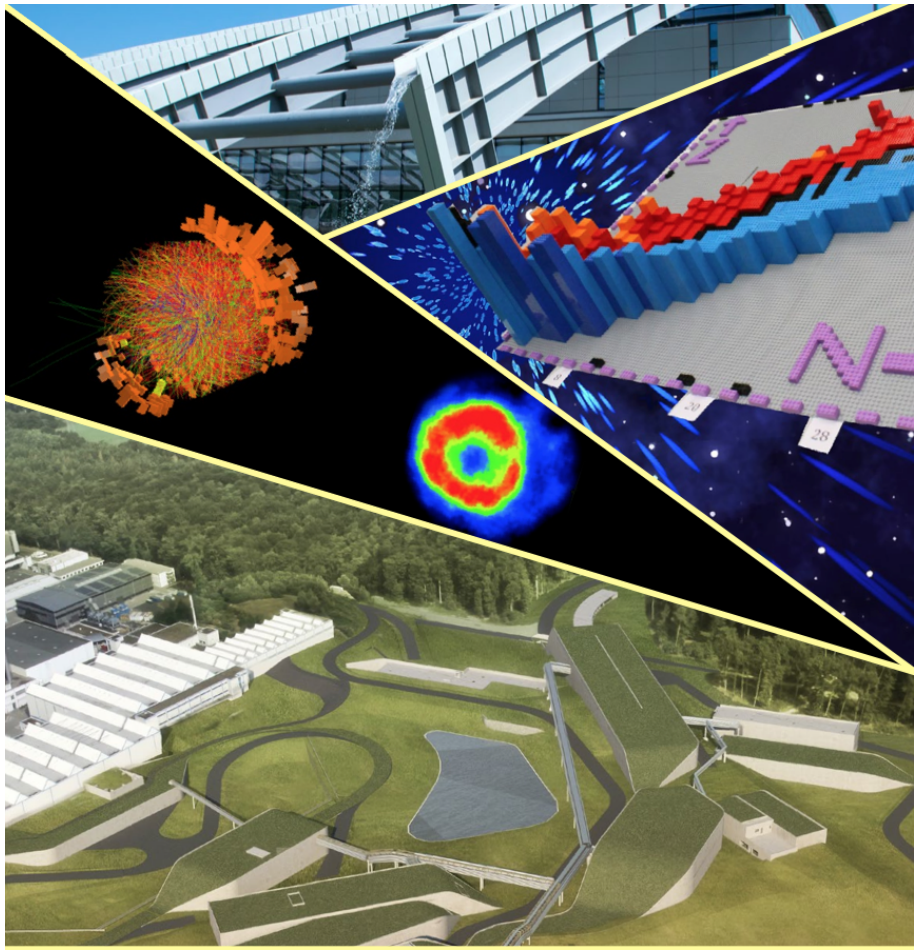


NuPECC
Long Range Plan 2017
Perspectives
in Nuclear Physics

European Science Foundation

17th International Conference on
Strangeness in
Quark Matter

Universiteit Utrecht
10-15 July 2017
Utrecht, the Netherlands

SQM2017, Utrecht, July 15, 2017

NuPECC long range plan

Silvia Masciocchi
Heidelberg University and GSI Darmstadt

UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

GSI

Nuclear Physics European Collaboration Committee

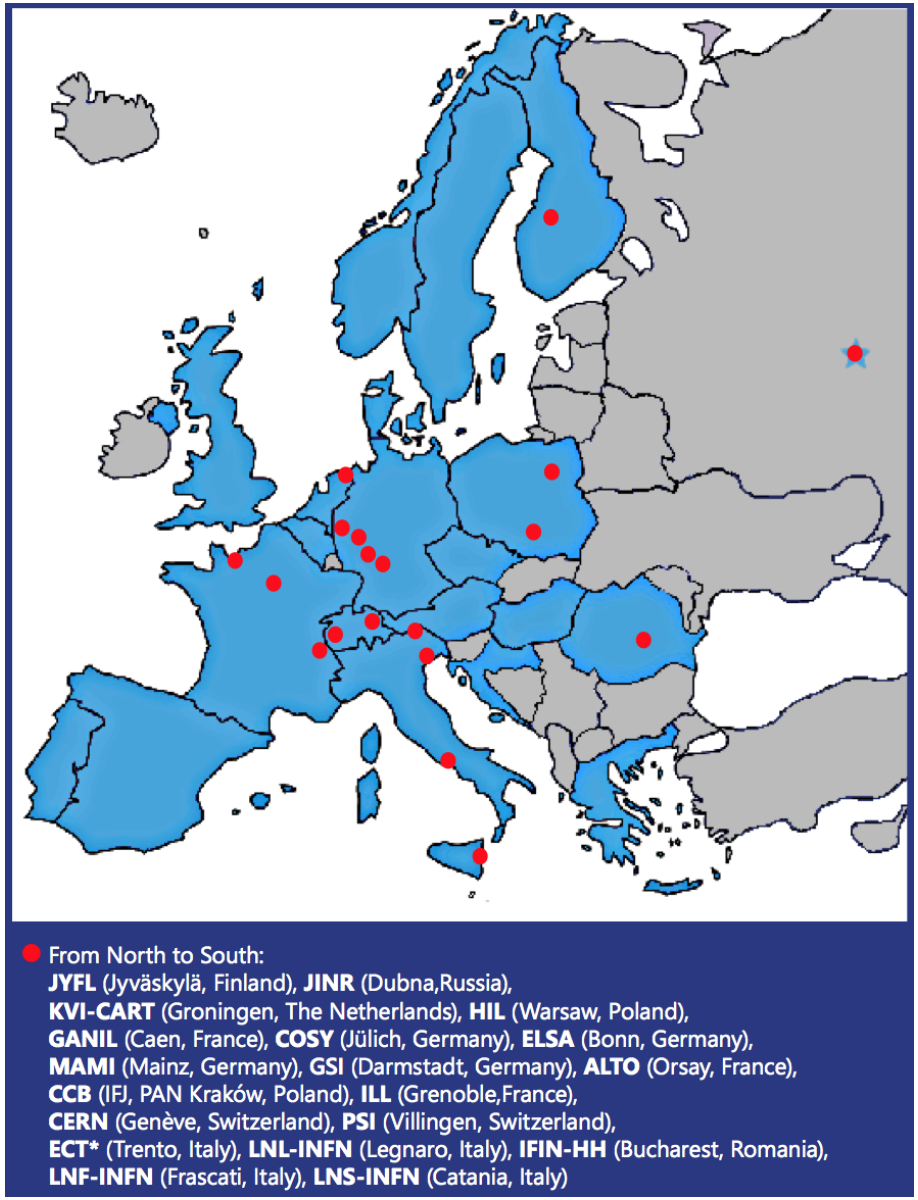
expert committee of the European Science Foundation

NuPECC LRP 2017

Nuclear Physics European Collaboration Committee

expert committee of the European Science Foundation

21 countries – 31 members



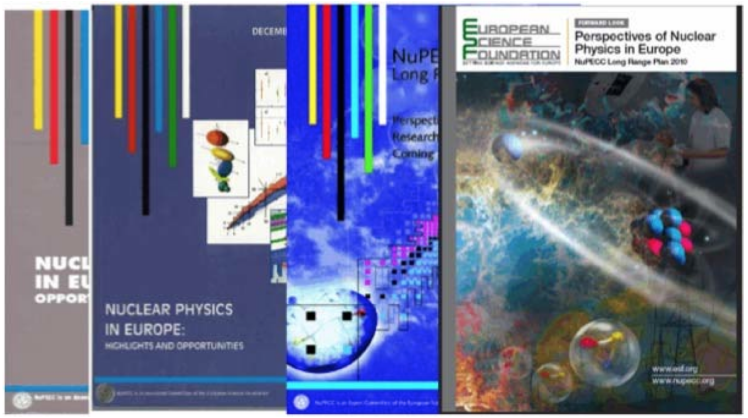
From North to South:
JYFL (Jyväskylä, Finland), **JINR** (Dubna,Russia),
KVI-CART (Groningen, The Netherlands), **HIL** (Warsaw, Poland),
GANIL (Caen, France), **COSY** (Jülich, Germany), **ELSA** (Bonn, Germany),
MAMI (Mainz, Germany), **GSI** (Darmstadt, Germany), **ALTO** (Orsay, France),
CCB (IFJ, PAN Kraków, Poland), **ILL** (Grenoble,France),
CERN (Genève, Switzerland), **PSI** (Villingen, Switzerland),
ECT* (Trento, Italy), **LNL-INFN** (Legnaro, Italy), **IFIN-HH** (Bucharest, Romania),
LNF-INFN (Frascati, Italy), **LNS-INFN** (Catania, Italy)

Mission:

"To provide advice and make recommendations on the development, organization and support of European nuclear research and of particular projects."

Long Range Plans

- November 1991
- December 1997
- April 2004
- December 2010



Long Range Plan 2017

Process initiated in October 2015, evolved through the NuPECC meetings in 2016 (ECT* Trento in March, Uppsala in June, Vienna in October)

→ Town meeting in Darmstadt, Germany, January 11-13, 2017

→ Finalization at NuPECC meeting at CERN, March 2017

It is strongly hoped that this plan will convince the European funding agencies to seek avenues for accomplishing the objectives outlined in the recommendations, in particular also those that go beyond the capabilities of an individual country

Long Range Plan 2017

Subfields of nuclear physics addressed ↔ **Working Groups**

1. Hadron physics
2. Properties of strongly interacting matter at extreme conditions of temperature and baryon number density
3. Nuclear structure and reaction dynamics
4. Nuclear astrophysics
5. Symmetries and fundamental interactions
6. Applications and societal benefits

Each working group:

2 conveners

3 liaison members of NuPECC

14-35 group members

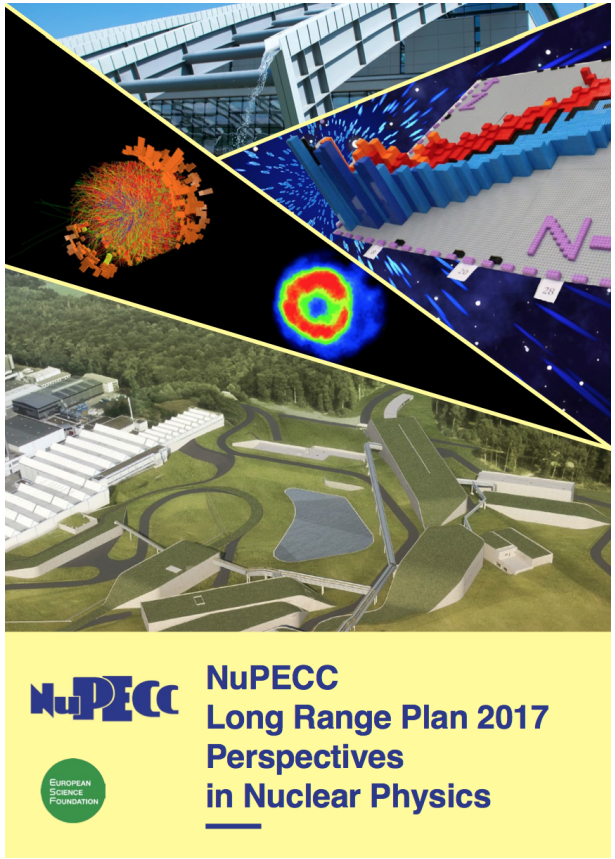
Long Range Plan 2017

Introduction:

Summary and recommendations

Research infrastructure and networking

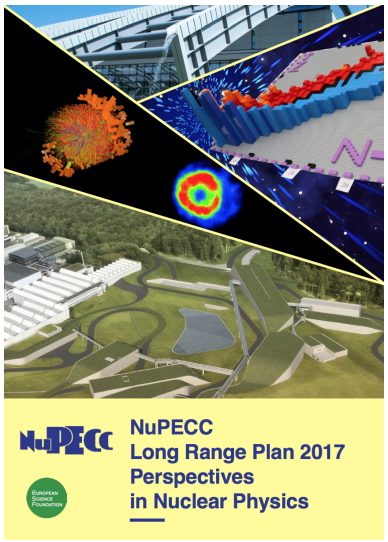
1. Hadron physics
2. Properties of strongly interacting matter at extreme conditions of temperature and baryon number density
3. Nuclear structure and reaction dynamics
4. Nuclear astrophysics
5. Symmetries and fundamental interactions
6. Applications and societal benefits



http://www.nupecc.org/lrp2016/Documents/lrp2017.pdf

Outline of my talk

NuPECC LRP 2017



Introduction:

Summary and recommendations

Education

Research infrastructure and networking

1. Hadron physics
2. **Properties of strongly interacting matter at extreme conditions of temperature and baryon number density**
3. Nuclear structure and reaction dynamics
4. Nuclear astrophysics
5. Symmetries and fundamental interactions
6. Applications and societal benefits

2

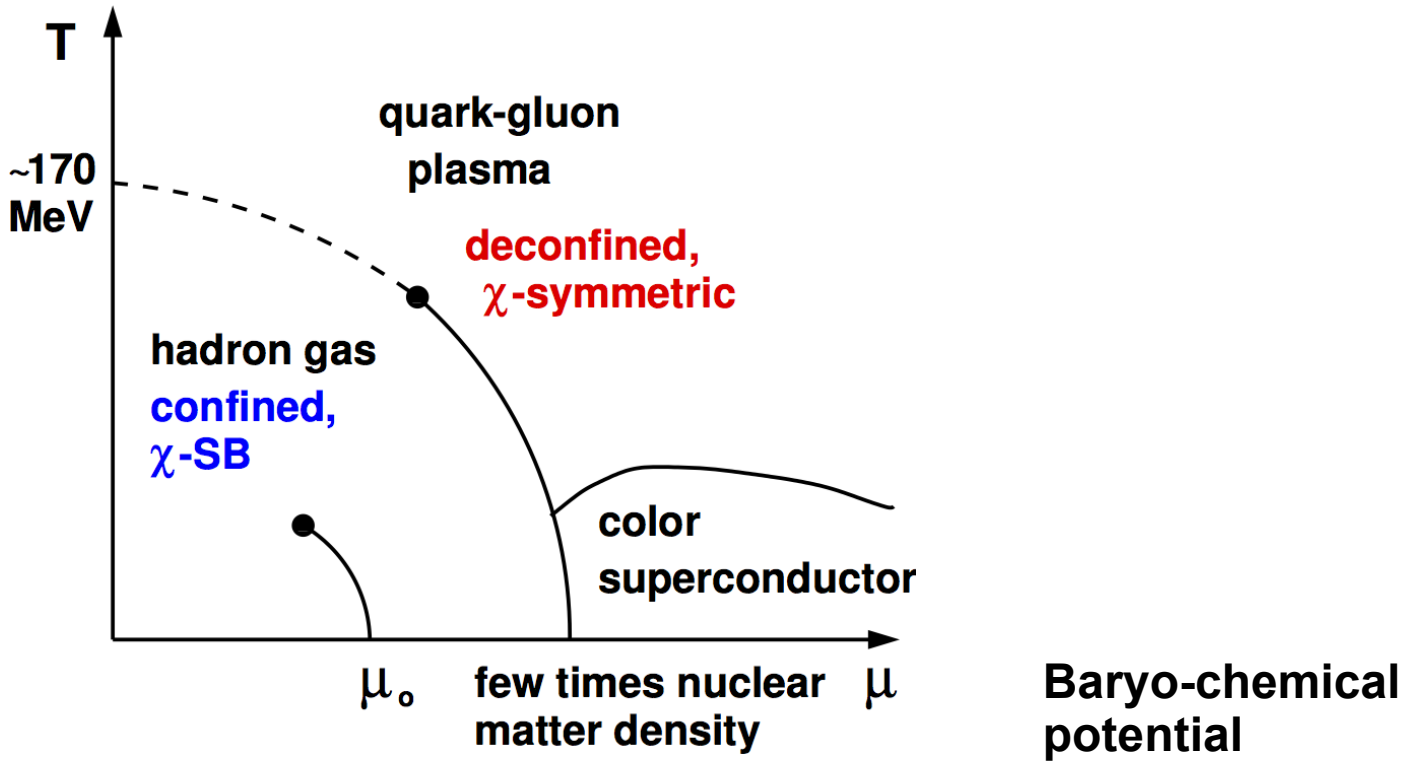
PROPERTIES OF STRONGLY INTERACTING MATTER AT EXTREME CONDITIONS OF TEMPERATURE AND BARYON NUMBER DENSITY

Conveners: Silvia Masciocchi (GSI Darmstadt), François Gélis (Saclay)
NuPECC Liaison Members: Eugenio Nappi, Christelle Roy, Raimond Snellings

WG2 members:
Giuseppe Bruno (Bari)
Peter Christiansen (Lund)
Wojciech Florkowski (Kraków)
Volker Friese (GSI)
Norbert Herrmann (Heidelberg)
Boris Hippolyte (Strasbourg)
Jean-Philippe Lansberg (Orsay)
Marco van Leeuwen (Utrecht)
Gines Martinez (Nantes)
Dirk Rischke (Frankfurt)
Piotr Salabura (Kraków)
Eugenio Scapparone (Bologna)
Hans Rudolf Schmidt (Tübingen)
Alexander Sorin (Dubna)
Vicente Vento (Valencia)

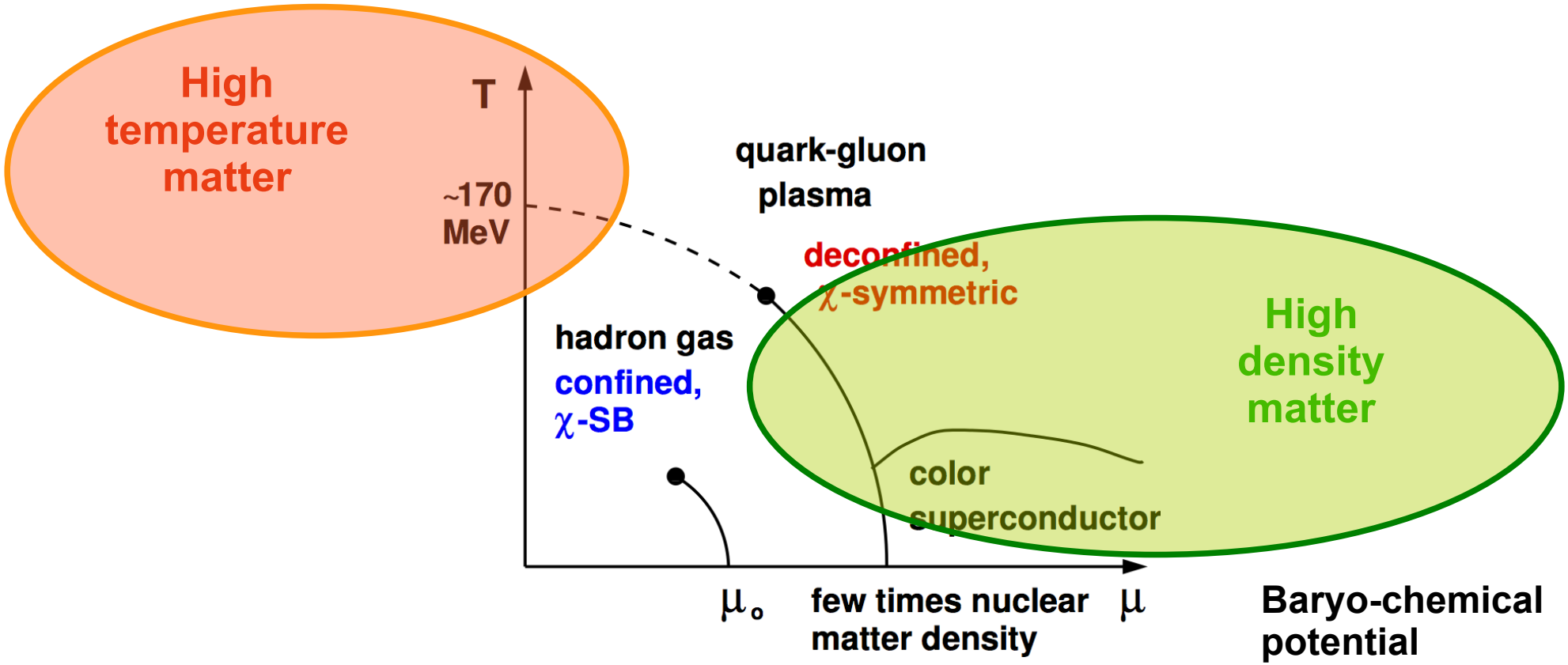
- Introduction
- High-temperature matter
- High-density matter
- Perspectives on
  - Facilities and experiments
  - Computing resources
  - Forthcoming detector challenges and new instrumentation
- Recommendations

The QCD phase diagram



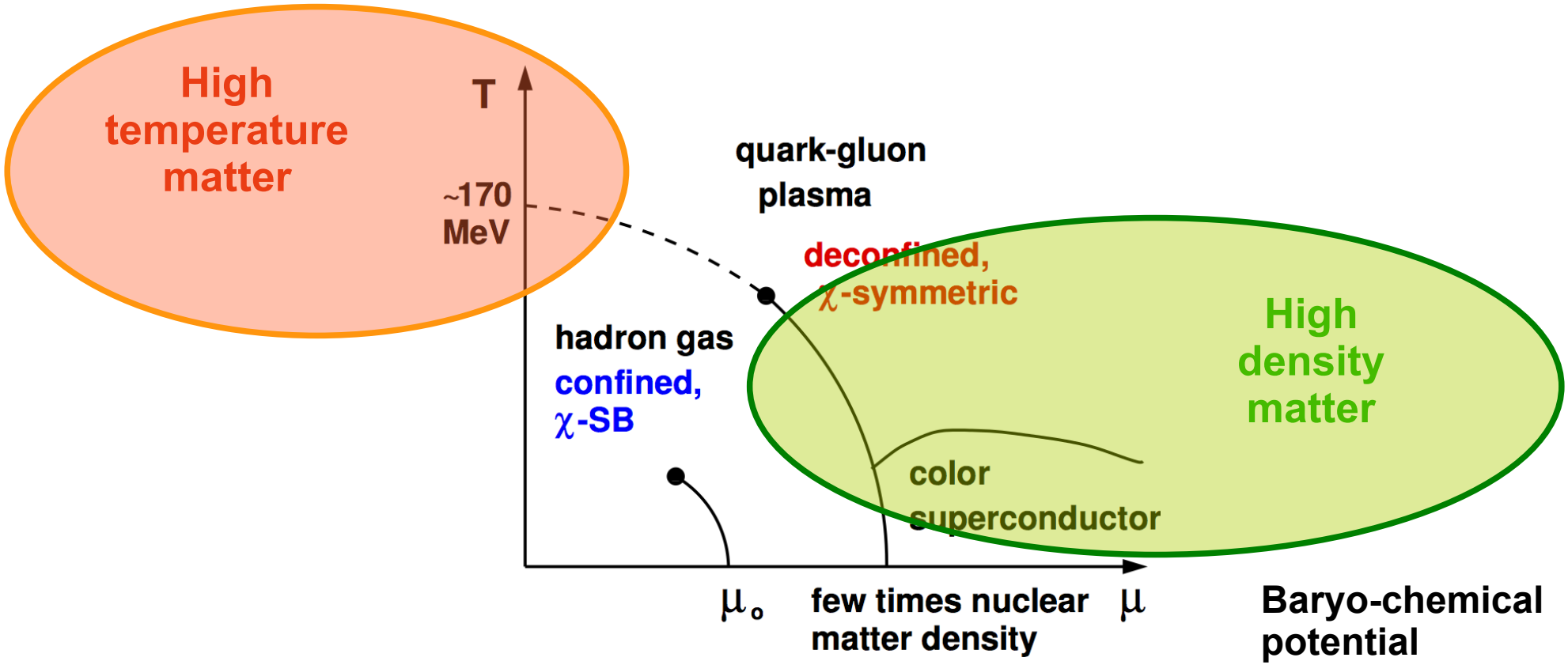
- General introduction (basics of QCD, phase diagram, heavy-ion collisions)

The QCD phase diagram



- General introduction (basics of QCD, phase diagram, heavy-ion collisions)
- High-temperature and high-density matter:

The QCD phase diagram



- General introduction (basics of QCD, phase diagram, heavy-ion collisions)
- High-temperature and high-density matter:
  - Recent experimental and theoretical developments
  - Future plans

Nuclear theory

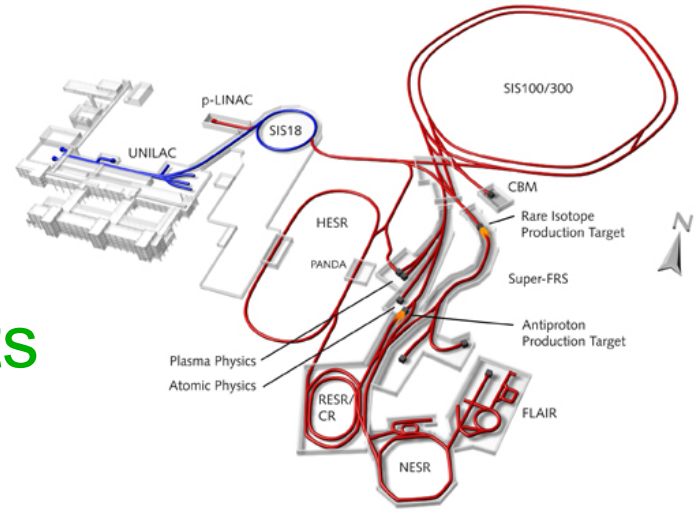
NuPECC LRP 2017

GLOBAL RECOMMENDATION

Support for Nuclear Theory

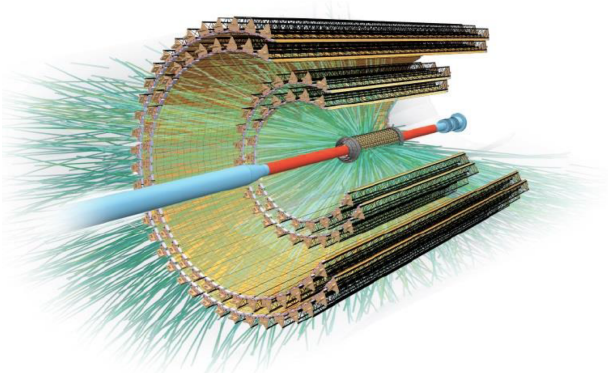
- Continued major conceptual and computational advances
- Crucial role in shaping experimental programmes
- Provide platform for scientific exchanges and the training of the next generation
- ECT* Trento

Future Plans



Facilities and experiments

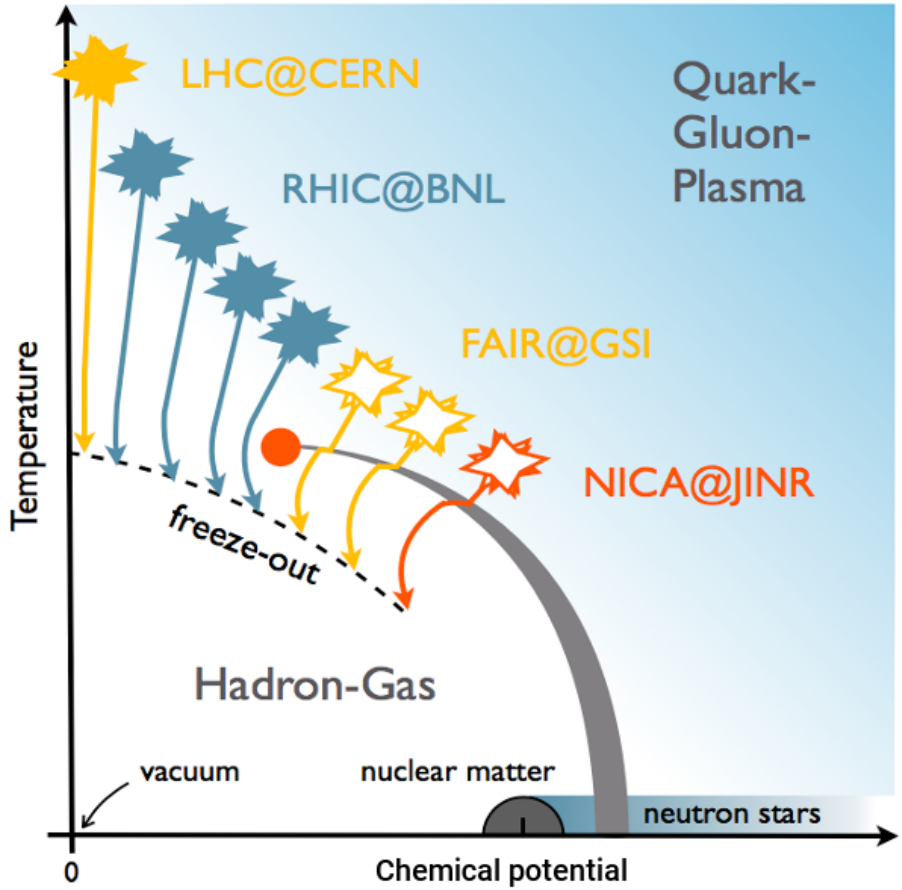
Computing



New instrumentation

Facilities and experiments

- Existing and operating:
  - LHC at CERN
- Realization approved and on-going:
  - FAIR at GSI
  - NICA at JINR
- Under exploration:
  - NA60+ at the SPS at CERN
  - AFTER at the LHC at CERN
  - The Future Circular Collider



Heavy-ion program at the LHC

High-temperature matter

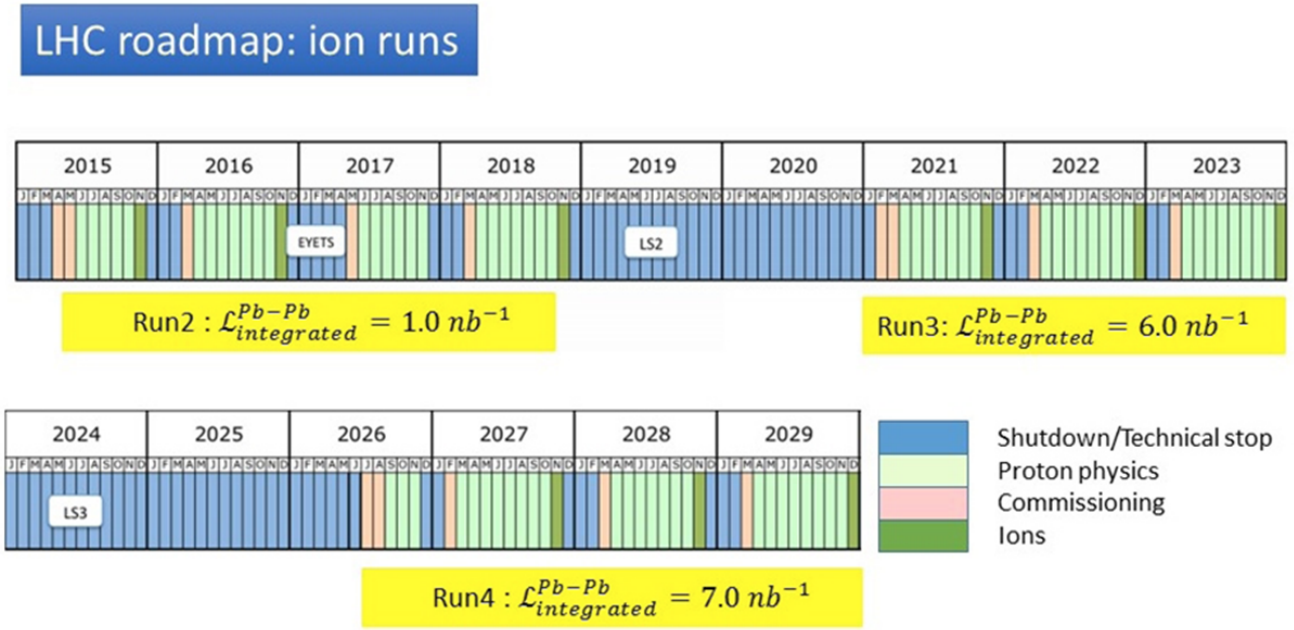
Pb-Pb collisions at

$\sqrt{s_{NN}}$ = 2.76 – 5.02 TeV

ALL 4 EXPERIMENTS

$L_{int} \approx 1\ nb^{-1}$

in Run-1 and 2 (2010-18)

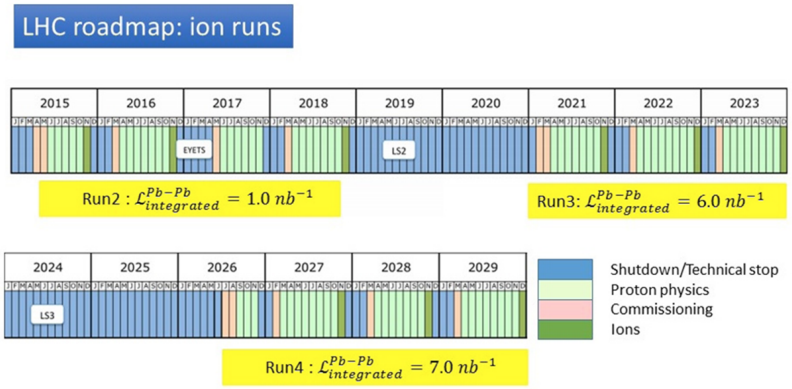


- Run 3 and 4: 2021 – 2029
- $\sqrt{s_{NN}}$ = 5.5 TeV
- $L_{int} > 10\ nb^{-1}$

- **Experiment upgrades**

Heavy-ion program at the LHC

- Charm and beauty energy loss and degree of thermalization in the medium
- Charmonium production mechanism and elliptic flow (hadronization at phase boundary or in medium?)
- (Anti-)(hyper-)nuclei
- Correlations and fluctuations
- Jet structure. Jet-photon and jet-Z^0 correlations
- Low-mass dileptons

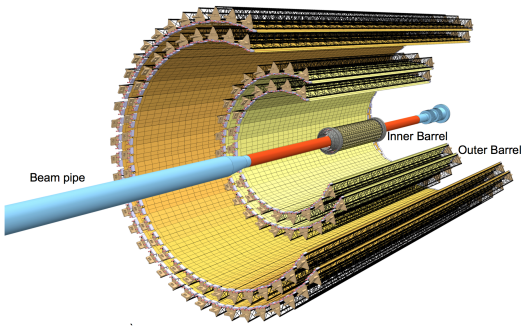


Experiment upgrades

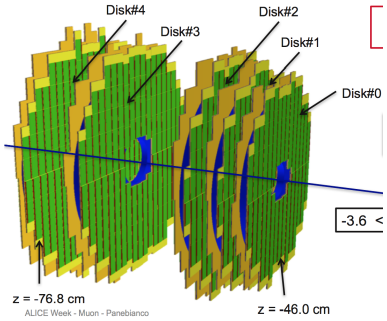
NuPECC LRP 2017

ALICE

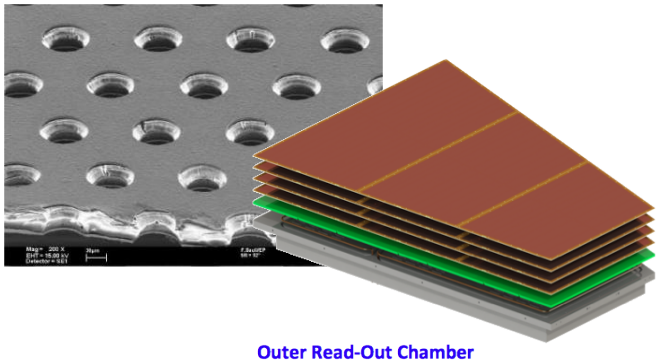
New inner tracking system with MAPS



Muon forward tracker with MAPS



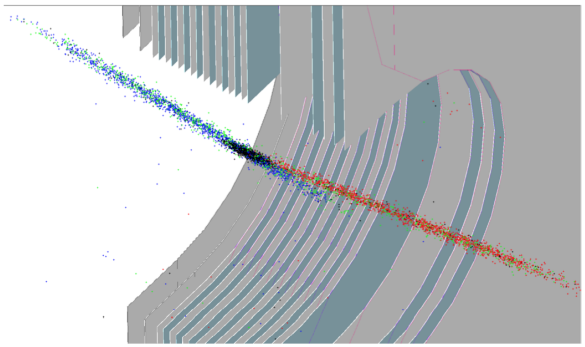
GEM-chambers for continuous readout of the TPC



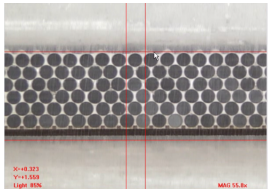
… new readout electronics. New online and offline (O^2) system

LHCb

Tracking system
→ all centralities



J. Instrum. 9 (2014) P12005.

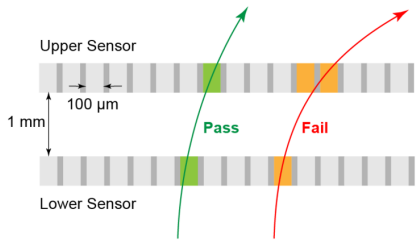


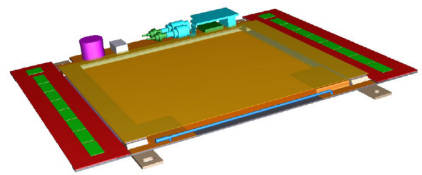
SMOG (System for Measuring the Overlap with Gas): gas injected in beam pipe (He, Ne, Ar)

CMS

ATLAS EXPERIMENT

p_T Module Concept





Heavy-ion program at the LHC

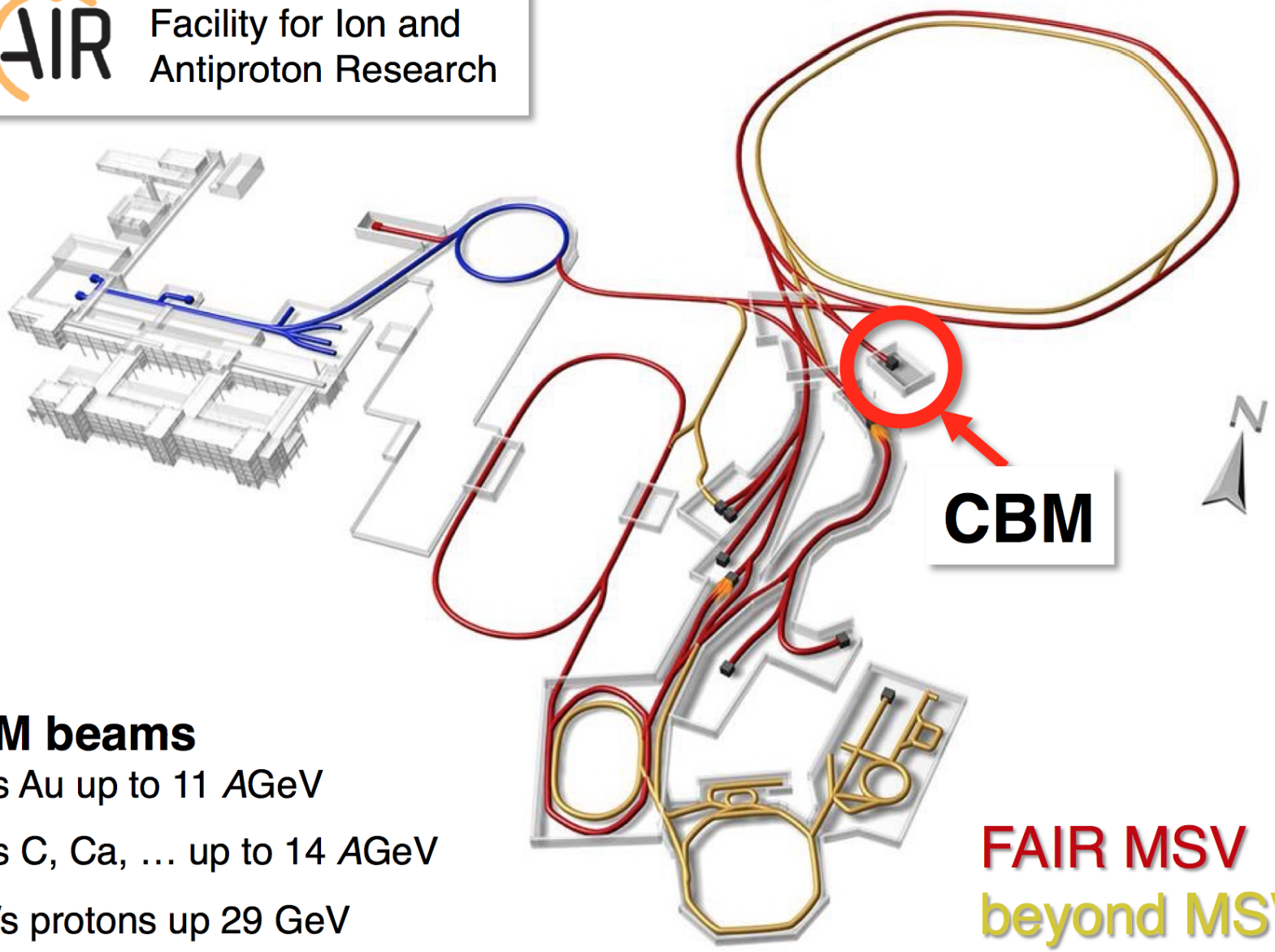
NuPECC LRP 2017

GLOBAL RECOMMENDATION

Support for ALICE and the heavy-ion programme at the LHC with the planned experimental upgrades.

Heavy-ion program at FAIR

FAIR Facility for Ion and Antiproton Research



CBM beams

10^9/s Au up to 11 *A*GeV

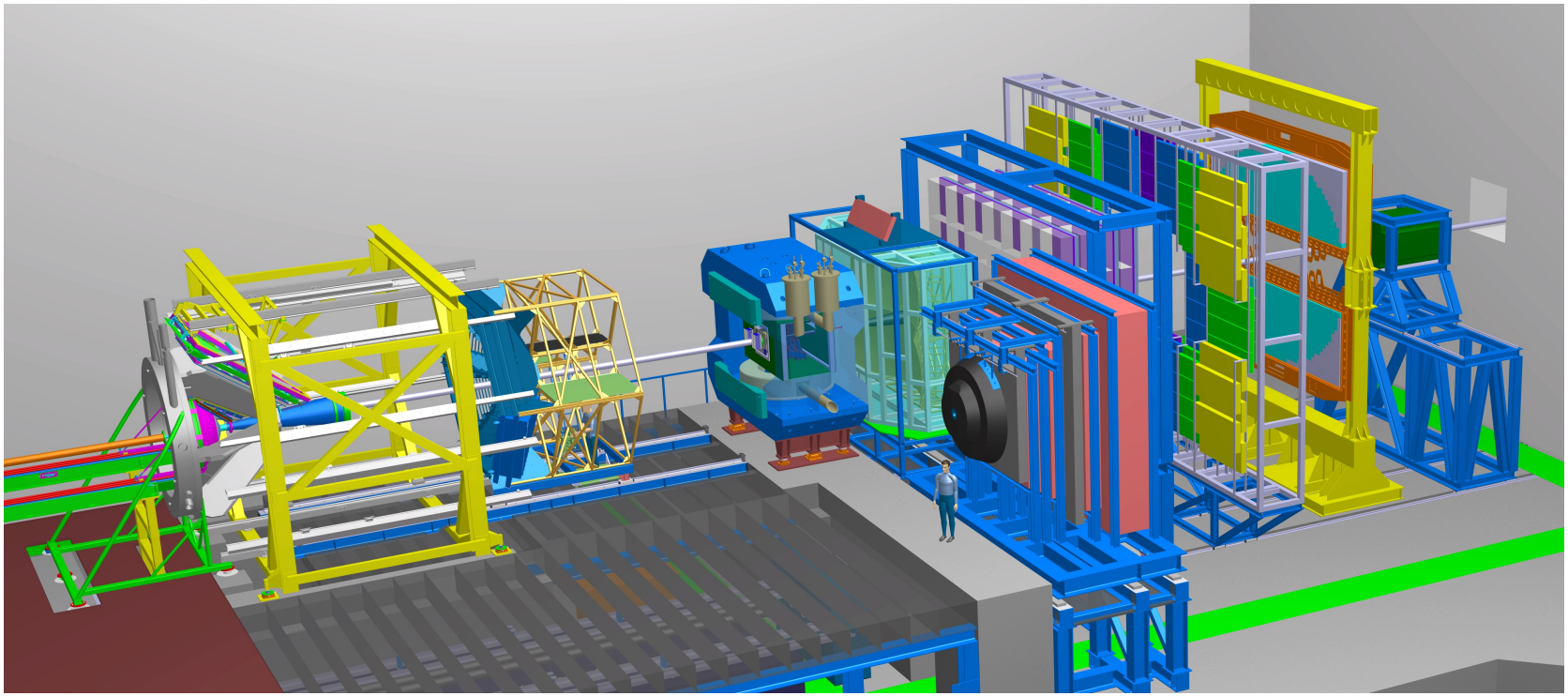
10^9/s C, Ca, … up to 14 *A*GeV

11^{11}/s protons up 29 GeV

FAIR MSV

beyond MSV

CBM and HADES at SIS-100



- Probe the QCD phase diagram at high net-baryon densities
  - Chiral symmetry, critical endpoint, new phases, etc.
- Strangeness, di-leptons, flow and correlations, fluctuation and higher moments, (double-)hypernuclei

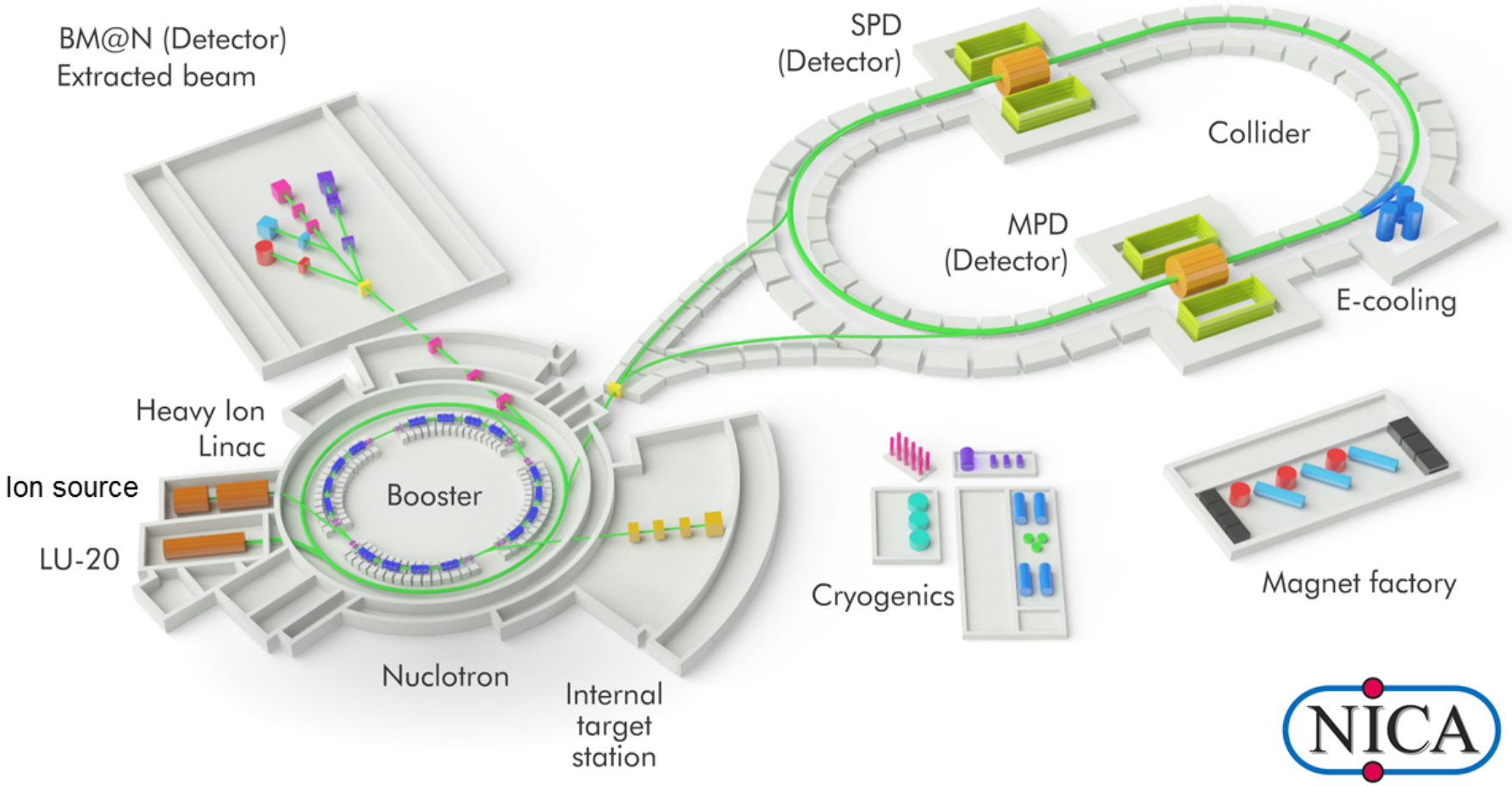
Heavy-ion program at FAIR

NuPECC LRP 2017

GLOBAL RECOMMENDATION

Complete urgently the construction of the ESFRI flagship FAIR and develop and bring into operation the experimental programme of its four scientific pillars APPA, CBM, NUSTAR and PANDA.

NICA at JINR Dubna



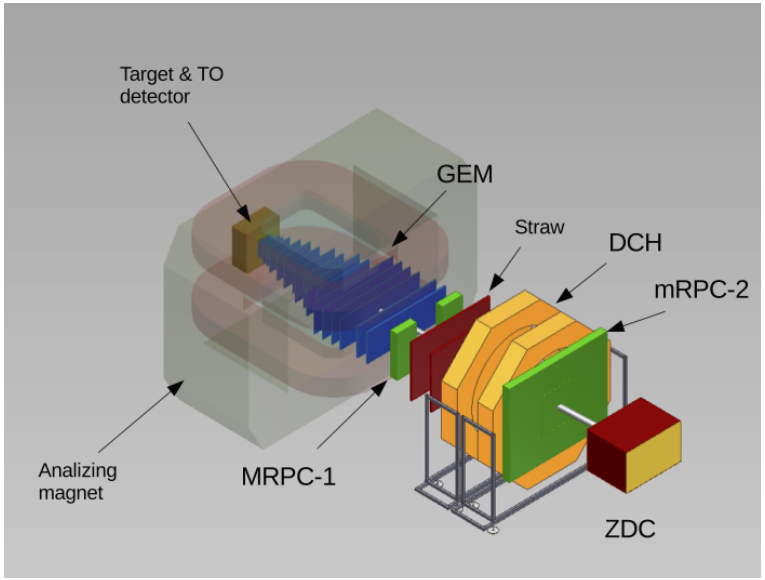
- First stage: BM@N fixed target detector at the nuclotron
  Au beams of 1-4.5 AGeV, protons up to 12.6 GeV
- Second stage: transfer line and collider, MPD collider experiment
  Design luminosity 10^{27} cm^{-2}s^{-1}, $\sqrt{s_{NN}}$ = 4-11 GeV

BM@N and MPD at NICA

Study of high-density matter

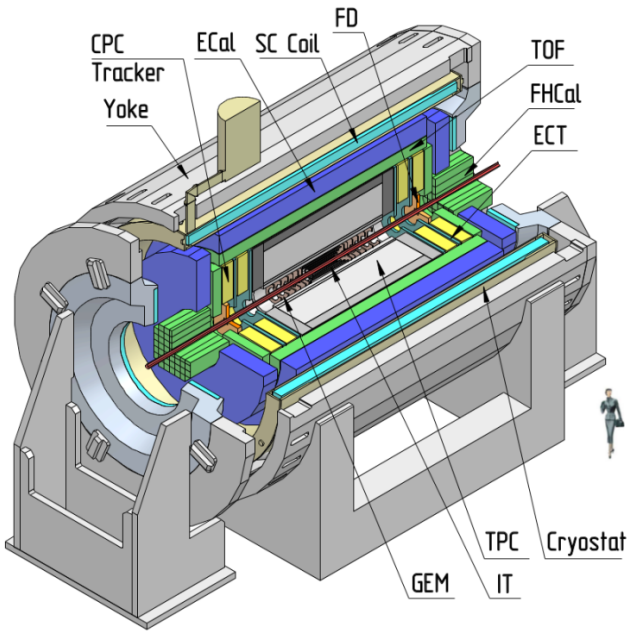
BM@N

- Fixed-target exp, beams from nuclotron
- High precision tracking and particle identification
- Expected start in 2017



MPD

- Collider experiment, intermediate reaction rat
- TPC, TOF, ECAL, FHCAL
- Completion of commissioning ~ 2023

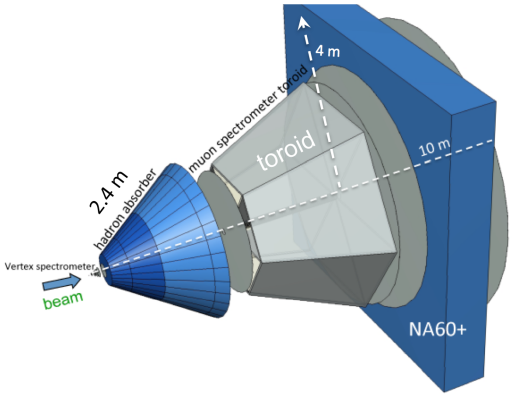


GLOBAL RECOMMENDATION

Support for the full exploitation of existing and emerging facilities

- For the up-coming NICA facility complete construction to study hot and baryon rich matter in heavy ion collisions at $\sqrt{s_{NN}}$ = 4 - 11 GeV. Develop and bring into operation the programme on BM@N, MPD and SPIN detectors as well as put into operation the SHE factory to search for a new stability regime for nuclei with Z beyond 118 (Og).

Projects under exploration

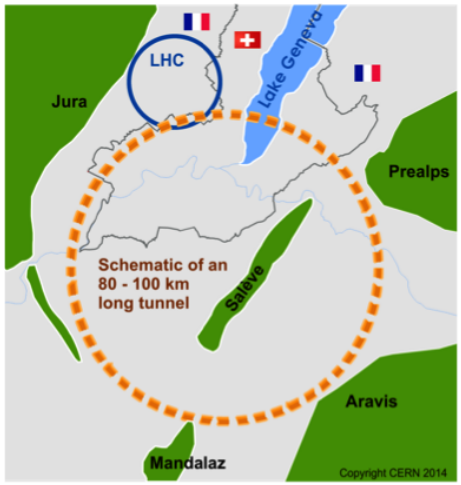


NA60+ at the SPS, at CERN

- Vertex + absorber + muon spectrometer
- Thermal radiation, light vector mesons and charmonia, chiral symmetry restoration, onset of deconfinement, critical endpoint
- Moderate to high baryonic density, 20-160 AGeV

AFTER @ LHC: fixed-target at TeV

- High luminosities, access to y<0, target versatility and polarization
- Bottomonium, charm to low p_T, Drell-Yan. Nuclear PDF factorisation



Future Circular Collider (FCC)

- 80-100 km long hadron collider → $\sqrt{s_{NN}}$ = 63 TeV Pb-Pb, $L_{int} \approx 33 nb^{-1}$/month
- Qualitatively different medium
- Collective effects, thermal charm, top quark, color coherence, new phenomena!

Computing: resources

Secure resources to face the increasing needs in

computing power and data storage

both by theory and by experiments

Large computing resources required by:

- **Theory:**

  Lattice QCD – power of peta-flops/s, accelerators like GPUs

  Needed resources double in ≈ 1.5 years

- **Experiments:**

  Storage of tens of peta-bytes of experimental and simulation data. World wide access.

  Future experiments produce few TB/s (to be reduced and compressed)

Green Cube, GSI

Computing: new solutions

Formidable needed resources call for strong support for

new developments

- **Theory:**
  - New multi-GPU and many-core CPU architectures
  - Complex memory hierarchies
  - Corresponding software developments
- **Experiments:**
  - Distributed cloud systems, high-bandwidth wide area networks
  - Intense online processing, filtering, data reduction
  - Less GRID and more optimized data centers
  - New computing models
- New multi-core and GPU architectures are relative programming software
- New data centers (Green Cube at GSI)

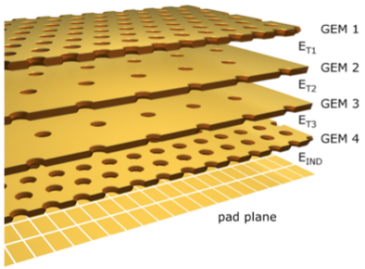
New instrumentation

Continue at all times R&D of detectors employing new techniques for:

- SPEED: faster signal production and collection
- RATES: higher interaction and data rates
- RAD HARDNESS: tolerate higher radiation levels

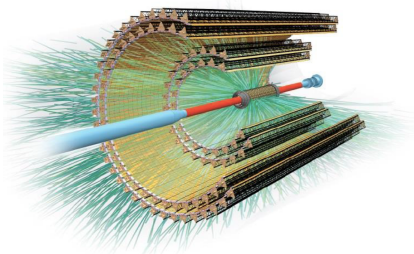
for the next generation of heavy-ion experiments ≡ high particle density

GEM Time Projection Chamber



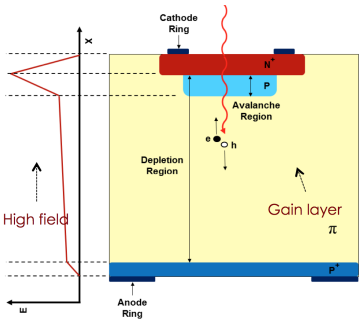
High rates, PID
ALICE

High resolution tracking and vertexing



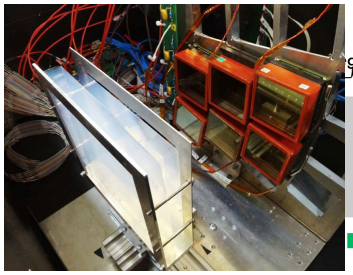
Monolithic Active Pixel Sensors
ALICE, CBM

Ultra-fast silicon detectors



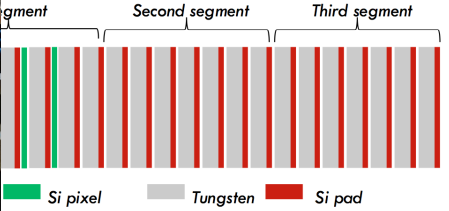
4D event reconstr.
Low-gain avalanche detectors

Compact RICH detectors



PID. Silica aerogel, pressurized gas

Silicon calorimeters



High segmen-tation, speed.
ALICE, SPHENIX

Chapter 2 recommendations

NuPECC LRP 2017

Experimental programme

- Vigorous efforts should be devoted to the continuation of the heavy-ion programme at the LHC with Runs 3 and 4, including manpower support and completing the planned detector upgrades
- At intermediate energies, we recommend the continuation of the on-going programmes: HADES at SIS-18, NA61 at the SPS
- In order to investigate nuclear matter at high baryonic density, the timely construction of SIS-100 at FAIR and the realization of the CBM experiment are of utmost importance
- In parallel, efforts should continue in order to support developments for a future SIS-300
- We recommend the completion of he BM@N experiment at JINR, and the construction of the NICA facility and the realization of the associated MPD experiment
- Exploratory studies on prospective future heavy ion projects, namely AFTER@LHC, NA60+ at the SPS, and a heavy-ion programme at the Future Circular Collider, should be considered

Chapter 2 recommendations

Theory developments

- Theoretical work in the field of heavy-ion collisions should be guaranteed continuous support, both in its phenomenological aspects (theoretical support needed to interpret the results and to provide feedback to the experimental programme) and in its more ab initio works (quantum chromodynamics).
- A close collaboration between theorists and experimentalists should be encouraged and nurtured, since most progress in heavy-ion physics stems from a continuous exchange between them.

LRP 2017

- Very interesting preparatory work, with many physics discussions!
- Assessment of current situation and main open questions
  Wide-breath summary of current and future projects
  List of recommendations

Now it is up to us, as heavy-ion (and nuclear physics) community, to make this plan REALITY in the next years

Explore the phase diagram
Work on new ideas

... and the new long range plan will be written with the NEXT generation of physics questions!

NuPECC and WG 2 composition

ANGELA BRACCO, NuPECC Chair

GABRIELE-ELISABETH KÖRNER, NuPECC Scientific Secretary

NuPECC liason members:

Eugenio Nappi, Christelle Roy, Raimond Snellings

WG2 conveners:

Francois Gelis (CEA Saclay), Silvia Masciocchi (GSI Darmstadt)

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Giuseppe Bruno (Bari), Peter Christiansen (Lund), Wojciech Florkowski (UJK Kielce and IFJ PAN Krakow), Volker Friese (GSI), Norbert Hermann (Heidelberg), Boris Hippolyte (IPHC Strasbourg), Jean-Philippe Lansberg (IPN Orsay), Marco van Leeuwen (Utrecht), Gines Martinez (Subatech Nantes), Dirk Rischke (Frankfurt), Piotr Salabura (Krakow), Eugenio Scapparone (Bologna), Hans Rudolf Schmidt (Tübingen), Alexander Sorin (Dubna), Vicente Vento (Valencia)

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Francois Gelis (CEA Saclay), Silvia Masciocchi (GSI Darmstadt)

WG2 members:

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