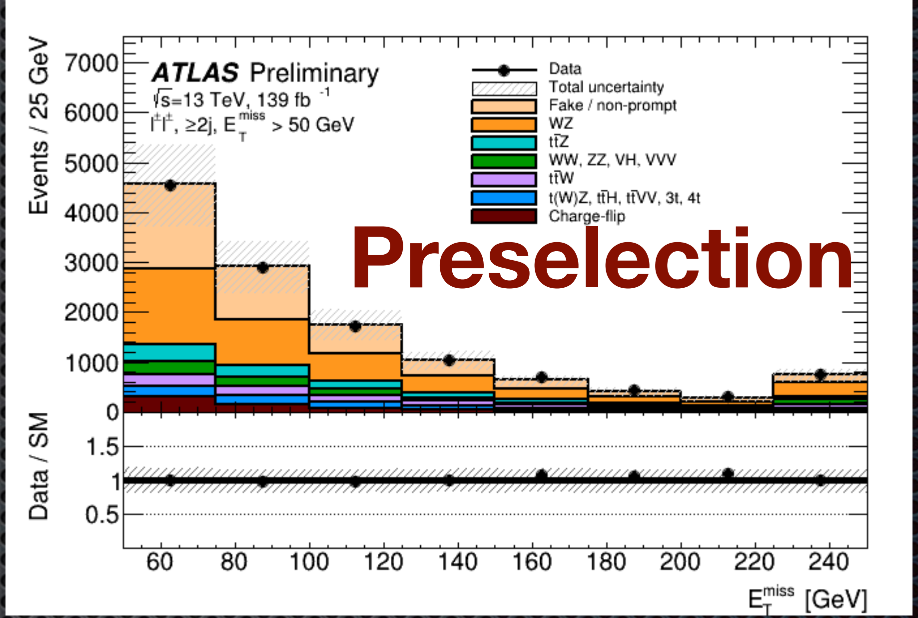
Inclusive SS leptons

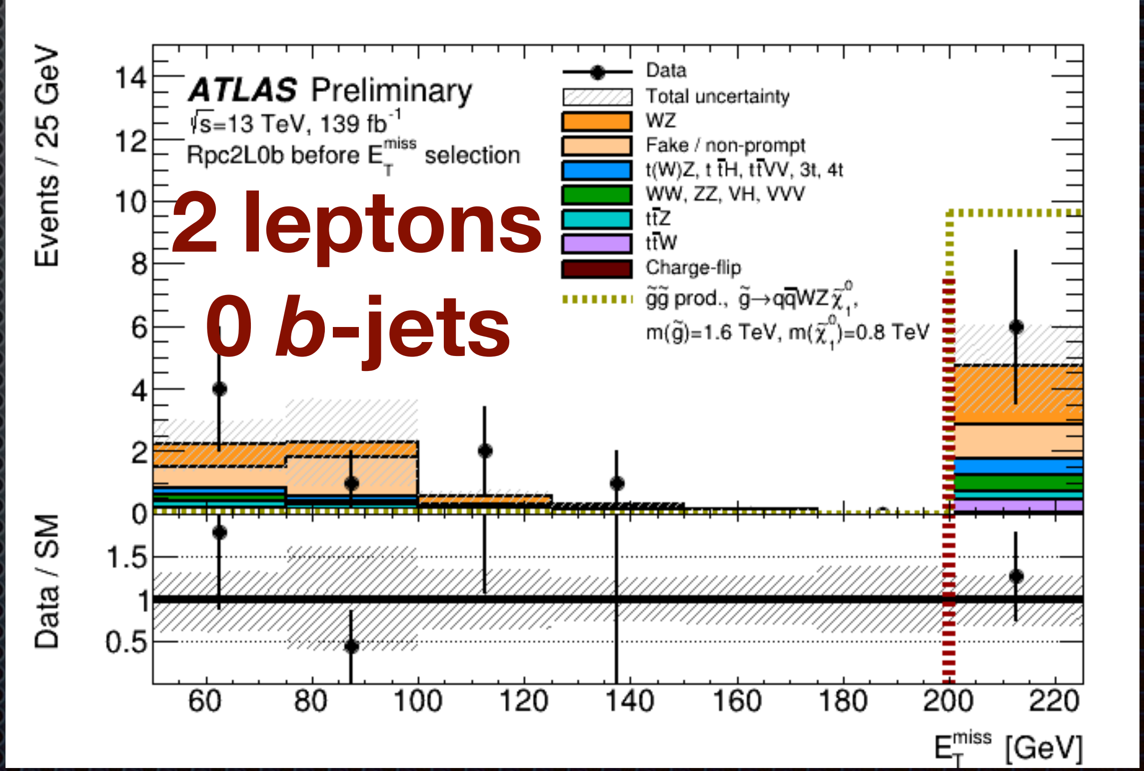




… (more diagrams not included)

targets





- MODEL PARAMETERS: $\tilde{g}$, $\tilde{t}$, $\tilde{b}$, $\tilde{\chi}_1^0$
- FINAL STATE: ≥ 2 SS leptons, ≥ 6 jets
- FOUR SIGNAL SCENARIOS (4 discovery regions):
  - $\tilde{b}_1 \to t W \tilde{\chi}_1^0$
  - $\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$
  - $\tilde{g} \to q\bar{q}WZ\tilde{\chi}_1^0$
  - $\tilde{t}_1 \to t W^\pm(W^*) \tilde{\chi}_1^0$
- DOMINANT BACKGROUNDS: WZ+jets, $t\bar{t}V$
- CHALLENGE: broad search, uncertainties of fake factors, theory uncertainty of diboson

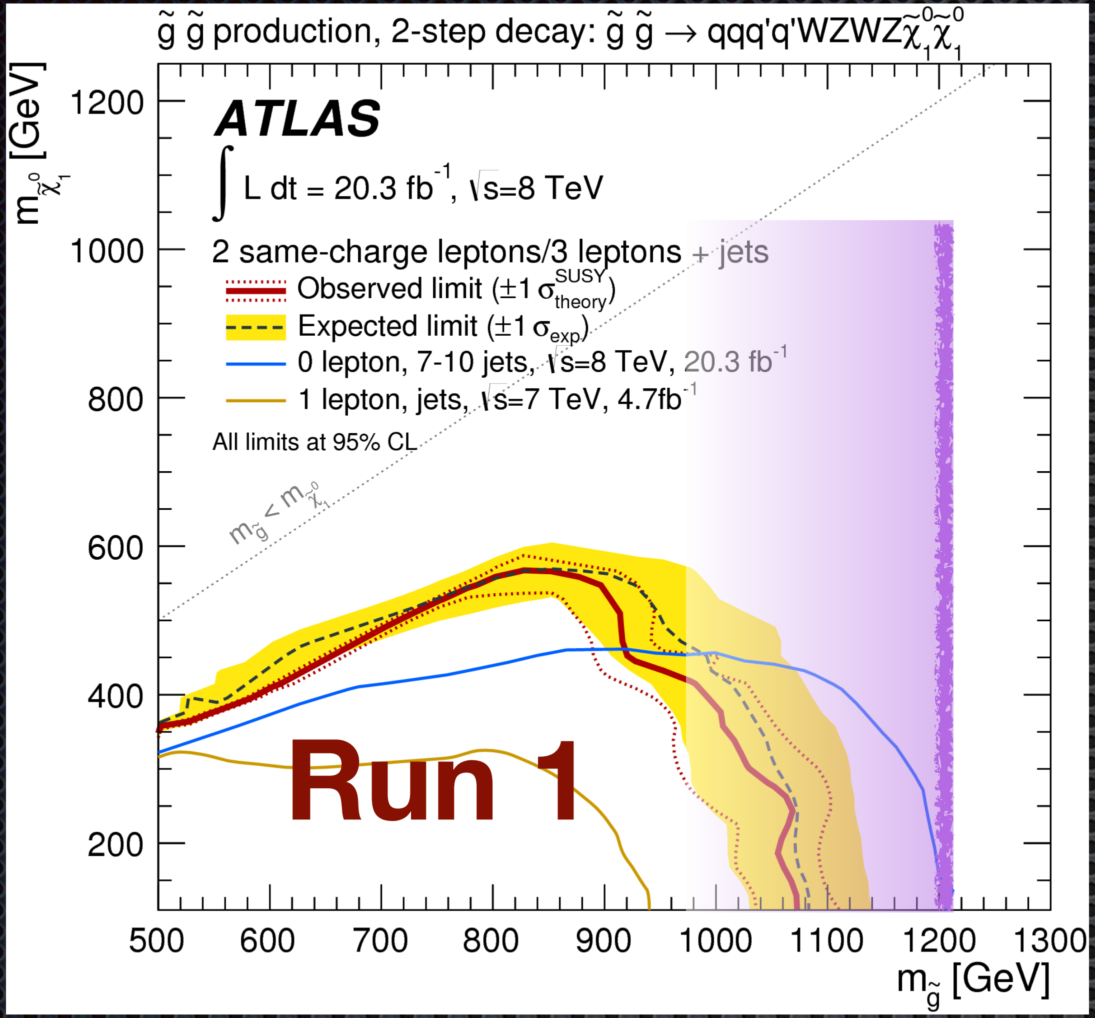
More details in Julien Maurer talk today @ 13h00

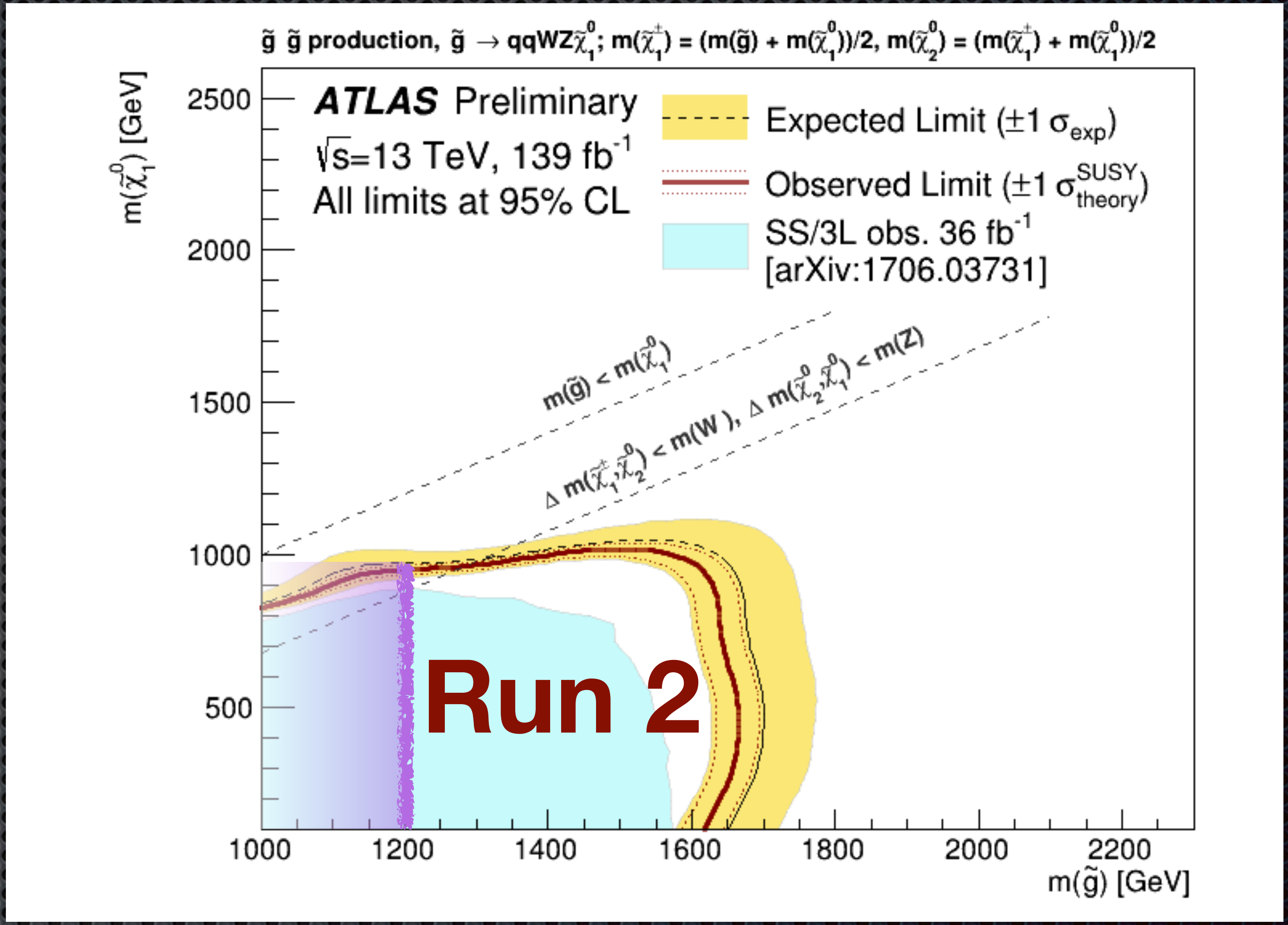
SS: Same-Sign (electric charge)

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-015/
https://arxiv.org/abs/1404.2500

Strong ($\tilde{g}$)
139 fb^{-1}
cut and count

Inclusive SS leptons





breadth of signatures done, see detailed talk later today

2 leptons, 0 b-jets (RPC)

Sensitivity increased from [1.1,0.6] to [1.6,1.0] TeV

More details in Julien Maurer talk today @ 13h00

SS: Same-Sign (electric charge)

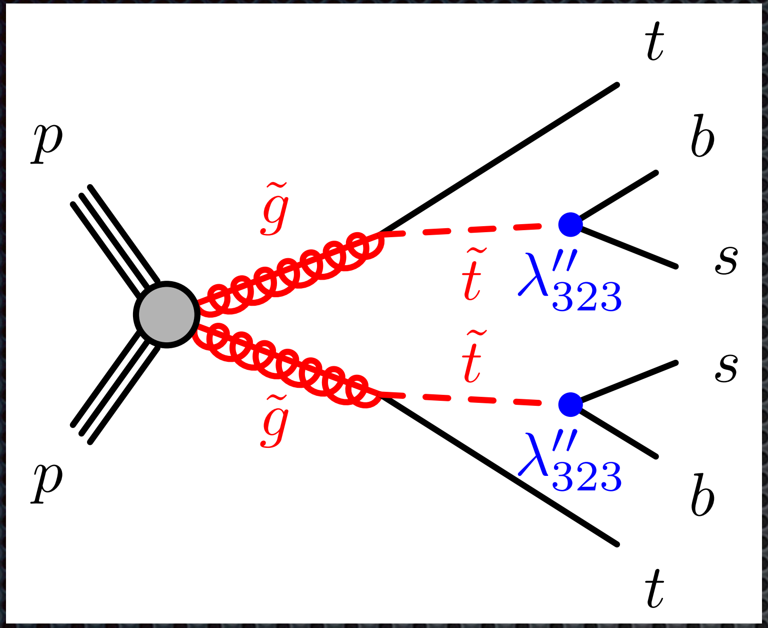
same analysis as strong, but ramp up λ'

RPVLL (λ',λ'')

139 fb^{-1}

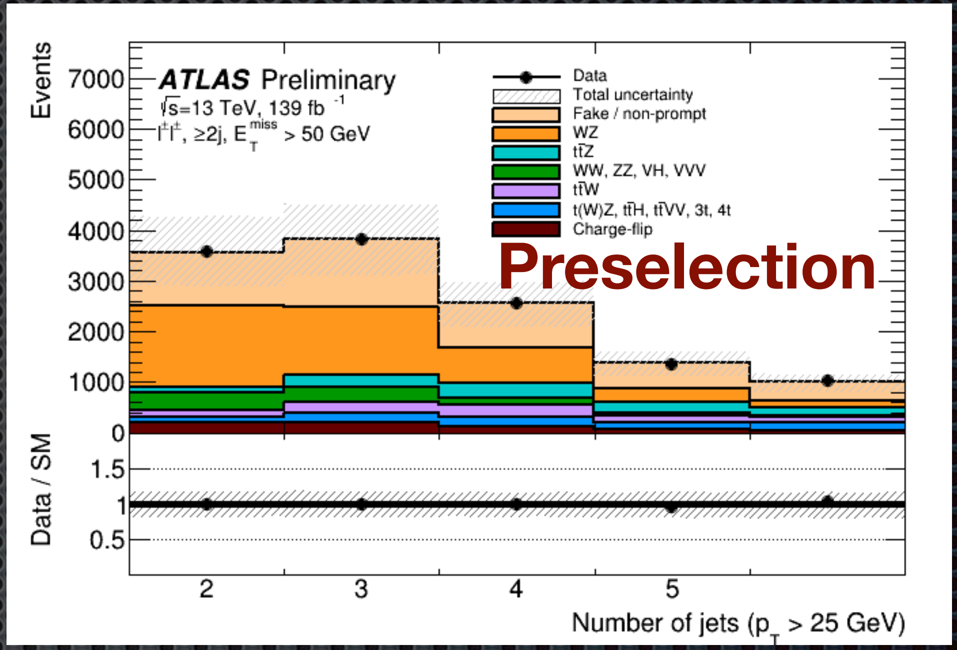
cut and count

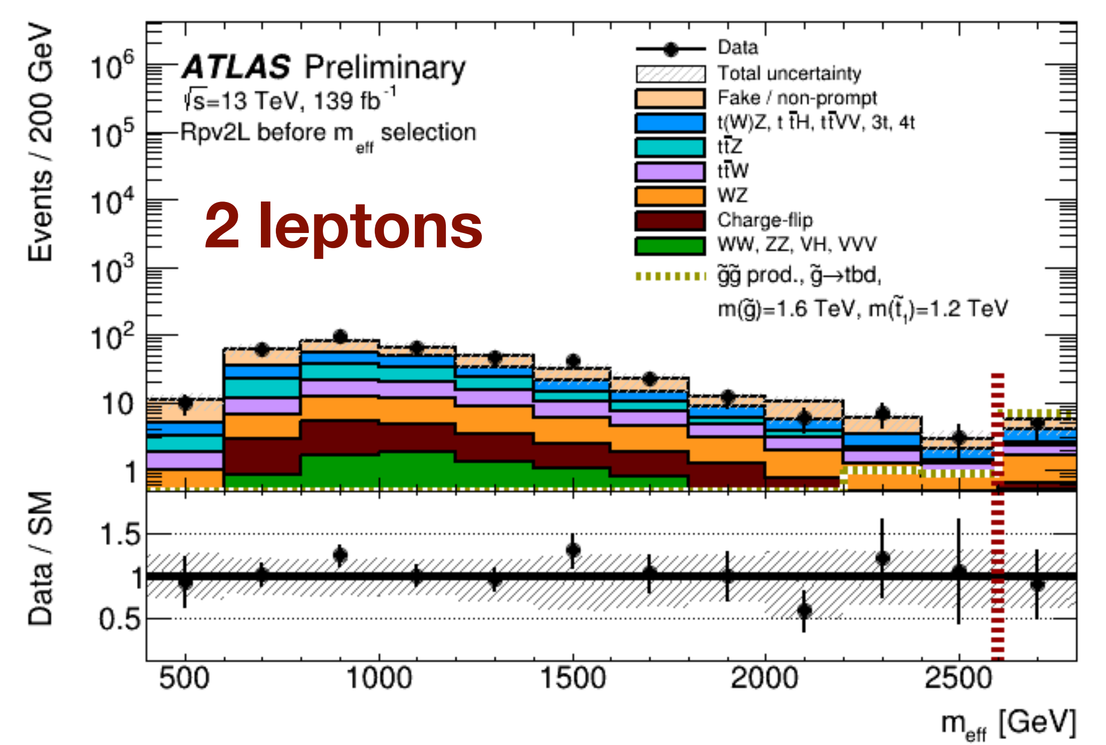
Inclusive SS leptons



… (more diagrams not included)

targets





- MODEL PARAMETERS: $\tilde{g}, \tilde{t}, \tilde{b}, \tilde{\chi}_1^0$
- FINAL STATE: ≥ 2 SS leptons, ≥ 6 jets
- THREE SIGNAL SCENARIOS (1 discovery region):
  - $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow 3q$
  - $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow qq'\ell$
  - $\tilde{g} \rightarrow t\bar{t}\,\tilde{t}_1^*, \tilde{t}_1^* \rightarrow qq'$
- DOMINANT BACKGROUNDS: WZ+jets, $t\bar{t}V$
- CHALLENGE: broad search, uncertainties of fake factors, theory uncertainty of diboson

More details in Julien Maurer talk today @ 13h00

SS: Same-Sign (electric charge)

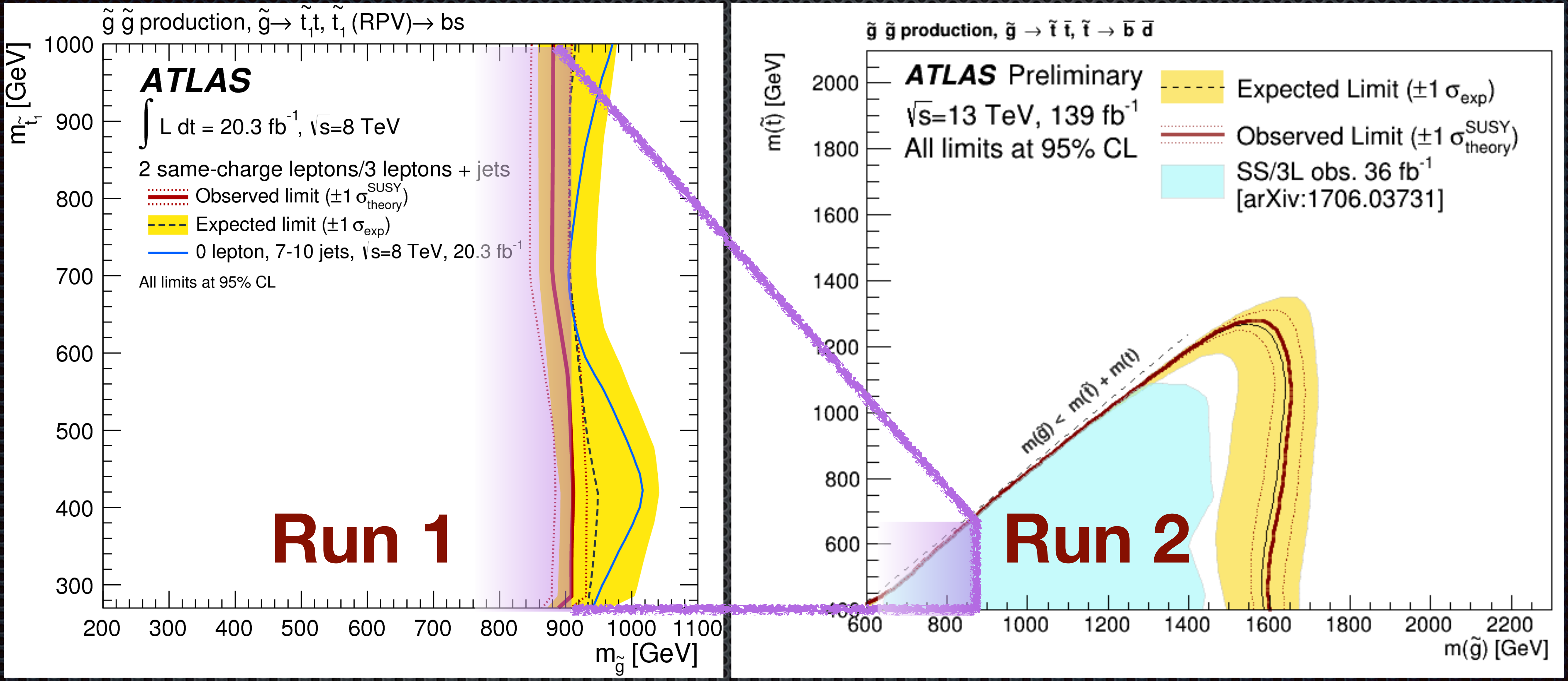
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-015/
https://arxiv.org/abs/1404.2500

RPVLL (λ',λ'')

$139\ \mathrm{fb}^{-1}$

cut and count

Inclusive SS leptons



breadth of signatures done, see detailed talk later today

Sensitivity increased from 0.9 to 1.6 TeV

More details in Julien Maurer talk today @ 13h00

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-006

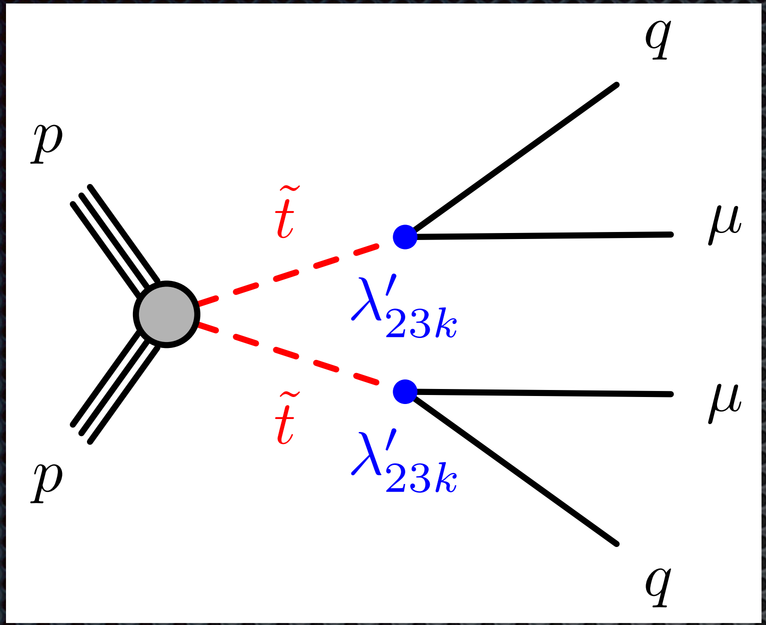
not as many jets/leptons as SS/3L

RPVLL (λ',λ'')

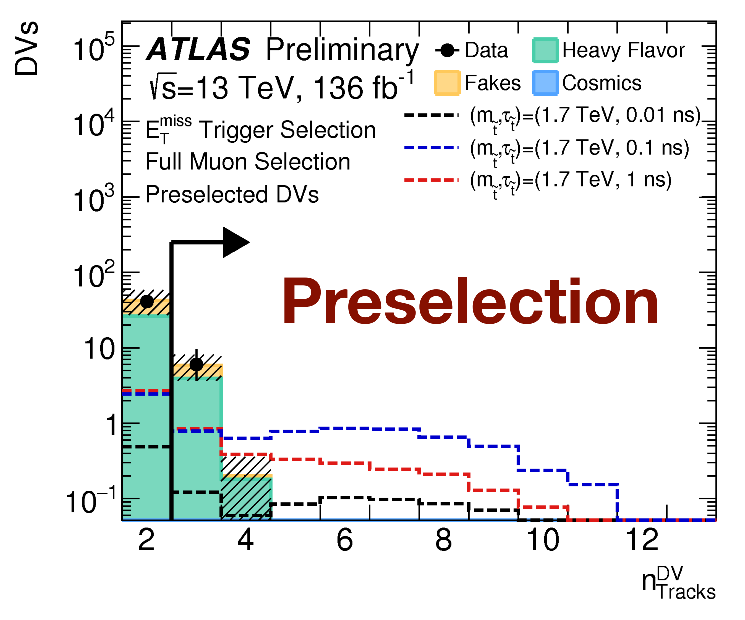
139 fb^{-1}

cut and count

Displaced Vertex + Muon

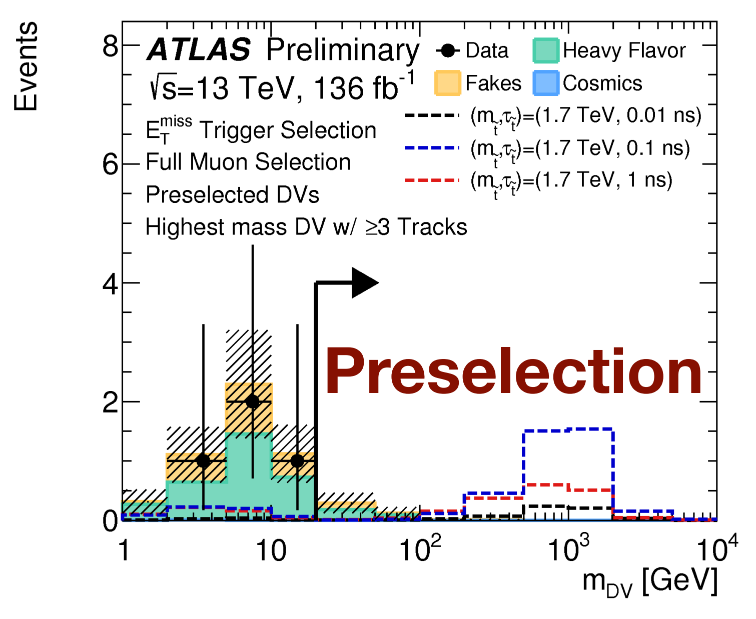


… (more diagrams not included)



Heavy Flavor can have longer decay chains

- Model parameters: λ'$_{ijk}$, $\tilde{t}$
- Final state: displaced muon, displaced vertex
- One signal scenario (2 signal regions):
  - $\tilde{t}\rightarrow q\mu$
- Dominant backgrounds: material interactions, randomly intersecting (soft) tracks
- Challenge: special track and vertex reconstruction!



More displaced tracks → higher mass vertex

More details in Hidetoshi Otono talk Thursday @ 14h50

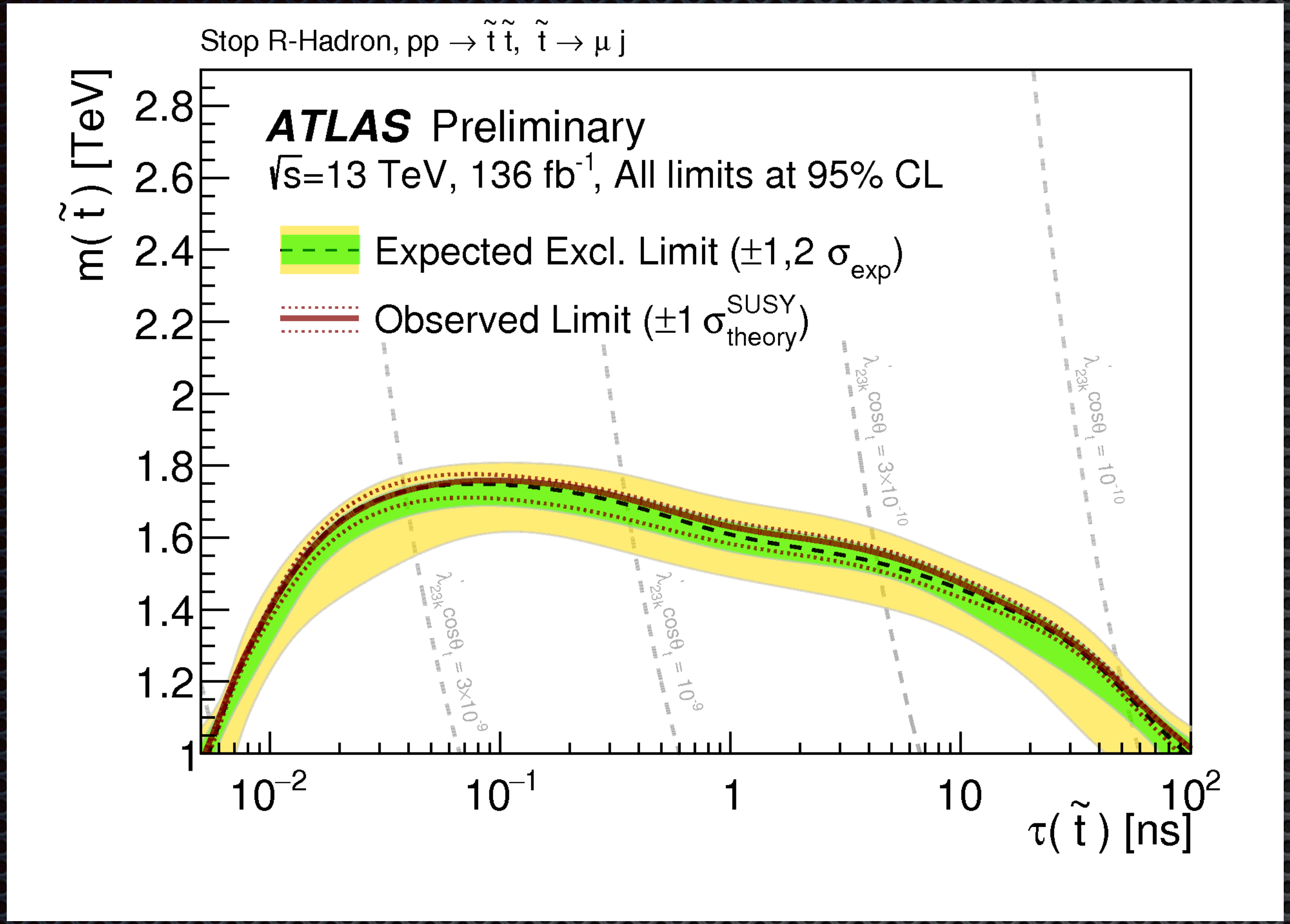
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-006

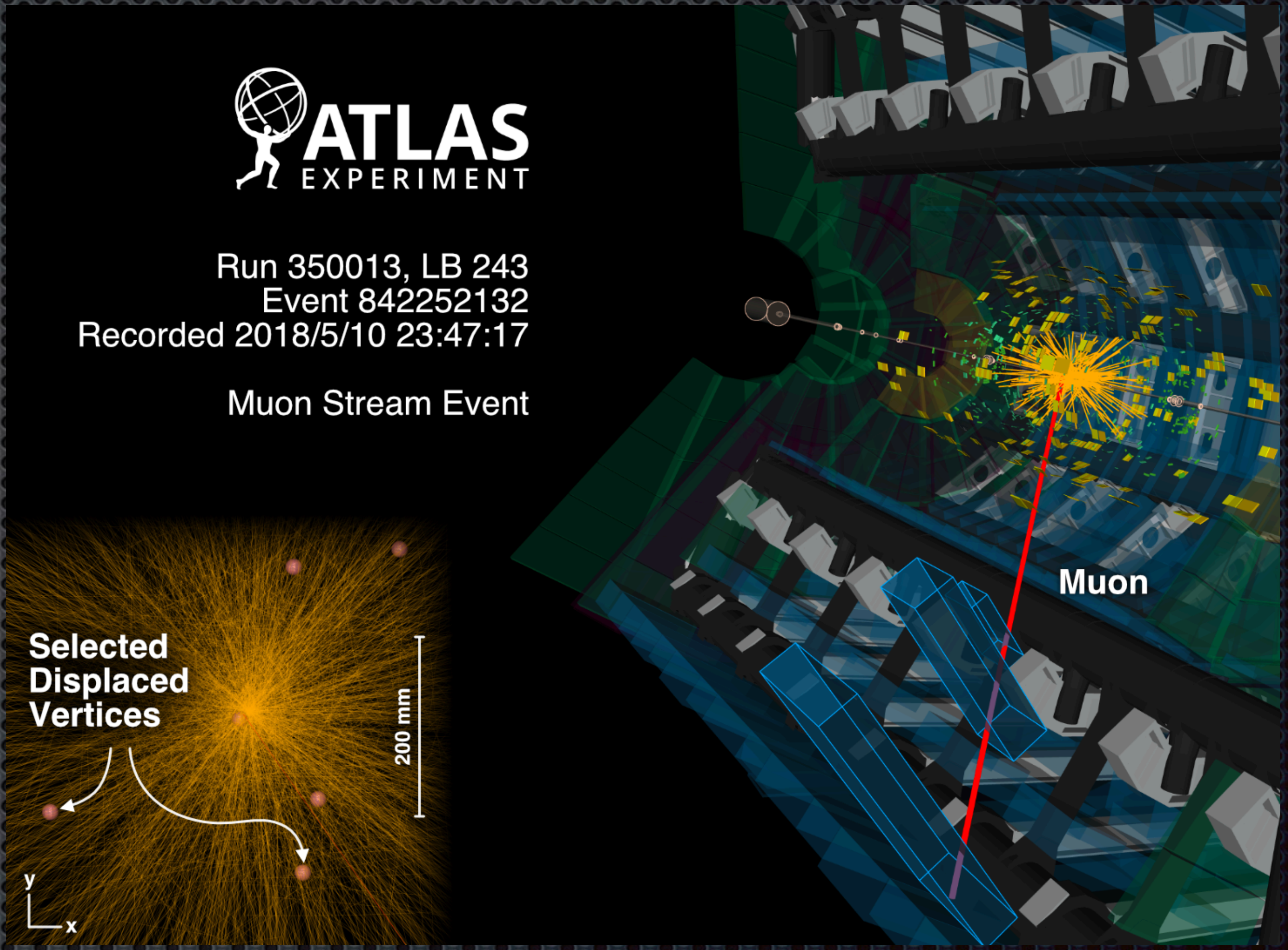
RPVLL (λ',λ'')

139 fb^{-1}

cut and count

Displaced Vertex + Muon





No excess observed in either signal region

Muon-triggered event

Sensitivity increased to 1.75 TeV

(for ~0.1ns lifetime)

First long-lived result with full dataset!

More details in Hidetoshi Otono talk Thursday @ 14h50

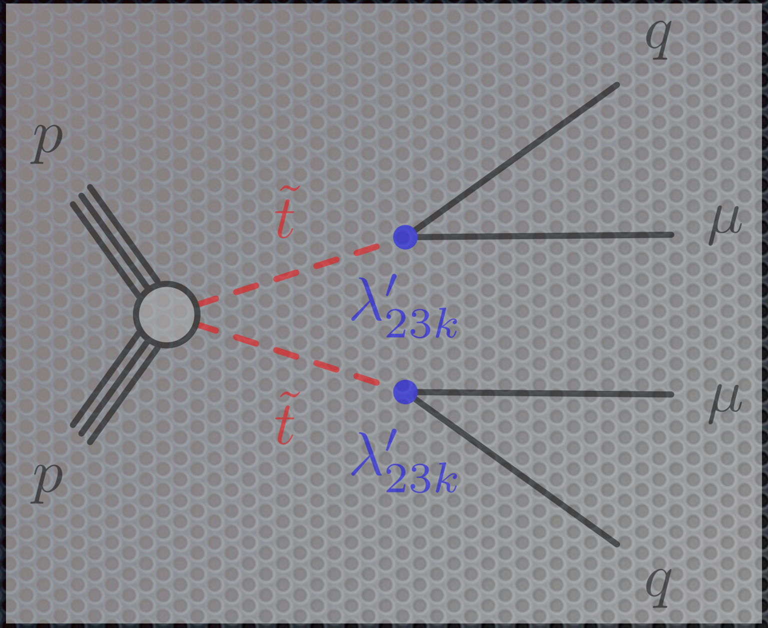
https://arxiv.org/abs/1810.12602
https://cds.cern.ch/record/2668727

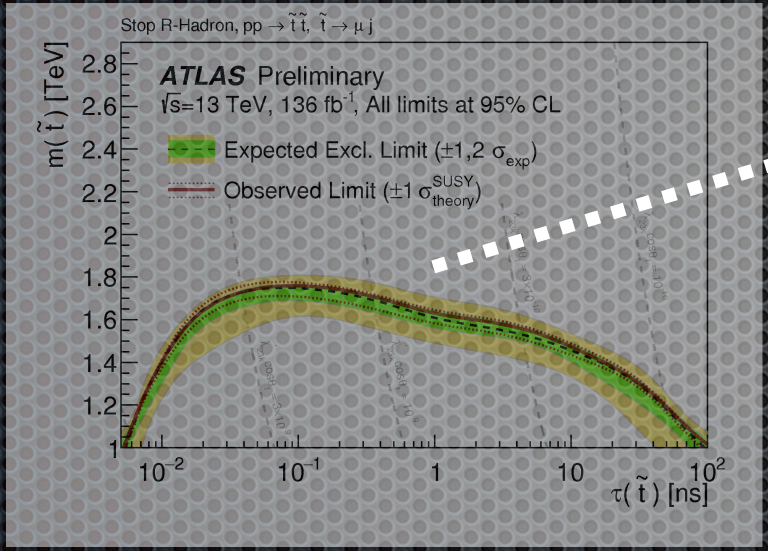
RPVLL (λ',λ'')

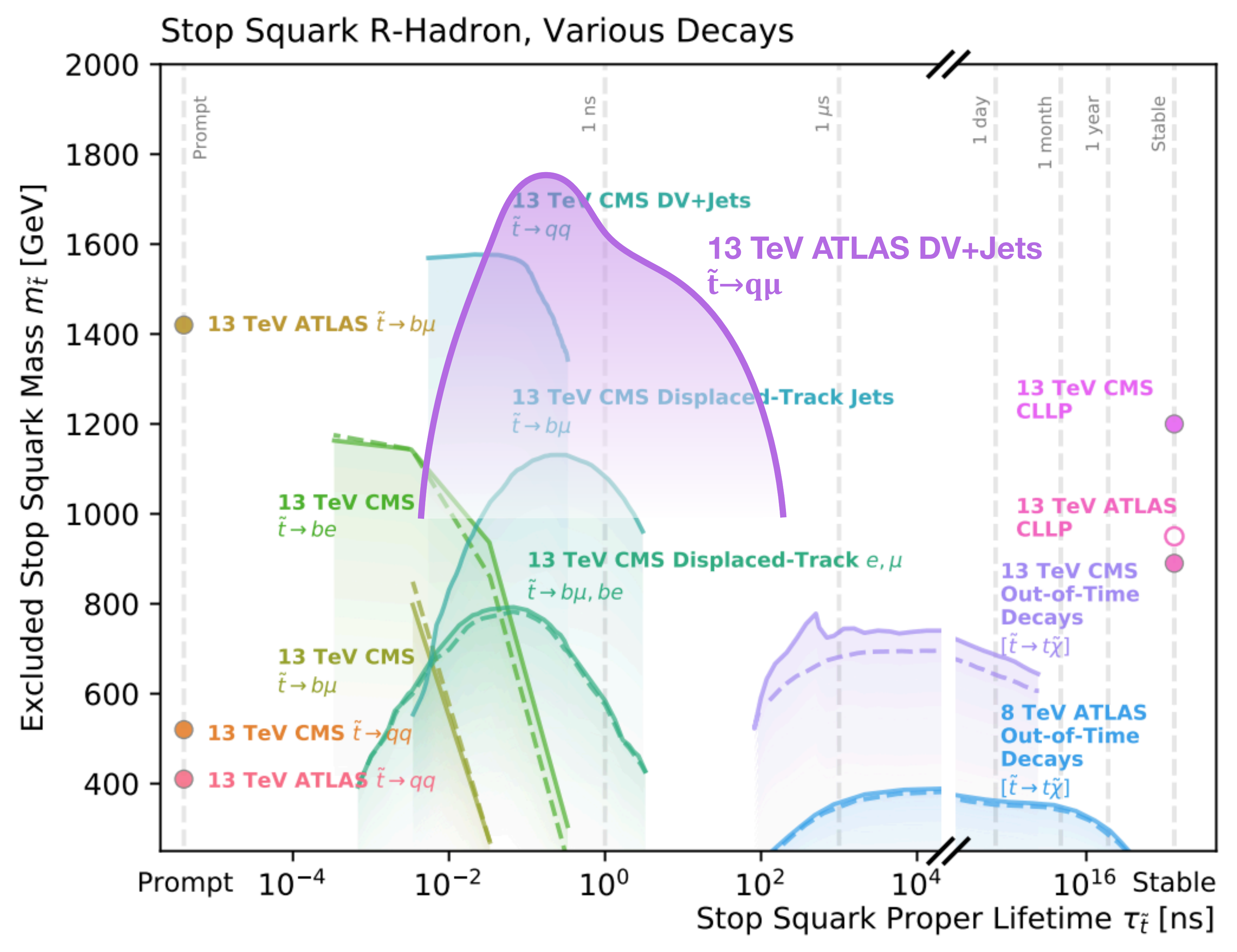
139 fb^{-1}

cut and count

Summary of RPV/LL







No ATLAS summary plot yet, but here's my attempt…

More details in Hidetoshi Otono talk Thursday @ 14h50

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-008/

regions with different/same flavor electrons/muons

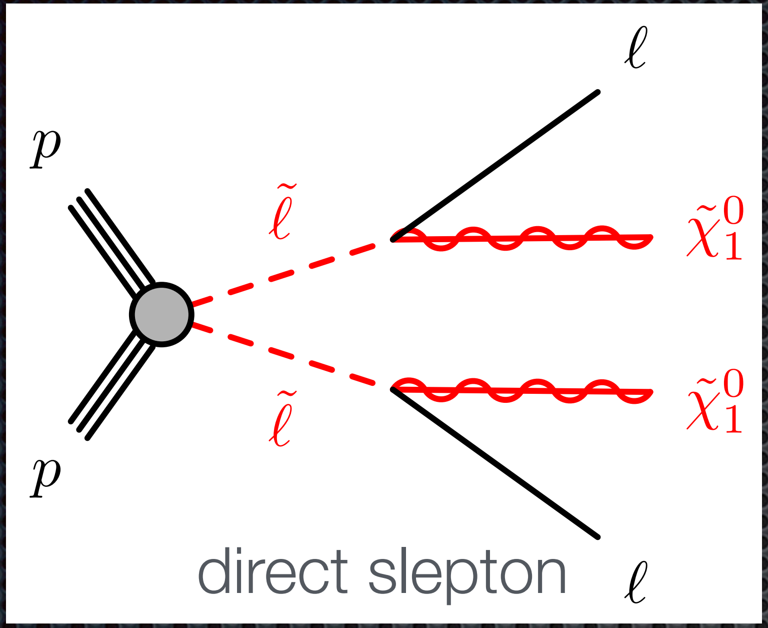
EWK ($\tilde{\ell}, \tilde{\nu}, \tilde{\chi}_1^{\pm}$)

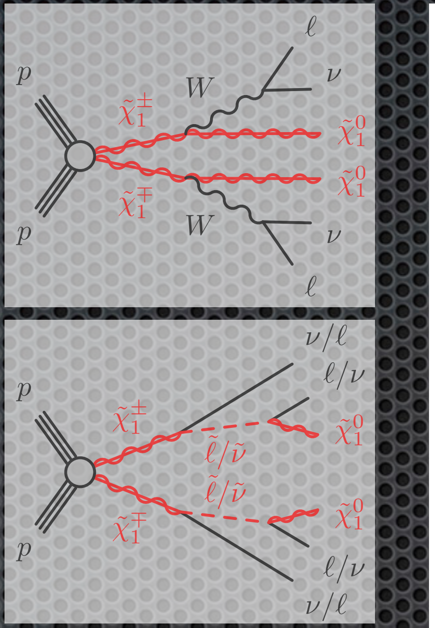
139 fb^{-1}

cut and count

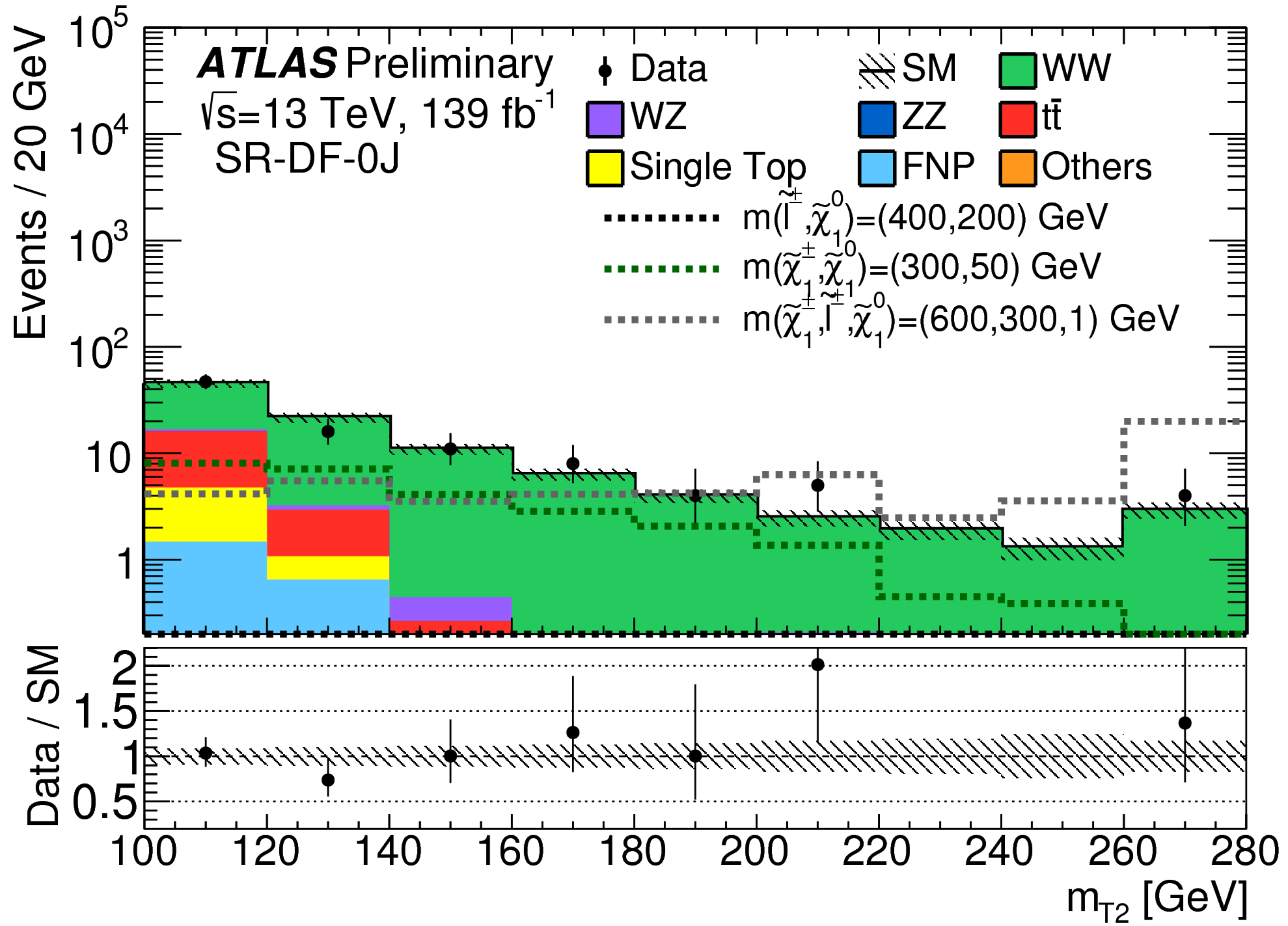
multi-bin

Sleptons: 2 lepton, 0 jet





- MODEL PARAMETERS: $\tilde{\ell}$, $\tilde{\nu}$, $\tilde{\chi}_1{}^0$, $\tilde{\chi}_1{}^{\pm}$
- FINAL STATE: =2 leptons (OS), MET
- THREE SIGNAL SCENARIOS (9 exclusion regions):
  - $\tilde{\ell} \rightarrow \ell\tilde{\chi}_1{}^0$, $\ell \in [e,\mu]$ (direct slepton)
  - $\tilde{\chi}_1{}^{\pm} \rightarrow W\tilde{\chi}_1{}^0$
  - $\tilde{\chi}_1{}^{\pm} \rightarrow \tilde{\ell}\nu/\tilde{\nu}\ell, \ \tilde{\ell}/\tilde{\nu} \rightarrow \tilde{\chi}_1{}^0 \ \ell/\nu$
- DOMINANT BACKGROUNDS: $t\bar{t}$, Wt, WW, WZ, ZZ
- CHALLENGE: theory uncertainties of diboson, top



different-flavor, 0-jet signal region

More details in Sonia Carra talk on Tuesday @ 13h30

OS: Opposite-Sign (electric charge)

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-008/

https://arxiv.org/abs/1403.5294

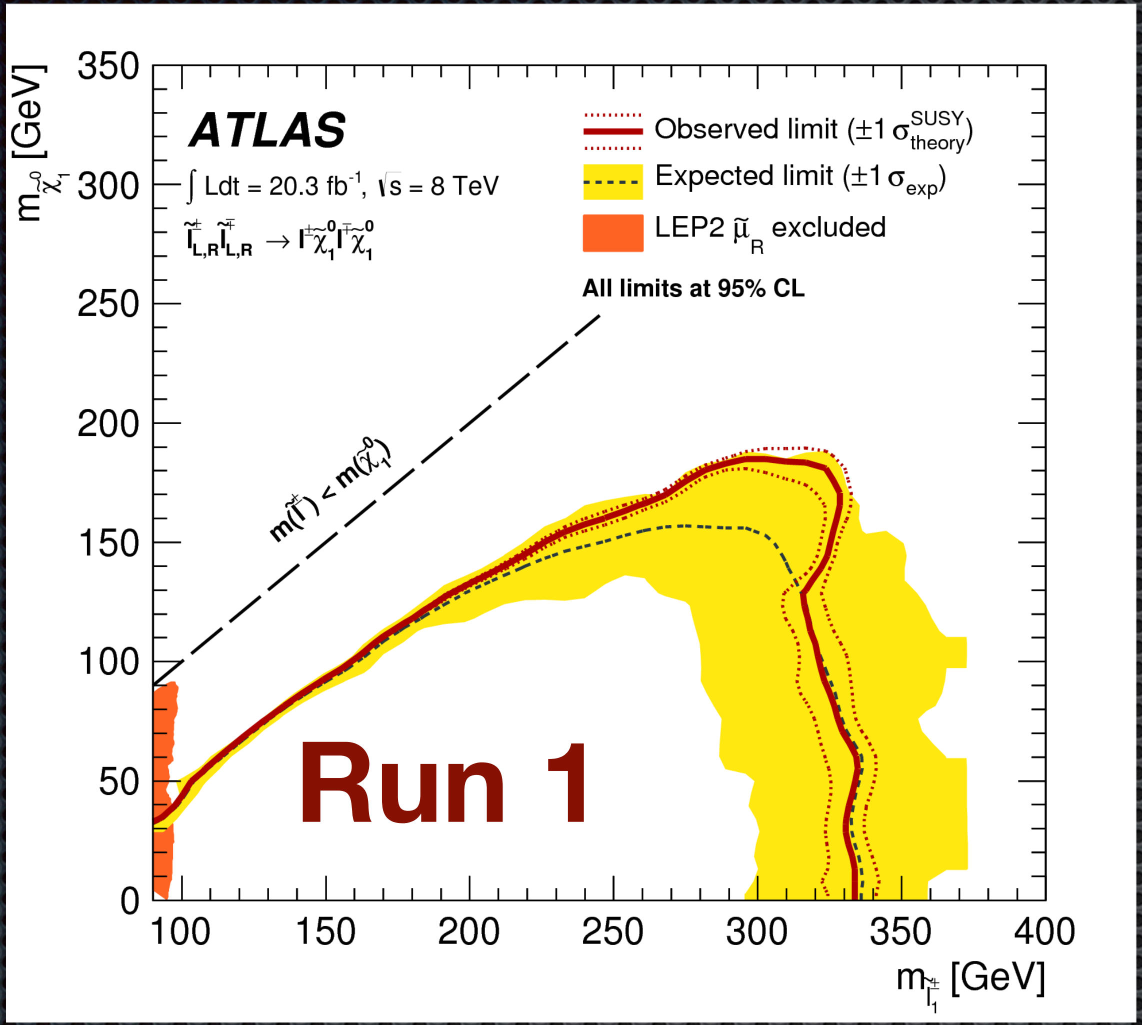
EWK ($\tilde{\ell},\tilde{\nu},\tilde{\chi}_1^\pm$)

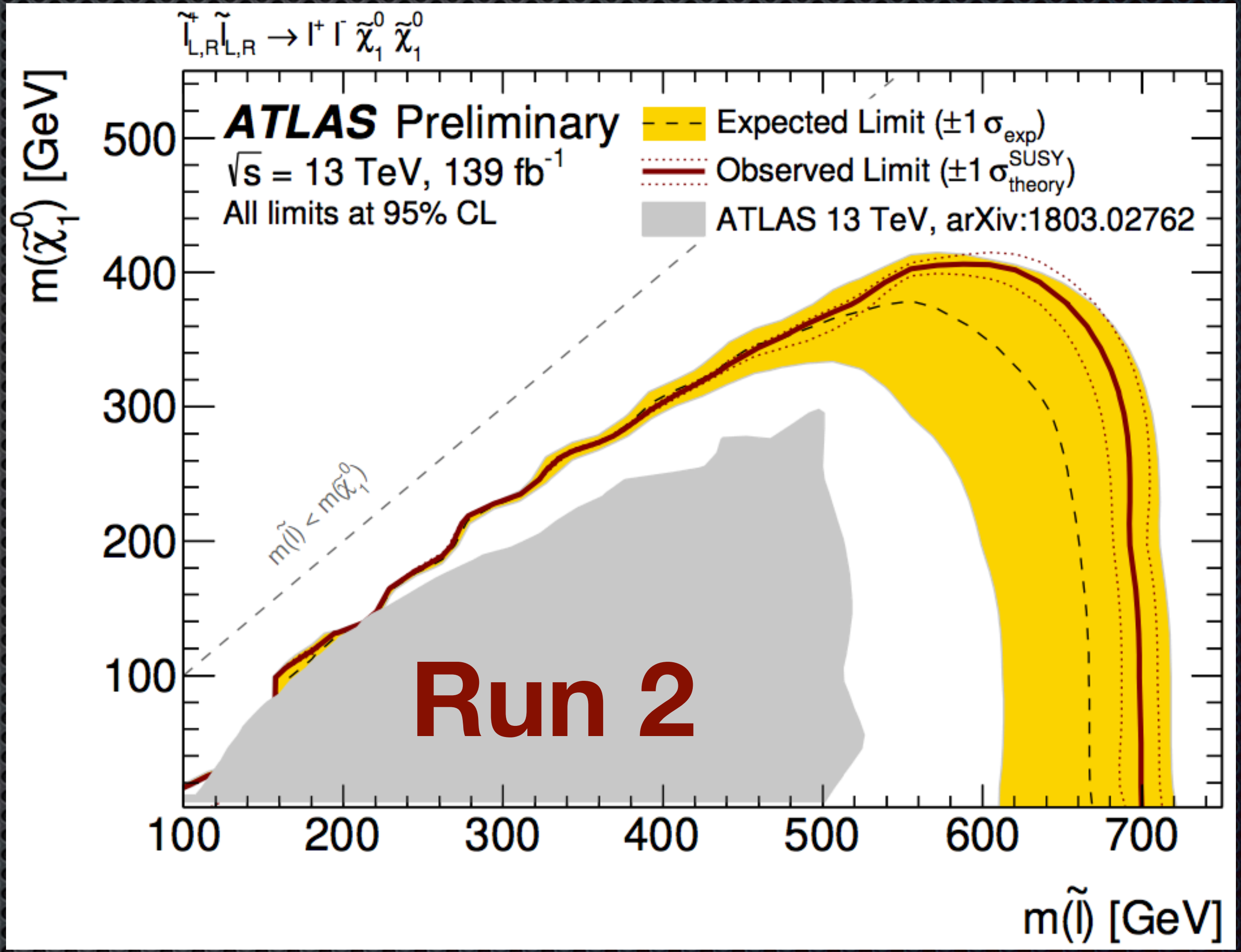
139 fb^{-1}

cut and count

multi-bin

Sleptons: 2 lepton, 0 jet





Optimized for direct sleptons

Sensitivity increased from 350 to 700 GeV

More details in Sonia Carra talk on Tuesday @ 13h30

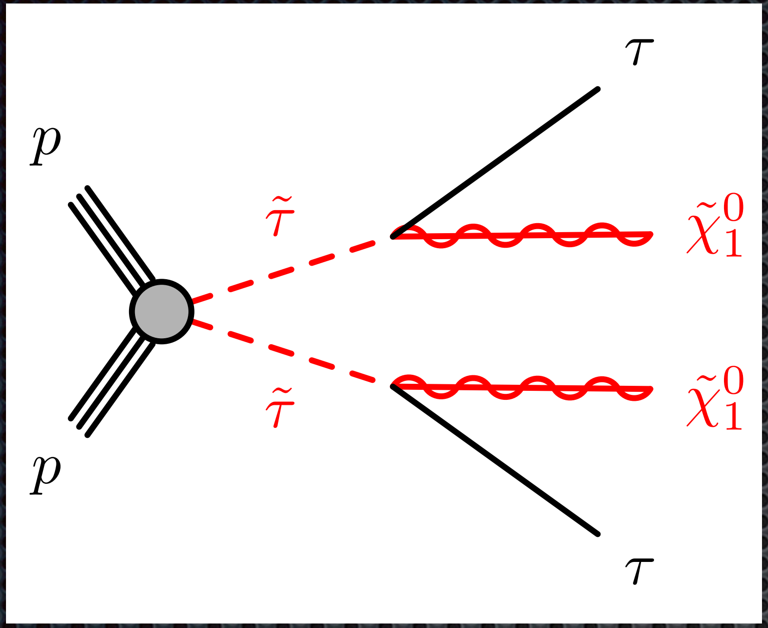
EWK ($\tilde{\ell}, \tilde{\nu}, \tilde{\chi}_1^{\pm}$)

139 fb^{-1}

cut and count

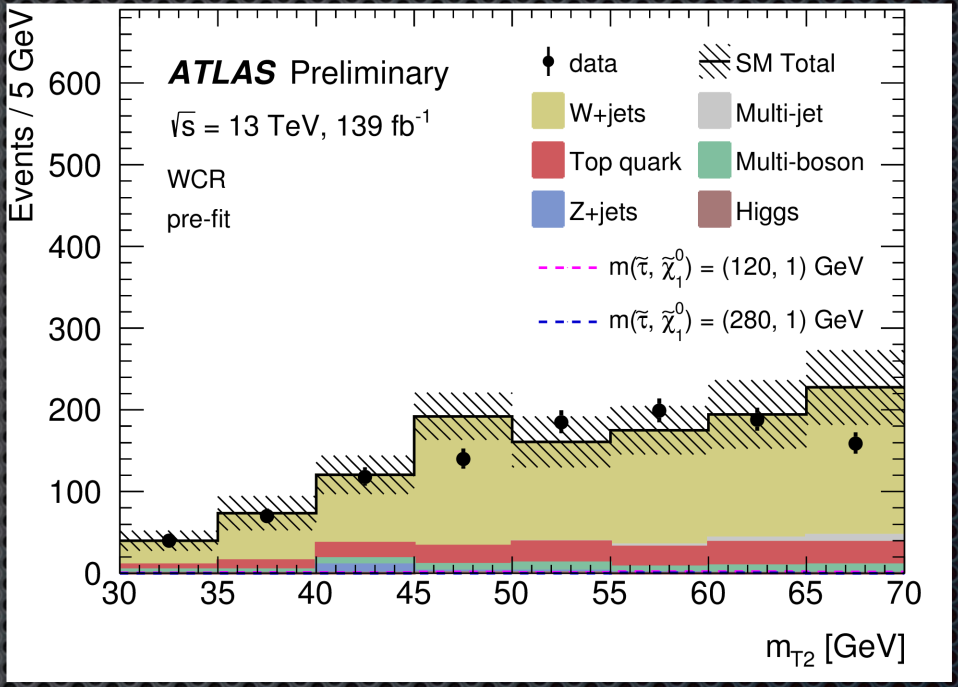
in memory of Jihyun Jeong

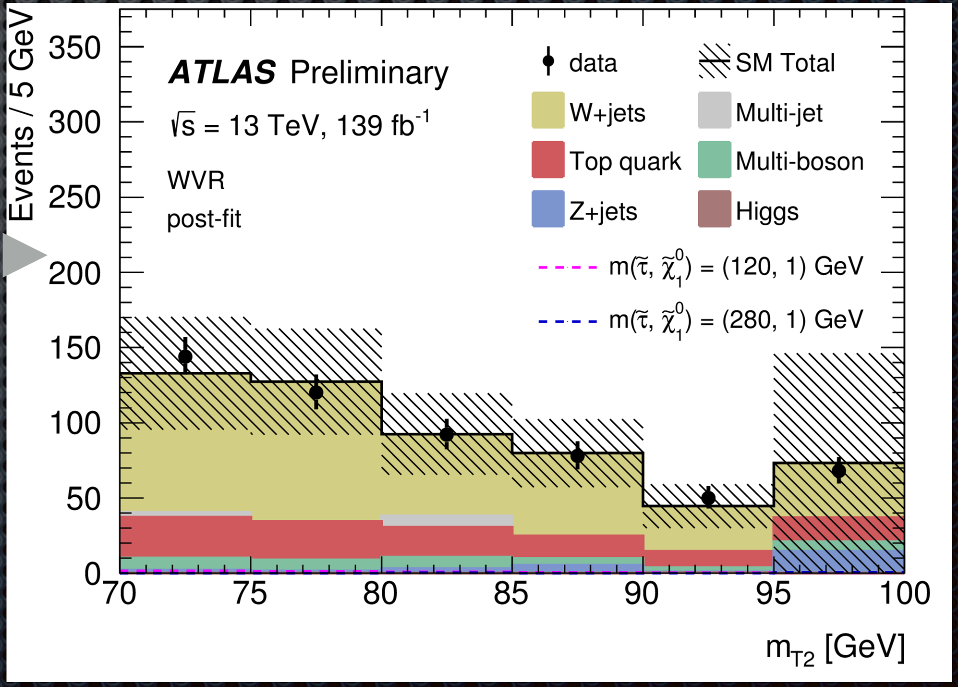
Sleptons: staus



derive

validate





W+jets data-driven normalization

- MODEL PARAMETERS: $\tilde{\tau}$, $\tilde{\chi}_1^0$, $m(\tilde{\tau}_R)=m(\tilde{\tau}_L)$
- FINAL STATE: =2 tau leptons (OS), MET
- ONE SIGNAL SCENARIO (2 discovery regions):
  - $\tilde{\tau}^{\pm} \rightarrow \tau^{\pm}\tilde{\chi}_1^0$, $\tau^{\pm} \rightarrow \text{hadrons}+\nu_\tau$
- DOMINANT BACKGROUNDS: multi-jet & W+jets (fake tau), diboson (real tau)
- CHALLENGE: background estimation and tau lepton identification

More details in Sonia Carra talk on Tuesday @ 13h30

OS: Opposite-Sign (electric charge)

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-018/

in memory of Jihyun Jeong

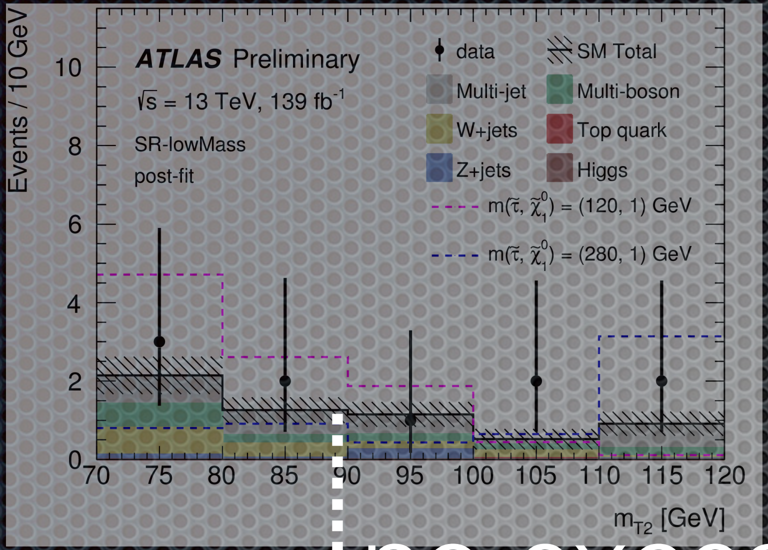
EWK ($\tilde{\ell}$, $\tilde{\nu}$, $\tilde{\chi}_1^{\pm}$)

139 fb^{-1}

cut and count

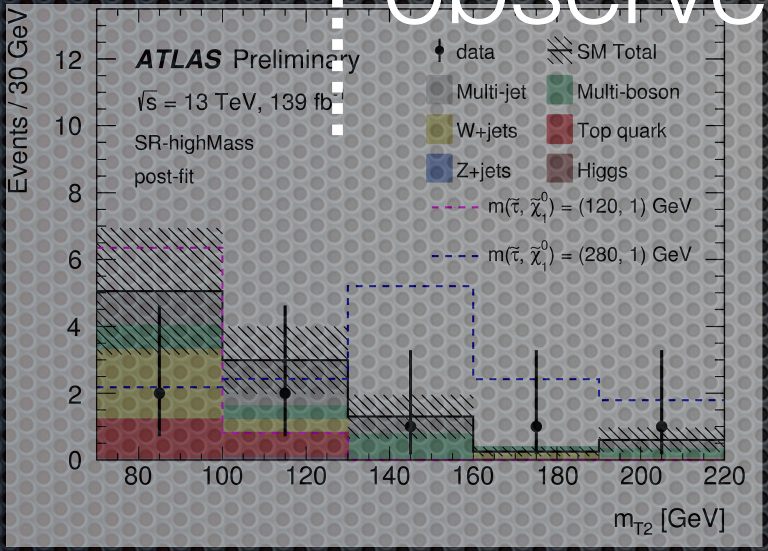
Sleptons: staus

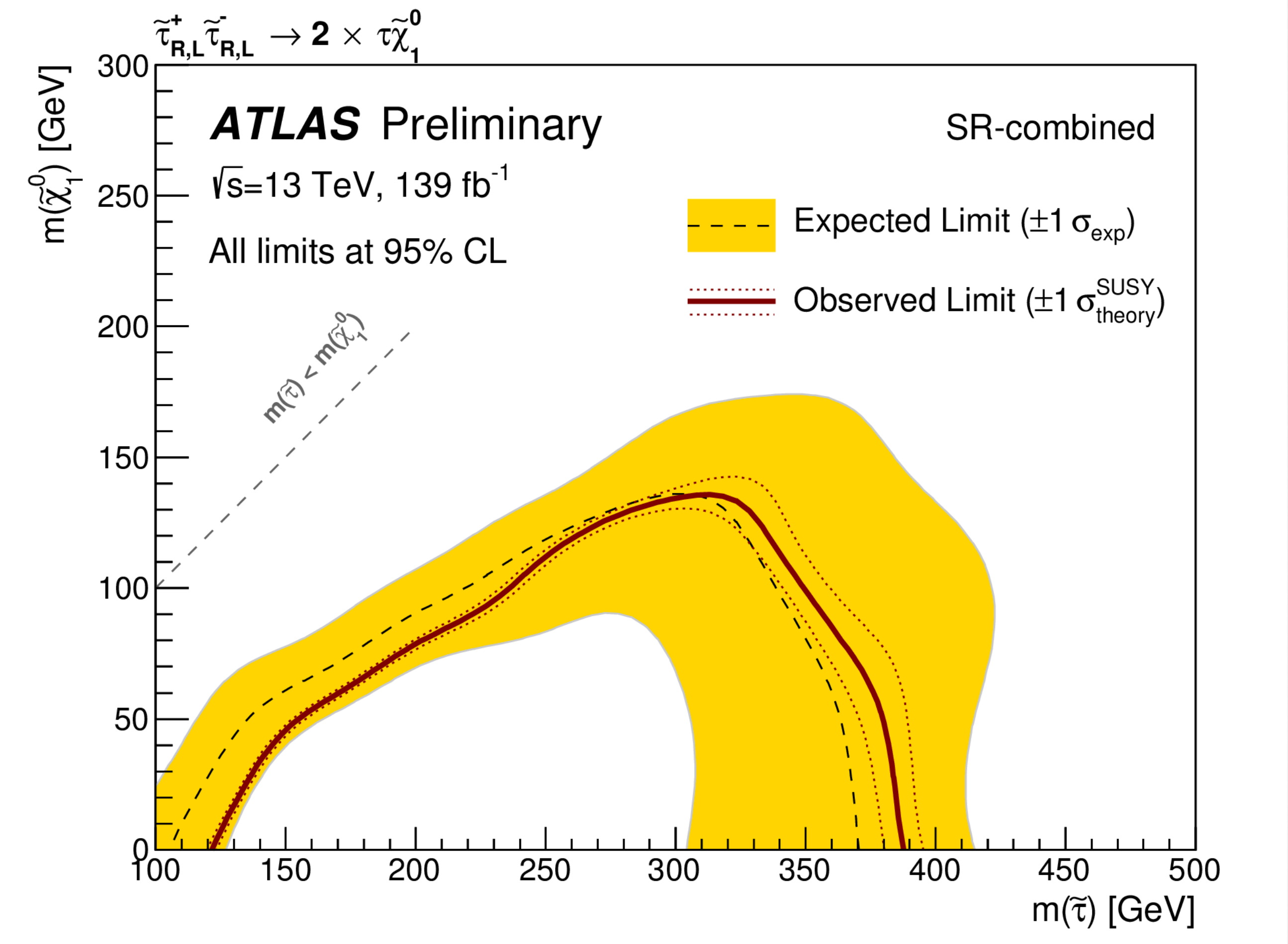
low mass



no excess observed

high mass





Combined left/right -handed staus

Sensitivity from 120 to 390 GeV

More details in Sonia Carra talk on Tuesday @ 13h30

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SUSY/

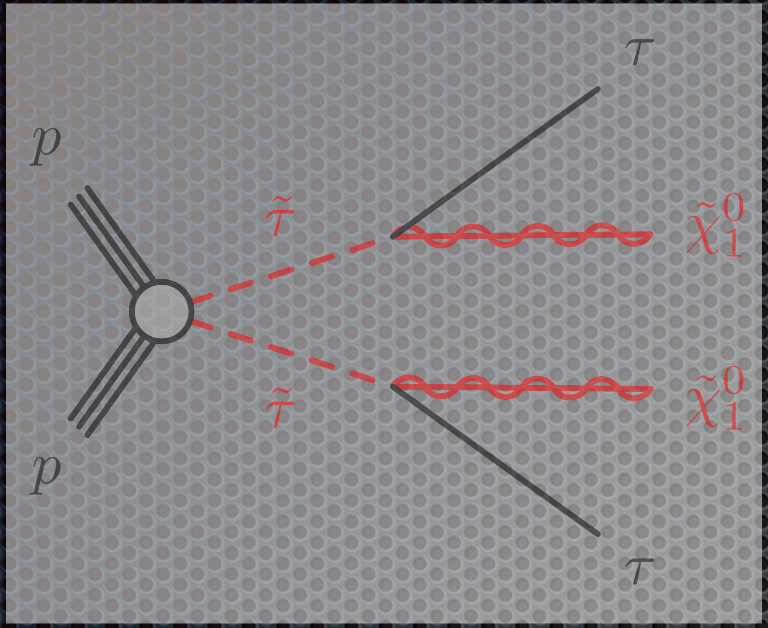
EWK ($\tilde{\ell}$,$\tilde{\nu}$,$\tilde{\chi}_1^{\pm}$)

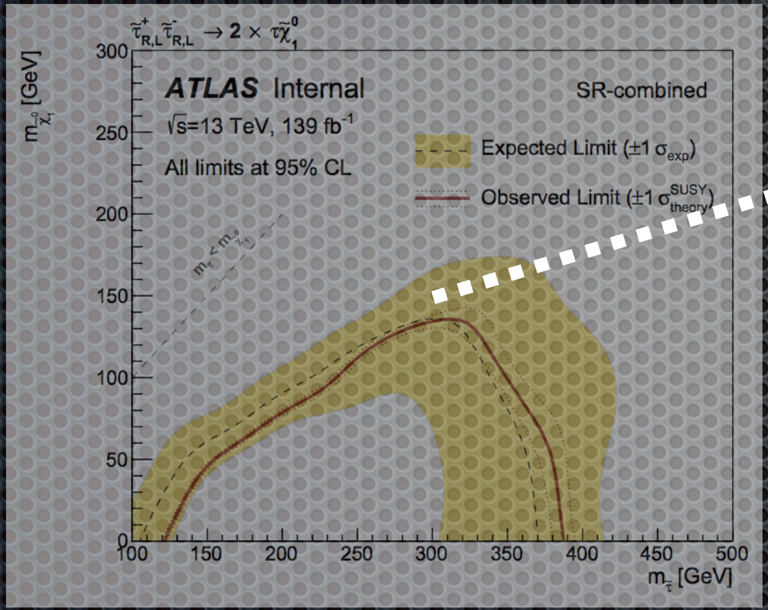
139 fb^{-1}

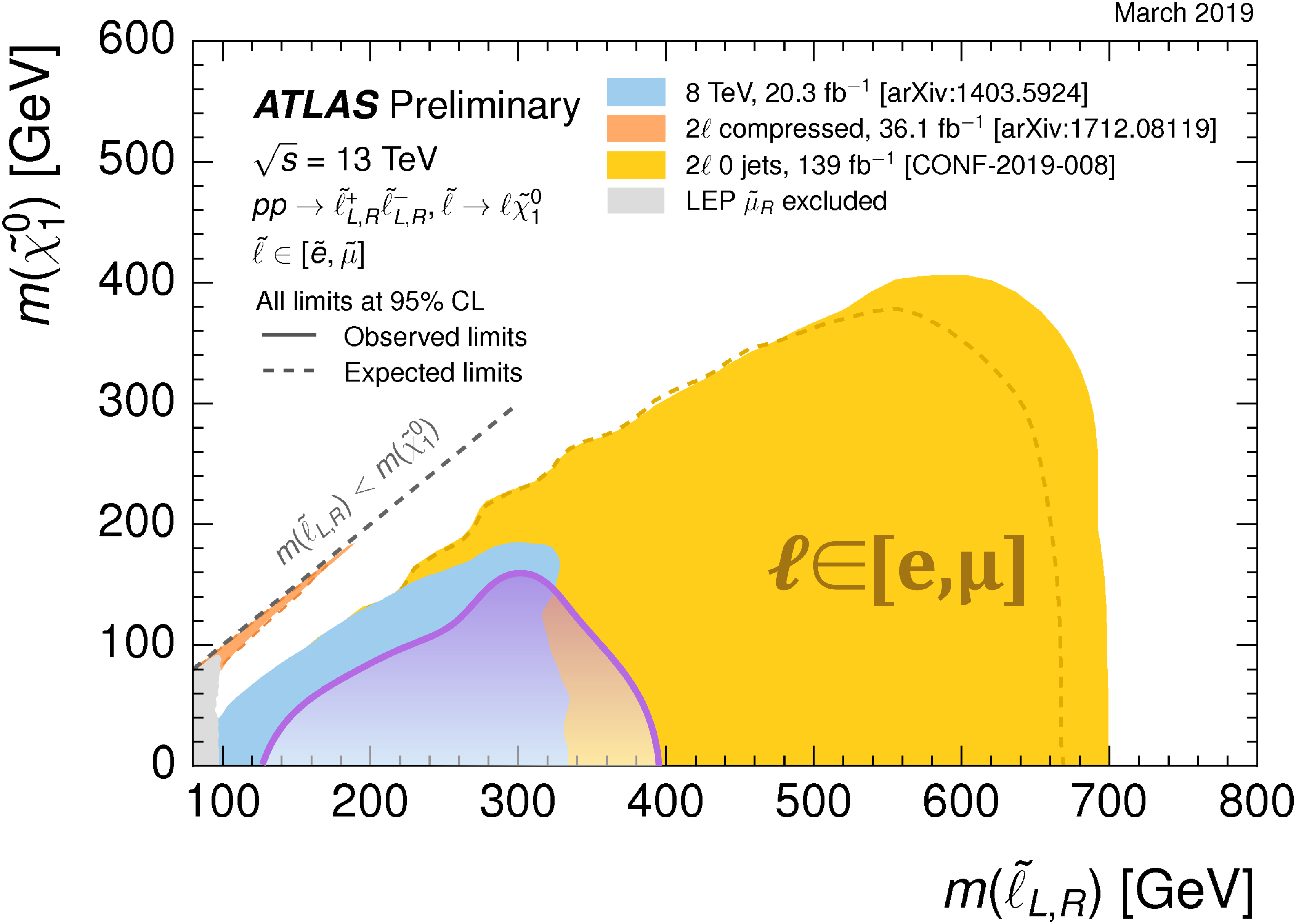
cut and count

multi-bin

Summary of Sleptons







Don't have staus included, but here's my attempt…

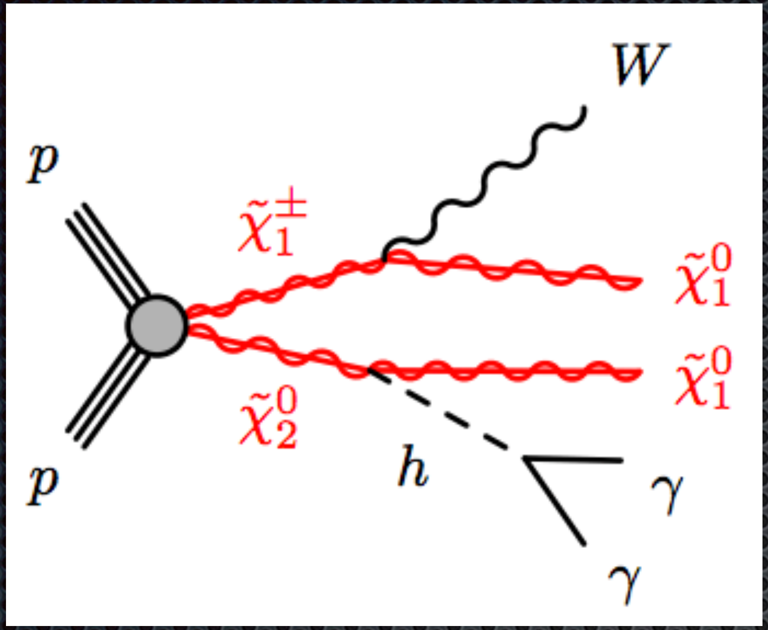
More details in Sonia Carra talk on Tuesday @ 13h30

EWK ($\tilde{\ell}$,$\tilde{\nu}$,$\tilde{\chi}_1^\pm$)

139 fb^{-1}

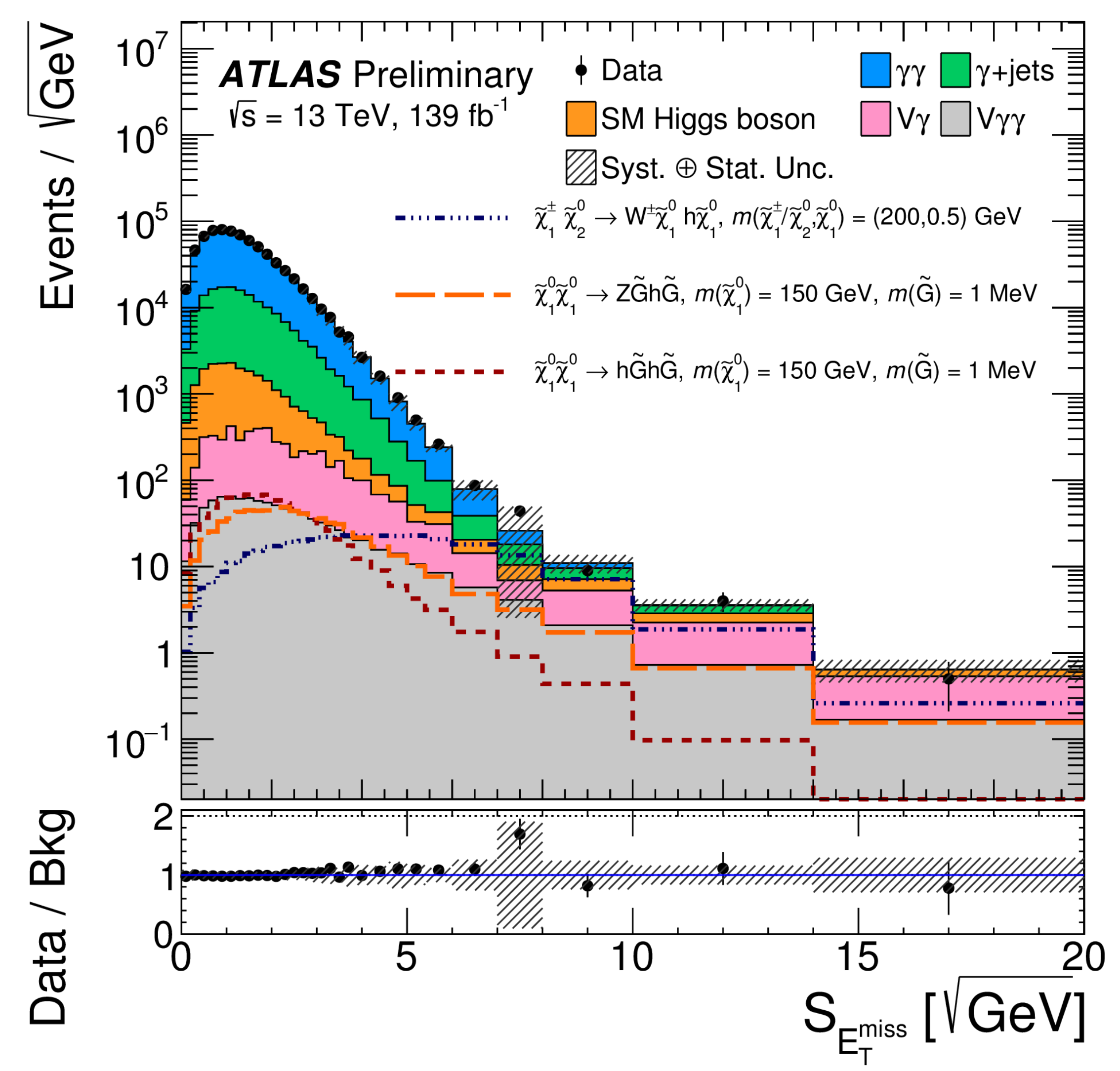
unbinned

EWKinos to photons via Higgs



… (more diagrams not included)

- MODEL PARAMETERS: $\tilde{\chi}_2^0$(=$\tilde{\chi}_1^\pm$), $\tilde{\chi}_1^0$
- FINAL STATE: ≥ 2 photons, MET
- THREE SIGNAL SCENARIOS (12 categorized regions):
  - $\tilde{\chi}_1^\pm \rightarrow W\tilde{\chi}_1^0$, $\tilde{\chi}_2^0 \rightarrow h\tilde{\chi}_1^0$ (optimized)
  - $\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \tilde{G}\tilde{G}Zh$ (GMSB)
  - $\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \tilde{G}\tilde{G}hh$ (GMSB)
- DOMINANT BACKGROUNDS: $h \rightarrow \gamma\gamma$, non-resonant photon processes ($\gamma\gamma$, γ+jet, $V\gamma$, $V\gamma\gamma$)
- CHALLENGE: non-resonant background modeling



12 categories binned in MET significance

More details in David Miller talk Tuesday @ 12h30

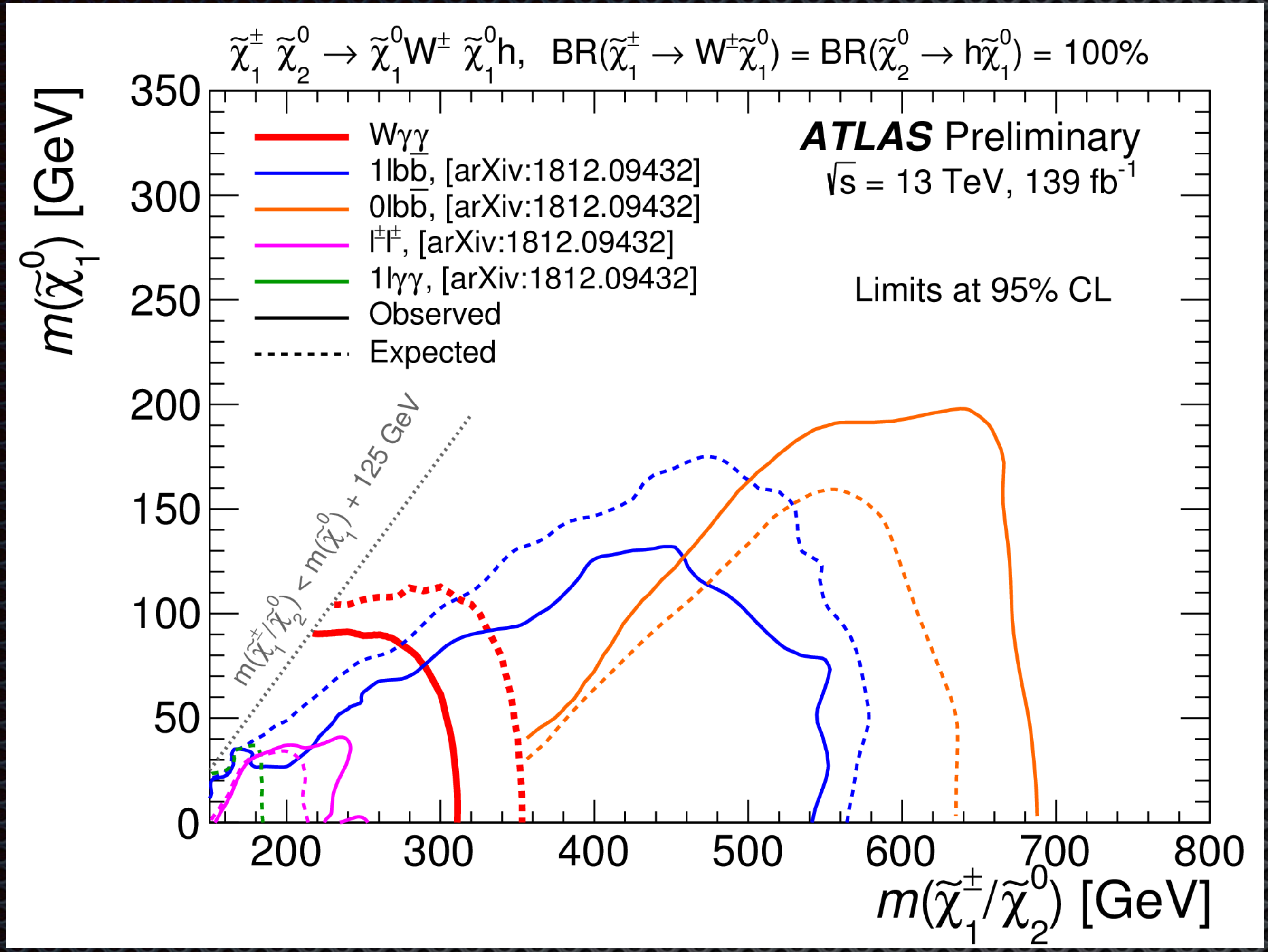
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-019/

EWK ($\tilde{\ell}$,$\tilde{\nu}$,$\tilde{\chi}_1^{\pm}$)

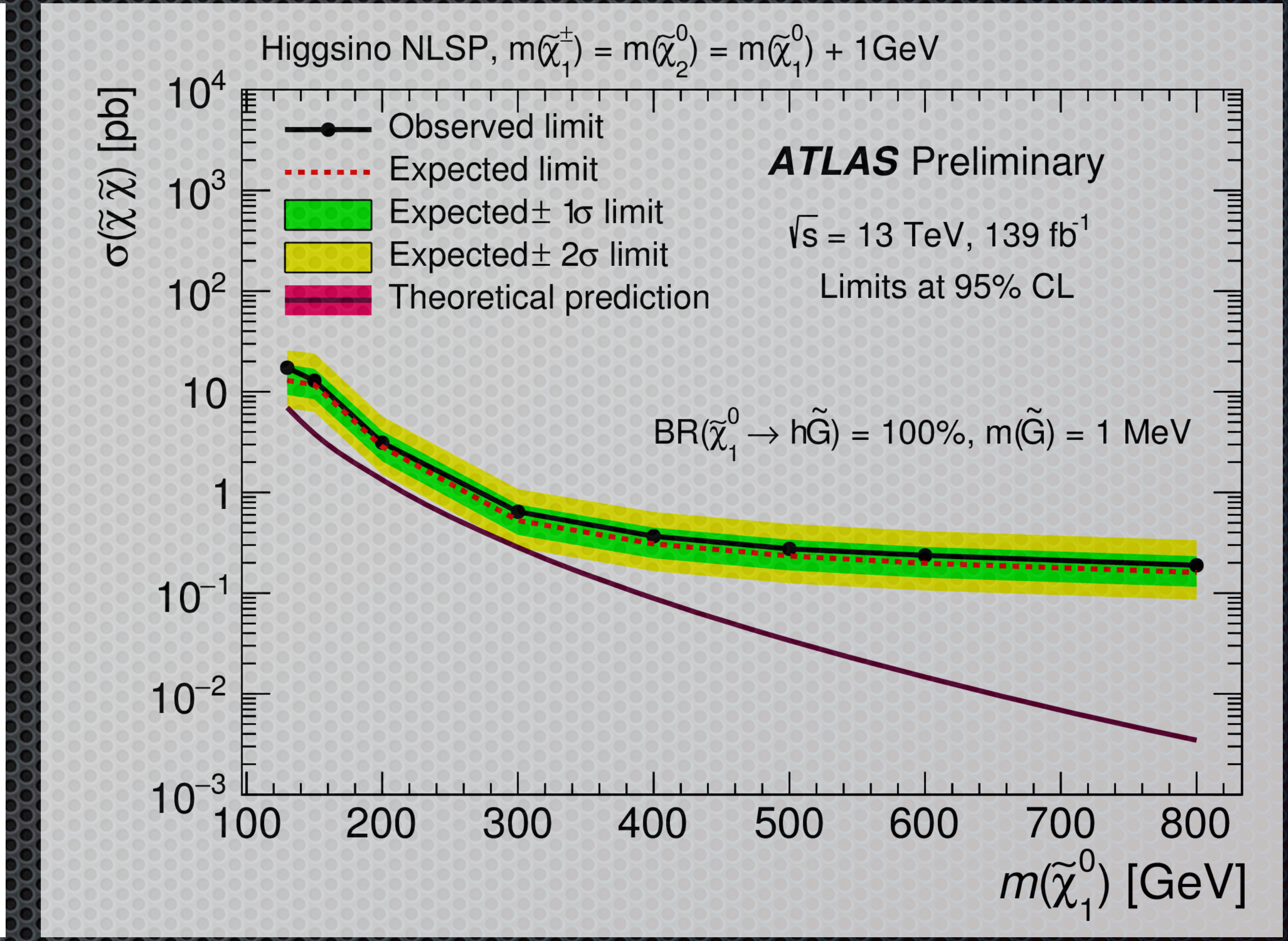
139 fb^{-1}

unbinned

EWKinos to photons via Higgs



diphoton triggers allow reach close to diagonal



interpretation of GMSB model

Sensitivity up to 315 GeV in m($\tilde{\chi}_1^{\pm}$,$\tilde{\chi}_2^0$)

More details in David Miller talk Tuesday @ 12h30

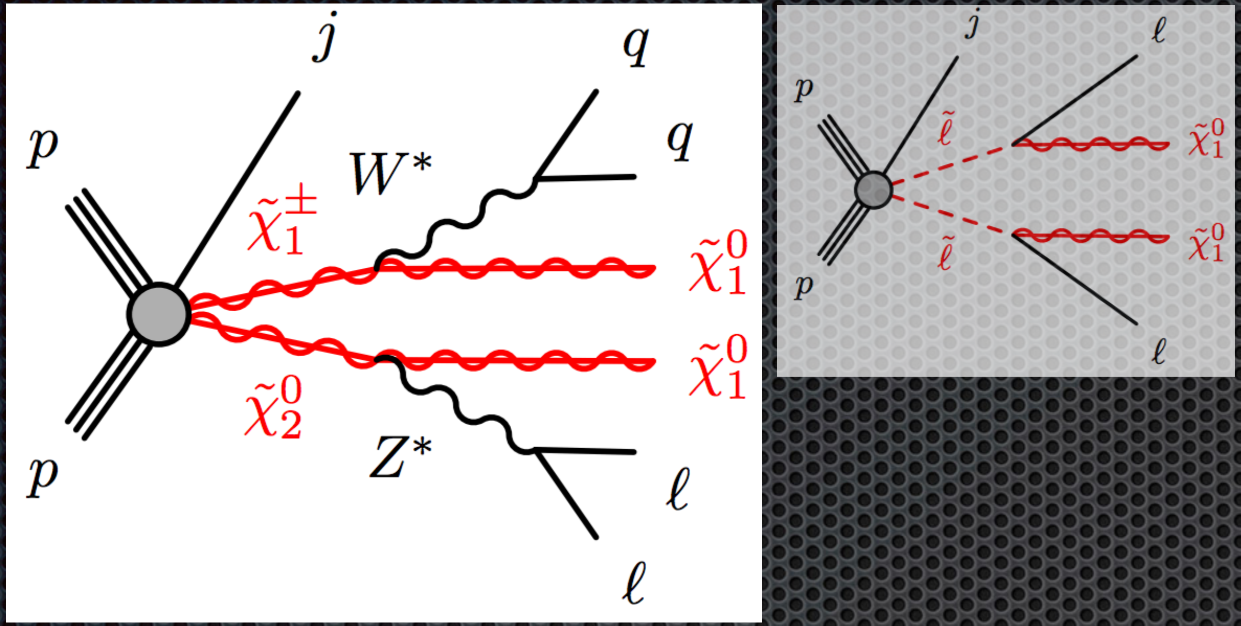
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-014/

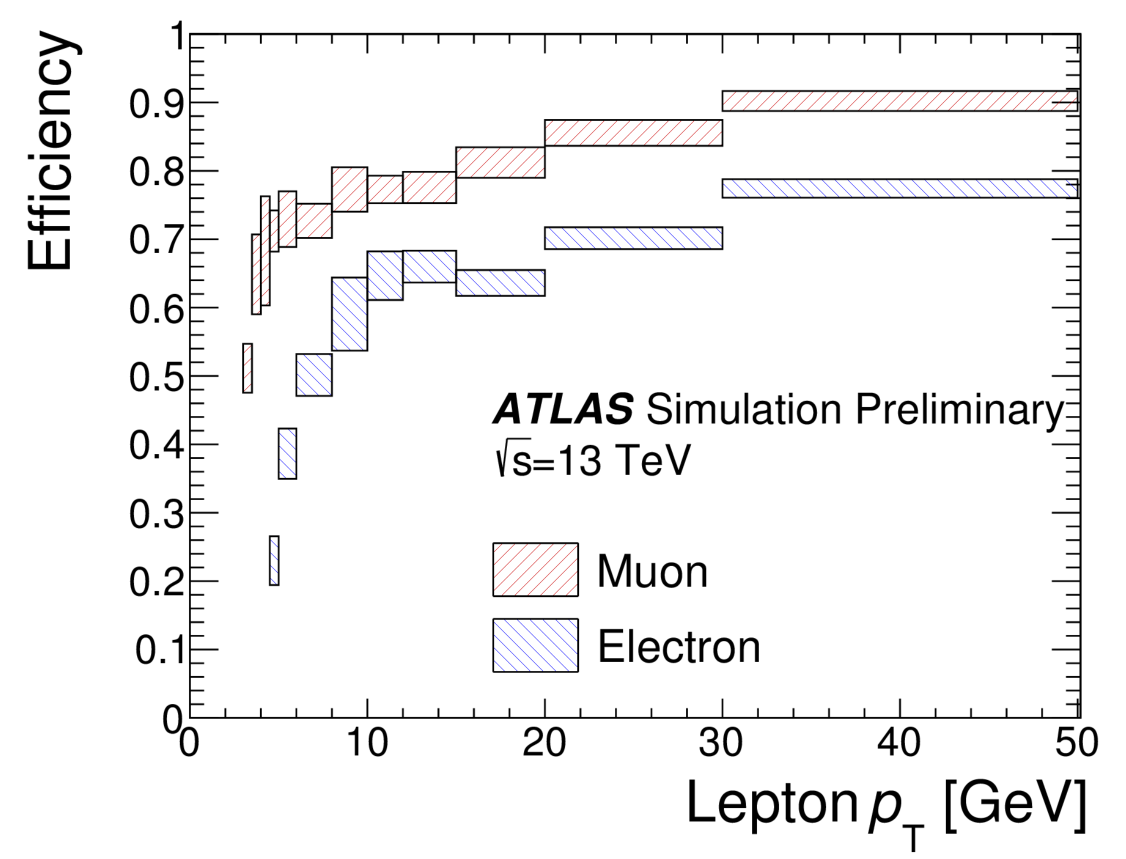
EWK ($\tilde{\ell},\tilde{\nu},\tilde{\chi}_1^\pm$)

139 fb^{-1}

multi-bin

Compressed EWK





reconstructing (very) soft leptons

- MODEL PARAMETERS: $\tilde{\chi}_2^0$, $\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm$, $\tilde{\ell}$
- FINAL STATE: =2 leptons [or 1 lepton+1 track] (OS-SF), MET, ISR jet
- TWO SIGNAL SCENARIOS (6 multi-bin regions):
    - $\tilde{\chi}_2^0 \to Z^* \tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm \to W^* \tilde{\chi}_1^0$
    - $\tilde{\ell} \to \ell \tilde{\chi}_1^0$, $\ell \in$[e,μ]
- DOMINANT BACKGROUNDS: $t\bar{t}$, singletop, Z(→ττ)+jets, diboson, multi-jet fake/nonprompt leptons
- CHALLENGE: compressed-mass search, fake/non-prompt lepton background

More details in Sezen Sekmen talk Thursday @ 12h00

OS-SF: *Opposite-Sign, Same-Flavor*

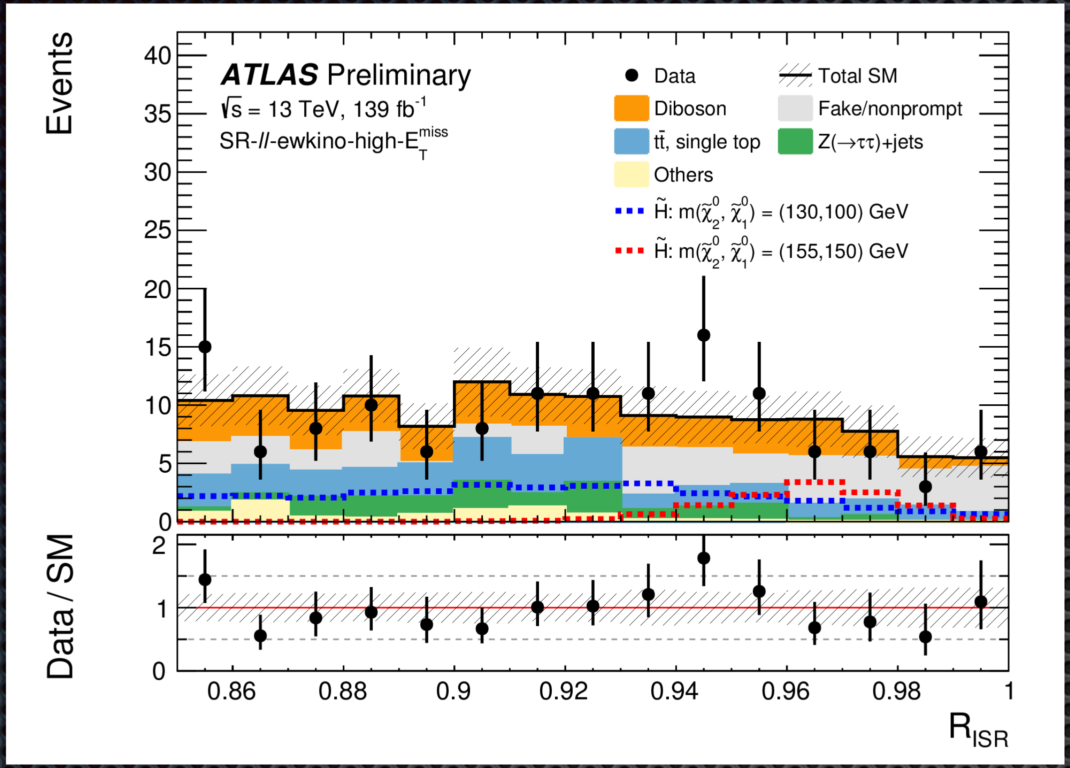
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-014/

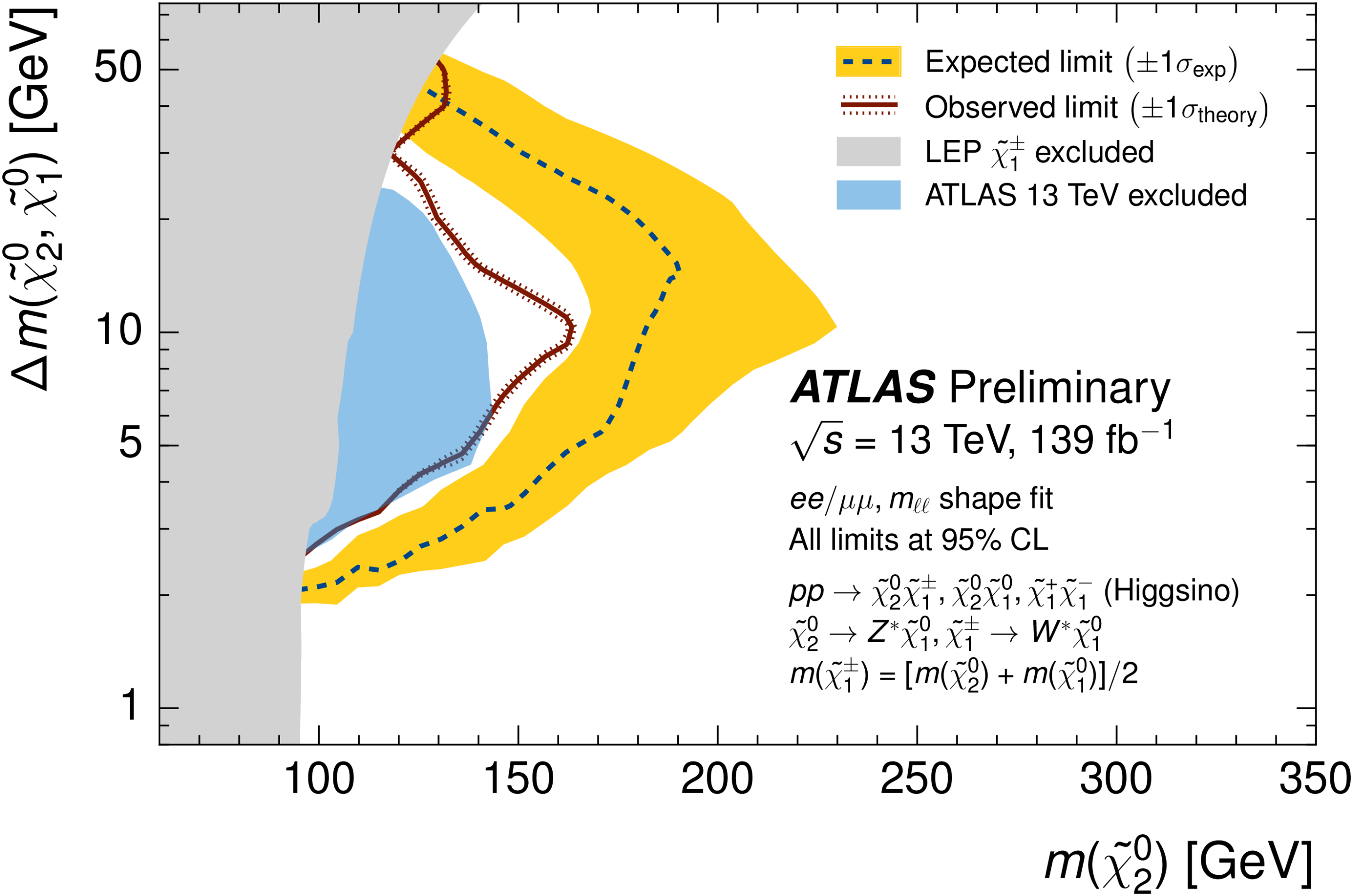
EWK ($\tilde{\ell}$,$\tilde{\nu}$,$\tilde{\chi}_1^\pm$)

139 fb^{-1}

multi-bin

Compressed EWK





R_{ISR} compares MET and ISR hemisphere momentum using recursive jigsaw reconstruction

Shape fit to mll/mT2 distributions

Sensitive to 160 GeV at mass splitting of 10 GeV

(also results for slepton searches not included in this talk)

More details in Sezen Sekmen talk Thursday @ 12h00

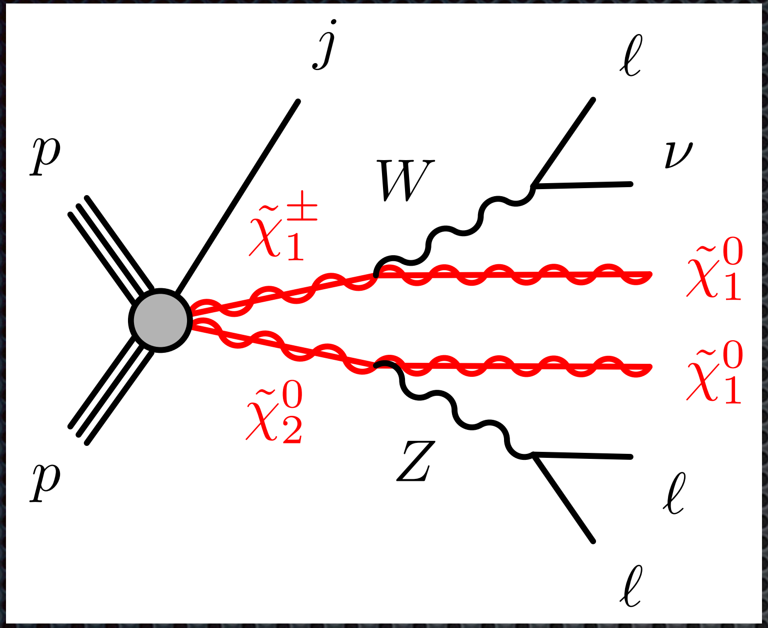
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-020/

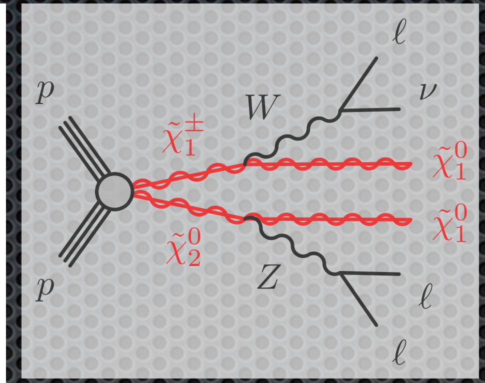
EWK ($\tilde{\ell}$,$\tilde{\nu}$,$\tilde{\chi}_1^\pm$)

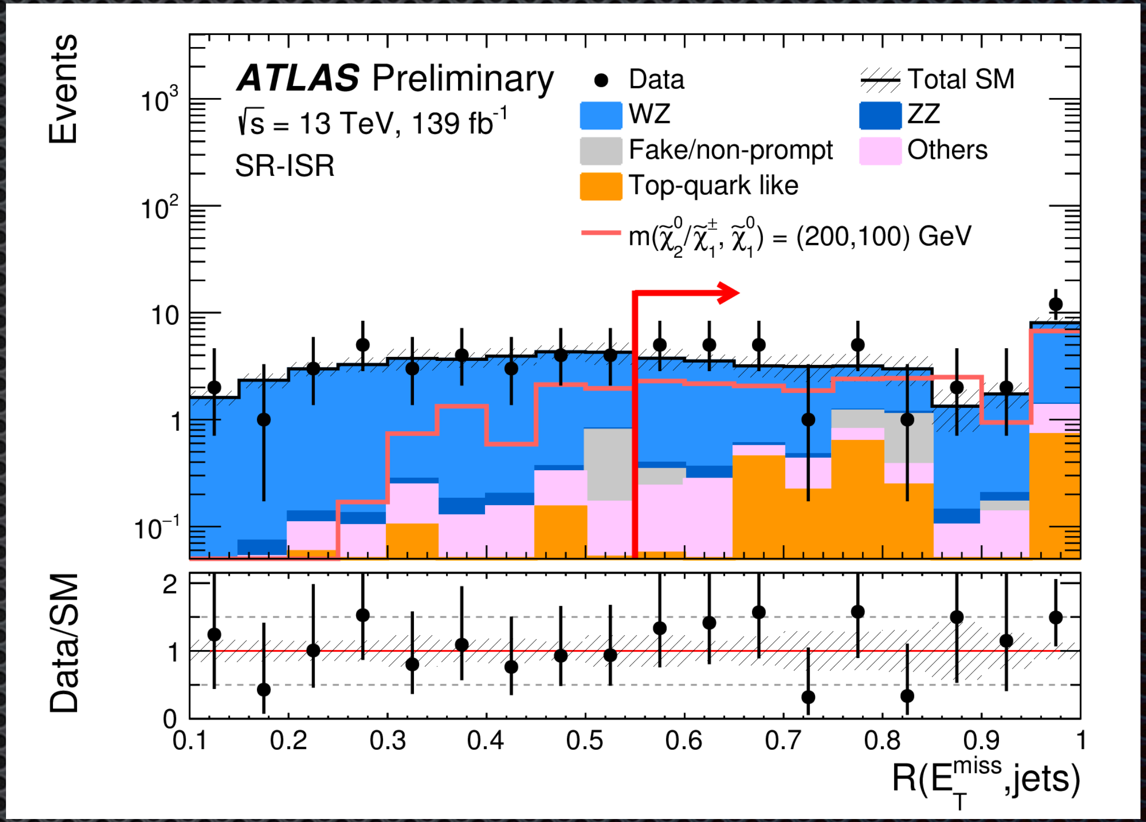
139 fb^{-1}

cut and count

3-lepton with (emulated) jigsaw







- MODEL PARAMETERS: $\tilde{\chi}_2^0$, $\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm$, $\tilde{\ell}$
- FINAL STATE: =3 leptons (OS-SF), MET, (and ISR jet)
- TWO SIGNAL SCENARIOS (6 multi-bin regions):
  - $\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm \to W\tilde{\chi}_1^0$ (with ISR)
  - $\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm \to W\tilde{\chi}_1^0$ (without ISR)
- DOMINANT BACKGROUNDS: **fully-eptonic WZ**
- CHALLENGE: normalization of WZ, theory systematics of WZ

emulates R_{ISR} jigsaw variable that was used in compressed

OS-SF: *Opposite-Sign, Same-Flavor*

More details in David Miller talk Tuesday @ 12h30

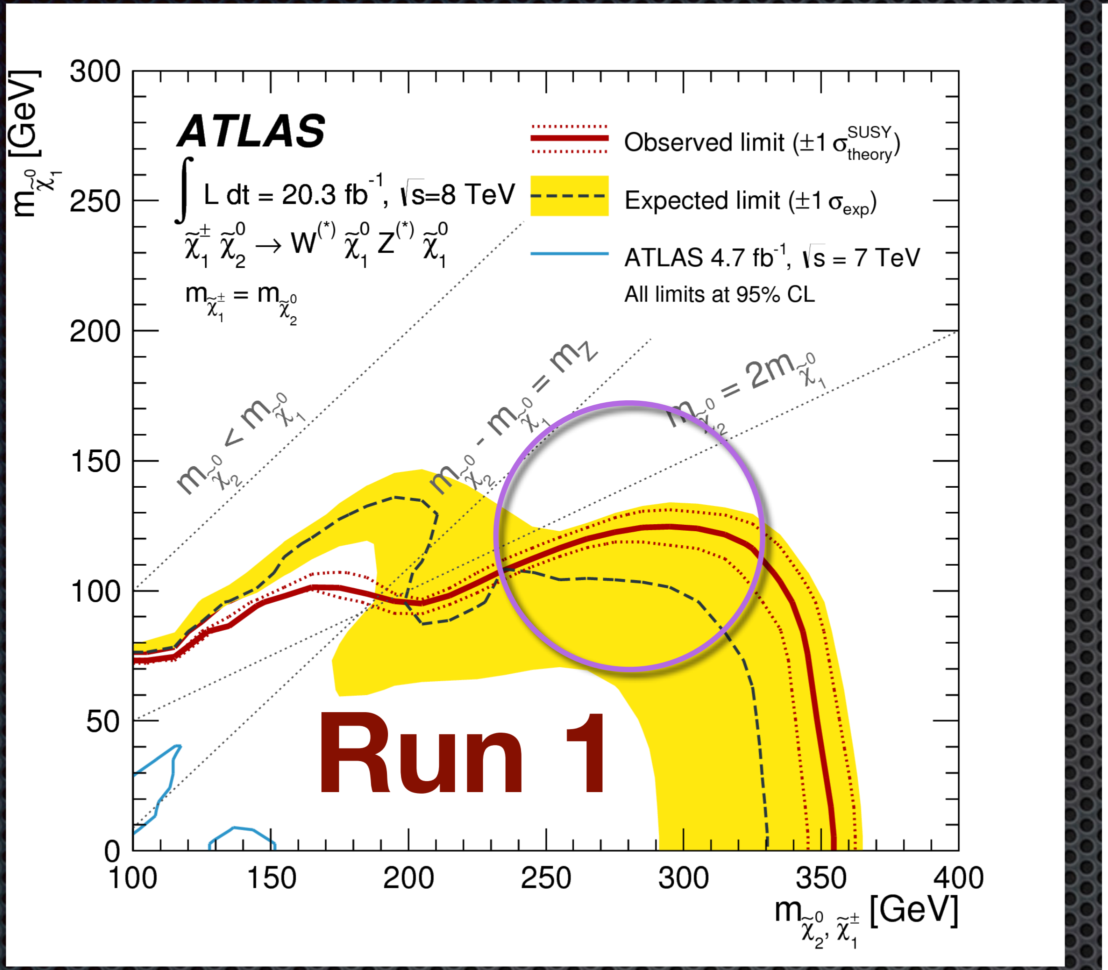
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-020/
https://arxiv.org/abs/1402.7029

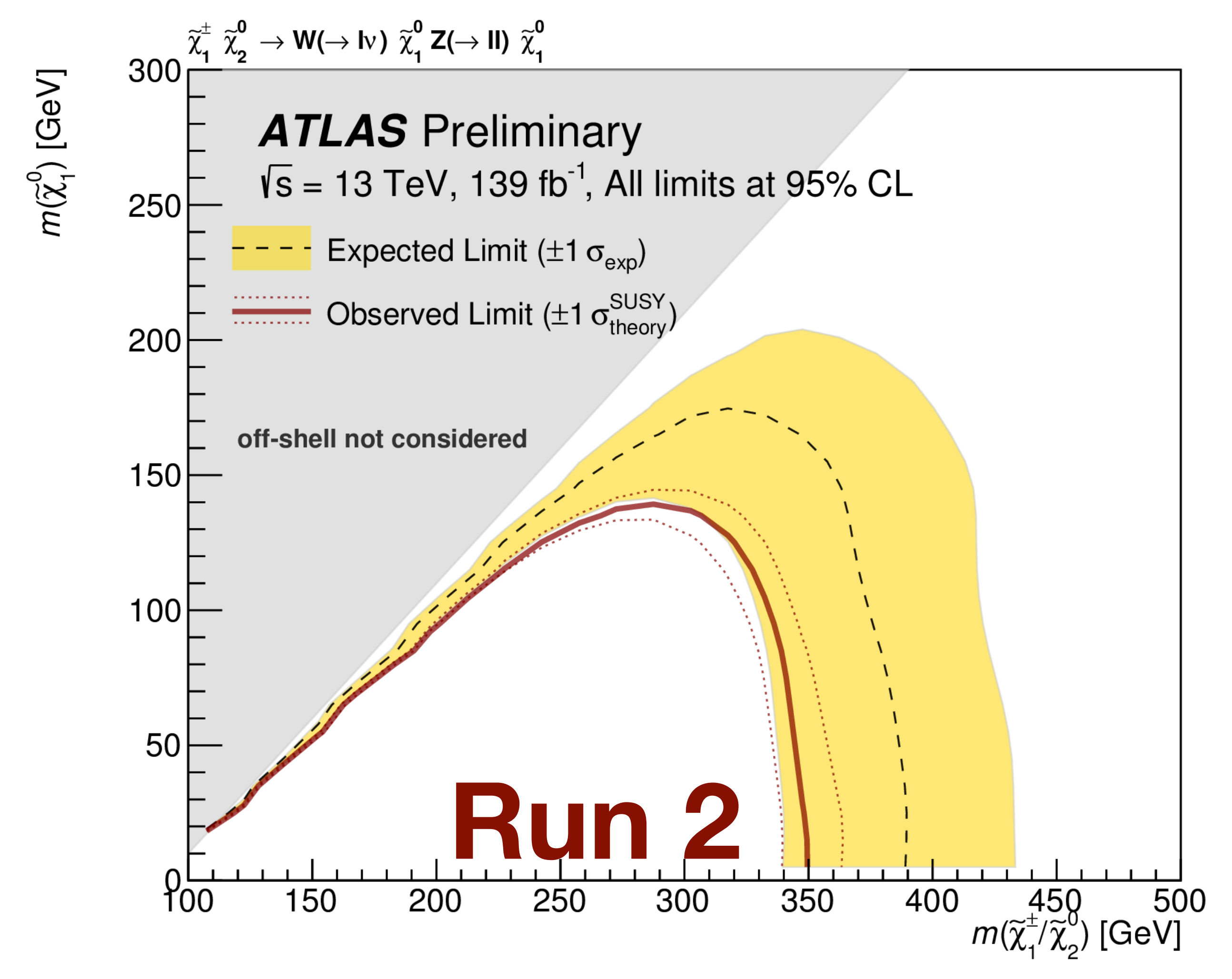
EWK $(\tilde{\ell},\tilde{\nu},\tilde{\chi}_1^{\pm})$

139 fb^{-1}

cut and count

3-lepton with (emulated) jigsaw





Sensitive to 350 GeV

(pushes the reach at lower mass-splitting)

More details in David Miller talk Tuesday @ 12h30

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SUSY/

EWK ($\tilde{\ell}$,$\tilde{\nu}$,$\tilde{\chi}_1^{\pm}$)

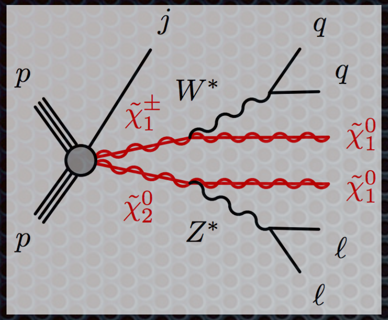
139 fb^{-1}

cut and count

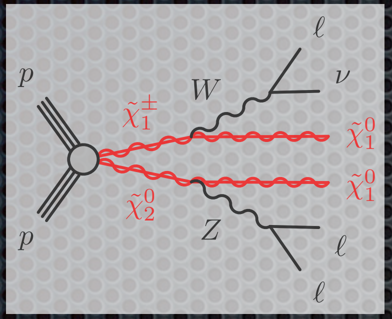
multi-bin

unbinned

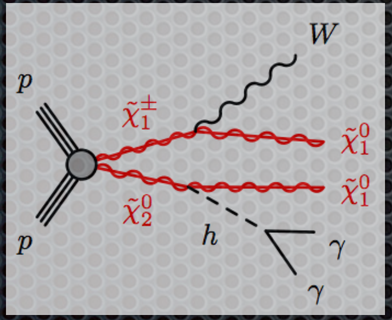
Summary of (some) EWK



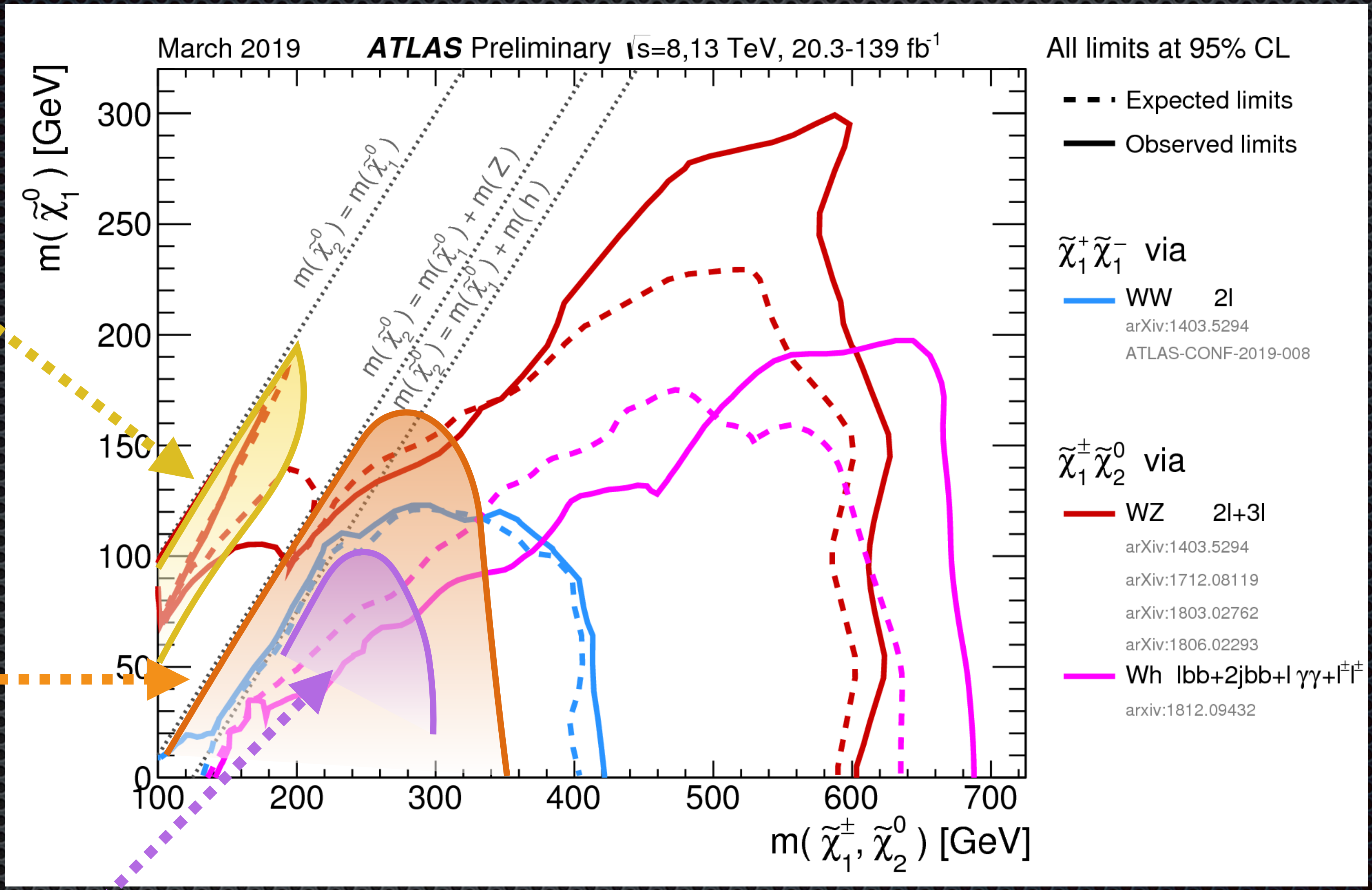
Compressed



3L jigsaw



EWKinos to photons



Here's my attempt

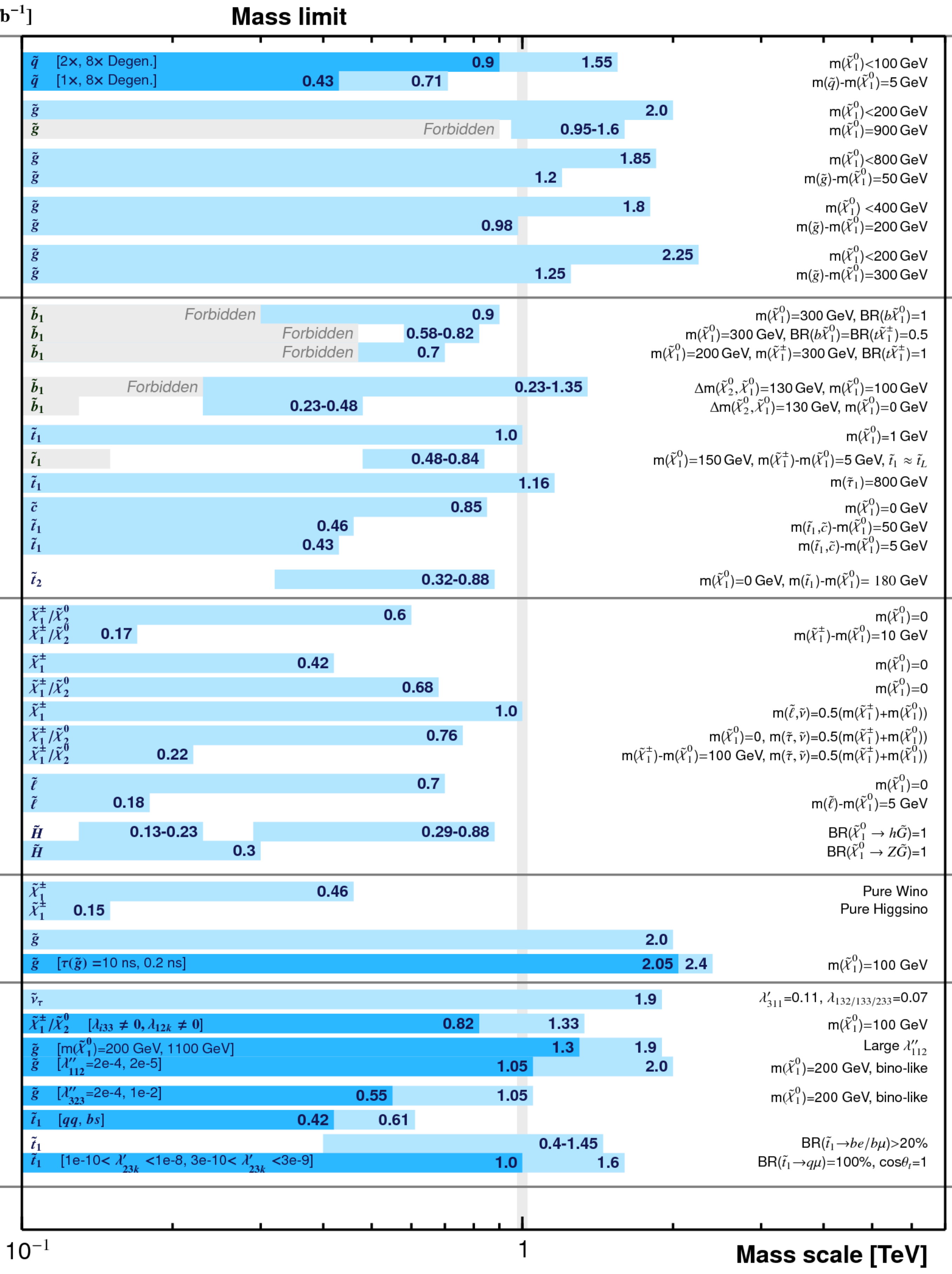
More details in David Miller talk Tuesday @ 12h30 and Sezen Sekmen talk Thursday @ 12h00

ATLAS SUSY Searches* - 95% CL Lower Limits

March 2019

ATLAS Preliminary

$\sqrt{s}$ = 13 TeV

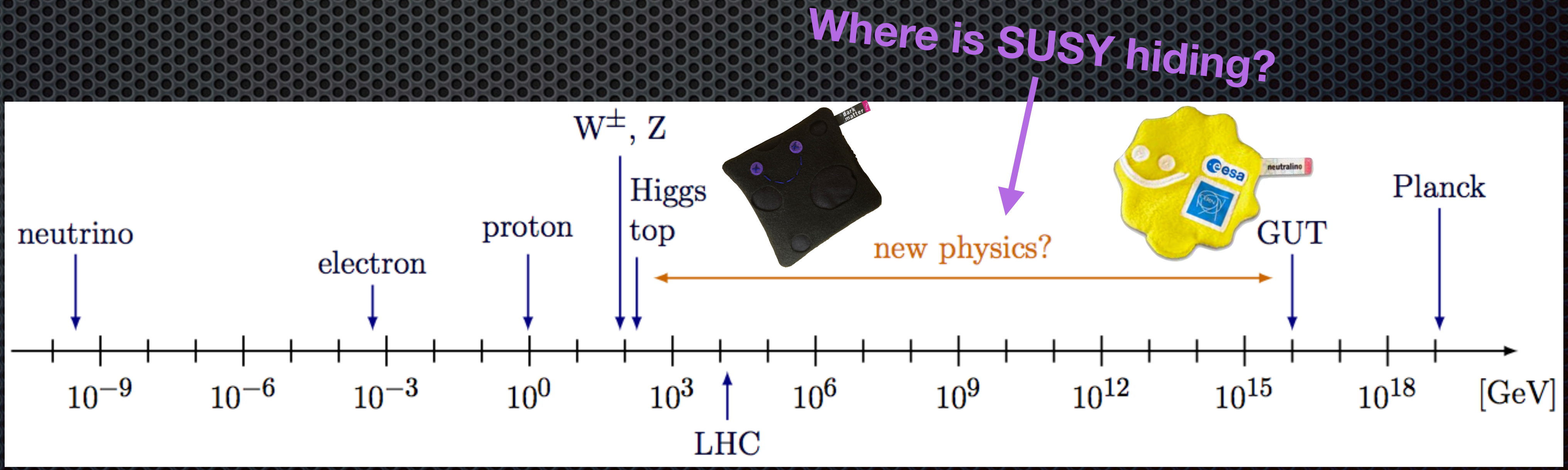


	Model	Signature			$\int\mathcal{L}\,dt$ [fb^{-1}]	Mass limit			Reference
Inclusive Searches	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}^0_1$	0 e,μ	2-6 jets	$E_T^{\rm miss}$	36.1	$\tilde{q}$	[2×, 8× Degen.] 0.9 1.55	m($\tilde{\chi}^0_1$)<100 GeV	1712.02332
		mono-jet	1-3 jets	$E_T^{\rm miss}$	36.1	$\tilde{q}$	[1×, 8× Degen.] 0.43 0.71	m($\tilde{q}$)-m($\tilde{\chi}^0_1$)=5 GeV	1711.03301
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}^0_1$	0 e,μ	2-6 jets	$E_T^{\rm miss}$	36.1	$\tilde{g}$	2.0	m($\tilde{\chi}^0_1$)<200 GeV	1712.02332
						$\tilde{g}$	Forbidden 0.95-1.6	m($\tilde{\chi}^0_1$)=900 GeV	1712.02332
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}(\ell\ell)\tilde{\chi}^0_1$	3 e,μ	4 jets		36.1	$\tilde{g}$	1.85	m($\tilde{\chi}^0_1$)<800 GeV	1706.03731
		$ee,\mu\mu$	2 jets	$E_T^{\rm miss}$	36.1	$\tilde{g}$	1.2	m($\tilde{g}$)-m($\tilde{\chi}^0_1$)=50 GeV	1805.11381
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}^0_1$	0 e,μ	7-11 jets	$E_T^{\rm miss}$	36.1	$\tilde{g}$	1.8	m($\tilde{\chi}^0_1$) <400 GeV	1708.02794
		3 e,μ	4 jets		36.1	$\tilde{g}$	0.98	m($\tilde{g}$)-m($\tilde{\chi}^0_1$)=200 GeV	1706.03731
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}^0_1$	0-1 e,μ	3 b	$E_T^{\rm miss}$	79.8	$\tilde{g}$	2.25	m($\tilde{\chi}^0_1$)<200 GeV	ATLAS-CONF-2018-041
		3 e,μ	4 jets		36.1	$\tilde{g}$	1.25	m($\tilde{g}$)-m($\tilde{\chi}^0_1$)=300 GeV	1706.03731
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}^0_1/t\tilde{\chi}^\pm_1$		Multiple		36.1	$\tilde{b}_1$	Forbidden 0.9	m($\tilde{\chi}^0_1$)=300 GeV, BR($b\tilde{\chi}^0_1$)=1	1708.09266, 1711.03301
			Multiple		36.1	$\tilde{b}_1$	Forbidden 0.58-0.82	m($\tilde{\chi}^0_1$)=300 GeV, BR($b\tilde{\chi}^0_1$)=BR($t\tilde{\chi}^\pm_1$)=0.5	1708.09266
			Multiple		36.1	$\tilde{b}_1$	Forbidden 0.7	m($\tilde{\chi}^0_1$)=200 GeV, m($\tilde{\chi}^\pm_1$)=300 GeV, BR($t\tilde{\chi}^\pm_1$)=1	1706.03731
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}^0_2\to bh\tilde{\chi}^0_1$	0 e,μ	6 b	$E_T^{\rm miss}$	139	$\tilde{b}_1$	Forbidden 0.23-1.35	Δm($\tilde{\chi}^0_2$,$\tilde{\chi}^0_1$)=130 GeV, m($\tilde{\chi}^0_1$)=100 GeV	SUSY-2018-31
						$\tilde{b}_1$	0.23-0.48	Δm($\tilde{\chi}^0_2$,$\tilde{\chi}^0_1$)=130 GeV, m($\tilde{\chi}^0_1$)=0 GeV	SUSY-2018-31
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}^0_1$ or $t\tilde{\chi}^0_1$	0-2 e,μ	0-2 jets/1-2 b	$E_T^{\rm miss}$	36.1	$\tilde{t}_1$	1.0	m($\tilde{\chi}^0_1$)=1 GeV	1506.08616, 1709.04183, 1711.11520
	$\tilde{t}_1\tilde{t}_1$, Well-Tempered LSP		Multiple		36.1	$\tilde{t}_1$	0.48-0.84	m($\tilde{\chi}^0_1$)=150 GeV, m($\tilde{\chi}^\pm_1$)-m($\tilde{\chi}^0_1$)=5 GeV, $\tilde{t}_1\approx\tilde{t}_L$	1709.04183, 1711.11520
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to\tilde{\tau}_1 b\nu$, $\tilde{\tau}_1\to\tau\tilde{G}$	1 τ + 1 e,μ,τ	2 jets/1 b	$E_T^{\rm miss}$	36.1	$\tilde{t}_1$	1.16	m($\tilde{\tau}_1$)=800 GeV	1803.10178
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}^0_1$ / $\tilde{c}\tilde{c}$, $\tilde{c}\to c\tilde{\chi}^0_1$	0 e,μ	2 c	$E_T^{\rm miss}$	36.1	$\tilde{c}$	0.85	m($\tilde{\chi}^0_1$)=0 GeV	1805.01649
						$\tilde{t}_1$	0.46	m($\tilde{t}_1$,$\tilde{c}$)-m($\tilde{\chi}^0_1$)=50 GeV	1805.01649
		0 e,μ	mono-jet	$E_T^{\rm miss}$	36.1	$\tilde{t}_1$	0.43	m($\tilde{t}_1$,$\tilde{c}$)-m($\tilde{\chi}^0_1$)=5 GeV	1711.03301
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+h$	1-2 e,μ	4 b	$E_T^{\rm miss}$	36.1	$\tilde{t}_2$	0.32-0.88	m($\tilde{\chi}^0_1$)=0 GeV, m($\tilde{t}_1$)-m($\tilde{\chi}^0_1$)= 180 GeV	1706.03986
EW direct	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2$ via WZ	2-3 e,μ		$E_T^{\rm miss}$	36.1	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$	0.6	m($\tilde{\chi}^0_1$)=0	1403.5294, 1806.02293
		$ee,\mu\mu$	≥ 1	$E_T^{\rm miss}$	36.1	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$	0.17	m($\tilde{\chi}^\pm_1$)-m($\tilde{\chi}^0_1$)=10 GeV	1712.08119
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1$ via WW	2 e,μ		$E_T^{\rm miss}$	139	$\tilde{\chi}^\pm_1$	0.42	m($\tilde{\chi}^0_1$)=0	ATLAS-CONF-2019-008
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2$ via Wh	0-1 e,μ	2 b	$E_T^{\rm miss}$	36.1	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$	0.68	m($\tilde{\chi}^0_1$)=0	1812.09432
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1$ via $\tilde{\ell}_L/\tilde{\nu}$	2 e,μ		$E_T^{\rm miss}$	139	$\tilde{\chi}^\pm_1$	1.0	m($\tilde{\ell}$,$\tilde{\nu}$)=0.5(m($\tilde{\chi}^\pm_1$)+m($\tilde{\chi}^0_1$))	ATLAS-CONF-2019-008
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1/\tilde{\chi}^0_2$, $\tilde{\chi}^+_1\to\tilde{\tau}_1\nu(\tau\tilde{\nu})$, $\tilde{\chi}^0_2\to\tilde{\tau}_1\tau(\nu\tilde{\nu})$	2 τ		$E_T^{\rm miss}$	36.1	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$	0.76	m($\tilde{\chi}^0_1$)=0, m($\tilde{\tau}$, $\tilde{\nu}$)=0.5(m($\tilde{\chi}^\pm_1$)+m($\tilde{\chi}^0_1$))	1708.07875
						$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$	0.22	m($\tilde{\chi}^\pm_1$)-m($\tilde{\chi}^0_1$)=100 GeV, m($\tilde{\tau}$, $\tilde{\nu}$)=0.5(m($\tilde{\chi}^\pm_1$)+m($\tilde{\chi}^0_1$))	1708.07875
	$\tilde{\ell}_{\rm L,R}\tilde{\ell}_{\rm L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}^0_1$	2 e,μ	0 jets	$E_T^{\rm miss}$	139	$\tilde{\ell}$	0.7	m($\tilde{\chi}^0_1$)=0	ATLAS-CONF-2019-008
		2 e,μ	≥ 1	$E_T^{\rm miss}$	36.1	$\tilde{\ell}$	0.18	m($\tilde{\ell}$)-m($\tilde{\chi}^0_1$)=5 GeV	1712.08119
	$\tilde{H}\tilde{H}$, $\tilde{H}\to h\tilde{G}/Z\tilde{G}$	0 e,μ	≥ 3 b	$E_T^{\rm miss}$	36.1	$\tilde{H}$	0.13-0.23 0.29-0.88	BR($\tilde{\chi}^0_1\to h\tilde{G}$)=1	1806.04030
		4 e,μ	0 jets	$E_T^{\rm miss}$	36.1	$\tilde{H}$	0.3	BR($\tilde{\chi}^0_1\to Z\tilde{G}$)=1	1804.03602
Long-lived particles	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^\pm_1$	Disapp. trk	1 jet	$E_T^{\rm miss}$	36.1	$\tilde{\chi}^\pm_1$	0.46	Pure Wino	1712.02118
						$\tilde{\chi}^\pm_1$	0.15	Pure Higgsino	ATL-PHYS-PUB-2017-019
	Stable $\tilde{g}$ R-hadron		Multiple		36.1	$\tilde{g}$	2.0		1902.01636,1808.04095
	Metastable $\tilde{g}$ R-hadron, $\tilde{g}\to qq\tilde{\chi}^0_1$		Multiple		36.1	$\tilde{g}$	[$\tau(\tilde{g})$ =10 ns, 0.2 ns] 2.05 2.4	m($\tilde{\chi}^0_1$)=100 GeV	1710.04901,1808.04095
RPV	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu$,$e\tau$,$\mu\tau$			3.2	$\tilde{\nu}_\tau$	1.9	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1/\tilde{\chi}^0_2\to WW/Z\ell\ell\ell\ell\nu\nu$	4 e,μ	0 jets	$E_T^{\rm miss}$	36.1	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$	[$\lambda_{i33}\neq 0, \lambda_{12k}\neq 0$] 0.82 1.33	m($\tilde{\chi}^0_1$)=100 GeV	1804.03602
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to qqq$		4-5 large-R jets		36.1	$\tilde{g}$	[m($\tilde{\chi}^0_1$)=200 GeV, 1100 GeV] 1.3 1.9	Large λ''_{112}	1804.03568
			Multiple		36.1	$\tilde{g}$	[λ''_{112}=2e-4, 2e-5] 1.05 2.0	m($\tilde{\chi}^0_1$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}\tilde{t}$, $\tilde{t}\to t\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to tbs$		Multiple		36.1	$\tilde{g}$	[λ''_{323}=2e-4, 1e-2] 0.55 1.05	m($\tilde{\chi}^0_1$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$		2 jets + 2 b		36.7	$\tilde{t}_1$	[qq, bs] 0.42 0.61		1710.07171
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to q\ell$	2 e,μ	2 b		36.1	$\tilde{t}_1$	0.4-1.45	BR($\tilde{t}_1\to be/b\mu$)>20%	1710.05544
		1 μ	DV		136	$\tilde{t}_1$	[1e-10< λ'_{23k} <1e-8, 3e-10< λ'_{23k} <3e-9] 1.0 1.6	BR($\tilde{t}_1\to q\mu$)=100%, cosθ_t=1	ATLAS-CONF-2019-006

*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

Conclusion

- Vibrant SUSY programme in ATLAS
- Starting to release papers with the full Run 2 dataset
- No SUSY found (yet!)

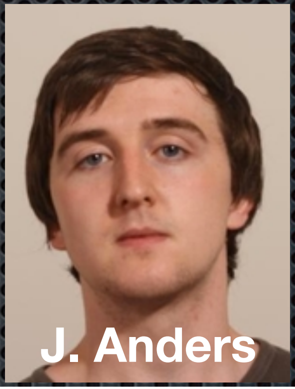


Where is SUSY hiding?

For more details…

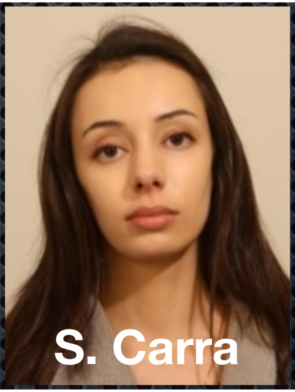
- MONDAY
  - **Julien Maurer @ 13h00** (Strong/Inclusive gluinos)
  - **John Anders @ 13h40** (3rd generation)


J. Maurer


J. Anders

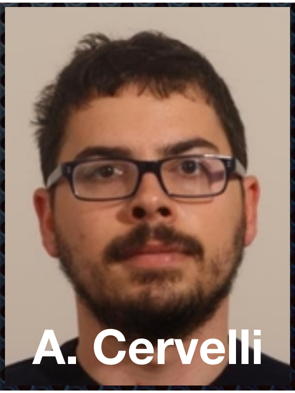
- TUESDAY
  - **David Miller @ 12h30** (EWK/Charginos)
  - **Sonia Carra @ 13h30** (EWK/Sleptons)


D. Miller


S. Carra

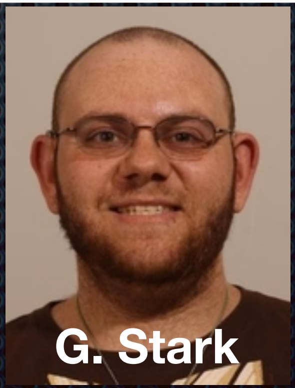
- WEDNESDAY
  - **Christophe Clement @ 13h40** (Techniques)
  - **Alberto Cervelli @ 14h40** (HL-LHC)


C. Clement


A. Cervelli

- THURSDAY
  - **Sezen Sekmen @ 12h00** (Compressed)
  - **Giordon Stark @ 12h40** (Likelihood Preservation)
  - **Hidetoshi Otono @ 14h50** (Long-lived)
  - **Javier Berlingen @ 15h50** (RPV)


S. Sekmen


G. Stark


H. Otono

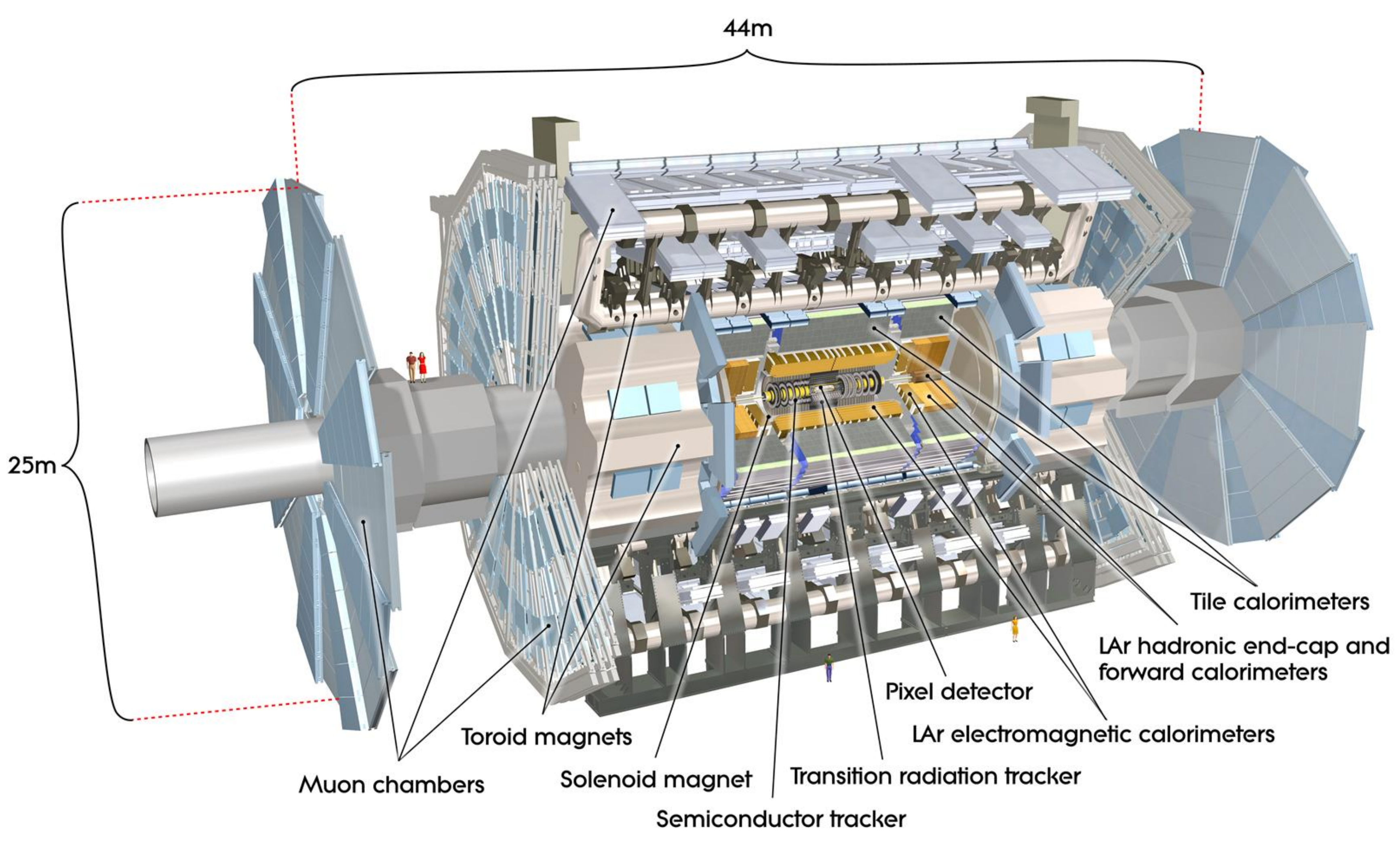

J. Berlingen

Backup

The ATLAS Detector

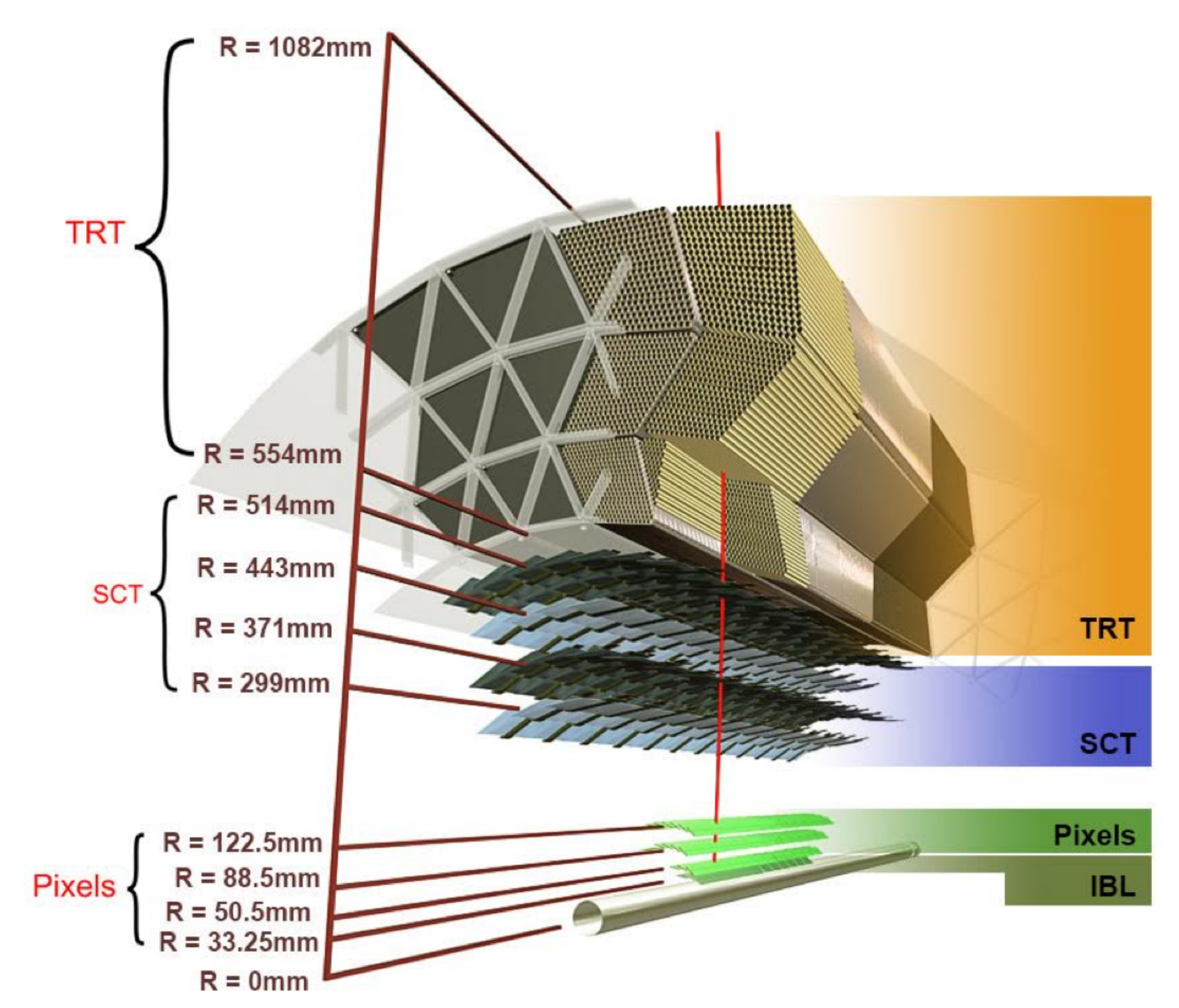
Four major subsystems

- Inner Detector
- Muon Spectrometer
- Calorimeters
- Trigger



A single complex detector compromised of many subsystems that total: 100 million electronic channels and 3000km of cables

Tracking — Inner Detector

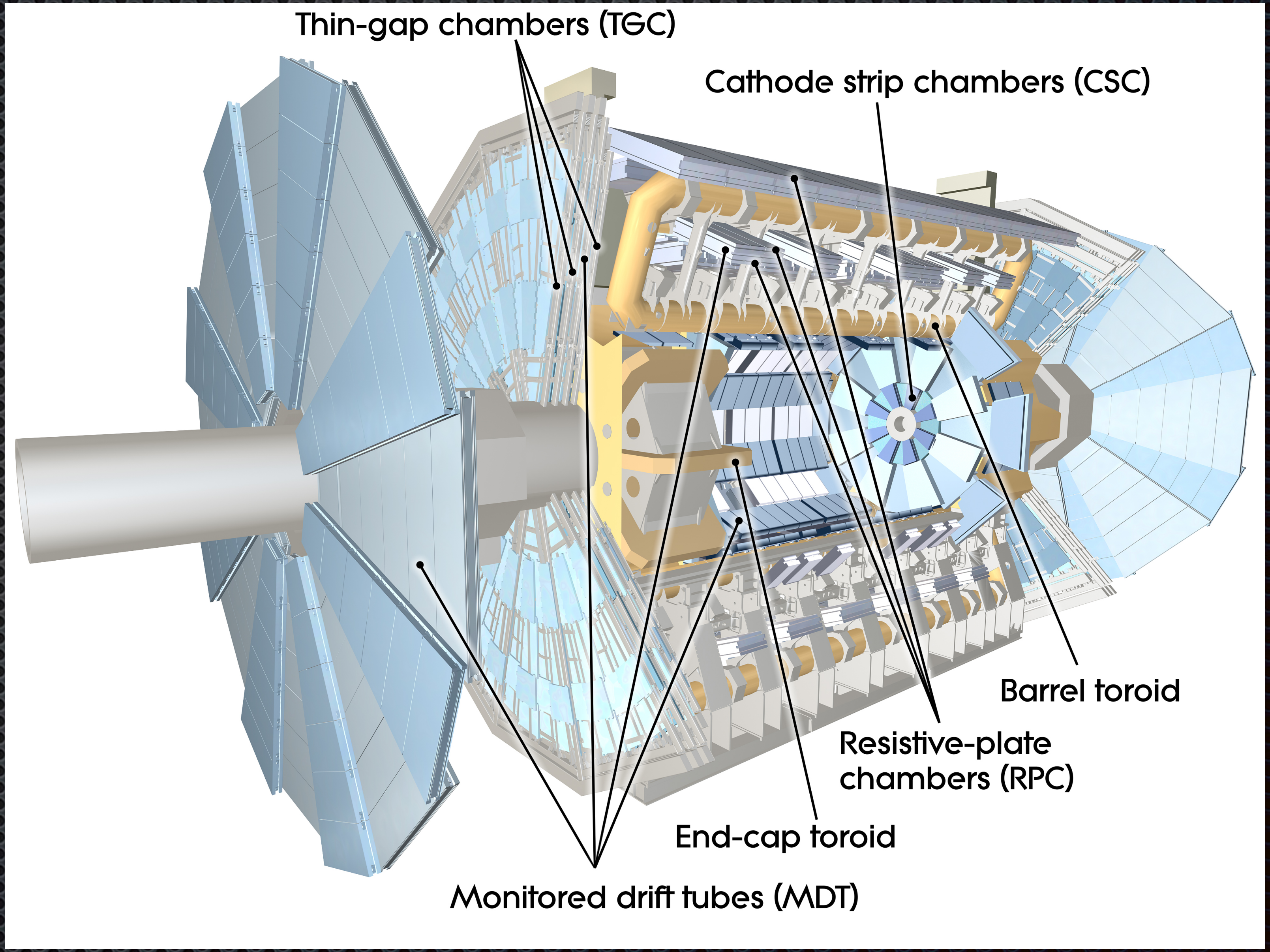


- Contained within a 2T solenoid magnet
- Four subsystems:
  - Insertable B-layer
  - Pixel Detector
  - Semiconductor Tracker
  - Transition Radiation Tracker
- Identifies charged particle tracks
- Reconstructs primary and secondary vertices

Coverage for $|\eta| < 2.5$

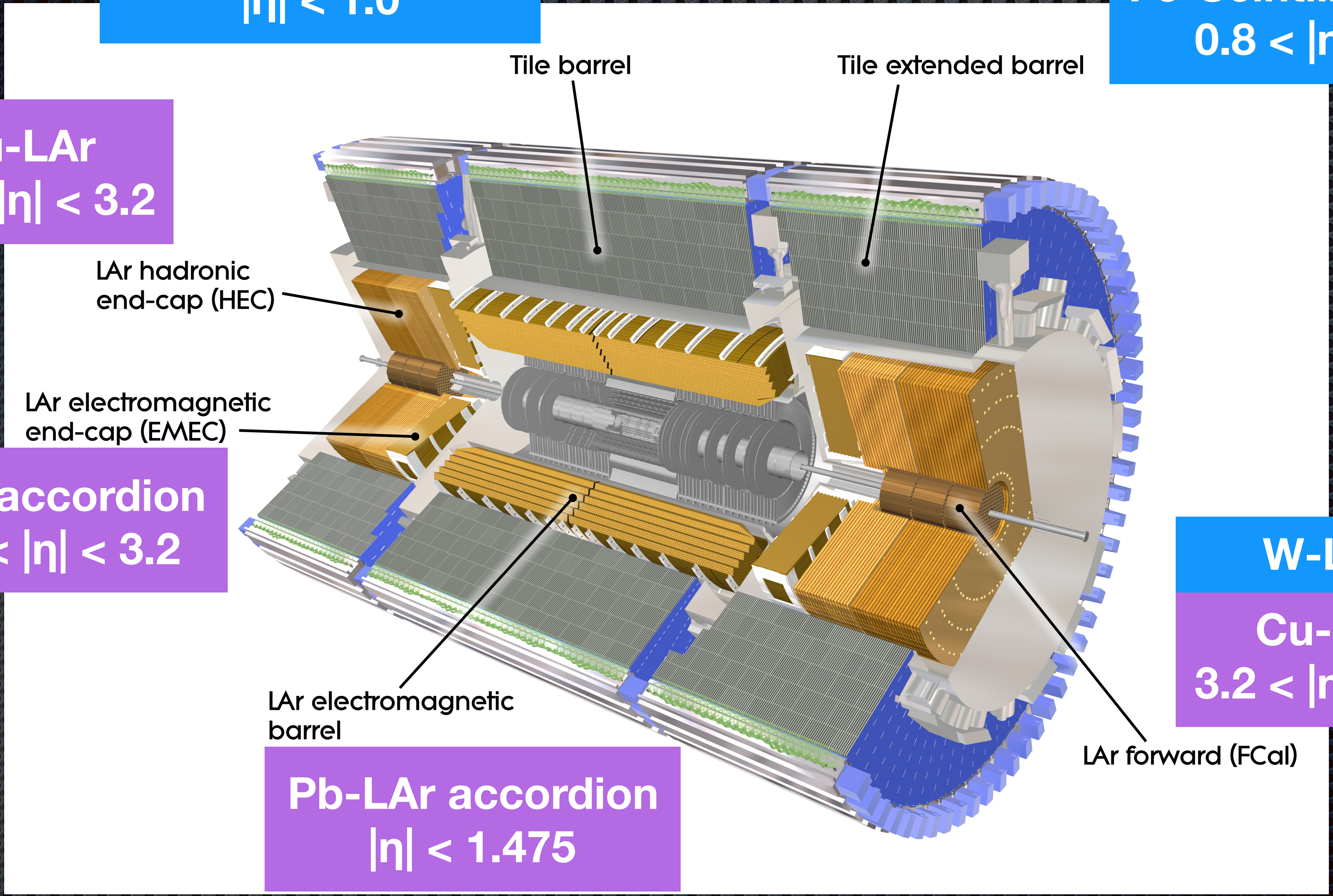
Tracking — Muon Spectrometer

- Uses large, superconducting 4T toroid magnets
- Four subsystems:
  - Monitored Drift Tubes
  - Cathode Strip Chambers
  - Resistive Plate Chambers
  - Thin-Gap Chambers
- Precision measurements of muons



Coverage for $|\eta| < 2.7$

Calorimetry (I)



Fe-Scintillating Tile
$|\eta| < 1.0$

Fe-Scintillating Tile
$0.8 < |\eta| < 1.7$

Cu-LAr
$1.5 < |\eta| < 3.2$

Pb-LAr accordion
$1.375 < |\eta| < 3.2$

W-LAr

Cu-LAr
$3.2 < |\eta| < 4.9$

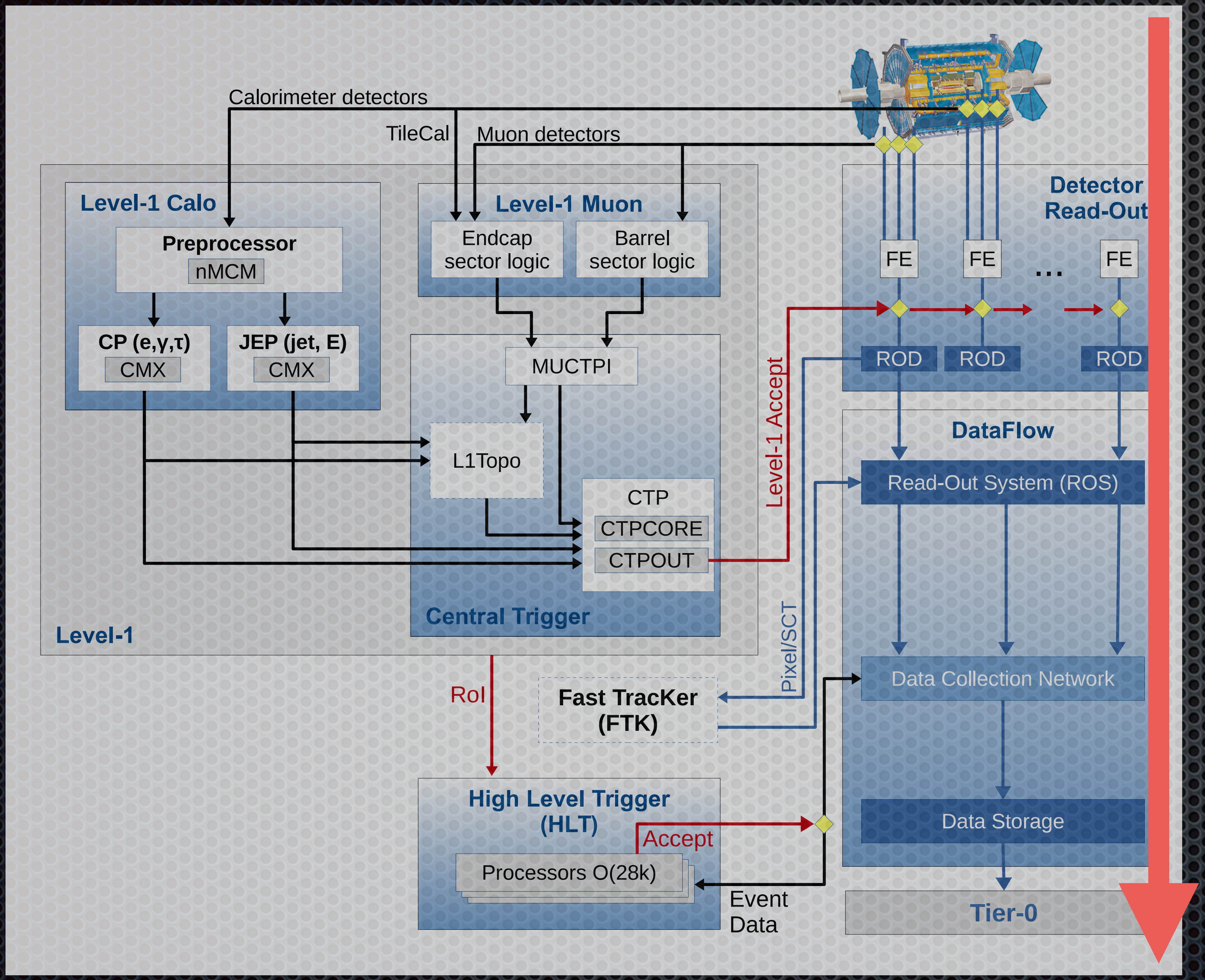
Pb-LAr accordion
$|\eta| < 1.475$

- **hadronic** and **electromagnetic** sampling calorimeters
- Alternating layers of **dense "absorber" material** (Lead, Copper, Tungsten, Steel) to reduce particle energy and **"active" material** (Liquid-Argon, Plastic Scintillator) to provide detectable signal

Will discuss planned upgrades later in this talk

Calorimetry and Trigger

Largely “junk” events **40MHz**



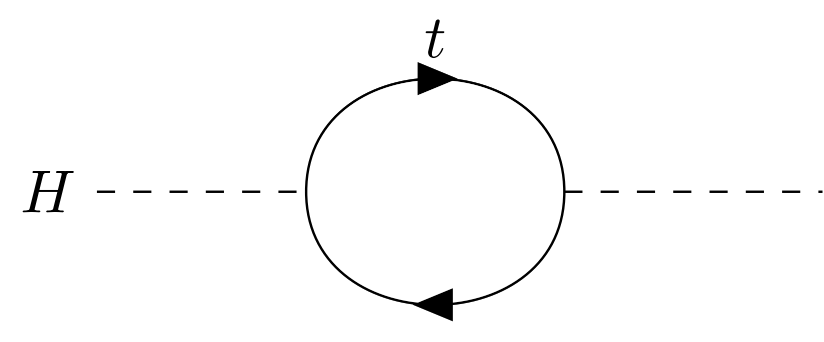
Largely “interesting” events **~1.5kHz**

- The trigger system uses data from the calorimeters
- Bunches of protons collide every 25 ns (**40 MHz** rate)
  - Need to reduce this rate to **~1 kHz** for writing to disk
- **Goal**: retain efficiency of processes sought for in ATLAS
  - Need a lot of smart rejection
  - Need it fast and performant
  - Keep rates under control

Higgs Mass?

- The process of renormalizing a theory, such as Standard Model, up to some chosen energy scale incorporates "loop terms" which corrects properties of the theory
  - **What are the corrections to the Higgs mass m_0?**

- Standard Model: mass of particle is strength of Higgs field coupling (e.g. Yukawa interaction)
  - The top quark, with the largest mass, has the largest correction to the Higgs mass



$$\Delta m_H^2 = -\frac{|\lambda_t|^2}{8\pi^2}\Lambda_{\mathrm{UV}}^2 + \ldots$$

- If the Higgs boson is observed at the electroweak scale, 125 GeV, then the Higgs mass m_0 needs to be **finely-tuned** to almost-perfectly cancel out with the $(10^{19})^2$ correction!
  - This correction is proportional to the square of the cut-off scale — the Planck scale

This **fine-tuning** is certainly **not natural**

“It was logical to start by looking at Supersymmetry. When you go to Rome you visit the Vatican or the Colosseum, not some weird corner of the city.”

— M. Mangano #SMatLHC2019

Beyond the Standard Model

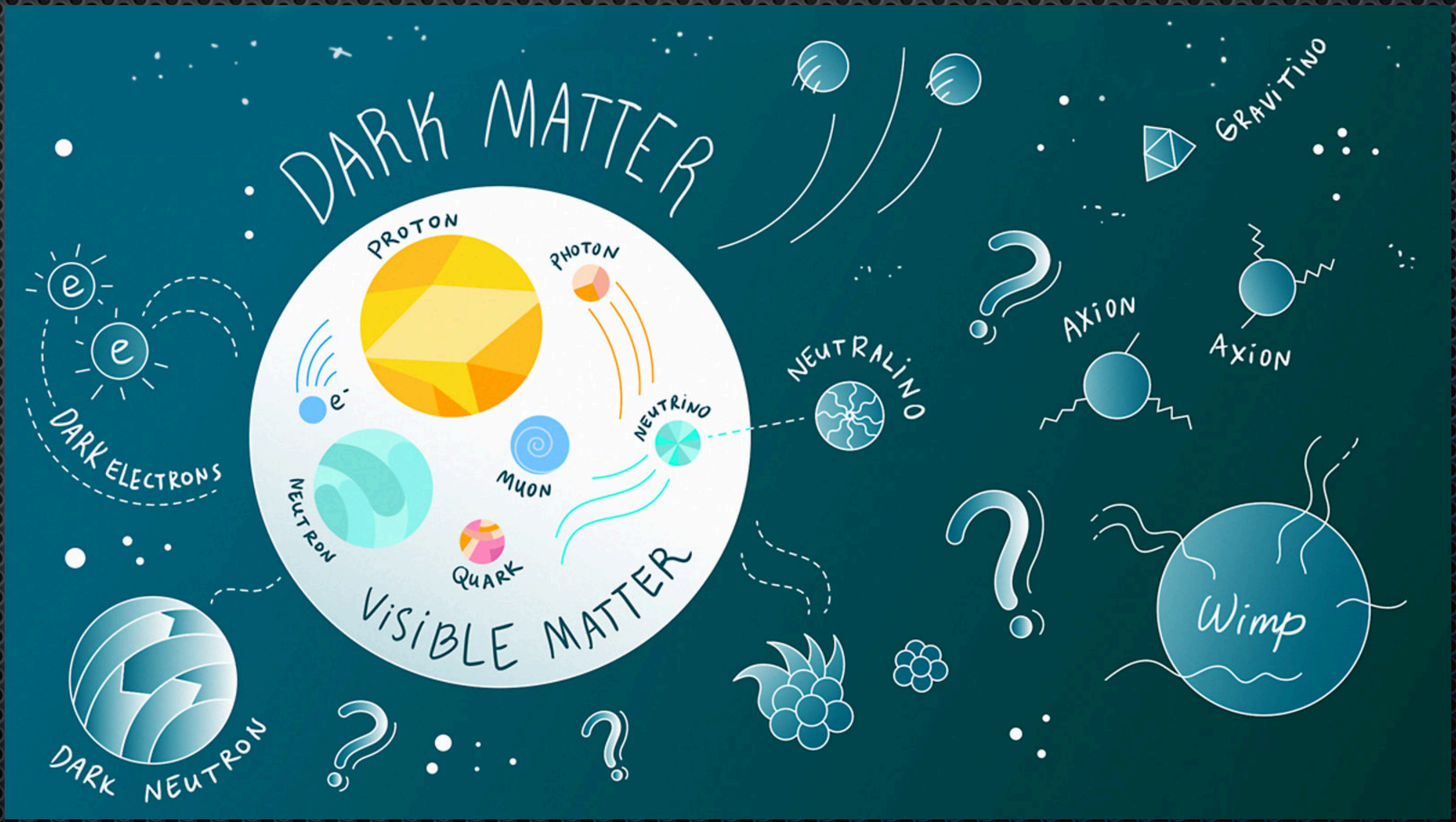
What *is* dark matter?

Where did all the antimatter go?

Why does the standard model look the way it does?

Why is the weak force so much stronger than gravity? (Hierarchy problem)

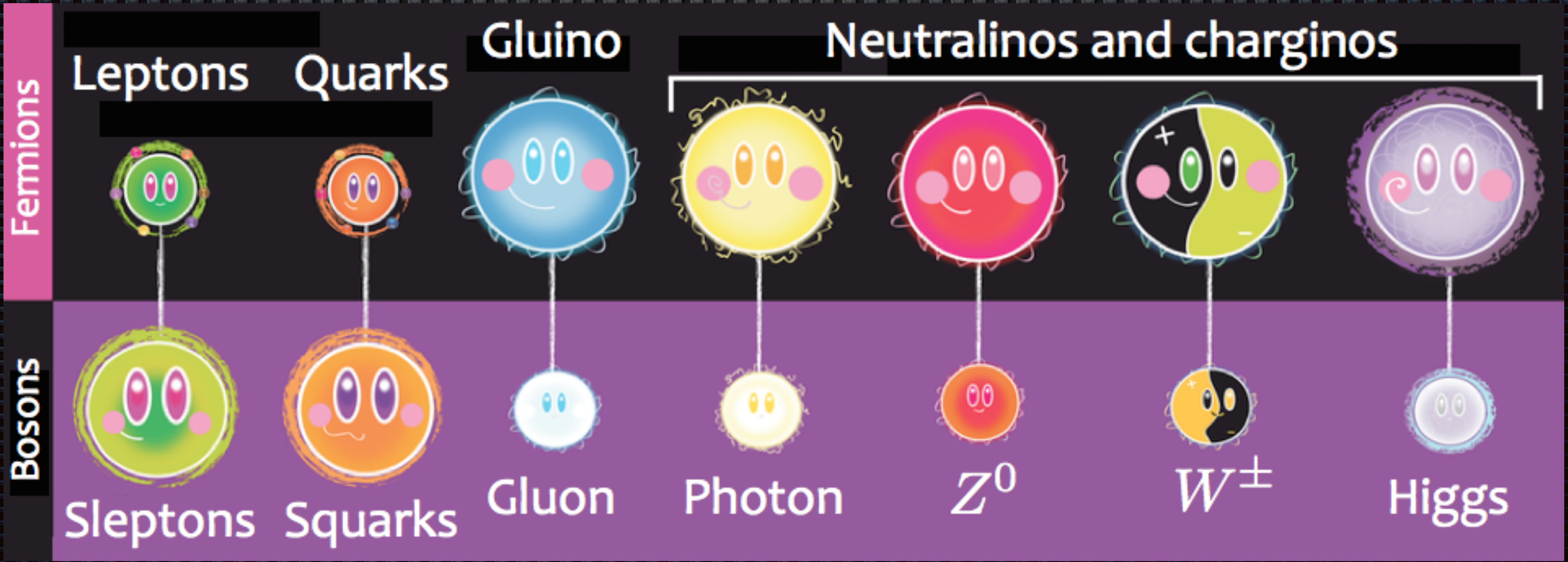
Supersymmetry (SUSY) is a framework with good theoretical motivations in which theorists can study BSM physics



Supersymmetry (SUSY) is a set of benchmark models to help experimentalists answer these questions!

What is supersymmetry?

- **A set of theories** that predicts new boson (fermionic) partners for the fermions (bosons) of the Standard Model — each with spin differing by 1/2 unit
- When undergoing electroweak symmetry breaking, the higgsinos and electroweak gauginos mix
  - neutral higgsinos and neutral electroweak gauginos mix to form **neutralinos**
  - charged higgsinos and charged electroweak gauginos mix to form **charginos**

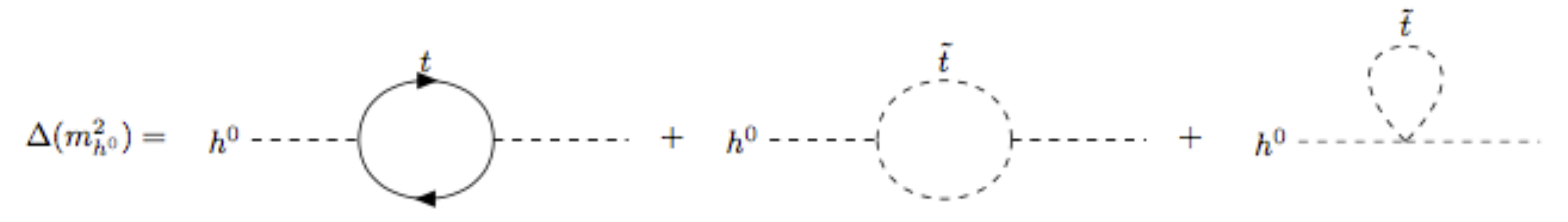


"It was logical to start by looking at Supersymmetry. When you go to Rome you visit the Vatican or the Colosseum, not some weird corner of the city."

— M. Mangano #SMatLHC2019

SUSY and naturalness

- 3rd generation fermions have large Yukawa couplings to the Higgs, treat the 1st and 2nd generation couplings as negligible in MSSM
- The stop squarks provide an equal and opposite contribution to the correction of the Higgs mass

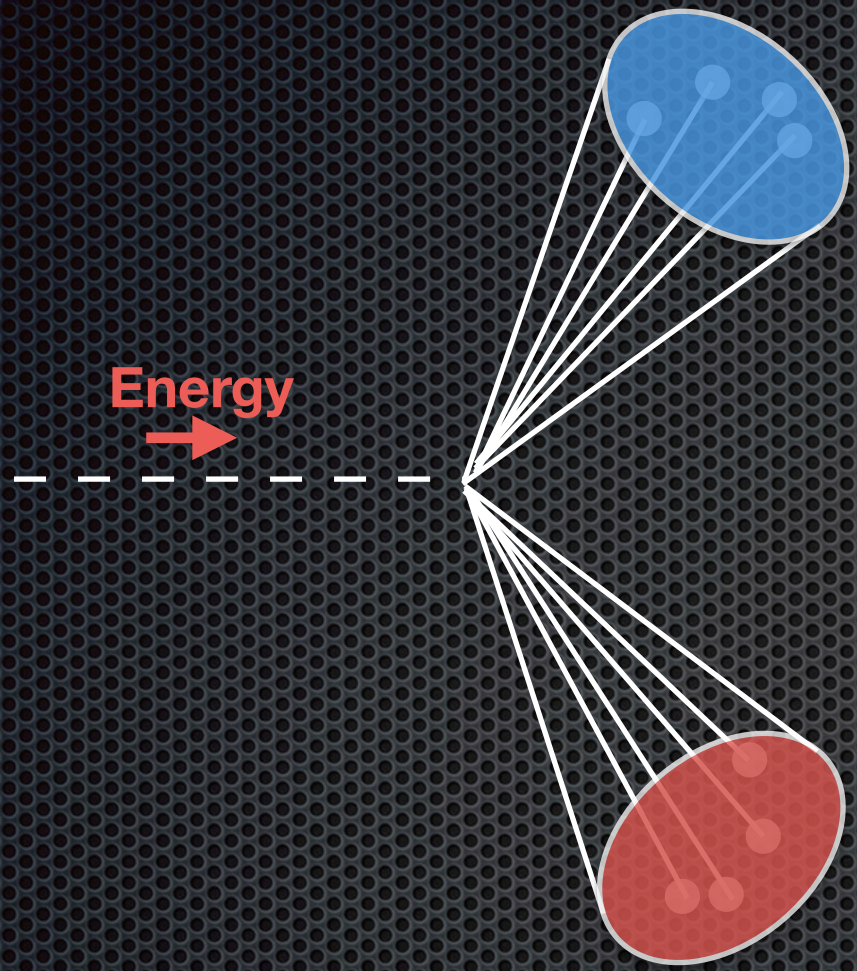


- To keep this **correction small**, a search for **light stops** is well motivated
  - Additionally, as gluinos couple to the stop squark, it pulls the mass up — a **light gluino** is well motivated

$$\Delta(m_{h^0}^2) = \frac{3}{4\pi^2}\cos^2\alpha\lambda_t^2 m_t^2\left[\ln(m_{\tilde{t}_1} m_{\tilde{t}_2}/m_t^2) + \Delta_{\text{threshold}}\right]$$

⚠ **If strongly produced sparticles are heavier, EWK could be discovered first**

What's a boosted jet?

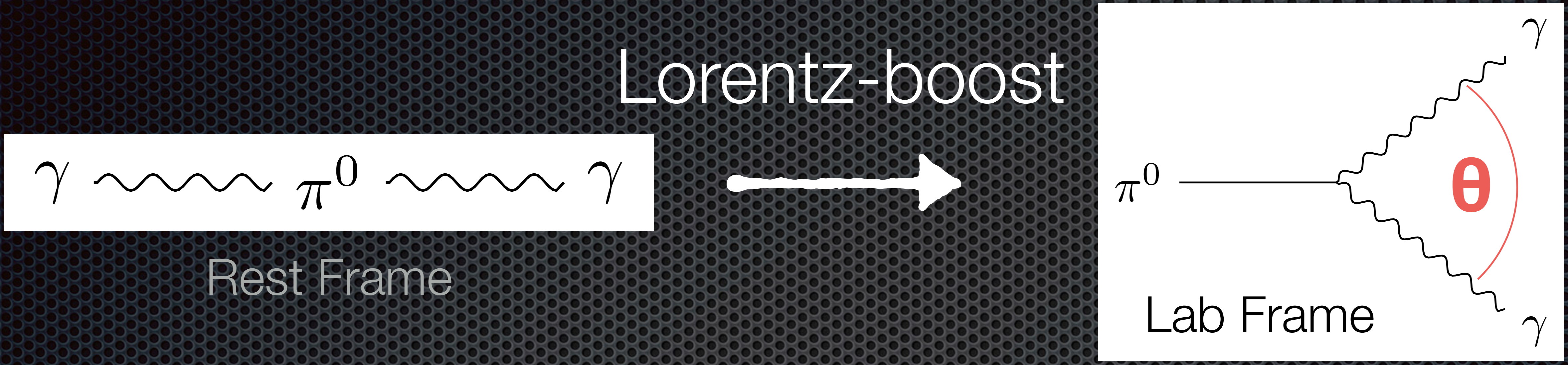


Particle decay at low
Lorentz boost

Particle decay at high
Lorentz boost

More (accidental) substructure!

How big is a boosted jet? (I)



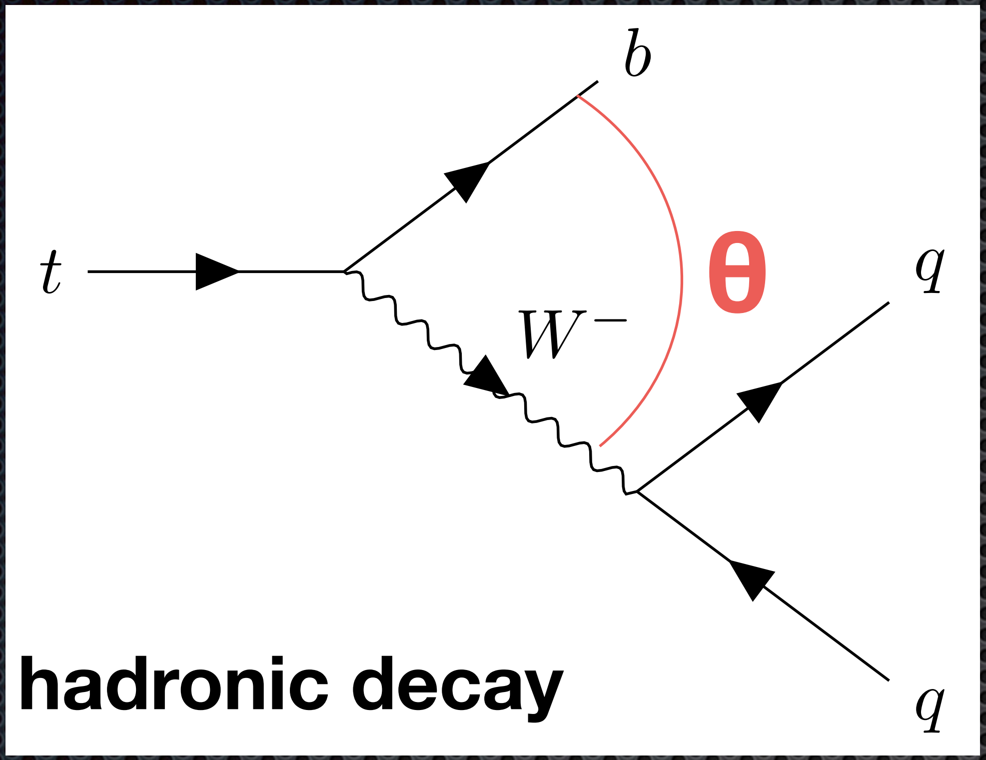
What is the angular separation between the decay products?

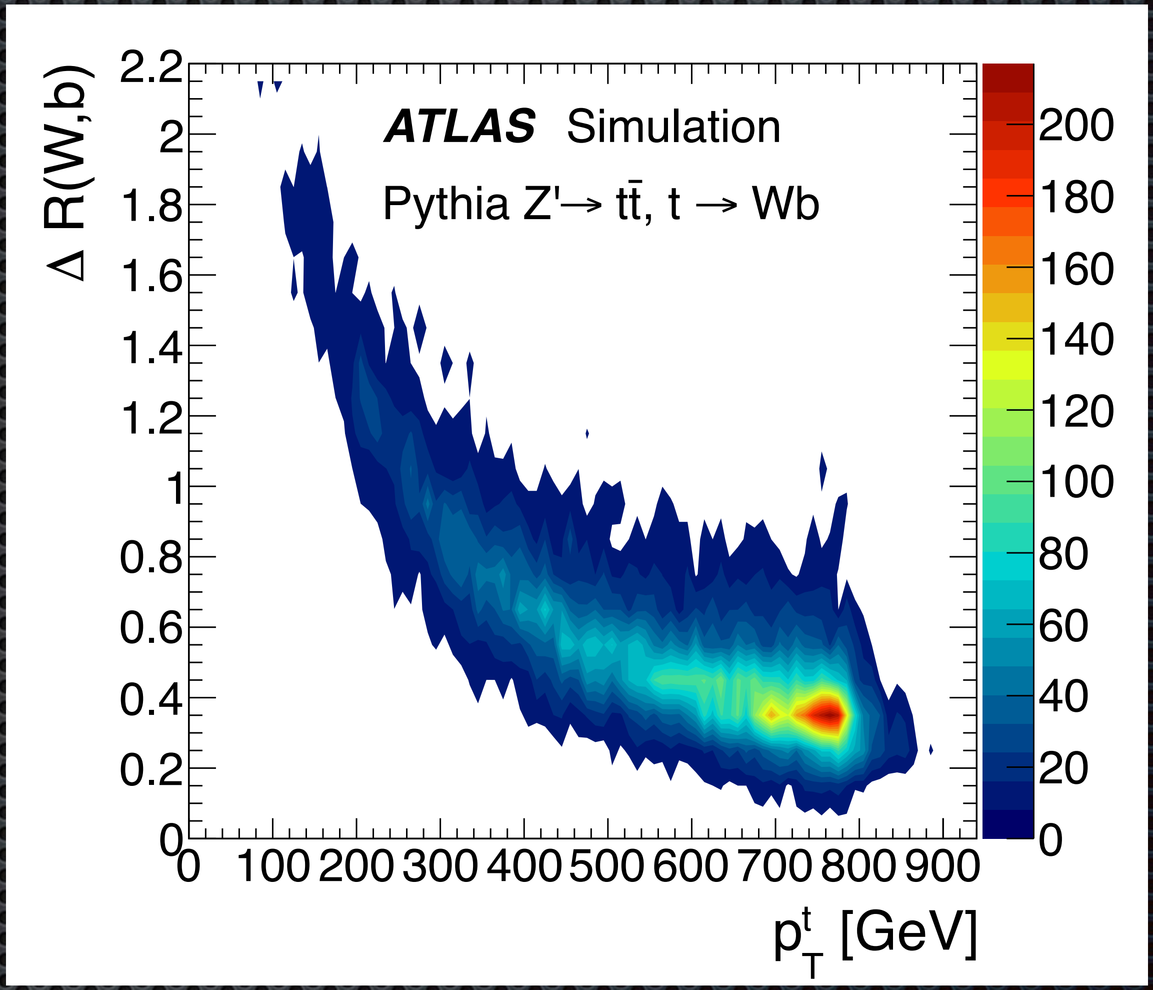
$$\cos\theta \approx 1 - \frac{1}{2}\theta^2 = 1 - \frac{2}{\gamma^2} \longrightarrow \Delta R \sim \frac{2m}{p_\mathrm{T}}$$

- The more massive the parent particle, the larger an area it decays over.
- The more boost the parent particle has, the smaller an area it decays over.

If the boost is large enough, can a large jet capture the entire decay?

How big is a boosted jet? (II)





1306.4945

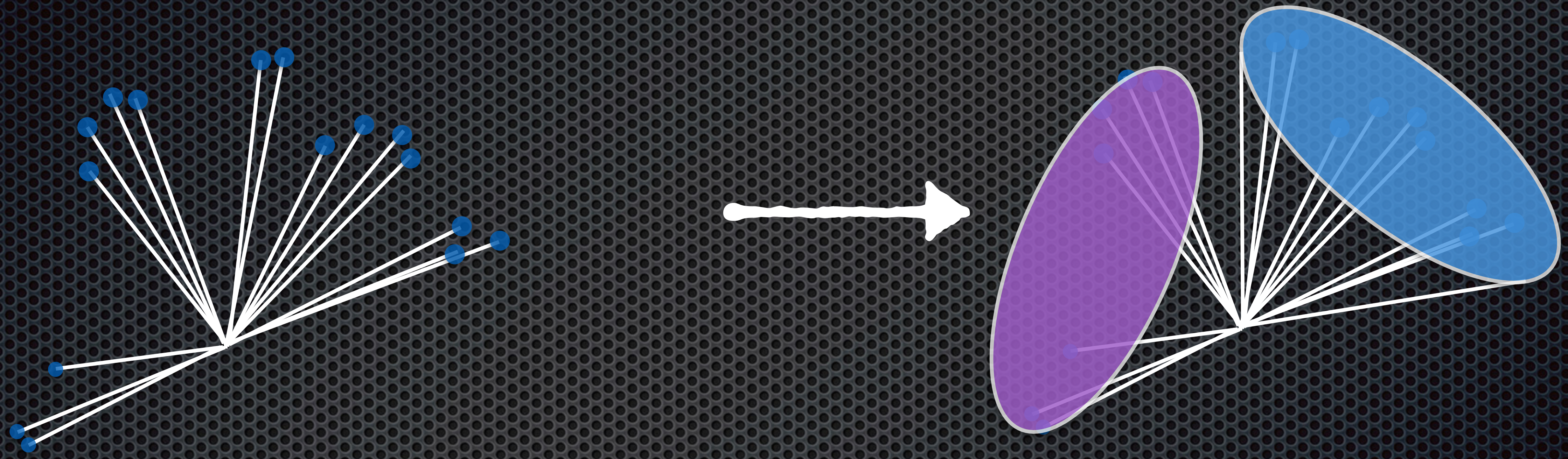
- The estimation of a jet size is modeled nicely in monte-carlo simulations of non-perturbative QCD for Z' to top-antitop

If the boost is large enough, can a large jet capture the entire decay?

YES!

Forming Large Jets (I)

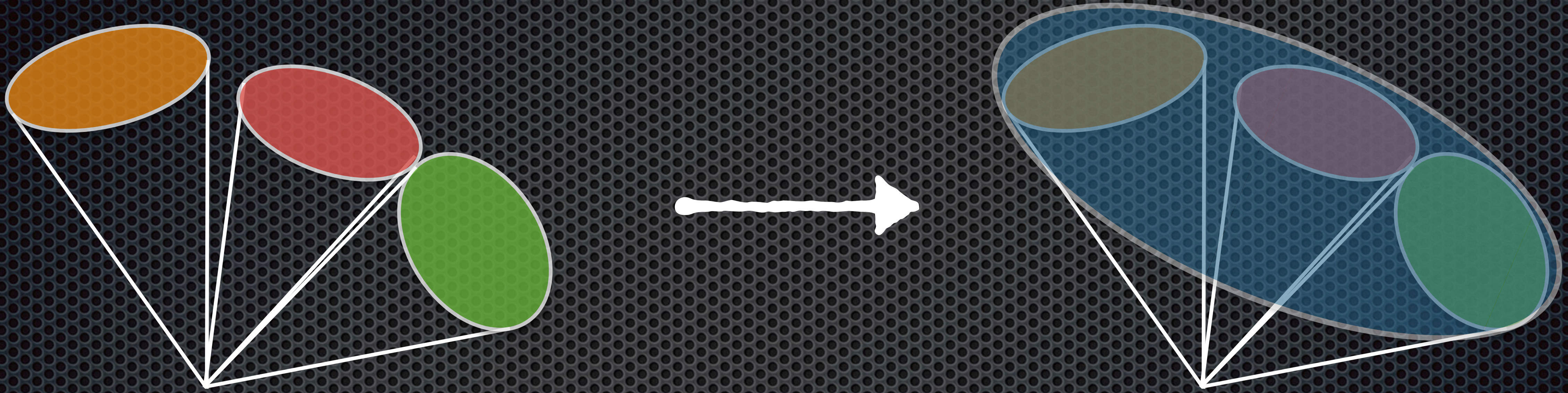
Larger jets can be formed from calorimeter clusters



- Apply same principles for reconstruction of smaller jets, to form large radius jets, (R=0.8, 1.0, 1.2, …)
- Formed from topoclusters and often **need grooming / pileup mitigation techniques, and large-R JES/JER calibrations**

Forming Large Jets (II)

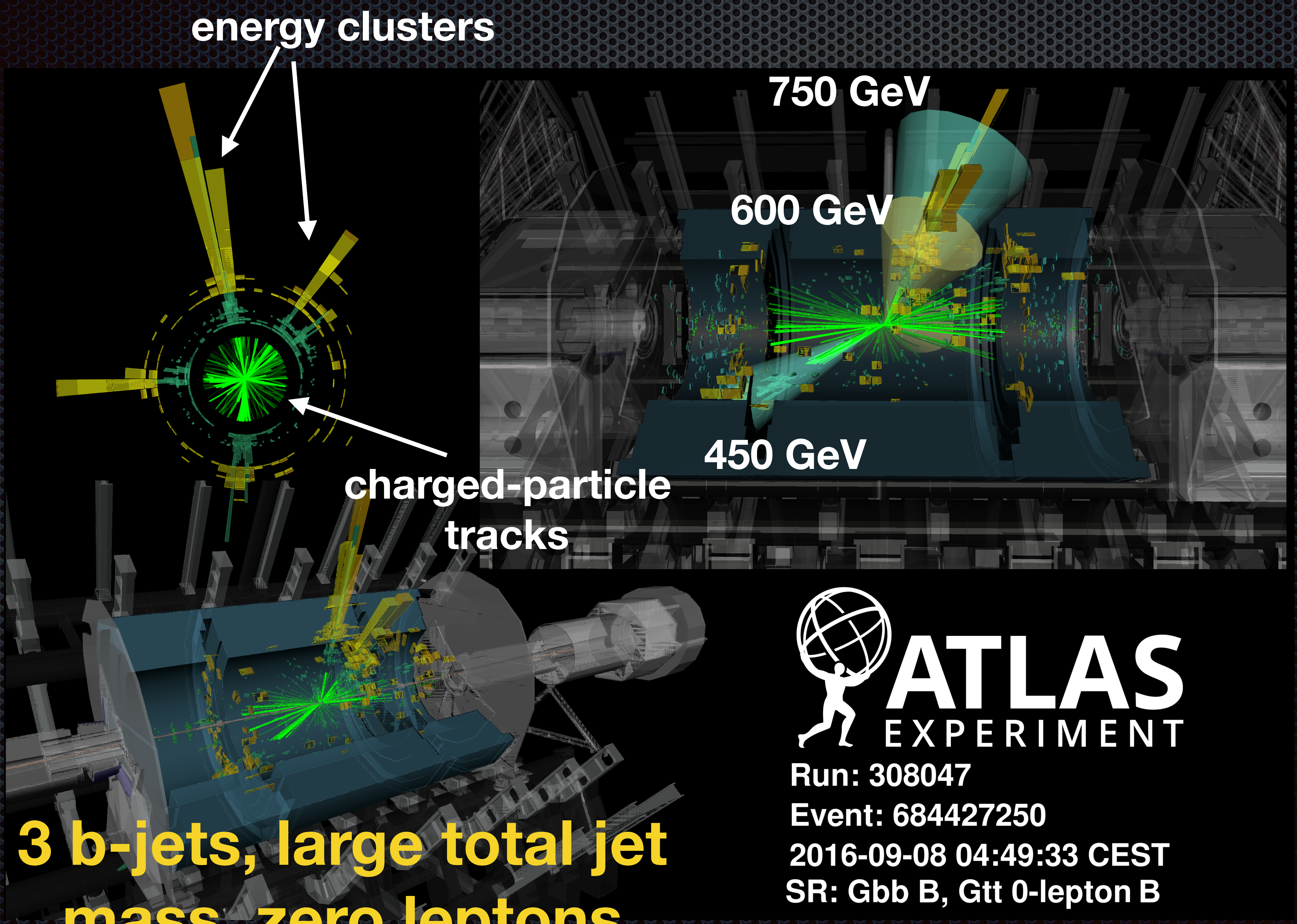
Larger jets can also be formed from smaller jets



This is known as **jet reclustering**

- Smaller jets are well-studied and better understood, reclustering from them takes advantage of this knowledge
- Large, reclustered jets can be used to calculate global quantities like a total jet mass, or the number of top quarks in an event

A fully reconstructed event



Run: 308047
Event: 684427250
2016-09-08 04:49:33 CEST
SR: Gbb B, Gtt 0-lepton B

3 b-jets, large total jet mass, zero leptons