The Electromagnetic Calorimeter of the future PANDA Detector

AntiProton ANnihilations at DArmstadt

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for the PANDA collaboration
- PANDA at FAIR/GSI
  - physics program
  - experimental requirements
- the detector concept of the EMC
- the new generation of PbWO₄: PWO-II
  - the scintillation properties
  - thermal quenching
  - response functions (PM- or APD-readout)
  - ongoing R&D
- status and time-schedule for operation
the GSI, Darmstadt (Germany): now and in near future

the present GSI facilities

- double ring synchrotron **SIS 100/300**
- Collector **Ring**
- New **Experimental Storage Ring**
- **HESR**
- super **FRagment Separator**

Panda

- **HESR**
- **0.8 – 14.5 GeV antiprotons**

- **2.4/34 GeV/u U**
- **740 MeV/u, A/q=2.7**
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June 05, 2006
the PANDA environment

- $\bar{P}$ - production similar to CERN
- **HESR** = High Energy Storage Ring
  - production rate $10^7$/s
  - $P_{\text{beam}} = 1.5 - 15 \text{ GeV/c}$
  - $N_{\text{stored}} = 5 \times 10^{10}$ p
- Gas-Jet/Pellet/Wire-Target
- **High luminosity mode**
  - luminosity $= 2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
  - $\delta p/p \sim 10^{-4}$ (stochastic cooling)
- **High resolution mode**
  - luminosity $= 10^{31} \text{ cm}^{-2}\text{s}^{-1}$
  - $\delta p/p \sim 10^{-5}$ (electron cooling)
physics objectives

- charmonium spectroscopy
- gluonic excitations (hybrids, glueballs, ...)
- open and hidden charm in nuclei
- $\gamma$-ray spectroscopy of hypernuclei

exploring non-perturbative QCD

- hybrids: “ordinary” quark states containing excited glue
- glueballs: gluonic states without valence quark contribution

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aimed detector capabilities

- high count rates
  - $2 \cdot 10^7$ interactions/s ($\sigma \sim 55\text{mb}$)
- vertex reconstruction
  - D, K$_s$, $\Lambda$, ...
- tracking in magnetic field
  - solenoid (2T), dipole (3.5T)
  - $\Delta p/p \sim 1\%$
- charged particle ID
  - $e^\pm$, $\mu^\pm$, $\pi^\pm$, p, ...
- EM calorimetry
  - $\gamma$, $\pi^0$, $\eta$, ...
- forward spectrometry
  - leading particles
- complex triggers
  - e, $\mu$, K, D, $\Lambda$
- modular design
  - hypernuclei studies
target spectrometer

- Target Generator
- Straws or TPC
- MVD
- barrel DIRC
- Solenoid
- Muon Detectors
- TOF stop
- Barrel DIRC
- Mini Drift - Chambers

EMC
electromagnetic calorimeter (EMC)

- nearly $4\pi$ coverage
- high rate capabilities
- high resolution
- 10 MeV $< E_\gamma < 8$ GeV

- compactness
- granularity
- fast response
- high luminescence
- efficient photosensor

- dense scintillator, small $X_0$, $R_M$
- fast scintillator, short decay time
- timing information
- bright scintillator
- insensitive to MF

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EMC  
**detector material:** PbWO$_4$ (PWO)

- **compact:** $X_0 = 0.9$ cm, $R_M = 2.2$ cm
- **fast:** $\tau < 10$ ns
- **radiation hard:** slight reduction of optical transmission monitoring
- **readout in magnetic field:** $\lambda = 420$ nm, adapted to APD
- **good energy resolution:** down to $10 - 20$ MeV

**barrel:**
- 11360 crystals

**forward endcap:**
- 6864 crystals

**backward endcap:**
- 816 crystals

**total ~ 20,000 modules**
EMC development of PWO-II

optimization of PbWO₄ in collaboration with RINP, Minsk and the manufacturer BTCP at Bogoroditsk, Russia

- reduction of defects (oxygen vacancies)
- reduced concentration of La-, Y-Doping
- better selection of raw material
- optimization of production technology

scintillation mechanism

- extreme short decay time (even at -25°C)
- no slow components
EMC development of PWO-II

optical quality

✓ no absorption bands
✓ low absorption edge

✓ extreme homogeneity along the full crystal length of 20cm
EMC development of PWO-II

luminescence yield

60 prototype crystals for PANDA

✓ mass production possible

✓ doubled light yield

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EMC development of PWO-II

luminescence at –25°C

light yield / a.u.

temperature / oC

reduction of thermal quenching

3-4-fold light yield compared to RT

\[ \frac{dL}{dT} \]

\[ \frac{dLY}{dT} \]

\[ \sigma/E = 18.2\% \]

\[ \sigma/E = 11.5\% \]

\[ ^{22}\text{Na} \]

LY = 92.2 pe/MeV

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\[ \text{counts} \]

\[ \text{energy / a.u.} \]

\[ \text{linear correlation} \]

\[ \text{LY} @ +25°C / \text{pe/MeV} \]

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EMC development of PWO-II

radiation hardness

- no permanent damage due to defect formation
- activation due to proton induced reactions
- reduction of optical transmission

monitoring mandatory

dose:
$10^{13}$ protons
$E_p = 90$ MeV
@ KVI, Groningen

int. flux: $5 \cdot 10^9 p/mm^2$

wavelength / nm

transmission / %
EMC development of PWO-II

response to high energy photons

3x3 Matrix
PM-Auslese
20x20x200 mm$^3$

tagged photon facility
@ MAMI, Mainz

$e^-$
$\gamma$‘s

$64 \text{ MeV} < E_\gamma < 520 \text{ MeV}$
EMC development of PWO-II

Comparison of 8 photon energies at 2 different temperatures:

- $T = -25^\circ C$
- $T = +10^\circ C$

Energy resolution $\frac{\sigma}{E}$:

$T = +10^\circ C$

- $\frac{\sigma}{E} = \frac{1.74}{\sqrt{E}} + 0.7 \%$
- $\frac{\sigma}{E} = \frac{0.95}{\sqrt{E}} + 0.91 \%$

$T = -25^\circ C$

- $\frac{\sigma}{E} = 2.45 \% @ 1 \text{ GeV}$
- $\frac{\sigma}{E} = 1.86 \% @ 1 \text{ GeV}$

The best ever achieved energy resolution is $\%61.4E$. The graph shows the energy resolution as a function of incident energy.
EMC

readout with Large Area Avalanche Photo Diodes (LAAPD)

in collaboration with Hamamatsu Photonics

• excellent performance at RT and \( T = -25^\circ C \)
• radiation resistant up to \( 10^{13} \) protons in particular at \( T = -25^\circ C \)

• preamplifier development

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EMC

energy resolution

excellent resolution in spite of:
- incomplete matrix
- shower leakage (3x3)


time resolution

central module versus tagger

no optimum setup, but:
- $\sigma_t < 1\text{ns}$ above $E_\gamma \sim 150\text{MeV}$
- fast calorimetry, PID
EMC calorimeter to be operated at \(- (25.0 \pm 0.1)^\circ C\)!

- cooling
- temperature stabilization

60 crystal prototype

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• very complex and ambitious detector

• concept mostly fixed, but R&D still ongoing:
  
  cooling technology
  
  FE-electronics (ASIC), large dynamic range
  
  energy and timing information
  
  photosensor of forward endcap (APD/VPT)

EMC very advanced – design to be fixed in middle of 2007

ordering crystals in 2008

• PANDA detector to be completed in 2011

• 2012: start of operation of PHASE 1
PANDA Collaboration

Universität Basel, IHEP Beijing, Ruhr-Universität Bochum, Universität Bonn, Università di Brescia + INFN, Università di Catania, University of Silesia, University Cracow, GSI Darmstadt, TU Dresden, JINR Dubna, JINR Dubna University Edinburgh, Universität Erlangen, Nürnberg University, INFN Sezione di Ferrara, INFN Sezione di Firenze, LNF-INFN Frascati, INFN Sezione di Genova, Universität Göttingen, IJCLab Glasgow, KVI Groningen, Institute for Nuclear Physics Helsinki, FZ Jülich - IKP I, FZ Jülich - IKP II, Universität Mainz, Universität München, Universität Münster, University of Oxford, IPN Orsay, Università di Pavia, PNPI St. Petersburg, IHEP Protvino, Stockholm University, Università di Torino, Università di Piemonte, Università di Trieste + INFN, Universität Tübingen, Uppsala Universität, TSL Uppsala, Universidad de Valencia, Stefan Meyer Institut für subatomare Physik, Vienna, SINS Warschau

15 countries – 47 institutes – 370 scientists