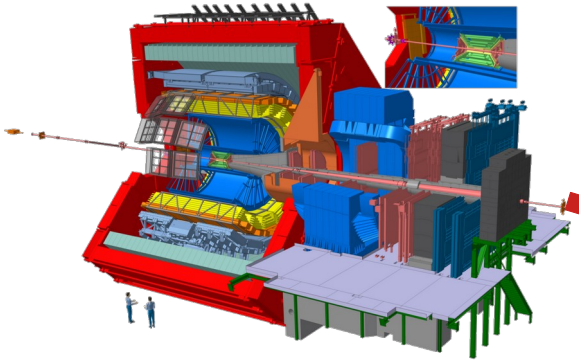
Heavy-ion Research at the Wigner Research Centre for Physics

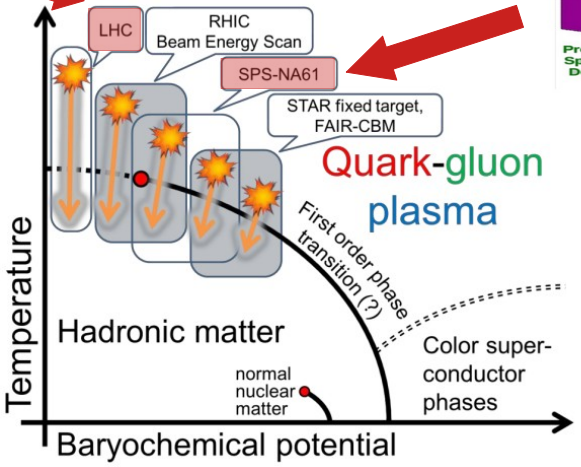
Róbert Vértesi & Gergely Gábor Barnaföldi,
Wigner RCP, CERN ALICE
Grants: NKFIK OTKA K135515, NEMZ_KI 2022-00007,8,9, FK131979

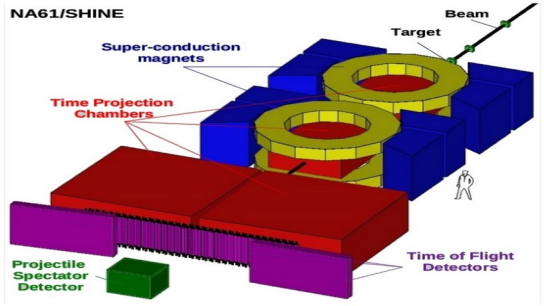
NuPECC, ATOMKI, Debrecen, 31st May 2023

High-enegy Heavy-ion Research at the Wigner RCP

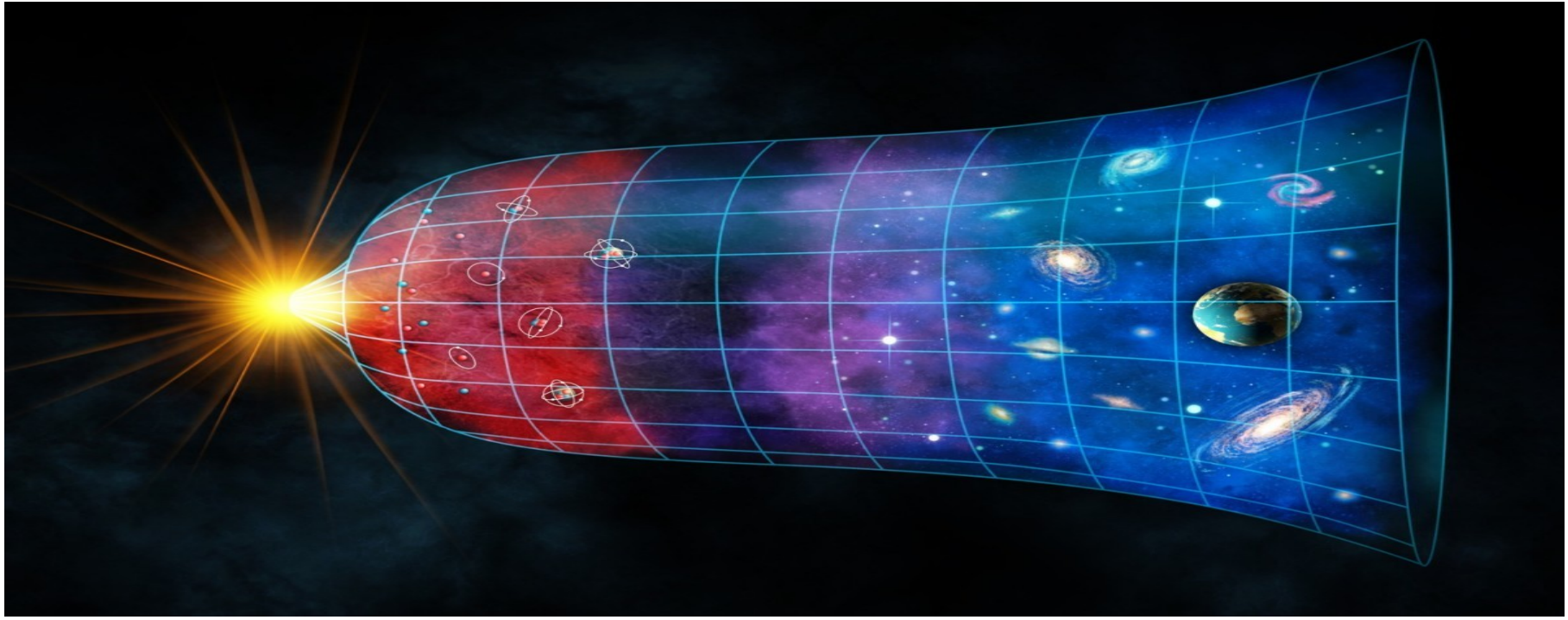
Aime: Exploring the QCD matter in the hot regions...





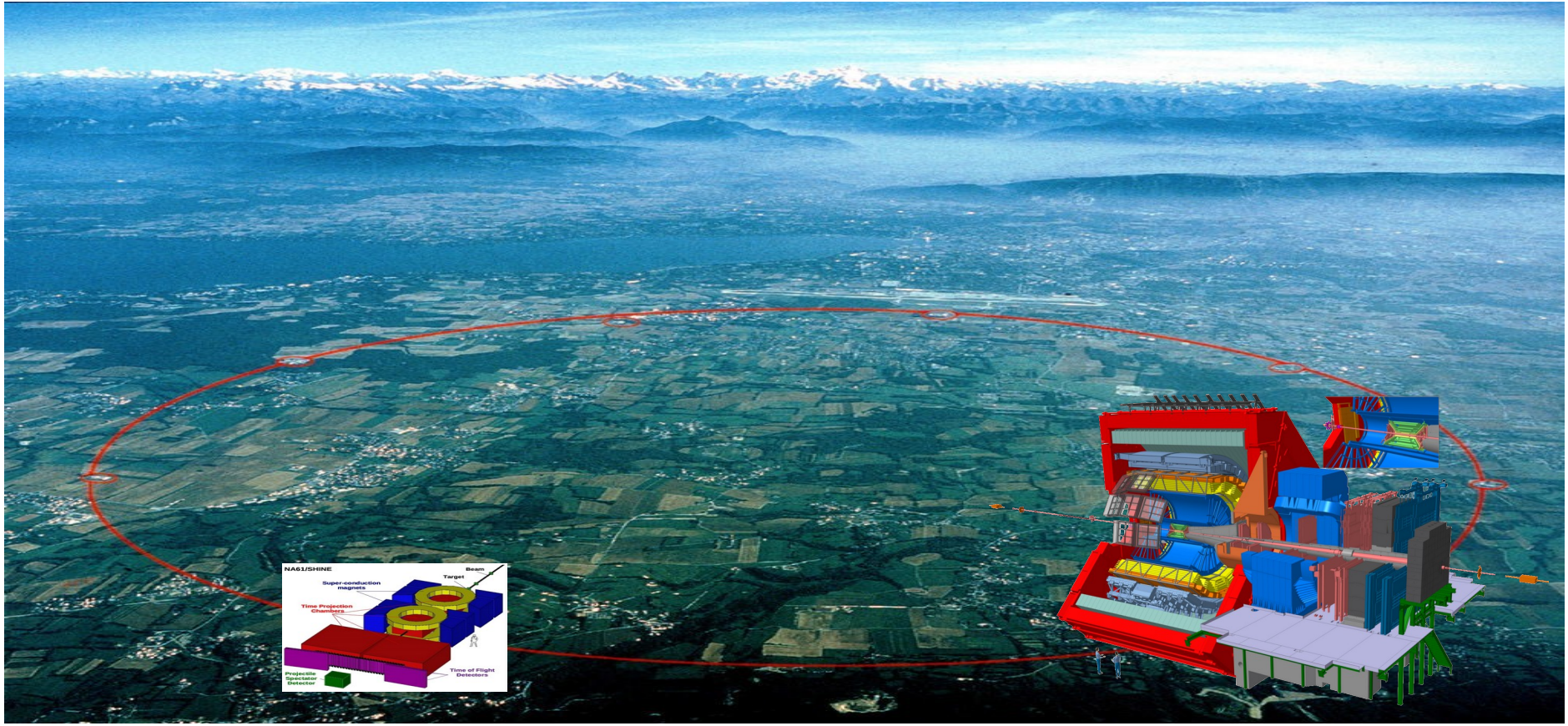


Why: Investigating the primordial matter of the Universe

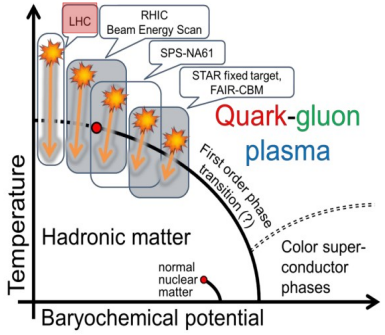


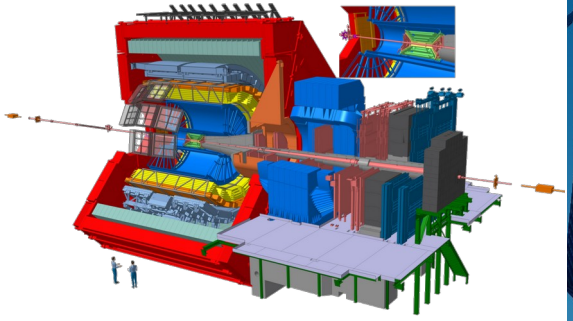
The Universe is 13.7 billion years old? How was it milliseconds after the Big Bang?

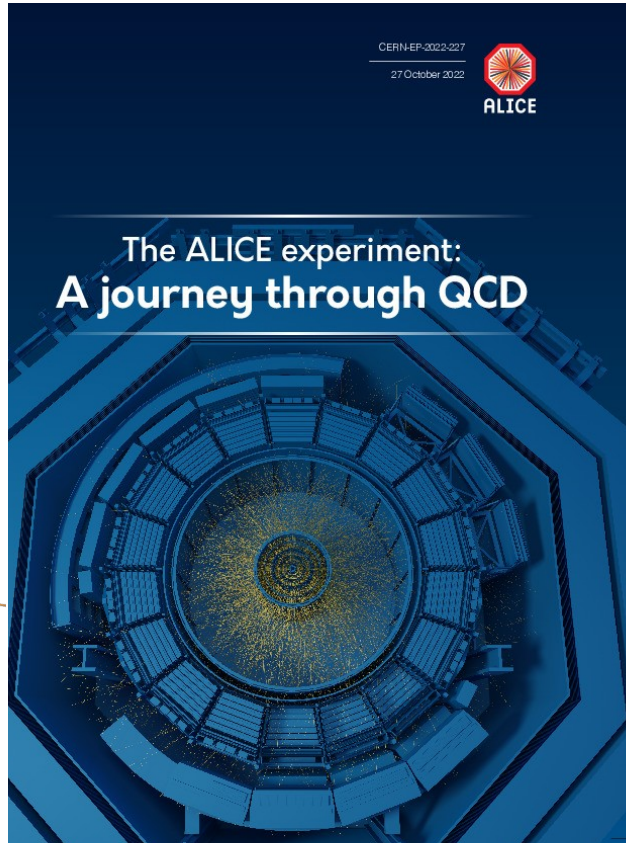
Devices: A Large Ion Collider Experiment & NA61, CERN LHC



1) 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 LoI 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

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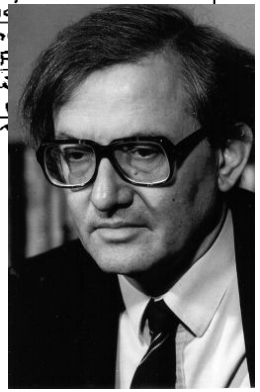
	CASTOR	



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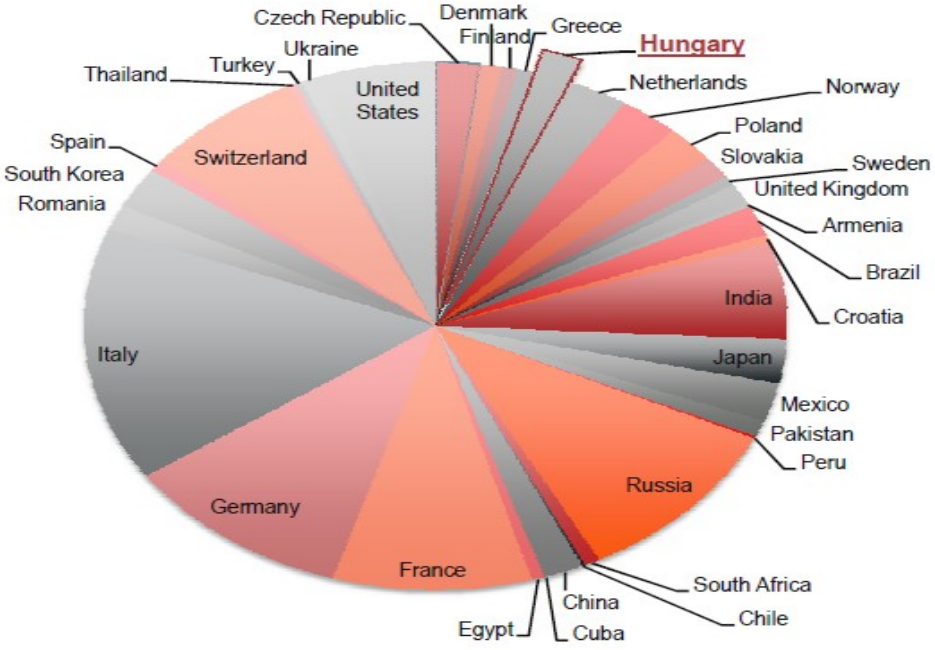
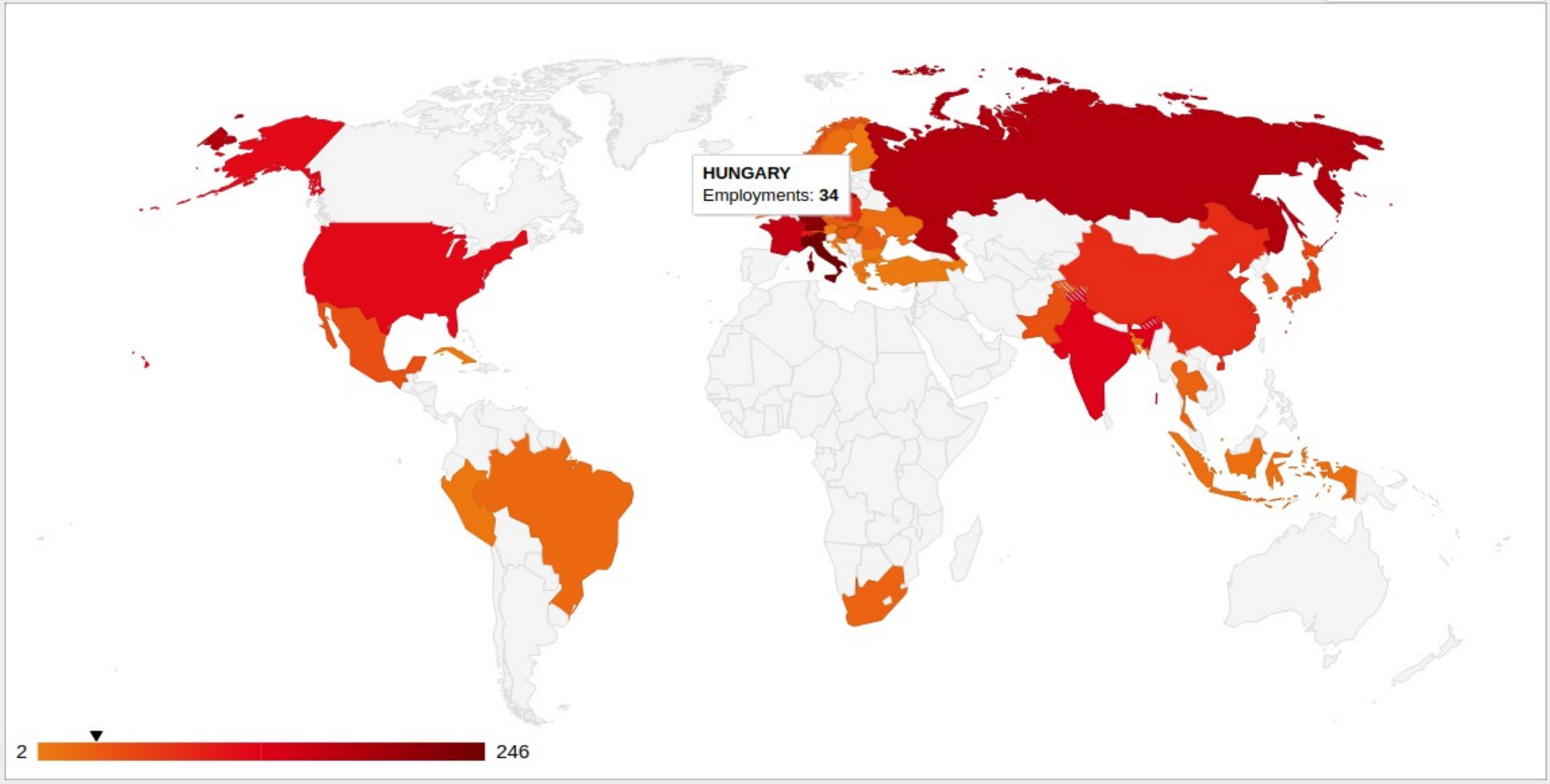
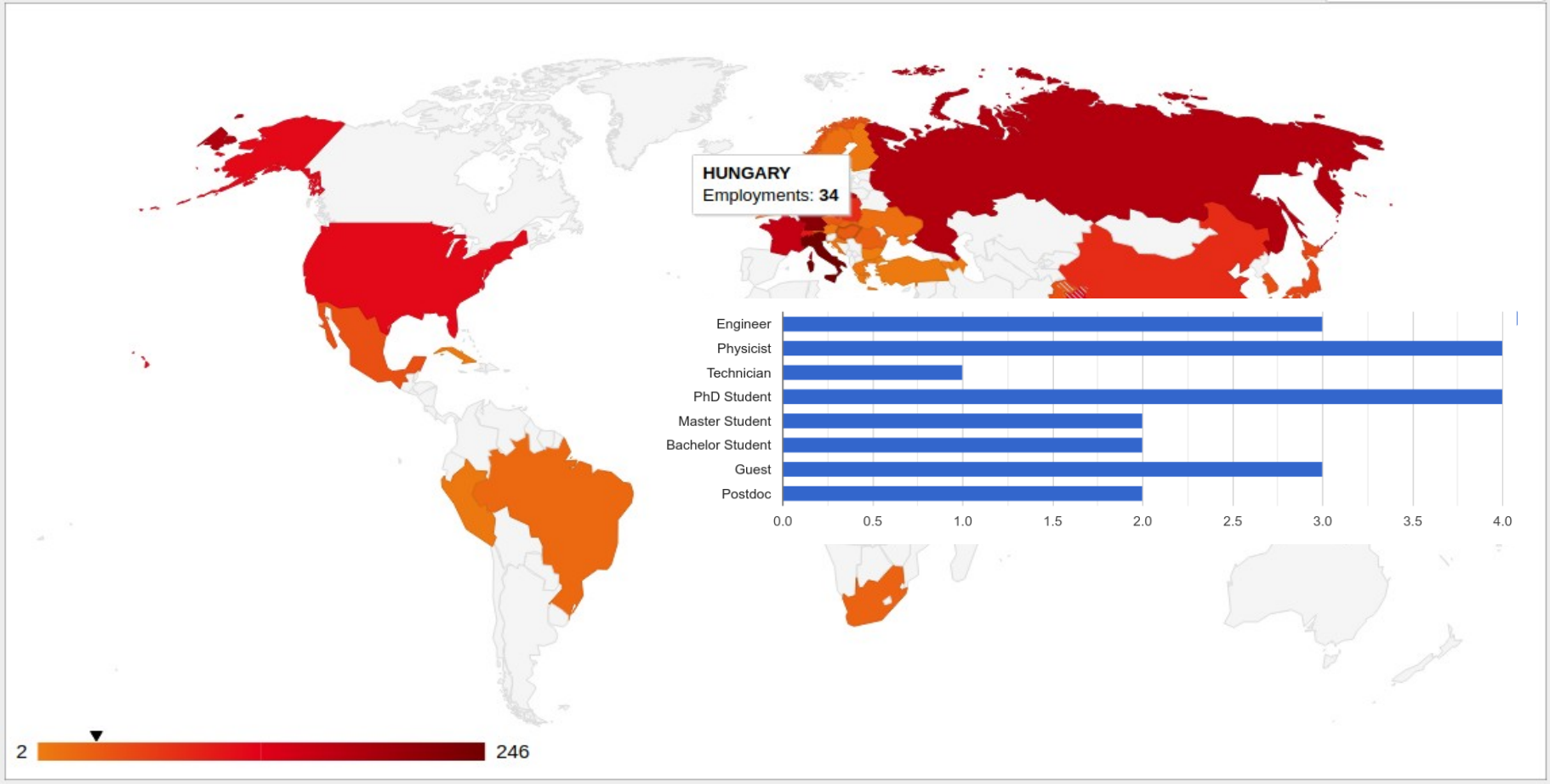


Who: Hungarian ALICE Group

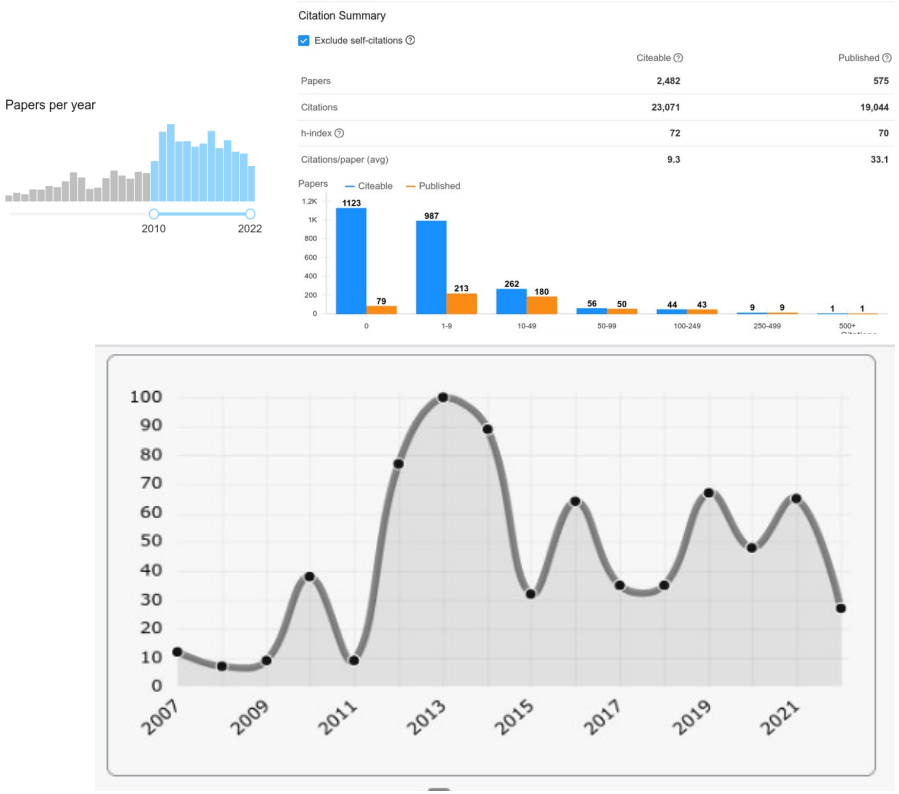


Who: Hungarian ALICE Group



Who: Hungarian ALICE Group (2010-2022)

- ✓ Q1-Q2 publications: 600+
- ✓ Total publications: 2500+
- ✓ PhD researches: 16
- ✓ Msc/Bsc works: 30
- ✓ National Competition (TDK) 20
- ✓ Posters 55+
- ✓ Conference contributions: 165+
- ✓ Prizes 9



Who: Hungarian ALICE Group (2010-2023)

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

- ✓ MNO-A & B for 6 scientists 9kCHF/MNO-A/years + students
- ✓ Related NRDIO grants

Running: 2020-2024:K135515, 2019-2023:FK131979, 2020-2023:2019-2.1.11-TÉT-2019-00050, 2023:2021-4.1.2-NEMZ_KI-2022-00007, 2023:2021-4.1.2-NEMZ_KI-2022-00009, 2023:2021-4.1.2-NEMZ_KI-2022-00018

Past: 2020-2022:2019-2.1.11-TÉT-2019-00078, 2020-2022:2019-2.1.6-NEMZ_KI-2019-00011, 2016-2020:K120660, 2012-2016:NK106119, 2009-2013:NK77816, 2009-2013:CK77815, 2007-2010:H07-C 70464, 2007-2008:IN 71374, 2006-2009:NK62044

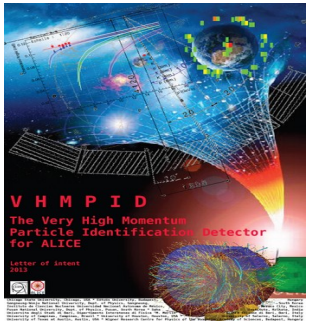
Who: Hungarian ALICE Group (2010-2023)

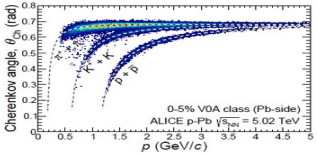
Further investment into ALICE projects by Hungary (salary of employed team members and experts, laboratories, etc.) during the period of 2009-2022:

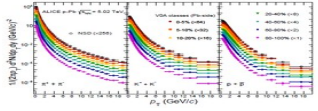
- ✓ VHMPID project: 1’000 kCHF → Letter of Intent, EPJ Plus 129 (2014) 91
- ✓ HMPID project: 200 kCHF (detector in operation 2009-2013, 20kCHF 2013-2022
- ✓ DAQ Upgrade: 50 kCHF (during the period 2009-2013)
- ✓ TPC Upgrade: 150 kCHF (Wigner Innovative Detector Laboratory, 2013)
- ✓ 200 kCHF for TPC upgrade cost (2014-2022)
- ✓ 20 kCHF yearly upgrade & other costs for (2022-2024)

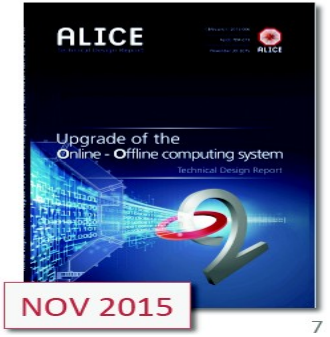
Directions: Hungarian ALICE Group (2010-2023)

1. Strong theoretical background in heavy-ion physics → Experiment & Theory (See Gy. Wolf)
2. Strong participation in R&D activity → LoI preparation and deliverables
3. Strong participation in data analysis → QGP: PID hadron spectra, Heavy Flavor physics, jet physics, correlations
4. Active in data taking → ALICE ROS, Remote Operation Site @ Wigner, Software & hardware development.
5. Leading role in Physics Analysis Groups → PWG-Heavy Flavour & Jets (R. Vértesi), PWG-MM Multiplicity (Gy. Bencédi), activity in IRCs



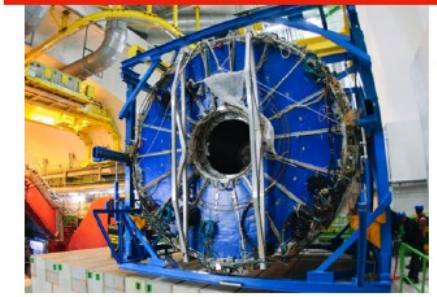


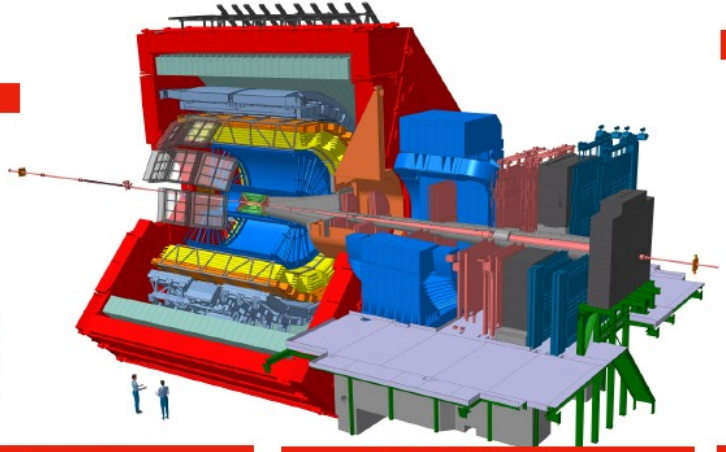




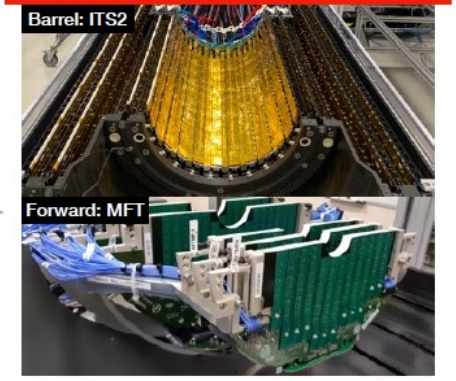
Recent: R&D ALICE LS2 R&D

GEM-based TPC

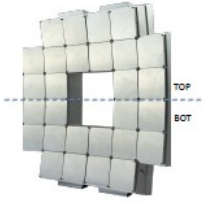




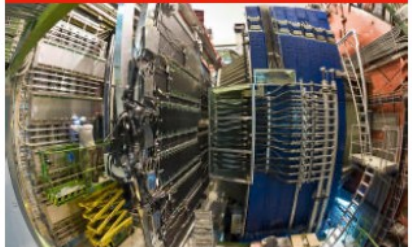
ALPIDE-based Monolithic Silicon Detectors



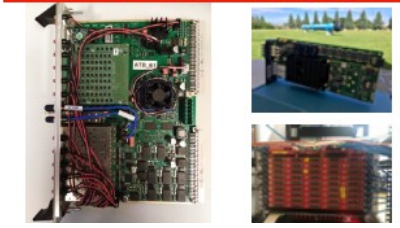
Fast interaction trigger (FIT)



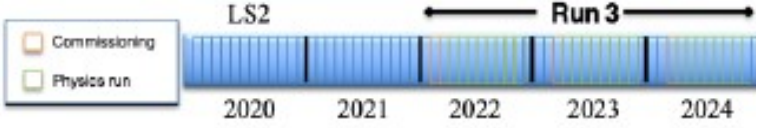
Muon Spectrometer



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

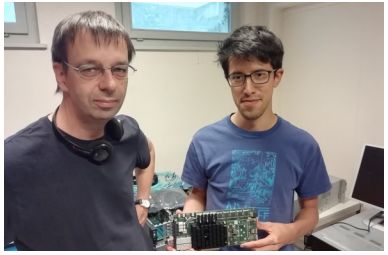


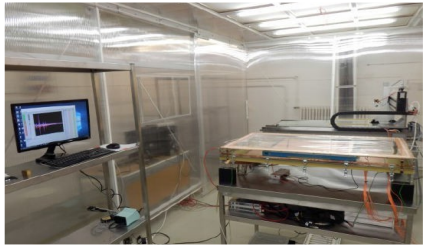
New computing infrastructure and framework: O2

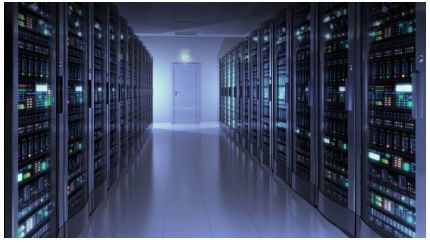


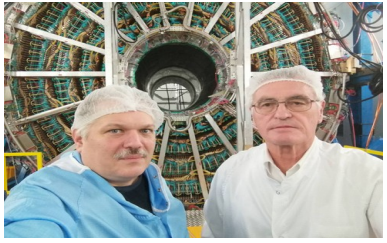
Recent: ALICE LS2 R&D – the Hungarian Contribution

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: 90m^3
3. Inner tracking system (ITS2) upgrade (silicon-pixel MAPS technology) test → 10m^2 & 13Gpixel
4. Big Data: First large scale Specialized Analysis Facility @ WDC → 100 PB adat
5. Data Analysis & software developments → 100 000 line of code









Now: ALICE Data Analysis – direct contributions

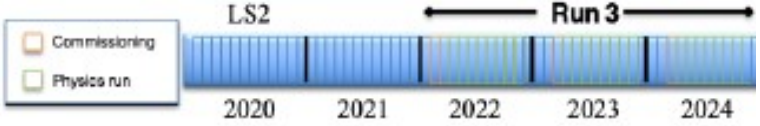
- **Light meson production, PID hadron spectra in pp at 7 and 13 TeV**
- **→ EPJC 81 256 (2021**

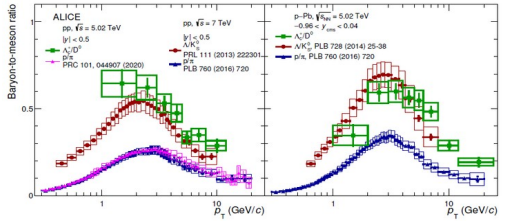
- **Heavy Flavour: b-jet production in pp & pPb:**
- **→ JHEP01 (2022)178**

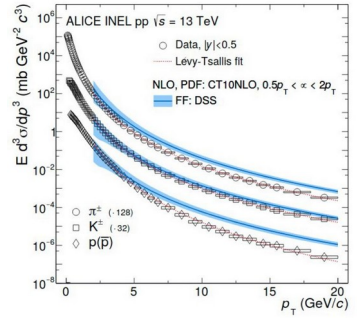
- **Investigating the charm hadron production (Λ_c/D ratio & DD correlations)**
- **→ EPJC82 335 (2022)**

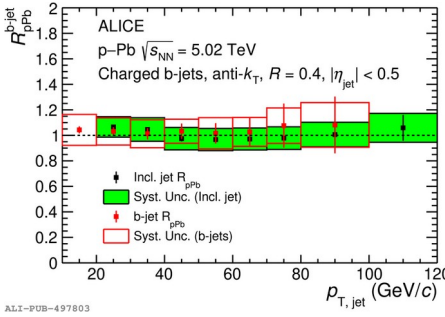
- **New: Underlying event & Heavy flavor production in XeXe and PbPb collisions**

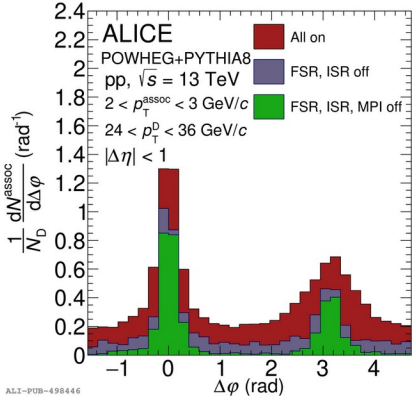
- **See full list of the group**











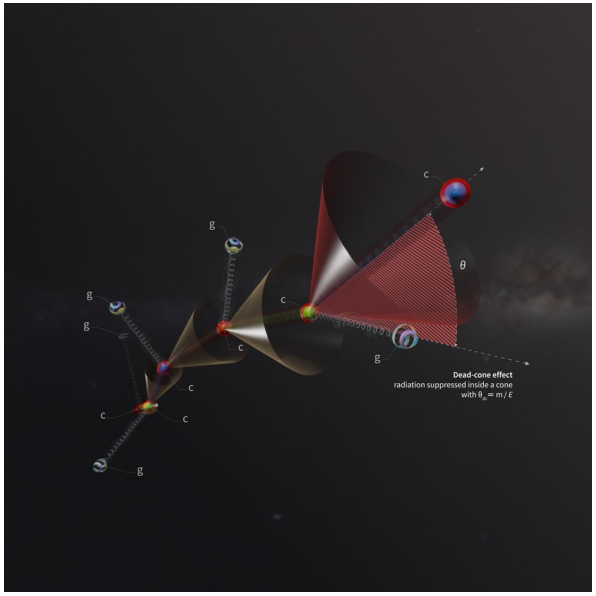
Now: ALICE's High-impact HF result (2022)

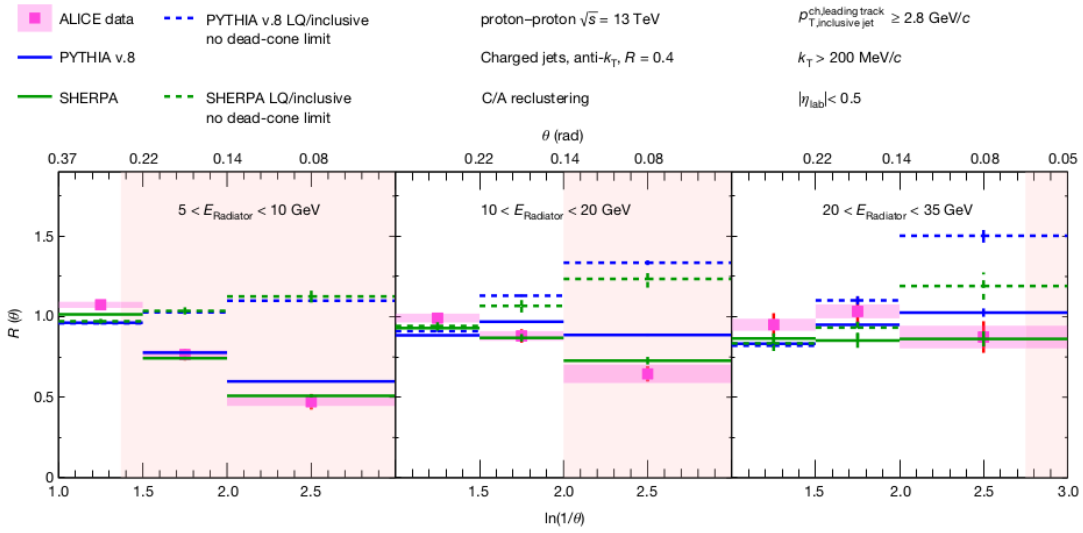
Direct observation of the dead-cone effect in quantum chromodynamics

https://doi.org/10.1038/s41586-022-04572-w

ALICE Collaboration*✉

nature

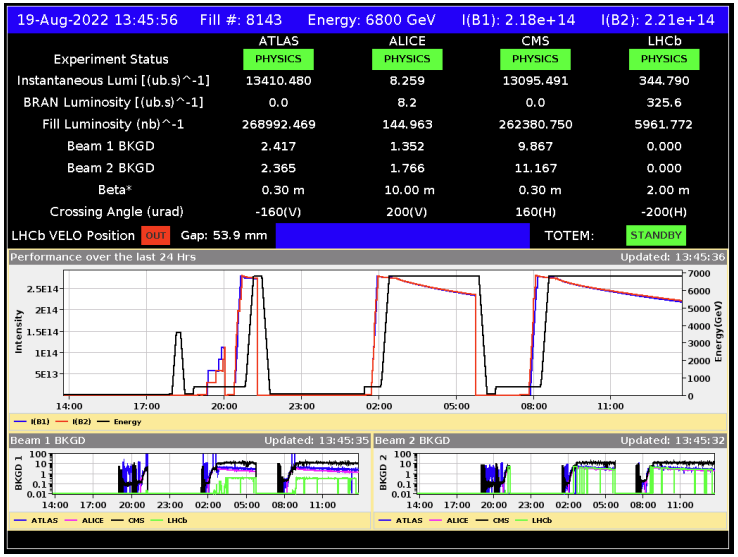


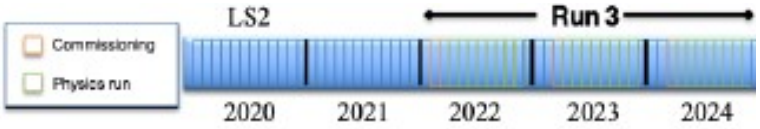


$$R(\theta) = \frac{1}{N^{\mathrm{D}^0\,\text{jets}}} \frac{\mathrm{d}n^{\mathrm{D}^0\,\text{jets}}}{\mathrm{d}\ln(1/\theta)} \Big/ \frac{1}{N^{\text{inclusive jets}}} \frac{\mathrm{d}n^{\text{inclusive jets}}}{\mathrm{d}\ln(1/\theta)} \Bigg|_{k_T, E_{\text{Radiator}}}$$

Now: ALICE LS2 R&D + Ongoing Run3

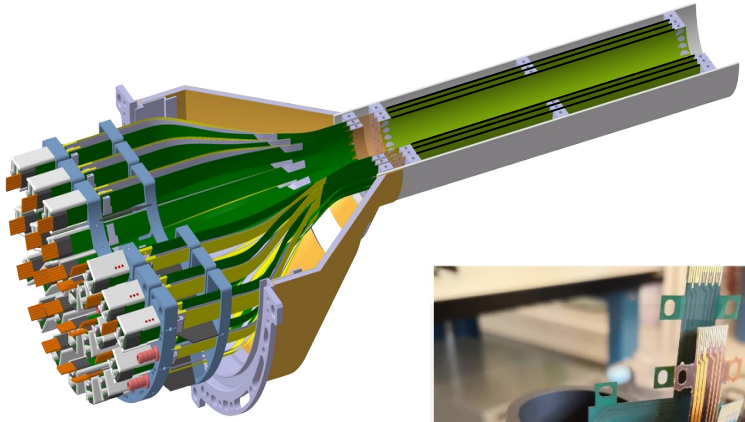
- More precise pesudo-rapidity distributiuon measurememnts, PID hadron spectra
- Jet-structure measurements: jet-fragmentation, hadronization, pp, pPb
- Deuteron-production: testing coalescence model
- Investigating the charm hadron production (Λc/D ratio & DD correlations)
- Heavy flavor production in XeXe and PbPb collisions (2023Q3 finally)!
- Status of today?

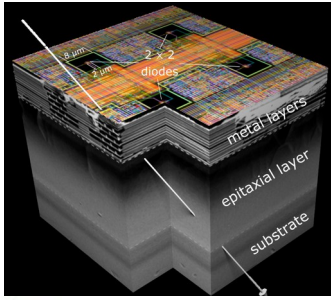


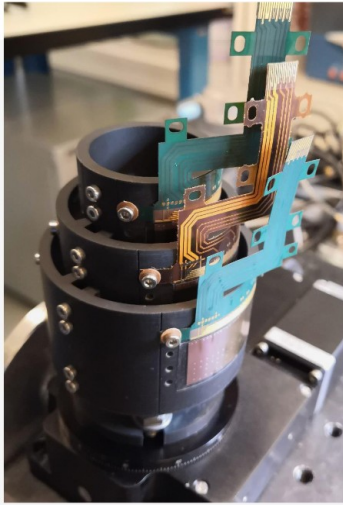


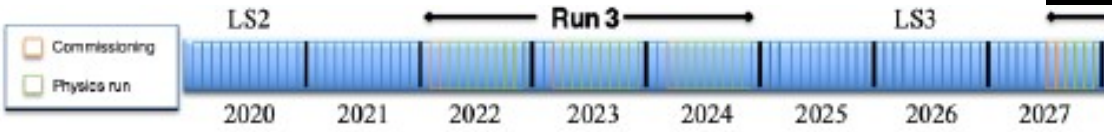
Next: R&Ds for the LS3 period

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









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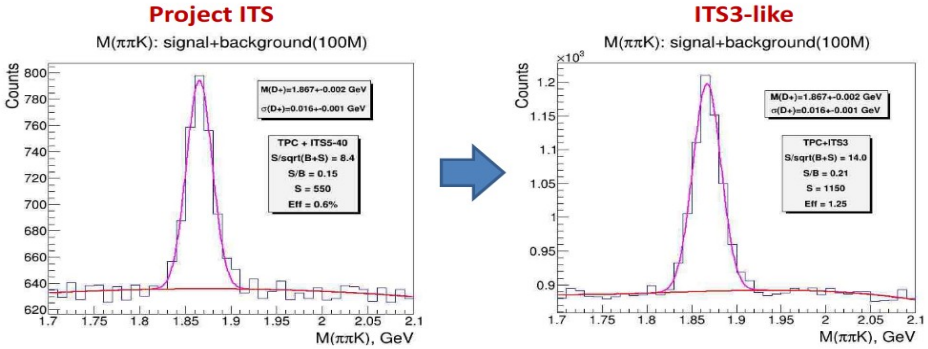
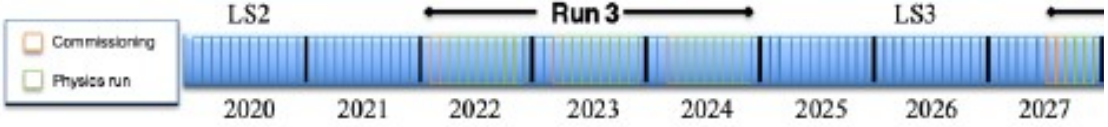
- **ITS3: bendt silicon pixel detector technology: MAPS has been tested at DESY. (Our task: Cooling simulations ITS3 WP5)**
- **Detector-part tests + DAQ-system R&D**
- **Better then 2x more precise heavy flavor measurements: fine structure of the jets, measuring fragmentation & hadronization.**

D^+ reconstruction efficiency with ITS3-like model



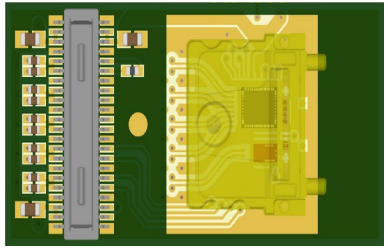
ITS	S	S/B	$S/\sqrt{S+B}$	Eff,%
Project	550	0.15	8.4	0.60
ITS3-like	1150	0.21	14.0	1.26

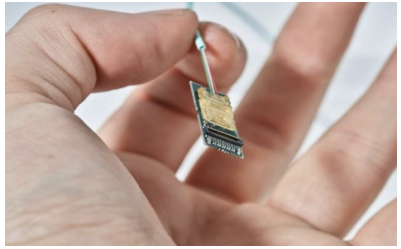


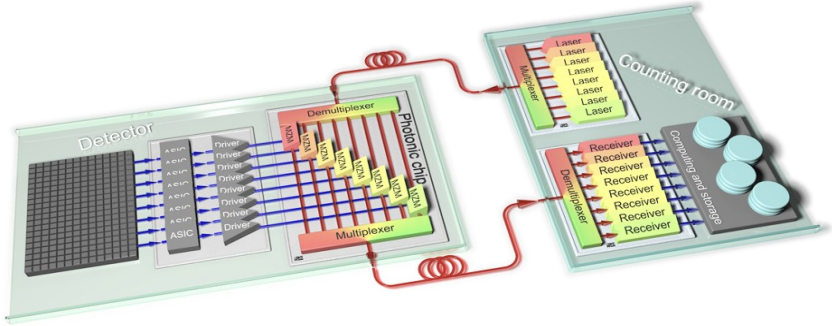
Next: R&Ds for the LS3 period

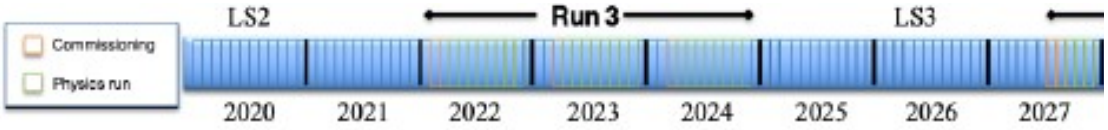
- **New radiation tolerant DAQ system R&D**

- **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**



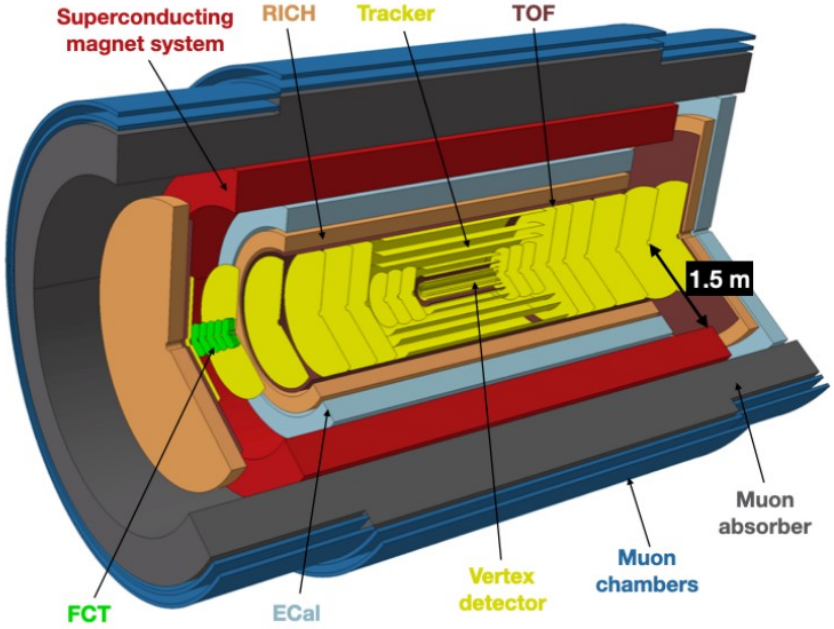


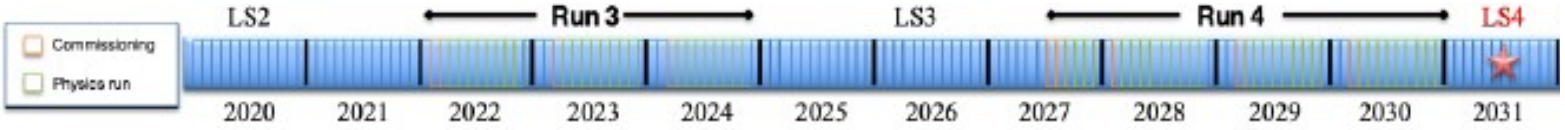




Future: ALICE3 Letter of Intent

- **Physics: Test of principles of quantum field theory (QFT), in medium effects (QCD chiral symmetry restoration, exotic hadrons, DM).**
- **Large Acceptance: Δη = 8**
- **PID: TOF 20 ps time resolution, aeroge-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**





Future: ALICE3 Letter of Intent

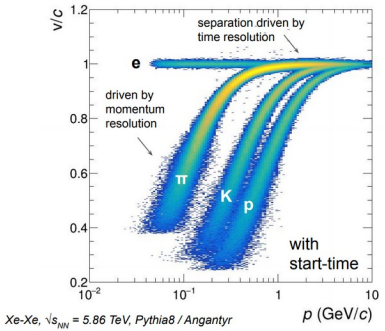
- **Electron ID**: Low-mass di-electron spektum:
- 50 MeV/c < pT < 3 GeV/c

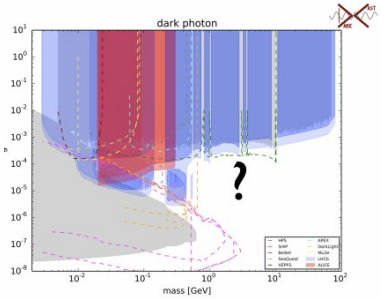
- **Hadron ID**: Heavy Flavor (secondary vertex)
- 50 MeV/c < p_T < 5 GeV/c, π/K/p ID with 3sigma

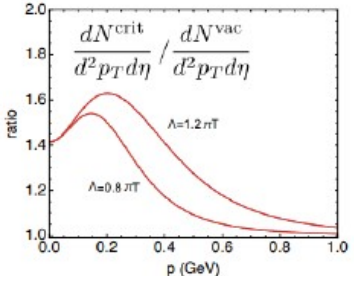
- **Photon detection**: ultra low energy photons,
- calorimetry for 10 MeV/c < p_T < 100 MeV/c

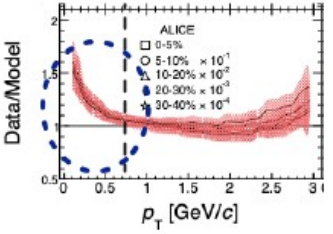
- **Primary vertex:** with mm resolution: bendt silicon pixel technology

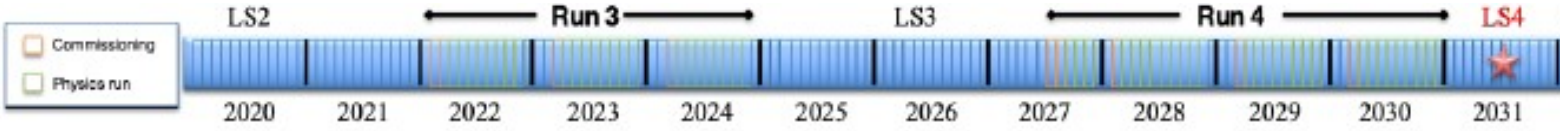
- **MuonID**: Search for quarkonia & exotic hadrons: precise muon detection around ~1 GeV/c







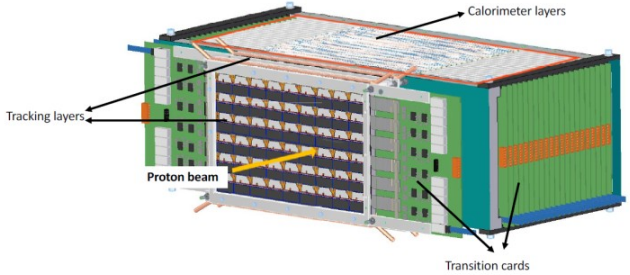




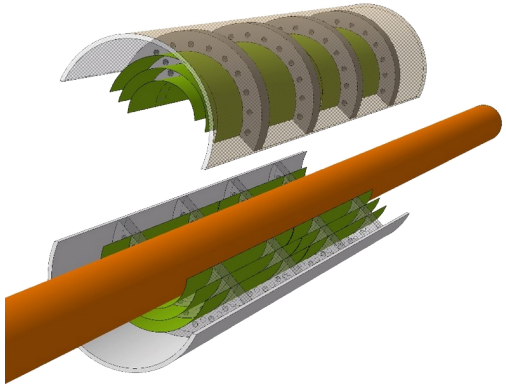
ALICE Technology Transfer → Medical Application

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



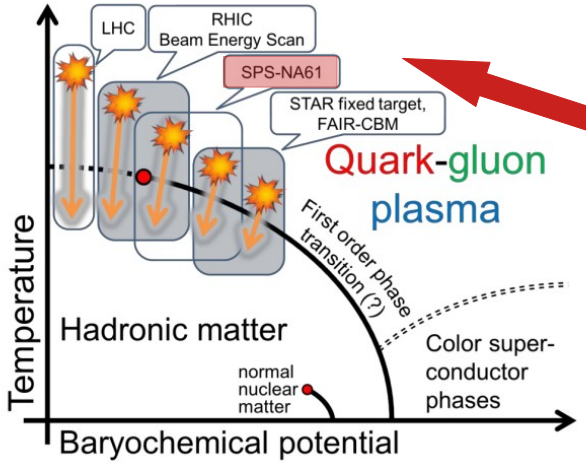
Hungarian ALICE Group (2002-2023)

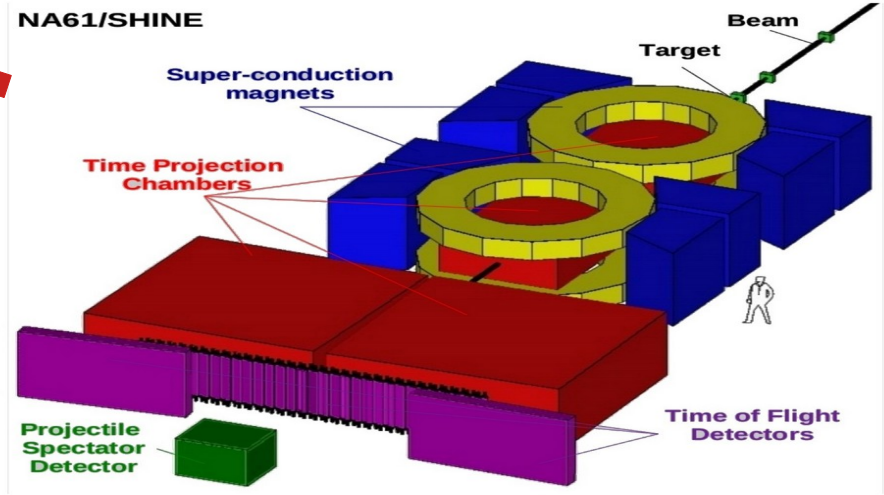
Support: NKFIH/OTKA FK131979, K135515, NEMZ_KI-2022-00009

Local Hungarian Web: http://alice.wigner.hu, http://alice.web.cern.ch

2) NA61/SHINE, CERN SPS

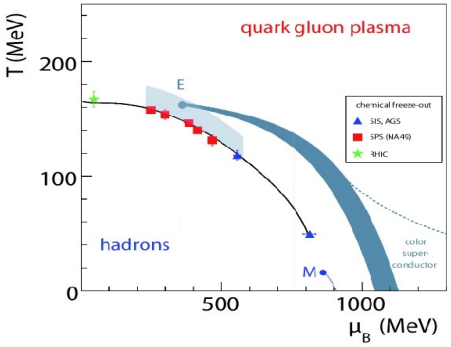
- *SHINE: SPS Heavy-Ion and Neutrino Experiment*

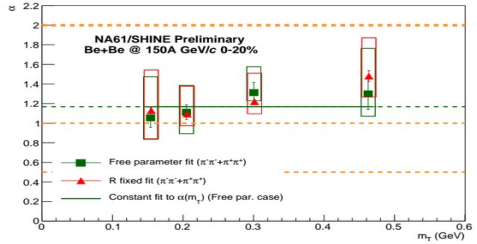


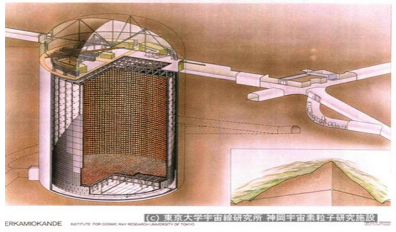


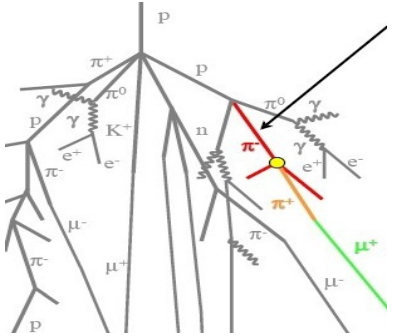
Device: NA61/SHINE Experiment

- NA61 is a large acceptance hadron spectrometer experiment at the CERN SPS. Main tracking components: 40m^3 TPC system.
- Main physics goals are to measure:
  - Hadronic spectra and fluctuactions in A+A for studying Onset of Deconfinement and searching for Critical Point in strong interactions, intermediate p_T physics in p+p,p+A,A+A, open charm measurement
  - Reference hadron spectra in p+A for DUNE, T2K (ν-beams)
  - Reference hadron spectra in π^-+A for the Pierre Auger Obs.









Who: Hungarian NA49, NA61/SHINE Group

- Past: NA49: earliest participation in the CERN's HI programme
- Present: Hungarian group is present in NA61 since its proposal.
  - Main interest is p+p and p+A physics, BE correlations in A+A, h+A hadron spectra for ν-beam experiments, detector devel.
  - Members: András László (Wigner, physicist, TL), Yoshikazu Nagai (ELTE, physicist, TL), Máté Csanád (ELTE, physicist), Ádám Gera (Wigner, engineer), Tivadar Kiss (Wigner, electronic engineer, DTL), Krisztina Márton (Wigner, PhD student), Botond Pálfi (Wigner, BSc student), Barnabás Pórfy (ELTE-Wigner, PhD student), Z.Fodor and G.Pálla (Wigner, emeritus physicists)
  - Close collaboration with Vesztergombi High Energy Physics Laboratory at Wigner RCP:

    Ferenc Siklér (contact), Dezső Varga (gaseous det.) et

Who: Hungarian NA49, NA61/SHINE Group

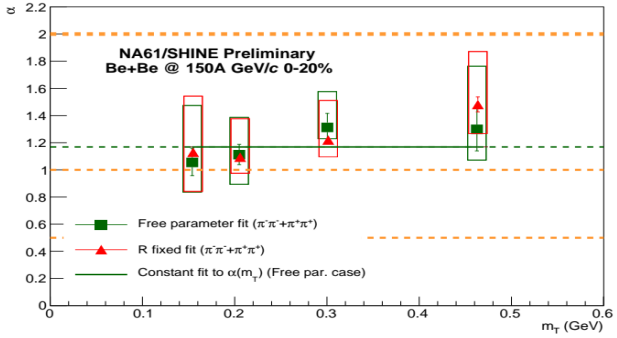
- Responsibilities within the experiment:
  - detector board coordinator, safety: Zoltán Fodor
  - software board & wg deputy coordinator: Yoshikazu Nagai
  - TPC calibration wg deputy coordinator: András László
  - active sw developers: Yoshikazu Nagai, András László
  - low-energy beamline coordinator: Yoshikazu Nagai
  - [former DAQ/online coordinator, until LS2: András László]

Who: Hungarian NA61/SHINE Group

- *Funding grants*:
  - FK123842-123959 (2017-2021): 46kCHF, over 4 years.
  - K138136-138152 (2021-2025): 58kCHF, over 4 years.
  - (NKFIH/OTKA: Hungarian Scientific Research Fund)
  - Largely used for M&O coverage, travels.
  - TKP2021-NK (NRDI Fund): joint use of VLAB infrastructure

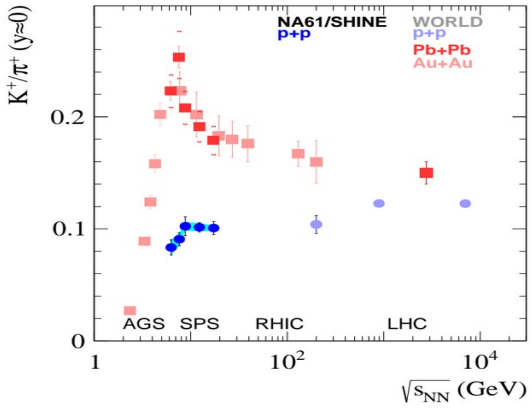
Results: Contributions of the Hungarian NA61/SHINE Group

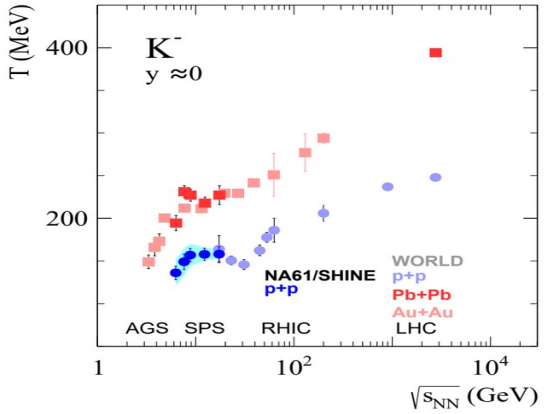
- [p+p, p+A physics part in EOI, LOI, Proposal]
- [specific detector development for p+A]
- [design, realization, operation of DAQ (until LS2), offline sw]
- analysis for Bose-Einstein correlations in A+A to scan E-A dep.
- change in Lévy exponent α as indicator of CEP
- Related PHENIX+STAR @ RHIC to explore phase diagram → M Csanád's talk



Recent: Heavy-ion physics with NA61/SHINE Group

- Change of energy dependence of hadronic observables around SPS energies in A+A.

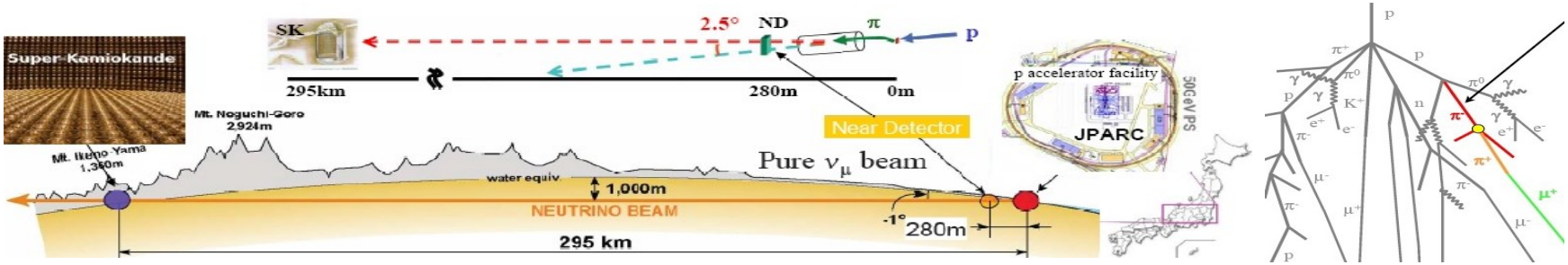




- Lattice QCD indicates existence of a critical point of strongly interacting matter at freeze-out termperatures forseen to be accessible around SPS energies.
- NA61 is searching for CP and is studying OoD by performing an E—A scan program with large statistics, optimal acceptance [PRC102(2020)011901].

Recent: Neutrino & CR physics with NA61/SHINE Group

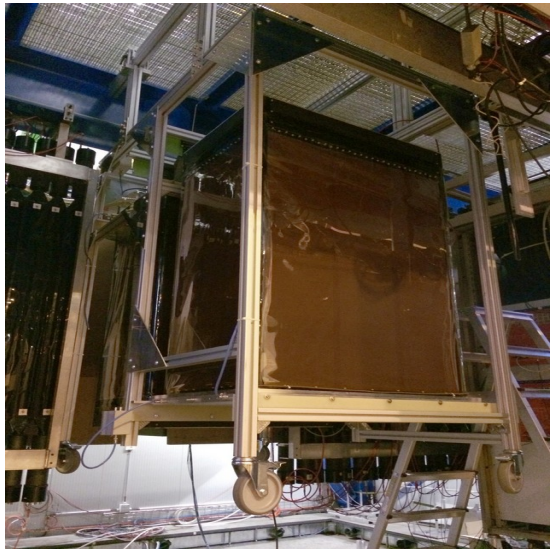
- In ν-beam experiments, such as T2K, mesons are produced with a proton beam on a production target. Neutrinos are produced from decay of mesons. Precise knowledge is needed on the meson production cross section differentiated in momentum space. NA61 provides these p+A reference spectra.

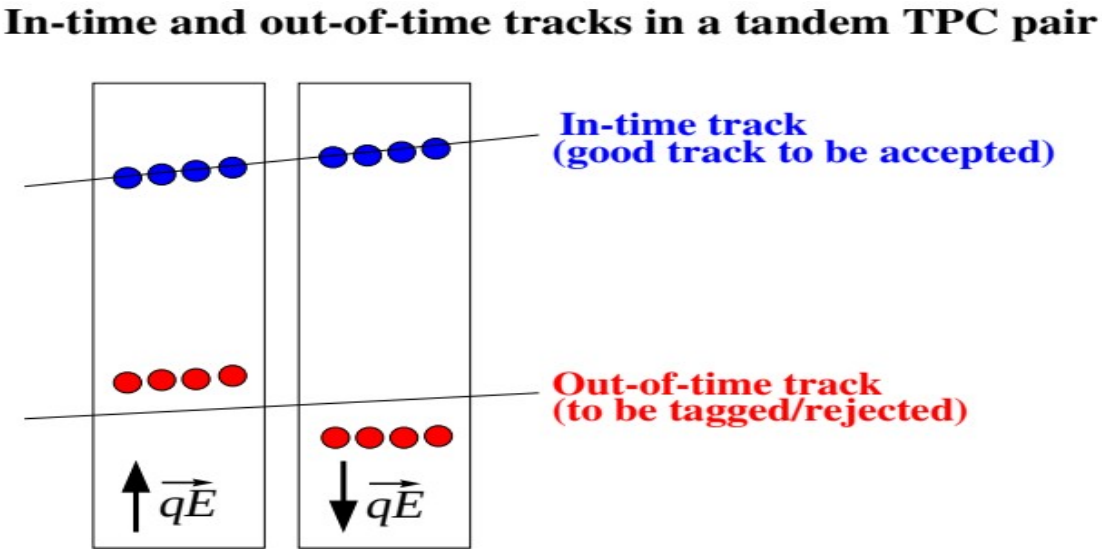


- In large coverage cosmic ray observatories, such as Pierre Auger Observatory, the modelling of cosmic air showers is most sensitive to $\pi^{\pm}/K^{\pm}$ production in $\pi^{\pm}/K^{\pm}$ + air nucleus collisions. NA61 provides precise $\pi^{\pm}/K^{\pm}$ spectra in $\pi^{\pm}/K^{\pm}$ + C collisions.

Future: R&D for NA61/SHINE

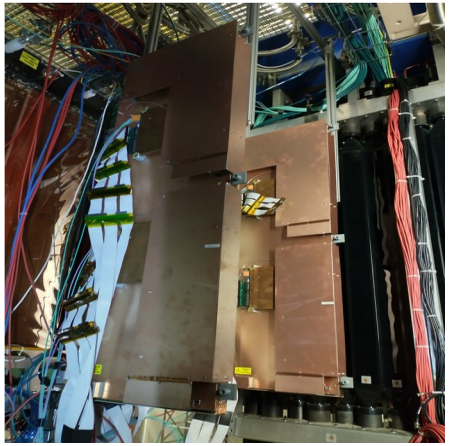
- Conceptualization, development, building of Forward TPCs: novel tandem-TPC concept for higher rates

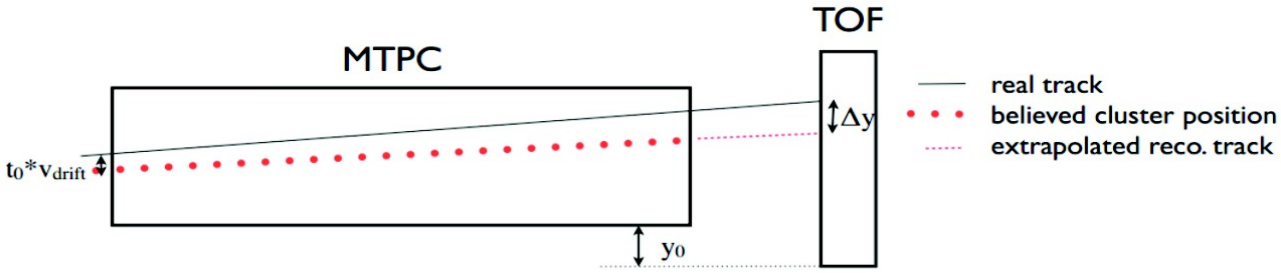




Future: R&D for NA61/SHINE

- Special auxiliary detector (Geometry Referenc Chamber) for in-situ drift velocity determination in large TPCs





- New challenge (ELTE-Wigner-Boulder): conceptualization of a high-resolution target tracker TPC

Message: Hungarian NA61/SHINE Group

- NA61 is a uniqe hadron spectrometer facility to study strongly interacting matter in the region of onset of deconfinement and close to presumed critical point (fixed-target SPS energies), quite unique facility for p+A hadron spectra for ν-beams ref.

- ELTE+Wigner Hungarian groups are present in NA61 with key contributions to the experiment from start. Main interest is measurement of BE correlations in A+A, hadron spectra in p+A up to intermediate p_T range and for ν-beams, detector development. The groups have a number of responsibilities within the collaboration.

Summary: Heavy-ion Research at the Wigner RCP

STRENGTH

- Well-defined physical programmes
- Strong groups, good local experts
- New technological challenges
- Supportive environment

WEAKNESS & RISKS

- Lack of economical stability
- Low salaries & inflation
- Eastern-European effects