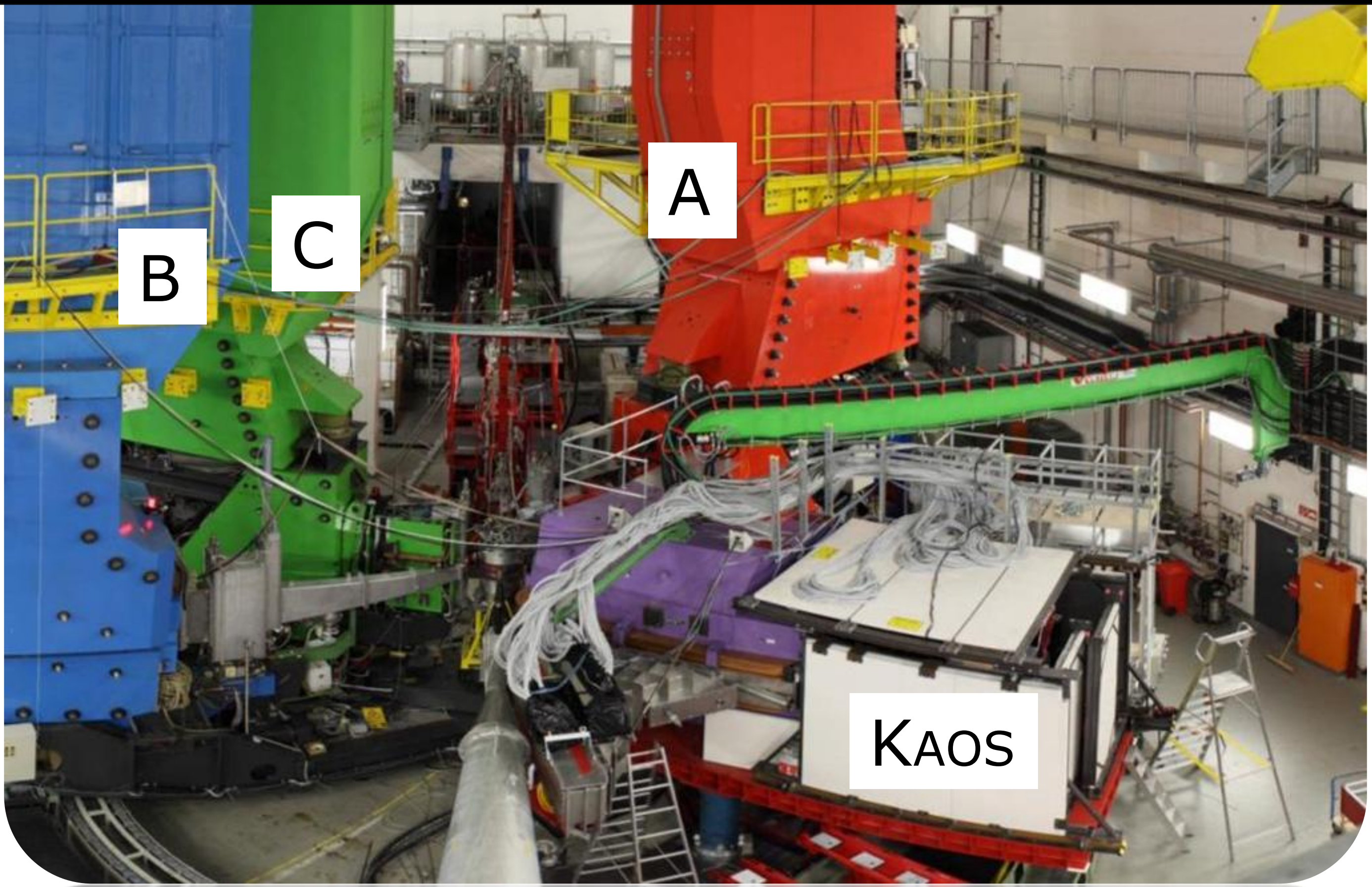
Overview of Measurements on Strange and Nuclear Systems at MAMI



Patrick Achenbach

for the Collaboration A1 at MAMI

2010

Strangeness physics and developments in Mainz

What is the topic of this talk?

- open strangeness electro-production at MAMI

What progress was made in the data analysis since 2oo9?

- final (much improved) version of the tracking code
- near-final study of efficiencies and acceptances
- ongoing study of kaon identification

What hardware was improved since 2oo9?

- near-final completion of the fibre detector
- successful beam-test of the spectrometer's electron-arm
- final (much improved) design of the pre-target beam chicane

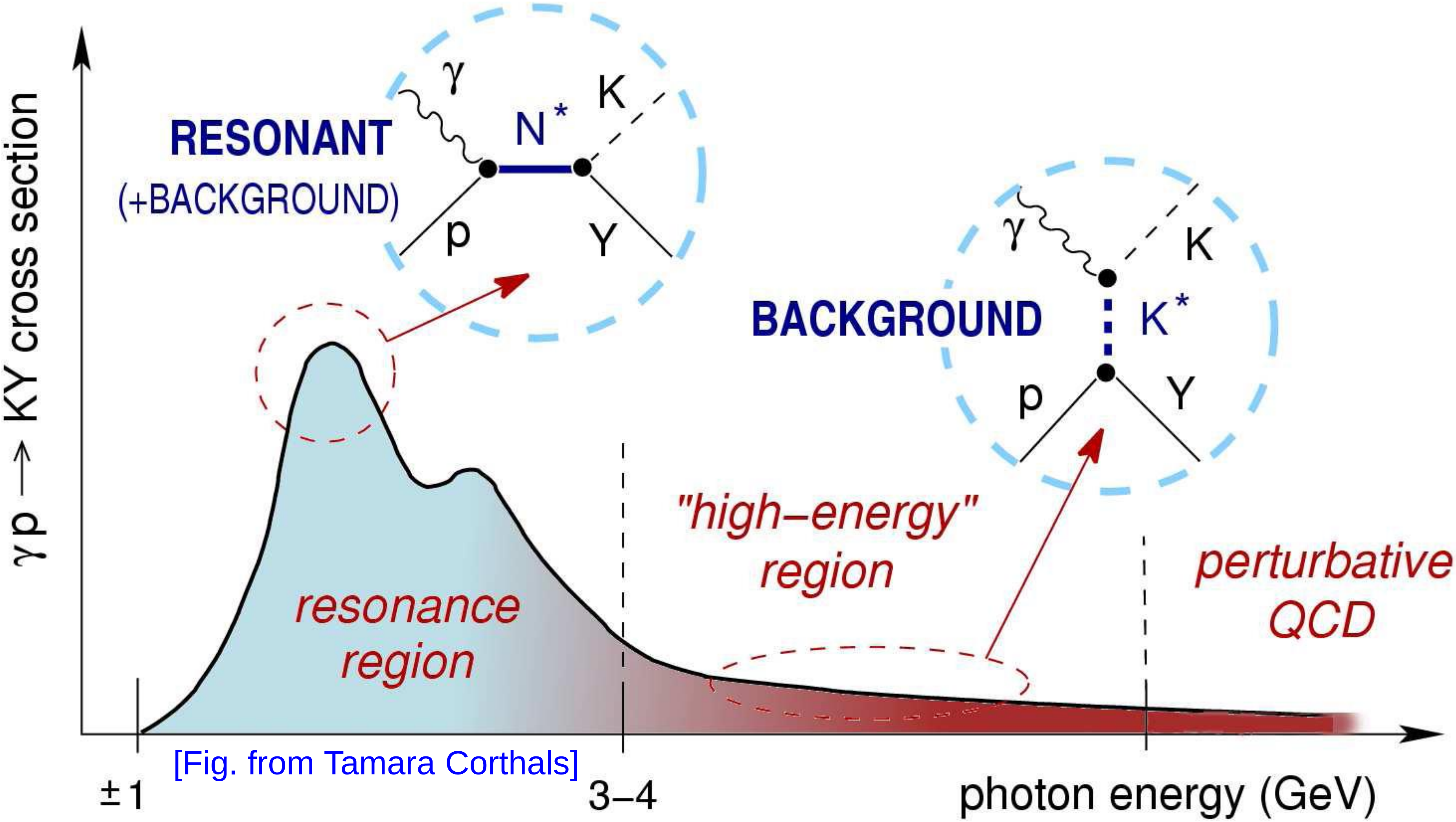
What else was done?

- two background studies on coherent φ-meson electro-production on nuclear targets in the two-kaon decay channel and the dilepton decay channel
- a feasibility study on hypernuclear decay pion spectroscopy in a single-arm measurement

Kaon electro-production

A glimpse at the theory

task: finding right degrees-of-freedom, interactions and structures



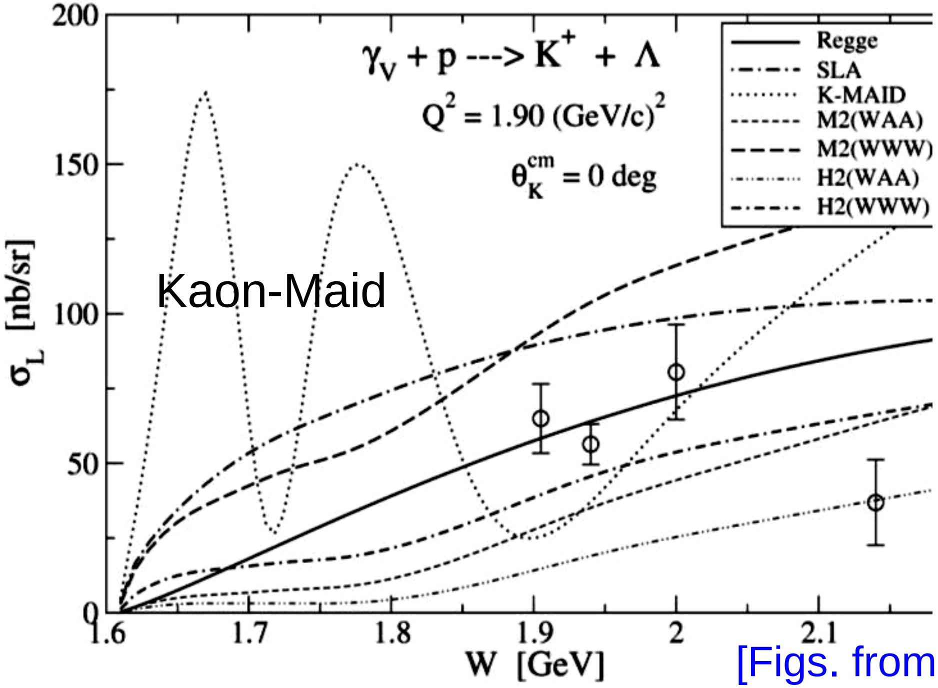
[Fig. from Tamara Corthals]

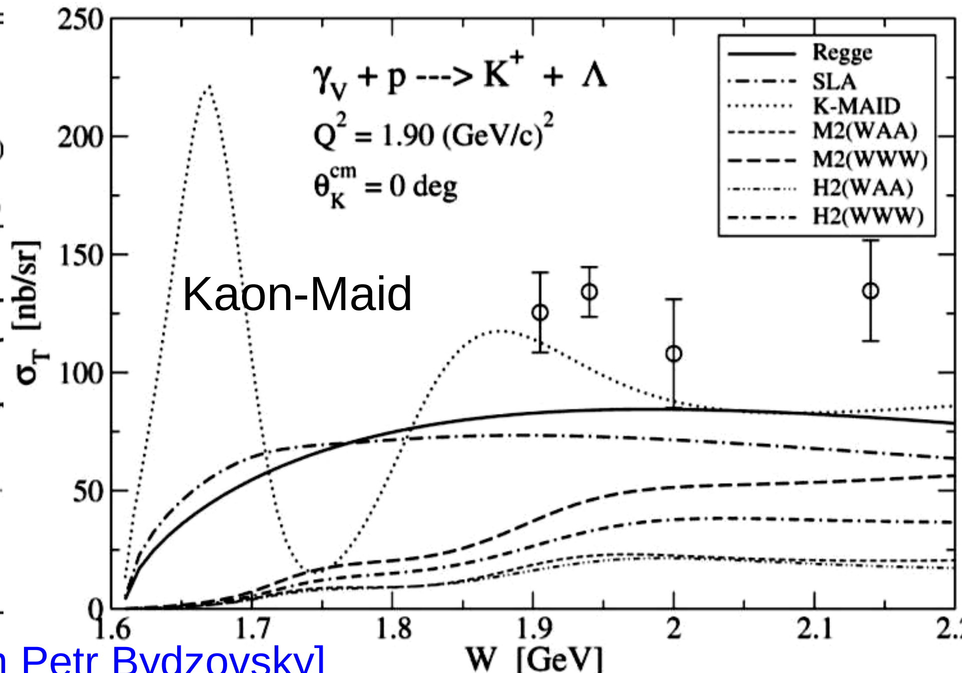
Isobar models for strange processes

- *Saclay-Lyon A*: no hadronic f. f., SU(3), crossing symmetry, nucleon (spin 1/2 and 3/2) and hyperon resonances [T. Mart, C. Bennhold, *Phys. Rev.* C 61 (2000) 012201(R)]

- *Kaon-MAID*: hadronic f. f., SU(3), no hyperon, only nucleon (spin 1/2 and 3/2) resonances [T. Mizutani *et al*., *Phys. Rev. C* 58 (1998) 75]

all models: extended Born terms (p, Λ, Σ, K), K(890), K_1(1270)*

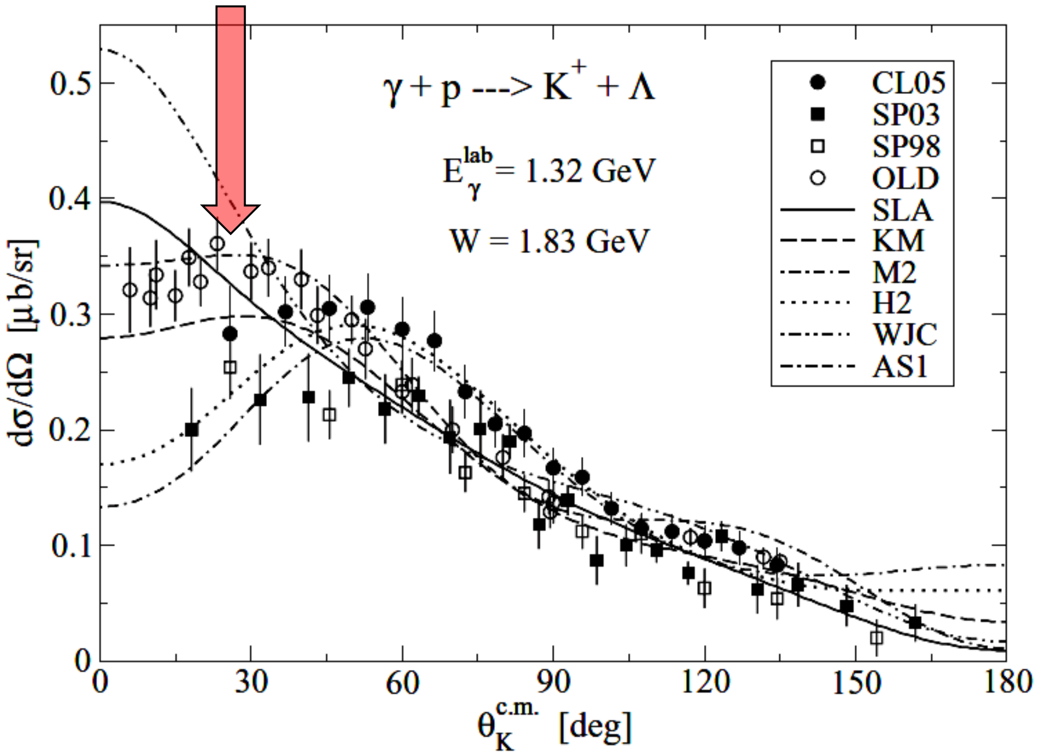




[Figs. from Petr Bydzovsky]

Kaon production at forward angles

Kaos data from 2o09 and 2o1o

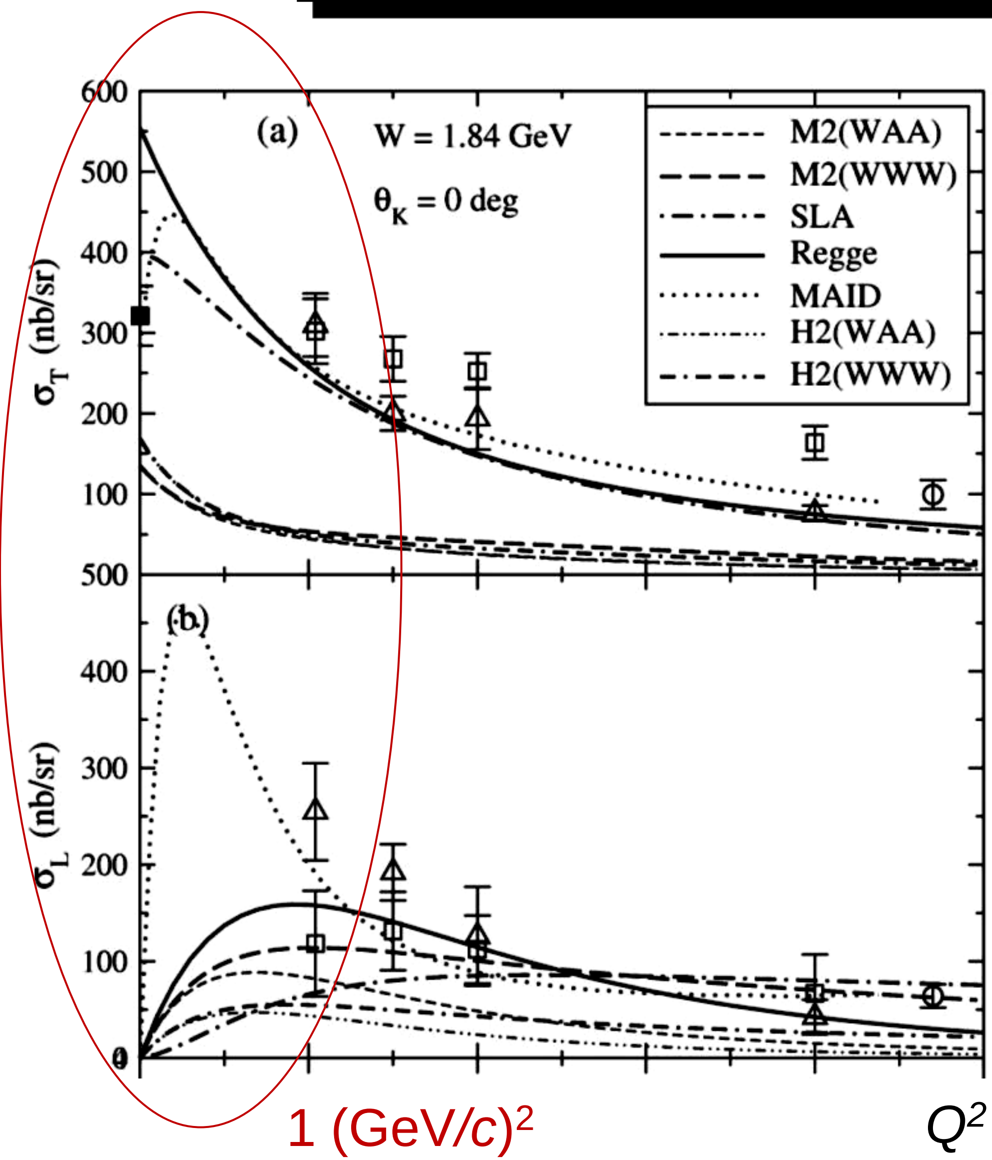


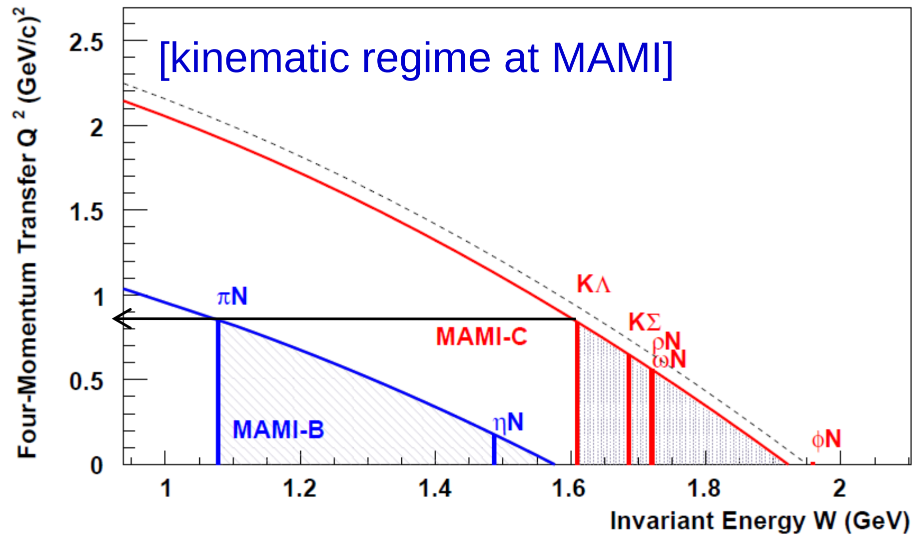
Name	Observable	Symbol
SAPHIR 2004	Differential cross section	$d\sigma/d\Omega$
	Recoil polarization	P
	Total cross section	σ_{tot}
CLAS 2006	Differential cross section	$d\sigma/d\Omega$
	Recoil polarization	P
	Total cross section	σ_{tot}
LEPS 2006	Differential cross section	$d\sigma/d\Omega$
	Photon asymmetry	Σ
OLD	Target asymmetry	T
	Total cross section	σ_{tot}
Total data		

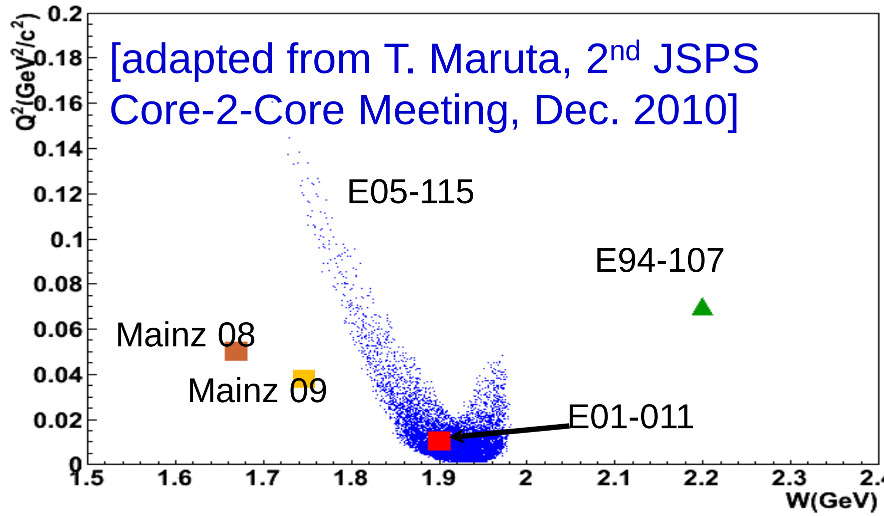
From: [T. Mart and A. Sulaksono, *Phys. Rev. C 74*, 055203 (2006).]

Data points: [K. H. Glander *et al.*, *Eur. Phys. J. A 19*, 251 (2004).
R. Bradford *et al.* *(CLAS Collaboration)*, *Phys. Rev. C 73*, 035202 (2006).
M. Sumihama *et al.* *(LEPS Collaboration)*, *Phys. Rev. C 73*, 035214 (2006).
K. H. Althoff *et al.*, *Nucl. Phys. B 137*, 269 (1978).
M. Q. Tran *et al.* *(SAPHIR Collaboration)*, *Phys. Lett. B 445*, 20 (1998).]

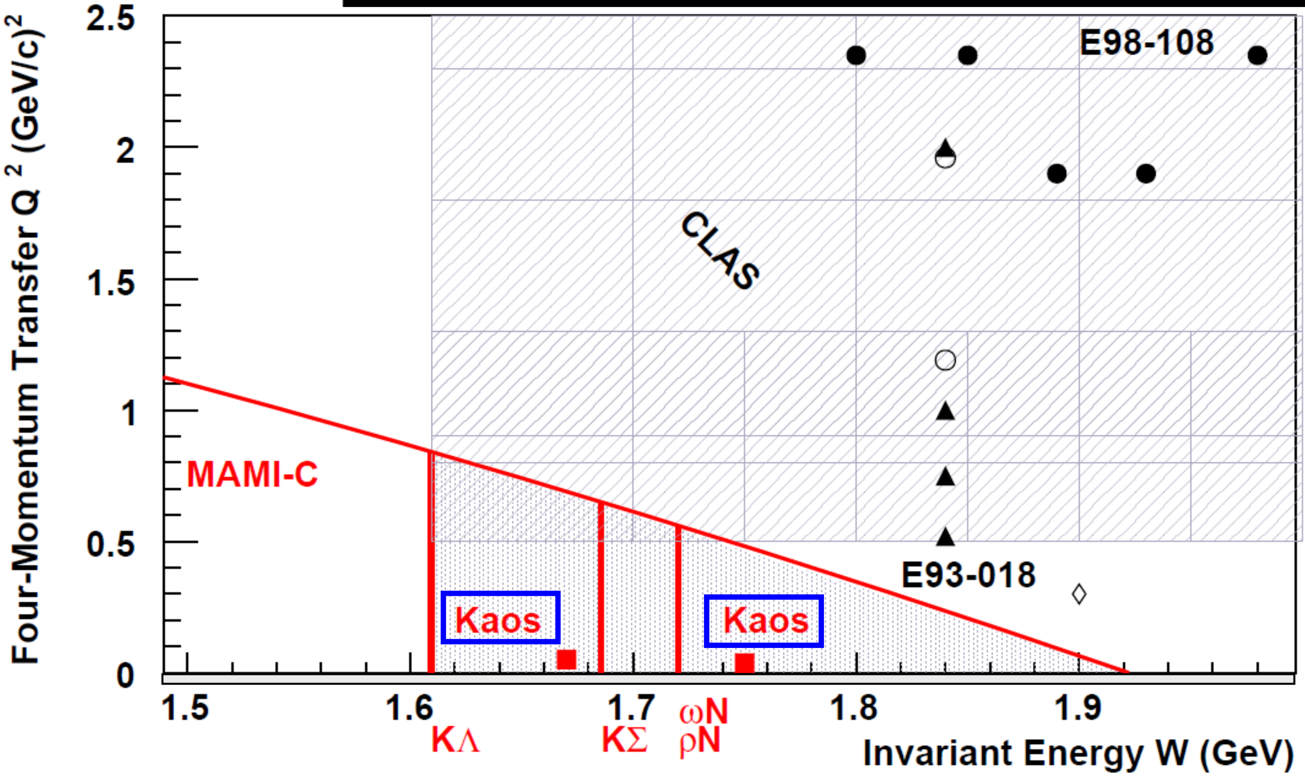
The importance of low momentum transfer







Kaon electro-production measurements



[E93-018: R. M. Mohring *et al.*, *Phys. Rev. C 67*, 055205 (2003); reanalysis in G. Niculescu *et al.*, *Phys. Rev. Lett. 81*, 1805 (1998).

E98-108: M. Coman, PhD thesis, Florida International University, 2005 (unpublished).

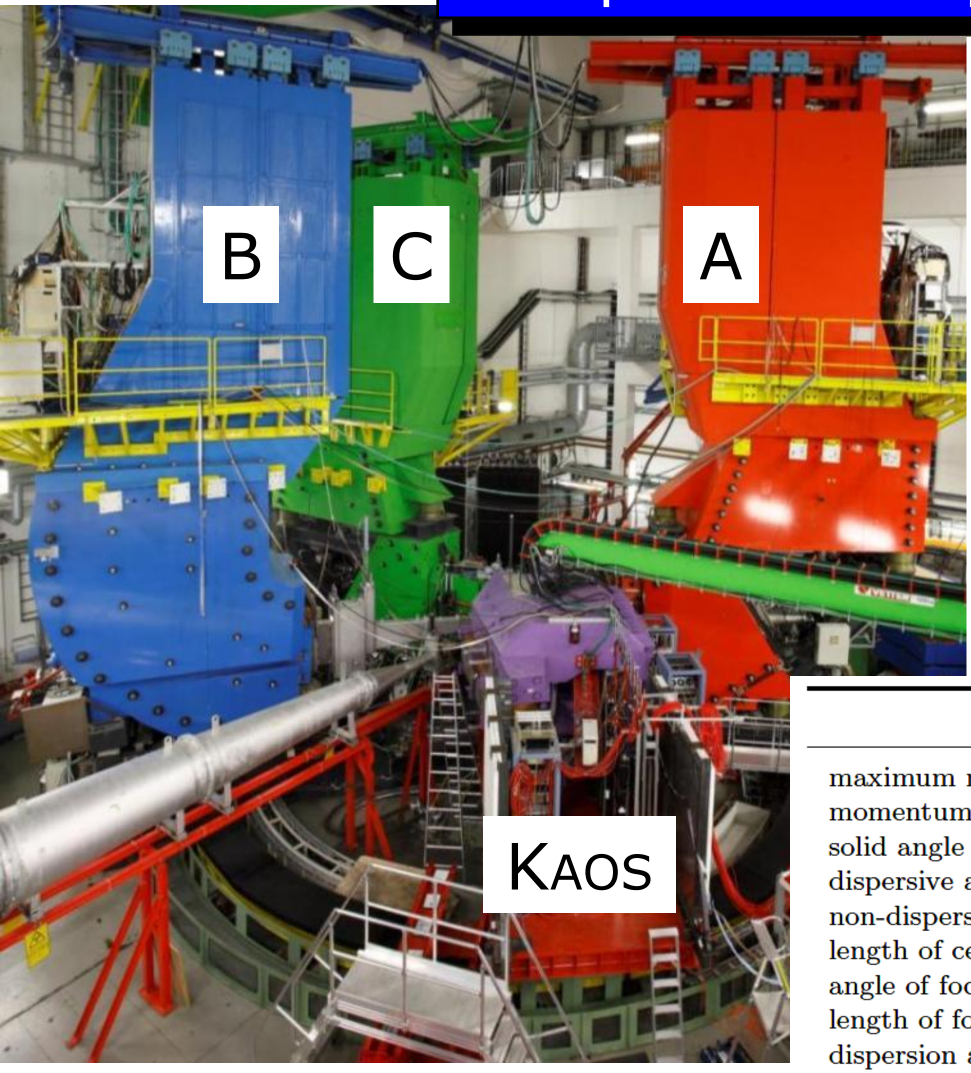
CLAS: Ambrozewicz *et al.*, *Phys. Rev. C 75*, 045203 (2007).]

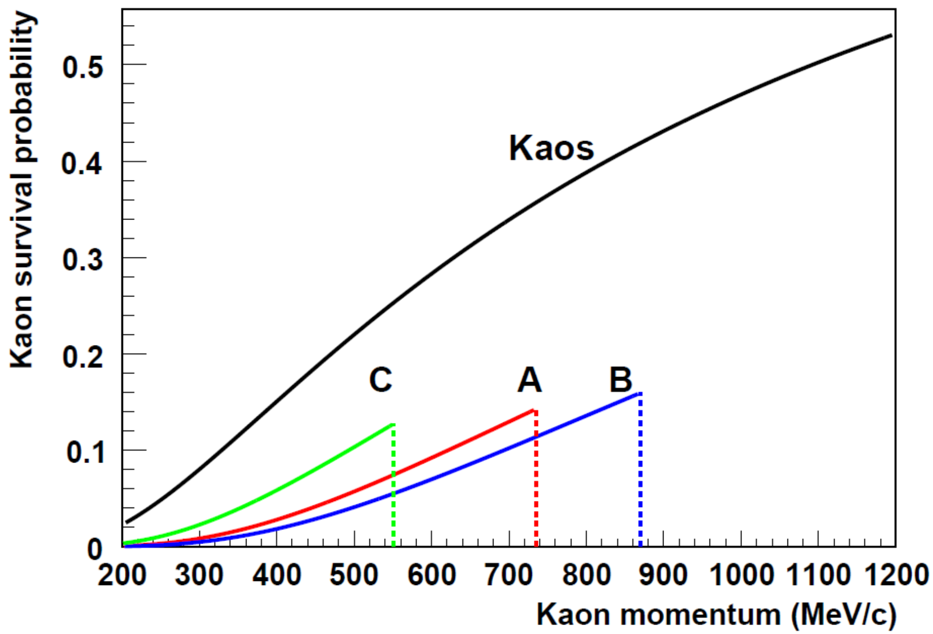
←*photo-production*

virt. photon				beam	electron arm		kaon arm	
$\langle Q^2\rangle$ $(\mathrm{GeV}/c)^2$	$\langle W\rangle$ GeV	$\langle\epsilon\rangle$ (trans.)	$\langle\omega\rangle$ GeV	E_e GeV	$\langle q_{e'}^{lab}\rangle$ GeV/c	$\langle\theta_{e'}^{lab}\rangle$ deg	$\langle p_K^{lab}\rangle$ GeV/c	$\langle\theta_K^{lab}\rangle$ deg
0.050	1.670	0.540	1.044	1.508	0.455	15.8	Λ : 0.466	-31.5
0.036	1.750	0.395	1.182	1.508	0.318	15.5	Λ : 0.642	-31.5
							Σ : 0.466	

Experimental aspects

Adaption of the spectrometer facility

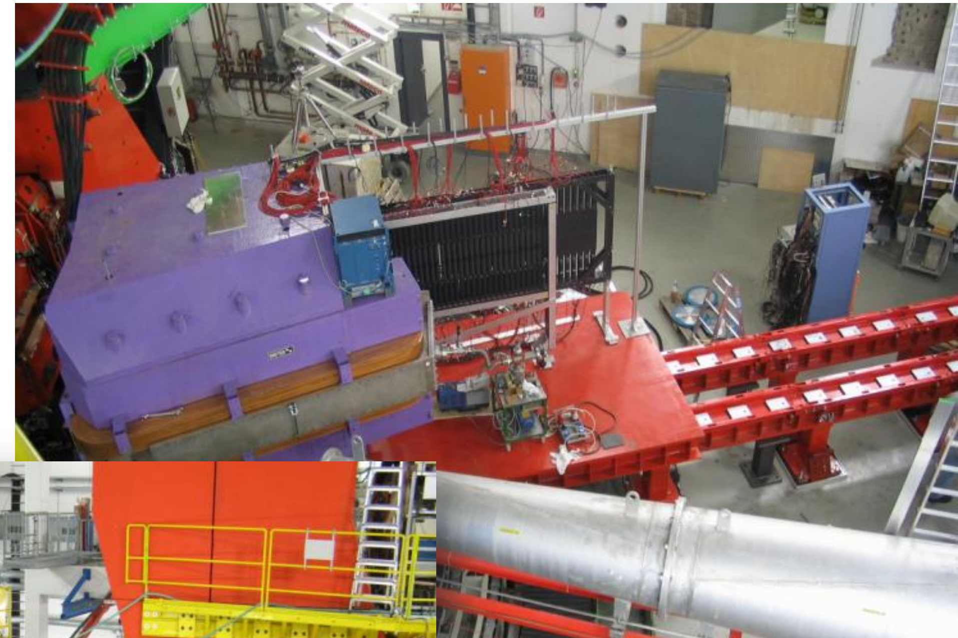


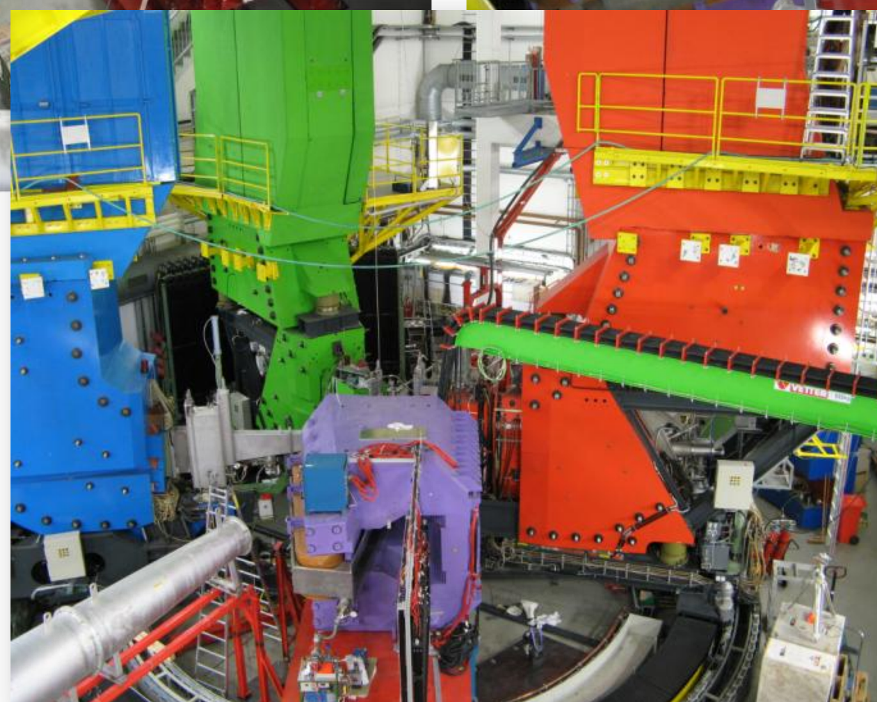


	spectrometer B	KAOS hadron arm
maximum momentum	$\boxed{870\,\mathrm{MeV}}$	$\boxed{2\,100\,\mathrm{MeV}}$
momentum acceptance	15 %	50 %
solid angle acceptance	5.6 msr	10.4 msr
dispersive angle acceptance	$\pm 70\,\mathrm{mrad} \simeq \pm 4°$	$\pm 185\,\mathrm{mrad} \simeq \pm 10.5°$
non-dispersive angle acceptance	$\pm 20\,\mathrm{mrad} \simeq \pm 1.15°$	$\pm 14\,\mathrm{mrad} \simeq \pm 0.8°$
length of central trajectory	$\boxed{12.03\,\mathrm{m}}$	$\boxed{5.3\,\mathrm{m}}$
angle of focal plane	47°	$\sim 45°$
length of focal plane	1.8 m	$\sim 1.2\,\mathrm{m}$
dispersion at central trajectory	8.22 cm/%	2.4 cm/%
magnification at central trajectory	0.85	2.0
dispersion to magnification	9.64 cm/%	1.2 cm/%
1st order resolving power	19 000	2 400
1st order momentum resolution	$\boxed{< 10^{-4}}$	$\boxed{\sim 10^{-3}}$

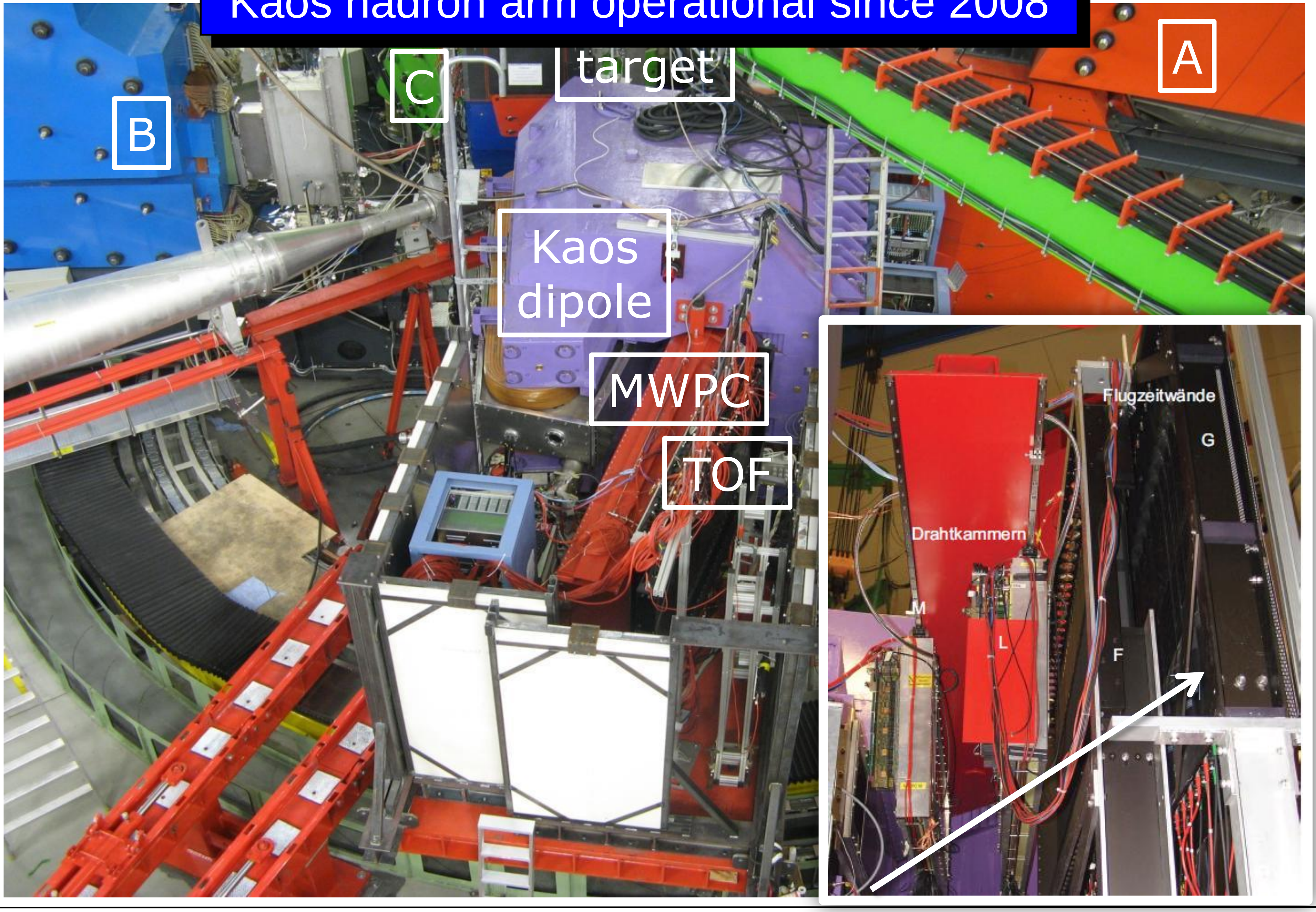
max momentum and path length limit
kaon survival probability < 15% in A/B/C

Installation of KAOS in 2007

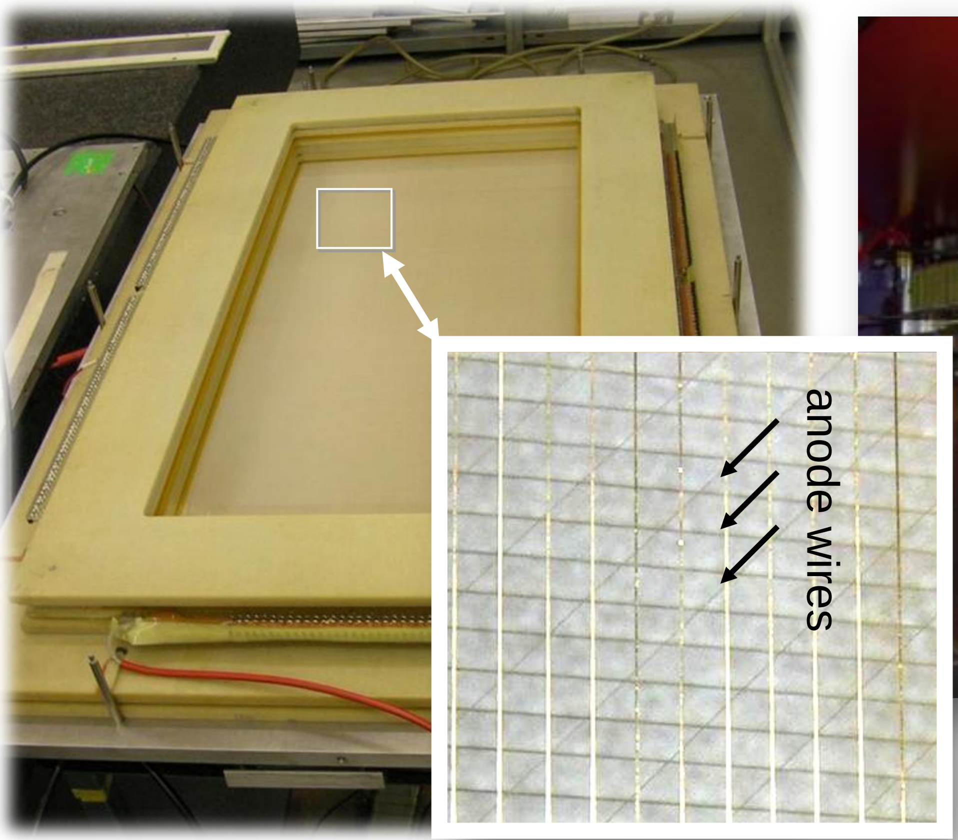




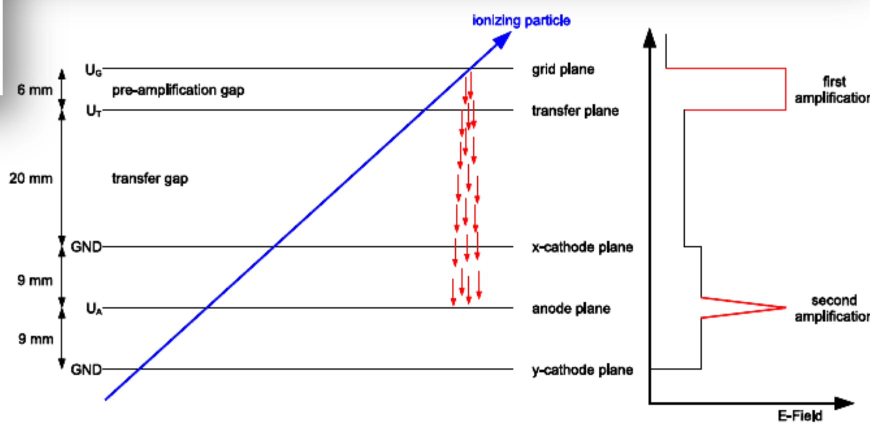
Kaos hadron arm operational since 2008



Tracking with two cathode-charge read-out MWPCs



- implementation of MWPC, new frontend read-out and cluster analysis in early 2oo8
- trigger, DAQ, and cluster analysis now consolidated



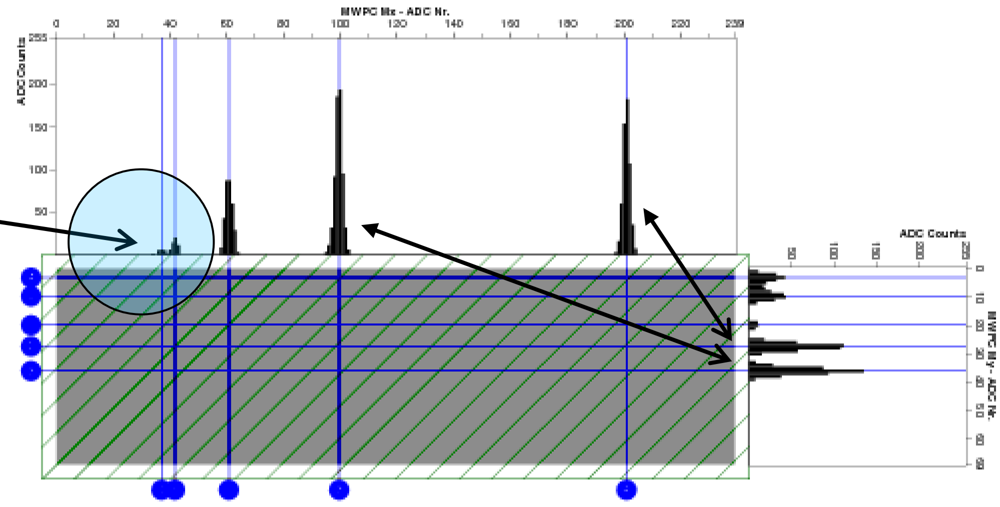
Cluster analysis

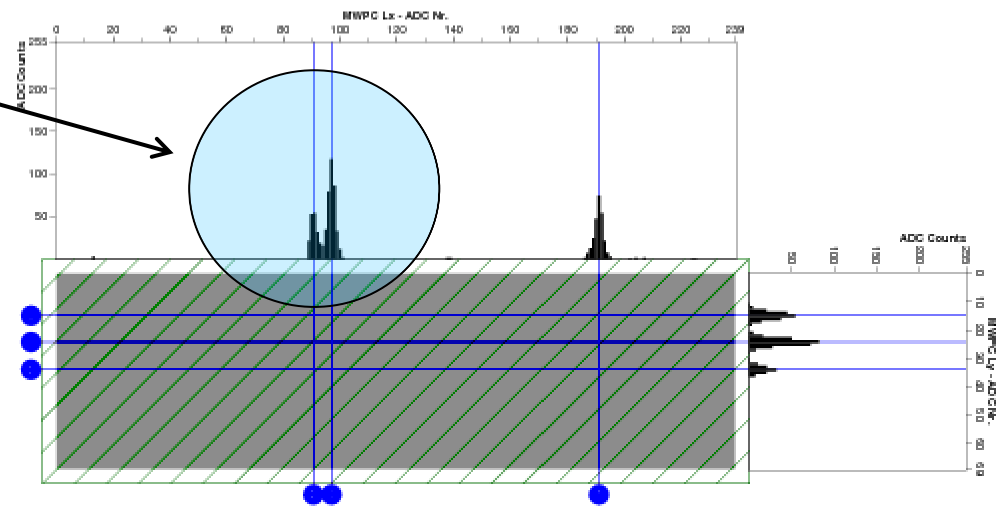
Challenges:

- charge centroids often do not correspond to the trajectory position

- correlation ←→ between induced charges

- other continuous clusters often divide into individual peaks



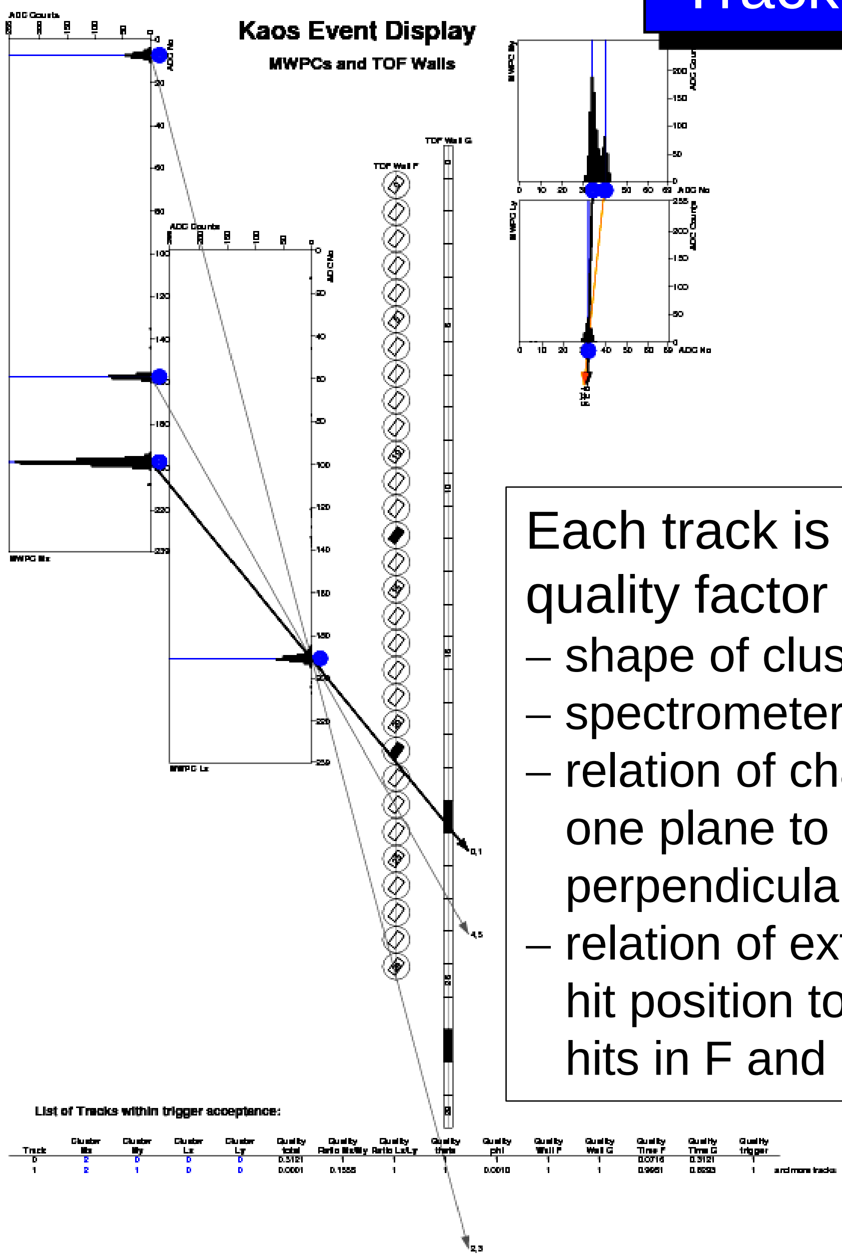


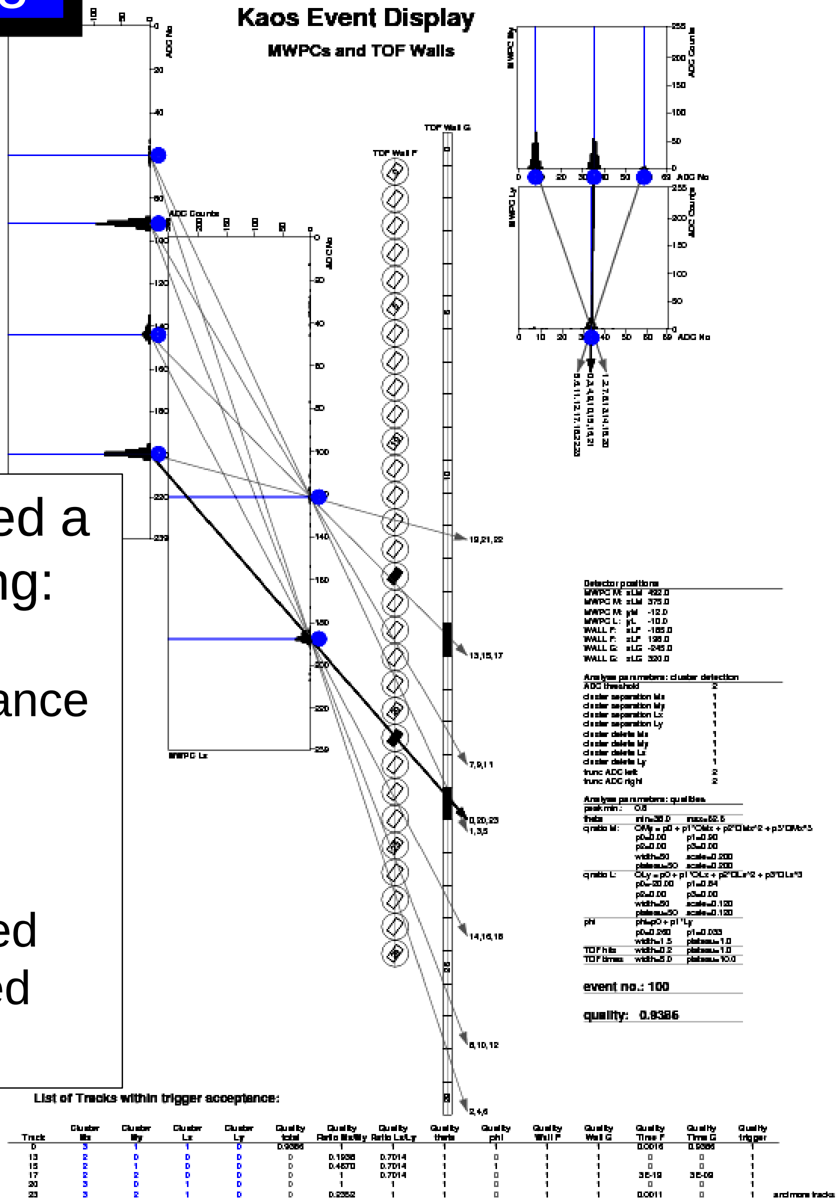
Task:
resolving multi-hit ambiguities important for beam currents above 1 μA

data taken with 2 μA beam current

[P. Achenbach et al., Particle tracking with cathode-charge sampling in multi-wire proportional chambers, in preparation]

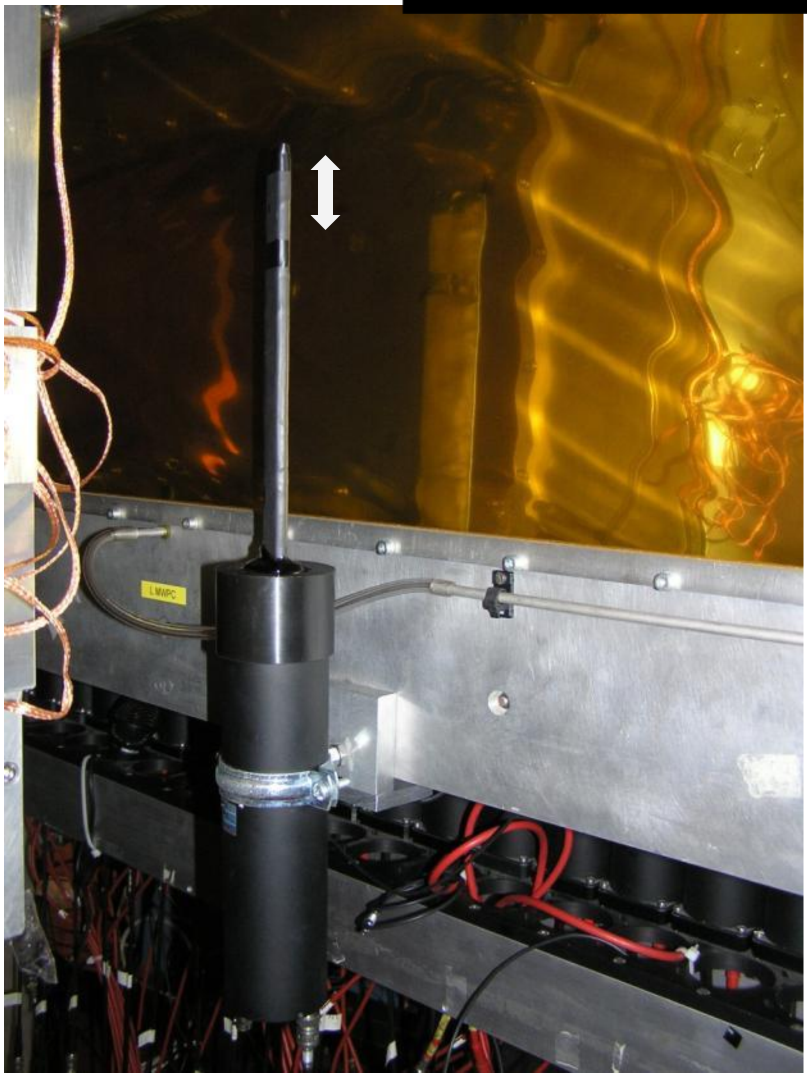
Track finding

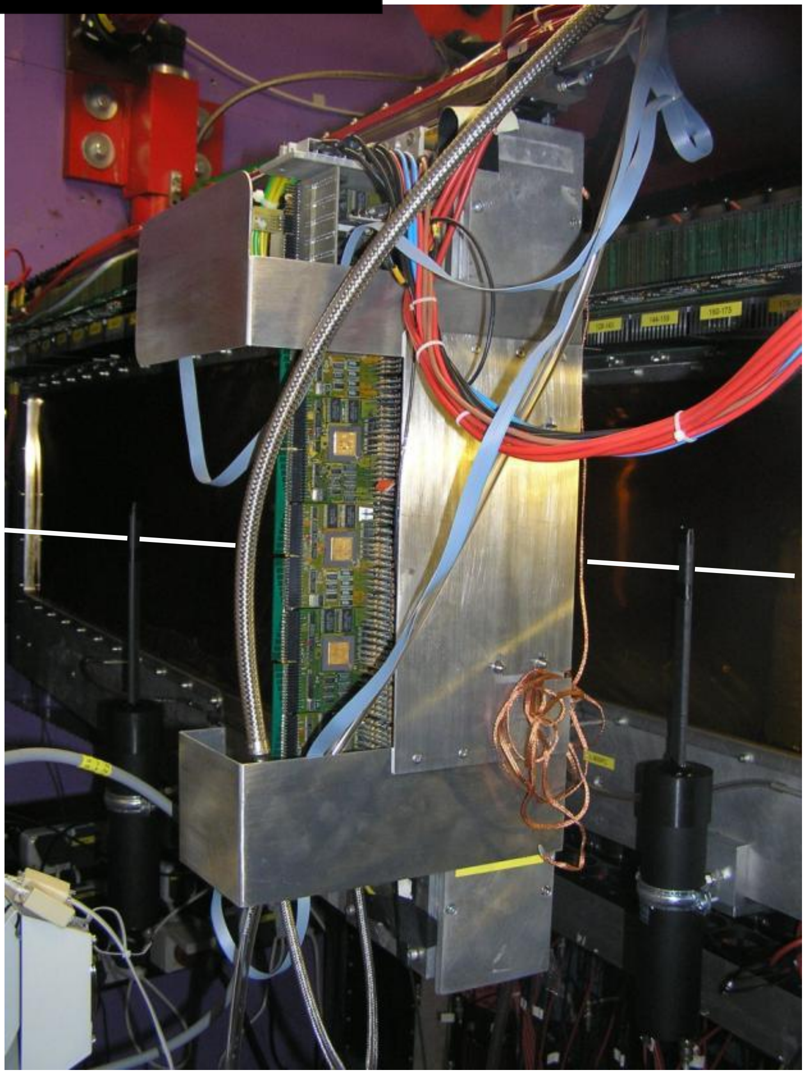




Each track is assigned a quality factor including:
- shape of clusters,
- spectrometer acceptance
- relation of charge in one plane to the perpendicular plane,
- relation of extrapolated hit position to detected hits in F and G, *etc.*

Efficiency counter set-up





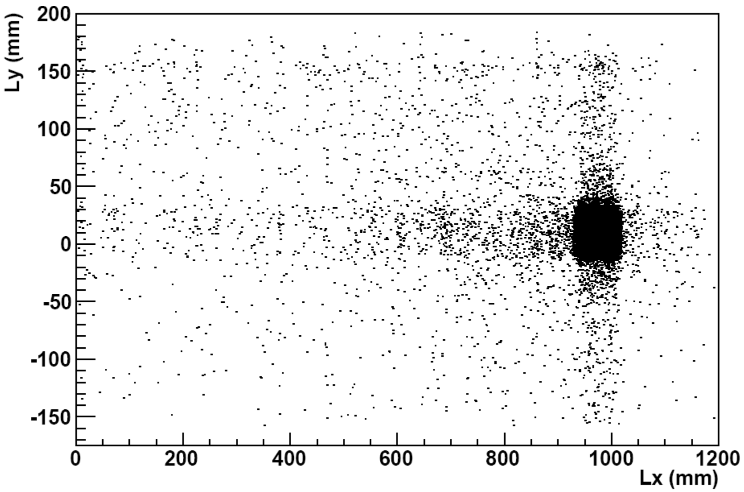
two 5 mm thick efficiency counters with minimum thickness were built and placed in front of MWPC L and M -- only top of the detectors were active

Extracted tracking efficiencies

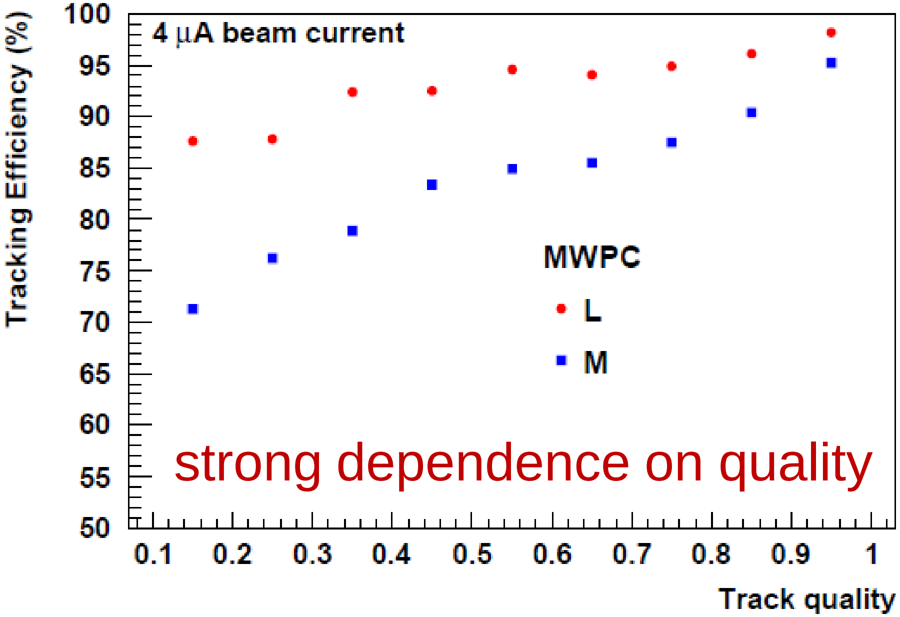
- intrinsic efficiency (L/M): any charge detected in the chamber,
- tracking efficiency: any track reconstructed from the charges,
- chamber efficiency (L/M): any track reconstructed to be in the valid acceptance region of the chamber

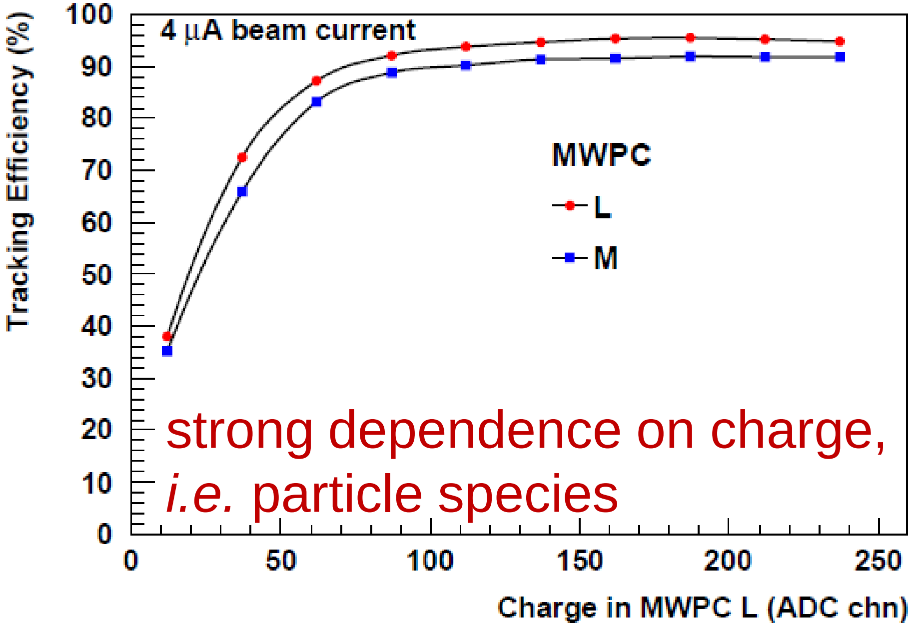
beam current	intrinsic (%)		tracking (%)			protons (%)		pions (%)	
I (μA)	L	M	any track	L	M	L	M	L	M
1	99.3	99.6	98.3	96.3	95.6	97.7	96.9	85.5	83.7
2	99.5	99.7	98.2	95.0	93.1	96.6	94.8	82.4	78.8
3	99.6	99.8	98.2	93.2	90.3	94.9	92.1	80.4	75.2
4	99.6	99.8	98.1	91.6	87.4	93.7	89.8	75.2	68.0

bad reconstruction example created by original analysis:



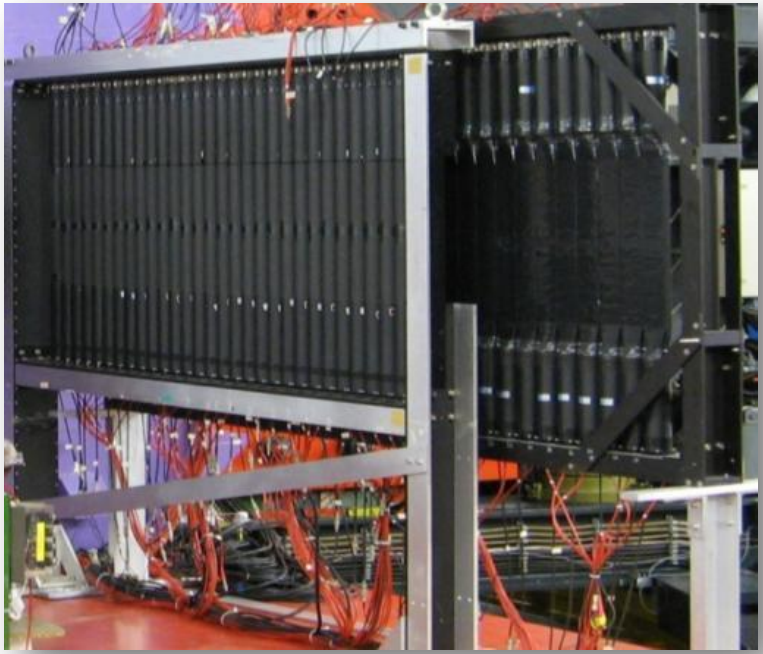
Track efficiency as a function of quality



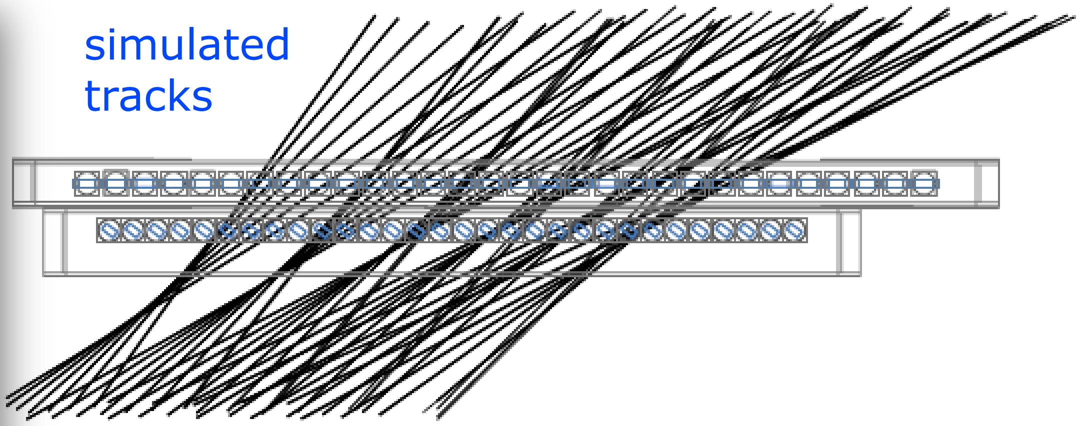


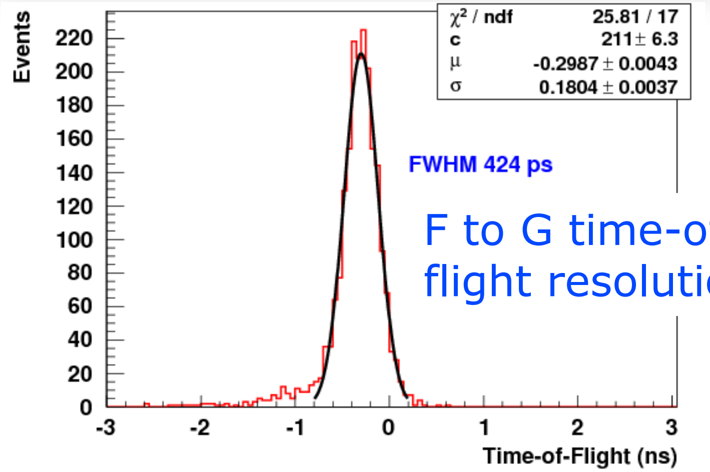
for the cross-section extraction kaon tracking efficiency for events passing the missing-mass cut are being deduced

TOF walls “along“ the focal plane



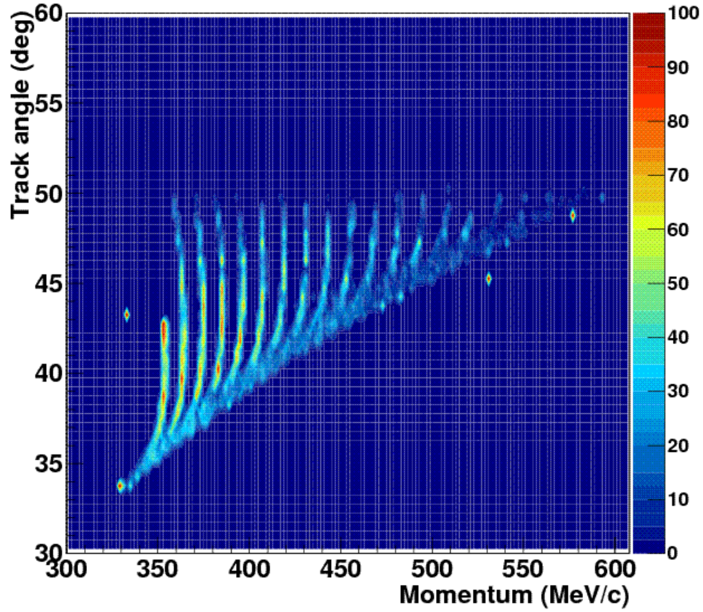
simulated tracks



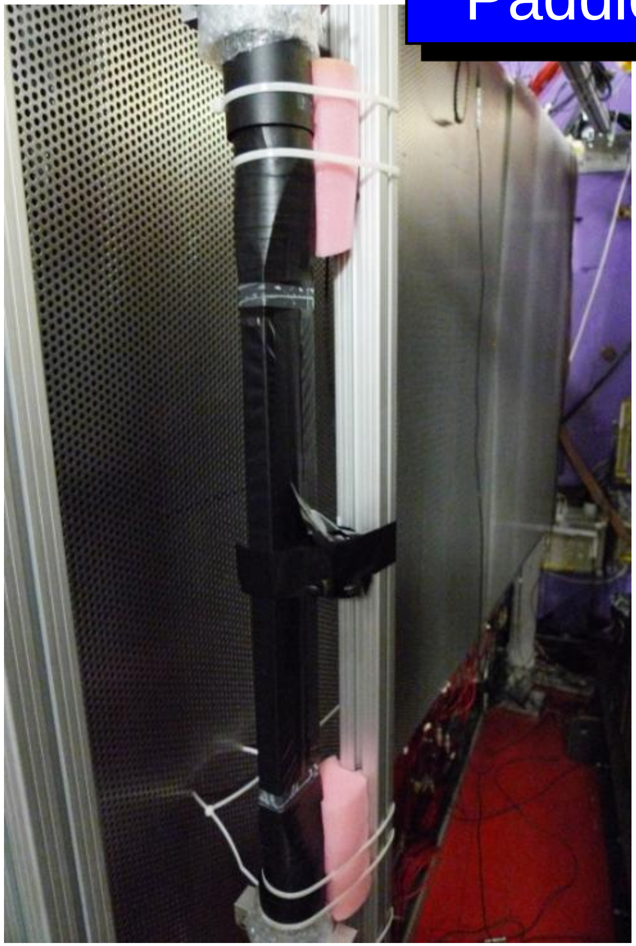


F to G time-of-flight resolution

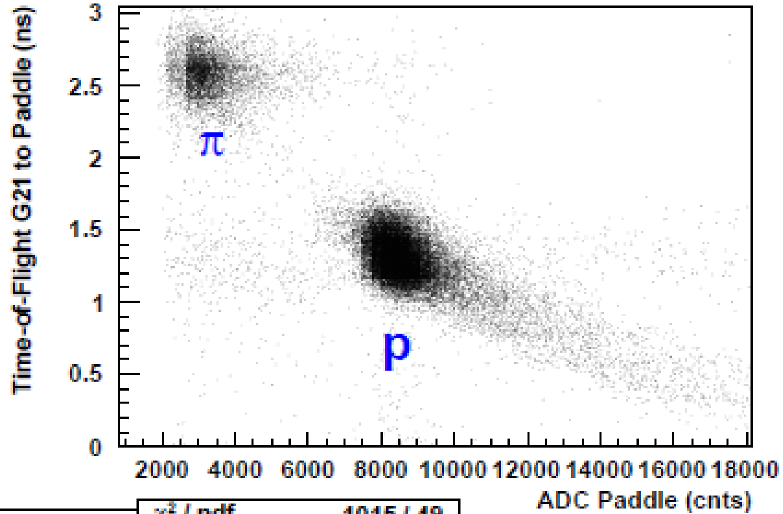
simulated trigger inefficiency

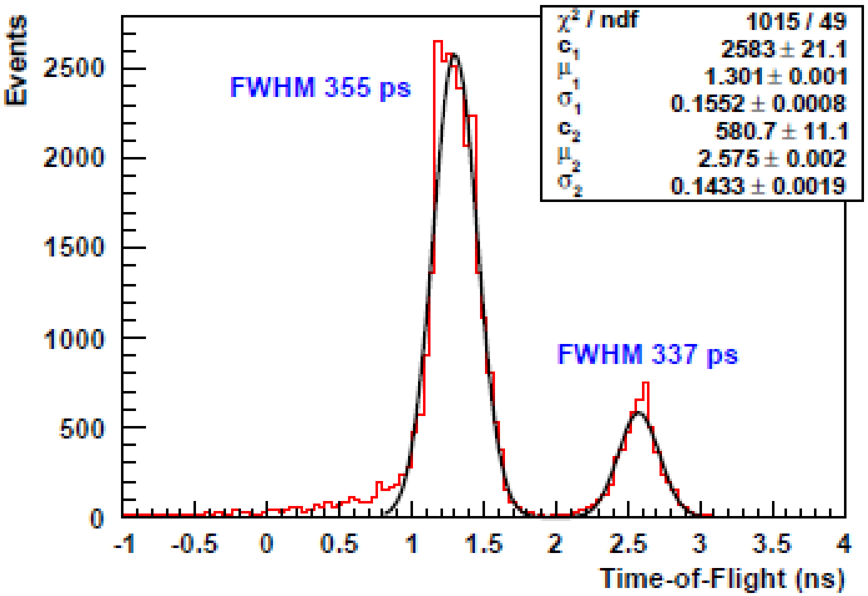


Paddle beam-test Aug. 2o1o



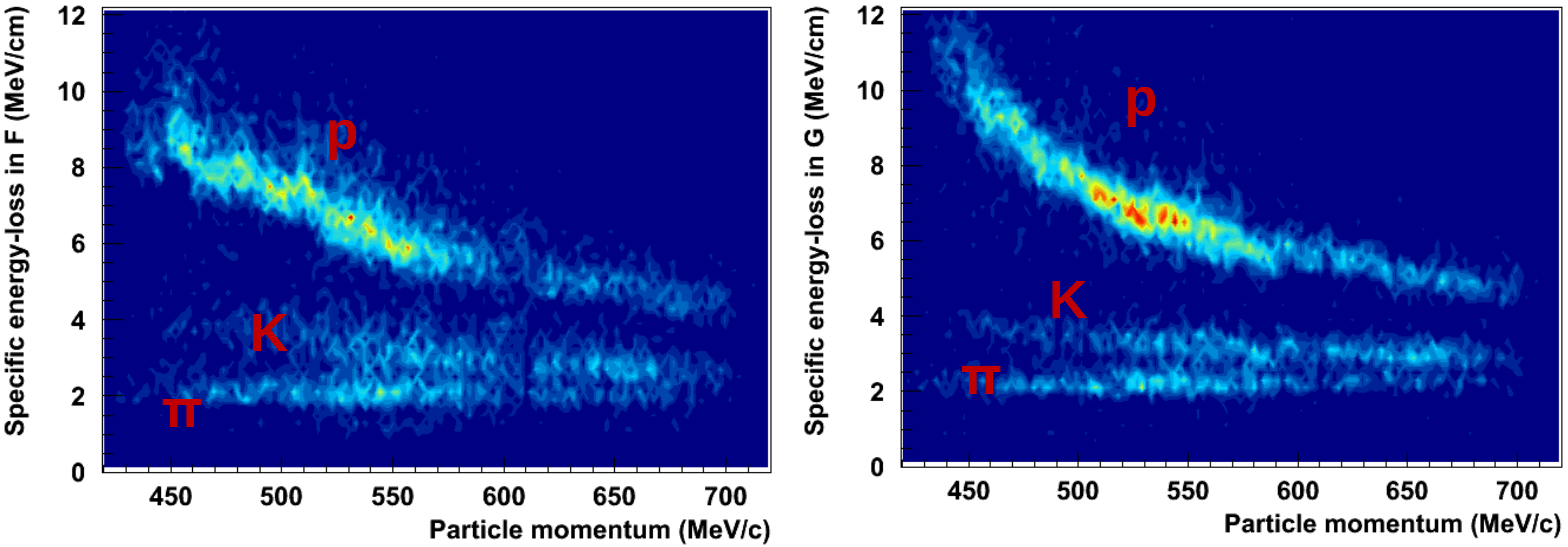
Task:
rebuilding at least one of the scintillator walls to overcome drawbacks of existing detectors





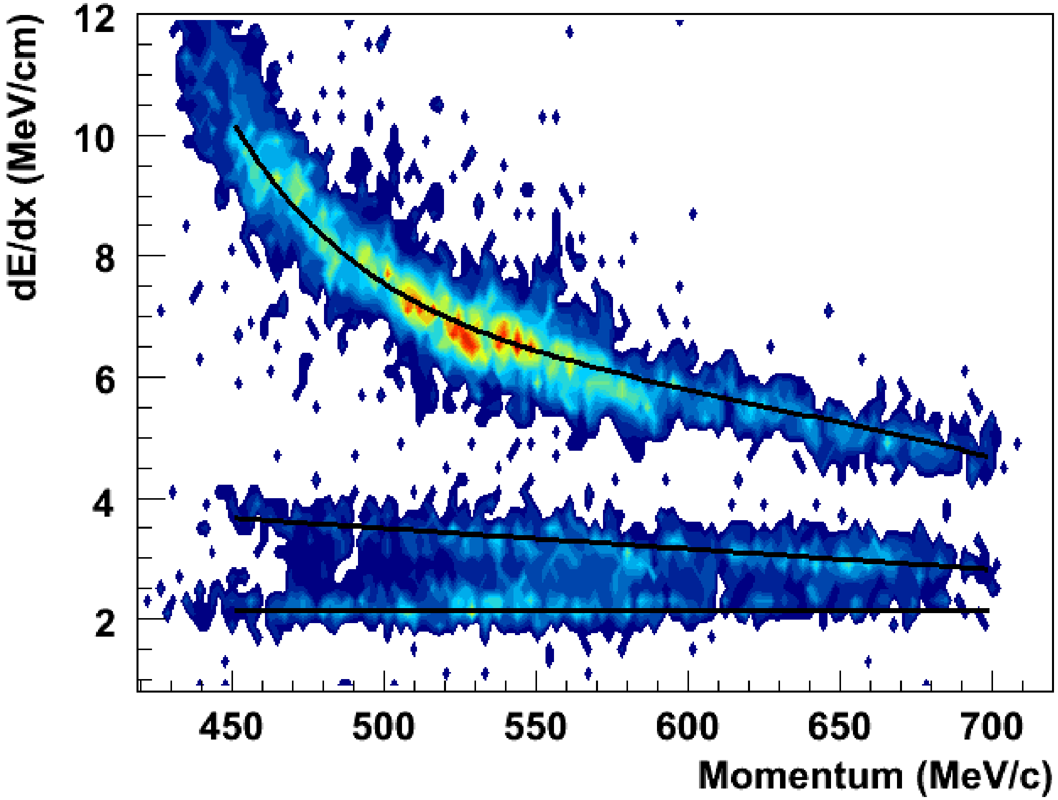
collaboration with Osamu Hashimoto, Satoshi ‘Nue’ Nakamura, and Satoshi Hirose

Pion/proton suppression by *dE/dx*



cuts on time-of-flight and missing mass to find *dE/dx* band for kaons

dE/dx cut efficiency

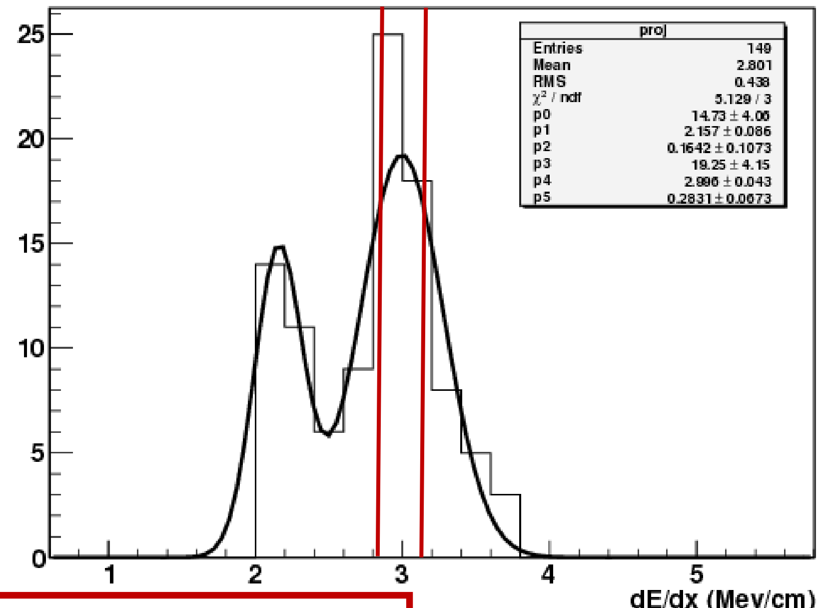


description of energy-loss:

p: 4^{th} order polynomial fit

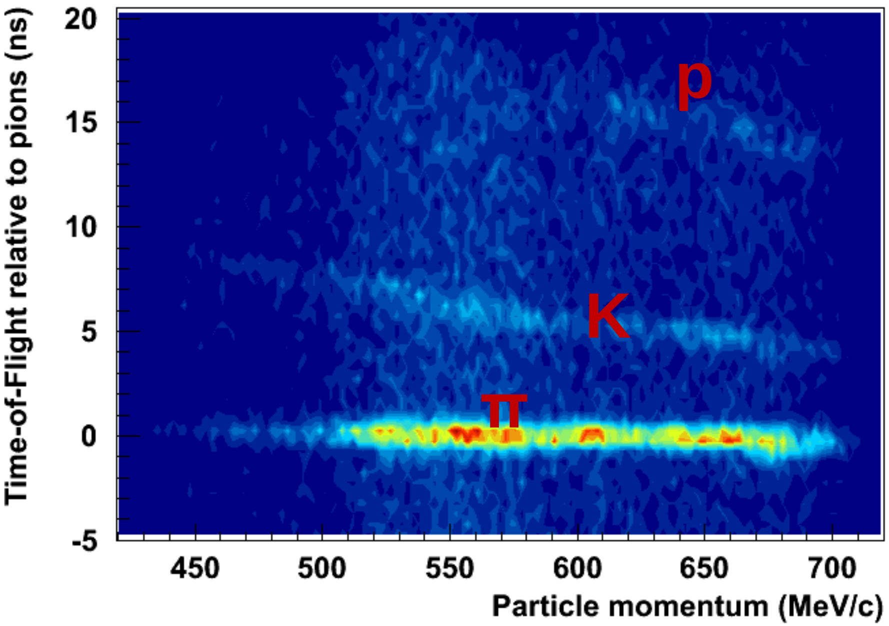
K: linear fit

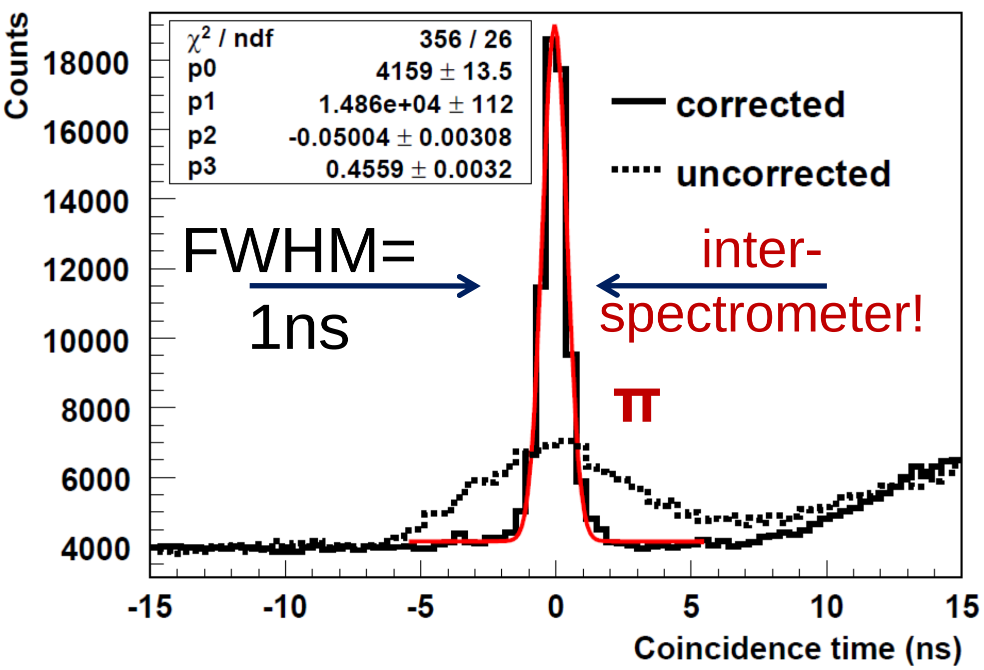
π: constant



original cut at ±150 keV/cm with approx. 50% cut efficiency (0.5 σ)

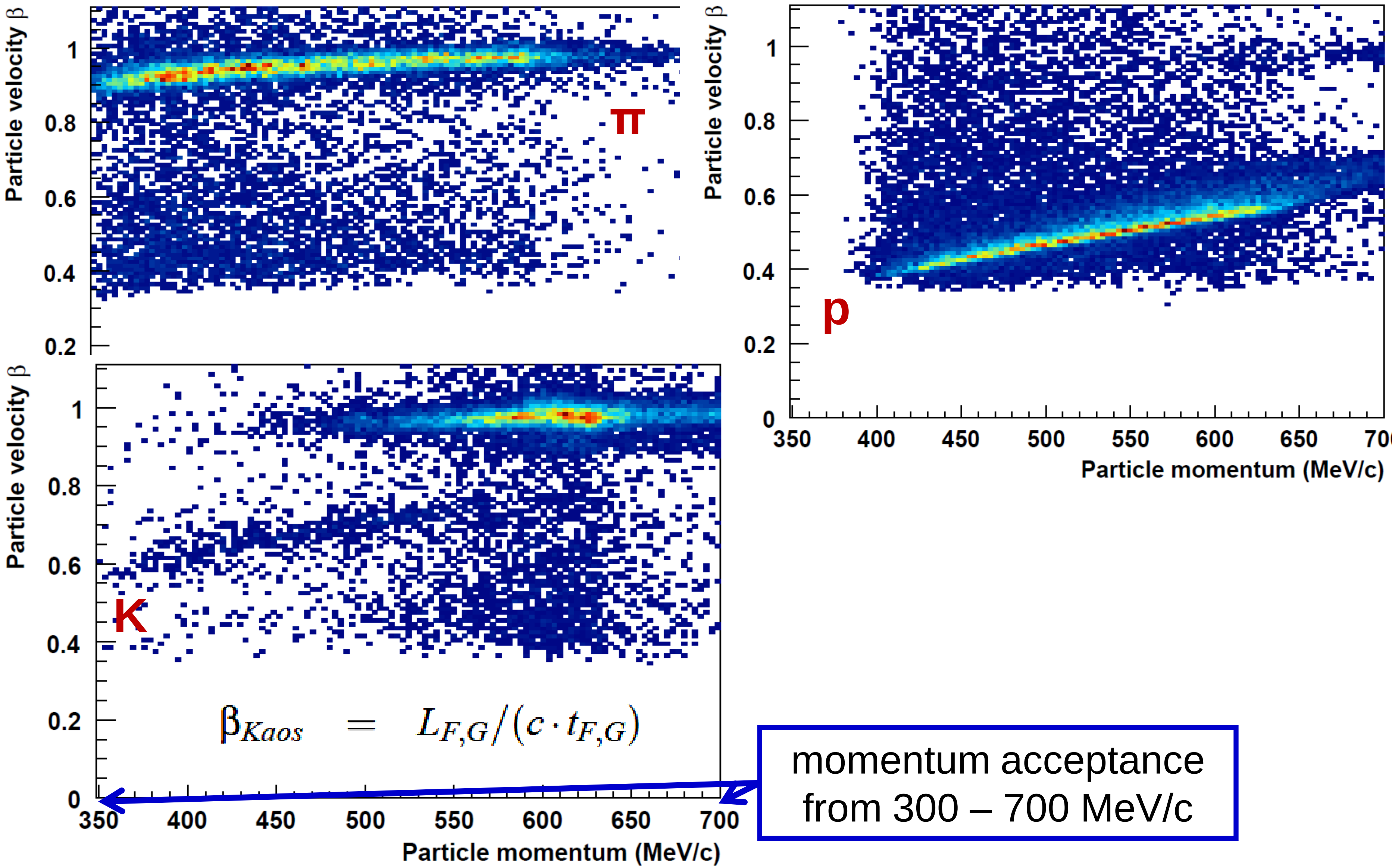
Time-of-flight and coincidence time resolution



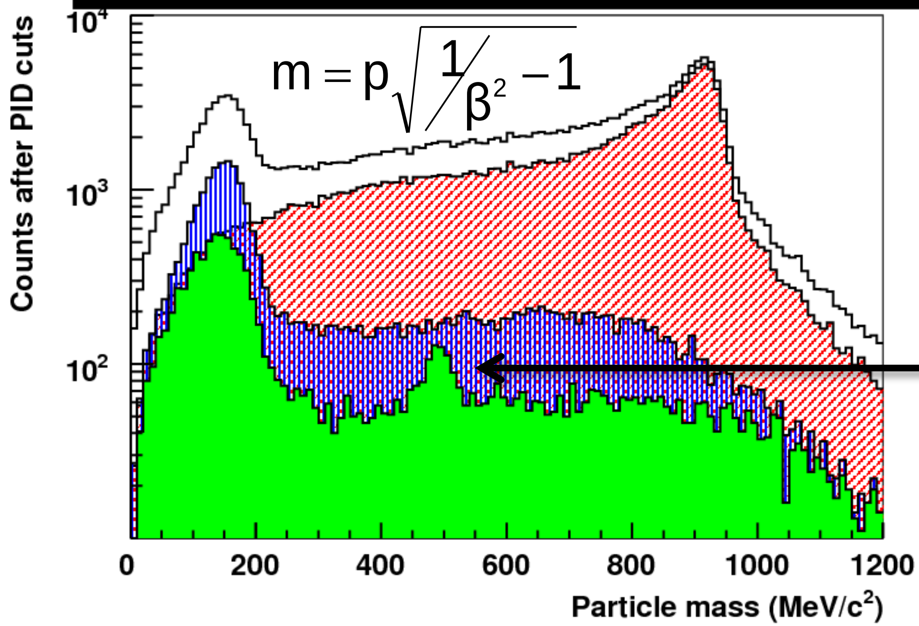


cuts on *dE/dx* and missing mass to find time-of-flight band for kaons

Particle velocities in the 400-600 MeV/*c* range



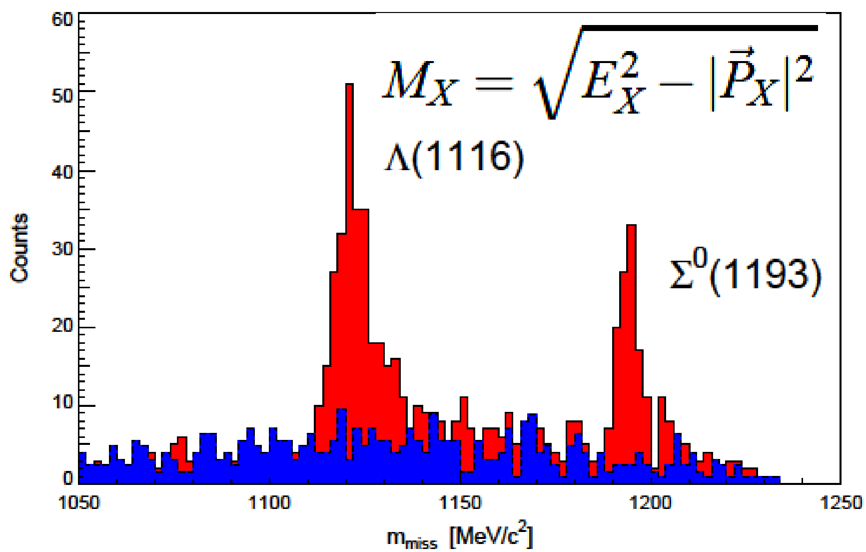
Event reconstruction

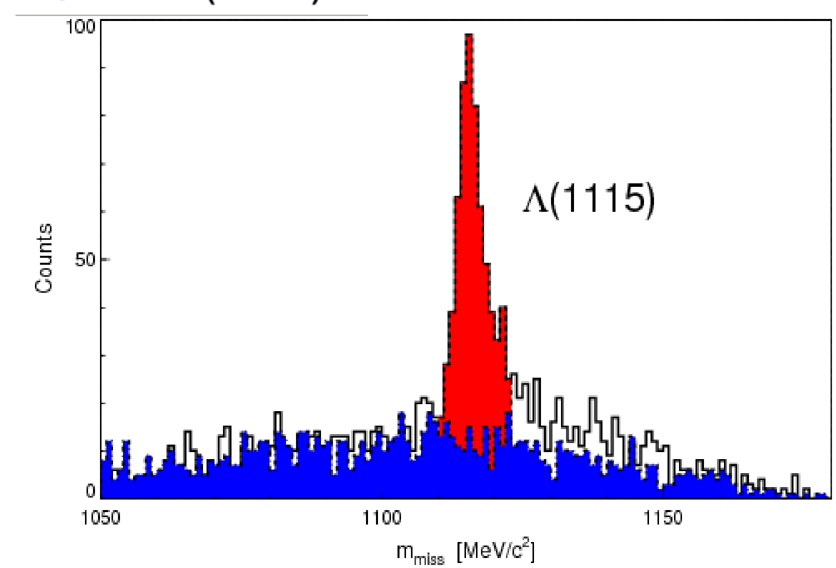


π : K : p =
1 : 0.03 : 1.38

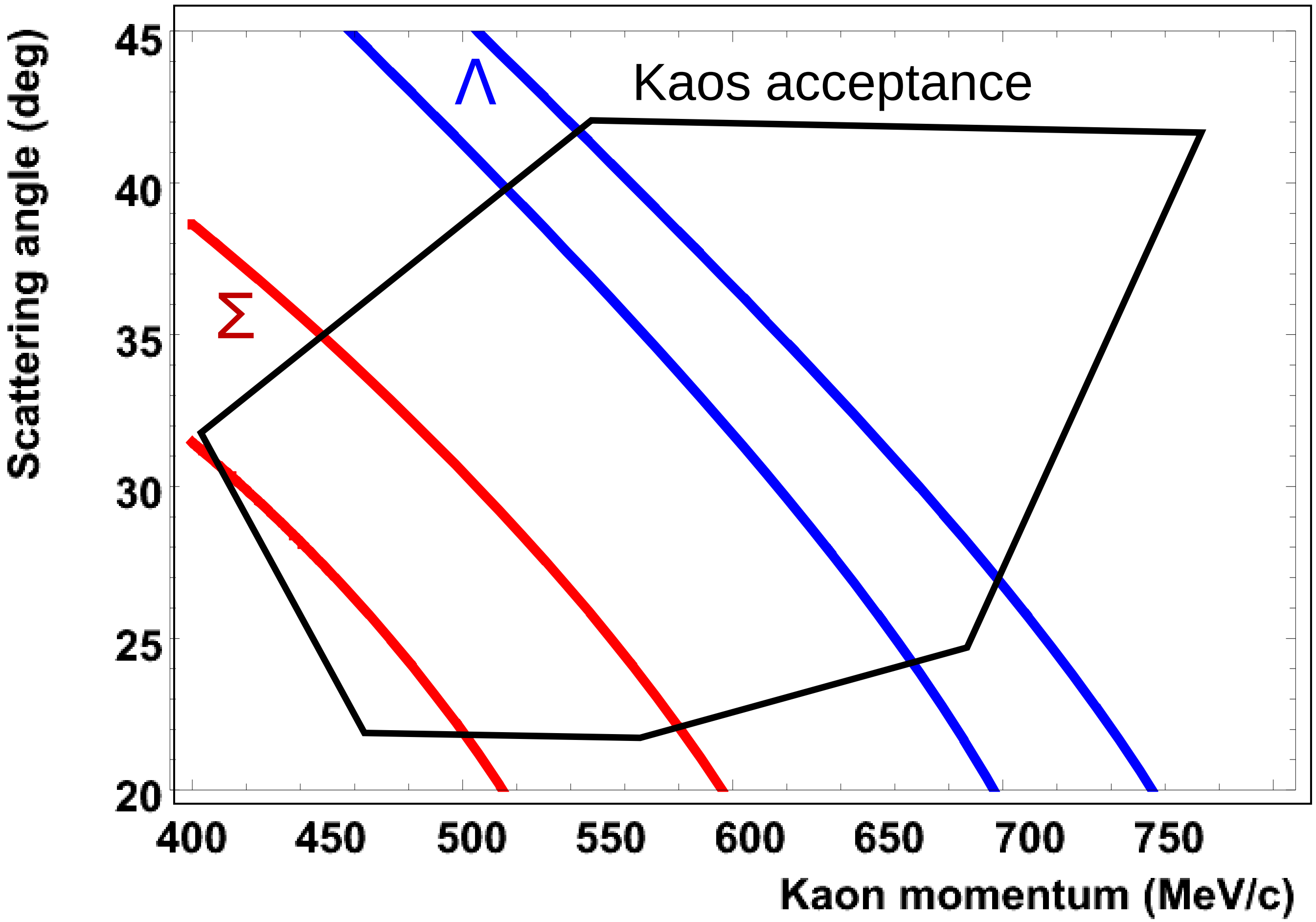
kaon peak after dE/dx cut

[Kaos 2oo8 data]





Λ- and Σ-hyperons in a single kinematic setting

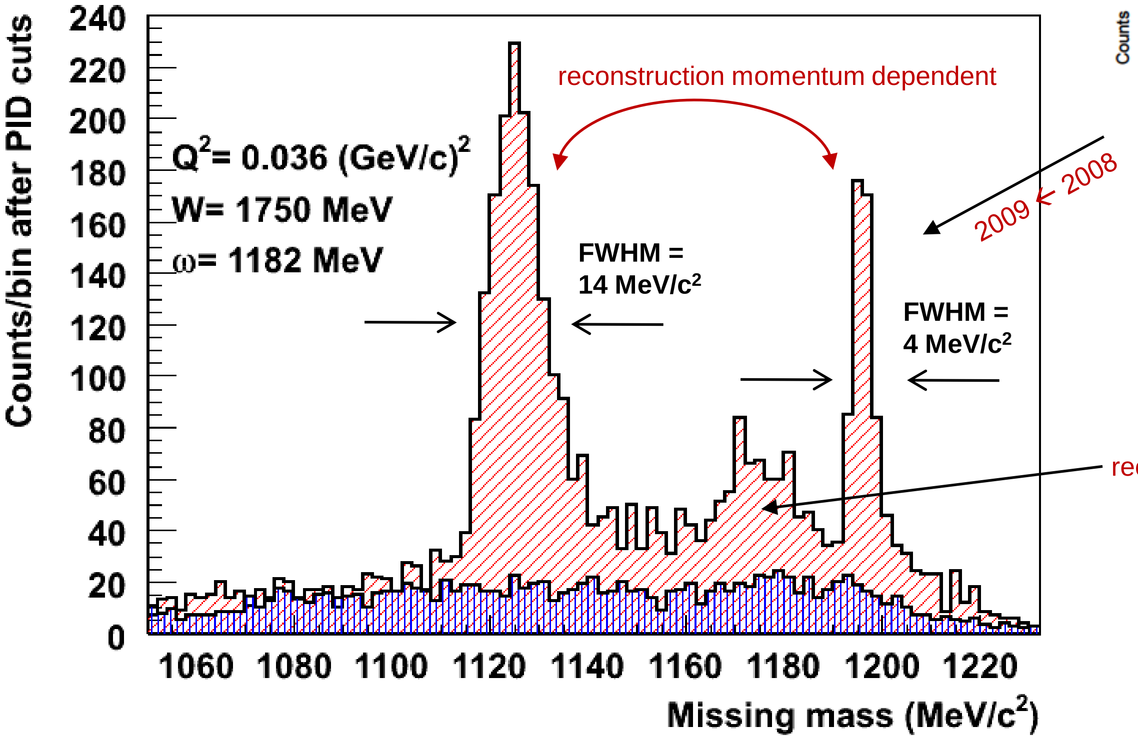


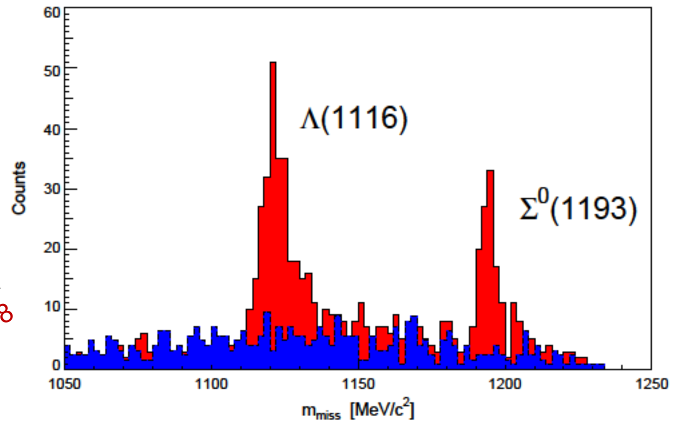
$\langle p_K \rangle$ = 466 MeV/c

$\langle p_K \rangle$ = 642 MeV/c

Λ and Σ yield extraction

[Kaos at MAMI:
preliminary analysis]





$$E_X = E_e - E_{e'} + M_{targ} - E_K = \omega + M_{targ} - E_K,$$

$$\vec{P}_X = \vec{q} - \vec{p}_K, \qquad M_X = \sqrt{E_X^2 - |\vec{P}_X|^2}$$

Cross-section determination

- cross-section extraction performed by scaling based on K-Maid

Monte Carlo

$$Y = L \times \int \left[\Gamma(Q^2, W)\frac{d^2\sigma}{d\Omega_K^*}\right] A(d^5V)R(d^5V)dQ^2dW\,d\phi_e d\Omega_K^*$$

measurements

measurements, simulations

$$Y = L \times \left(\frac{d^2\sigma}{d\Omega_K^*}\right)_{CA} \times \boxed{\int \left[\Gamma(Q^2, W)\frac{\frac{d^2\sigma}{d\Omega_K^*}}{\left(\frac{d^2\sigma}{d\Omega_K^*}\right)_{CA}}\right] A(d^5V)R(d^5V)dQ^2dW\,d\phi_e d\Omega_K^*}$$

Kaon-Maid

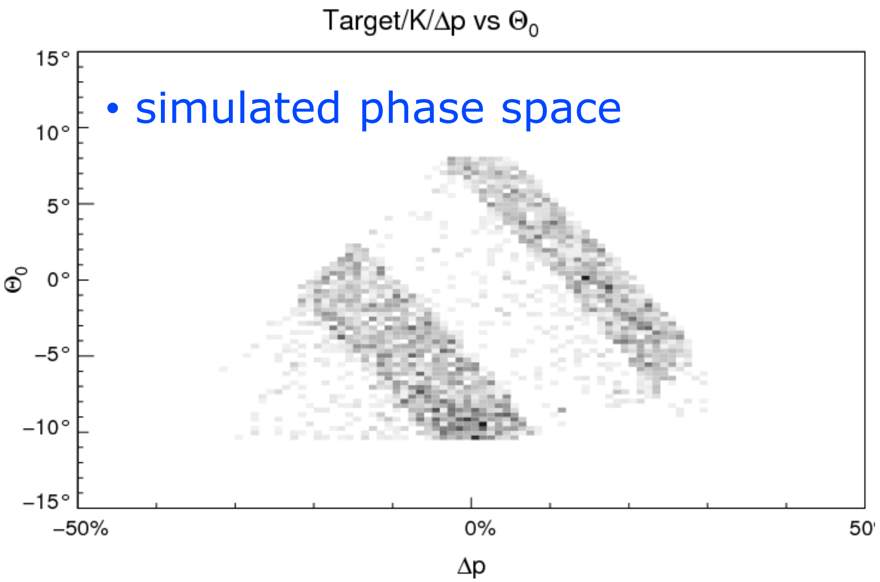
- angular dependency is strong in this kinematic region
- cross-section given for 7 kaon centre-of-mass angular bins

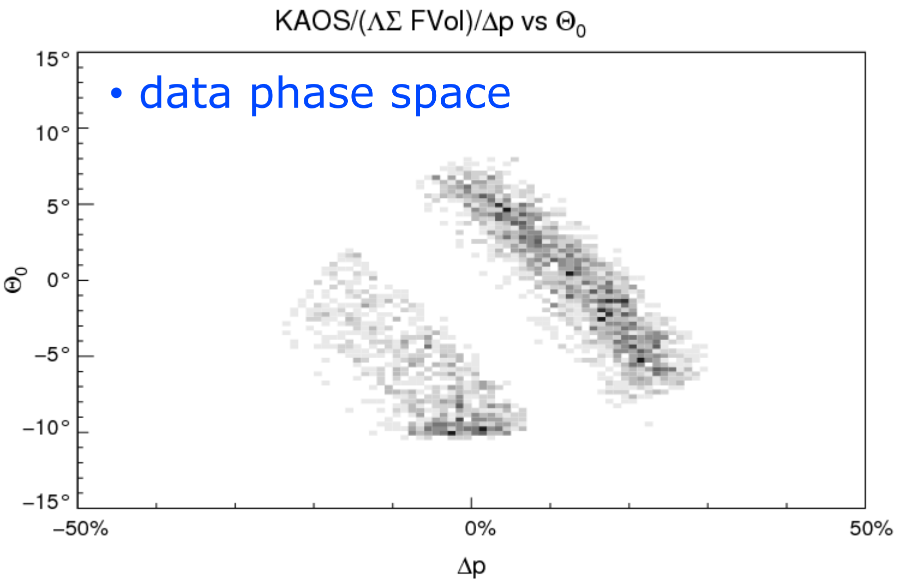
- equivalent Monte Carlo yield determined for a cross-check of procedure

$$Y_{\mathrm{MC}} = L_H \times \int \left[\frac{d^5\sigma}{dQ^2dW\,d\phi_e d\Omega_K^*}\right] A(d^5V)\,R(d^5V)\,dQ^2dW\,d\phi_e d\Omega_K^*$$

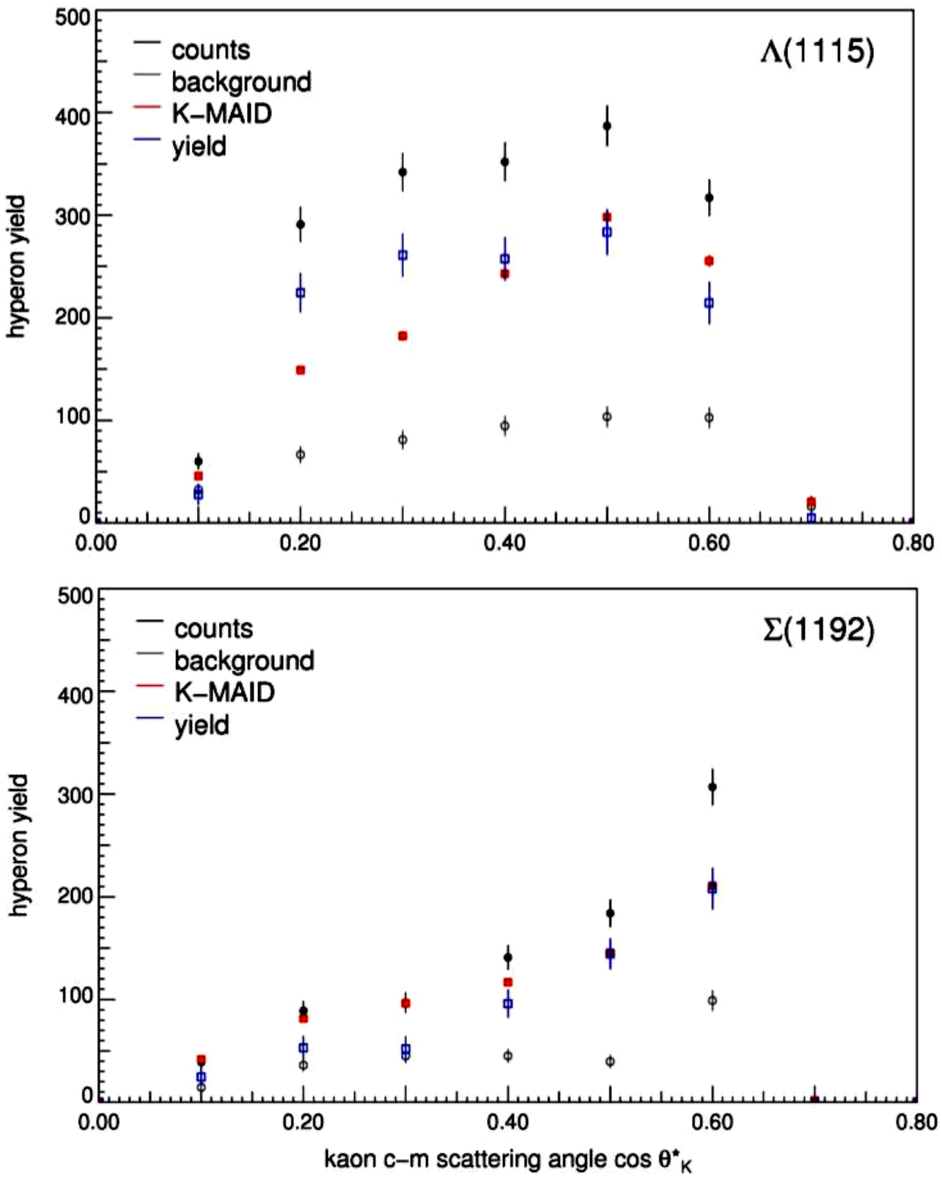
Kaon-Maid + simulation + measured efficiencies and luminosity

Phase space simulation





Extracted kaon yields



in both channels models folded with acceptances and efficiencies reproduce the angular distributions

<u>no surprise</u>

data prefer Saclay-Lyon A or K-Maid without longitudinal coupling of D_{13}

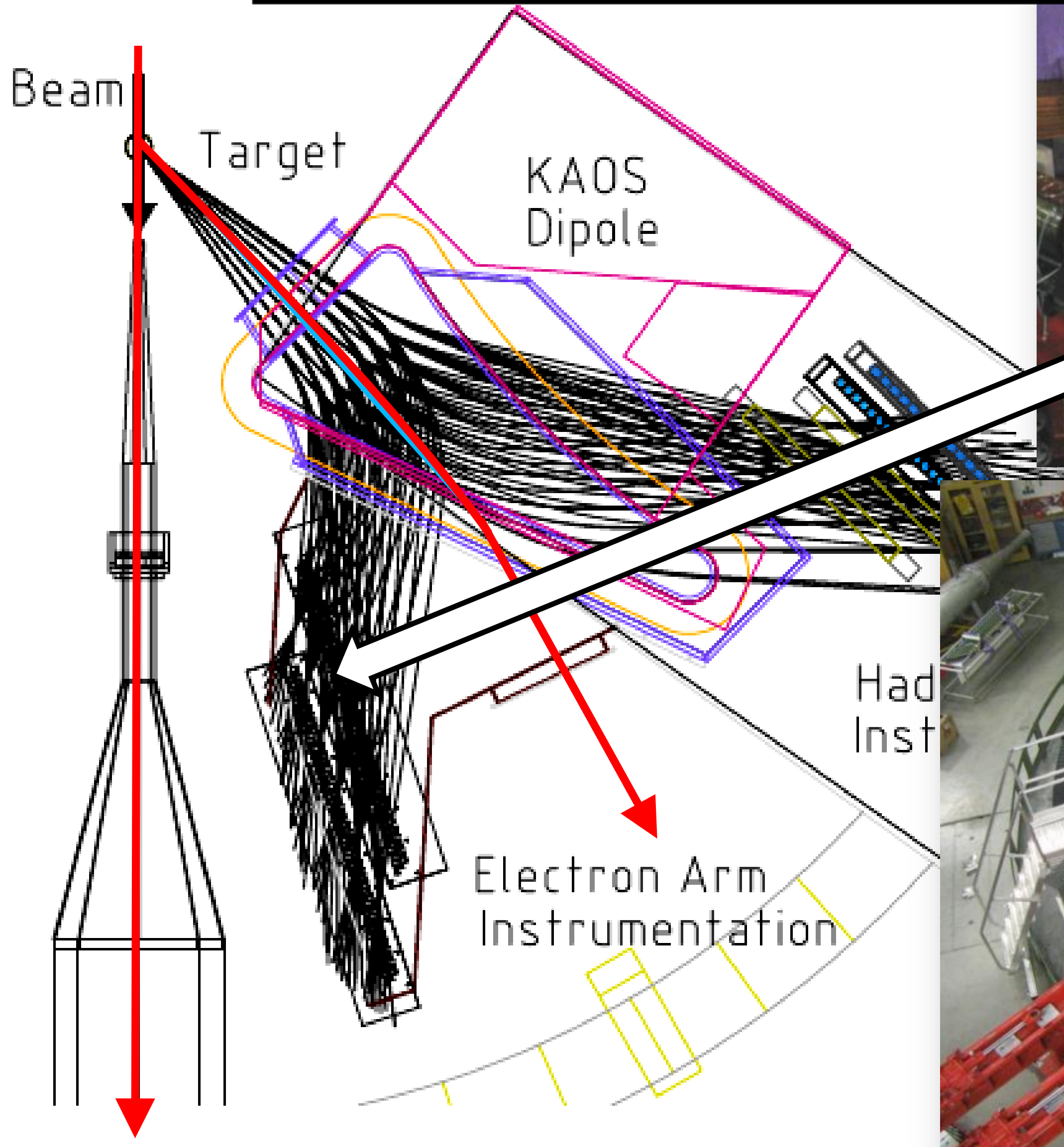
<u>still preliminary</u>

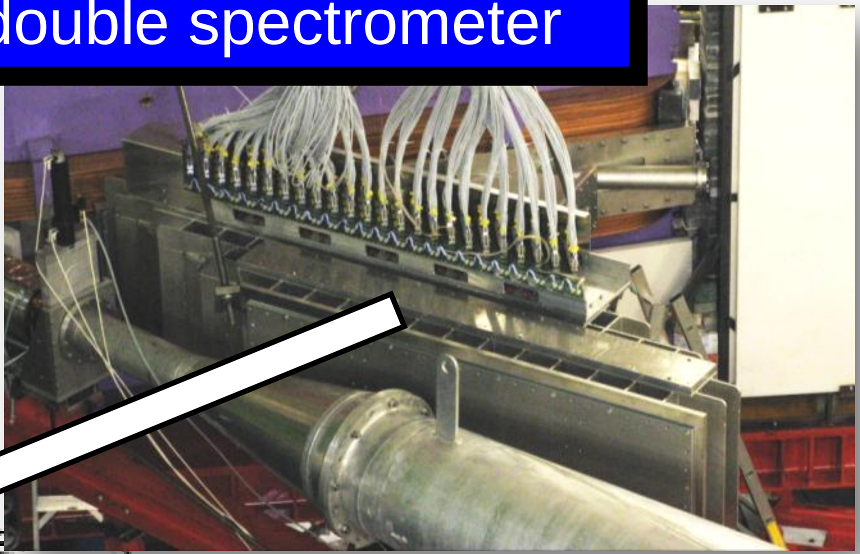
because

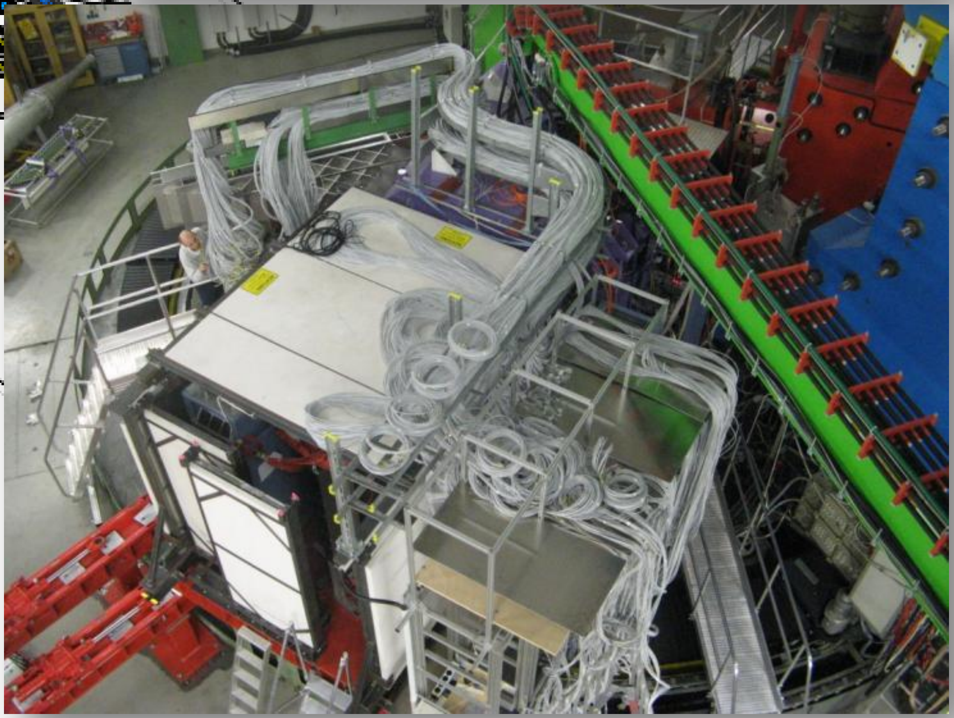
- efficiencies not yet fixed
- background subject to cuts

Towards a zero-degree experiment at MAMI

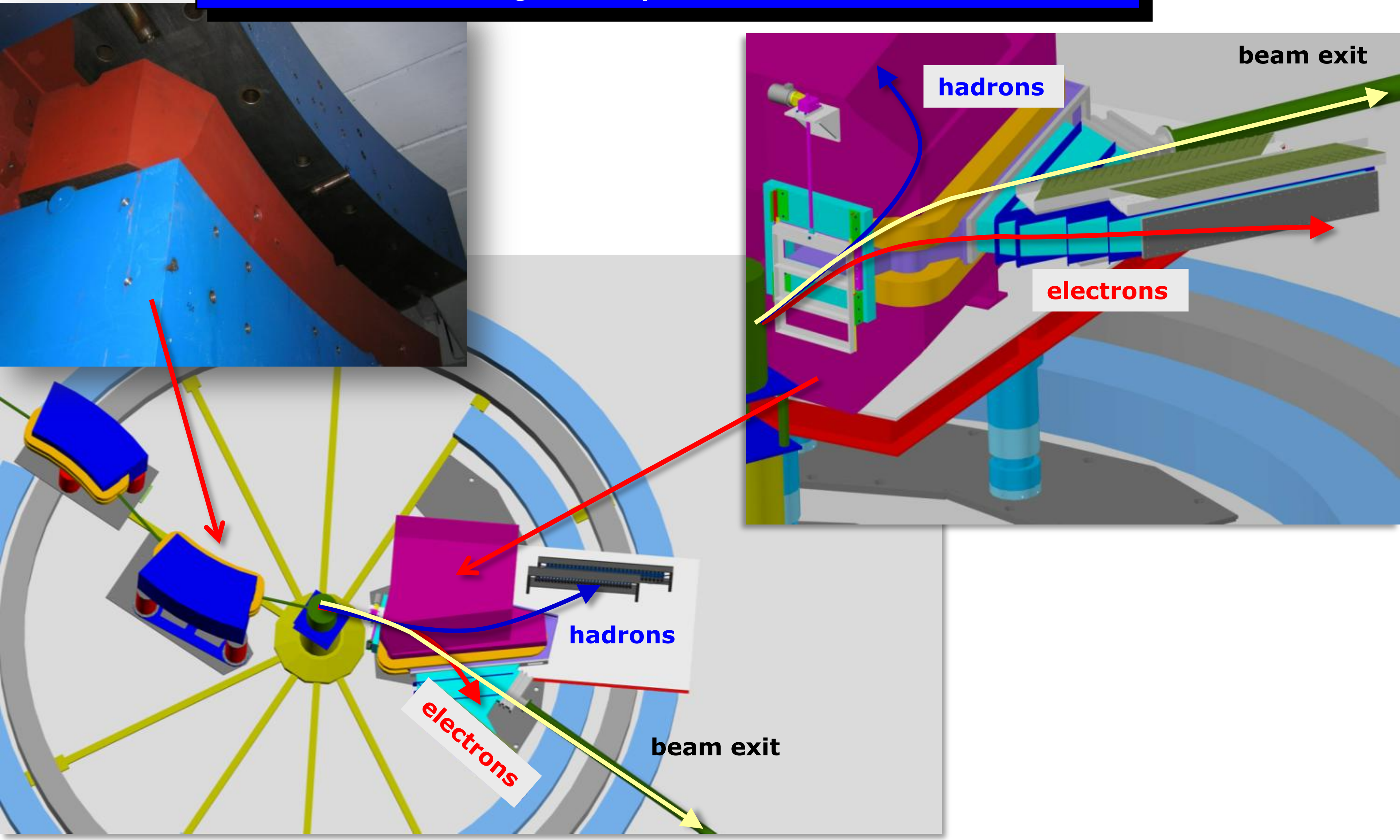
Realisation of Kaos as a double spectrometer





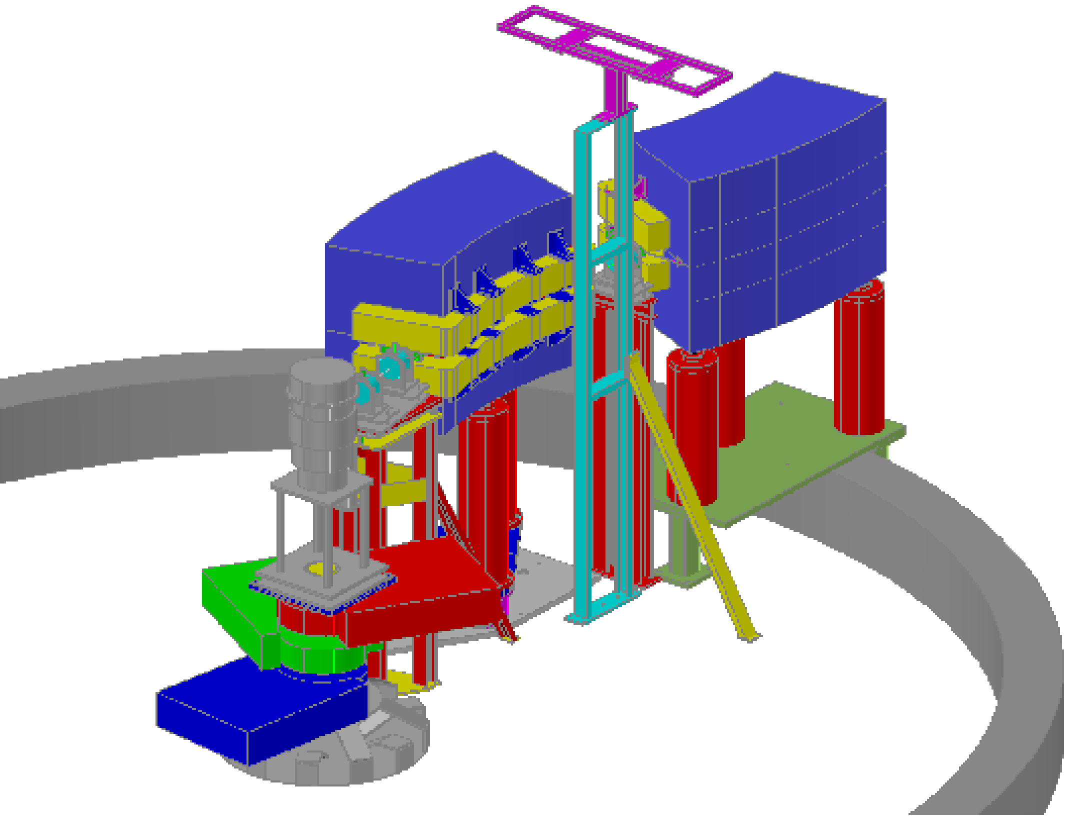


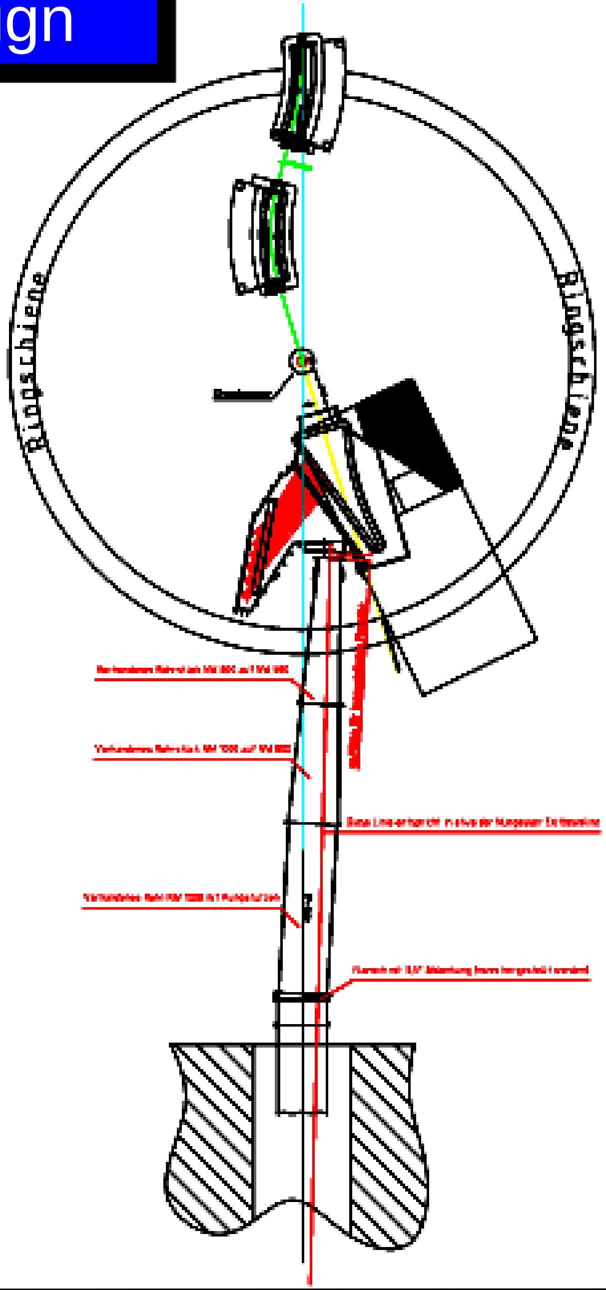
Installation of a beam chicane for a zero-degree operation of KAOS



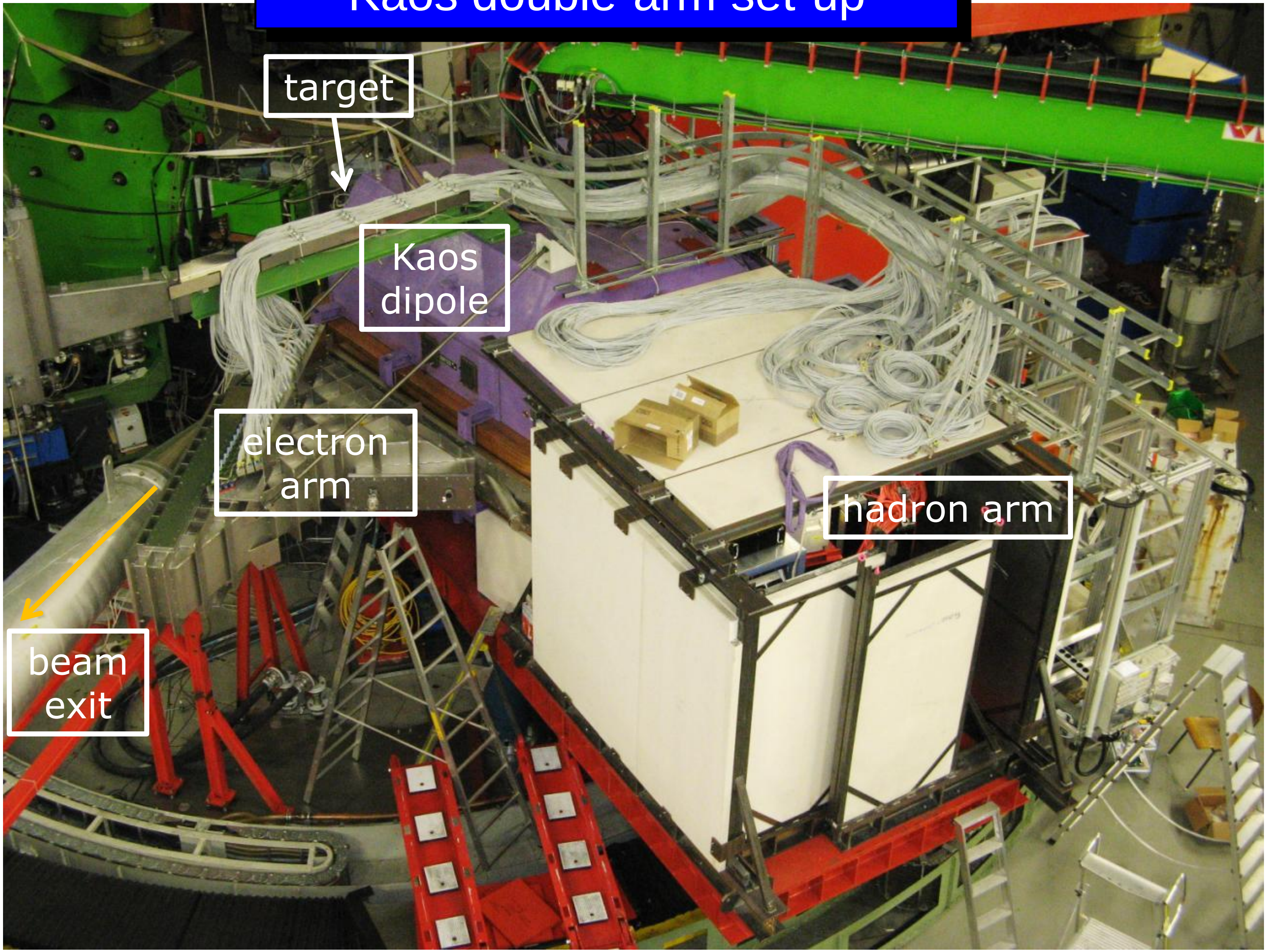
Final beam chicane design

- all pre-target components available
- installation work started last week
- former head of the MAMI accelerator took responsibility for beam transport and monitoring

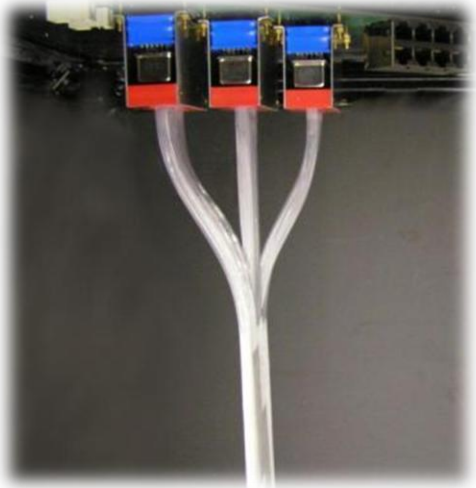


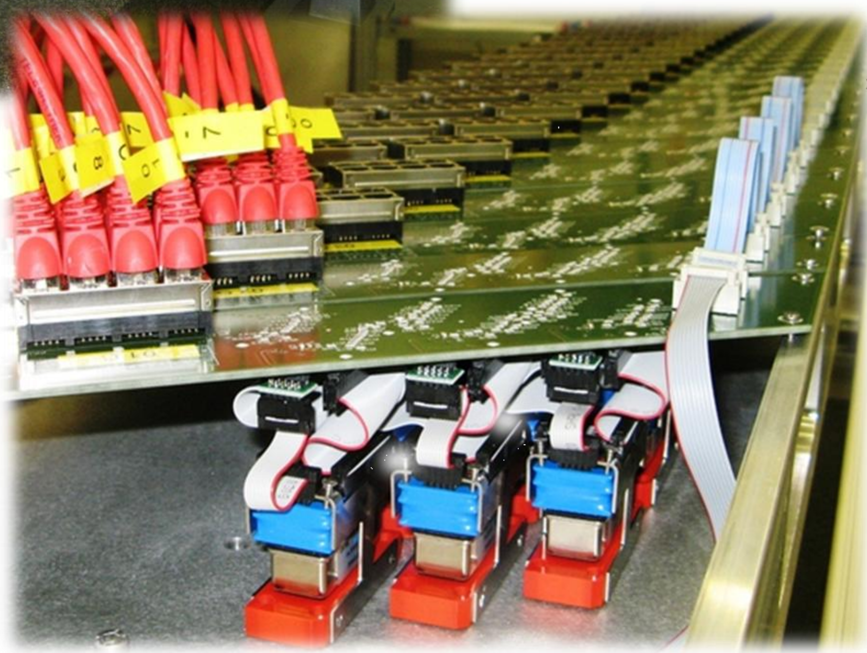


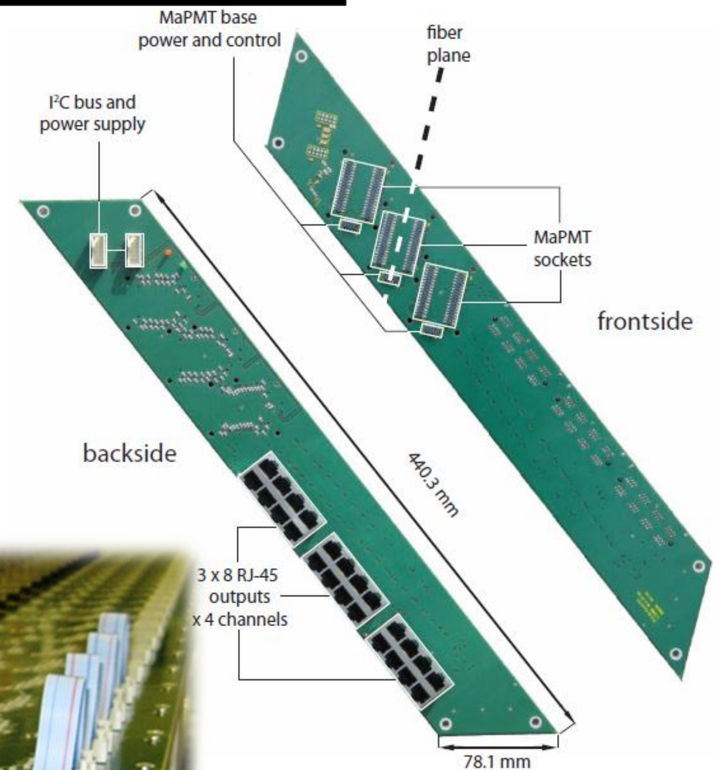
Kaos double-arm set-up



Electron arm Detector Front-End

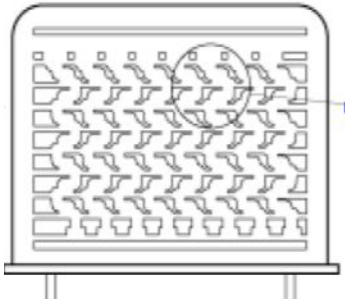


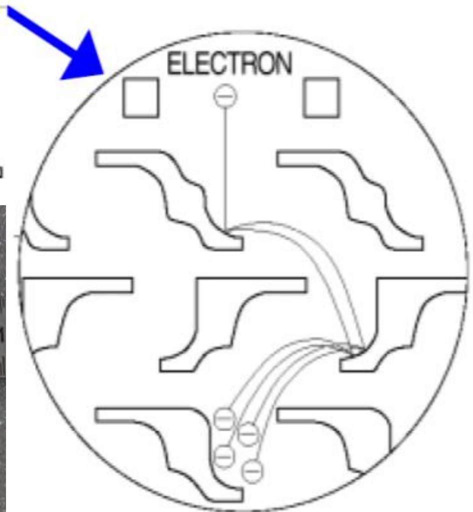


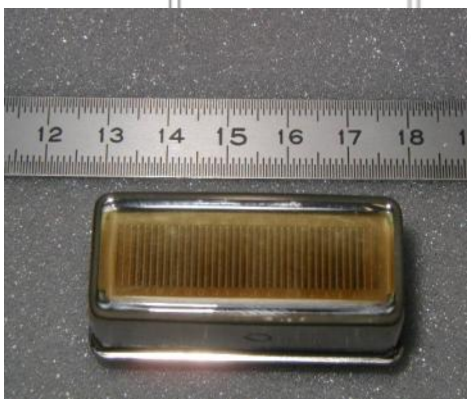


[P. Achenbach *et al.*,
Front-end electronics for the Kaos spectrometer at MAMI, IEEE Trans. Nucl. Sci. 56 (2009)]

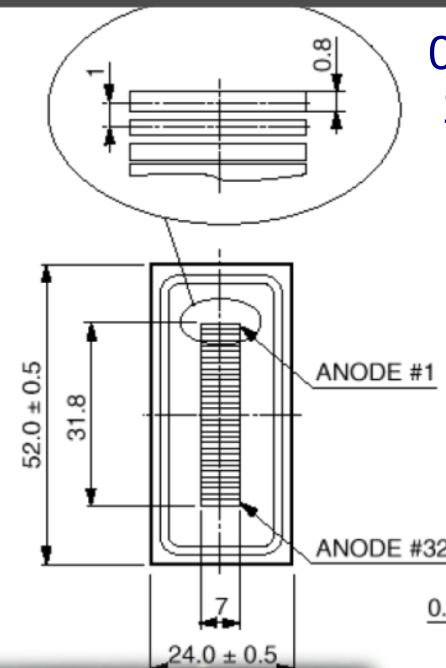
Read-out with position-sensitive photomultipliers



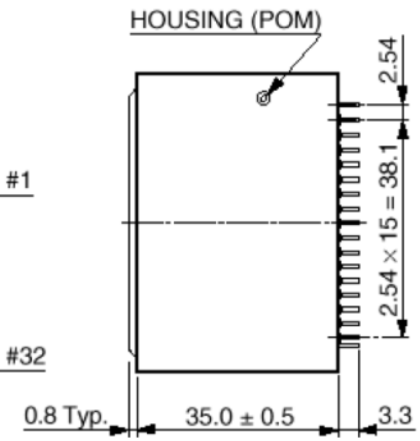


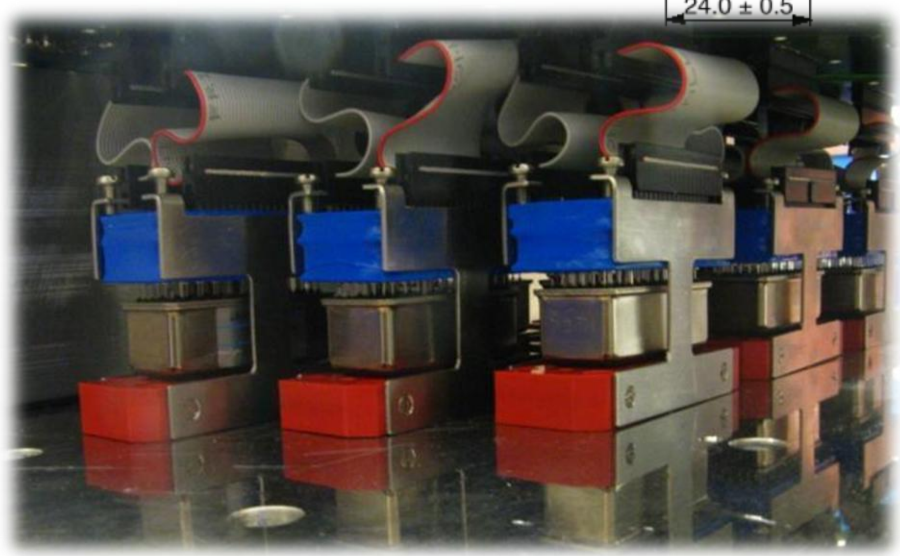


R7259K linear array



0.8 x 7 mm² anode,
1 mm channel pitch

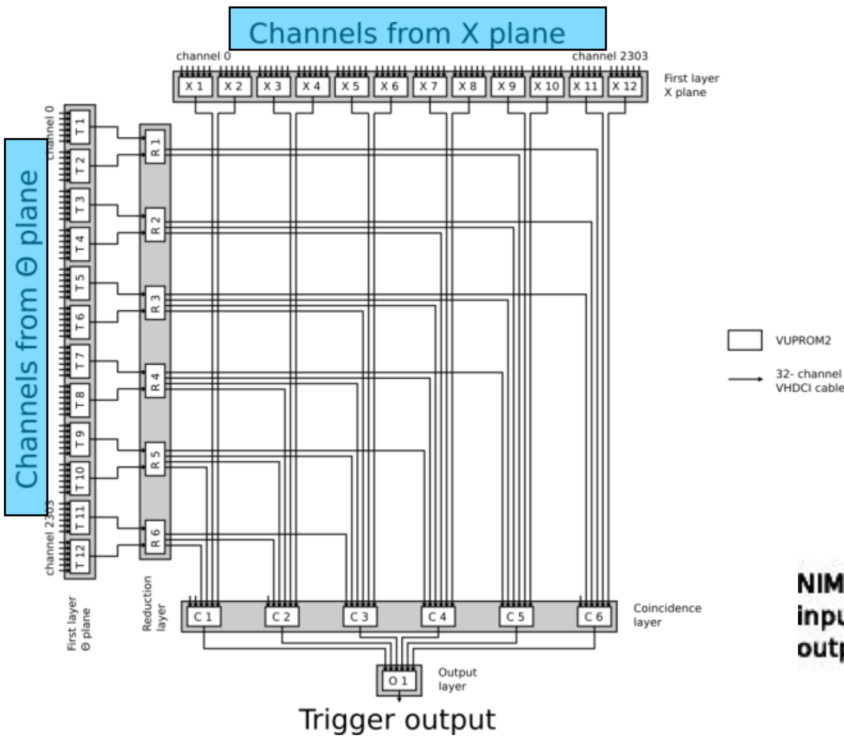


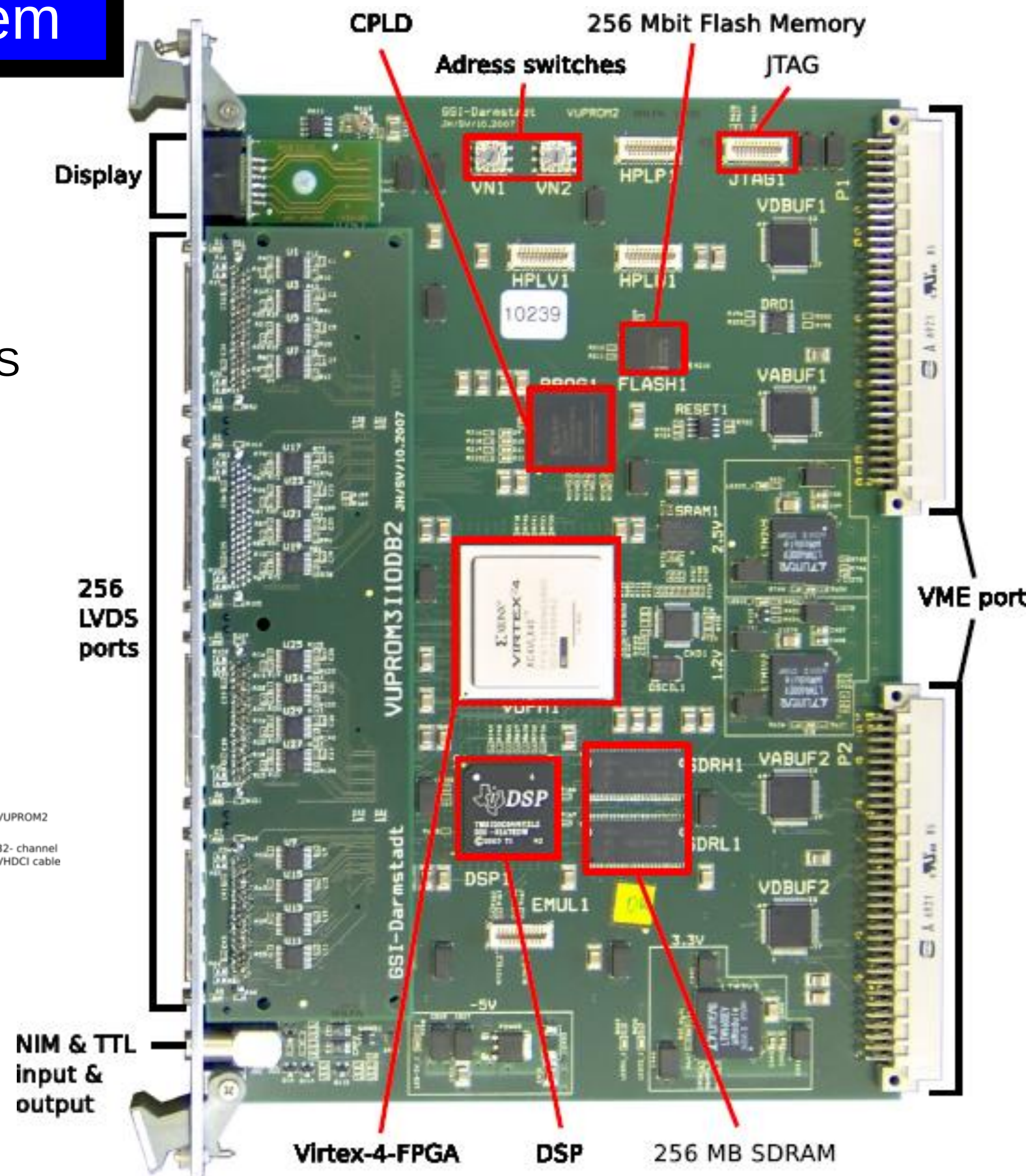


[P. Achenbach, et al., New detectors for the kaon and hypernuclear experiments with KAOS at MAMI and with PANDA at GSI, Proc. SNIC06 (2006)]

VUPROM Trigger System

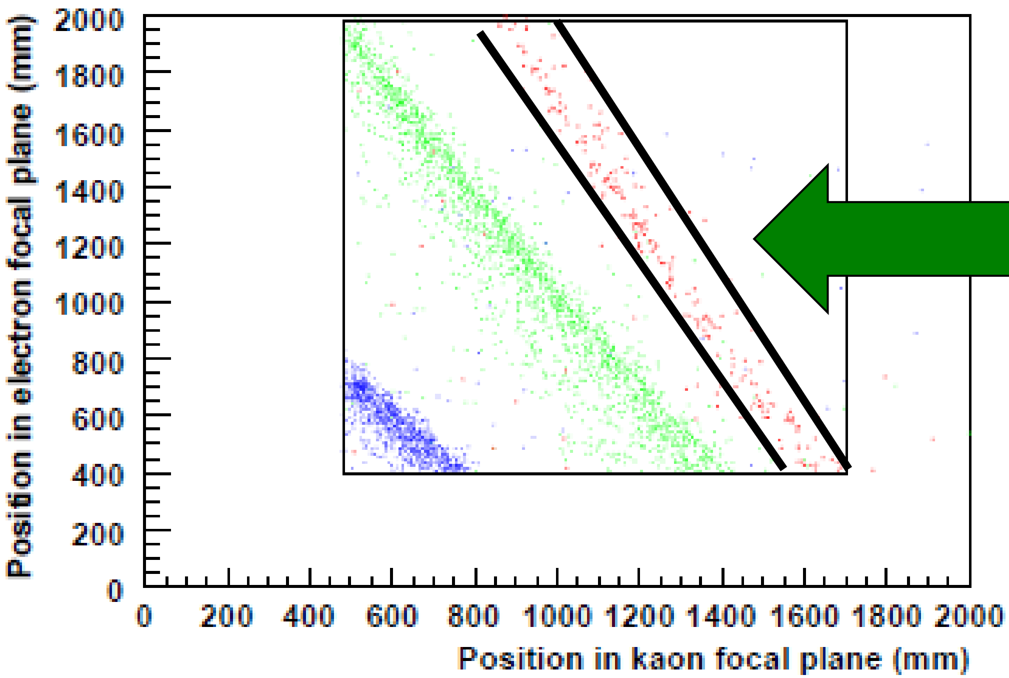
- 256 LVDS I/O
- 6U VME card
- 400 MHz FPGA
- 37 cards used with the KAOS spectrometer:

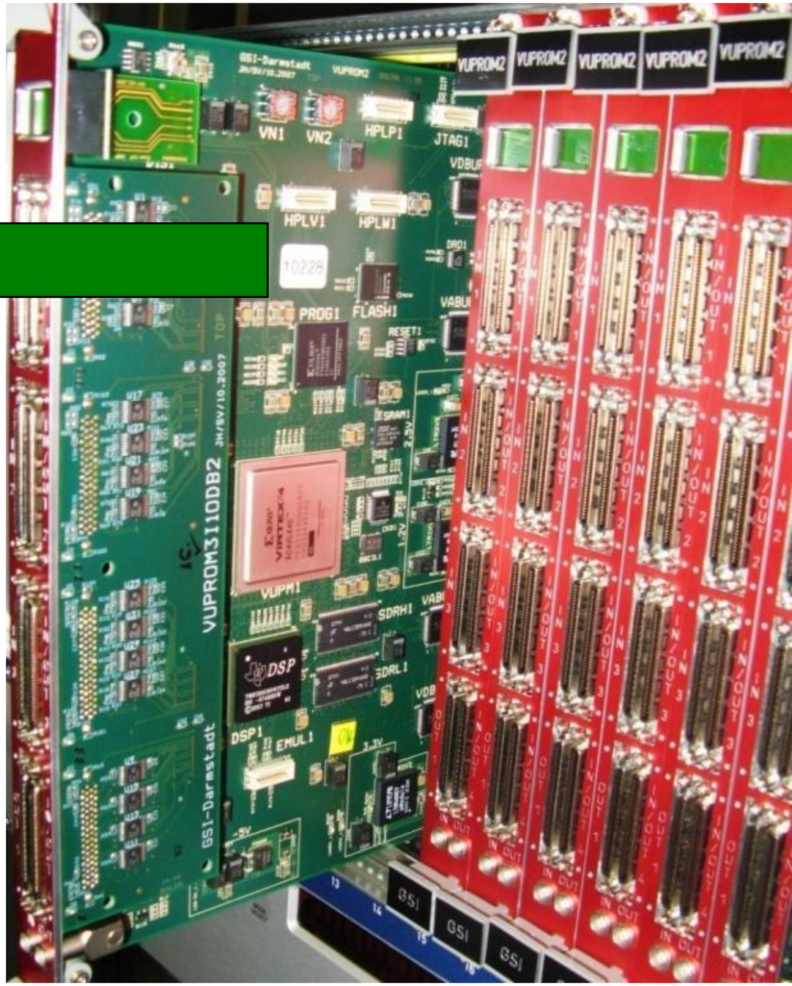




Flexible trigger concept

– e.g. strong correlation between momenta/positions





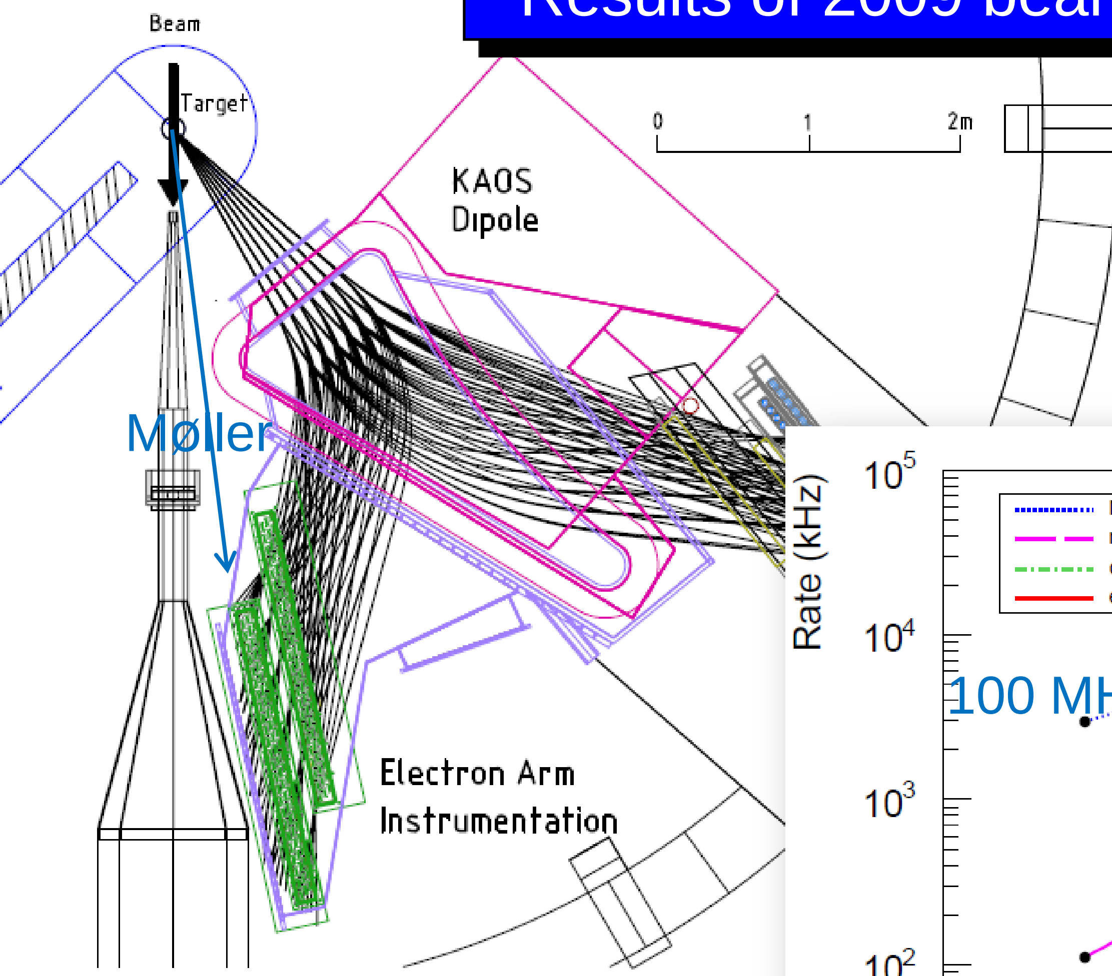
– goal: suppression of background on trigger level

– requirements:

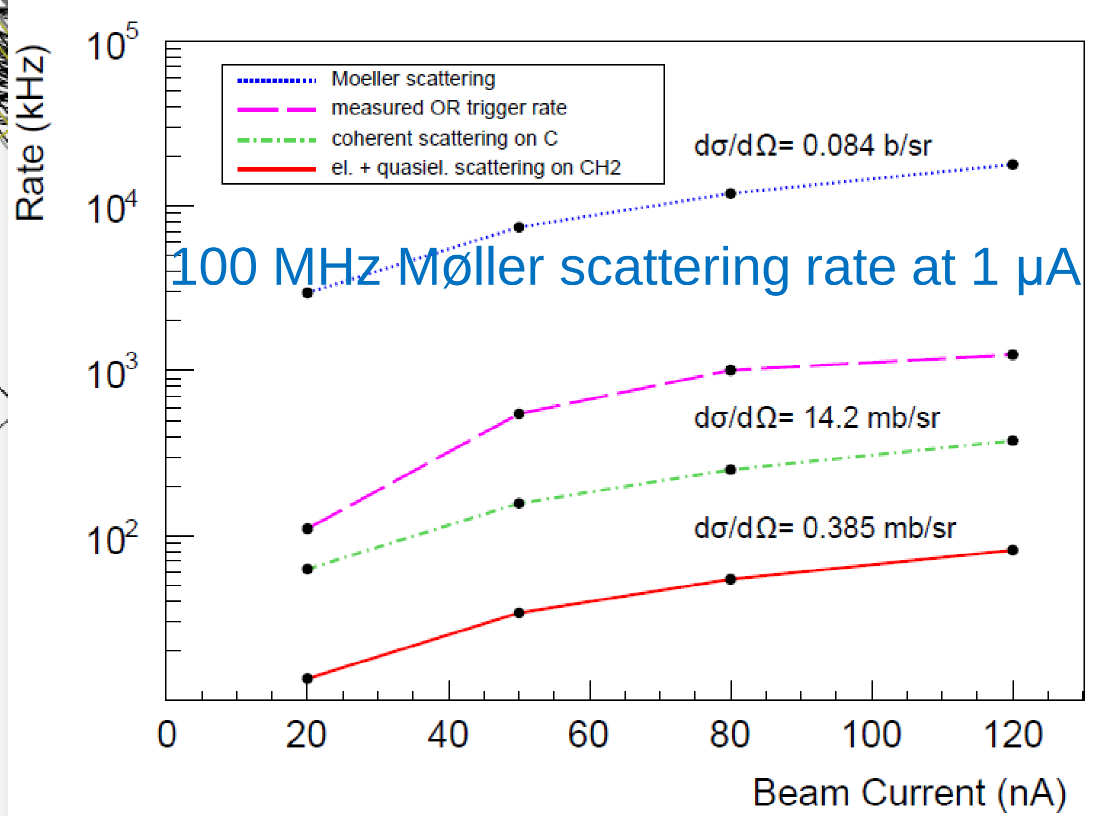
1) correlation of > 60 ⊗ 4000 channels
2) tracking information (clustering)
3) flexibility (different beams, magnet settings…)

→ programmable, fast trigger decision

Results of 2009 beam-tests



Trigger Type	Trigger Rate (kHz)
Raw Signal Rate	1 120 ± 30
Clusters in x	47.0 ± 0.2
Clusters in θ	37.3 ± 0.2
x OR θ	83.9 ± 0.3
x AND θ	0.49 ± 0.02
Random Coincidences	0.140 ± 0.001



[P. Achenbach et al., A Large-Scale FPGA-Based Trigger and Dead-Time Free DAQ System for the Kaos Spectrometer at MAMI, IEEE Real-Time 2010 Conference Record]

Detector production finished in 2010

18 432 fibres in 144 bundles with associated 144 bundle connectors, MaPMTs, front-end boards, etc...

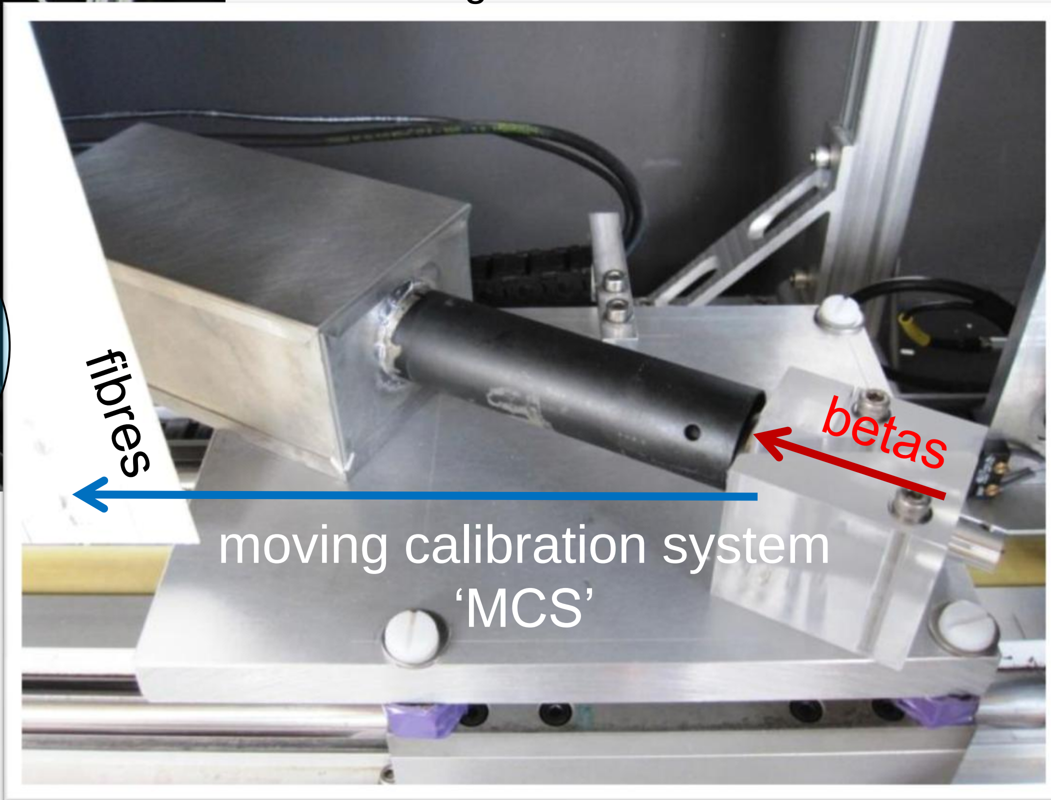
- all work done by 'HiWi' and doctorate students
- quality control after each production stage:

→ fibre bundle rejection,
→ cable rejection,
→ connector rejection

for more on detector production, quality control, test-stands for PMT alignment
→ see talk by Anselm Esser

Detector calibration and characterisation

- collimated ^{90}Sr source
- short fibre with PMT as trigger
- automatic course of action:
  – computer controlled carriage moves along detector
  – data-taking for precise positioning
  – data taking for fibre bundle calibration

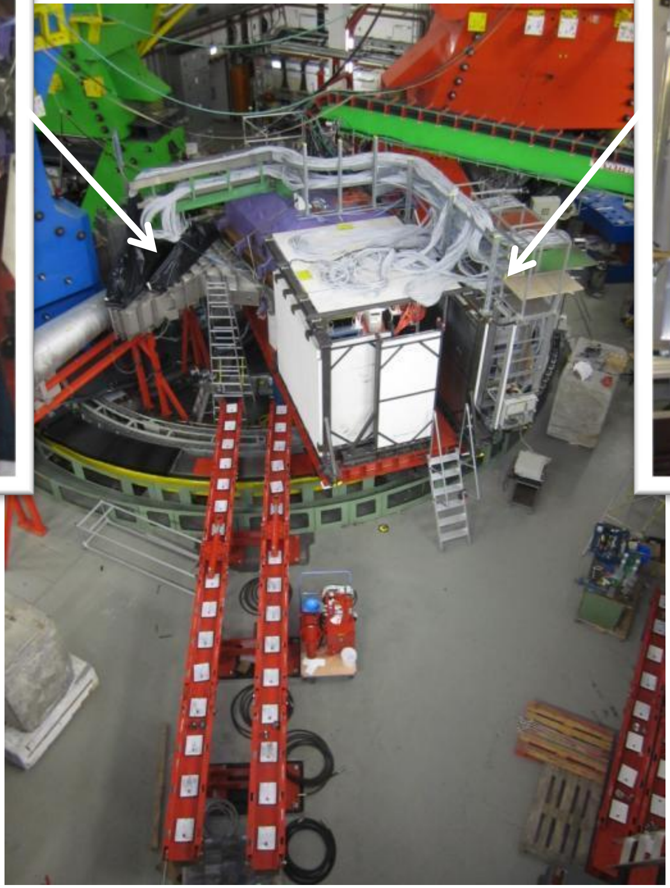


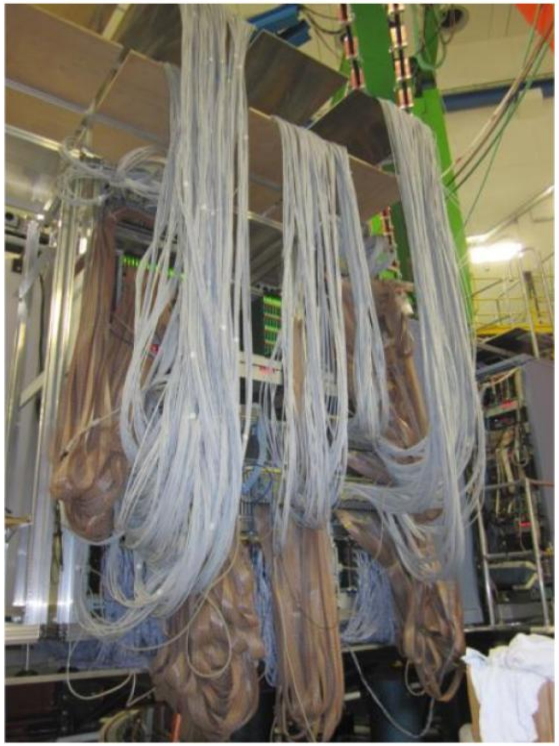
several months of preparation work for gain calibration and final control of all detector modules

details → see talk by Anselm Esser

Beam-tests 24–29 August 2010

beam energy: 510 MeV
beam intensity: 0.1–100 μA
spectrometer angle: 37.5°
targets: CH_2 and ^{12}C



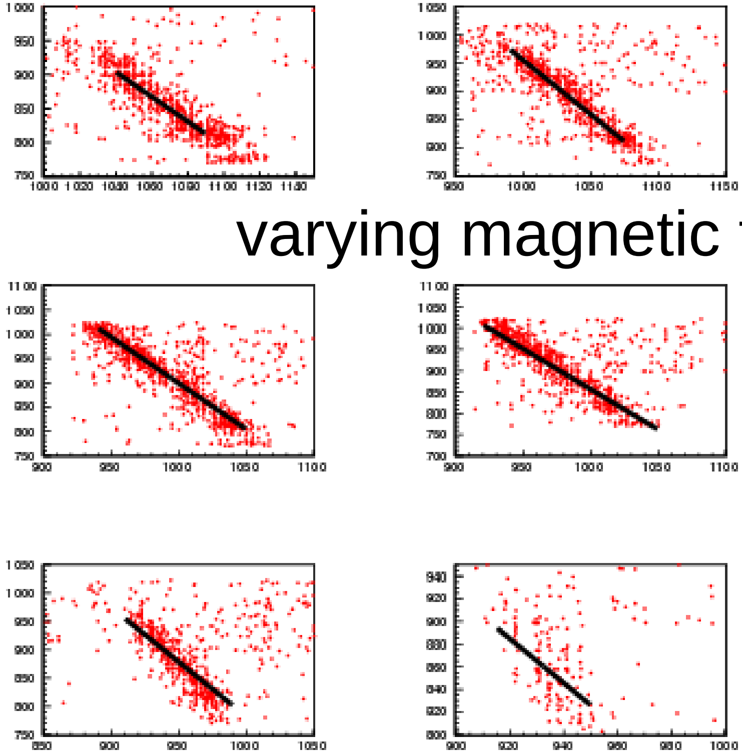


~ 120 fibre detectors in two planes placed in high radiation environment

7 front-end CPUs
~ 4 000 detector signals
~ 40 trigger modules with FPGA programming
~ 6 kHz data-taking rate in each ROB PC

Fibre detector as electron arm spectrometer

θ (dispersive coordinate)



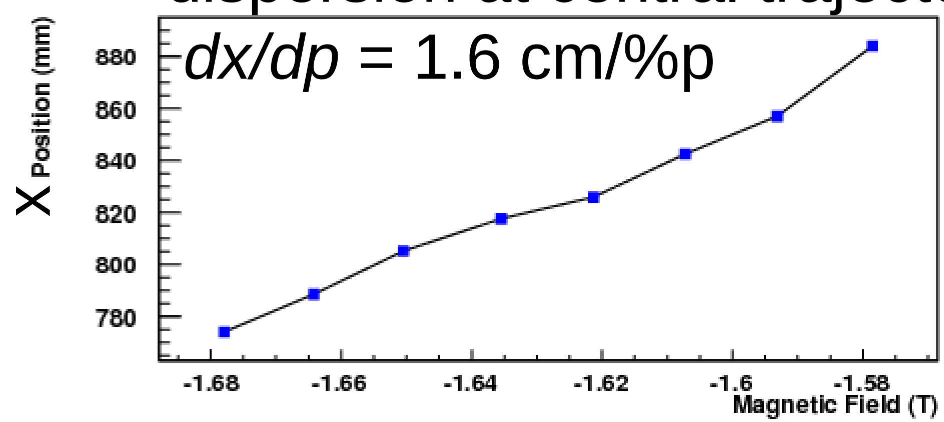
varying magnetic field

x (dispersive coordinate)

with p(e,C:e'K:p)
θe = 80.4°±5°
θp = 37.5°±10°

coincidence acceptance limited by SpekC

dispersion at central trajectory:



dx/dp = 1.6 cm/%p

Further studies

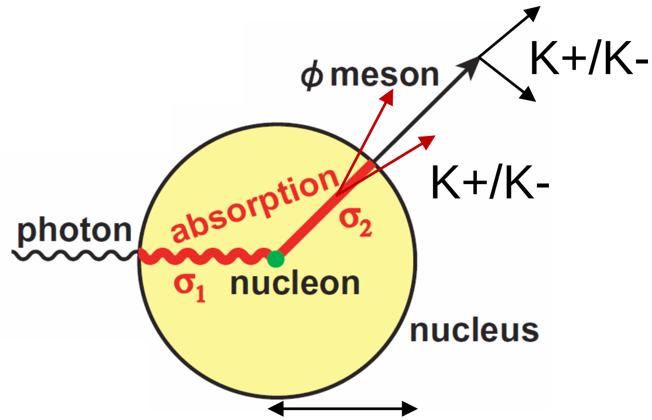
Concept for a study of φ vector mesons

Invariant mass distributions of φ vector mesons inside and outside the nuclear medium via K^+/K^- pair spectroscopy at $\rho_N \cong \rho_0$ and T=0

modification studied by two decay channels:

di-lepton: difficulty in the treatment of the background

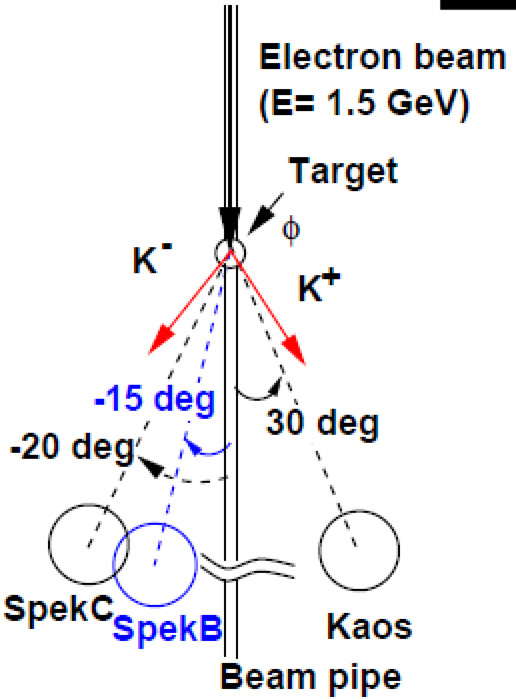
KK: distortion by the *KN* and *KN* interactions



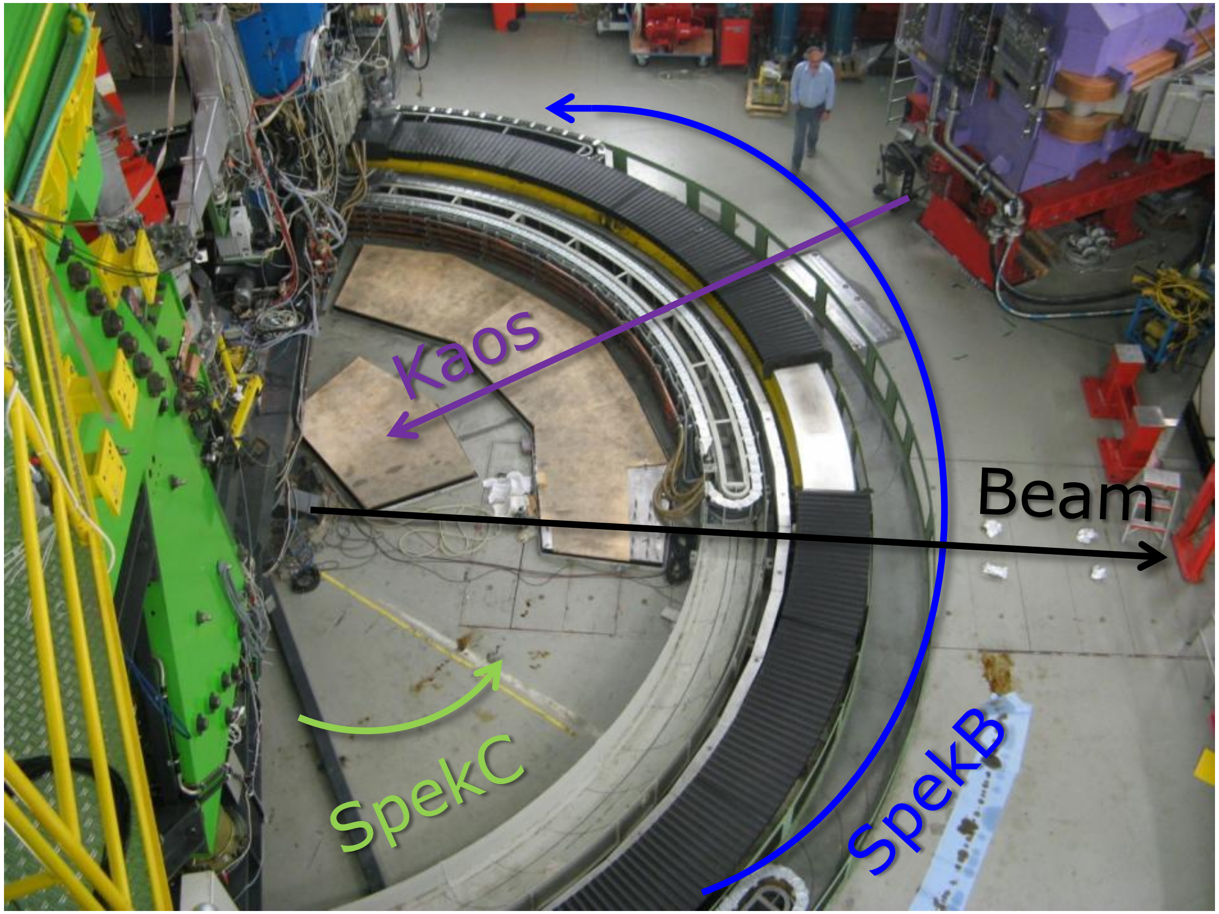
r (A=60) ≈ 4 fm

Meson	Mass (MeV/c²)	Γ (MeV/c²)	cτ (fm)	Main decay	e⁺e⁻ BR
ρ	768	152	1.3	$\pi^+\pi^-$	4.4×10^{-5}
ω	782	8.43	23.4	$\pi^+\pi^-\pi^0$	7.2×10^{-5}
ϕ	1019	4.43	44.4	$K^+ K^-$	3.1×10^{-4}

Experimental set-up at MAMI



new demands on spectrometer set-up:
SpekB at 90°; SpekC at -20°; Kaos at 35°



Trajectory length:
SpekB: 12.03 m
SpekC: 8.53 m
Kaos: 5.50 m

Solid angle:
SpekB: 5.6 msr
SpekC: 28 msr
Kaos : 11 msr

Count rate estimate

Kaon survival:

$$Y_\phi = N_e \rho L_{target} \frac{N_a}{A} \Delta\sigma(\Omega, t)$$

$$Y_\phi \simeq 600 \times \Delta\sigma(\Omega, t)\ [1/\mathrm{nb}]$$

P = $\exp(-L/(c\tau_K \beta\gamma))$
P(Kaos) = 0.11
P(SpekC) = 0.04
P(KK) = 4.4 x 10^{-3}

	SpekB at -15°	SpekC at -20°
$\mathrm{N}^{\phi}_{\mathrm{gen}}$	2.4×10^7	2.0×10^7
$\mathrm{N}^{KK}_{\mathrm{coin}}$	54	282
$\mathrm{N}^{KK}_{\mathrm{coin}}/\mathrm{N}^{\phi}_{\mathrm{gen}}$	$23/10^7$	$127/10^7$
KK-survival probability	0.002	0.004
$Br(\phi \to K^+K^-)$	0.49	0.49
wt	0.3	0.3
η_{eff}	0.5	0.5
K^+K^- coincidence rate	0.6/hour	7/hour

$\varphi \rightarrow$ di-lepton background study

set-up:

SpekA at -51.3°, negative polarity, central momentum= 646 MeV/*c*
SpekB at +52.8°, positive polarity, central momentum= 646 MeV/*c*
25 μA electron beam of 1508 MeV on 45 mg/cm^2 ^{12}C target

data:

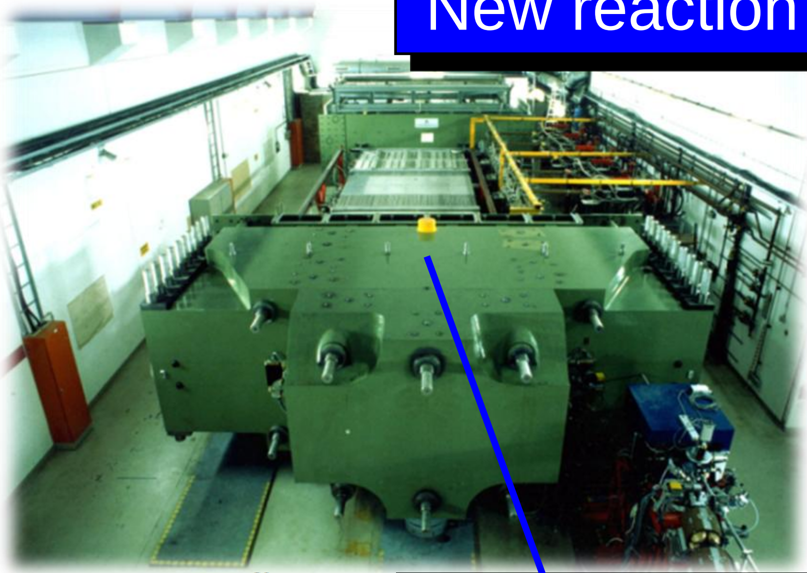
27 runs x 30 min.:	13.5 h
coincidence rate:	2 Hz
coincident events:	86 827
missing mass events:	33 487
coincidences in 1.6 ns:	889
random coincidences:	330
positron ID (Cherenkov):	35

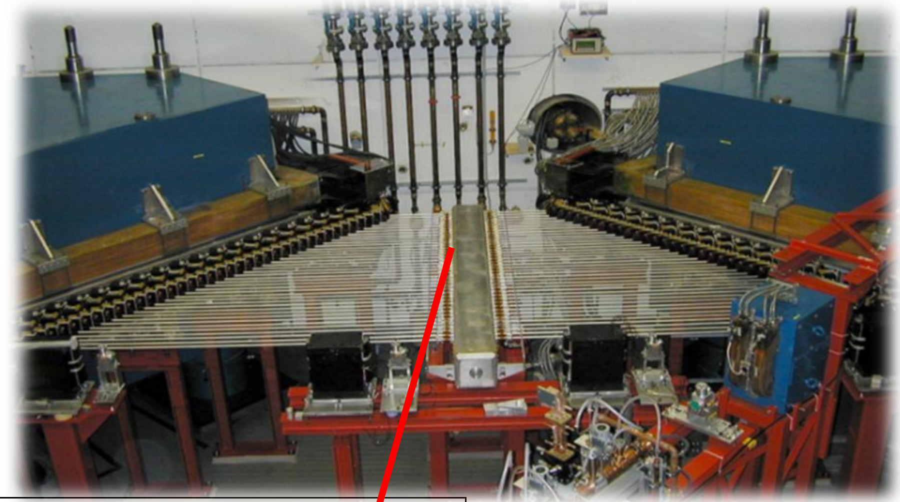
Time-line 2o1o onwards

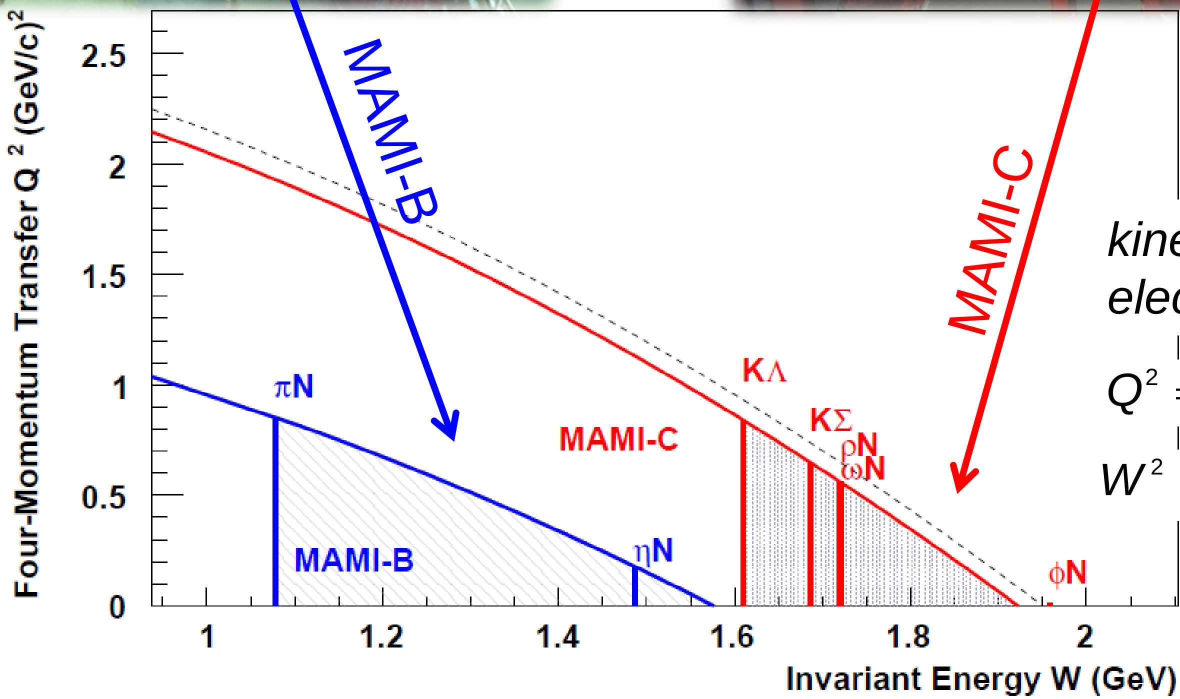
Time	Activities at MAMI
August 2010	In-beam tests of electron arm detectors and sophisticated FPGA trigger system at very forward angles (8-10 degrees to the beam-line); measurements of background rates; implementation of different trigger options for background suppression; in-beam test of a prototype scintillator paddle
September – November 2010	Installation work for the pre-target beam chicane: primary dipole (DCI I), positioning plates, mountings, vacuum chambers, beam pipes, secondary dipole (DCI II), pre-target steering system, beam position monitors, exit beam-line
Winter 2010/11	Possibility for in-beam tests of new scintillator wall elements Elementary kaon electroproduction measurements with the Kaos spectrometer at zero degree using the commissioned beam chicane?
Spring 2011	Commissioning of a new scintillator wall? First decay pion spectroscopy experiment using the new scintillator wall in the Kaos spectrometer as kaon tagger and SpekA for pion detection?
Summer 2011	First hypernuclear spectroscopy experiment using the Kaos spectrometer at zero degree and the electron arm detector for small angle electron tagging?

Thank you!

New reaction channels with MAMI-C







kinematic plane in electro-production:

$$Q^2 = -q^2 = (q_e^\mu - q_{e'}^\mu)^2$$

$$W^2 = s = (q^\mu + p_{target}^\mu)^2$$