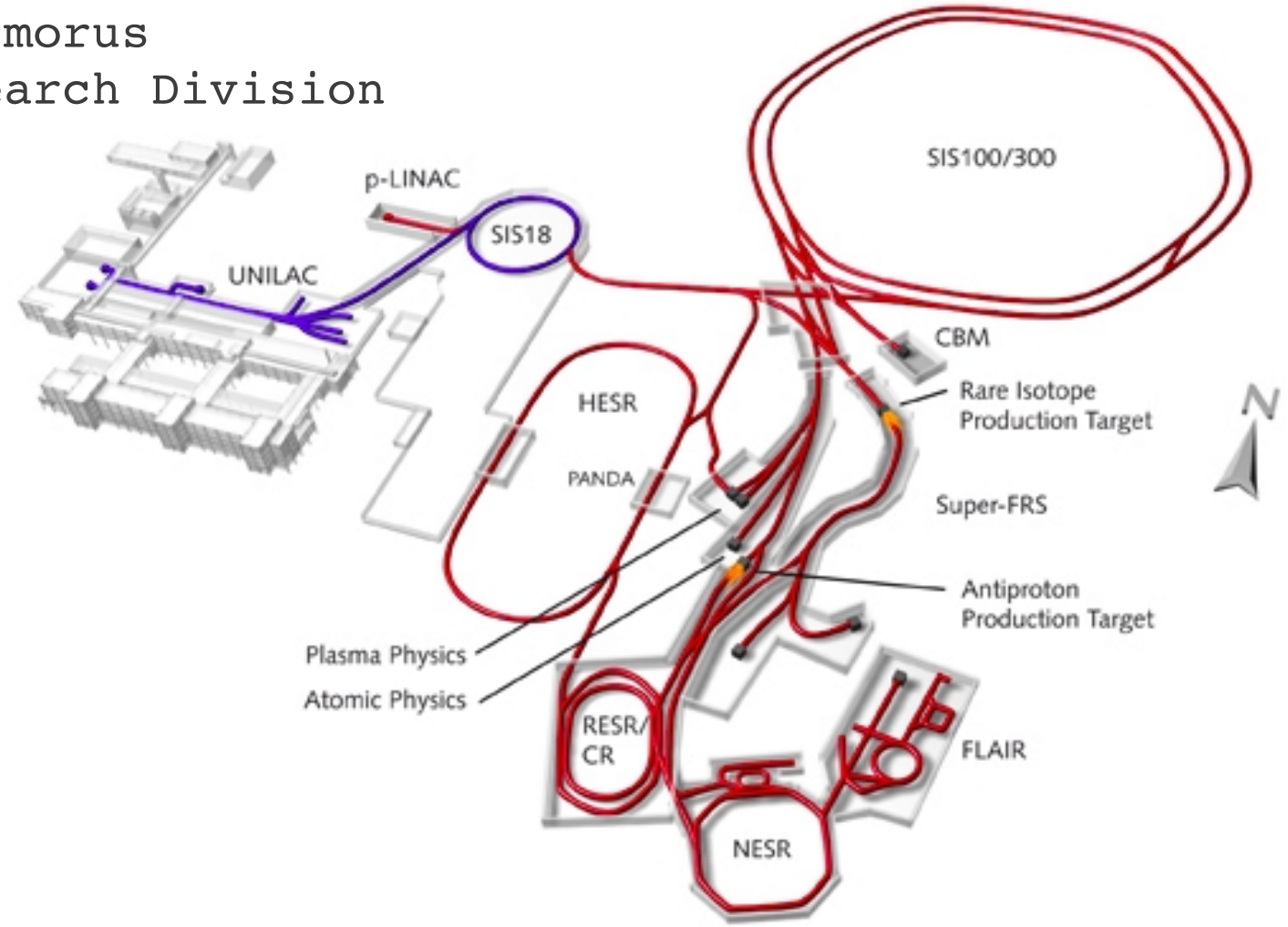
FAIR: exploring the nature of matter and its evolution

Diana Nicmorus
FAIR Research Division




Finland
France
Germany
India
Poland
Romania
Russia
Slovenia
Spain
Sweden
Darmstadt, Hesse,
Germany
Longitude 8.676107
Latitude 49.930908
FAIR

What is FAIR?

- International accelerator facility for the research with antiprotons and ions
- Limited Liability Company (GmbH) – Research, Technical, Site & Buildings, Administration Divisions – Management Board
- Founded on 4th of October 2010 by international partners/shareholders: signed a treaty under international law
- Financed by 10 member states:
  Germany & State of Hesse ~ 70% construction costs
  Fi, Fr, In, Pl, Ro, Ru, Si, Es, Se ~ 30% construction costs
- Financial contribution, in-kind contribution, technical and scientific expertise
- Advisors/observers: EU, USA, Hungary

FAIR

What is FAIR?

- Four scientific pillars:
  APPA - Atomic, Plasma and Applied Physics)
  NUSTAR - Nuclear Structure, Astro Physics and Reactions
  PANDA - antiProton ANihilation at DArmstadt
  CBM - Compressed Baryonic Matter

- Involved: The staff of FAIR GmbH, international scientists and engineers (R&D, technical staff), doctoral students.

- About 3000 international scientists will be working in the experiments at FAIR

- Civil construction planned to end in 2018. Experiments could move in as soon as 2017.

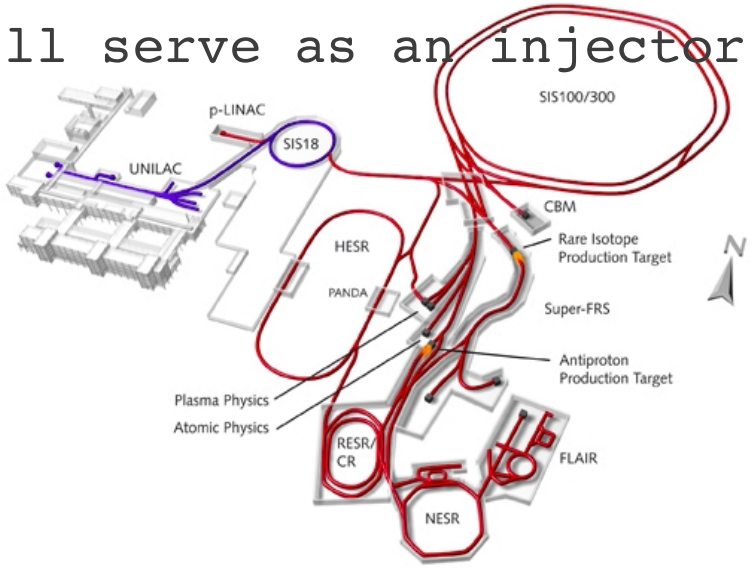
- Total cost as of 2005: 1,027 billion Euro – about 75% Germany, the rest from partner countries. China and Uk want to contribute to the experiments.

FAIR will provide antiproton and ion beams with highest beam intensities, unprecedented beam quality, high beam energies, highest beam power.

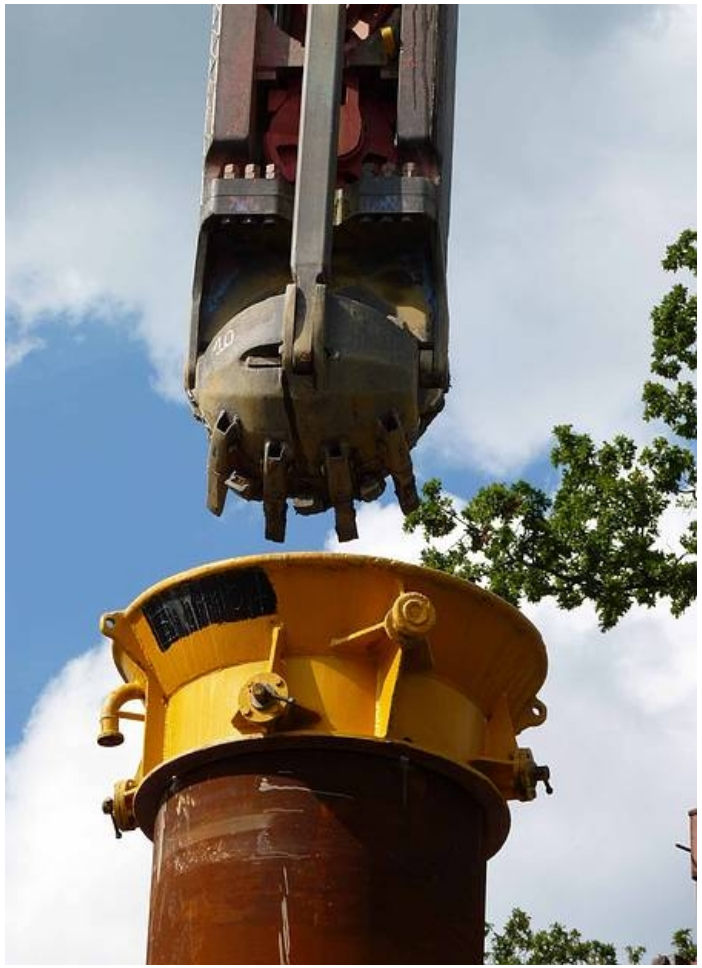
In the final construction FAIR will consist of eight storage rings with up to 1,100 meters in circumference, two linear accelerators and about 3.5 kilometers beam transfer line.

The large double ring will be laid out underground in a ring tunnel at a maximum depth of 17 meters.
The construction of the above-ground buildings requires clearing of about 20 hectares of forest.

The existing GSI accelerator will serve as an injector for FAIR.



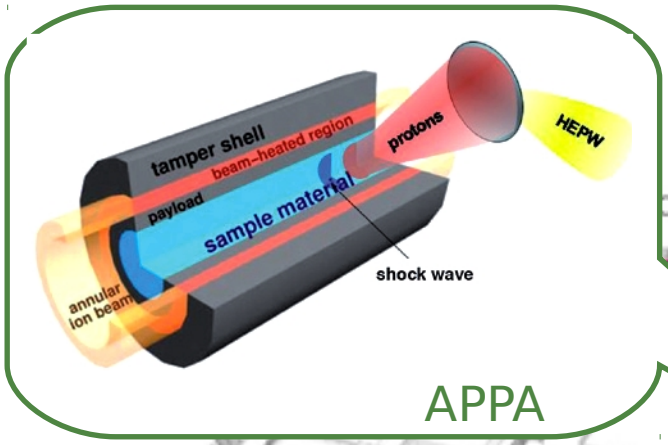
Finland France Germany India Poland Romania Russia Slovenia Spain Sweden



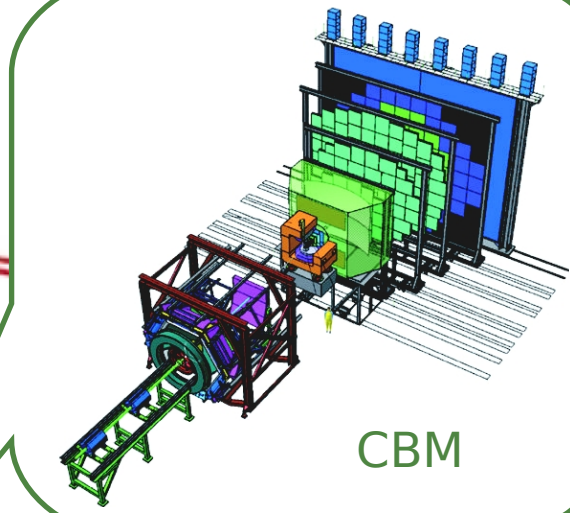
Recent:
1st bored pile August 2011, 2 bored pile September 2011

Finland France Germany India Poland Romania Russia Slovenia Spain Sweden

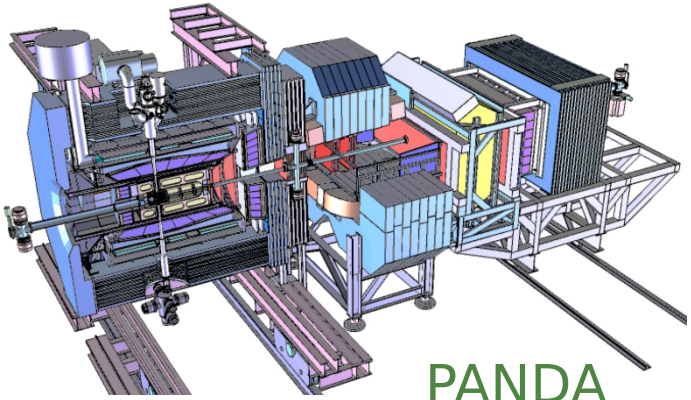
FAIR Experiments



APPA



CBM



PANDA

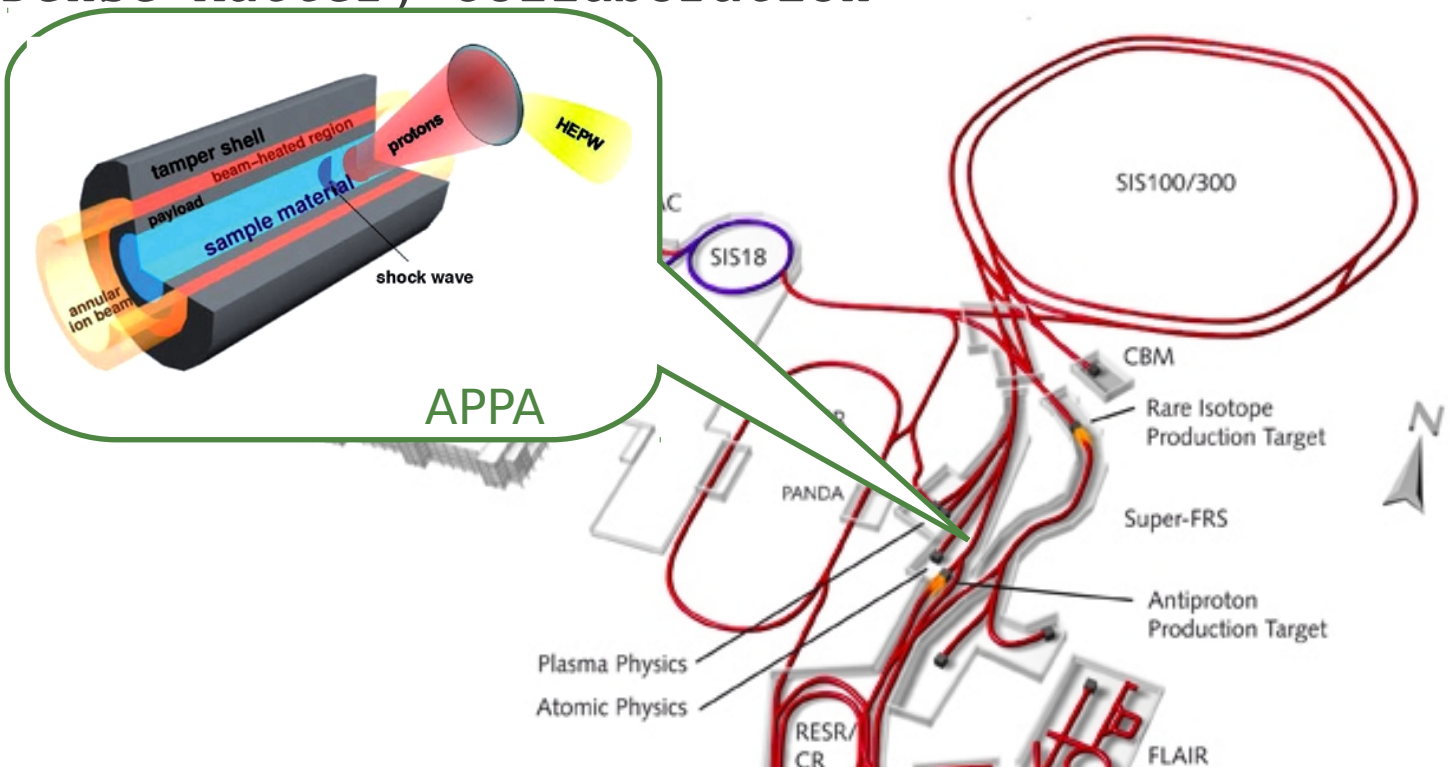
Super-FRS

NuSTAR

FAIR

APPA - Atomic Physics, Plasmaphysics and Applied Physics

- Collaborations:
  BIOMAT (Biology and Material Science)
  FLAIR (Facility for Low-Energy Antiproton and Heavy Ion Research)
  HEDgeHOB (High Energy Density Matter generated by Heavy Ion Beams)
  SPARC (Stored Particles Atomic Research Collaboration)
  WDM (Warm Dense Matter) collaboration



APPA

- Physics:

Atomic Physics
SPARC: 284 members from 26 countries
FLAIR: 144 members from 15 countries

QED in the non-perturbative regime
Correlated multi-body dynamics for atoms and ions
Precision determination of fundamental constants
Influence of the atomic structure on nuclear decay properties

Plasma Physics
HEDgeHOB & WDM: 175 members from 16 countries

Interaction of ions and photons with plasmas
Equation of state, phase transitions, transport phenomena
Matter under high pressure
Intense Laser (PHELIX): plasma production, particle acceleration

APPA

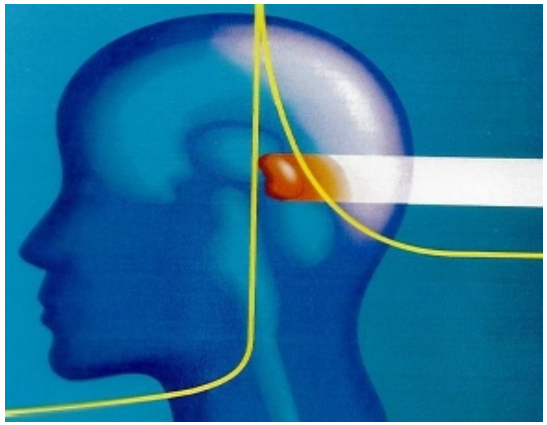
- Physics:

Materials Research and Biophysics
BIOMAT: 110 members from 12 countries

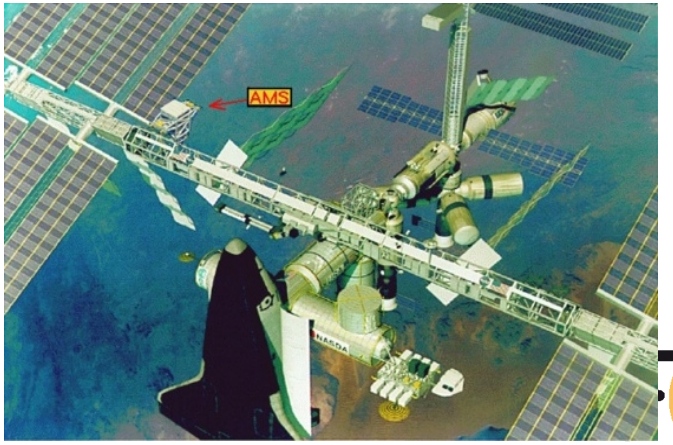
Material modifications
Ion-track nanotechnology
High-pressure irradiations

Applications:

Cancer therapy

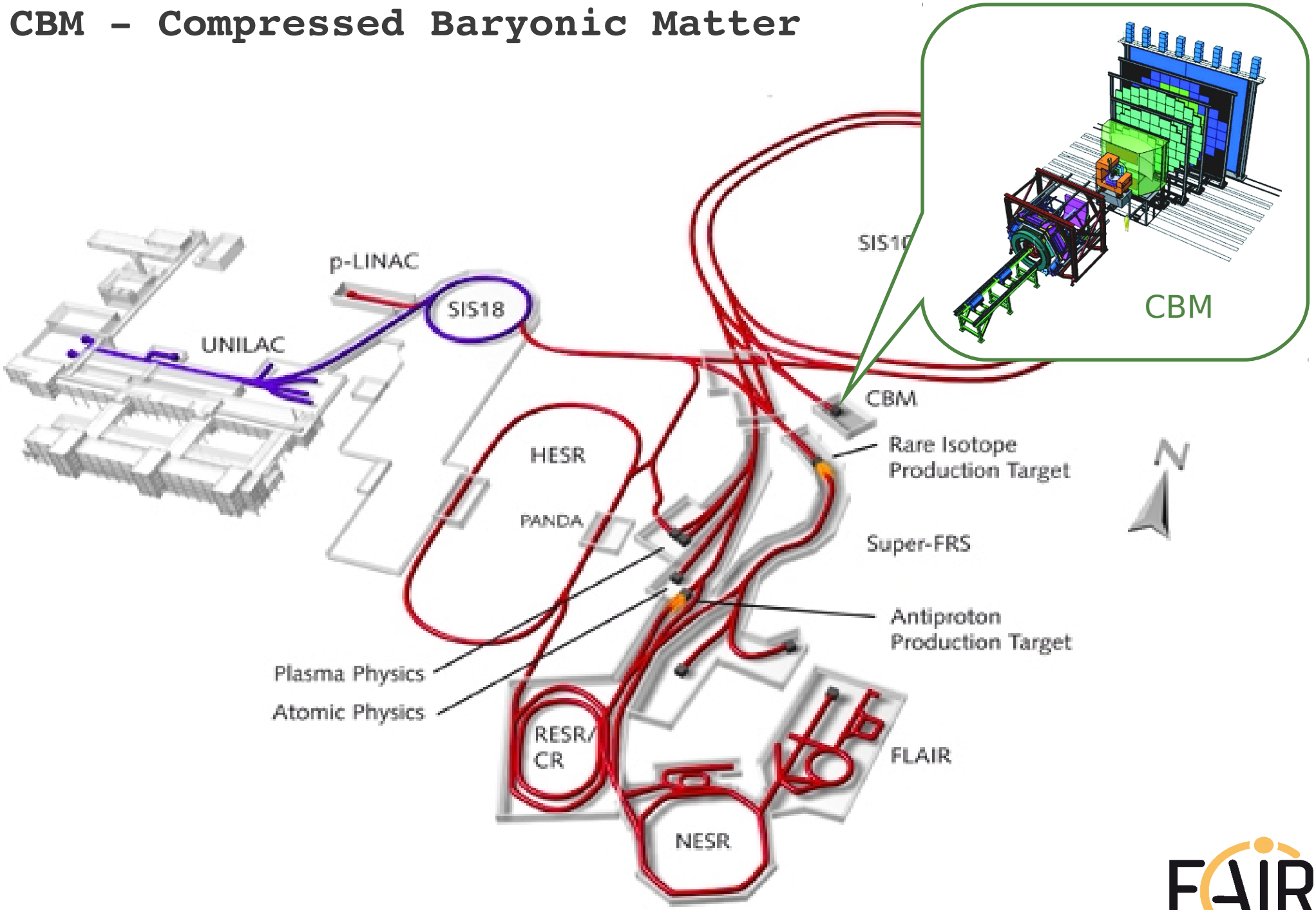


Aerospace engineering



Finland France Germany India Poland Romania Russia Slovenia Spain Sweden

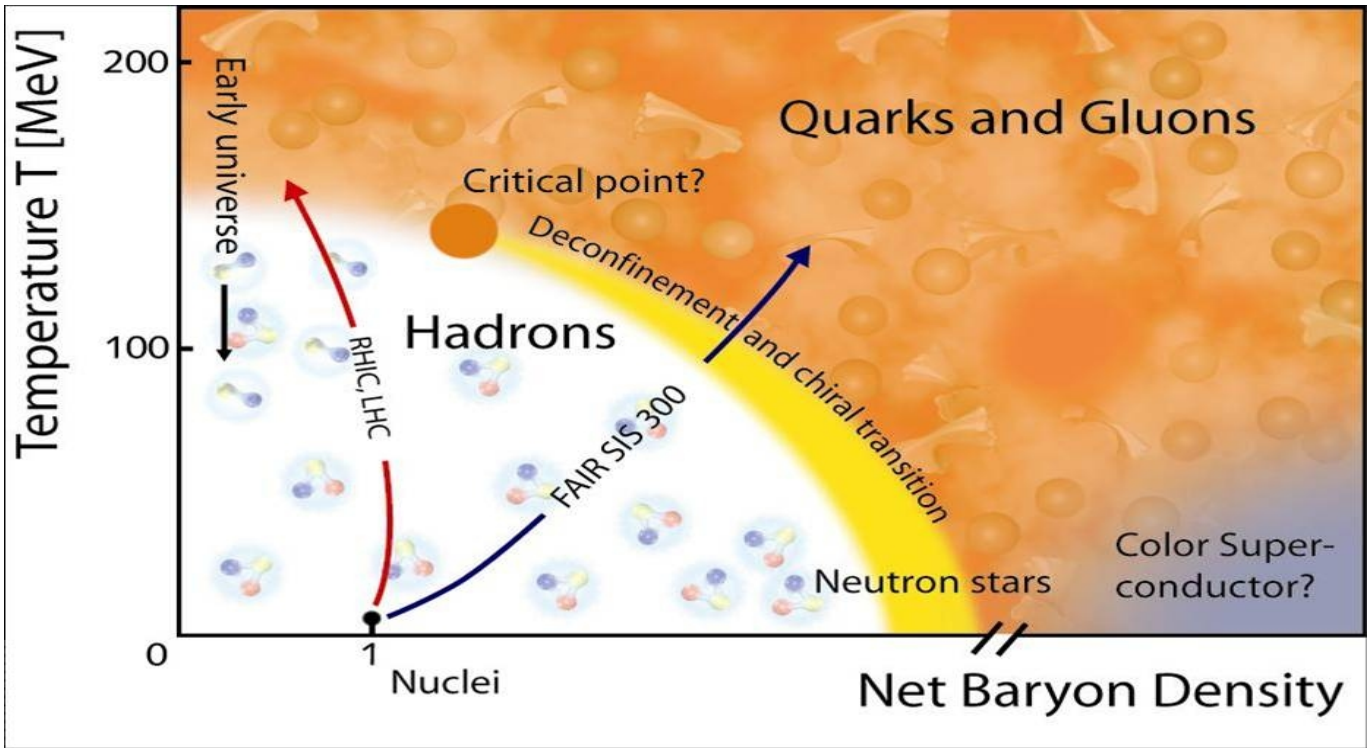
CBM – Compressed Baryonic Matter



CBM

- Physics: nuclear matter under extreme conditions

Nucleus-nucleus collisions: highly compressed nuclear matter
Baryonic matter at highest densities (neutron stars, core of supernova explosions)
Phase transitions (1st order deconfinement and chiral, chiral restoration at high densities), QCD critical endpoint
In-medium modifications of hadrons in dense matter
Exotic states of matter such as condensates of strange particles



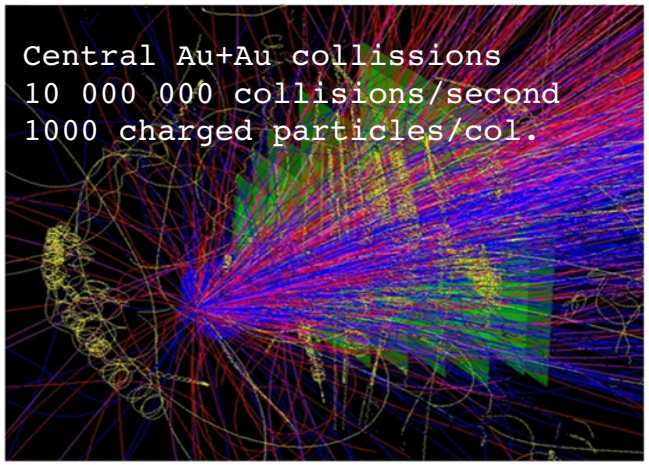
CBM

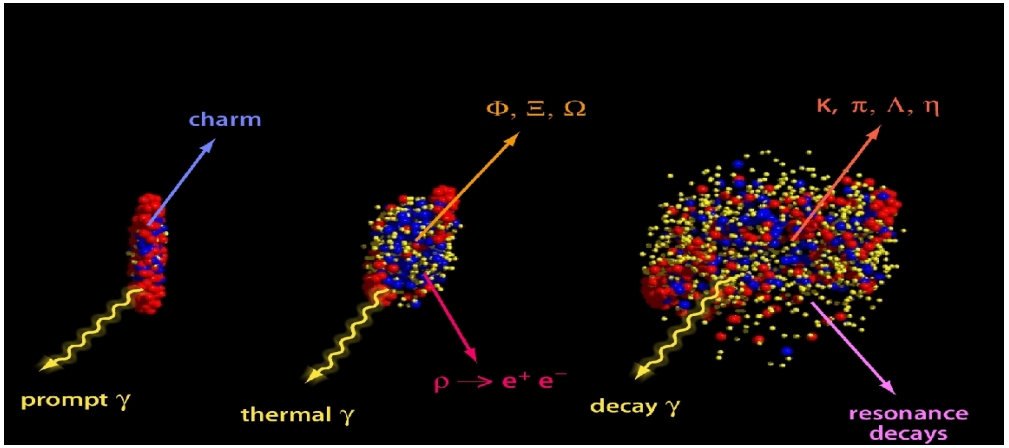
- Physics:

Measure simultaneously observables which are sensitive to high density effects and phase transitions.
- short-lived light vector mesons (e.g. the rho-meson)
- strange (anti-) baryons containing more than one (anti-) strange quark, so called multistrange hyperons
- mesons containing charm or anti-charm

Study of collective flow of charmonium and multi-strange hyperons – insight in the propagation of these rare probes.

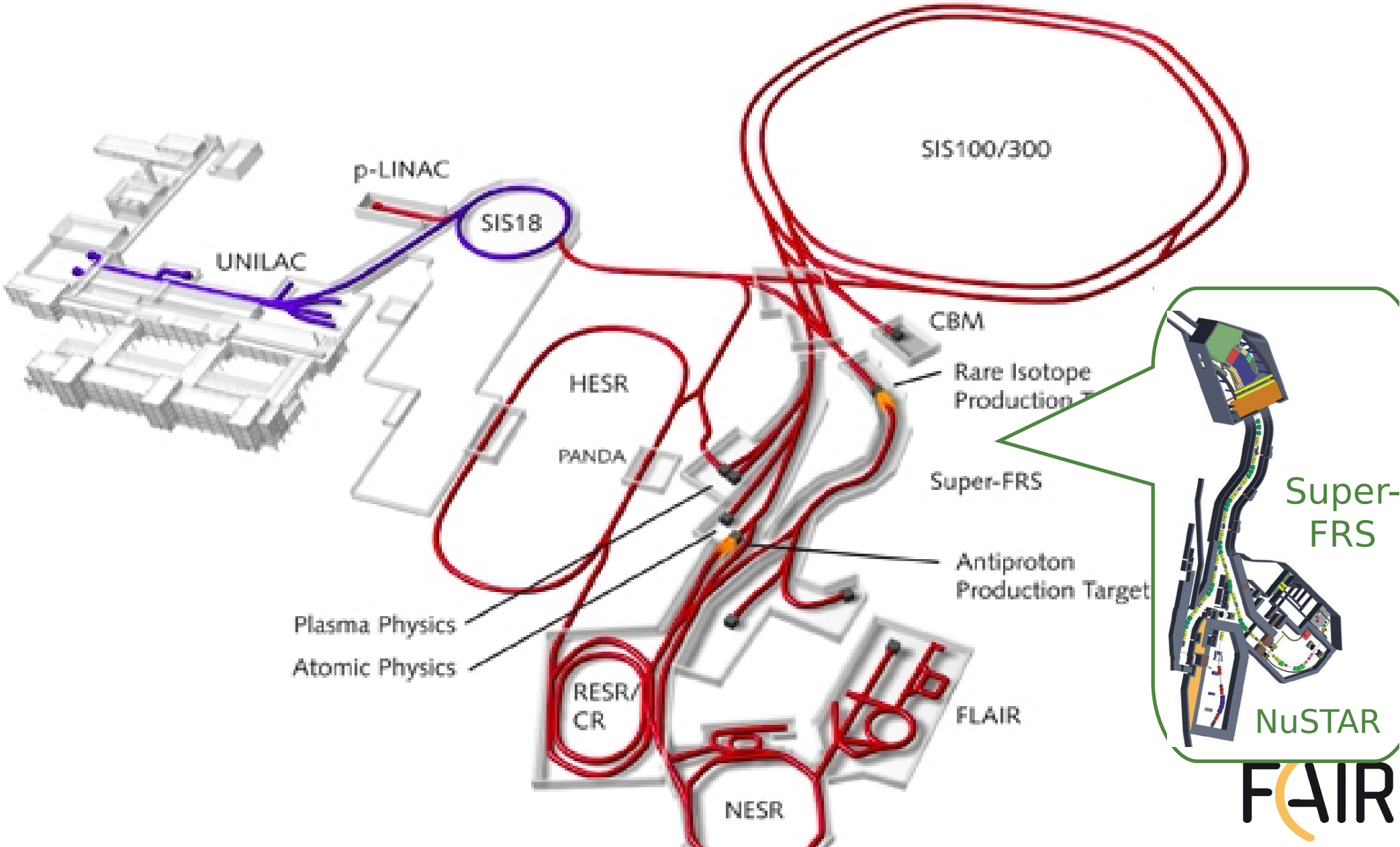
- Complement investigations at RHIC and LHC





Finland France Germany India Poland Romania Russia Slovenia Spain Sweden

NUSTAR - Nuclear Structure, Astrophysics and Reactions



NUSTAR

- Collaborations:

DESPEC/HISPEC (Decay Spectroscopy/High-Resolution Spectroscopy)

ELISe (Electron-Ion Scattering in a Storage Ring)

EXL (Exotic nuclei studied in light-ion induced reactions at the NESR storage ring) experiment

ILIMA (Isomeric Beams, Lifetimes and Masses)

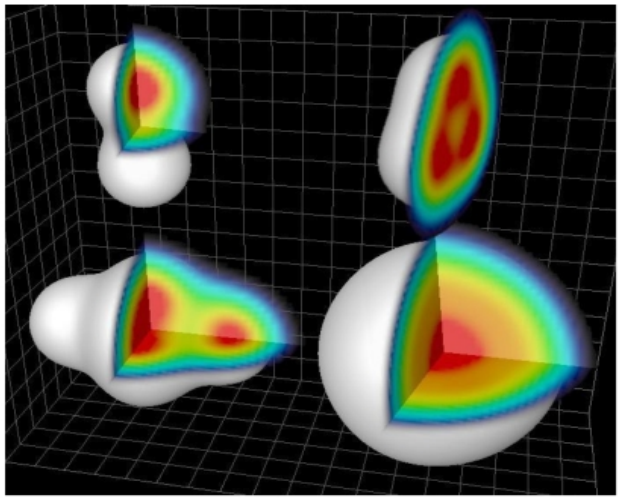
LaSpec (Laser Spectroscopy)

MATS (Precision Measurements of very short-lived nuclei with Advanced Trapping System)

R3B (Reactions with Relativistic Radioactive Beams)
SuperFRS (Super Fragment Separator) project

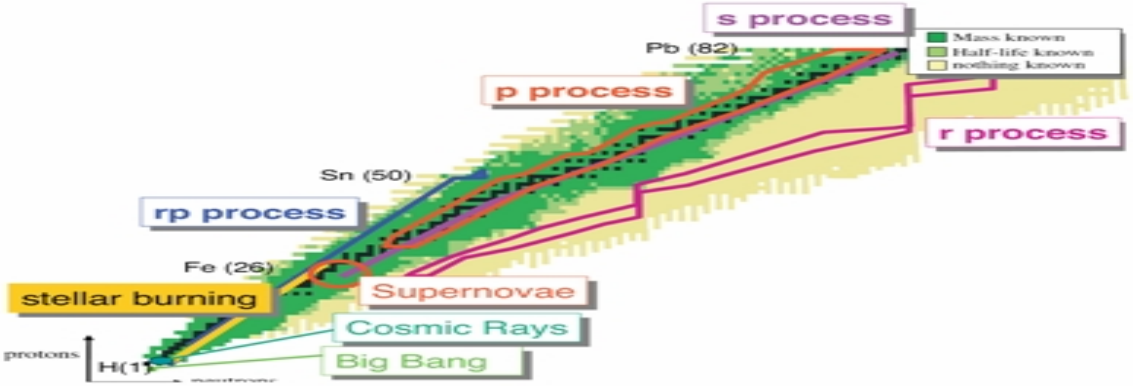
NUSTAR

- Physics: Interest focused on the use of beams of radioactive species separated and identified by the Superconducting Fragment Recoil Separator (Super-FRS)



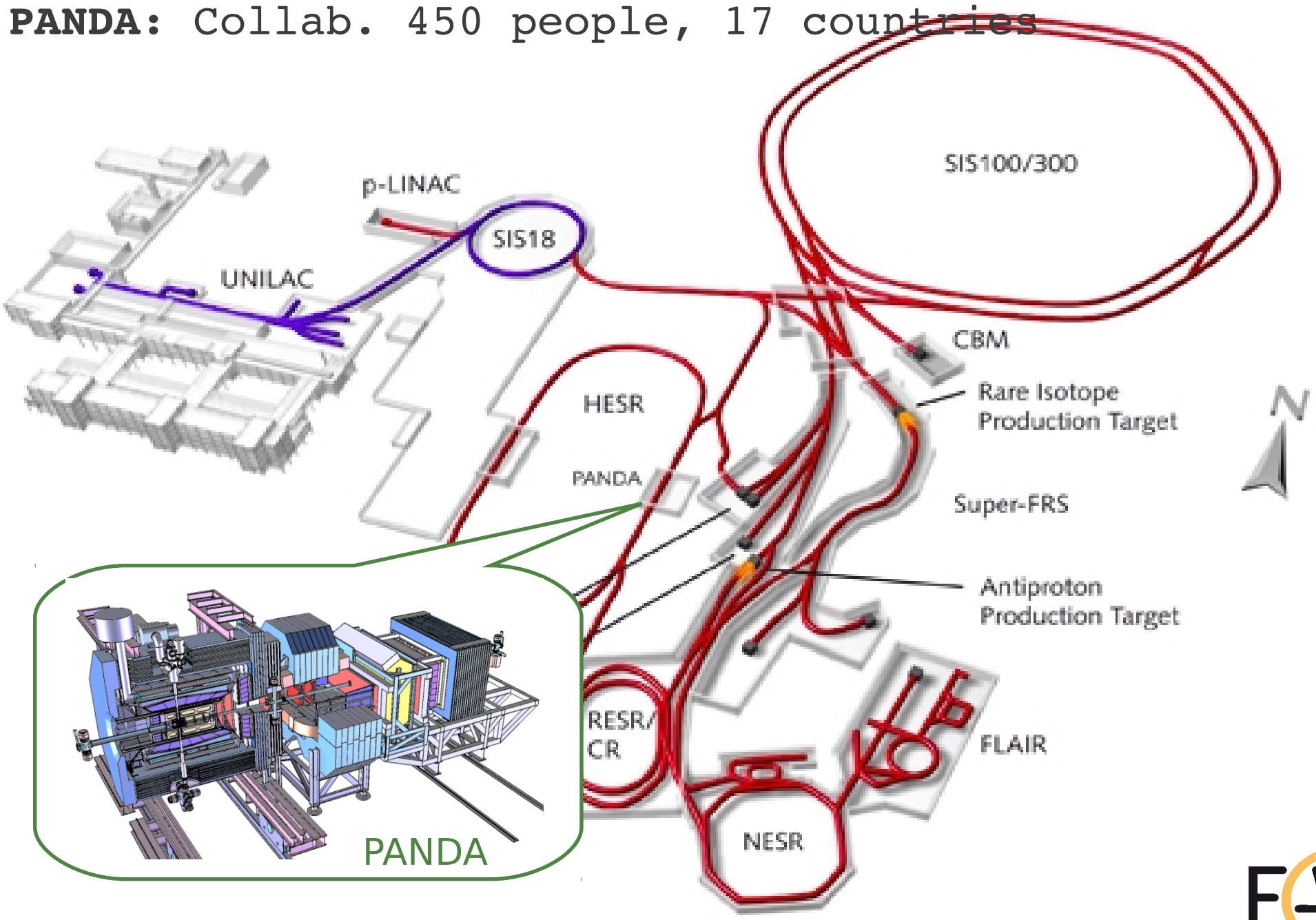
Nuclear structure - underlying QCD structure - complex nucleon-nucleon force.
Study of exotic short lived nuclei far off stability (proton/ neutron skins or halos, new magic numbers...)

Astrophysics - origin of the heavy elements? Physics of stellar explosions (core-collapse, thermonuclear supernovae, nucleosynthesis in stars and supernovae).
Compact objects and the explosions on their surfaces (x-ray bursts)



Finland France Germany India Poland Romania Russia Slovenia Spain Sweden

PANDA: Collab. 450 people, 17 countries

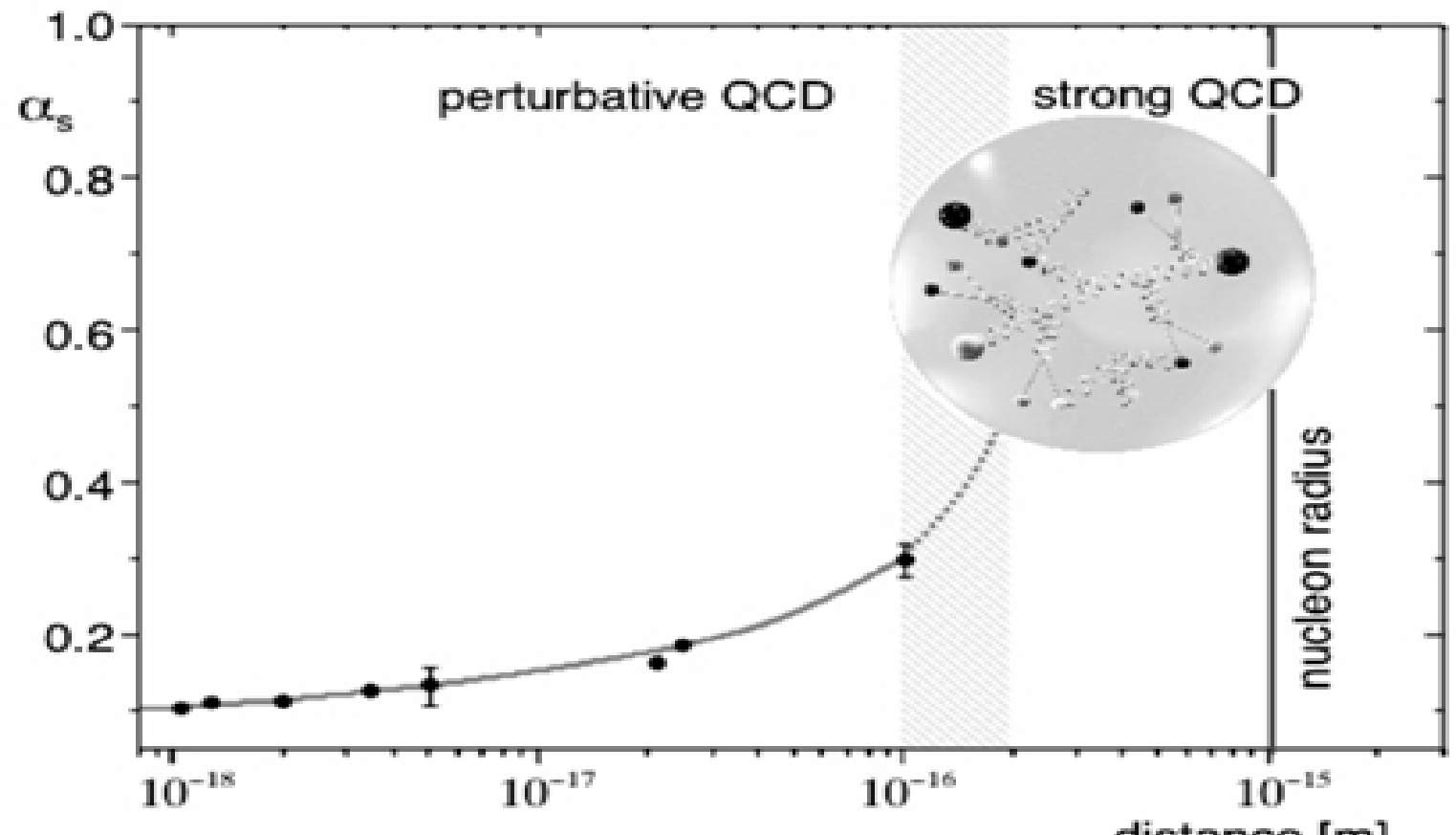


PANDA

- Physics:

Antiproton beams.

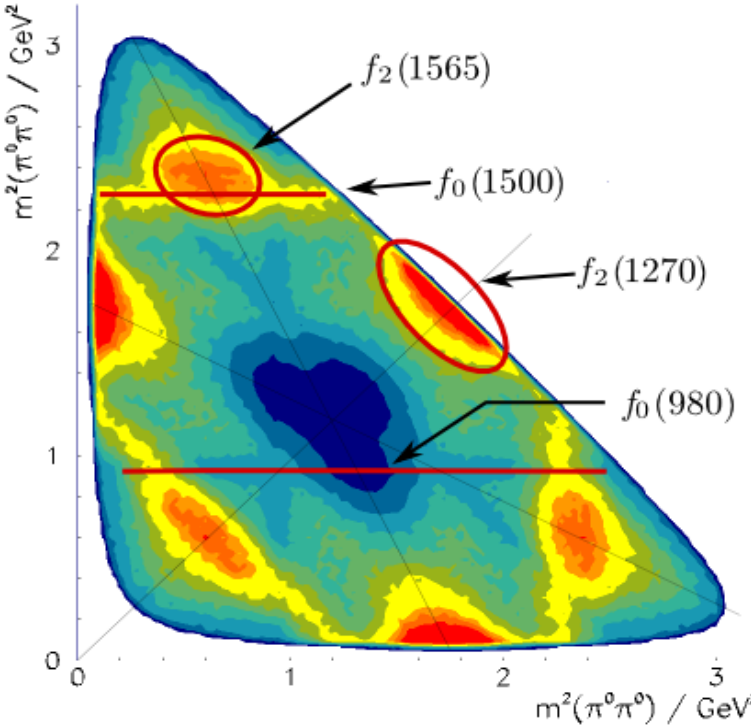
Testing non-perturbative QCD: quark confinement, mass generation, gluon self interaction.



PANDA

- Physics:

Hadron structure
Hadron spectroscopy
Strangeness
Charmonium
Glueballs
Gluonic matter

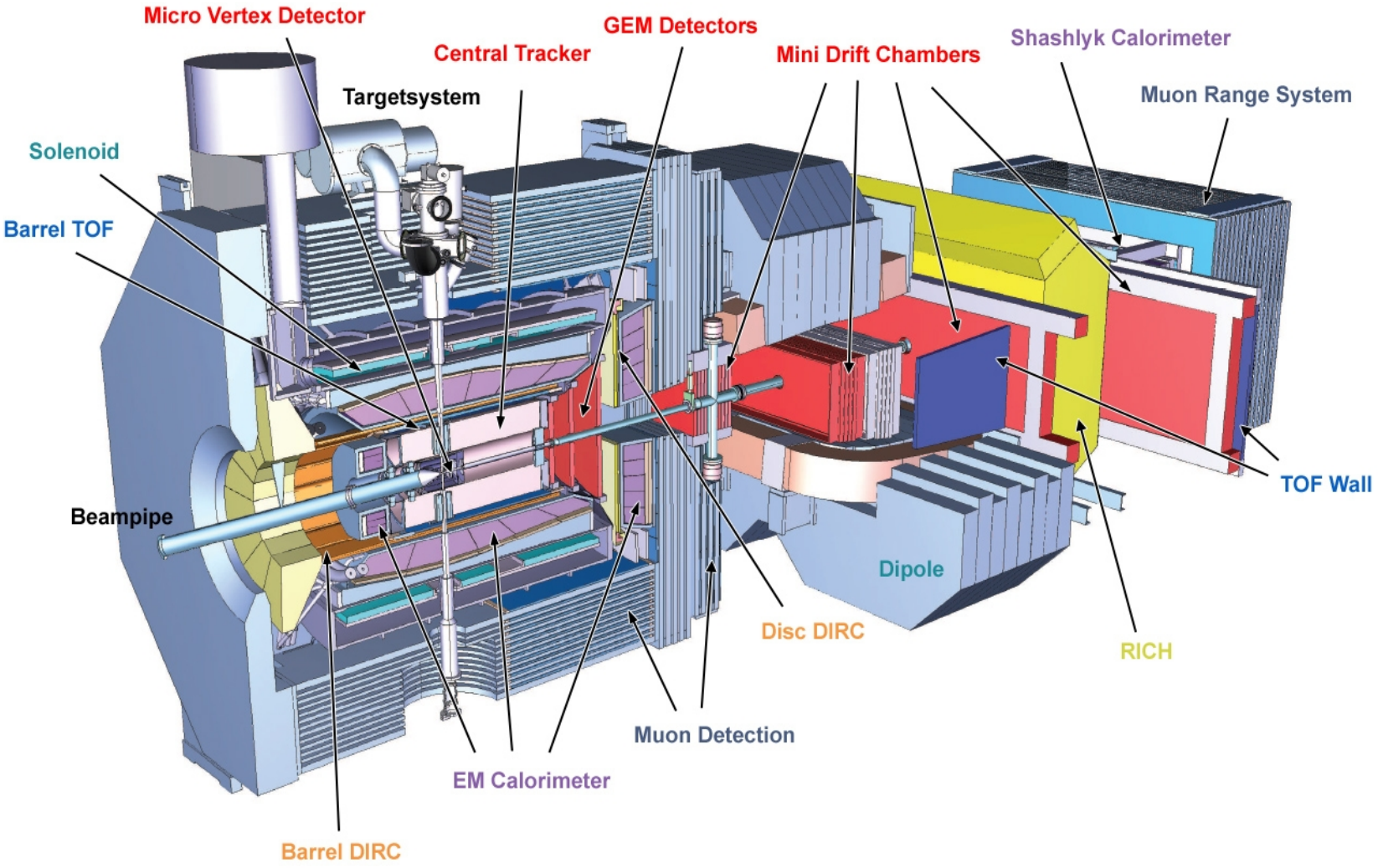


Nuclear matter and hypernuclei

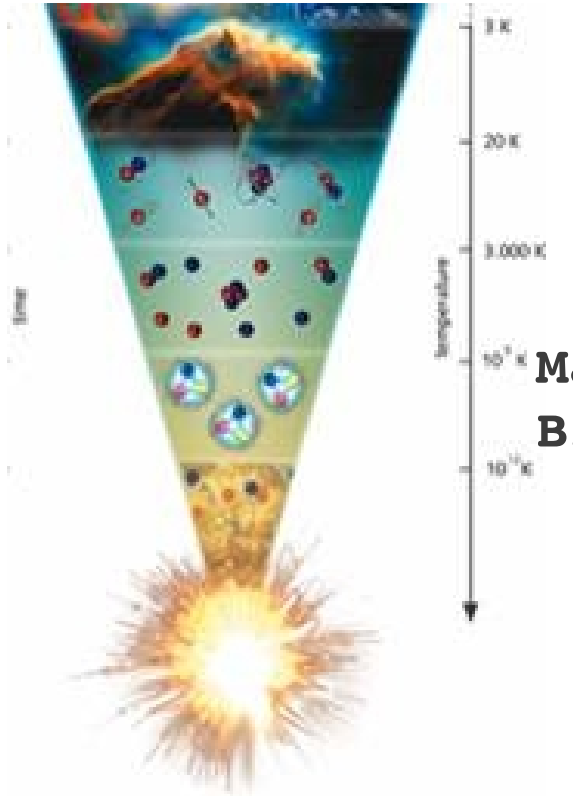
PANDA

High luminosity mode, high resolution mode...

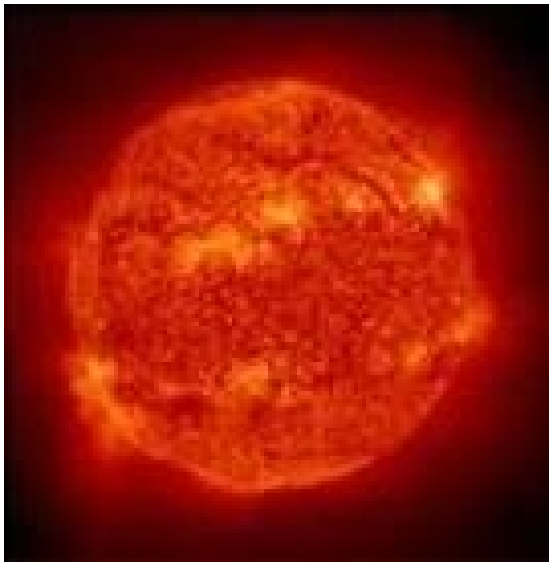
See Tord's talk!



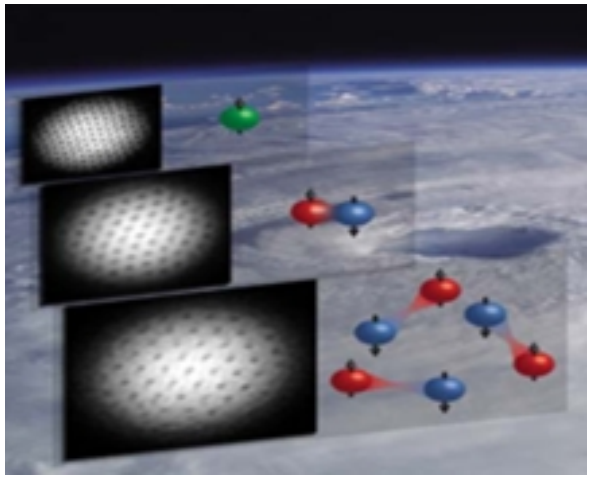
Physics at FAIR on one slide



Mass generation
Big bang



Sun fusion



Atomic systems
Condensates

Neutron stars
Supernovae

What is the nucleon made of? Mass? Spin?

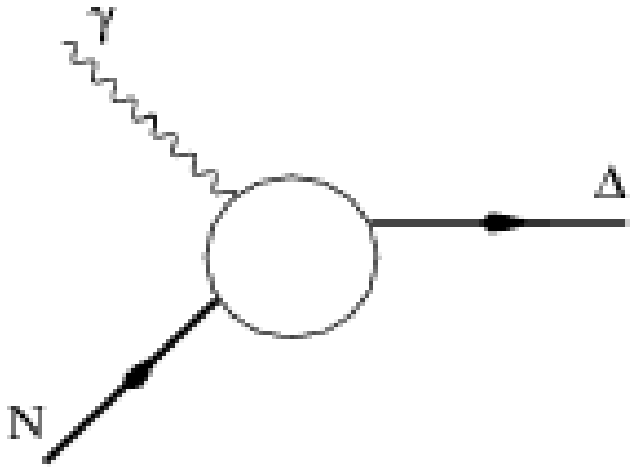
Experiment: precise tests of nucleon structure at JLab-CEBAF, MIT-BATES, Mainz-MAMI – polarizabilities, transition form factors (shape of nucleon??)

Theory: good description of data - constituent quark models, pion cloud models, EFTs,...

Experimental Form Factor ratios

$$EMR(\%) = \frac{E2}{M1} = -2.5 \pm 0.5$$

$$CMR(\%) = \frac{C2}{M1} = -4.81 \pm 0.27$$



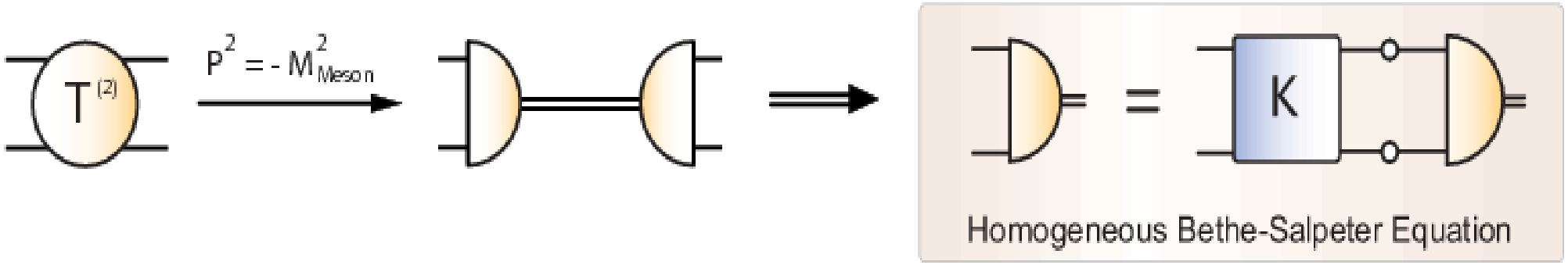
Improved models – correct sign and reasonable results.
Price to pay: overestimated or underestimated results for other transition observables!

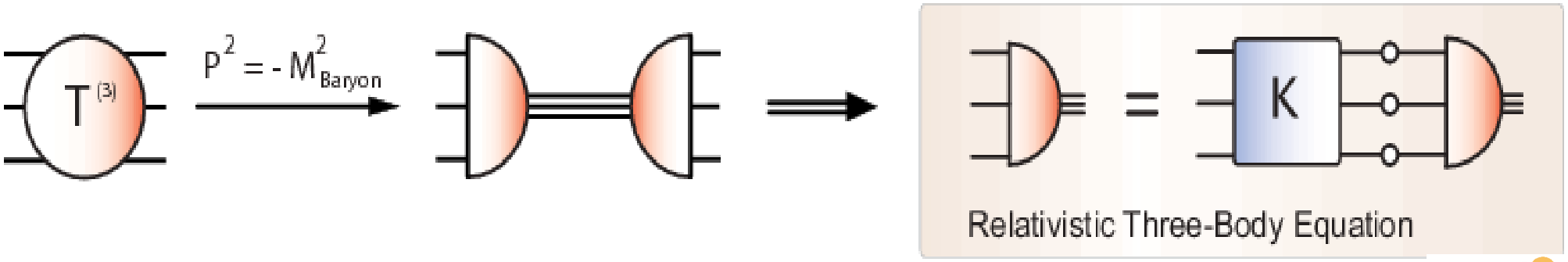
Missing info – chiral symmetry and its dynamical breaking, relativistic effects, proper and complete partial wave decomposition.

Bound-state equations.

How are quarks and gluons distributed in hadrons?
A Poincaré covariant hadron's amplitude in terms of QCD degrees of freedom is needed!
Dyson-Schwinger equation and bound-state equations enable a study of hadrons as composites of dressed-quarks and dressed-gluons.

Bound-state poles in 4-point and 6-point Green functions lead to bound-state equations for mesons and baryons.

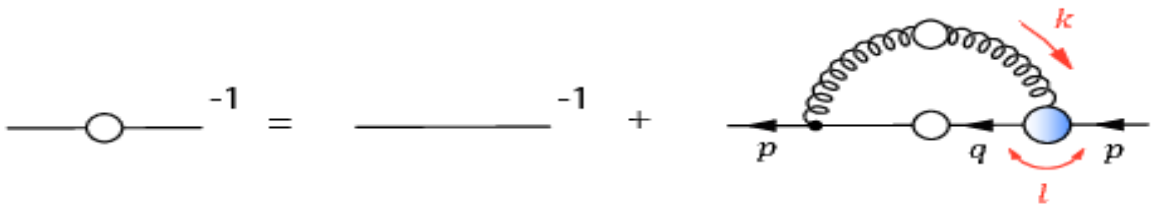




Solution - covariant hadron amplitude fct(P, relative q).

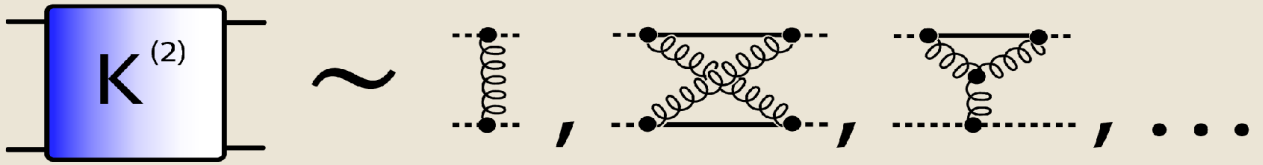
Bound-state equations ingredients.

Dressed-quark propagator

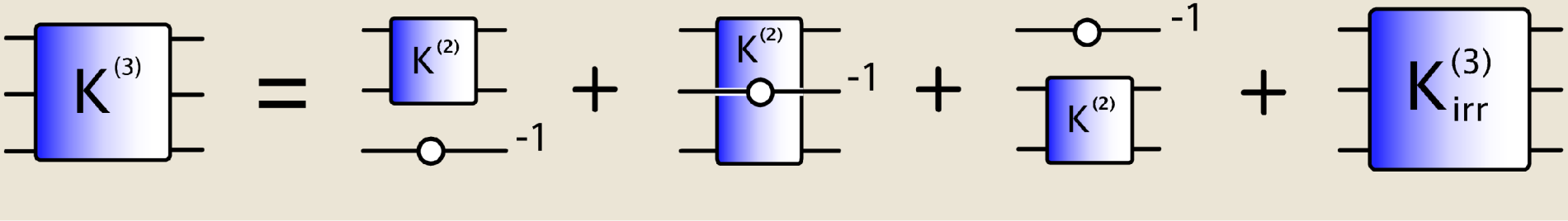


Interaction kernel

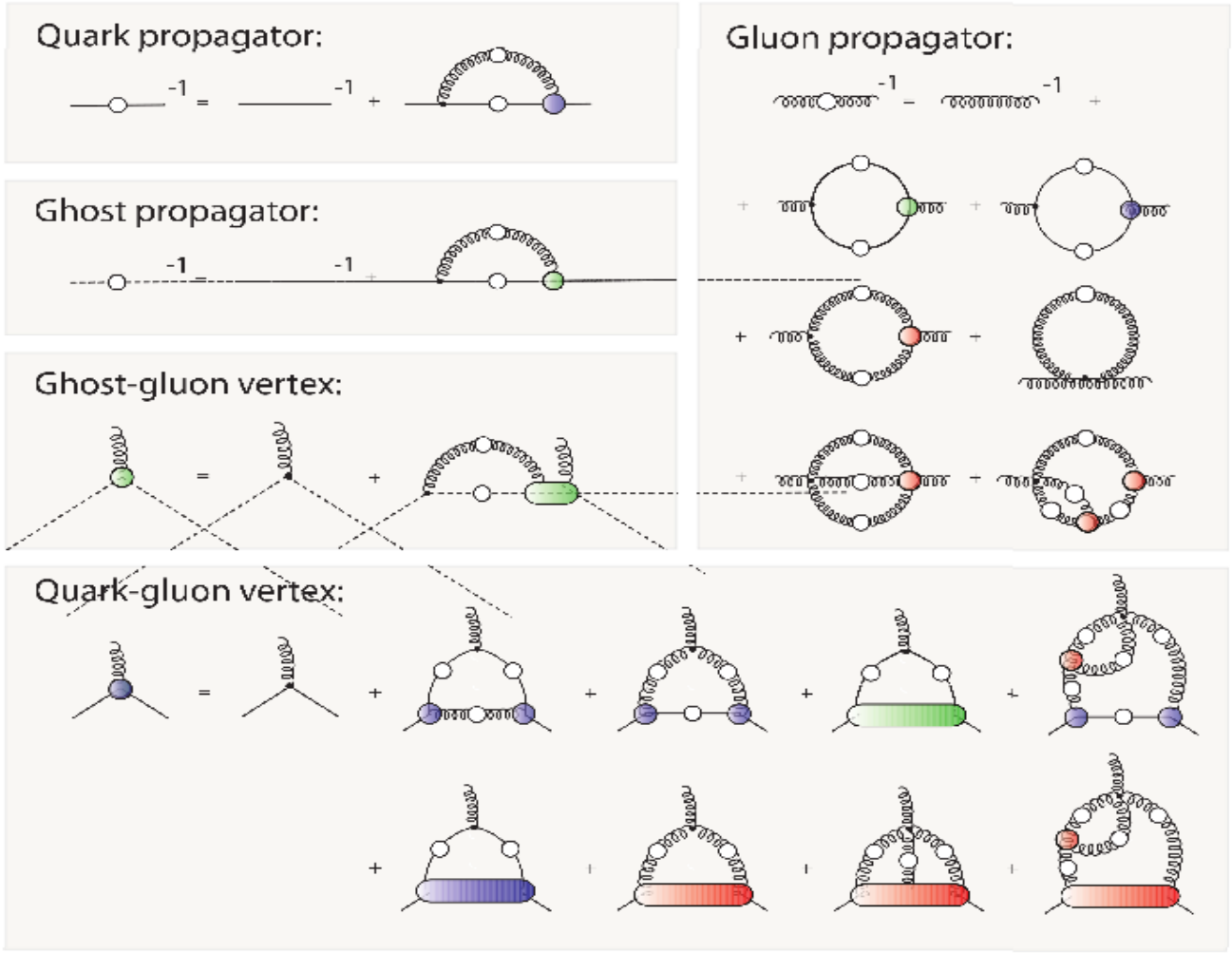
2-body:



3-body:



DSEs are equations of motions for QCD's Green functs.

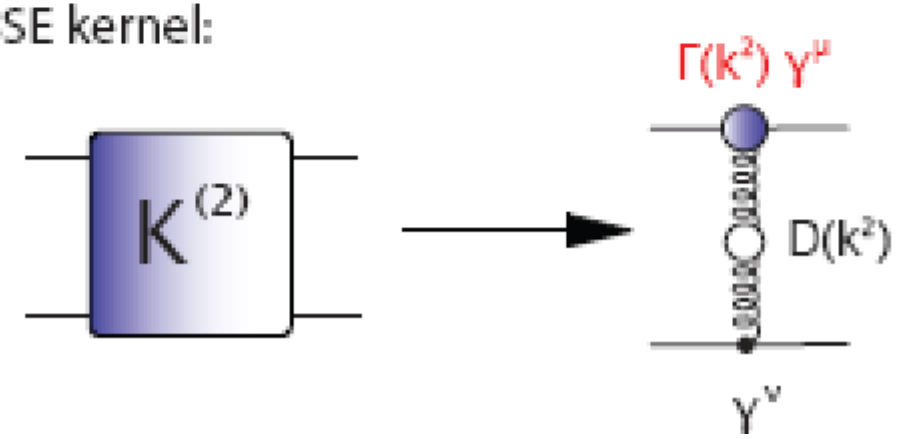


Infinite set of coupled integral equations.

Truncations are needed (must satisfy QFT identities!).

Rainbow-ladder truncation.

Quark-gluon vertex consists of 12 tensor structures.
Rainbow truncation retains only the vector part.

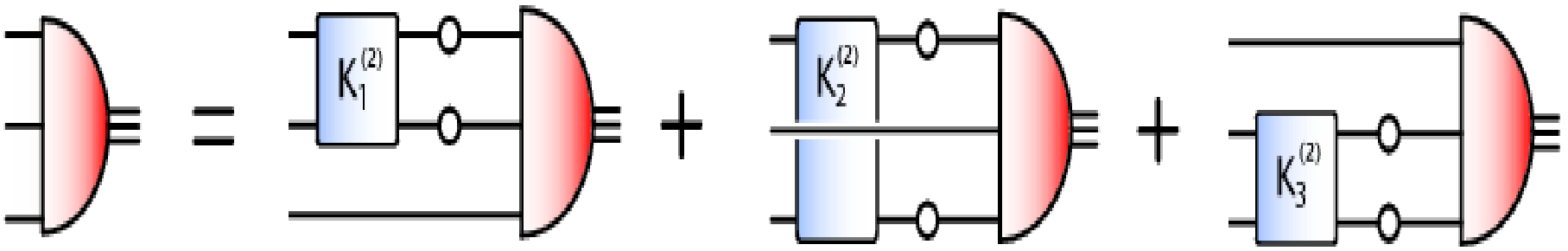


Ladder exchange of one dressed-gluon.

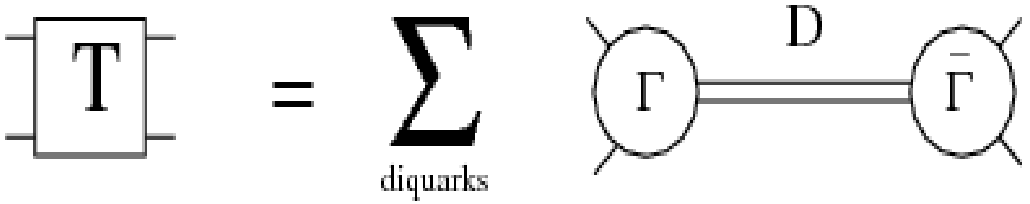
Dressings of the quark-gluon vertex and gluon propagator absorbed in an effective coupling $\alpha_{eff}(k^2) \sim D(k^2)\,\Gamma(k^2)$

Baryons as quark-diquark bound-states.

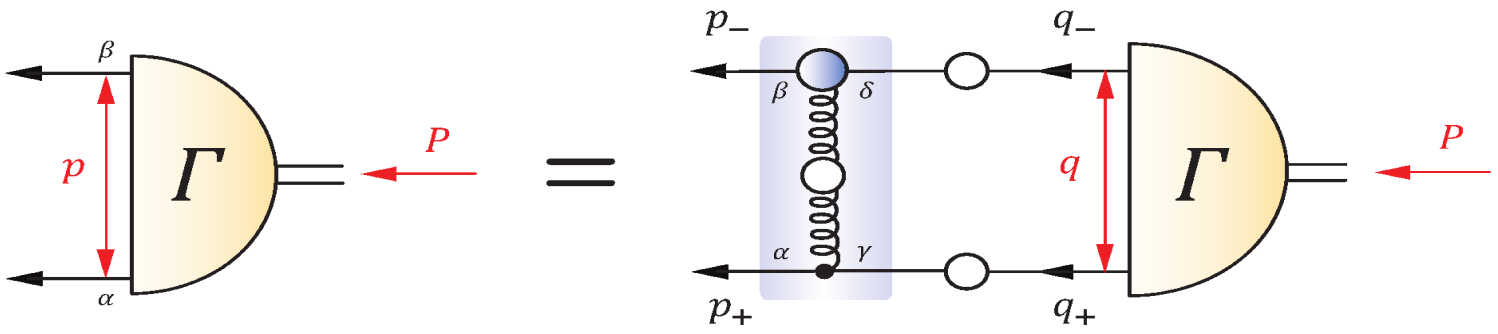
Faddeev truncation of the three-body problem:
qq correlations dominant structure in baryons.



Diquarks - separable pole ansatz in qq scattering matrix.
- non-pointlike.
- rainbow-ladder artifacts.

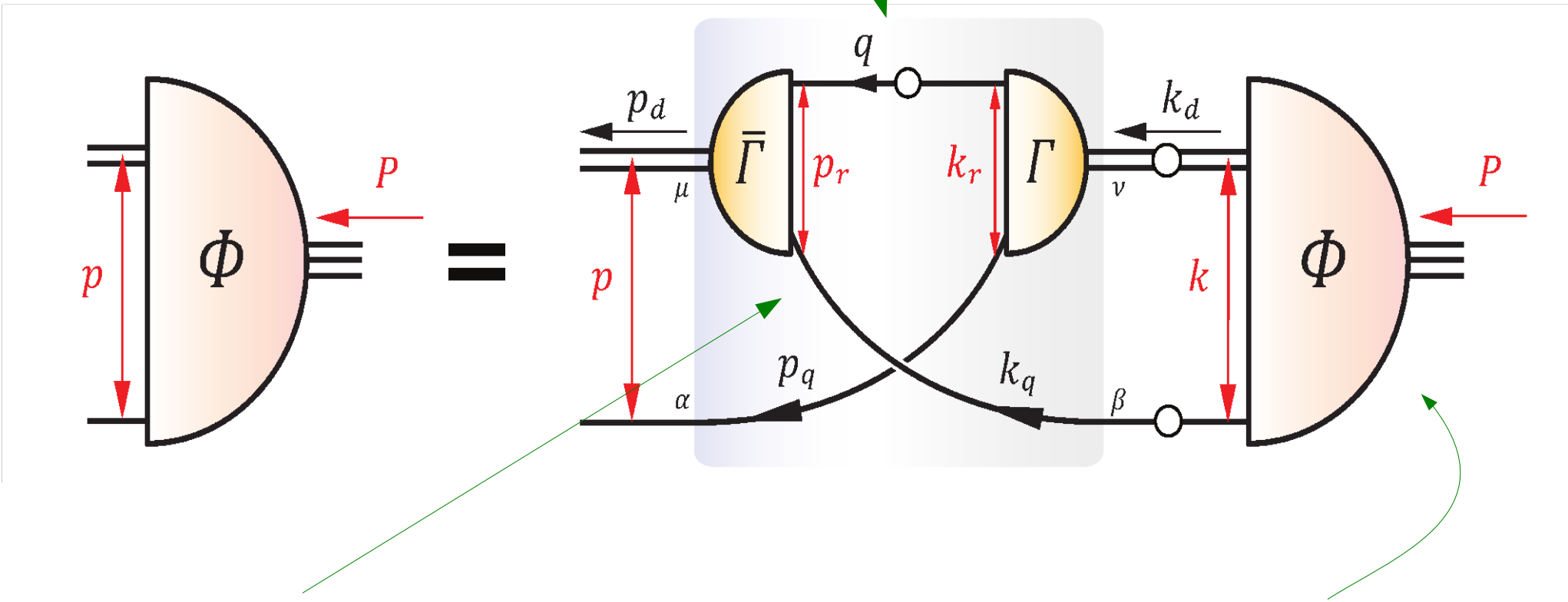


Rainbow-ladder diquark BSE (analogy to meson sector).



Quark-diquark Bethe-Salpeter equation.

Quark propagator (DSE)



Diquark amplitude (BSE)

Quark-diquark (BSE)

Quark-diquark core contributions to Nucleon and Delta masses

At physical point M_{pion} = 140 MeV :

Bands: core-version;

C fixed to reproduce hadron's core.

M_{Delta}^{core} = 1.73 GeV

D.N. et al. PRD 80 (2009)

$M_{Nucleon}^{core}$ = 1.26 GeV

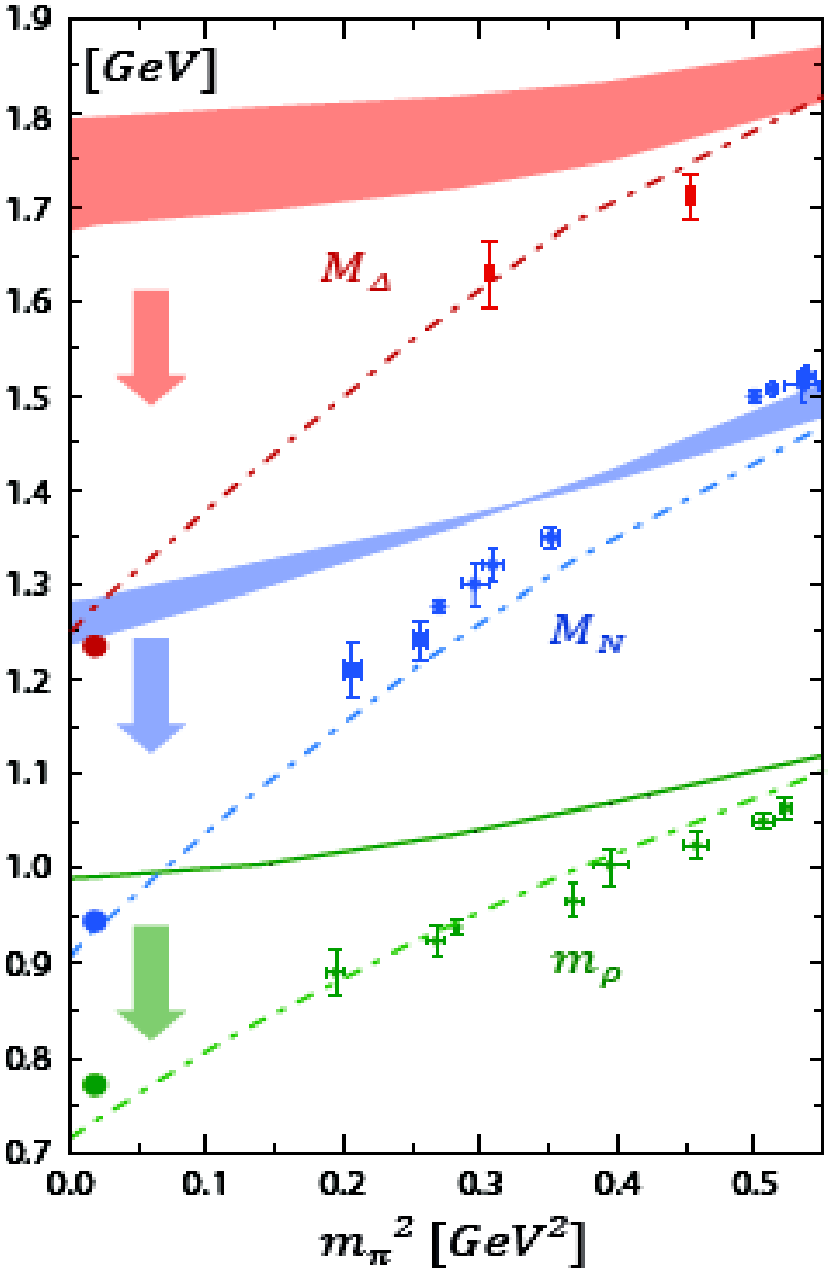
G. Eichmann et al. PRC79 (2009)

M_{rho} = 990 MeV

Dashed lines: Maris-Tandy model;

C fixed to reproduce the pion.

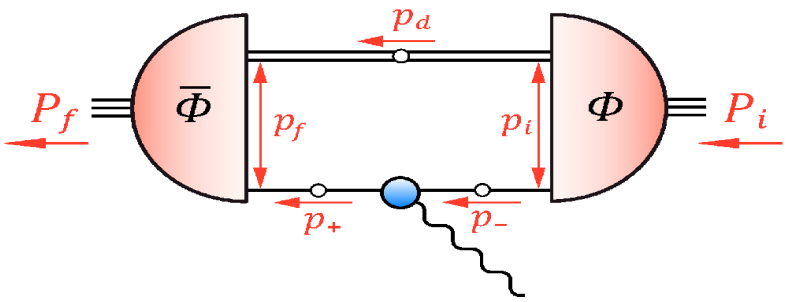
Points: lattice data,
chiral extrapolation methods; exp.
Zanotti et al. PRD 68 (2003)
Ali Khan et al. Nucl.Phys.B 689 (2004)
Allton et al. PLB 628 (2005)
Frigori et al. PoS(LAT2007)



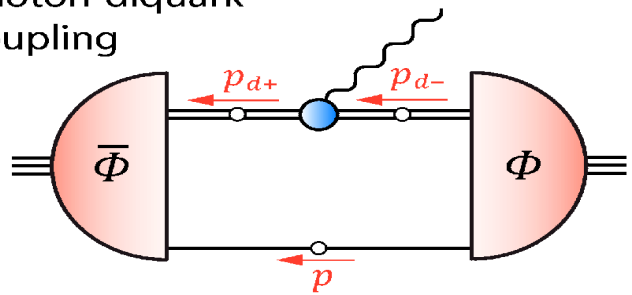
Baryon-photon coupling.

Current conservation requires the following diagrams.
Oettel, Pichowsky, von Smekal, EPJ A 8, 2000.

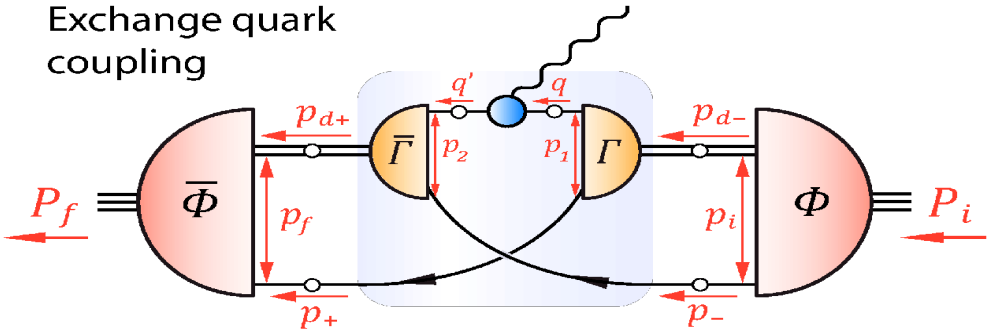
Photon-quark coupling



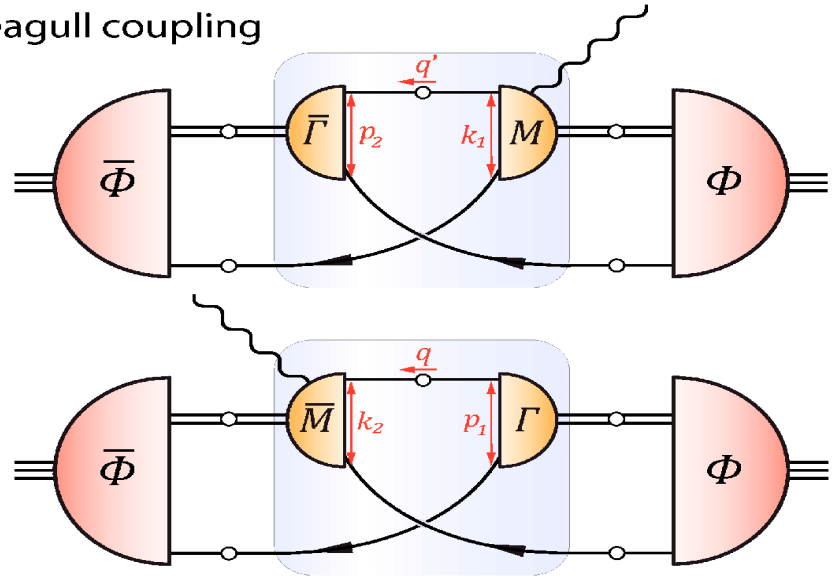
Photon-diquark coupling



Exchange quark coupling



Seagull coupling



All vertices depend on dressed-quark propagators.

N-Delta electromagnetic form factors.

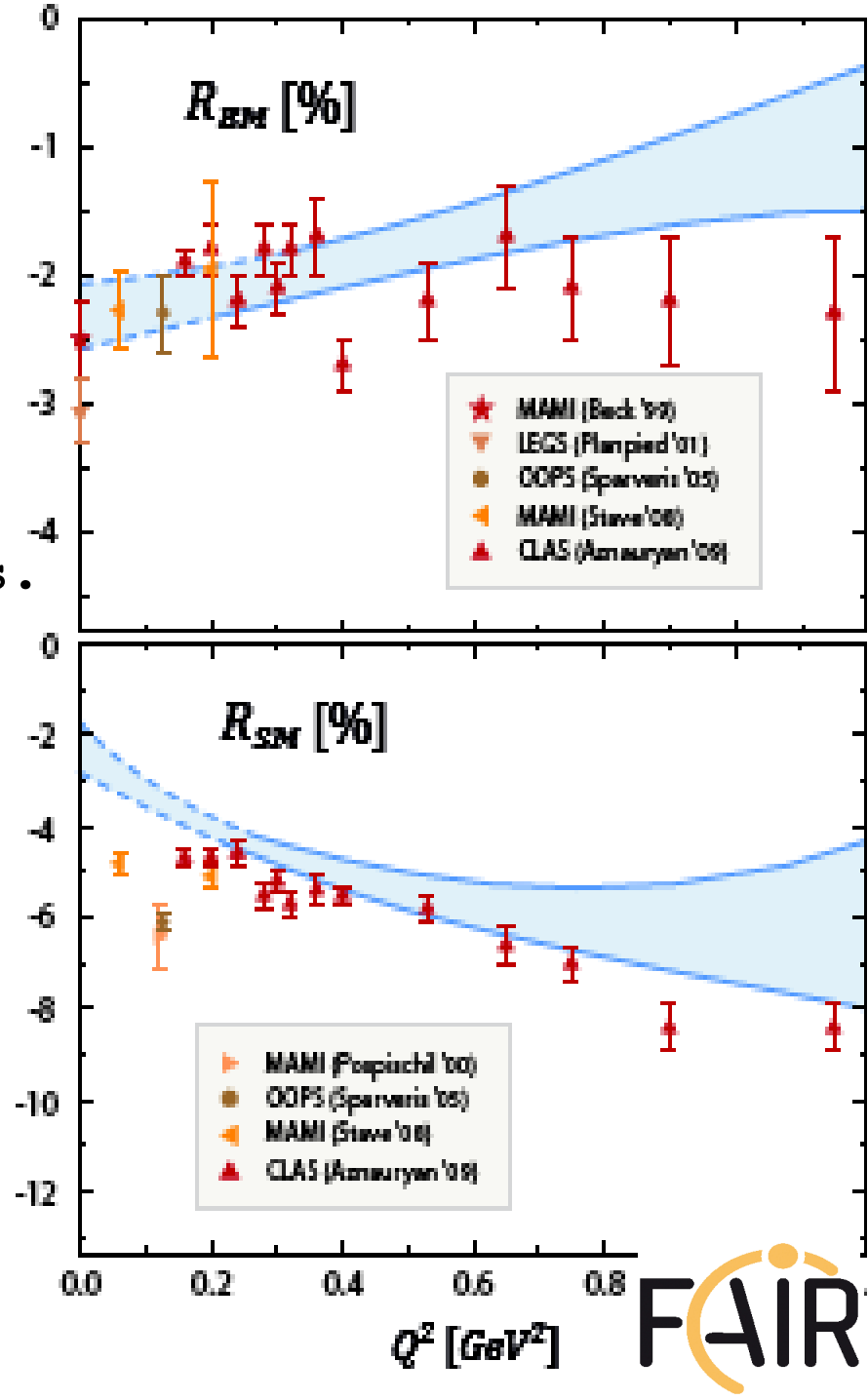
Magnetic dipole FF – dominant
Electric and Coulomb quadrupole FF
  - small but negative – deformation

p-waves dominate GE2!
s-waves dominate GM1 and GC2.
d-waves very small contribution.
quark models need d-waves, clouds.

FF ratios reproduced without clouds.
weak dependence of all FF on
  the current-quark mass.
EFTs need sizeable pion clouds.

disfavor arguments which promote clouds/d-waves as prevailing missing effects for a proper description of the non-spherical character of the transition.
Poincare covariance is essential!

Eichamnn & Nicmorus arxiv:1112.2232
as of today published in PRD .



Improvements/Outlook

Nucleon and Delta mass in a three-body Faddeev approach given by a consistent rainbow-ladder gluon exchange between any two quarks. Diquark pole ansatz is abandoned in favor of the full qq scattering kernel.

Sanchis-Alepuz et al.,PRD 84 (2011)
Eichmann et al., PRL 104 (2010)

Wish-list:

N and Delta FF in 3-body Faddeev approach.
Excited states!!
Beyond RL truncation: chiral corrections, scalar part of quark-gluon vertex...
Nonperturbative description of hadron-photon and hadron-meson scattering, Eichmann PRD 85 (2012)

Are you interested in physics at FAIR?
Take your chance to stand out from the crowd and join us in Hersonissos this year.

FAIRNESS

Workshop for young scientists with research interests focused on physics at FAIR

Hersonissos, Greece — Sept. 3-8, 2012

Chairs: A. Arcones, M. Bleicher, M. Fritsch, T. Galatyuk, D. Nicmorus, H. Petersen, C. Ratti, L. Tolos.

FAIR