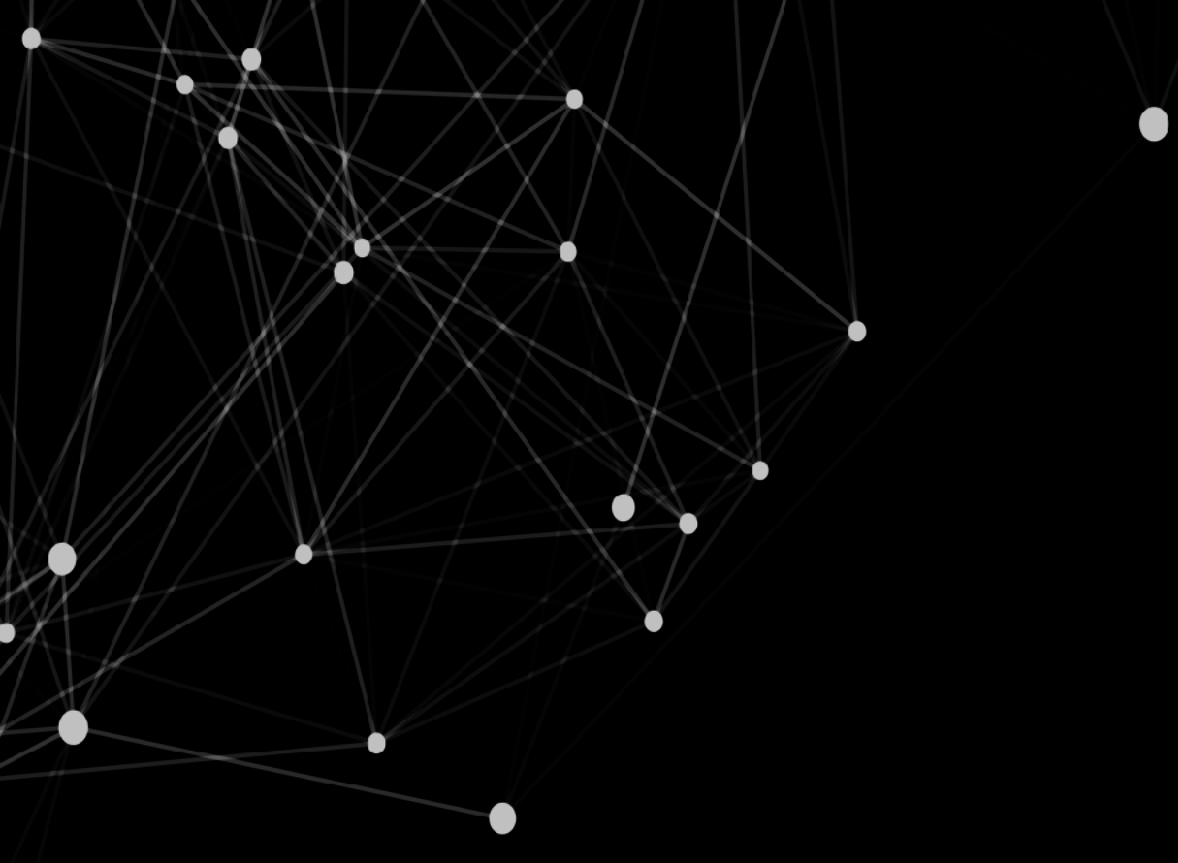


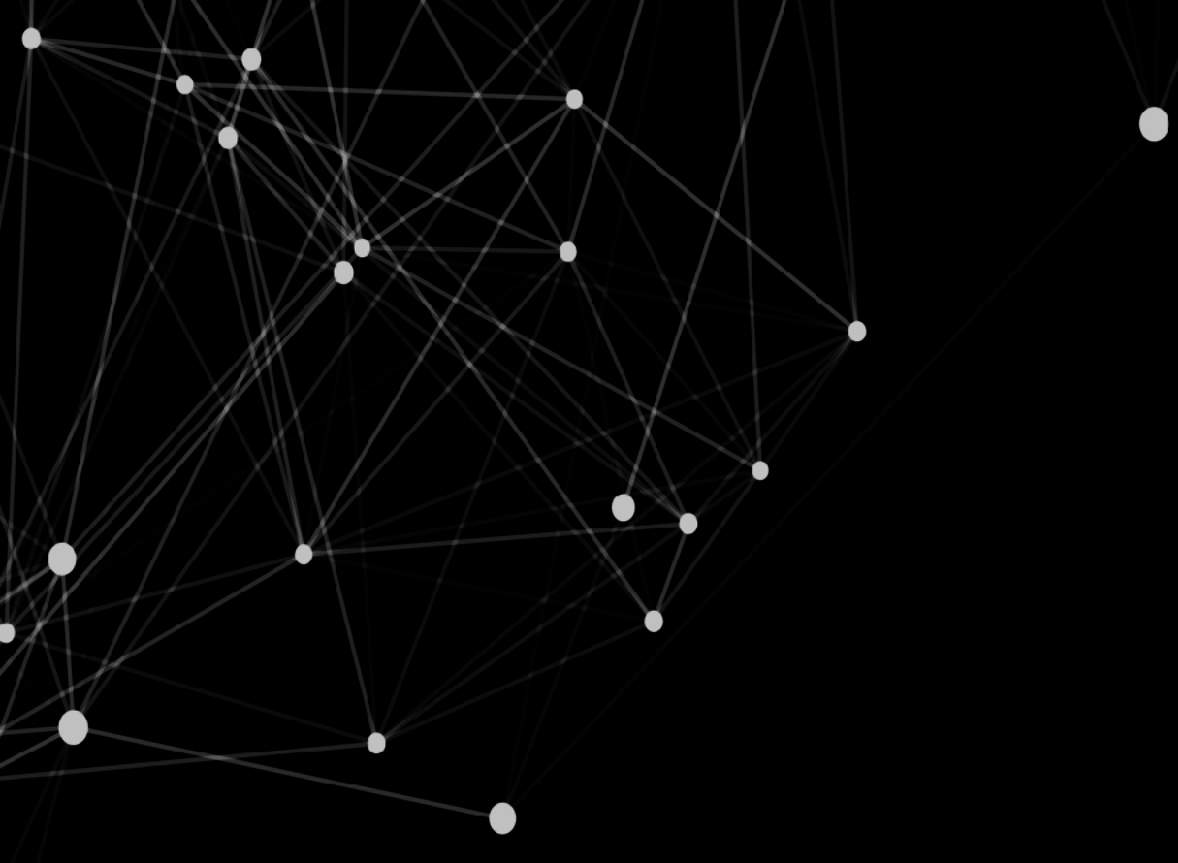
# Conquering Large Numbers at the LHC

Breaking down 14 Orders of Magnitude



We are doing data analysis as part of the ATLAS collaboration at the LHC at CERN.





We are doing data analysis as part of the ATLAS collaboration **at the LHC at CERN.**



# Why particle collisions?

$$E = mc^2$$

Kinetic energy  $\Rightarrow$  mass of new particles

A decorative graphic on the left side of the slide, consisting of a network of white dots connected by thin white lines, resembling a molecular structure or a data network. The dots are of varying sizes and are scattered across the left edge, with some lines extending towards the center.

# Ingredients for Studying Collisions

1. Protons with a lot of energy
2. A place where the protons collide
3. A huge detector to snapshot the collisions
4. Tools and infrastructure to analyse the collision data

# Accelerating the protons

[Source: CERN-VIDEO-2013-041-001]



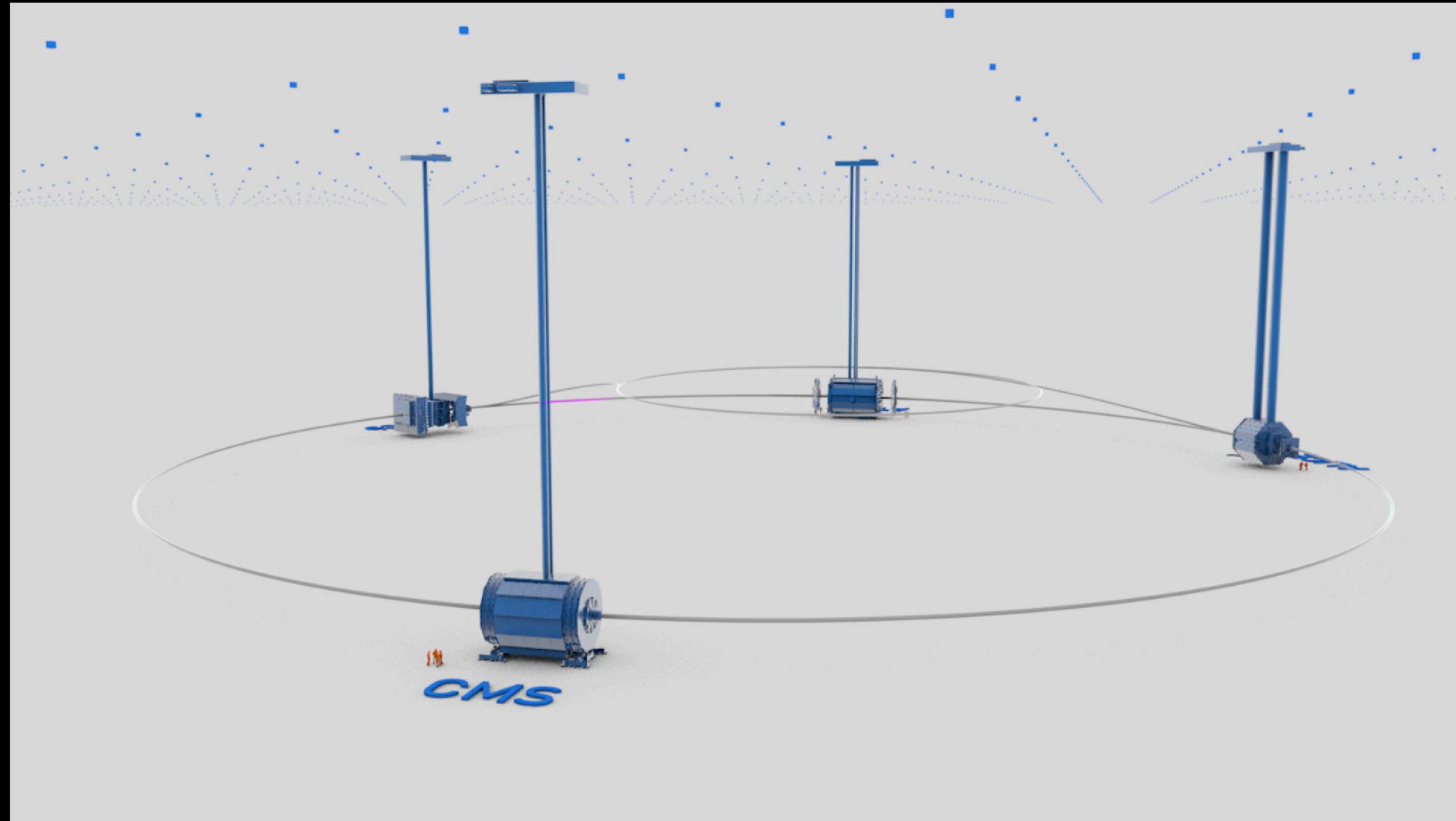
# Accelerating the protons

[Source: CERN-VIDEO-2013-041-001]



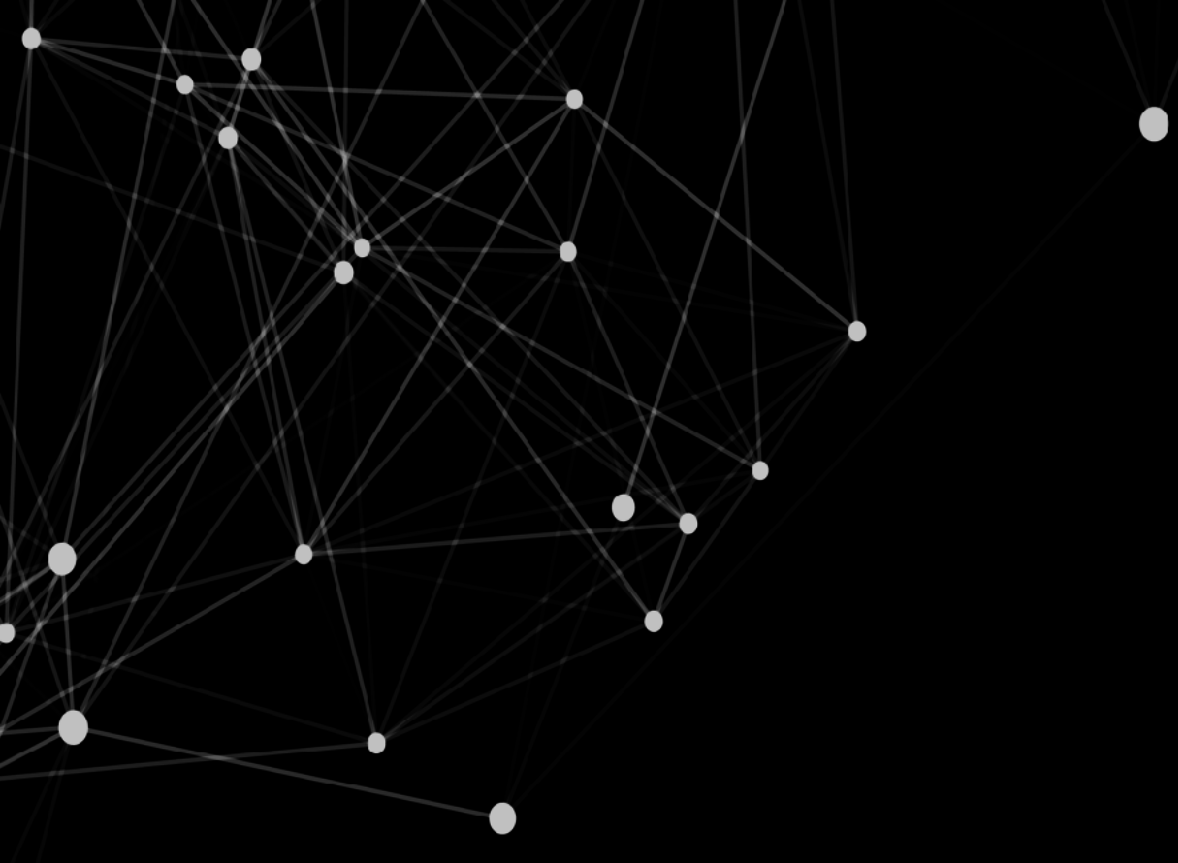
# The Large Hadron Collider

[Source: CERN-VIDEO-2013-041-001]



Four main experiments: ALICE, LHCb, CMS, ATLAS

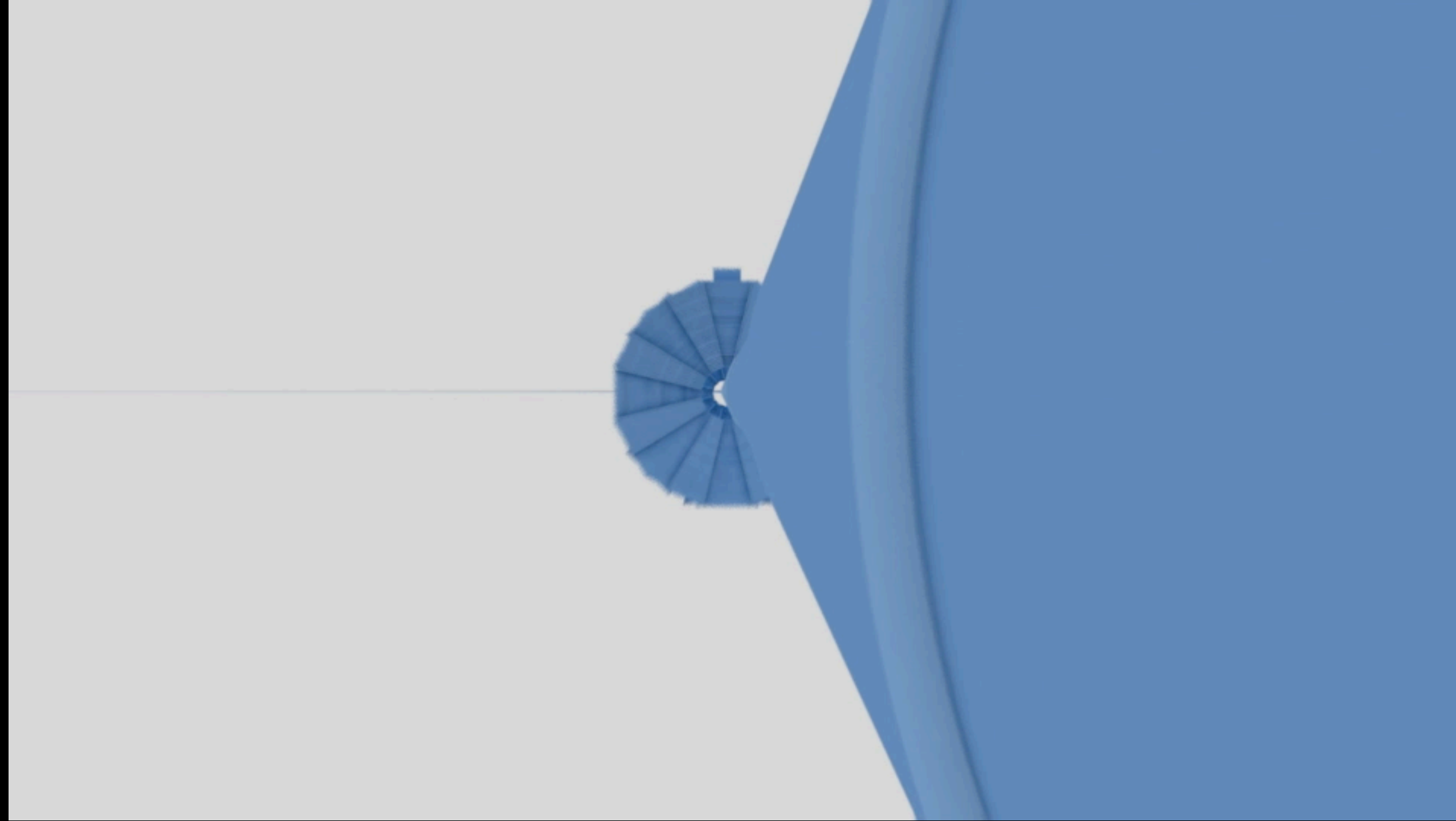




We are doing data analysis as part of **the ATLAS collaboration** at the LHC at CERN.

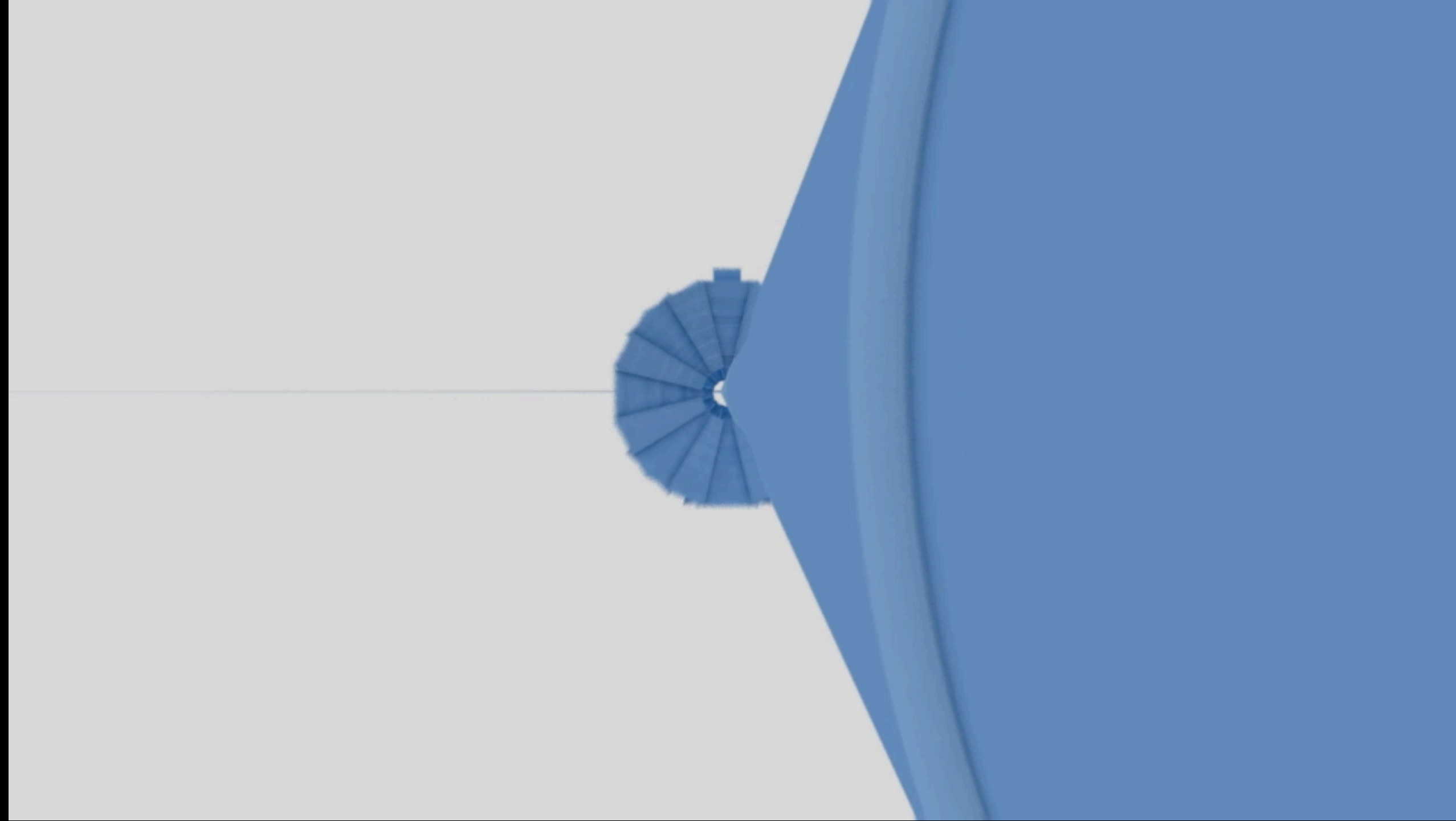
# Collisions in ATLAS

[Source: CERN-VIDEO-2013-041-001]



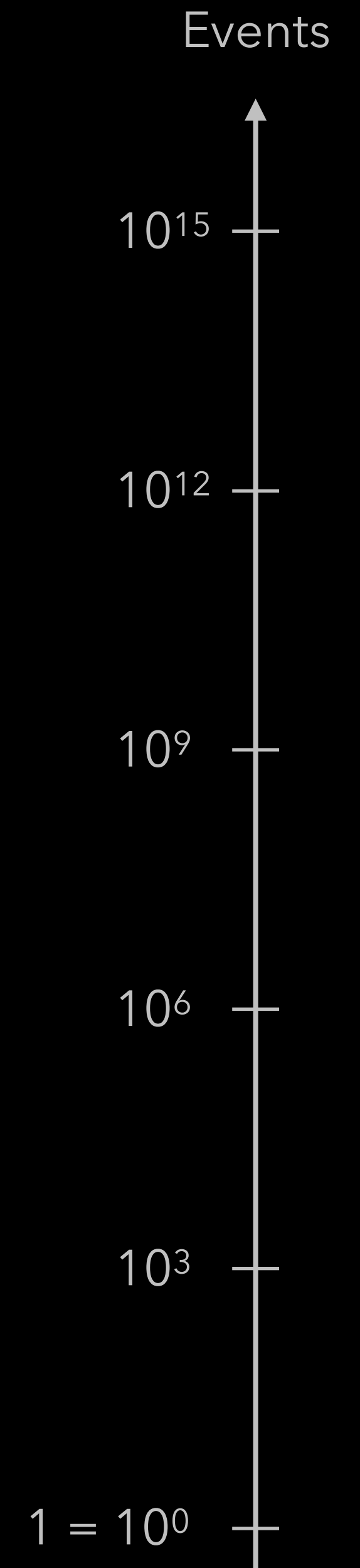
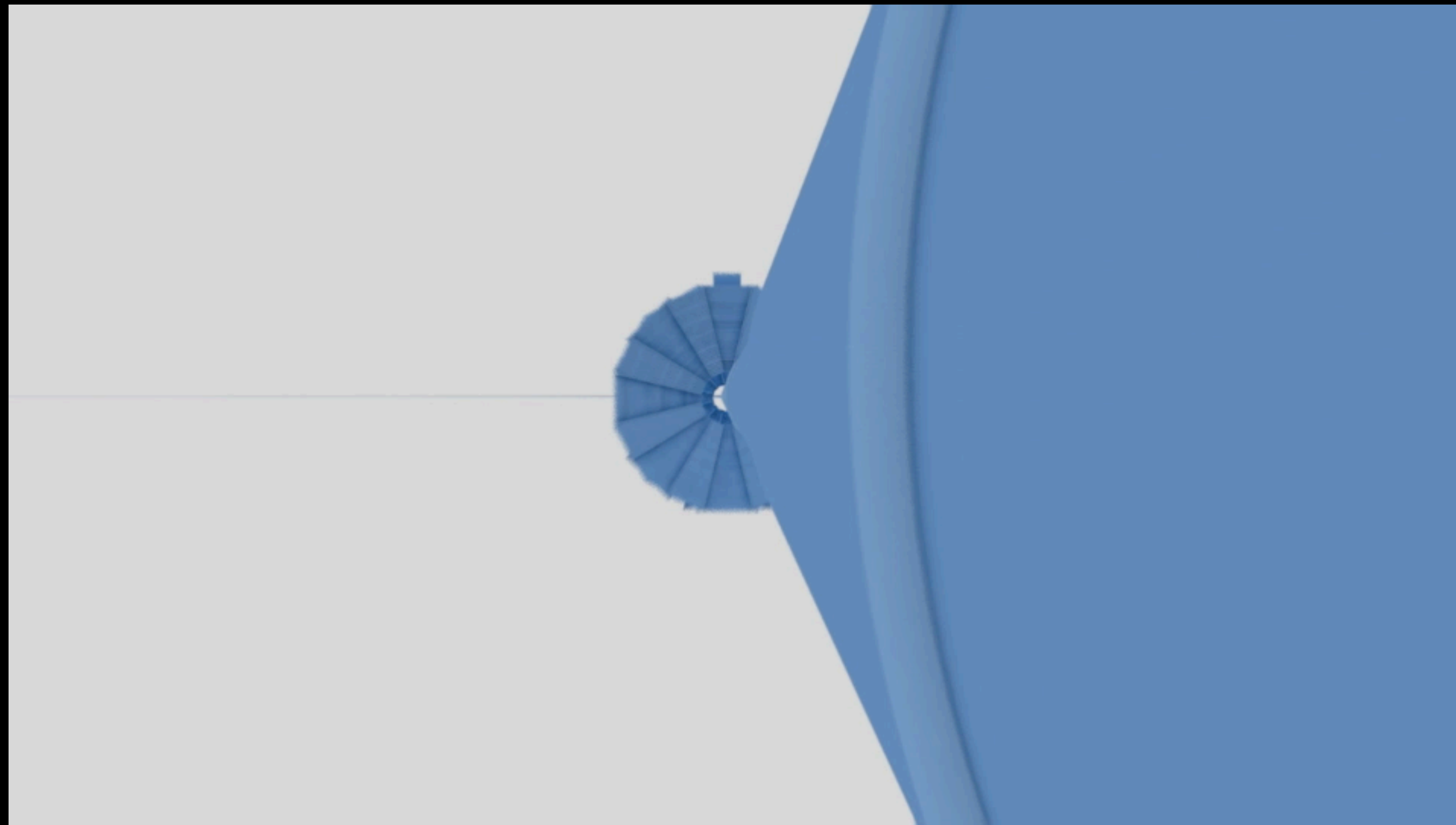
# Collisions in ATLAS

[Source: CERN-VIDEO-2013-041-001]



# Collisions in ATLAS

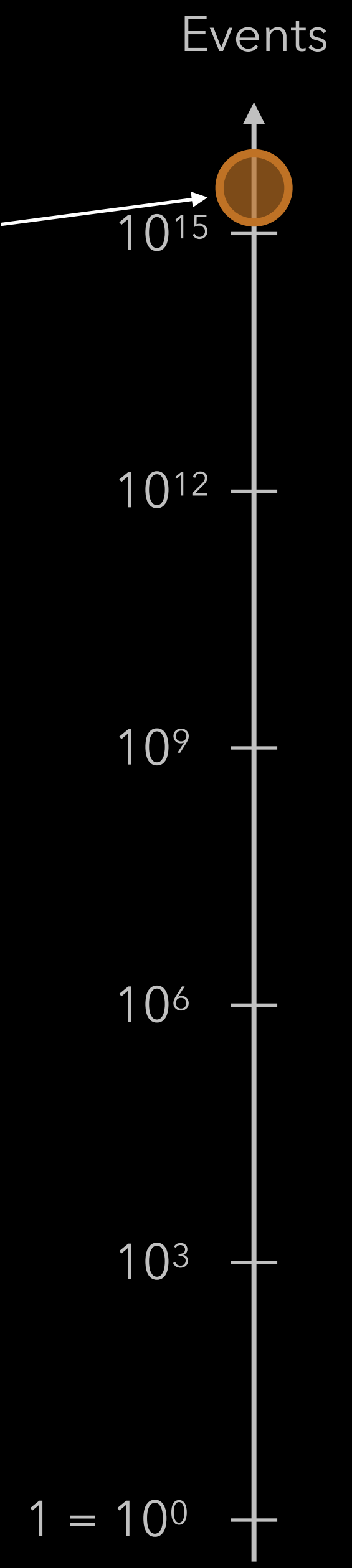
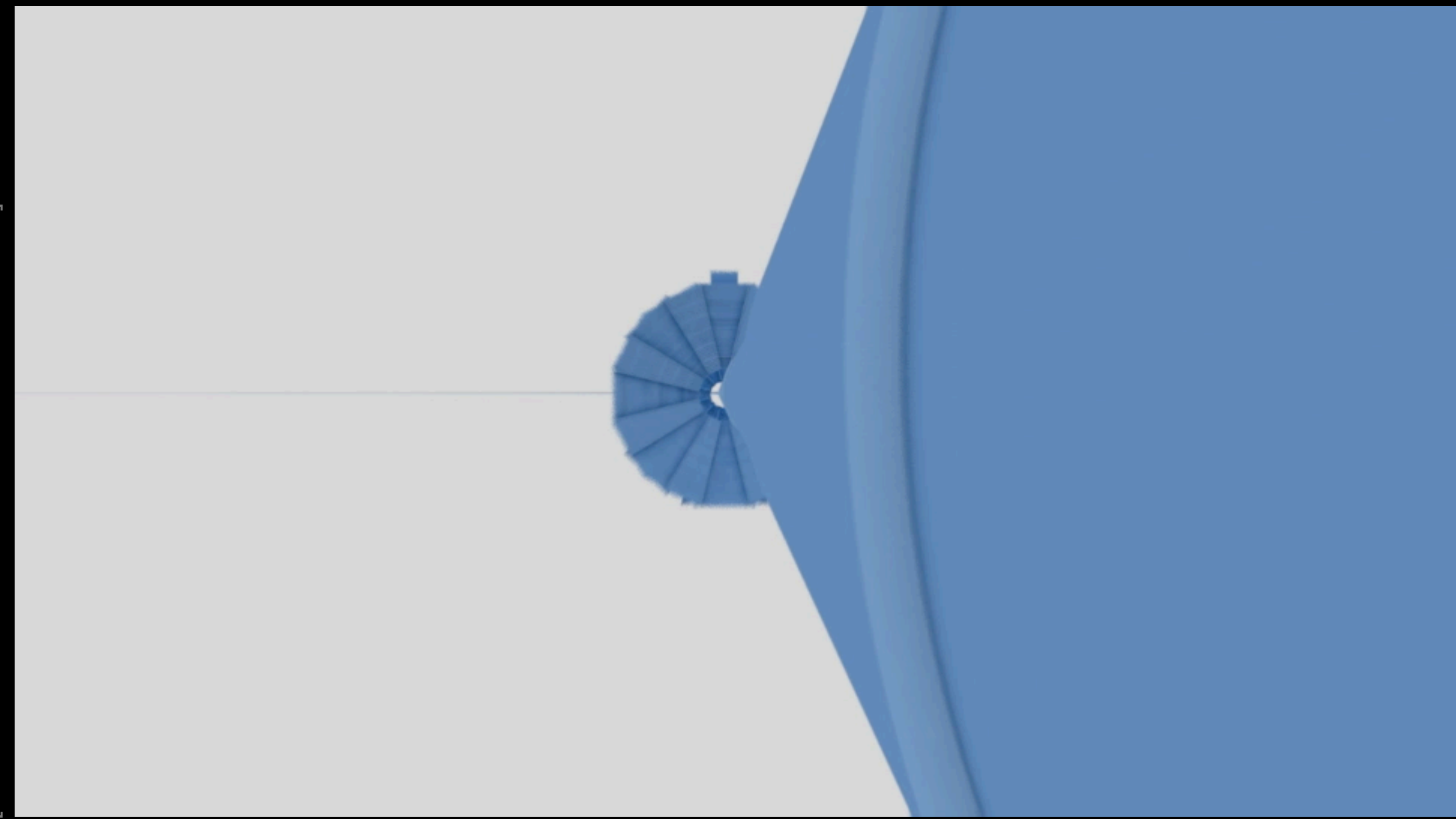
[Source: CERN-VIDEO-2013-041-001]



- now: 1 billion proton proton collisions per second

# Collisions in ATLAS

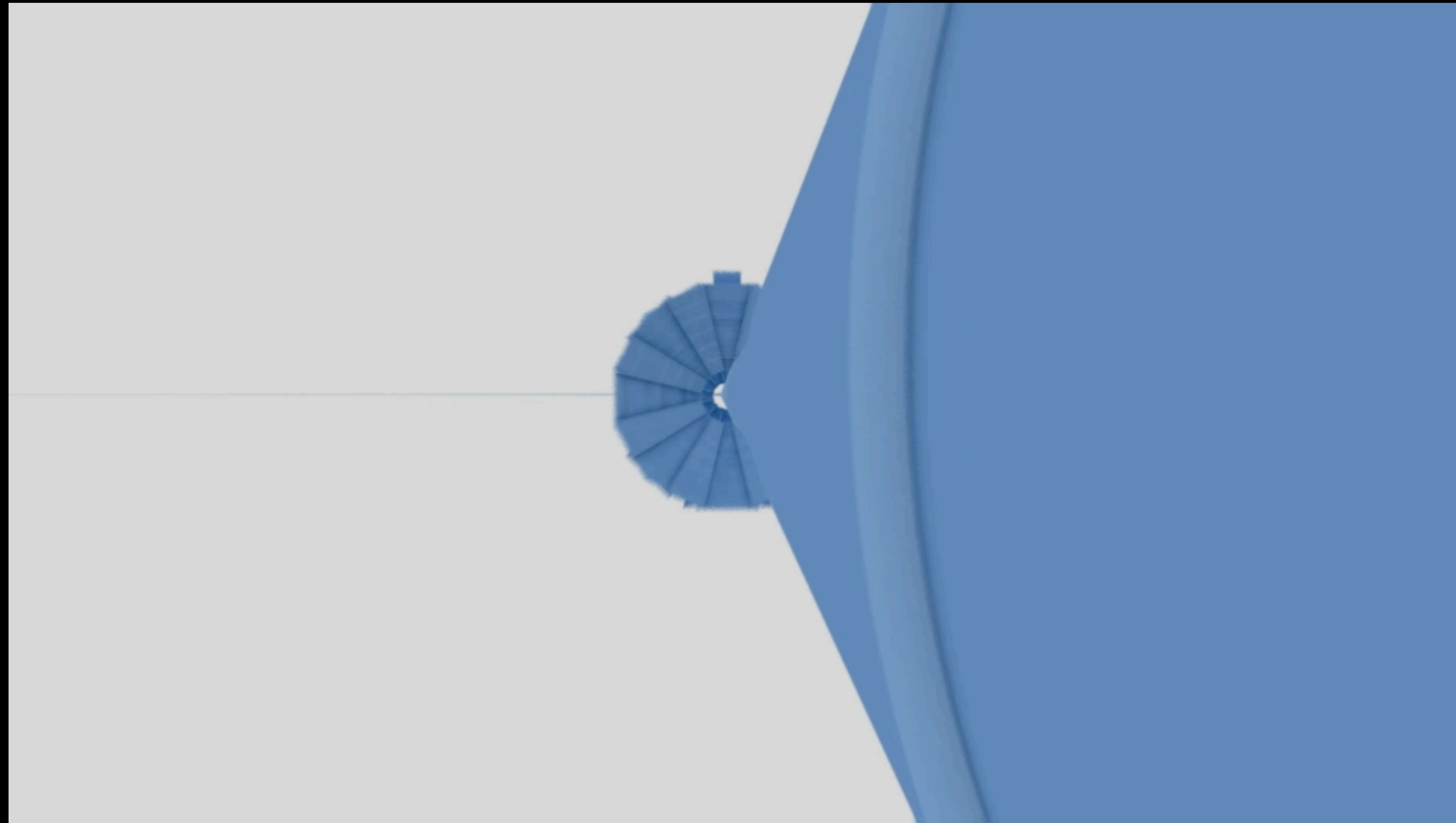
2 500 000 000 000 000 pp collisions



- now: 1 billion proton proton collisions per second

# Collisions in ATLAS

[Source: CERN-VIDEO-2013-041-001]



Events

$10^{15}$

$10^{12}$

$10^9$

$10^6$

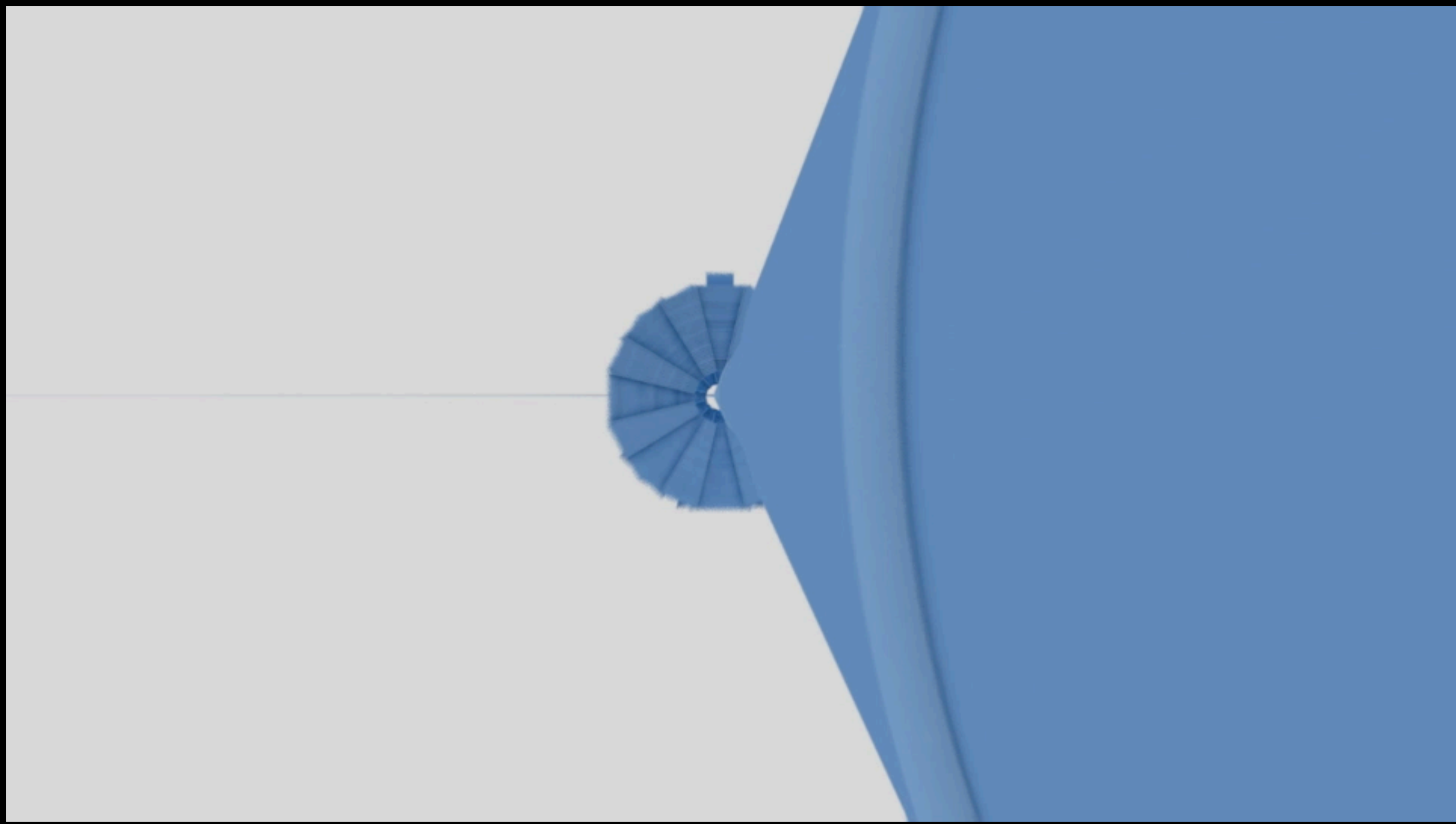
$10^3$

$1 = 10^0$

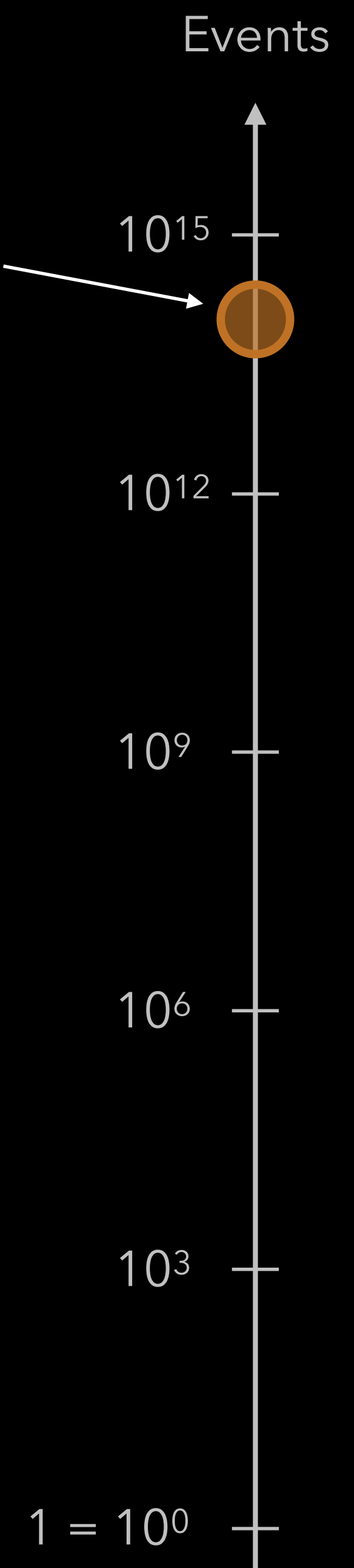
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# Collisions in ATLAS

[Source: CERN-VIDEO-2013-041-001]



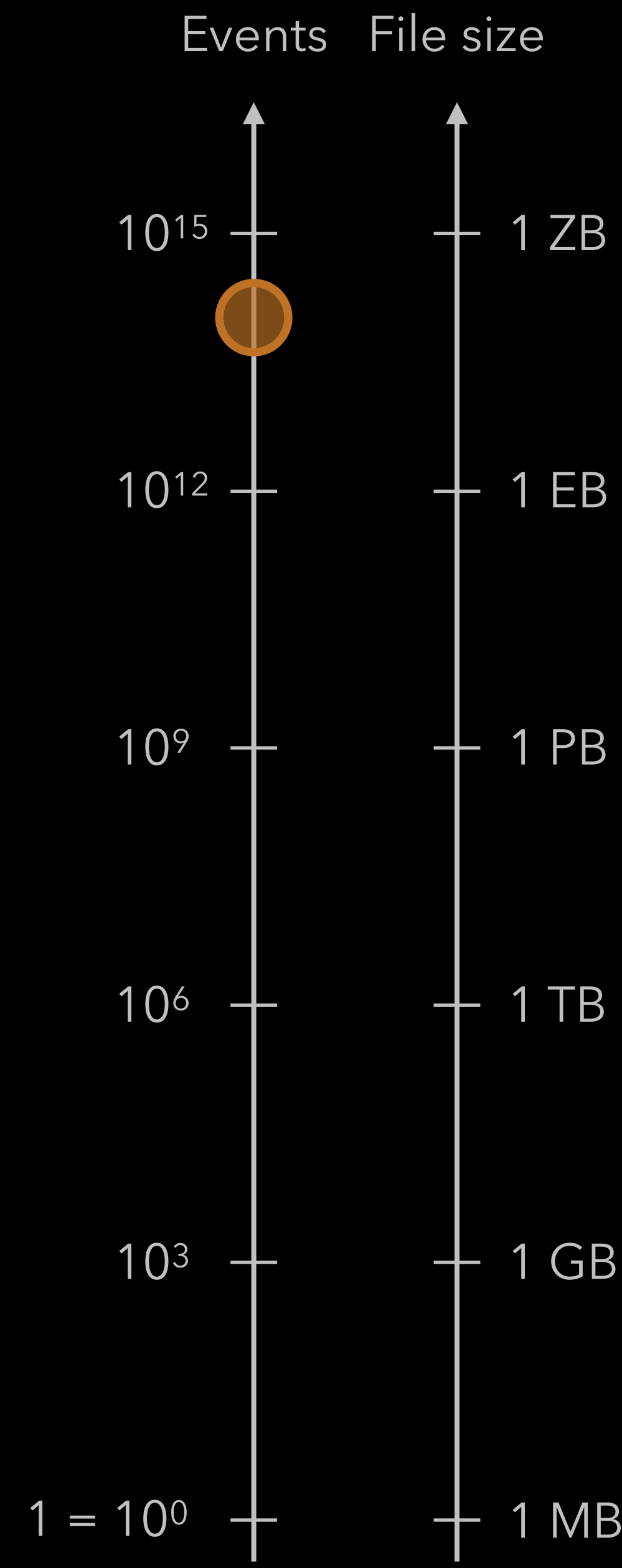
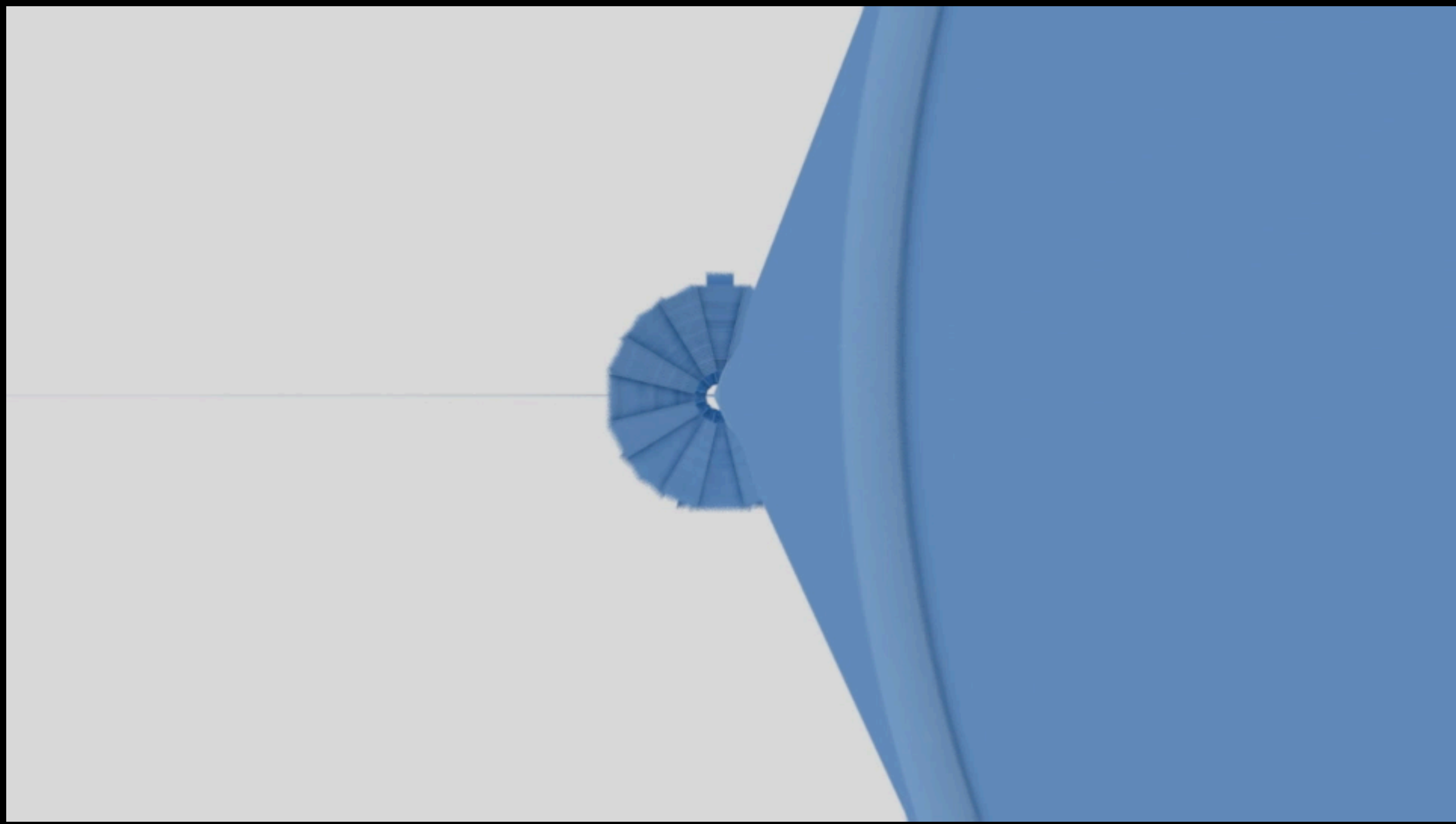
100 000 000 000 000 events



- now: 1 billion proton proton collisions per second

# Collisions in ATLAS

[Source: CERN-VIDEO-2013-041-001]

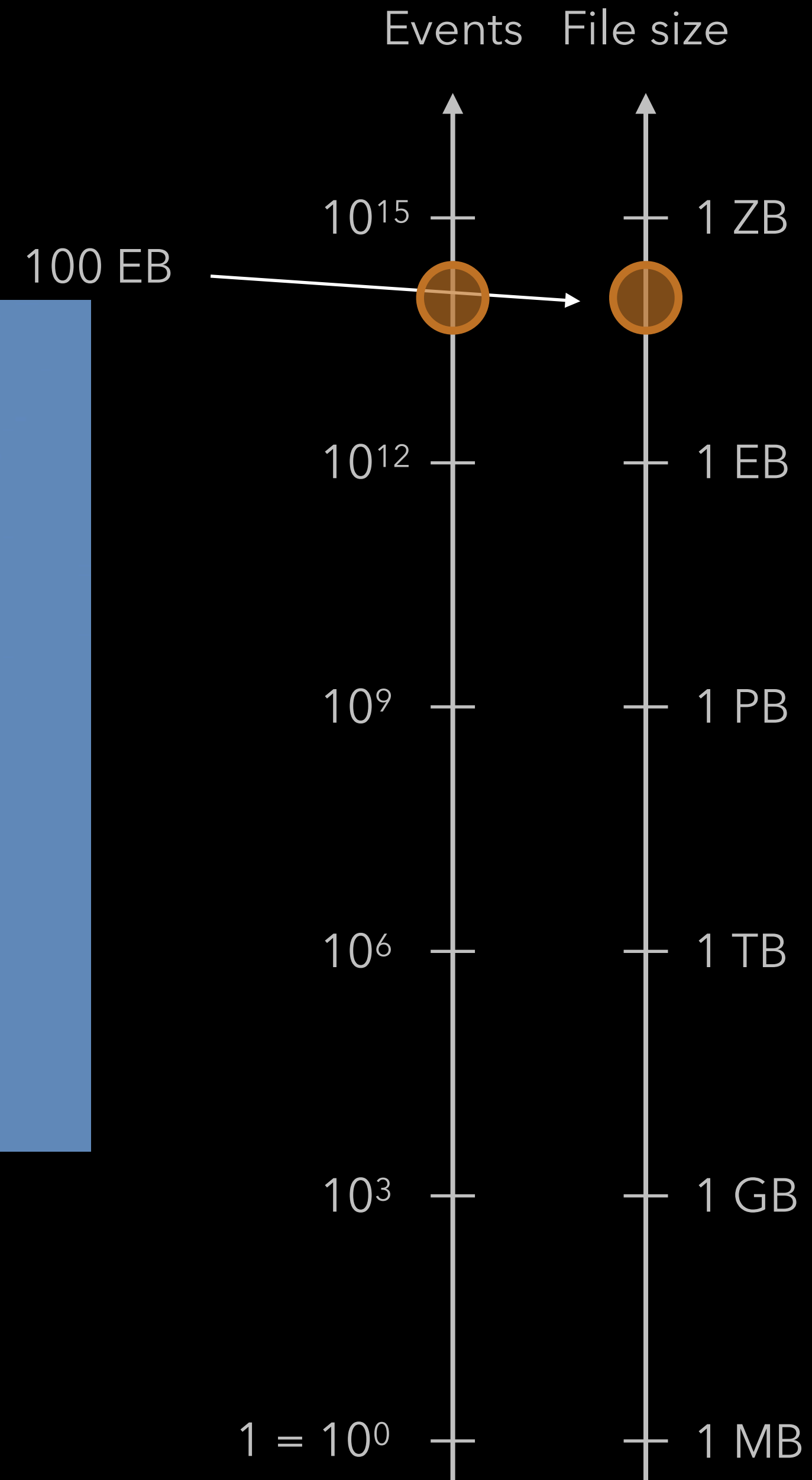
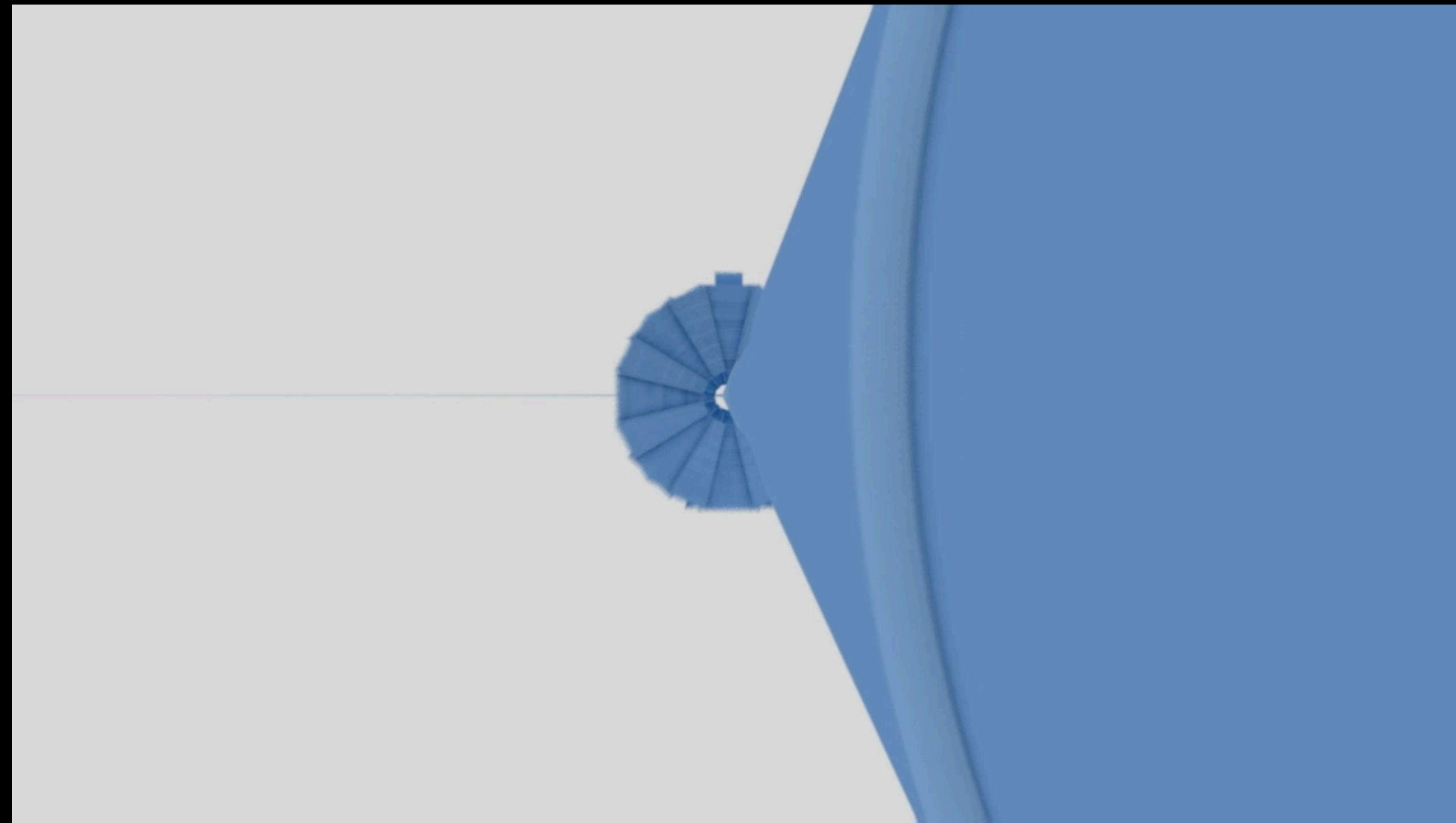


- now: 1 billion proton proton collisions per second
- roughly 1 MB / event



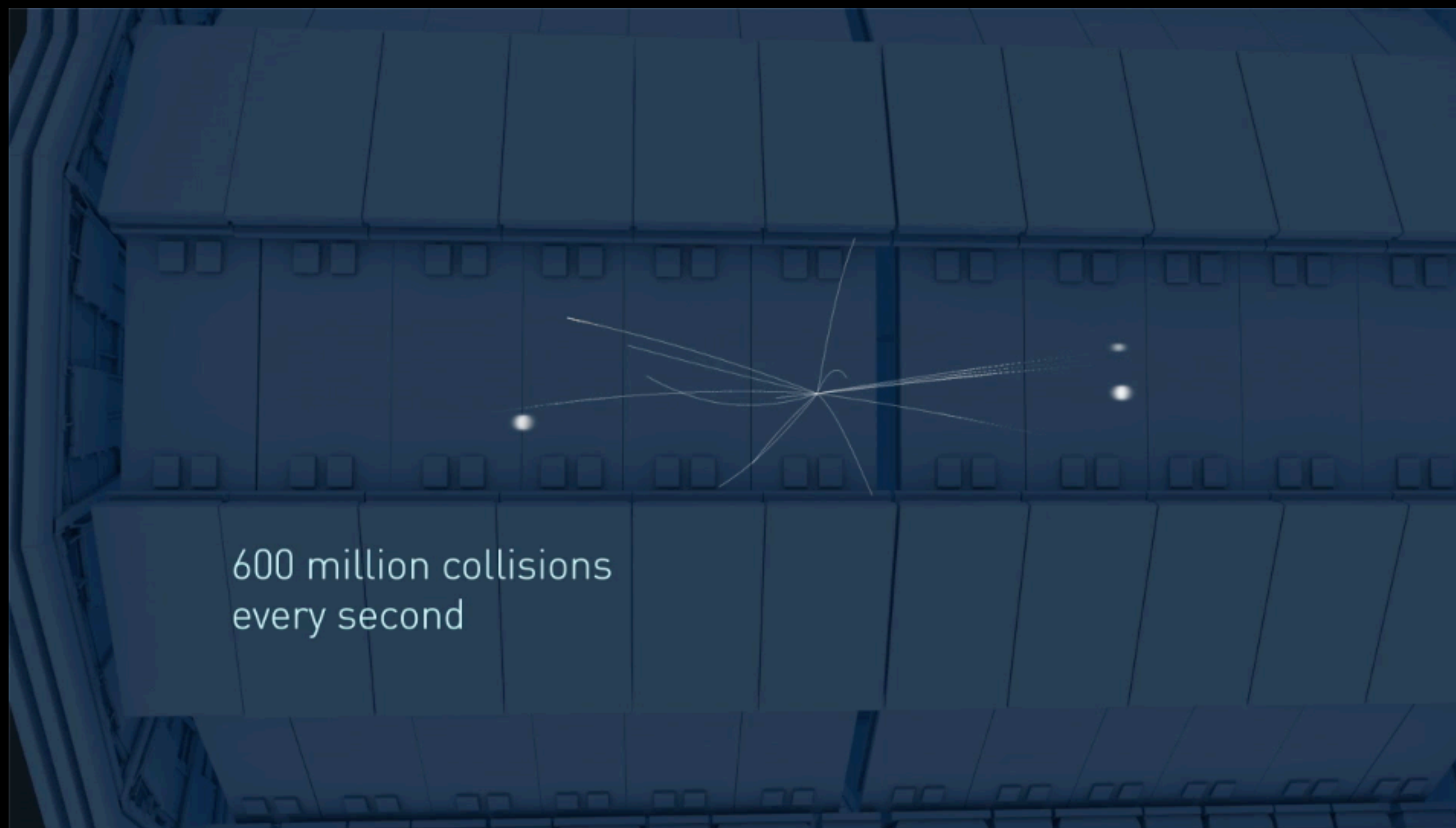
# Collisions in ATLAS

[Source: CERN-VIDEO-2013-041-001]

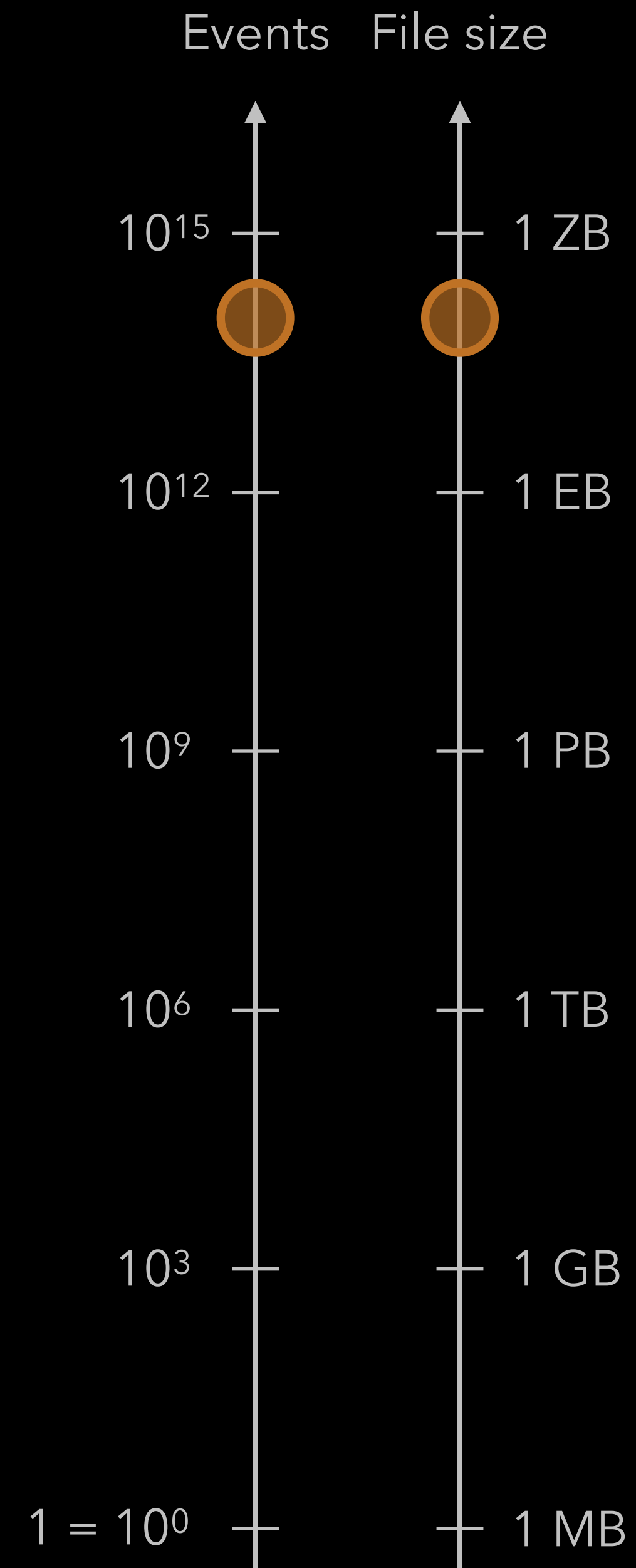


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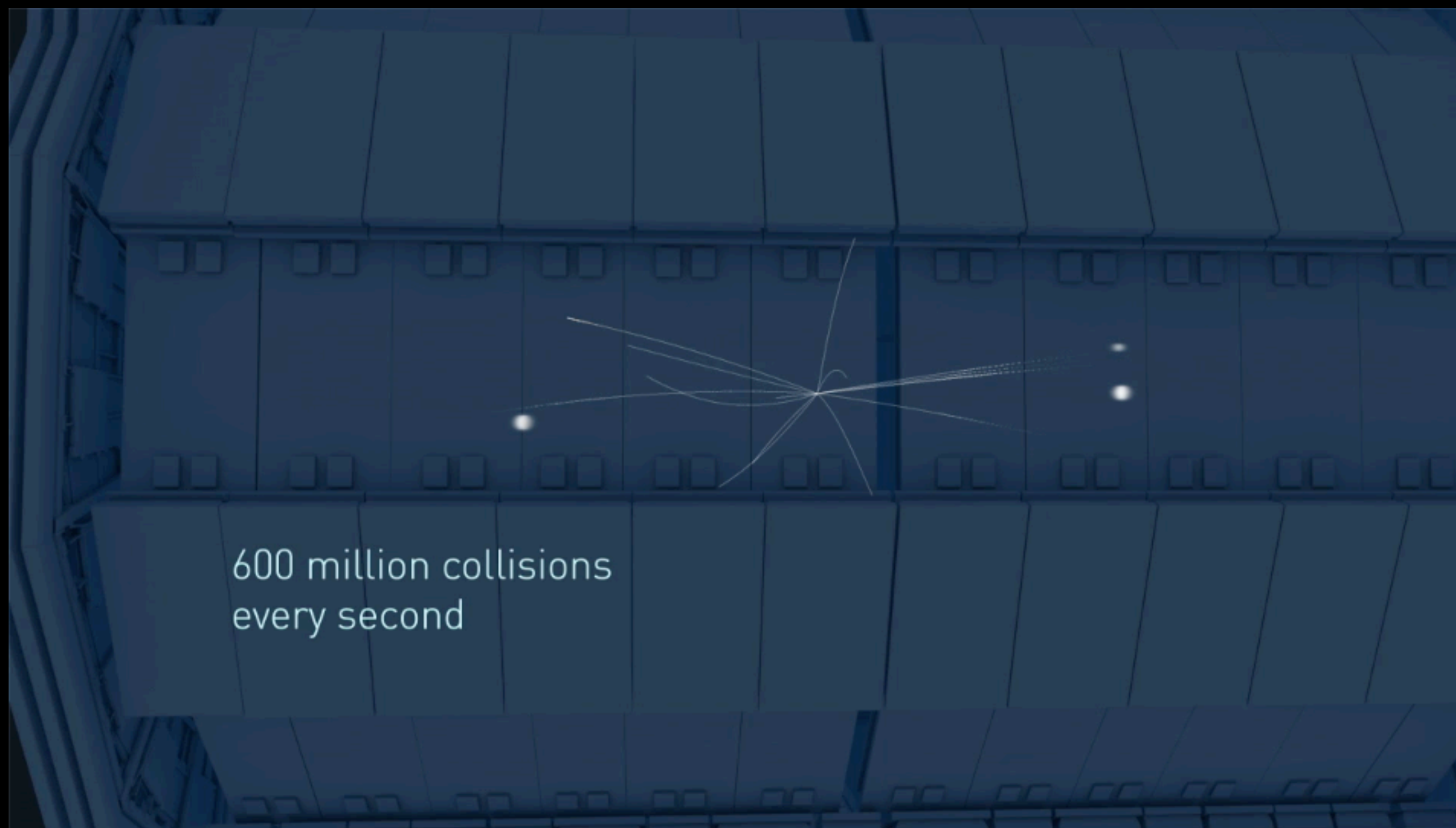
# Trigger System



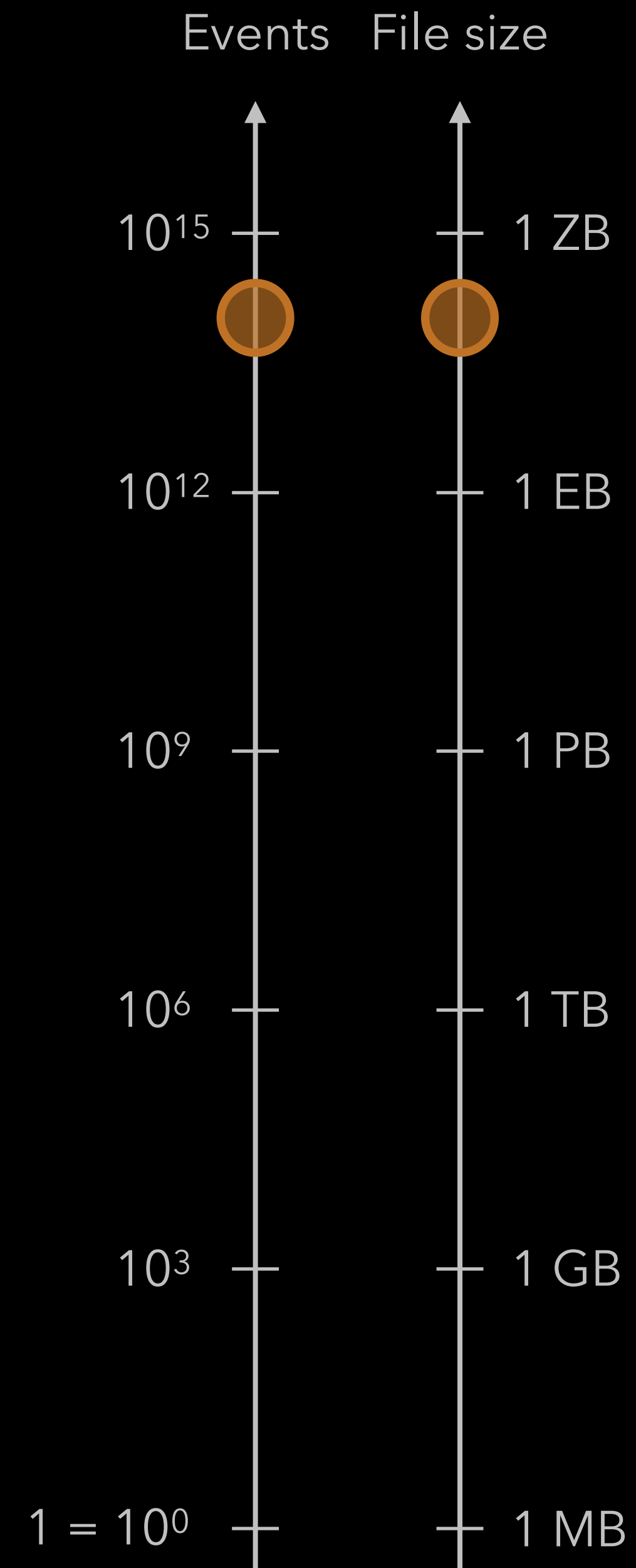
[Source: CERN-VIDEO-2013-041-001]



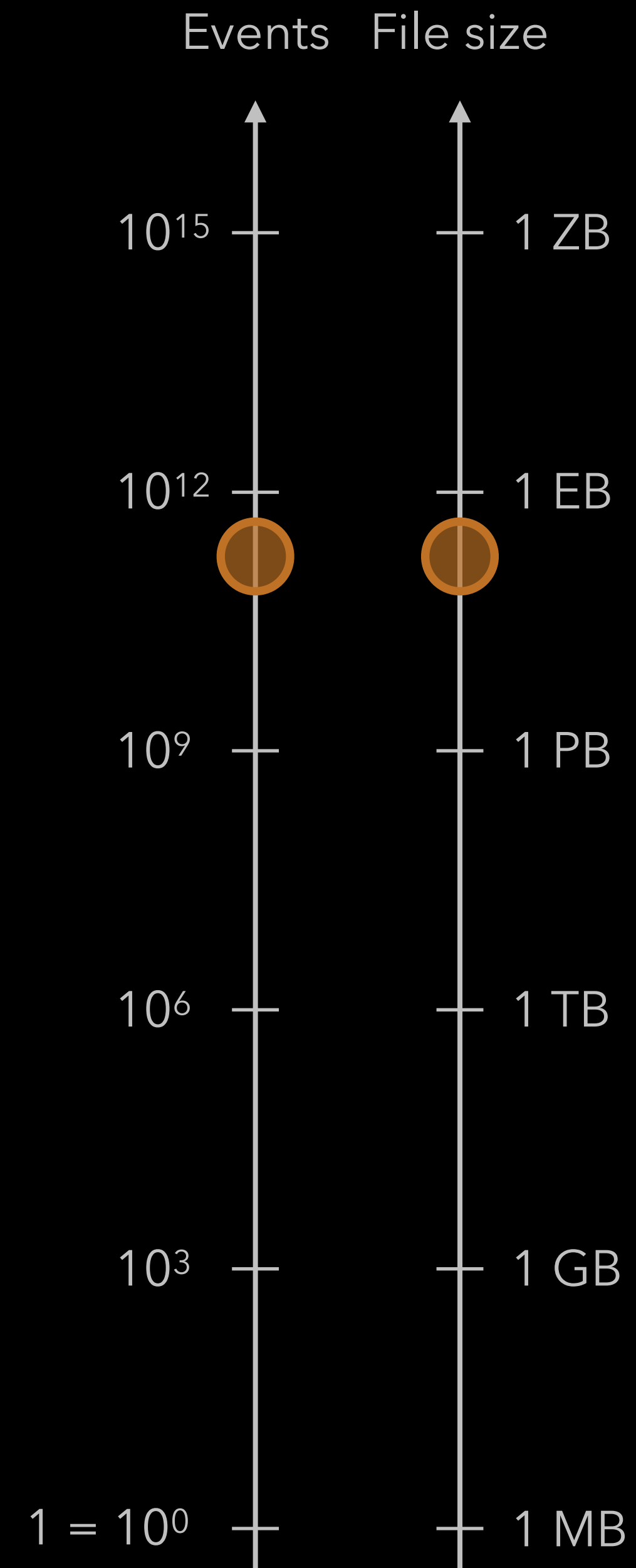
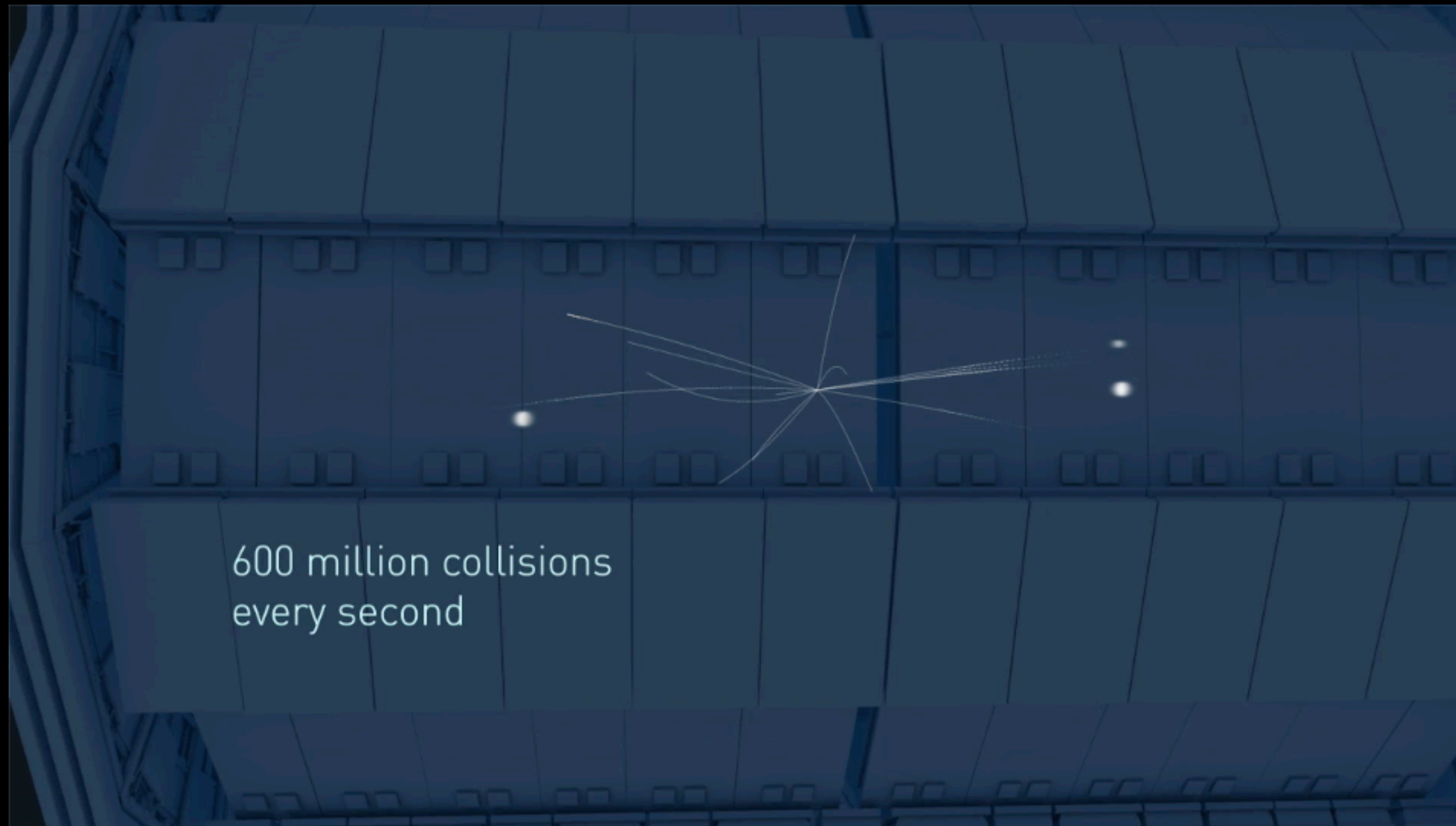
# Trigger System



[Source: CERN-VIDEO-2013-041-001]



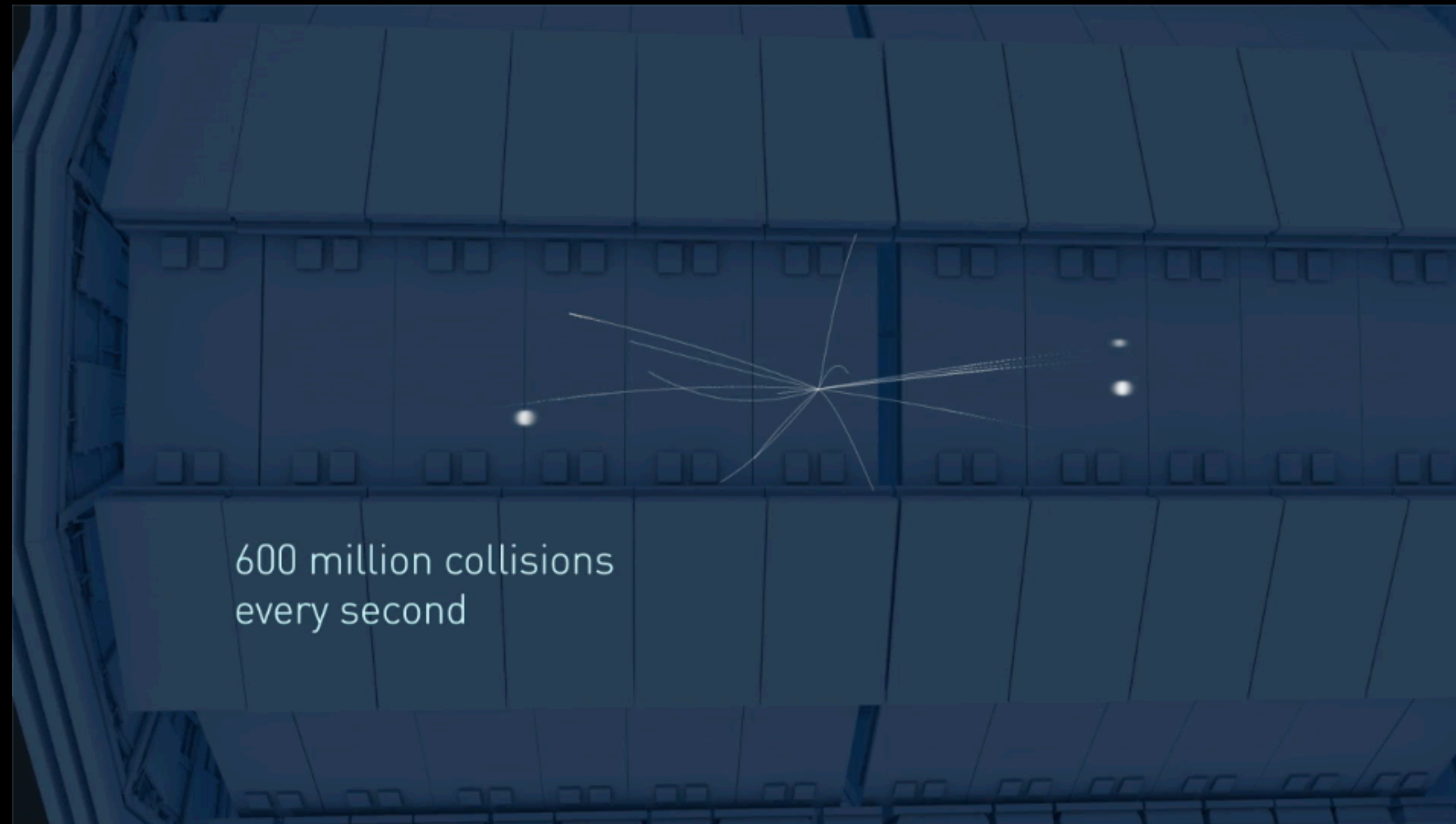
# Trigger System



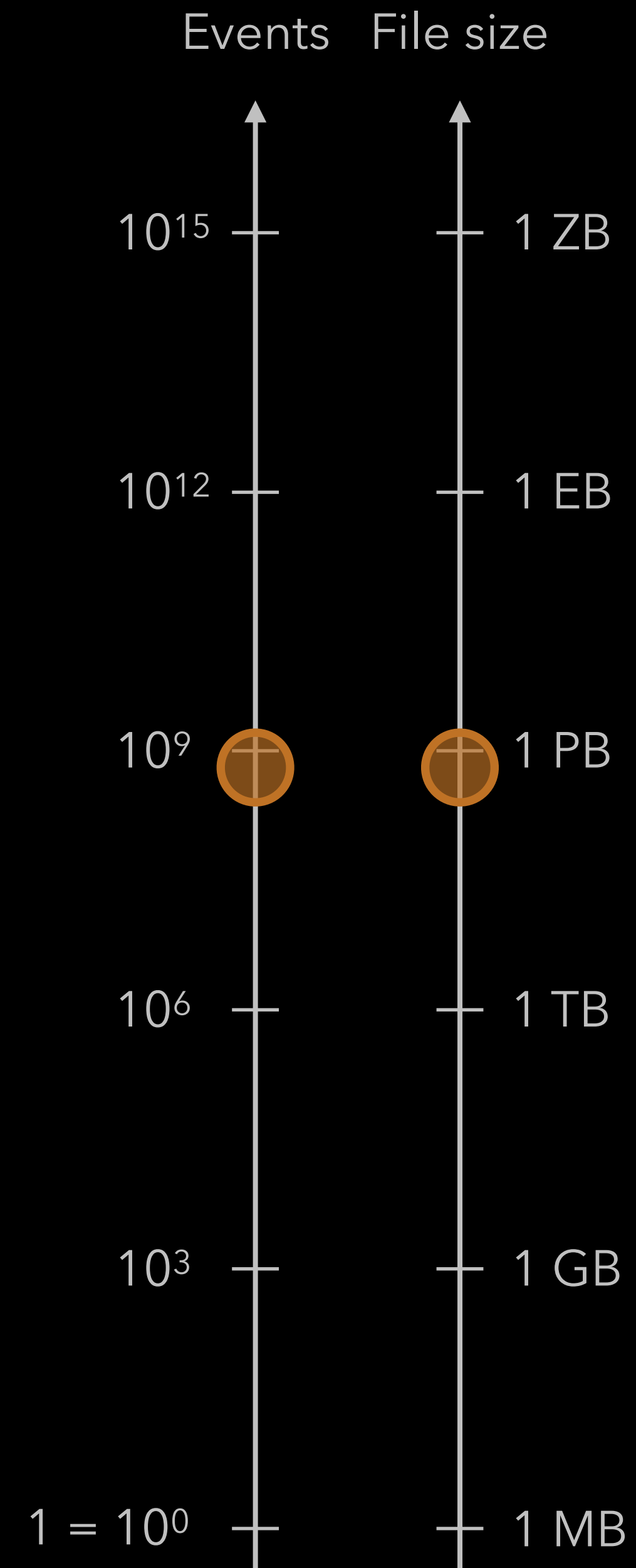
- 1st level trigger accepts events at a rate of 100 kHz

# Trigger System

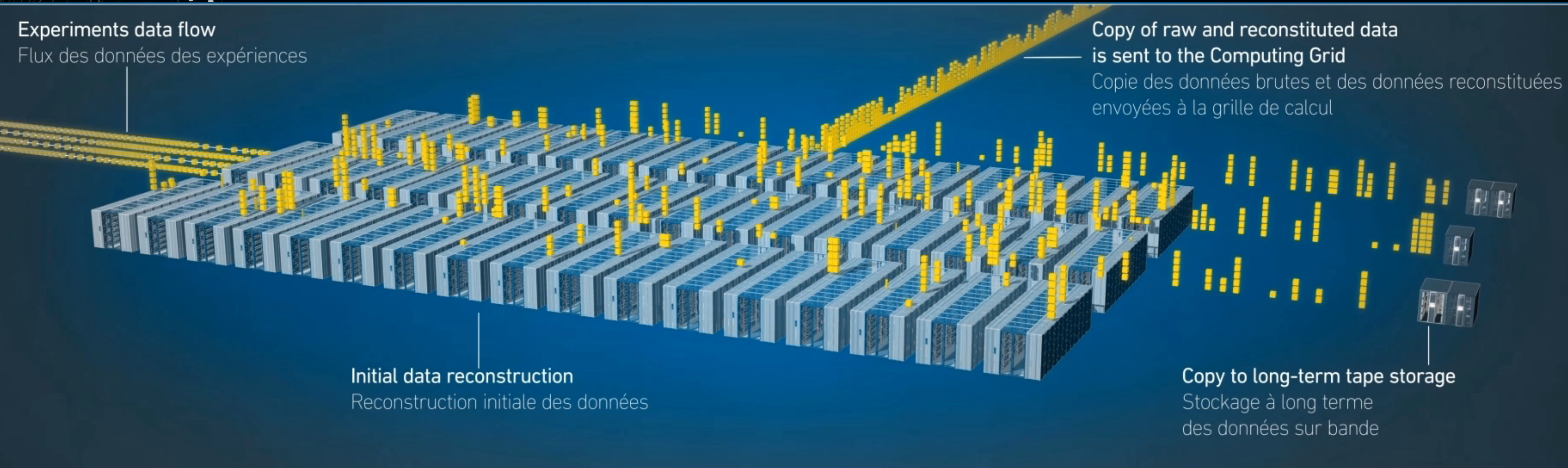
[Source: CERN-VIDEO-2013-041-001]



- 1st level trigger accepts events at a rate of 100 kHz
- 2nd level trigger accepts events at a rate of 1 kHz



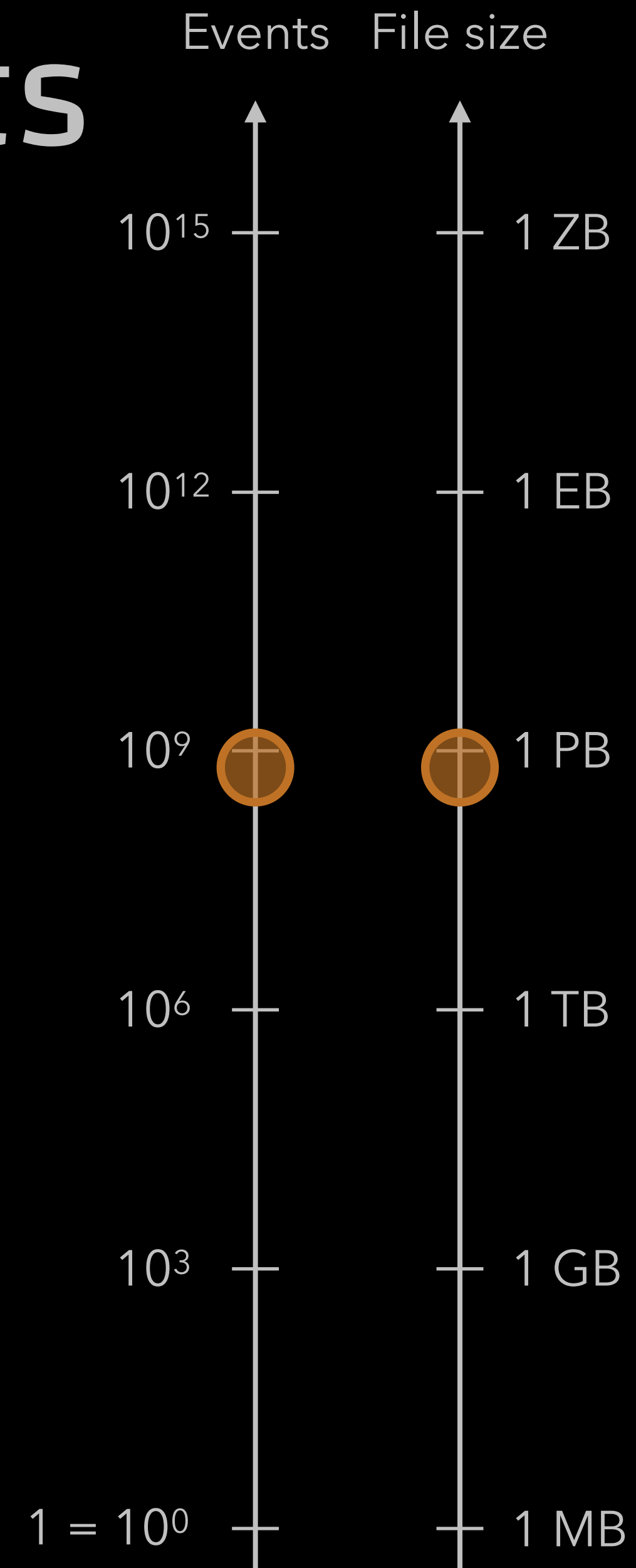
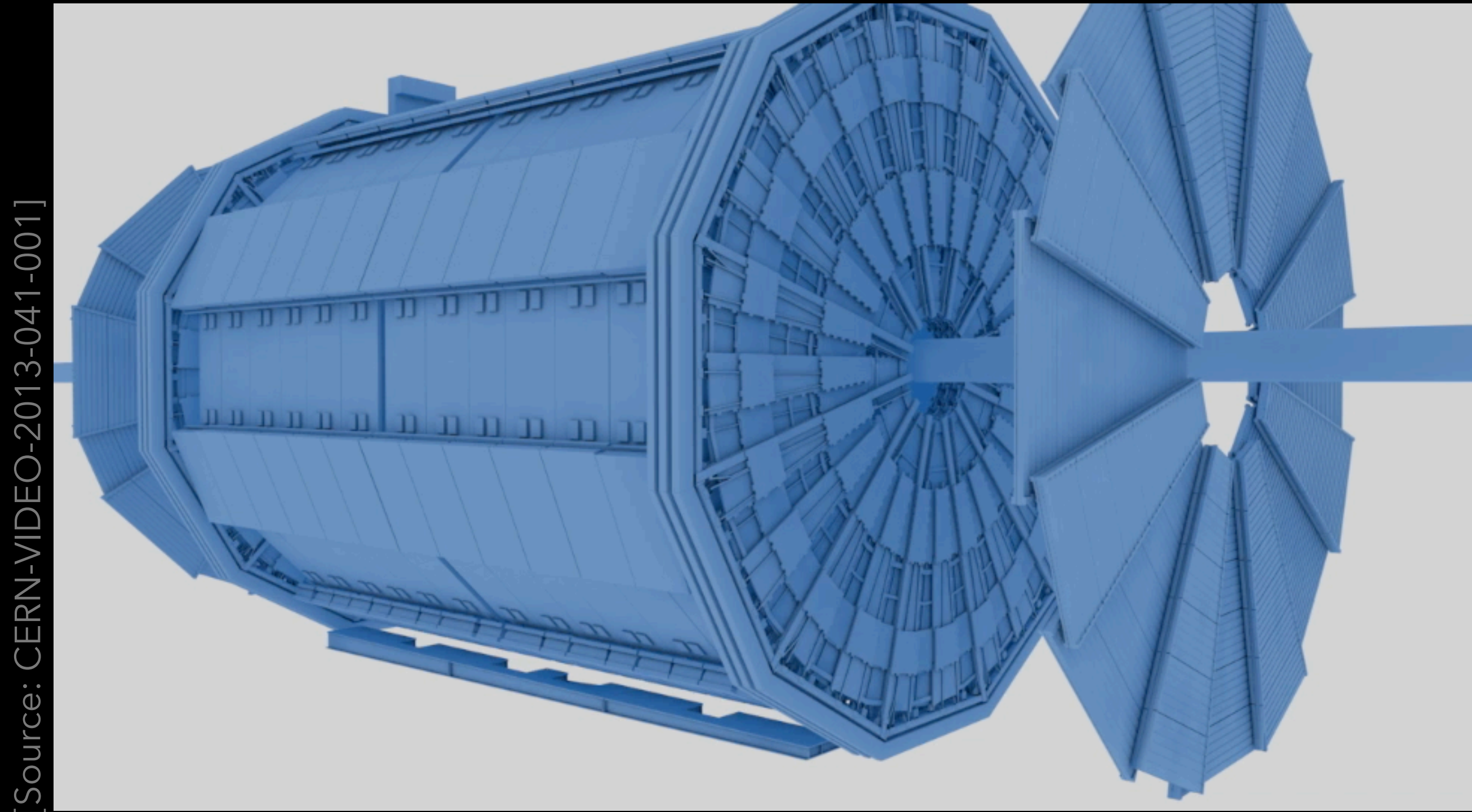
# Data Preparation



[Source: CERN-VIDEO-2013-041-001]

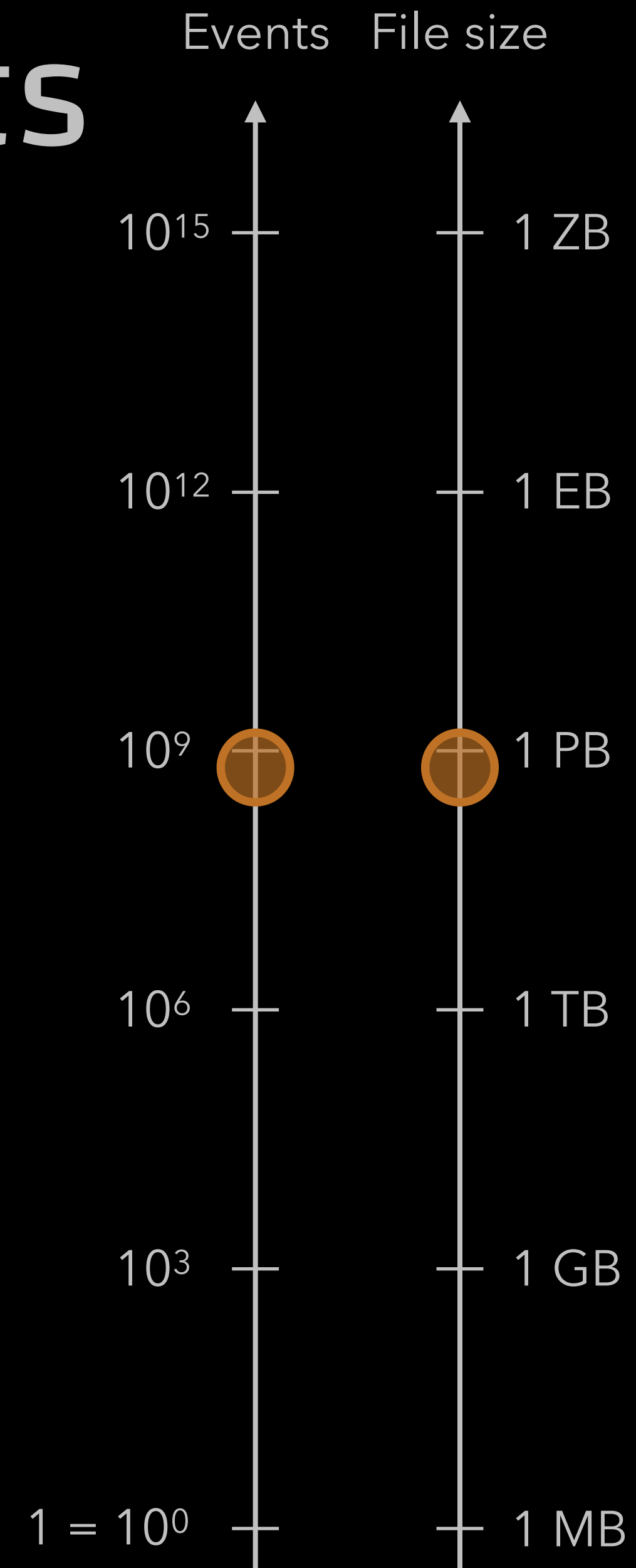
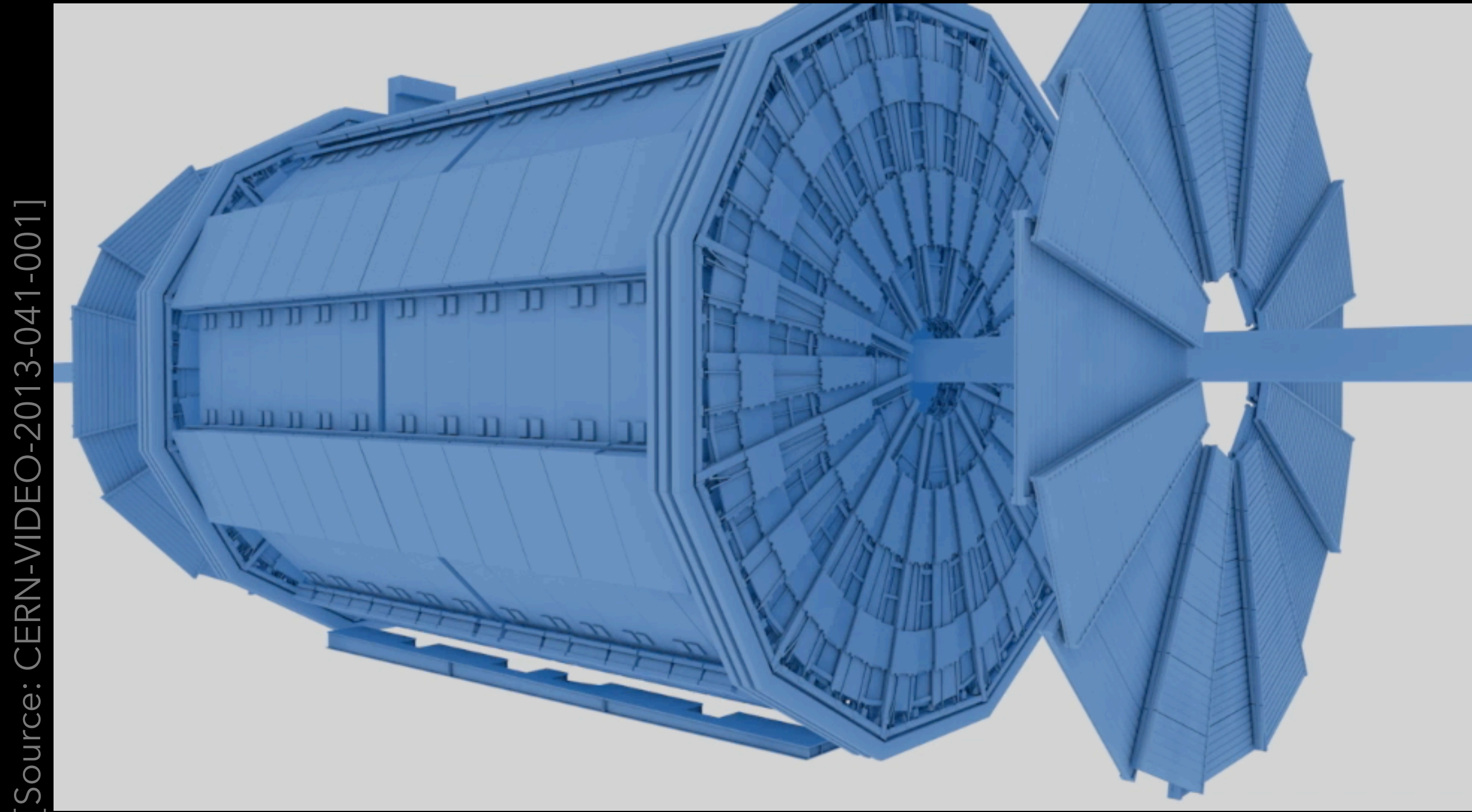
- Copy to long term storage on tape
- Reconstruction at TIER0 data centre at CERN and Hungary

# From Raw Data to Physics Objects



- From electrical pulses of the detector to a data format that we use for every day physics analysis

# From Raw Data to Physics Objects



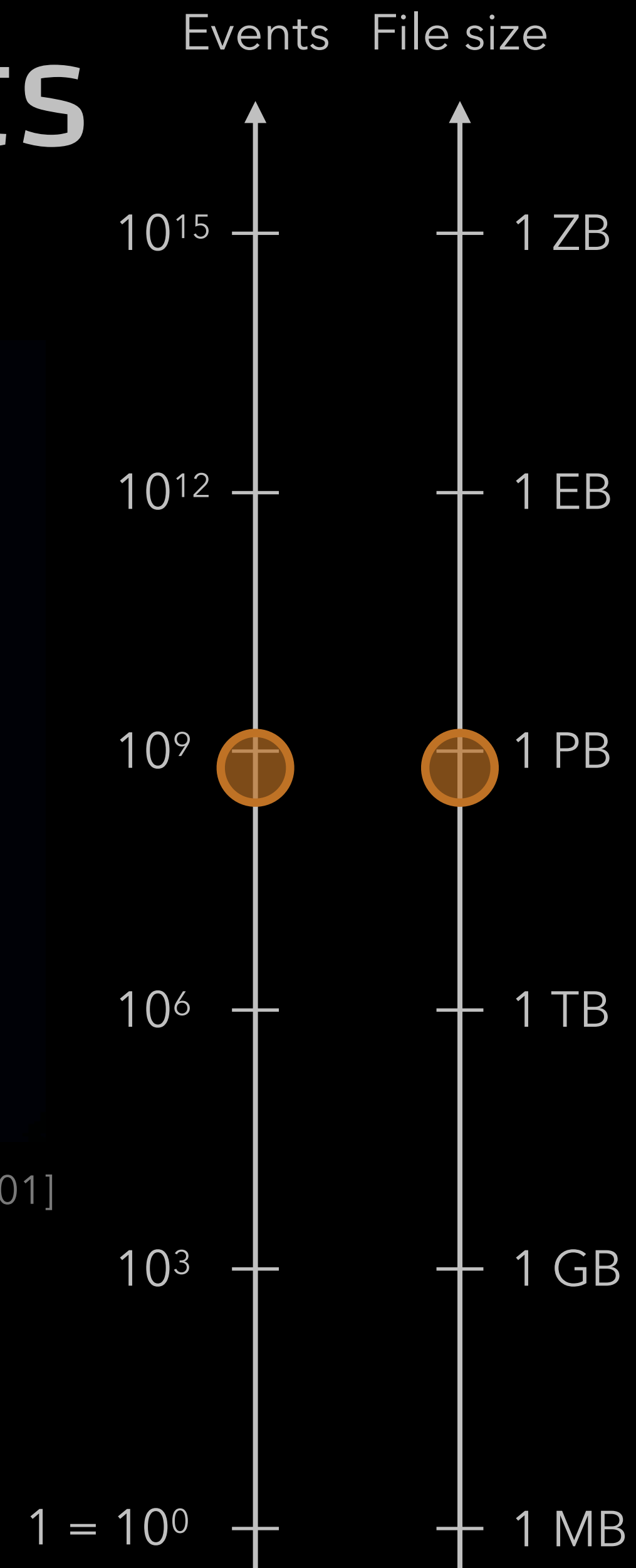
- From electrical pulses of the detector to a data format that we use for every day physics analysis



# From Raw Data to Physics Objects

- Calibration and alignment of detectors
- Data quality assessment
- Addition of metadata
- Transformation of hits in detector to physics objects (e.g. electrons)

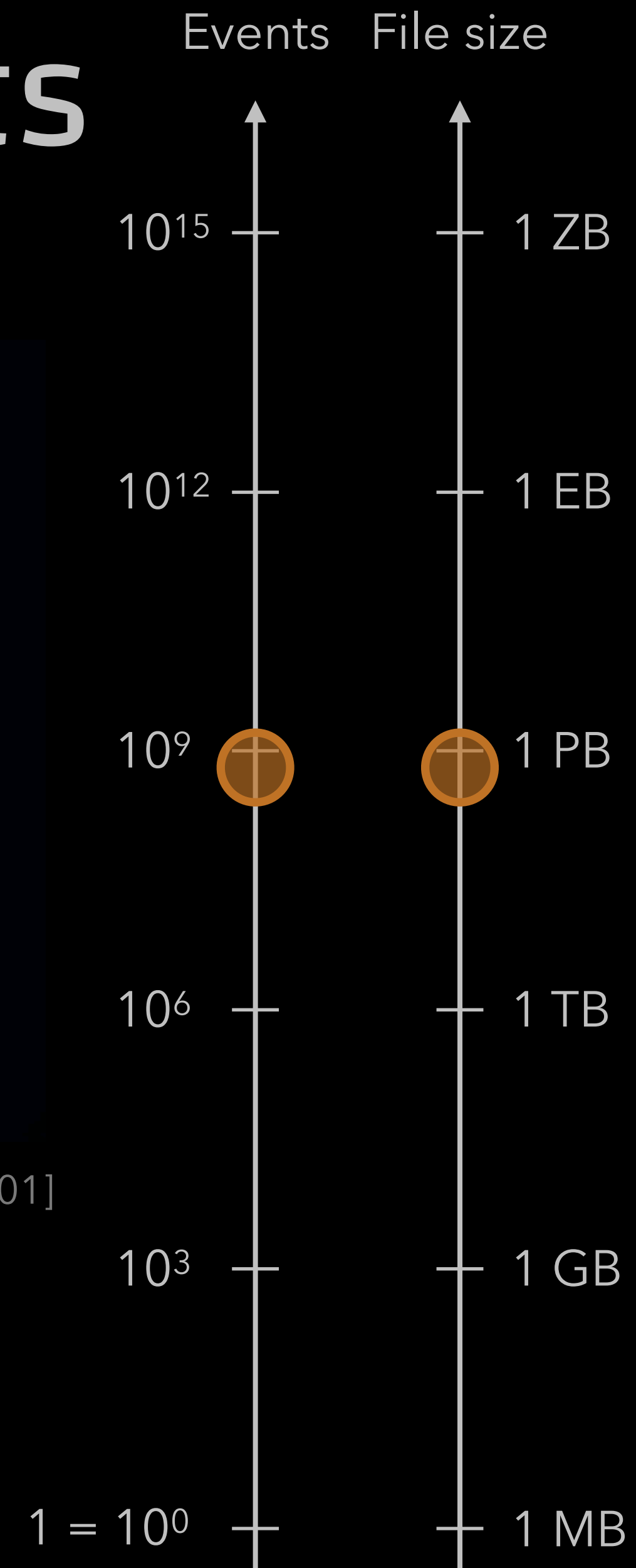
[Source: CERN-VIDEO-2013-041-001]



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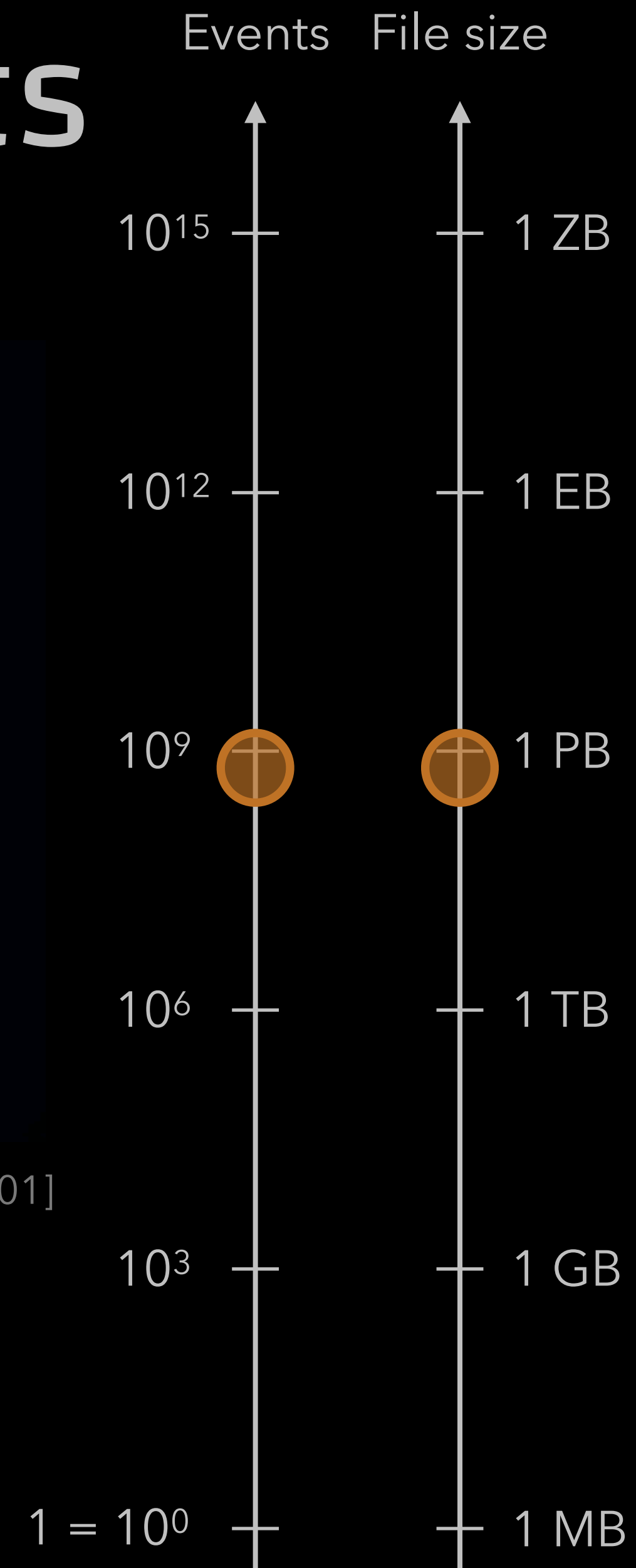
[Source: CERN-VIDEO-2013-041-001]



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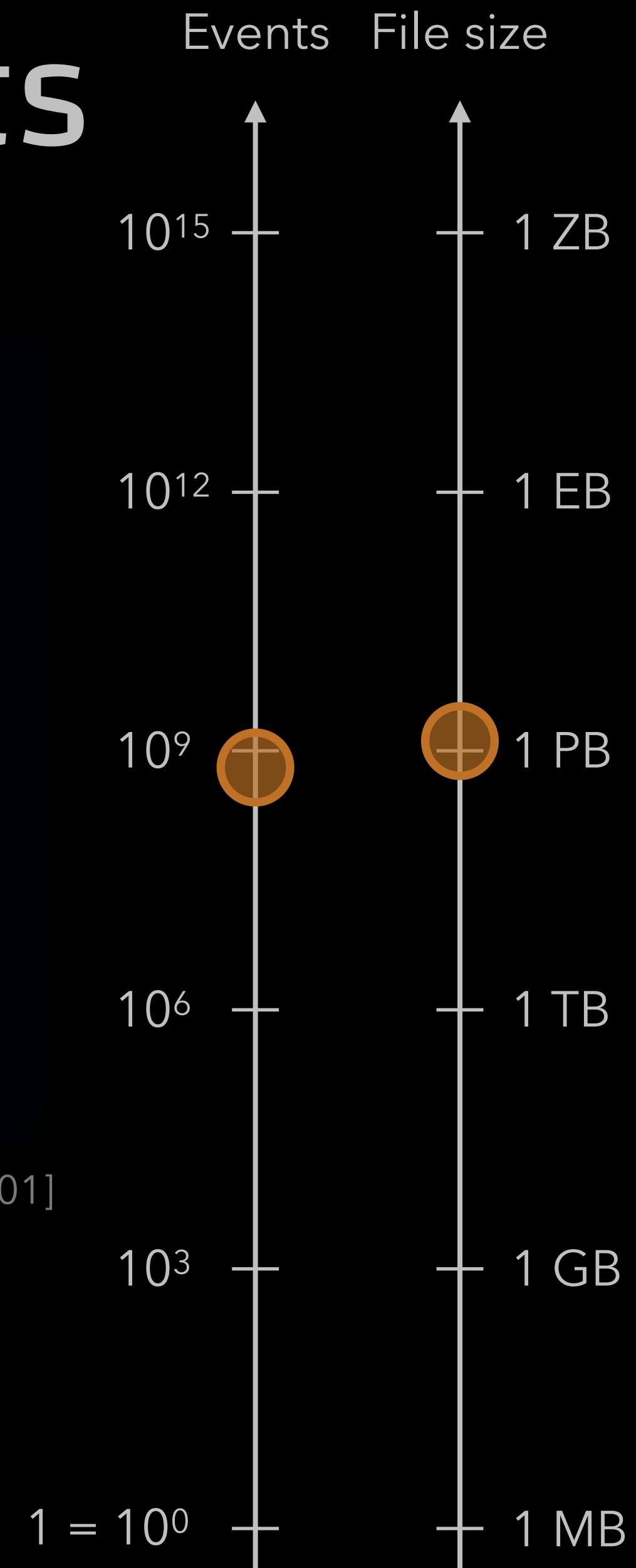
[Source: CERN-VIDEO-2013-041-001]



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[Source: CERN-VIDEO-2013-041-001]

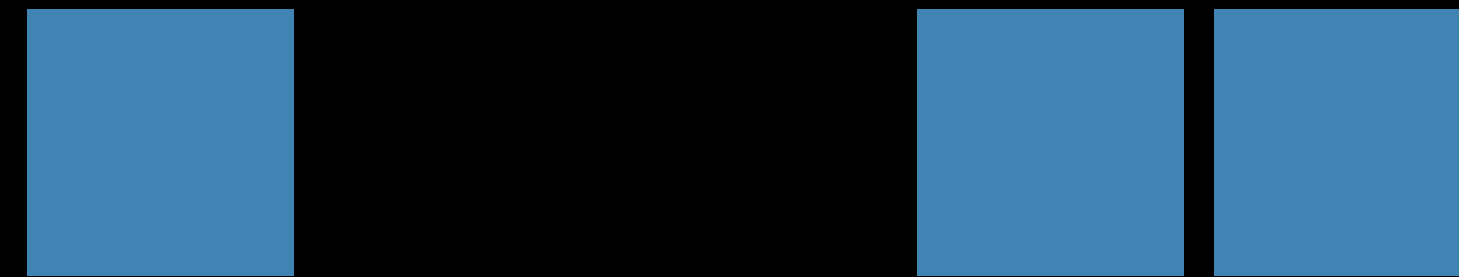
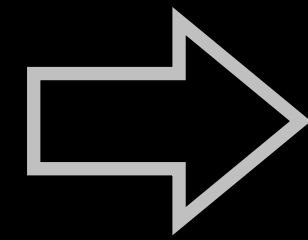


# Data Size Reduction

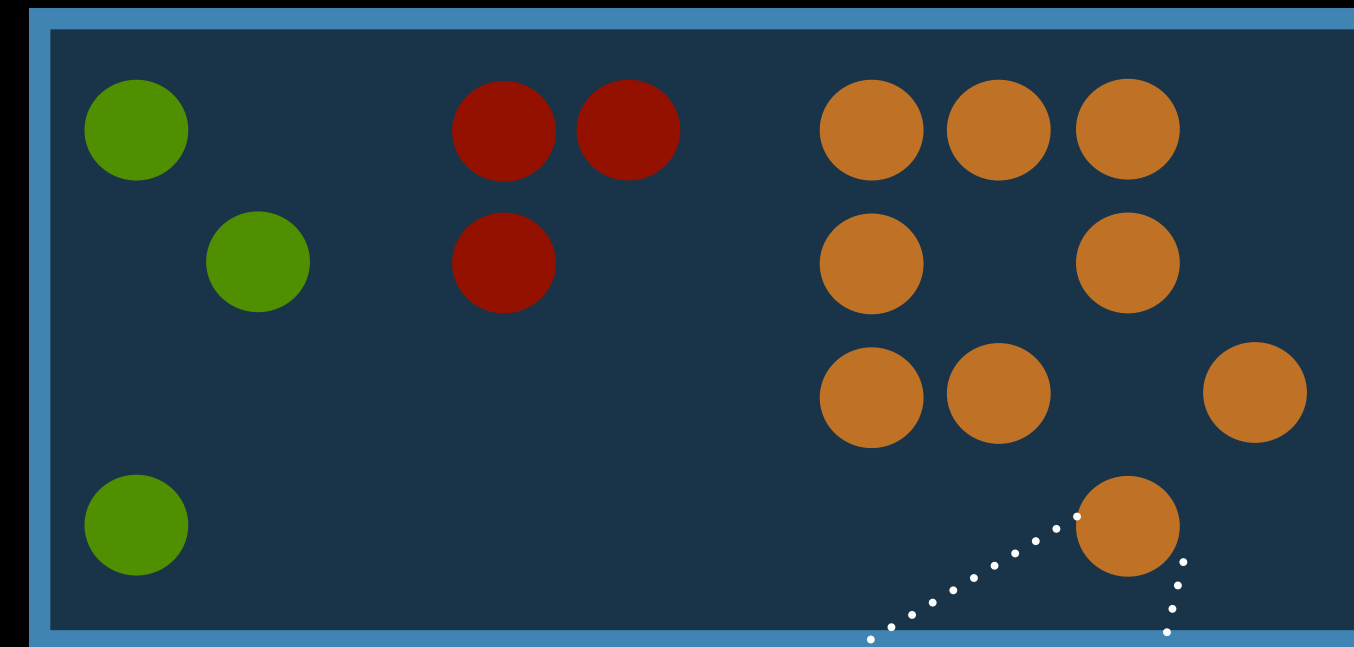
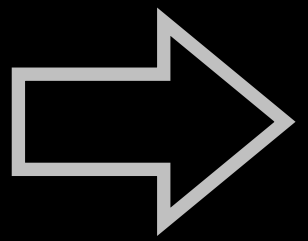
[Inspired by slide from James Catmore]



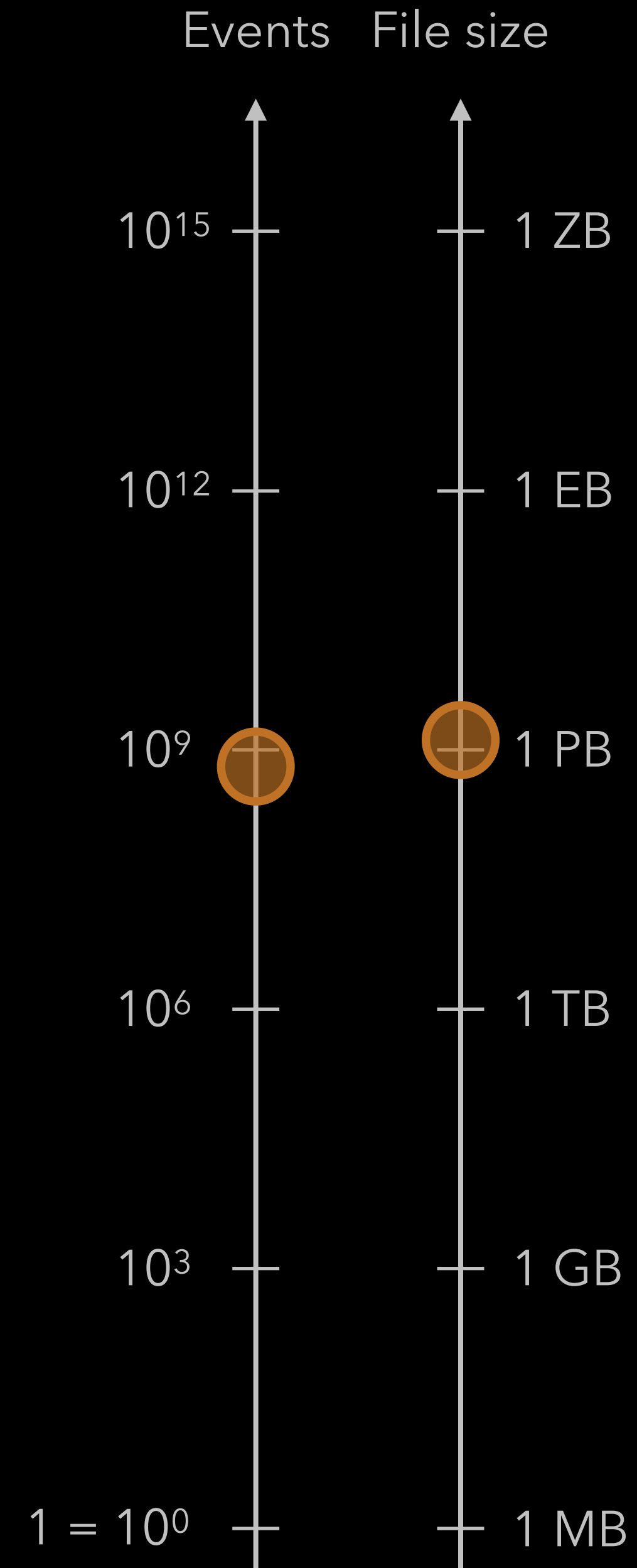
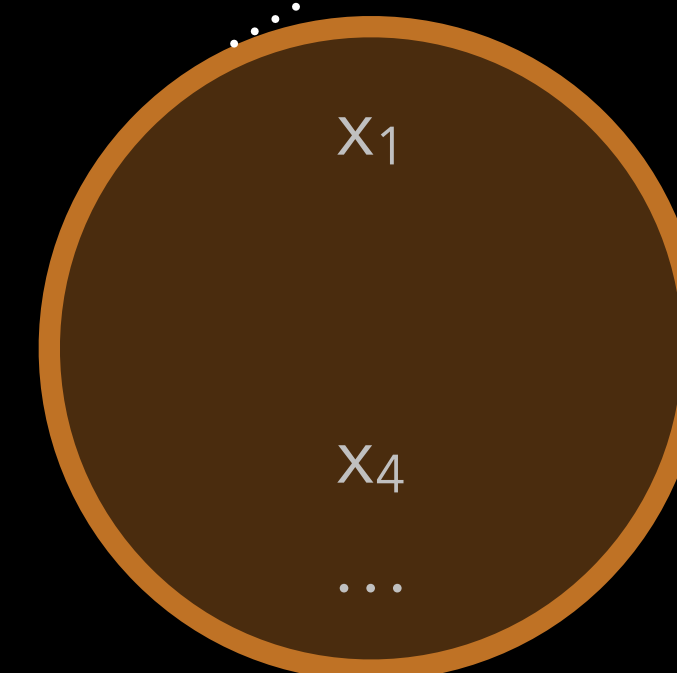
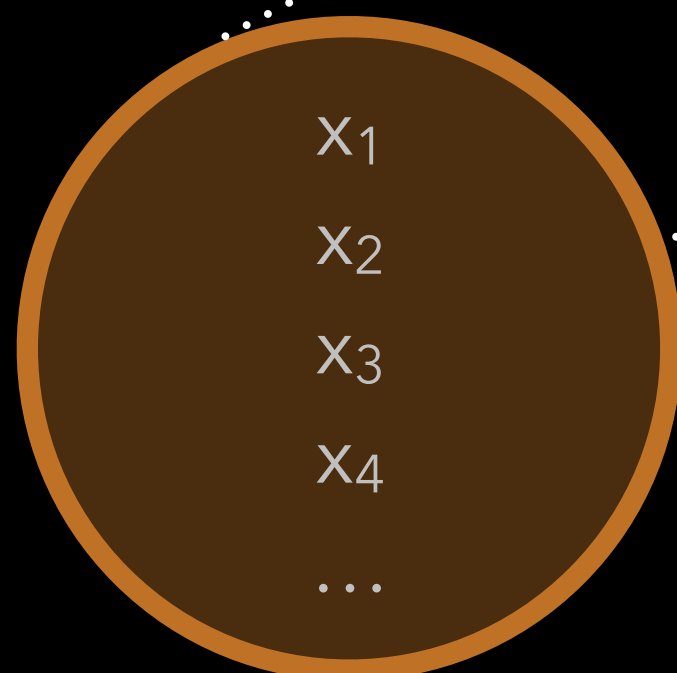
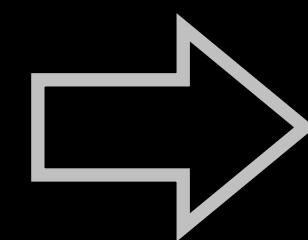
remove events



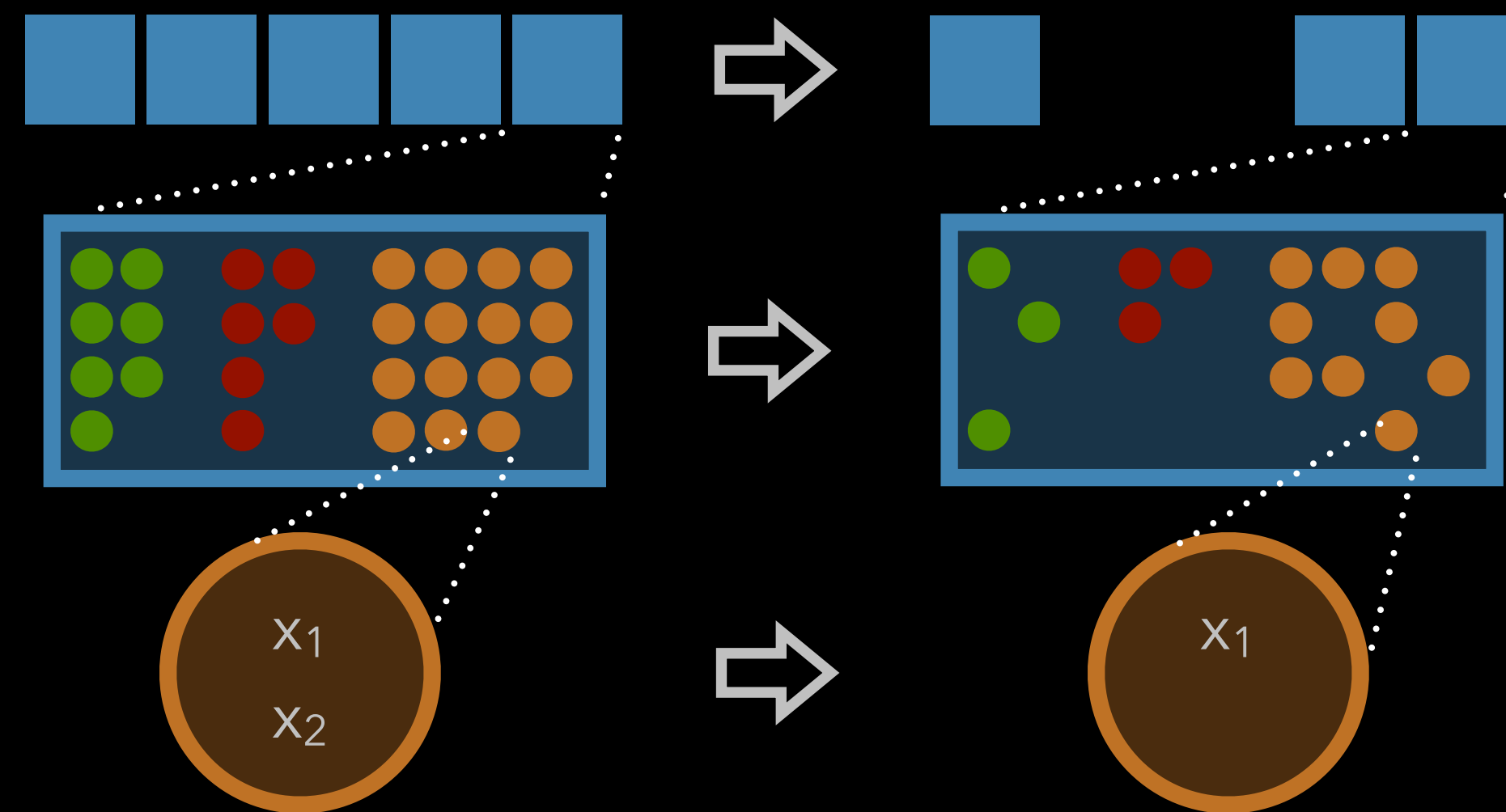
remove analysis objects



remove information about objects

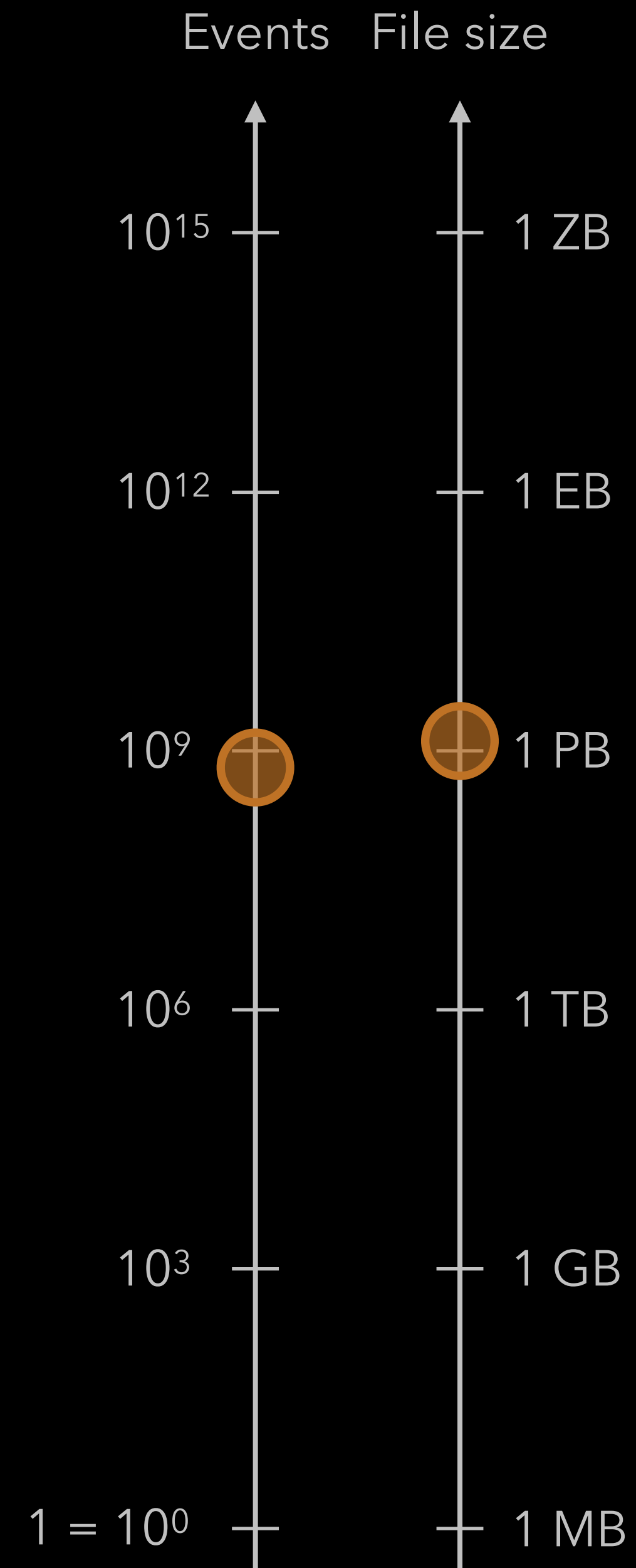


# Physics Selection

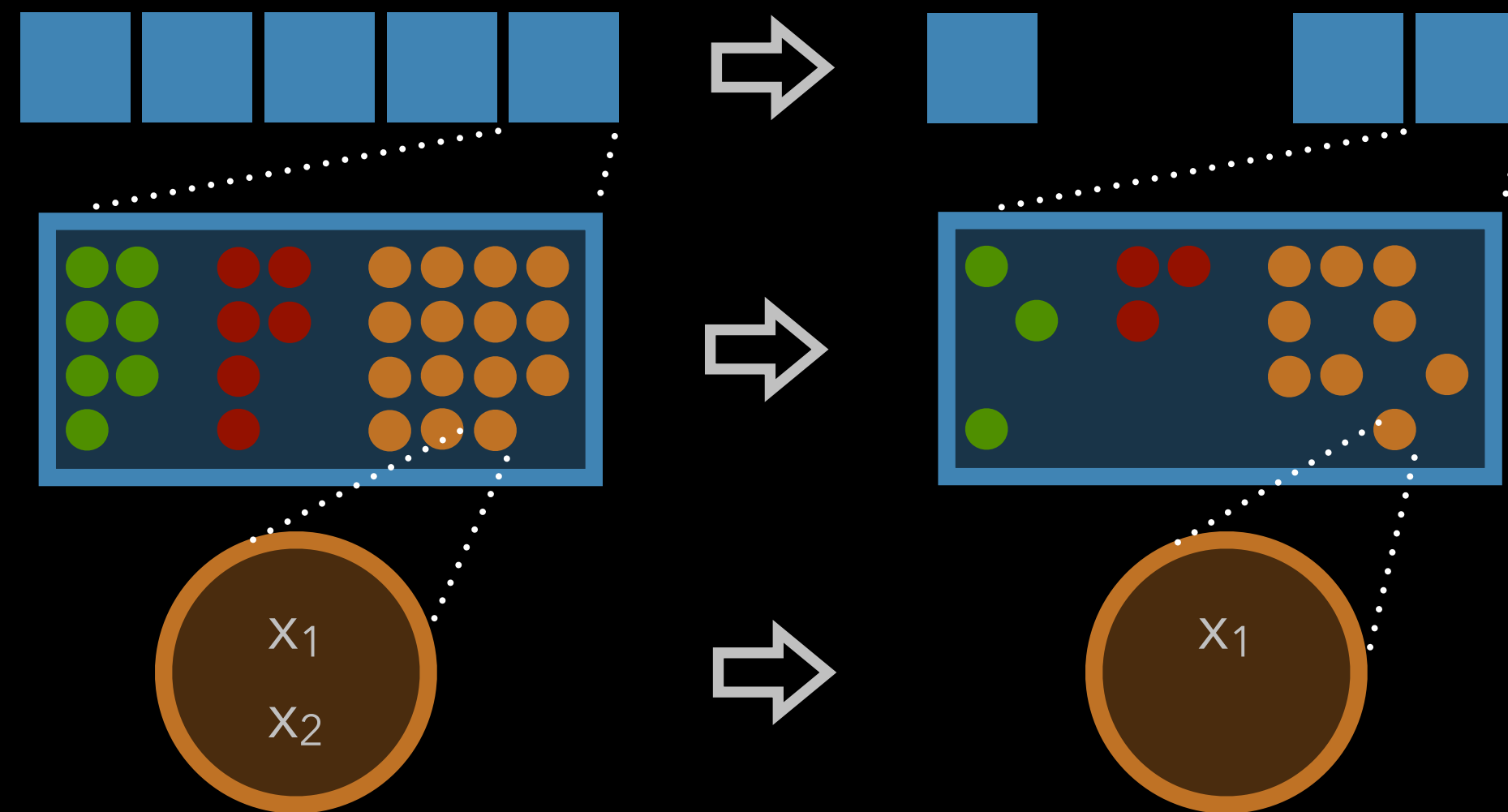


Multi-step approach:

- Rough physics selection for multiple analyses (for local cluster)
- Analysis specific selection (for your laptop)

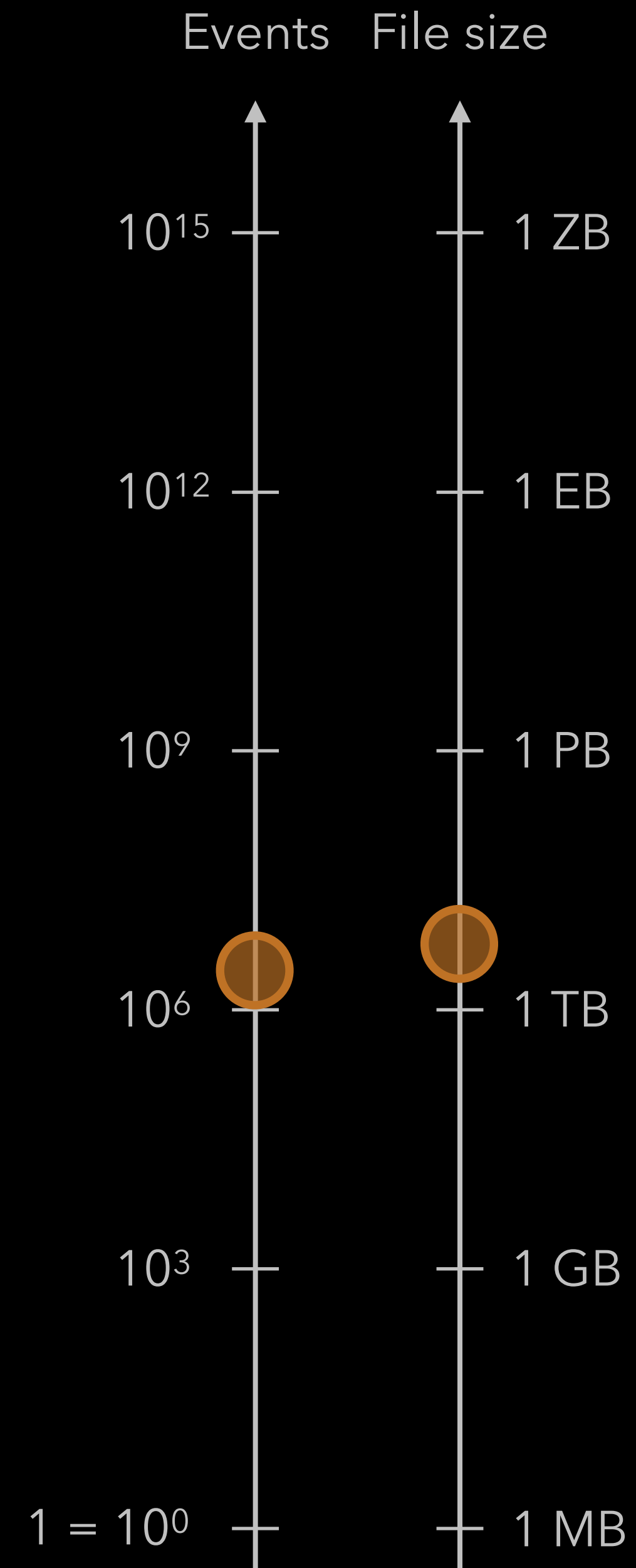


# Physics Selection

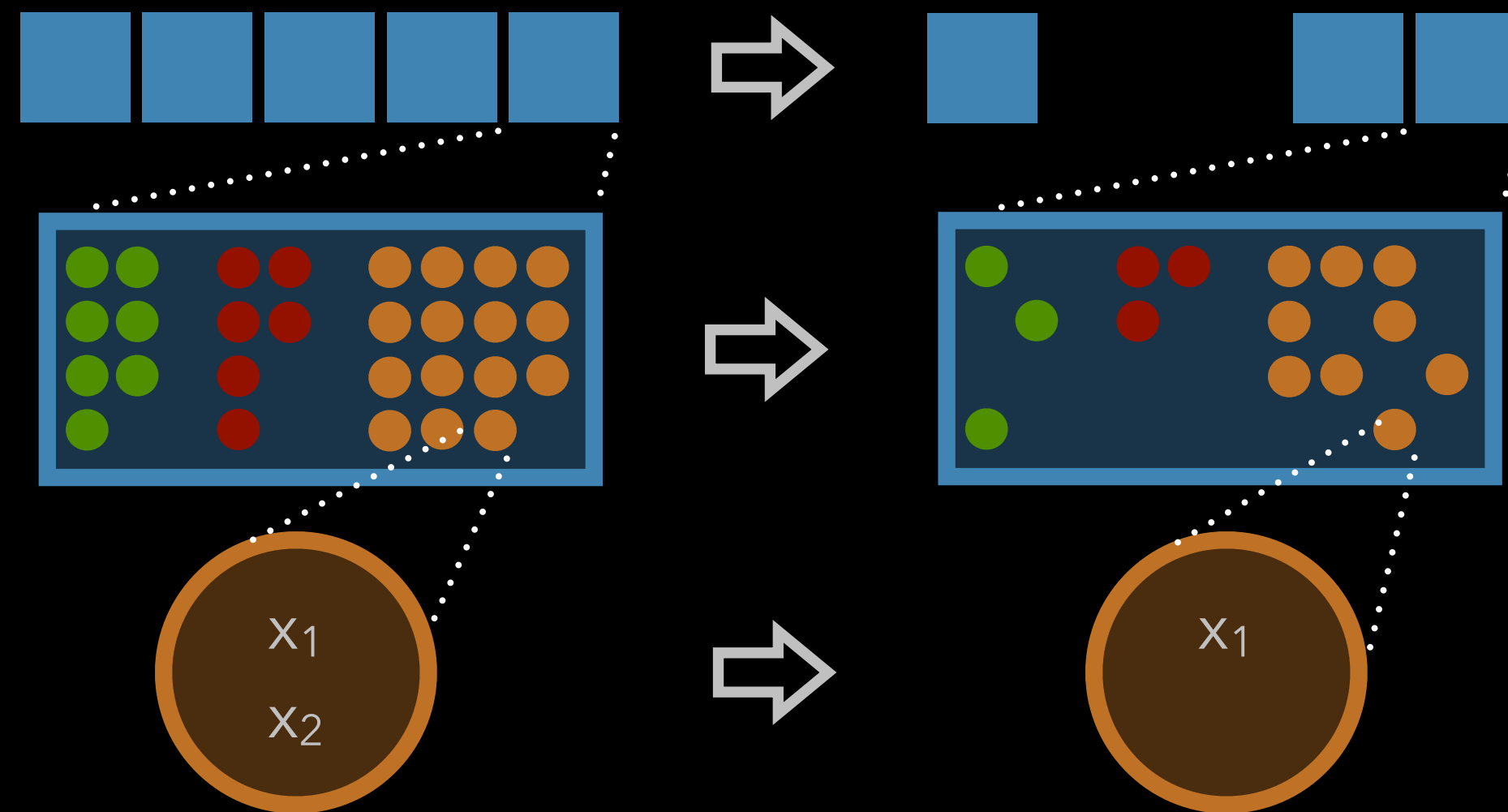


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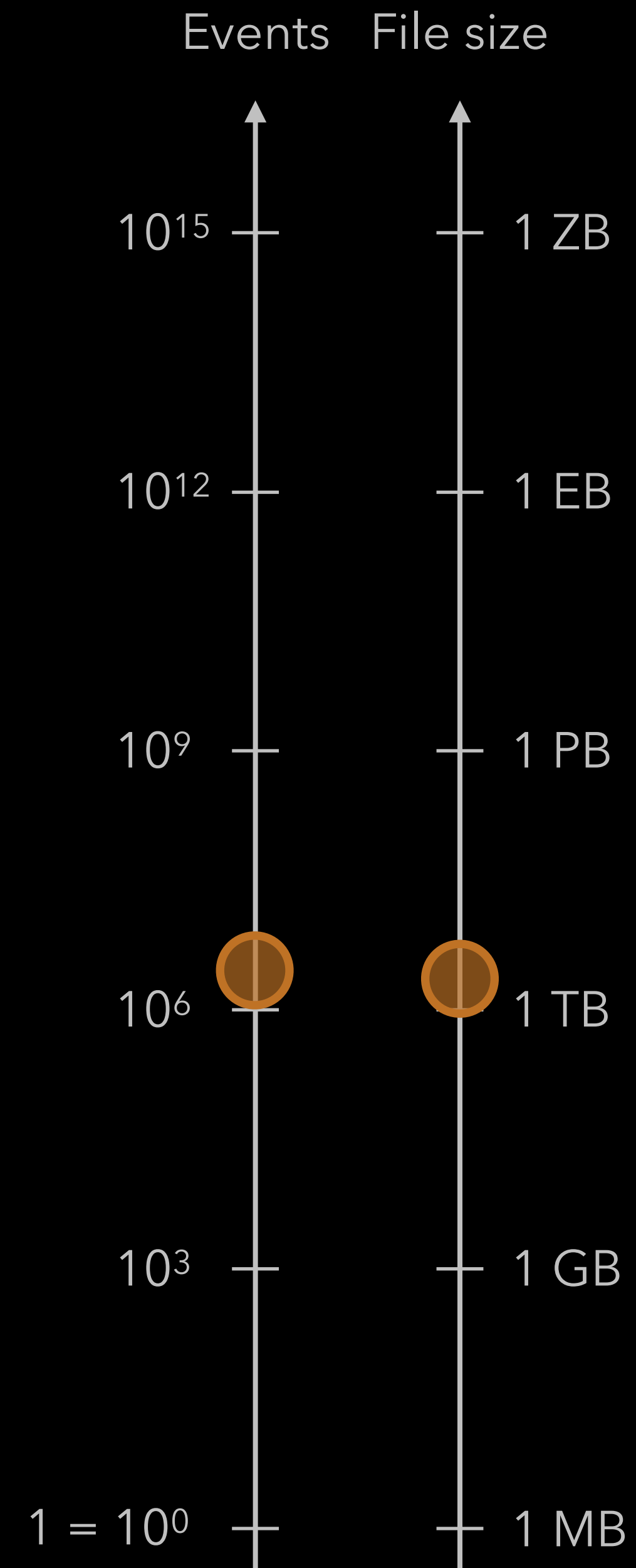


# Physics Selection



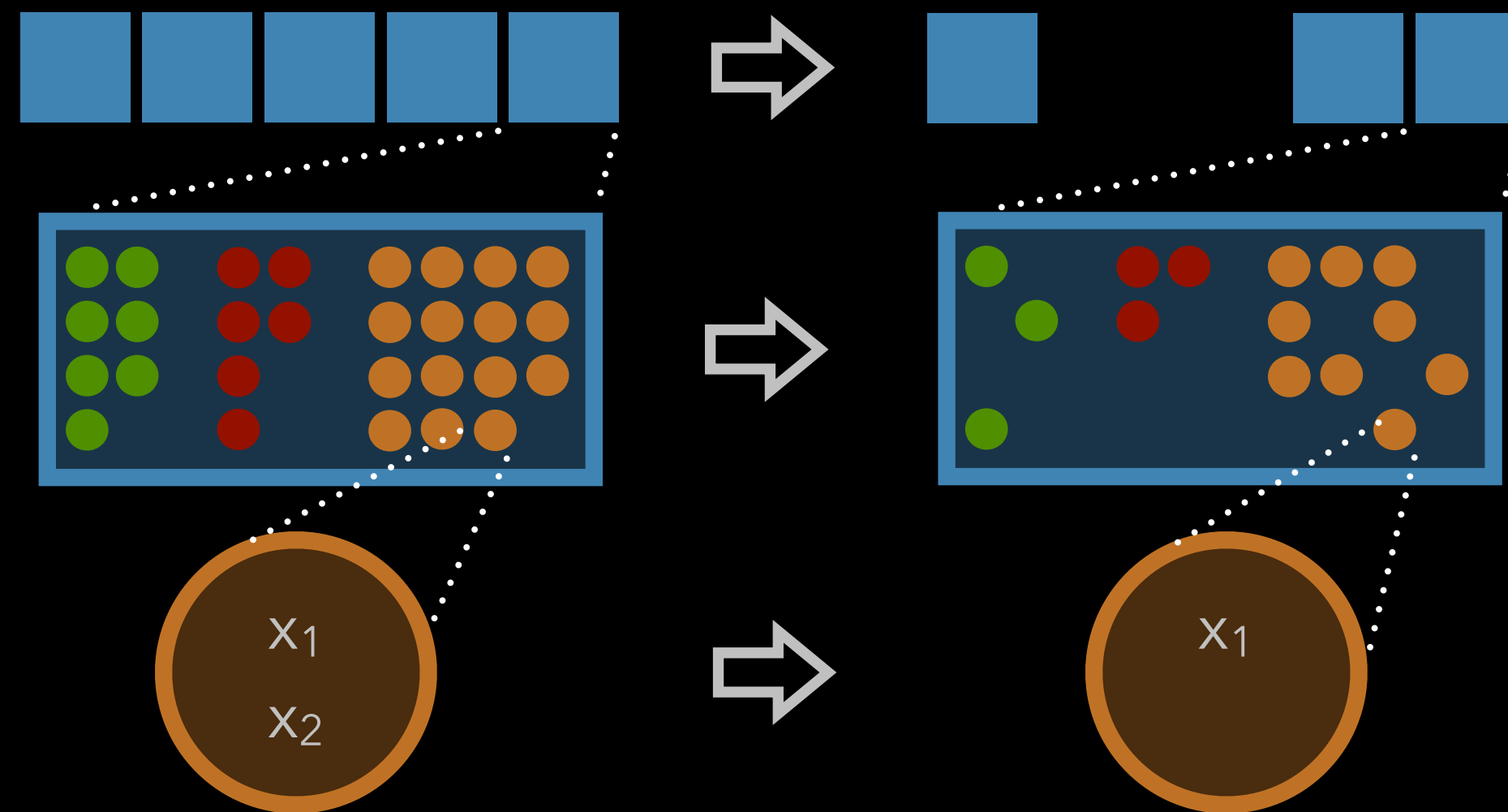
Multi-step approach:

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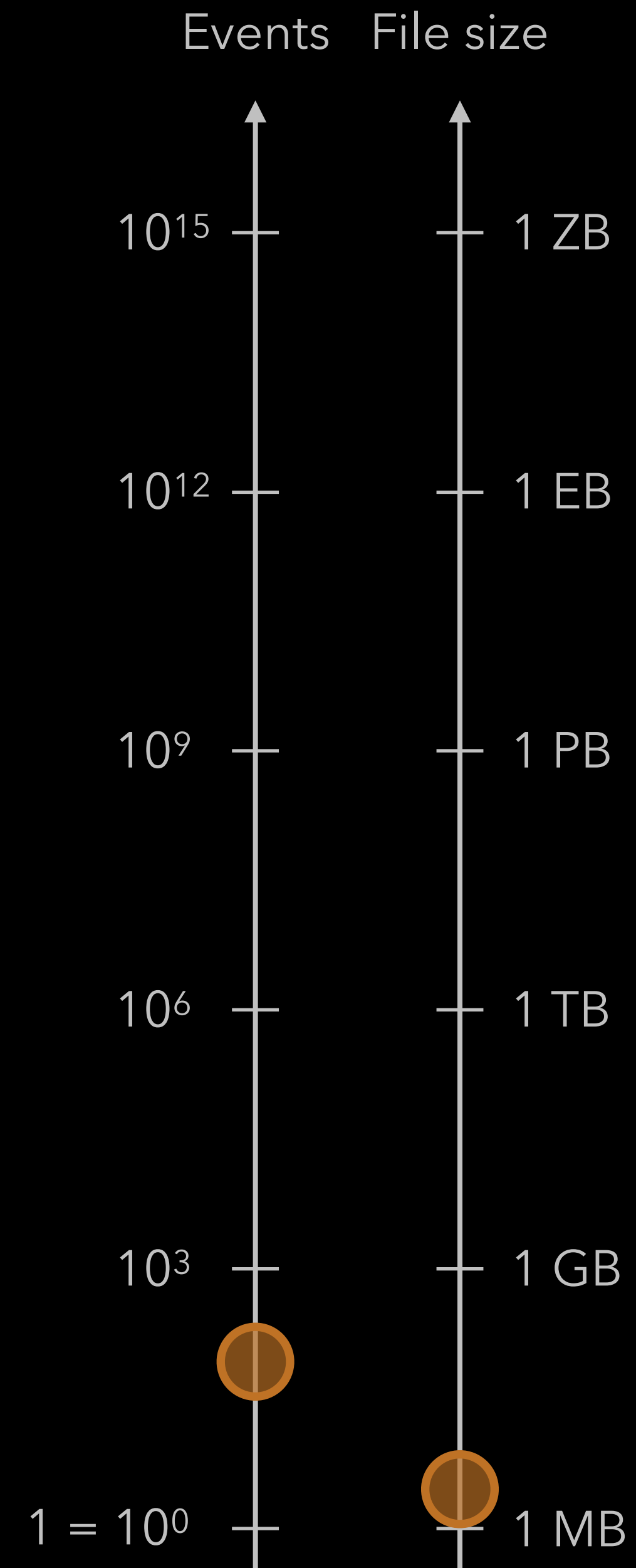


# Physics Selection



Multi-step approach:

- Rough physics selection for multiple analyses (for local cluster)
- Analysis specific selection (for your laptop)

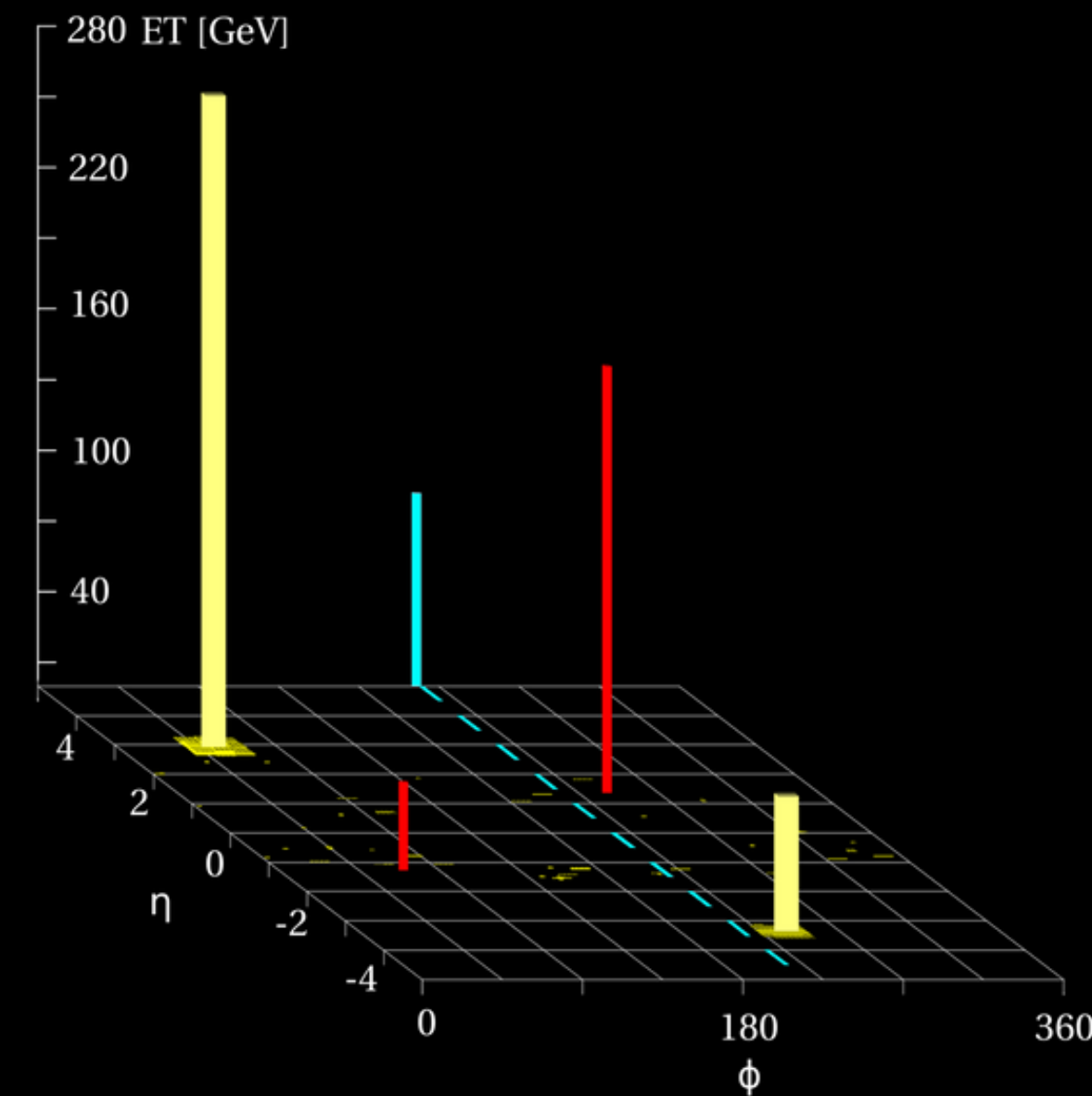
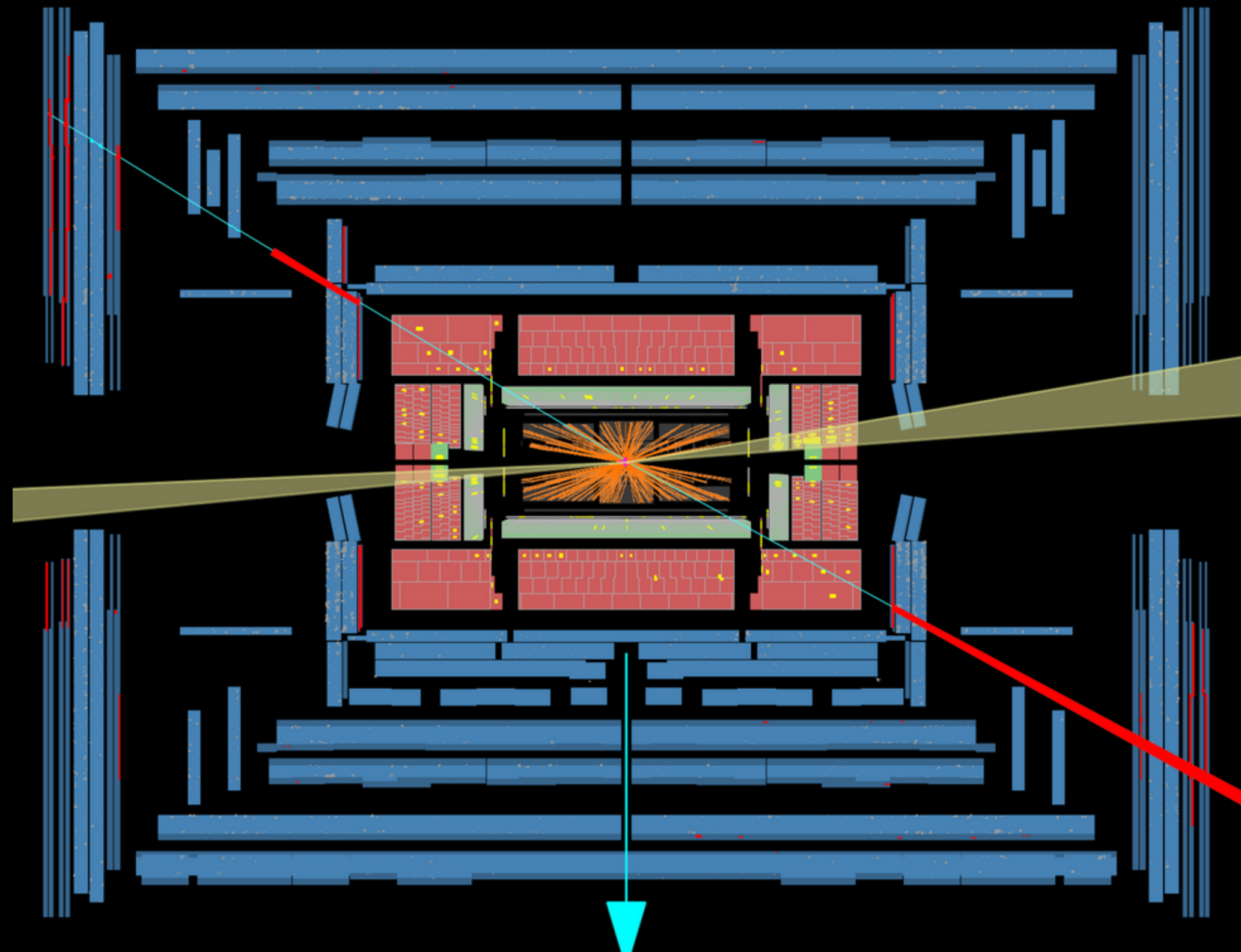


# Eventdisplay

$\mu^+\mu^+jj$  Candidate Event

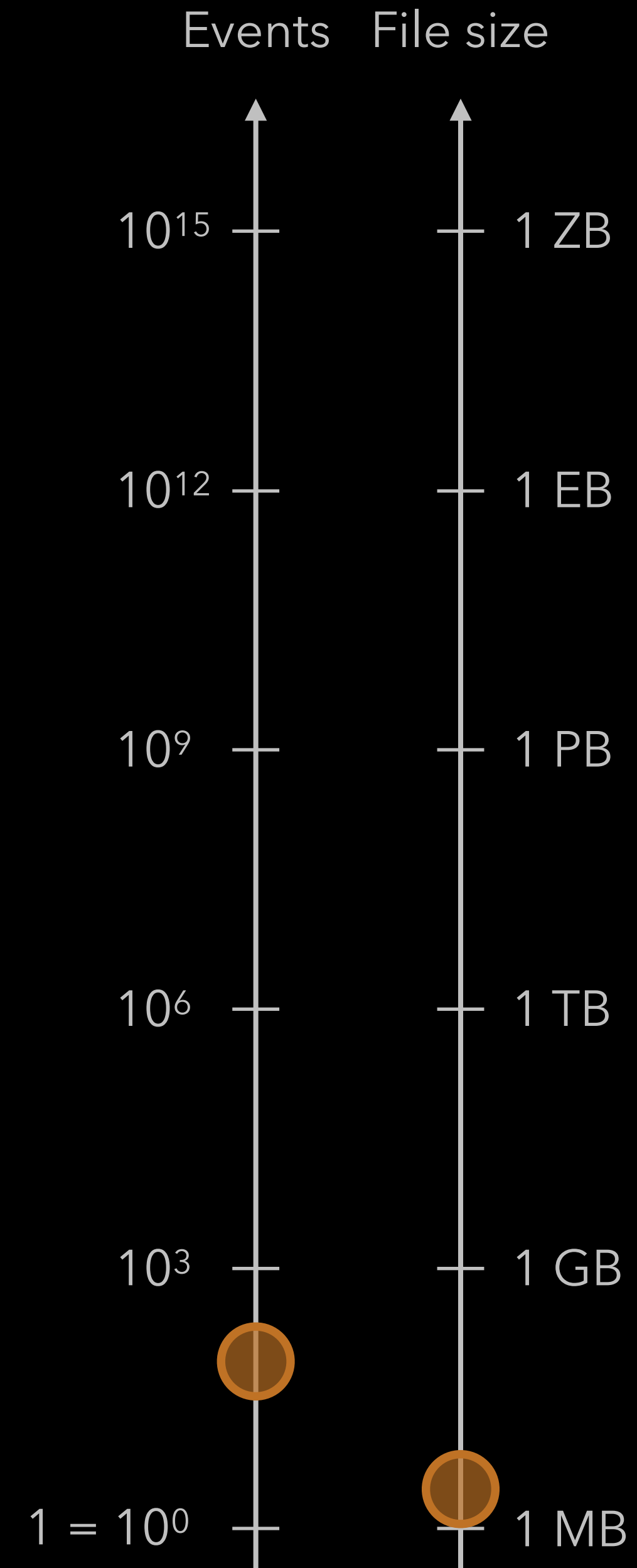
$m_{jj}=2800$  GeV

$|\Delta y_{jj}|=6.3$



Run Number: 207490, Event Number: 33152138

Date: 2012-07-26 04:16:35 UTC



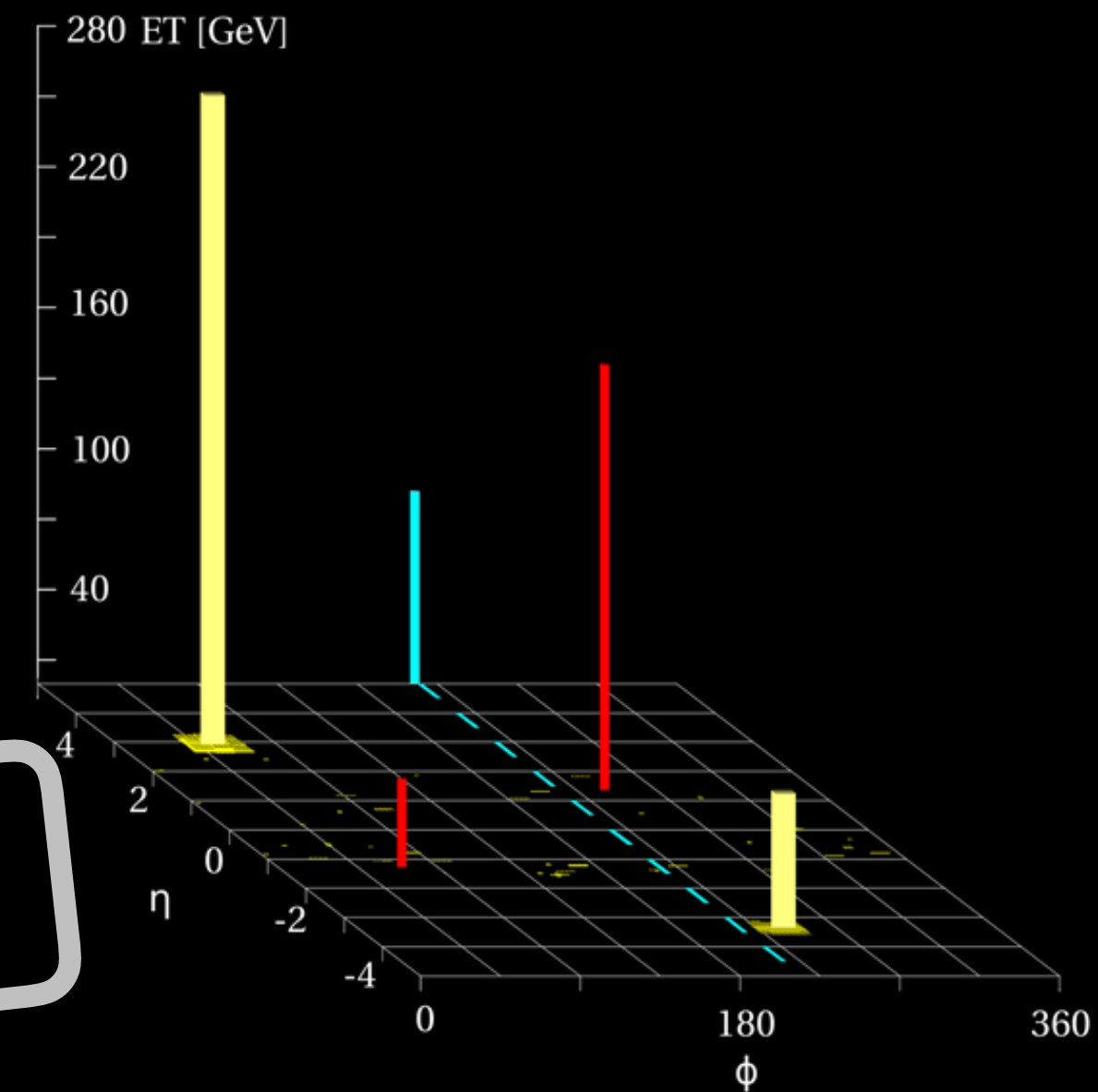
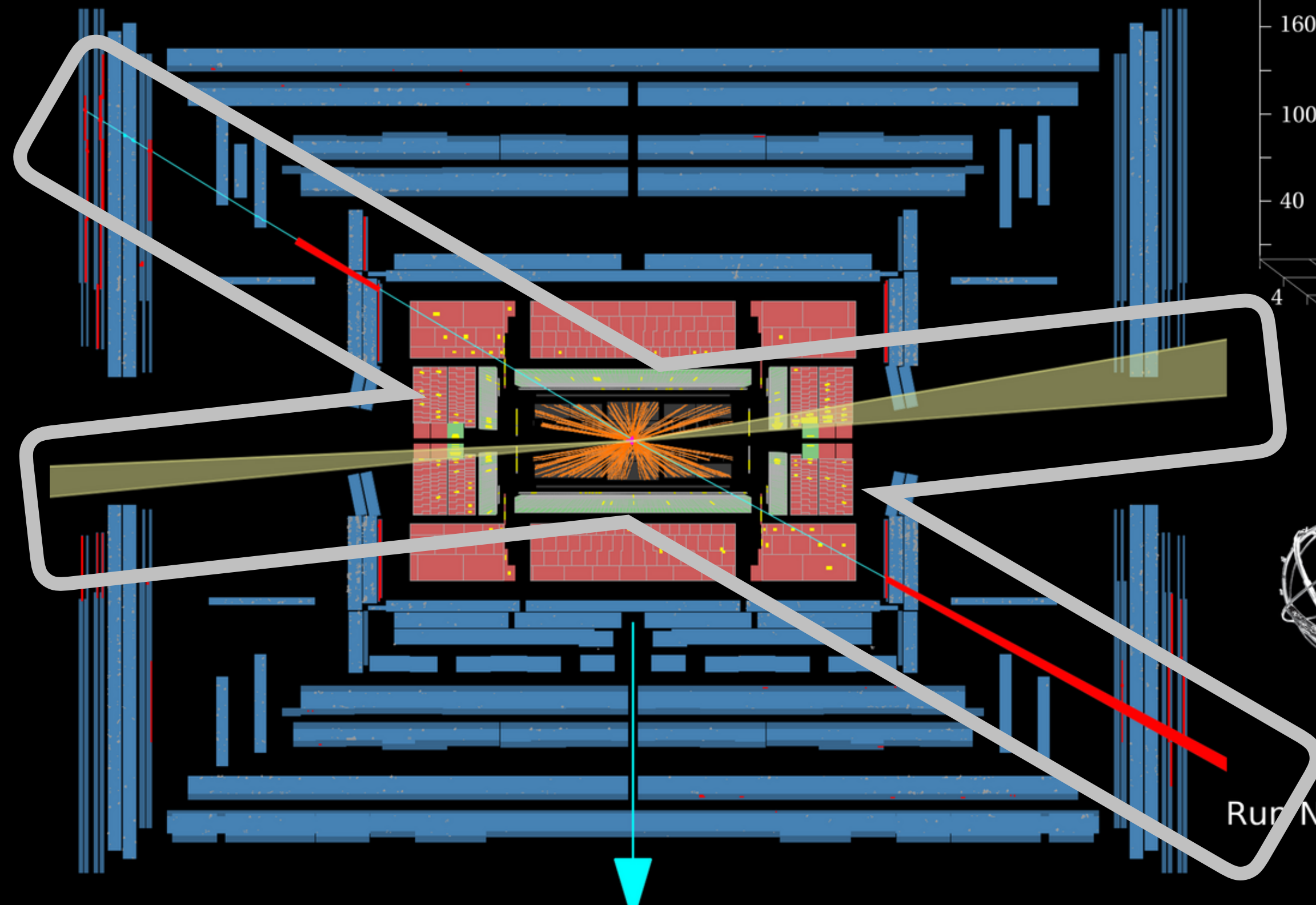
[Source: ATLAS Collaboration, PRL 113, 141803]

# Eventdisplay

$\mu^+\mu^+jj$  Candidate Event

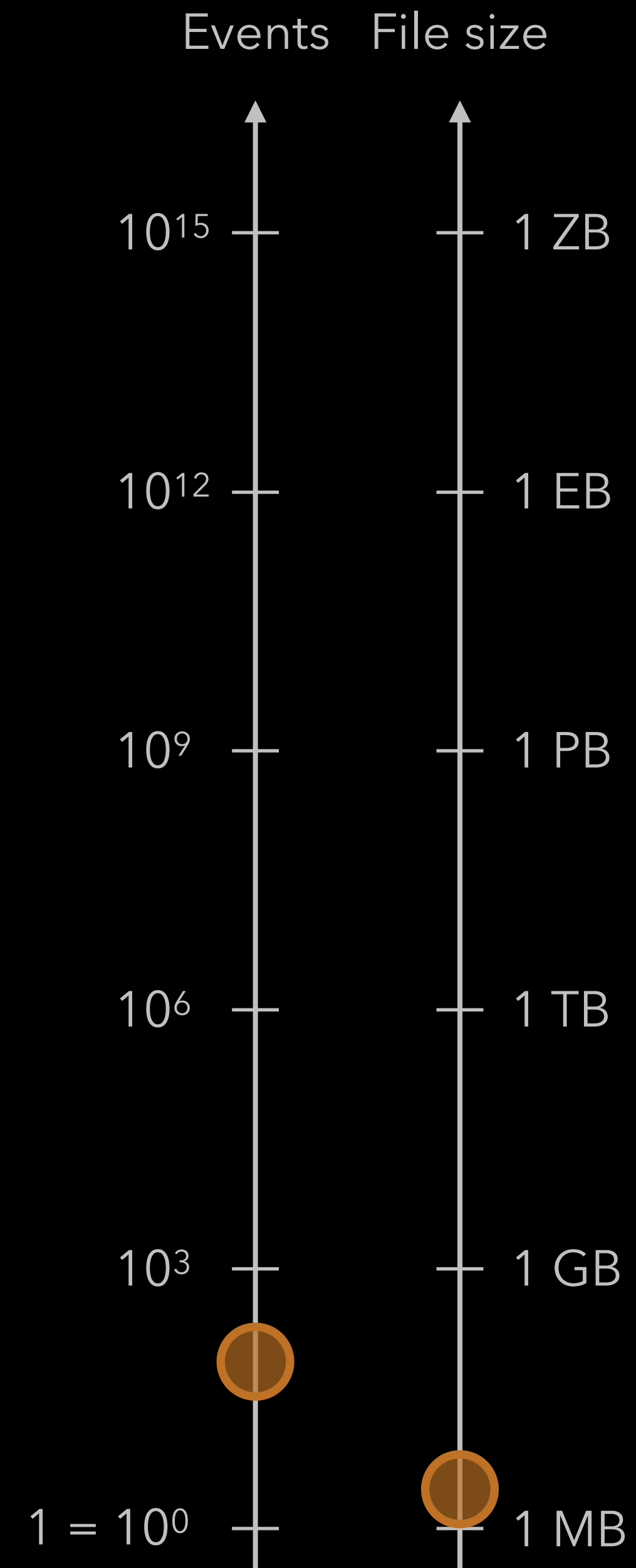
$m_{jj}=2800$  GeV

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Run Number: 207490, Event Number: 33152138

Date: 2012-07-26 04:16:35 UTC



[Source: ATLAS Collaboration, PRL 113, 141803]



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# Studying the Events: Count

Example:

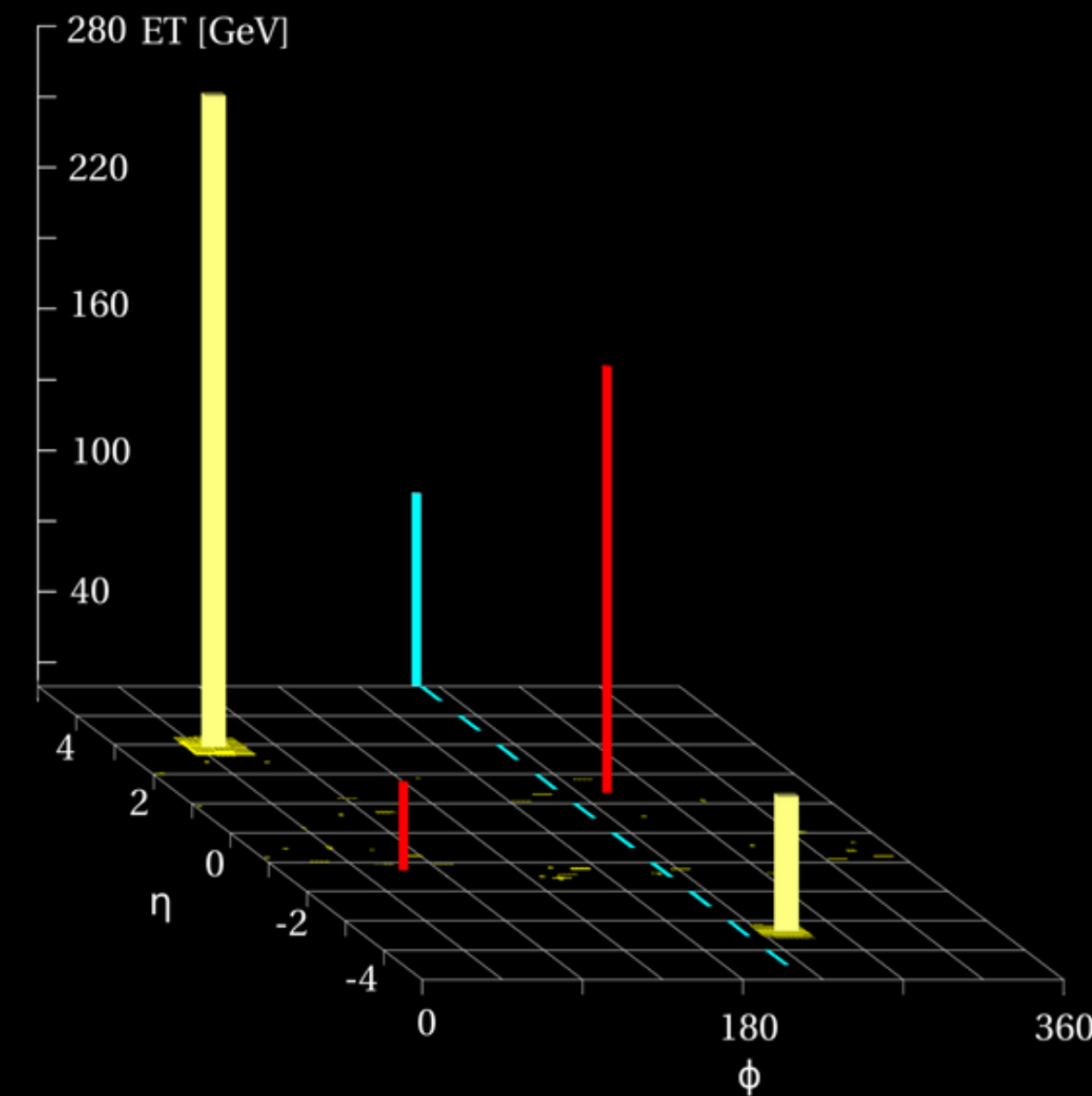
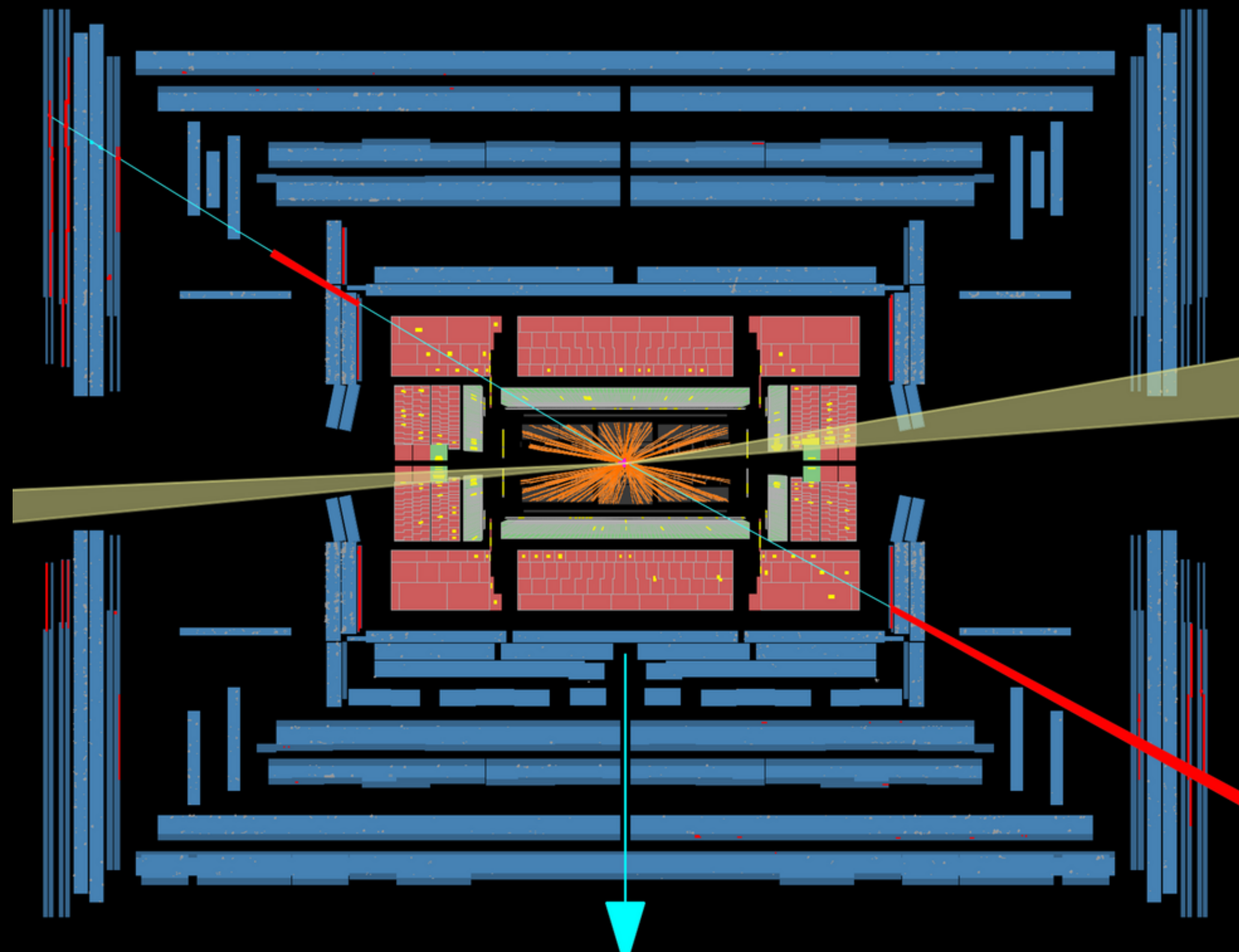
- Prediction for background processes:  $N_B = 7$
- Prediction for signal processes:  $N_S = 1$
- Observed number of events in data:  $N_{\text{data}} = 8$

# Studying the Events: Kinematic

$\mu^+\mu^+jj$  Candidate Event

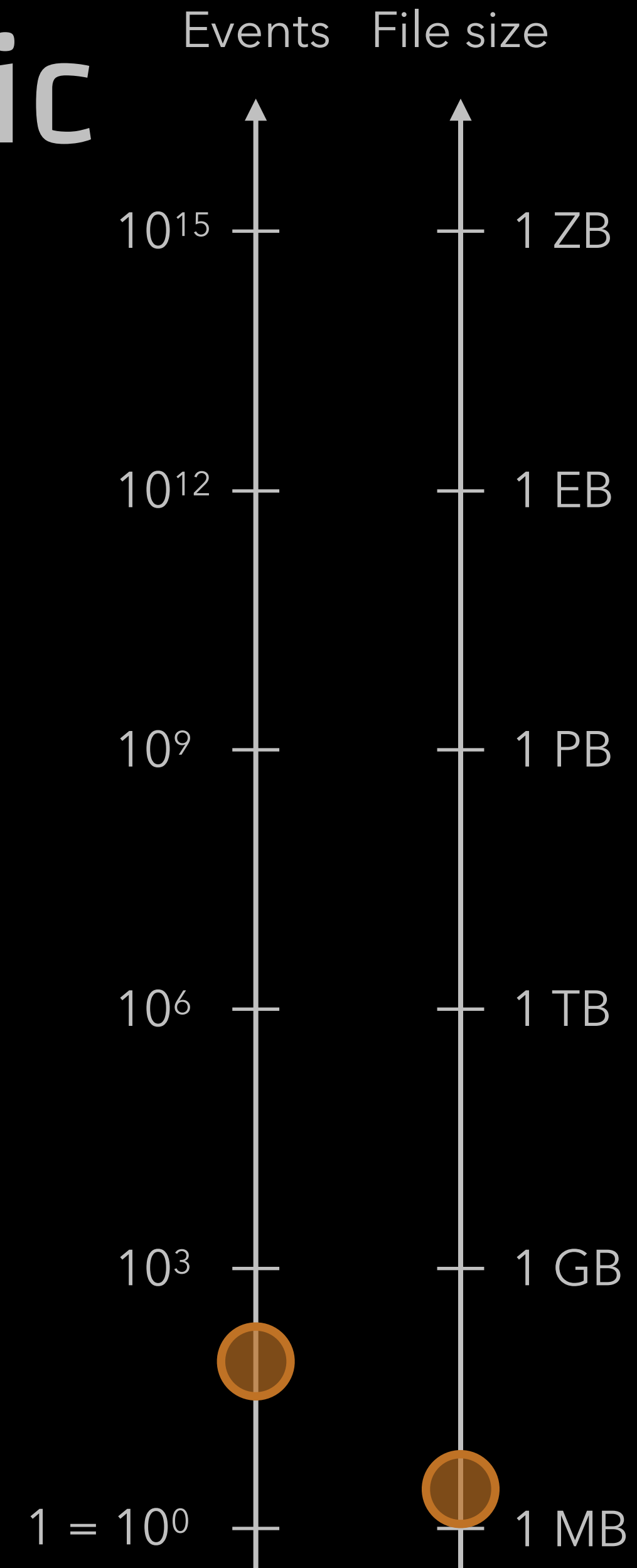
$m_{jj}=2800$  GeV

$|\Delta y_{jj}|=6.3$



Run Number: 207490, Event Number: 33152138

Date: 2012-07-26 04:16:35 UTC



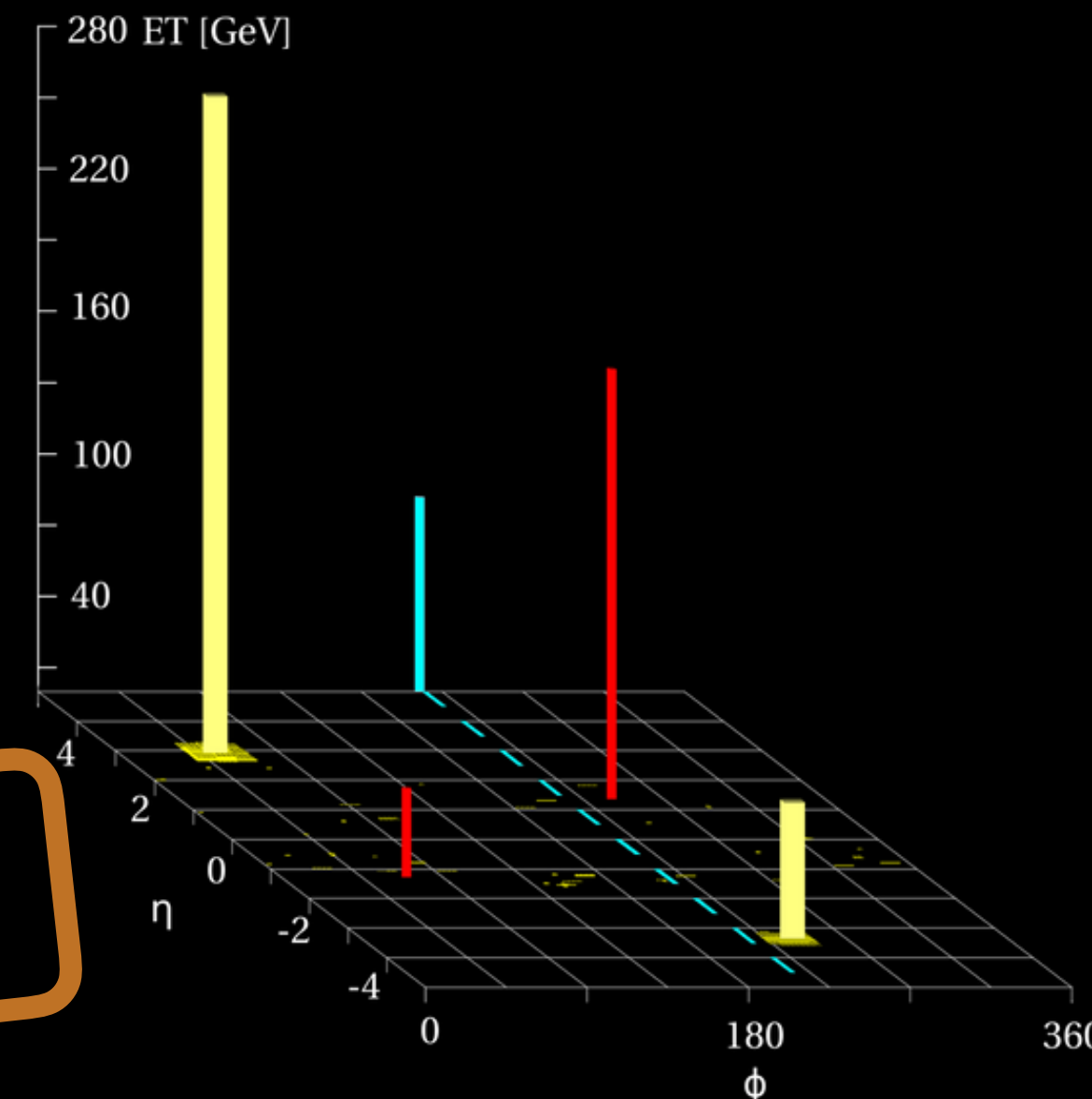
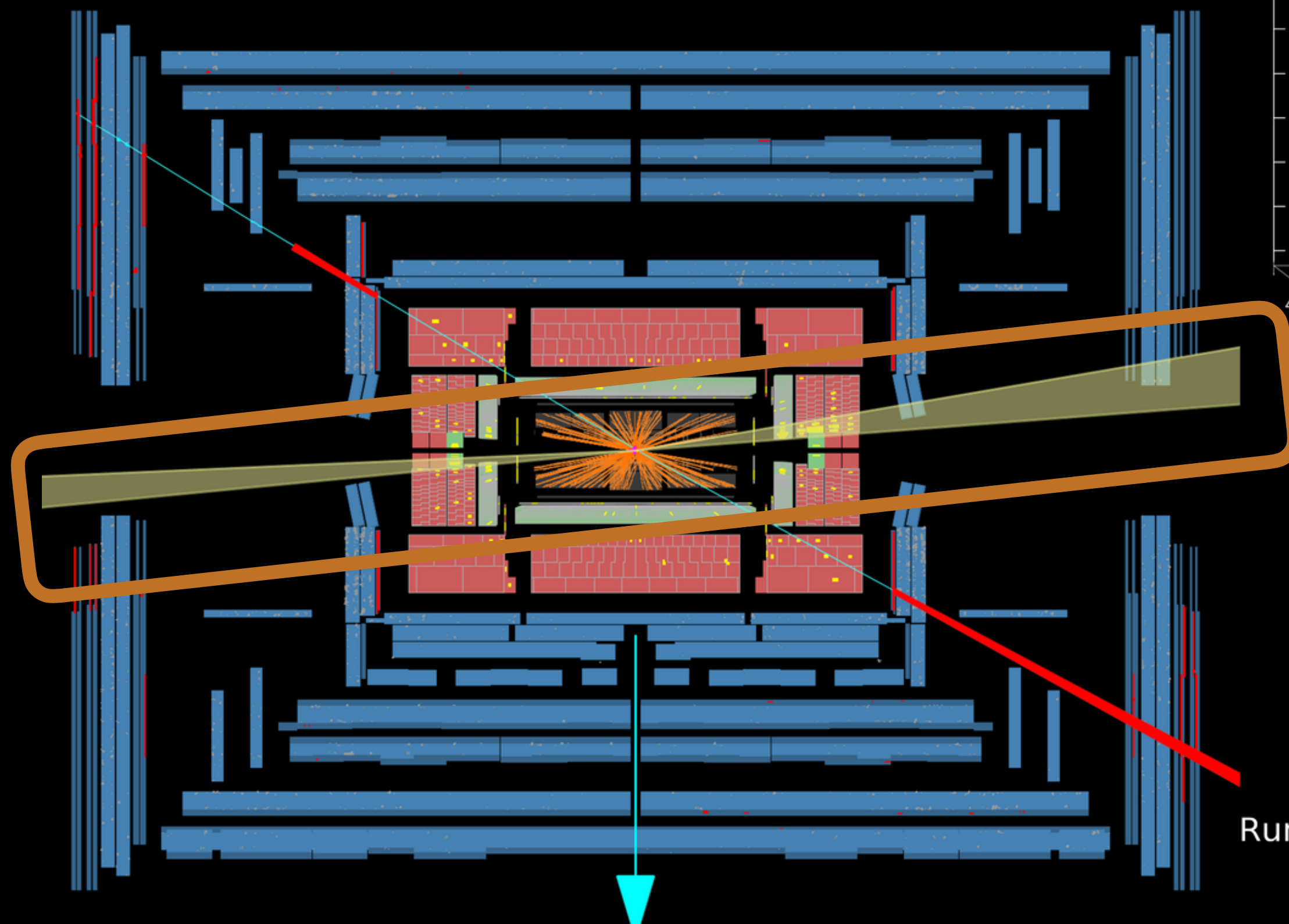
[Source: ATLAS Collaboration, PRL 113, 141803]

# Studying the Events: Kinematic

$\mu^+\mu^+jj$  Candidate Event

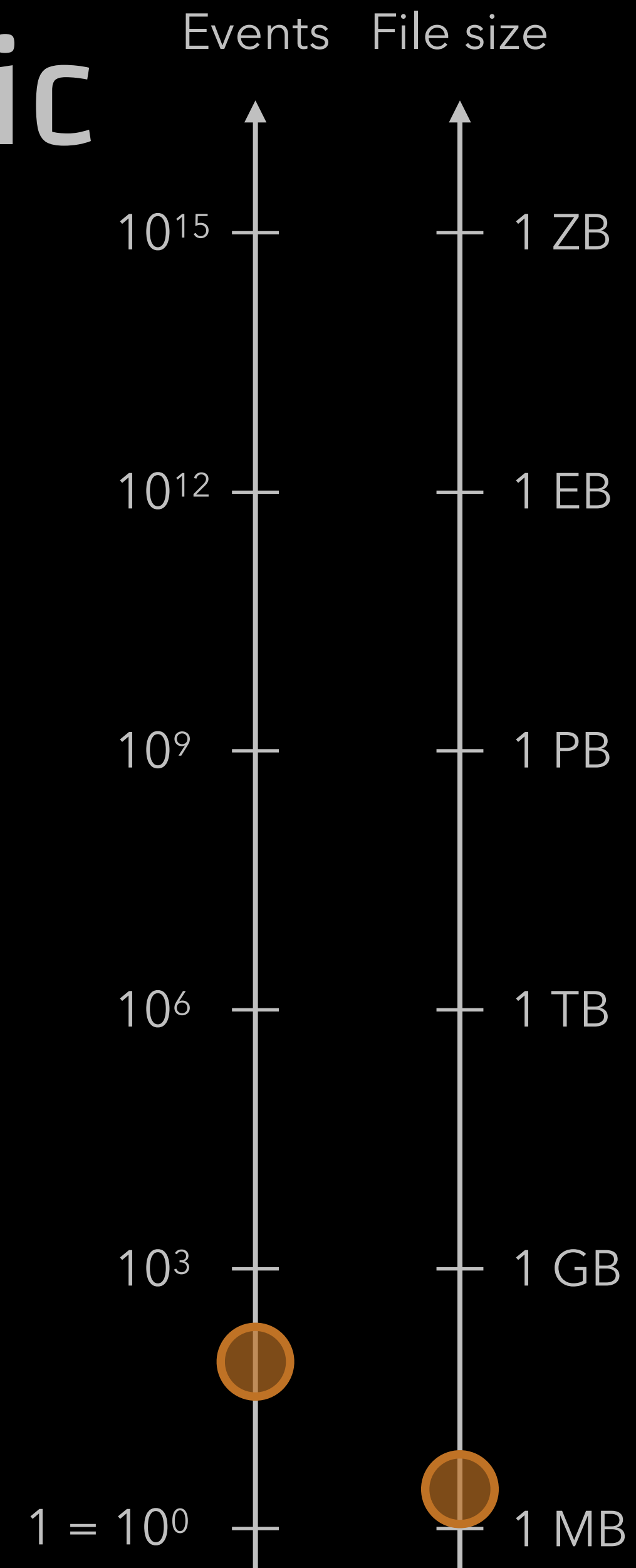
$m_{jj}=2800$  GeV

$|\Delta y_{jj}|=6.3$



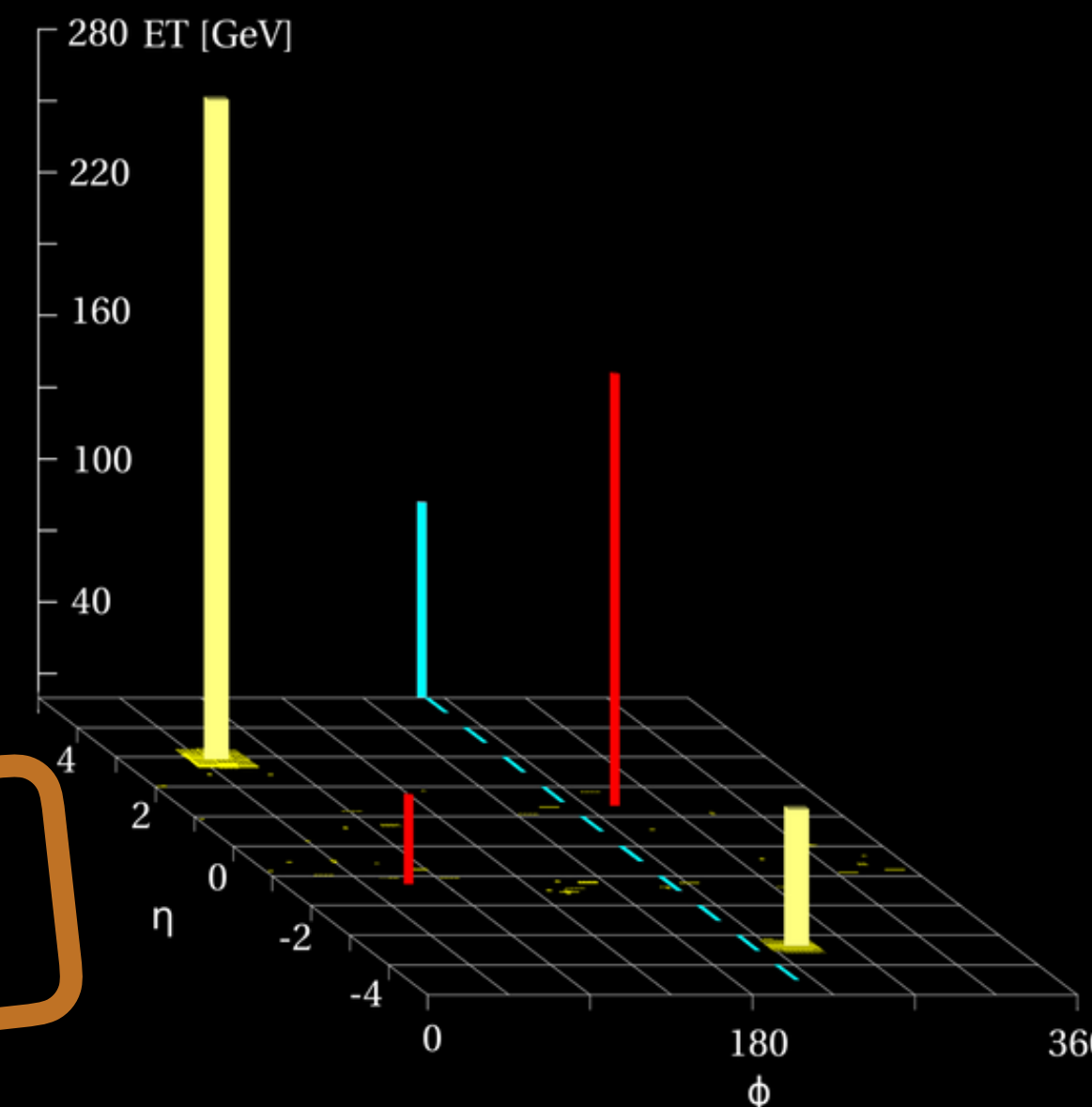
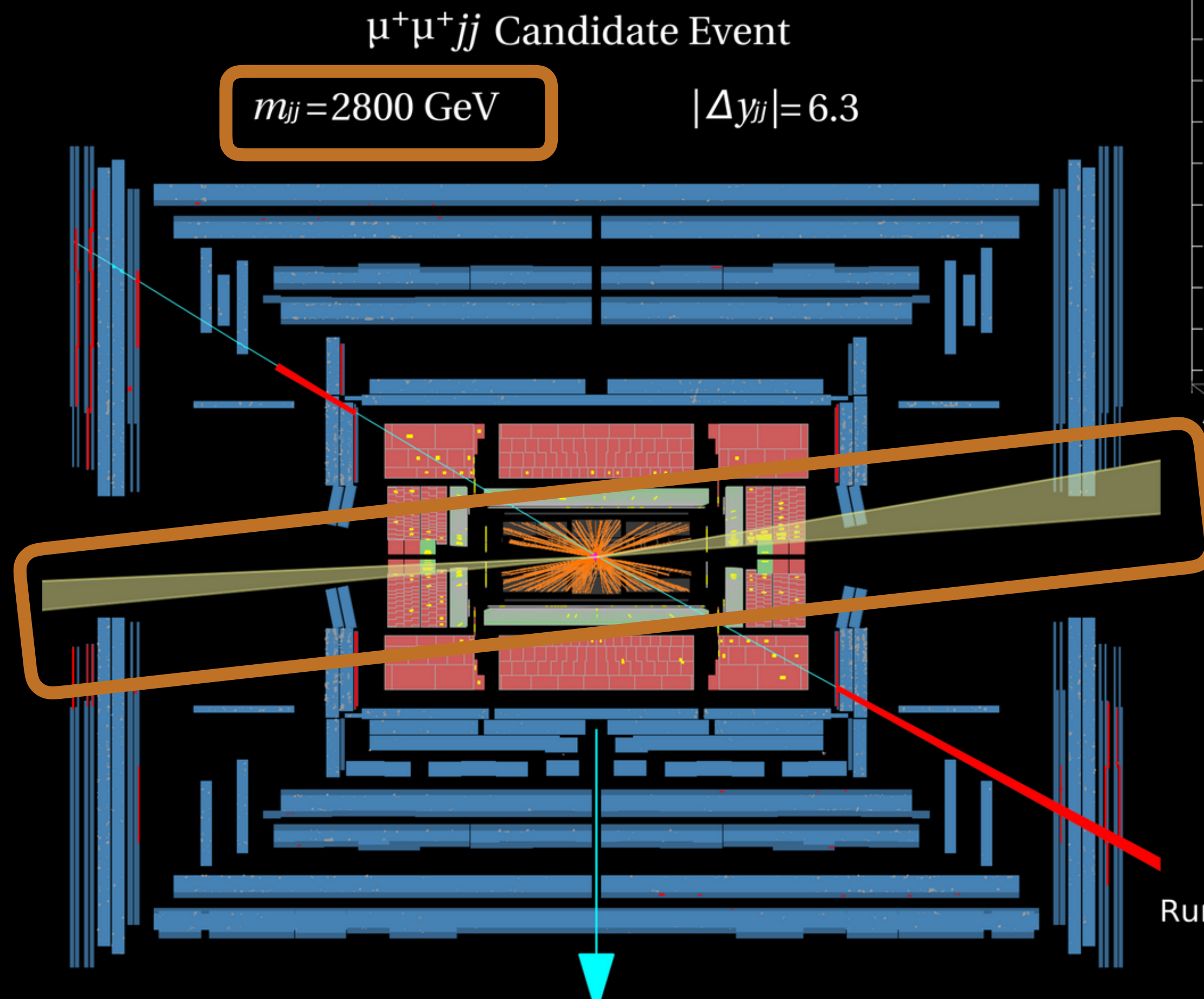
Run Number: 207490, Event Number: 33152138

Date: 2012-07-26 04:16:35 UTC



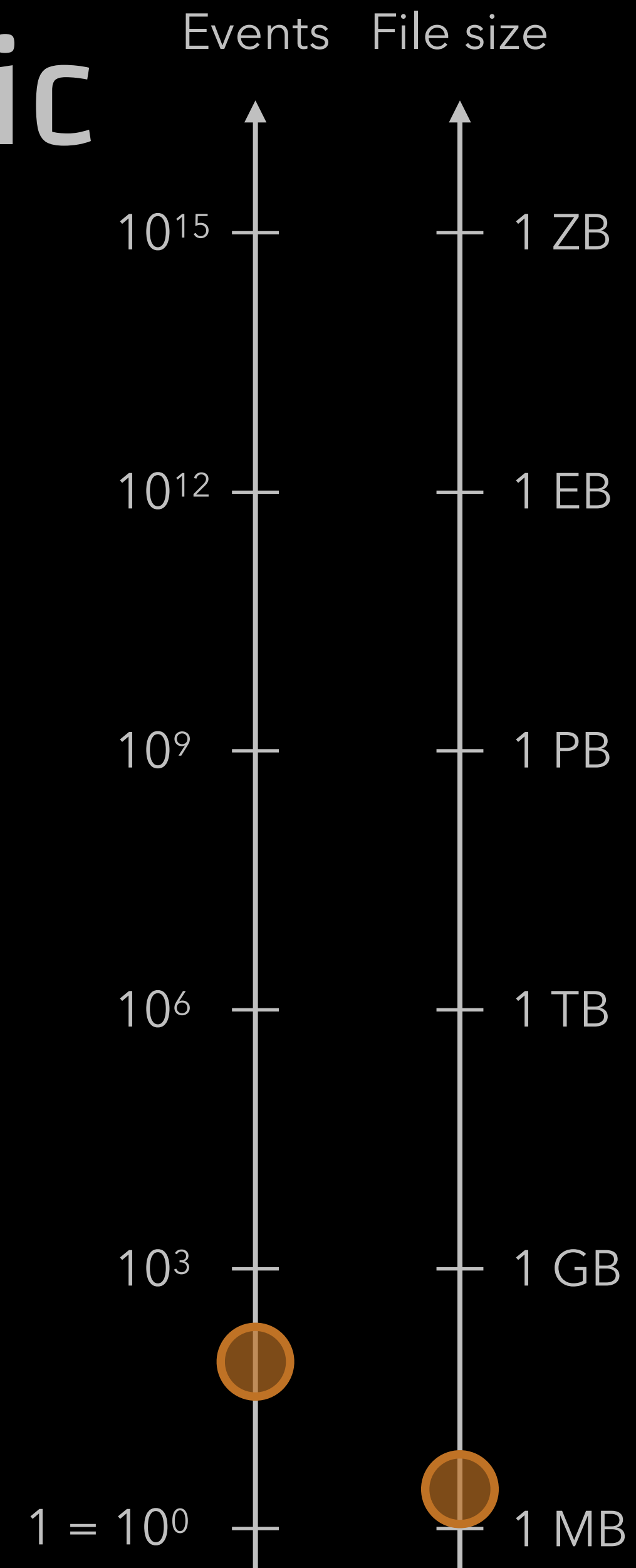
[Source: ATLAS Collaboration, PRL 113, 141803]

# Studying the Events: Kinematic



Run Number: 207490, Event Number: 33152138

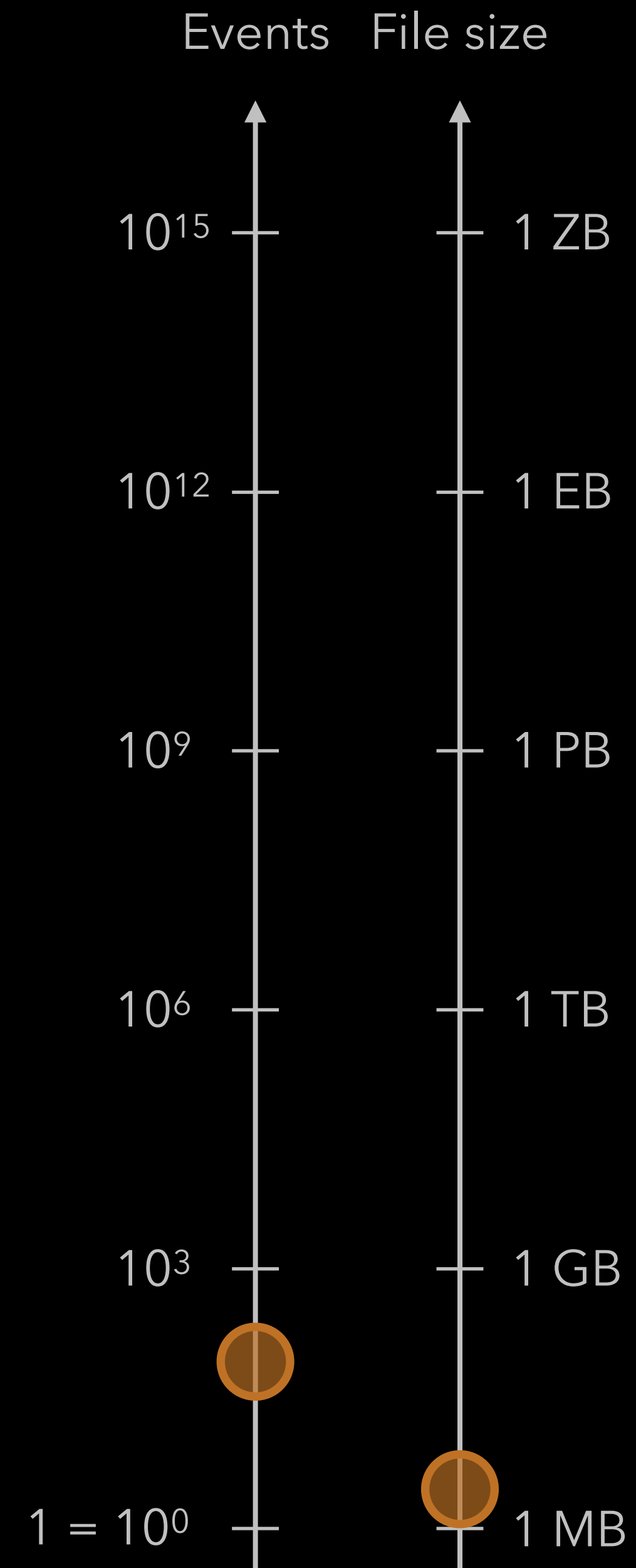
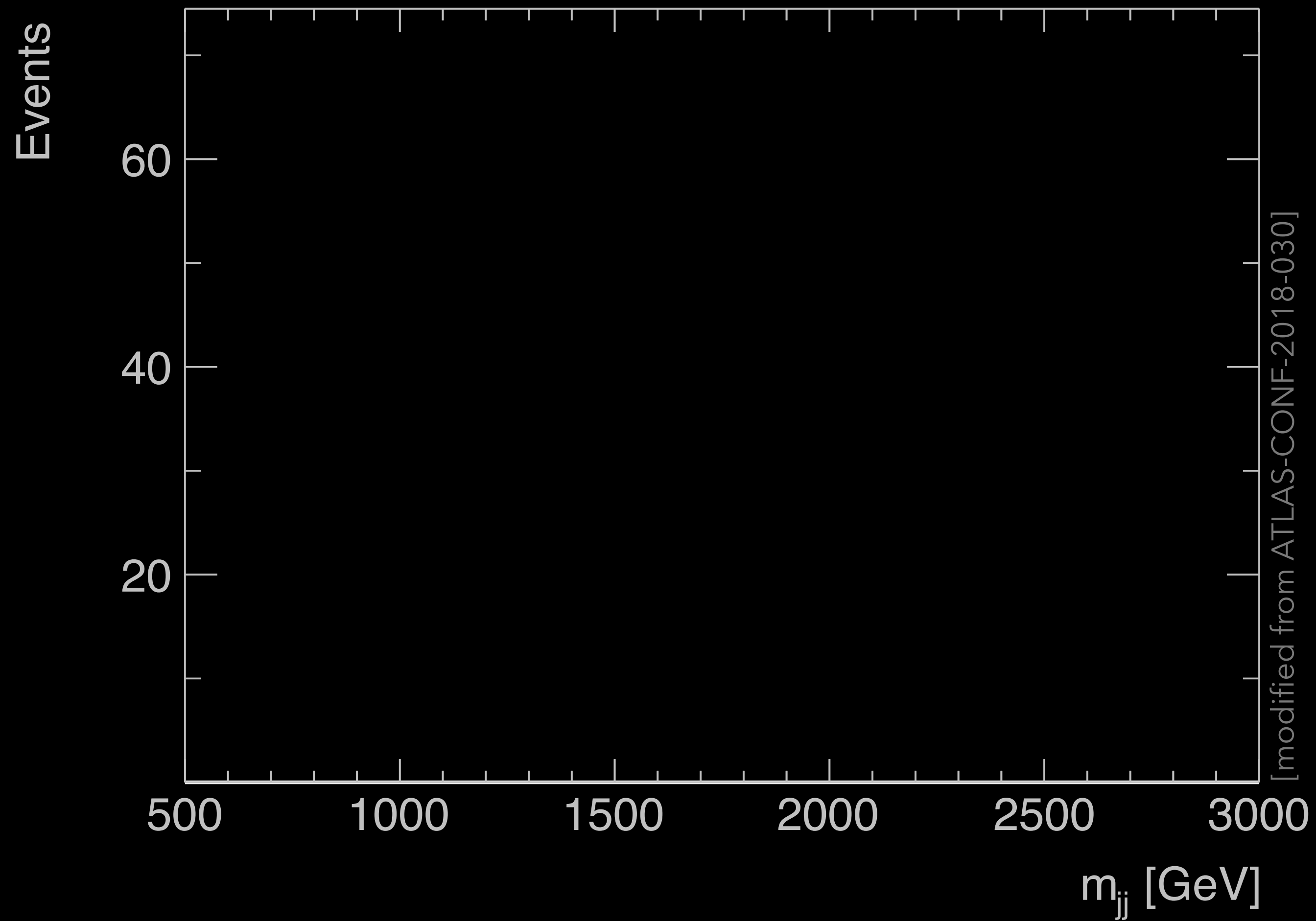
Date: 2012-07-26 04:16:35 UTC



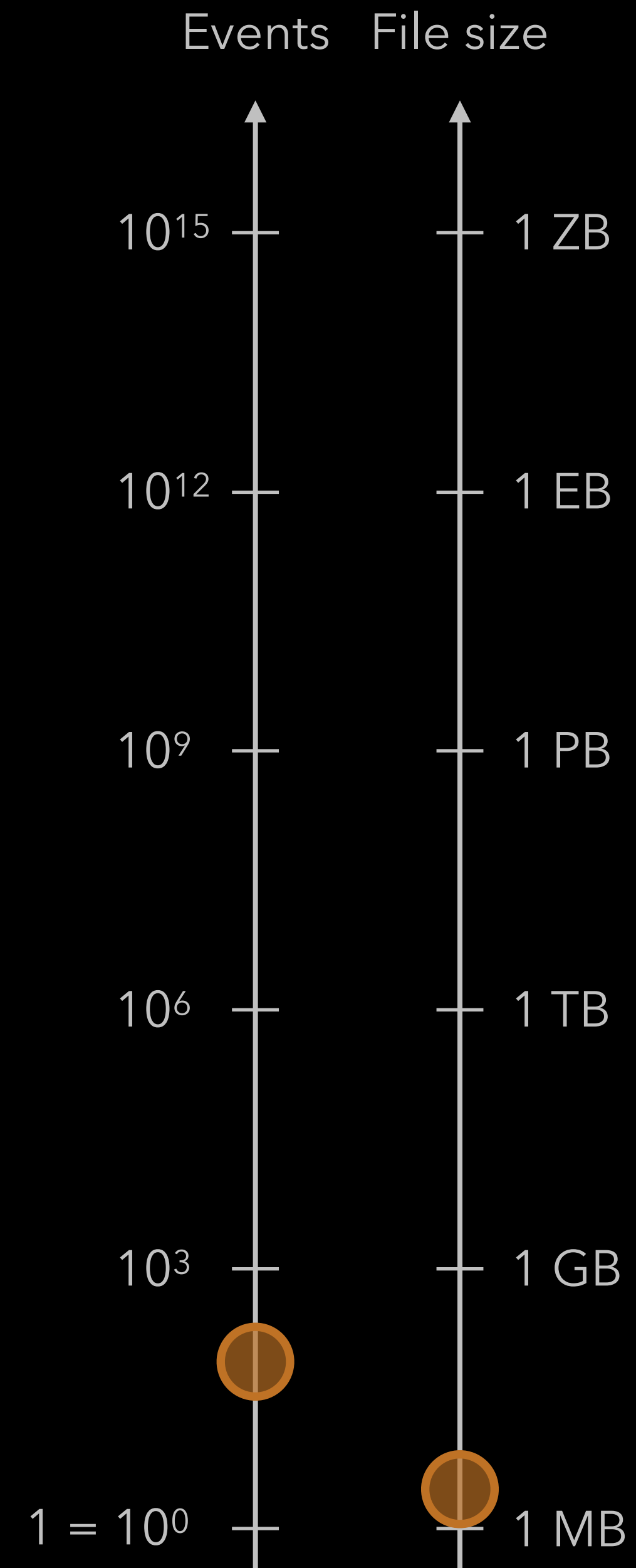
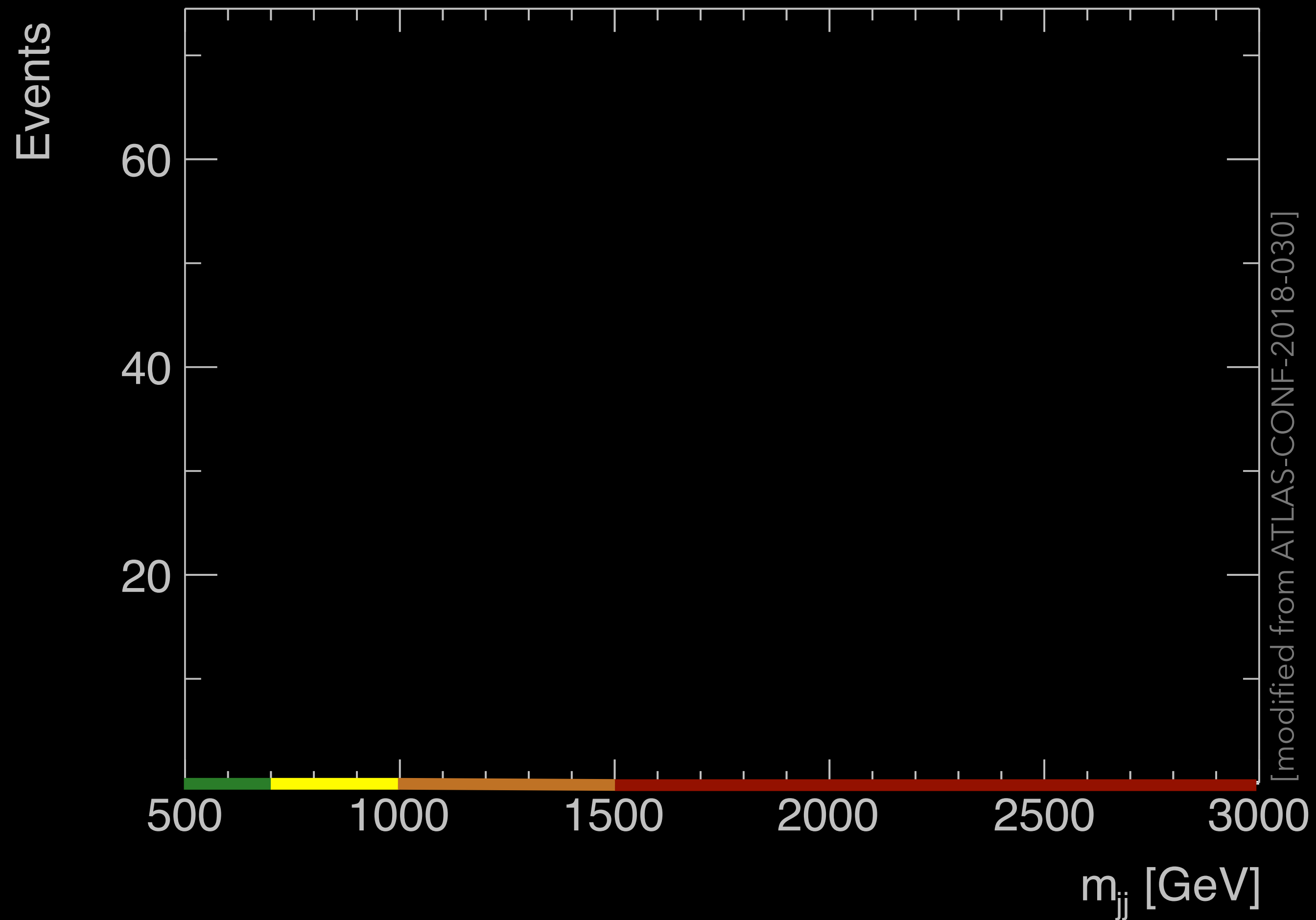
[Source: ATLAS Collaboration, PRL 113, 141803]



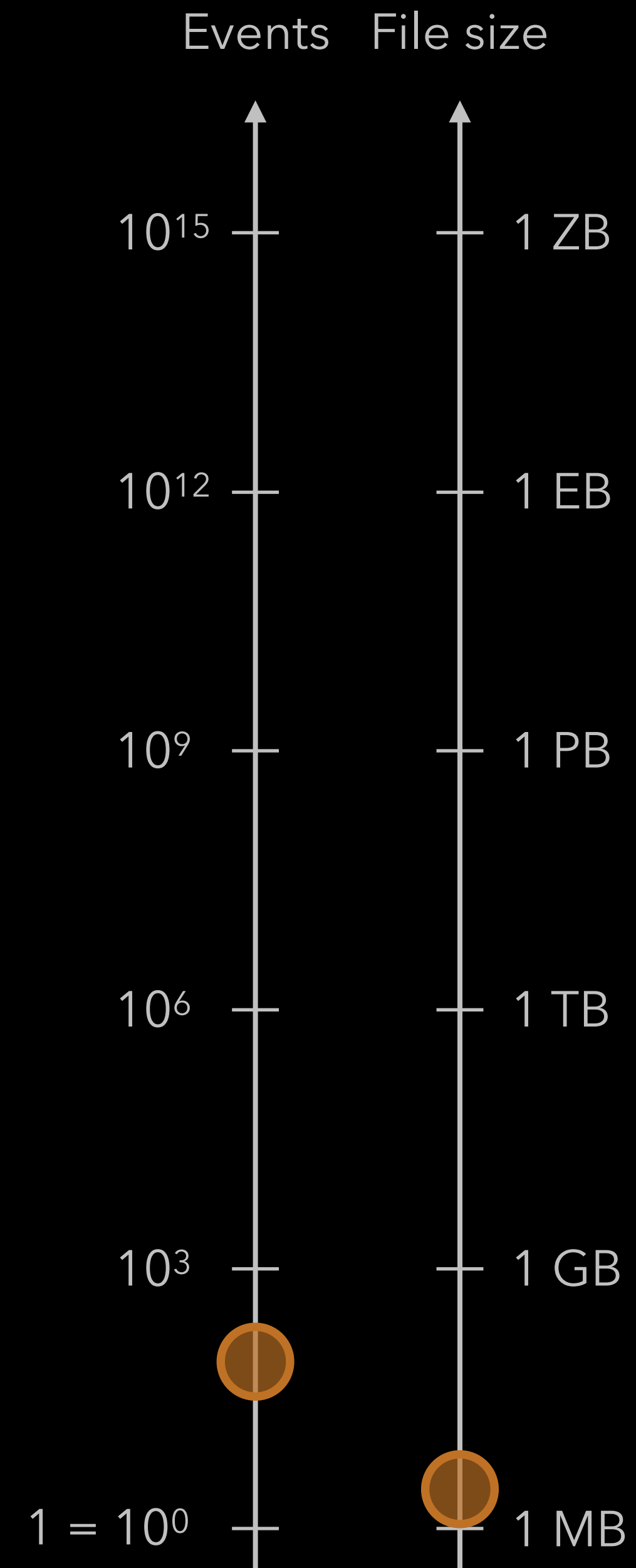
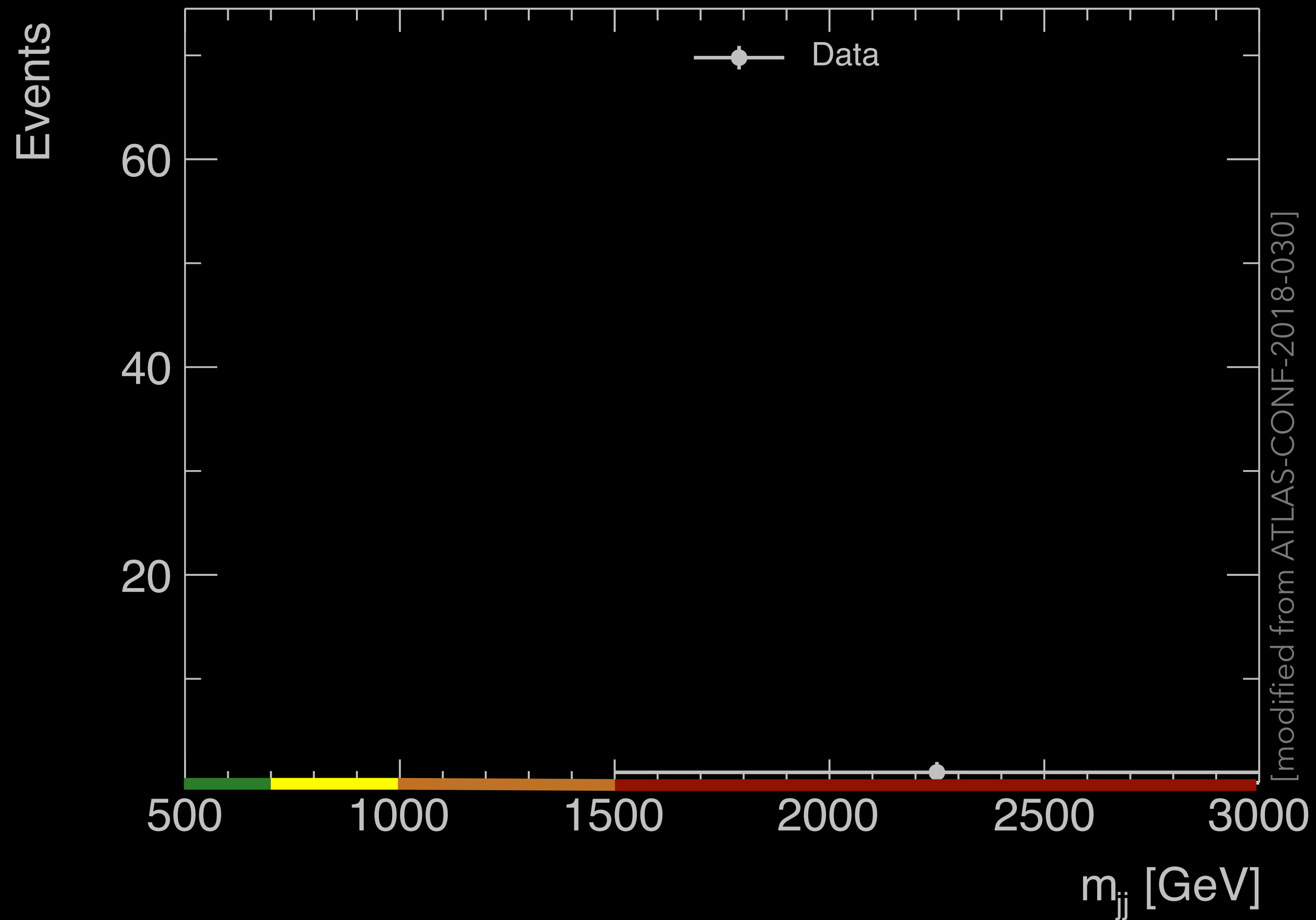
# Looking at Distributions



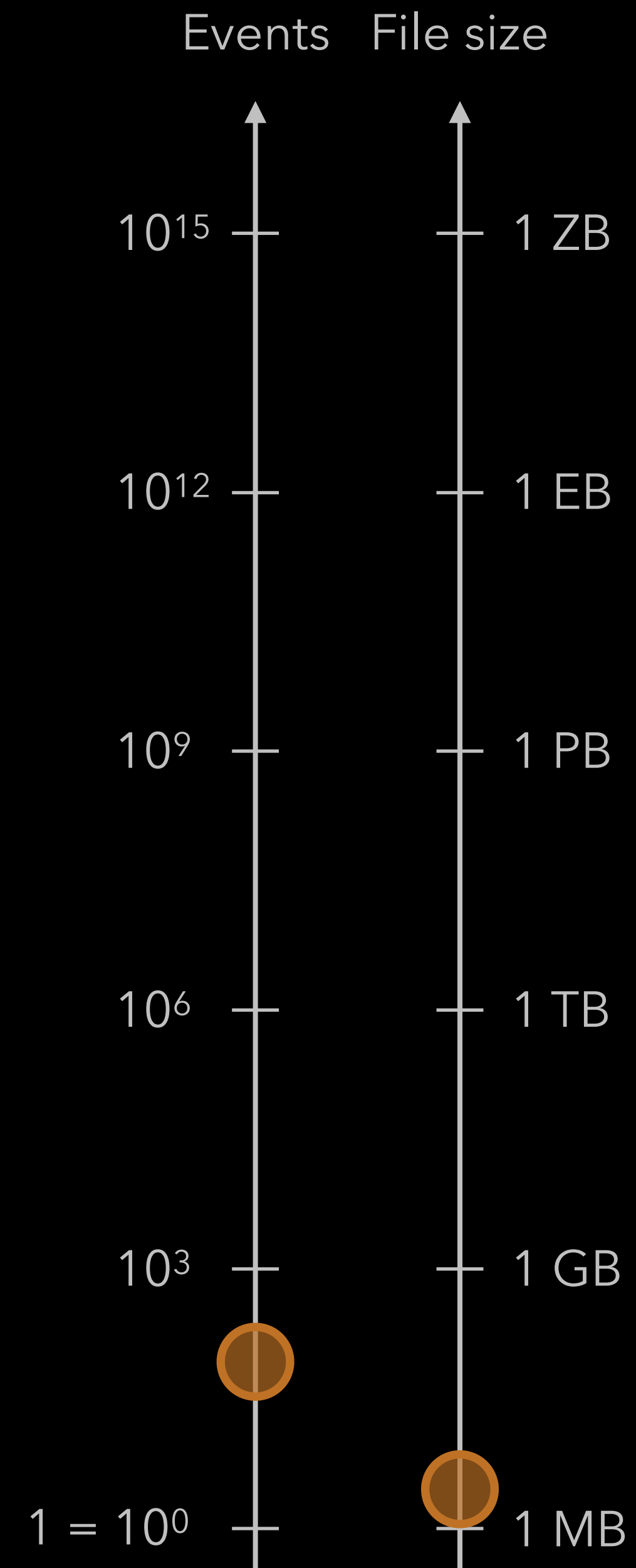
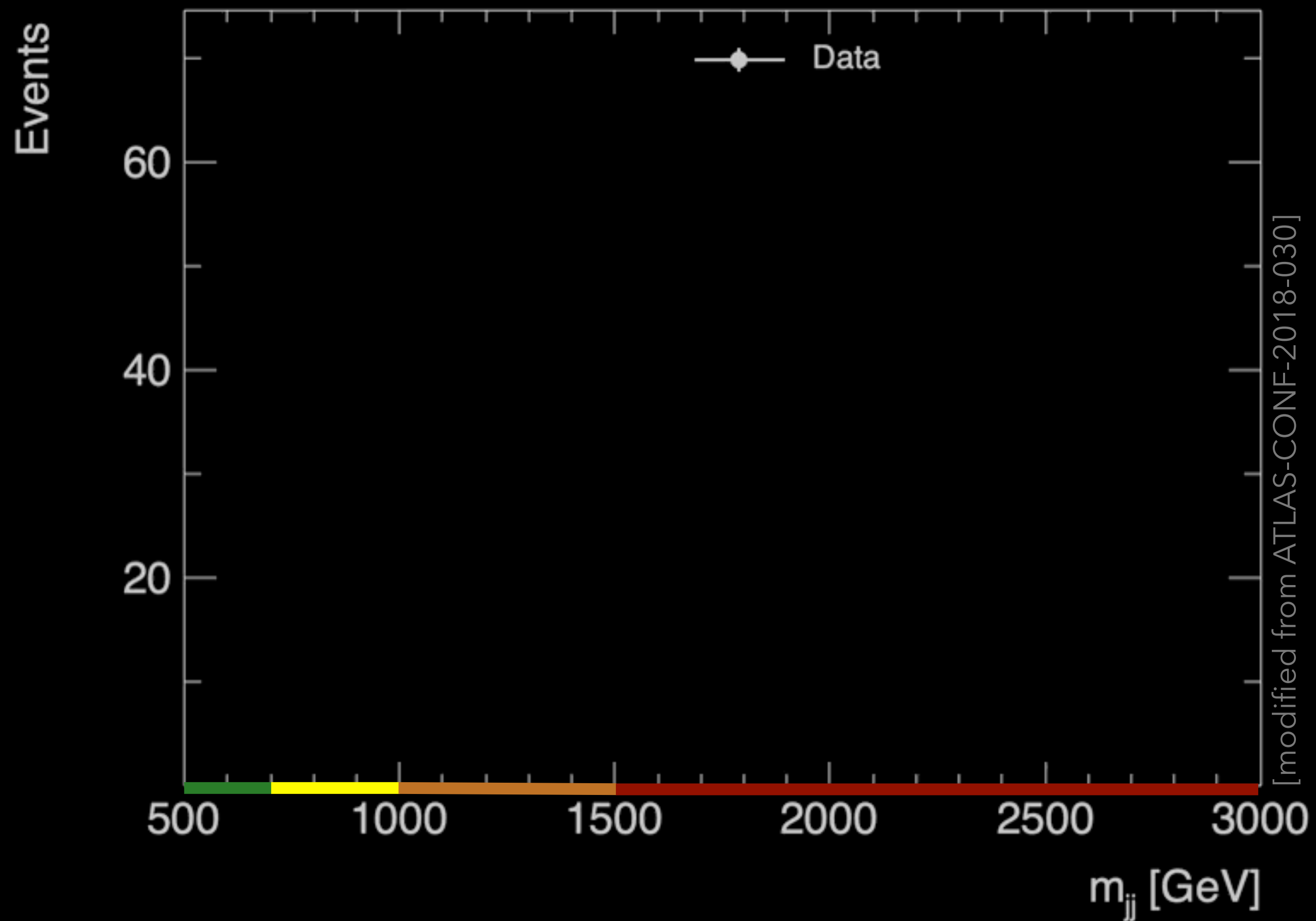
# Looking at Distributions



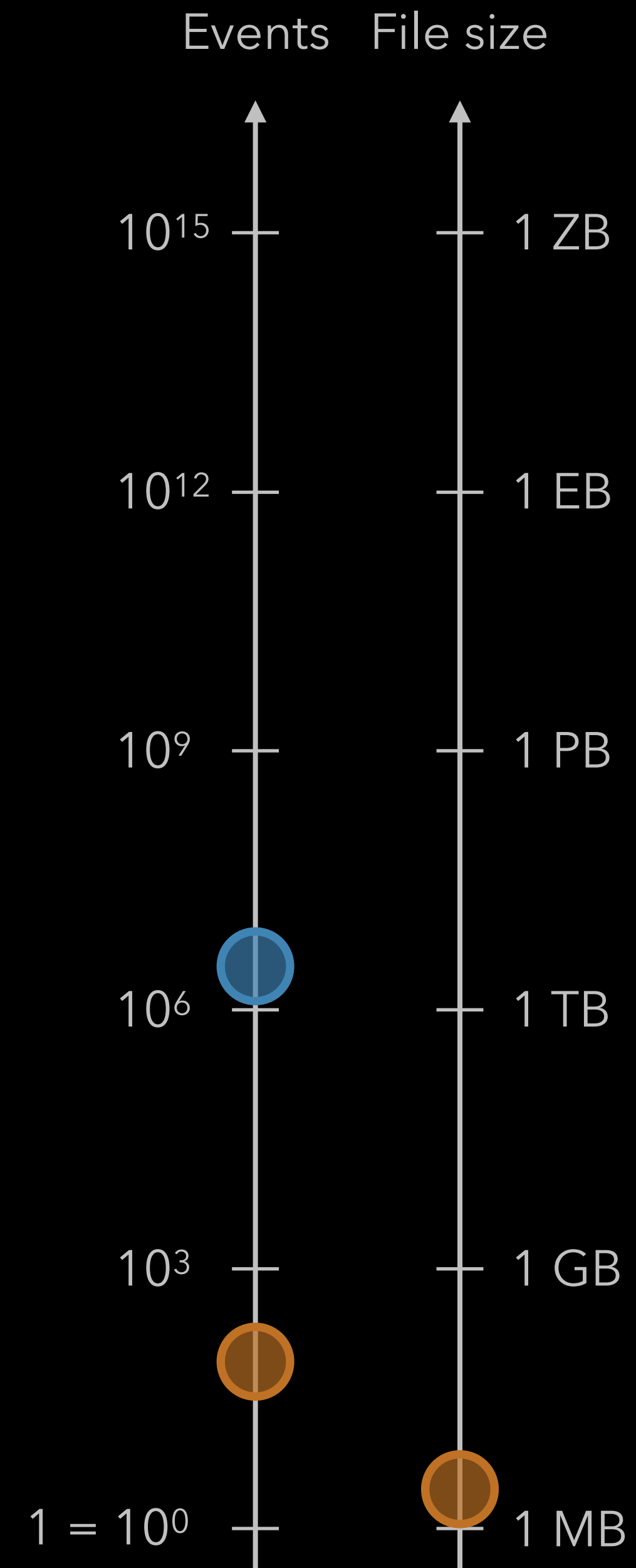
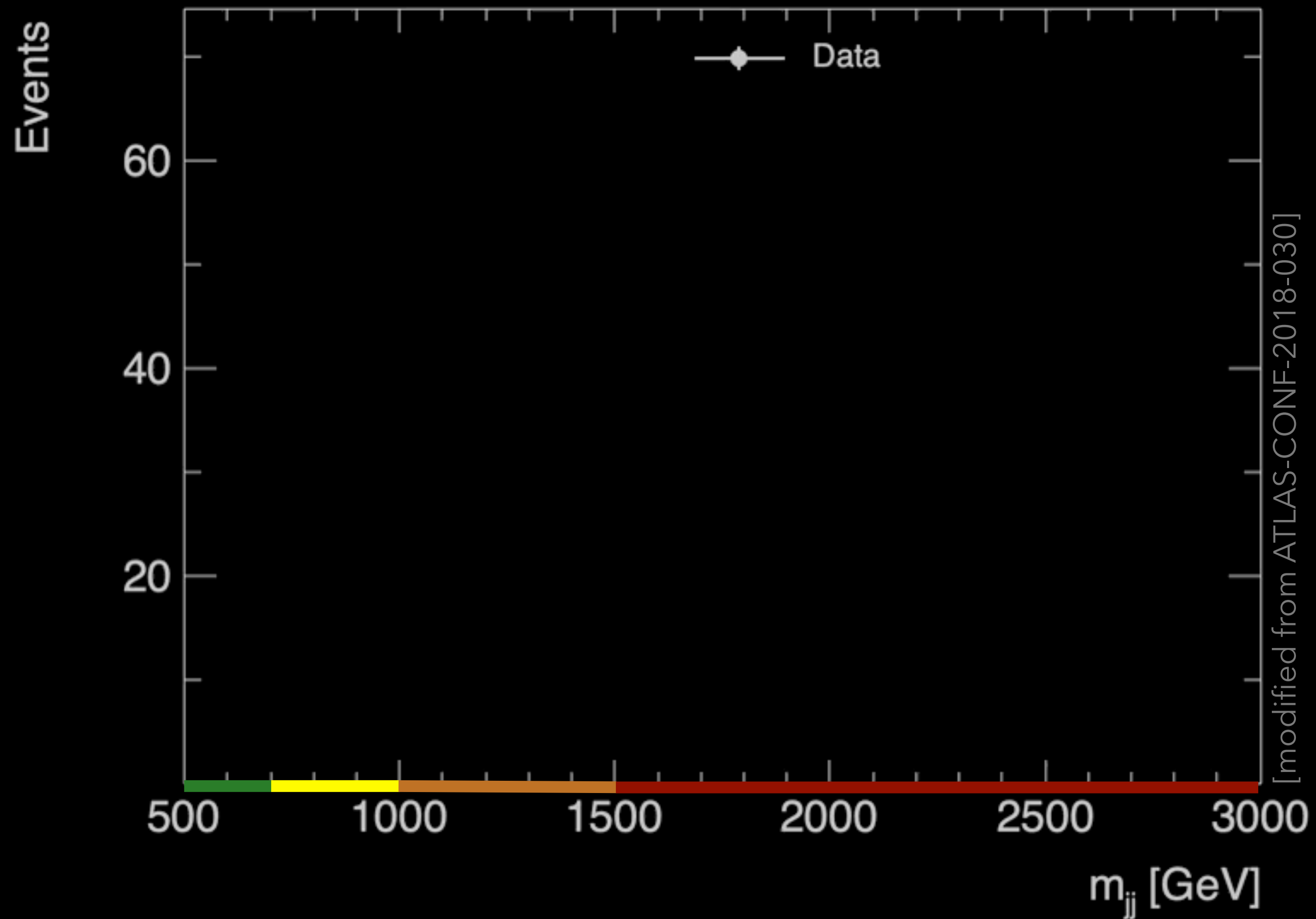
# Looking at Distributions



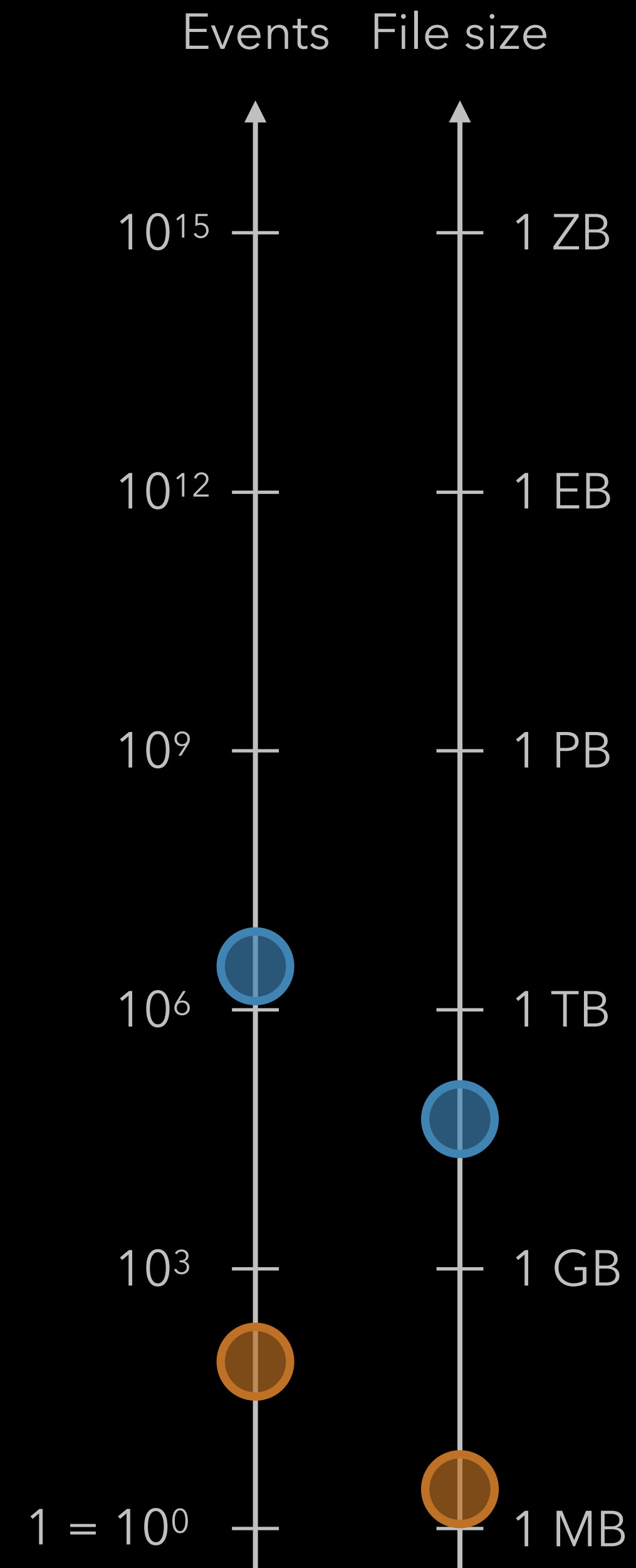
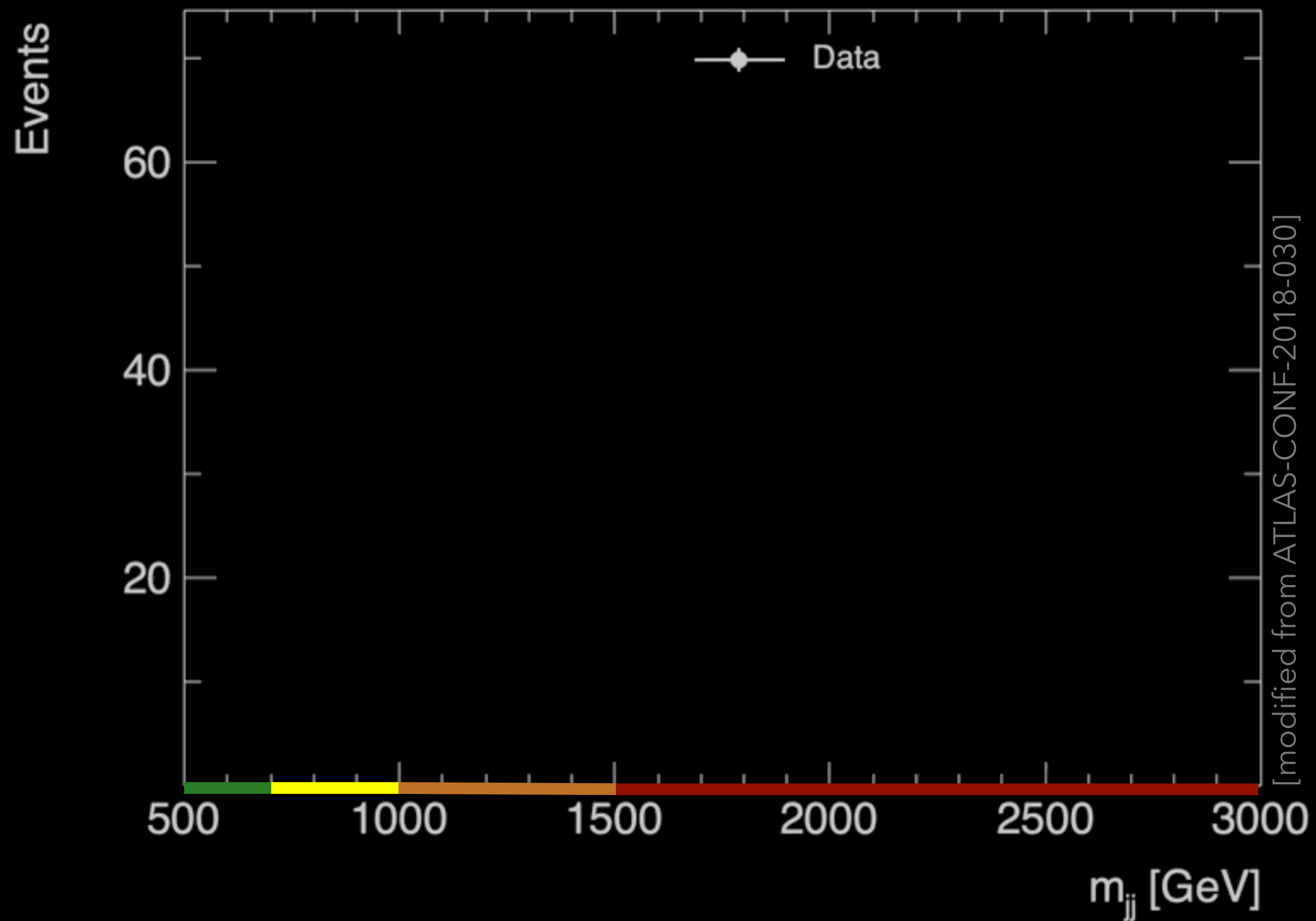
# Looking at Distributions



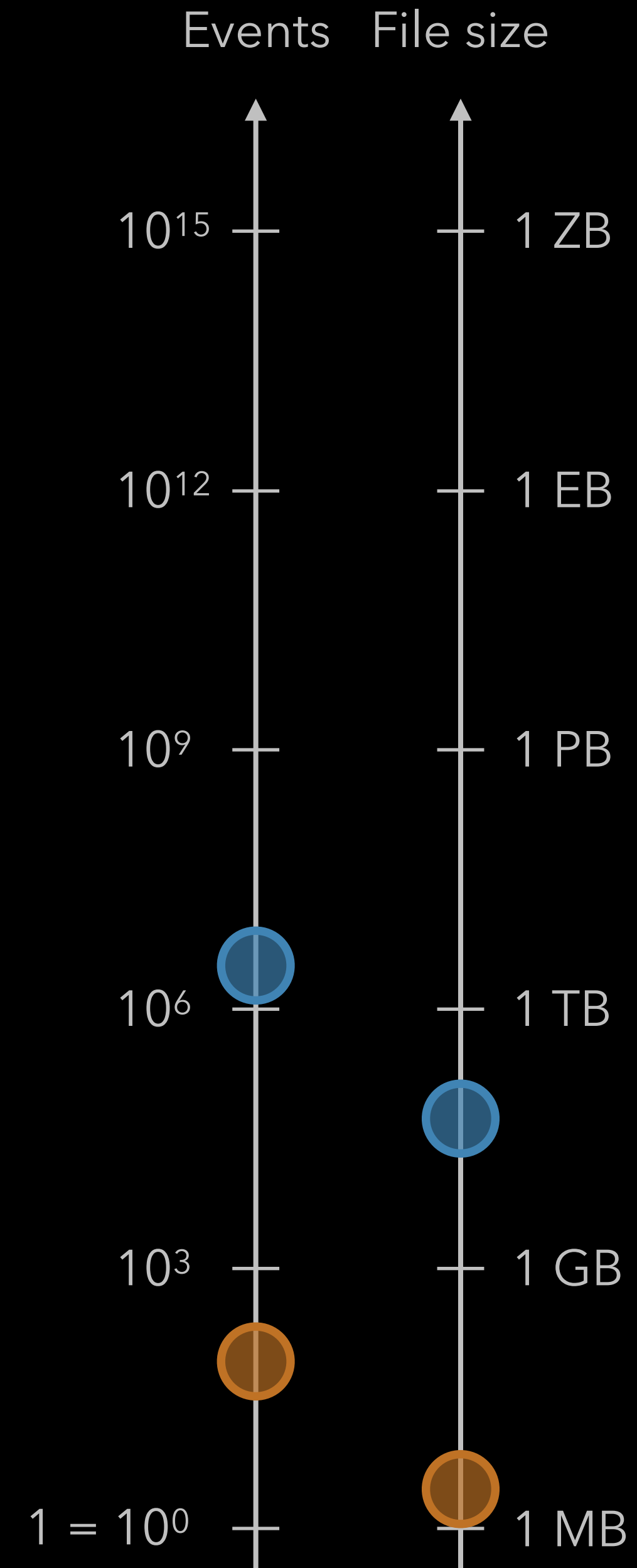
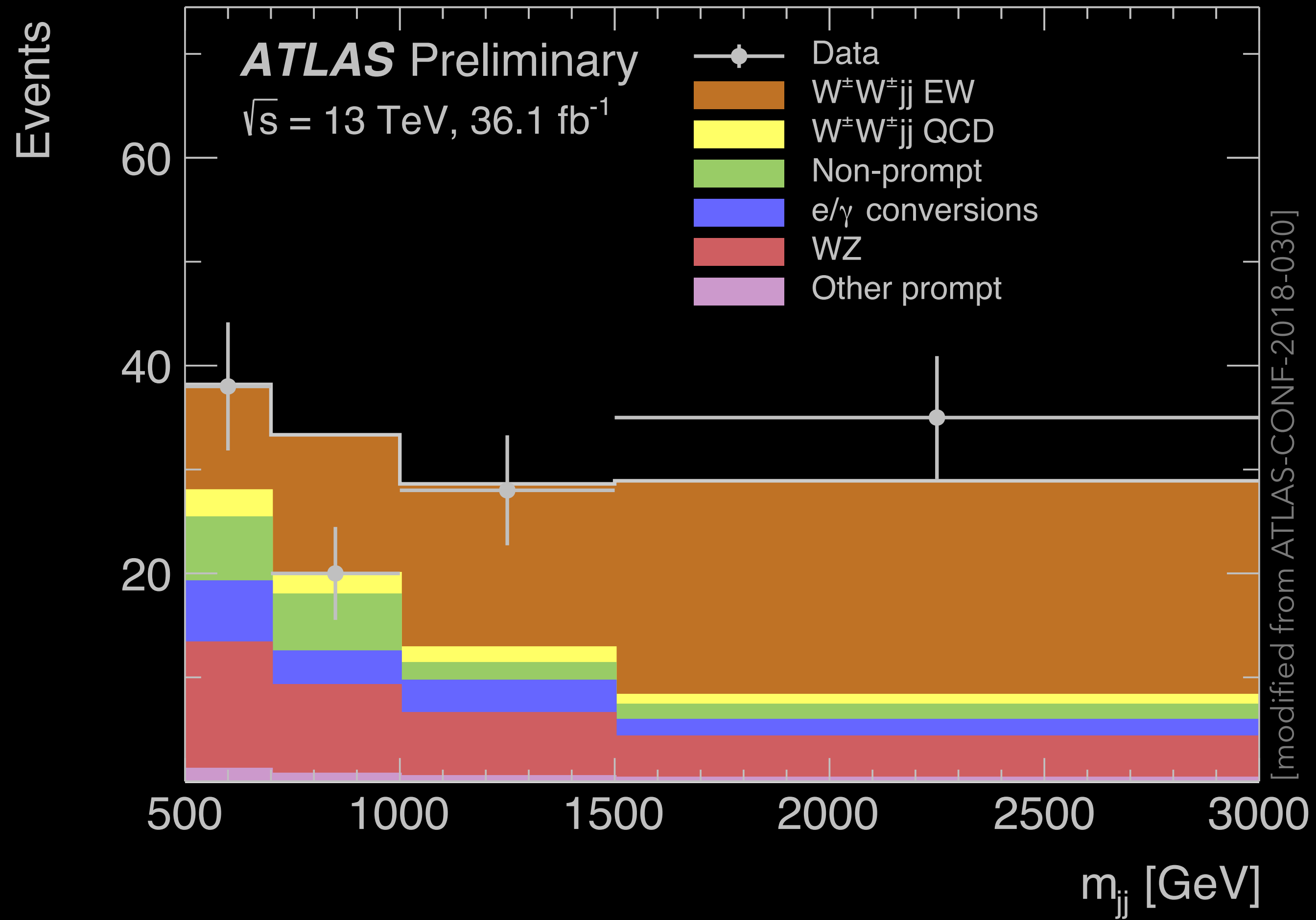
# Looking at Distributions



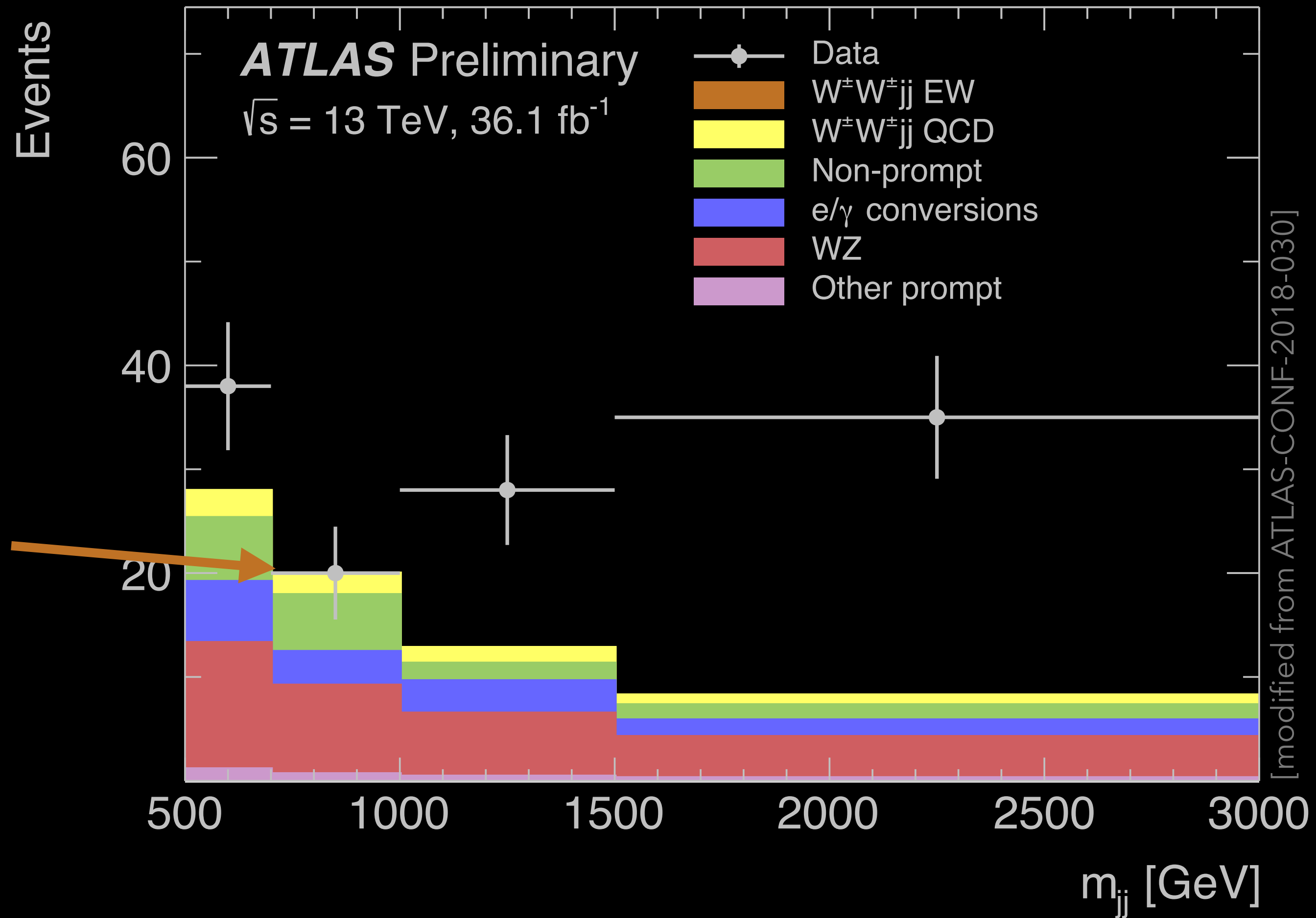
# Looking at Distributions



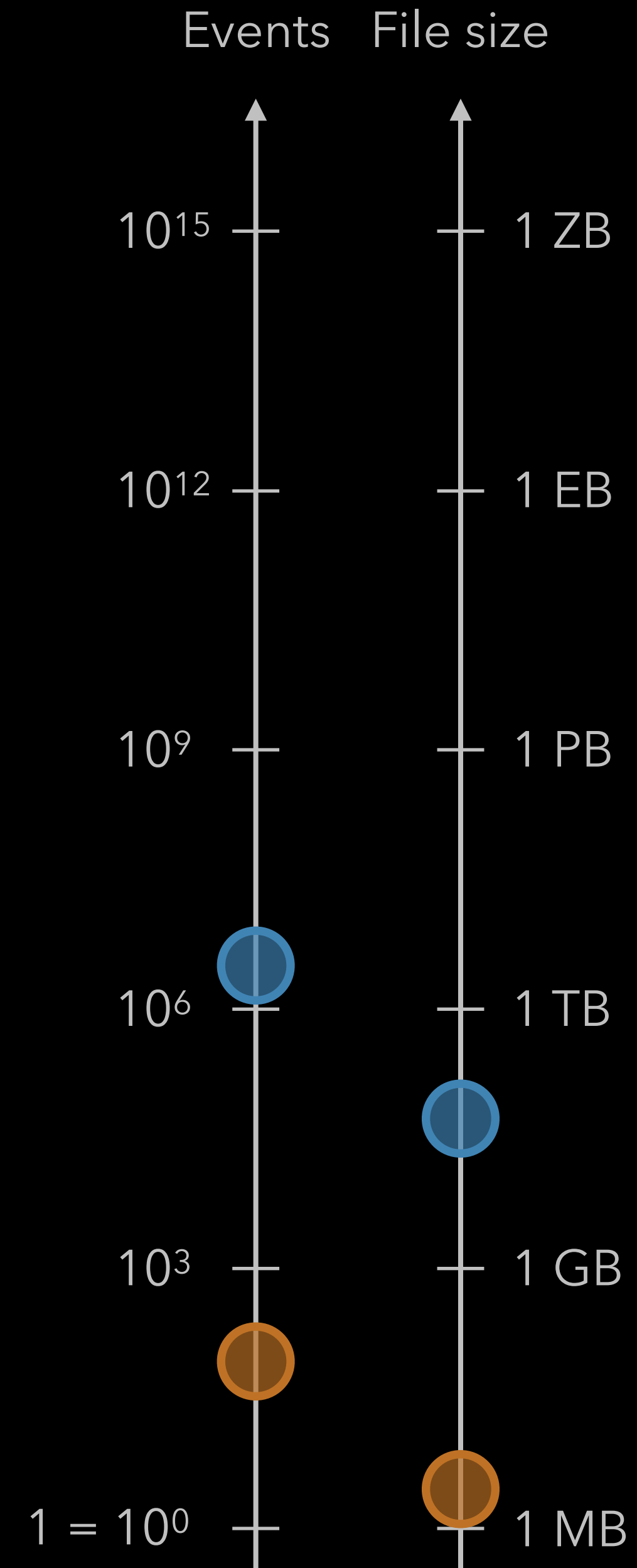
# Looking at Distributions



# Looking at Distributions

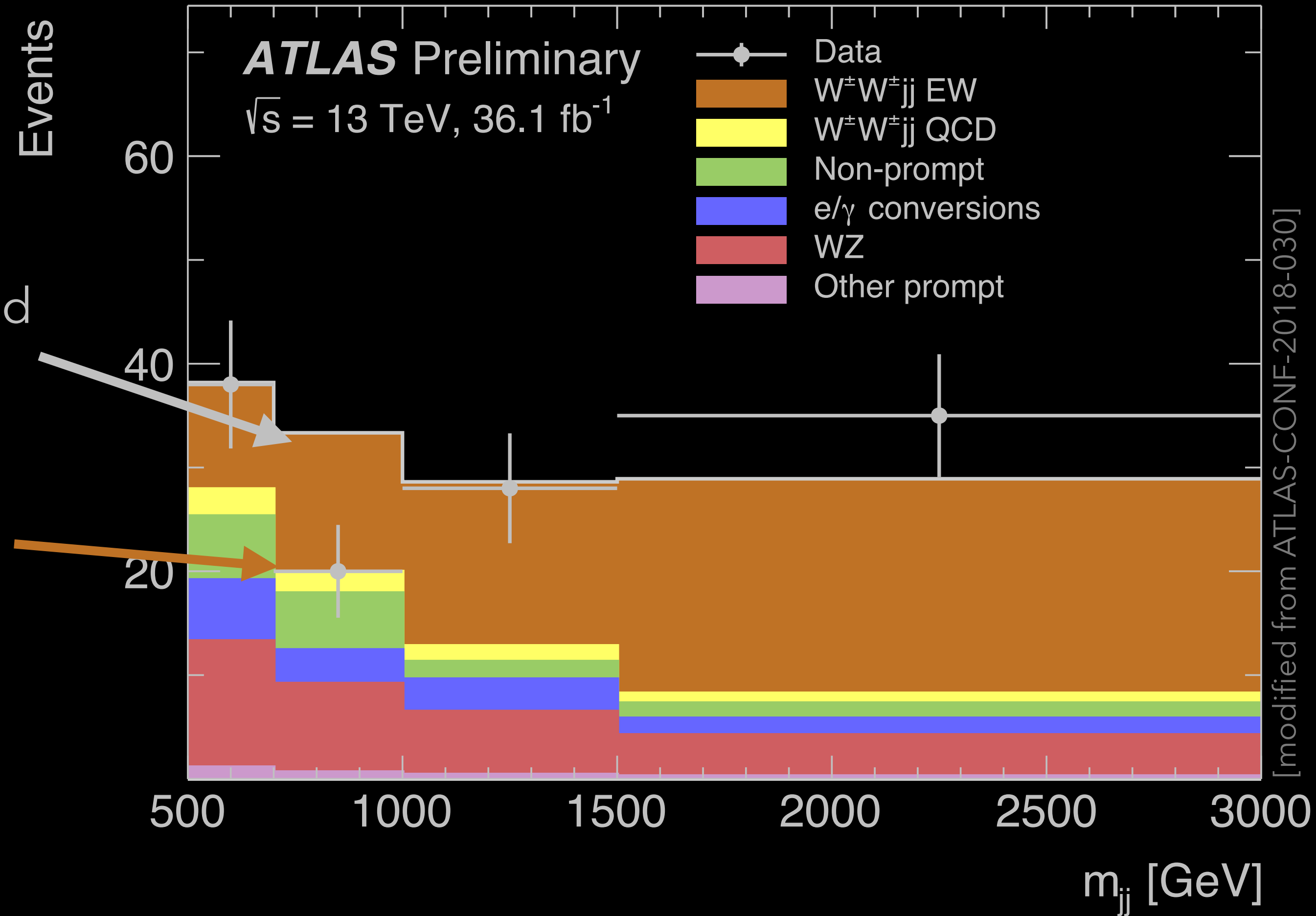


background only prediction



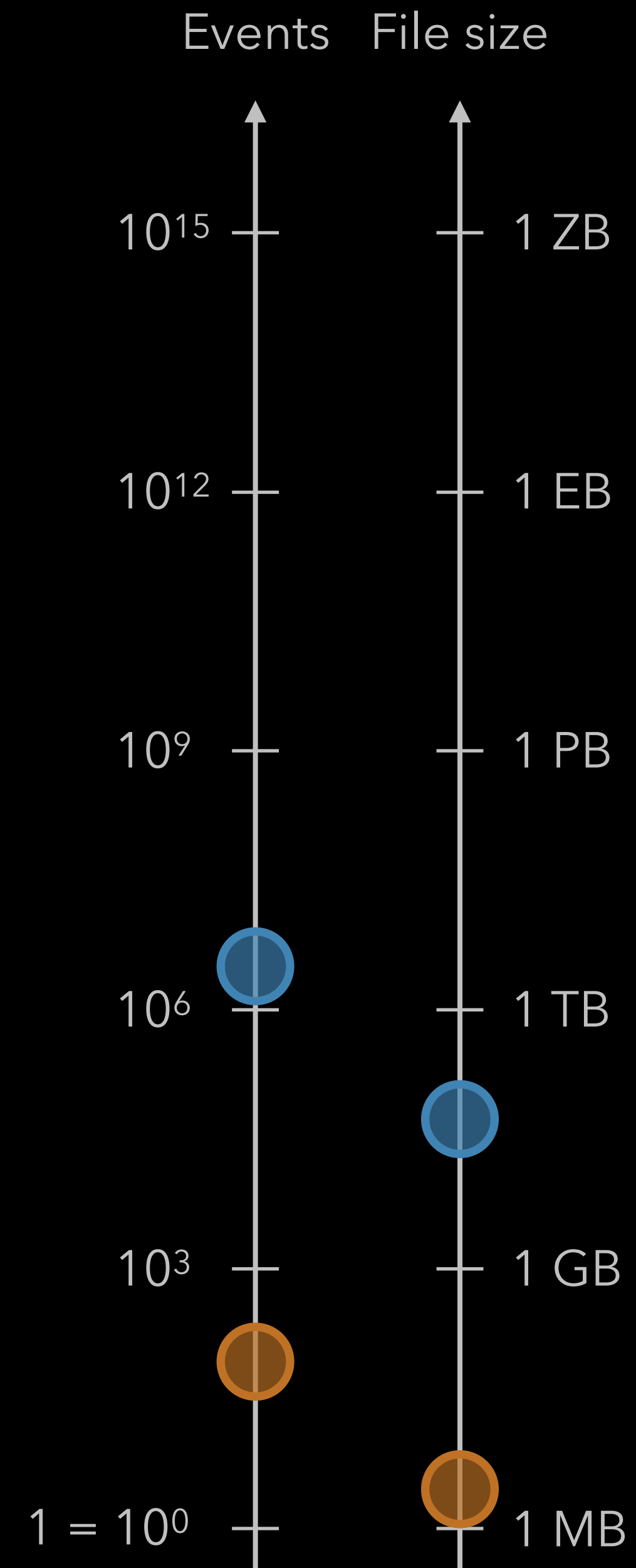


# Looking at Distributions

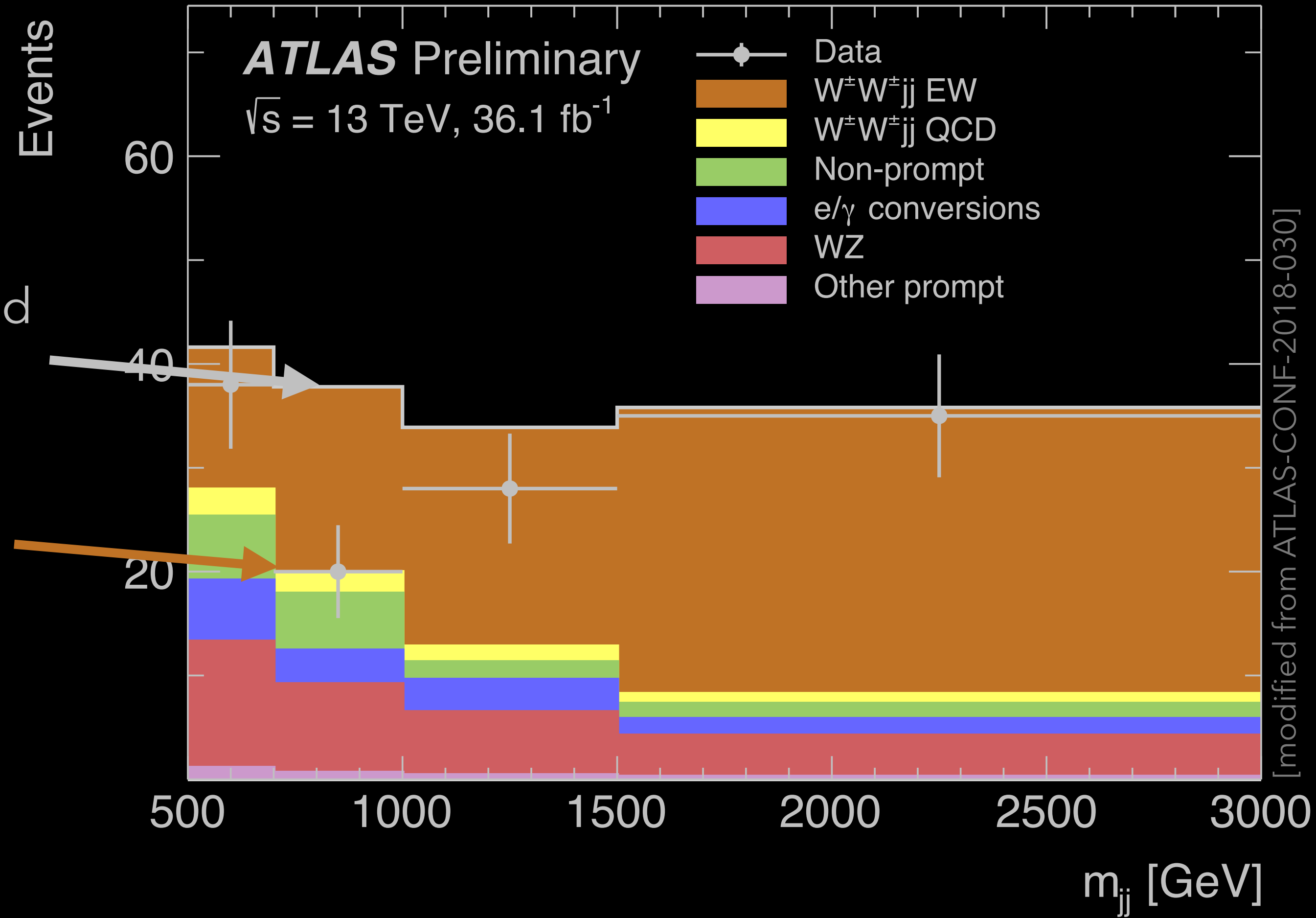


signal + background prediction

background only prediction

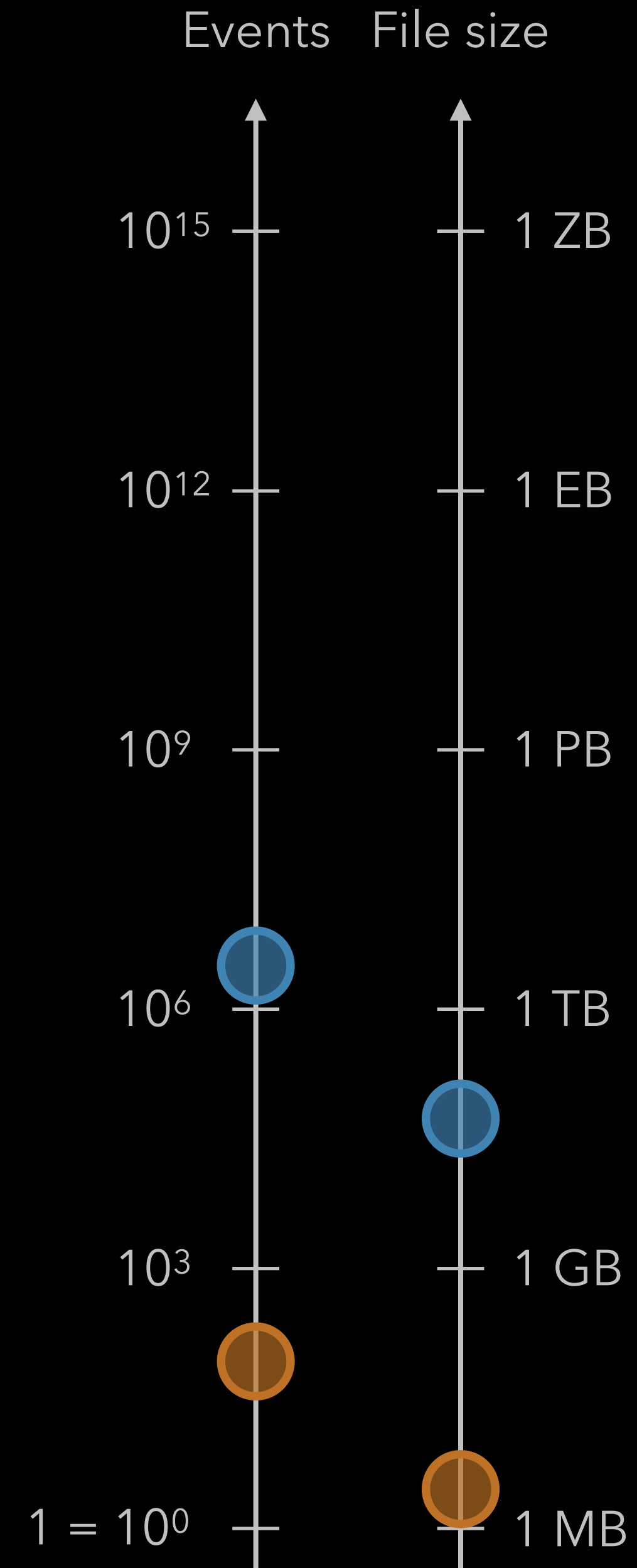


# Looking at Distributions

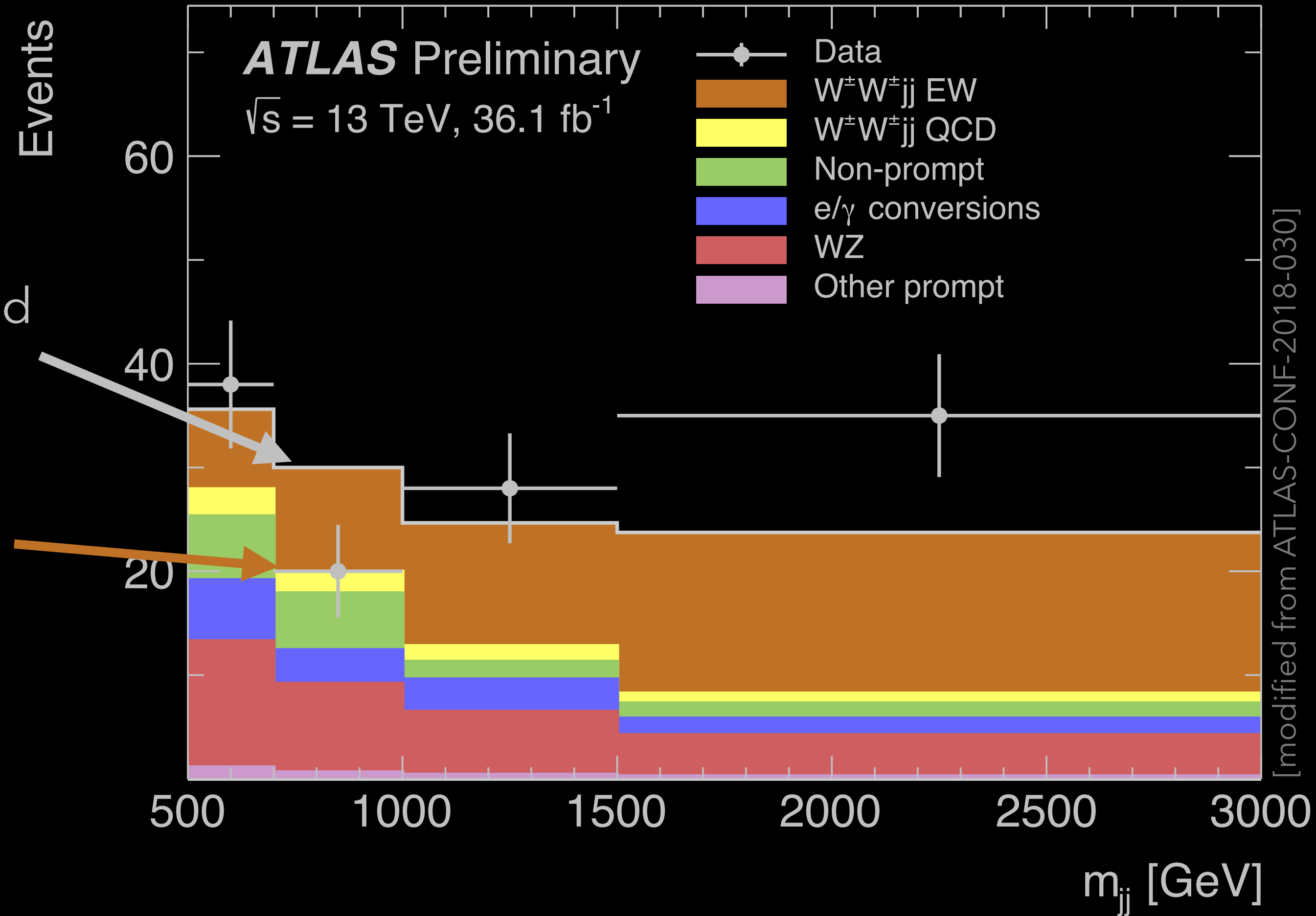


signal + background prediction

background only prediction

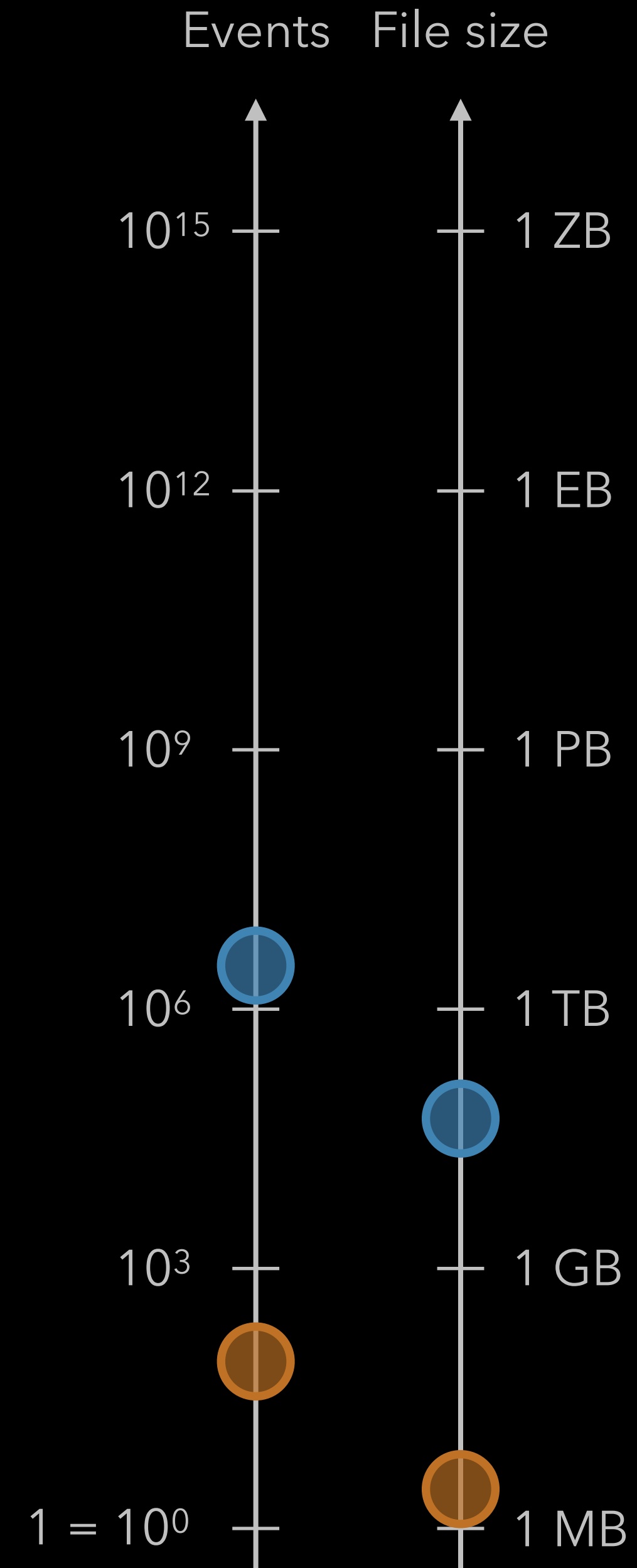


# Looking at Distributions

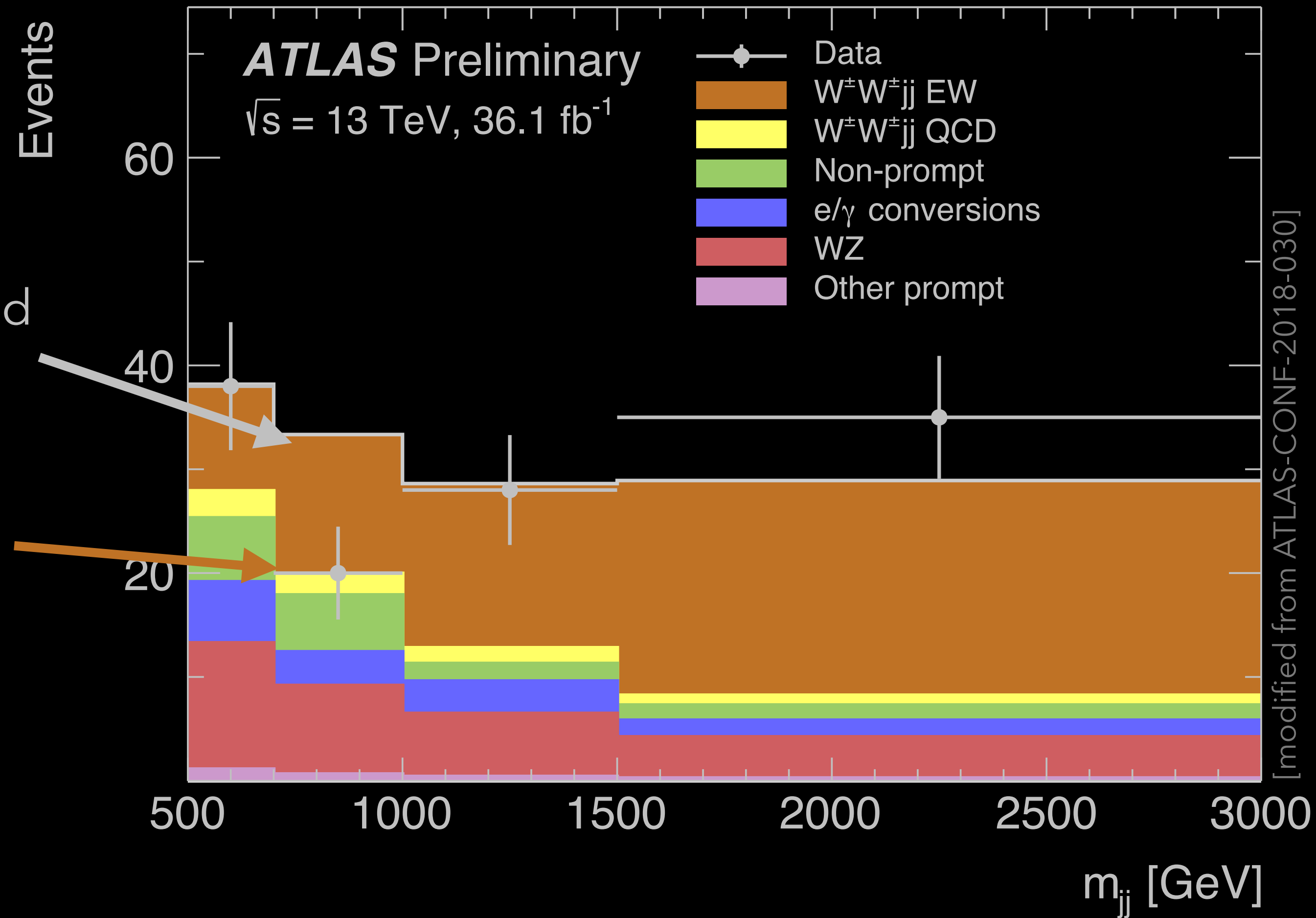


signal + background prediction

background only prediction

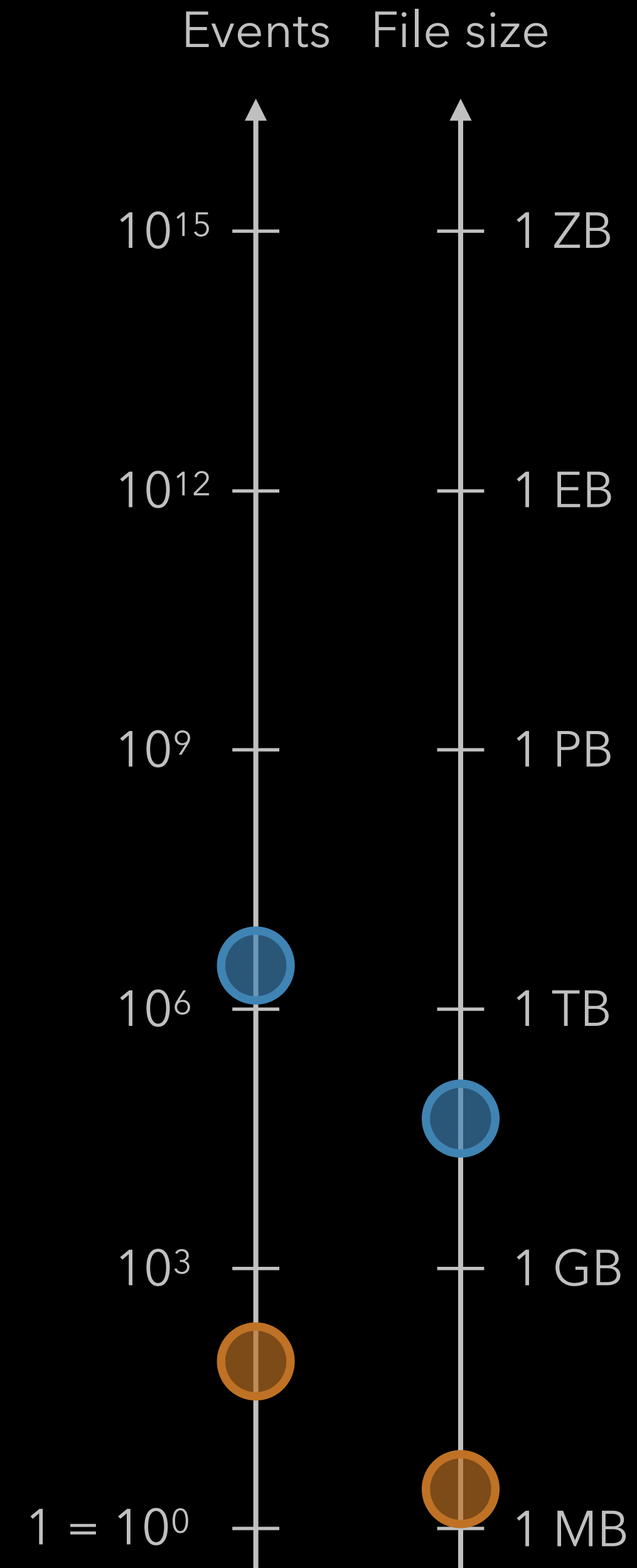


# Looking at Distributions

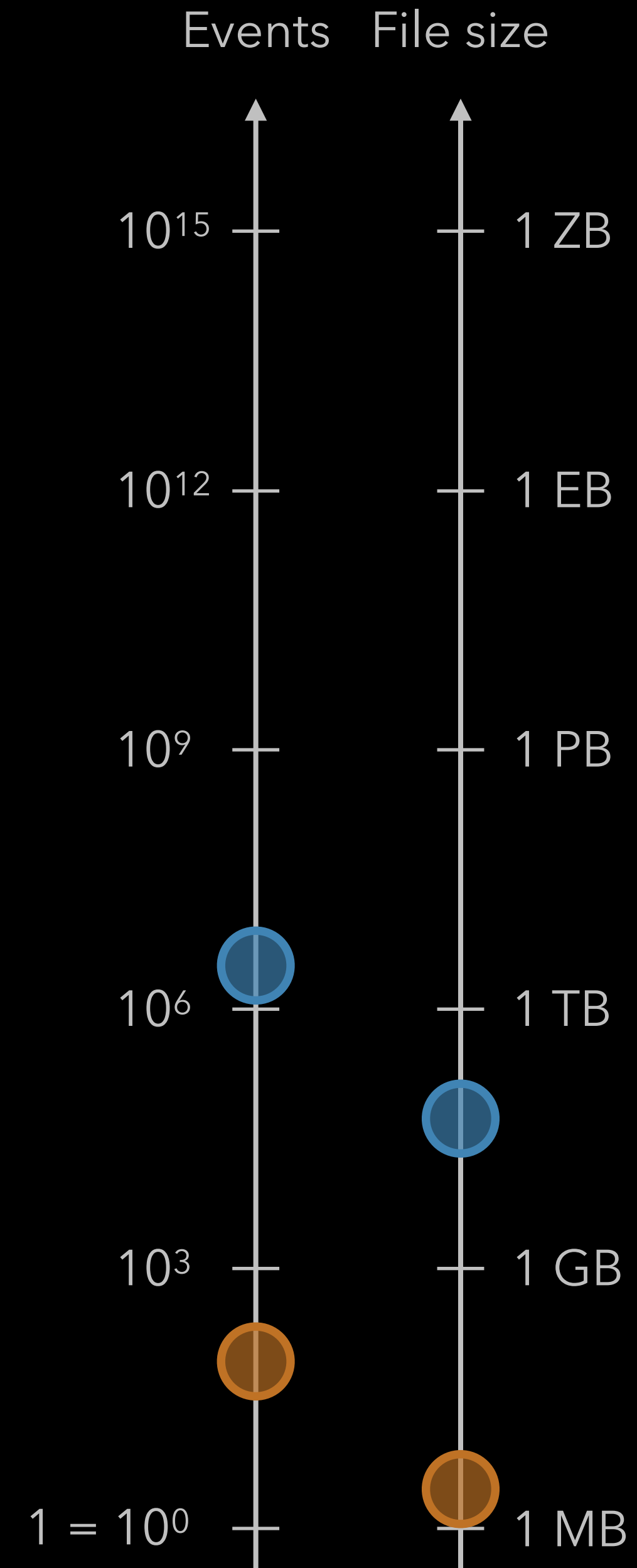
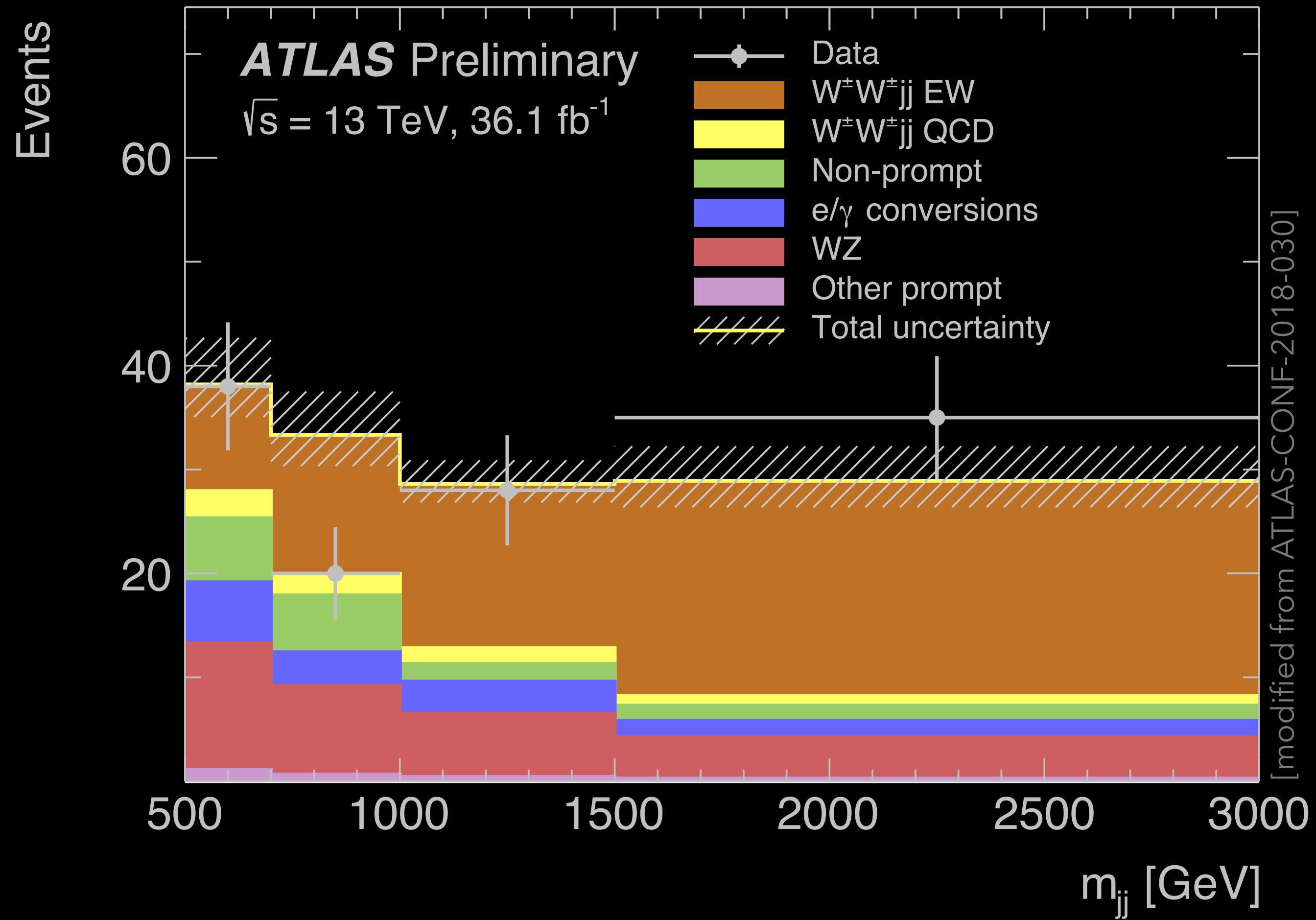


signal + background prediction

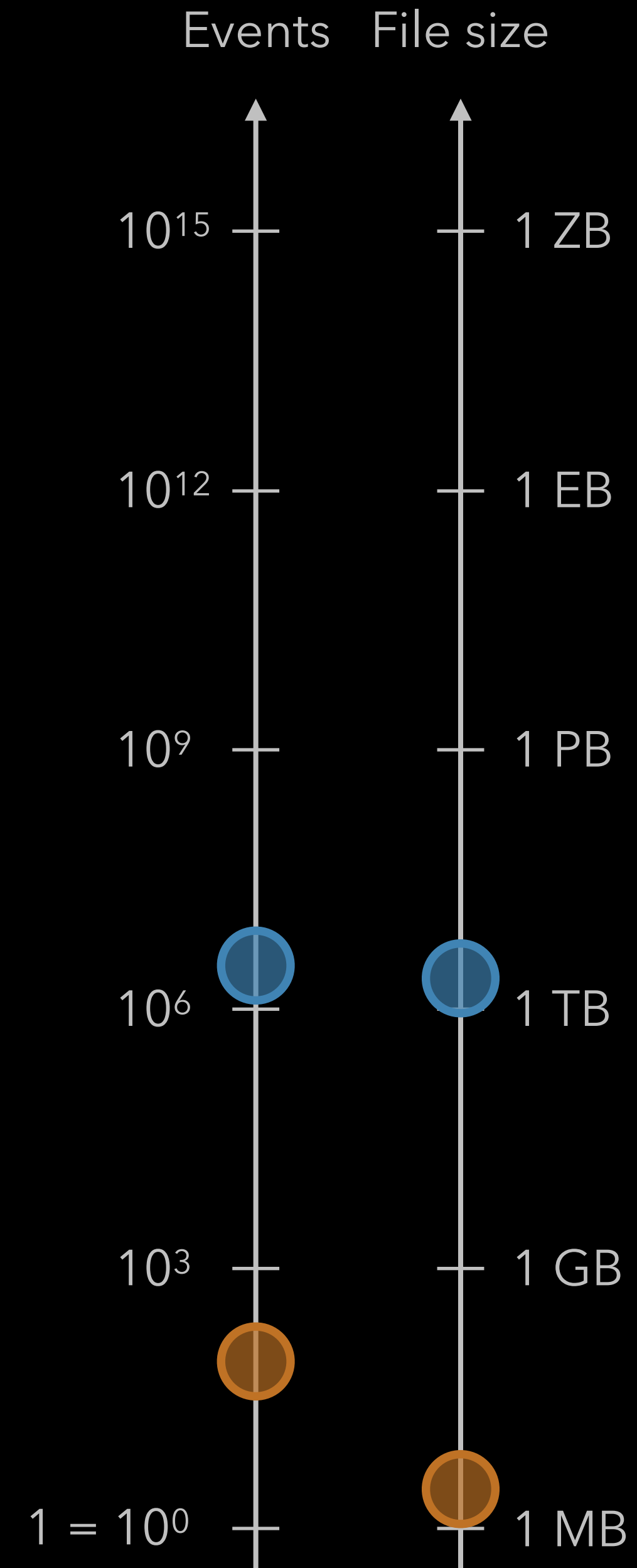
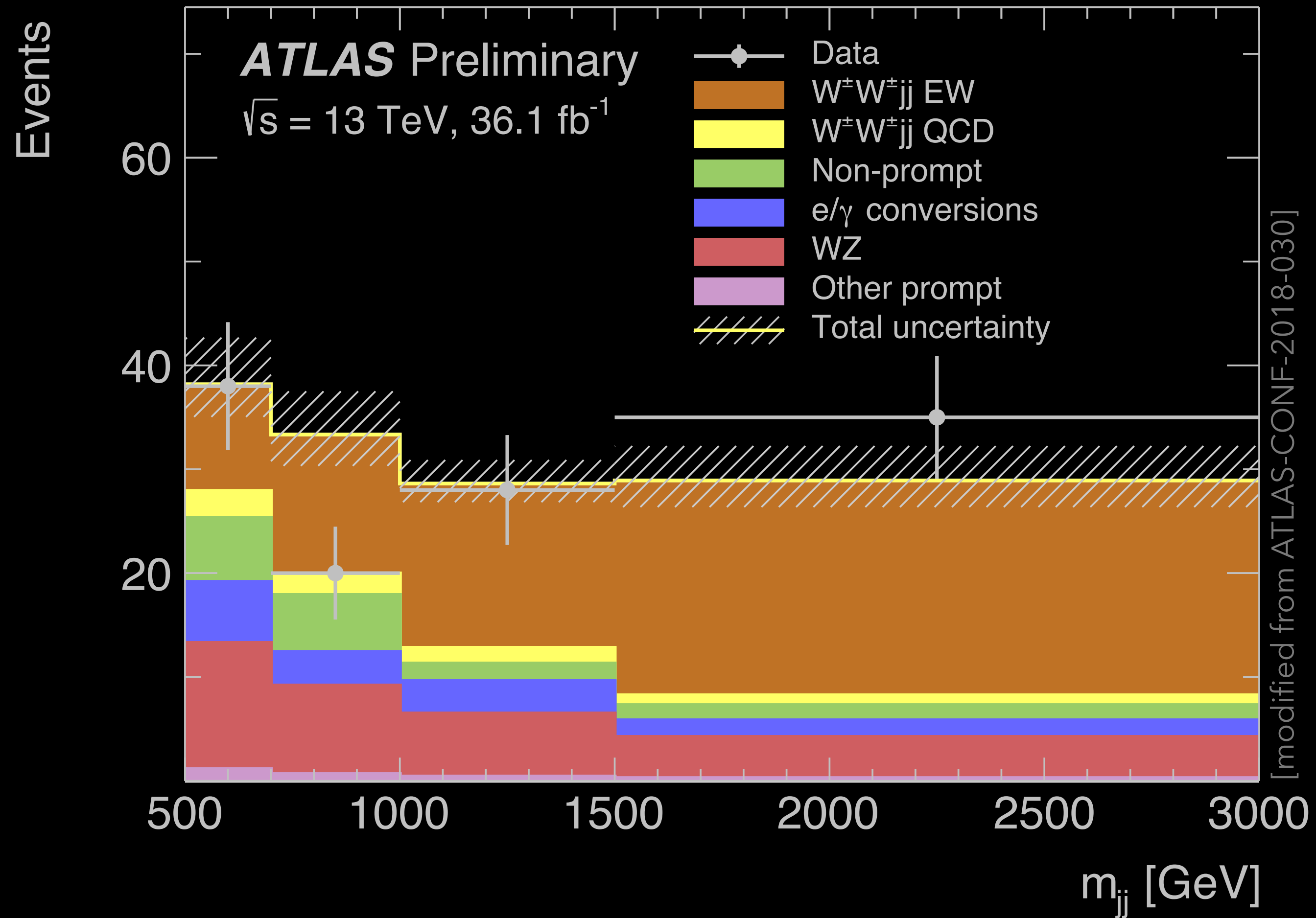
background only prediction



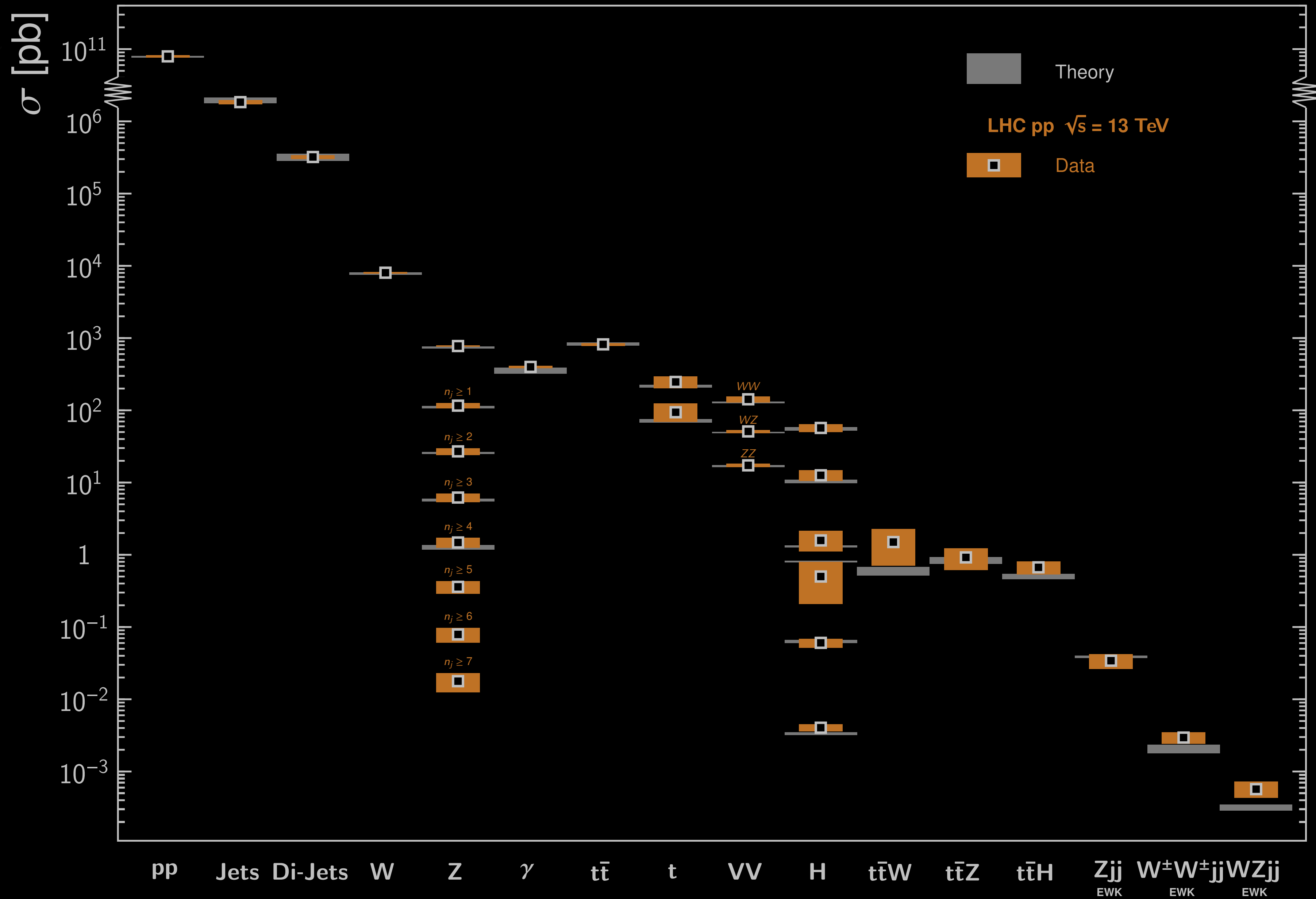
# Looking at Distributions



# Looking at Distributions

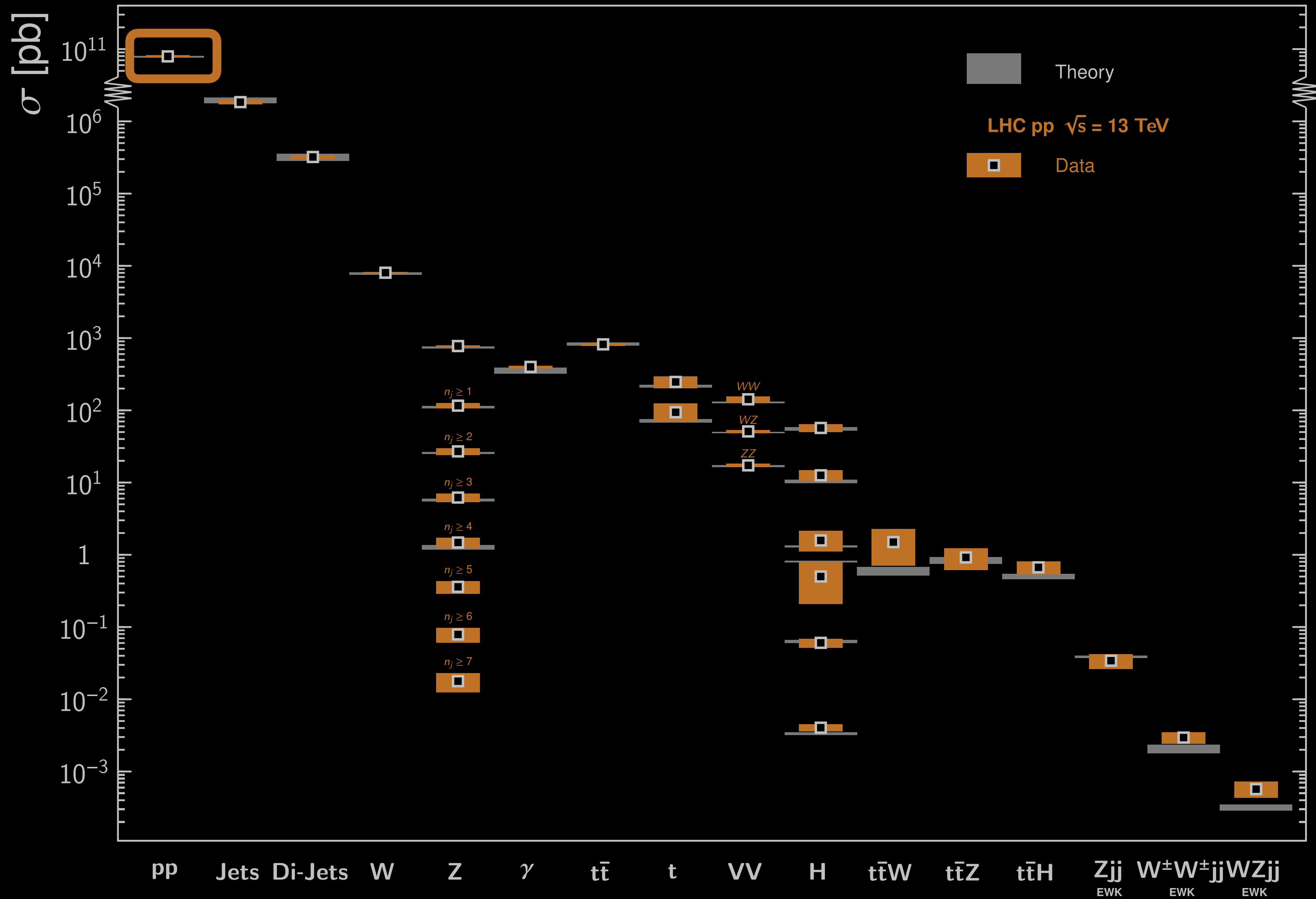


# Standard Model Production Cross Section Measurements at ATLAS



[modified from SM summary plots by the ATLAS Collaboration]

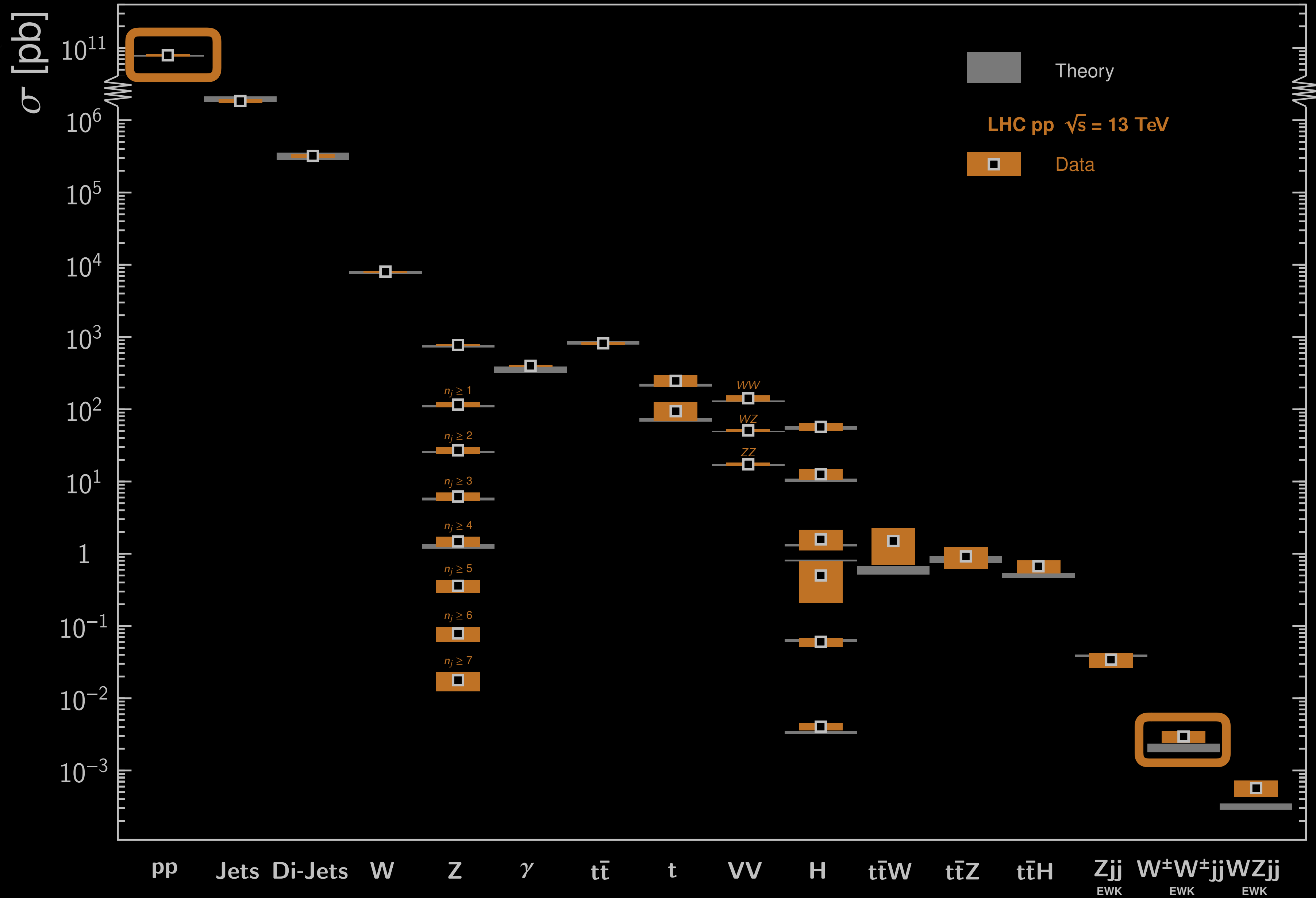
# Standard Model Production Cross Section Measurements at ATLAS



[modified from SM summary plots by the ATLAS Collaboration]

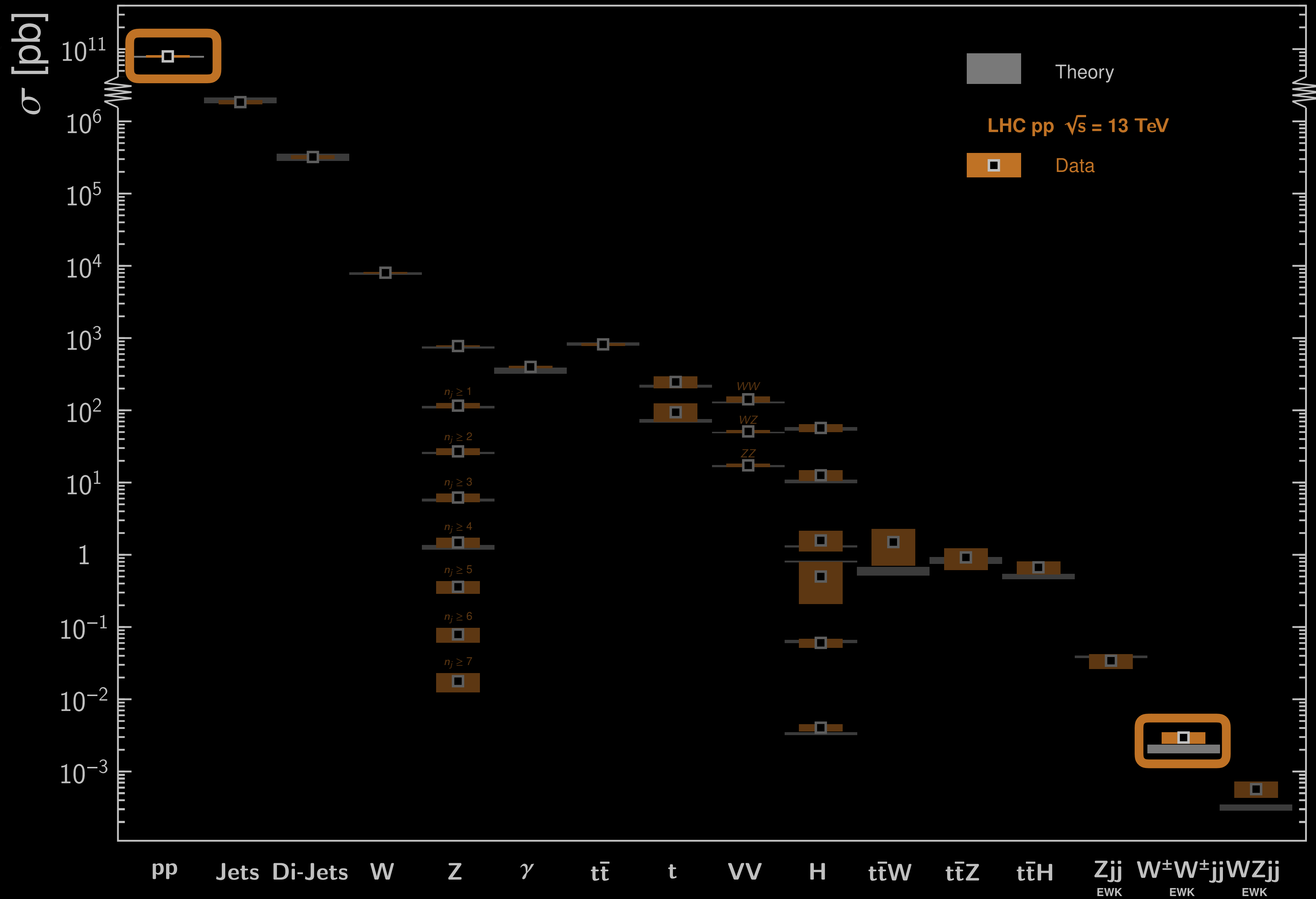


# Standard Model Production Cross Section Measurements at ATLAS



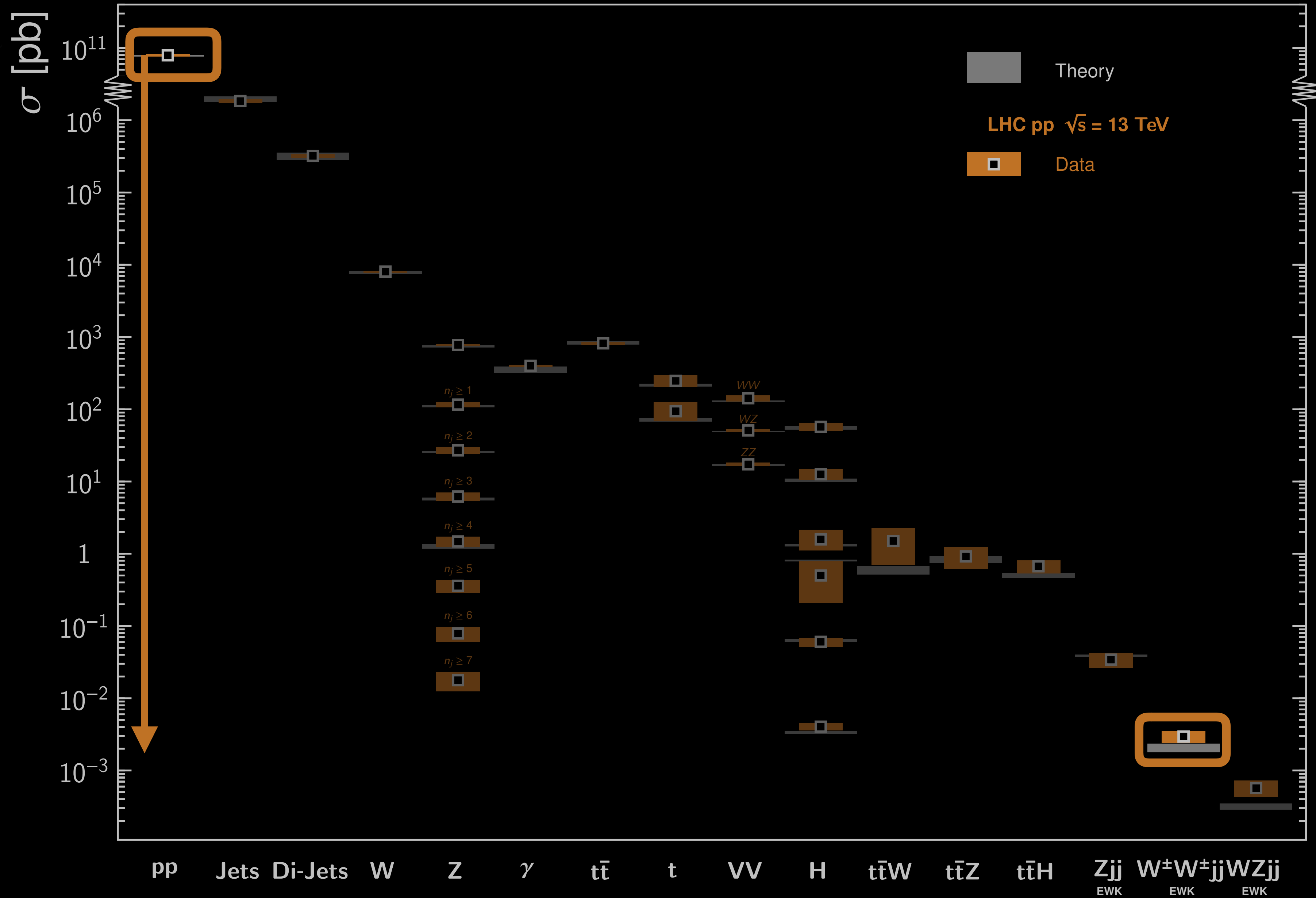
[modified from SM summary plots by the ATLAS Collaboration]

# Standard Model Production Cross Section Measurements at ATLAS



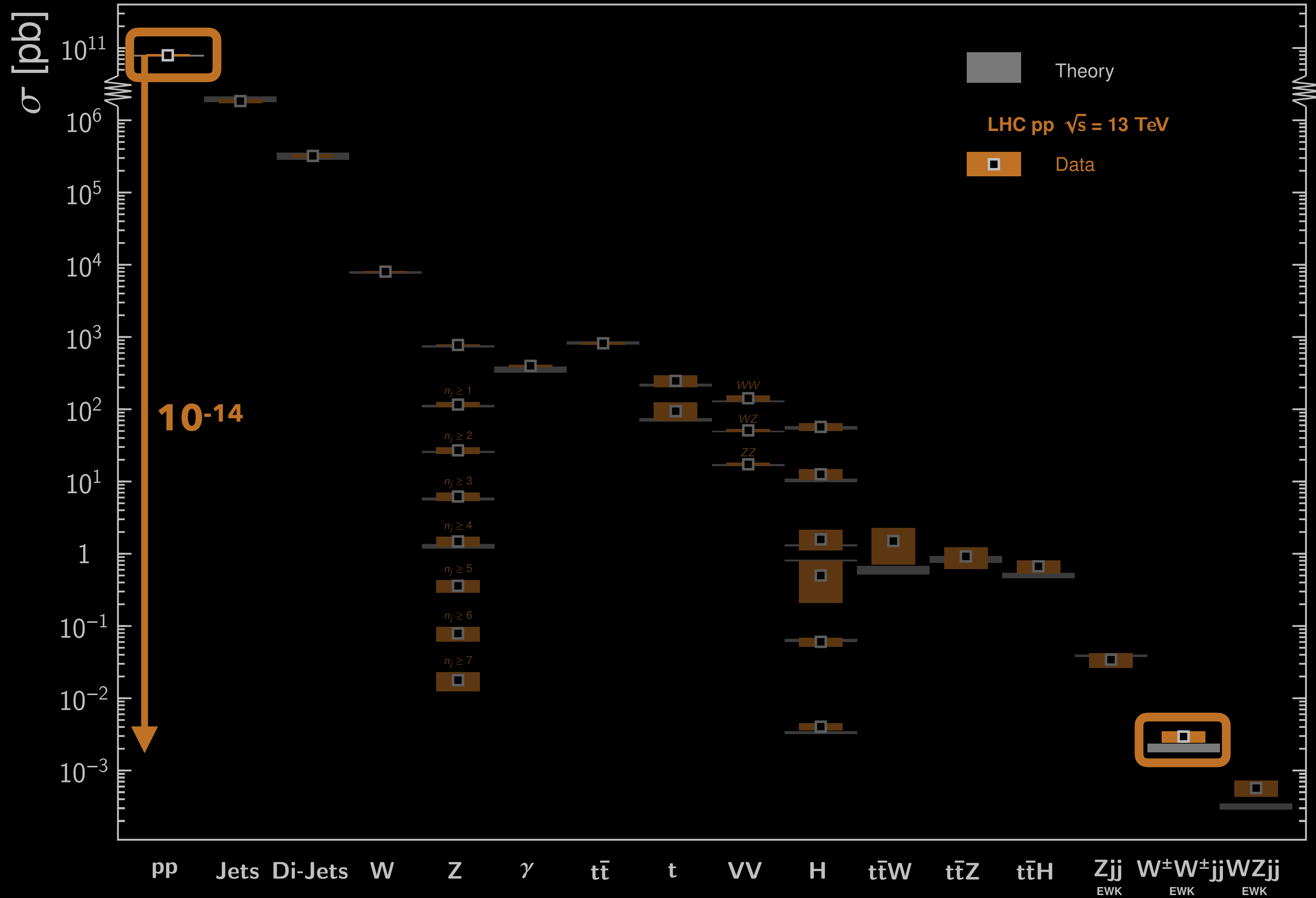
[modified from SM summary plots by the ATLAS Collaboration]

# Standard Model Production Cross Section Measurements at ATLAS



[modified from SM summary plots by the ATLAS Collaboration]

# Standard Model Production Cross Section Measurements at ATLAS



[modified from SM summary plots by the ATLAS Collaboration]

# Come Visit Us!

LHC Page1

Fill: 7494

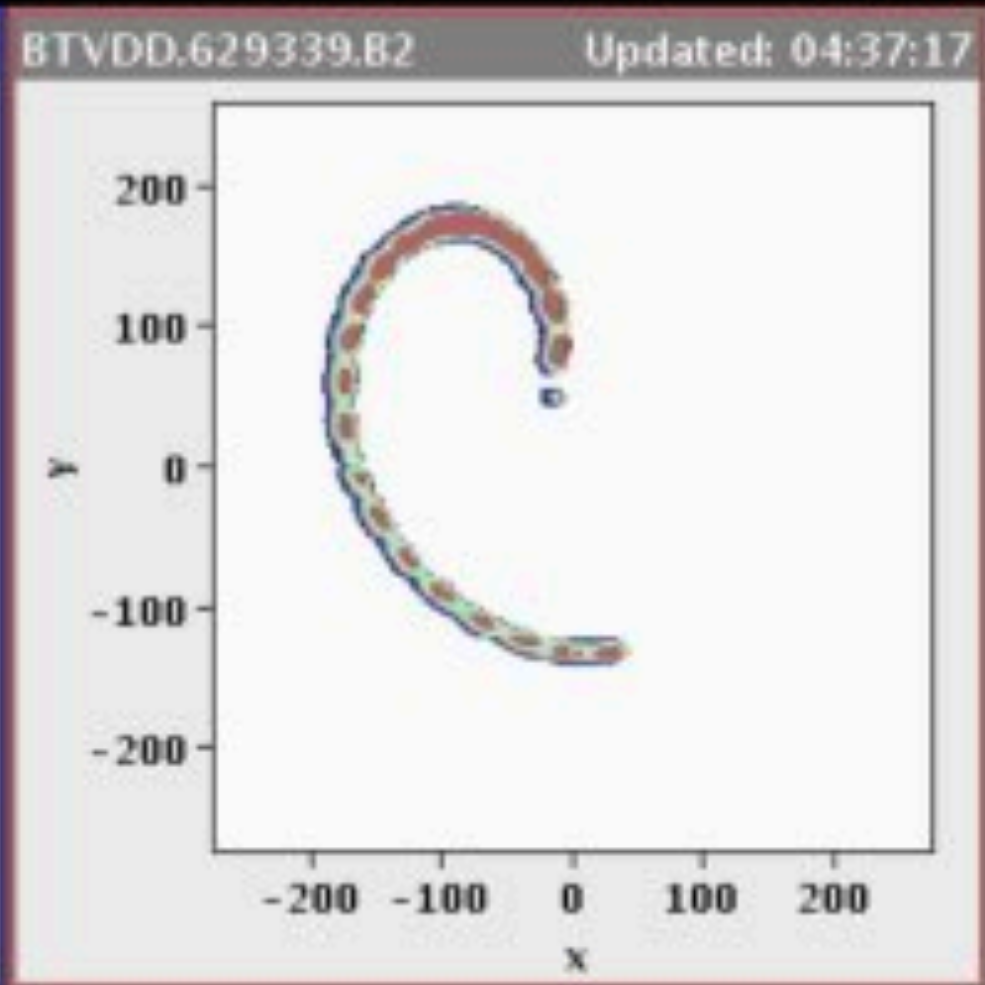
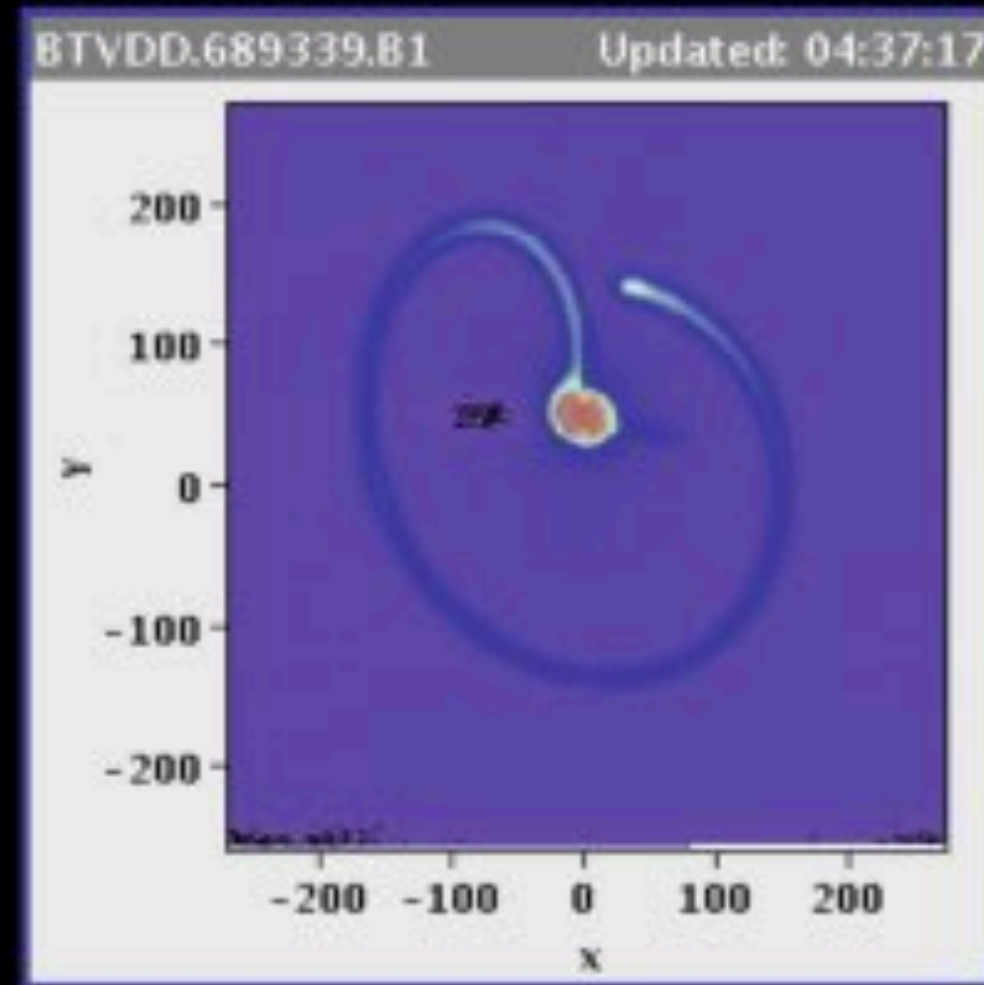
E: 450 Z GeV

t(SB): 00:00:00

03-12-18 04:40:09

## MACHINE DEVELOPMENT: BEAM DUMP

Energy:	450 Z GeV	I(B1):	4.24e+08	I(B2):	0.00e+00
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Comments (03-Dec-2018 04:38:24)  
 This was the last dump of Run2 !  
 Going to access today, estimate 2 years

BIS status and SMP flags	B1	B2
Link Status of Beam Permits	false	false
Global Beam Permit	false	false
Setup Beam	true	true
Beam Presence	false	false
Moveable Devices Allowed In Stable Beams	false	false

AFS: 75\_150ns\_733Pb\_733\_702\_468\_42bpi\_20inj

PM Status B1 **ENABLED** PM Status B2 **ENABLED**

[public status monitor LHC page 1 by CERN]

A decorative graphic in the top-left corner consisting of a network of white dots connected by thin white lines, resembling a web or neural network structure.

# Further Links

- More information about visiting CERN: <https://visit.cern>
- Volunteer computing with LHC@home <http://lhathome.web.cern.ch>
- Study partial datasets at <http://opendata.cern.ch>
  
- Title font: <https://www.fontsquirrel.com/fonts/changa>
- Slide template based on designs by GarryKillian - [Freepik.com](https://www.freepik.com)

An abstract network graphic consisting of numerous white circular nodes of varying sizes connected by thin, light gray lines. The nodes are scattered across the black background, with a higher density in the top-left and bottom-right corners, creating a sense of interconnectedness and complexity.

Backup



# The LHC - Numbers to remember

- Protons per bunch:  $\sim 10^{11}$
- Number of bunches:  $\sim 3000$
- Rate collisions:  $\sim 11000$  per second (collision rate?)
- 2015+2016 LHC stable beam uptime: 1680h