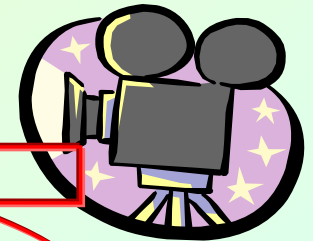


Atomi esotici: DEAR/SIDDHARTA



Catalina Curceanu (Petrascu)

LNF - Giugno 2005

Contenuto:

- 1. Il Modello Standard*
- 2. Com'è composto l'Universo?*
- 3. Il problema della massa*
- 4. Atomi kaonici: cosa impariamo?*
- 5. Dove: acceleratore DAFNE*
- 6. La situazione ad oggi: esperimento DEAR*
- 7. Da DEAR a SIDDHARTA*
- 8. Conclusioni*

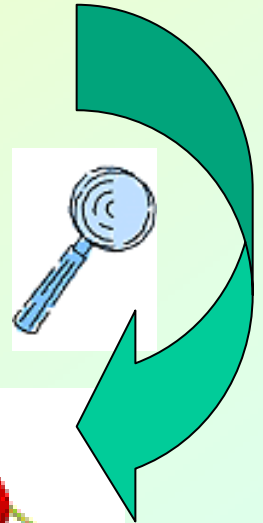
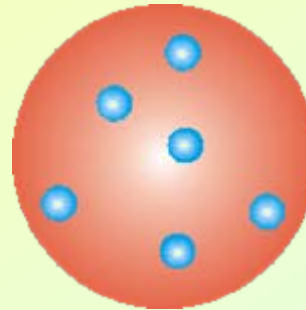


1. Il modello Standard

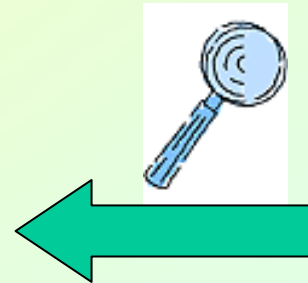
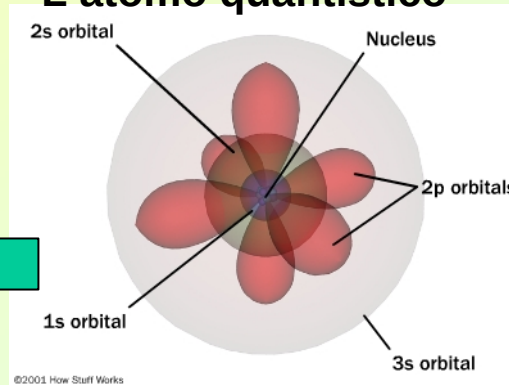
L'atomo all'inizio del '900



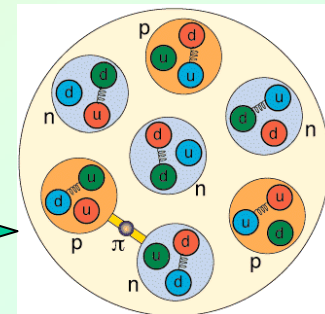
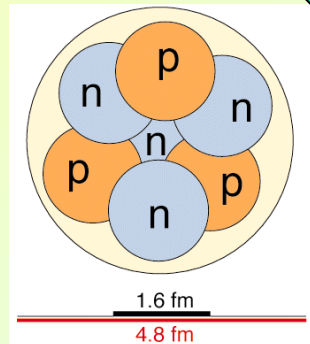
L'atomo di Thompson



L'atomo quantistico



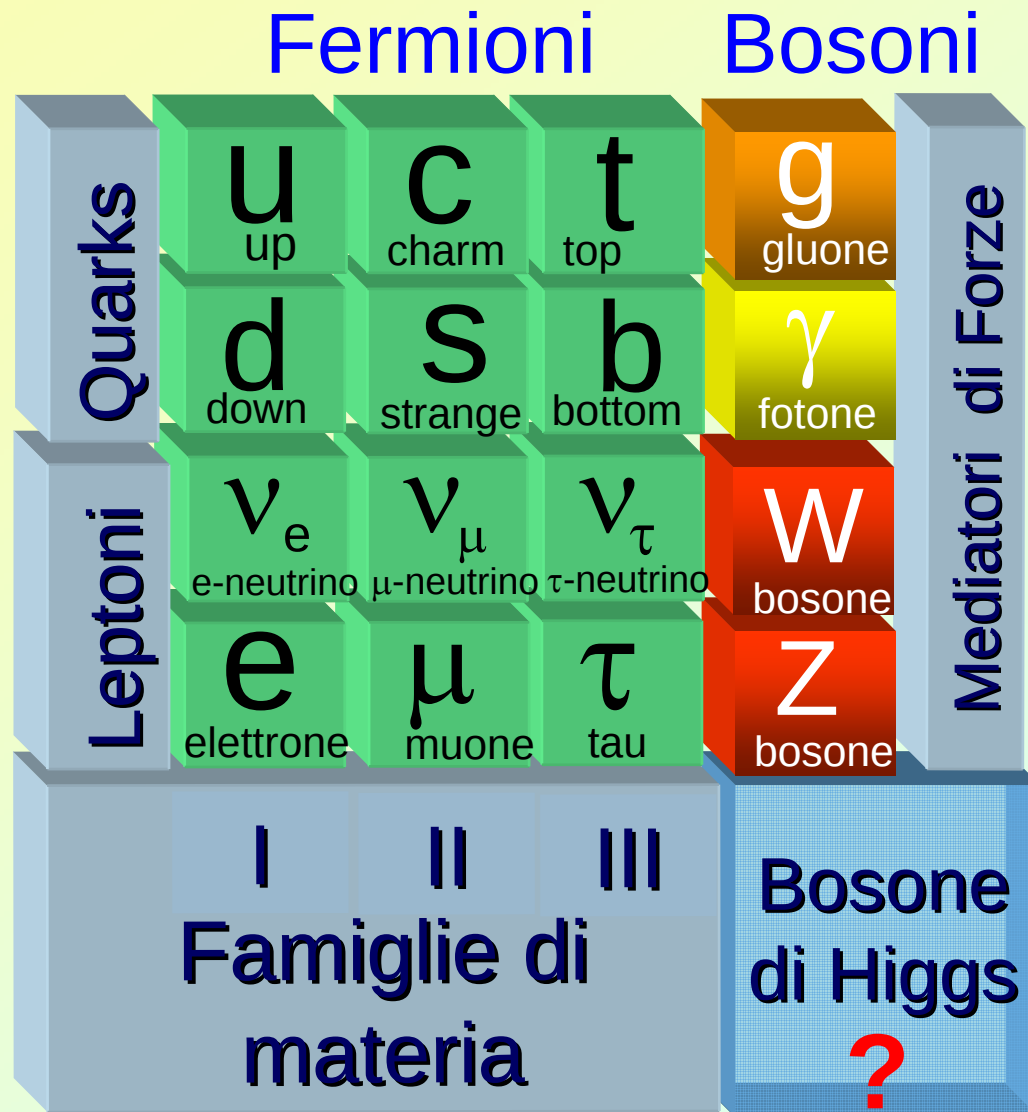
L'atomo di Rutherford e Bohr



Il nucleo oggi

La struttura del nucleo

Il Modello Standard



Standard Model of FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (quantum chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactions even though not part of the "Standard Model."

FERMIONS

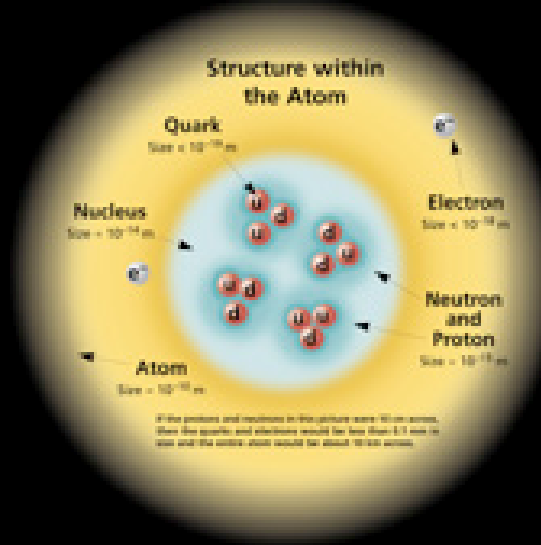
matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2			Quarks spin = 1/2		
Flavor	Mass GeV/c ²	Electric charge	Flavor	Approx. Mass GeV/c ²	Electric charge
ν_e electron neutrino	$<1 \times 10^{-9}$	0	u up	0.003	2/3
e^- electron	0.000511	-1	d down	0.006	-1/3
ν_μ muon neutrino	<0.0002	0	c charm	1.3	2/3
μ^- muon	0.106	-1	s strange	0.1	-1/3
ν_τ tau neutrino	<0.02	0	t top	175	2/3
τ^- tau	1.7771	-1	b bottom	4.3	-1/3

Spin is the intrinsic angular momentum of particles. Spin is given in units of $\hbar$, which is the quantum unit of angular momentum, where $\hbar = 6.58 \times 10^{-25}$ GeV s = 1.05×10^{-34} J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The energy unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. Masses are given in GeV/c² (remember $E = mc^2$), where $1 \text{ GeV} = 10^9 \text{ eV} = 1.60 \times 10^{-10}$ joule. The mass of the proton is 0.938 GeV/c² = 1.67×10^{-27} kg.



BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1			Strong (color) spin = 1		
Name	Mass GeV/c ²	Electric charge	Name	Mass GeV/c ²	Electric charge
γ photon	0	0	g gluon	0	0
W^-	80.4	-1			
W^+	80.4	+1			
Z^0	91.187	0			

Color Charge

Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons, just as electrons interact by exchanging photons, in strong interactions color-charged particles interact by exchanging gluons. Leptons, photons, and W and Z bosons have no strong interactions and hence no color charge.

Quarks Confined in Mesons and Baryons

One cannot isolate quarks and gluons; they are confined in color-neutral particles called hadrons. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color force field between them increases. This energy eventually is converted into additional quark antiquark pairs (see figure below). The quarks and antiquarks then combine into hadrons; these are the particles with which we interact. Two types of hadrons have been observed in nature: mesons ($q\bar{q}$) and baryons (qqq).

Residual Strong Interaction

The strong binding of color-neutral protons and neutrons to form nuclei is due to residual strong interactions between their color-charged constituents. It is similar to the residual electrical interaction that binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.

PROPERTIES OF THE INTERACTIONS

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$					
Baryons are fermionic hadrons. There are about 120 types of baryons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c ²	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	-1	0.938	1/2
n	neutron	udd	0	0.940	1/2
$\bar{n}$	anti-neutron	$\bar{u}\bar{d}\bar{d}$	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
$\bar{\Lambda}$	anti-lambda	$\bar{u}\bar{s}\bar{s}$	-1	1.112	1/2

Matter and Antimatter

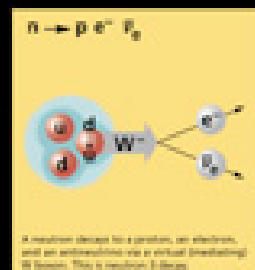
For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless a $+$ or $-$ charge is shown). Particle and antiparticles have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0 , γ , and g , and $g_s = g$), but not π^0 or K^0), are their own antiparticles.

Figures

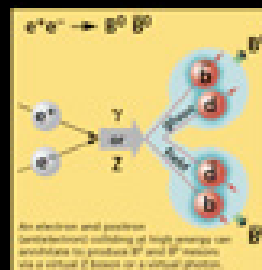
These diagrams are an artist's conception of physical processes. They are not meant to reflect any mathematical details. Green shaded areas represent the cloud of gluons in the gluon field, and red lines the quark paths.

Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic	Strong	
				Fundamental	Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength relative to electromagnetism for two u quarks at:	10^{-42}	0.8	1	25	Not applicable to quarks
	10^{-41}	10^{-4}	1	60	
for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

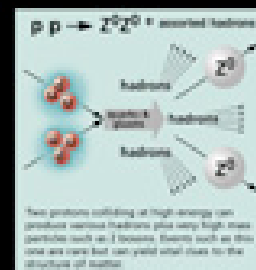
Mesons $q\bar{q}$					
Mesons are bosonic hadrons. There are about 140 types of mesons.					
Symbol	Name	Quark content	Electric charge	Mass GeV/c ²	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^+	kaon	$u\bar{s}$	+1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.775	1
B^0	B meson	$d\bar{b}$	0	5.279	0
B_c^+	B meson	$c\bar{b}$	0	2.860	0



A neutron decays to a proton, an electron, and an antineutrino via a virtual (mediating) W^- boson. This is neutron β decay.



An electron and positron (antiparticle) colliding at high energy can produce the photon γ and Z^0 bosons via a virtual Z^0 boson or a virtual photon.



Two protons colliding at high energy can produce various hadrons plus very high mass particles such as Z^0 bosons. Events such as this one are rare but can yield vital clues to the structure of matter.

The Particle Adventure

Visit the award-winning web feature The Particle Adventure at <http://pdg.lbl.gov/pep/adventure.html>

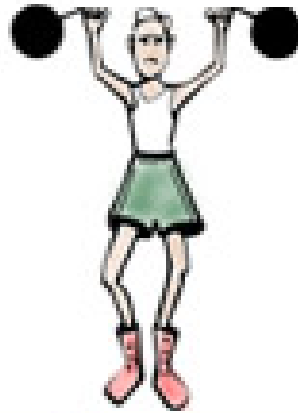
Sponsors

This chart has been made possible by the generous support of U.S. Department of Energy, Lawrence Berkeley National Laboratory, Stanford Linear Accelerator Center, American Physical Society, Division of Particle and Field Studies, and SLAC.

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<http://pdg.lbl.gov/pep.html>

Fundamental interactions



	Gravity	Weak (Electroweak)	Electromagnetic	Strong
Carried By	Graviton (not yet observed)	$W^+ W^- Z^0$	Photon	Gluon
Acts on	All	Quarks and Leptons	Quarks and Charged Leptons and $W^+ W^-$	Quarks and Gluons

1

10^{29}

10^{40}

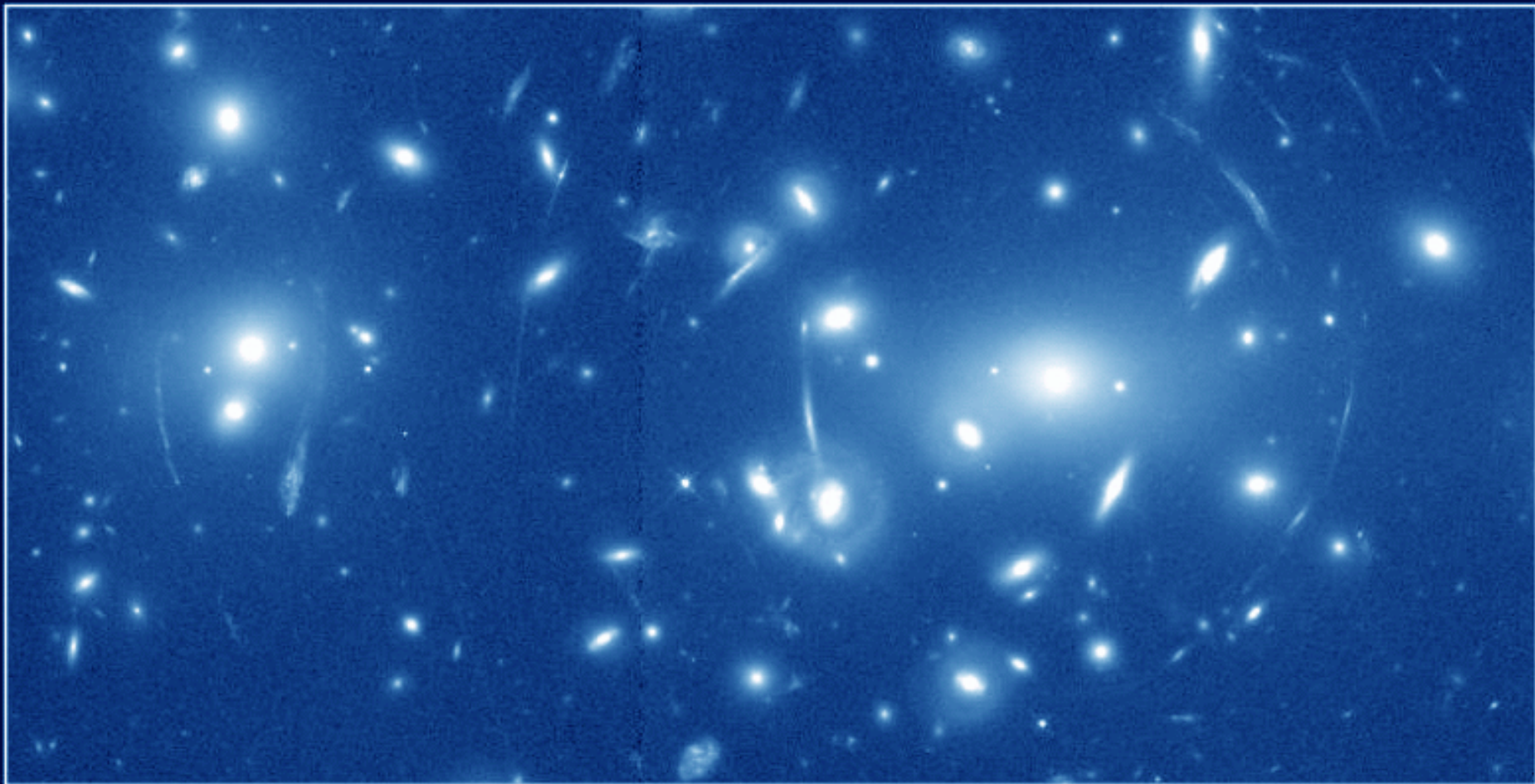
10^{43}

Tante domande:

1. Perché 3 famiglie?
 2. Da dove proviene la massa?
 3. Perché 4 interazioni? (anche se la gravita' non e' compresa nel MS....)
-

2 Com'e' composto l'Universo?



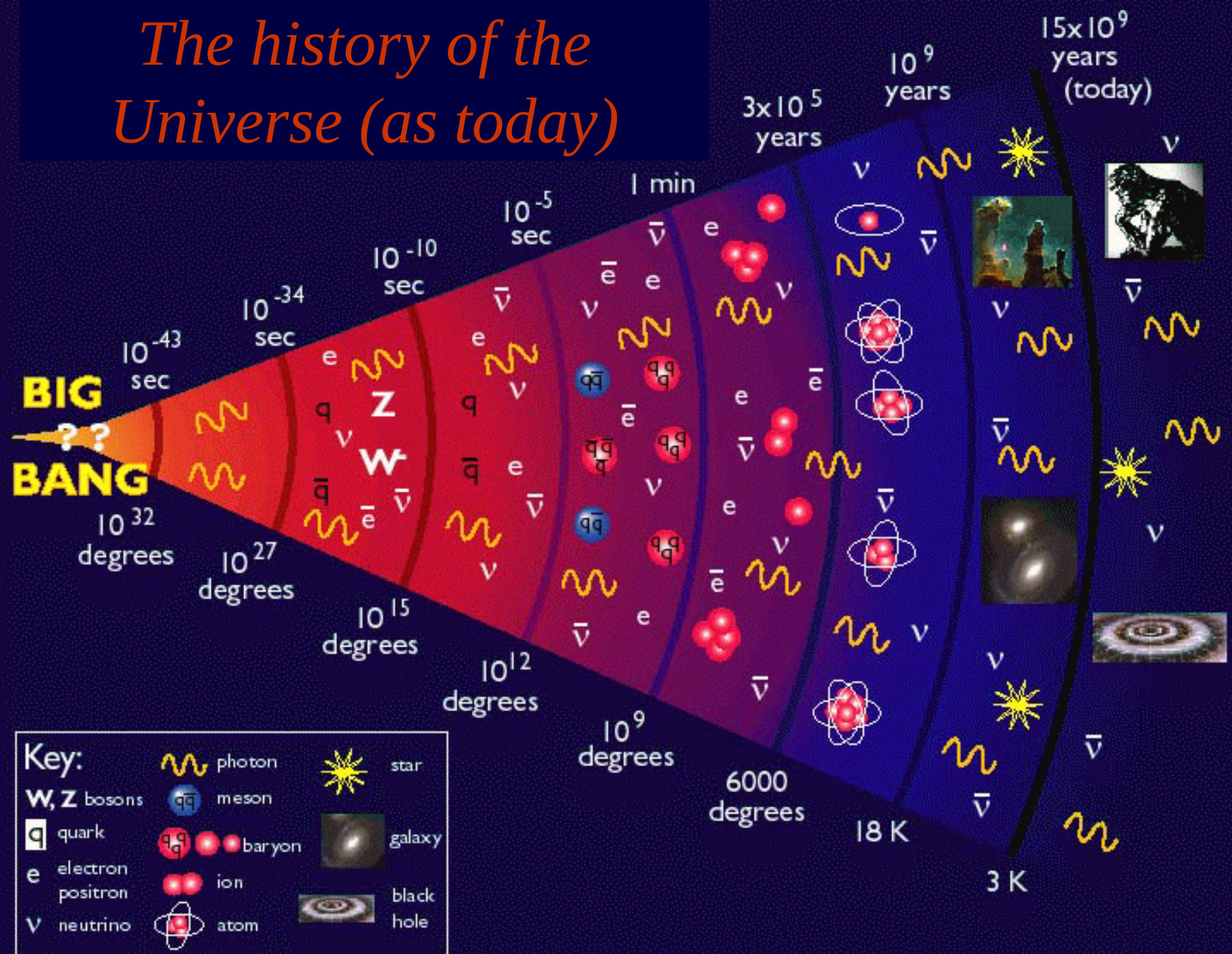


Gravitational Lens in Abell 2218

HST • WFPC2

PF95-14 • ST ScI OPO • April 5, 1995 • W. Couch (UNSW), NASA

The history of the Universe (as today)



Composition of the universe



**Non sappiamo di cos'e' fatto
95% dell'Universo**

Dobbiamo capire meglio il 5% che conosciamo ...

e così si può imparare qualcosa di più

anche sul restante 95%

3. Il problema della massa

Il problema della massa

Perche i quark hanno massa?

Higgs mechanism



U

5 MeV



d

10 MeV



S

100 MeV

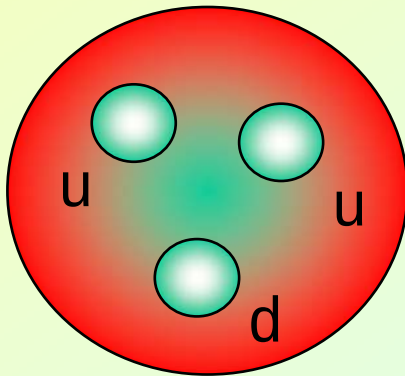
Si studia attraverso lo studio della rottura
della cosiddette simmetria chirale

Il problema della massa

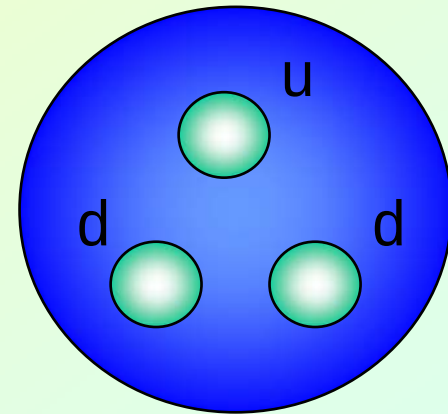
m_p non e' uguale a

$$m_u + m_u + m_d$$

(ci sono contributi dai "sea quarks" e dai gluoni)



protone



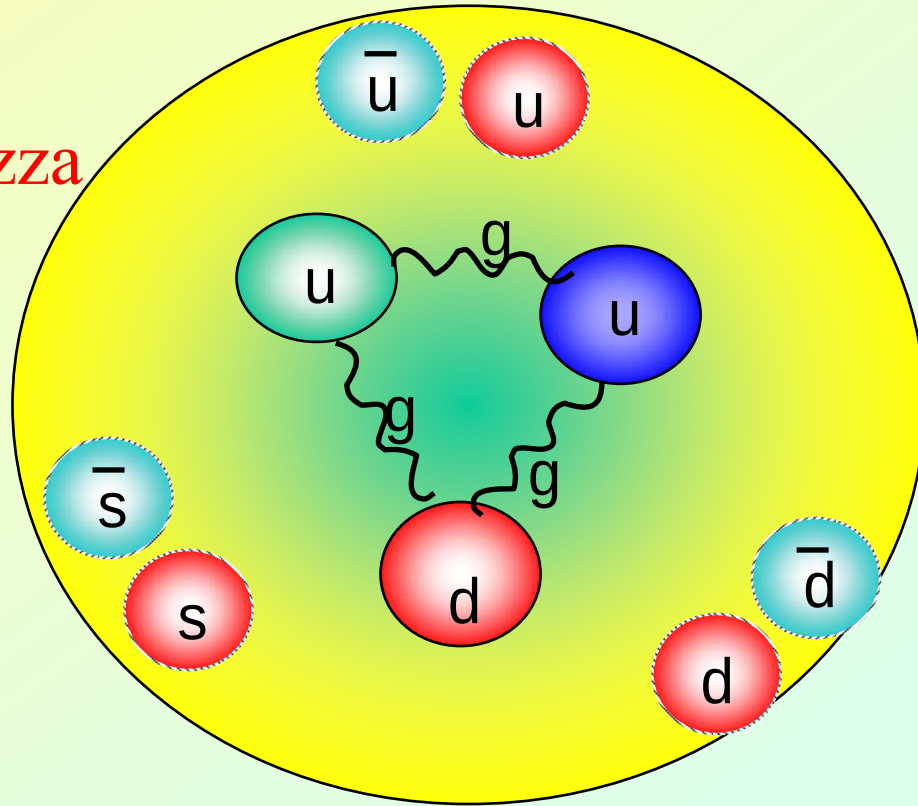
neutrone

m_n non ee uguale a

$$m_u + m_d + m_d$$

Il problema della massa

- Contenuto di stranezza del protone



protone

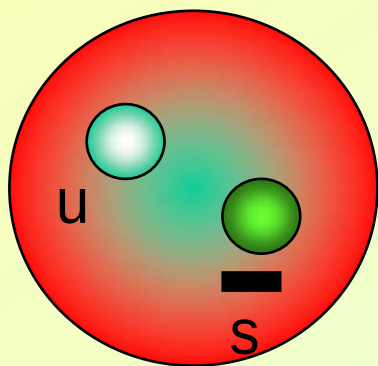
Con lo studio degli atomi kaonici

- La rottura della simmetria chirale
- Contenuto di stranezza del protone

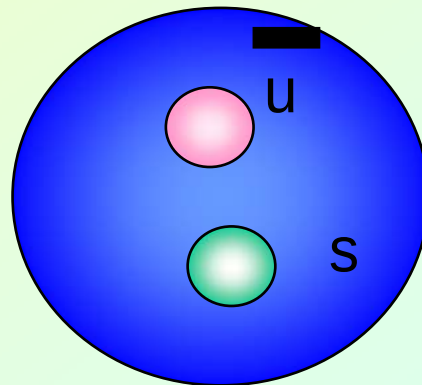
Attraverso lo studio degli atomi
kaonici si può imparare di più sul
meccanismo di generazione della
massa e anche sulla materia
nell'Universo

4. Atomi kaonici – cosa si impara

Il kaone carico



K +

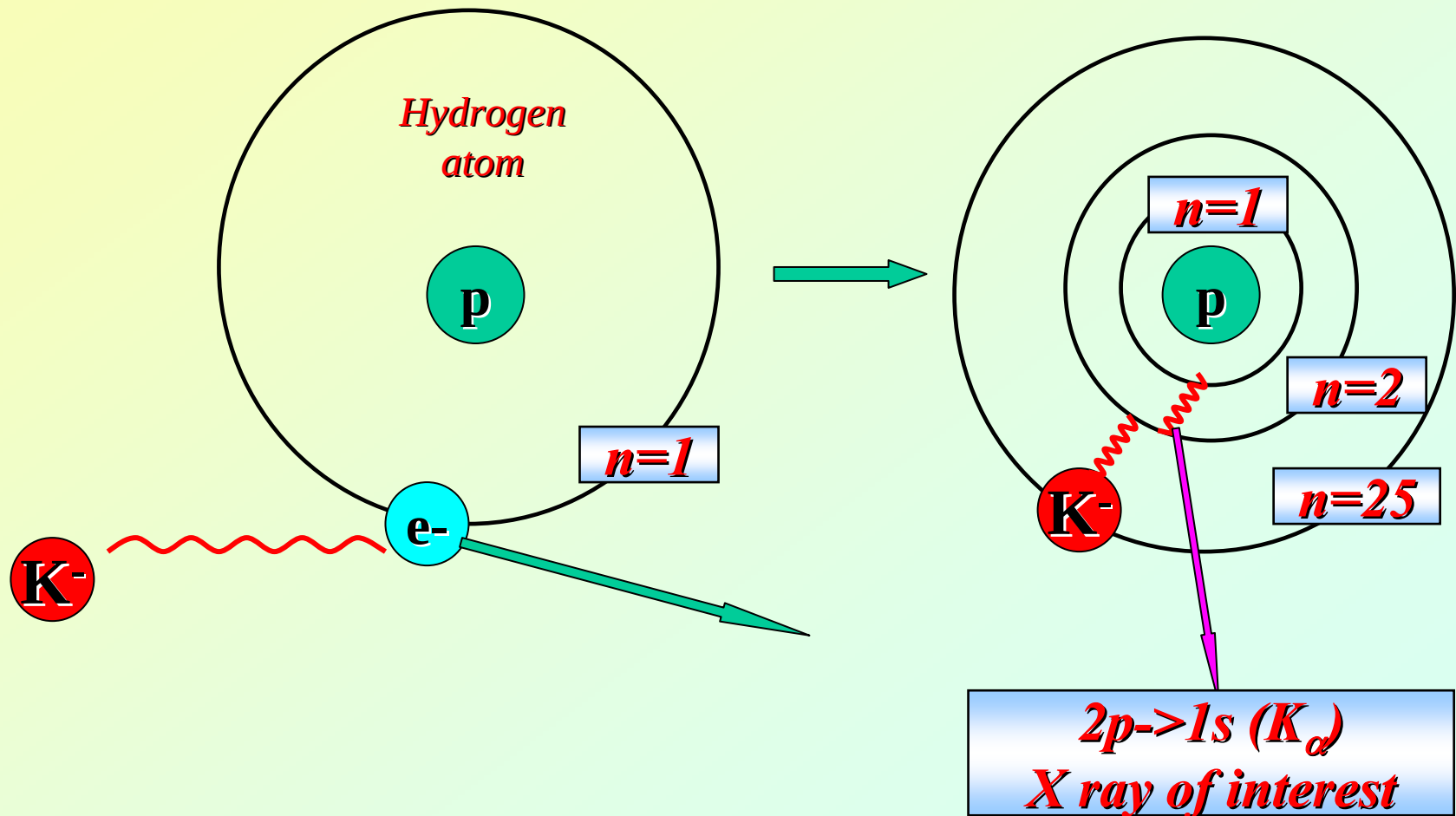


K -

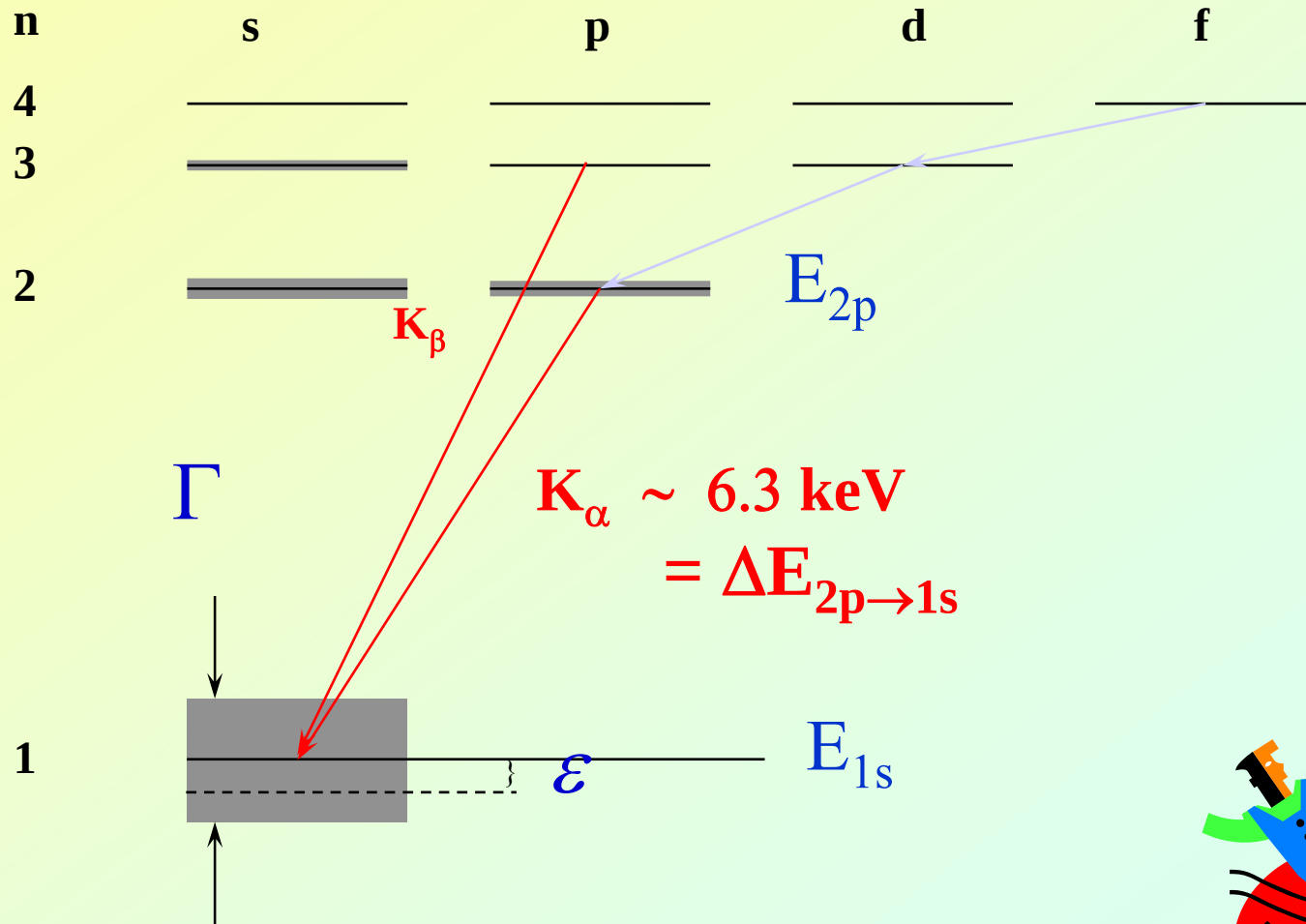
DEAR =
DAΦNE Exotic Atom Research

Electronic hydrogen

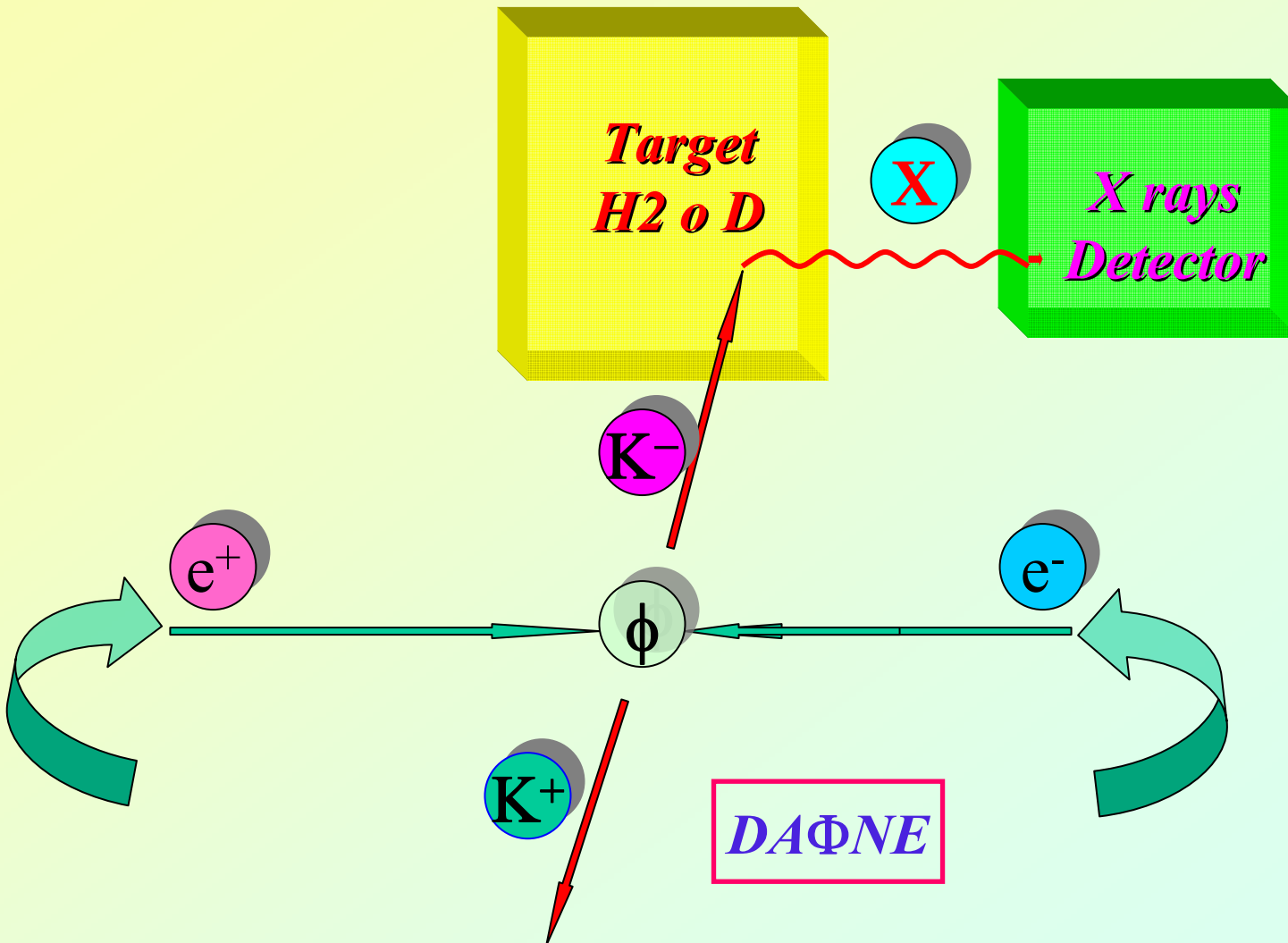
Kaonic hydrogen



Cascata atomica e l'interazione forte



Il principio del metodo sperimentale



Lo scopo dell'esperimento

*una misura di precisione (eV) dello spostamento e
dell'allargamento del livello $1s$ nell'idrogeno
e
nel deuterio kaonici*



DEAR/SIDSDHARTA Scientific program

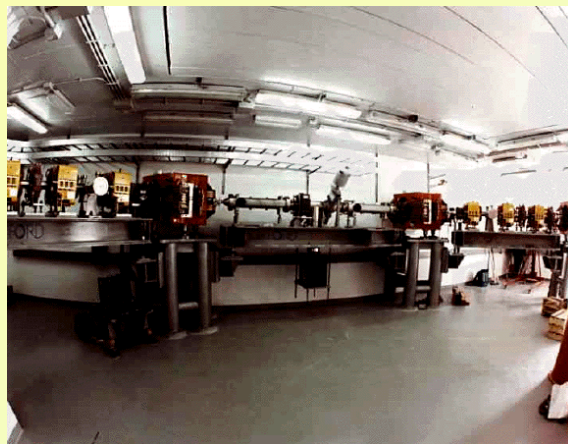
Measuring the KN scattering lengths with the precision of a few percent will drastically change the present status of low-energy $\bar{K}N$ phenomenology and also provide a clear assessment of the $SU(3)$ chiral effective Lagrangian approach to low energy hadron interactions.



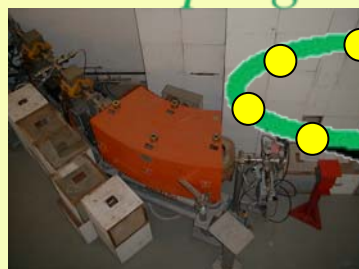
1. Breakthrough in the *low-energy KN phenomenology*;
2. Threshold amplitude in QCD: Chiral 2003 (Bonn); Hadat03 (Trento); Varenna2004...
3. Determination of the *KN sigma terms*, which give the degree of chiral symmetry breaking;
4. Determination of the *strangeness content of the nucleon* from the KN sigma terms.

5. Dove: a DAFNE

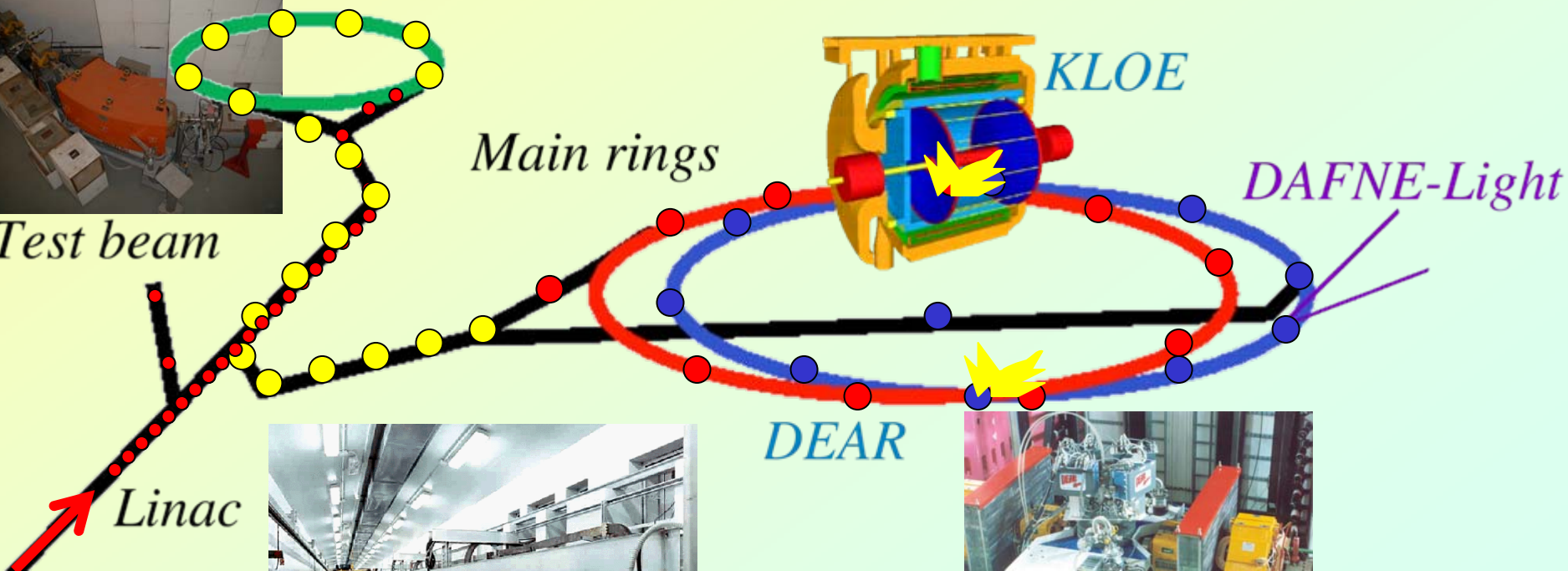
DAΦNE *@ 2002*



Damping ring



Test beam

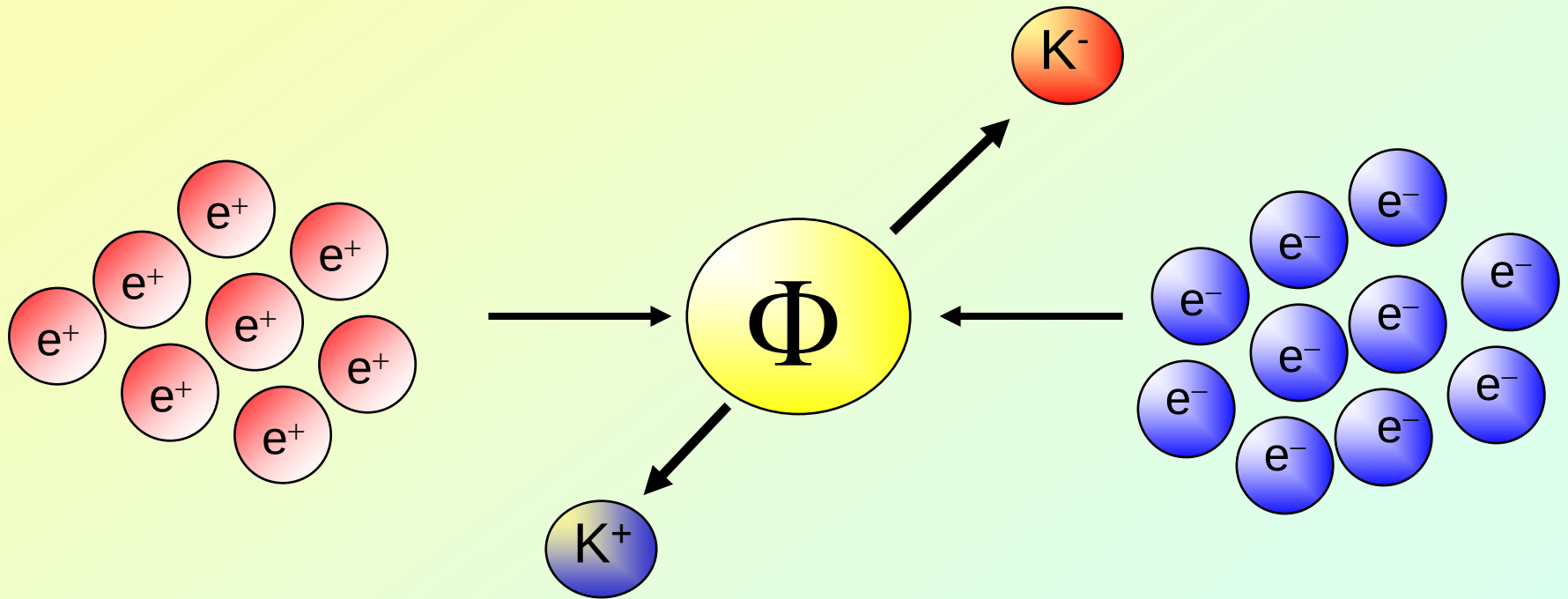


DAΦNE



Kaoni negativi a DAΦNE

Dalle collisioni tra elettroni e positroni puo' essere prodotto il mesone Φ , che decade immediatamente in altre due particelle, i Kaoni K . I due K possono essere entrambi carichi o neutri.



I K^- sono le particelle usate da DEAR



6. La situazione ad oggi

DEAR Collaboration:

LNF- INFN, Frascati, Italy



IMEP- ÖAW, Vienna, Austria



IFIN – HH, Bucharest, Romania



INFN, Trieste, Italy



RIKEN, Japan

Univ. Fribourg, Switzerland



Univ. Neuchâtel, Switzerland

Univ. Tokyo, Japan

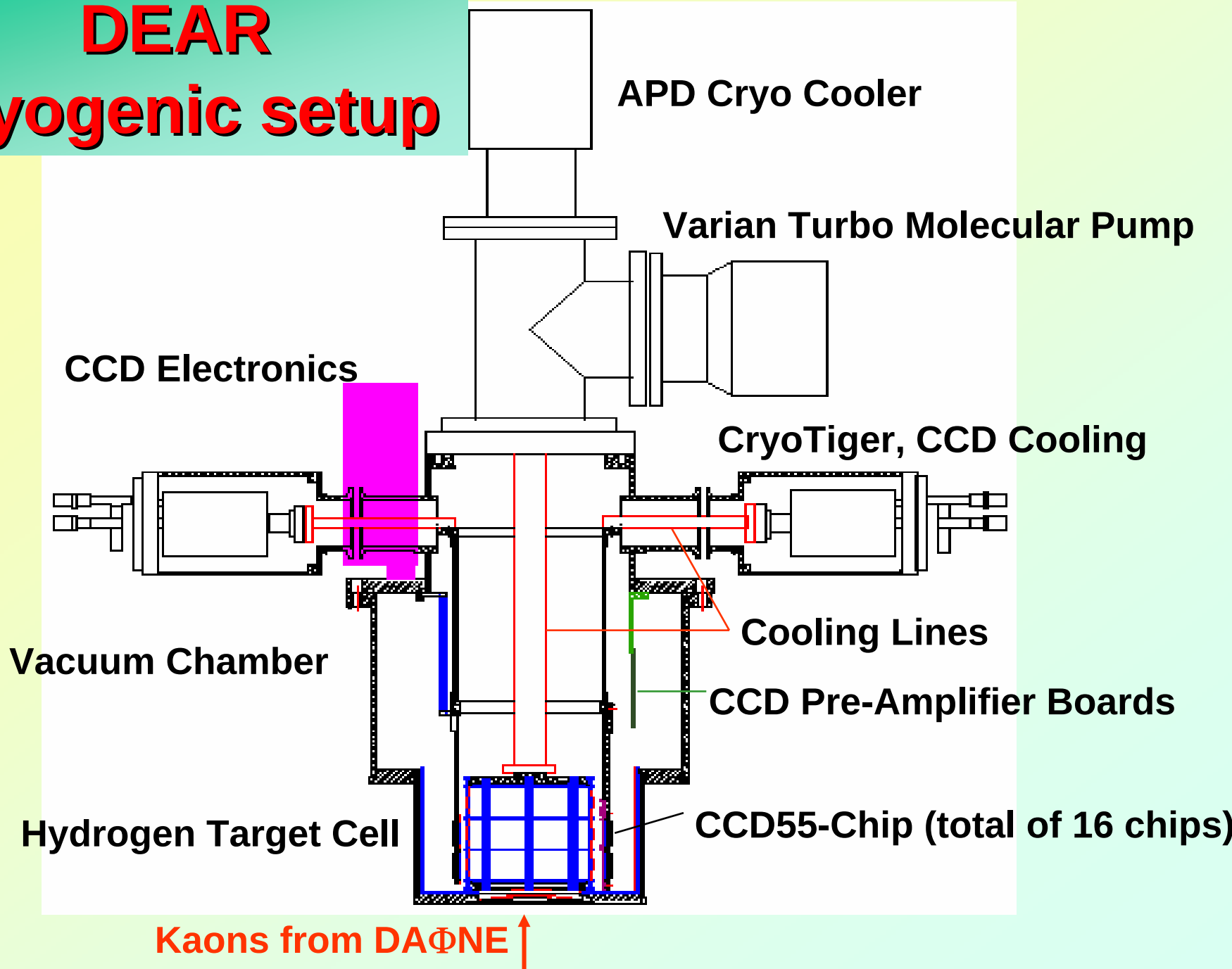
Univ. Victoria, Canada



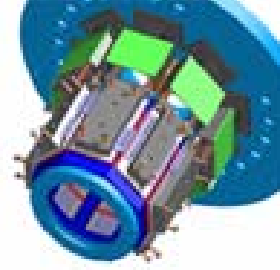
Caltech, USA



DEAR Cryogenic setup

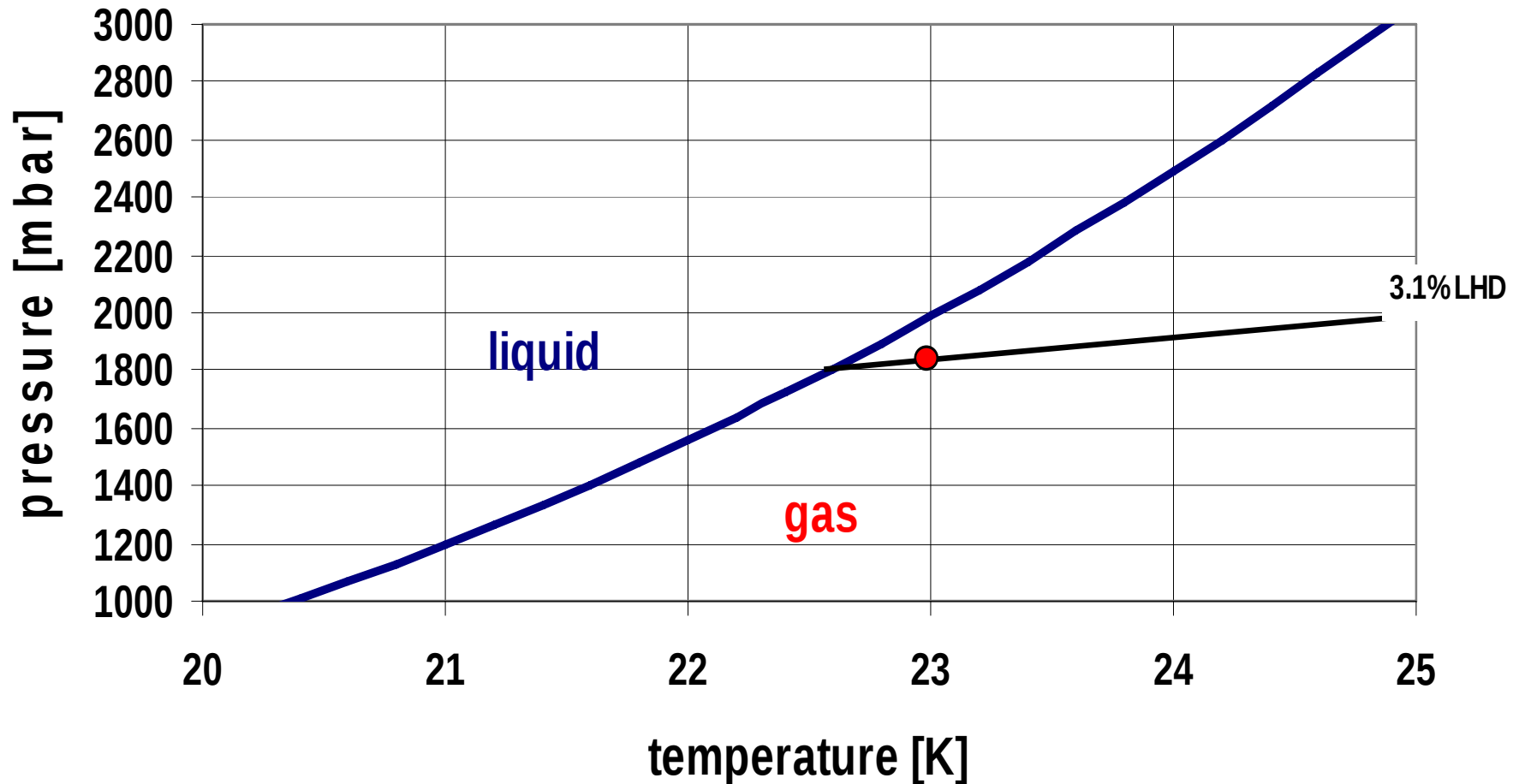


Cryogenic Hydrogen Target



working point: $T = 23 \text{ K}$, $P = 1.82 \text{ bar}$

hydrogen density: 3.1% of LHD, 2.2 g/l

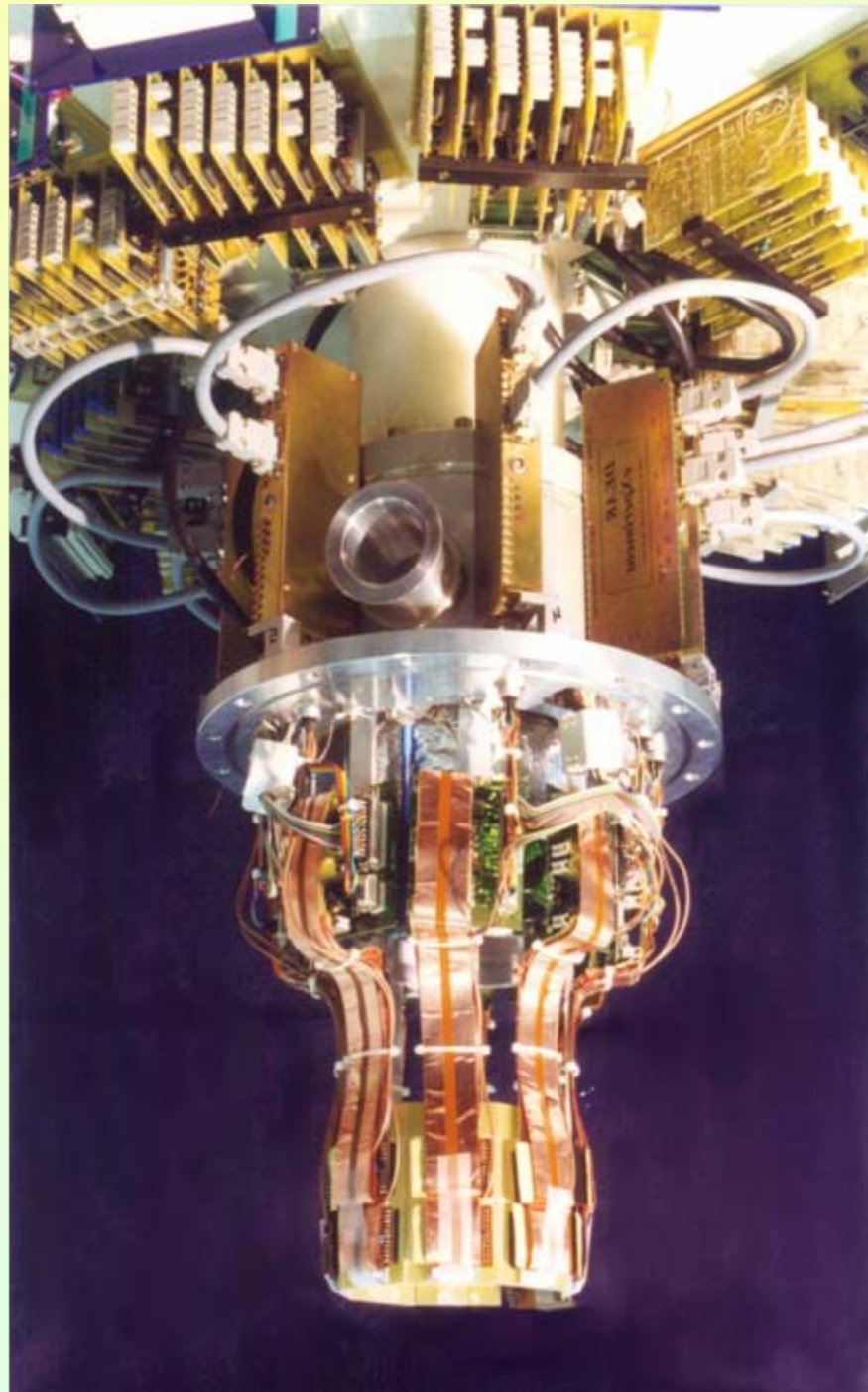


DEAR Cryogenic Target Cell



CCD mounting, cryogenics and on-cell electronics

- fiber-glass frames
- cooling system mounted on the top
- minimized Al cold finger (behind CCDs)
- reduced diameter of the socket group and, consequently, of the vacuum chamber



DEAR on DAΦNE



October – December 2002 DAQ set of “good quality” data

Collected data:

-Kaonic Nitrogen:

6 – 28 October (about 17 pb^{-1} – 10 pb^{-1} in stable conditions);

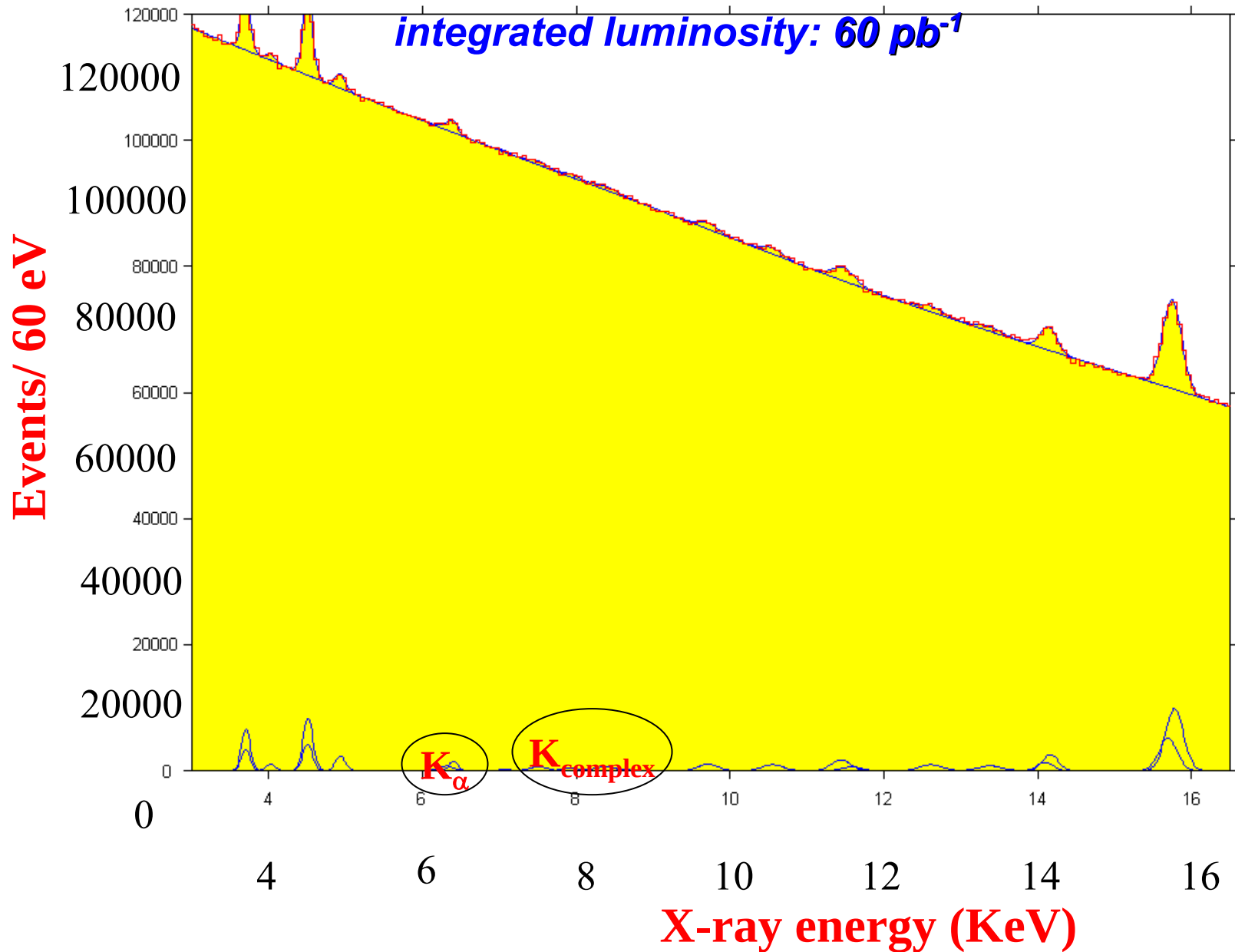
-Kaonic Hydrogen:

30 October – 16 December: about 60 pb^{-1}

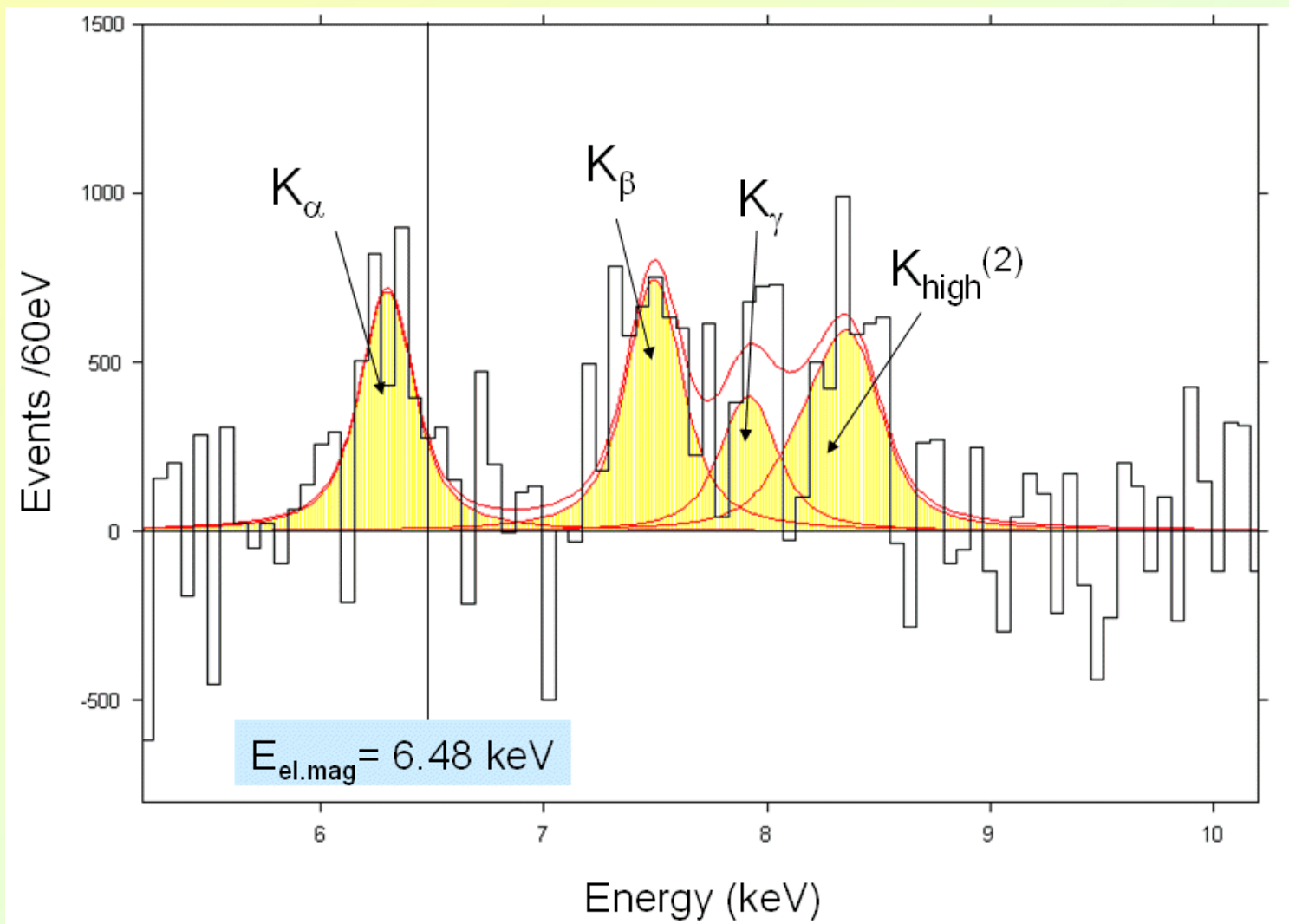
-Background data (no collisions) for KH:

16 – 23 December

Kaonic Hydrogen (2002 data)- global fit



Lo spettro di raggi X K α

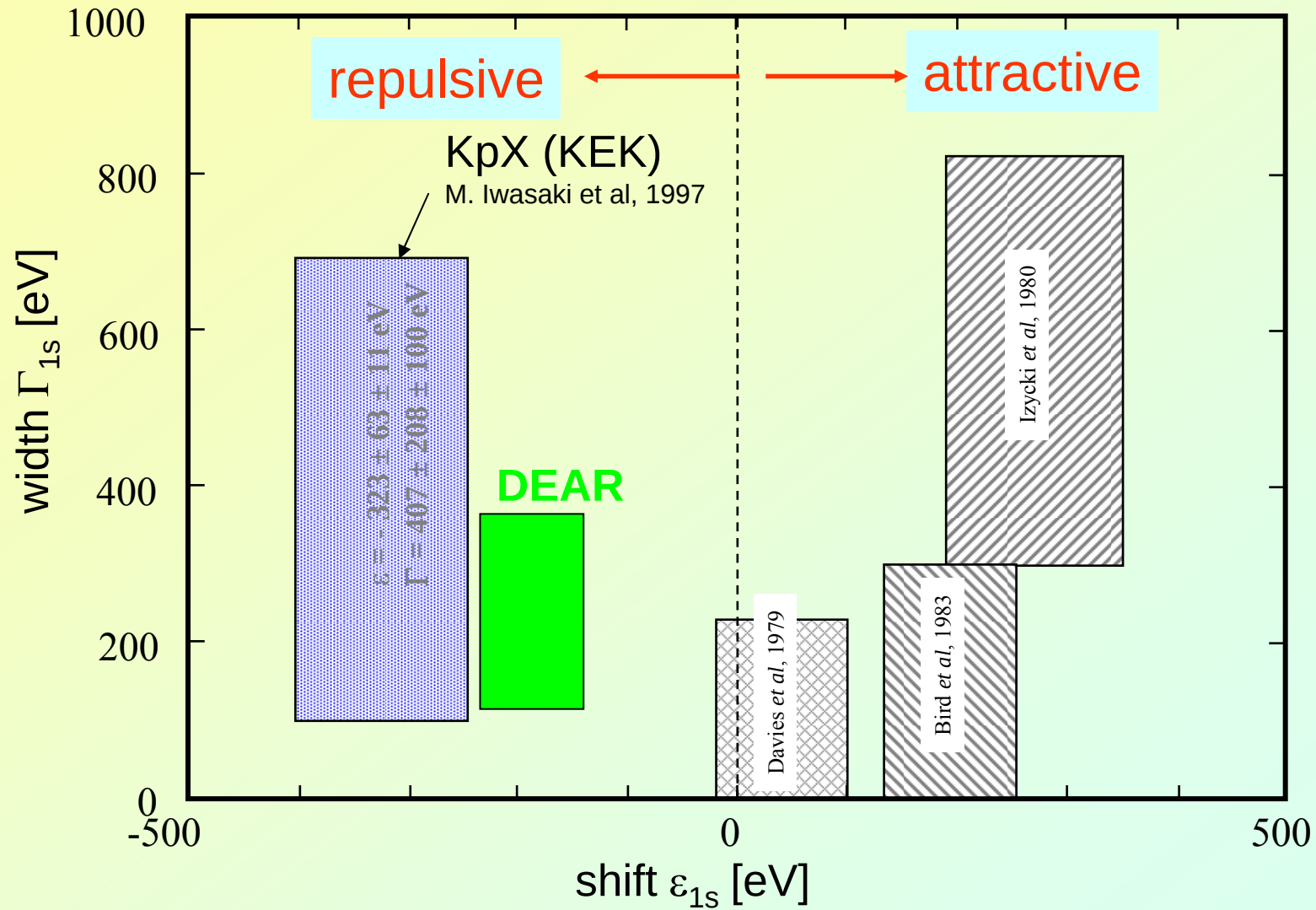


Risultati

Shift: $\varepsilon_{1s} = -194 \pm 37 \text{ (stat.)} \pm 6 \text{ (syst.) eV}$

Width: $\Gamma_{1s} = 249 \pm 111 \text{ (stat.)} \pm 30 \text{ (syst.) eV}$

DEAR Results



7. Da DEAR a SIDDHARTA

L'analisi KH in DEAR

**Il risultato di DEAR:
rappresenta la miglior misura al mondo
MA**

Cosa si vuol fare =>

Programma scientifico

**# una misura con precisione $\sim$ eV per l'idrogeno
kaonico;**

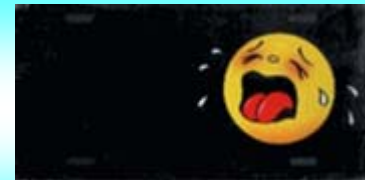
**# la prima misura in assoluto del deuterio
kaonico**

Nell'ambito di DEAR ?

S/B ~ 1/80

Non si puo andare oltre di molto;

La risposta e NO



Si deve cercare un'altra strada

Utilizzo di nuovi rivelatori (triggerabili)

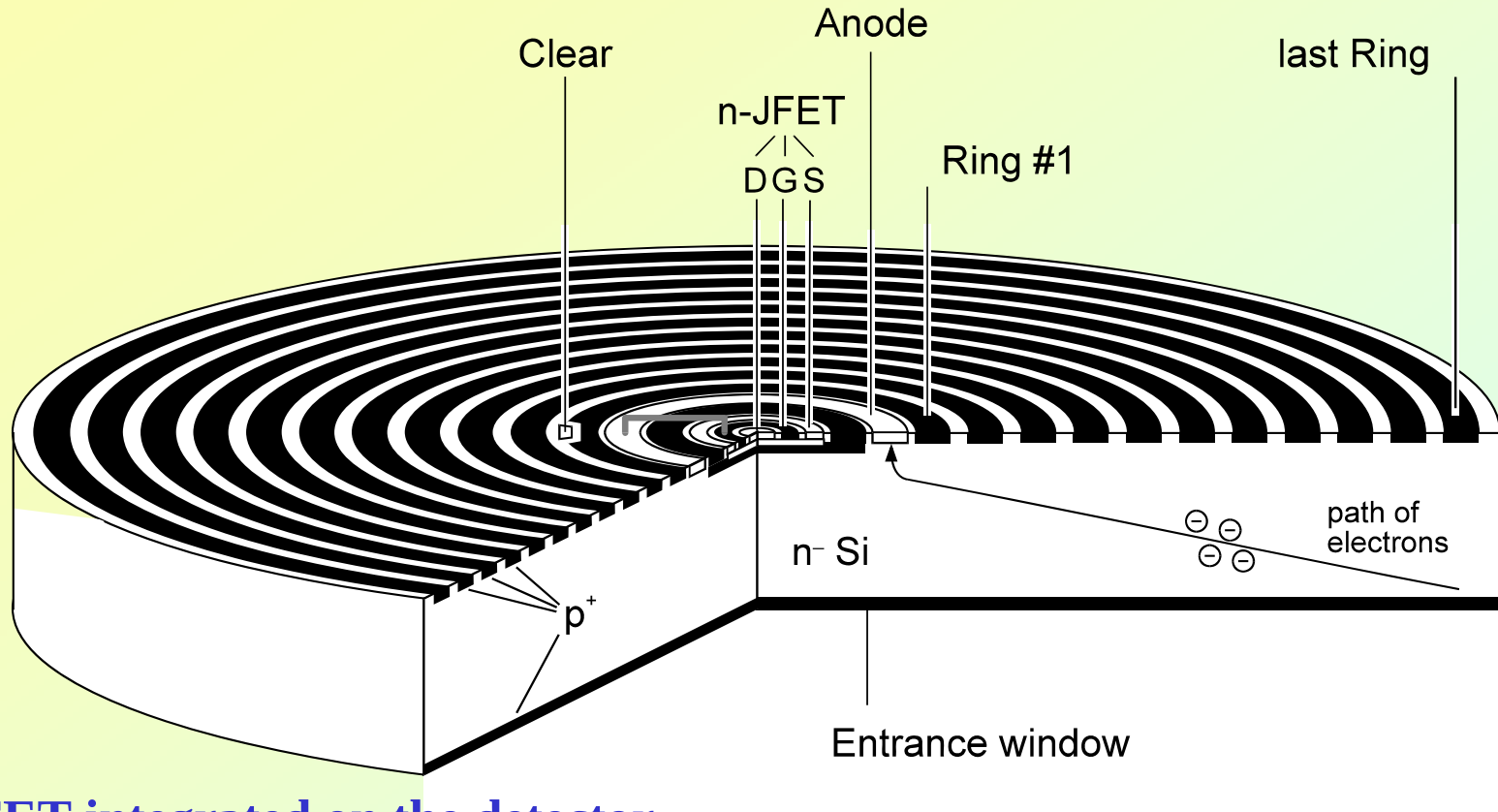
Scelta del nuovo rivelatore:

- Riproduca tutti i vantaggi delle CCD (efficienza e risoluzione in energia);
- Siano VELOCI $\sim 1 \mu\text{s}$ – trigger

=> Silicon Drift Detector



The Silicon Drift Detector with on-chip JFET

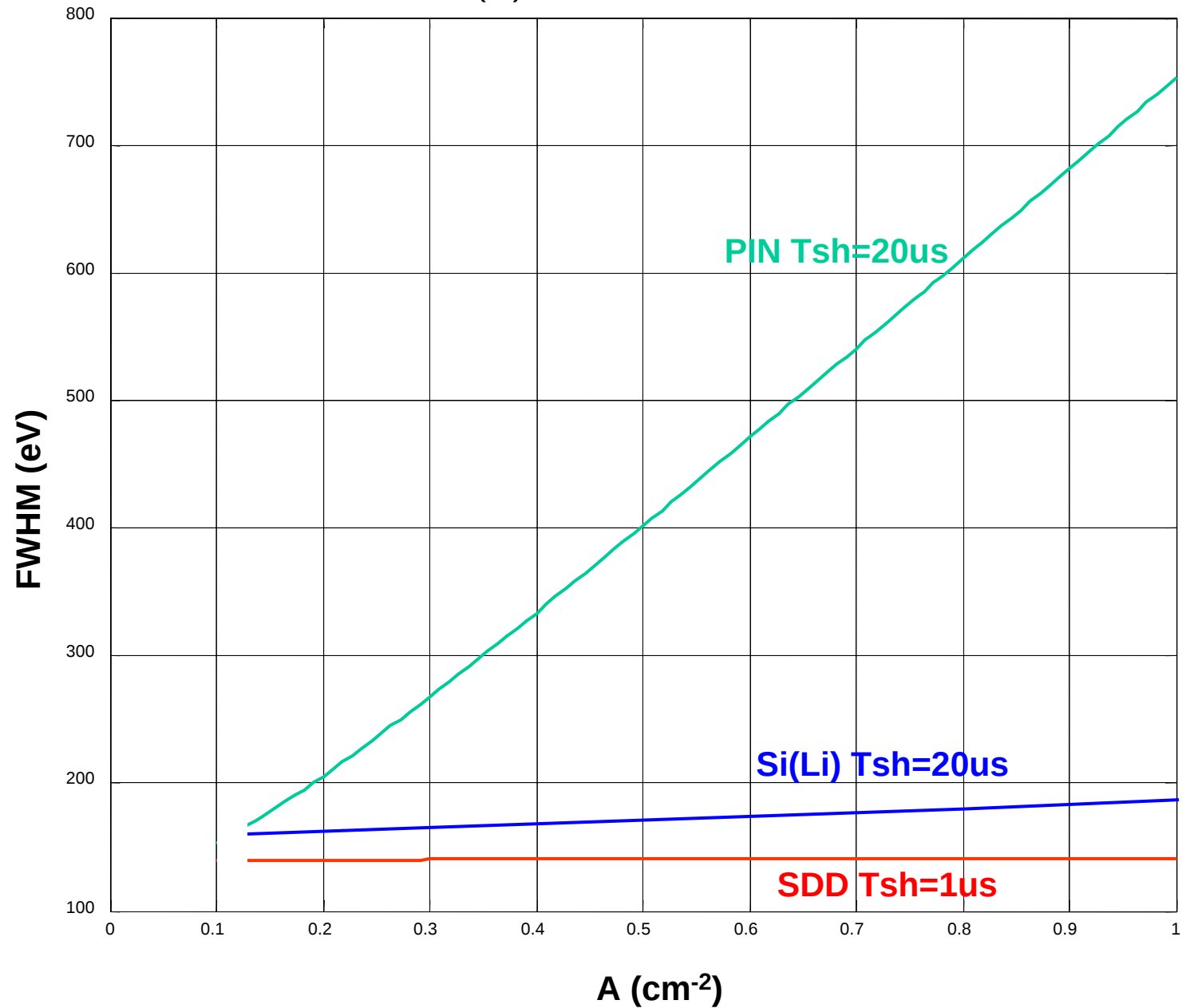


JFET integrated on the detector

- capacitive ‘**matching**’: $C_{\text{gate}} = C_{\text{detector}}$
- minimization of the **parasitic capacitances**
- reduction of the **microphonic noise**
- **simple solution** for the connection detector-electronics in monolithic **arrays** of several units

Spectroscopic resolution and timing : detector comparison

SDD PIN Si(Li) 150 K 5.9 keV line



SIDDHARTA Collaboration:

LNF- INFN, Frascati, Italy

IMEP- ÖAW, Vienna, Austria

IFIN – HH, Bucharest, Romania

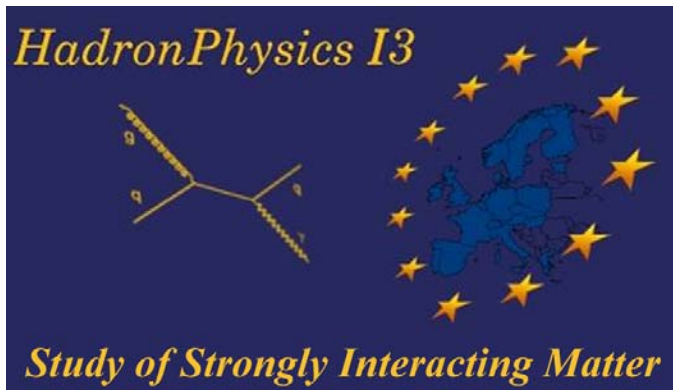
Politecnico, Milano, Italy

MPE, Garching, Germany

PNSensors, Munich, Germany

RIKEN, Japan

Victoria Univ., Canada



***Si*licon *D*rift *D*etector for *H*adronic *A*tom
*R*esearch by *T*iming *A*pplications**

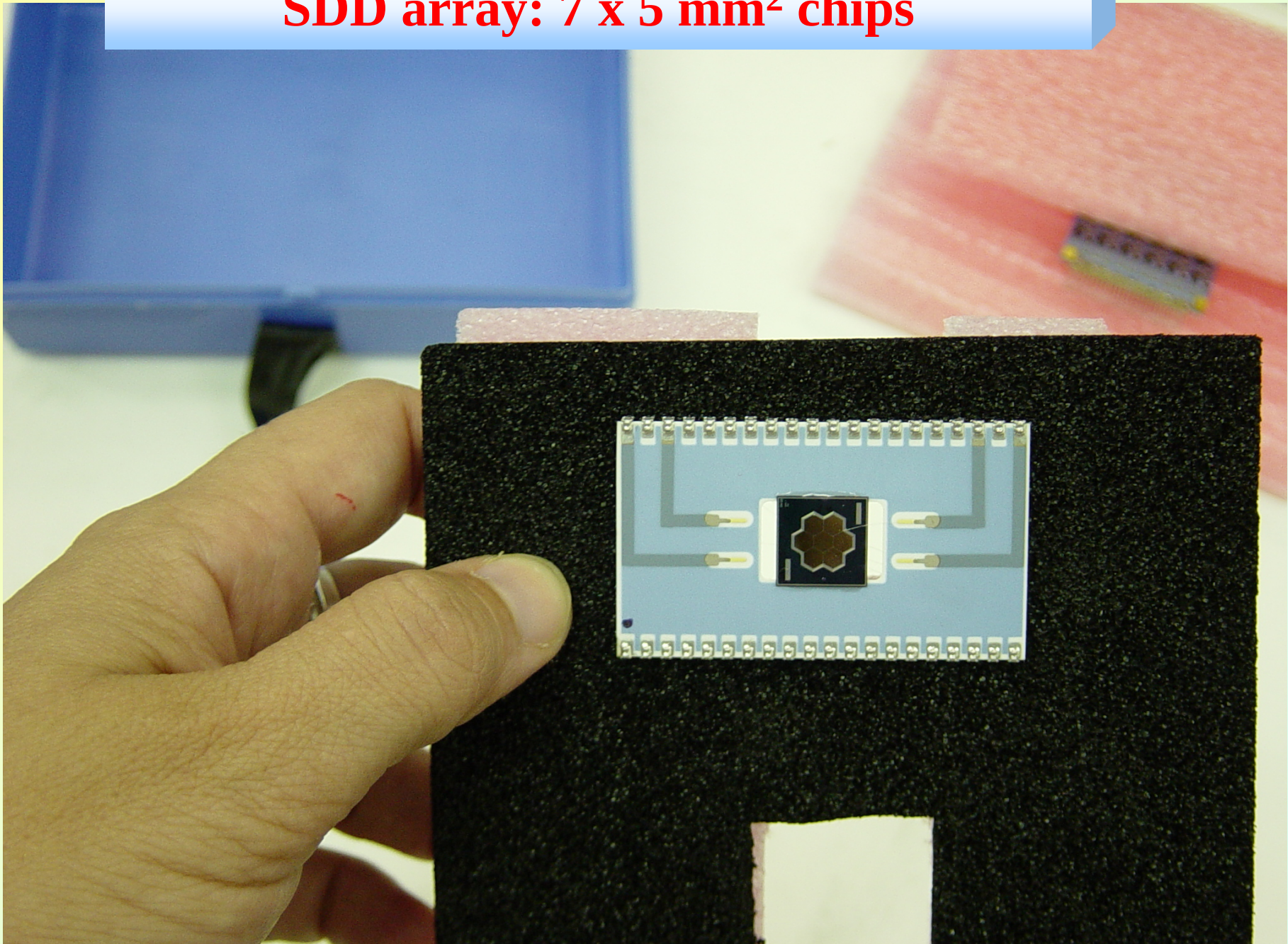
***Transport of setup
from DEAR lab to
BTF***

or

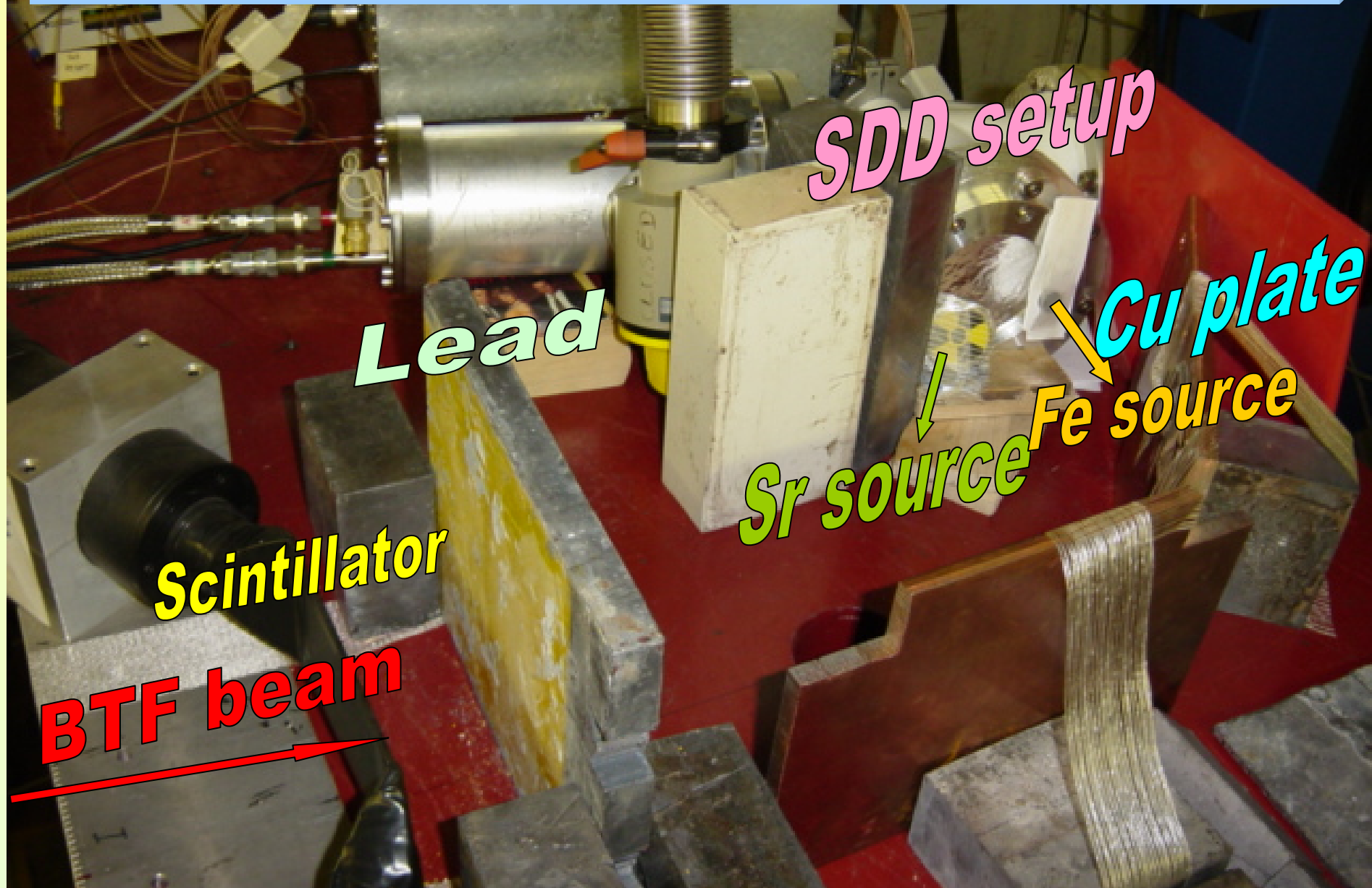
***high-technology
not always a must***



SDD array: 7 x 5 mm² chips

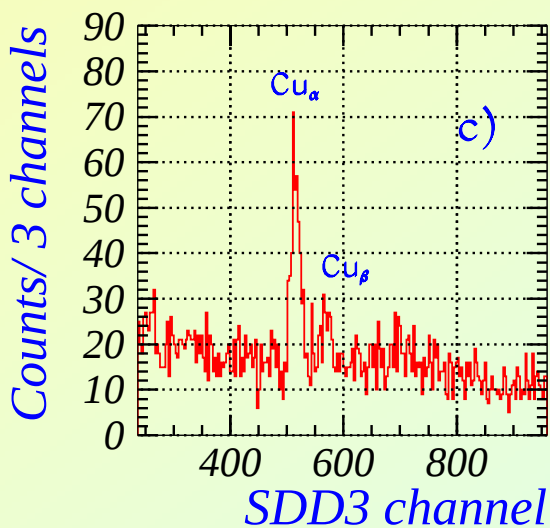
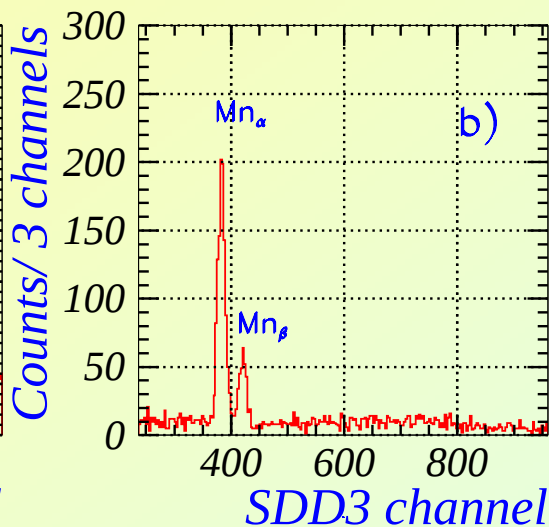
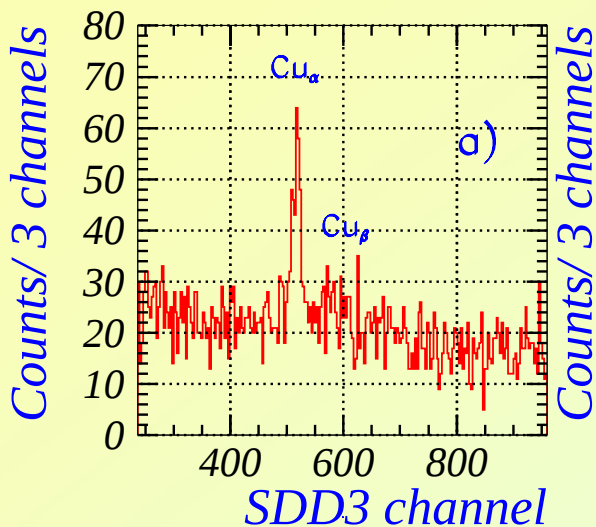


The test setup installed at BTF with the two sources (Fe and Sr) to generate asynchronous background



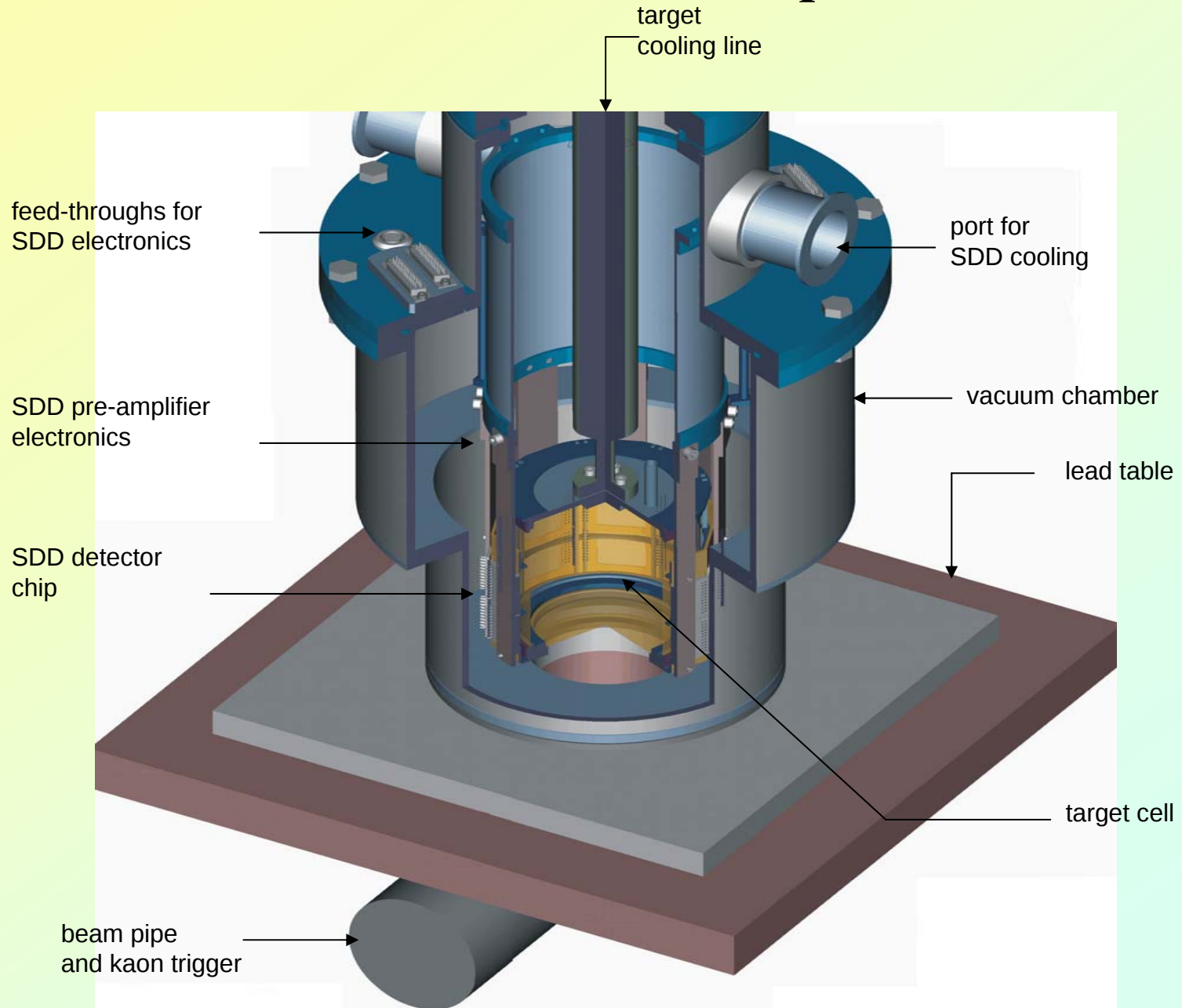
Test of SDD triggering capability

Incident rate: 60 Hz on 7 channels => 8.5 Hz/channel

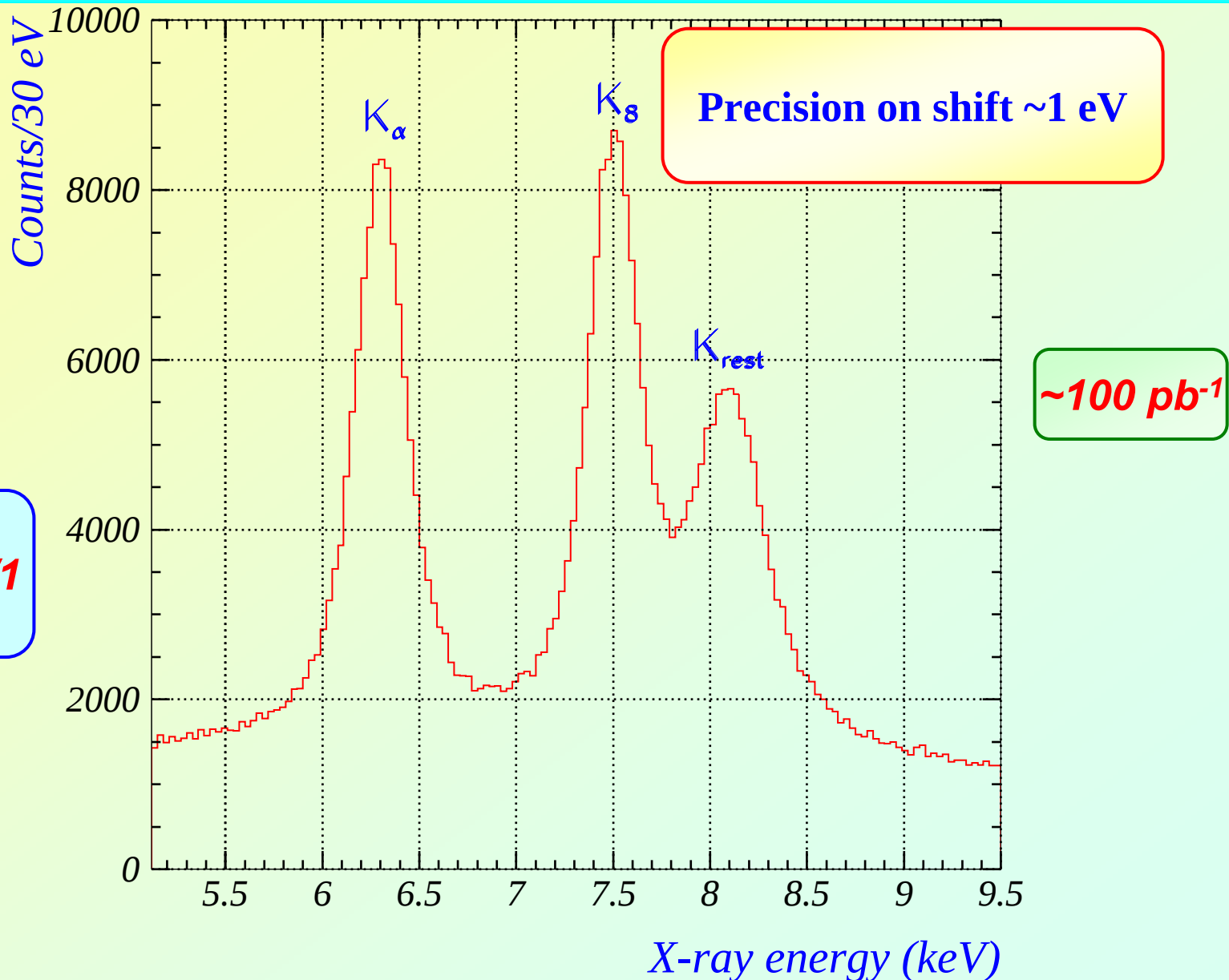


- a) # **Trigger OFF (16 hours.)**
Cu signal visible;
No asynchronous backgr (55Fe and 90Sr)
Continuous background:
- synchronous from primary beam
5 Hz
- b) # **Trigger OFF (20 min.)**
Cu signal embedded in backc.
Structured asynchronous backgr:
- Mn Ka and Kb from 55 Fe
Continuous background:
- synchronous from primary beam
- asynchronous from 90 Sr source
60 Hz
- b) # **Trigger ON (~ 16 hours)**
Cu signal visible
Structured asynchronous backgr.
completely cut;
Continuous background:
- synchronous from primary beam
5 Hz – as a)

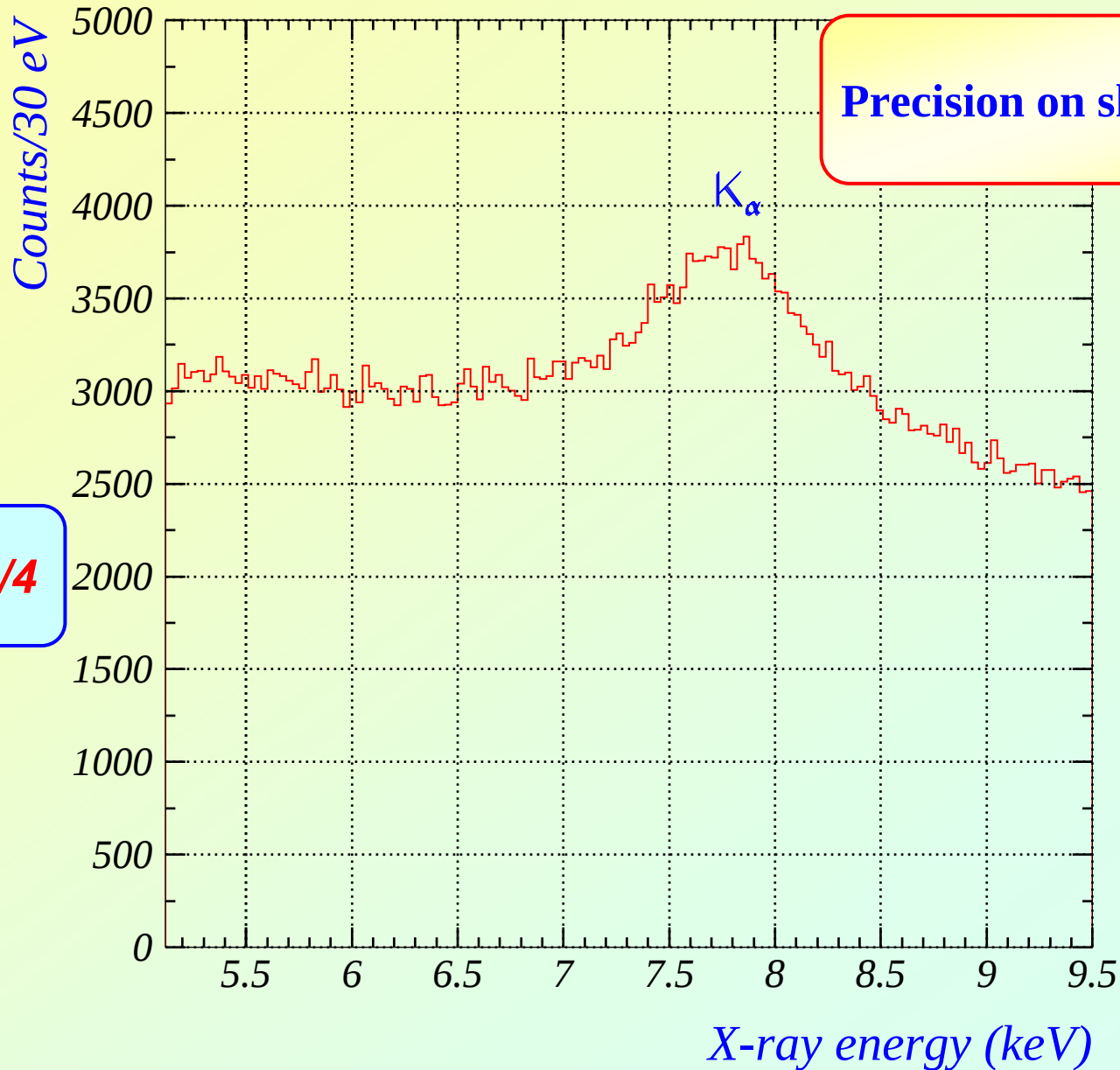
SIDDHARTA setup

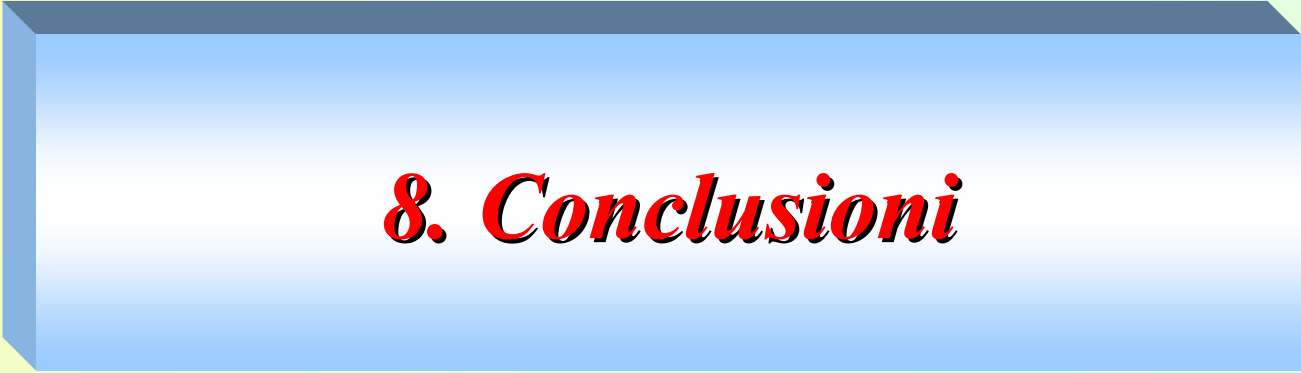


SIDDHARTA Kaonic hydrogen simulated spectrum



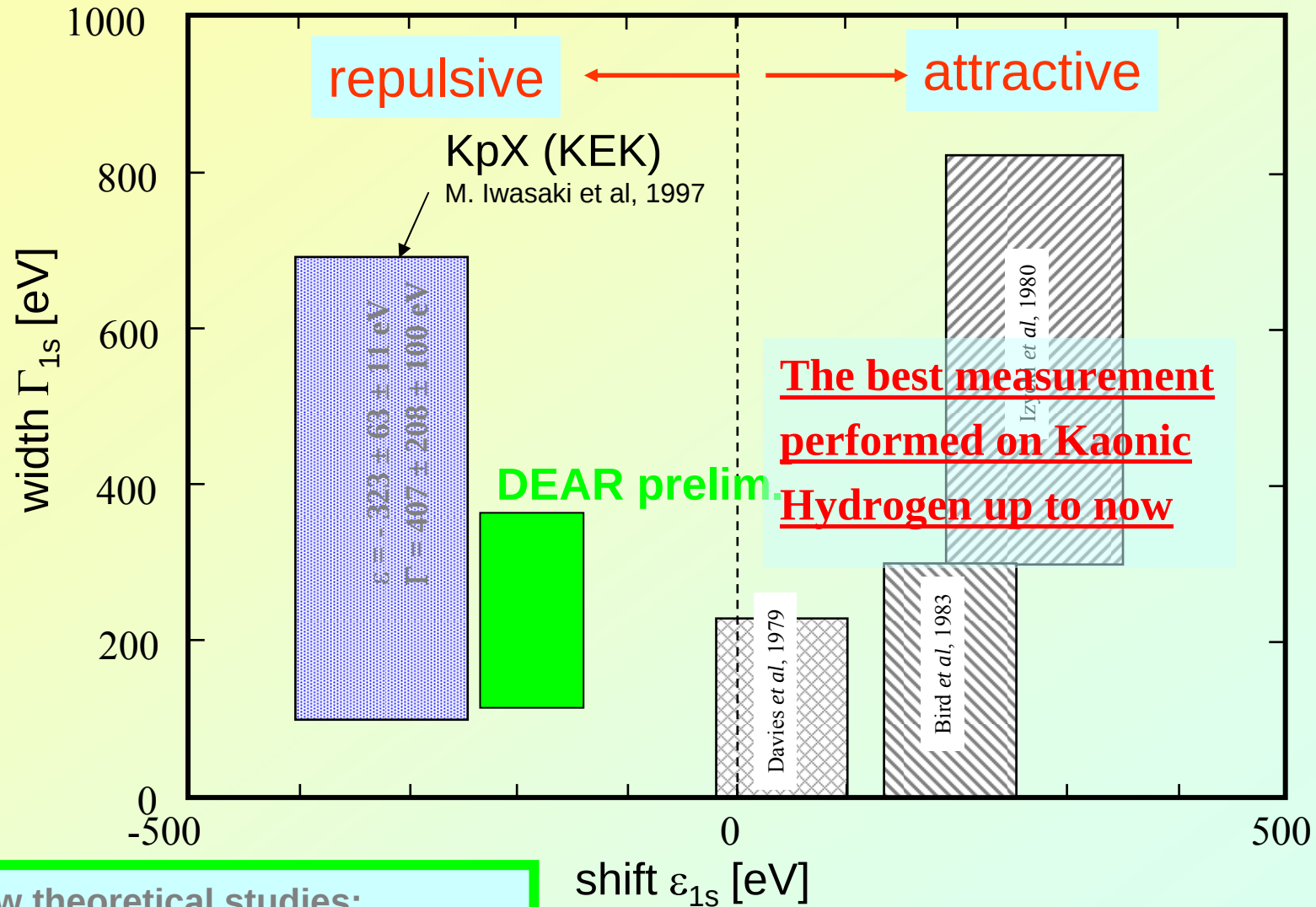
SIDDHARTA Kaonic deuterium simulated spectrum





8. Conclusioni

DEAR Results (preliminary)



New theoretical studies:
Ivanov *et al.* 2003 / 2004
Meißner, Raha, Rusetsky 2004

SIDDHARTA plans (from 2007)

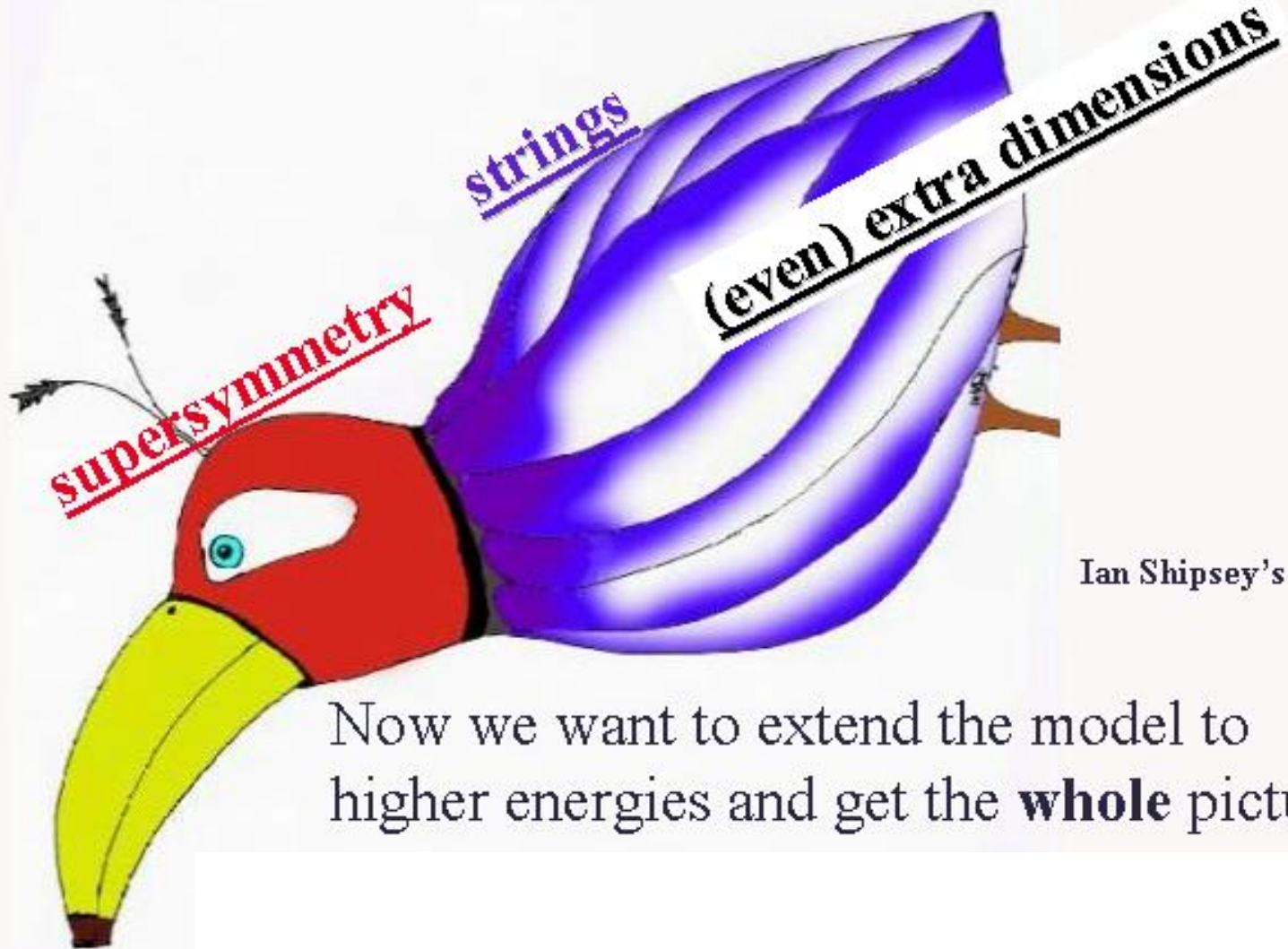
- 1) $\sim$ eV level precision measurement of kaonic hydrogen;
- 2) first measurement of kaonic deuterium
- 3) Kaonic helium measurement (“kaonic helium puzzle” and implications on deeply bound kaonic nuclear states);
- 4) Kaon mass precision measurement at the level of 10 keV
- 5) Other light kaonic atoms measurement (Li, Be...);
- 6) Investigate the possibility of the measurement of other types of hadronic exotic atoms (sigmonic hydrogen ?)

the Bigger Big picture

The Standard Model describes everything that we have seen to extreme accuracy.



the Bigger Big picture



Ian Shipsey's bird

Now we want to extend the model to higher energies and get the **whole** picture



HIS MOST FAMOUS NOVEL

SIDDHARTHA

HERMANN HESSE

"He saw trees, stars, animals, clouds, rainbows, rocks, weeds, flowers, brook and river, the sparkle of dew on bushes in the morning, distant high mountains blue and pale; birds sang, bees hummed, the wind blew gently across the rice fields. All this, colored and in a thousand different forms, had always been there. The sun and moon had always shone; the rivers had always flowed and the bees had hummed, but in previous times all this had been nothing to **Siddhartha** but a fleeting and illusive veil before his eyes, regarded with distrust, condemned to be disregarded and ostracized from the thoughts, because it was not reality, because reality lay on the other side of the visible.

But now his eyes lingered on this side..."

(H. Hesse, SIDDHARTHA)

