IKON, a study of the $\bar{K}N$ interaction with in-flight low momentum kaons

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IKON : Interacting Kaons On Nucleons

- A research project for the measurement of low momentum cross-sections of Kaon/Antikaon induced reactions at DAΦNE

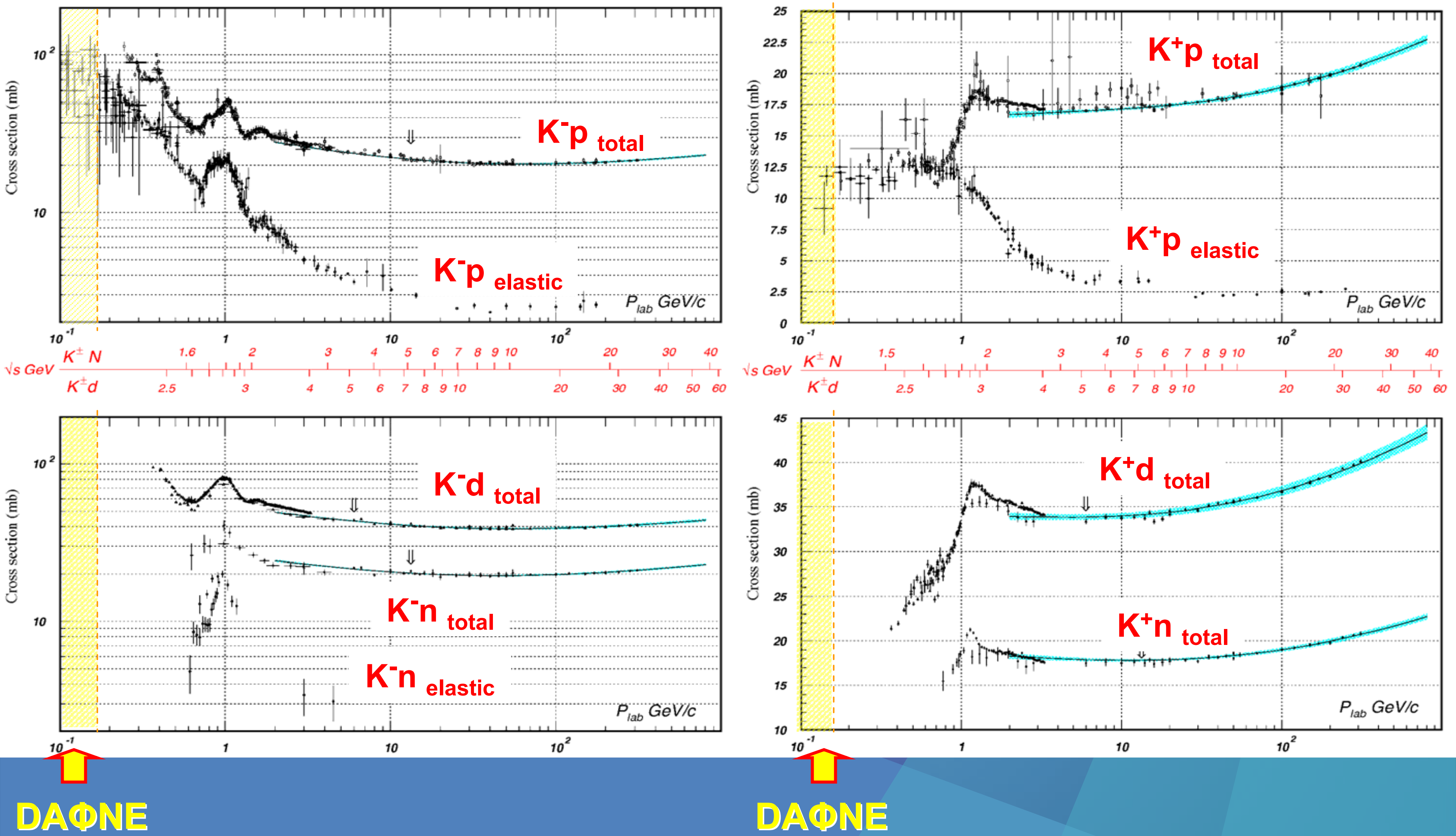
- Participating institutions
  - INFN Bari
  - Dip. Meccanica Uni-BS and INFN Pavia
  - INFN LNF
  - INFN Torino, Dip. Fisica Generale & Sperimentale Uni-TO, INAF-IFSI Torino
  - INFN Trieste and Dip. Fisica Uni-TS
  - TRIUMF, Canada

  - Theoretical support: Rez (Prague)

Overview

- Slow kaons at DAΦNE: unique features
- The physics of charged kaon scattering:
  - Kaons
  - Antikaons
  - Open issues
  - Reasons of interest
- IKON: an experiment at DAΦNE to perform precision cross-section measurements of in-flight low momentum kaons
  - VDET+KLOE: high precision general purpose detector
  - Feasibility studies (VDET simulations, kinematics, yields)
  - Practical infos: time scale, plans for 2011…
- Conclusions

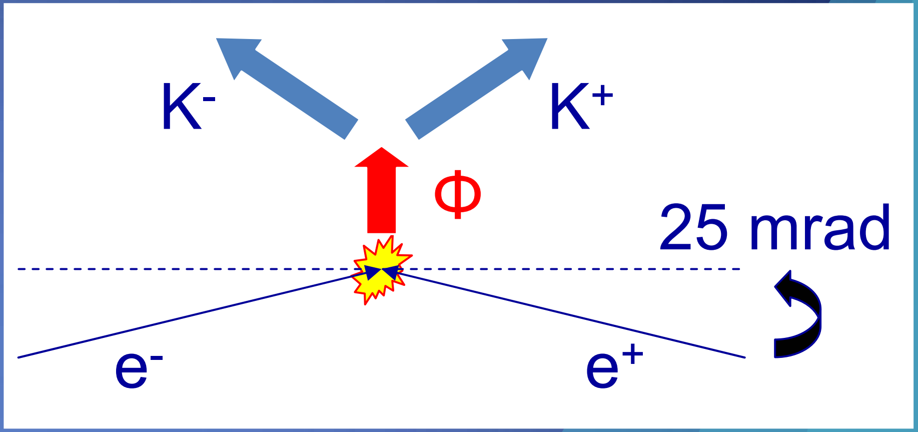
Kaon-Nucleon scattering database

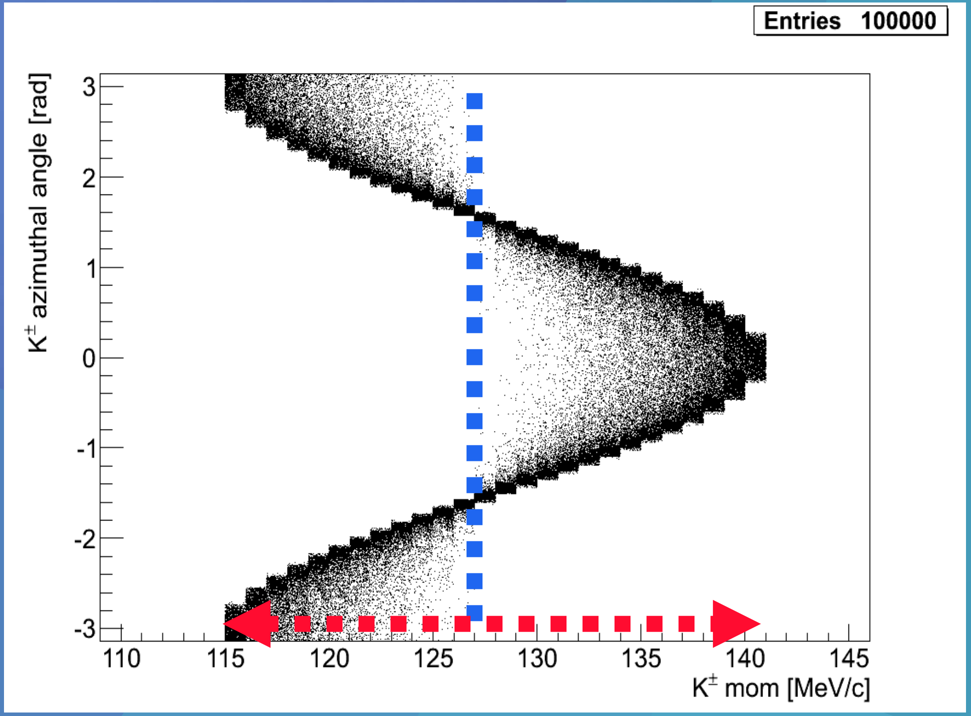


- at low energy **POOR WORLD DATABASE** and **LARGE ERROR BARS**
- DAΦNE is the only world facility for near-threshold KN measurements

K±'s at DAΦNE: experimental conditions

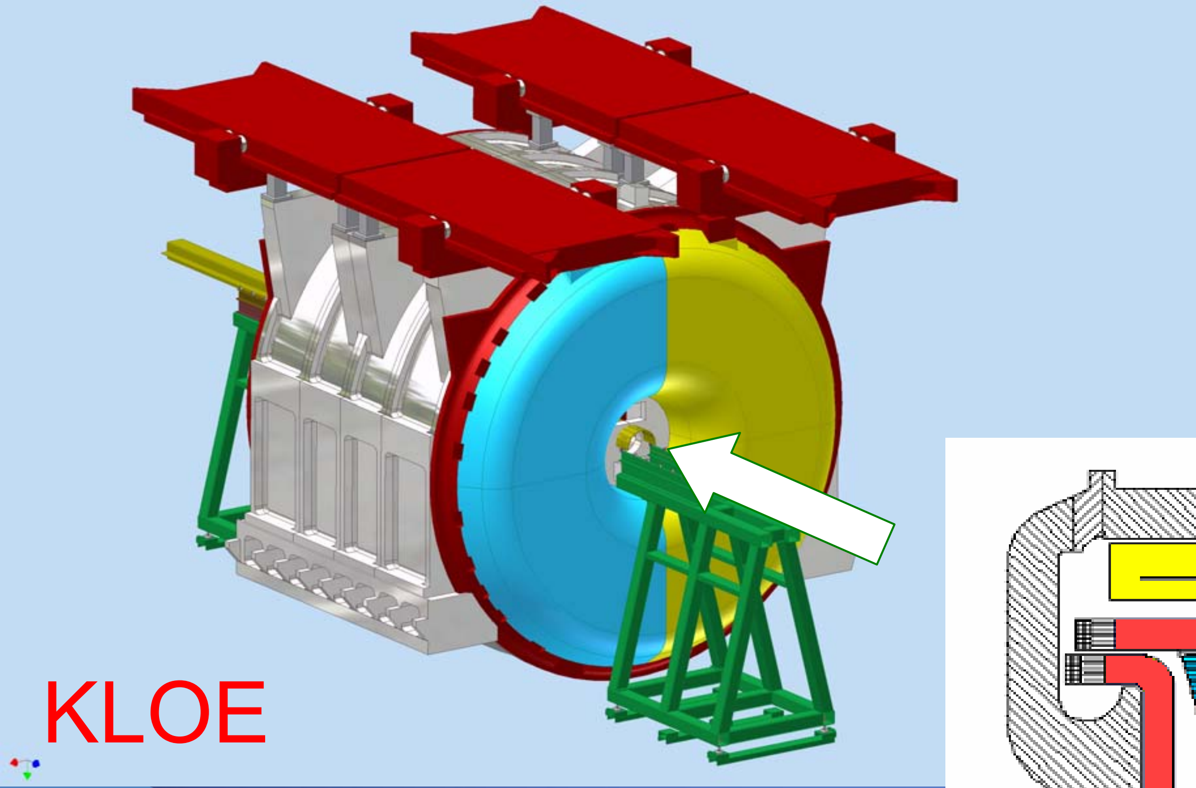
- Crab Waist Crossing: 25 mrad
- $\phi(1020)$ produced with boost:
  ~12 MeV/c
- Kaons from ϕ decay:
  $\phi(1020) \rightarrow K^+K^-$, B.R. 48%
- 115-141 MeV/c decay kaons
- $\sim 10^3\ \phi(1020)$ / s



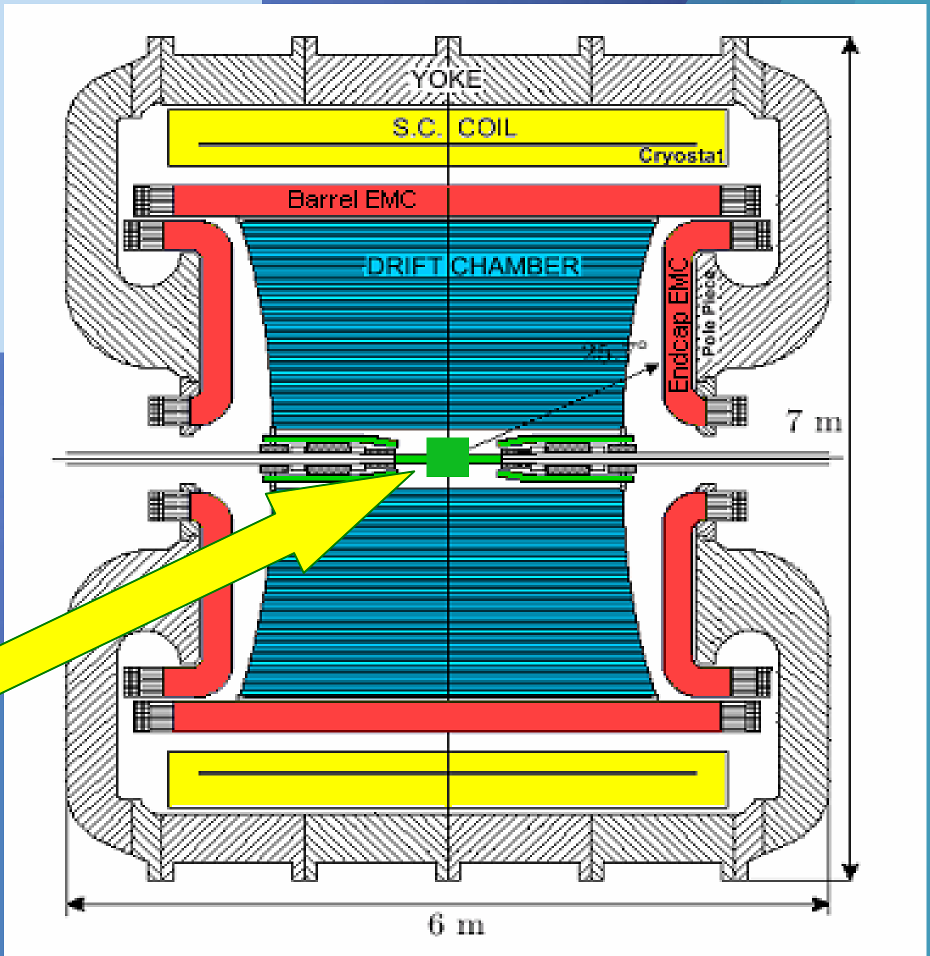


Experimental challenge:
- Track kaons and measure their momentum *before* their interaction
- Track final state products of K± scattering

KLOE + VDET = IKON



$\color{yellow}{\text{VDET}}$: KLOE can host a vertex detector with a gas target (H_2/D_2), available room r=20 cm



The physics issues: K^+N and K^-N

Different features of the $K^{\pm}N$ interaction call for different theoretical approaches

K^+N

$K^+ = (u\bar{s})$

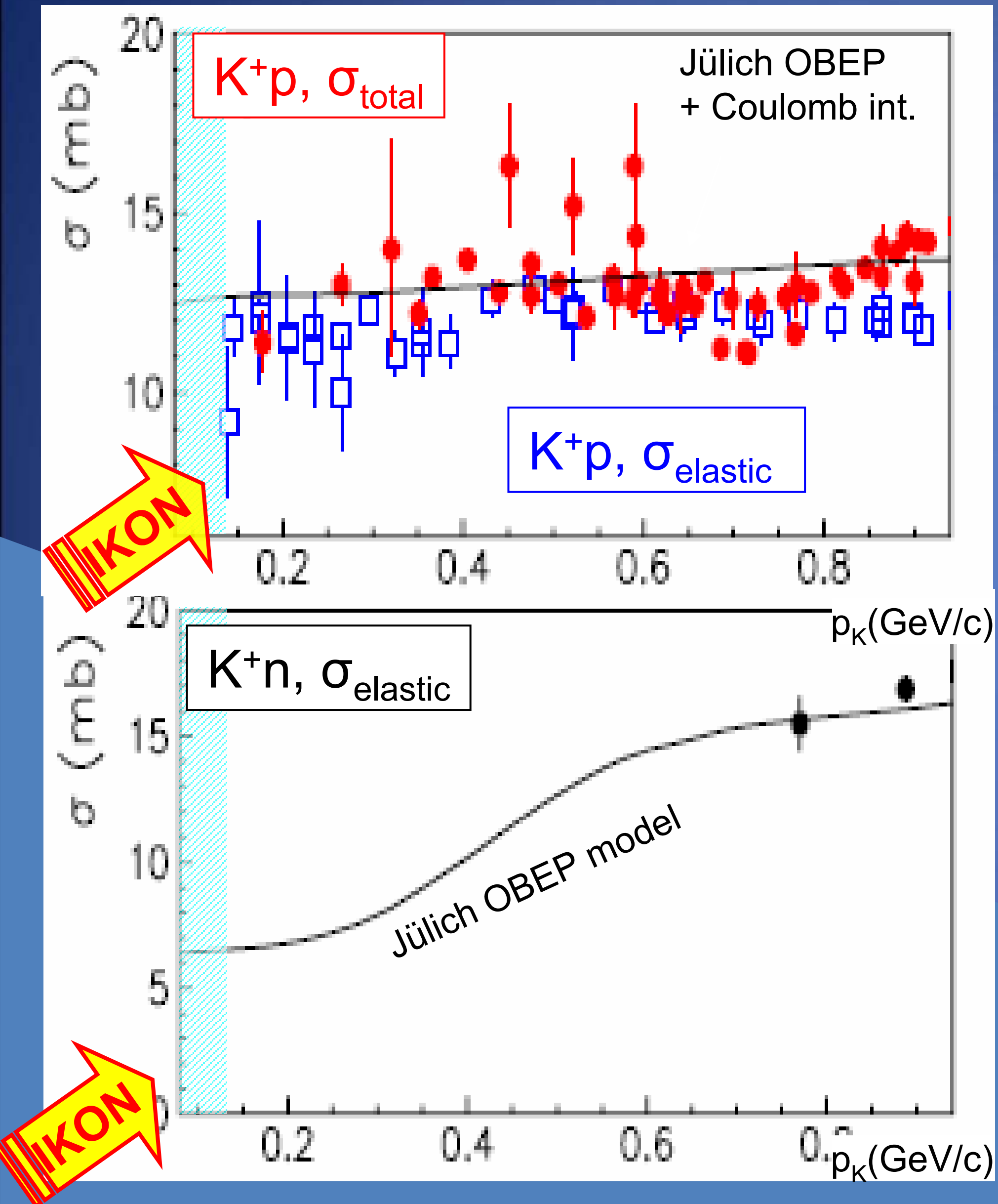
- Small cross sections
- Absence of resonances
  - Only elastic and CEX reactions possible
- Studied with perturbative approaches or meson exchange models

K^-N

$K^- = (\bar{u}s)$

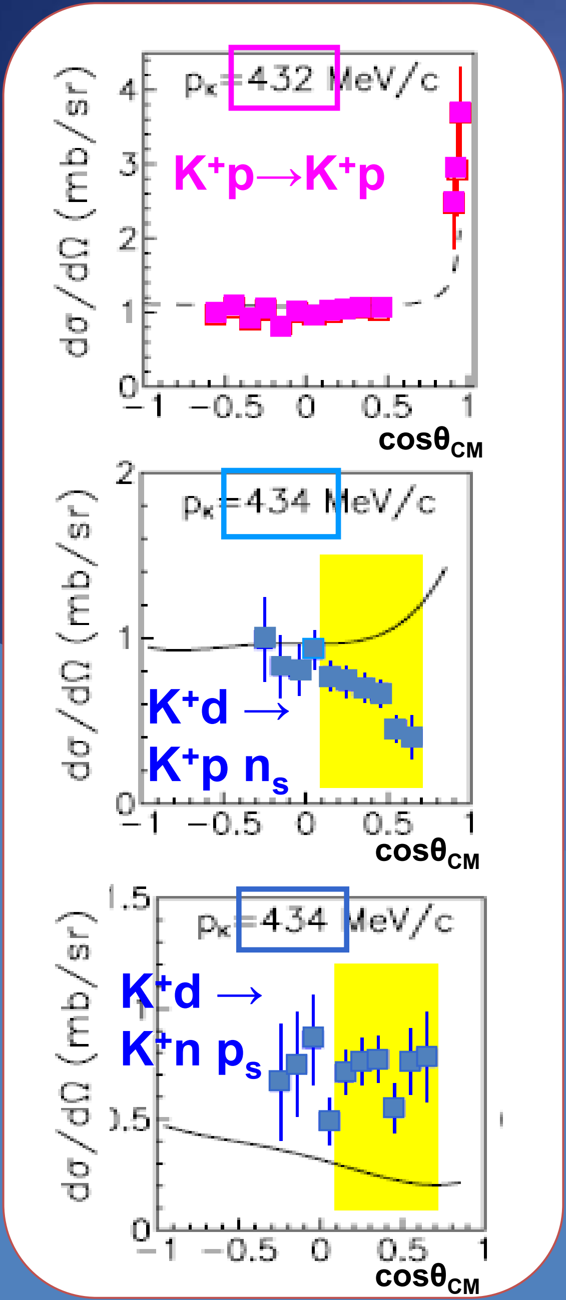
- Existence of I=0,1 resonances, even below threshold
- Strong coupling to many channels
- Perturbative methods cannot be applied
  - Approximated models with coupled channels

K^+N: present experimental situation I



- **TOTAL $\sigma(K^+p)$ on Hydrogen (I=1)**
  - Dominant: elastic channel
  - No measurements $p_K < 150$ MeV/c
- **TOTAL $\sigma(K^+n)$ on Deuterium (I=0,1)**
  - Elastic + CEX reactions
  - Only source of I=0 KN interaction

K^+N: present experimental situation II



- **DIFFERENTIAL dσ/dΩ**
  - K^+p data: different trend between interactions in $\mathbf{H_2}$ and $\mathbf{D_2}$
  - K^+d: disagreement with theoretical predictions, both on p and n
  - General lack of low momentum measurements
    - K^+d: no data < 342 MeV/c

Why new K^+N measurements needed?

- **Low energy data crucial to tune Chiral SU(3) theories**
  - Better understanding of SU(3) at low energy
  - Fix low energy parameters
    - **I=0 K^+N scattering lengths**
      - Known at 10%, based on data > 130 MeV/c
    - **Nuclear phase shift sign (+/-)**
  - Make "educated guess" of higher energy behaviour (Θ^+)

- **Precision measurement of KN Σ-term**
  - More sensitive to the nucleon strangeness content than πN σ-term
  - Existing measurements very old and with large errors
    - Precision improvement: factor >5 with σ evaluations @ 10%

K^-N interaction: overview

- **NO ChPT**
- **Baryonic resonances, I=0,1:** Λ(1115), Σ(1190), **Σ(1385), Λ(1405)**…
- Non-perturbative coupled-channel approach to describe all aspects of the K^-N interaction
- Low-energy data crucial input to enhance the predicting power of the KN models
  - Lack of experimental constraints close to threshold
    - scarcely selective models
    - poor below-threshold predictive power
    - Exp.data with inconsistencies
      - No model able to account for them

KON → Scattering cross sections for elastic & inelastic processes

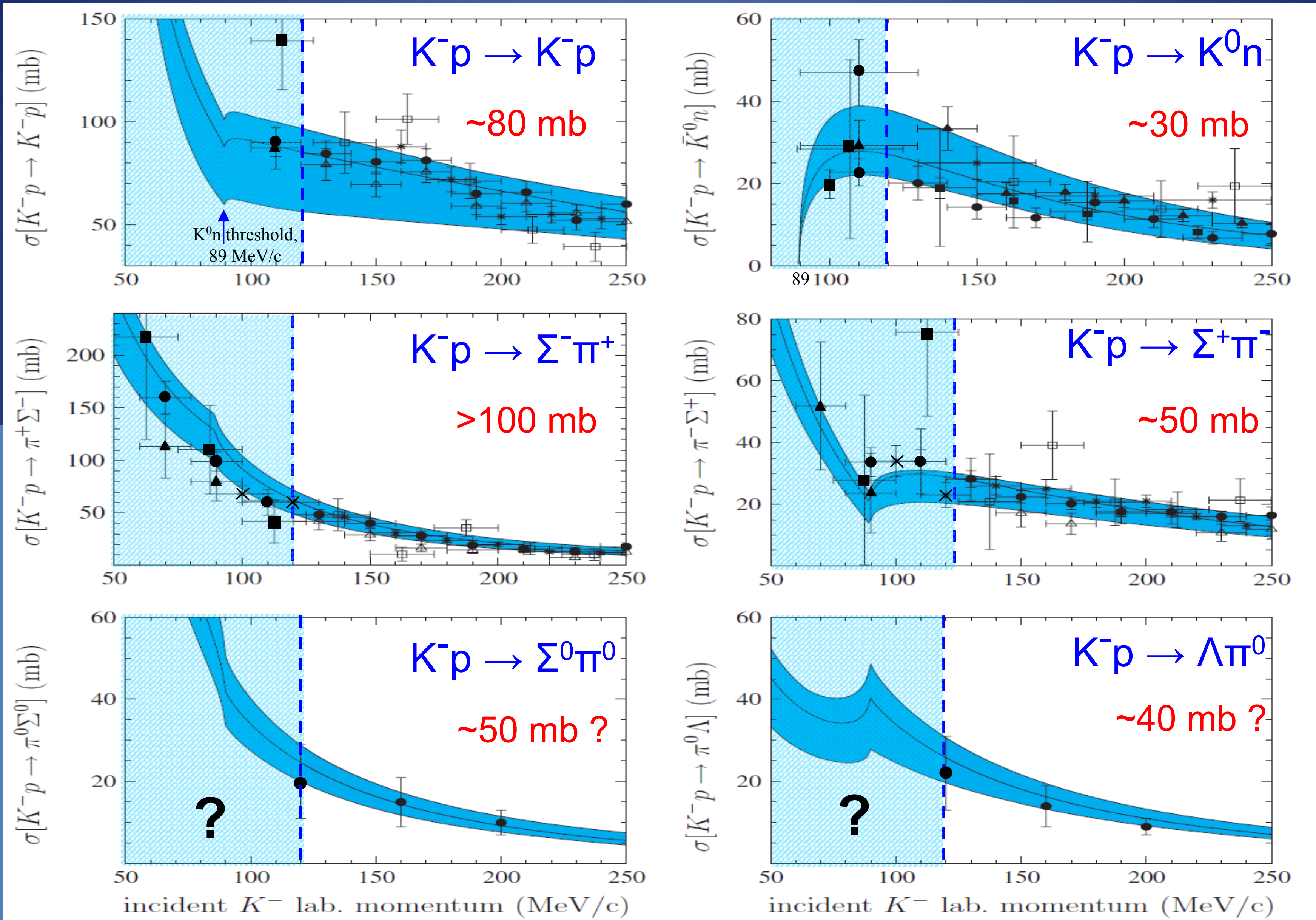
KON → Hadronic branching ratios close to threshold

KON → Data for below threshold resonance excitations: $\Sigma\pi$ spectra

Energy shift & width of kaonic atoms

K⁻N cross sections: available data & best fit

Experimental data with 20% precision *at most*



CC Model by Borasoy, Meißner, Nißler (2006), 1σ C.L.bands

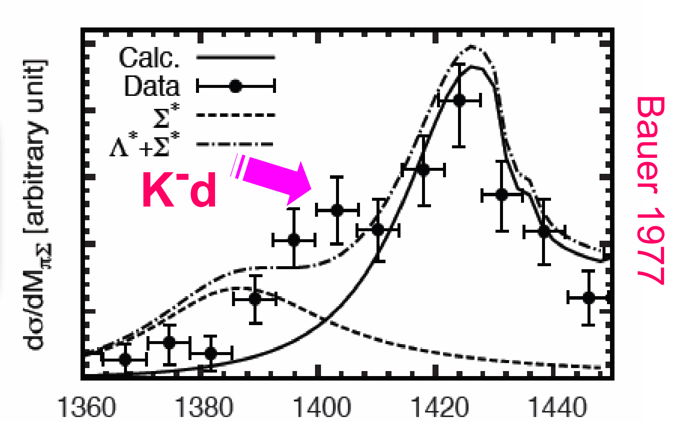
Excitation of resonances below threshold: the Λ(1405) case

Produced below the K^- N thr.

- $\gamma p \rightarrow \Lambda(1405)\, K^*$
- $K^- p \rightarrow \Lambda(1405)\, \gamma$
- $K^- p \rightarrow \Lambda(1405)\, \pi^0$

} Small σ

- **$K^- d \rightarrow \Lambda(1405)\, n$** IKON KLOE



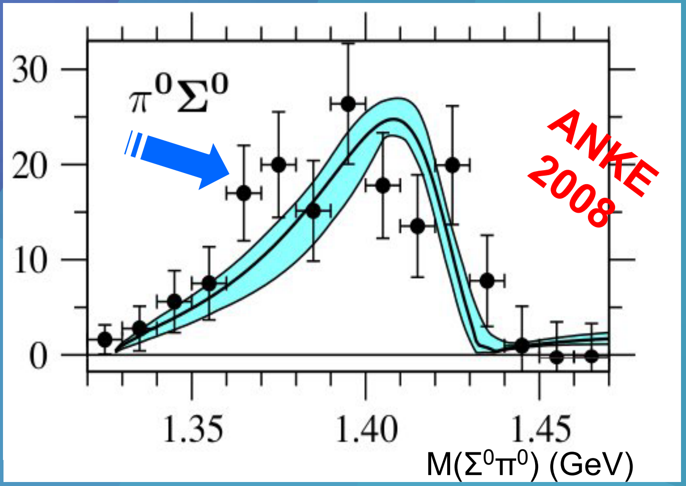
Λ (1405) observed via its Σπ decay

$\Sigma^\pm \pi^\mp$ decay: high precision on sec. vertex

– $\Sigma^0 \pi^0$ decay forbidden to Σ*(1385)

IKON KLOE

- Σπ measured lineshapes not reproduced satisfactorily by models yet
  - Old experiments measured $\Sigma^\pm \pi^\mp$ channels only, at high momentum
  - New results by ANKE & CLAS, also on $\Sigma^0 \pi^0$
- More data still needed



Summary: possible Kp(d) measurements

All of them will be collected *at the same time*

- $K^{\pm}$ **elastic scattering** on protons: $K^{\pm} p \to K^{\pm} p$
- $K^{\pm}$ quasi-elastic scattering on neutrons: $K^{\pm} d \to K^{\pm} np$
- $K^{\pm}$ elastic scattering on deuterons: $K^{\pm} d \to K^{\pm} d$

- **Inelastic** K^- reactions on **protons** close to threshold (**Y prod**.)
  - $K^- p \to \Lambda\pi^0$
  - $K^- p \to \Sigma^{\pm}\pi^{\mp}$

- **Inelastic** K^- interactions on **deuterons** close to thr. (**Y prod.**)
  - $K^- d \to YN\pi$ ($Y = \Lambda, \Sigma$)

- **Charge-exchange reactions** (threshold: 89 MeV/c)
  - $K^- p \to K^0 n$, $K^+ n \to K^0 p$
  - $K^0_L p \to K^+ n$

- **Regeneration reaction**: $K^0_L p \to K^0_S p$

Experimental setup: general requirements

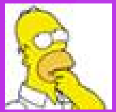
- **VDET TRACKING**
  - Fine segmentation
    - Resolution below 50 μm
    - secondary vertex reconstruction
  - Very low mass
    - minimize ΔE & multiple scattering
  - Capable of operating in magnetic field (B=0.6 T)

- **TARGETS** IKON
  - Solid targets (CH/CD)
    - Active (trigger)
    - Very thin (~500 μm)
    - Background from C
  - Gaseous (H_2/D_2)

    - Large dimension (~2 cm)
    - High pressure (~2-3 bar)
    - Mylar walled (beware! Material budget)
    - Clean vertex identification

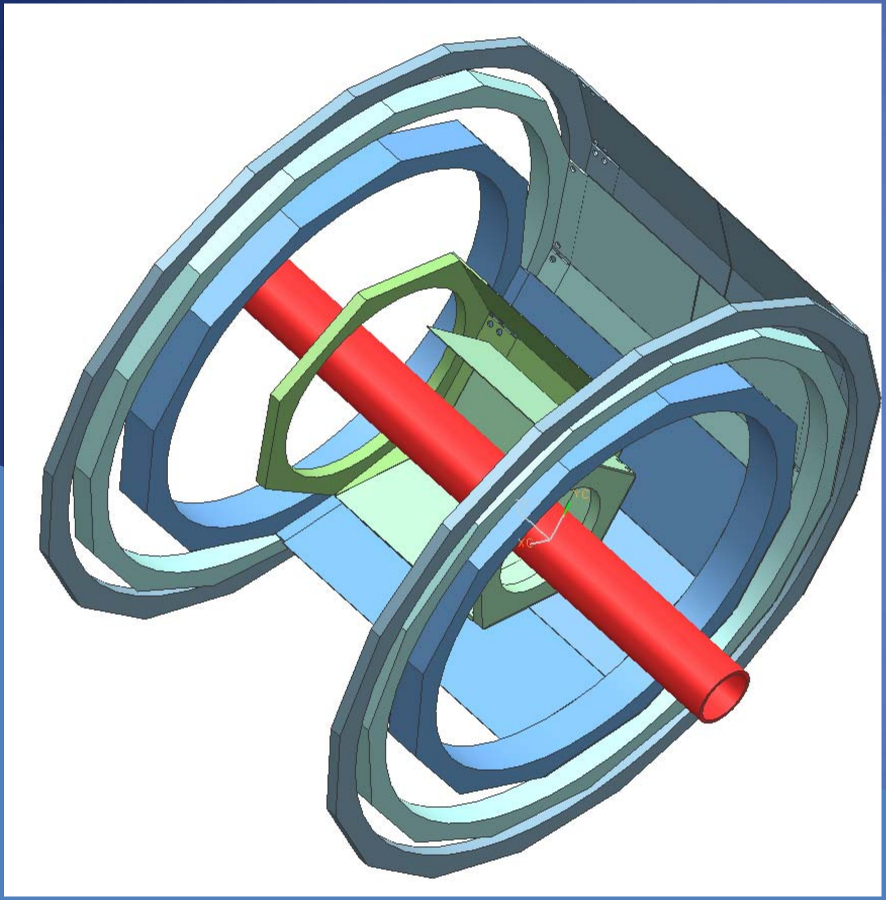
- **PARTICLE ID.**
  - Charged Particles: mass identification (dE/dx)
    - IKON — Highly ionizing kaons
    - IKON KLOE — Outgoing protons
    - Outgoing pions (MIPs)
  - Neutral particles
    - KLOE — Pions & Neutrons

- **TRIGGER** IKON
  - Fast trigger required on incoming K^+K^- pairs



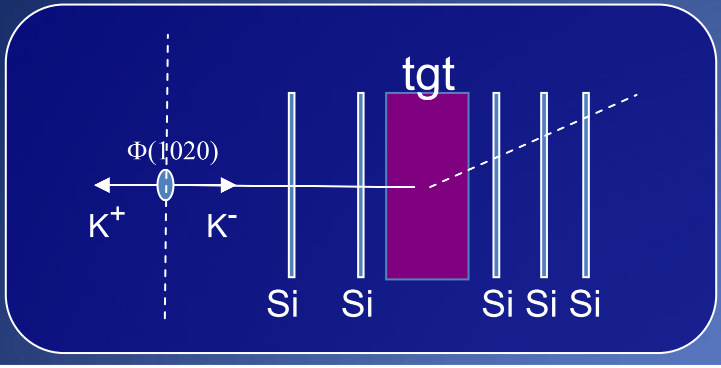
    - Thin segmented scintillator (500 μm) – mat. budget!
    - Self-triggering Si modules

Proposed VDET architecture I

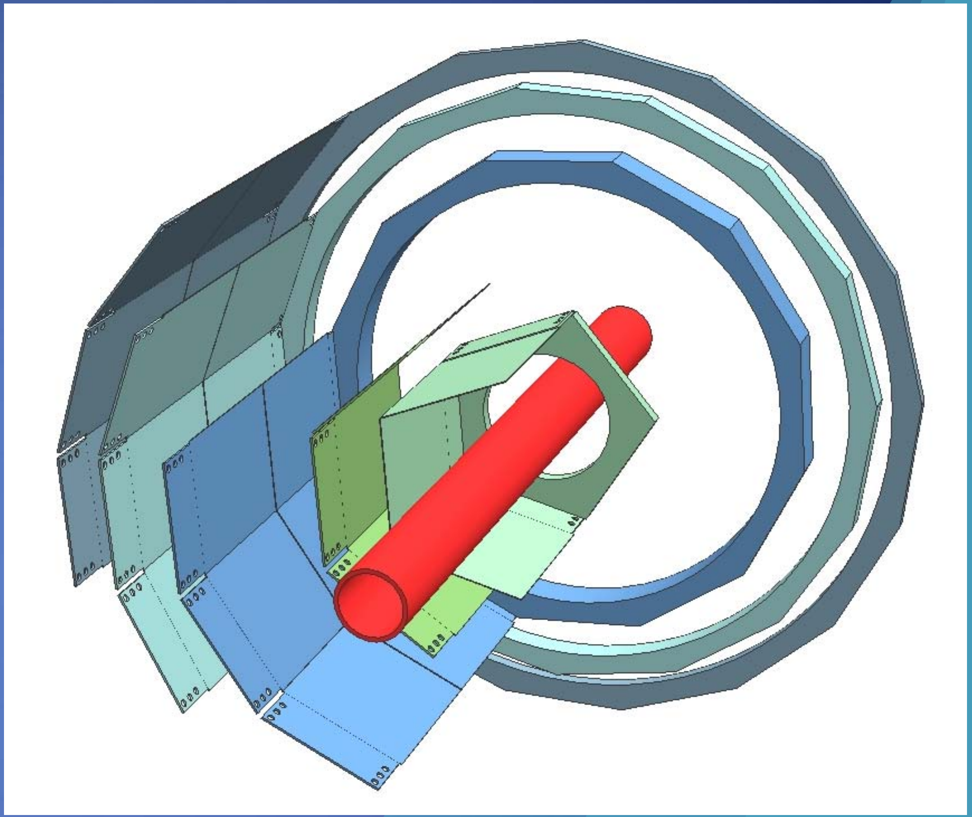


- **Sensor type**: **double sided micro-strip based on Silicon technology**
- 200 μm x (~6 x 5 cm^2) modules
  - state-of-the-art: 300 μm thickness
- Spatial resolution: < 50 μm
- Wide dynamic range for mass discrimination (1-20 MIPs)
- Cylindrical symmetry around beam axis
  - large angular coverage
  - 100 equal modules arranged in prisms

Proposed VDET architecture II

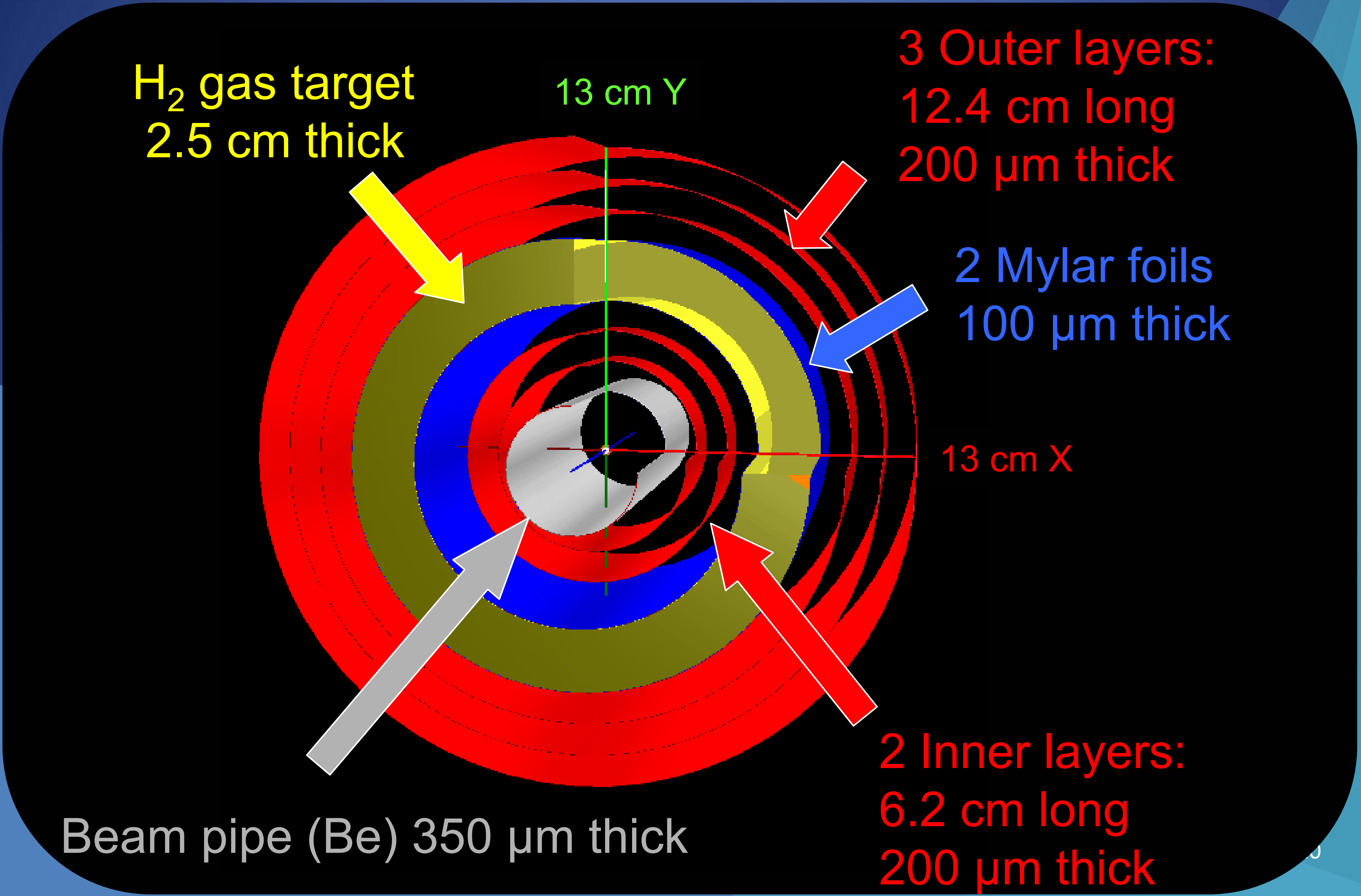


Layer	# sensors	Radius [mm]
1	5	44.7
2	7	51.9
3	12×2	93.3
4	15×2	117.0
5	17×2	133.0



- 2 Inner layers
  - discrimination and reconstruction of K^-K^+ tracks coming from Φ's (primary vertex)
- 3 Outer layers
  - discrimination and reconstruction of K^-,K^+,π^-,π^+,p tracks coming from the interaction of K^-K^+ pairs in the target (interaction vertex)

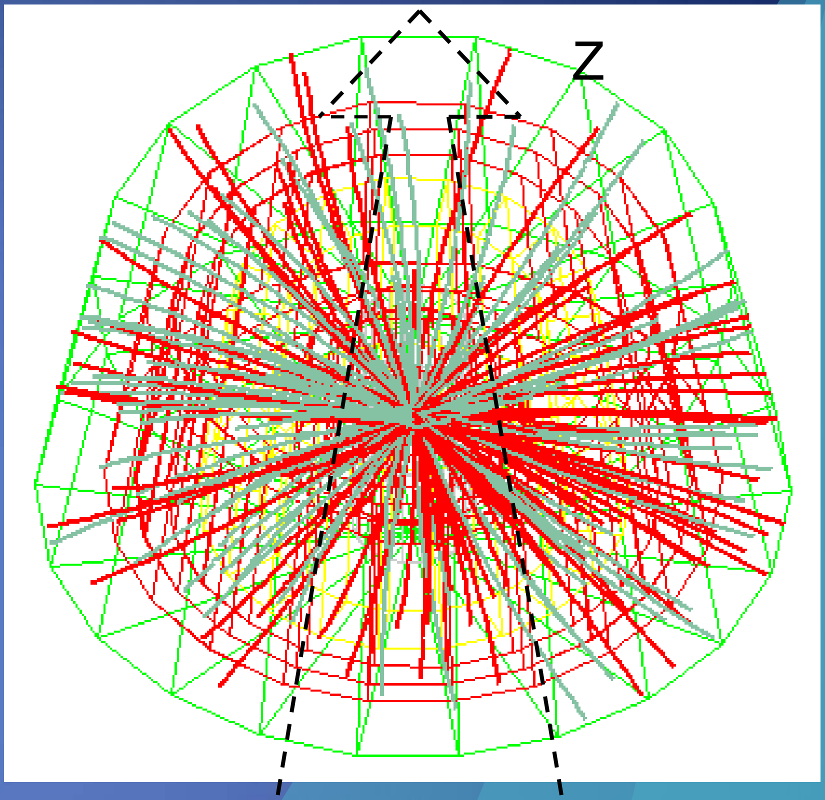
Simulations and feasibility studies I
geometry

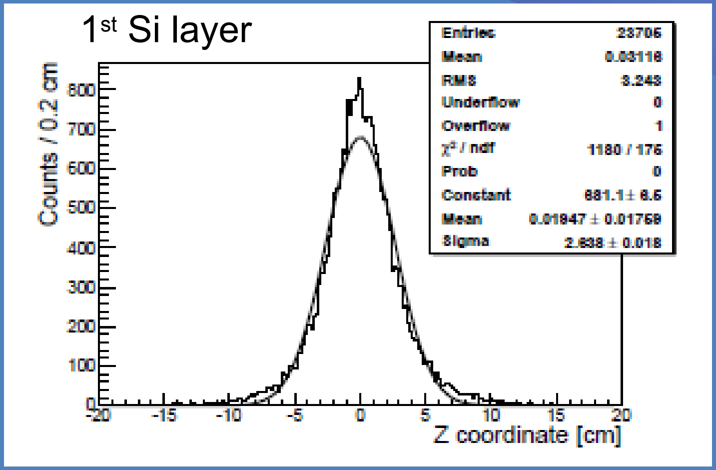


Simulations and feasibility studies II

beam and primary kaons

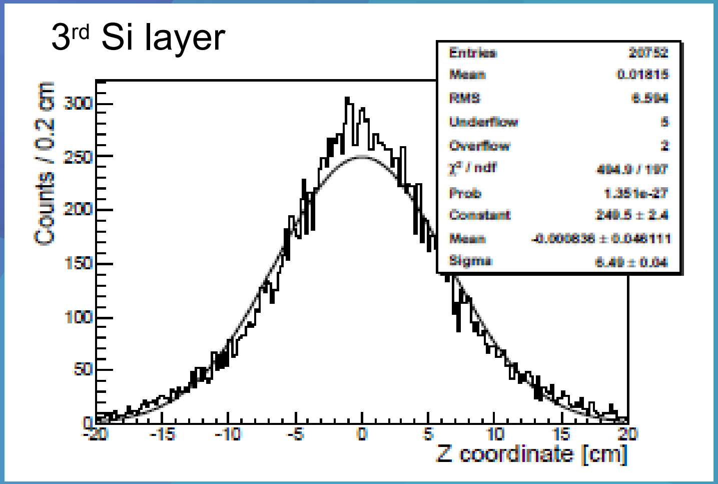
1. Φ generation with the present phase space configuration (Crab Waist)
2. $\Phi \rightarrow K^+ K^-$ decay
3. Beam spread: $\sigma_z \sim 1.5$ cm
4. Magnetic field: 0.6 T
5. Realistic VDET geometry
6. Simulations with Virtual MonteCarlo Tools (Geant3 + Geant4 engines)



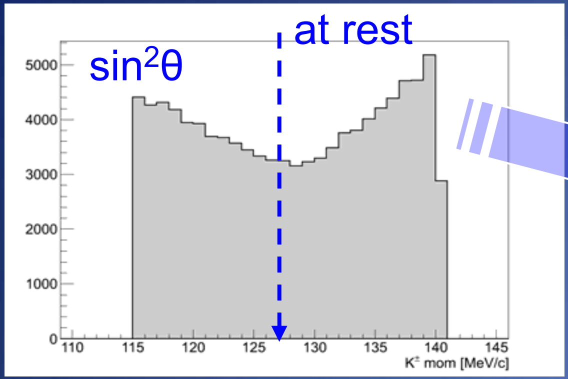


Beam spread along z:

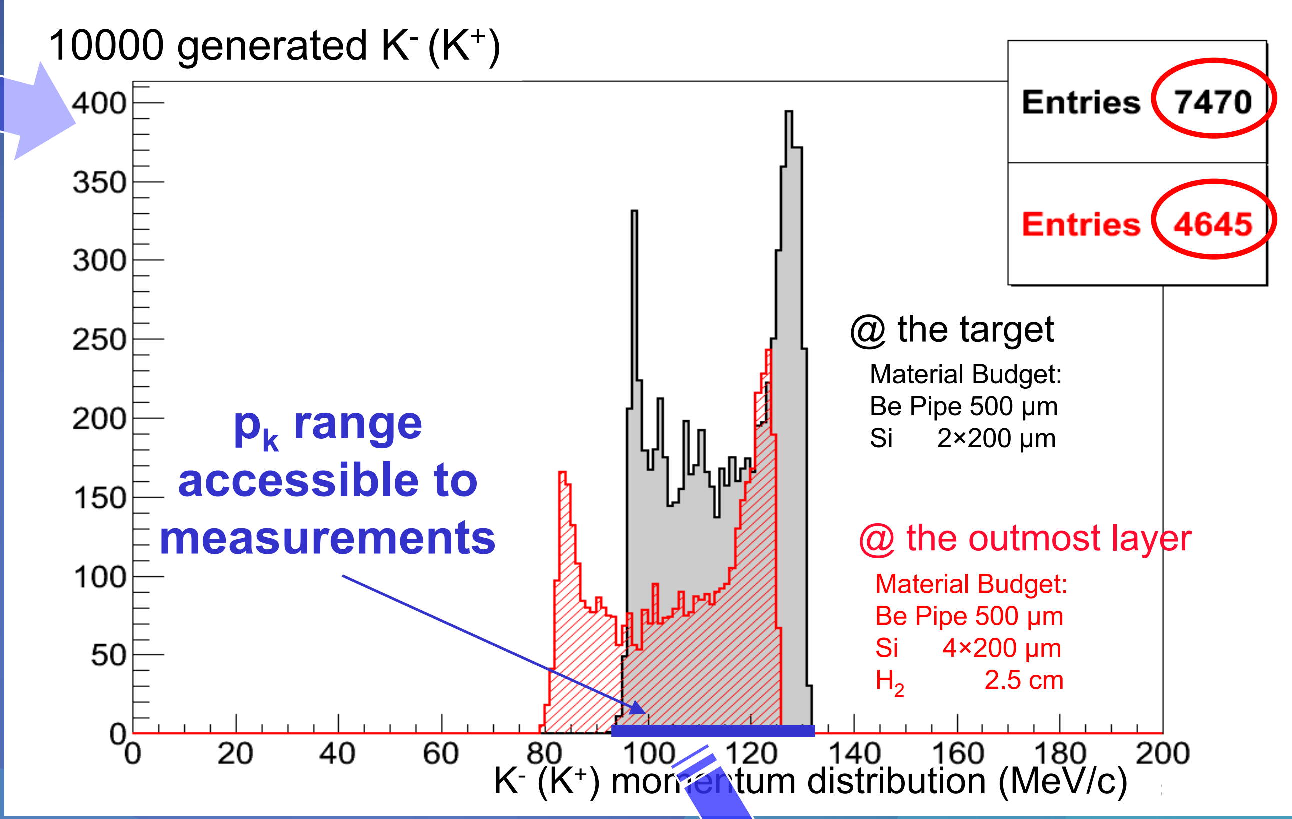
± 3.25 cm inner layers
± 6.5 cm outer layers



Simulations and feasibility studies III



Generated @ Φ vertex



75%: K^+K^- acceptance

46%: generated kaons reaching the outmost layer (decay)

Average entrance kaon momentum in layers:

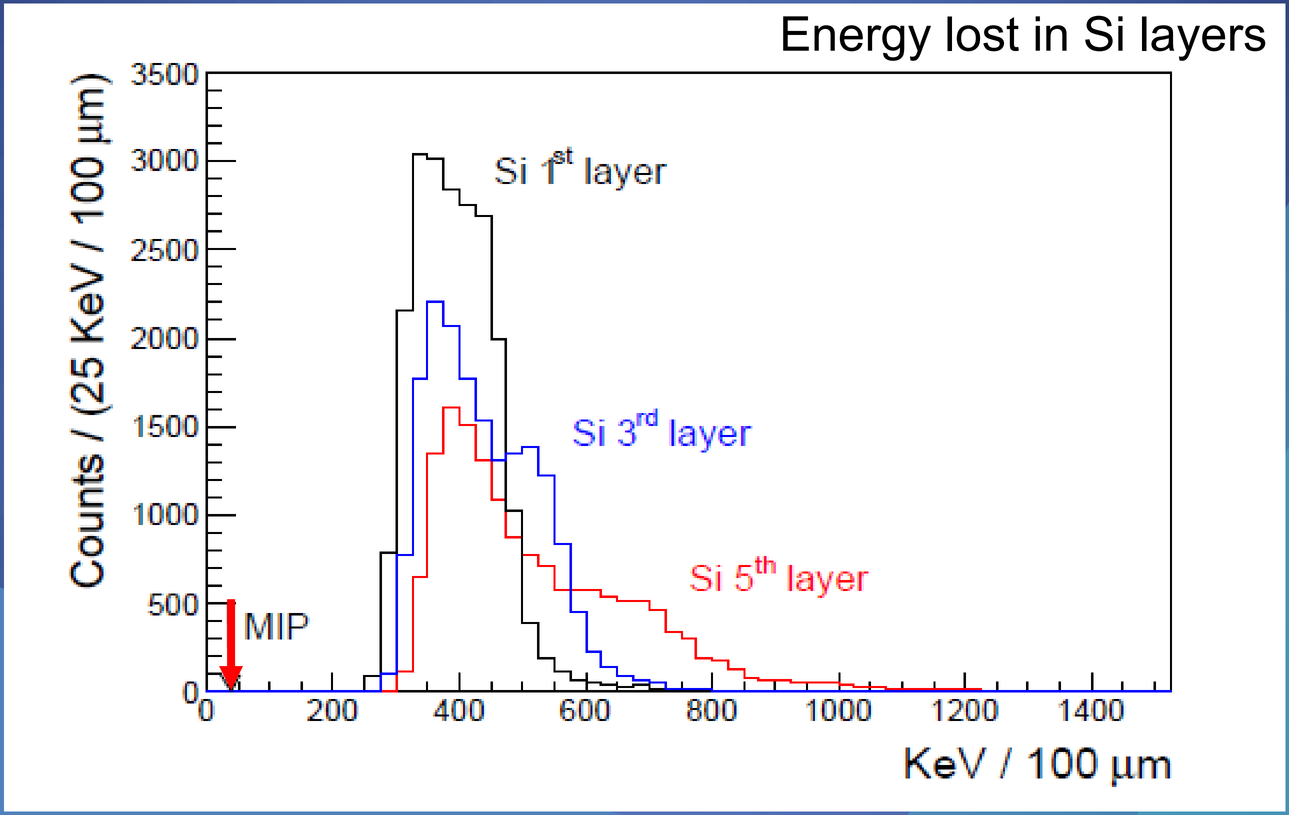
		Δp (MeV/c)
• Beam pipe:	127 MeV/c	26
• 1st Si layer:	121 MeV/c	33
• 3rd Si layer:	114 MeV/c	38
• 5th Si layer:	103 MeV/c	45

Measurements @ 2-3 momenta:

- **125 ± 10 MeV/c**
- **105 ± 10 MeV/c**
- **< 95 MeV/c (possibly)**

Simulations and feasibility studies IV

specific energy loss

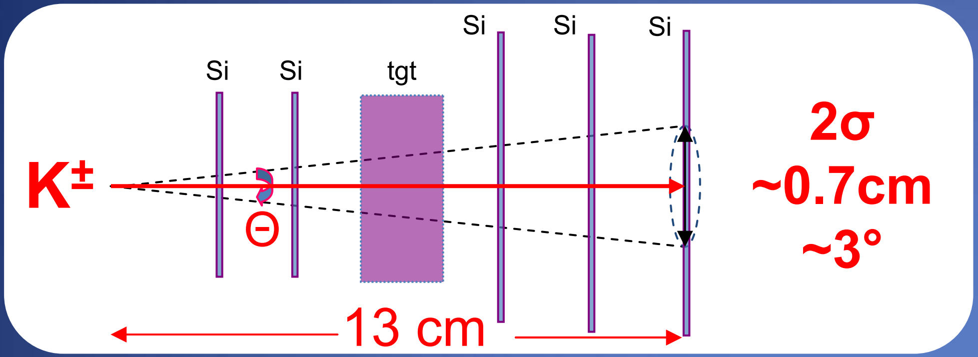


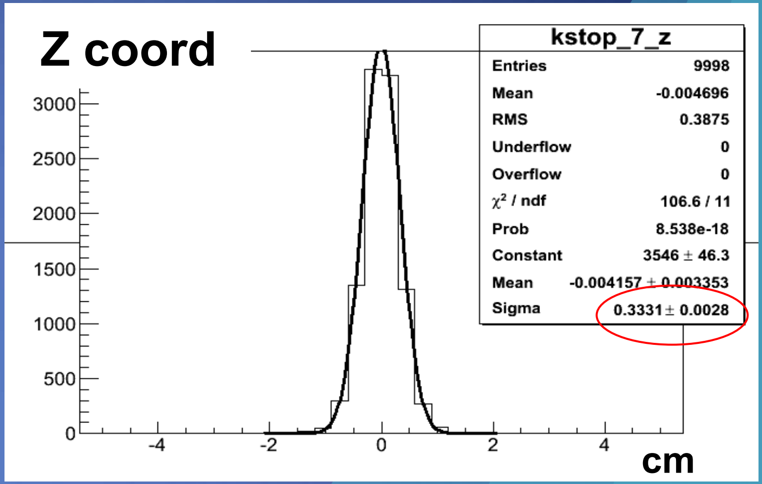
- Simulation of energy loss in 200 µm sensors:
  - Every layer can easily mass discriminate kaons from MIPs
  - Same technique as applied in FINUDA

Simulations and feasibility studies V

kaon multiple scattering

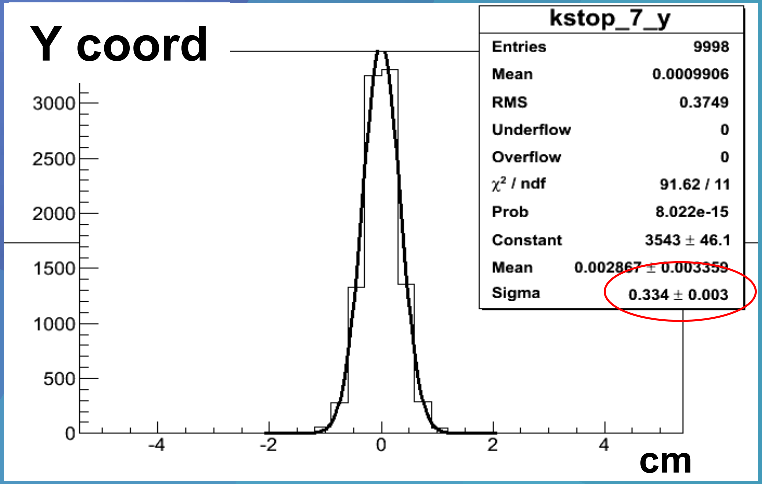
(picture not to scale)





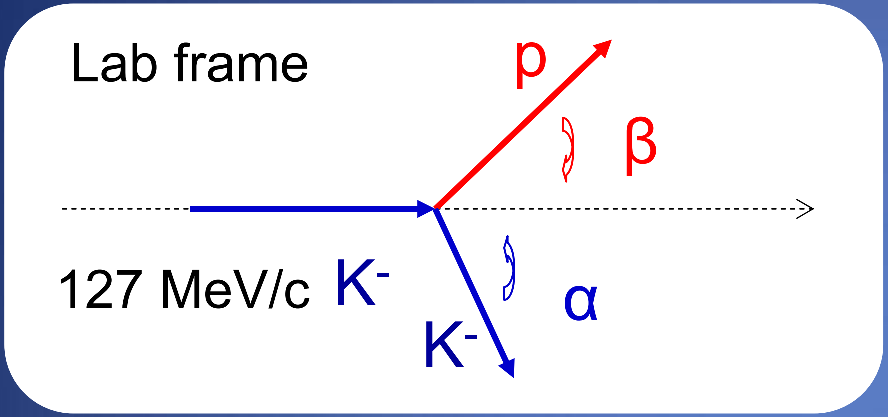
angular uncertainty due to Coulomb scattering:
Θ ~ 3 - 4° FWHM

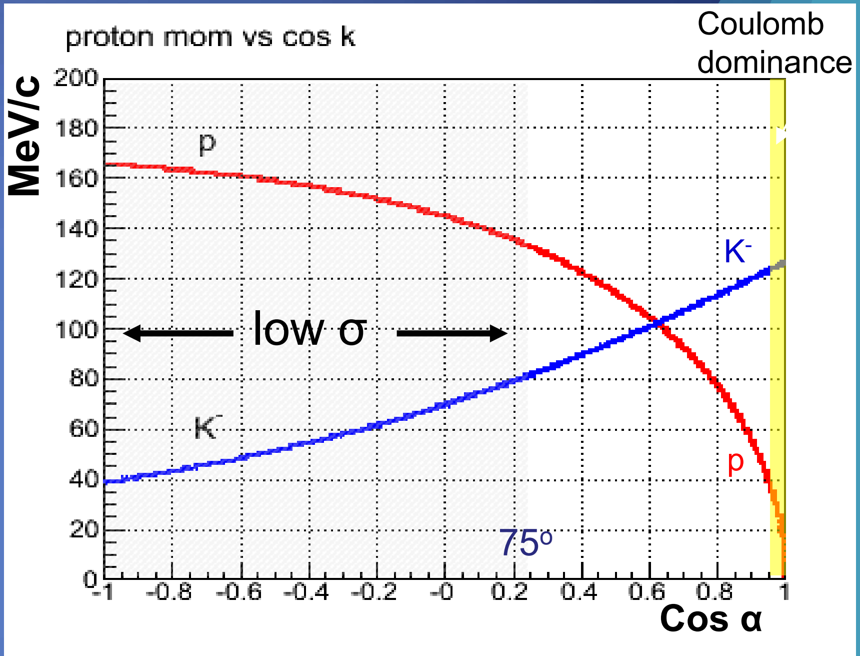
VDET with 100 μm pitch OK



Simulations and feasibility studies VI

$K^{\pm}N \rightarrow K^{\pm}N$ elastic scattering, **kinematics and yields**





Differential xsections measurable in the angular range 4° -75°

$K^{\pm}N \rightarrow K^{\pm}N$ expected yields @ p_K=100 MeV/c

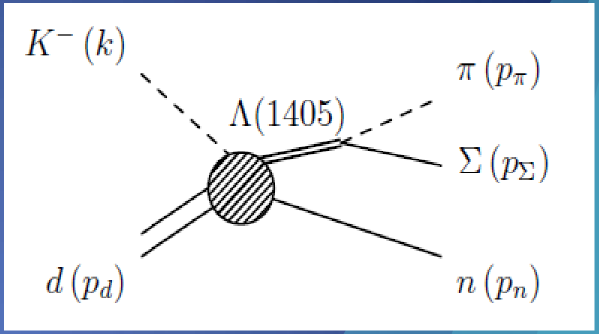
- $\sigma_{el}(K^-p)$ = 80 mb, $\sigma_{el}(K^+p)$ = 10 mb
- **DAΦNE integrated luminosity: 1 fb^{-1} / 2-3 months**
- VDET acceptance/tracking eff.: ~ 50%
- H_2 target at 2 bar

$N(K^-p) = 6.4\times10^3$ ev. $N(K^+p)$ = 800 ev.

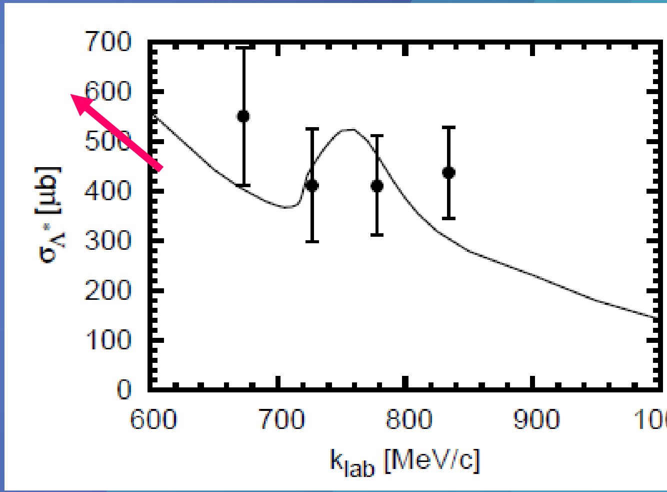
x 2 targets (H_2, D_2)
x 2-3 mom. bins

Simulations and feasibility studies VIII

$K^-d \rightarrow \Sigma\pi n$ @ $\Lambda(1405)$ peak



- **How many $\Lambda(1405)$ events in ~3 fb^{-1}?**
  - Cross section: 600 μb @ 600 MeV/c, rising at lower momenta
  - Neutron detection: KLOE/CAL
    - Realistic efficiency for neutrons ~30%
  - $\Sigma^{\pm}\pi^{\mp}$ detection: IKON (sec. vertex) + KLOE/DCH
    - VDET acceptance ~80%
    - Reconstruction efficiency ~30%
  - D_2 target at 2 bar



Model by Jido et al, nucl-th:0904.3410v2

➡ ~300 useful events in the $\Lambda(1405)$ peak

Project time-scale

- **Vertex detector ready in 4 years (from 2011)**
  - Reduced VDET R&D (known technology, expertise already available)
    - prototyping phase **1 year**
  - Construction extimated time: **3 years**
    - Start 2012 - end 2015

- **Running time: 1.5 years**
  - 2x targets, 2-3x mom. bins

IKON working program for 2010-2011

- **Simulations**
  - Further improvements + implementations
  - Integration of KLOE geometry in the simulation program
  - Implementation of VDET realistic geometry (prisms)
  - Detailed study of all reaction kinematics
  - Development of reconstruction program
- **Detector R&D**
  - Study of 200 μm modules
  - Microcables or double metal fan-out
  - Self-triggering performances
- **Effective construction will begin in 2012**
  - Final decision on Super-B pending

Summary and Conclusions

- DAΦNE is at present the only world facility where low momentum kaon scattering studies can be performed
  - Missing data
  - Needed inputs for low energy strong interaction theories
- First feasibility studies performed: geometry, detector requirements, reaction kinematics, multiple scattering and energy loss effects, expected yields
  - Si Vertex-Detector + KLOE spectrometer & calorimeter
- Full know-how on Silicon Detectors, reduced R&D phase needed
  - Re-use of some of FINUDA components
- The project (at present) involves the core part of the FINUDA collaboration (TS+TO+BA+LNF+BS)
  - Open to all external collaborations – support by theoretical groups (Prague)
  - Agreement with KLOE for training/integration
  - First phase mostly dedicated to simulations
- Project time scale fitting to KLOE/DAΦNE schedule for the next 3-4 years