

High-energy Heavy-ion Physics in Hungary with ALICE

Gergely Gábor Barnaföldi, Wigner RCP, CERN ALICE
Grants: NKFIK OTKA K135515, NEMZ_KI 2019-00011, FK131979



RECFA visit to Hungary, HAS, Budapest, 24 September 2022

High-energy Heavy-ion Research in Hungary

Past – Present – Future – Beyond

Why?

Where?

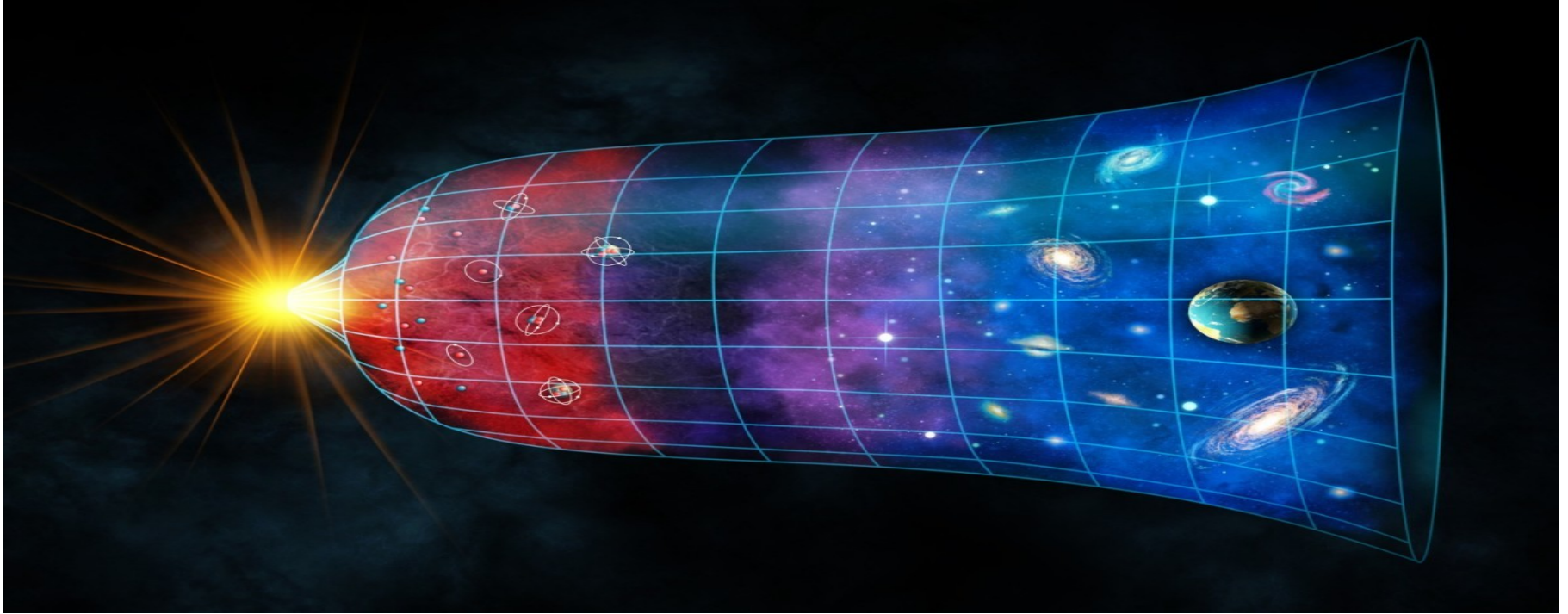
Who?

What?



WHY?

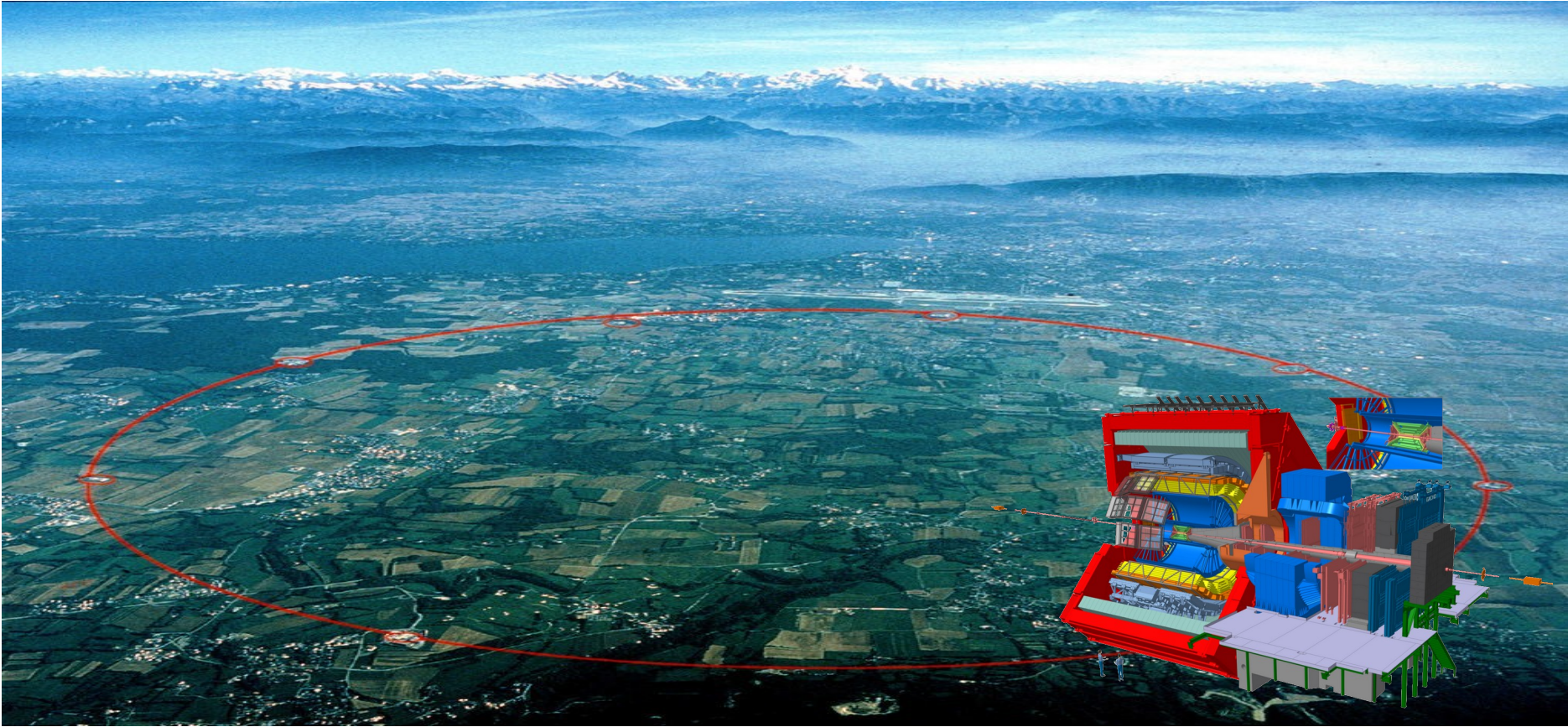
Investigating the primordial matter of the Universe



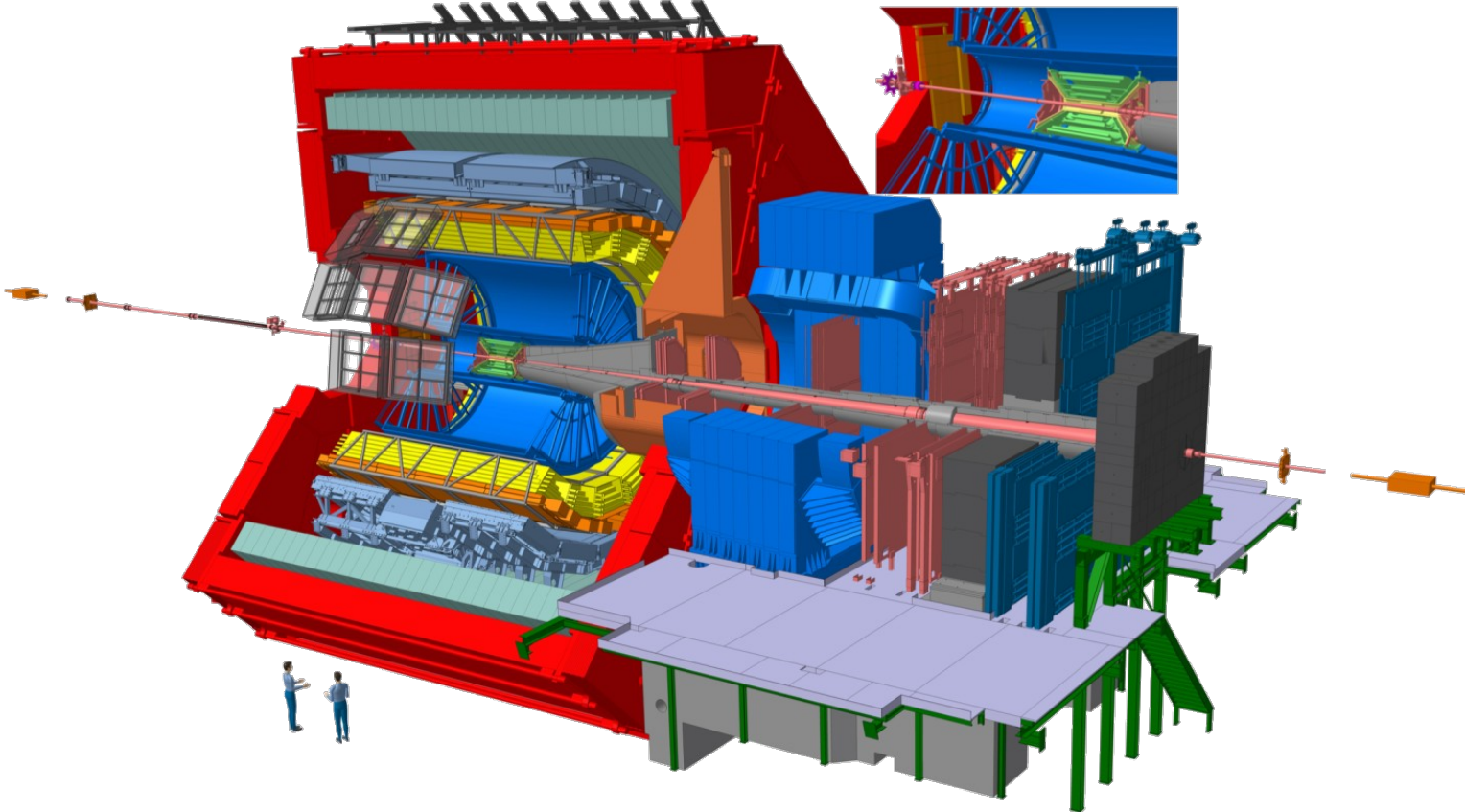
The Universe is 13.7 billion years old? How was it milliseconds after the Big Bang?

WHERE?

A Large Ion Collider Experiment, CERN LHC



A Large Ion Collider Experiment, CERN LHC



A Large Ion Collider Experiment, CERN LHC



WHO?

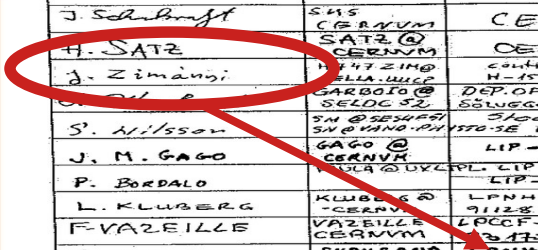
Hungarian ALICE Group



History of the ALICE Experiment:

- 1990-1996 Design
- 1992-2002 R&D
- 2000-2010 Construction
- 2002-2007 Installation
- 2008 -> Commissioning
- 4 TP addenda along the way:
 - 1996 Muon spectrometer
 - 1999 TRD
 - 2006 EMCAL
 - 2007 DCAL
- 2012 Lol for the Upgrade
- 2012-2014 R&D
- 2014-2016 Procurement/Fabrication
- 2016-2017 Integration, pre-commissioning
- 2018-2019 Installation, commissioning
- 2019-2020 Full deployment of DAQ/HLT

Name	E-Mail address	Institute/Mail address
J. Schuchnig	S415 CERNVM	CERN IEP
H. Satz	SATZ@ CERNVM	CERN-TH
J. Zimanyi	H-47.ZIM@ ELLA.WULF	Central Research Institute for Physics H-1525 Budapest 114, P.O. Box Hungary
G. Garabatos	GARABO@ SELDC.SZ	DEP. OF PHYSICS UNIV. OF LUND SÖLVEGATAN 17, S-223 62 LUND, SWEDEN
S. Nilsson	SN@SELDC.SZ	Stockholm Univ. 113.15, 17, Fysikum S-141 86 Stockholm, Sweden
J. M. Gago	GAGO@ CERNVM	LIP - Av. Elias Garcia, 14 - 1000 Lisboa
P. Bordalo	P.BORDALO@ LIP	LIP - Av. Elias Garcia, 14 - 1000 Lisboa
L. Kluberg	KLUBERG@ CERNVM	LPNHE Ecole Polytechnique 91128 Palaiseau FRANCE
F. Vazeille	VAZEILLE@ CERNVM	LPCF - Chemin de Sermond 3472 AUBIERS FRANCE
B. Chaurand	CHAURAND@ LPCF	LPCF - Chemin de Sermond 3472 AUBIERS FRANCE
J. Castor	CASTOR@ FRCPN11	LPCF - Chemin de Sermond 3472 AUBIERS FRANCE
C. Voltolini	VOLTOLINI@ FRCPN11	LPCF - Chemin de Sermond 3472 AUBIERS FRANCE
R. Renfordt	RENFORDT@ CERN	CERN
S. Wenig	SIGIS@ CERN	CERN
H.H. Gutbrod	22618::GUTBRD	CERN
A. Drazek	DIARZEK@ CERN	L.P. 7823
Peschanski	PESCH@ CERN	CERN
Clivio Garabatos	VXG@ CERN	G.A.B.
C. Fabjan	FABJAN@ CERN	CERN



J. Zimanyi: Zimanyi medal for HI theory
 Gy. Vesztergombi: Vesztergombi HEP Lab

Hungarian ALICE Group



History of the ALICE Experiment:

1990-1996 Design

1992-2002 R&D

2000-2010 Construction

2002-2007 Installation

2008 -> Commissioning

4 TP addenda along the way:

1996 Muon spectrometer

1999 TRD

2006 EMCAL

2007 DCAL

2012 Lol for the Upgrade

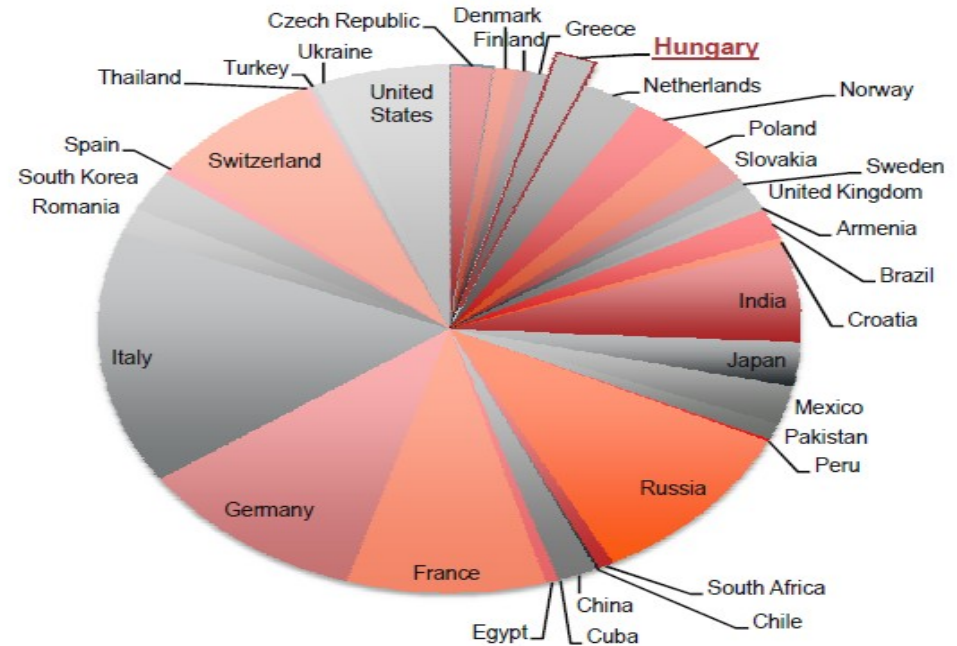
2012-2014 R&D

2014-2016 Procurement/Fabrication

2016-2017 Integration, pre-commissioning

2018-2019 Installation, commissioning

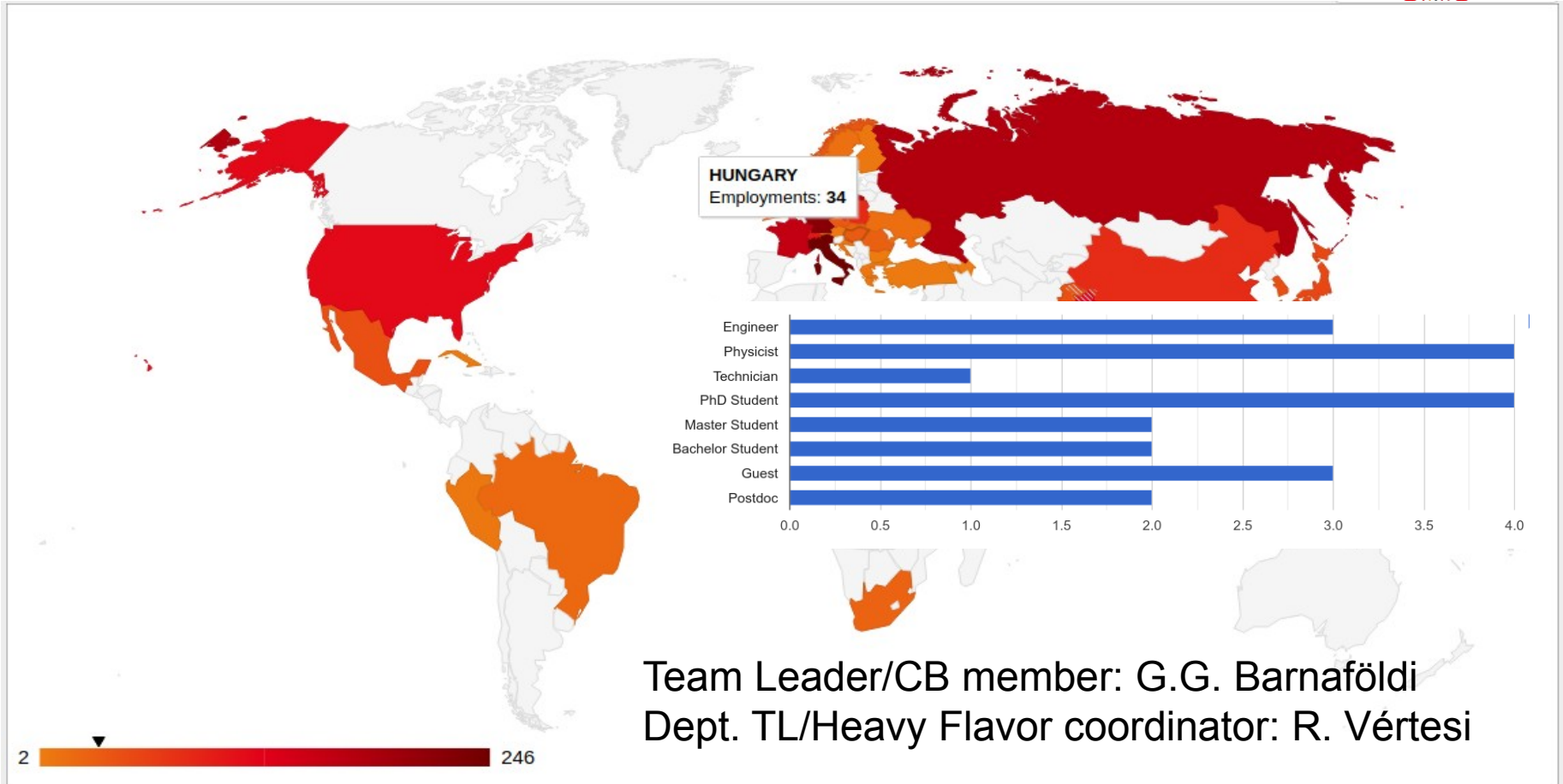
2019-2020 Full deployment of DAQ/HLT



Hungarian ALICE Group



Hungarian ALICE Group



Hungarian ALICE Group Members (2002-2022)

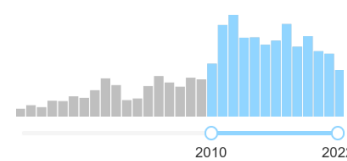


Hungarian ALICE Group (2010-2022)

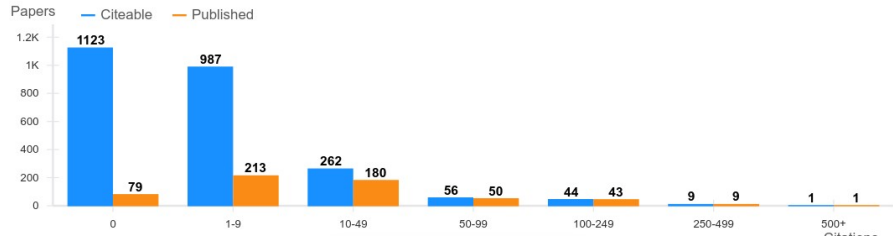


- ✓ Q1-Q2 publications: 570+
- ✓ Total publications: 2480+
- ✓ PhD researches: 16
- ✓ Msc/Bsc works: 26

Papers per year



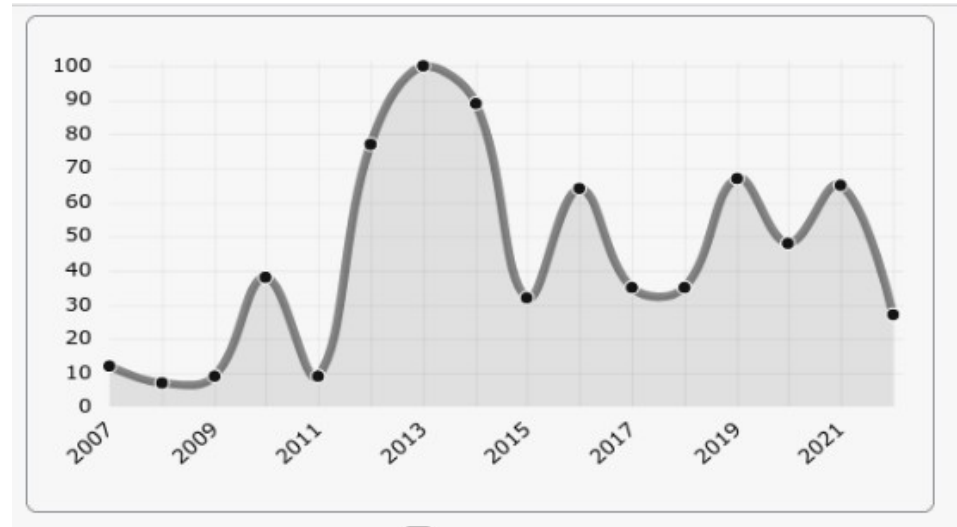
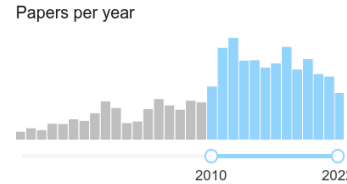
	Citeable ⓘ	Published ⓘ
Papers	2,482	575
Citations	23,071	19,044
h-index ⓘ	72	70
Citations/paper (avg)	9.3	33.1



Hungarian ALICE Group (2010-2022)



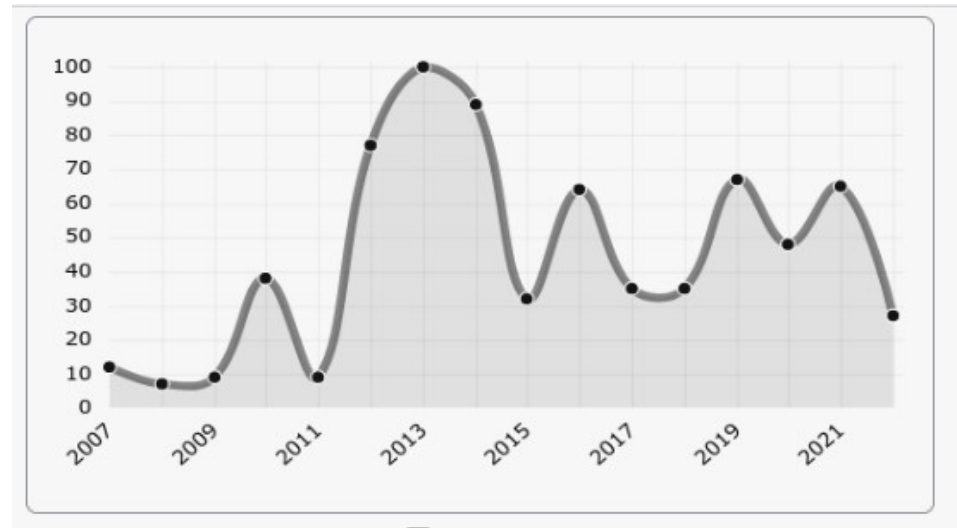
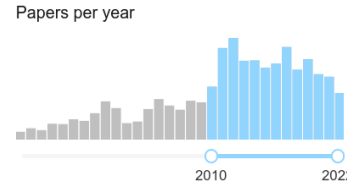
- ✓ Q1-Q2 publications: 570+
- ✓ Total publications: 2480+
- ✓ PhD researches: 16
- ✓ Msc/Bsc works: 26



Hungarian ALICE Group (2010-2022)



- ✓ Q1-Q2 publications: 570+
- ✓ Total publications: 2480+
- ✓ PhD researches: 16
- ✓ Msc/Bsc works: 26
- ✓ National Competition (TDK) 18
- ✓ Posters 50+
- ✓ Conference contributions: 160+
- ✓ Prizes 9



Hungarian ALICE Group (2010-2022)



Funding Agency: NRDIO (NKFIH in Hungarian)
Grant Holder: Wigner Research Centre for Physics



- ✓ MNO-A & B for 6(7) scientists ~9kCHF/MNO-A/year + students
- ✓ Related NRDIO grants
 - ~ Running: 2020-2024:K135515, 2019-2023:FK131979, 2020-2022:2019-2.1.11-TÉT-2019-00050, 2020-2022:2019-2.1.11-TÉT-2019-00078, 2020-2023:2019-2.1.6-NEMZ_KI-2019-00011
 - ~ Past: 2016-2020:K120660, 2012-2016:NK106119, 2009-2013:NK77816, 2009-2013:CK77815, 2007-2010:H07-C 70464, 2007-2008:IN 71374, 2006-2009:NK62044
- ✓ In connection with National TOP50 Research Infrastructures
 - ~ Vesztergombi High-energy Research Laboratory (VLAB)
 - ~ Wigner Scientific Computing Laboratory (WSCLAB)



Hungarian ALICE Group (2010-2022)



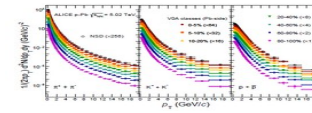
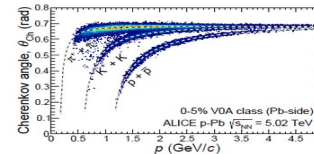
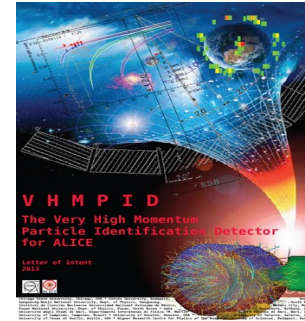
Further investment into ALICE projects by Hungary (salary of employed team members and experts, laboratories, etc.) during the period of 2009-2022:

- ✓ VHMPID project: 1000 kCHF → Letter of Intent, EPJ Plus 129 (2014) 91
- ✓ HMPID project: 200 kCHF → detector in operation 2009-2013, 20kCHF 2013-2022
- ✓ DAQ Upgrade: 50 kCHF → during the period 2009-2013
- ✓ TPC Upgrade local: 150 kCHF → Wigner Innovative Detector Laboratory, 2013
- ✓ TPC Upgrade cost: 200 kCHF → 2014-2022
- ✓ Yearly upgrade & other costs 10kCHF → 2022-2024

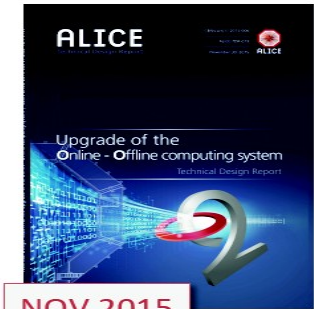
Hungarian ALICE Group (2010-2022)



1. Well developed theoretical background in heavy-ion physics → **Theory talk (Z. Trócsányi)**
2. Intense participation in R&D activity → **LoI preparation and deliverables (D. Varga)**
3. Intense participation in data analysis → **QGP: PID hadron spectra, Heavy Flavor physics, jet physics, correlations**
4. Enhanced activity in data taking → **ALICE Remote Operation Site @Wigner RCP**
5. Intense computing activities at large scale → **Software & hardware development (G. Bíró)**



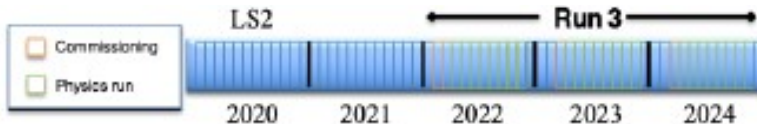
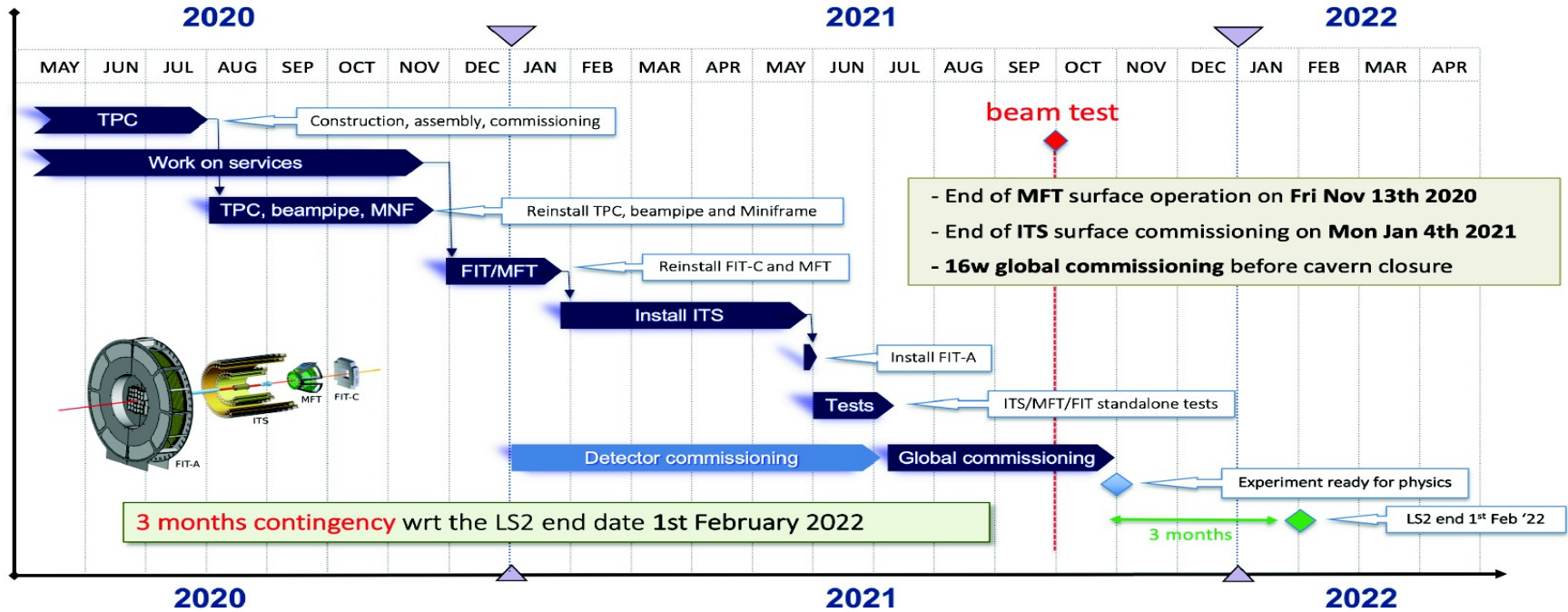
MAR 2014



NOV 2015

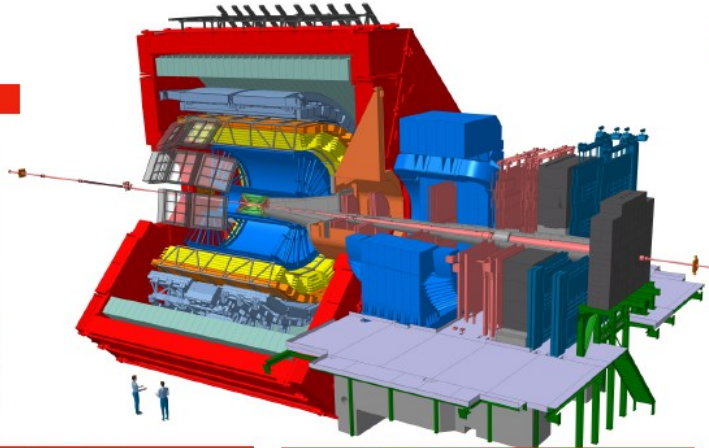
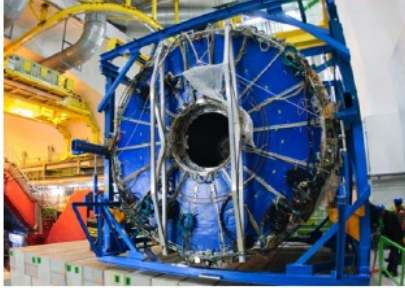
WHAT?

ALICE LS2 R&D



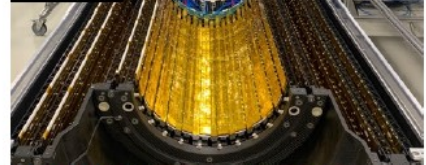
ALICE LS2 R&D

GEM-based TPC

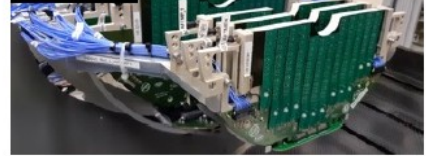


ALPIDE-based Monolithic Silicon Detectors

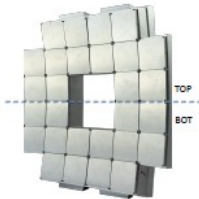
Barrel: ITS2



Forward: MFT



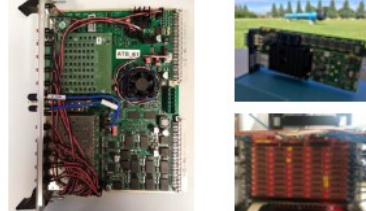
Fast interaction trigger (FIT)



Muon Spectrometer

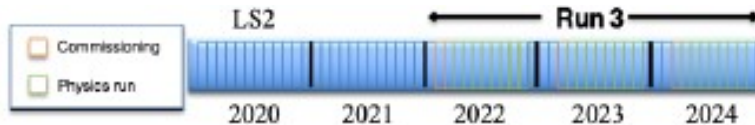


New Central Trigger System
new RDO for EMCal, PHOS, TRD, HMPID, ZDC



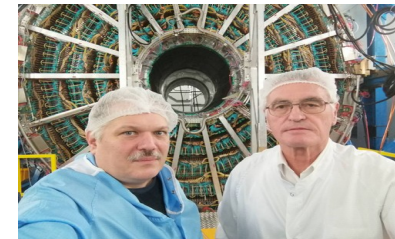
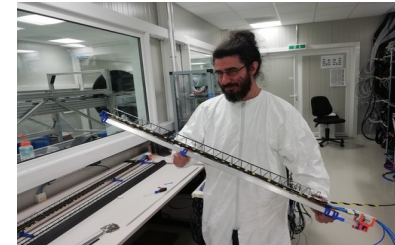
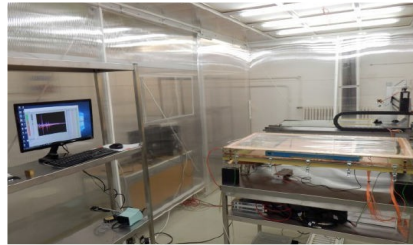
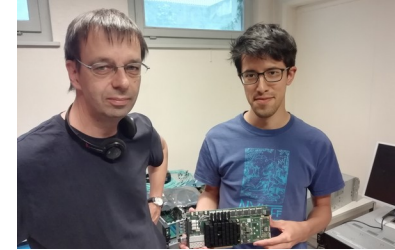
New computing infrastructure and framework: O2

Farm at P2



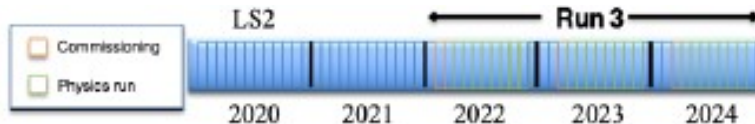
ALICE LS2 R&D – the Hungarian Contribution

1. The upgrade of the ALICE's DAQ system, CRU2 R&D → **4TB/s speed**
2. QA & building the new, GEM-based ALICE TPC R&D → **World record: 90m³**
3. Inner tracking system (ITS2) upgrade (silicon-pixel MAPS technology) test → **10m² & 13Gpixel**
4. Big Data: First large scale Specialized Analysis Facility @ WDC → **100 PB adat**
5. Data Analysis & software developments → **100 000 line of code**



ALICE LS2 R&D + Ongoing Run3

- More precise pseudo-rapidity distribution measurements, **PID hadron spectra**
- **Jet-structure measurements:** jet-fragmentation, hadronization, pp, pPb
- Deuteron-production: testing coalescence model
- **Investigating the charm hadron production (Λ_c/D ratio & DD correlations)**
- **Heavy flavor production in XeXe and PbPb collisions**



PRL 119, 102301 (2017)

PHYSICAL REVIEW LETTERS

week ending
8 SEPTEMBER 2017

Anomalous Evolution of the Near-Side Jet Peak Shape in Pb-Pb Collisions at $\sqrt{s_{NN}} = 2.76$ TeV

J. Adam *et al.**
(ALICE Collaboration)



PUBLISHED FOR SISSA BY SPRINGER

RECEIVED: October 27, 2017
ACCEPTED: December 14, 2017
PUBLISHED: January 28, 2018

Measurement of inclusive charged-particle b-jet production in pp and p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

Eur. Phys. J. C (2021) 81:256
<https://doi.org/10.1140/epjc/s10052-020-08690-5>

THE EUROPEAN
PHYSICAL JOURNAL C



Regular Article - Experimental Physics

Production of light-flavor hadrons in pp collisions at $\sqrt{s} = 7$ and $\sqrt{s} = 13$ TeV

ALICE Collaboration*
CERN, 1211 Geneva 23, Switzerland

Received: 7 June 2020 / Accepted: 19 November 2020 / Published online: 24 March 2021
© CERN for the benefit of the ALICE Collaboration 2021

PHYSICAL REVIEW C 96, 034904 (2017)

Evolution of the longitudinal and azimuthal structure of the near-side jet peak in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

J. Adam *et al.**
(ALICE Collaboration)
(Received 28 September 2016; published 8 September 2017)

*To see complete candidate selection measurements, see also doi:10.5902/physproc.2017.11001

Eur. Phys. J. C (2022) 82:335
<https://doi.org/10.1140/epjc/s10052-022-10267-3>

THE EUROPEAN
PHYSICAL JOURNAL C



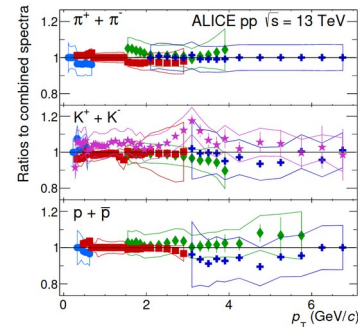
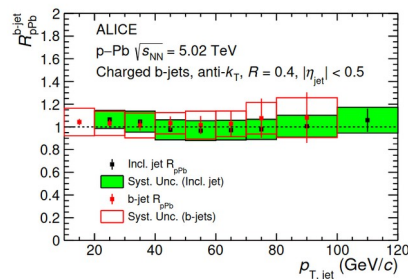
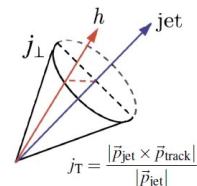
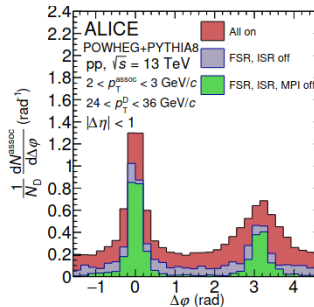
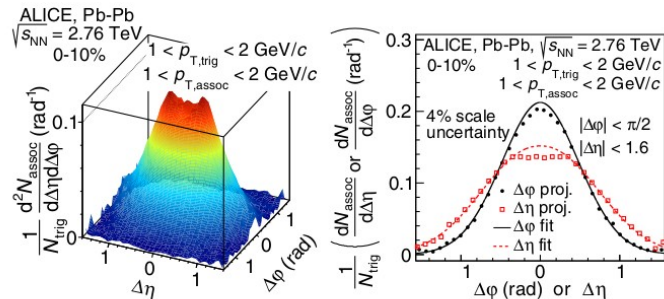
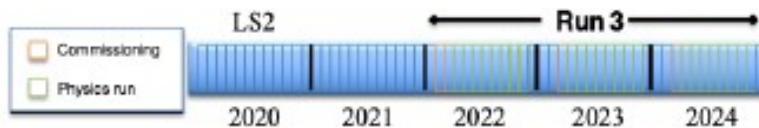
Regular Article - Experimental Physics

Investigating charm production and fragmentation via azimuthal correlations of prompt D mesons with charged particles in pp collisions at $\sqrt{s} = 13$ TeV

ALICE Collaboration*

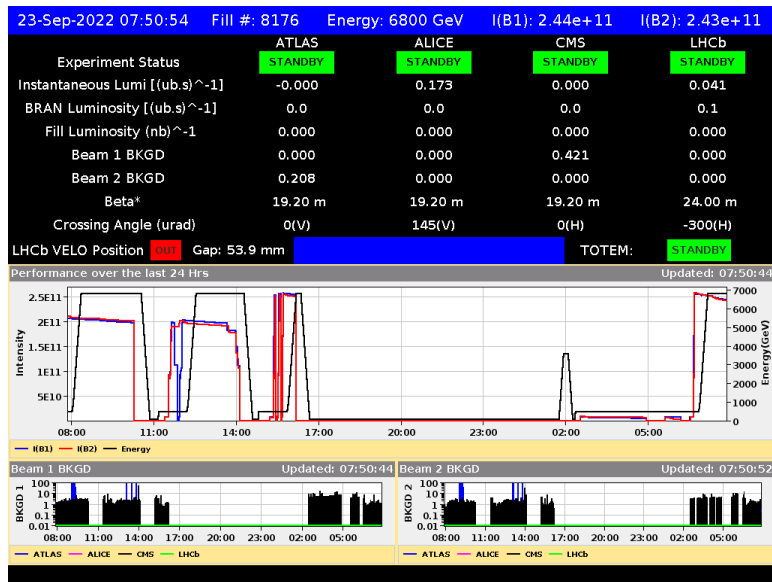
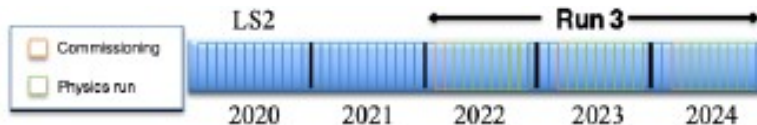
ALICE LS2 R&D + Ongoing Run3

- More precise pseudo-rapidity distribution measurements, **PID hadron spectra**
- **Jet-structure measurements:** jet-fragmentation, hadronization, pp, pPb
- Deuteron-production: testing coalescence model
- **Investigating the charm hadron production (Λ_c/D ratio & DD correlations)**
- **Heavy flavor production in XeXe and PbPb collisions**



ALICE LS2 R&D + Ongoing Run3

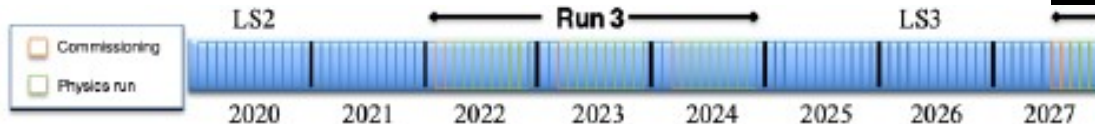
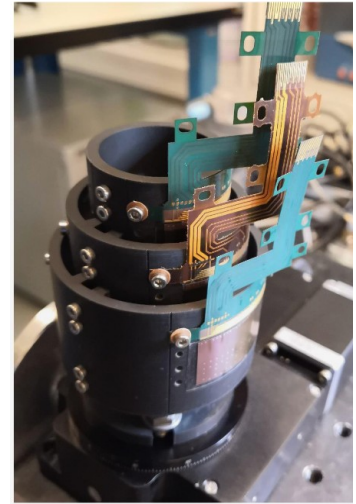
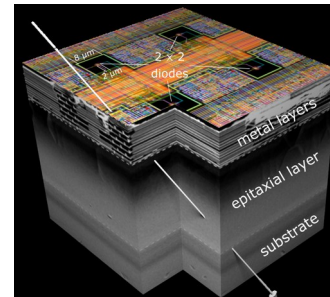
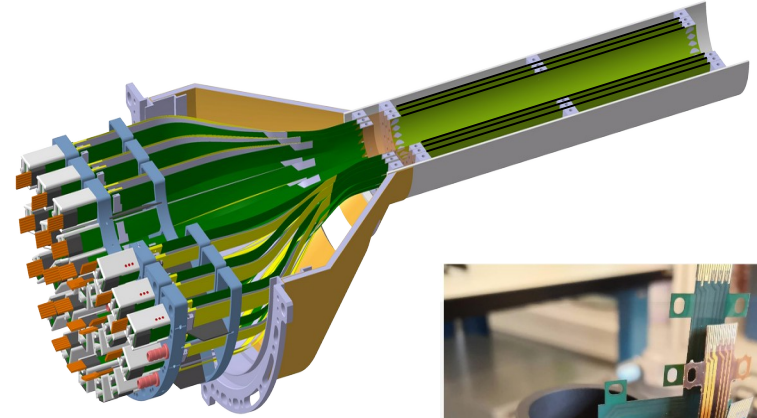
- More precise pseudo-rapidity distribution measurements, **PID hadron spectra**
- **Jet-structure measurements:** jet-fragmentation, hadronization, pp, pPb
- Deuteron-production: testing coalescence model
- **Investigating the charm hadron production (Λ_c/D ratio & DD correlations)**
- **Heavy flavor production in XeXe and PbPb collisions** → Vote for HI Run in 2022!
- **Status of today?**



WHAT ELSE?

R&Ds for the LS3 period

- FOCAL and **ITS3** R&D in ALICE
- ITS3: bendt silicon pixel detector technology: MAPS has been tested at DESY. (**Our task: Cooling simulations ITS3 WP5**)

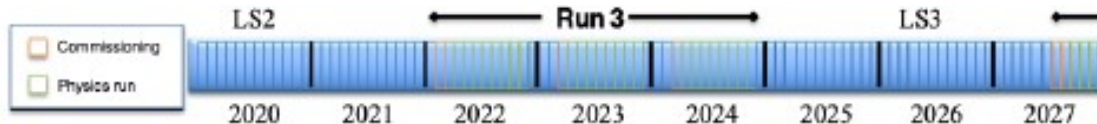
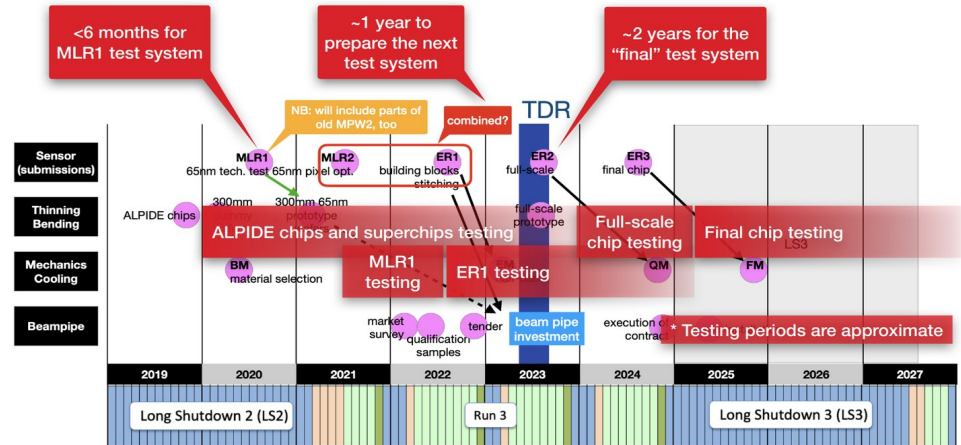


R&Ds for the LS3 period

- FOCAL and **ITS3** R&D in ALICE
- ITS3: bendt silicon pixel detector technology: MAPS has been tested at DESY. (**Our task: Cooling simulations ITS3 WP5**)
- **Detector-part tests + DAQ-system R&D**



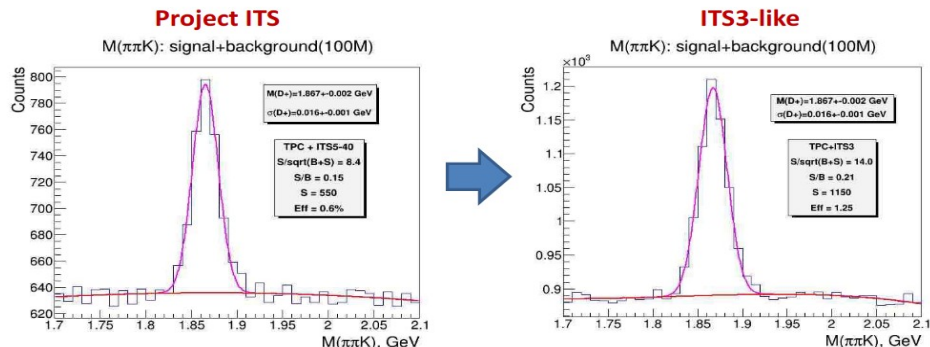
ITS3 project timeline



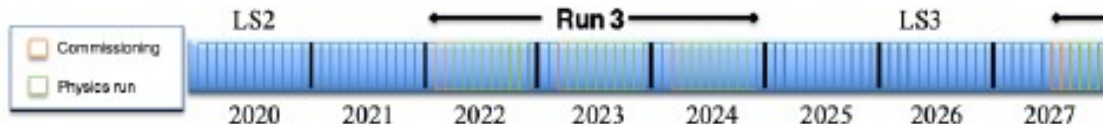
R&Ds for the LS3 period

- FOCAL and **ITS3** R&D in ALICE
- ITS3: bendt silicon pixel detector technology: MAPS has been tested at DESY. (**Our task: Cooling simulations ITS3 WP5**)
- Detector-part tests + DAQ-system R&D
- Better then 2x more precise heavy flavor measurementns: fine structure of the jets, measuring fragmentation & hadronization.

D⁺ reconstruction efficiency with ITS3-like model

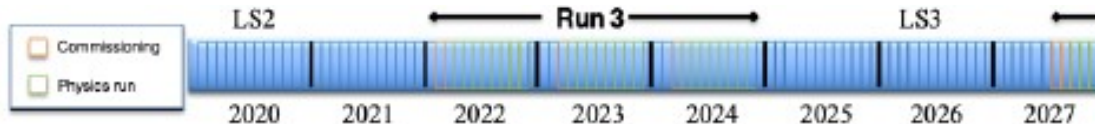
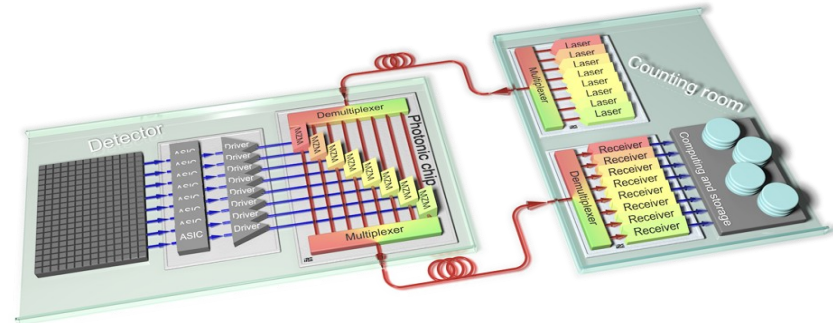
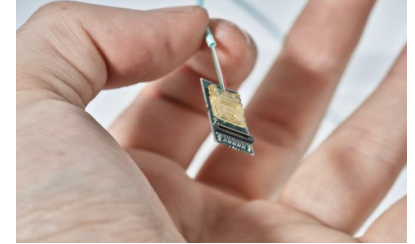
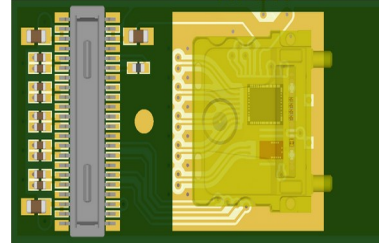


ITS	S	S/B	S/ $\sqrt{S+B}$	Eff,%
Project	550	0.15	8.4	0.60
ITS3-like	1150	0.21	14.0	1.26



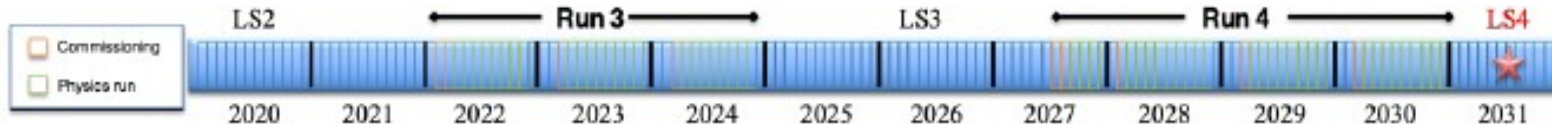
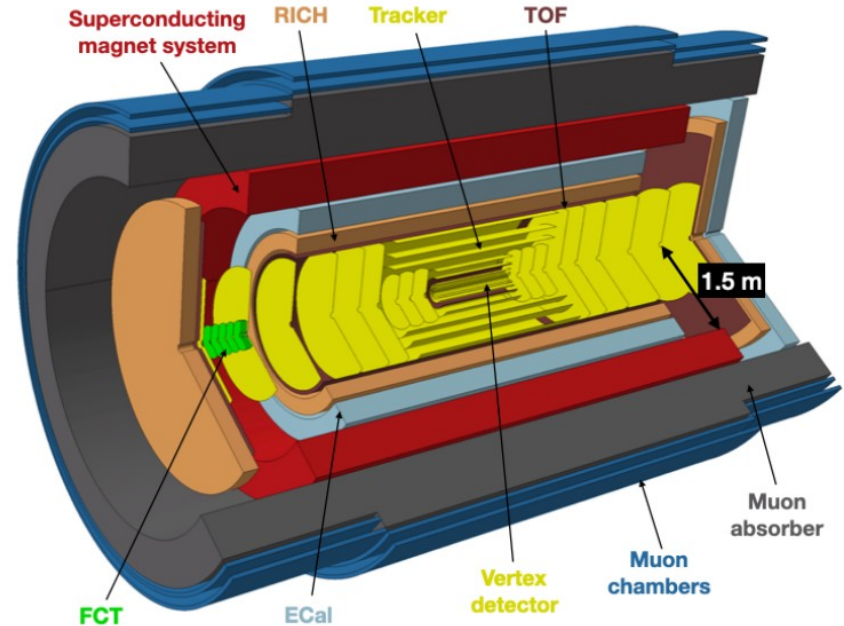
R&Ds for the LS3 period

- **New radiation tolerant DAQ system R&D**
- **Versatile+ link optical receiver**
 - **20x10x2,5 mm**
 - **4x5-10 Gb/s download + 1x2,5 Gb/s upload**
 - **Between -35C and 60C**
 - **Radiation tolerance: 1 MGy or 1000+hadron/cm²**
- **Optoelectronic data transfer: 28/56 Gb/s**



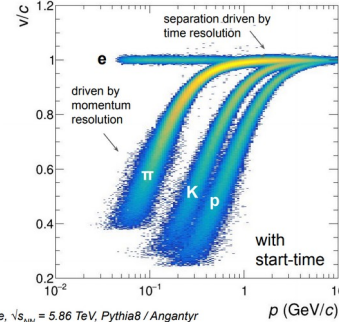
ALICE3 Letter of Intent

- **Physics:** Test of principles of quantum field theory (QFT), in medium effects (QCD chiral symmetry restoration, exotic hadrons, DM).
- **Large Acceptance:** $\Delta\eta = 8$
- **PID:** TOF 20 ps time resolution, aerogel-based RICH
- **Zero momentum detector:** $p_T \lesssim 50$ MeV/c (at mid rapidity); $\lesssim 10$ MeV/c (forward)
- **MAPS detector systems:** 12 layer + CMOS-disks + Cherenkov detectors

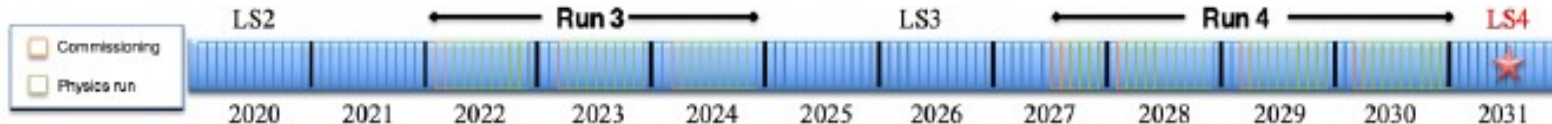
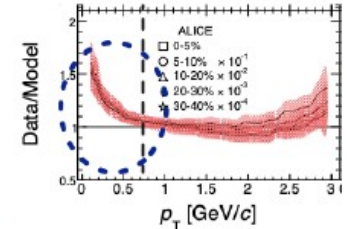
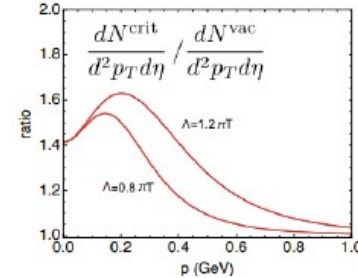
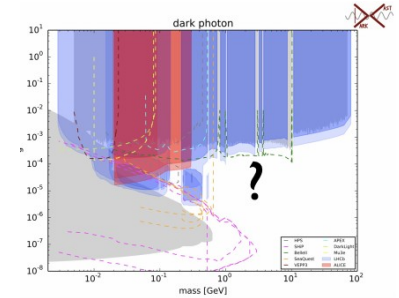


ALICE3 Letter of Intent

- **Electron ID:** Low-mass di-electron spectrum:
 - $50 \text{ MeV}/c < p_T < 3 \text{ GeV}/c$
- **Hadron ID:** Heavy Flavor (secondary vertex)
 - $50 \text{ MeV}/c < p_T < 5 \text{ GeV}/c$, $\pi/K/p$ ID with 3sigma
- **Photon detection:** ultra low energy photons, calorimetry for $10 \text{ MeV}/c < p_T < 100 \text{ MeV}/c$
- **Primary vertex:** with mm resolution: bend silicon pixel technology
- **MuonID:** Search for quarkonia & exotic hadrons: precise muon detection around $\sim 1 \text{ GeV}/c$



Xe-Xe, $\sqrt{s_{NN}} = 5.86 \text{ TeV}$, Pythia8 / Angantyr



ALICE3 Letter of Intent

- ✓ Physics, analysis, performance simulations
- Contribution to the ALICE3 Lol:
E. Frajna, R. Vértési

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH



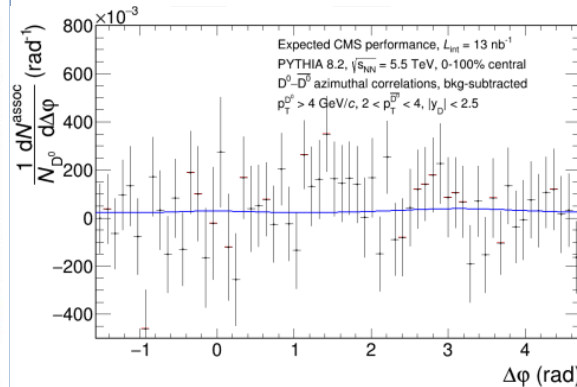
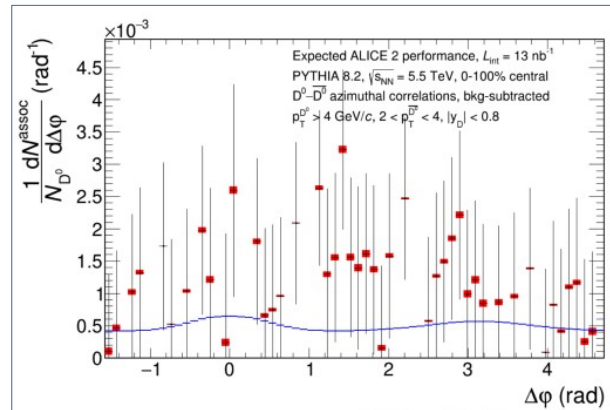
CERN-LHCC-2021-xxx
ALICE-PUBLIC-2021-xxx

3.3.1.5 $D^0\bar{D}^0$ azimuthal correlations Azimuthal correlations of $D^0\bar{D}^0$ pairs in Pb-Pb collisions provide a direct measure of momentum broadening by the QGP, which is sensitive to the

**Letter of Intent:
ALICE 3**

Draft v4
Monday 24th January, 2022

ALICE Collaboration

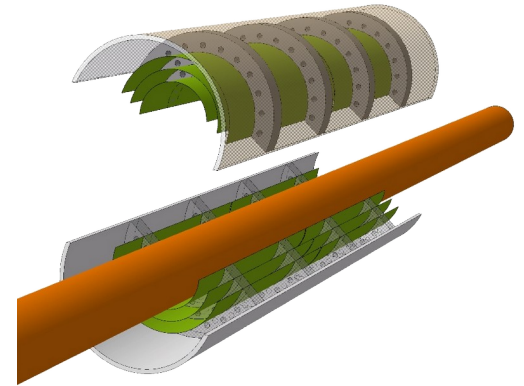
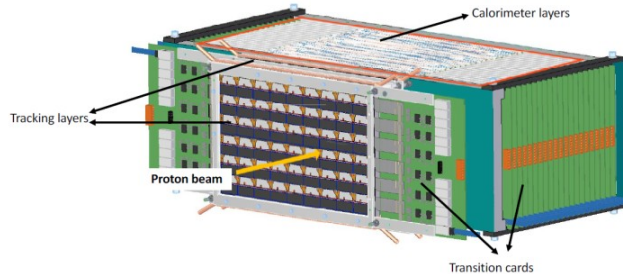


EVEN MORE?

ALICE Technology Transfer → Medical Application

HADRON THERAPY R&D

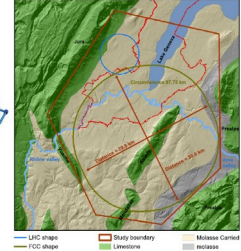
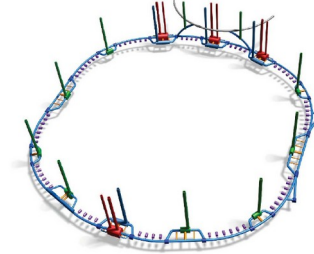
- ✓ Detector UG & Medical applications (Á. Sudár, M. Varga-Kőfaragó, GGB)
 - ITS3 → ALICE3 MAPS technology, DAQ systems, cooling
 - Bergen Proton CT collaboration
 - RICH technologies (earlier HMPID/VHMPID group)



Front. in Phys. Med. Phys. Im. ID: 568243,
Nucl. Instrum. Methods Phys. Res. Im. ID: 162626

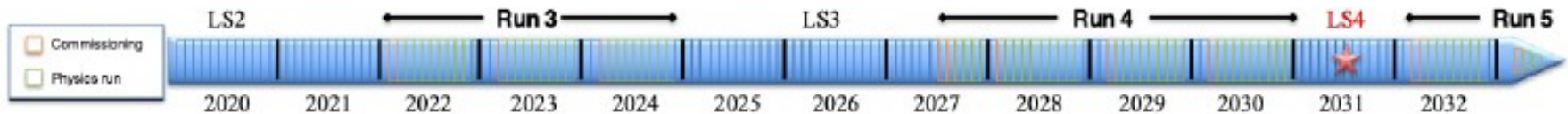
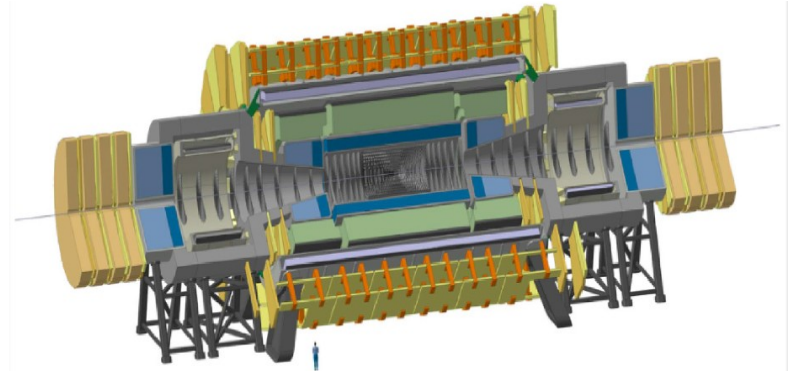
Participation in FCC-hh heavy-ion programme planning

- **FCC-hh**: A general purpose ,100km circumference hadron collider → proposal for detector optimized for heavy-ion programme



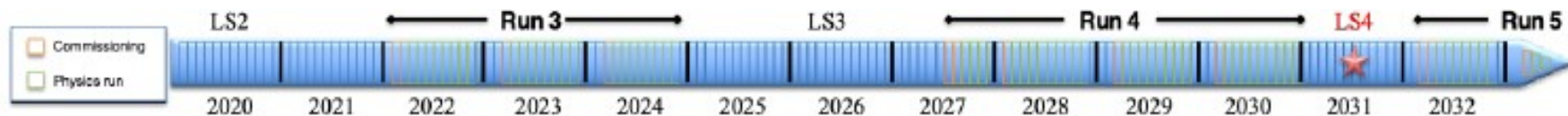
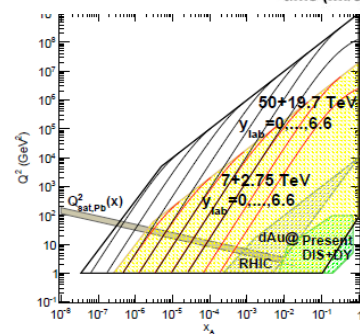
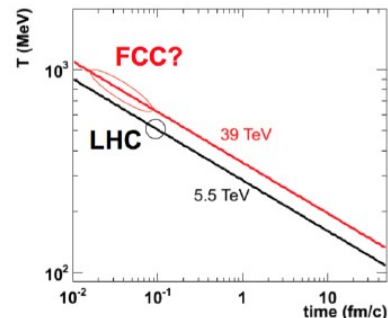
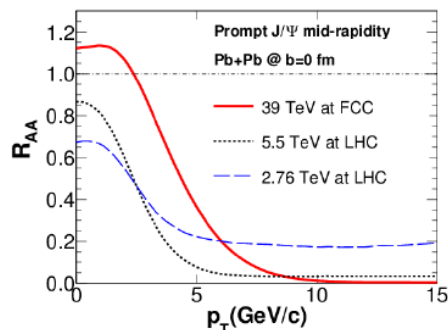
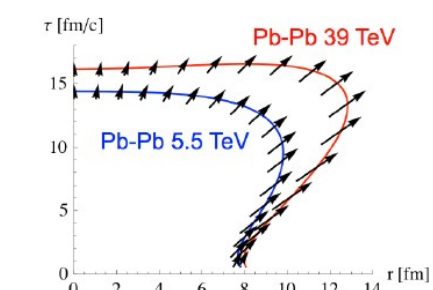
System	$\sqrt{s_{NN}}$	\mathcal{L}_{int}	$t\bar{t} \rightarrow b\bar{b}l\bar{l}\nu\nu$	$tW \rightarrow bll\nu\nu$
Pb–Pb	39 TeV	33 nb ⁻¹	3.1×10^5	8.6×10^3
p–Pb	63 TeV	8 pb ⁻¹	8×10^5	2.1×10^4

Quantity	Pb–Pb 2.76 TeV	Pb–Pb 5.5 TeV	Pb–Pb 39 TeV
$dN_{ch}/d\eta$ at $\eta = 0$	1600	2000	3600
Total N_{ch}	17000	23000	50000
$dE_T/d\eta$ at $\eta = 0$	1.8–2.0 TeV	2.3–2.6 TeV	5.2–5.8 TeV
Homogeneity volume	5000 fm ³	6200 fm ³	11000 fm ³
Decoupling time	10 fm/c	11 fm/c	13 fm/c
ε at $\tau = 1$ fm/c	12–13 GeV/fm ³	16–17 GeV/fm ³	35–40 GeV/fm ³



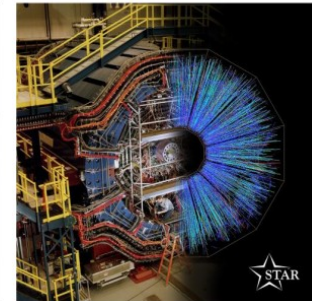
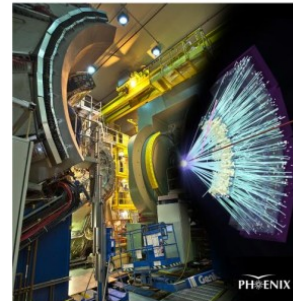
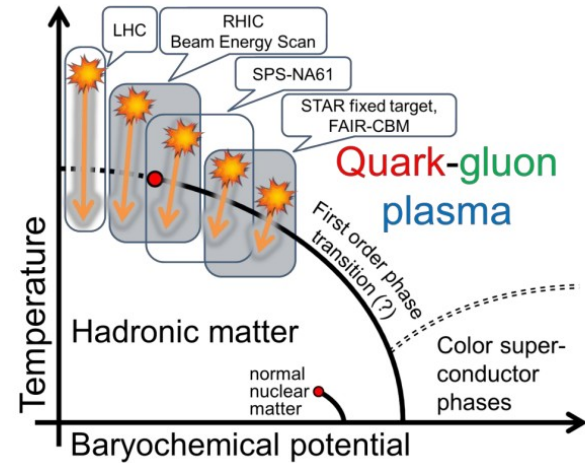
Participation in FCC-hh heavy-ion programme planning

- **An order of magnitude higher c.m. energy:** Testing the primordial matter EoS at unknown energy regimes.
- **Heavy quark production:** top physics beside beauty and bottom.
- **Small-x physics:** New regimes for PDF/FF.
- **→ Nuclear effects with new HI MC generator, HIJING++ (new, fast, parallel)**



Heavy-ion Research at RHIC (M Csanád)

- Goal: explore the QCD phase diagram
 - Cover largest part of landscape, SPS-RHIC-LHC
- Hungarian participation:
 - PHENIX (disassembled) + STAR (data taking)
 - 3 institutes: Eötvös U, Wigner, MATE
 - 4 staff, 1 postdoc, 1 PhD + 1 MSc + 1 BSc
 - Covered by NRDI grants (OTKA, TÉT, TKP)
- Research topics:
 - Femtoscopy, quantum statistics
 - Critical point search
 - Hydrodynamics and flow, small QGP droplets



Summary: Heavy-ion Research with ALICE

STRENGTH

- Well-defined physical programme
- Relevant group, good local experts
- New technological challenges
- Supportive environment

WEAKNESS & RISKS

- Lack of stability
- Low salaries
- Eastern-European effects



To infinity and beyond! - Buzz Lightyear

The Hungarian ALICE Group (2002-2022)



Support: NKFIH/OTKA FK131979, K135515, NEMZ_KI-2019-00011

Web: <http://alice.wigner.hu>, <http://alice.web.cern.ch>