Progress and perspectives in the low-energy kaon-nucleon/nuclei interaction studies at the DAΦNE collider

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on behalf of the SIDDHARTA, SIDDHARTA-2 and AMADEUS collaborations

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SIDDHARTA collaboration

SIlicon Drift Detector for Hadronic Atom Research by Timing Applications

LNF- INFN, Frascati, Italy

SMI - ÖAW, Vienna, Austria

IFIN – HH, Bucharest, Romania

Politecnico, Milano, Italy

MPE, Garching, Germany

PNSensors, Munich, Germany

RIKEN, Japan

Univ. Tokyo, Japan

Victoria Univ., Canada

EU Fundings: JRA10 – FP6 - I3HP
Network WP9 – LEANNIS – FP7- I3HP2

Hadronic atoms

Objects of type $(\bar{K}\ X)$, $(\pi^- X)$ with X = p, d, ^{3}He, ^{4}He,.. or $\pi^+ \pi^-$, π K

Bound electromagnetically, binding well known

Strong interaction → modifies the binding (energy shift with respect to EM value)
→ induces the meson absorption on the nucleis (enlarges significantly the lowest levels width)

in some cases (mostly for light atoms): small perturbation, transition to significantly modified levels possible before nuclear absorption occurs **-> emitted Xrays are carying info about the strong interaction**

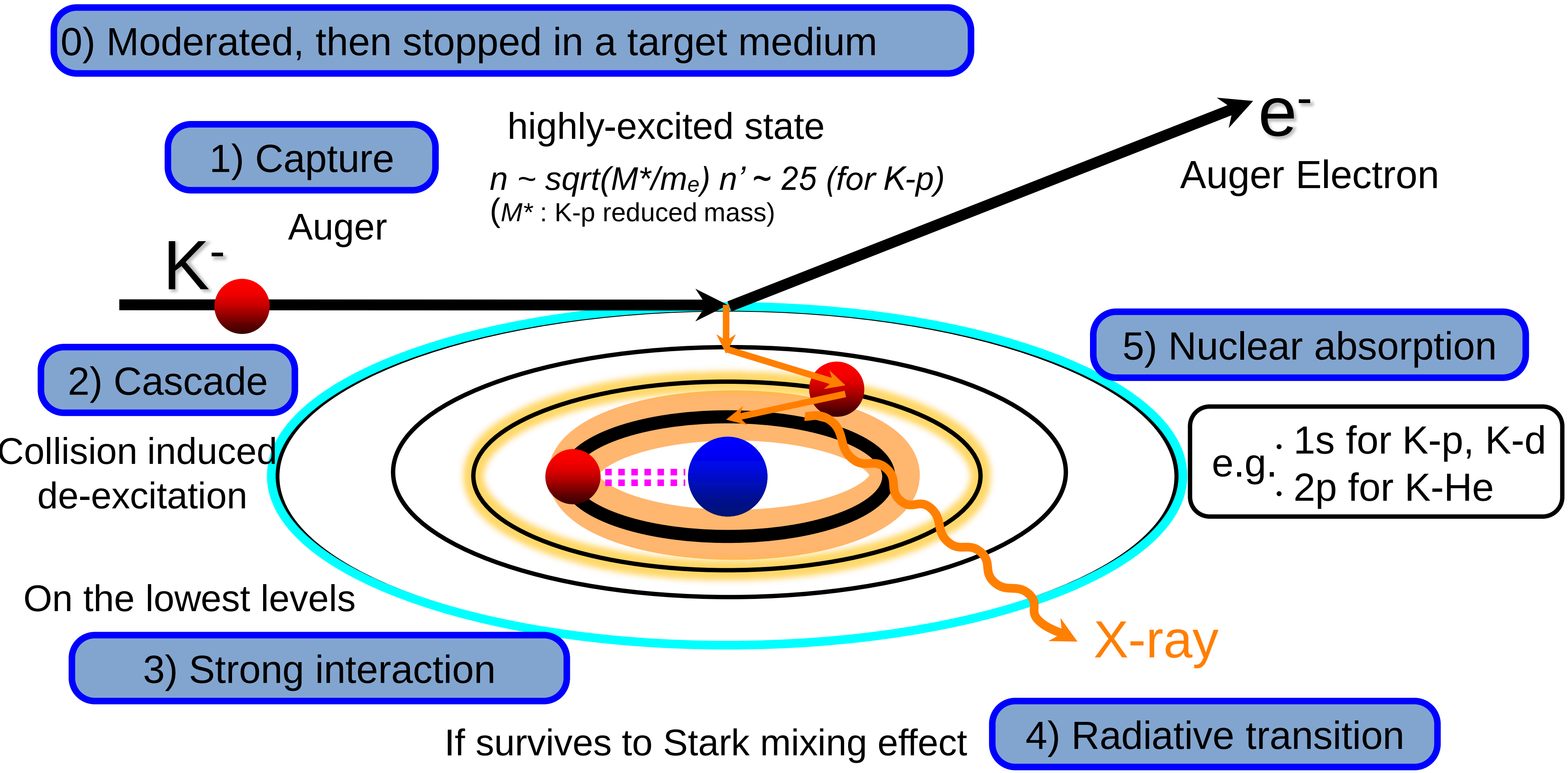
→ energy shift and width can be related to T-matrix elements at threshold (Deser[1] type formulas)

compare to results from low energy scattering experiments[2]

Low energy phenomena in strong interaction are hardly described in terms of quarks and gluons; instead, *effective theories* are used (they have some degrees of freedom to accomodate experimental data)

[1] Deser relation in some cases not sufficient to compare to high precision experimental data
[2] Problems: extrapolation to E=0 and quality of old experimental data

Kaonic atom processes



The strong interaction width >> E.M. radiative transition width
The level shift is of the same order of magnitude ->
direct information about the scattering amplitude at threshold

QCD predictions

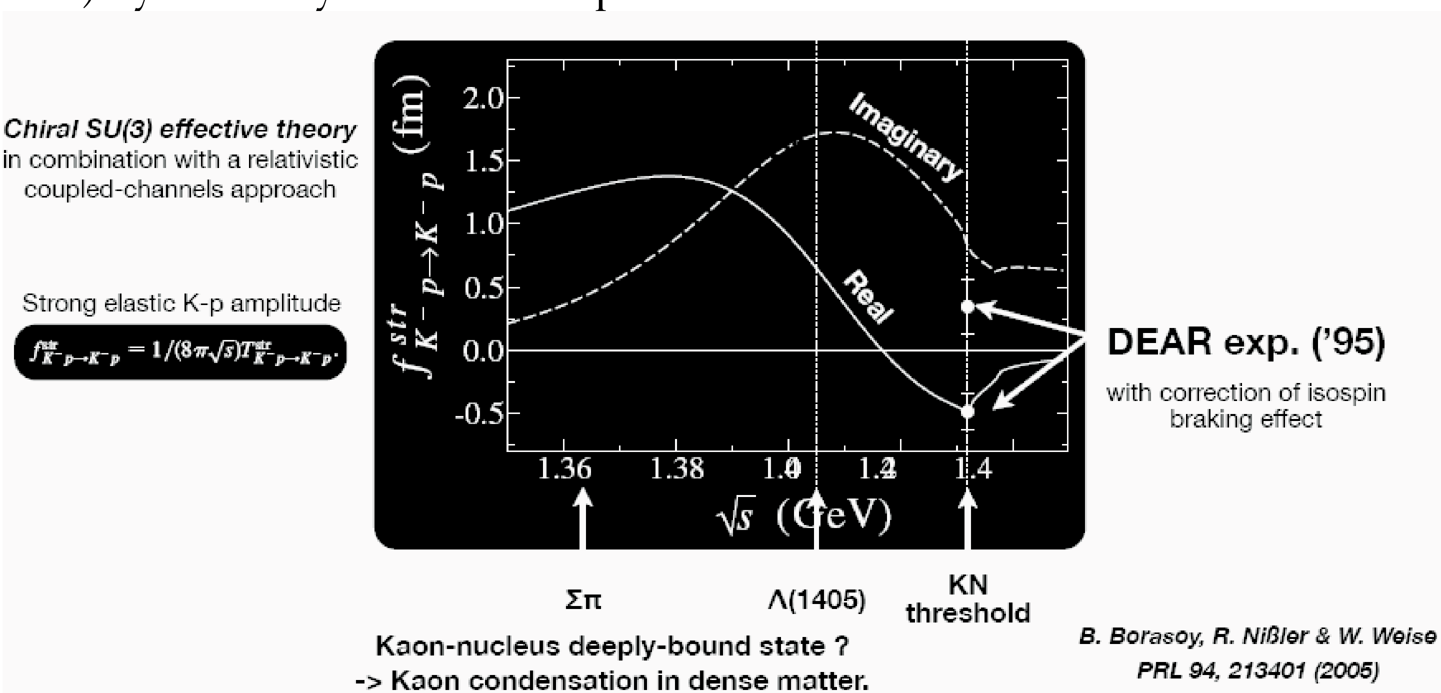
Chiral perturbation theory was successful in describing systems like πH, but encountered serius difficulties in KH. Main reason is the presence of the Λ(1405) resonance only 25 MeV below threshold.

Effective field theory ⟷ scattering data

Effective field theory ⟷ atomic X ray data

Effective field theory ⟷ energy, width of resonances

There are non-perturbative coupled channel techniques which are able to generate the Λ(1405) dynamically as a Kbar N quasibound state and as a resonance in the π Σ channel



Kaonic hydrogen – Deser formula

With a_0, a_1 standing for the I=0,1 S-wave $\bar{K}N$ complex scattering lengths in the isospin limit ($m_d = m_u$), μ being the reduced mass of the K^-p system, and neglecting isospin-breaking corrections, the relation reads:

$$\varepsilon + i\frac{\Gamma}{2} = \frac{2\pi}{\mu} 2\alpha^3 \mu^2 a_{K^-p} = 412 \ fm^{-1} \cdot eV \cdot a_{K^-p}$$

$$a_{K^-p} = \frac{1}{2}(a_0 + a_1)$$

… a linear combination of the isospin scattering lengths a_0 and a_1; to disentangle them, the kaonic deuterium scattering length is needed, as well

"By using the non-relativistic effective Lagrangian approach a complete expression for the isospin-breaking corrections can be obtained; in leading order, parameter-free modified Deser-type relations exist and can be used to extract scattering lenghts from kaonic atom data"[1]

$$\Delta E_n^s - \frac{i}{2}\Gamma_n = -\frac{\alpha^3 \mu_c^3}{2\pi M_{K^+} n^3} \times \mathcal{T}_{KN}\left\{1 - \frac{\alpha \mu_c^2}{4\pi M_{K^+}} \mathcal{T}_{KN}(s_n(\alpha) + 2\pi i) + \delta_n^{vac}\right\}$$

[1]Meißner,Raha,Rusetsky, 2004

Kaonic deuterium

For the determination of the isospin dependent scattering lengths a_0 and a_1 the hadronic shift and width of kaonic hydrogen *and* kaonic deuterium are necessary !

Elaborate procedures needed to connect the observables with the underlaying physics parameters.

$$a_{K^- p} = \frac{1}{2}\left[a_0 + a_1\right]$$

$$a_{K^- n} = a_1$$

Impulse approximation term

$$a_{K^- d} = \frac{4\left[m_N + m_K\right]}{\left[2m_N + m_K\right]} \cdot a^{(0)} + C$$

larger than leading term

$$a^{(0)} = \frac{1}{2}\left[a_{K^- p} + a_{K^- n}\right] = \frac{1}{4}\left[a_0 + 3a_1\right]$$

"To summarize, one may expect that the combined analysis of the forthcoming high-precision data from DEAR/SIDDHARTA collaboration on kaonic hydrogen and deuterium will enable one to perform a stringent test of the framework used to describe low–energy kaon deuteron scattering, as well as to extract the values of a0 and a1 with a reasonable accuracy. However, in order to do so, much theoretical work related to the systematic calculation of higher-order corrections within the non-relativistic EFT is still to be carried out." (from: Kaon-nucleon scattering lengths from kaonic deuterium, **Meißner, Raha, Rusetsky, 2006,** arXiv:nucl-th/0603029)

Summary of physics framework and motivation

- Exotic (kaonic) atoms – probes for strong interaction
  - hadronic shift ε_{1s} and width Γ_{1s} directly observable
  - experimental study of low energy QCD. Testing chiral symmetry breaking in strangeness systems (intermediate sector between light and heavy quark)
- Kaonic hydrogen
  - Kp simplest exotic atom with strangeness
  - kaonic hydrogen"puzzle" solved – but: more precise experimental data important
  - kaonic deuterium never measured before
- Information on $\Lambda(1405)$ sub-threshold resonance
  - responsible for negative real part of scattering amplitude at threshold
  - important for the search for the controversial "deeply bound kaonic states"
  - present / upcoming experiments (KEK,GSI,DAFNE,J-PARC)
- Determination of the isospin dependent KN scattering lengths
  - **no extrapolation to zero energy**

Experimental data available:

- K^- p cross section for elastic and inelastic processes.
- Branching ratios for K^- p absorption at rest.
- $\pi\Sigma$ invariant mass distribution below K^- p threshold, wich exhibits the $\Lambda(1405)$ resonance.
- 1s level shift and width of K^- p atom determined through Xray measurements. (SIDDHARTA)

Why it takes so long?

"A measurement of the energy-level shifts and widths for the atomic levels of kaonic hydrogen (and deuterium) would give a valuable check on analyses of the NK amplitudes, since the energy of the K p atom lies roughly midway between those for the two sets of data." Dalitz 1981

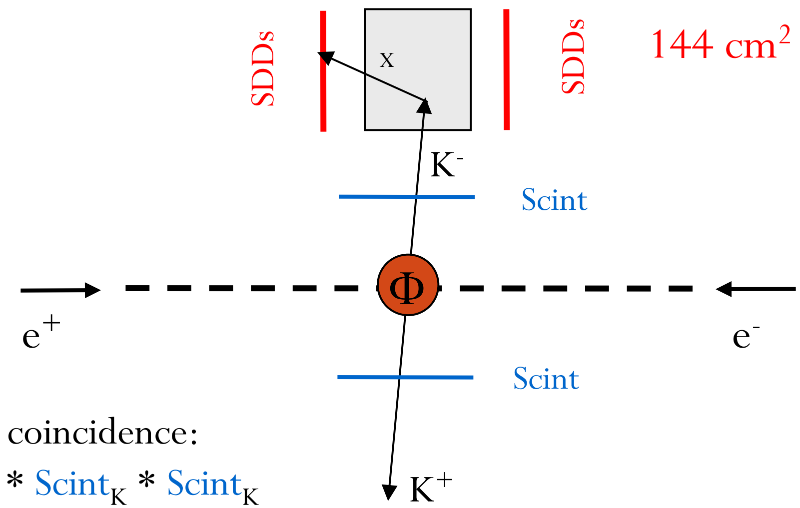
-yield strongly reduced by the Stark mixing (~10^{-2} KH, 10^{-3} or below for KD)
(monocromatic pure kaon beam, high density gaseous target)

-large area, fast, high resolution X-ray detectors are required, not available before SIDDHARTA

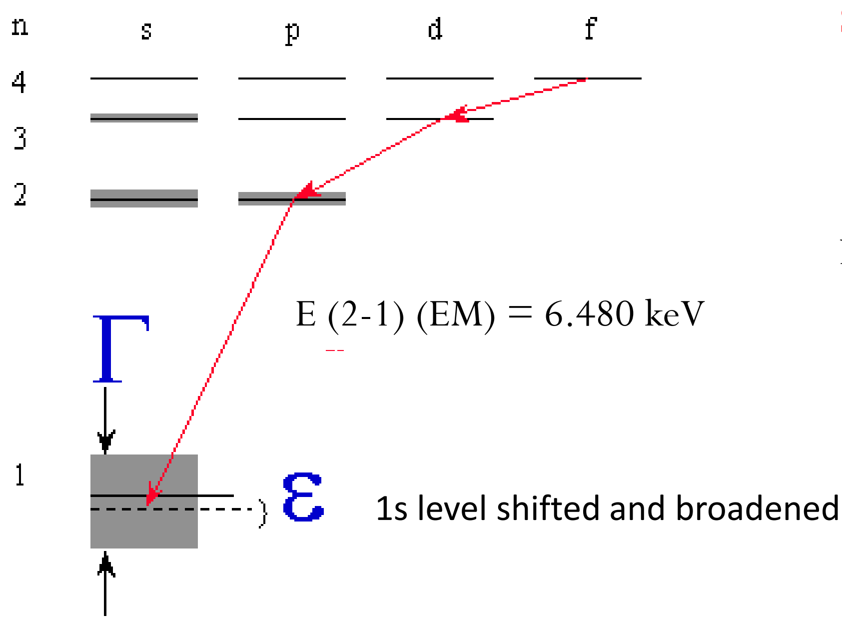
-X-ray background is huge, either on extracted beams, due to pion contamination and on colliders, due to cm range placement of the target with respect to the interaction point, in a region were large EM showers are induced by the particles lost from the beam.

SIDDHARTA experimental method

- Goal: measure the shift and broadening of the X ray transition of light kaonic atoms.
- The ground state is affected by the strong interaction of the kaon and the nucleus.
- Delivers input for effective theories in low energy QCD.



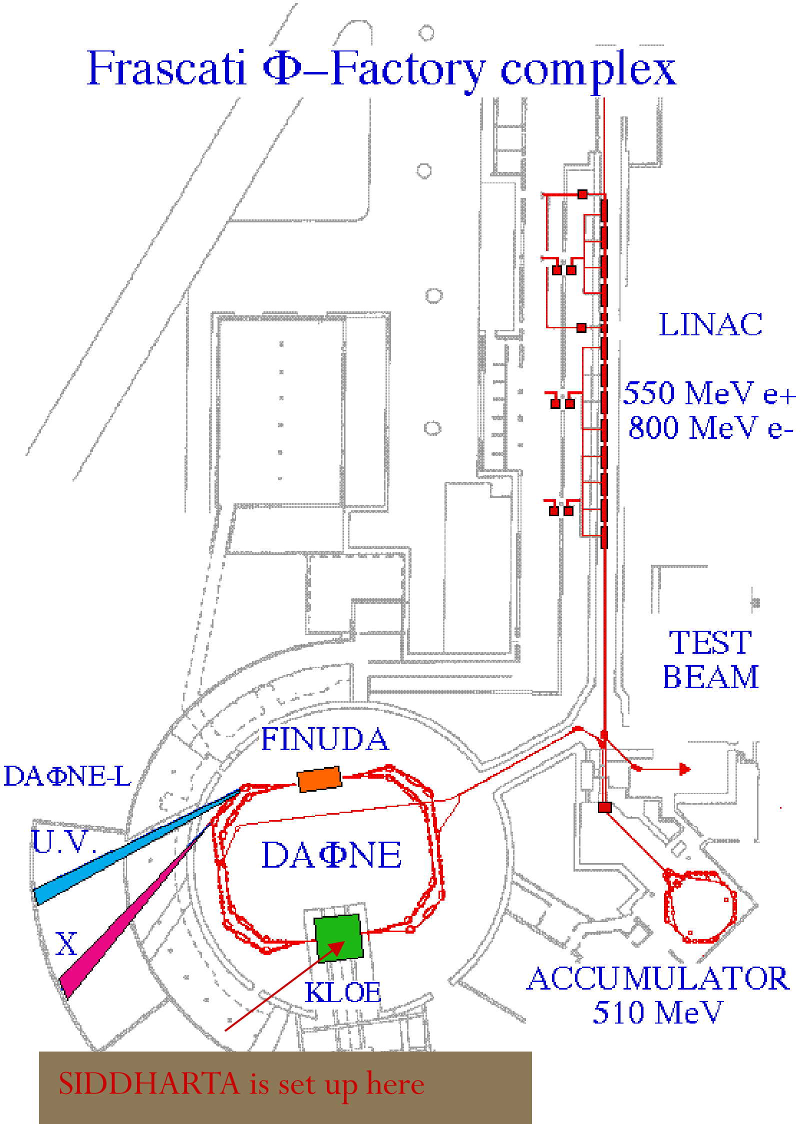
Triple coincidence:
$SDD_X * Scint_K * Scint_K$



New X-ray detectors (SDD Silicon Drift Detectors)

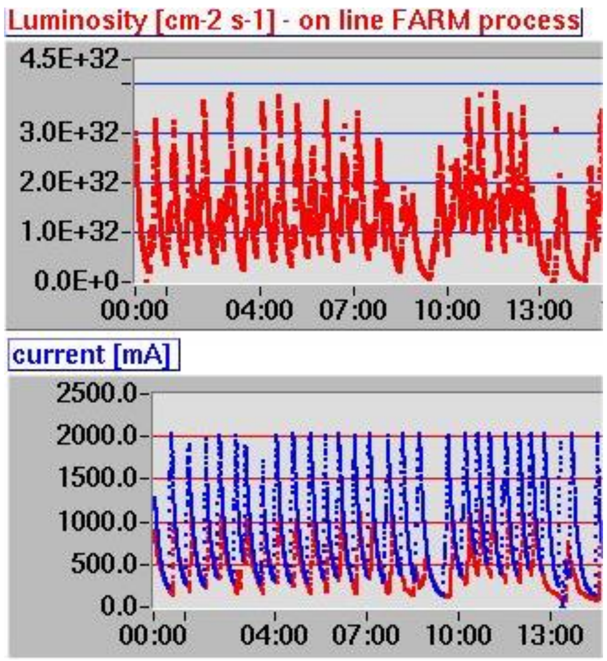
- timing capability (trigger for background suppression)
- excellent energy resolution (140 eV at 6.0 KeV)
- high efficiency, large solid angle.
- good performance in accelerator environment

DAΦNE



during DEAR data taking **(2002)**
currents ~ 1200/800 ~ 1 pb^{-1} per day, peak ~ 3×10^{31} cm^{-2} s^{-1}

Electron-positron collider, energy at Φ resonance (produced nearly at rest)
boost: 55 mrad crossing angle ⟶ 28 MeV/c
charged kaons from phi decay: E_k = 16 MeV
degrade to < 4MeV to stop in gas target



Φ production cross section ~ 3000 nb (loss-corrected)
Integr. luminosity 2009 **~ 6 pb^{-1} per day** [1)] (~ 10^7 $K^{\pm}$)
(increased by crabbed waist scheme)
Peak luminosity ~ 4×10^{32} cm^{-2} s^{-1} = 550 Hz $K^{\pm}$
1) we can not use kaons produced during injections.

Why at DAΦNE?

- Almost monochomatic charged kaon beam from Φ decay => facilitates stopping the kaons in a *small volume* => allows to produce the exotic atoms before kaons decay and enhace the detection efficiency for rare events

-Minimum beam-related hadronic background (Φ decays in 49% back-to-back charged and 31% neutral kaons)

-High luminosity

-Φ is polarized, so the kaon flux emitted mostly on transverse plane to machine beam pipe ($\sin^2$ distribution)=> easier to capture a high fraction on a reduced solid angle

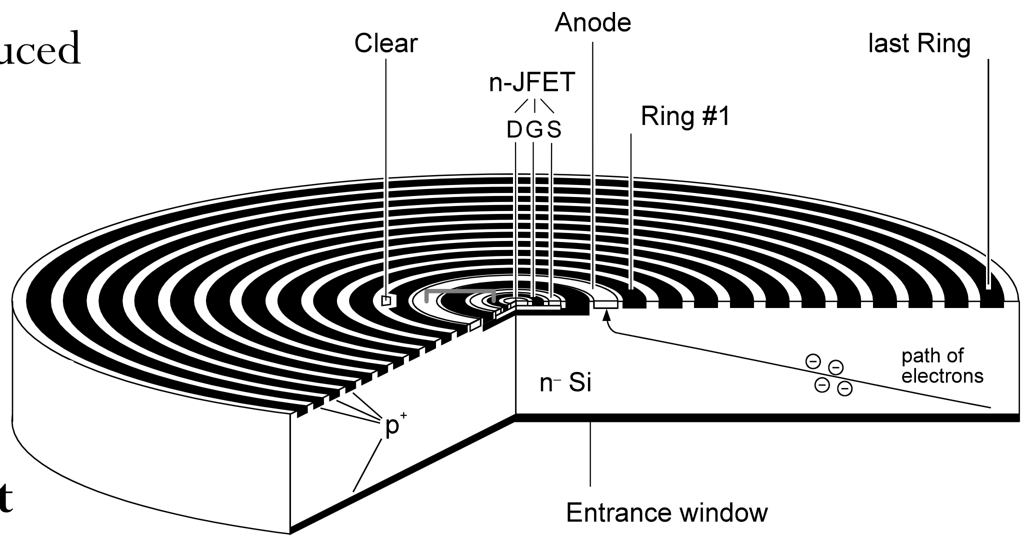
DAFNE background

SYNCRONOUS: It's associated to K production, or other Φ decay channels. It can be considered a hadronic background.

ASYNCRONOUS: It's due to the final component of electromagnetic cascade produced in the accelerator pipe and other setup materials invested by electrons lost from the beam. The main contribution comes from Touschek effect (particle scattering inside the bunch).

The asyncronous background can be reduced by shielding, trigger and the use of fast response X-ray detectors:
SDD (Silicon Drift Detector of a new design, developed inside the SIDDHARTA collaboration)

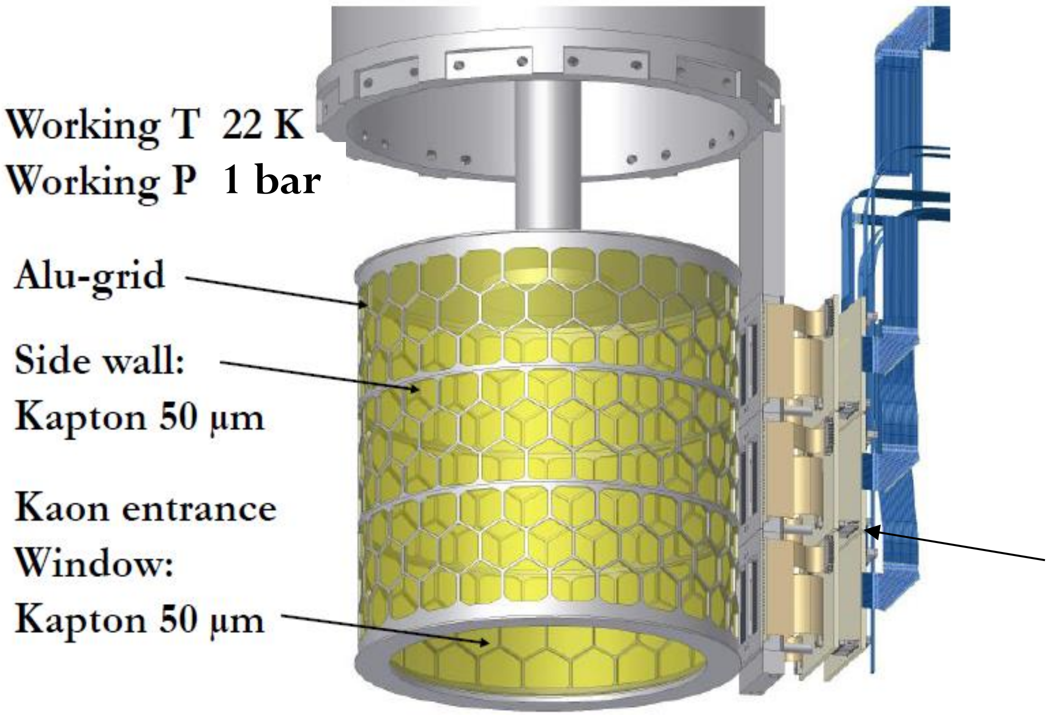
-large area (3x1 cm^2)
-high resolution, near to Fano limit
-charge collection time (drift) ~700ns



Cryo target

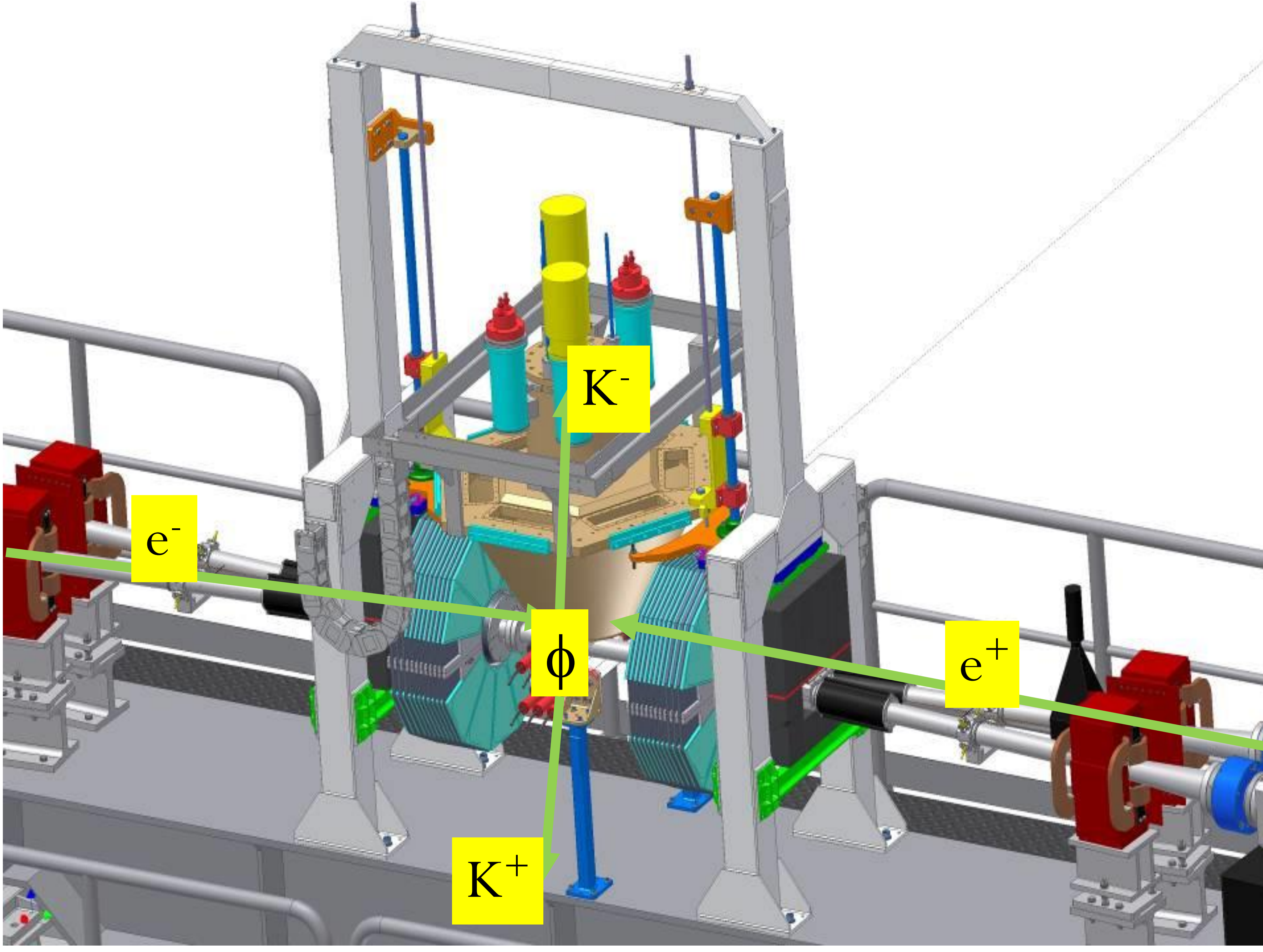
The optimization of the target density took into account the balance between the Stark effect and kaon stopping power. The chosen density was ~30x STP, which would require thick windows to stand the high corresponding pressure. Since thick windows would not allow X-rays to reach the SDD detectors, a cryogenic target was designed and build, operating near the H_2 L.P. A 2-stage He expansion cryostat grants the necessary cooling. In order to minimize the detector noise, the SDDs were also operated under cryogenic conditions (~150K). The whole setup is installed in a high vacuum insulation chamber.

Cryogenic target cell

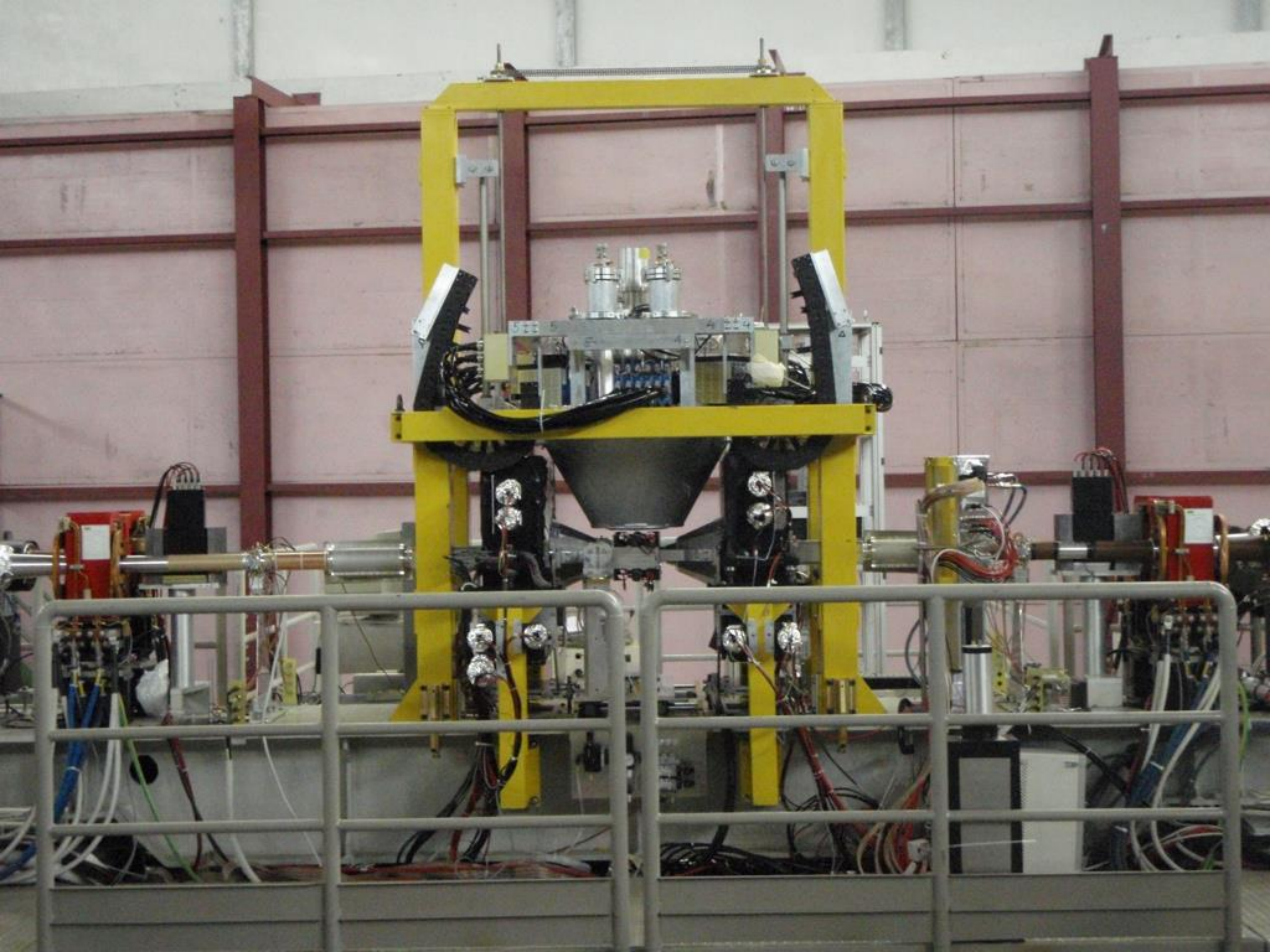


Operated with:

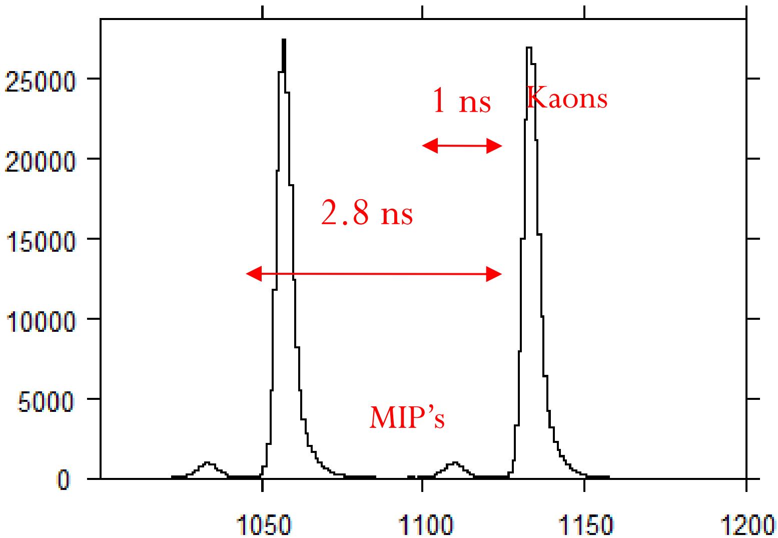
- Hydrogen
- Deuterium
- Helium4, Helium3



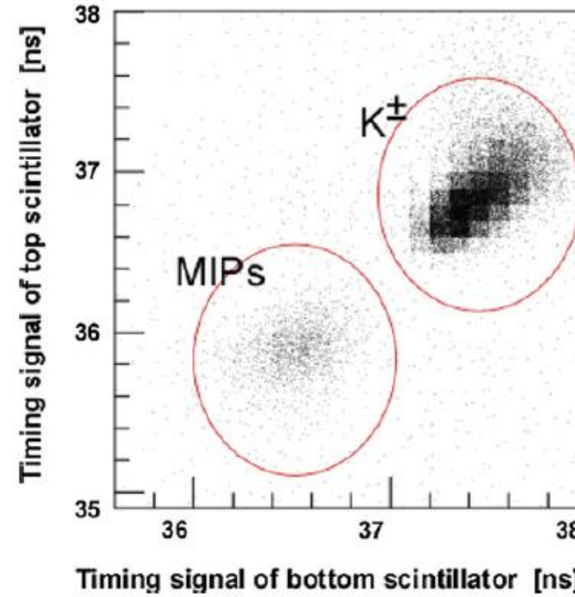
K-
e-
ϕ
e+
K+

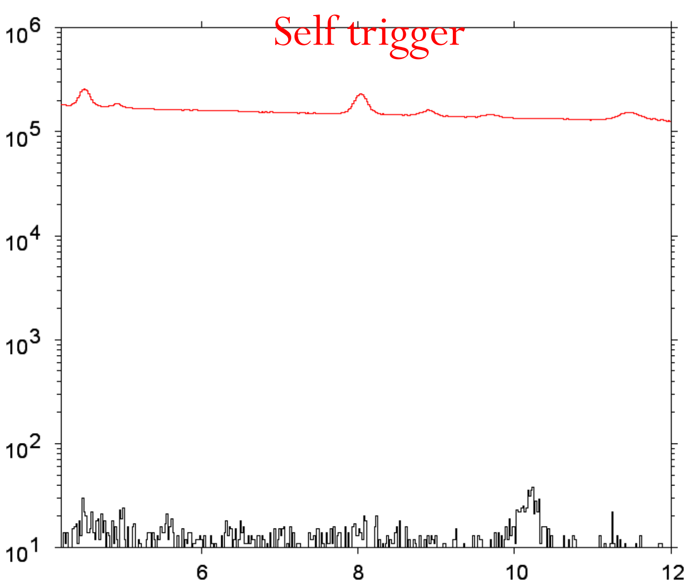


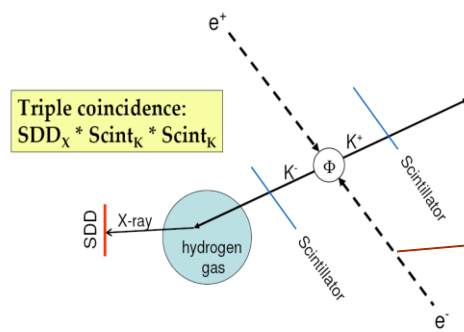
Trigger

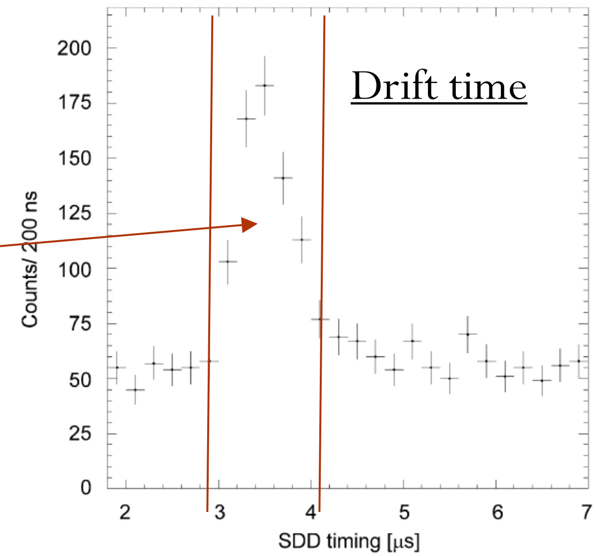


The trigger is generated by the coincidence of 2 back-to-back scintillators. Further kaon ID is given by the specifc TOF, measured from the collision time, marked by RF.









Rejection factor $>10^4$

SIDDHARTA results:

- Kaonic Hydrogen: 400pb^{-1}, most precise measurement to date,
Phys. Lett. B 704 (2011) 113, Nucl. Phys. A881 (2012) 88; Ph D

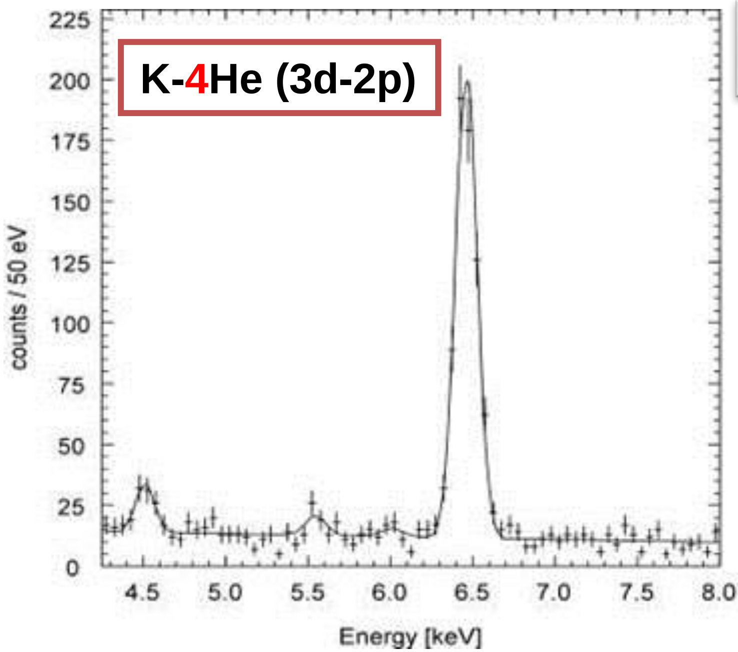
- Kaonic Deuterium: 100 pb^{-1}, as an exploratory first measurement,
Nucl. Phys. A907 (2013) 69; Ph D

- Kaonic Helium 4 – first measurement ever in gaseous target; published in
Phys. Lett. B 681 (2009) 310; NIM A628 (2011) 264 and Phys. Lett. B 697 (2011);; PhD

- Kaonic Helium 3 – 10 pb^{-1}, first measurement in the world,
shift value published in Phys. Lett. B 697 (2011) 199; Ph D,
(Successive analysis of the Kaonic Helium 3 strong interaction width)
Phys. Lett. B714 (2012) 40

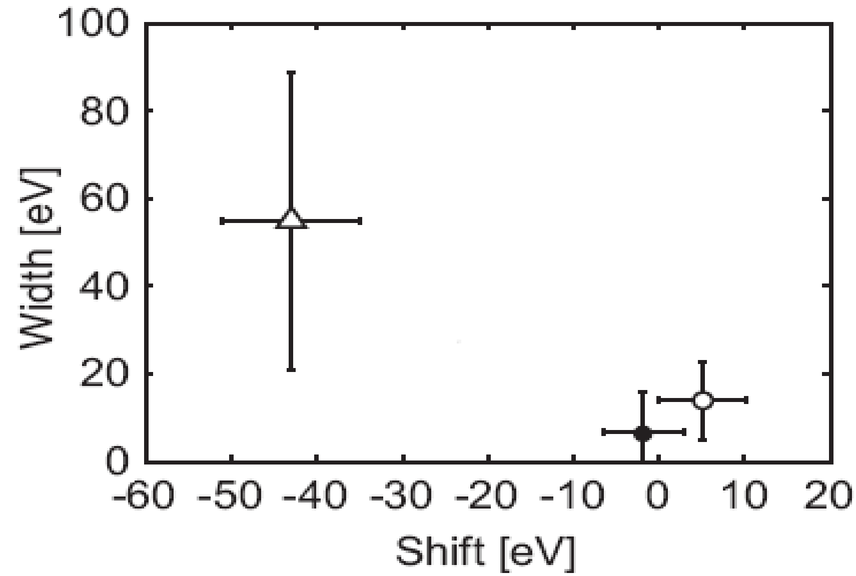
- Widths and yields of KHe3 and KHe4 - Phys. Lett. B714 (2012) 40; ongoing:
KH yields; kaonic kapton yields -> draft for publications

Kaonic Helium results

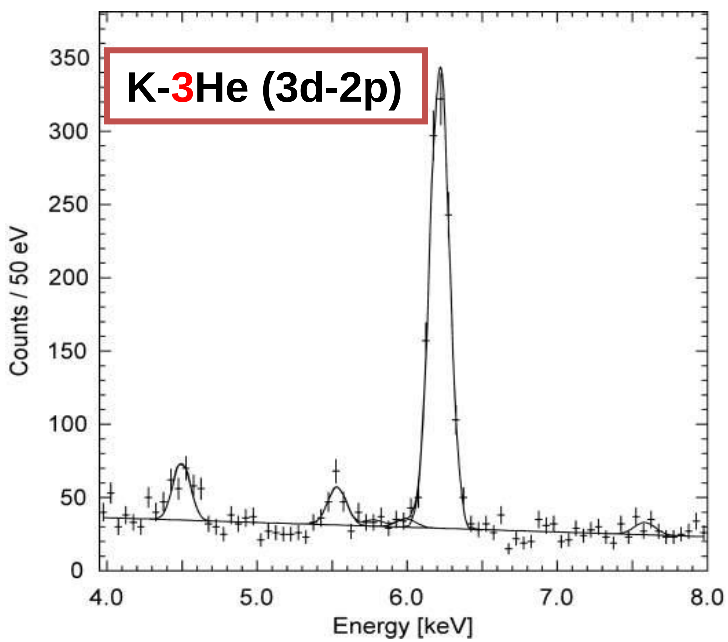


$$\Delta E_{2p} = +5 \pm 3(sta) \pm 4(sys)\ \text{eV}$$

$$\Gamma_{2p} = 14 \pm 8\ (\text{stat.}) \pm 5\ (\text{syst.})\ \text{eV},$$



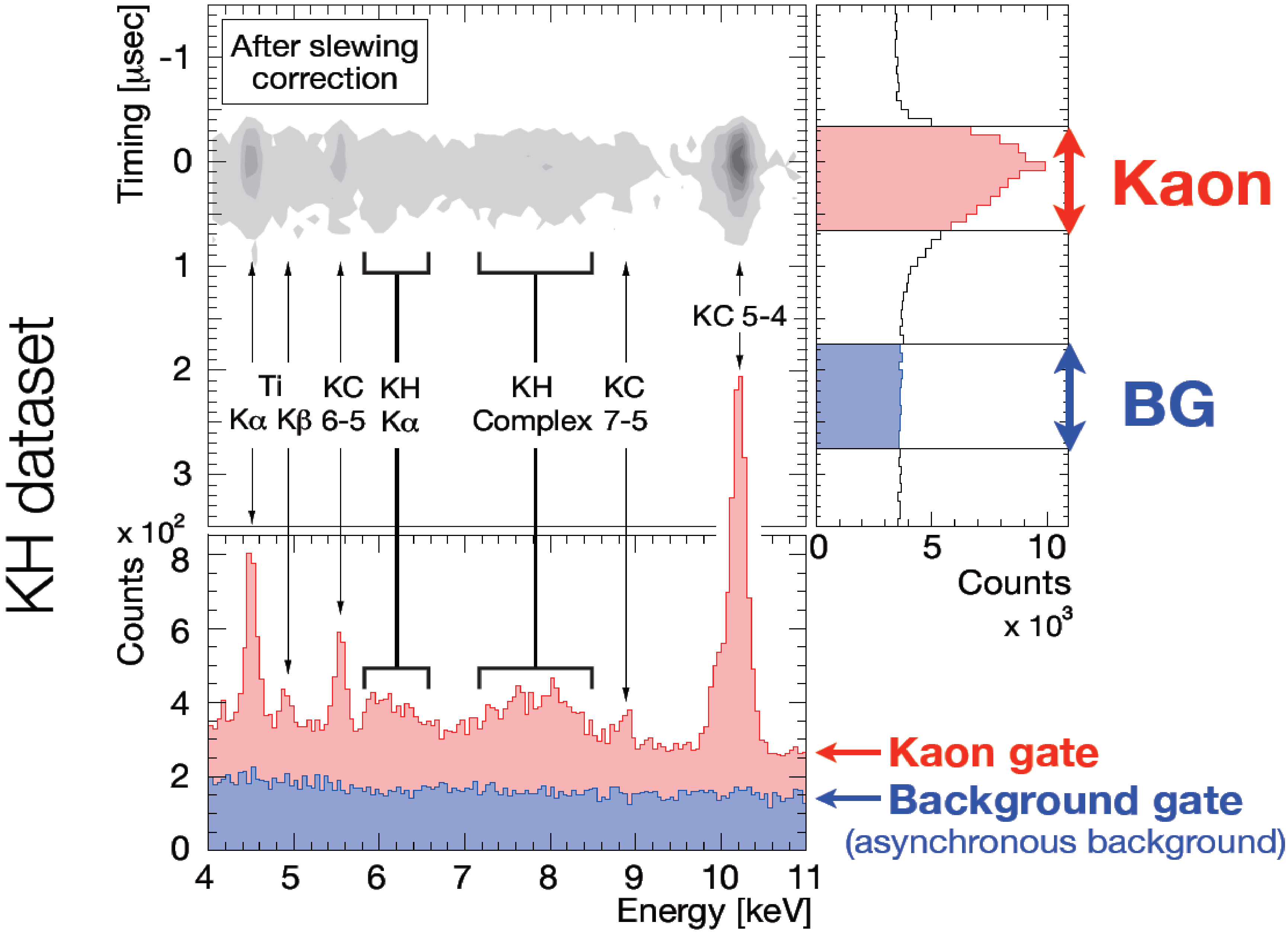
Open circle: K-4He 2*p* state; filled circle: K-3He 2*p* state. Both are determined by the SIDDHARTA experiment. The open triangle is the average value of the previous K-4He experiments.



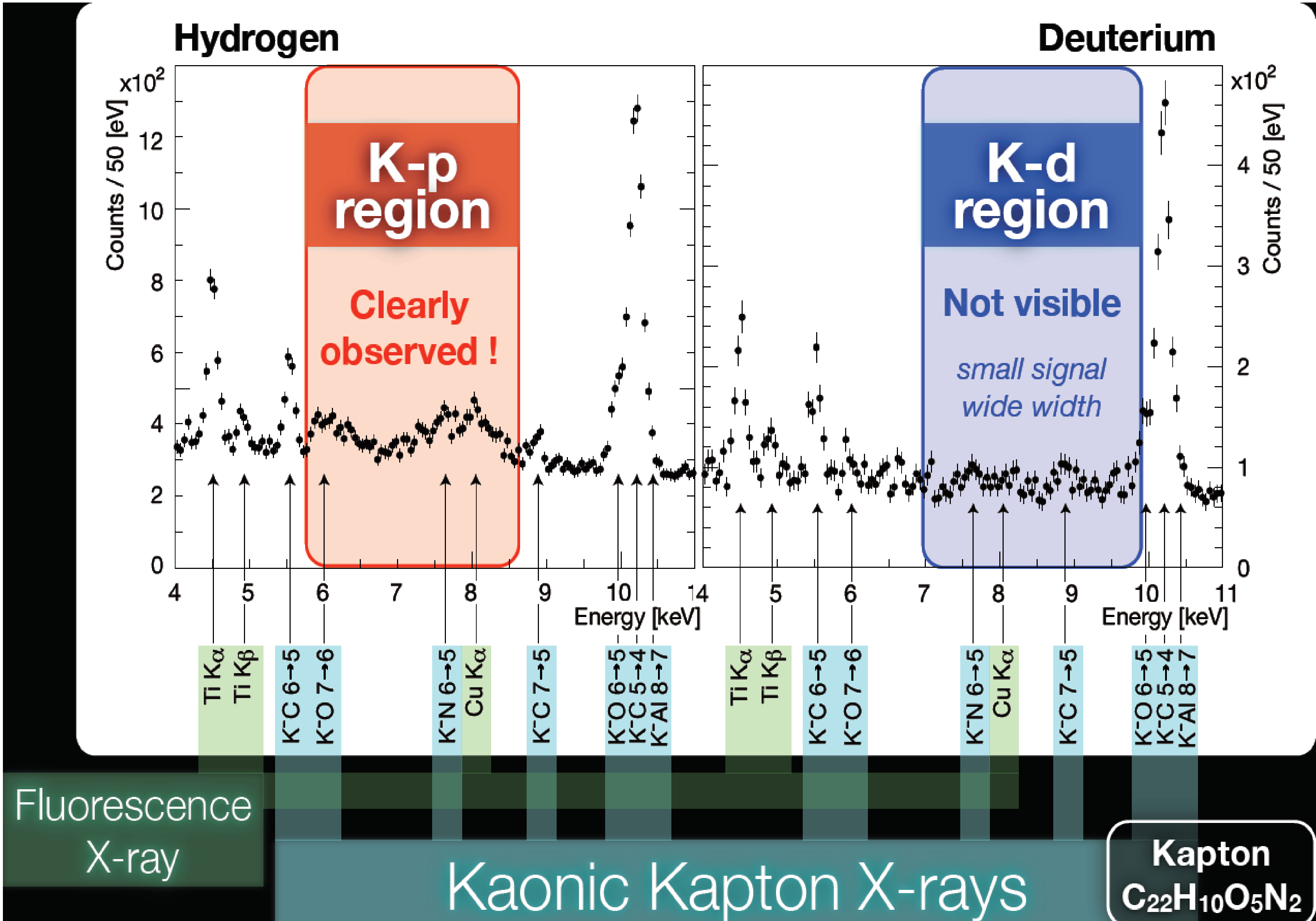
$$\Delta E_{2p} = -2 \pm 2(sta) \pm 4(sys)\ \text{eV}$$

$$\Gamma_{2p} = 6 \pm 6\ (\text{stat.}) \pm 7\ (\text{syst.})\ \text{eV},$$

Kaonic hydrogen data



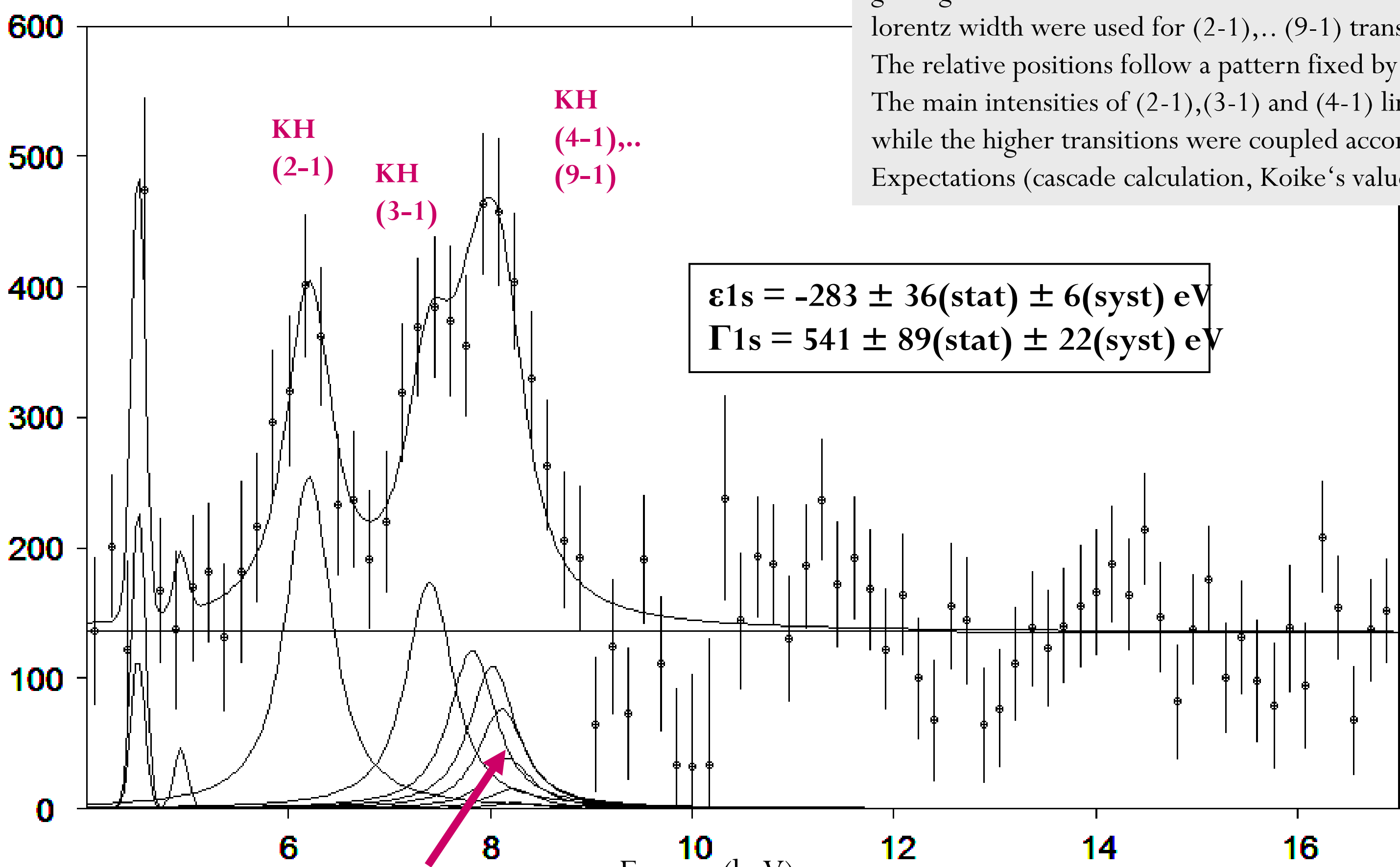
Kaonic hydrogen and kaonic deuterium



Kaonic hydrogen fit

The Kd specturm was subtracted from the kaonic hydrogen one, to get rid of the kaonic background lines (KO, KN). The overall integrated luminosity for the KH run was 290 pb^{-1}.

For the signal component 8 voigtians with given gauss resolution and free identical lorentz width were used for (2-1),.. (9-1) transitions.
The relative positions follow a pattern fixed by the QED values.
The main intensities of (2-1),(3-1) and (4-1) lines were left are free, while the higher transitions were coupled according to theoretical Expectations (cascade calculation, Koike's values).



$\varepsilon 1s = -283 \pm 36(stat) \pm 6(syst)$ eV
$\Gamma 1s = 541 \pm 89(stat) \pm 22(syst)$ eV

Note: K_{high} yield pattern

In the final analysis the backgound shape is determined by fitting the KD data and including the pattern function in the KH fit.

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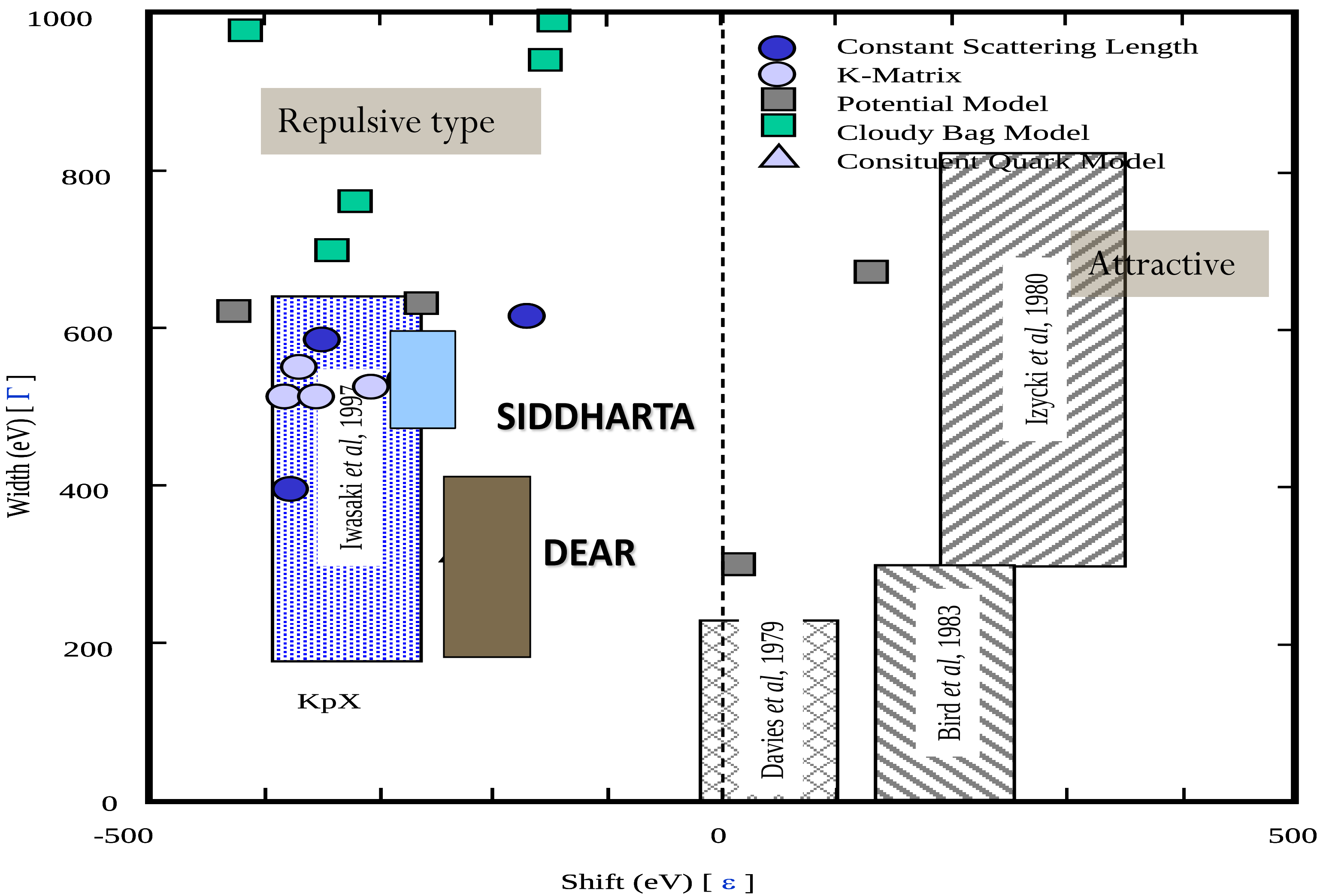
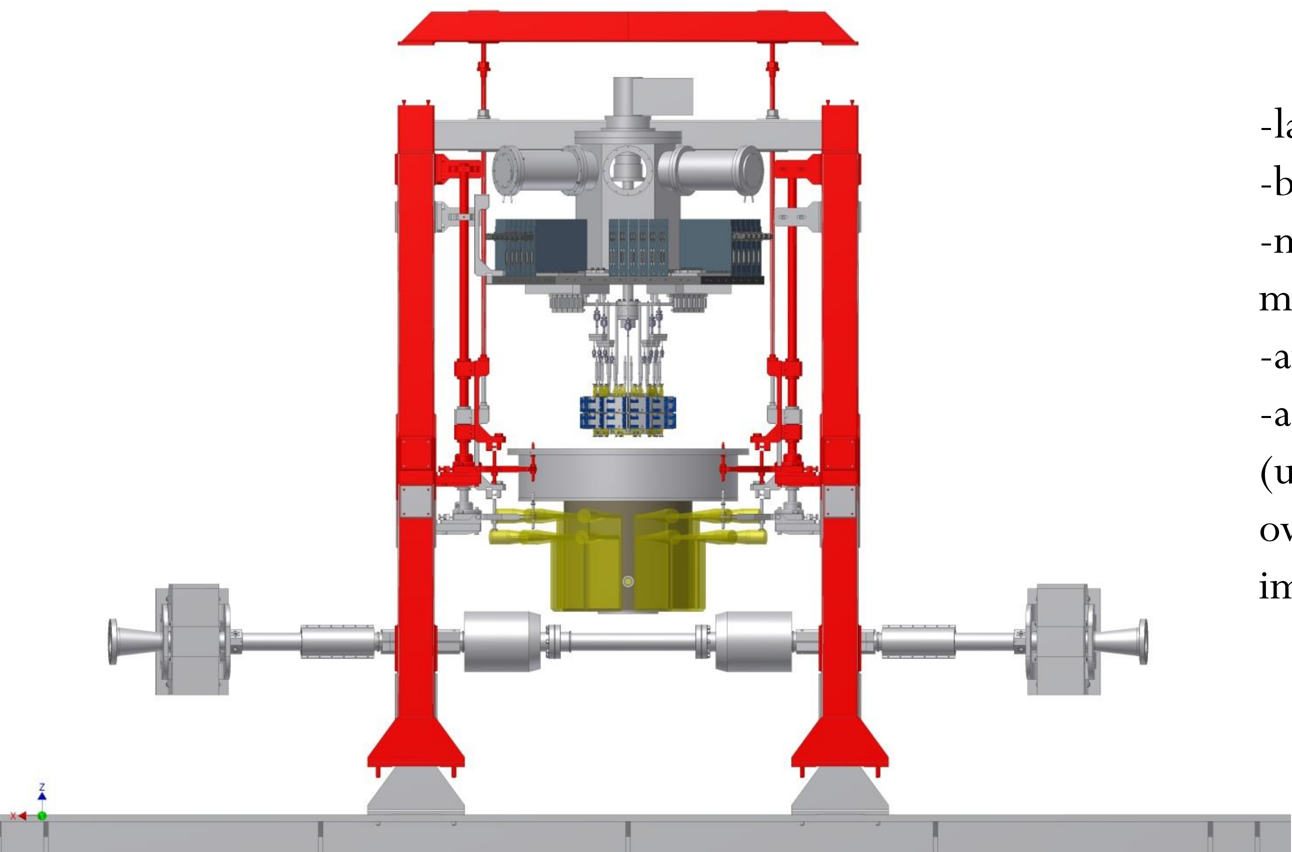
Kaonic Hydrogen X-ray measurements summary



SIDDHARTA 2

SIDDHARTA upgrade for :

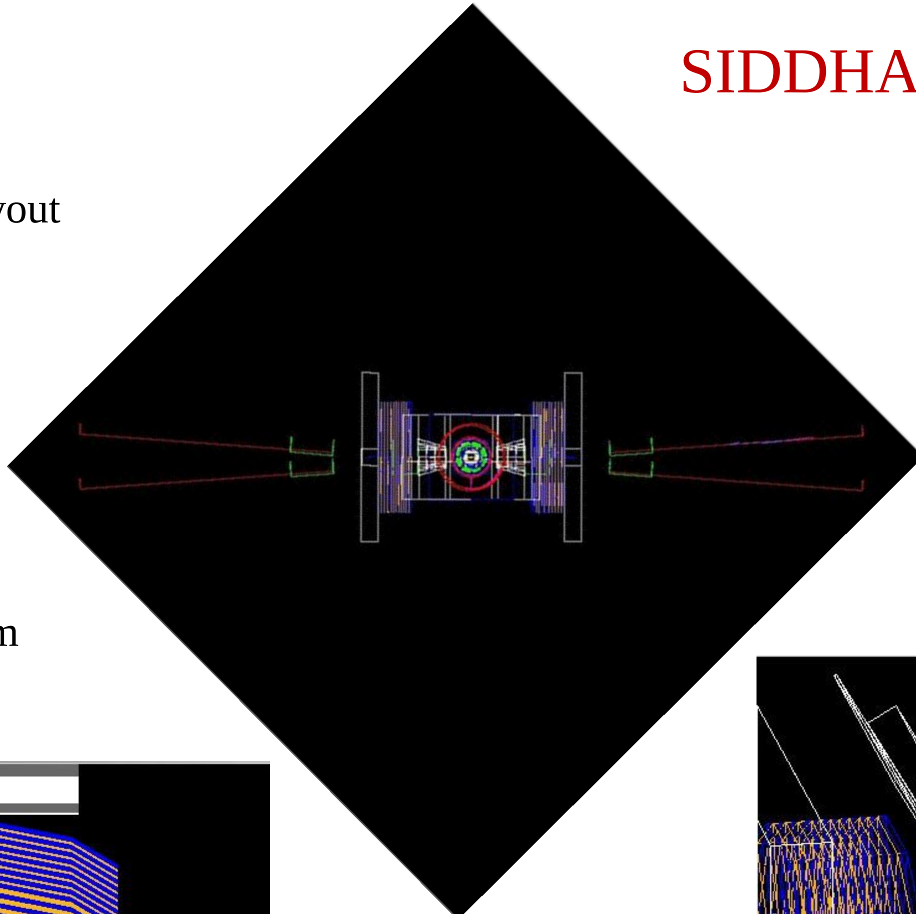
- **Kaonic deuterium precision measurement**
- **Other kaonic atoms (light and heavy) (Si,Pb …)**
- **Charged kaon mass precision measurement.**
- **Feasibility study for Sigmonium atoms.**
- **Kaonic Helium transitions to the 1s level.**



-larger target, higher density
-better shielding and trigger system
-new detectors for kaon gas moderation timing
-anticoincidence detectors
-additional SDD arrays (under development)
overall signal/background improvement: 20~30x

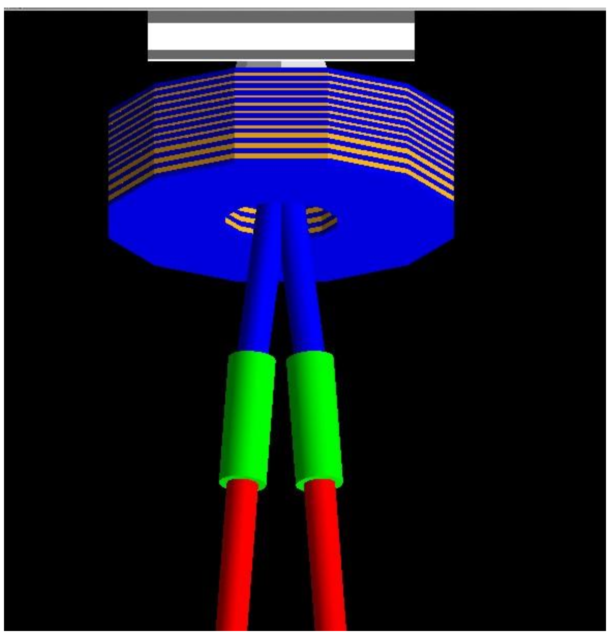
SIDDHARTA 1 (MC check)

General layout

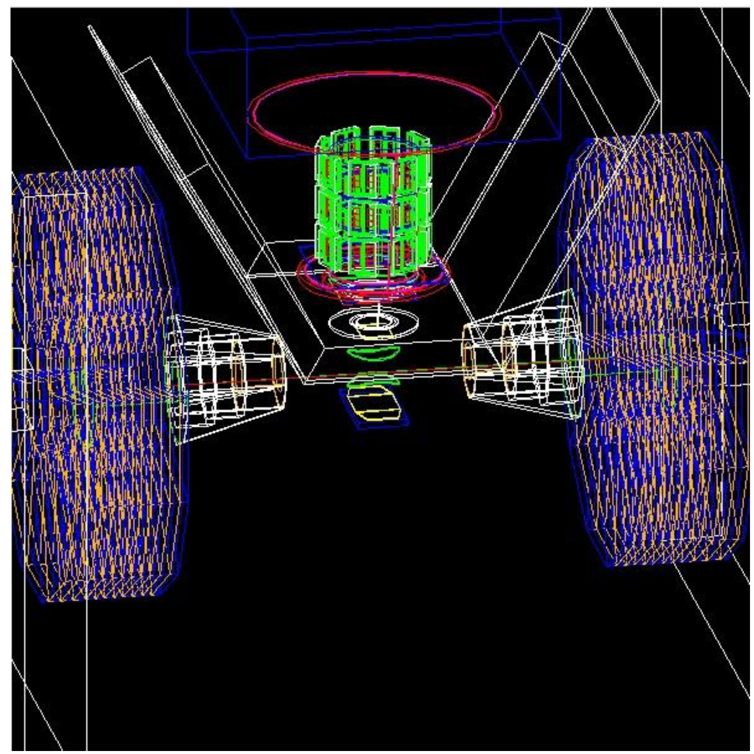


Performed after completion, due to the new, experimental machine regime under crab-waist optics.

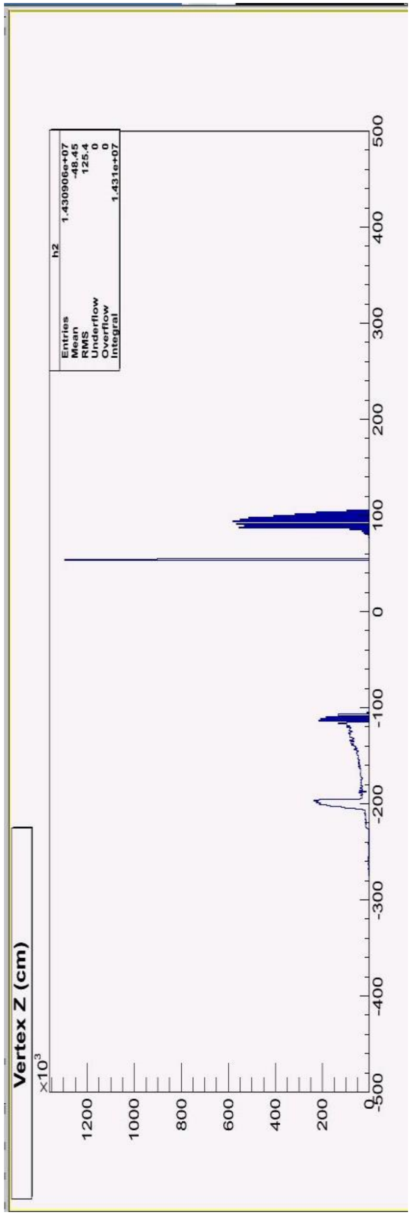
Detail of the beam pipes outside IR

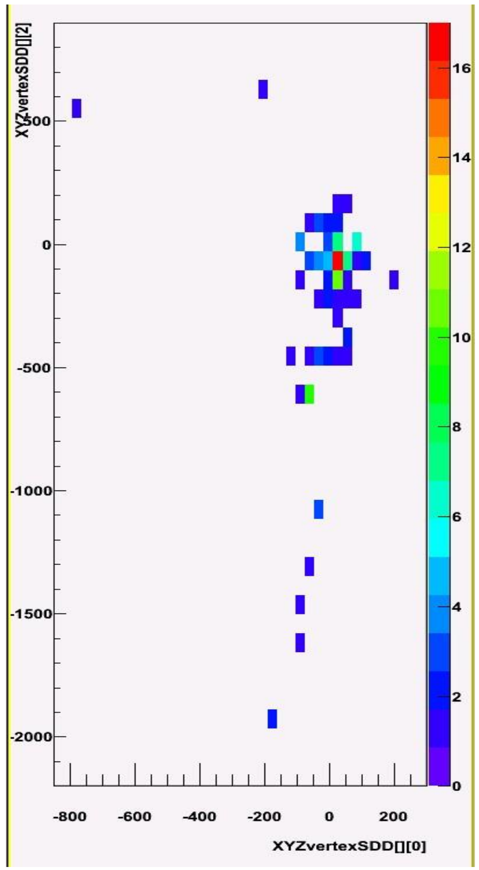


Setup detail



Simulation of Touschek background





Rate$_{(MC)}$: 49-62 Hz/2 A
Rate$_{(measured)}$: 60-80Hz/2 A

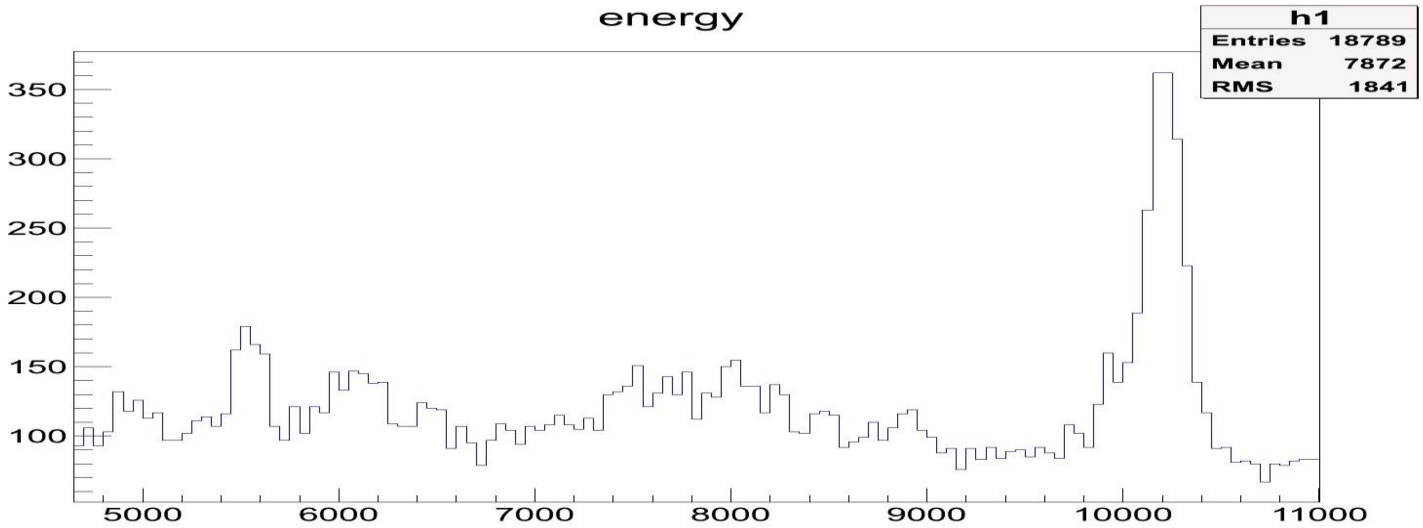
(obs: data file for 1 A, rates not linear)

HT/X (3-18keV) (MC) = 7.5±2.3

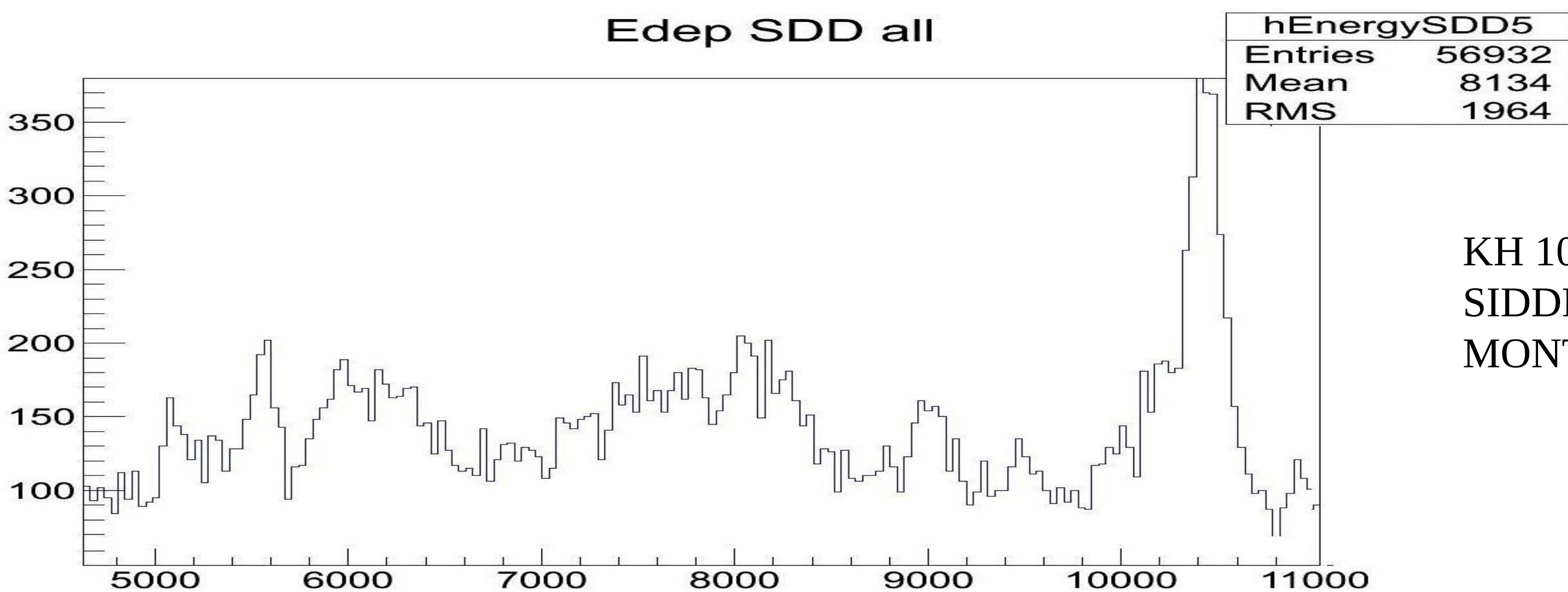
HT/X (3-18keV)(measured) = 6.2 (1 run)

DAFNE simulated distribution of particles lost due to Touschek effect (left) and SIDDHARTA SDD vertex distribution (right)

Comparison between MC and real data for SIDDHARTA 1

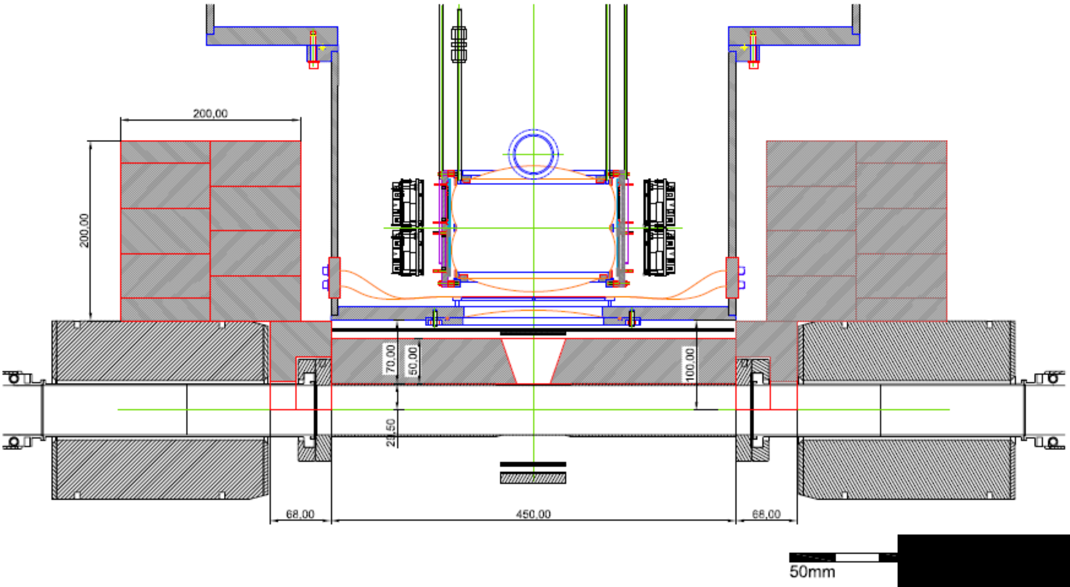


KH 106 pb
SIDDHARTA2
REAL DATA



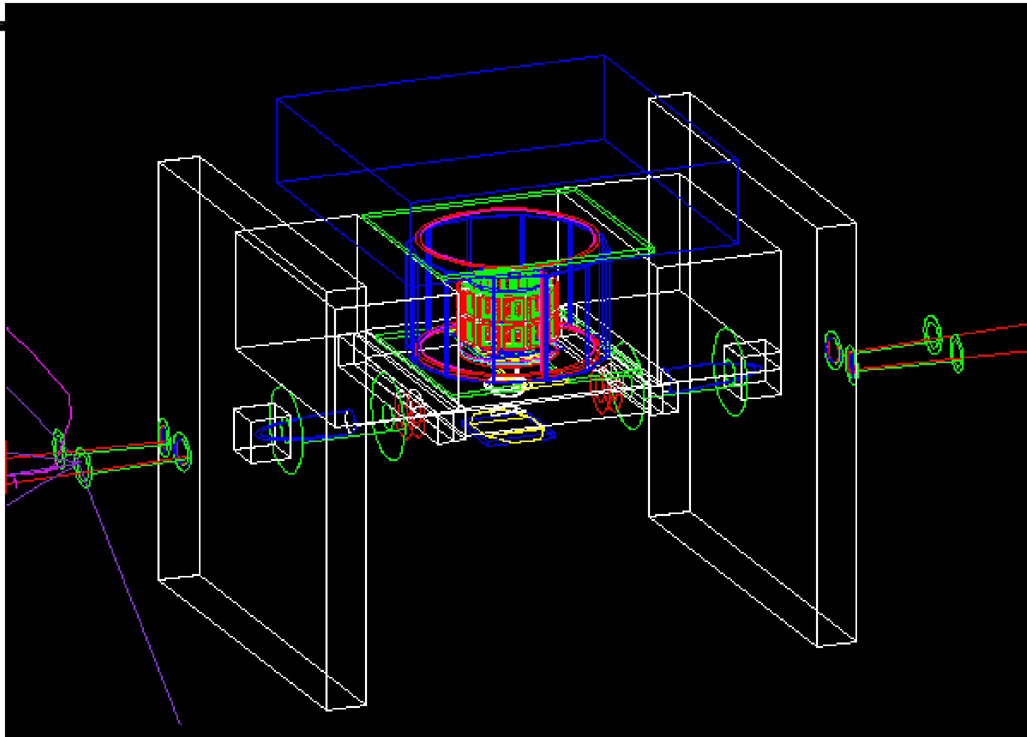
KH 106 pb
SIDDHARTA1
MONTE CARLO

SIDDHARTA 2 MC implementation

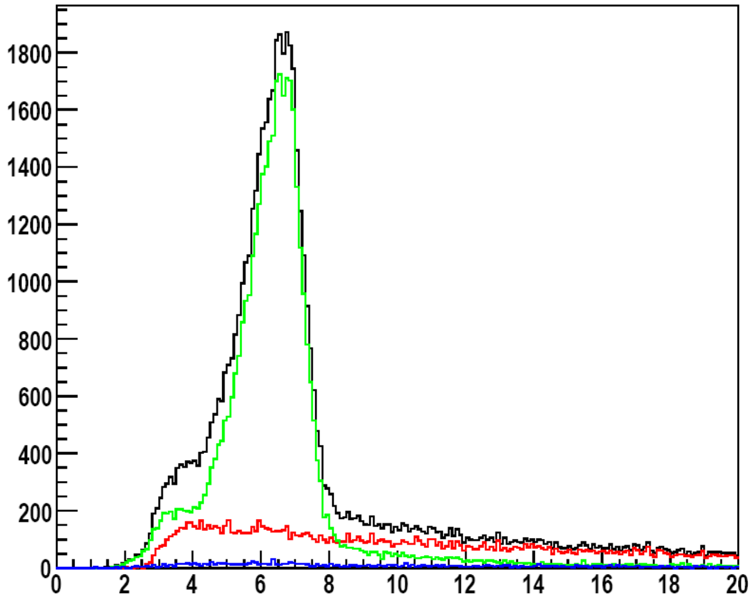


Technical drawing

Monte Carlo geometry

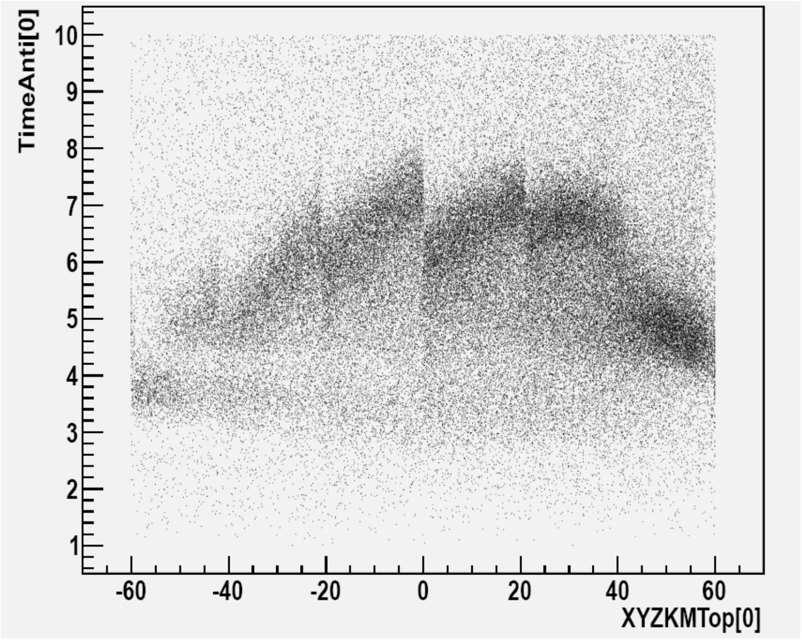


Trigger 2 for kaon gas moderation prompt signal



Time prompt on Trigger 2 for k- (green) k+ (red) and non-kaonic Φ decay (red)
FWHM ~ 2 ns, so <1 ns detector required

Degrader optimization by using the Trigger 2 barrel and the top scintillator of Ktrigger.



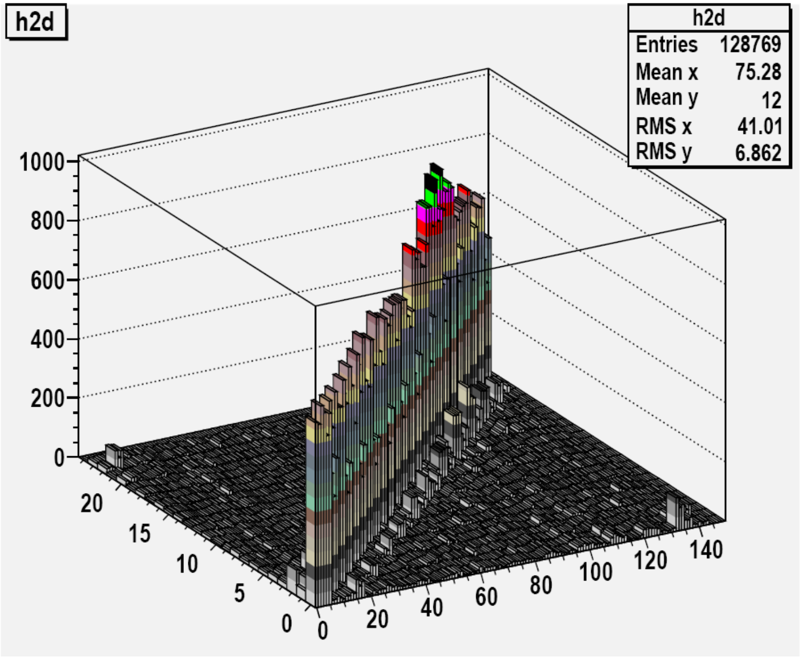
The MC factors for signal and background corresponding to each optimization step

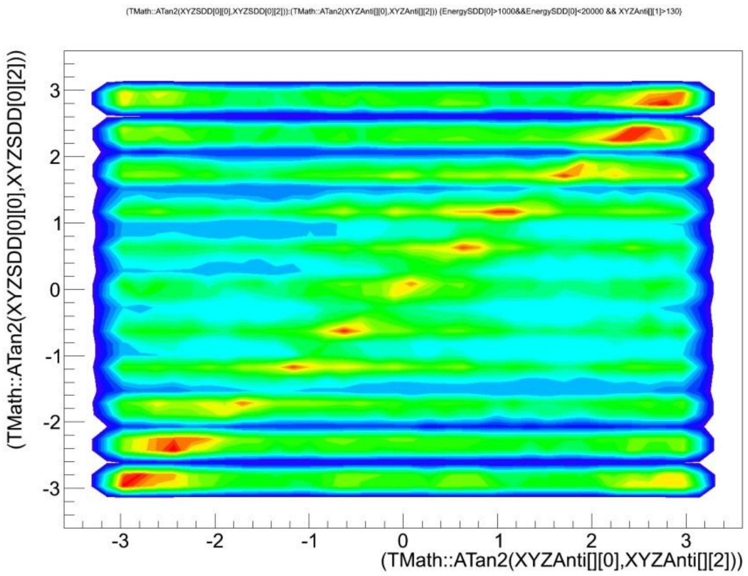
	N of triggers	Signal	Hadr. background	Machine background	Total background
Target closer to IP	1.0	1.38	1.33	-	-
Density 3% LHD	1.0	1.64	1.08	-	-
Geometry change	0.67	1.25	0.56	0.25	0.47
Trigger 2	0.33	0.72	0.39	0.33	0.16
K detector	0.73	0.93	0.76	0.73	-
Drift time	-	-	-	0.63	0.12
All	0.16	1.89	0.24	0.038	0.12

Overall S/B improvement factor ≈ 16

Other background reduction tools

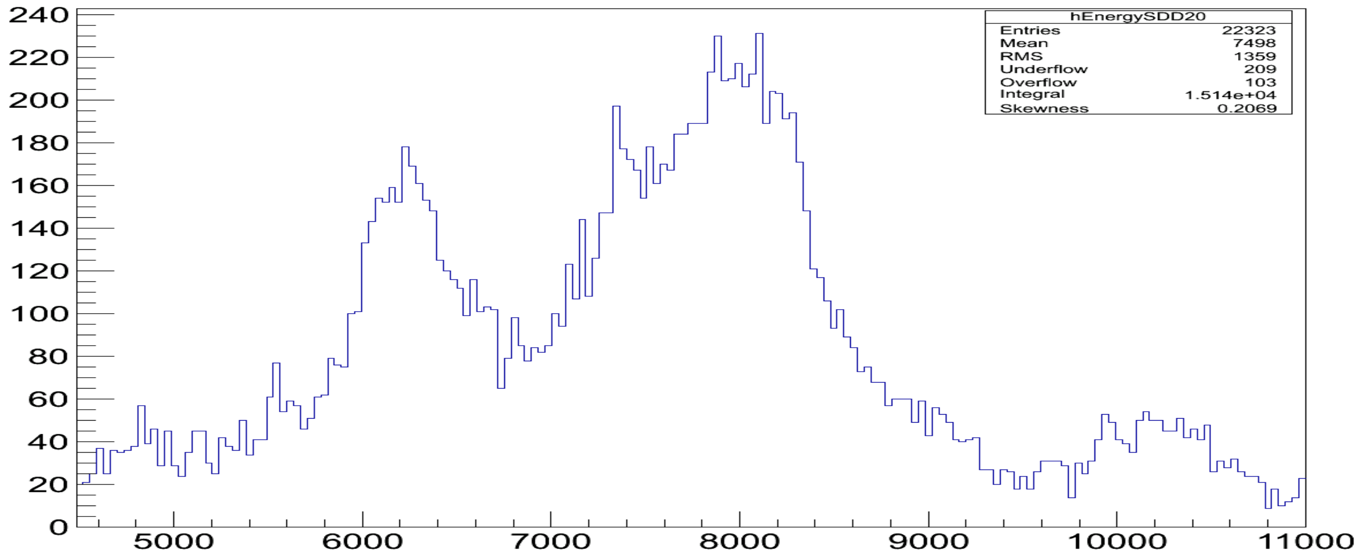
-anticoincidence scintillators placed behind SDDs ~ 0.6 Hbkg
-anticoincidence with Trigger 2 scintillators ~ 0.8 Hbkg (not multiplicative to the first)
-K+ detector ~0.8
-Trigger 2 as active shielding ~.65 (on EM bkg)
-anticoincidence with upper K trigger ~.85 (on EM bkg)



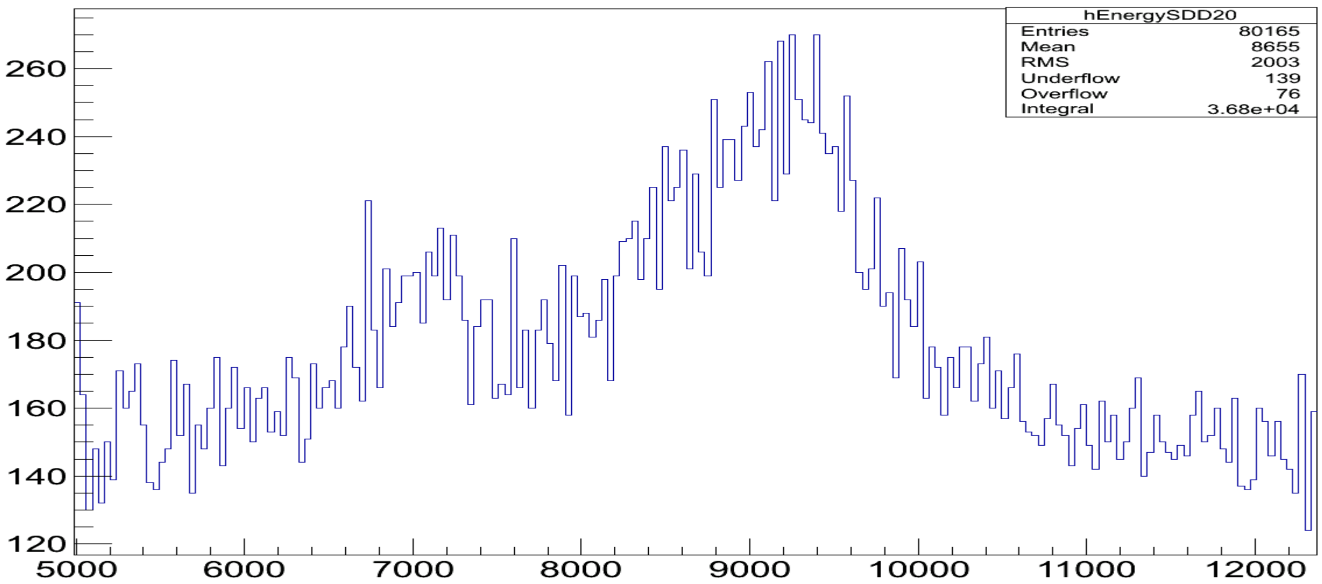


Correlation between SDDs and back scintillators (left) and Trigger 2 scintillators (right)

<u>MC results for SIDDHARTA2</u> (only "basic" reduction applied)

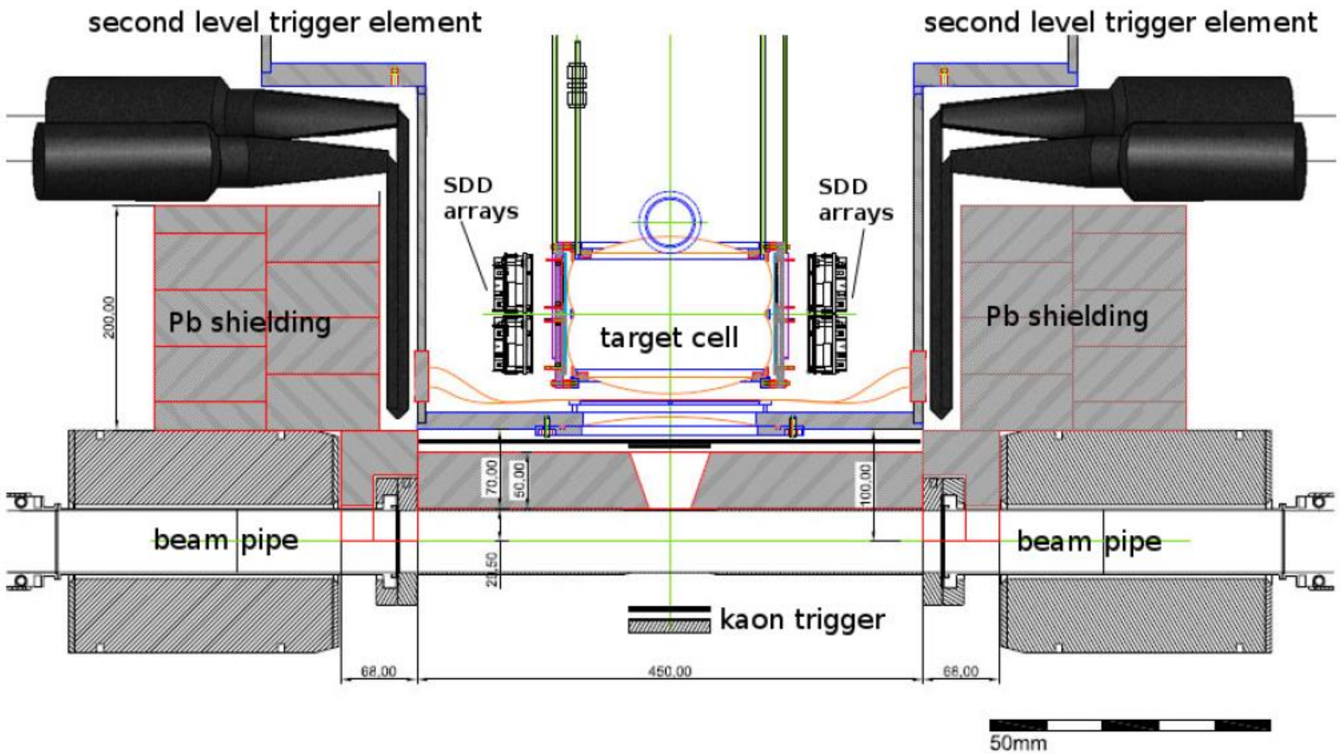


KH 106 pb
SIDDHARTA2
MONTE CARLO



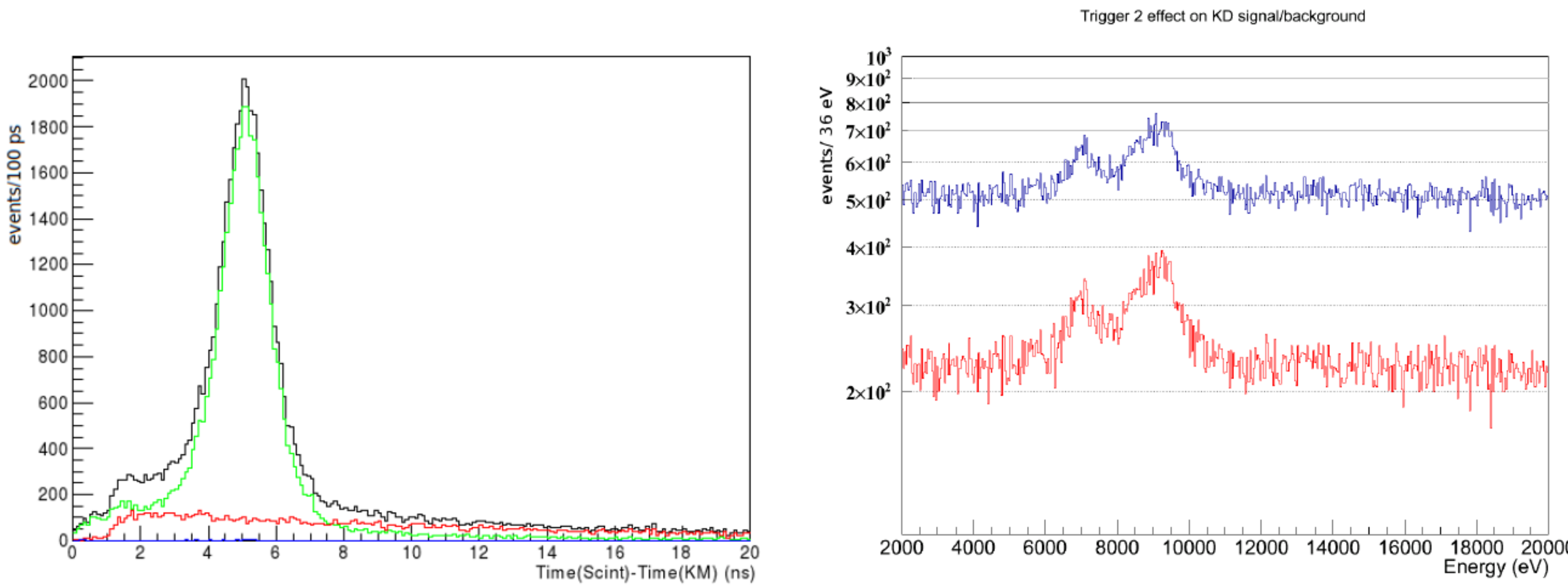
KD 800 pb
SIDDHARTA2
MONTE CARLO
800 eV width
$y=1.2\ 10^{-3}$

SIDDHARTA-2 Trigger level 2



. A detailed technical drawing of the SIDDHARTA-2 experimental setup sideview section (details can be found in text and in [12]). The elements of the second level trigger (T2L), placed around the vacuum chamber, are showed in black.

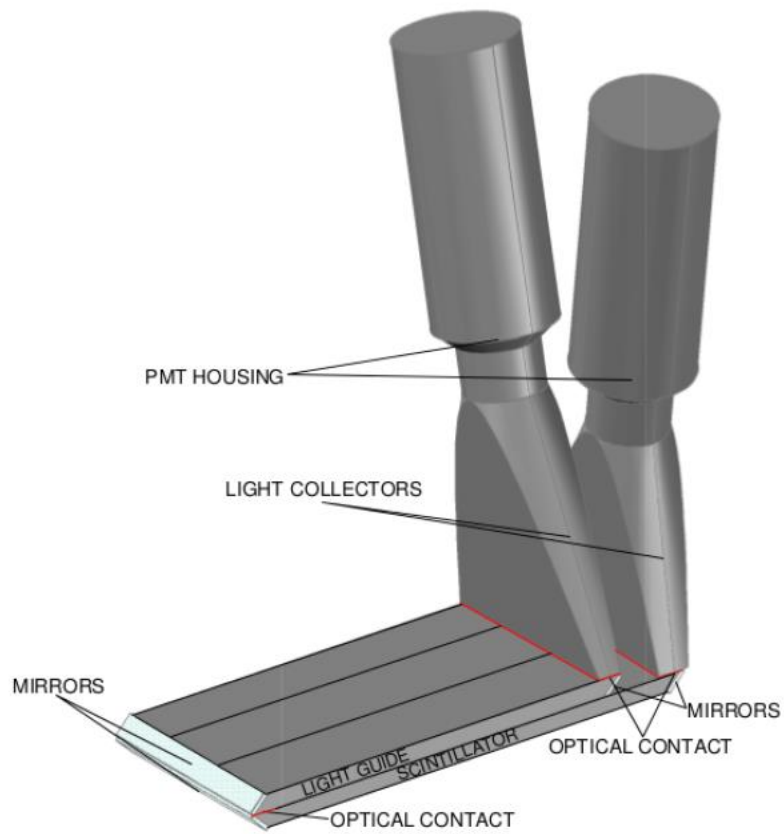
SIDDHARTA-2 Trigger level 2



Left: GEANT4 simulated time spectrum for 2×10^6 Φ decays of a scintillator placed outside the vacuum chamber. The main peak corresponds to particles produced by the K^- absorption by a gas nucleus. Right: Simulated KD X-ray spectrum (in a logaritmic scale) using the T2L (red) and without it (blue).

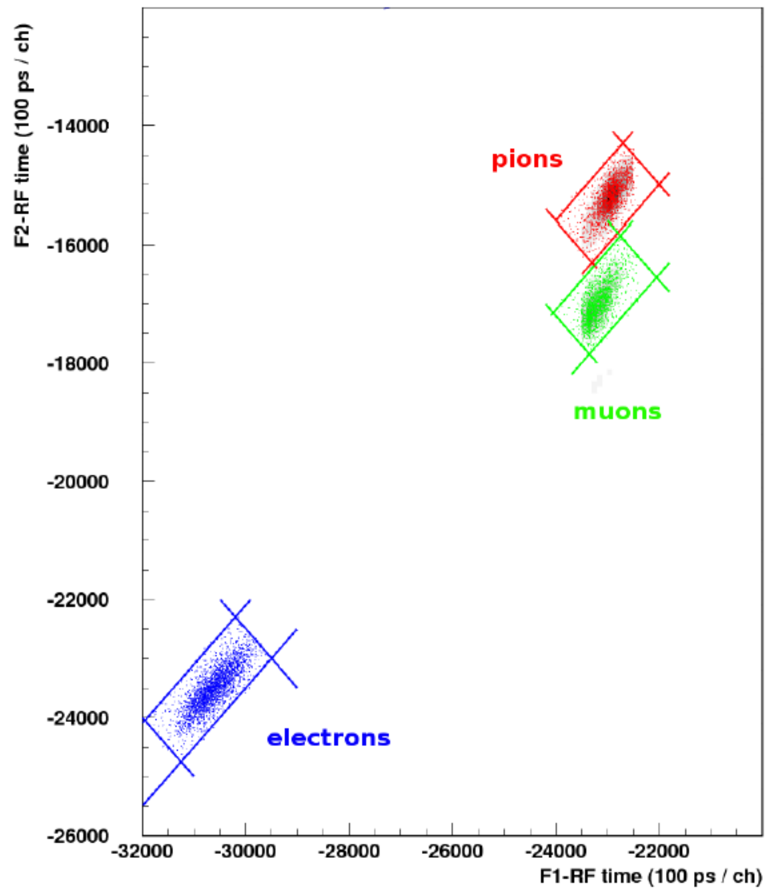
In the left part of fig. 2 the black line represents the time difference between a trigger signal (K^+K^- produced by the Φ decay in DAΦNE in a back-to-back configuration) and a $\pi^\pm$ signal on the scintillator. The green peak shows the subset of events in which a K^+ crosses the bottom side of the kaon detector (implying a K^- reached the target) while the red one shows the ones in which a

SIDDHARTA-2 Trigger level 2



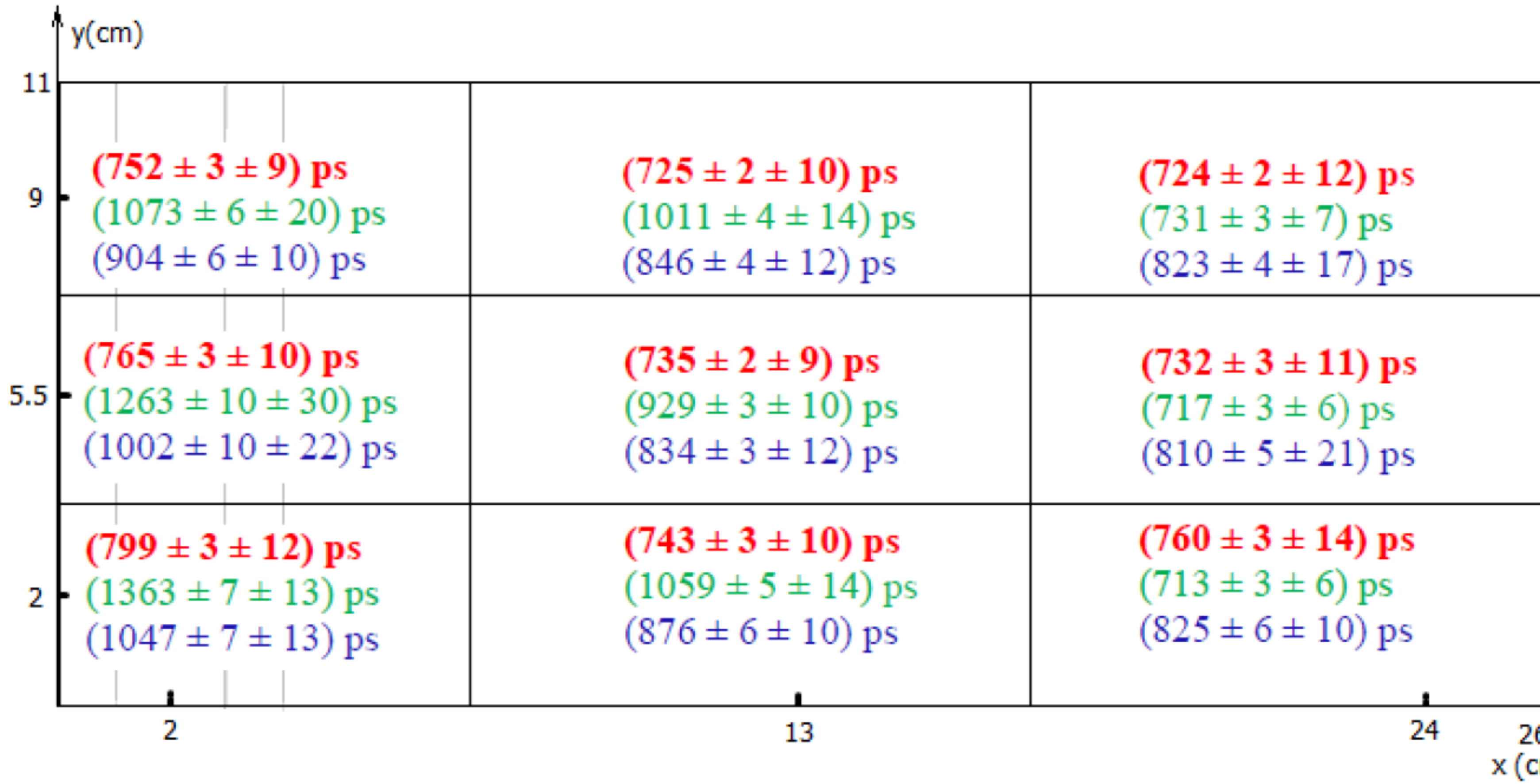
The T2L prototype scheme; 3 stripes of scintillator are coupled each with a stripe of light guide by an optical grease. Light collectors leading to photomultipliers (PMTs) are glued both on scintillators and light guides by optical glue. At the ends of the 45° cuts of the scintillators and light guides there are aluminized mirrors placed to lead the photons towards the PMTs.

SIDDHARTA-2 Trigger level 2



2D graph of the TDC signals of F1 and F2. The selection plot for the 170 MeV/c momen

SIDDHARTA-2 Trigger level 2



Measured mean time resolutions (FWHM) for 170 MeV/c momentum pions (red), muons (green and electrons (blue).

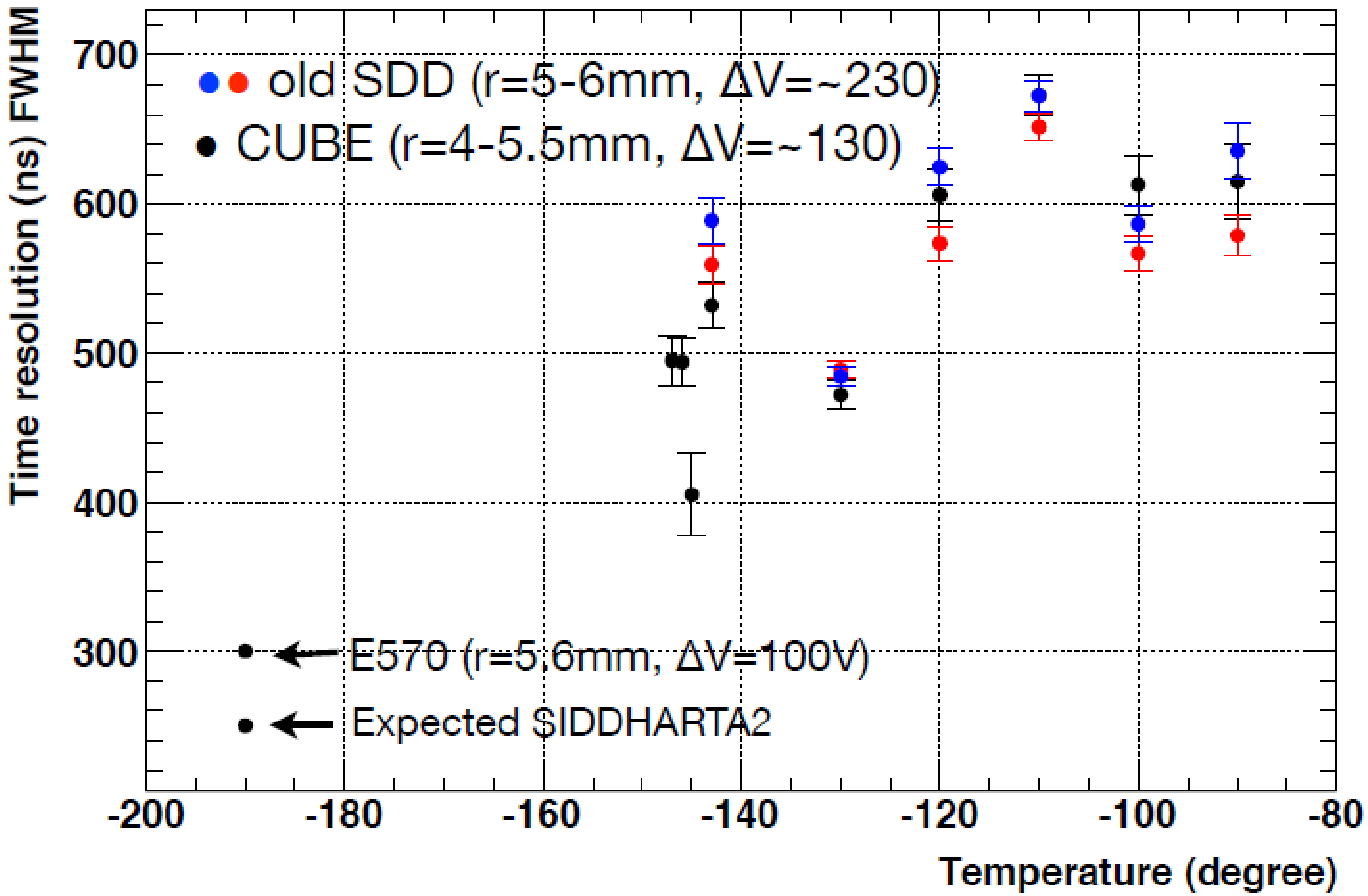
SIDDHARTA-2 Trigger level 2

y(cm) \ x	2	13	24
9	(94.6 ± 0.6 ± 0.1) % (95.91 ± 0.78 ± 0.04) % (99.33 ± 1.34 ± 0.01) %	(96.03 ± 0.51 ± 0.08) % (97.00 ± 0.64 ± 0.05) % (99.876 ± 1.111 ± 0.006) %	(96.50 ± 0.55 ± 0.07) % (96.42 ± 0.70 ± 0.03) % (99.891 ± 1.207 ± 0.02) %
5.5	(96.39 ± 0.62 ± 0.07) % (97.86 ± 0.80 ± 0.02) % (99.973 ± 1.338 ± 0.001) %	(96.68 ± 0.37 ± 0.07) % (97.82 ± 0.48 ± 0.04) % (99.960 ± 0.816 ± 0.001) %	(96.19 ± 0.61 ± 0.07) % (96.94 ± 0.79 ± 0.03) % (99.98 ± 1.40 ± 0.01) %
2	(96.11 ± 0.61 ± 0.07) % (97.11 ± 0.78 ± 0.06) % (99.919 ± 1.427 ± 0.009) %	(93.5 ± 0.6 ± 0.1) % (93.9 ± 0.8 ± 0.3) % (98.0 ± 1.3 ± 0.2) %	(95.96 ± 0.61 ± 0.08) % (96.00 ± 0.77 ± 0.12) % (99.93 ± 1.44 ± 0.02) %

Measured efficiencies (MT) for the 170 MeV/c momentum pions (red) muons (green) a
trons (blue).

Temperature dependence of time resolution

almost same resolution for old and CUBE SDDs



AMADEUS

Antikaon Matter At DAΦNE: Experiments with Unraveling Spectroscopy

AMADEUS collaboration
116 scientists from 14 Countries and 34 Institutes

lnf.infn.it/esperimenti/siddharta
and
LNF-07/24(IR) Report on lnf.infn.it web-page (Library)

AMADEUS started in 2005 and
was presented and discussed in all the LNF Scientific Committees

EU Fundings FP7 – I3HP2:
Network WP9 – LEANNIS;
WP24 (SiPM JRA);
WP28 (GEM JRA)

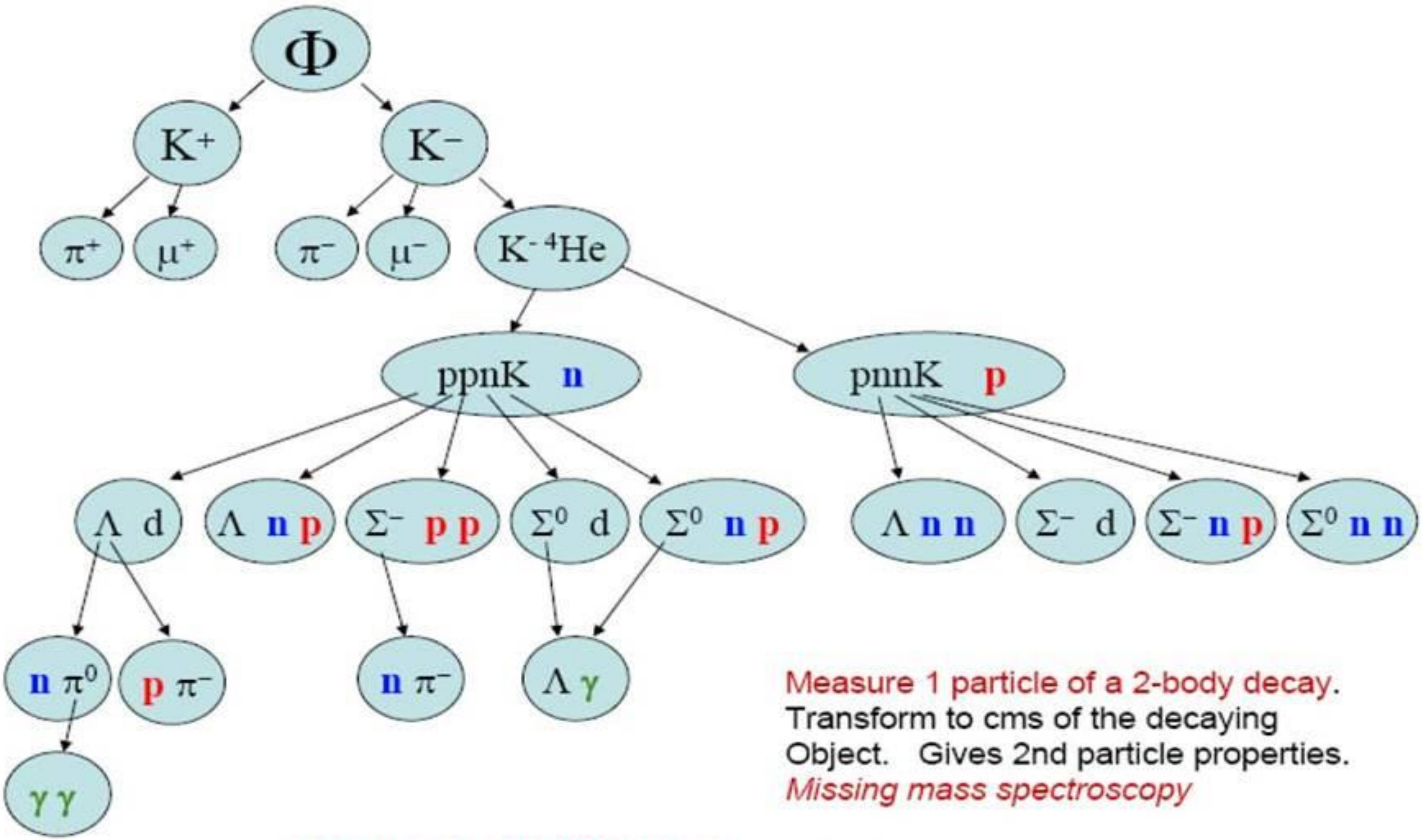
HadronPhysics2
Study of Strongly Interacting Matter

Experimental program of AMADEUS

Unprecedented studies of the low-energy charged kaons interactions in nuclear matter: solid and gaseous targets (d, ^{3}He, ^{4}He) in order to obtain unique quality information about:

- Nature of the controversial **Λ(1405)**
- Possible existence of **kaonic nuclear clusters** (deeply bound kaonic nuclear states)
- Interaction of K^- with **one** and **two nucleons.**
- Low-energy charged kaon **cross sections** for momenta lower than 100 MeV/c (missing today)
- Many other processes of interest in the low-energy QCD in strangeness sector -> implications from particle and nuclear physics to astrophysics (dense baryonic matter in **neutron stars**)

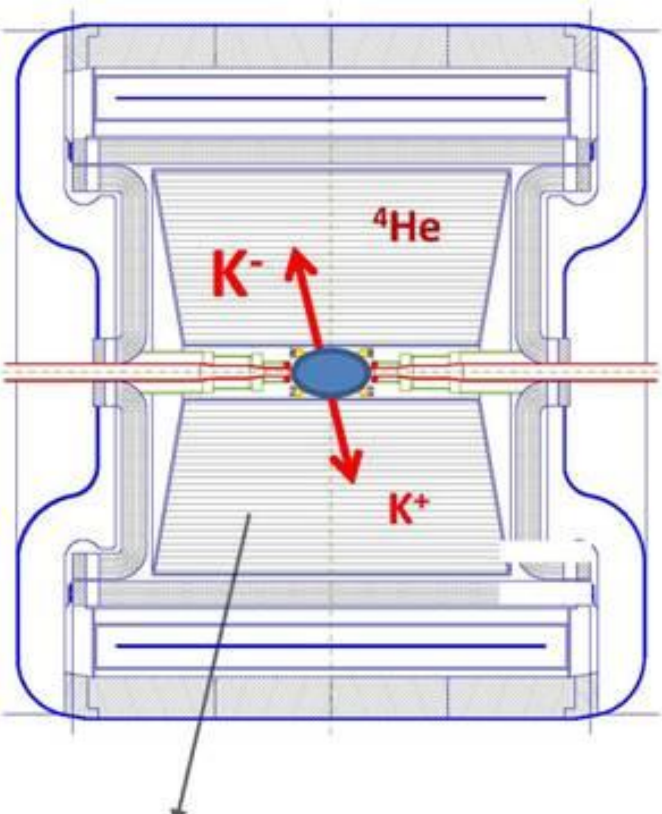
Reactions channels (simplified)



Measure 1 particle of a 2-body decay. Transform to cms of the decaying Object. Gives 2nd particle properties. *Missing mass spectroscopy*

Measure all outgoing particles to obtain the total cms energy = *invariant mass of the object*

Hadronic interactions of K^- in KLOE



KLOE Drift Chamber

- The Drift Chambers of KLOE contain mailny **^{4}He**

- From analysis of KLOE data and Monte Carlo:
  0.1 % of K^- from daΦne should **stop in the DC volume**

- This would lead to hundreds of possible kaonic clusters produced in the 2 fb^{-1} of KLOE data.

AMADEUS status

- Analyses of the **2002-2005 KLOE data**:

- Dedicated **2012** run with pure **Carbon target** inside KLOE

  - **Λp** from 1NA or 2NA (single or multi-nucleon absorption)
  - **Λd** and **Λt** channels
  - Λ (1405) -> **$\Sigma^0\pi^0$**
  - Λ (1405) -> **$\Sigma^+\pi^-$**
  - ΣN/ΛN internal conversion rates

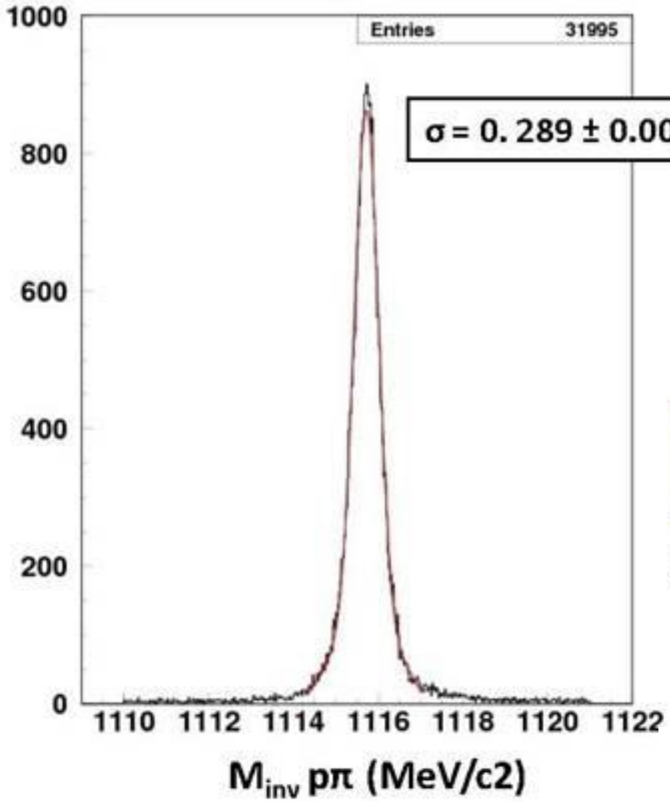
- R&D for more refined setup

- Future possible scenario

Oton Vázquez Doce

Lambda invariant mass

$\Lambda \rightarrow p + \pi^-$



$\sigma = 0.289 \pm 0.003$ MeV/c^2

-Dedicated event selection to avoid Energy loss in the DC wall

- Best $\chi 2$ tracks and vertices

PRELIMINARY

$M_{inv} = 1115{,}723 \pm 0.003$ stat (MeV/c^2)

PDG: $M_\Lambda = 1115{,}683 \pm 0.006$ stat $\pm\ 0.006$ syst (MeV/c^2)

-Sistematics dependent of momentum calibration

Preliminary evaluation with 2-body decay

$K^\pm \rightarrow \mu^\pm \nu$

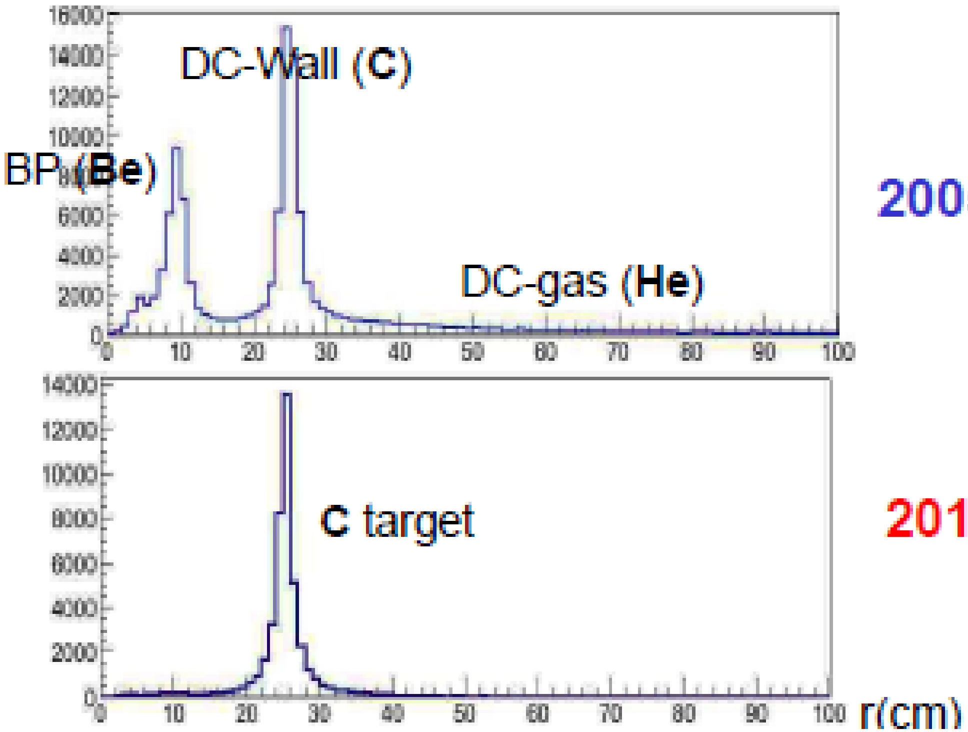
$K^\pm \rightarrow \pi^\pm \pi^0$

KLOE data on K^- nuclear absorption

Use of two different data samples:

- KLOE data from 2004/**2005** (2.2 fb^{-1} total, 1.5fb^{-1} analyzed)
- Dedicated run in november/december **2012** with a **Carbon target** of 4/6 mm of thickness (~90 pb^{-1}; analyzed 37 pb^{-1}, x1.5 statistics)

Position of the K^- hadronic interaction inside KLOE:



2005 data

2012 with Carbon target

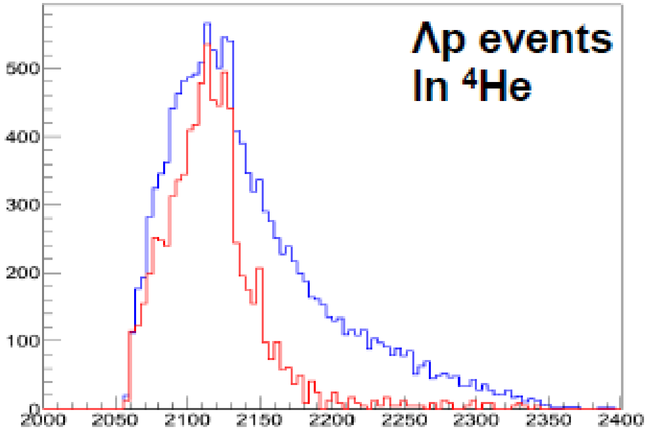
Λp analysis

-Competing processes:

1NA: $K^- N \rightarrow \Lambda \pi^-$ (N from residual nucleus)

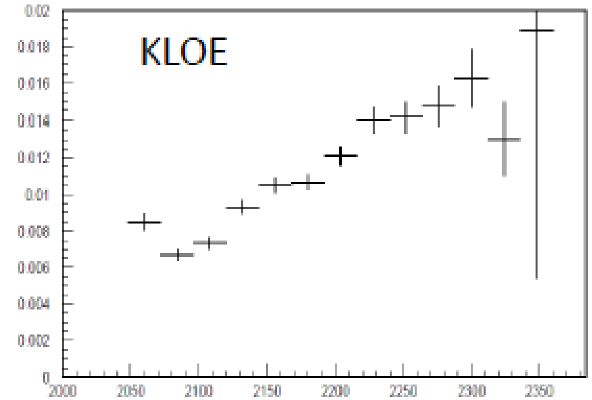
2NA: $K^- NN \rightarrow \Lambda N$ (pionless)

A perfect disentanglement between single and multi-nucleon absorption can be achieved thanks to the **nice acceptance:**

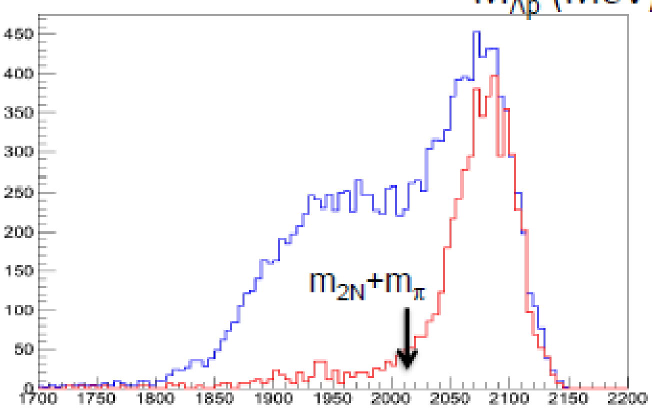


$M_{\Lambda p}$ (MeV)

Λp all events
$\Lambda\pi^-$(p) events
(arbitrary normalization)

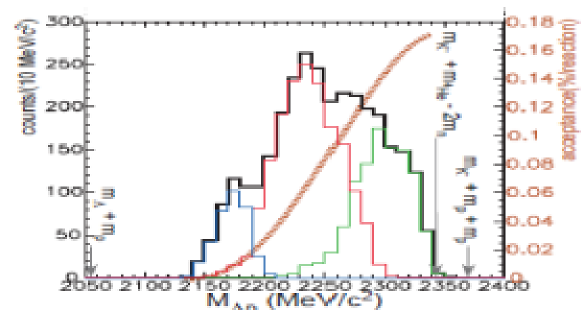


Acceptance in $M_{\Lambda p}$ (MeV)
(arbitrary normalization)



Λp missing mass (MeV)

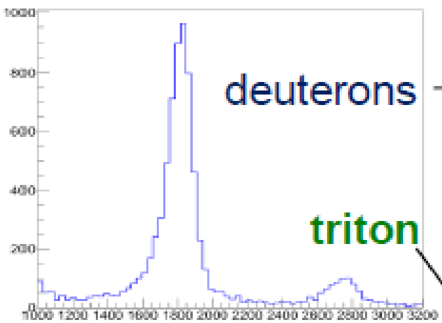
The Λp missing mass for the $\Lambda\pi^-$(p) events lies exactly In the $2N+\pi^-$ mass region

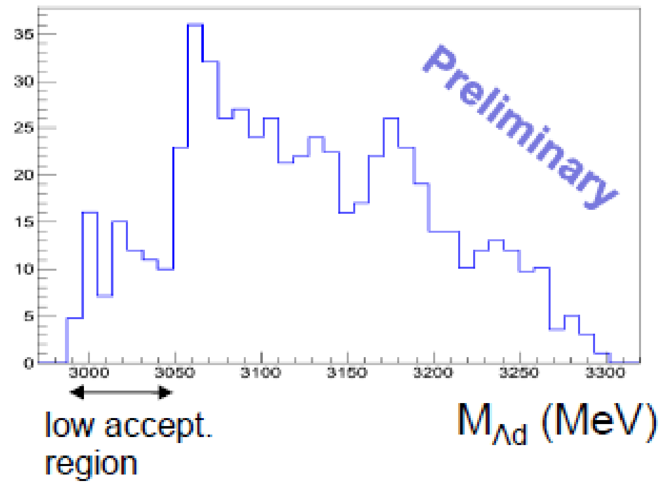


KEK-E549
Mod.Phys.Lett.A23, 2520 (2008)

Λd, Λt analyses

- Search for signal of bound states in the **Λd** channel. Candidate to be a **K^-ppn** cluster. Observed spectra from FINUDA and KEK again showing possible bound states in the in the high invariant mass region.

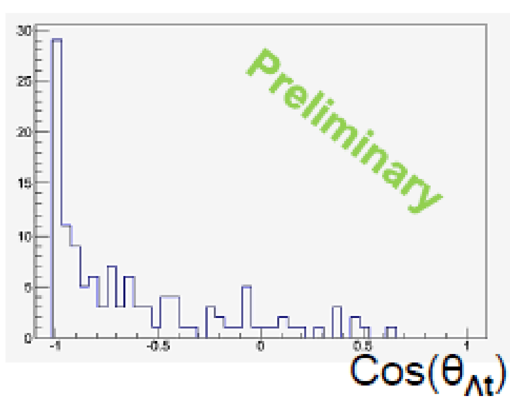


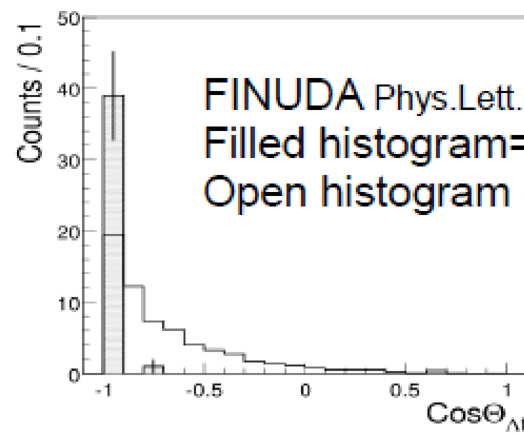


Λd events
In ^{4}He

Only FINUDA and an old experiment (with only 4 events!) have shown **Λt** spectra from K^- absorption

Λt events
In ^{4}He





FINUDA Phys.Lett.B 229, 229 (2008)
Filled histogram= data
Open histogram = Phase space simulation

Λ(1405) scientific case

$(M\,,\,\Gamma) = (1405.1^{+1.3}_{-1.0}\,,\,50 \pm 2)$ MeV, $I = 0$, $S = -1$, $J^p = 1/2^-$, Status: ****, strong decay into $\Sigma\pi$

Its **nature** is being a **puzzle now for decades**:

1) ***three quark state***: expected mass ~ 1700 MeV

2) ***penta quark***: more unobserved excited baryons

3) ***unstable* KN *bound state***

4) ***two poles***: ($z_1 = 1424^{+7}_{-23}$, $z_1 = 1381^{+18}_{-6}$) MeV (Nucl. Phys. A881, 98 (2012))

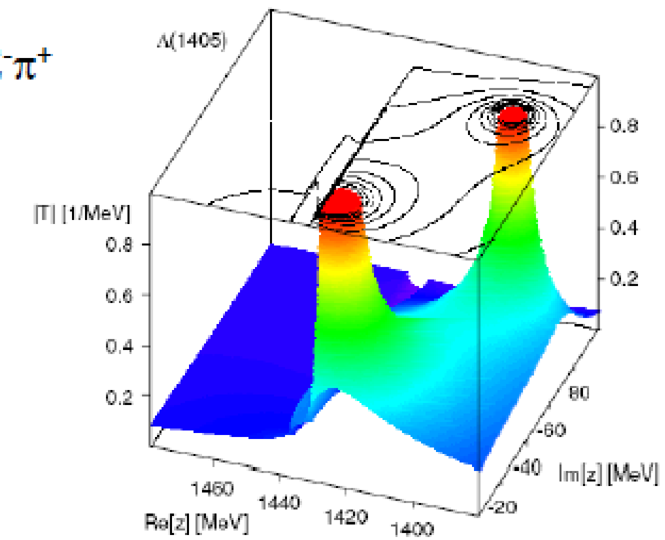
Higher mass pole mainly coupled to KN

mainly coupled to $\Sigma\pi$ -> **line-shape depends on production mechanism**

Line-shape also depends on the decay channel : $\Sigma^0\pi^0$ $\Sigma^+\pi^-$ $\Sigma^-\pi^+$

BEST CHOICE:

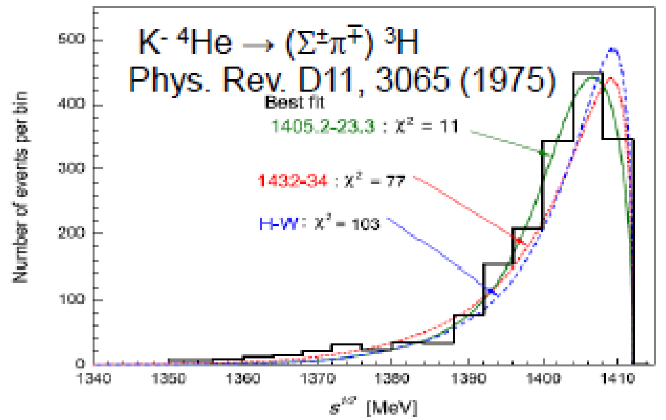
production in KN reactions (only chance to observe the high mass pole) **decaying in $\Sigma^0\pi^0$** (free from $\Sigma(1385)$ background)

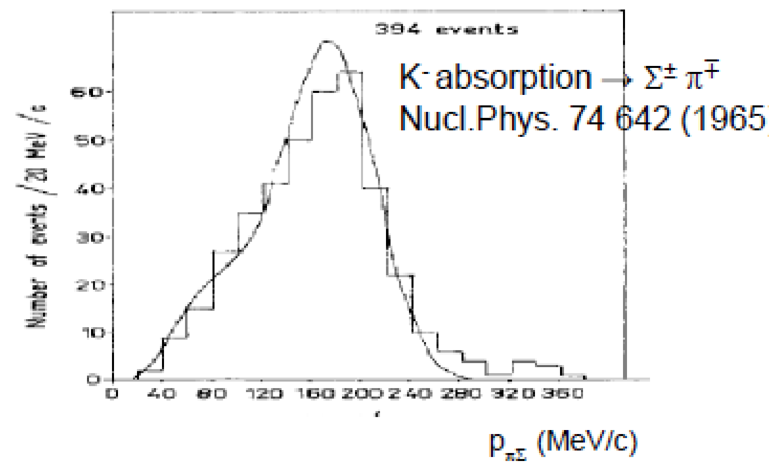


Λ(1405) previous experiments

Old **absorption experiments:**

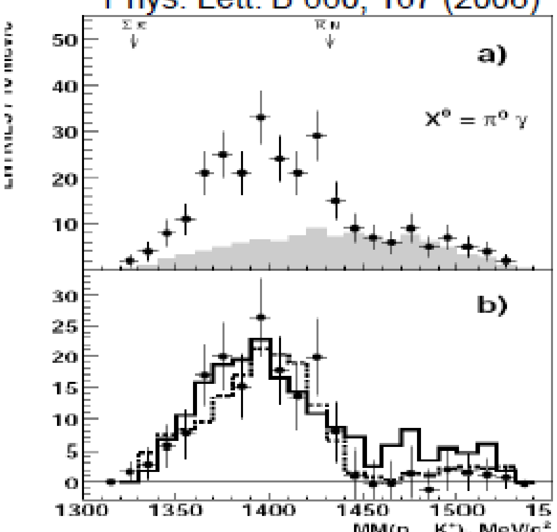
- $M_{\pi\Sigma}$ spectra always cut at the atrest limit
- $\Sigma^{\pm}\pi^{\mp}$ spectra suffer Σ(1385)contamination



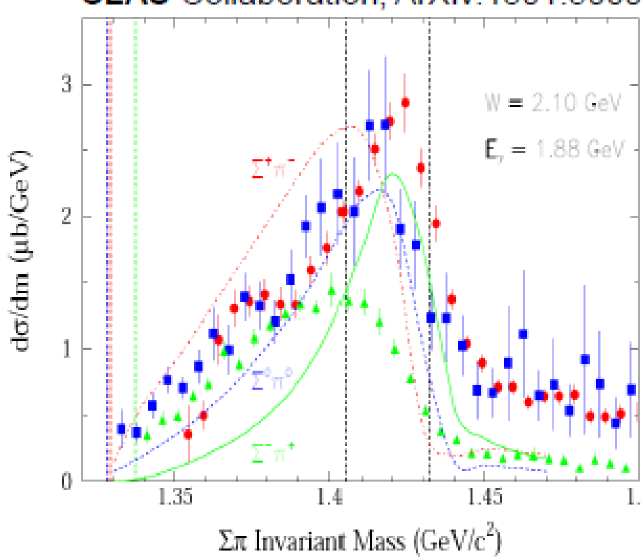


Other (**non-absorption**) experiments present spectra in the $\Sigma^0\pi^0$ channel (only three experiments…with different lineshapes!):

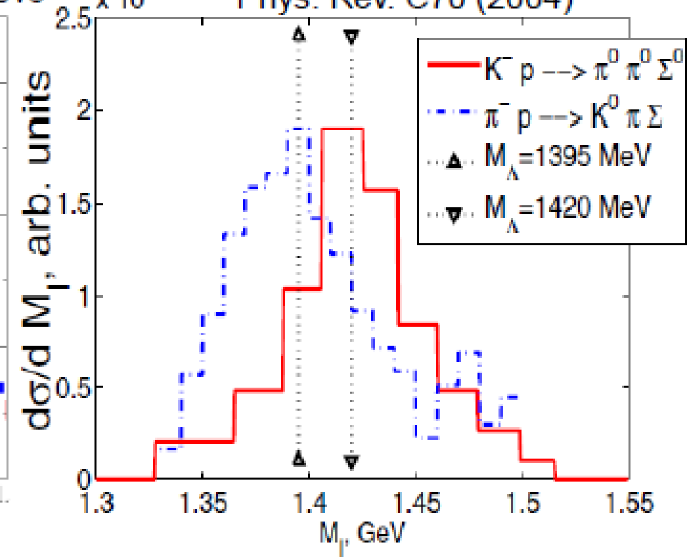
Phys. Lett. B 660, 167 (2008)



CLAS Collaboration, ArXiv:1301.5000v3



Phys. Rev. C70 (2004)

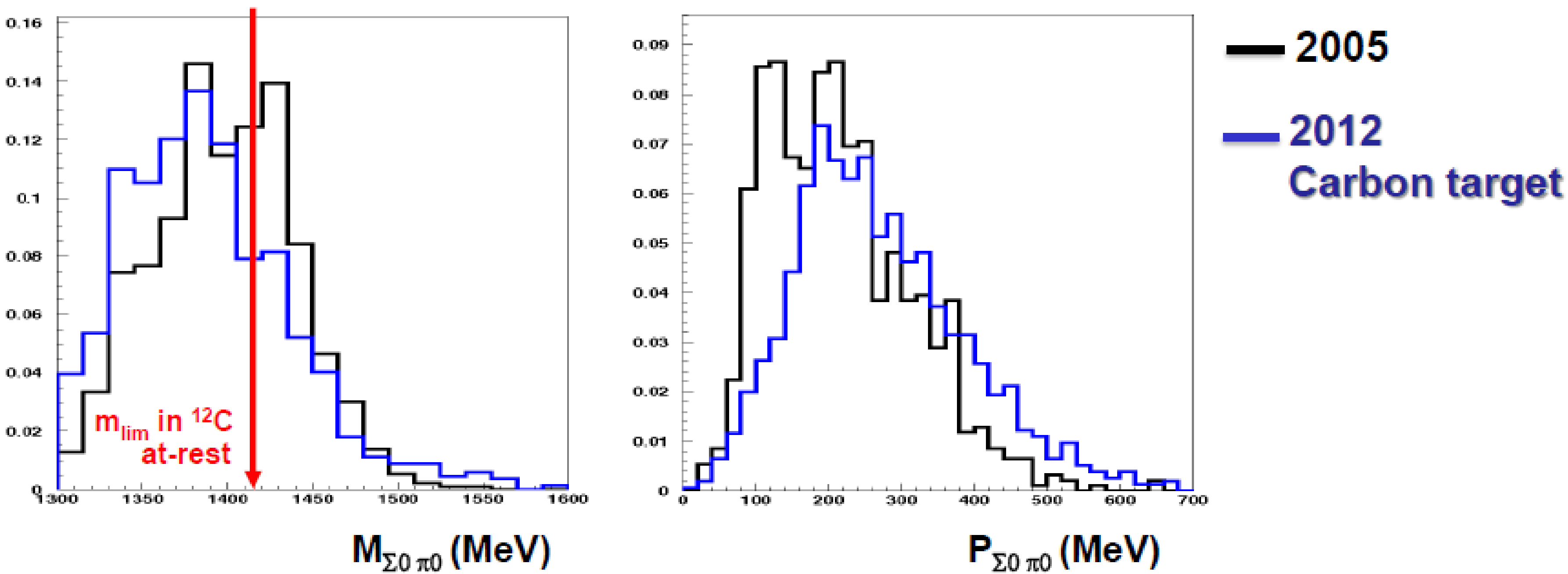


Analysis of $\Sigma^0\pi^0$ channel

$\Lambda(1405)$ signal searched by K^- interaction with a **bound proton** in Carbon

$K^- p \rightarrow \Sigma^0\pi^0$ detected via: $(\Lambda\gamma)(\gamma\gamma)$

K^- absorption in the DC wall (mainly ^{12}**C** with H contamination –epoxy-)

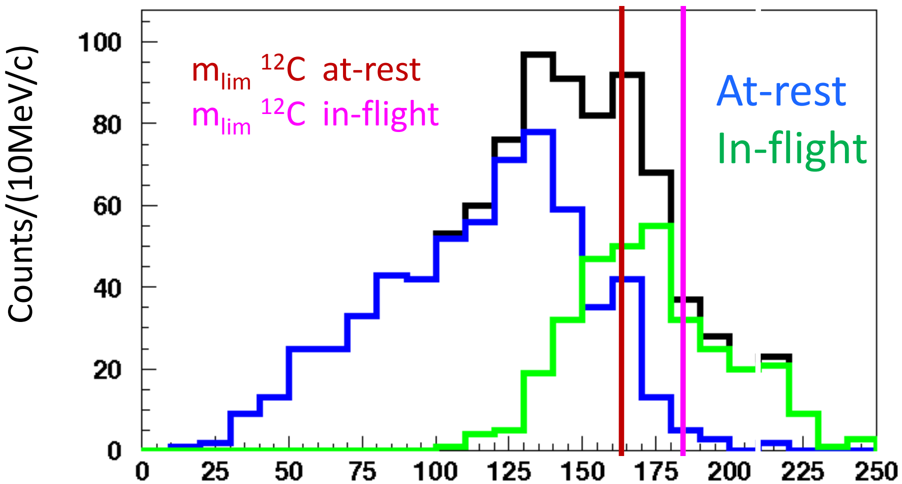


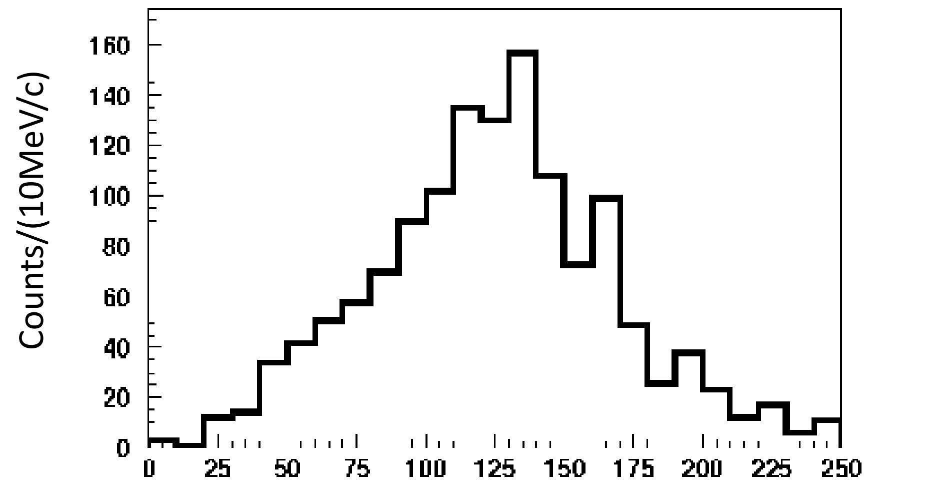
$m_{\pi0\Sigma0}$ resolution $\sigma_m \approx 32$ MeV/c^2 ; **$p_{\pi0\Sigma0}$ resolution:** $\sigma_p \approx 20$ MeV/c.

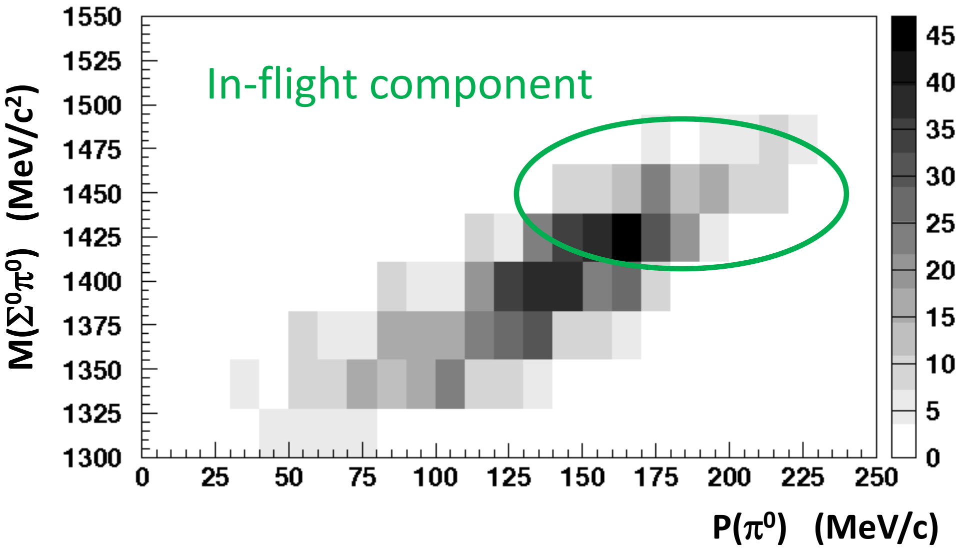
Negligible ($\Lambda\pi^0$ + internal conversion) background =(3±1)%, no I=1 contamination

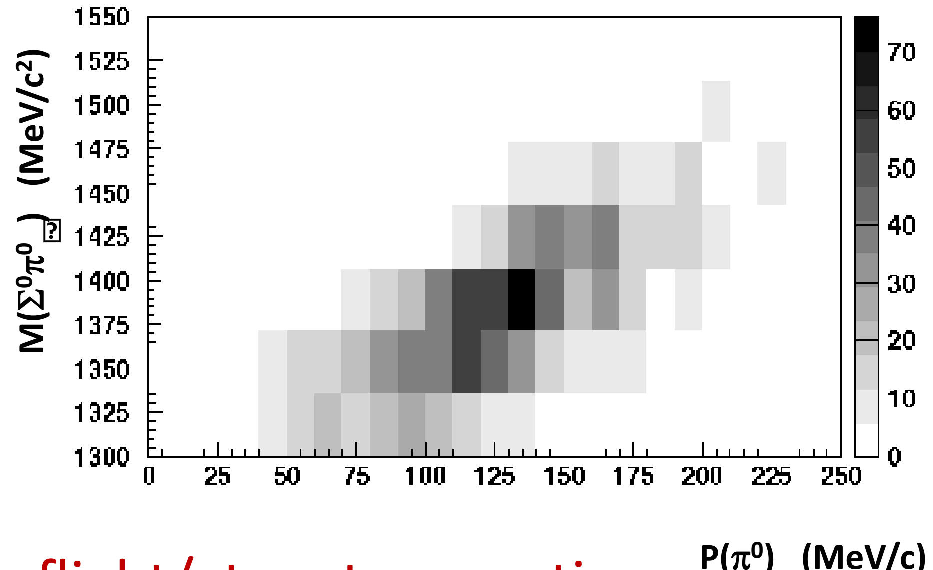
$\Sigma^0 \pi^0$ channel : the π^0 momentum

$P(\pi^0)$ resolution: $\sigma_p \approx 12$ MeV/c







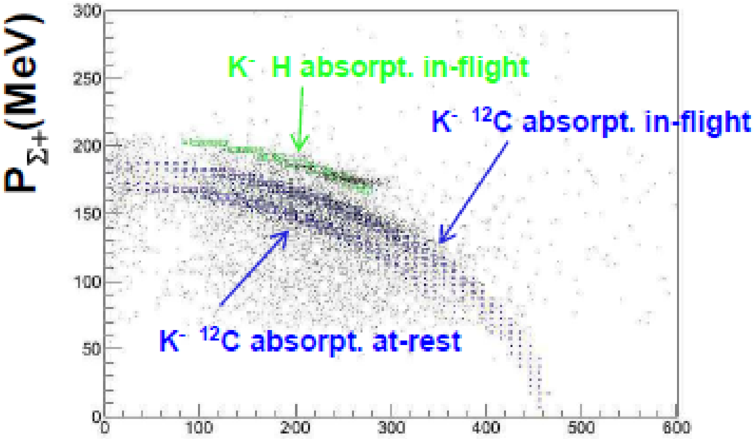


$P(\pi^0)$ could be used for in-flight/at-rest separation

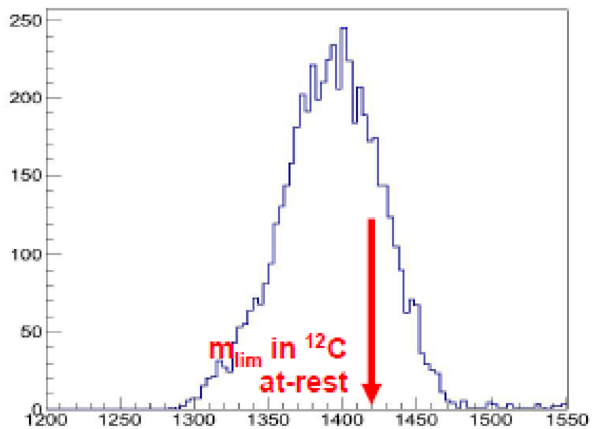
Λ(1405) charged channel: $\Sigma^+\pi^-$

Λ(1405) signal searched in $K^- p \rightarrow \Sigma^+ \pi^-$ detected via: $(p\pi^0)\pi^-$

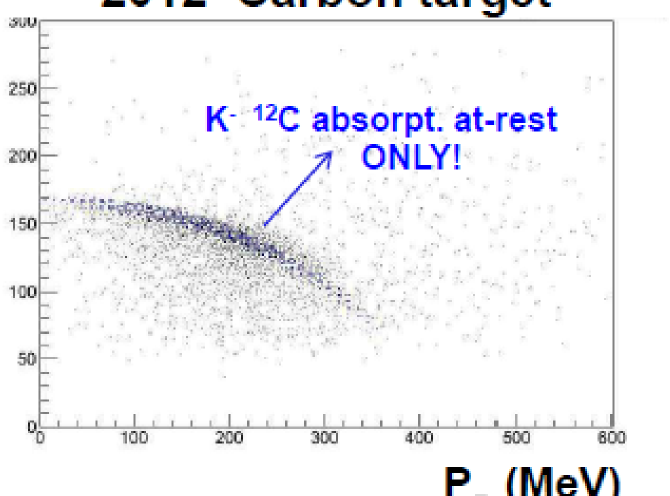
2005 data



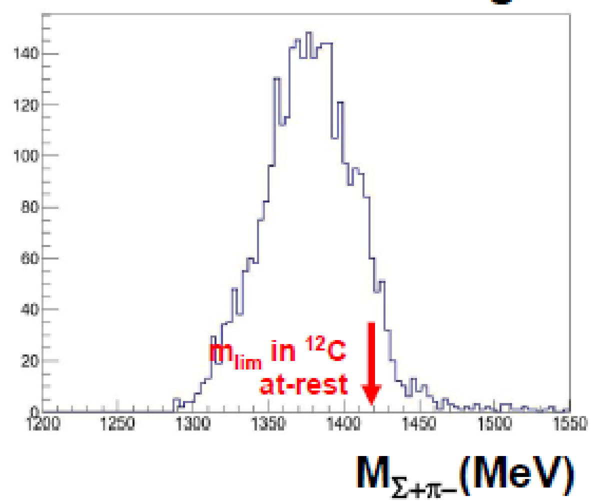
2005 data



2012 Carbon target



2012 Carbon target

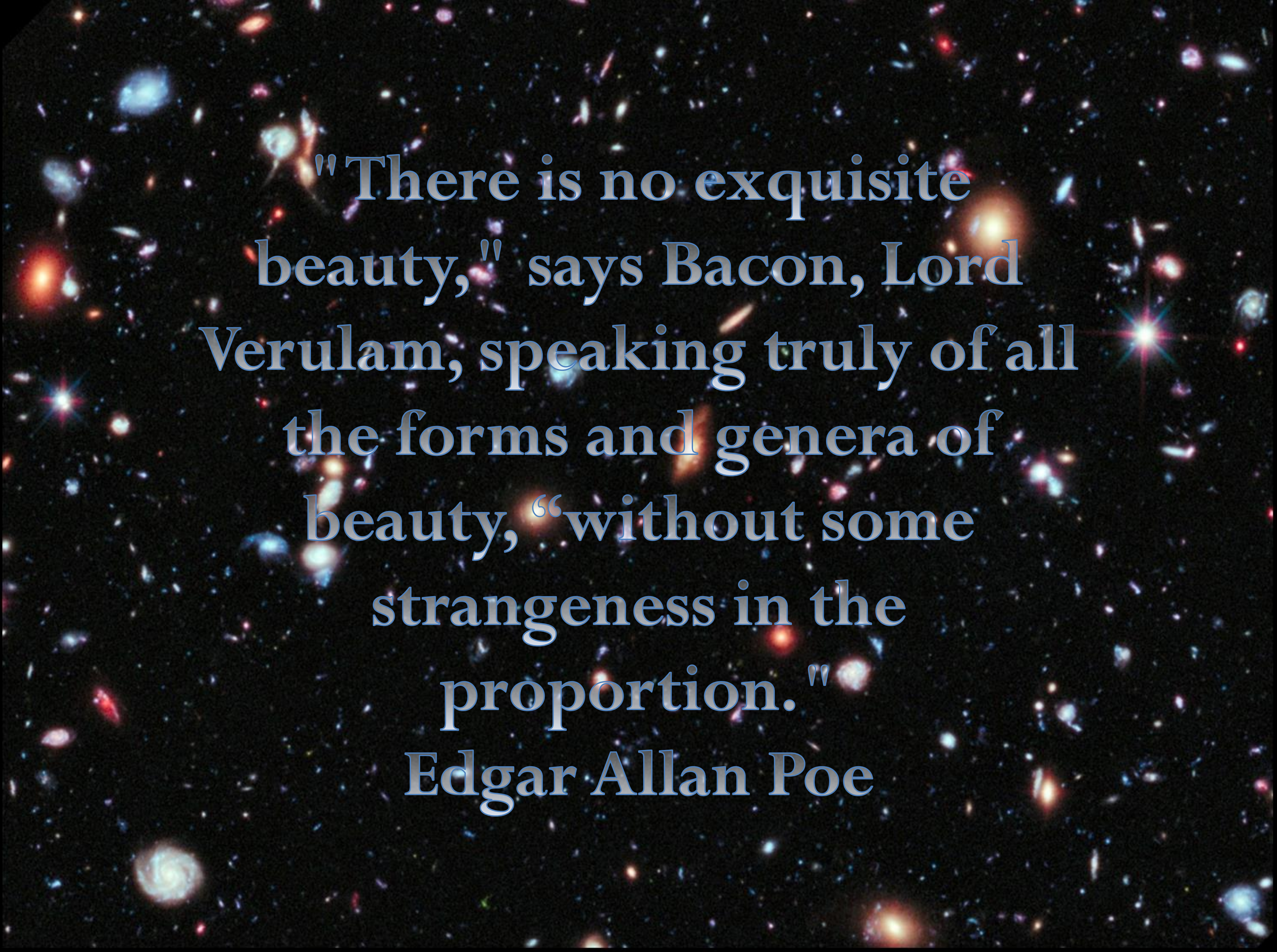


Conclusions for AMADEUS

- **AMADEUS has a strong potential to perform complete measurements of low-energy kaon-nuclei interactions in various targets**

- **Data analyses ongoing**

- **For future: use of other dedicated targets (gas and solid)**


"There is no exquisite beauty," says Bacon, Lord Verulam, speaking truly of all the forms and genera of beauty, “without some strangeness in the proportion."
Edgar Allan Poe