Probing hypernuclei at $\overline{\text{P}}$anda and at MAMI-C

IX International Conference on Hypernuclear and Strange Particle Physics

P Achenbach, U Mainz

14 October 2006

outline of the talk

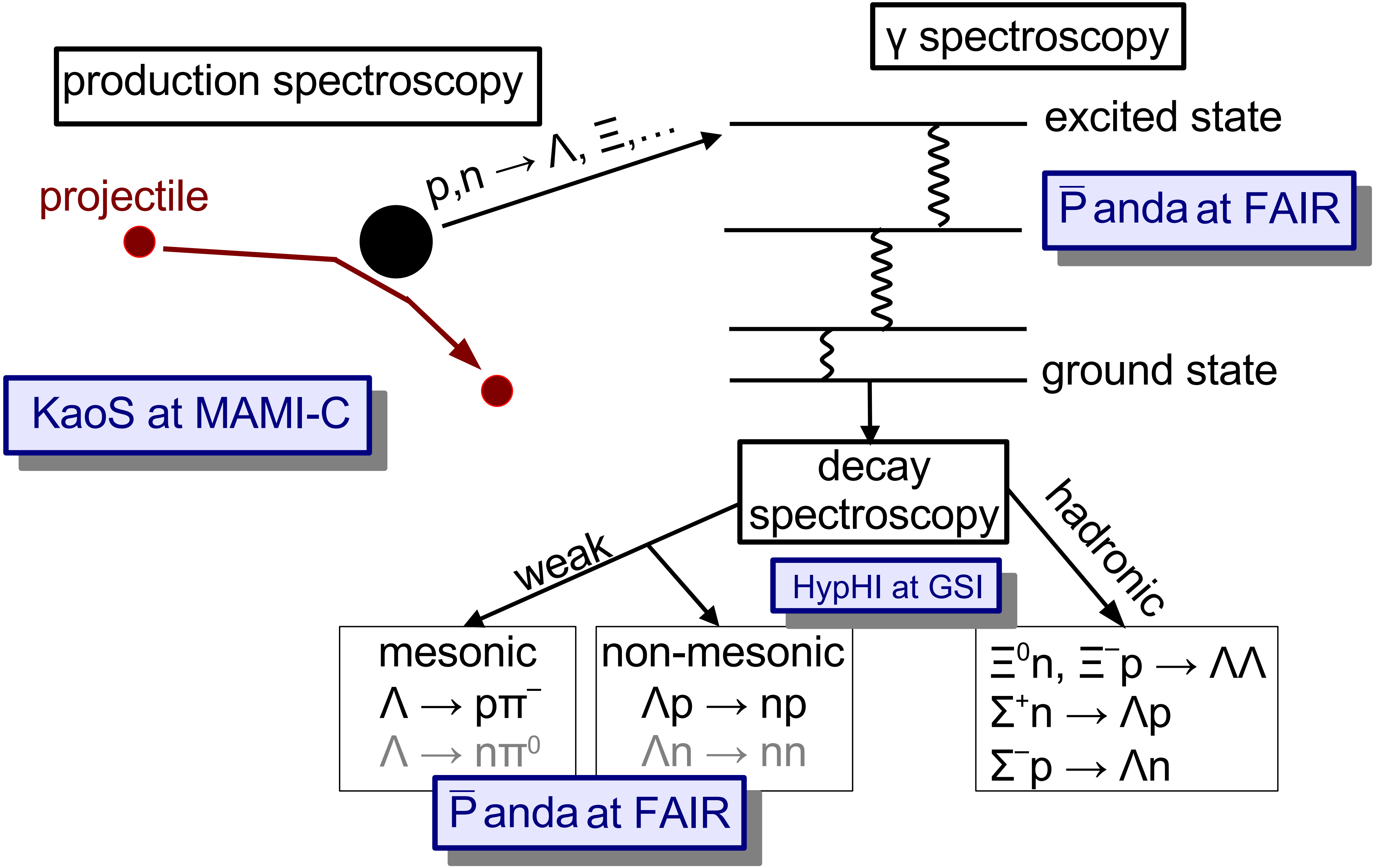
- **setting the stage with MAMI-C**
  - "old" and "new" spectrometers in Mainz
  - developments in detectors and electronics

  (also poster presentation: *A1 Collaboration*: Detector developments for the kaon spectrometer at MAMI)

  - hypernuclear formation in electroproduction
- **hypernuclear physics with $\overline{\text{P}}$anda**
  - production of multistrange systems
  - HPGe detectors under extreme conditions

  (also poster presentation: *A. Sanchez Lorente et al.*: Production and spectroscopy of double hypernuclei at $\overline{\text{P}}$anda)
- **summary of the activities**

Future hypernuclear spectroscopy in Mainz and Darmstadt



≫ it's a machine's world ≪

[Queen, 1984]

Systematics of the $(e, e'K^+)$ reaction

- electron beams: excellent spatial and energy spread

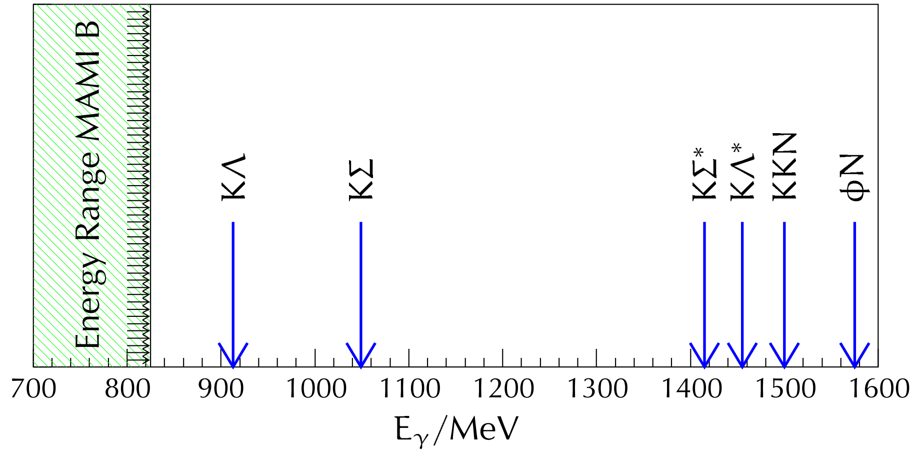
  855 MeV electron beam at MAMI:

  - **energy spread 13 keV (1 σ width)**
  - **horizontal emittance 13 π mm mrad (1 σ width)**
  - **vertical emittance 0.84 π mm mrad (1 σ width)**

- 100 % duty factor with modern electron machines
- singles rates in focal plane detectors limit luminosity

$\Downarrow$

- open strangeness at MAMI-C



[photon energy thresholds on the free nucleon]

- double coincidence spectroscopy
  - **electron detection close to zero degree**
    [definition of scattering plane]
  - **kaon detection in forward direction**
    [definition of reaction plane]

determines choice of spectrometer and detectors $\Leftarrow$

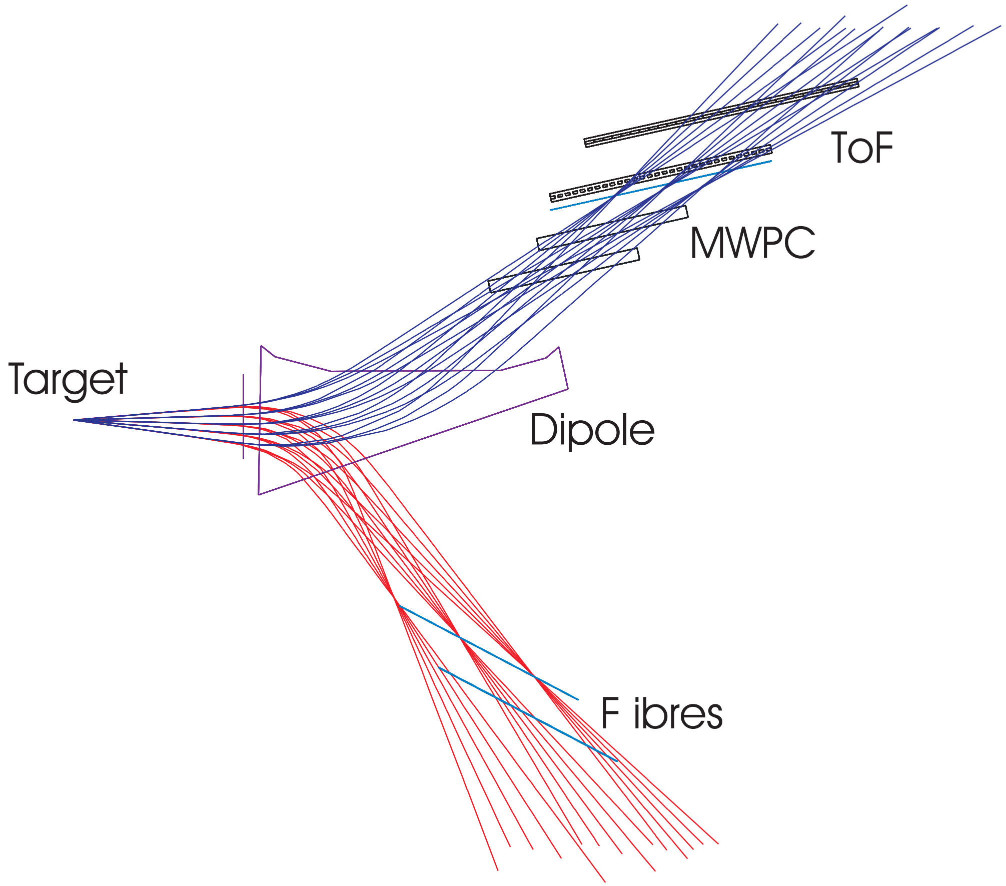
The proposed operation of KaoS as a double spectrometer

issues for kaon detection:

- critical: Bremsstrahlung and pair production
- studies of positron background

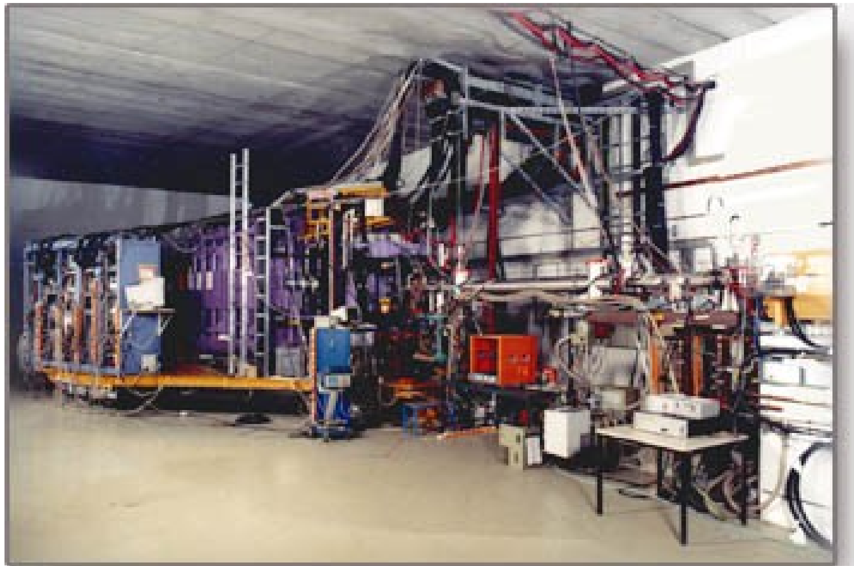
issues for electron detection:

- critical: Bremsstrahlung and Møller electrons
- new focal plane detector with high rate capability



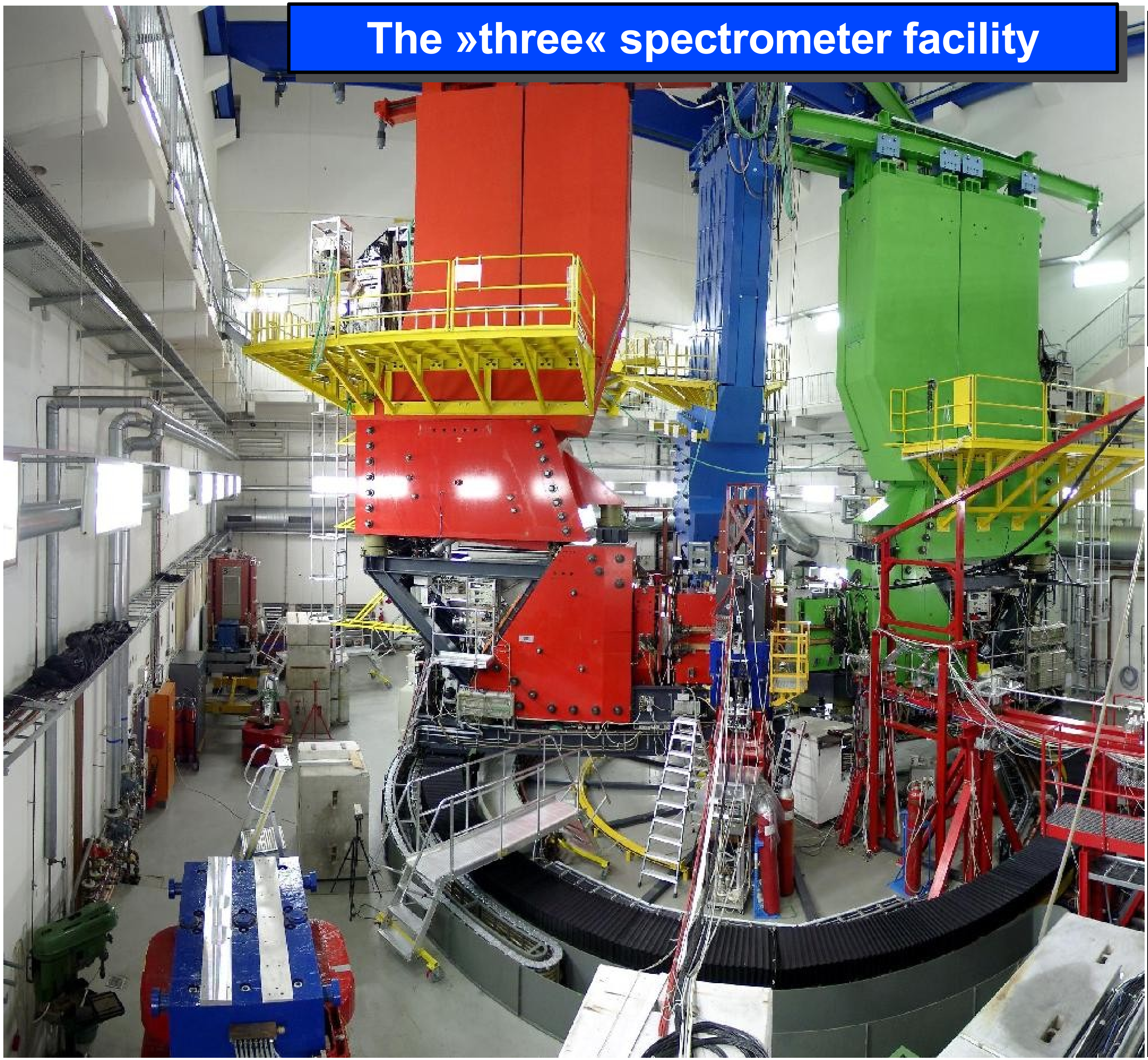
both pole face edges accessible for focusing

The KaoS spectrometer at GSI, Darmstadt, 1994 - 2002



[photos (c) by GSI]

The »three« spectrometer facility



Spectrometer A:

$$\begin{aligned} \alpha &> 20^\circ \\ p &< 735\,\frac{\text{MeV}}{c} \\ \Delta\Omega &= 28\,\text{msr} \\ \Delta p/p &= 20\% \end{aligned}$$

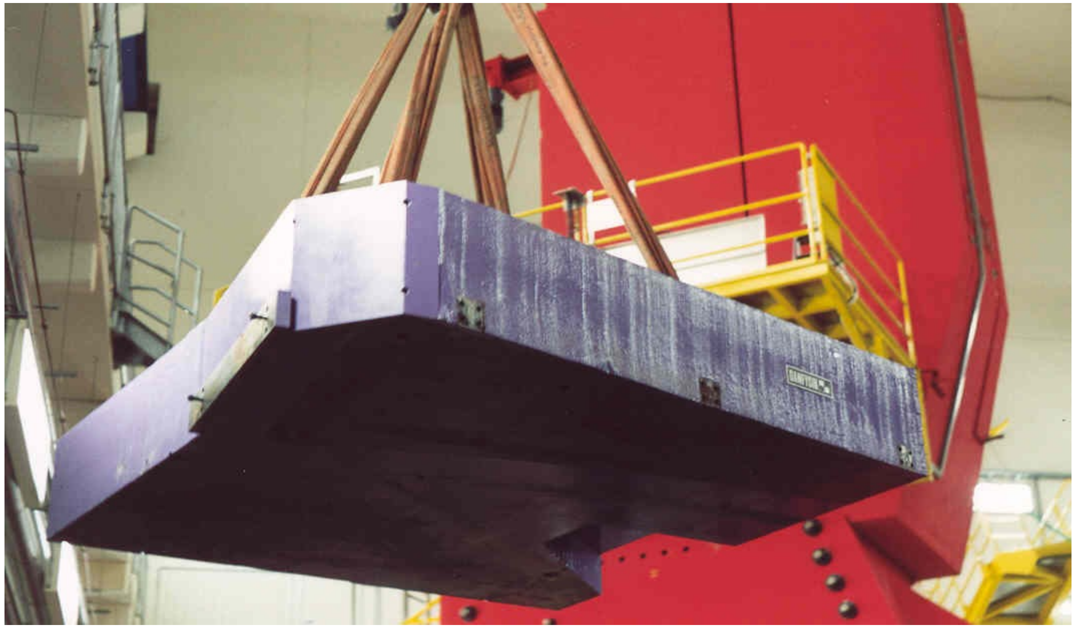
Spectrometer B:

$$\begin{aligned} \alpha &> 8^\circ \\ p &< 870\,\frac{\text{MeV}}{c} \\ \Delta\Omega &= 5.6\,\text{msr} \\ \Delta p/p &= 15\% \end{aligned}$$

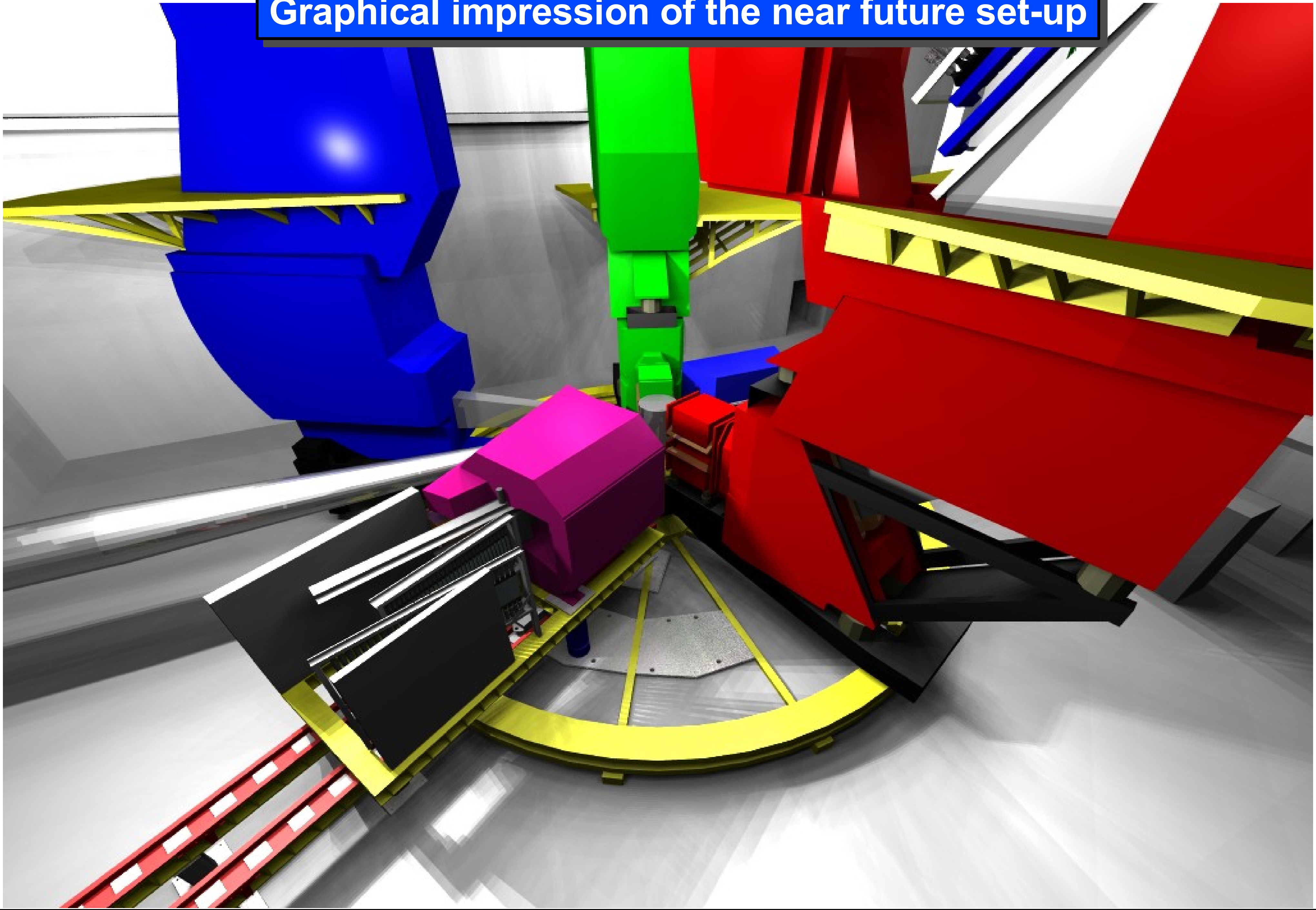
Spectrometer C:

$$\begin{aligned} \alpha &> 55^\circ \\ p &< 655\,\frac{\text{MeV}}{c} \\ \Delta\Omega &= 28\,\text{msr} \\ \Delta p/p &= 25\% \end{aligned}$$

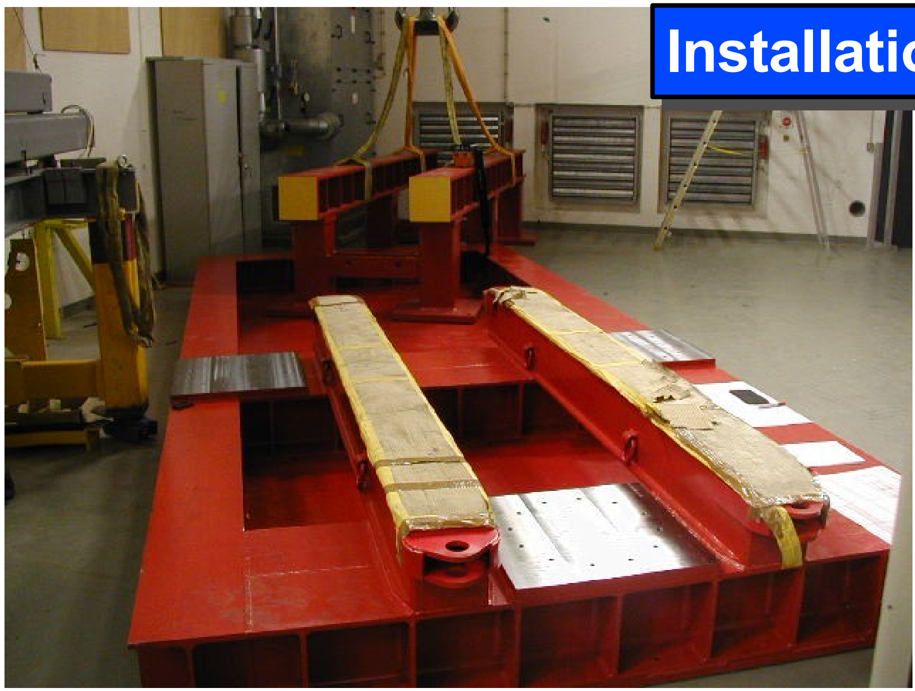
Arrival of KaoS at spectrometer hall on 11 June 2003



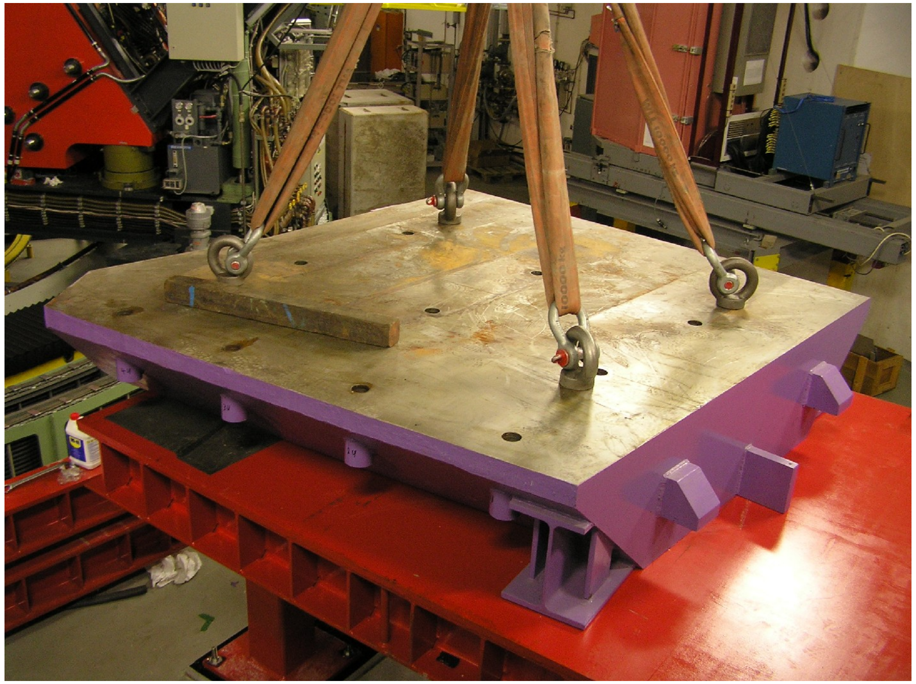
Graphical impression of the near future set-up

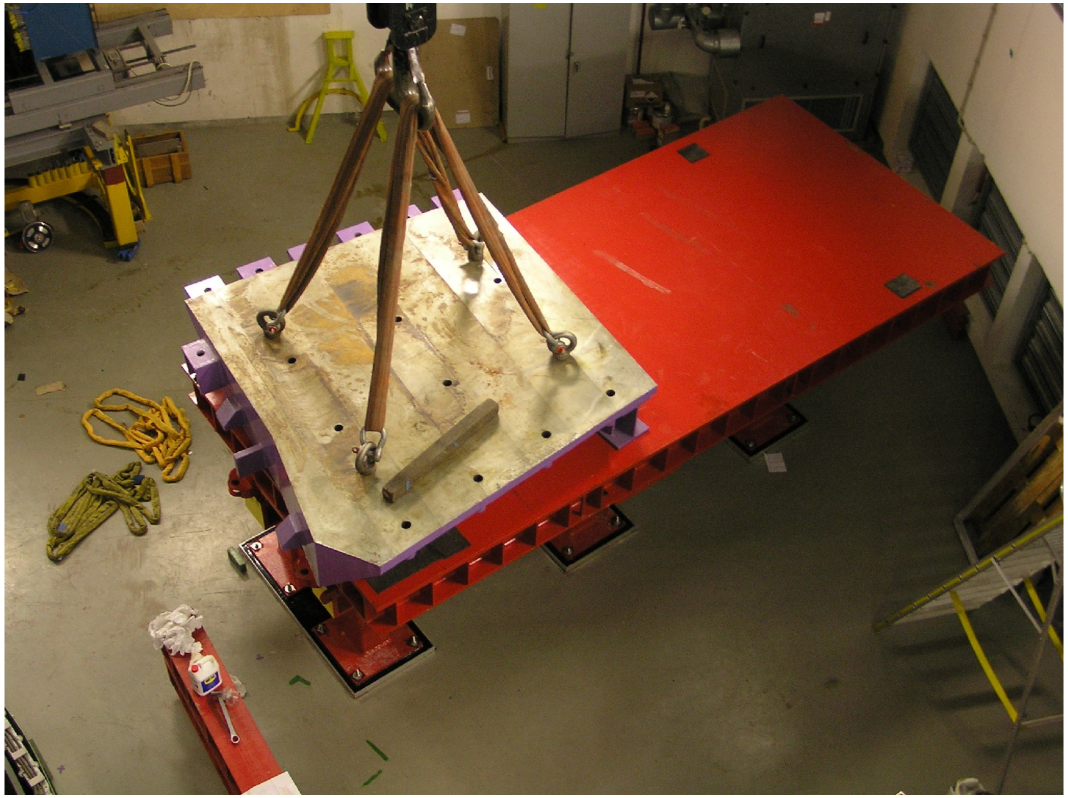


Installation of the spectrometer



- mechanical parts delivered in 2004/5
- mounting of parts started in 2006
- parking position for installation and tests





Magnetic chicane in the entrance beam-line

large aperture and small angle acceptance

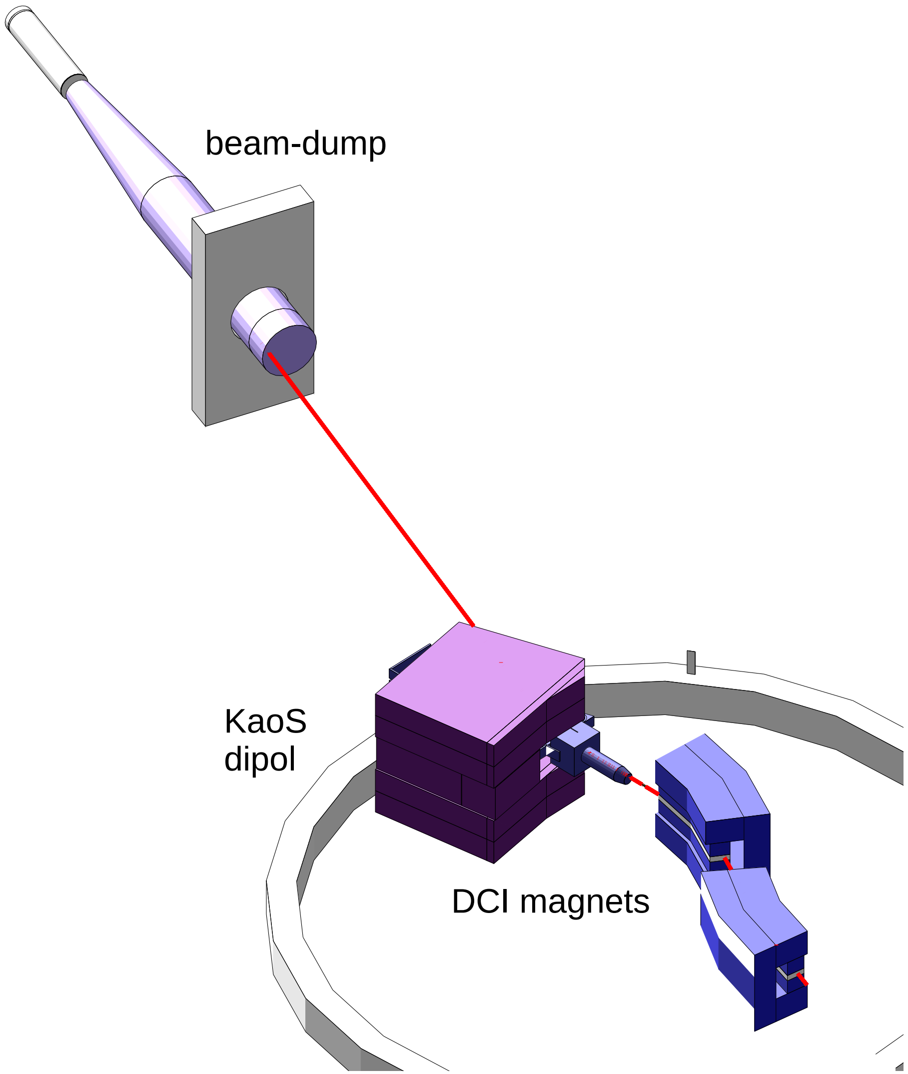
$\longrightarrow$ deflection of primary beam

$\Downarrow$

magnetic chicane needed for re-direction of beam

$\Downarrow$

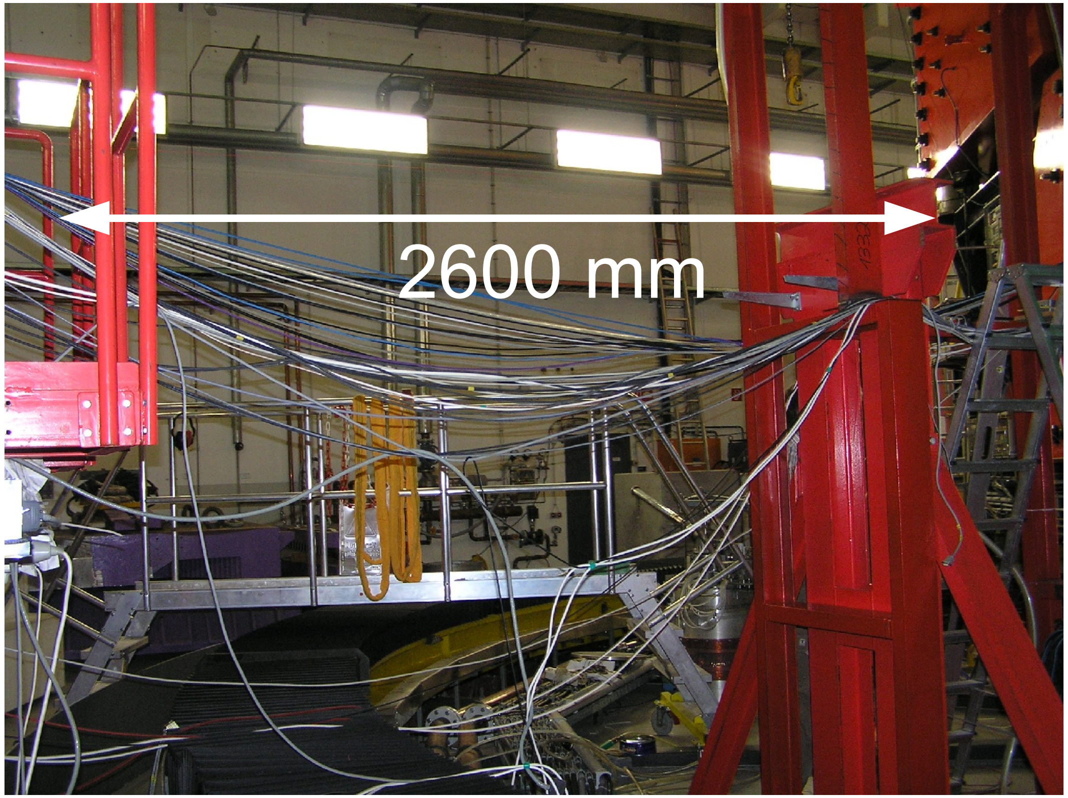
- two 30° sector magnets available
- beam transport and beam losses calculated
- position and choice of magnets optimized



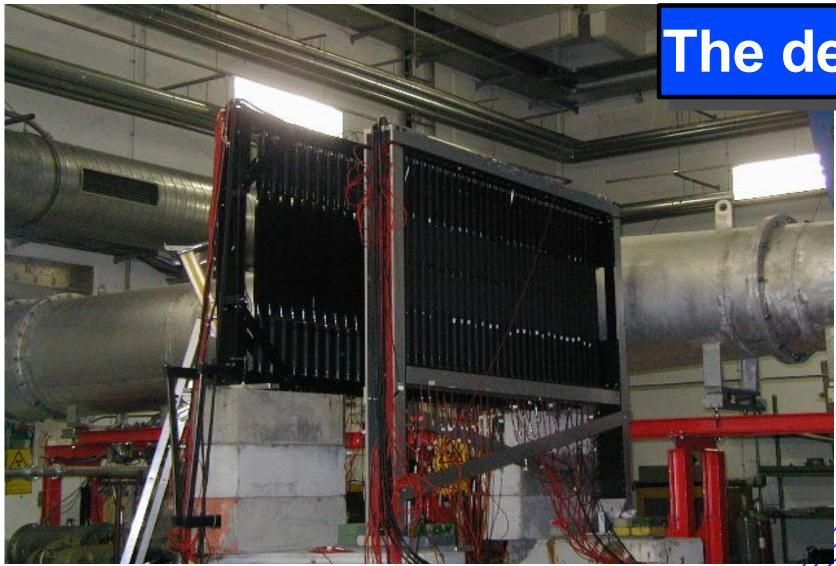
A new beam-line for zero-degree acceptance

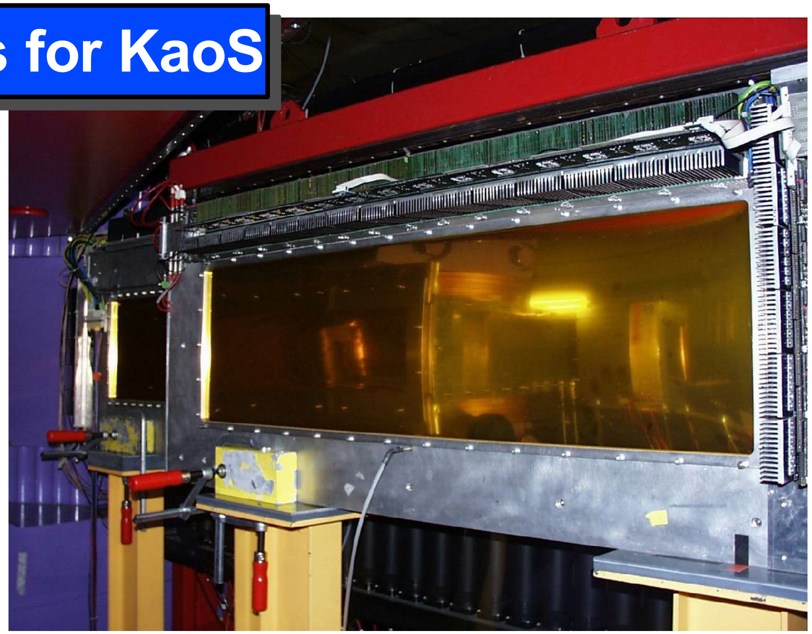
- modification of existing beam line
- adding 30 tons weight in 2.3 m length

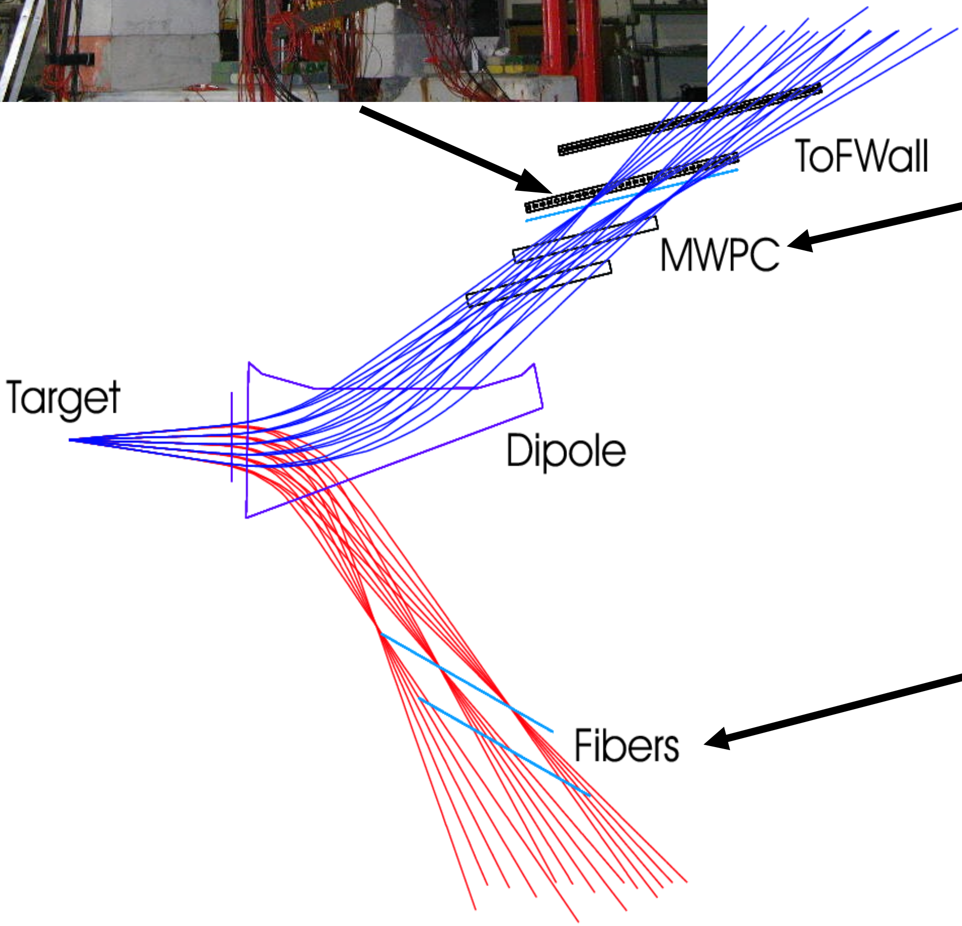
(magnets originally used in the e^{-}-e+ ring DCI Saclay)

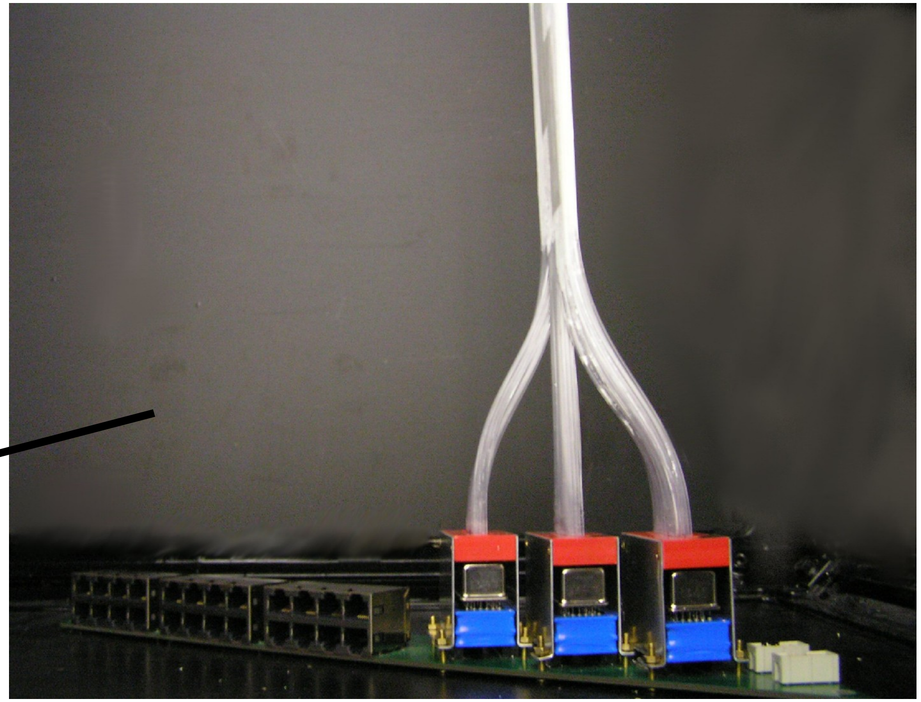


The detector packages for KaoS

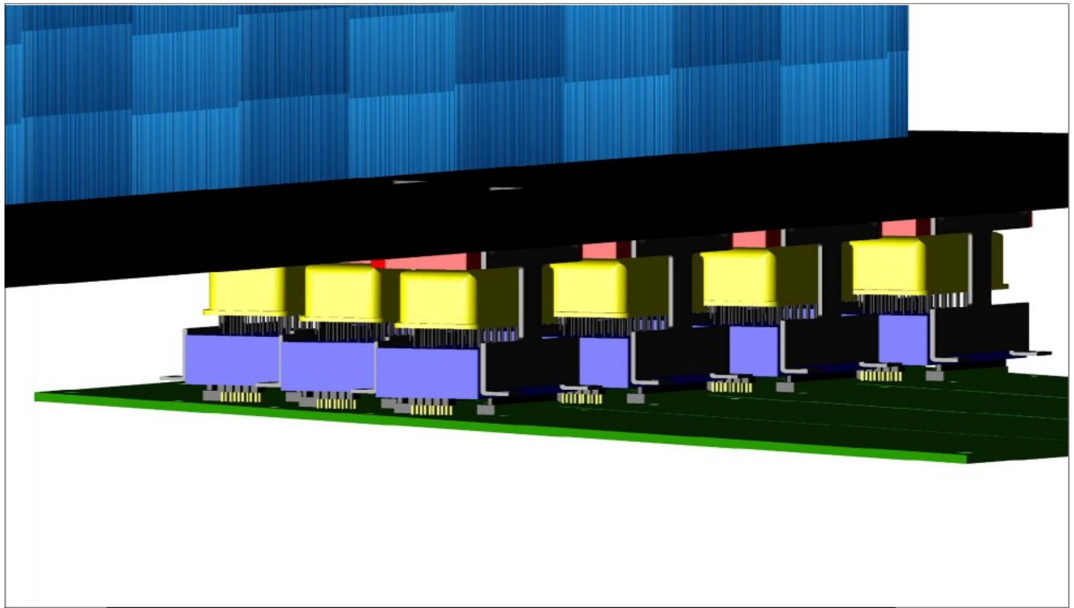




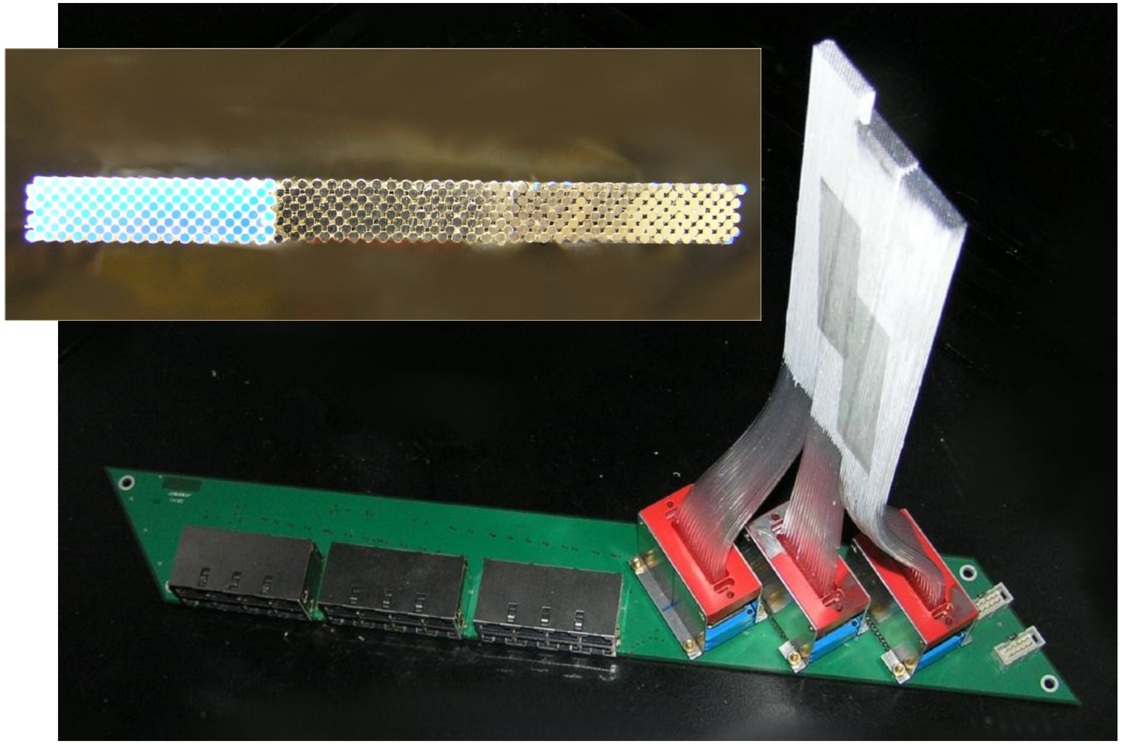




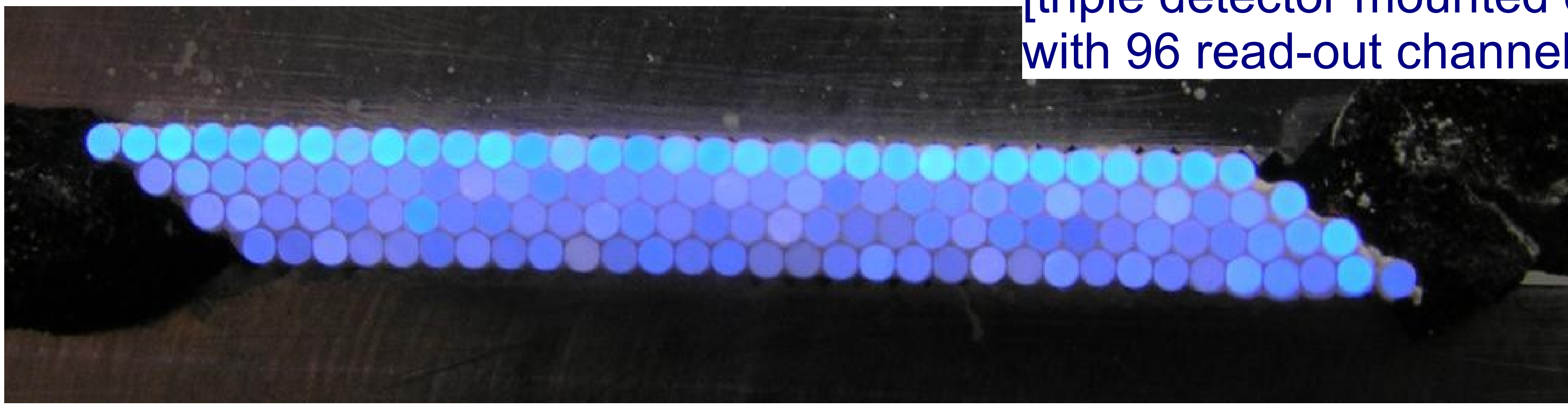
Development of a triple detector for the focal plane



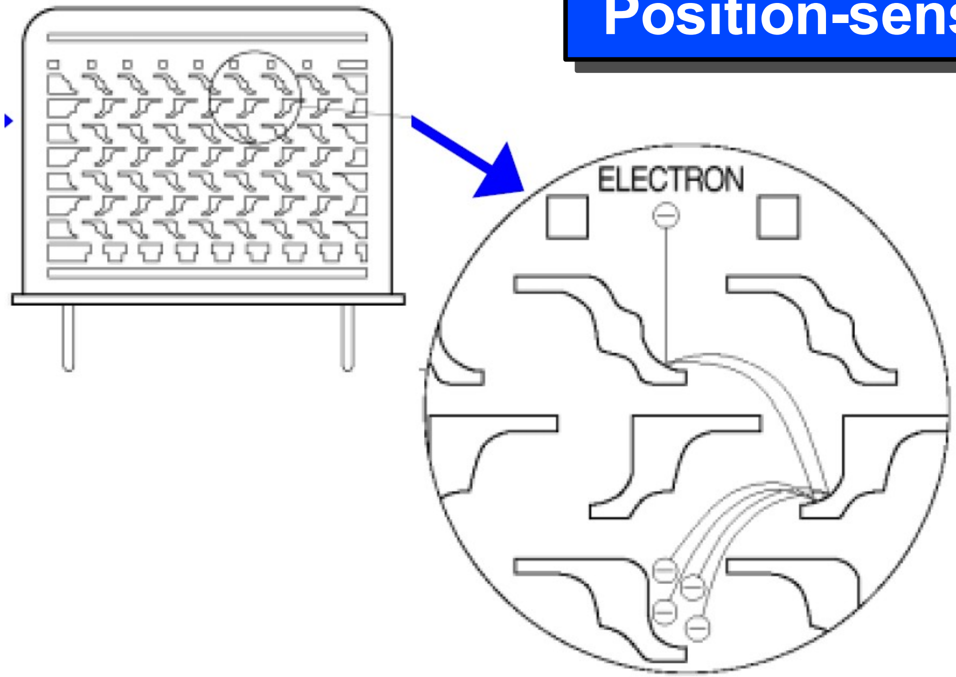
- 20 triple boards per plane
- 120 cm x 30 cm active area
- 60º detector configuration

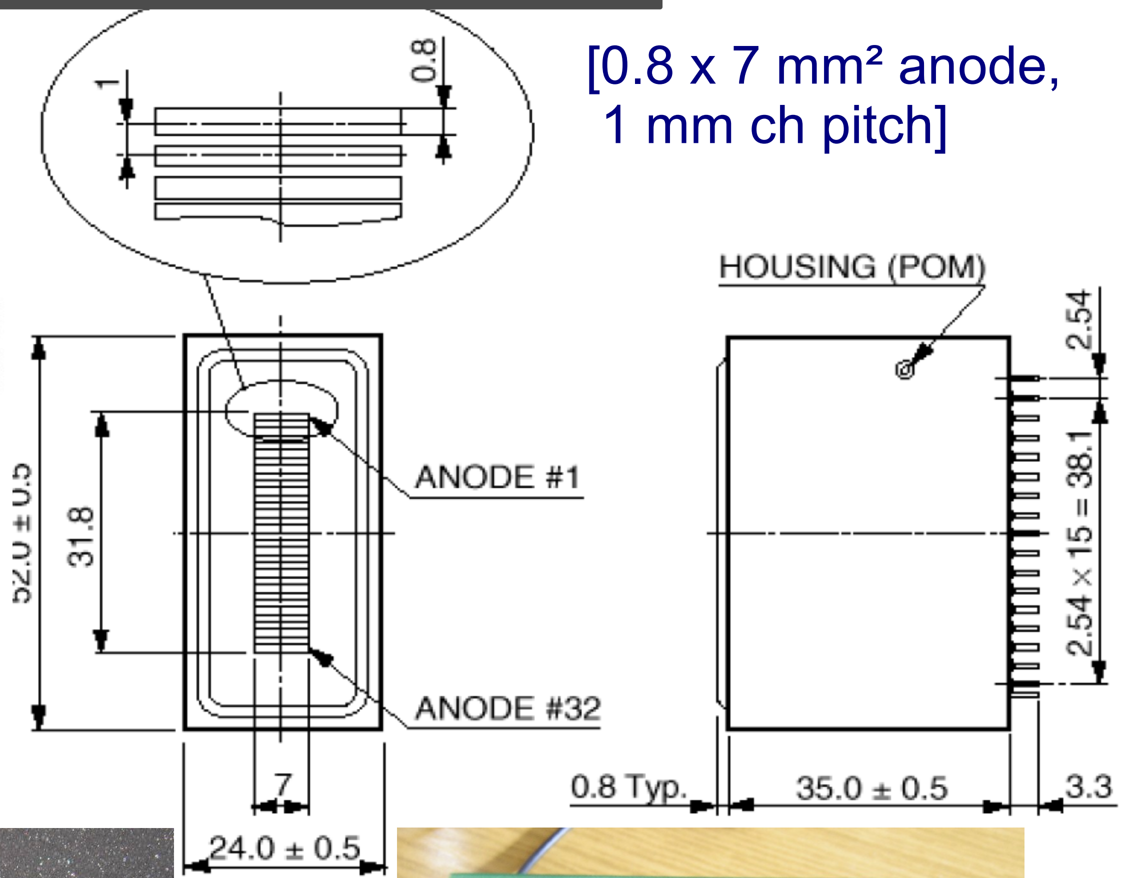


[triple detector mounted on front-end board with 96 read-out channels (384 fibres)]

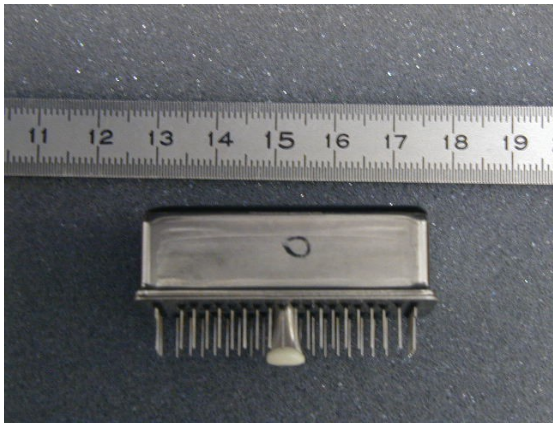


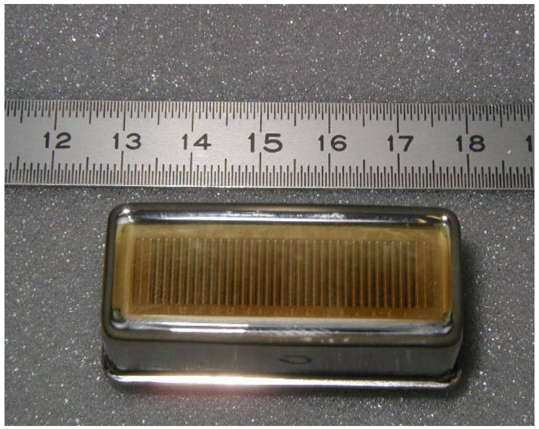
Position-sensitive photomultipliers





[0.8 x 7 mm² anode,
1 mm ch pitch]

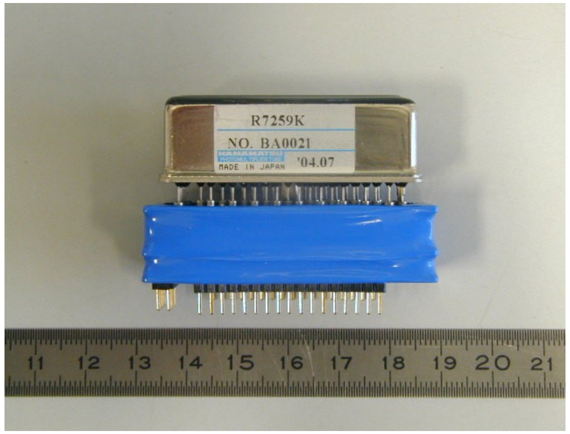


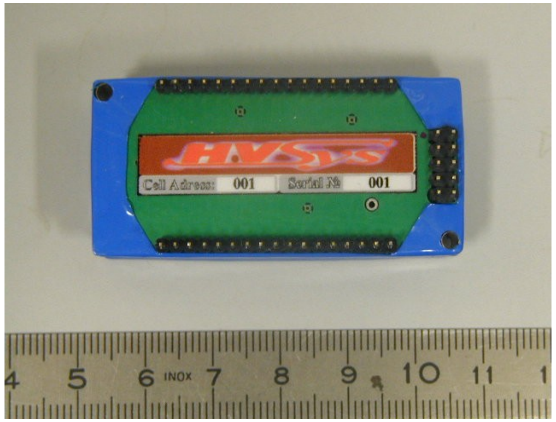


[R7259K 32-channel linear array w/o base]

[H7260 32-channel with base]

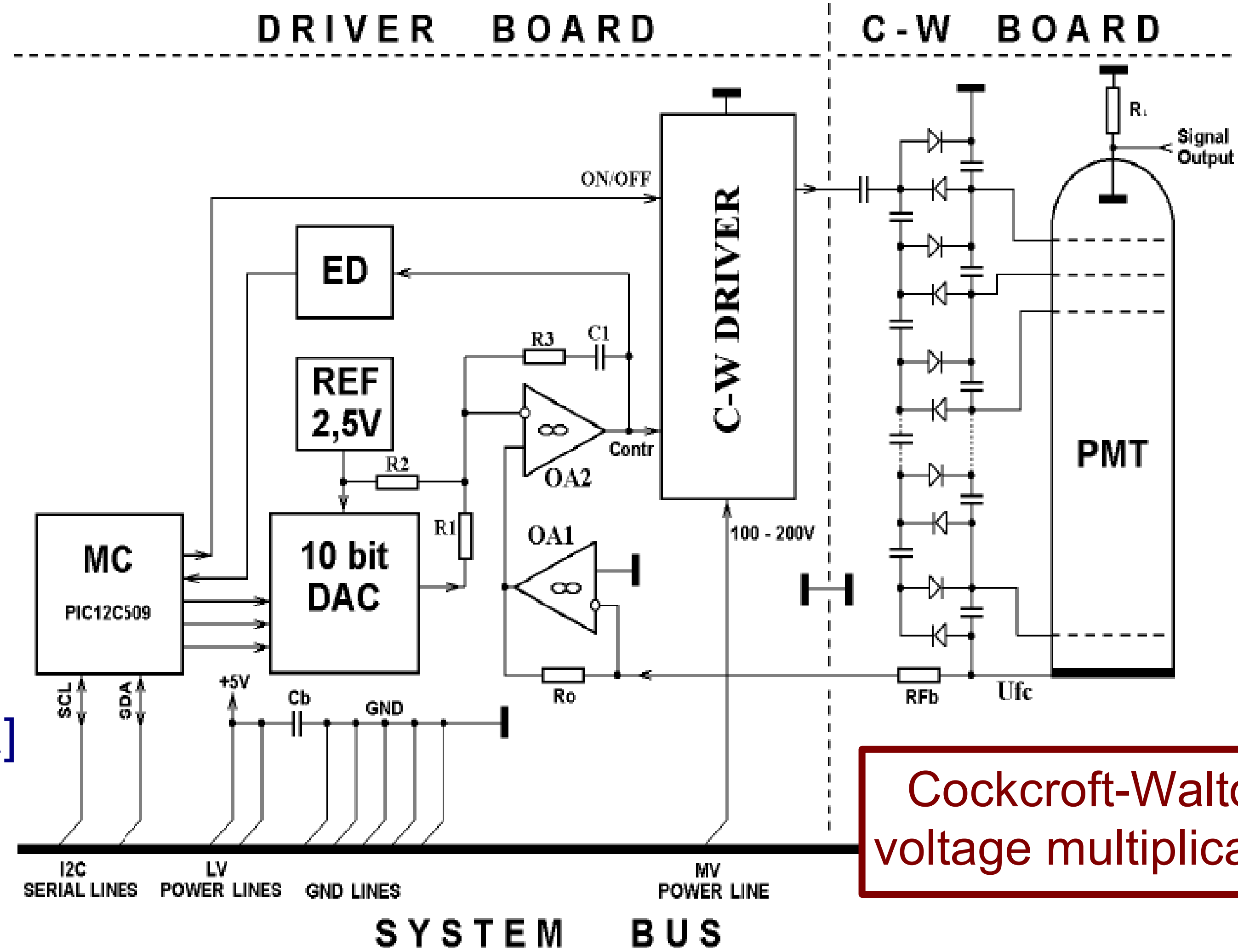
Active high-voltage generation in the base





[provided by HVSys, Russia]

- base voltage 140 V dc → no expensive connectors or stiff cables
- control module serves up to 508 bases

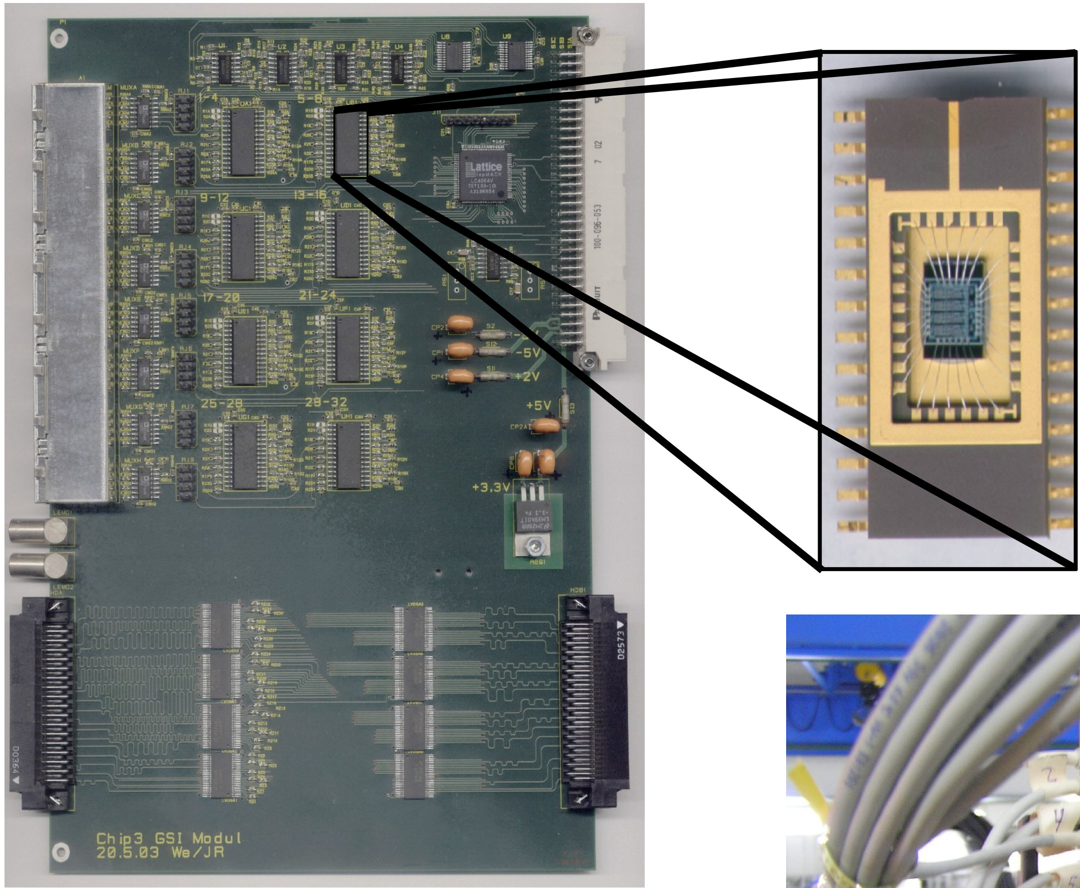


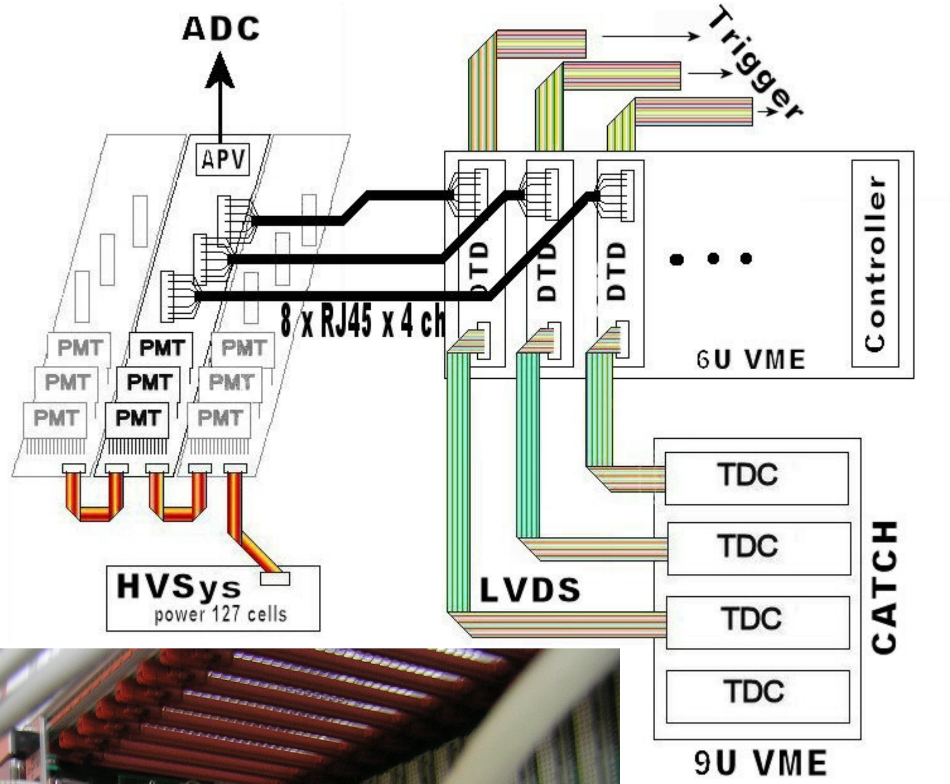
Cockcroft-Walton voltage multiplication

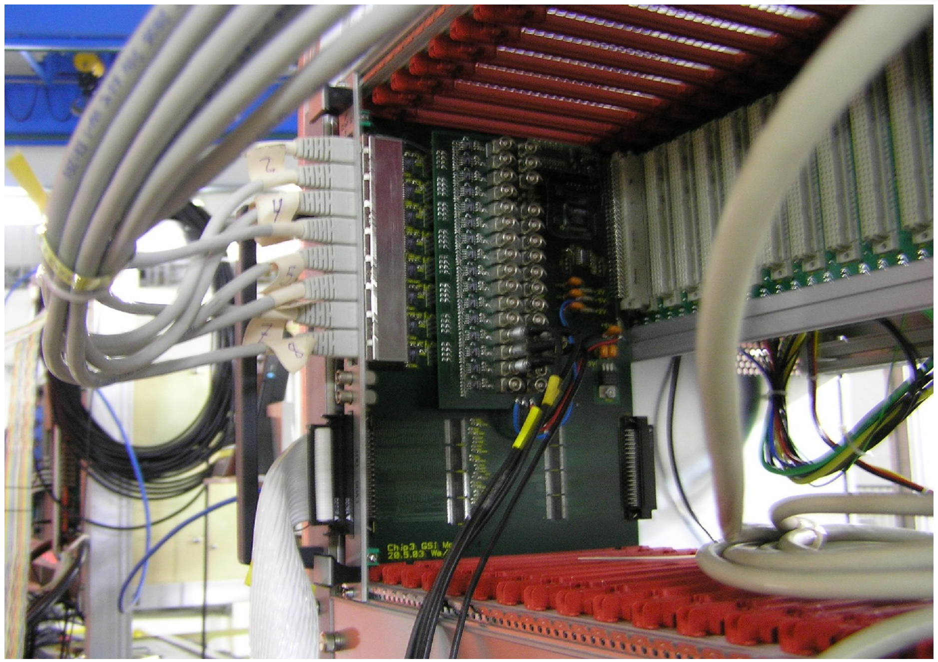
<u>specifications:</u>
max anode current: < 2 mA
voltage stability: 0.05 %

[discriminator card based on GSI-Chip3]

Signal discrimination and processing







- 4 channels per DTD chip
- double threshold principle
- LVDS output signals

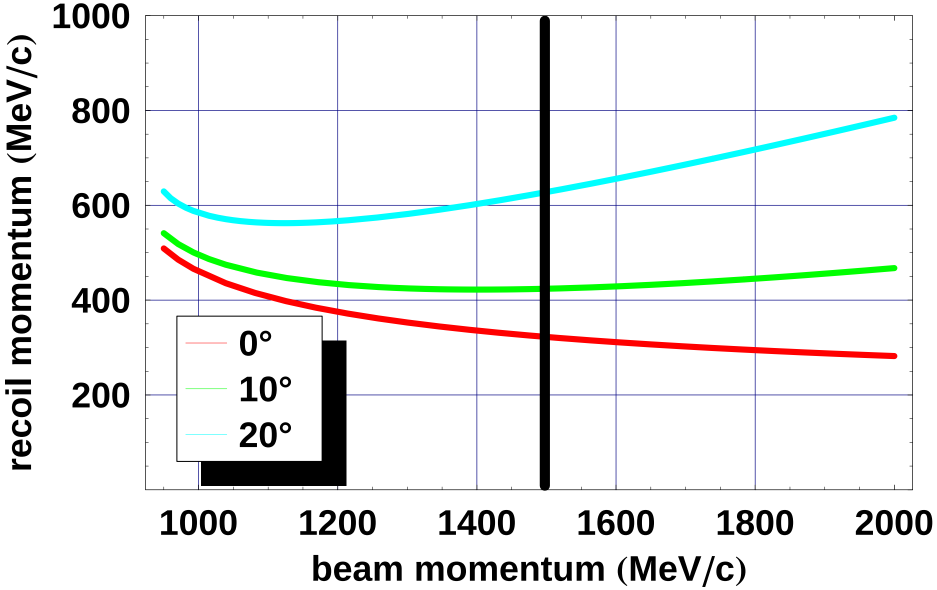
Kinematical definition of a hypernuclear electroproduction at MAMI-C

Recoil momentum in strangeness production

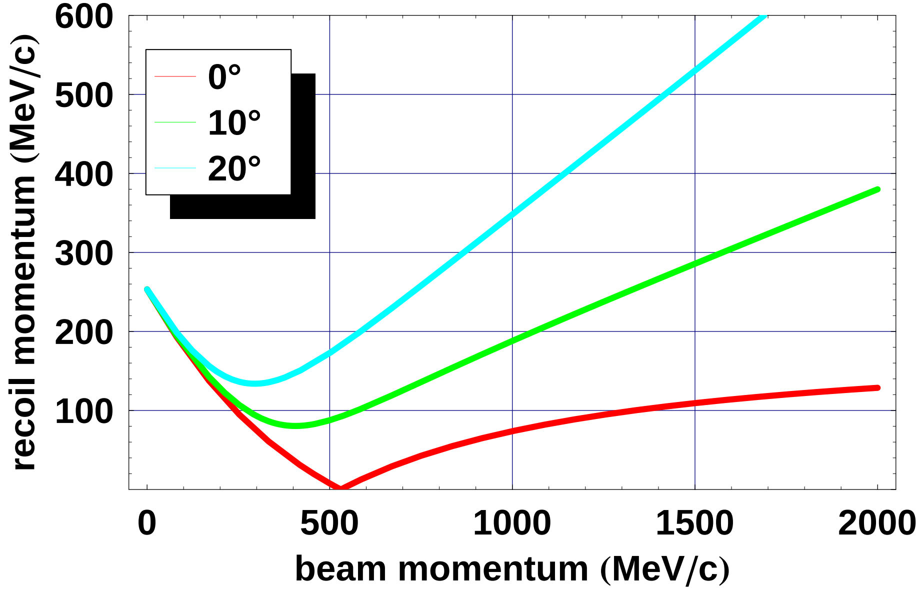
- typical momentum transfers: $\approx 300 - 600$ MeV/*c*
- minimum momentum transfer for $\theta_K = 0^\circ$
- energy and momentum transfer independent:

$$Q^2 = -q_\mu q^\mu = \omega^2 - \vec{q}^{\,2}$$

- momentum transfer $\longrightarrow 0$ for "magic momentum"
- minimum momentum transfer for $\theta_\pi = 0^\circ$
- momentum distributions cannot be measured



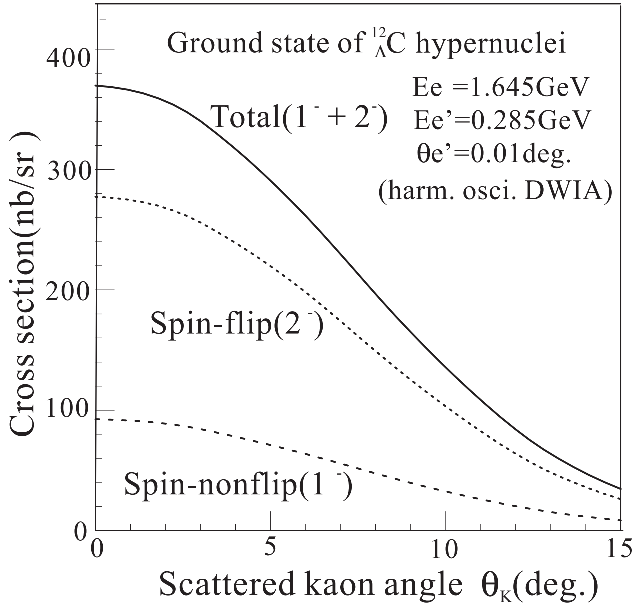
[strangeness electroproduction $(e, e'K^+)$]



[strangeness exchange (K^-, π^-)]

Extracting hypernuclear structure information

- cross sections calculated with harmonic oscillator potential and DWIA
- typical K^+ angular distributions peaked at 0°, falling rapidly:



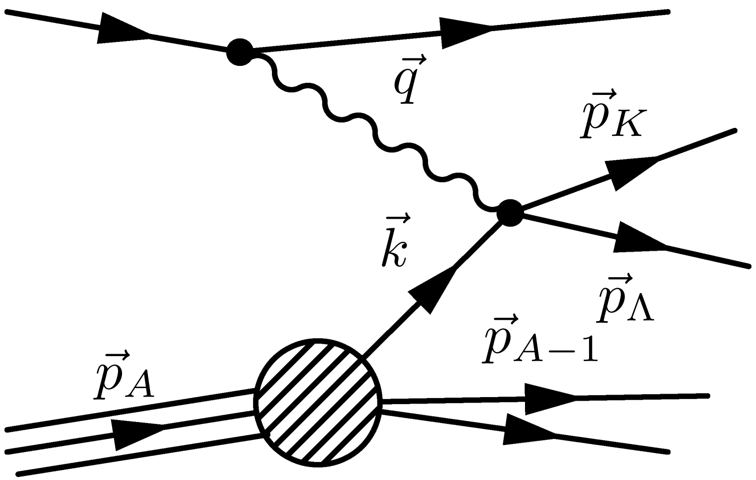
[M. Sotona and S. Furullani, Prog. Theor. Phys. Suppl. **117**, 151 (1994)]

angular distribution of kaons associated with a hypernuclear state sensitive to Λ wave function

Hypernuclear formation in impulse approximation

impulse approximation:

$$\vec{p}_{A-1} = -\vec{k}$$



3-momentum conservation at the vertices:

$$\vec{p}_Y = \vec{p}_{A-1} + \vec{p}_\Lambda$$

$$\Rightarrow q(k) \equiv \left|\vec{p}_\Lambda - \vec{p}_{A-1}\right| = \left|\vec{p}_Y + 2\vec{k}\right|$$

with $\vec{k}$ the momentum of the virtual proton,

and $\vec{p}_Y$ the recoil momentum of the hypernucleus

proton momentum distribution:

approximate Fermi Gas distribution

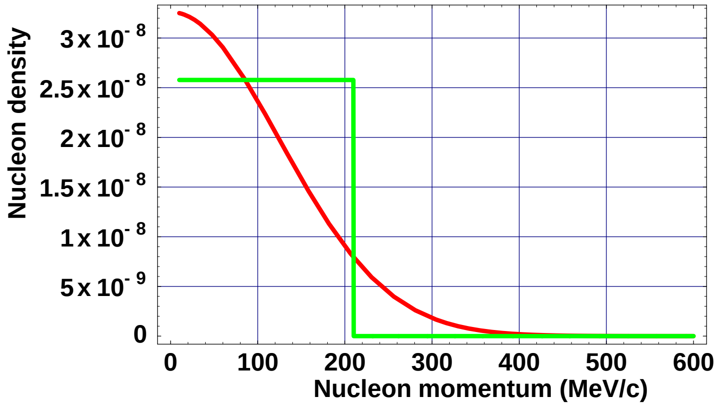
$$F = 2\pi \int_0^\infty n(k) k^2 \mathrm{d}k,$$

where the distribution function, $n(k)$, is Gaussian:

$$n(k) = \frac{1}{(2^{-4} k_F \sqrt{\pi})^3} e^{-\frac{\sqrt{2}k^2}{k_F^2}}$$

Fermi momentum $k_F(^{12}$C)= 210 MeV/c

[R.R. Whitney et al., Phys. Rev. C **9(6)**, 2230 (1974)]



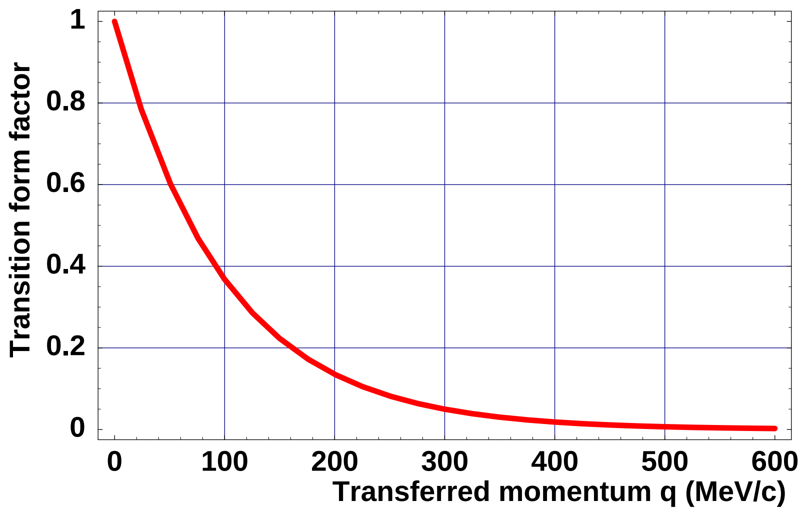
Transition form factor for N $\longrightarrow$ Λ

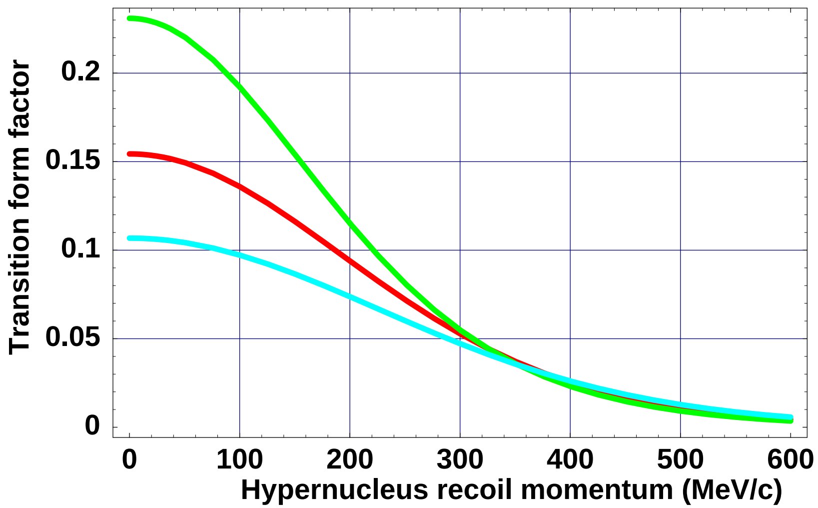
$$F_{N\Lambda} = \iint e^{-\frac{q(k)}{p_\sigma}} n(k)\, k^2 \mathrm{d}k\, \mathrm{d}\cos\theta$$

$$= \frac{1}{2p_Y\sigma_p}\Big\{ e^{\frac{k_F^2}{\sqrt{2}\sigma_p^2} - \frac{p_Y}{\sigma_p}} \Big(\left(-\sqrt{2}k_F^2 + p_Y\sigma_p\right) \mathrm{erfc}\left[-\frac{p_Y}{\sqrt{2\sqrt{2}}k_F} + \frac{k_F}{\sqrt{\sqrt{2}}\sigma_p}\right]$$

$$+ e^{\frac{2p_Y}{\sigma_p}} \left(\sqrt{2}k_F^2 + p_Y\sigma_p\right) \mathrm{erfc}\left[\frac{p_Y}{\sqrt{2\sqrt{2}}k_F} + \frac{k_F}{\sqrt{\sqrt{2}}\sigma_p}\right]\Big)\Big\}$$

^{11}B + $\Lambda \longrightarrow {}^{12}_{\Lambda}$B ; $\sigma_p = 100$ MeV/c $k_F = 150$ MeV/c, 200 MeV/c, 250 MeV/c

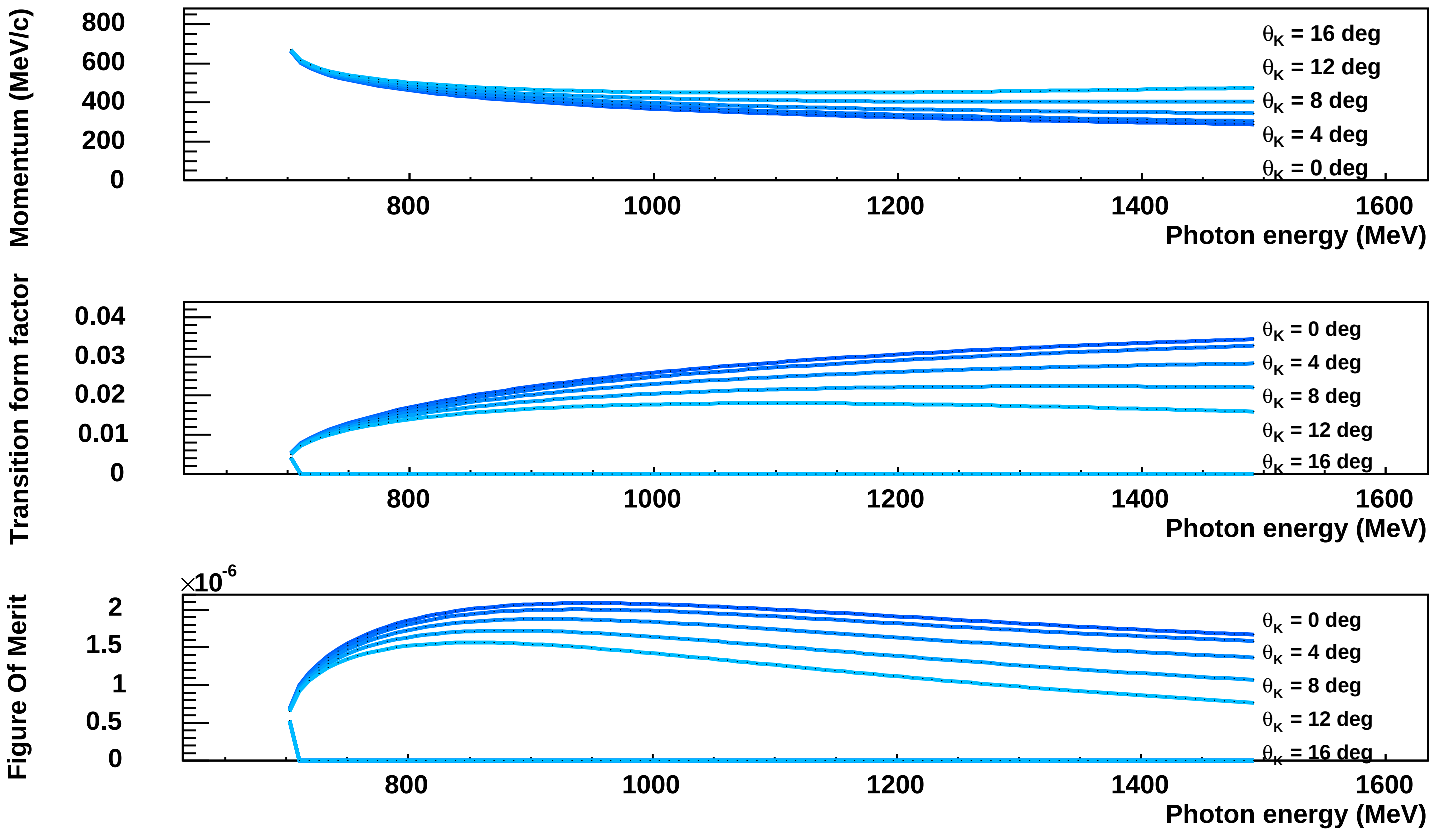




Kinematical optimisation using a *F*igure *O*f *M*erit for formation rate

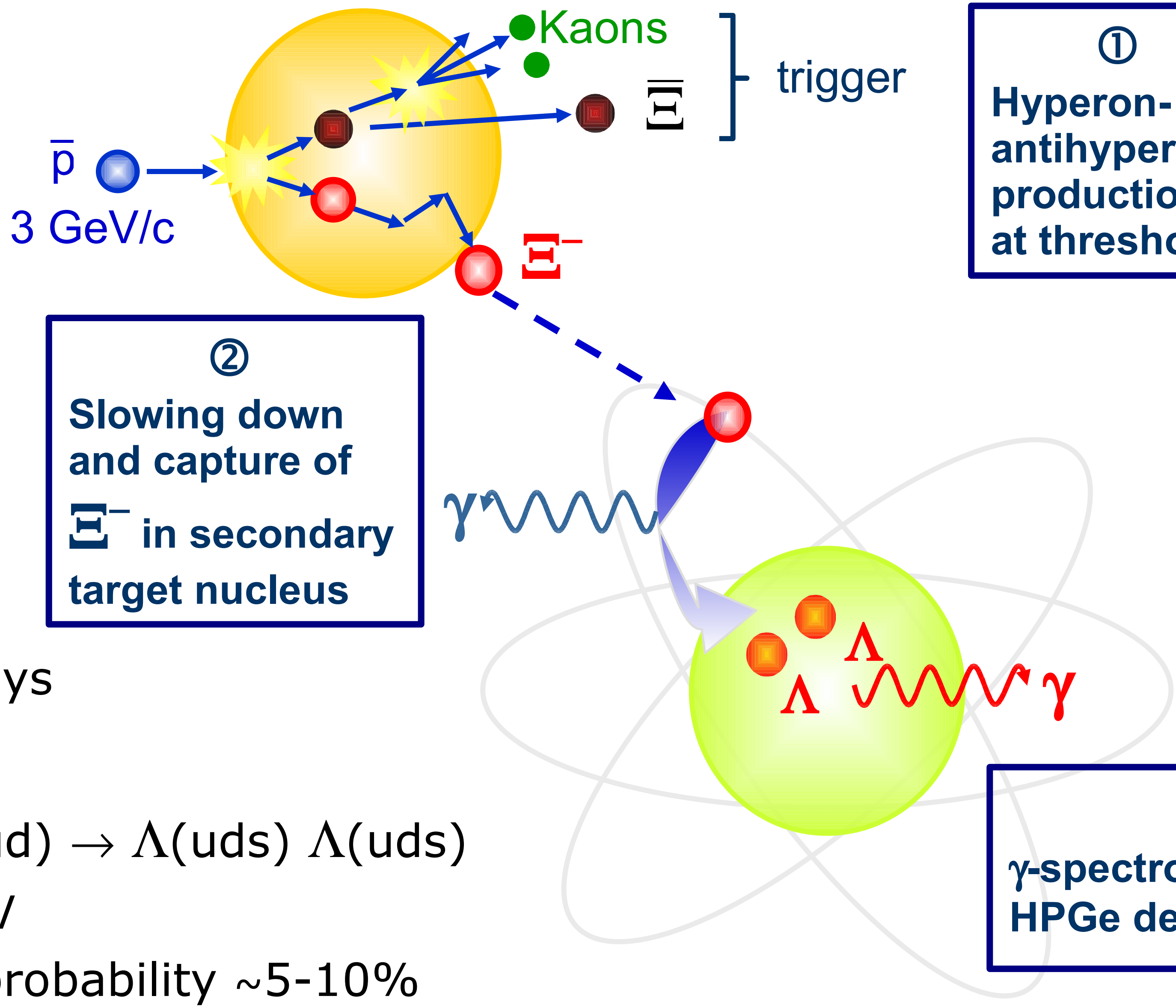
$$\text{FOM} = S_\Lambda \times \Gamma \quad \text{with} \quad \Gamma = \frac{\alpha}{2\pi^2}\frac{E'}{E}\frac{k_\gamma}{Q^2}\frac{1}{1-\epsilon}$$

[$Q^2 = 0.01\,\text{GeV}^2/c^2$, $W = 11.995\,\text{GeV}$, $E = 1.50\,\text{GeV}$, $E' = 0.650\,\text{GeV}$, $\theta_e = 5.8°$, $p_K = 0.446\,\text{GeV}/c$, $p_Y = 0.423\,\text{GeV}/c$, and $\theta_K = 5.5°$]



Production of multistrange systems at $\overline{\text{P}}$anda

Double Λ hypernucleus production



① **Hyperon-antihyperon production at threshold**

② **Slowing down and capture of Ξ^- in secondary target nucleus**

③ **γ-spectroscopy with HPGe detectors**

- Ξ^- atoms: x-rays
- conversion:

  Ξ^-(dss) p(uud) → Λ(uds) Λ(uds)

  ΔQ = 28 MeV

  conversion probability ~5-10%

[Y. Hirate et al., Nucl. Phys. **A639**, 389c (1998),
Y. Hirate et al., Prog. Theor. Phys. **102**, 89 (1999)]

Expected count rates

$$\sigma_{\bar{p}p}(\Xi\bar{\Xi}) = 2 \quad \mu b \quad @ \quad 3 \quad \mathrm{GeV}/c$$

$$\sigma_{\bar{p}A}(\Xi\bar{\Xi}) = A^{2/3} \cdot \sigma_{\bar{p}p}(\Xi\bar{\Xi})$$

by using, e.g., a ^{12}C wire target:

@ $\mathcal{L} = 10^{32}$ cm^{-2} s^{-1} HESR will produce $\Xi^-\bar{\Xi}$ pairs @ ~ 7×10^2 Hz

- joint $\Xi^-\bar{\Xi}$ escape probability: 5×10^{-4}
  (trigger on $\bar{\Xi}$ + p_{Ξ^-} = 100 – 500 MeV/c)
- $\bar{\Xi}$ reconstruction efficiency: ~ 50%
- Ξ^- stopping and capture probability: ~ 20%

~ 3×10^3 captured Ξ^- /d

- $\Xi^- p \rightarrow \Lambda\Lambda$ conversion probability: 5%

~ 150 $\Lambda\Lambda$-hypernuclei /d

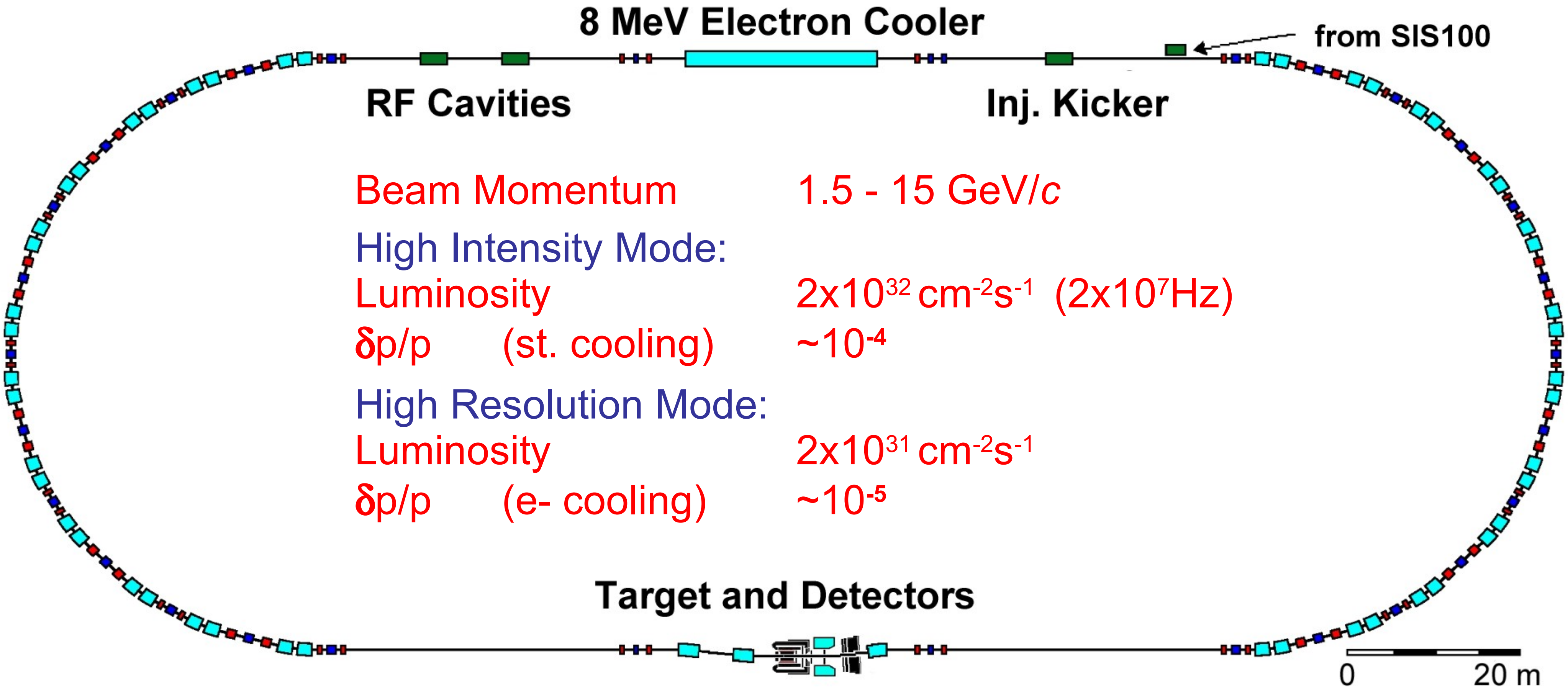
- γ-ray emission/event: 50%
- γ-ray Ge photopeak efficiency: 10%

~ 7 "golden events" /d

- K^+K^+ trigger

~ 700 events /d

HESR: High Energy Storage Ring



Beam Momentum 1.5 - 15 GeV/*c*

High Intensity Mode:

Luminosity 2×10^{32} cm^{-2}s^{-1} (2×10^{7}Hz)

$\delta p/p$ (st. cooling) $\sim 10^{-4}$

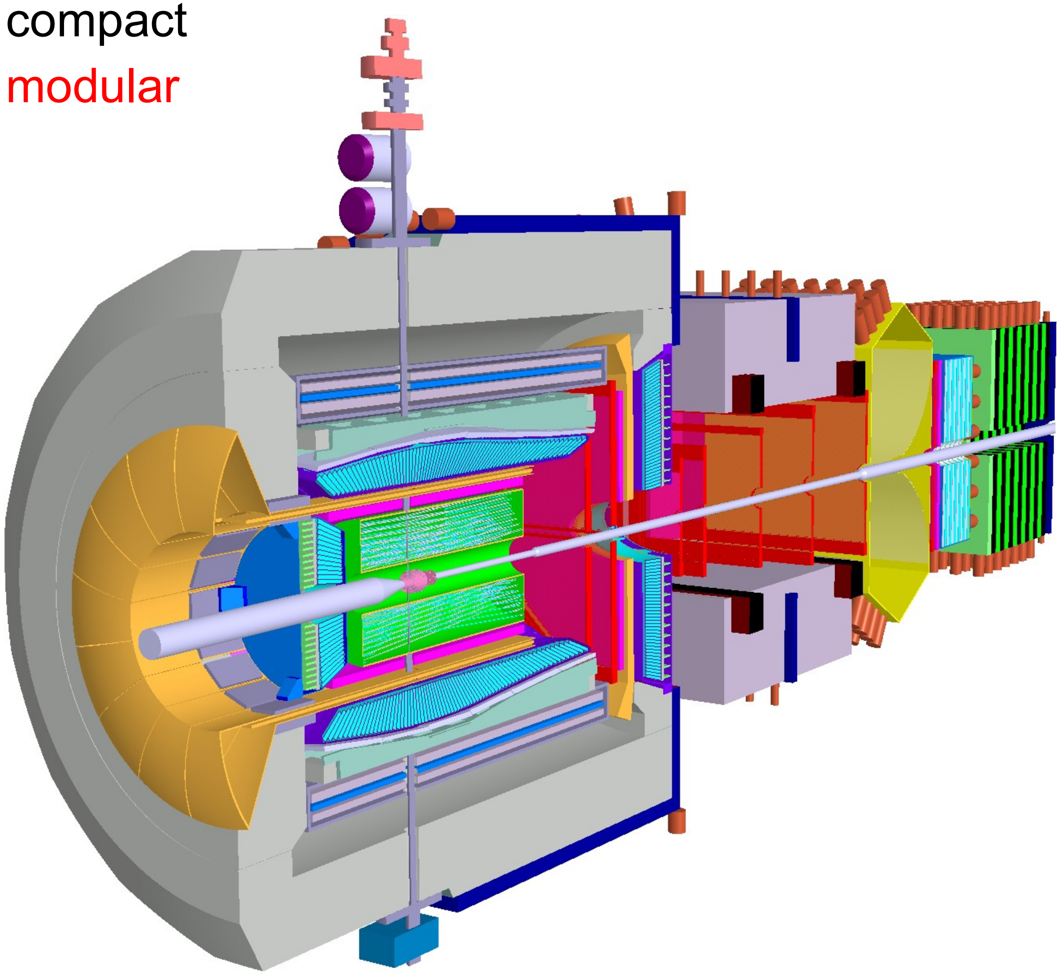
High Resolution Mode:

Luminosity 2×10^{31} cm^{-2}s^{-1}

$\delta p/p$ (e- cooling) $\sim 10^{-5}$

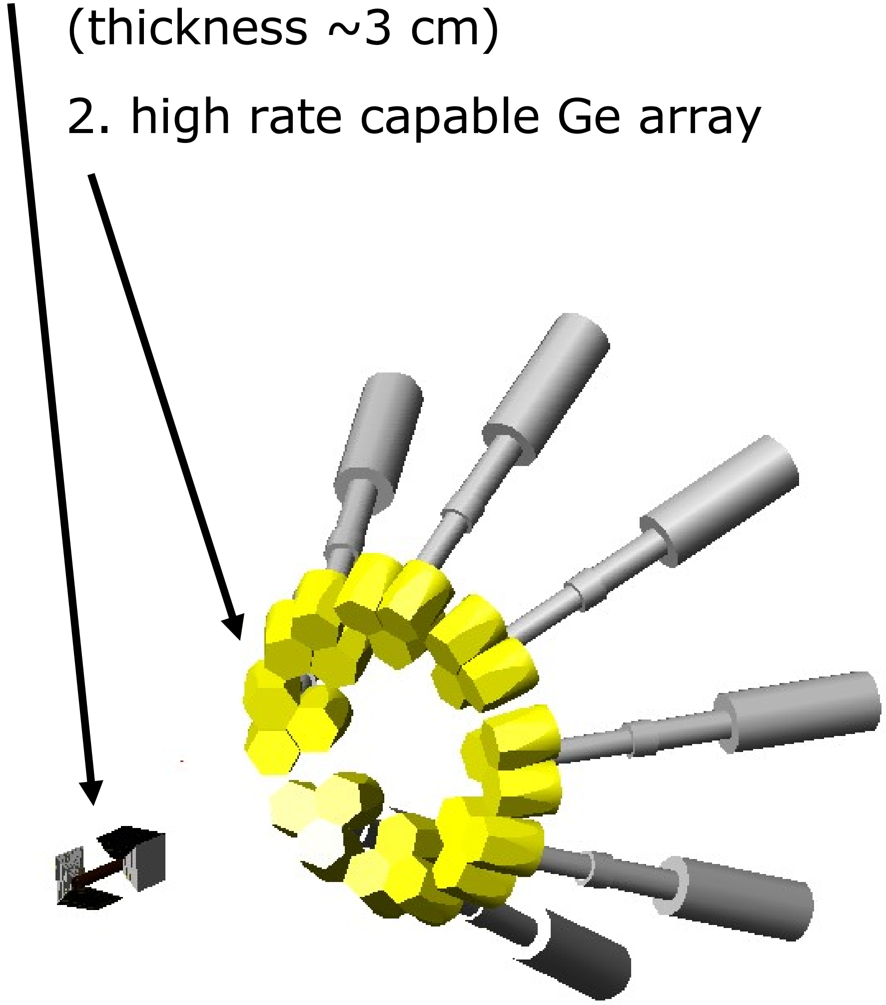
The Panda detector

- hermetic (4π)
- high rate
- PID (γ, e, μ, π, K, p)
- trigger (e, μ, K, D, Λ)
- compact
- modular



Hypernuclei detection

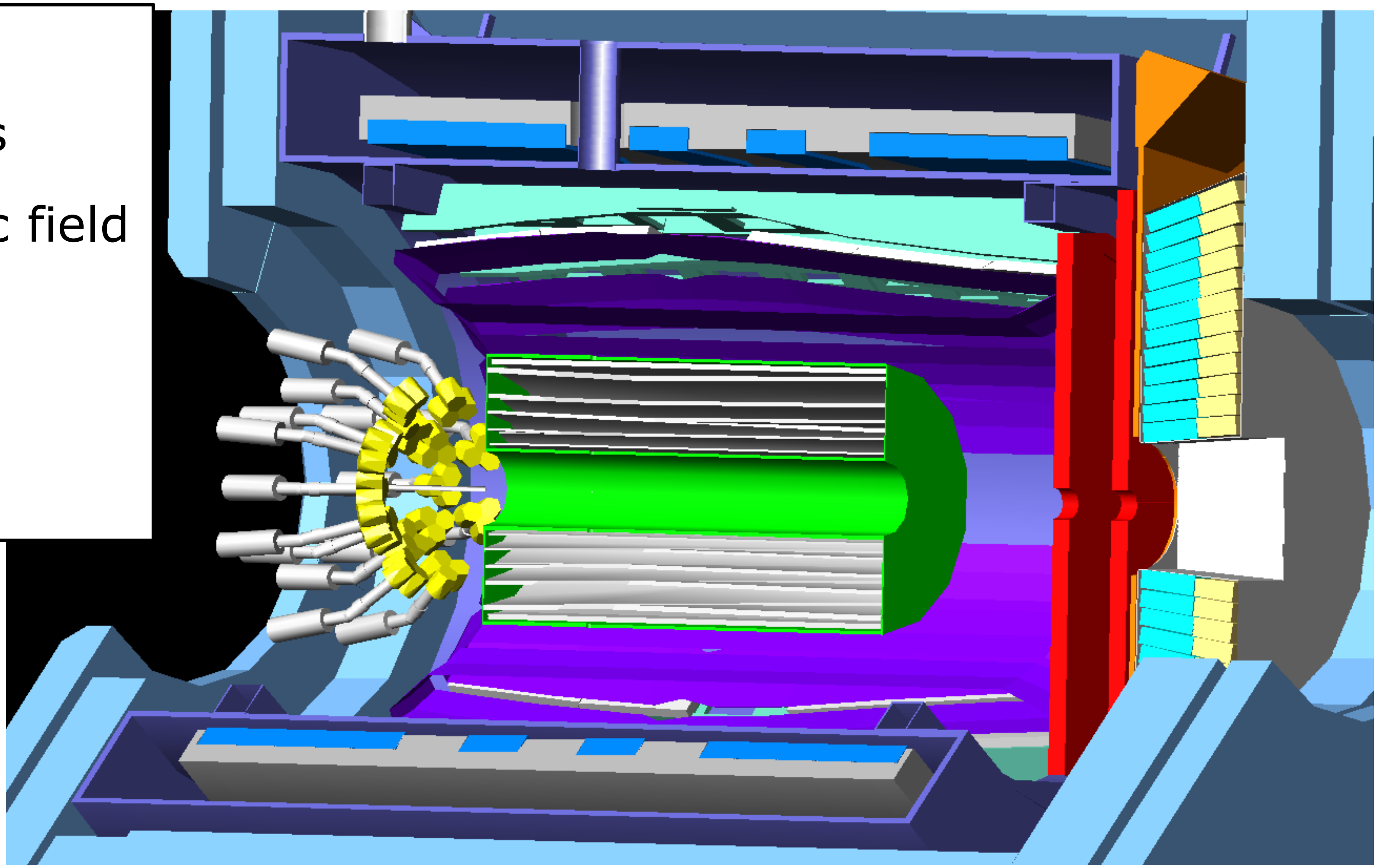
1. solid state micro-tracker
   (thickness ~3 cm)
2. high rate capable Ge array



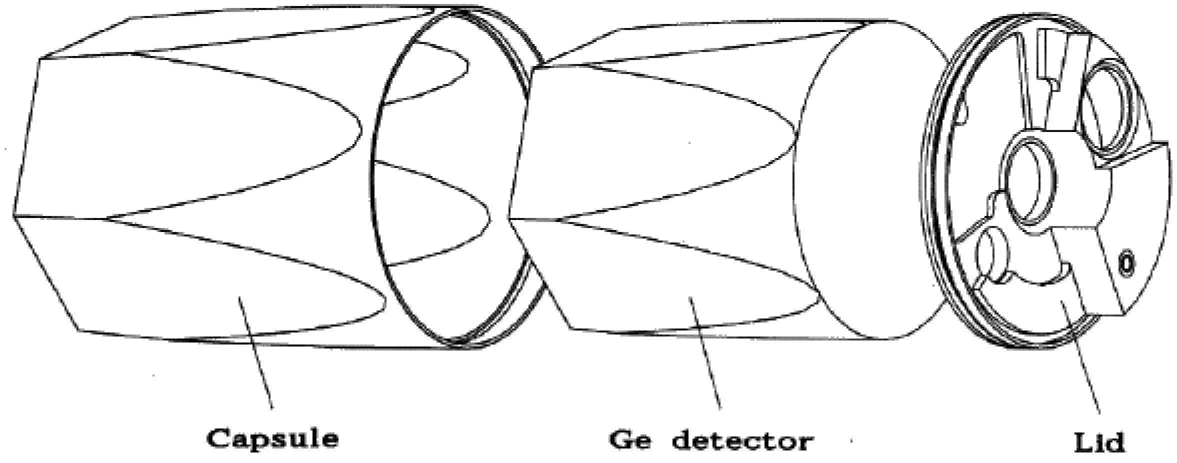
HPGe array implementation into the Panda detector

<u>Problems</u>

- large volume detectors
- high ambient magnetic field
- limited access
- long operation time
- spatial constraints



Ge detectors under extreme conditions

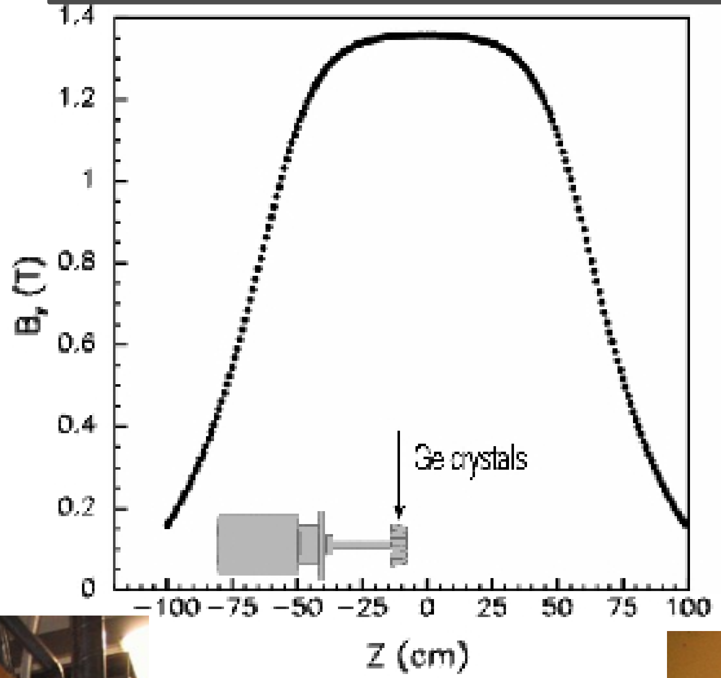


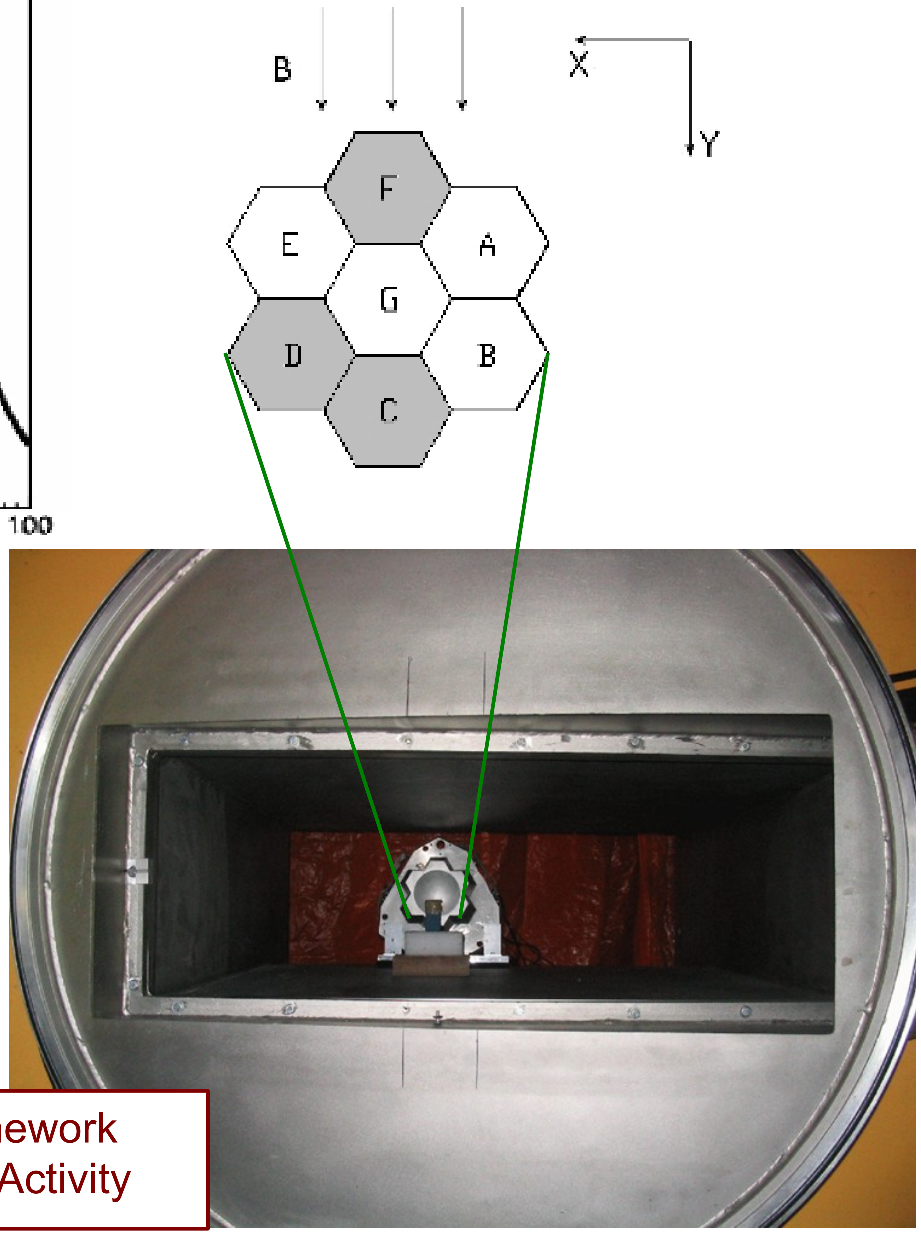
Solution of ℓN_2 free autonomous cooling:
electromechanical cooling (ORTEC X-cooler II)
based on Klemenko cycle (mixed gas refrigerants)

Experiments at GSI in 2004-5

experimental set-up:

- ALADiN dipole magnet
- Co source of 370 kBq
- VEGA clover and Euroball cluster

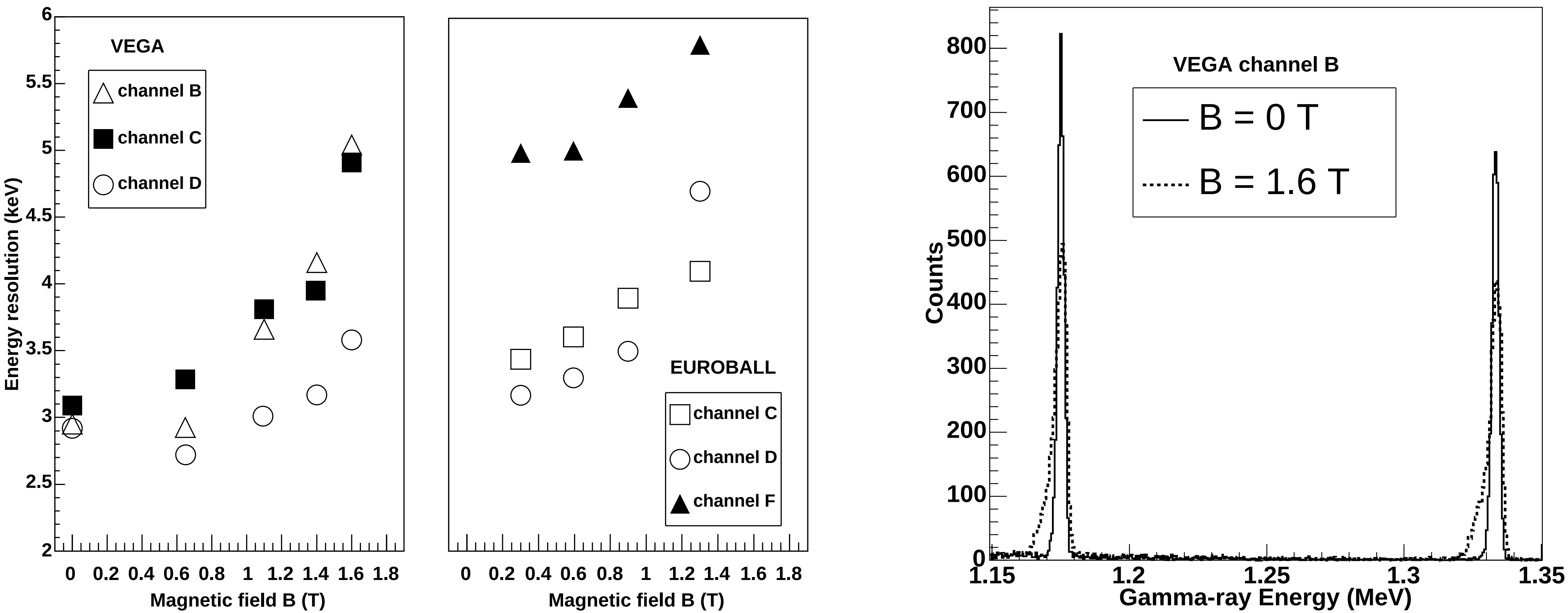




supported by a 6th European Framework HadronPhysics I3 Joint Research Activity

Performance of HPGe detectors in high magnetic fields

VEGA and Euroball cluster HPGe detectors were tested in the field provided by the ALADiN magnet at GSI



- no problems in the electronics due to the magnetic field were observed.
- a small degradation of the energy resolution by $1 - 2$ keV was found.

Summary on open strangeness production at $\overline{\text{P}}$anda and at MAMI-C

- experiments with KaoS at MAMI-C
  - (separation of longitudinal and transverse cross sections in $^{1}\text{H}(e, e'K^{+})\Lambda$)
  - Λ hypernuclei: by measuring the kaon angular distribution mapping the bound Λ wave function

  $\Rightarrow$ installation of the KaoS spectrometer in progress

- multistrange systems at $\overline{\text{P}}$anda: $\bar{\text{p}}\text{p} \longrightarrow \Xi^{-}\overline{\Xi}^{+}, \quad \bar{\text{p}}\text{n} \longrightarrow \Xi^{-}\overline{\Xi}^{0}$
  - $\Lambda\Lambda$ hypernuclei production
  - (Ω atom production)

  $\Rightarrow$ incorporation of HPGe detectors into $\overline{\text{P}}$anda in progress