

ATLAS ..after the Higgs boson discovery ..

ATLAS ?

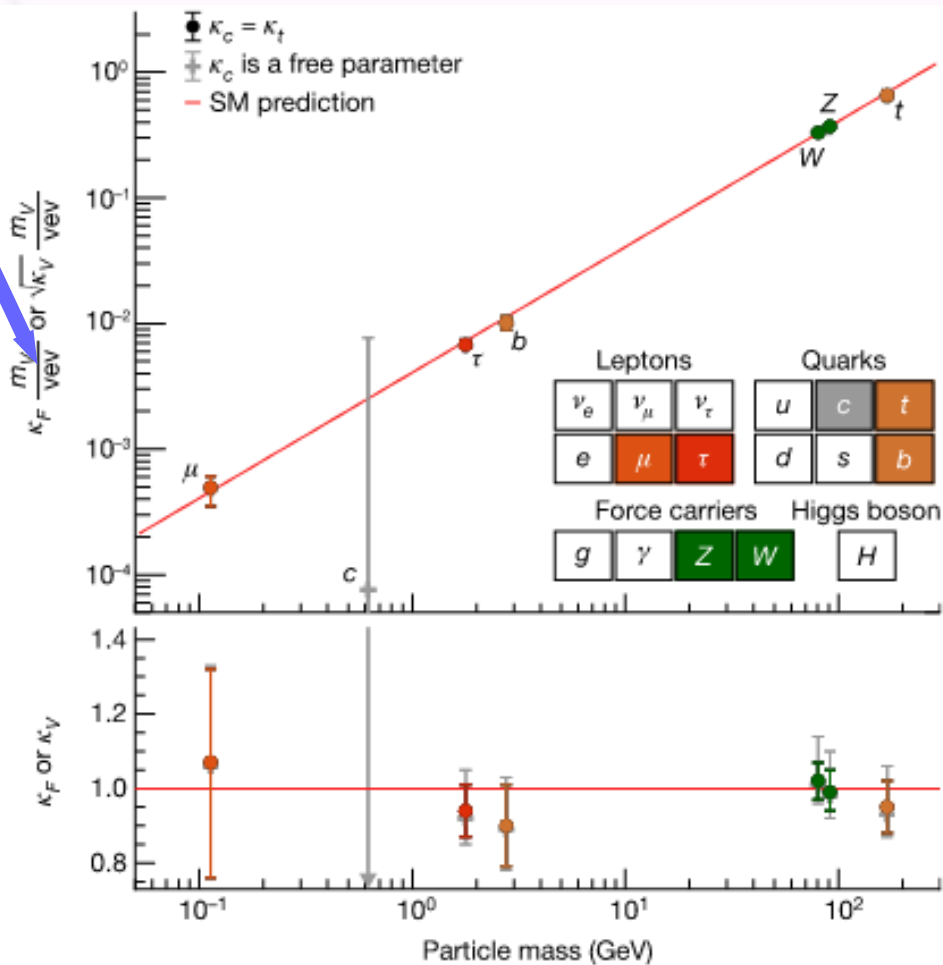
ATLAS in Norway

ATLAS !

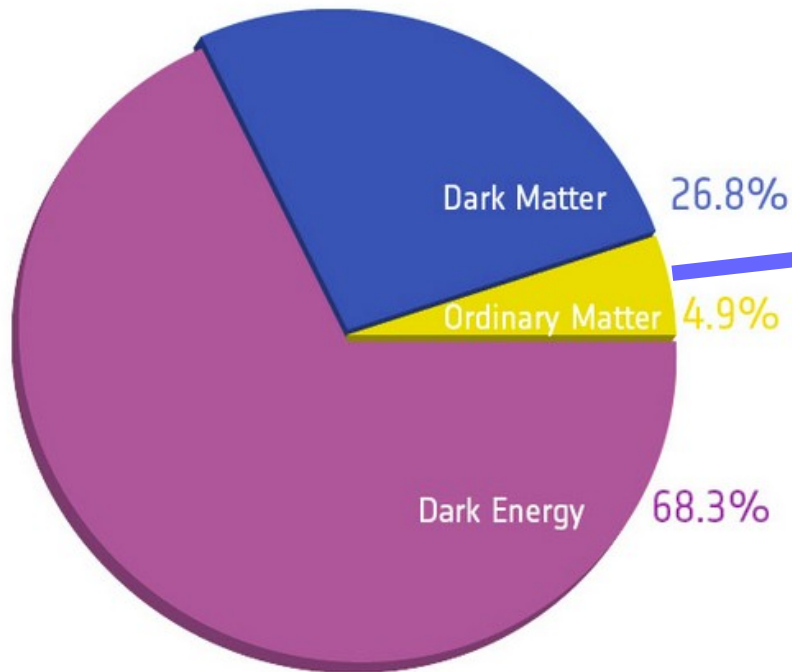


The Standard Model's Higgs boson

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

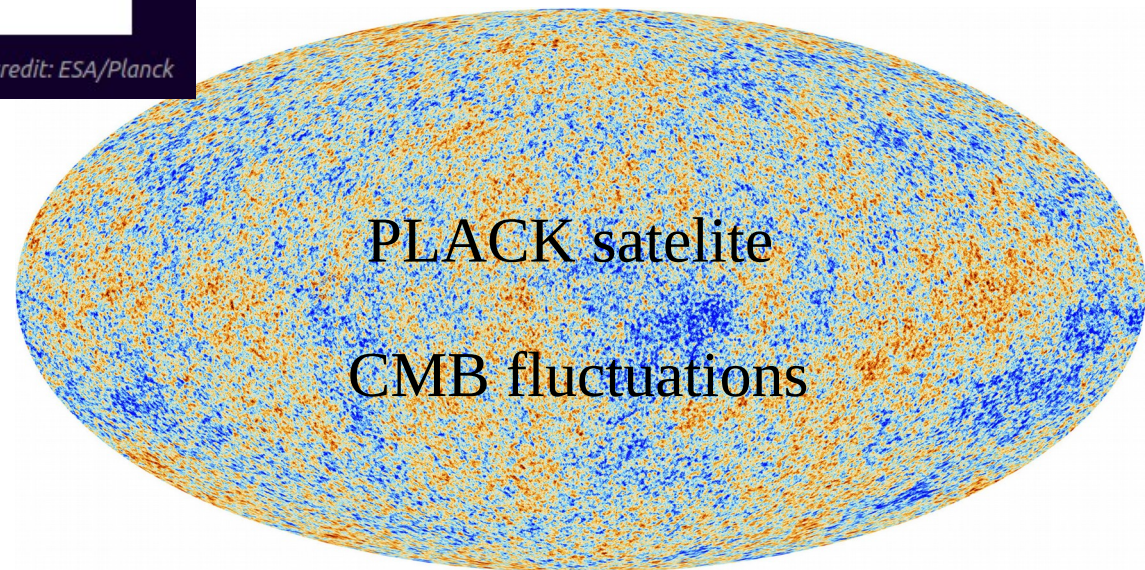


The Standard Model makes only 5% of the Universe

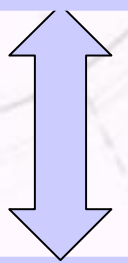


The relative amounts of the different constituents of the Universe. Image credit: ESA/Planck

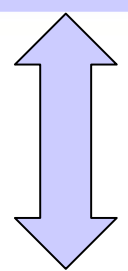
The Higgs boson
and the rest of SM
We do not even know
Why this 5% exists.
It should have annihilated
Away, but did not (CPV?)



Cosmology



Astroparticle physics



Particle physics

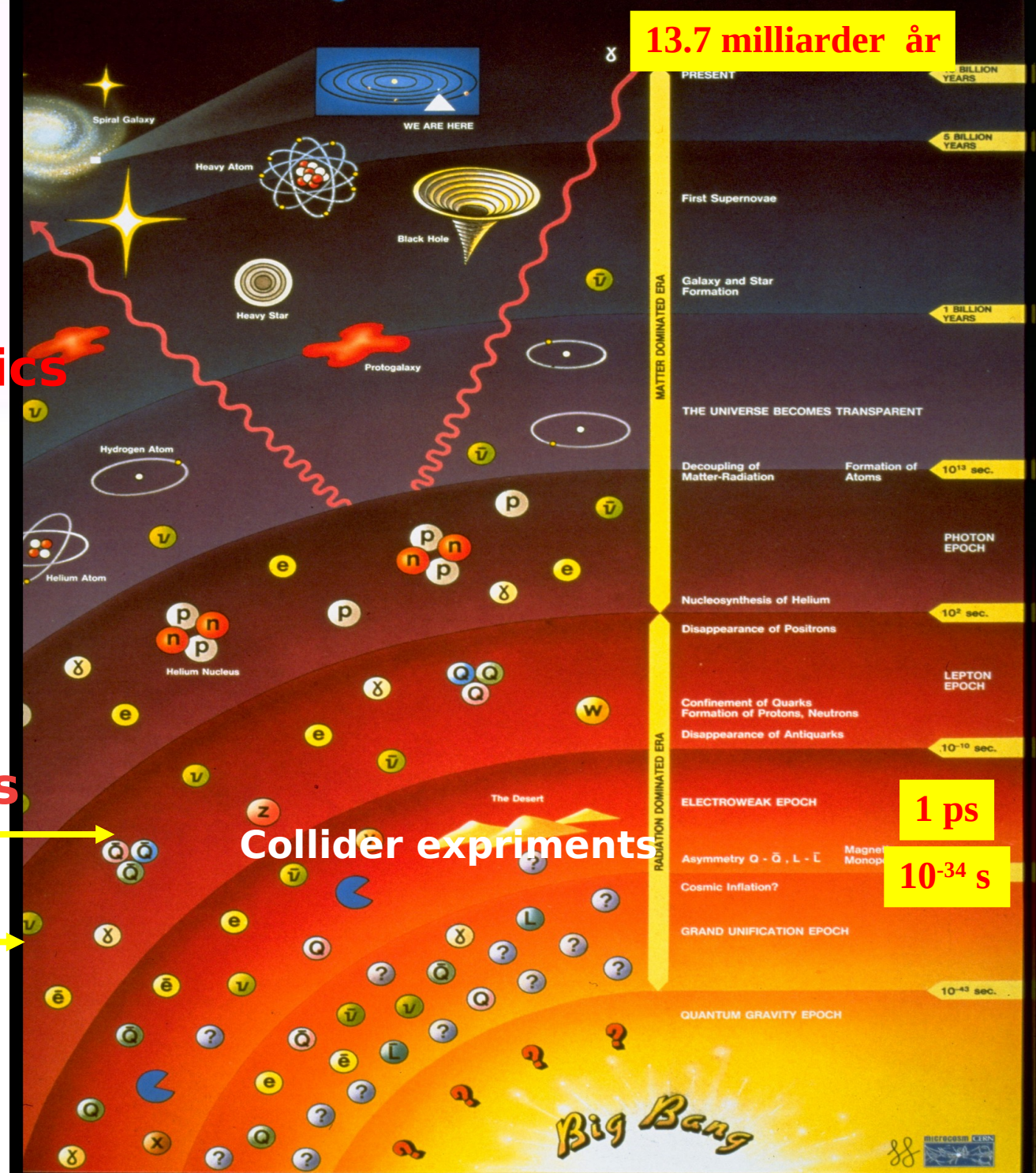
Higgs field arises (EWSB)?



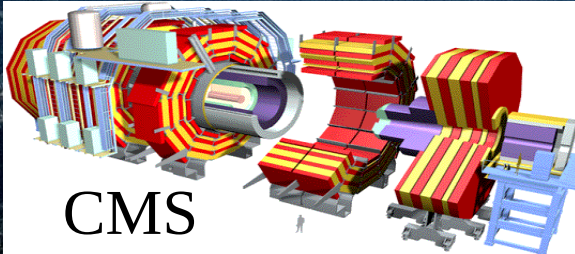
Matter takes over?



History of the Universe



The Large hadron Collider and its experiments



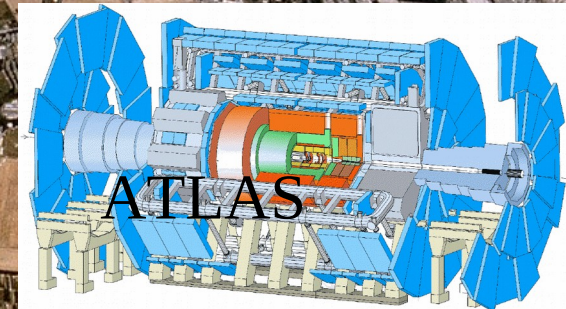
Collisions of Protons= hadrons,
(and also heavy ions).

Design energy collision

$14,000,000,000,000 \text{ eV} = 14000 \text{ GeV} = 14 \text{ TeV}$

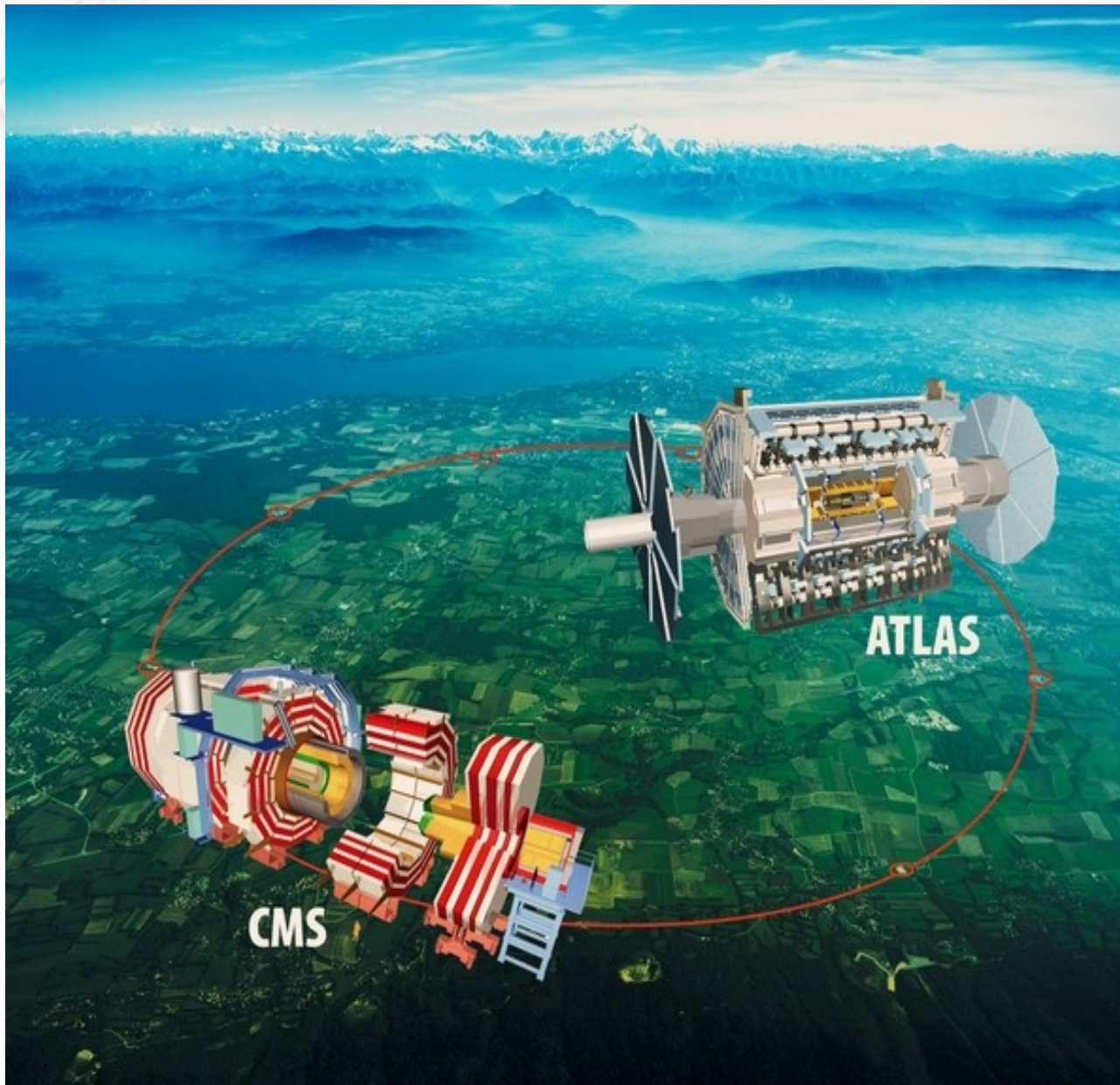
Rest energy of a proton is ca 1 GeV

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



ATLAS and CMS have similar capabilities now and in the future

ATLAS after Higgs and the LHC



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(UiB+HVL
&Oslo*

Particle Physics, High Energy Physics

**ATLAS
Collaboration**

Armenia	Netherlands
Australia	Norway
Austria	Poland
Azerbaijan	Portugal
Belarus	Romania
Brazil	Russia
Canada	Serbia
China	Slovakia
Czech Republic	Slovenia
Denmark	Spain
France	Sweden
Georgia	Switzerland
Germany	Taiwan
Greece	Turkey
Israel	UK
Italy	USA
Japan	CERN
Morocco	JINR

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

UiB(perm): Anna Lipniacka, Bjarne Stugu, Bertrand Martin Dit Latour

Postdoc: Simen Hellesund

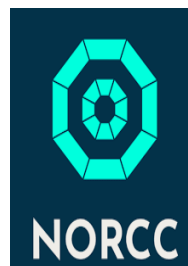
PhD: Erlend Aakvaag, Simon Huiberts, Sohaib Hassan, +1

HVL (perm) Therese Sjursen, Steffen Maeland, Trygve Buanes,

Dag Toppe Larsen

Postdoc: Igor Slazyk

PhD. Tarje Solberg(UiB), Aurora Grefsrud



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
<i>In progress</i>	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

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Positions of responsibility, current, future ?

Level	Roles held
Executive board	Trigger coordinator (?)
CB and senior committees	committee, outreach (current) Statistics committee (current)
Activity coordinators	Software coordinator (current) Upgrade software coordinator (current) Trigger validation coordinator (current) Trigger conditions coordinator (current) Trigger automated tests coordinator (current)
Physics coordination (sub-group conveners)	Fake Tau Task Force (current) Strong production (current)

In Bergen (UiB+HVL):

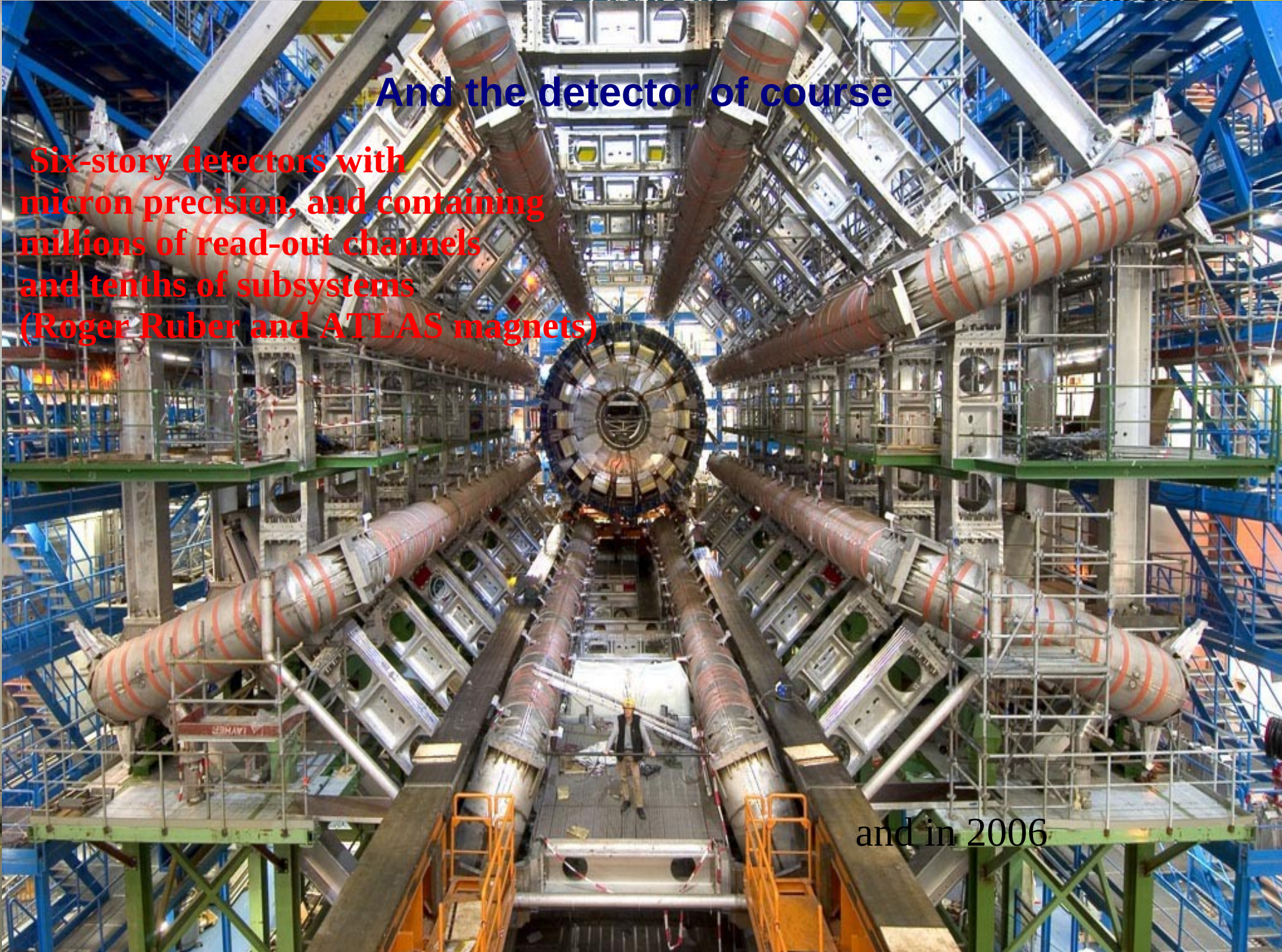
Tau trigger and tau reconstruction with ML methods.

Data analysis: Dark Matter and Higgs (also ML methods)

“Phase 2” upgrade: 3D silicon detectors for upgraded inner tracker: electrical test, Beam tests, tests with radioactive sources

And the detector of course

Six-story detectors with micron precision, and containing millions of read-out channels and tenths of subsystems (Roger Ruber and ATLAS magnets)



and in 2006

The Large Hadron Collider

The Beauty or

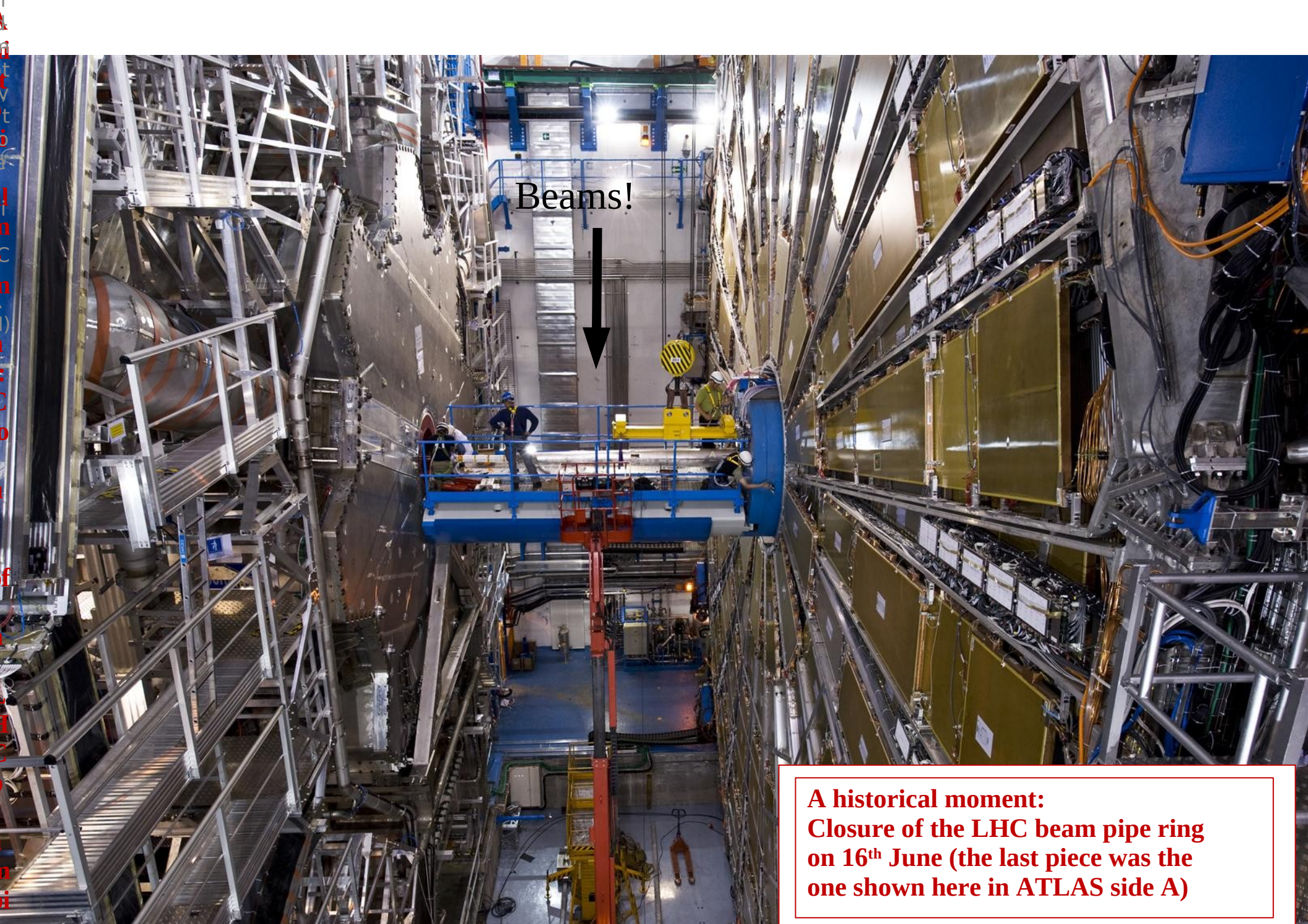


ATLAS, situated in the largest man-made cavern.

Summer 2003



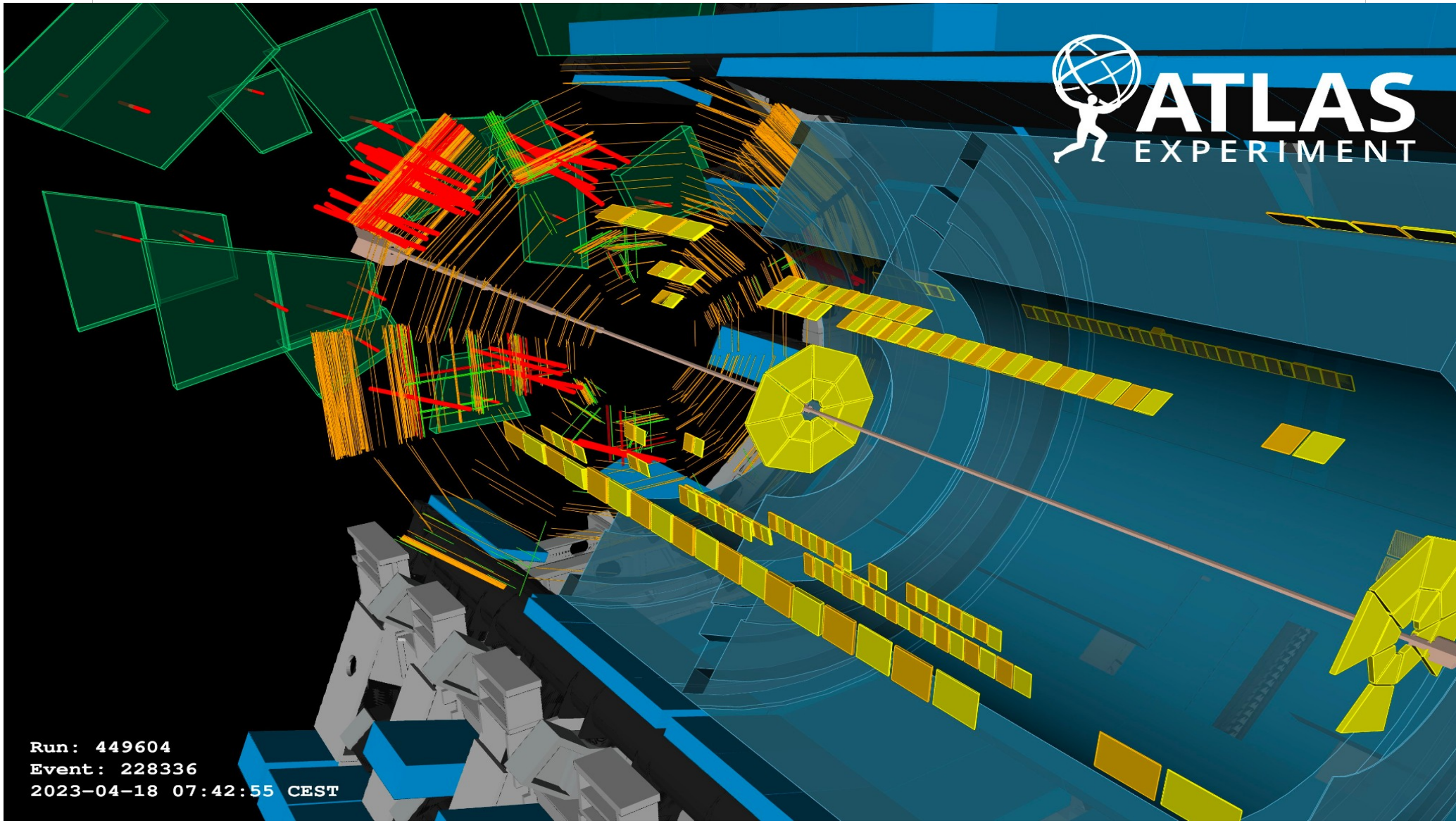
Slide 13



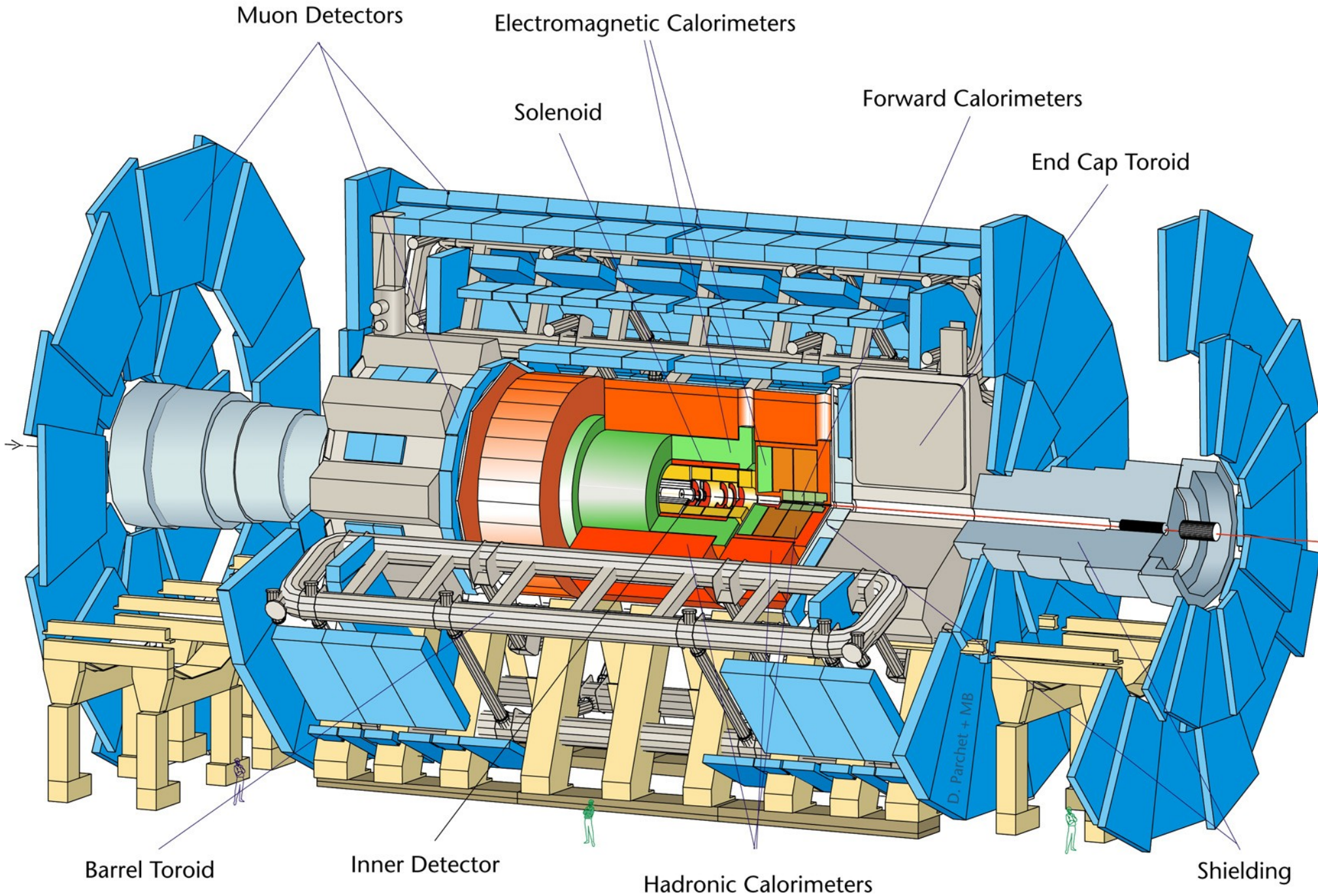
Beams!



**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)**



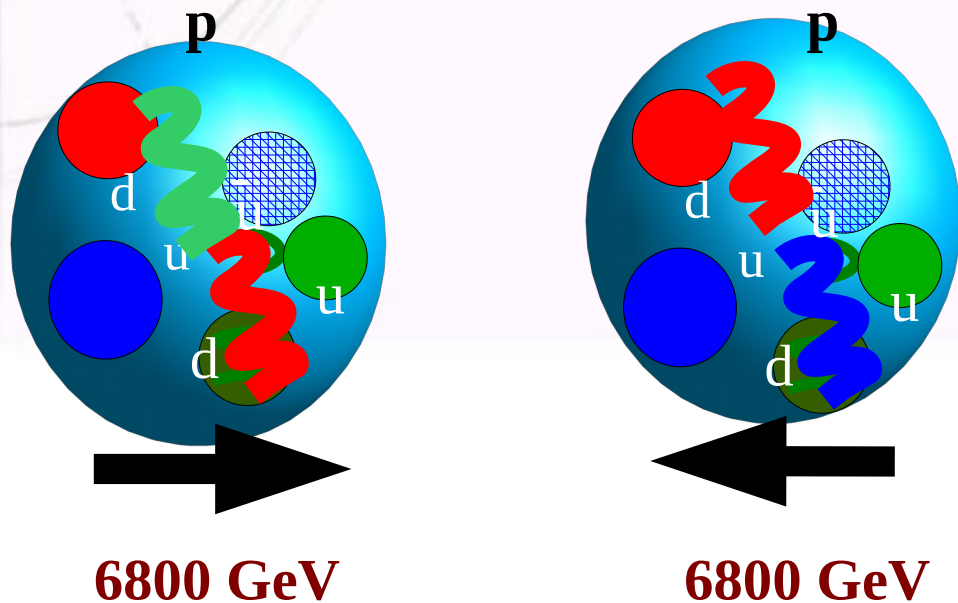
Run: 449604
Event: 228336
2023-04-18 07:42:55 CEST



Slide 16

Accelerator-driven physics, the paradigm

ATLAS after Higgs and the LHC



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”**

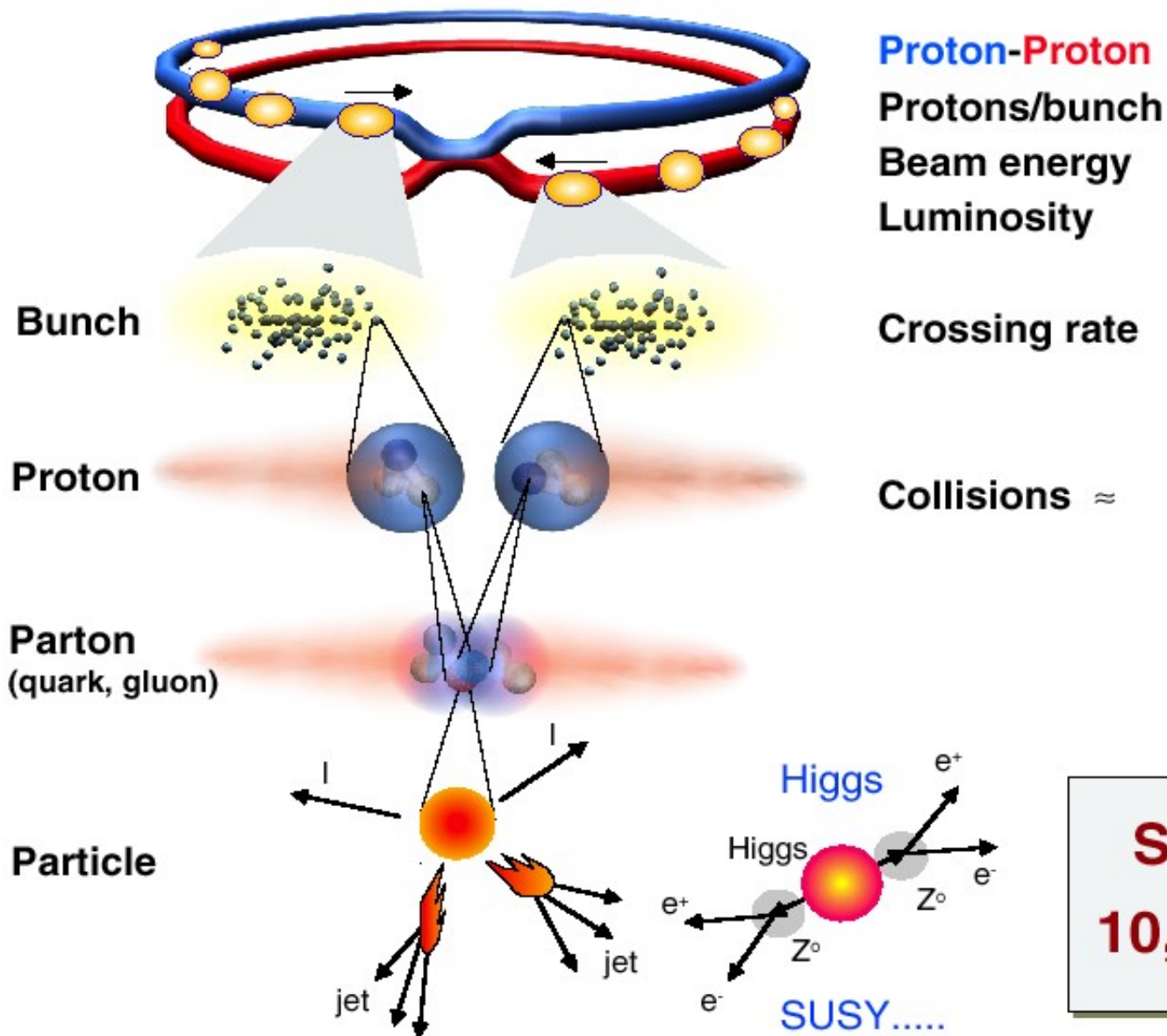
Energetic particles:
need lots of material
to contain and measure
their energy.

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

Simulated

$H \rightarrow ZZ \rightarrow e e \mu \mu$

Collisions at LHC



Proton-Proton
 Protons/bunch
 Beam energy
 Luminosity

2835 bunch/beam
 10^{11}
 6.8 TeV
 $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

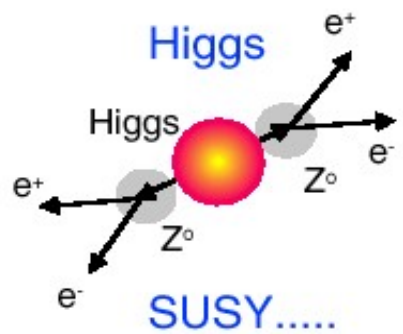
Crossing rate

40 MHz

Collisions \approx

$10^7 - 10^9 \text{ Hz}$

**Selection of 1 in
 10,000,000,000,000**



**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

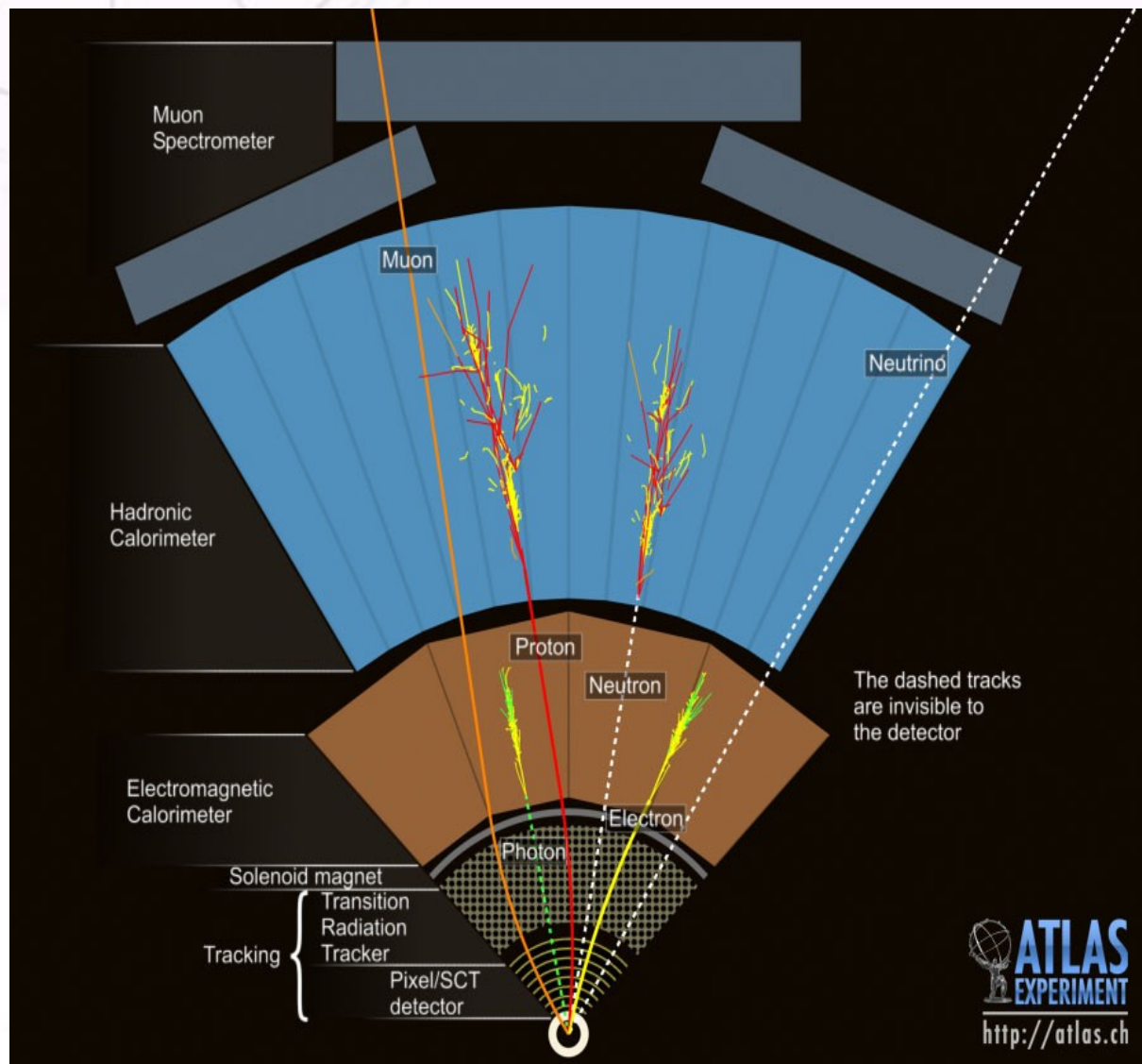
CPU: 2 x Intel Harpertown quad-core 2.5 GHz

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**

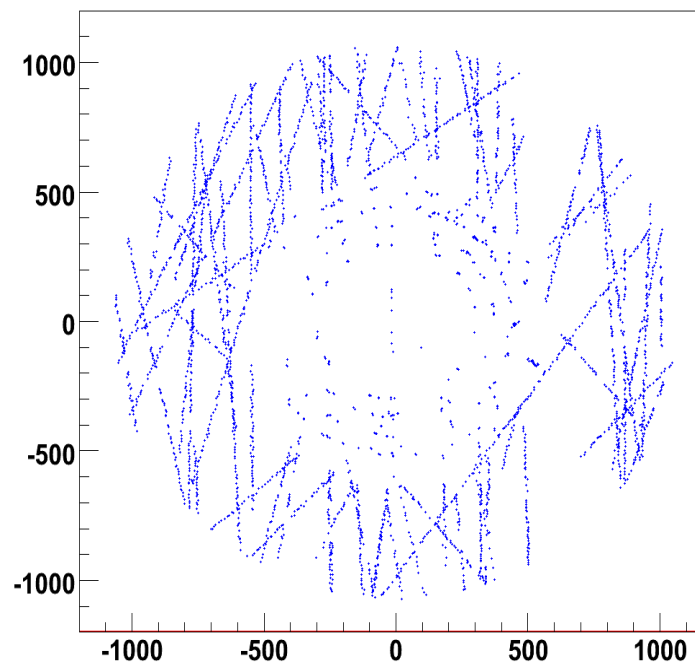
SILAF AE, Bariloche,
14/15 1 09 P Jenni
(CERN)

How do we see particles in ATLAS?



Another example
cosmic muons,
software made in Bergen

Map of ID hits in x vs y (mm)



We are in the second year of Run 3 but Run 2 Data Set of the Large Hadron Collider still being exploited:

ATLAS after Higgs and the LHC

Particle	Produced in 139 fb^{-1} at $\sqrt{s} = 13 \text{ TeV}$
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)

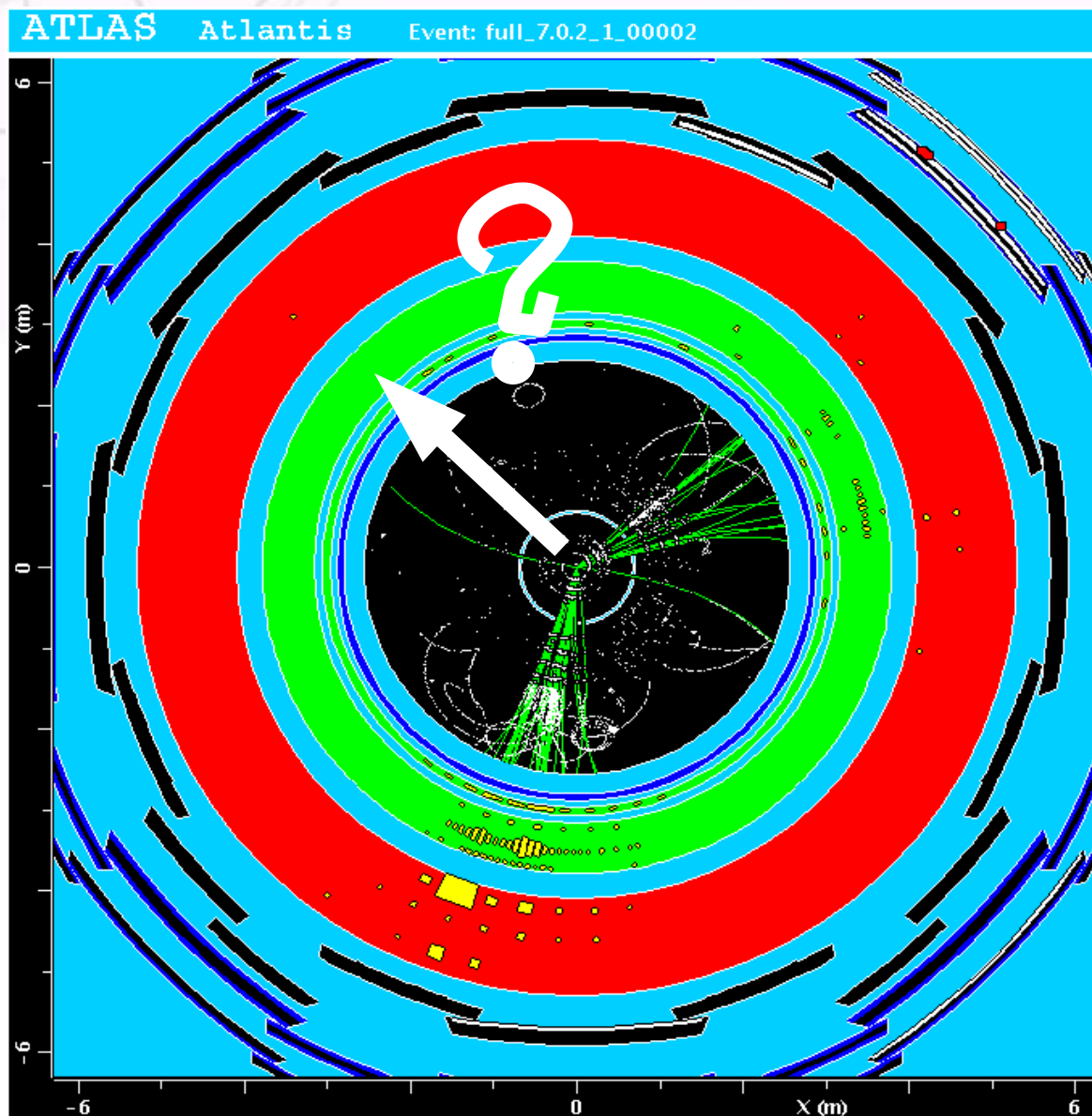
Run 3+2	(2022- end of 2025)	$\sim 500 \text{ 1/fb}$	(factor 4)
Run 4+3+2	(2029 end of 2032)	$\sim 1000 \text{ 1/fb}$	(factor 7)
Run 5+4+3+2	(- end of 2041)	$\sim 3000 \text{ 1/fb}$	(factor 20)

(far future -if there is any..)

\sim statistical improvement factor $\sim 2, \sim 2.5, \sim 4.5$

Dark Matter production in the ATLAS detector

ATLAS after Higgs and the LHC

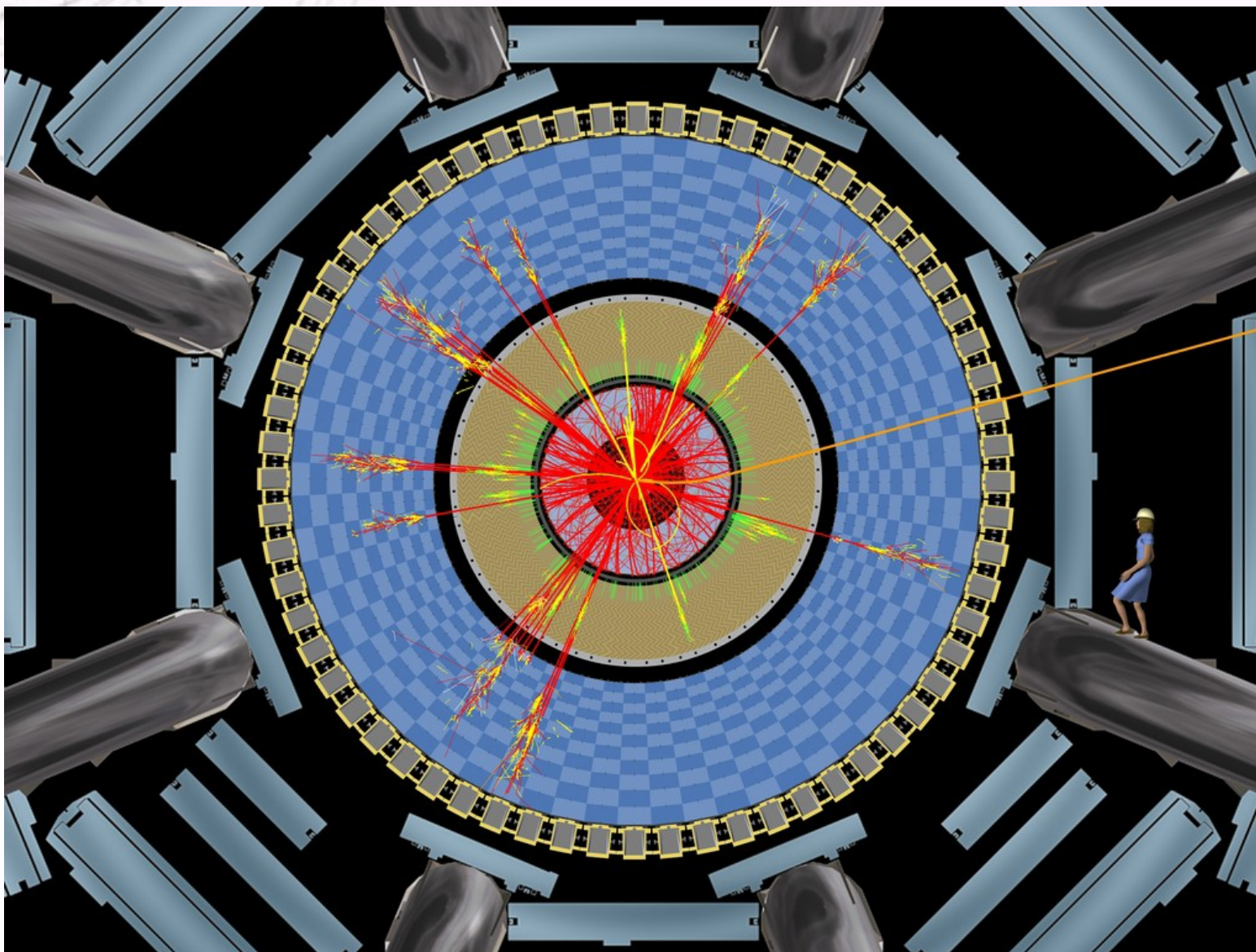


Can we see it ?
An
example event
with missing
transverse
momentum
and two jets.



A Black Hole in ATLAS

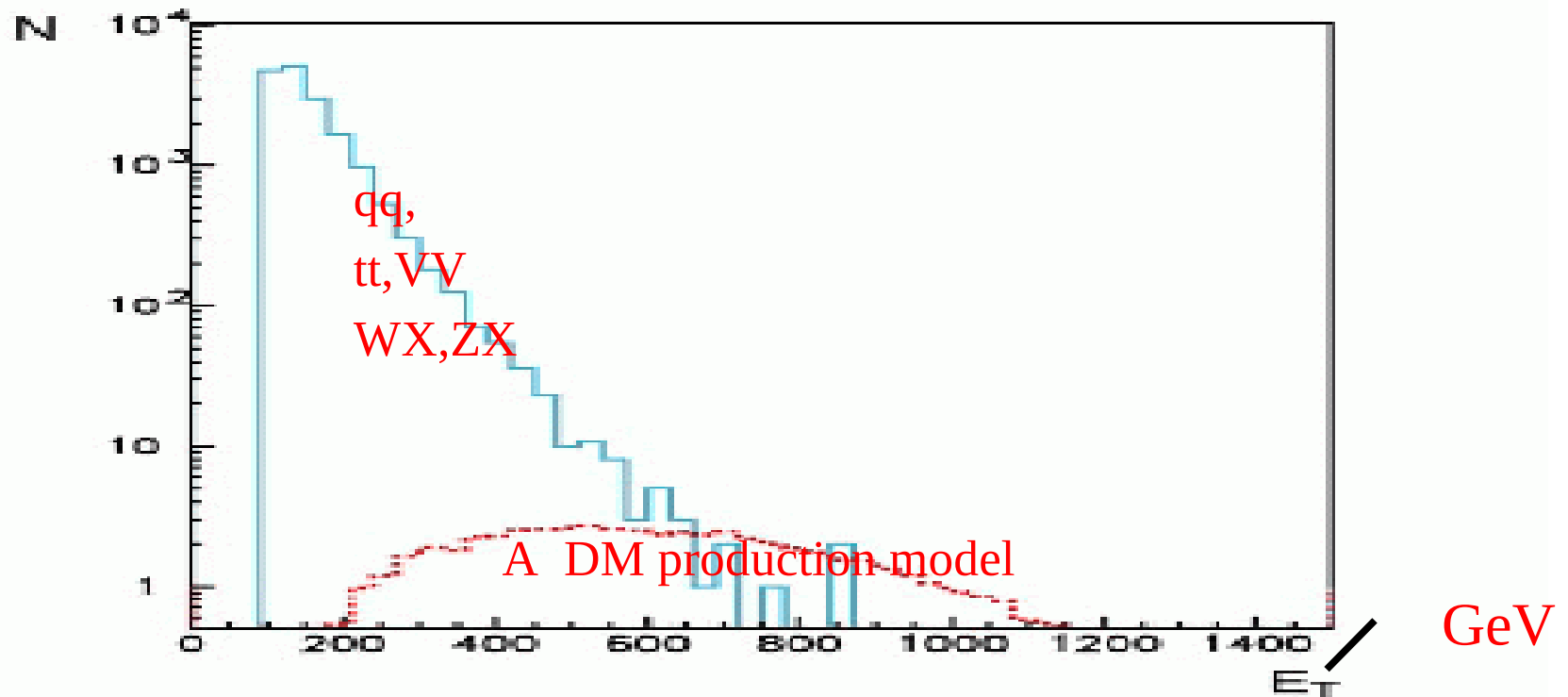
ATLAS after Higgs and the LHC



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”

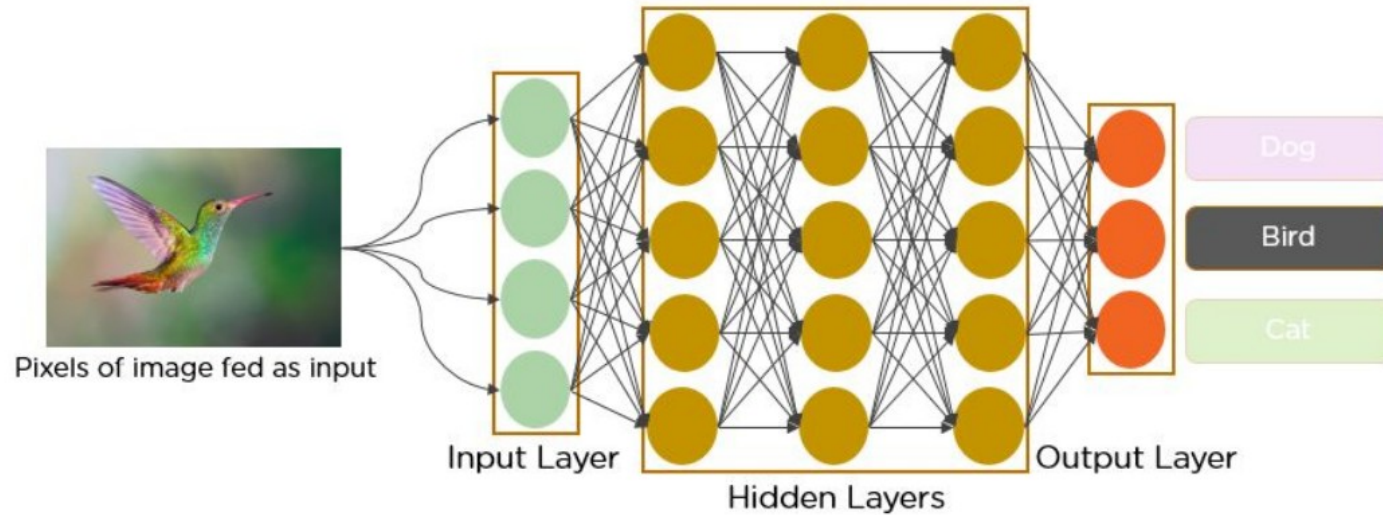
Momentum in the plane perpendicular to the beam is the same before and after collision, thus has to be zero after collision. Unless we missed some particles, as they are not interacting with the detector.



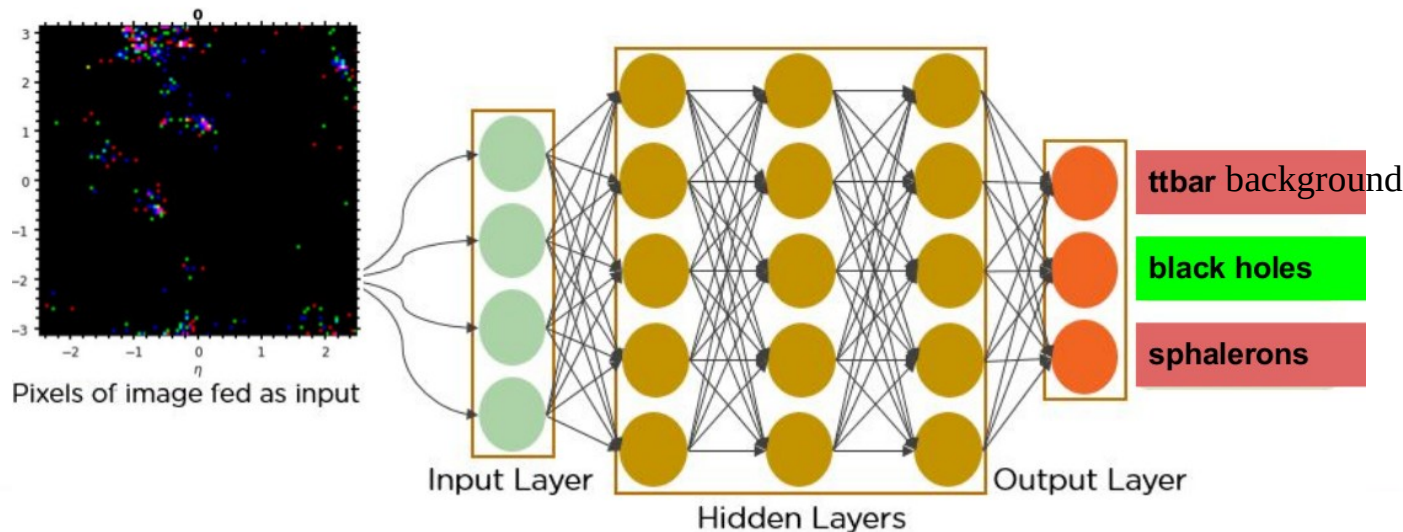
Look for very high E_T events

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

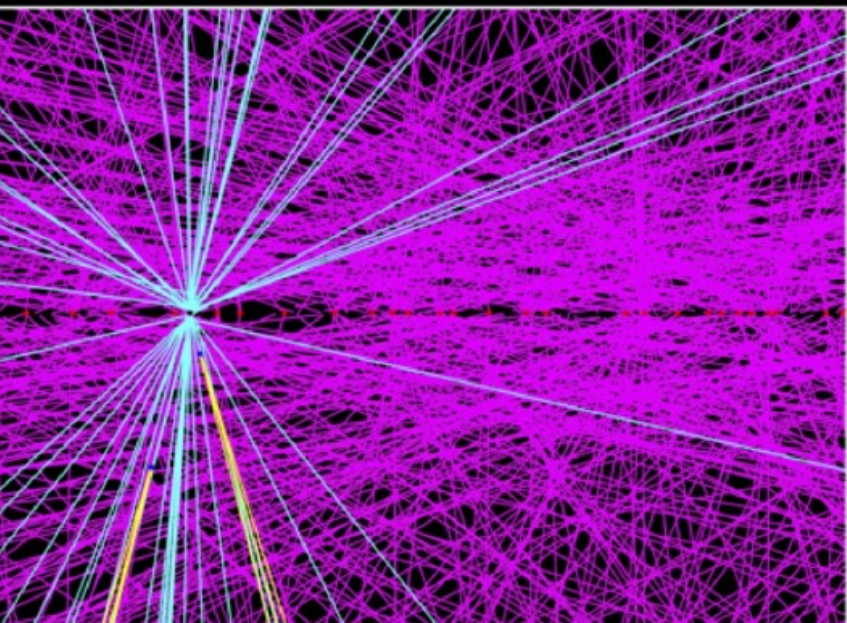


The future at the HL-LHC

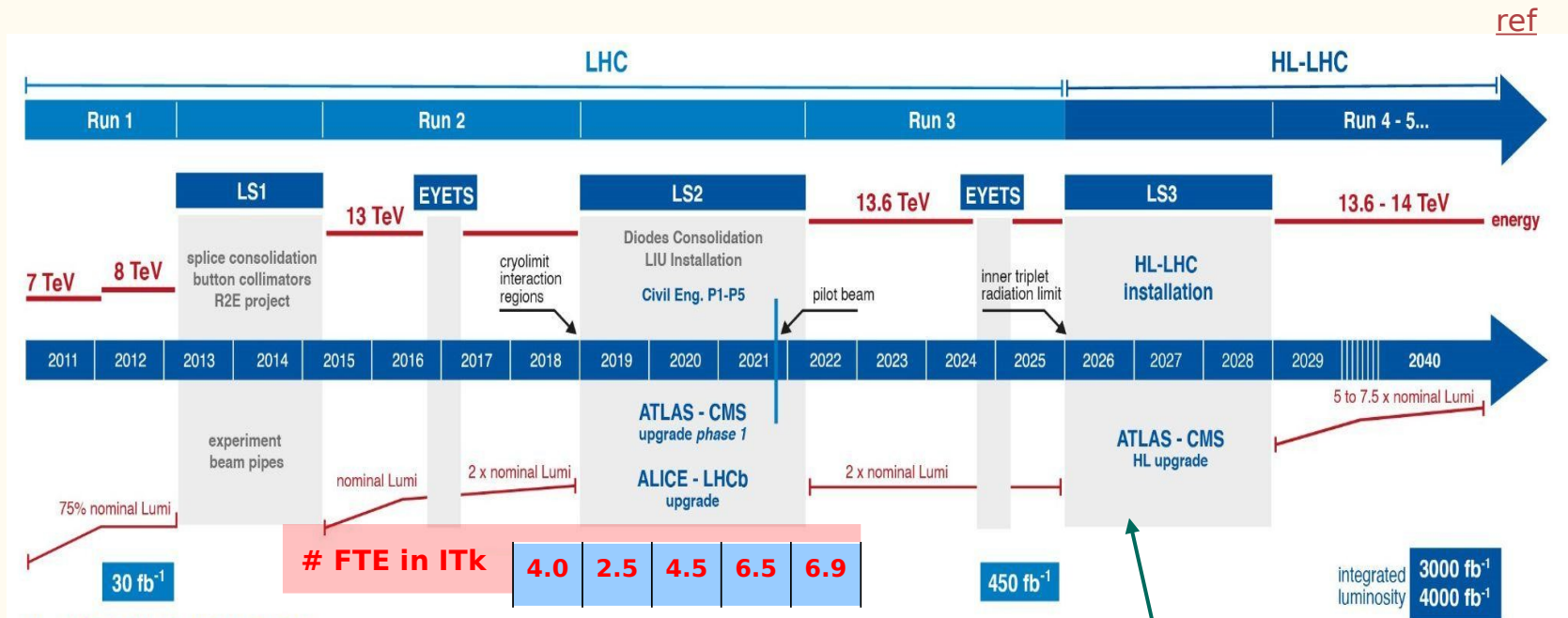


ATLAS
EXPERIMENT

HL-LHC $t\bar{t}$ event in ATLAS
at $\langle\mu\rangle=200$



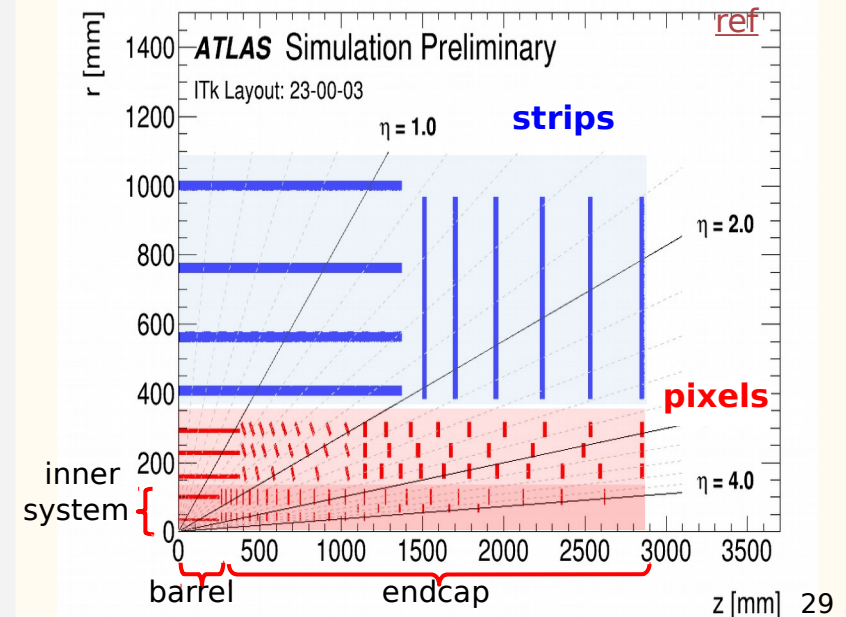
Detector upgrade



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.

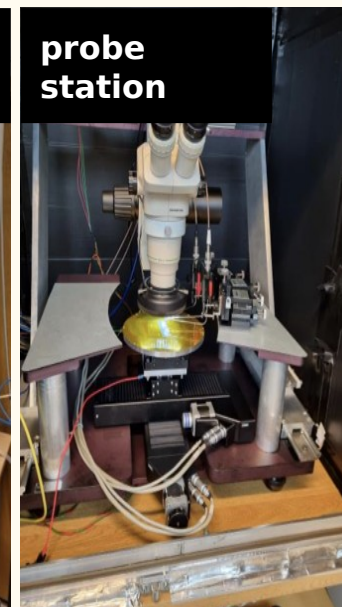
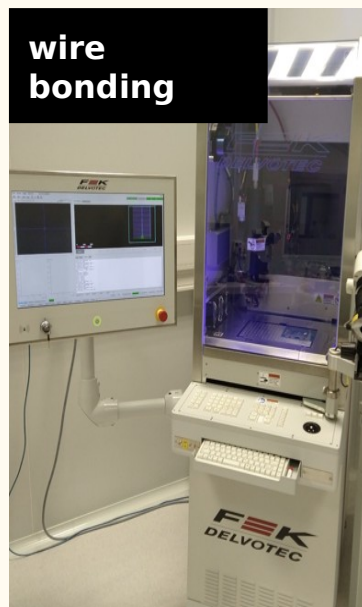
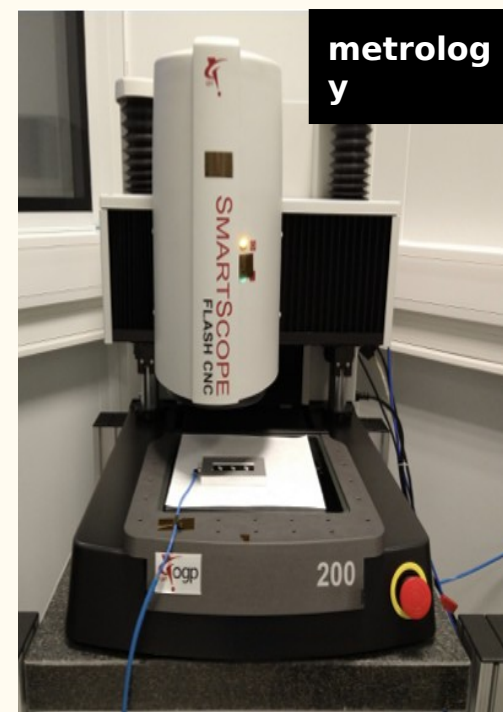
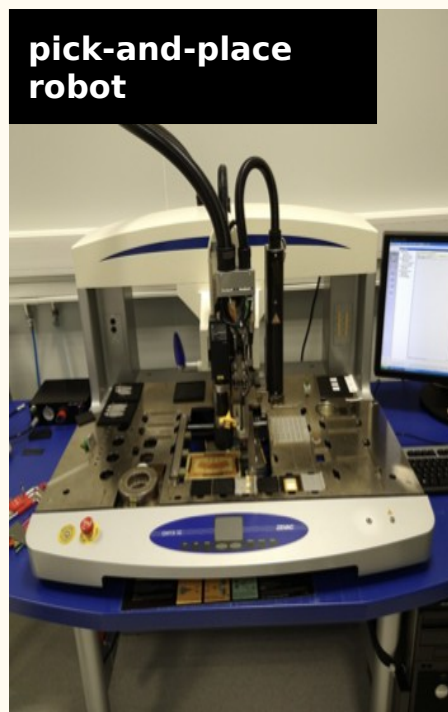
Developing module building tools and instrumentation was an important R&D effort.

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.

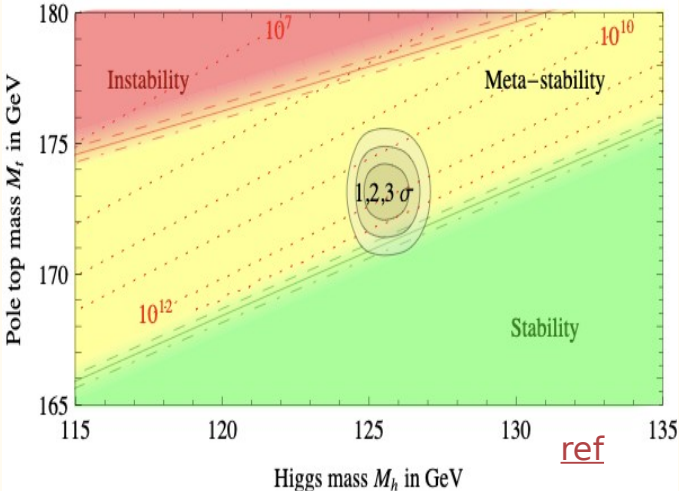


Physics exploitation (Norway)

Higgs boson properties

$H(\gamma\gamma)$

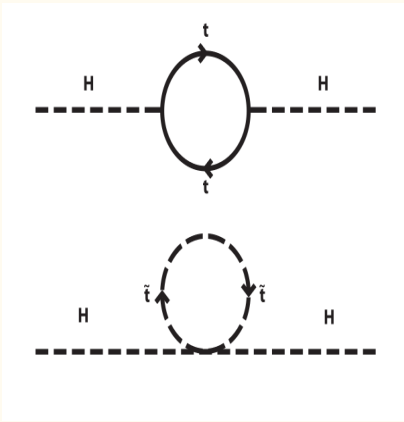
$H(\tau\tau)$



Supersymmetry

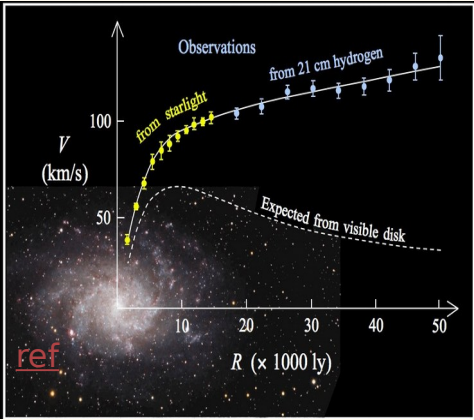
squarks/gluinos

sleptons/EWinos



Exotic physics

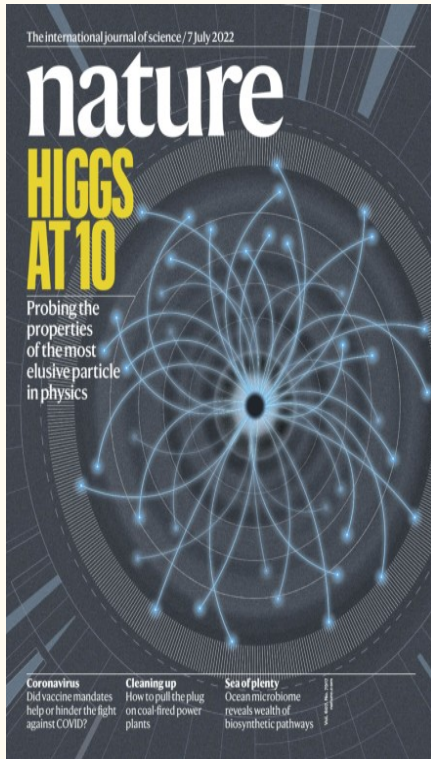
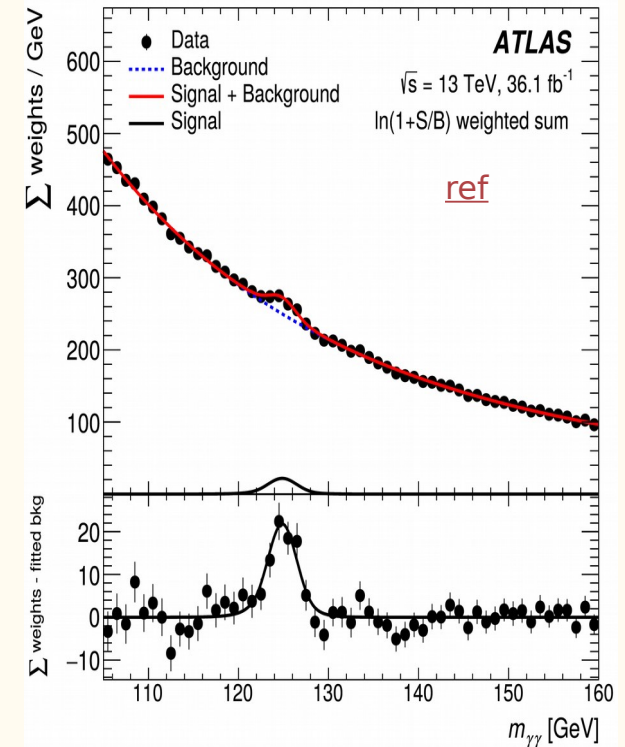
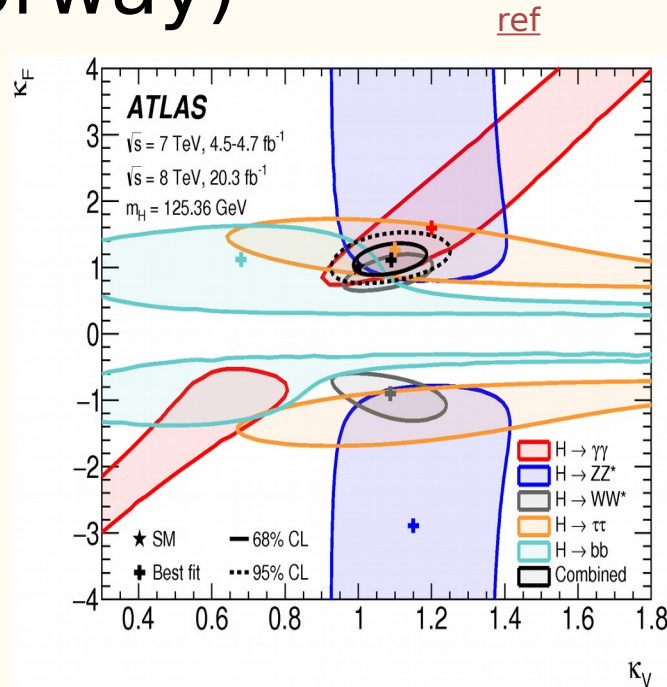
heavy resonances
non-resonant searches
X + Dark Matter



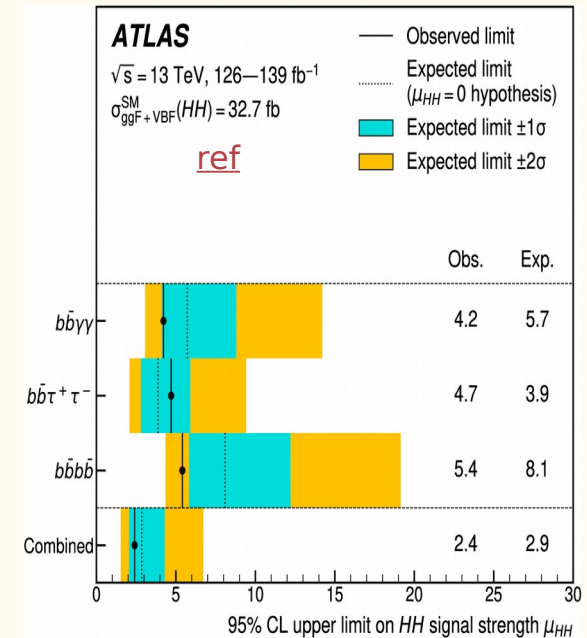
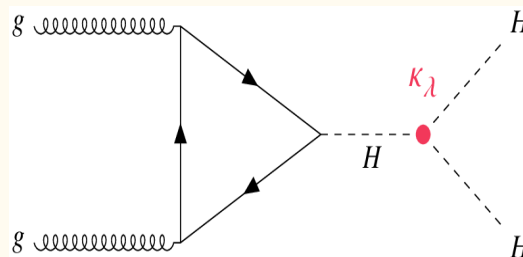
Higgs physics(Norway)

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.



$HH \rightarrow \gamma\gamma + \text{leptons}$:
 - HL-LHC projection in progress
 - Run 3 analysis: focus on BSM

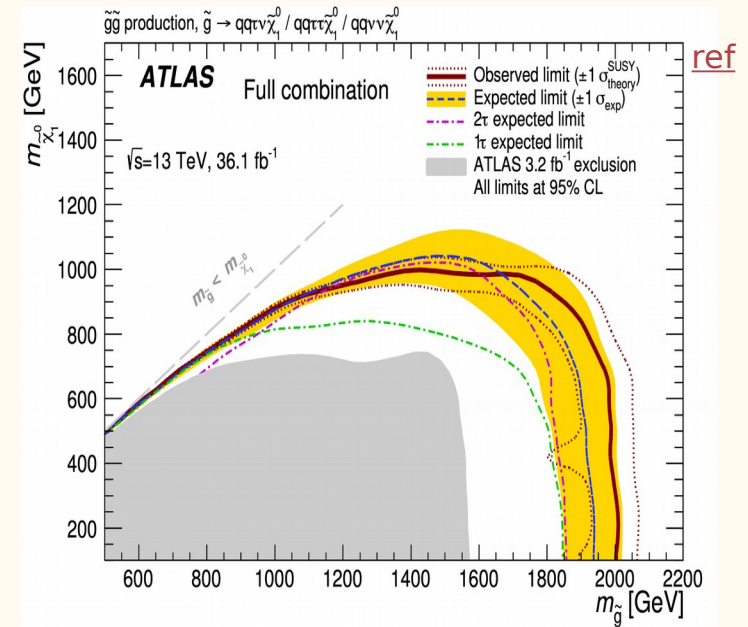
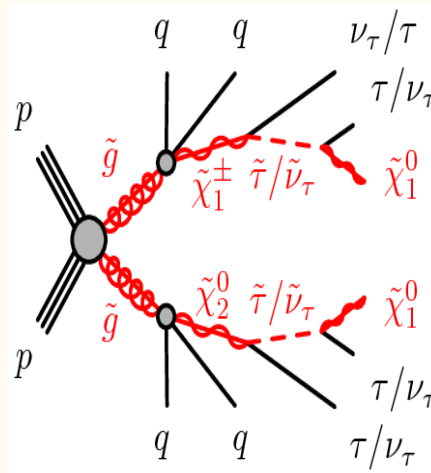


Supersymmetry (strong)

Run2+Run3 search with simplified model.

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

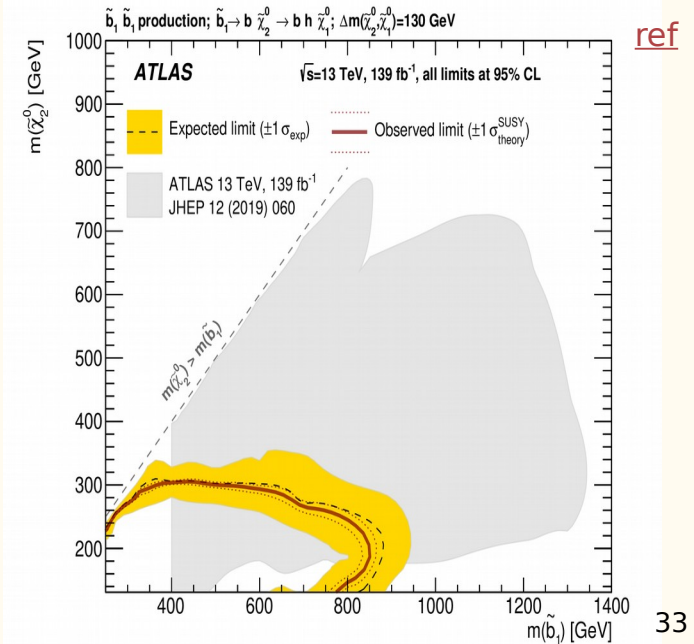
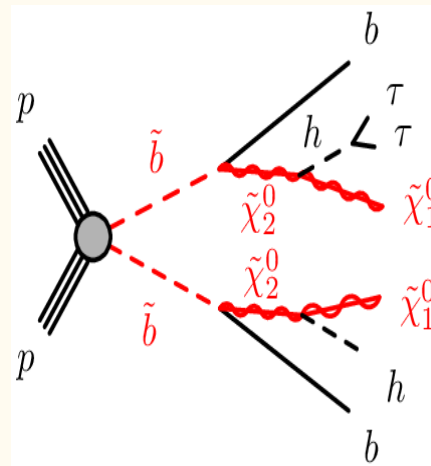
Use tau triggers developed inhouse.
ML to separate sig/bkg.



Search with unique sensitivity:

- low SM background with $2\tau + 2 b$ -jets
- $\tau \rightarrow \tau_{\text{had}} \nu$ provides extra MET

Complementary to multi-bjet search that requires large MET.



ref

ref

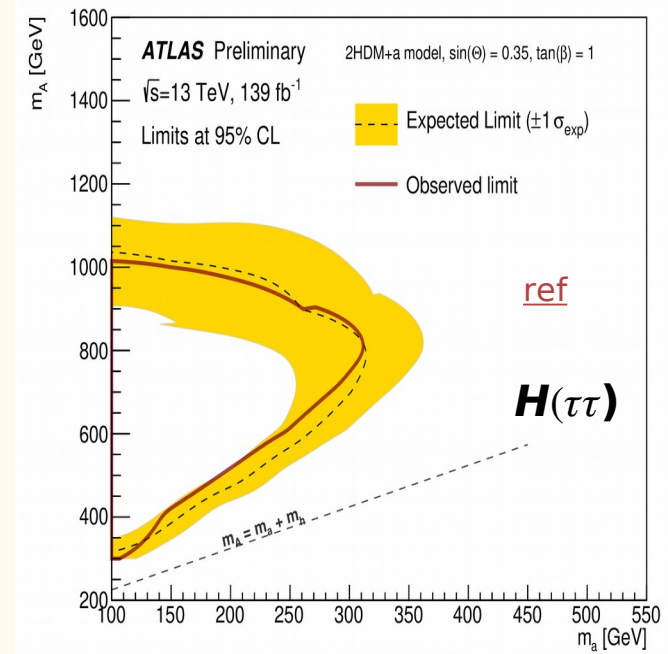
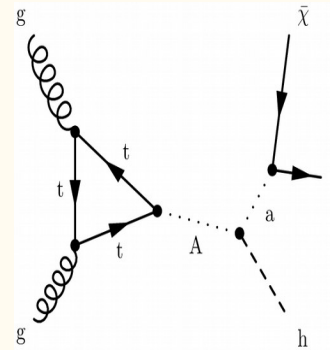
Exotics and Dark Matter

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).

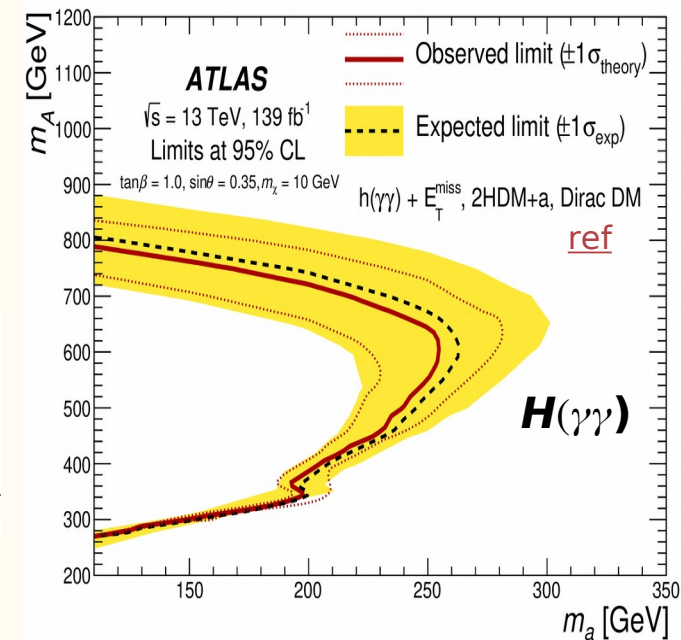
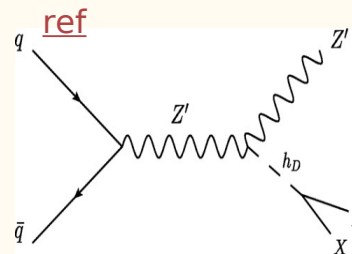
Participating in ATLAS-wide combination.



$Z'(II)$ +MET 2D-search, DM-aware Z' models (dark Higgs, light vector, inelastic EFT).

Results interpreted in bins of m_{II} and MET.

(PhD thesis and conf. note summer 2023, followed by $Z' + X$ publication)



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

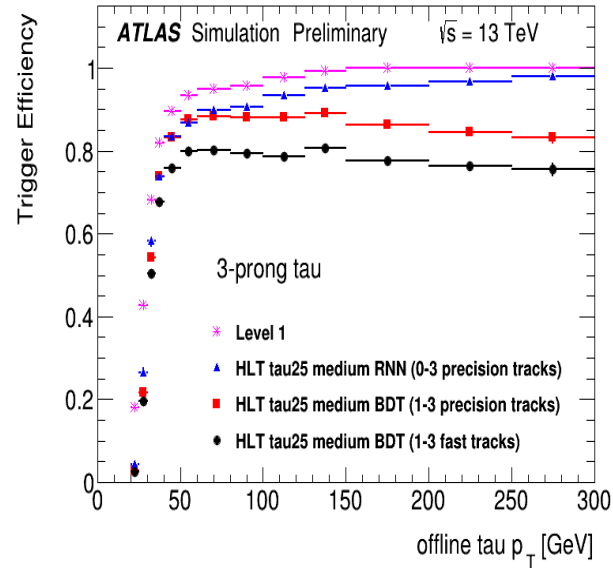
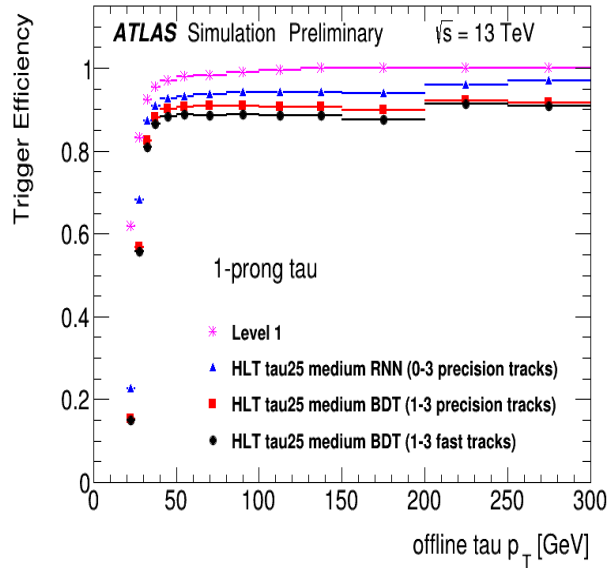
Many ongoing tasks undertaken by students relevant to tau reconstruction in run 3 (efficiency, boosted di-tau (had-had) reconstruction algorithm, NN TES calibration)

Production of analysis data

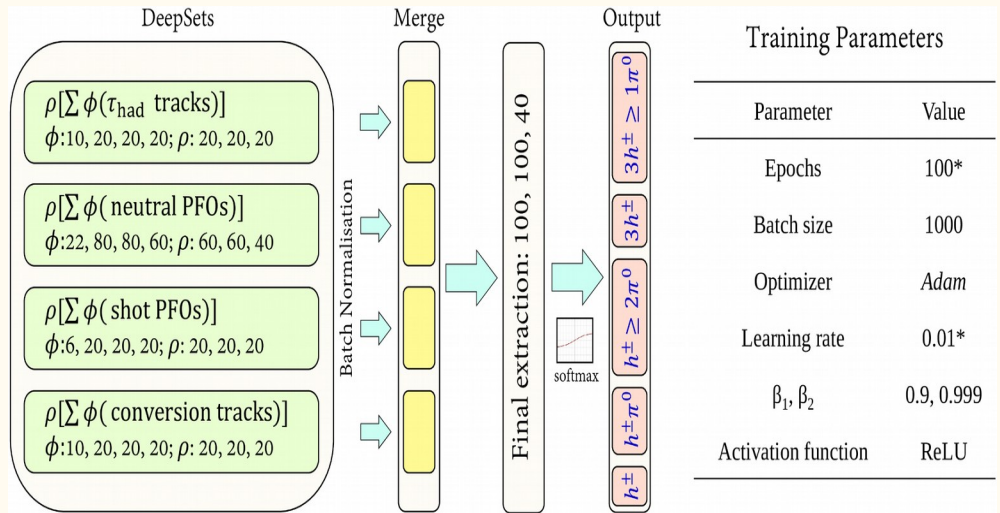
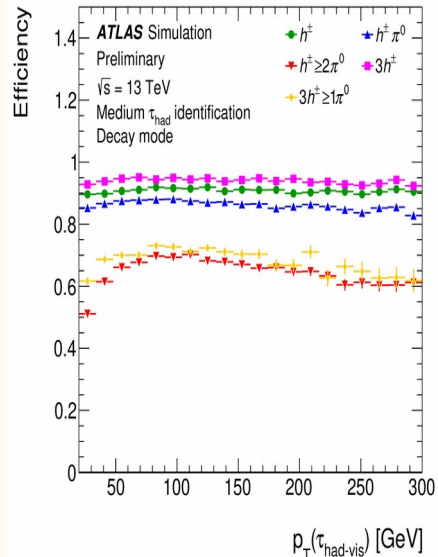
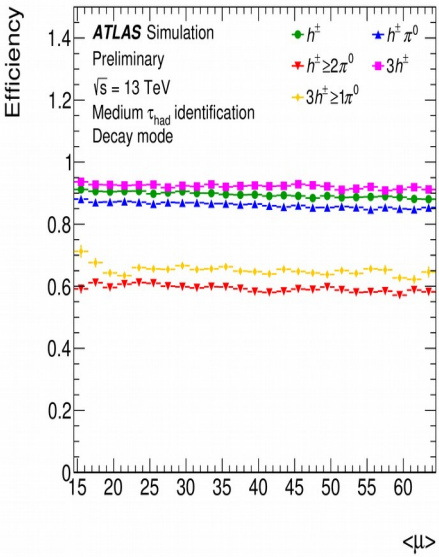
Norwegian personnel develop and maintain the software framework for producing analysis data, and developed the new compact data types for run 3 and run 4

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 !