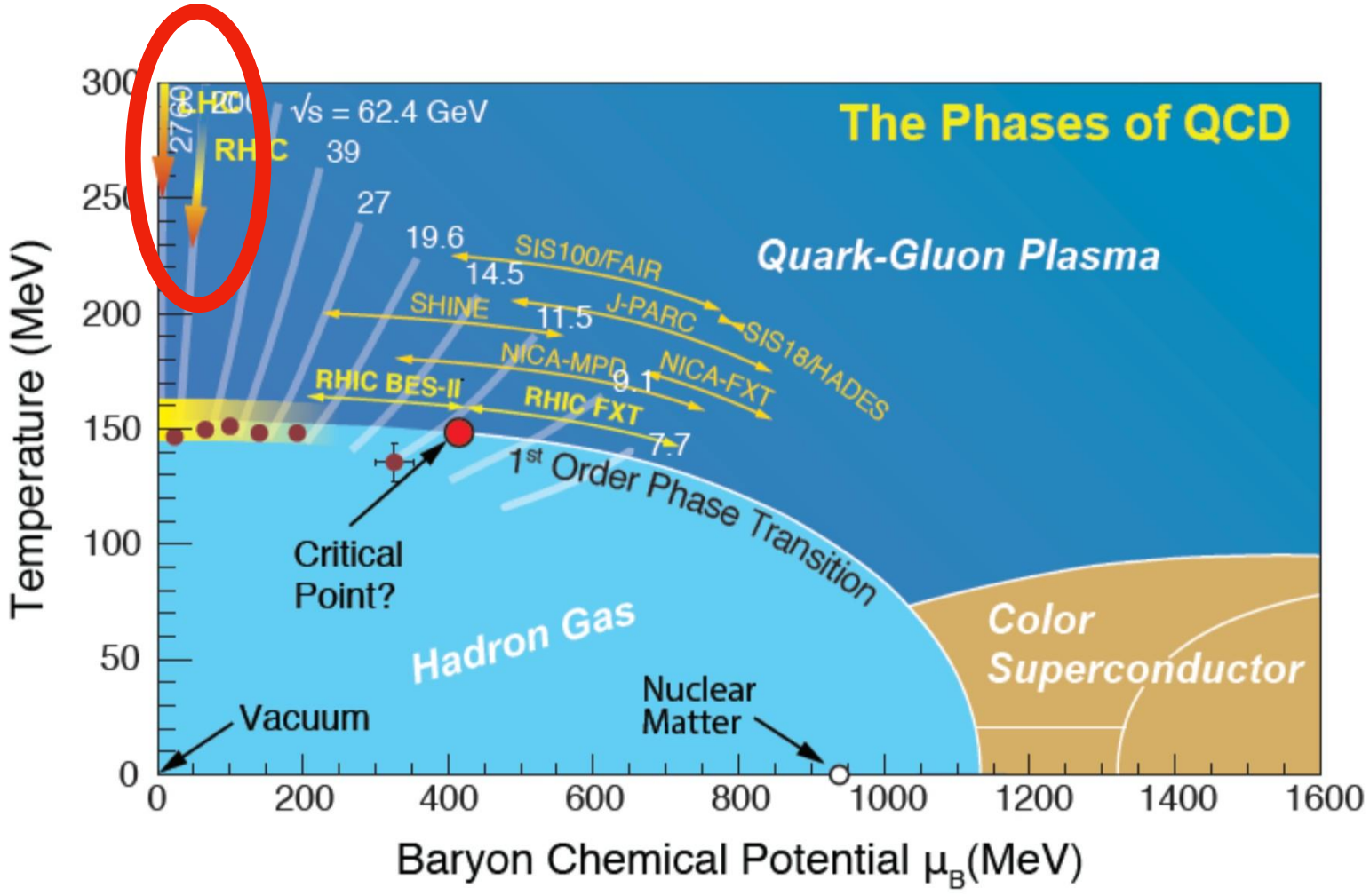
Panorama des installations experimentales

Séminaire Thématique Physique Hadronique

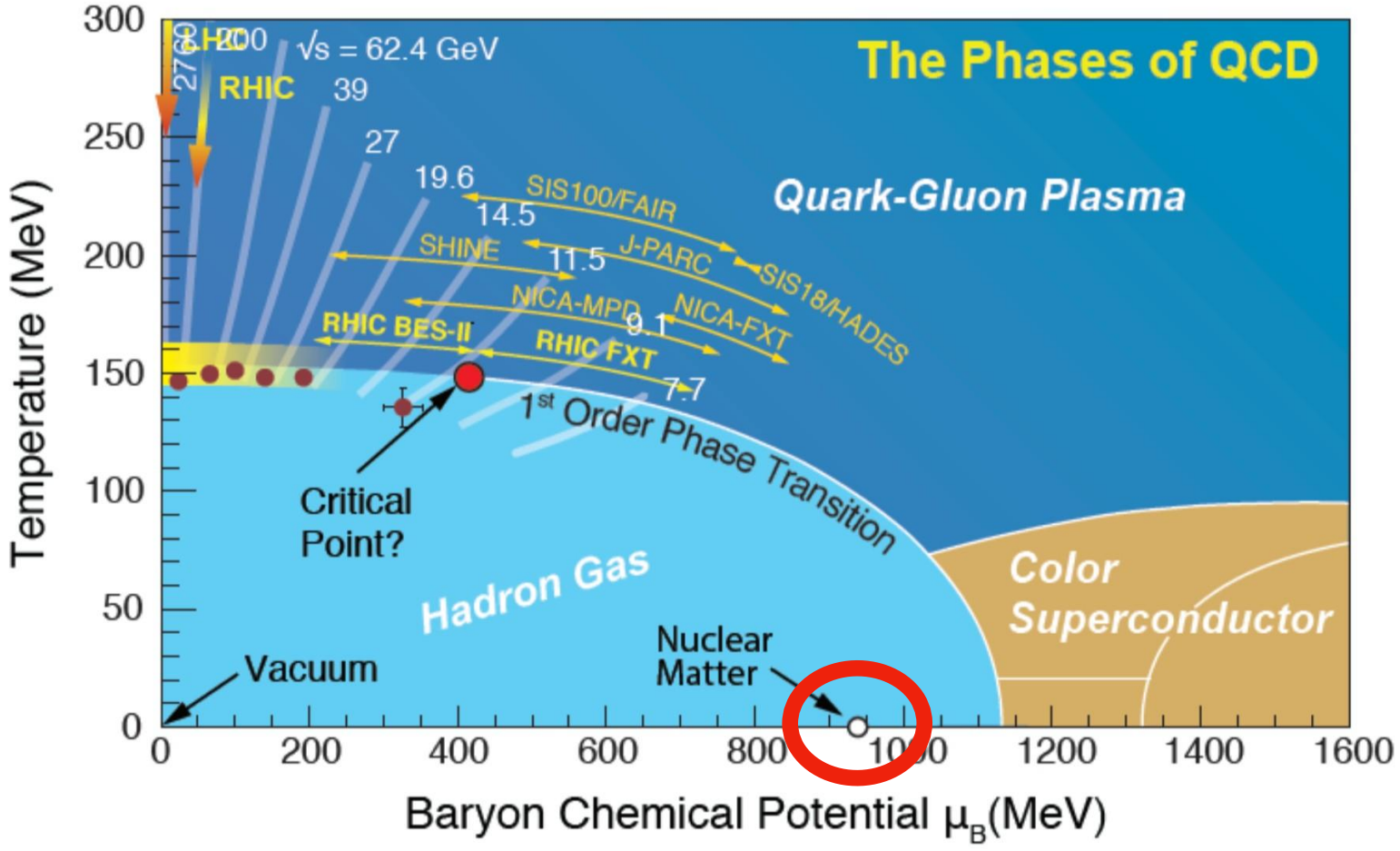
Barbara Erazmus
SUBATECH

Nantes, le 2 mars 2020

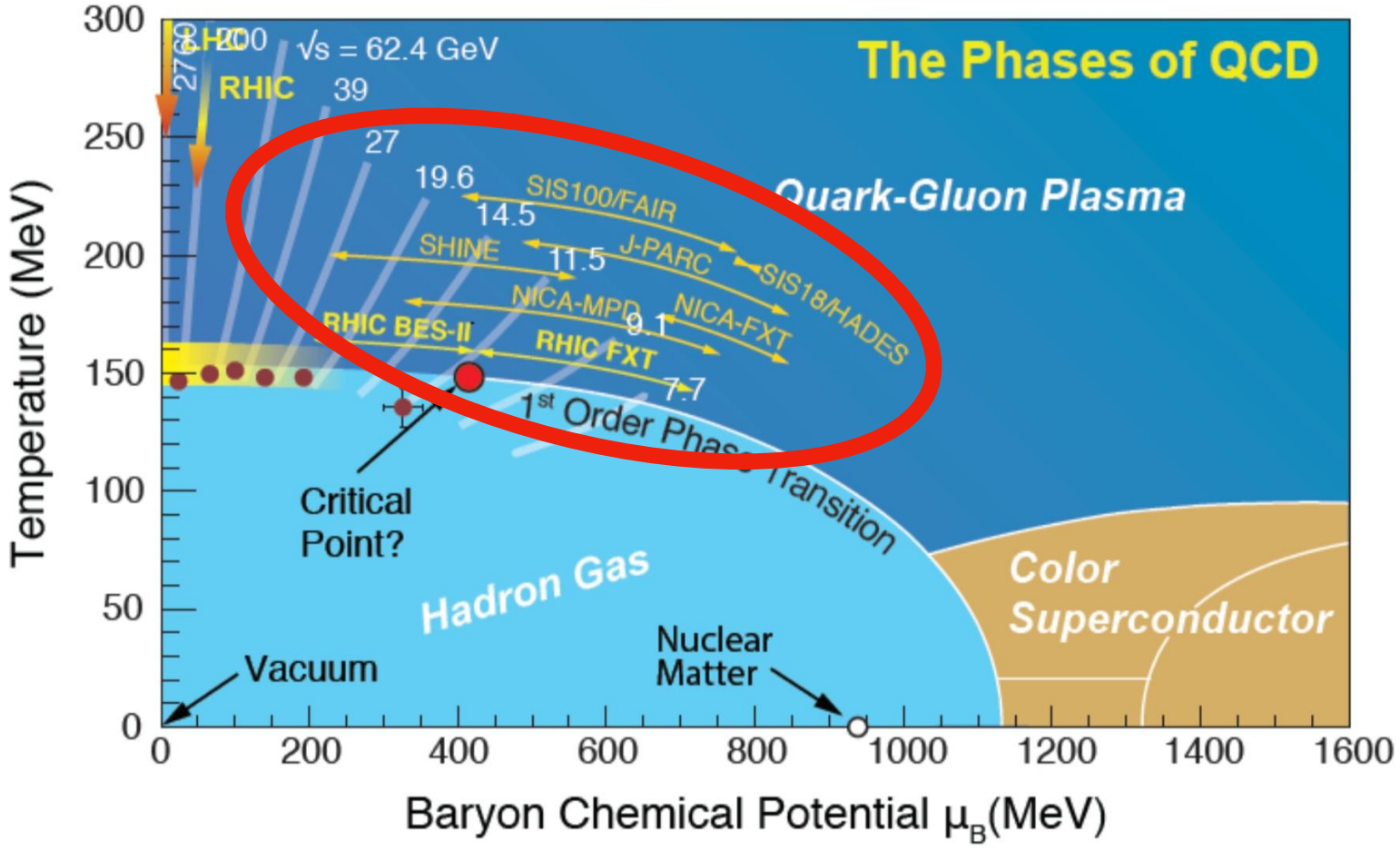
High-energy frontier



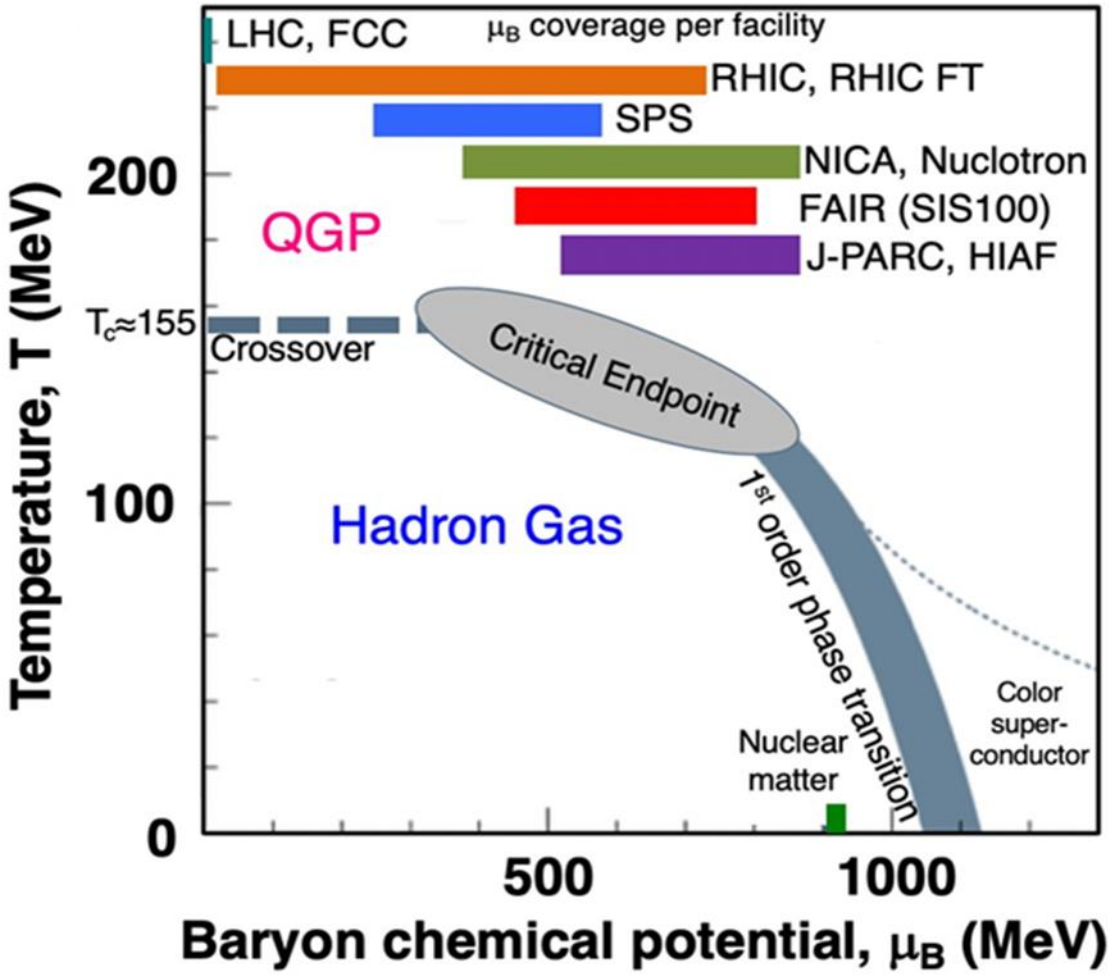
Cold nuclear matter



High-density frontier

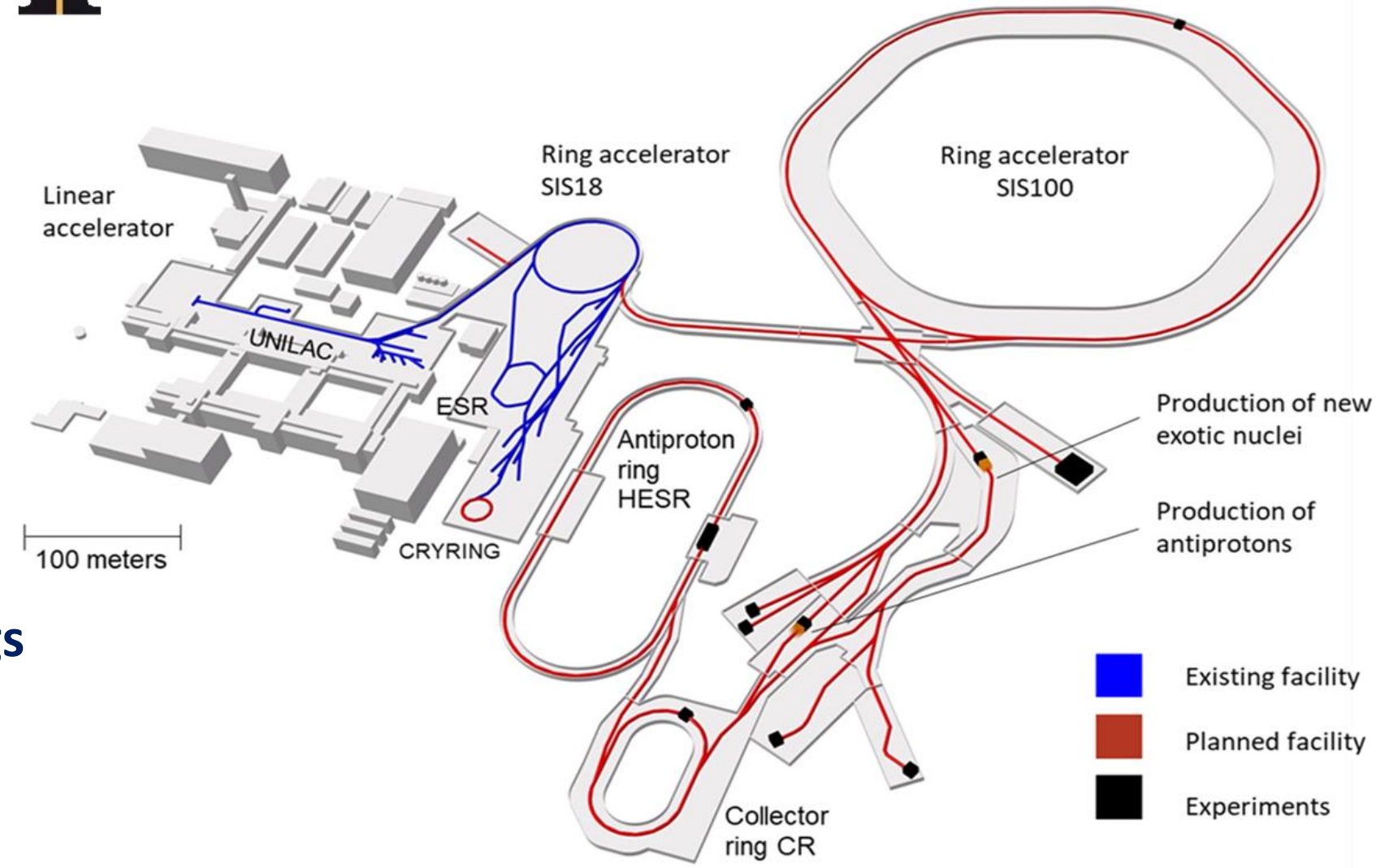


Future landscape of HI facilities



adapted from A. Dainese et al., arXiv:1602.04120

- **Intensity gain: x 100 – 1000**
- **10 x energy (comp. to GSI)**
- **Antimatter: antiproton beams**
- **Precision: System of storage and cooler rings**



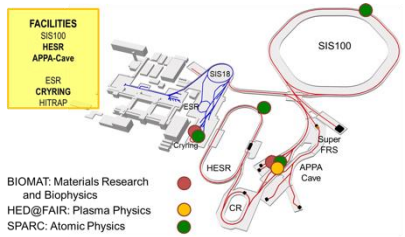
Schedule for FAIR Science

- Working towards the completion of FAIR by 2025
- Major thrust is on construction of FAIR accelerators and experiments.
- At the same time ***staged approach to FAIR science and progressive commissioning of accelerators and detectors***:

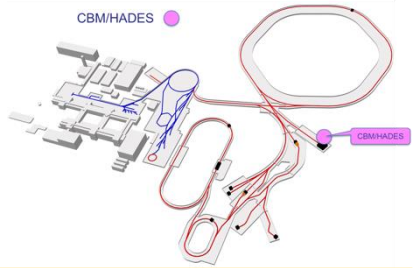
- ***FAIR phase 0 : start in 2018/2019***
- FAIR day 1 configurations/ phase 1 experiments with FAIR accelerators progressively approaching design parameters → 2025 …
- Full FAIR operation 2025+

FAIR Phase 0 Research Program

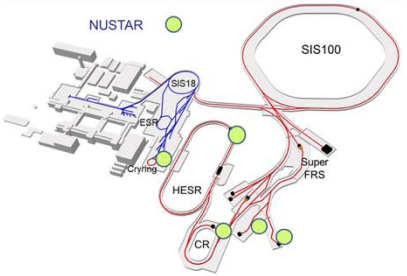
APPA



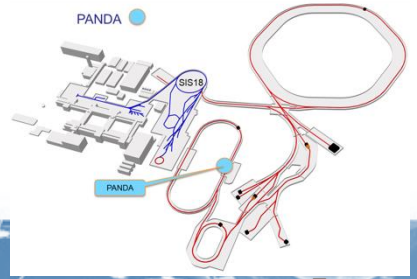
CBM



NUSTAR

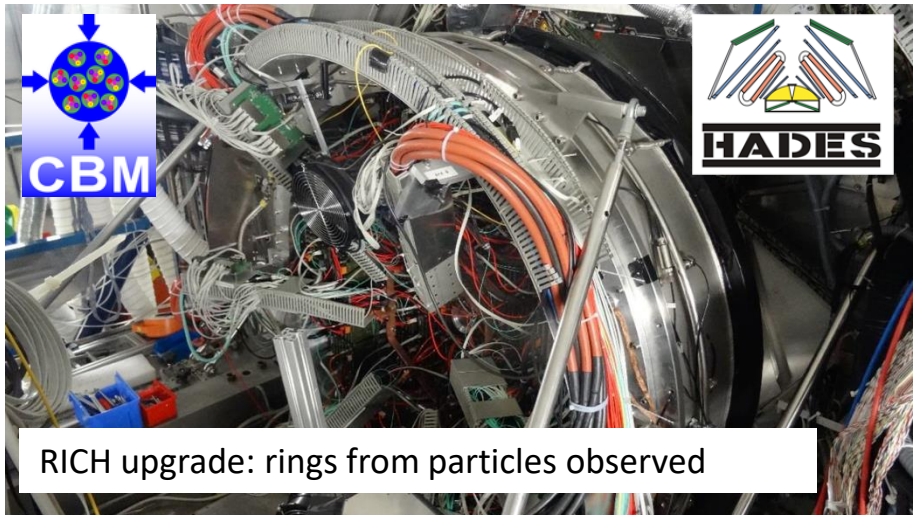


PANDA



Phase-0 highlights:
HADES (CBM, PANDA)

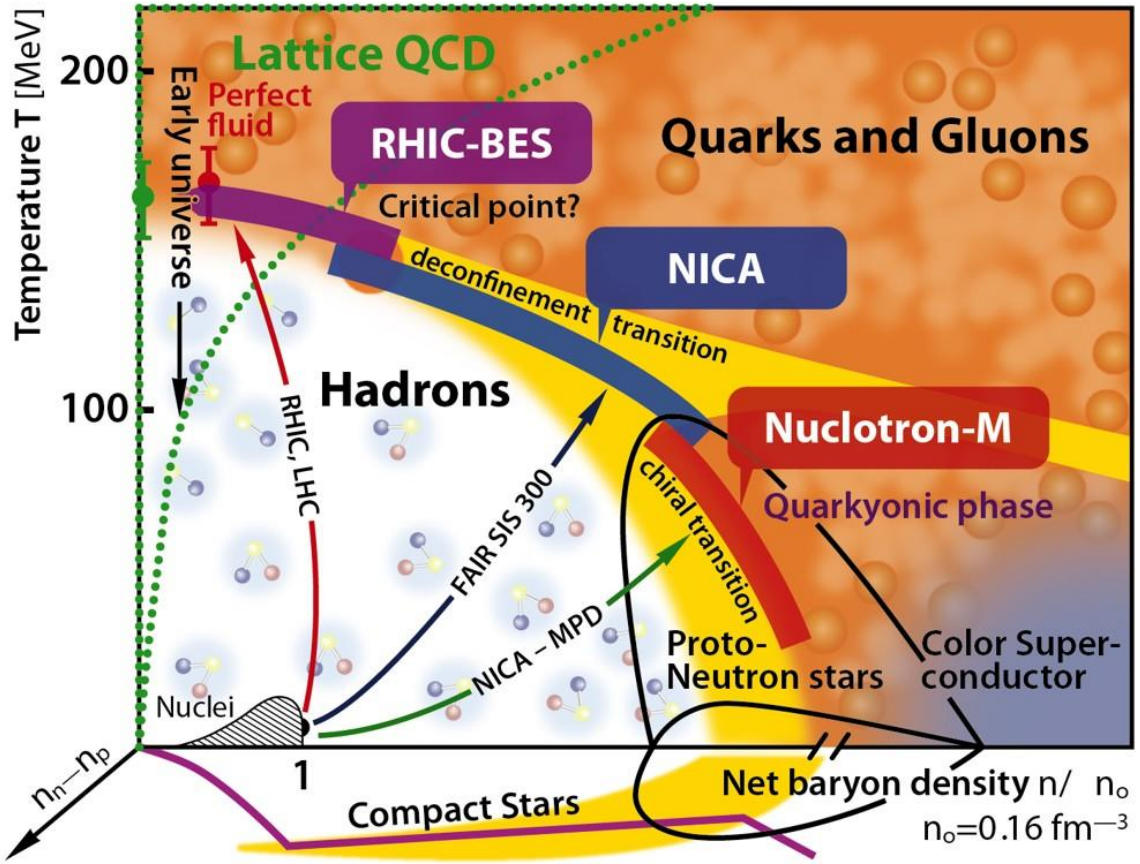
ECAL upgrade: 4 sectors tested with beam



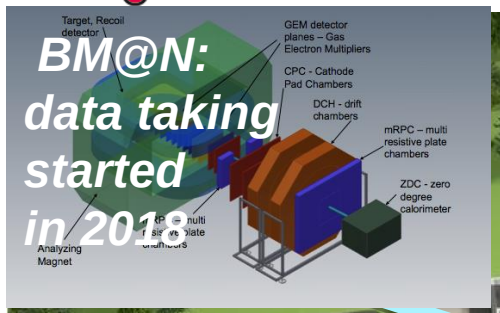
RICH upgrade: rings from particles observed

- **First HADES beam data obtained** in February 2019 during commissioning of the beam on target
- **HADES production beam time** 28 days in March 2019
  Unique studies of baryon-rich matter through 14 billion recorded events of Ag+Ag
- **HADES forward detection** system to be complemented this year utilising technology developed for and in close cooperation with **PANDA**

Straw Tube Tracker


Temperature T [MeV]
200
100
Lattice QCD
Perfect fluid
Early universe
RHIC-BES
Critical point?
Quarks and Gluons
NICA
deconfinement
transition
Hadrons
RHIC, LHC
FAIR SIS 300
NICA – MPD
Nuclotron-M
chiral transition
Quarkyonic phase
Proto-Neutron stars
Color Super-conductor
Nuclei
1
$n_n - n_p$
Compact Stars
Net baryon density n/ n_o
n_o=0.16 fm^{-3}

NICA Accelerator Complex in Dubna



BM@N: data taking started in 2018

SPD TDR - 2021

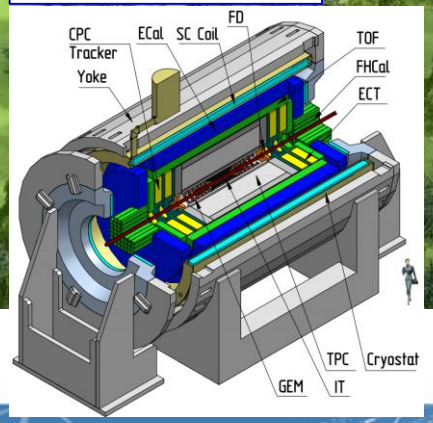
Collider - 2022

applied research infrastructure- 2021

Booster - 2020

Nuclotron (c=251,5 m)

MPD - 2021



NICA Center - 2021

MPD (Multi-Purpose Detector) Physics Programme

Global observables

- Total event multiplicity
- Total event energy
- Centrality determination
- Total cross-section measurement
- Event plane measurement at all rapidities
- Spectator measurement

Spectra of light flavor and hypernuclei

- Light flavor spectra
- Hyperons and hypernuclei
- Total particle yields and yield ratios
- Kinematic and chemical properties of the event
- Mapping QCD Phase diagram

Correlations and Fluctuations

- Collective flow for hadrons
- Vorticity, Λ polarization
- E-by-E fluctuation of multiplicity, momentum and conserved quantities
- Femtoscopy
- Forward-Backward corr.
- Jet-like correlations

Electromagnetic probes

- Electromagnetic calorimeter measurements
- Photons in ECAL and central barrel
- Low mass dilepton spectra and search for in-medium modification of resonances and intermediate mass region

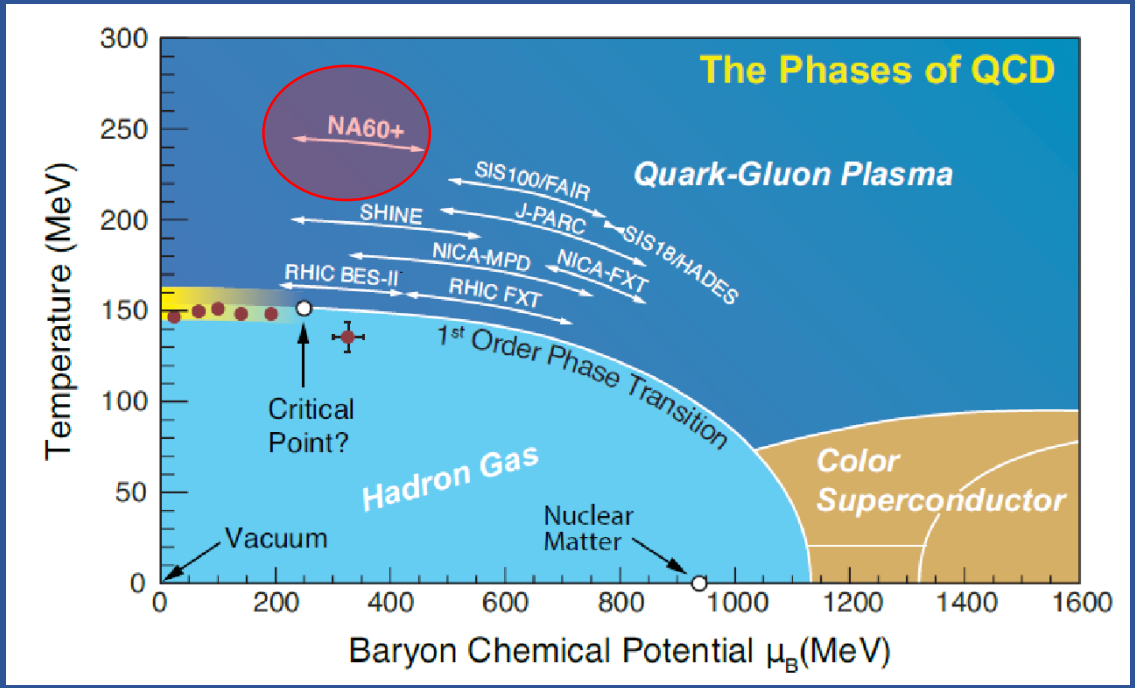
Heavy flavor

- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

The NA60+ proposal

Physics goal

Study of hard and electromagnetic processes at CERN-SPS energies: an investigation of the high-μ_B region of the QCD phase diagram



Electromagnetic processes: information on the temperature of the system (QGP and/or hadronic), the nature of the phase transition and the approach to QCD chiral symmetry restoration

Hard QCD processes: probe the Quark-Gluon Plasma and study its transport properties

No results exist below top SPS energy, $\sqrt{s_{NN}}$=17.3 GeV for Pb-Pb

Strong physics case for a new experiment, proposing to study Pb-Pb collisions at lower SPS energies, down to $\sqrt{s_{NN}}$=4.9 GeV for Pb-Pb, via an energy scan

Cost and timeline (preliminary!)

Cost: first estimate contained in the EOI

Vertex tracker

Item	R&D (kCHF)	Construction kCHF)	Total Cost kCHF)
Pixel CMOS sensors	700	700	1400
Sensor test	100	150	250
Thinning/dicing	200	300	500
Total	**1000**	**1150**	**2050**

Mechanics, cooling, readout electronics: ~1.5 MCHF

Muon tracker

	Baseline 4 stations (kCHF)	Expanded 6 stations (kCHF)
GEM foils	1000	1500
NS2 frames	400	600
Drift + Readout	250	375
FEE	2800	4200
HV system	100	150
Mechanical support	500	750
Gas system	200	300
TOTAL	**5250**	**7875**

Magnets:
to be evaluated

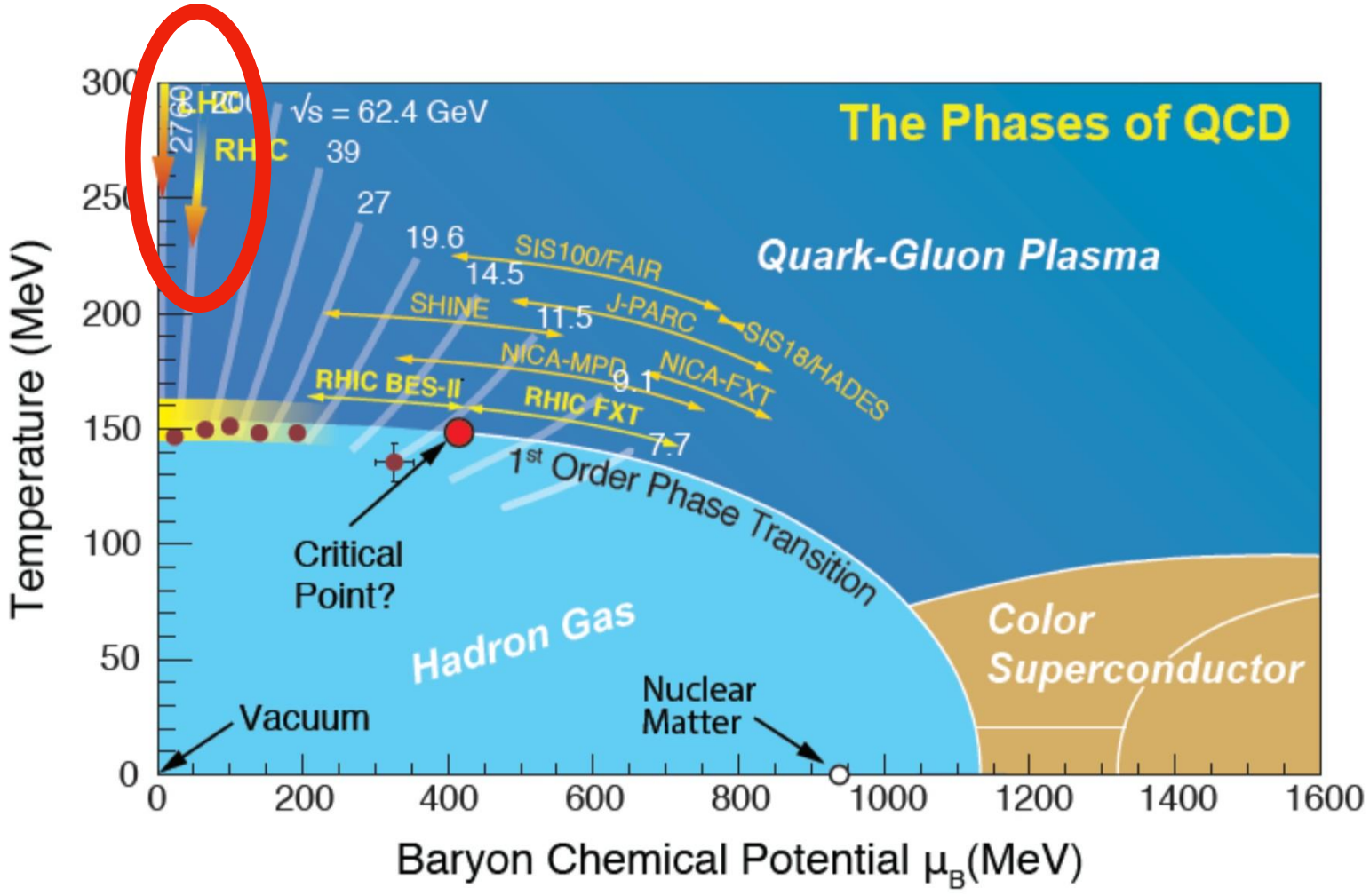
Trigger system:
3.5 – 4 MCHF

Sharing of responsibilities necessitates the completion of the formation process of the collaboration → goal for LOI

Timeline

- 2020-2022 → project finalization, submission and approval of the proposal
- 2023-2025 → construction
- 2026 and beyond → data taking in parallel with the LHC run 4

High-energy frontier



Relativistic Heavy Ion Collider (RHIC)

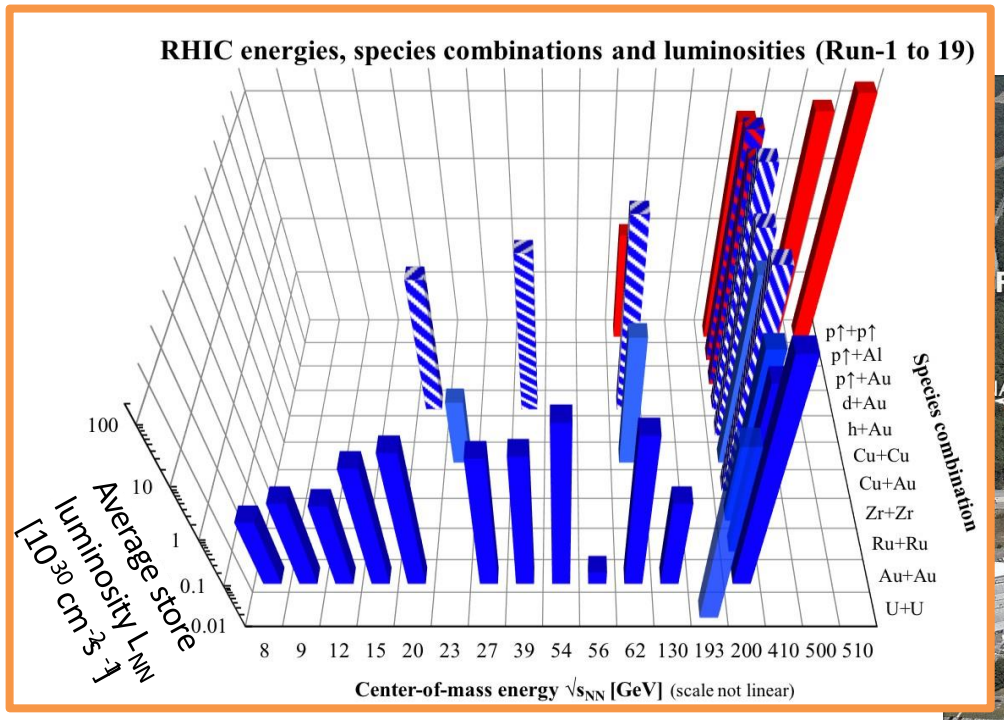
The most versatile particle collider

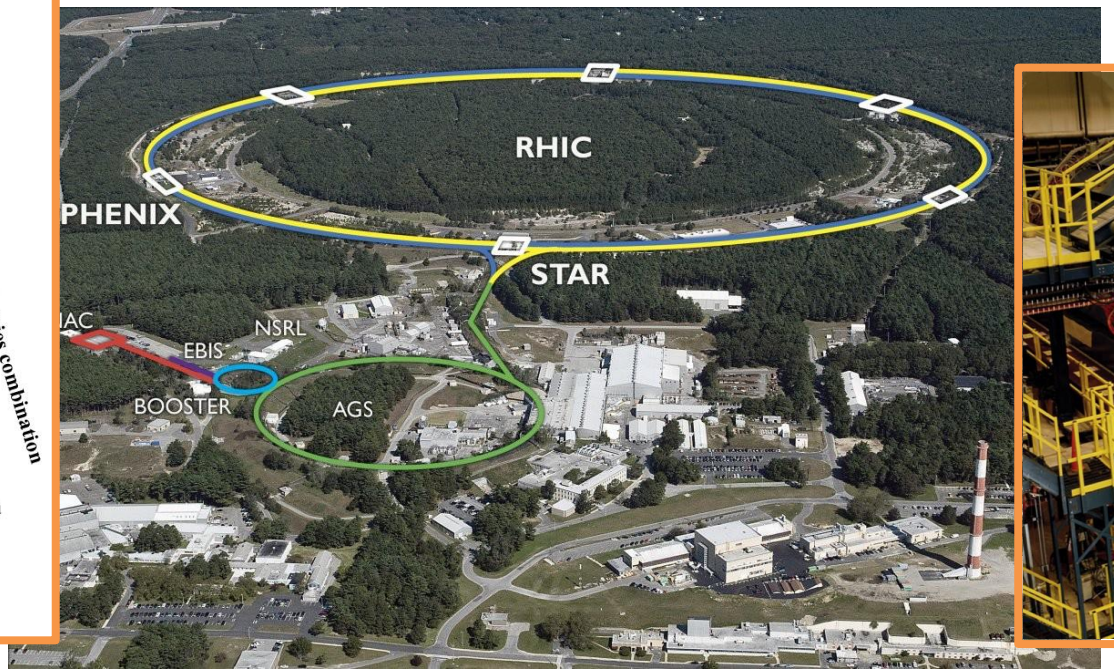
The only **polarized proton** collider in the world

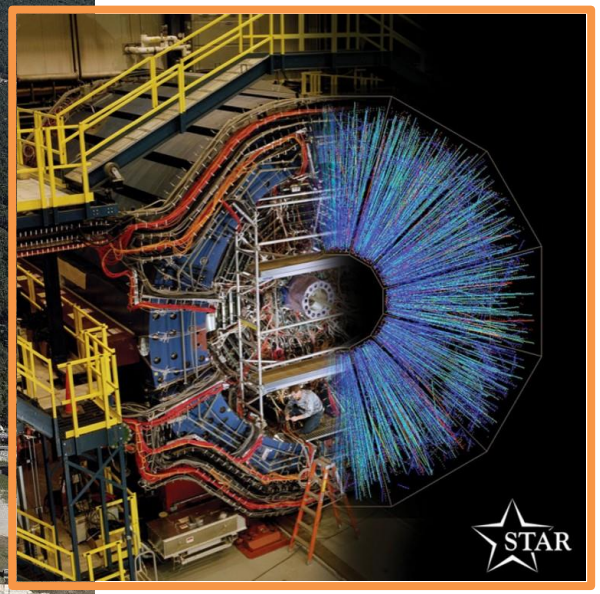
Type of collisions: p+p, p+Au, Au+Au, d+Au, U+U, Zr+Zr, …

Center-of-mass energy for Au+Au collisions: 3.0 - 7.7 - 200 GeV

Fixed-Target mode Collider mode







Beam Energy Scan (BES) Program @ RHIC

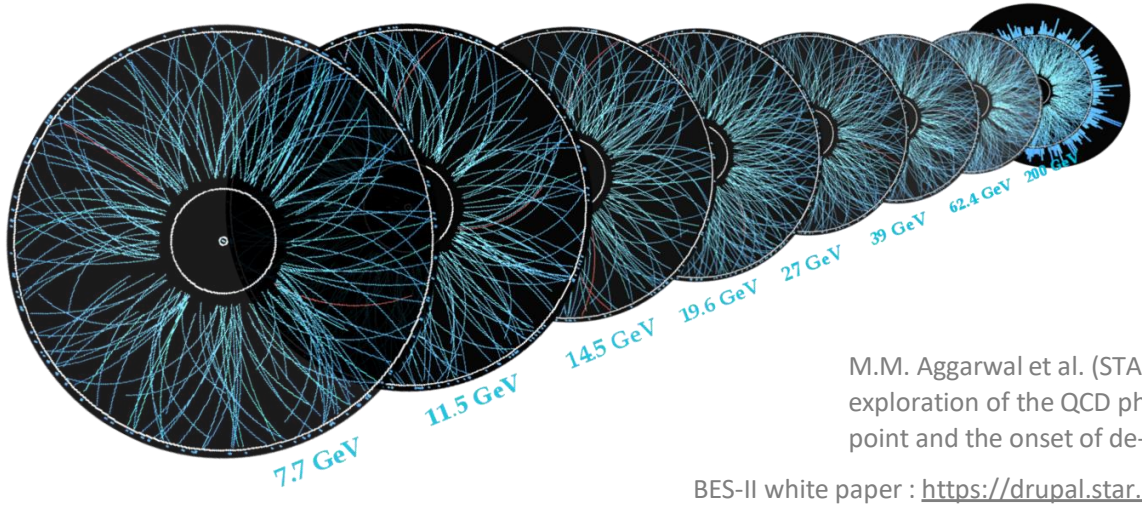
RHIC provides a unique opportunity to explore the QCD phase diagram with different collision energies

Search for QCD critical point, 1st order phase transition, turn-off of QGP, etc.

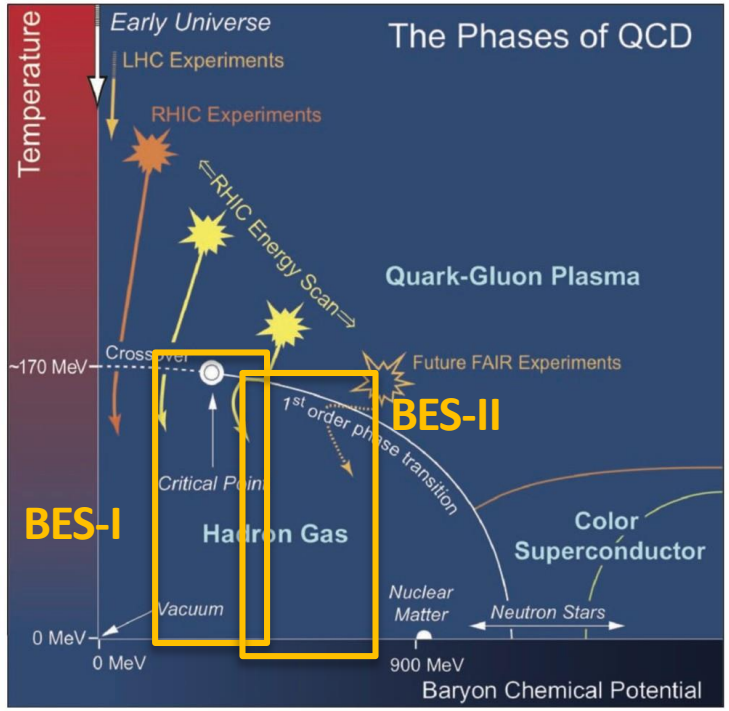
BES-I (2010 – 2011, 2014): $\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39, 54.4, 62.4, 200 GeV

BES-II (2019 – 2021): Collider mode: $\sqrt{s_{NN}}$ = 7.7, 9.1, 11.5, 14.6, 16.7. 19.6 GeV

Fixed-Target mode: $\sqrt{s_{NN}}$ = 3.0, 3.2, 3.5, 3.9, 4.5, 5.2, 6.2, 7.7 GeV

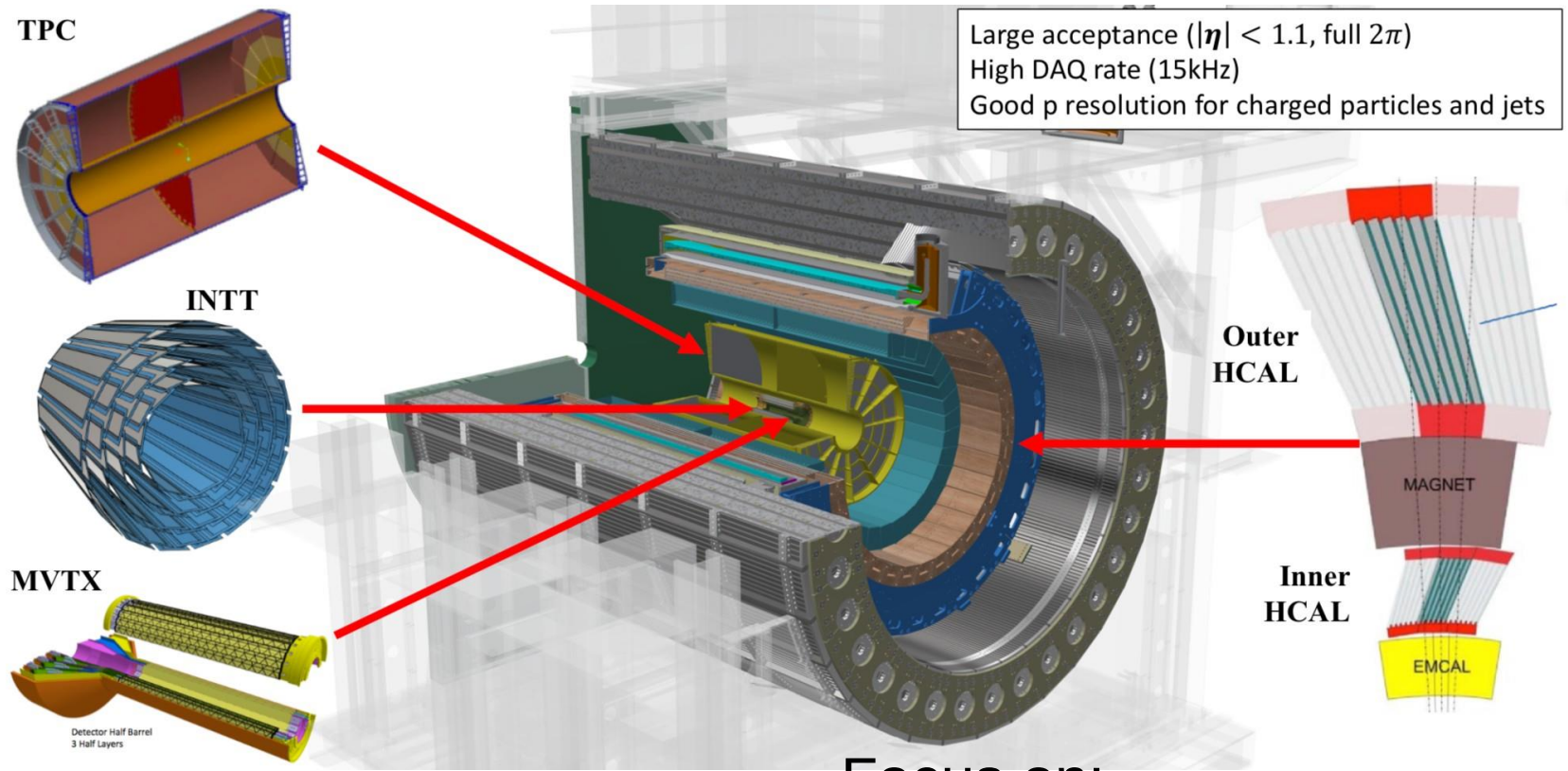


M.M. Aggarwal et al. (STAR Collaboration), An experimental exploration of the QCD phase diagram: the search for the critical point and the onset of de-confinement. arXiv: 1007.2613



BES-II white paper : https://drupal.star.bnl.gov/STAR/starnotes/public/sn0598

sPHENIX @ RHIC (2023)



Ultimate performance for jets and HQs at RHIC

Got CD2/3: construction can start

Compact and hermetic design

Continuous readout at 15 kHz

- ~100B Au-Au events per year

Focus on:

- Fully reconstructed jets, with HCAL
- Bottomonium states
- HF mesons and baryons, with MAPS

Y. Ji

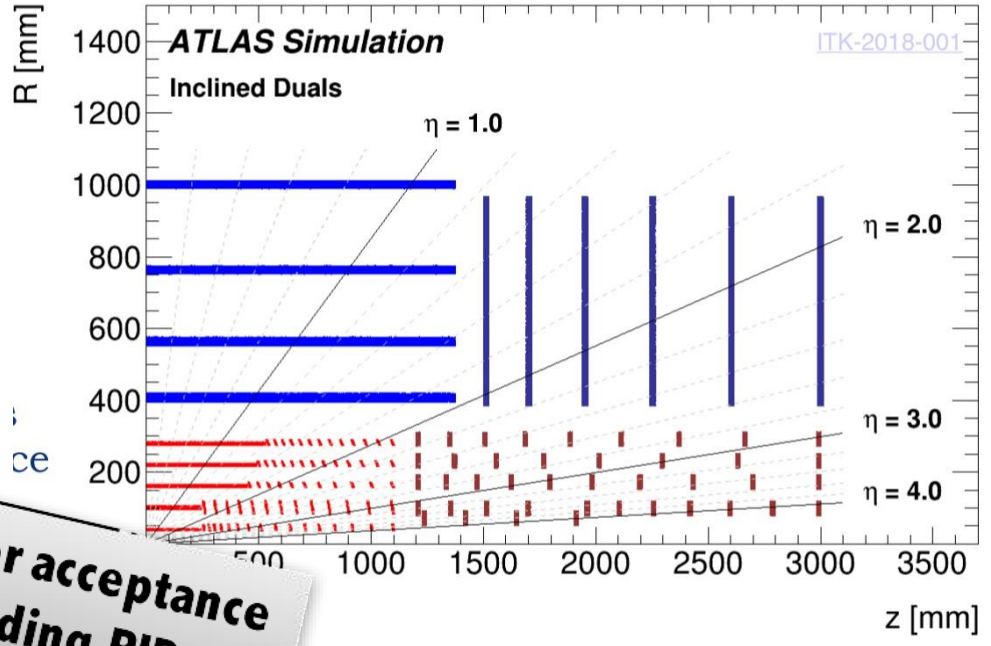
ATLAS and CMS LS3 Upgrades (2026)

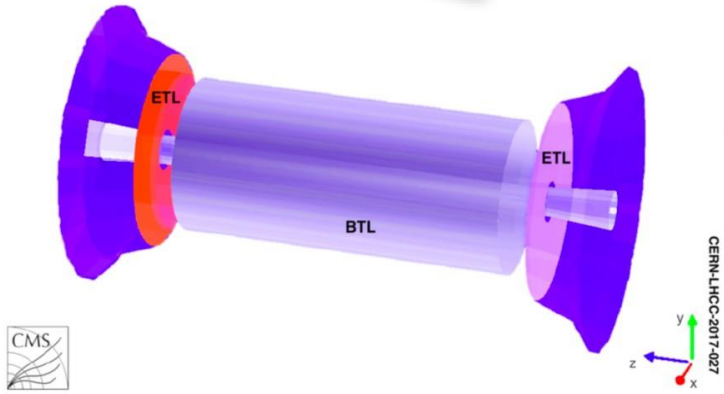
Run 3+4: goal 13/nb Pb-Pb, focus on rare triggers

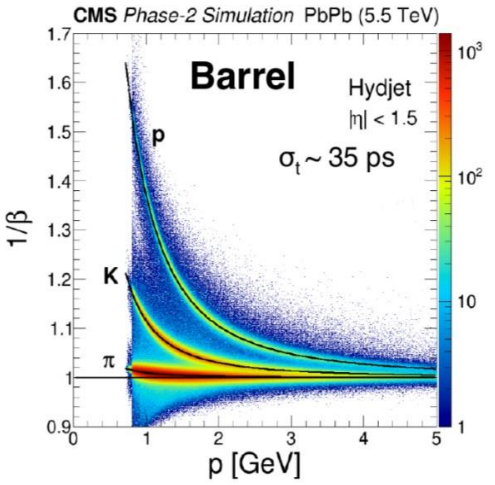
CMS, also large bandwidth for MB events: 6 kHz in Run 3, goal to increase for Run 4

Major Phase-2 upgrades for HL-LHC

- Extension of tracker acceptance from $|\eta|<2.5$ to $|\eta|<4$
- Endcap calorimeters with higher granularity
- Precise timing detectors for pile-up rejection t.o.f. PID
  - ATLAS $2.5 < |\eta| < 5$
  - CMS $|\eta| < 4$







A. Govinda Stahl Leiton (CMS)

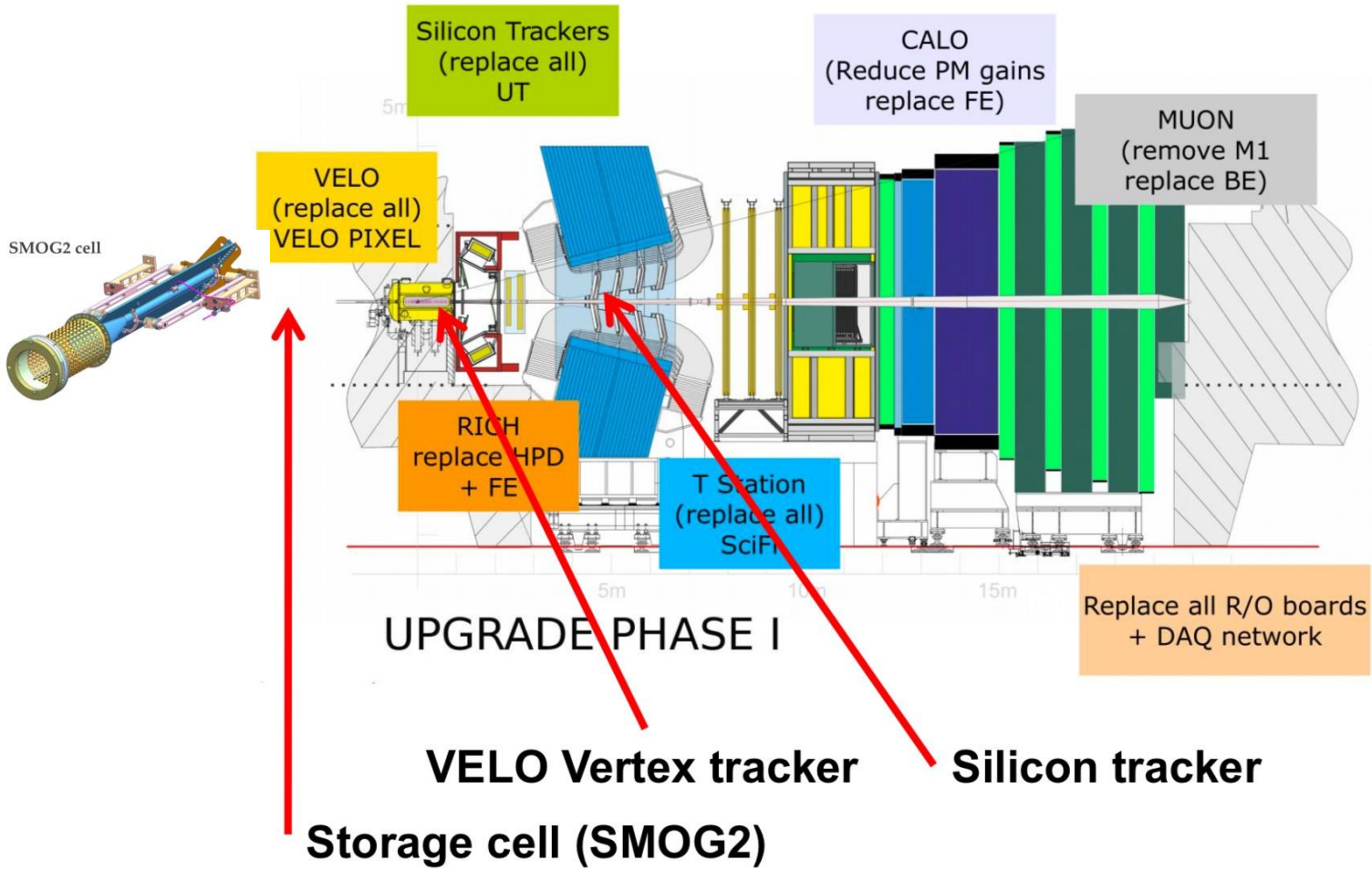
LHCb LS2 Upgrade (2021)

Ongoing LS2 upgrade:

- Tracker with higher granularity
  - à **Pb-Pb 30-100%**
- New **storage cell for fixed-target collisions** at up to x100 higher rates

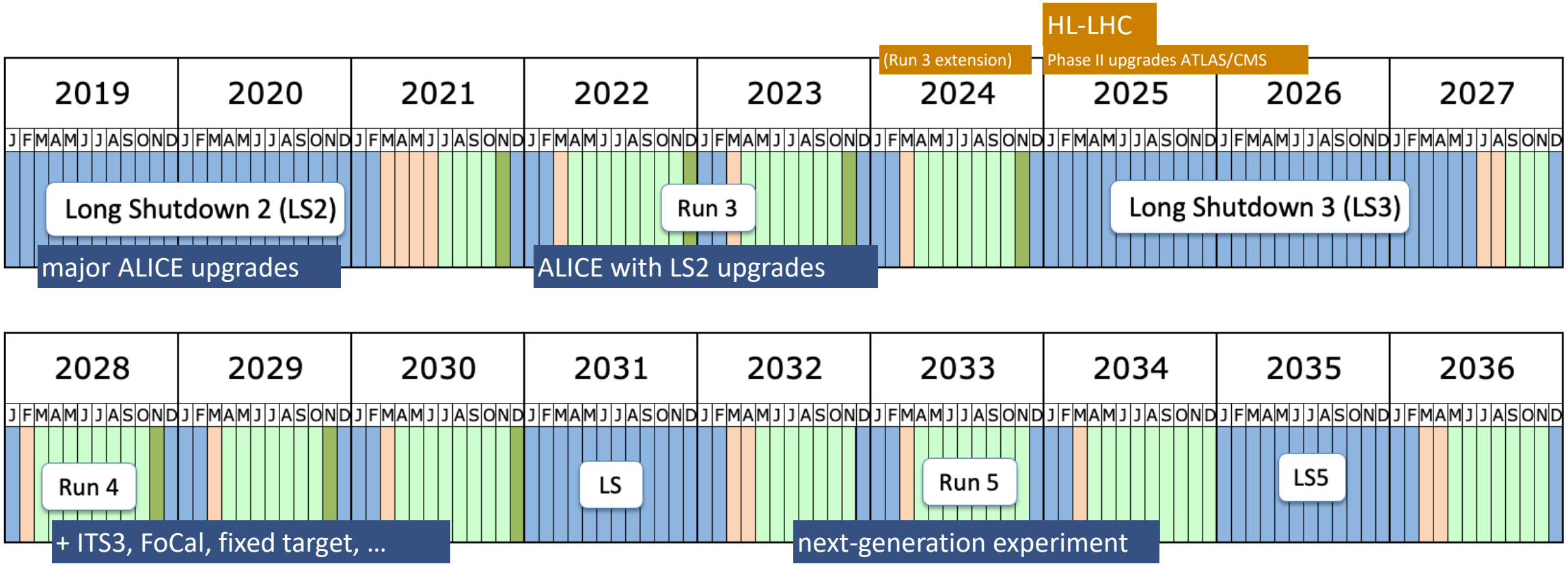
Proposal for phase-2 upgrade for Run 5 (2031)

- Increased readout rate and granularity **central Pb-Pb**
- Extended PID performance



P. Di Nezza

ALICE upgrades



- conceptually new detector opens up **possibilities for qualitatively new measurements**

Pb-Pb in Run 3+4:
$\mathcal{L}$ = 13 nb^{-1}

ALICE LS2 Upgrade

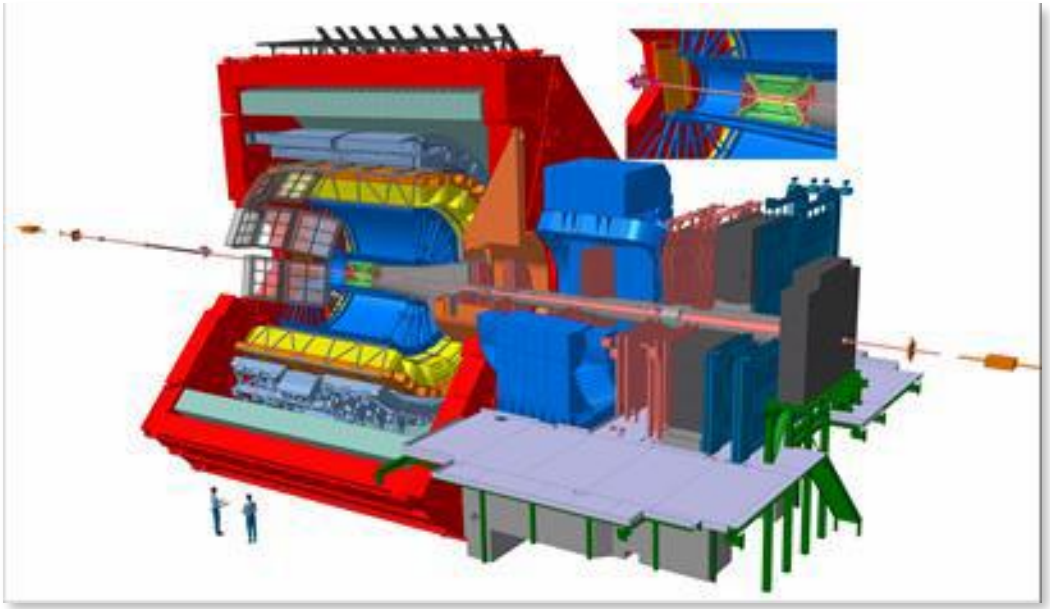
ALICE LS2 Upgrade Strategy

Goal

- **Physics program for LHC Run 3+4:** moving from an exploratory phase to a precision-measurement phase
- **Luminosity target:** (10 +3) nb^{-1} with Pb-Pb collisions ➡ gain of a factor 100 in statistics over the Run 1+Run 2 programme

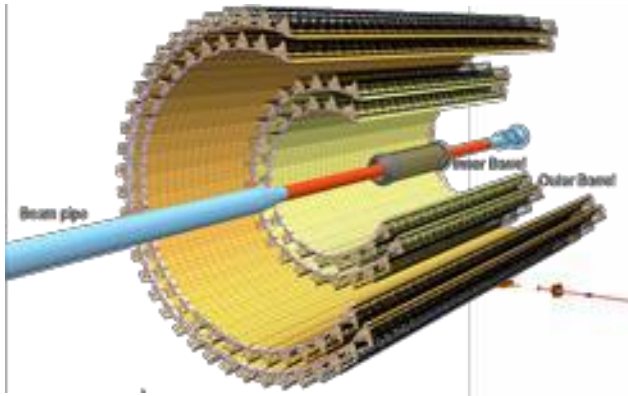
How

- **Read out all Pb-Pb interactions** at a maximum rate of 50 kHz
- Improve vertexing and tracking at low p_T
- Improve Muon Performance
- **Preserve and strengthen detector specificities**: PID, lightweight and precise trackers, low magnetic field

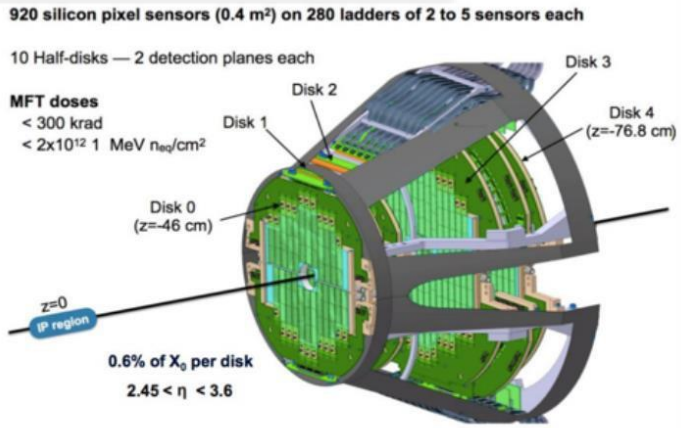


ALICE LS2 Upgrade

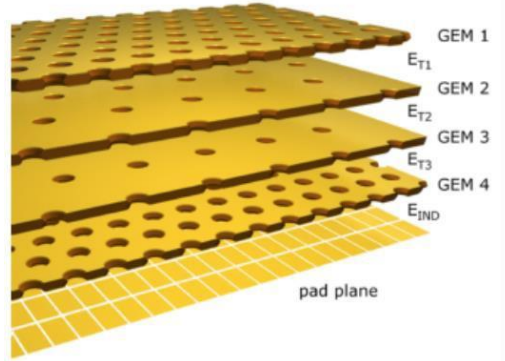
Inner Tracking System

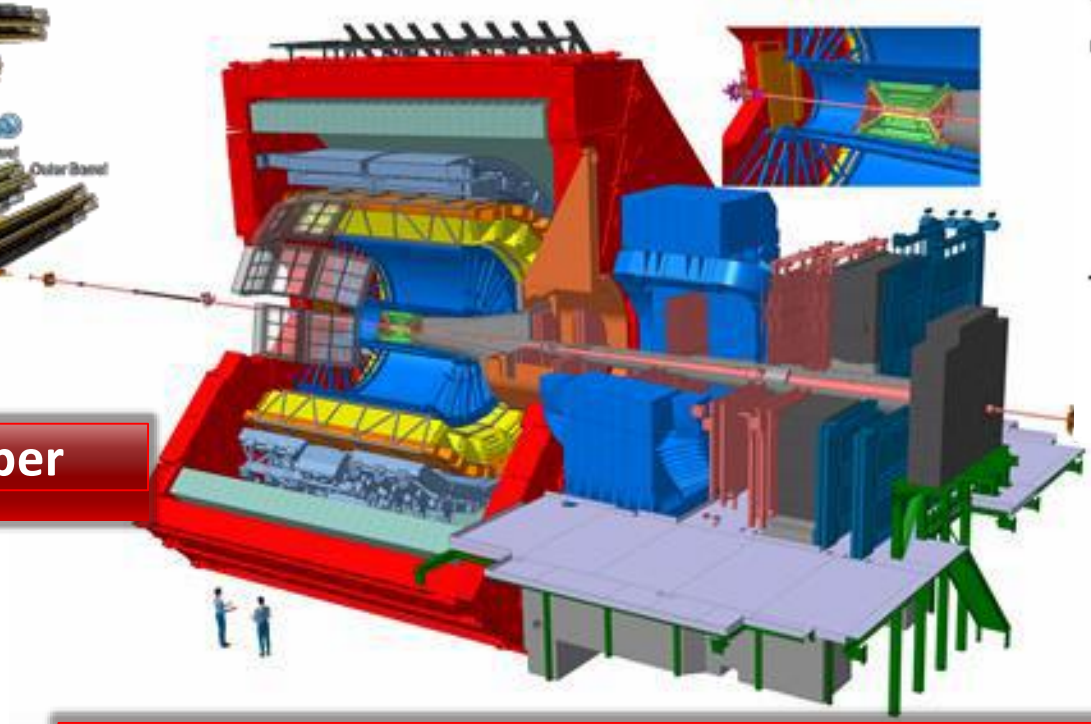


Muon Forward Tracker

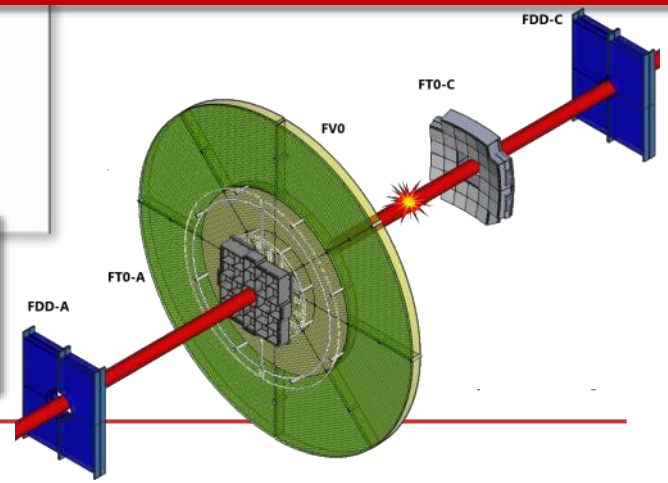


Time Projection Chamber



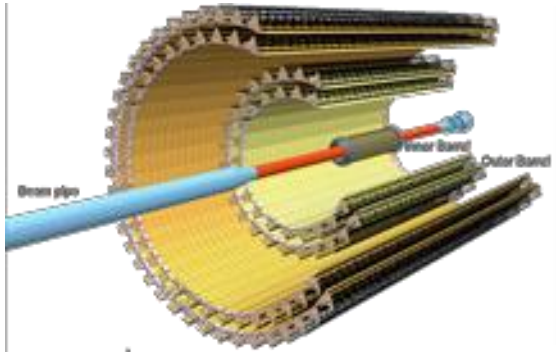


Fast Interaction Trigger



Upgraded readout for TOF, TRD, Muon, ZDC, calorimeters

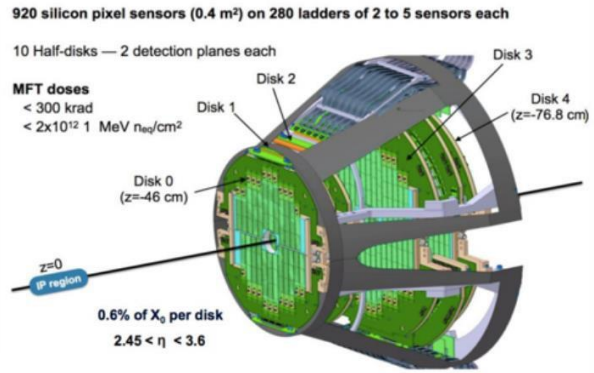
ALICE LS2 Upgrade

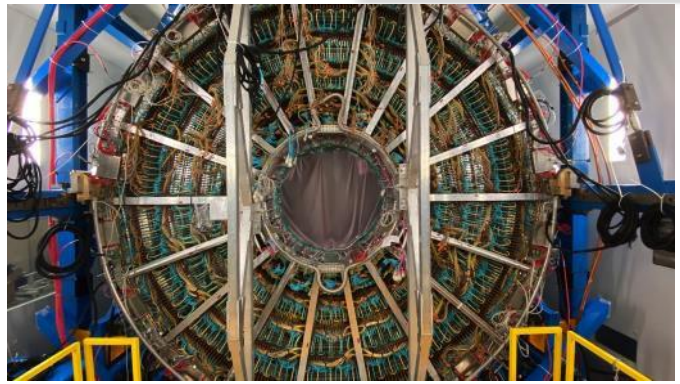


New Inner Tracking System + Muon Forward Tracker

10 m^2 of CMOS monolithic active pixel sensors

- higher granularity and reduced material budget
- improved resolution for heavy-flavor vertices
- faster readout





TPC Upgrade

Replacement of the MWPC-based readout by detectors employing GEMs to allow TPC operation in continuous mode

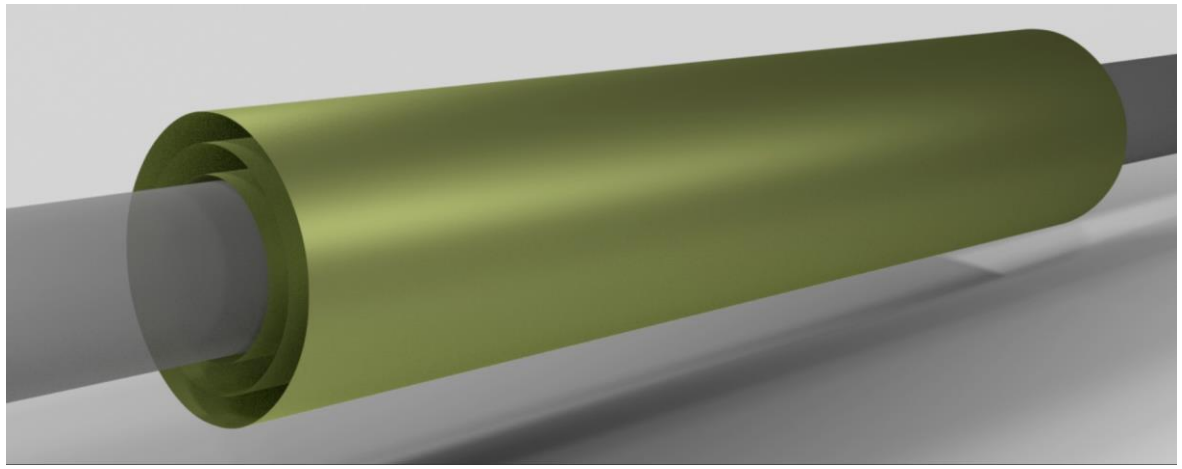
Upgraded read-out for many detectors, new integrated Online-Offline, new Fast Interaction Trigger detector

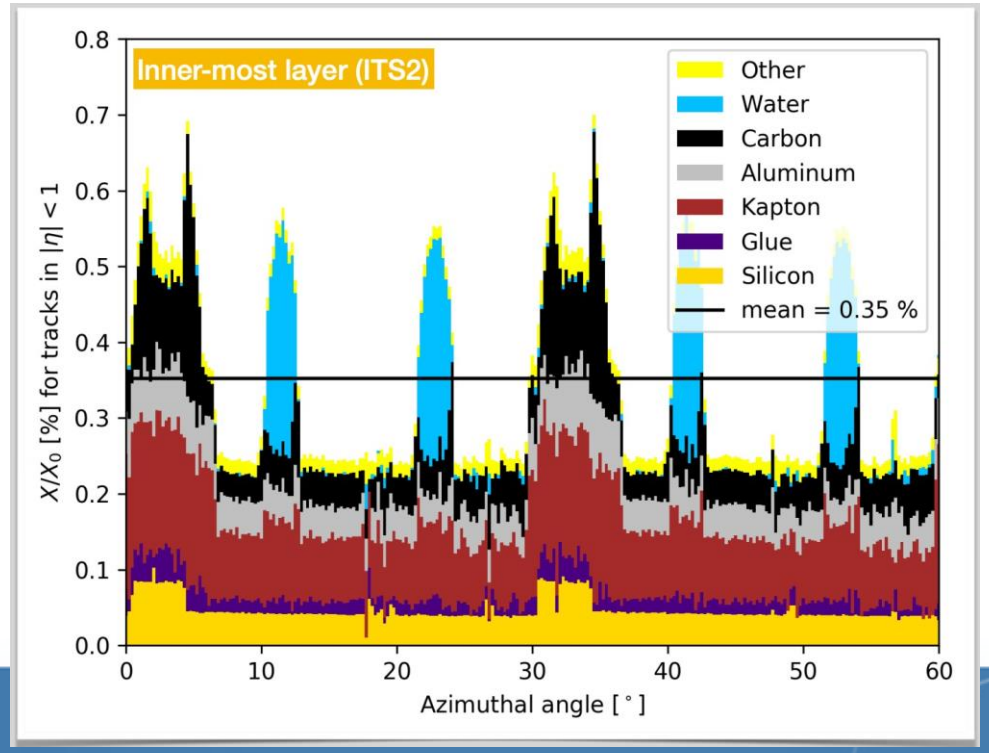
- Record all events at up to 50 kHz in Pb-Pb (1 kHz during Run2)
- Data reduction from 1 TB/s to 85 GB/s via online reconstruction
- Continuous readout of all data into a dedicated computing facility

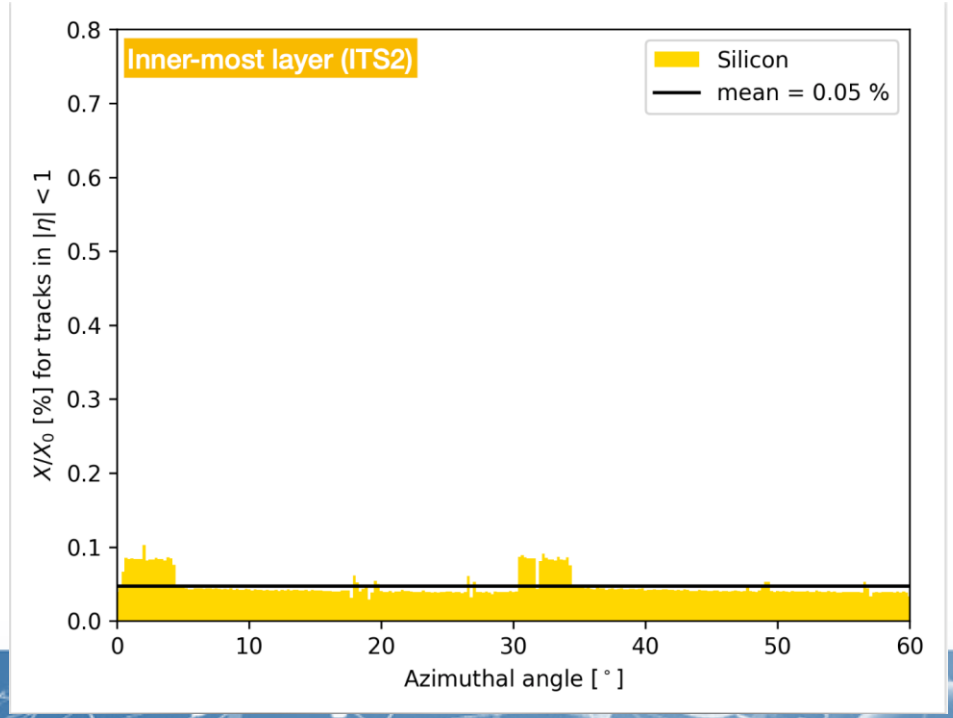
ALICE LS3 Upgrade

ITS 3

- fully-cylindrical, (almost) mass-less Inner Barrel proposed for installation in LS3
- R&D towards TDR endorsed by LHCC



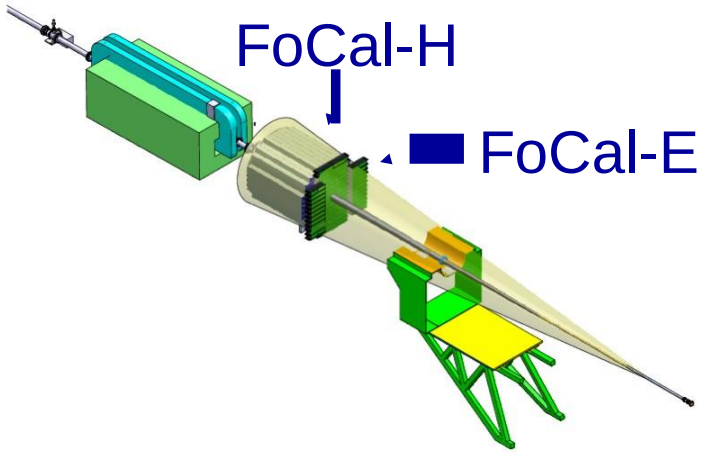




The FoCal proposal

See ALICE-PUBLIC-2019-005

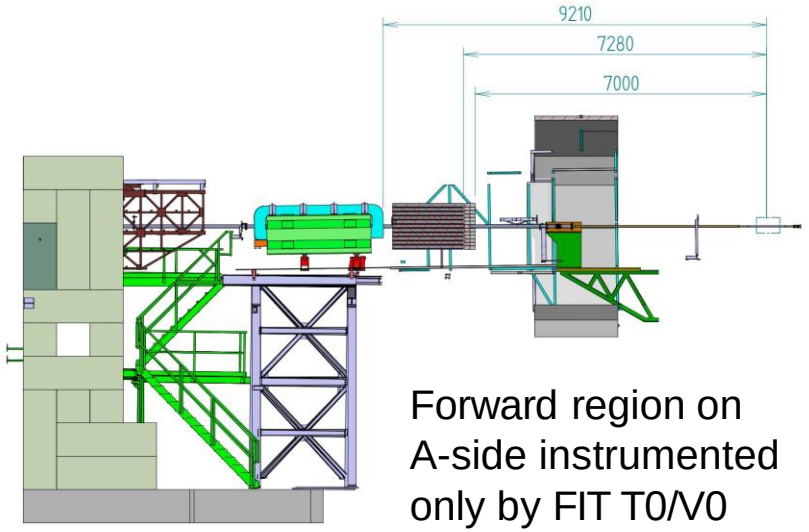
$3.2 < \eta < 5.8$
(baseline design @7m)



FoCal-E: high-granularity Si-W sampling calorimeter for photons and π^0
FoCal-H: conventional Pb-Sc sampling calorimeter for photon isolation and jets

Observables:

- π^0 (and other neutral mesons)
- Isolated photons
- Jets (and di-jets)
- J/ψ (Υ) in UPC
- W, Z
- Event plane and centrality



Forward region on A-side instrumented only by FIT T0/V0

Fixed-target experiments at LHC

FT@LHC

- Energy range: 7 TeV proton / 2.76 A TeV Pb LHC beams on a fixed target

- Already running in LHCb with a gas system, SMOG, but at low luminosity: *PRL 121, 222001 (2018)* , *PRL 122, 132002 (2019)*

Physics motivations

- Advance our understanding of the high-*x* gluon, antiquark and heavy-quark content in the nucleon and nucleus and its connection to astroparticles
- Unravel the spin of the nucleon: dynamics and spin distributions of quarks and gluons inside (un)polarised nucleons
- Study the quark-gluon plasma between SPS and RHIC energies towards large rapidity

Physics motivations and performances studies detailed in the AFTER@LHC study group *arxiv:1807.00603*

FT@LHC: status and prospectives

LHCb-FT

Unpolarised internal gas target

- SMOG upgraded with a storage cell attached to the VELO: higher gas density → *SMOG2 project*

- Possible gases used so far with SMOG: He, Ne, Ar
- Current and future studies:
  - usage of other gas targets (H_2, D_2, N_2, O_2, Kr, Xe)
  - trigger and track reconstruction in LHCb with SMOG2
  - parallel running of SMOG2 to the main LHCb Run 3 programme possible: define achievable luminosities

Polarised internal gas target

- Storage cell (as SMOG2) with a polarised atomic beam source: *LHCSpin project* for Run 4
- R&D ongoing from both LHC and project (target in LHCb) sides

ALICE-FT

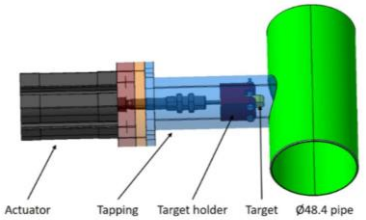
Possible fixed-target system for Run 4

CERN-PBC-Note-2019

- Beam halo deflected with bent crystal on an internal solid target
- Internal gas target

Layout for ALICE with bent crystal

- Bent crystal with UA9 Collaboration
- Solid target system with target from Be to W
- Current and future studies:
  - LHC collimation studies and proton flux estimation
  - target integration, impedance and vacuum



  - tracking reconstruction with shifted target
  - SPS beam test foreseen in 2021 with UA9

A post-LS4 heavy-ion experiment

- Idea for new dedicated heavy-ion experiment at the LHC
  developed within ALICE in the course of 2018/19
- Discussed at the heavy-ion town meeting (CERN, Oct 2018)
- Expression of Interest submitted as input (Feb 2019)
  to the European Particle Physics Strategy Update (Granada, May 2019)
- Active work (within ALICE) towards a Letter Of Intent
  (aimed for submission by end of 2021)
- Physics program to exploit the unique possibilities from a novel concept
  with unprecedented low material budget and rate capability in heavy-ion

Step forward in physics reach
from both detector capabilities *and* luminosity

Physics motivation

- **Heavy-flavour and quarkonia**
  - multiply heavy-flavoured hadrons, e.g.: Ξ_{cc}, Ω_{cc}, Ω_{ccc}
  - $\chi_{c1,2}$ states
  - ultimate precision on B mesons at low p_T
  - X, Y, Z charmonium-like states, e.g. X(3872)

hadron formation from deconfined QGP

chiral symmetry restoration, electrical conductivity

- **Low-mass dielectrons**
  - thermal dilepton continuum ($0 < m_{ee} < 3$ GeV) with unprecedented precision

QGP temperature evolution

QGP radiation

- **Real (ultra-)soft photons**
  - down to 50 MeV/c
  - very low p_T photons: 1 MeV/c < p_T < 100MeV/c
  - dedicated small forward spectrometer at $3.5 < |\eta| < 5$

femtoscopy, condensation

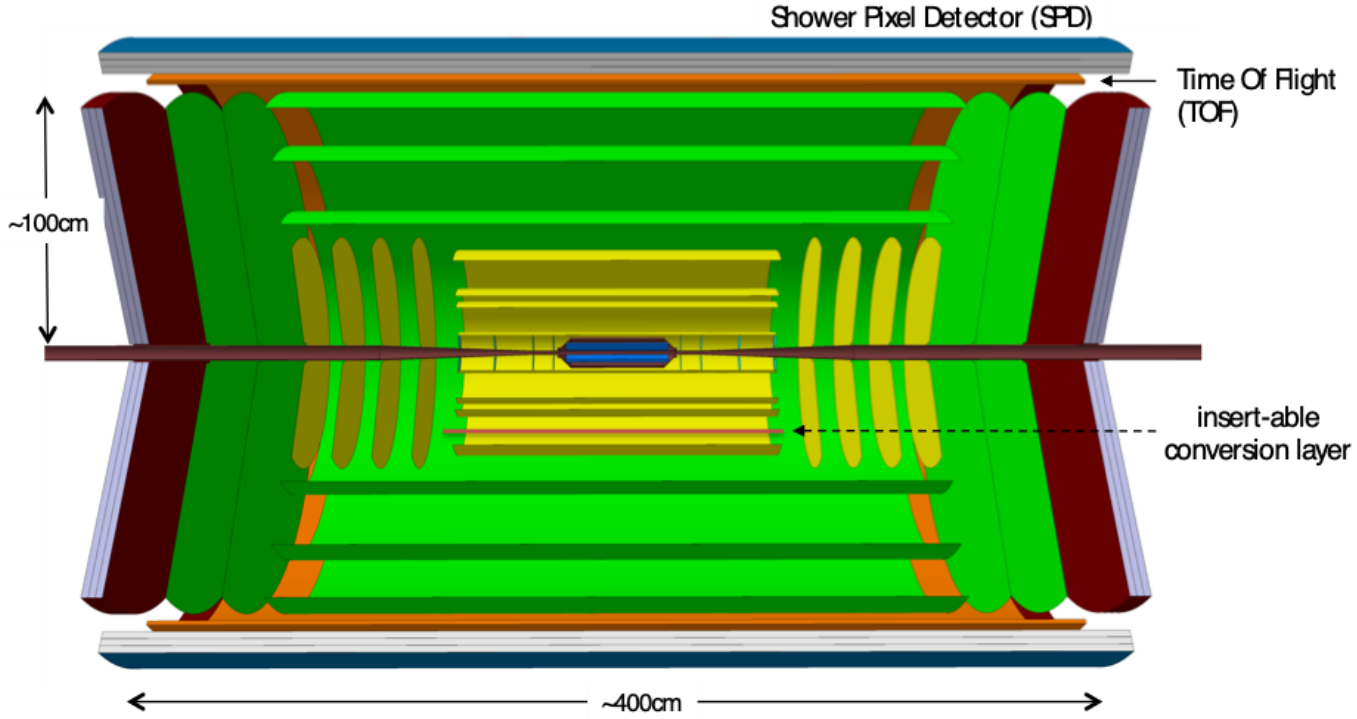
- **Exploration of further physics potential**

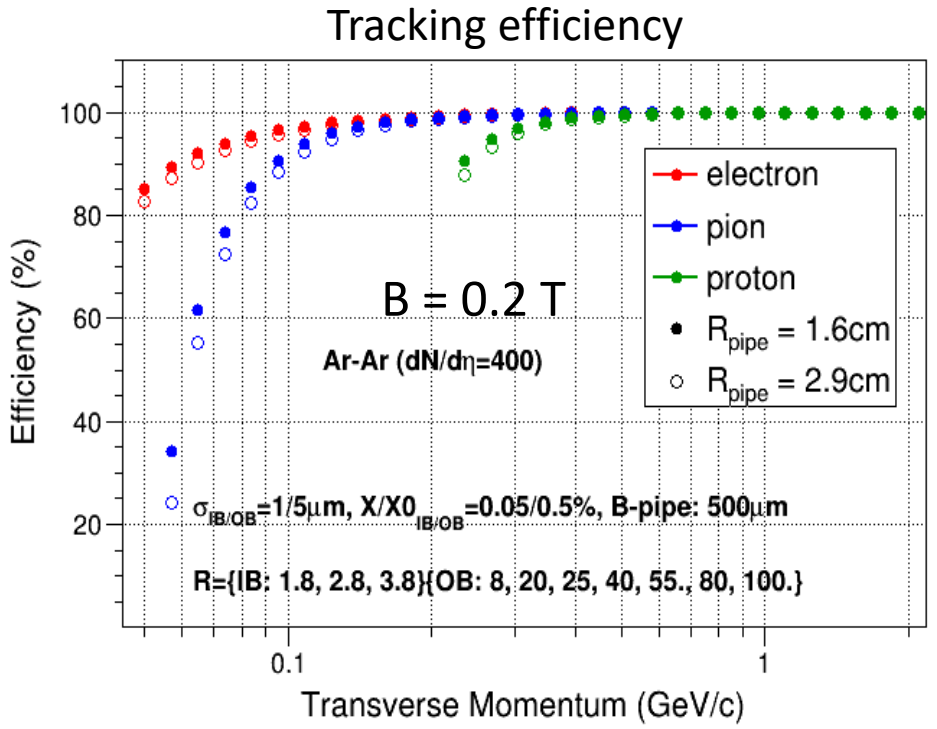
test of soft theorems

requires increase in (per-nucleon) luminosity up to 10^{34} cm^{-2} s^{-1} and acceptance (incl. low p_T reach)
→ new experiment and collision system(s)

Detector concept

a thin, light, fast all-silicon tracking & PID detector





- tracking
  - ~10 layers (blue, yellow, green) based on MAPS
- particle identification
  - time-of-flight with outer silicon layer (orange)
  - Shower Pixel Detector (outermost blue)
- **large acceptance** ($\eta \sim 8$)

- excellent spatial resolution
  - innermost layers: $\sigma < 3$ µm
  - outer layers: $\sigma \sim 5$ µm
- ultra-low material budget
  - $X/X_0 \sim 0.05$ % / layer
- precise time measurement
  - $\sigma \sim 20$ ps

References

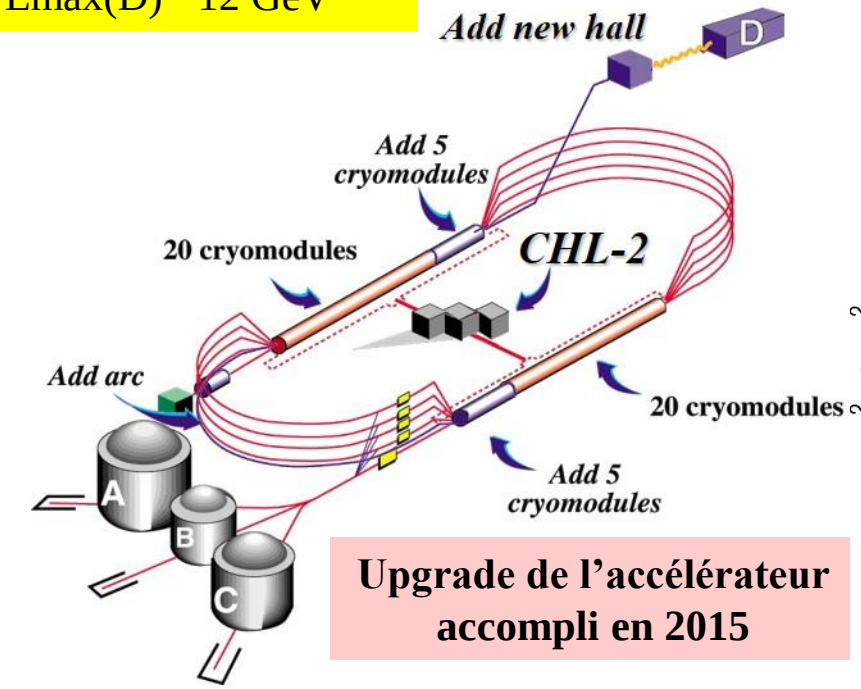
- Heavy-Ion town meeting (CERN, 10/2018), summarizing document
- Yellow Report (WG5: Future physics opportunities for high-density QCD at the LHC with heavy-ion and proton beams)
- Expression of Interest, arXiv:1902.01211
- European Particle Physics Strategy Update (Granada workshop, May 2019)
  - Briefing Book
  - Presentation Johanna Stachel
  - Summary Strong Interactions
- Conference presentations
  - XXV Cracow EPIPHANY Conference on Advance in Heavy Ion Physics, January 2019 Luciano Musa
  - Strangeness in Quark Matter, June 2019 Johanna Stachel, Luciano Musa

e A colliders

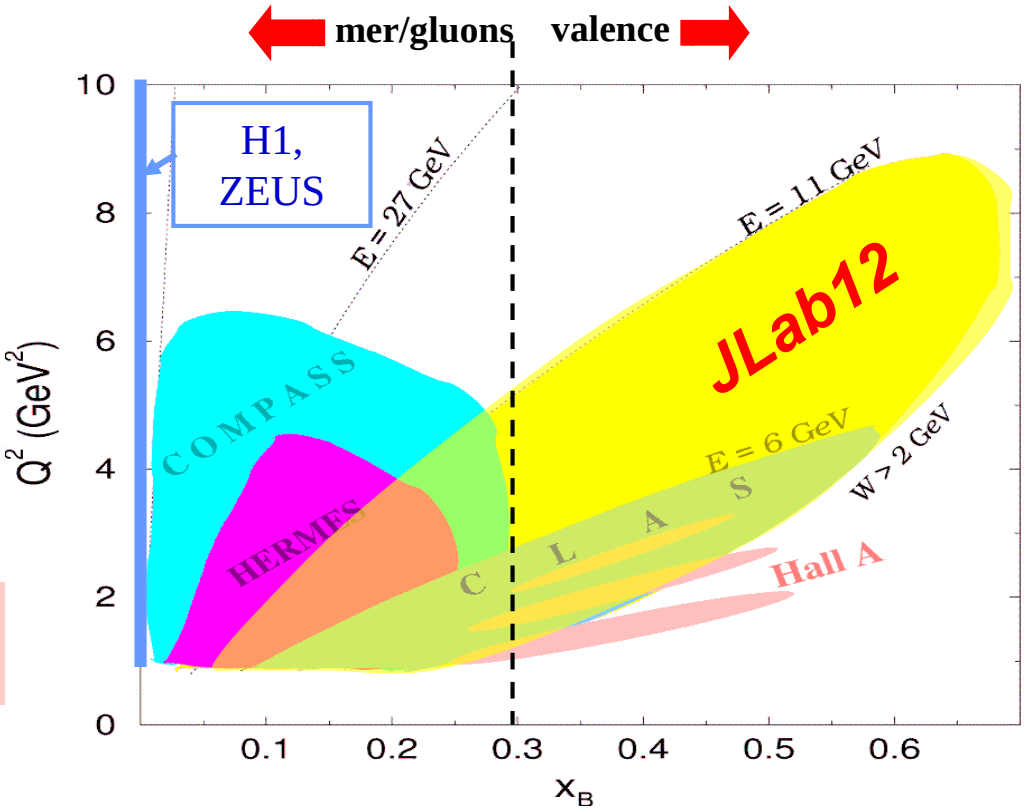
Precision cold-QCD measurements

JLab@12 GeV

E_{max}(A,B,C) ~ 11 GeV
Emax(D) ~12 GeV



Upgrade de l'accélérateur accompli en 2015



- **Halls A, B,** et **C:** Expériences de ***structure du nucléon et des noyaux*** 🇫🇷
  Détecteurs différentes/programmes complémentaires :
  - cinématiques différentes
  - précisions/résolutions différentes
  - observables différentes
- **Hall D**: ***photoproduction de mésons exotiques***

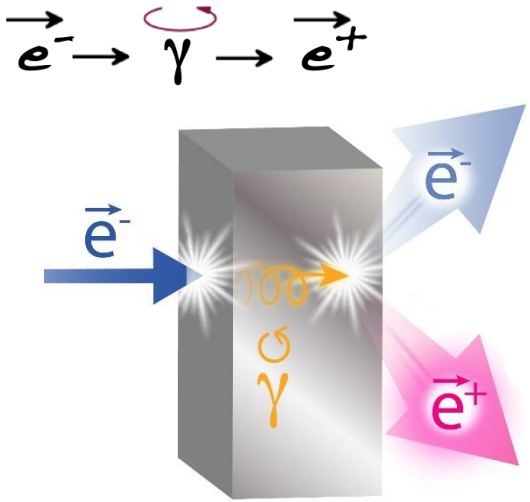
Machine en opération depuis 2016
Au moins ~10 ans de prises de données prévues

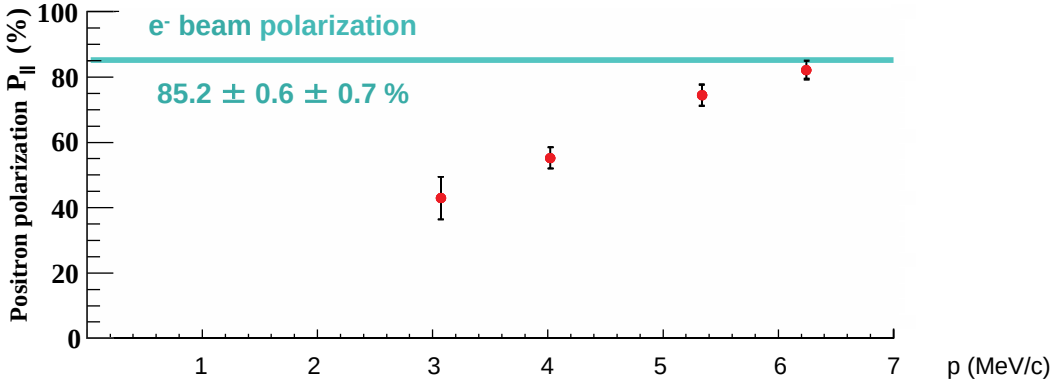
Faisceau de positrons à JLab 12 GeV

***PEPPo** (Polarized Electrons for Polarized Positrons)* :

LOI12-18-004 – J. Grames, E. Voutier et al.

Conception/construction d'une source **polarisée continue** de **positrons** pour **CEBAF**.





Principe : **transfer** de la **polarisation** d'un faisceau initial d'**électrons** de faible énergie (~**10 MeV/c**) à un faisceau secondaire de **positrons** produits par le rayonnement de freinage des électrons dans une cible de Z élevé.

Objectifs : une source PEPPo se distingue d'une source conventionelle par la sélection de l'énergie des positrons

I(e^+) variable **50 nA - 1 µA** selon la polarization P_{e^+} > **40%**

Challenges : cible de puissance (10 kW); système supraconducteur pour la capture et la réduction d'émittance du faisceau de positrons.

Avantages : source **radioactivement propre** et de **faible coût**.

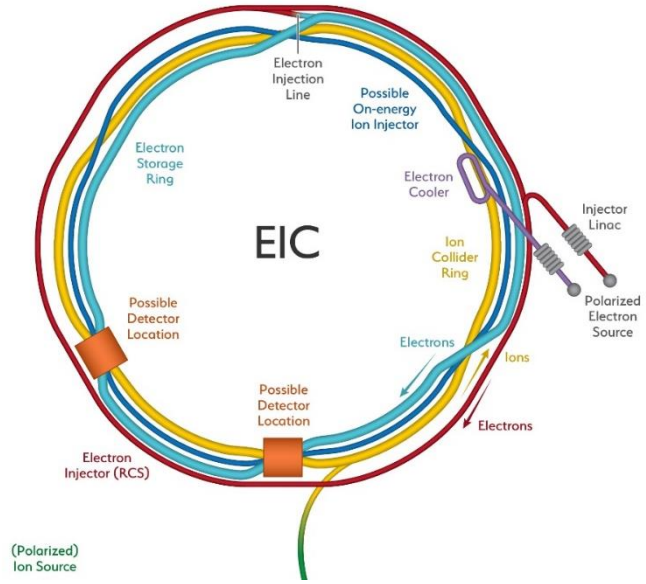
Applications : **CEBAF**, **EIC**…

Electron Ion Collider (EIC) : CD-0 et sélection du site

Questions ouvertes en QCD:

- ✓ Saturation: QCD dans le régime non linéaire
- ✓ Distributions en position, impulsion, moment angulaire…
- ✓ Rôle des gluons dans le milieu nucléaire

EIC: Le site futur le mieux adapté pour l'étude de la QCD à haute *E*/petit *x*



9 janvier 2020: annonce du DoE (USA) "Critical Decision 0 (Mission Need) for an US-based Electron Ion Collider"

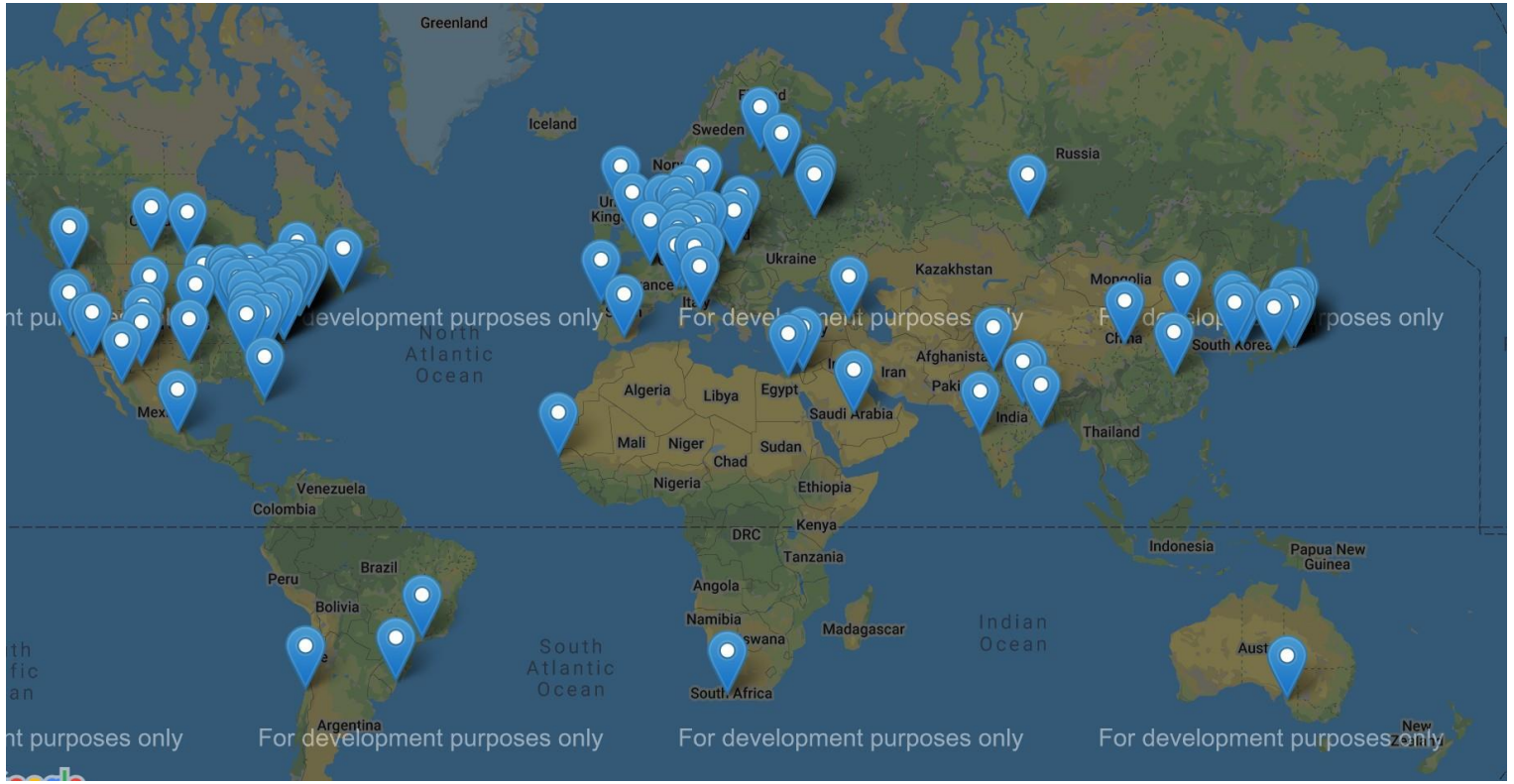
- ➢ Maintenant EIC est un projet official du DoE
- ➢ Brookhaven National Laboratory (Upton, NY) a été choisi comme site pour la nouvelle machine

Calendrier préliminaire

		2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
DOE Driven	**CD0**	19/12											
	Site selection		9/01										
	CD1												
	CD2/CD3												
	Construction												
	CD4/EIC operations												
Users Driven	**Physics/Detector study**												
	Call for detectors/collaborations												
	Design of detectors												
	Detector construction												
	Physics												

Size and demographics (1)

- EICUG organization established in summer 2016
- In numbers….: 995 members (Experimental scientists: 581 / Theory scientists: 249 / Accelerator scientists: 147 / Support: 3 / Other: 15), 205 institutions, 30 countries, 6 world regions
- World map:



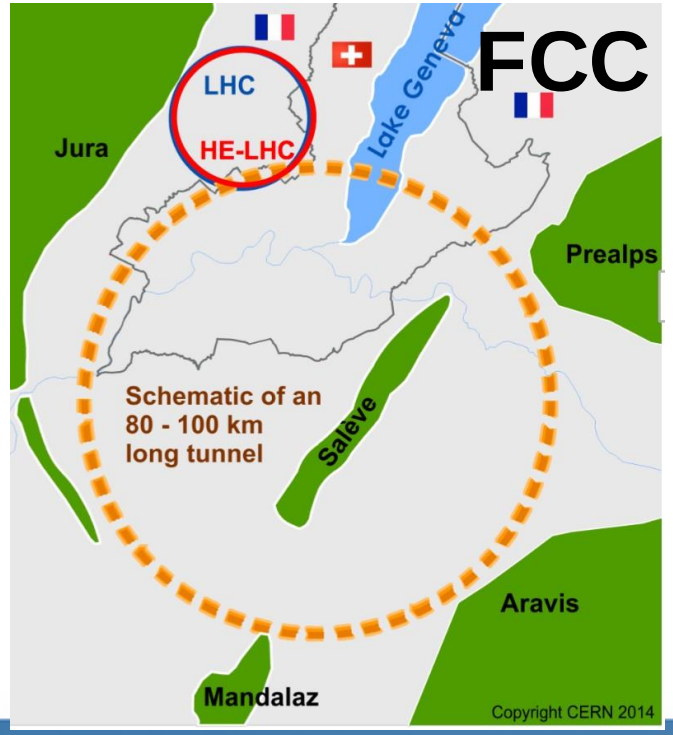
Far future: HIs in a 100 km collider? FCC / SppC

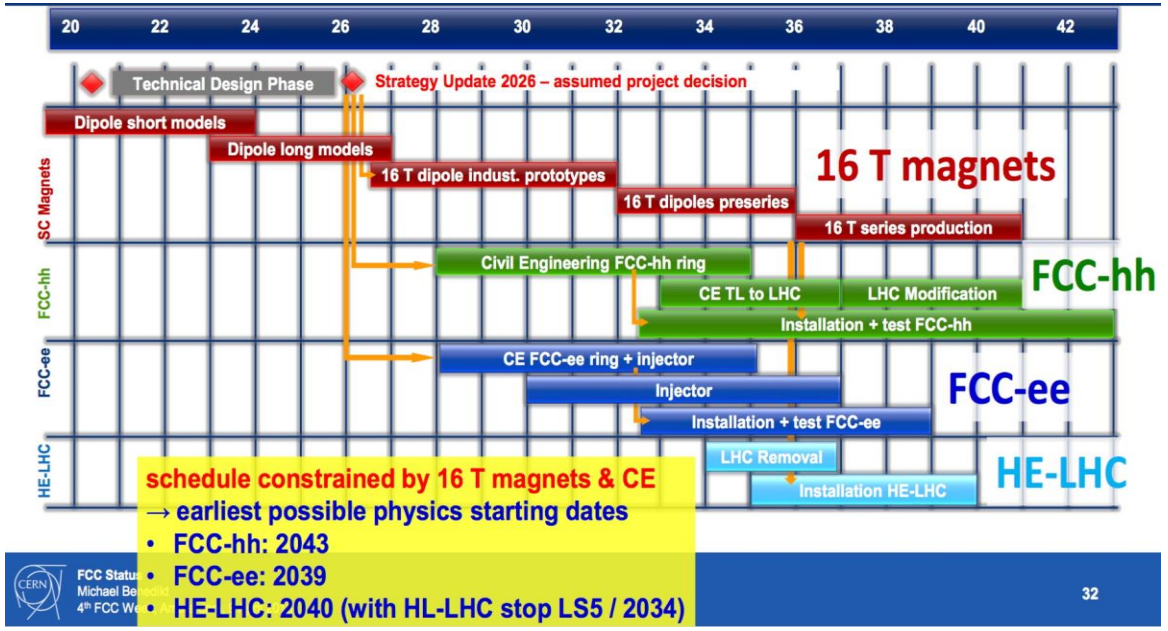
100 km tunnel: one of the options for HEP in the 2040s-50s

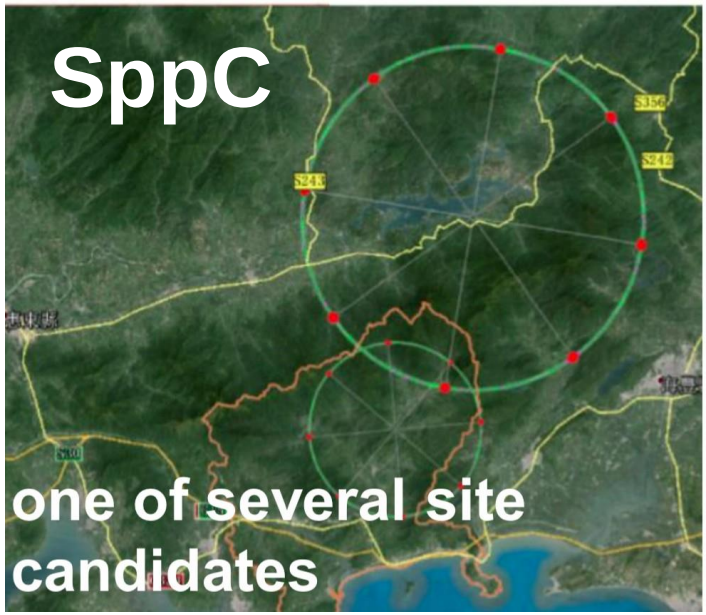
Two studies: CERN-FCC (CDR done), Chinese SppC (pre-CDR)

Both could start as e^+e^- Higgs/W/Z/top-factories

AA and eA operation in baseline design



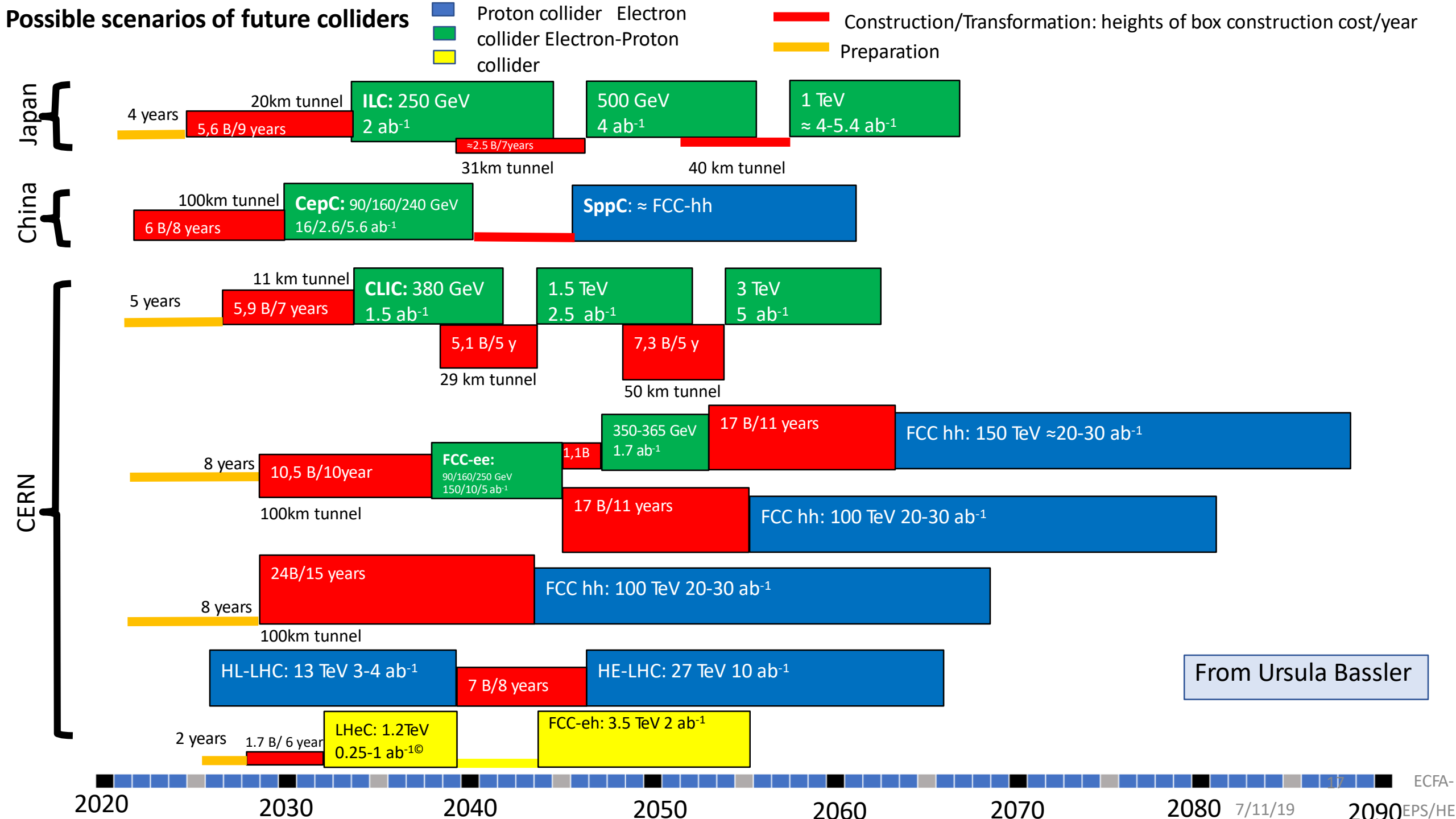




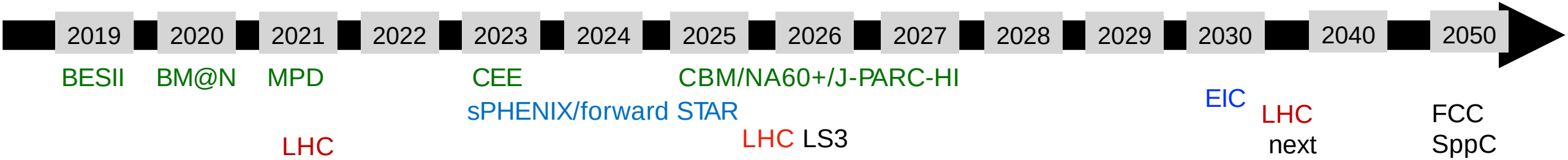
FCC CDR:
https://fcc-cdr.web.cern.ch

SppC pre-CDR:
http://cepc.ihep.ac.cn/preCDR/volume.html

Possible scenarios of future colliders



From Ursula Bassler



Very rich experimental programme

Broad range of energy and density :

- colliders and fixed target
- pp, pA, AA collisions
- precision cold-QCD measurements

Challenging detector developments

Future perspectives ESPPU

Official Web Site

STRONG-2020 Web Site

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Scientific Frontiers

Transnational Access

- TA1- COSY
- TA2-MAMI
- TA3-LNF
- TA4-FTD/ELSA
- TA5-GSI
- TA6-ECT*
- TA7-CERN

Virtual Access

- VA1-NLOAccess
- VA2-3DPartons

Relations to other laboratories in the world

JINR (Dubna)	TJNAF	KEK (J-PARC)	EIC
• NA1-FAIRnet • NA4-PREN • NA5-THEIA (NICA) • JRA10-CryPTA	• NA4-PREN • NA5-THEIA • JRA3-PrecisionSM • JRA4-TMD-next • JRA5-GPD-ACT • JRA6-next-DIS • JRA7-HaSP • JRA10-CryPTA • JRA13-P3E • JRA14-MPGD_HP	• NA5-THEIA • JRA3-PrecisionSM • JRA7-HaSP • JRA8-ASTRA	• VA2-3DPartons • NA2-Small-x • JRA4-TMD-next • JRA5-GPD-ACT • JRA6-next_DIS • JRA13-P3E • JRA14-MPGD_HP

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