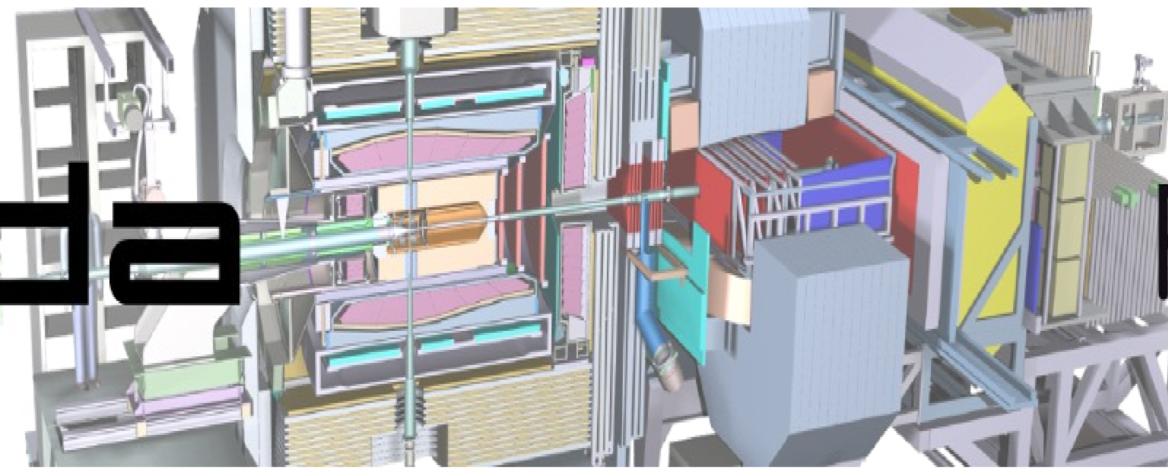
FAIR Status & PANDA Detector



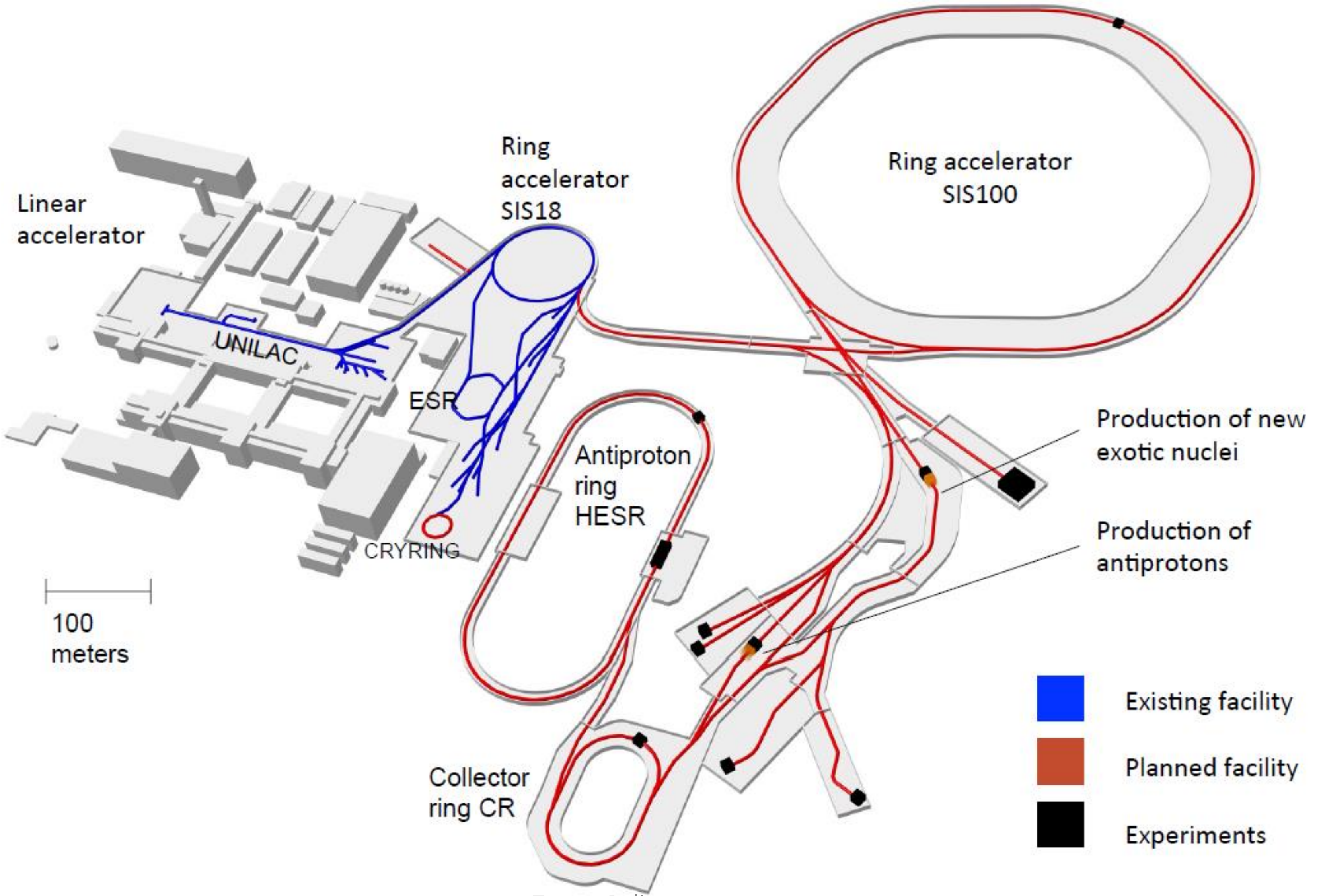
Anastasios Belias

Informal workshop on low-energy accelerator facilities in Europe, the Balkan area and the Middle-East

NCSR "Demokritos", Athens, 11-June-2018

Facility for Antiproton and Ion Research

@ GSI, near Darmstadt, Germany



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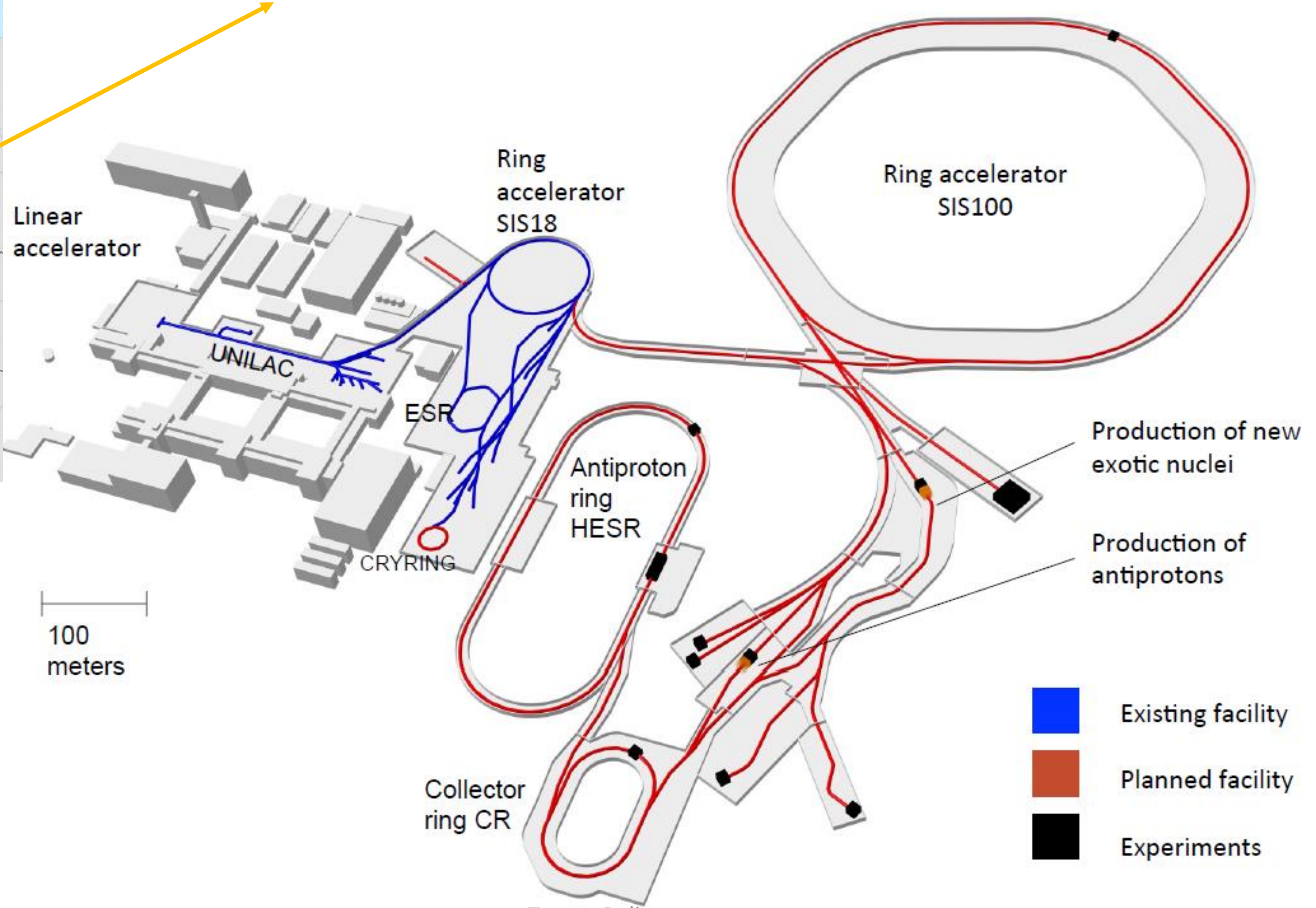
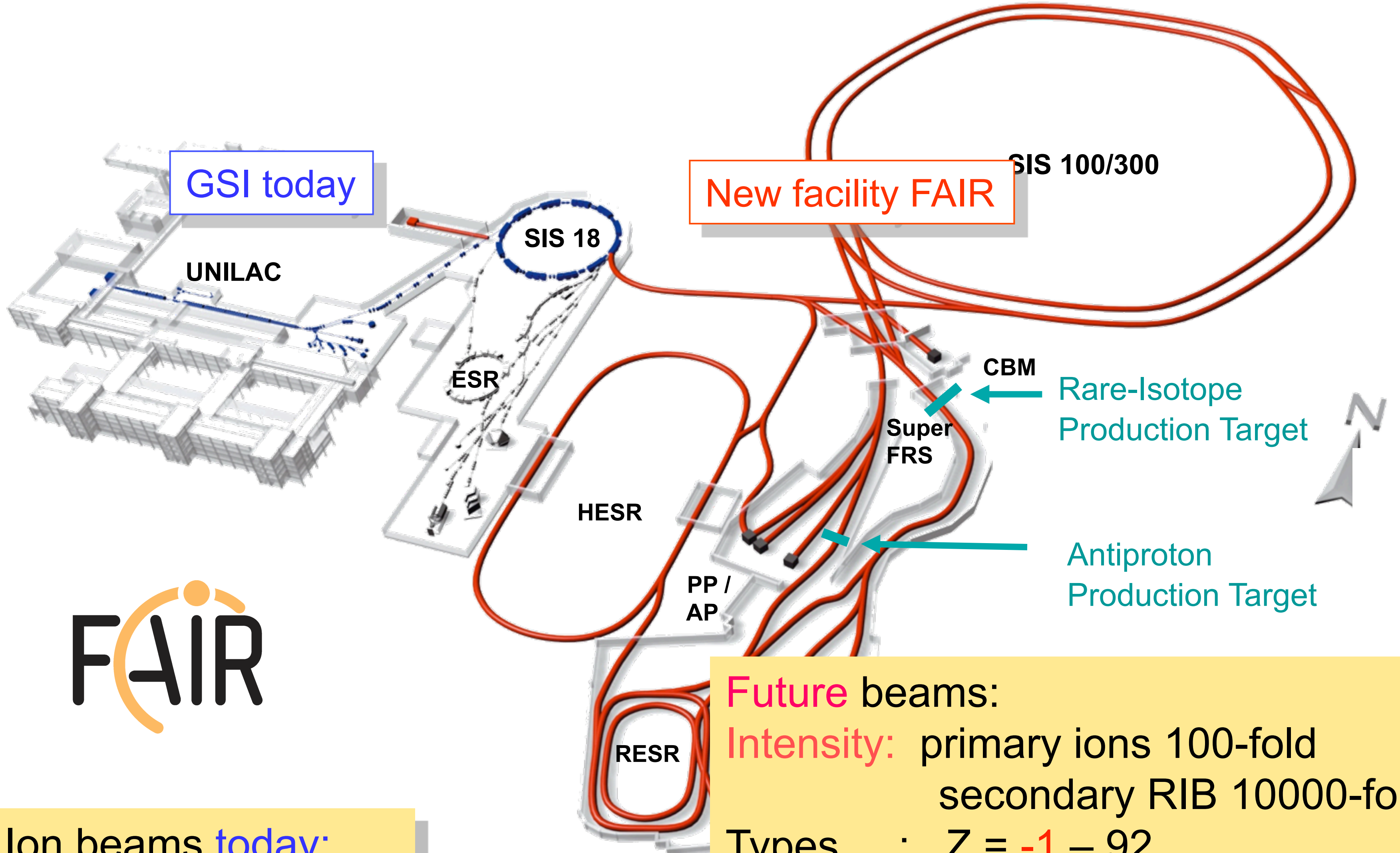


FAIR Facility for Antiproton and Ion Research

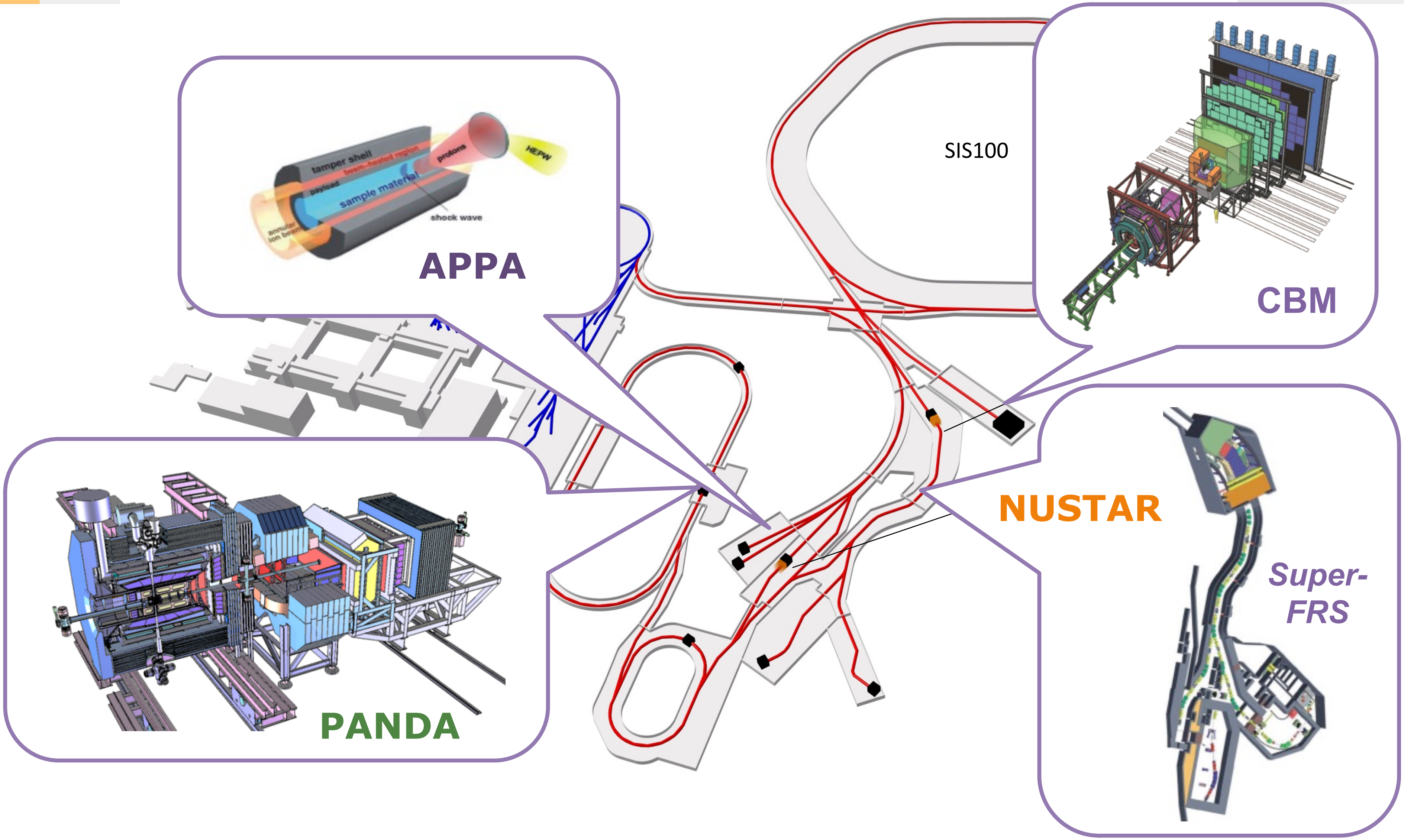
- ESFRI Landmark
- Driver for Innovation in Science and Technology
- Top priority for European Nuclear Physics Community



Ion beams today:
Z = 1 – 92
(Protons til uranium)
Up to 2 GeV/nucleon

Future beams:
Intensity: primary ions 100-fold
secondary RIB 10000-fold
Types : Z = -1 – 92
(Antiprotons til uranium)
Energies: ions up to 35 - 45 GeV/u
antiprotons 0 -15 GeV/c

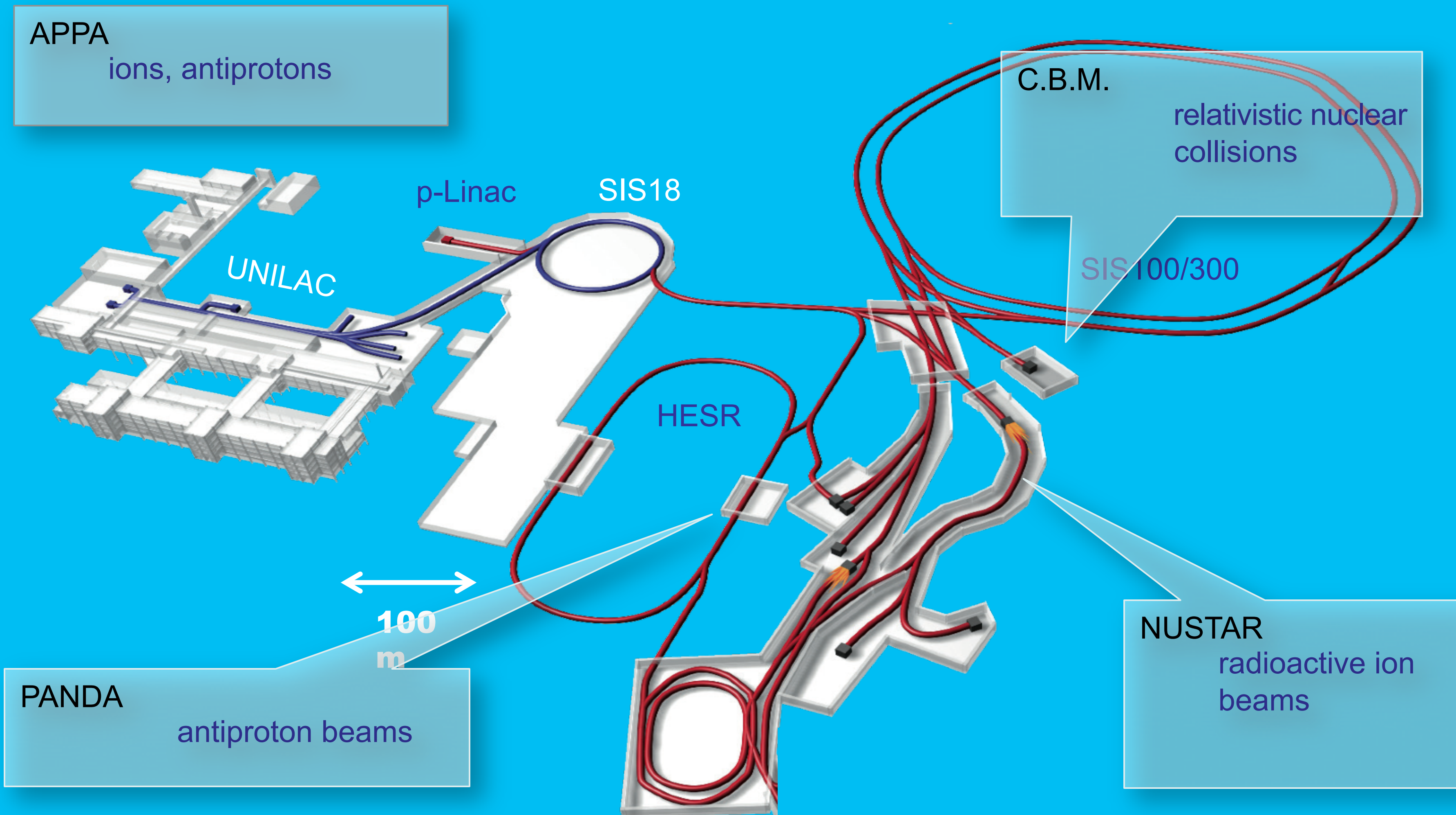
FAIR – four research pillars



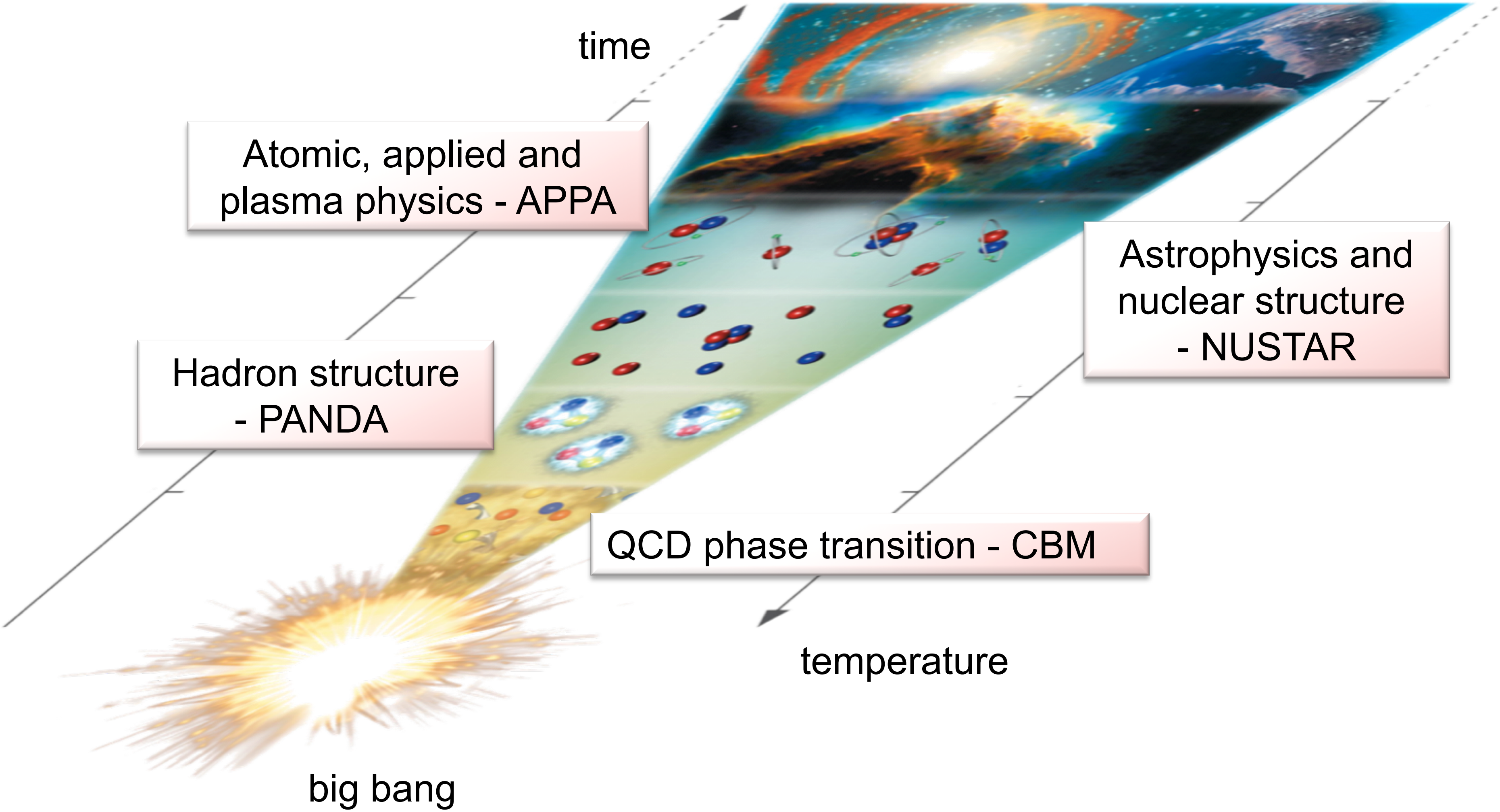
Four Scientific Collaborations

APPA	- Atomic Physics and Fundamental Symmetries, - Plasma Physics, - Materials Research, - Radiation Biology, - Cancer Therapy with Ion Beams / Space Res.
CBM	- Dense and Hot Nuclear Matter
NUSTAR	- Nuclear Structure far off stability, Physics of Explosive Nucleosynthesis (r process)
PANDA	- Hadron Structure & Dynamics with cooled antiproton beams

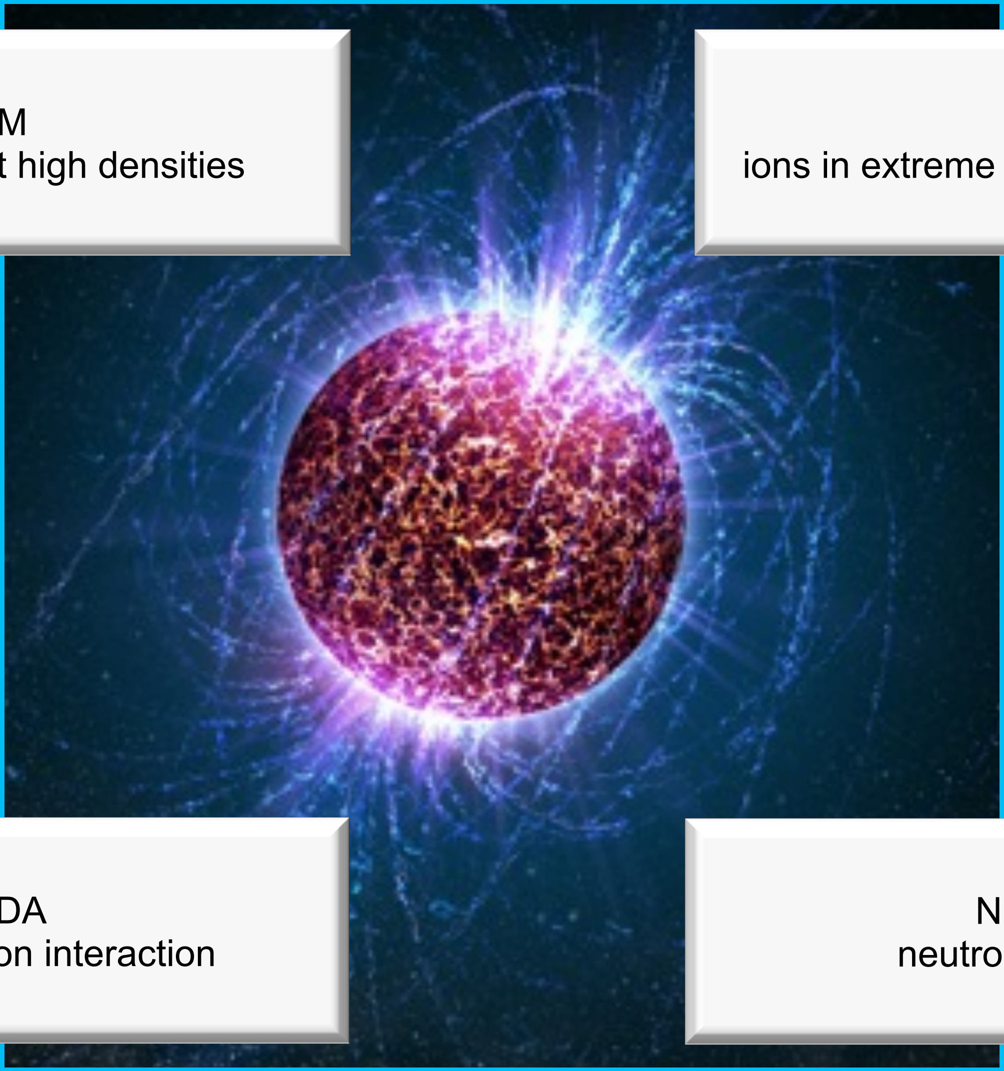
Accelerator complex



FAIR Science Sketch



Neutron stars – Universe's lab of exotic matter



CBM
nuclear matter at high densities

APPA
ions in extreme electro-magnetic fields

PANDA
hyperon-hyperon interaction

NUSTAR
neutron-rich nuclei

International Participation in FAIR

- FAIR governed by international convention
  - 9 shareholders + 1 assoc. partner (orange)
- Scientists from all over the world are engaged
  - More than 200 institutions from 53 countries are involved with their scientists (orange + blue)

Anti-**P**roton **AN**nihilation in **DA**rmstadt

Antiprotons

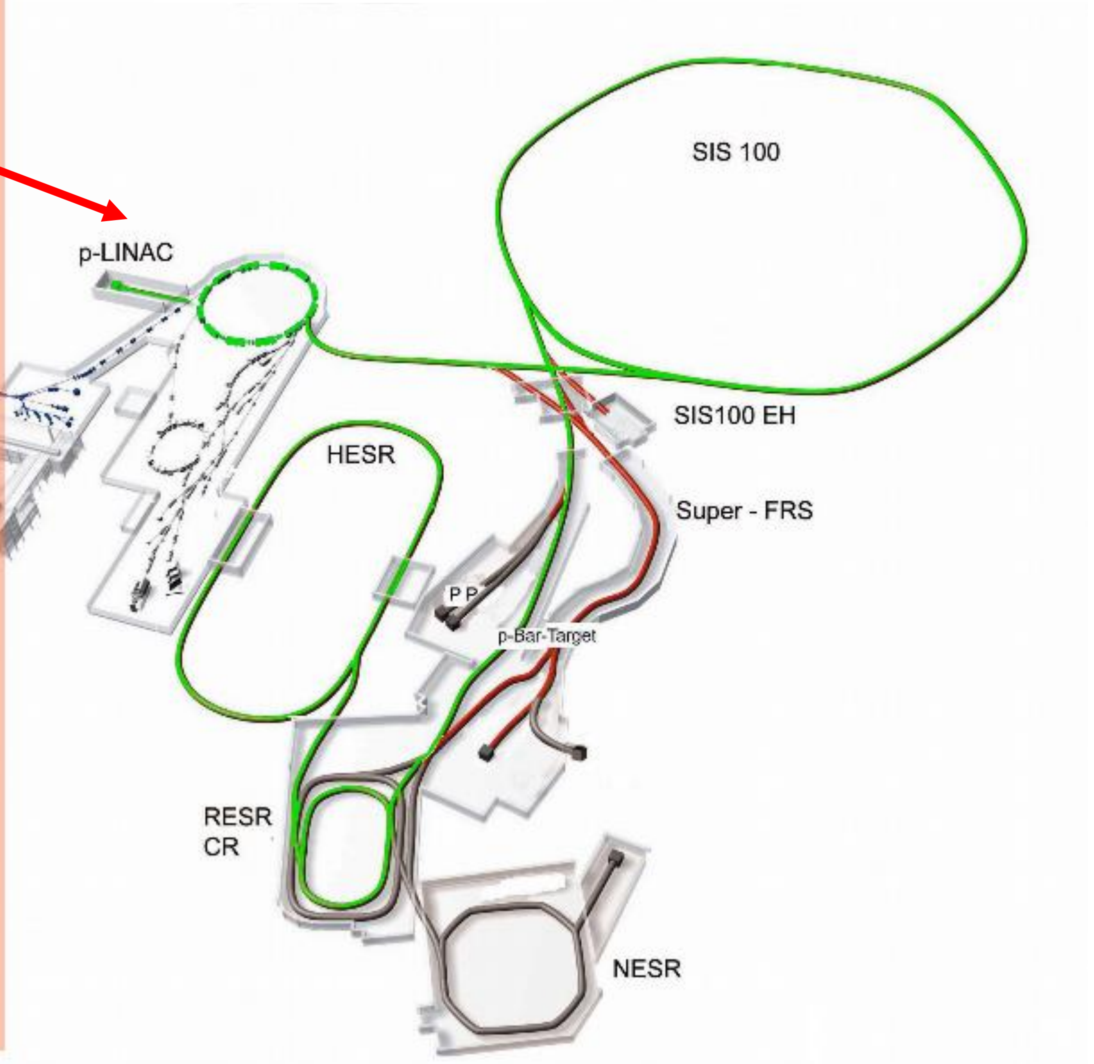
Antiproton production

- Proton Linac 70 MeV
- Accelerate **p** in SIS18 / 100
- Produce $\bar{p}$ on Cu target

- Collection in CR, fast cooling
- Accumulation in RESR, slow cooling
- Storage in HESR and usage in PANDA

Modularised Start Version

- RESR is postponed (Mod. 4)
- Accumulation in HESR
- 10x lower luminosity



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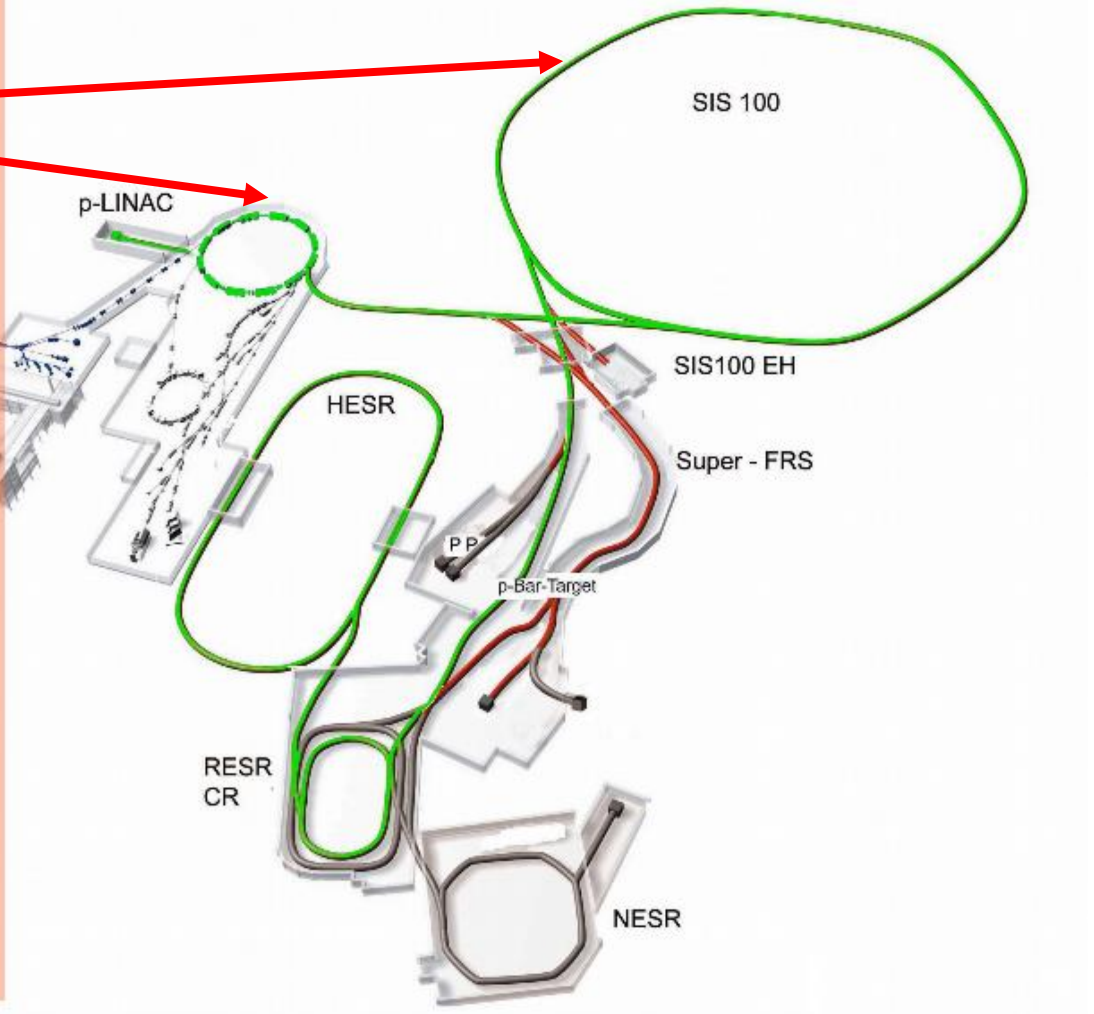

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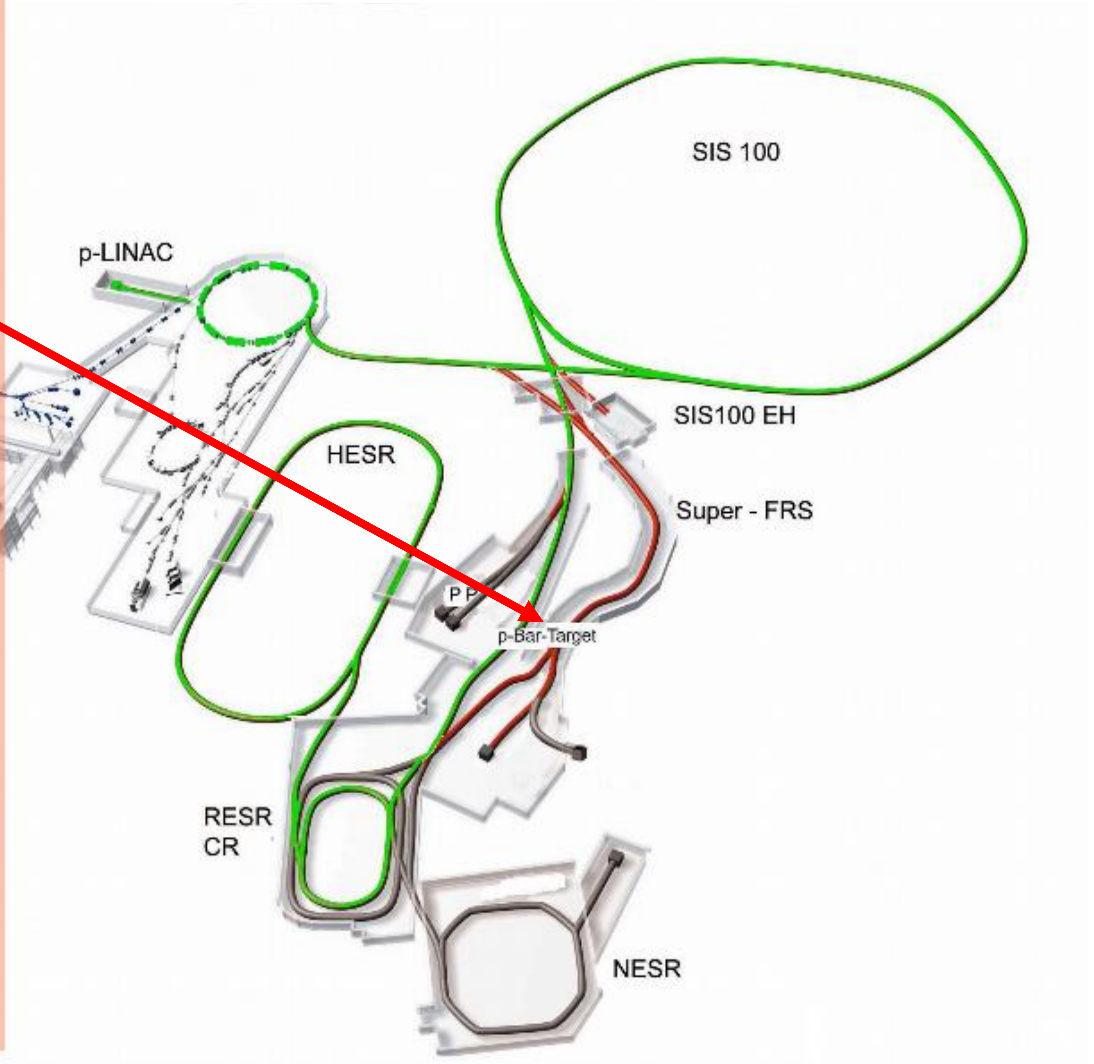

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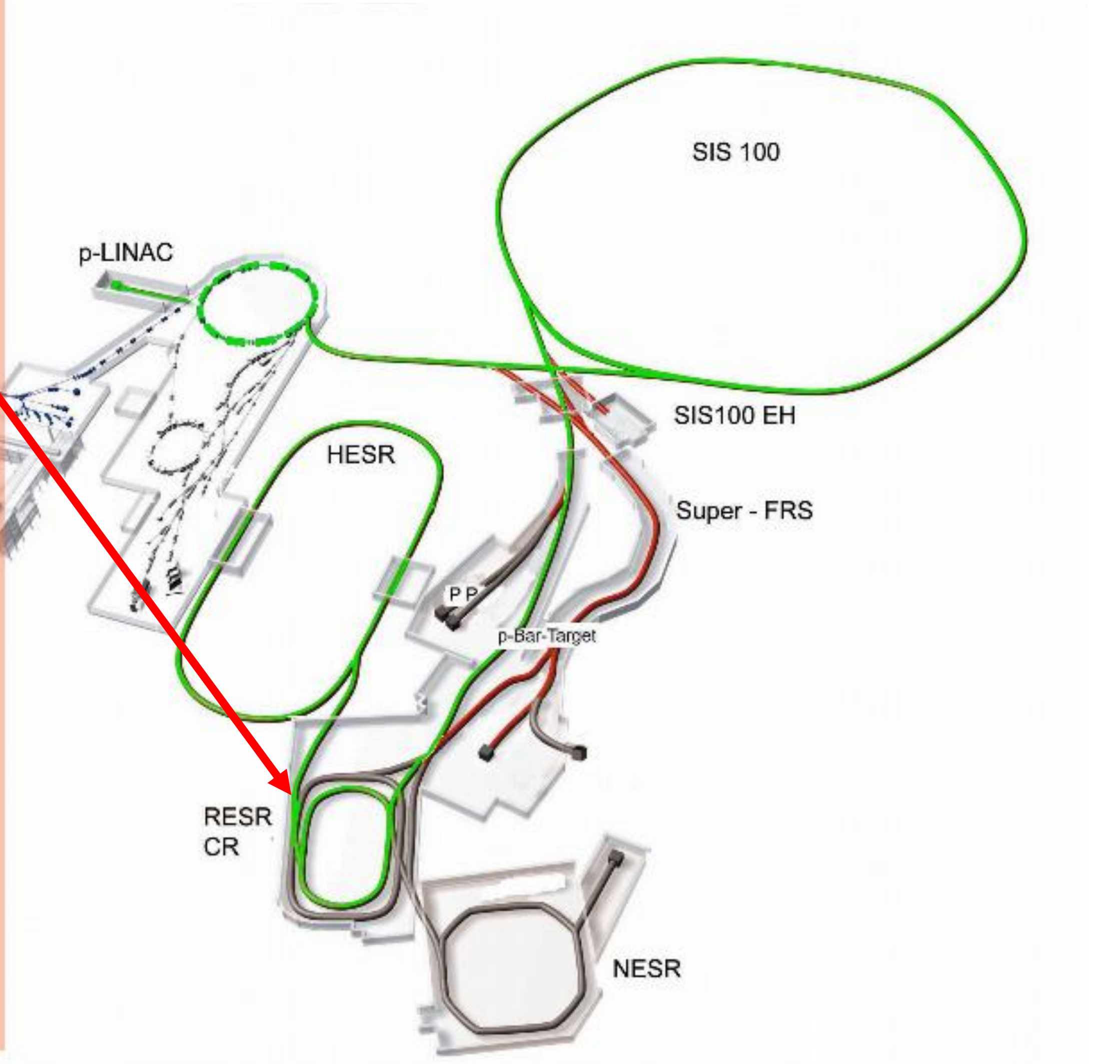

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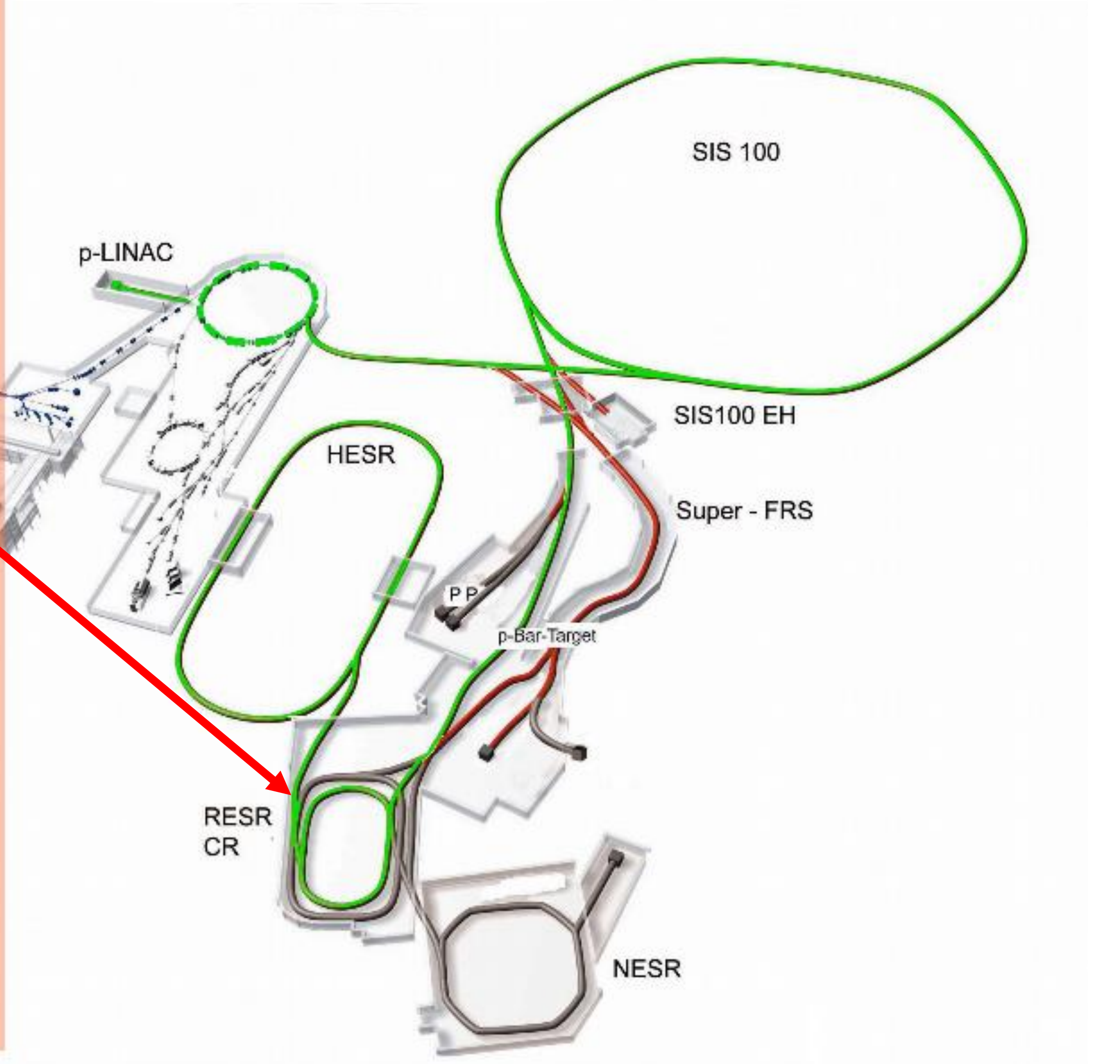

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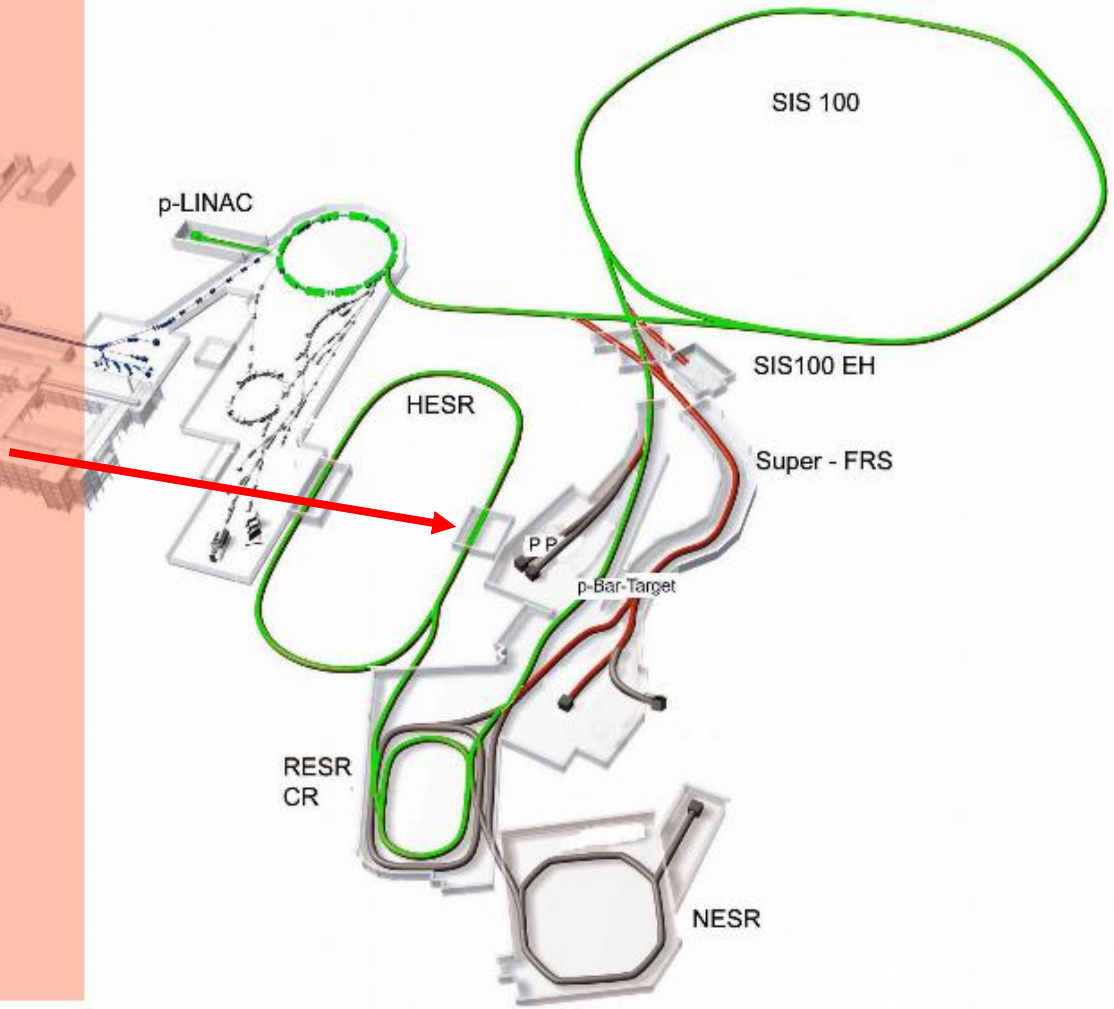
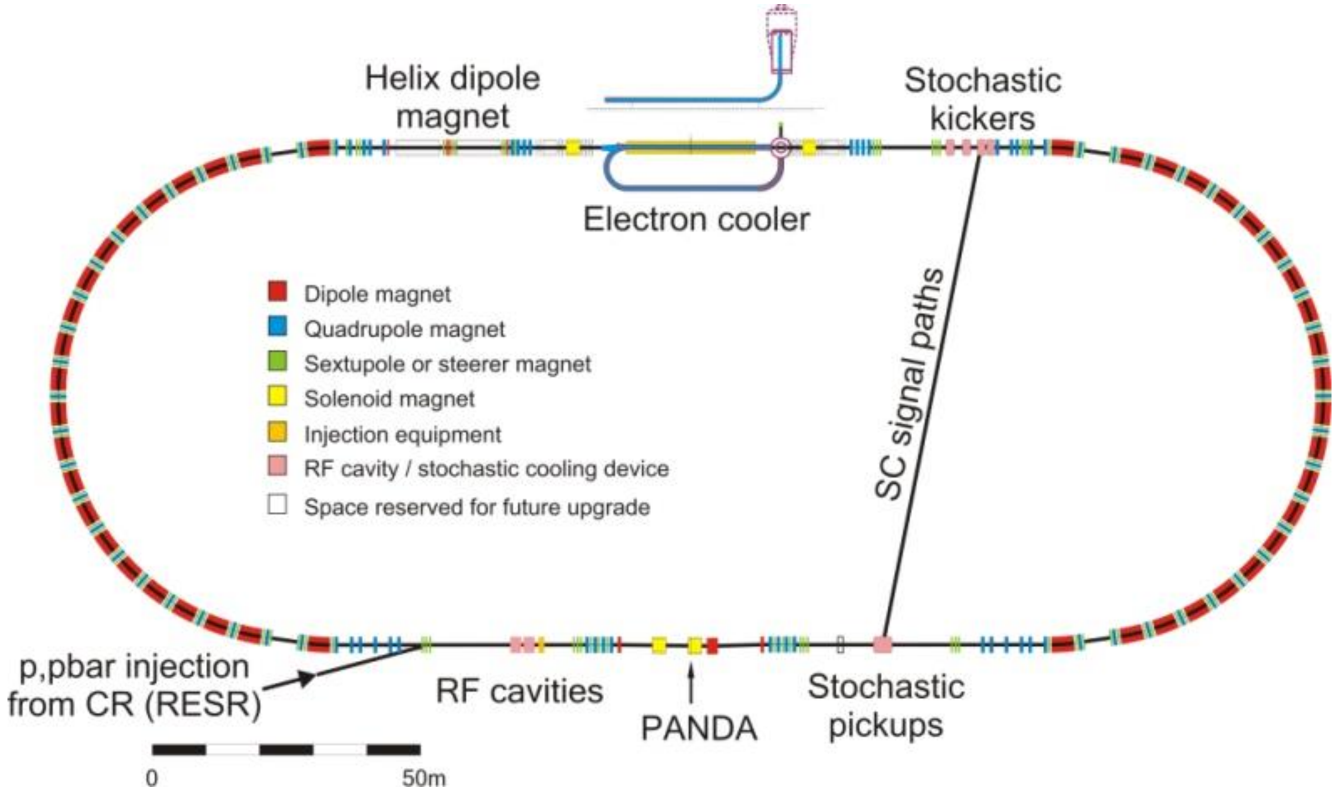


HESR - High Energy Storage Ring

Circumference	575 m
Momentum	1.5 – 15 GeV/c
Electron Cooling	up to 9 GeV/c
Stochastic Cooling	Full range

Mode	High luminosity (HL)	High resolution (HR)
Δp/p	~10^{-4}	~4×10^{-5}
L($cm^{-2}s^{-1}$)	2×10^{32}	2×10^{31}
Stored p̄	10^{11}	10^{10}



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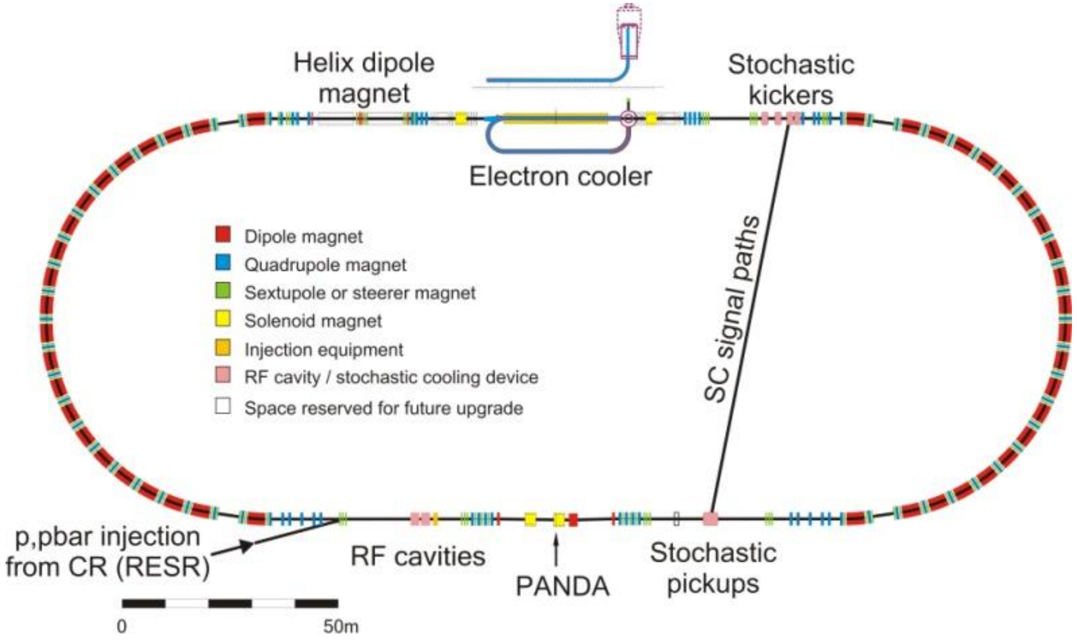
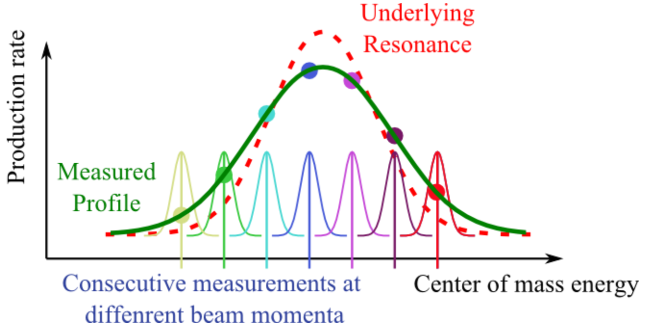


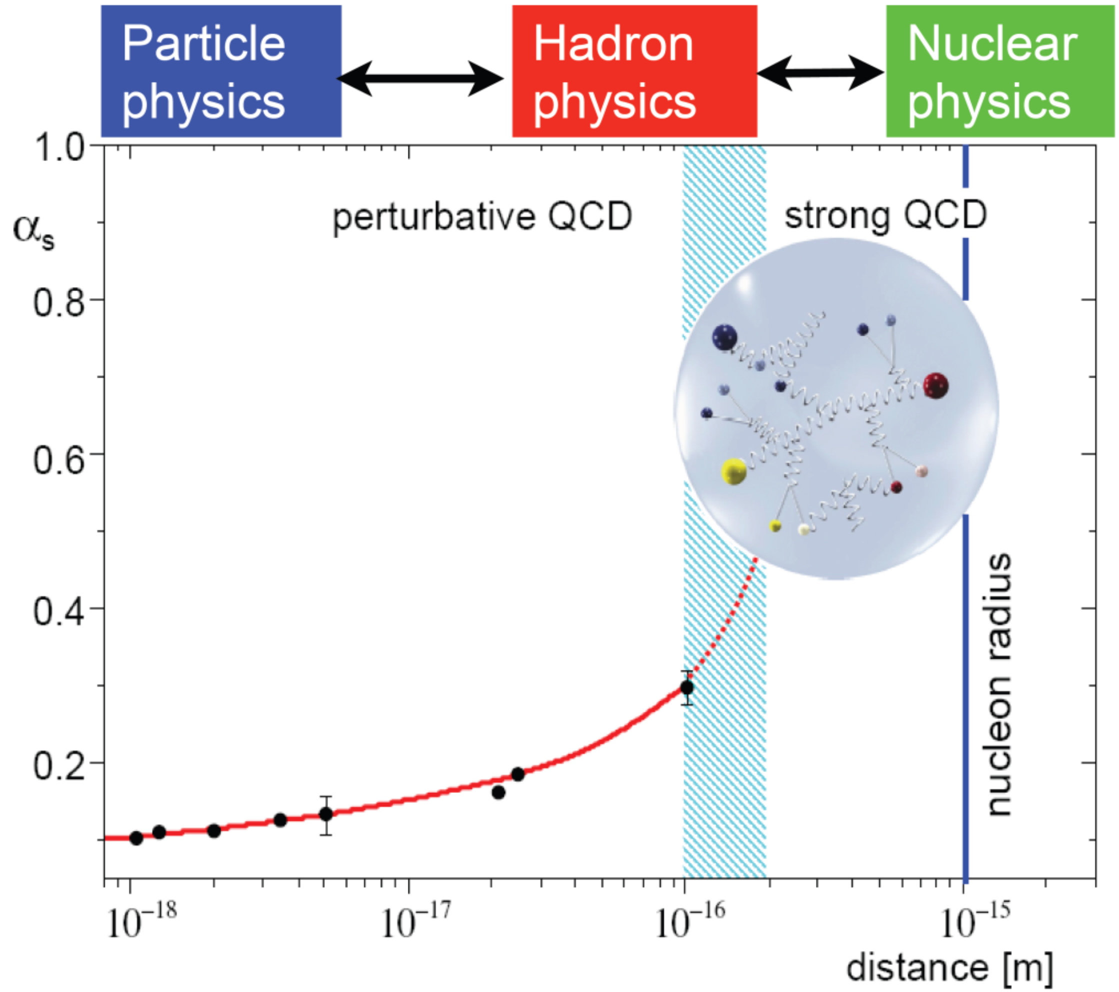
$e^+ e^-$	p p̄
Low hadronic background	High hadronic background
Direct production restricted to 1^{--} states	Direct production of various states

Production experiments

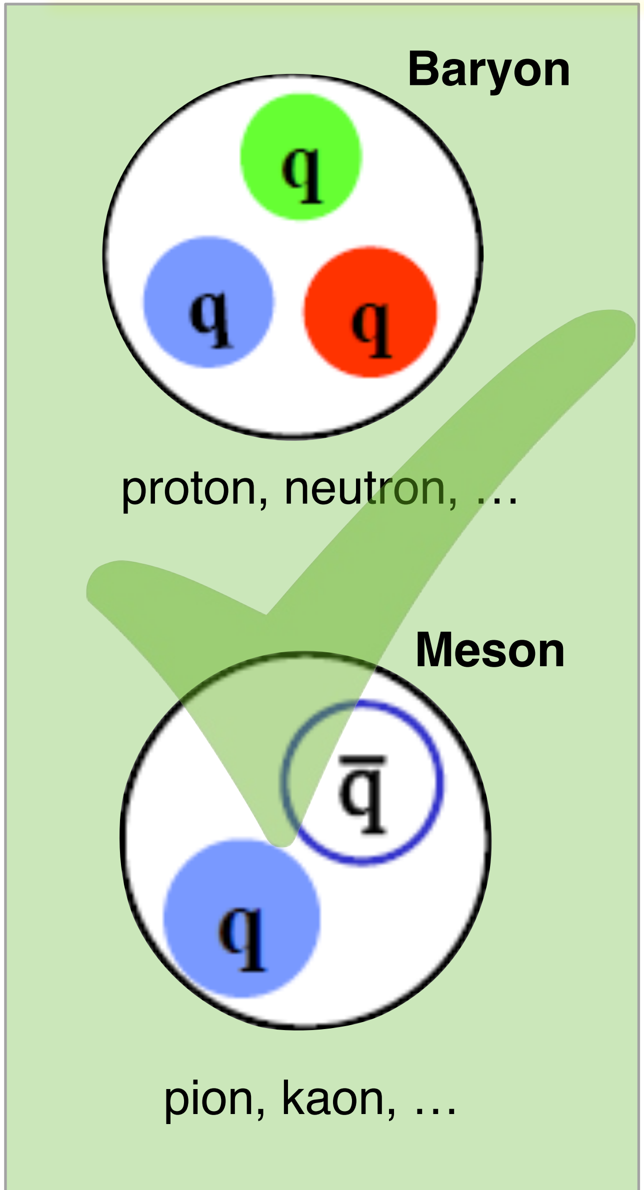


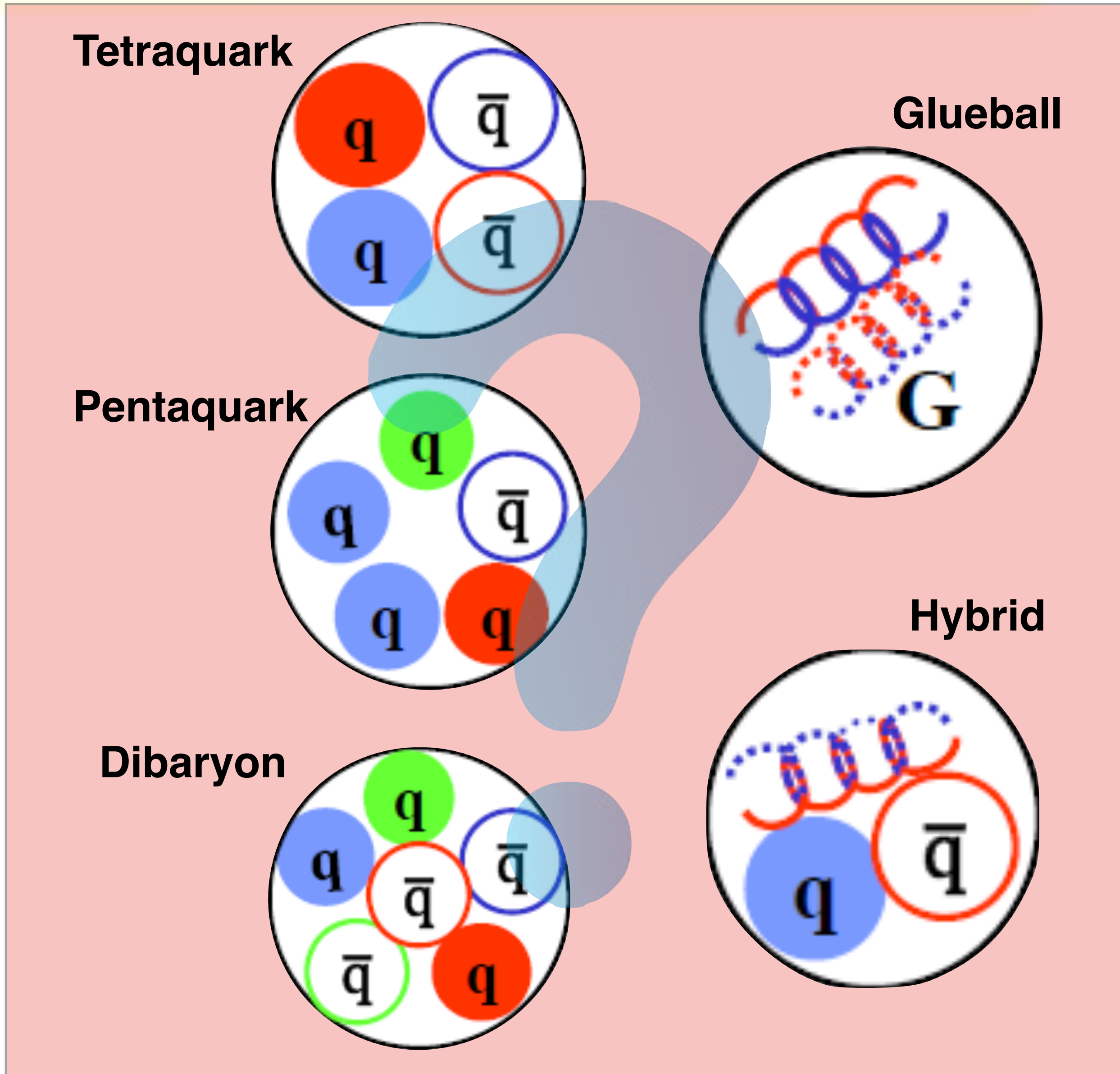
Hadron Physics and QCD

- Why are there no free quarks?
- Are there other colour neutral objects?
- What is the structure of the nucleon?
- What are the spin degrees of freedom?



Ordinary versus "exotic" matter



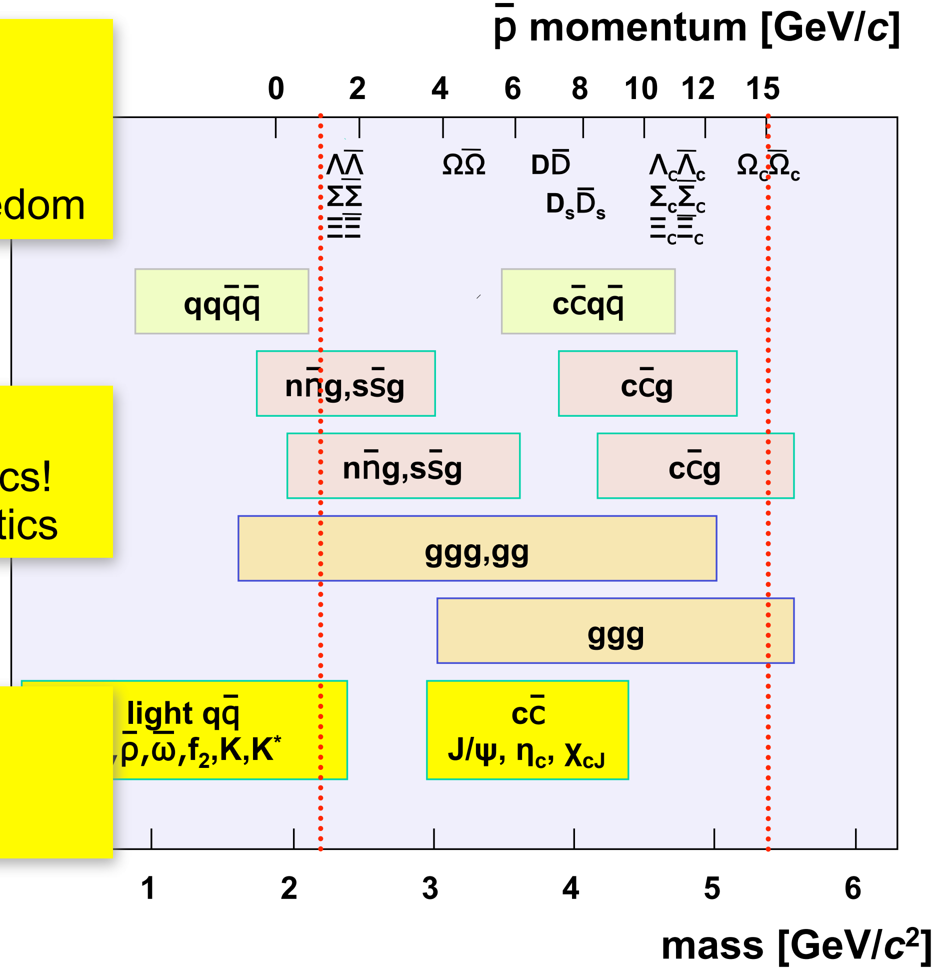


Versatility of antiprotons at PANDA

Large mass-scale coverage
- center-of-mass energies from 2 to 5.5 GeV
- from light, strange, to charm-rich hadrons
- from quark/gluons to hadronic degrees of freedom

High hadronic production rates
- charm+strange factory -> discovery by statistics!
- gluon-rich production -> potential for new exotics

Access to large spectrum of J^{PC} states
- direct formation of *all* conventional J^{PC} states
- large sensitivity to high spin states



Systematic and precise tool to rigorously study the dynamics of QCD

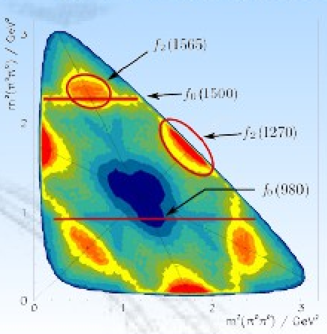
PANDA Physics

Hadron Spectroscopy

Experimental Goals: *mass, width & 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:

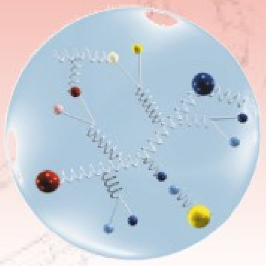
Production of states of all quantum numbers

Resonance scanning with high resolution

Hadron Structure

Time-like Nucleon Formfactors

→ Measurable in annihilation, discrepancy with space-like



Generalized Parton Distributions

Drell-Yan Process

Nuclear Physics

Hypernuclei: Production of double Λ-hypernuclei

→ γ-spectroscopy of hypernuclei, YY interaction

Hadrons in Nuclear Medium

PANDA Physics Program

HEP underlying elementary processes

Spectroscopy

HEP interference of coupled channels

New narrow XYZ:
Search for partner states

Production of exotic QCD states:
Glueballs & hybrids

Nucleon Structure

Generalized parton distributions:
Orbital angular momentum

Drell Yan process:
Transverse structure, valence anti-quarks

Time-like form factors:
Low and high E, e and μ pairs

Bound States of Strong Interaction

astrophysics
strange n-stars

Strangeness

Strange baryons:
Spectroscopy
Polarization

nuclear physics
hyper-nuclear spectroscopy

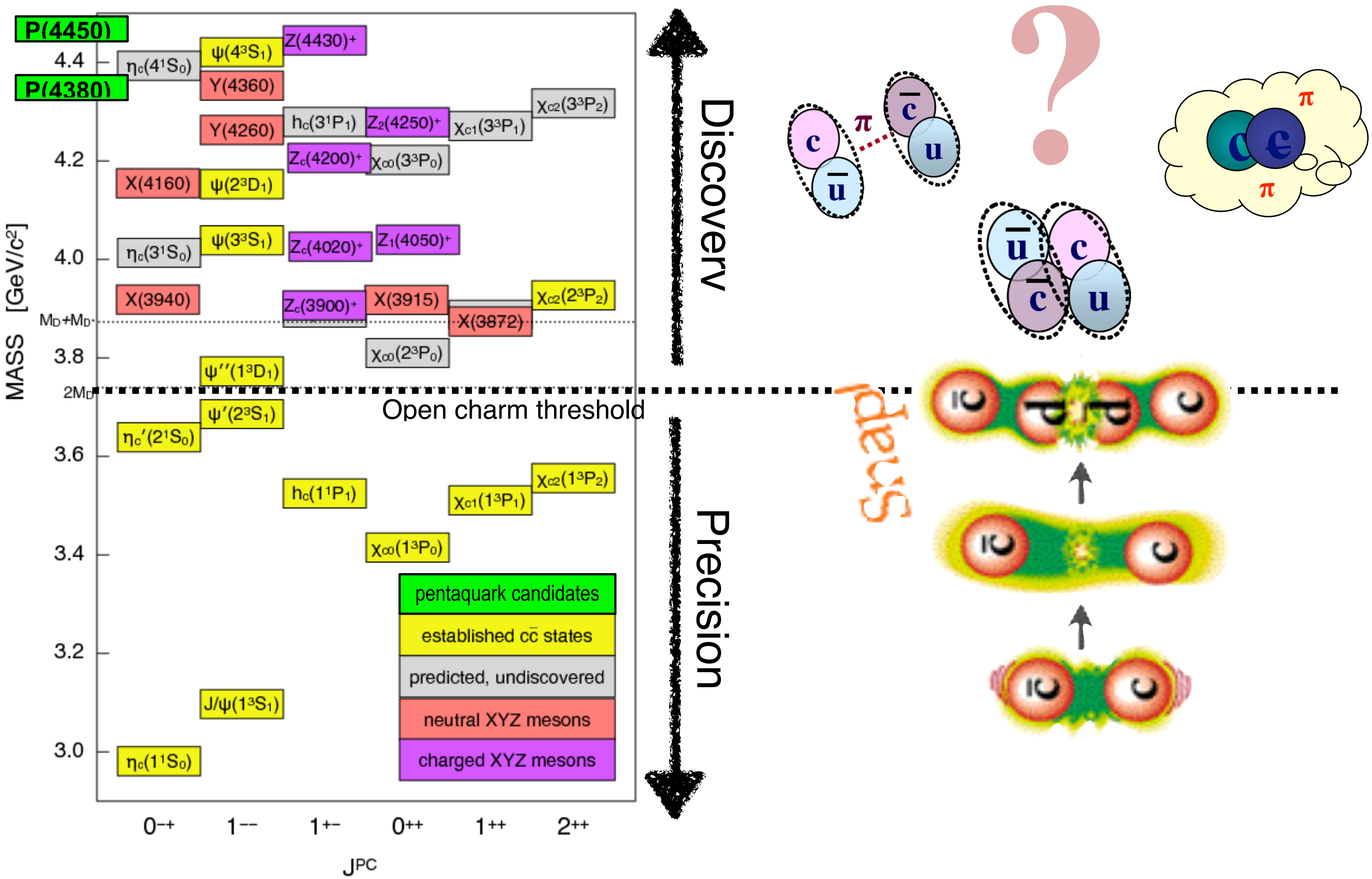
Nuclear Physics

Hypernuclear physics:
Double Λ hypernuclei
Hyperon interaction

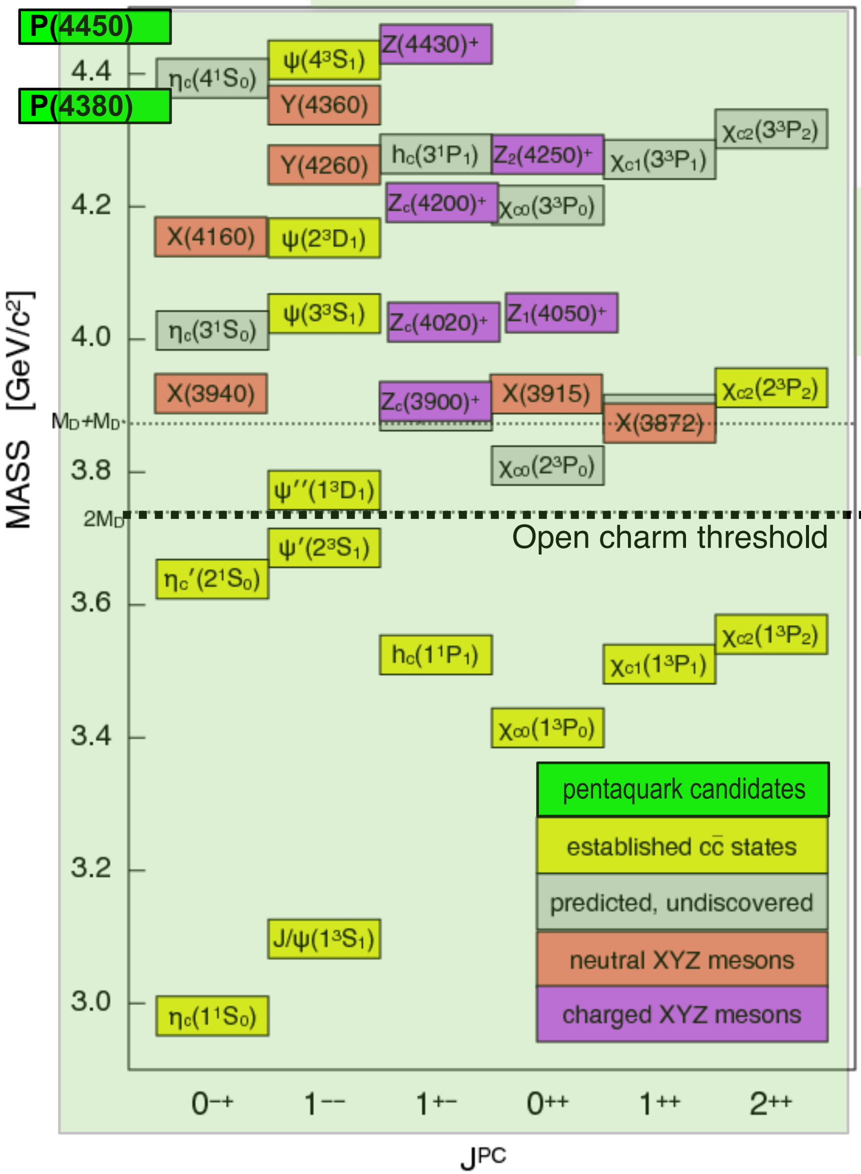
HI collisions
comparing QGP to elementary reactions

Hadrons in nuclei:
Charm and strangeness in the medium

Charmonium and Exotics



Charmonium-like particles - PANDA opportunities

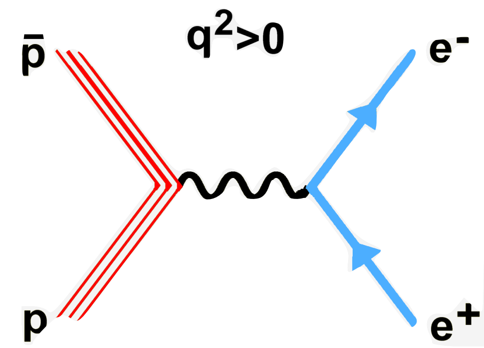


- line shape of X(3872)
- neutral+charged Z-states
- hidden-charm pentaquark
- X,Y,Z decays
- search for h_c', $^3F_4$, …
- spin-parity/mass&width of $^3D_2$

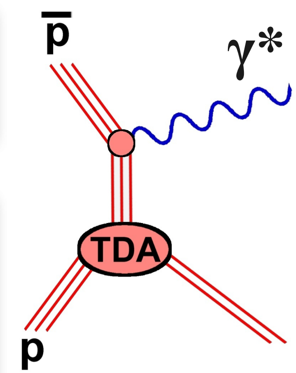
- line shape/width of the h_c
- radiative decays (multipole)
- light-quark spectroscopy

The structure of the proton

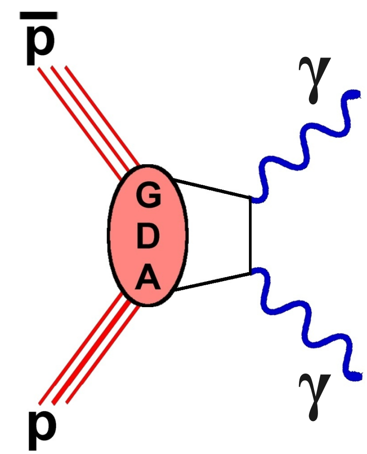
Time-like Electromagnetic Form Factors
(lepton pair production) arXiv:1606.01118



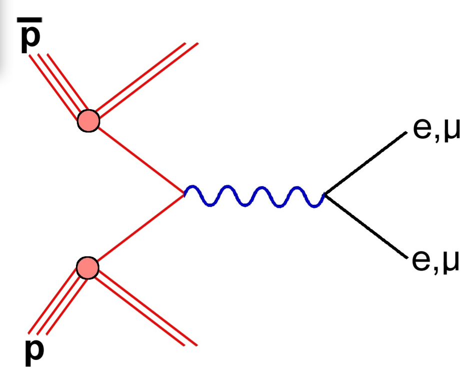
Transition Distribution Amplitudes
(meson production) arXiv:1409.0865



Generalised Distribution Amplitudes
(time-like Compton, hard exclusive processes)



Transverse Parton Distribution Functions
(Drell-Yan production)



Hyperon Factory

Karin Schoenning

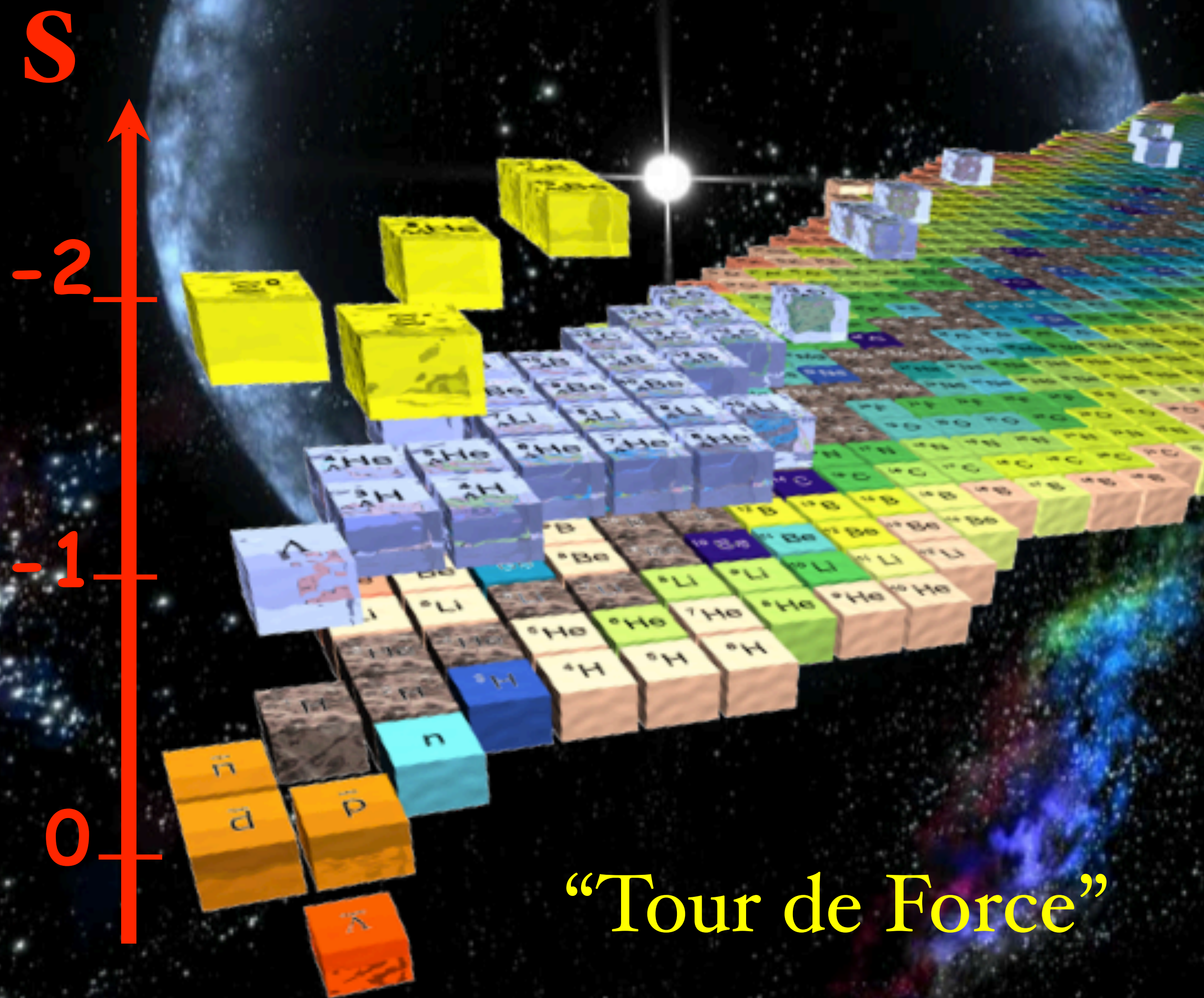
$$\bar{p}p \rightarrow \bar{\Lambda}\Lambda,\ \bar{\Sigma}^{-}\Sigma^{+},\ \bar{\Sigma}^{0}\Sigma^{0},\ \bar{\Sigma}^{-}\Sigma^{+},\ \bar{\Xi}^{0}\Xi^{0},\ \bar{\Xi}^{+}\Xi^{-},\ \bar{\Omega}^{+}\Omega^{-},\ \bar{\Lambda}_c^{-}\Lambda_c^{+}$$

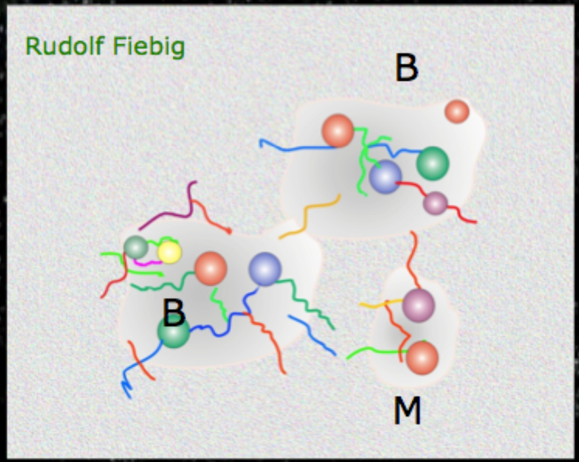
Decay	$\Lambda \rightarrow p\pi^{-}$	$\Sigma \rightarrow p\pi^{0}$	$\Sigma^0 \rightarrow \Lambda\gamma$	$\Sigma \rightarrow n\pi$	$\Xi^0 \rightarrow \Lambda\pi^{0}$	$\Xi \rightarrow \Lambda\pi$	$\Omega \rightarrow \Lambda K$	$\Lambda_c \rightarrow \Lambda\pi$
Branching	64%	52%	$\approx 100\%$	$\approx 100\%$	$\approx 100\%$	$\approx 100\%$	68%	$\approx 1\%$

Momentum (GeV/c)	Reaction	σ (μb)	Efficiency (%)	Rate (with 10^{31} $cm^{-2}s^{-1}$)
1.64	$\bar{p}p \rightarrow \bar{\Lambda}\Lambda$	64	11	29 s^{-1}
4	$\bar{p}p \rightarrow \bar{\Lambda}\Sigma^{o}$	~40	~30	50 s^{-1}
4	$\bar{p}p \rightarrow \bar{\Xi}^{+}\Xi^{-}$	~2	~20	1.5 s^{-1}
12	$\bar{p}p \rightarrow \bar{\Omega}^{+}\Omega^{-}$	~0.002	~30	~4 h^{-1}
12	$\bar{p}p \rightarrow \bar{\Lambda}_c^{-}\Lambda_c^{+}$	~0.1	~35	~2 day^{-1}

Phase 1

HYPERNUCLEI





“Tour de Force”

Ξ^- production

$\bar{p}N \rightarrow \Xi^- \bar{\Xi}$

rescattering in
primary target nucleus

deceleration in
secondary target

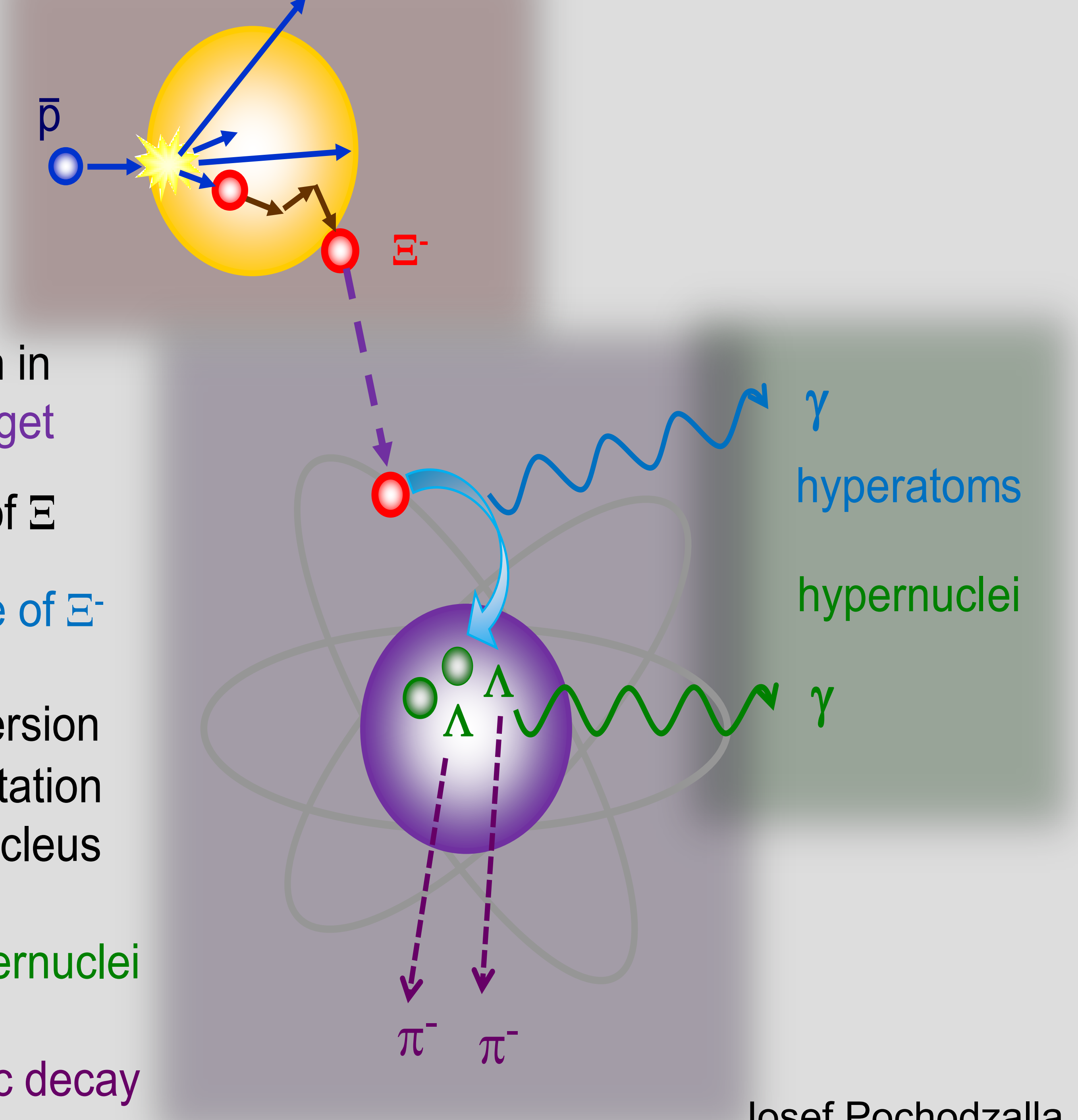
capture of Ξ

atomic cascade of Ξ^-

$\Xi^- p \rightarrow \Lambda\Lambda$ conversion
fragmentation
$\rightarrow$ excited $\Lambda\Lambda$-nucleus

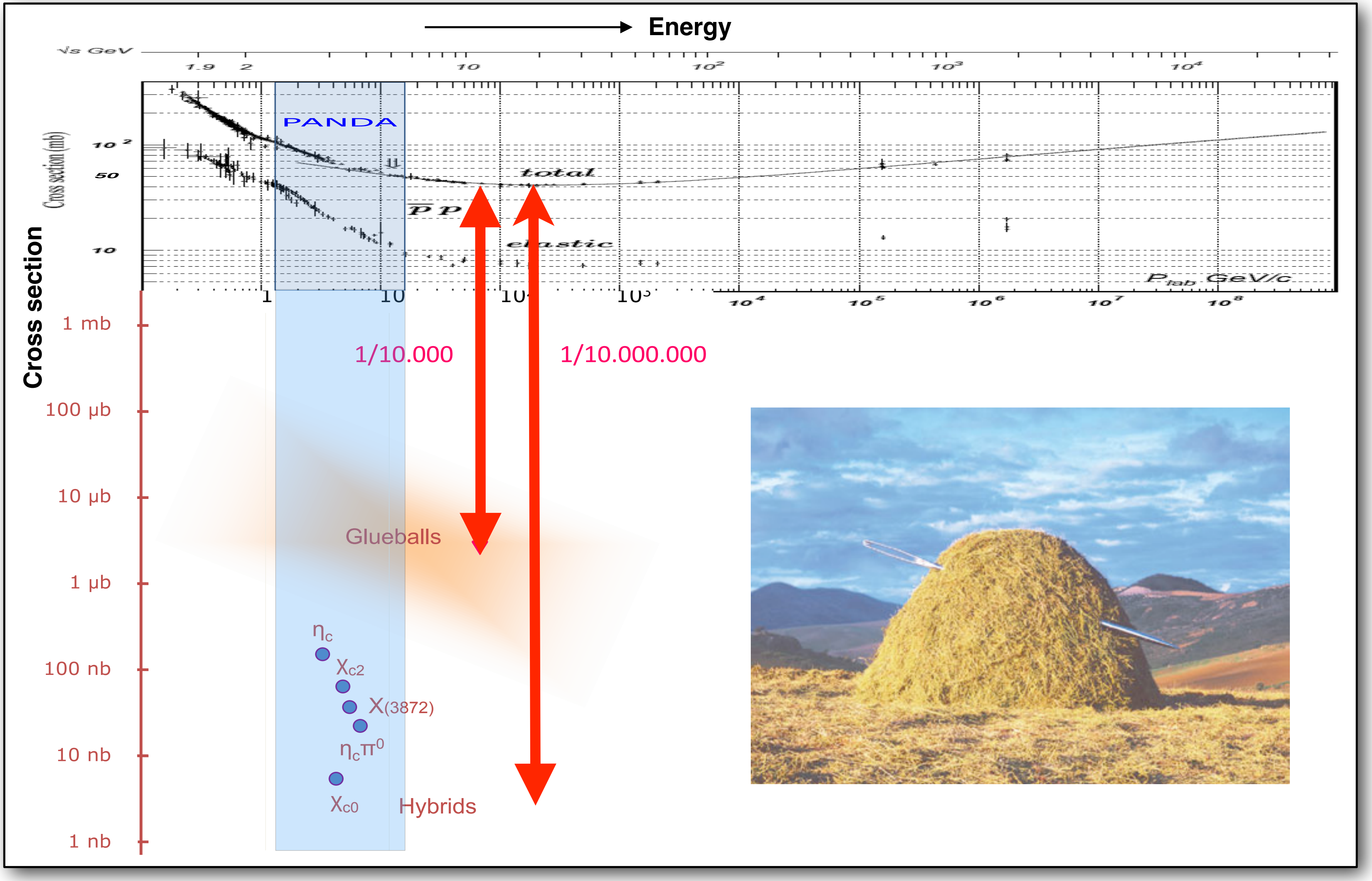
γ-decay of $\Lambda\Lambda$ hypernuclei

weak pionic decay



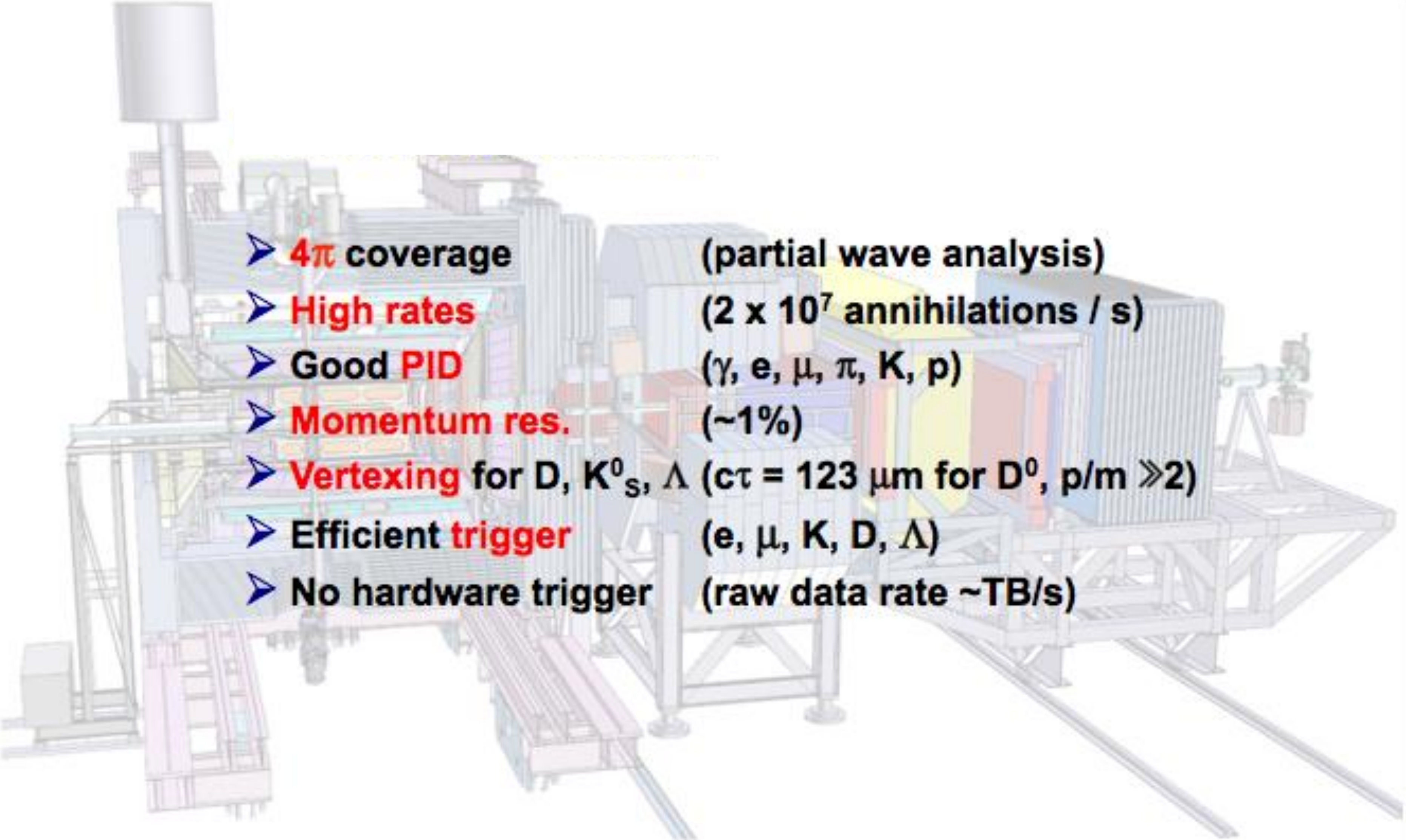
Josef Pochodzalla

Needle-in-a-haystack



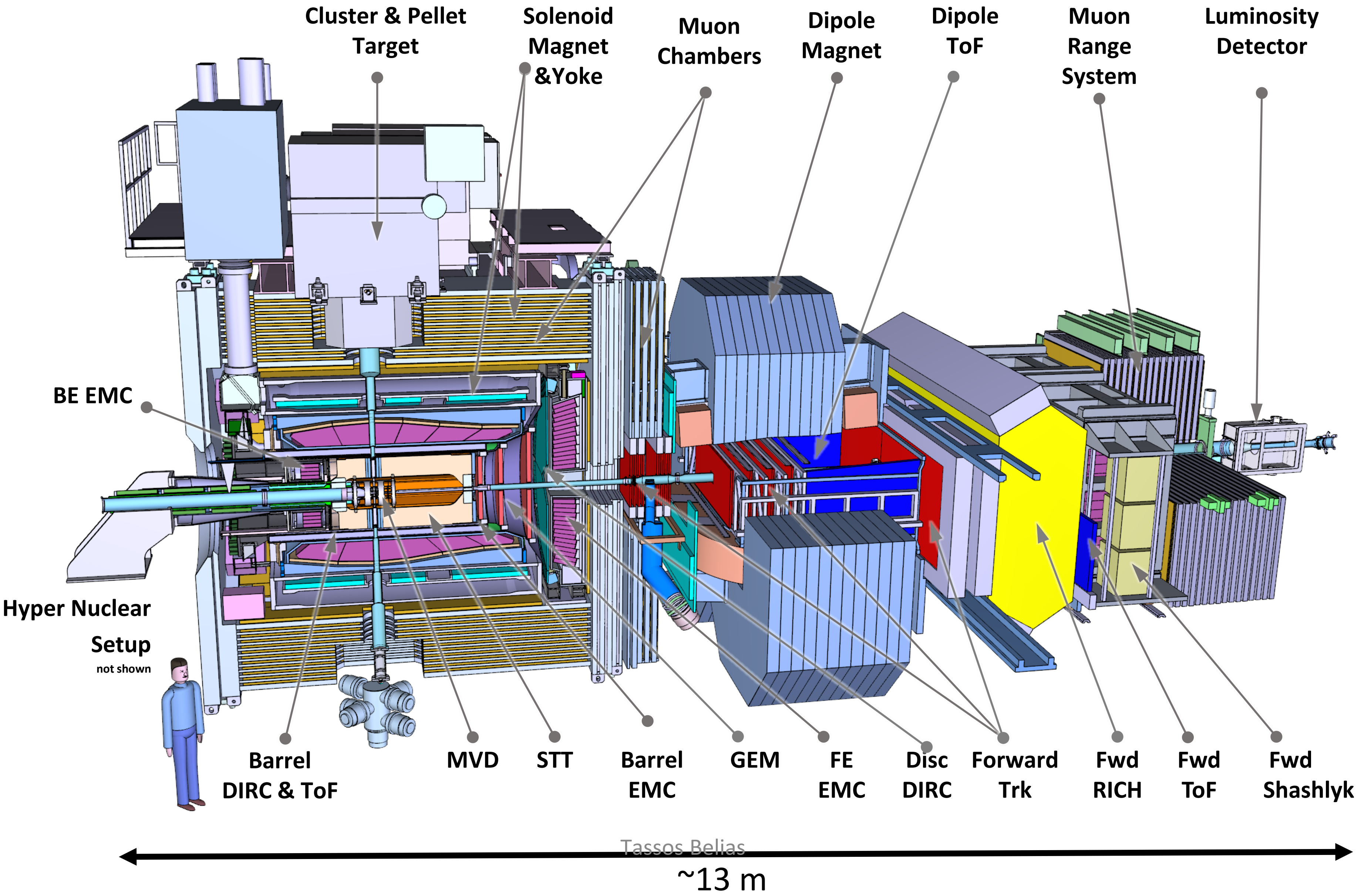
What we need

Detector requirements



- 4π coverage (partial wave analysis)
- High rates (2×10^7 annihilations / s)
- Good PID (γ, e, μ, π, K, p)
- Momentum res. (~1%)
- Vertexing for D, K^0_S, Λ ($c\tau$ = 123 μm for D^0, p/m ≫2)
- Efficient trigger (e, μ, K, D, Λ)
- No hardware trigger (raw data rate ~TB/s)

The PANDA Detector



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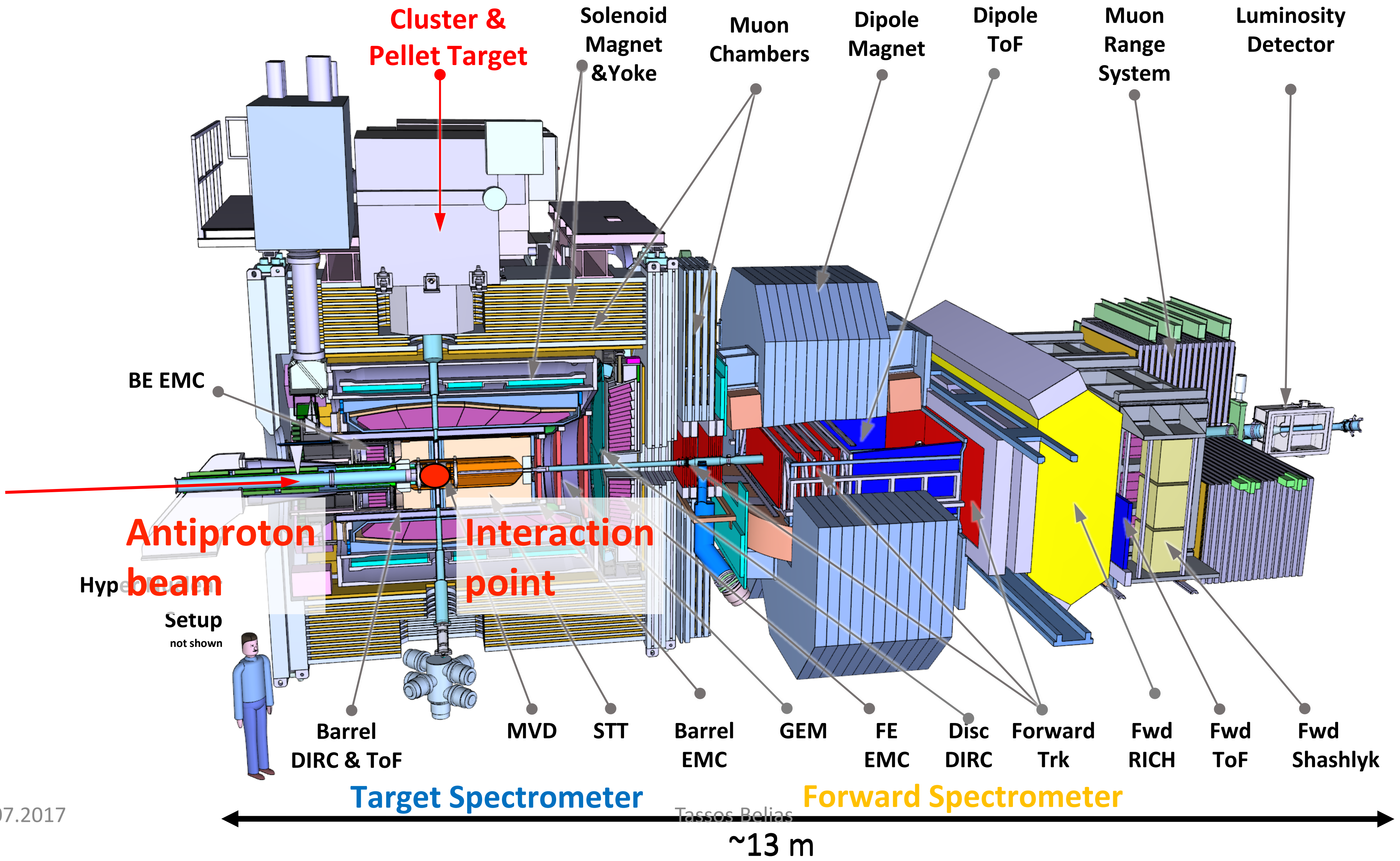


PANDA Targets

Luminosity Considerations

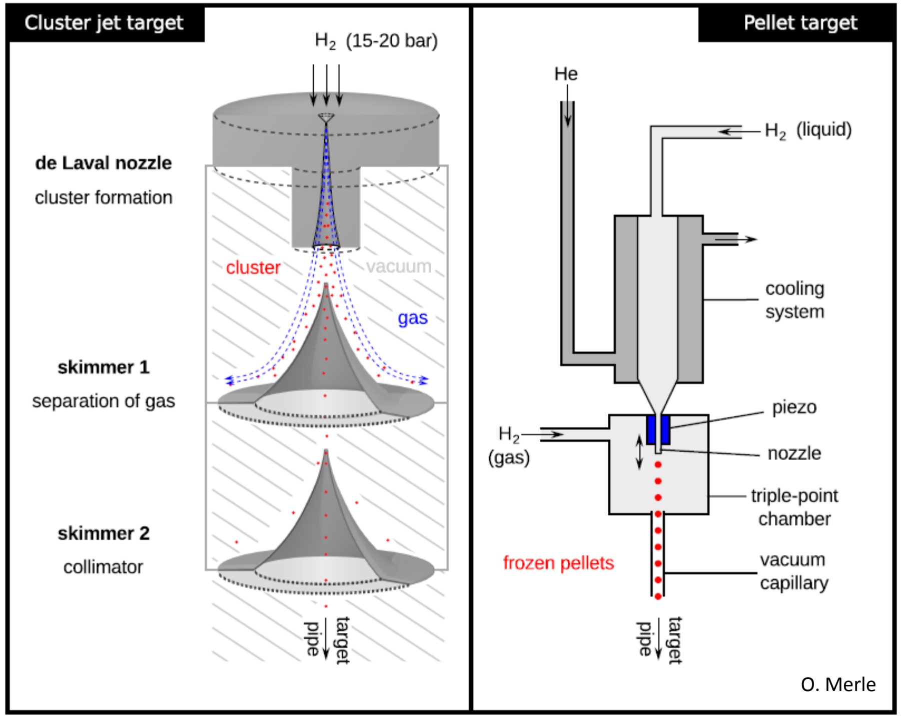
- Goal: $2 \times 10^{32}\ cm^{-2}s^{-1}$ for HL mode
- With 10^{11} p̄ stored and 50 mb cross section:
  → $\rho_p \times d = 4 \times 10^{15} cm^{-2}$ target density
- 1 µm gold foil has about $5.9 \times 10^{18} cm^{-2}$

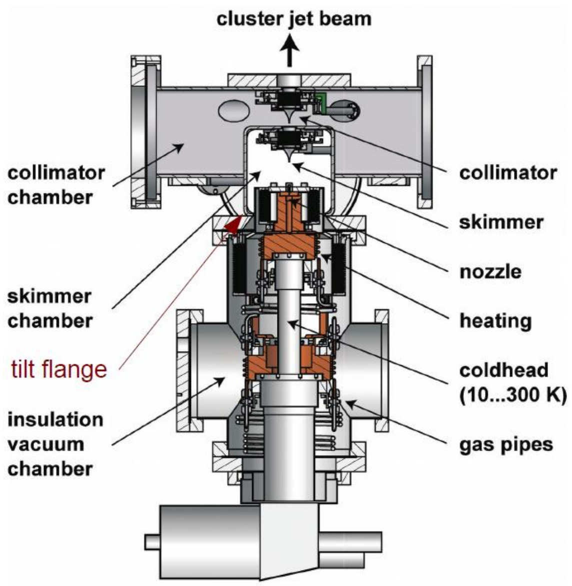
Cluster Jet Target

- Continuous development
  - Nozzle improvement
  - Better alignment by tilting device
  - Record of $2 \times 10^{15} cm^{-2}$ already achieved
- TDR approved

Pellet Target

- $> 4 \times 10^{15} cm^{-2}$ feasible
- Prototype under way
- Pellet tracking prototype
- Second TDR part 2016

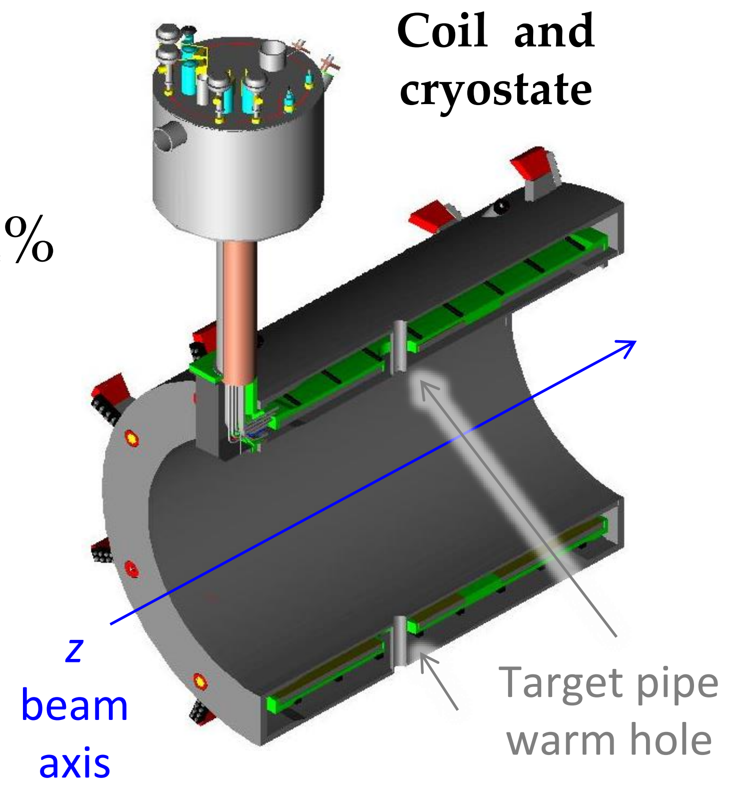


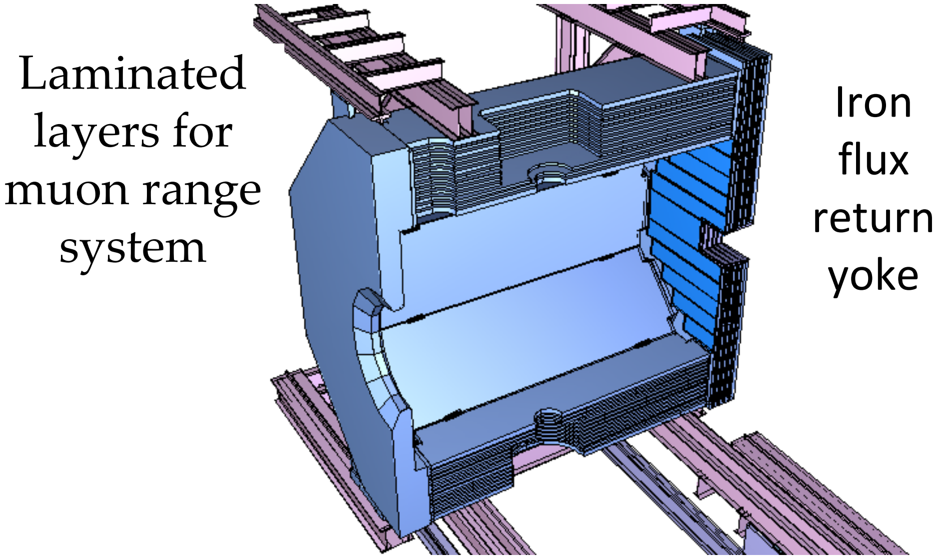


PANDA - Solenoid

Superconducting magnet

- Central field: $|\boldsymbol{B}| = B_z = 2$ T
- High field homogeneity: ≤ 2%
- Dimensions inner bore: ∅ 1.9 m / length: 2.7 m





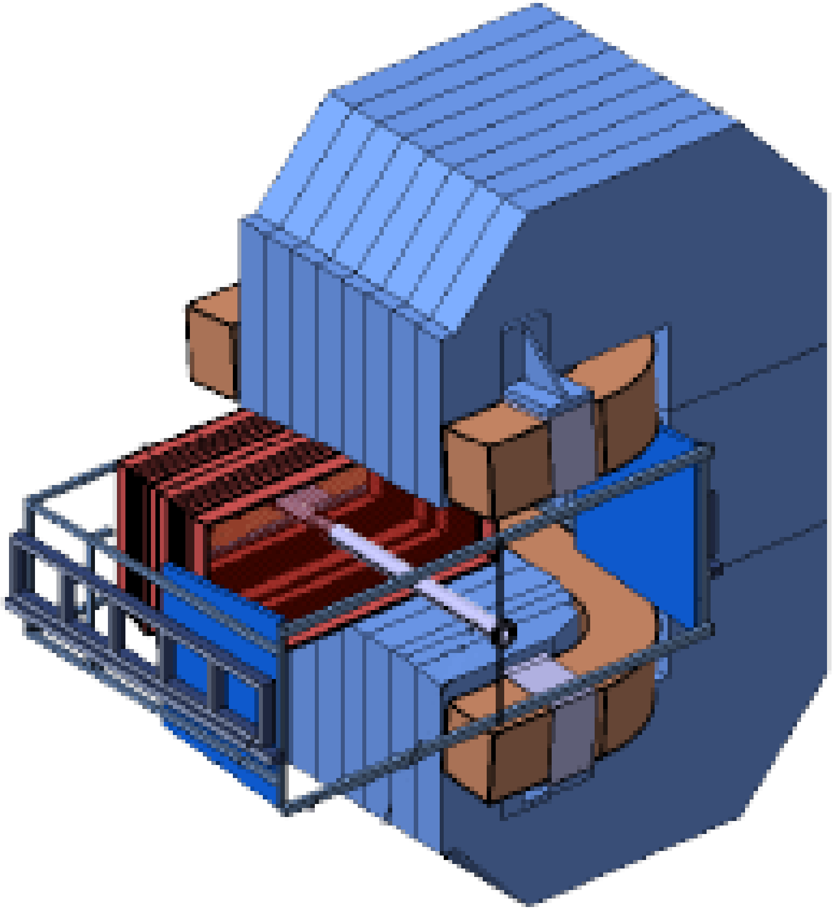
- Outer yoke dimension: ∅ 2.3 m / length: 4.9 m
- Total weight: ~ 300 t

PANDA – Dipole magnet

Normal conducting magnet

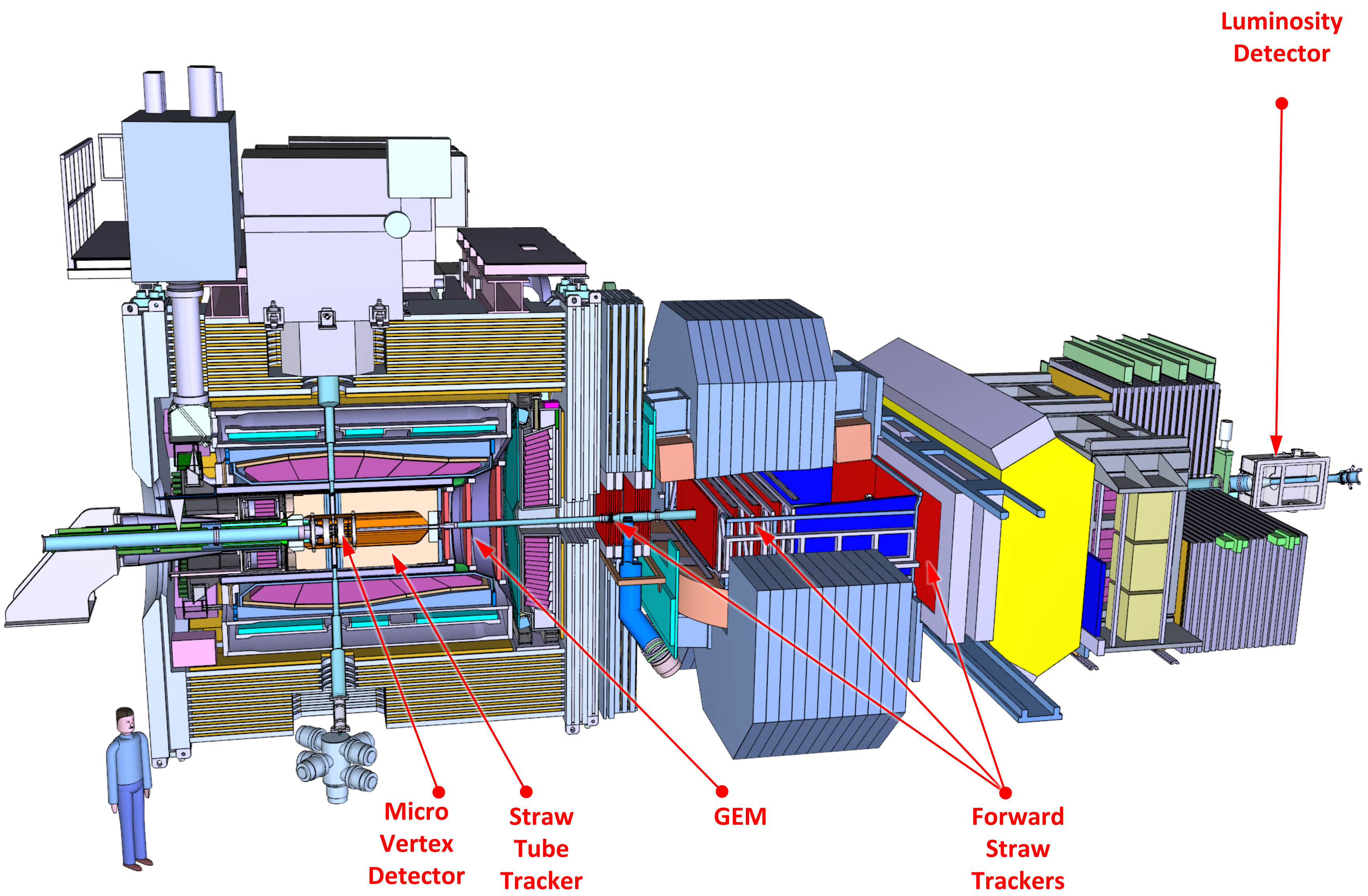
- Field integral (bending power): 2 Tm

  → Deflection of antiprotons with p =15 GeV/c: 2.2°
- Bending variation: ≤ 15%
- Vertical acceptance: ± 5°
- Horizontal acceptance: ± 10°
- Total weight: 200 t



Forward tracking detectors partly integrated

The PANDA Detector - Tracking



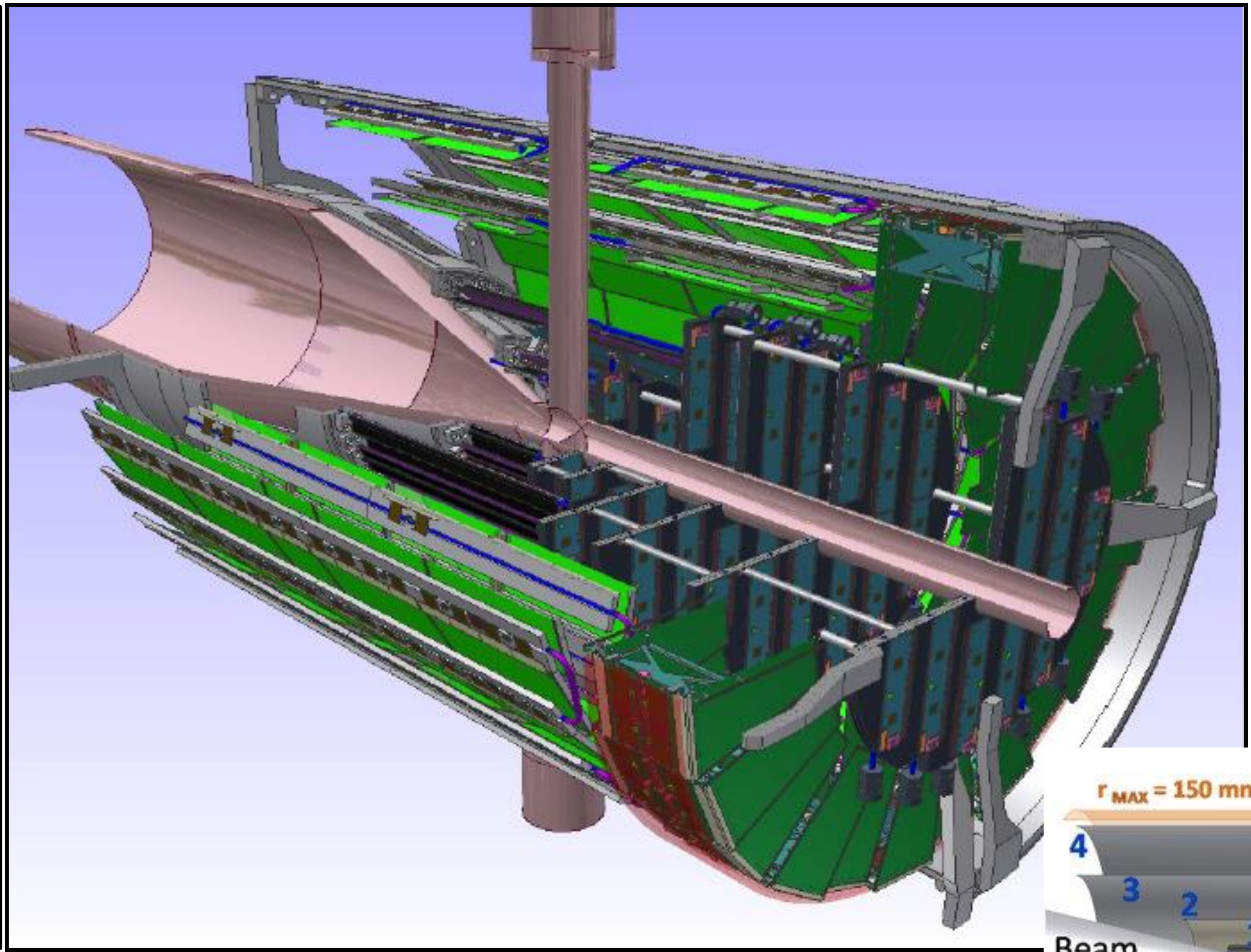
Silicon Micro Vertex Detector

Design of the MVD

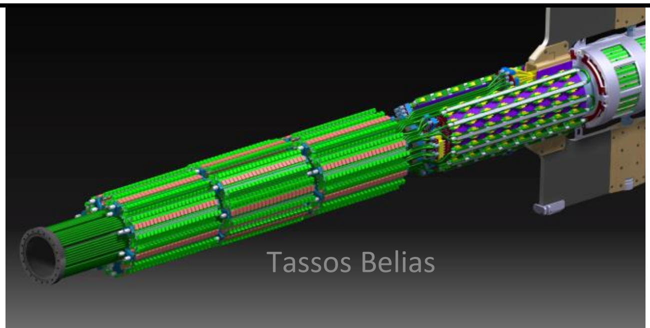
- 4 barrels & 6 disks
- 6 ns timing resolution
- 50 µm vertex resolution
- Inner layers: hybrid pixels ($100 \times 100\ \mu m^2$)
  - ToPiX chip, 0.13 µm CMOS
  - Thinned sensor wafers
  - 28 µm position resolution
- Outer layers: double sided strips
  - Rectangles & trapezoids
  - Custom 64 channel ASIC: PASTA
  - 14 µm position resolution
- Mixed forward disks (pixels & strips)

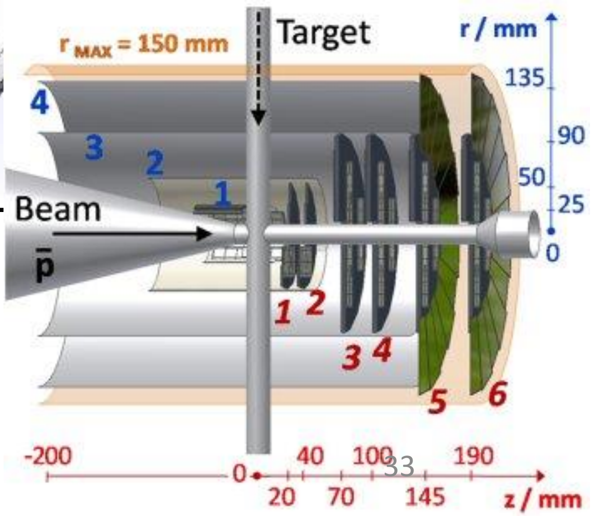
Challenges

- Low mass supports
- Cooling in small volume
- Radiation tolerance



- ASIC prototypes tested
- Radiation tolerant links from CERN
- **Detailed service planning**





Straw Tube Tracker

Detector Layout

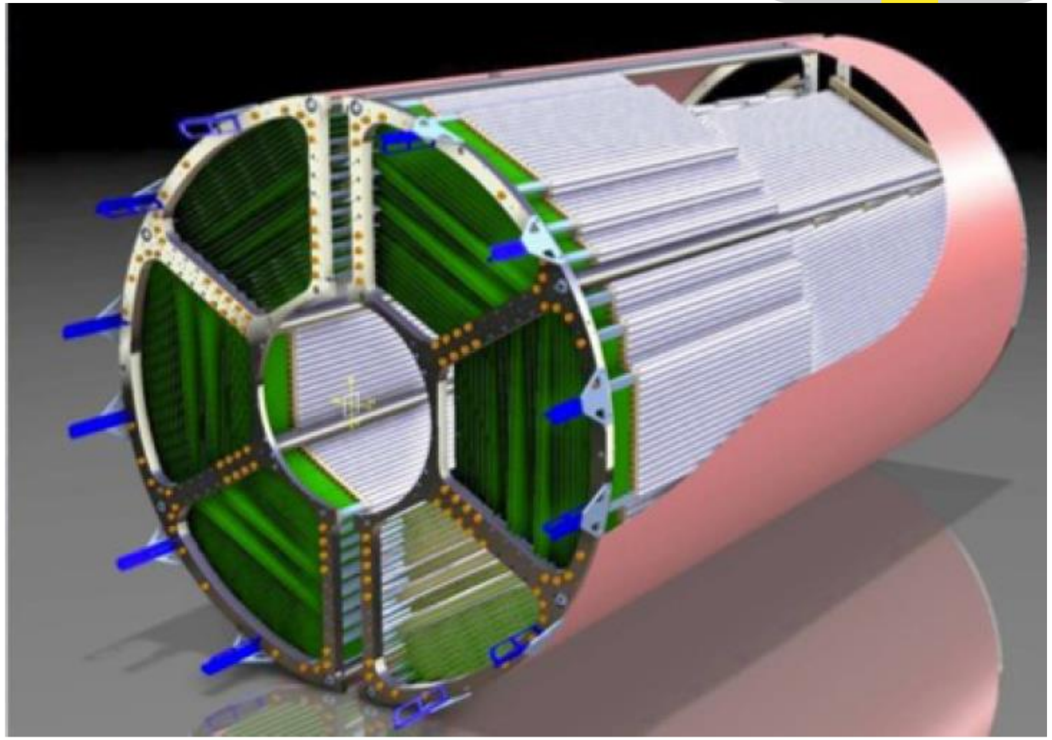
- 4600 straws in 21-27 layers, of which 8 layers skewed at ~3°
- Tube made of 27 μm thin Al-mylar, Ø=1cm
- R_{in}= 150 mm, R_{out}= 420 mm, l=1500 mm
- **Self-supporting straw double layers at γ 1 bar overpressure (Ar/CO_2)**
- Readout with ASIC+TDC or FADC

Material Budget

- Max. 26 layers,
- 0.05 % X/X_0 per layer
- **Total 1.3% X/X_0**

Project Status

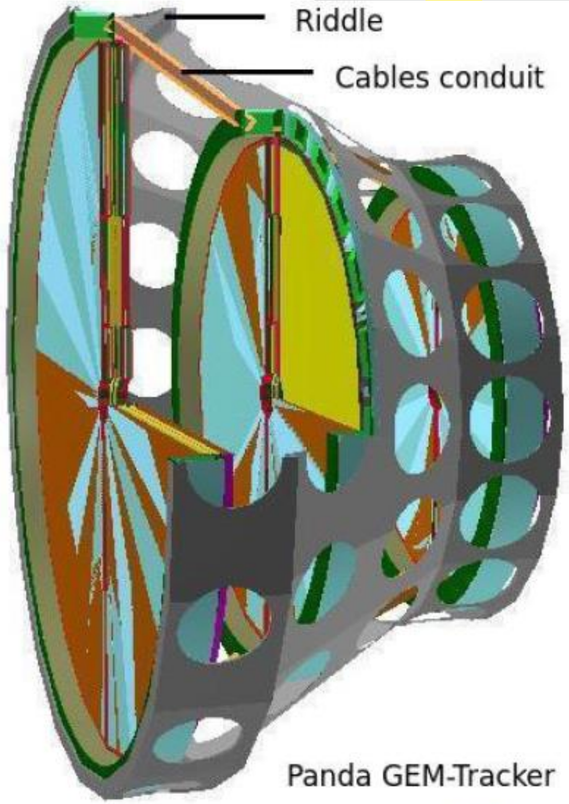
- Readout prototypes & beam tests
- Ageing tests: up to 1.2 C/cm^2
- Straw series production ongoing: 3000 straws produced till end 2015



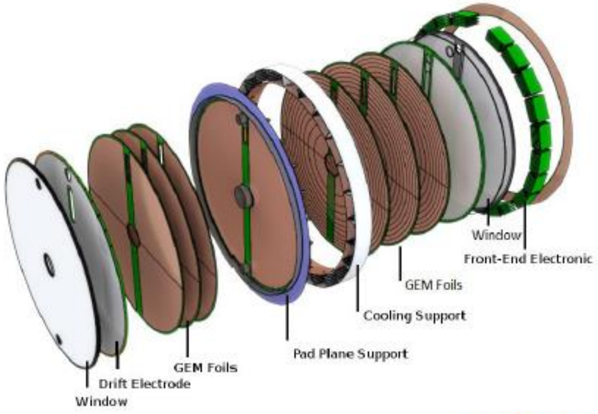
GEM Tracker

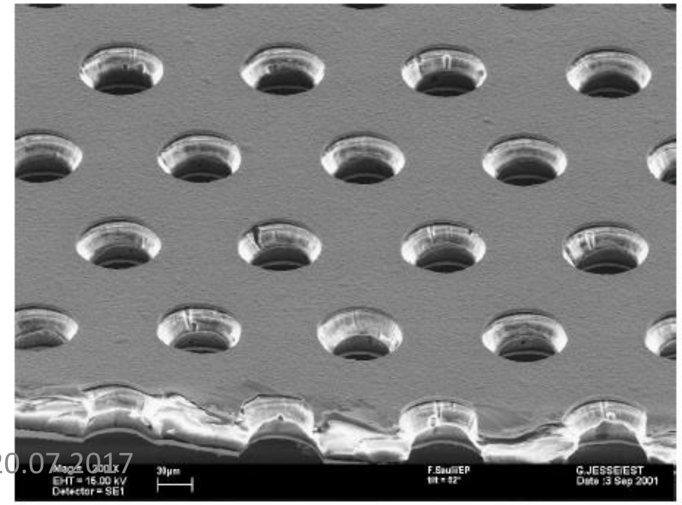
Forward Tracking inside Solenoid

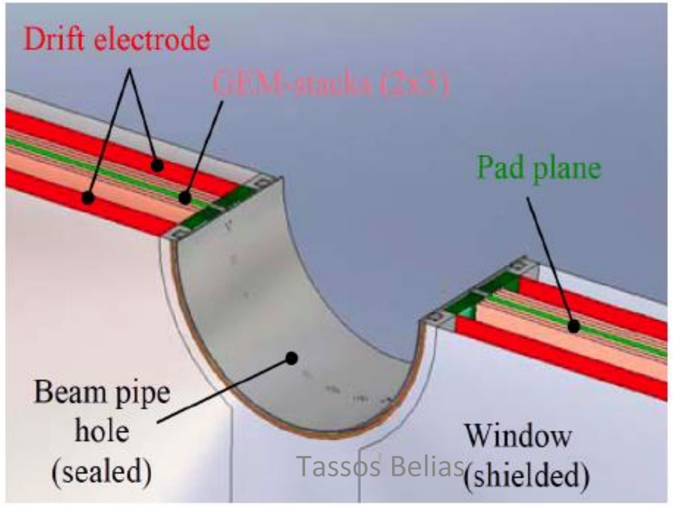
- 3 stations with 4 projections each
  - → Radial, concentric, x, y
- Central readout plane for 2 GEM stacks
- Large area GEM foils developed at CERN (50μm Kapton, 2-5μm copper coating)
- ADC readout for cluster centroids
  - → Approx. 35000 channels total
- Challenge to minimize material



Panda GEM-Tracker



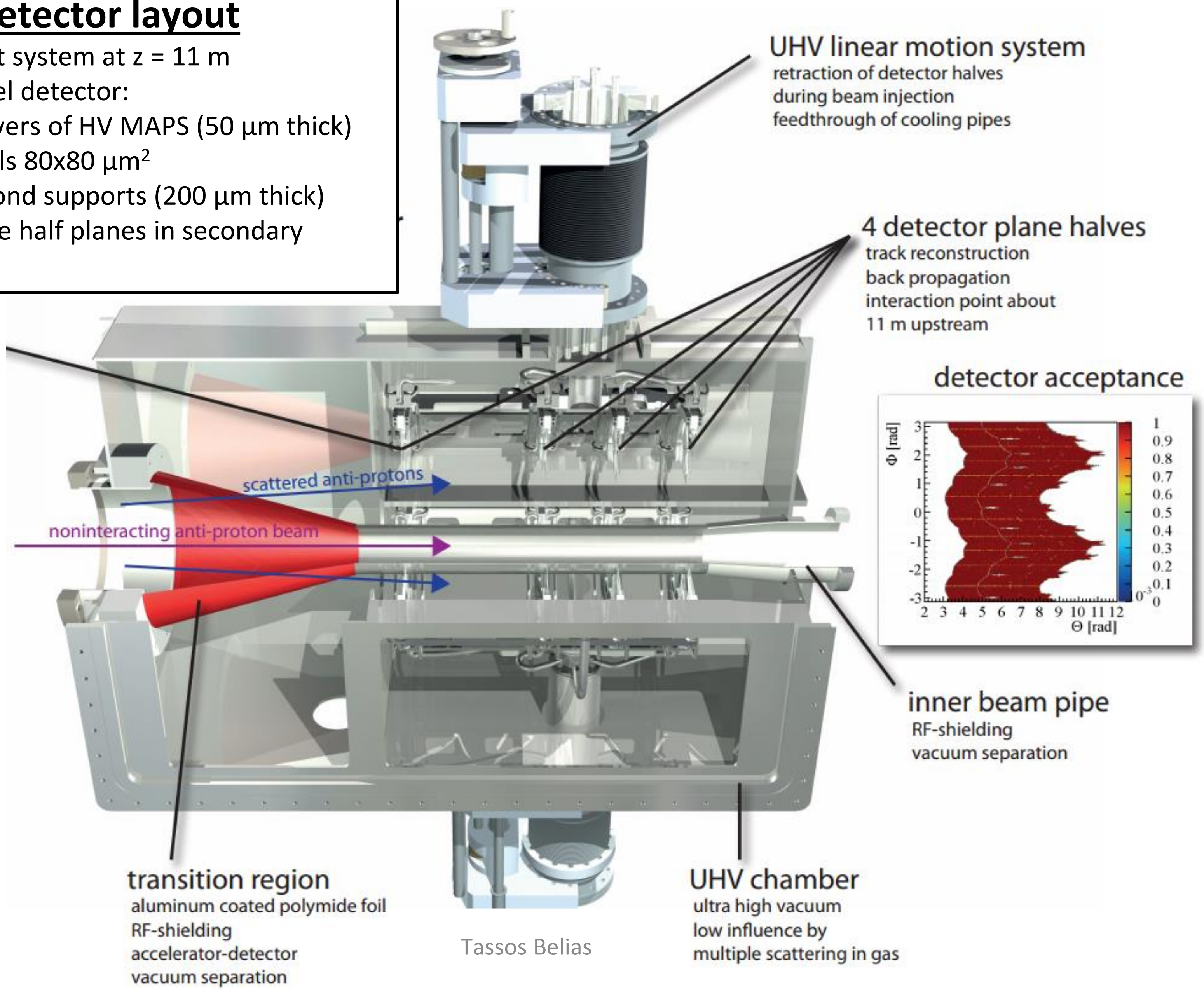




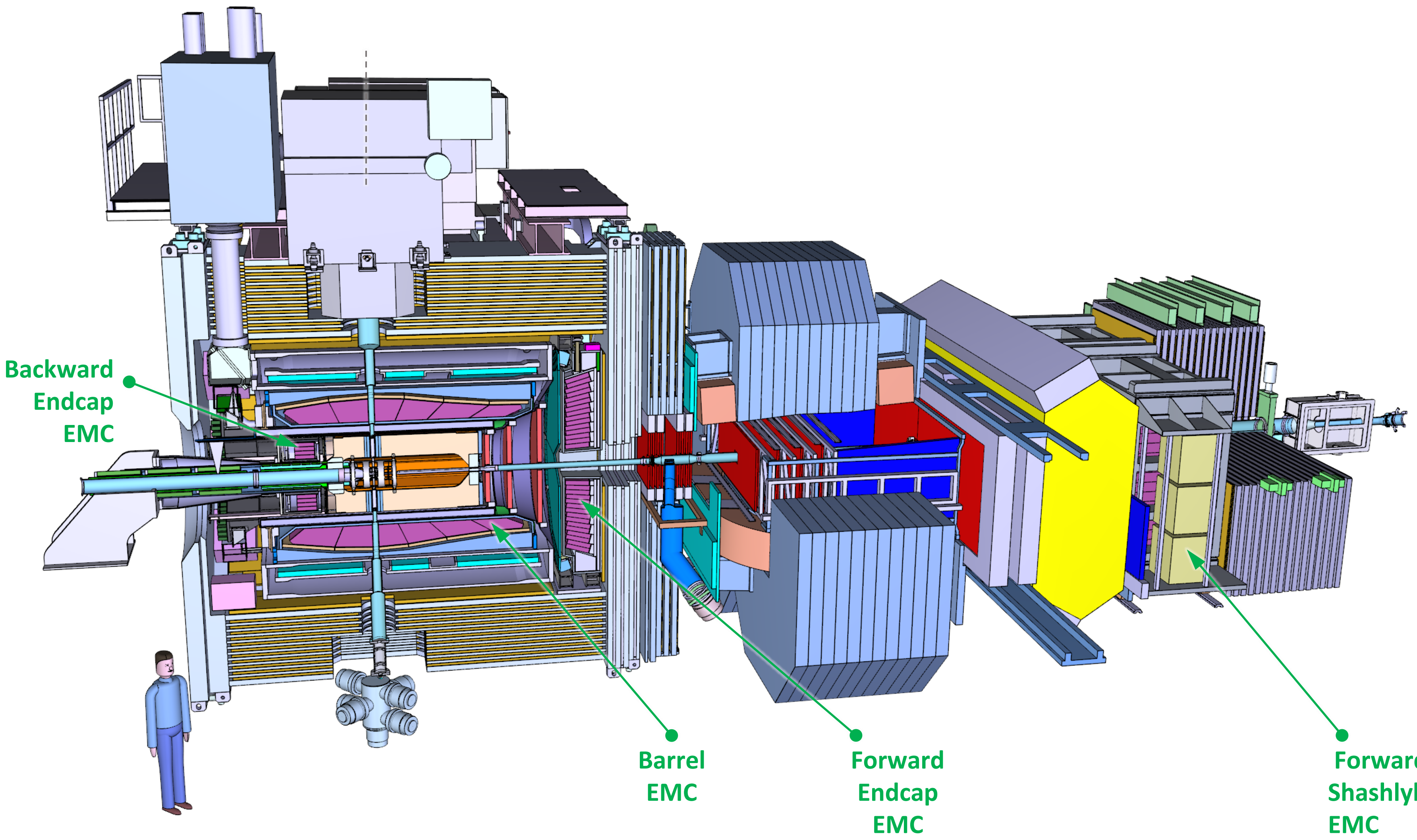
Luminosity Detector

Detector layout

- Roman pot system at z = 11 m
- Silicon pixel detector:
  - 4 layers of HV MAPS (50 µm thick)
  - Pixels 80x80 μm^2
- CVD diamond supports (200 µm thick)
- Retractable half planes in secondary vacuum



The PANDA Detector - Calorimetry



Target Spectrometer EMC

PANDA PWO Crystals

PWO is dense and fast

Low γ threshold is a challenge

Increase light yield

- improved PWO II (2xCMS)
- operation at -25°C (4xCMS)

Challenges

- temperature stable to 0.1°C
- control radiation damage
- low noise electronics

Delivery of crystals 54 %

Large Area APDs

Barrel Calorimeter

11000 PWO Crystals

LAAPD readout, 2x1cm^2

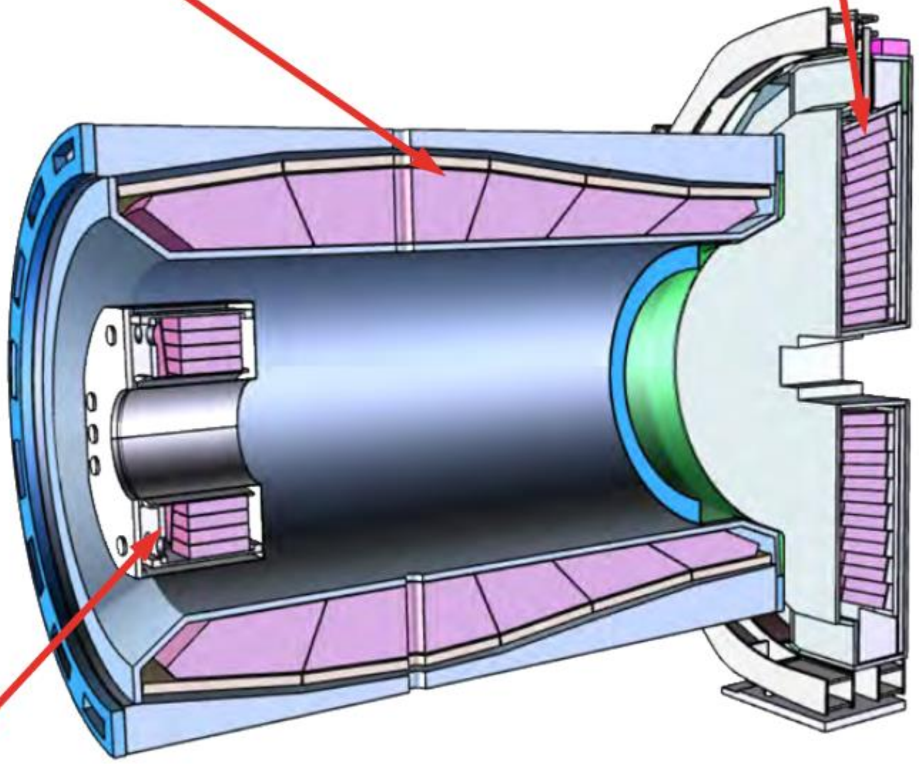
$\sigma(E)/E \sim 1.5\%/\sqrt{E}$ + const.

Forward Endcap

4000 PWO crystals

High occupancy in center

LA APD and VPTT



Backward Endcap for hermeticity, 530 PWO crystals

Forward Shashlik Calorimeter

Forward electromagnetic calorimeter:

- Interleaved scintillator and absorber layers
- 380 layers of 0.3 mm lead and 1.5 mm scintillator, total length 680 mm
- Transverse size 55x55 mm^2
- WLS fibers for light collection
- PMTs for photon readout
- FADCs for digitization
- Active area size 297x154 cm^2

Project Status:

- Module design 2 x 2 cells of 5.5 x 5.5 cm^2 verified
- Tests with electrons and tagged photons:

→ **Energy resolution:**

- $\frac{\sigma_E}{E} = 5.6/E \oplus 2.4/\sqrt{E[GeV]} \oplus 1.3\ \%$

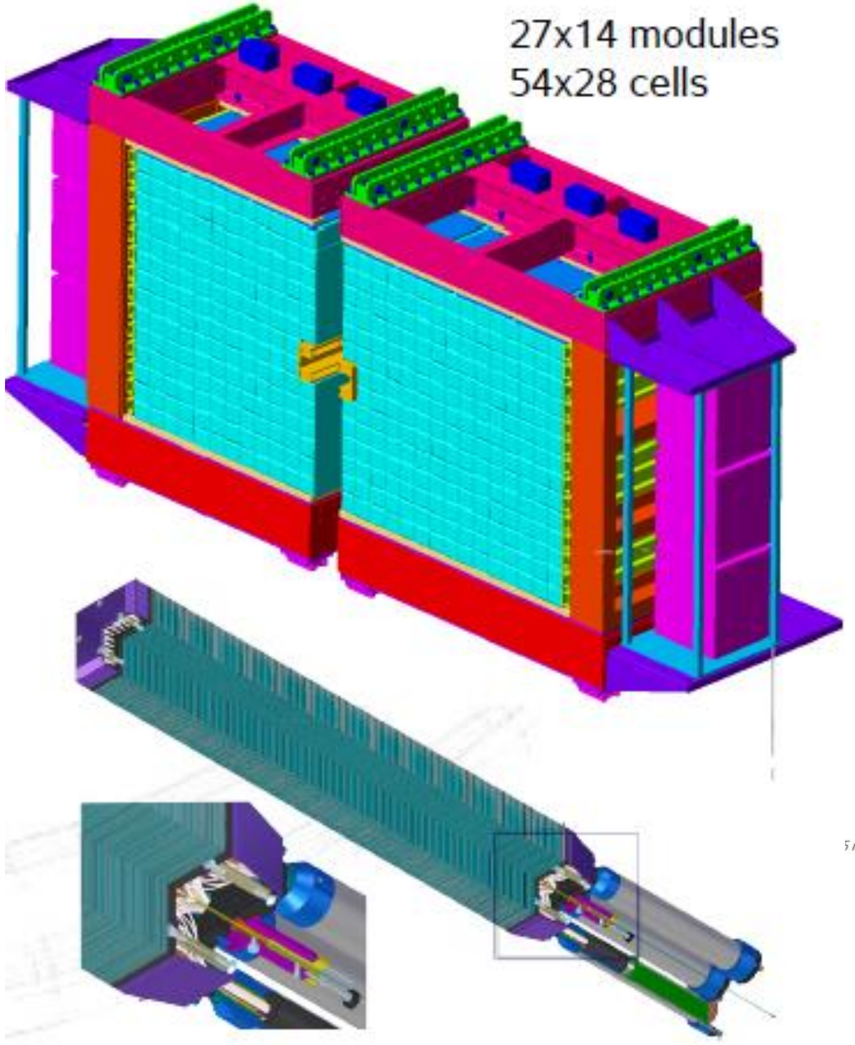
  ~ 1-19 GeV for e$^-$
- $\frac{\sigma_E}{E} = 3.7/\sqrt{E[GeV]} \oplus 4.3\ \%$

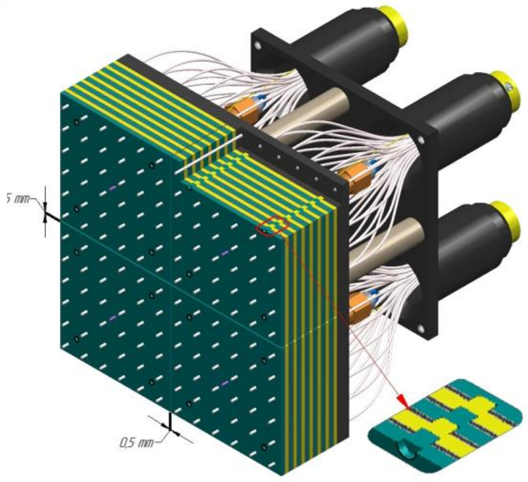
  ~ 50-400 MeV for γ

→ **Time resolution:**

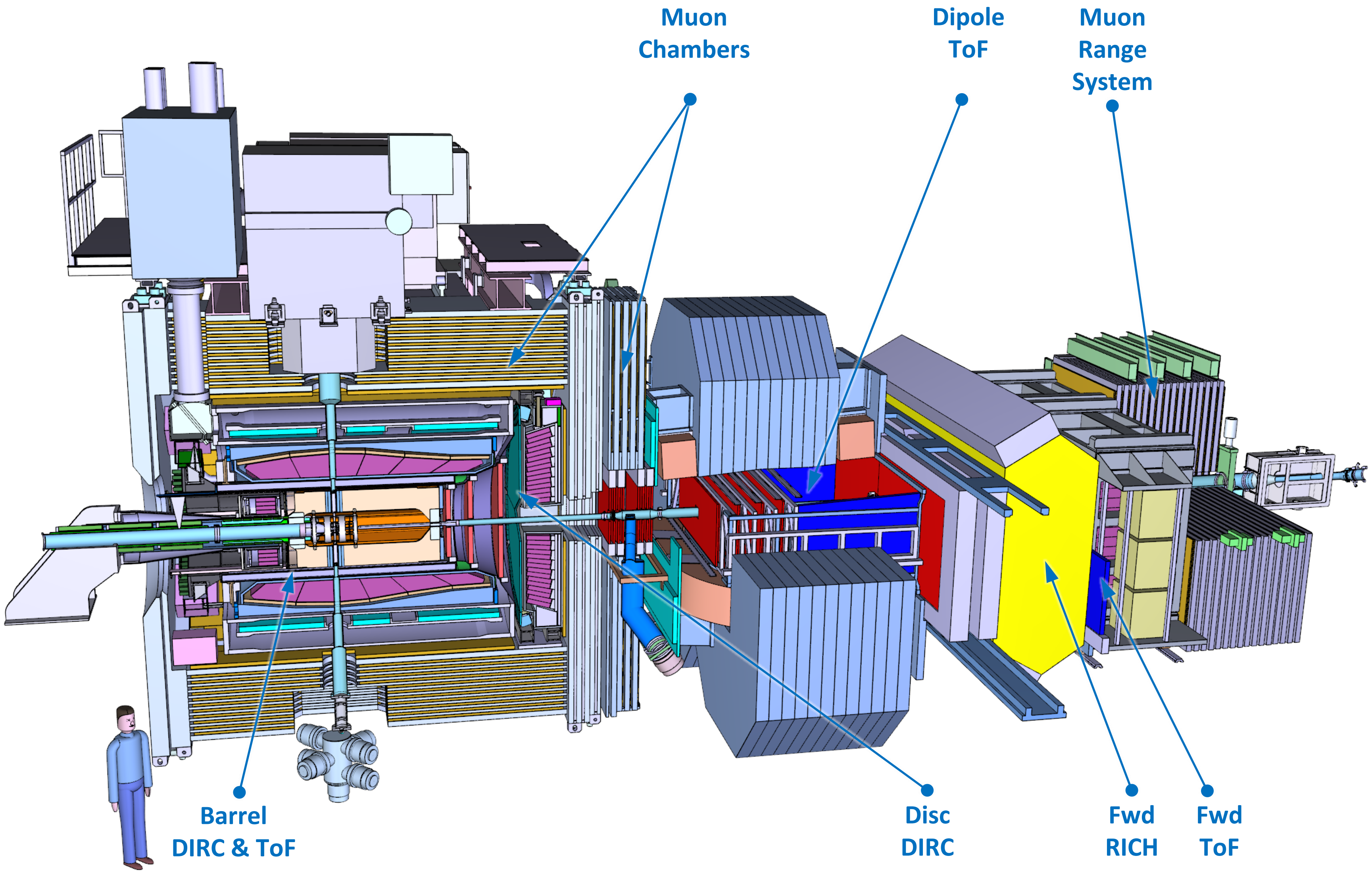
- $100\ ps/\sqrt{E[GeV]}$

27x14 modules
54x28 cells

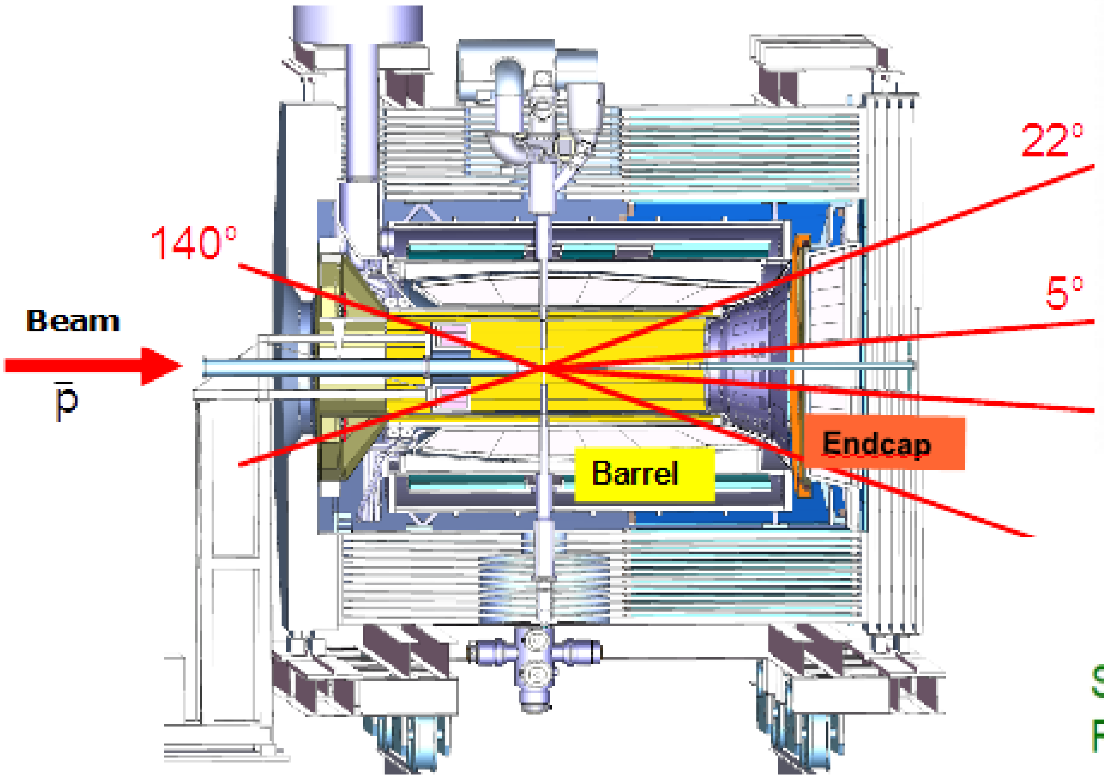


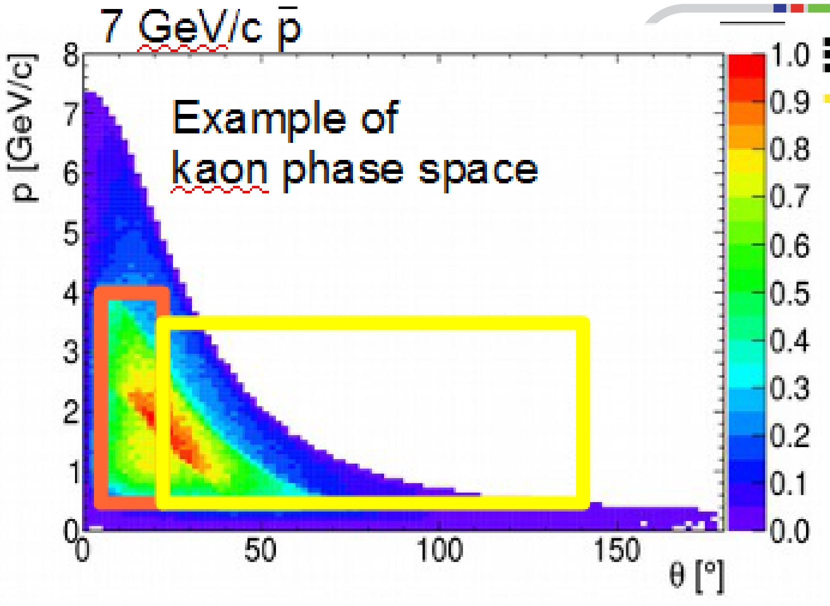


The PANDA Detector – Partcile ID



PANDA DIRC counters



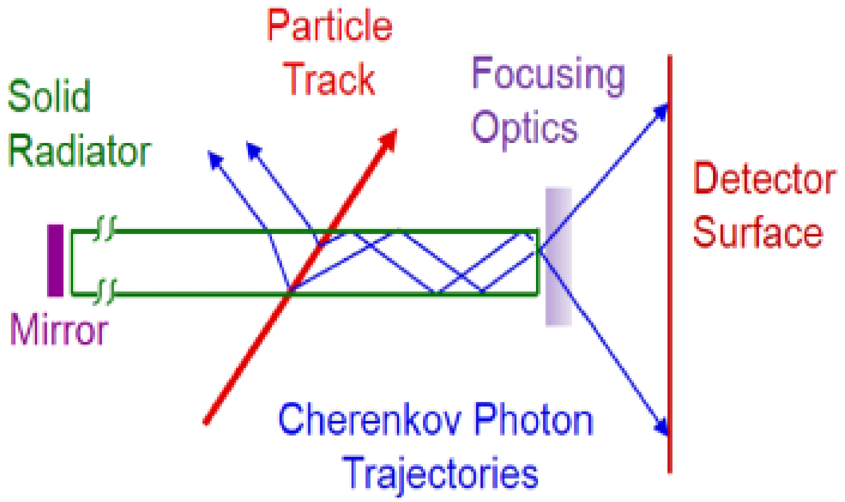


Barrel DIRC

Goal: 3 s.d. π/K separation up to 3.5 GeV/c

Endcap disc DIRC

Goal: 4 s.d. π/K separation up to 4 GeV/c



Magnitude of photon angles
in radiator preserved

Barrel DIRC

Baseline design: based on BABAR DIRC with key improvements

Barrel radius ~48 cm; expansion volume depth: 30 cm

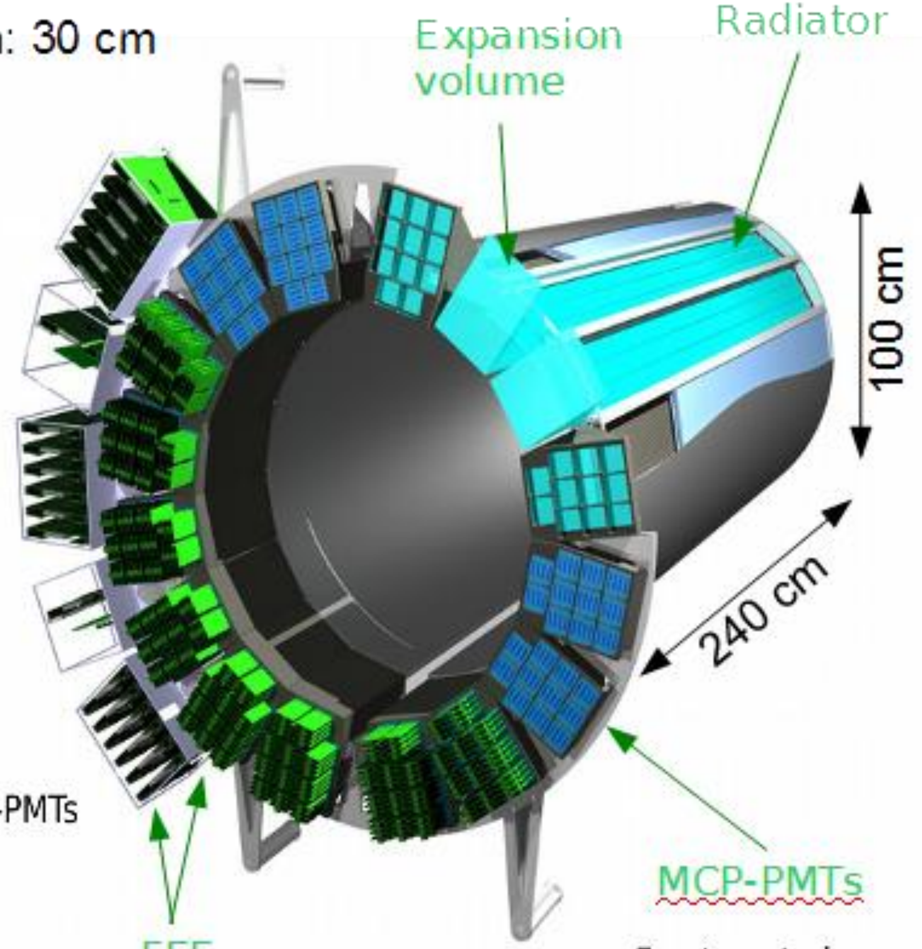
48 narrow radiator bars, synthetic fused silica

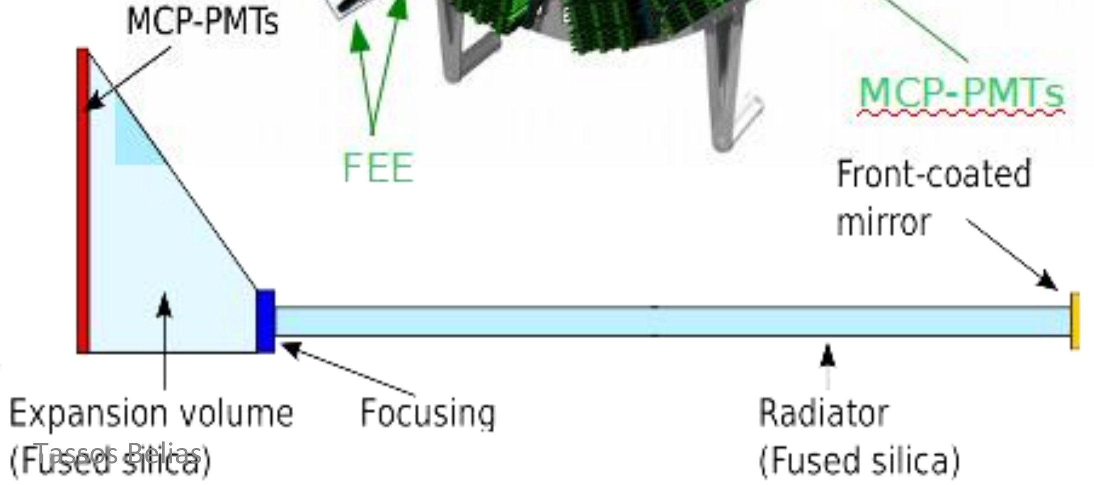
17 mm (T) x 53 mm (W) x 2400 mm (L).

- Focusing optics:
  triplet spherical lens system
- Compact expansion volume:
  30 cm deep solid fused silica prisms
  ~11000 channels of MCP-PMTs
- Fast FPGA based read out electronics:
  ~ 100 ps per photon timing resolution

- Expected performance:
  better than 3 s.d. π/K separation
  for entire acceptance

- Conservative design:
  similar to proven BaBar DIRC design,
  which would meet PANDA
  PID requirements

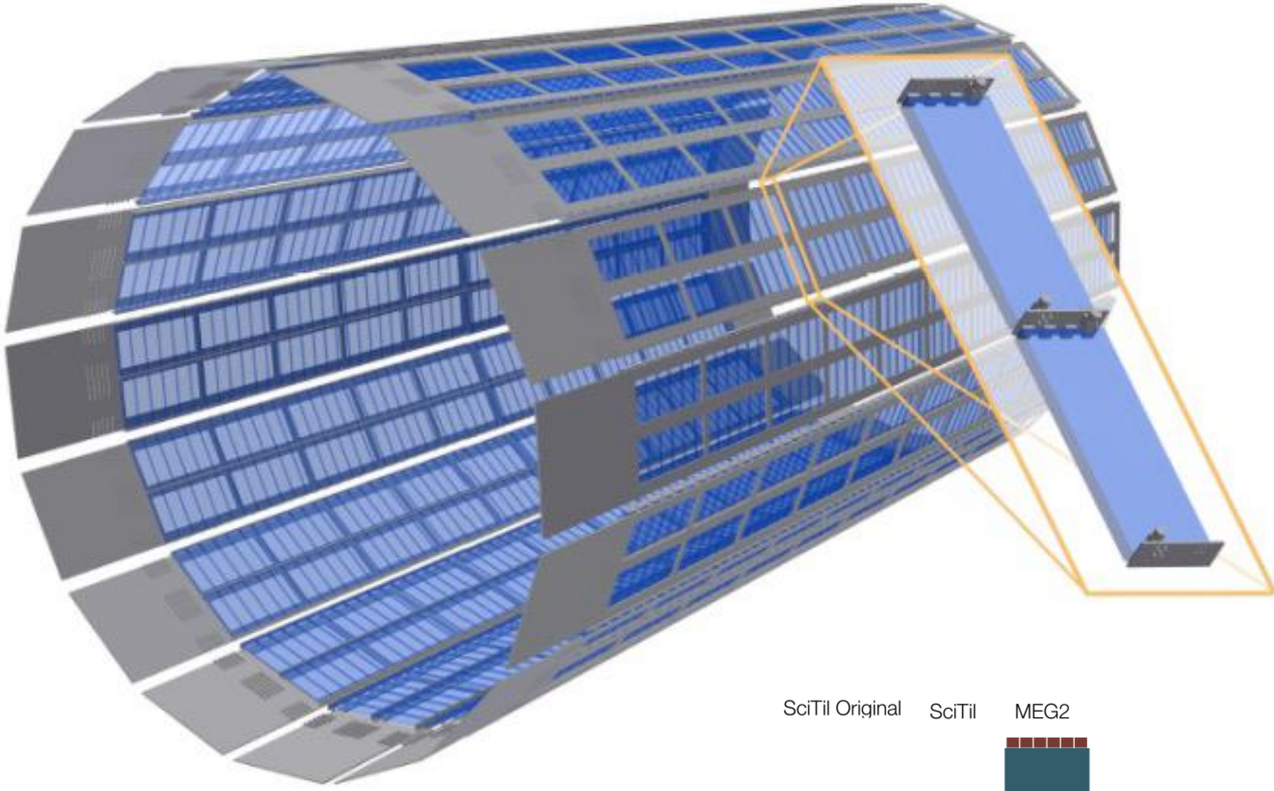


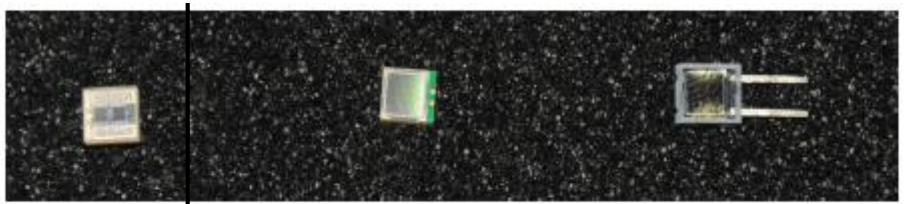


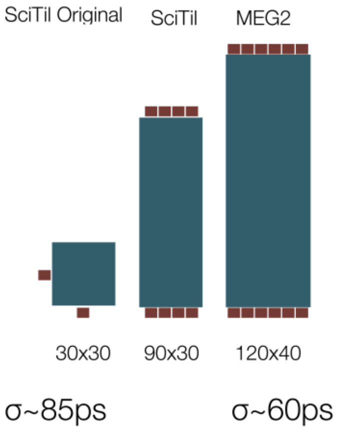
Barrel ToF - Scintillator Tile Hodoscope

Detector for ToF and event timing:

- Scintillator tiles 5 mm thick
  - BC 404, BC 408 or BC 420
  - Space points with precision timing
  - Lowest possible material budget
- Photon readout with SiPMs (3x3 mm^2)
  - High PDE, time resolution, rate capability
  - Work in B-fields, small, robust, low bias
  - *High intrinsic noise*
  - *Temperature dependence*
- System time resolution: <100 ps
- ToFPET ASIC for SiPM readout
- Layout optimizatoion
  - Serial readout, more SiPM
  - Multilayer PCB for transmission







very first result
σ<75ps

Muon Detector System

Challenge

- Muons have low momenta, high π-BG
→ Multi-layer range system

System layout

- Barrel: 12+2 layers in yoke
- Endcap: 5+2 layers
- Muon Filter: 4 layers
- Fw Range System: 16+2 layers
- Detectors: Drift tubes with wire & cathode strip readout

System status

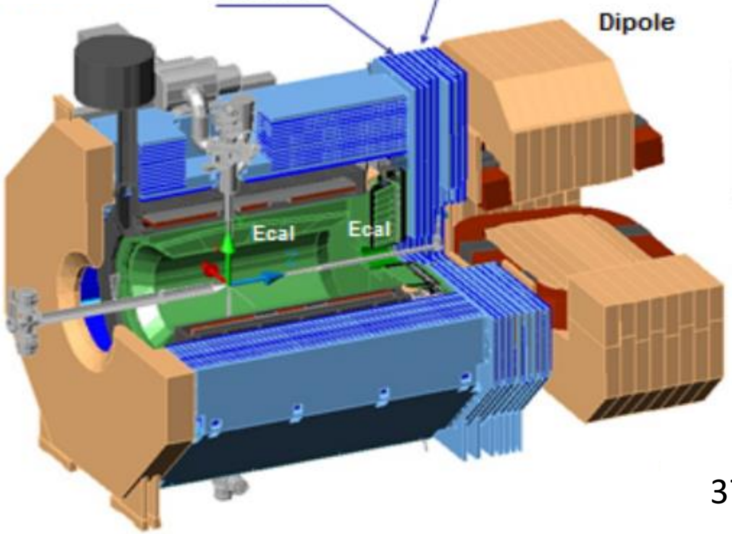
- TDR approved Sep 2014
- Range system tests at CERN

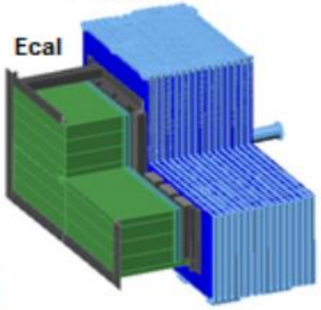
Barrel
2133 MDTs

Endcap
618 MDTs

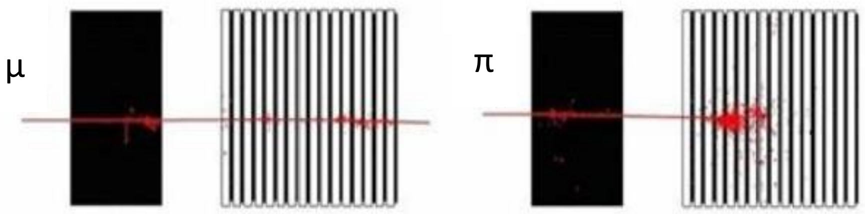
μ-Filter
424 MDTs

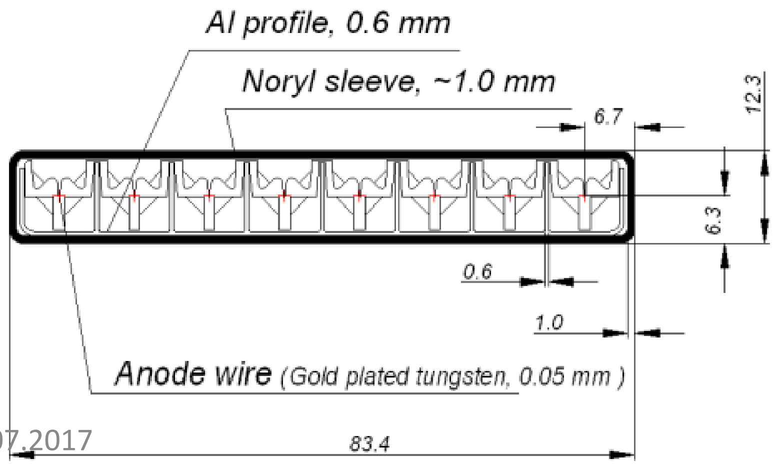
FRS
576 MDTs





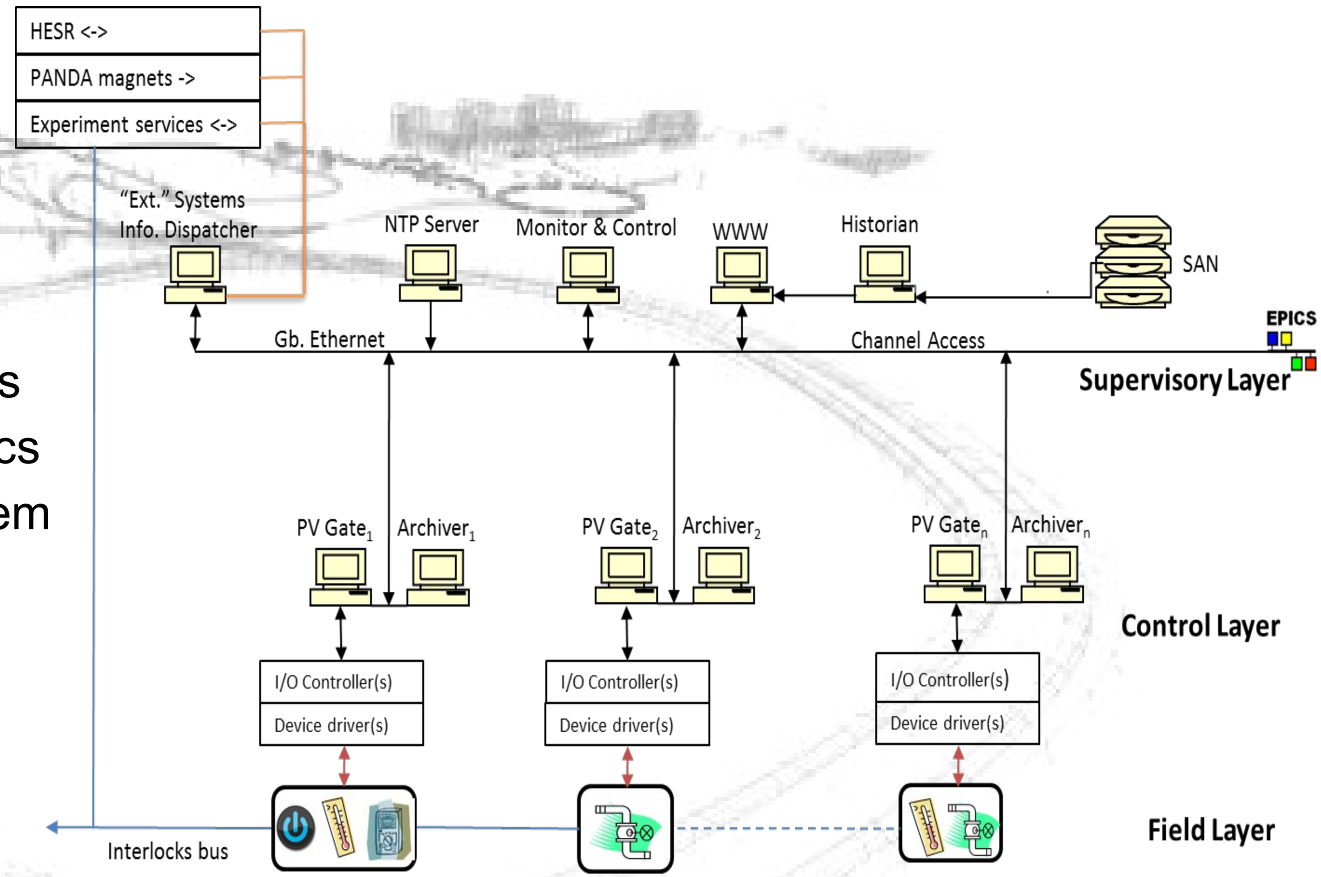
Total
3751 MDTs





Detector Controls

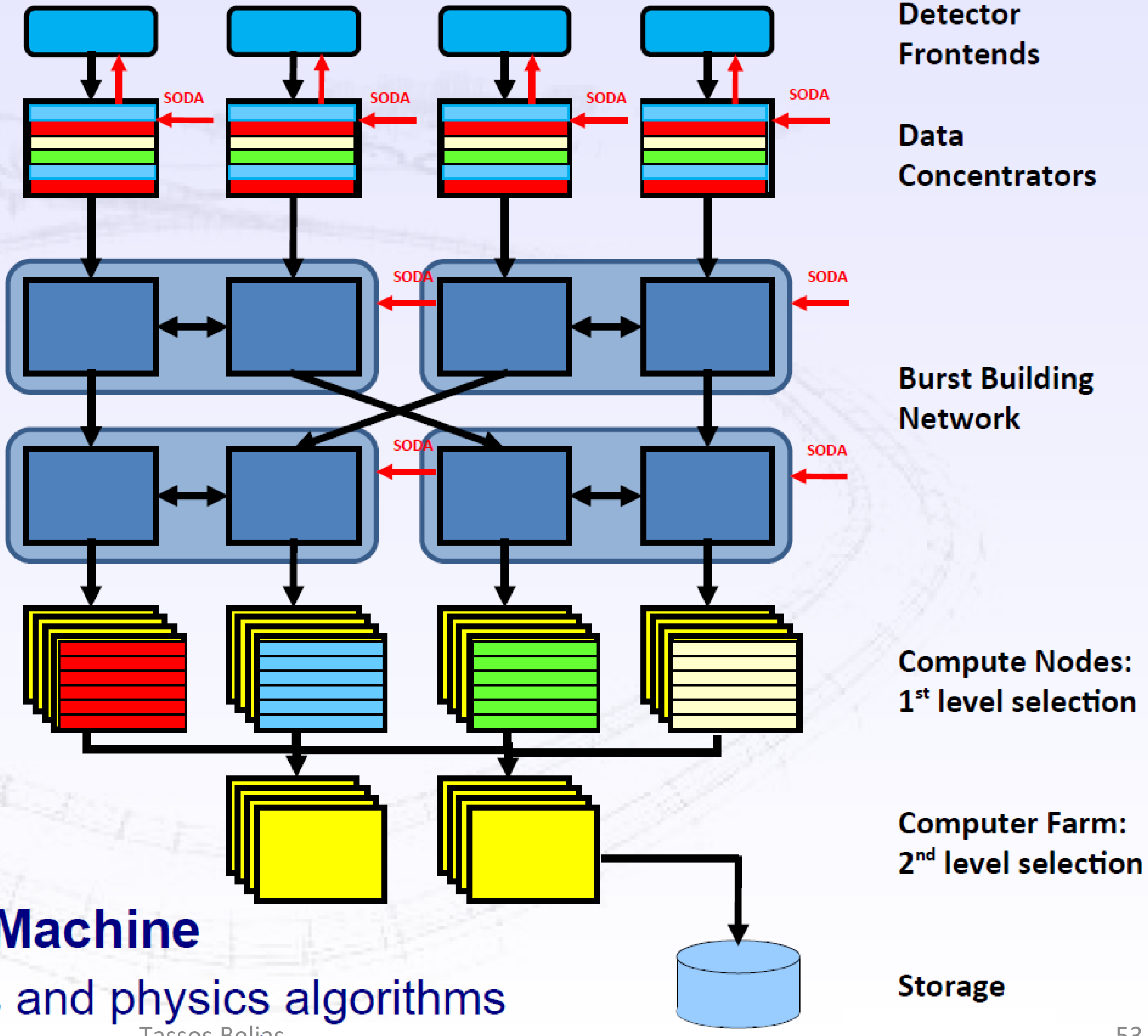
- Field Layer
  - PANDA systems specific
  - Detector Safety System
- Control Layer
  - Native EPICS I/O controllers
  - Target: hybrid LabView-Epics
  - Archiving by each sub-system
- Supervisory Layer
  - Controls GUI interface
  - Interface with HESR
  - Storage of PV databases
- TDR work:
  - Writing of first draft is going on,
  - Need demonstrator for multiple systems:
    → Joint testbed with 3 systems in Mainz set up for Apr/May



DAQ – No hardware trigger

Self triggered readout

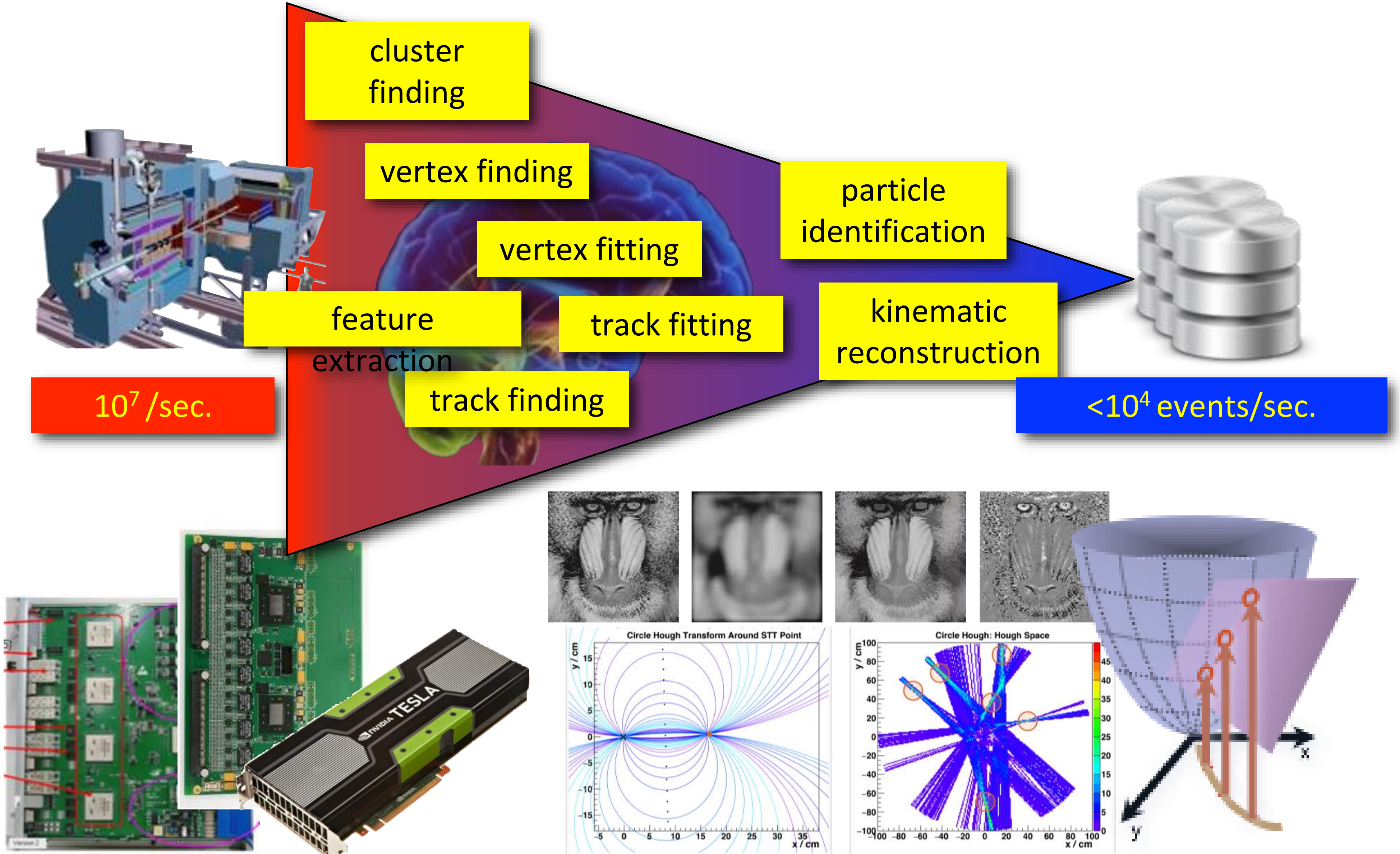
- Components:
  - Time distribution: SODA
  - Intelligent frontends
  - Powerful compute nodes
  - High speed network
- Data Flow:
  - Data reduction
  - Local feature extraction
  - Data burst building
  - Event selection
  - Data logging after online reconstruction



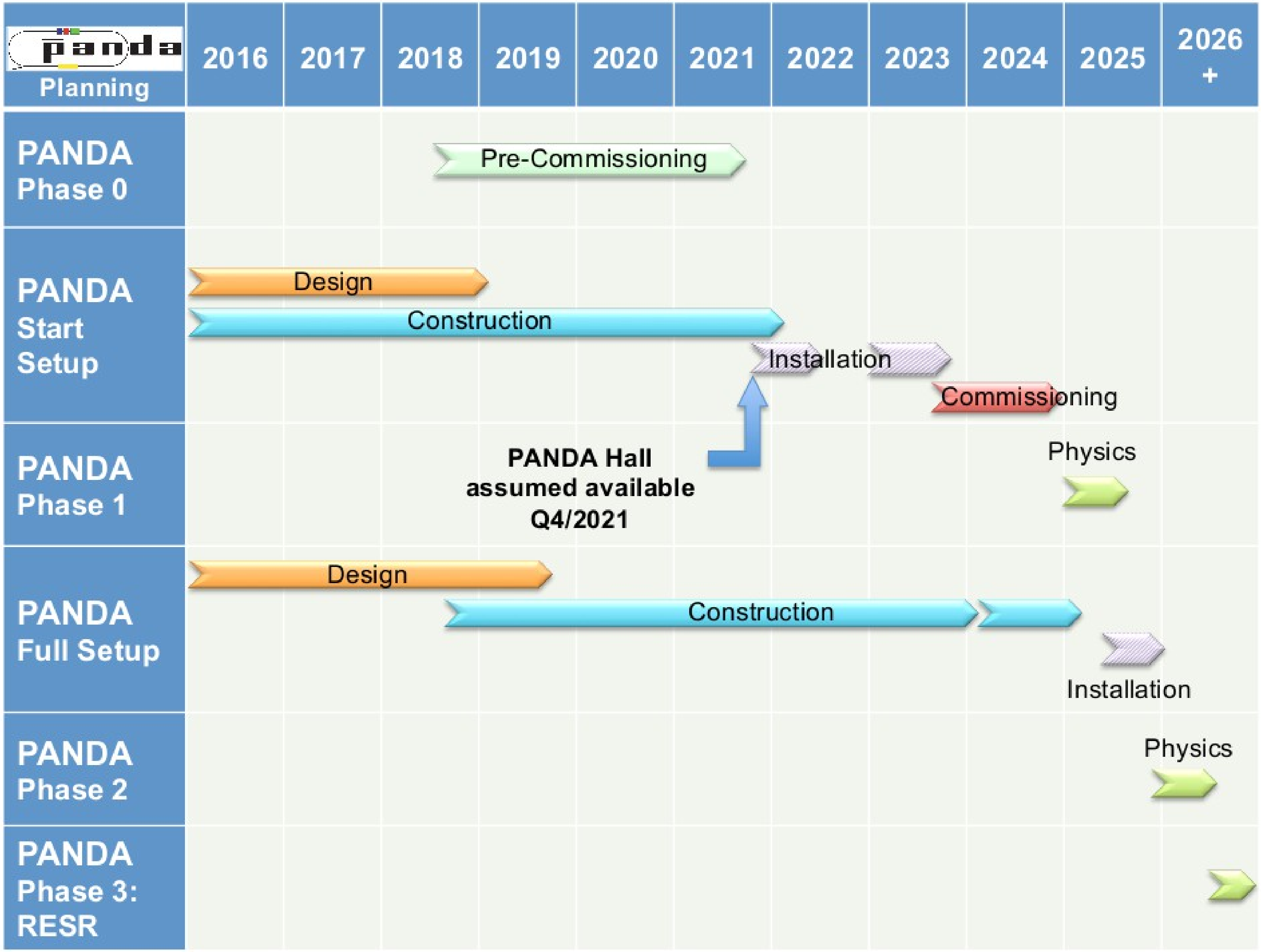
→ **Programmable Physics Machine**

Online selection schemes and physics algorithms are a key for successful measurements

Intelligent *in-situ* data processing



PANDA Schedule



- Construction of Phase 1 systems has started

- Installation periods:
- 10/2021- 6/2022: solenoid, dipole, supports etc.
- 1/2023-10/2023: all other systems

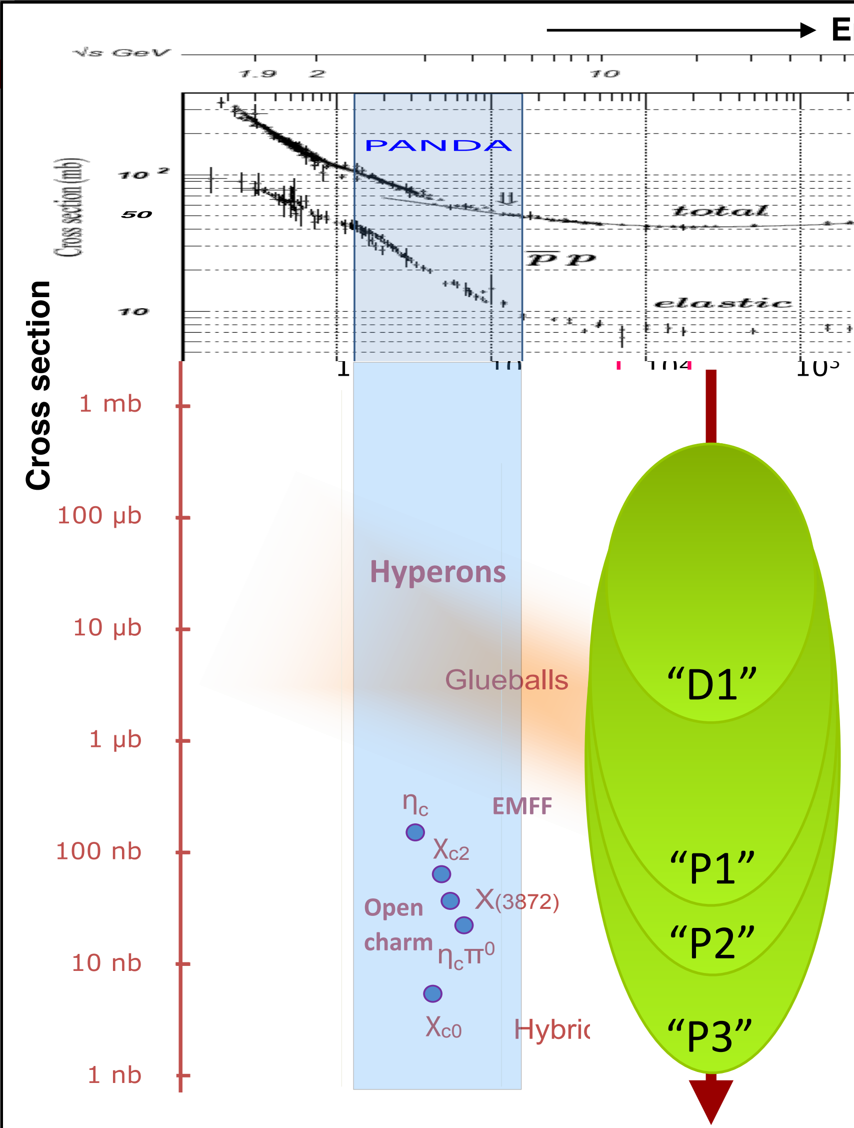
- Commissioning with protons 2024

- Start of physics with antiprotons in 2025

Status of TDRs (Phase-1)

2018 DCS and DAQ TDR
2019 GEM TDR
and Computing TDR after FAIR Comp CDR is accepted

From “day-one” to “phase-3”



- Staging of physics program guided by available luminosity.
- PANDA physics program is HUGE, enough opportunities at each stage.

The PANDA Collaboration

More than 450 physicists from 70 institutions in 19 countries

Aligarh Muslim University
U Basel
IHEP Beijing
U Bochum
Magadh U, Bodh Gaya
BARC Mumbai
IIT Bombay
U Bonn
IFIN-HH Bucharest
U & INFN Brescia
U & INFN Catania
NIT, Chandigarh
AGH UST Cracow
JU Cracow
U Cracow
IFJ PAN Cracow
GSI Darmstadt

Karnatak U, Dharwad
TU Dresden
JINR Dubna
U Edinburgh
U Erlangen
NWU Evanston
U & INFN Ferrara
FIAS Frankfurt
LNF-INFN Frascati
U & INFN Genova
U Glasgow
U Gießen
Birla IT&S, Goa
KVI Groningen
Sadar Patel U, Gujart
Gauhati U, Guwahati
IIT Guwahati
Jülich CHP

Saha INP, Kolkata
U Katowice
IMP Lanzhou
INFN Legnaro
U Lund
HI Mainz
U Mainz
U Minsk
ITEP Moscow
MPEI Moscow
U Münster
BINP Novosibirsk
Novosibirsk State U
IPN Orsay
U & INFN Pavia
Charles U, Prague
Czech TU, Prague
IHEP Protvino

PNPI St. Petersburg
U of Sidney
U of Silesia
U Stockholm
KTH Stockholm
Suranree University
South Gujarat U, Surat
U & INFN Torino
Politecnico di Torino
U & INFN Trieste
U Tübingen
TSL Uppsala
U Uppsala
U Valencia
SMI Vienna
SINS Warsaw
TU Warsaw

PANDA: physics and technology

PANDA offers a *physics-driven* environment to …

… study the dynamics of Quantum Chromodynamics.

… bring together the experts in nuclear/hadron/particle physics.

… build on the next generation instruments and techniques.

http://www-panda.gsi.de/

Civil Construction 2017/18

Official ground breaking
in summer 2017

Same area now

Ready 2025