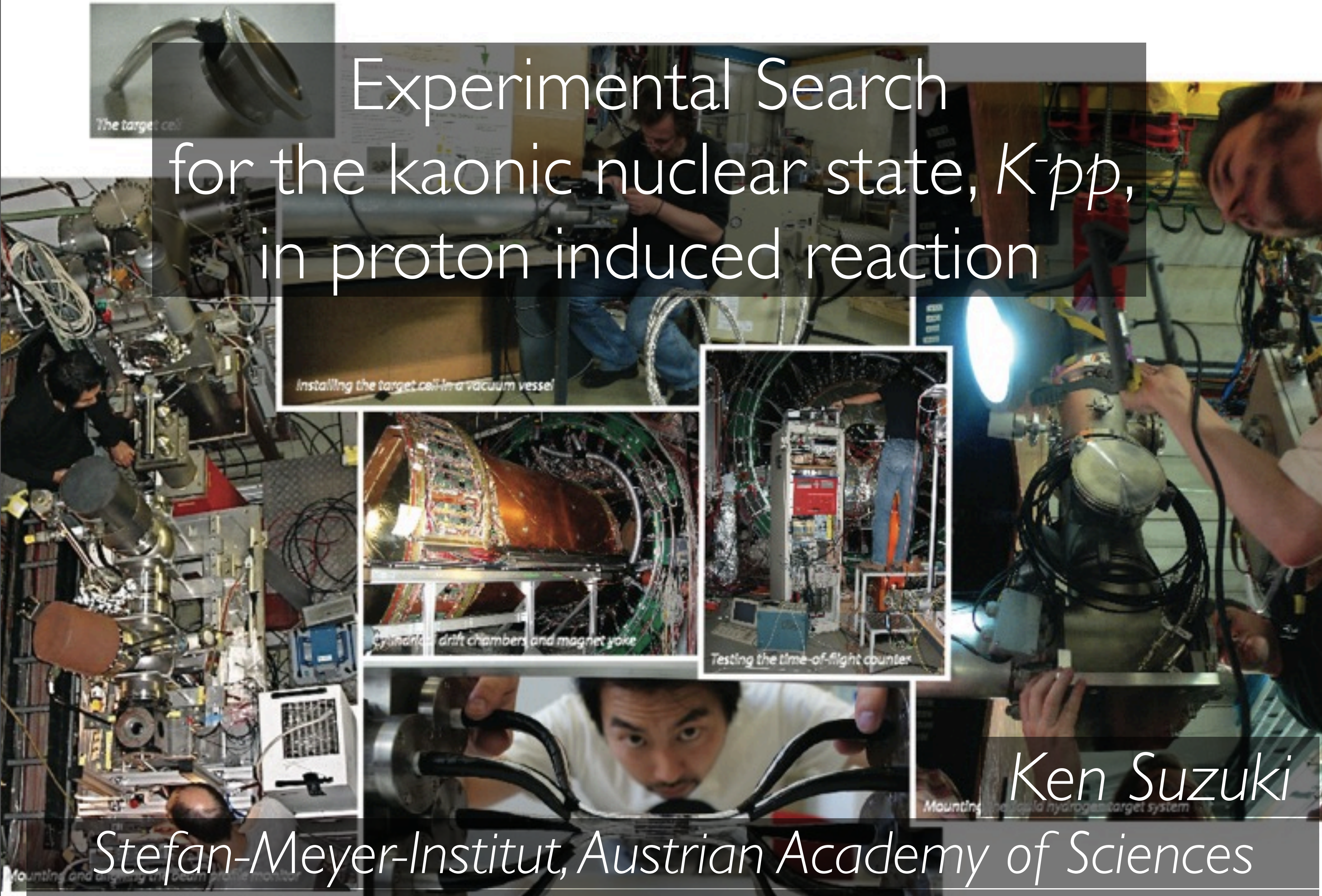
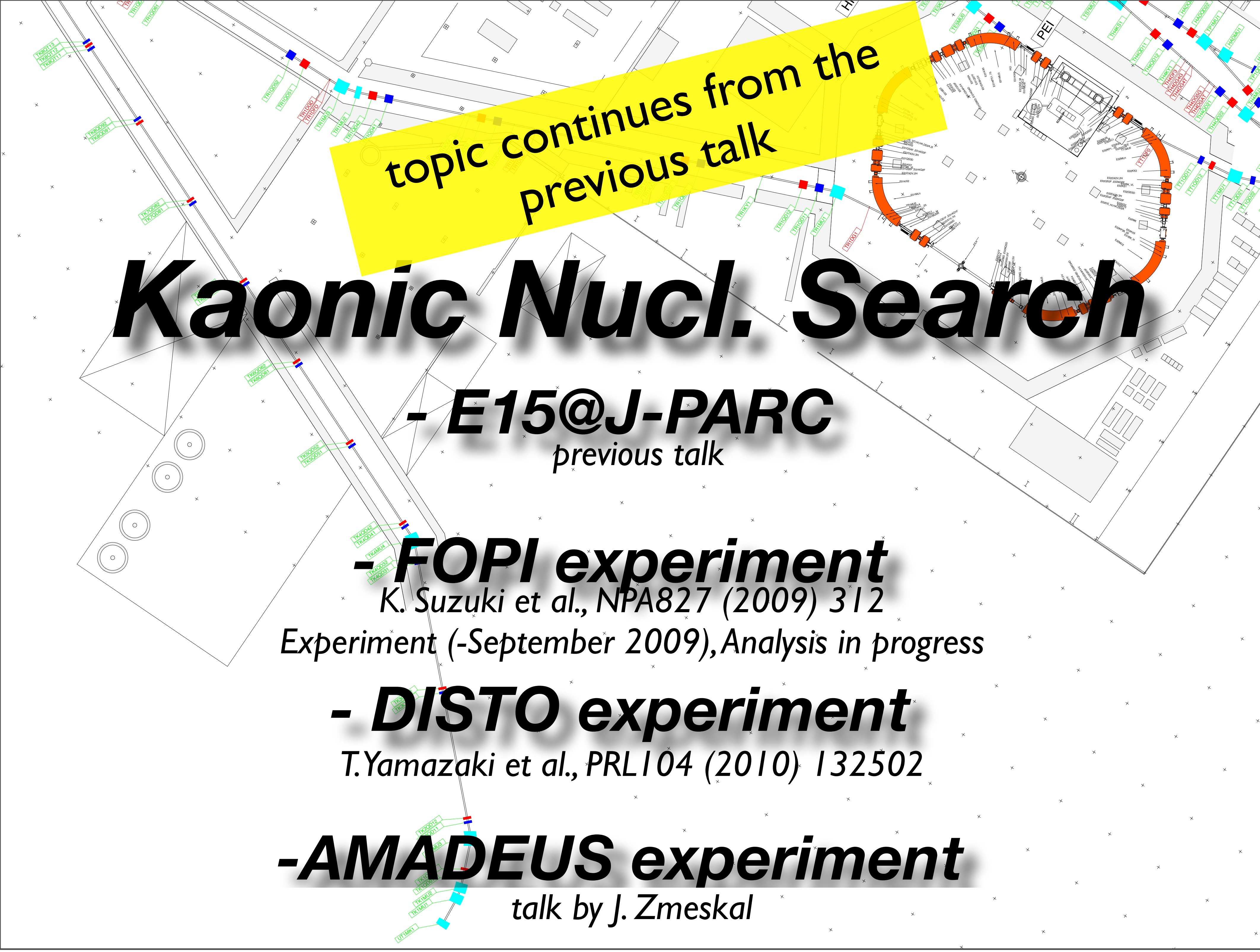
Experimental Search for the kaonic nuclear state, $K^{-}pp$, in proton induced reaction



Ken Suzuki
Stefan-Meyer-Institut, Austrian Academy of Sciences

MESON2010, Kraków, 11 June 2010



topic continues from the previous talk

Kaonic Nucl. Search

- E15@J-PARC

previous talk

- FOPI experiment

K. Suzuki et al., NPA827 (2009) 312

Experiment (-September 2009), Analysis in progress

- DISTO experiment

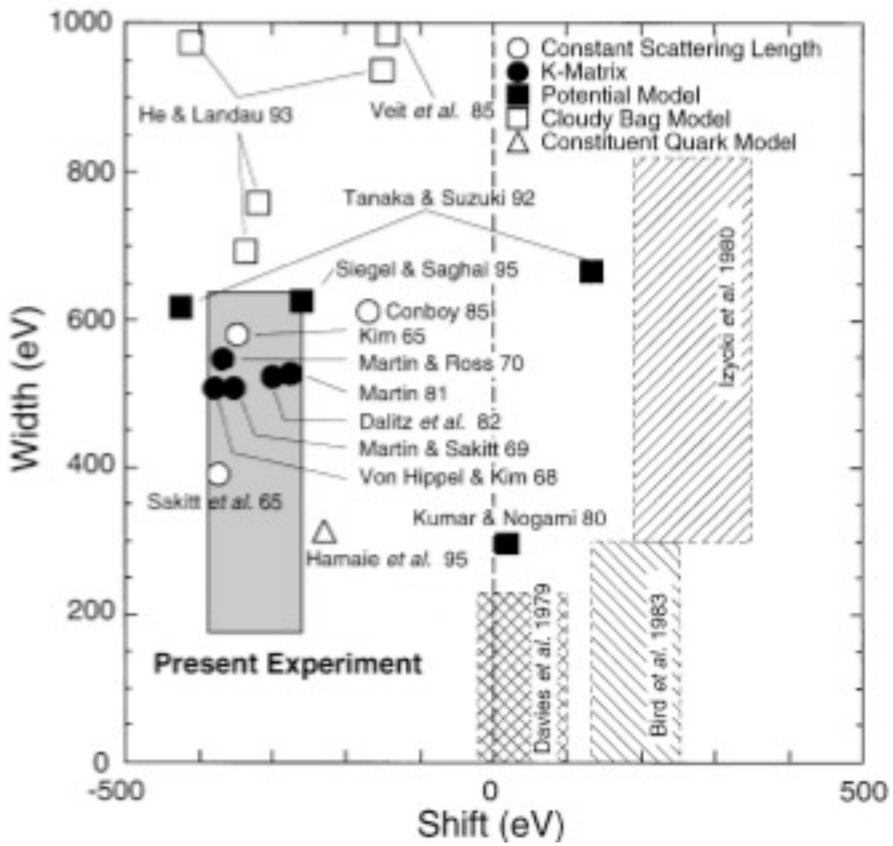
T. Yamazaki et al., PRL104 (2010) 132502

-AMADEUS experiment

talk by J. Zmeskal

Introduction

Kaonic hydrogen puzzle, just ~10 years ago
key ingredient: $K^{\text{bar}}N$ interaction



M. Iwasaki et al., Phys. Rev. Lett. 78 (1997) 3067

Experimental principle

„ordinary process“

$$p + p \rightarrow \Lambda + p \quad + K^{+}$$

Experimental principle

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„exotic process“

$$p + p \rightarrow \underline{\text{"}K^{-}pp\text{"}} + K^{+}$$

$$\text{"}K^{-}pp\text{"} \rightarrow \Lambda + p$$

Experimental principle

„exotic process“

$$p + p \rightarrow \underline{\text{"}K^- pp\text{"}} + K^+$$

$$\Lambda + p$$

Experimental principle

Production Channel
Missing Mass: K⁺

„exotic process“

$$p + p \rightarrow \text{"}K^- pp\text{"} + K^+$$

$$\Lambda + p$$

Experimental principle

Production Channel
Missing Mass: K^+

„exotic process“

$$p + p \rightarrow \text{"}K^- pp\text{"} + K^+$$

$$\Lambda + p$$

From Decay Channel
Invariant Mass: $\Lambda(\pi^- + p) + p$

Experimental principle

Production Channel
Missing Mass: K^+

„exotic process“

$$p + p \rightarrow \underline{\text{"}K^- pp\text{"}} + K^+$$

$$\Lambda + p$$

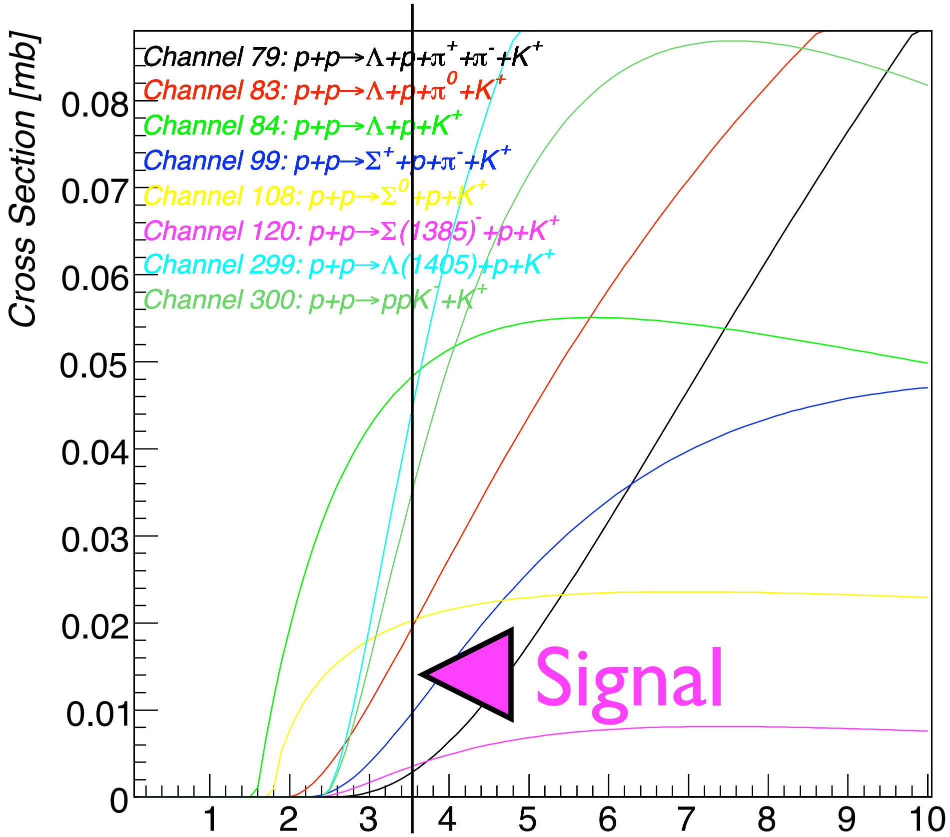
From Decay Channel
Invariant Mass: $\Lambda(\pi^- + p) + p$

Exclusive measurement
with a large acceptance detector

Background Suppression

Channels which can have same event topology as signal

: 2 proton, 1 π^- and 1 K^+ in backward



KS2006

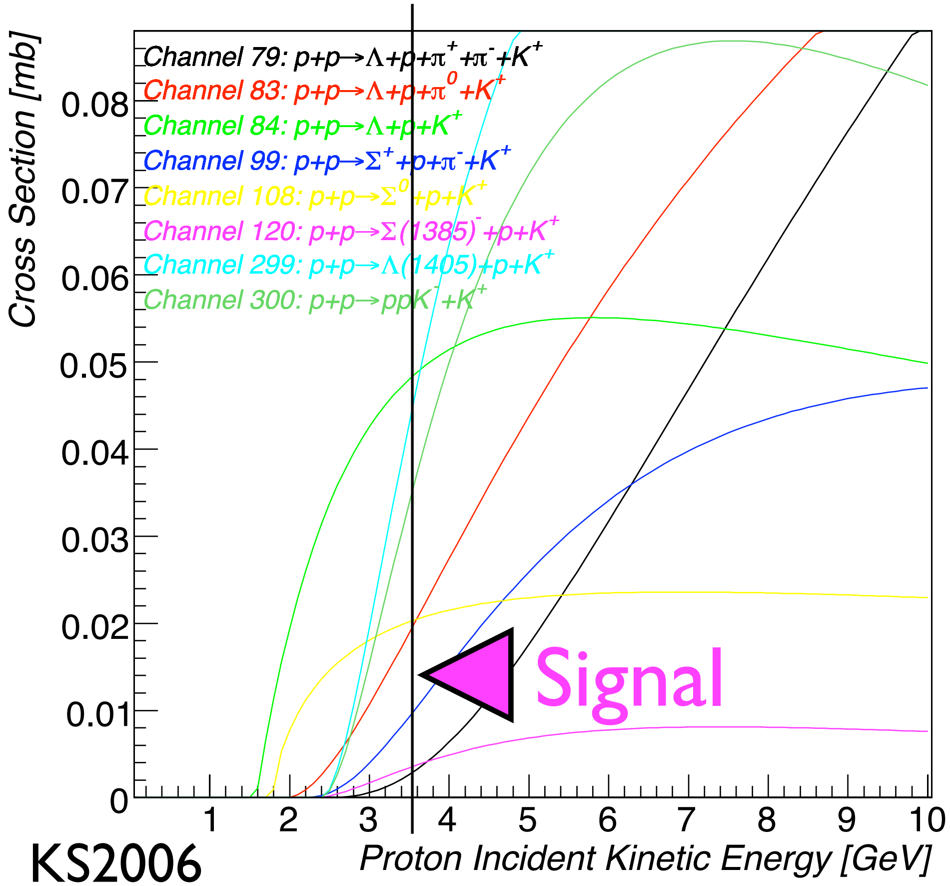
chi	threshol	reaction	@Tp=3.0GeV
77	2.798	$\Lambda+p+\pi^++\pi^0+\pi^-$	2
79	2.382	$\Lambda+p+\pi^++\pi^-+K^+$	11
83	1.958	$\Lambda+p+\pi^0+K^+$	96
84	1.582	$\Lambda+p+K^+$	339
97	2.592	$\Sigma^++p+\pi^0+\pi^-+K^+$	2
99	2.185	$\Sigma^++p+\pi^-+K^+$	52
106	2.616	$\Sigma^0+p+\pi^++\pi^-+K^+$	3
108	1.794	Σ^0+p+K^+	123
120	2.348	$\Sigma(1385)^-+p+K^+$	6
195	2.943	$p+p+\pi^-+K^+ +K^0$	1
299	2.415	$\Lambda(1405)+p+K^+$	25
300	2.412	ppK^-+K^+	61

signal on the „physics background“, $p\Lambda K^+$ dalitz decay

Background Suppression

Channels which can have same event topology as signal

: 2 proton, 1 π^- and 1 K^+ in backward



KS2006

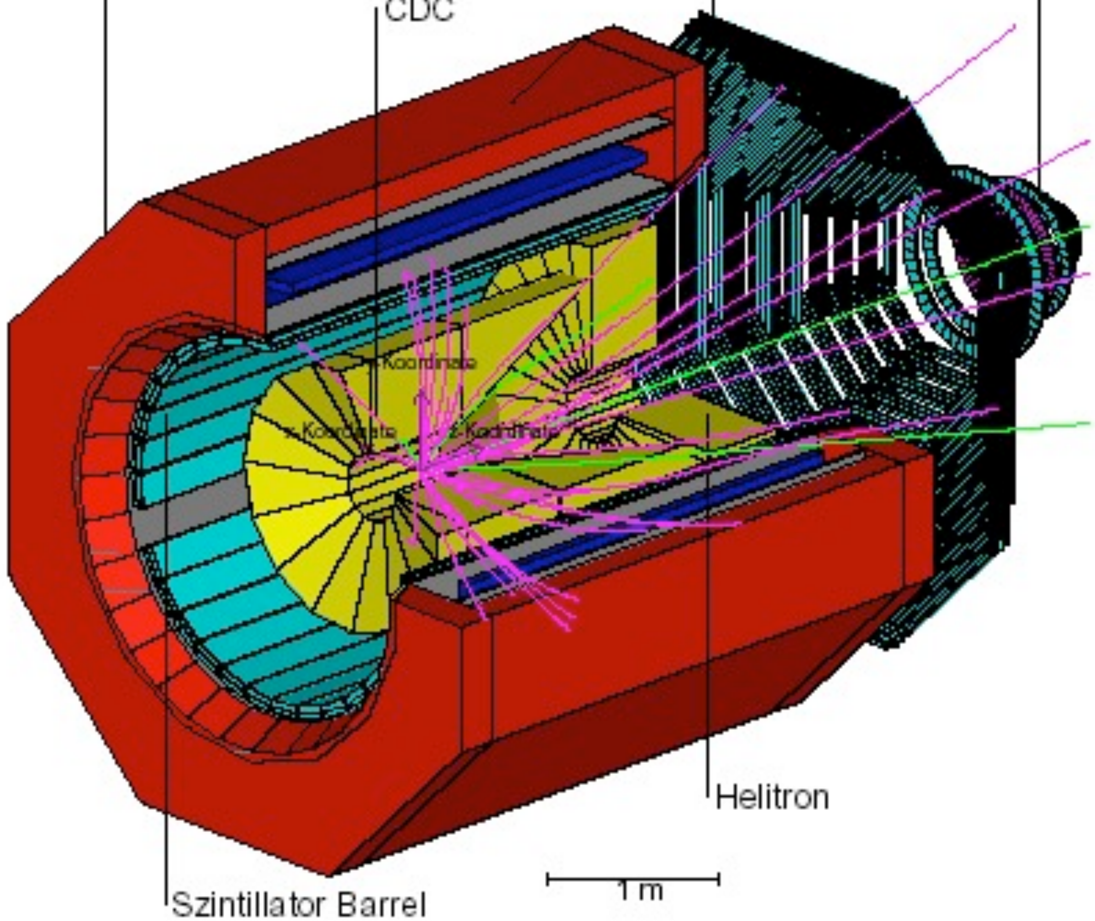
full kinematics information

chi	threshol	reaction	@Tp=3.0GeV
~~77~~	~~2.798~~	~~$\Lambda+p+\pi^++\pi^0+\pi^-$~~	~~2~~
~~79~~	~~2.382~~	~~$\Lambda+p+\pi^++\pi^-+K^+$~~	~~11~~
~~83~~	~~1.958~~	~~$\Lambda+p+\pi^0+K^+$~~	~~96~~
84	1.582	$\Lambda+p+K^+$	339
~~97~~	~~2.592~~	~~$\Sigma^++p+\pi^0+\pi^-+K^+$~~	~~2~~
~~99~~	~~2.185~~	~~$\Sigma^++p+\pi^-+K^+$~~	~~52~~
~~106~~	~~2.616~~	~~$\Sigma^0+p+\pi^++\pi^-+K^+$~~	~~3~~
~~108~~	~~1.794~~	~~Σ^0+p+K^+~~	~~123~~
~~120~~	~~2.348~~	~~$\Sigma(1385)^-+p+K^+$~~	~~6~~
~~195~~	~~2.943~~	~~$p+p+\pi^-+K^++K^0$~~	~~1~~
~~299~~	~~2.415~~	~~$\Lambda(1405)+p+K^+$~~	~~25~~
300	2.412	ppK^-+K^+	61

signal on the „physics background", $p\Lambda K^+$ dalitz decay

FOPI Apparatus

Fixed target experiment designed for heavy-ion-collision study



R. Kutsche Ph.D.Thesis
K. Wisniewski Ph.D.Thesis

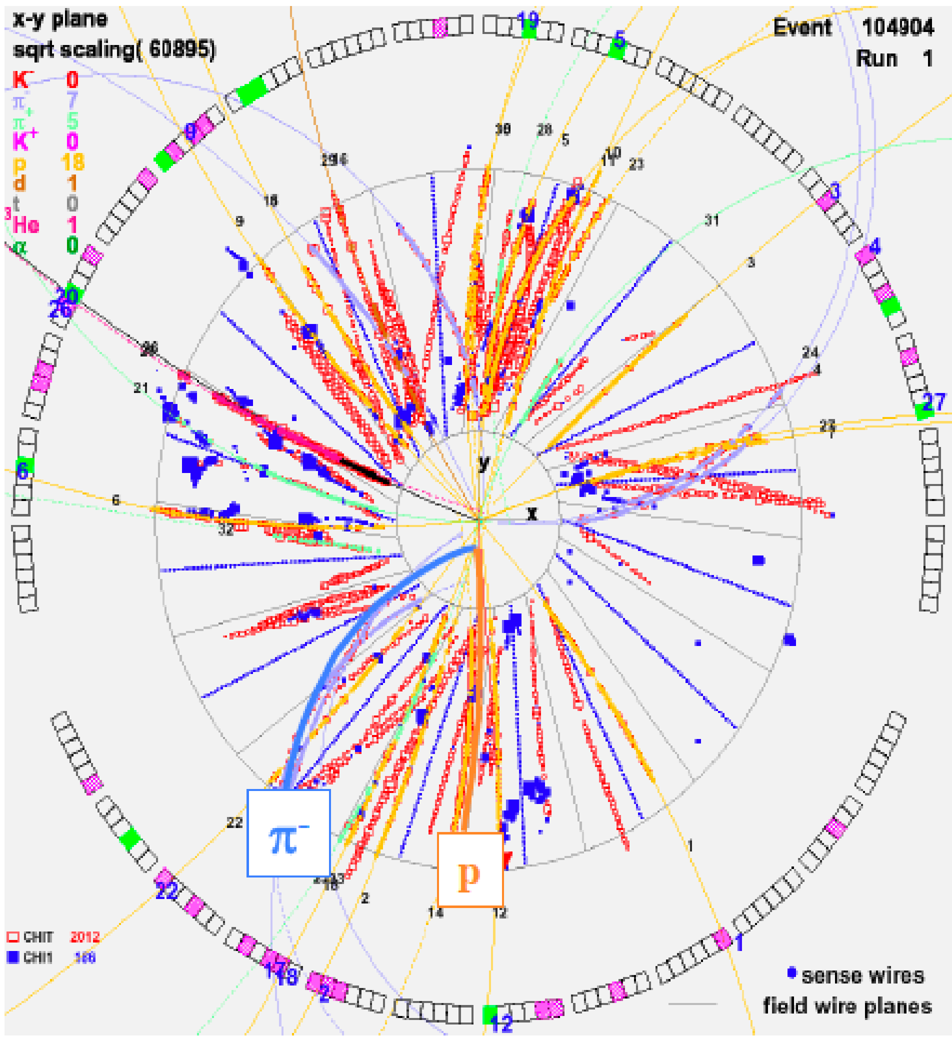
Magnetic Field: 0.6T
Trigger Rate: 200~500Hz
Particle/event: ~100

θ_{lab}	Tracking	TOF
35-150	CDC	Sci. Barrel
7.5-35	Helitron	PLAWA
1.2-7.5		ZD

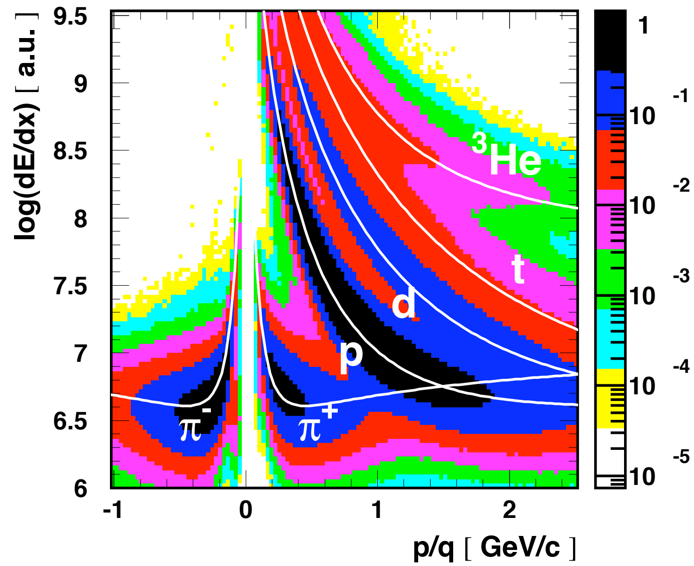
FOPI performance: charged particle

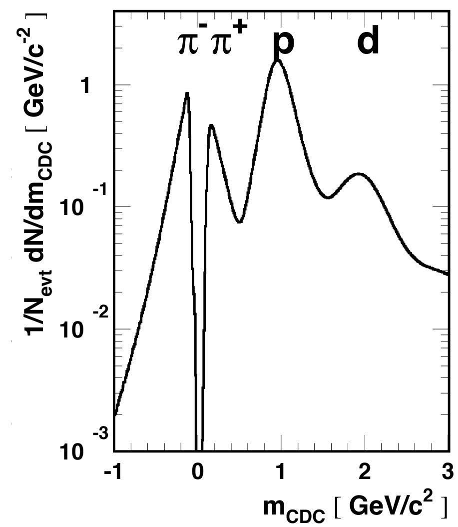
ex. event monitor

Ni+Ni @ 1.93 AGeV (2003)

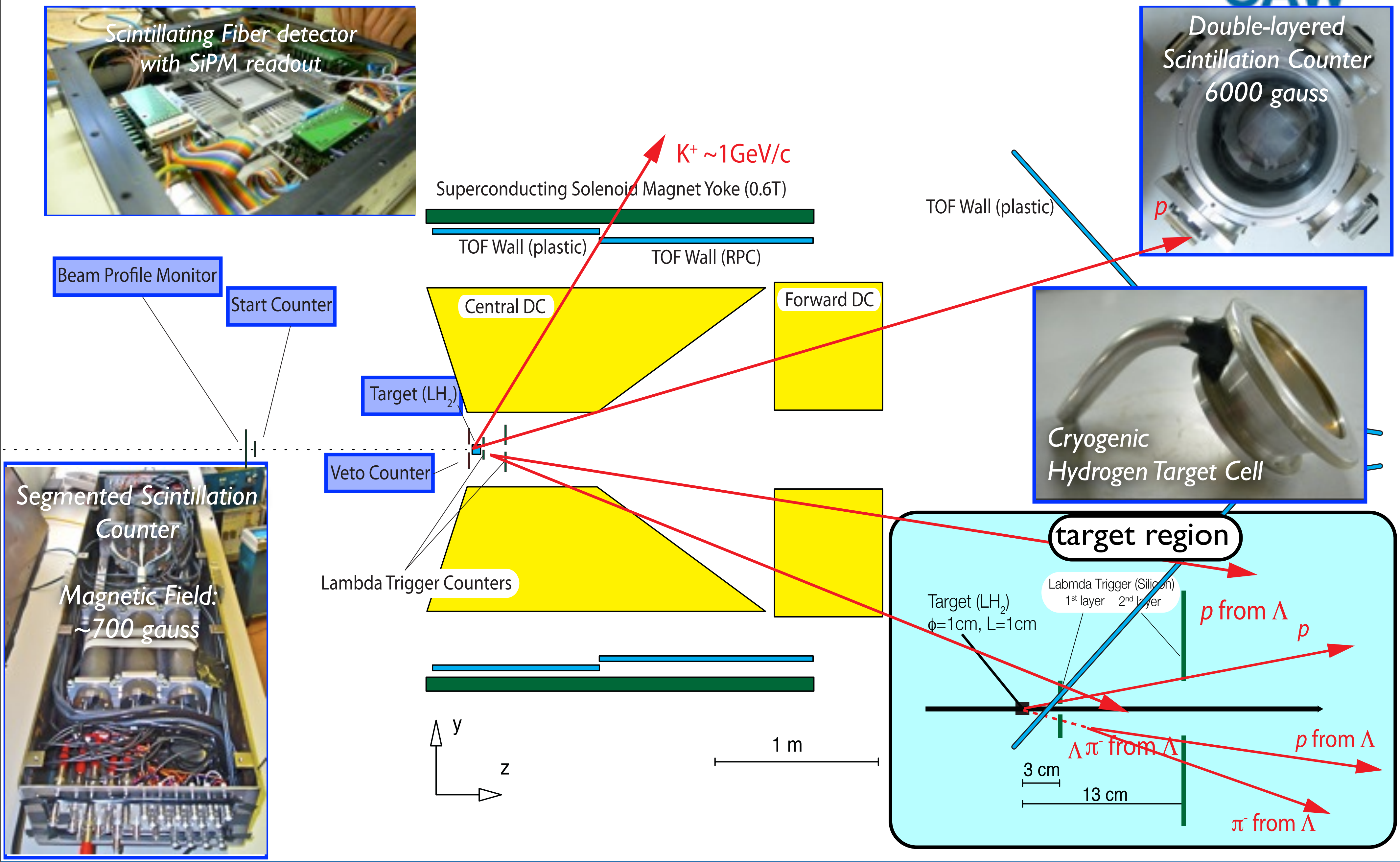


ex. particle id





Experimental Setup at FOPI

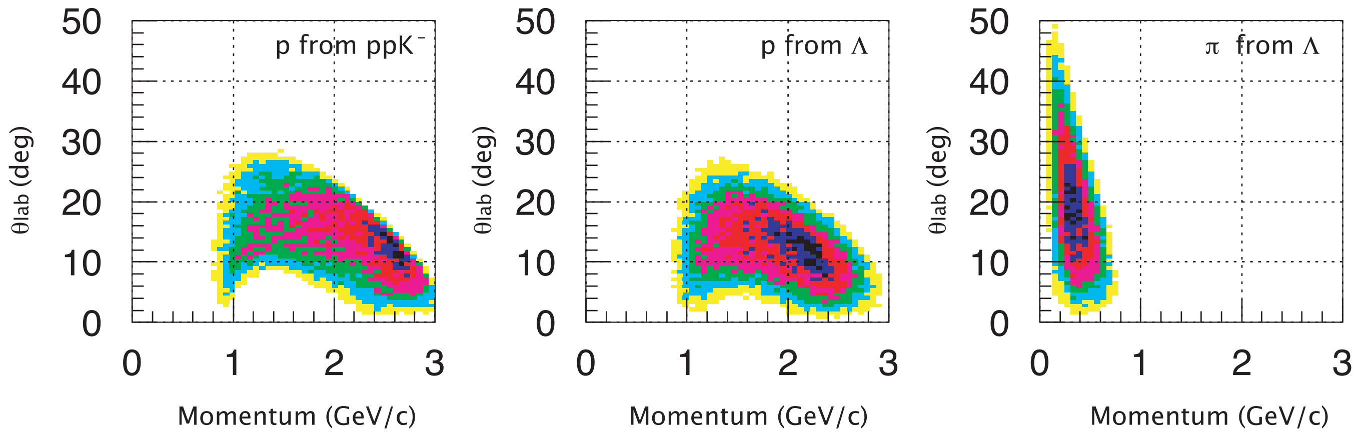


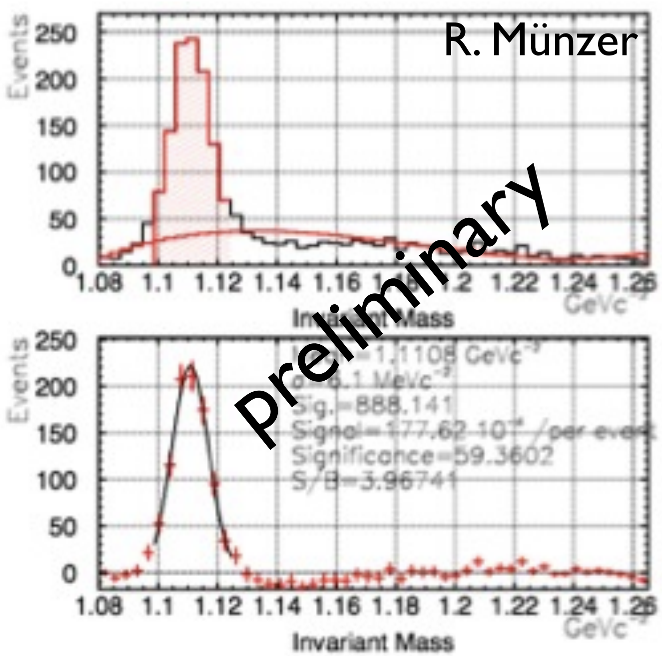
Data taking

- -September 2009 (effectively ~2wks data taking)
- Tp=3.1 GeV, 10-15 M /spill, spill cycle=10 s
- LH_2 target (2 cm = ~0.4 %)
- ~80 M „Lambda-Trigger“ events

IM (K^-pp decay products)

$$K^-pp \longrightarrow p+\Lambda \longrightarrow p+(p+\pi^-)$$

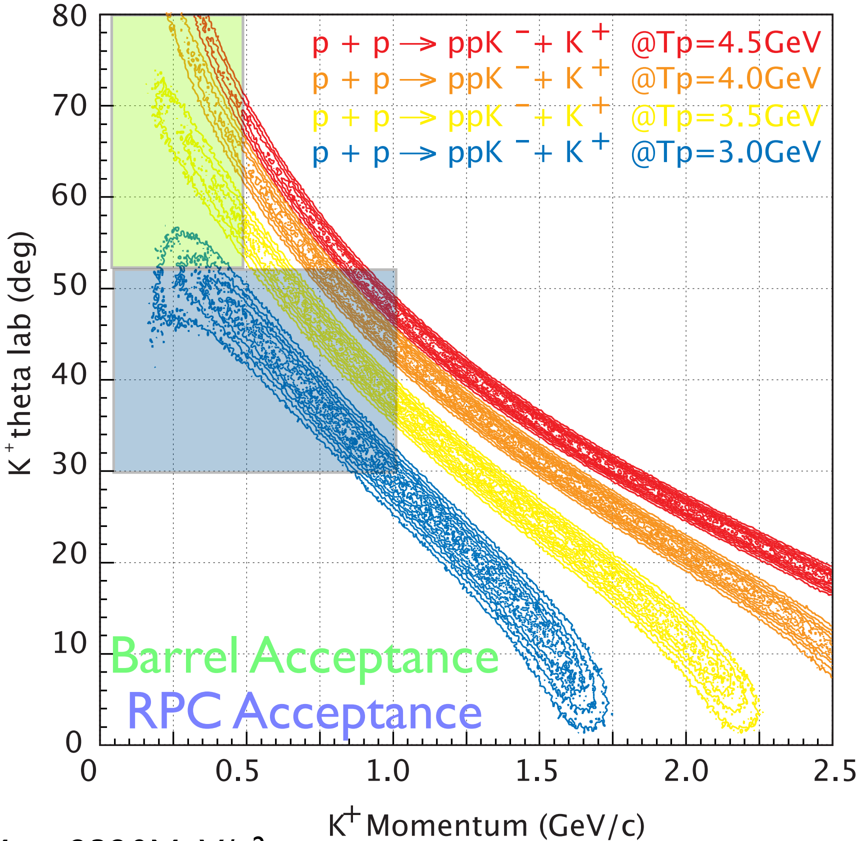




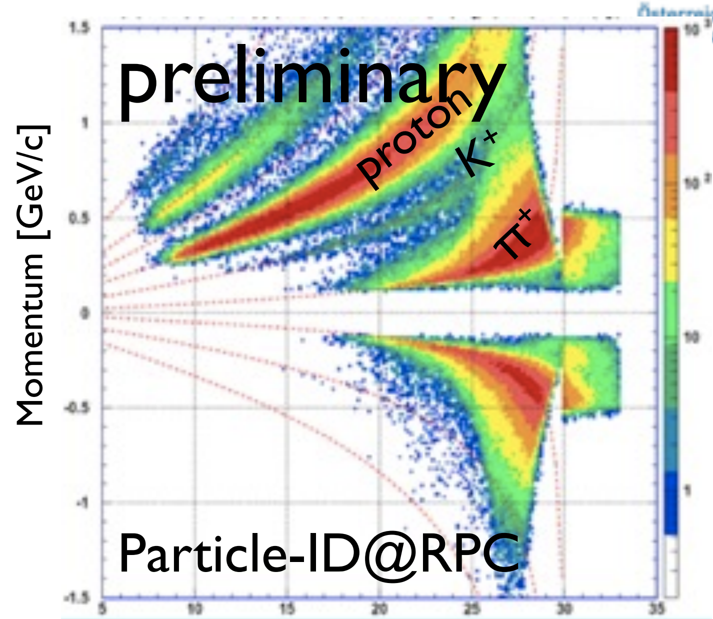
$M_{ppK^-} = 2279 MeV/c^2$

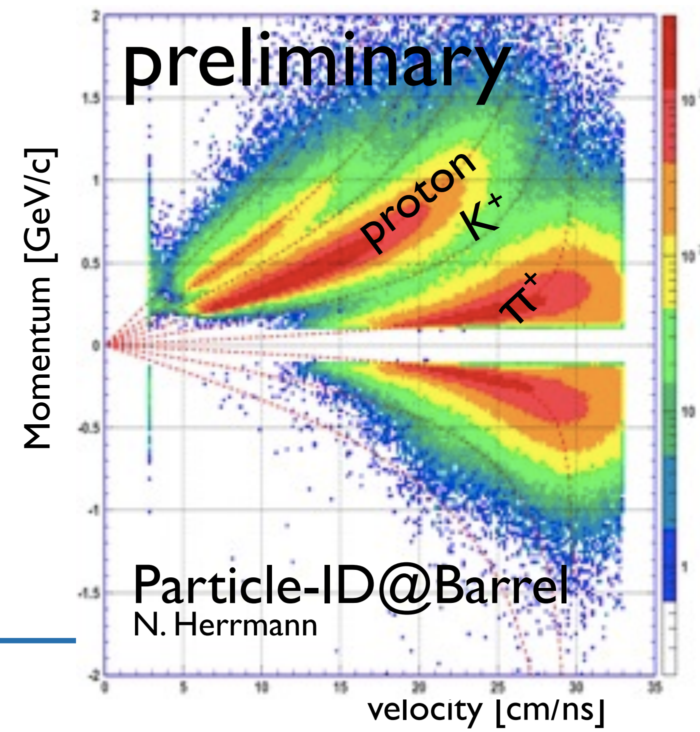
@Tp=3.0GeV

K^+ analysis



Mass 2320MeV/c^2
width 60MeV/c^2





(DISTO) Analysis Strategy

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1. Selection of exclusive $p+p \to p+\Lambda+K^+$ final state events (Ordinary+Exotic process)
2. „Acceptance Correction“
3. Look for a binary process: $p+p \to$ “K^-pp“$+K^+$ (Exotic Process) as a deviation from the ordinary process,
4. Analyze the binary process
    1. Consistency check with production ch. (MM) and decay ch. (Minv)
    2. Kinematics
    3. Further cross checks (high momentum transfer)
5. Interpretation

Comparison: FOPI DISTO

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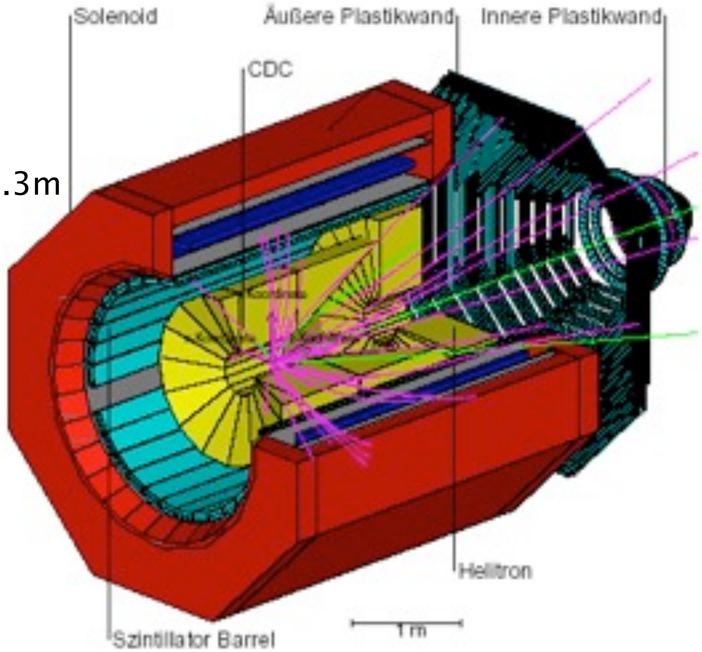
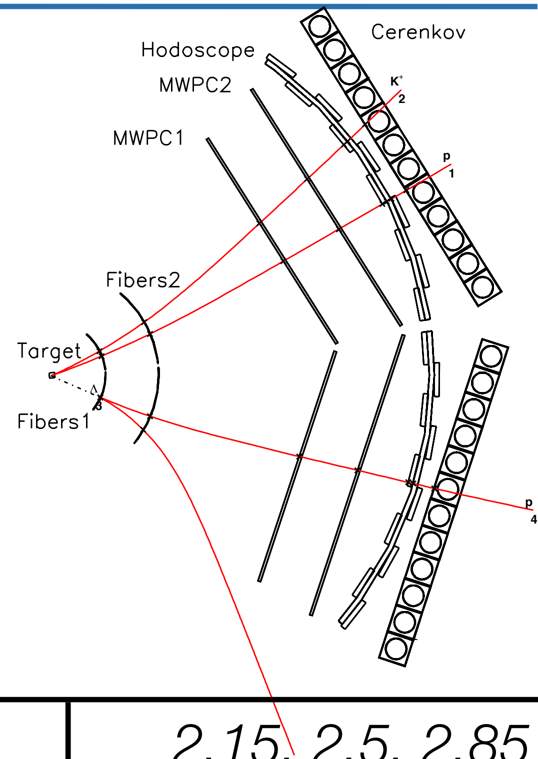
ø2.4m x 3.3m

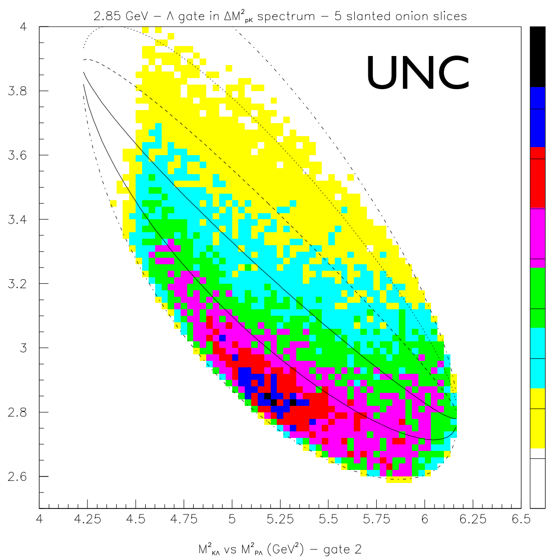


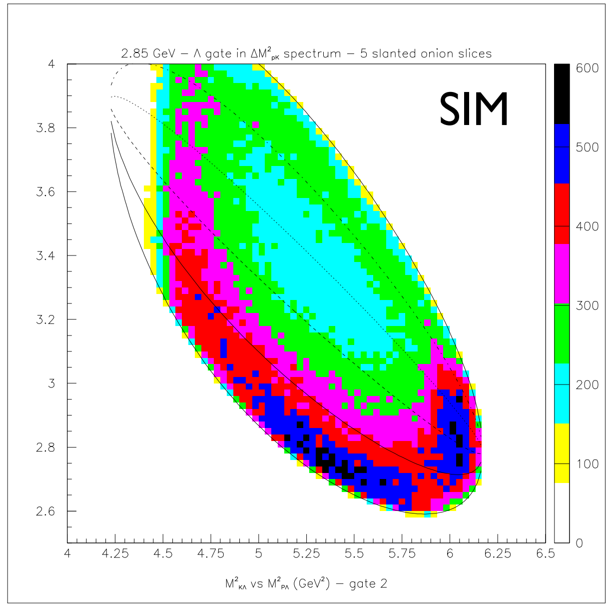


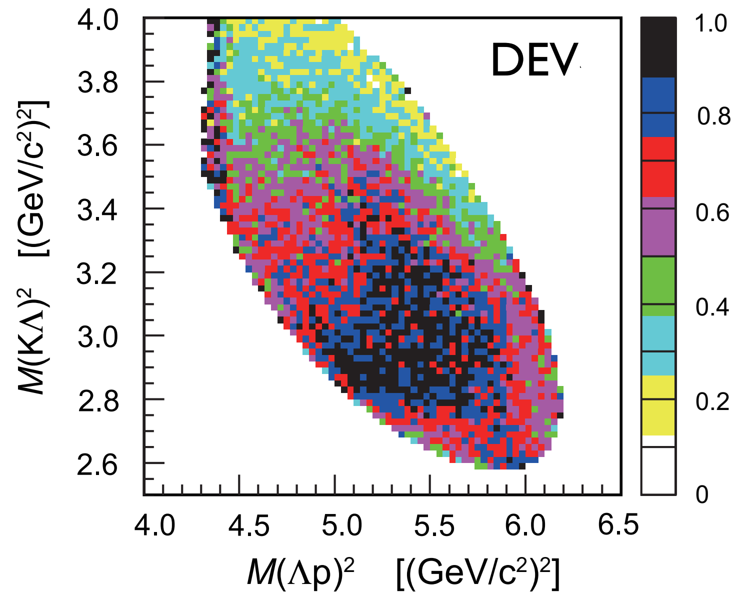
Beam Energy	*3.1 GeV*	*2.15, 2.5, 2.85 GeV*
Prim. Det. Design	*Heavy-Ion-Collision*	*hyperon spin physics*
Magnet	*Cylindrical*	*Dipole*
Λ Trigger	*Yes*	*Yes*
Direct $K^{\pm}$ ID	*Yes*	*No*
Venue	*GSI, Darmstadt*	*Saclay, Paris*
Statistics		*177k pΛK events*

R. Kutsche Ph.D.Thesis

Acceptance Correction







UNC: Acceptance non-corrected data

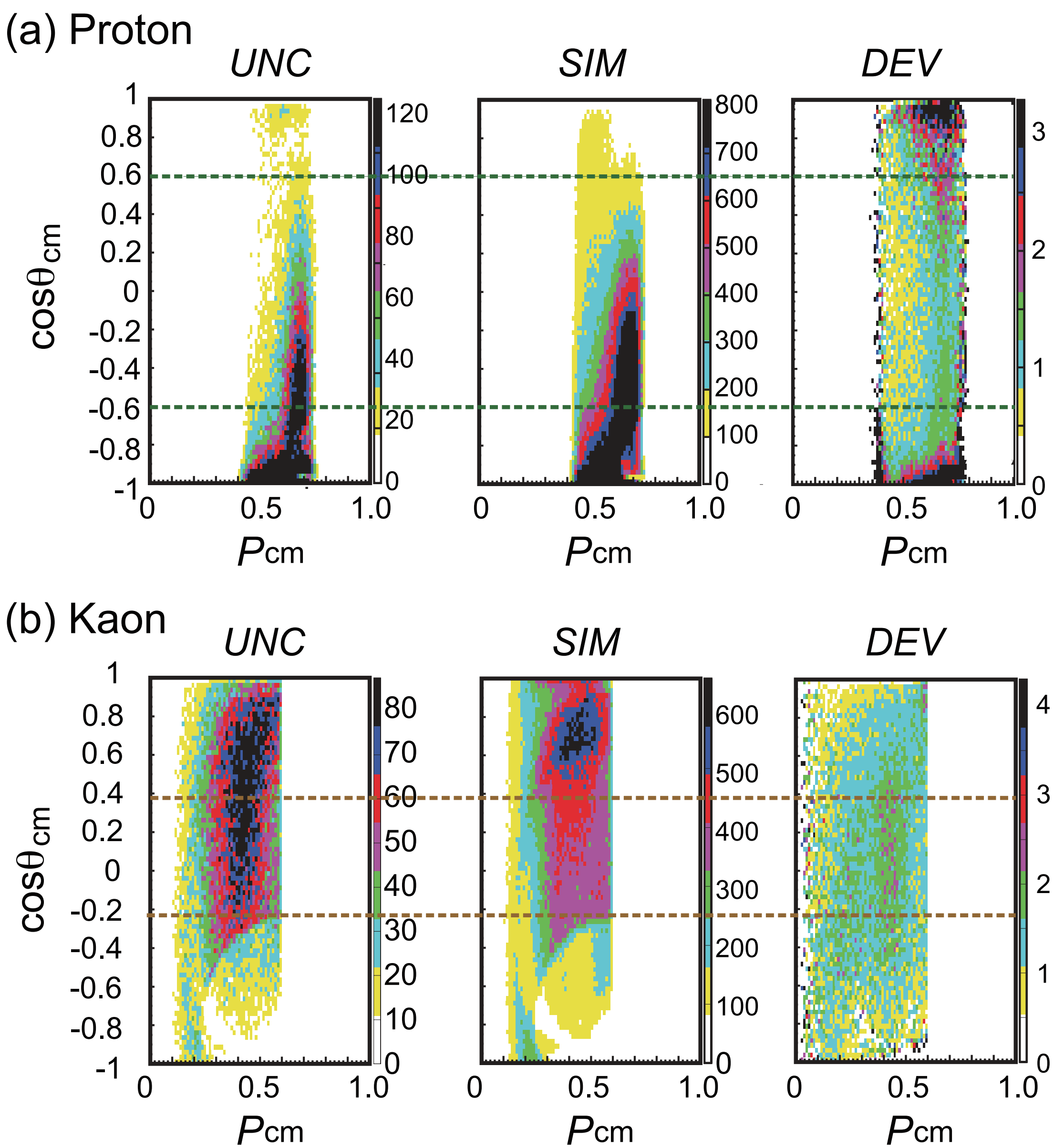
SIM: „ordinary" $pp \rightarrow p\Lambda K$ events with flat phase space assumption

DEV: UNC/SIM (bin by bin), deviation from flat distribution

Powerful technique which works only with this specific case

Valid if the event sample is only $p\Lambda K$ final state. Purity~a few %

$\cos\theta_{cm}$ vs P_{cm}



Very backward peaked proton (UNC)

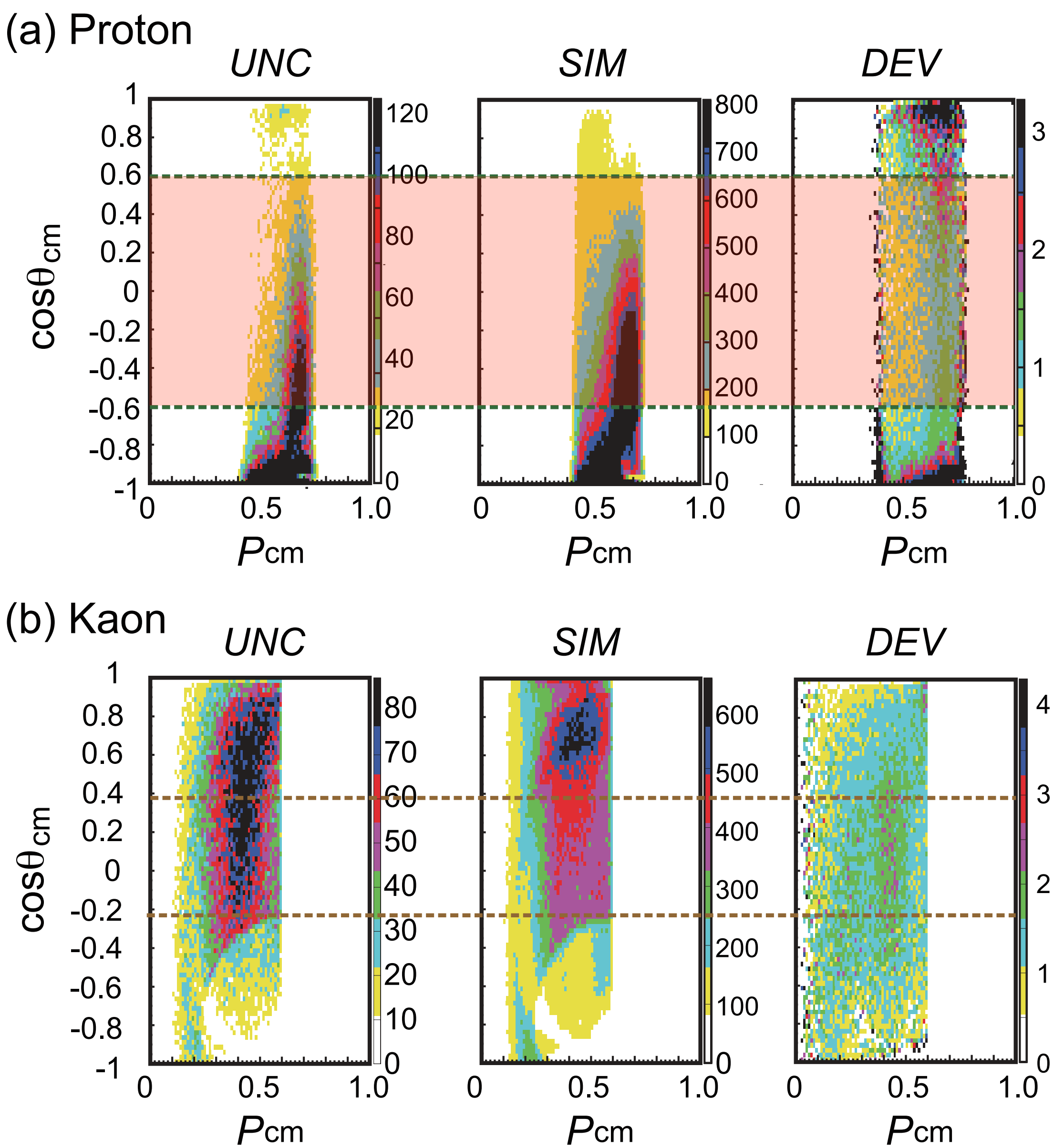
Higher acceptance of Lambda in forward

Symmetric *pp* scattering in CM (DEV)

Monoenergetic kaon component at P_{cm}~0.4GeV/c

„ordinary“ ΛpK event dominant at low p_T

$\cos\theta_{cm}$ vs P_{cm}



Very backward peaked proton (UNC)

Higher acceptance of Lambda in forward

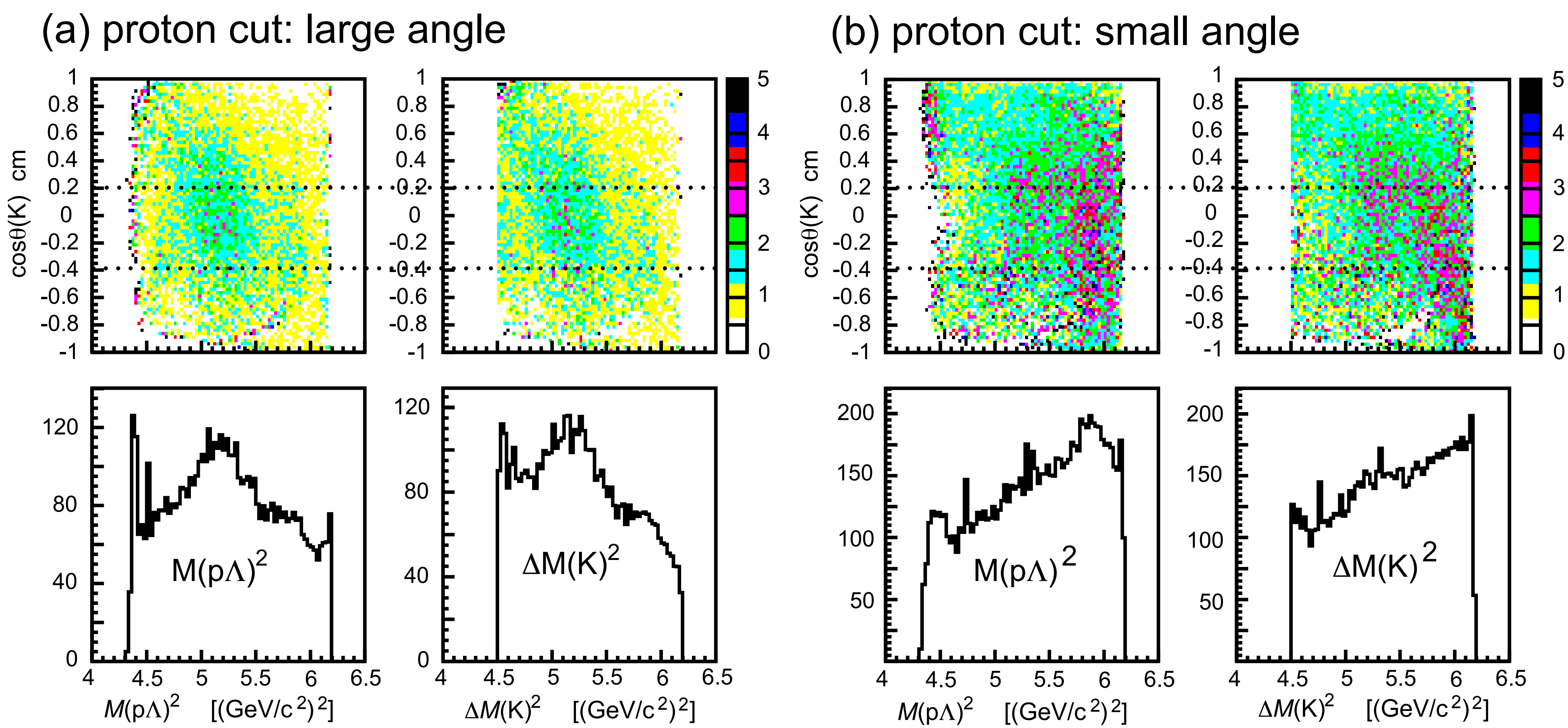
Symmetric *pp* scattering in CM (DEV)

Monoenergetic kaon component at P_{cm}~0.4GeV/c

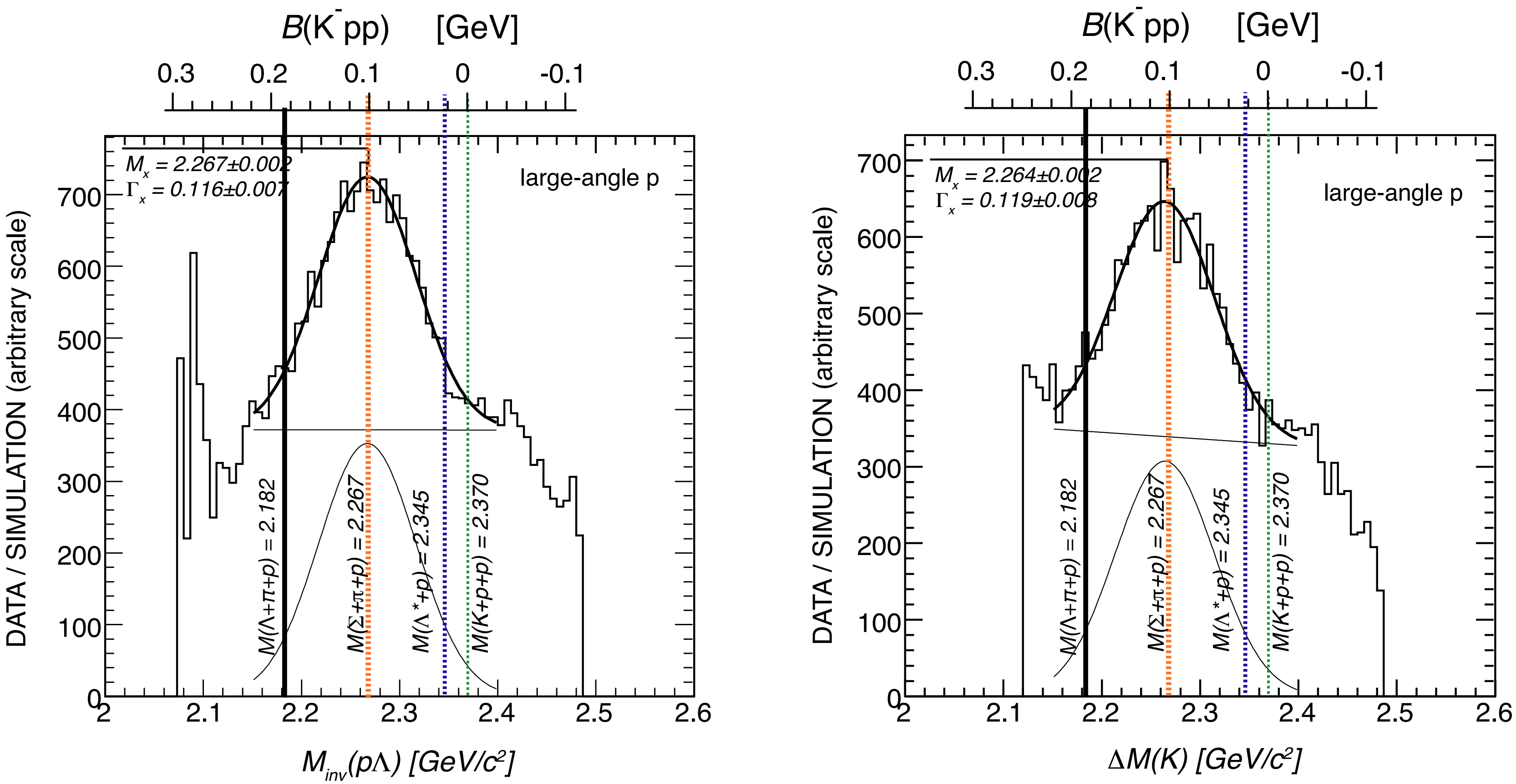
„ordinary“ ΛpK event dominant at low p_T

Large Angle Proton

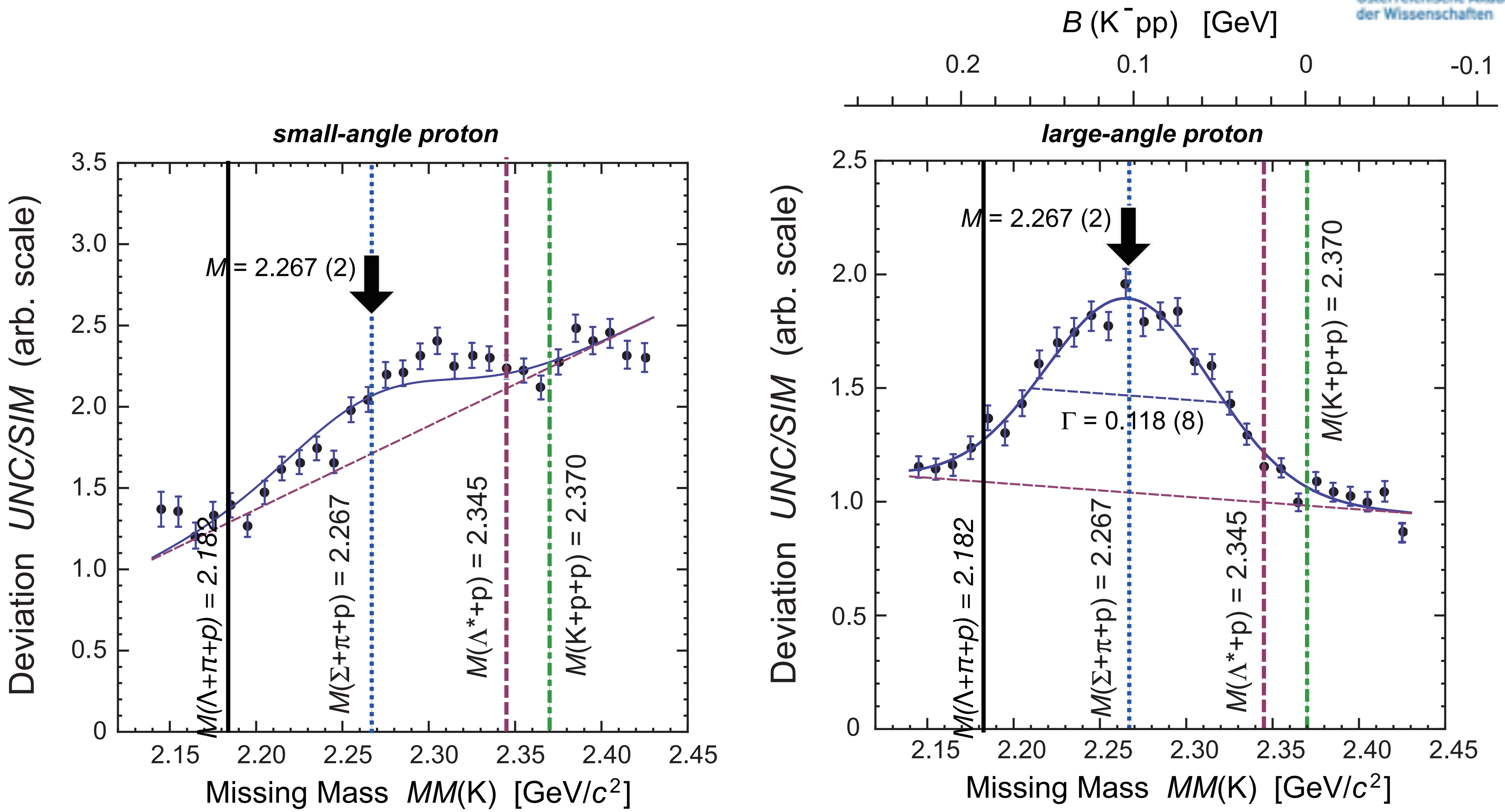
Large/Small Proton Angle Cut



MM / M_{inv} spectrum



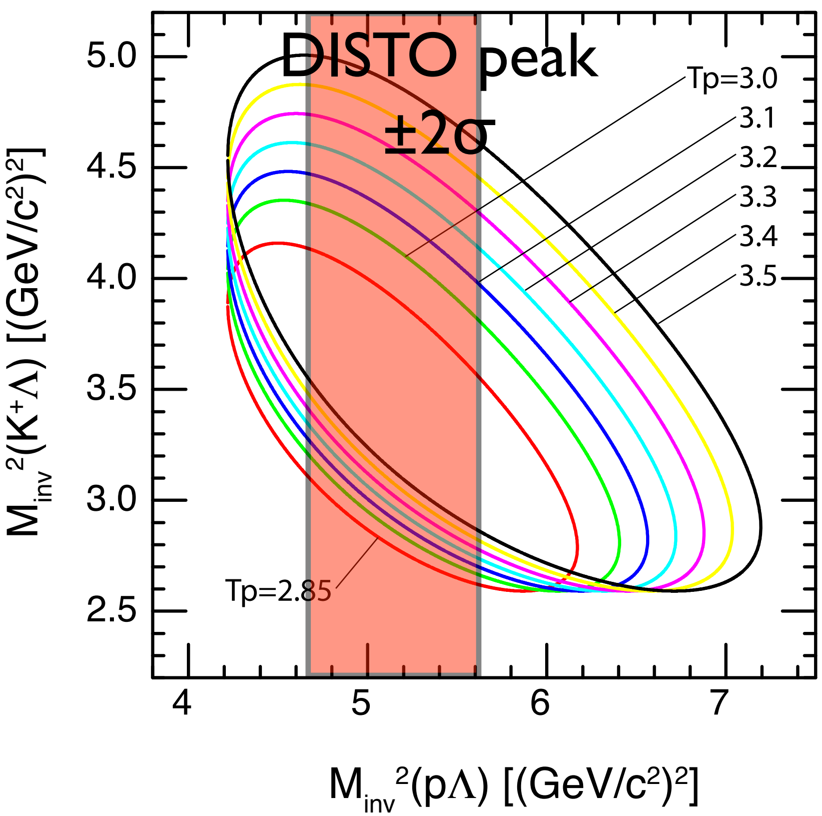
- *X component consistent in both cases,*
  - *symmetric shape*
  - *background description still primitive*

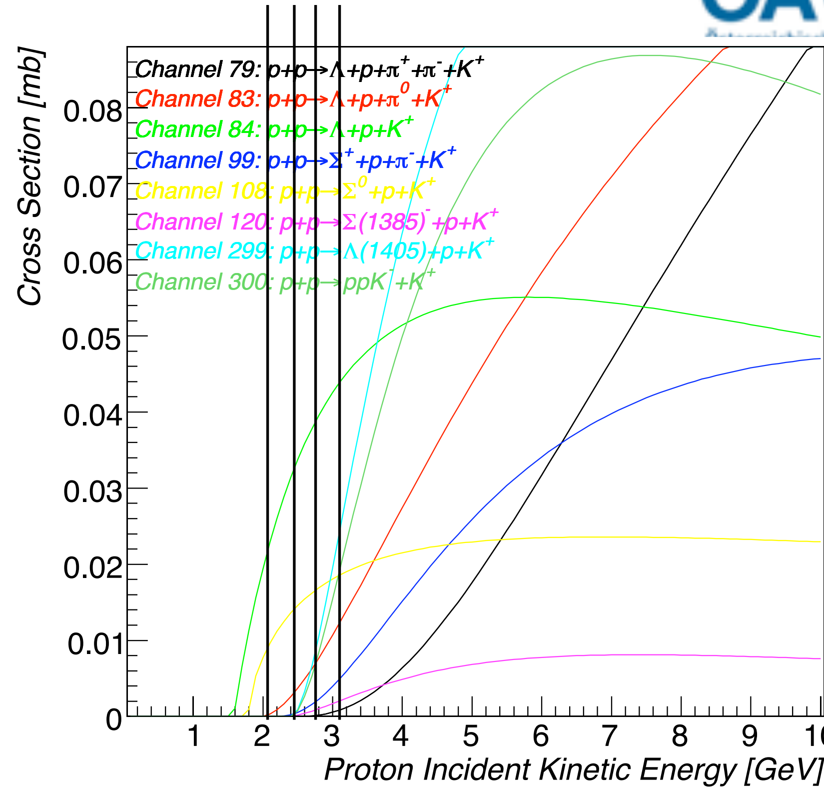


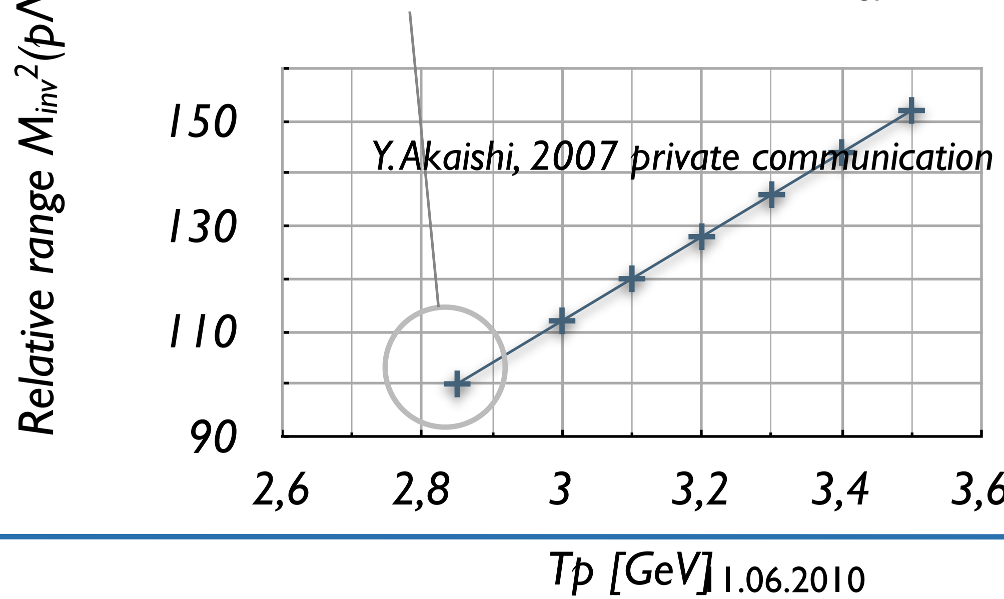
- *Binding energy and width does not much with any theory*

Beam Energy Dependence

$p+p \rightarrow p+\Lambda+K^+$







Outlook and Perspectives

- *Exclusive measurement of pp→pΛK^+ reaction, to the question of an existence of kaonic nuclear states at FOPI and DISTO*
- *DISTO sees pp→K^+X process which fulfills a certain (but not full) picture of K^-pp production („Indication“: PRL104 2010 132502)*
  - *Mid. July DISTO analysis week*
- *FOPI analysis in progress*
- *Energy dependence study: lower (less/no knucl.) energy (DISTO, COSY?), higher (<u>more optimal</u>) energy (FOPI).*

Collaboration

FOPI Collaboration

Anton Andronic[4], Valerie Barret[3], Zoran Basrak[16], Nicole Bastid[3], Mohammed Lotfi Benabderrahmane[6], Martin Berger[10], Paul Bühler[14], Roman Čaplar[16], Ivana Carević[12], Michael Cargnelli[14], Mircea Ciobanu[6], Philippe Crochet[3], Ingo Deppner[6], Pascal Dupieux[3], Mile Dželalija[12], Laura Fabbietti[10], Piotr Gasik[15], Igor Gašparić[16], Yuri Grishkin[8], Olaf Hartmann[14], Norbert Herrmann[6], Klaus Dieter Hildenbrand[4], Byungsik Hong[11], Tae Im Kang[11], Jozsef Kecskemeti[2], Young Jin Kim[4], Paul Kienle[14], Marek Kirejczyk[15], Mladen Kiš[4], Milorad Korolija[14], Roland Kotte[5], Piotr Koczoń[4], Alexander Lebedev[8], Yvonne Leifels[4], Xavier Lopez[3], Vladislav Manko[9], Johann Marton[14], Tomasz Matulewicz[15], Markus Merschmeyer[6], Robert Münzer[10], Mihail Petrovici[1], Krzysztof Piasecki[6], Dominik Pleiner[10],Fouad Rami[13], Andreas Reischl[6], Willibrord Reisdorf[4], Min Sang Ryu[11], M. Schaffhauser[14], Andreas Schüttauf[4], Zoltan Seres[2], Brunon Sikora[15], Kwang Souk Sim[11], Victor Simion[1], Krystyna Siwek-Wilczyńska[15], Vladimir Smolyankin[8], Ken Suzuki[14], Zbigniew Tyminski[15], Jakob Wierzbowski[10], Eberhard Widmann[14], Krysztof Wisńiewski[15], Zhi Gang Xiao[7], Hu Shang Xu[7], Igor Yushmanov[9], Xue Ying Zhang[7], Alexander Zhilin[8] und Johann Zmeskal[14]

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DISTO Collaboration

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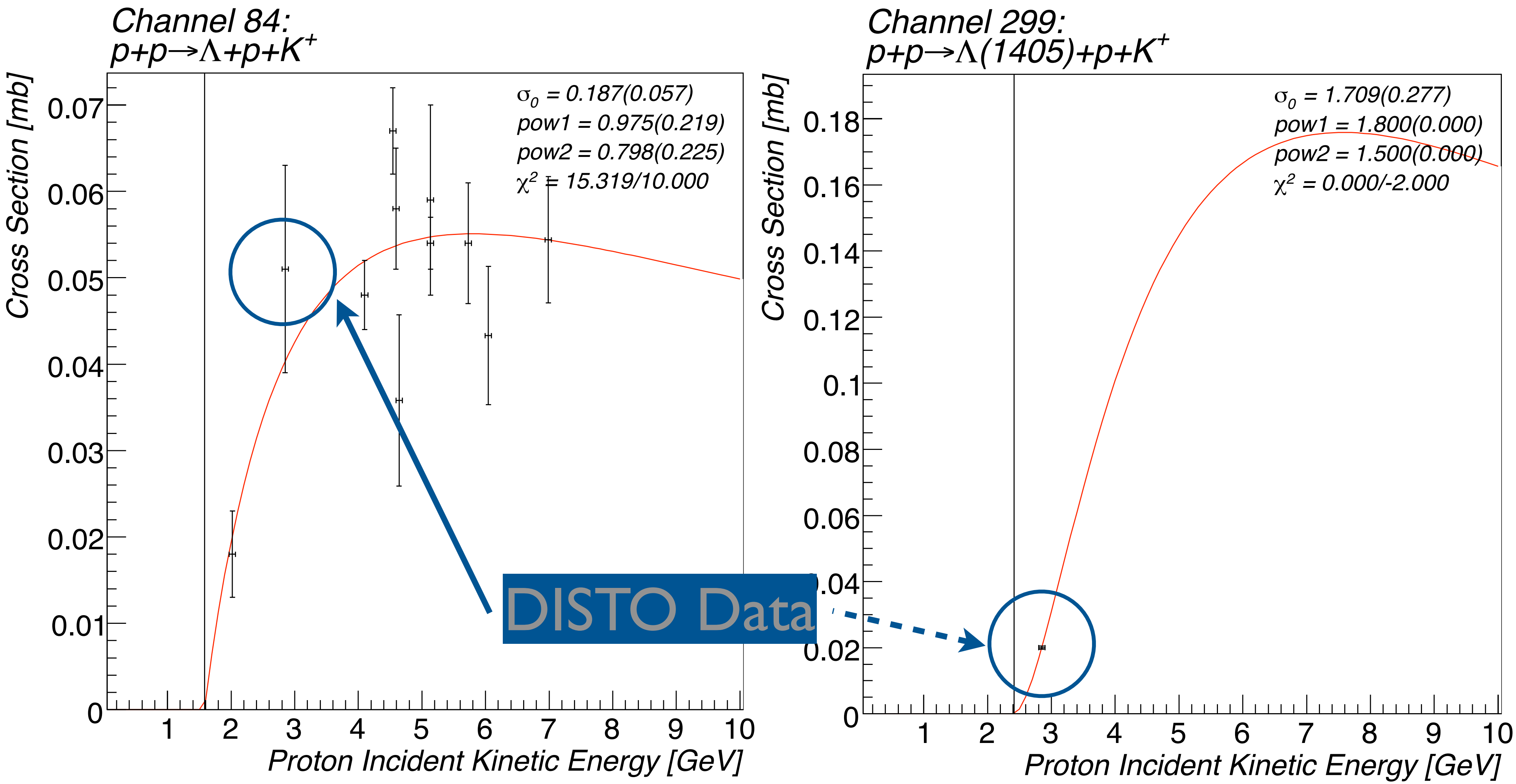
[1]University of Tokyo, [2]RIKEN, [3]INFN, Torino, [4]Stefan Meyer Institute for Subatomic Physics, Austrian Academy of Sciences, Vienna, [5]Excellence Cluster Universe, Technische Universität München, [6]Saclay, [7]Indiana University, [8]Universität Gießen, [9]Forschungszentrum Rossendorf, [10]Jagellonian University, Kraków, [11]H. Niewodniczanski Institute of Nuclear Physics, Kraków, [12]Universita` del Piemonte Orientale and INFN, Torino, Italy

Spare Slides

DISTO Data


Channel 84:
p+p→Λ+p+K+
σ0 = 0.187(0.057)
pow1 = 0.975(0.219)
pow2 = 0.798(0.225)
χ2 = 15.319/10.000
Cross Section [mb]
Proton Incident Kinetic Energy [GeV]
DISTO Data
Channel 299:
p+p→Λ(1405)+p+K+
σ0 = 1.709(0.277)
pow1 = 1.800(0.000)
pow2 = 1.500(0.000)
χ2 = 0.000/-2.000
Cross Section [mb]
Proton Incident Kinetic Energy [GeV]

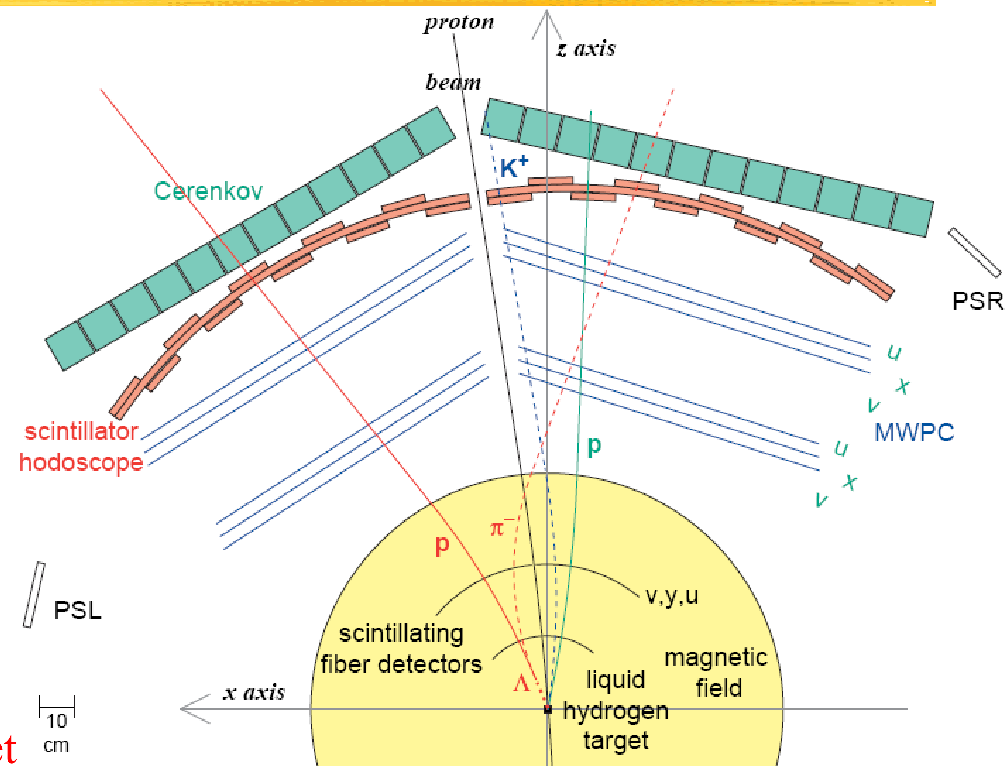
DISTO Experiment

DISTO @ Saturne: polarised proton beam up to T = 2.9 Gev

Acceptance:

$\Delta\varphi = \pm\, 15.5^{\circ}$

$\Delta\theta = \pm\, 45^{\circ}$



- 2-cm thick unpolarised LH_2 target
- S170 magnet (< 14.7 KGauss, $\Delta\theta = \pm\ 120^{\circ}$, $\Delta\varphi = \pm\ 20^{\circ}$)
- semi-cylindrical 1mm-square scintillating fibers triplets inside magnet
- MWPC planar triplets outside magnet
- scintillator hodoscopes vertically and horizontally segmented
- scintillator hodoscopes as polarimeter slabs
- doped water Cerenkov counters

M. Maggiora, HYP-X at Tokai, Japan 2009

$pp \rightarrow p\Lambda K(x)$

Österreichische Akademie der Wissenschaften

Hyperon production @ DISTO

Reaction	T_{thr}	Detected Prongs
$\vec{p}\,p \rightarrow p\,K^{+}\vec{\Lambda}$	1.58	$p\,K^{+}(p\,\pi^{-})$
$\vec{p}\,p \rightarrow p\,K^{+}\vec{\Sigma}^{0}$; $\vec{\Sigma}^{0} \rightarrow \vec{\Lambda}\,\gamma$	1.79	$p\,K^{+}(p\,\pi^{-})$
$\vec{p}\,p \rightarrow p\,K^{+}\Sigma^{*0}_{(1385)}$	2.34	$p\,K^{+}(p\,\pi^{-})$ from $\Lambda\,\pi^{0}$ or $\Sigma^{0}\pi^{0}$ $p\,K^{+}\pi^{+}(\pi^{-})$ from $\Sigma^{-}\pi^{+}$ $p\,K^{+}\pi^{-}(p)$ or (π^{+}) from $\Sigma^{+}\pi^{-}$
$\vec{p}\,p \rightarrow p\,K^{+}\Lambda^{*}_{(1405)}$	2.40	$p\,K^{+}\pi^{+}(\pi^{-})$ from $\Sigma^{-}\pi^{+}$ $p\,K^{+}(p\,\pi^{-})$ from $\Sigma^{0}\pi^{0}$ $p\,K^{+}\pi^{-}(p)$ or (π^{+}) from $\Sigma^{+}\pi^{-}$

M. Maggiora, HYP-X at Tokai, Japan 2009

$pp \rightarrow p\Lambda K(x)$

Hyperon production @ DISTO

Lambda Gate on $\Delta M_{pK\,thr}$		Detected Prongs
$\vec{p}\,p \rightarrow p\,K^{+}\vec{\Lambda}$	1.58	$p\,K^{+}(p\,\pi^{-})$
$\vec{p}\,p \rightarrow p\,K^{+}\vec{\Sigma}^{0}$, $\vec{\Sigma}^{0} \rightarrow \vec{\Lambda}\,\gamma$	1.79	$p\,K^{+}(p\,\pi^{-})$
$\vec{p}\,p \rightarrow p\,K^{+}\Sigma^{*0}_{(1385)}$	2.34	$p\,K^{+}(p\,\pi^{-})$ from $\Lambda\pi^{0}$ or $\Sigma^{0}\pi^{0}$ $p\,K^{+}\pi^{+}(\pi^{-})$ from $\Sigma^{-}\pi^{+}$ $p\,K^{+}\pi^{-}(p)$ or (π^{+}) from $\Sigma^{+}\pi^{-}$
$\vec{p}\,p \rightarrow p\,K^{+}\Lambda^{*}_{(1405)}$	2.40	$p\,K^{+}\pi^{+}(\pi^{-})$ from $\Sigma^{-}\pi^{+}$ $p\,K^{+}(p\,\pi^{-})$ from $\Sigma^{0}\pi^{0}$ $p\,K^{+}\pi^{-}(p)$ or (π^{+}) from $\Sigma^{+}\pi^{-}$

M. Maggiora, HYP-X at Tokai, Japan 2009