Physics Beyond Colliders @CERN

And the 2020 Update on the European Strategy for Particle Physics

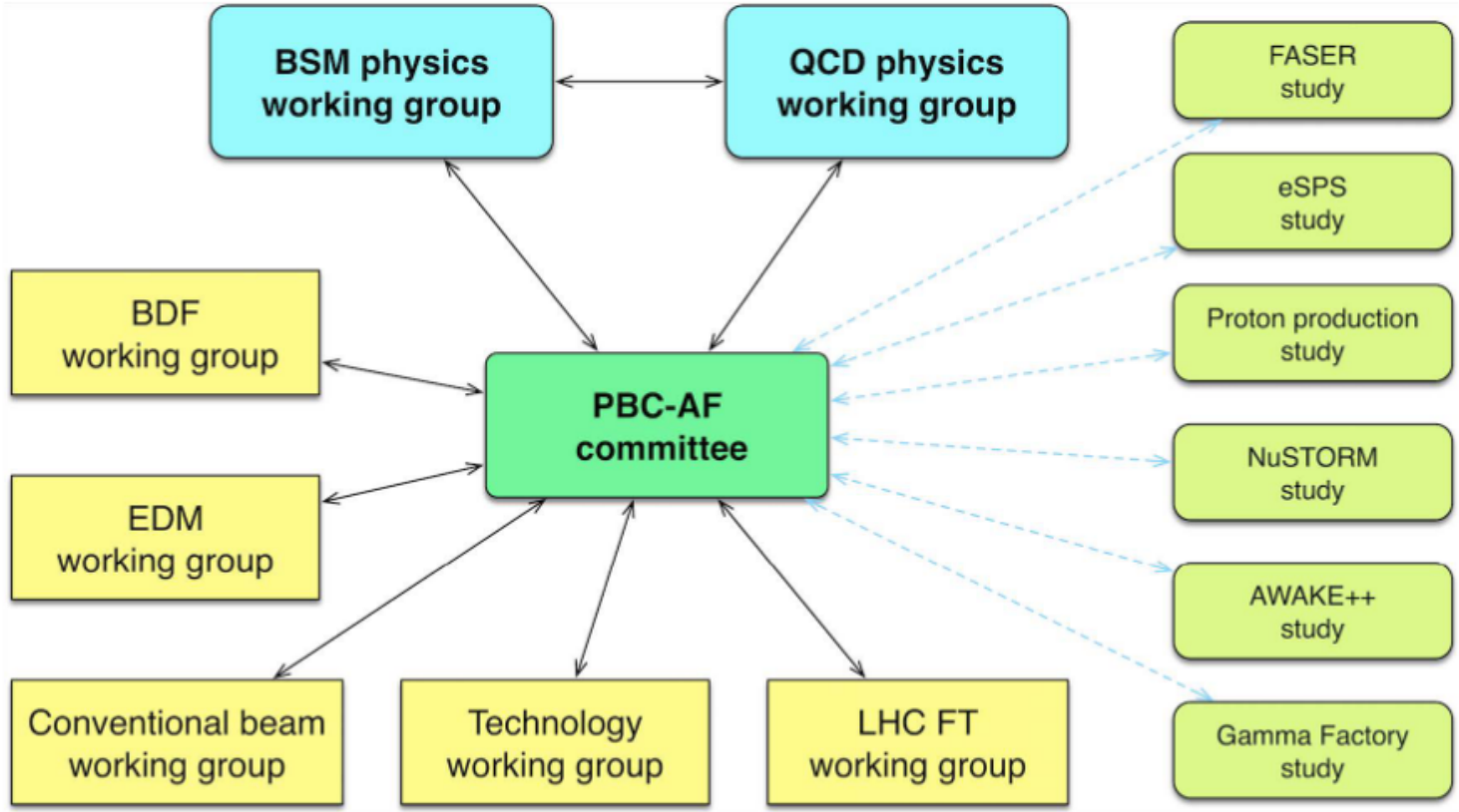
Catarina Quintans, LIP

"projects complementary to LHC and HL-LHC, and to possible future colliders as HE-LHC, CLIC or FCC"

…

"targeting fundamental physics questions that are similar in spirit to those addressed by high-energy colliders, but that require different types of beams and experiments."

PBC WORKING GROUP STRUCTURE



Forward Search@LHC

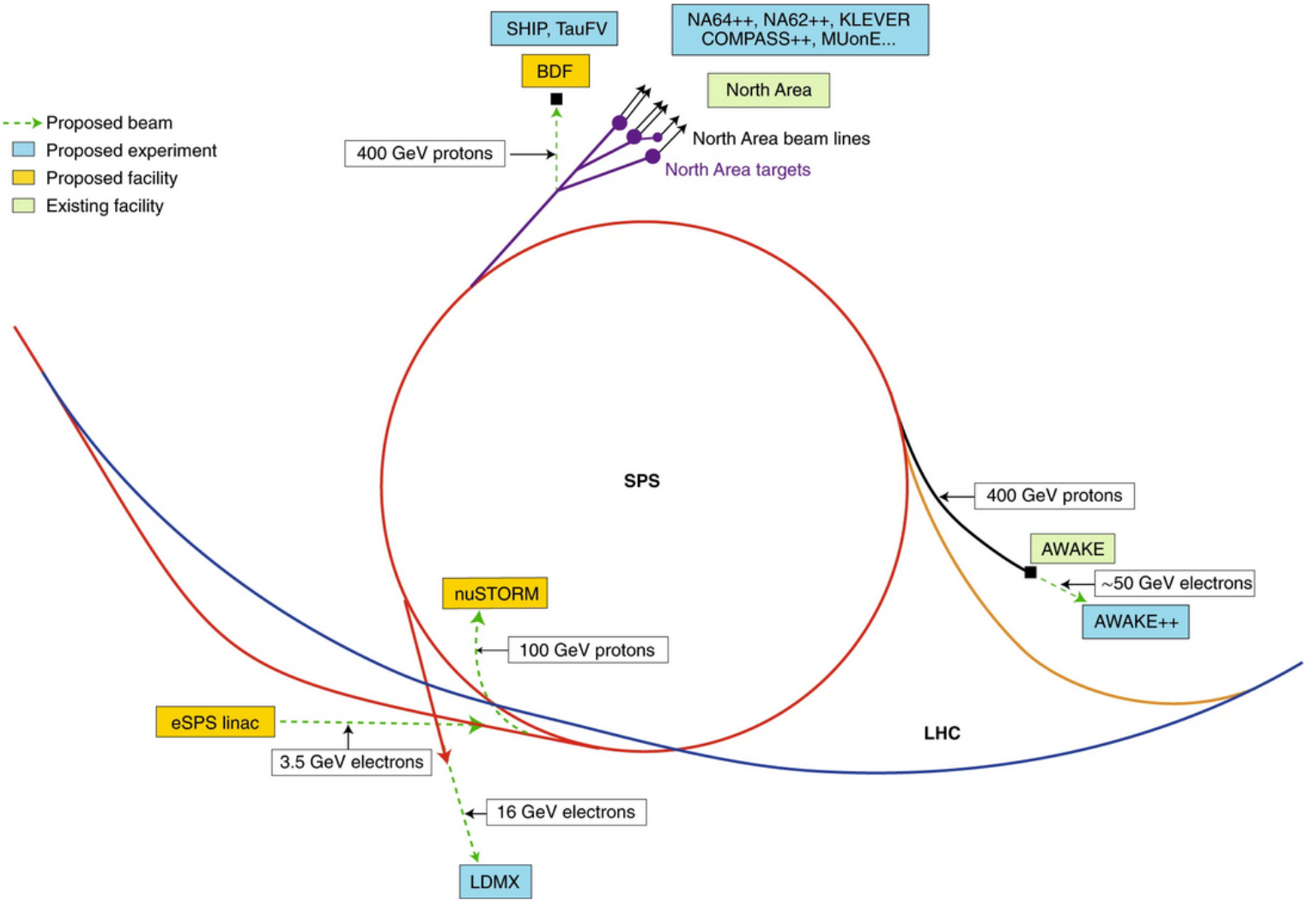
Beam Dump Facility

Electric Dipole Moment

Neutrino beam

Fixed target at LHC


CERN


Proposed beam
Proposed experiment
Proposed facility
Existing facility
SHIP, TauFV
NA64++, NA62++, KLEVER
COMPASS++, MUonE...
BDF
North Area
400 GeV protons
North Area beam lines
North Area targets
SPS
400 GeV protons
AWAKE
~50 GeV electrons
AWAKE++
nuSTORM
100 GeV protons
eSPS linac
3.5 GeV electrons
LHC
16 GeV electrons
LDMX

Experiment	Physics case	Status	Time scale
NA61++	Charm in QCD phase transition	Operational/upgrade studies	Near
NA60++	Caloric curve of QCD phase transition	Feasibility study	Medium
DIRAC++	QCD with pionic and kaonic atoms	Feasibility study	Medium
COMPASS++	QCD dynamics	Operational/upgrade studies	Near
MUonE	Hadronic vacuum polarization for $(g-2)_\mu$	Prototype/tests with beam	Near
LHC FT (gas storage cell)	QCD dynamics and phase transition	Installation/further studies	Near
LHC FT (bent crystal)	Magnetic and electric dipole moment of short-lived baryons	Prototype planned/studies	Medium
KLEVER	Ultra-rare decays of neutral kaons	Feasibility studies	Medium
TauFV	Ultra-rare decays of tau leptons	Design study in progress	Long
REDTOP	Ultra-rare decays of eta meson	Proposal	Medium
NA64++	Dark photon searches with electron and/or muon beam dump	Operational/upgrade studies	Near
LDMX	Dark photon searches	Design study in progress	Medium
AWAKE++	Dark photon searches	Exploratory studies	Long
NA62++	Dark sector searches with proton beam dump	Beam dump option studies	Near
SHiP	Dark sector, study of tau neutrinos	Design study complete	Medium
BabyIAXO/IAXO	Axion search (helioscope)	Conceptual design/prototyping	Medium
JURA	Axion and axion-like particle searches	Exploratory studies	Long
VMB@CERN	Vacuum magnetic birefringence	Letter of intent/studies	Medium

Facility	Beam type	Status	Time scale
BDF	High intensity 400 GeV protons for SHiP and TauFV	Design study complete	Medium
eSPS	16 GeV electrons	Design study in progress	Medium
nuSTORM	Neutrino beam from a muon storage ring for cross-section measurements	Feasibility study complete	Long
EDM ring	Polarized proton storage ring for EDM measurement	Feasibility study complete	Medium
Gamma Factory	High intensity gamma-ray beam	Design study in progress	Long

Physics projects submitted

for the period 2022-203X

Quote:	A	ready	ready	adequate	< 10 M€	Run 3
	B	need upgrade	under design	to strengthen	10-50 M€	Run 4
	C	to be built	need R&D	to be built	> 50 M€	Run 5

Project	**Physics highlight**	**Beam requirement**	**Detector maturity**	**Collaboration**	**Cost beam+det**	**Earliest operation**
NA61++	QGP Charm	B	B	A	A	A
COMPASS+	R_p & QCD	A	B	A	A	A
COMPASS++	QCD	B	B	B	B	B
MUonE	HVP(g-2)$_\mu$	A	B	B	A	A
LHC-FT	QCD	A	B	B	A	A
LHC-FT++	spin/MM/EDM	A	C	B	A	B
NA60++	QGP phase	C	B	C	B	B
DIRAC++	chiral QCD	C	B	C	B	B
NA62++	dark sector	B	A	A	A	A
KLEVER	$K^0 \to \pi^0 \nu\bar{\nu}$	B	C	B	B	B
NA64++	dark photon	A	B	A	A	A
SHiP	dark sector & ν_τ	C	B	A	C	B
TauFV	$\tau \to 3\mu$	C	C	B	C	C
REDTOP	η decays	B	C	B	B	B
EDM ring	p EDM	C	C	B	C	C
eSPS	dark photon	C	B	B	C	B
AWAKE++	dark photon	C	B	A	B	B
nuSTORM	$\sigma(\nu)$	C	C	B	C	B
γ-Factory	high rate γ	C	C	C	-	C

Status of projects (as of 2019)

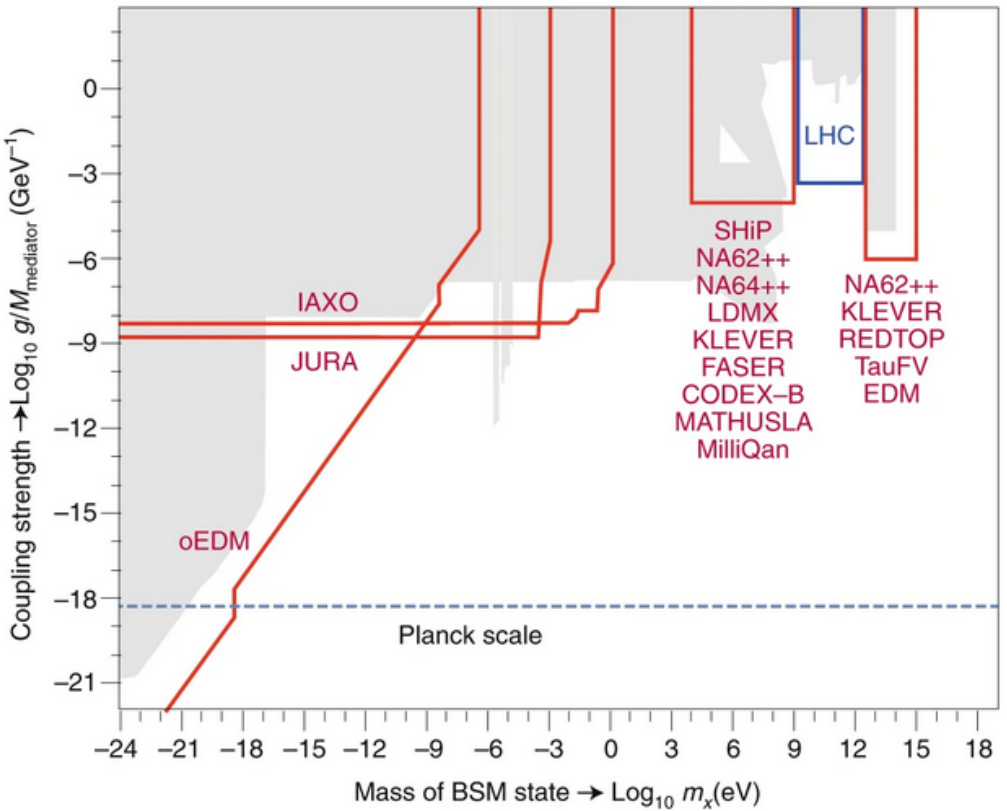
Run 3: 2021-2024

Runs 4 and 5:
From mid 2027 on...

Beyond Standard Model searches

See Nuno Leonardo talk

Nature Phys.16 (2020) 393-401



- Dark photons
  (photons that do not couple to massive SM particles)
- Right-handed neutrinos
- New scalar particles
  (only interacting with Higgs boson)
- Axions
  (new pseudo-scalar light particles, solving the strong CP problem)
- …

Experiments proposed for the new Beam Dump Facility: SHiP and TauFV

QCD at extreme densities/temperatures

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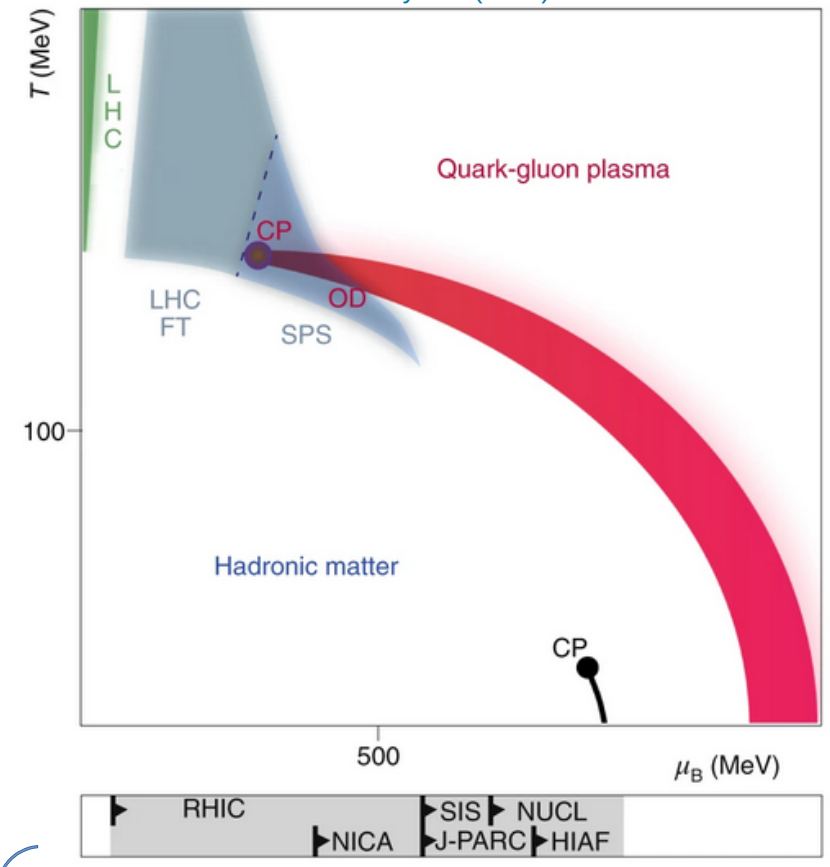


See Liliana Apolinário talk

SPS experiments had a leading role in the search for the Quark Gluon Plasma

The heavy-ion program at the LHC is presently exploring its properties

A complementary phase-space region can be accessed by LHC-FT (AFTER@LHC):

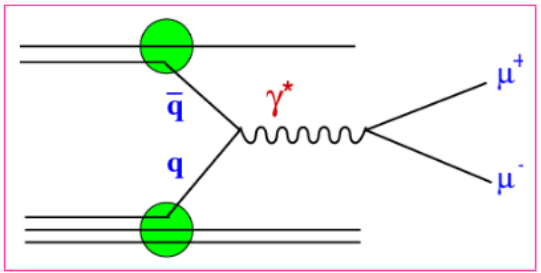
- Fixed target with ALICE detector
- Fixed target with LHCb detector

Other future projects at SPS are proposed:
NA60++, NA61++ (follow-ups of past experiments)

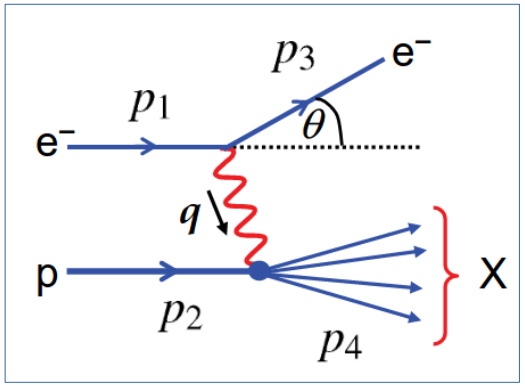
Competition/complementarity world-wide, present and future

QCD and Hadron Structure

$\pi^{\pm}$, $K^{\pm}$ and $\bar{p}$ Induced Drell-Yan



Deep inelastic scattering



COMPASS: "present flagship QCD programme at SPS"

Precision measurements done at the LHC are often limited by QCD theoretical uncertainties

Efforts to overcome these limitations, in several fronts:

- Lattice QCD
- *Ab initio* approaches (Dyson-Schwinger)

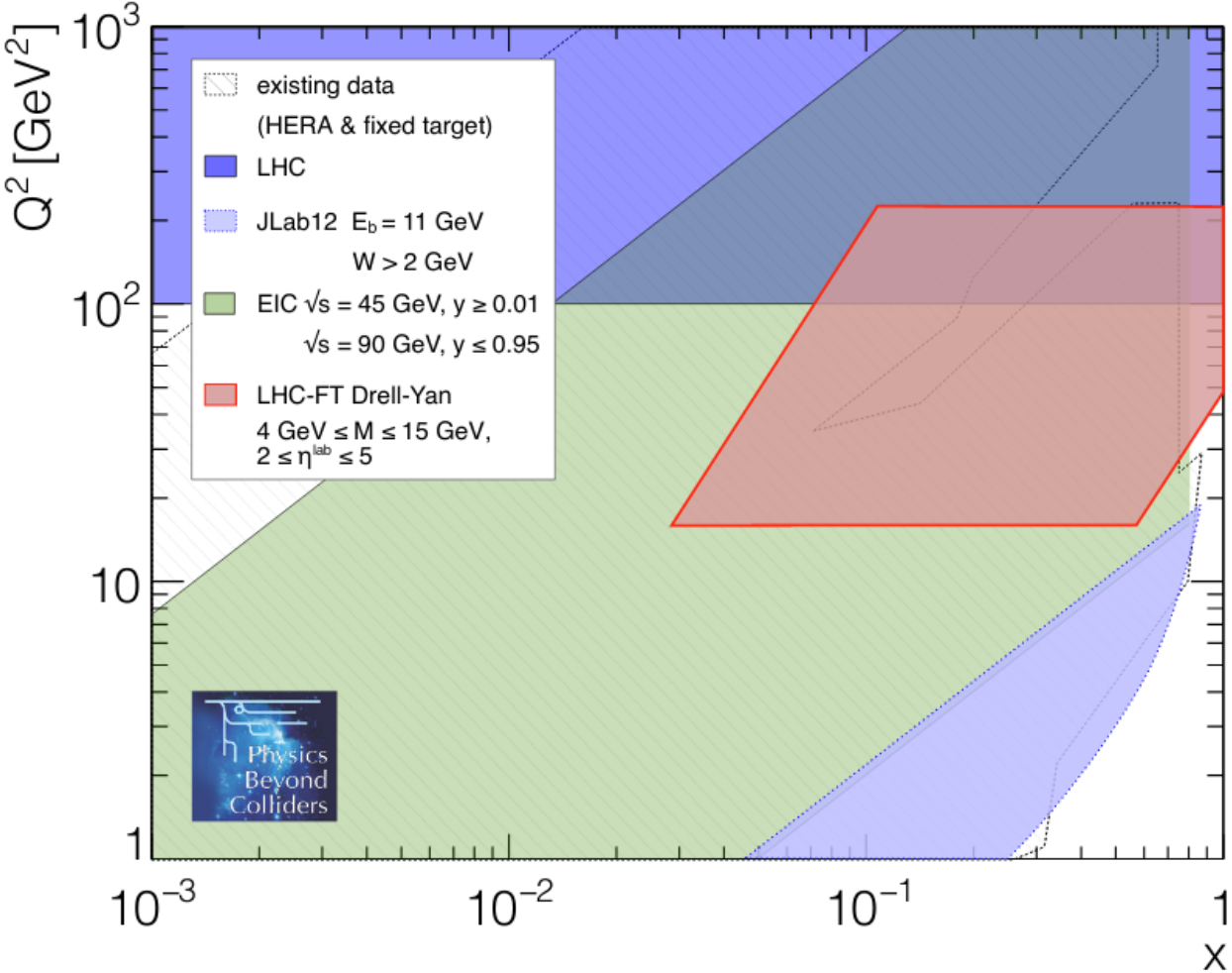
but, first of all:

- **Experimental measurements, done at low(er) energies**

new COMPASS++/AMBER at SPS

Competition/complementarity: JLab12 and EIC and NICA in the future

QCD: proton PDFs



The proton PDFs are an essential input to LHC measurements..

In the past, HERA and fixed target Exps at SPS played the leading role.

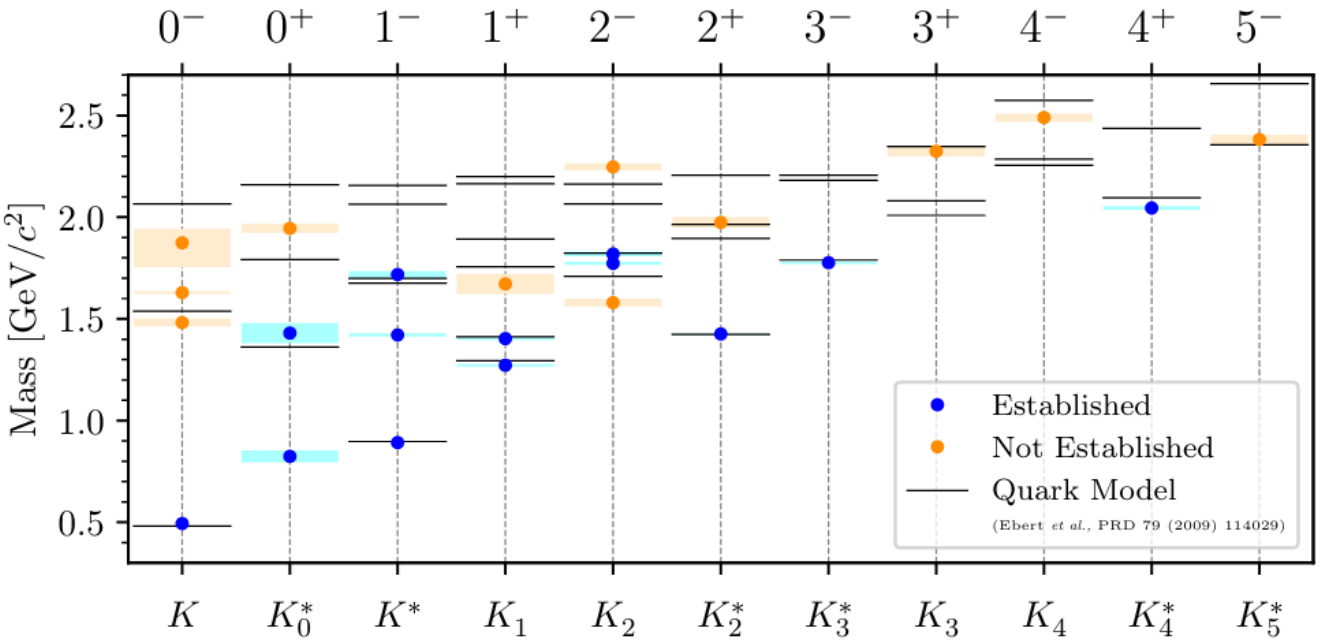
Presently new data is coming from JLab12 and from LHC itself.

EIC will bring unprecedented precision

At CERN, also the fixed-target program at LHC may contribute.

QCD and Hadron Spectroscopy

Spectroscopy of **strange mesons**: only half of the expected kaon states were observed so far (PDG 2019)



[Courtesy S. Wallner, TUM]

A new beamline from the SPS, using RF-separation technique:

- Kaon and antiproton beams of high intensity and energy (~100 GeV)

COMPASS++/AMBER

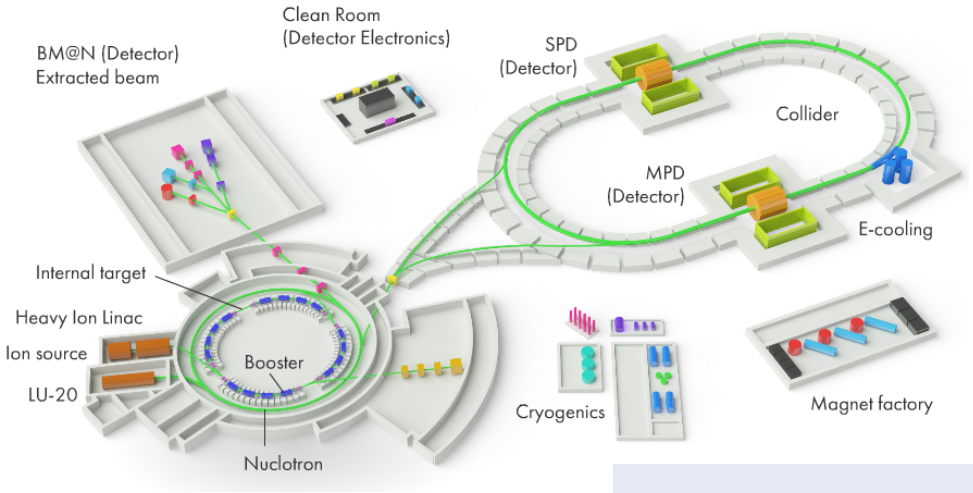
Competition/complementarity: JLab12 and FAIR

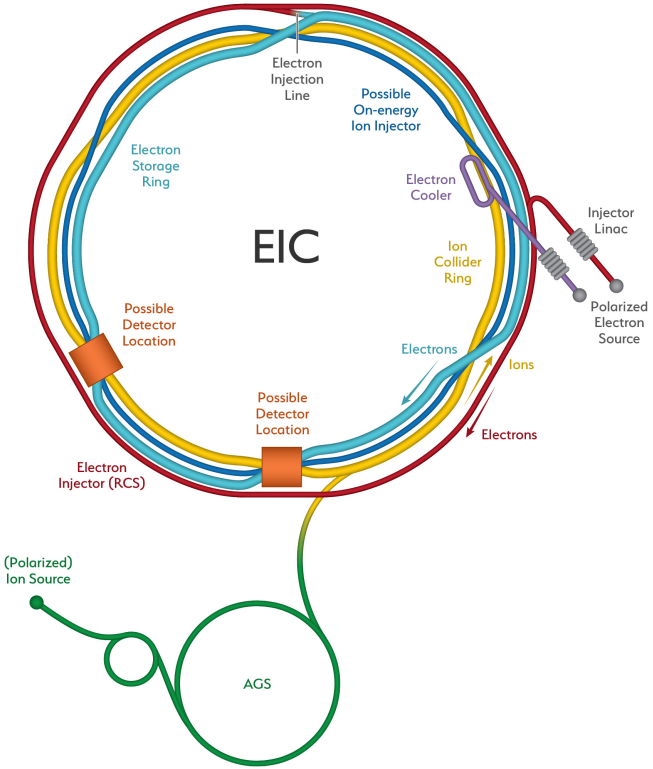
Other fixed-target projects at SPS

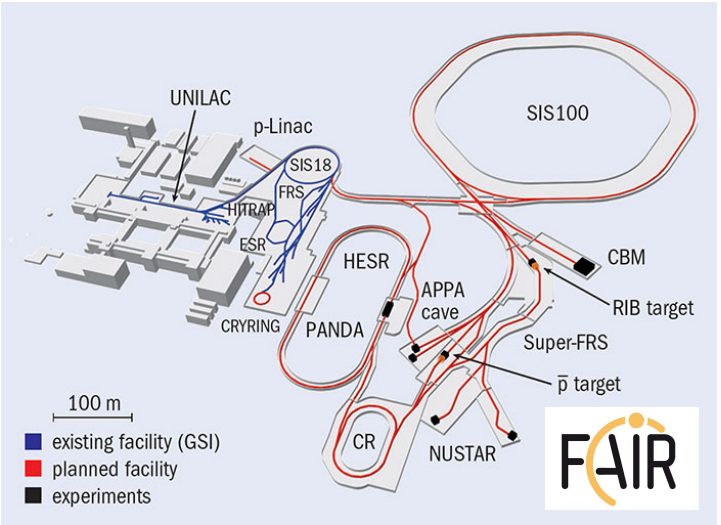
- NA64+: search for dark photon decays using muon and electron beams
- MUonE: muon (g-2) measurement (the anomalous magnetic dipole moment of the muon), via muon-electron elastic scattering
- NA62++ and KLEVER: measure branching ratios for $K \to \pi\nu\bar{\nu}$ (charged and neutral channels). These neutral current flavor-changing decays are highly suppressed in SM – this very sensitive channel to New Physics
- DIRAC++: study of pionic and kaonic atoms
- ...

Other future facilities

NICA Nuclotron-based Ion Collider fAcility







And more:
EIC-China, J-PARC,...