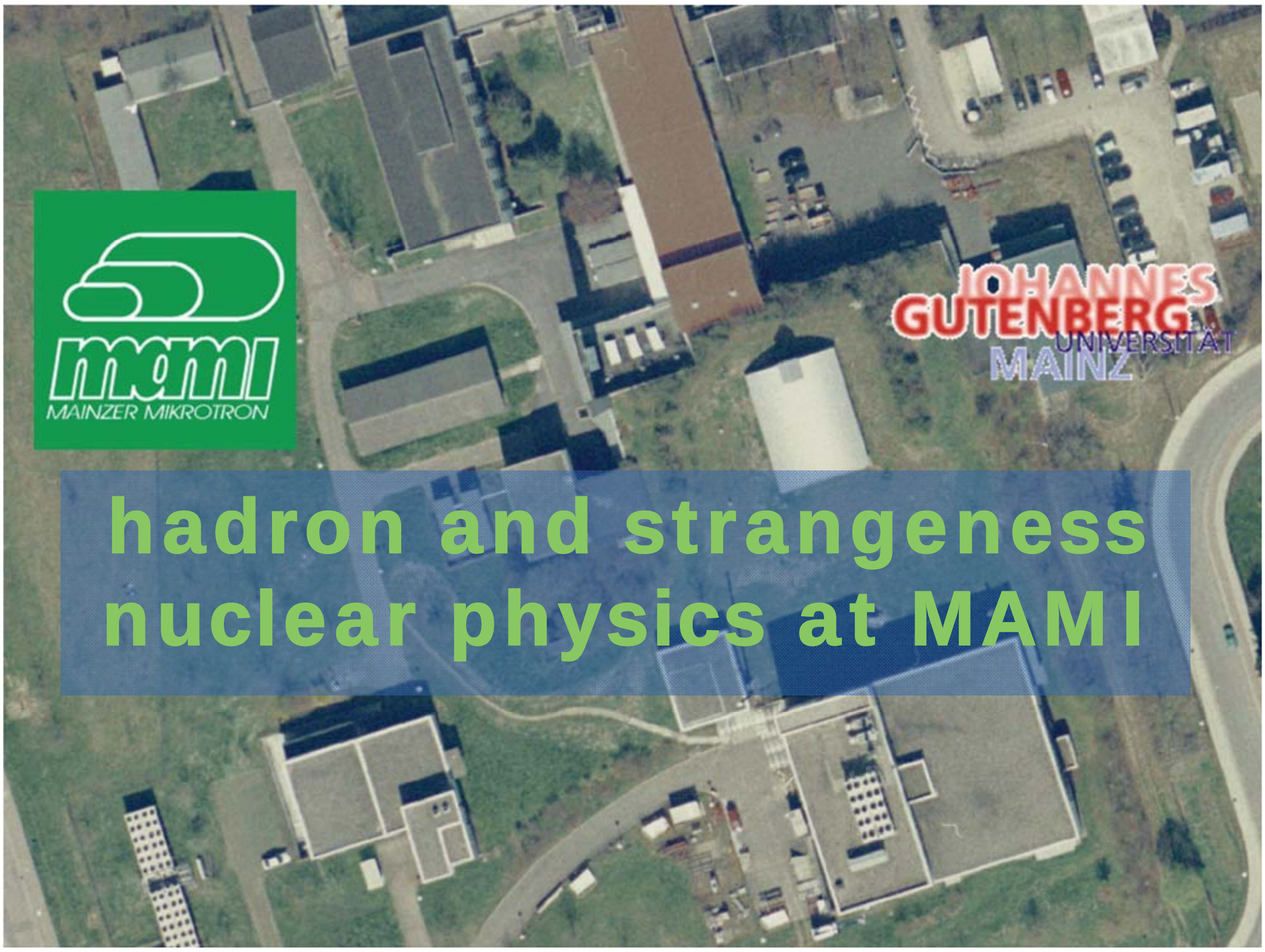
MAMI-C and PANDA for hadron and strangeness nuclear physics

Josef Pochodzalla SNP School 2012

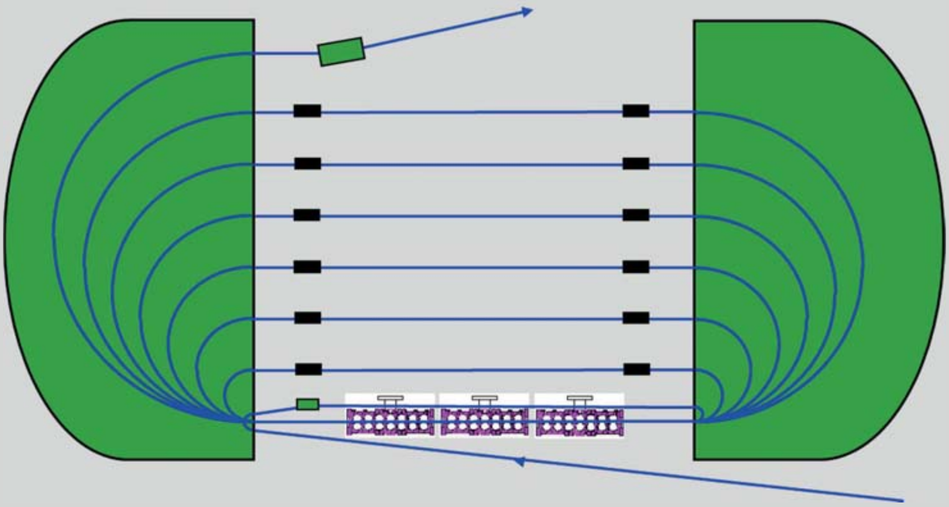
Osamu Hashimoto

HYP 2006



Race-Track Microtron (RTM)

- 2 magnets + x times the same linac



- e.g.: single pass energy gain 7.5MeV, 90 turns ⇒ 675MeV total energy gain
- and only 163kW for 67.5kW of beam power (100mA) h=41.4%

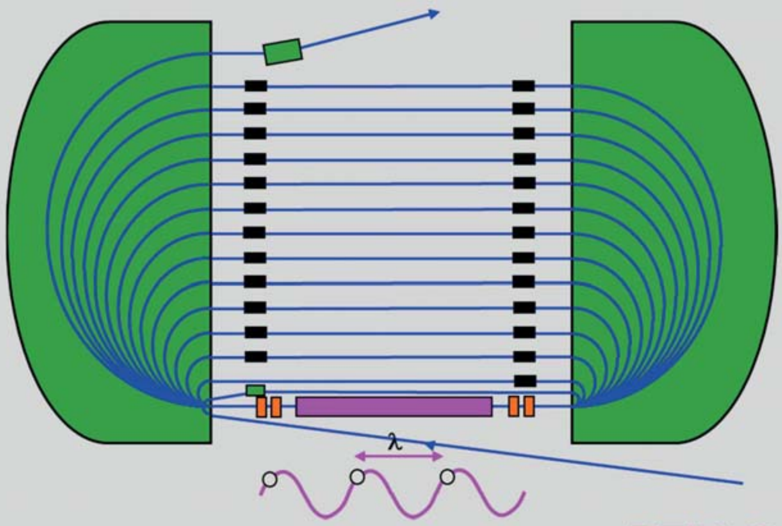
RTM basics

Dipole:
field B

$$R = \frac{E}{e \cdot c \cdot B}$$

$$\Rightarrow$$

$$\Delta R = \frac{\Delta E}{e \cdot c \cdot B}$$



- Dynamic coherence condition

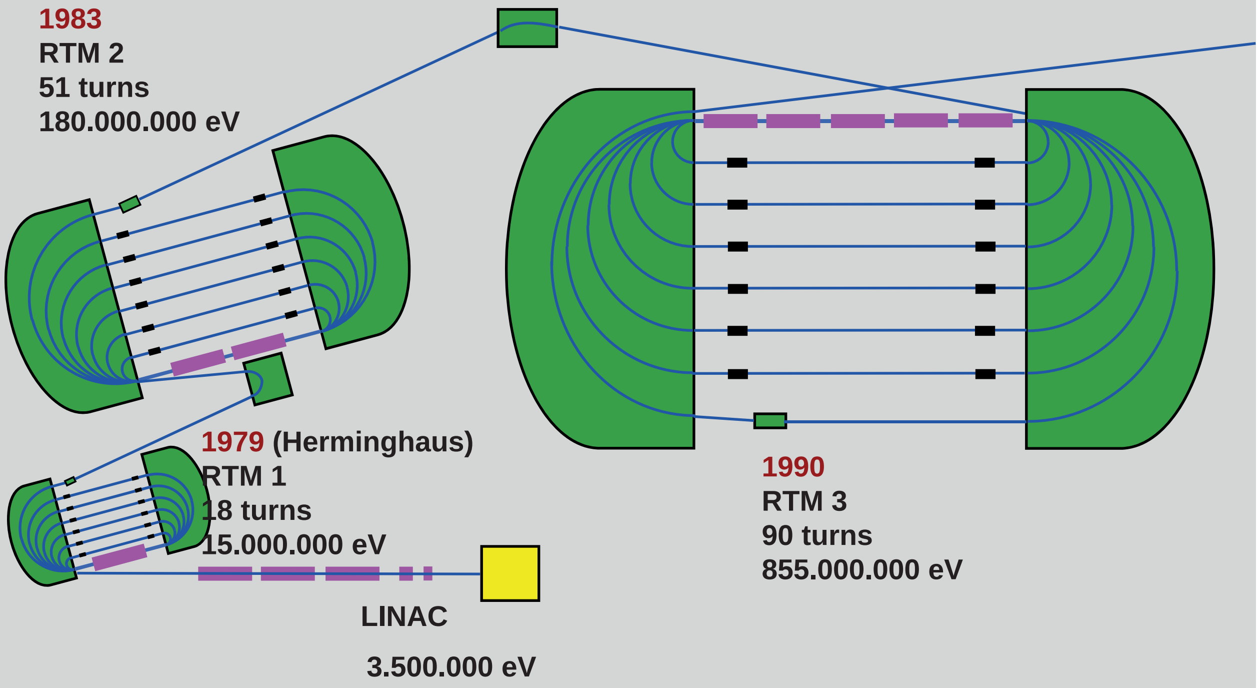
$$L_{i+1} - L_i = n \cdot \lambda \quad (= 2\pi \cdot \Delta R)$$

$$\Delta E = \frac{e \cdot c \cdot B}{2\pi} \cdot n \cdot \lambda$$

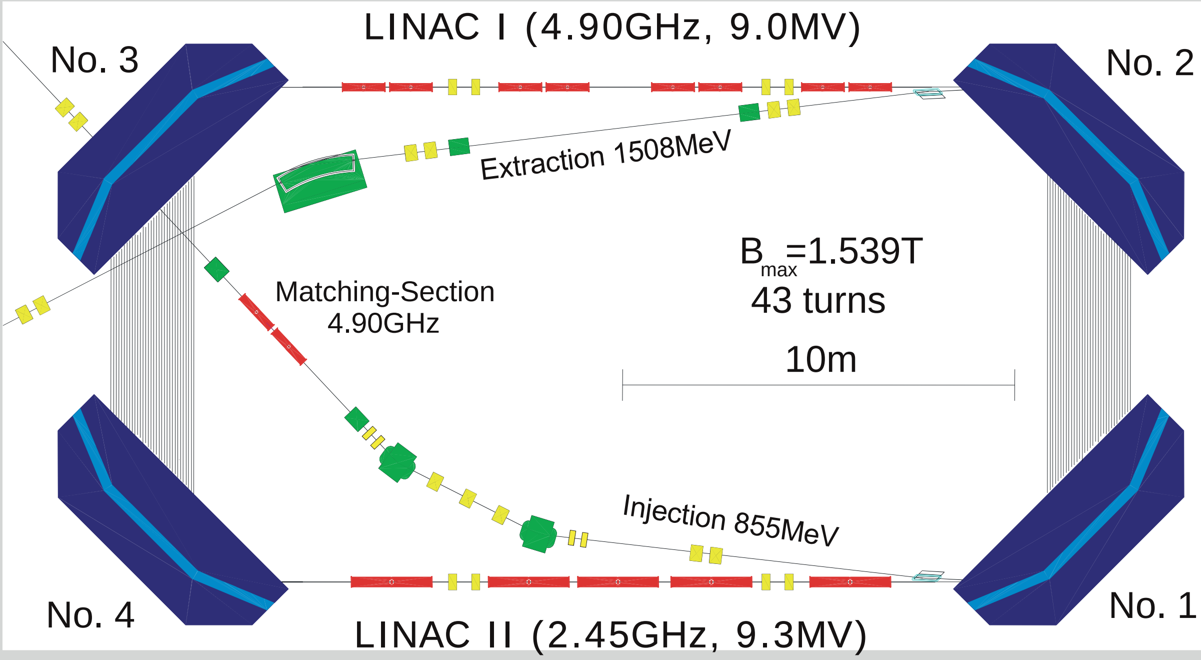
RTM 3
(180MeV - 855MeV)

n=1,B=1.28T
λ=0.1224m
(2.45GHz)
→ ΔE=7.48MeV
length: 9m

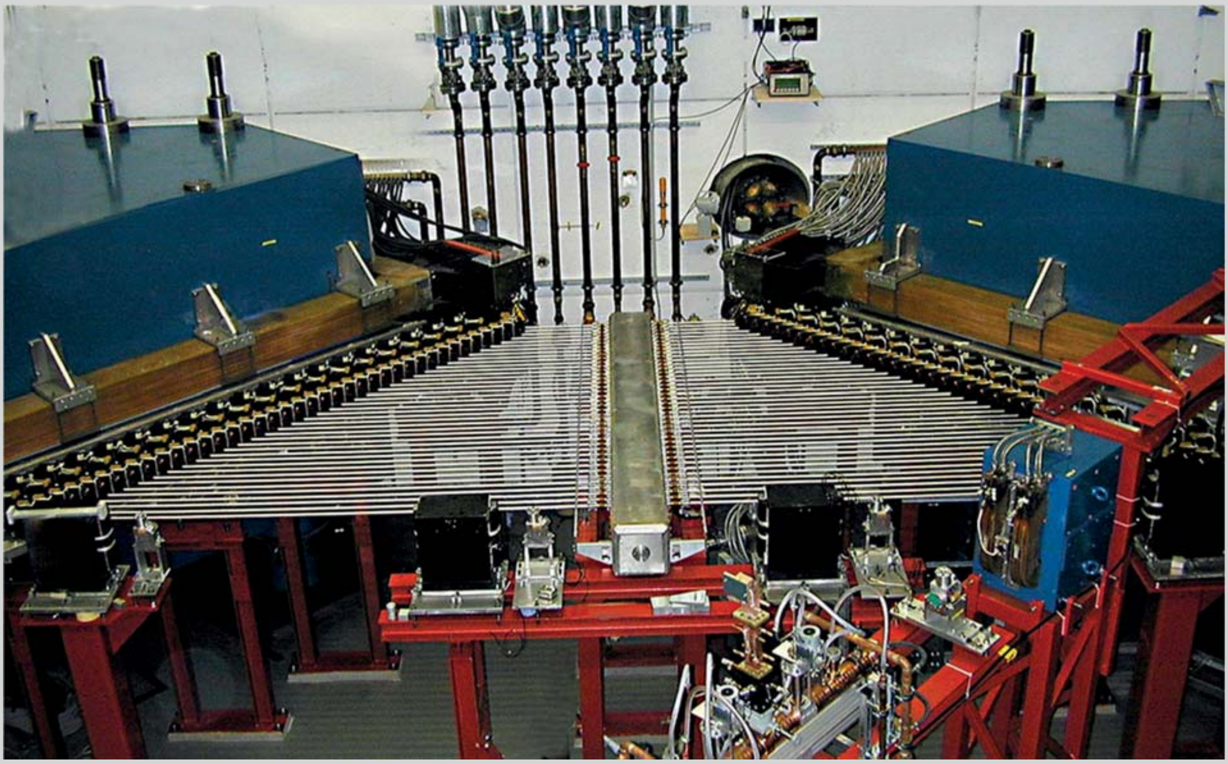
MAMI-B microtron cascade scheme



MAMI-C

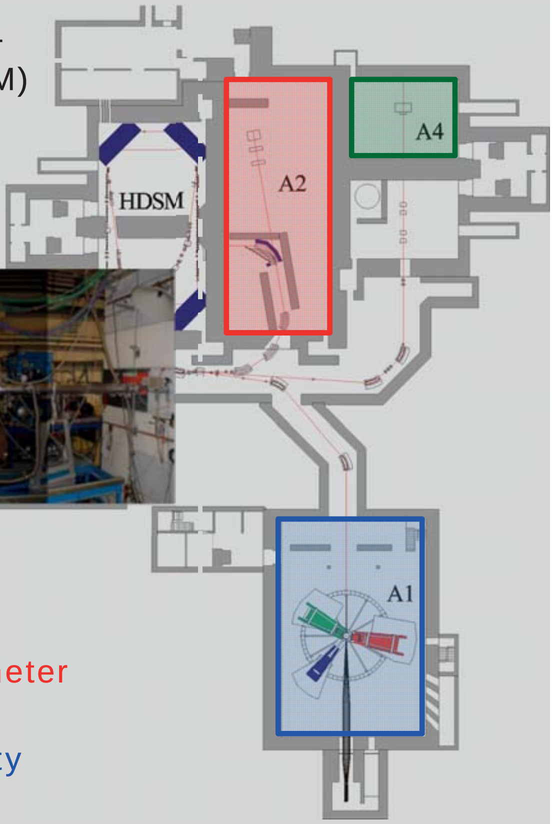


- Doubling the maximum energy of MAMI-B
- Best approximation to the inherent stable and reliable RTM principle



The MAMI Experiments

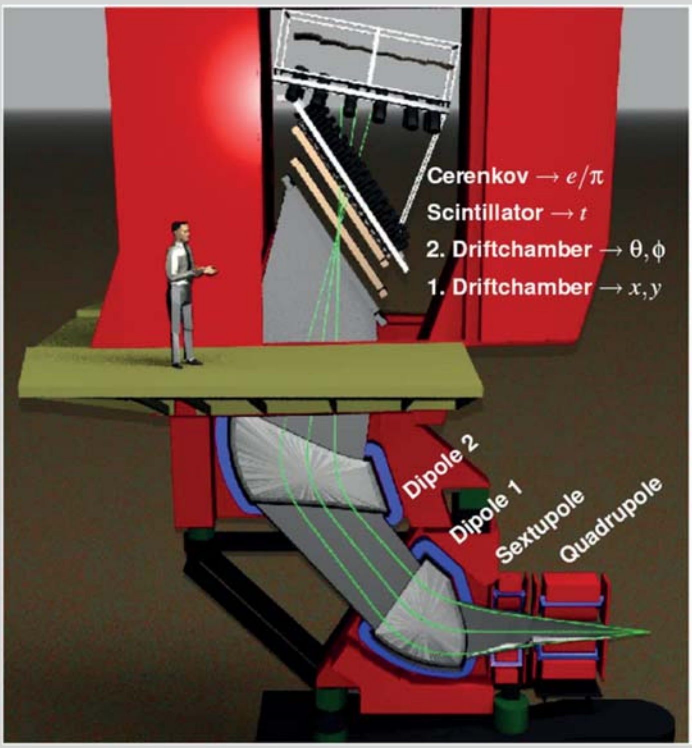
- Cascade of three race track microtrons + **H**armonic **D**ouble **S**ided **M**icrotron (HDSM)

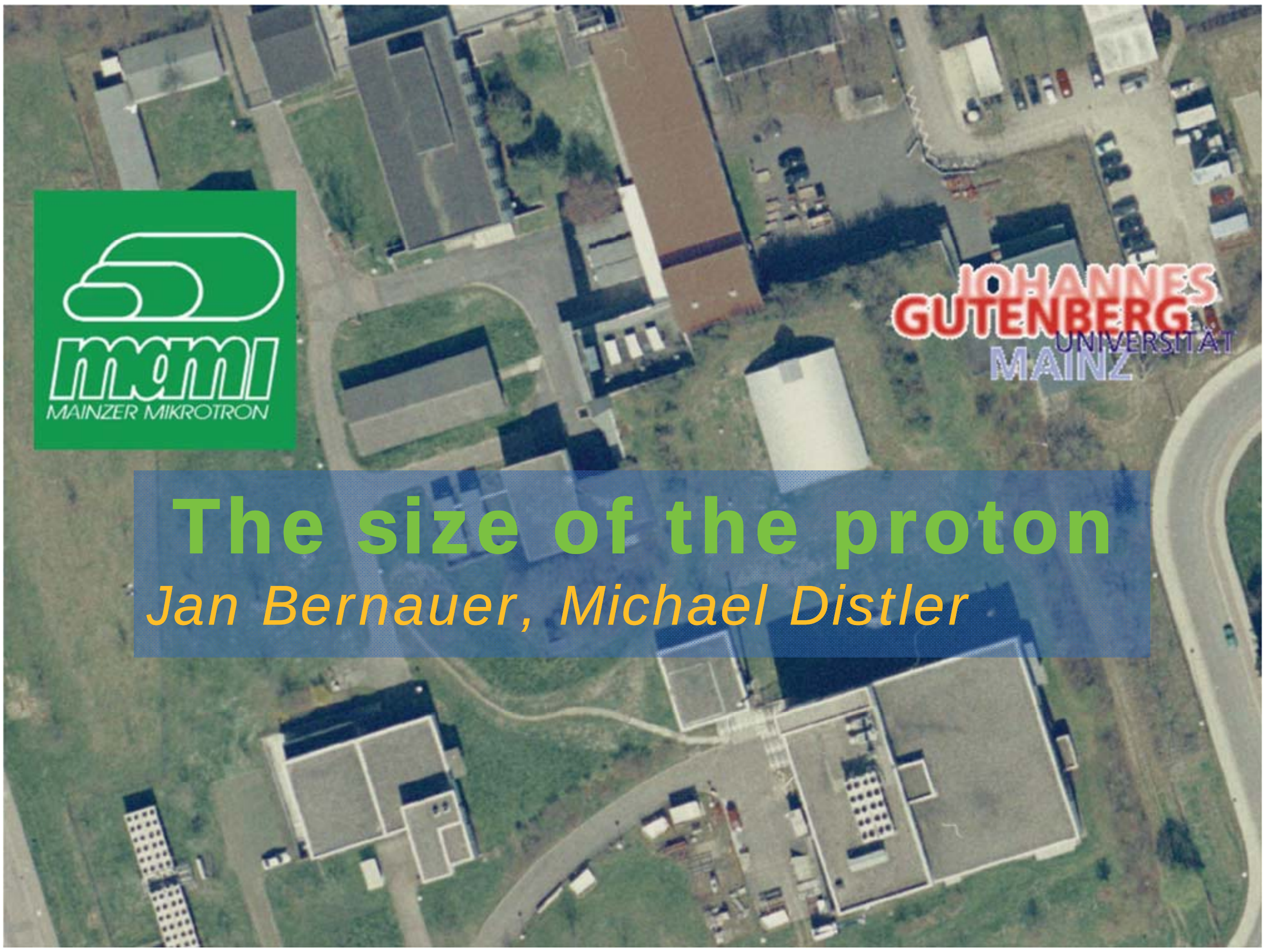


- A4 - Compton backscatter polarimeter
  - fast PbF_2 calorimeter
- A2 - photon tagger and photon spectrometer
  - Crystal Ball
- A1 - charged particle spectrometer facility

High resolution spectrometers A-B-C

- Momentum resolution
  - $\delta p/p < 10^{-4}$
- Momentum acceptance
  - $\Delta p/p = 20\%$
- Accepted solid angle
  - $\Delta\Omega = 11.5° \times 8.0° = 28\text{msr}$





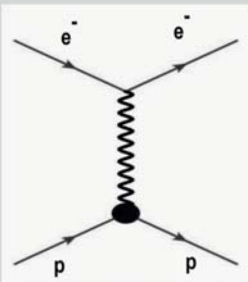
The size of the proton

Jan Bernauer, Michael Distler

JG|U

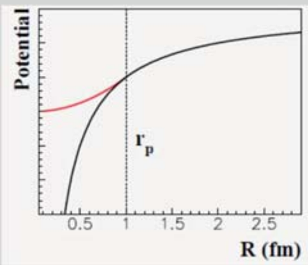
The Size of Proton

- Proton radius is a fundamental quantitiy of one of the most important objects in QCD
- There are two completely different sources of experimental information on proton charge rms radius
  - Elastic electron-proton scattering



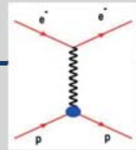
$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \frac{1}{\varepsilon\left(1+Q^2/4m_p^2\right)}\left(\varepsilon \cdot G_E^2(Q^2) + \frac{Q^2}{4m_p^2} \cdot G_M^2(Q^2)\right)$$

  - Precision spectroscopy of hydrogen atoms (lambshift)



$$V(r) = \begin{cases} -\frac{Z\alpha}{2r_p}\left(3 - \frac{r^2}{r_p^2}\right) & (r < r_p) \\ -\frac{Z\alpha}{r_p} & (r \geq r_p) \end{cases}$$

The Size of Proton



- Two methods for elastic e-p scattering
  - unpolarized elastic e-p scattering   e p → e p
  - "Rosenbluth separation" to separated $G_E(Q^2)$ and $G_M(Q^2)$

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \frac{1}{\varepsilon\left(1+Q^2/4m_p^2\right)}\left(\varepsilon \cdot G_E^2(Q^2) + \frac{Q^2}{4m_p^2}\cdot G_M^2(Q^2)\right)$$

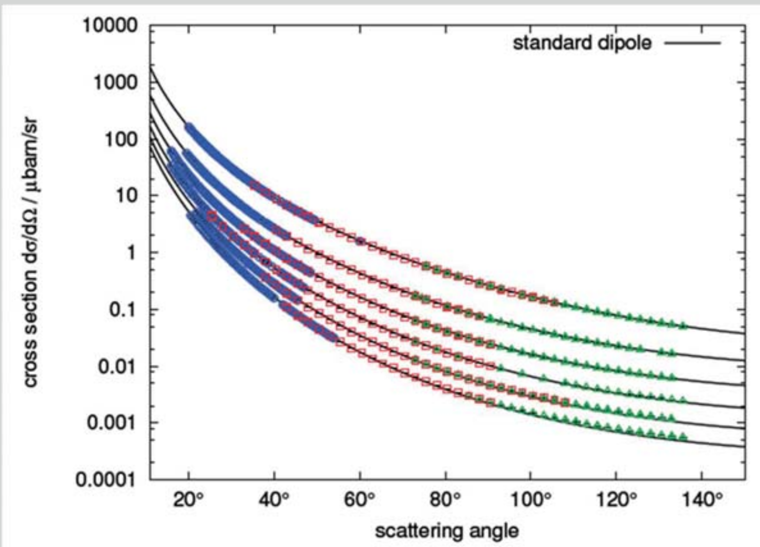
with photon polarization $\varepsilon = \left(1+2\left(1+Q^2/4m_p^2\right)\cdot \tan^2(\theta_e/2)\right)$

  - For small Q^2 $r_p = \sqrt{\langle r_{ep}^2 \rangle} = \sqrt{-6\frac{dG_E(Q^2)}{dQ^2}}\Bigg|_{Q^2\to 0}$

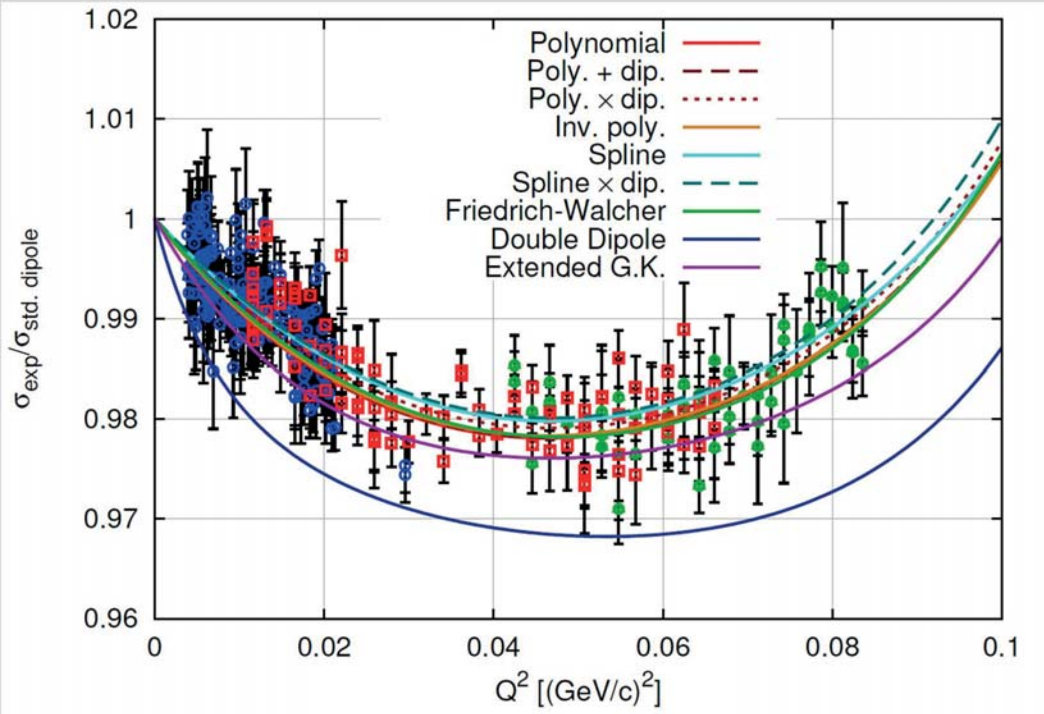
  - Longitudinal polarized electron scattering $\vec{e}p \to e\vec{p}$
    - polarization transfer from electron to proton
    - polarized electrons scattered from polarized targets
    - Recoil proton is analyzed in a magnetic spectrometer with polarimeter

Precision studies at MAMI

- E_0=855, 720, 585, 450 315, 180 MeV
- about 1400 points of angular distributions (0.1% statistical error)
- change of angle by remote control of spectrometer rotation
- angular precision < 0.5 mrad vertical and horizontal
- high quality control of luminosity to reduce systematic errors
- ...



Example: $E_0 = 180$ MeV

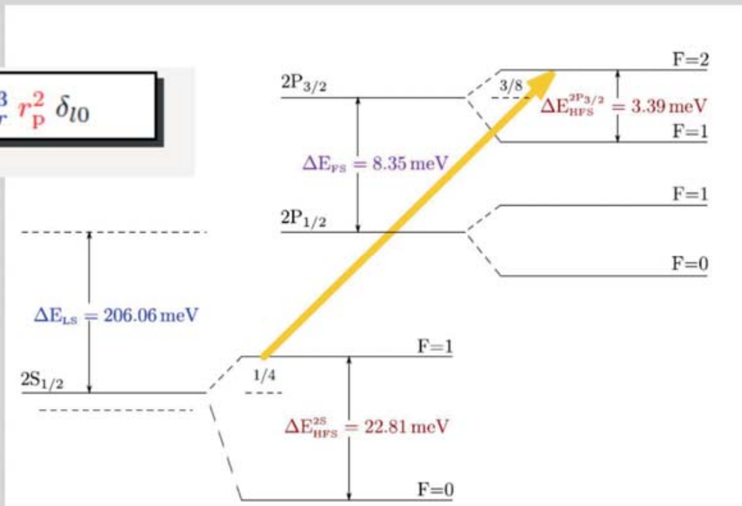


$r_p = 0.879(8)\ fm$ J.C.Bernauer etal. (A1 Collaboration), PRL 105, 242001 (2010)

Lamb shift

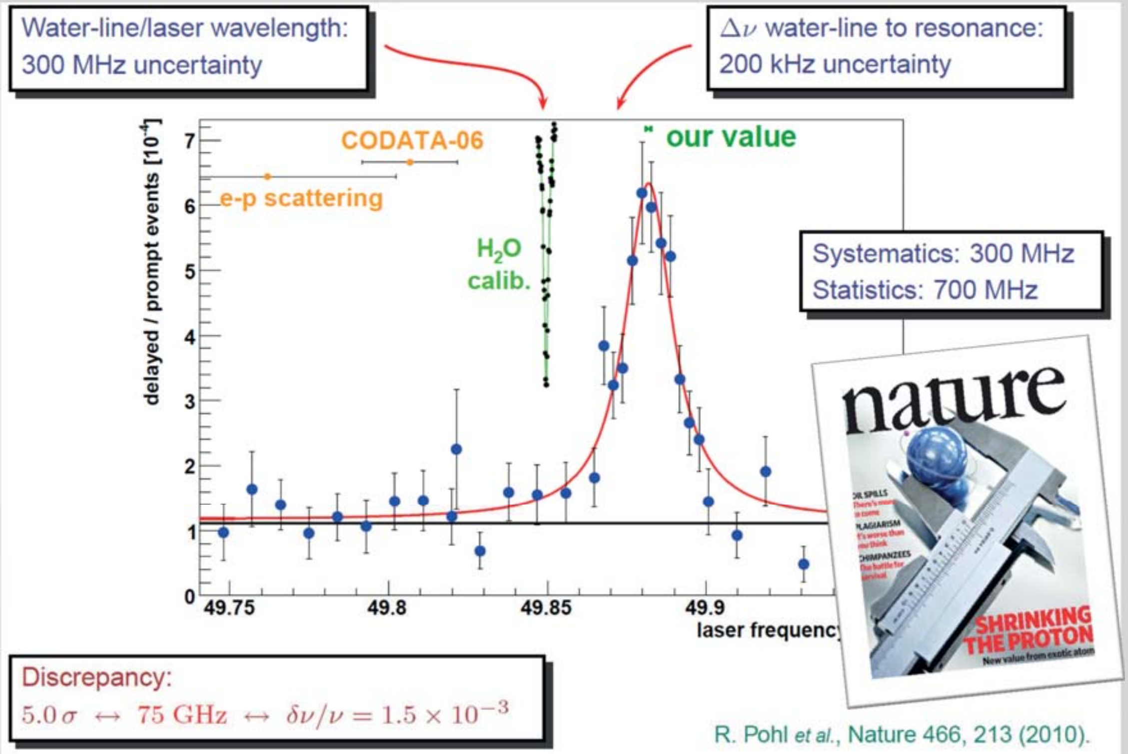
- energy difference measurement between $2S_{1/2}$ and $2P_{3/2}$ states in the hydrogen atom and its comparison with a theoretical formula for this energy difference

$$\Delta E^{FS} = \frac{2(Z\alpha)^4}{3n^3} m_r^3\, r_p^2\, \delta_{l0}$$



- Why muonic hydrogen?
  - the muon is about 200 times heavier than the electron
  - the atomic Bohr radius is correspondingly about 200 times smaller
  - effects of the finite size of the proton on the muon hydrogen atom spectroscopy are thus enhanced

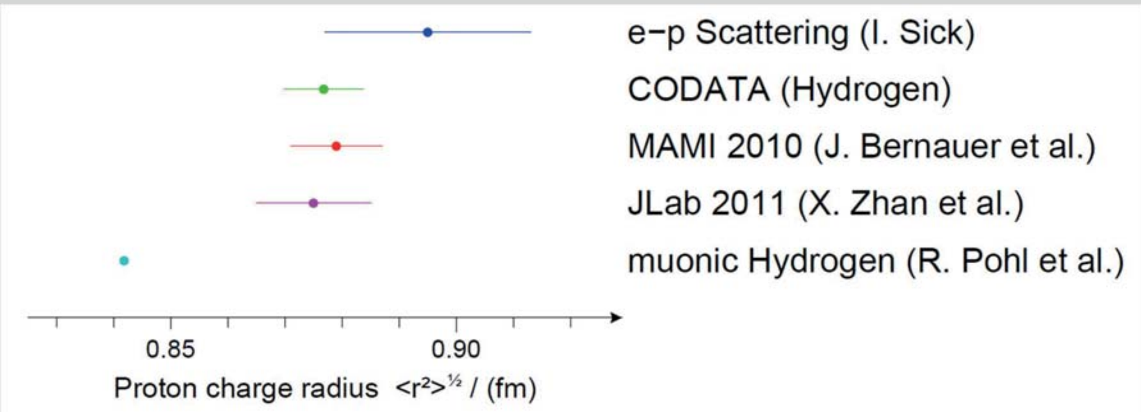
Muonic hydrogen seen by CREMA



See talk of Ryugo Hayano

Proton Radius Puzzle

- 2005: Re-analysis e-p scattering — r_p = 0.897(18) fm
  P.G.Blunden, I.Sick, Phys. Rev. C**72** (2005) 057601
- 2008: Hydrogen spectroscopy (CODATA) — r_p = 0.8768(69) fm
  P.J. Mohr *et al*, Rev. Mod. Phys.**80**, 633 (2008)
- 2010: muonic hydrogen Lamb Shift — r_p = 0.84184(67) fm
  R. Pohl *et al.*, Nature **466**, 213 (2010)
- 2010: Mainz e-p cross section — r_p = 0.879(8) fm
  J.C. Bernauer et al., Phys. Rev. Lett. **105**, 242001 (2010)
- Recoil polarization — r_p = 0.875(10) fm
  X. Zahn et al., arXiv:1102.0318



Ingo Sick´s conclusion...

Overall conclusion: problem with R^{ch}_{rms} persists

Many speculations on origin

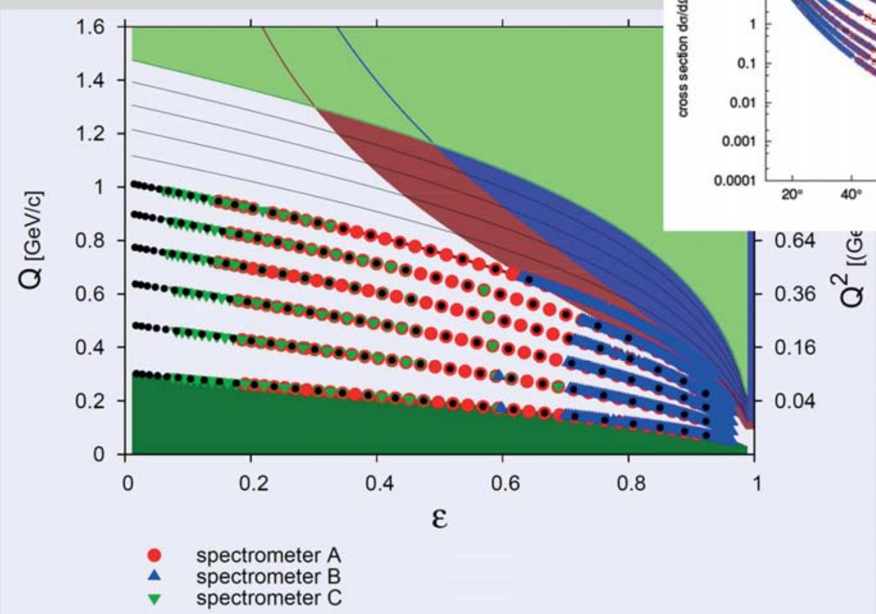
- Missing QED terms?
- Two-photon effects in (e,e)?
- Polarization of proton in μH?
- Problems with radiative corrections?
- Wrong Zemach moment?
- Recoil terms in μH?
- (e,e) and μH not measuring same thing?

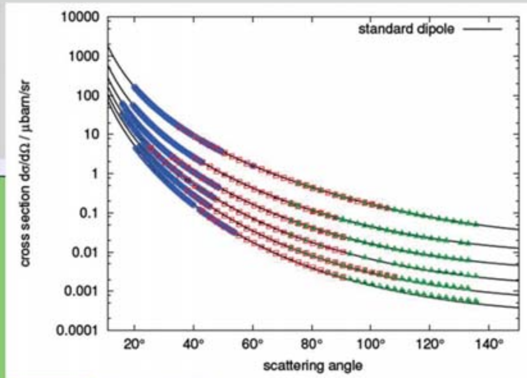
.... but there are plausible arguments against all

Upshot: no clear idea available, and there is a real problem

What‘s next?

- Goal
  - lower Q^2
  - smaller sytematic errors

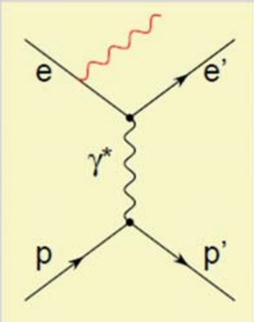


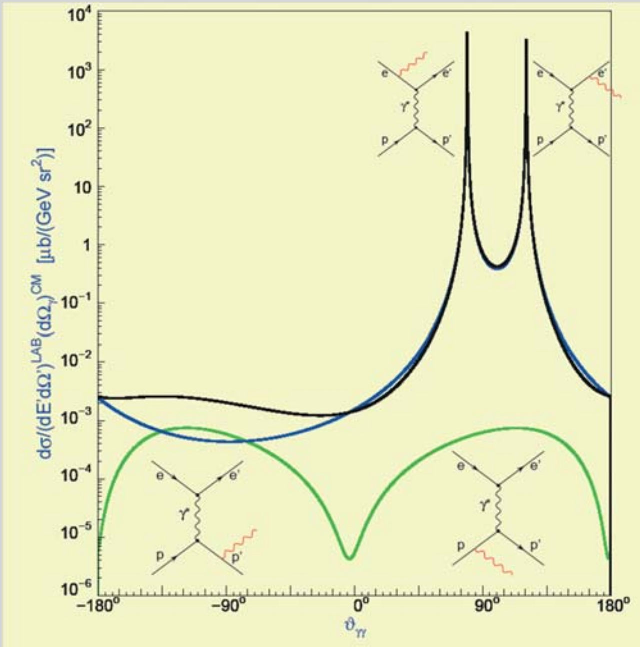


- Smaller angles $\rightarrow$ forward spectrometer
- Smaller systematic errors $\rightarrow$ „stable“ experimental setting

low Q^2 extension: ISR @ MAMI

- Map electron energy by initial state radiation

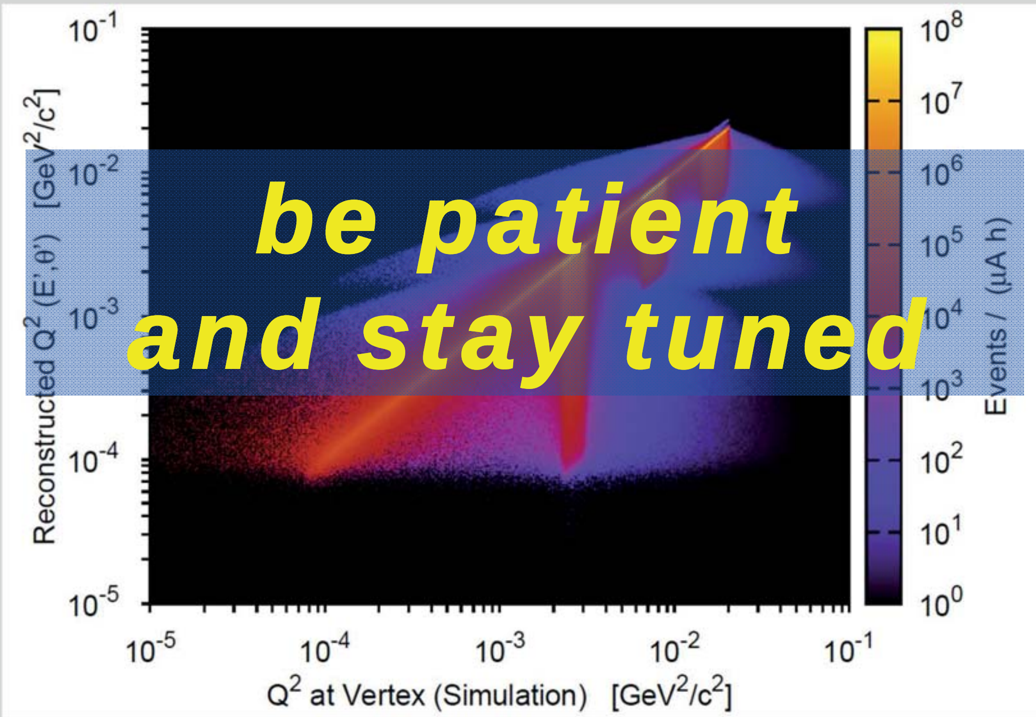


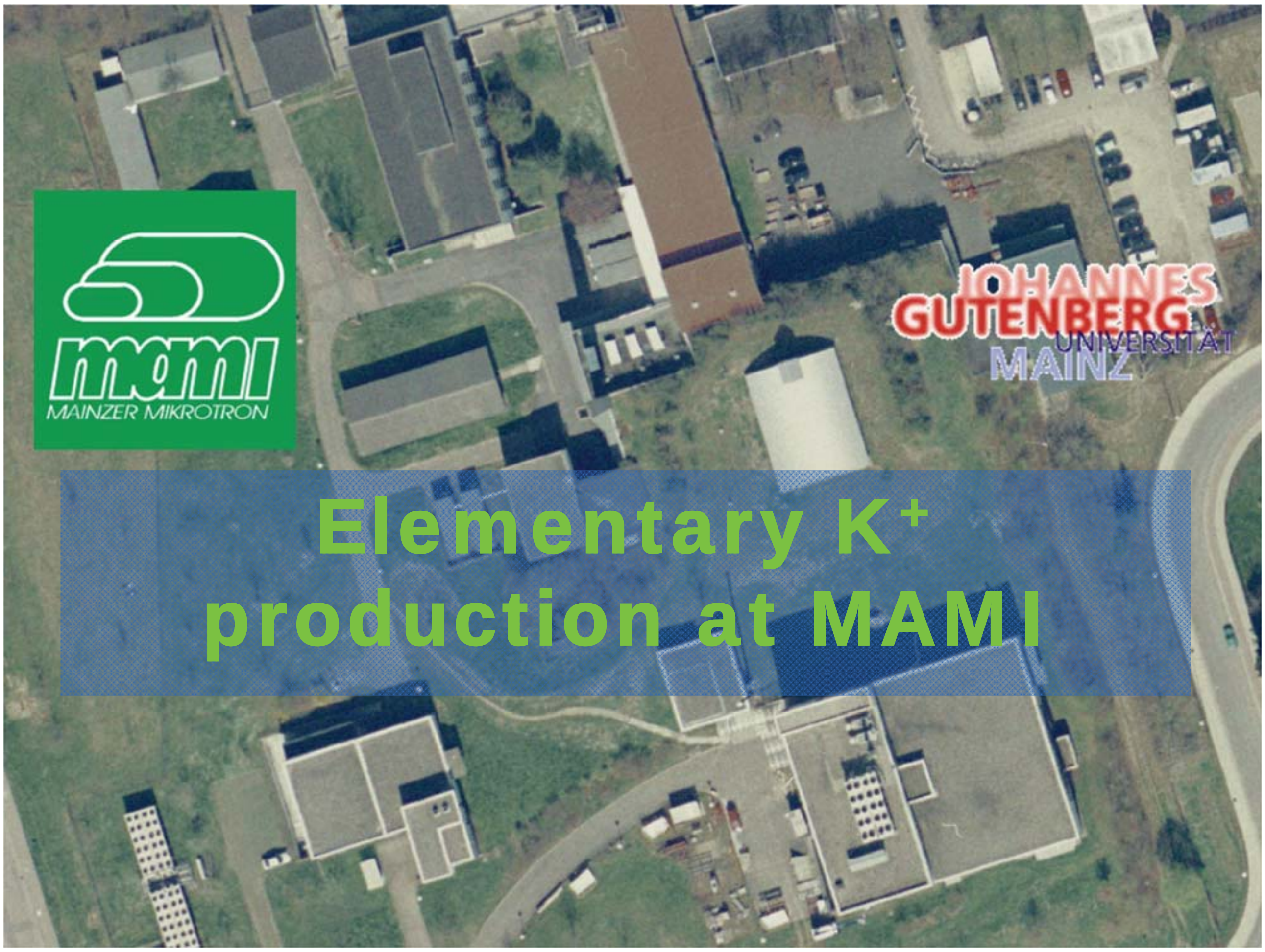


- measured at single MAMI energy ⇒ reduced systematics error

Initial State Radiation ISR

- Example E_e= 195, 330, 495 MeV
- $\theta_{e'}$ =15.3°





Elementary K^+ production at MAMI

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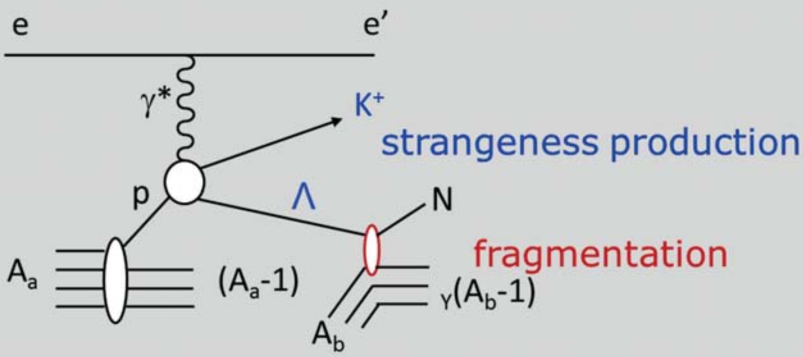
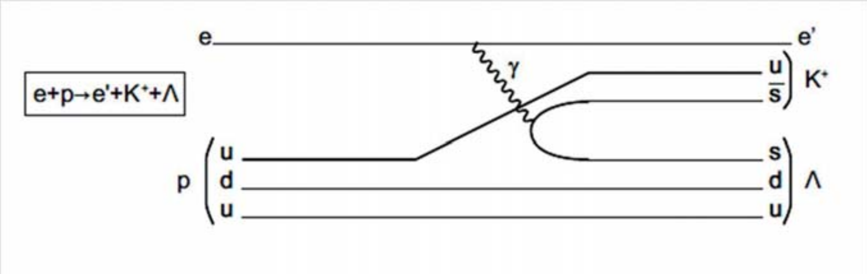
Electroproduction of Strangeness

- electron vertex is well-known from QED
- one-photon exchange is accurate on the % level



- electro production is a clean tool to study the structure of hadrons
- ...and the properties of strange hadrons in nuclei

Kaon production with em probes



$$\gamma^{(*)} + N \rightarrow K + Y$$

$$\gamma^{(*)} + p \rightarrow K^+ + \Lambda$$
$$\gamma^{(*)} + p \rightarrow K^+ + \Sigma^0$$
$$\gamma^{(*)} + p \rightarrow K^0 + \Sigma^+$$
$$\gamma^{(*)} + n \rightarrow K^0 + \Lambda$$
$$\gamma^{(*)} + n \rightarrow K^0 + \Sigma^0$$
$$\gamma^{(*)} + n \rightarrow K^+ + \Sigma^-$$

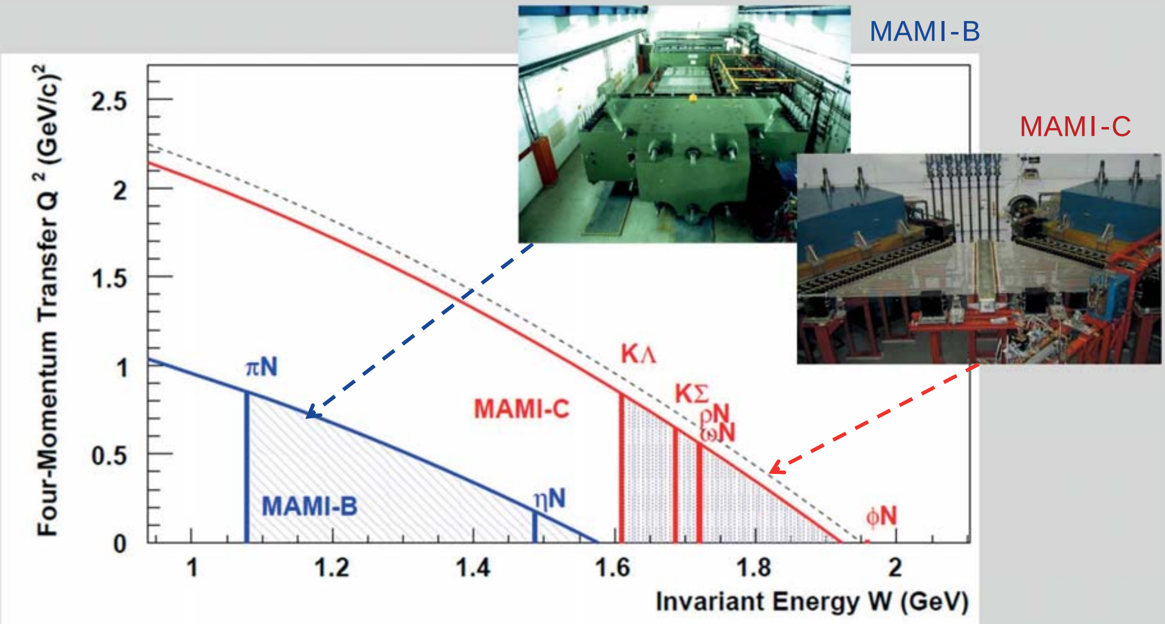
- high energy electron on nucleons/nuclei
  - electron accelerator
  - fixed target
- charged kaon production channels
  - multi spectrometer setup (A1)
  - delayed decay – Crystal Ball (A2)
- neutral kaon production channels
  - decay photon detectors
  - Crystal Ball (A2 Collaboration)

$$E_{CM} = \sqrt{2E_\gamma M_p + M_p^2} = M_\Lambda + M_{K^+} = 1.6GeV \quad \Rightarrow E_{\gamma,\min} = 0.9GeV$$

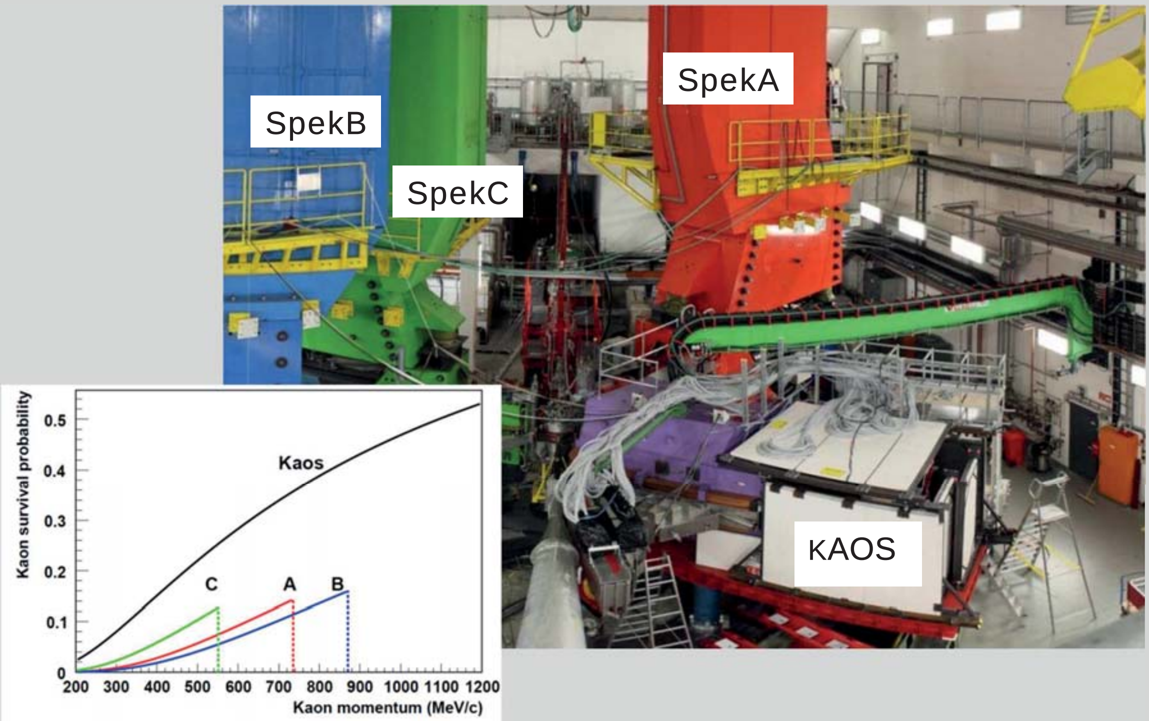
Electroproduction at MAMI

- Four momentum transfer $Q^2 = -(q^\mu)^2 = -(q_e^\mu - q_{e'}^\mu)^2$
- Invariant mass of the photon-proton system

$$\sqrt{s} = W = \sqrt{(q^\mu + p_{\text{target}}^\mu)^2} = \sqrt{M_p^2 - Q^2 + 2M_p(E_e - E_e')}$$



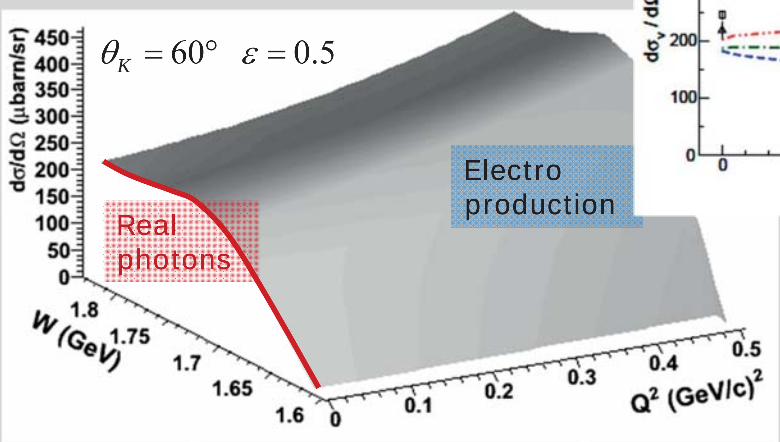
KAOS spectromter

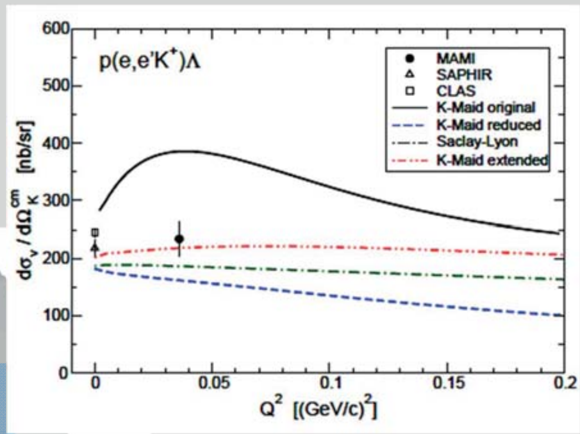


Kinematic variables

- Threshold for strangeness production W>1.6GeV
- A1 collaboration measures close to threshold
  - Q^2 dependence of cross section contains information on longitudinal contribution
  - W dependence of cross section information on nucleon resonances

See talk of Reinhard Schumacher

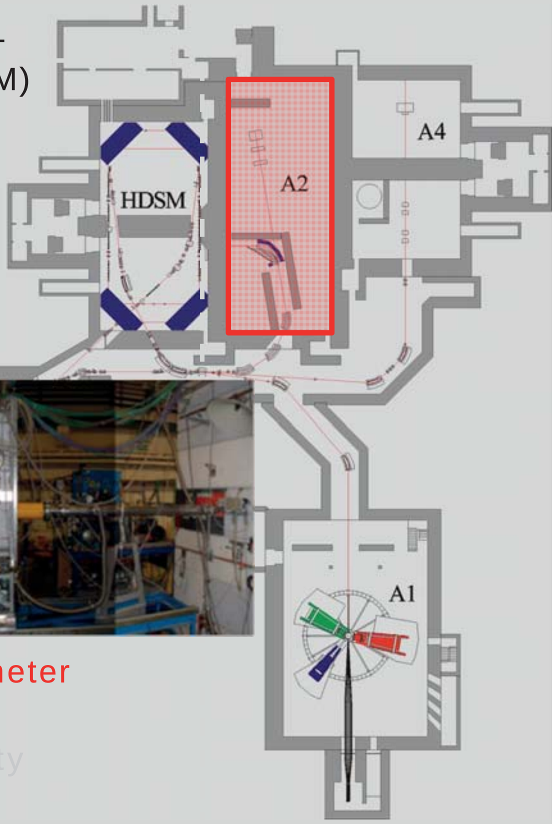


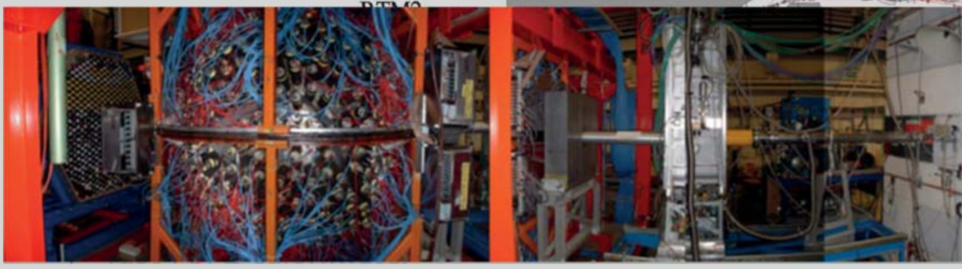


Achenbach *et al.*,Eur. Phys. J. A (2012) **48**: 14

The MAMI Experiments

- Cascade of three race track microtrons + **H**armonic **D**ouble **S**ided **M**icrotron (HDSM)
  - 1600MeV
  - σ_E < 0.100MeV
  - max. 100μA
  - ε_h=9 nm rad, ε_v < 1 nm rad (allows for beam foci of ~μm)
  - halo: < 10^{-5} at r > 5·σ_r

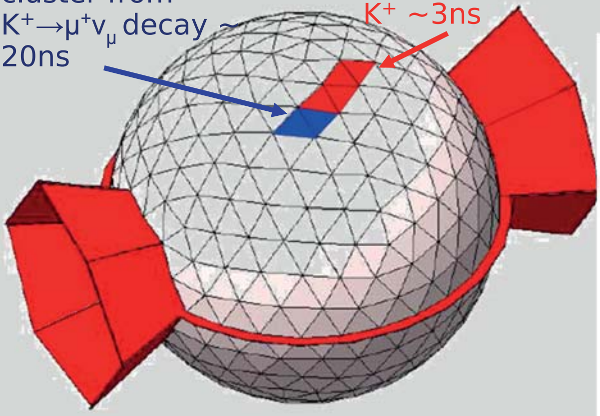




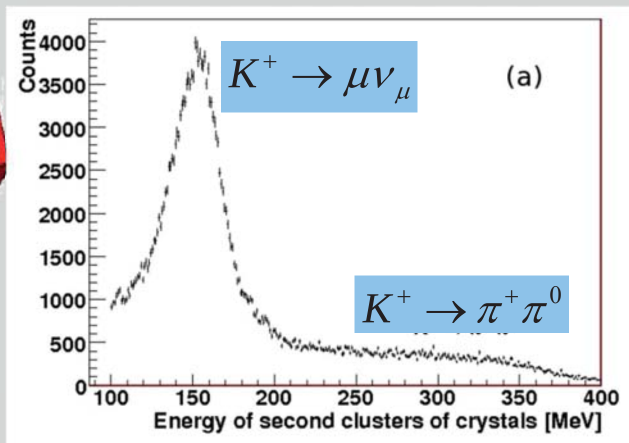
- A2 - photon tagger and photon spectrometer
  - Crystal Ball
- A1 - charged particle spectrometer facility

K^+ Photoproduction with the Crystal Ball

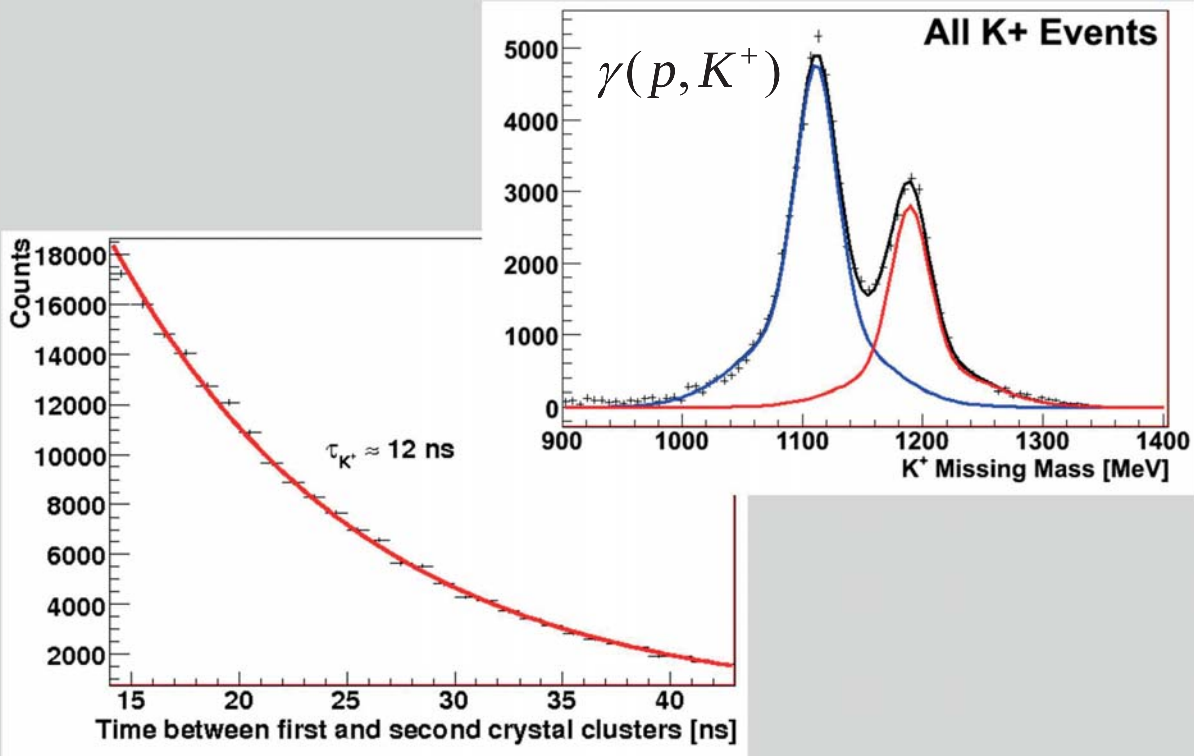
- K^+ properties
  - τ=12.38 ns
  - BR($K^+ \rightarrow \mu^+ \nu_\mu$) = 63.5% p=236MeV/c
  - BR($p^+ \pi^0$) = 20.7% p=205MeV/c
- Detection technique: delayed decay (>10ns) of stopped K^+



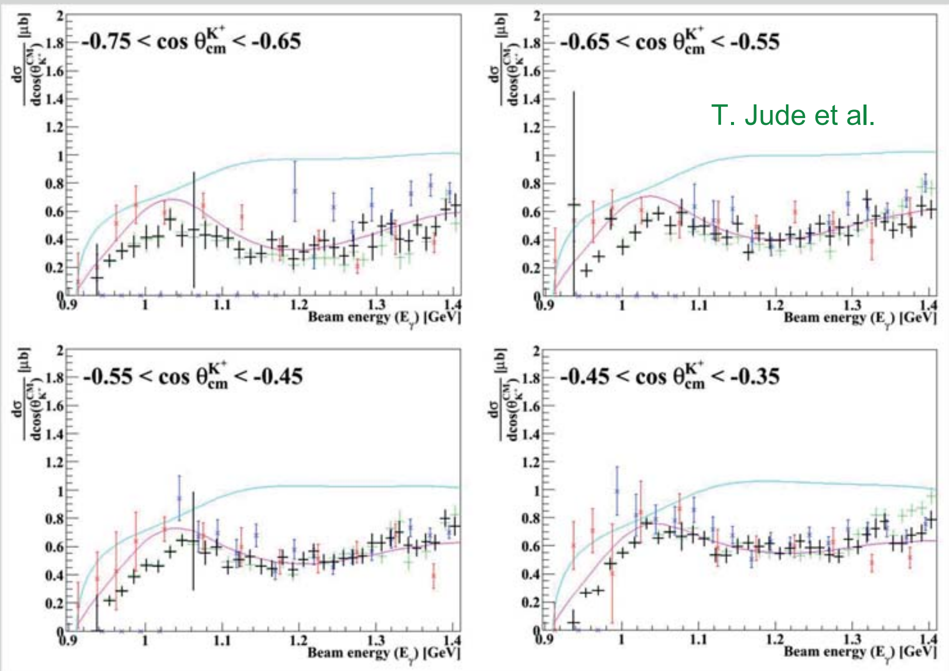
T. Jude *et al.*



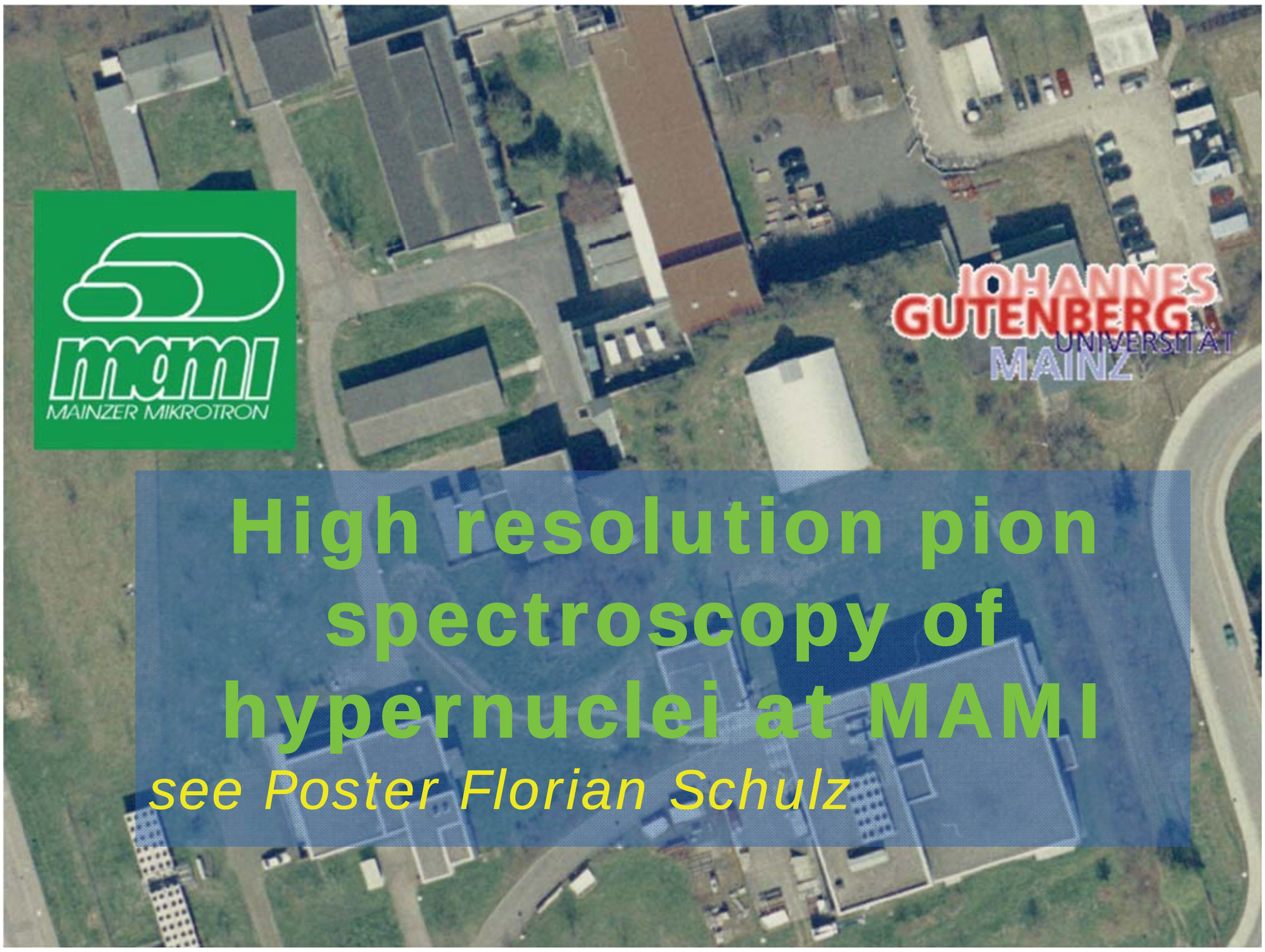
K^+ Photoproduction



Kaon Photoproduction $\gamma p \rightarrow \Lambda K^+$ (Preliminary)



SAPHIR: K.H. Glander *et al.*, Eur Phys. J. A **19**, 251 (2004)
JLAB (blue): R. Bradford *et al.*, Phys Rev. C **73**, 035202 (2006)
Kaon MAID with S_{11}(1650), P_{11}(1710), P_{13}(1720) and D_{13}(1900)
Regge-Plus Resonance (RPR) Model: T. Van Cauteren *et al.* Phys. Rev. C 73, 045207 (2006), Pieter Vancraeyveld, The University of Ghent. Priv. com. (2010)



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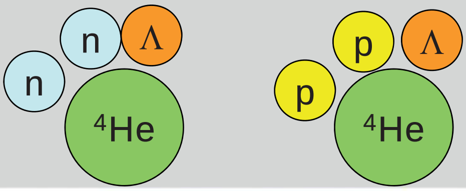
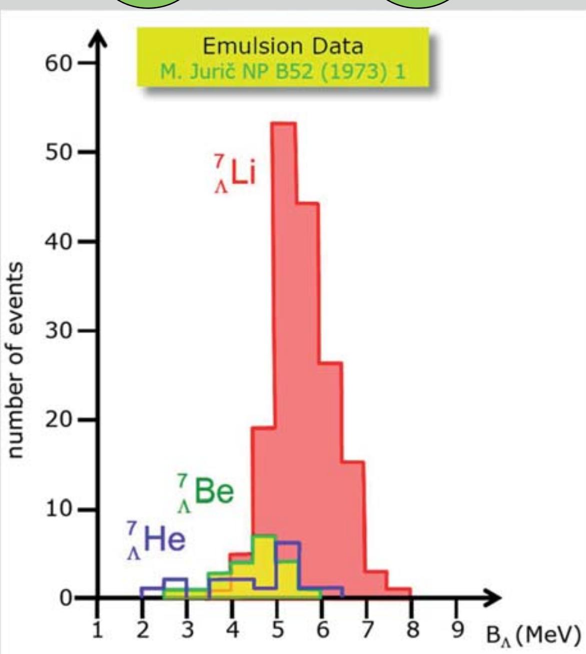
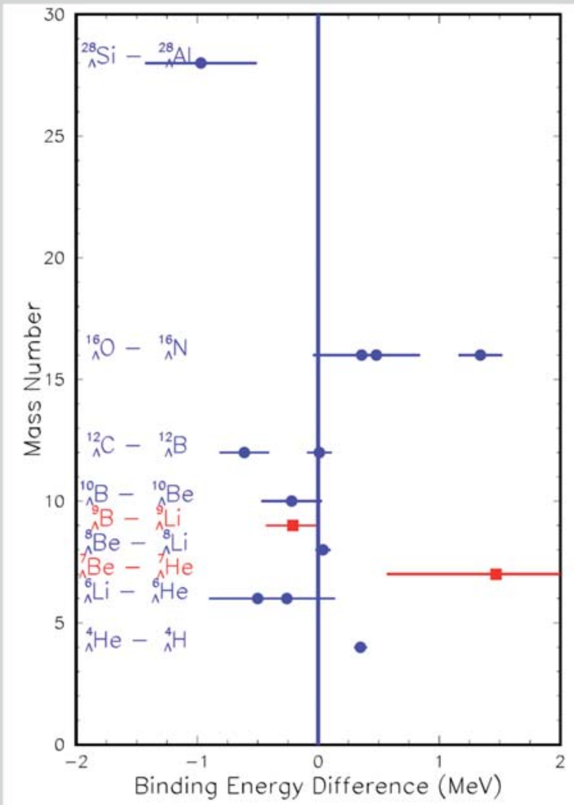
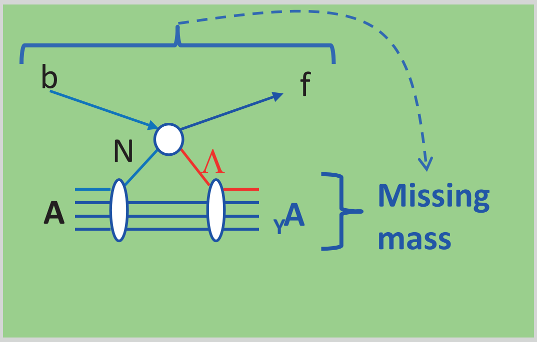
Strange Mirror Nuclei (Talk of Emiko Hiyama ?)

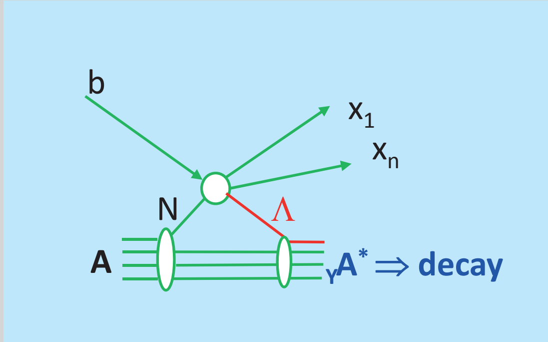






The twofold way

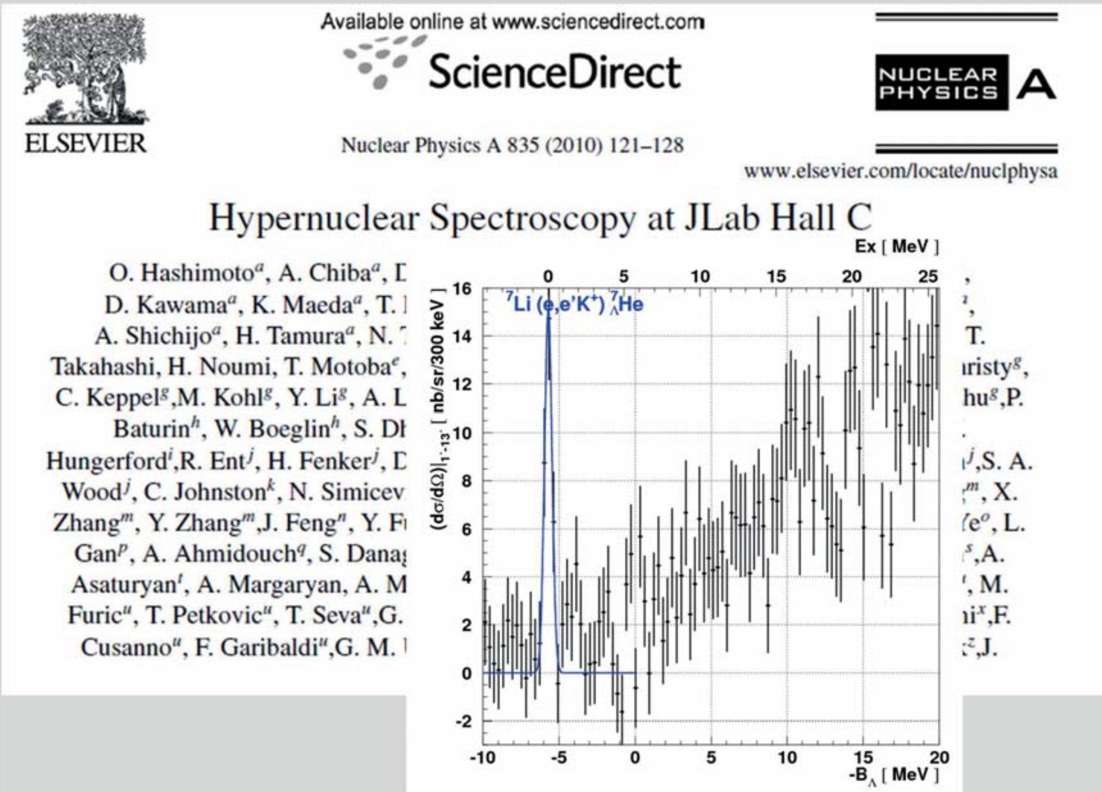




- Direct production spectroscopy
- Examples
  - strangeness production (π^+, K^+), (π^-, K^0)
  - strangeness exchange (K^-, π^-) ,(K^-, π^0), (K^-,K^+)
  - electroproduction (e,e´K^+) , (γ,K^+)

- Decay spectroscopy
  - γ-decay
  - π from weak decay
  - Charged fragments
- Examples
  - nuclear emulsions
  - heavy ion reactions
  - antiproton induced reactions
  - continuum excitation in (e,e´K+)

Osamu Hashimoto´s heritage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Hypernuclear Spectroscopy at JLab Hall C

O. Hashimoto[a], A. Chiba[a], D. Kawama[a], K. Maeda[a], T. A. Shichijo[a], H. Tamura[a], N. Takahashi, H. Noumi, T. Motoba[e], C. Keppel[g],M. Kohl[g], Y. Li[g], A. L Baturin[h], W. Boeglin[h], S. Dh Hungerford[i],R. Ent[j], H. Fenker[j], D Wood[j], C. Johnston[k], N. Simicev Zhang[m], Y. Zhang[m],J. Feng[n], Y. Fu Gan[p], A. Ahmidouch[q], S. Danag Asaturyan[r], A. Margaryan, A. M Furic[u], T. Petkovic[u], T. Seva[u],G. Cusanno[u], F. Garibaldi[u],G. M. ... T. ... risty[g], ... hu[g],P. ... [j],S. A. ... [m], X. ... e[o], L. ... [s],A. ... , M. ... i[x],F. ... [z],J.

Missing Mass Experiments

Proton Number																				
10						$^{17}_{\Lambda}$Ne	$^{18}_{\Lambda}$Ne	$^{19}_{\Lambda}$Ne	$^{20}_{\Lambda}$Ne	$^{21}_{\Lambda}$Ne	$^{22}_{\Lambda}$Ne	$^{23}_{\Lambda}$Ne	$^{24}_{\Lambda}$Ne	$^{25}_{\Lambda}$Ne	$^{26}_{\Lambda}$Ne	$^{27}_{\Lambda}$Ne	$^{28}_{\Lambda}$Ne	$^{29}_{\Lambda}$Ne	$^{30}_{\Lambda}$Ne	$^{31}_{\Lambda}$Ne
9						$^{16}_{\Lambda}$F	$^{17}_{\Lambda}$F	$^{18}_{\Lambda}$F	$^{19}_{\Lambda}$F	$^{20}_{\Lambda}$F	$^{21}_{\Lambda}$F	$^{22}_{\Lambda}$F	$^{23}_{\Lambda}$F	$^{24}_{\Lambda}$F	$^{25}_{\Lambda}$F	$^{26}_{\Lambda}$F	$^{27}_{\Lambda}$F	$^{28}_{\Lambda}$F	$^{29}_{\Lambda}$F	$^{30}_{\Lambda}$F
8				$^{13}_{\Lambda}$O	$^{14}_{\Lambda}$O	$^{15}_{\Lambda}$O	$^{16}_{\Lambda}$O	$^{17}_{\Lambda}$O	$^{18}_{\Lambda}$O	$^{19}_{\Lambda}$O	$^{20}_{\Lambda}$O	$^{21}_{\Lambda}$O	$^{22}_{\Lambda}$O	$^{23}_{\Lambda}$O	$^{24}_{\Lambda}$O	$^{25}_{\Lambda}$O	$^{26}_{\Lambda}$O	$^{27}_{\Lambda}$O		
7				$^{12}_{\Lambda}$N	$^{13}_{\Lambda}$N	$^{14}_{\Lambda}$N	$^{15}_{\Lambda}$N	$^{16}_{\Lambda}$N	$^{17}_{\Lambda}$N	$^{18}_{\Lambda}$N	$^{19}_{\Lambda}$N	$^{20}_{\Lambda}$N	$^{21}_{\Lambda}$N	$^{22}_{\Lambda}$N	$^{23}_{\Lambda}$N	$^{24}_{\Lambda}$N				
6			$^{10}_{\Lambda}$C	$^{11}_{\Lambda}$C	$^{12}_{\Lambda}$C	$^{13}_{\Lambda}$C	$^{14}_{\Lambda}$C	$^{15}_{\Lambda}$C	$^{16}_{\Lambda}$C	$^{17}_{\Lambda}$C	$^{18}_{\Lambda}$C	$^{19}_{\Lambda}$C	$^{20}_{\Lambda}$C	$^{21}_{\Lambda}$C						
5			$^{9}_{\Lambda}$B	$^{10}_{\Lambda}$B	$^{11}_{\Lambda}$B	$^{12}_{\Lambda}$B	$^{13}_{\Lambda}$B	$^{14}_{\Lambda}$B	$^{15}_{\Lambda}$B	$^{16}_{\Lambda}$B	$^{17}_{\Lambda}$B	$^{18}_{\Lambda}$B								
4		$^{7}_{\Lambda}$Be	$^{8}_{\Lambda}$Be	$^{9}_{\Lambda}$Be	$^{10}_{\Lambda}$Be	$^{11}_{\Lambda}$Be	$^{12}_{\Lambda}$Be	$^{13}_{\Lambda}$Be	$^{14}_{\Lambda}$Be	$^{15}_{\Lambda}$Be										
3		$^{6}_{\Lambda}$Li	$^{7}_{\Lambda}$Li	$^{8}_{\Lambda}$Li	$^{9}_{\Lambda}$Li	$^{10}_{\Lambda}$Li	$^{11}_{\Lambda}$Li	$^{12}_{\Lambda}$Li												
2	$^{4}_{\Lambda}$He	$^{5}_{\Lambda}$He	$^{6}_{\Lambda}$He	$^{7}_{\Lambda}$He	$^{8}_{\Lambda}$He	$^{9}_{\Lambda}$He														
1	$^{3}_{\Lambda}$H	$^{4}_{\Lambda}$H																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

Neutron Number

$n \rightarrow \Lambda$: (K^-, π^-), (K^-_{stop}, π^-), (π^+, K^+)

$p \rightarrow \Lambda$: $(e, e'K^+)$, (K^-_{stop}, π^0)

$pp \rightarrow n\Lambda$: (π^-, K^+)

Two body decay of a hypernucleus

$$^{9}_{\Lambda}\mathrm{Be} \rightarrow \pi^- + {}^{9}\mathrm{B} \quad ({}^{9}\mathrm{B} \rightarrow 2\alpha + p)$$

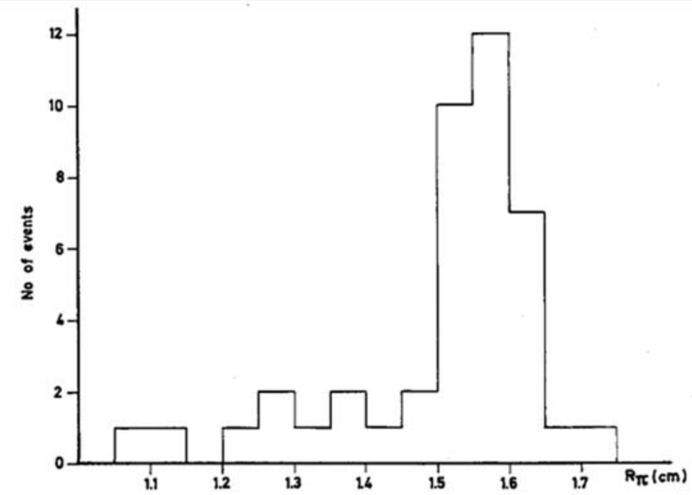
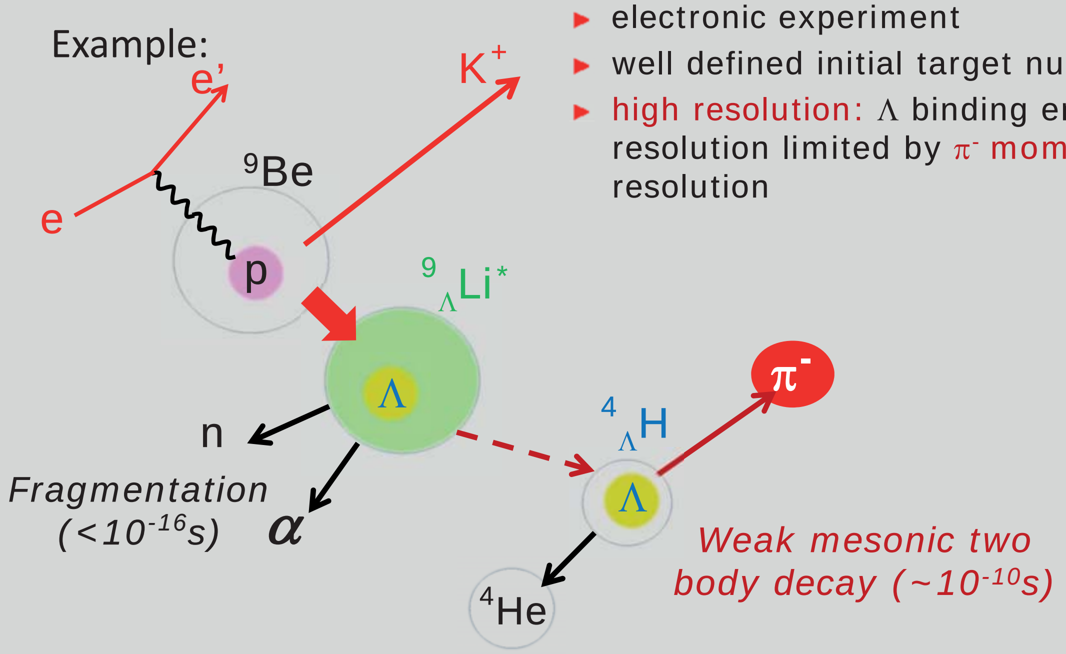


Fig. 1. Range distribution of π^- mesons from the events of the type (π + 2 or 3 stub-like tracks).

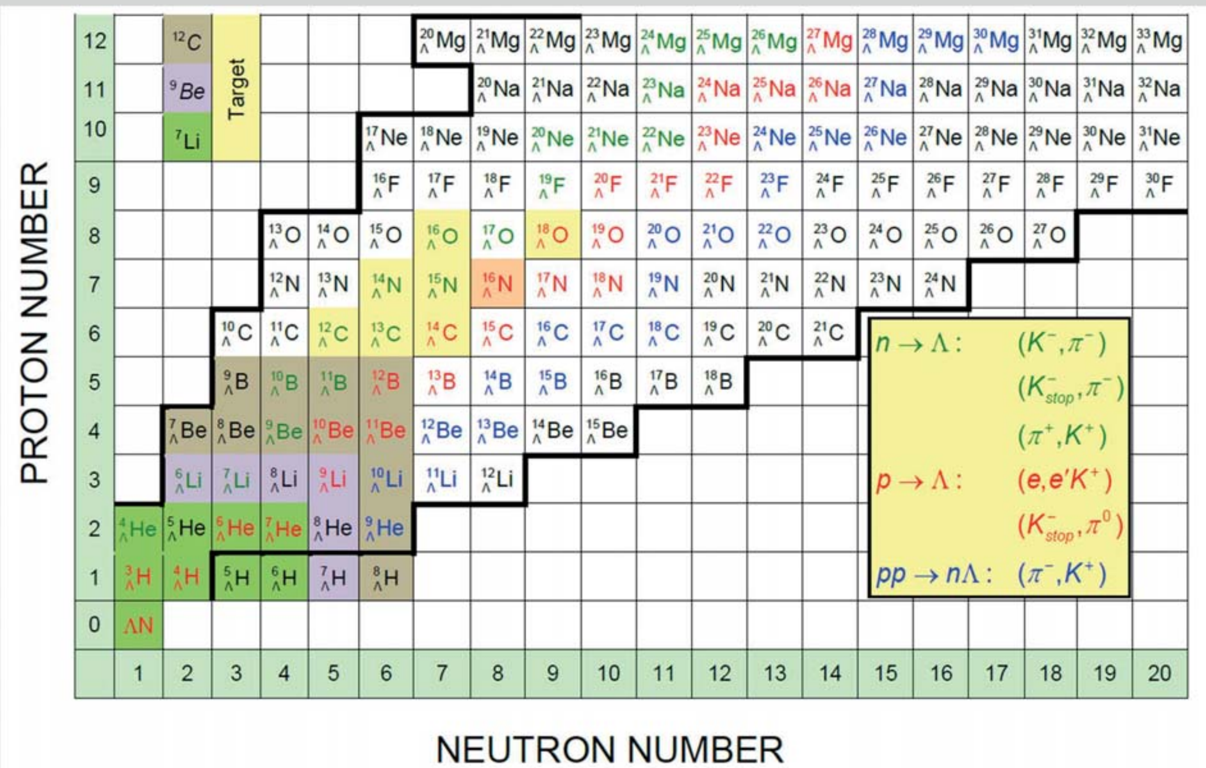
Gajewski et al., Nucl. Phys. B1, 105 (1967)

Decay pion spectroscopy

- Two-body decay ⇒ mono-energetic pions
- Like in emulsion access to variety of light and exotic hypernuclei, but
  - electronic experiment
  - well defined initial target nucleus
  - high resolution: Λ binding energy resolution limited by π^- momentum resolution

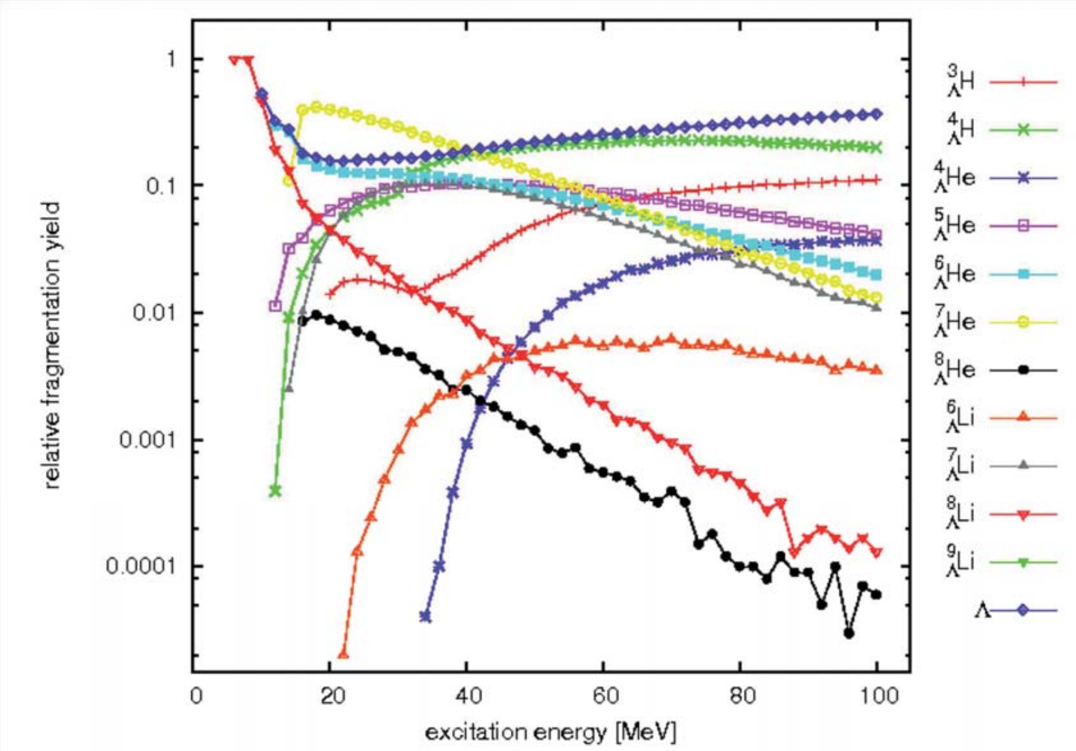


The prospects

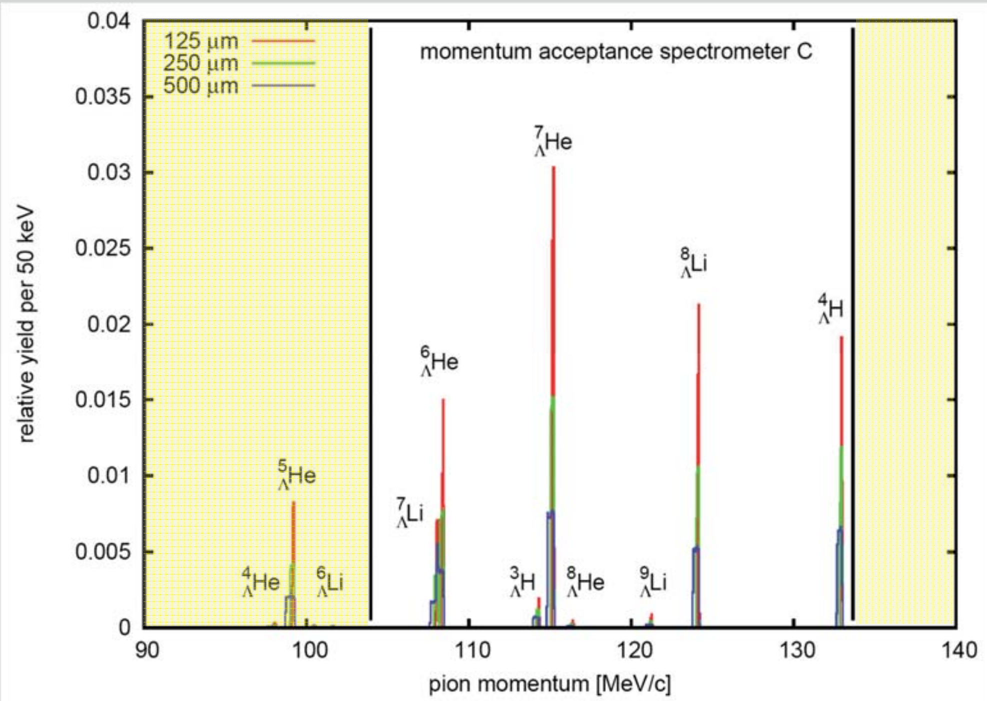


Fermi breakup of excited hypernuclei

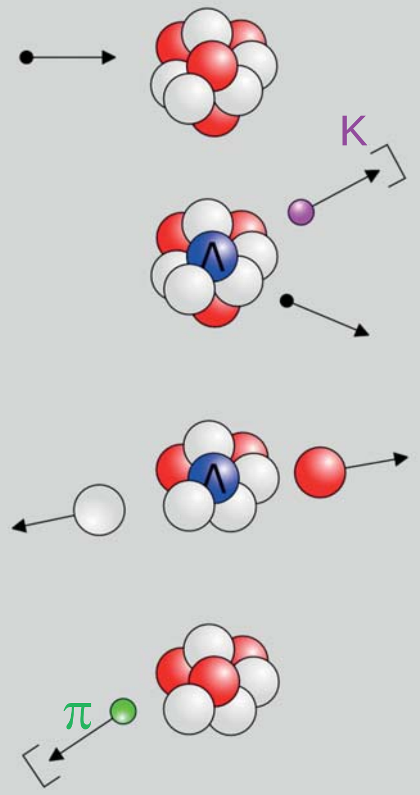
- Decay of ${}^{9}_{\Lambda}Li^{*}$ (A. Botvina, A. Sanchez, J. P.)



What can be expected

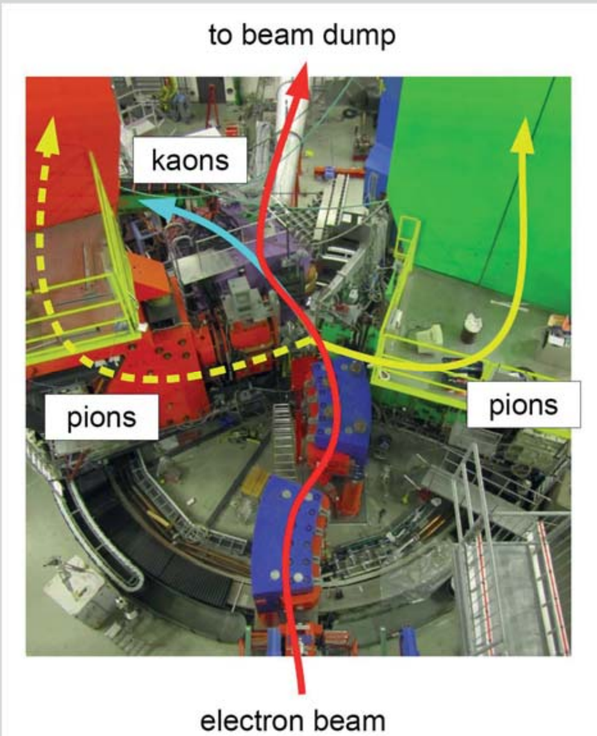


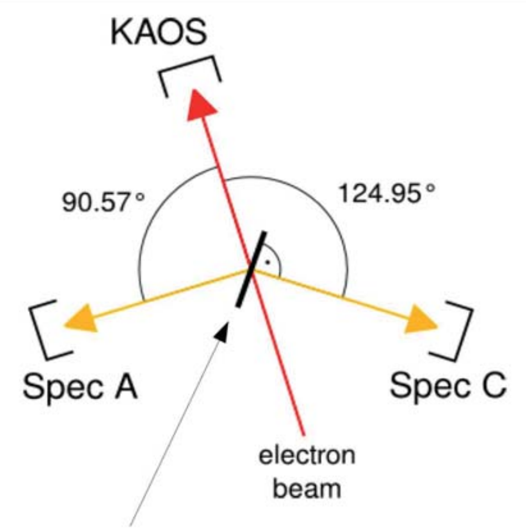
The experiment in a nutshell



- Electroproduction of excited hypernuclei on ^{9}Be Target
- Event tagging by kaon detection
- Fragmentation produces several light hypernuclei
- Mesonic weak decay and groundstate mass reconstruction by spectroscopy of pions from two-body decay

The real experiment



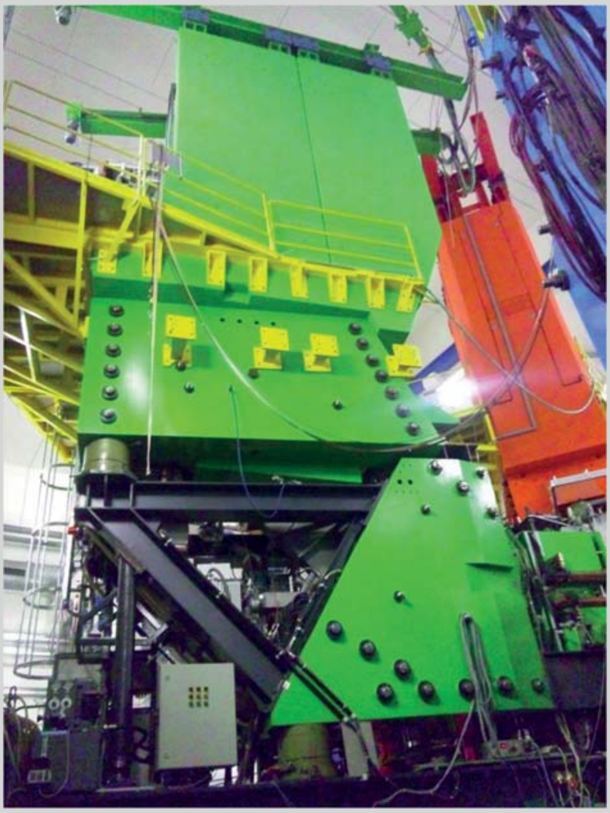


Target rotated 54° wrt beam:
→ Reduced energy loss variation for pions

⇒Poster: Florian Schulz

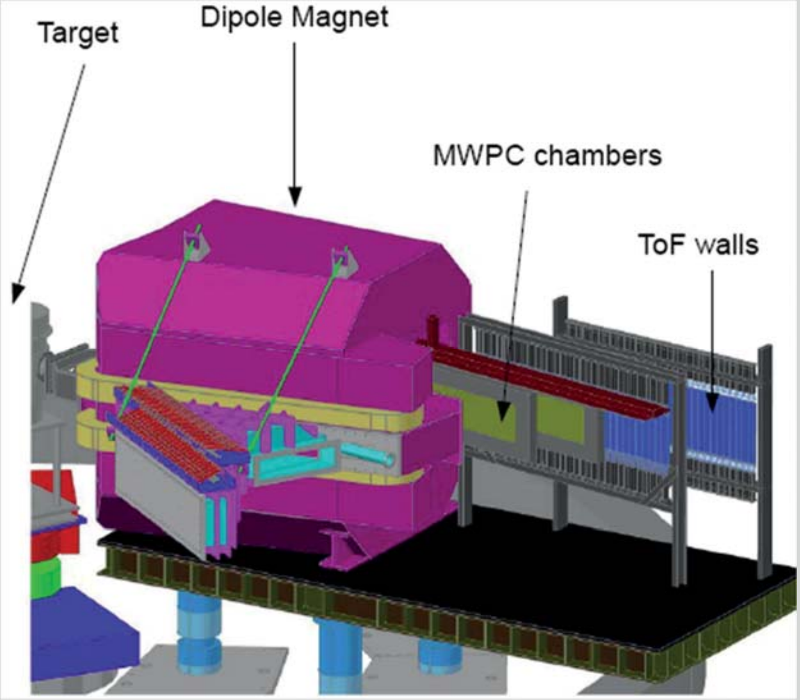
Pion detection

- Spectromter C (green)
- Spectrometer A (red)
- Momentum resolution $\Delta p/p = 10^{-4} \Rightarrow \Delta m < 20keV/c$
- Solid angle: 28 msr
- Momentum acceptance
  - Spec A: 20%
  - Spec C: 25%
- Length of trajectories
  - Spec A:10.75m
  - Spec C: 8.53m
- Gas threshold Cherenkov detectors for pion/electron separation



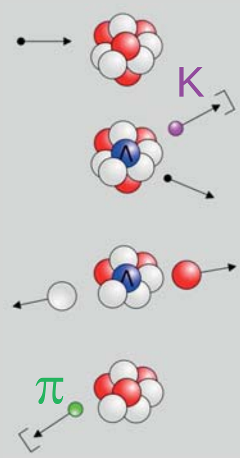
Kaon Tagger

- Double arm, short orbit spectrometer
- Placed at 0°
- Momentum acceptance 50%
- Flight path 7m

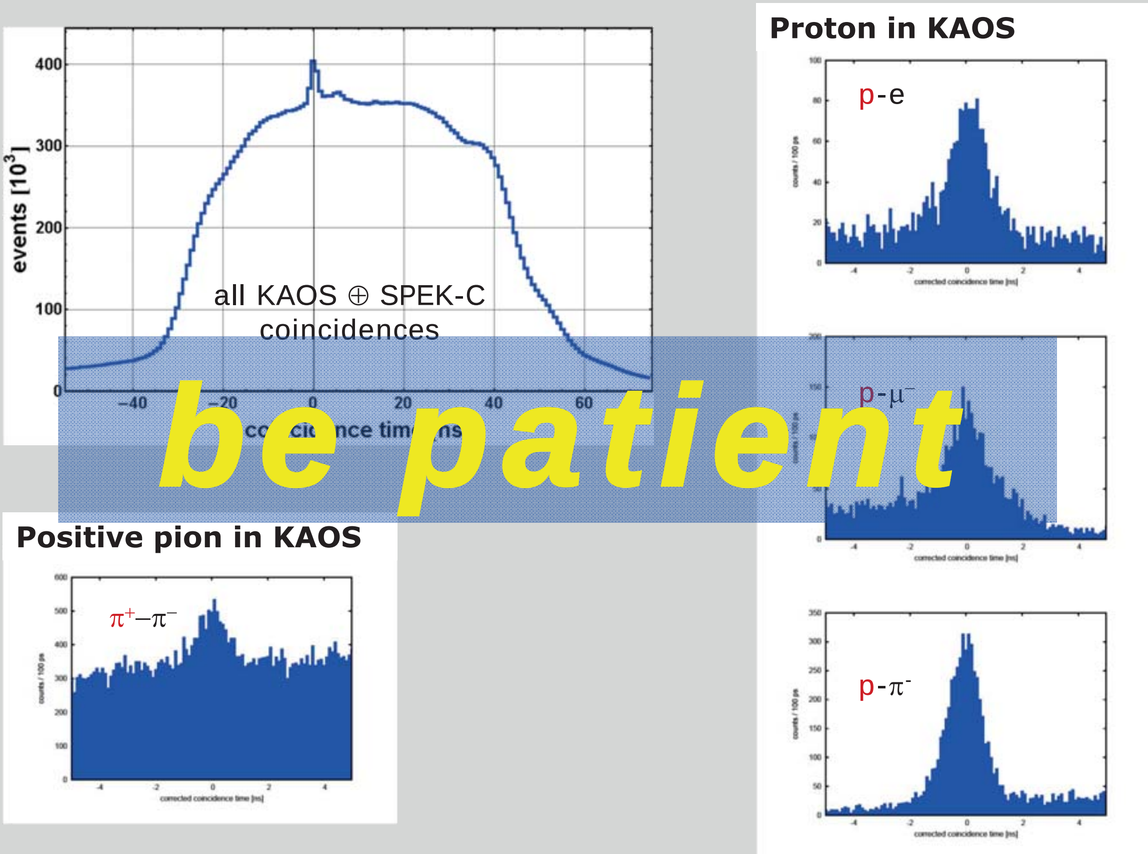


Pilot experiment summer 2011

- First experiment with KAOS at 0°
- Pion detection in SPEK-A or SPEK-C straight forward
  - Rate $f_{A/C} \sim 10^3$Hz for 1μA electron beam
- Kaon tagging more difficult: huge background of bremstrahlung positrons!
  - Rate $f_{KAOS} \sim 10^6$Hz for 1μA electron beam
- Random coincidence rate
  - $f_{A/C} \times f_{KAOS} \times \Delta t_{COINCIDENCE} \sim 10^3\text{Hz} \times 10^6\text{Hz} \times 1\text{ns} \sim 1\text{Hz}$
  - Expected real π-K-rate significantly lower
- Task:
  - suppress positron, proton, pion background in KAOS by several orders of magnitude
  - Improve relative time resolution to a level of $\Delta t_{COINCIDENCE}$ <1ns



KAOS ⊕ SPEK Timing



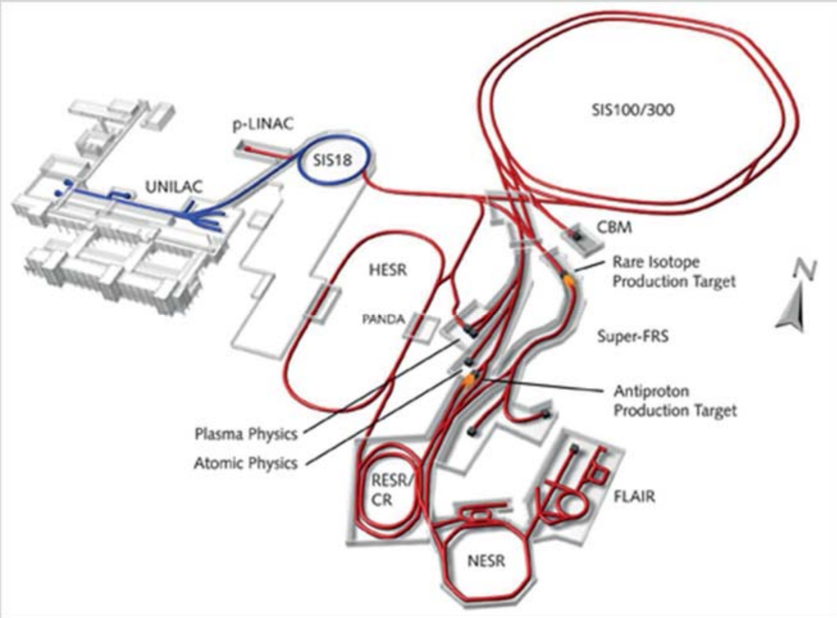
FAIR Facility for Antiproton and Ion Research

- **GSI, Darmstadt**
  - heavy ion physics
  - nuclear structure
  - atomic and plasma physics
  - cancer therapy

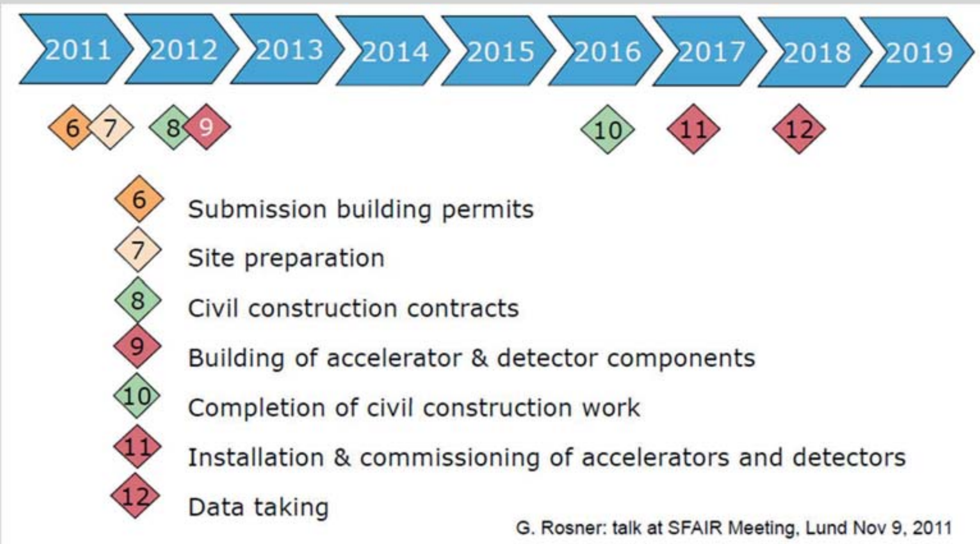
- **FAIR: New facility**
  - higher intensities & energies
  - **Antiproton Physics**

The FAIR Facility

- Uranium up to 35 AGeV
- Protons up to 30 GeV/c
- Broad range of secondary radioactive beams, up to 10000 more
- Antiprotons 0 - 15 GeV/c



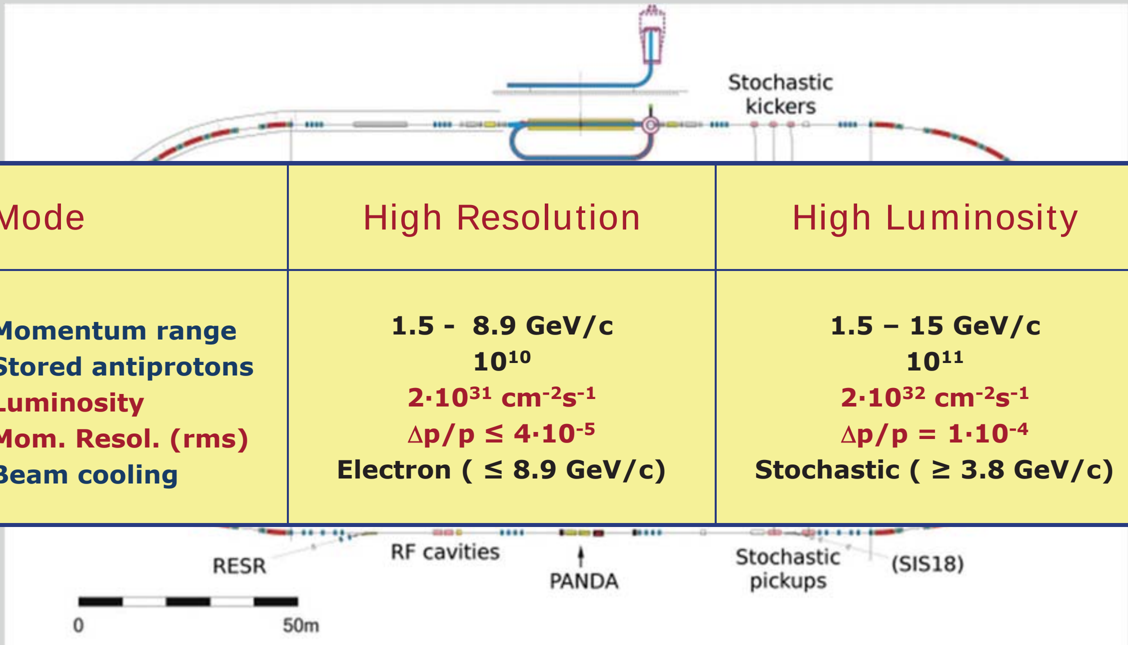
Timeline of FAIR



- At present only „**Modularized Start Version**“ financed
  - SIS 100
  - Experimental halls for CBM and APPA
  - SUPER FRS for NuSTAR
  - Antiproton facility for PANDA

HESR

- 10^{11} Antiprotons from 1.5-15 GeV/c, fixed target L=10^{32}
- Initially without RESR, stacking in HESR
- Stochastic and electron cooling $\delta\sqrt{s}$=20-100 keV



Mode	High Resolution	High Luminosity
Momentum range	**1.5 - 8.9 GeV/c**	**1.5 – 15 GeV/c**
Stored antiprotons	**10^{10}**	**10^{11}**
Luminosity	**$2\cdot10^{31}$ cm^{-2}s^{-1}**	**$2\cdot10^{32}$ cm^{-2}s^{-1}**
Mom. Resol. (rms)	**$\Delta p/p \leq 4\cdot10^{-5}$**	**$\Delta p/p = 1\cdot10^{-4}$**
Beam cooling	**Electron (≤ 8.9 GeV/c)**	**Stochastic (≥ 3.8 GeV/c)**

History

1997

Bemerkungen zu einem Hochenergie-Experimentierspeicherring Projekt bei GSI

Paul Kienle, Physik-Department E12, TU München

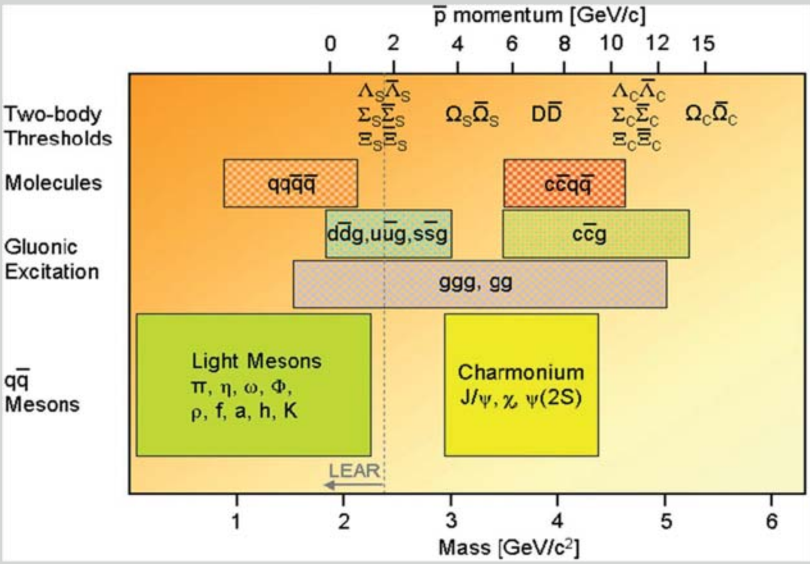
Im Zusammenhang mit den Ausbauplänen der GSI wird ein 200 Tm Hochenergie-Experimentierspeicherring HESR vorgeschlagen, der zusammen mit einem 100 Tm Synchrotron SIS 100 eine neue Experimentiereinrichtung ergäbe, die einmalige Experimente zur Untersuchung der Struktur und Dynamik von Hadronen mit schweren Quarks (s,c), verdichteter und erhitzter hadronischer Materie und der Struktur von neutronenarmen und -reichen Kernen erlauben würde.

Zur Physik am HESR

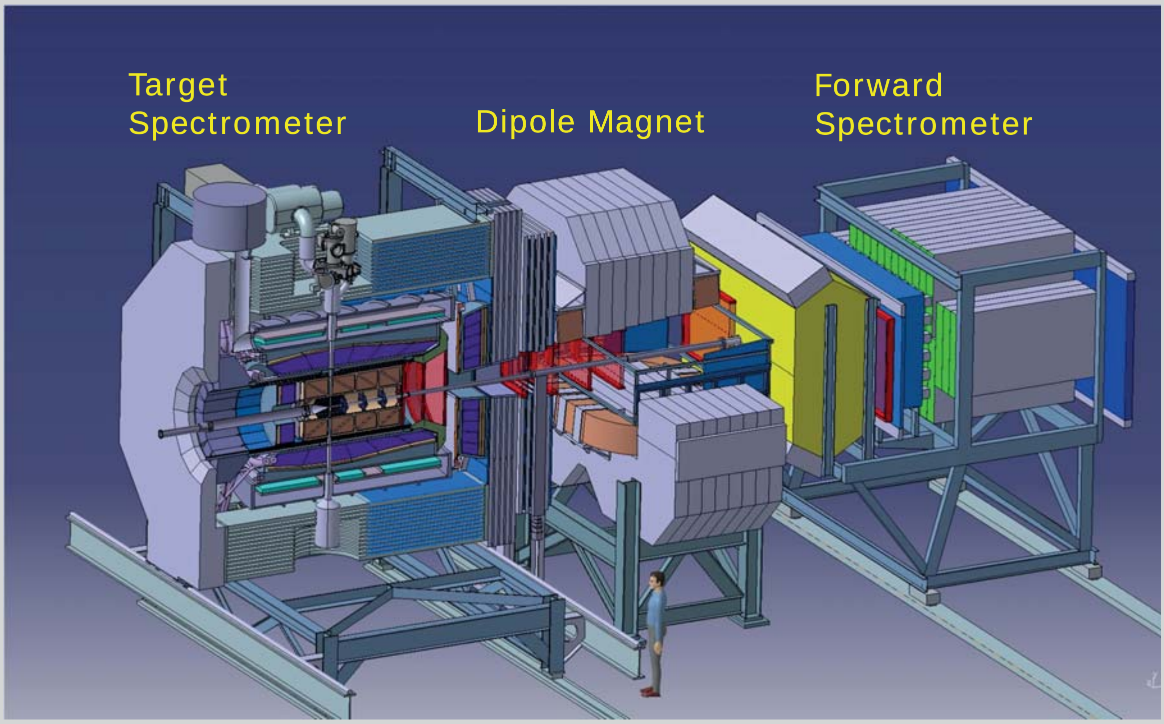
Mögliche Physikprogramme schließen Experimente ein, die im Rahmen des LISS-Projekts und früher für SuperLEAR diskutiert wurden. Die höhere Energie des HESR im Vergleich zu LISS und SuperLEAR, die Hochenergie-Elektronenkühlerausstattung, die Verfügbarkeit von Schwerionenstrahlen und von SIS 100-Sekundärstrahlen lassen darüber hinaus ein wesentlich breiteres Experimentierprogramm zu. Einige der im folgenden angesprochenen

PANDA physics potential

- search for exotic particles such as glueballs, hybrids, tetraquarks,..
- spectroscopy of charmonium states
- study double hypernuclei
- properties of hadrons in nuclear matter
- Strange and charmed baryons
- Structure of the nucleon
  - time-like form factors $\bar{p}p \to e^+e^-$, $\bar{p}p \to \gamma\gamma$
  - Cross channel of DVCS
  - Drell-Yan
- etc.

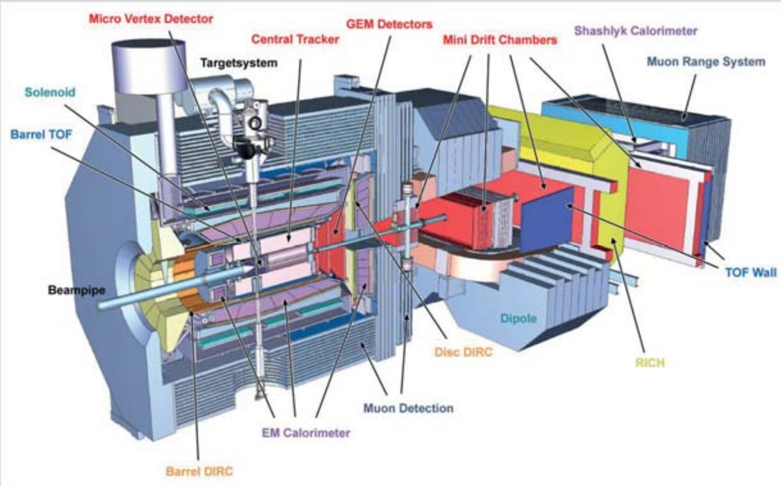


The $\bar{\text{P}}$ANDA detector

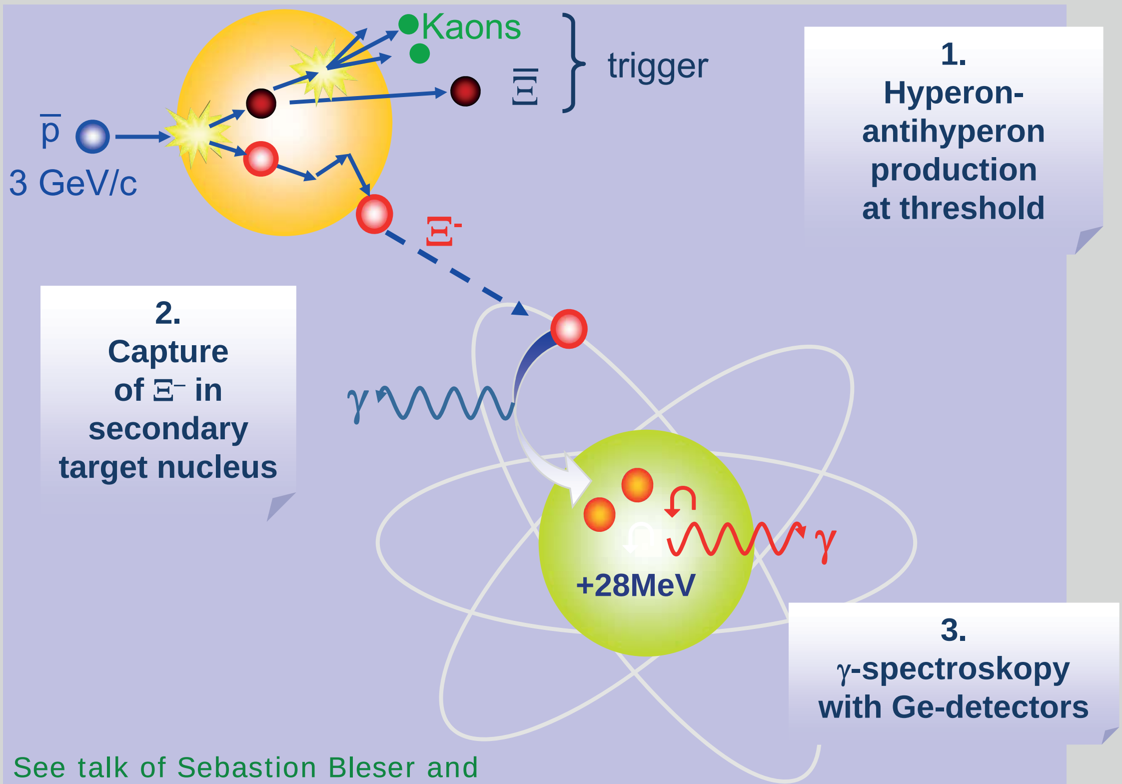


Properties of the PANDA Detector

▶ 4π coverage	partial wave analysis
▶ high rates	2×10^{7} annihilations/s
▶ good PID	γ,e,μ,K,p
▶ momentum resolution	~1%
▶ Vertexing for D,K^0_s,Λ,..	$c\tau$=123μm for D0 at p/m≈2
▶ efficient trigger	e,μ,K,D,Λ
▶ no hardware trigger	raw data rate~ TB/s



Production of Double Hypernuclei



See talk of Sebastion Bleser and
poster of Marcell Steinen

The Discovery of the anti-Xi

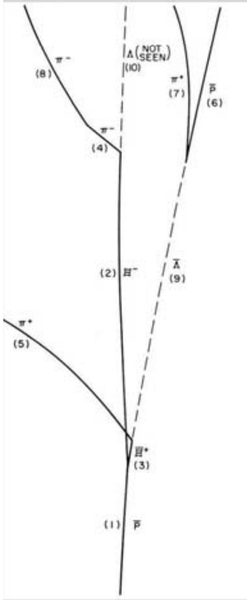
- discovered simultaneously at CERN and SLAC

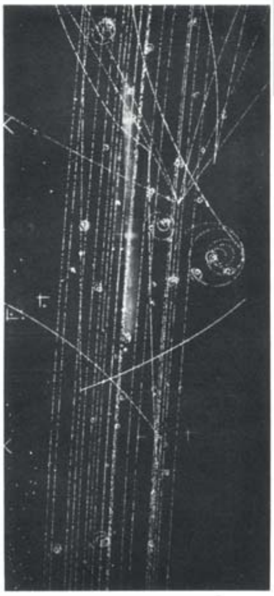
$\bar{p} + p \rightarrow \Xi^- + \bar{\Xi}^+$

VOLUME 8, NUMBER 6 PHYSICAL REVIEW LETTERS MARCH 15, 1962

OBSERVATION OF PRODUCTION OF A $\Xi^- + \bar{\Xi}^+$ PAIR*

H. N. Brown, B. B. Culwick, W. B. Fowler, M. Gailloud,† T. E. Kalogeropoulos, J. K. Kopp, R. M. Lea, R. I. Louttit, T. W. Morris, R. P. Shutt, A. M. Thorndike, and M. S. Webster
Brookhaven National Laboratory, Upton, New York
and
C. Baltay, E. C. Fowler, J. Sandweiss,‡ J. R. Sanford, and H. D. Taft
Yale University, New Haven, Connecticut
(Received February 19, 1962)





VOLUME 8, NUMBER 6 PHYSICAL REVIEW LETTERS MARCH 15, 1962

EXAMPLE OF ANTICASCADE ($\bar{\Xi}^+$) PARTICLE PRODUCTION IN $\bar{p}$-p INTERACTIONS AT 3.0 Gev/c

CERN, Geneva, Switzerland *
Laboratoire de Physique, Ecole Polytechnique, Paris, France
and
Centre d' Etudes Nucléaires, Département Saturne, Saclay, France
(Received February 19, 1962)

An experiment is in progress at the CERN proton synchrotron to study the interactions of fast antiprotons with protons. A high-energy separated beam[1] has been installed and optimized to provide, in the first instance, a high-purity beam of 3.0-Gev/c antiprotons. The interactions are being produced and observed in the Saclay 81-cm hydrogen bubble chamber.[2]

In the methodical scanning of the first ten thousand photographs (with an average of seven antiprotons per photograph) an event has been found showing the production of an anticascade particle ($\bar{\Xi}^+$). The object of this Letter is to present the data and the analysis leading to this conclusion.

One of the three views of the event is reproduced in Fig. 1. Briefly, the event is as follows: After travelling 20 cm in the chamber, a beam particle interacts at point A, producing two charged particles. The positive particle decays at point B (distant 6 cm from A) and the negative at point D (4 cm from A). Both decay secondaries are light particles, as we will see. At C—about 20 cm downstream from B—there appears a V^0, which will be identified later as the decay of a $\bar{\Lambda}^0$ particle. Near point B another two-prong interaction can be seen at point I: Stereoscopic reconstruction shows that there is no direct link between this interaction and the $\bar{\Lambda}^0$ decay.

The event can be analyzed in several ways. We have chosen to proceed in two steps: We first analyze the event connected with the positive particle from apex A, and then with the improved knowledge thus derived we analyze the complete interaction at the same apex.

Expected production rate

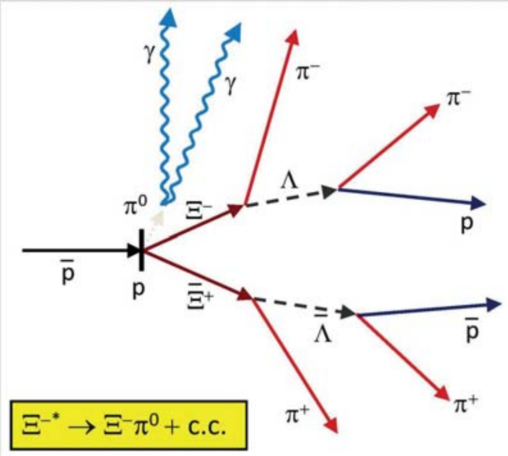
Production Rates (1-2 (fb)$^{-1}$/y)

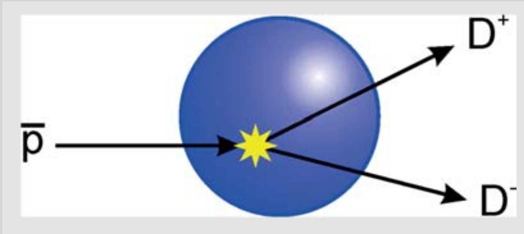
Final State	cross section	# reconstr. events/y
Meson resonance + anything	100µb	10^{10}
$\Lambda\bar{\Lambda}$	50µb	10^{10}
$\Xi\bar{\Xi}$	2µb	10^{8}
$D\bar{D}$	250nb	10^{7}
$J/\psi\,(\rightarrow e^+e^-, \mu^+\mu^-)$	630nb	10^{9}
$\chi_2\,(\rightarrow J/\psi + \gamma)$	3.7nb	10^{7}
$\Lambda_c\bar{\Lambda}_c$	20nb	10^{7}
$\Omega_c\bar{\Omega}_c$	0.1nb	10^{5}

- Common feature
  - Low multiplicity events
  - Moderate particle energies
  - For pairs: charge symmetrc conditions: trigger on sone, investigate the other one

$\bar{p}p \to \bar{\Lambda}\Lambda, \bar{\Lambda}\Sigma, \bar{\Lambda}\Sigma, \bar{\Sigma}\Sigma, \bar{\Xi}\Xi, \bar{\Omega}\Omega, \bar{\Lambda}_c\Lambda_c, ...$

- characteristic event topology of $\Xi\Xi^*$ and $\Omega\Omega^*$ events.
- ~μb cross section for ΞΞ; ~10^6 Ξ /day reconstructed with full luminosity

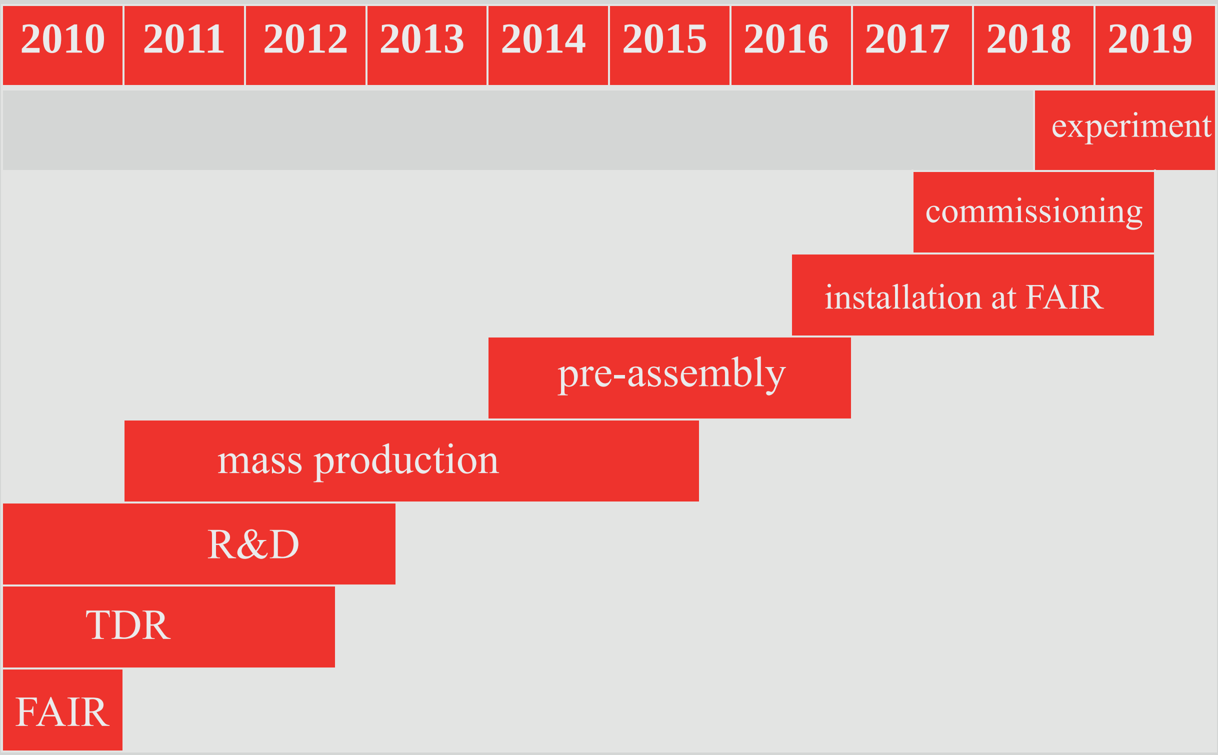




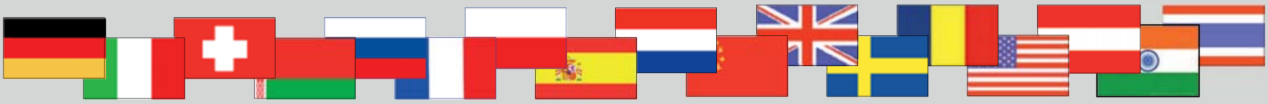
- tagged (anit)hyperon beam e.g. $\bar{p}+p \to \bar{\Sigma}^+\Sigma^-$
- in nuclei: information on $\bar{Y}$–potential

J.P., Physics Letters B **669** (2008) 306–310

Schedule of $\bar{P}$ANDA



JG|U panda Colaboration



At present a group of about **500 physicists** from 55 institutions of 17 countries

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

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

[redacted]