
# $\overline{\mathrm{P}}$ANDA Experiment at FAIR

- The FAIR facility;
- The $\overline{\mathrm{P}}$ANDA experiment;
- The $\overline{\mathrm{P}}$ANDA scientific program;
- Double strange system.

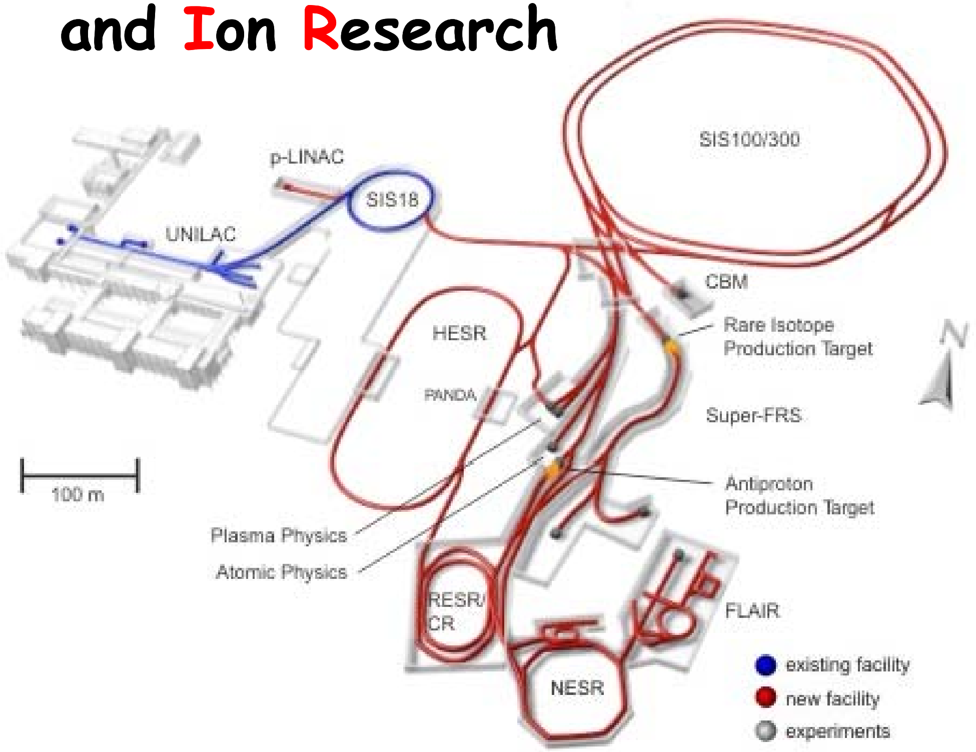
INFN
Paola Gianotti
Istituto Nazionale di Fisica Nucleare

# Facility for Antiproton and Ion Research

- FAIR (Facility for Antiproton and Ion Research) will provide scientists in the world with an outstanding accelerator and experimental facility for studying matter at the level of atoms, atomic nuclei, and other sub-nuclear constituents of matter.

# The FAIR Facility

**Facility for Antiproton and Ion Research**




**Antiproton production**

- Proton Linac 50 MeV
- Accelerate p in SIS18 / 100
- Produce p on Cu target
- Collect in CR, cool in RESR

## Primary Beams

- $10^{12}$/s; 1.5-2 GeV/u; $^{238}U^{28+}$
- Factor 100-1000 over present intensity
- $2\times10^{13}$/s 30 GeV protons up to 90 GeV
- $10^{10}$/s $^{238}U^{73+}$ up to 35 GeV/u
- 50 MeV new proton Linac

## Secondary Beams

- Broad range of radioactive beams up to 1.5 - 2 GeV/u
- Intensity up to factor 10 000 over present
- Antiprotons 1.5 - 15 GeV/c

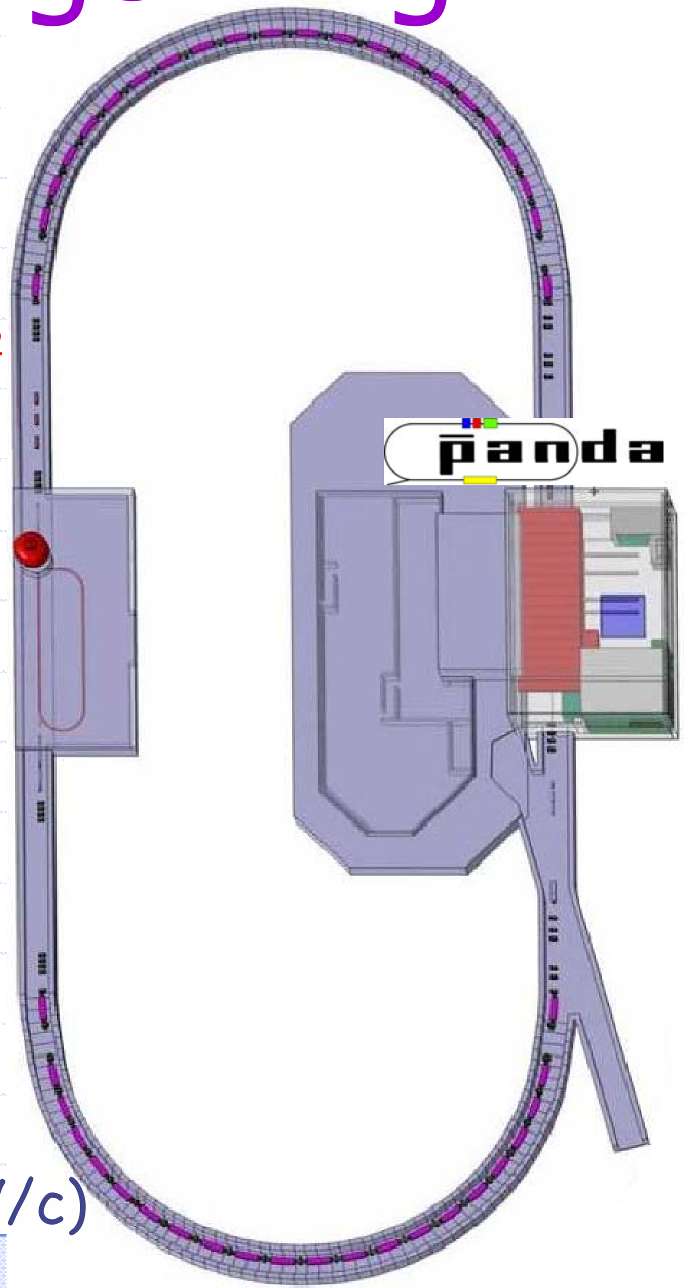
## Storage and Cooler Rings

- $10^{11}$ stored and cooled 0.8 - 14.5 GeV antiprotons

## Parallel operation

- up to 4 different independent experiments

# The High Energy Storage Ring




- Circumference 574 m
- $P_{beam}$ = 1,5 – 15 GeV/c
- $N_{stored}$ = $5x10^{10}$ p
- Internal thick Target $4x10^{15}$ $cm^{-2}$
- Beam lifetime > 30 min

High resolution mode

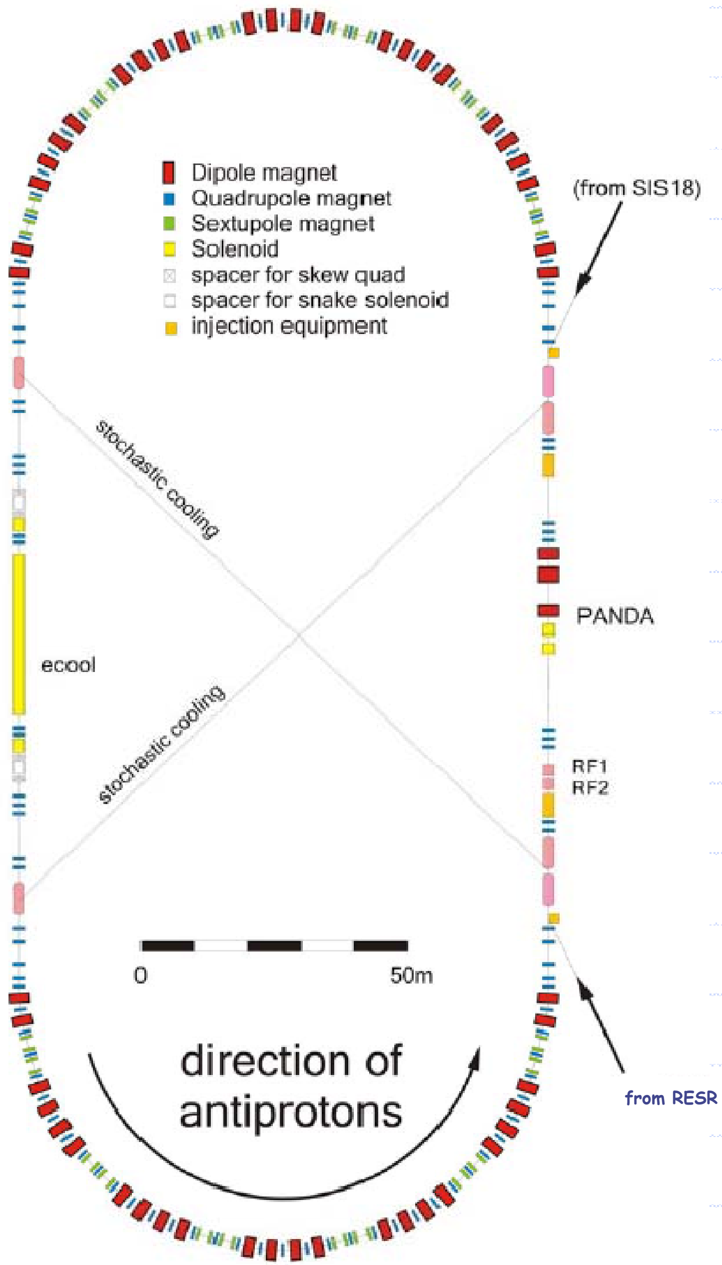
- $\delta p/p \sim 4x10^{-5}$ (electron cooling up to 8.9 GeV/c)
- Luminosity = $10^{31}$ $cm^{-2}$ $s^{-1}$

High luminosity mode

- Luminosity = $2 \times 10^{32}$ $cm^{-2}$ $s^{-1}$
- $\delta p/p \sim 10^{-4}$ (stochastic cooling from 3.8 GeV/c)

# The HESR operation

| **Effective target thickness (pellets): $4 \times 10^{15}$ cm$^{-2}$**<br>**Beam radius at target (rma): 0.3 mm** | | |
|---|---|---|
| | High Resolution Mode | High Luminosity Mode |
| Momentum range | 1.5 – 8.9 GeV/c | 1.5 – 15 GeV/c |
| Number of antiprotons | $10^{10}$ | $10^{11}$ |
| Peak luminosity | $2 \times 10^{31}$ cm$^{-2}$s$^{-1}$ | **$2 \times 10^{32}$ cm$^{-2}$s$^{-1}$** |
| Momentum resolution (rma) | **$\Delta p/p \leq 4 \times 10^{-5}$** | $\Delta p/p \leq 1 \times 10^{-4}$ |
| Beam cooler | Electron ≤ 8.9 GeV/c | Stochastic ≥ 3.8 GeV/c |



# The HESR operation

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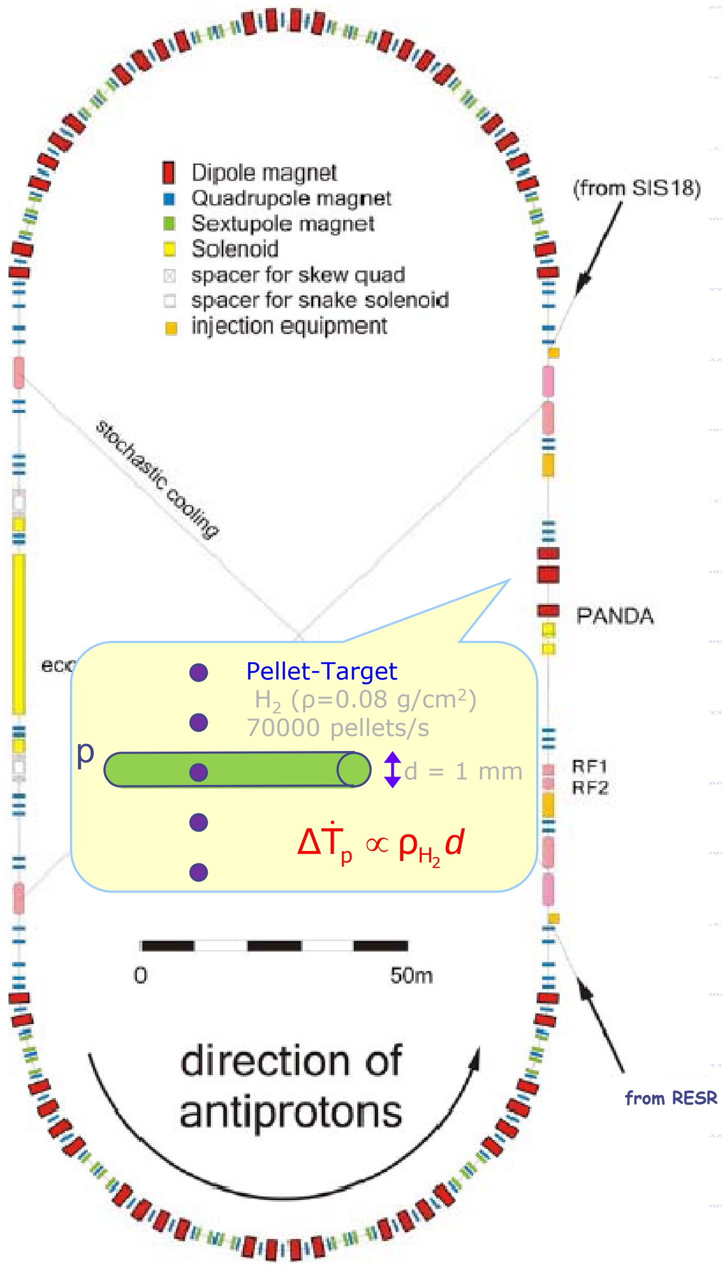
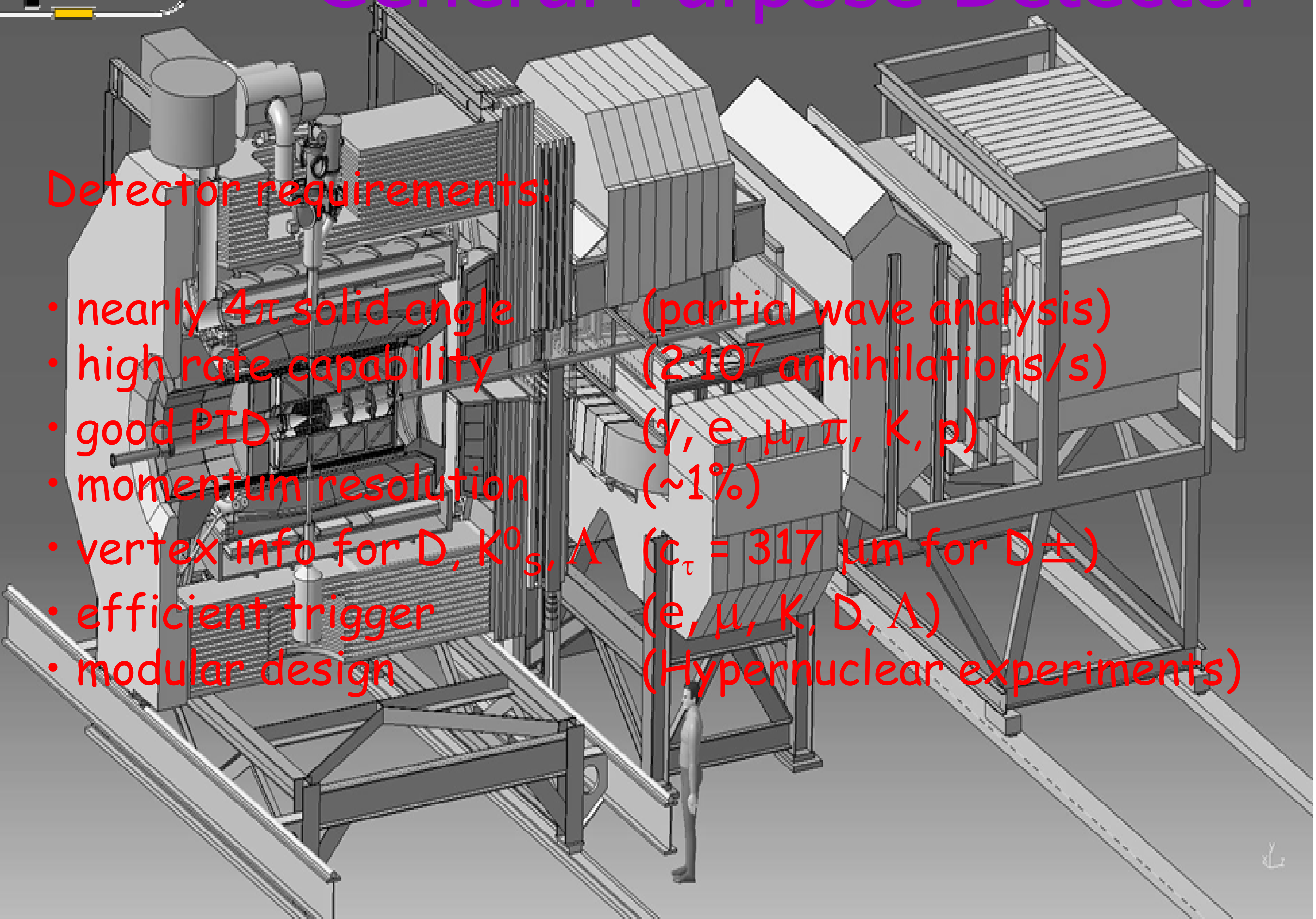
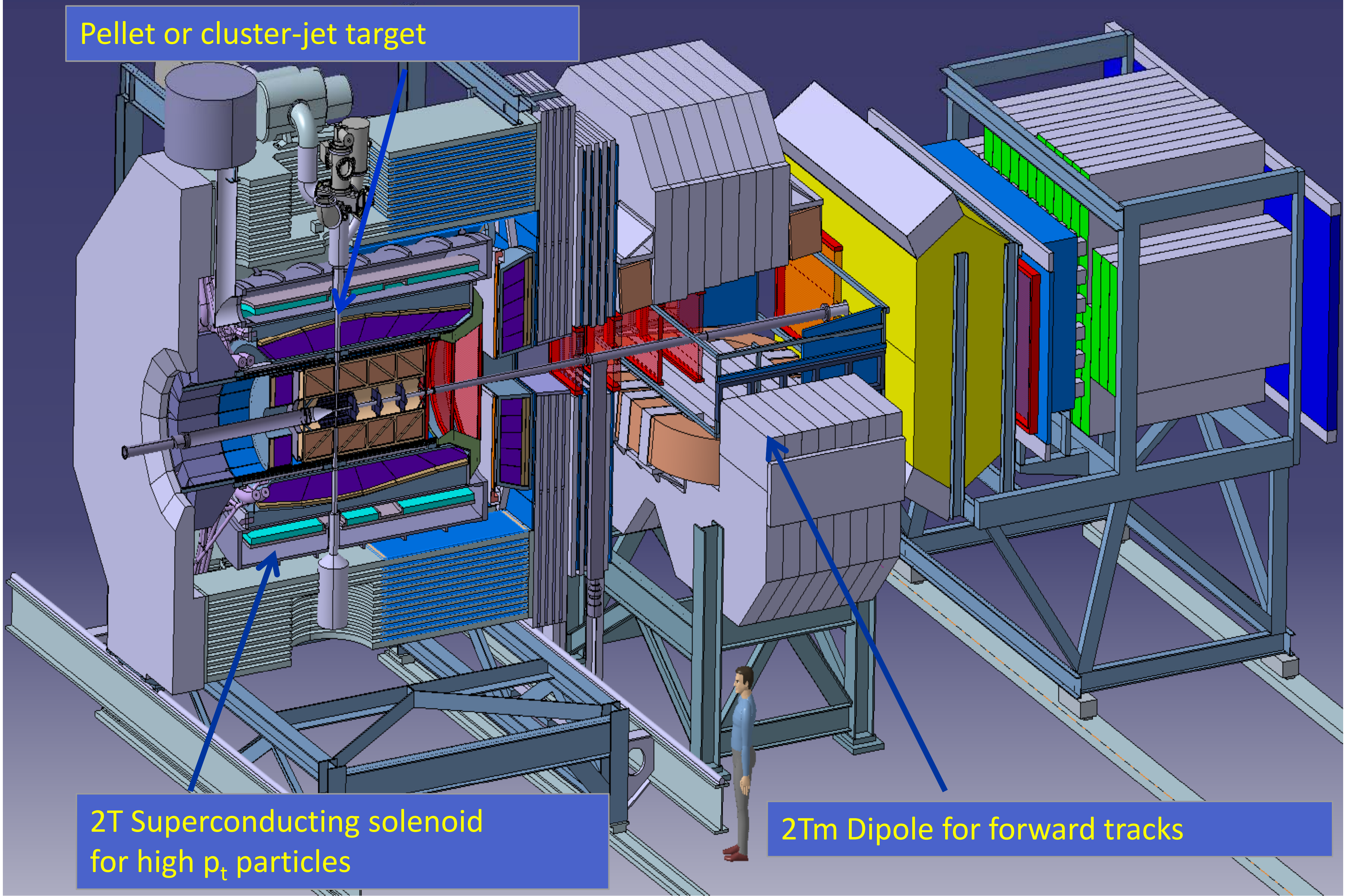


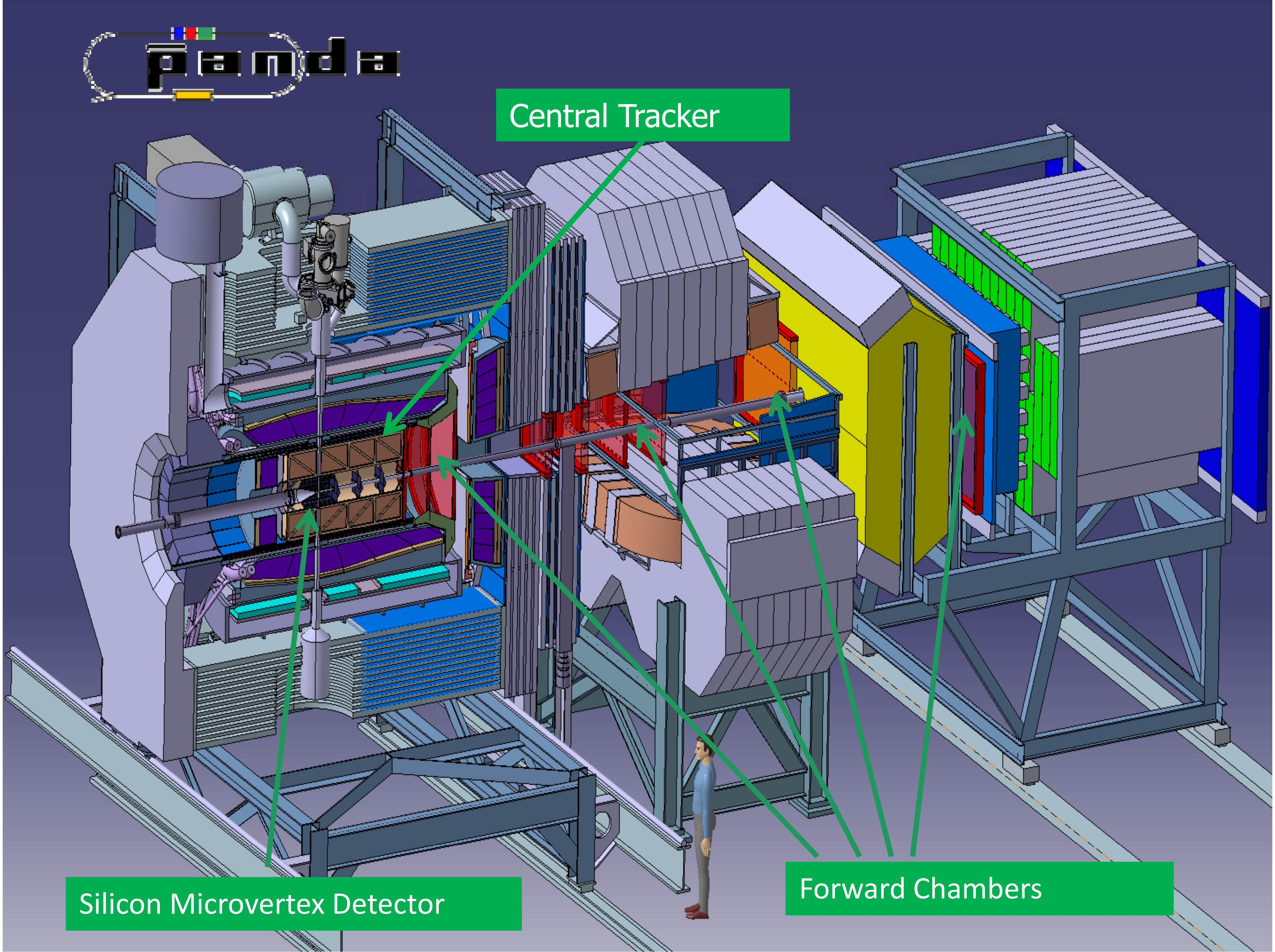
# General Purpose Detector

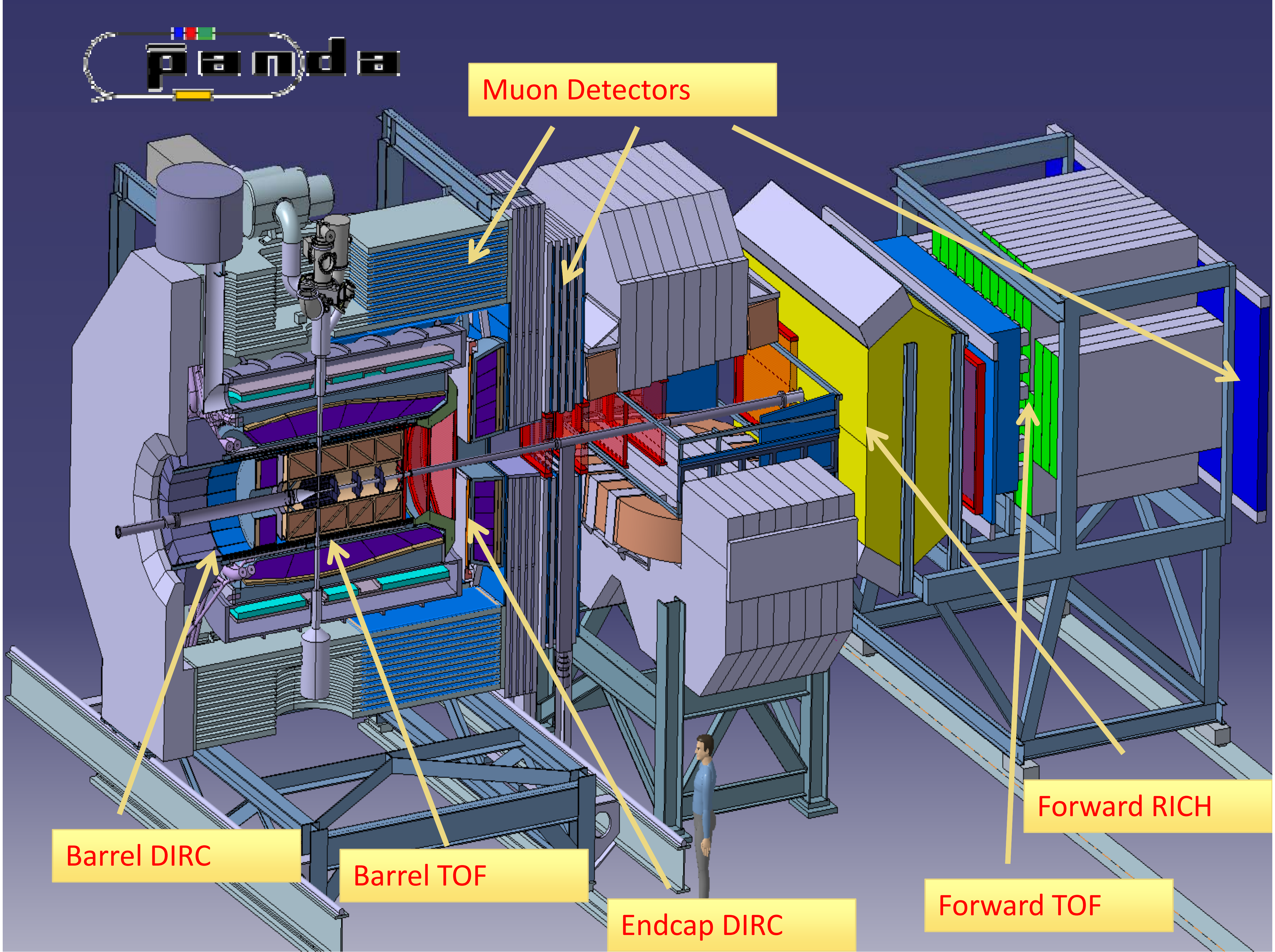


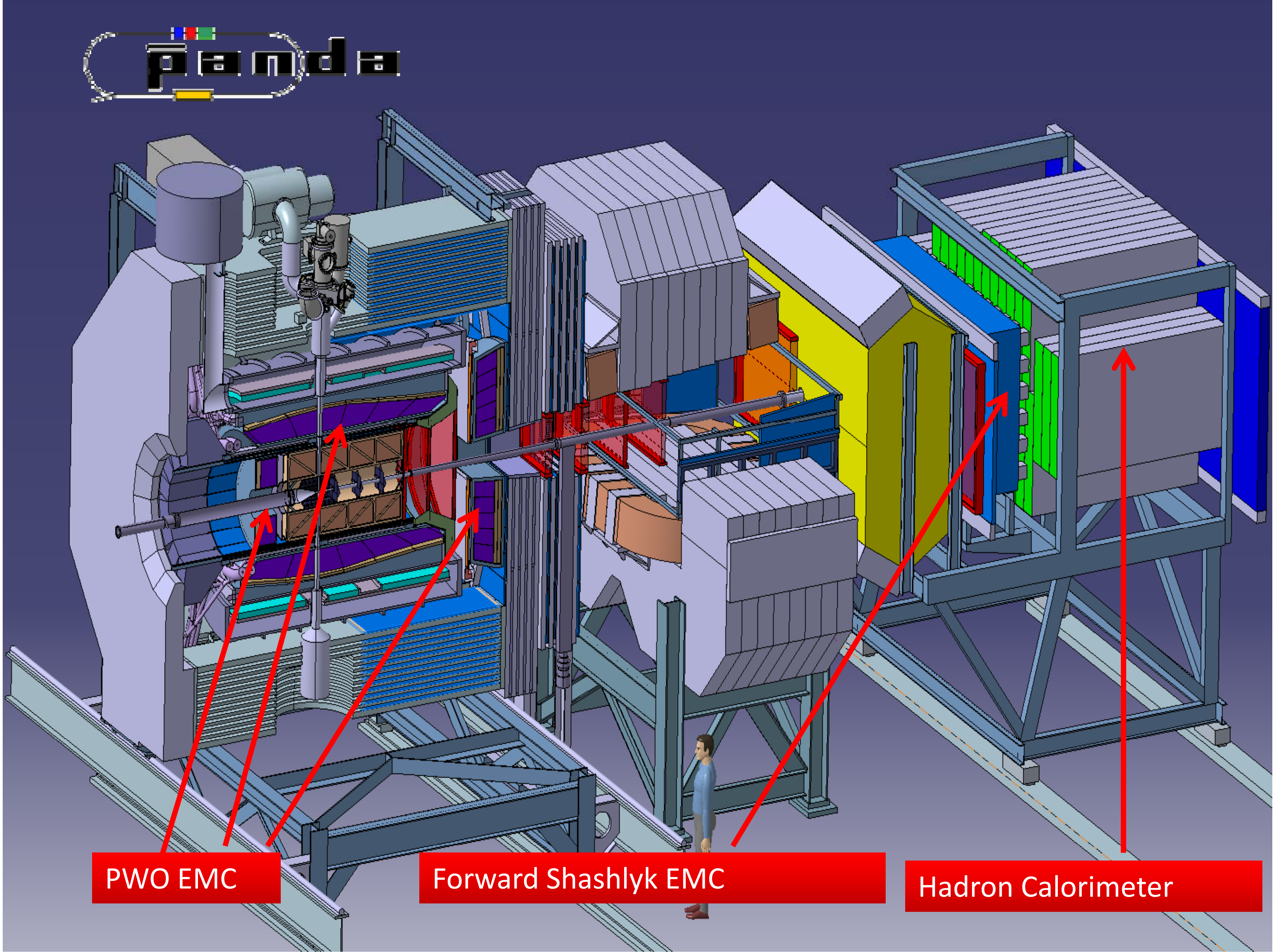
Detector requirements:

- nearly $4\pi$ solid angle (partial wave analysis)
- high rate capability ($2\cdot10^7$ annihilations/s)
- good PID ($\gamma$, e, $\mu$, $\pi$, K, p)
- momentum resolution (~1%)
- vertex info for D, $K^0_S$, $\Lambda$ ($c_\tau$ = 317 $\mu$m for D±)
- efficient trigger (e, $\mu$, K, D, $\Lambda$)
- modular design (Hypernuclear experiments)

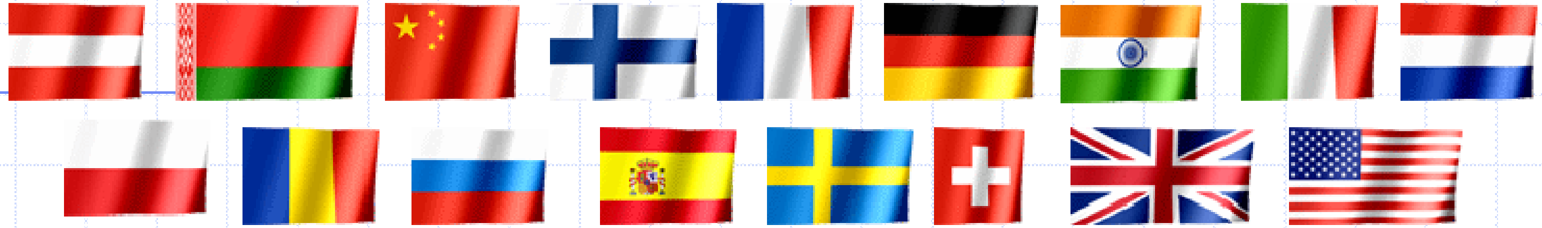

Pellet or cluster-jet target
2T Superconducting solenoid for high $p_t$ particles
2Tm Dipole for forward tracks


panda
Central Tracker
Silicon Microvertex Detector
Forward Chambers


panda
Muon Detectors
Barrel DIRC
Barrel TOF
Endcap DIRC
Forward TOF
Forward RICH


PWO EMC
Forward Shashlyk EMC
Hadron Calorimeter

# The Collaboration



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SMI Vienna
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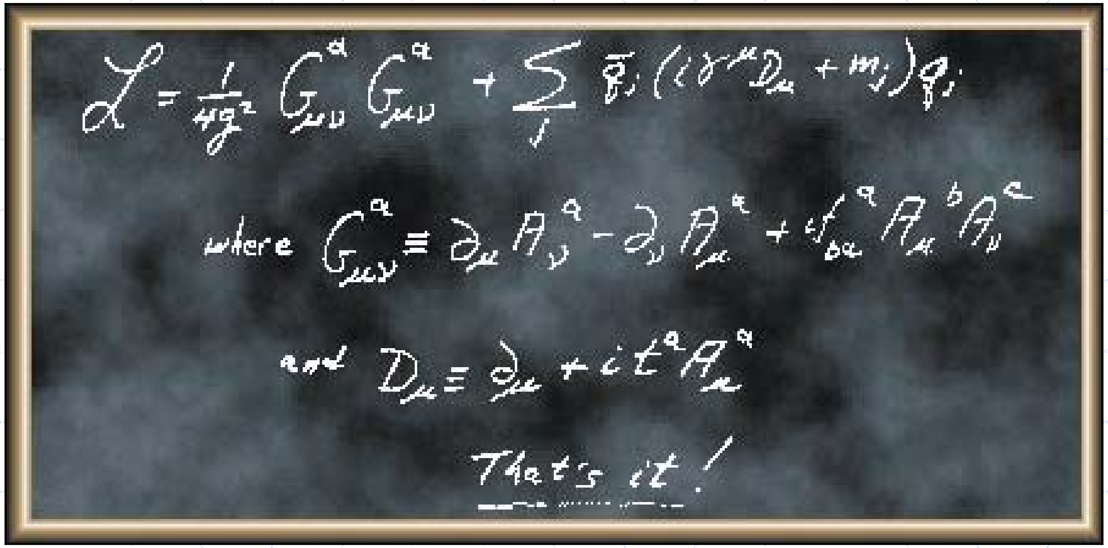
U Warsaw

More than 420 physicists from 55 institutions in 17 countries

# Quantum Chromodynamics




**The QCD Lagrangian** is, in principle, a simple and complete description of the strong interaction:

- there is just one overall coupling constant $g$

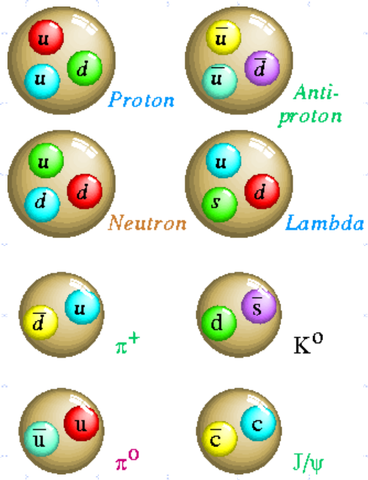
and

- six quark-mass parameters $m_j$ for the six quark flavors

But,
it leads to equations that are hard to solve

# The Confinement

None of the particles that we've actually seen appear in the formula and none of the particles that appear in the formula has ever been observed.

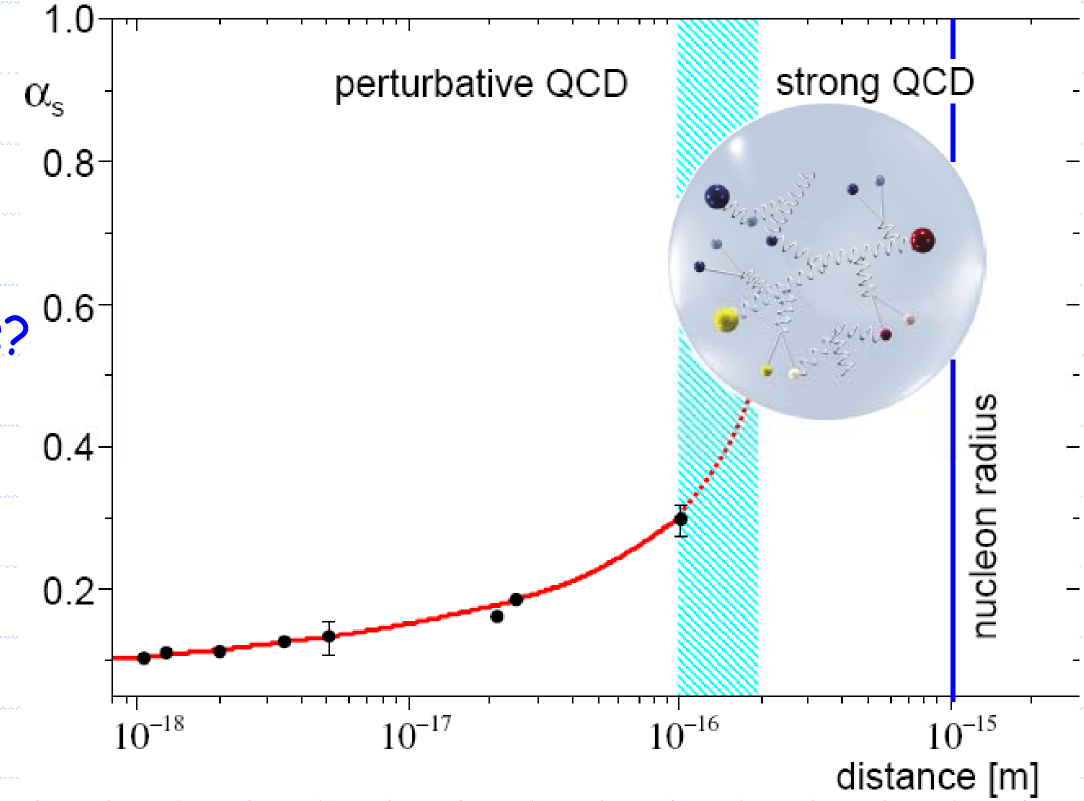



Furthermore, we've never seen particles carrying fractional electric charge, which we nonetheless ascribe to the quarks.

And certainly we haven't seen anything like gluons--massless particles mediating long-range strong forces.

So if QCD is to describe the world, it must explain why quarks and gluons cannot exist as isolated particles. That is the so-called confinement problem.

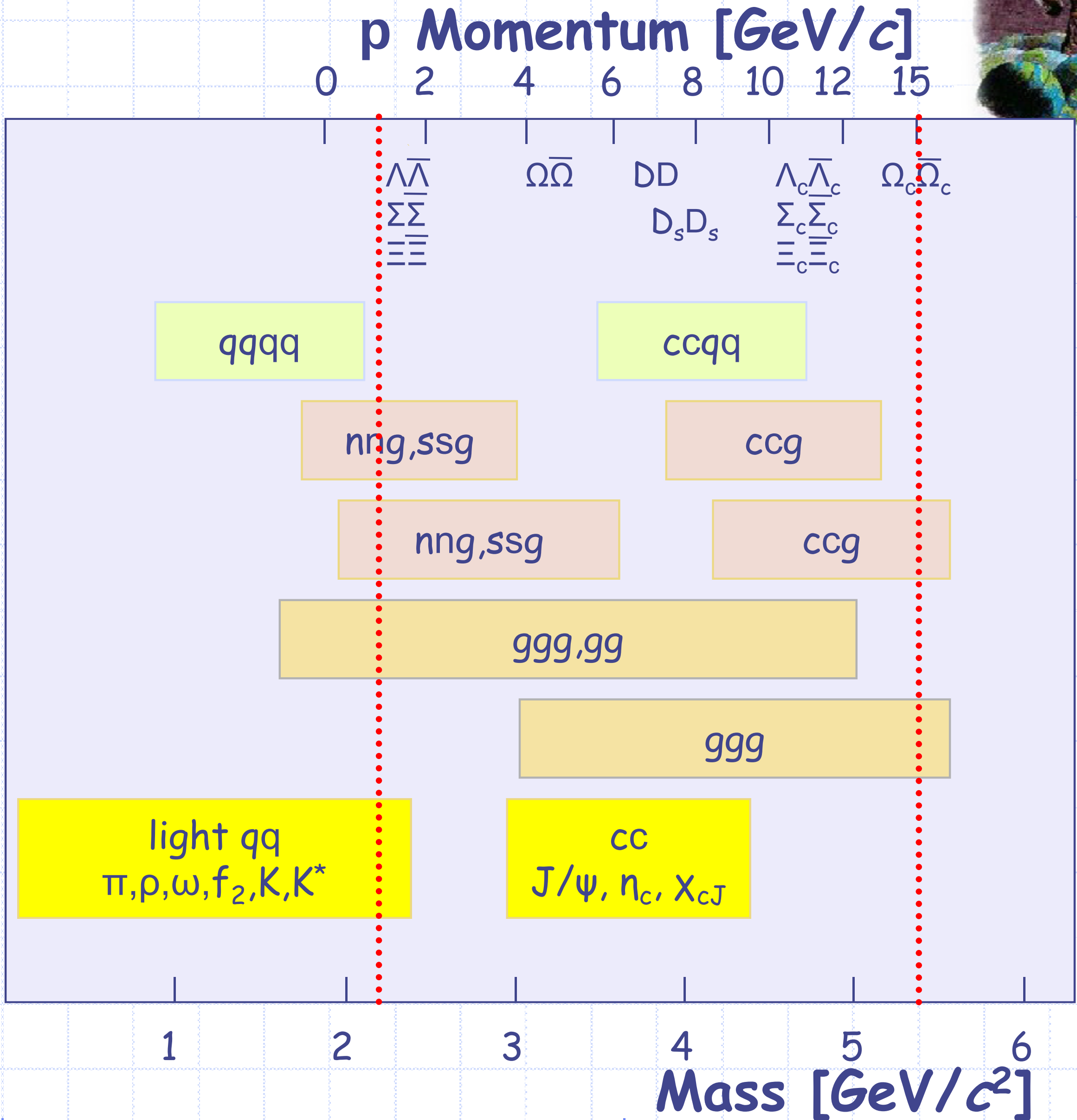
# Open Problems




- Why we do not observe free quarks?
  Charmonium spectroscopy
  → quark confinement
- Why only color singlet are allowed?
  Hadrons (qqq or $q\bar{q}$)
  Gluonic excitations
  Multi-quark systems
- Which is the mechanism giving mass to hadrons?
  Partial restoration of chiral symmetry → $\bar{p}A$ interaction
  Meson properties in the nuclear medium
- Which is the structure of the Nucleon?
  Hard scattering processes & soft fragmentation
  → From partons to hadrons

# PANDA playground

- Meson spectroscopy
  - light mesons
  - charmonium
  - exotic states
    - ✓glueballs
    - ✓ hybrids
    - ✓molecules/multiquarks
  - open charm
- Baryon/antibaryon production
- Charm in nuclei
- Strangeness physics
  - Hyperatoms
  - S = -2 nuclear system
    - ✓ $\Xi^-$ nuclei
    - ✓ $\Lambda\Lambda$ hyepernuclei
- e.m. processes



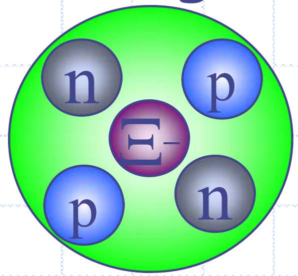

HYP-X @J-PARC

# Double Strange Systems (DDS)

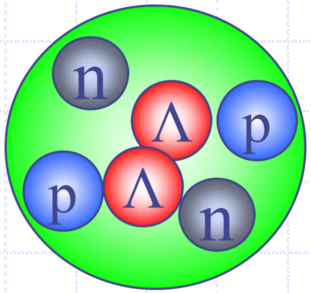
3 different systems containing double strangeness (S=-2)

## $\Xi^-$ hypernuclei:

Interaction: $\Xi^-N$




**From $\Xi^-$hypernucleus to $\Lambda\Lambda$ hypernucleus: $\Xi^-N$-$\Lambda\Lambda$ coupling**

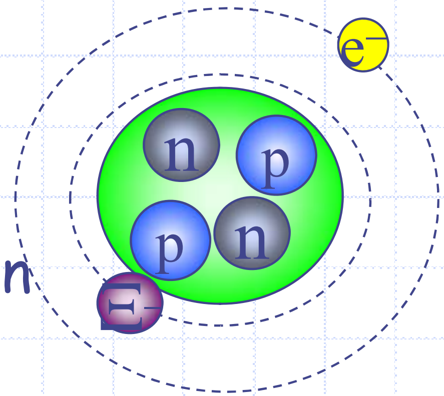



## Double $\Lambda$-hypernuclei:

Interactions: $\Lambda-\Lambda$

## Exotic hyperatoms:

Interactions: $\Xi^-$-nucleus: interplay between the Coulomb and nuclear potential



# $\Xi^-$N interaction

## Status of the art: (few data)

- $\Xi^- p \rightarrow \Xi^- p$ $\sigma_{el} \approx 24$mb (PLB633,2006,214)
  $\Xi^- p \rightarrow \Lambda\Lambda$ $\sigma \approx 4.3$mb
  ($\Xi^-$ produced in $(K^-,K^+)$ on p, with $p_{K^-}$=1.66GeV/c)
- $K^- (p) \rightarrow \Xi^- K^+$ on emulsions (NPA644,1998,365)
  mean free path in nucleus $\approx 4.7$fm for $p_{\Xi^-}$ = 0.6 GeV/c
- $K^-$ $^{12}C \rightarrow K^+$ $^{12}B_{\Xi}$ : (PRC61,2000,054603)

## Features:

- $\Xi$–N interaction: no contribution of I=1/2 *strange mesons* only $\pi, \rho, \omega, \eta$ ...
- $\Xi$-nucleus potential $V_{\Xi N}$
- $\Xi p \rightarrow \Lambda\Lambda$ coupling: contribution **only** from *strange mesons* only *K*

# A new way to Double Strange Systems: antiprotons

Up to now double strange systems have been produced with $K^-$ beam via the reaction:

$K^-$ (N, $\Xi^-$) $K^+$ (N- quasi free or bound in nucleus)

**PANDA idea is to use the high intensity antiproton beam**

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

$$\bar{p} + n \rightarrow \Xi^- + \bar{\Xi}^0$$

$\sigma_{reaction}$ = 2μb at 3GeV/c

Goal:

**maximize the "stopped $\Xi^-$" with a suitable set-up**

Target choice:

- **Advantages of nuclear target** :

  a) higher cross section (scaling as ~$A^{2/3}$)

  b) $\Xi^-$ slowing down in dense (nuclear) matter

- **Disadvantages of nuclear target** :

  c) high background (annihilation)

  d) high beam consuming (beam losses)

# ΛΛ Hypernuclei

## Status of the art:

| Nucleus | $B_{\Lambda\Lambda}({}_{\Lambda\Lambda}{}^{A}Z)$ [MeV] | $\Delta B_{\Lambda\Lambda}({}_{\Lambda\Lambda}{}^{A}Z)$ [MeV] | Reference | Reaction |
|---|---|---|---|---|
| ${}_{\Lambda\Lambda}{}^{10}\mathrm{Be}$ | 17.7± 0.4 | 4.3±0.4 | M.Danysz et al., PRL.11(1963) 29 | $K^- + A \rightarrow K^+ + \Xi^-$ |
| ${}_{\Lambda\Lambda}{}^{6}\mathrm{He}$ | 10.9±0.5 | 4.6±0.5 | D.J.Prowse, PRL.17(1966) 782 | $K^- + A \rightarrow K^+ + \Xi^-$ |
| ${}_{\Lambda\Lambda}{}^{10}\mathrm{Be}$ | 8.5±0.7 | -4.9±0.7 | KEK-E176 | $K^- + p \rightarrow K^+ + \Xi^-$ (q.f) |
| ${}_{\Lambda\Lambda}{}^{13}\mathrm{B}$ | $27.6\pm0.7^{+0.18}_{-0.11}$ | $4.9\pm0.7^{+0.18}$ | S.Aoki et al., PTP.85(1991) 1287 | $K^- + p \rightarrow K^+ + \Xi^-$ (q.f) |
| ${}_{\Lambda\Lambda}{}^{12}\mathrm{B}$ | | $4.5\pm0.5^{0.11}$ | P.Khaustov et al., PRC.61(2000)027601 | $({}^{12}C)_{atom}\Xi^- \rightarrow {}^{12}B_{\Lambda\Lambda} + n$ |
| ${}_{\Lambda\Lambda}{}^{6}\mathrm{He}$ | 7.25±0.19 | 1.01±0.2 | KEK-E373,NAGARA H.Takahashi et al., PRL.87(2001)212502-1 | $K^- + p \rightarrow K^+ + \Xi^-$ (q.f) |
| ${}_{\Lambda\Lambda}{}^{12}\mathrm{B}$ | | $\sigma\ (\theta<8^0) \approx$ 6-10nb | K.Yamamoto et al., PLB.478(2000) 401 | $K^- + {}^{12}C \rightarrow K^+ + {}^{12}B_{\Lambda\Lambda}$ |

## Features:

$$-V_{\Lambda\Lambda} = \Delta B_{\Lambda\Lambda}({}_{\Lambda\Lambda}^{A}Z) \equiv B_{\Lambda\Lambda}({}_{\Lambda\Lambda}^{A}Z) - 2B_{\Lambda}({}_{\Lambda}^{A-1}Z)$$

- **Binding energy →** parameters in potential models
- **Core of the ΛΛ interaction ($V_{\Lambda\Lambda}$)** : needs of several A-hypernuclei
- Λ Λ interaction: only I=0 *non-strange mesons* contributes (only $\omega,\eta$)
- **Weak Decay presents some peculiarities**

# Weak Decay of Double Hypernuclei

- Both $\Lambda\Lambda$ mesonic: $\Lambda\Lambda \rightarrow \pi N + \Lambda \rightarrow \pi N + \pi N$
- Both $\Lambda\Lambda$ non mesonic: $\Lambda\Lambda + NN \rightarrow \Lambda N + NN \rightarrow NN + NN$
- Mixed mesonic & non mesonic: $\Lambda\Lambda N \rightarrow \pi N + \Lambda N \rightarrow \pi N + NN$

A new kind of **N**on **M**esonic **W**eak **D**ecay: <u>one $\Lambda$ decays interacting with the other one</u>

New mechanism**: Hyperon Induced Non Mesonic Weak Decay (HINMWD):**

- $\Lambda\Lambda \rightarrow \Lambda N$ ($\mathbf{p}_{\Lambda/N}$ = 433 MeV/c) $\rightarrow NN$ **(only in DH)**
- $\Lambda\Lambda \rightarrow \Sigma N$ ($\mathbf{p}_{\Sigma/N}$ = 321 MeV/c) $\rightarrow NN$ **(only in DH)**

**HINMWD** related to **YY** interaction: <u>complementary to **DH** spectra</u>

Decay into Hyperfragments:

Excited $\Lambda\Lambda$-Hypernucleus $\rightarrow$ breakup channels:

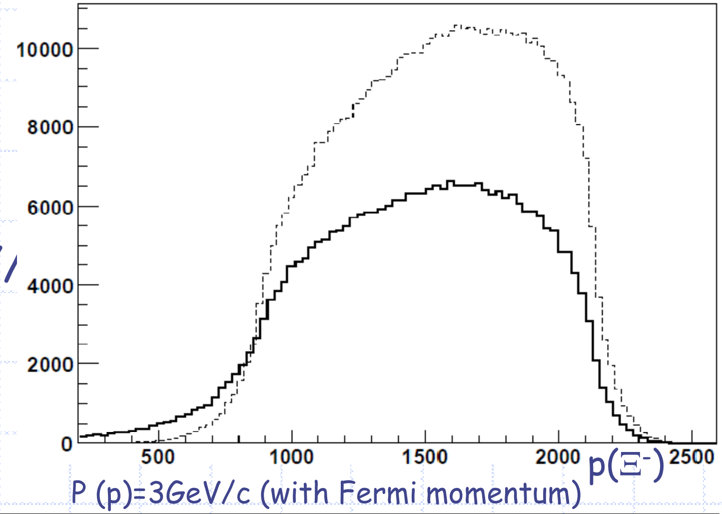
- $\Lambda + {}^{A}Z_{\Lambda}$ + others
- ${}^{A1}Z_{1\Lambda} + {}^{A2}Z_{2\Lambda}$ + others
- ${}^{A}Z_{\Lambda\Lambda}$ + others

More details: J.Pochodzalla talk in the parellel session

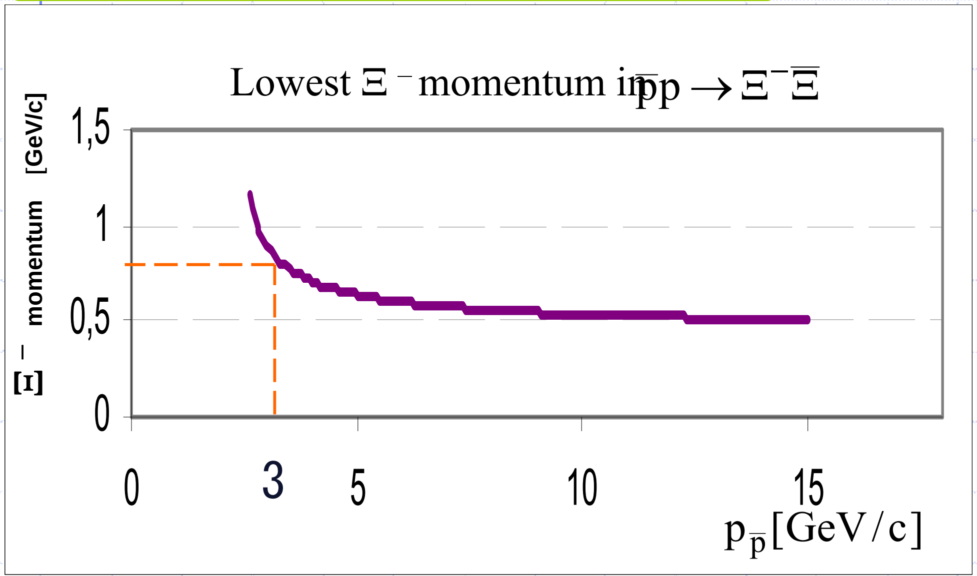
# Best beam conditions

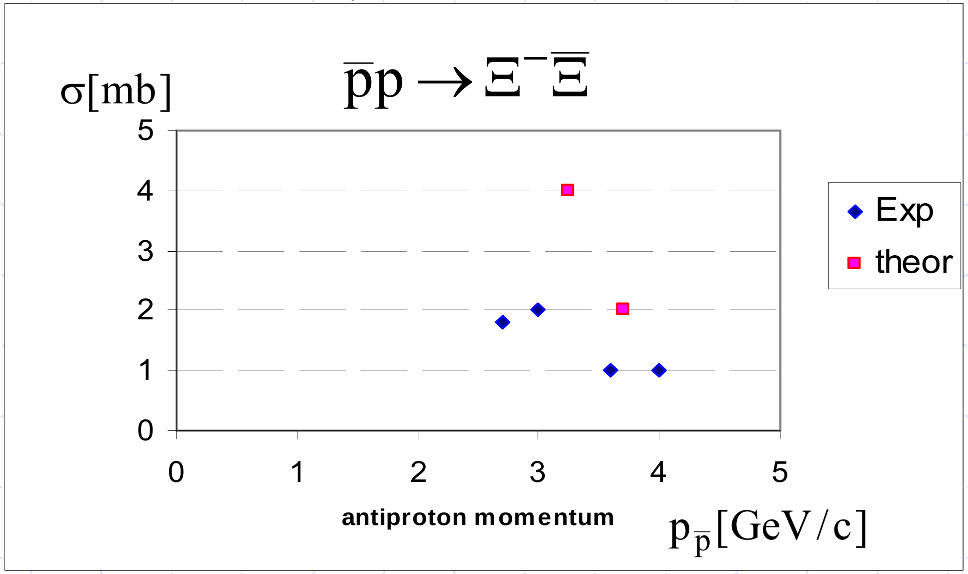
**Kinematical Features of the reactions:**

- $\Xi^-$ production threshold: 2.6 GeV/c
- $\pi$ production threshold: $(\bar{p},N) \rightarrow (\Xi^-, \bar{\Xi}, \pi)$: 3.1 GeV/
- $\sigma(\bar{p}\,p \rightarrow \Xi^-\bar{\Xi})$ has a maximum around 3 GeV/c



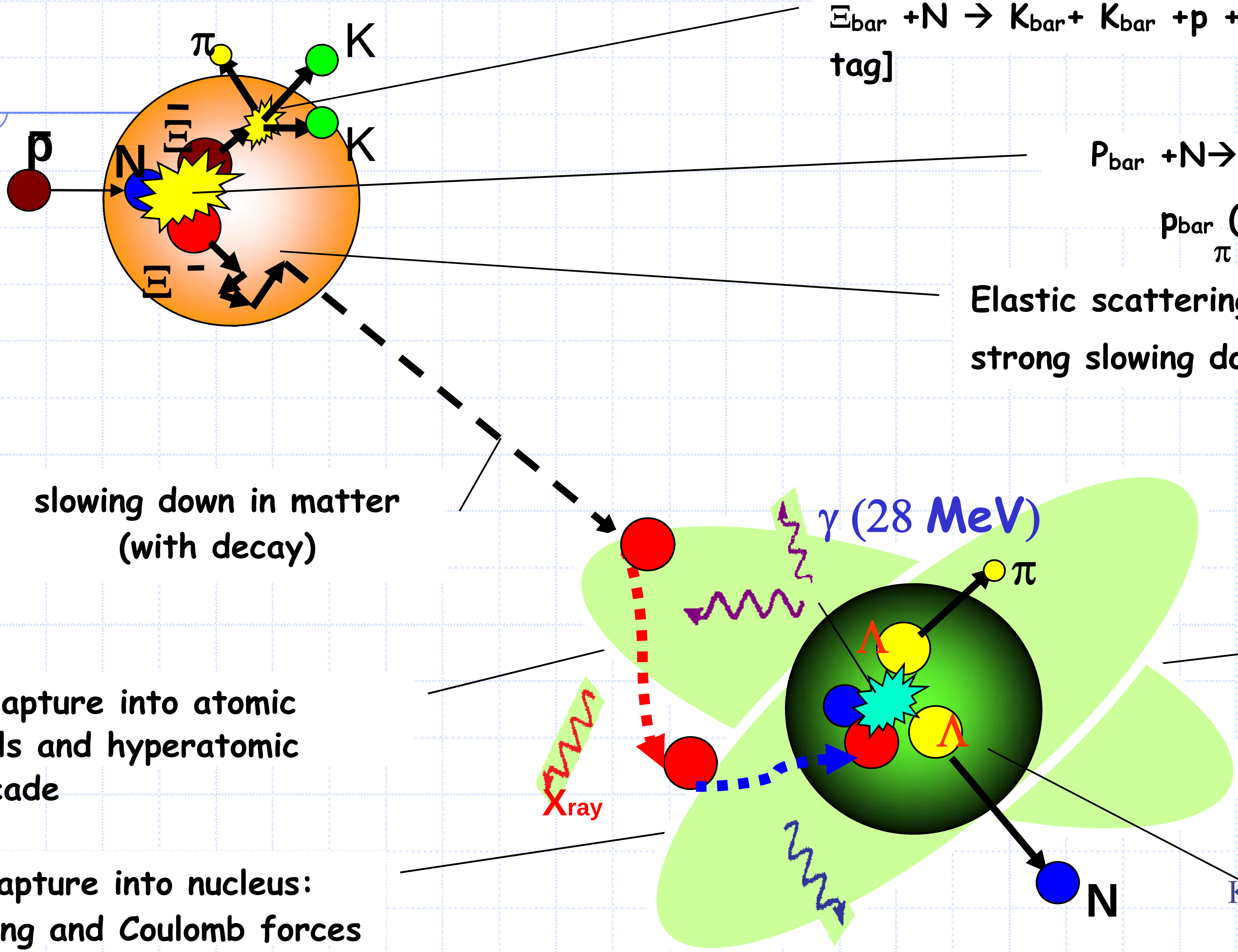

*p(Ξ⁻) > 0.5 GeV/c up to p(pbar)=15 GeV/c*




**PANDA will use antiprotons @ 3 GeV/c**

# From pbar to DSS




$\Xi_{bar}$ +N → $K_{bar}$+ $K_{bar}$ +p + … [ $\Xi^-$ production tag]

$P_{bar}$ +N→ $\Xi^-$ + $\Xi_{bar}$ : σ = 2 μb;
$p_{bar}$ (3GeV/c) below
π production

Elastic scattering in nucleus:

strong slowing down (a challenge)

slowing down in matter
(with decay)

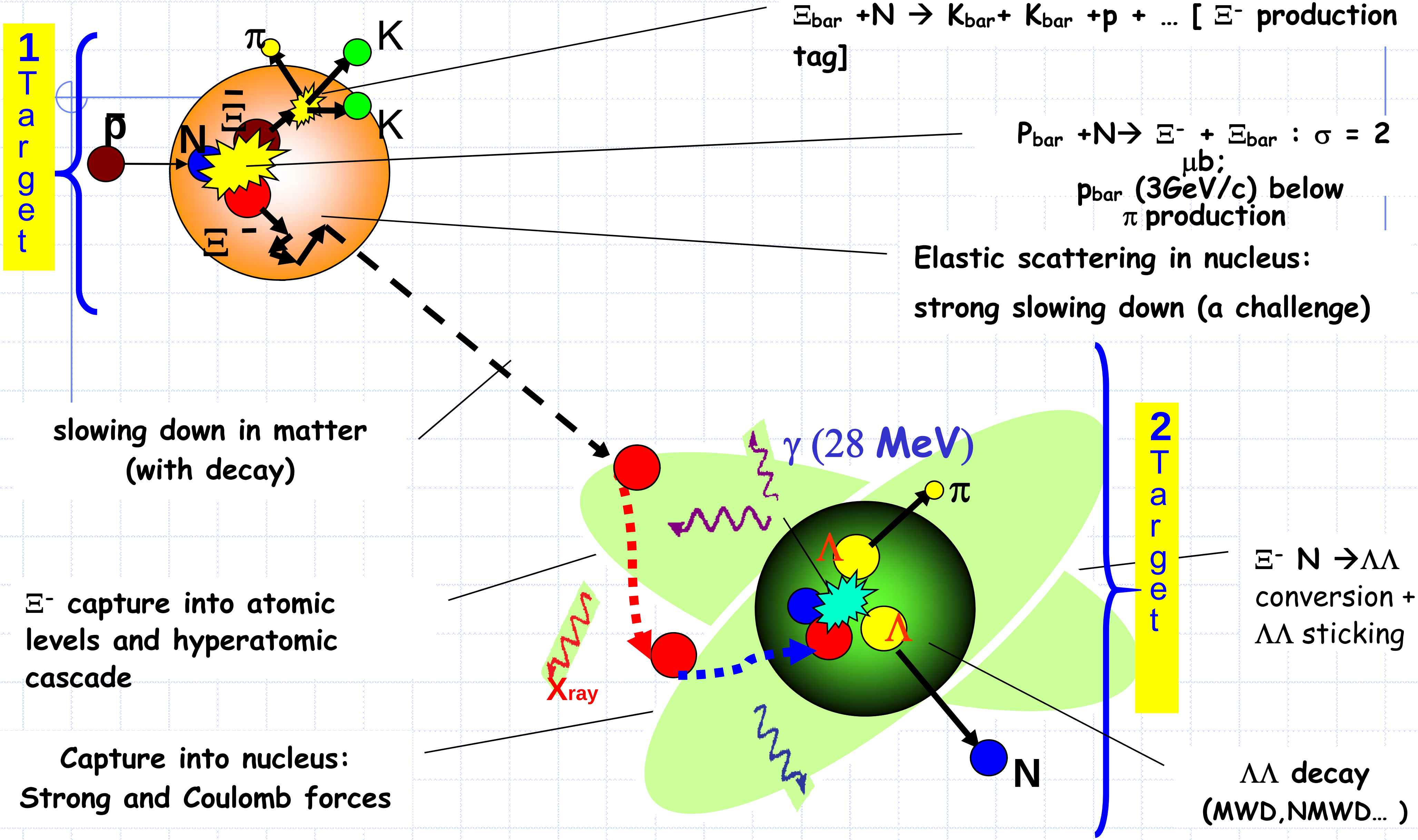
$\Xi^-$ capture into atomic levels and hyperatomic cascade

Capture into nucleus:
Strong and Coulomb forces

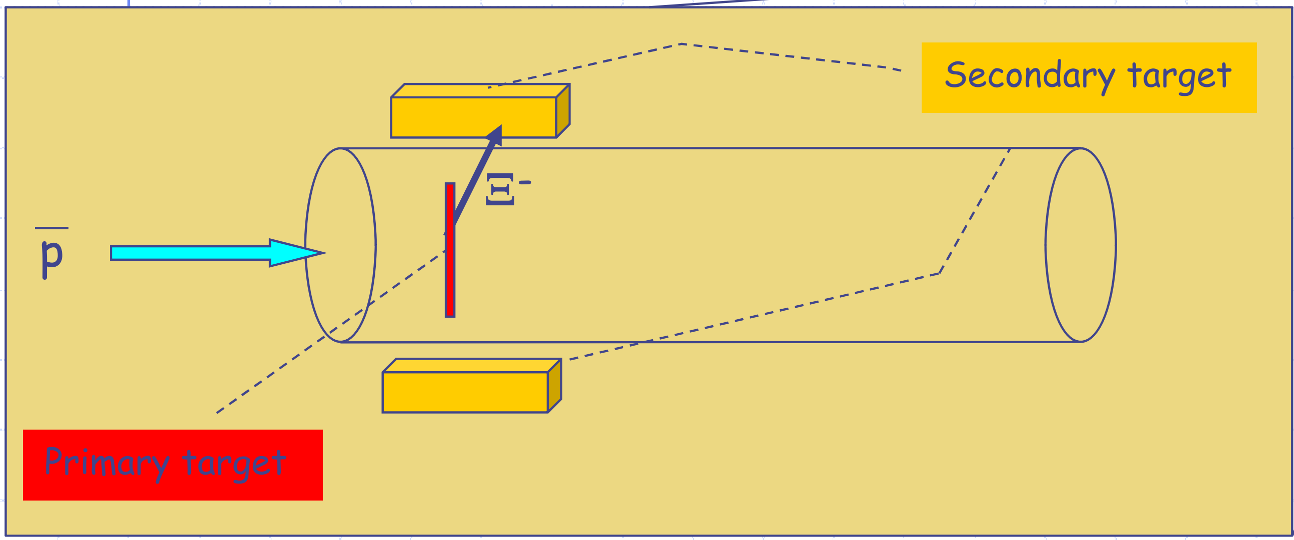
$\Xi^-$ N →ΛΛ
conversion +
ΛΛ sticking

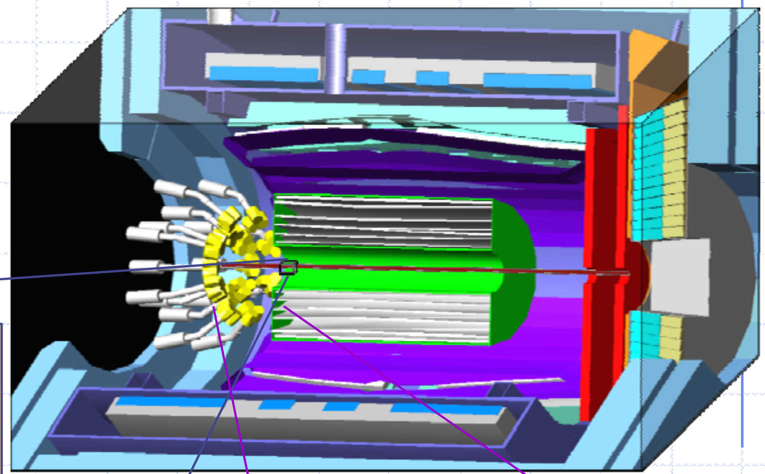
ΛΛ decay
(MWD,NMWD… )

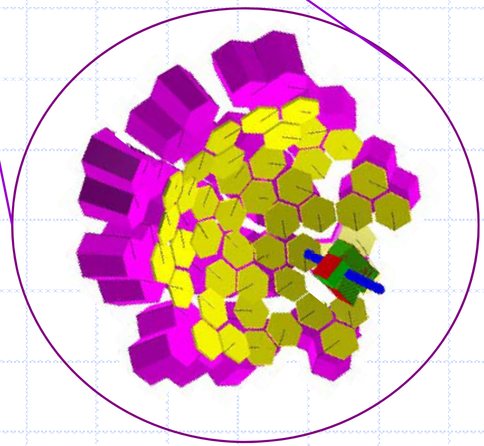
# DSS production in PANDA



# PANDA set-up





- $\Xi^-$ production target is different from DSS target:
  → optimization of $\Xi^-$ production rate is independent on the S =-2 system to be studied

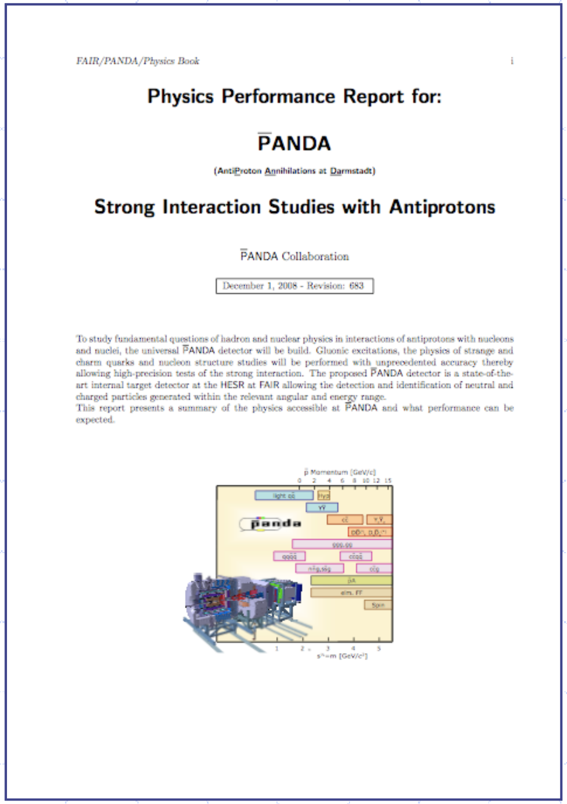
- Two steps of slowing down
  a) in the nucleus (intra-nuclear scattering)
  b) in the secondary target (energy loss until to stop)

**DSS production rate per produced $\Xi^-$ : about $10^{-3}$ (in $^{12}C$)** → **High intensity pbar beam is necessary**

# The $\overline{\text{P}}$ANDA Physics Book

The PANDA Collaboration has recently realized a big effort preparing the Physics Performance Report.

More than 200 pages have been produced to describe all the aspects of the scientific program.
Detailed simulations have been performed to evaluate detector performance on many benchmark channels.


FAIR/PANDA/Physics Book i

Physics Performance Report for:

$\overline{\text{P}}$ANDA

(AntiProton Annihilations at Darmstadt)

Strong Interaction Studies with Antiprotons

$\overline{\text{P}}$ANDA Collaboration

December 1, 2008 - Revision: 683

To study fundamental questions of hadron and nuclear physics in interactions of antiprotons with nucleons and nuclei, the universal $\overline{\text{P}}$ANDA detector will be build. Gluonic excitations, the physics of strange and charm quarks and nucleon structure studies will be performed with unprecedented accuracy thereby allowing high-precision tests of the strong interaction. The proposed $\overline{\text{P}}$ANDA detector is a state-of-the-art internal target detector at the HESR at FAIR allowing the detection and identification of neutral and charged particles generated within the relevant angular and energy range.
This report presents a summary of the physics accessible at $\overline{\text{P}}$ANDA and what performance can be expected.

arXiv:0903.3905v1

# Summary

- A new international Hadron-Facility is underway in Europe: FAIR

- A wide experimental physics program will be accessible with the new FAIR antiproton beam

- New and interesting results will come also in the field of Double Strange System thanks to the unprecedented characteristics of the beam and to the feaures offered by the PANDA general purpose detector