Status of the LHC Experimental Program

(ATLAS / CMS)

John Alison

Carnegie Mellon University

CMS

ATLAS EXPERIMENT

Carnegie Mellon University

LHC

rogram

S)

ersity

LHC
rogram

ersity

"Isn't this a boring time for LHC physics ?"

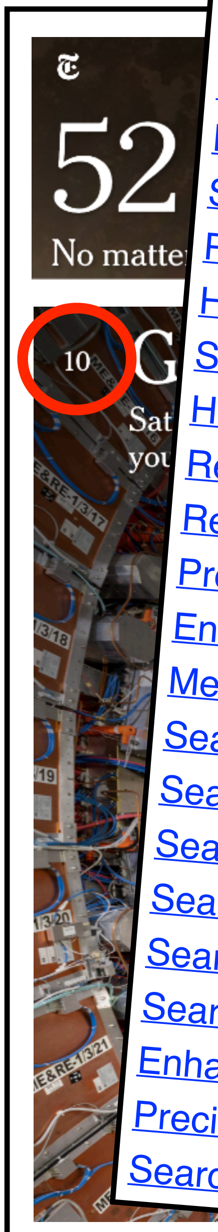
- "You already found the Higgs",
- ΔE_{cm} only 0.6 TeV,
- Not yet the HL-LHC,
- …

Overview will not be exhaustive!

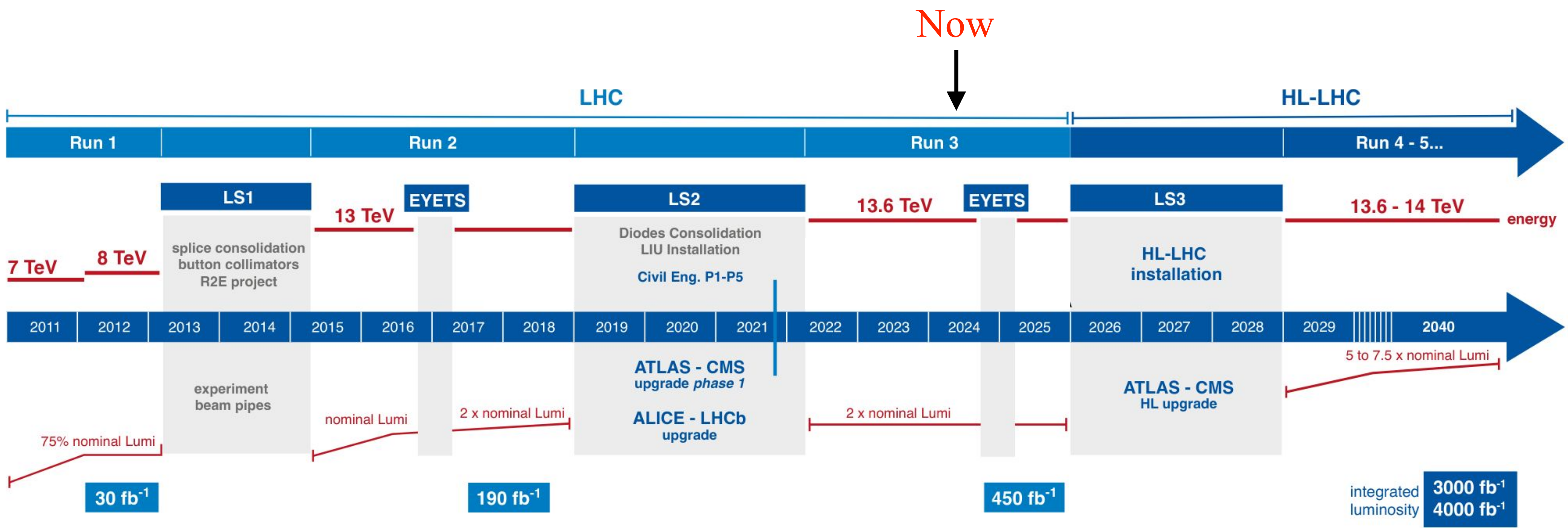
LHC
rogram
ersity

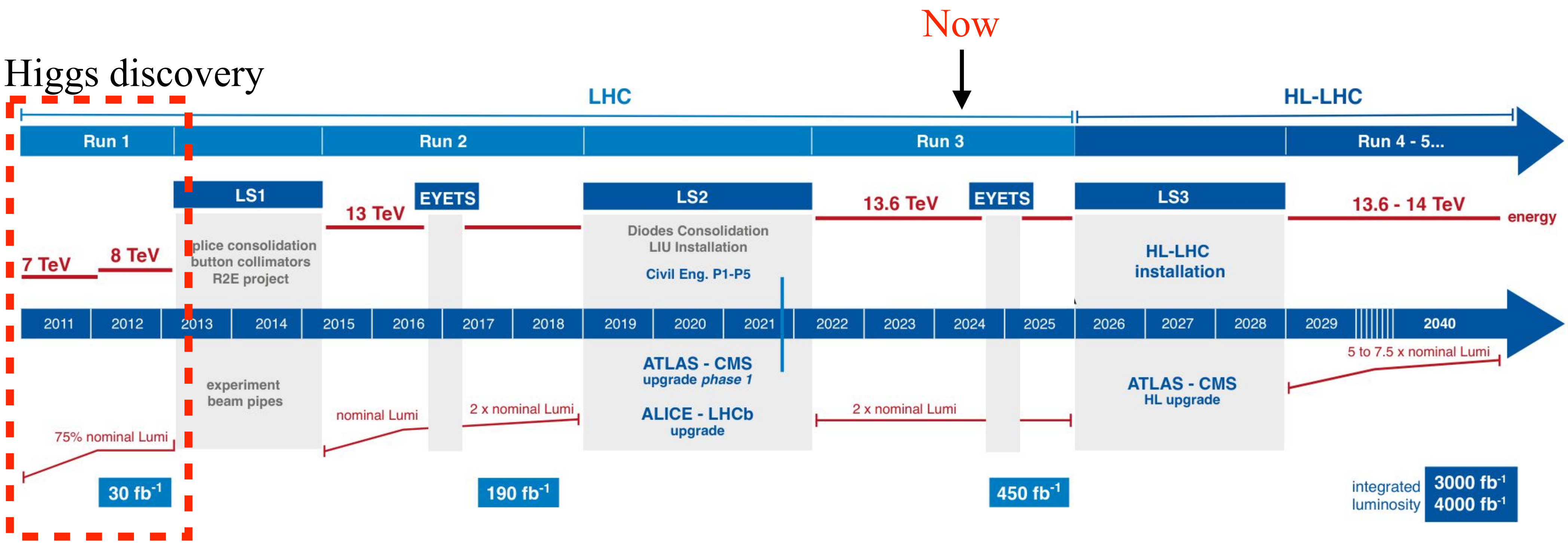
"Isn't this a boring time for LHC physics ?"

- "You already found the Higgs",
- ΔE_{cm} only 0.6 TeV,
- Not yet the HL-LHC,
- …

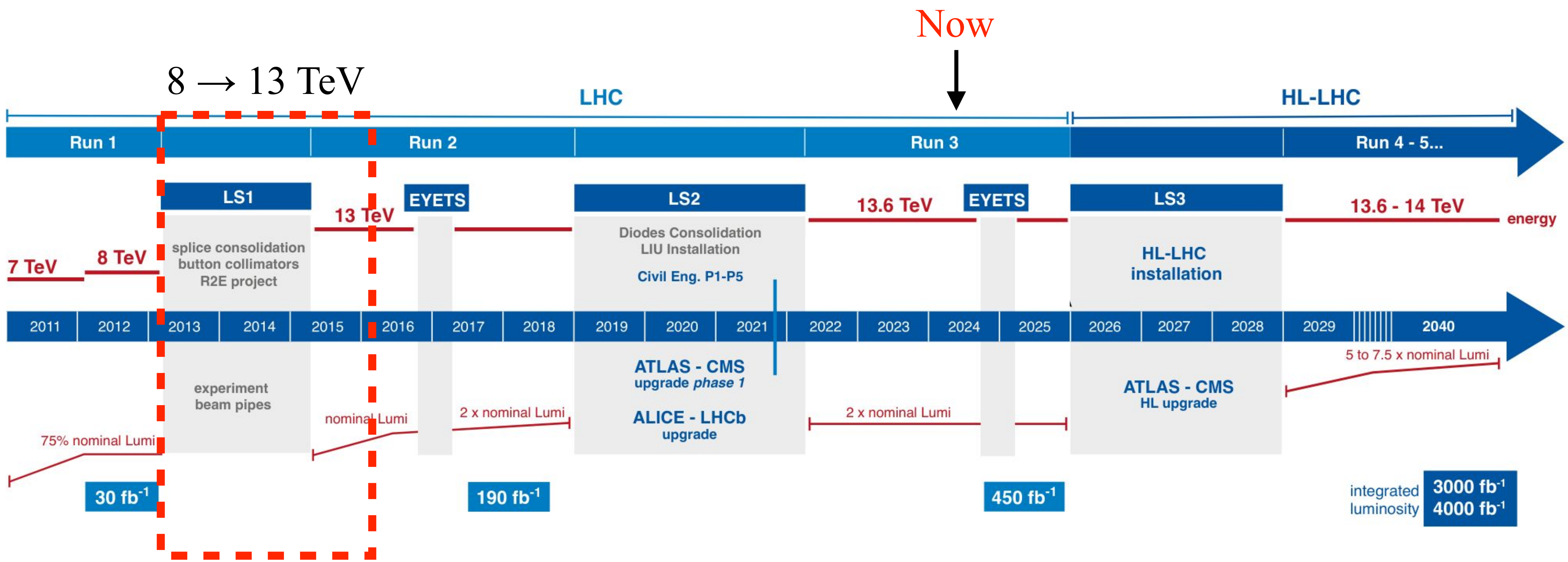


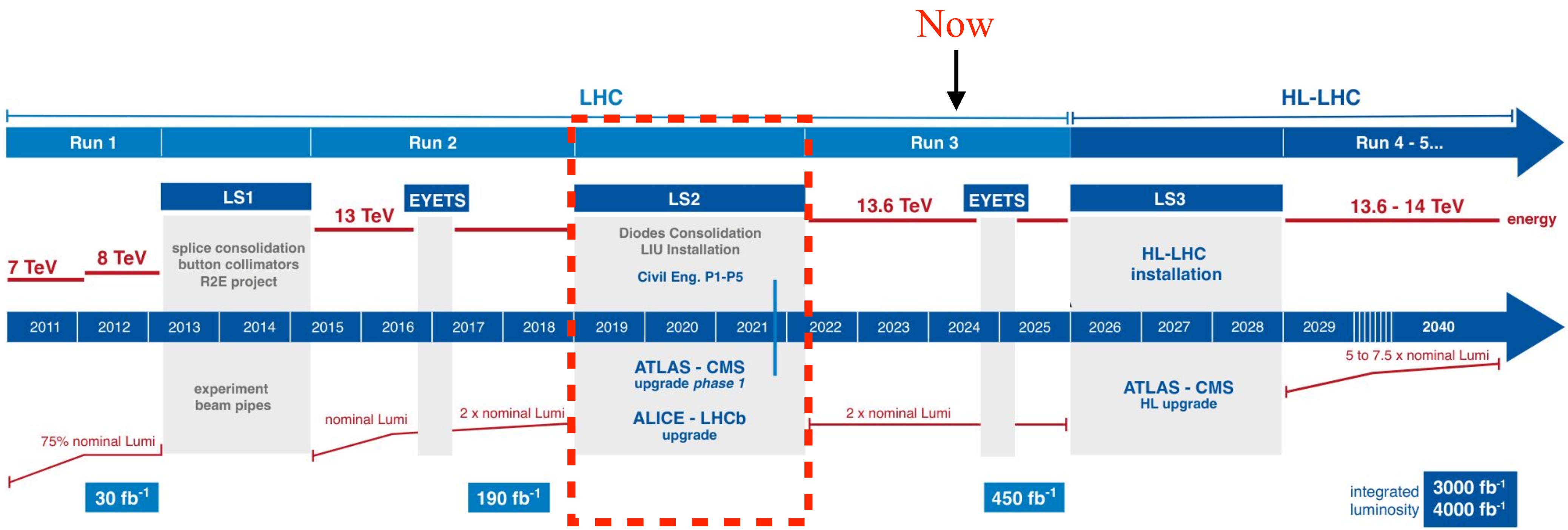
Testing the electroweak theory in multiboson measurements in ATLAS **Gia Khoriauli**
Vector bosons production and properties at CMS. **Patrizia Azzi**
Properties of the Higgs boson measured by ATLAS collaboration **Meng-Ju Tsai**
Probing the nature of electroweak symmetry breaking with Higgs boson pairs in ATLAS **Maximilian Swiatlowski**
Search for emerging jets with graph neural networks using CMS Run 2 data **Claire Savard**
Precision Timing with the CMS MIP Timing Detector for High-Luminosity LHC **Daniel Spitzbart**
Higgs boson production and decay rate measurements with the ATLAS experiment **Weitao Wang**
Searching for additional Higgs bosons at ATLAS **Liron Barak**
High precision physics at LHC **Kirill Melnikov**
Recent highlights of top measurements with the ATLAS detector at the LHC **Stefan Richter**
Recent results on associated top production and searches for new physics with the ATLAS detector **Sahal Yacoob**
Probing EFT couplings in the top quark sector **Kelci Ann Mohrman**
Entanglement of top quarks with CMS **Andrew Wildridge**
Measurements of QCD with the ATLAS Detector **Jonathan Butterworth**
Searches for Dark Matter with the ATLAS Experiment at the LHC **Matteo Bauce**
Searches for Supersymmetry with CMS **Valentina Dutta**
Searches for BSM physics in low-mass, non-resonant, or long-lived signatures with ATLAS **Tiesheng Dai**
Searches for Exotic Heavy Resonances with the ATLAS detector **Marija Marjanovic**
Searches for resonances decaying to pairs of heavy bosons in ATLAS **Francesco Conventi**
Searches for neutral heavy Higgs bosons in CMS **Khawla Jaffel**
Enhanching CMS low-mass searches with data scouting: from Run 2 to Run 3 **Elisa Fontanesi**
Precision measurements in W and Z decays with the ATLAS Experiment **Federico Sforza**
Searching for additional Higgs bosons at ATLAS **Huacheng Cai**


Now
LHC
HL-LHC
Run 1
Run 2
Run 3
Run 4 - 5...
LS1
EYETS
LS2
EYETS
LS3
7 TeV
8 TeV
13 TeV
13.6 TeV
13.6 - 14 TeV
energy
splice consolidation
button collimators
R2E project
Diodes Consolidation
LIU Installation
Civil Eng. P1-P5
HL-LHC
installation
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2040
experiment
beam pipes
ATLAS - CMS
upgrade phase 1
ALICE - LHCb
upgrade
ATLAS - CMS
HL upgrade
75% nominal Lumi
nominal Lumi
2 x nominal Lumi
2 x nominal Lumi
5 to 7.5 x nominal Lumi
30 fb-1
190 fb-1
450 fb-1
integrated
luminosity
3000 fb-1
4000 fb-1

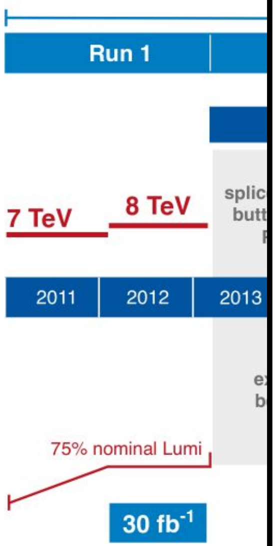


Now
Higgs discovery
LHC
HL-LHC
Run 1
Run 2
Run 3
Run 4 - 5...
LS1
EYETS
LS2
EYETS
LS3
7 TeV
8 TeV
13 TeV
13.6 TeV
13.6 - 14 TeV
energy
plice consolidation
button collimators
R2E project
Diodes Consolidation
LIU Installation
Civil Eng. P1-P5
HL-LHC
installation
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2040
experiment
beam pipes
ATLAS - CMS
upgrade phase 1
ALICE - LHCb
upgrade
ATLAS - CMS
HL upgrade
75% nominal Lumi
nominal Lumi
2 x nominal Lumi
2 x nominal Lumi
5 to 7.5 x nominal Lumi
30 fb-1
190 fb-1
450 fb-1
integrated
luminosity
3000 fb-1
4000 fb-1


Now
8 → 13 TeV
LHC
HL-LHC
Run 1
Run 2
Run 3
Run 4 - 5...
LS1
EYETS
LS2
EYETS
LS3
7 TeV
8 TeV
13 TeV
13.6 TeV
13.6 - 14 TeV
energy
splice consolidation
button collimators
R2E project
Diodes Consolidation
LIU Installation
Civil Eng. P1-P5
HL-LHC
installation
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2040
experiment
beam pipes
ATLAS - CMS
upgrade phase 1
ALICE - LHCb
upgrade
ATLAS - CMS
HL upgrade
75% nominal Lumi
nominal Lumi
2 x nominal Lumi
2 x nominal Lumi
5 to 7.5 x nominal Lumi
30 fb⁻¹
190 fb⁻¹
450 fb⁻¹
integrated
luminosity
3000 fb⁻¹
4000 fb⁻¹



Now
LHC
HL-LHC
Run 1
Run 2
Run 3
Run 4 - 5...
LS1
EYETS
LS2
EYETS
LS3
7 TeV
8 TeV
13 TeV
13.6 TeV
13.6 - 14 TeV
energy
splice consolidation
button collimators
R2E project
Diodes Consolidation
LIU Installation
Civil Eng. P1-P5
HL-LHC
installation
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2040
experiment
beam pipes
ATLAS - CMS
upgrade phase 1
ALICE - LHCb
upgrade
ATLAS - CMS
HL upgrade
75% nominal Lumi
nominal Lumi
2 x nominal Lumi
2 x nominal Lumi
5 to 7.5 x nominal Lumi
30 fb-1
190 fb-1
450 fb-1
integrated
luminosity
3000 fb-1
4000 fb-1



ATLAS DETECTOR LS2 UPGRADES

MUON NEW SMALL WHEELS (NSW)

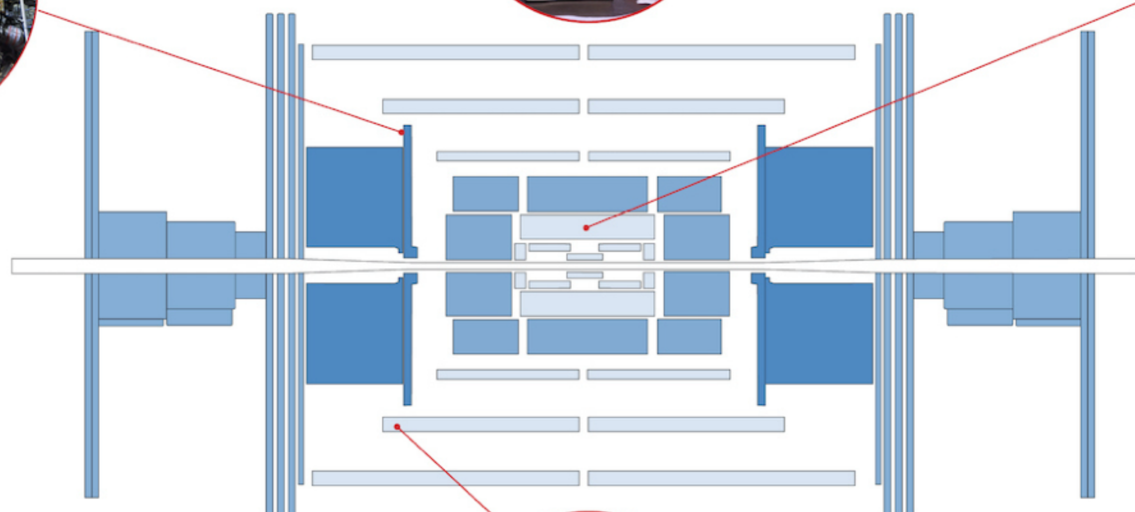
Installed new muon detectors with precision tracking and muon selection capabilities. Key preparation for the HL-LHC.

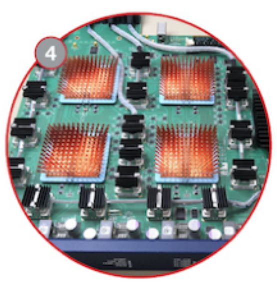
NEW READOUT SYSTEM FOR THE NSWs

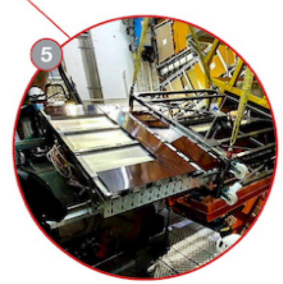
The NSW system includes two million micromega readout channels and 350 000 small strip thin-gap chambers (sTGC) electronic readout channels.

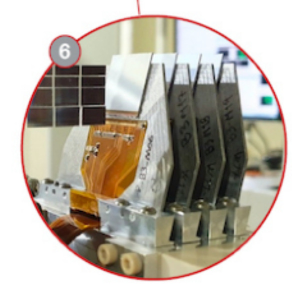
LIQUID ARGON CALORIMETER

New electronics boards installed, increasing the granularity of signals used in event selection and improving trigger performance at higher luminosity.









TRIGGER AND DATA ACQUISITION SYSTEM (TDAQ)

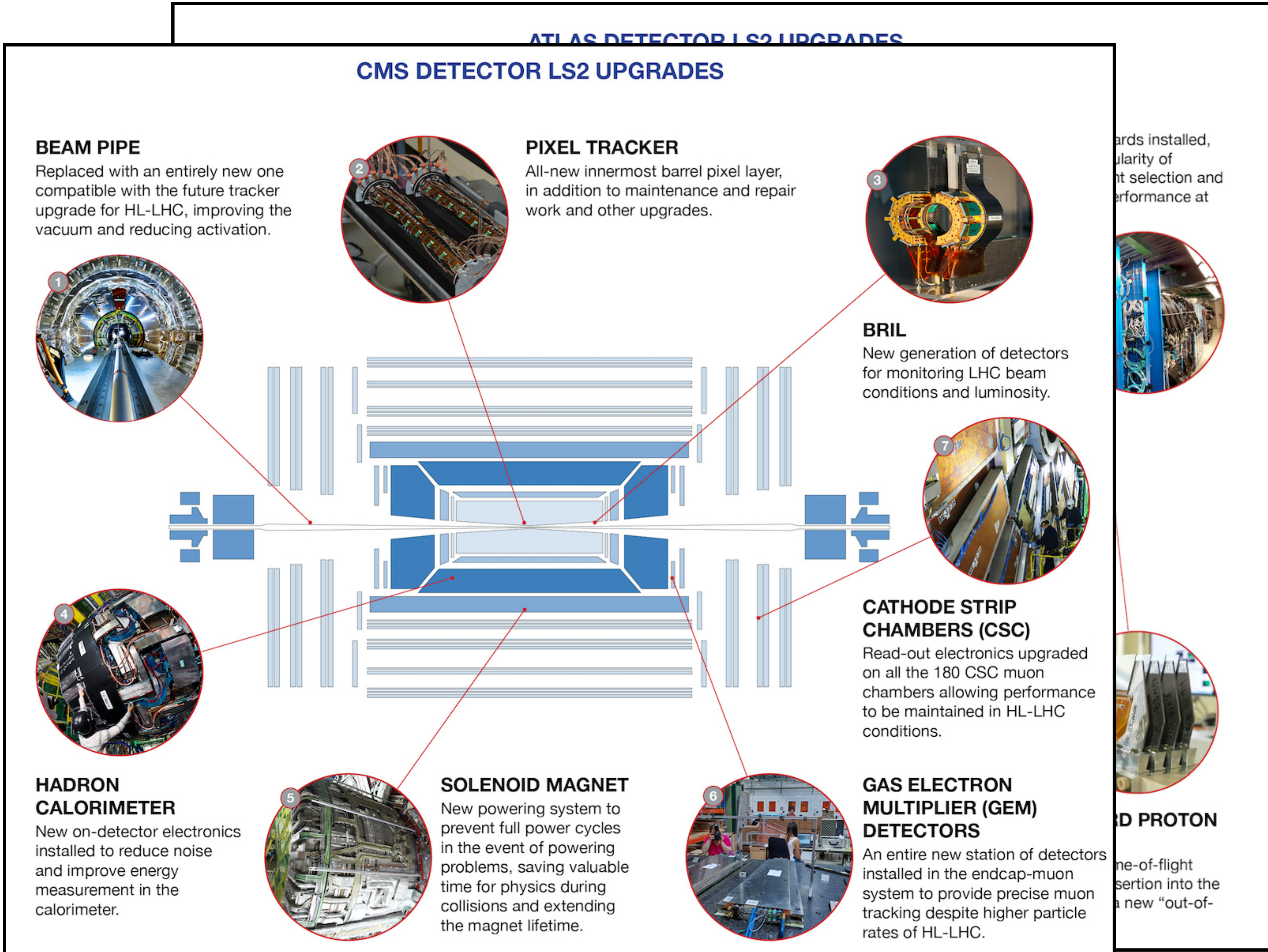
Upgraded hardware and software allowing the trigger to spot a wider range of collision events while maintaining the same acceptance rate.

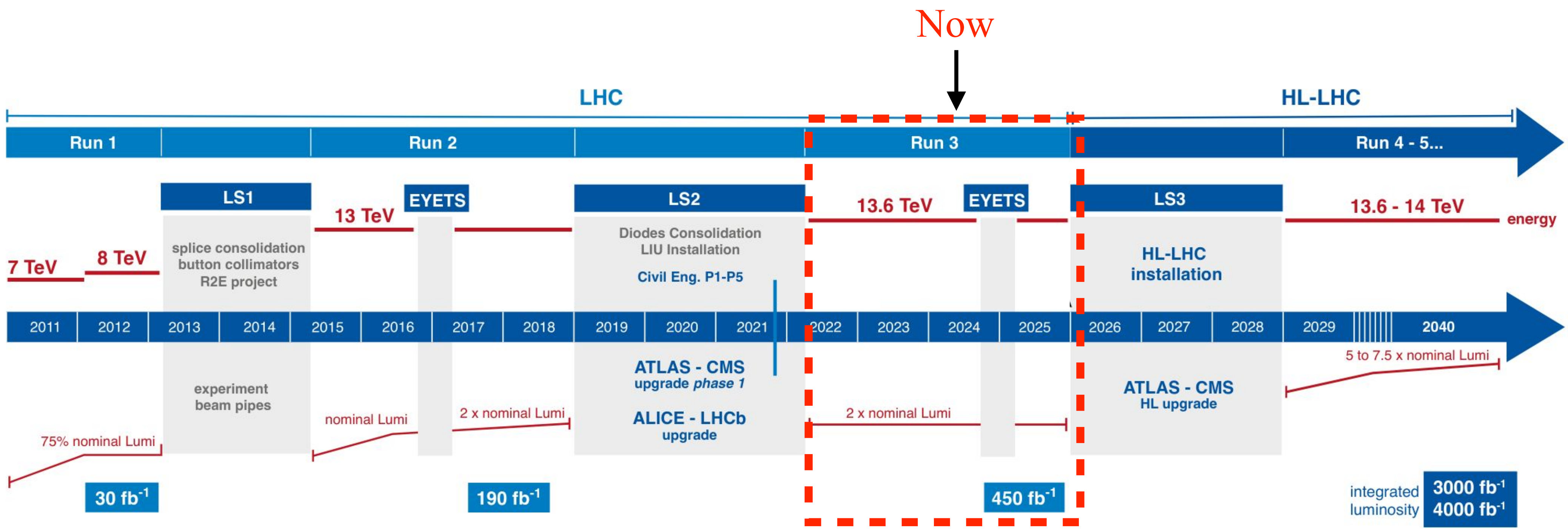
NEW MUON CHAMBERS IN THE CENTRE OF ATLAS

Installed small monitored drift tube (sMDT) detectors alongside a new generation of resistive plate chamber (RPC) detectors, extending the trigger coverage in preparation for the HL-LHC.

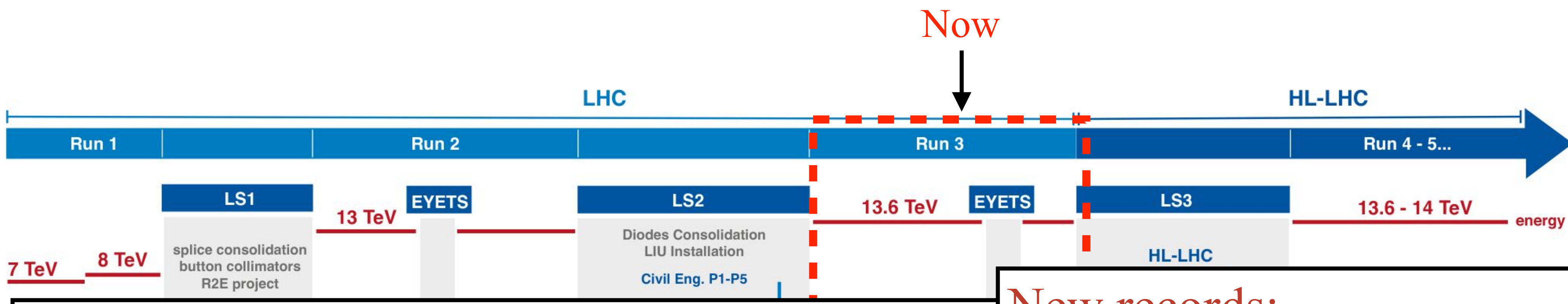
ATLAS FORWARD PROTON (AFP)

Re-designed AFP time-of-flight detector, allowing insertion into the LHC beamline with a new “out-of-vacuum” solution.

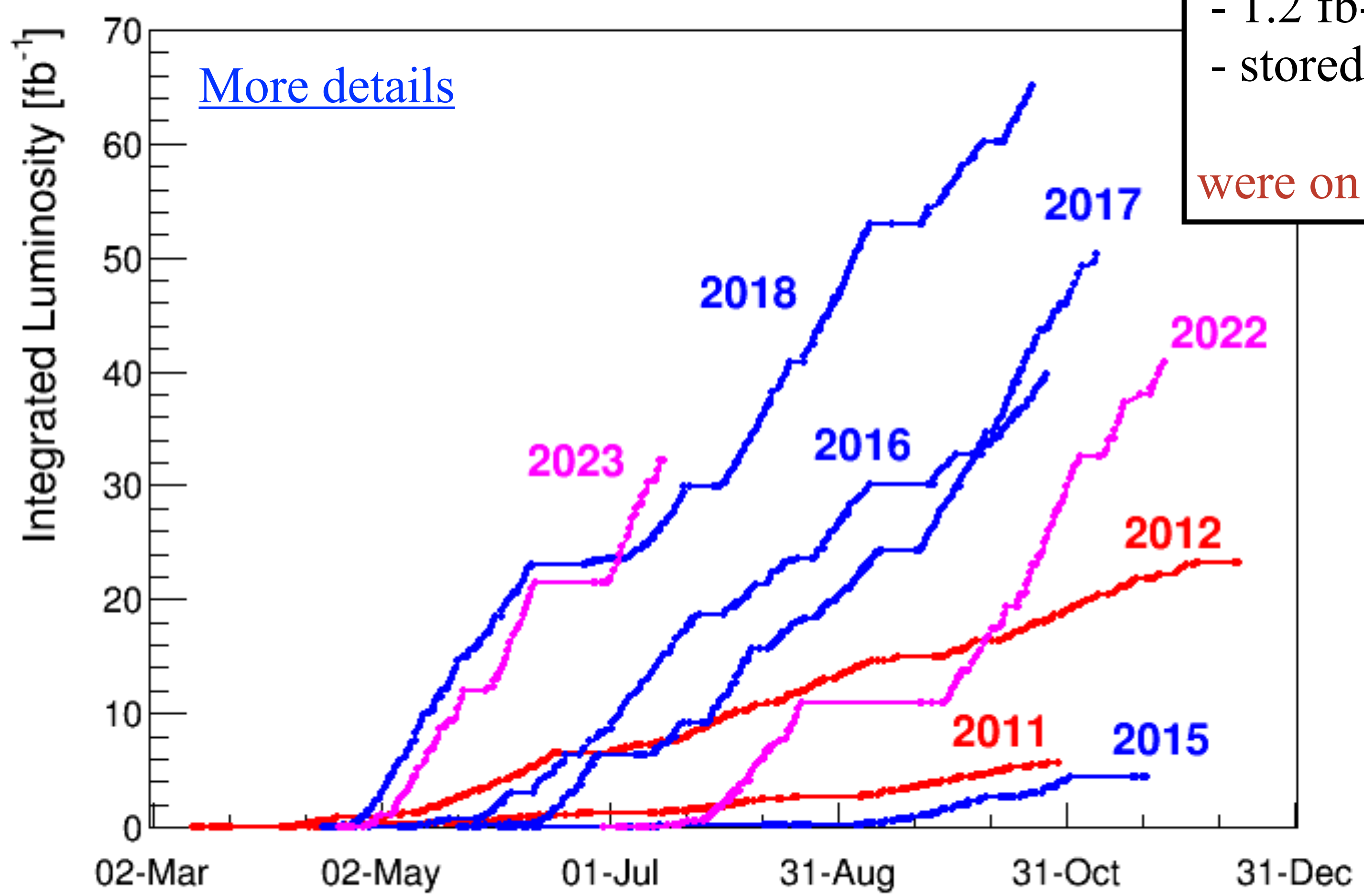

CMS DETECTOR LS2 UPGRADES
BEAM PIPE
Replaced with an entirely new one compatible with the future tracker upgrade for HL-LHC, improving the vacuum and reducing activation.
PIXEL TRACKER
All-new innermost barrel pixel layer, in addition to maintenance and repair work and other upgrades.
BRIL
New generation of detectors for monitoring LHC beam conditions and luminosity.
CATHODE STRIP CHAMBERS (CSC)
Read-out electronics upgraded on all the 180 CSC muon chambers allowing performance to be maintained in HL-LHC conditions.
HADRON CALORIMETER
New on-detector electronics installed to reduce noise and improve energy measurement in the calorimeter.
SOLENOID MAGNET
New powering system to prevent full power cycles in the event of powering problems, saving valuable time for physics during collisions and extending the magnet lifetime.
GAS ELECTRON MULTIPLIER (GEM) DETECTORS
An entire new station of detectors installed in the endcap-muon system to provide precise muon tracking despite higher particle rates of HL-LHC.



Now
LHC
HL-LHC
Run 1
Run 2
Run 3
Run 4 - 5...
LS1
EYETS
LS2
EYETS
LS3
7 TeV
8 TeV
13 TeV
13.6 TeV
13.6 - 14 TeV
energy
splice consolidation
button collimators
R2E project
Diodes Consolidation
LIU Installation
Civil Eng. P1-P5
HL-LHC
installation
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2040
experiment
beam pipes
ATLAS - CMS
upgrade phase 1
ALICE - LHCb
upgrade
ATLAS - CMS
HL upgrade
75% nominal Lumi
nominal Lumi
2 x nominal Lumi
2 x nominal Lumi
5 to 7.5 x nominal Lumi
30 fb-1
190 fb-1
450 fb-1
integrated
luminosity
3000 fb-1
4000 fb-1



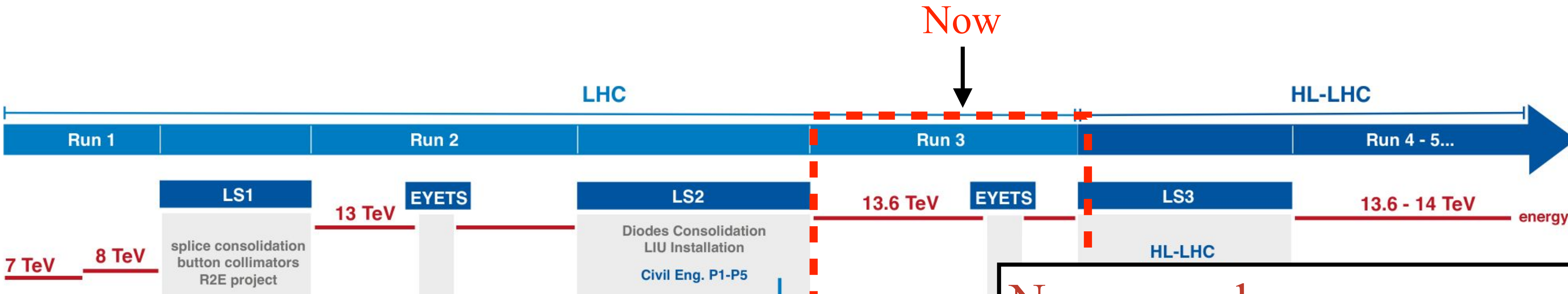
2023 best LHC operational period:



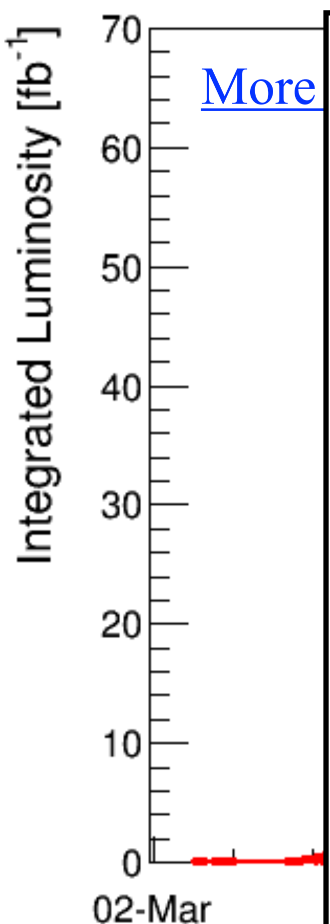
New records:

- Inst. Lumi: 2e34/cm2s (leveled),
- 1.2 fb-1 in 24 hours
- stored beam energy ~ 400 MJ

were on track for 70/fb in 2023 …



2023 best LHC operational period:



More

New records:

- Inst. Lumi: 2e34/cm2s (leveled),
- 1.2 fb-1 in 24 hours

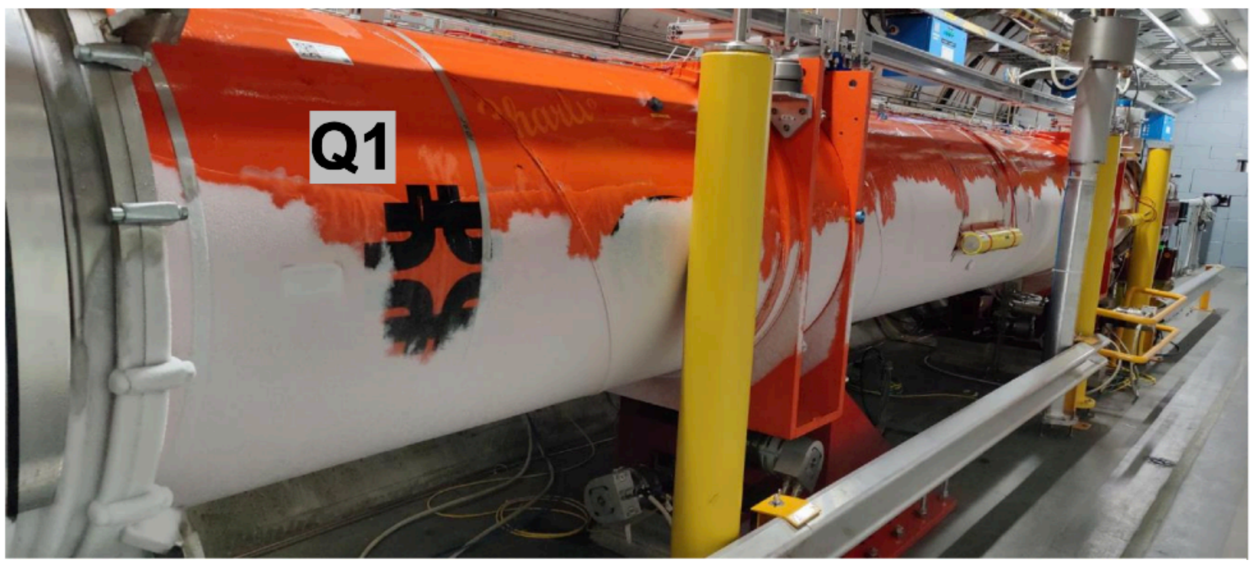
400 MJ

n 2023 …

Vacuum leak (July)

More details

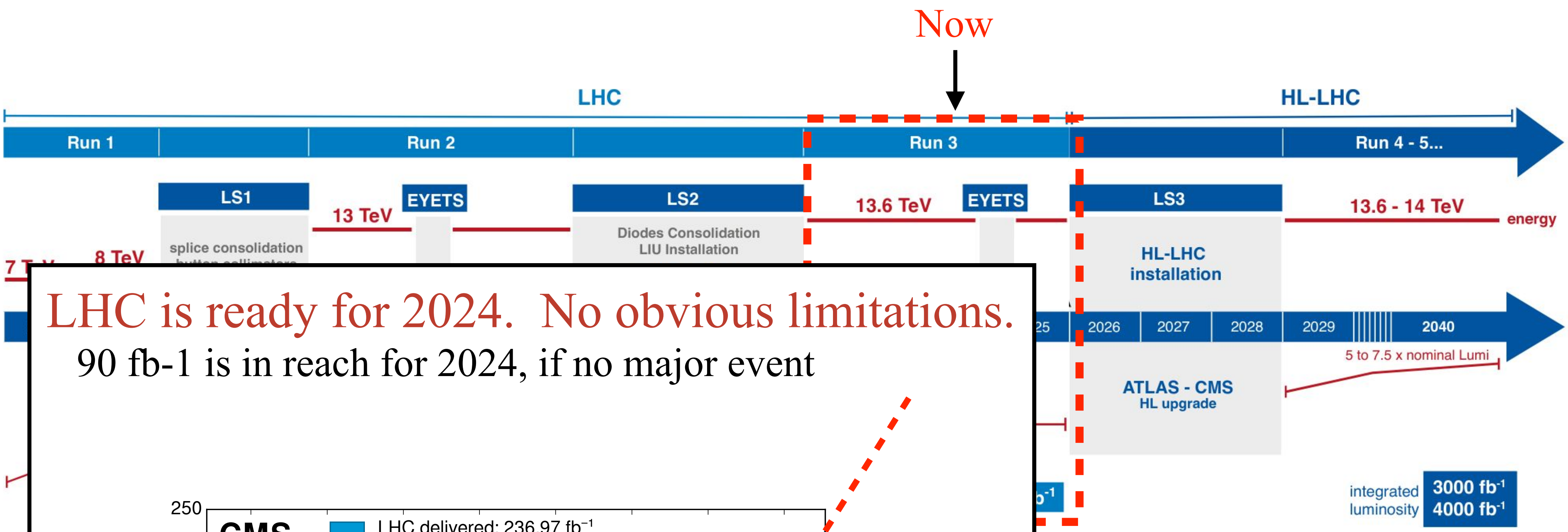
Electrical glitch → quench → leak in vacuum assembly



Repair: only 1.5 months without beam in LHC

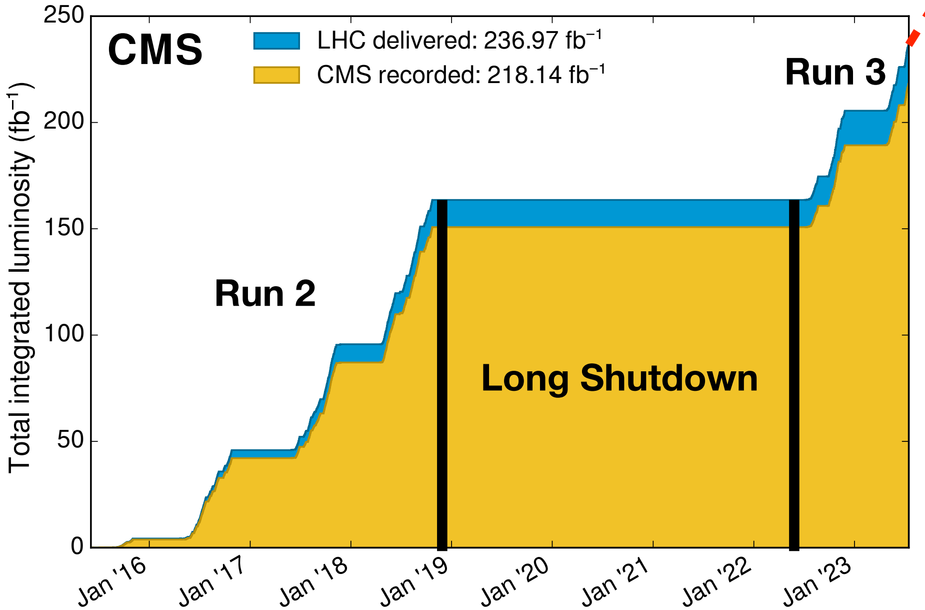
Very fast recommissioning after repair:

- LHC proved (again!) to be a very reproducible machine



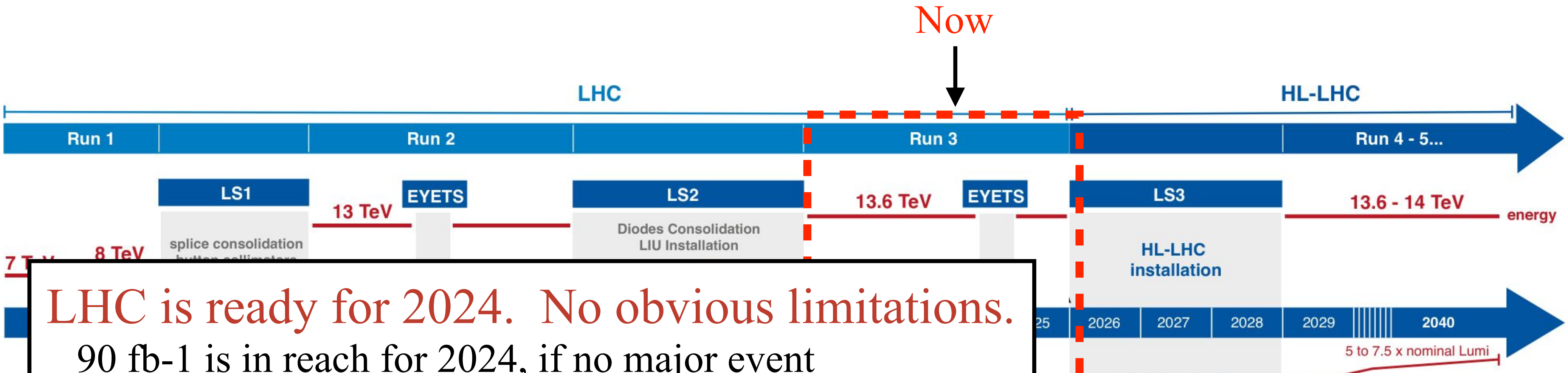
LHC is ready for 2024. No obvious limitations.

90 fb-1 is in reach for 2024, if no major event



Availability key factor for LHC performance:

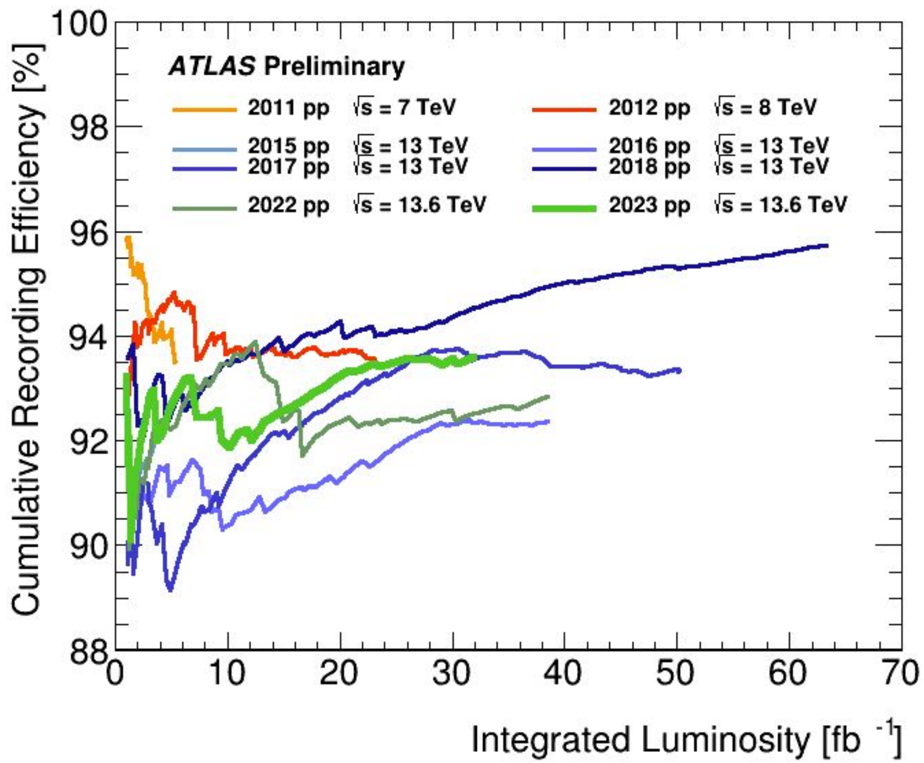
- Small faults: ~constant Run 2 & 3
- Long faults: dominant factor Run 3

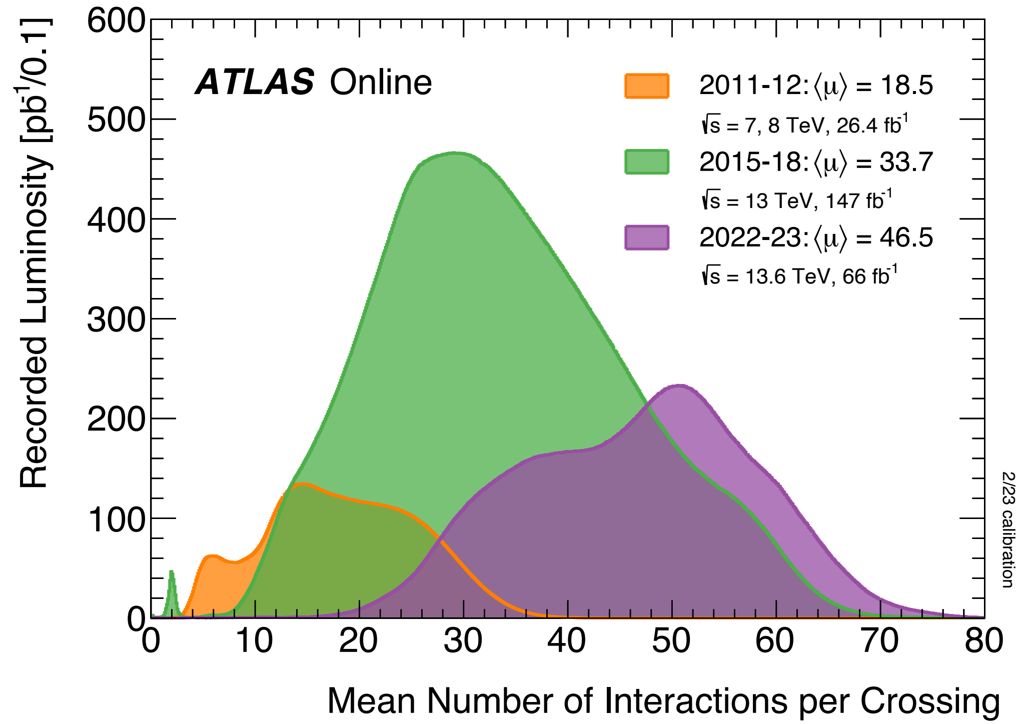


LHC is ready for 2024. No obvious limitations.

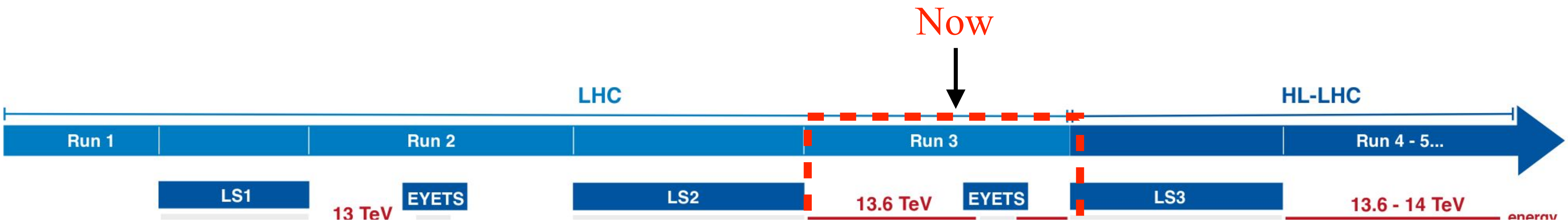
90 fb-1 is in reach for 2024, if no major event

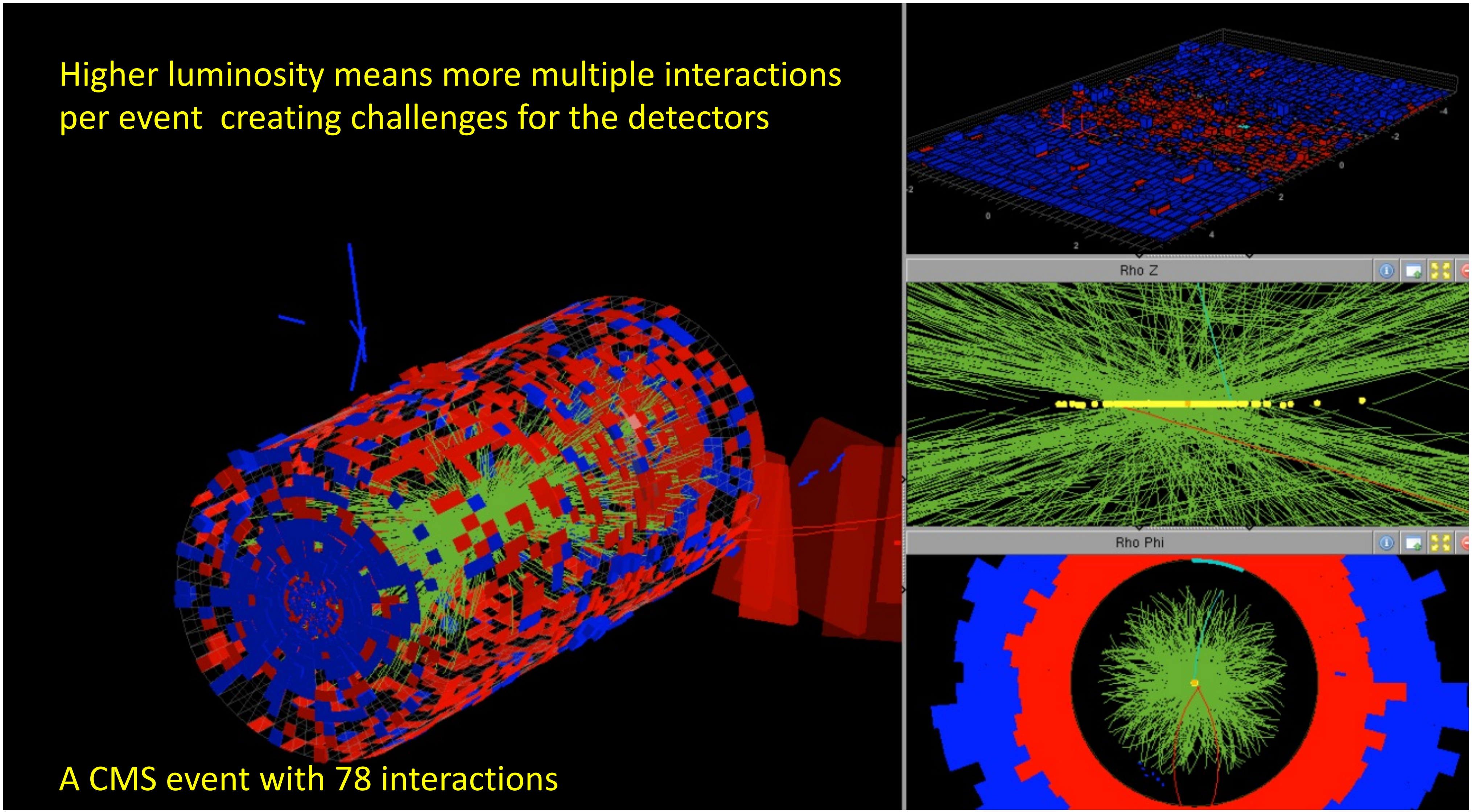
ATLAS/CMS ready for 2024





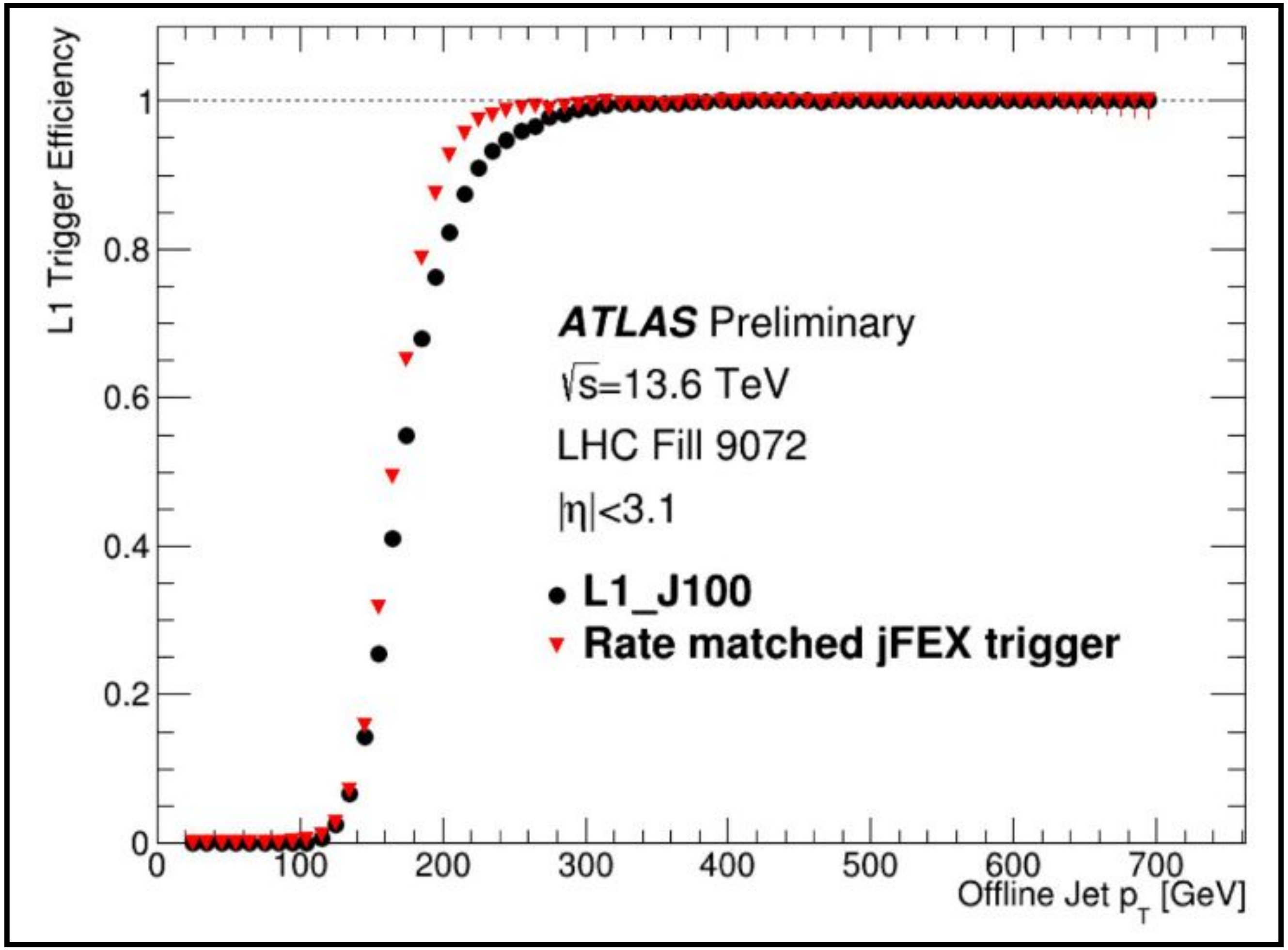
- Long faults: dominant factor Run 3



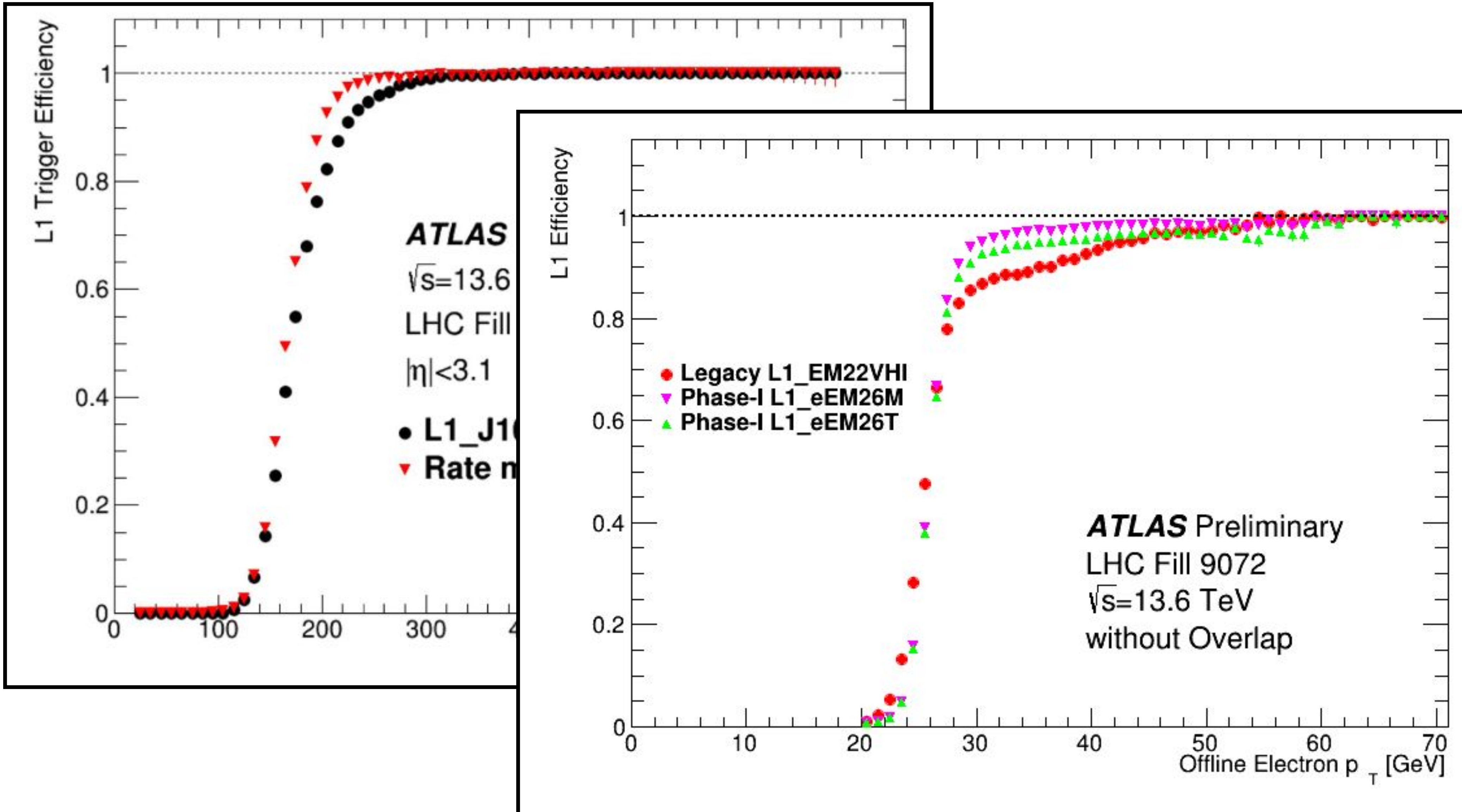


- Long faults: dominant factor Run 3

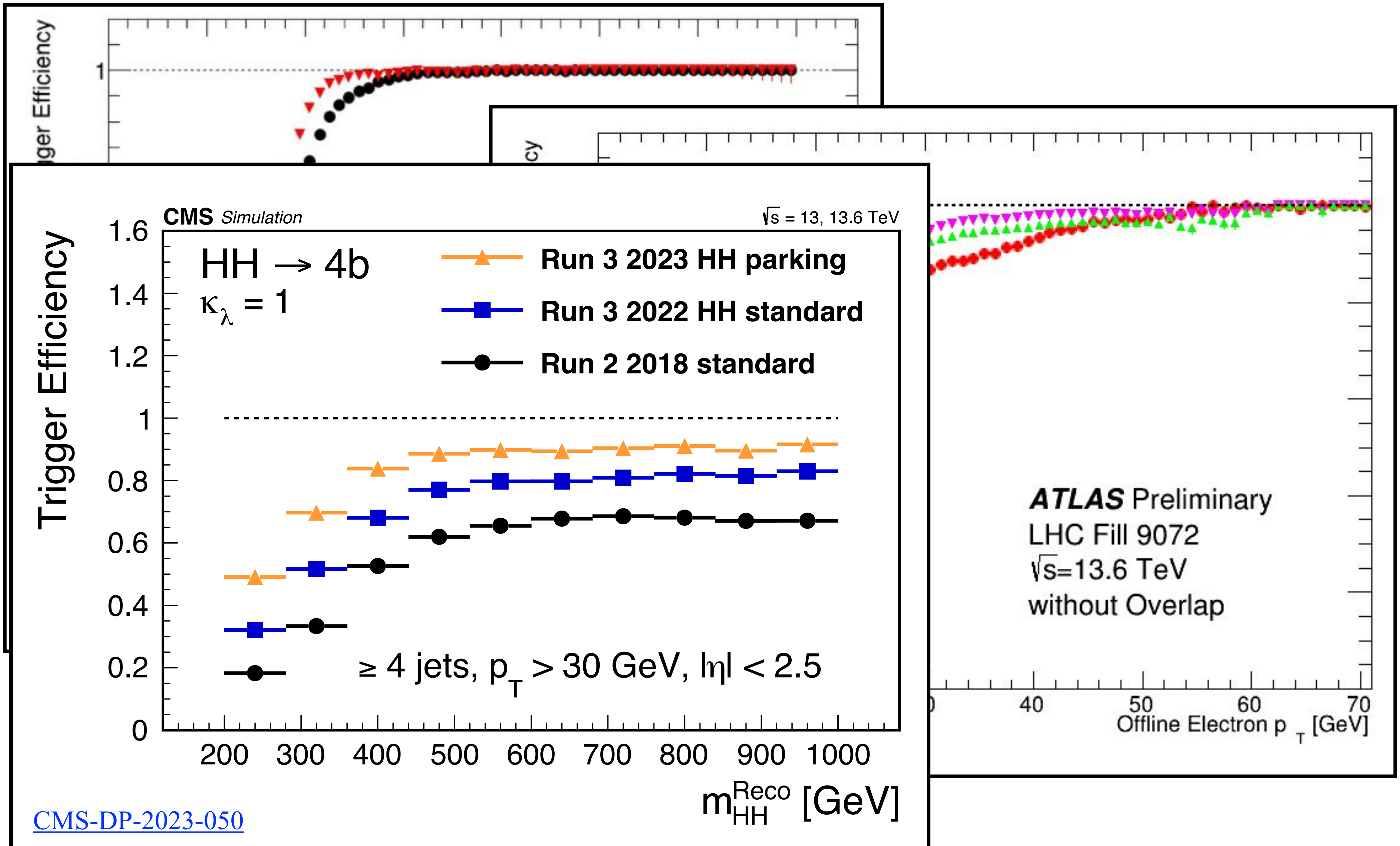
Trigger Improvements for Run3



Trigger Improvements for Run3

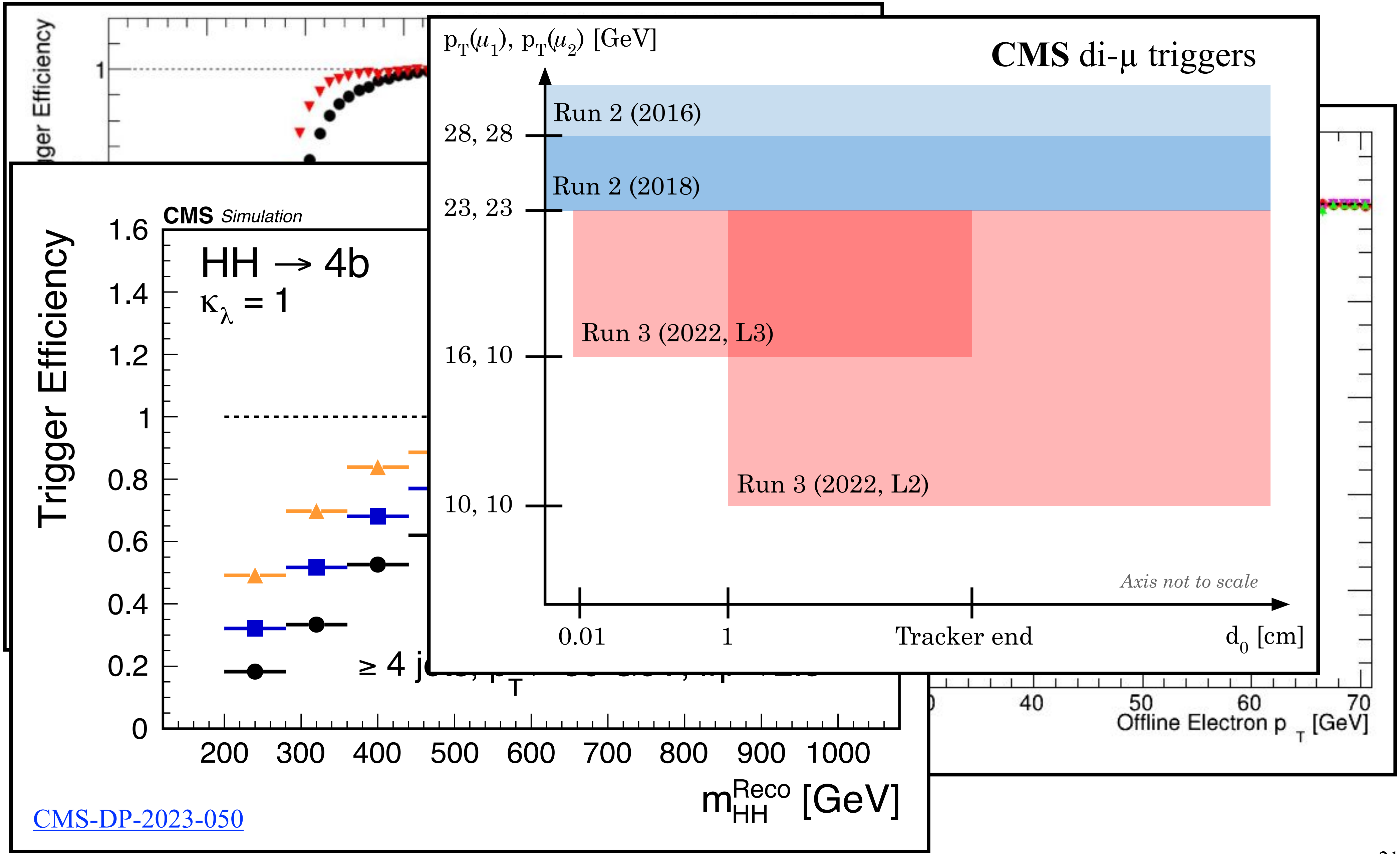


Trigger Improvements for Run3



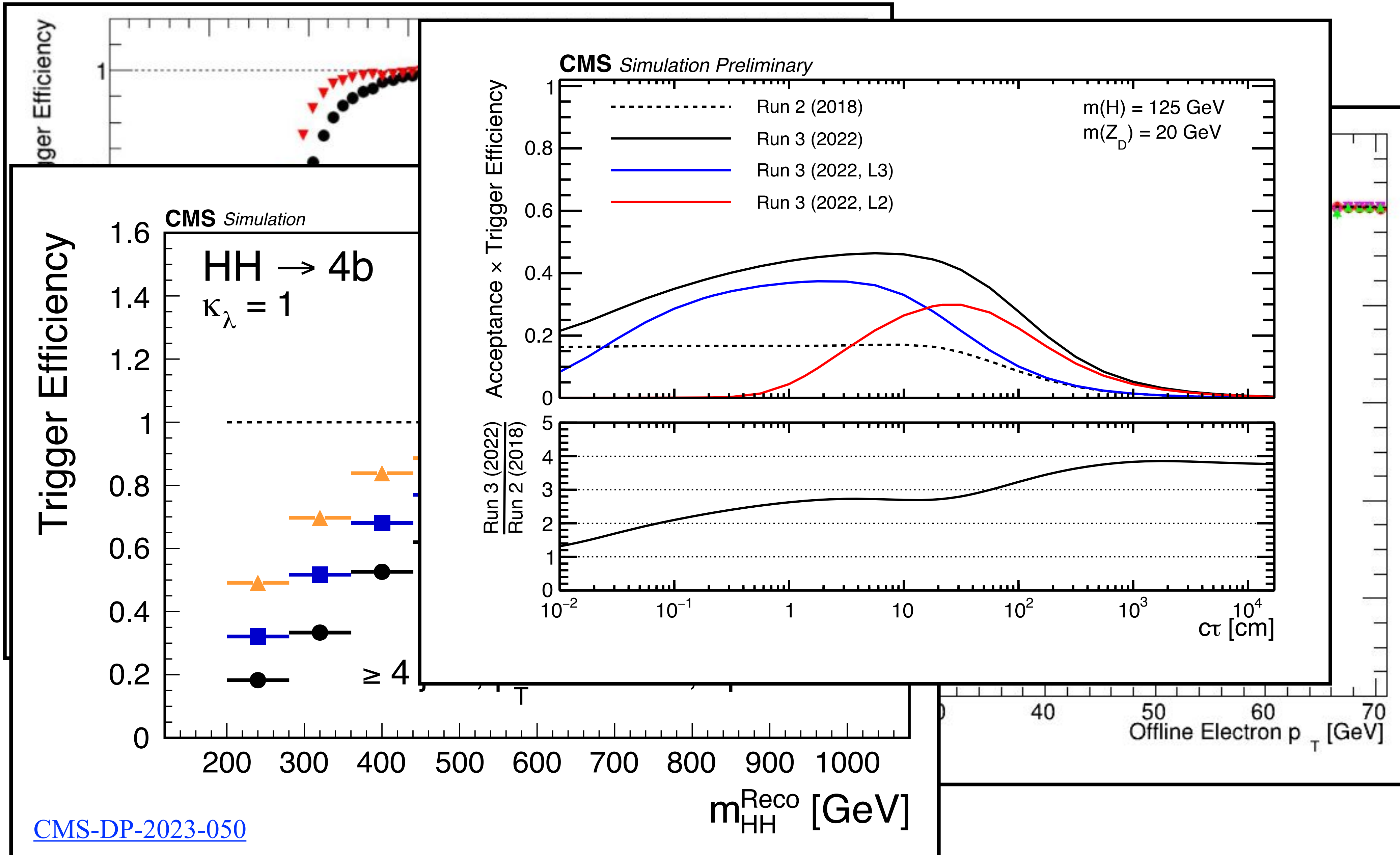
CMS-DP-2023-050

Trigger Improvements for Run3



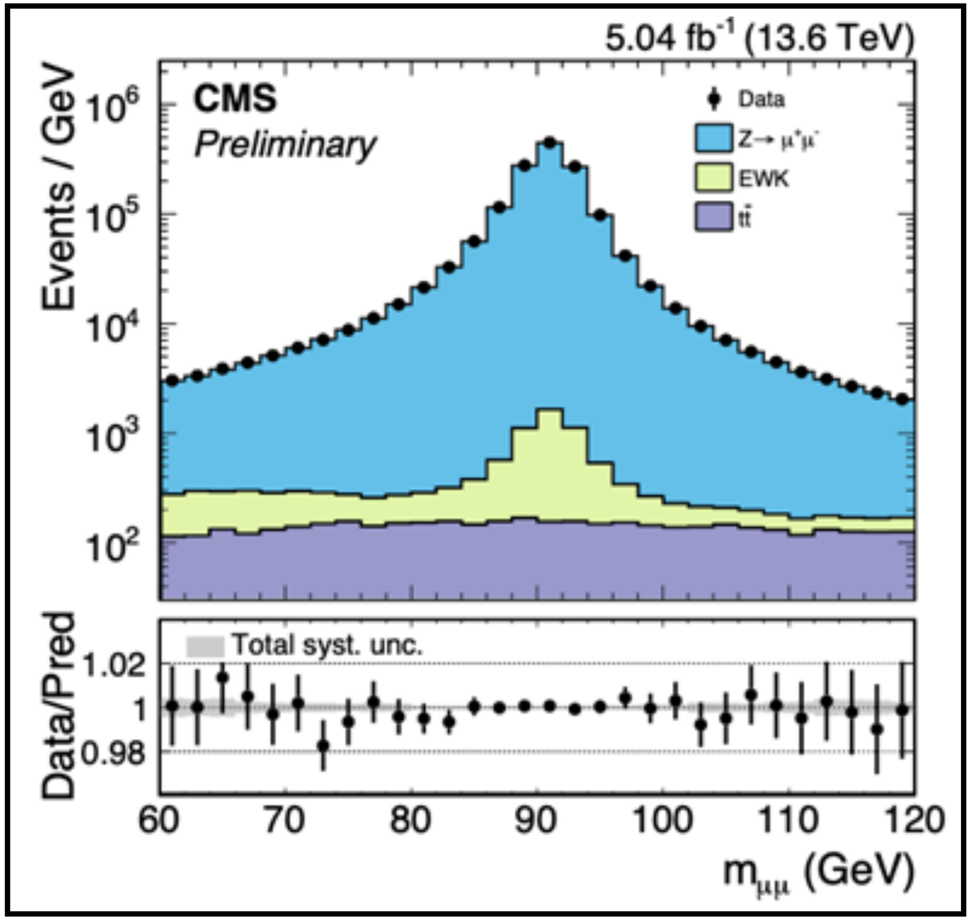
CMS-DP-2023-050

Trigger Improvements for Run3

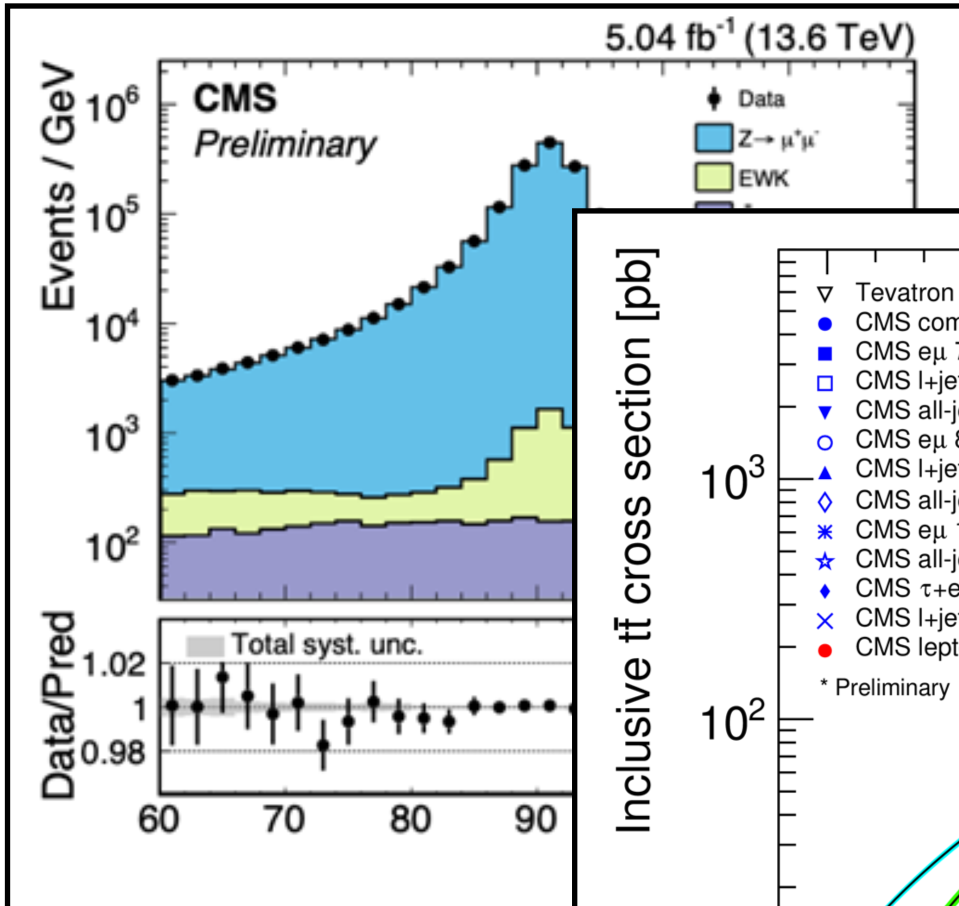


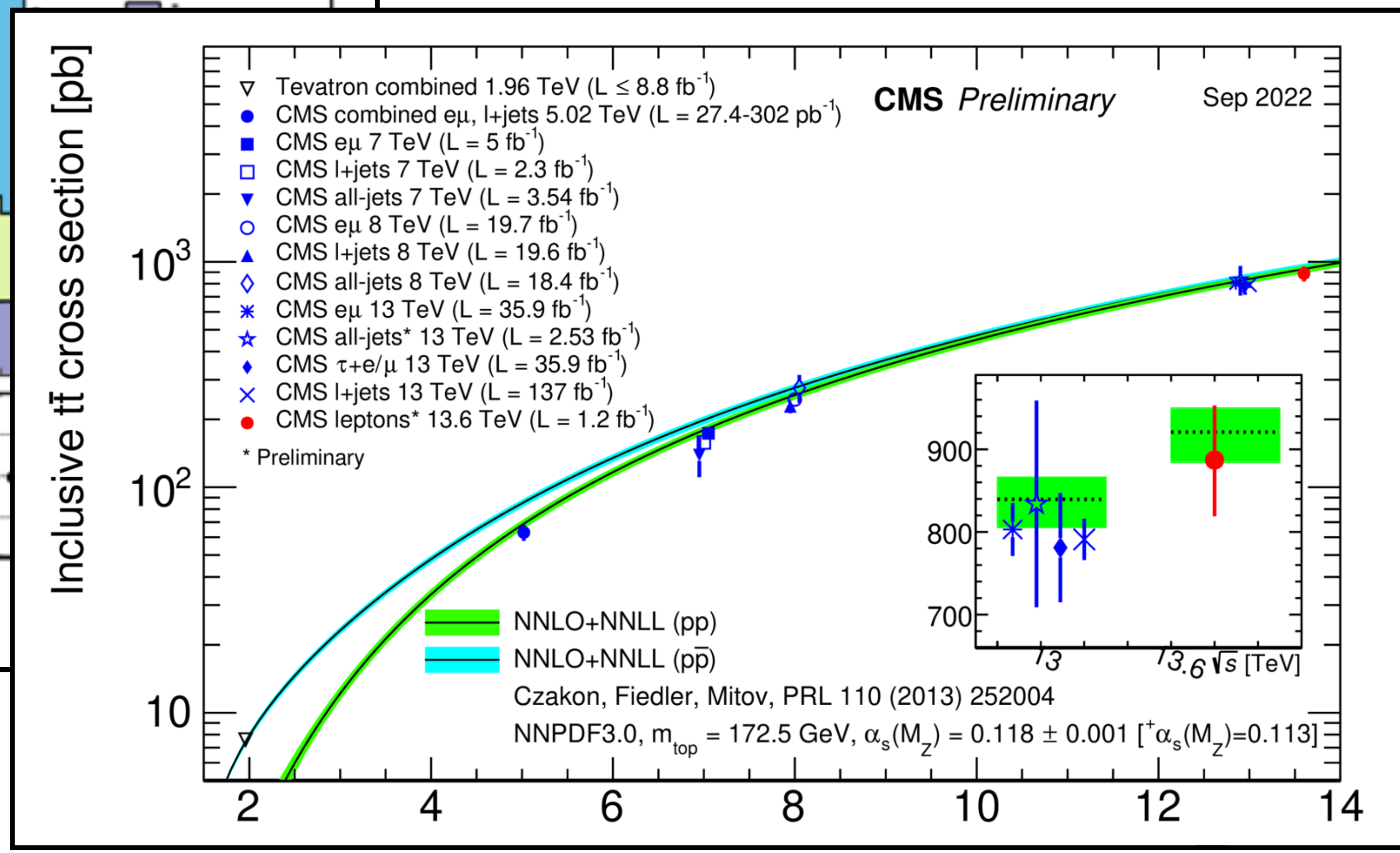
[CMS-DP-2023-050]

First Run-3 Results

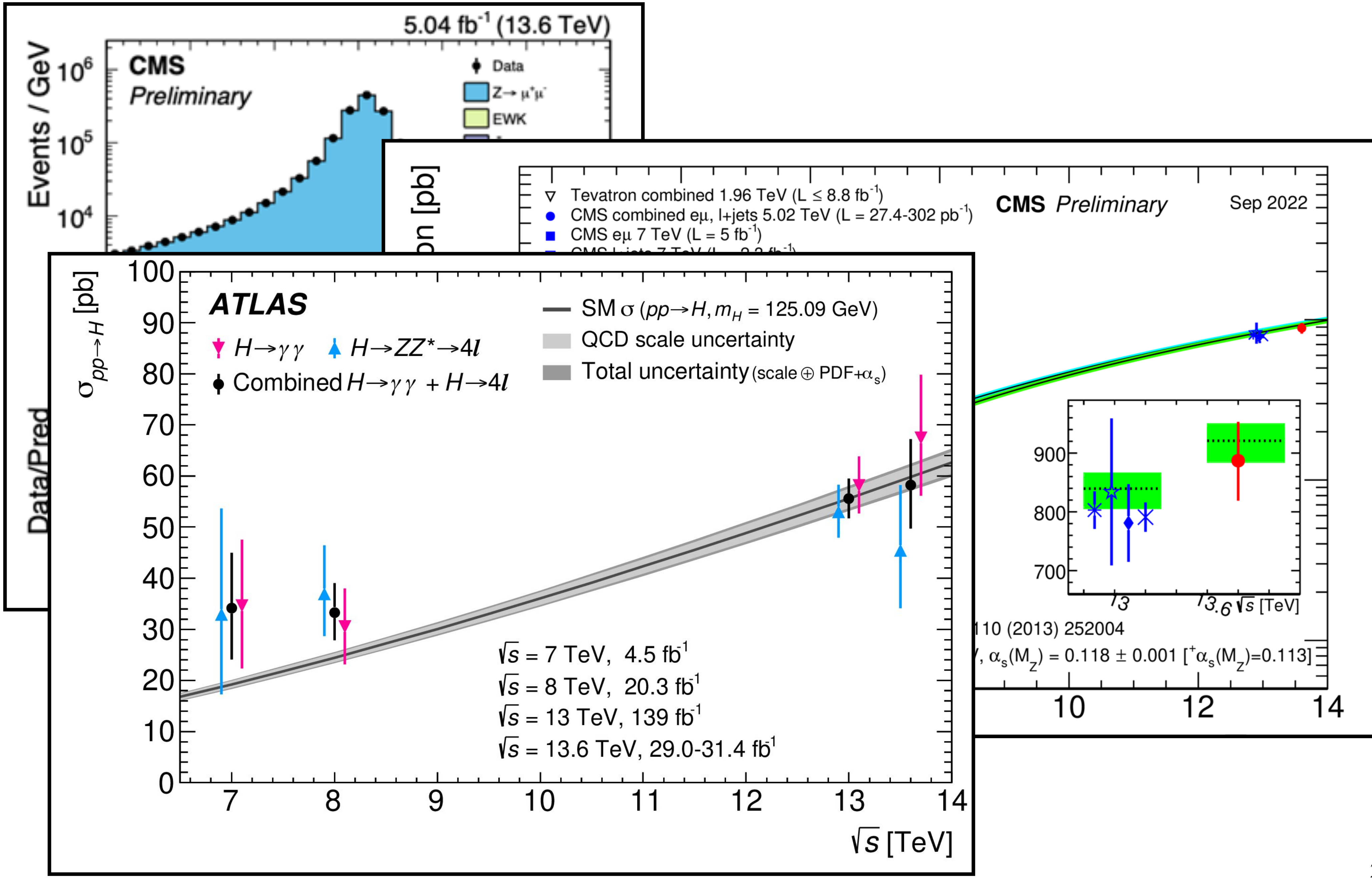


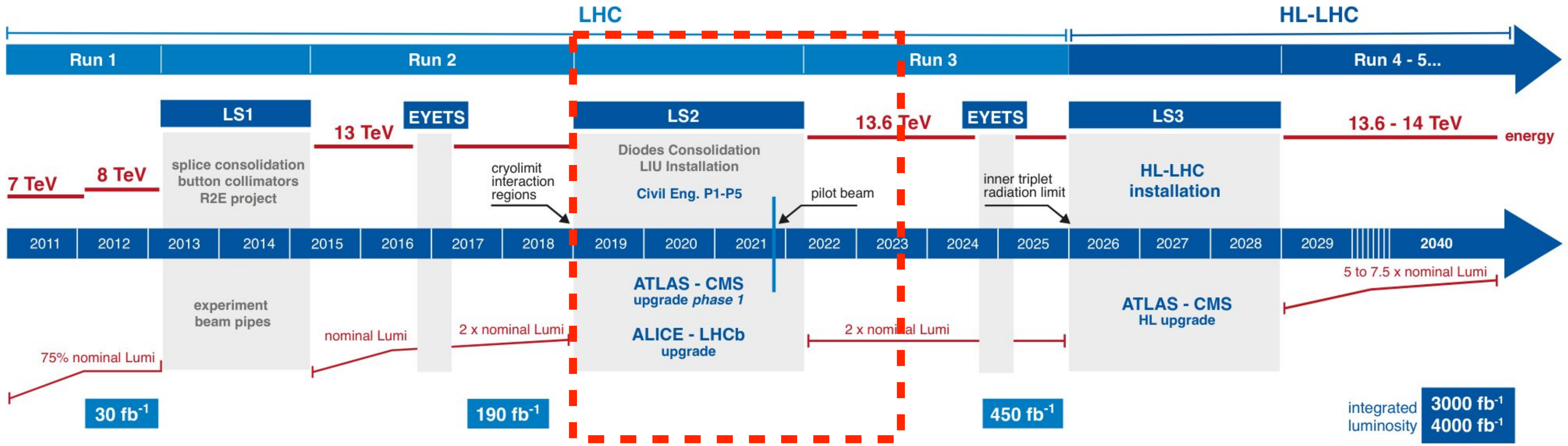
First Run-3 Results





First Run-3 Results





Understanding/Improving:

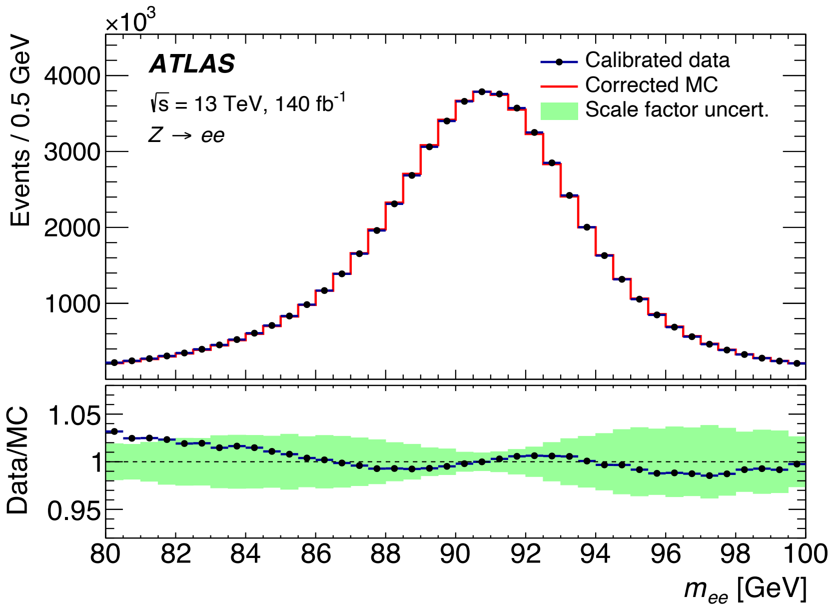
Detectors Calibration

Reconstruction Algorithms

Detector Understanding/Calibration

Improving understanding / calibration of detectors

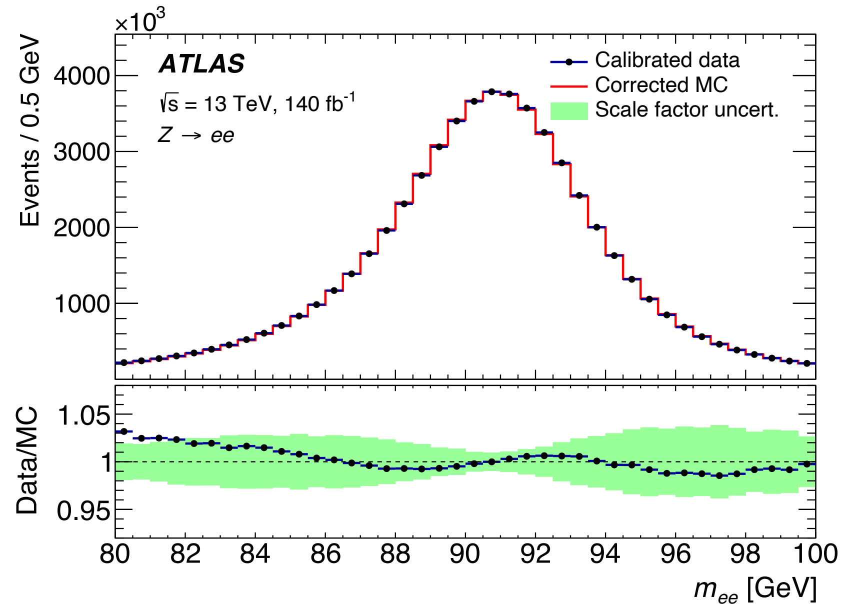
arXiv:2309.05471

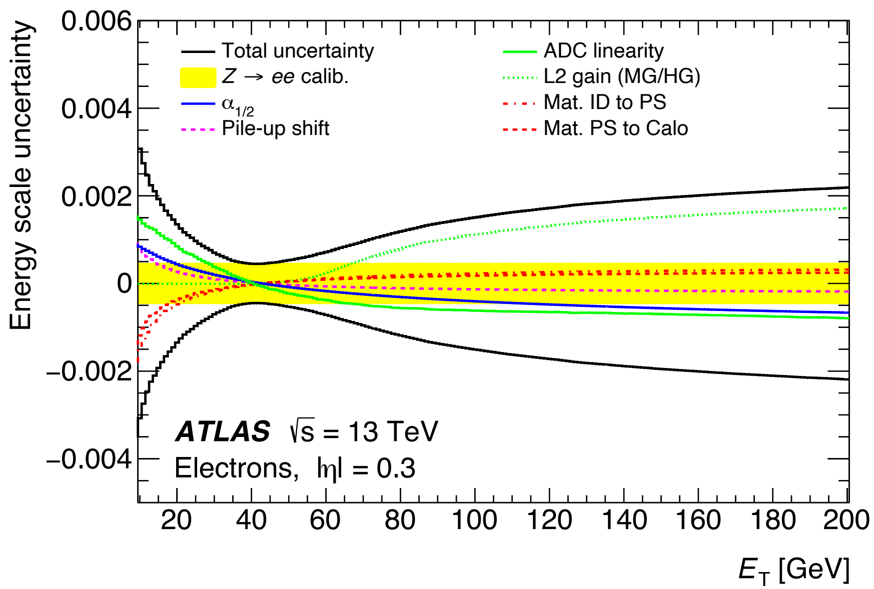


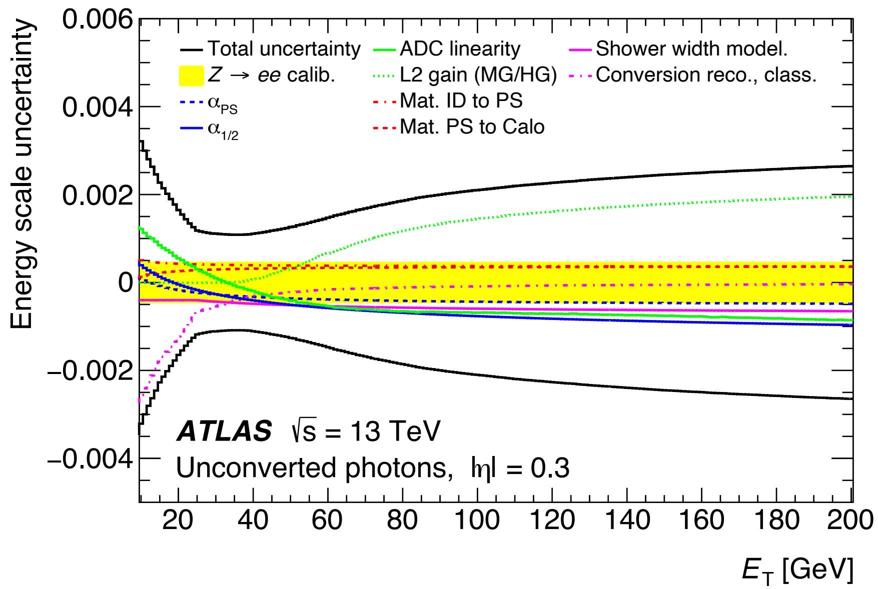
Detector Understanding/Calibration

Improving understanding / calibration of detectors

arXiv:2309.05471



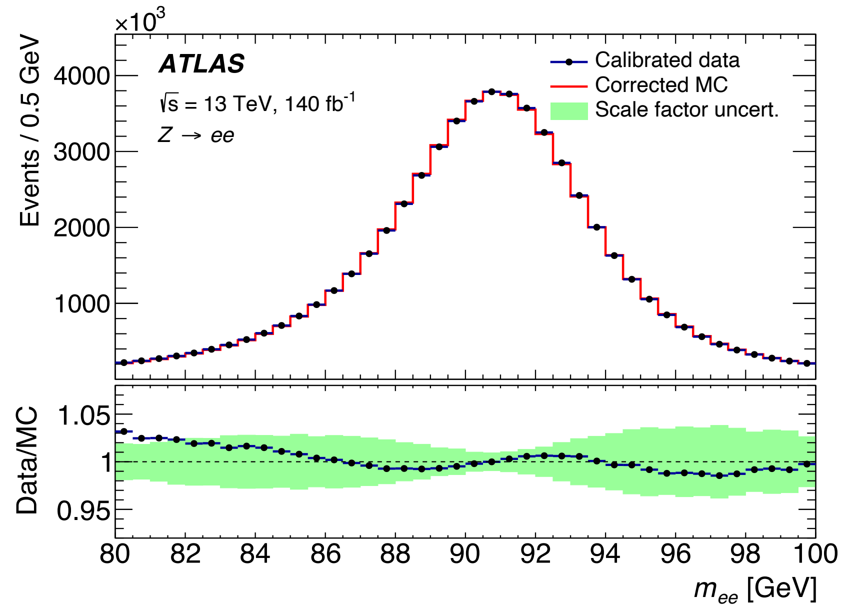


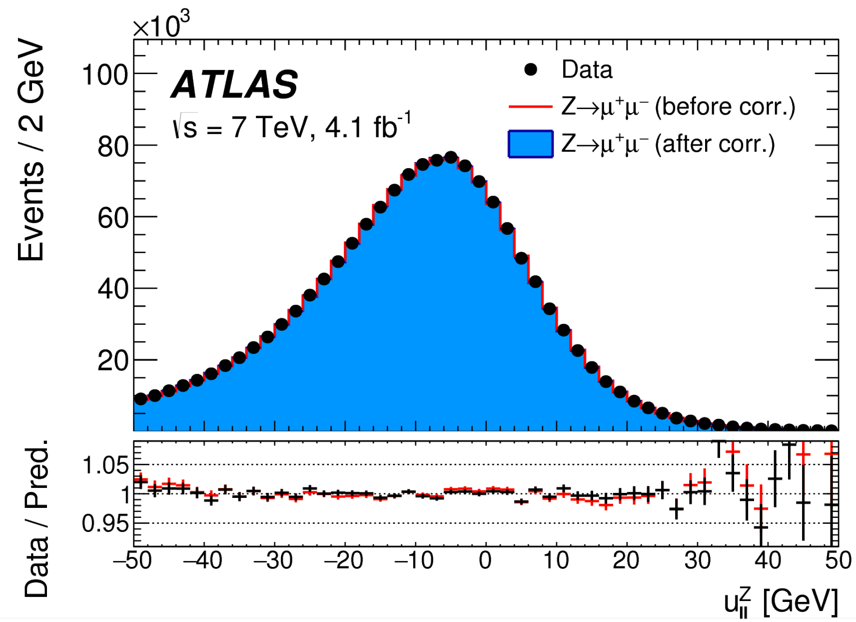


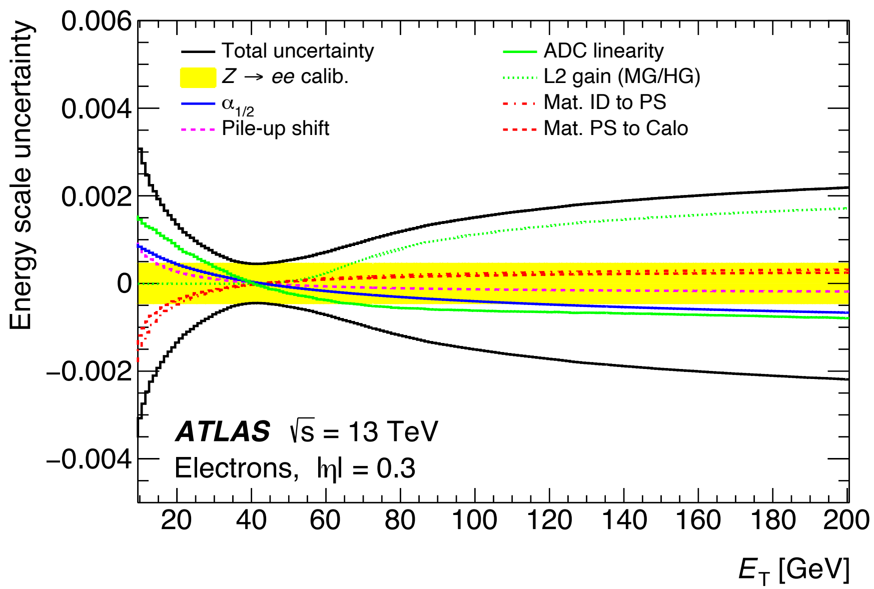
Detector Understanding/Calibration

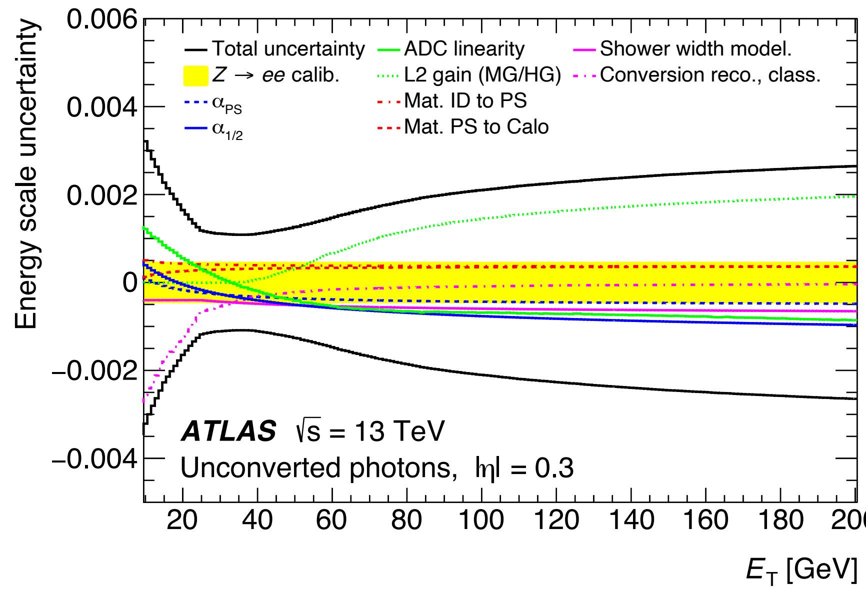
Improving understanding / calibration of detectors

arXiv:2309.05471
Eur. Phys. J. C 78 (2018)







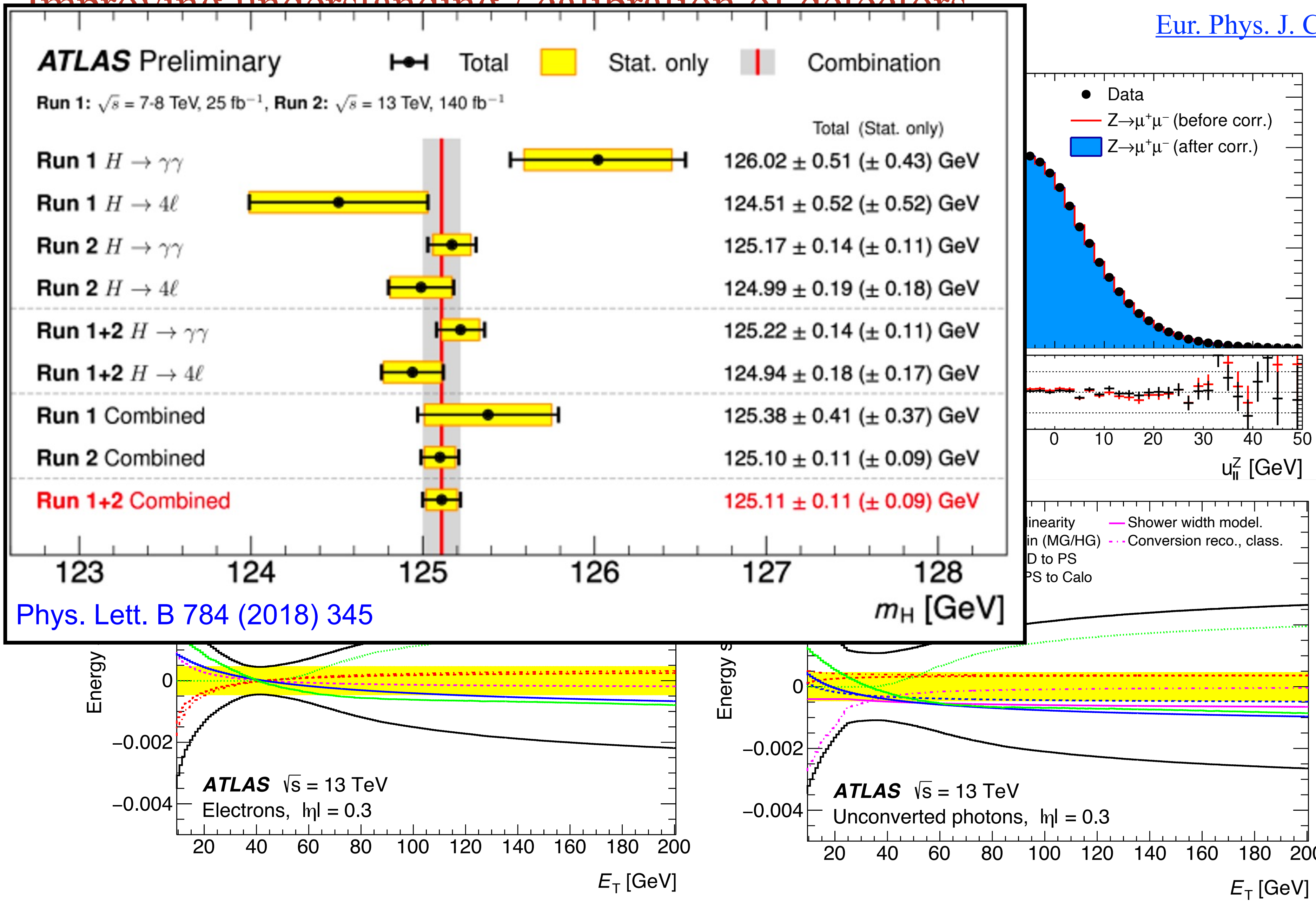


Detector Understanding/Calibration

Improving understanding / calibration of detectors

[arXiv:2309.05471](https://arxiv.org/abs/2309.05471)

[Eur. Phys. J. C 78 (2018)]()

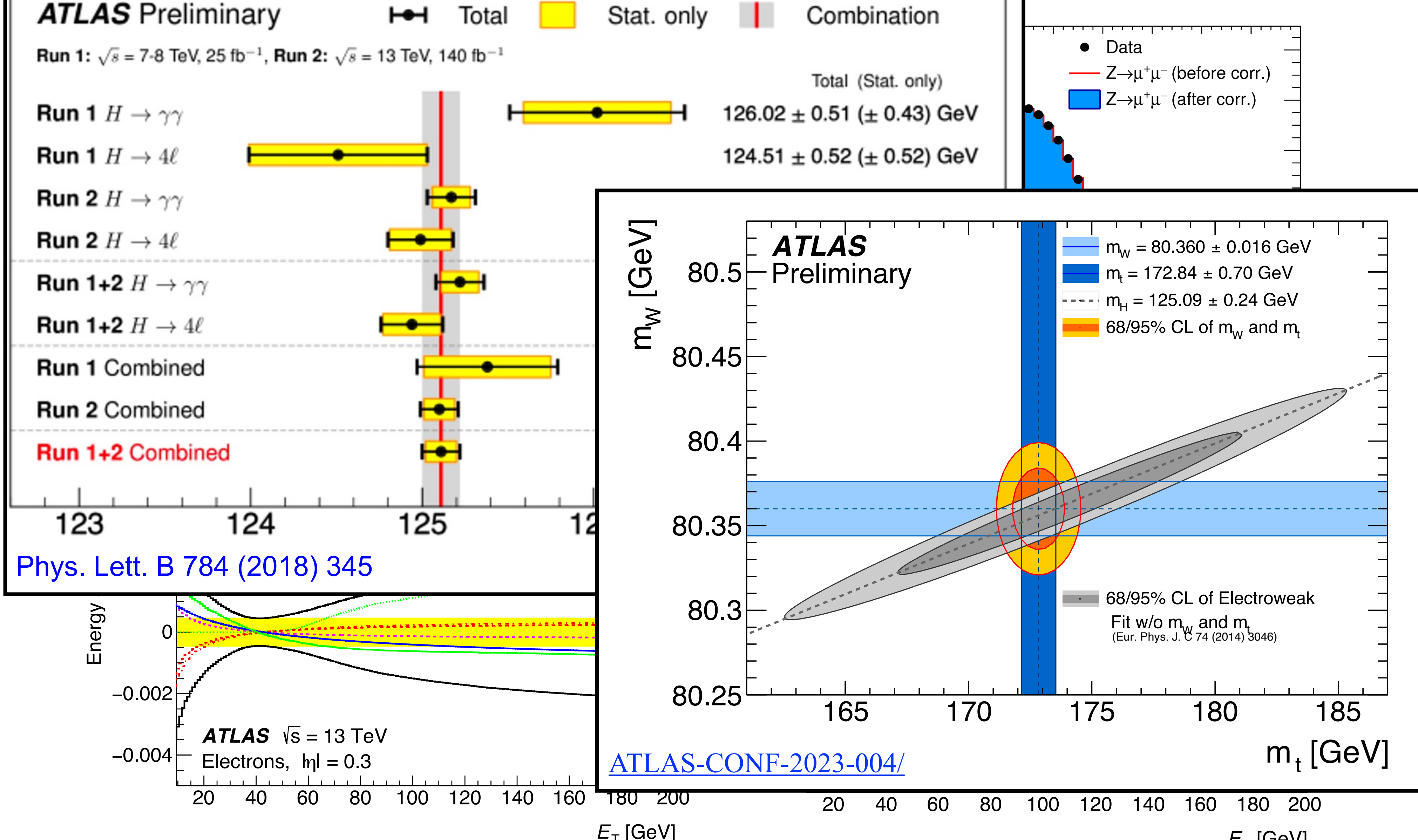


Detector Understanding/Calibration

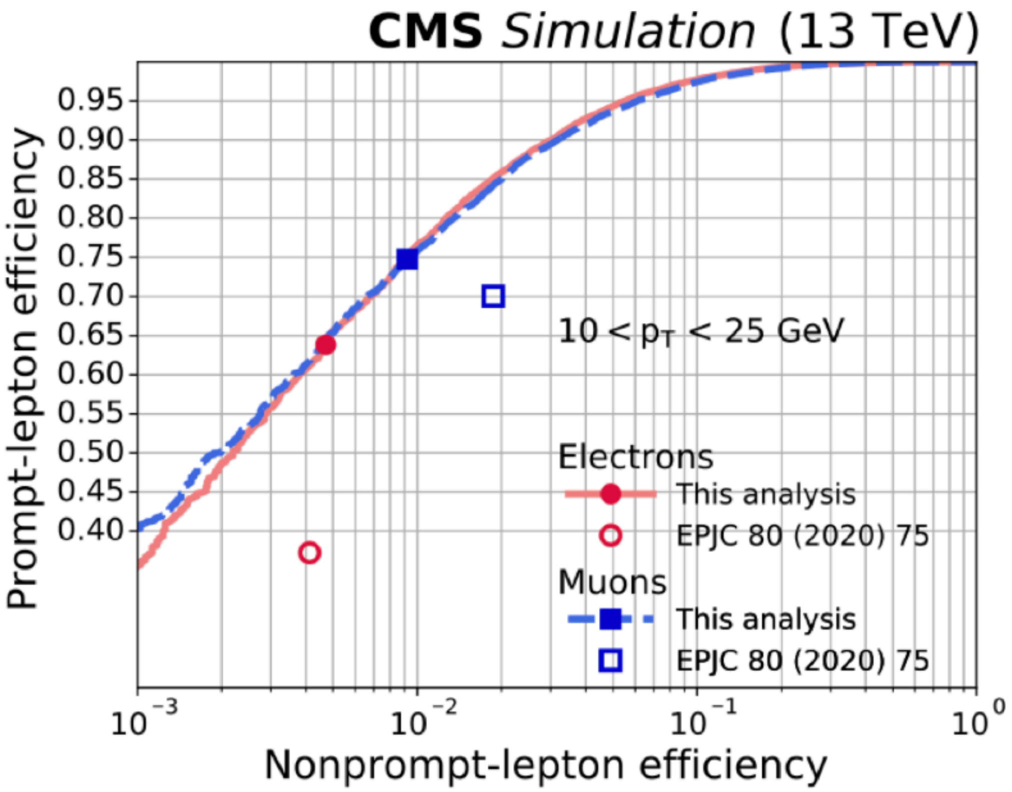
Improving understanding / calibration of detectors

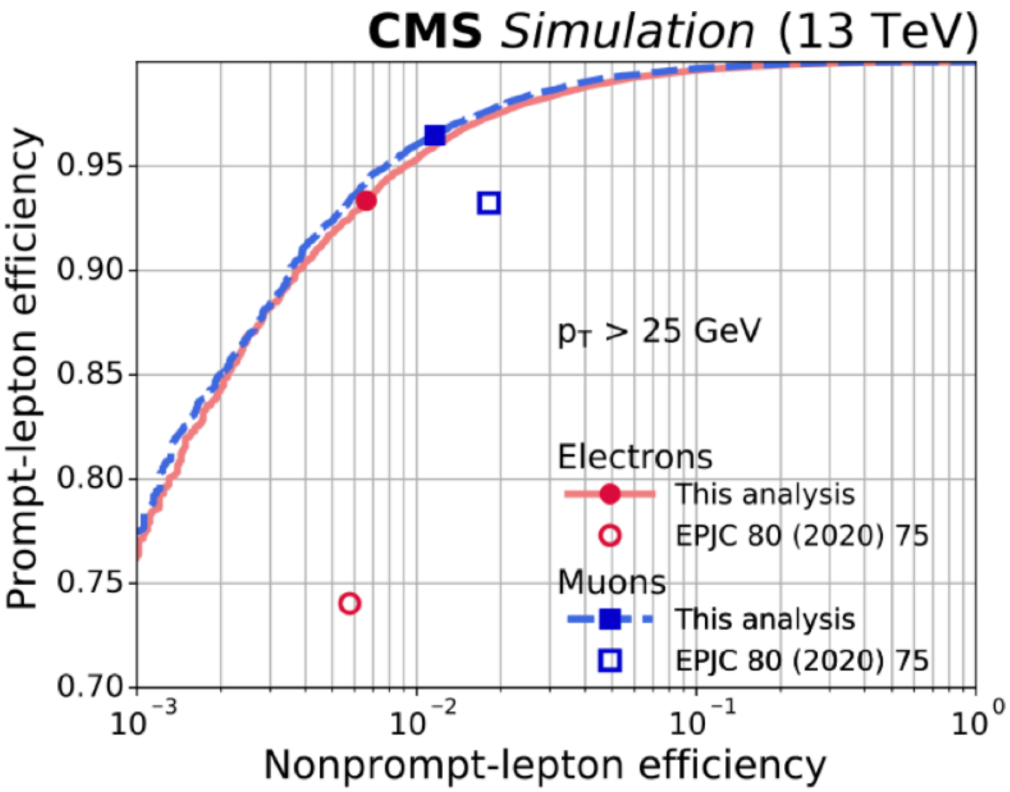
arXiv:2309.05471

Eur. Phys. J. C 78 (2018)



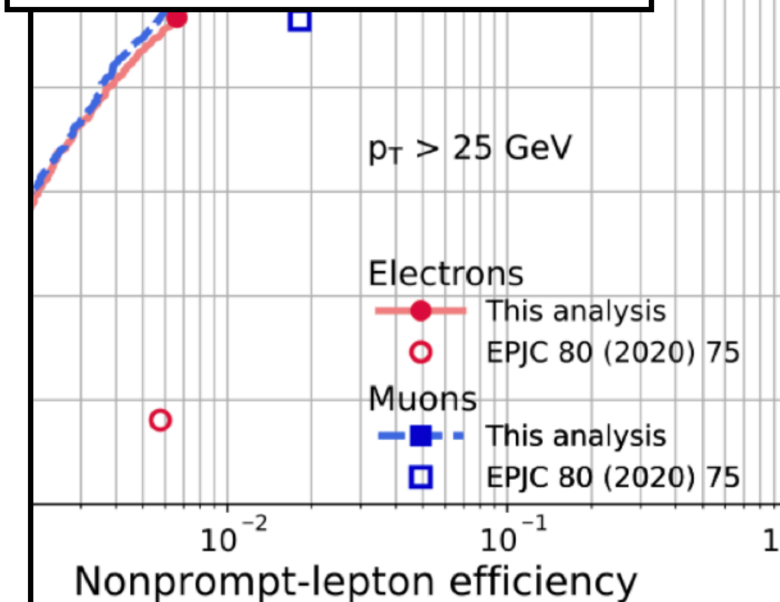
Prompt Lepton Identification

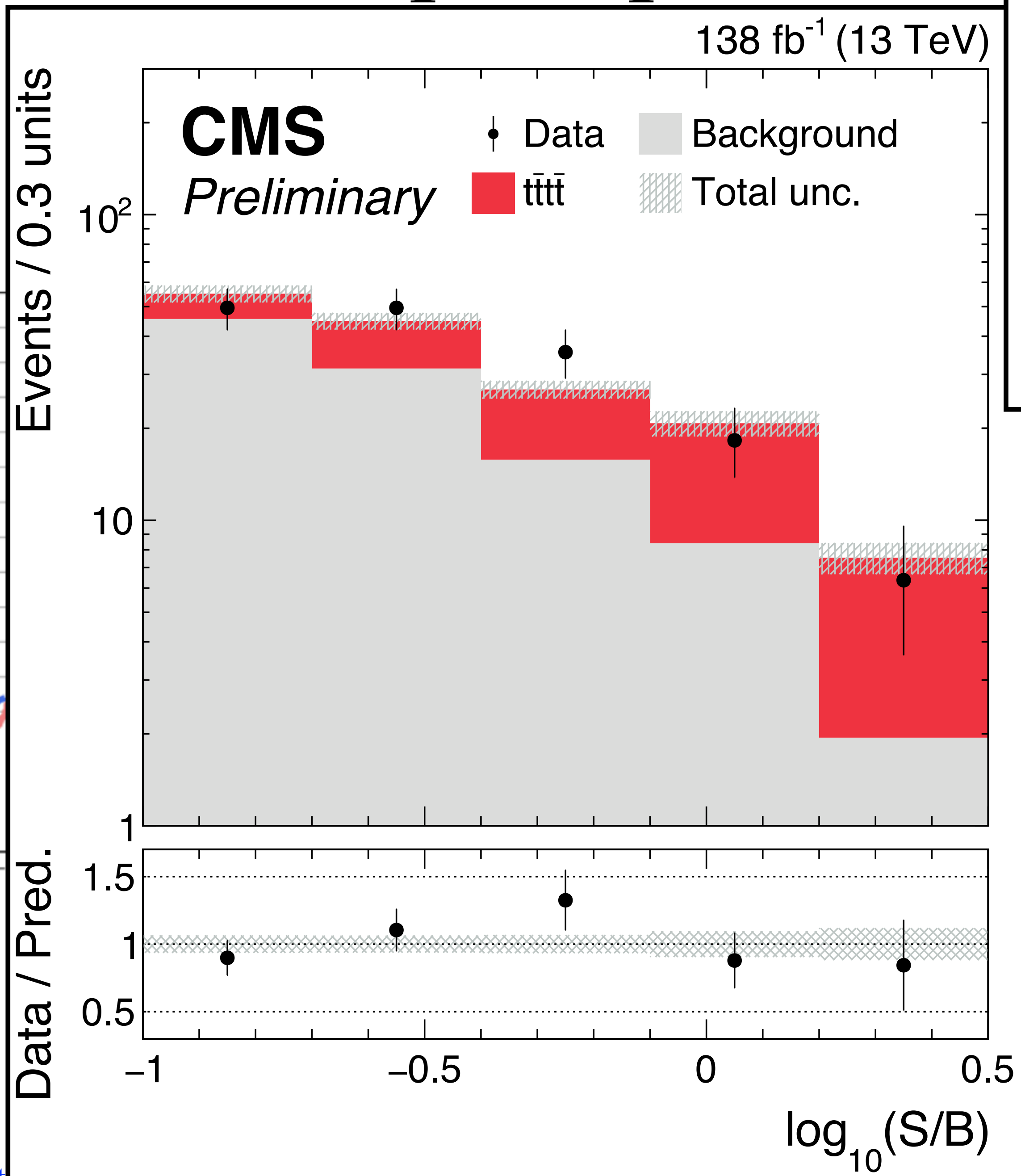


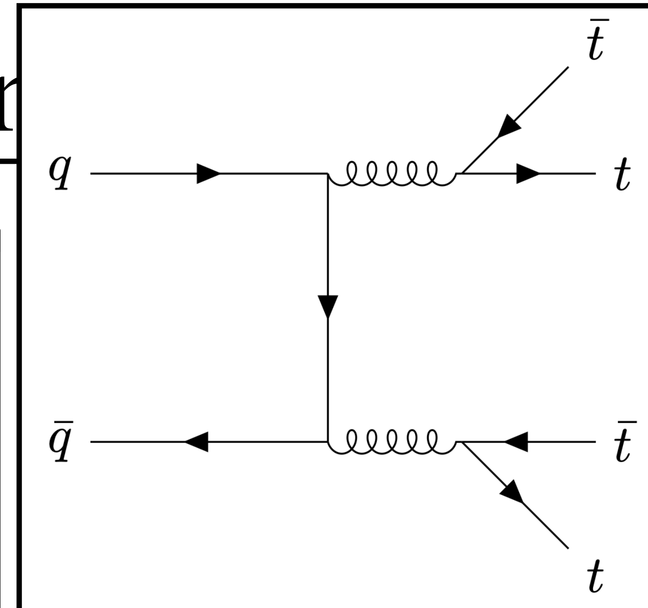


Phys. Lett. B 847 (2023) 138290

Prompt Lepton Ider







Observation of 4top
5.6σ (4.6σ expected)

Phys. Lett

B-Quark Identification

Machine Learning major impact in b-tagging

B-Quark Identification

Machine Learning major impact in b-tagging

Evolution of heavy Flavor tagging

<u>Theme</u>: *Deeper, fancier networks with lower-level inputs*

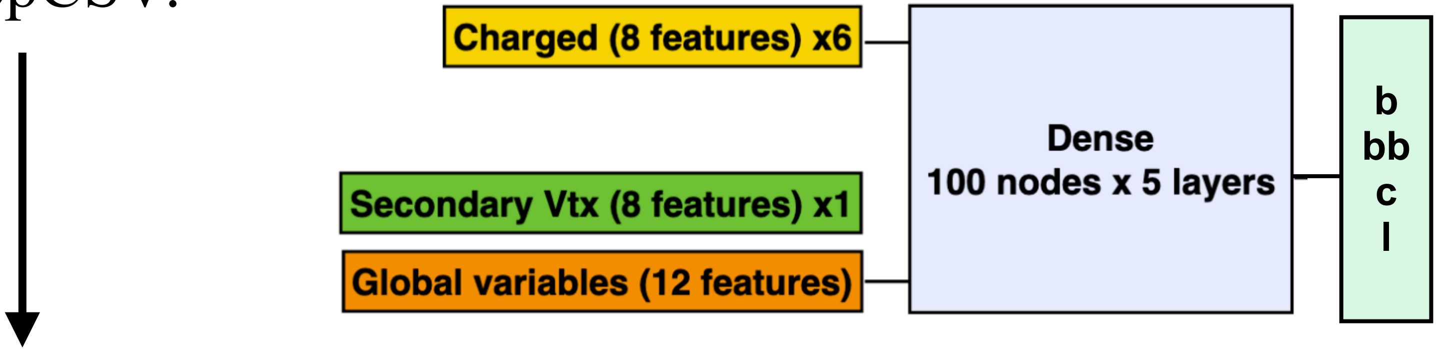
B-Quark Identification

Machine Learning major impact in b-tagging

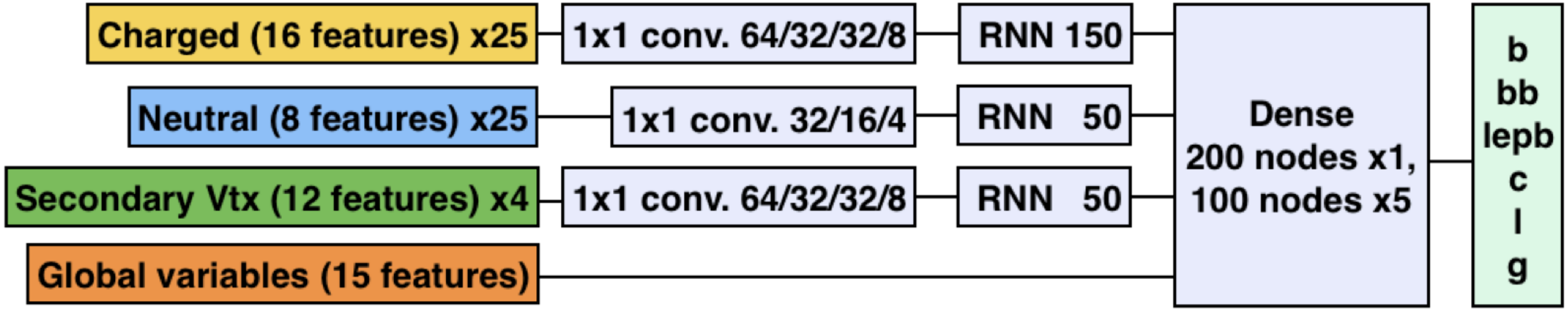
Evolution of heavy Flavor tagging

Theme: *Deeper, fancier networks with lower-level inputs*

DeepCSV:



DeepJet:



B-Quark Identification

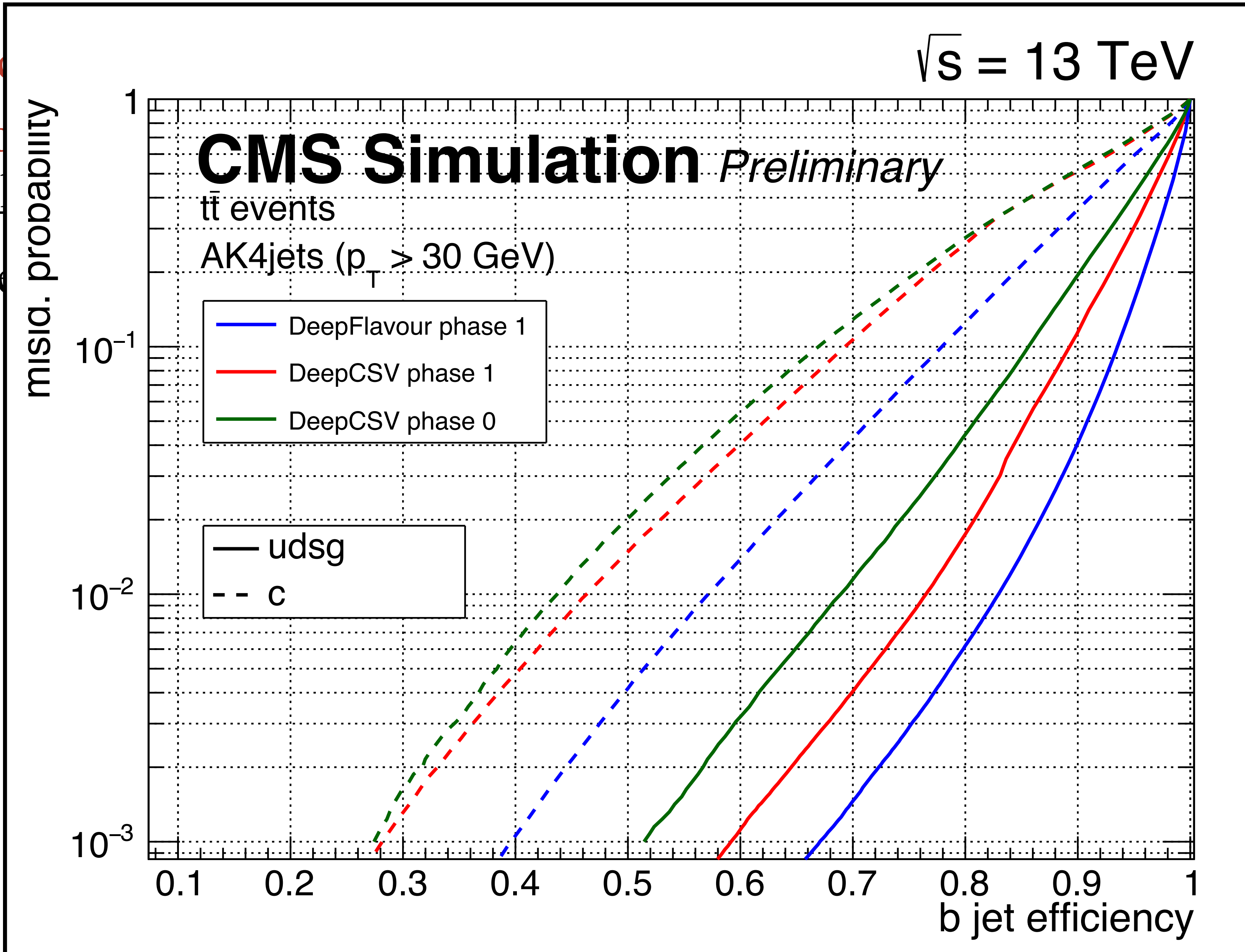
Mac

Evo

T

De

D



b
bb
lepb
c
l
g

B-Quark Identification

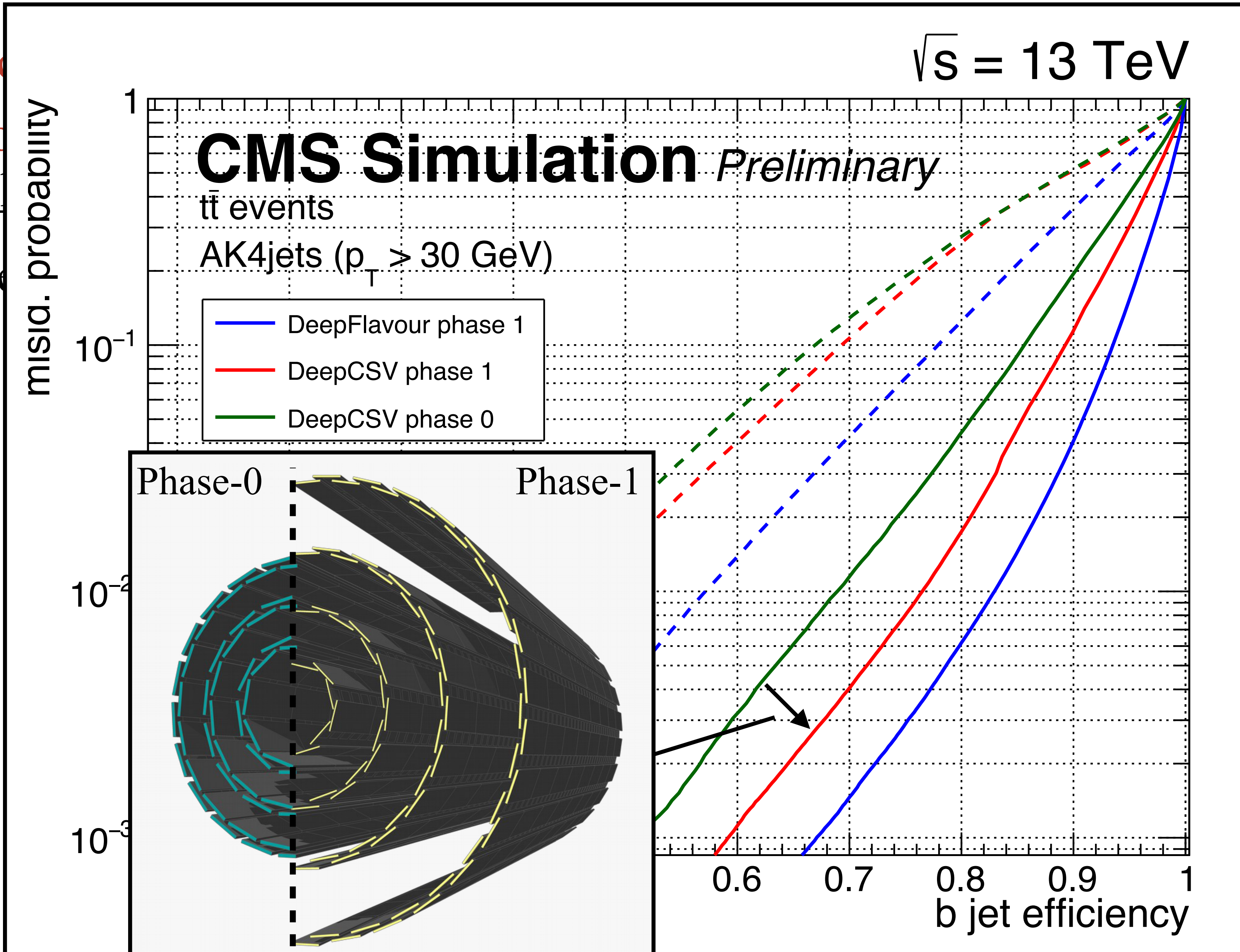
Ma

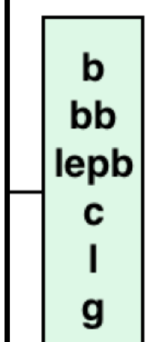
Evo

T

De

D





B-Quark Identification

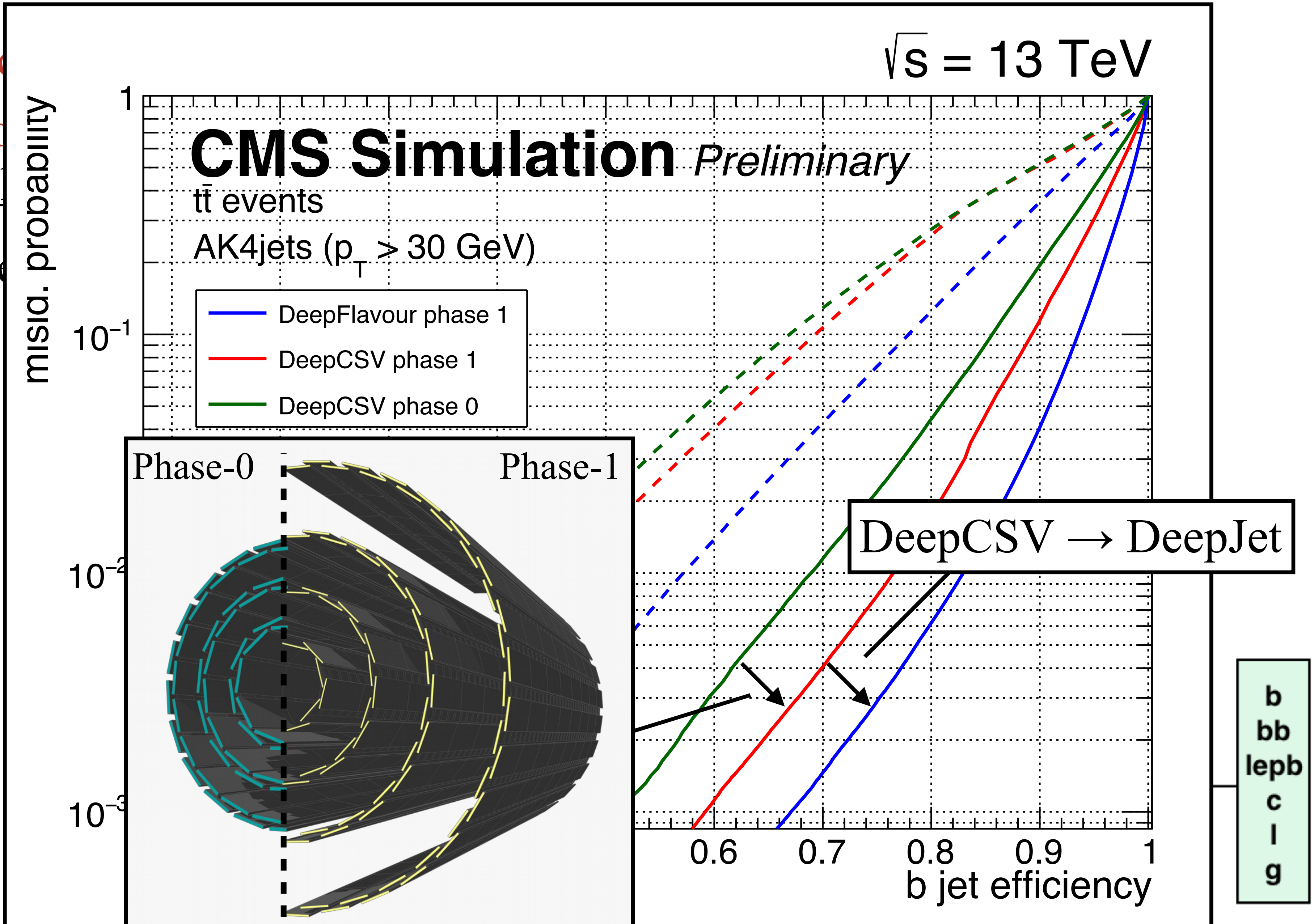
Ma

Evo

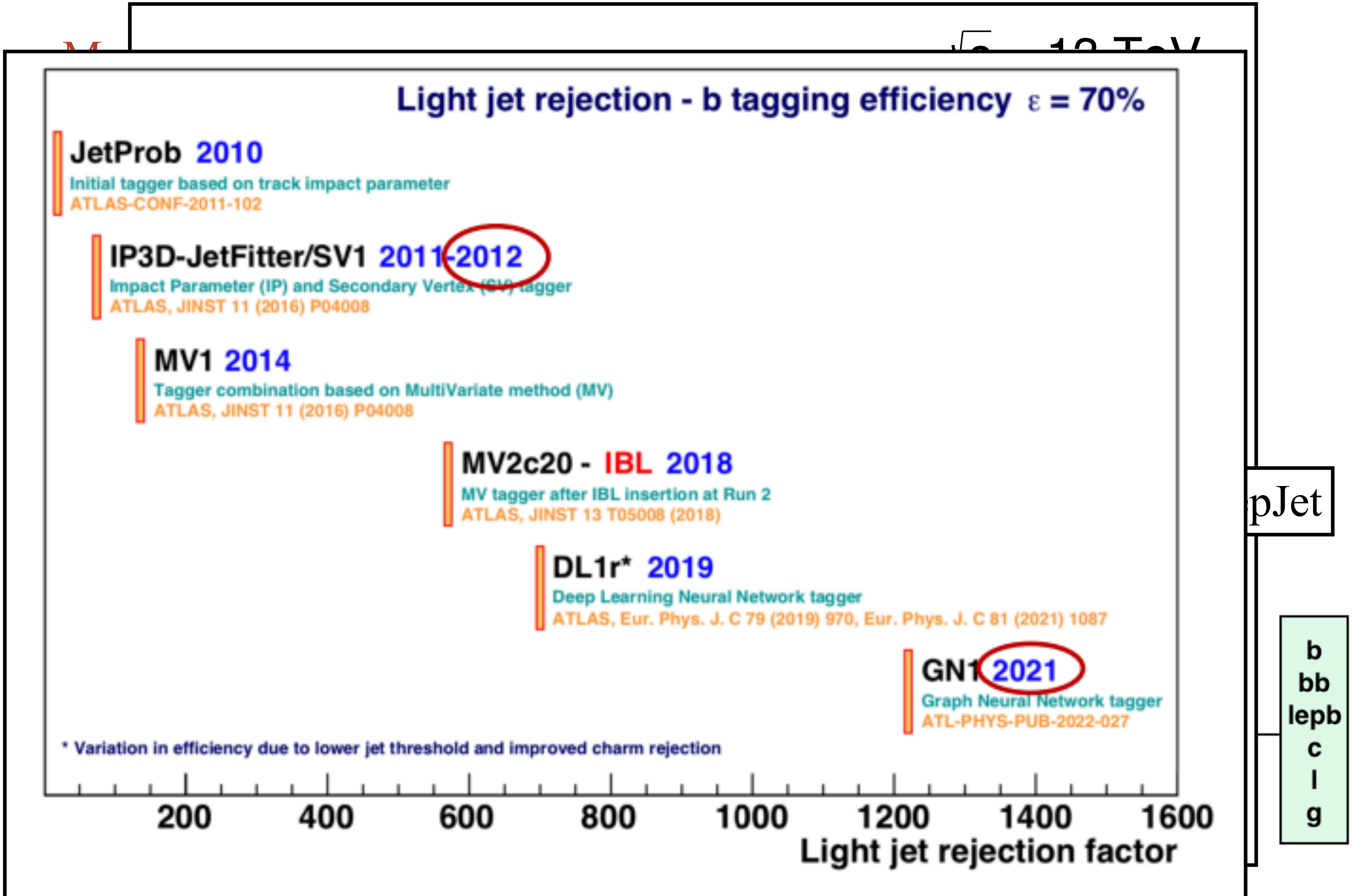
T

De

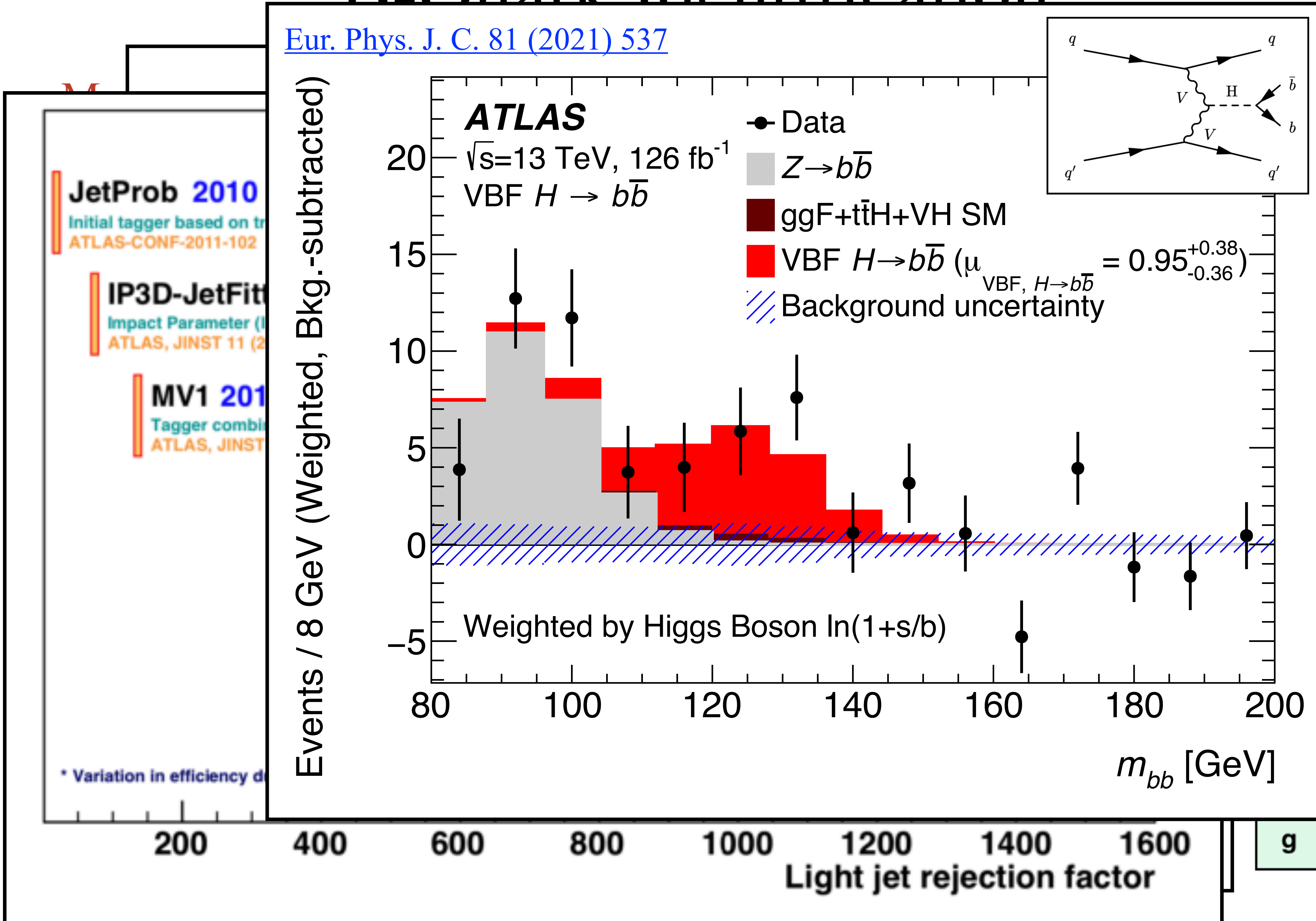
D



B-Quark Identification



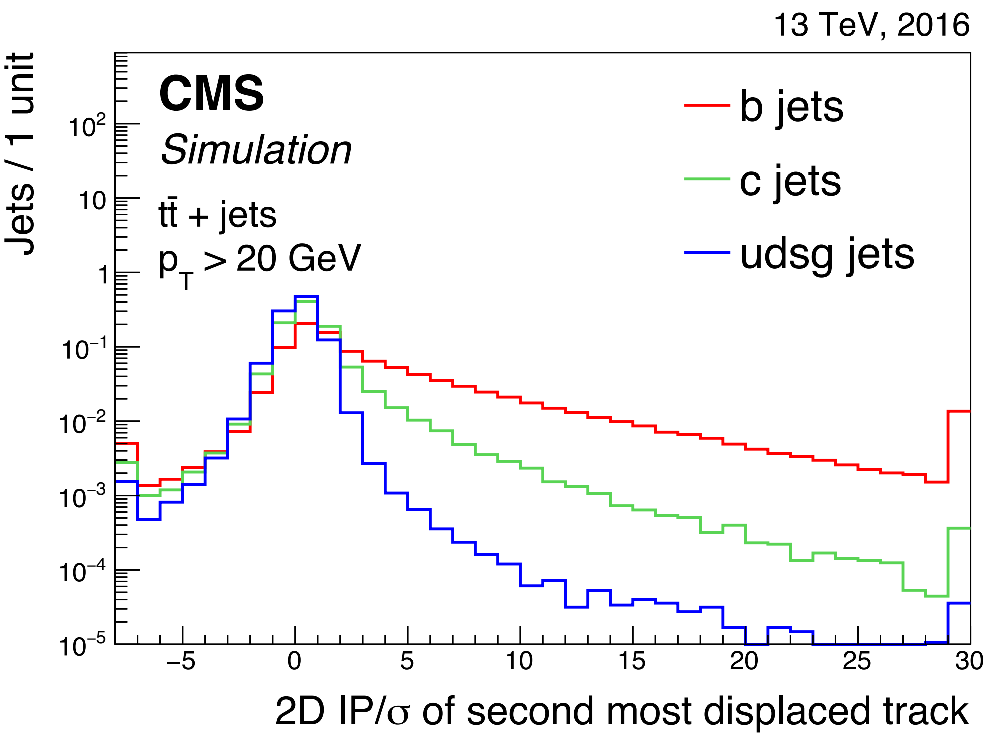
B-Quark Identification

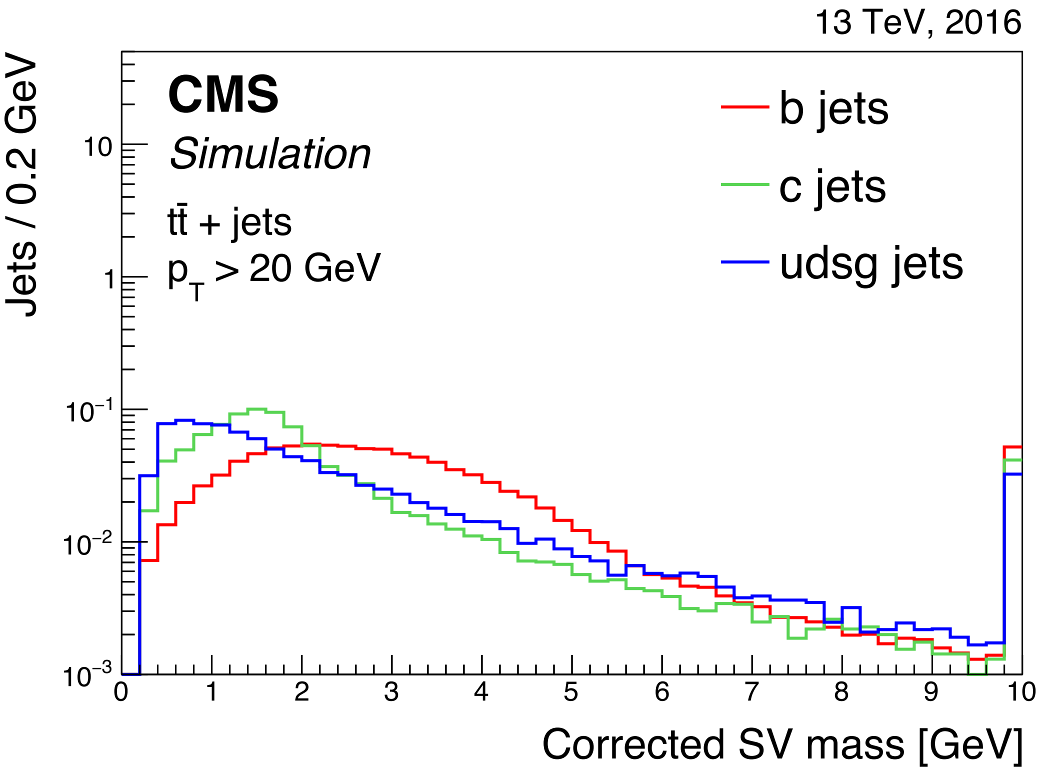


Things Once Thought Impossible:

Things Once Thought Impossible:
Charm Jet Tagging

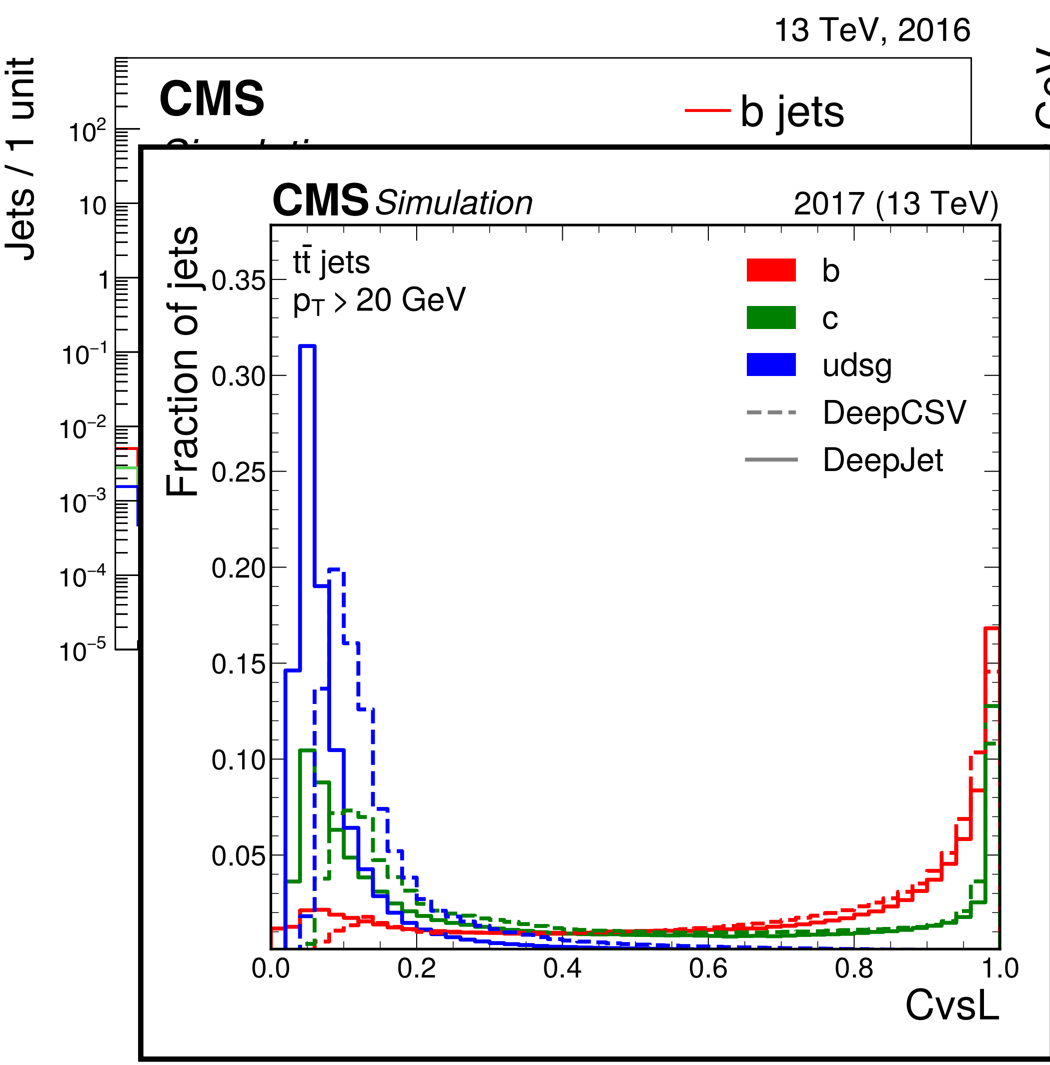
Challenging, background from both sides:

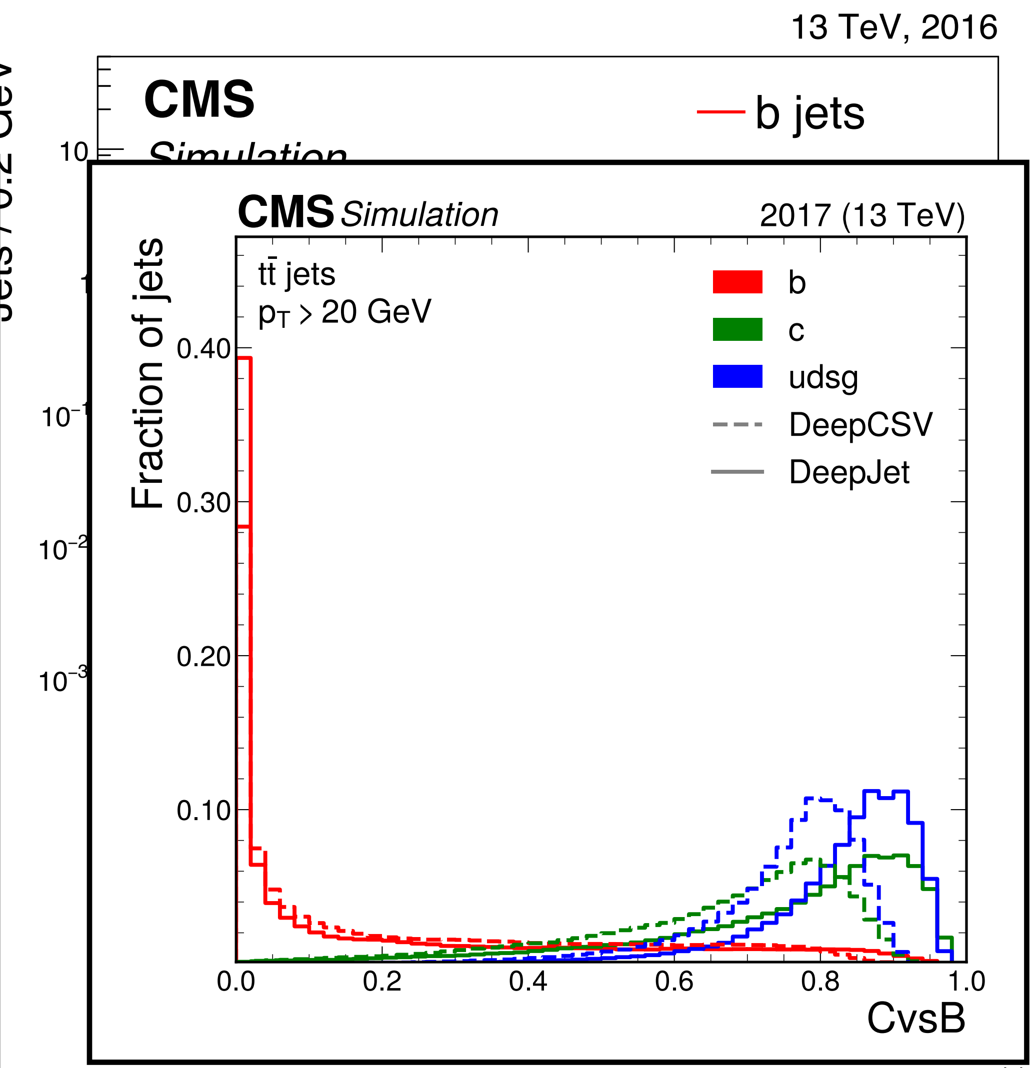




Things Once Thought Impossible: Charm Jet Tagging

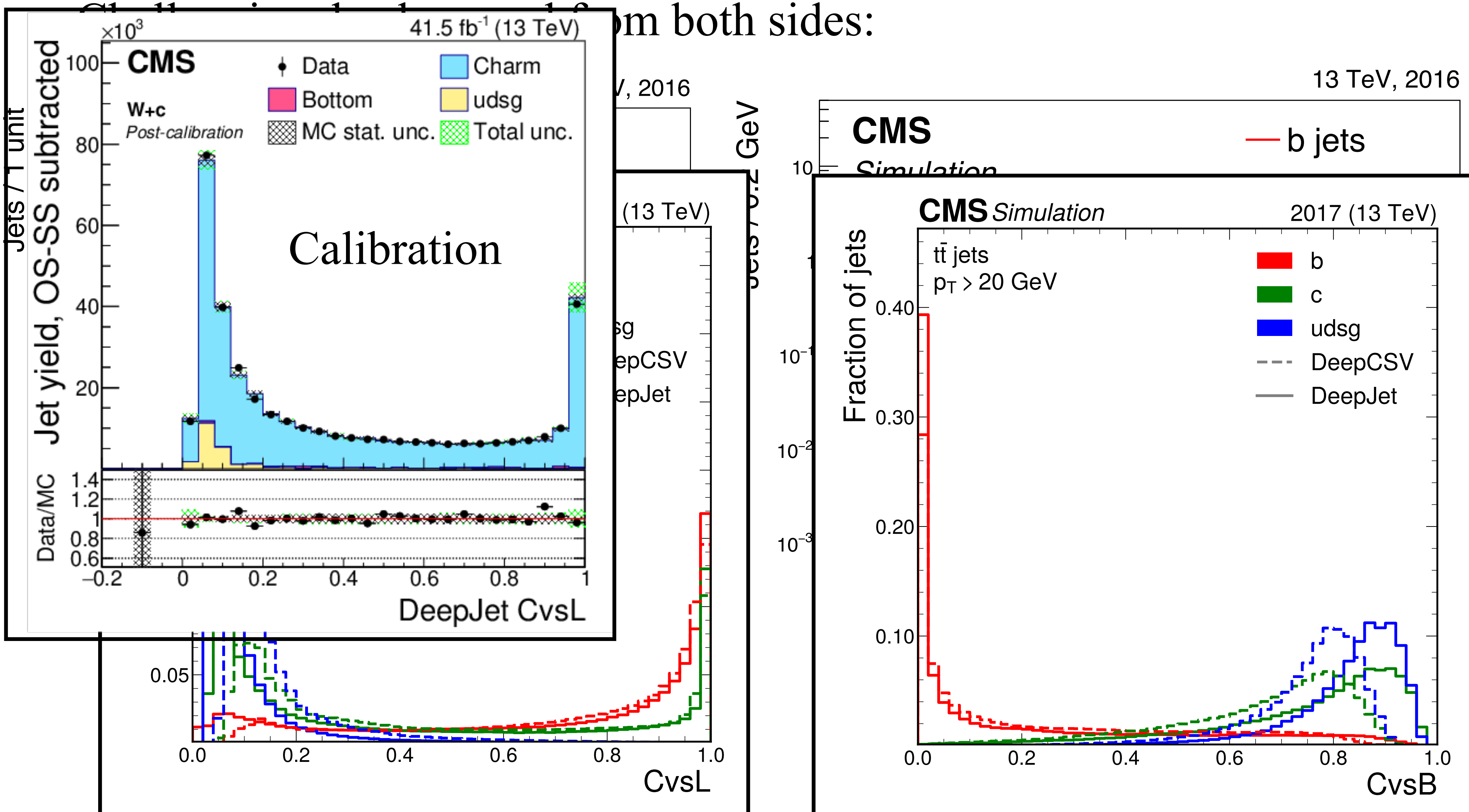
Challenging, background from both sides:



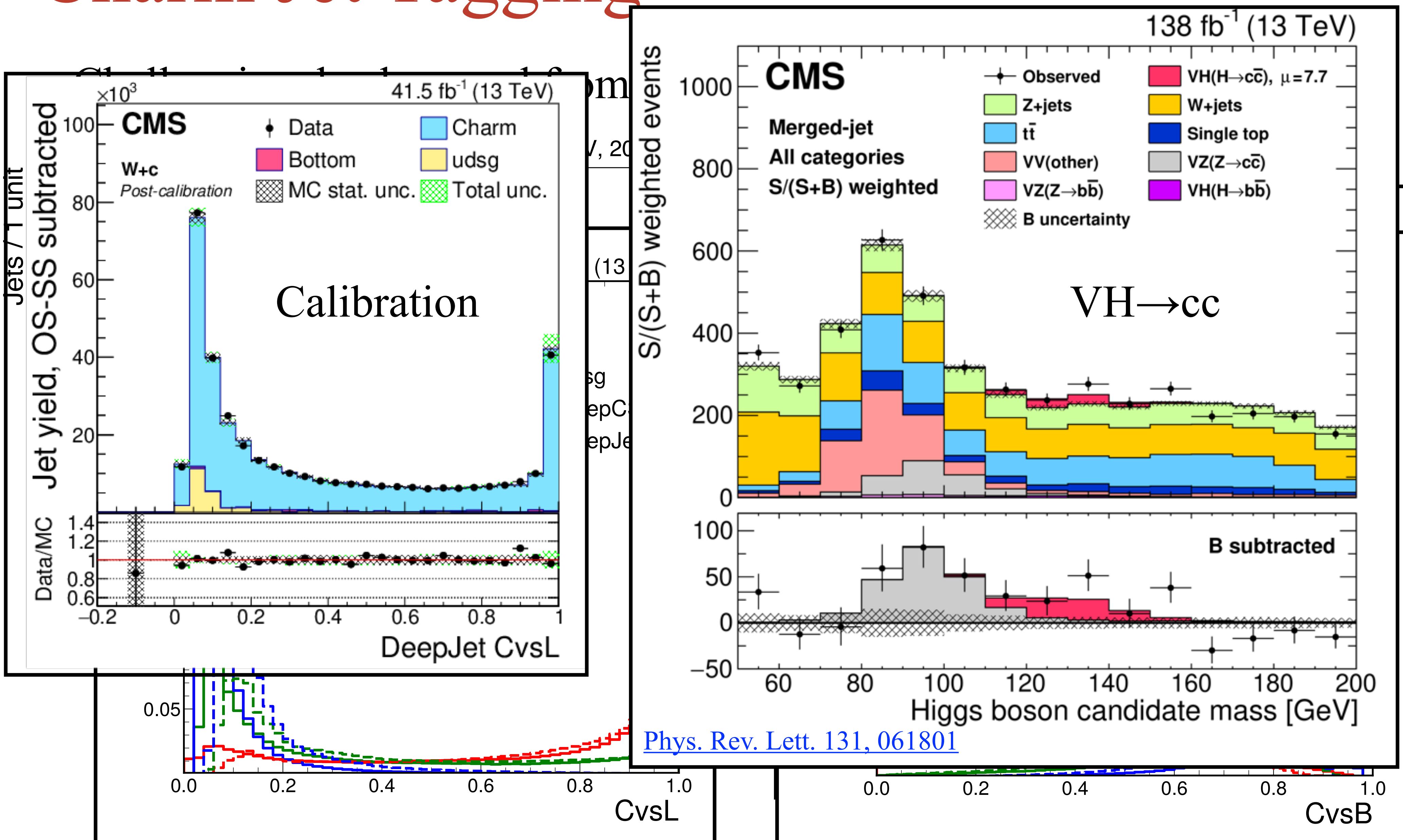


Things Once Thought Impossible: Charm Jet Tagging

…m both sides:



Things Once Thought Impossible: Charm Jet Tagging

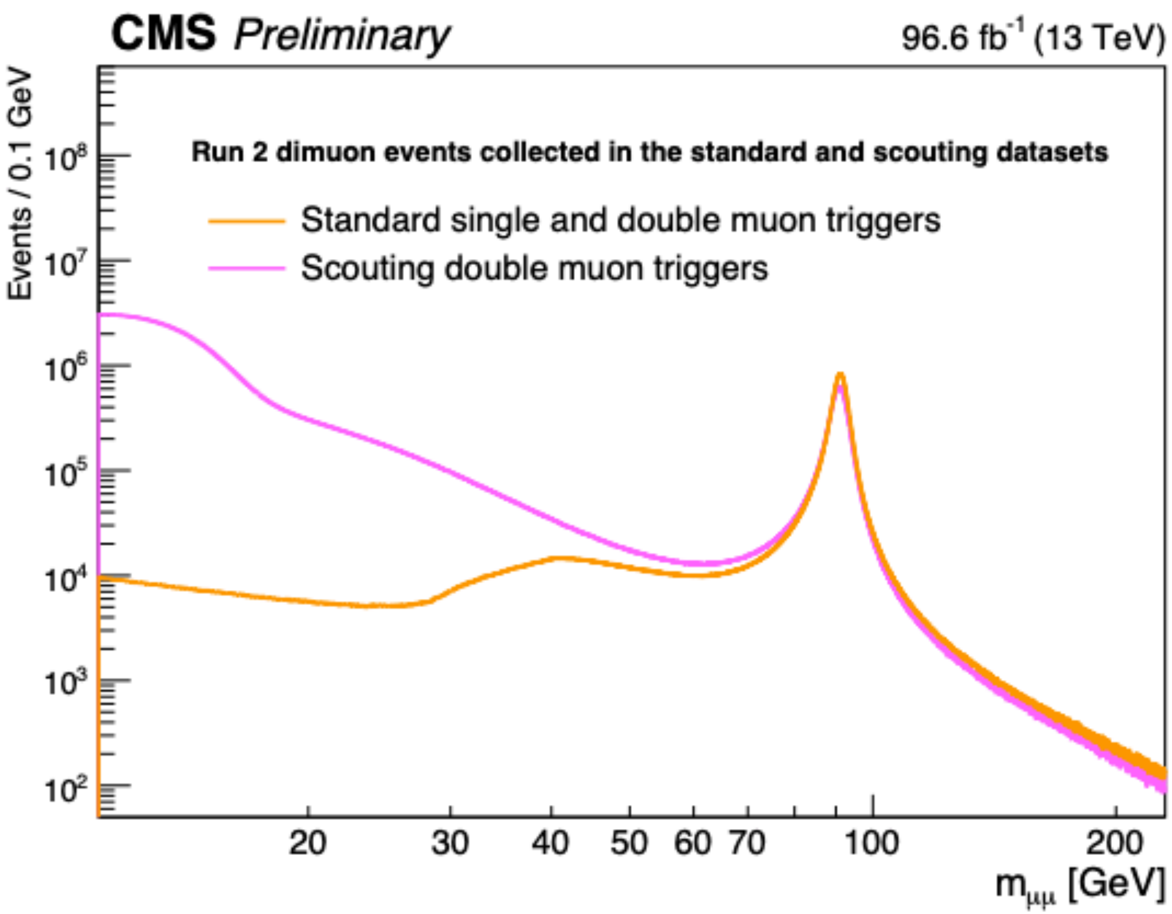


Things Once Thought Impossible: Data Scouting

HLT output limitation bandwidth / not event rate.
Reduce event size (only store HLT objects)
$\Rightarrow$ can increase output event rate

Things Once Thought Impossible: Data Scouting

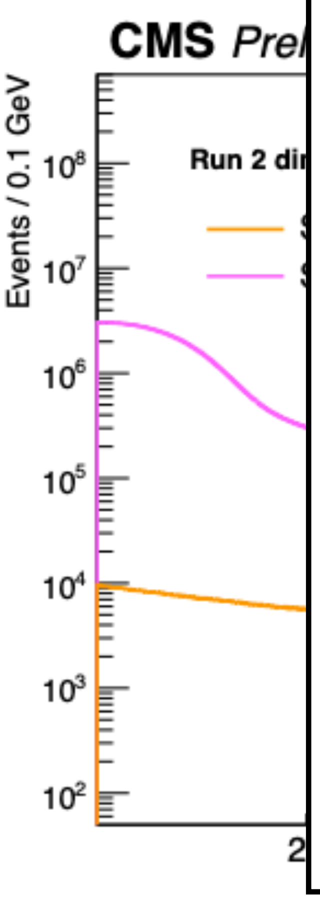
HLT output limitation bandwidth / not event rate.
Reduce event size (only store HLT objects)
$\Rightarrow$ can increase output event rate

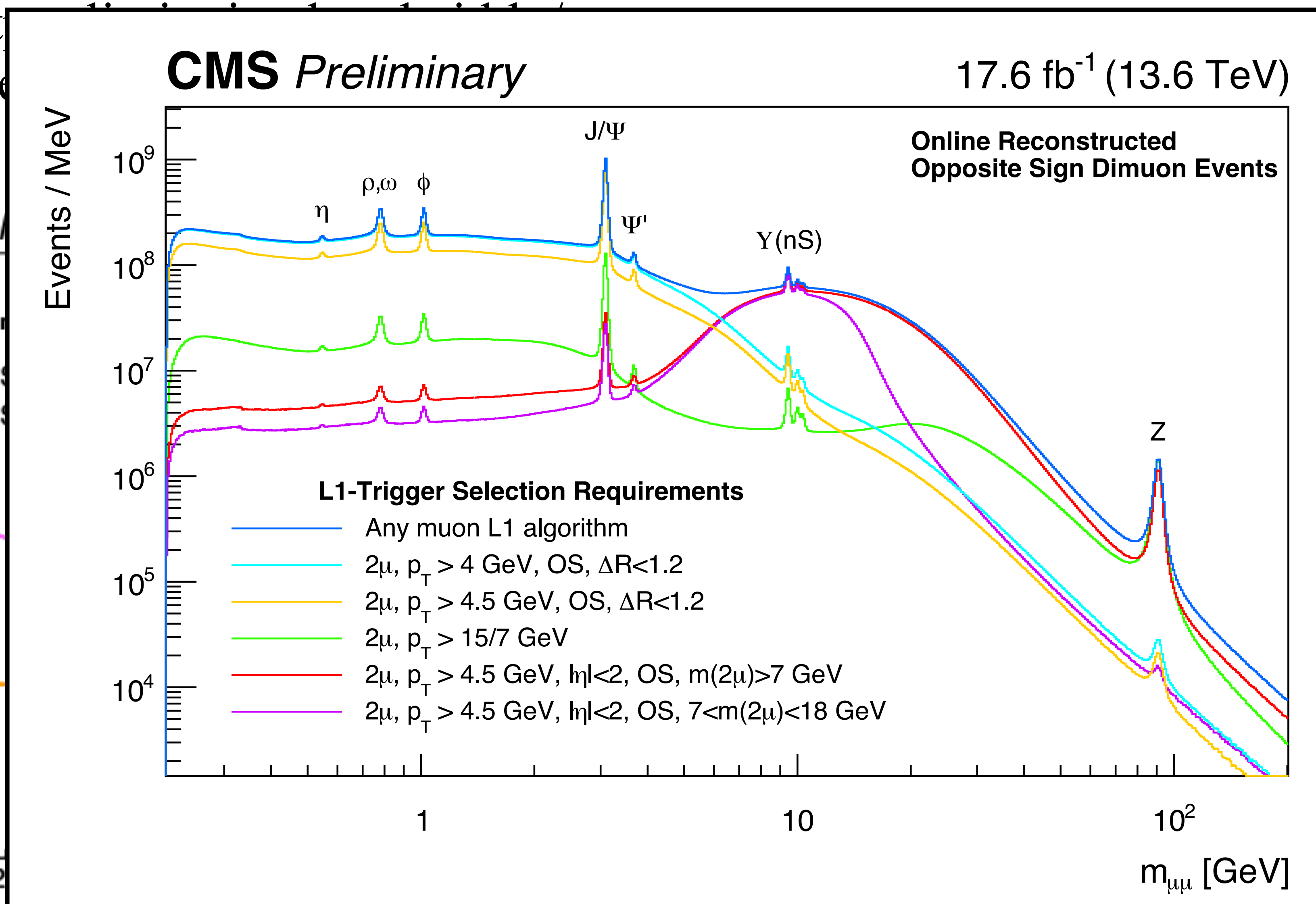


Things Once Thought Impossible:
Data Scouting

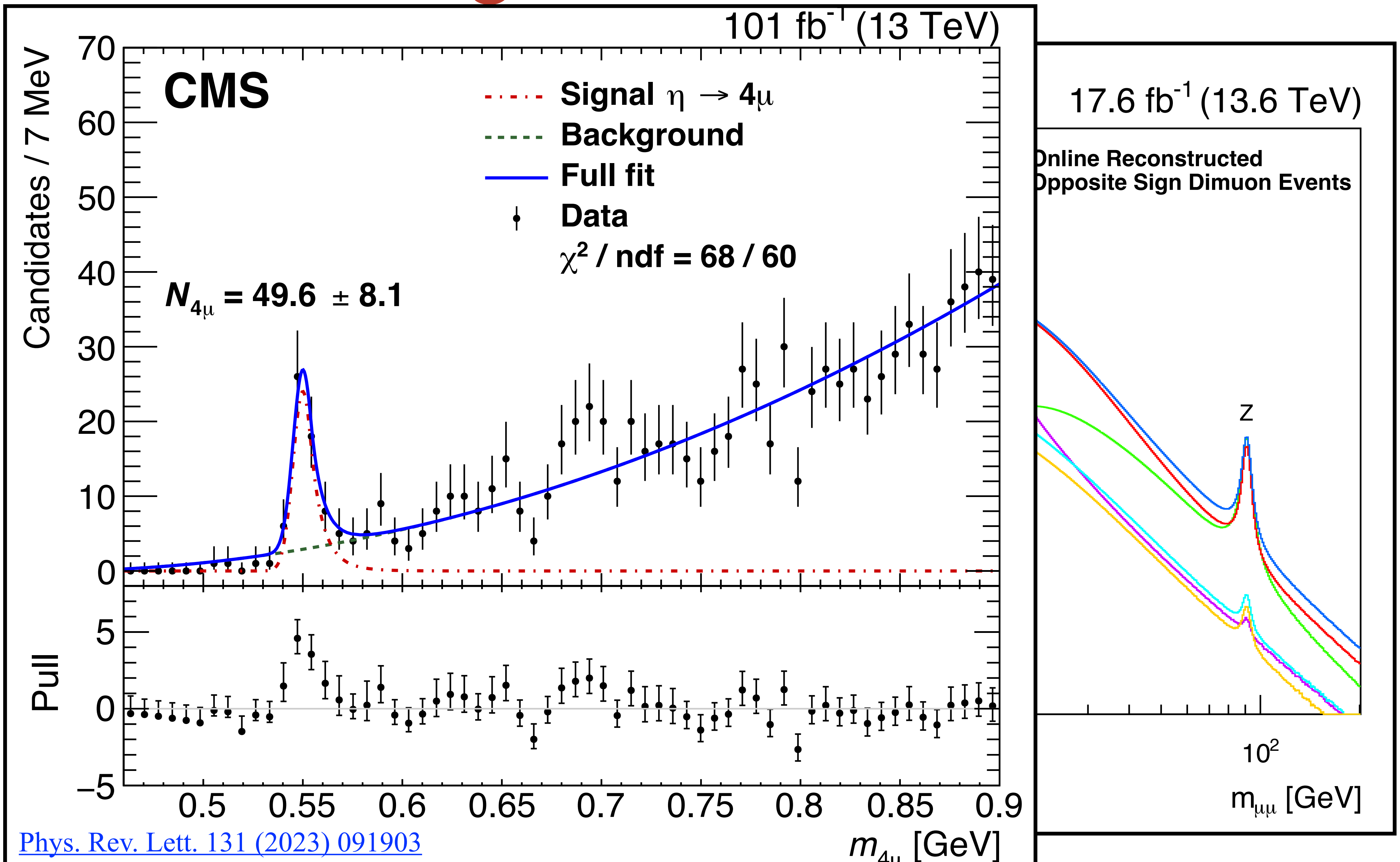
HLT out

Reduce e





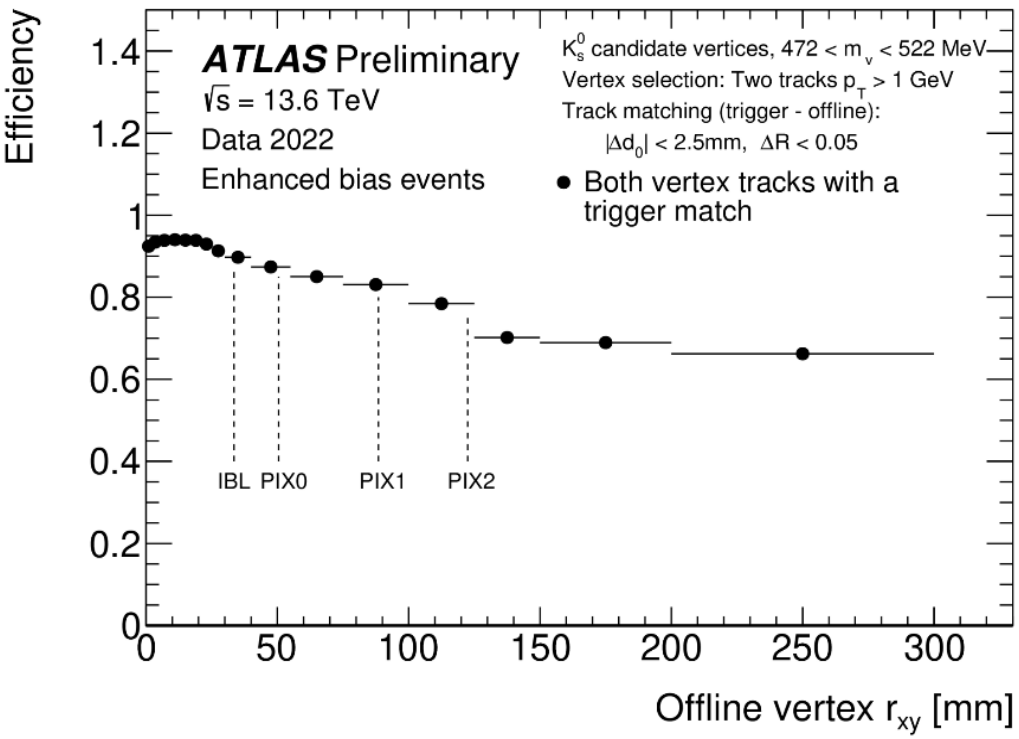
Things Once Thought Impossible:
Data Scouting



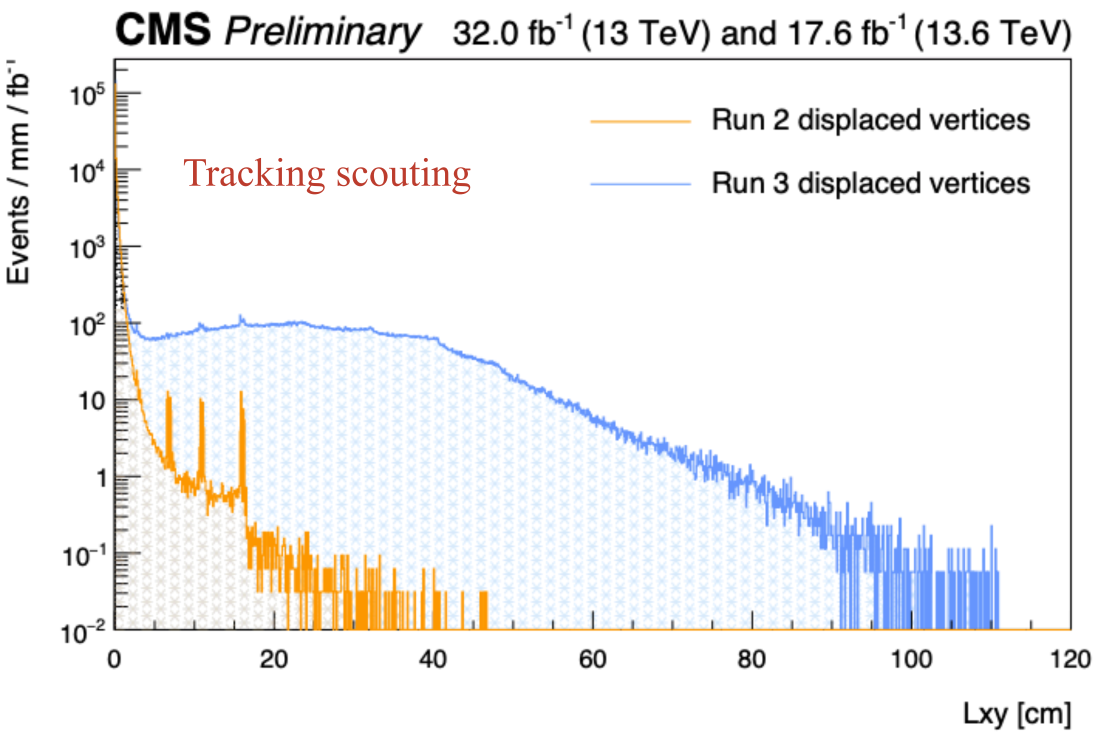
Phys. Rev. Lett. 131 (2023) 091903

Things Once Thought Impossible: Displaced Trigger Tracking

Displaced Tracks



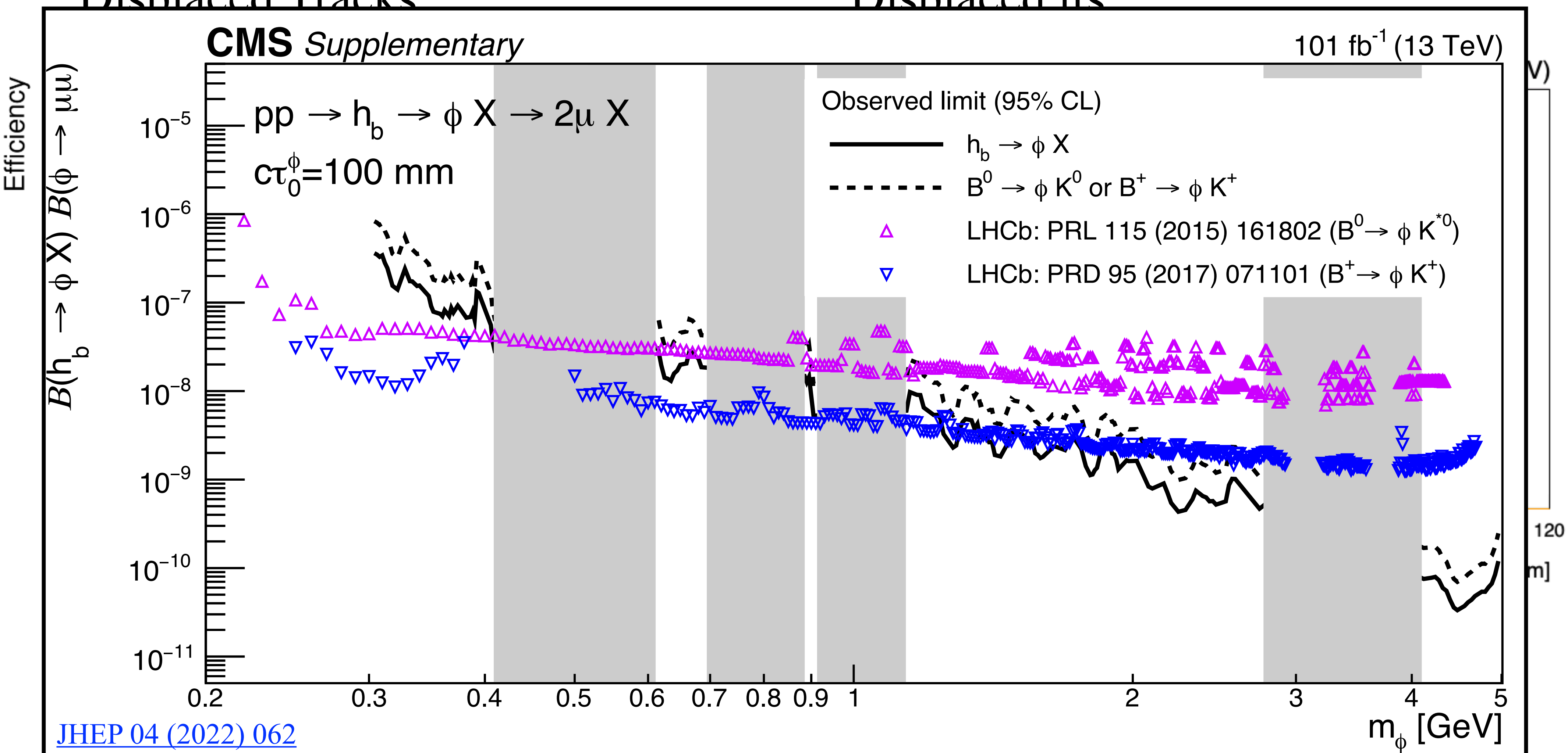
Displaced μs



Things Once Thought Impossible:
Displaced Trigger Tracking

Displaced Tracks

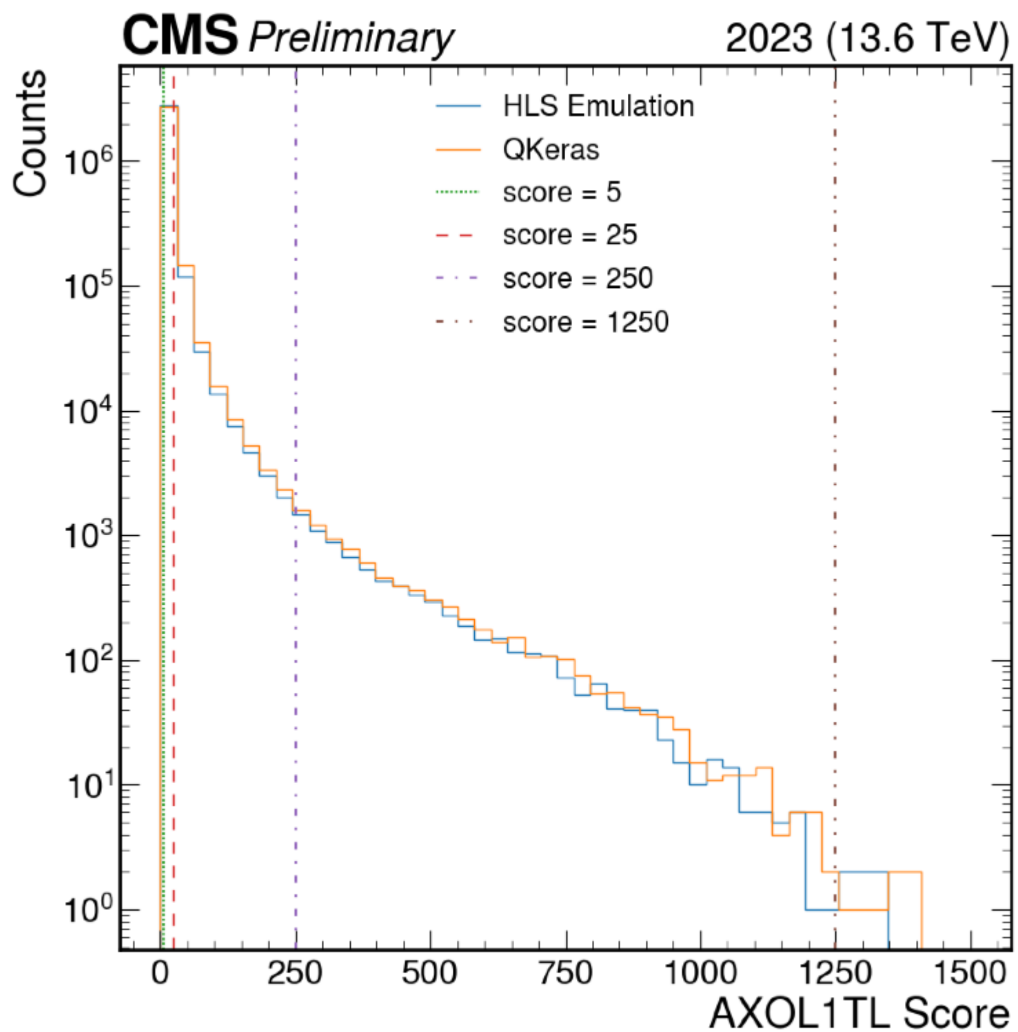
Displaced μs



JHEP 04 (2022) 062

Things Once Thought Impossible: Anomaly Detection at L1

More Info

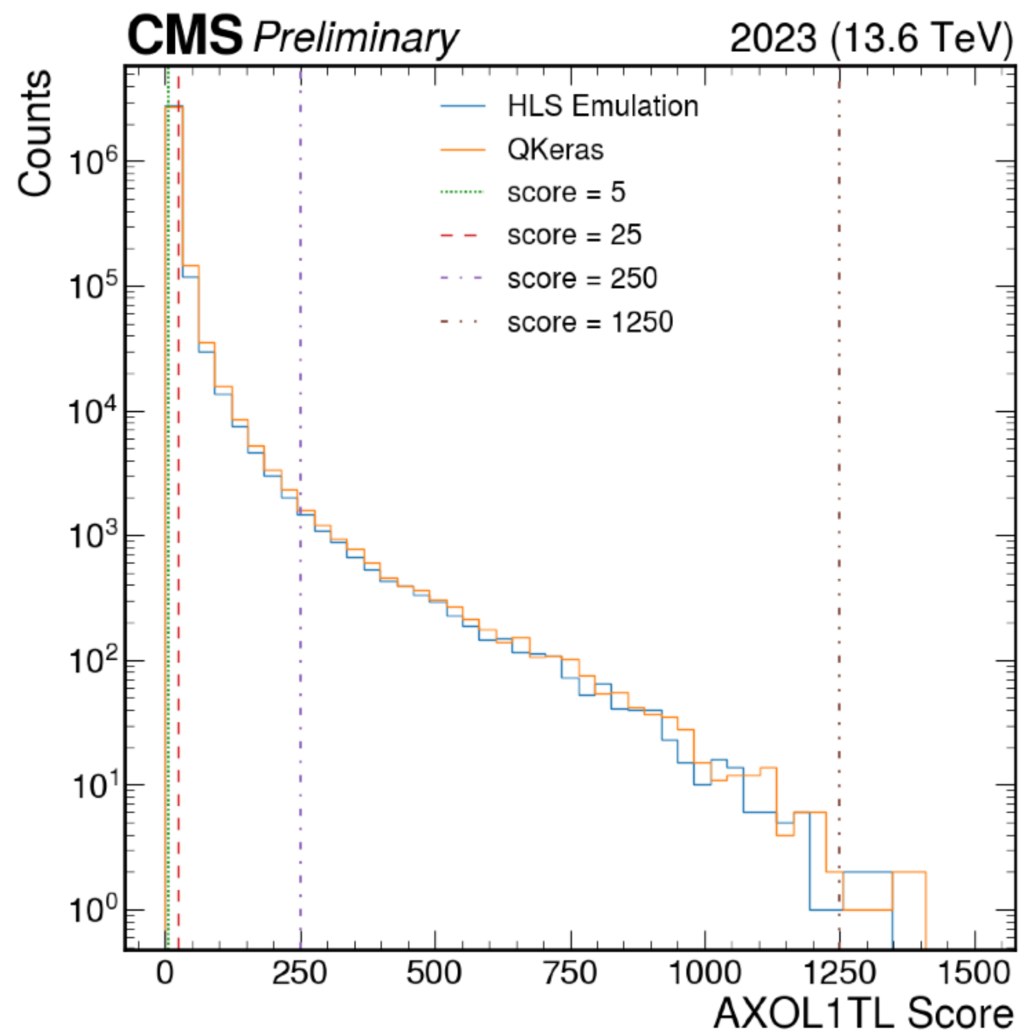


Selects anomalous events in real-time

- Auto encoder (VAE)
- Trained on 2023 zero bias data
- L1 inputs: MET, e/γ, μ, and 10 jets
- Xilinx Virtex-7 FPGA

Things Once Thought Impossible: Anomaly Detection at L1

More Info



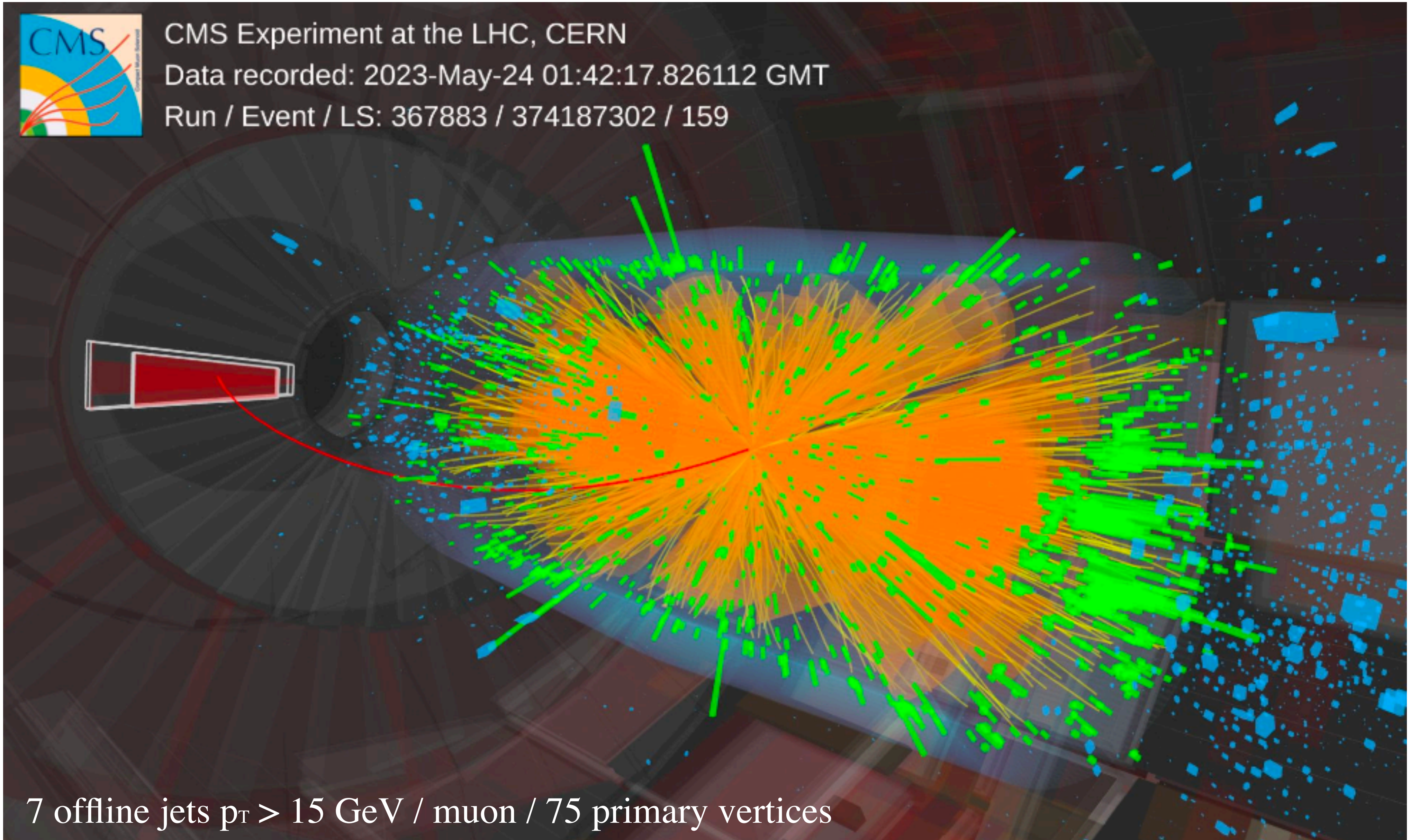
Selects anomalous events in real-time

- Auto encoder (VAE)
- Trained on 2023 zero bias data
- L1 inputs: MET, e/γ, μ, and 10 jets
- Xilinx Virtex-7 FPGA

Example: H→aa→4b signal

AXOL1TL Rate	1 kHz	5 kHz	10 kHz
Signal Efficiency Gain	46%	100%	133%

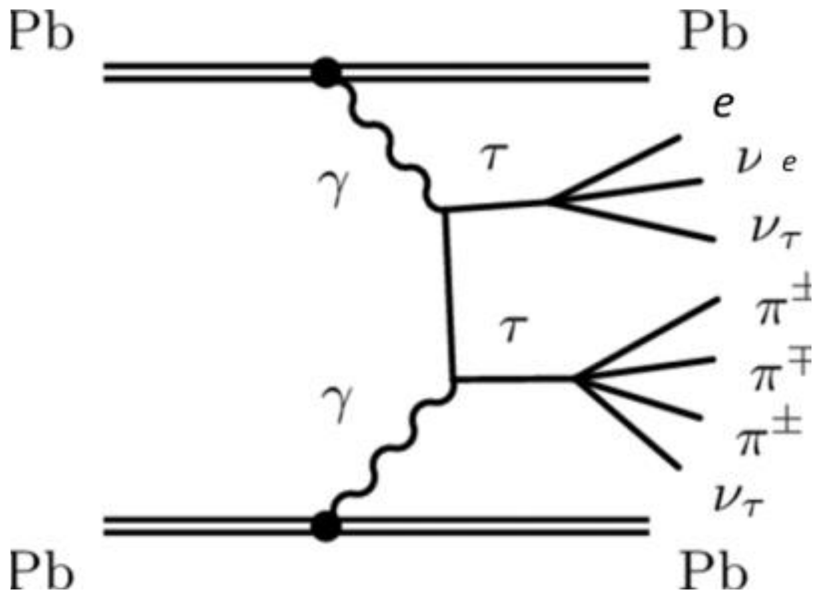
Things Once Thought Impossible:



Signal Efficiency Gain	46%	100%	133%

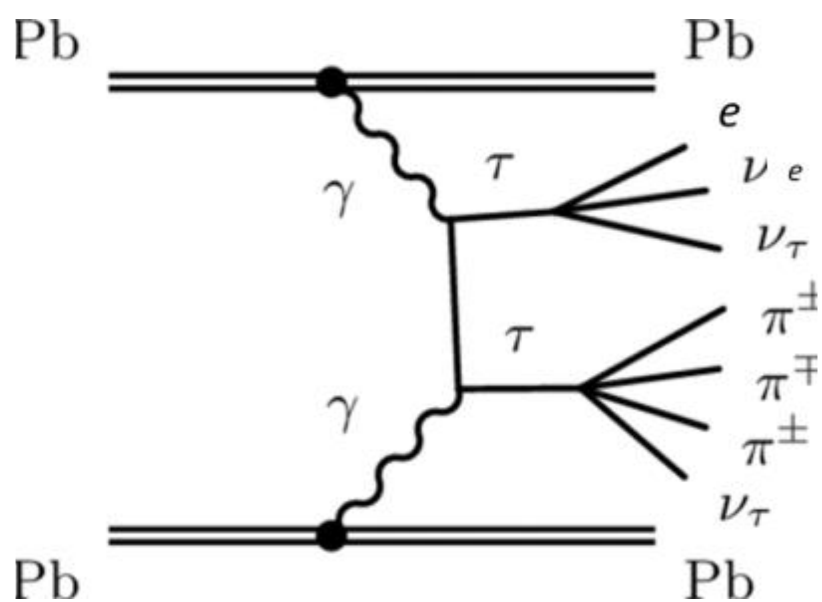
Things Once Thought Impossible: L1 Track Trigger for Pb-Pb

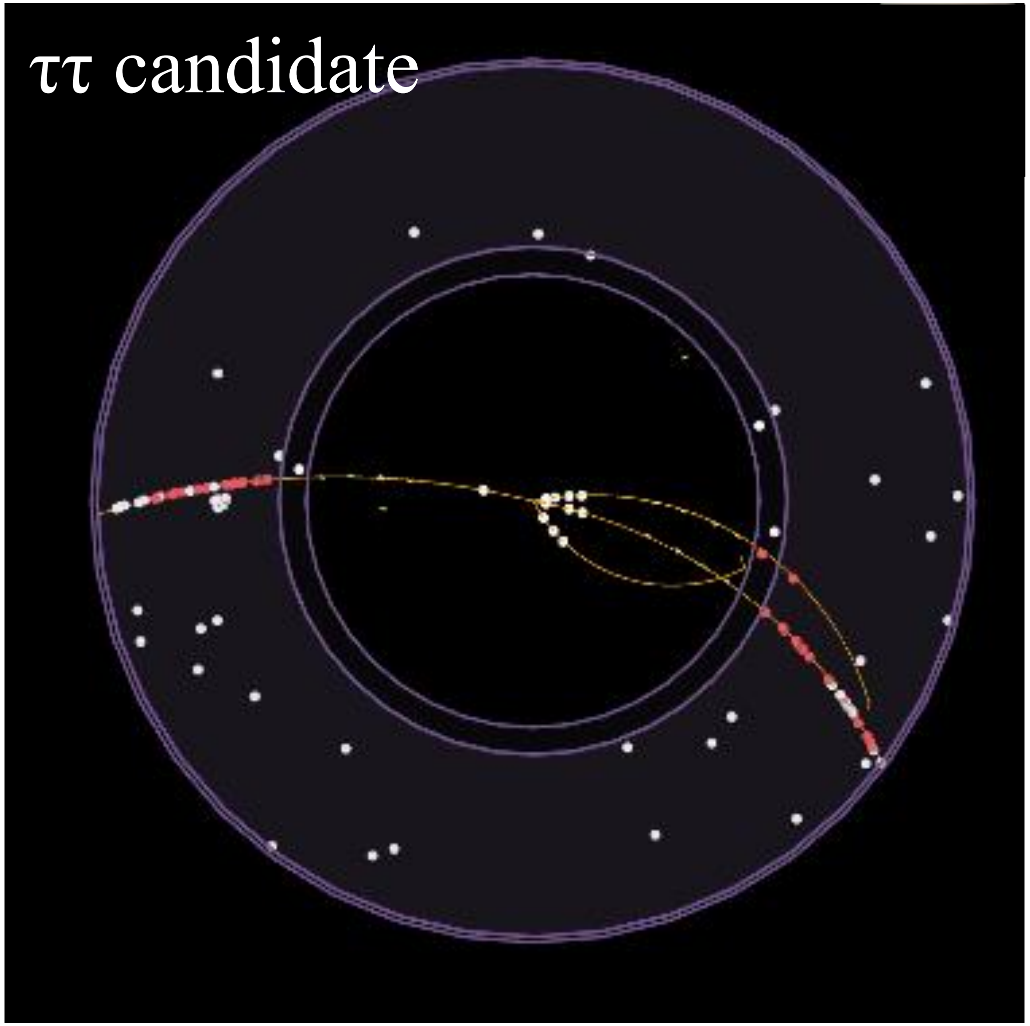
Ultra Peripheral Pb-Pb events ~ γγ collider



Things Once Thought Impossible:
L1 Track Trigger for Pb-Pb

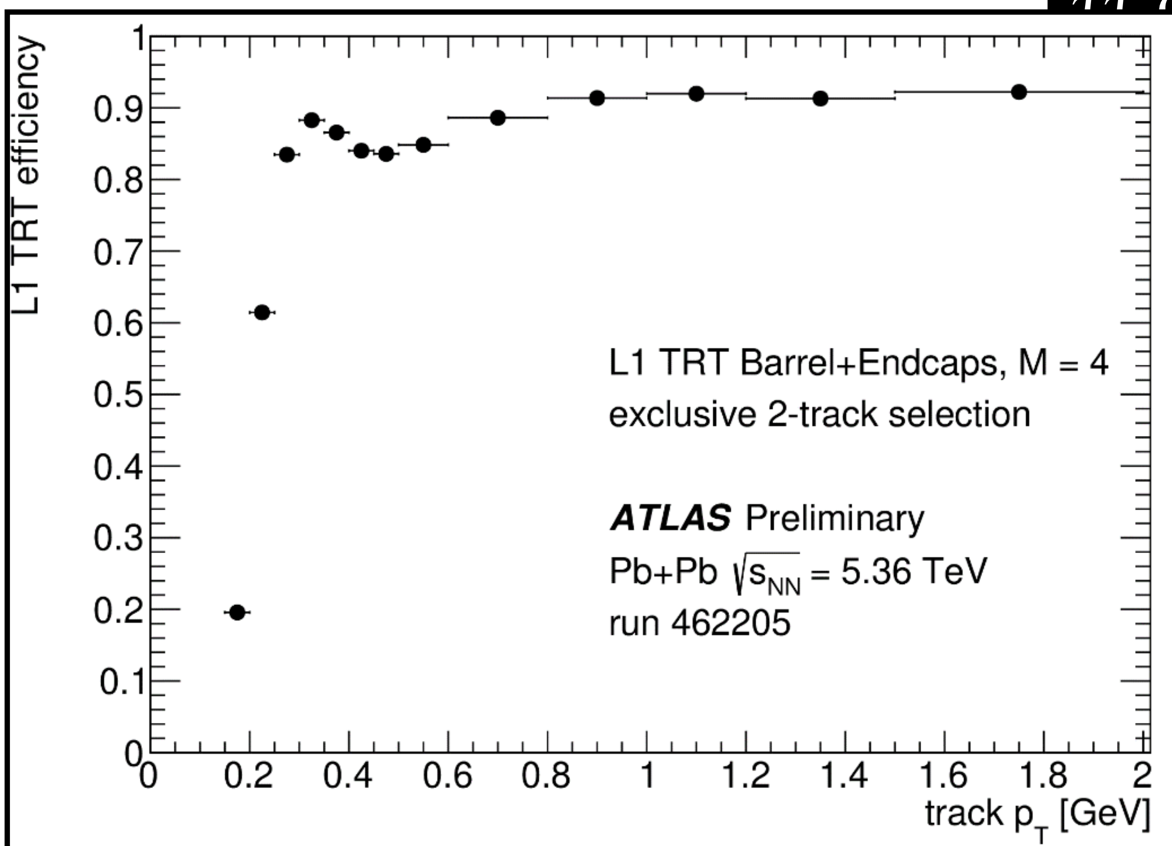
Ultra Peripheral Pb-Pb events ~ γγ collider
Transition Radiation Tracker (TRT) for track trigger.

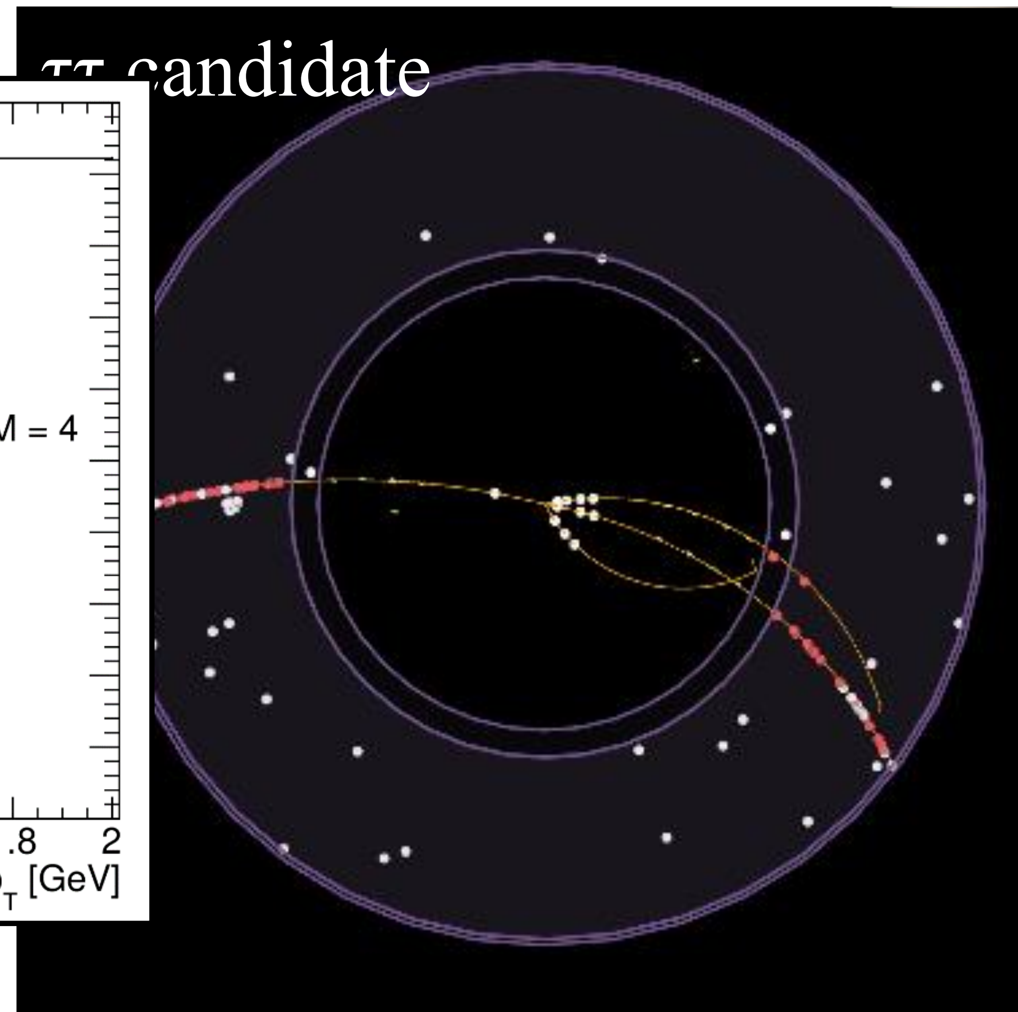


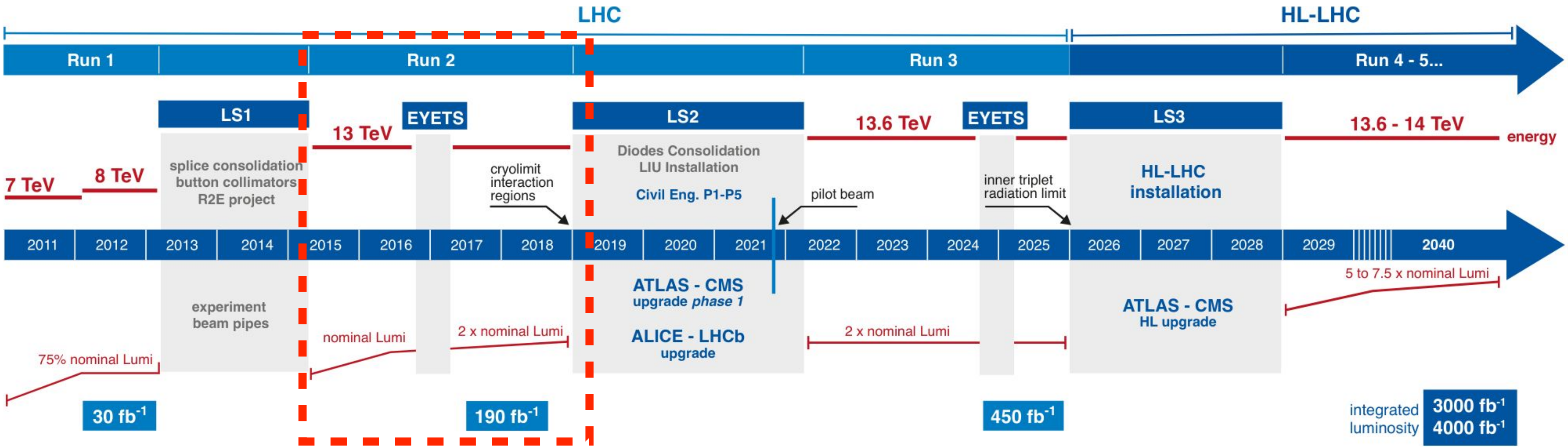


Things Once Thought Impossible:
L1 Track Trigger for Pb-Pb

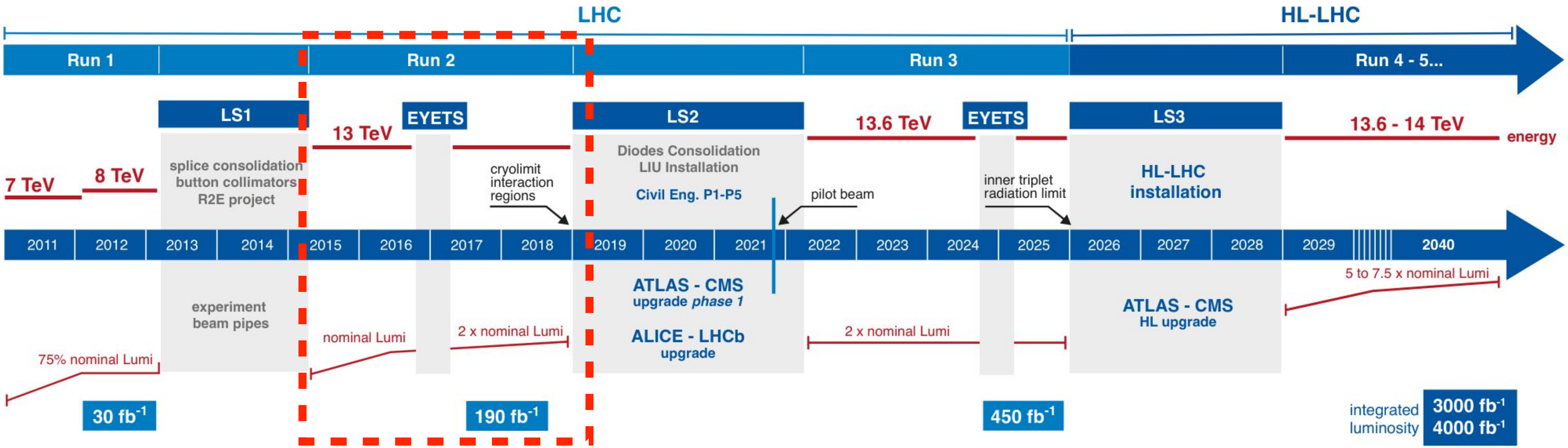
Ultra Peripheral Pb-Pb events ~ γγ collider
Transition Radiation Tracker (TRT) for track trigger.



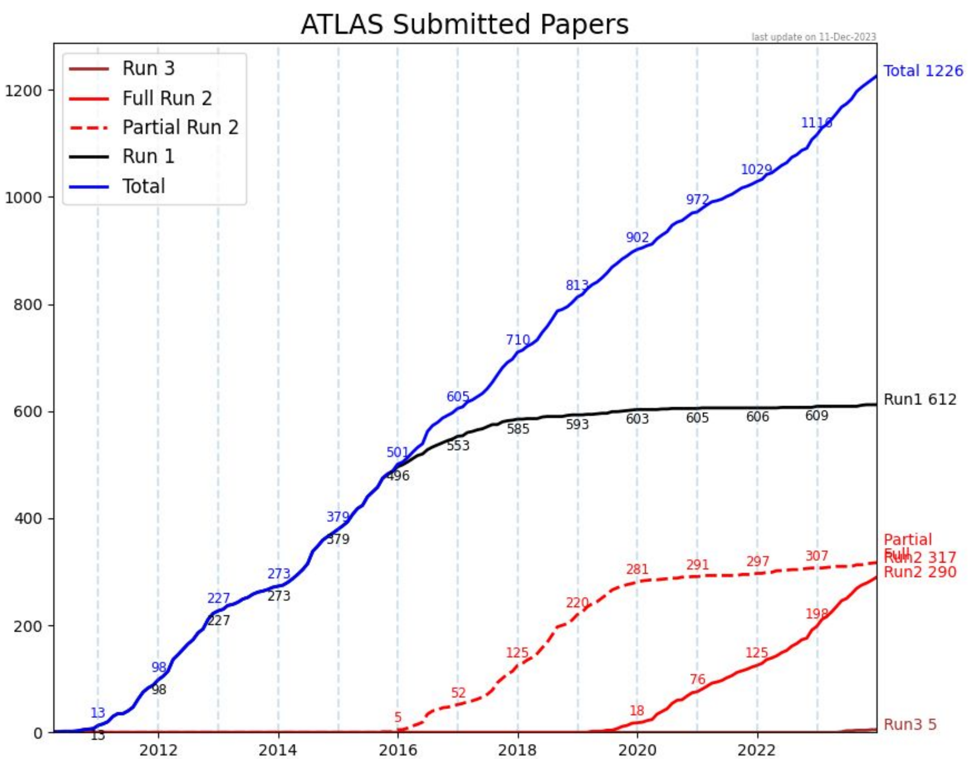




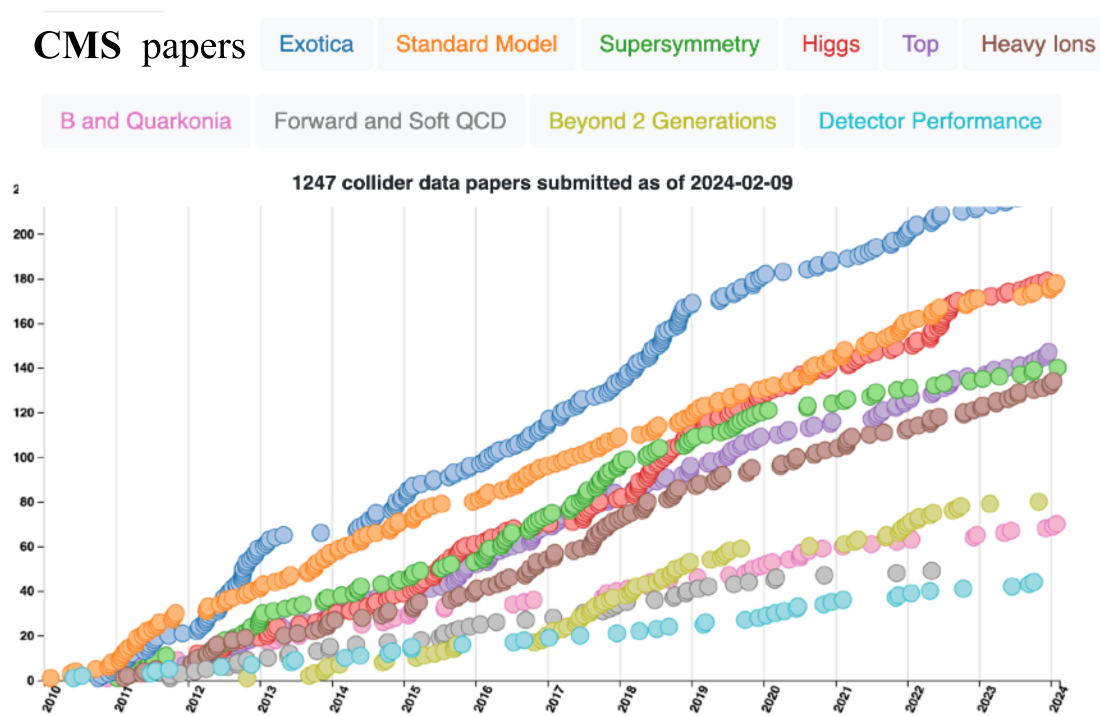
Highlights from Physics Program



LHC
HL-LHC
Run 1
Run 2
Run 3
Run 4 - 5...
LS1
EYETS
LS2
13.6 TeV
EYETS
LS3
13.6 - 14 TeV
energy
7 TeV
8 TeV
13 TeV
splice consolidation
button collimators
R2E project
cryolimit
interaction
regions
Diodes Consolidation
LIU Installation
Civil Eng. P1-P5
pilot beam
inner triplet
radiation limit
HL-LHC
installation
2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2040
experiment
beam pipes
ATLAS - CMS
upgrade phase 1
ALICE - LHCb
upgrade
ATLAS - CMS
HL upgrade
75% nominal Lumi
nominal Lumi
2 x nominal Lumi
2 x nominal Lumi
5 to 7.5 x nominal Lumi
30 fb-1
190 fb-1
450 fb-1
integrated
luminosity
3000 fb-1
4000 fb-1



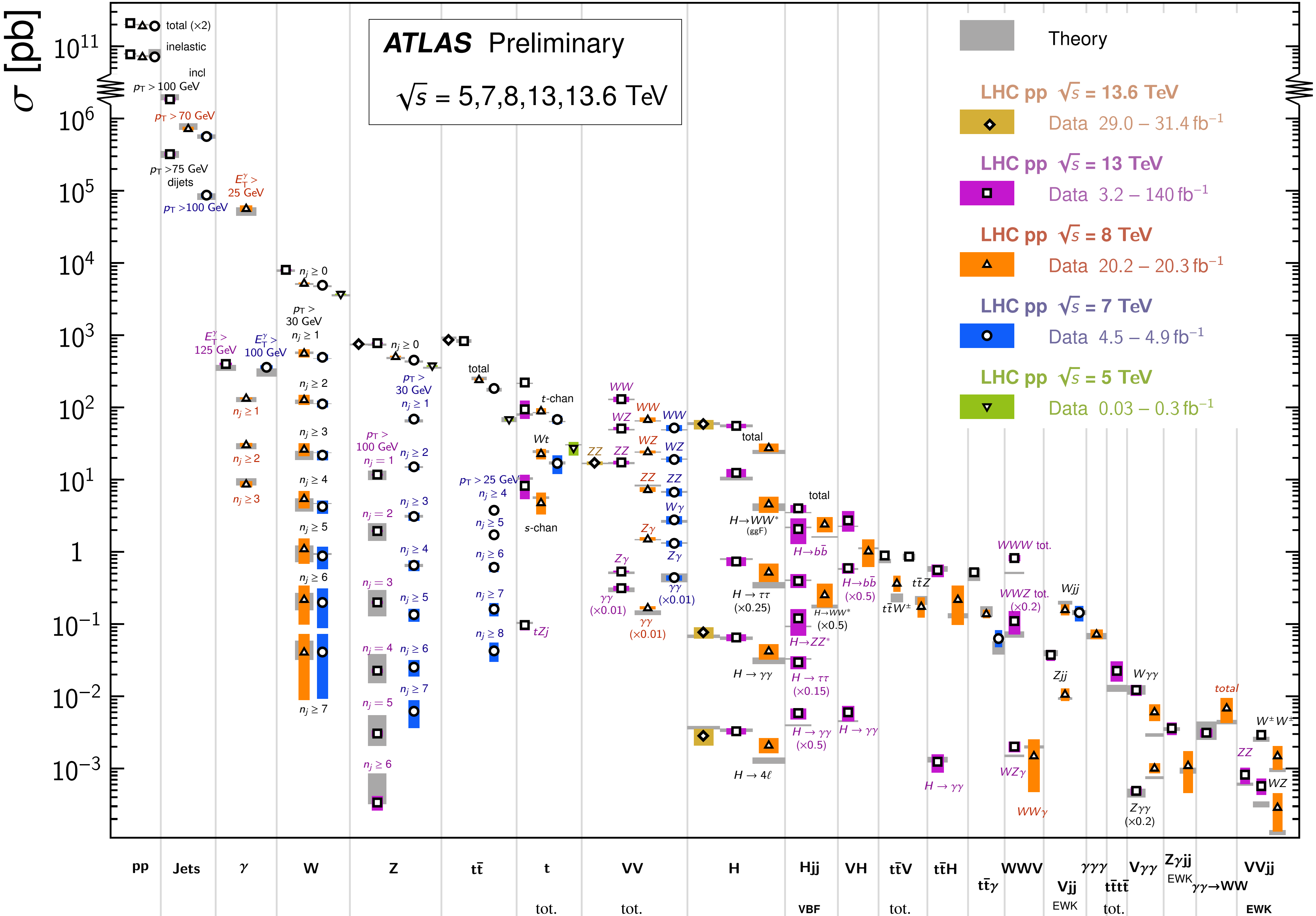
ATLAS Submitted Papers
Run 3
Full Run 2
Partial Run 2
Run 1
Total
Total 1226
Run1 612
Partial Run2 317
Full Run2 290
Run3 5
2012
2014
2016
2018
2020
2022



CMS papers
Exotica
Standard Model
Supersymmetry
Higgs
Top
Heavy Ions
B and Quarkonia
Forward and Soft QCD
Beyond 2 Generations
Detector Performance
1247 collider data papers submitted as of 2024-02-09

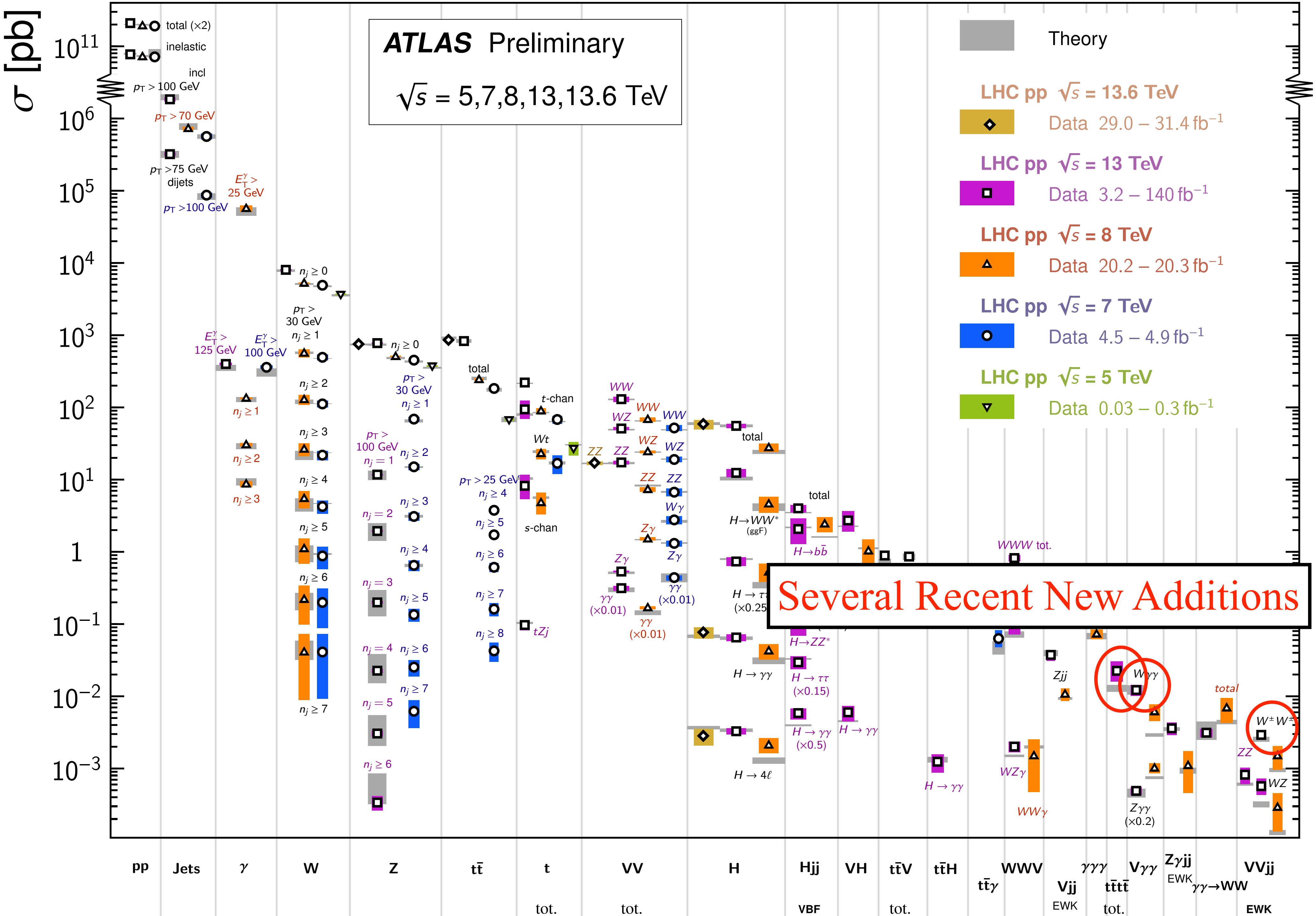
Standard Model Production Cross Section Measurements

Status: October 2023



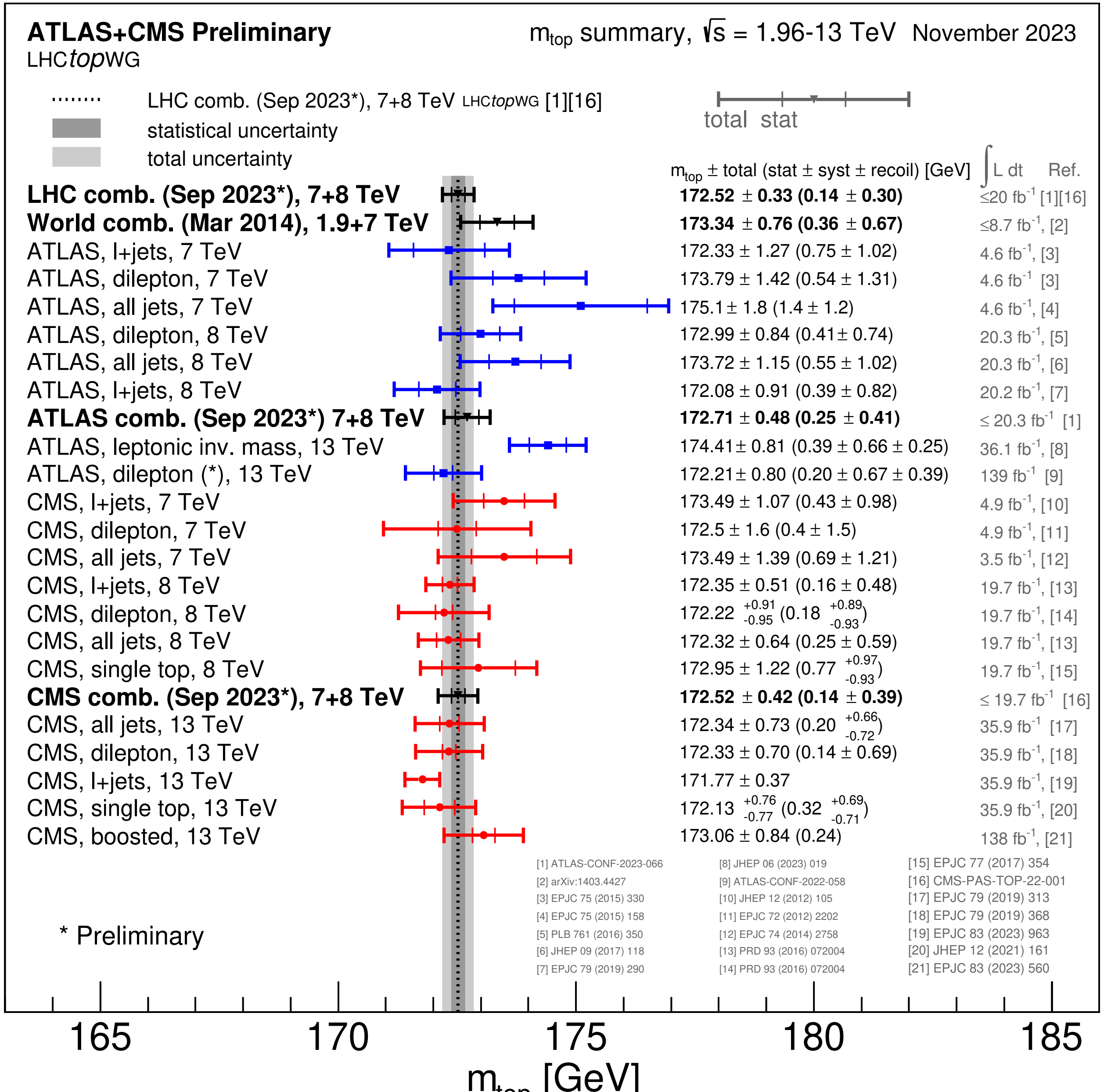
Status: October 2023

Standard Model Production Cross Section Measurements



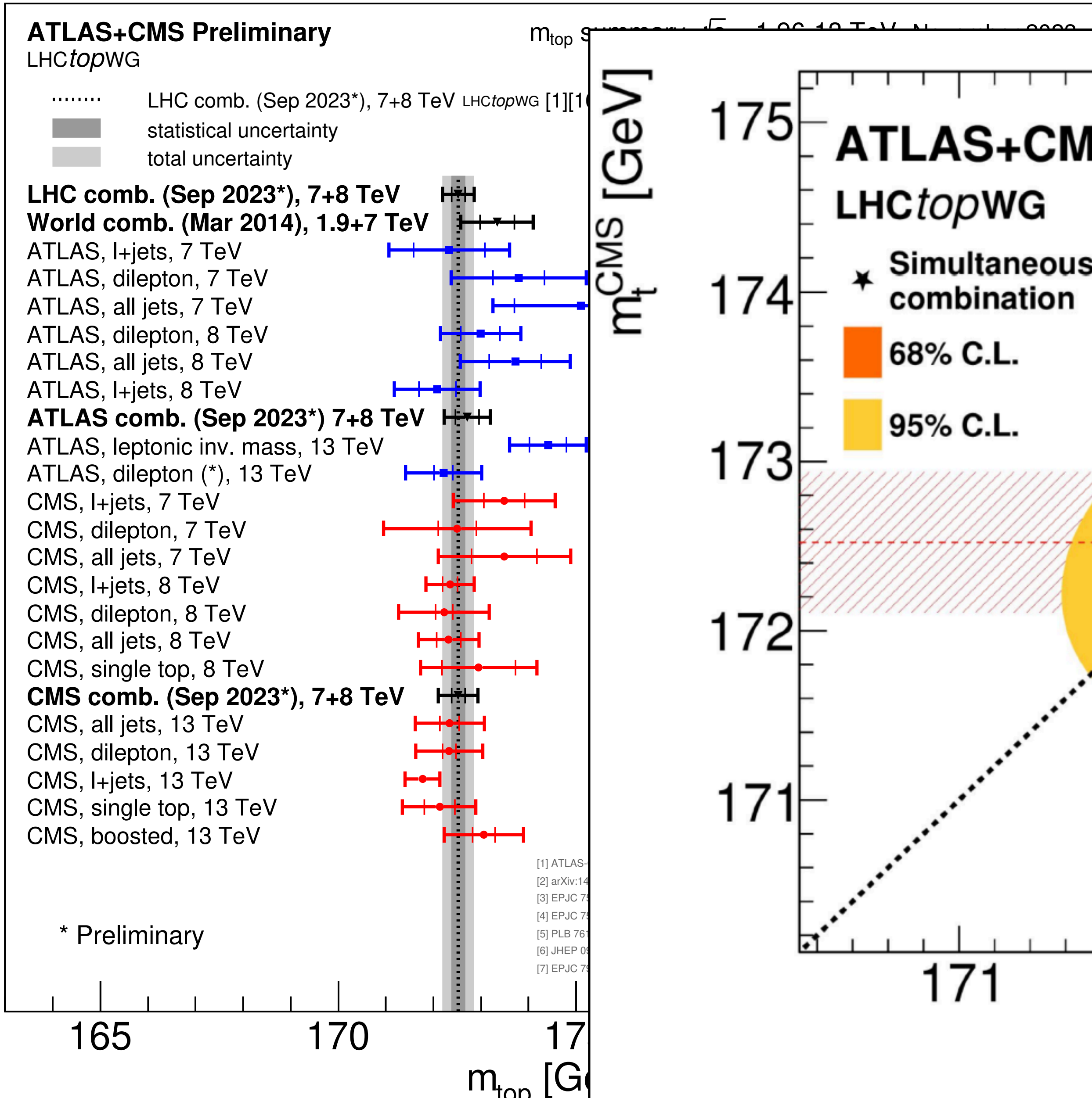
Measuring m_{Top}

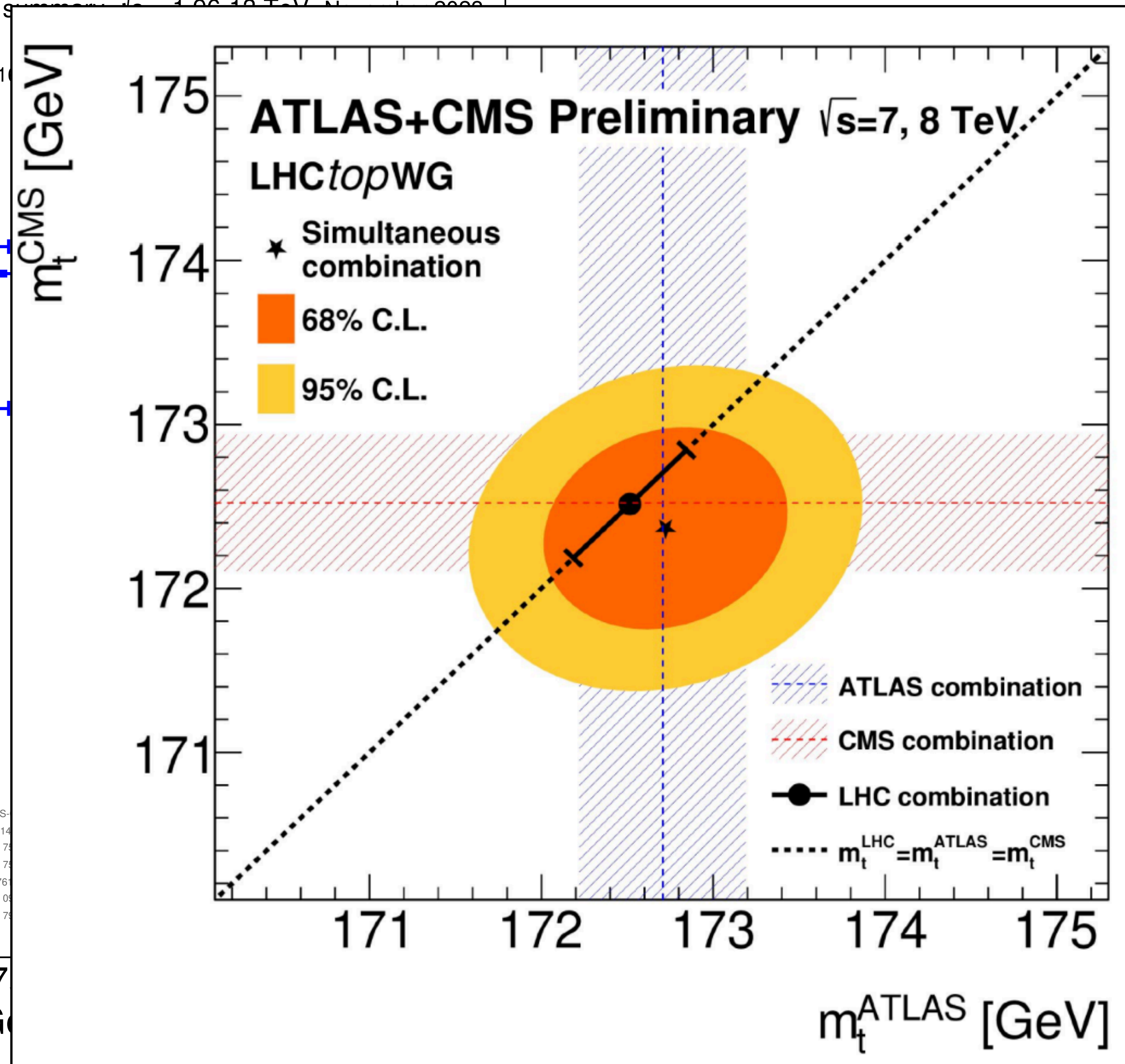
LHCTopWGSummaryPlots



Measuring m_{Top}

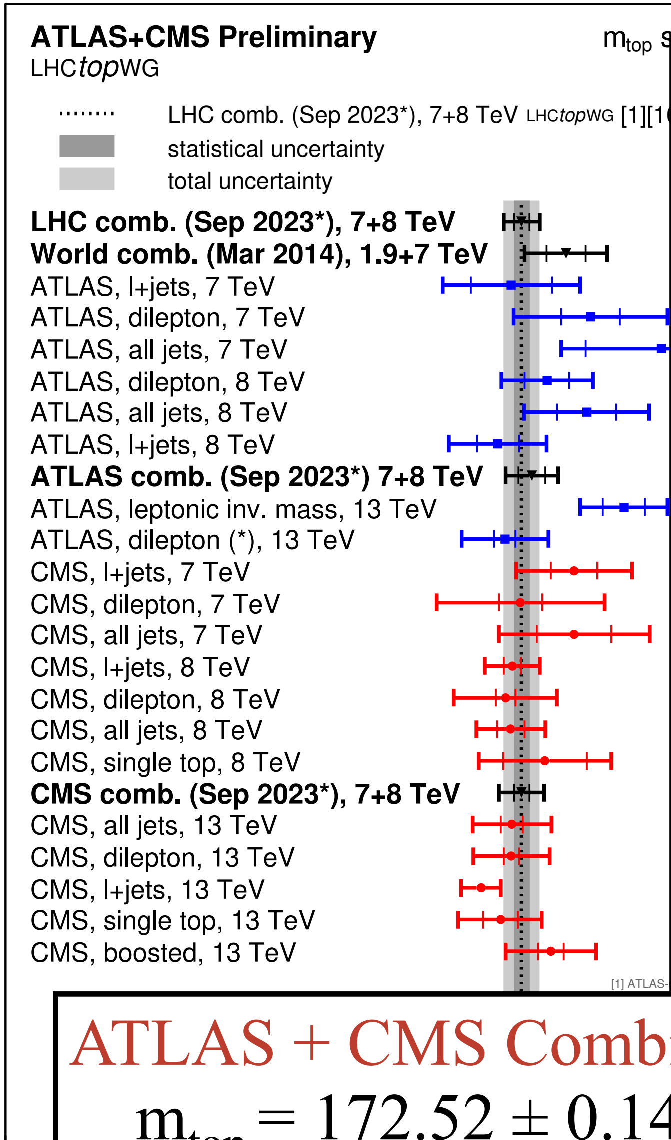
LHCTopWGSummaryPlots

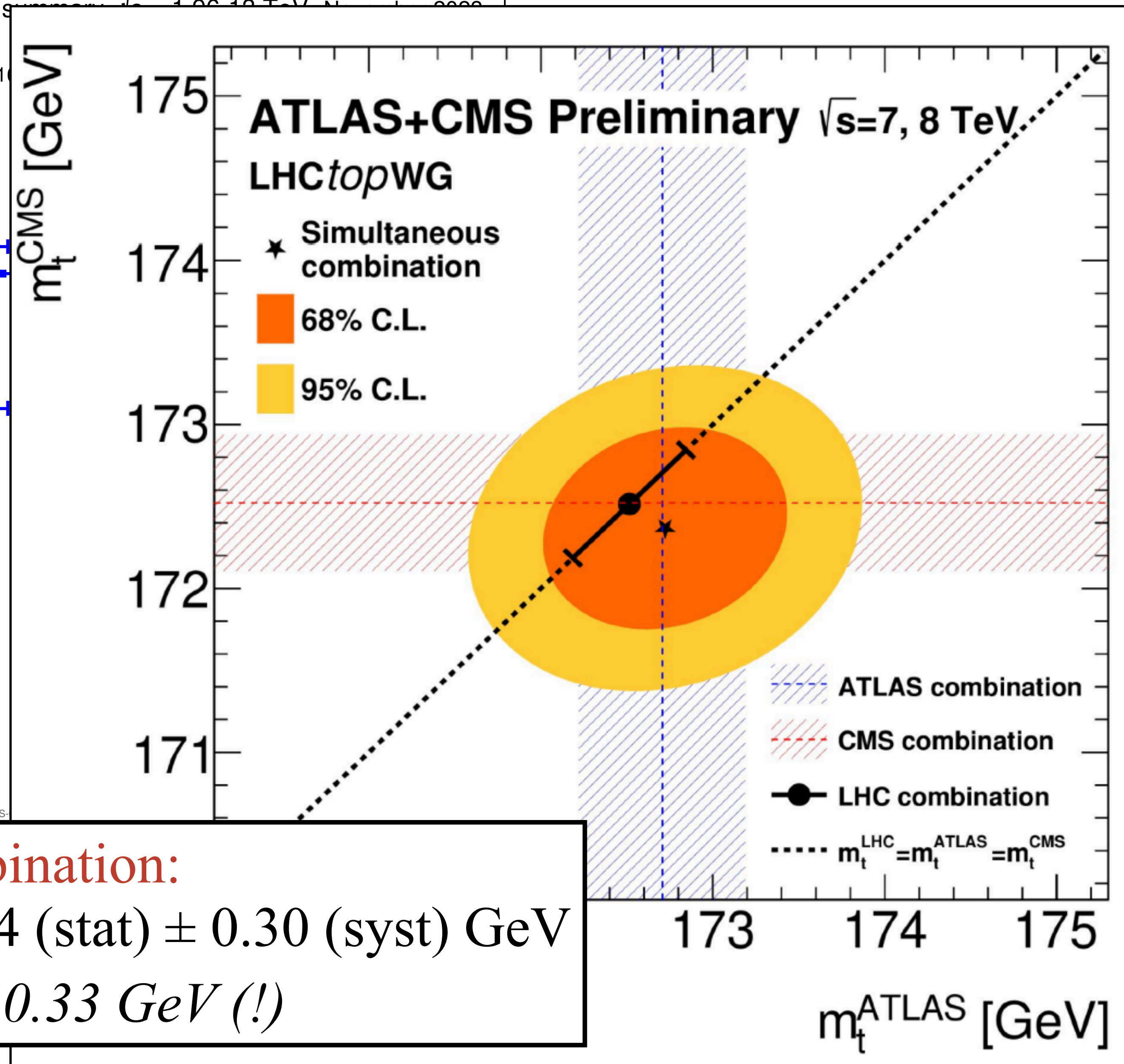




Measuring m_{Top}

LHCTopWGSummaryPlots





ATLAS + CMS Combination:

$m_{top} = 172.52 \pm 0.14\ (stat) \pm 0.30\ (syst)$ GeV

total uncertainty of 0.33 GeV (!)

Why measure m_{Top} ?

Stability of effective SM Higgs potential sensitive to m_{Top}/m_H

Is the Standard Model Vacuum stable?

If not ⇒ new BSM physics to stabilize it

Why measure m_{Top} ?

Stability of effective SM Higgs potential sensitive to m_{Top}/m_H

Is the Standard Model Vacuum stable?

If not ⇒ new BSM physics to stabilize it

J. High Energ. Phys. 2012, 98 (2012).

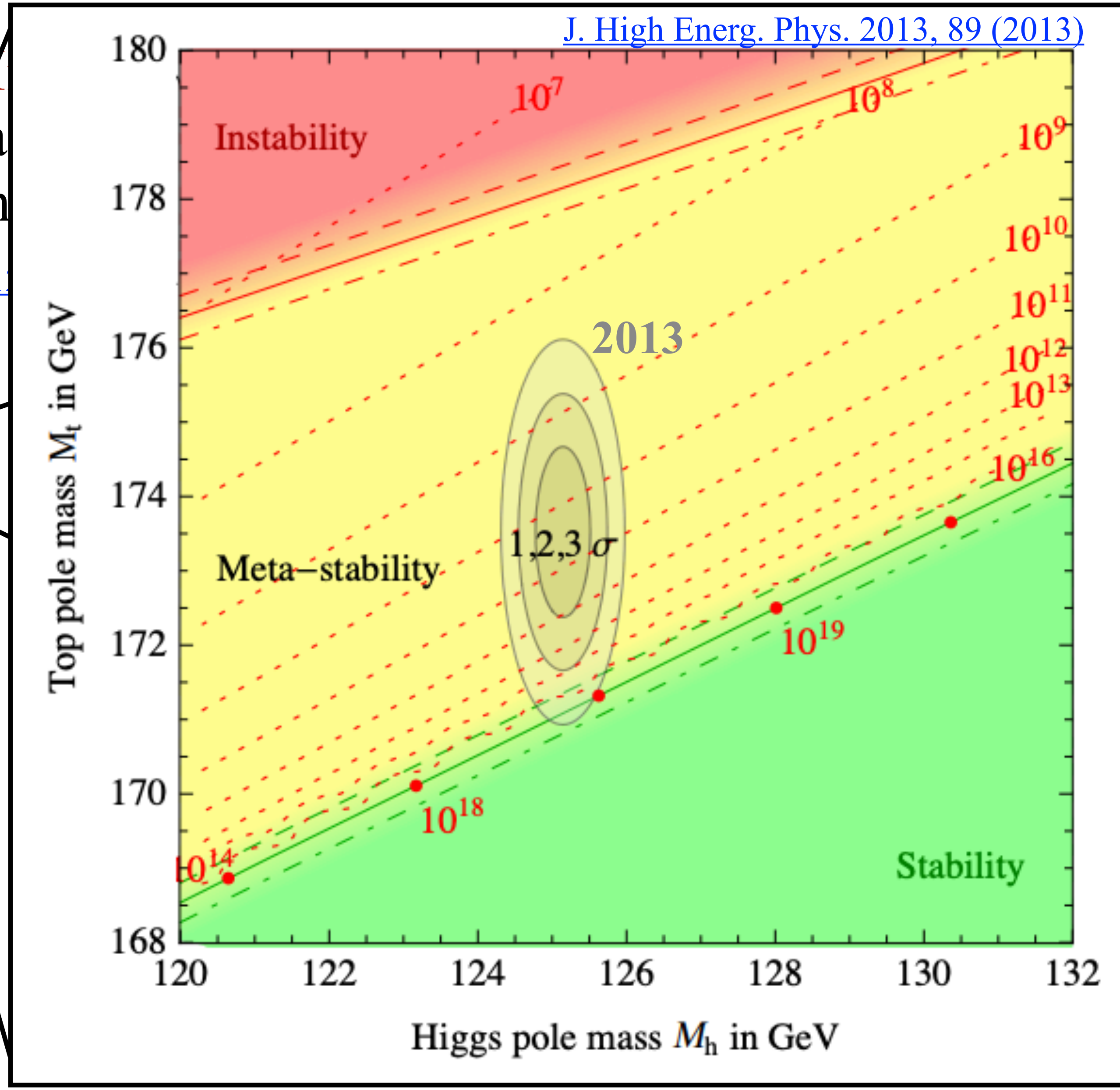
Why measure m_{Top} ?

Stability of effective SM H

Is the Standard Model Va

If not ⇒ new BSM ph

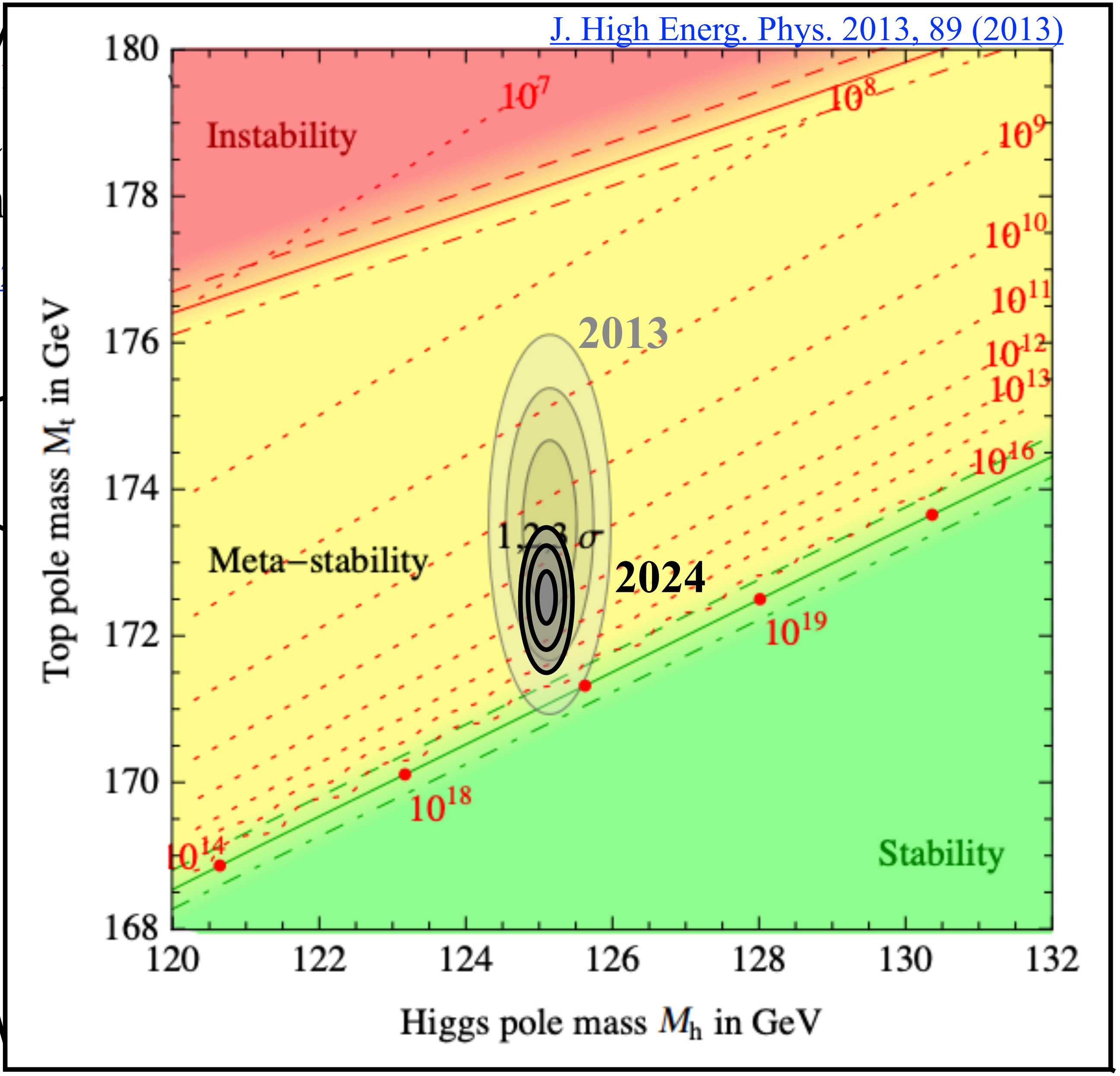
J. High Energ. Phys. 201



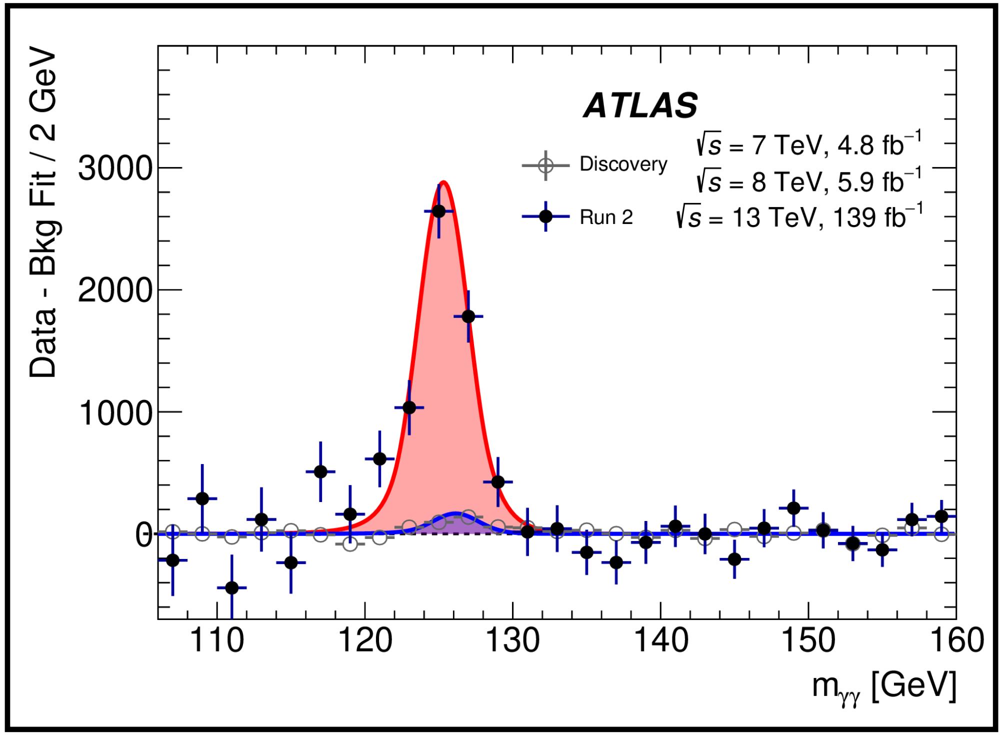
Why measure m_{Top} ?

Stability of effective SM H
Is the Standard Model Va
If not ⇒ new BSM ph

J. High Energ. Phys. 201

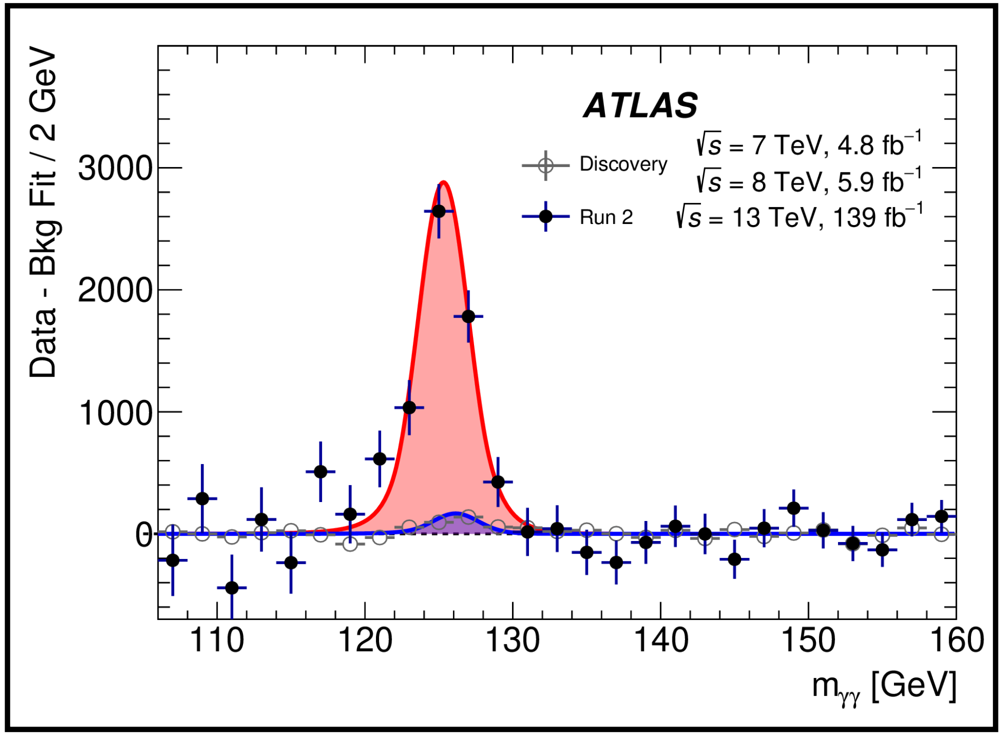


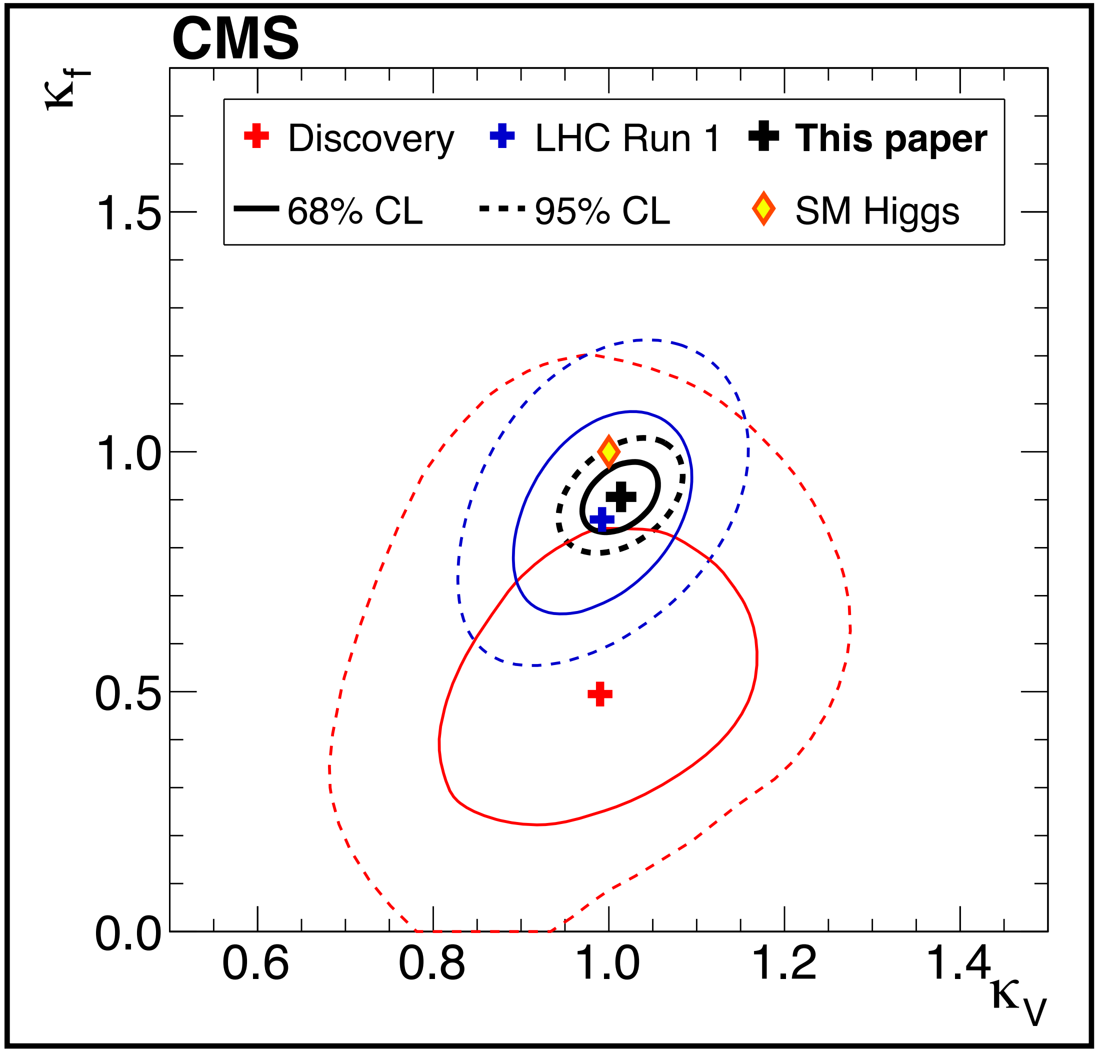
Higgs Physics



Nature volume 607, (2022)

Higgs Physics

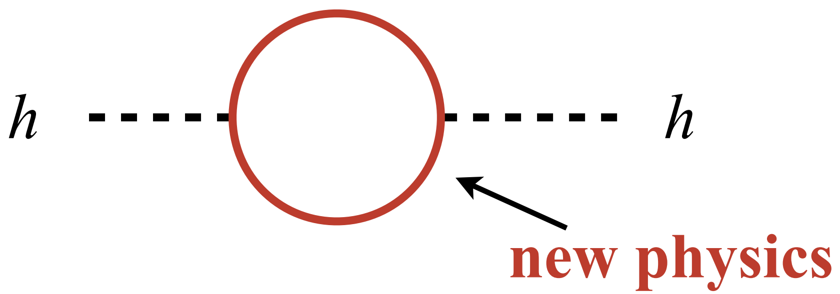




[Nature volume 607, (2022)]

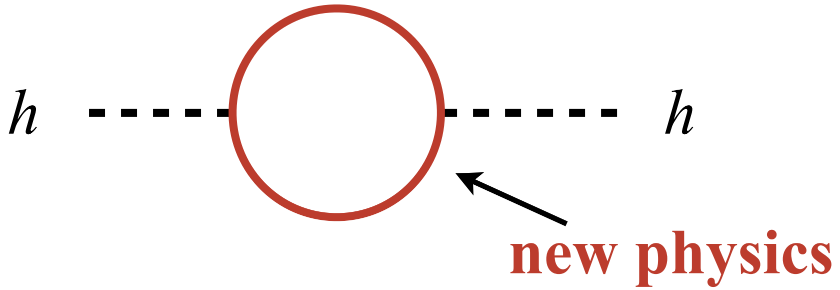
Why keep measuring the Higgs ?

Expect contributions from new physics to correct Higgs mass:

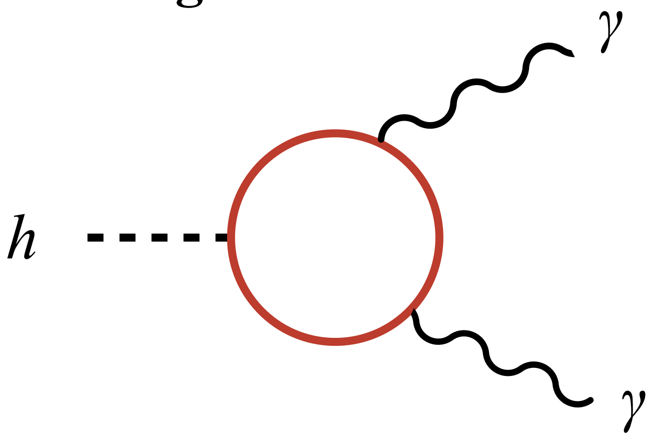


Why keep measuring the Higgs ?

Expect contributions from new physics to correct Higgs mass:



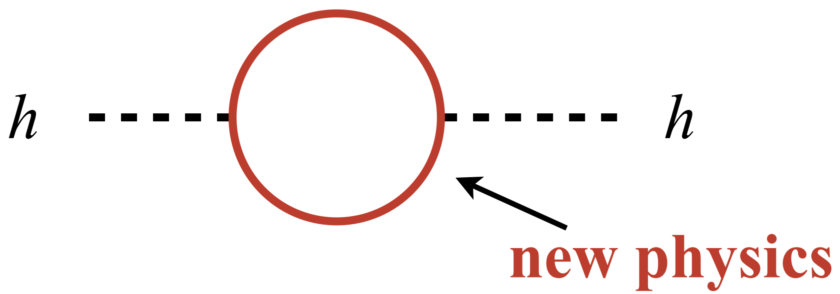
If new physics interacts with the **electro-magnetic:**



Modifies rate a which Higgs bosons decay to photons.

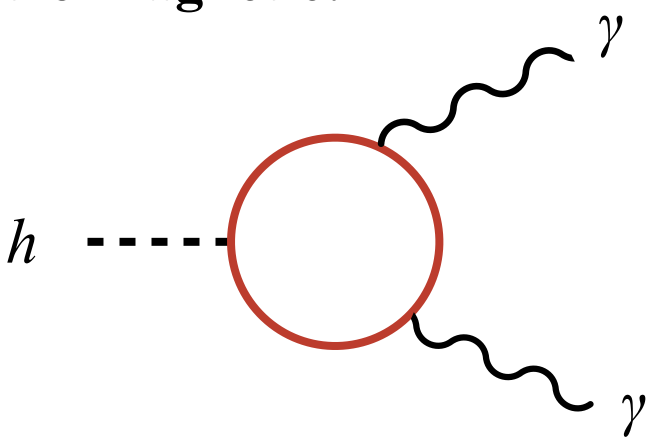
Why keep measuring the Higgs ?

Expect contributions from new physics to correct Higgs mass:



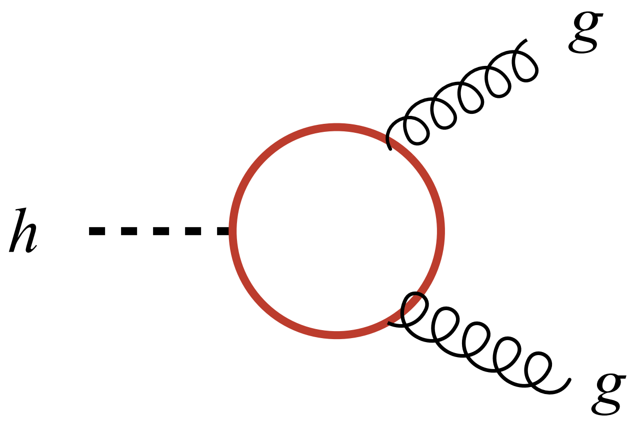
If new physics interacts with the

electro-magnetic:



Modifies rate a which Higgs bosons decay to photons.

strong force:



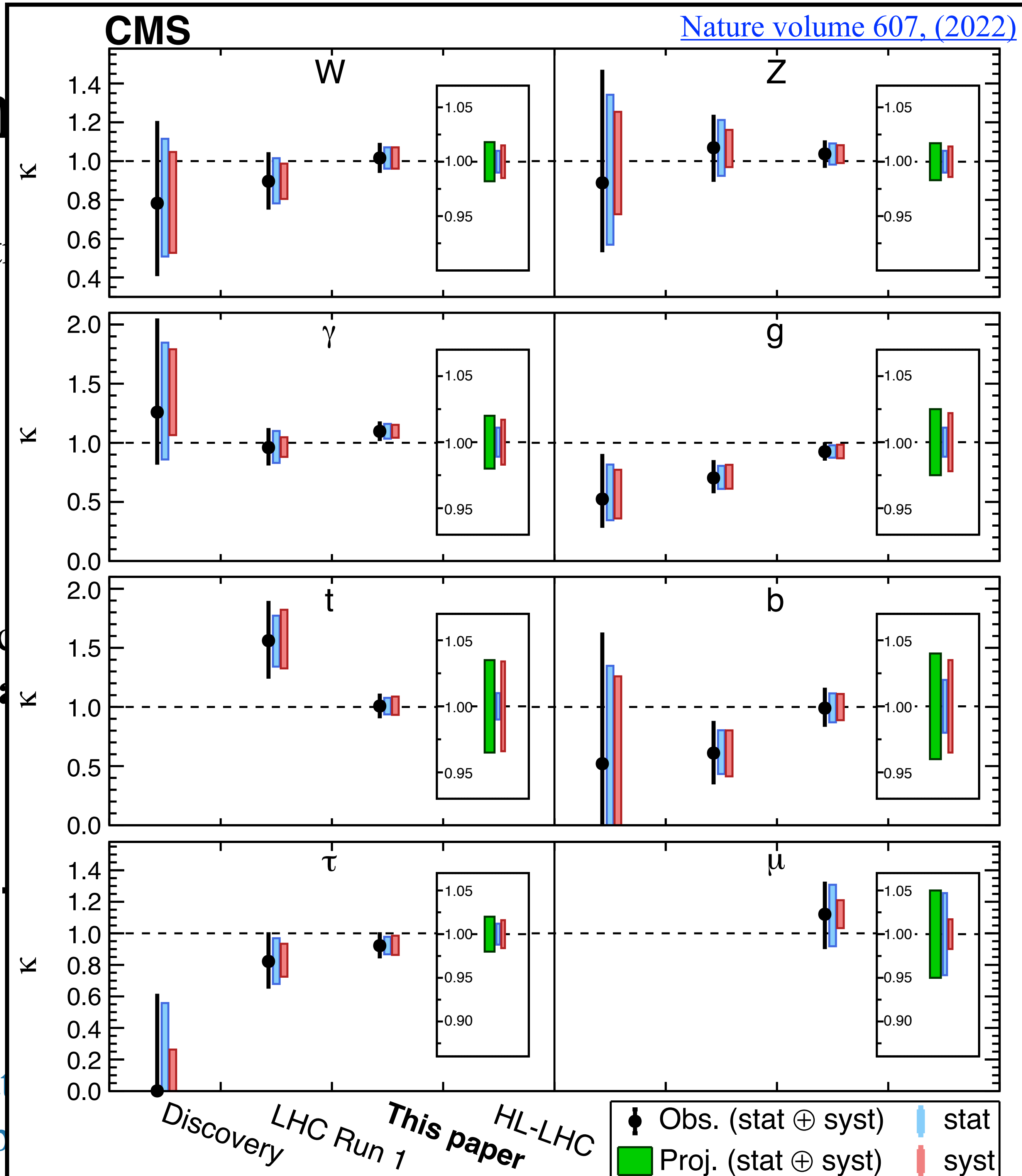
Modifies rate a which Higgs bosons are produced at LHC

Wh ?

Expect cont

If new physic
electro-ma

h

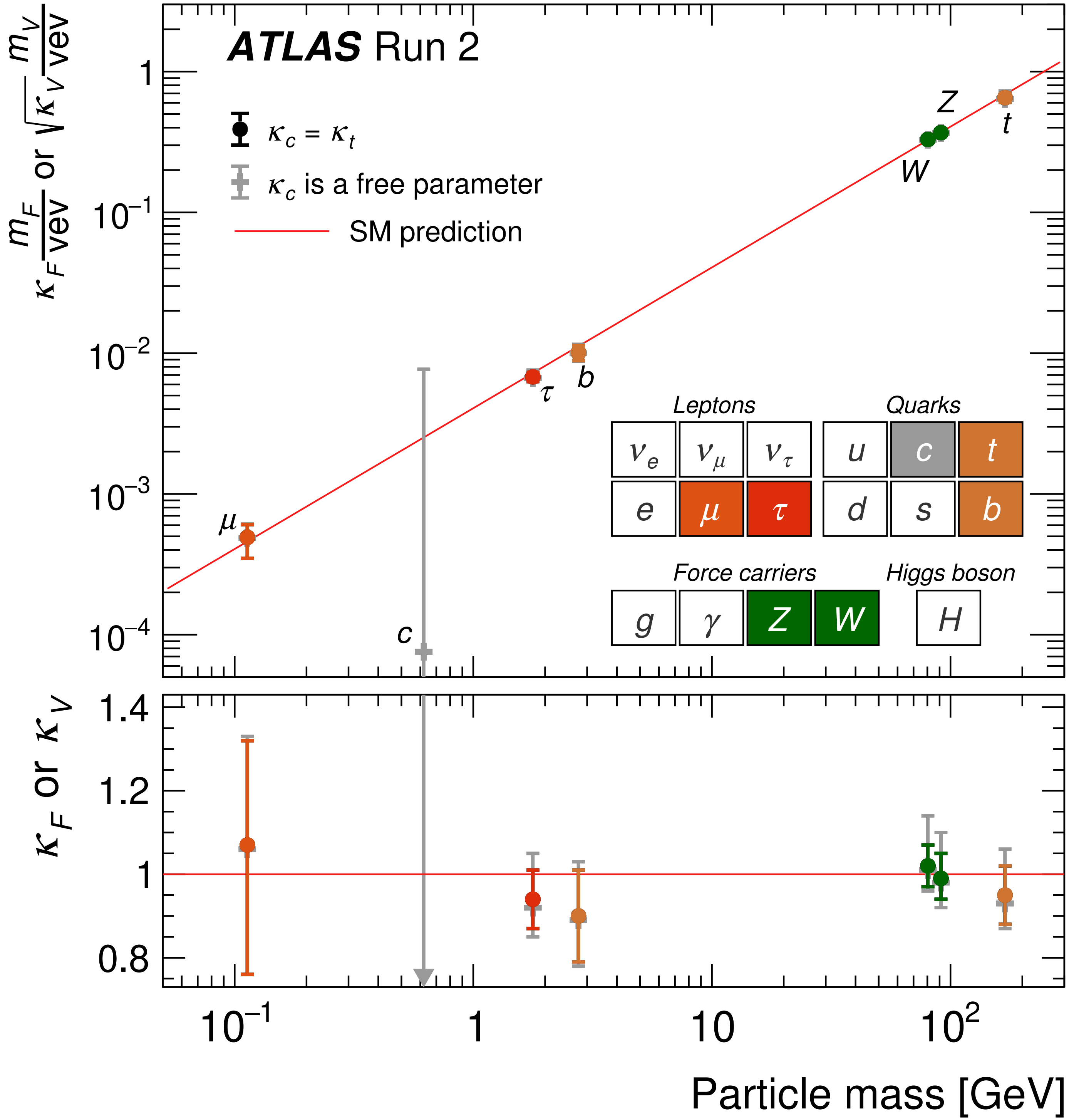


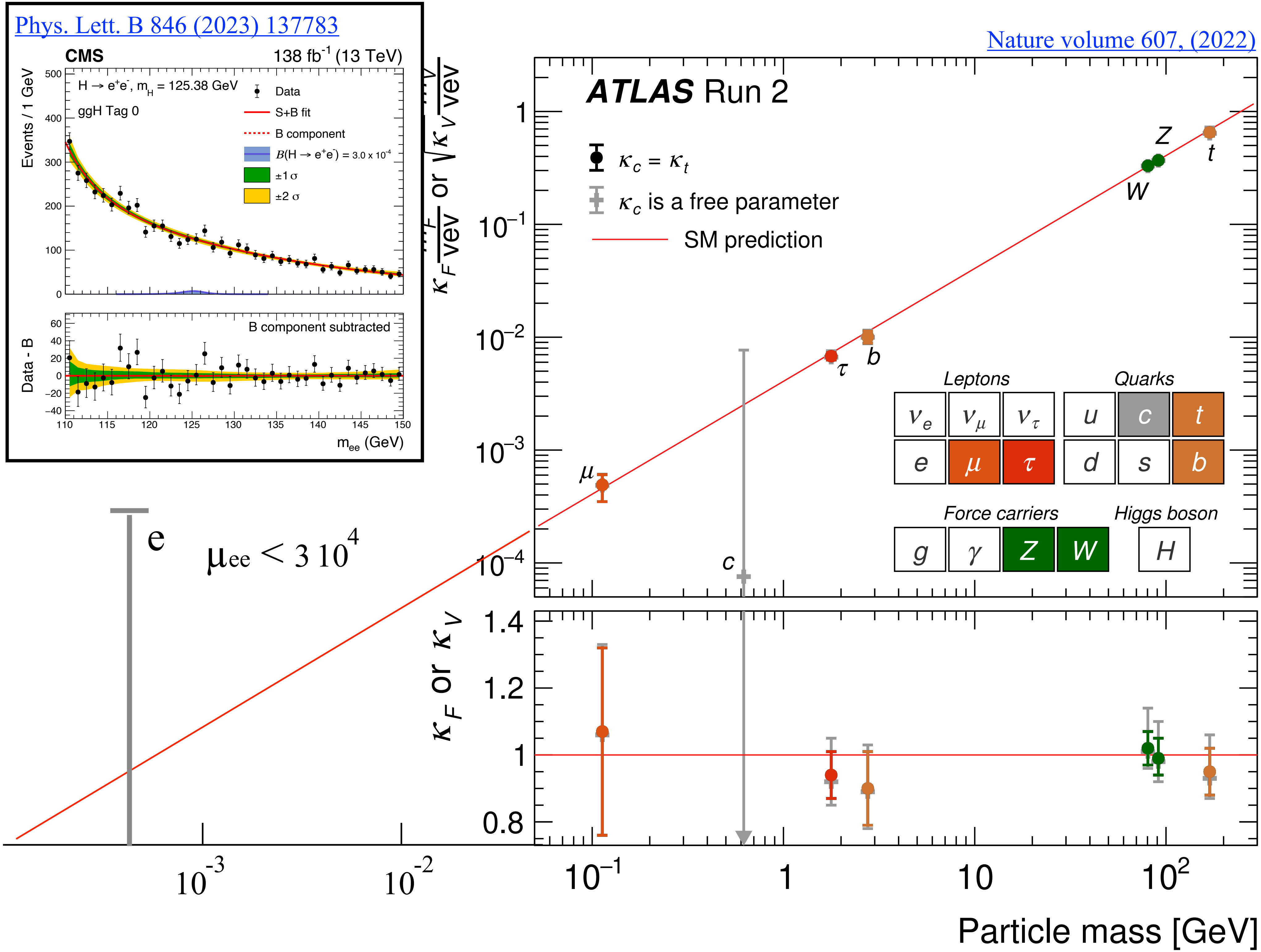
g

g

Modifies rat s bosons
decay to p

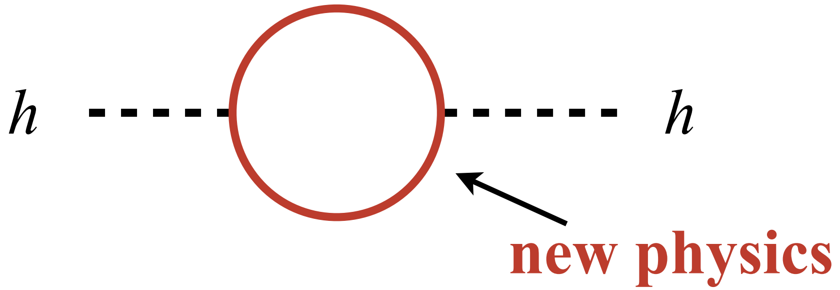
Nature volume 607, (2022)




Phys. Lett. B 846 (2023) 137783
CMS
138 fb^{-1} (13 TeV)
H → e$^+$e$^-$, m$_H$ = 125.38 GeV
ggH Tag 0
Data
S+B fit
B component
B(H → e$^+$e$^-$) = 3.0 x 10^{-4}
±1 σ
±2 σ
Events / 1 GeV
B component subtracted
Data - B
m$_{ee}$ (GeV)
Nature volume 607, (2022)
ATLAS Run 2
$\kappa_c = \kappa_t$
κ_c is a free parameter
SM prediction
Leptons
Quarks
Force carriers
Higgs boson
$\kappa_F \frac{m_F}{vev}$ or $\sqrt{\kappa_V} \frac{m_V}{vev}$
κ_F or κ_V
Particle mass [GeV]
e
$\mu_{ee} < 3\ 10^4$

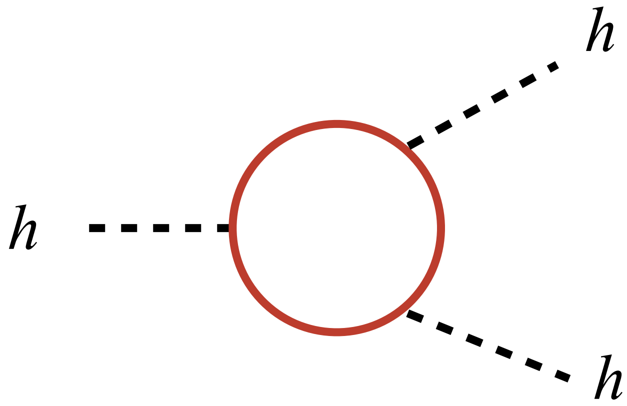
The Higgs Self-Coupling

Expect contributions from new physics to correct Higgs mass:



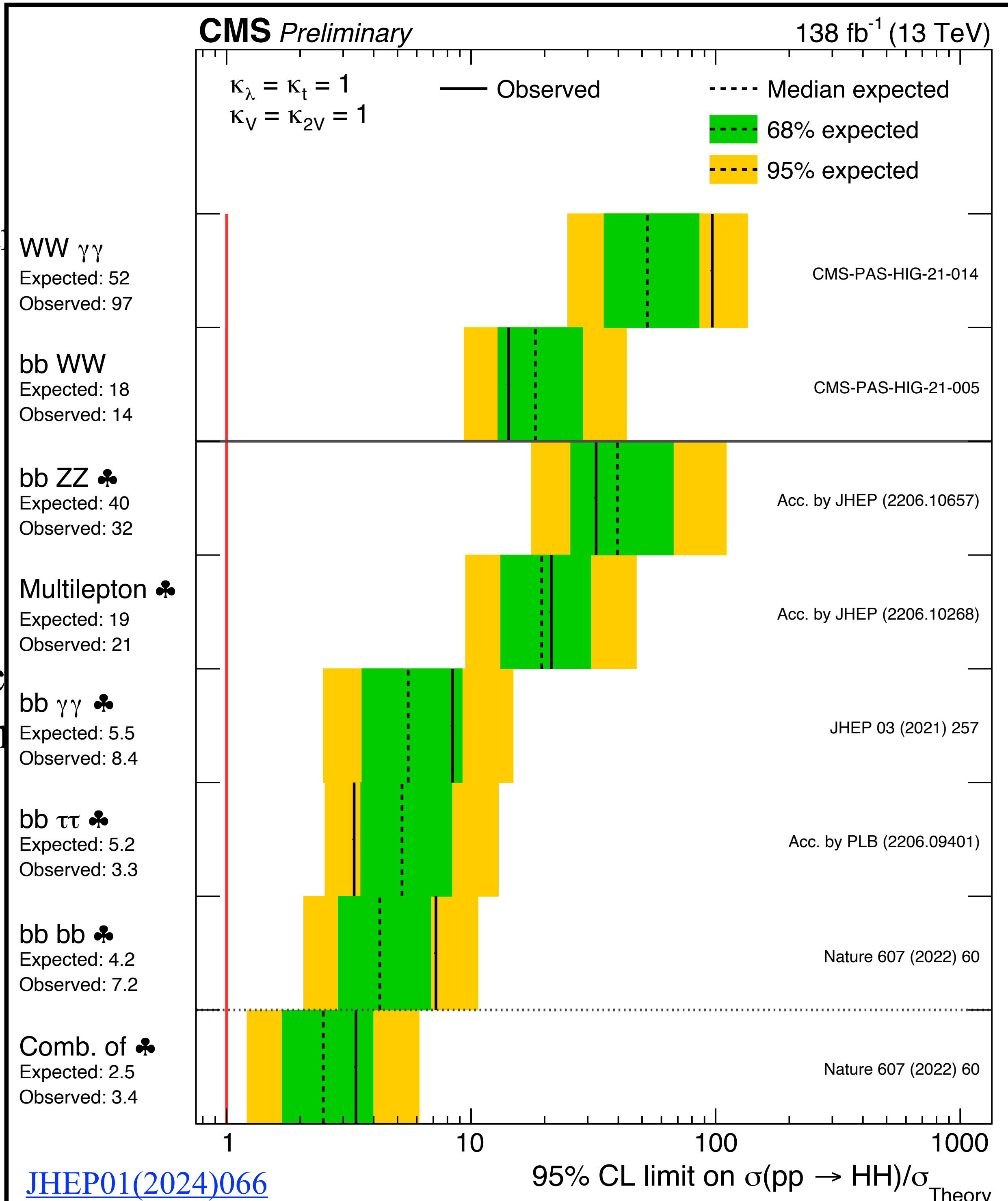
by construction, cannot avoid:

Higgs interaction:



Modifies Di-Higgs production

Expect cont



[JHEP01(2024)066]

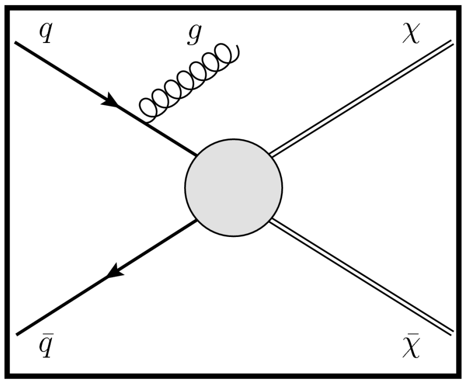
g

by construc

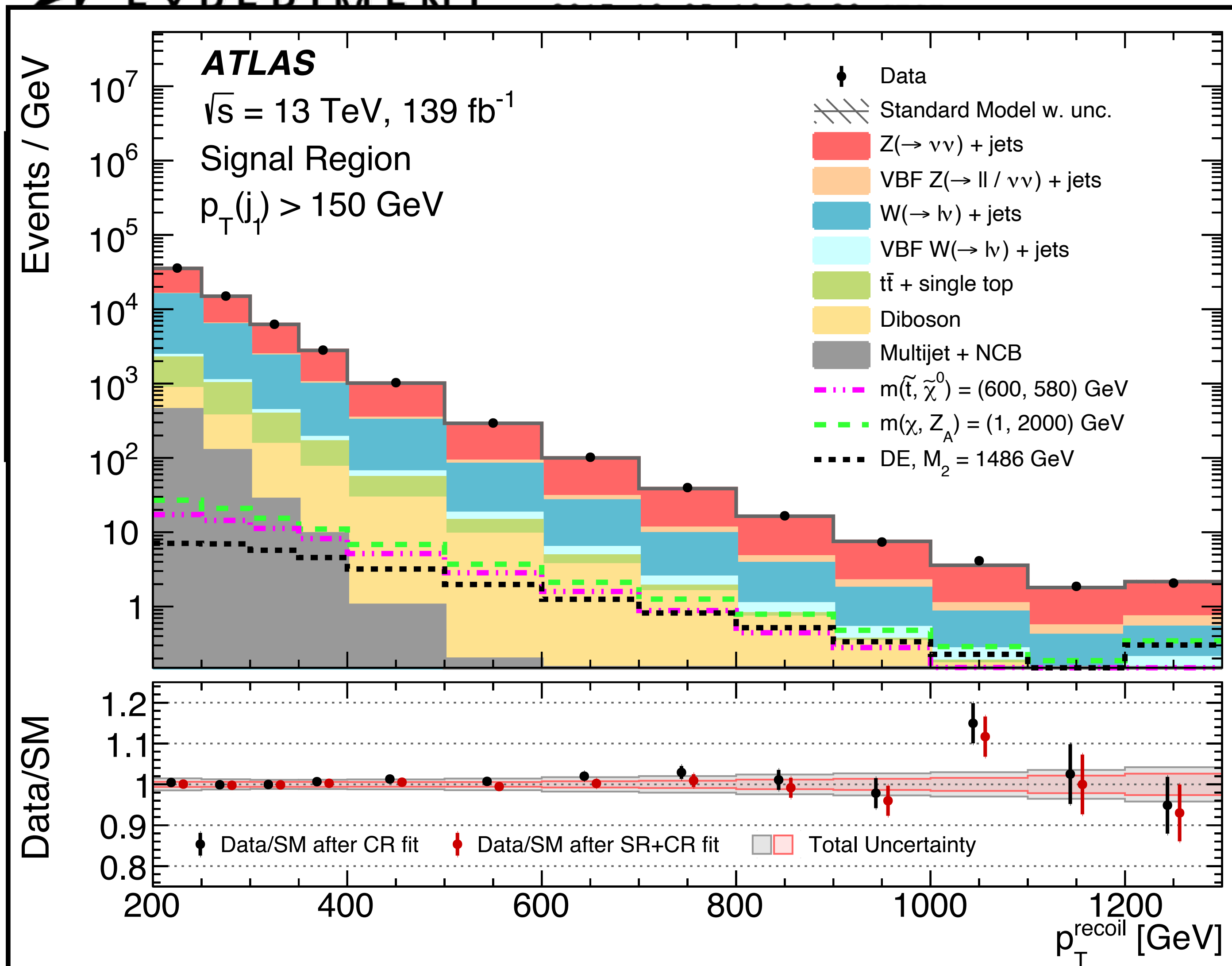
Higgs in

Searches for New Physics

Mono-Jet

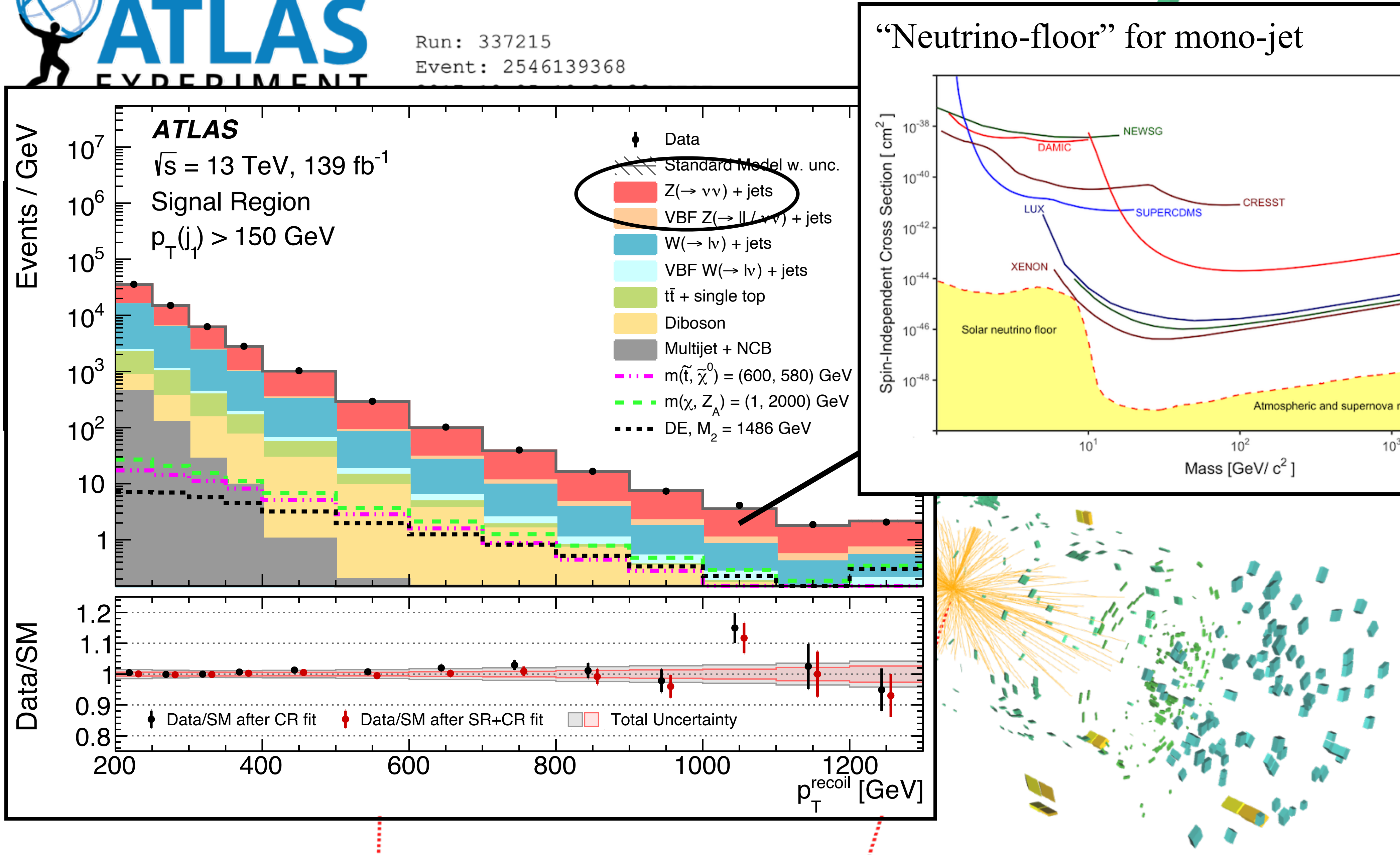


Mono-Jet



[Phys. Rev. D 103, 112006 (2021)]

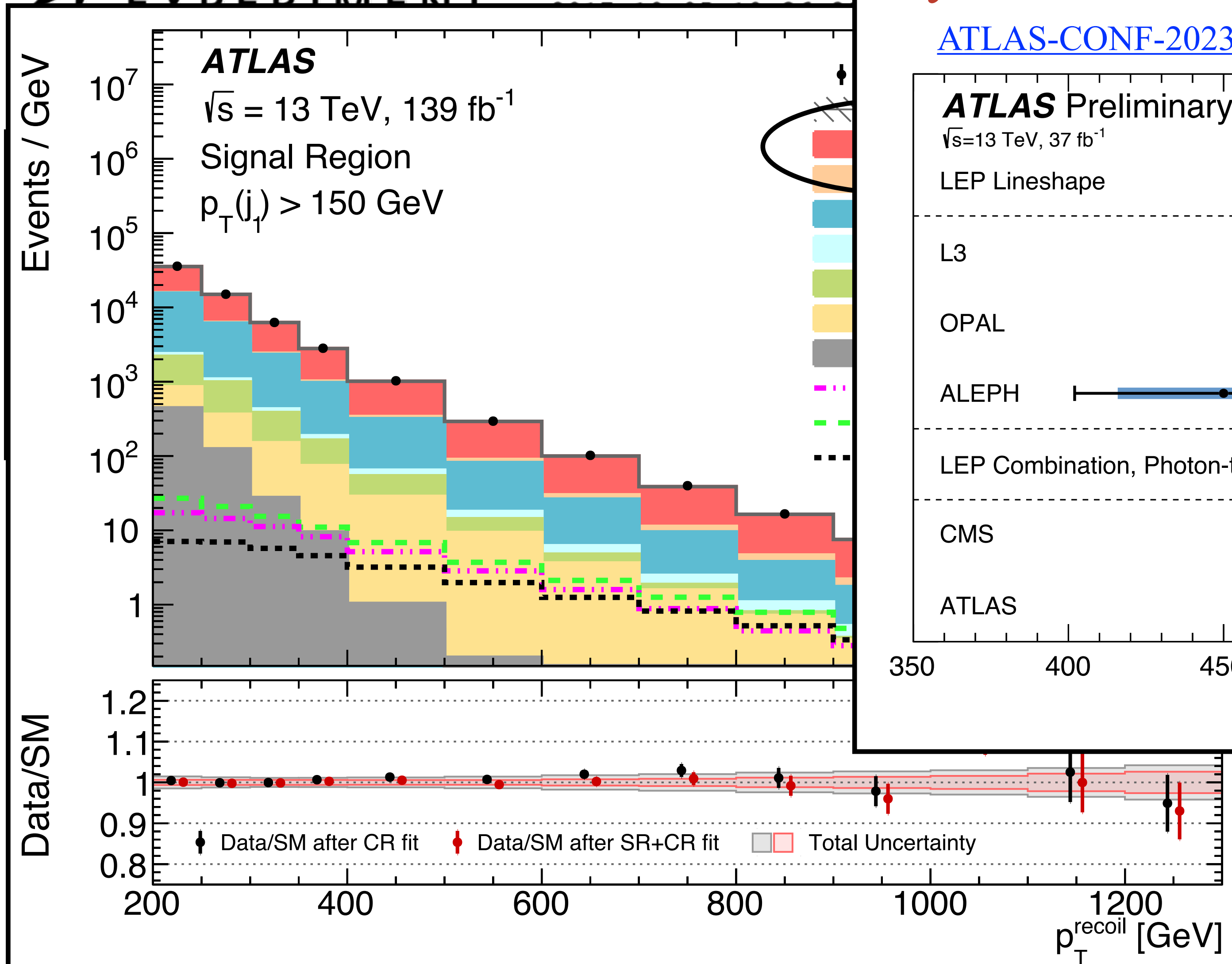
Mono-Jet



[Phys. Rev. D 103, 112006 (2021)]

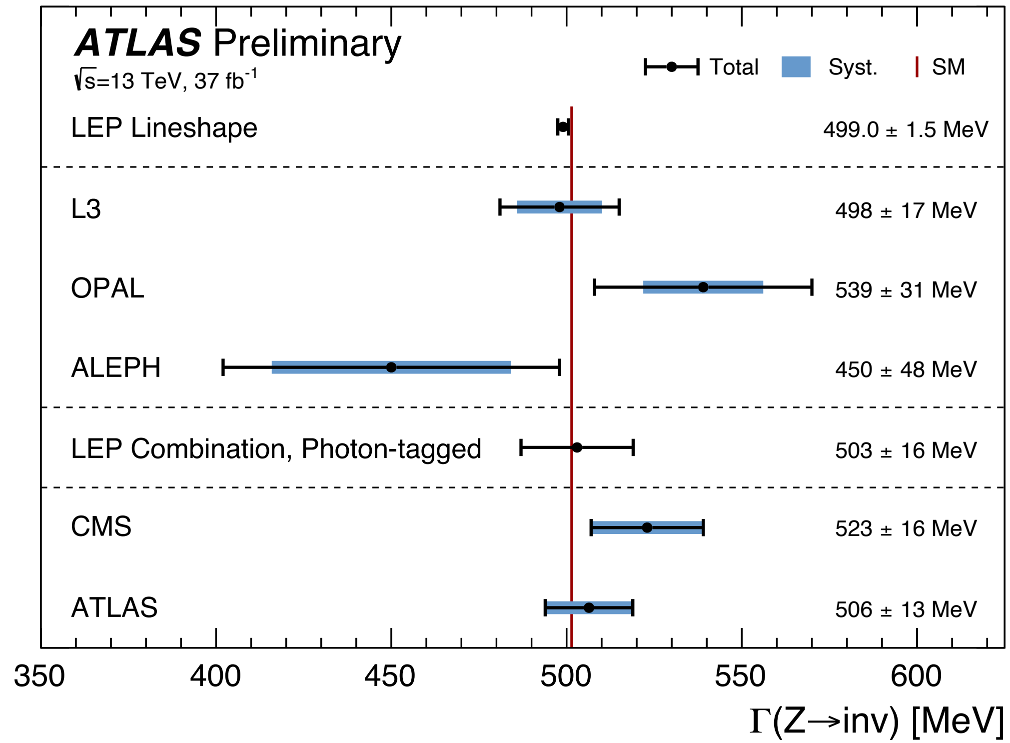
Mono-Jet

Run: 337215
Event: 2546139368



If you cant beat'em … join'em

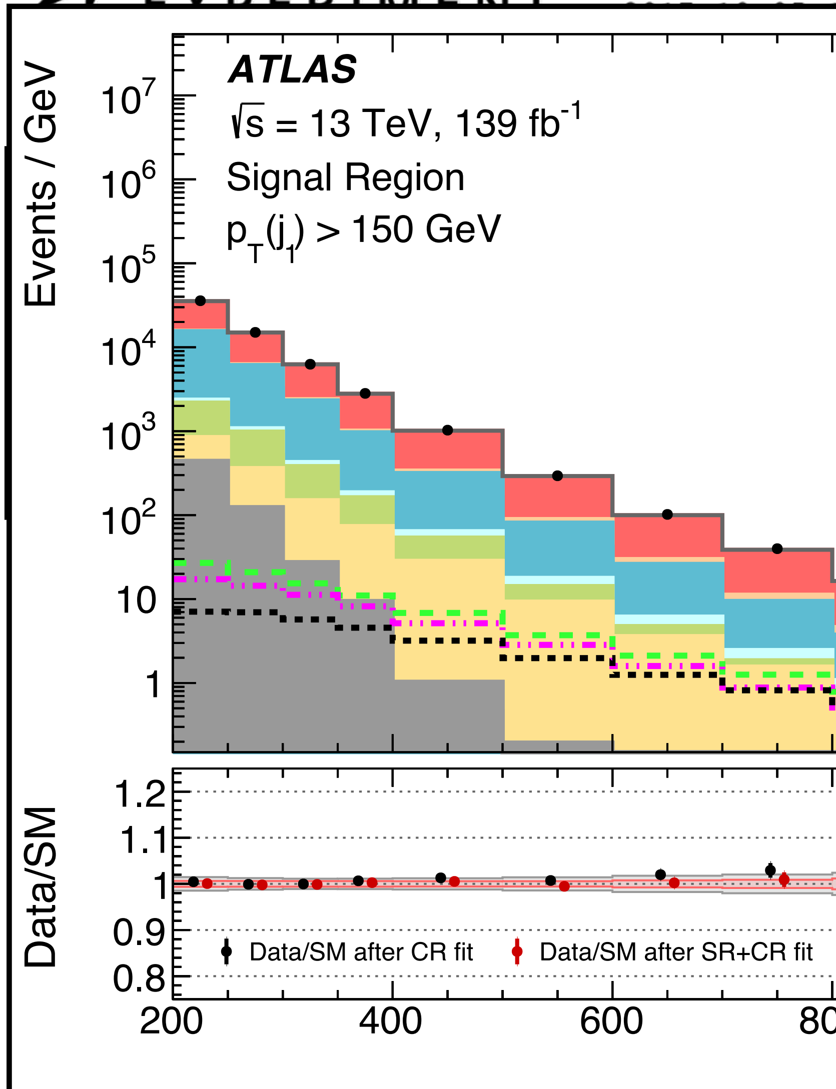
ATLAS-CONF-2023-053

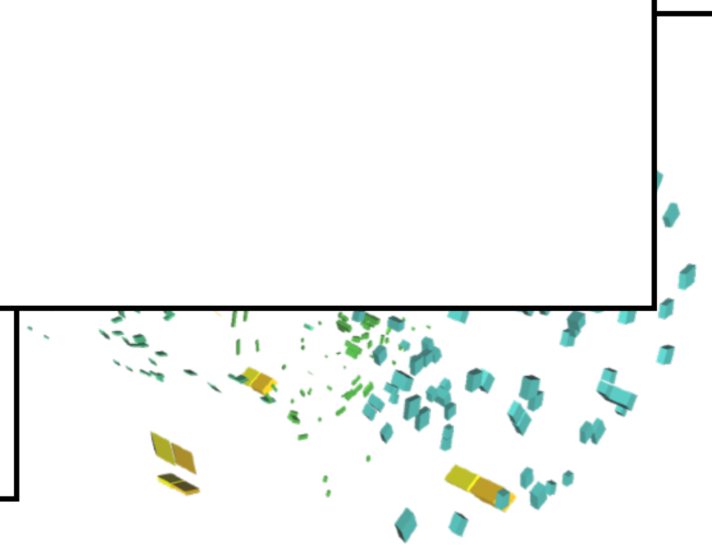


Phys. Rev. D 103, 112006 (2021)

Mono-Jet

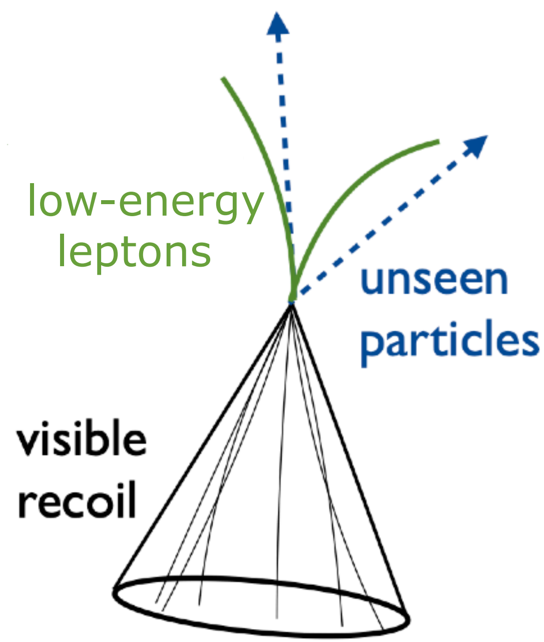
Run: 337215
Event: 25461





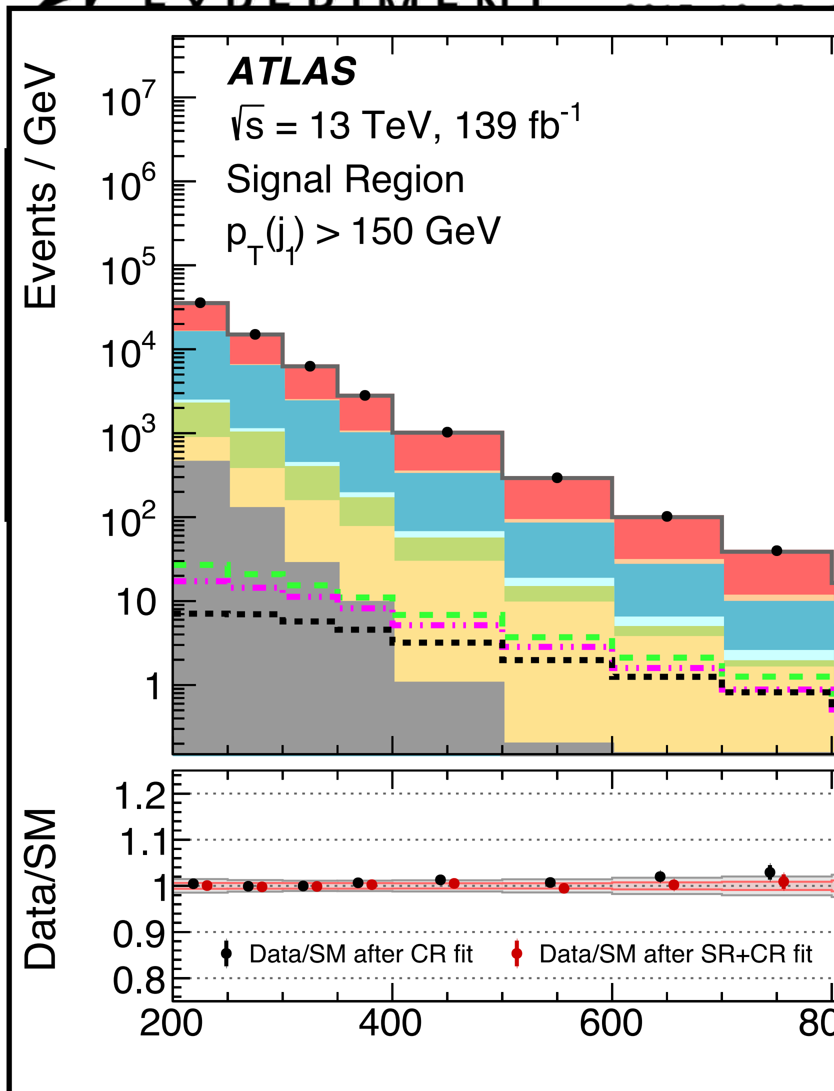
Just add leptons…

Kills $Z \rightarrow \nu\nu$



[Phys. Rev. D 103, 112006 (2021)]

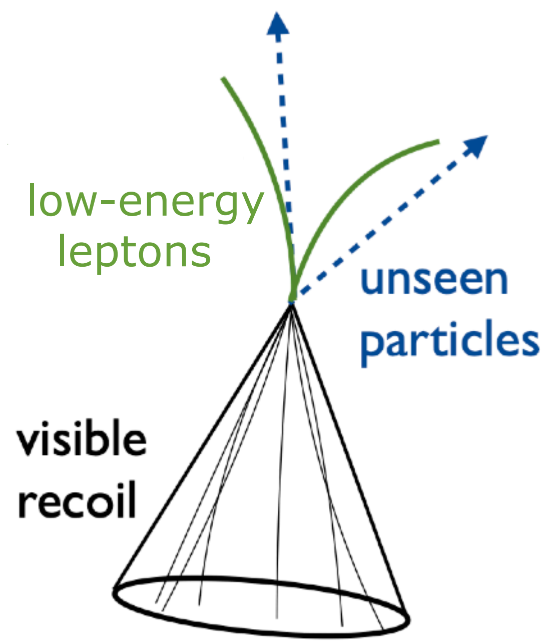
Mono-Jet

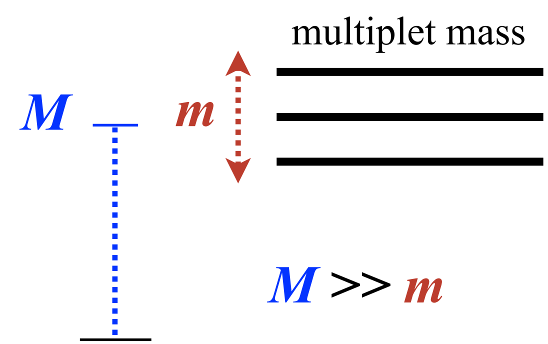


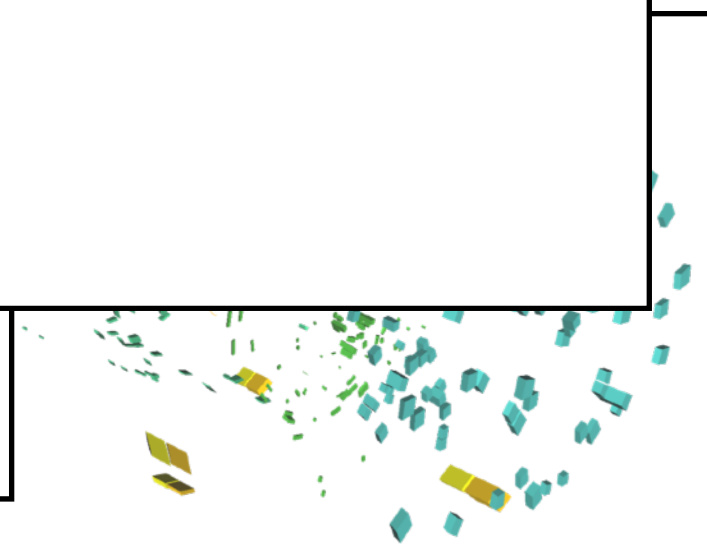
Just add leptons…

Kills $Z \to \nu\nu$

Theoretically Motivated

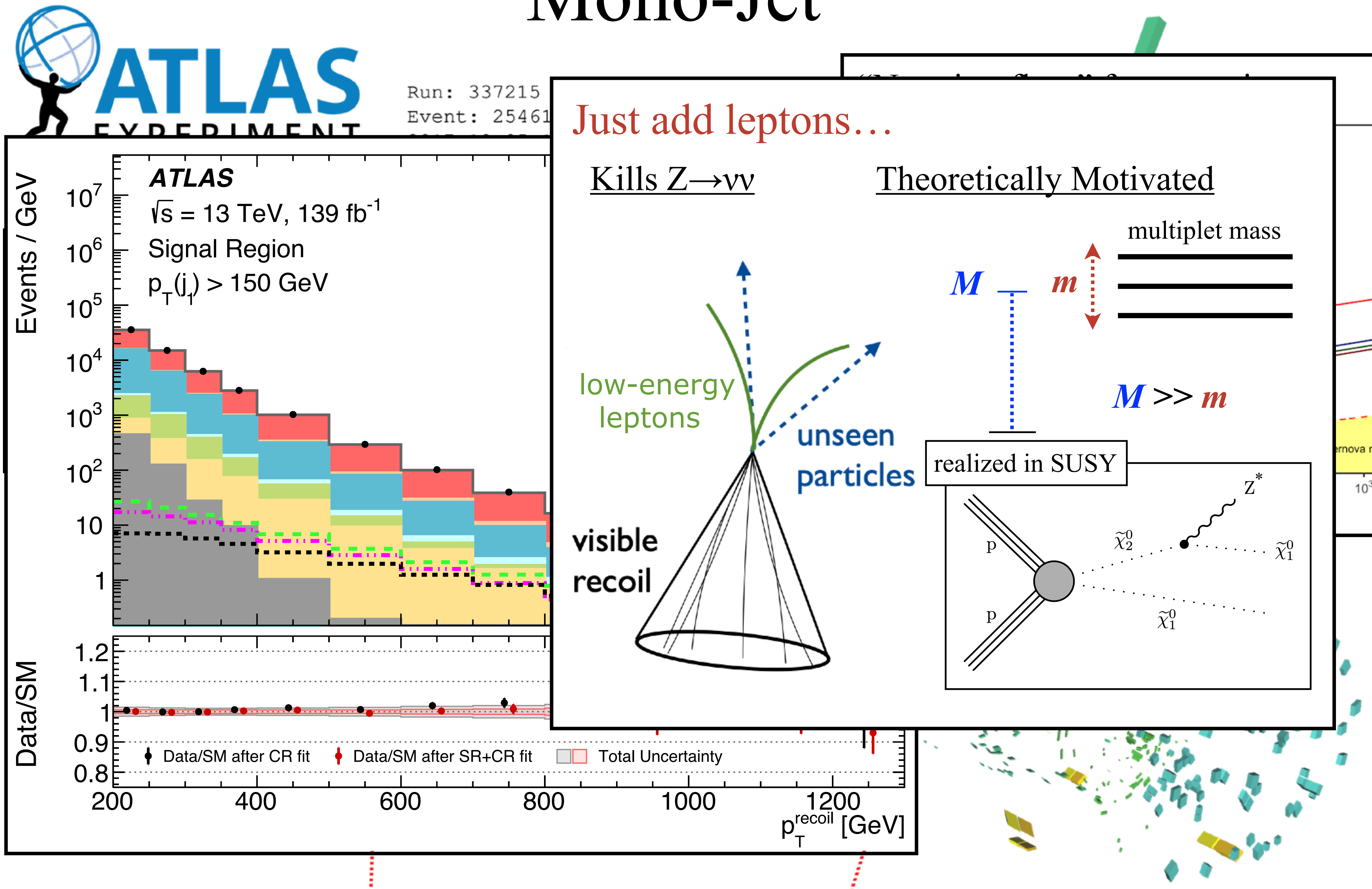






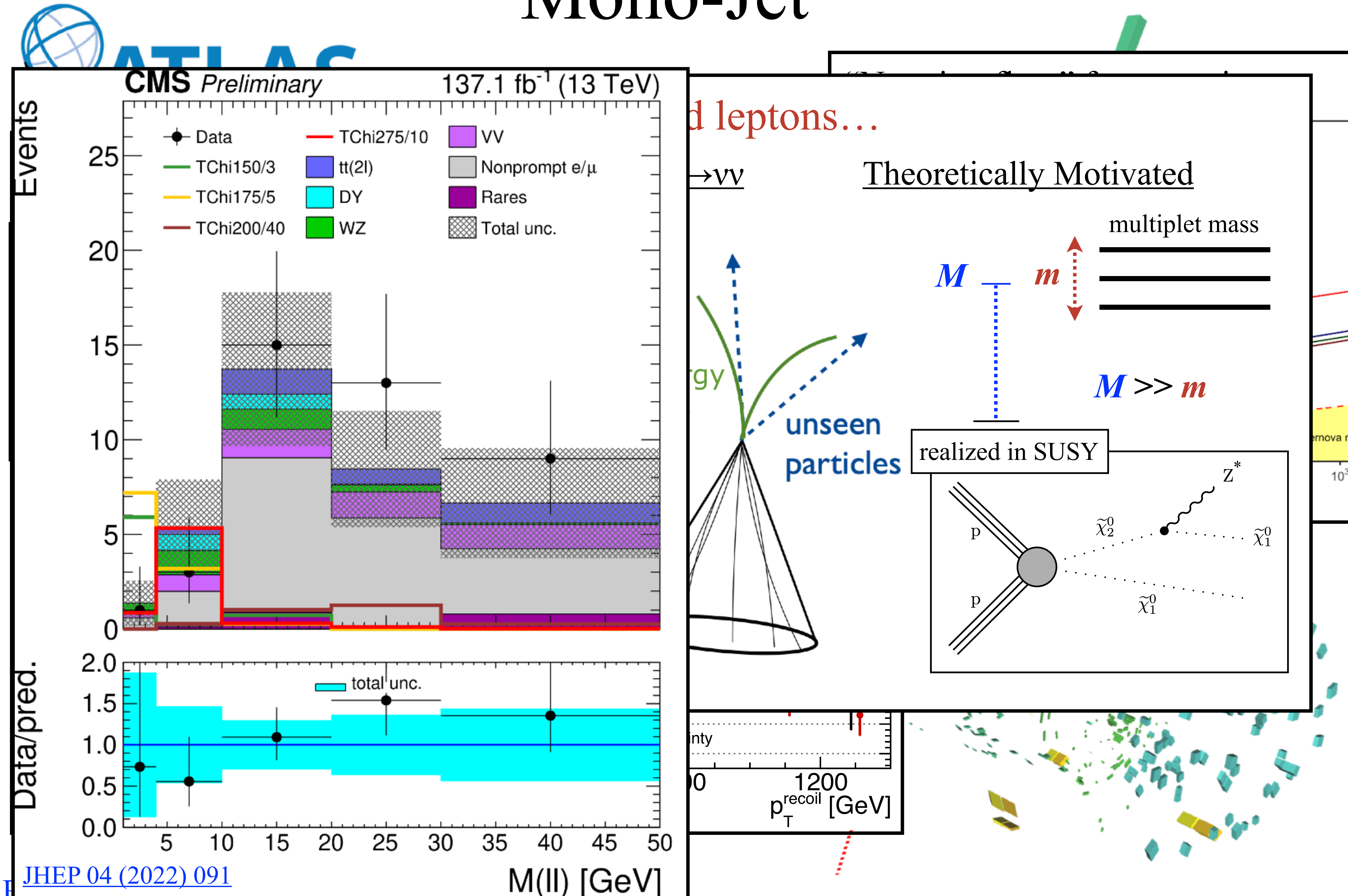
[Phys. Rev. D 103, 112006 (2021)]

Mono-Jet

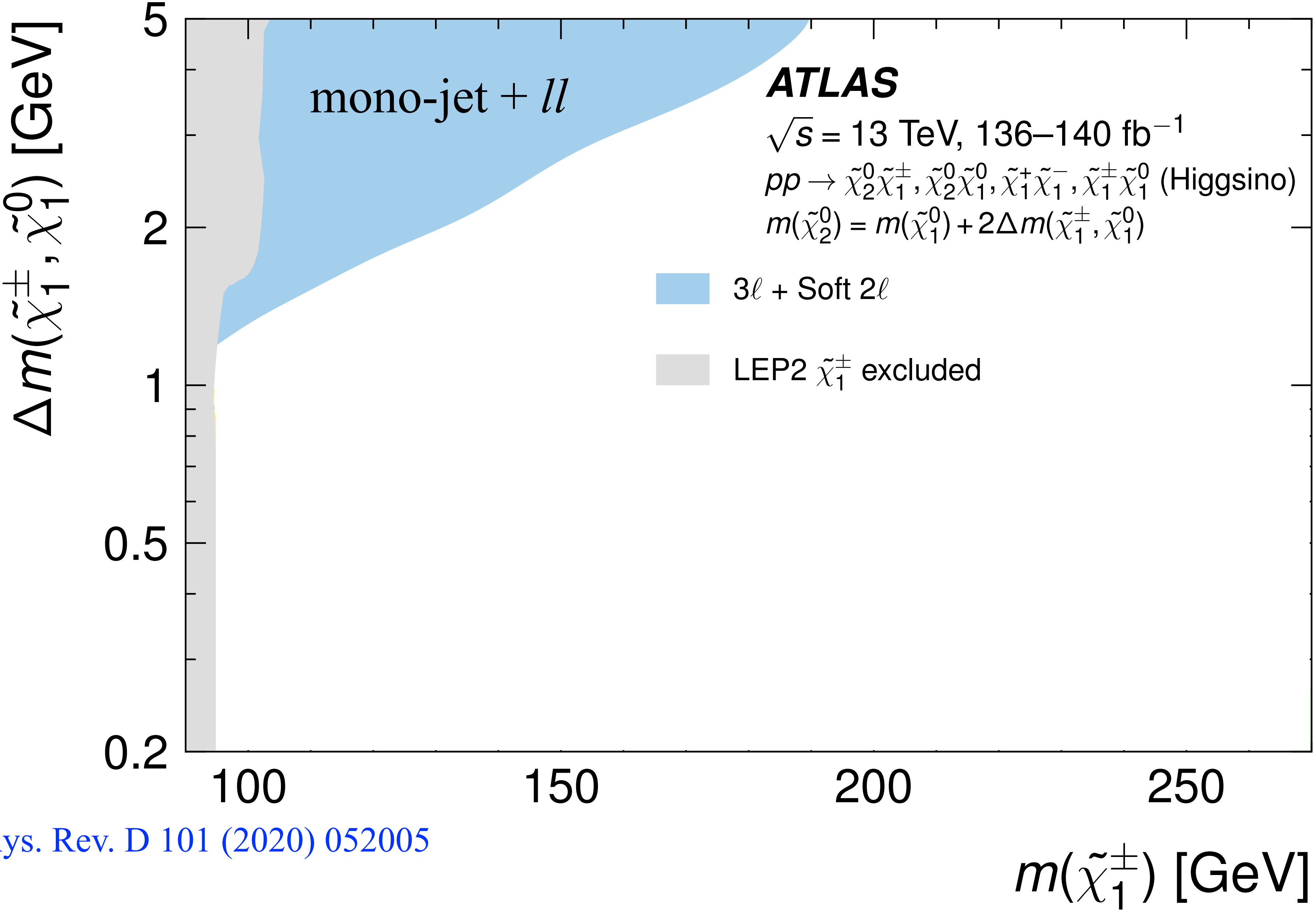


[Phys. Rev. D 103, 112006 (2021)]

Mono-Jet

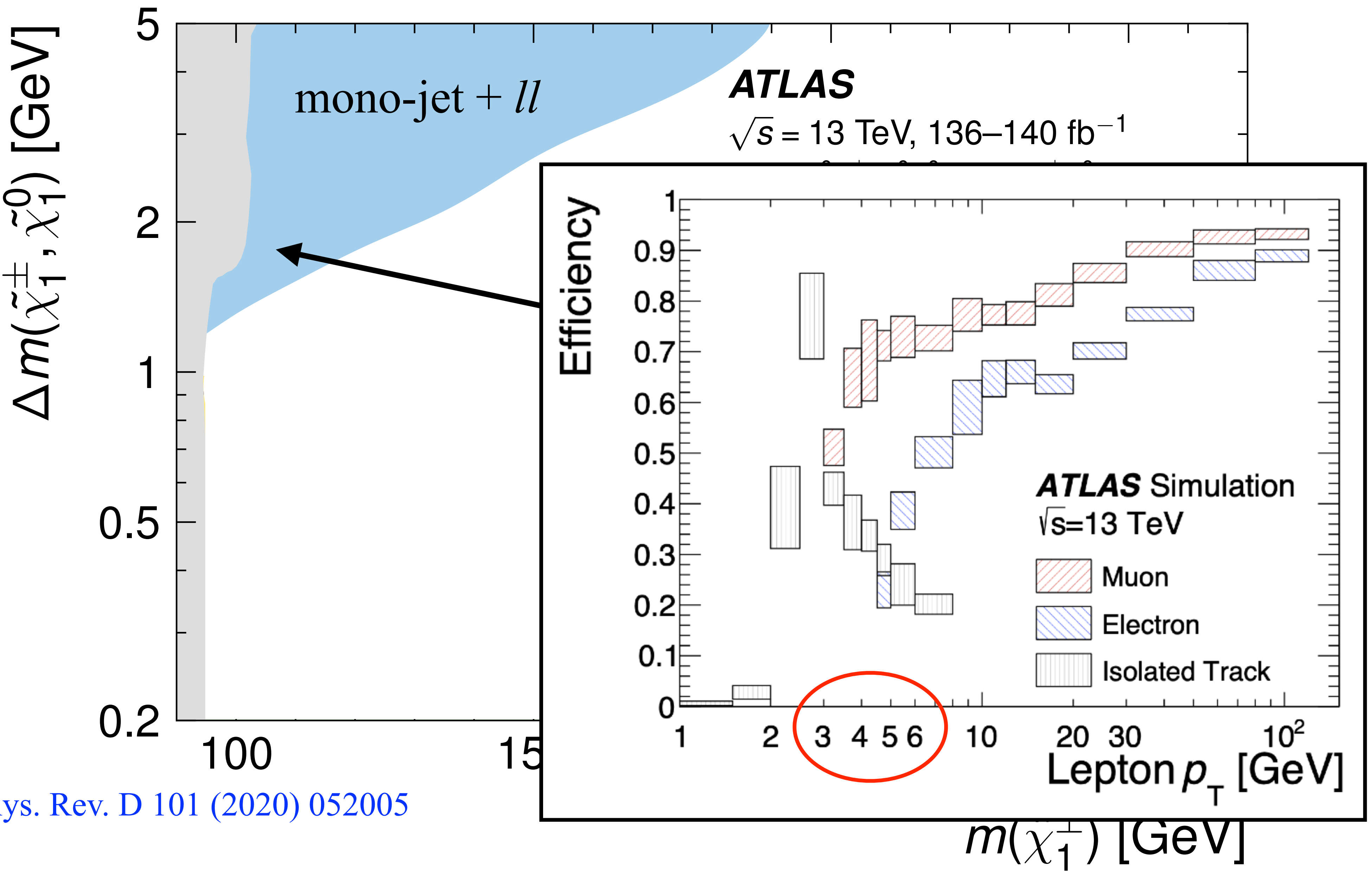

CMS Preliminary
137.1 fb^{-1} (13 TeV)
Events
Data
TChi150/3
TChi175/5
TChi200/40
TChi275/10
tt(2l)
DY
WZ
VV
Nonprompt e/μ
Rares
Total unc.
Data/pred.
total unc.
M(ll) [GeV]
JHEP 04 (2022) 091
d leptons…
→νν
Theoretically Motivated
multiplet mass
M
m
M >> m
gy
unseen
particles
realized in SUSY
p
p
Z*
$\tilde{\chi}_2^0$
$\tilde{\chi}_1^0$
$\tilde{\chi}_1^0$
inty
1200
p_T^{recoil} [GeV]

Compressed Mass Spectra



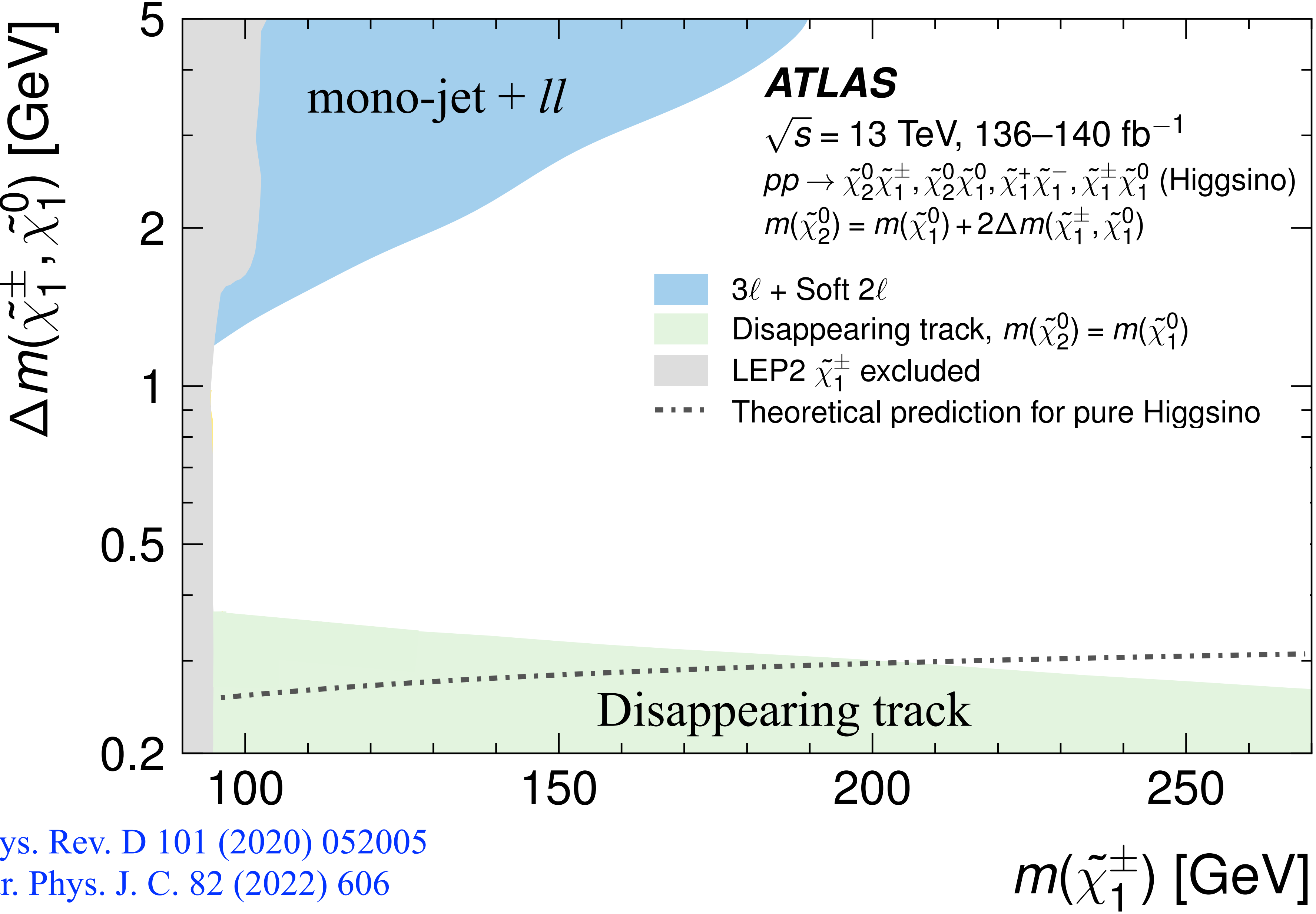
Phys. Rev. D 101 (2020) 052005

Compressed Mass Spectra



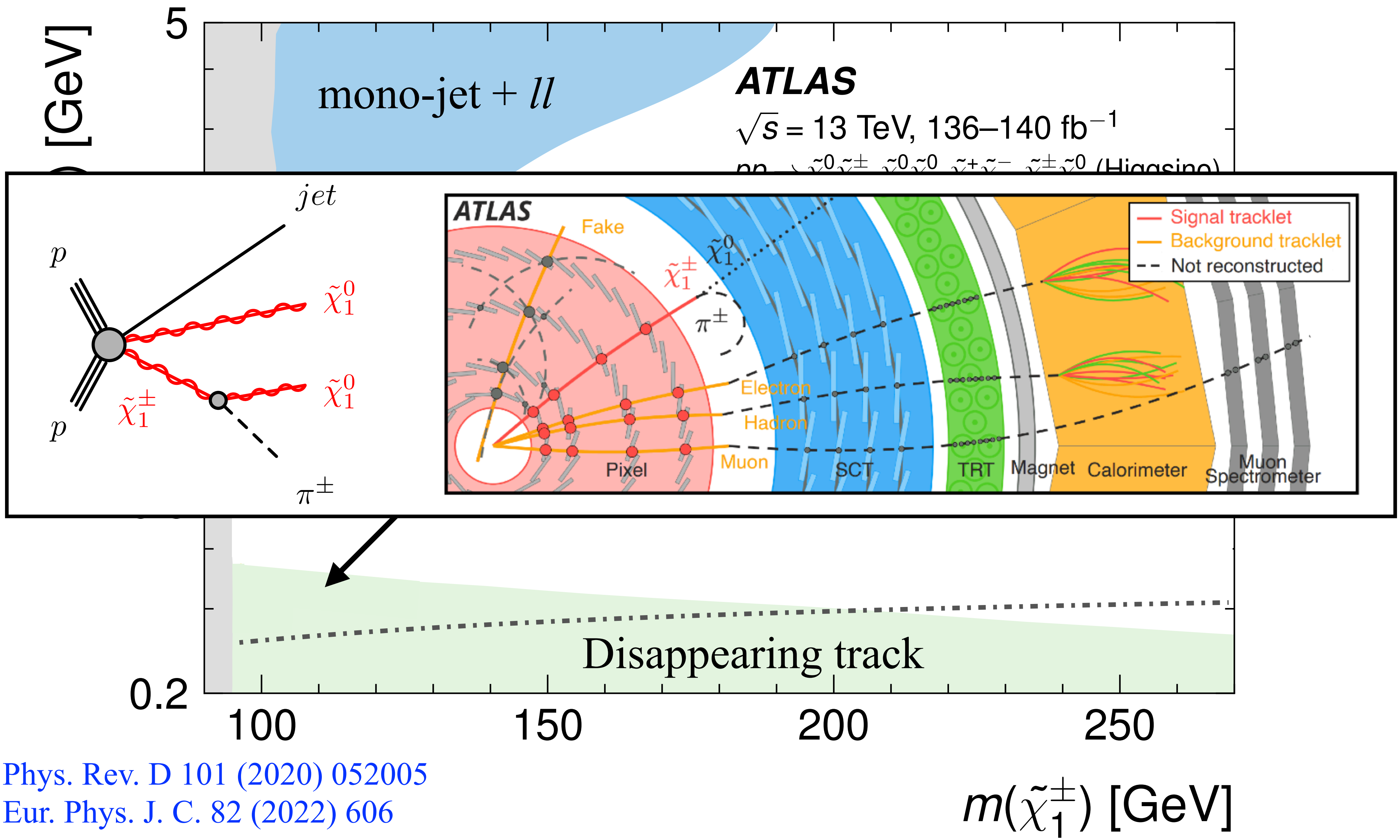
Phys. Rev. D 101 (2020) 052005

Compressed Mass Spectra



Phys. Rev. D 101 (2020) 052005
Eur. Phys. J. C. 82 (2022) 606

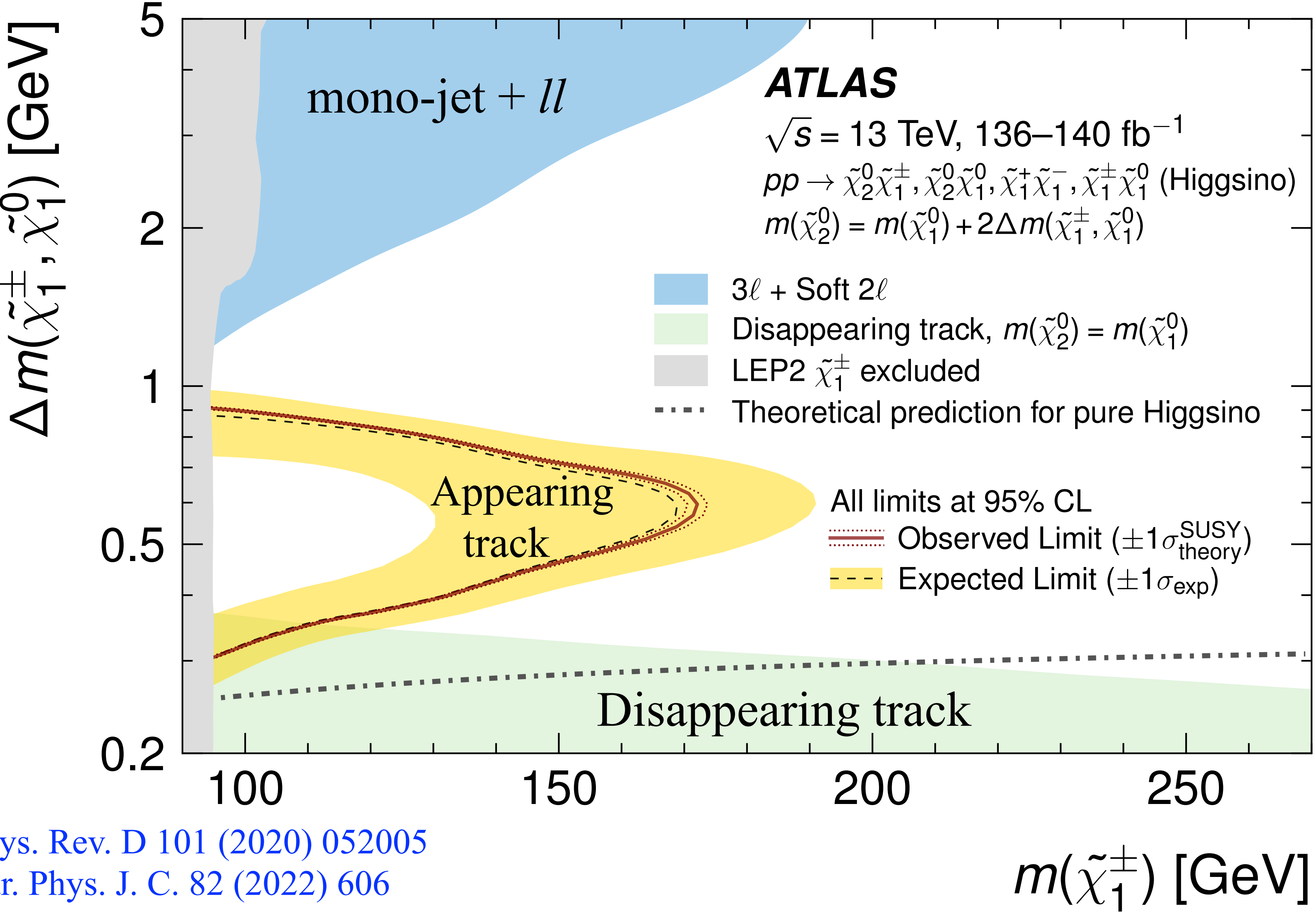
Compressed Mass Spectra



Phys. Rev. D 101 (2020) 052005

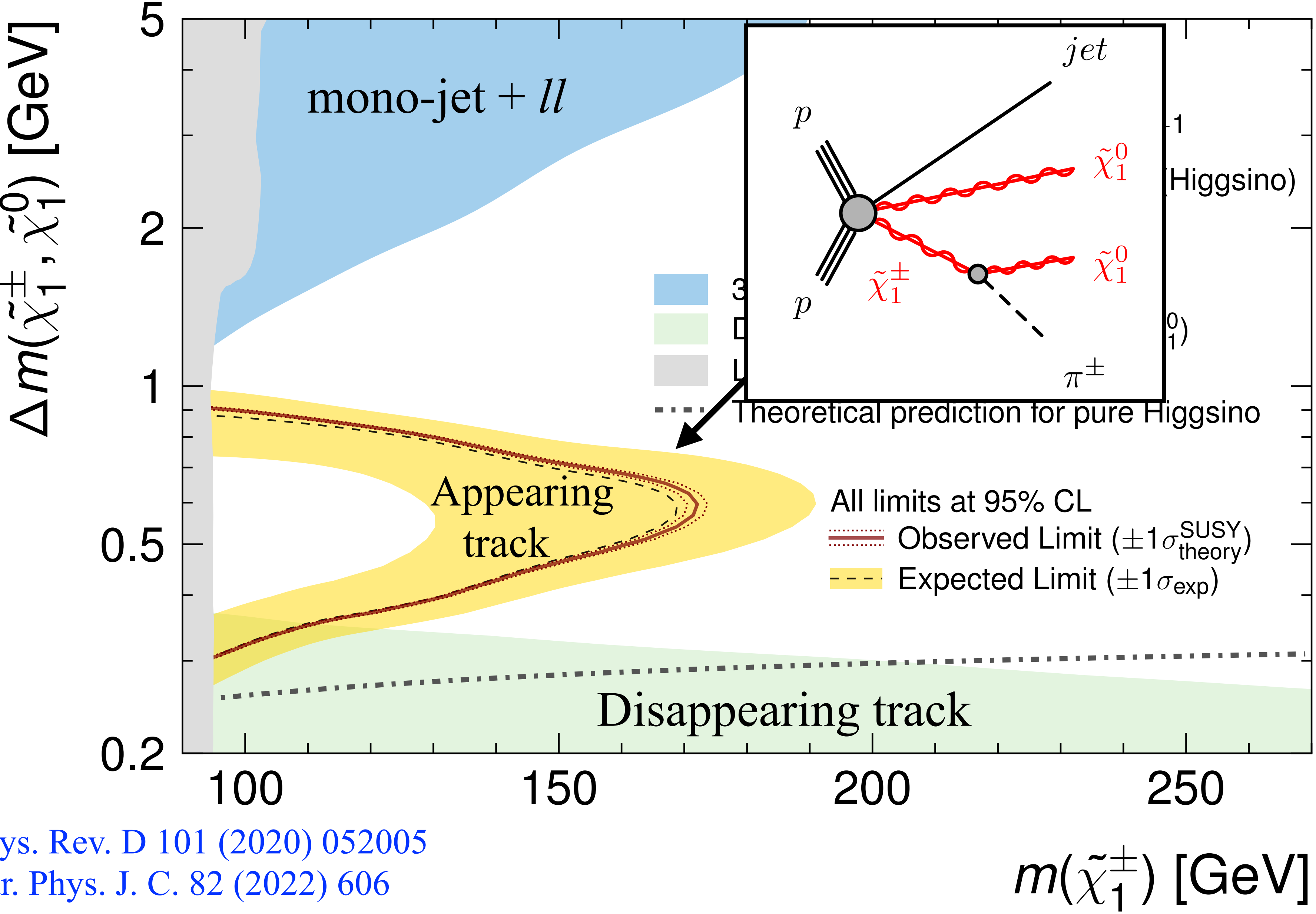
Eur. Phys. J. C. 82 (2022) 606

Compressed Mass Spectra



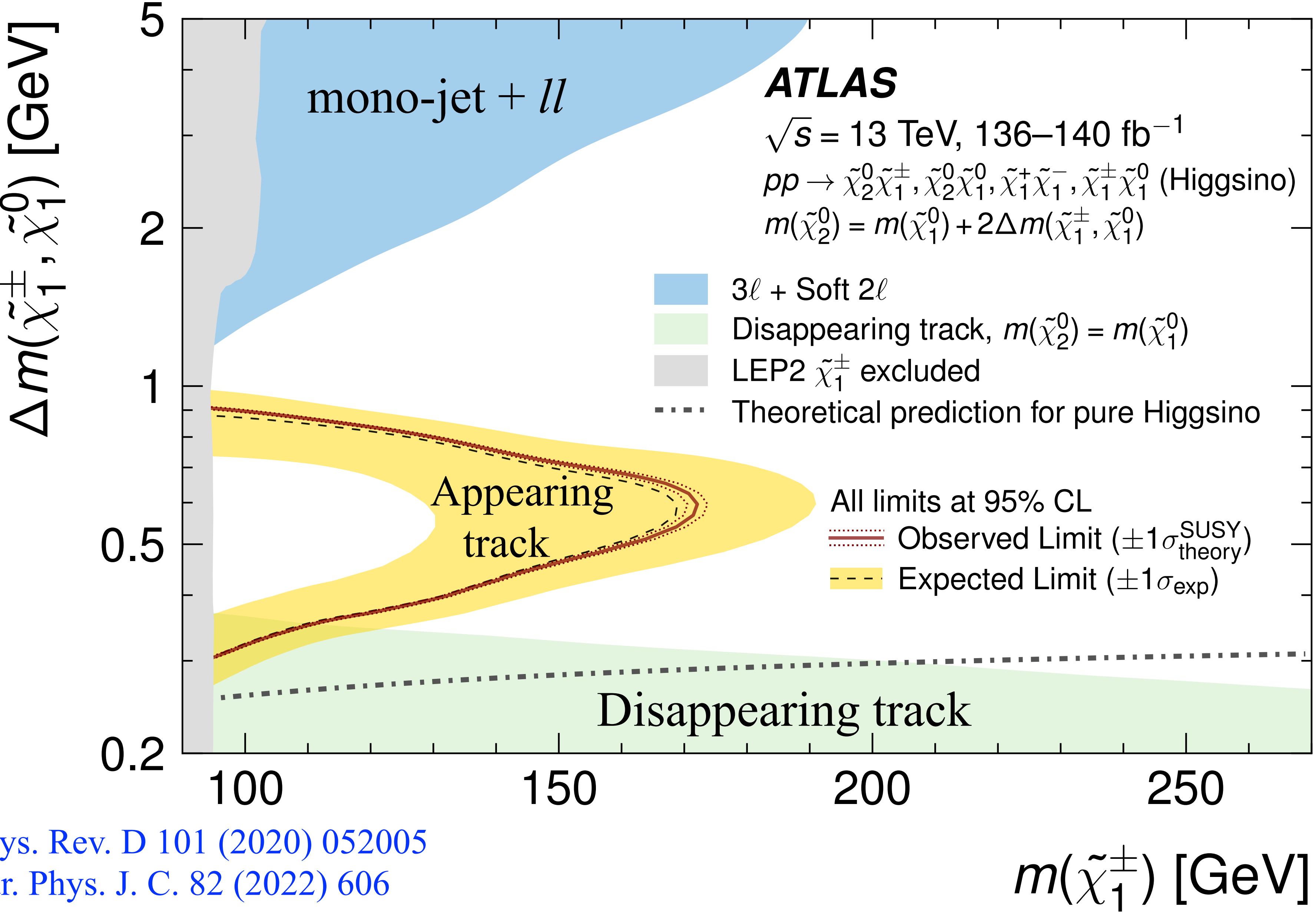
Phys. Rev. D 101 (2020) 052005
Eur. Phys. J. C. 82 (2022) 606
Phys. Rev. Lett: arXiv:2401.14046v1

Compressed Mass Spectra



Phys. Rev. D 101 (2020) 052005
Eur. Phys. J. C. 82 (2022) 606
Phys. Rev. Lett: arXiv:2401.14046v1

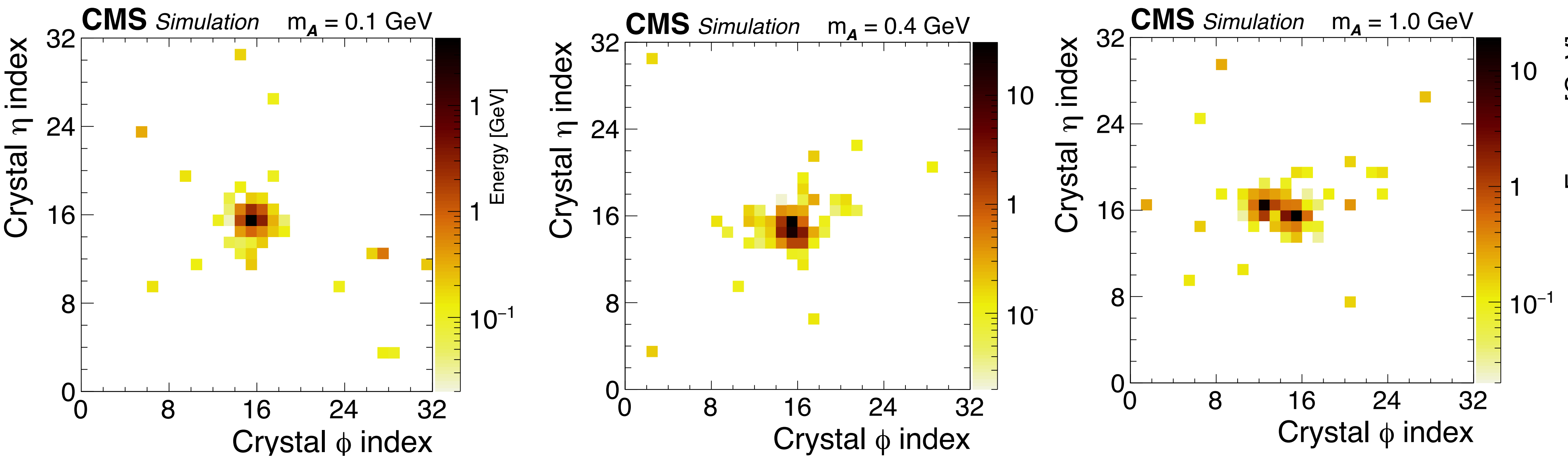
Compressed Mass Spectra



Phys. Rev. D 101 (2020) 052005
Eur. Phys. J. C. 82 (2022) 606
Phys. Rev. Lett: arXiv:2401.14046v1

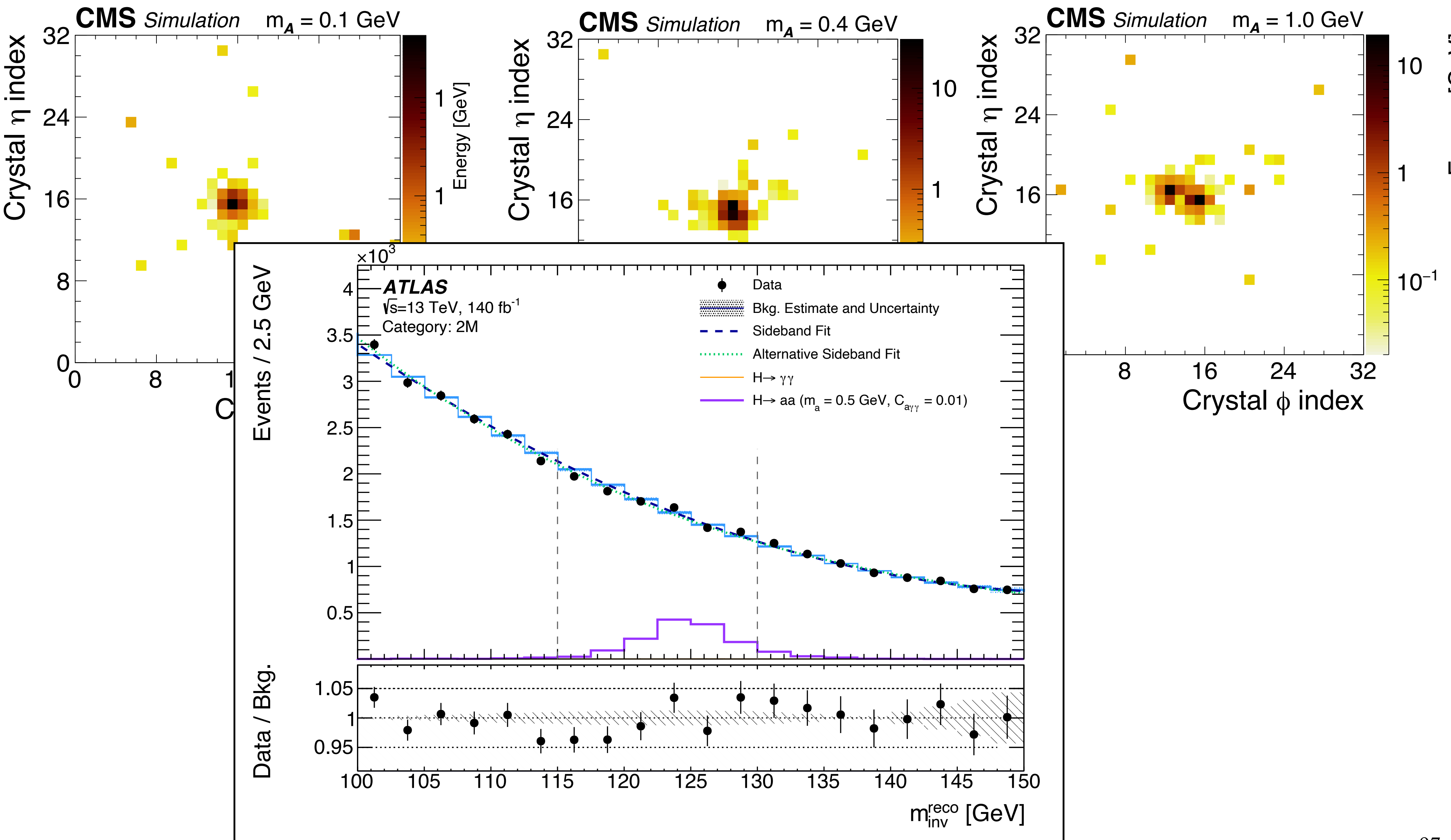
Case Study: H→aa →4γ

[Submitted to: Eur. Phys. J. C](#)
[Phys. Rev. D 108 (2023) 052002](#)



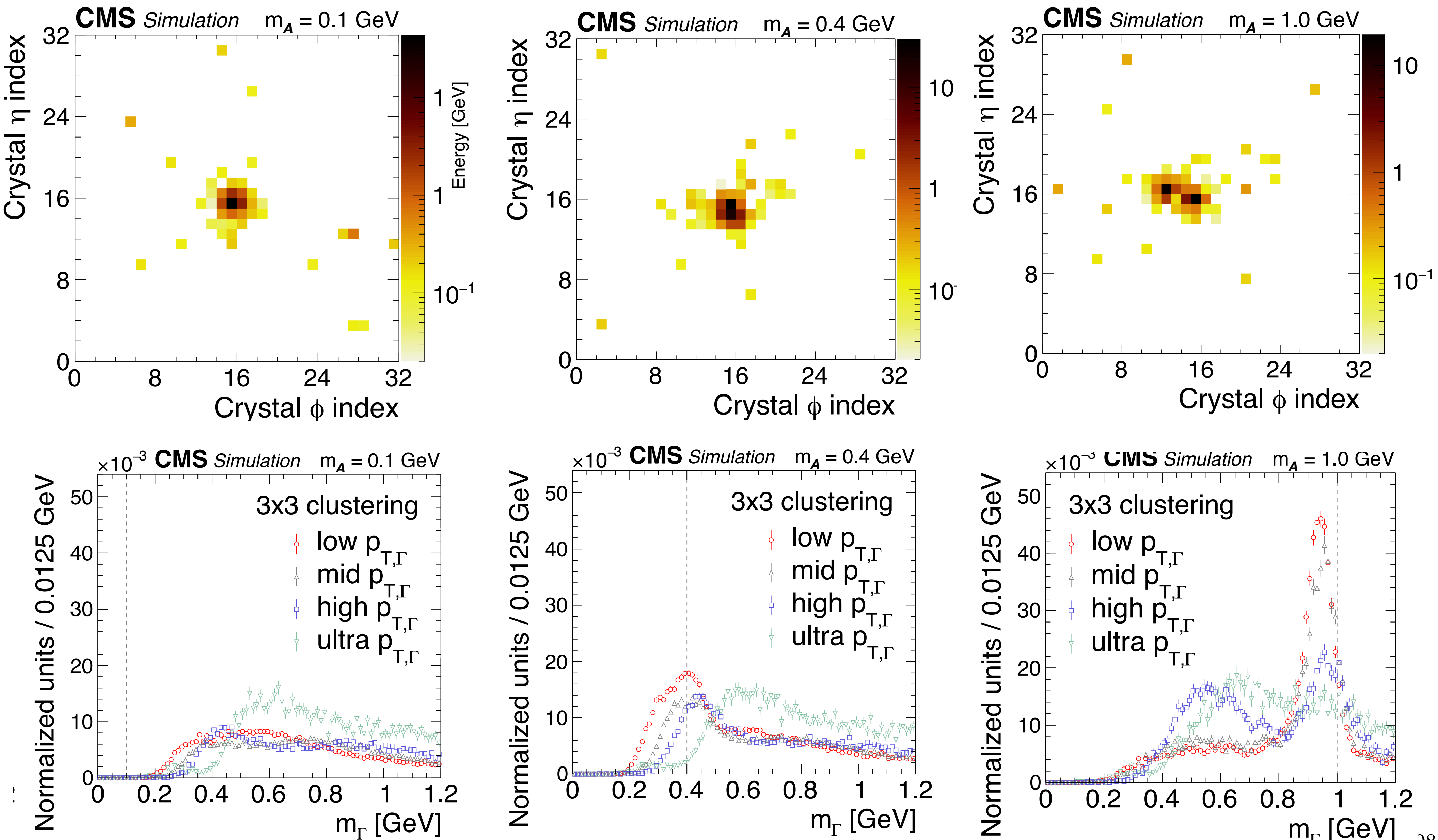
Case Study: H→aa →4γ

[Submitted to: Eur. Phys. J. C](#)
[Phys. Rev. D 108 (2023) 052002](#)



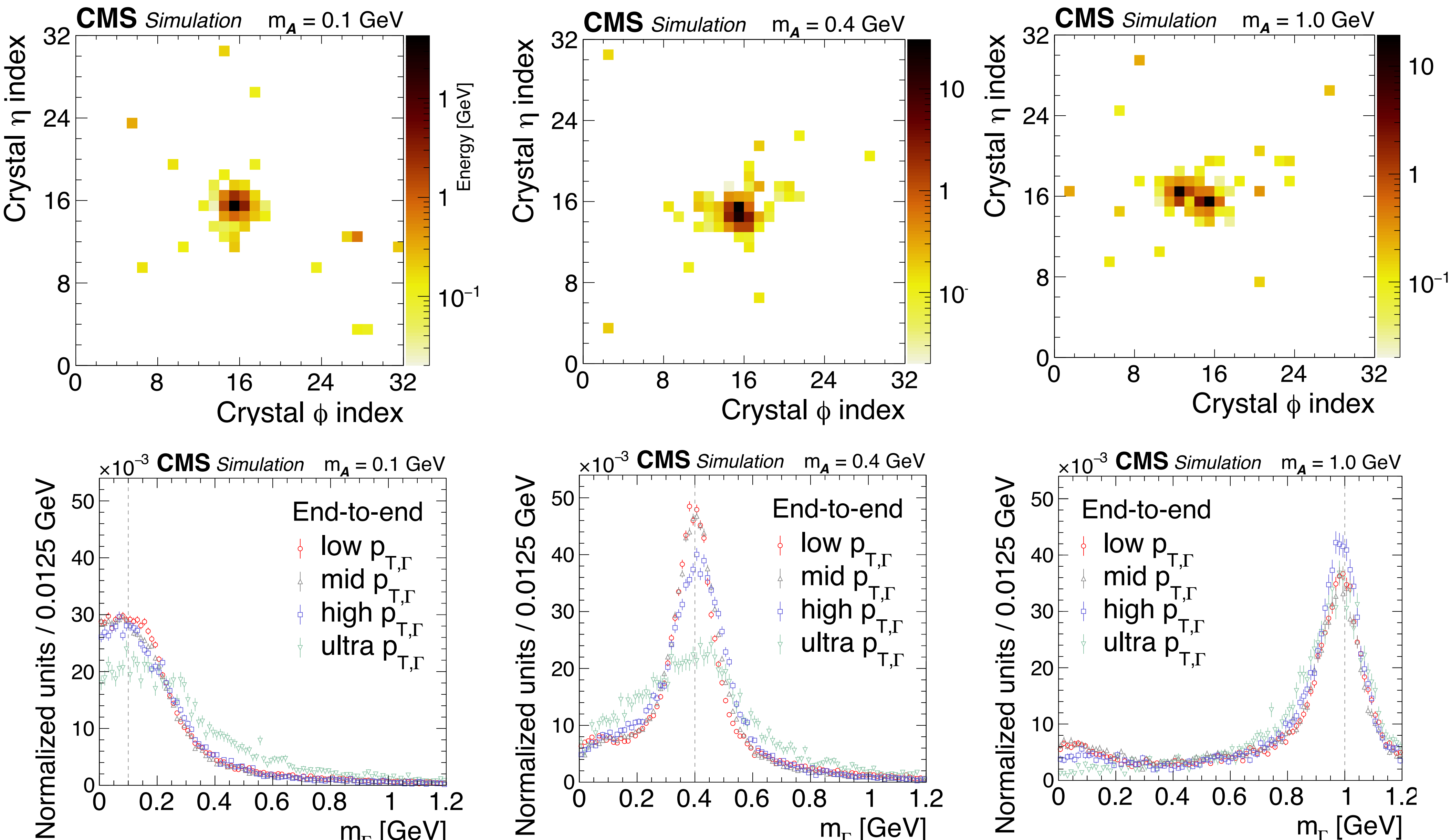
Case Study: H→aa →4γ

[Submitted to: Eur. Phys. J. C](#)
[Phys. Rev. D 108 (2023) 052002](#)



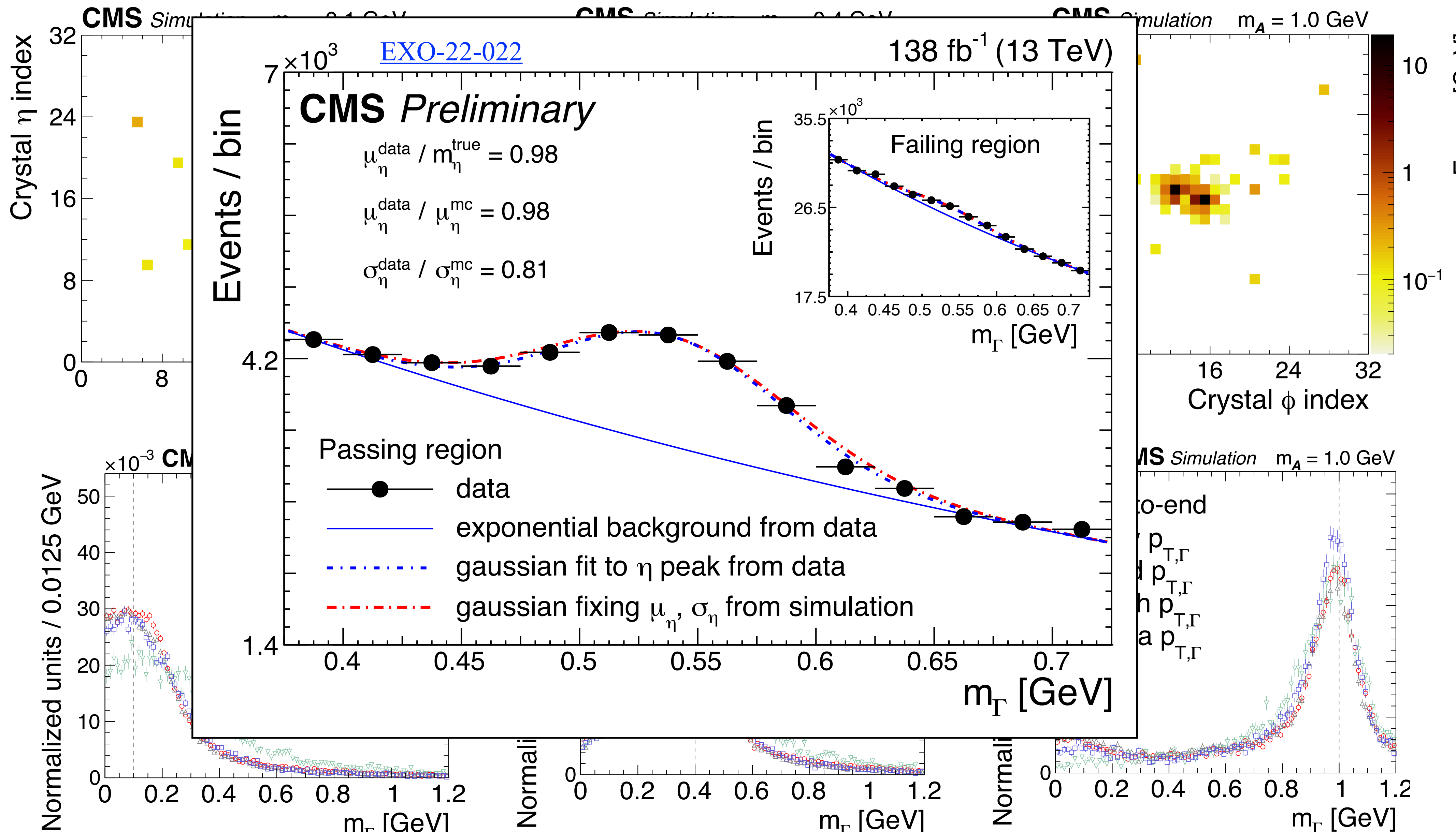
Case Study: H→aa →4γ

[Submitted to: Eur. Phys. J. C](#)
[Phys. Rev. D 108 (2023) 052002](#)



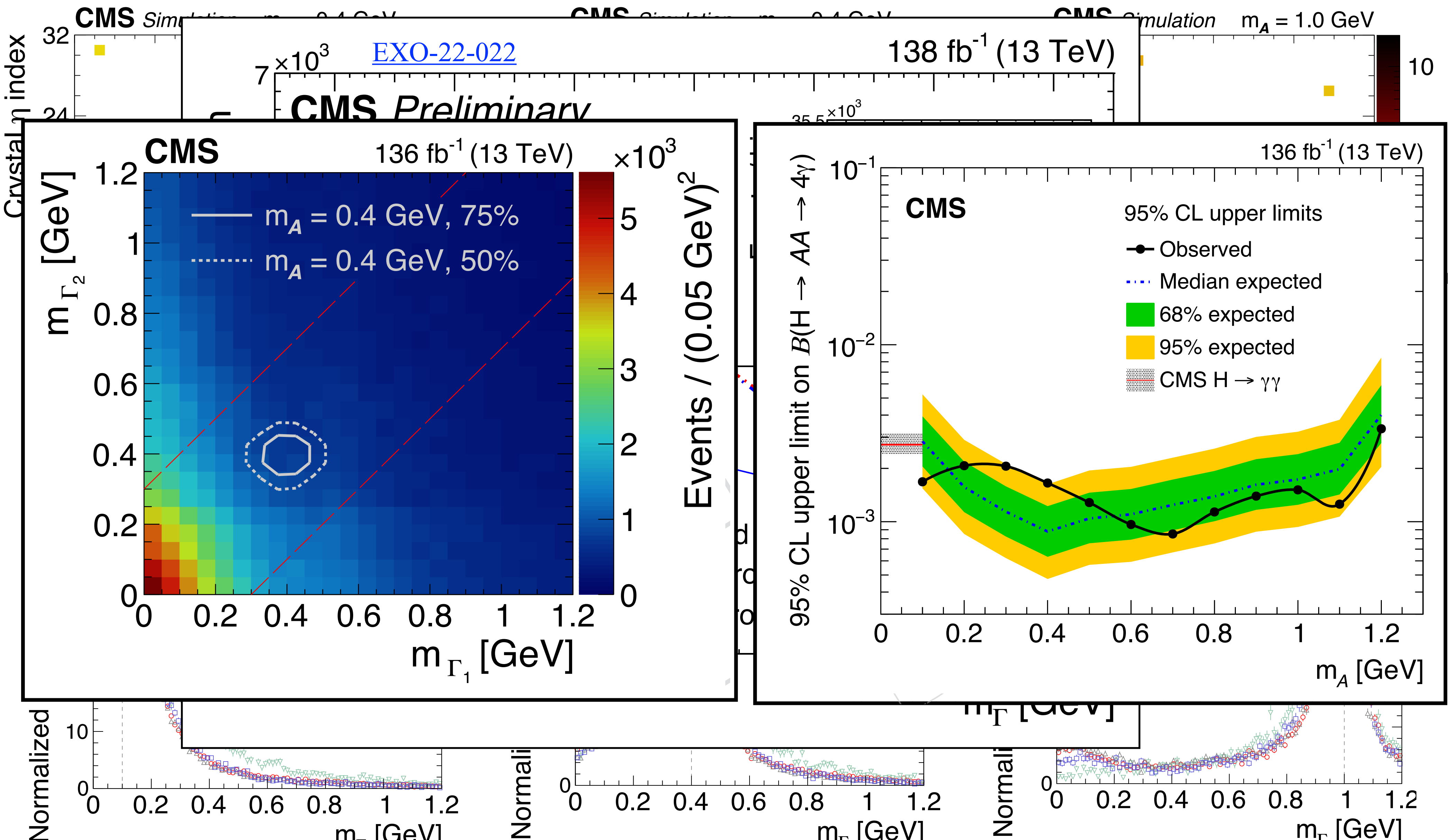
Case Study: H→aa →4γ

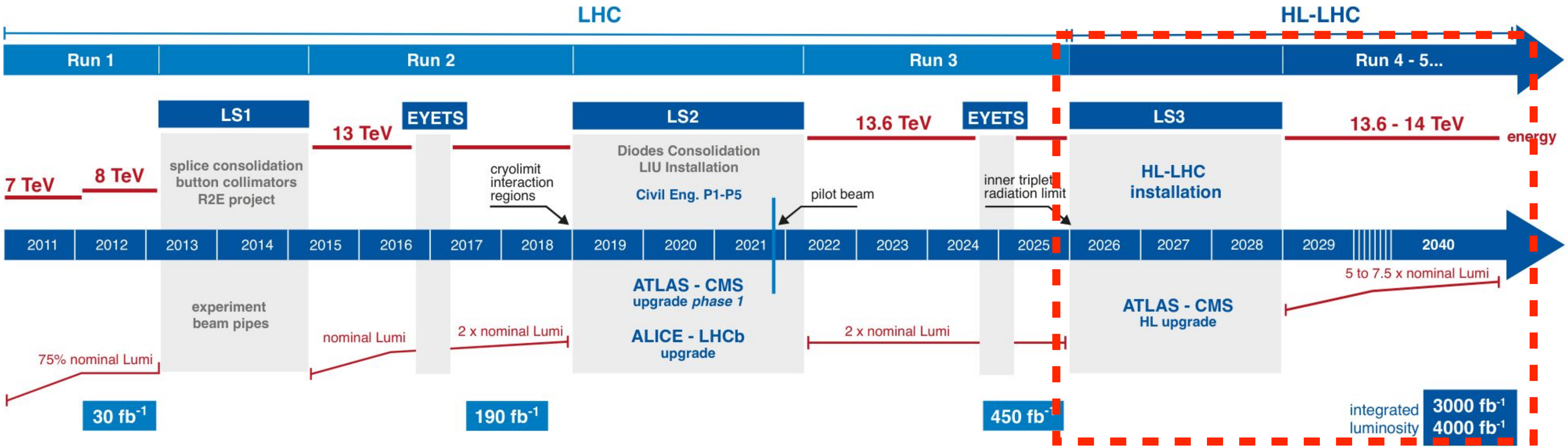
[Submitted to: Eur. Phys. J. C](#)
[Phys. Rev. D 108 (2023) 052002](#)



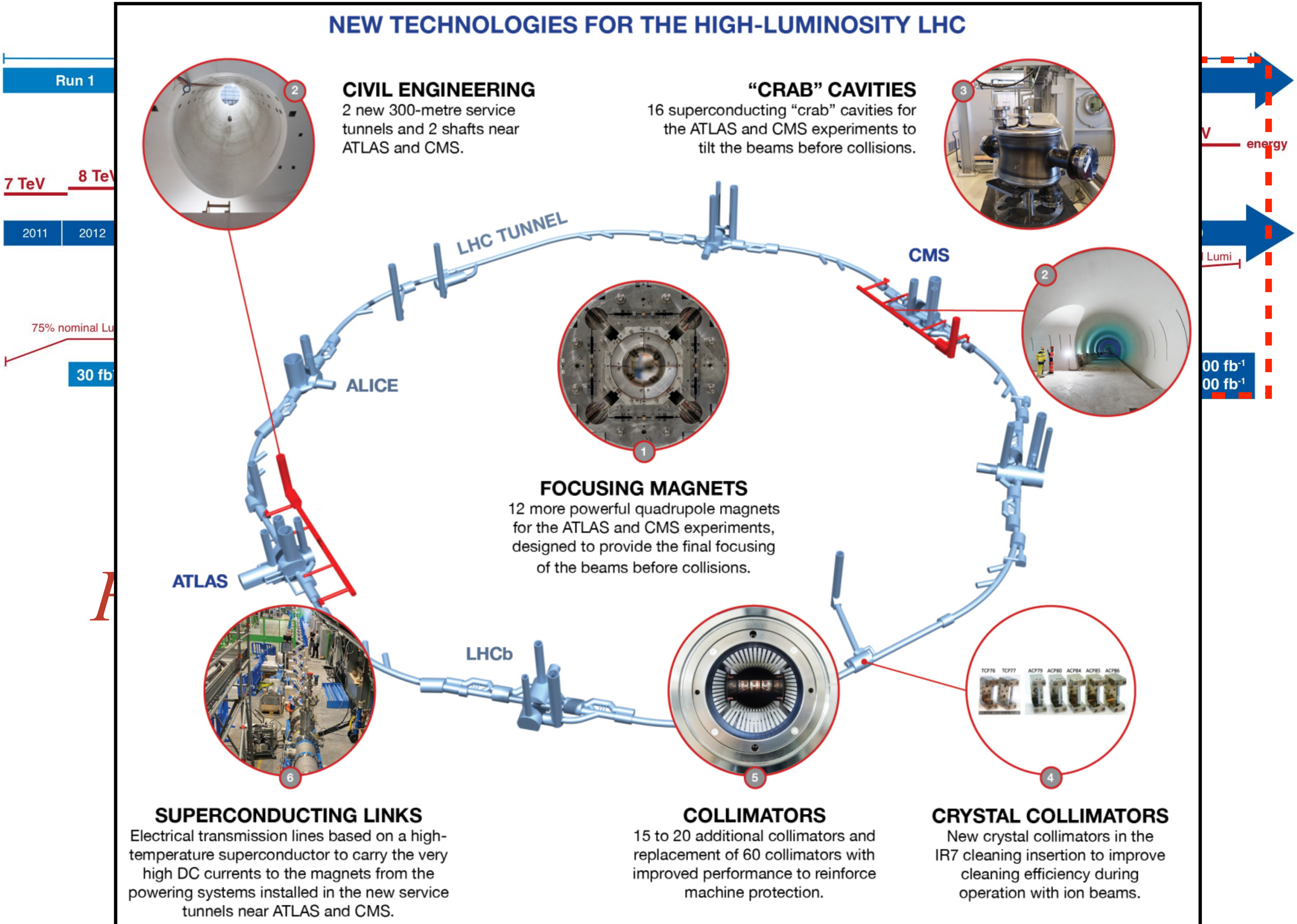
Case Study: H→aa →4γ

[Submitted to: Eur. Phys. J. C](#)
[Phys. Rev. D 108 (2023) 052002](#)

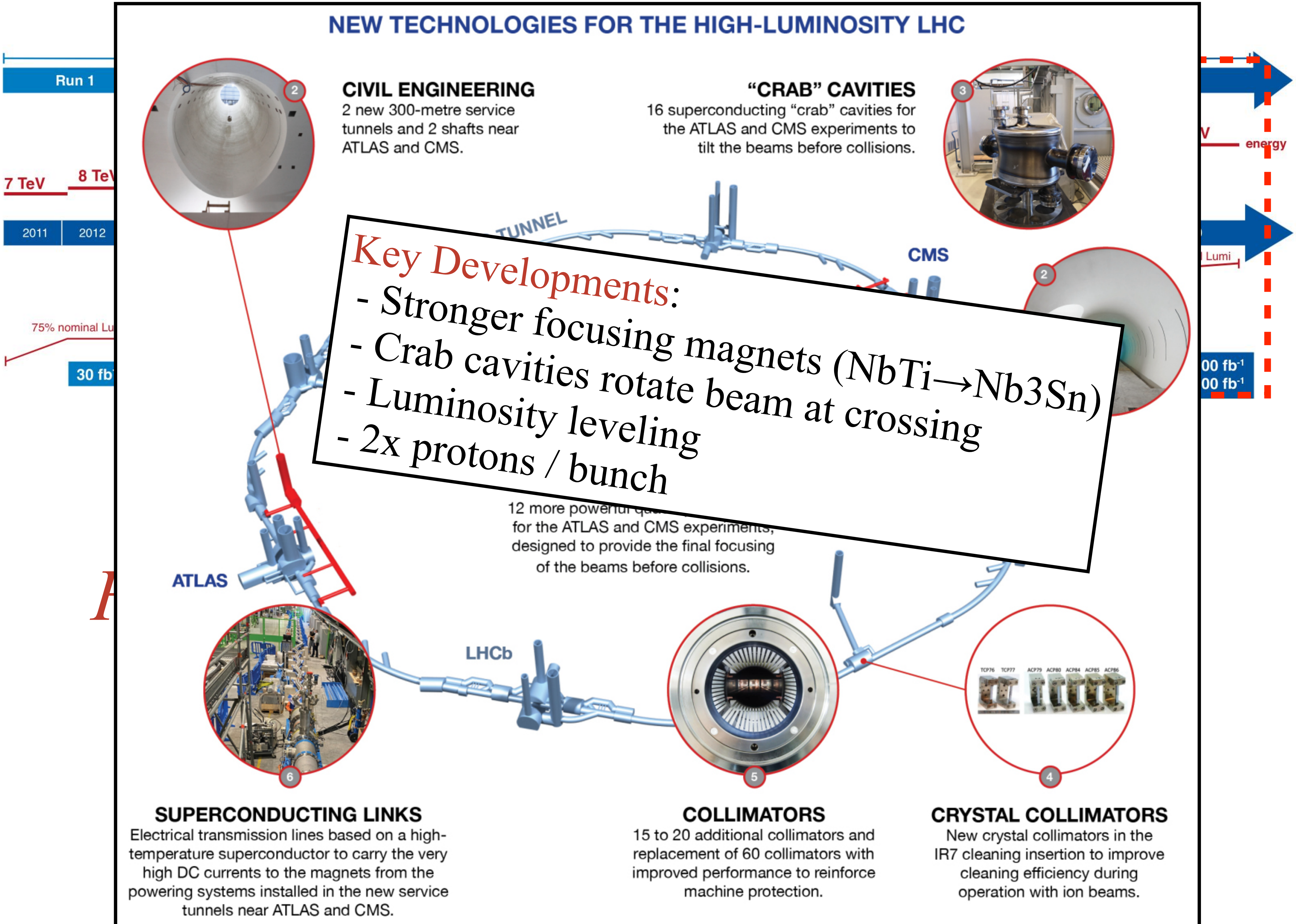




Future HL-LHC "Upgrades"



https://home.cern/science/accelerators/high-luminosity-lhc/technologies



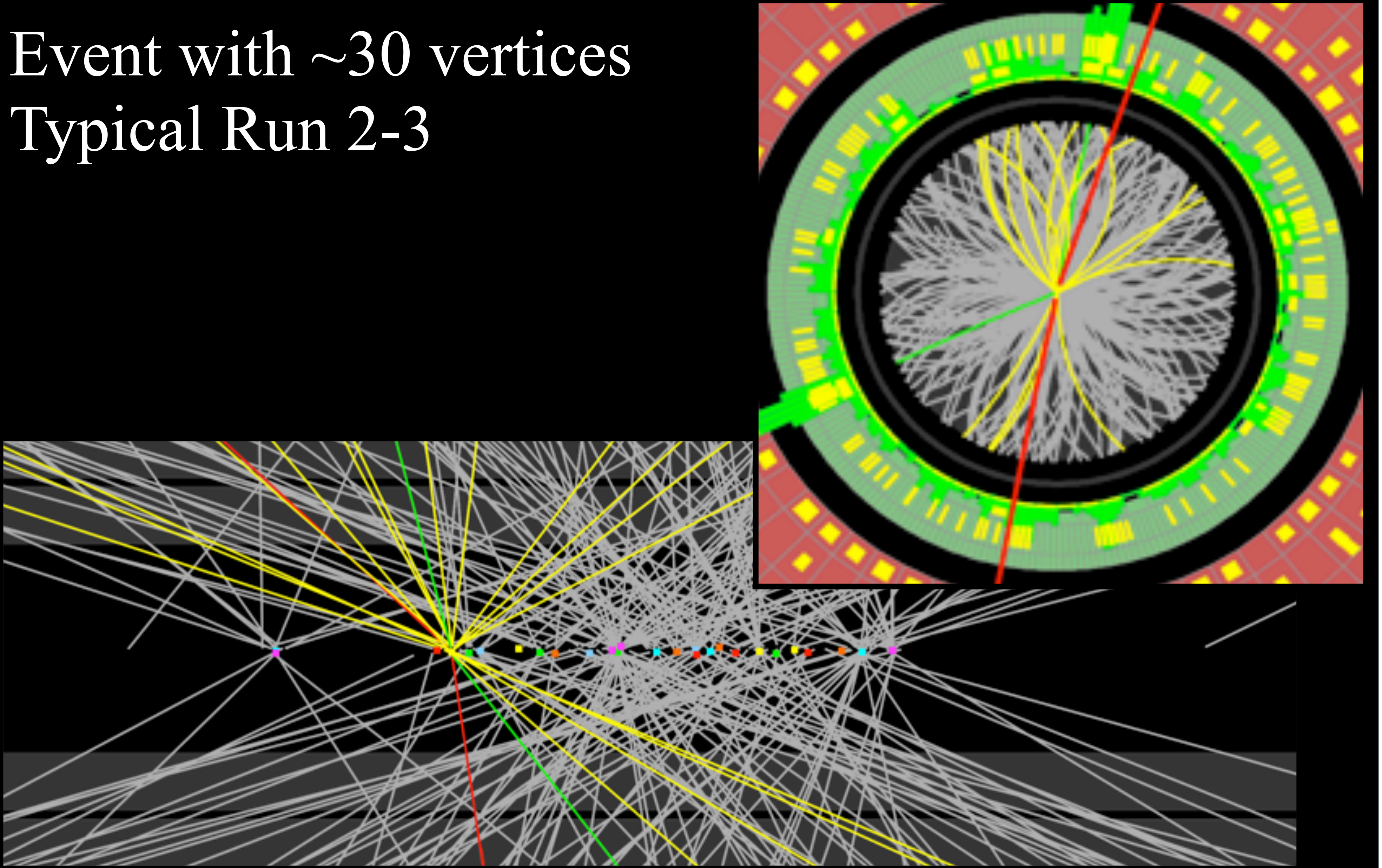
Key Developments:

- Stronger focusing magnets (NbTi→Nb3Sn)
- Crab cavities rotate beam at crossing
- Luminosity leveling
- 2x protons / bunch

https://home.cern/science/accelerators/high-luminosity-lhc/technologies

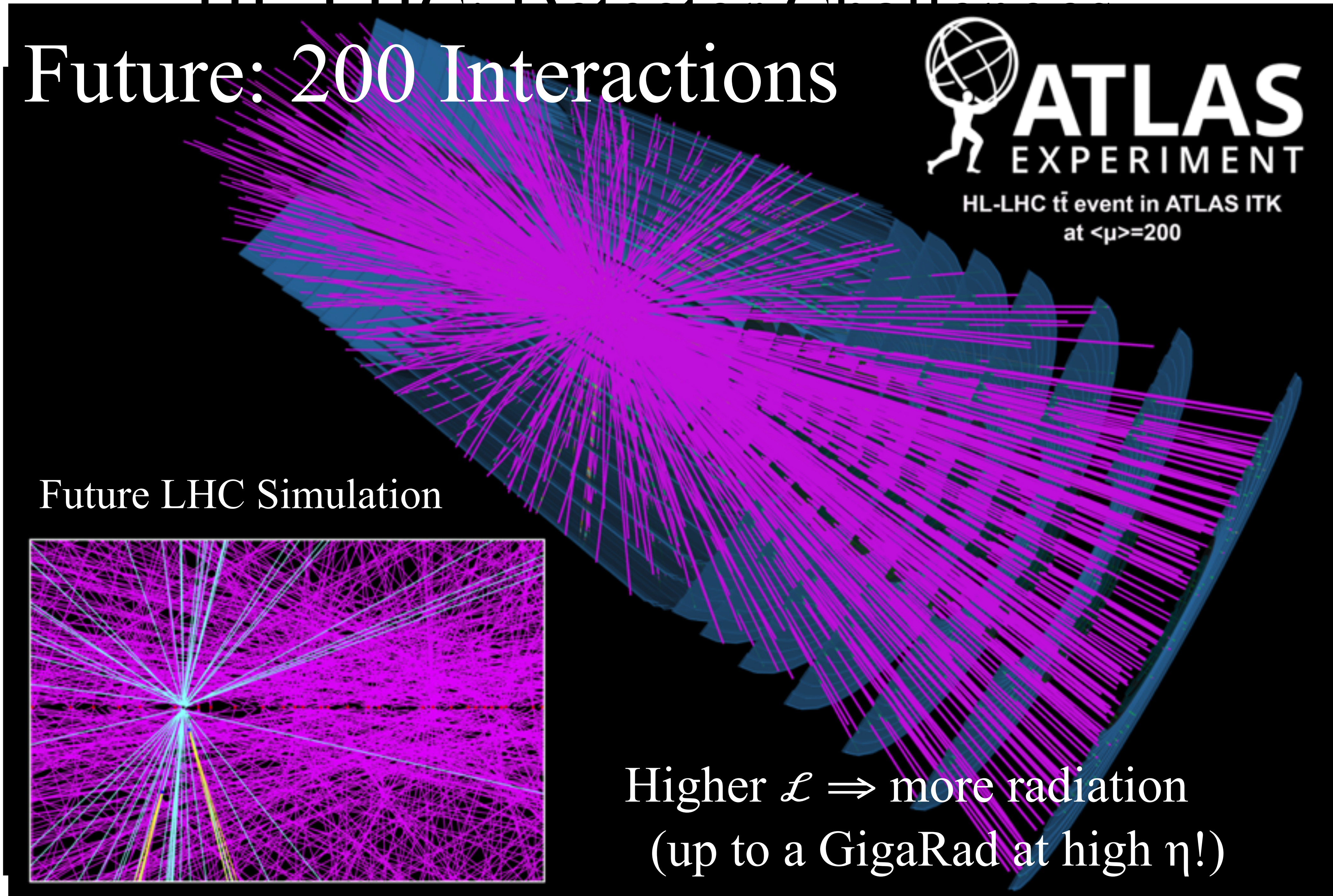
HL-LHC: Detector Challenges

Event with ~30 vertices
Typical Run 2-3



HL-LHC: Detector Challenges

Future: 200 Interactions



Future LHC Simulation

Higher $\mathcal{L} \Rightarrow$ more radiation
(up to a GigaRad at high η!)

HL-LHC "Upgrades"

ATLAS: All-silicon inner tracker
~1 MHz tracking in trigger
Endcap Timing layer (LGAD)
New Muon chambers
Electronics upgrades

CMS: All-silicon inner tracker
40 MHz tracking in trigger
High-Granularity Calorimeter Endcap
Barrel and Endcap timing layers (LYSO+SiPM / LGAD)
New Muon chambers
Electronics upgrades

HL-LHC "Upgrades"

ATLAS: All-silicon inner t
~1 MHz tracking
Endcap Timing l
New Muon char
Electronics upgr

Themes:
- More silicon (high radiation tolerance)
- Higher-granularity (fight PU)
- Precision timing (4d reco)
- Faster/Smarter triggers

Goal: Maintain/Improve current performance

CMS: All-silicon inner tracker
40 MHz tracking in trigger
High-Granularity Calorimeter Endcap
Barrel and Endcap timing layers (LYSO+SiPM / LGAD)
New Muon chambers
Electronics upgrades

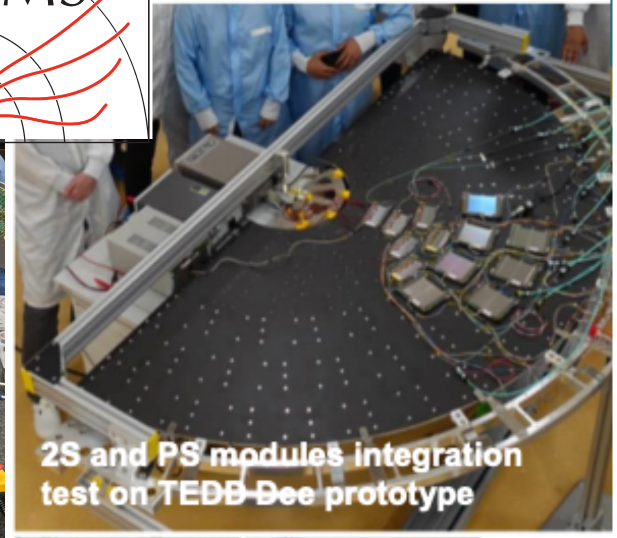
Upgrade Status

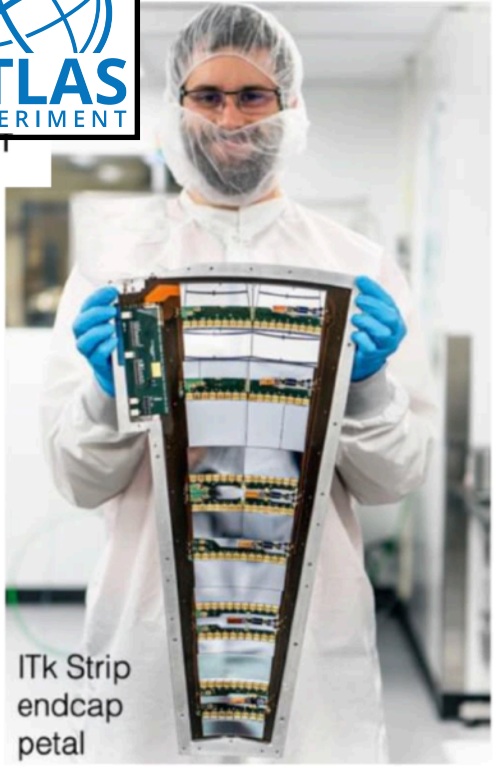
ATLAS & CMS upgrades making good progress

Transitioning to pre-production

Schedule extremely tight !

Highest priority of experiments and CERN



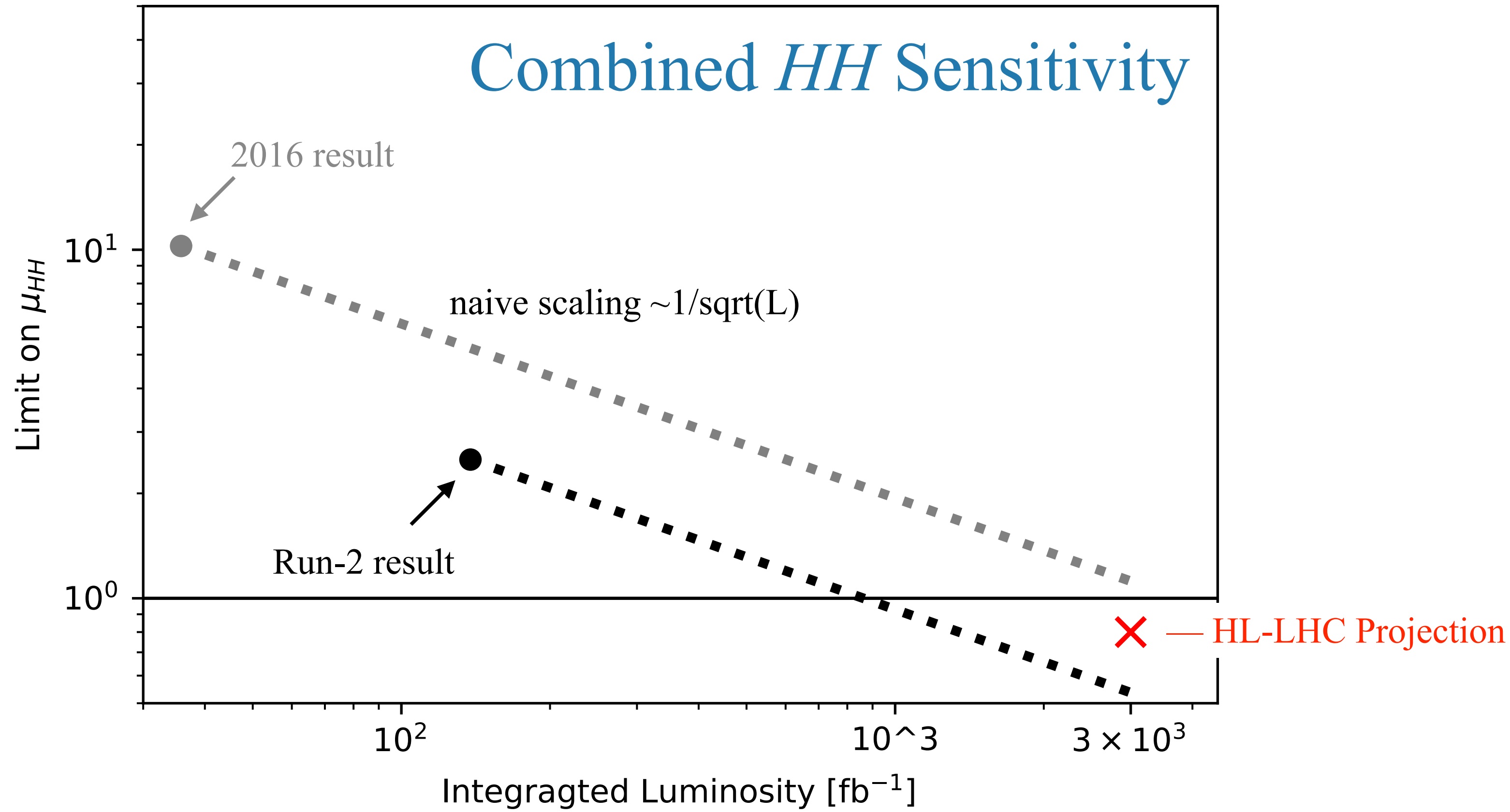


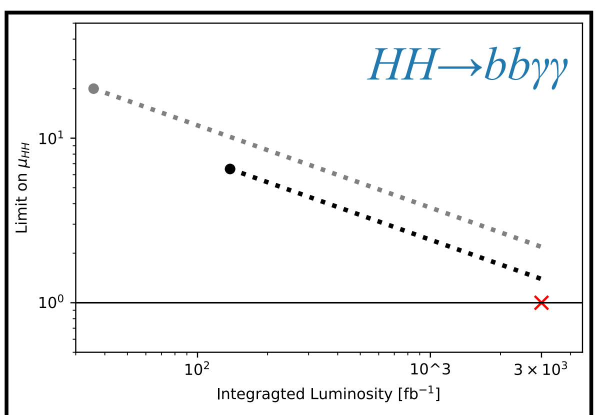
AT

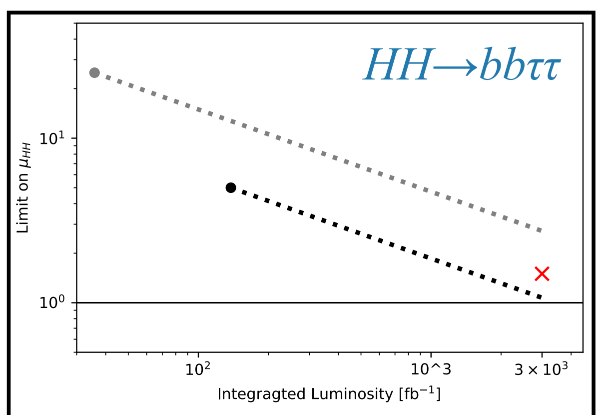
Sc

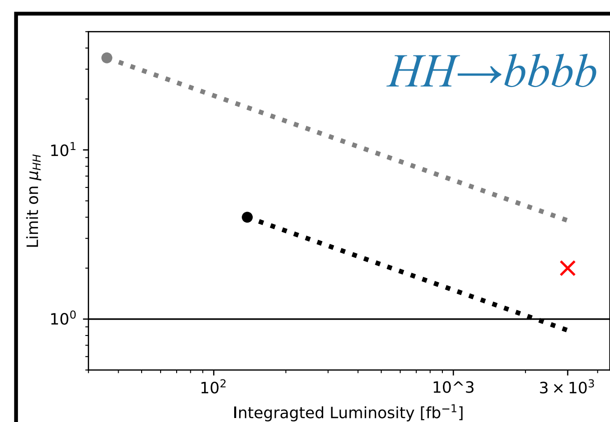
Hi

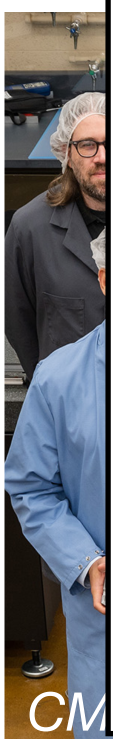
Nature **607**, 60–68 (2022).











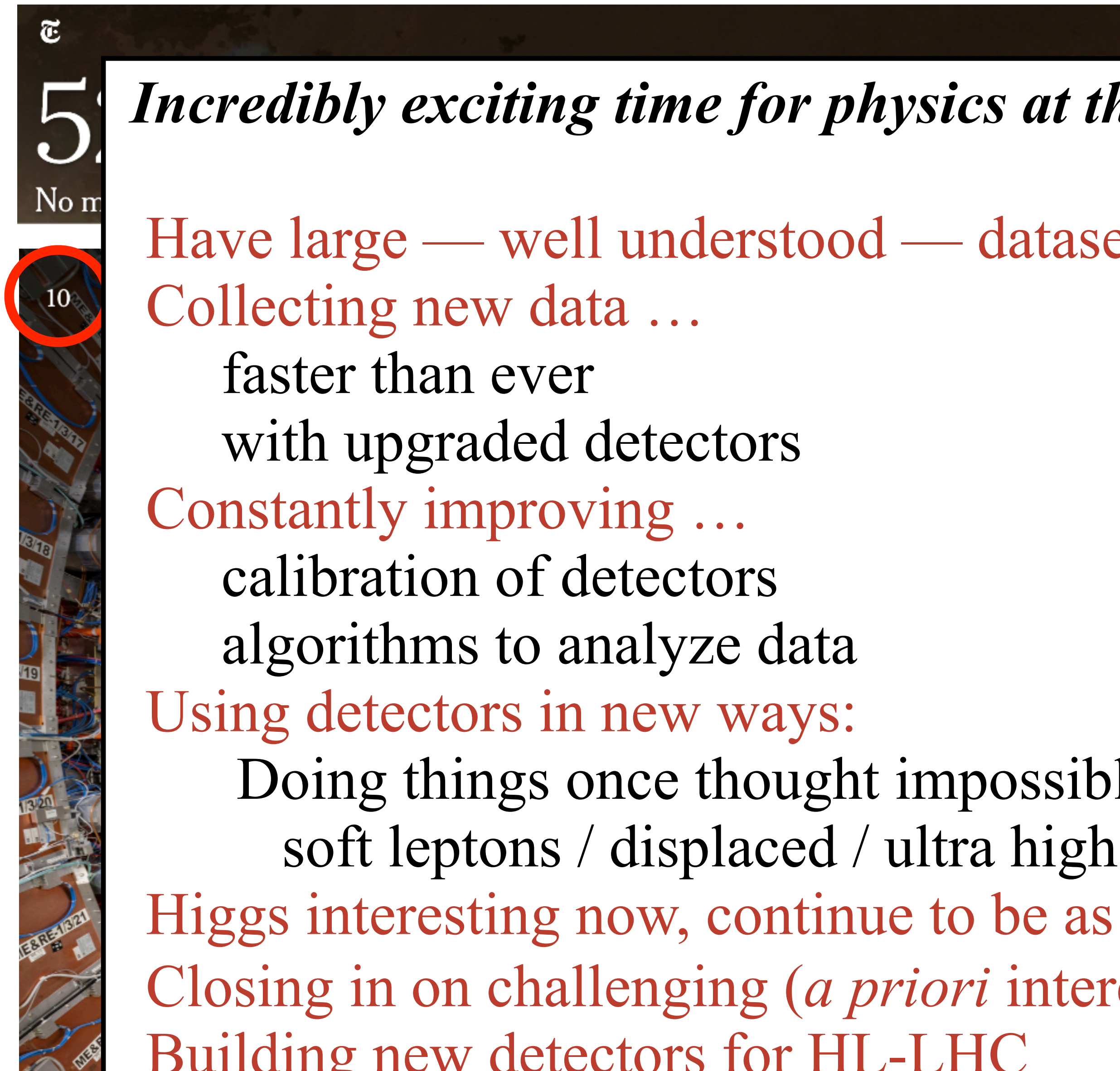
LHC
rogram

ersity

“Isn’t this a boring time for LHC physics ?”

- You already found the Higgs,
- ΔEcm only 0.6 TeV,
- Not yet the HL-LHC,
- …

Conclusions



Incredibly exciting time for physics at the LHC !

Have large — well understood — datasets in hand

Collecting new data …

- faster than ever
- with upgraded detectors

Constantly improving …

- calibration of detectors
- algorithms to analyze data

Using detectors in new ways:

- Doing things once thought impossible
  - soft leptons / displaced / ultra high-precision

Higgs interesting now, continue to be as $\mathcal{L}$ grows

Closing in on challenging (*a priori* interesting) phase space

Building new detectors for HL-LHC

Back-up