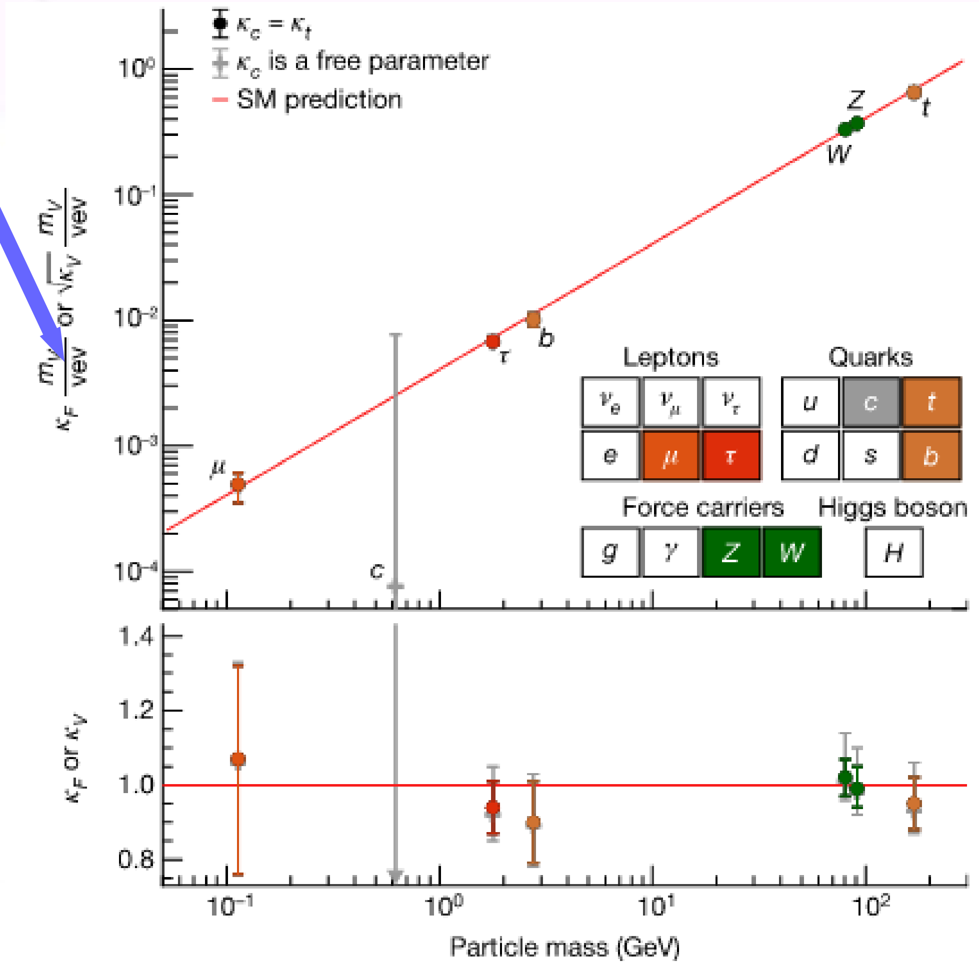
ATLAS ..after the Higgs boson discovery ..

ATLAS ?
ATLAS in Norway
ATLAS !

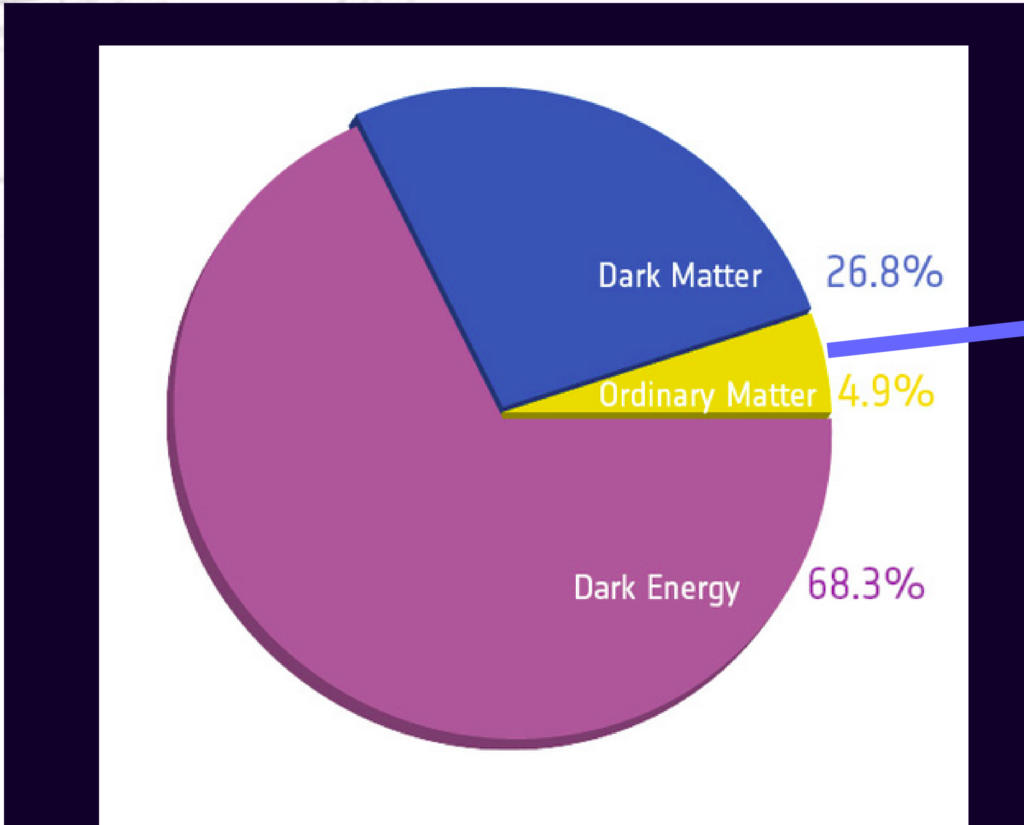
The Standard Model's Higgs boson

Discovered in 2012 by ATLAS and CMS Collaborations. Its mass and interactions precisely measured by now. The strength of interactions is indeed proportional to the mass of particles it interacts with



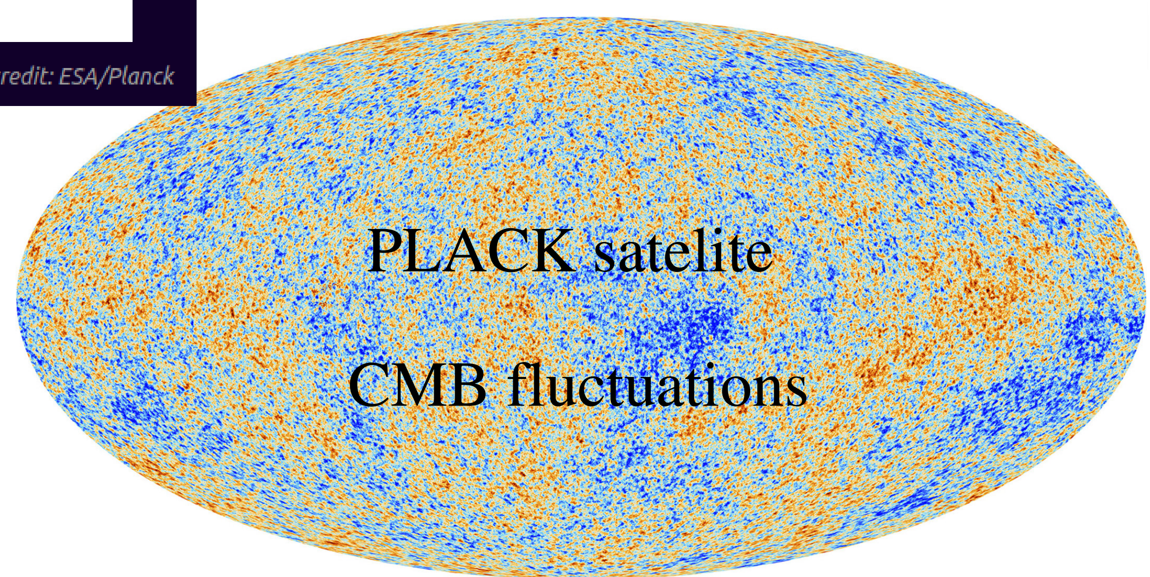
so far in agreement with the SM from https://www.nature.com/articles/s41586-022-04893-w.pdf

The Standard Model makes only 5% of the Universe



The relative amounts of the different constituents of the Universe. *Image credit: ESA/Planck*

The Higgs boson and the rest of SM



ATLAS after Higgs and the LHC

Cosmology

↕

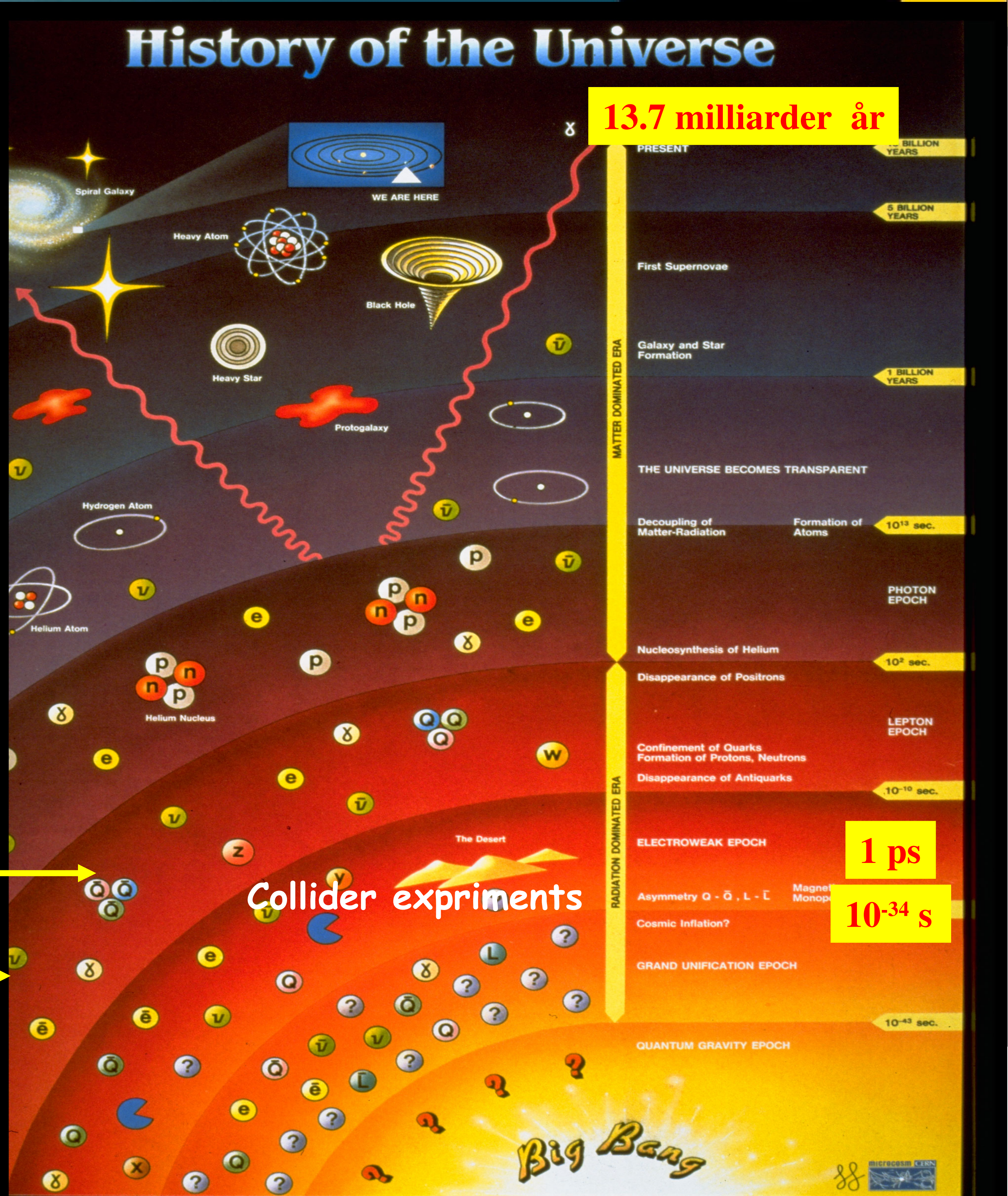
Astroparticle physics

↕

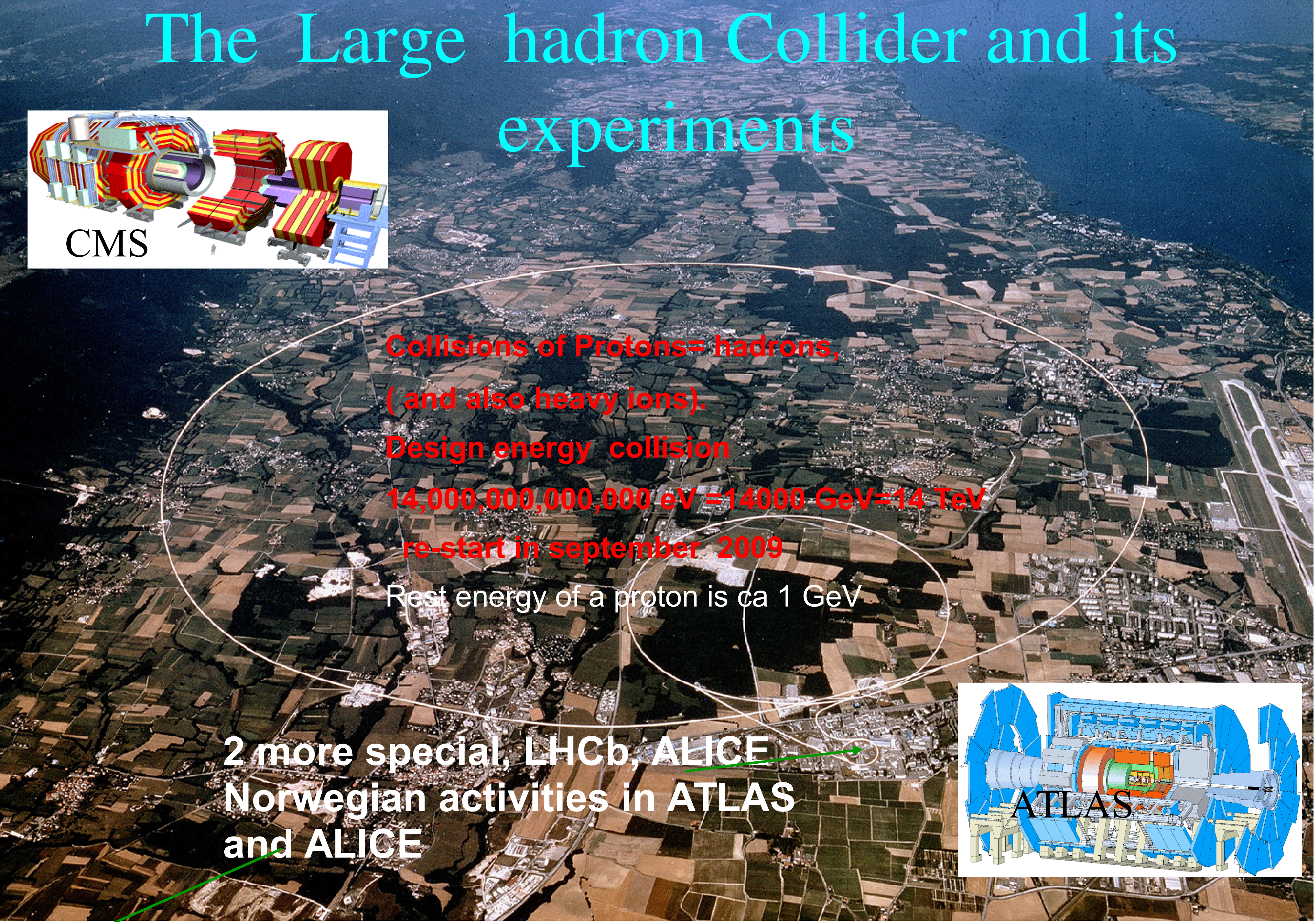
Particle physics

Higgs field arises (EWSB)?

Matter takes over?



The Large hadron Collider and its experiments



Collisions of Protons= hadrons,

(and also heavy ions).

Design energy collision

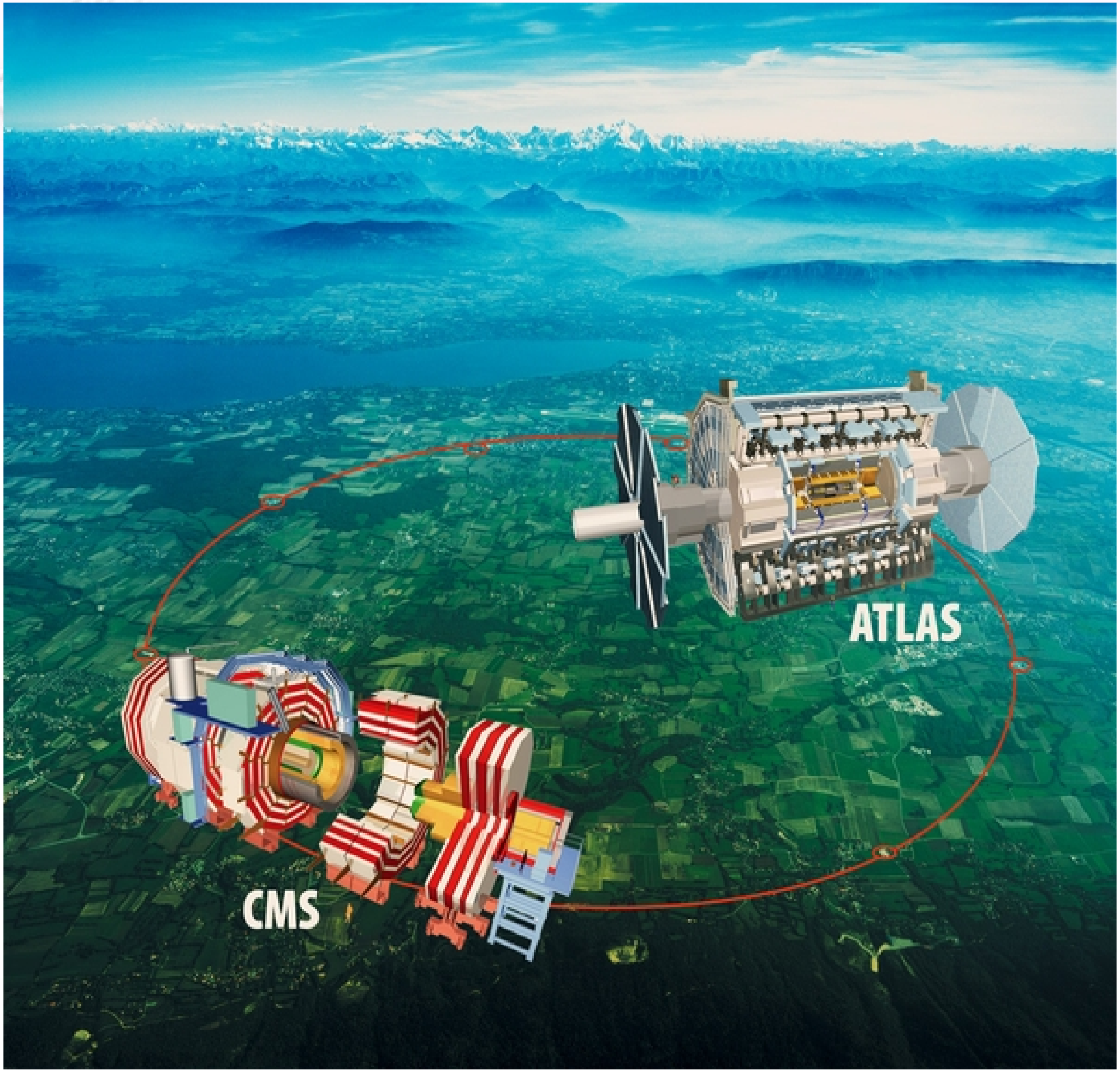
14,000,000,000,000 eV =14000 GeV=14 TeV

re-start in september 2009

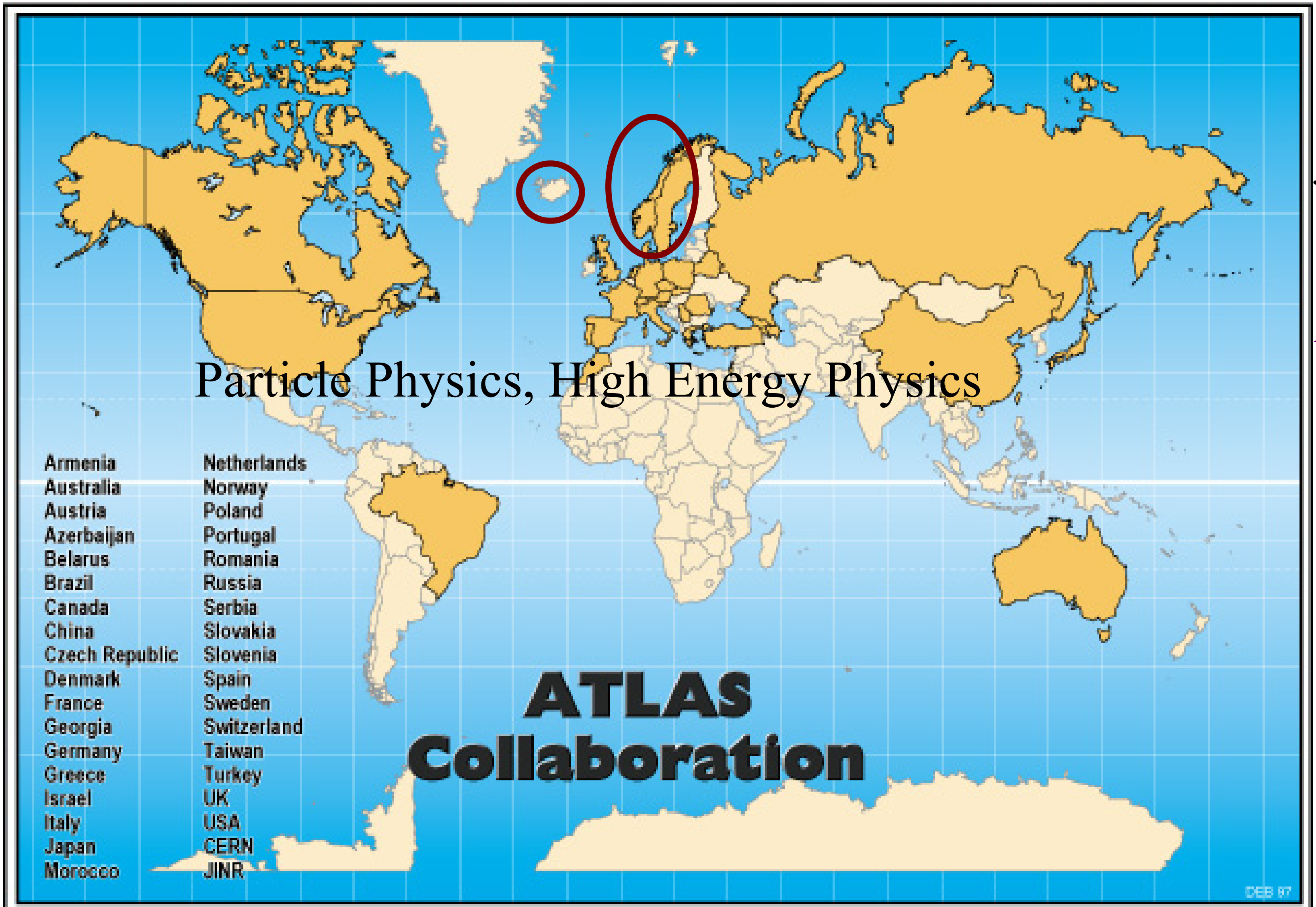
Rest energy of a proton is ca 1 GeV

2 more special, LHCb, ALICE
Norwegian activities in ATLAS and ALICE

ATLAS and CMS have similar capabilities now and in the future



ATLAS Collaboration www.atlas.ch



ATLAS in the World

3300 participants

~180 institutions

ATLAS i Norden

main activity in
Denmark
Norway
Sweden

ATLAS i Norge

~60 participants
Bergen&Oslo

A Toroidal LHC ApparatuS

Permanent staff, researchers, postdocs

Professors/assoc. Profs:		3 UiO, 2 UiB, 4 HVL
Researchers/postdocs	funded by RCN/NORCC/ATLAS/NG	3 UiO, 2 UiB
Researchers/postdocs	funded by RCN/NorLHC	1 UiO
Researcher/postdoc	funded by University	1 UiO
Researcher/postdoc	funded by NFM/EEA	1 UiB
Researcher/postdoc	funded by other RCN funding	1 HVL
Engineers/technicians	funded by RCN/NorLHC	4 UiO, 1 UiB
Engineers/technicians	funded by Universities	2 UiO, 1.5 UiB
Engineers/technicians	funded by IT-UiO/NeiC/NG	2 UiO

Norwegian Financial Mechanism years 2014-2021
grant 2019/34/H/ST2/00707

Master and PhD students

 # theses finishing each year

	06-11	12	13	14	15	12-15	16	17	18	19	16-19	20	21	22	23
Master	**30**	6	1	1	4	**12**	9	8	8	3	**28**	**6**	**7**	**1**	**8**
Experiment	**22**	3	1	1	2	**7**	2	4	1	2	**9**	**6**	**7**	**1**	**8**
Theory	**8**	3			2	**5**	7	4	7	1	**19**	**-**	**-**	**-**	**-**
PhD	**15**	1	4	4	4	**13**	3	1	2	2	**8**	**1**	**1**	**2**	**6?**
Experiment	**12**	1	3	2	2	**8**	2	1	2		**5**	**1**	**1**	**2**	**6?**
Theory	**3**		1	2	2	**5**	1			2	**3**	**-**	**-**	**-**	**-**

- *Note some delays, especially due to Covid*
- *See list of finished and current theses in backup*

Direct contributions to ATLAS

Direct contributions to publications as editor, analyst

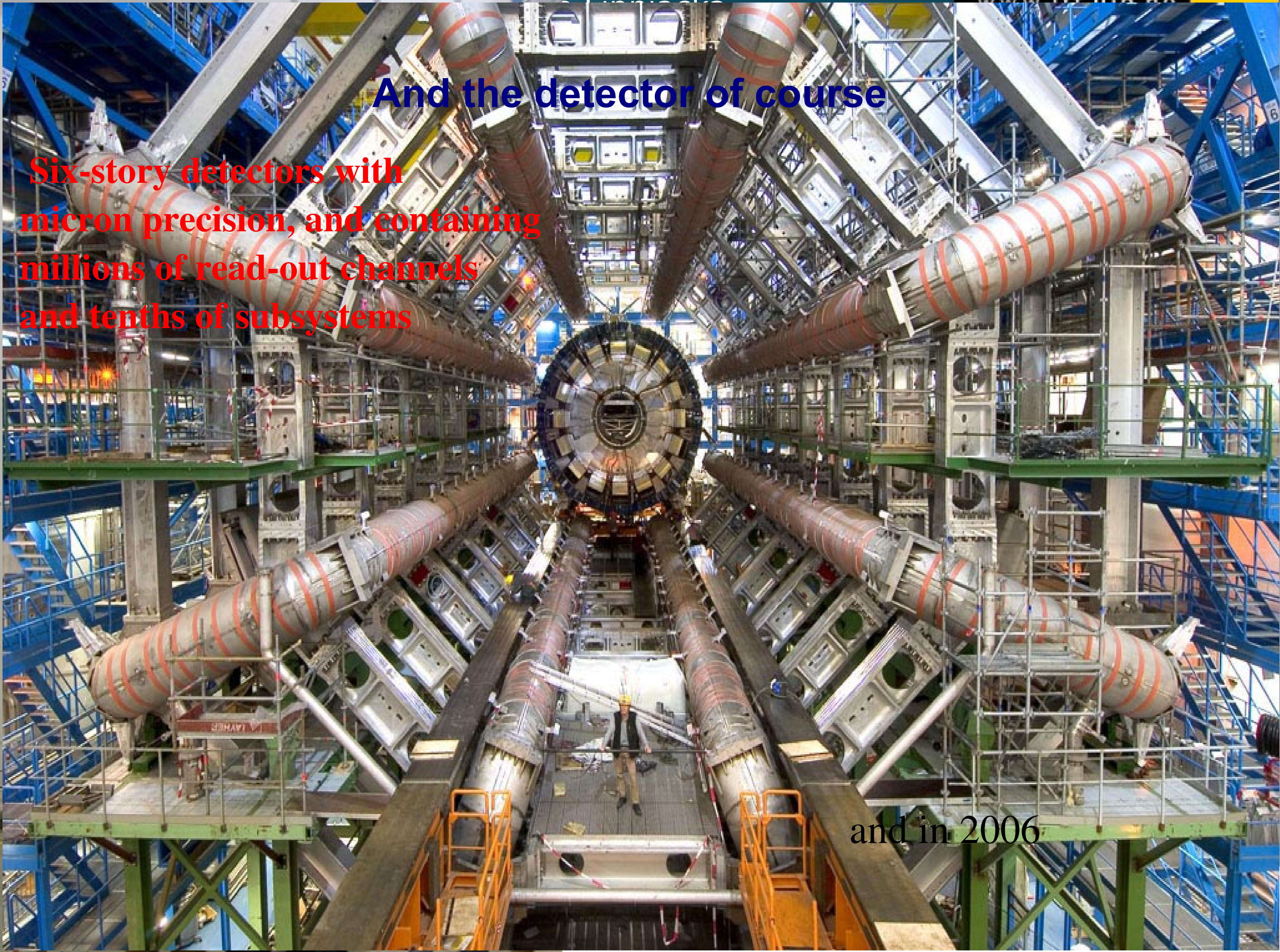
Publication type	Norway	All ATLAS	Ratio [%]
Papers	89	1058	8.4
Conf. notes	90	1196	7.5
Public notes	19	479	4.0
In progress	*9*	*375*	*2.4*
TOTAL	**207**	**3108**	**6.7**
Authors (incl. signing-only)	**26**	**~3000**	**0.9**

Positions of responsibility since 2016

Level	Roles held
Executive board	Computing coordinator
CB and senior committees	CB Chair Advisory Group Physics office Speakers' committee & computing speakers' committee, outreach (current) Statistics committee (current)
Activity coordinators	Software coordinator (current) Distributed computing coordinator Derived data production coordinator Upgrade software coordinator (current) Software performance coordinator Trigger validation coordinator (current) Trigger conditions coordinator (current) Trigger automated tests coordinator (current)
Physics coordination (group conveners)	Tau combined performance Tau trigger
Physics coordination (sub-group conveners)	Fake Tau Task Force (current) Lepton + X Strong production (current) Tracking and Vertexing for Prompt and Displaced Particles Muon performance working points

And the detector of course

Six-story detectors with micron precision, and containing millions of read-out channels and tenths of subsystems

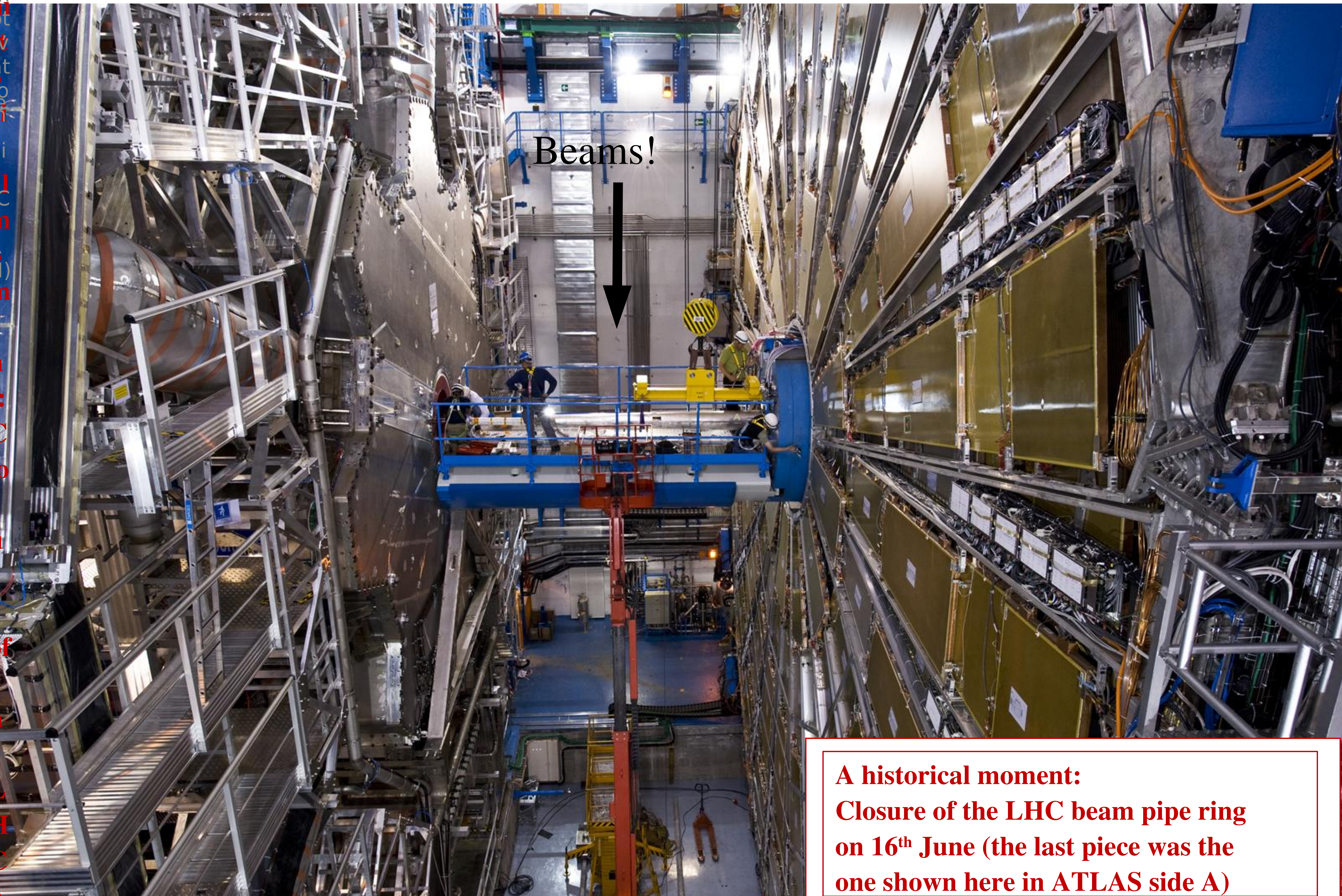


and in 2006

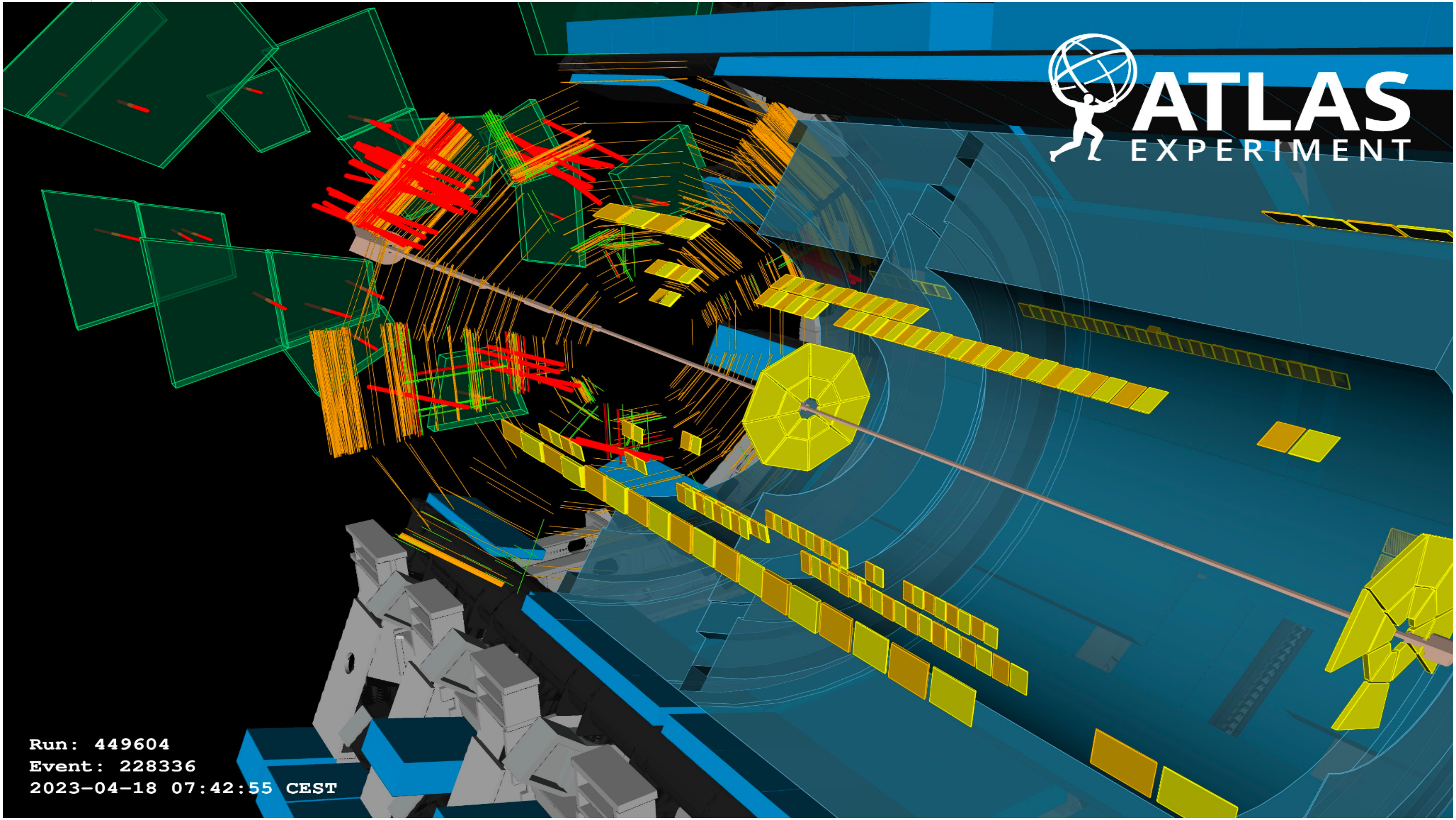

The Large Hadron Collider
The Beauty or .....

ATLAS, situated in the largest man-made cavern.

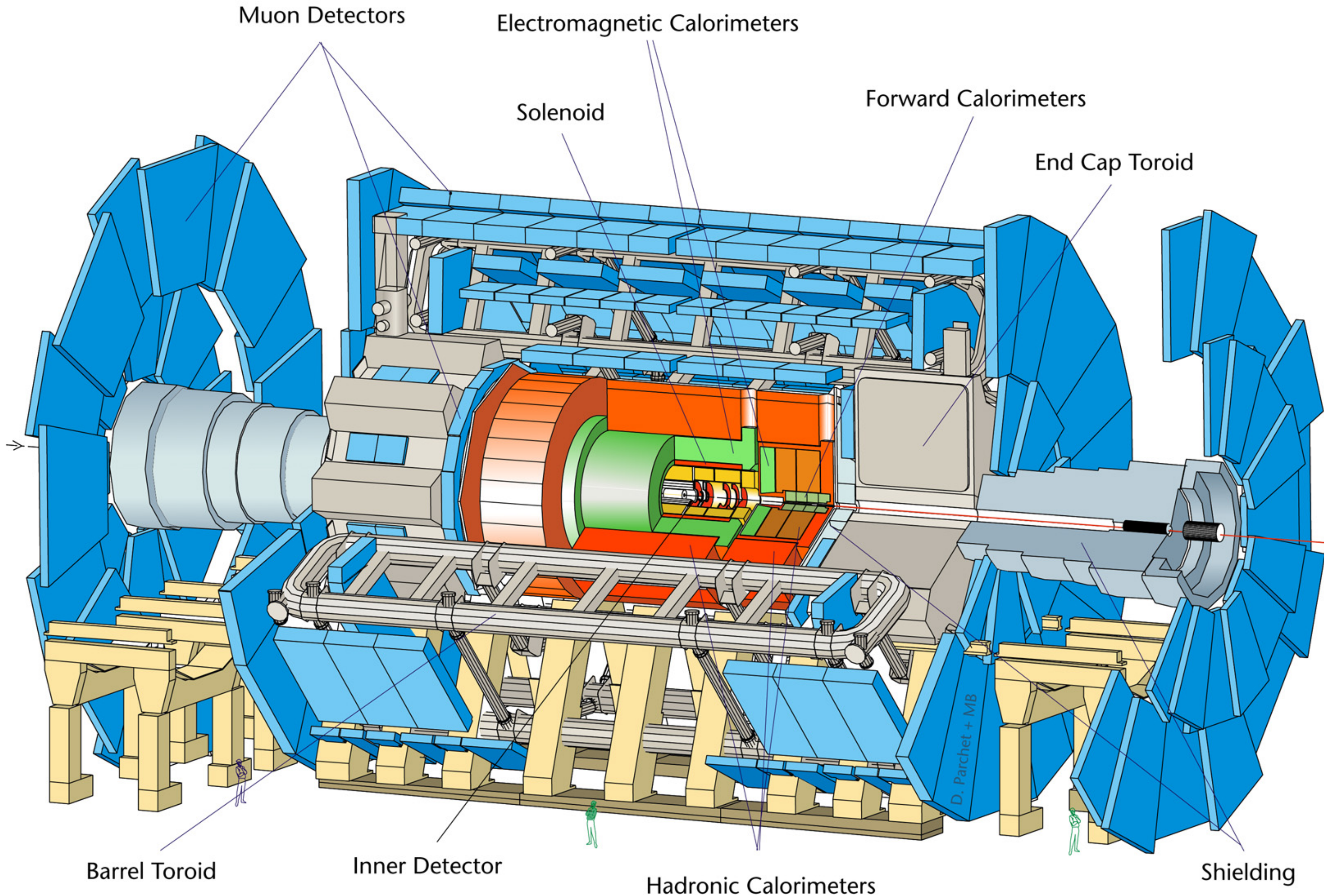
Summer 2003



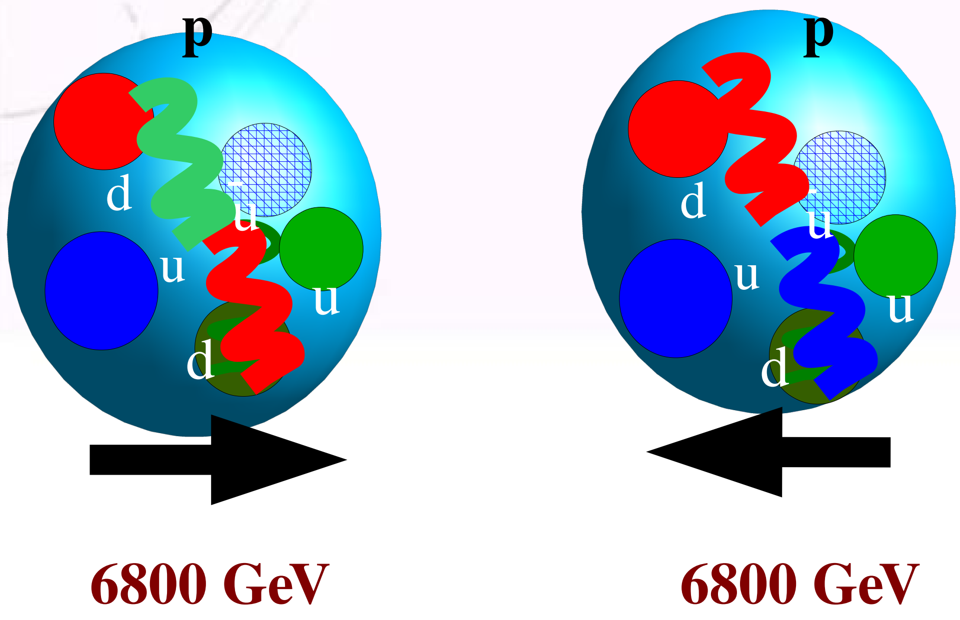
A historical moment:
Closure of the LHC beam pipe ring on 16th June (the last piece was the one shown here in ATLAS side A)


ATLAS
EXPERIMENT
Run: 449604
Event: 228336
2023-04-18 07:42:55 CEST

D712/mb-26/06/97



Accelerator-driven physics, the paradigm



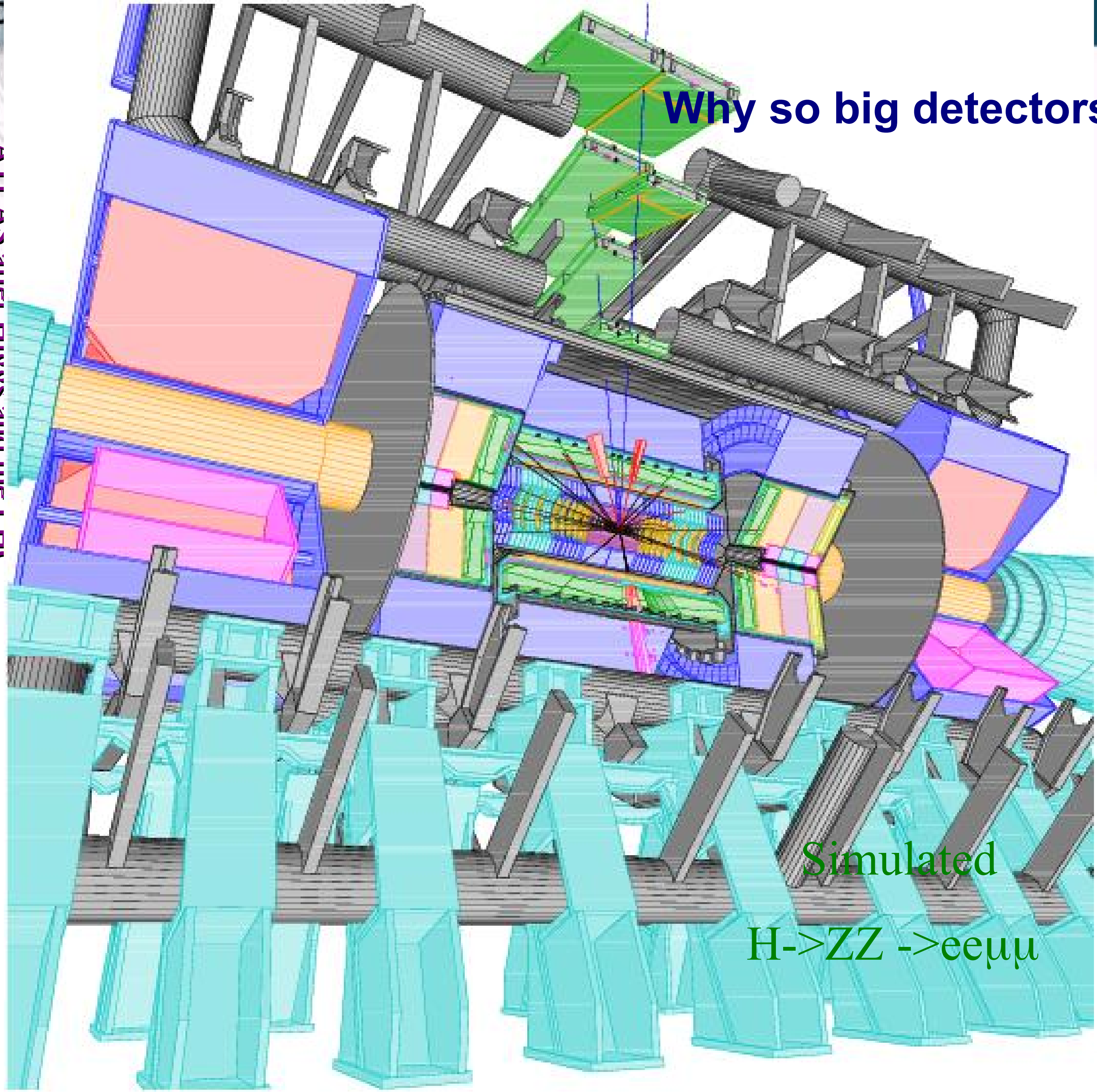
1) take stable, easy available particles and collide them at the highest energy the tax payers accept -> known initial state (as much as QM allows) !

2) The final state must decay to Standard Model particles and Dark Matter (as Big Bang experience shows).

3) Register all SM particles and missing energy in your detector and try to "decipher" the final state.

4) Subtract "non interesting" part-> measure it and use enlighten extrapolation from other experiments.

Why so big detectors?

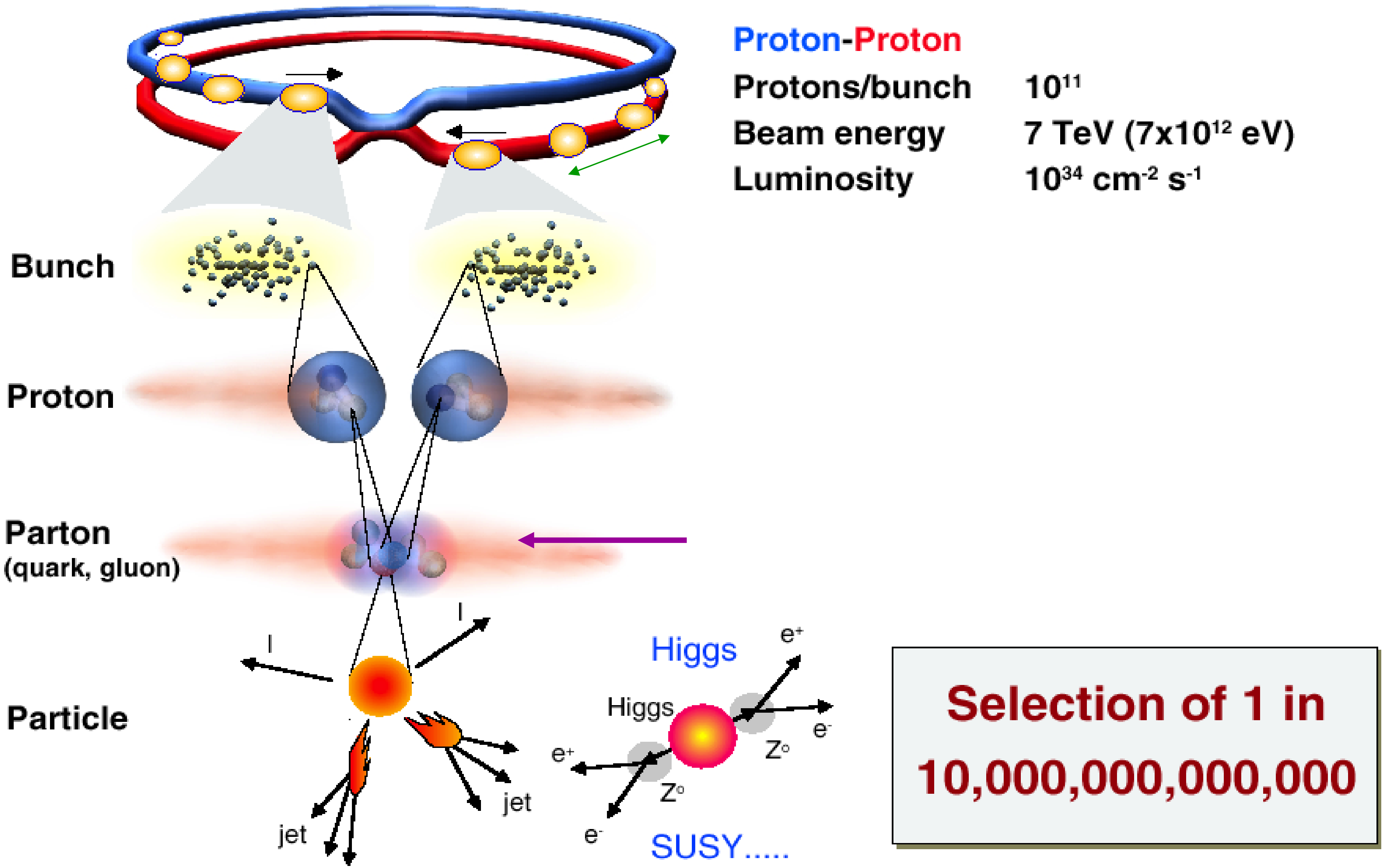


"Contain" the small "Big Bang"

Energetic particles:
need lots of material to contain and measure their energy.

Energetic particles:
need lots space or very high magnetic fields to bend their tracks enough to measure their momenta.

Collisions at LHC



This is a TINY part of ATLAS computing, event filter close to the detector

HLT Farms

Final size for max L1 rate *(TDR)*

~ ***500 PCs for L2 + ~ 1800 PCs for EF***

(multi-core technology)

For 2008 : **850 PCs installed**

total of 27 XPU racks = 35% of final system

(1 rack = 31 PCs)

(XPU = can be connected to L2 or EF)

x 8 cores

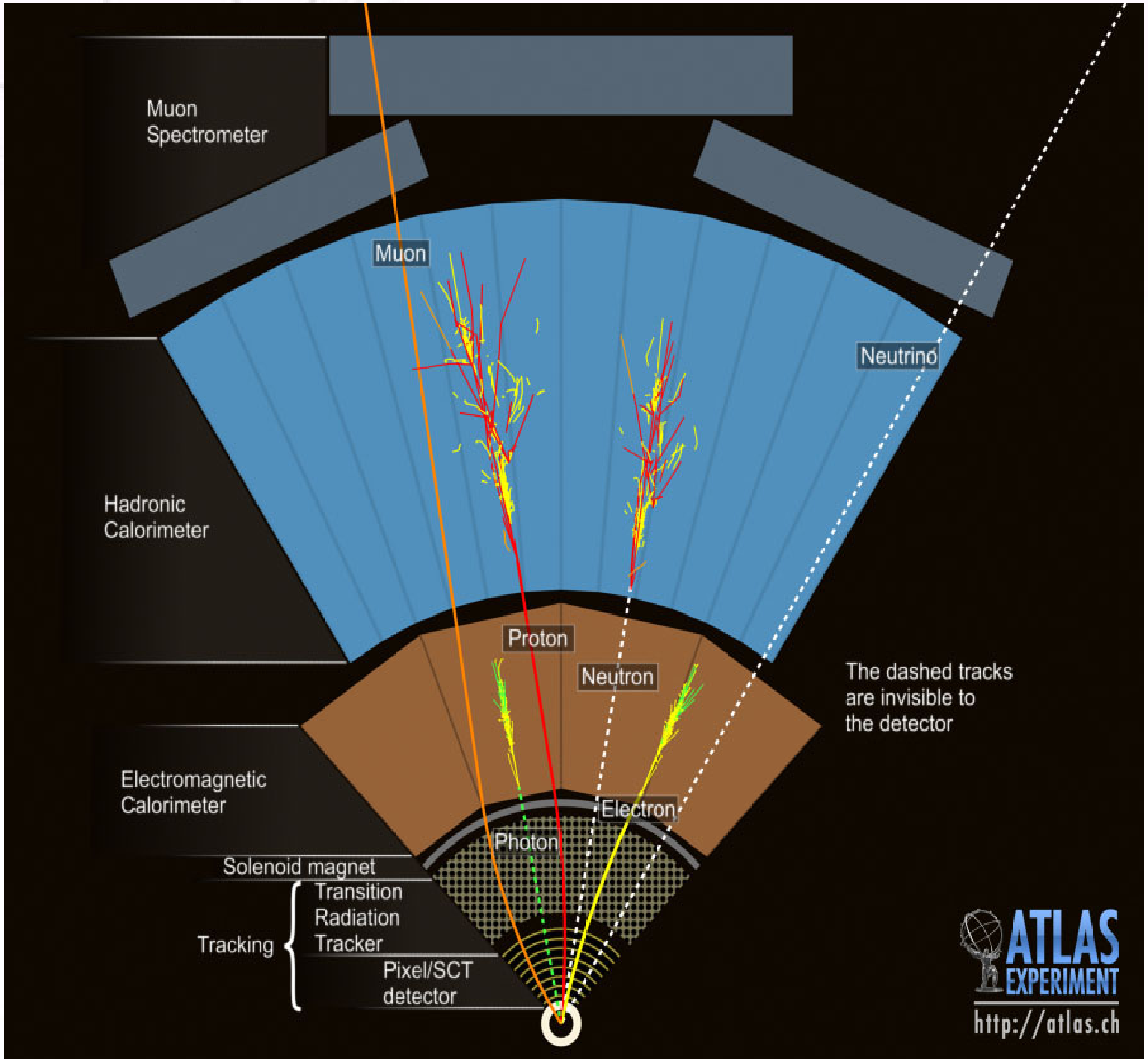
CPU: 2 x Intel Harpertown quad-core 2.5 GHz

RAM: 2 GB / core, i.e. 16 GB

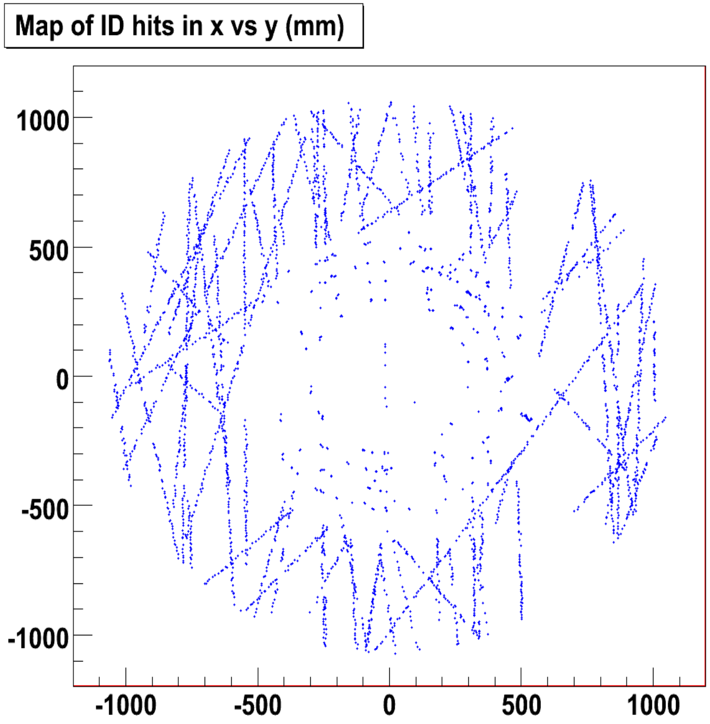
Final system : total of 17 L2 + 62 EF racks

of which 28 (of 79) racks as XPU

How do we see particles in ATLAS?



Another example
cosmic muons,
software made in Bergen



"Run 2" Data Set of the Large Hadron Collider still being exploited:

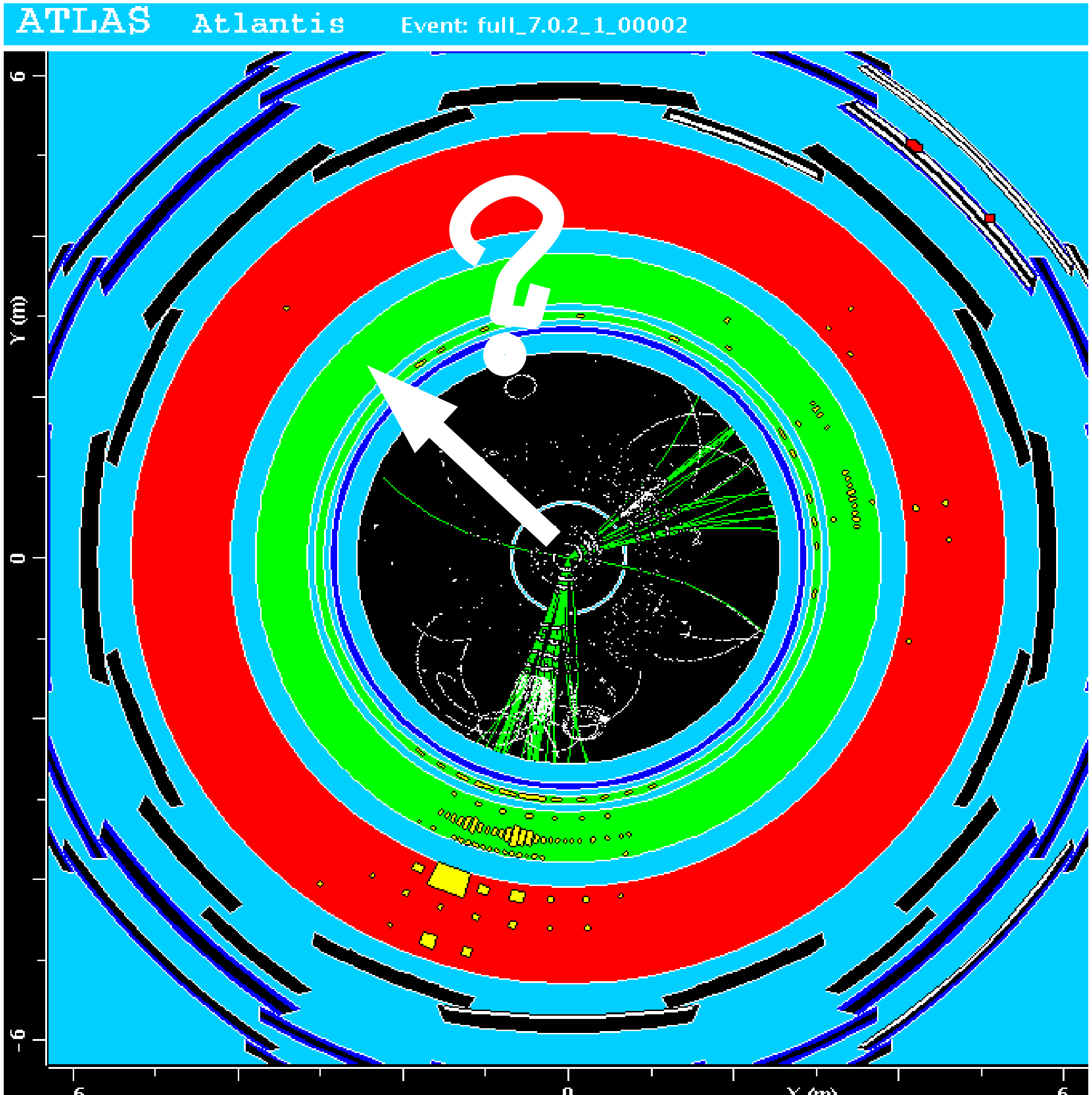
Particle	Produced in 139 fb^{-1} at $\sqrt{s}$ = 13 TeV	
Higgs boson	7.7 million	
Top quark	275 million	
Z boson	2.8 billion	($\rightarrow \ell\ell$, 290 million)
W boson	12 billion	($\rightarrow \ell\nu$, 3.7 billion)
Bottom quark	~40 trillion	(significantly reduced by acceptance)

Run 3+2 (2022- end of 2025) ~500 1/fb (factor 4)
Run 4+3+2 (2029 end of 2032) ~1000 1/fb (factor 7)
Run 5+4+3+2 (– end of 2041) ~3000 1/fb (factor 20)

(far future -if there is any..)

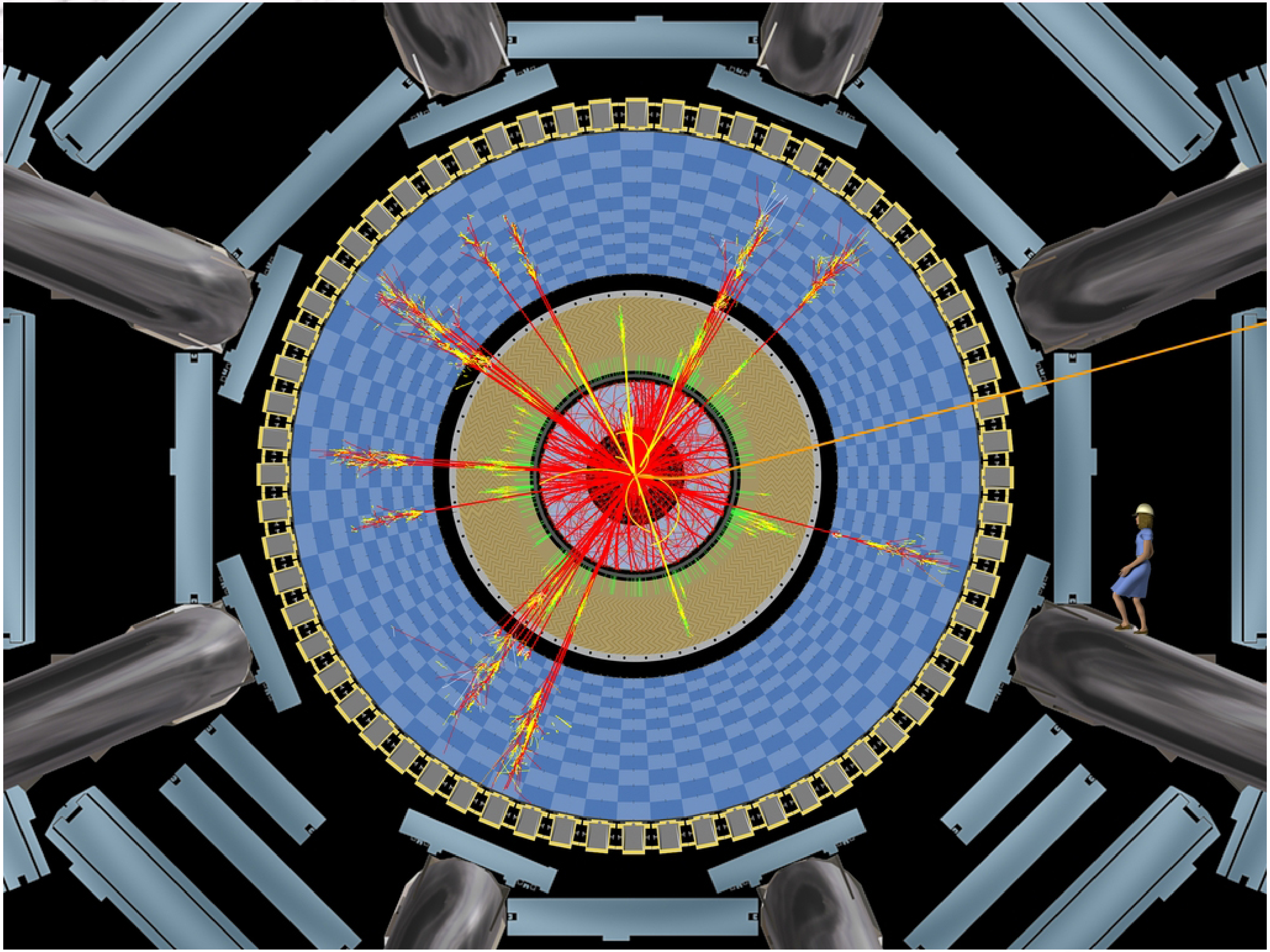
~statistical improvement factor ~2, ~2.5 , ~4.5

Dark Matter production in the ATLAS detector



Can we see it ?
An
example event
with missing
transverse
momentum
and two jets.

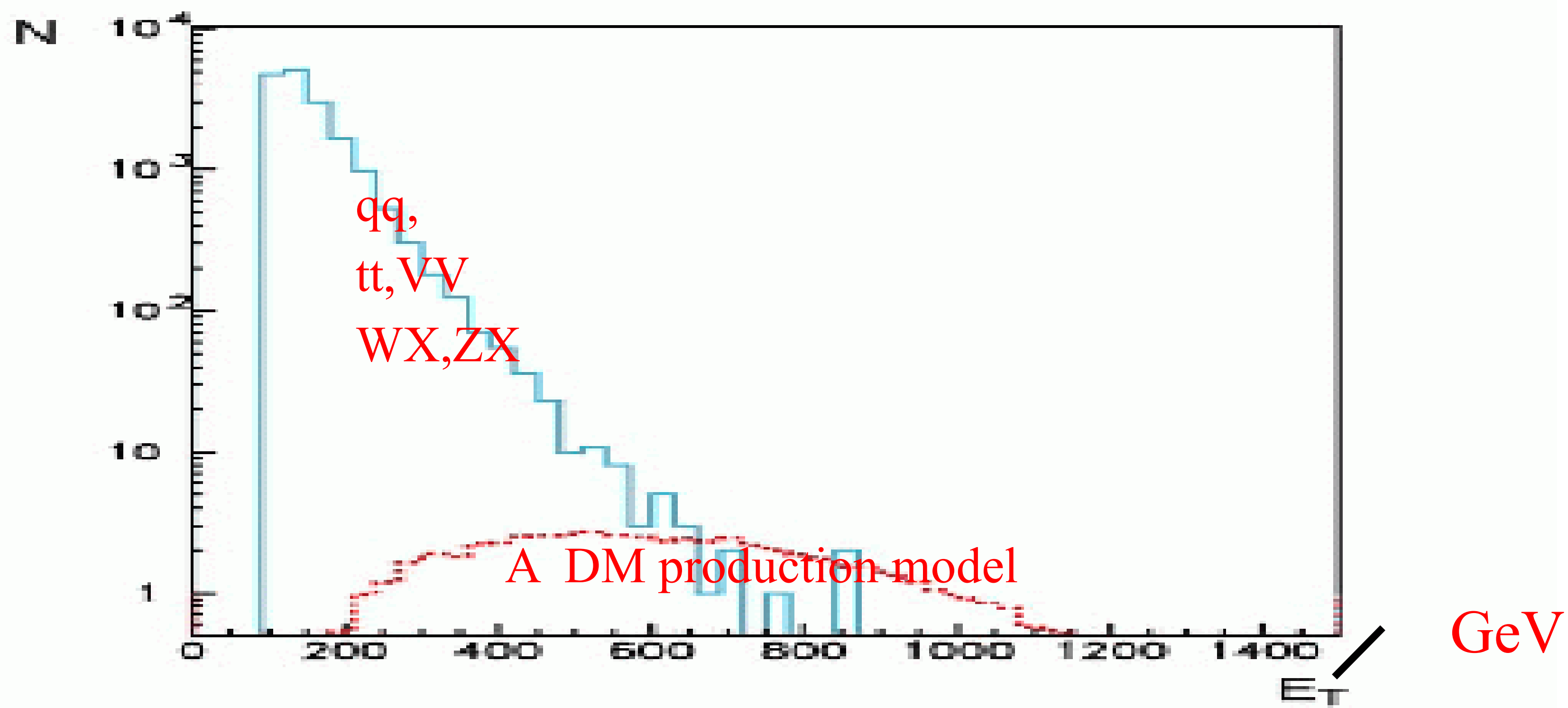
A Black Hole in ATLAS



If our space has more dimensions than 3, gravity can be stronger at the microscopic scale of these extra-dimensions, than it is on our macroscopic scales. Microscopic Black Holes can be produced

“Missing transverse energy”

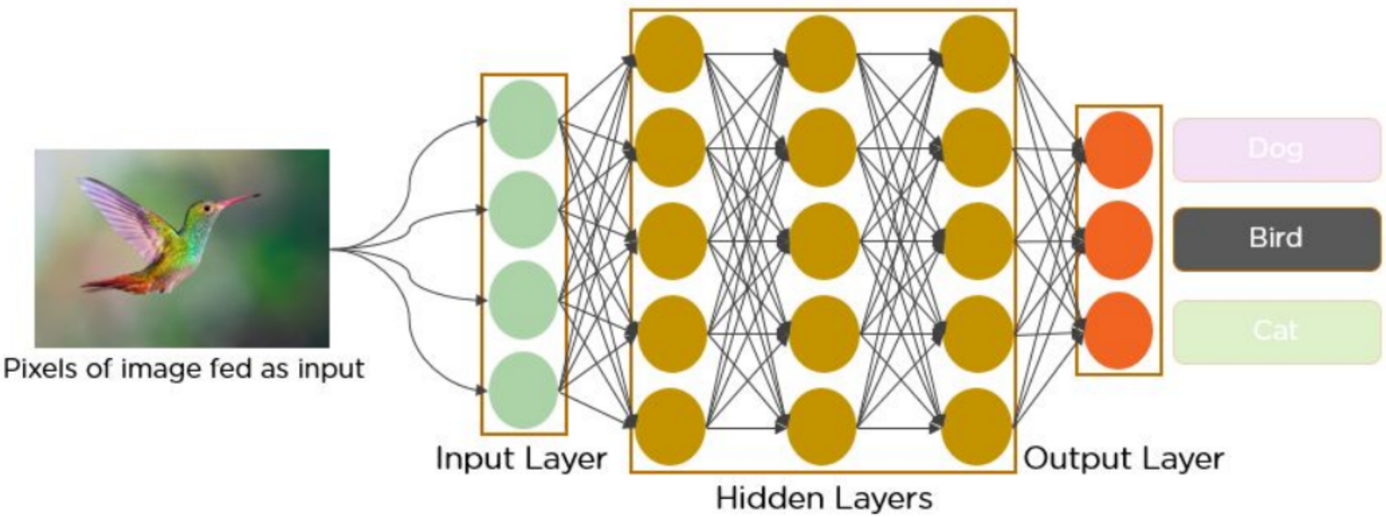
Momentum in the plane perpendicular to the beam is the same before and after collision, thus has to be zero after collision. Unless we missed some particles, as they are not interacting with the detector.



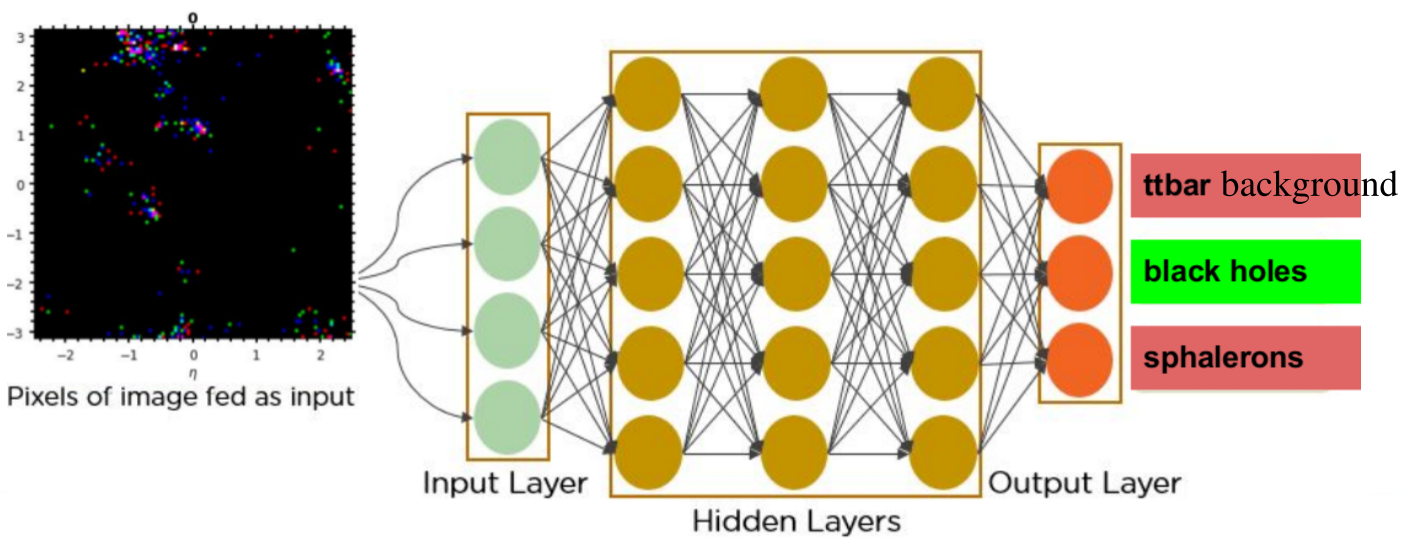
Look for **very** high $\not\!\!E_T$ events

Can we distinguish sphalerons from micro black holes with ML?

Apply ML computer vision techniques on LHC data.

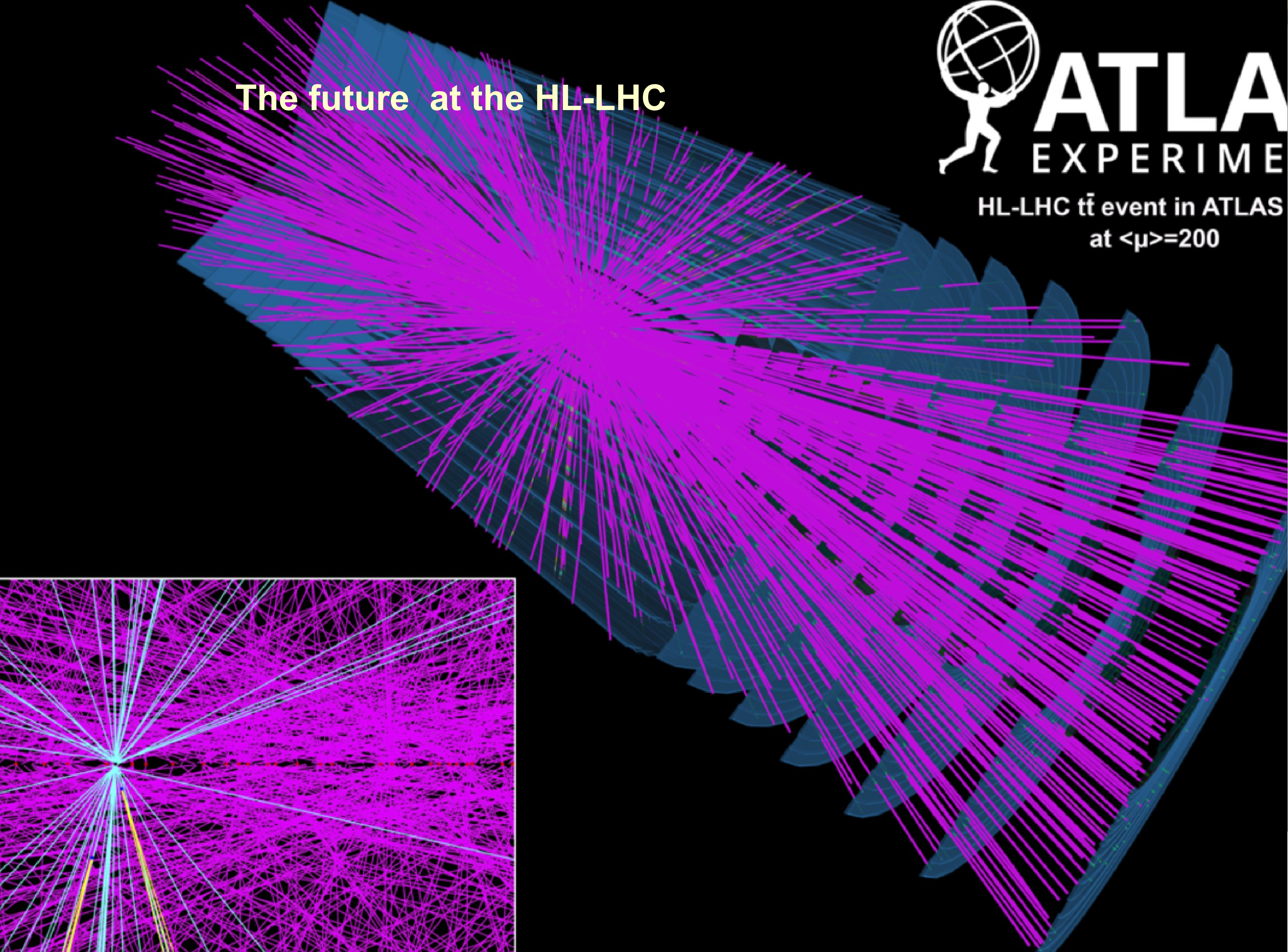


Machine Learning computer vision techniques widely used for picture recognition



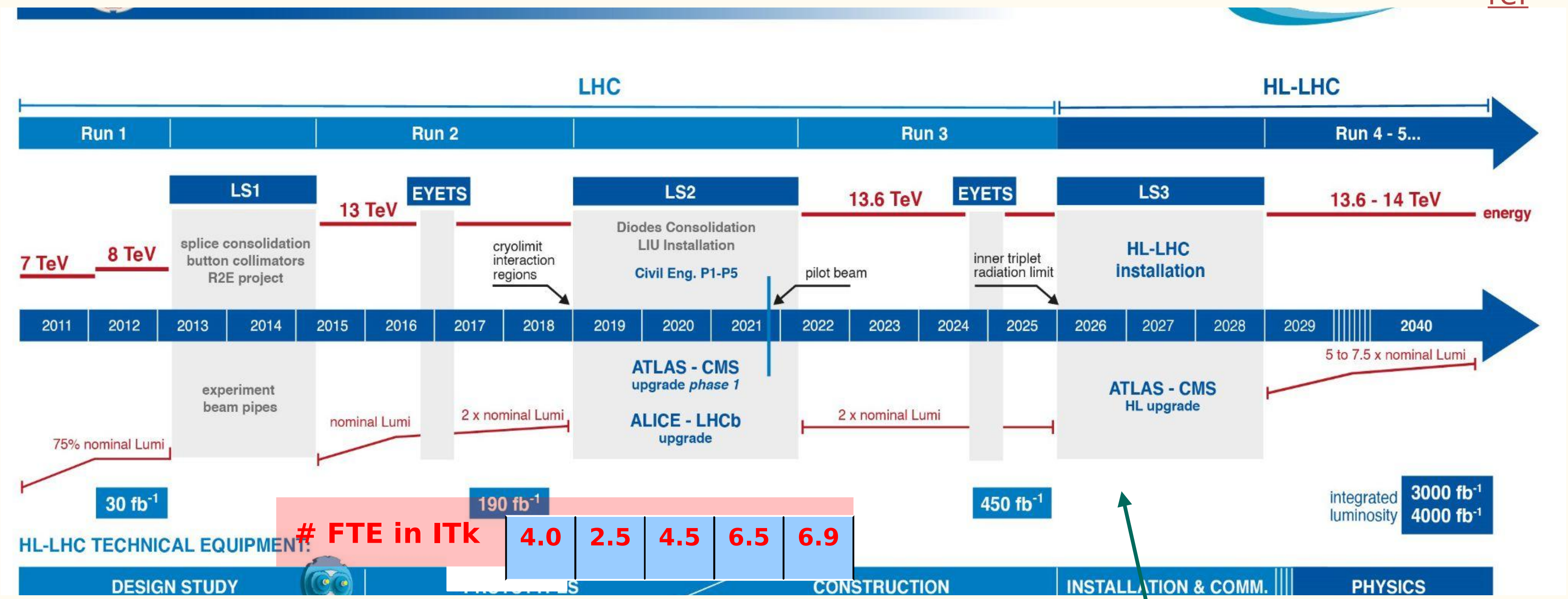
We treat the detector as a camera and energy deposits as pixels. Some promising results in distinguishing SPH from BH

The future at the HL-LHC



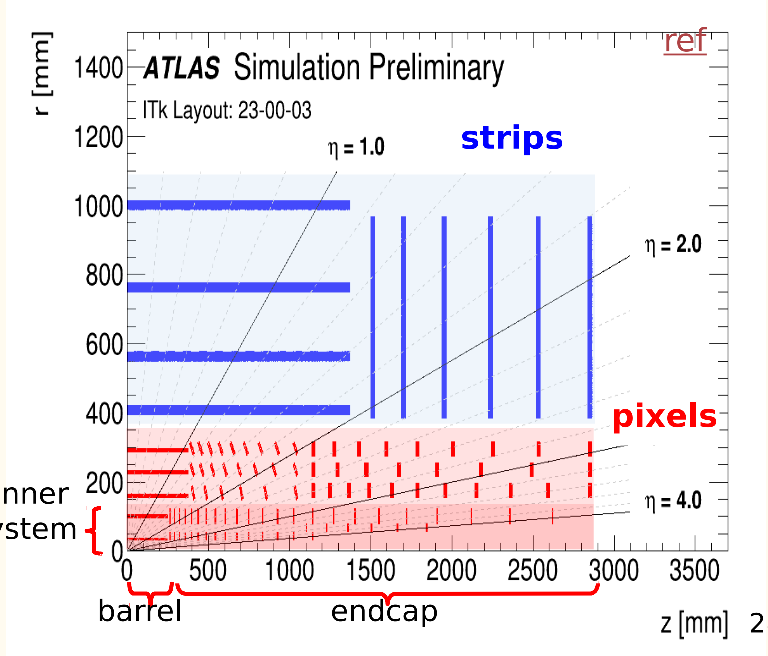
Detector upgrade

ref



Past involvement in SCT, IBL (AFP) detector construction, online sw.

Major effort from Norway in construction of new all-Si tracker ITk (pixels) that will replace current tracker during LS3:
- design and deliver **3D Si pixel sensors**
- design and test **readout frontend ASIC**
- design and deliver 3 types of **flex PCB for inner system**
- **assemble and test pixel modules** (innermost endcap rings)
- **wire-bonding of strip modules**



Detector upgrade (Norway)

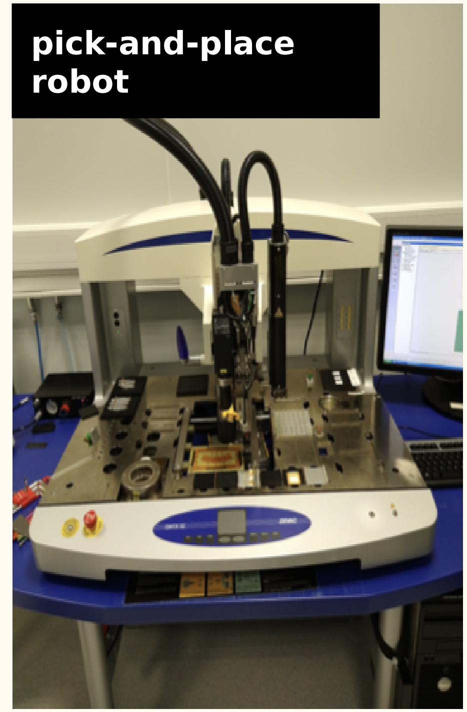
Norway has actively participated in the R&D of 3D silicon pixel sensors together with SINTEF.

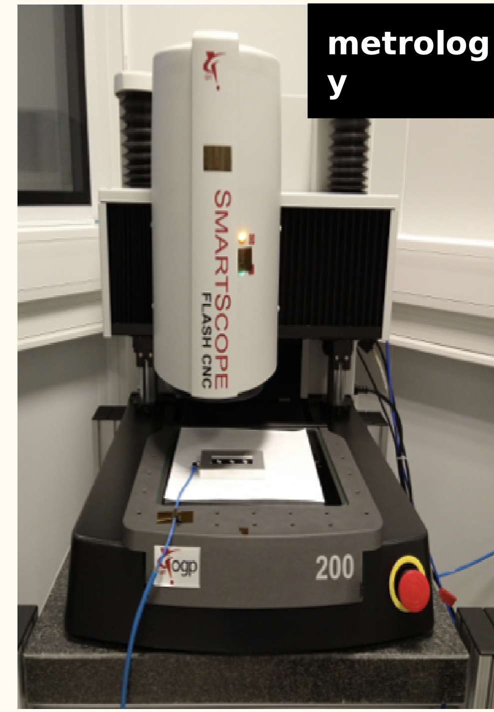
Developing module building tools and instrumentation was an important R&D effort.

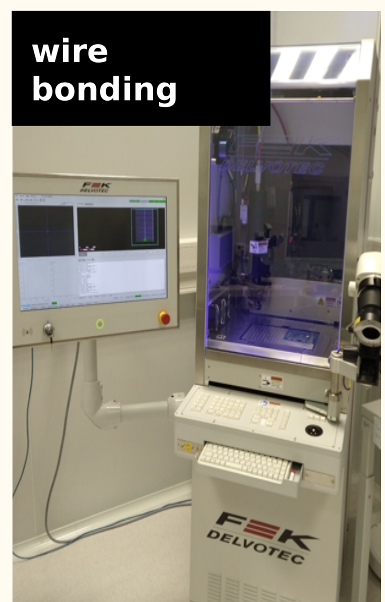
Strong support of NFR and universities was vital, esp. in Oslo where **state-of-the art laboratories have been equipped, now ready for ITk module production**.
Sites ongoing qualification process.

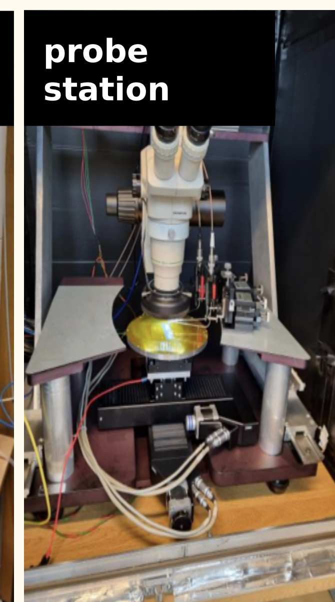
Norway is very well positioned in terms of competences and laboratory facilities (UiO) to do important R&D on future detectors, e.g. DRD collaborations. *Clean-room facilities at UiB needs to be upgraded.*

Testbeam activities before covid **very successful**, and have just resumed.







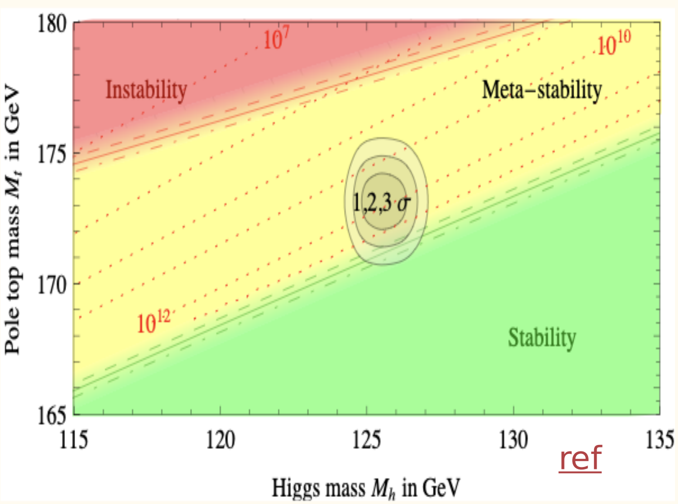


Physics exploitation (Norway)

Higgs boson properties

$H(\gamma\gamma)$

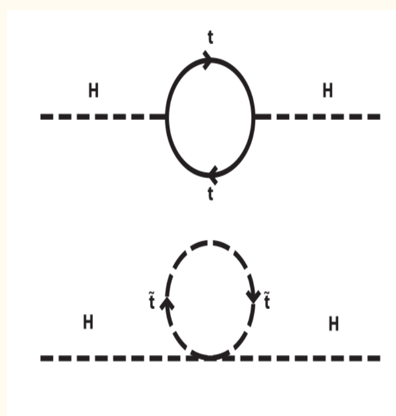
$H(\tau\tau)$



Supersymmetry

squarks/gluinos

sleptons/EWinos

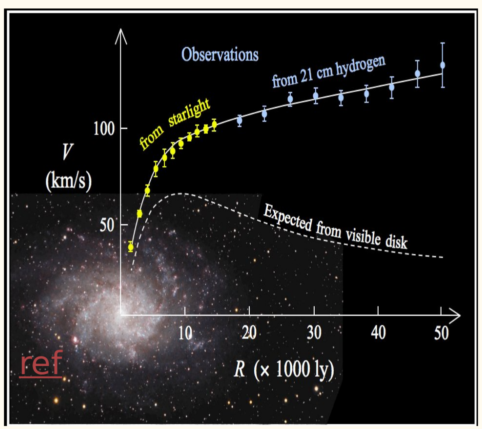


Exotic physics

heavy resonances

non-resonant searches

X + Dark Matter

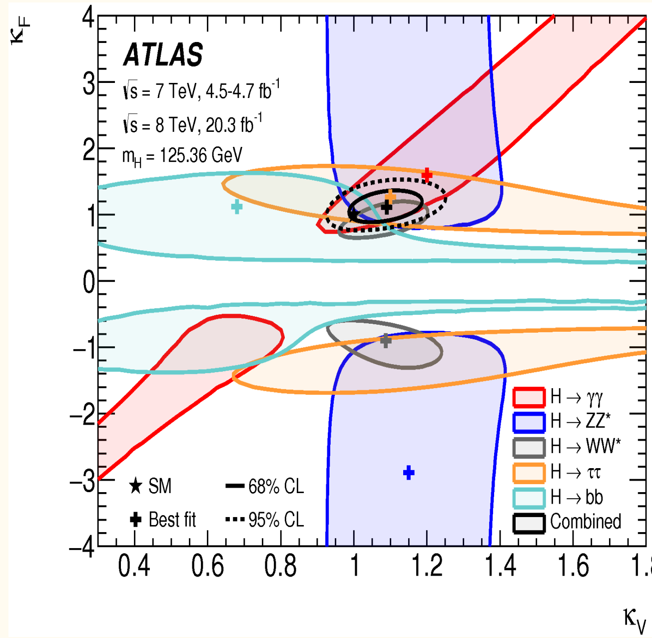


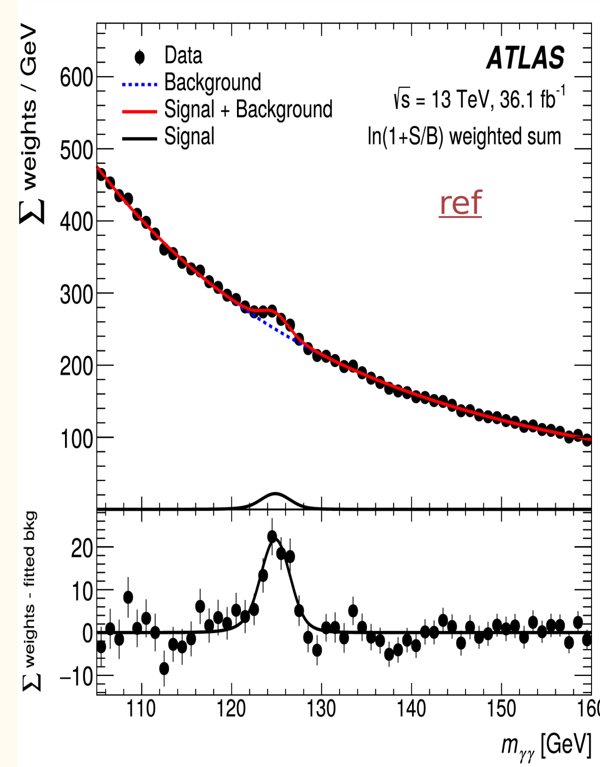
Higgs physics(Norway)

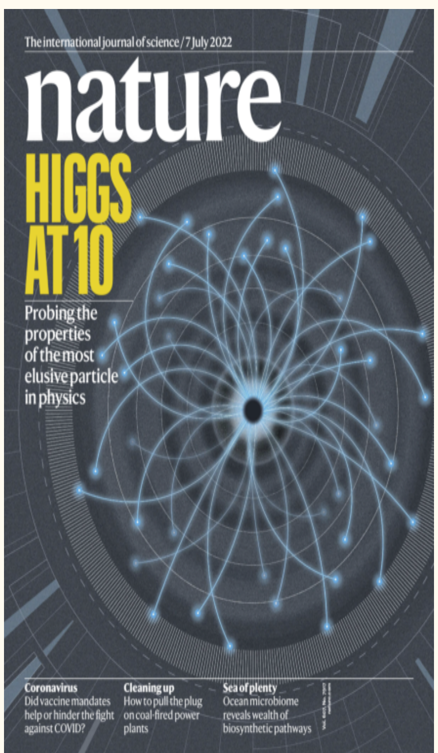
Run 1: Higgs boson discovery, ***H***$(\gamma\gamma)$ **couplings measurement**.

Run 2: ***H***$(\gamma\gamma)$ **mass measurement**, background modeling studies. $H(ZZ^*\rightarrow 4l)$ mass and couplings.

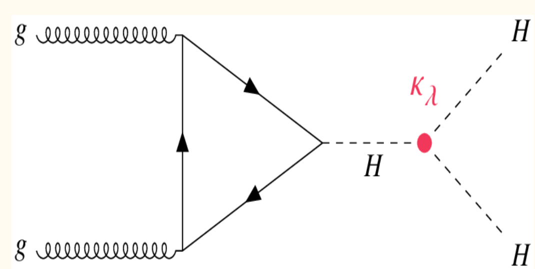
ref

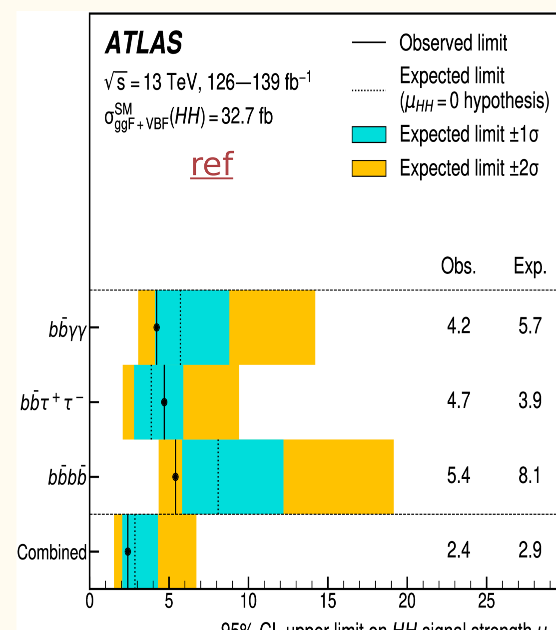






HH **→** $\gamma\gamma$ **+ leptons**:
- **HL-LHC projection** in progress
- **Run 3 analysis**: focus on BSM





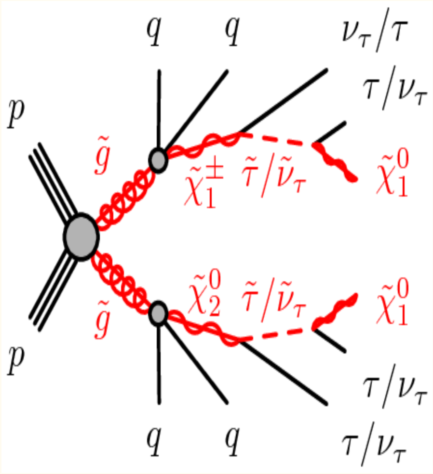
Supersymmetry (strong)

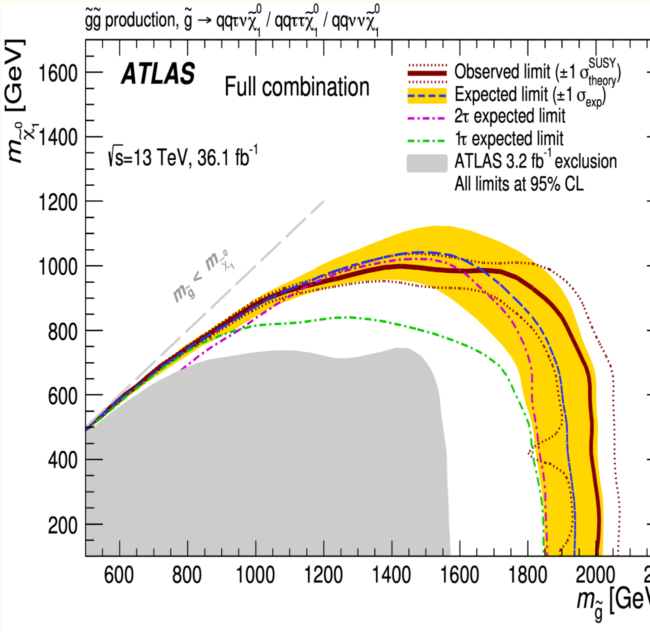
Run2+Run3 search with simplified model.

Improved low-p_T taus reconstruction beneficial for compressed mass spectra.

Use tau triggers developed inhouse.

ML to separate sig/bkg.

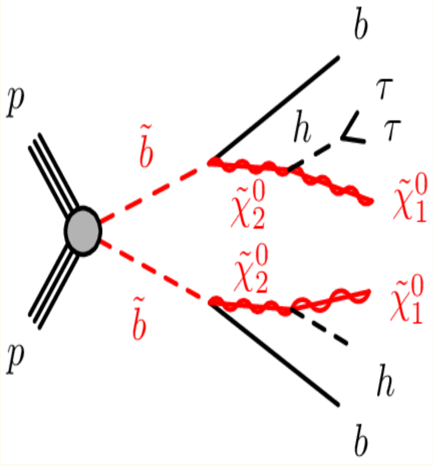


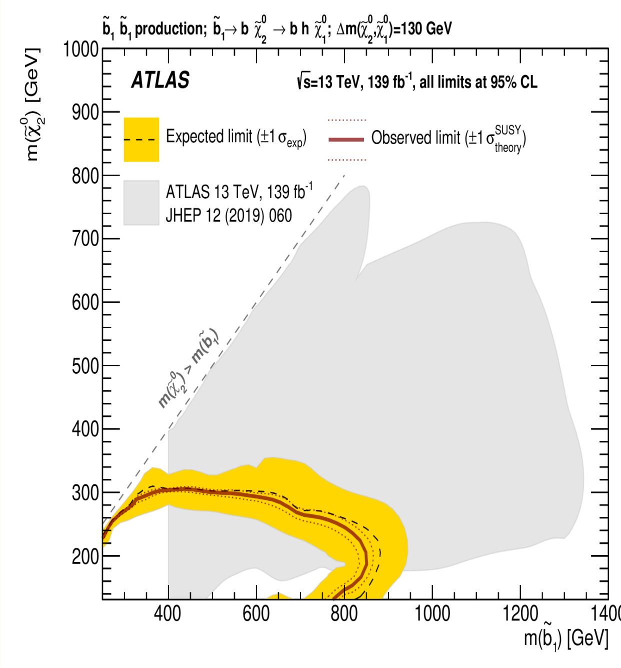


ref

Search with unique sensitivity:
- low SM background with 2τ + 2 b-jets
- $\tau \rightarrow \tau_{had}\nu$ provides extra MET

Complementary to multi-bjet search that requires large MET.



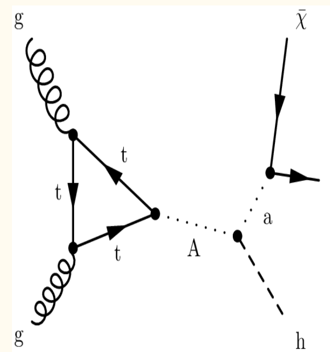


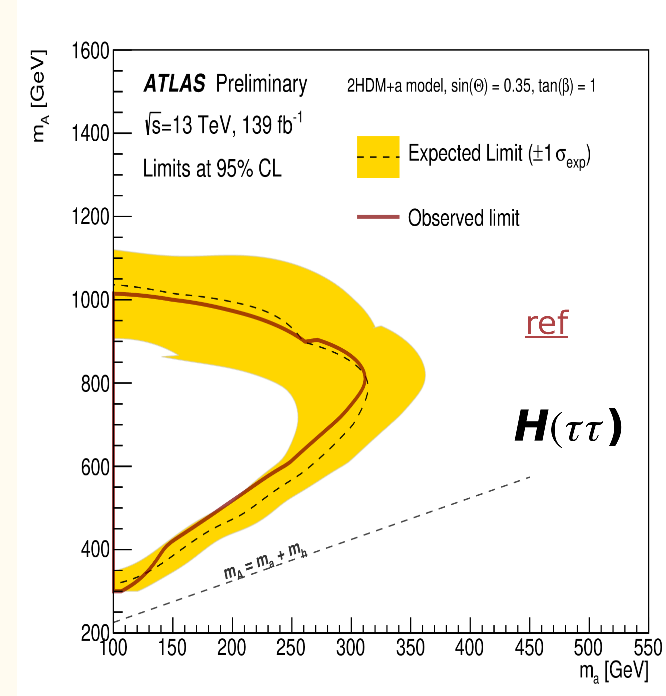
ref

Exotics and Dark Matter

***H*+MET searches** with Dirac fermion Dark Matter χ.
Z' models, 2 Higgs Doublet Model + pseudoscalar *a*.

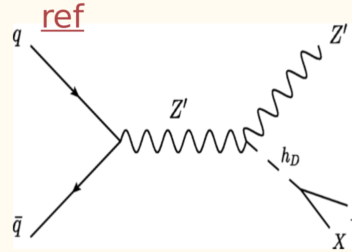
Searches in *H*($\tau\tau$) and *H*($\gamma\gamma$).
Limits competitive with direct DM experiments for light DM (few GeV).
Participating in ATLAS-wide combination.

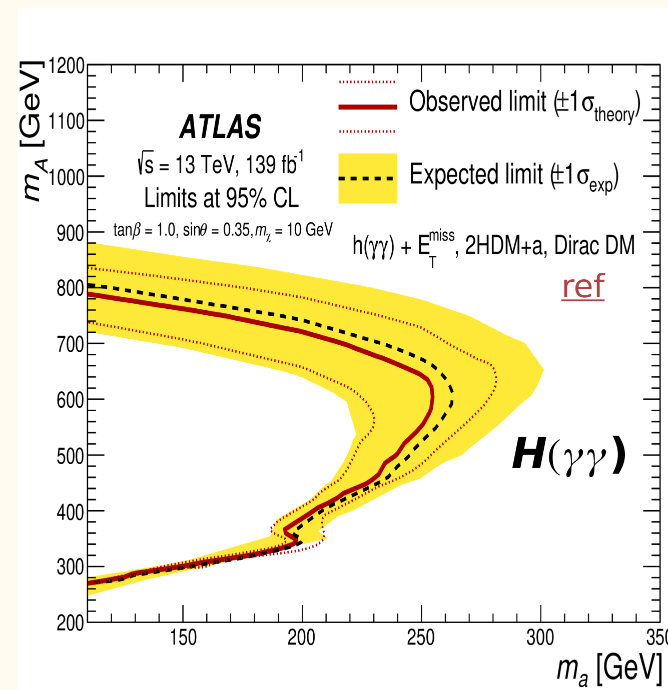




***Z'*(*ll*)+MET 2D-search**, DM-aware Z' models (dark Higgs, light vector, inelastic EFT).
Results interpreted in bins of *m*$_{ll}$ and MET.
(PhD thesis and conf. note summer 2023, followed by Z´+X publication)

ref





Computing

Norway has played a major and long-standing role in the development and management of distributed computing, both for ATLAS and more widely

- NorduGrid’s Advanced Resources Connector (ARC) middleware
- Contributions to the data management layer (DQ2, latterly Rucio)
- Development of the distributed Nordic Tier-1
- Development of ATLAS@Home
- Personnel from Norway coordinated the overall ATLAS computing and software project from 2018-2020, and the distributed computing activity from 2020 until 2023
    - Hugely experienced and key member of personnel left in 2023, personpower to be replaced but serious loss of experience
- Significant collaboration and synergies with UiO IT and NeIC on hardware provision and also applications

Trigger and offline software for run 3

Significant Norwegian involvement in ATLAS trigger and offline software, both in development and coordination

Trigger coordination and management

Norwegian personnel:

- coordinate physics validation of the high level high level trigger
- coordinate trigger conditions data
- are members of the trigger management board

Software coordination

- One of the ATLAS software coordinators, and one of the upgrade software coordinators, are Norway-based
- The panel responsible for developing and monitoring the roadmap and milestones for HL-LHC computing contains a member of Norwegian personnel

Tau trigger

Norwegian personnel:

- coordinate the tau trigger group
- are responsible for tau trigger algorithm tuning (tau energy calibration, NN Tau ID)

Tau reconstruction

Norwegian personnel:

- coordinate the tau combined performance group and the fake tau subgroup
- are responsible for liaising for tau energy calibration
- re-optimised tau reconstruction during wider migration to multi-threaded software

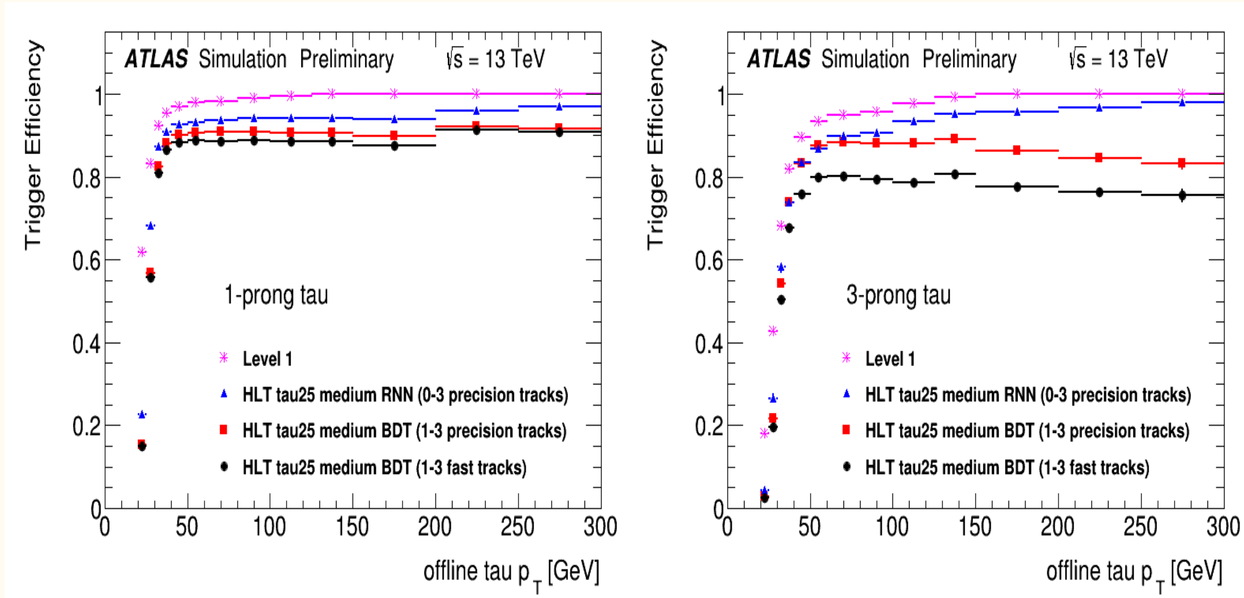
Many ongoing tasks undertaken by students relevant to tau reconstruction in run 3 (efficiency, boosted di-tau (had-had) reconstruction algorithm, NN TES calibration)

Production of analysis data

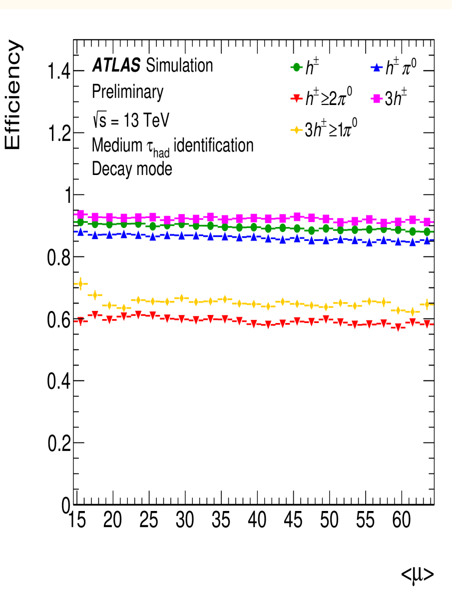
Norwegian personnel develop and maintain the software framework for producing analysis data, and developed the new compact data types for run 3 and run 4

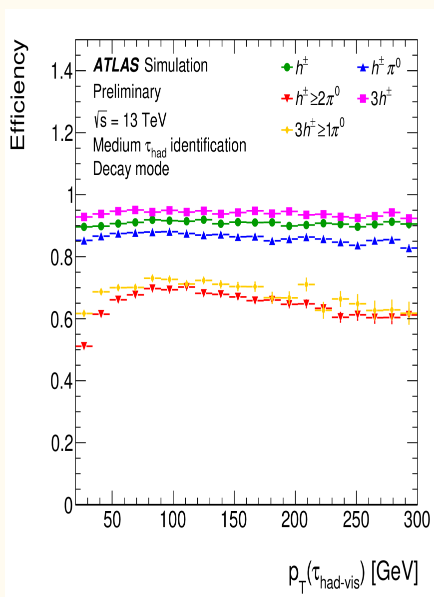
Tau trigger and reconstruction highlights

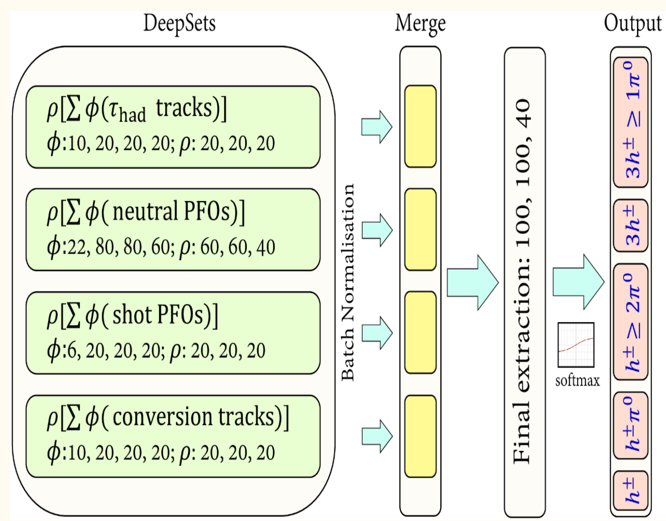
Continued improvements in tau trigger efficiency for one-prong decays…



… and three prong decays







Training Parameters

Parameter	Value
Epochs	100*
Batch size	1000
Optimizer	*Adam*
Learning rate	0.01*
β_1, β_2	0.9, 0.999
Activation function	ReLU

Discrimination efficiency of a new DeepSets neural network for different tau decay channels

Conclusions

ATLAS Experiment and ATLAS in Norway, we do lots of interesting thing- join us !