Задачи модернизации детектора ATLAS

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Ломоносовские чтения МГУ

18 апреля 2018

Немного истории создания детектора

Дата рождения

CPPM Marseille, Melbourne, Milano, Montreal,
ITEP Moscow, Lebedev Moscow, MEPhI Moscow,
MSU Moscow, Munich, MPI Munich, Nijmegen

The birth of ATLAS

March 1992 – Summer 1992

Merging of ASCOT and EAGLE

September 1992: Decision on the name

1st round		2nd round	
ATLAS	31	ATLAS	40
ALICE	12	ALICE	13
ACE	5		
ALEX	5		
LHD	0		

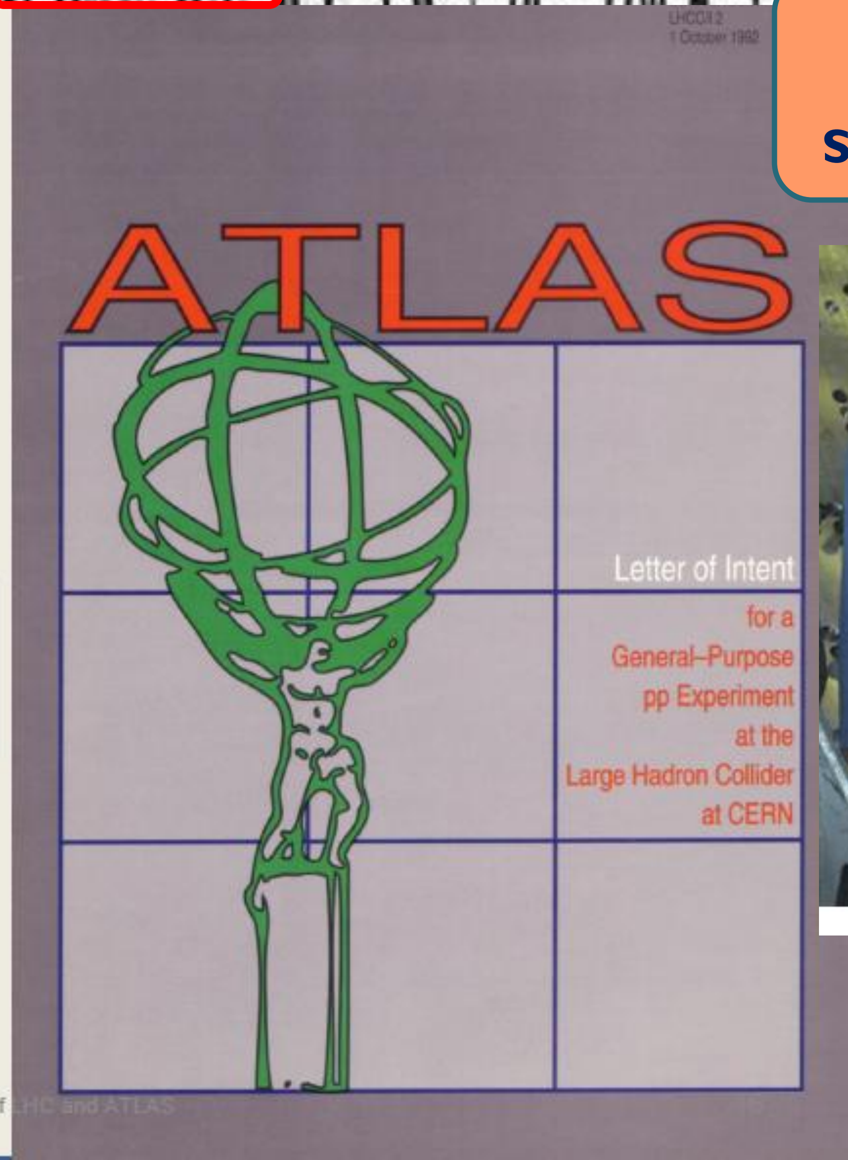
1st October 1992

ATLAS LoI submitted to the LHCC
(Co-spokespersons Friedrich Dydak and PJ)

'Official birth of the ATLAS Collaboration'

25y LoI, Bratislava, 12-10-2017
Peter Jenni (Freiburg and CERN)

Birth of LHC and ATLAS



F.Dydak
P.Jenni
Spokepersons

P. Jenni
12.10.2017

Начало сотрудничества России и ЦЕРН

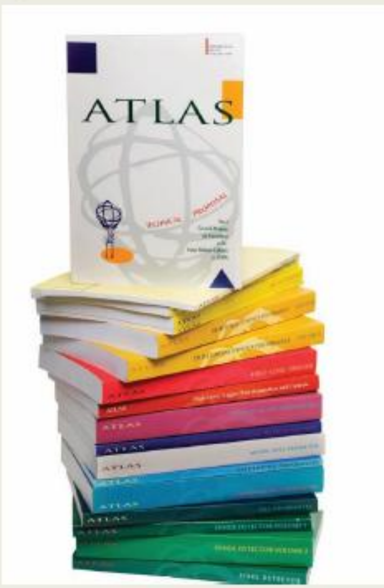
1991 December CERN Council: 'LHC is the right machine for advance of the subject and the future of CERN' (thanks to the great push by DG C Rubbia)

1993 December proposal of LHC with commissioning in 2002

Minister Boris Saltykov and DG Carlo Rubbia signing an updated Cooperation Agreement Russia and CERN (28 June 1993)

От начальной идеи – долгий путь сокращения, упрощения… до технического проекта и проверок финансовых ресурсов через RRB дважды в год

Anything worked out fine, and alltogether we produced an impressive series of TDRs…



The formal construction approval was then given with the approval of the first TDRs, namely for the calorimeters

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
Laboratoire Européen pour la Physique des Particules
European Laboratory for Particle Physics

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Director General
CH - 1211 Geneva 23, Switzerland
Telephone Direct: (41 22) 767 23 00
Secretary: (41 22) 767 35 96
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E-mail: Christopher.Llewellyn.Smith@cern.ch

Our Ref. DG/mnd/2540

Dr Peter Jenni
PPE Division
CERN

Geneva, 1st July 1997

Dear Peter,

Following the thorough discussion of the status of ATLAS and CMS by Council and its Committees two weeks ago, the way is now open for construction to begin. I am therefore pleased to inform you that I have decided to *i)* set the cost ceiling for ATLAS at 475 MCHF (1995 prices), and *ii)* approve the TDR of the ATLAS calorimeters on the following basis formulated by the LHCC and endorsed by the Research Board at its meeting on 12th June:

*"The LHCC **recommends general approval** of the ATLAS Calorimetry Technical Design Report describing design, performance, construction, and installation in 2004. The review **identified some concerns** in limited areas, which require resolution (LHCC 97–27). The LHCC considers that the schedules and milestones given in the TDR are reasonable, and these will be used by the committee to measure and regulate the future progress of the project."*

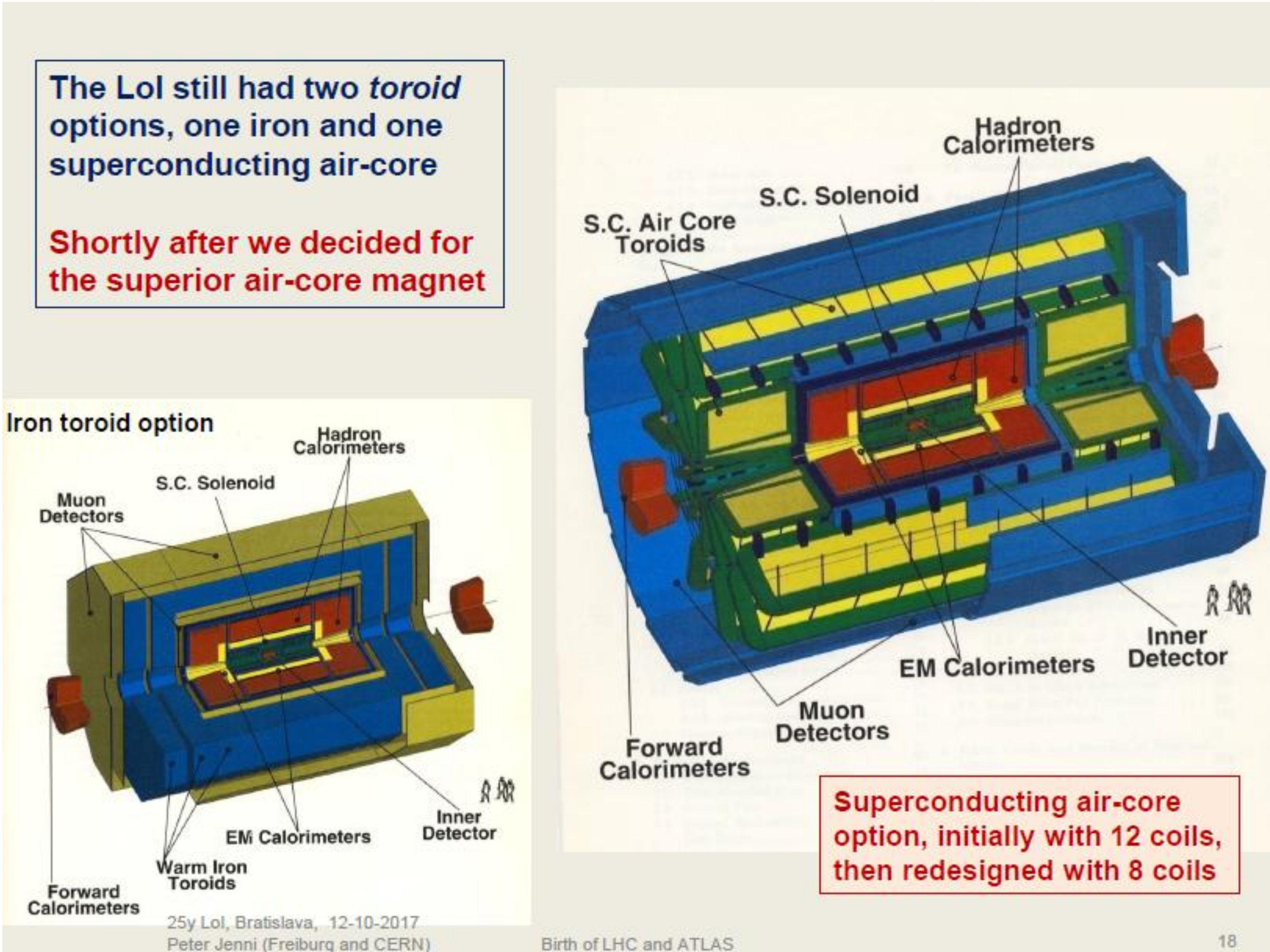
Yours sincerely,

Chris

Chris Llewellyn Smith

cc: L Foà
E Iarocci

Эволюция общей конструкции



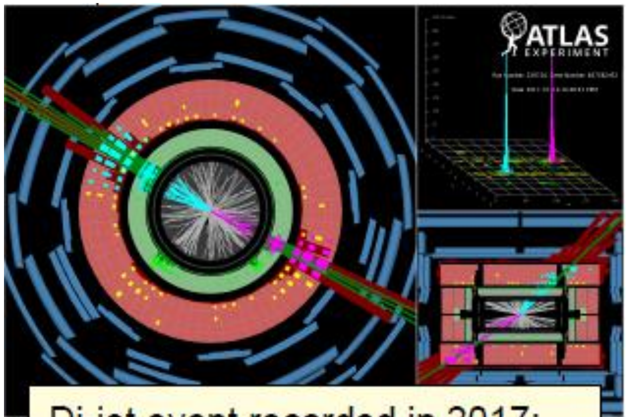
Россия – ЦЕРН сегодня

Recently, the Russian Federation withdrew its application (which had been stalled for > 2 years).
In a formal letter to the President of Council, the Minister of Education and Science states:
"... I wish to take this opportunity to assure the CERN Council that the Russian Federation ... remain extremely interested in continuing and expanding their fruitful cooperation with CERN, as their principal partner in the field of particle physics. ... The Russian Federation ... will be working very actively with the CERN Management, in particular through the recently re-established CERN-Russia committee, ..."
CERN-Russia Committee (re-established in 2016) brings together CERN Directorate and high-level representatives of Russian Institutions (led by Deputy Minister for Education and Science).
It has been very useful to re-establish the dialogue and to secure Russian contribution to Phase-1 upgrades of LHC experiments. Now discussing contributions to Phase-2 upgrades and HL-LHC accelerator.

6 Observers:

Japan, Russia, USA, European Union, JINR, UNESCO

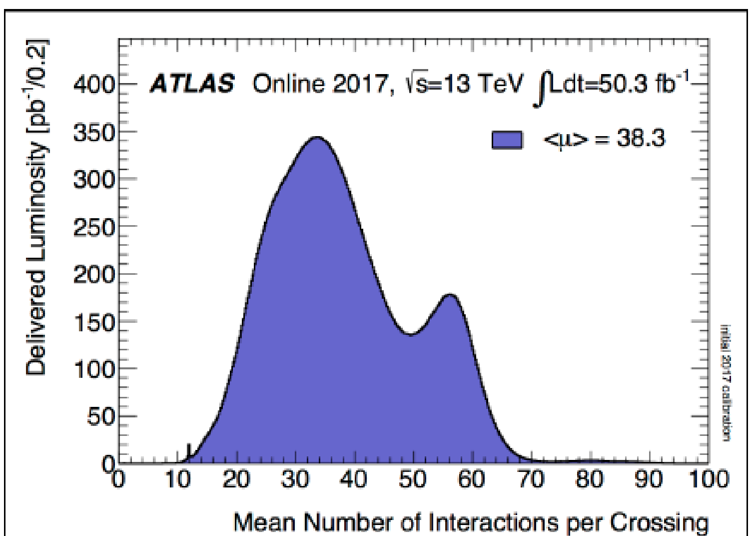
Некоторые итоги к 2018г. – F.Gianotti, DG



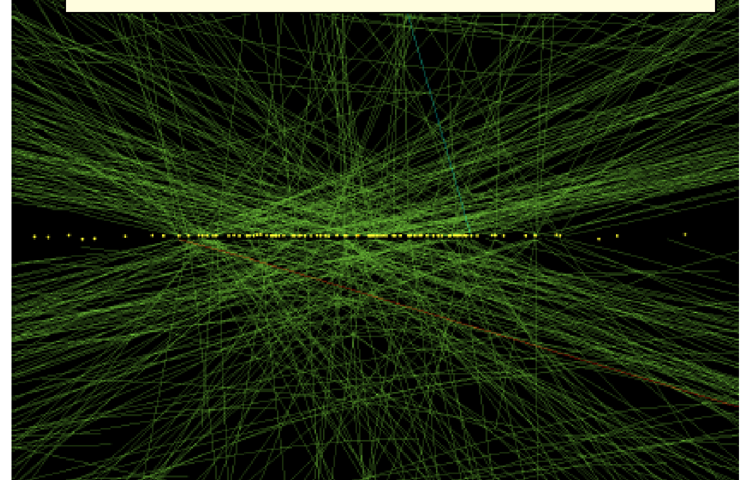
Di-jet event recorded in 2017:
$M_{jj} \sim$ **9.3 TeV**, $p_T (j_1, j_2) \sim 2.9$ TeV

ATLAS and CMS had to cope with monster pile-up

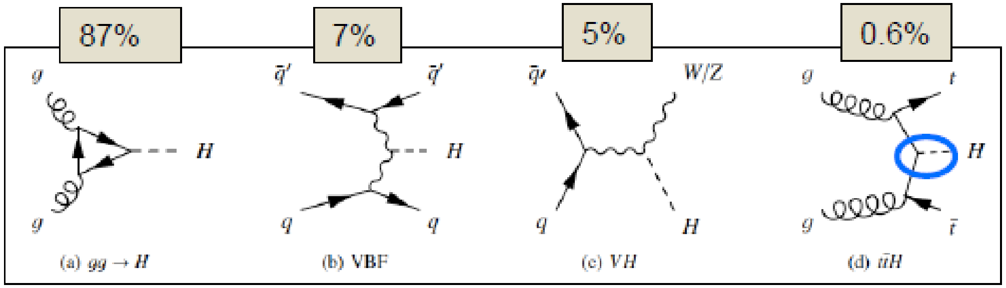
With $L=1.5 \times 10^{34}$ cm^{-2} s^{-1} and 8b4e bunch structure → pile-up of ~ 60 events/x-ing
(note: ATLAS and CMS designed for ~ 20 events/x-ing)



CMS: event with 78 reconstructed vertices

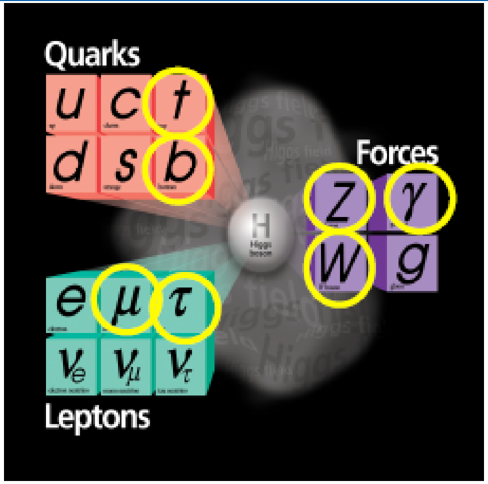


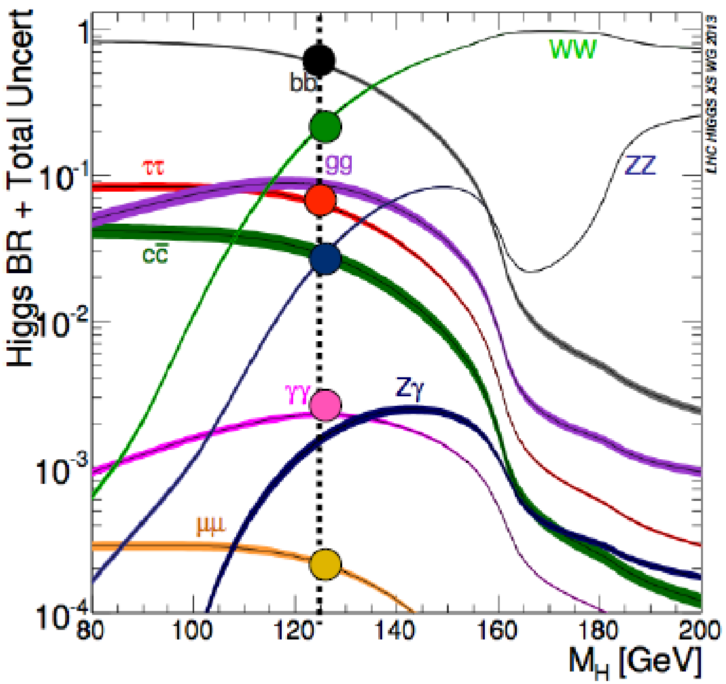
Progress on Higgs boson studies



$$g_{Hf\bar{f}} = \frac{m_f}{v}$$

$$g_{HVV} = \frac{2m_V^2}{v}$$





Higgs boson discovered and now well measured in H→ γγ, H→ZZ*→4l, H→ WW* → lνlν channels (small branching ratios but clean final states)

Decays and couplings to 3rd generation fermions (H→ bb, H → ττ, Htt production) experimentally more difficult as affected by huge backgrounds

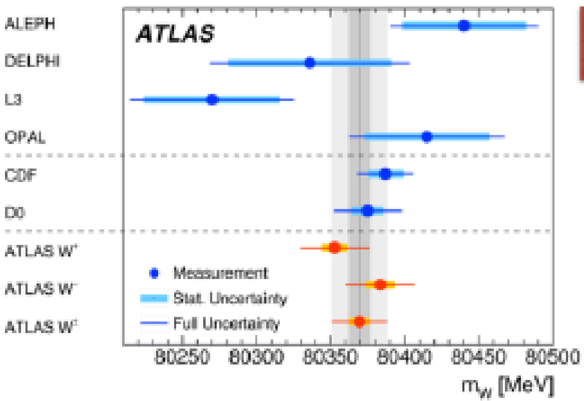
Couplings to 2nd generation fermions (through rare H→ μμ decay) will only be accessible at HL-LHC

We are entering the era of precision physics

Example for precision analysis

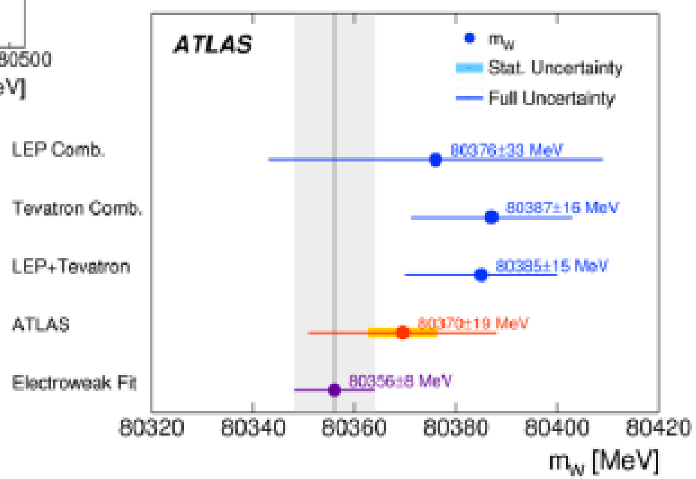
W-Mass Measurement

ATLAS

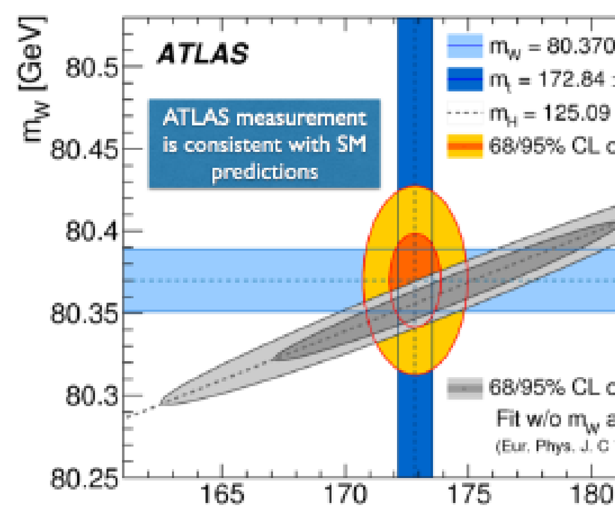


$M_W = 80370 \pm 19$ MeV

±7 statistics
±11 systematic
±14 modelling



ATLAS measurement has similar precision to the current best measurement



Run 1 data only.

A very exciting (and puzzling …) time for particle physics

Main results from LHC so far:
- ❑ discovery of the Higgs boson → Standard Model completed, it works beautifully
- ❑ no sign of physics beyond the Standard Model (yet!)

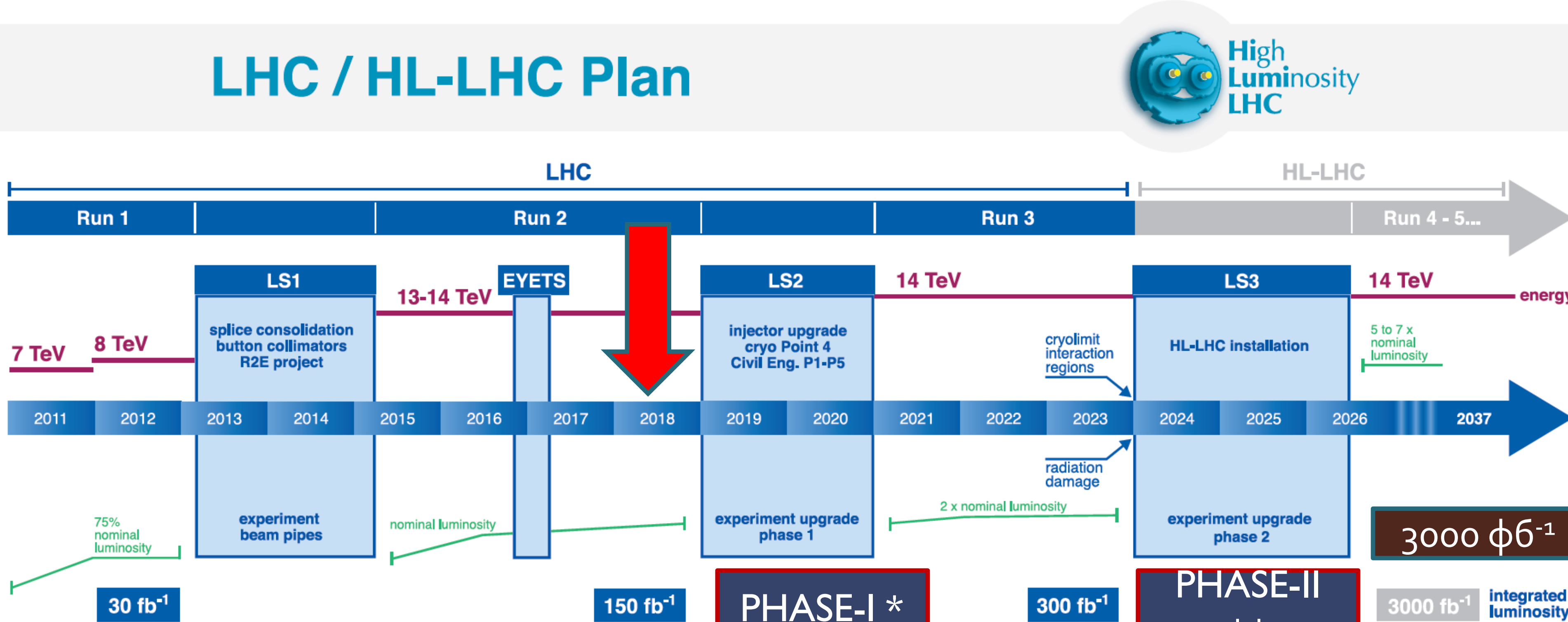
⬇

PUZZLING: the SM is not a complete theory of particle physics, as several outstanding questions remain that cannot be explained within the SM

What is the composition of dark matter (~25% of the Universe) ?
What is the cause of the Universe's accelerated expansion (today: dark energy?; primordial: inflation?)
What is the origin of neutrino masses and oscillations ?
Why 3 fermion families ? Why do neutral leptons, charged leptons and quarks behave differently?
What is the origin of the matter-antimatter asymmetry in the Universe ?
Why is the Higgs boson so light (so-called "naturalness" or "hierarchy" problem) ?
Why is Gravity so weak ?
Etc. etc.

These questions require NEW PHYSICS
→ but where is the new physics in terms of E-scale and couplings to SM particles ???

Режимы работы БАК и детекторов



3000 фб-1

PHASE-I *

PHASE-II **

Фазы модернизации ATLAS

PHASE-0

IBL
AFP

Мюонная система (NSW)
Быстрый трекер (FTK)
Жидкоаргоновый калориметр (LiAr)
Триггер и съем данных (TDAQ)

Внутренний детектор (ITK: pixel, strip)
Жидкоаргоновый и Тайл калориметры (LiAr, Tile Calo)
Триггер и съем данных (TDAQ)

LHCC-I-020, Dec. 2011 *
LHCC-I-023,Dec. 2012 **

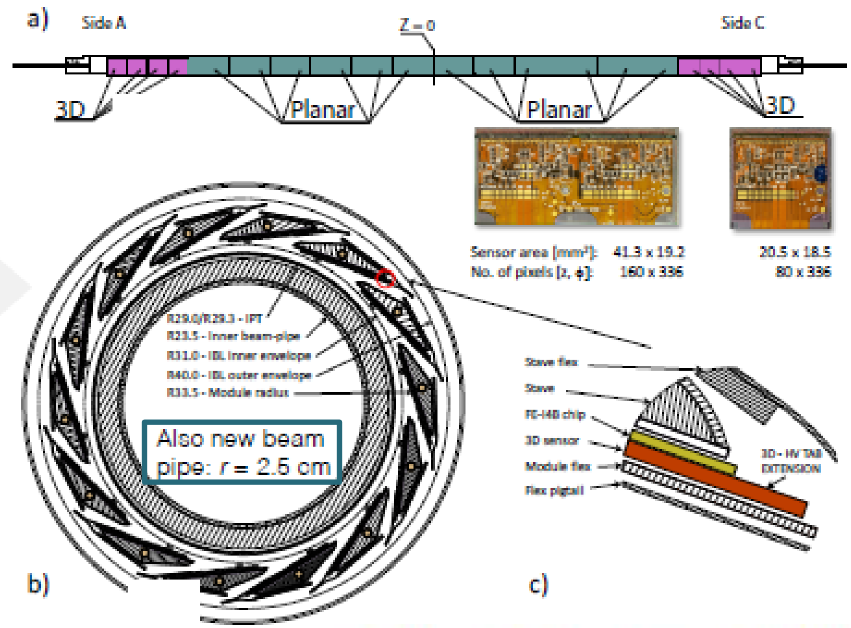
Итоги модернизации 2012-13гг. PHASE - 0

- Внутренний слой пиксельных детекторов (IBL) улучшил координатное разрешение и реконструкцию вершин
- Создание передних детекторов для изучения дифракционных процессов (AFP)
- В системе триггера два верхних уровня объединены в один триггер высокого уровня (HLT), обновлены центральный и L1 триггерные процессоры

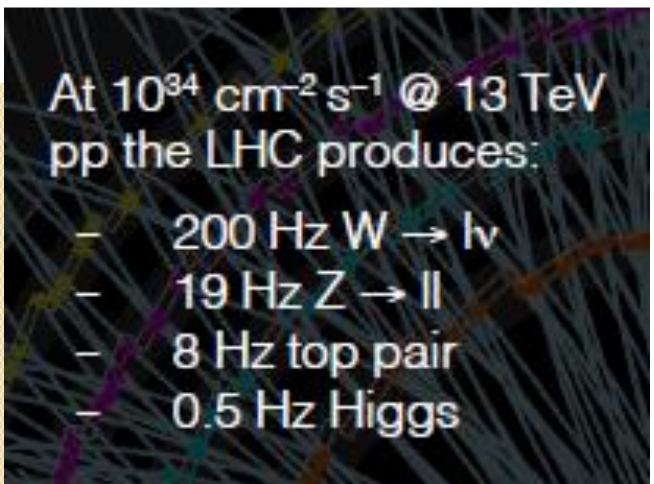
New topological L1 trigger and new central trigger processor, restructured high-level trigger

New *Insertable B-layer*: fourth pixel layer at 3.3 cm from beam, consisting of planar & 3D (forward) silicon sensors, smaller pixels

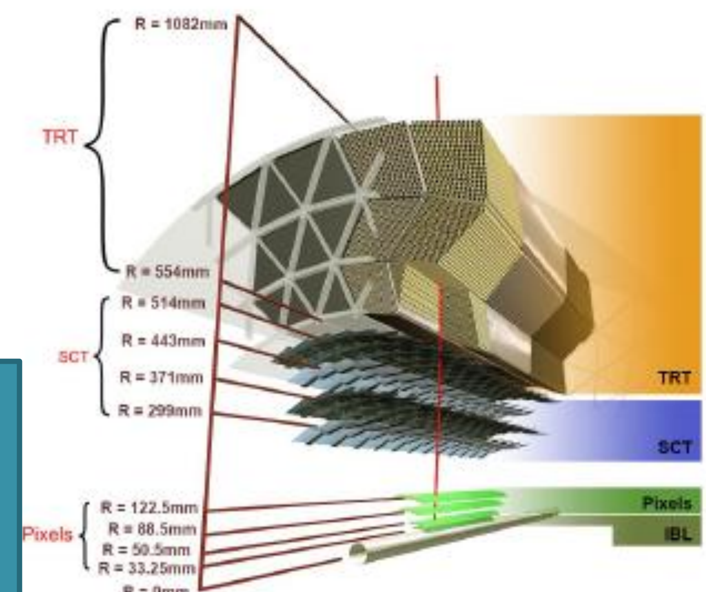
New software, new production system, new analysis model, …



IBL



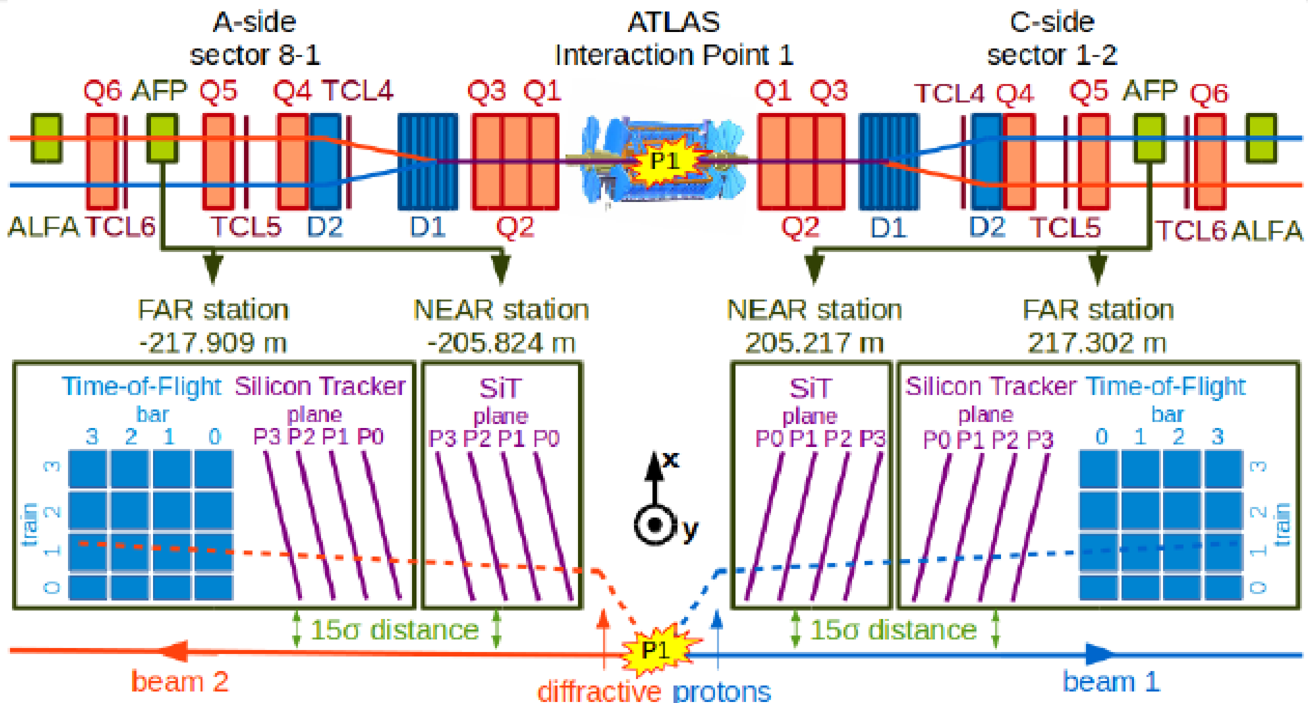
Sketch of ATLAS inner tracking detectors



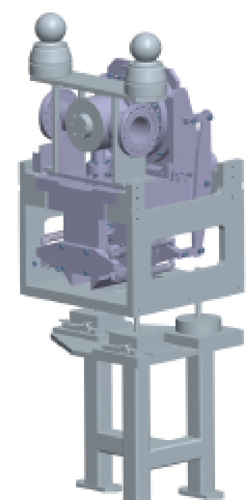
R (IBL) = 33.25 mm
Next PIXELS at 50.5, 88.5 and 122.5 mm

ATLAS Forward Proton

AFP: Setup in 2017



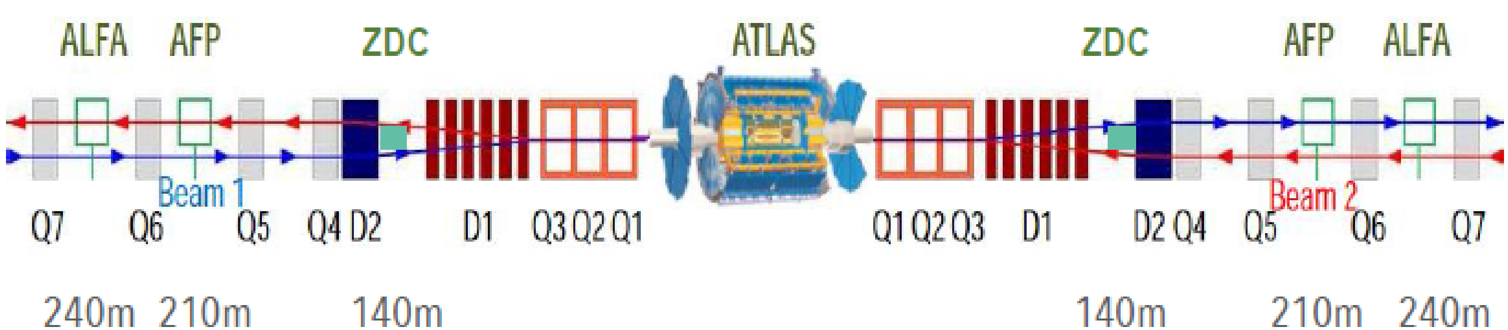
- Two stations on each side of ATLAS:
  - NEAR: ∼205 m,
  - FAR: ∼217 m.
- Design based on the CMS-PPS/TOTEM horizontal stations.
- NEAR stations contain silicon trackers (SiT).
- FAR stations are equipped with SiT and Time-of-Flight detectors.



ATLAS Forward Detectors

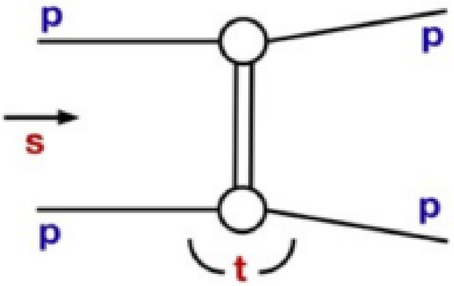
Instrumentation

- ZDC (will be reinstalled in 2018)
    - electromagnetic and hadronic calorimeter
    - measure γ, n, $\pi^0(\rightarrow \gamma\gamma)$ energy deposits $|y|>8.3$
- Proton spectrometers (installed)
    - Several active layers placed in Roman Pot used to reconstruct proton tracks
    - ALFA: vertical approach to beam, optical fibers
    - AFP: horizontal approach to beam, silicon pixel detectors (rad. hard)
        - Time measurement with ToF using Cherenkov light
- All detectors can provide L1 trigger to ATLAS

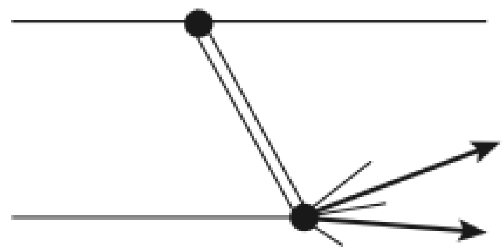


What can we measure?

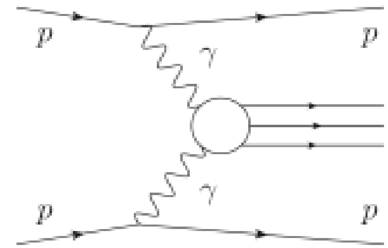
Elastic scattering



Diffractive production



Photon induced process

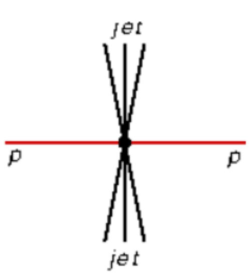


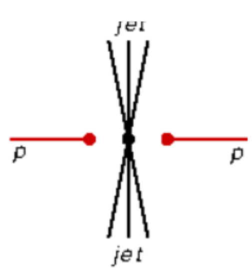
- Use (ξ, p_T, ϕ) variables instead of (y, p_T, ϕ)
- Production exponentially suppressed in p_T (< few GeV)
- (Longitudinal) momentum fraction loss:

$$\xi = 1 - |\vec{p}|/|\vec{p}_{\mathrm{beam}}|$$

- Rapidity gaps too small for heavy systems to be seen in ATLAS $\quad \Delta\eta \sim -\ln(\xi)$
- Double tagged events - reconstruct mass of centrally produced system

$$m = \sqrt{s\xi_1\xi_2}$$





Match proton arrival time ToF measurement ($\sigma_t \sim 25$ ps) with PV in ATLAS

$$(t_A - t_C) \cdot c/2 - z_{PV} \sim 0$$

Модернизация Фаза 1 (2019-2020г)

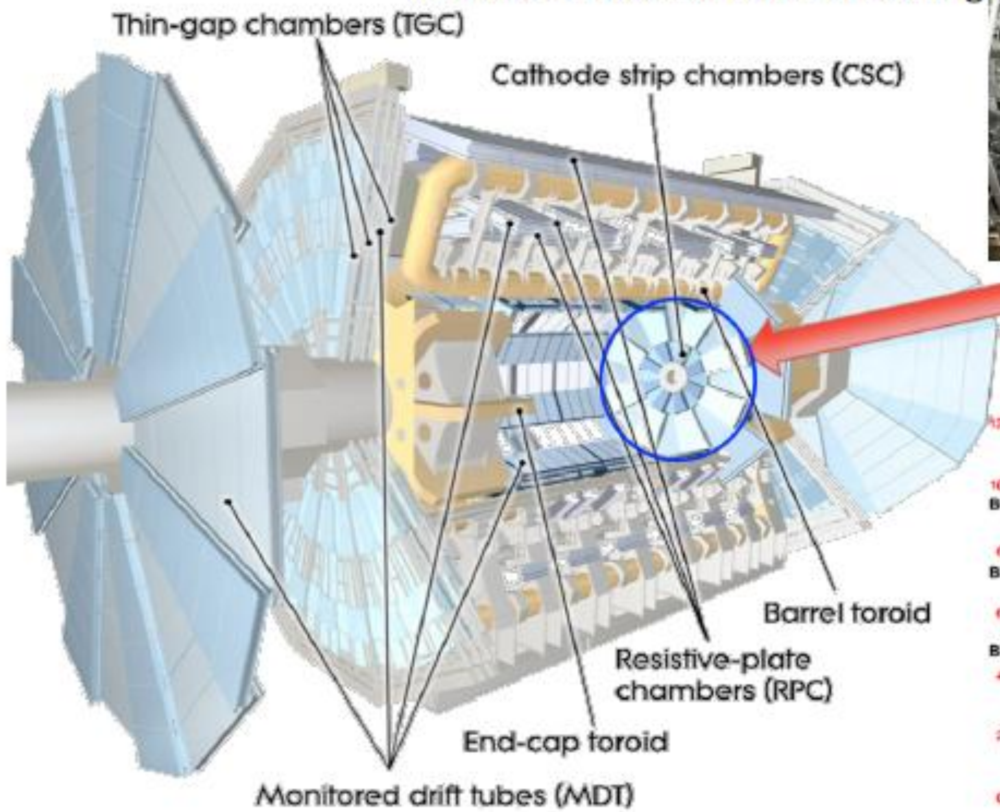
Новые малые мюонные модули (NSW)

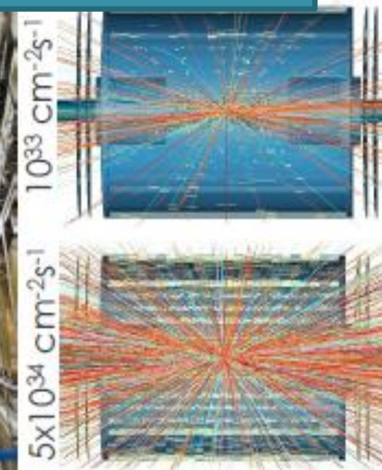
The **New Small Wheel** (NSW) upgrade is motivated primarily by the high background rate that is expected at L = 2 - $5\times10^{34} cm^{-2}s^{-1}$ during LHC Run-3 and HL-LHC

→Replace SW *with fast, high rate, precision* detectors

BCID up to 15 kHz/cm² <100 μm/plane

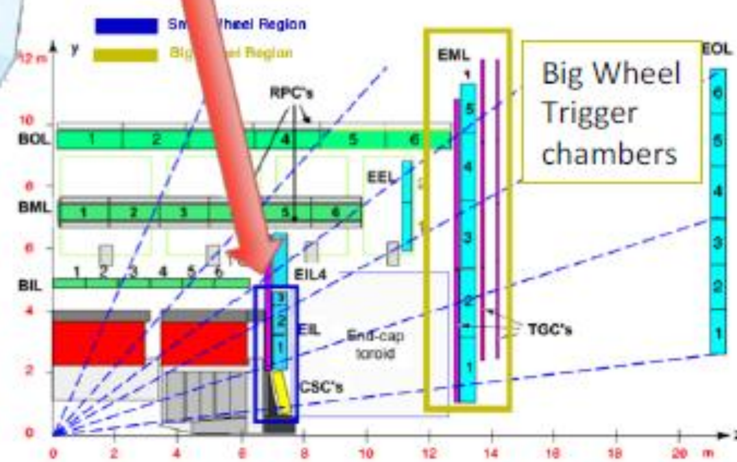
+ *new* structure and JD shielding



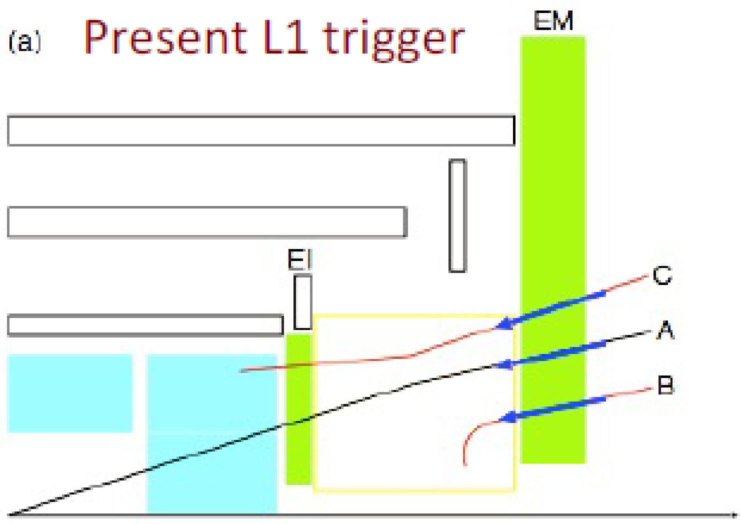


Coverage:
1.2 < |η| < 2.7

Small Wheel (SW)



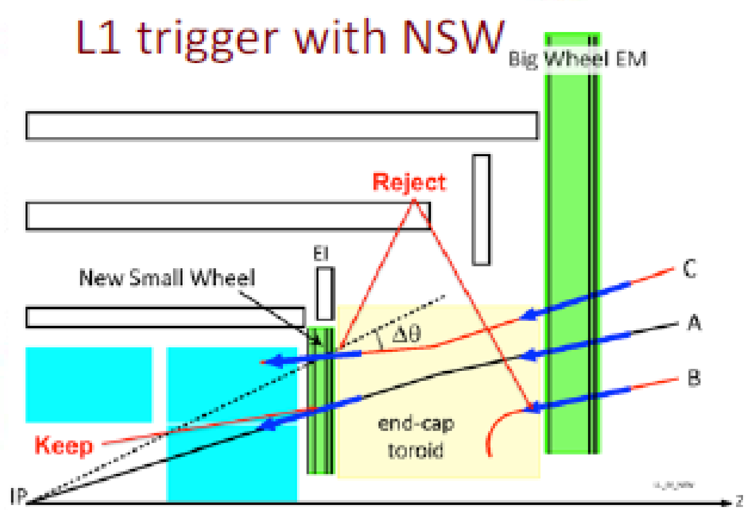
Enhanced ATLAS Muon Trigger with NSW

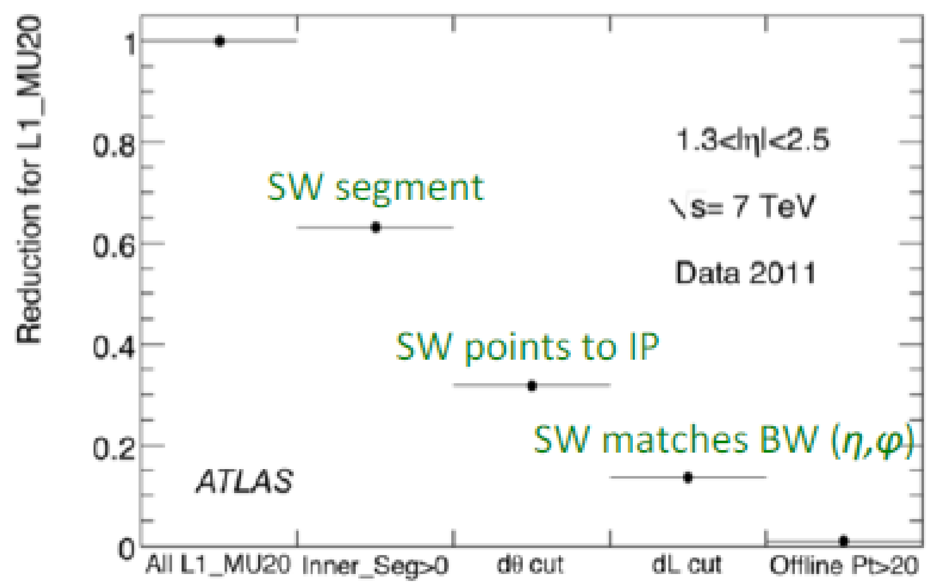


NSW will provide improved trigger for forward muons and improved tracking

New (fast) precision tracker in NSW
that works up to the ultimate luminosity, with some safety margin ($7x10^{34}cm^{-2}s^{-1}$)

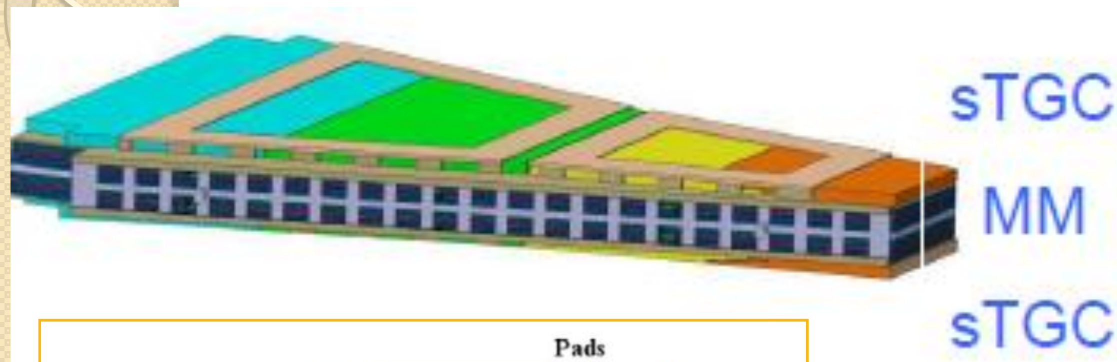
Kill the fake triggers
by requiring high quality (σ_θ~ 1mrad) pointing segments in NSW

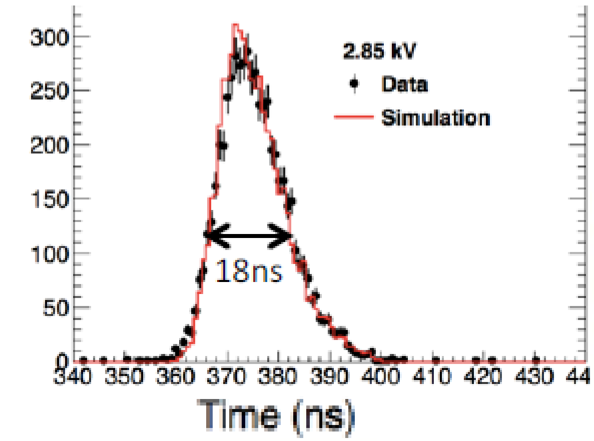


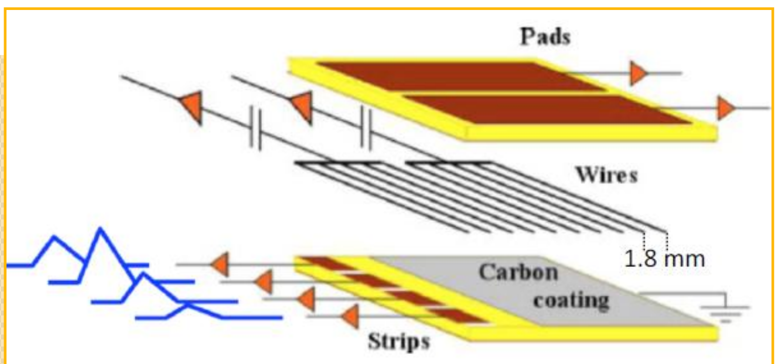


NSW will utilize two detector solutions:

- Small strip Thin Gas Chambers (sTGC) as primary trigger
- Micromegas (MM) for primary precision tracker



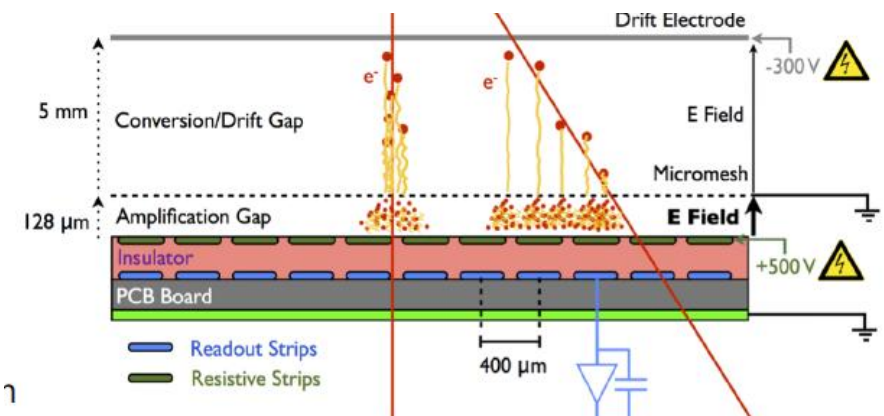


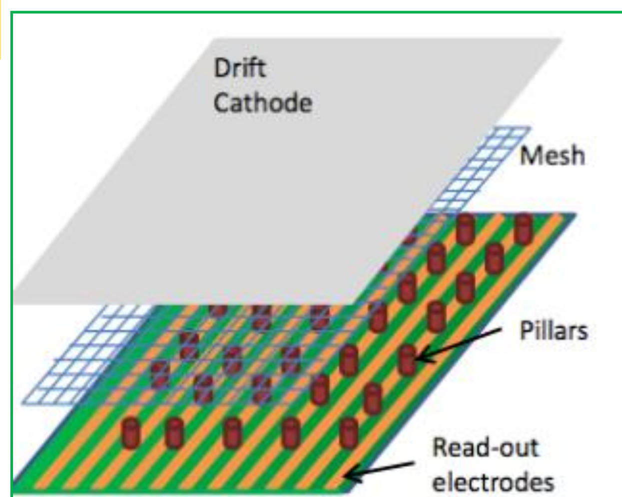


- Fast, thin gap wire chambers (2.8 mm gap)
- Used for the endcap trigger

sTGC

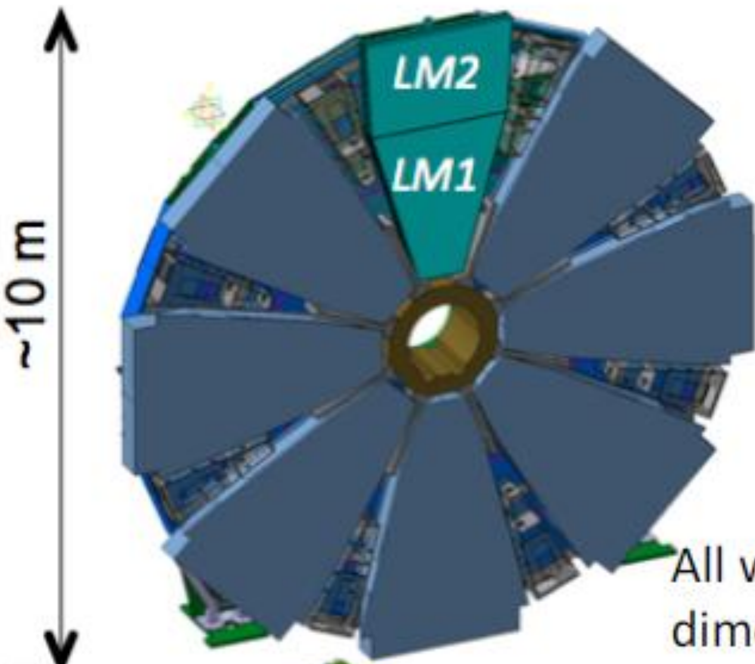
MM





Production of Micromegas

MM Large Sector

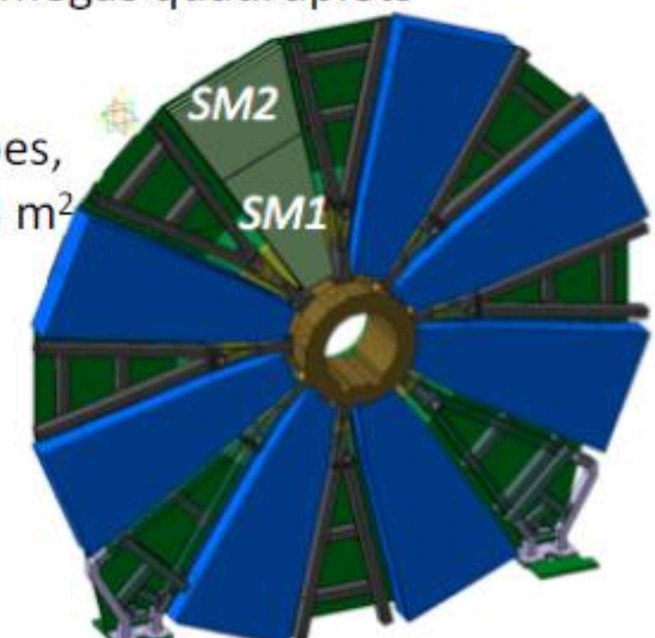


MM Small Sector

Four types of Micromegas quadruplets

All with trapezoidal shapes, dimensions between 2-3 m^2

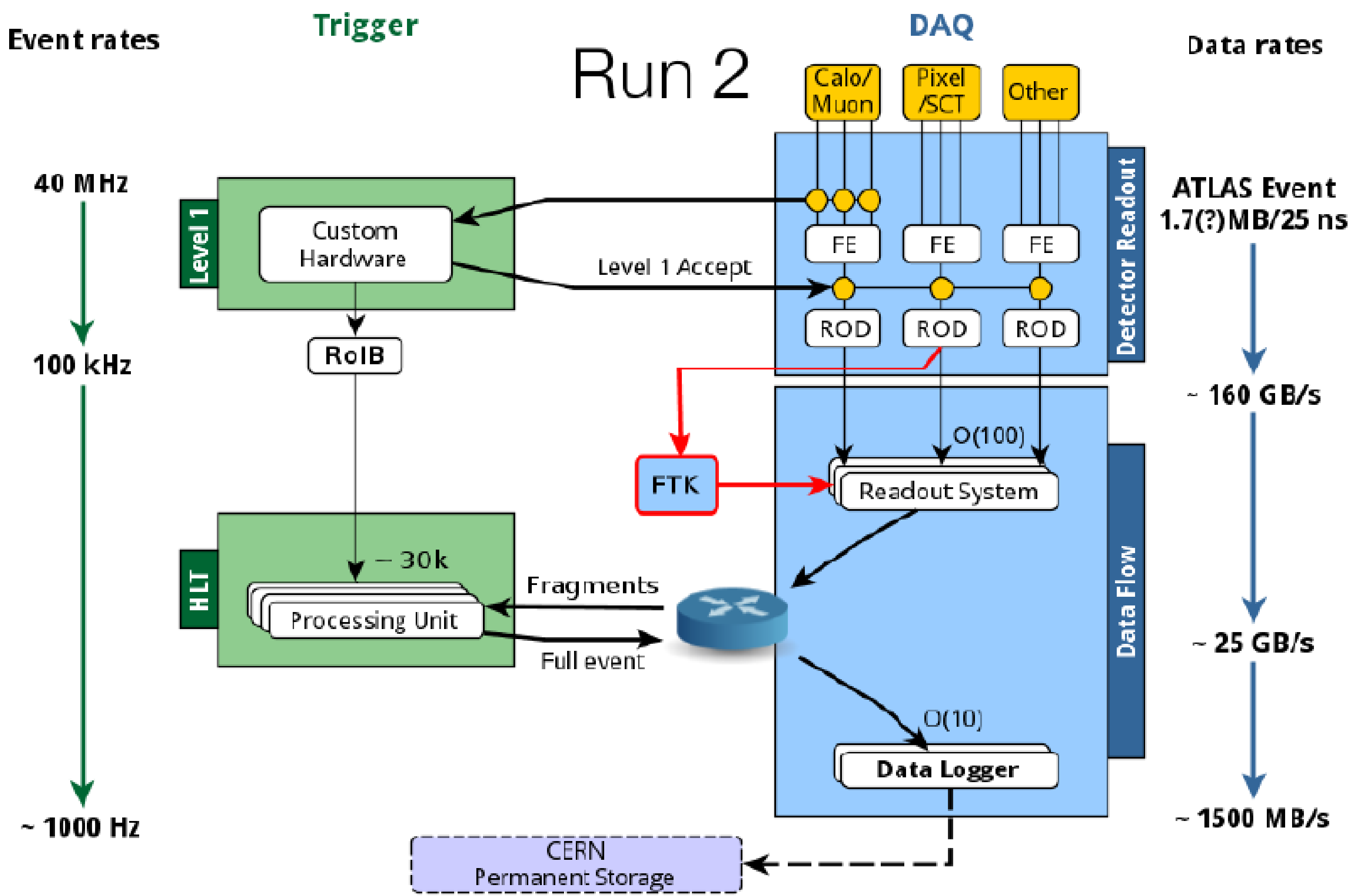
МИФИ+ФИАН+МГУ создали рентгеновский сканер для контроля сборки детекторов (2016)



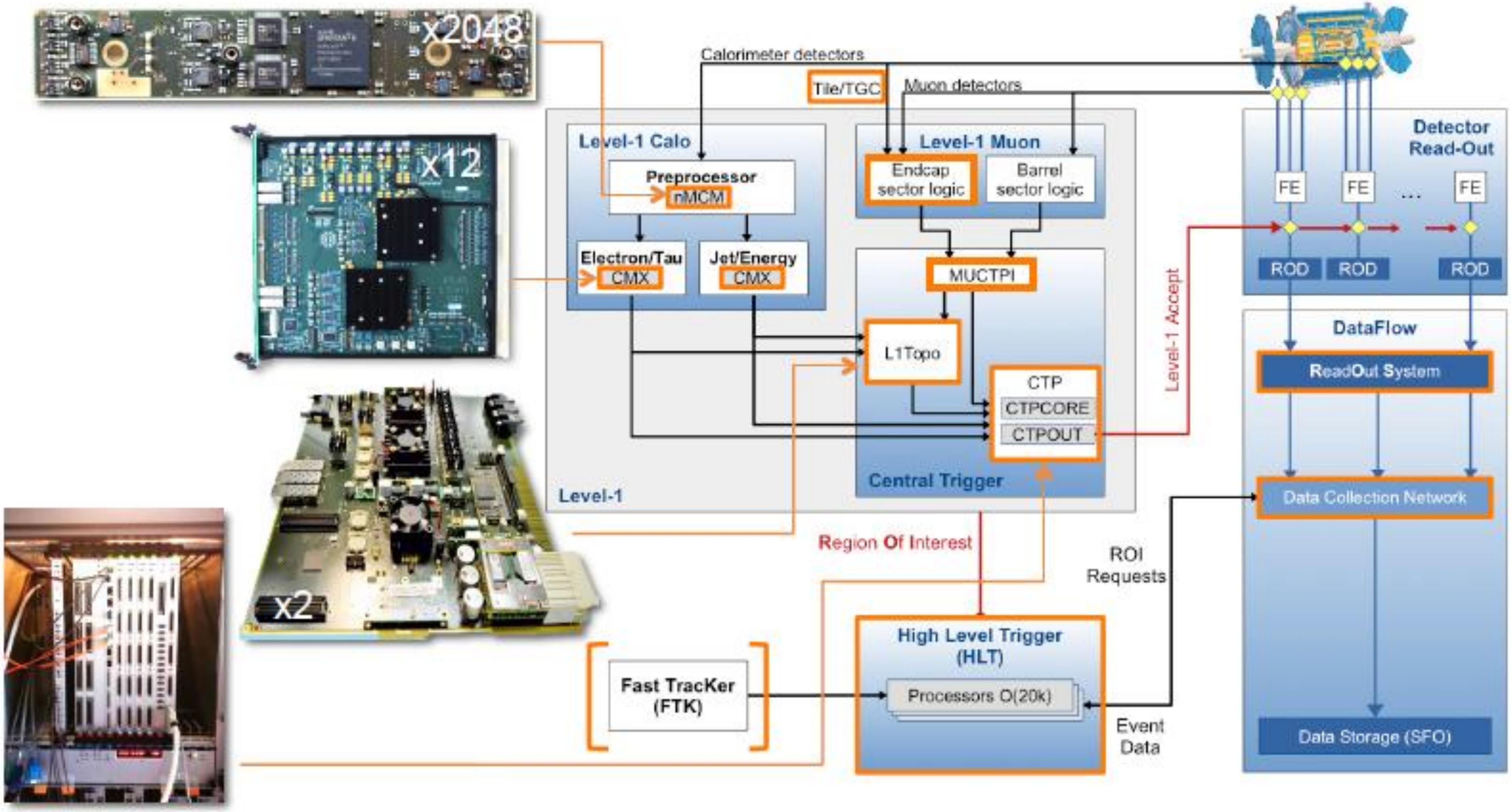
Full site wide production starting in 2015.

Fast Tracker - Фаза 1/2

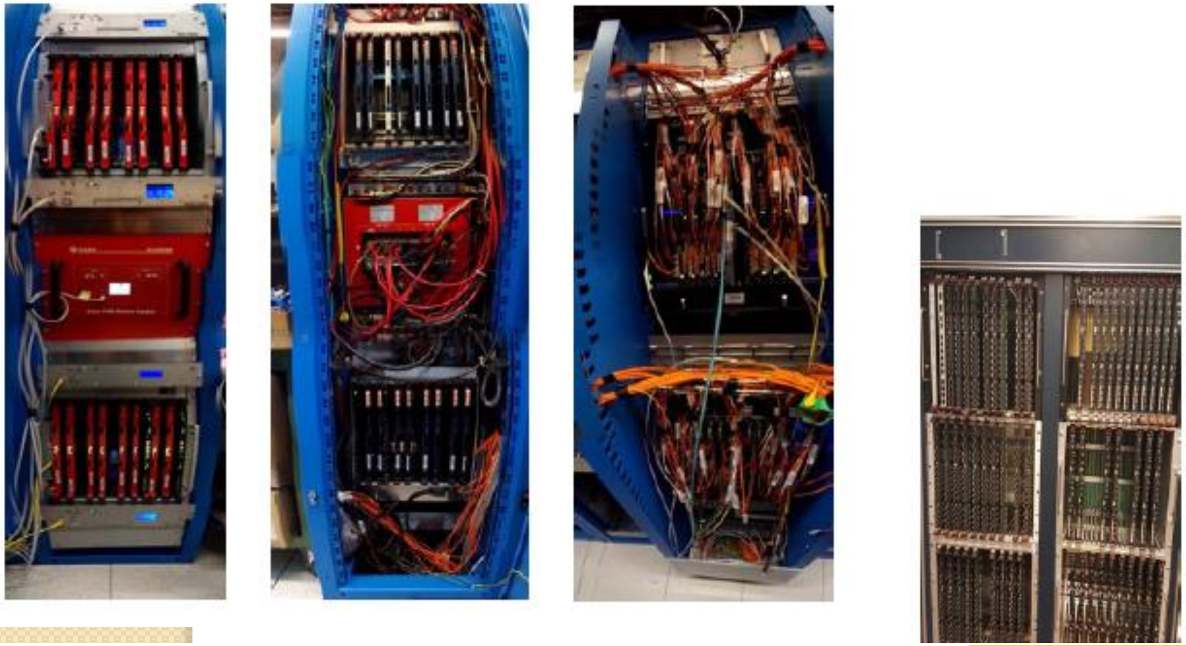
Схема функционирования триггера и системы съёма данных ATLAS в сеансе Run 2.



Электронная система считывания треков для триггера HLT



FTK undergoing challenging commissioning



Часть системы работает

Полная готовность ожидается к сеансу 3

HLT INTEGRATION

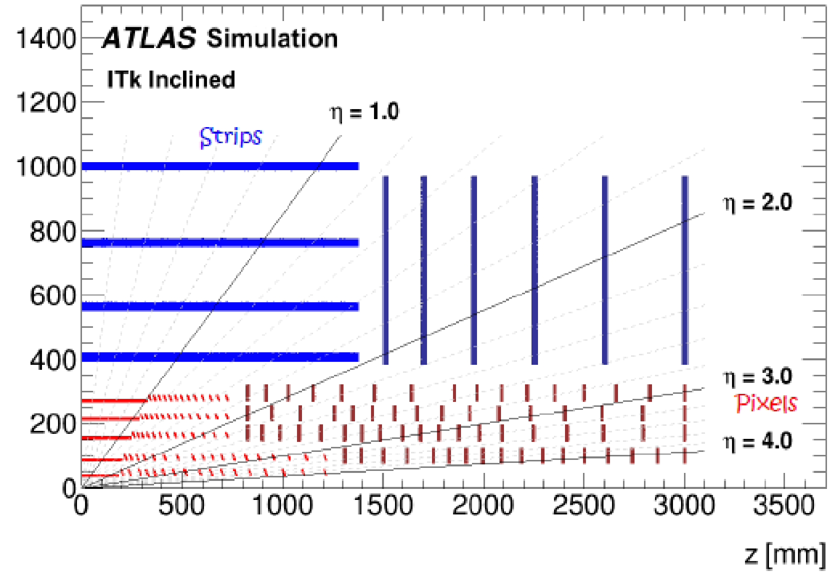
Участвует МГУ

- HLT-FTK integration software in place and extensively validated using MC & data with FTKSim tracks:
    - ATN and RTT nightly tests ; MC production: 10k ttbar events ; FTK reprocessings: 1M Enhanced Bias events (2016 and 2017 EB runs)
- FTK menu items in place: Beamspot, Muon, Tau, Bjet and new Jet & MET chains
    - Active development by many trigger signature groups

B-Phys Trigger

Фаза 2 – новый внутренний детектор ITk (готовность к 2024г.)

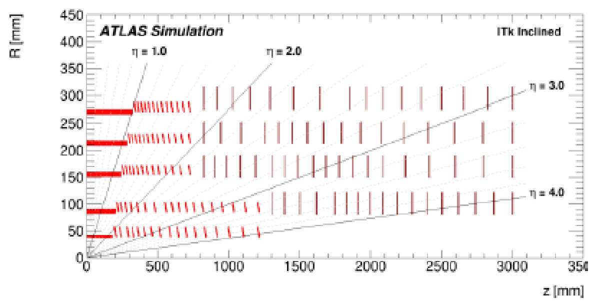
- HL-LHC environment demands
  - Increased radiation hardness
  - Higher granularity of pixel detector to reduce the occupancy and to handle the high pile-up environment
  - Reduction of material to benefit tracking and calorimeter performance
  - Extended coverage of the tracking volume up to $|\eta| < 4.0$ mainly to identify pile-up jets and mitigiate their effect

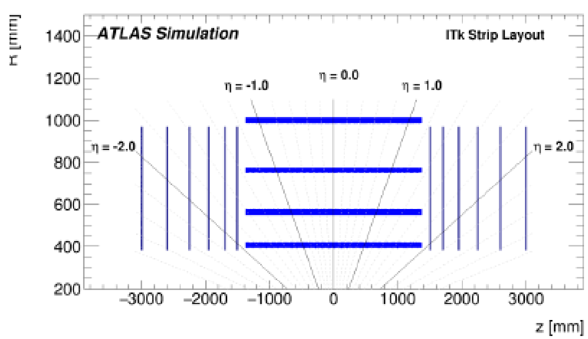


В проекте участвует группа ФИАН, в которую входят наши аспиранты

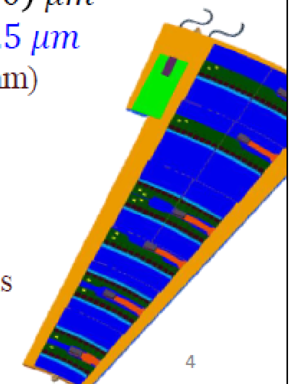
Характеристики ITk

Phase-II Inner Tracker Upgrade

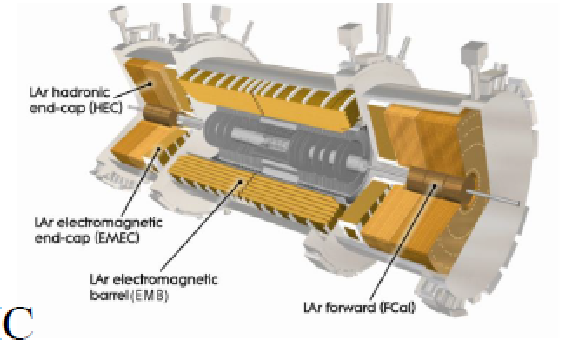




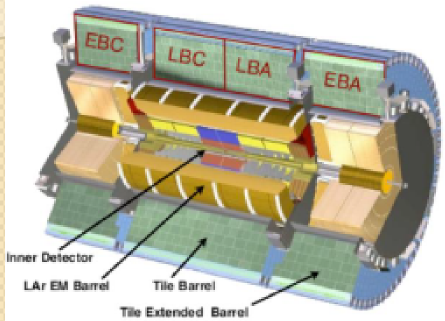
- The Pixel detector consists of five barrel layers with inclined sensors starting from $|\eta| < 1.0$
  - Reduces the material traverse by particles and improves tracking performance (and energy measurements of the calorimeter)
  - Less silicon surface than a traditional barrel needed to cover the same detector volume
- Endcap rings replacing traditional disks to improve the coverage and at cost of less silicon surface
- Two pixel pitches still under consideration $50x50$ or $25x100\ \mu m^2$ - current ID using $50x250$ (400) μm^2
- Four strip barrel layers with strip pitch of 75.5 μm
  - Inner most two layers using short strips (24 mm)
  - Outer layers using long strips (48 mm)
  - Modules at a stereo angle of 52 mrad
- Six endcap disks on each side of the barrel
  - Strips covering up to $|\eta| < 2.6$
  - Overlapping petal-shapes to make up the disks
  - Modules at a stereo angle of 40 mrad



Phase-II Liquid Argon Upgrade



- ATLAS Liquid Argon (LAr) Calorimeters
  - EM calorimeter $|\eta| < 3.2$
  - Hadronic calorimeter for $1.5 < |\eta| < 4.9$
- Calorimeters expected to operate without a problems at HL-LHC
- *For HL-LHC* a total replacement of the electronic readouts and low voltage powering is planned
- Main motivations for the upgrade
  - Required by restricted radiation tolerance of current front-ends
  - Present readout system to become incompatible with the planned Phase-II upgrade of the ATLAS trigger system
  - Necessary to avoid degradation of performance in high pile-up environment
- New readout architecture more acquiescent
  - Will allow for higher resolution information of the calorimeters to be available at the lowest level of the trigger system
- This yields enhanced capabilities to develop trigger algorithms to benefit *physics!*

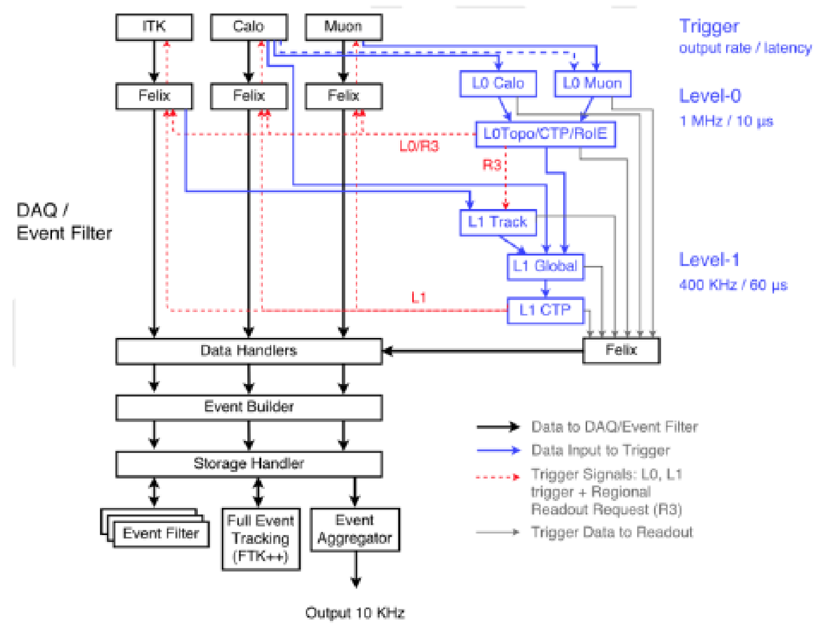


Phase-II Tile Calorimeter Upgrade

- The Tile Calorimeter (TileCal)
  - The hadronic calorimeter that captures about 30% of the jet energy
  - Total coverage for $|\eta| < 1.6$
- Calorimeters and optics expected to operate without problems at HL-LHC
- *Phase-II upgrade* to replace all front-end and back-end electronics and the power supplies
  - Outdated readout electronics and on-detector components to suffer from increased radiation dosage
    - HL-LHC dosage an order of magnitude larger than design values for the current components
- Yield significant improvements of the readouts
  - Full information from TileCal available for the trigger system at 40MHz

Phase-II Trigger and Acquisition Upgrade

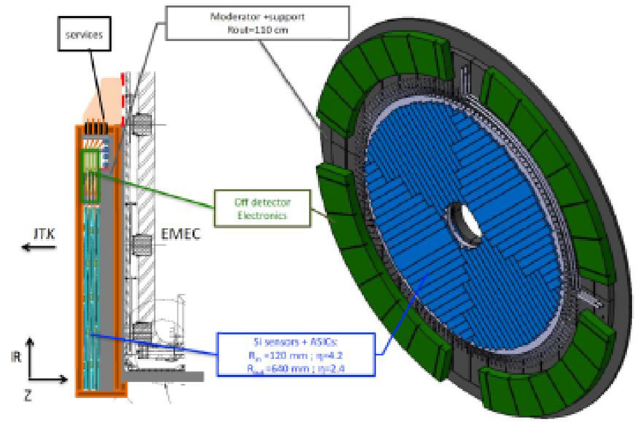
- A complete upgrade of the Trigger and Acquisition (TDAQ) is required to cope with the conditions at HL-LHC
- Phase-I:
  - Calorimeter information available at higher granularity at hardware level
  - Hardware tracking - Fast Tracker (FTK)
    - Including tracking information at trigger level-1
  - Increased coverage of the muon triggers



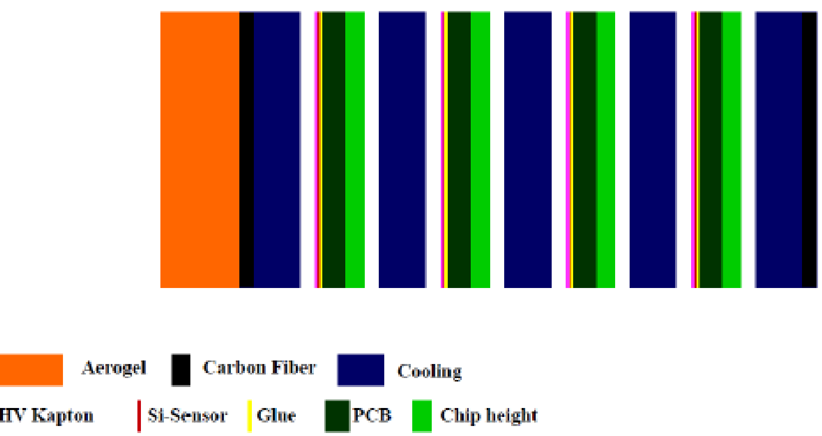
- Phase-II:
  - The readout capacity is increased from 100kHz to 1 MHz and the output data are increased from 1 kHz to 10 kHz
  - Tracking information to be made available earlier in the trigger architecture

Проект нового временного детектора

High-Granularity Timing Detector

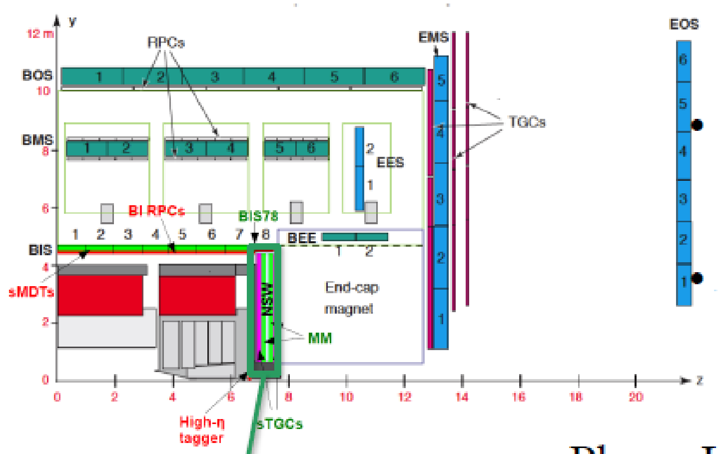


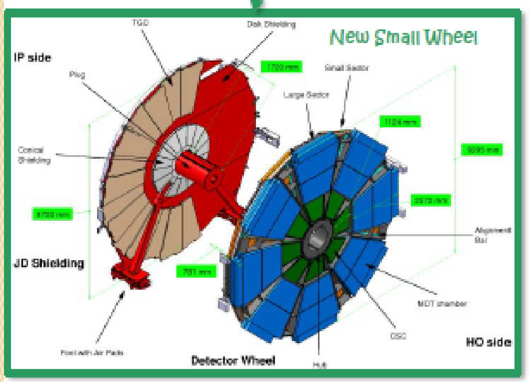
- *Under consideration:* Forward timing detector
- Located at just outside of the ITk envelop at z ~ 3500 mm and spans 120 to 640 mm in r
  - Cover the forward region $2.4 < |\eta| < 4.2$
- Consists of four silicon layers
  - $1.3 \times 1.3\ mm^2$ silicon sensors



- Expected 180 ps spread of collisions at HL-LHC
  - A time resolution of 30 ps helps assign a collision vertex to every charged particle
- Additional information to help with resolving low momentum particles from pile-up interactions
  - Especially, in the very forward region where ITk impact parameter resolution is of $\mathcal{O}(mm)$
- Improves general performance due to pile-up suppression
- Capabilities for luminosity monitoring

Phase-I/II Muon Upgrade





- Upgrades needed to the whole Muon Spectrometer (MS)
  - Motivated by the need to meet demands on the trigger and partial detector replacements to maintain performance
- Upgrades to the trigger and readout electronics
  - Partial upgrades to front-ends and power systems

- Phase-I:
  - Installation of the New Small Wheel (NSW) with Micromegas (MM) and small-strips Thin Gap Chambers (sTGC)
  - Upgrades to the inner barrel resistive plate chambers (RPC)
- Phase-II:
  - Major upgrades to the barrel to increase acceptance and robustness
    - New inner RPC stations to allow for 3 out of 4 layer coincidence
    - To make place for the RPCs, some of the old Monitored Drift Tubes (MDTs) are to be removed
  - Investigating the addition of a high-η tagger

Заключение

- Significant upgrades planned to for the ATLAS detector for phase-I and phase-II
  - Complete replacement of the Inner Detector
    - Improved tracking performance and extended coverage!
  - Upgrades to the Liquid Argon and Tile calorimeters readouts and electrons to provide more information to be available at L0 trigger
  - New barrel trigger chambers to be installed in the Muon Spectrometer to improve trigger acceptance and to maintain current efficiency for HL-LHC
- Maintaining the same excellent performance as the current ATLAS in very dense pile-up environments of up to $\mu \sim 200$ is a though challenge
  - Doing very well so far and the expected performance for physics objects is on par or better than the current detector and the future looks bright for physics!
    - Excellent tracking and vertexing performance, high capabilities of pile-up mitigation, good energy and momentum resolutions, low fake rates, excellent b-tagging, etc...

МГУ участвует в проектах модернизации ATLAS на всех стадиях!

ATLAS Collaboration

(Status January 2017)

38 Countries
182 Institutions
2900 Scientific authors total
(1000 Students)

ATLAS EXPERIMENT

Adelaide, Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, UT Austin, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, UAN Bogota, Bologna, Bonn, Boston, Brandeis, Brazil Cluster, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, CERN, China IHEP-NJU-THU, China USTC-SDU-SJTU, Chicago, Chile, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, SMU Dallas, UT Dallas, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Edinburgh, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, Göttingen, LPSC Grenoble, Technion Haifa, Harvard, Heidelberg, Hiroshima IT, Hong Kong, NTHU Hsinchu, Indiana, Innsbruck, Iowa SU, Iowa, UC Irvine, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Kyushu, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Louisiana Tech, Lund, UA Madrid, Mainz, Manchester, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, RUPHE Morocco, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, LMU Munich, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, Northern Illinois, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Olomouc, Oregon, LAL Orsay, Osaka, Oslo, Oxford, LPNHE Paris VI and VII, Pavia, Pennsylvania, NPI Petersburg, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, Irfu Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, South Africa, Stockholm, KTH Stockholm, Stony Brook, Sydney, Sussex, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Tokyo Tech, Tomsk, Toronto, Trento, TRIUMF, Tsukuba, Tufts, Udine/ICTP, Uppsala, UI Urbana, Valencia, UBCVancouver, Victoria, Warwick, Waseda, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Würzburg, Yale, Yerevan


LHC Point 1 - UX 15 Cavern - Concrete walls 6th lift - 20-02-2003 - CERN ST-CE


20-Oct-1997
SLOVENIA
Birth of LHC and ATLAS