International Conference on Exotic Atoms and Related Topics
September 5-9, 2011, Vienna, Austria

Thomas Würschig
on behalf of the $\bar{P}$ANDA collaboration

# The $\bar{P}$ANDA detector at FAIR

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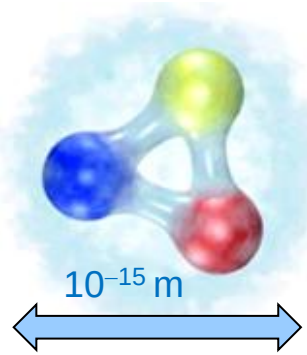
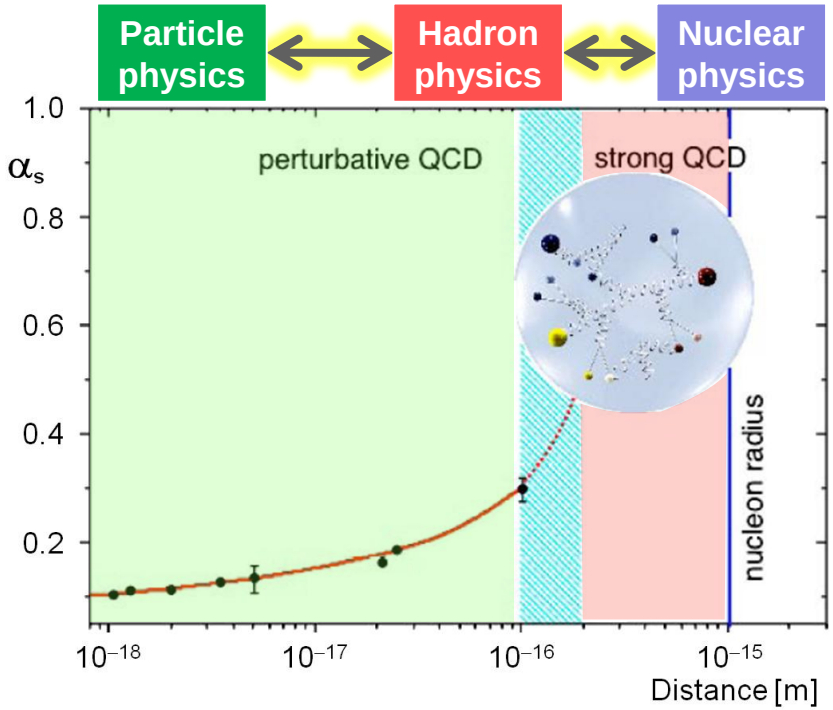
# Introduction

- $\bar{P}$ANDA ($\bar{\text{Anti}}$**P**roton **An**nihilations at **Da**rmstadt)
  - Study of **strong interaction** with antiprotons



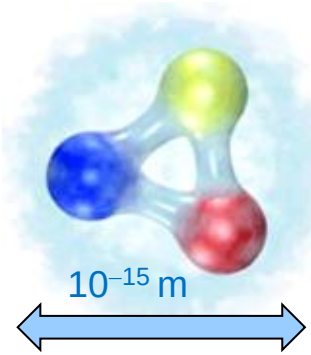



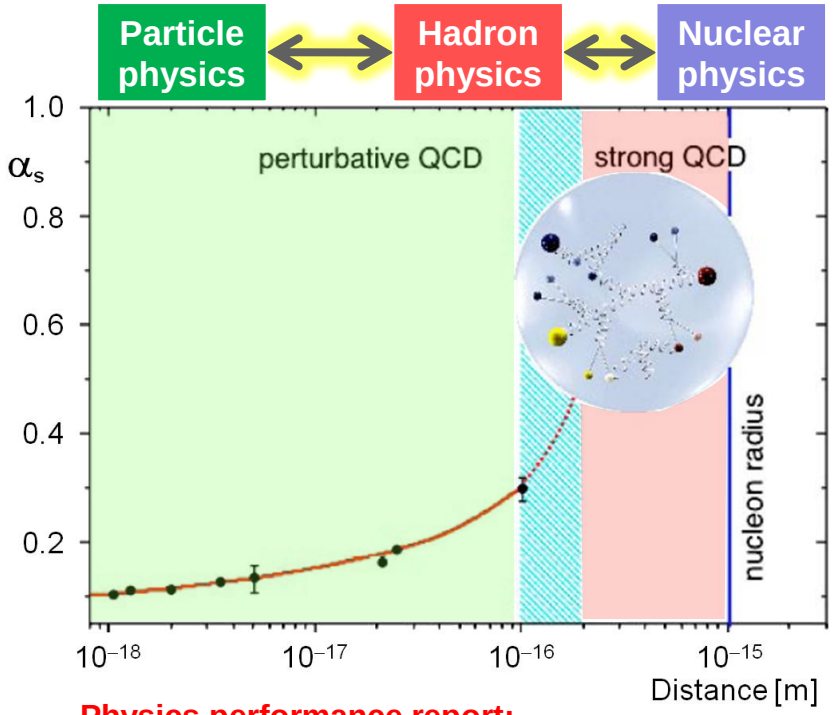

- ✓ Long distance features of QCD?

- Questions ...
  - ✓ Mechanism of confinement ?
  - ✓ Inner structure of hadrons ?
  - ✓ Origin of mass and spin (macroscopic properties) ?
  - ✓ Exotic colour neutral objects?

# Introduction

- $\bar{P}$ANDA ($\bar{A}$nti**P**roton **An**nihilations at **Da**rmstadt)
  - Study of **strong interaction** with antiprotons




**Physics performance report:**

*arXiv:0903.3905v1* [hep-ex]

- ✓ Long distance features of QCD?

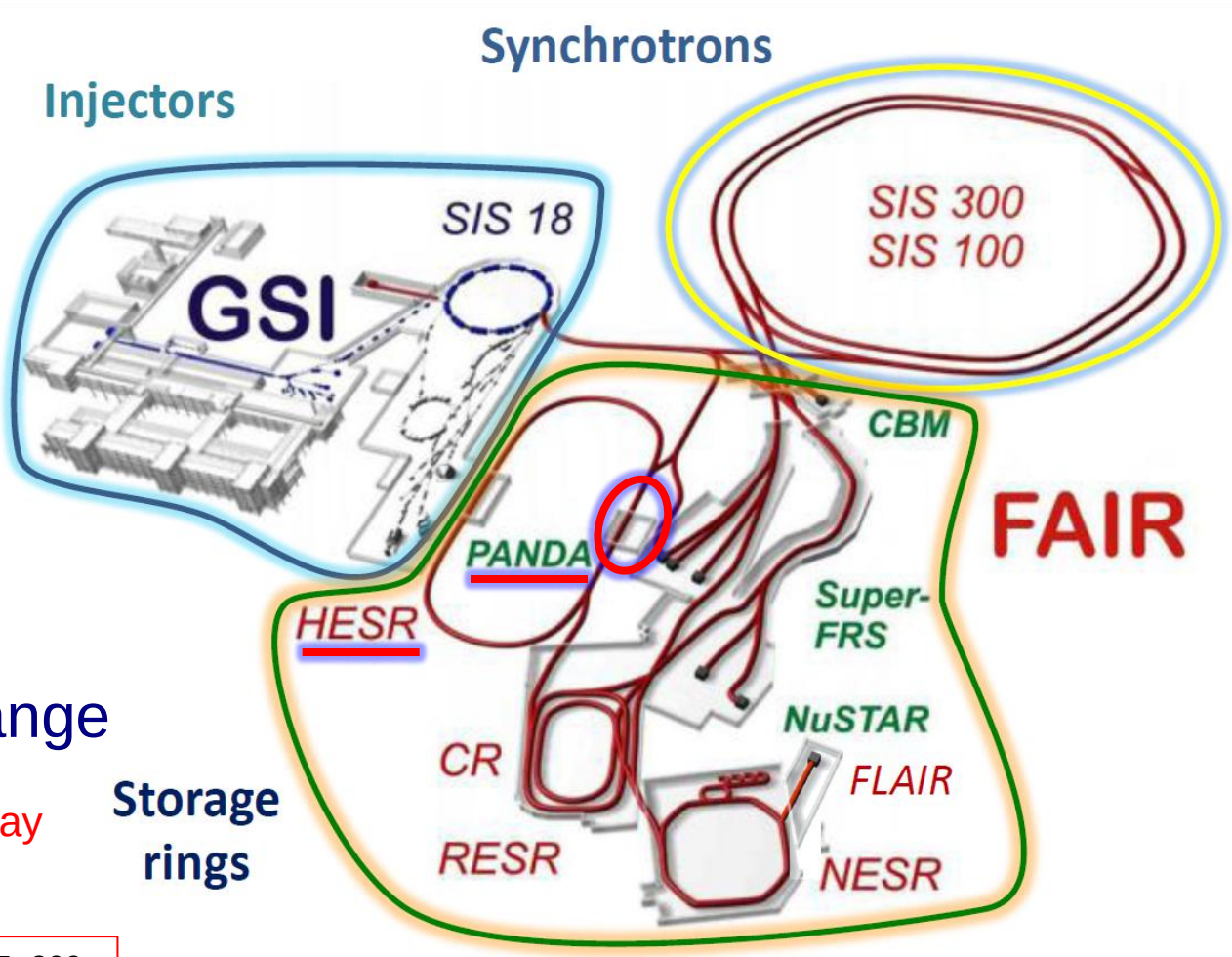
- Broad physics program ...
  - ✓ Structural analysis of nucleons
  - ✓ Hypernuclei physics
  - ✓ In-medium effects of hadrons
  - ✓ Hadron spectroscopy
- → Focus on the charm quark sector

Details presented yesterday by Simonetta Marcello

# Introduction

- FAIR facility
  - Very intense beams of protons, antiprotons and ions
  - High resolution
  - Wide energy range

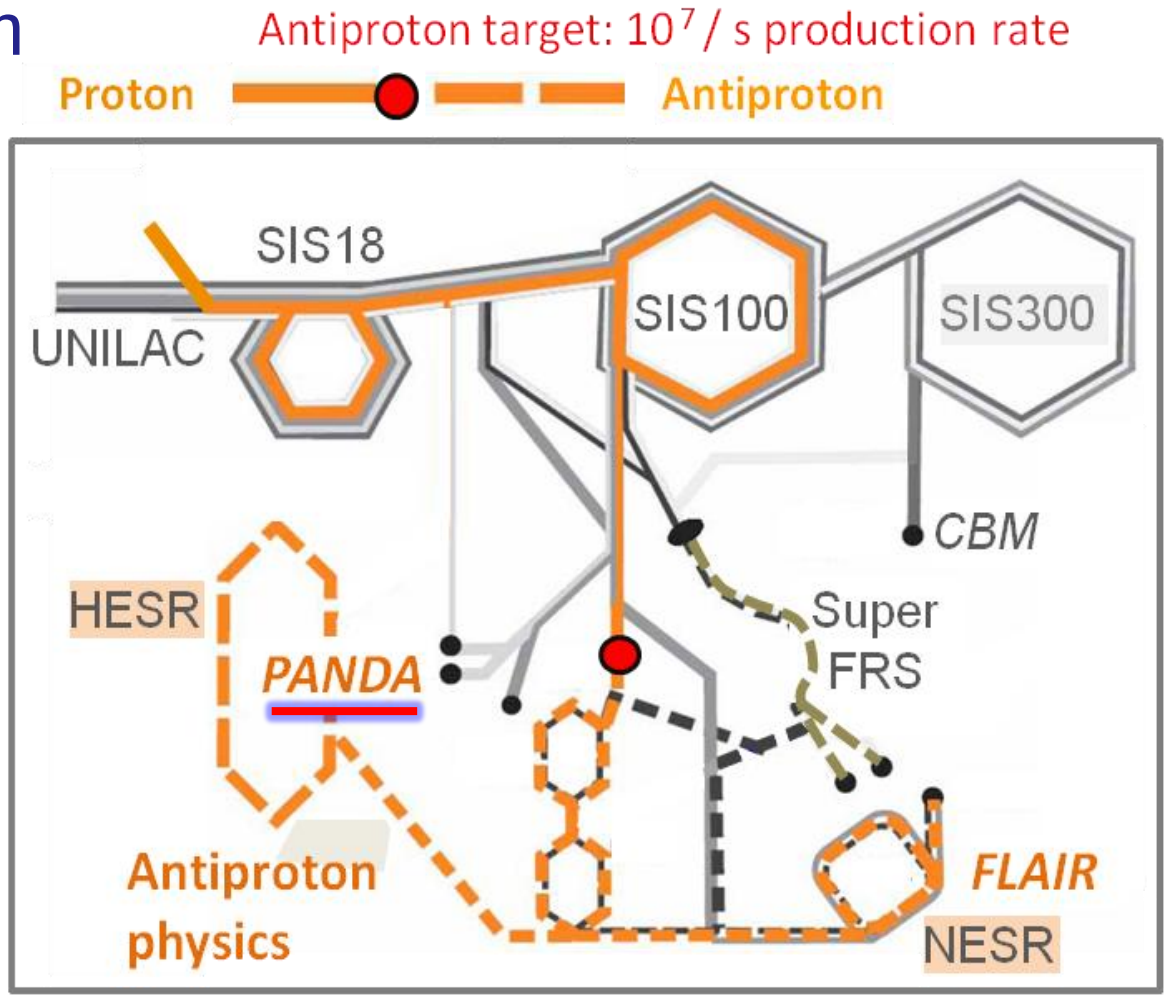
Details presented yesterday by Günther Rosner




Nucl. Instr. Meth. A 561 (2006) 305–309

# $\bar{P}$ANDA at FAIR

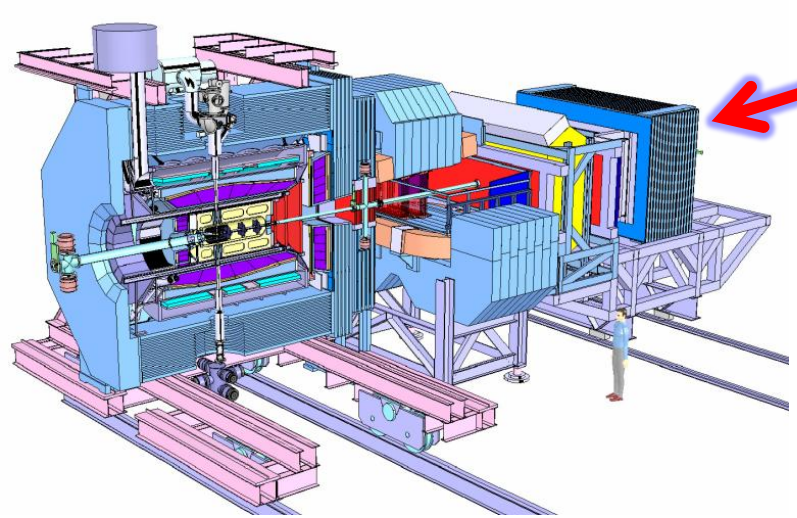
- Extended program with antiprotons
- Antiproton production
  - ✓ Nickel target
  - ✓ Bunched mode (50 ns bunches, Cycle time: 10 s)
  - ✓ $10^8$ per bunch
- High-energy branch: PANDA

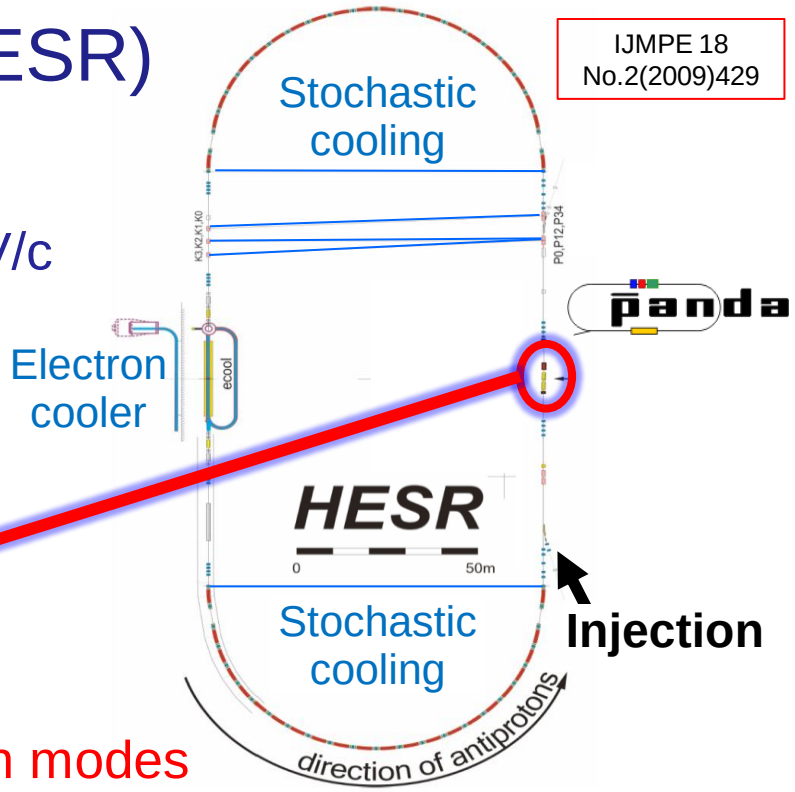


# $\bar{P}$ANDA at FAIR

- **H**igh **E**nergy **S**torage **R**ing (HESR)
  - Up to $10^{11}$ stored antiprotons
    - ✓ Beam momentum: (1.5 ... 15) GeV/c
    - ✓ Phase-space cooling
  - Fixed internal target

IJMPE 18
No.2(2009)429






Operation modes

a) High luminosity:
$L = 2 \cdot 10^{32}\ \mathrm{cm^{-2}\,s^{-1}} \Leftrightarrow \Delta p/p \approx 10^{-4}$

b) High resolution:
$L = 10^{31}\ \mathrm{cm^{-2}\,s^{-1}} \Leftrightarrow \Delta p/p \approx 4 \cdot 10^{-5}$

# $\bar{P}$ANDA at FAIR

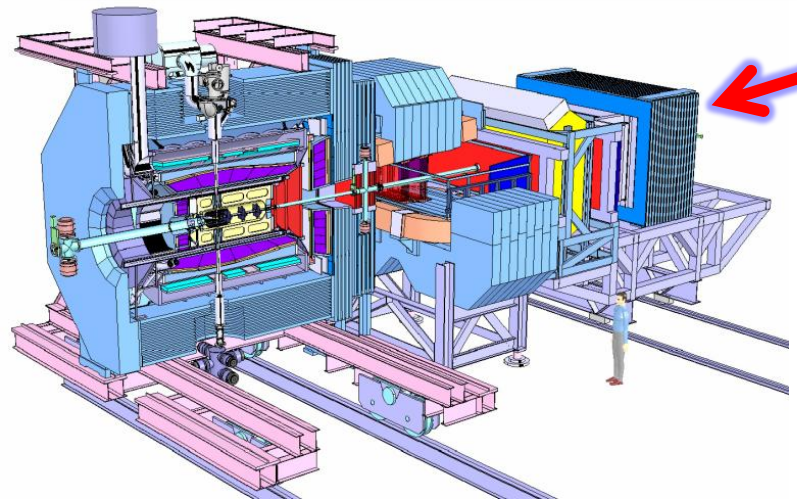
- **H**igh **E**nergy **S**torage **R**ing (HESR)

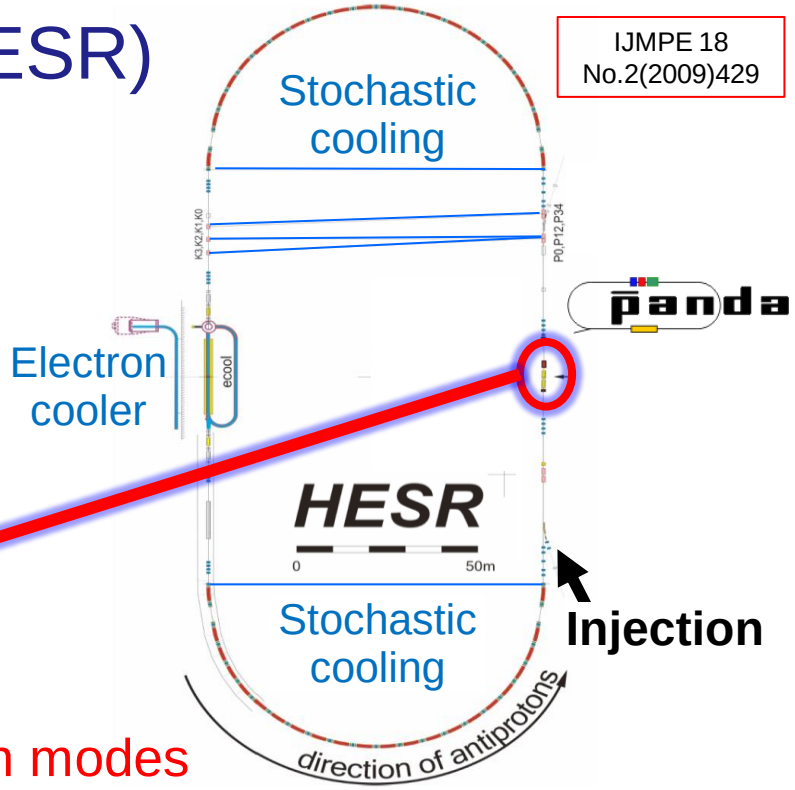
**Beam-target interaction:**

**$\propto$ 20 million annihilations / s**

Quasi continuous

time distribution of events



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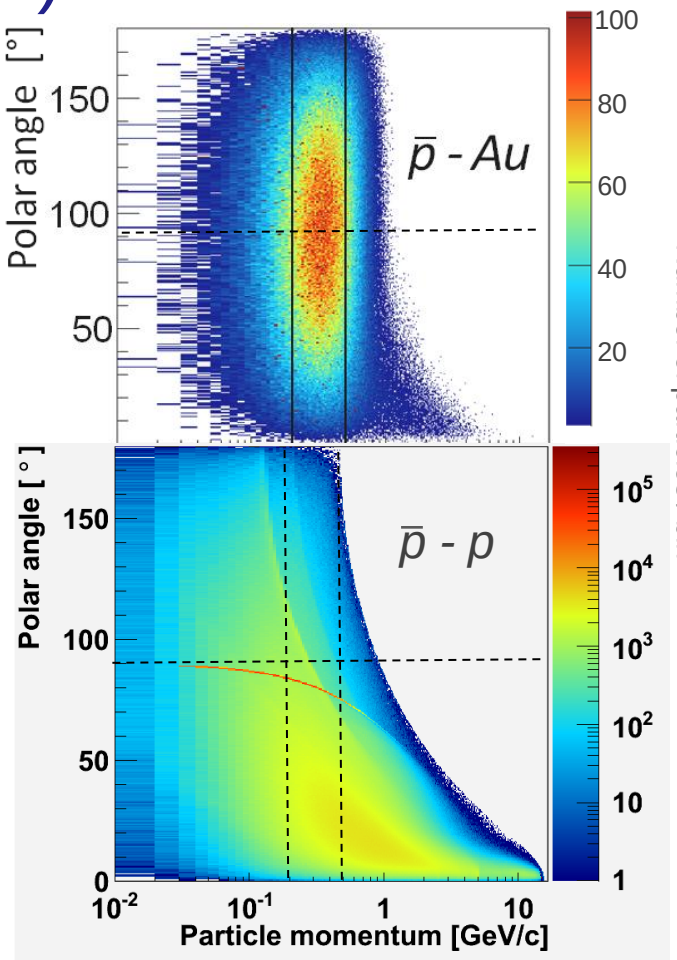
# $\bar{P}$ANDA at FAIR

- **H**igh **E**nergy **S**torage **R**ing (HESR) *Beam momentum:* 15 GeV/c

**Beam-target interaction:**
**$\propto$ 20 million annihilations / s**
Quasi continuous
time distribution of events



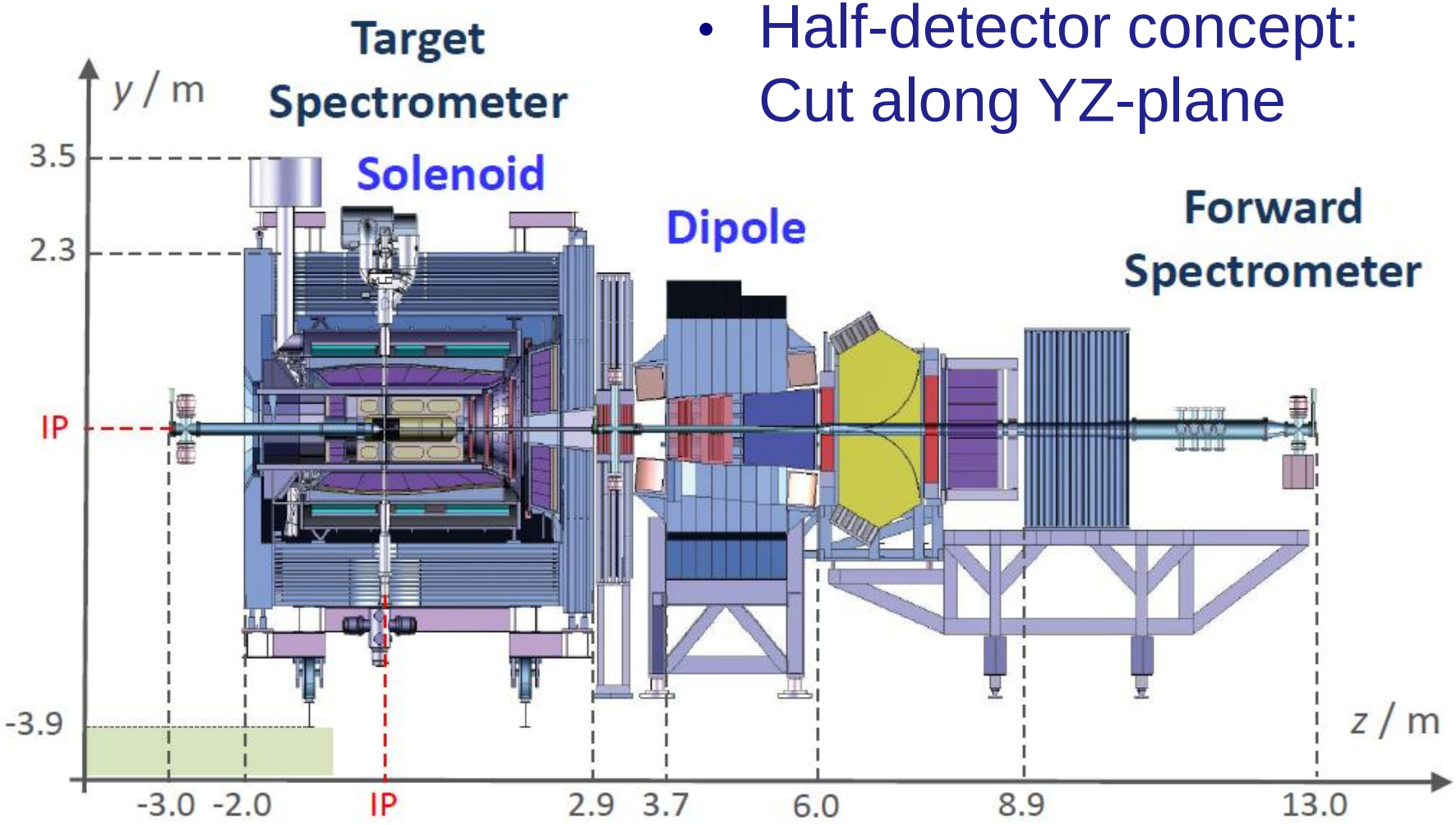

- Particle distribution
  - Forward boost
    (Fixed target setup)
  - Slower particles **(200...500) MeV/c**
    in a large polar angle interval ($\approx 2\pi$)

# Basic approach

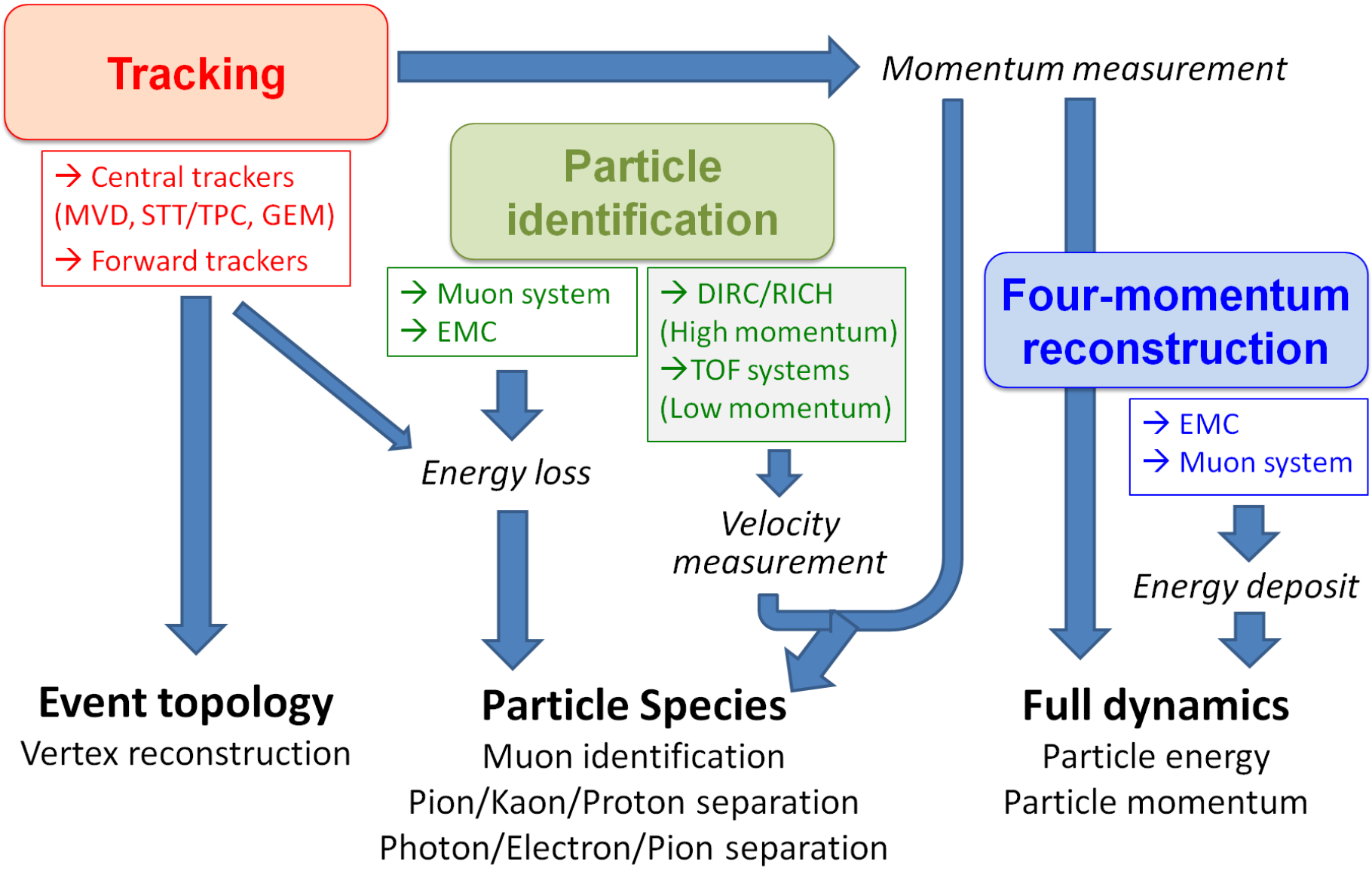
| High luminosity | High beam quality | Optimized detector setup |
|---|---|---|
| ↓ | ↓ | ↓ |
| **High statistics** | **High resolution** | **Highly efficient reconstruction** |
| High-rate capability<br>Radiation tolerance<br>Sophisticated DAQ concept:<br>No hardware trigger | High-performance tracking, vertexing and calorimetry | $4\pi$ coverage<br>Measurement of charged and neutral particles<br>Good PID |

# Main setup

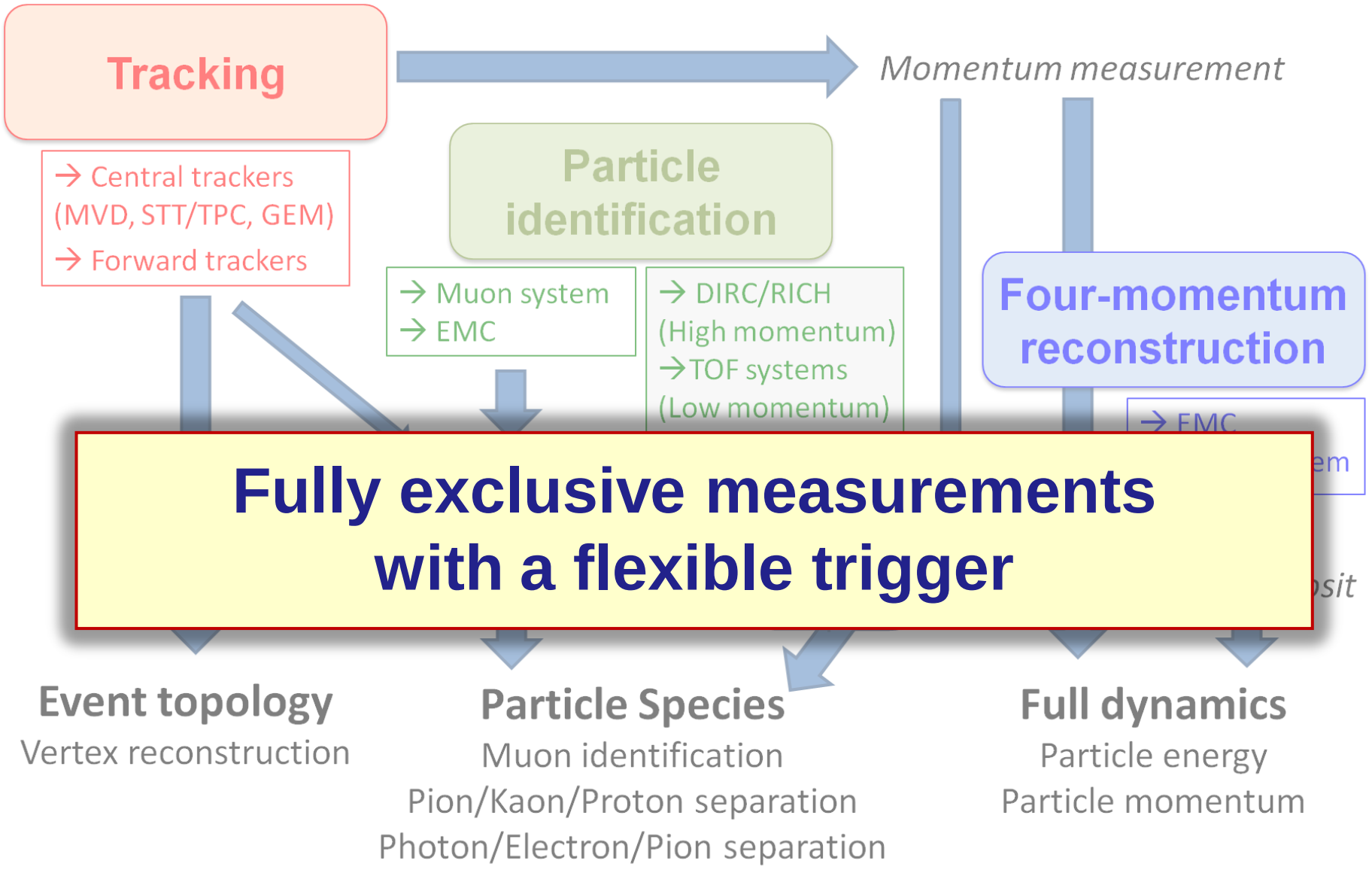
- Half-detector concept: Cut along YZ-plane



# Detection concept



# Detection concept



# Main components

- Target system
  ↔ Initial antiproton reactions
- Solenoid and dipole magnet
  ↔ Analyzing elements (charged particles)
- Instrumentation
  - Muon range system
  - Tracking systems
  - Calorimeters
  - Cherenkov detectors and TOF systems
  - Luminosity monitor
- Data acquisition concept

# Target system

## Gaseous targets

**Hydrogen***

**Heavier nuclear targets:**
**$N_2$ … Ar  Cu … Au**

**Combined**
**C…Au + $^{12}$C**

Antiproton-proton annihilations

Antiproton-nucleon reactions

Hypernuclei production

*Option A:* Cluster-jet target

*Option B:* Pellet target

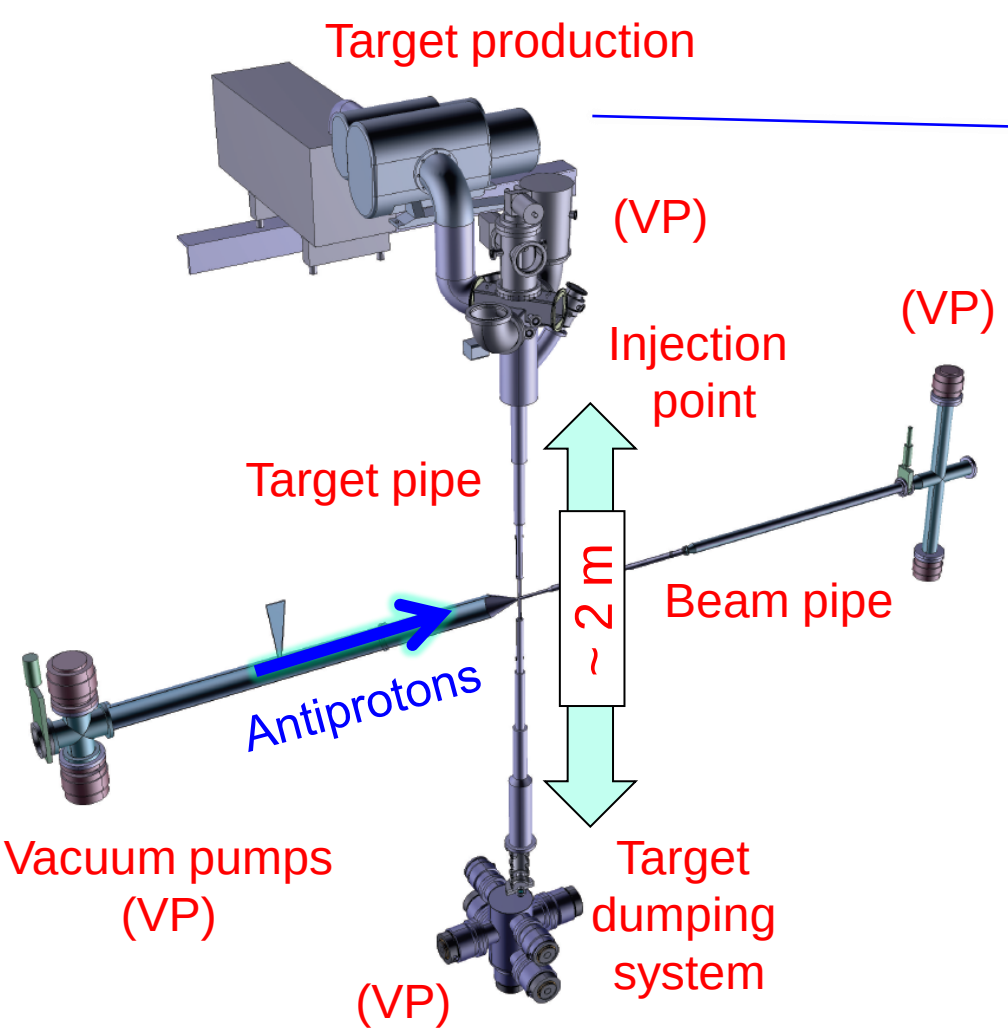
*Design goal: $4 \times 10^{15}$ atoms / cm$^2$

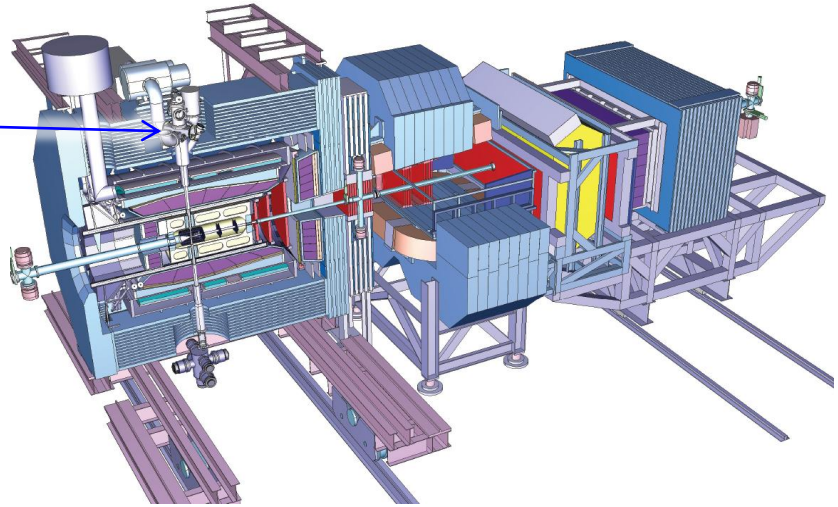
## Solid targets

Wire or foil targets

Primary + secondary target

# Target system

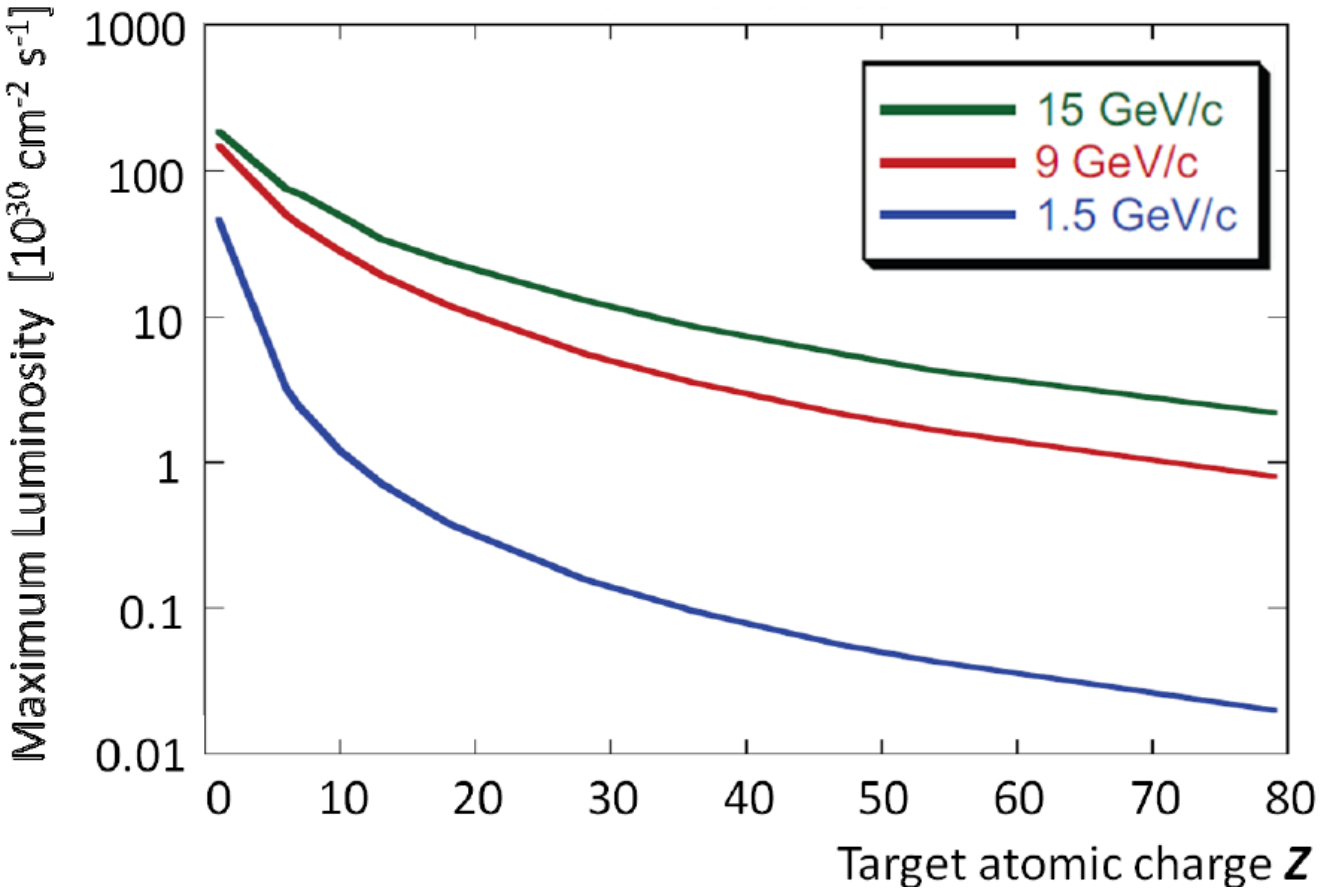


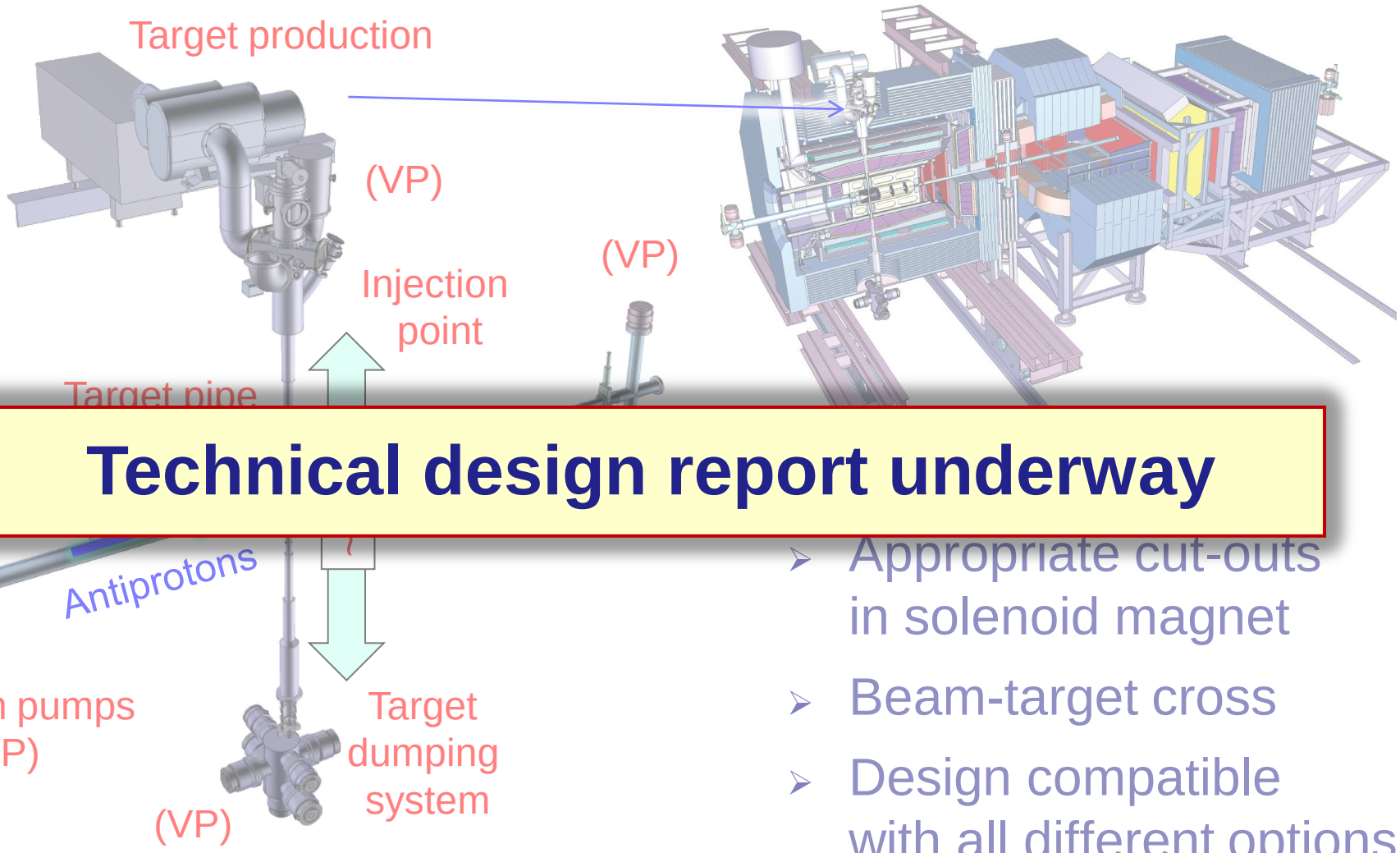
- Primary target setup
  - Appropriate cut-outs in solenoid magnet
  - Beam-target cross
  - Design compatible with all different options

# Target system

- Maximum achievable cycle-averaged luminosity



# Target system

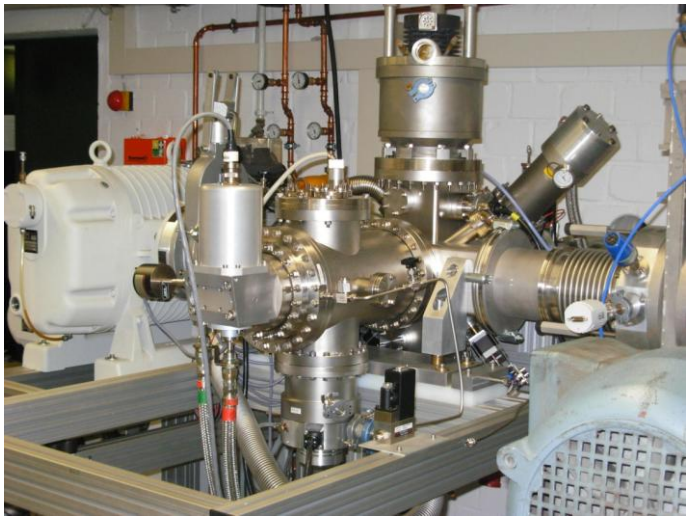


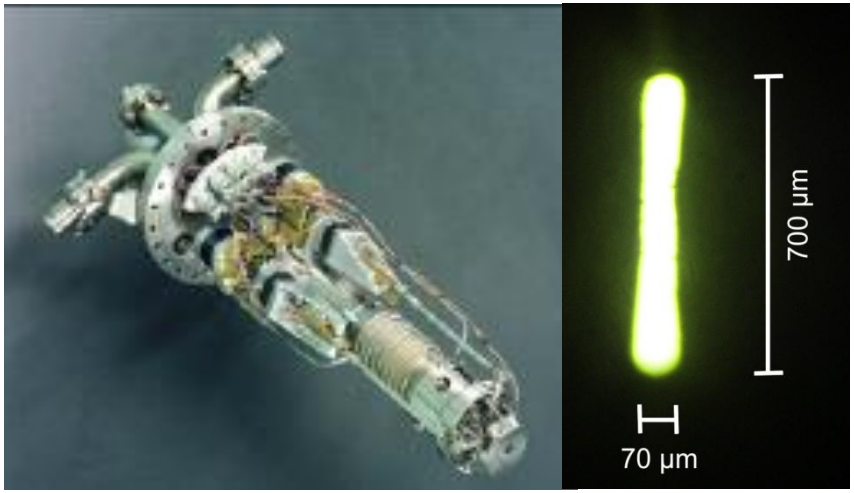

**Technical design report underway**

- Appropriate cut-outs in solenoid magnet
- Beam-target cross
- Design compatible with all different options

# Target system

- Cluster-jet target
  - Well adjustable density
  - Constant luminosity
  - Jet-diameter ~ 70 μm
    → $\sigma_z$ ~ 1 mm
  - Cluster size: 100 ... 1000 atoms



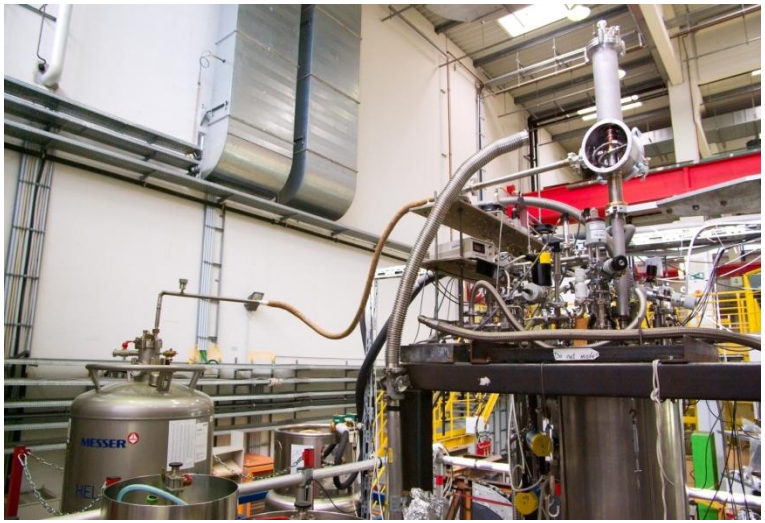



- Full-size prototype
  - ✓ Achieved density:
    max. $8 \times 10^{14}$ atoms / $cm^2$
  - ✓ Stable operation
  - ✓ Further density increase:
    Composite nozzles

# Target system

- Pellet target
  - Higher density
  - Better vertex definition
    → Pellet tracking system
  - Pellet size: ≤ 30 μm
  - Pellet frequency: 10 kHz
  - Problem:
    Luminosity variations
    → Smaller pellet sizes
    → Higher frequency

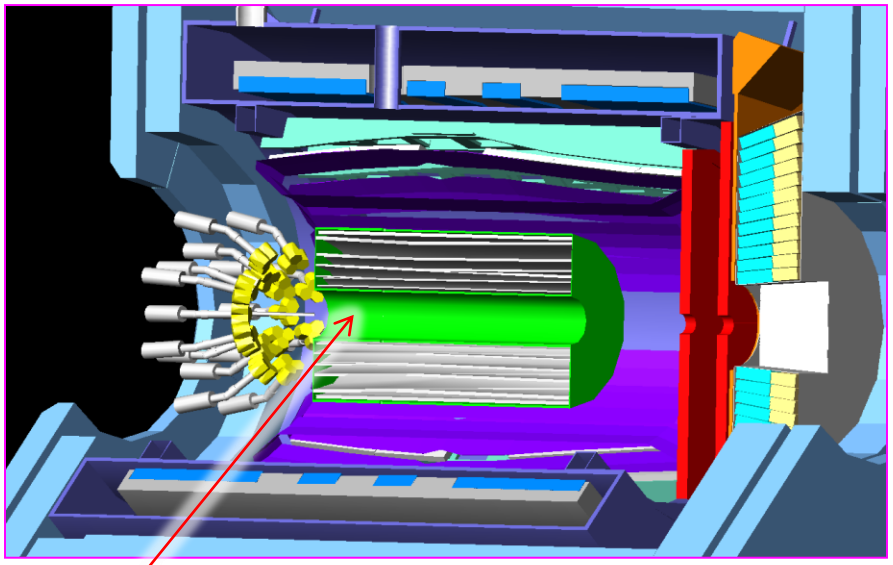
Hydrogen droplets:
< 10 μm, 144 kHz




- Dedicated prototypes
  - ✓ Achieved density:
    ≤ $4 \times 10^{15}$
    atoms / $cm^2$
  - ✓ Pellet stream:
    ∅ 3 mm

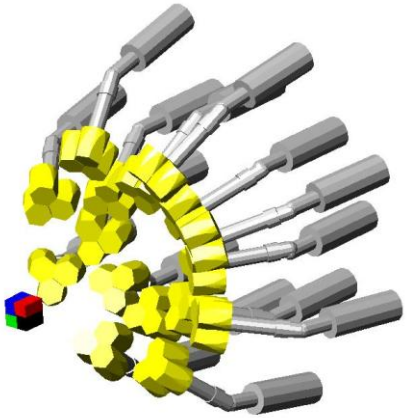
# Target system

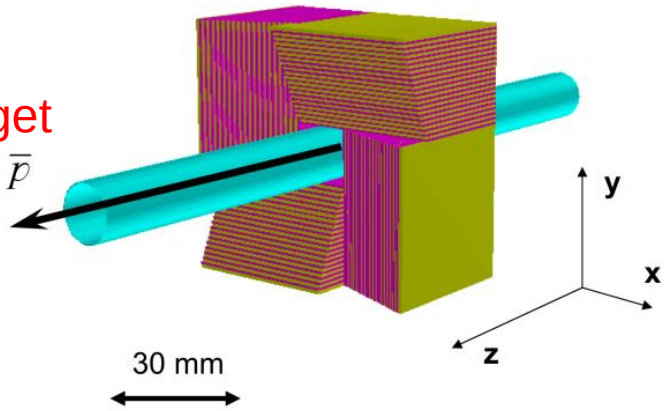
- Hypernuclei target
  - Modification of innermost detector part and beam-target geometry
  - Secondary target: Sandwiched structure Si-detector / $^{12}C$



Primary and secondary target

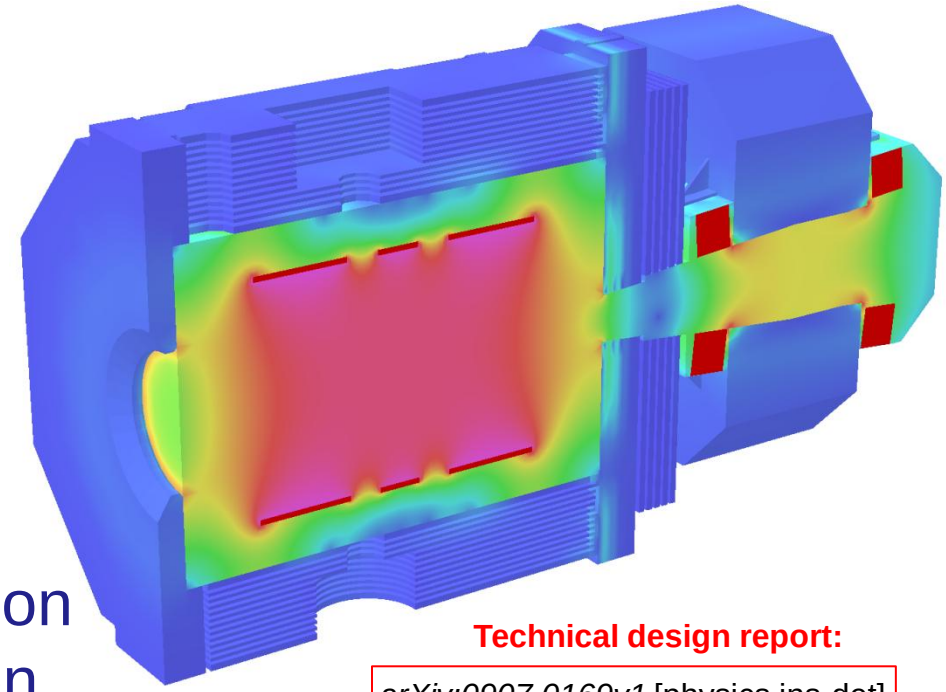
Gamma detectors





# Analyzing magnets

- Combination of solenoid magnet (central part) and dipole magnet (forward part)
  - Prerequisite for momentum reconstruction and particle identification



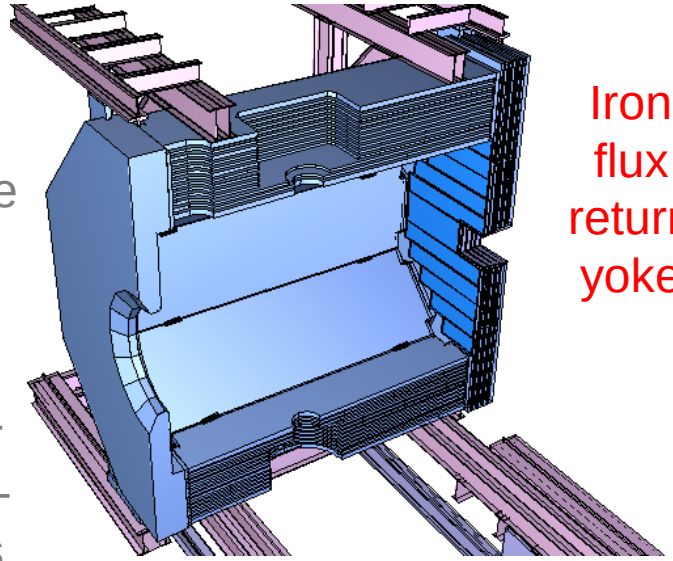
**Technical design report:**

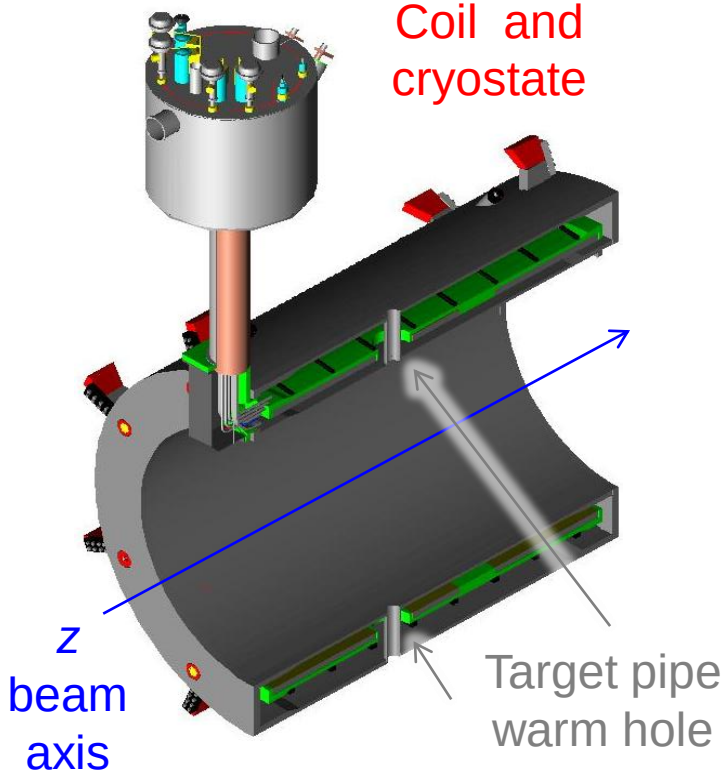
*arXiv:0907.0169v1* [physics.ins-det]

**Technical design finished and first parts ordered**

# Solenoid

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



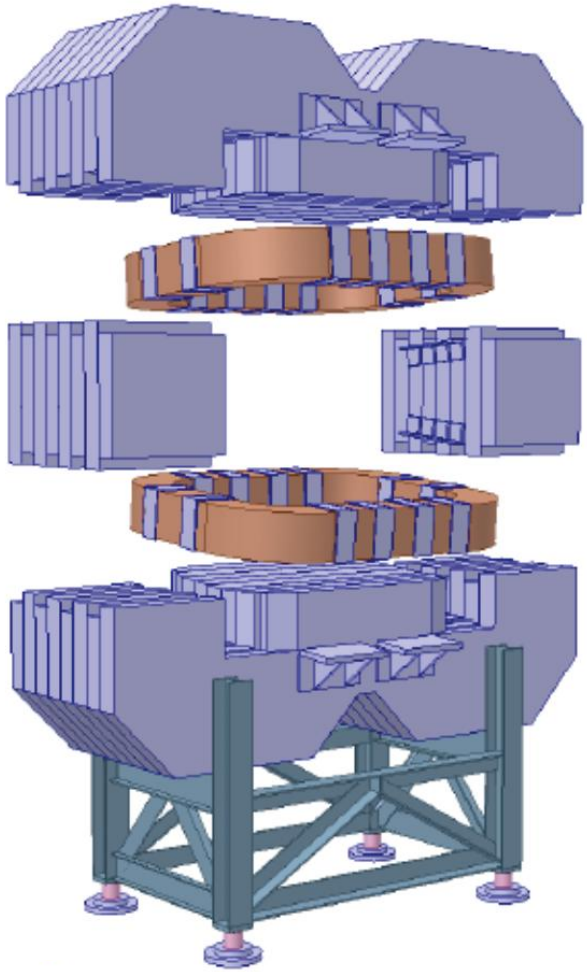

- Outer yoke dimension:
  ∅ 2.3 m / length: 4.9 m
- Total weight: ~ 300 t

# Dipole

- Superconducting magnet
  - Field integral (bending power): 2 Tm

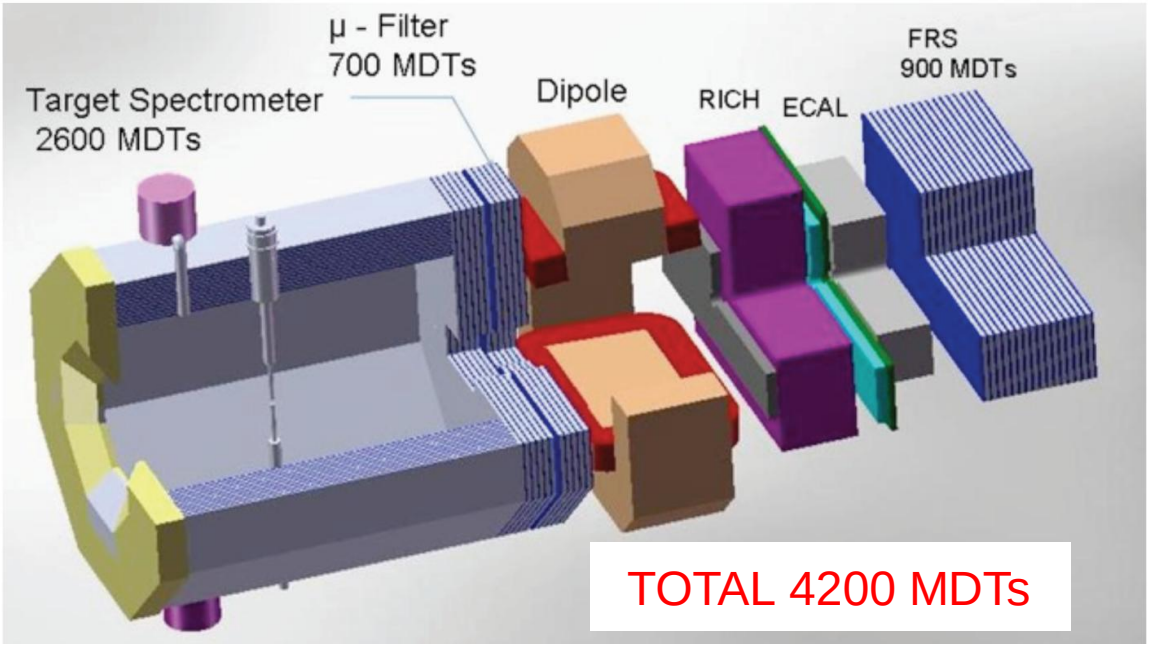
    → Deflection of antiprotons with $p$ =15 GeV/c: 2.2°
  - Bending variation: ≤ 15%
  - Vertical acceptance: ± 5°
  - Horizontal acceptance: ± 10°
  - Total weight: 220 t

Forward tracking detectors partly integrated



# Muon range system

- Mini Drift Tubes (MDT)
  - Instrumentation inside the yoke of the solenoid magnet
  - Additional muon filters moved between solenoid and dipole
  - Range system in downstream part




Prototype systems developed

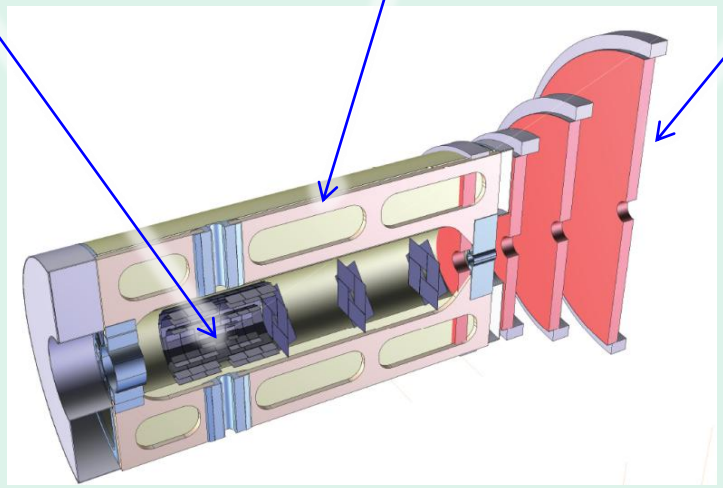
# Tracking systems

## Target spectrometer

**Micro-Vertex Detector**

**Outer tracker**

**GEM stations**



Central tracking
(Helix fit)

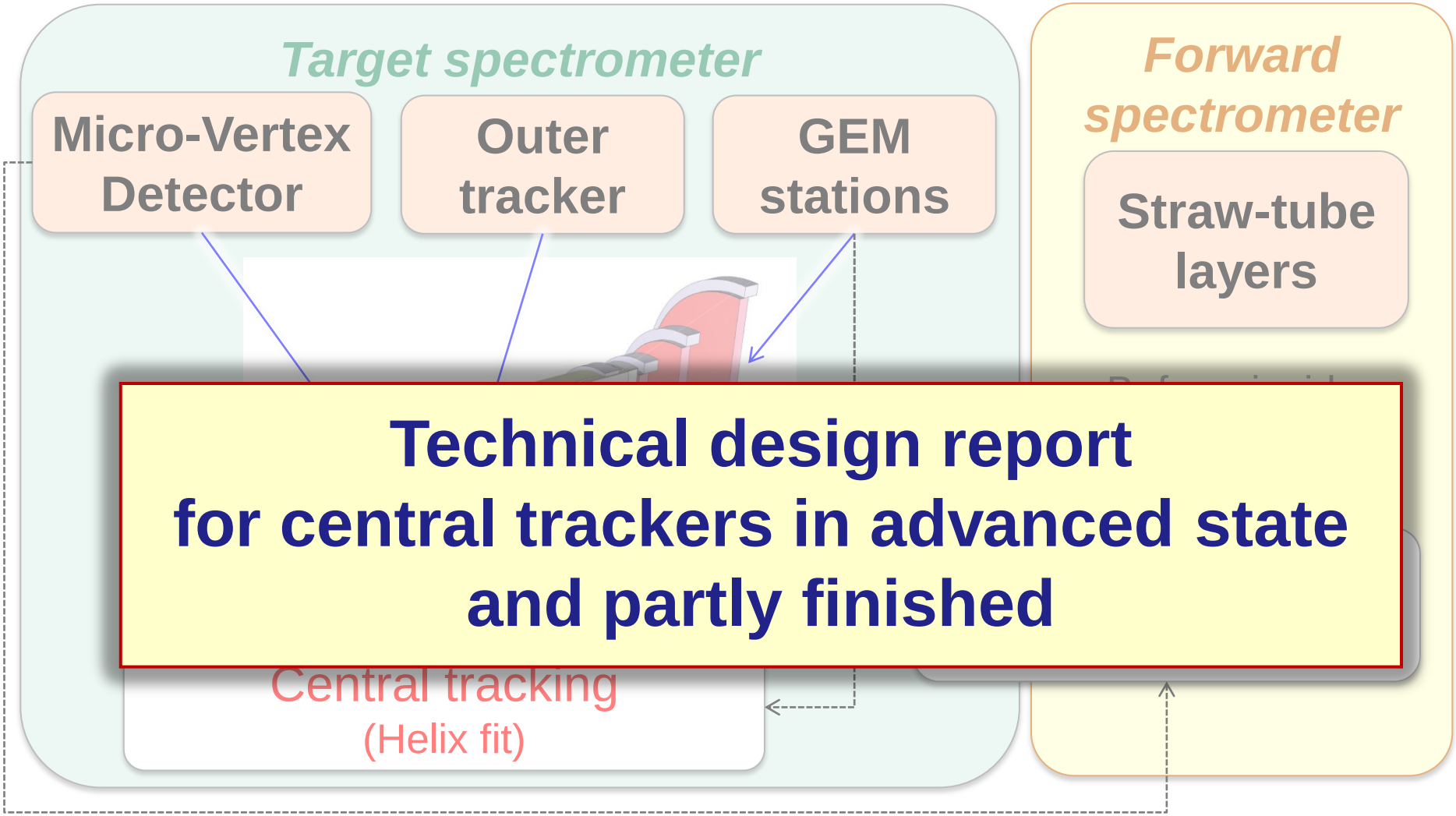
## Forward spectrometer

**Straw-tube layers**

Before, inside and behind dipole magnet

Forward tracking
(Straight lines)

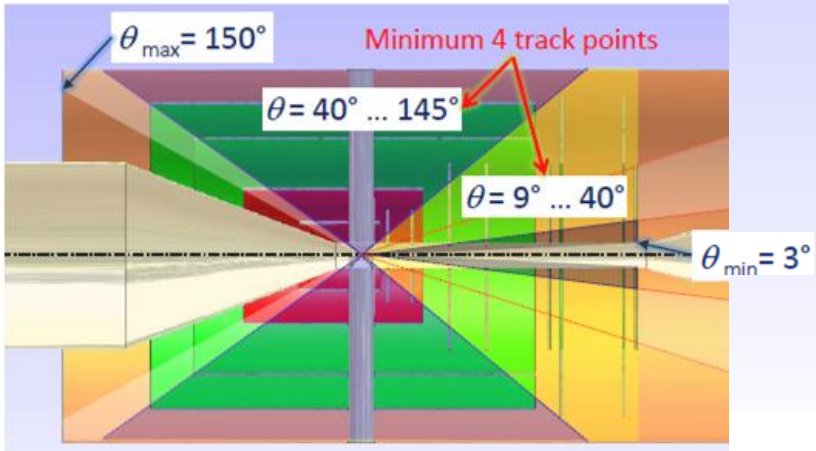
# Tracking systems

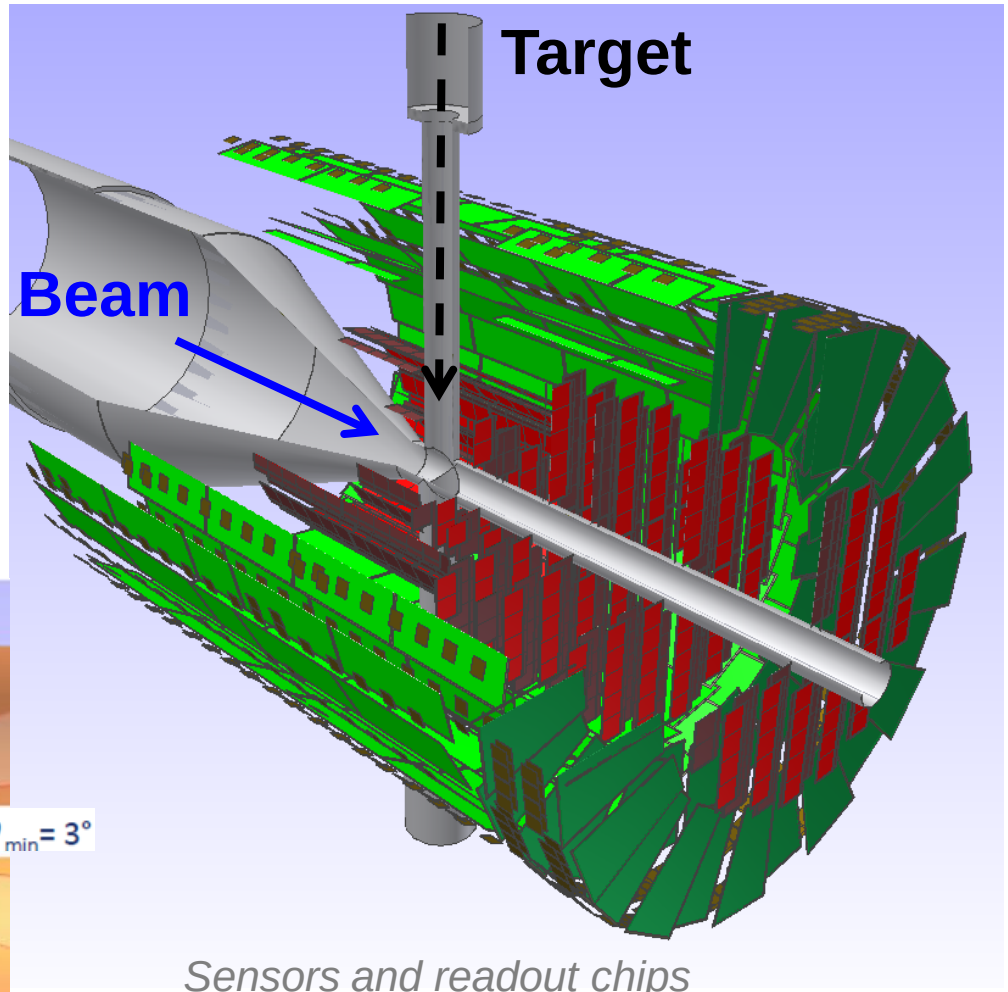



**Technical design report for central trackers in advanced state and partly finished**

# Micro-Vertex-Detector

- Basic design
  - Four barrel layers
  - Six disk layers
  - Silicon detectors:
    - ✓ Hybrid pixel detectors
    - ✓ Double-sided microstrip detectors

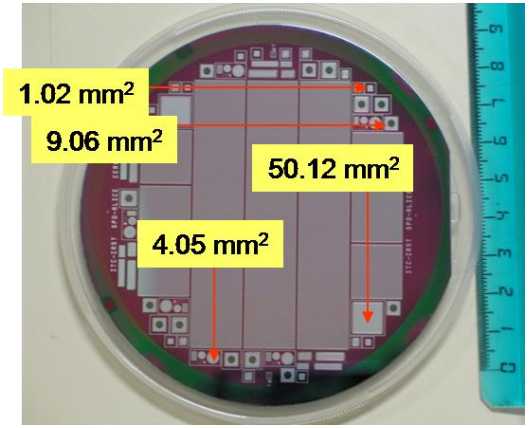


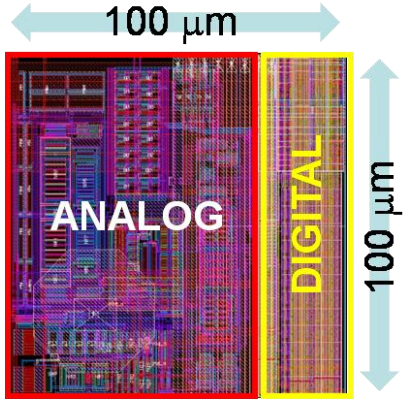



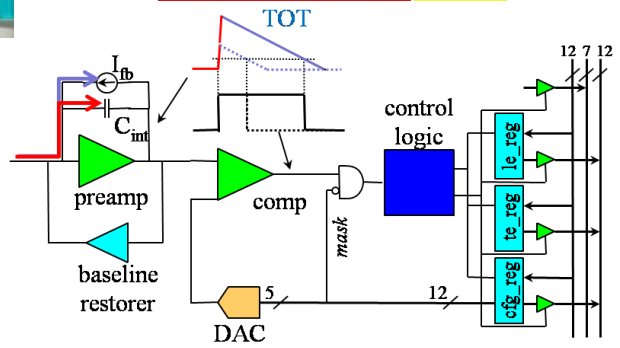

*Sensors and readout chips*

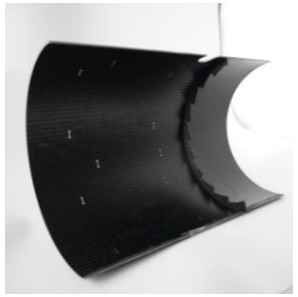
# Micro-Vertex-Detector

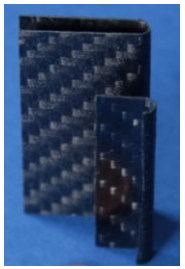
- Pixel sensors
  - Pixel cell size: $100 \times 100\ \mu m^2$
- Strip sensors
  - Strip pitch: 70 μm (trapezoidal)
    130 μm (rectangular)
- Advanced hardware developments
  - Triggerless readout chip: *TOPIX*
  - Sensor prototypes
  - Lightweight carbon support structures



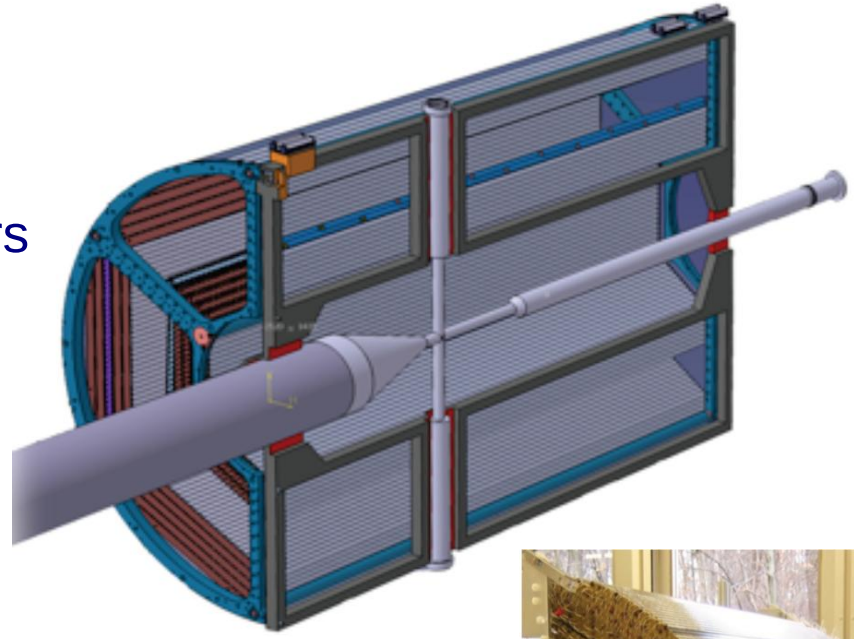



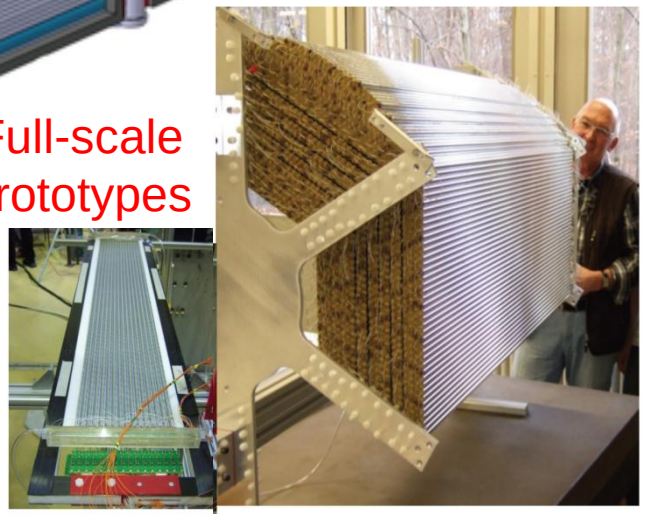


# Outer tracker: STT

- Basic design
  - Hexagonal shape (XY)
  - ~ 4500 straws in 20-26 layers
  - 8 skewed layers
    Skew angle: ~ 3°
  - Tubes:
    - ✓ Operated with gas mixture ($Ar/CO_2$) at 1 bar pressure
    - ✓ 27 μm thin Al-mylar tubes
- Performance
  - r/φ resolution: 130 μm
  - z resolution: ~ 1 mm
  - Prototype test at COSY-TOF

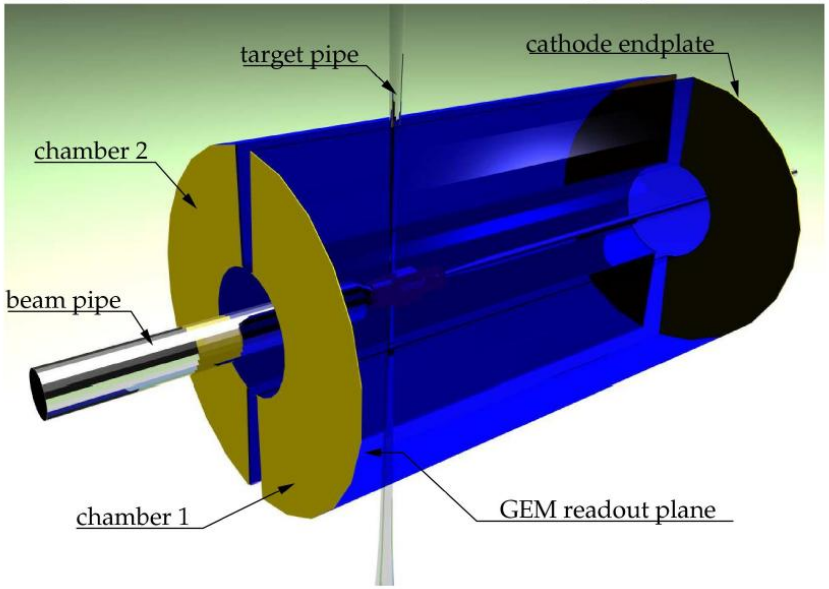


Full-scale prototypes



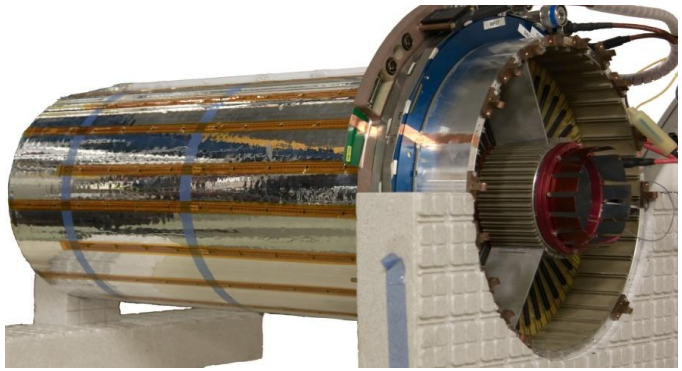
# Outer tracker: TPC

- Basic design
  - 2 half-cylinders
  - Segmented pad readout plane: ~ 100,000 channels
  - Gas mixture: Ne//$CO_2$
  - Signal amplification by GEM foils → Reduction of ion feedback
  - Continuous sampling




- Performance
  - r/φ resolution: 150 μm
  - z resolution: < 1 mm
  - Prototype test at FOPI (GSI)

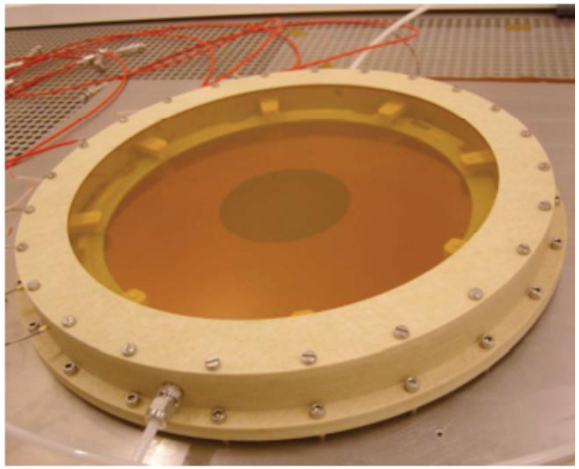
Dedicated prototype



More details by Roman Schmitz (poster session) and Martin Berger (today afternoon)

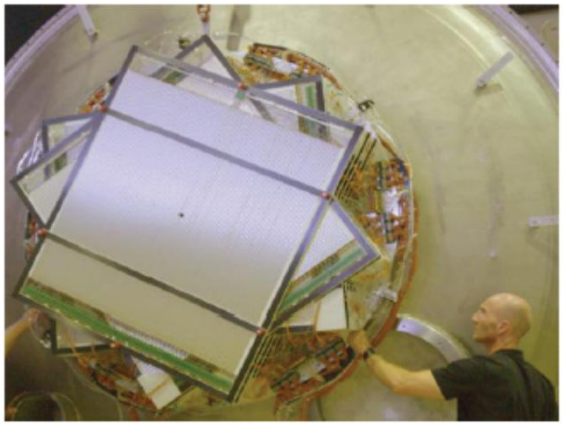
# Forward trackers

- GEM foils
  (Target spectrometer)
  - 3 stations at $z$ = 1.1 m / 1.4 m / 1.9 m
  - Sophisticated support concept



Full-scale prototypes

- STT layers
  - Basic concept similar to the one used in the outer central tracker
  - Track information:
    3 pairs of double layers
  - Integration:
    1+2 inside the myon filter
    3+4 inside the dipole
    5+6 further downstream

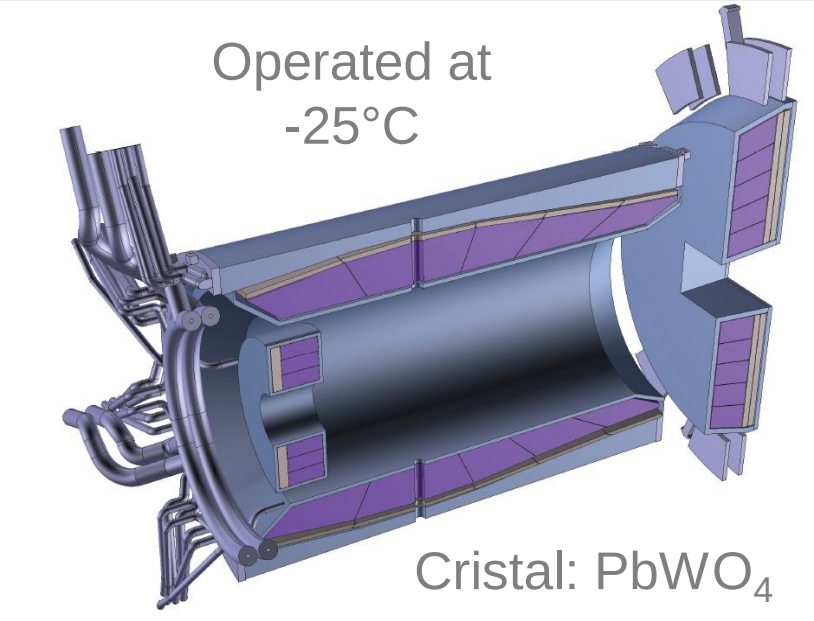


# Calorimetric system

## Target spectrometer

**Barrel EMC**

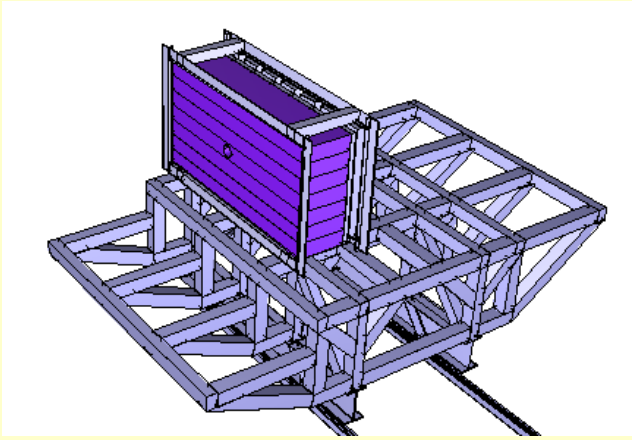
**Endcap structures**




**~ 15,000 cristals**

## Forward spectrometer

**Shashlyk calorimeter**



Lead-scintillator sandwiches
351 modules
(13 rows / 27 columns)

# Calorimetric system

Measurement results:
✓ Energy resolution:
1.54%/√E + 0.3%
✓ Time resolution: < 20 ns

Measurement results:
✓ Energy resolution:
3.5%/E + 2.8%/√E + 1.3%

**Technical design report finished**
**First crystals delivered**

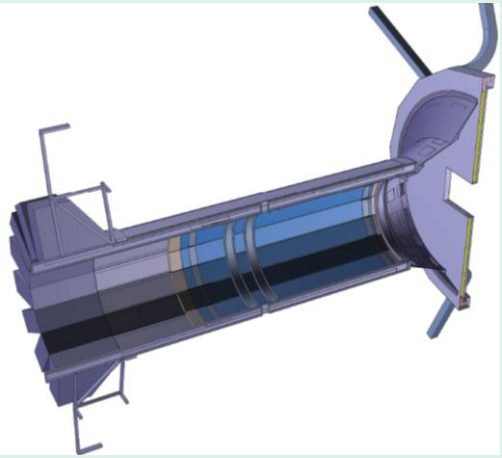
**Technical design report:** *arXiv:0810.1216v1* [physics.ins-det]

# Cherenkov detectors

## Target spectrometer

**Barrel DIRC**

**Disc DIRC**

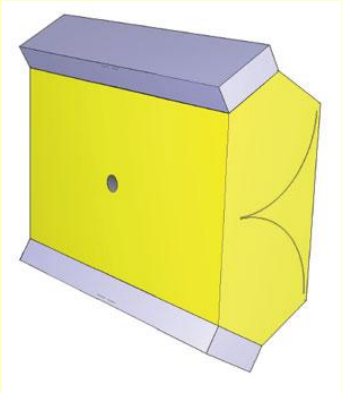


**D** etection of
**I** nternally
**R** eflected
**C** herenkov
light

Radiator material: Fused silica
→ 3σ π/K separation
0.8 GeV/c ≤ *p* ≤ 5 GeV/cC

## Forward spectrometer

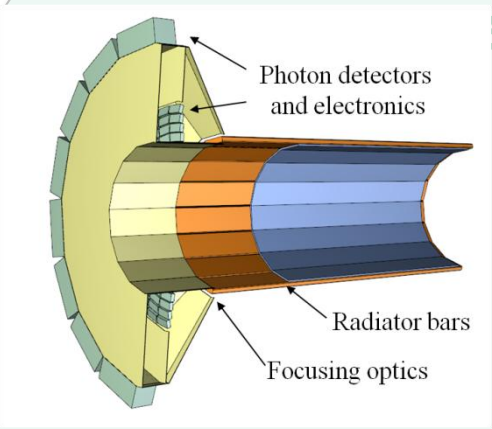
**RICH**

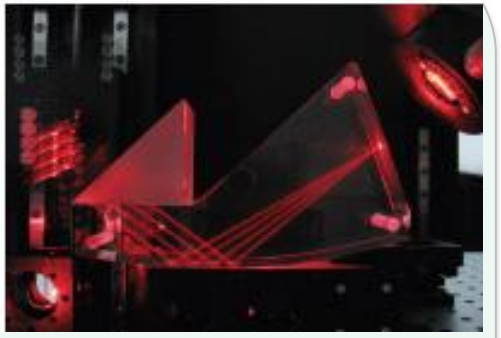


**R** ing
**I** maging
**CH** erenkov
detector

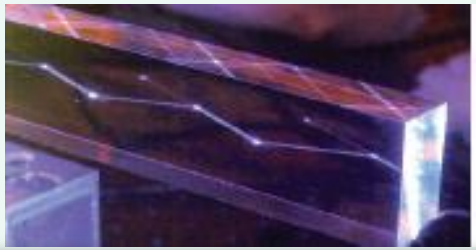
Radiator materials:
Aerogel / $C_{14}F_{10}$
→ π/K separation
2 GeV/c ≤ *p* ≤ 15 GeV/c

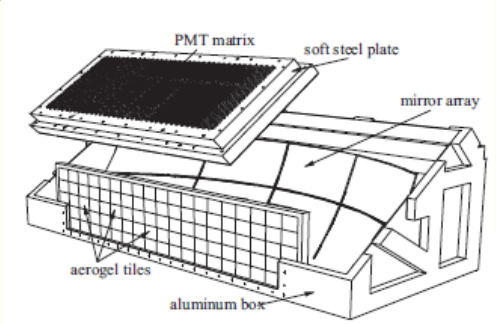
# Cherenkov detectors



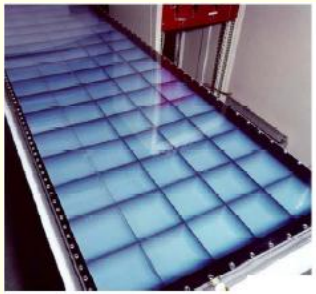



DIRC prototypes






Possible re-use of HERMES RICH



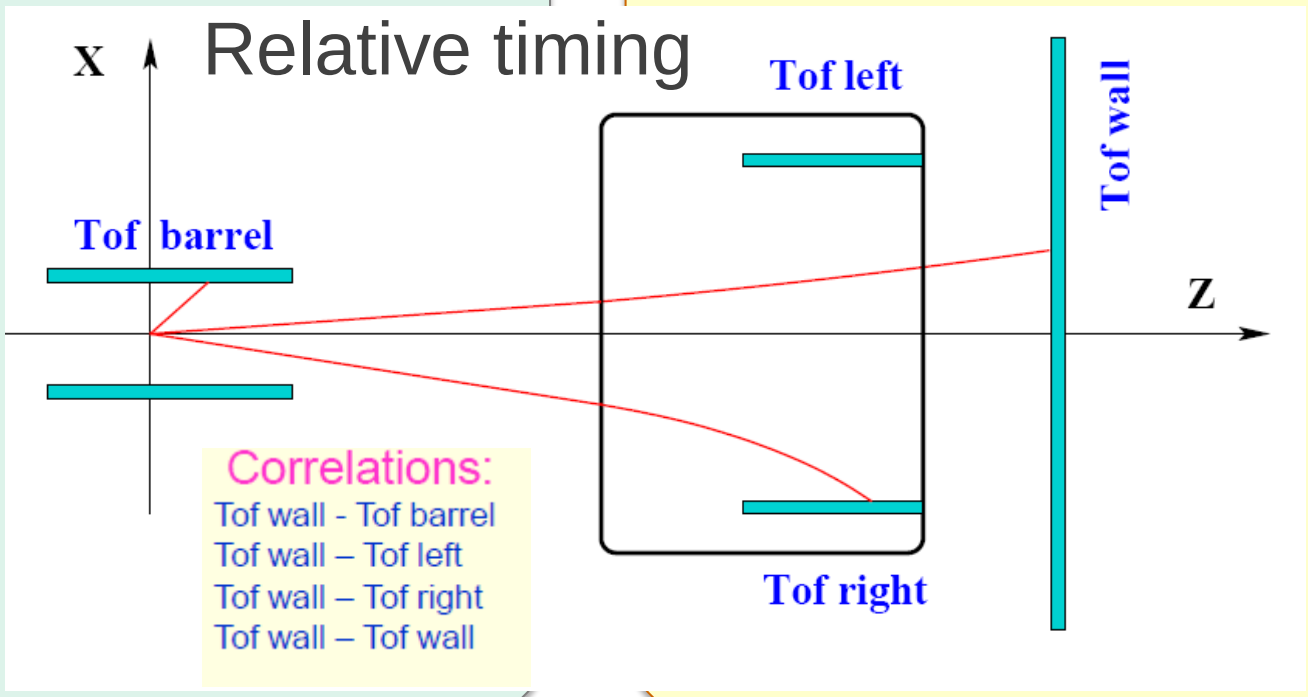
**Extensive studies in particular for PANDA DIRCs**

See e.g. Nucl. Instr. Meth. A 595 (2008) 1108-111 and 12–115

# Time-of-flight system

## Target spectrometer

## Forward spectrometer

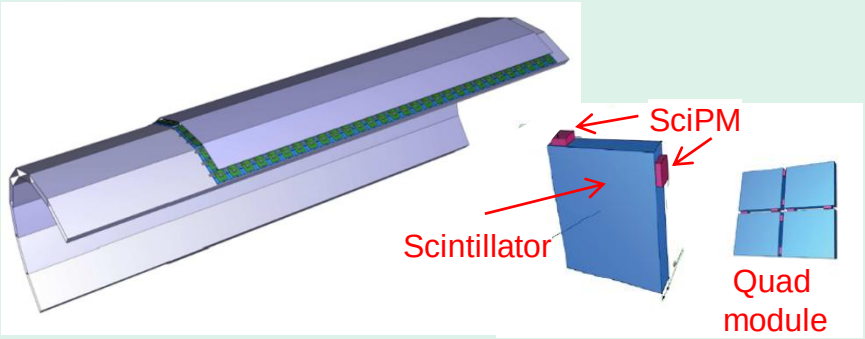



- PID: Important input for slower particles ($p$ < 0.8 GeV/c)
- Triggerless DAQ: Definition of event start time

# Time-of-flight system

## Target spectrometer

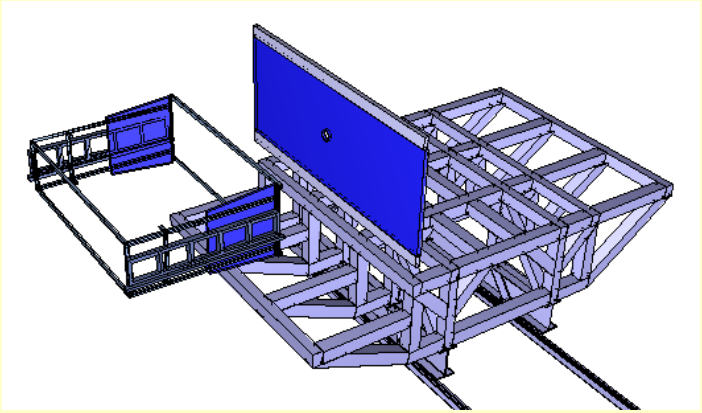
**Barrel tile hodscope**




Time resolution: (50...100) ps
Scintillator slabs or
pads of multigap resistive plate chambers (RPC)

## Forward spectrometer

**Scintillator wall**

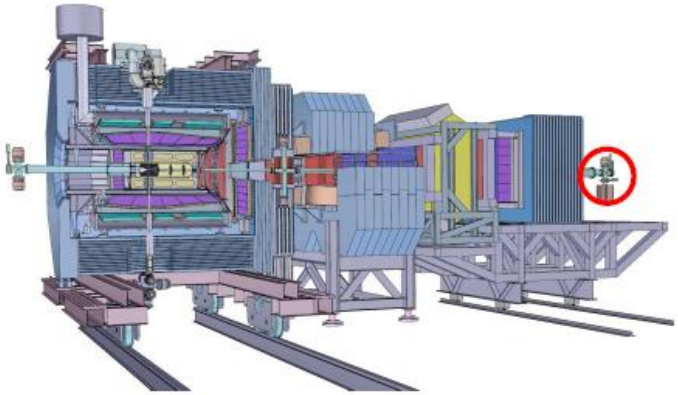


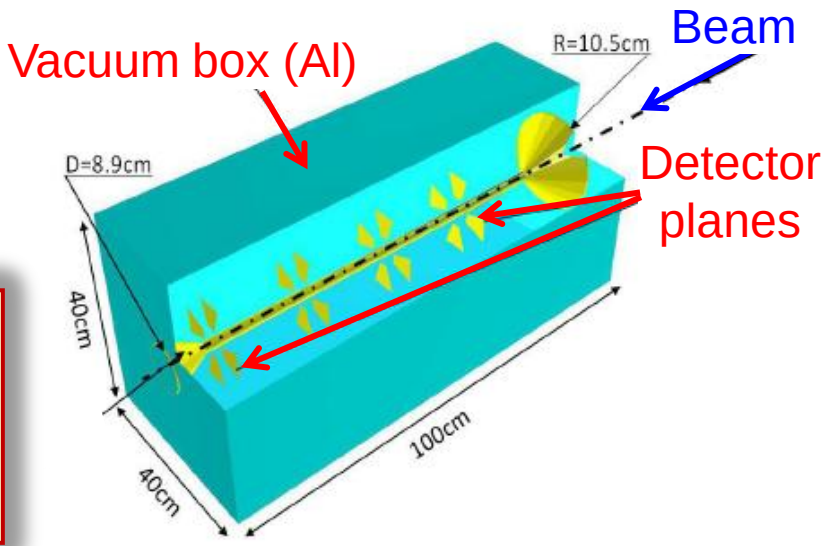
Scintillator slabs
Time resolution: ~ 50 ps

**Conceptual design phase**

# Luminosity monitor

- Basic design
  - 4 layers of double-sided silicon strip detectors (50 μm pitch)
  - Covered angular range: (3 ... 8) mrad → Low-*t* scattered antiprotons
- Performance
  - Design goal: 3% absolute precision on luminosity

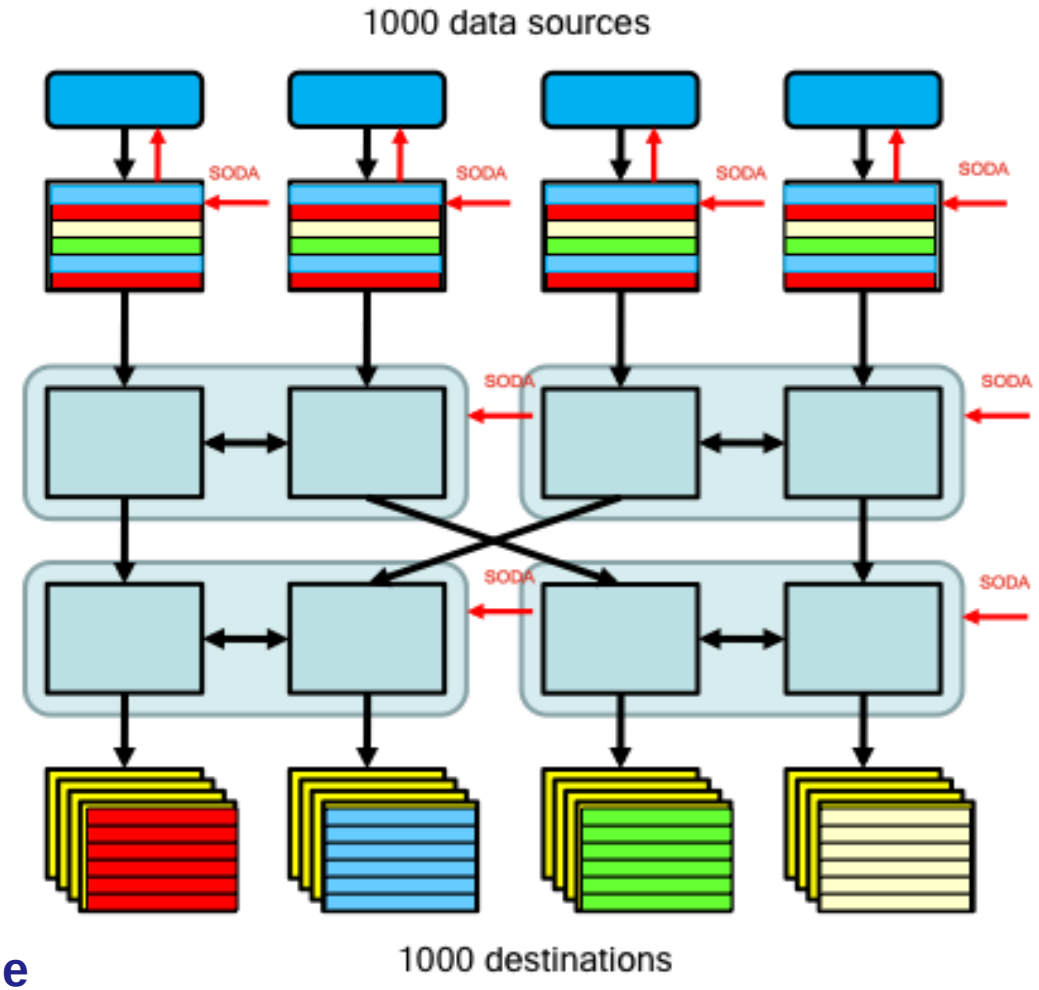





**Conceptual design phase**

# DAQ

- **Components**
  - Time distribution system
  - 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**

# Summary

- PANDA is a **unique tool** to access the physics in the charm quark sector
  - High beam quality and intensity
  - Optimized detector setup and sophisticated DAQ concept
- Key features of the PANDA spectrometer
  - Nearly $4\pi$ acceptance
  - High momentum resolution ~1%
  - Precise vertex resolution ~ 100 $\mu$m
  - Good particle identification ( $\gamma$, $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, $p$ )
  - Photon detection in a wide range ( 1 MeV ... 10 GeV)
  - High energy resolution ~ few % (or better)

# Summary

**PANDA has exceeded initial phase of conceptual design studies**

**Technical design reports of the main parts are finished or underway**

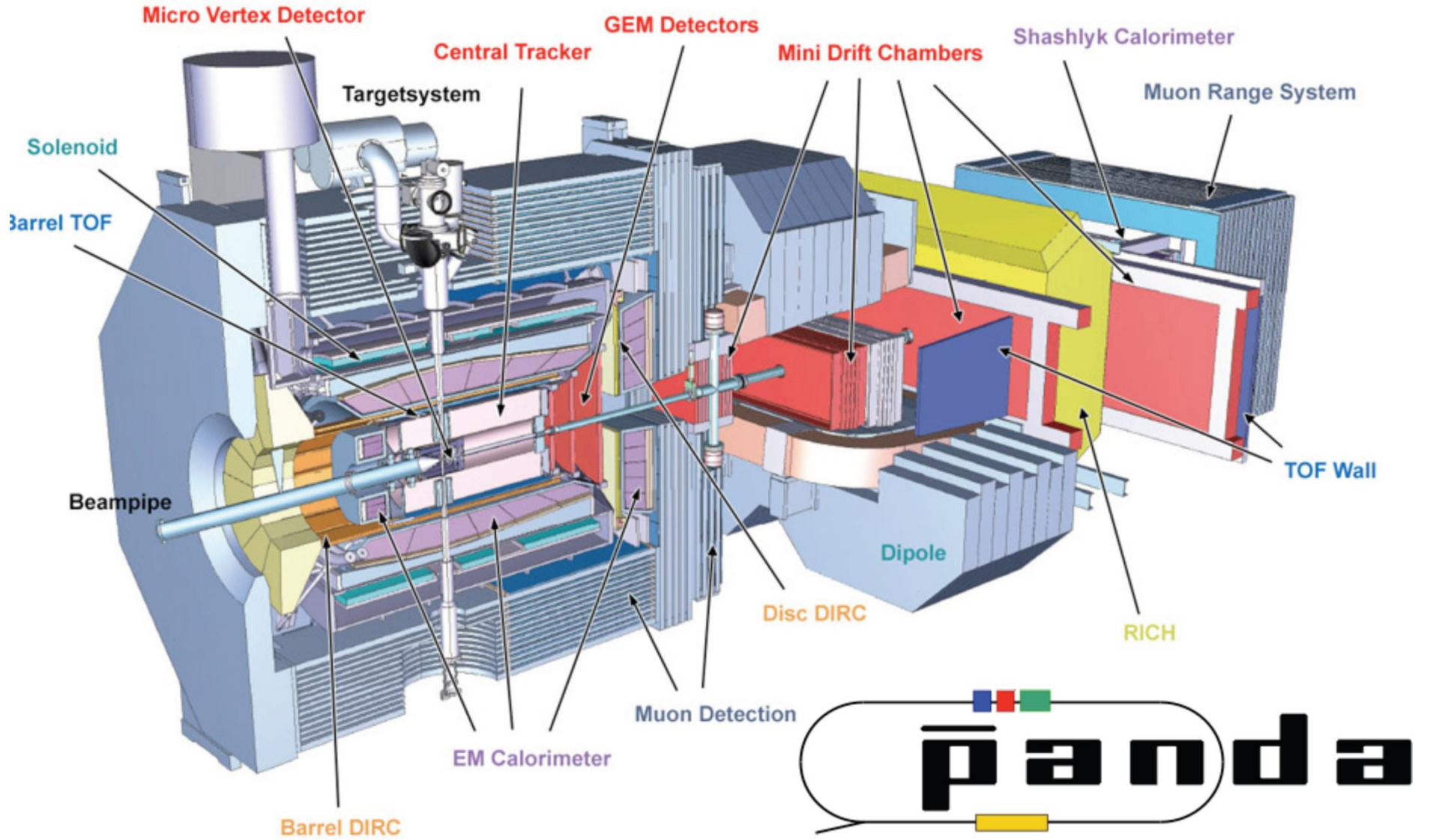
**Exciting period ahead towards the final detector assembly**

# More than 400 physicists from 53 institutions in 16 countries

U Basel
IHEP Beijing
U Bochum
IIT Bombay
U Bonn
IFIN-HH Bucharest
U & INFN Brescia
U & INFN Catania
JU Cracow
TU Cracow
IFJ PAN Cracow
GSI Darmstadt
TU Dresden
JINR Dubna
(LIT,LPP,VBLHE)
U Edinburgh
U Erlangen
NWU Evanston

U & INFN Ferrara
U Frankfurt
LNF-INFN Frascati
U & INFN Genova
U Glasgow
U Gießen
KVI Groningen
IKP Jülich I + II
U Katowice
IMP Lanzhou
U Lund
U Mainz
U Minsk
ITEP Moscow
MPEI Moscow
TU München
U Münster
BINP Novosibirsk

IPN Orsay
U & INFN Pavia
IHEP Protvino
PNPI Gatchina
U of Silesia
U Stockholm
KTH Stockholm
U & INFN Torino
Politechnico di Torino
U & INFN Trieste
U Tübingen
TSL Uppsala
U Uppsala
U Valencia
SMI Vienna
SINS Warsaw
TU Warsaw


Micro Vertex Detector
Central Tracker
GEM Detectors
Mini Drift Chambers
Shashlyk Calorimeter
Muon Range System
Targetsystem
Solenoid
Barrel TOF
Beampipe
TOF Wall
Dipole
Disc DIRC
RICH
Muon Detection
EM Calorimeter
Barrel DIRC
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