Facility for Antiproton and Ion Research

FAIR

Overview of Facility and Experiments

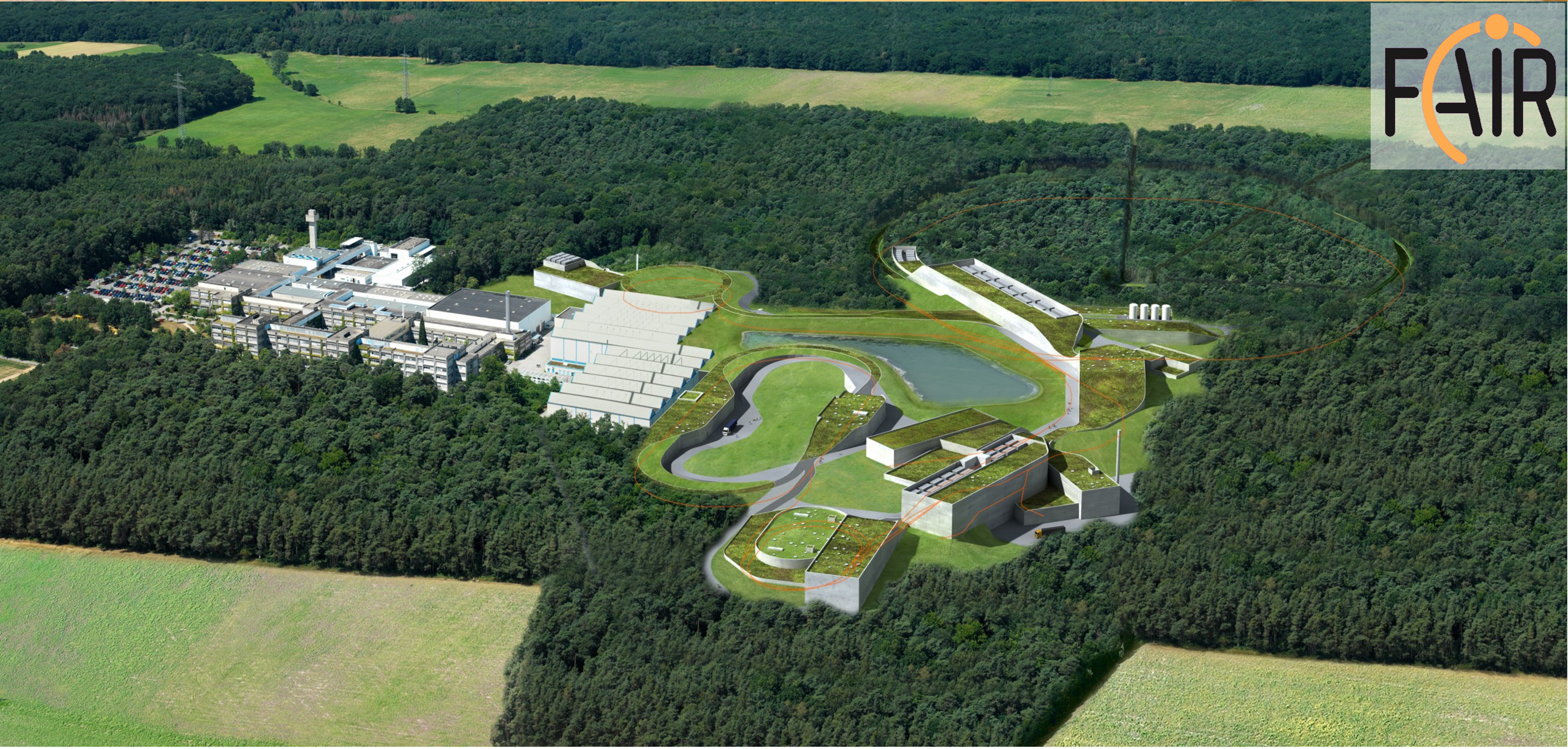
Lars Schmitt, GSI Darmstadt

QWG Workshop 2011, Darmstadt, Oct 4th 2011

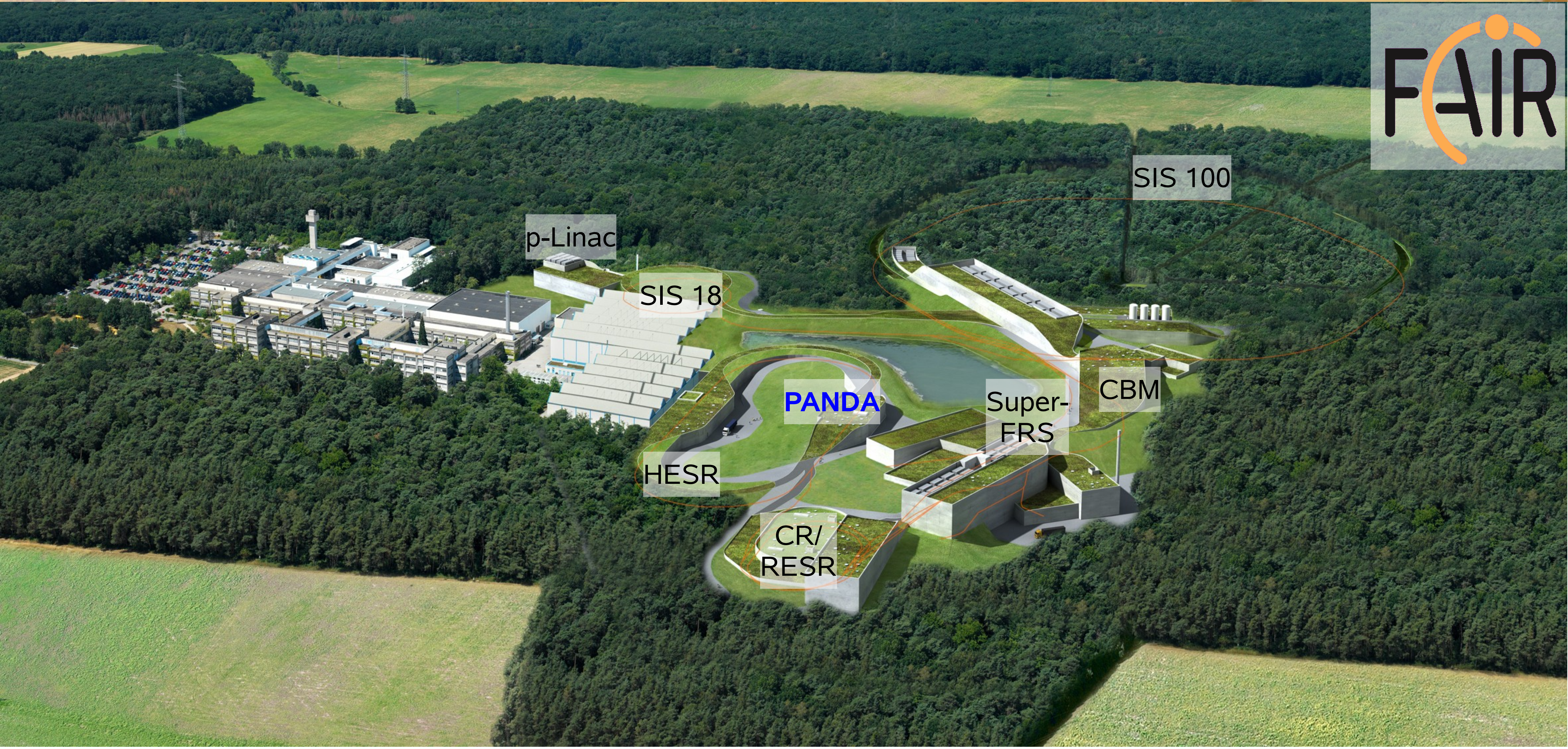
- The Facility
- PANDA: Hadron Physics
- CBM: Heavy Ion Physics
- NuSTAR: Nuclear Physics

GSI

Facility for Antiproton and Ion Research



Facility for Antiproton and Ion Research



New facility featuring:

Rare isotope beams, heavy ion beams, anti-protons

→ Optimal usage of accelerator facilities

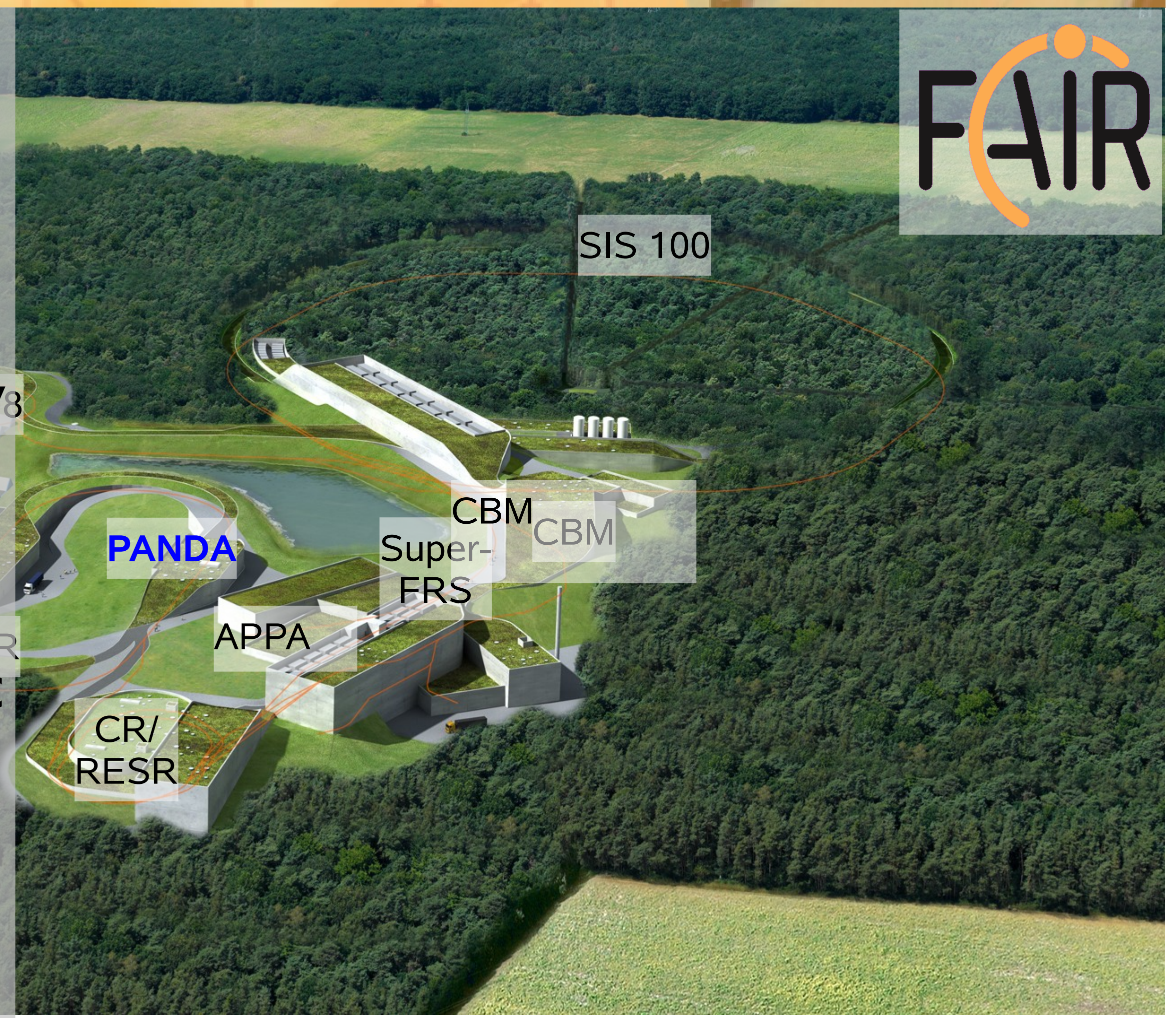
Facility for Antiproton and Ion Research

Physics pillars:

- APPA: applied physics, atomic and plasma physics
- NUSTAR: Nuclear structure, astrophysics and reactions
- PANDA: Hadron physics with $\bar{p}$ annihilations
- CBM: Compressed baryonic matter with heavy ions

Key features:

- Fast ramping synchrotrons
- Unprecedented intensities



Founding FAIR on Oct 4th 2010

Signatory Ceremony at Wiesbaden
4th October 2010

Foundation act of FAIR GmbH

The convention was signed by

- Finland
- France
- India
- Poland
- Romania
- Russia
- Slovenia
- Sweden
- Germany

The foundation papers for the FAIR GmbH were signed by
Horst Stöcker
Hartmut Eickhoff
at 2010, 4th of October

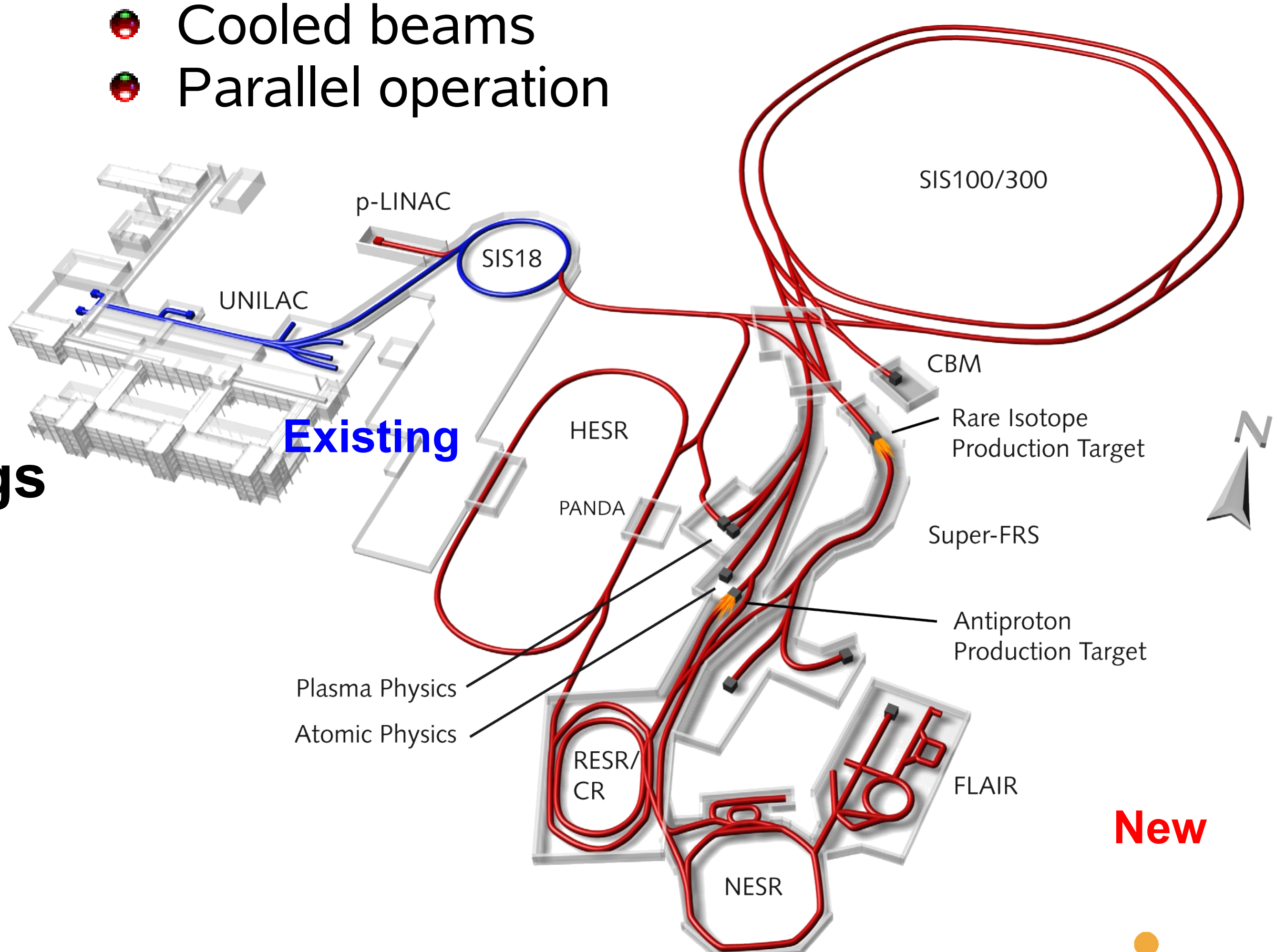
Layout of the Facility

Primary beams
- U up to 35 AGeV
- Protons up to 30 GeV/c
- 100-1000x more

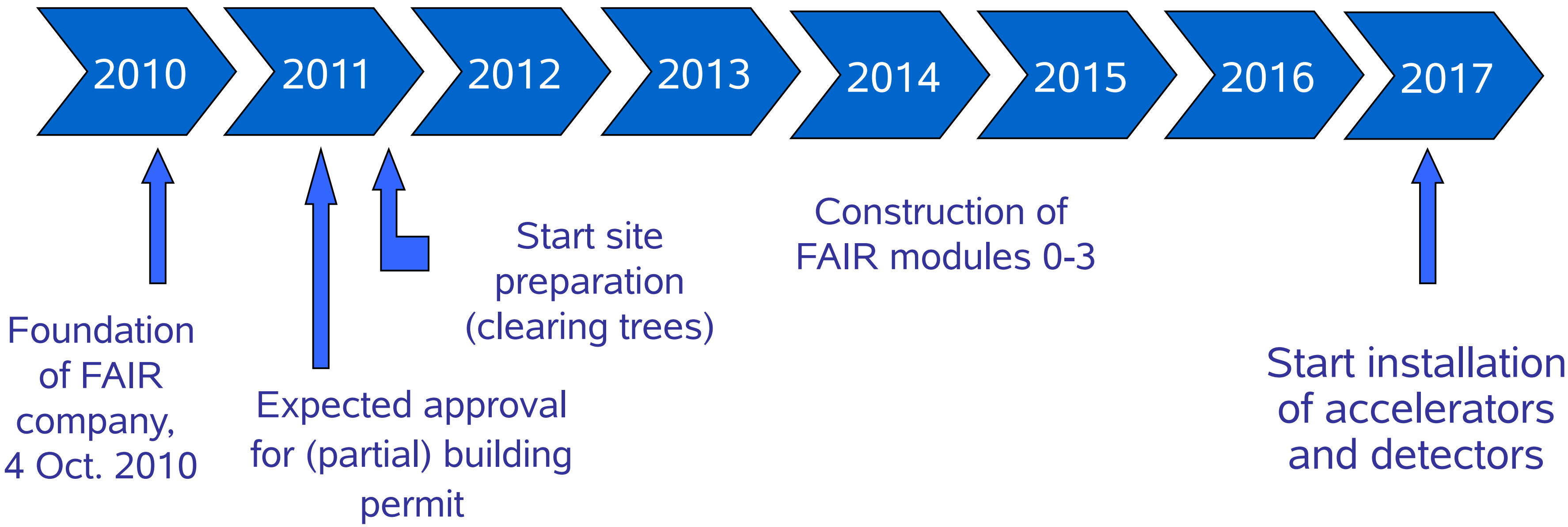
Secondary beams
- Broad range of rare isotopes, 10000x more
- $\bar{p}$: 0-15 GeV/c

Storage and cooler rings
- Radioactive beams
- e^-- A (or $\bar{p}$ - A) collider
- Antiprotons

Key features
- Rapidly cycling SC magnets
- Cooled beams
- Parallel operation



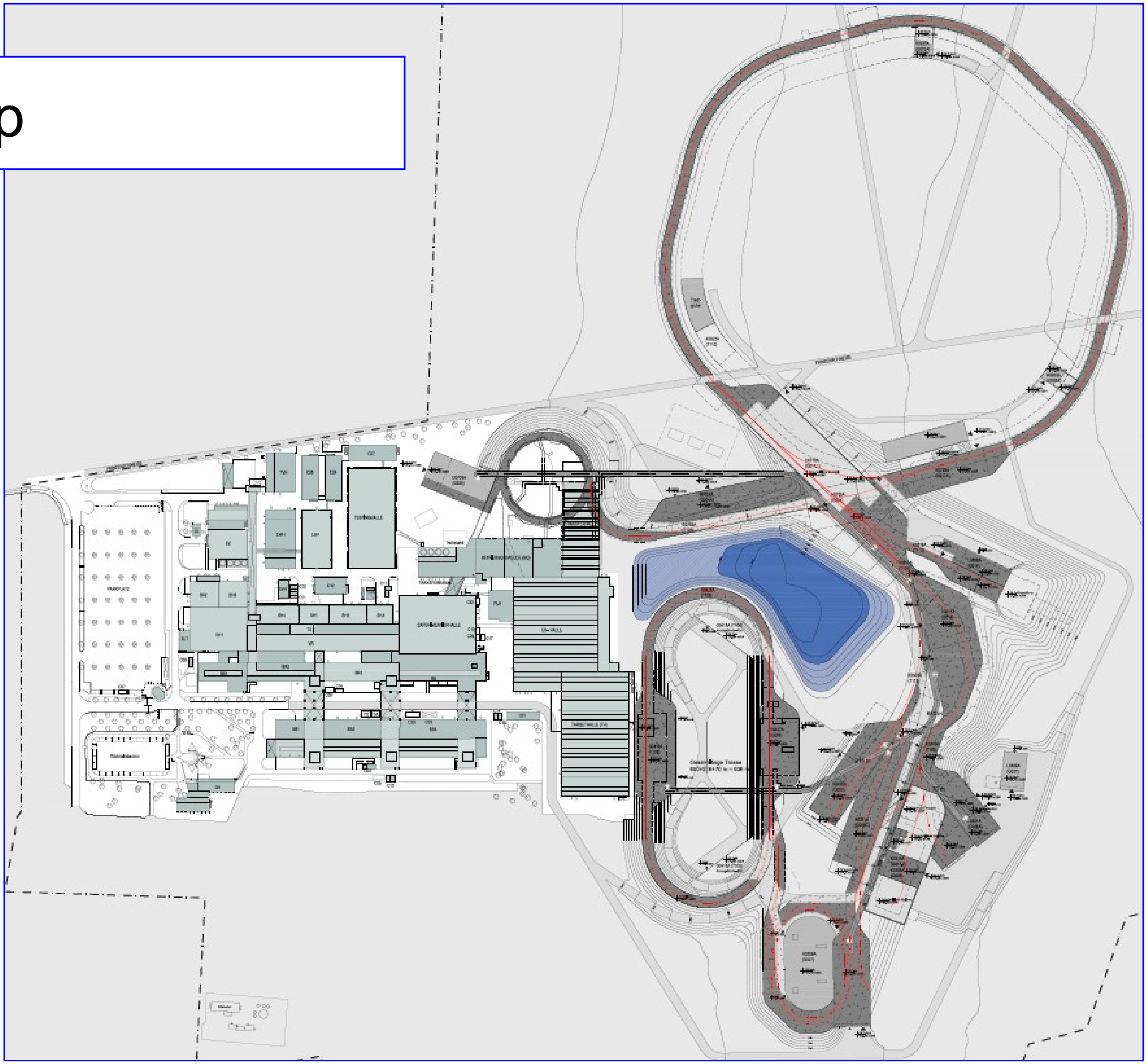
FAIR Timeline



Phase A						Phase B SIS300
Module 0 SIS100	**Module 1** experimental areas CBM/HADES and APPA	**Module 2** Super-FRS fixed target areas and CR NuSTAR	**Module 3** pbar facility, incl. CR for PANDA, options for NuSTAR	**Module 4** LEB cave for NuSTAR, NESR for NuSTAR and APPA, FLAIR for APPA	**Module 5** RESR	**Module 6** SIS300 HESR Cooler ER

Construction Cycle

2012: Site set-up

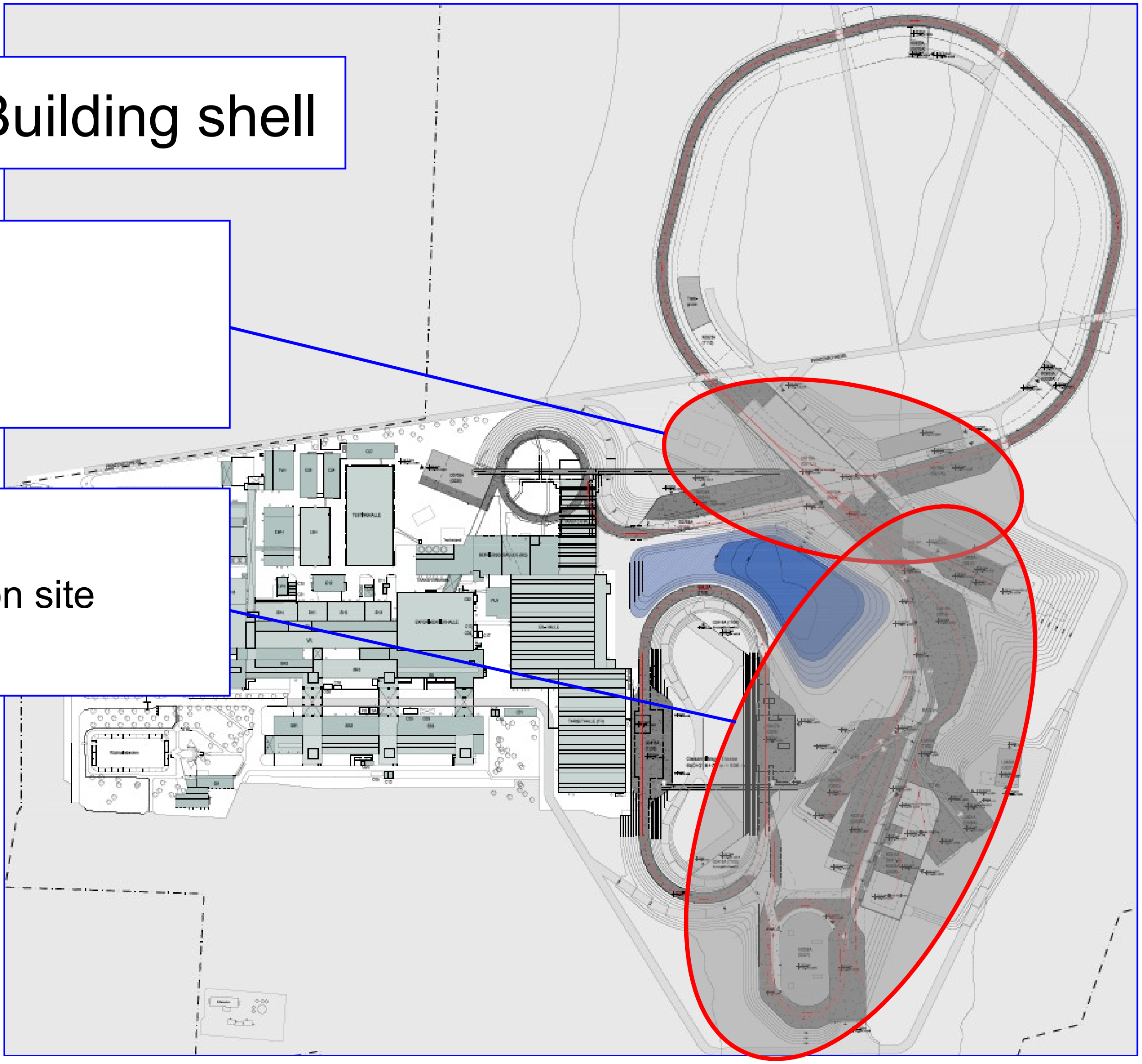


Construction Cycle

2013 – 2014: Building shell

1. Cross-way building:
- dewatering
- excavation pit
- cross-way building

2. Bored piles:
- southern construction site
- cross-way building



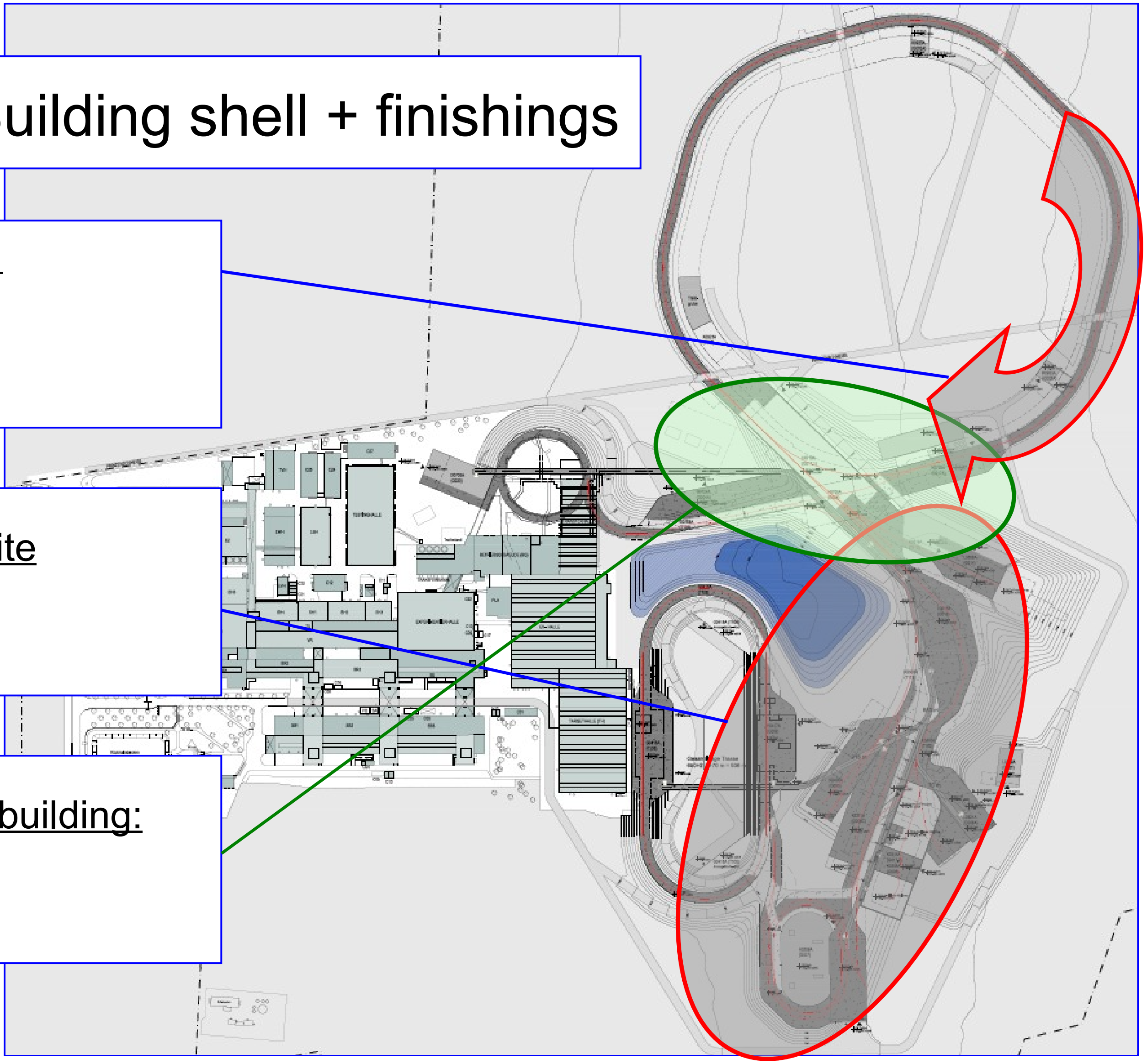
Construction Cycle

2015 – 2016: Building shell + finishings

3. Synchrotron tunnel:
- excavation pit
- tunnel
- dewatering

4. Buildings southern site
- buildings
- cross-way building

5. Finishing cross-way building:
- building services
- terrain modelling



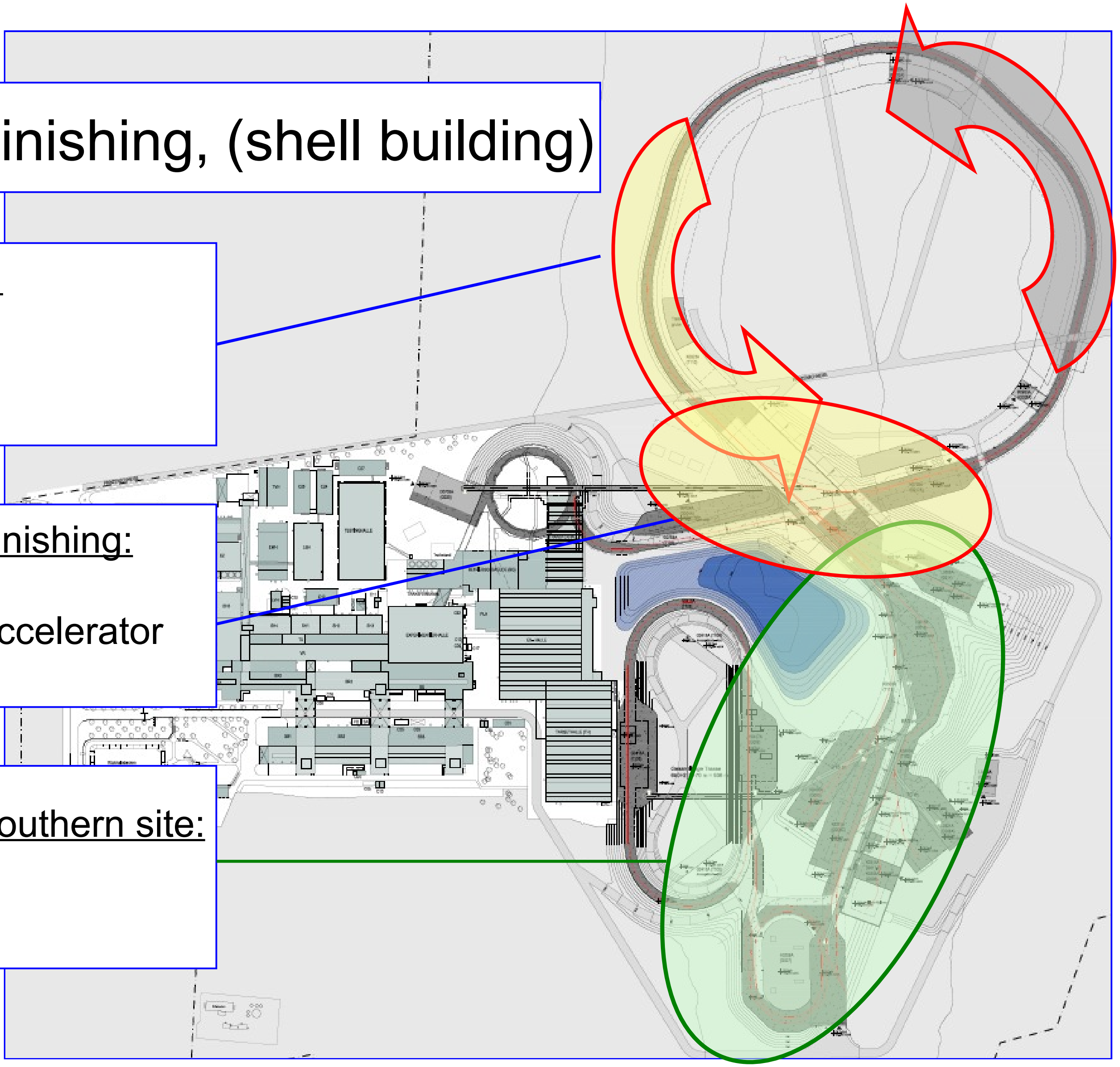
Construction Cycle

2016 – 2017: Finishing, (shell building)

3. Synchrotron tunnel:
- excavation pit
- tunnel
- dewatering

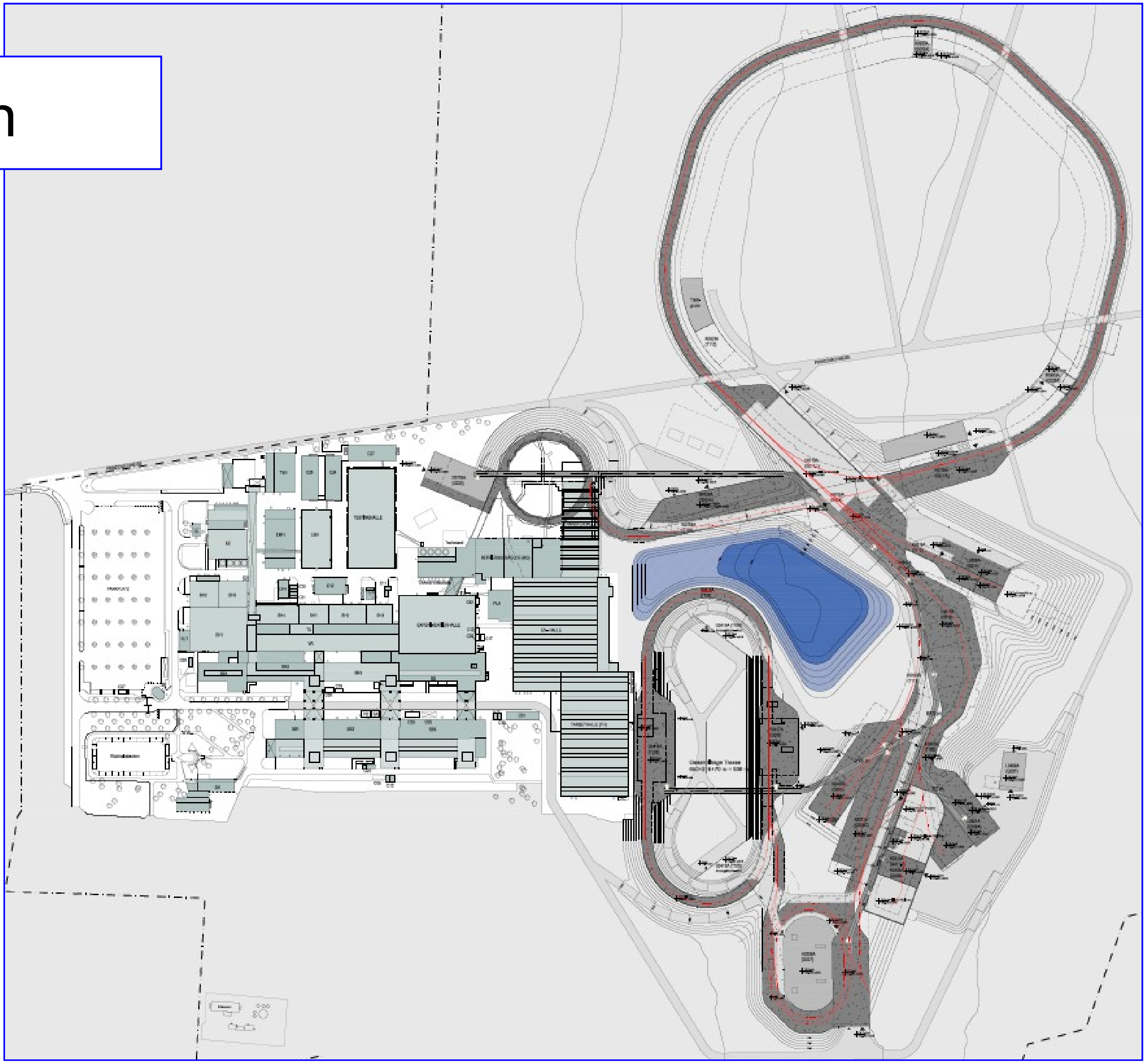
6. Synchrotron tunnel finishing:
- building services
- Start installation of accelerator components

7. Finishing buildings southern site:
- building services
- terrain modelling

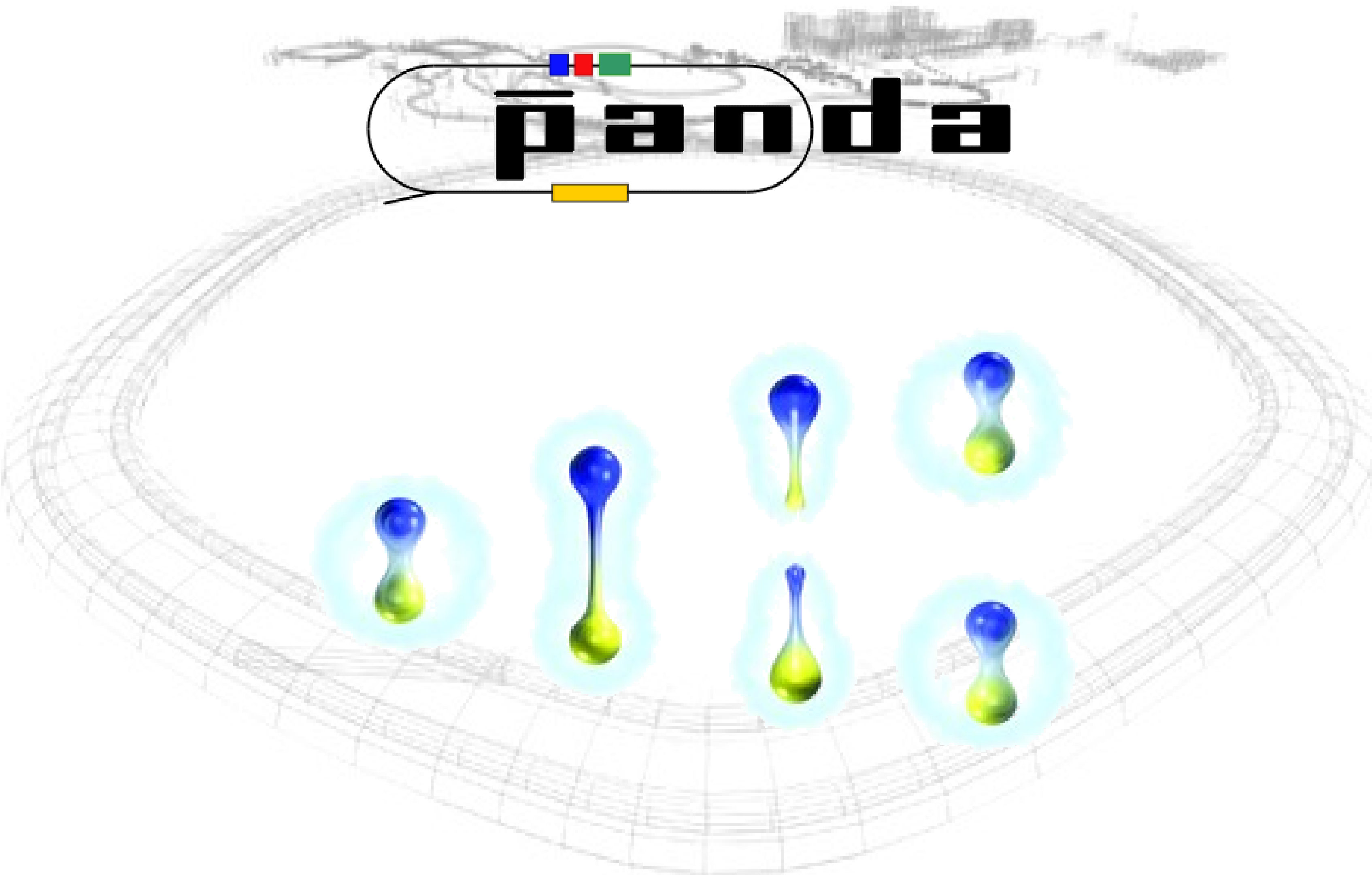


Construction Cycle

2018 Completion



anti-Proton Annihilations at DArmstadt



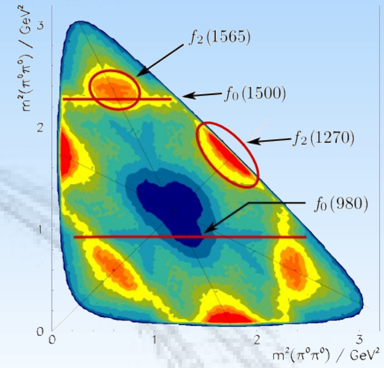
The Physics of PANDA

Hadron Spectroscopy

Observables: *masses, widths & quantum numbers J^{PC} of resonances*

Charm Hadrons*: charmonia, D-mesons, charm baryons*

➔ Understand new XYZ states, $D_s(2317)$ and others



Exotic QCD States*: glueballs, hybrids, multi-quarks*

Spectroscopy with Antiprotons:

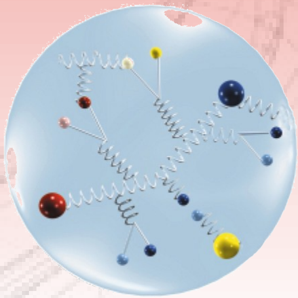
Production of states of all quantum numbers

Resonance scanning with high resolution

Hadron Structure

Generalized Parton Distributions

➔ Formfactors and structure functions, L_q



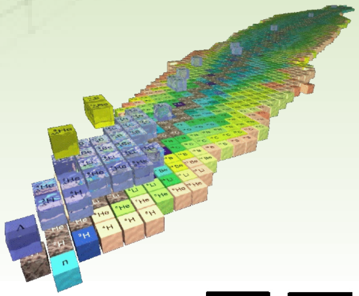
Timelike Nucleon Formfactors

Drell-Yan Process

Nuclear Physics

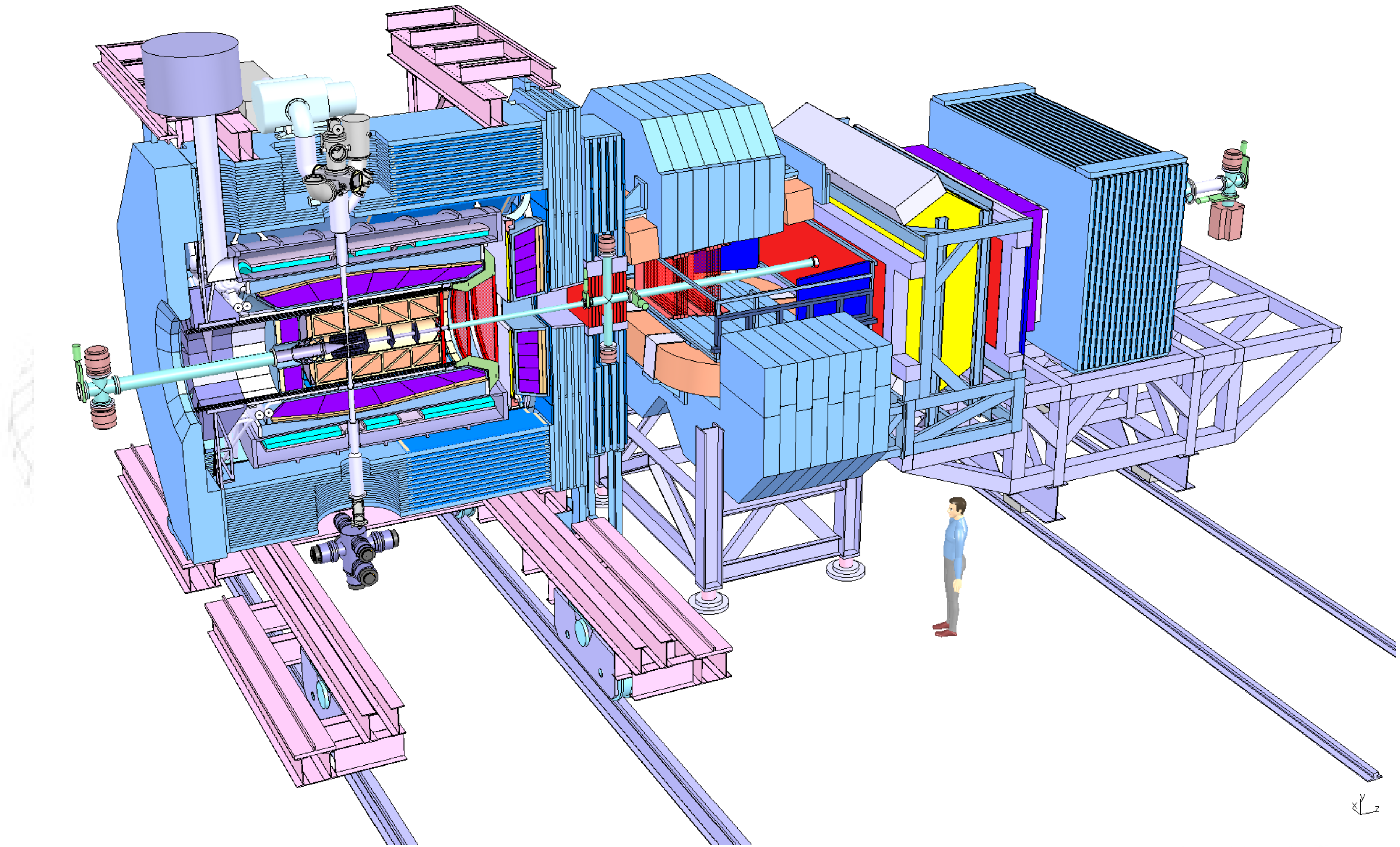
Hypernuclei*:* Production of double Λ-hypernuclei

➔ γ-spectroscopy of hypernuclei, YY interaction



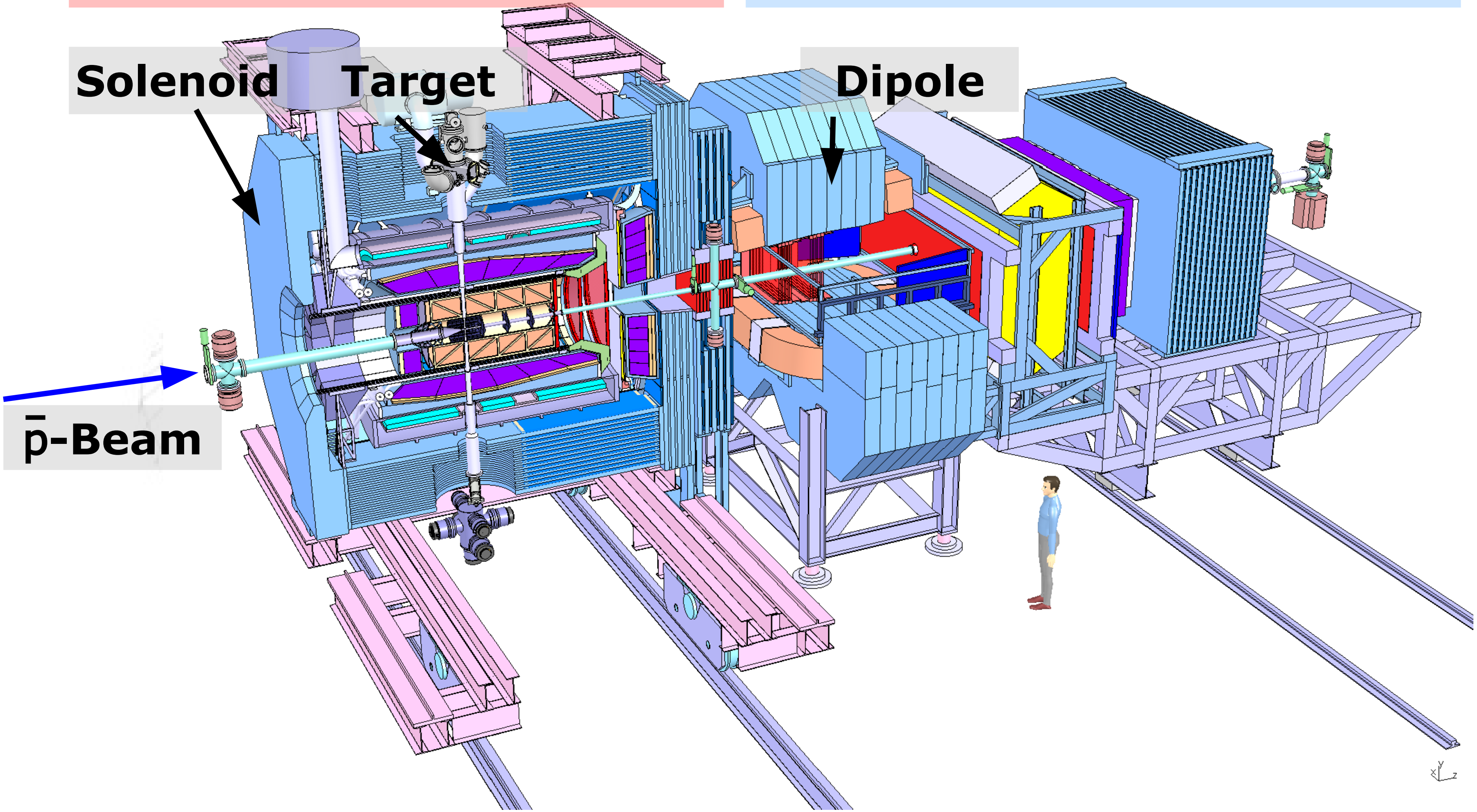
Hadrons in Nuclear Medium

PANDA Spectrometer

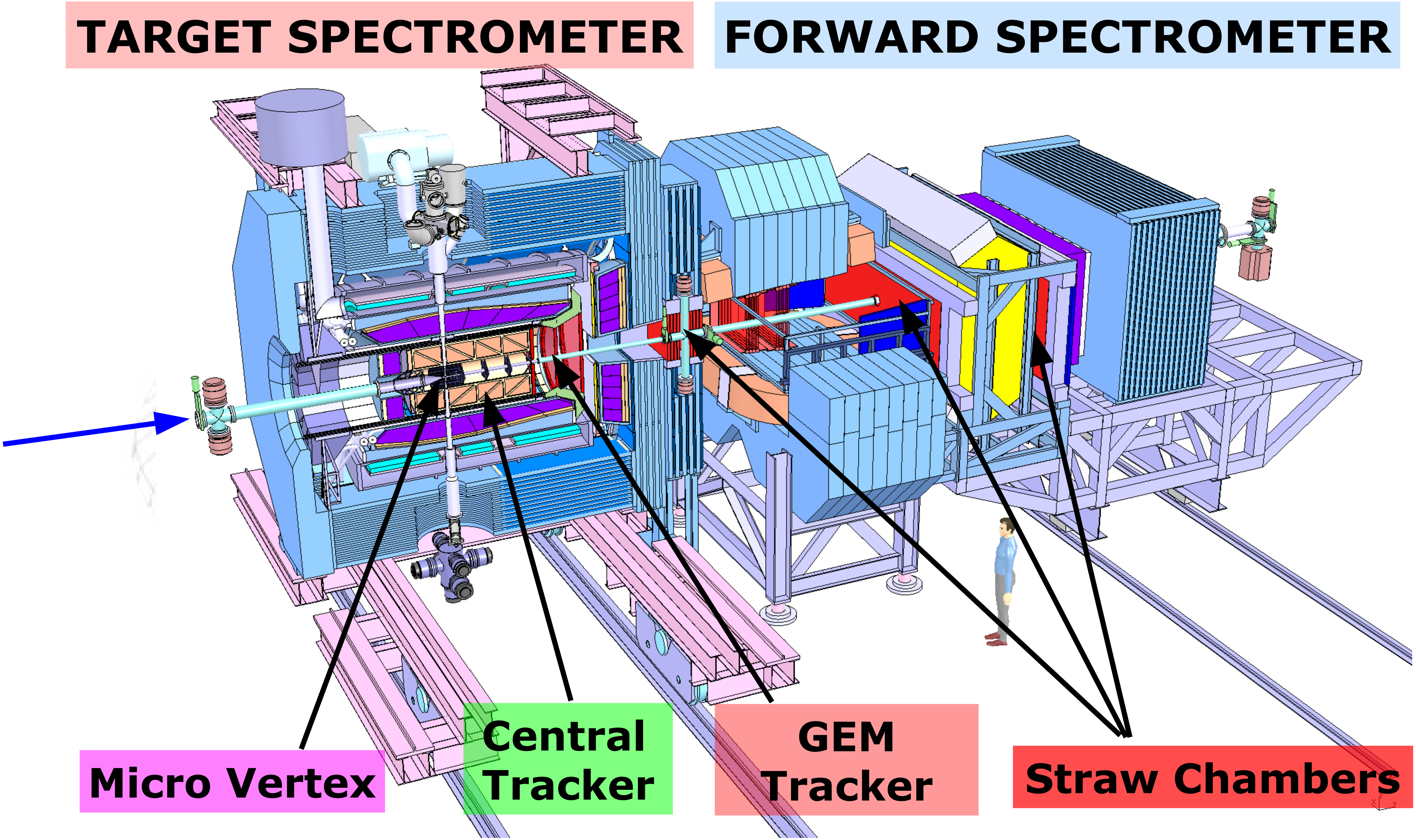


PANDA Spectrometer

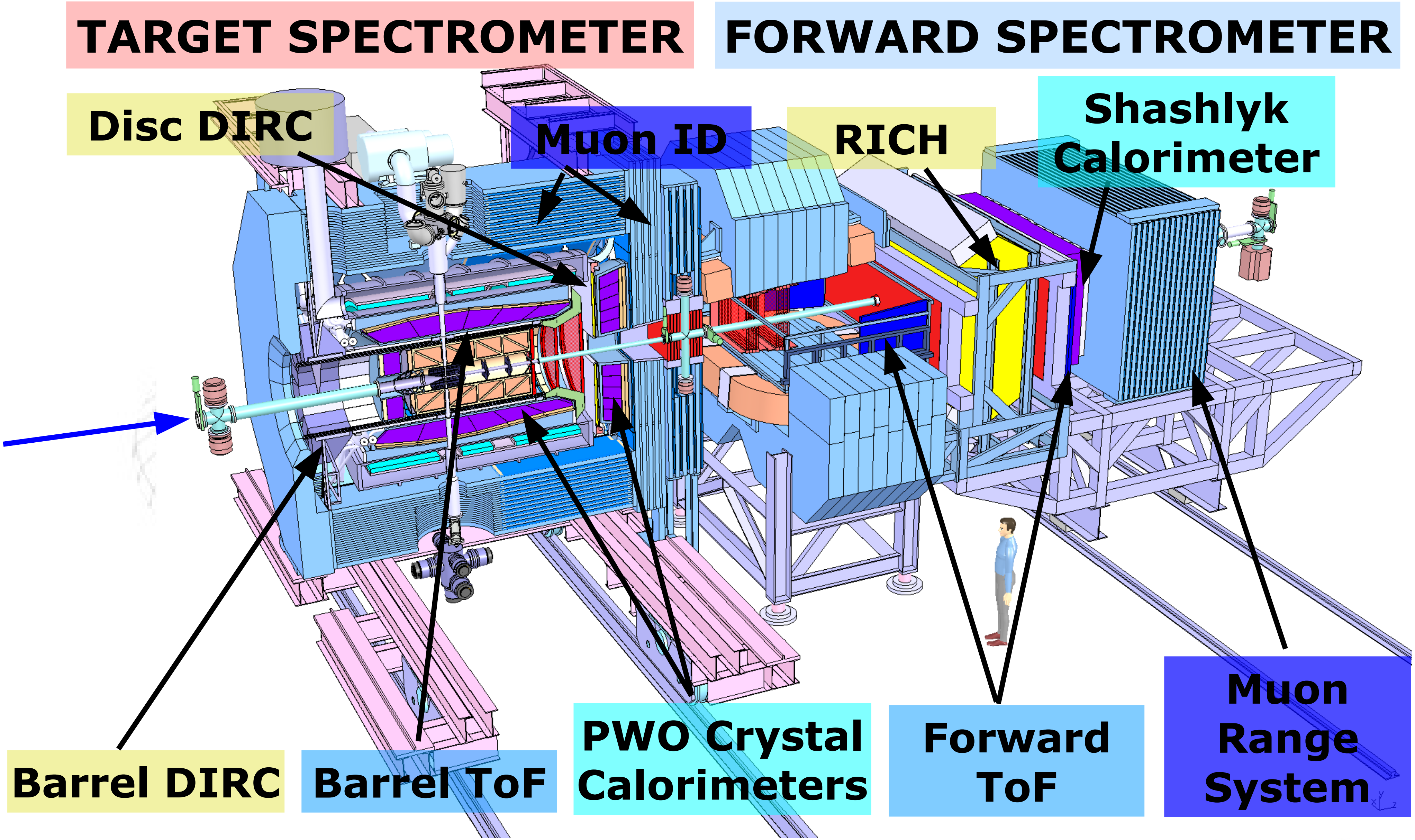
TARGET SPECTROMETER | FORWARD SPECTROMETER



PANDA Spectrometer



PANDA Spectrometer



Spectroscopy with Antiprotons

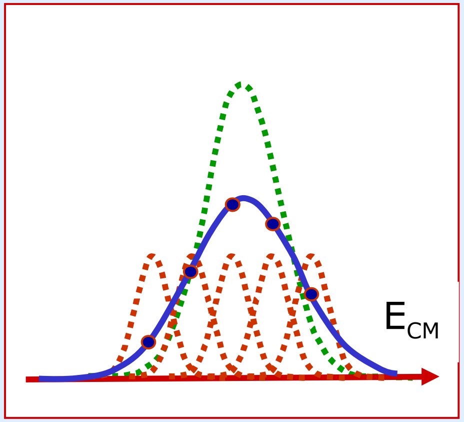
Spectroscopy with antiprotons

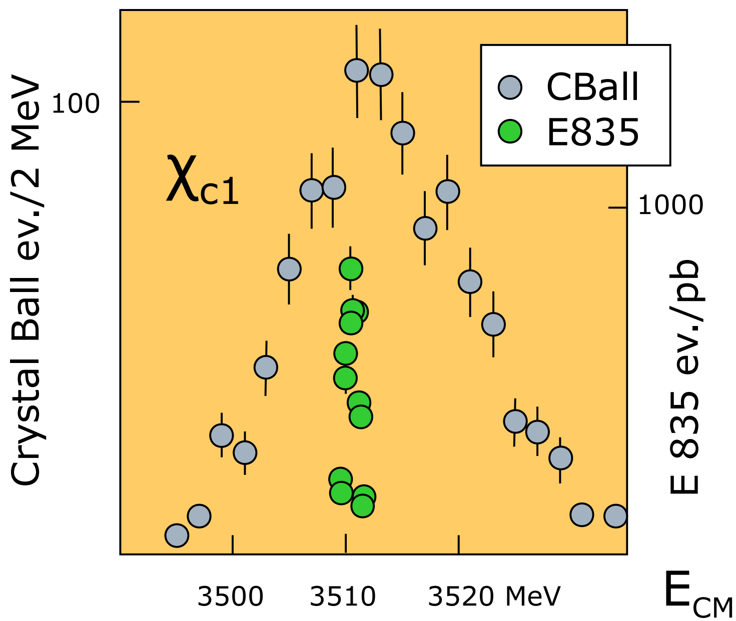
- $p\bar{p}$ machine allows ΔE ~ 50 keV (beam) vs. ΔE ~5 MeV in e^+e^- (detector)
- e^+e^- directly produces only $J^{PC} = 1^{--}$ (γ) others via ISR and other higher orders
- $p\bar{p}$ accesses all states

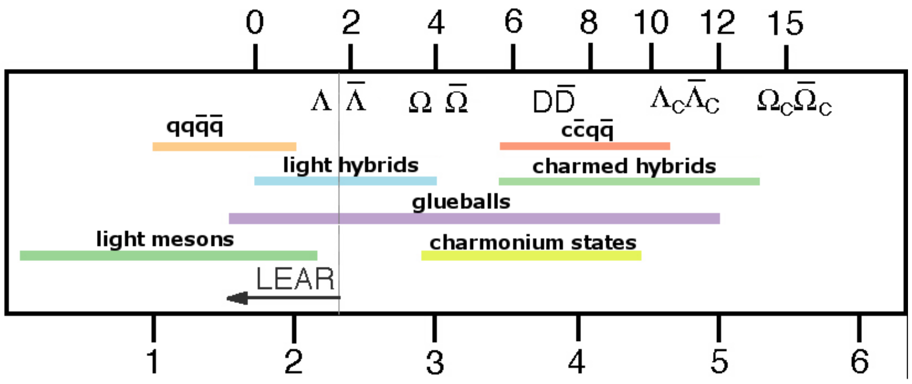
Resolution with antiprotons

Resonance scan:

- Energy resolution ~50 keV
- Tune E_{CM} to probe resonance
- Get precise mass and width

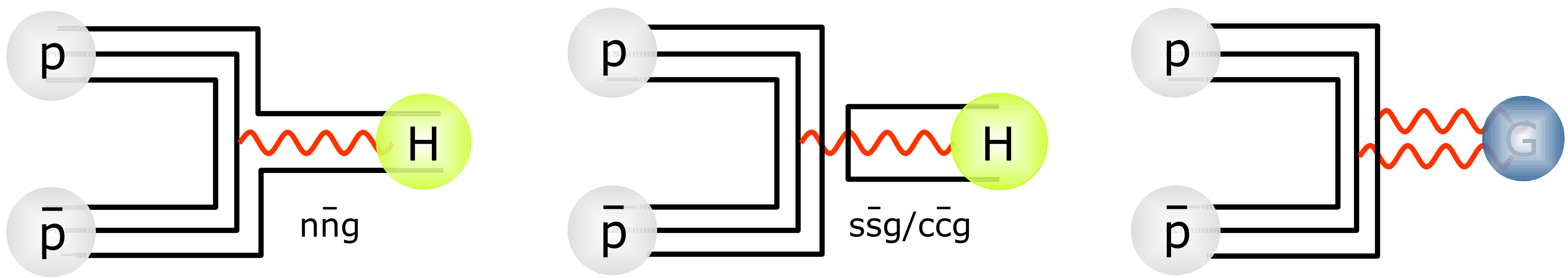




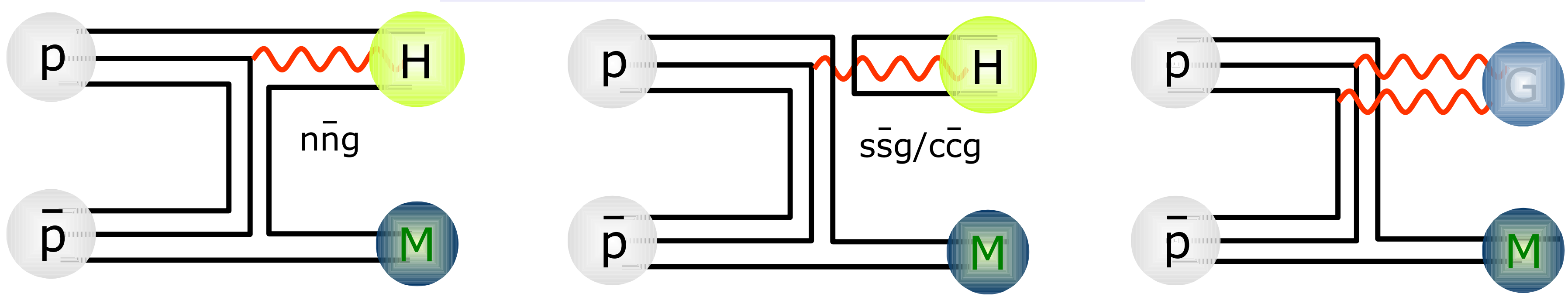


Hadrons from Antiproton Annihilations

Formation: only selected J^{PC}



Production: all J^{PC} available

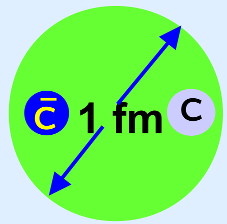


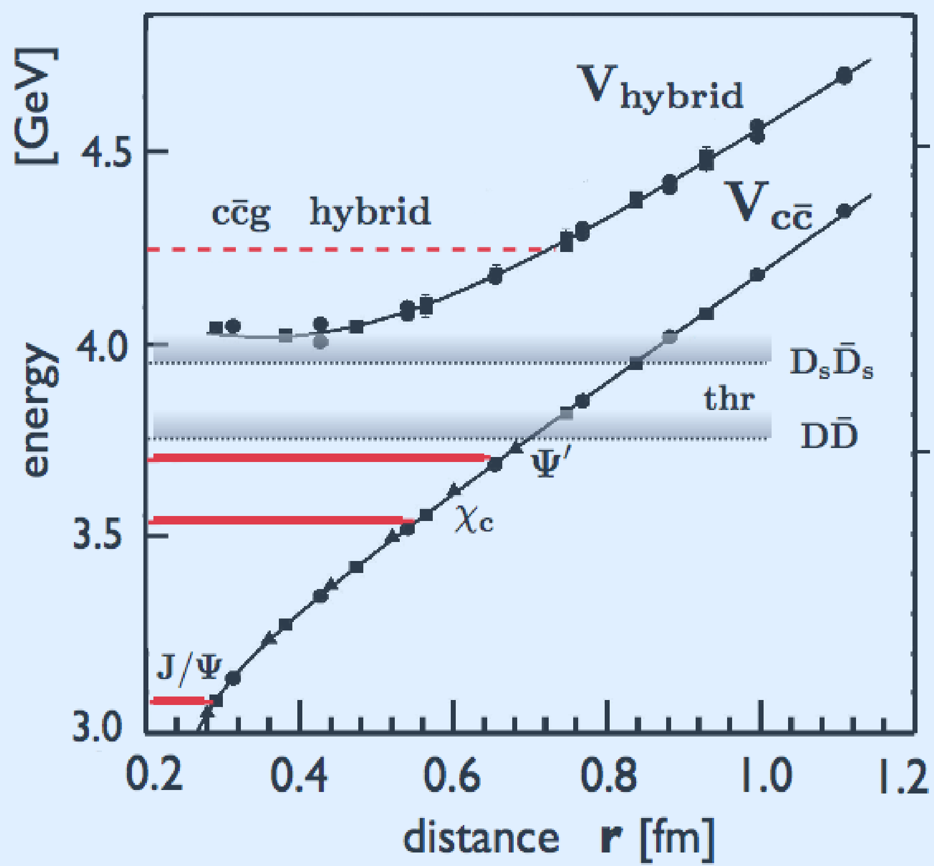
- Gluon rich process creates gluonic excitation directly
  - $c\bar{c}$ requires the quarks to annihilate (no rearrangement)
  - yield of hybrids comparable to charmonium production
  - even at low momenta large exotic content has been proven

Charmonium Spectroscopy

Charmonium

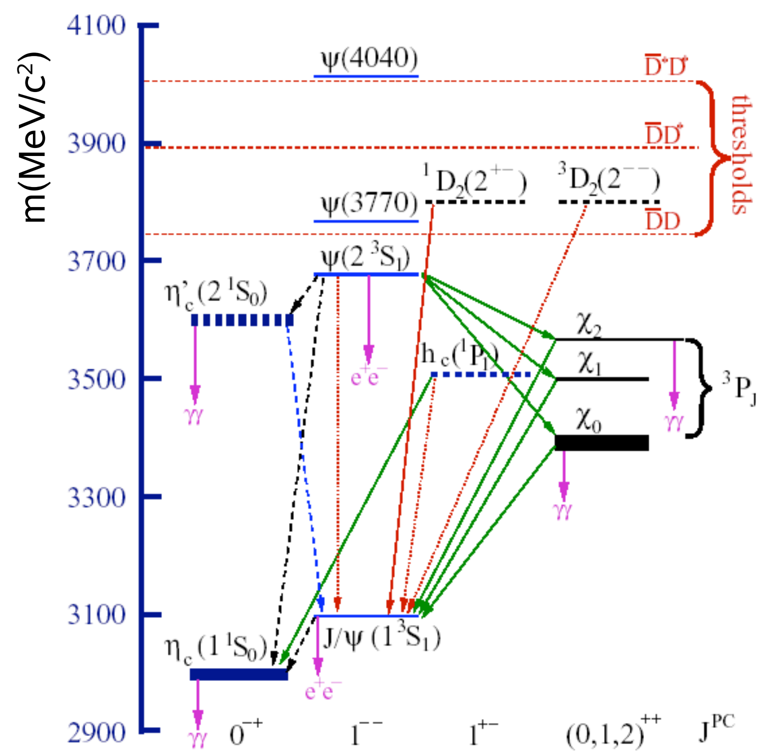
- Positronium of QCD: Potential of $c\bar{c}$ calculable
- → Prediction of states





Status below $D\bar{D}$ threshold

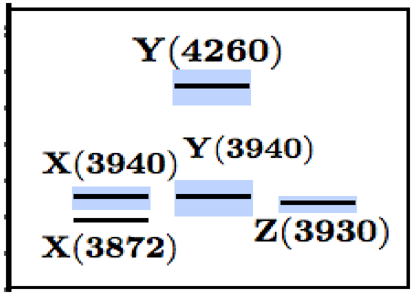
- $J^{PC}=1^{--}$ well measured
- Low resolution on $J^{PC}=0^{-+}$ states
- η_c' was rediscovered 40 MeV higher
- Low statistics on h_c



New Charmonium States

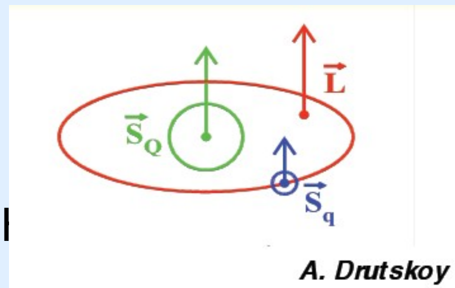
Renaissance in Charmonium Spectroscopy:

- Belle, BaBar, CLEO, CDF and D0 find new states above $D\bar{D}$
- Many of these states are problematic: mass not predicted, width too small, decay pattern unusual
- Challenge for better understanding and high precision data



State	Experiments	Nature/Remarks
X(3872)	Belle, BaBar, CDF, D0	D^0D^{0*} molecule, 4-quark state
X(3943)	Belle	maybe η''_c
Y(3940)	Belle	maybe 2^3P_1
Z(3930)	Belle	maybe χ'_{c2}
Y(4260)	BaBar, Belle, CLEO-c	Hybrid, $\omega\chi_{c1}$-molecule, 4q state
Y(4350)	BaBar, Belle	?
$Z^{\pm}(4430)$	Belle	No charged $c\bar{c}$, molecule or 4q state
Y(4660)	Belle	?

D-Meson Spectroscopy



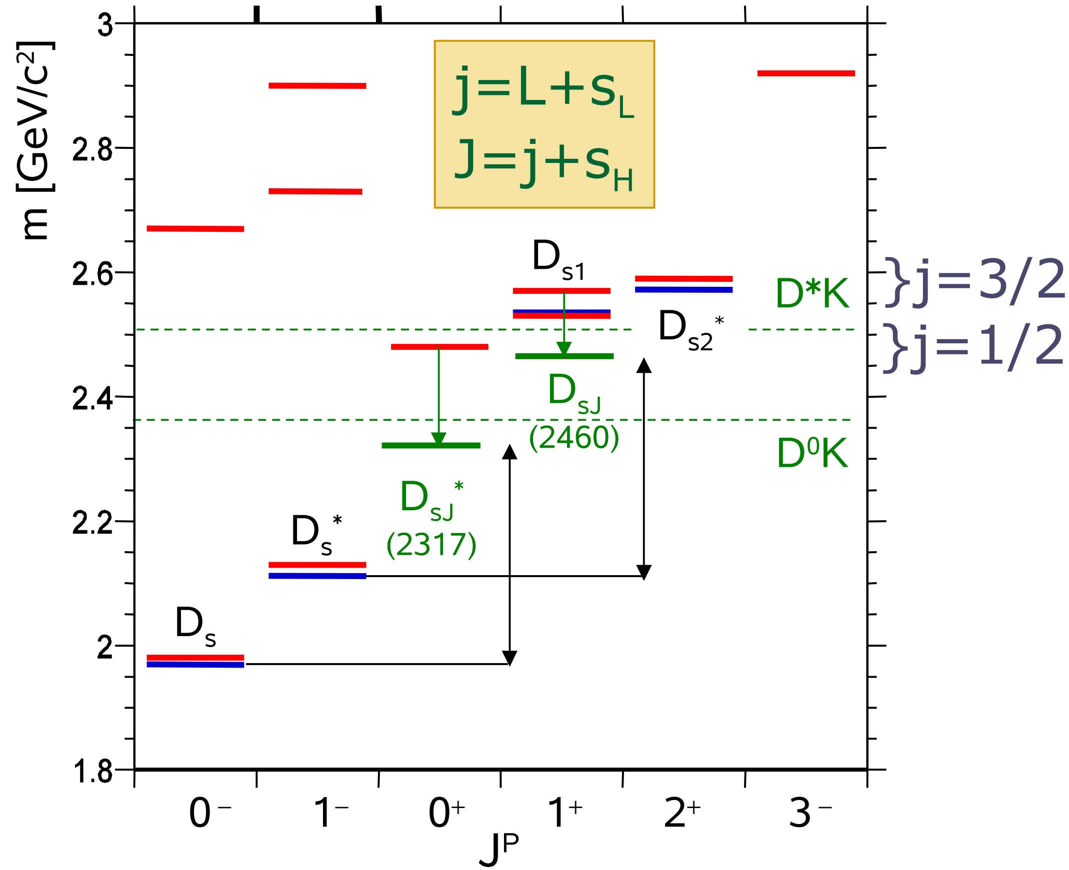
-atom:

ed by light q

- ordered by property of light q
- approximate j degeneracy
- → Spectroscopic predictions
- → Works fairly well in $\bar{c}(u/d)$ system

D_s mesons surprise

- Narrow $D_{s0}(2317)$ and $D_{s1}(2460)$ do not fit theoretical calculations.
- Quantum numbers for states $D_{sJ}(2700)$ and $D_{sJ}(2880)$ are open



- $D_{s0}(2317) \rightarrow D_s^+\pi^0$, but not $D_s^+\pi^+\pi^-$
- $D_{s1}(2460)$ in $D_s^+\pi^0\gamma$, $D_s^+\gamma$, $D_s^+\pi^+\pi^-$
- Experimentally well established
- Nature unclear: 4q states, molecules?

Exotic Hadrons

Exotic Hadrons

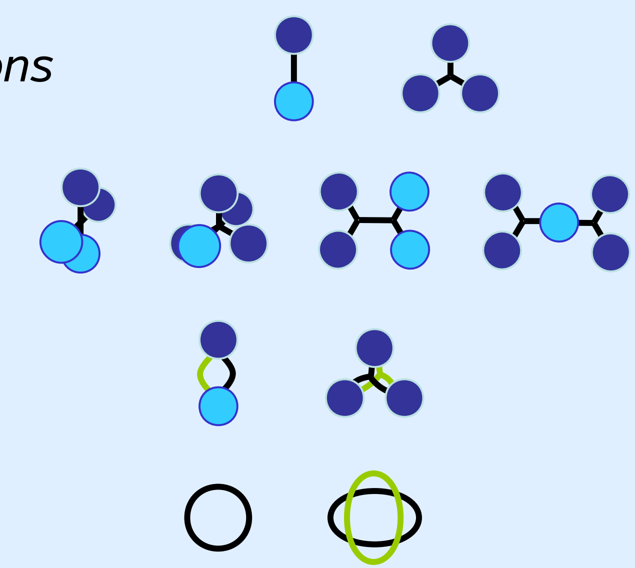
- Normal hadrons: $(q\bar{q})$ or (qqq)
- Gluonic degrees of freedom:
  - Hybrid mesons $(q\bar{q}g)$
  - Glueballs
- Multi-quark states
- Molecules
- Exotic mesons can have exotic quantum numbers

Mesons, Baryons

Multi-quarks

Hybrids

Glueballs



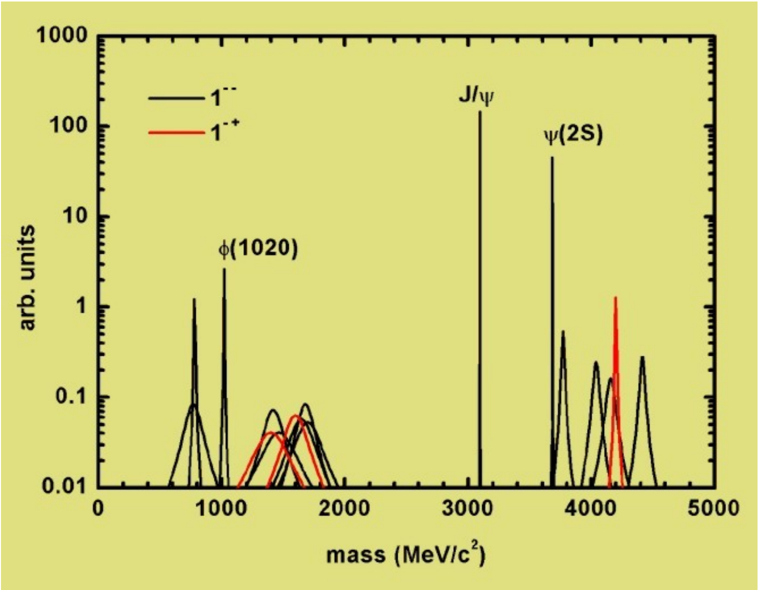
Charm Spectroscopy

- Charm quark: $m_c \gg m_{u,d,s}$

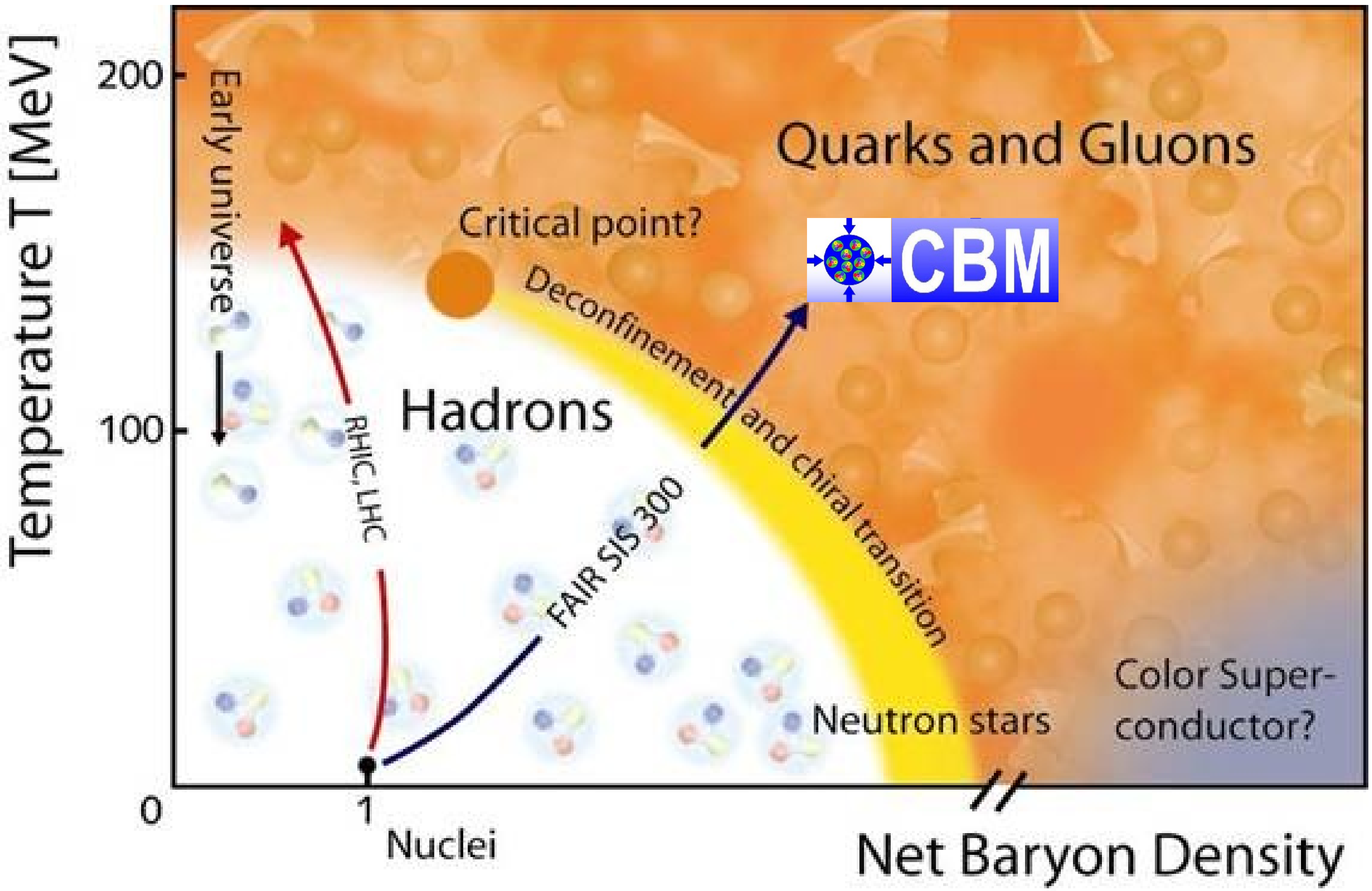
➔ Between perturbative & strong coupling

Charm Hybrids

- c-states narrow, understood
- Little interference of $c\bar{c}g$ & $c\bar{c}$-states
- Mass 4–4.5 GeV, $c\bar{c}g$ narrow,
- Production ~ $\sigma(p\bar{p} \rightarrow c\bar{c})$

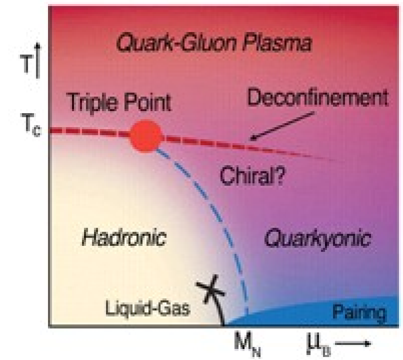


Compressed Baryonic Matter

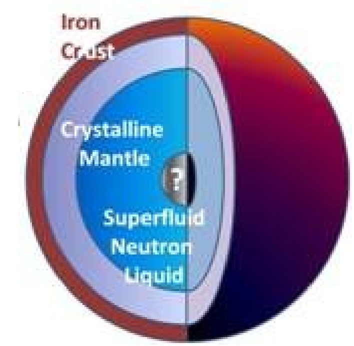


CBM Physics Topics

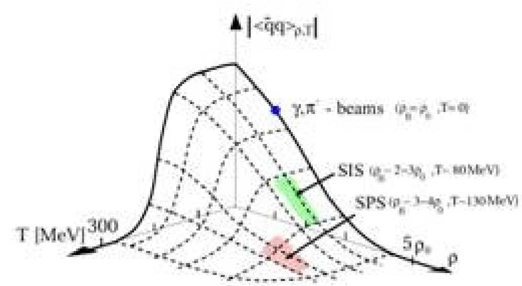
- Exploring the phase diagram of QCD:
  - Equation-of-state at high χ_B
  - Deconfinement phase transition
  - QCD critical endpoint
  - Chiral symmetry restoration



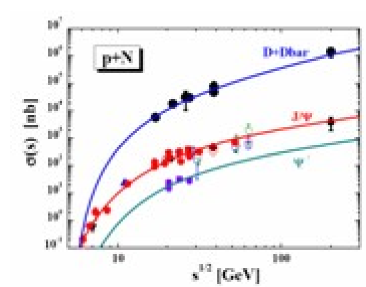
- Nuclear EoS, quarkyonic matter at high densities:
  Properties and degrees-of-freedom of nuclear matter at neutron star core densities



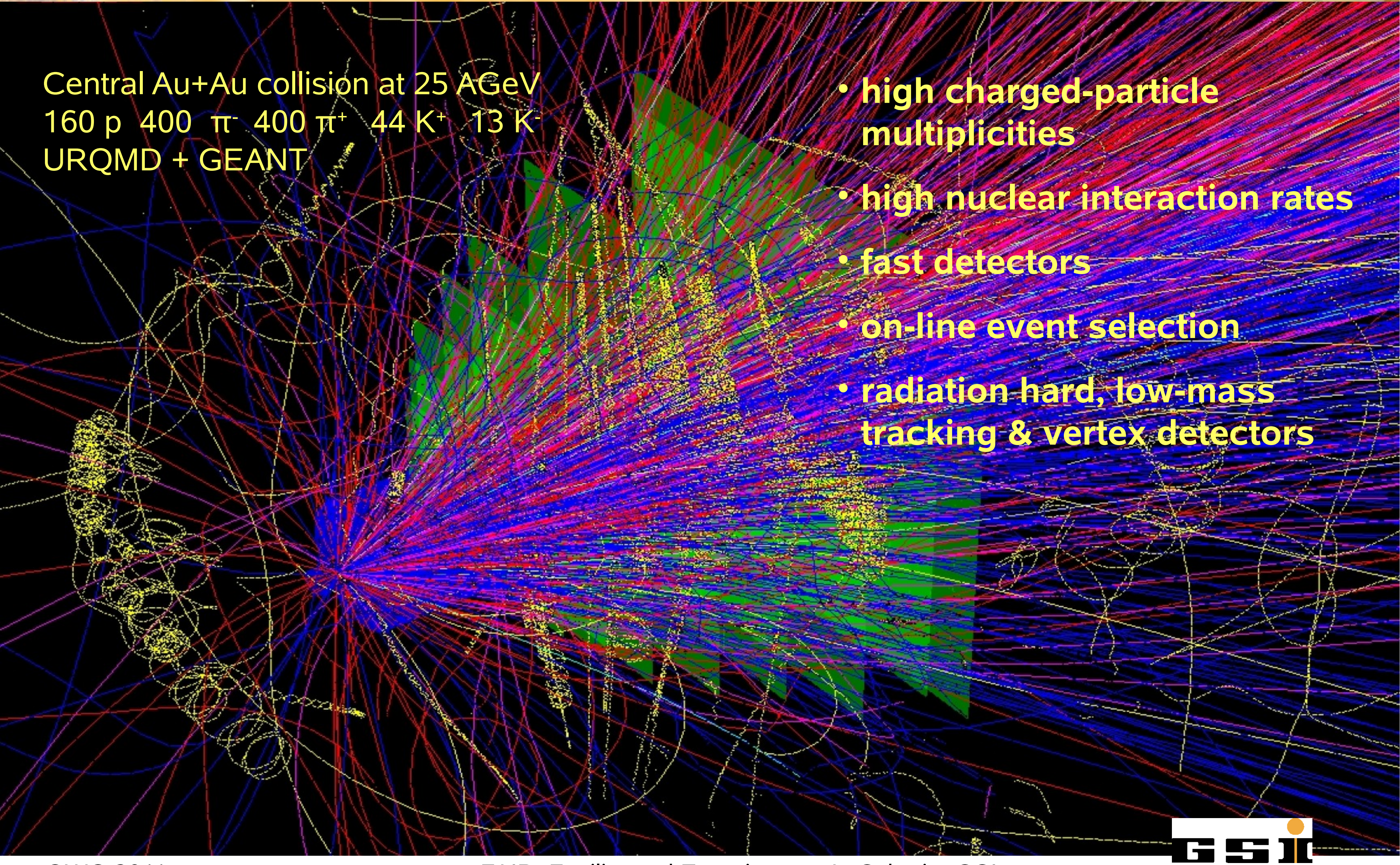
- Hadrons in dense matter:
  - In-medium properties of hadrons,
  - Chiral symmetry restoration at very high baryon densities



- Heavy flavor physics:
  - Charm production at low beam energies,
  - Charm propagation in cold nuclear matter



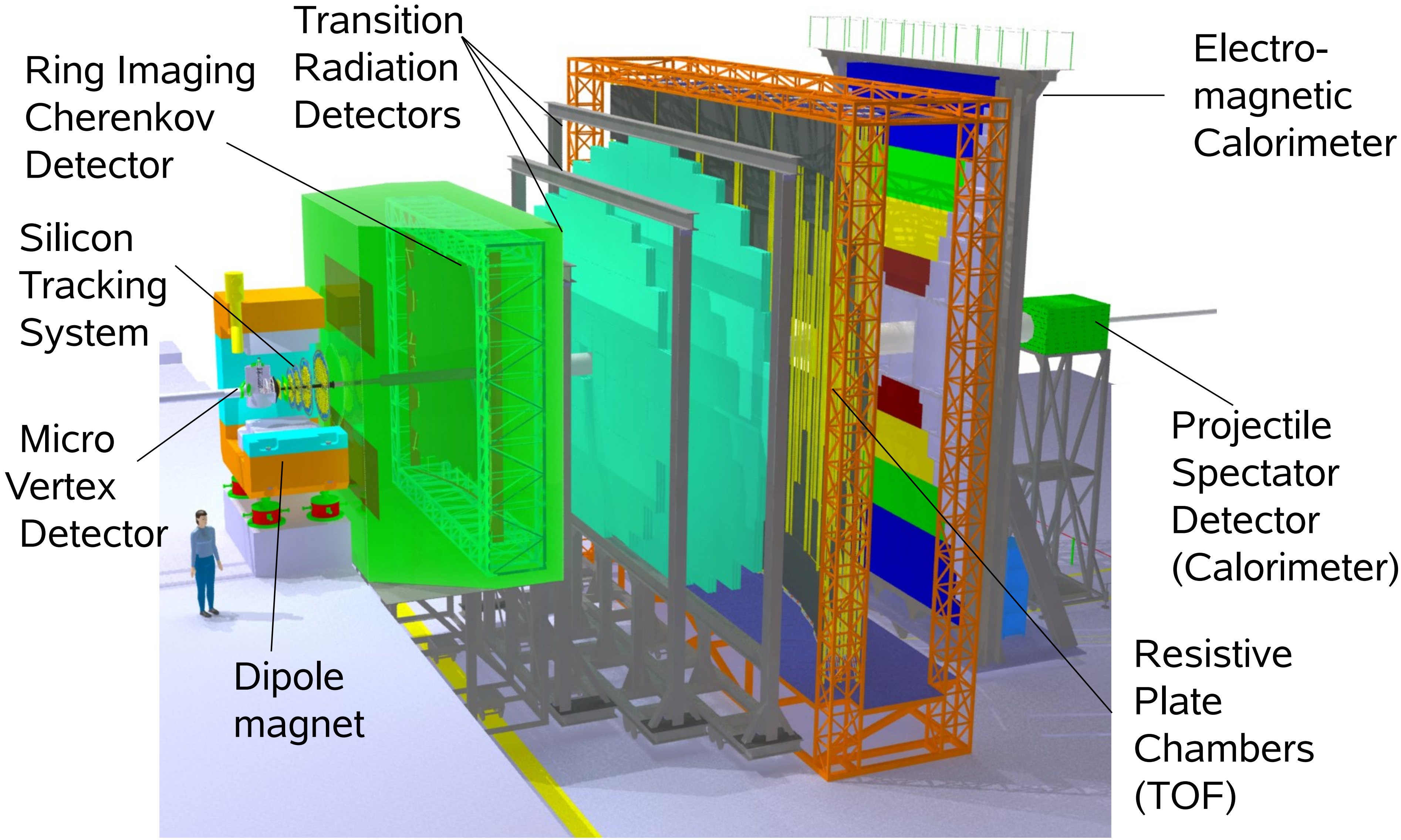
Experimental Challenges



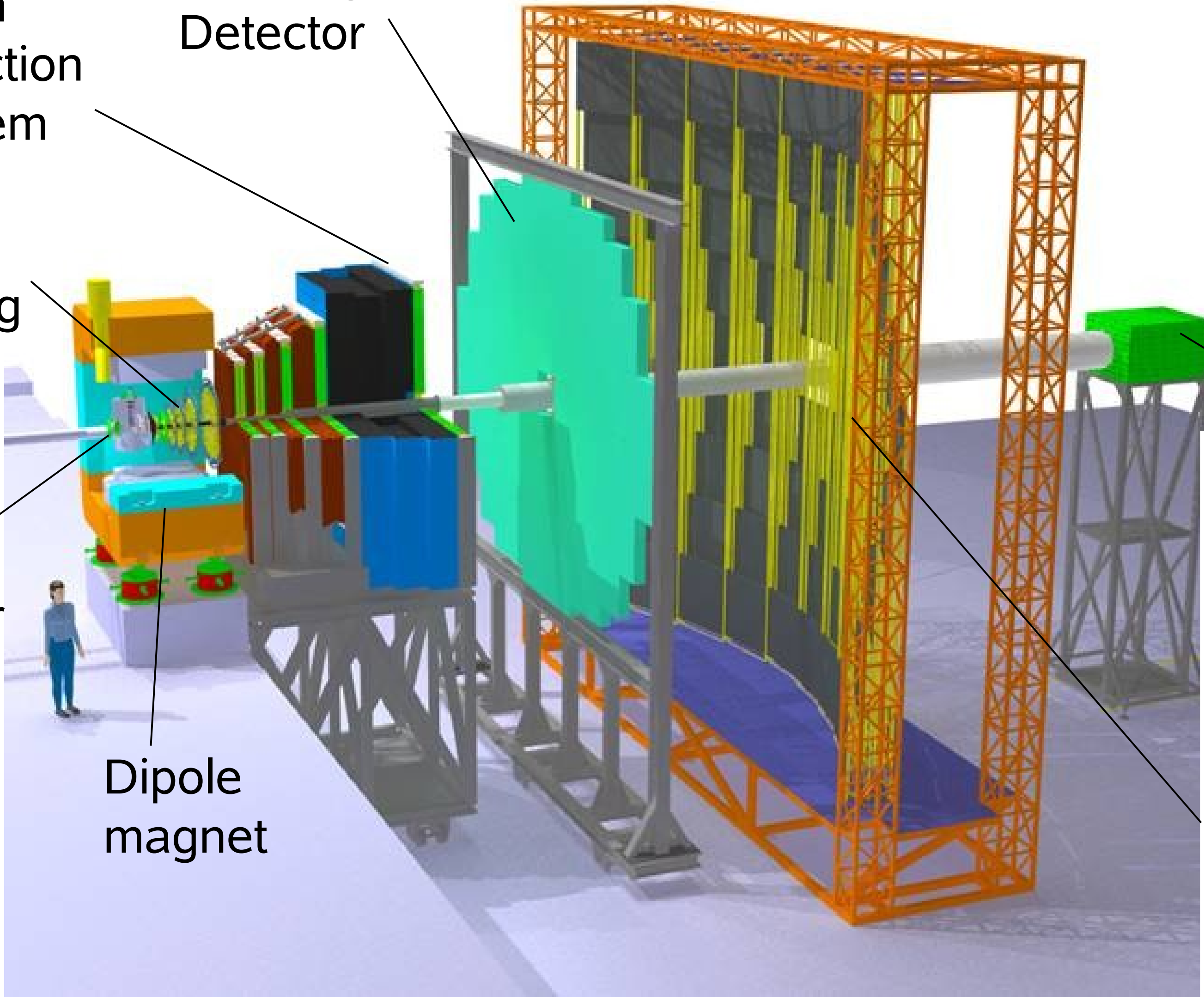
Central Au+Au collision at 25 AGeV
160 p 400 π^- 400 π^+ 44 K^+ 13 K^-
URQMD + GEANT

- high charged-particle multiplicities
- high nuclear interaction rates
- fast detectors
- on-line event selection
- radiation hard, low-mass tracking & vertex detectors

CBM Setup: Electrons



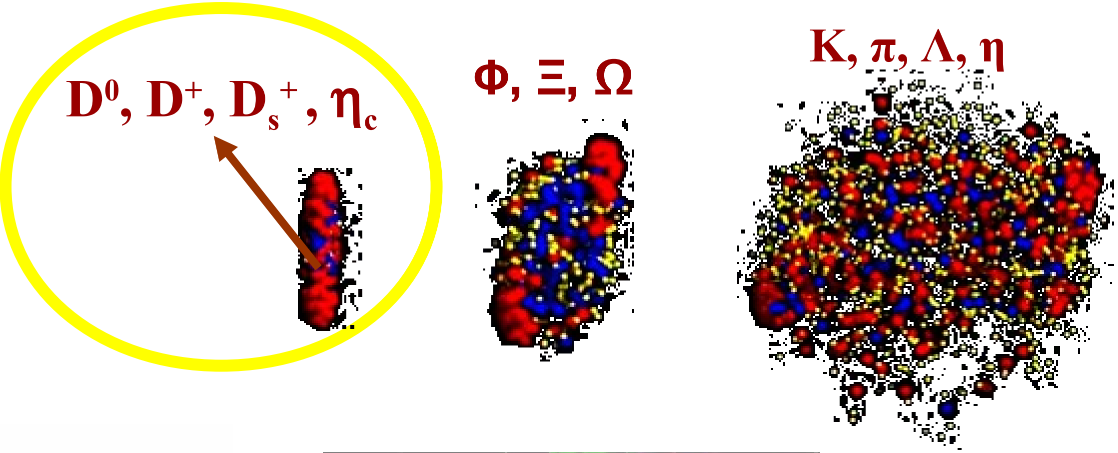
CBM Setup: Muons

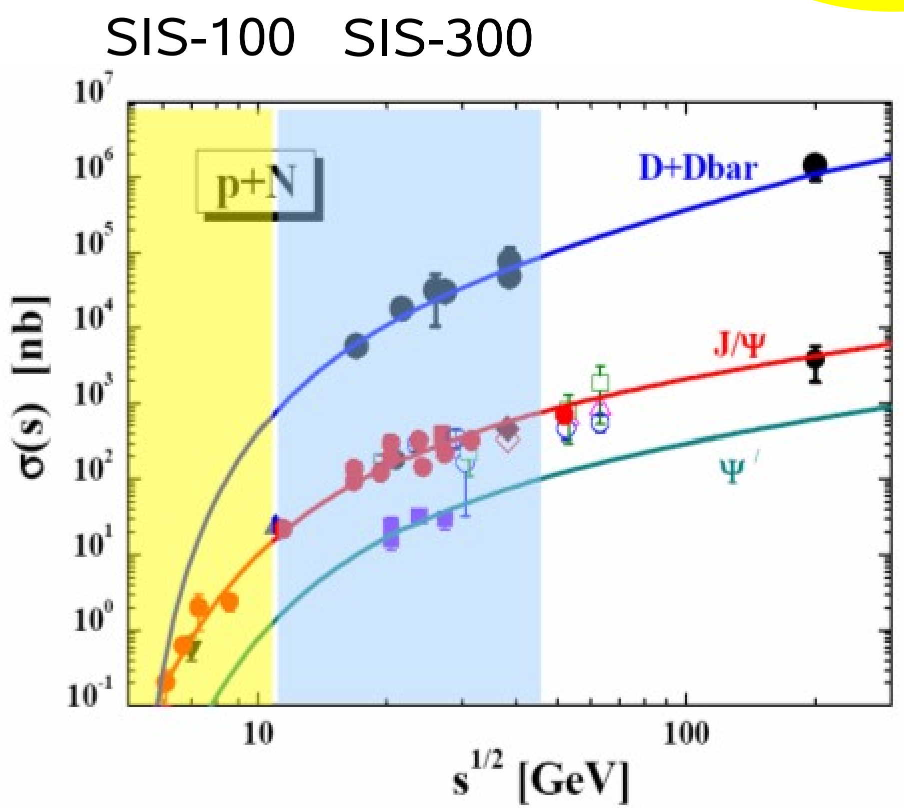


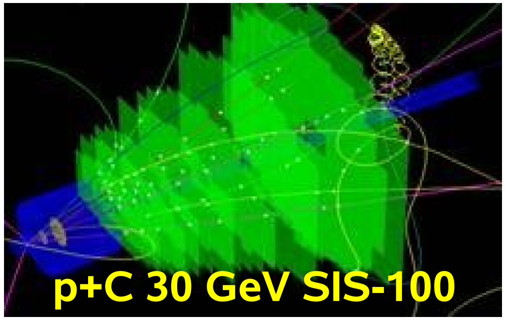
Open Charm Production at CBM

Motivation:

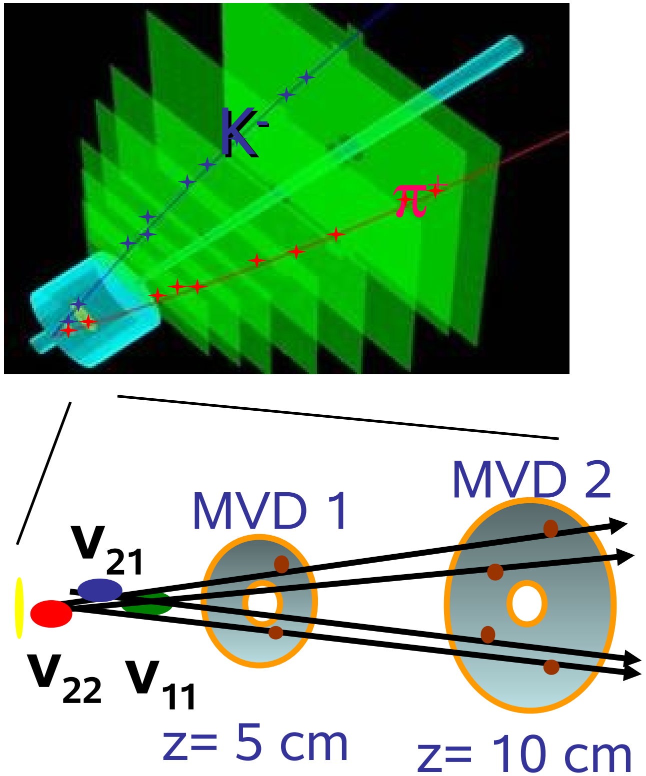
probe the dense phase



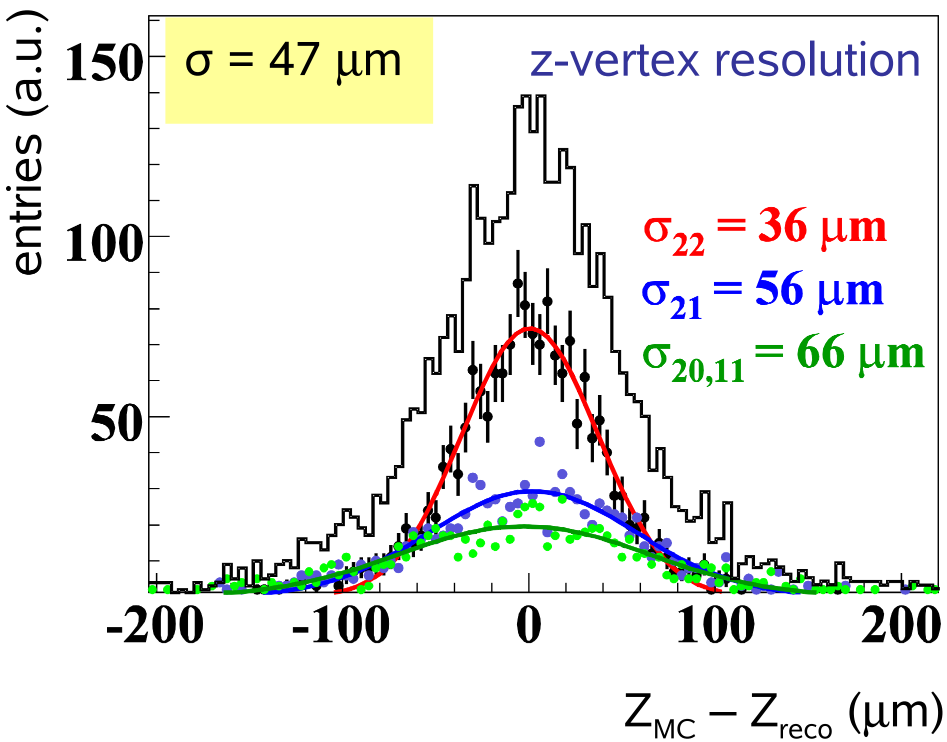




Open Charm Detection at CBM



e.g. $D^0 \rightarrow K^- \pi^+$



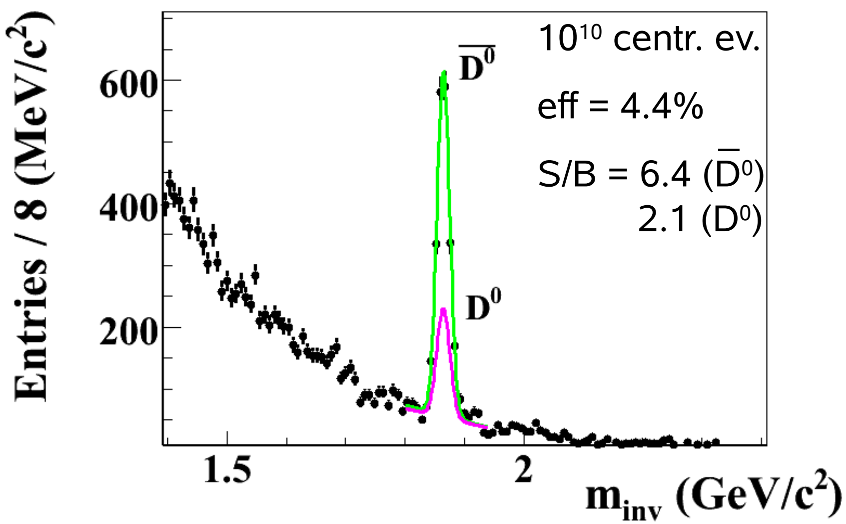
- Ultrathin Micro Vertex Detector
- Monolithic Active Pixel Sensors
- high-performance carbon supports
- material budget <0.5 % X_0 per station

Measuring Open Charm at SIS300

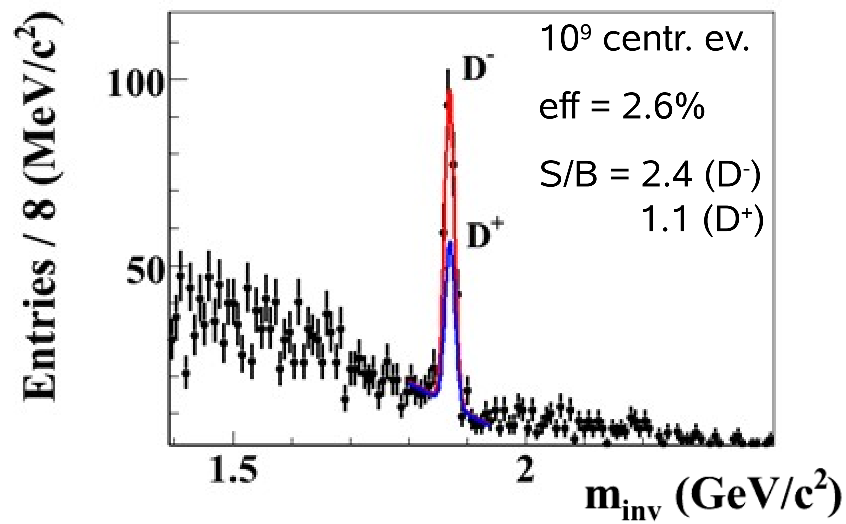
Au+Au collisions, 25*A* GeV

STS tracking, **MVD** vertexing, **proton rejection via TOF**

$D^0 \rightarrow K\,\pi$, $c\tau$= 123 µm



$D^\pm \rightarrow K\,\pi\,\pi$, $c\tau$= 317 µm



10^{12} min. bias events,
ca. 2-20 weeks @ reduced
interaction rate 10^5-10^6/s:

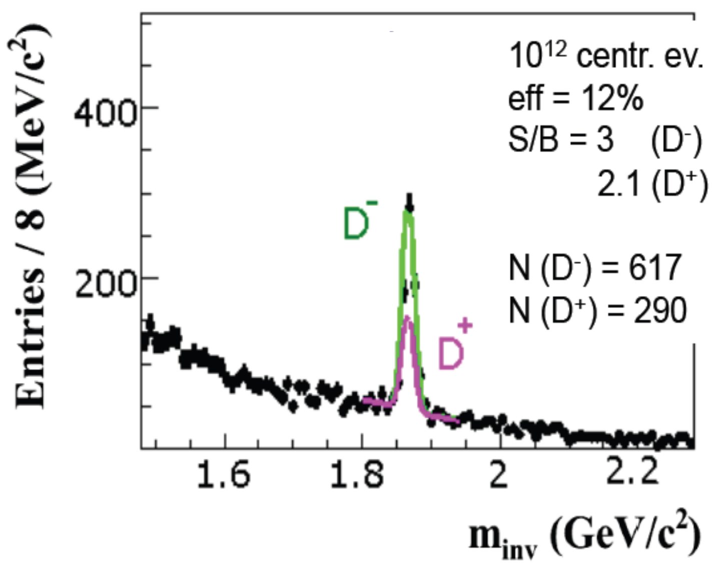
16k D^0 + 46k $\bar{D}^0$ and **26k D^+ + 49k D^-** (HSD)

87k D^0 + 251k $\bar{D}^0$ and **52k D^+ + 98k D^-** (SHM)

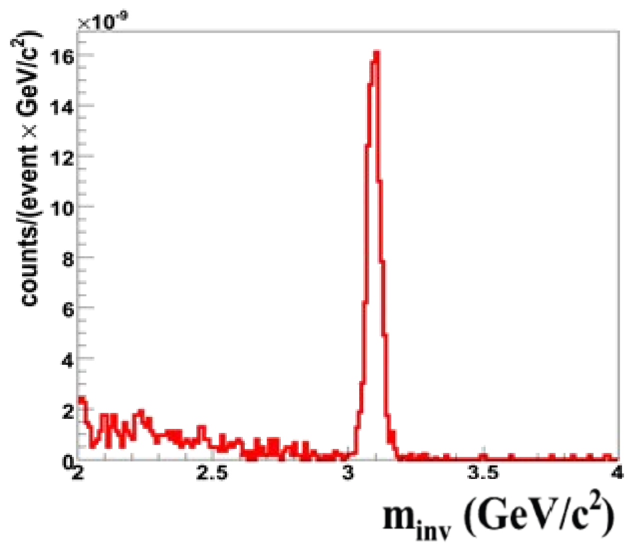
Charm & Charmonium at SIS100

p+C collisions, 30 GeV

$D^{\pm}$ + X, $D^{\pm} \longrightarrow K\pi\pi$



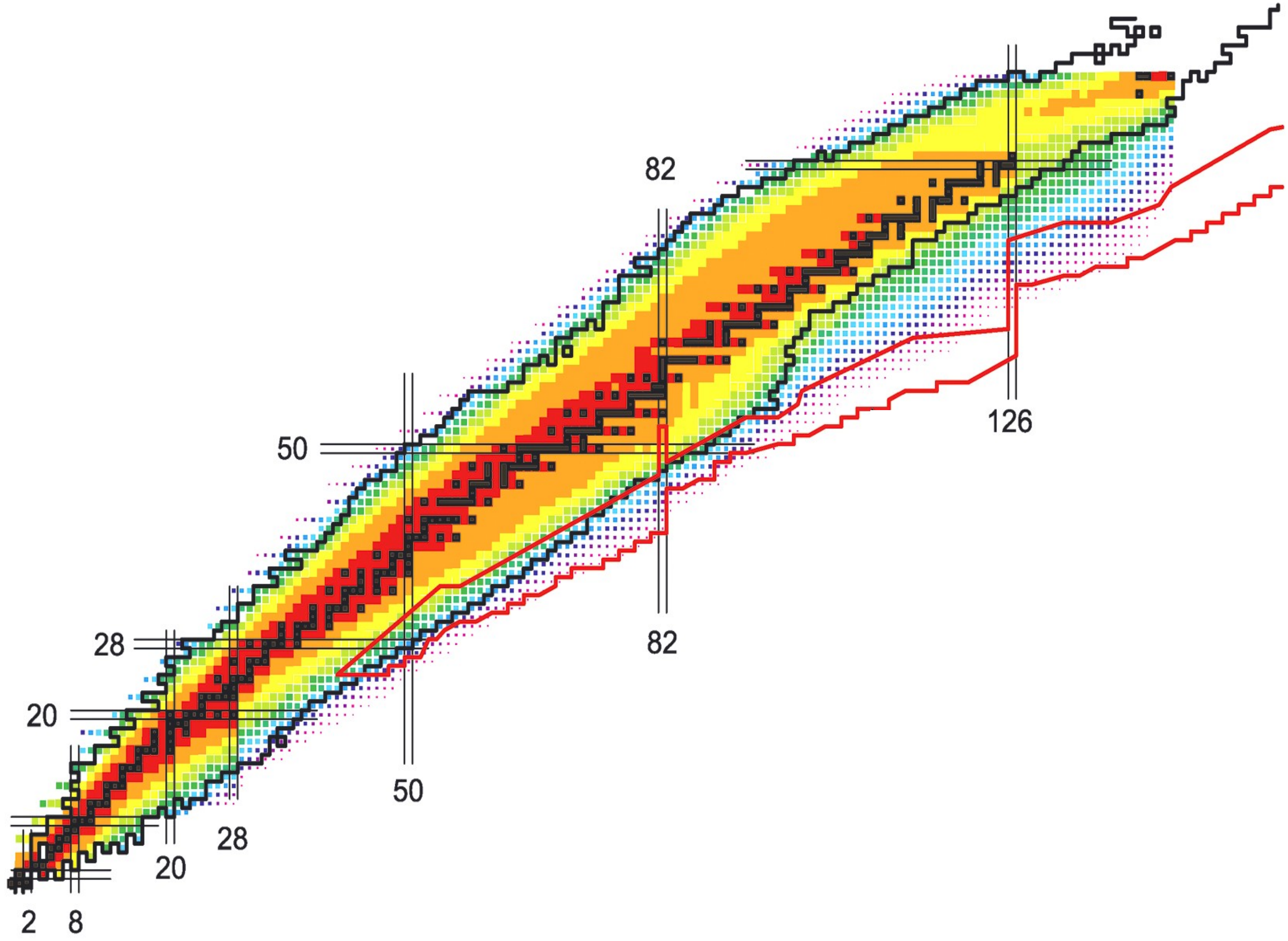
J/ψ + X, $J/\psi \longrightarrow \mu^+\mu^-$



- small statistics
- assuming a high-rate Micro Vertex Detector

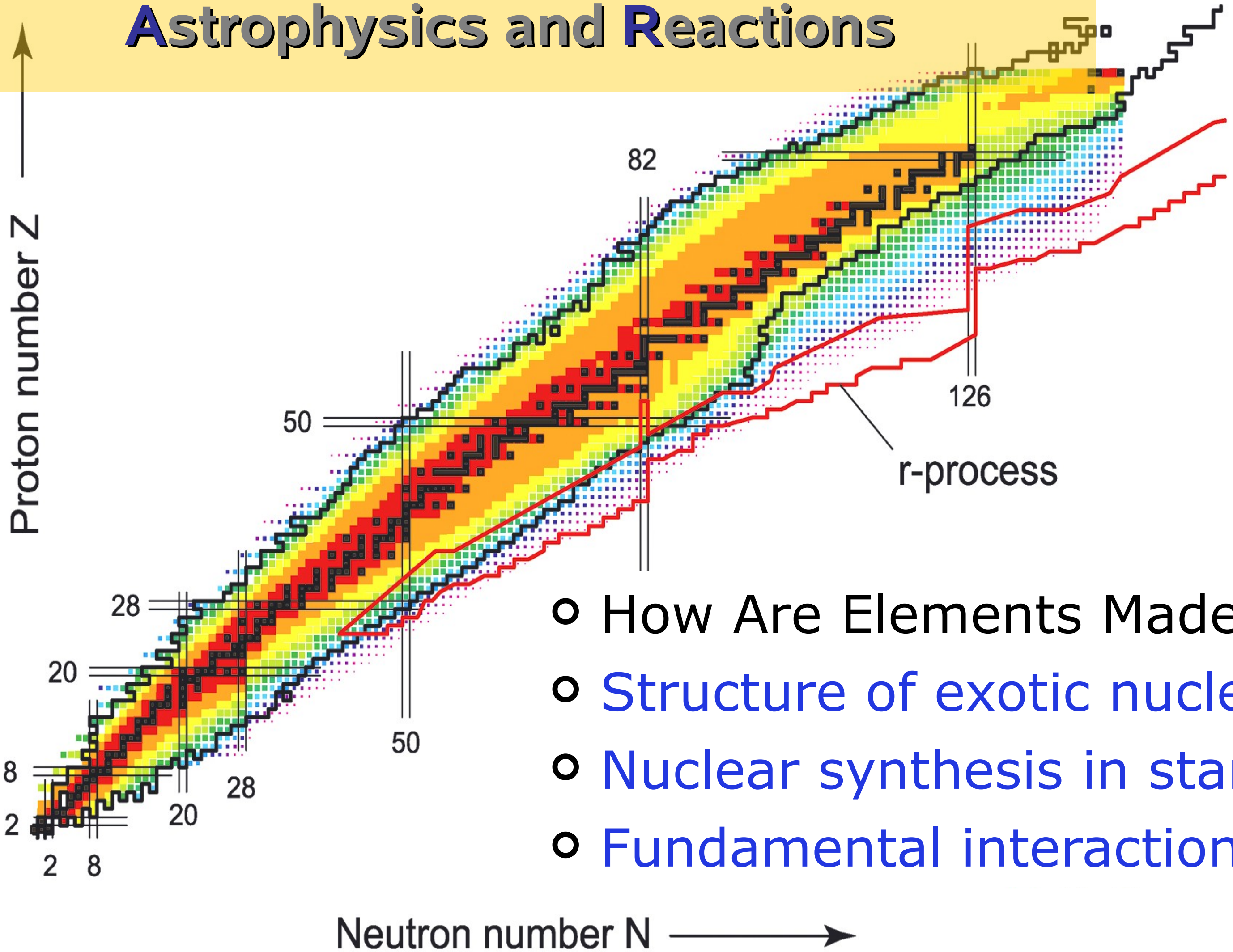
6 J/ψ recorded in 10^{10} events (b=0)
($3 \cdot 10^4$ J/ψ per week)

Nuclear Structure, Astrophysics & Reactions



NUSTAR Physics

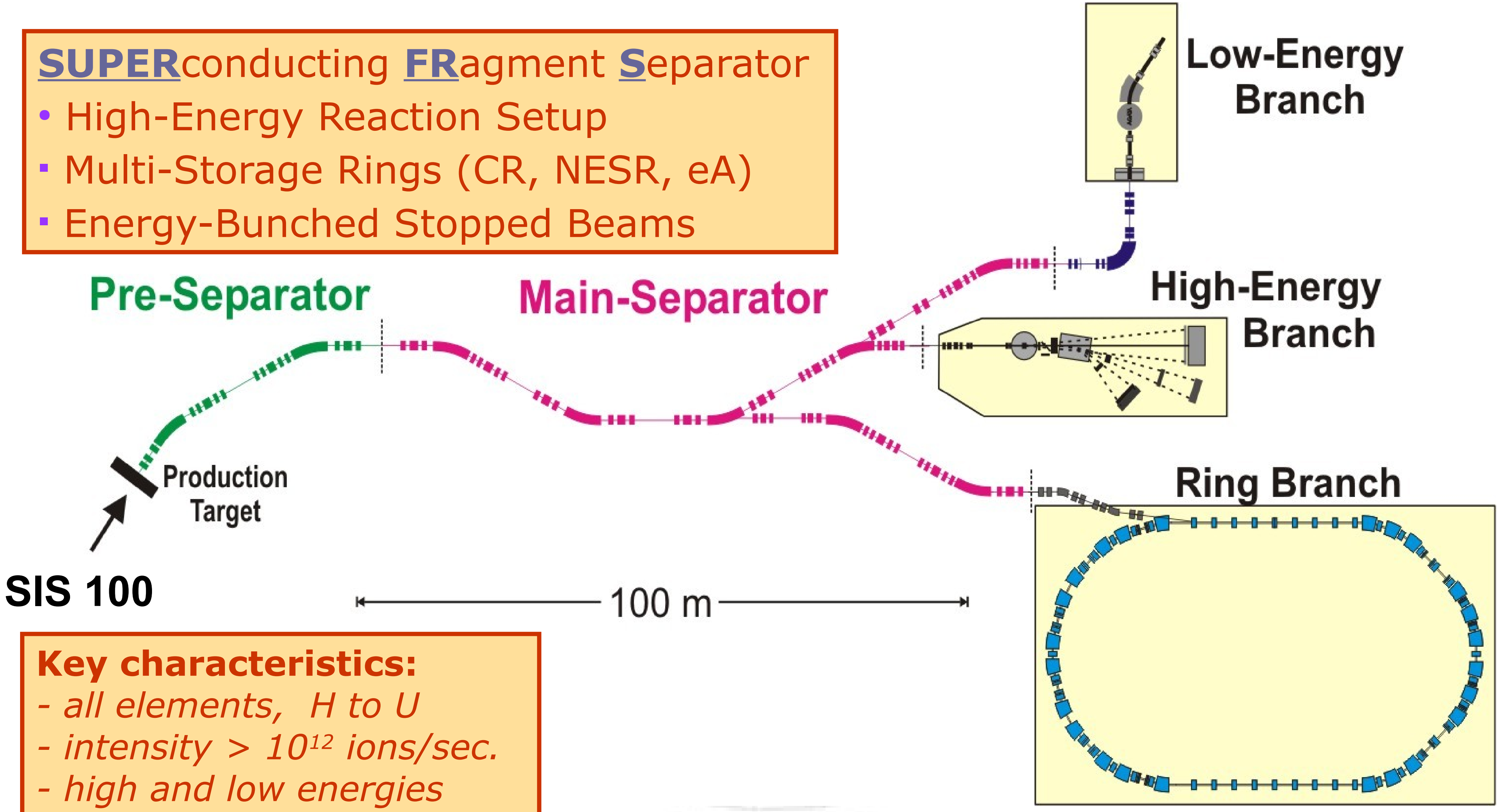
NUSTAR: Facility for NUclear STructure Astrophysics and Reactions



- How Are Elements Made ?
- Structure of exotic nuclei far off stability
- Nuclear synthesis in stars and star explosions
- Fundamental interactions and symmetries

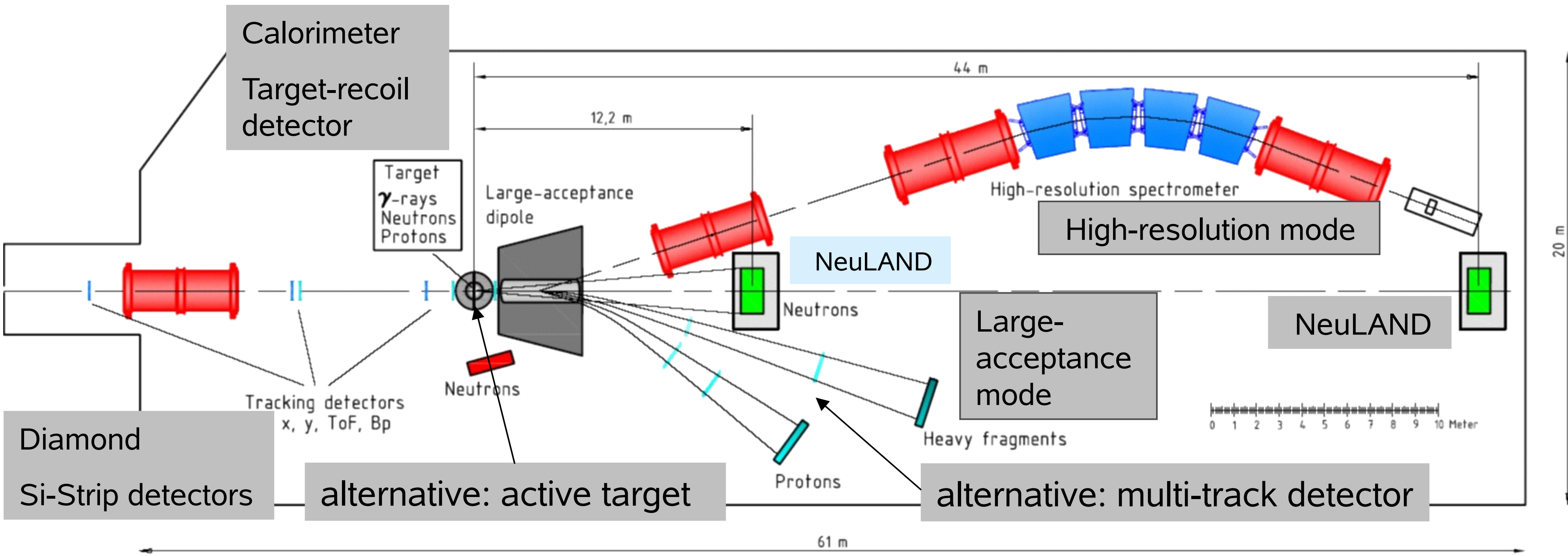
Super Fragment Separator

SUPERconducting **FR**agment **S**eparator
- High-Energy Reaction Setup
- Multi-Storage Rings (CR, NESR, eA)
- Energy-Bunched Stopped Beams



Key characteristics:
- *all elements, H to U*
- *intensity > 10^{12} ions/sec.*
- *high and low energies*
- *pulsed and CW beams*

R3B: Reactions of Relativistic Radioactive Beams



Kinematically complete measurement of reactions with high-energy secondary beams (~ 700 MeV/nucleon)

- Nuclear Astrophysics
- Structure of exotic nuclei
- Neutron-rich matter

High efficiency

High acceptance

High resolution

The EXL Experiment

EXotic nuclei in Light ion induced reactions

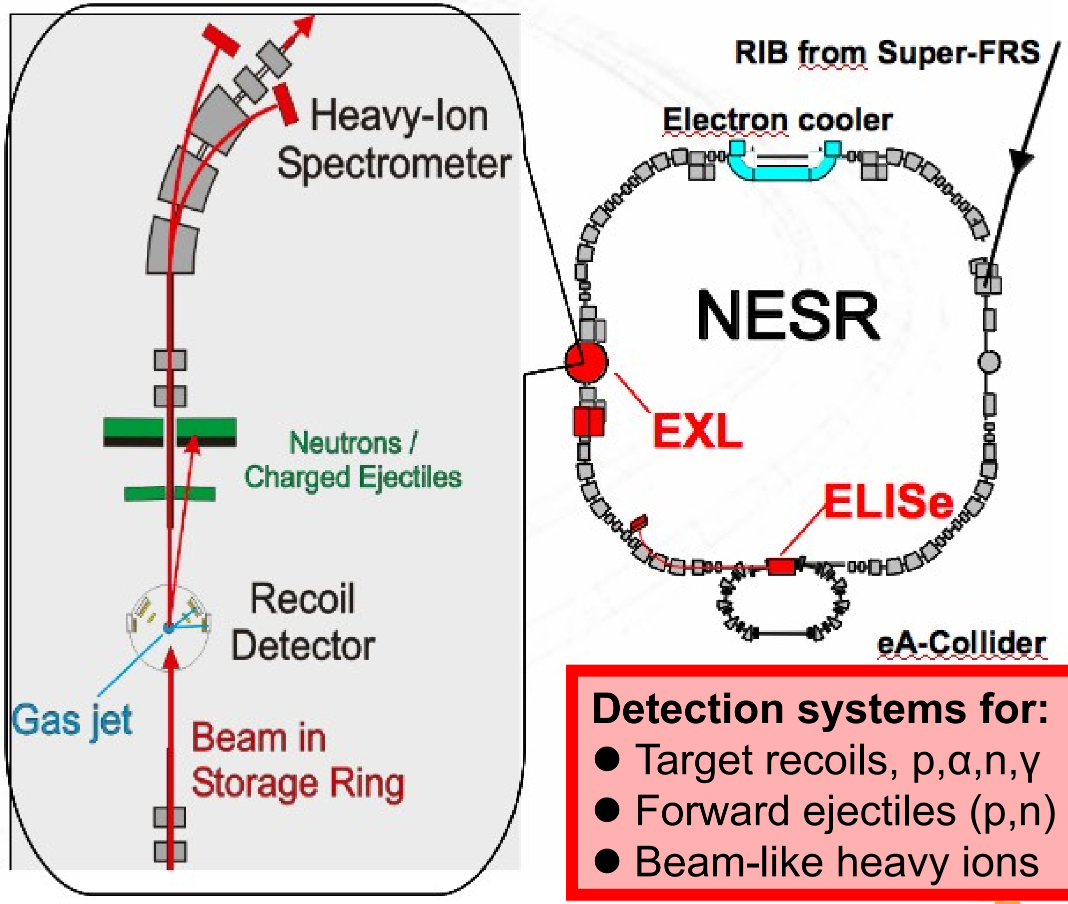
- Towards driplines for heavier nuclei
- Skin and halo distributions
- Nuclear EoS
- Astrophys. r- and rp-process
- NN correlations

Reactions:

- Scattering (elastic/inelastic)
- Charge exchange
- Knock-out or transfer
- Access via low q reactions
- ➔ Complementary to R3B

Design goals:

- Universality: applicable to a wide class of reactions
- Good energy and angular resolution
- Large solid angle acceptance
- Low q measurements with high lumi (> 10^{28} cm^{-2} s^{-1})



Detection systems for:

- Target recoils, p,α,n,γ
- Forward ejectiles (p,n)
- Beam-like heavy ions

Summary & Outlook

- FAIR will be a major facility in fundamental physics research
  - World class RIB facility
  - Heavy ion program complementary to RHIC and LHC
  - Hadron physics with antiprotons unique
  - Atomic physics and plasma research with ion beams
- FAIR-Experiments use advanced technologies
  - Fast precision calorimetry
  - High rate silicon vertex detectors
  - Compact Cherenkov counters
  - High speed continuous DAQ
- Upcoming Milestones:
  - Planning and building permits until end 2011
  - Experiment TDRs until end of 2012
  - Begin of civil construction in 2012 lasting 36 months
  - First physics in 2018