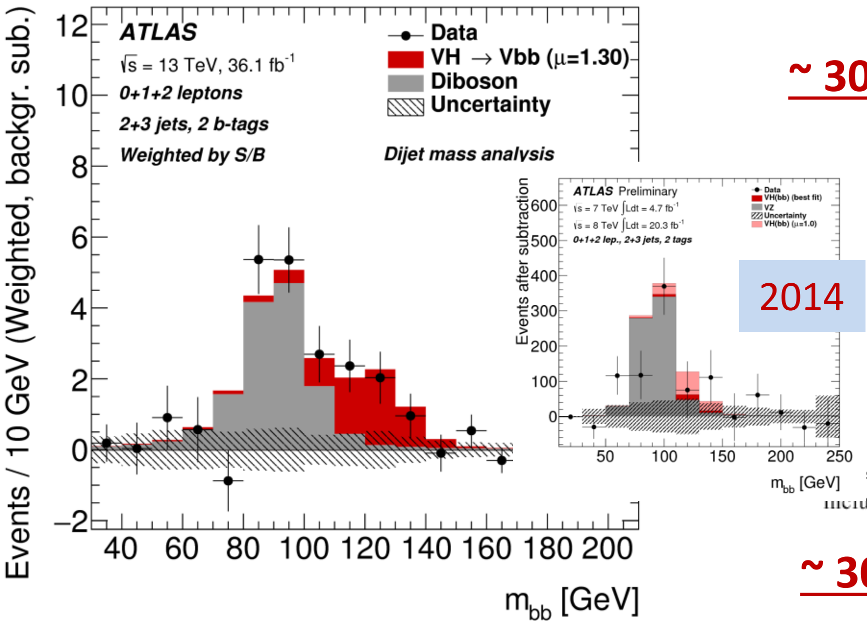
Upgrade of the ATLAS Detector

A. Cheplakov (VBLHEP)

- *Motivation*
- *LHC upgrade and modernization of the ATLAS Detector*
- *Contribution from the JINR group and plans*

HL-LHC: expectations for *HW/Z ($H \to b\bar{b}$)*



~ 36 fb^{-1}

Observed (expected) excess is 3.5σ (3.0σ), whereas the ratio μ of the measured signal to the one expected in the Standard Model

$$\mu = 1.20^{+0.24}_{-0.23}(stat)^{+0.34}_{-0.28}(sys).$$

ATLAS Collaboration, "Evidence for the H→bb decay with the ATLAS detector", JHEP 12 (2017) 024

ATL-PHYS-PUB-2014-016

~ 300 fb^{-1}:

		One-lepton	Two-lepton	One+Two-lepton
Stat-only	Significance	5.5	4.6	7.1
	$\hat{\mu}_{\rm Stats}$ error	+0.18 −0.18	+0.23 −0.22	+0.14 −0.14
Theory-only	$\hat{\mu}_{\rm Theory}$ error	+0.08 −0.05	+0.08 −0.06	+0.09 −0.08
Scenario I	Significance	1.8	3.5	3.9
	$\hat{\mu}_{\rm w/Theory}$ error	+0.57 −0.57	+0.30 −0.29	+0.27 −0.26
	$\hat{\mu}_{\rm wo/Theory}$ error	+0.56 −0.57	+0.29 −0.29	+0.26 −0.26
Scenario II	Significance	2.1	-	4.1
	$\hat{\mu}_{\rm w/Theory}$ error	+0.48 −0.47	-	+0.26 −0.25
	$\hat{\mu}_{\rm wo/Theory}$ error	+0.46 −0.46	-	+0.25 −0.24

Expected signal sensitivity as well as the precision on the signal strength measurement for = 125 GeVfor the one-lepton, two-lepton and combined searches with 300 fb^{-1} and $\langle\mu\rangle_{\rm pu}$ = 60 after including the perspective of a more performant analysis.

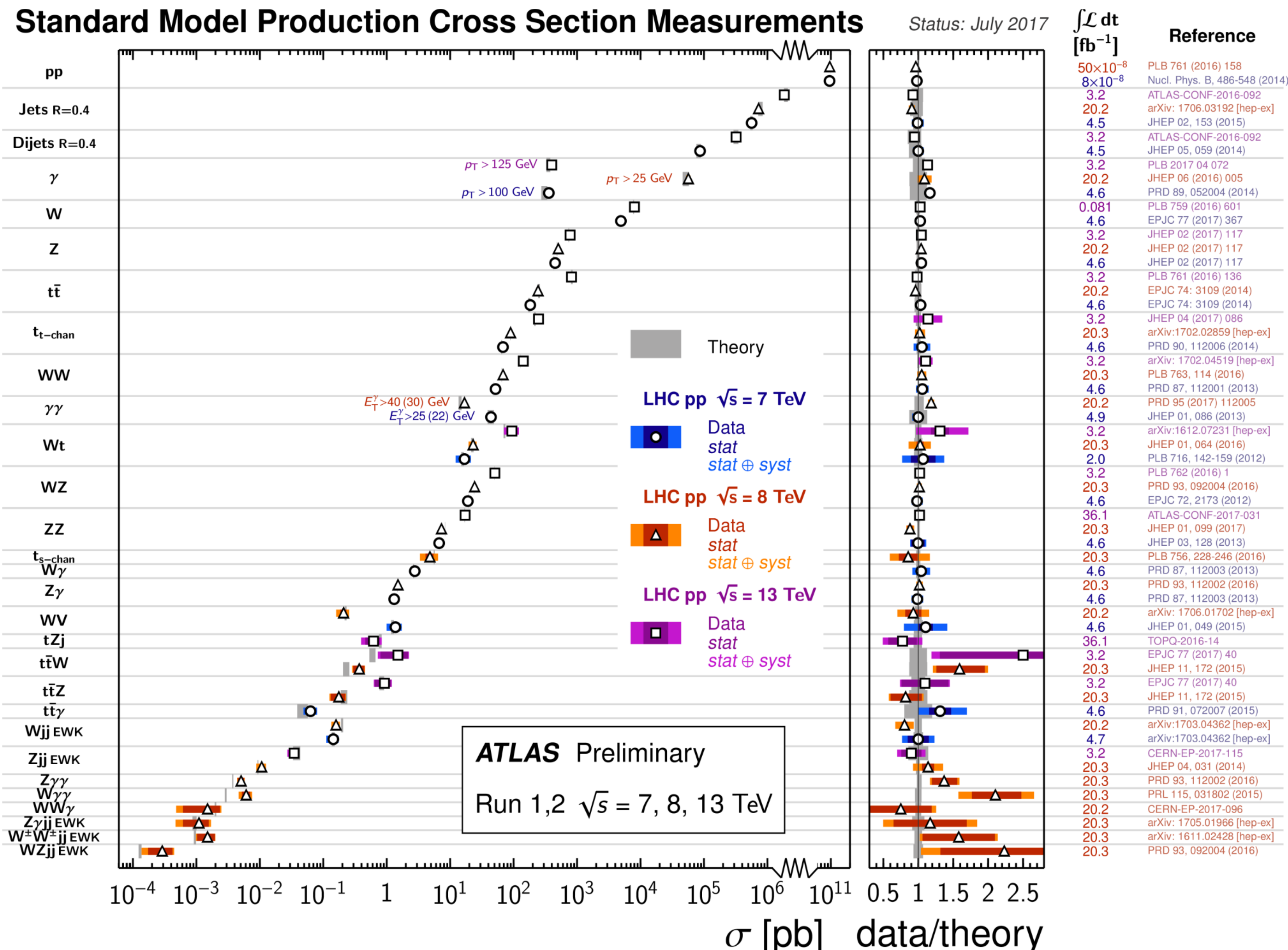
~ 3000 fb^{-1}:

		One-lepton	Two-lepton	One+Two-lepton
Stat-only	Significance	7.7	7.5	10.7
	$\hat{\mu}_{\rm Stats}$ error	+0.13 −0.13	+0.14 −0.13	+0.09 −0.09
Theory-only	$\hat{\mu}_{\rm Theory}$ error	+0.09 −0.07	+0.07 −0.08	+0.07 −0.07
Scenario I	Significance	1.8	5.6	5.9
	$\hat{\mu}_{\rm w/Theory}$ error	+0.56 −0.54	+0.20 −0.19	+0.19 −0.19
	$\hat{\mu}_{\rm wo/Theory}$ error	+0.54 −0.54	+0.18 −0.18	+0.18 −0.17
Scenario II	Significance	3.2	-	6.4
	$\hat{\mu}_{\rm w/Theory}$ error	+0.33 −0.32	-	+0.18 −0.17
	$\hat{\mu}_{\rm wo/Theory}$ error	+0.32 −0.32	-	+0.16 −0.16

Expected signal sensitivity as well as the precision on the signal strength measurement for m_H = 125 GeVfor the one-lepton, two-lepton and combined searches with 3000 fb^{-1} with $\langle\mu\rangle_{\rm pu}$ = 140.

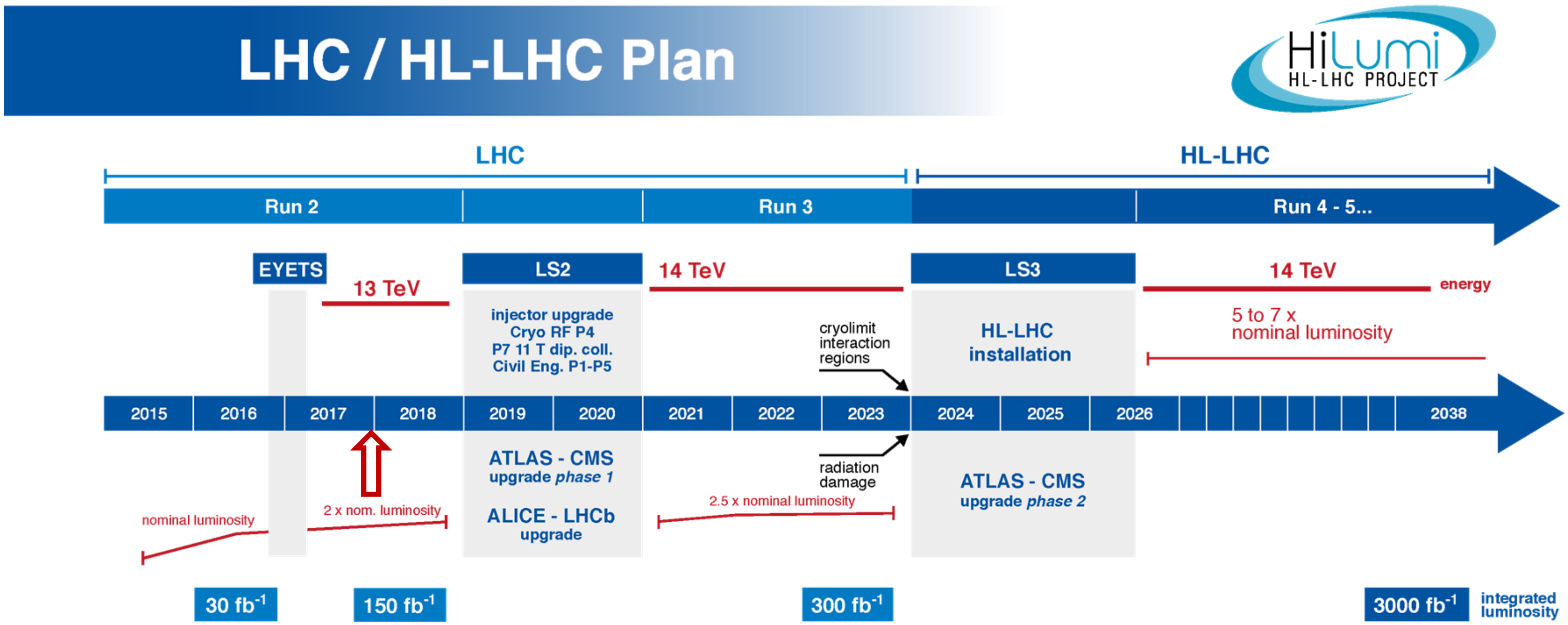
3000fb^{-1}: 150M H & 120K HH events

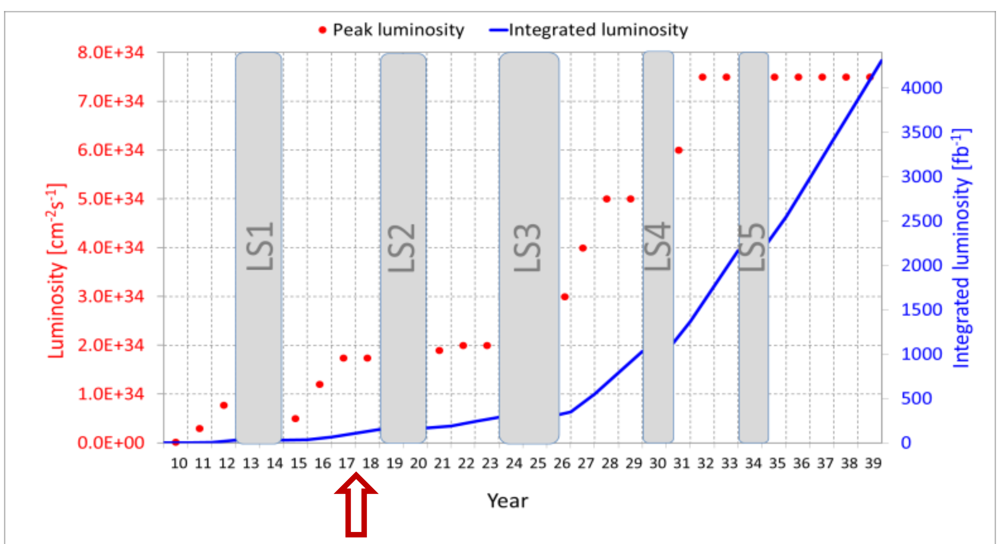
The search for SUSY retains highest priority.



(NLO and higher)

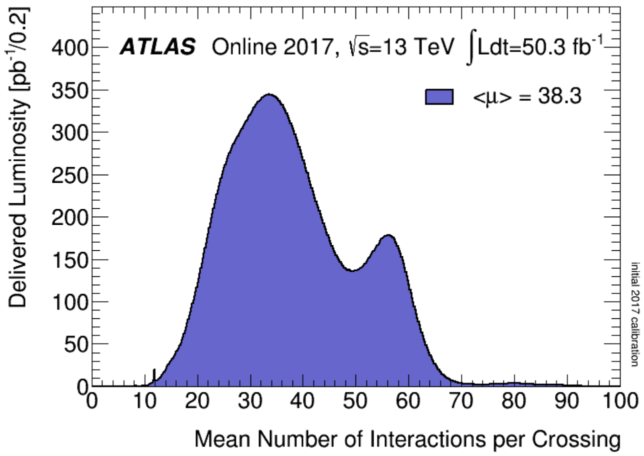
HL-LHC will remain the proton-proton discovery machine at the high energy frontier





The ATLAS detector upgrade programme follows the LHC upgrade scenario. The installation period of the ongoing Phase-I upgrade will start in the second long shutdown (LS2) in 2019-2020. The High Luminosity upgrade of the LHC (HL-LHC) is currently expected to begin operations in the second half of 2026 providing total integrated luminosity of 3000 fb^{-1} by ~2035.

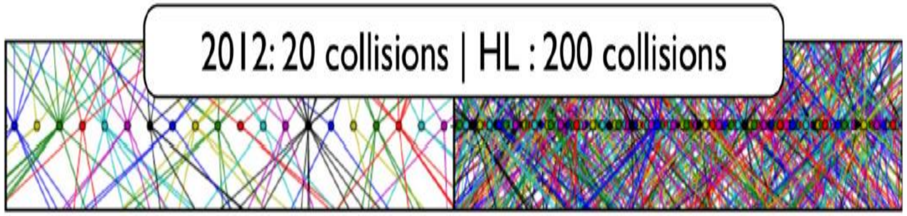
ATLAS at HL-LHC

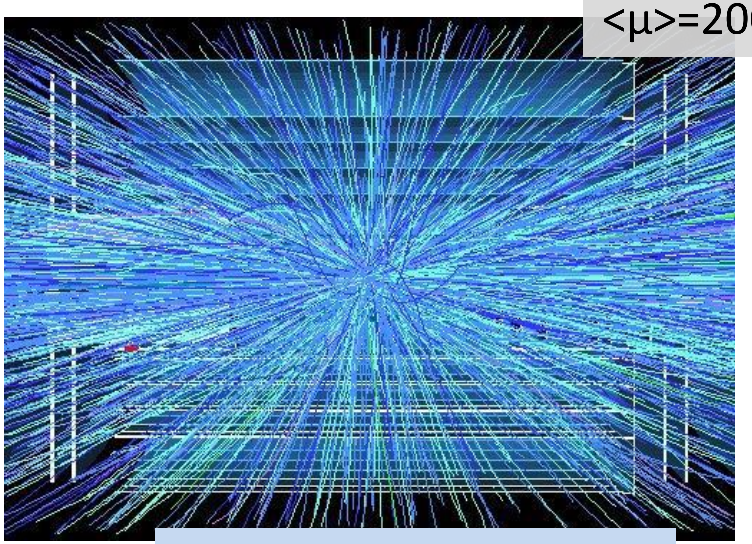


2017 was a record year:

- 43.8 fb^{-1} of collected luminosity (good for physics)
- data taking efficiency of 93.6% with $\langle\mu\rangle \approx 38.3$
- $\langle\mu\rangle \approx 56$ @ $1.5\cdot10^{34} cm^{-2}s^{-1}$ of levelling luminosity

Upgrade is aimed on maintaining high efficiency of the detector operation and quality of the experimental data, giving access to a very rich and unique physics programme





12000 tracks in the tracker acceptance (each 25 ns)

ATLAS Phase-I Upgrade includes five main projects:

- **New small wheel (NSW) for Muon spectrometer**
  - will allow maintainence of good muon tracking performance
  - will also improve the Level-1 trigger performance without raising the p_T thresholds

JINR

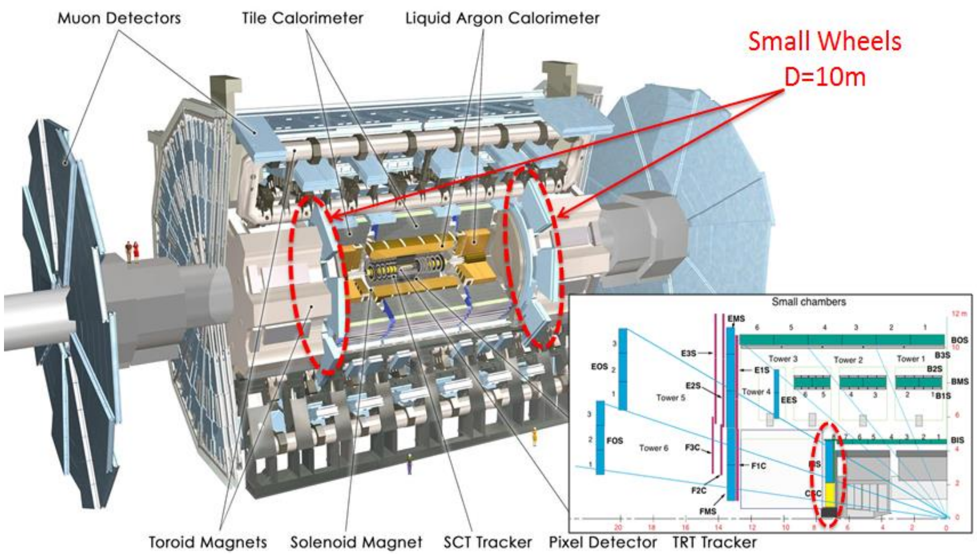
- **Liquid argon calorimeter (LAr)**
  - aimed at improving the Level-1 calorimeter decision for Run 3 and beyond
  - the trigger decision will be based on information about the jet shape

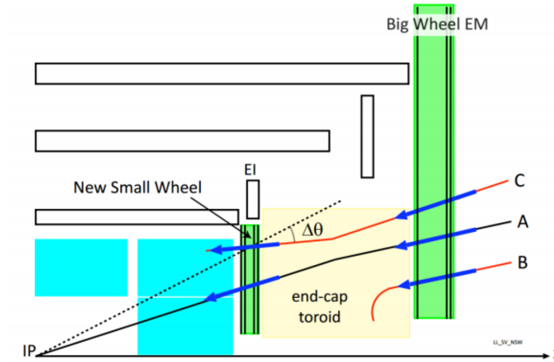
- **Hardware track finder (FTK)**
  - will provide fast tracking information as input to the high-level trigger
- **TDAQ upgrades**
  - are focused primarily on the Level-1 calorimeter trigger, to take full advantage of the finer segmentation of LAr
- **Forward detector of protons (AFP, ±240m)**
  - registration of pair of protons at small angles

(more details in the backup)

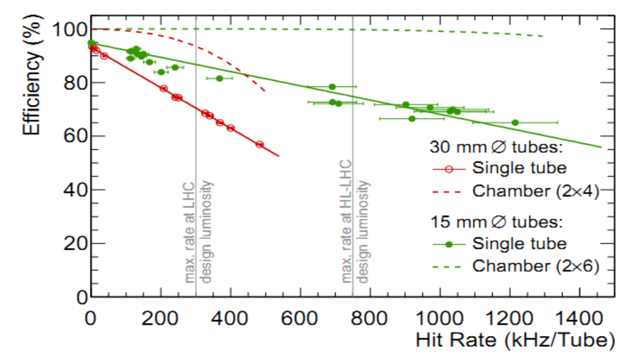
The majority of these upgrades are designed to satisfy Phase-II requirements, and will continue operating in ATLAS throughout the Phase-II period. The Phase-I upgrades form the foundation for Phase-II upgrades

Upgrade of the Muon Spectrometer (NSW project)





“False” trigger

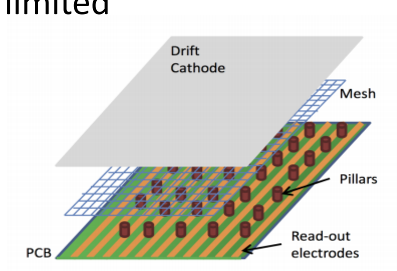


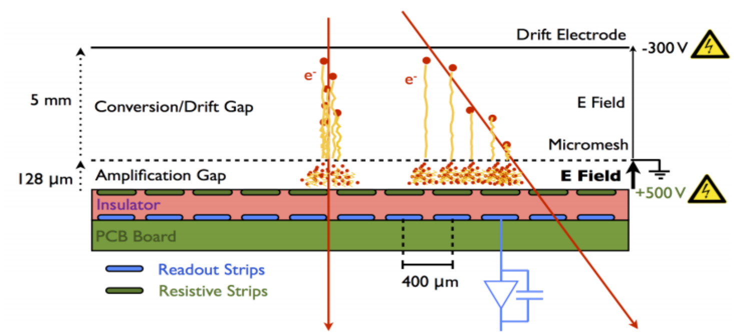
MDT degradation

MM advantages

- Planar geometry
- Simple components: cathode, readout PCBs, mesh
- Large area can be achieved fairly simply and with relatively low cost
- Industrialization (PCB fabrication)
- Excellent high rate capability
- Small amplification gap (50 – 150 µm)
  → space charge effects are very limited
- Segmentation of readout strips
  → limit “dead” time

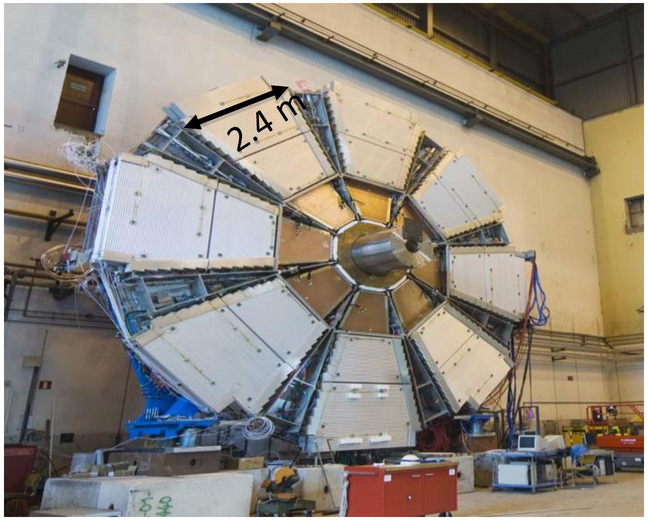
Operation of the MicroMegas chamber





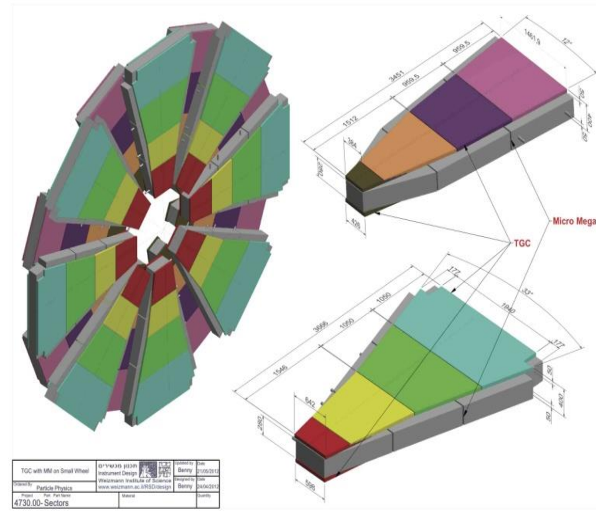
NSW Project

Old SW = CSC+MDT+TGC

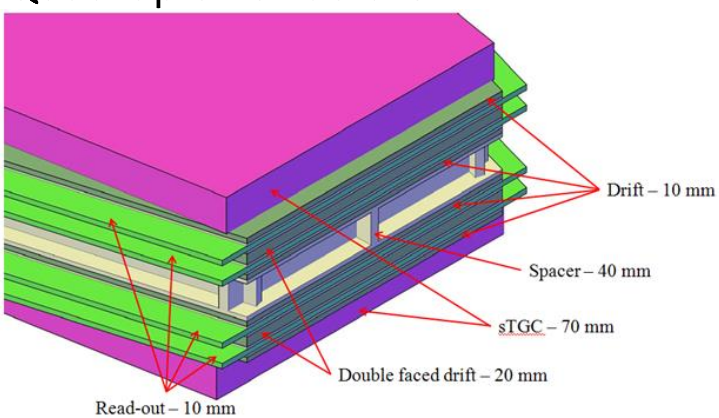


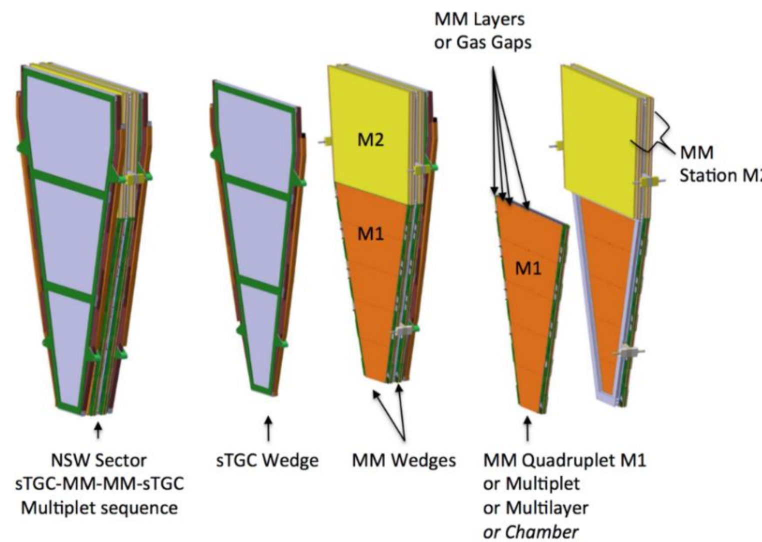
NSW = Micromegas+sTGC

128 MM & 192 sTGC chambers in 16 sectors



Quadruplet structure

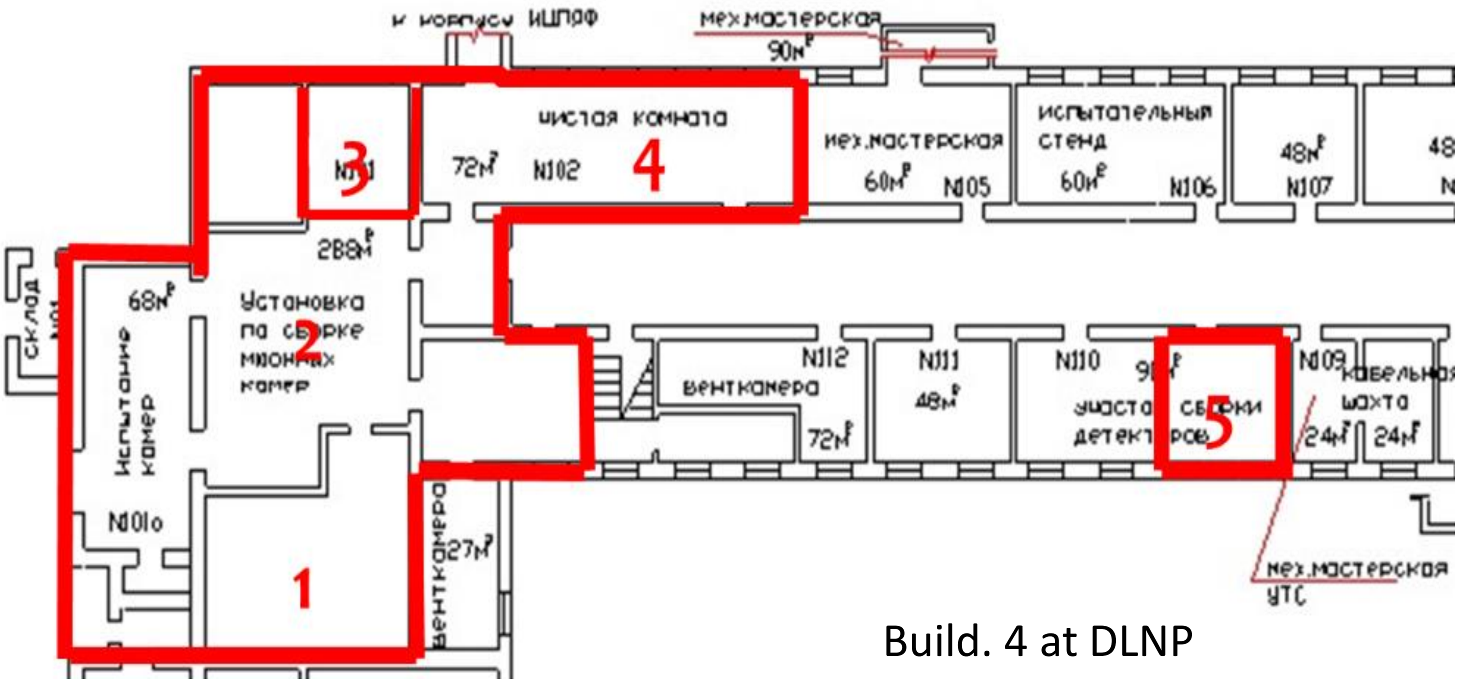




JINR (+AUTh):

- **production of LM2 MM RO - 64 pcs**
- **assembly of 32 quadruplets**

Site plan for MM production and detector assembly



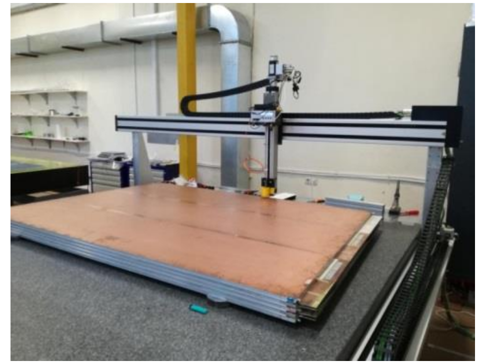
Build. 4 at DLNP

5 compartments (forced ventilation, temperature and humidity control):

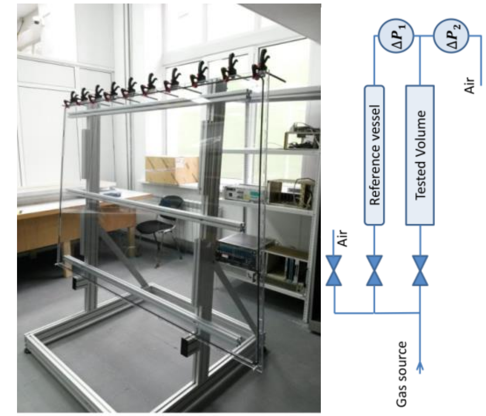
1 - Clean room (72м^2, ISO 7) for panel production and testing
2 - Hall (150m^2) for testing quadruplets with cosmic muons
3 - Room (25m^2) to check panels for gas leaks
4 - Clean room (50m^2, ISO 6) for assembly and testing of quadruplets
5 - Room (25m^2) for cleaning panels

MM production - from the inside

Stages of the MM panel assembly

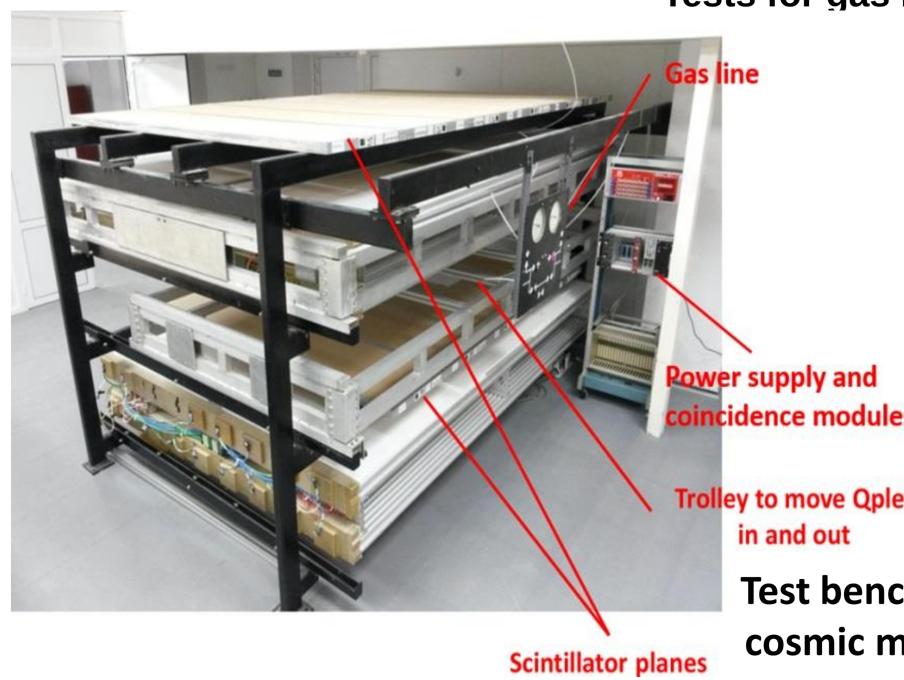


Testing geometry of panels and quadruplets (100µm @ 3m^2)



Tests for gas leak

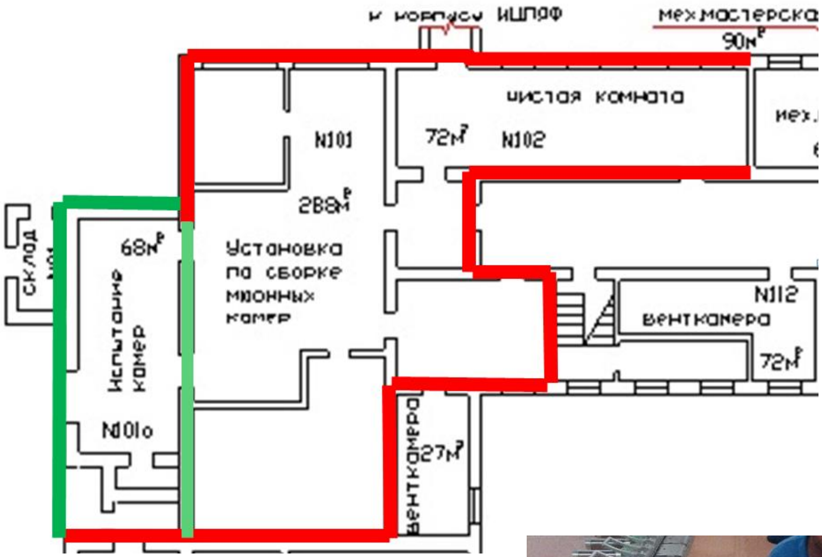
Quadruplet assembly



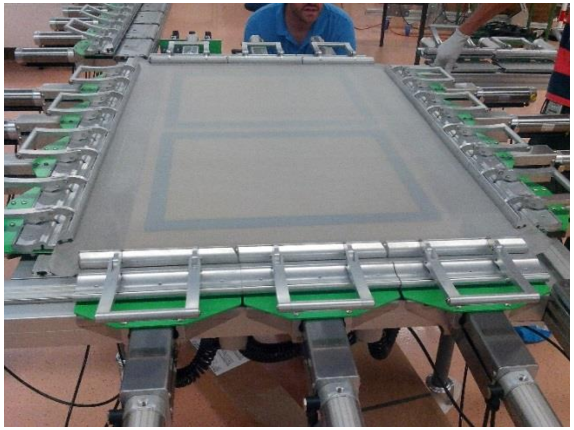
Test bench for cosmic muons

July 2017 – Site Review. The first 8 MM RO have been produced.
The new batch of PCB has been delivered to JINR in January. + 2 MM by today

Delivering MM technology for the in-house experiments!



Second workshop

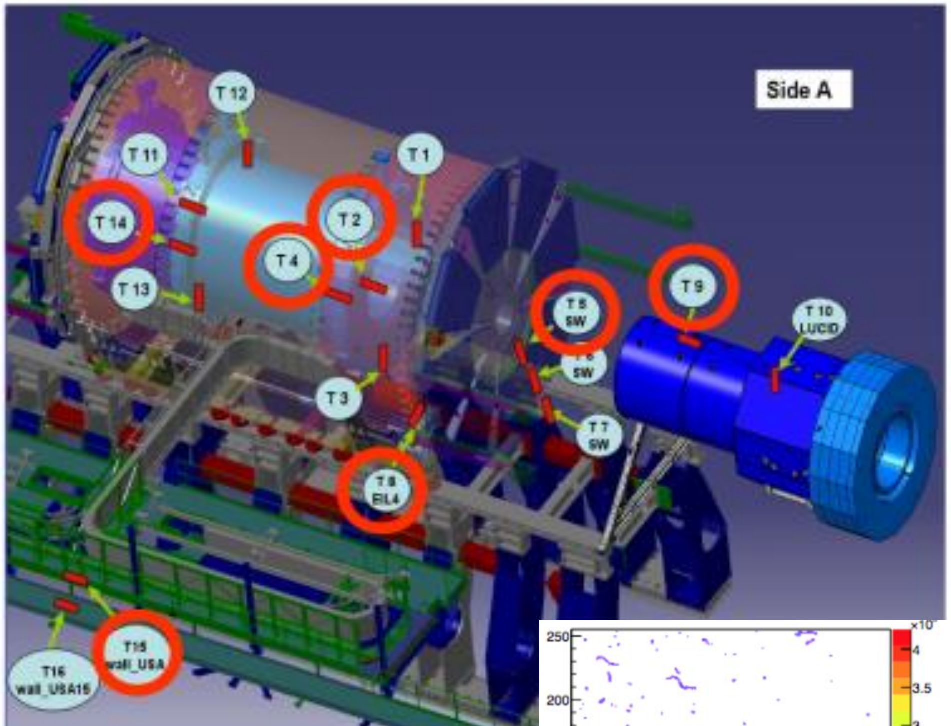


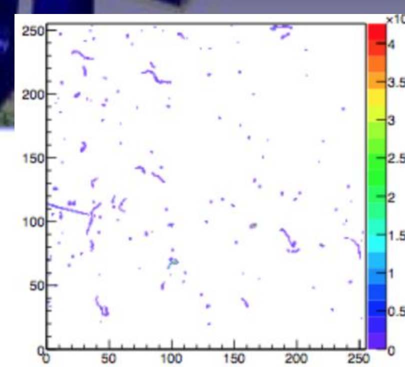
Necessary equipment for the MM "bulk" production was purchased and installed

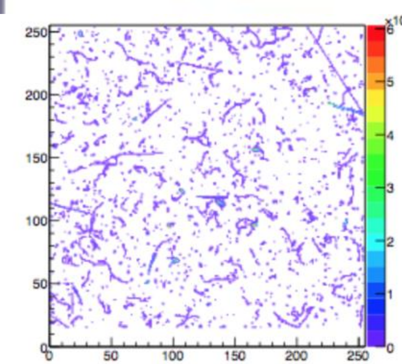
- Oven
- DuPont photoresist PC1025 (64 мкм)
- Mesh
- Test PCBs and photomasks from our Gerber files

ATLAS GaAsPix

10 GasAs:Cr based Timepix detectors were installed in the ATLAS pit in 2016-2017 to monitor the radiation background







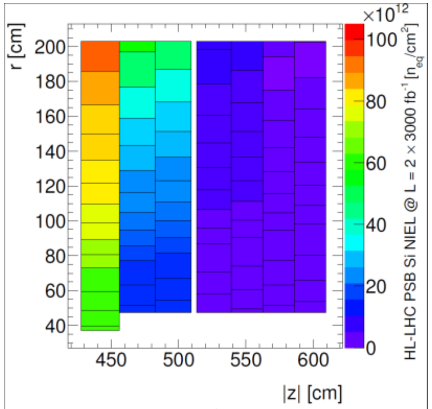
Work is ongoing on development of on-line processing algorithms, pattern recognition and data visualization

Pictures from one sensor: 1 frame (500μs) and 100 frames

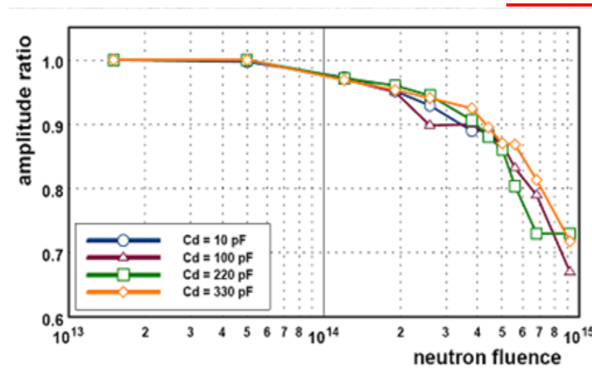
Upgrade of calorimeters (LAr) - 1

Until recently, several upgrade scenarios remained open:
- will "cold" electronics survive → will there be a need to open a cryostat?
- do we need to replace the forward calorimeter or add a new miniFCal?

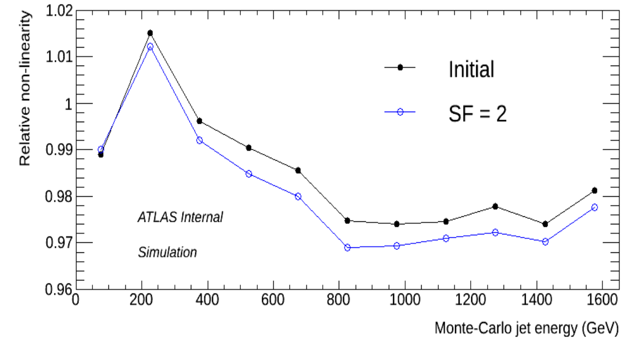
HEC electronics



Neutrons in HEC

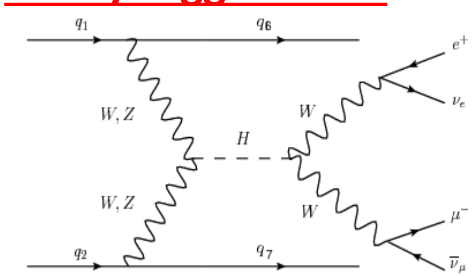


HEC signal degradation (IBR-2 in 90-s)

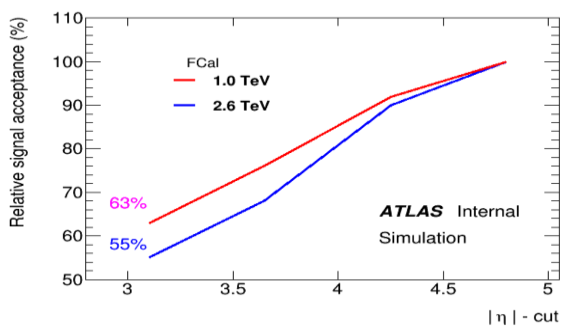


Deterioration of linearity ~0.5% - OK

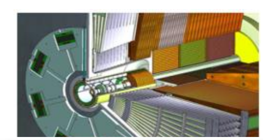
Heavy Higgs in FCal

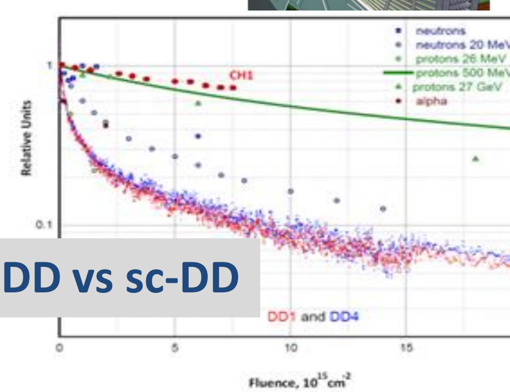


VBF (2 forward jets)



miniFCal

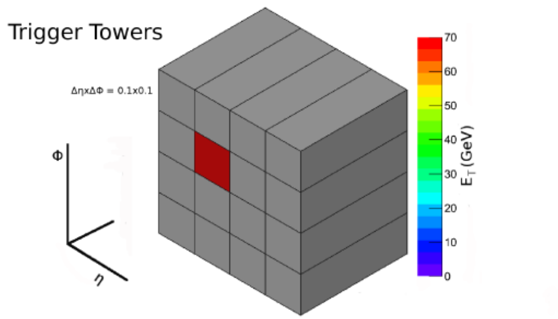




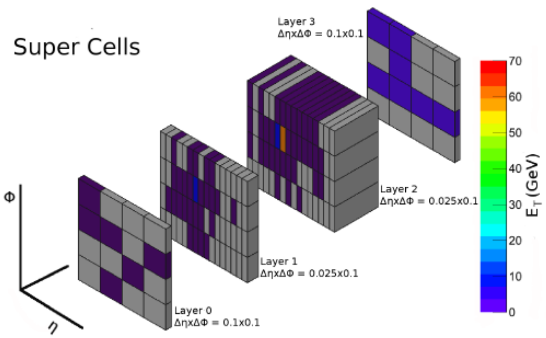
pc-DD vs sc-DD

Expected level of the detector degradation found to be “acceptable»…

Upgrade of calorimeters (LAr) - 2

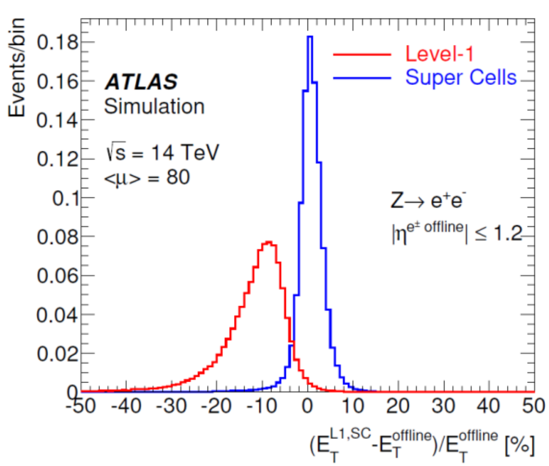


(a)



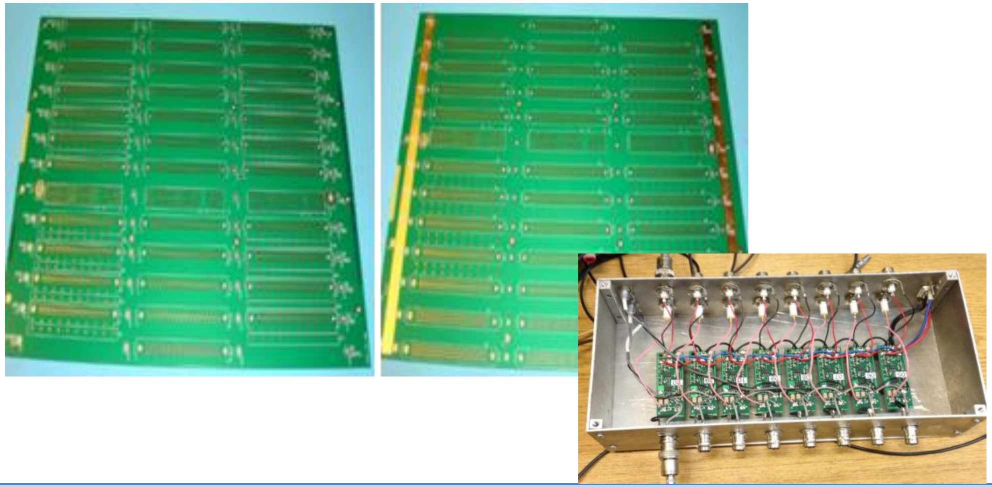
(b)

An electron (with 70 GeV of transverse energy)



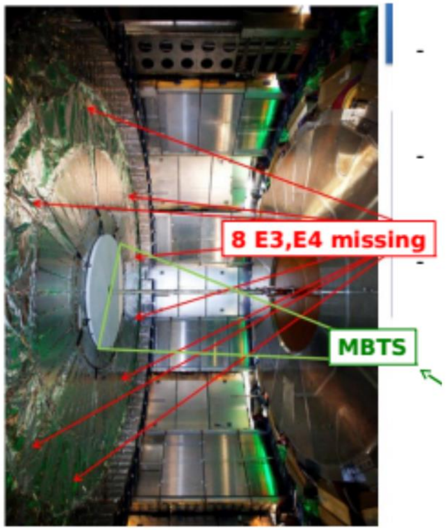
Aimed at improvements of the L1-trigger performance by enhancing jet rejection and pile-up subtraction capabilities.
Trigger decision will be based on increased information about the calorimeter energy deposits in both the transverse and longitudinal directions by defining **10 "supercells"** for each of the previous trigger towers.

- Trigger electronics and baseplane replacement
- New modules LTDB (LAr Trigger Digitizer Board)
- Optical cables…

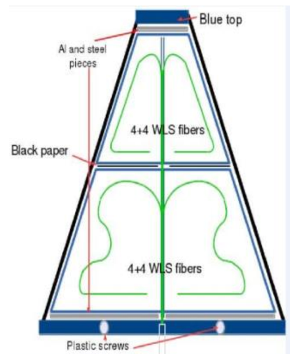


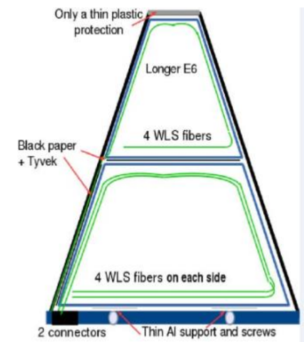
- ✓ **Prototype of the Baseplane**
- ✓ **Prototype of the preamplifier-shaper**
- ✓ **Radiation tests of the readout boards and cables at IBR-2**

Upgrade of calorimeters (TILE)

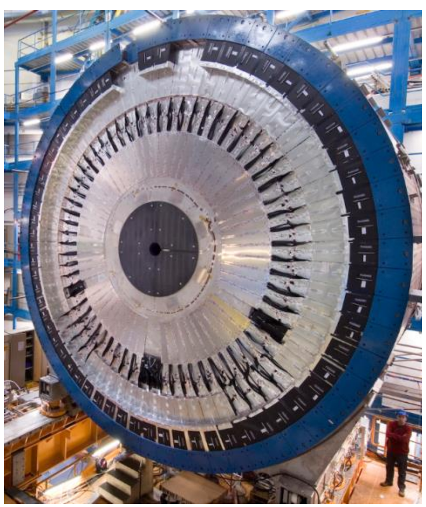


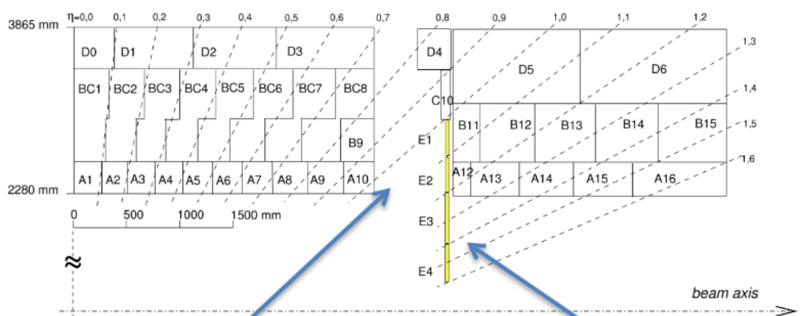
New MBTS scintillators were developed and supplied to CERN for replacement (incl. test bench, prototypes, selection of the new design)





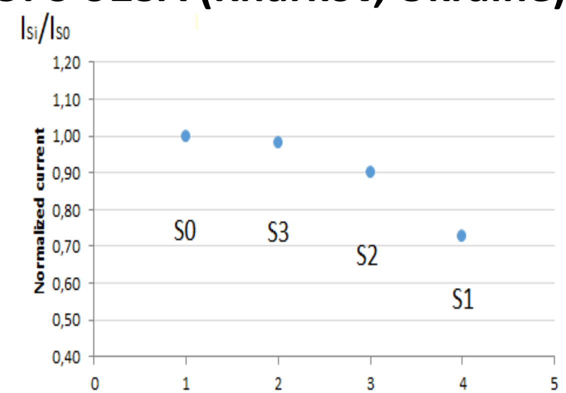
New radiation hard scintillators, UPS-923A (Kharkov, Ukraine)





Gap scintillators
E1 (1.0 < |η| < 1.1)
E2 (1.1 < |η| < 1.2)

Crack scintillators
E3 (1.2 < |η| < 1.4)
E4 (1.4 < |η| < 1.6)



Tests at IBR-2 reactor: up to $2 \cdot 10^{14}$ n/cm^2

Elements of the ATLAS Phase-II upgrade program (until 2026)

Inner Tracker - ITk replacement; major upgrades of the electronics

Muon Spectrometer - Electronics replacements, plus upgrade of chambers in the inner barrel layer **JINR: new sRPC**

Trigger and DAQ - Major upgrade to provide >10 increase in trigger rate capability

Calorimeters - Electronics replacements for LAr and Tile calorimeters;

JINR TILE – "Demonstrator" project – L1 rate increase from 100kHz to 40 MH

- **Study of rad. hard scintillators**

LAr – HEC trigger board (LTDB) development;

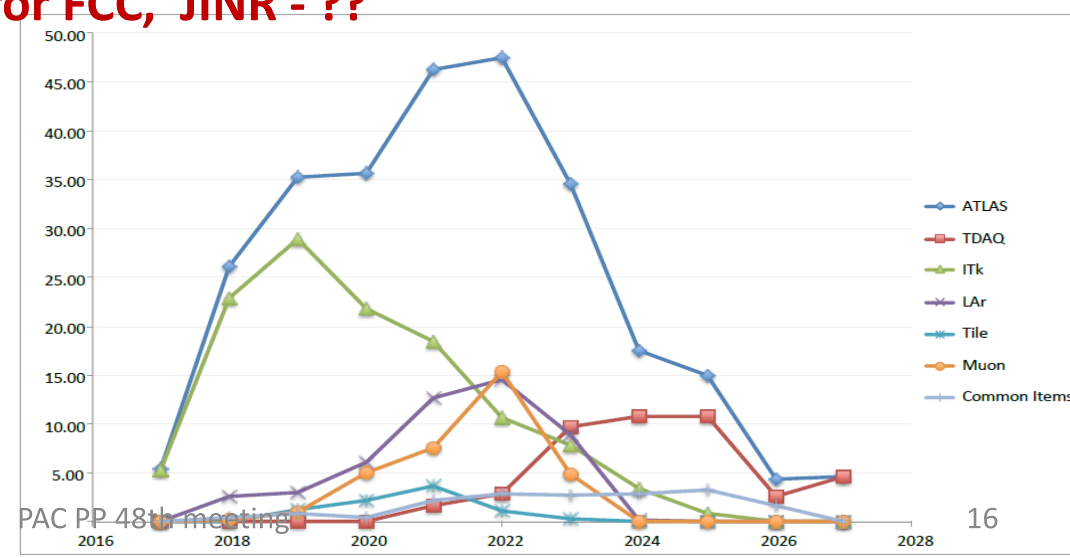
- **HEC preamps design for common ASIC;**
- **HiLum-2 experiment at U-70 to study calorimeter signal at HL-LHC**
- **HGTD (technology for FCC, JINR - ??**

Timeline:

2017 – TDR submission;

2018 – MoUs

CORE scenario - 270 MCHF



List of the project participants
(including FTE)

Muon spectrometer

A. Gongadze-1, G. Chelkov-1 (DLNP), N. Zimine-1 (VBLHEP) - coordinators
I. Gongadze-1, L. Gongadze -1, M. Gostkin-0.5, A. Guskov-0.1, D. Dedovich-0.9, M.Demichev-0.5, D. Kharchenko-0.5, D. Kozhevnikov-0.2, U. Kruchonak-0.4, N. Kuznetsov-0.1, I. Minashvili-1, S. Mokrenko-0.2, A. Nozdrin-0.1, S. Porokhovoy-0.2, I. Potrap-1, T. Rudenko-0.9, P. Smolyanskiy-0.8, R. Sotenskii-1, I. Troeglazov-1, E. Tskhadadze-0.2, A. Zhemchugov-0.2 (DLNP)
Yu. Filippov-1, A. Ivanov-0.3 (VBLHEP),
I. Titenkov-0.4, A. Zabaluev-0.2 (ATOM)

Calorimeters

A. Cheplakov-1, E. Ladygin-1, (VBLHEP), I. Minashvili-1 (DLNP) - coordinators
V. Kukhtin-1, S.Nagorny-1, N. Javadov-0.9, F. Ahmadov-0.2 (LHEP)
A. Artikov-0.5, N. Atanov-0.3, Yu. Davydov-0.5, V. Glagolev-0.2, A. Shalyugin-0.3, A. Simonenko-0.3, V. Tereschenko-0.4 (DLNP)
S. Kulikov-0.1, M. Bulavin-0.1 (FLNP)

Collaborators:

CERN (Switzerland), **CEA Saclay** (France), **INFN** (Italy), **German cluster, Univ. of Thessaloniki** (Greece), **Tomsk State University** (Russia), **Czech TU in Prague, Institute of Experimental and Applied Physics,** (Czech Republic), **X-Ray Imaging Europe** (Germany)**, Freiburg; FMF, Universitat Freiburg** (Germany), **MPI Munchen** (Germany), **BNL** (USA), **INFN Milano** (Italy), **TRIUMF** (Canada) **Stockholm University** (Sweden), **Institute of Physics, Prague** (Czech Republik), **Charles University, Prague** (Czech Republik), **Univ. Blaise Pascal Clermont-Ferrand** (France), **Uni. Arizona** (USA), **Slovak Academy of Sciences, Bratisvala** (Slovakia)

44 participants = **27 FTE** (27 physicists, 13 engineer and 4 technicians)

Request for resources

Expenditures, resources, financing sources			Costs (kUSD) Resource requirements	Proposals of the Laboratory on spending profile - finances and resources		
				1st year	2nd year	3rd year
Expenditures		LM2 quadruplets production, transportation, integration and commissioning	220	90	70	60
		R&D for LAr electronics	95	10	55	30
		GaAsPix visualization project	45	15	15	15
		R&D for TILE scintillators and electronics	55	15	15	15
		Construction/repair of premises				
		Materials:				
		FE electronics for ATLAS MM	40	40		
		Aluminum profiles and corners	15	15		
		Epoxy glue	5	5		
		Different materials	6	2	2	2
		LAr readout chips	10		5	5
		Rad hard scintillators	30	10	10	10
Required resources	Standard hour	Resources of – Laboratory design bureau; – JINR Experimental Workshop; – Laboratory experimental facilities division; – accelerator; – computer. Operating costs.				
Financing sources	Budgetary resources	Budget expenditures including foreign-currency resources.	511	202	172	137
	External resources	Contributions by collaborators. Grants. Contributions by sponsors. Contracts. Other financial resources, etc.	180	**250?**	?	?

Estimated expenditures for the Project "Upgrade of the ATLAS Detector"

	Expenditure items	Full cost, kUSD	1st year	2nd year	3rd year
	Direct expenses for the Project				
1.	Accelerator, reactor (hours)	800h	400	200	200
2.	Materials	106	72	17	17
3.	Equipment	405	130	155	120
4.	Payments for agreement-based research	100	100		
5.	Travel allowance, including:	296			
	a) non-rouble zone countries	290	90	100	100
	b) rouble zone countries	6	2	2	2
	c) protocol-based				
	Total direct expenses	907	394	274	239

PROJECT LEADER

LABORATORY DIRECTOR

LABORATORY CHIEF ENGINEER-ECONOMIST

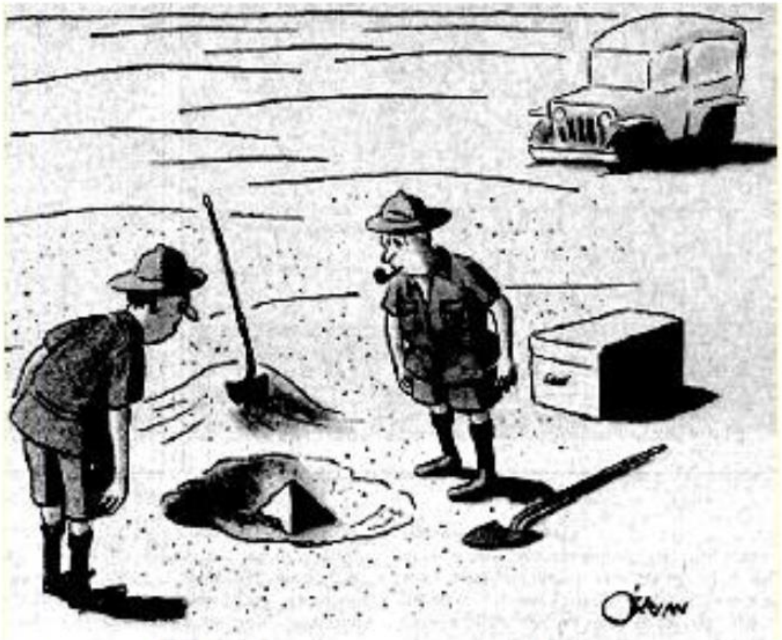
Grant of the Ministry of Education and Science

… more details in the backup

Conclusions

- ✓ All ATLAS sub-systems will pass through a serious modernization in the Phase-1 and Phase-2 periods.
- ✓ Participation of the JINR in this project is in demand and appreciable.
- ✓ The JINR group makes significant contribution to modernization of the Muon spectrometer and Calorimeters.
- ✓ We plan to continue this work.

So far, 100fb^{-1}, i.e. only 3% of the LHC data. If new physics is there it should start to pop up soon (!?)

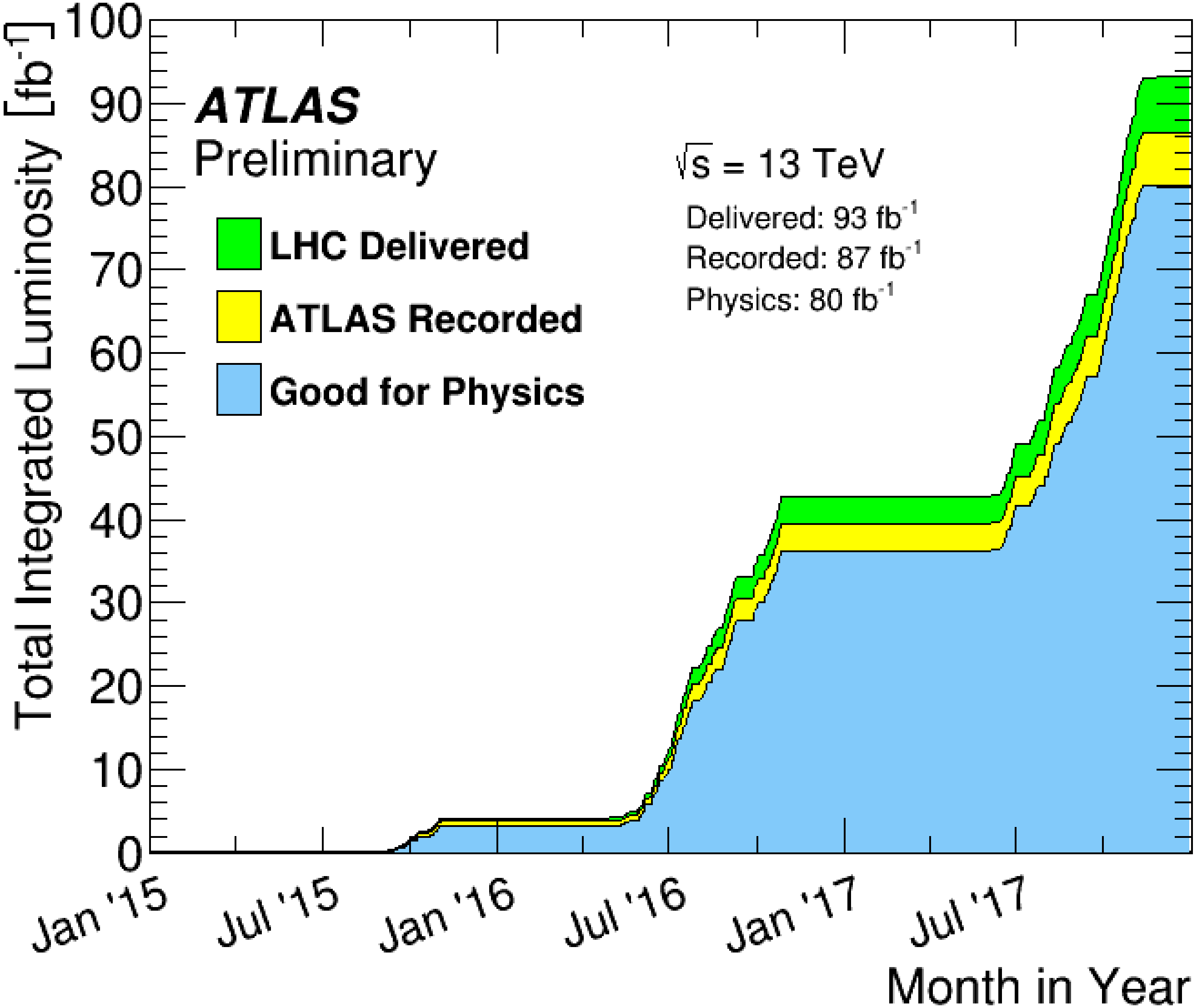


"This could be the discovery of the century. Depending, of course, on how far down it goes"

Please support our application for renewal the project "Upgrade of ATLAS detector" (theme 0-2-1081-2009/2019) for the period 2019-2021

Backup slides

Within the upgrade project for Calorimeters we will continue R&D work on development of the front-end readout electronics, new scintillators, testing and products certification.
Study and development of the analog part of the HEC LTDB trigger block, mock-up construction, test bench and tests of the performance – 30kUSD
Development of the analog part of amplification block of the main HEC FEB ASIC, including simulation, prototyping and mock-up for the performance tests- 30kUSD
Purchase and performance study of the integral version of the main amplifying chip for HEC FEB: purchase - 100kUSD, test stand construction - 30kUSD, clean room equipment - 5kUSD
Radiation tests of the LAr readout electronics - 10kUSD
Development of gap/crack scintillators for TILE Calorimeter and radiation hardness tests, purchase of composite scintillators - 50kUSD
Test bench upgrade for TILE electronics: scope, FADC, power suppliers, FRGA - 50kUSD
Development of PMT blocks and their certification: test stand for electronics development - 25kUSD
Within the upgrade project for Muon Spectrometer we will continue intensive mass-production of the MicroMegas chambers and quadruplets assembly for the NSW projects. The chambers will be supplied to CERN and our team will participate in their integration in the NSW structure and final detector commissioning.
Development of the project for data analysis and visualization (station of 5 PC, ethernet link blocks, measurement tools - generator, FPGA)~35kUSD
LM2 quadruplets production, transportation, integration and final commissioning:
Transportation tools for quadruplets, lifting tools for quadruplets integration into NSW frame, rotating tools for LM2 quadruplets – 55 kUSD
LM2 quadruplets shipment to CERN – 15 kUSD
FE electronics for ATLAS Micromegas chambers, purchase – 40 kUSD
Precise aluminum profiles, epoxy glue and Mixer-dispenser for MM production and the quadruplets assembling – 30 kUSD
Low-noise preamplifier chips production for Micromegas – 30 kUSD
Trigger system for large-area detector’s cosmic tests – 60 kUSD
Accompanying laboratory equipment (power supplies, oscilloscope, Keithley HV picoampermeter, profilometer, optical ruler, etc.) – 60 kUSD
R&Ds for Micromegas chambers and sRPC – 40 kUSD



ATLAS
Preliminary
$\sqrt{s}$ = 13 TeV
Delivered: 93 fb^{-1}
Recorded: 87 fb^{-1}
Physics: 80 fb^{-1}
LHC Delivered
ATLAS Recorded
Good for Physics
Total Integrated Luminosity [fb^{-1}]
0
10
20
30
40
50
60
70
80
90
100
Jan '15
Jul '15
Jan '16
Jul '16
Jan '17
Jul '17
Month in Year

Phase-I - Summary

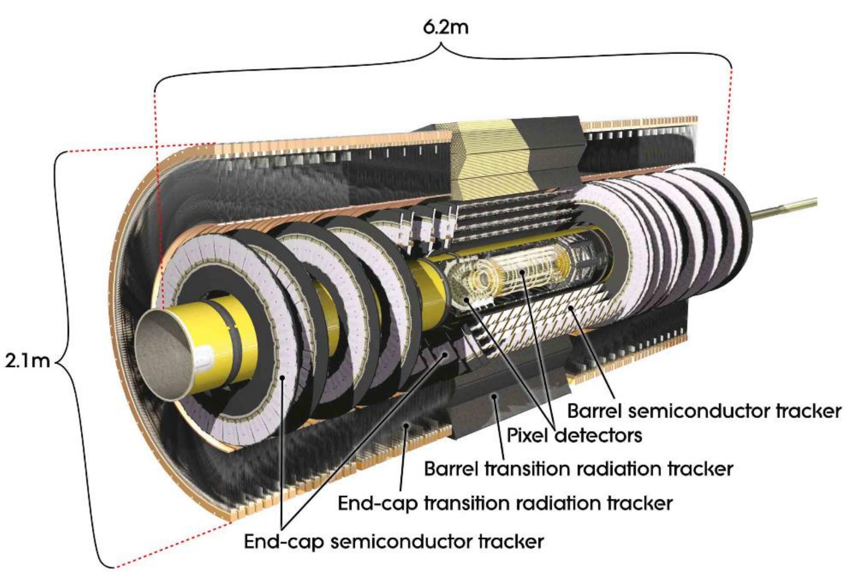
- The **FTK** has been transferred to the TDAQ operation organization
- **TDAQ** : no problems are expected in delivering the system for LS2 installation.
- The **NSW** project continues to face major schedule challenges in three areas – on-detector electronics, MM and sTGC production. A detailed overall NSW schedule is created, it has 1500 tasks (we remain optimistic)
- **LAr** progressing well (two ASICs to be completed by Q2 2018)
- **AFP** – commissioning is ongoing during the 2017 pp run

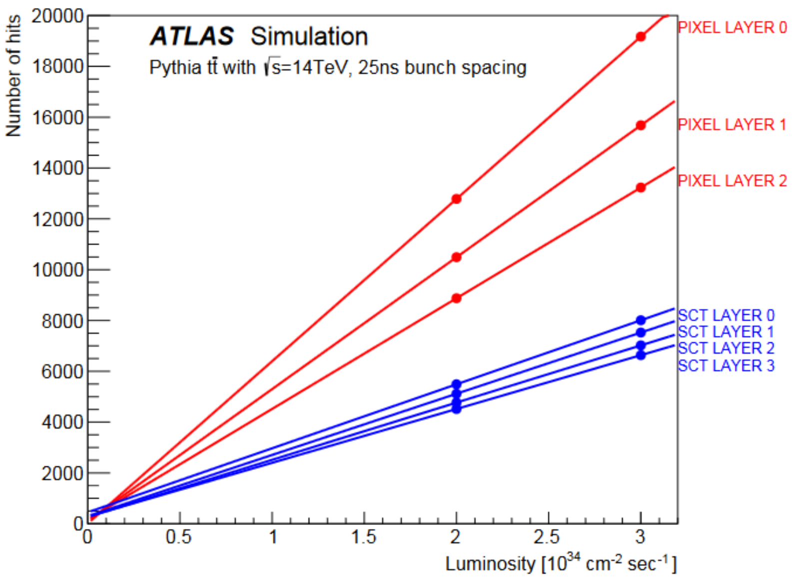
- CORE values (deliverables) – 269 kCHF (MoUs, 2014) of 33.6 MCHF
  - 2017: 43 kCHF (NSW) + 16 (LAr) + 50 (TILE)
  - 2018: 77 kCHF (NSW) + 83 (LAr)

The majority of these upgrades are designed to satisfy Phase-II requirements, and will continue operating in ATLAS throughout the Phase-II period. The Phase-I upgrades form the foundation for Phase-II upgrades

The **Phase-I hardware track finder (FTK)** is an electronics system that rapidly finds and reconstructs tracks in the inner-detector pixel and SCT layers for every event that passes the level-1 trigger, and provides fast tracking information as input to the high-level trigger.

- copy of data from 8 of 12 silicon tracking layers (Pixel and SCT) are processed by an associative memory system
- track candidates are identified by rapid comparison to roughly one billion track templates
- extrapolate from the track candidates to perform fits to information from all 12 silicon layers
- produce lists of fitted tracks for use by the HLT.





The Phase-I TDAQ upgrades are focused primarily on the Level-1 calorimeter trigger, to take full advantage of the finer segmentation available after the Phase-I LAr upgrade.

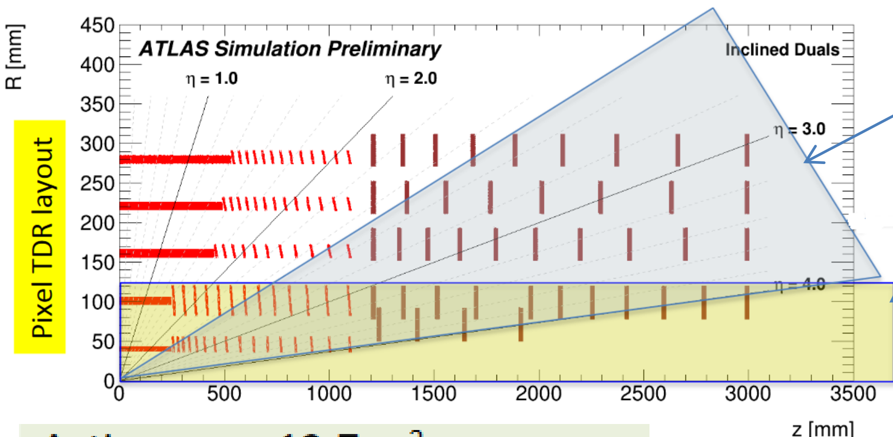
- Sophisticated algorithms are implemented in new Feature Extractor processors (FEX) for electron/photon reconstruction (eFEX), jet reconstruction (jFEX) and for global hadronic variables (gFEX). [plus new NSW trigger component]
- Several prototypes of the three FEX boards have been extensively tested.
- Finally, the Phase-I DAQ will transit towards a network-switch based data collection system using a custom interface to the detector front-end electronics (FELIX). All of the new Phase-I detectors will use this new data-acquisition infrastructure, which will also handle all DAQ functions for the Phase-II upgrade.

The rapid and remarkable progress of the **ATLAS Forward Proton (AFP)** project continues in 2017. The first arm installed in YETS 2015–2016 has been commissioned successfully. The hardware for the second arm has been installed during EYETS 2016–2017.

Now - **LUCID** (±17m from the IP), **ZDC** (±140m), **AFP** (205m, 217m) & **ALFA** (±240m).

ITk: The new ATLAS Inner Tracker

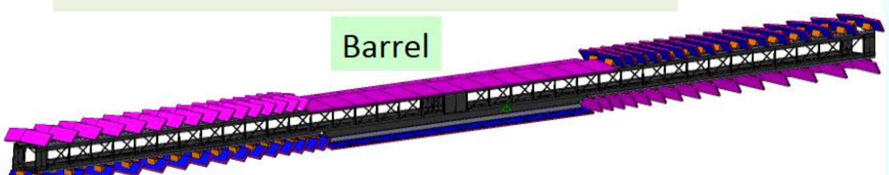
- Major component of the Phase-II upgrade: ~44% of the total cost
- All-silicon tracker will provide tracking to |η|<4.0 and occupy the maximum coverage available out to active radius of ~1m and ~7m length
- > 5 hits close to the interaction point with high granularity and accuracy ~10µm
- > 9 precision hits over the full acceptance (-4<η<4) and up to R~1m



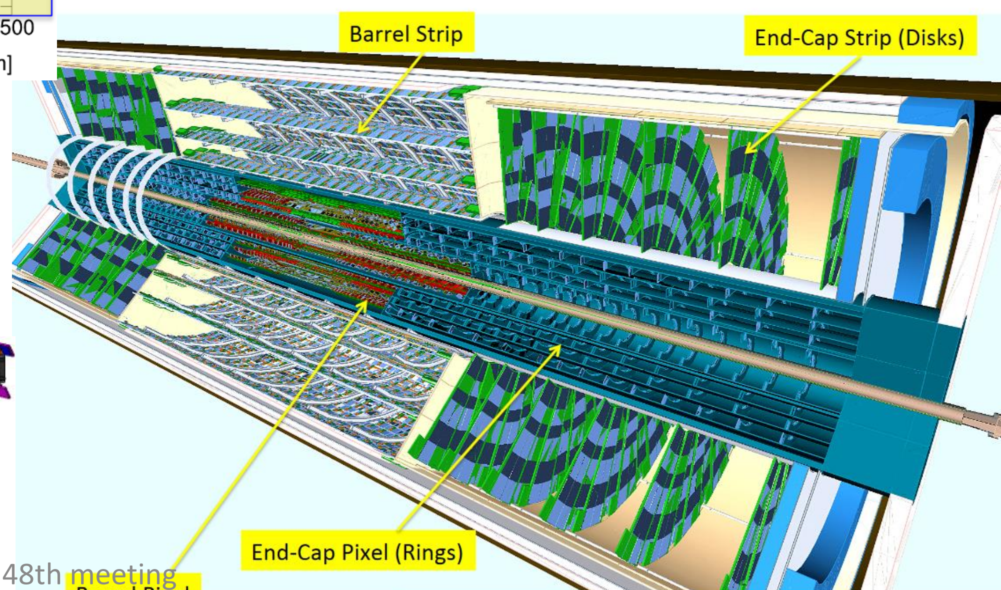
Additional η acceptance

Insertable inner layers

Active area: 12.7 m^2
Pixel size: 50x50 (or 25x100) µm^2
# of modules: 10276
# of FE chips: 33184
# of channels: ~5 10^9

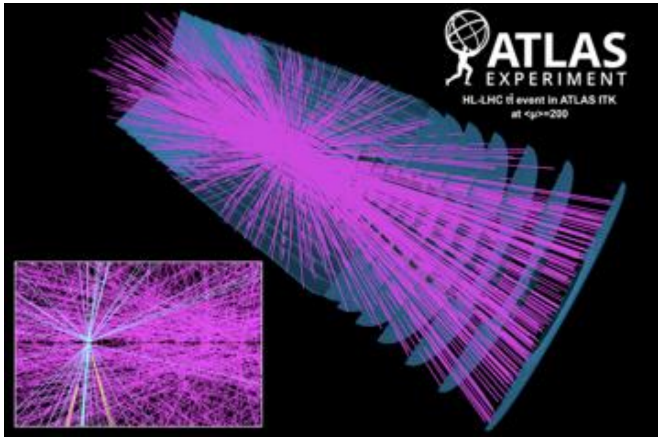


An artistic view to get a better feeling of the ITk layout



R~1m, L~7m

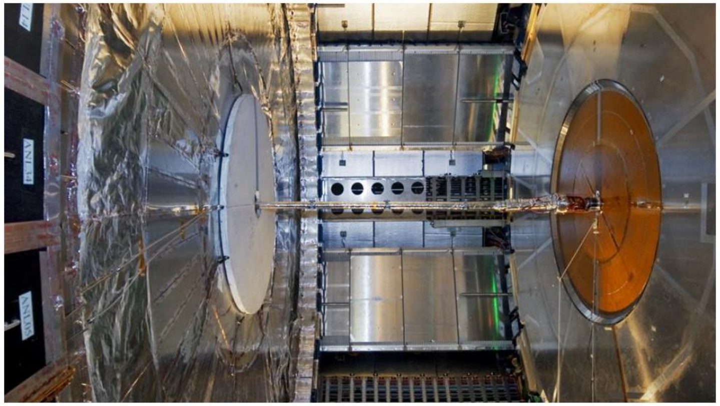
High Granularity Timing Detector, HGTD



HL-LHC (<μ>=200):

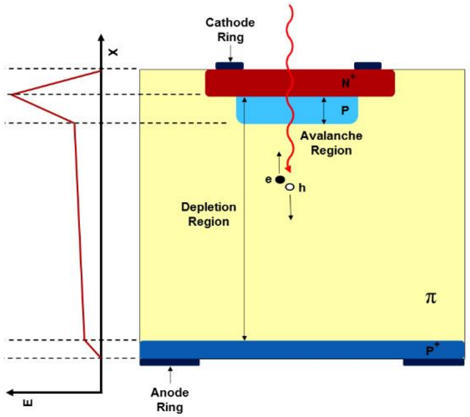
- “IP” about 50 mm RMS along the beam axis
- 180 ps RMS spread of collisions
- up to an average of 1.6 collisions/mm
- ITk – z_0 << 0.6mm in central region
  ~ 5mm in endcap (low pT)

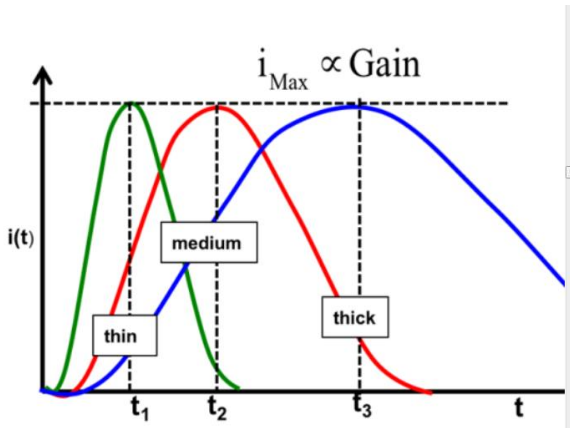
A powerful new way to address this challenge is to exploit the time spread of the interaction region to distinguish between tracks originating in collisions occurring very close in space but well-separated in time.

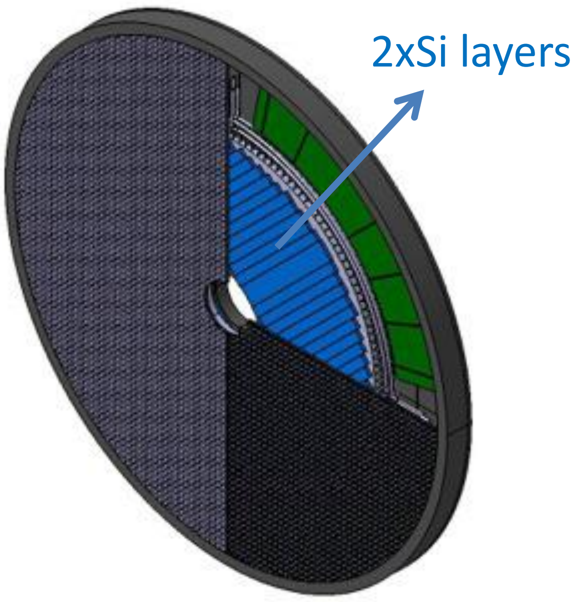


- Available space: 65 mm @ |z| = 3.5 m (2.4 <|η|< 4.2)
- Radiation levels up to 3 MGy, 4 x 10^{15} N_{eq}/cm^2
- Occupancy < 10% → pads of 1x1 - 2x2 mm^2
- Defining layout of electronics, mechanics, integration
- Studies with full simulation ongoing
- Good progress on sensors, intensive R&D on radiation resistance (within RD50)
- Promising tests with beams in 2016, more this year
- First tests of ASIC, radiation hardness, etc

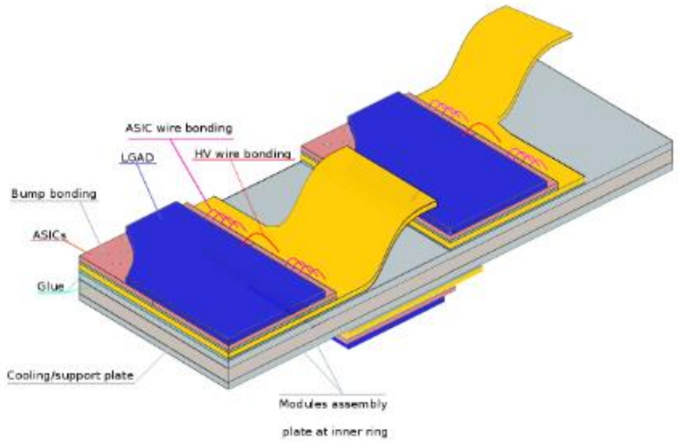
High Granularity Timing Detector - Sensors



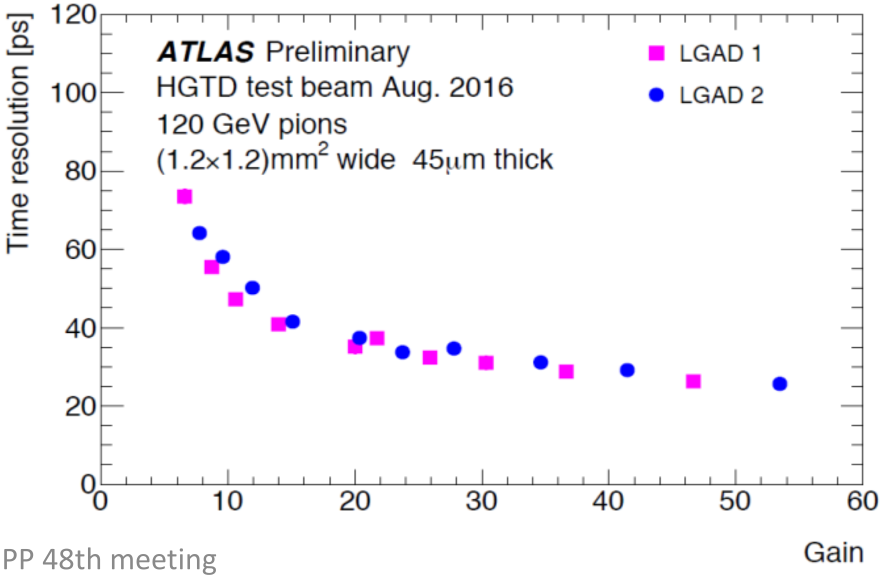




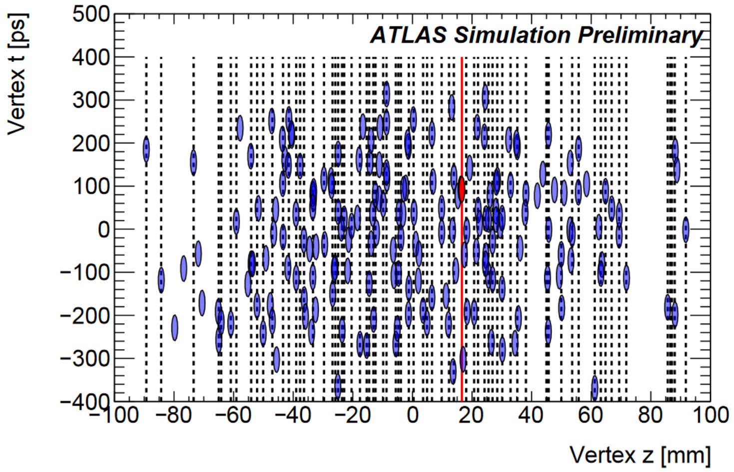
The LGAD sensor module will have an area of 2×4 cm^2
with 1.3×1.3mm^2 pixels, equipped with two front-end ASICs



(a) Schematic showing the components of the modules.



High Granularity Timing Detector - Bonuses



HGTD with a timing resolution of ~30 ps for MIPs will extend the ITk forward tracking to:

- provide maximal pileup mitigation out to η=4, covering the critical VBF jet region
- provide vertex timing for essentially all primary vertices,
- provide track timing for all charged tracks beyond η~2.4,
- provide powerful luminosity and background measurements for each BCID.

- With the HGTD, the performance of pileup-jet suppression, b-jet tagging, and lepton isolation in the forward region reaches the same level as in the central region.
- The rejection of <u>pileup jets</u> improves by a factor of 4, the <u>light-jet rejection</u> at a b-jet efficiency of 70% improves by a factor of 1.8, and the <u>lepton isolation</u> efficiency increases by 13%.
- HGTD can improve the uncertainty on the signal strength determination of VBF-produced Higgs bosons decaying to H→WW by 8% and the signal significance of tH(→$b\bar{b}$) by 11%.

FCC+