P̄ANDA PHYSICS @ FAIR

- The FAIR project
- The Antiproton Physics Program
- Status of the FAIR project

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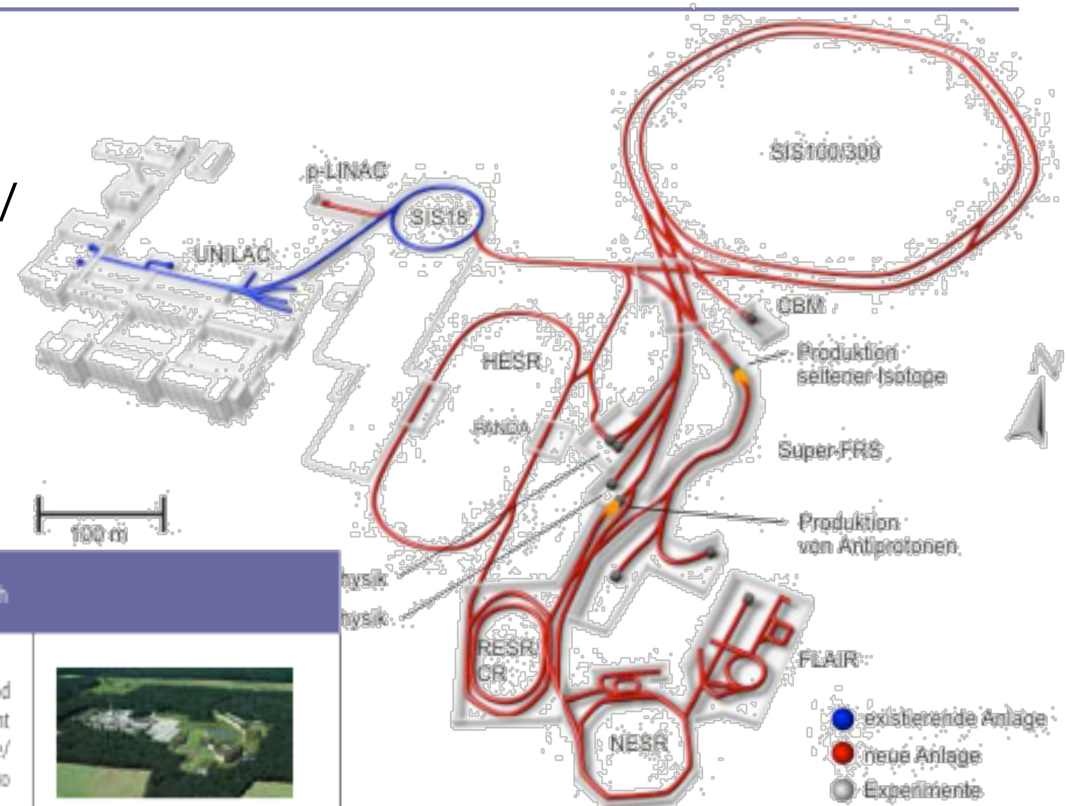
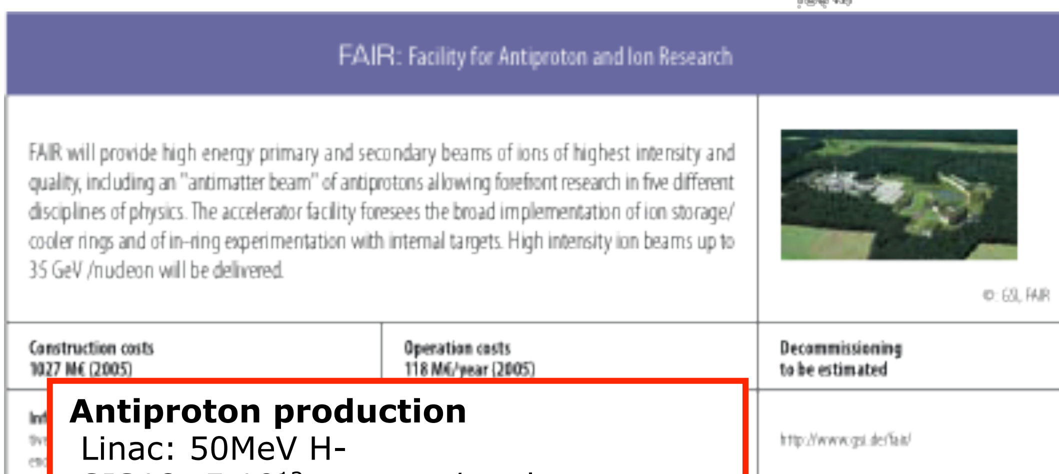
FAIR Facility



Primary Beams

- $^{238}U^{28+}$ 1.5 GeV/u; 10^{12}/s ions/ pulse
- 30 GeV protons; 2.5×10^{13}/s
- $^{238}U^{73+}$ up to 25 (- 35) GeV/u 10^{10}/s



FAIR: Facility for Antiproton and Ion Research

FAIR will provide high energy primary and secondary beams of ions of highest intensity and quality, including an "antimatter beam" of antiprotons allowing forefront research in five different disciplines of physics. The accelerator facility foresees the broad implementation of ion storage/ cooler rings and of in-ring experimentation with internal targets. High intensity ion beams up to 35 GeV /nucleon will be delivered.

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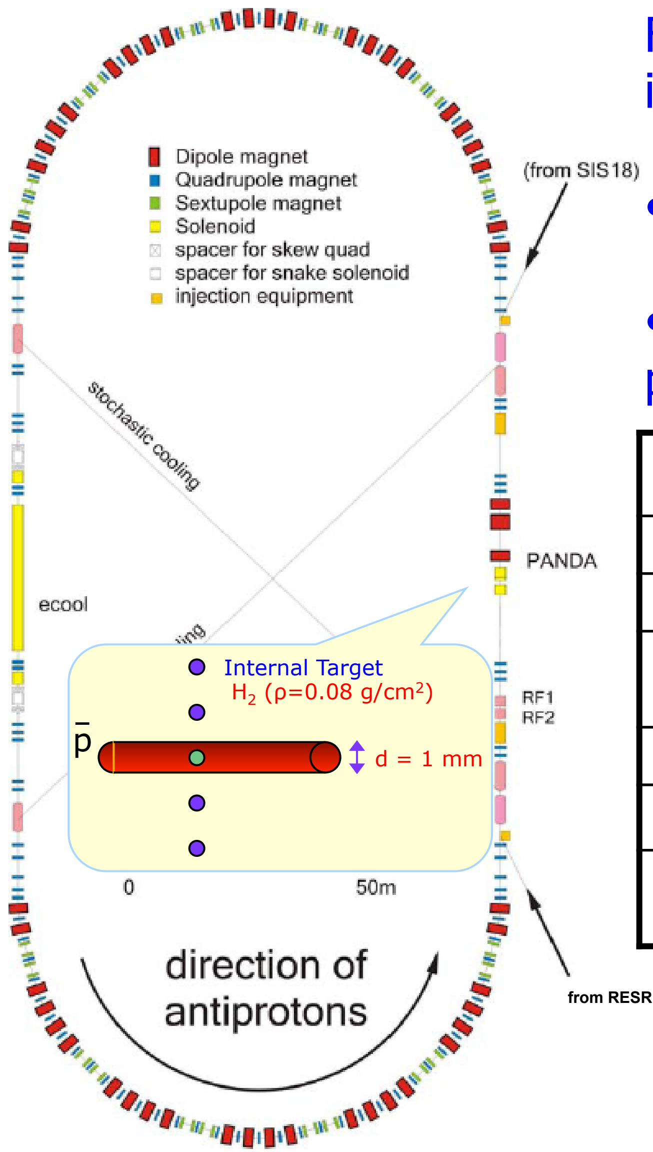
Construction costs	Operation costs	Decommissioning
1027 M€ (2005)	118 M€/year (2005)	to be estimated
		http://www.gsi.de/fair/

Antiproton production
Linac: 50MeV H-
SIS18: $5 \cdot 10^{12}$ protons / cycle
SIS100: $2\text{-}2.5 \cdot 10^{13}$ protons / cycle
Production target: 29 GeV protons
bunch compressed to 50nsec
$2 \cdot 10^{7}$/s ($7 \cdot 10^{10}$/h) antiprotons

Secondary Beams

- Broad range of radioactive beams up to 1.5 - 2 GeV/u
- Antiprotons 3 (0) - 30 GeV

HESR - High Energy Antiproton ring



For commissioning **protons** can be injected from:

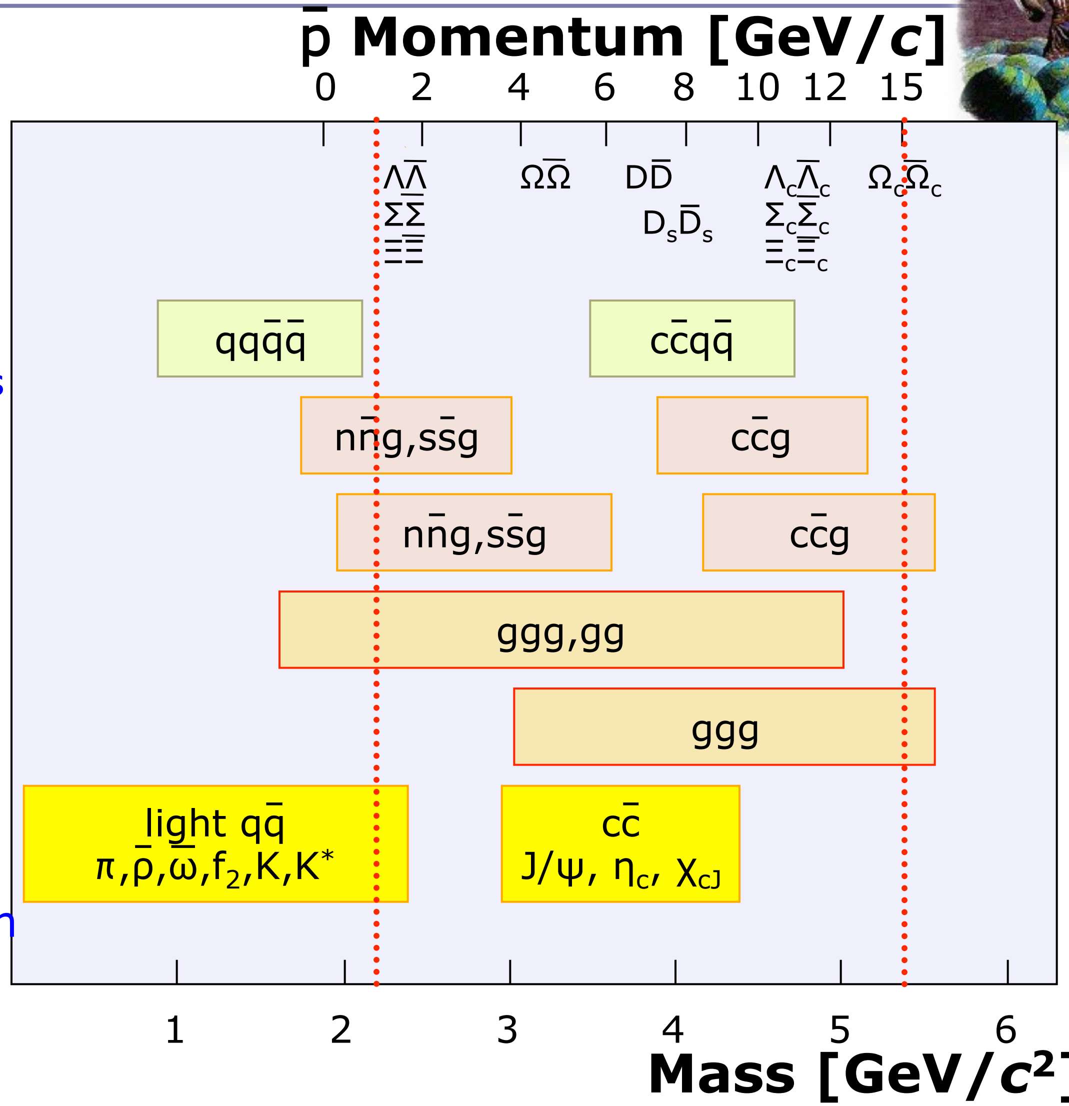
- RESR at reversed field polarities
- SIS 18 at 12.7 Tm with same field polarity, but opposite direction

Experiment Mode	**High Resolution Mode**	**High Luminosity Mode**
Target	Pellet Target with $4 \cdot 10^{15}$ cm^{-2}	
rms-emittance	1 mm mrad	
Momentum range	1.5 – 8.9 GeV/c	1.5 – 15.0 GeV/c
Intensity	$1 \cdot 10^{10}$ $\bar{p}$	$1 \cdot 10^{11}$ $\bar{p}$
Luminosity	$2 \cdot 10^{31}$cm^{-2}s^{-1}	$2 \cdot 10^{32}$cm^{-2}s^{-1}
rms-momentum resolution	10^{-5}	10^{-4}

The $\bar{p}$ -beam is injected from RESR at 3.8 GeV/c

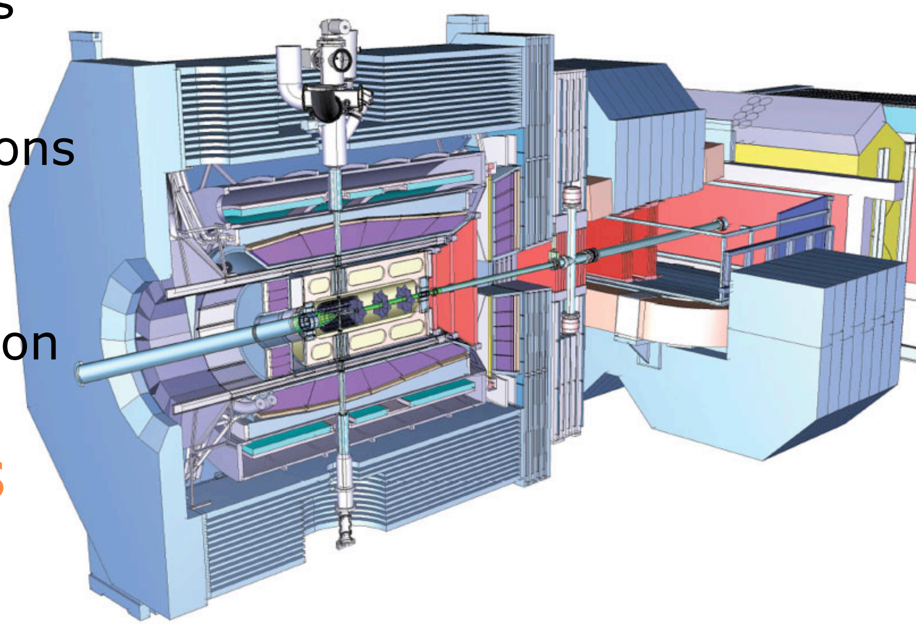
$\overline{\text{P}}$ANDA playground

- 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
    - ✓ Ξ^- nuclei
    - ✓ ΛΛ hyepernuclei
- e.m. processes



$\bar{P}$ANDA Scientific program

- **Charmonium/Open Charm States**
  - Precise Spectroscopy
  - Investigation of Confinement Potential
  - X, Y, Z, D_{sJ} States up to 5.5 GeV
- **Exotic Matter**
  - Search for Glueballs and Hybrids
- **Hadrons in Media**
  - In-medium Modification of Hadrons
- **Nucleon-Structure**
  - Generalized Parton Distributions
  - Timelike Form Factor of the Proton
  - Drell-Yan Processes
- **Double-Strange Systems**
  - Ξ-atoms and Nuclei
  - ΛΛ-hypernuclei



Experimental Techniques

e^+e^- collisions
direct formation
two-photon production
initial state radiation (ISR)
B meson decay
(BaBar, Belle, BES, CLEO(-c), LEP ...)

+ low hadronic background
+ high discovery potential
− direct formation limited to vector states
− limited mass and width resolution for non vector states

$\bar{p}p$ annihiliation
(LEAR, Fermilab E760/E835, $\bar{P}$ANDA)

− high hadronic background
+ high discovery potential
+ direct formation for all (non-exotic) states
+ excellent mass and width resolution for all states

Hadroproduction
(CDF, D0, LHC)

Electroproduction
(HERA)

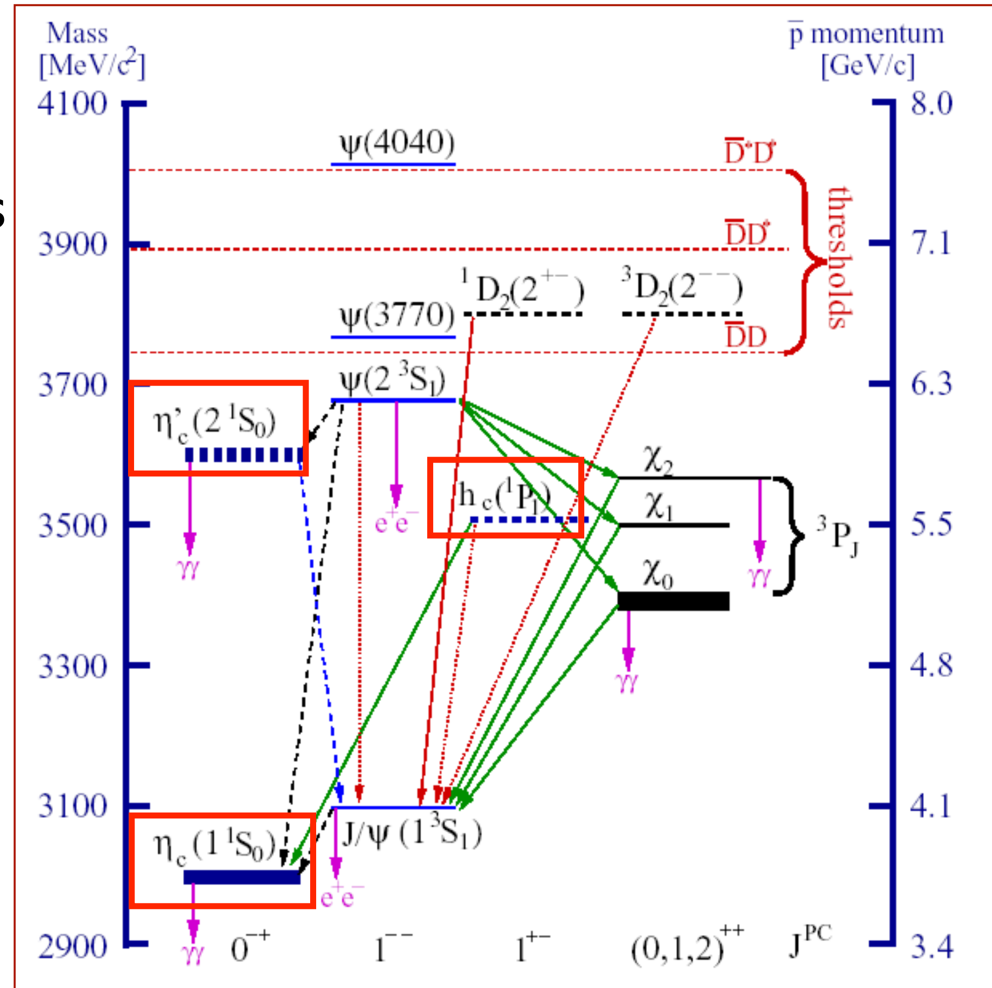
Charmonium spectroscopy

Charmonium spectrum
is nowadays more clear…

- new precise measurements of η_c mass
- η'_c unambiguously seen. Width 14±7 keV
- h_{1c} seen even if width is still not measured

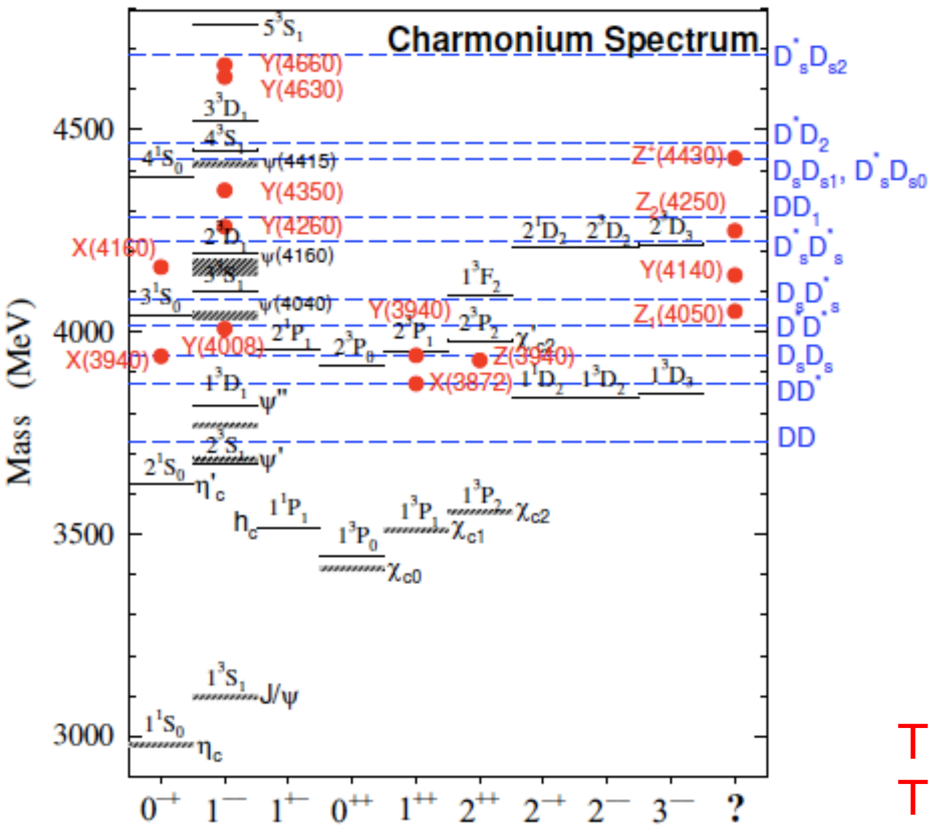
Open questions…

- States above $D\bar{D}$ thr. are not well established



Mesons

Without entering into the details of each state some general consideration can be drawn.



Arxiv:09010.3409v2 [hep-th]

- masses are barely known;
- often widths are just upper limits;
- few final states have been studied;
- statistics are poor;
- quantum number assignment is possible for few states;
- some resonances need confirmation…

There are problems of compatibility Theory - Experiment

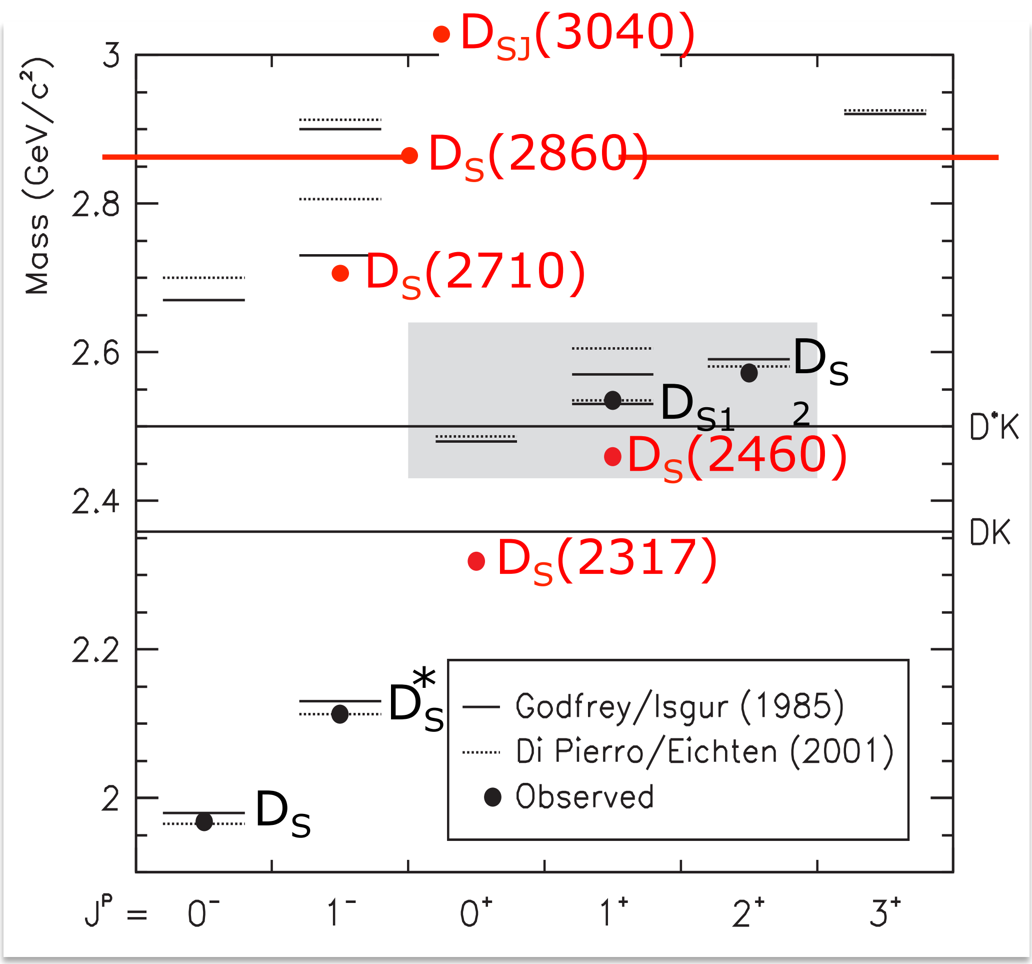
OpenCharm states

For the states $c(\bar{u}/\bar{d})$ theory and experiment were in agreement.

The quark model describes the spectrum of heavy-light systems and it was expected to be able to predict unobserved excited $D_S(c\bar{s})$ mesons with good accuracy

The discovery of the new D_{SJ} states has brought into question potential models

Nowadays, there is a problem to reconcile Theory and Experimental results

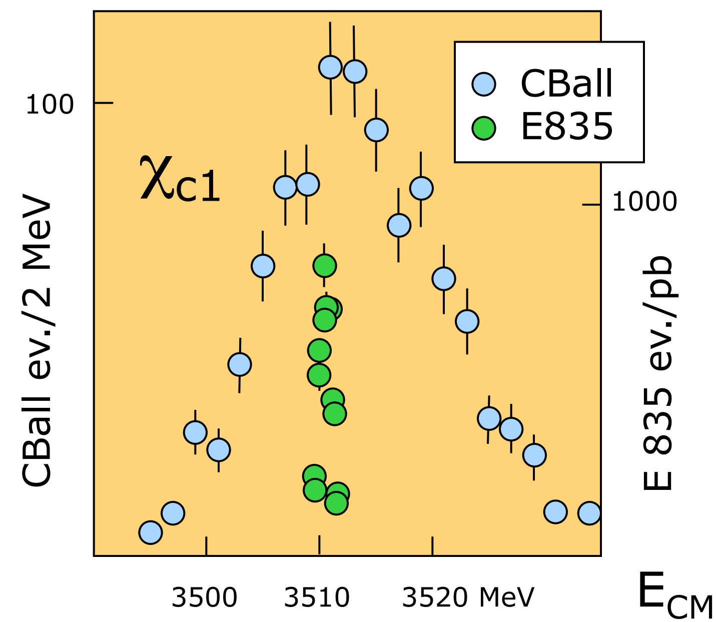


Charmonium spectroscopy

$e^+e^- \rightarrow \psi' \rightarrow \gamma\chi_{1,2} \rightarrow \gamma\gamma J/\psi \rightarrow \gamma\gamma e^+e^-$

$p\,\bar{p} \rightarrow \chi_{1,2} \rightarrow \gamma J/\psi \rightarrow \gamma e^+e^-$

- e^+e^- interactions:
  - Only 1^{--} states are formed
  - Other states only by secondary decays (moderate mass resolution)



- $p\bar{p}$ reactions:
  - All states directly formed (very good mass resolution)

$Br(p\bar{p} \rightarrow \eta_c) = 1.2\ 10^{-3}$

$Br(e^+e^- \rightarrow \psi) \cdot Br(\psi \rightarrow \gamma\eta_c) = 2.5\ 10^{-5}$

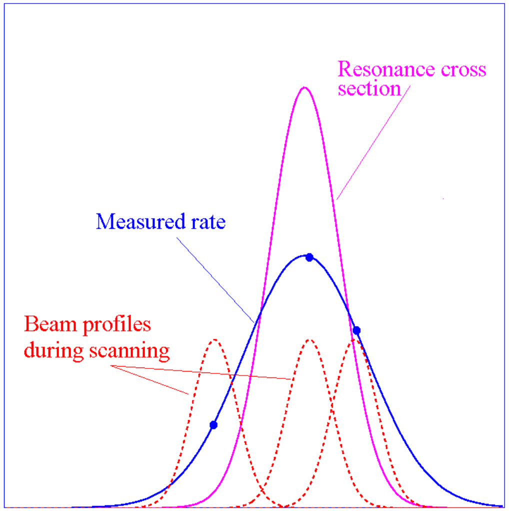
Charmonium spectroscopy

The cross section for the process:

$\bar{p}p \rightarrow \bar{c}c \rightarrow$ final state

is given by the Breit-Wigner formula:

$$\sigma_{BW} = \frac{2J+1}{4}\frac{\pi}{k^2}\frac{B_{in}B_{out}\Gamma_R^2}{(E-M_R)^2+\Gamma_R^2/4}$$



The production rate ν is a convolution of the BW cross section and the beam energy distribution function *f(E,ΔE)*:

$$\nu = L_0\left\{\varepsilon\int dE f(E,\Delta E)\sigma_{BW}(E)+\sigma_b\right\}$$

The resonance mass M_R, total width Γ_R and product of branching ratios into the initial and final state $B_{in}B_{out}$ can be extracted by measuring the formation rate for that resonance as a function of the cm energy E.

What PANDA can do for charmonium physics?

- States below $D\bar{D}$ threshold
  - The study of the h_c remains of very high priority. The width can be determined precisely with an energy scan of the resonance
  - The study of the η'_c is just started. Small splitting from the ψ' have to be understood. Width and decay modes must be measured.
- The energy region above open charm threshold is the most interesting for the future and will have to be explored in great detail:
  - find all missing states, measure their properties.
  - explain nature of existing states (X(3872), Y(3940) ...)
  - study radiative and strong decays, e.g. $\psi(4040) \to D^* \bar{D}^*$ and $\psi(4160) \to D^* \bar{D}^*$, multi amplitude modes which can test the mechanisms of the open-charm decay.

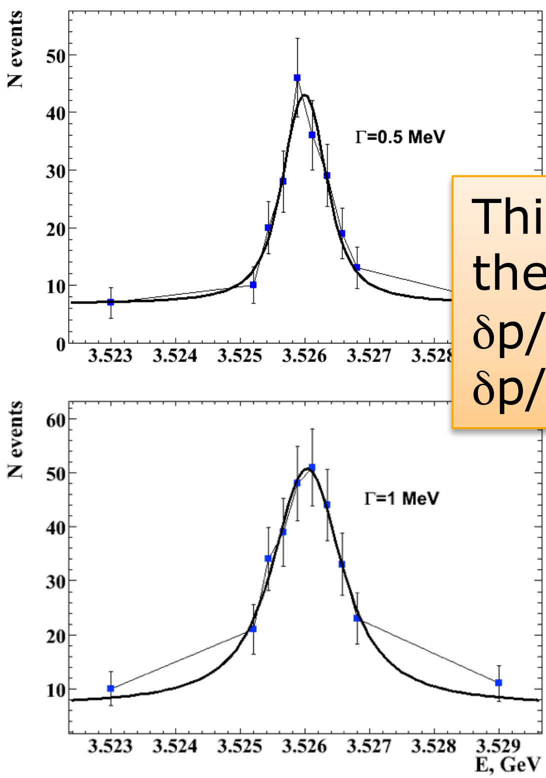
What PANDA can do for charmonium physics?

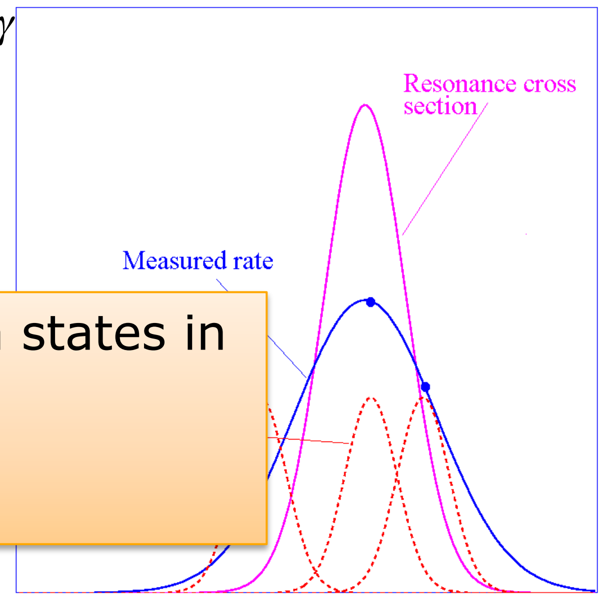
- At $2\times10^{32}cm^{-2}s^{-1}$ accumulate 8 pb^{-1}/day (assuming 50 % overall efficiency) $\Rightarrow$ $10^4 \div 10^7$ ($c\bar{c}$) states/day.
- Total integrated luminosity 1.5 fb^{-1}/year (at $2\times10^{32}cm^{-2}s^{-1}$, assuming 6 months/year data taking).
- Improvements with respect to Fermilab E760/E835:
  - Up to ten times higher instantaneous luminosity.
  - Better beam momentum resolution $\Delta p/p = 10^{-5}$ (FAIR) vs 2×10^{-4} (FNAL)
  - Better detector (higher angular coverage, magnetic field, ability to detect hadronic decay modes).

Charmonium states width

Thanks to the precise HESR momentum definition, widths of known states can be precisely measured with an energy scan.

Energy scan of 10 values around the h_c mass, width upper limit is 1MeV; each point represents a 5 day data taking in high luminosity mode, module 5 available, for the channel: $h_c \to \eta_c \gamma \to \phi\phi\gamma \to 4K\gamma$ with a S/B 8:1





This holds for all known states in the charmonium region
$\delta p/p\ 10^{-4} \longrightarrow \Gamma$ 100 KeV
$\delta p/p\ 10^{-5} \longrightarrow \Gamma$ 10 KeV

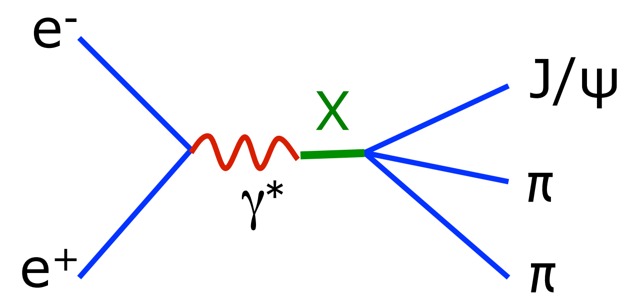
Sensitivity

$\Gamma_{R,MC}$ [MeV]	$\Gamma_{R,reco}$ [MeV]	$\Delta\Gamma_R$ [MeV]
1	0.92	0.24
0.75	0.72	0.18
0.5	0.52	0.14

The X(3872) state

A charmonium(-like) state found in $e^+ e^-$

X(3872) → $J/\psi\ \pi^+\pi^-$



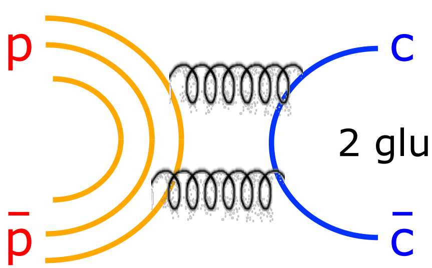
Not found in formation in e^+e^- collision
→ Not $J^{PC} = 1^{--}$

Observation of decay into $J/\psi\ \gamma$
→ C=+1

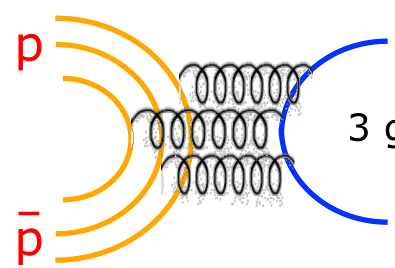
Mass of X(3872) → $D^0\bar{D}^{*0}$ shifted by ~3 MeV/c^2
→ S-wave molecular state?

Width is unknown lower limit $\Gamma < 2.3$ MeV/c^2 (Belle)

Helicity amplitude analysis from CDF
→ E.g. $J^{PC} = 1^{++}$ or 2^{-+}



2 gluons: 0^{++}, 1^{++} 2++ (L=0)
0^{-+}, 2^{-+} (L=1)

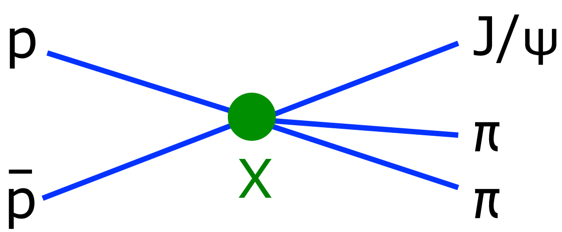


3 gluons: 1^{--}, 1^{+-}

Quantum numbers can be determined by studying angular distributions

X(3872) → J/ψ π⁺π⁻ simulation

Formation



Either neutral and charged pions!

It is interesting to check breaks isospin in the decays $J/\psi\rho(\to\pi^+\pi^-)$, $J/\psi\omega(\to\pi^+\pi^-\pi^0)$ → is it charmonium?

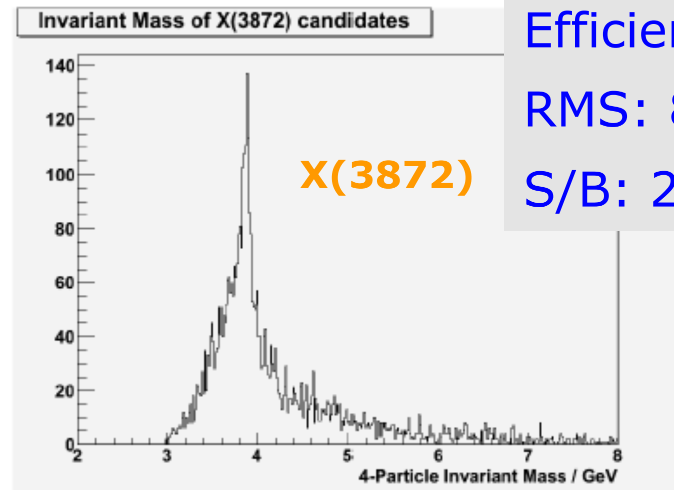
Simulation at $\sqrt{s}$ = 3872 MeV/c^2
p_{beam}=6.99100 GeV/c
Baseline assumption: σ_{peak} = 50 nb

$J/\psi \to e^+e^-$ or $\mu^+\mu^-$

Selection of inv. J/ψ-mass

Combination with $\pi^+\pi^-$

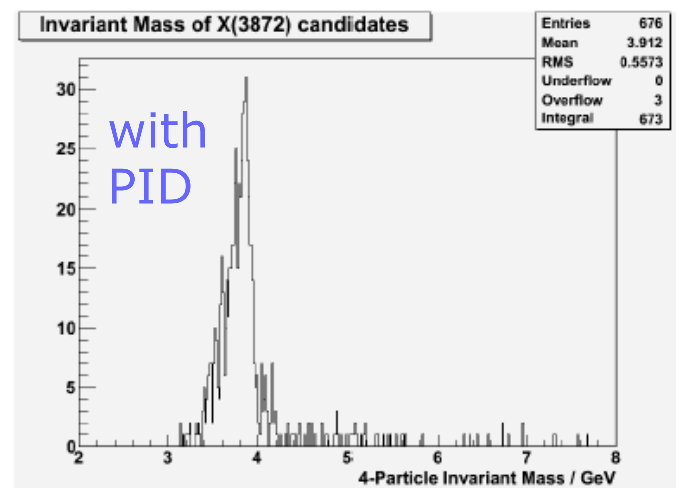
4-particle invariant mass



Efficiency: 72%

RMS: 8.3 MeV/c^2

S/B: 2



Measurement of X(3872) width

$m = 3872.01 \pm 0.03$ MeV/c^2

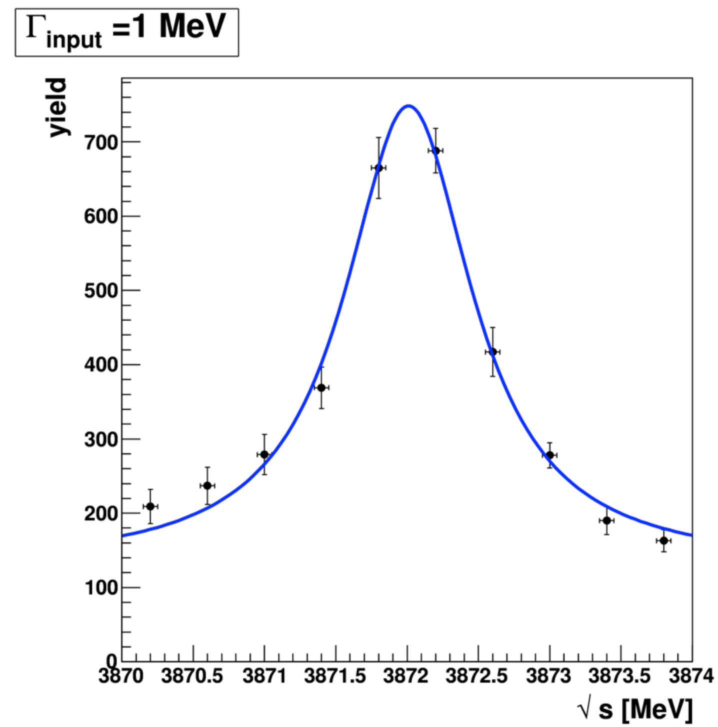
$\Gamma = 1.11 \pm 0.08$ MeV/c^2

→ Unfolding beam profile

($\Delta p/p = 3 \cdot 10^{-5}$)

Mass resolution ~ 50 keV/c^2

Width precision ~ 10%



each data point 2 days data taking

10 steps a 400 keV/c^2

3870.2 – 3873.8 MeV/c^2

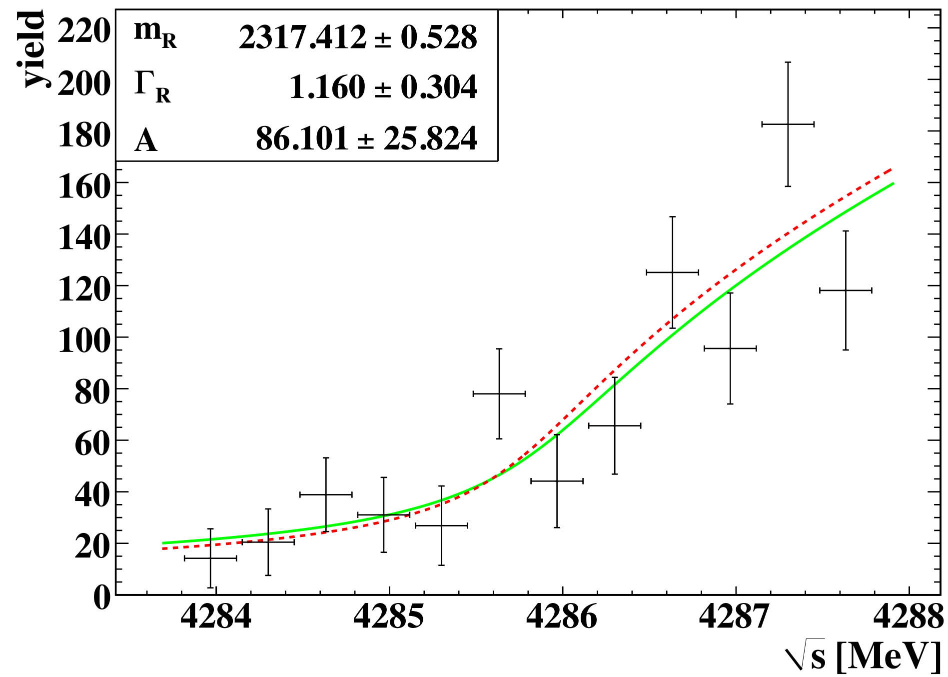
$\Delta p/p = 3 \cdot 10^{-5}$

Heavy-light D_{sJ} systems

Up to now the widths of the new discovered D_{sJ} state are only constrained by upper limits of few MeV due to detector resolution.

the $\bar{p}$ momentum spread in the HESR is sufficiently small to allow the measurement of the D_{sJ} widths in a threshold scan of the reaction

$$\bar{p}p \rightarrow \bar{D}_s D_{sJ}$$



Fit of the excitation function obtained from the reconstructed signal events

Exotic hadrons

In the light meson region, about 10 states have been classified as "Exotics". Almost all of them have been seen in $p\bar{p}$…

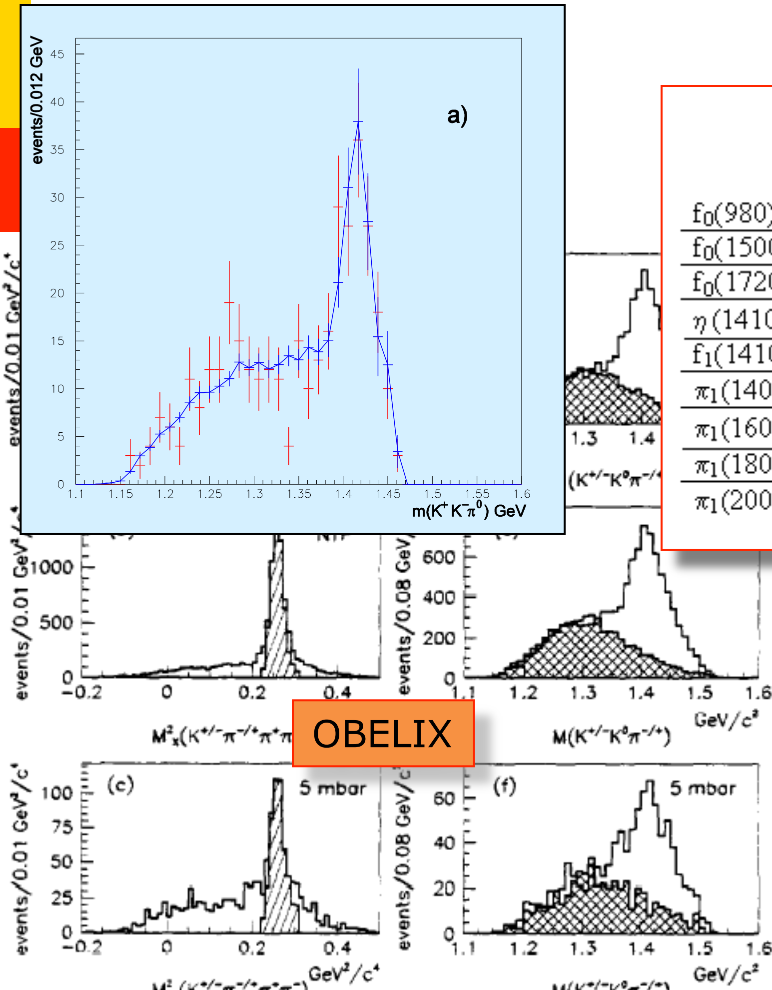
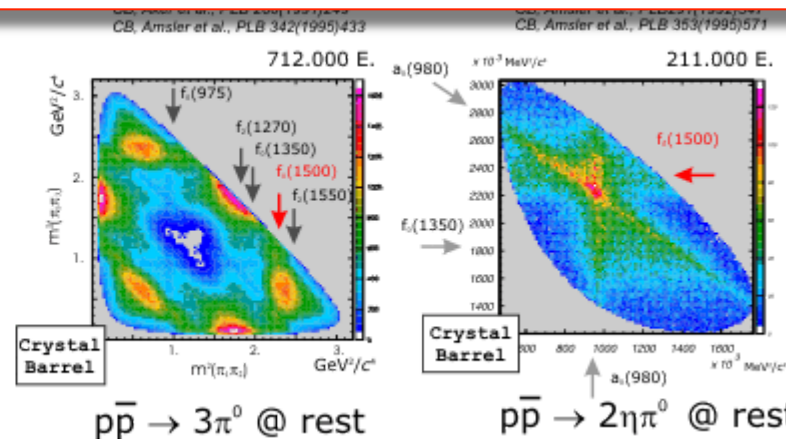


TABLE I. Main non-$q\bar{q}$ candidates.

$f_0(980)$	4q state
$f_0(1500)$	0^{++} glueball candidate
$f_0(1720)$	0^{++} glueball candidate
$\eta(1410)$, $\eta(1460)$	0^{-+} glueball candidate
$f_1(1410)$	hybrid, 4q state
$\pi_1(1400)$	hybrid candidate
$\pi_1(1600)$	hybrid candidate
$\pi_1(1800)$	hybrid candidate
$\pi_1(2000)$	hybrid candidate

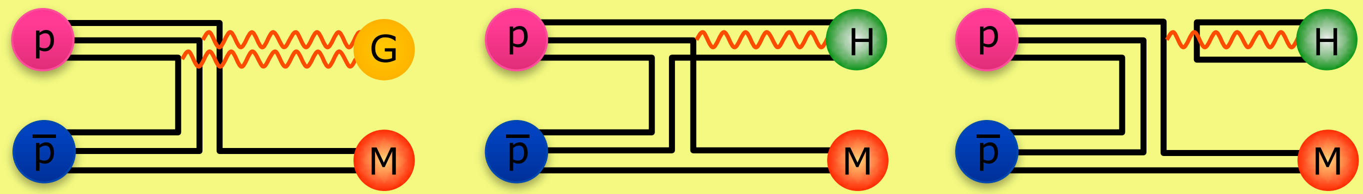


Crystal Barrel

A.Bertin et al.,Physics Letters **B361**, (1995), 187.
A.Bertin et al.,Physics Letters **B385**, (1996), 493.
A.Bertin et al.,Physics Letters **B400**, (1997), 226.
F.Nichitiu et al.,Physics Letters **B545**, (2002), 261.

Spectroscopy with antiprotons

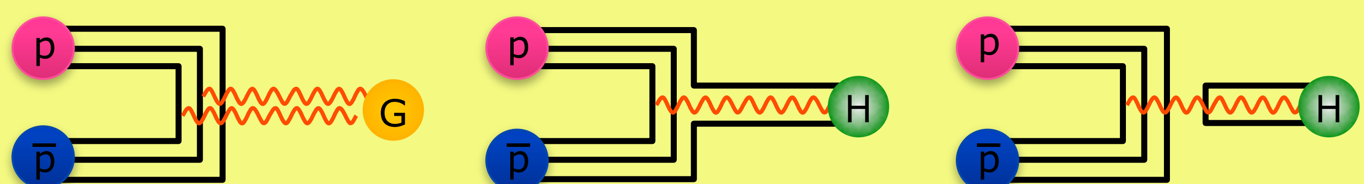
Two are the mechanisms to access particular final states:



Even exotic quantum numbers can be reached σ ~100 pb

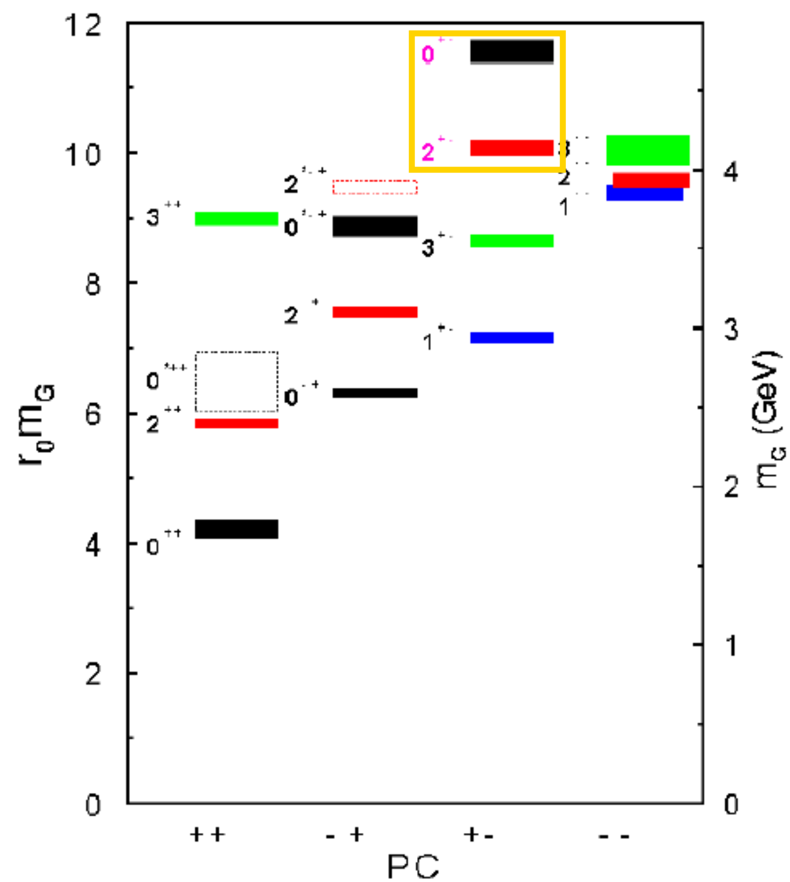
Exotic states are produced with rates similar to $q\bar{q}$ conventional systems

All ordinary quantum numbers can be reached σ ~1 μb



Glueballs

- Light gg/ggg-systems are complicated to be identified
- Oddballs:exotic heavy glueballs
  - m(0+-) = 4740(50)(200) MeV
  - m(2+-) = 4340(70)(230) MeV
- Glueballs decays most favourable to PANDA are:
  - ΦΦ or Φη if mass < 3.6 GeV/c^2
  - J/ψη or J/ψΦ if mass > 3.6 GeV/c^2
  - heavy oddballs (4-5GeV/c^2) $DD^*\eta/\pi^0$,
- Same run period as hybrids



Morningstar und Peardon, PRD60 (1999) 034509

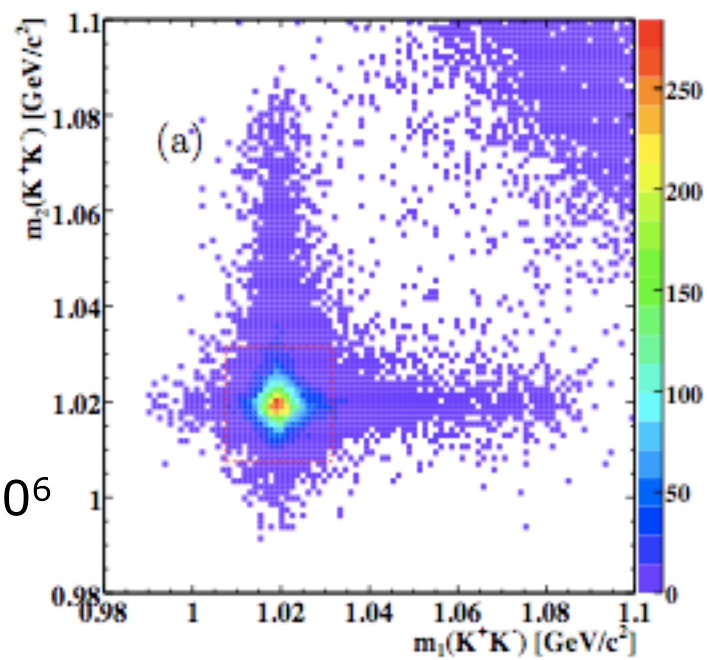
$\bar{p}p \rightarrow f_2(2000\text{-}2500) \rightarrow \phi\phi$

The primary goal of this study is to test our capability of reconstructing $\phi\phi$ final states which are expected to be good for exotics (glueball) searching.

This is the region where the BES experiment found an evidence for a tensor ($J^{PC} = 2^{++}$) glueball candidate $\xi(2230)$.

The detection of a possible resonant signal require an energy scan around the central energy value in order to measure the dynamic behavior of the cross-section.

$$\bar{p}p \rightarrow f_2 \rightarrow \phi\phi \rightarrow K^+K^-K^+K^-$$



The analysis consists in 3 steps:

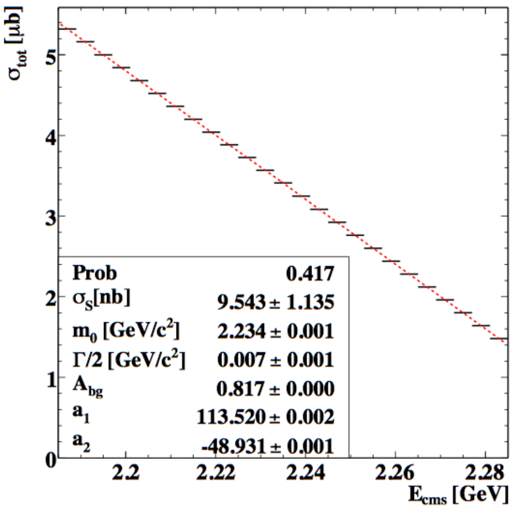
- reconstruction of the signal;
- evaluation of the background level;
- simulation of the energy scan.

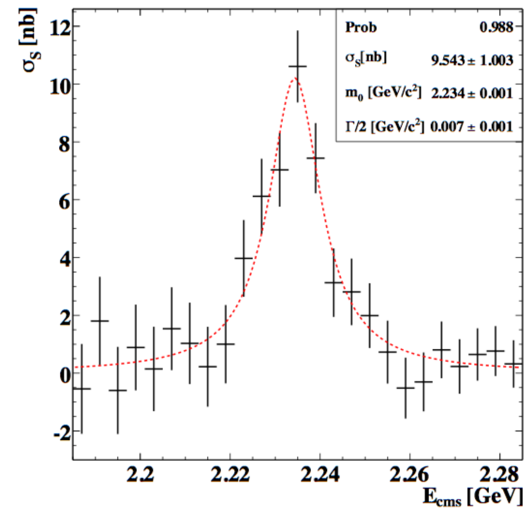
We generated 50 $\bullet 10^3$ signal events and 10^6 bck events.

4C fit: efficiency 25%

$f_2(2235)$ energy scan

We made the assumption of a mass value of 2235 MeV/c^2 and a widths of 15 MeV/c^2





Fit of the total cross section and the derived signal cross-section
For a scan width of 10 nb

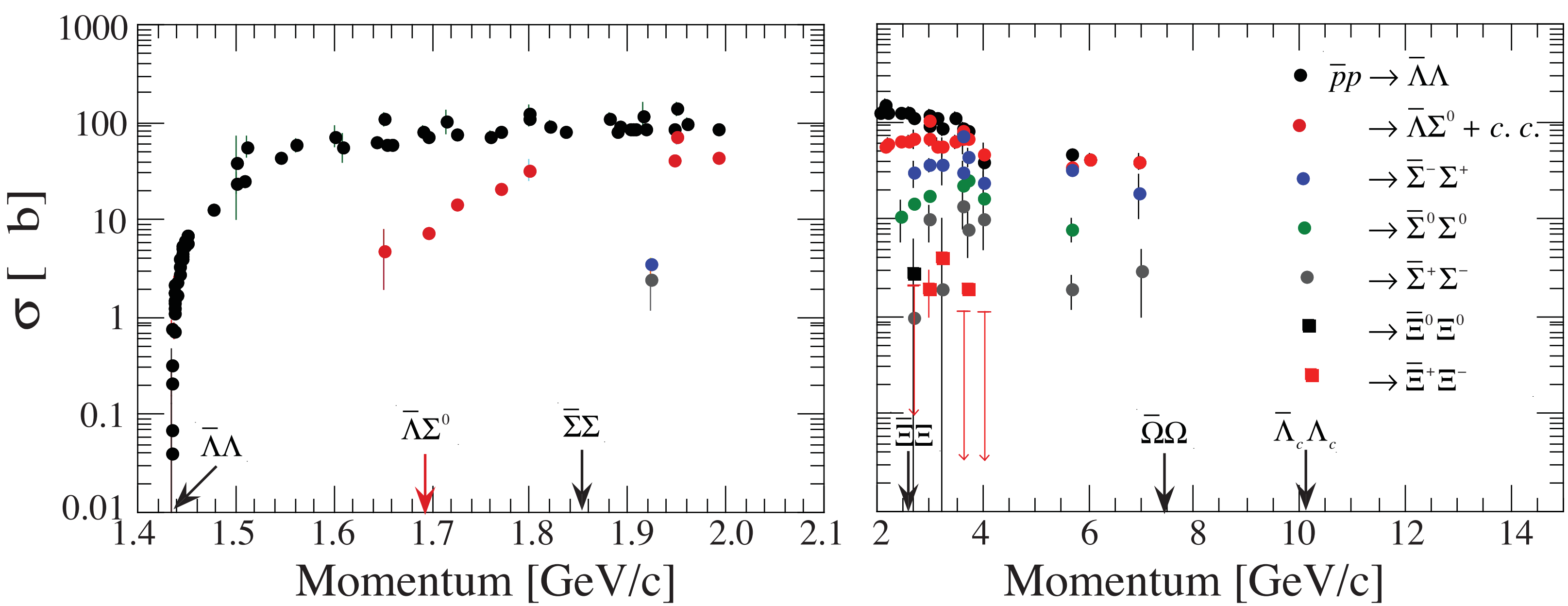
Needed beam time to achieve a 10σ significance

σ_S [nb]	Beam time T_b ($\approx$)
1	13.7 y
5	200 d
10	50 d
100	12 h
500	0.5 h
1000	7.2 min

QCD dynamics

In the quark picture hyperon pair production either involves the creation of a quark-antiquark pair or the knock out of such pairs out of the nucleon sea.

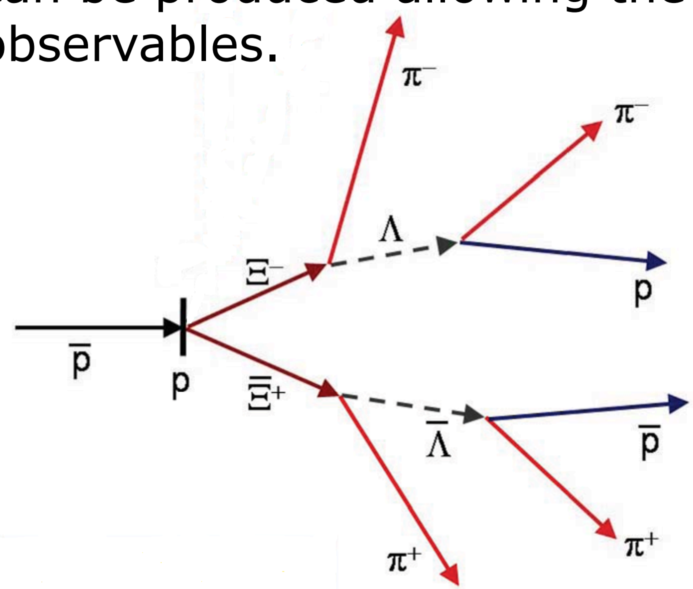
Hence, the iimportance of quark degrees of freedom with respect to the hadronic ones can be studied by measuring the reactions of the type $\bar{p}p \rightarrow \bar{Y}Y$



QCD dynamics

The experimental data set available is far from being complete. All strange hyperons and single charmed hyperons are energetically accessible in $\bar{p}p$ collisions at PANDA.

In PANDA $\bar{p}p \rightarrow \Lambda\bar{\Lambda}$, $\bar{\Lambda}\Xi$, $\Lambda\bar{\Xi}$, $\Xi\bar{\Xi}$, $\Sigma\bar{\Sigma}$, $\Omega\bar{\Omega}$, $\Lambda_c\bar{\Lambda}_c$, $\Sigma_c\bar{\Sigma}_c$, $\Omega_c\bar{\Omega}_c$ can be produced allowing the study of the dependences on spin observables.



Channel 1.64 GeV/c	Rec. eff.	σ [μb]	Signal
$\bar{p}p \rightarrow \Lambda\bar{\Lambda}$	0.11	64	1
$\bar{p}p \rightarrow \bar{p}p\pi^+\pi^-$	$1.2 \cdot 10^{-5}$	~ 10	$4.2 \cdot 10^{-5}$
Channel 4 GeV/c			
$\bar{p}p \rightarrow \Lambda\bar{\Lambda}$	0.23	~ 50	1
$\bar{p}p \rightarrow \bar{p}p\pi^+\pi^-$	$< 3 \cdot 10^{-6}$	$3.5 \cdot 10^3$	$< 2.2 \cdot 10^{-3}$
$\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0$	$5.1 \cdot 10^{-4}$	~ 50	$2.2 \cdot 10^{-3}$
$\bar{p}p \rightarrow \bar{\Lambda}\Sigma(1385)$	$< 3 \cdot 10^{-6}$	~ 50	$< 1.3 \cdot 10^{-5}$
$\bar{p}p \rightarrow \bar{\Sigma}^0\Sigma^0$	$< 3 \cdot 10^{-6}$	~ 50	$< 1.3 \cdot 10^{-5}$
Channel 15 GeV/c			
$\bar{p}p \rightarrow \Lambda\bar{\Lambda}$	0.14	~ 10	1
$\bar{p}p \rightarrow \bar{p}p\pi^+\pi^-$	$< 1 \cdot 10^{-6}$	$1 \cdot 10^3$	$< 2 \cdot 10^{-3}$
$\bar{p}p \rightarrow \bar{\Lambda}\Sigma^0$	$2.3 \cdot 10^{-3}$	~ 10	$1.6 \cdot 10^{-2}$
$\bar{p}p \rightarrow \bar{\Lambda}\Sigma(1385)$	$3.3 \cdot 10^{-5}$	60	$1.4 \cdot 10^{-3}$
$\bar{p}p \rightarrow \bar{\Sigma}^0\Sigma^0$	$3.0 \cdot 10^{-4}$	~ 10	$2.1 \cdot 10^{-3}$
DPM	$< 1 \cdot 10^{-6}$	$5 \cdot 10^4$	$< .09$
Channel 4 GeV/c	Rec. eff.	σ (μb)	Signal
$\bar{p}p \rightarrow \bar{\Xi}^+\Xi^-$	0.19	~ 2	1
$\bar{p}p \rightarrow \bar{\Sigma}^+(1385)\Sigma^-(1385)$	$< 1 \cdot 10^{-6}$	~ 60	$< 2 \cdot 10^{-4}$

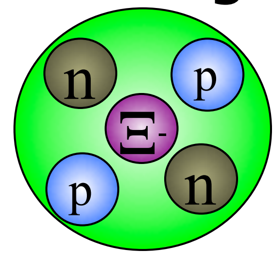
By comparing several reactions involving different quark flavours the OZI rule and its possible violation, can be tested

Double Strange Systems (DDS)

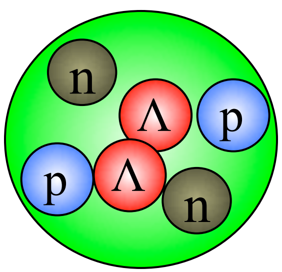
3 different systems containing double strangeness (S=-2)

Ξ^- hypernuclei:

Interaction: Ξ^-N



From Ξ^-hypernucleus to ΛΛ hypernucleus: Ξ^-N-ΛΛ coupling

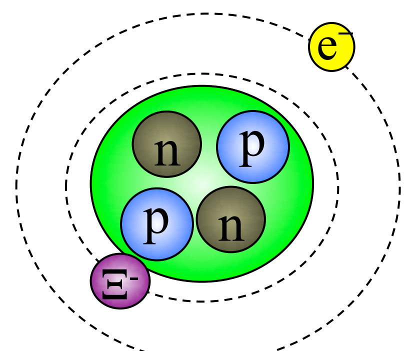


Double Λ-hypernuclei:

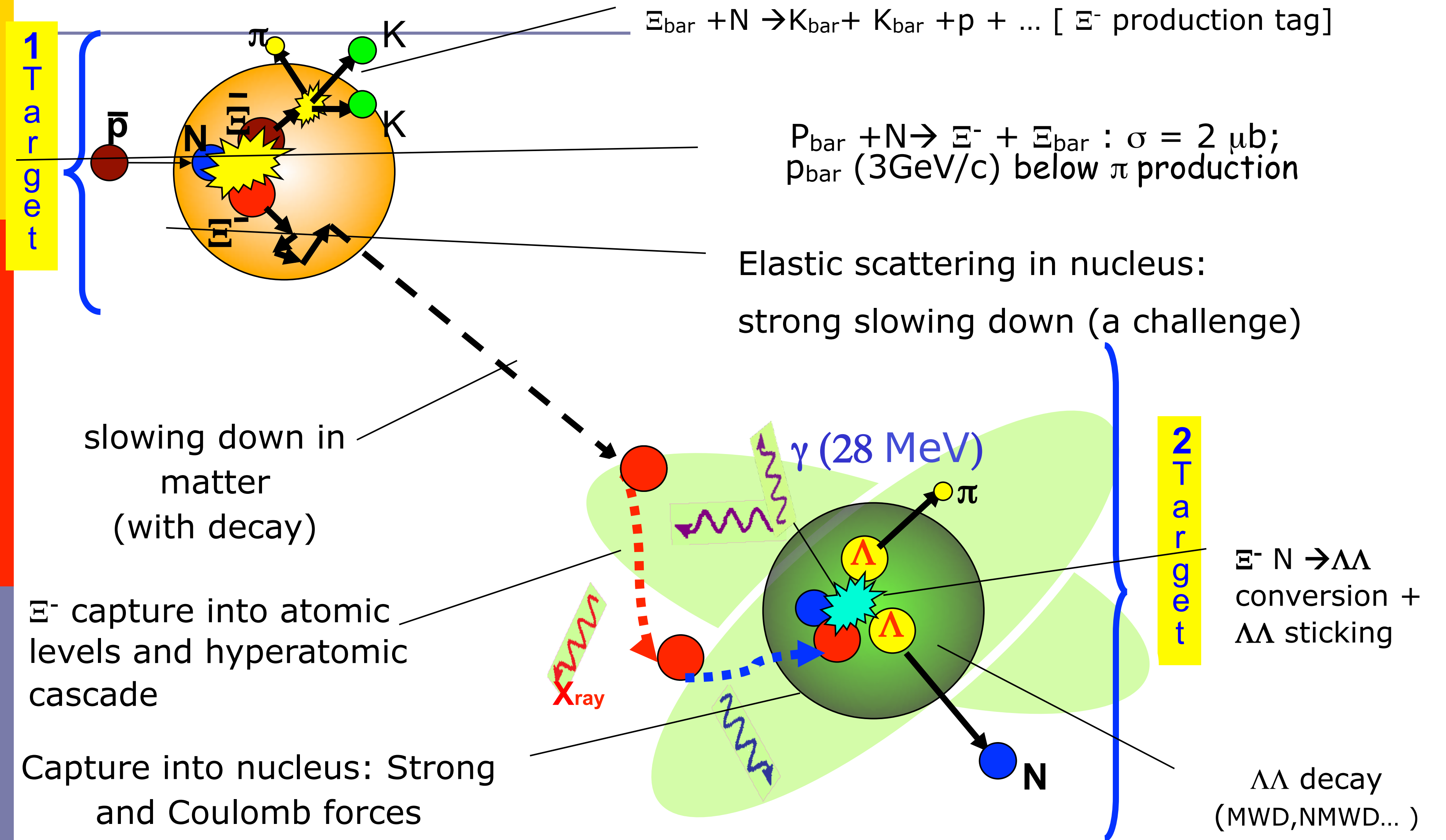
Interactions: Λ–Λ

Exotic hyperatoms:

Interactions: Ξ^--nucleus: interplay between the Coulomb and nuclear potential



DSS production in PANDA

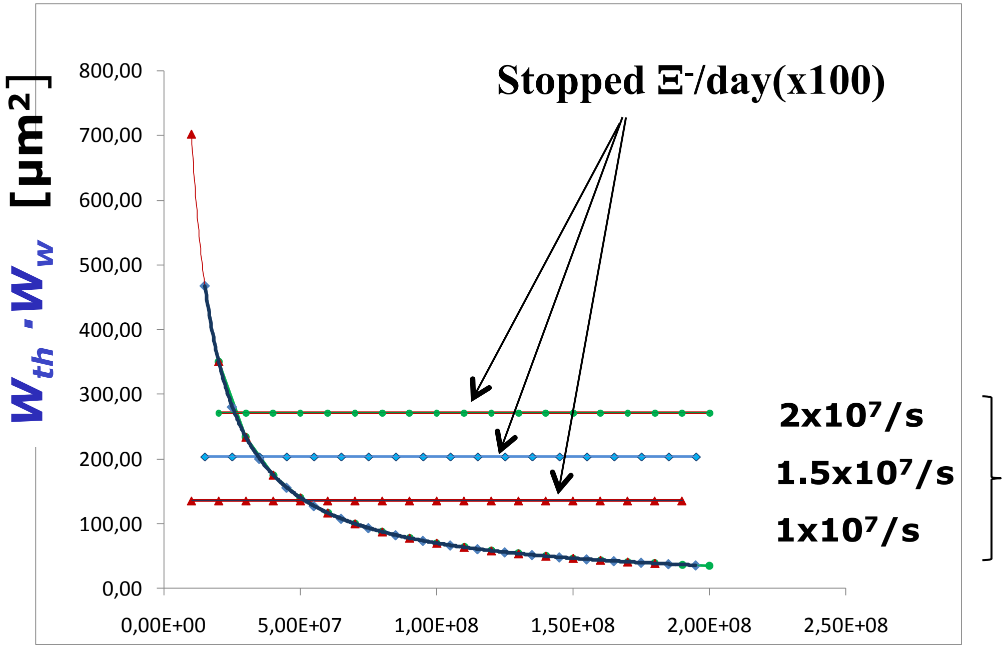


Ξ^- rates

Ξ^- rates & target sizes vs bunch contents
(for different p_{bar} production, satisfying background constraints)

Remarks:

- target sizes can be very small
- thickness of 3 μm is under test
- mechanical and thermal properties to be evaluated



Result: 1400 ÷ 2700 stopped Ξ^-/day expected

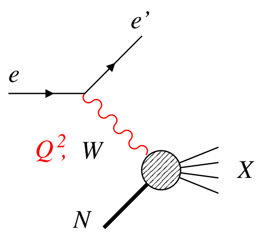
At J-PARC 5800 are expected

Nucleon structure

In 50 years of activity eN scattering experiments succeeded in describing Nucleon structure

Overview: Basic eN scattering experiments

high–Q^2 inclusive scattering

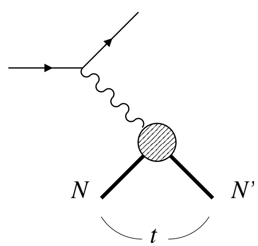


parton distributions

longitudinal momentum distribution of quarks/gluons in fast–moving nucleon

$Q^2 \leftrightarrow$ resolution scale

elastic scattering

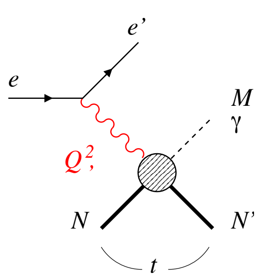


form factors

spatial distribution of charge/magnetization

$t \leftrightarrow$ size of object

high–Q^2 exclusive processes

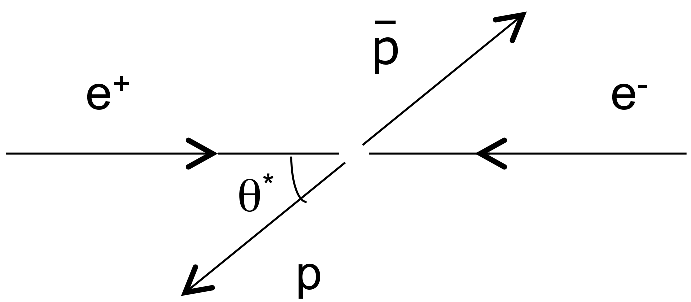


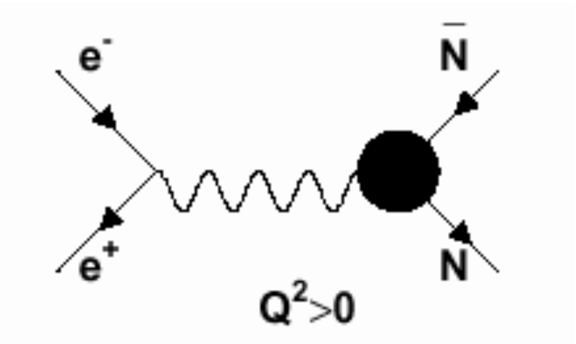
generalized parton distributions

longitudinal momentum + transverse spatial distribution of quarks/gluons

Nucleon form factor

The simplest structure function the Nucleon form-factor was considered well understood with the Rosenbluth approach (1γ exch.)





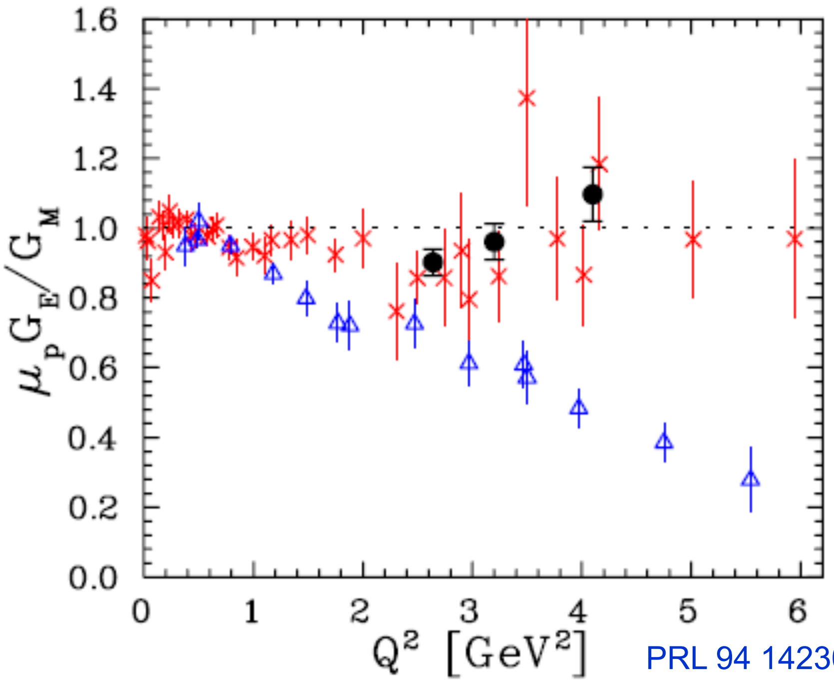
$$s = Q^2 > 0$$

time-like $q^2 > 0$ space-like $q^2 < 0$

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 \beta C}{4s}\left[|G_M(s)|^2 (1+\cos^2\theta^*) + \frac{4m_N^2}{s} |G_E(s)|^2 \sin^2\theta^* \right]$$

Most experiments could not determine $|G_M|$ and $|G_E|$ separately from the analysis of the angular distributions, but extracted $|G_M|$ using the (arbitrary) assumption $|G_E| = |G_M|$.

Nucleon ff in the space-like region



PRL 94 142301 (2005)

Data on the ratio G_E/G_M for the proton including the older Rosenbluth separation data (crosses), most recent JLab Rosenbluth separation data (filled circles), and polarization transfer data (triangles)

New Jlab data have been obtained with the recoil polarization method stating that: $\frac{G_E}{G_M} = -\frac{P_t}{P_l}\frac{(E_e + E_{e'})}{2m}\tan\frac{\theta_e}{2}$

The old assumption $G_N(q^2) = \left(1 + \frac{q^2}{\lambda_D^2}\right)^{-2}$ seems no more valid

$$\lambda_D^2 = 0.71 GeV^2$$

Nucleon ff in the time-like region

- $|G_E|$ and $|G_M|$ in the Time-Like region can be determined by the reactions

$$\bar{p}p \leftrightarrow e^+e^-$$

- Presently statistics is limited → no real separation $|G_E|/ |G_M|$
- $|G_M|$ extracted assuming $|G_E| = |G_M|$ (true at threshold)
- G_E in Time-Like region is today unknown
- Recent data from BaBar → extraction of the ratio $R = |G_E|/ |G_M|$ through the ISR method ($e^+e^- \rightarrow \gamma pp$) ($q^2<7$ $(GeV/c)^2$)

PANDA plans for the ff

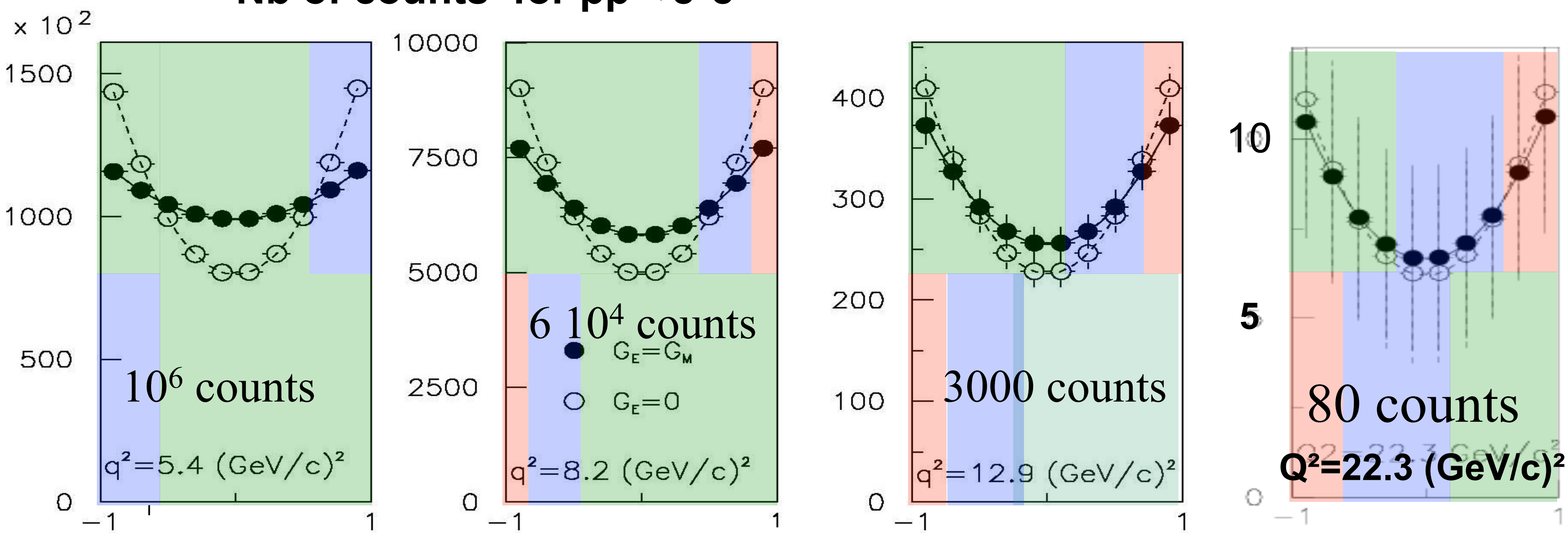
- Separate measurement of $|G_E|$ et $|G_M|$
- Precisions on the ratio $R=|G_E|/|G_M|$ and σ_R
  - $\Delta R/R < 1\%$ at low Q^2
  - $\Delta R/R = 10\%$ at $Q^2=10\ (GeV/c)^2$
  - Separation possible up to $Q^2=15\ (GeV/c)^2$
- Test of the 1 γ hypothesis (symmetry of the angular distribution)
- Measure $|G_M|$ up to $Q^2=25\ (GeV/c)^2$

PANDA plans for the ff

~100 days, $\mathcal{L}$ = 2. 10^{32} $cm^{-2}s^{-1}$

$$d\sigma/d\Omega \propto [\ |G_M(q^2)|^2(1+\cos^2\theta)+4m_N^2/q^2\ |G_E(q^2)|^2 \sin^2\theta)]$$

Nb of counts for $\bar{p}p \rightarrow e^+e^-$

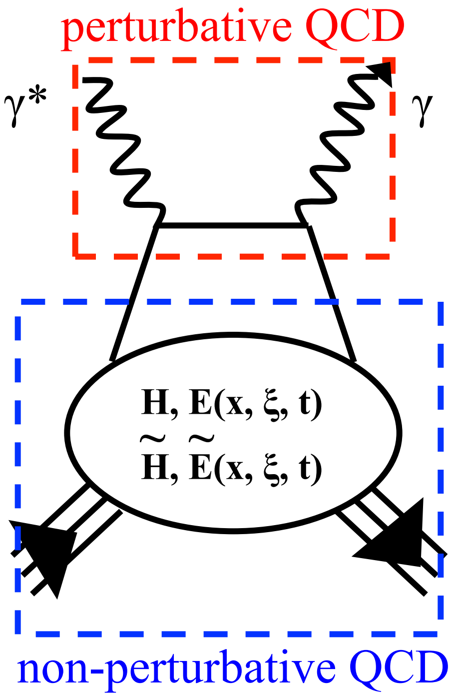


R=|GE|/|GM|

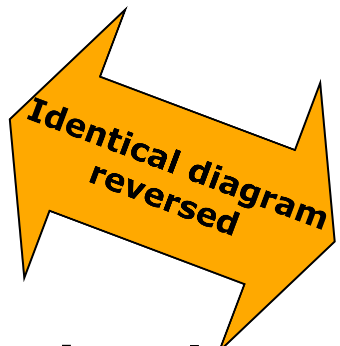
cosθ

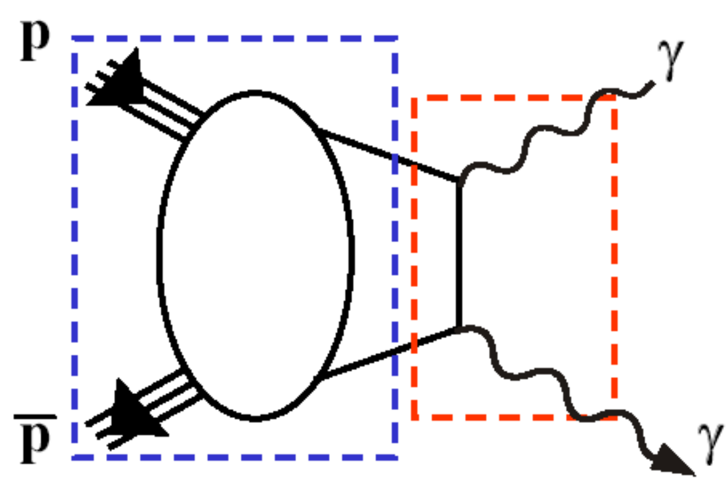
E_{lab}=1 GeV	E_{lab}=2.5 GeV	E_{lab}=5 GeV	E_{lab}=10 GeV
$s=q^2$=5.4 $(GeV/c)^2$	q^2= 8.2 $(GeV/c)^2$	q^2=12.9 $(GeV/c)^2$	q^2=22.3 $(GeV/c)^2$
$N_{tot}=10^6$	N_{tot}=66000	N_{tot}=2750	N_{tot}=82
ΔR=0.6%	ΔR=3%	ΔR=25%	ΔR= 100%

Generalized Parton Distributions



Wide angle Compton scattering
factorisation into hard amplitude
(calculable in perturbative QCD)
and soft amplitude
(information on parton distributions)





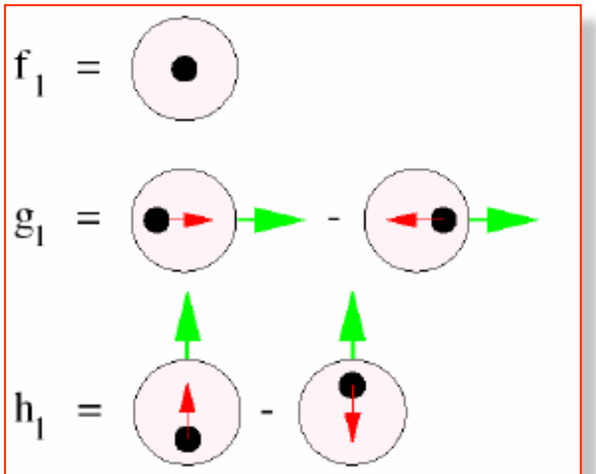
Reversed Deeply Virtual Compton Scattering

$\bar{p}p \rightarrow \gamma\gamma$

clear experimental signature
both baryons in ground state
$\sigma \approx 2.5\text{pb}$ @ $s \approx 10\ \text{GeV}^2$
$L = 2\cdot 10^{32}\ \text{cm}^{-2}\ \text{s}^{-1} \rightarrow 10^3$ events per month

Transversity

In the QCD description of the partonic structure of the nucleon last leading-twist missing piece is transversity



$q(x,Q^2)$ unpolarized quark distribution

$\Delta q(x,Q^2)$ helicity distribution

$h_1^q(x,Q^2)$ transversity distribution

In deep-inelastic lepton scattering transversity distribution folded with fragmentation functions

transversity distribution **directly accessible** via the double transverse spin asymmetry (A_{TT}) in Drell-Yan production of lepton pairs

$$A_{TT} \equiv \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}} = \hat{a}_{TT} \cdot \frac{\Sigma_q e_q^2 \, h_1^q(x_1,M^2)\, h_1^{\bar{q}}(x_2,M^2)}{\Sigma_q e_q^2 \, q(x_1,M^2)\, \bar{q}(x_2,M^2)}$$

$q = u, \bar{u}, d, \bar{d}, \ldots$
M = invariant mass of lepton pair

$$\bar{p}p \rightarrow \mu^+ \mu^- X$$

European Strategy Forum on Research Infrastructures

ESFRI

Research Infrastructures on the Roadmap

Out of the 14 Research Infrastructure projects published in the 2008 Roadmap update, five are now implemented: ESRF Upgrade, European XFEL, FAIR, ILL 20/20 upgrade and SPIRAL2. The on-going upgrade process of the existing Research Infrastructures ESRF and ILL will be completed in 2015, construction work for the European XFEL has started in 2009 and FAIR has reached the next stage of implementation with the official signing of the convention by several partner countries. The start of construction for this facility is foreseen for the end of 2011.

On 3 May 2011 the ESFRI-Chair Beatrix Vierkorn-Rudolph has handed over to the European Commissioner for Research, Innovation and Science ***the ESFRI Strategy Report and Roadmap Update 2010***

Taken from the ESFRI Strategy Report and Roadmap Update 2010

FAIR project status

The signing of the FAIR Convention toke place on 4th Oct. 2010 in Wiesbaden.

Finland	Petteri Kauppinen
France	Laurence Piketty
Germany	Beatrix Vierkorn-Rudolph
India	A. K. Sood
Poland	Agnieszka Ratajczak
Romania	Ionel Andrei
Russia	Oleg Patarakin
Slovenia	Urška Klopčič
Spain	Esther Martín Malagón
Sweden	Mats Johnsson

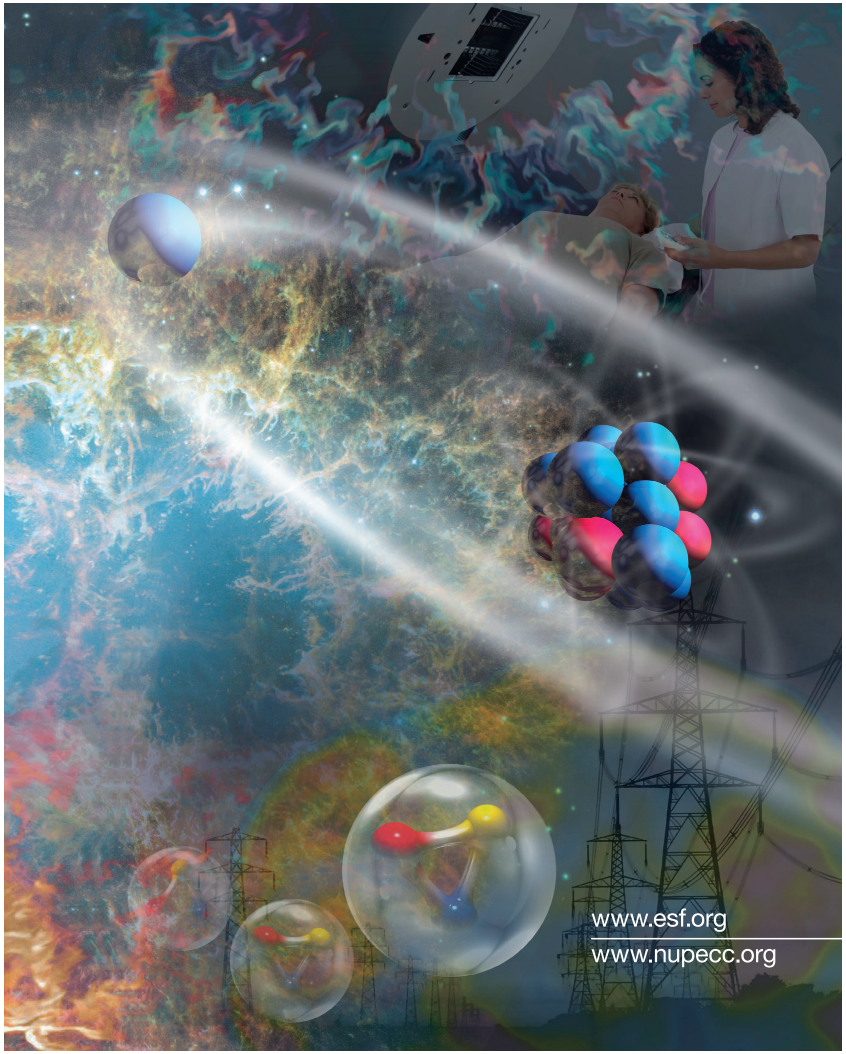
FAIR Countries	Total declared Contribution (k€)
Austria	5.000
China	12.000
Finland	5.000
France	27.000
Germany	705.000
Great Britain	8.000
Greece	4.000
India	36.000
Italy	42.000
Poland	23.740
Romania	11.870
Russia	178.050
Slovenia	12.000
Slovakia	6.000
Spain	19.000
Sweden	10.000
Total	**1.104.660**
Firm Commitments	**1.038.660**

EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

FORWARD LOOK

Perspectives of Nuclear Physics in Europe

NuPECC Long Range Plan 2010



1.1.1 Scientific Scope

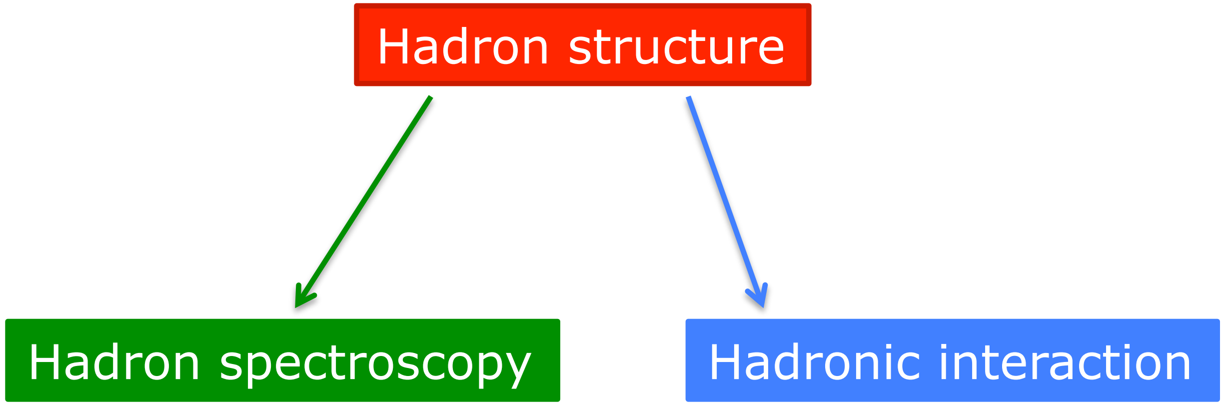
The scientific scope of this Forward Look is to advance the case for:

- Studying the fundamental strong interaction (as described by Quantum Chromodynamics) that holds hadrons such as protons and neutrons together. Investigations of hadron internal structure and spectroscopy require both lepton (electron, positron and muon) on hadron and hadron on hadron scattering facilities as a tool.
- Better understanding the strong interaction by studying the phase-diagram of matter that primarily interacts via the strong force. Relativistic heavy ion beam facilities are the tools needed for such studies.
- Investigating the structure of nuclei far from stability by using, in particular, radioactive heavy ion beams produced by both in-flight fragmentation and Isotope Separator On-Line, ISOL, techniques. In addition, the capabilities of high-intensity stable heavy ion beam facilities should be further improved, and plans should be developed for upgrading or building new small-scale accelerators dedicated to nuclear astrophysics.

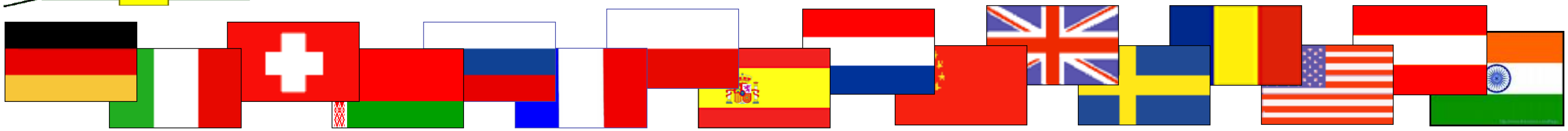
NuPECC Road-map

At their spring meeting 2009, NuPECC identified six main scientific topics (Themes) to be developed in LRP2010:

- Hadron Structure and Spectroscopy
- Phases of Strongly Interacting Matter
- Nuclear Structure and Dynamics
- Nuclear Astrophysics
- Fundamental Interactions
- Nuclear Physics Tools and Applications



panda Collaboration



- At present a group of **460 physicists** from 54 institutions of 16 countries

Austria – Belaruz - China - France - Germany – India - Italy – The Nederlands - Poland – Romania - Russia – Spain - Sweden – Switzerland - U.K. – U.S.A..

Basel, Beijing, Bochum, IIT Bombay, Bonn, Brescia, IFIN Bucharest, Catania, IIT Chicago, AGH Krakow, IFJ PAN Krakow, JU Krakow, Krakow UT, Edinburgh, Erlangen, Ferrara, Frankfurt, Genova, Giessen, Glasgow, GSI, FZ Jülich, JINR Dubna, Katowice, KVI Groningen, Lanzhou, LNF, Lund, Mainz, Minsk, ITEP Moscow, MPEI Moscow, TU München, Münster, Northwestern, BINP Novosibirsk, IPN Orsay, Pavia, IHEP Protvino, PNPI St.Petersburg, KTH Stockholm, Stockholm, INFN Torino, Torino, Torino Politecnico, Trieste, TSL Uppsala, Tübingen, Uppsala, Valencia, SINS Warsaw, TU Warsaw, SMI Wien

http://www.gsi.de/panda

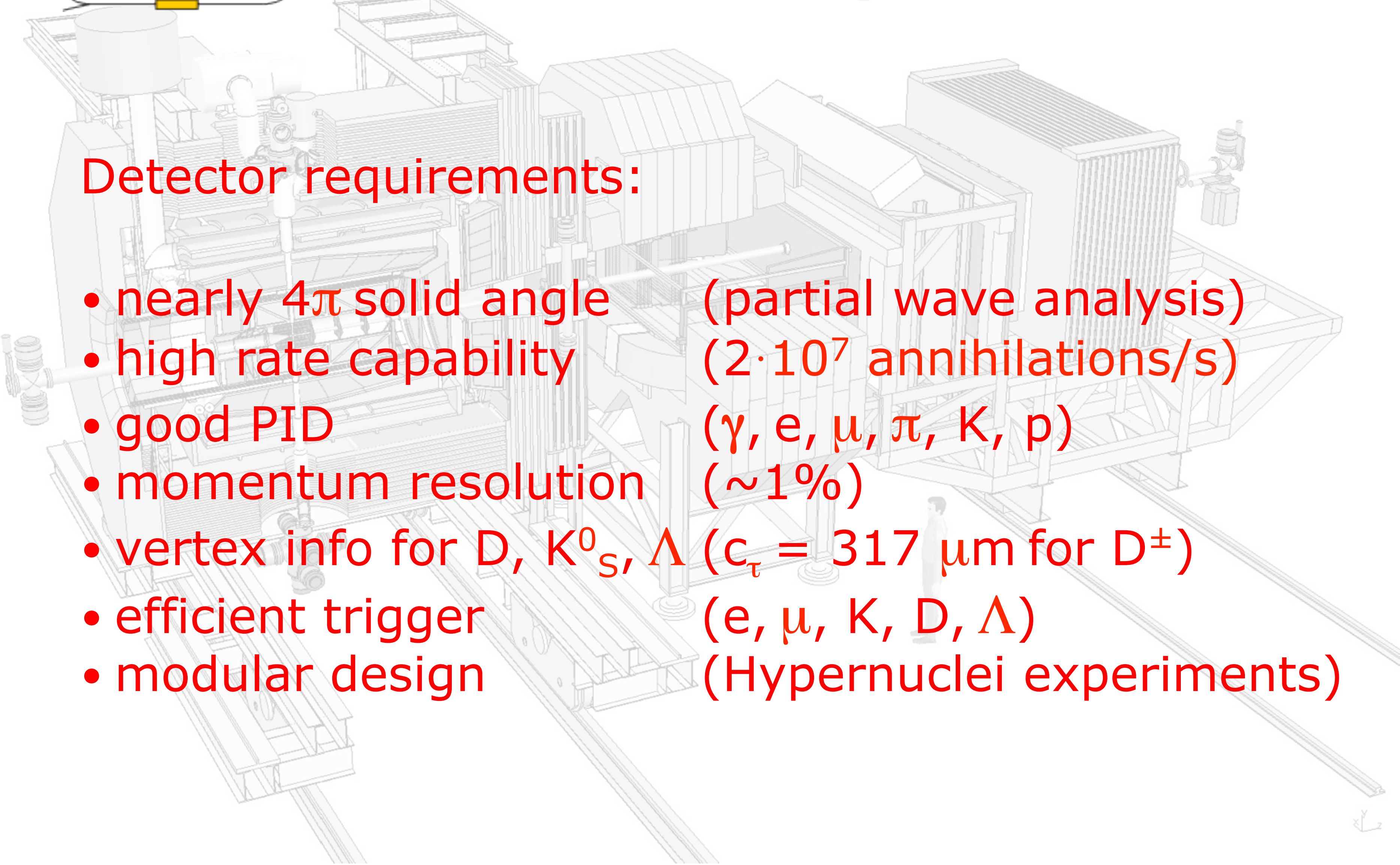
Summary

The High Intensity and High Resolution antiproton beam available at FAIR will offer unique opportunities complementary to those offered by e^+e^- facilities:

- Charmonium spectroscopy
    - ➢ Sub MeV widths measurements
- Exotic non $q\bar{q}$ states
    - ➢ Formation⟷ Production techniques
- Double-strange nuclear systems
- Hyperon and Barion resonances
- Nucleon structure functions
    - ➢ Form Factors
    - ➢ GPD, transversity
- …

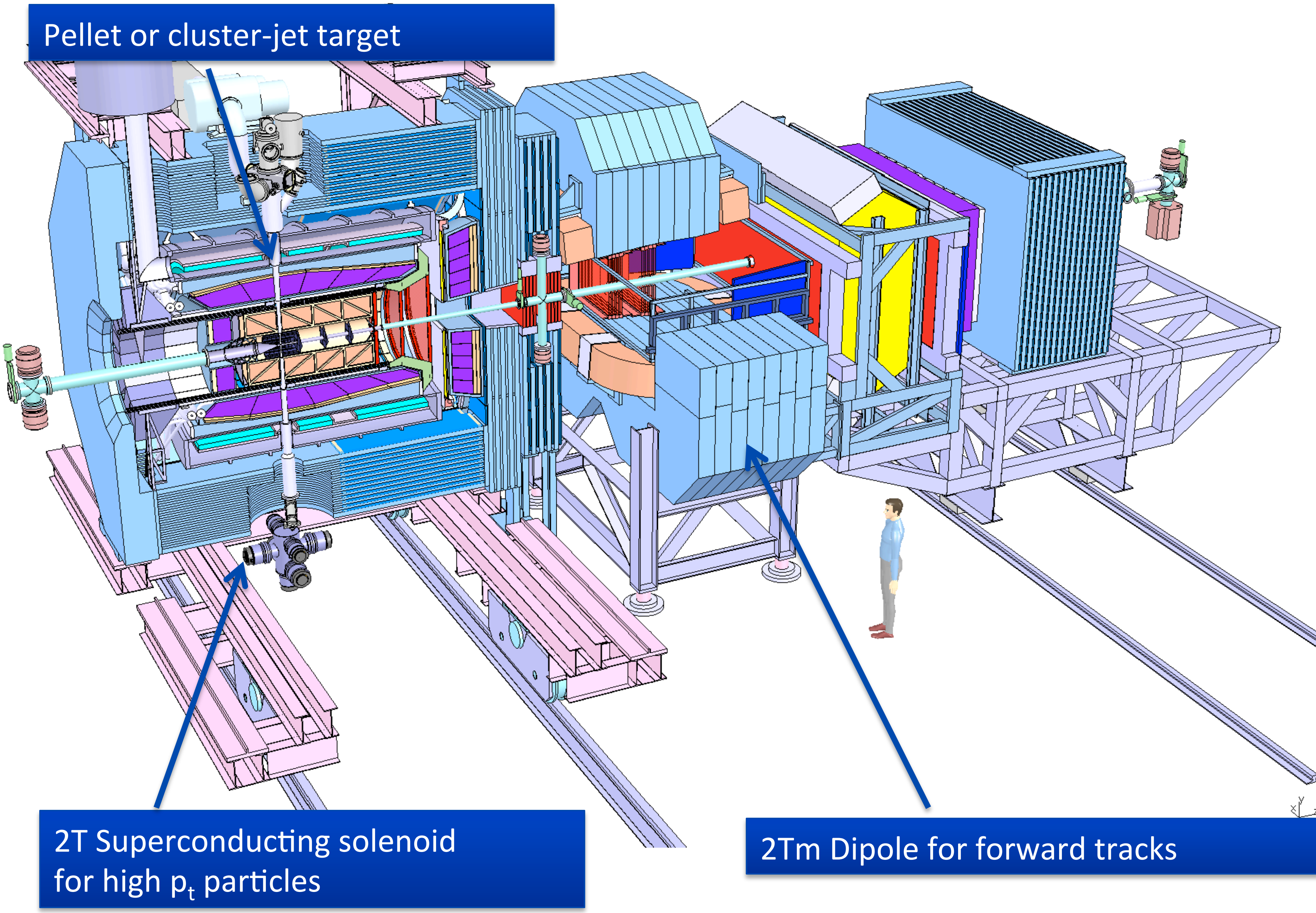
New collaborators are welcome

General Purpose Detector



Detector requirements:

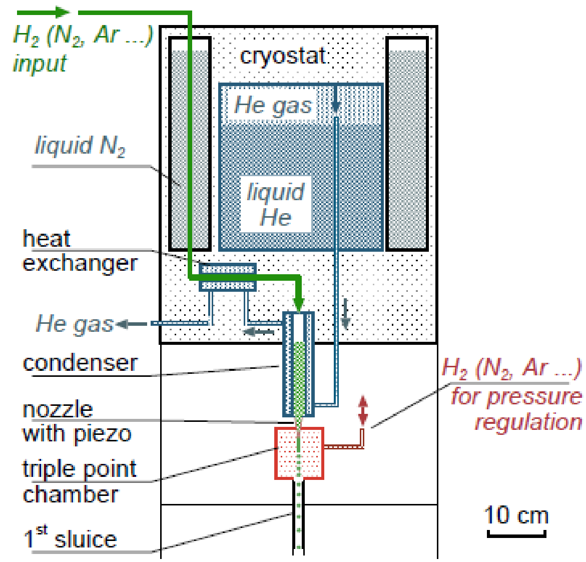
- nearly 4π solid angle (partial wave analysis)
- high rate capability ($2 \cdot 10^7$ annihilations/s)
- good PID (γ, e, μ, π, K, p)
- momentum resolution (~1%)
- vertex info for D, K^0_S, Λ (c_τ = 317 μm for $D^\pm$)
- efficient trigger (e, μ, K, D, Λ)
- modular design (Hypernuclei experiments)

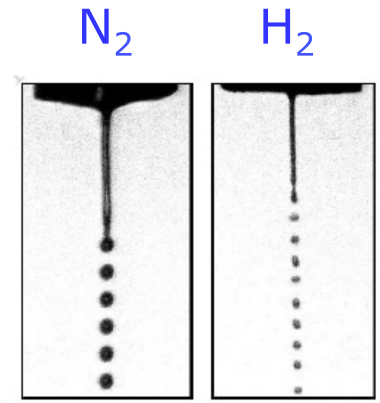

Pellet or cluster-jet target
2T Superconducting solenoid
for high p_t particles
2Tm Dipole for forward tracks

Target system

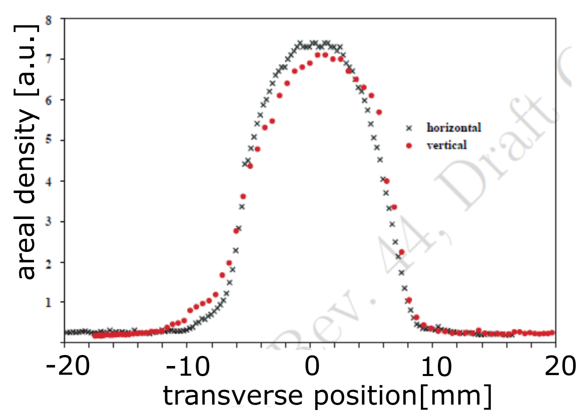
- **Requirements**
  - Proton Target
  - 5×10^{15} cm^{-2} for maximum luminosity

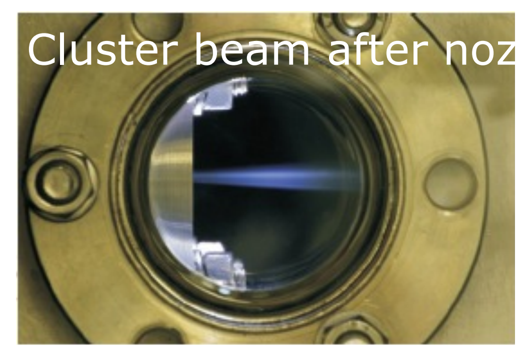
- **Pellet Target**
  - Frozen droplets ∅ 20μm
  - also possible: D_2, N_2, Ne, ...
  - Status: $\rho \sim 5 \times 10^{15}$

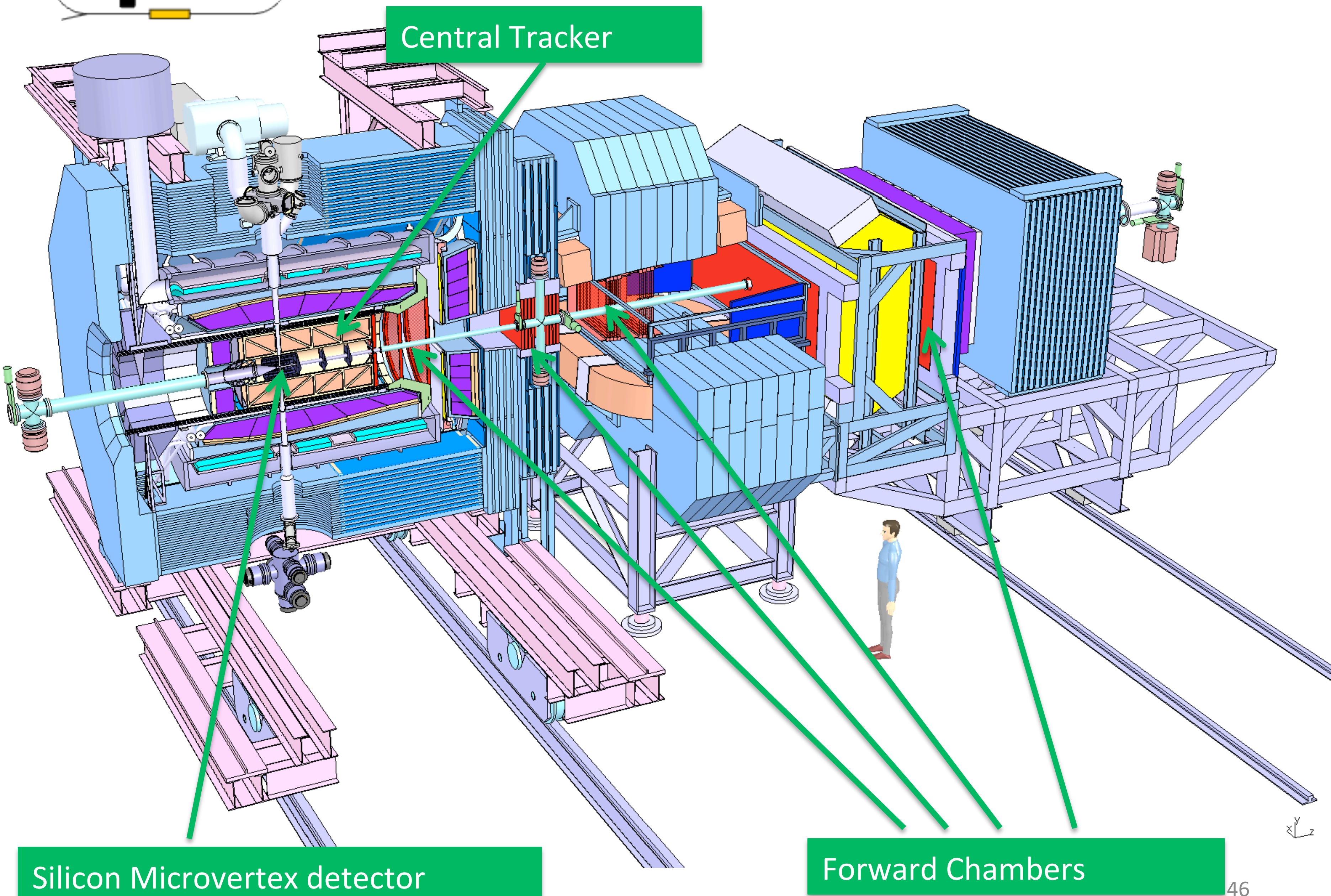




- **Cluster Jet Target**
  - Dense gas jet
  - also D_2, N_2, Ne, ...
  - Status: $\rho \sim 8 \times 10^{14}$






Central Tracker
Silicon Microvertex detector
Forward Chambers

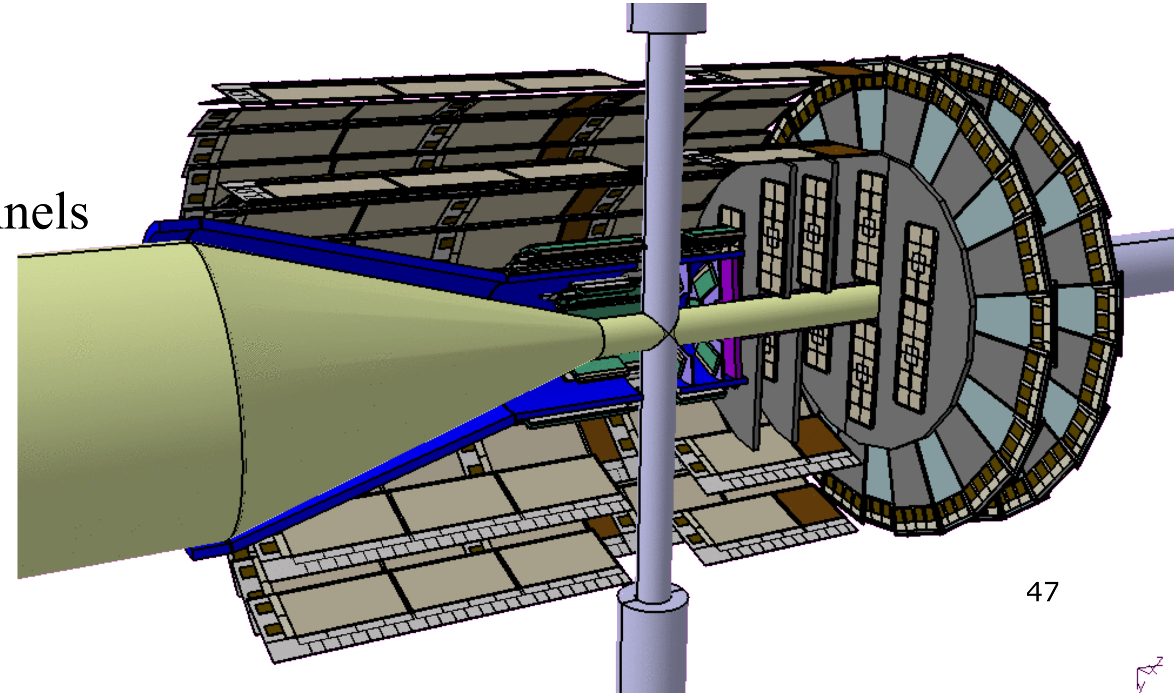
Silicon Micro Vertex Detector

Micro Vertex Detector

- 4 barrels and 6 disks
- Inner layers:
  hybrid pixels (100x100 μm^2)
  - 140 module, 12M channels
- Outer layers:
  silicon strip detectors
  - double sided strips
  - 400 modules, 200k channels
- Mixed forward disks
- Continuous readout

Requirements

- $c\tau(D^{\pm}) \sim 312\ \mu m$
  $c\tau(D_s^{\pm}) \sim 147\ \mu m$
- Vertex resolution ~ 50 µm



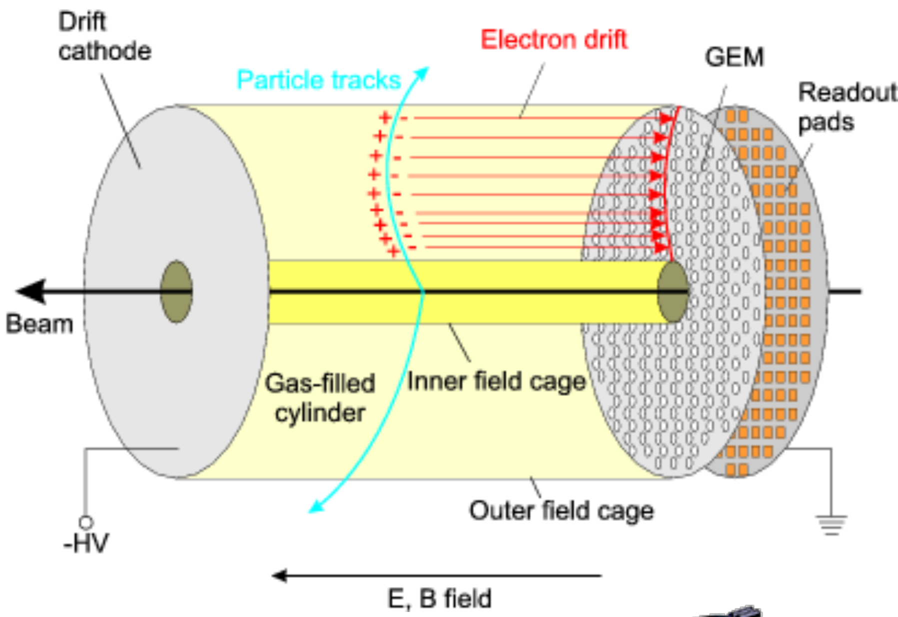
Central Tracker

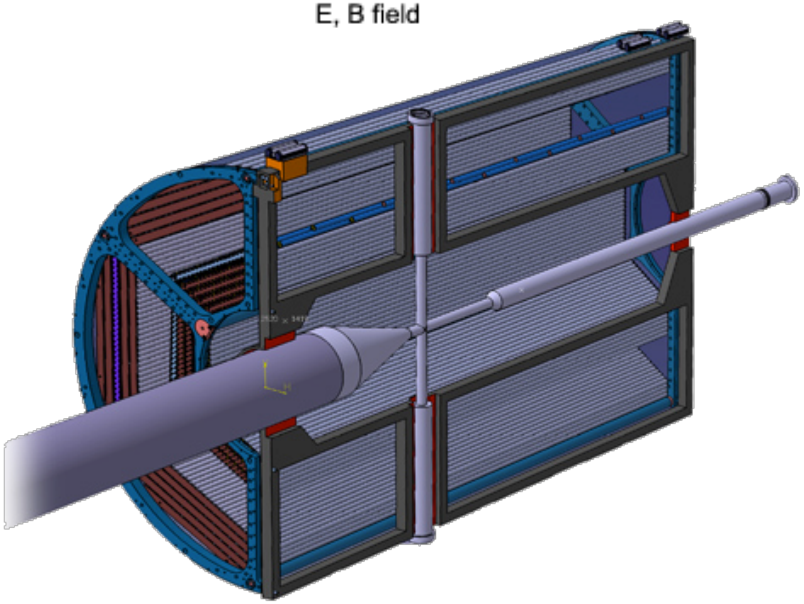
- Design figures:
  - $\sigma_{r\varphi} \sim 150\mu m$, $\sigma_z \sim 1mm$
  - $\delta p/p \sim 1\%$ (with MVD)
  - Material budget ~ 1% X_0

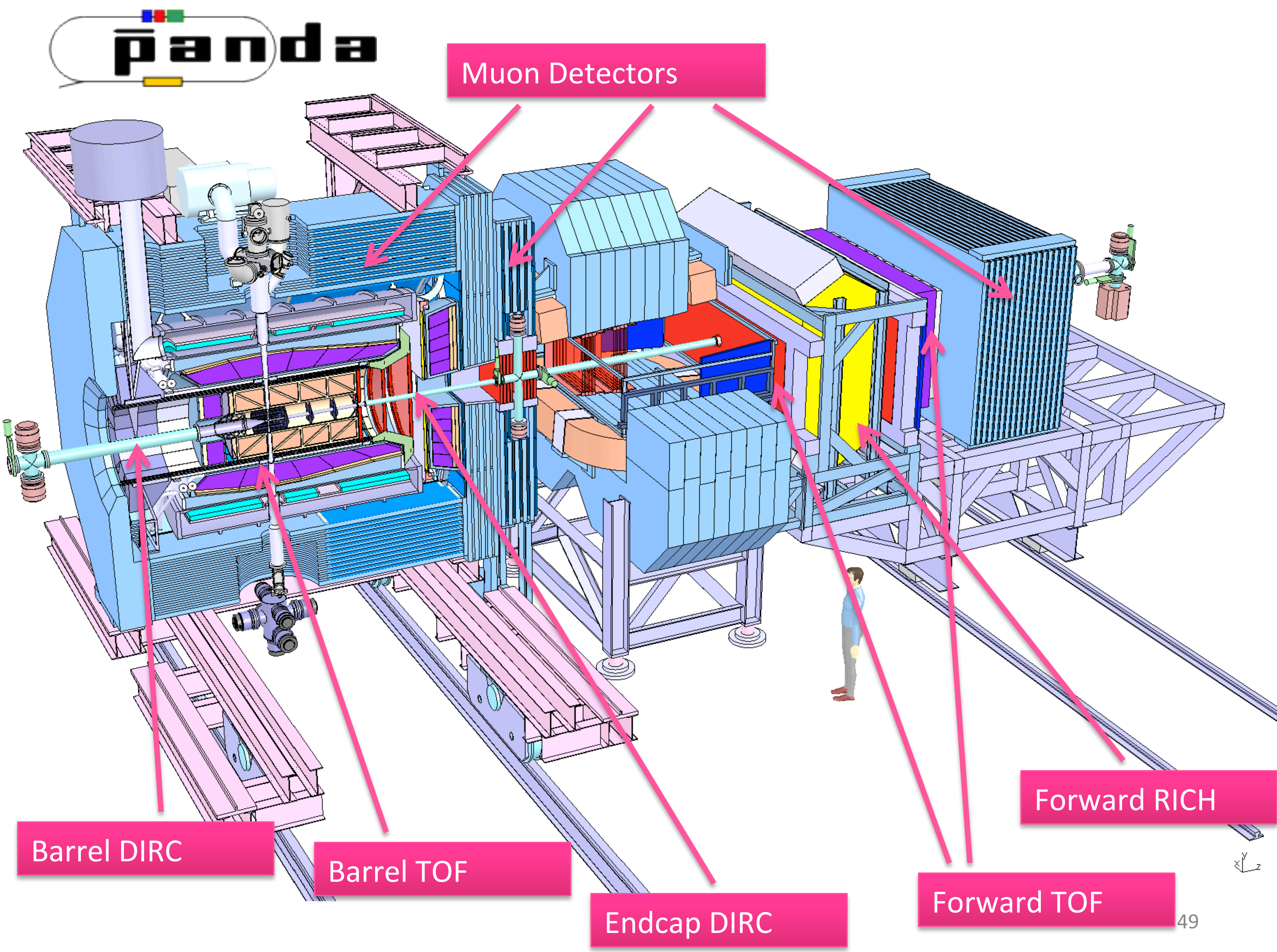
2 Alternatives:

- **Time Projection Chamber**
  - Continuous sampling
    GEMs readout plane
    (Ion feedback suppression)
    Online tracklet finding

- **Straw Tube Tracker**
  - about 4000 straws
  - 27 µm thin mylar tubes, 1 cm Ø
  - Stability by 1 bar overpressure







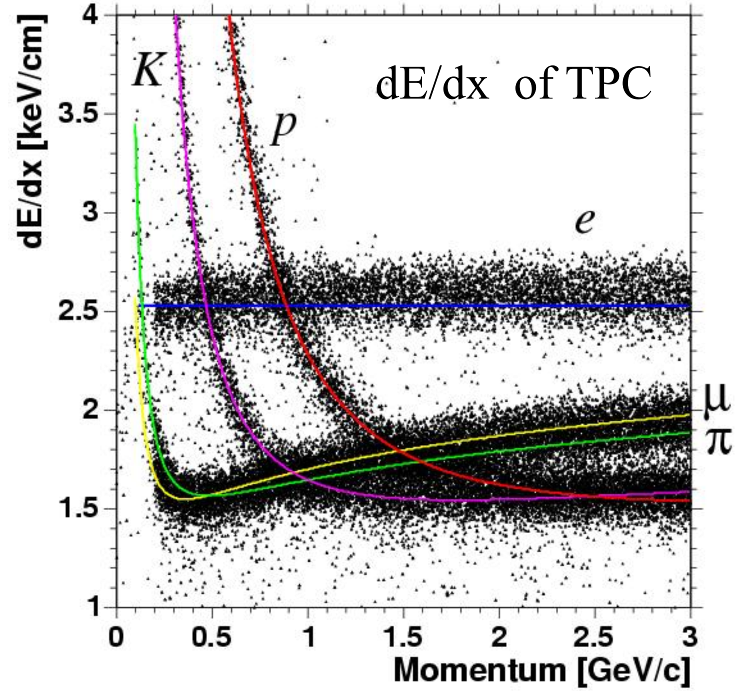
panda
Muon Detectors
Barrel DIRC
Barrel TOF
Endcap DIRC
Forward TOF
Forward RICH

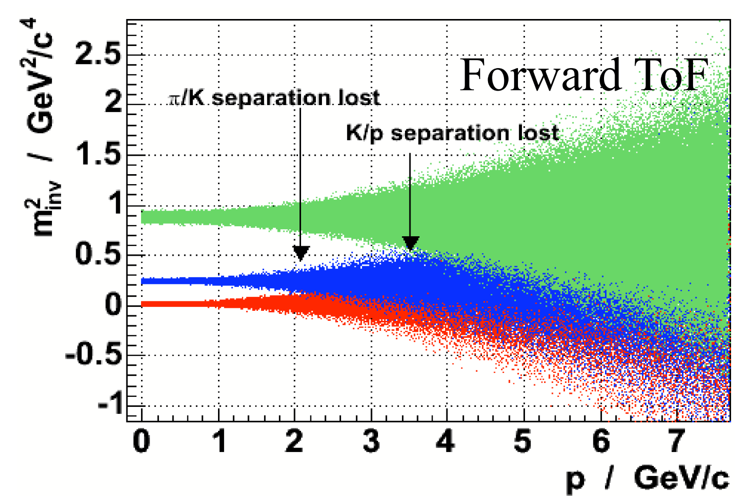
PANDA PID Requirements

- Particle identification essential tool
- Momentum range 200 MeV/c – 10 GeV/c
- Different processes for PID needed

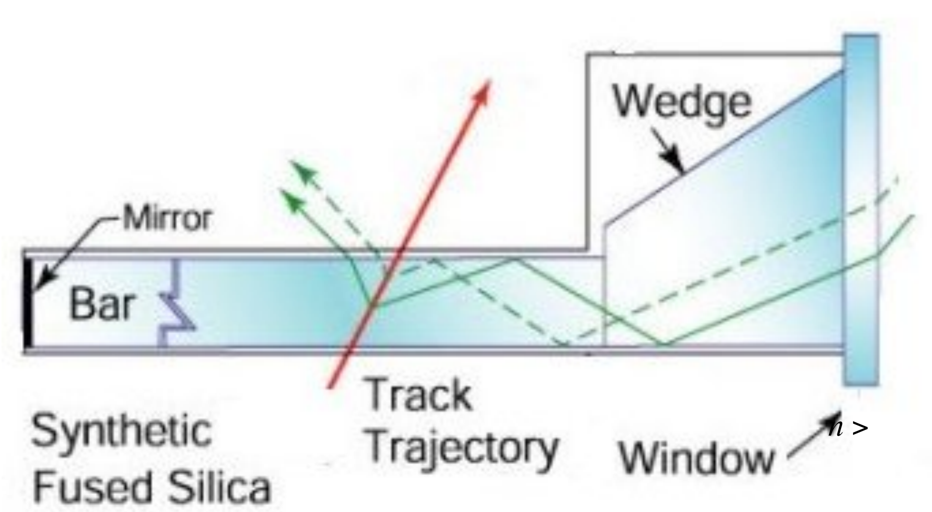
PID Processes

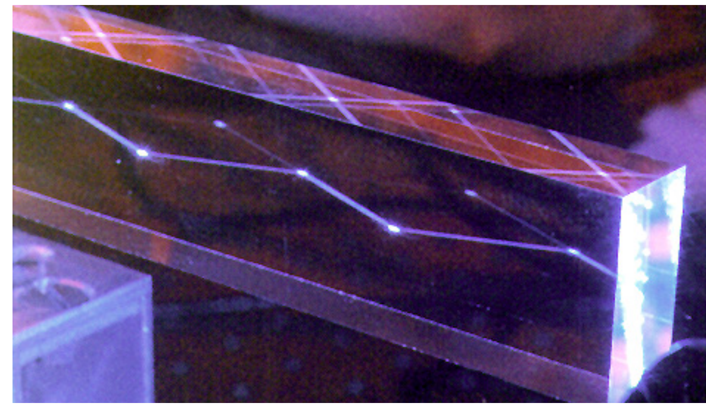
- Čerenkov radiation: p > 1 GeV
  Radiators: quartz, aerogel, C_4F_{10}
- Energy loss: p < 1 GeV
  Good accuracy with TPC,
  Stt system dE/dx under study
- Time of flight:
  needs a start detector
- Electromagnetic showers:
  EMC for e and γ





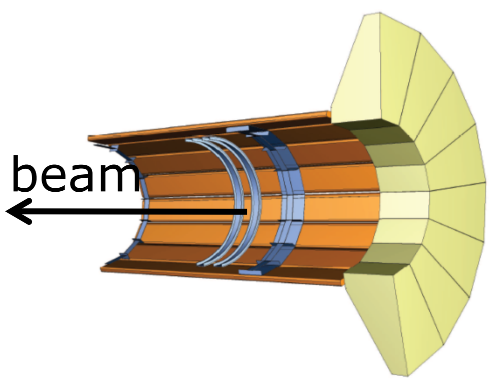
DIRC



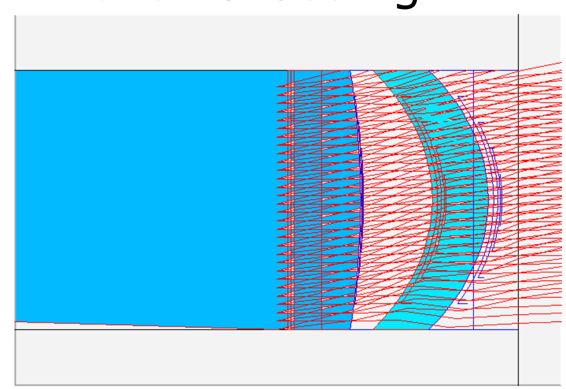


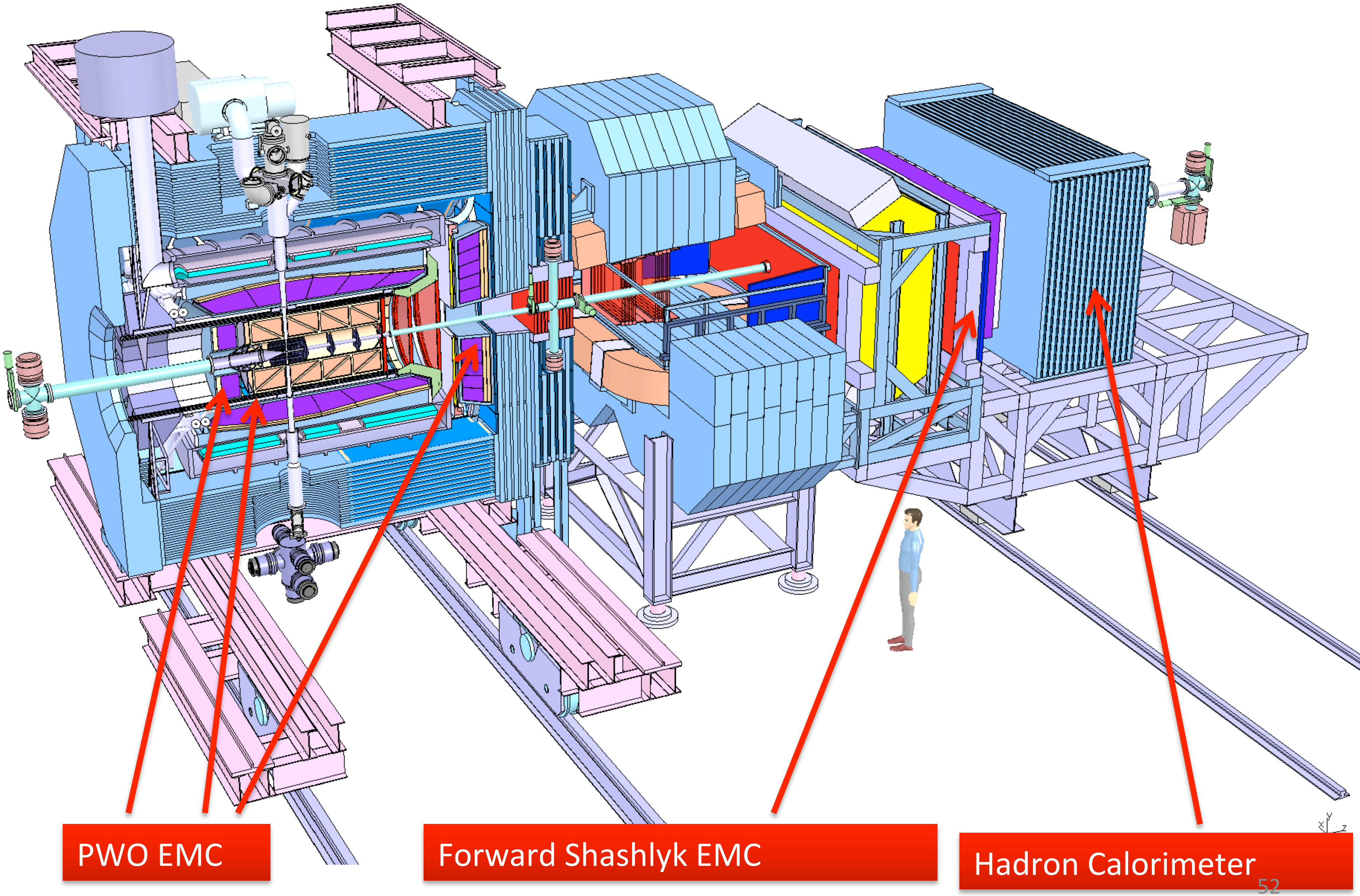
PANDA DIRC

- Lens focussing
- shorter radiator
- no water tank
- compact pixel readout
  (CP-PMTs or APDs)



Lens Focussing



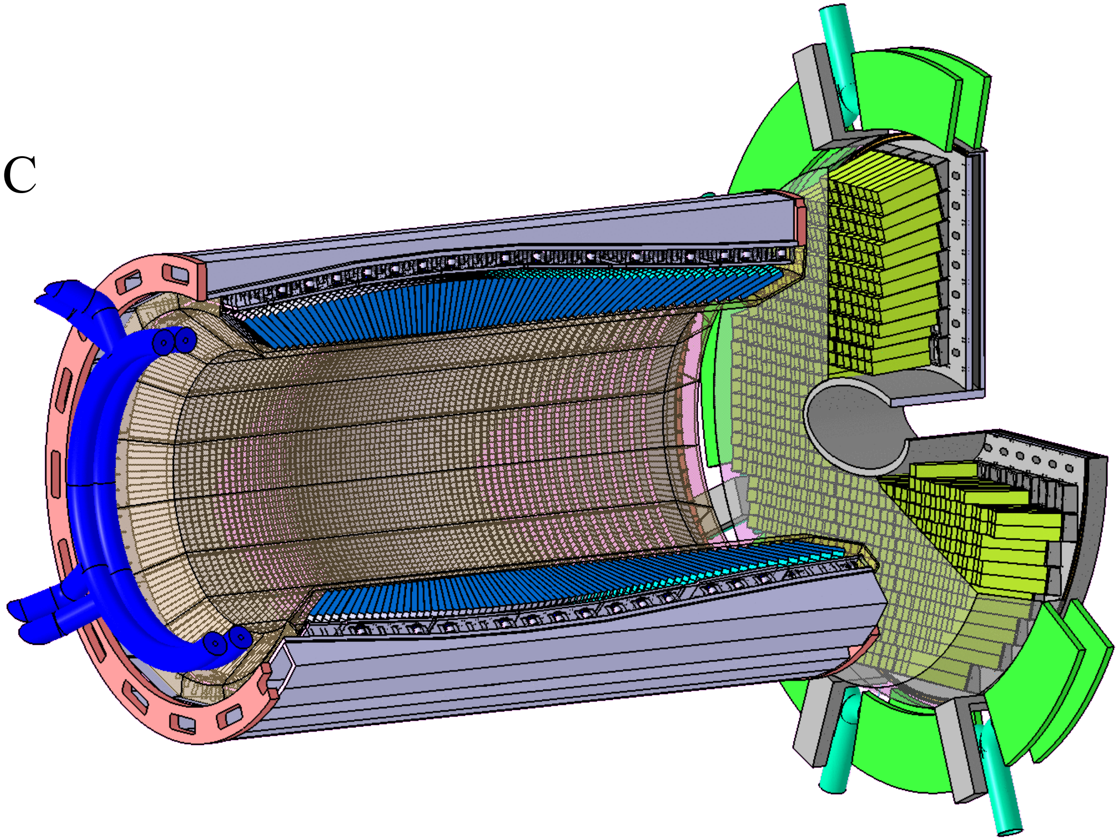

PWO EMC
Forward Shashlyk EMC
Hadron Calorimeter

PANDA PWO Calorimeters

- PWO is dense and fast
- Increase light yield:
  - improved PWO II
  - operation at -25°C
- Challenges:
  - temperature stable to 0.1°C
  - control radiation damage
  - low noise electronics
- Delivery of crystals started

Barrel Calorimeter
- 11000 PWO Crystals
- LAAPD readout, 2 x 1cm^2
- $\sigma(E)/E \sim 1.5\%/\sqrt{E}$ + const.

Forward Endcap
- 4000 PWO crystals
- High occupancy in center
- LAAPD readout



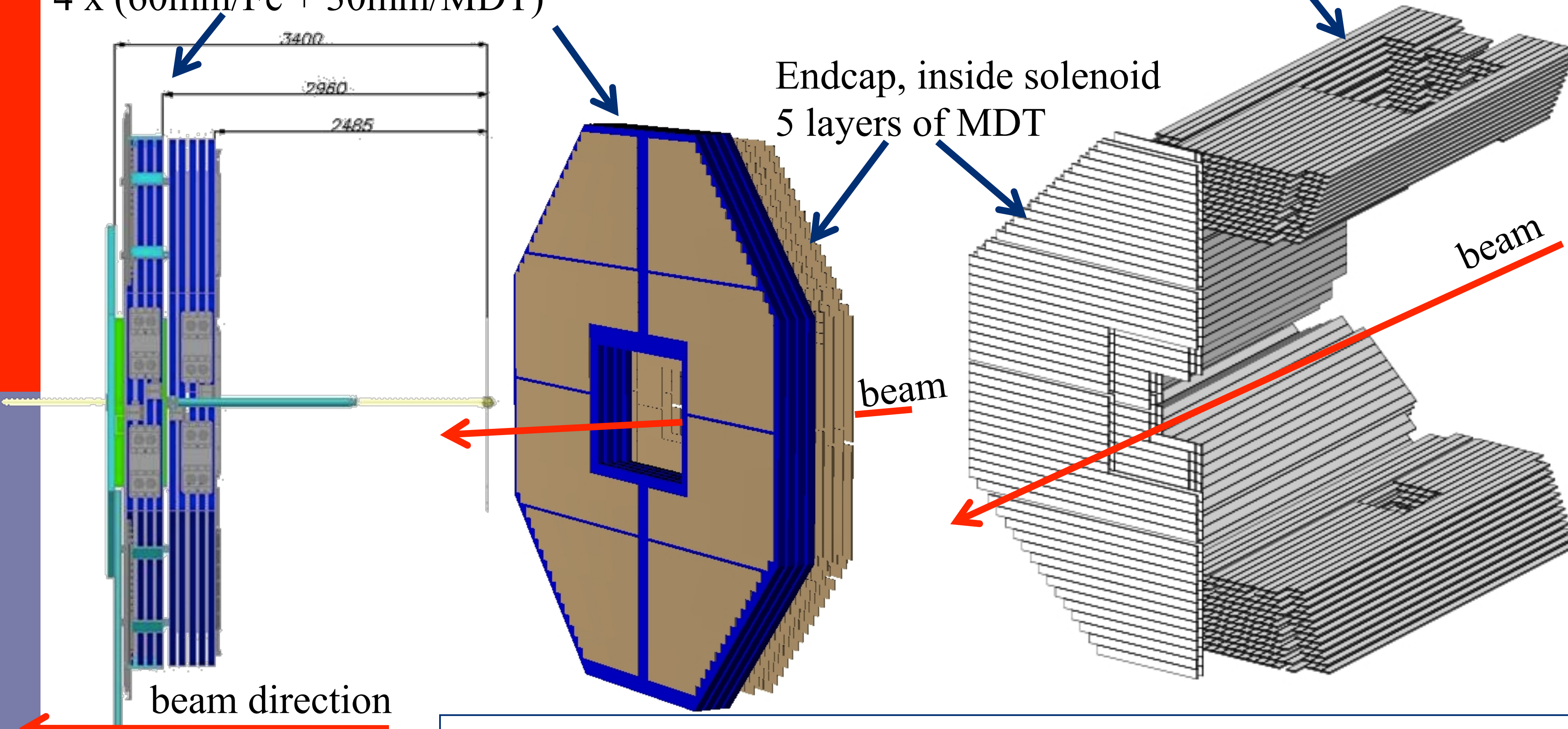
Muon Detector

Outside the solenoid
"Muon Filter", 4 layers

Inside the solenoid
Barrel: 12 layers inside the yoke + 1 bi-layer ("zero" bi-layer) in before iron
Endcap: 5 layers + "zero" bi-layer before iron

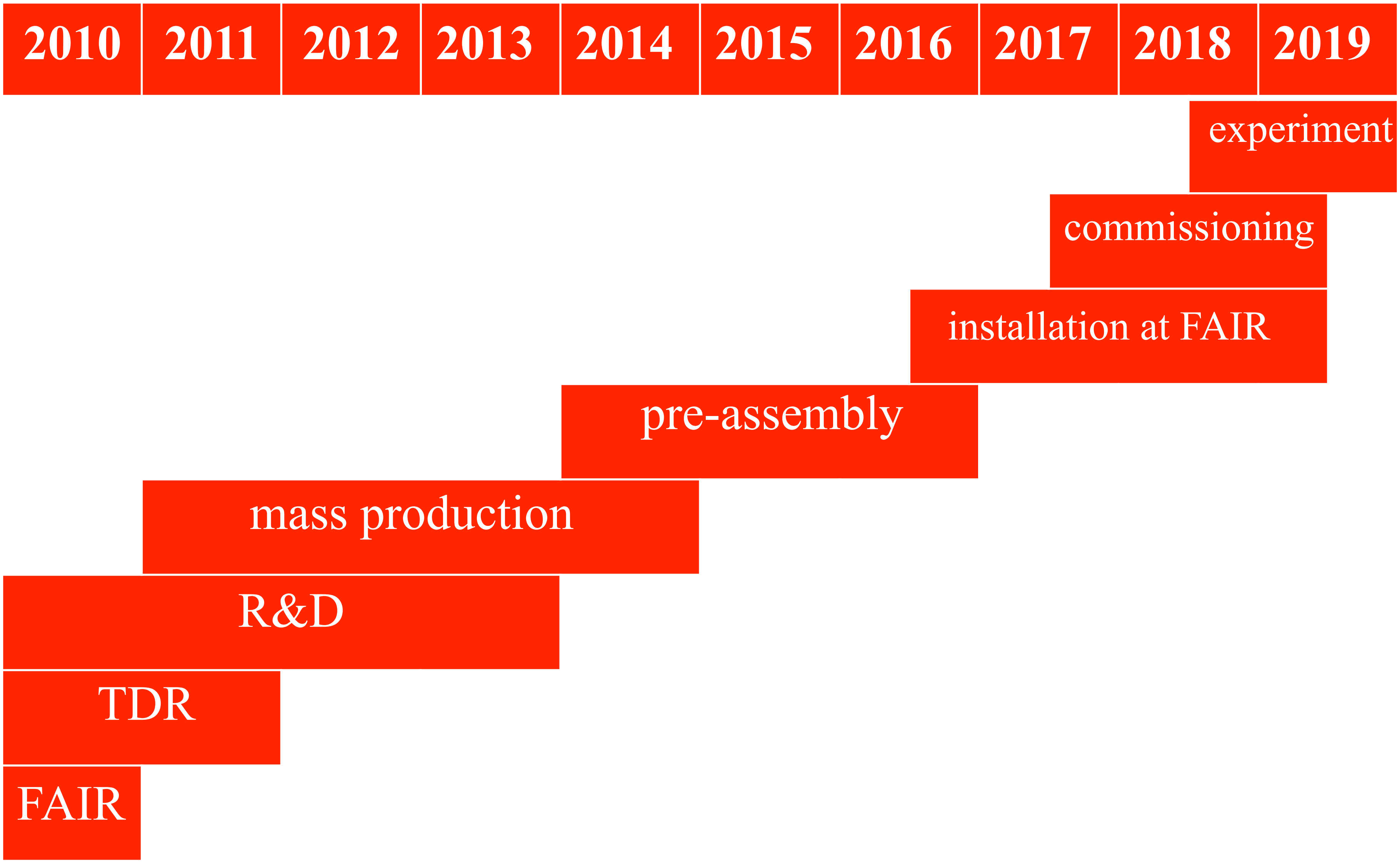
Muon Filter, outside solenoid
4 x (60mm/Fe + 30mm/MDT)

Barrel, inside solenoid
12 layers of MDT + "zero" bi-layer



Proportional tubes : anode signal and induction signal on 1 cm strips

Schedule – FAIR Start Version



Hypernuclear Detector

Internal C target to produce $\Xi\bar{\Xi}$
Active silicon target to stop the Ξ and detect the hypenuclei decay products

Germanium γ array detector, with 15 clusters of 3 gemanium

Forseen 2 KeV γ enery resolution, 1.3 MeV π energy resolution