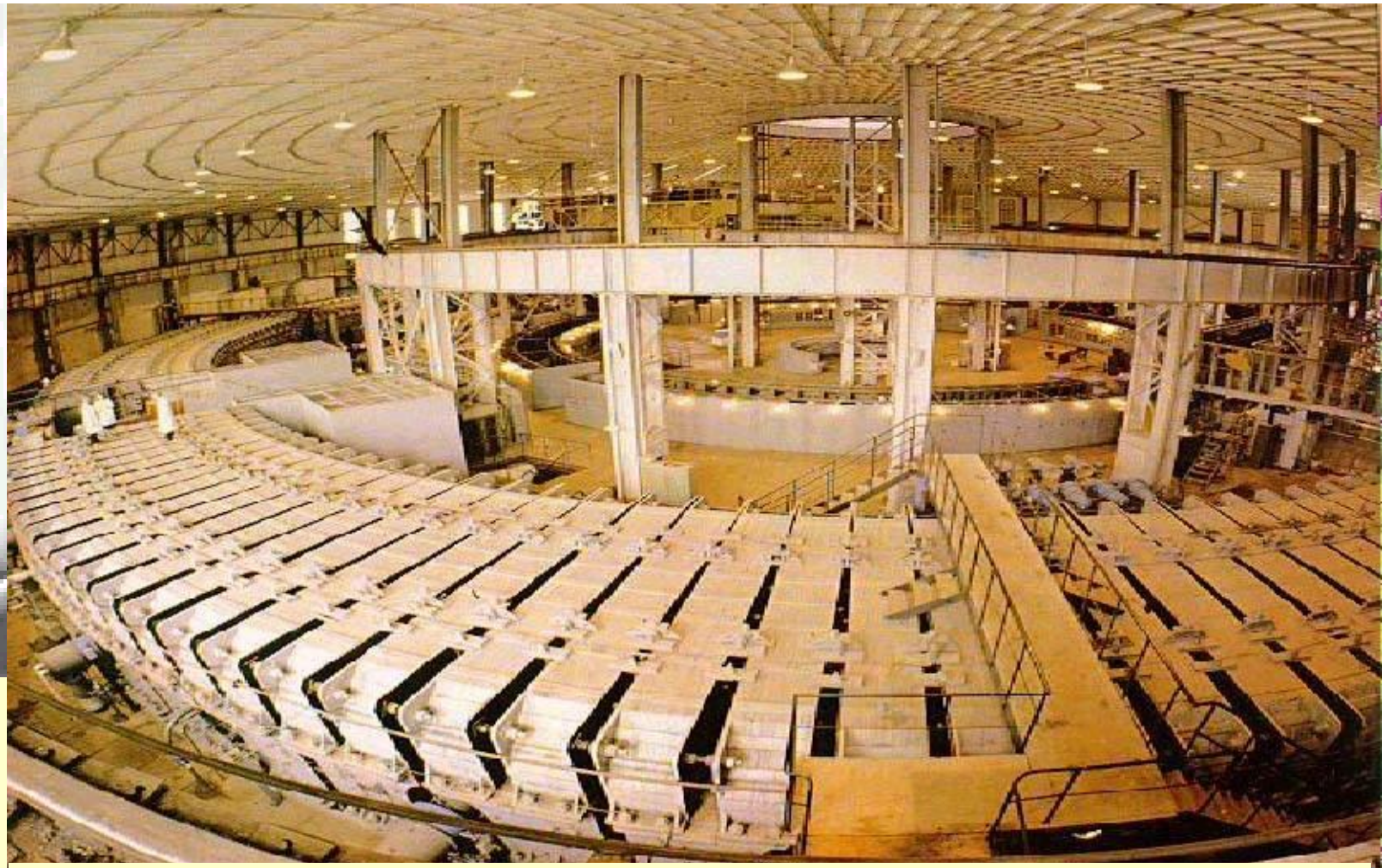
On celebration of the 85th Jubilee of Prof. I.A. Golutvin

Experiments at Synchrophasotron

V.Veksler

Director of LHE

Designer of Synchrophasotron



SPT parameters:	energy	10 GeV
	intensity	4 10^{12} ppp

Enthusiasts of Tracking Detectors

Well known wire chamber inventors:

G.Charpak - MWPC and A.Walenta - DC

But the way for gaseous tracking detection was opened due to development of the **filmless readout**

at CERN **- F.Krienen**

at JINR **- I.Golutvin –**

pioneer and enthusiast of the tracking detectors development and its on-line applications at JINR and abroad

The first in USSR HEP on-line experiment

1967 $\pi^- p$ scattering at small transfer momenta at Dubna Synchrophasotron

Goal:

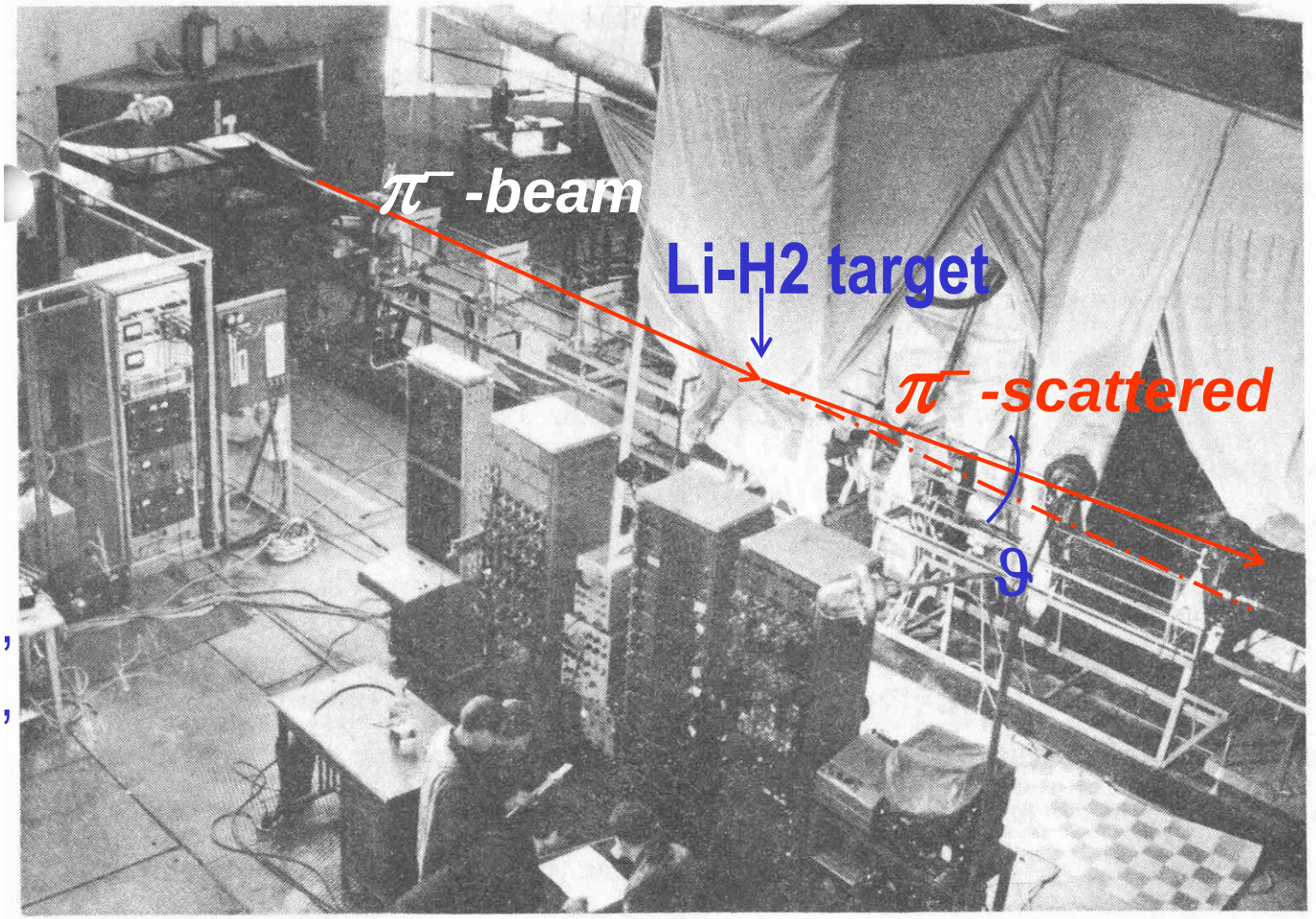
verification of forward dispersion relations

$10^{-4} \leq -t \leq 10^{-2}$ (GeV/c)^2

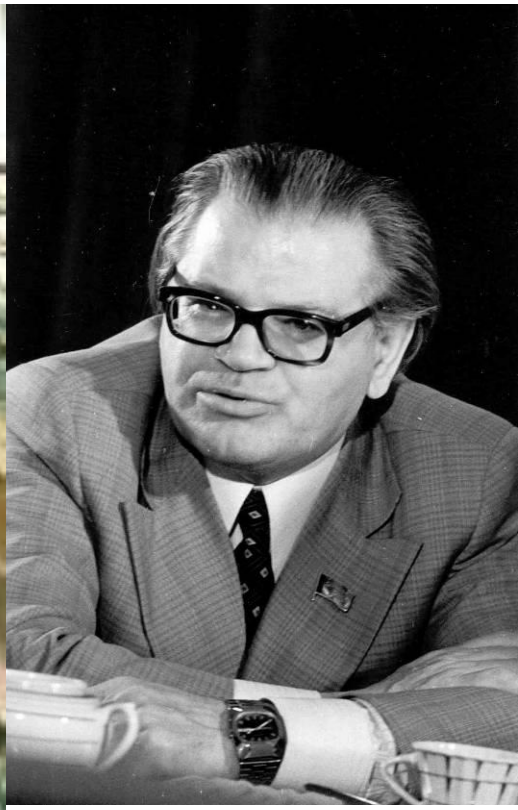
P_π = 1 - 7 GeV/c

2 mrad $\leq \vartheta \leq \pm 22$ mrad

- angular resolution < 1 mrad,
- momentum resolution ~ 1%,
- high statistics ($\Delta\sigma$~1%),
- small systematics



Experiments at U-70 in Protvino



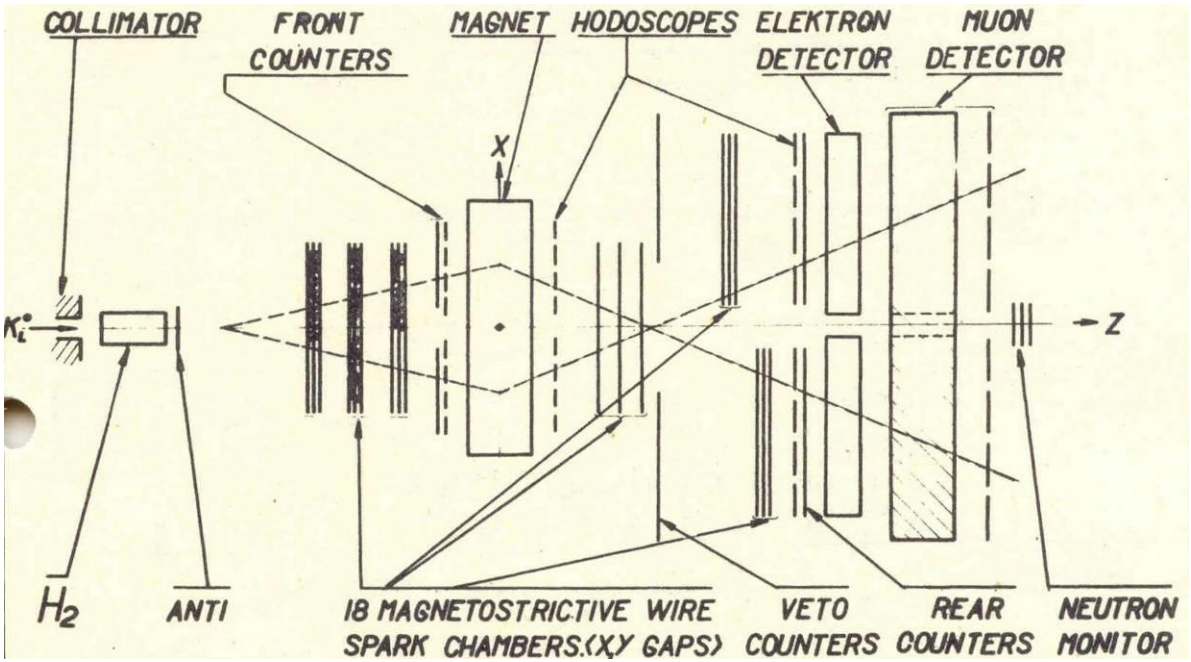
A.Logunov

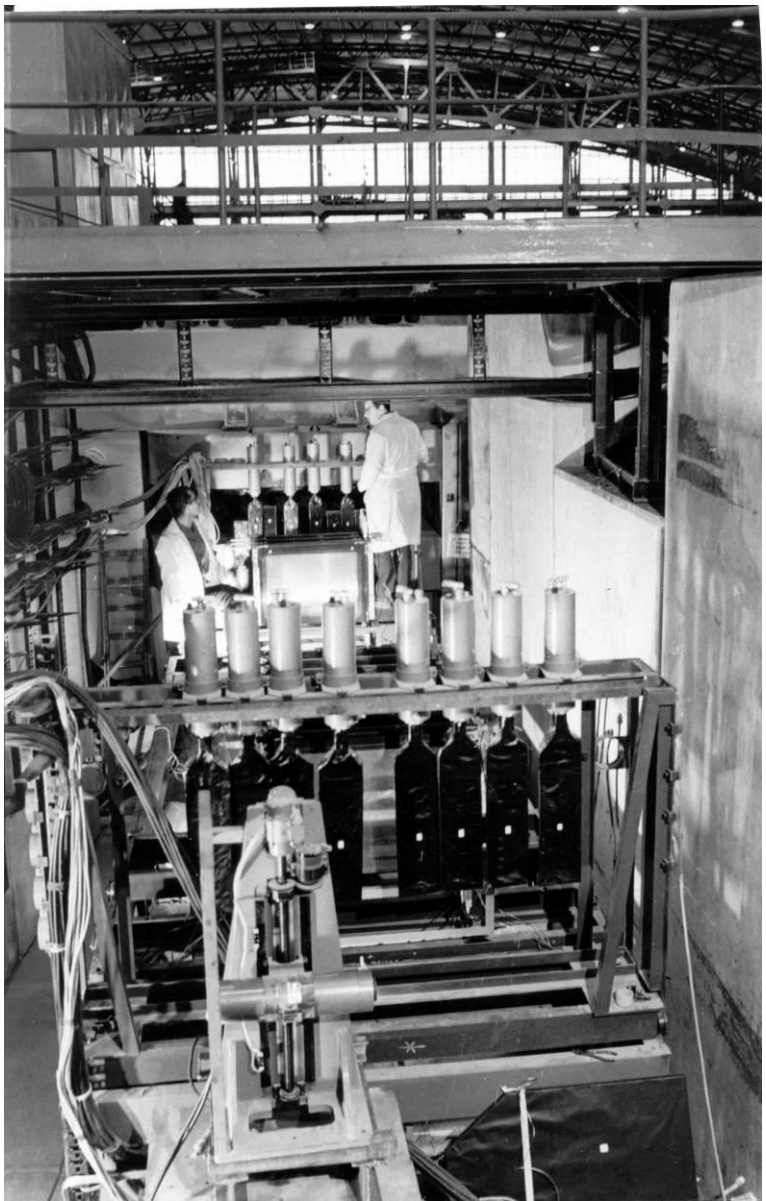
Director of IHEP

U-70 parameters: energy 76 GeV

intensity $1.7\ 10^{13}$ ppp

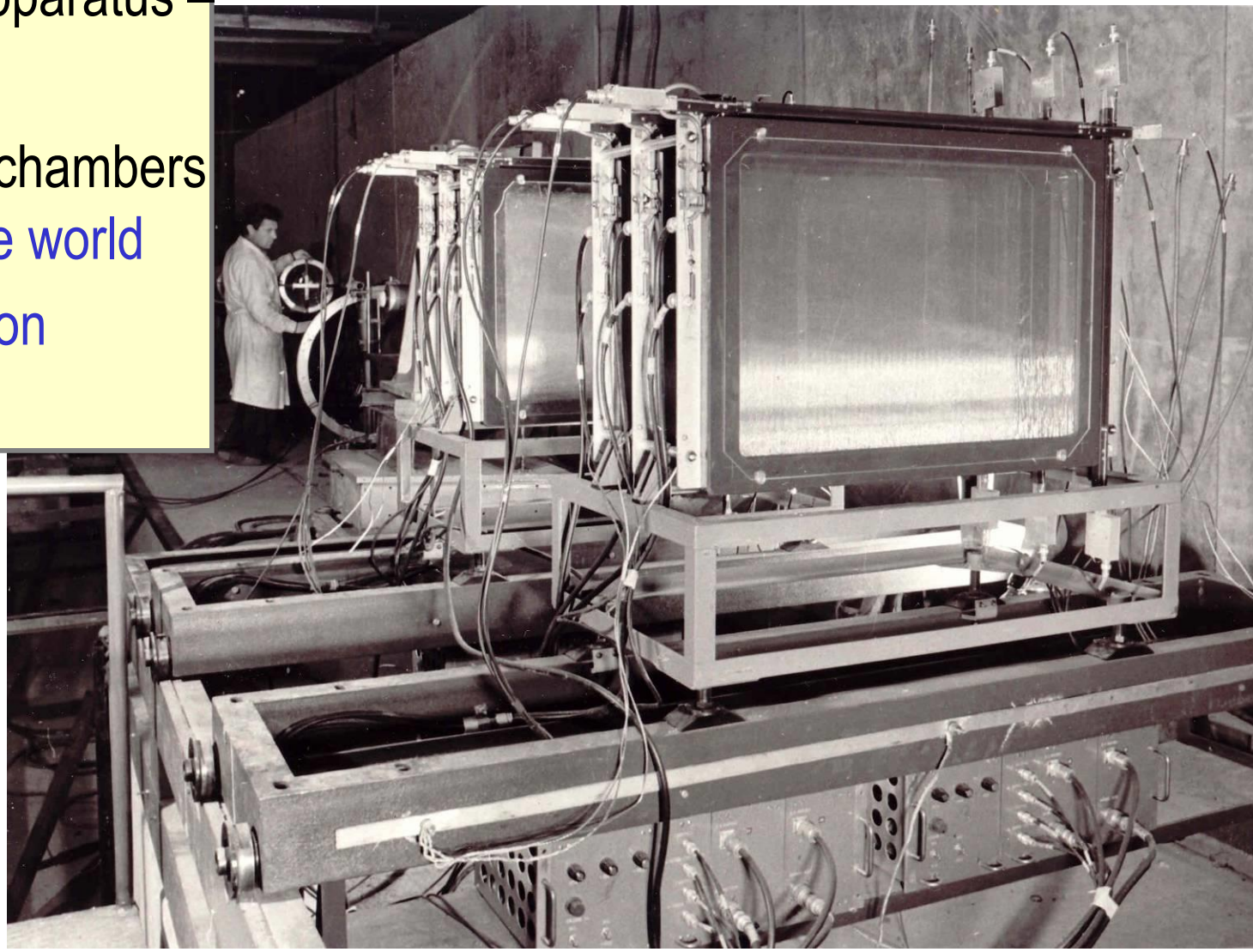
Experiment on K^0_L – K^0_S regeneration





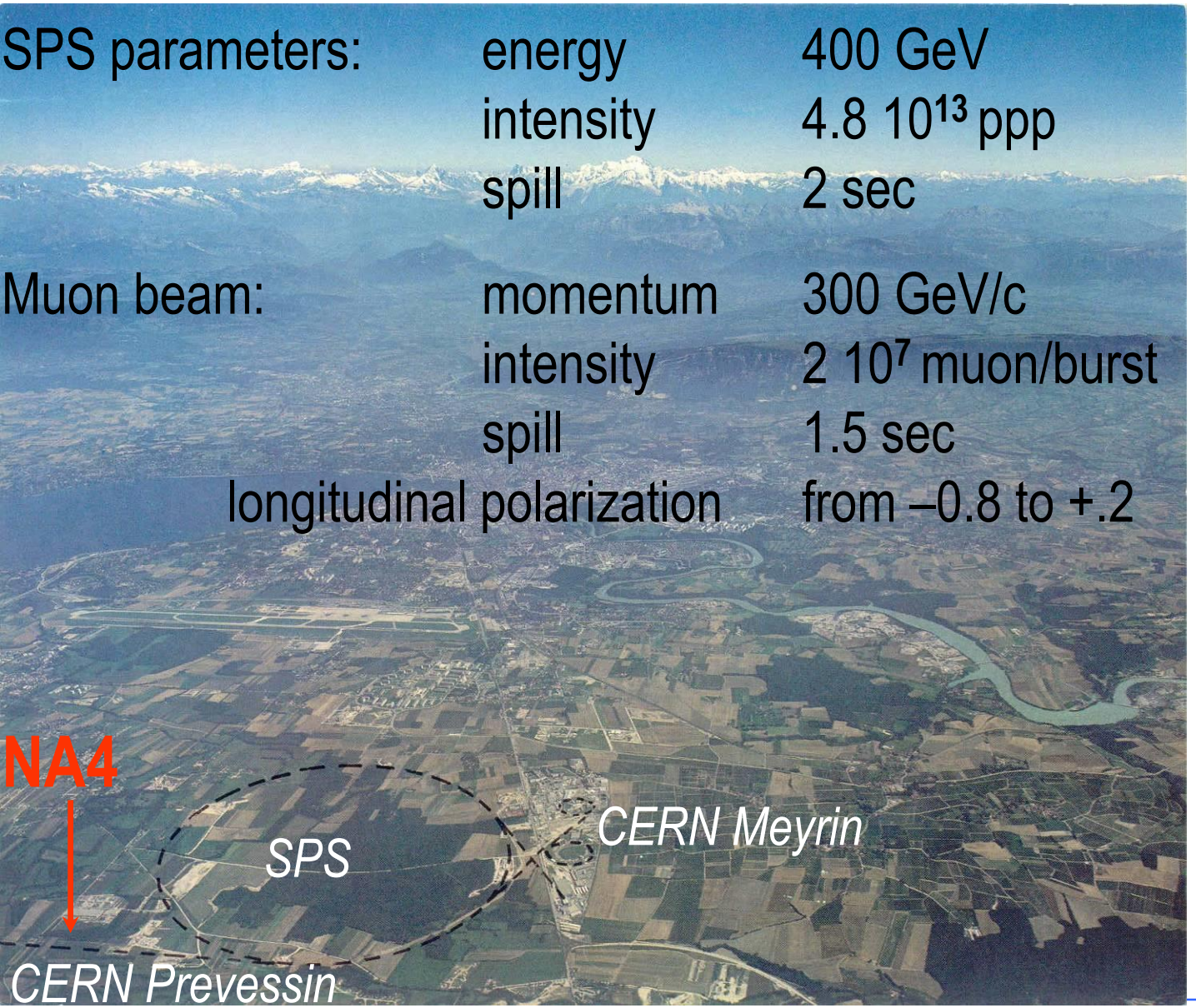
Experiment on $K^0_L - K^0_S$ regeneration

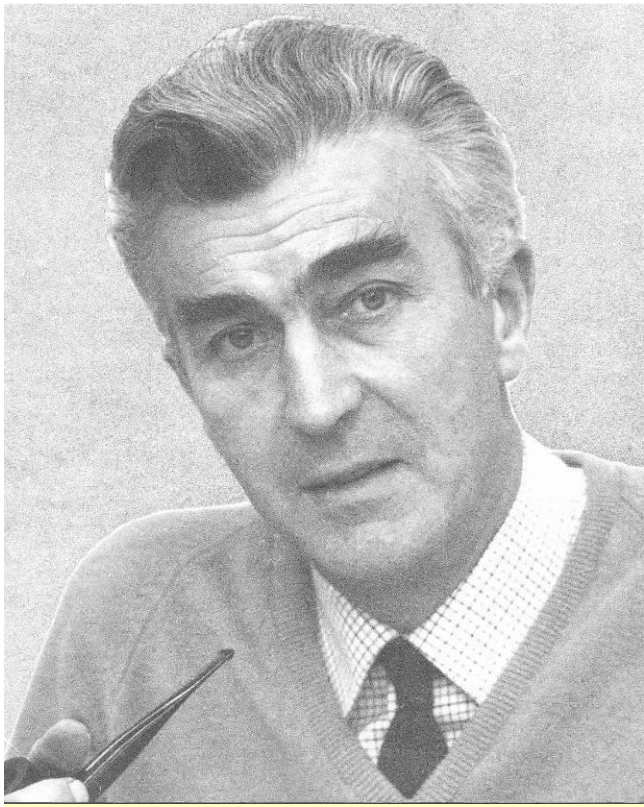
The main part of the apparatus – 18 double coordinate magnitostrictive spark chambers provided the best in the world invariant mass resolution



Co-operation with CERN at SPS

SPS parameters:	energy	400 GeV
	intensity	4.8 10^{13} ppp
	spill	2 sec
Muon beam:	momentum	300 GeV/c
	intensity	2 10^{7} muon/burst
	spill	1.5 sec
	longitudinal polarization	from –0.8 to +.2





John Adams

Director – General of CERN

Director of the SPS project – Super Proton Synchrotron

Co-operation with CERN at SPS

High Luminosity spectrometer for deep inelastic muon scattering

07 May 1975 – 16 August 1985

BCDMS
NA4 Collaboration

Bologna

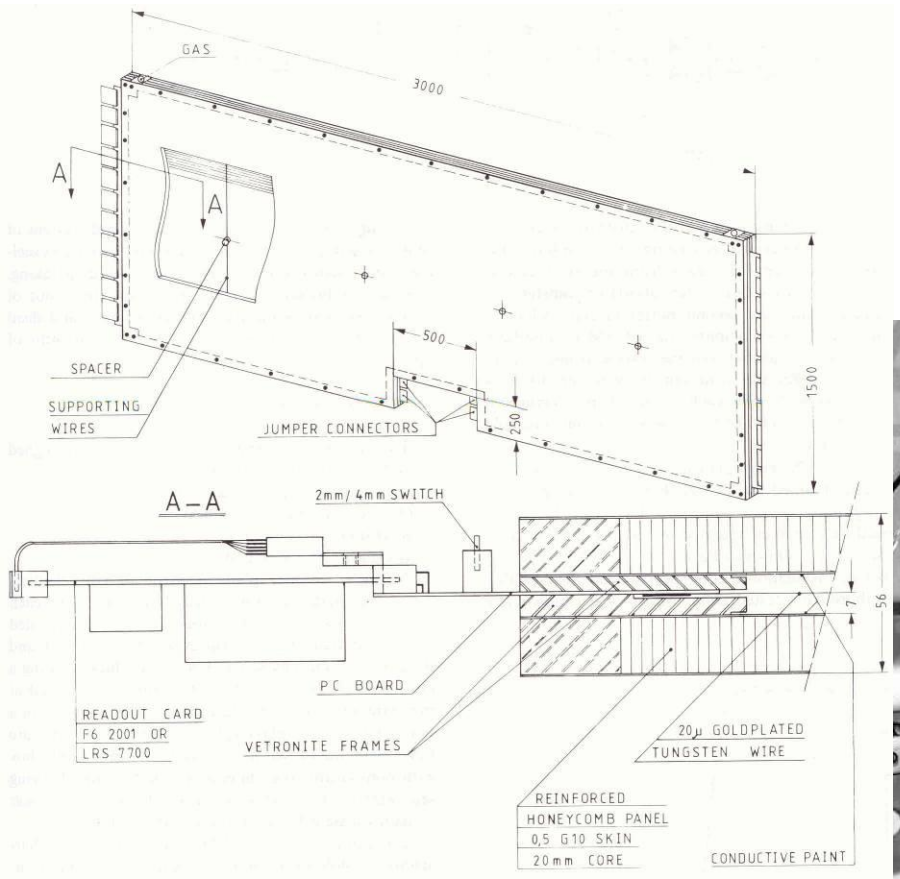
CERN

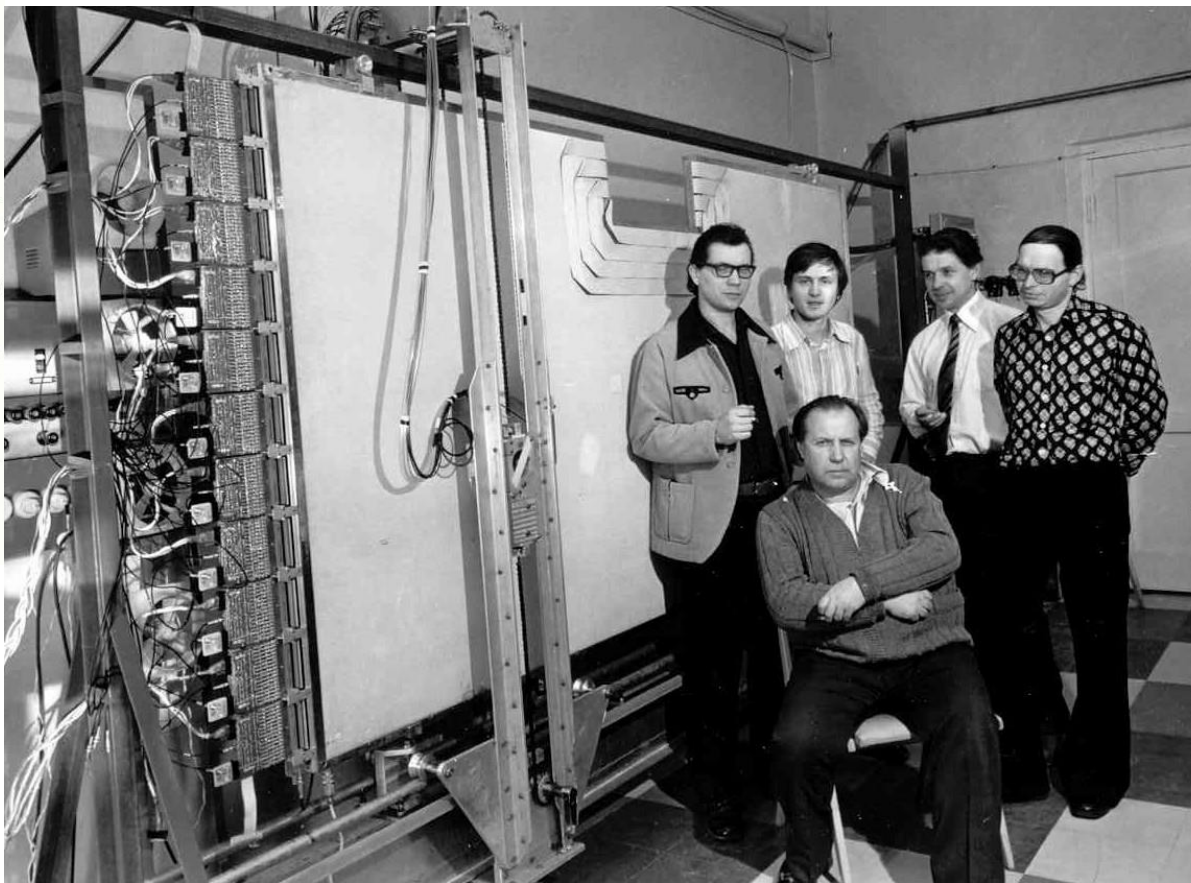
Dubna

Munich

Saclay

Co-operation with CERN at SPS

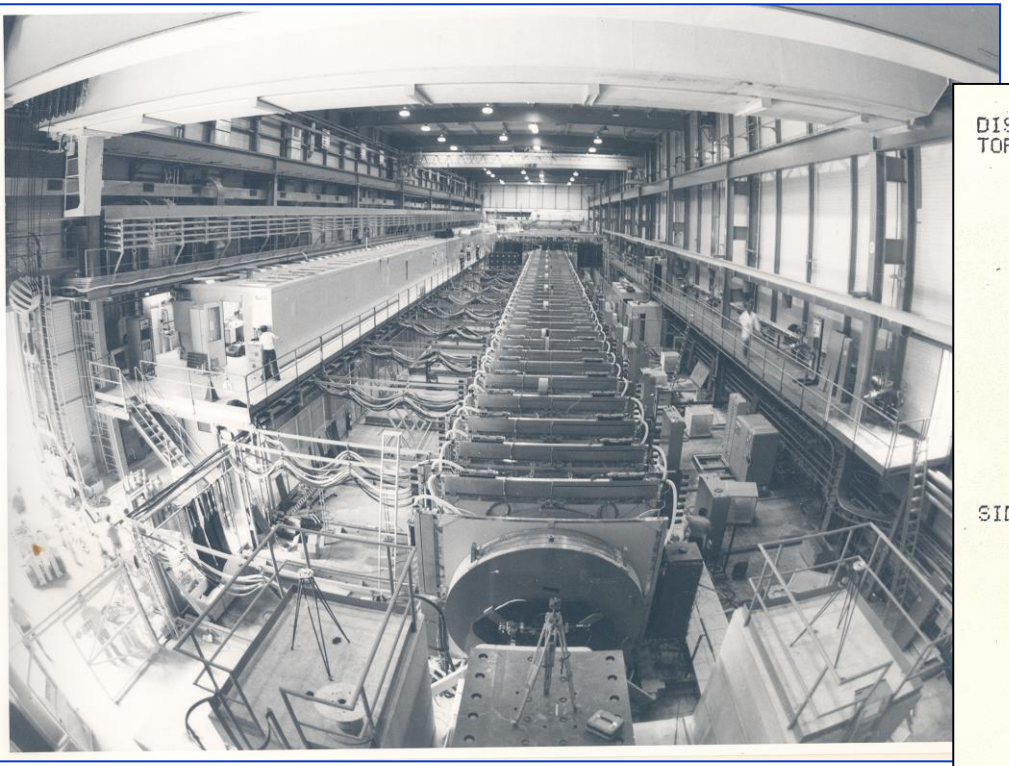




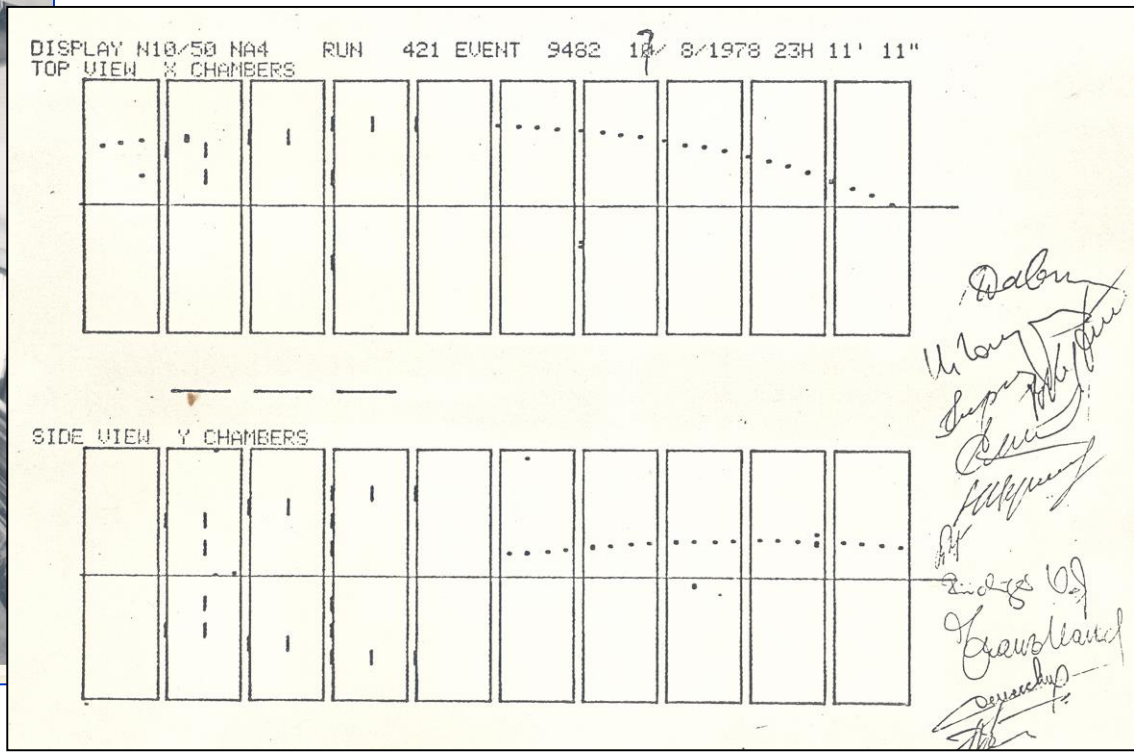
Co-operation with CERN at SPS

Installations

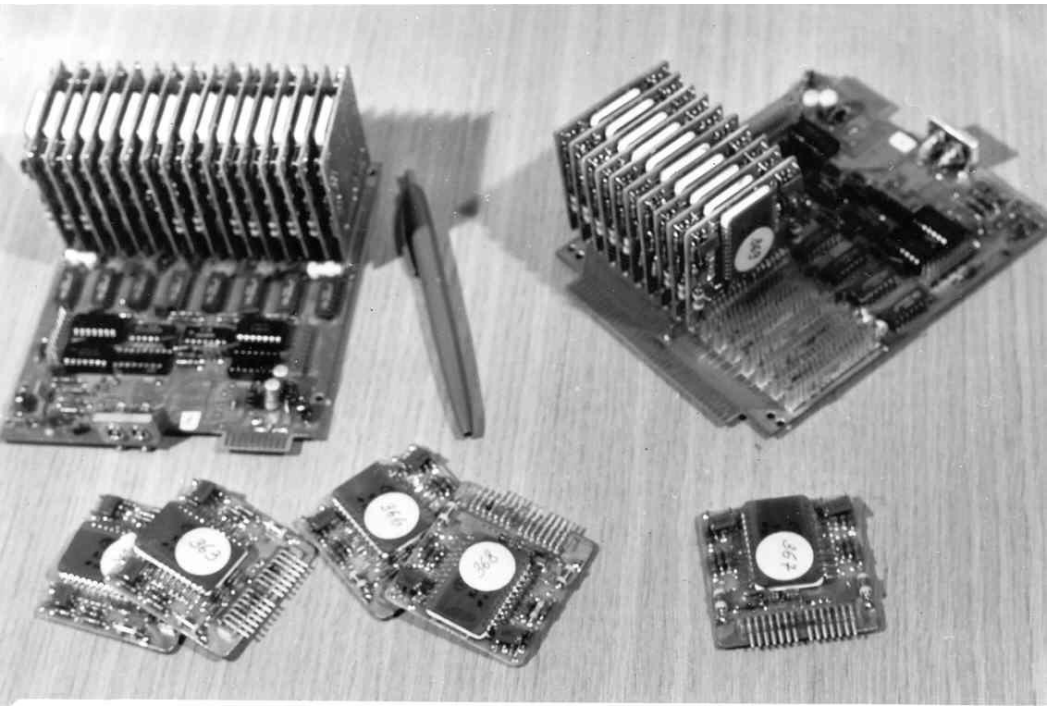
Chambers were tested before and after transportation, installed in the magnet and putted in operation in 1978



The very first muon track recorded by the spectrometer in the Dubna chambers with signatures of participants

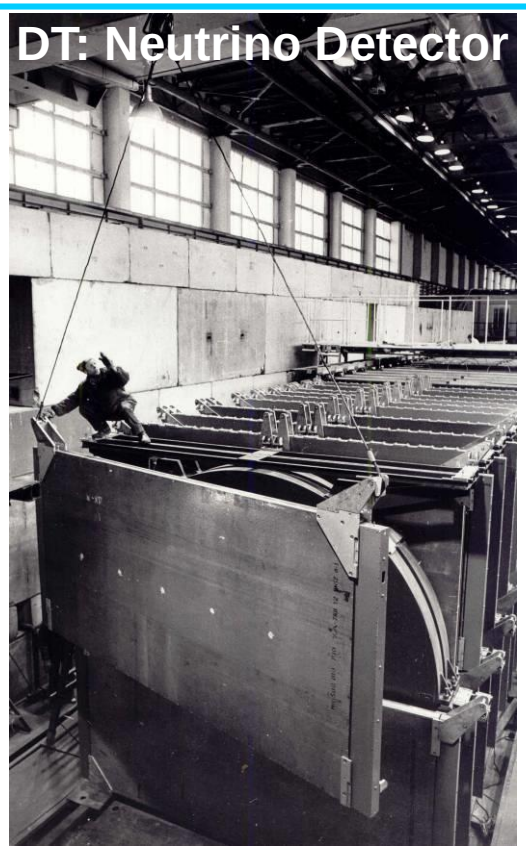


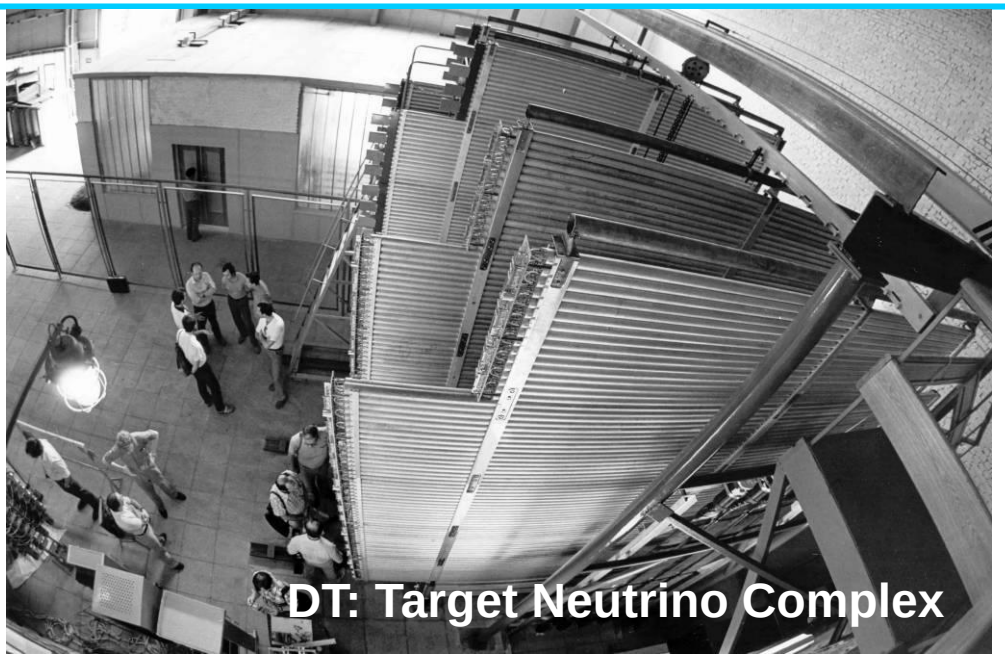
Industrial MWPC electronics RPK-32

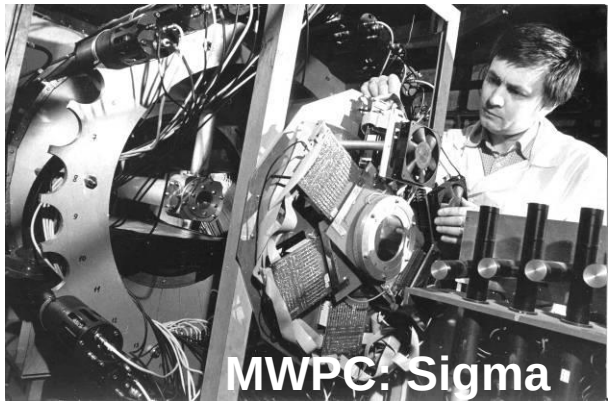


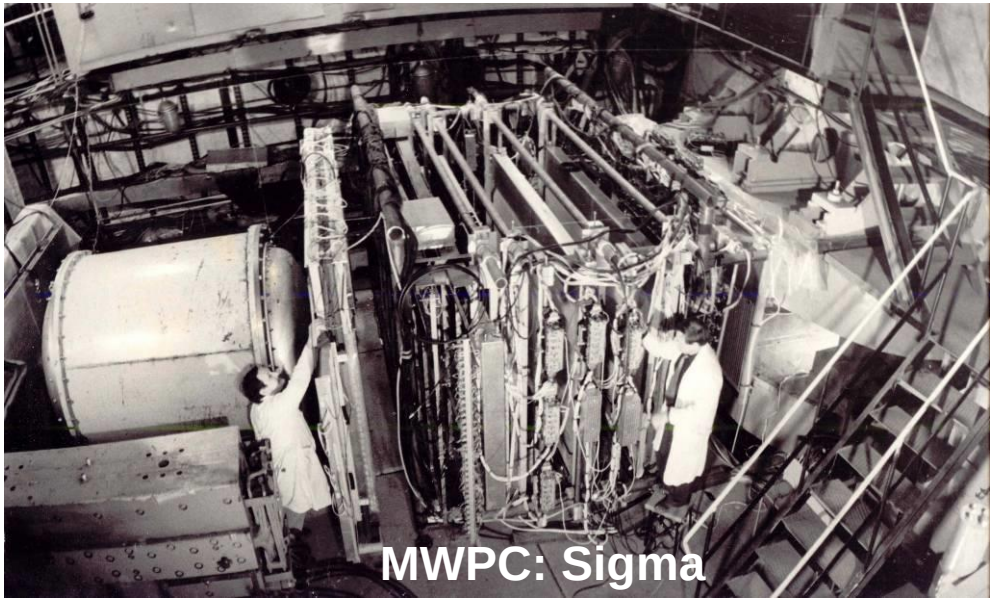
RPK-32 MWPC readout electronics were widely used
in many HEP experiments

Installations in 80-90th at IHEP

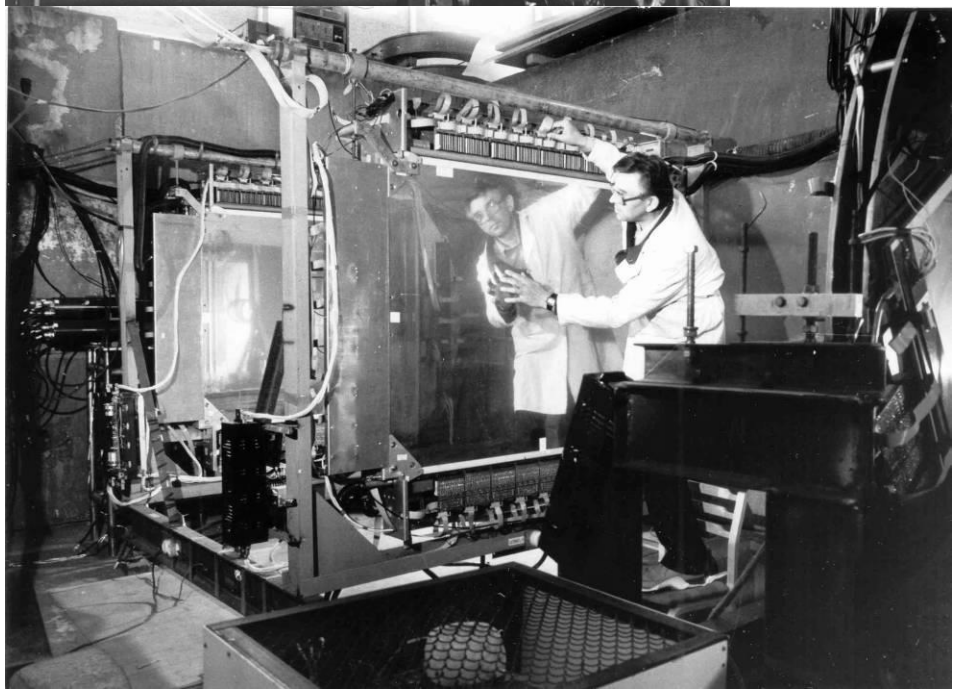


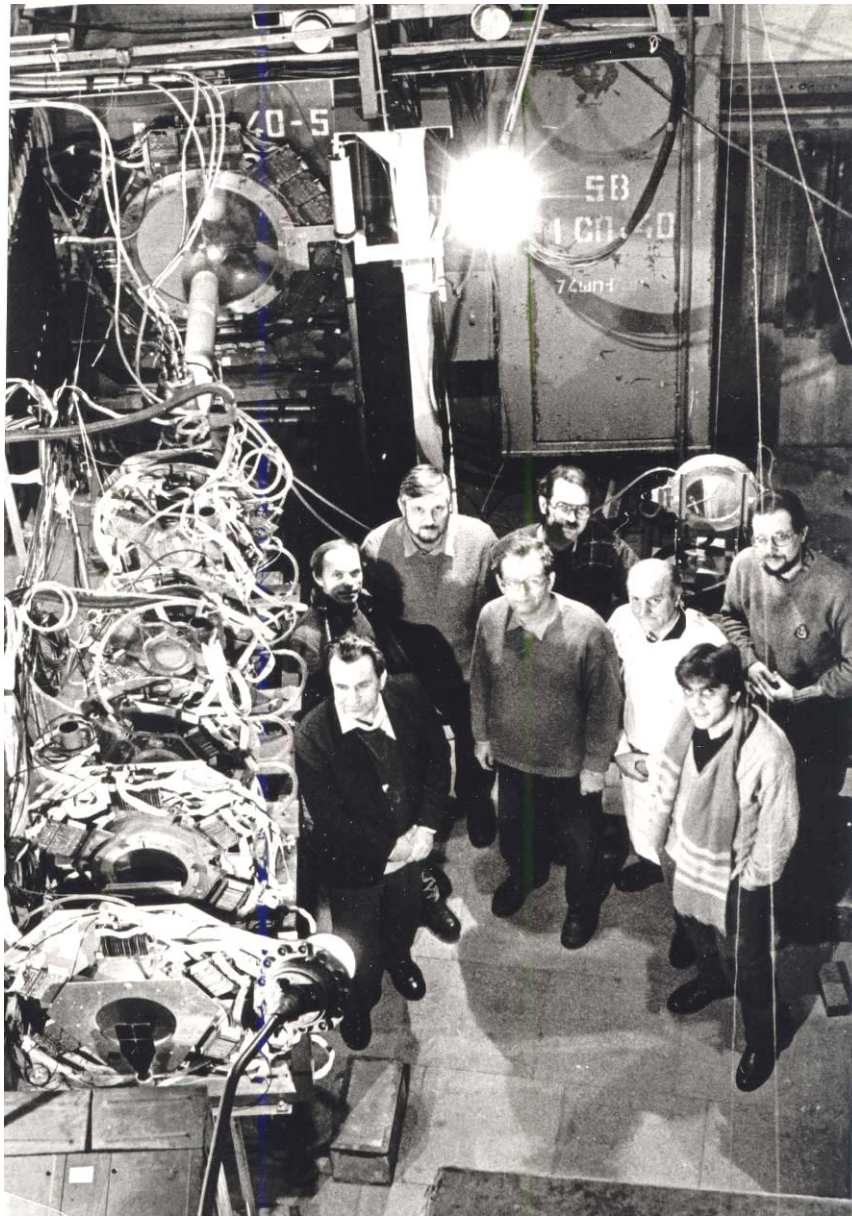




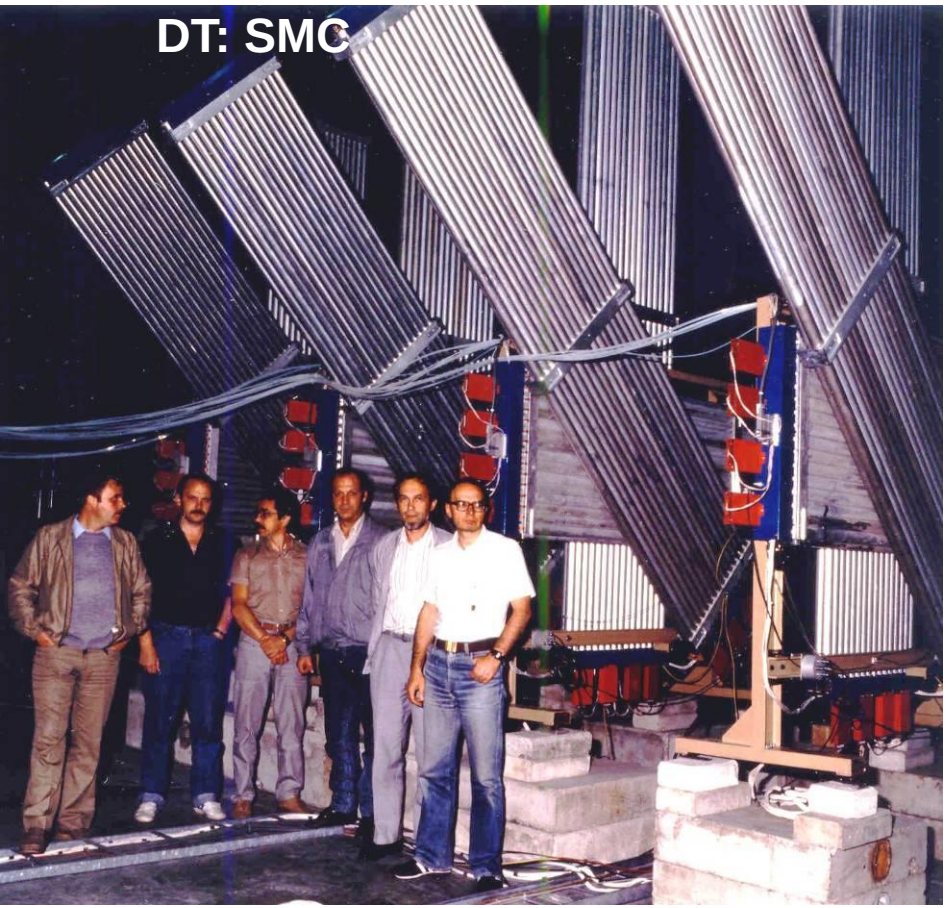


Installations in 80-90th at JINR

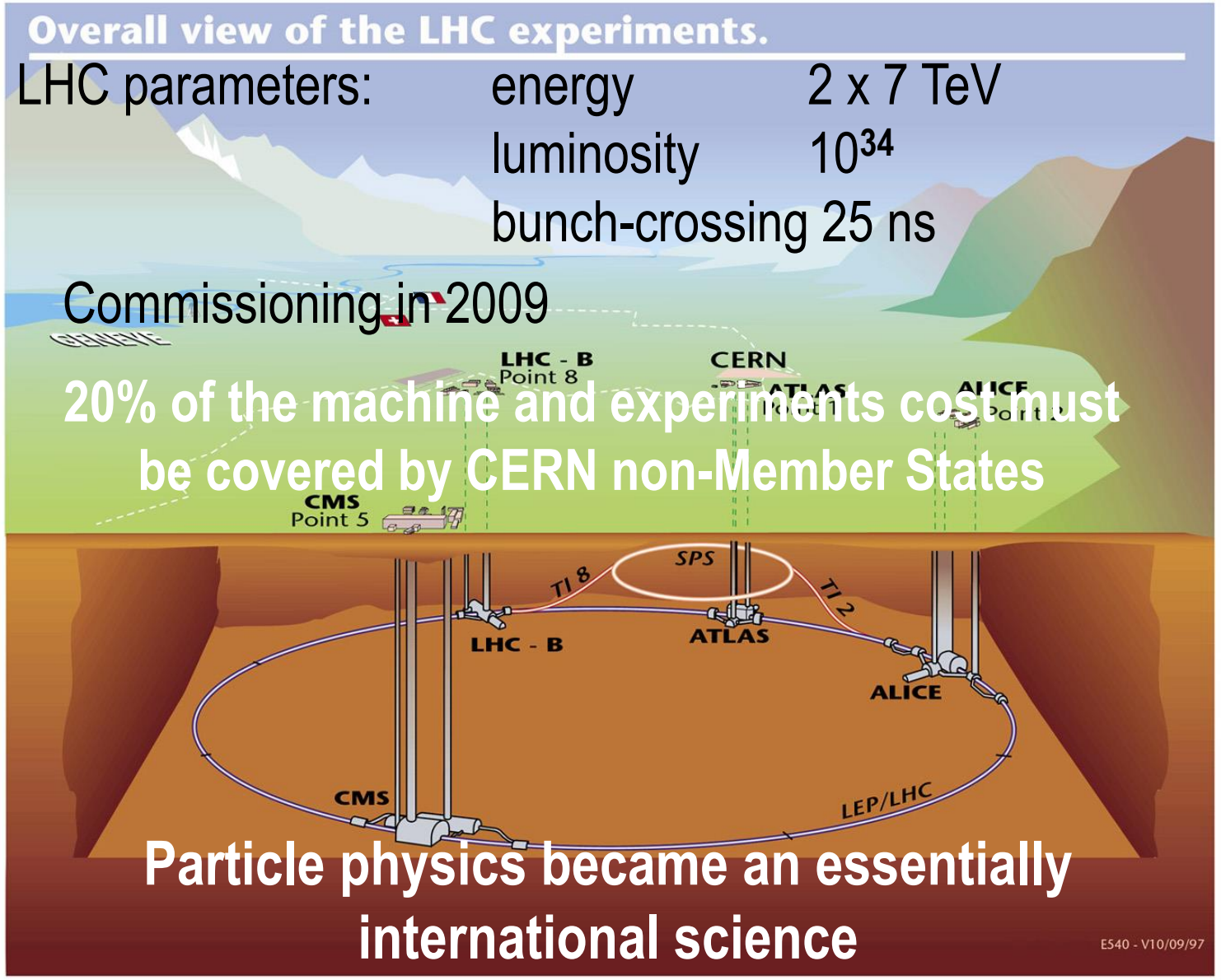




Installations in 90th at CERN and DESY



Co-operation with CERN at LHC



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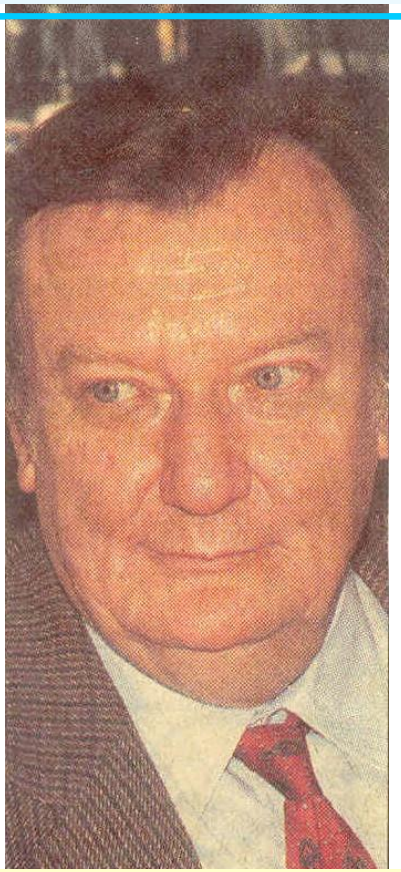


Carlo Rubbia

Director – General of CERN

Initiator of the LHC project – Large Hadron Collider

CMS Foundation, March 1992, Evian

- **5 - 8 March 1992: 650 physicists meet in Evian to discuss experiments on CERN's new accelerator project, the Large Hadron Collider (LHC)**
- **Michel Della Negra presented a concept of LHC Experiment based on super conducting solenoid with a strong magnetic field "Compact Muon Solenoid - CMS"**
- **I.Golutvin was one of the founder of the CMS experiment. CMS Expression of Interest was signed by 49 Institutions from 21 countries**

In a short time - 6 month later:

- **Letter of Intent on 1 October 1992 was signed by 62 Institutions from 25 countries**
  - powerful tracker based on Silicon and MSGC
  - precise crystal electromagnetic calorimeter
  - two options of hermetic hadron calorimeter
    - **cooper + scintillator**
    - **cooper + silicon**
  - precise muon system
  - magnetic field 3.8 T in a large volume

Letter of Intent, 1 October 1992. Physics Goal

- **Abstract of the CMS Letter of Intent, submitted to the LHC Experiments Committee (LHCC) on 1 October 1992**
- *"We propose to build a general purpose detector designed to run at the highest luminosity at the LHC. The CMS (Compact Muon Solenoid) detector has been optimized for the search of the* ***SM Higgs boson*** *over a mass range from 90 GeV to 1 TeV, but it also allows detection of a wide range of possible* ***signatures from alternative electro-weak symmetry breaking mechanisms.*** *"*

CMS was designed as an experiment for discovery!

And required an excellent Collaboration

RDMS CMS Foundation, 1994, by I.Golutvin

- **JINR member-states participate in CMS Project in frame of Russia and Dubna Member States – RDMS CMS Collaboration**
- **Formally RDMS was established in Dubna on 27 September 1994**
- **In fact RDMS physicists have participated in CMS since 1992 before formal decision were made**
- **In RDMS there are about 300 scientists and 32 Students, from 7 States and 23 Institutions**

- **Main principles of the RDMS Collaboration:**
  - participation of Institutions in the CMS experiment as independent scientific groups;
  - unification of technical and financial contributions and obligations of different Institutions as the joint Collaboration deliverables to experiment
- **Main aims of the Collaboration strategy:**
  - unification of the efforts of many groups from different institutions and countries;
  - concentration of efforts at several well defined CMS sub-systems (for example Endcap)
  - and broad involvement of Industry of participating States

In RDMS Collaboration are about 300 scientists

Russia

Russian Federation

- Institute for High Energy Physics, Protvino
- Institute for Theoretical and Experimental Physics, Moscow
- Institute for Nuclear Research, RAS, Moscow
- Moscow State University, Institute for Nuclear Physics, Moscow
- Petersburg Nuclear Physics Institute, RAS, St.Petersburg
- P.N.Lebedev Physical Institute, Moscow

Associated members:

- High Temperature Technology Center of Research & Development Institute of Power Engineering, Moscow
- Myasishchev Design Bureau, Zhukovsky
- Electron, National Research Institute, St. Petersburg

JINR

- Joint Institute for Nuclear Research, Dubna

Dubna Member States

Armenia

- Yerevan Physics Institute, Yerevan

Belarus

- Byelorussian State University, Minsk
- Research Institute for Nuclear Problems, Minsk
- National Centre for Particle and High Energy Physics, Minsk
- Research Institute for Applied Physical Problems, Minsk

Bulgaria

- Institute for Nuclear Research and Nuclear Energy, BAS, Sofia
- University of Sofia, Sofia

Georgia

- High Energy Physics Institute, Tbilisi State University, Tbilisi
- Institute of Physics, Academy of Science ,Tbilisi

Ukraine

- Institute of Scintillation Materials of National Academy of Science, Kharkov
- National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov
- Kharkov State University, Kharkov

Uzbekistan

- Institute for Nuclear Physics, UAS, Tashkent

JINR, Dubna - 68

Since last years also 5 universities jointed:

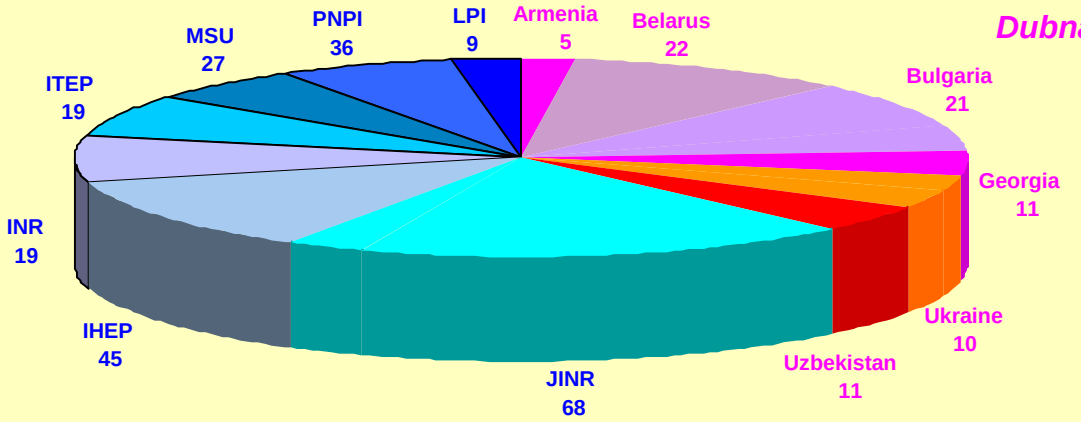
MEPhI, Moscow

MPTI, Dolgoprudny

NSU, Novosibirsk

TPU and TSU, Tomsk

Russian Federation - 155



Dubna Member States - 80

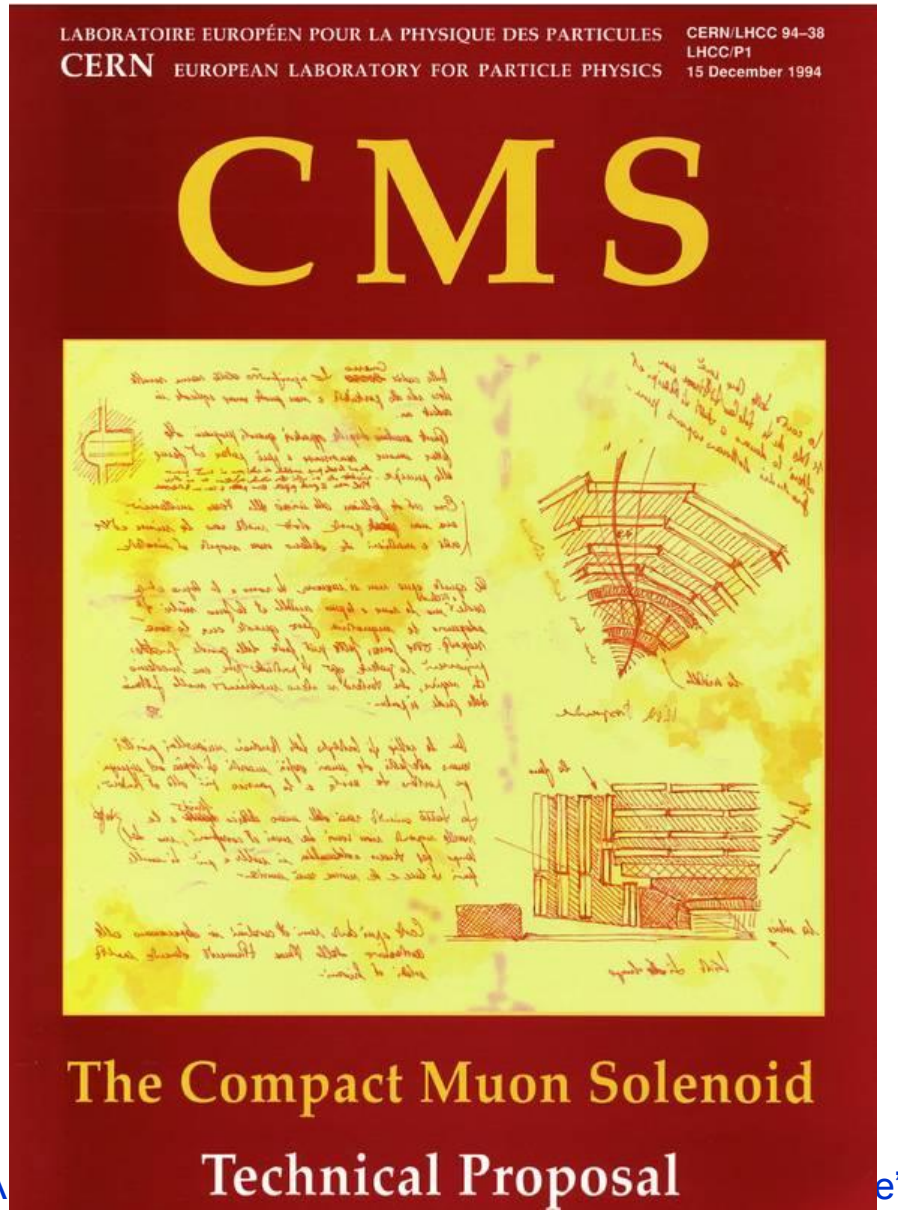
CMS members:

countries	7
institutions	20
scientists	303
students	32

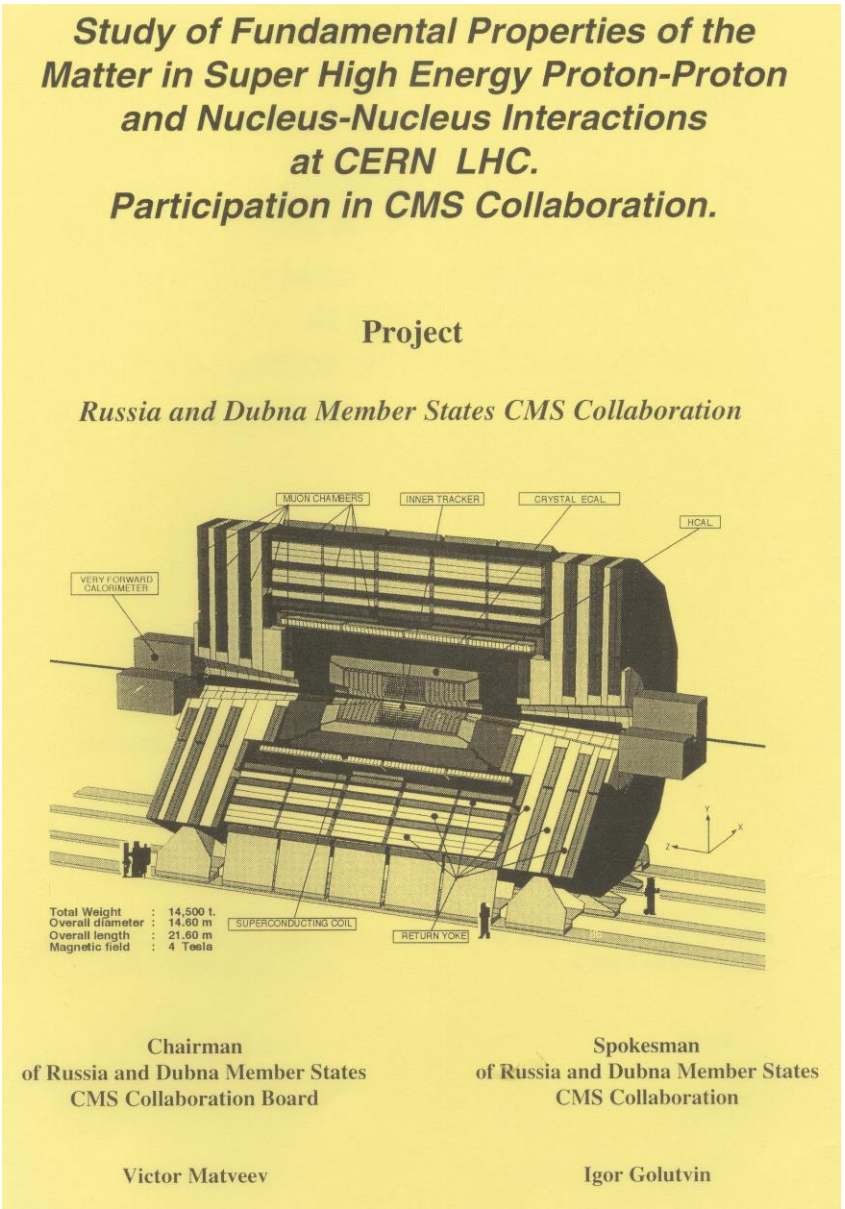
Associated members:

institutions	3

CMS TP December 1994



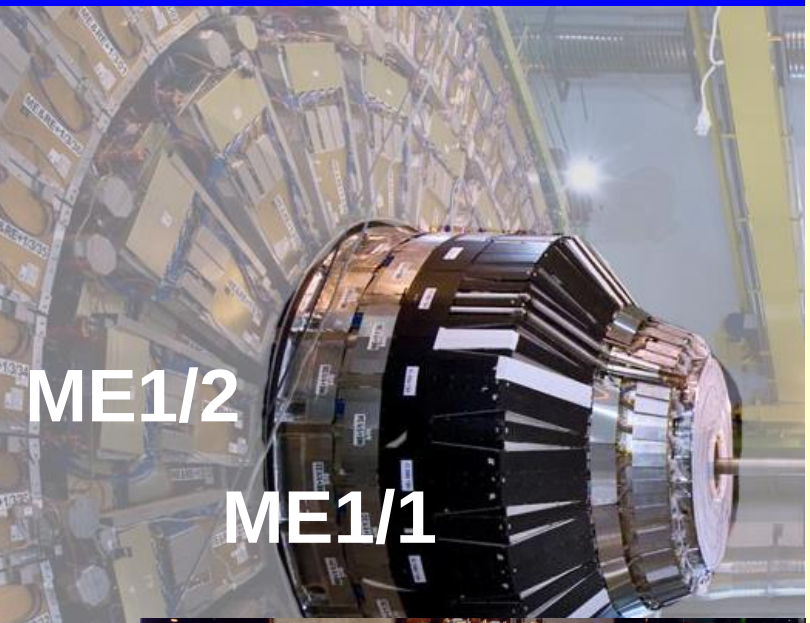
RDMS Project September 1995



Wide application of CSC in HEP

$H \rightarrow \nu\nu$

I.Golutvin invented, proposed and developed a wide application of new detectors in order to construct a frontier CMS



Cathode Strip Chambers, CSC

Cathode Strip Chambers were proposed for CMS Endcap Muon System. The first prototype in 1993 demonstrate precision of 53 mkm

I. Golutvin et al
Dubna 0.5x0.5 m2 RD5 CSC prototype, 1993:
Milestones Report, CMS Collaboration,
CERN/LHCC 93-48, p.70, 1993

The innermost ME1/1 stations of Endcap muon system located in 4Tesla solenoid developed by JINR in cooperation with Minsk, with I.Golutvin as Project Leader. Other endcap station were build by US institutes in cooperation with Gatchina

310 CSCs, 340,000 channels in CMS

1979 First Cathode Strip Chamber

1979:

- The very first Cathode Strip Chamber was designed at JINR for NA4 R&D in 1979 to improve vertex:

Chamber size	- 3x1.5 m
Strip length	- 1.5 m
Strip width	- 20 mm
Gap	- 7 mm
Wires	- 20 mkm

Cathode resolution ~ 2 mm

- Next studies of set of small prototypes demonstrate cathode resolution of 50 mkm

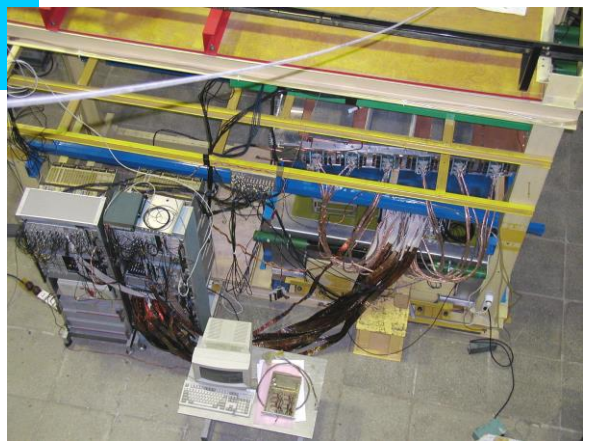
Cathode Strip Chambers Mass-production



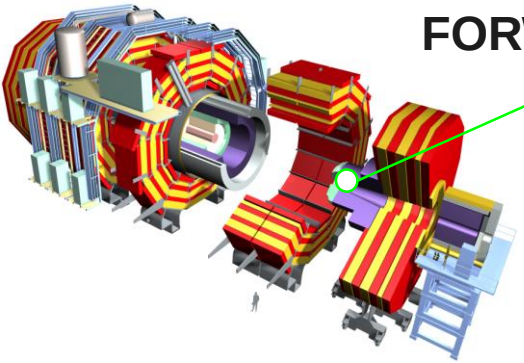

JINR (Dubna), Belarusian and Bulgarian institutions bear **full responsibility for design and construction of the First Forward ME1/1** Muon station based on technology of cathode strip chambers. 76 chambers with precise spatial and excellent timing resolution manufactured in Dubna and delivered to CERN



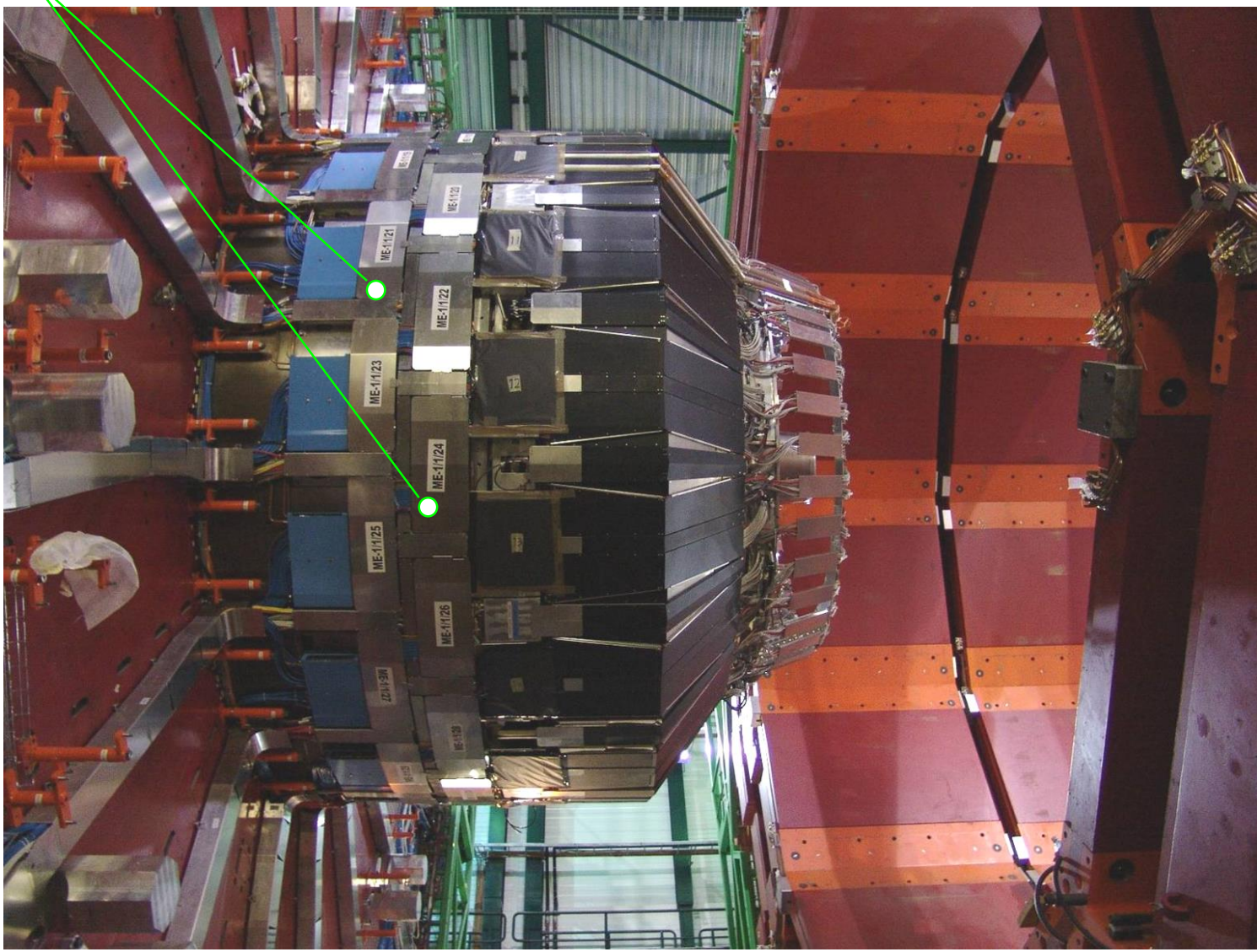


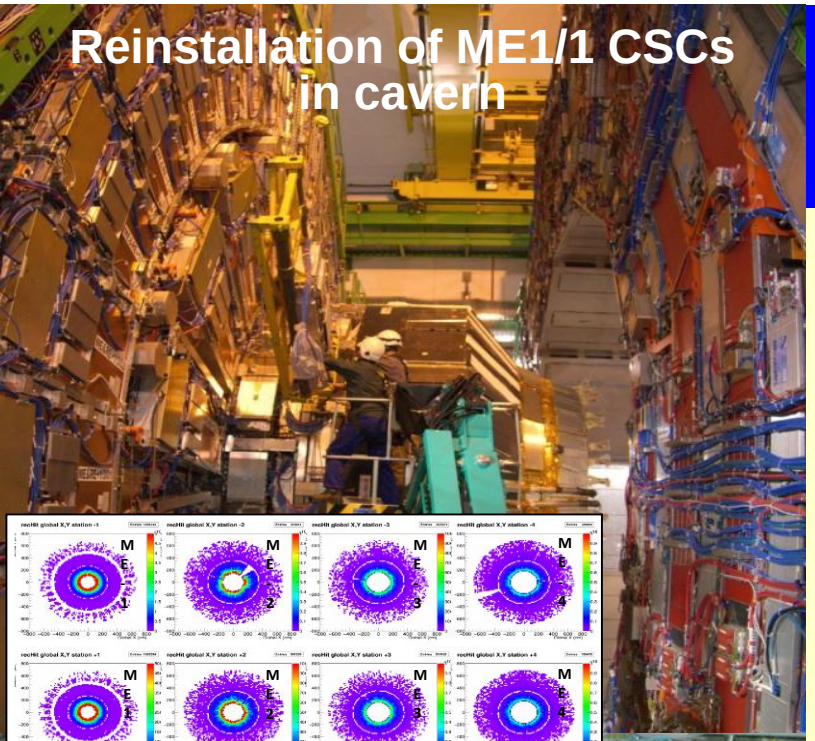
ME1/1 Cathode Strip Chambers

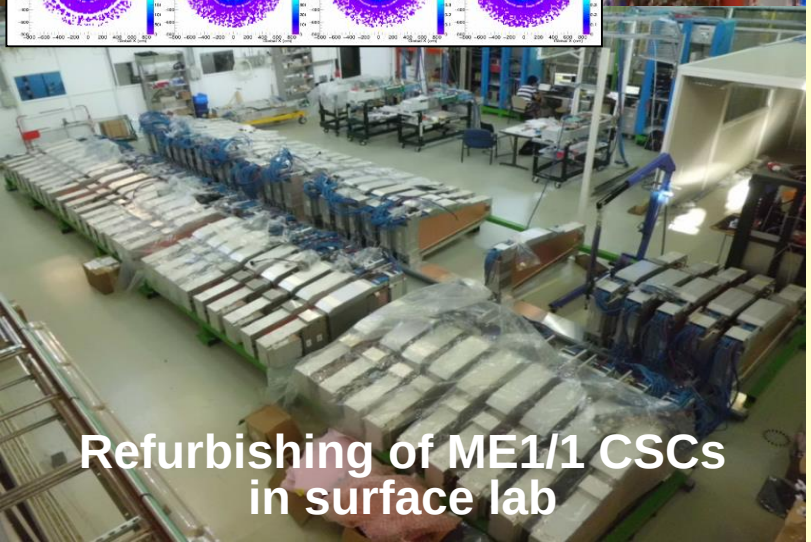


FORWARD MUON ME-1/1 STATION



Muon system Upgrade CMS@LHC





RDMS Scientists participate in Phase1 CMS Upgrade

in 2015 the Upgrade of the innermost ME1/1 and outer ME4/2 stations of Endcap muon system was successfully completed.

During several years all 72 chambers were removed from CMS Detector, equipped with new fast electronics developed in cooperation with Minsk and US groups, and reinstalled to CMS.

72 new chambers were build by Gatchina experts for Muon Station ME4/2 and equipped with "old" electronics from ME1/1

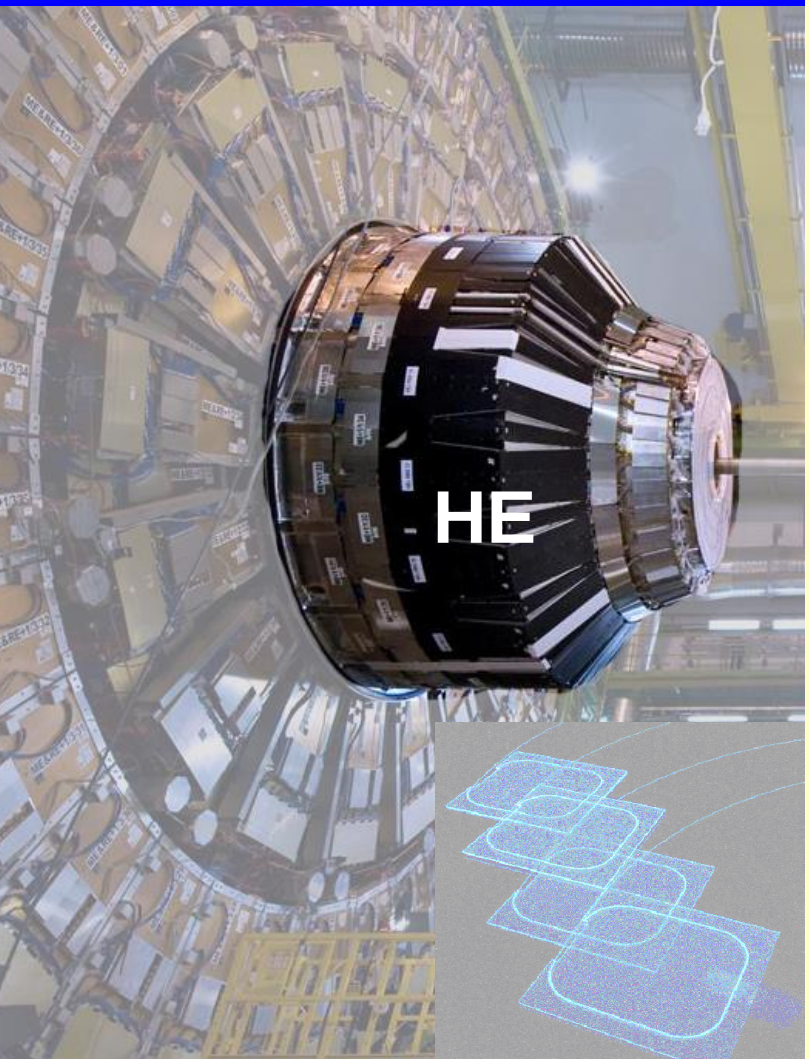
As a result Muon system performance is improved:

- acceptance of Muon System increased up pseudorapidity 2.4
- spatial resolution reach 50-60 mkm per station
- high rate capability is achieved

Upgraded ME Stations demonstrate high operation and trigger efficiency and muon identification in Run 2 at 13 TeV

Wide application of Sigma Tiles in HEP

RDMS Scientists invented and developed a wide application of new detectors in order to construct a frontier CMS



Hadron Calorimetry

Based on plastic scintillators with embedded WLS fibers, so called sigma tiles, proposed for Hadron calorimetry in 1986 in IHEP, Protvino

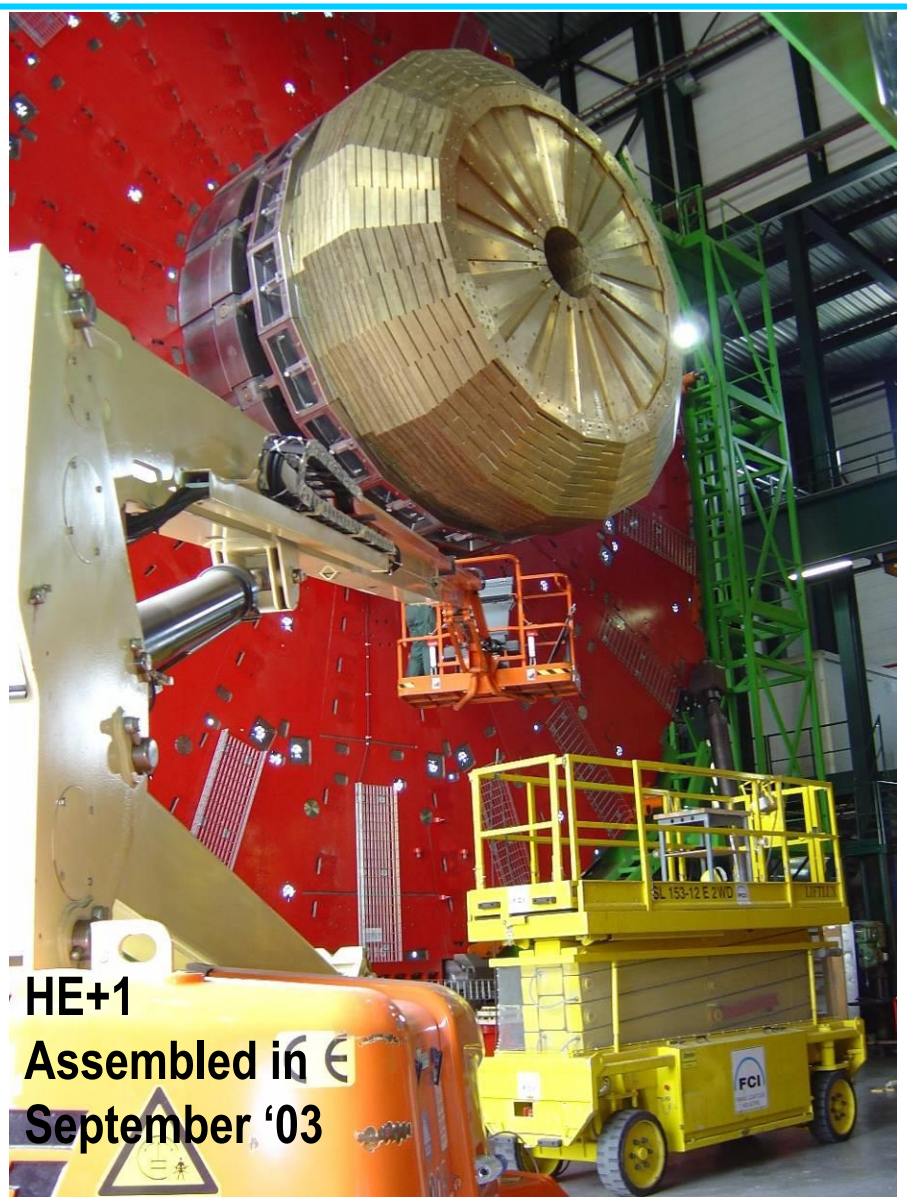
V. I. Kryshkin and A. I. Ronzhin,
Nucl. Instr. Meth. A 247 (1986) 583

Endcap calorimeters developed by RDMS under leadership of I.Golutvin as Project Manager in cooperation with Rosatom enterprises and MZOR, Minsk

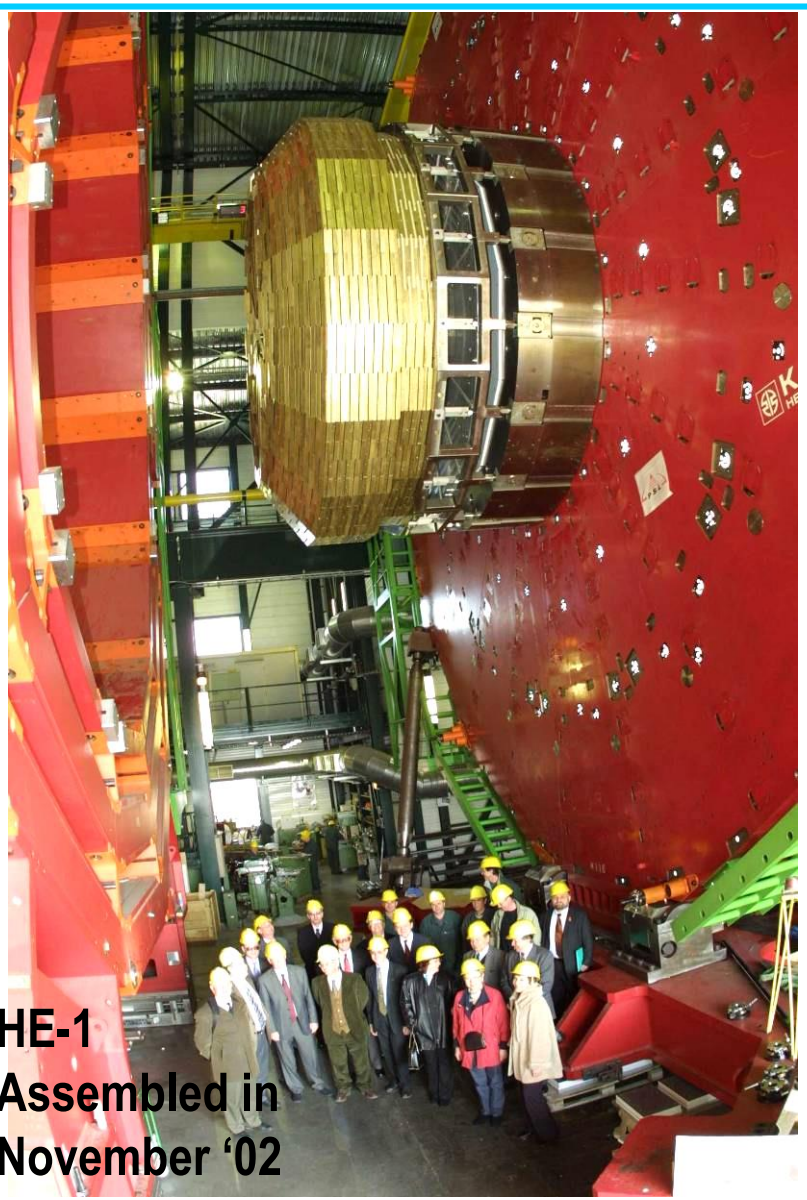
600 tons of brass absorber were made of military shells

8,000 channels in CMS

HE , Hadronic Endcap, 300 tons



HE+1
Assembled in
September '03



HE-1
Assembled in
November '02

Wide application of SiPM. Calorimetry Upgrade

$H \rightarrow \nu\nu$

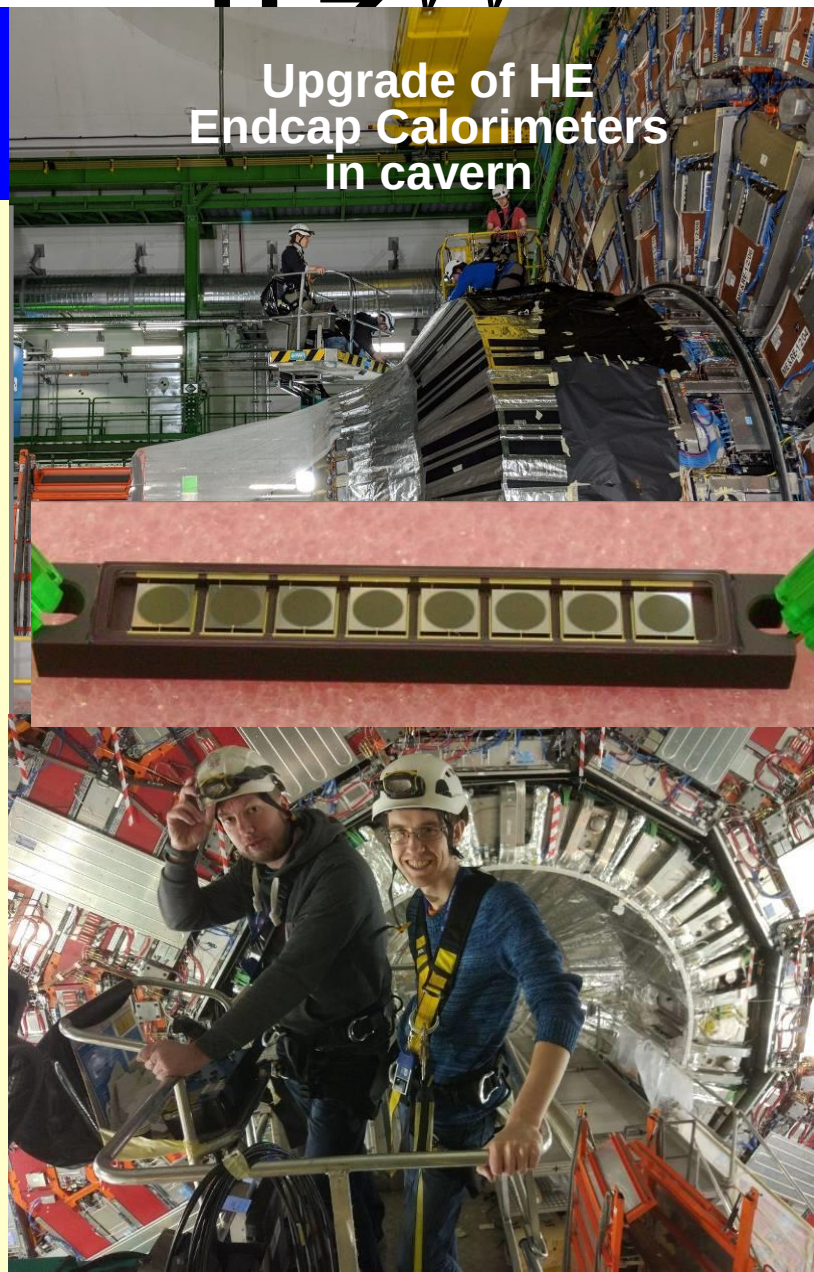
RDMS Scientists participate in Phase1 CMS Upgrade

in April 2018 the Upgrade of Front-End Endcap calorimeters HE with SiPMs was successfully completed by RDMS team of qualified experts.

Intense but smooth operation, confirming excellent experience with HEP17 pilot SiPM system in 2017

- HPDs replaced with SiPMs – 7,500 channels
  - Eliminated dominant source of HE signal loss (HPD photocathode deterioration)
  - x2.5 increase in photo-detection efficiency (SiPM vs HPD)
  - Eliminated sources of coherent noise (HPD discharges and HPD HV system)
- Increased longitudinal segmentation (2-3 → 6-7 readout depths)
- Added TDC information

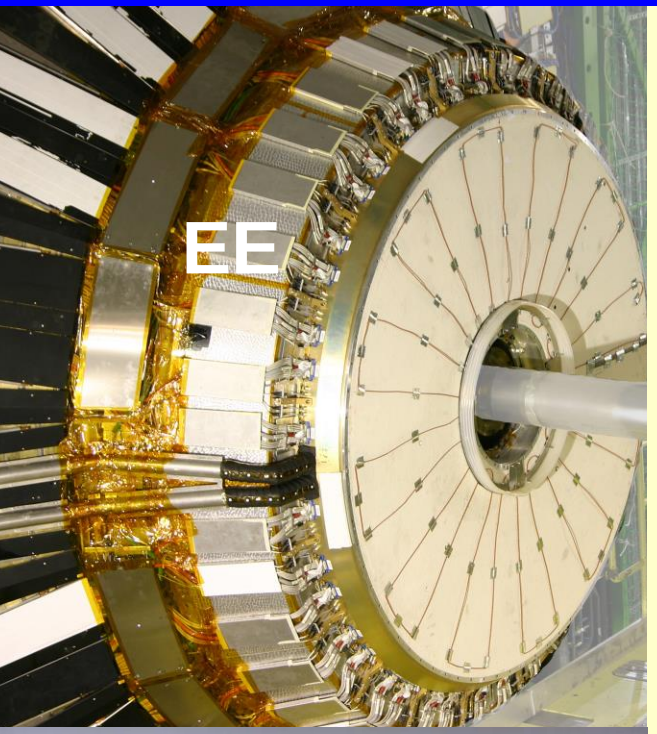
Upgraded and pre-calibrated Endcap calorimeters HE demonstrate high operation efficiency and jet identification in 2018 Run 2 at 13 TeV



Wide Application of PWO crystal in HEP

$H \rightarrow \gamma\gamma$ candidate

RDMS Scientists invented and developed a wide application of new detectors in order to construct a frontier CMS.



PWO crystal was born in "SingleCrystal", Kharkov

PWO_4 crystals were proposed for EM-calorimetry in 1992 by IHEP, Protvino

V. A. Kachanov.
"Study of characteristics of real-size $PbWO_4$ crystal cells for precise EM-calorimeters to be used at LHC energies" Workshop, Chamonix, 1992

This R&D led to wide application of PWO in HEP

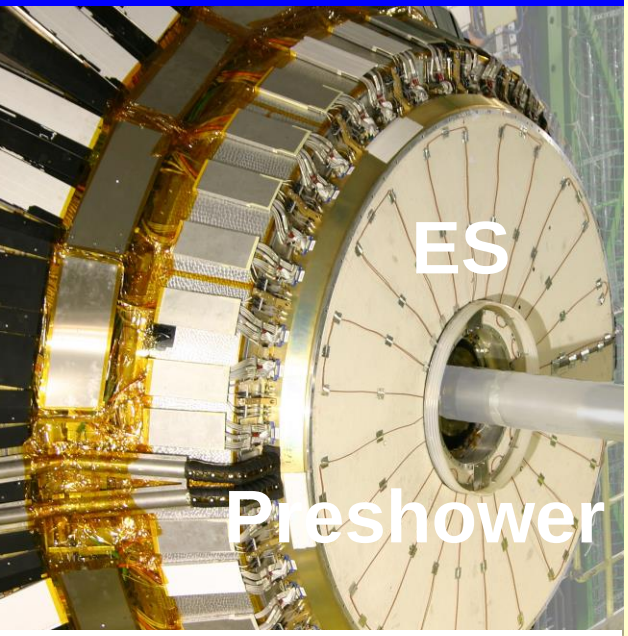
Precise Electromagnetic Calorimeters, EB for barrel and EE for endcaps were developed by RDMS and other CMS institutes in cooperation with Bogoroditsk plant

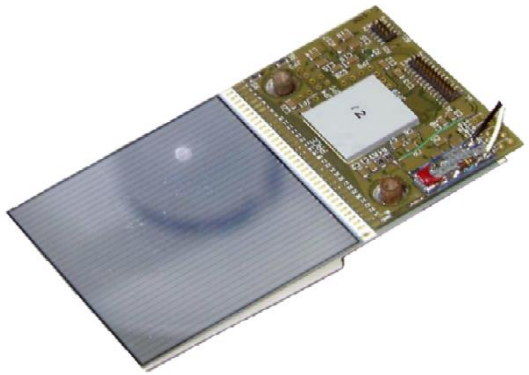
76,000 crystal channels in CMS

Also PWO crystals widely used in ALICE at LHC and many other HEP experiments

Wide application of Si detectors in HEP

I.Golutvin proposed, invented and developed a wide application of new detectors in order to construct a frontier CMS





Based on Dubna Silicon Program in cooperation with Italian scientists a new technology for pad (pixel), thin and coarse strip Si-detectors was developed in 90-th.

Also Silicon Option for the Endcap HCAL invented for CMS LoI in 1992.

I.A.Golutvin et al.
RD35: "Silicon Hadron Calorimeter module for LHC",
CERN/DRDC/91-54, DRDC/P34, January 13th 1992

This R&D led to wide application of Si tracking in HEP

CMS Preshower developed by JINR in cooperation with Zelenograd, ELMA and other CMS groups
18 m^2, 144,000 channels in CMS

All Si Tracker developed by CMS

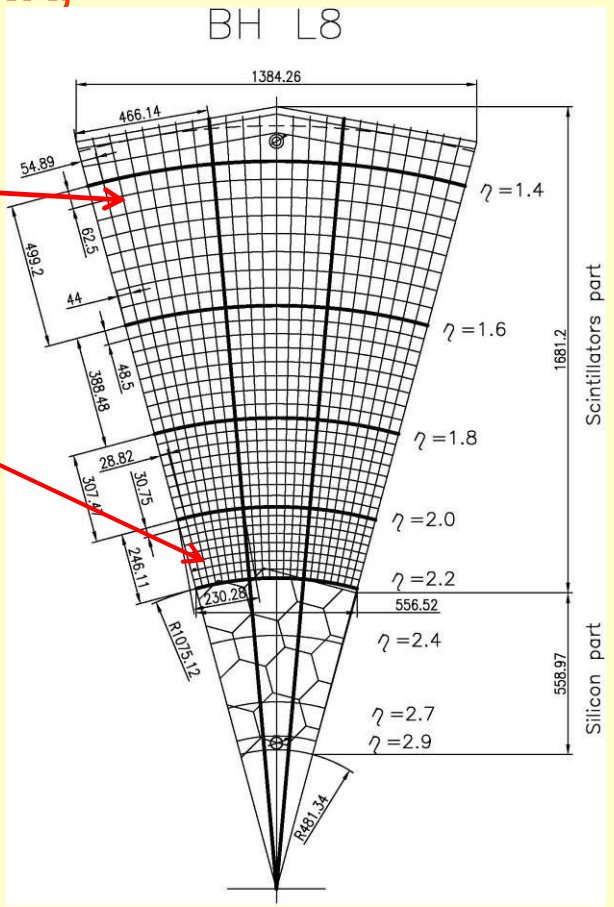
Today, 25 years later, the idea of Si tracking HCAL accepted by CMS at the modern level as High Granularity Calorimeter for HL-LHC

On Phase 2 Upgrade of Endcap Hadron Calorimeter BH (HGCAL)

Study of possibility of RDMS networking for scintillator module production site in Dubna with participation of: JINR, LPI (Moscow), ISMA (Kharkov), MEPhI (Moscow), INR (Moscow), INP (Tashkent), as well as DESY and CERN

Scintillator module (64 tiles). Type 4

Scintillator module (64 tiles). Type 1



12 Scintillator modules in 30 degrees cassette 64 tiles are in the module

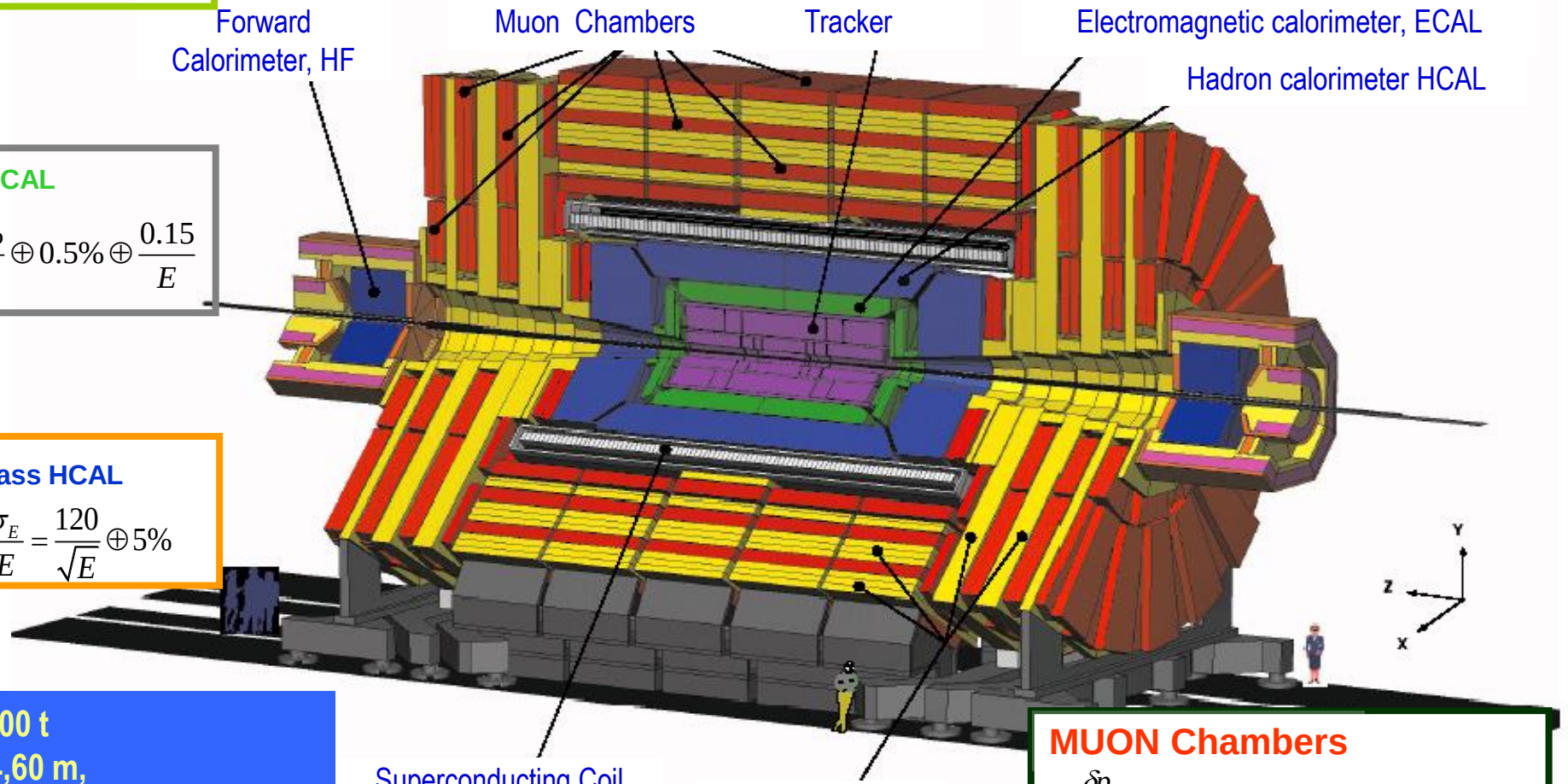
- "Macrotile" concept for scintillation part of HGCAL was proposed, developed, prototyped in Dubna, based on the commercially produced scintillator (EJ 260 or similar).
- Wide R&D with selected types of detectors (scintillators and SiPM) is well going on.
- **Choice and selection by CMS of scintillator technology is planed in the mid of October 2019**

RDMS is about 25 years in CMS

Silicon Tracker

$$\delta p_T / p_T \sim 15 \times p_T(TeV)\%$$

Detector subsystems are designed as discovery experiment to measure: the energy and momentum of photons, electrons, muons, jets, missing E_T up to a few TeV



$PbWO_4$ ECAL

$$\frac{\sigma_E}{E} = \frac{2.7\%}{\sqrt{E}} \oplus 0.5\% \oplus \frac{0.15}{E}$$

sampling brass HCAL

$$\frac{\sigma_E}{E} = \frac{120}{\sqrt{E}} \oplus 5\%$$

weight - 14500 t
diameter - 14,60 m,
length - 21,60 m,
B-field - 4 T

MUON Chambers

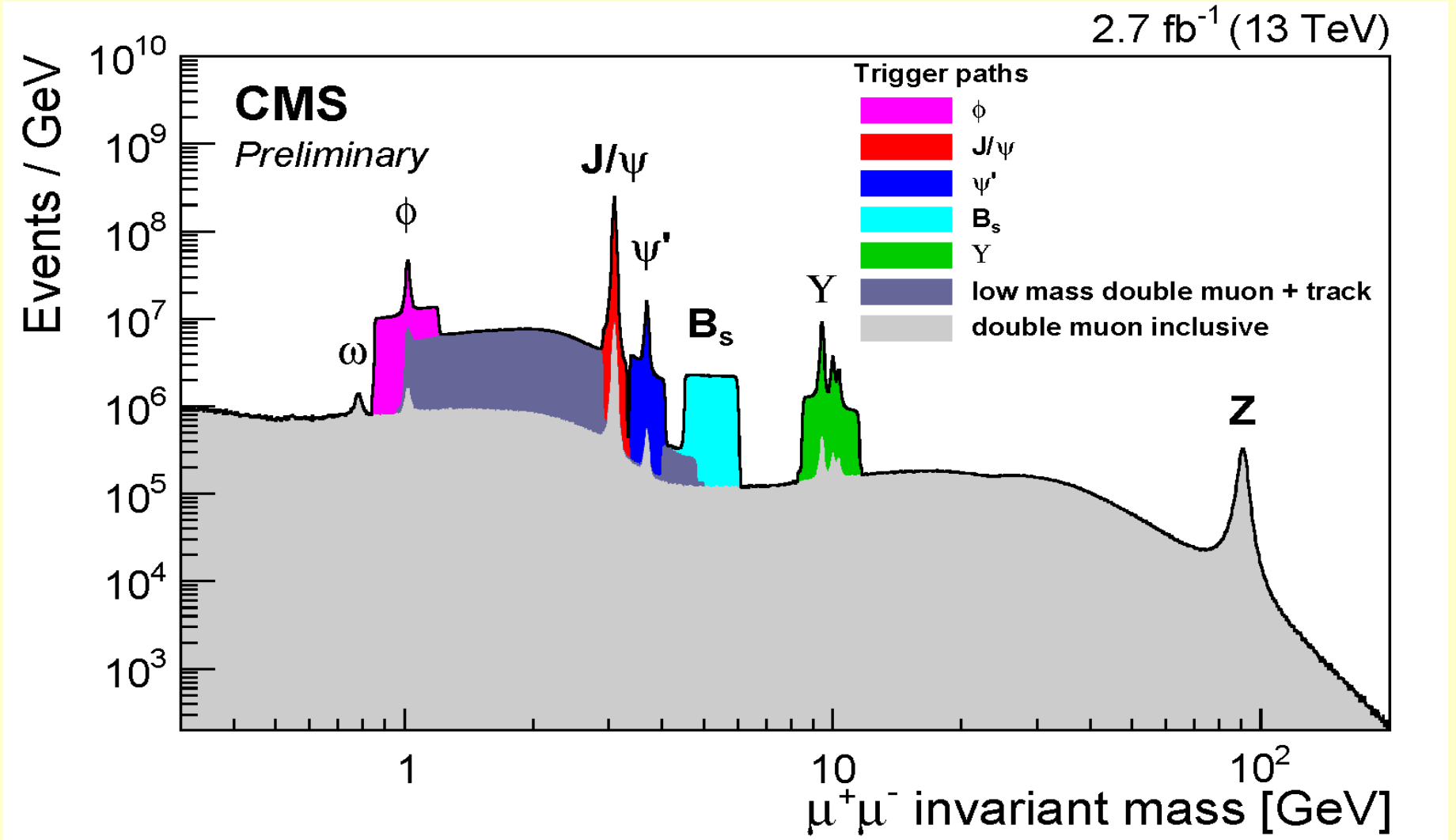
$$\frac{\delta p_T}{p_T} \sim 1.0 - 1.5\% @ 100 GeV$$

RDMS Achievement in CMS@LHC. Physics

- RDMS scientists developed an adequate computing based on GRID technology, including CMS Tier-1 in JINR with regional Tier-2's at RDMS institutions associated with physics tasks
- CMS Remote Operational Centres for data monitoring and certification developed in Dubna and all RDMS institutes help for data taking and certification
- Data processing and physic analysis performed by RDMS scientists demonstrate manifestation of the Standard Model at 7 and 13 TeV
- No evidence for New Physics beyond SM
- Regular Joint sessions of RDMS Collaboration Board and Executive Committee, All RDMS remote seminar "Physics at LHC", Annual RDMS Conferences are helpful to joint efforts

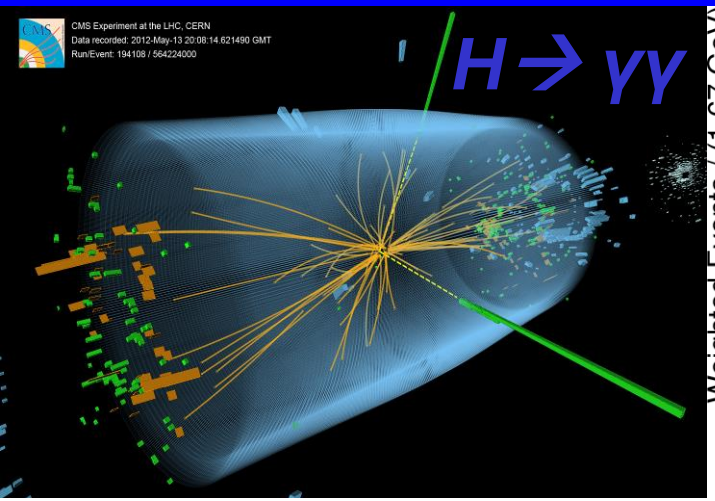
SM verification. Physics Objects@13 TeV

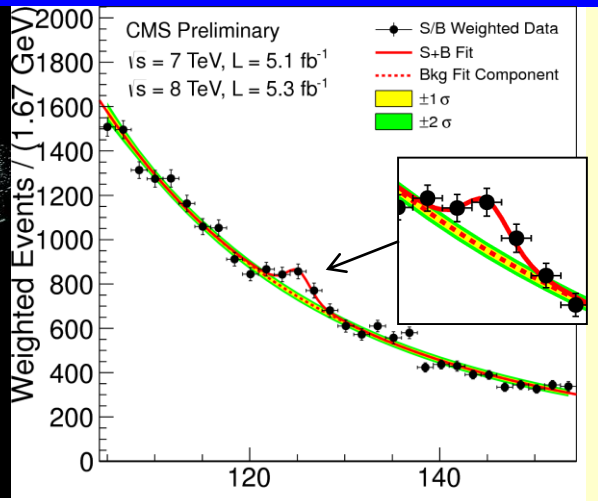
CMS shows an excellent performance to detect different signals

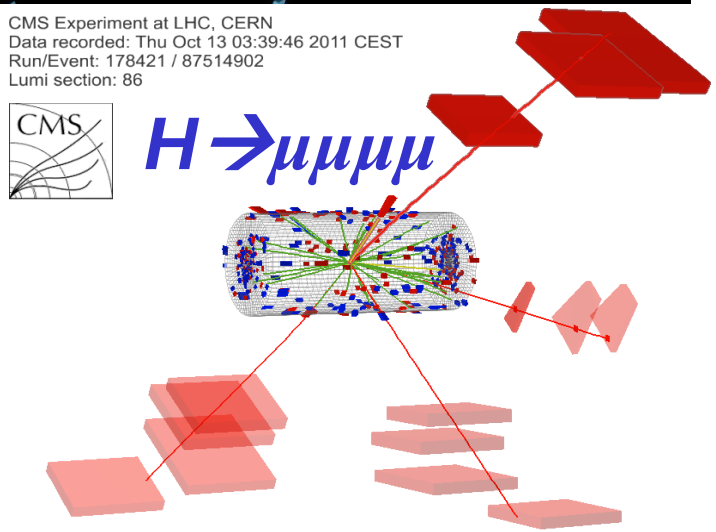


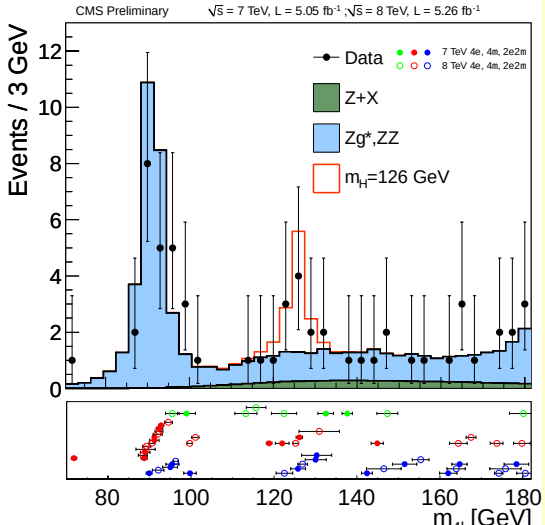
Breakthrough in Experiments @ LHC

The most important event in Particle Physics in XXI century – is the discovery of the Higgs Boson at CMS and ATLAS at LHC, announced by two Collaborations on 4 July 2012 at scientific seminar at CERN



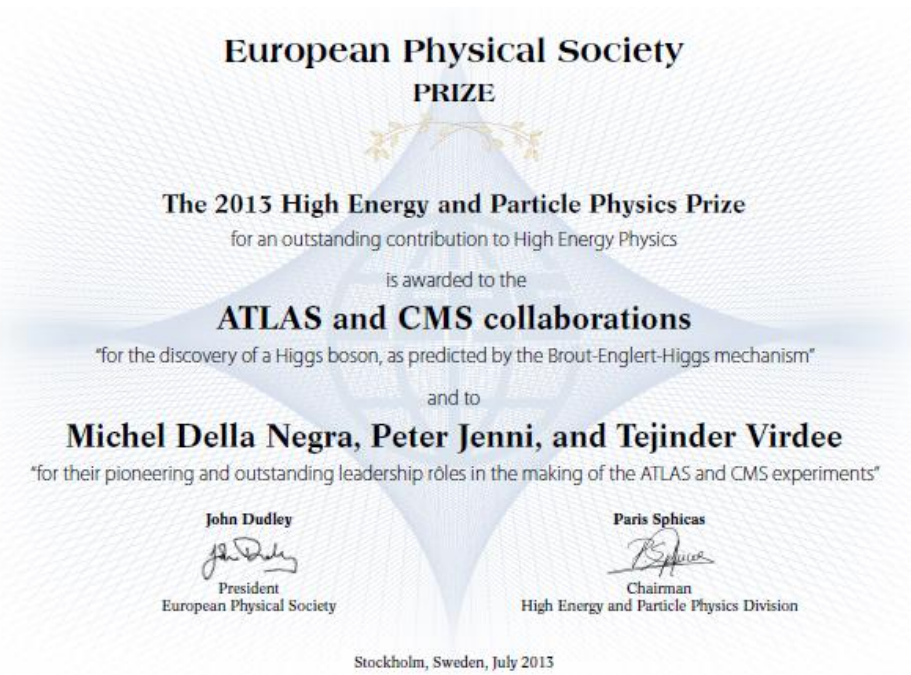






The key and decisively contribution in the discovery of Higgs Boson of RDMS scientists from JINR Member States is honoured with commendation by CMS Spokesperson Joe Incandela in his letter addressed to RDMS authors of discovery on 31 July 2012

Breakthrough in Experiments @ LHC



European Physical Society
PRIZE

The 2013 High Energy and Particle Physics Prize
for an outstanding contribution to High Energy Physics
is awarded to the
ATLAS and CMS collaborations
"for the discovery of a Higgs boson, as predicted by the Brout-Englert-Higgs mechanism"
and to
Michel Della Negra, Peter Jenni, and Tejinder Virdee
"for their pioneering and outstanding leadership rôles in the making of the ATLAS and CMS experiments"

John Dudley
President
European Physical Society

Paris Sphicas
Chairman
High Energy and Particle Physics Division

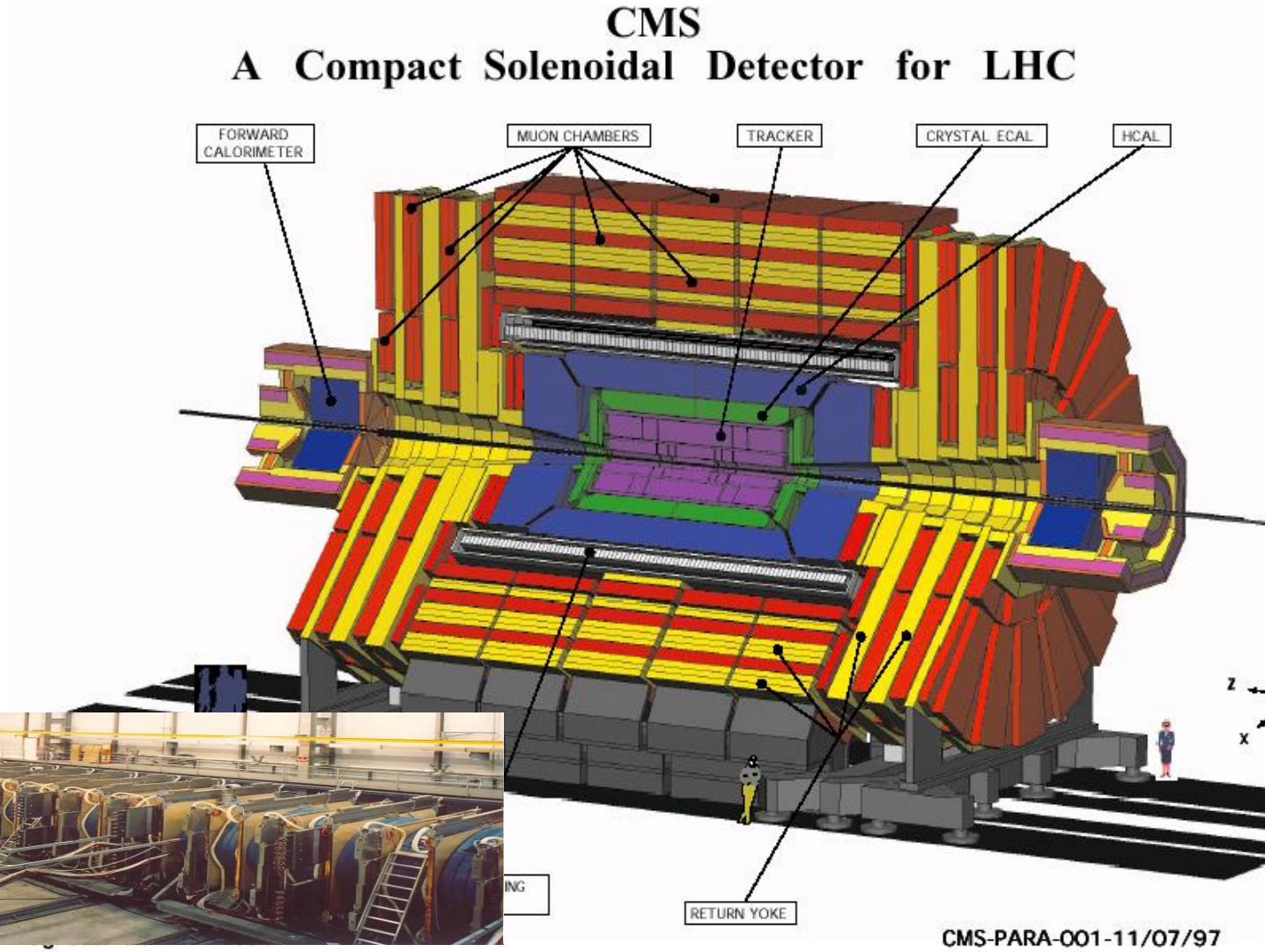
Stockholm, Sweden, July 2013

$H \rightarrow \gamma\gamma$ candidate

Contribution of the RDMS scientists in the discovery of a Higgs Boson, as predicted by the Brout-Englert-Higgs mechanism, is awarded by European Physical Society Prize on the strength of the CMS and ATLAS Collaborations on July 2013.

For outstanding contribution in CMS and ATLAS experiments resulting in discovery of Higgs Boson the leader of Russian team in ATLAS A.M.Zaitsev (IHEP) and the RDMS CMS Spokesperson I.A.Golutvin (JINR) are awarded by P.A.Cherenkov Prize of RAS in 2014

Conclusion: Scale of the progress



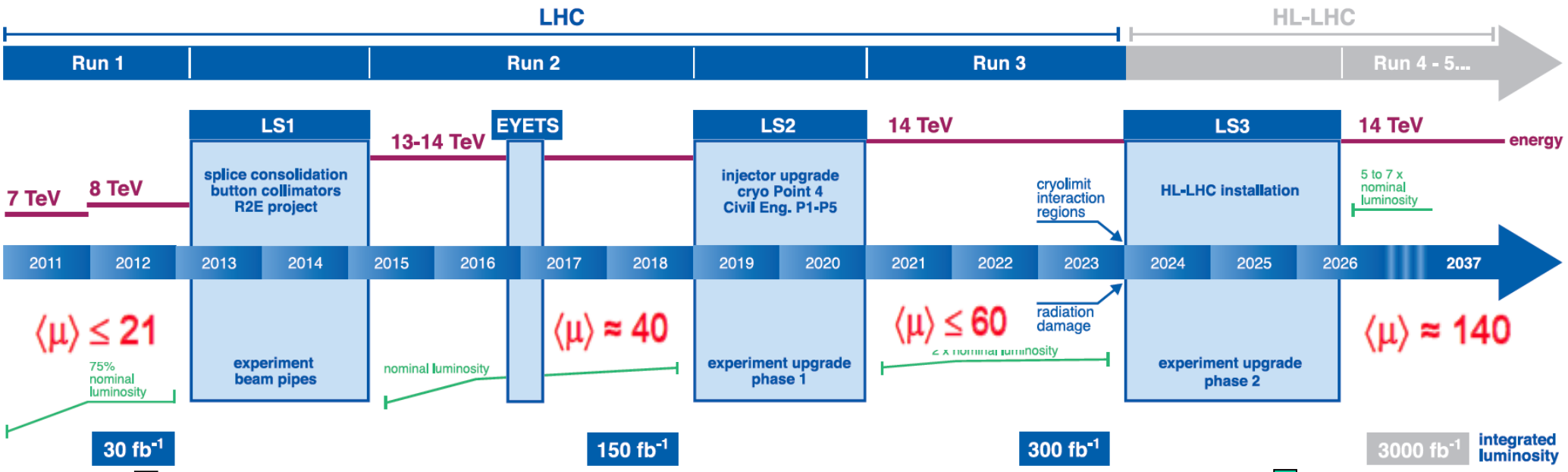
BCDMS

BIS

πp

Our life with LHC

LHC / HL-LHC Plan



Higgs Discovery
7 TeV (5.1 fb^{-1}) +
8 TeV (5.3 fb^{-1})

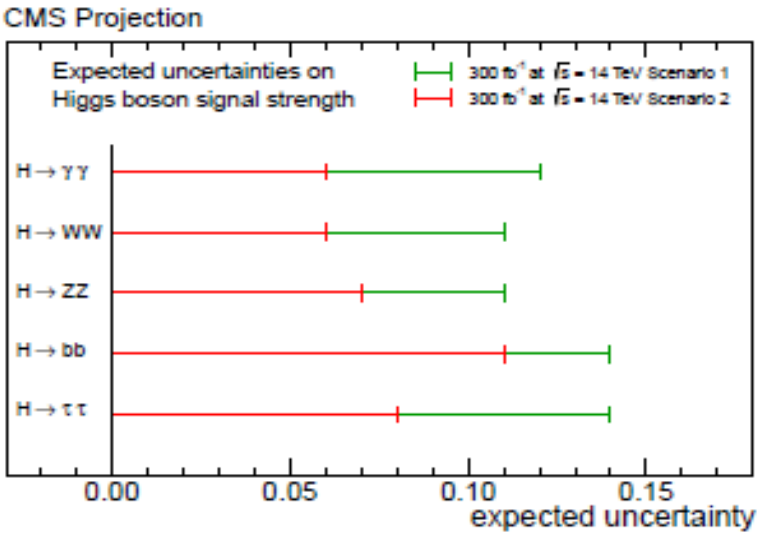
today
162.9 fb^{-1} @ 13 TeV

HL-LHC era
"Attobarn" Physics

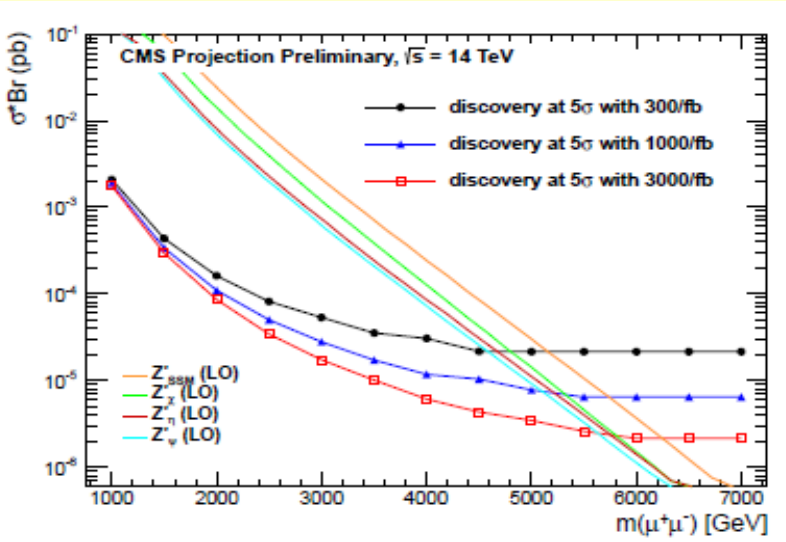
Expected Results in Run2 at 13 TeV

The main goals of the RDMS groups in Run 2 are:

Studies of the Higgs boson properties such as the spin-parity and rare decays etc., increasing of accuracy of the measurements of the branchings (6-14 %), couplings (5-15 %), signal strength (6-14%)



Precise tests of the Standard Model and searching for new physics in the dimuon channel: TeV-scale gravity, new gauge bosons with a mass up to 6 TeV



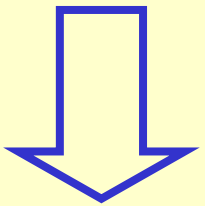
New physics can be discovered if exists !

Main Objectives for Future

- RDMS under leadership of I.Golutvin made it possible to build the CMS experiment with a wide participation of JINR Member States, and
- gave Equal Opportunities for each group and new generation of physicists to participate in frontier Physics

Next steps:

- Study of the Brout-Engelert-Higgs mechanism is still a main focus
- Search for Supper Symmetry signals
- …



CMS Phase 2 Upgrade at HL-LHC

I would wish to I.Golutvin be always a leader looking for the future, and great scientific success !

On celebration of the 85th Jubilee of Prof. I.A. Golutvin