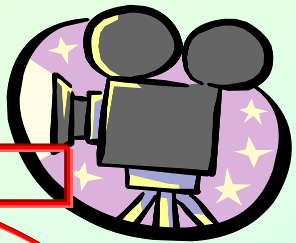
Atomi esotici: DEAR/SIDDHARTA



Catalina Curceanu (Petrascu)

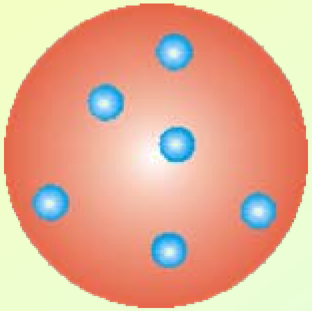
LNF – Giugno 2005

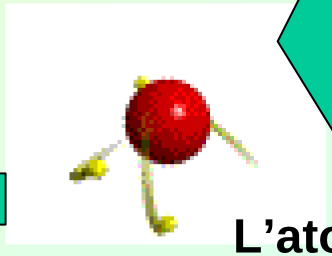
Contenuto:

1. Il modello Standard

L’atomo all’inizio del ‘900

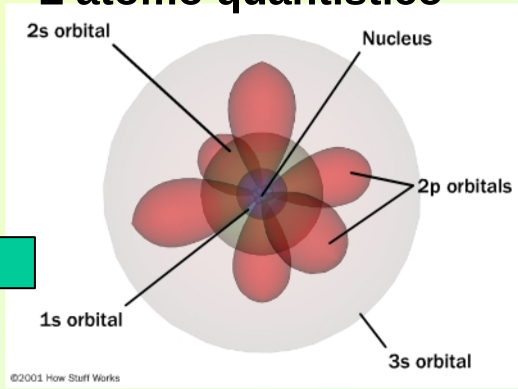
L’atomo di Thompson

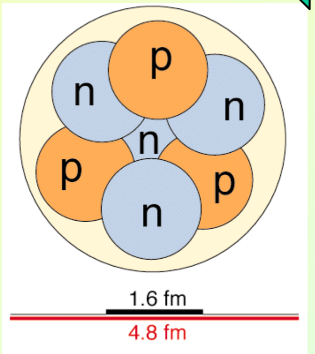




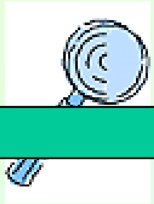
L’atomo di Rutherford e Bohr

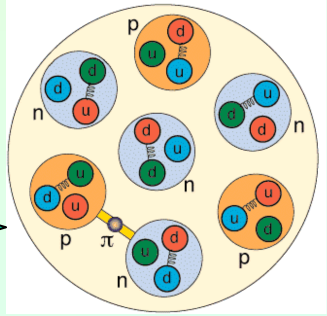
L’atomo quantistico





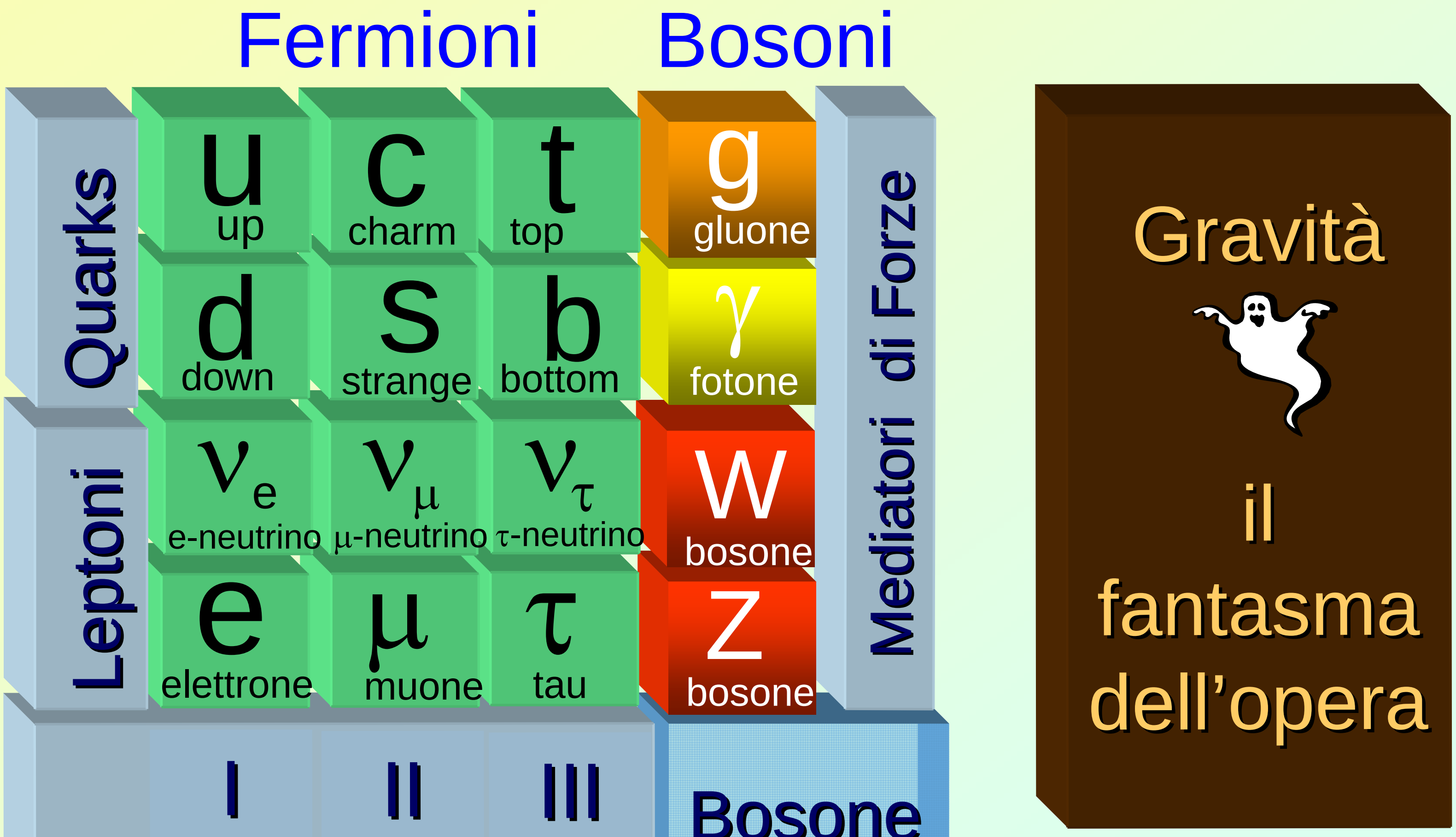
La struttura del nucleo

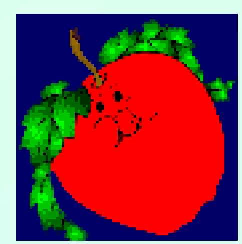


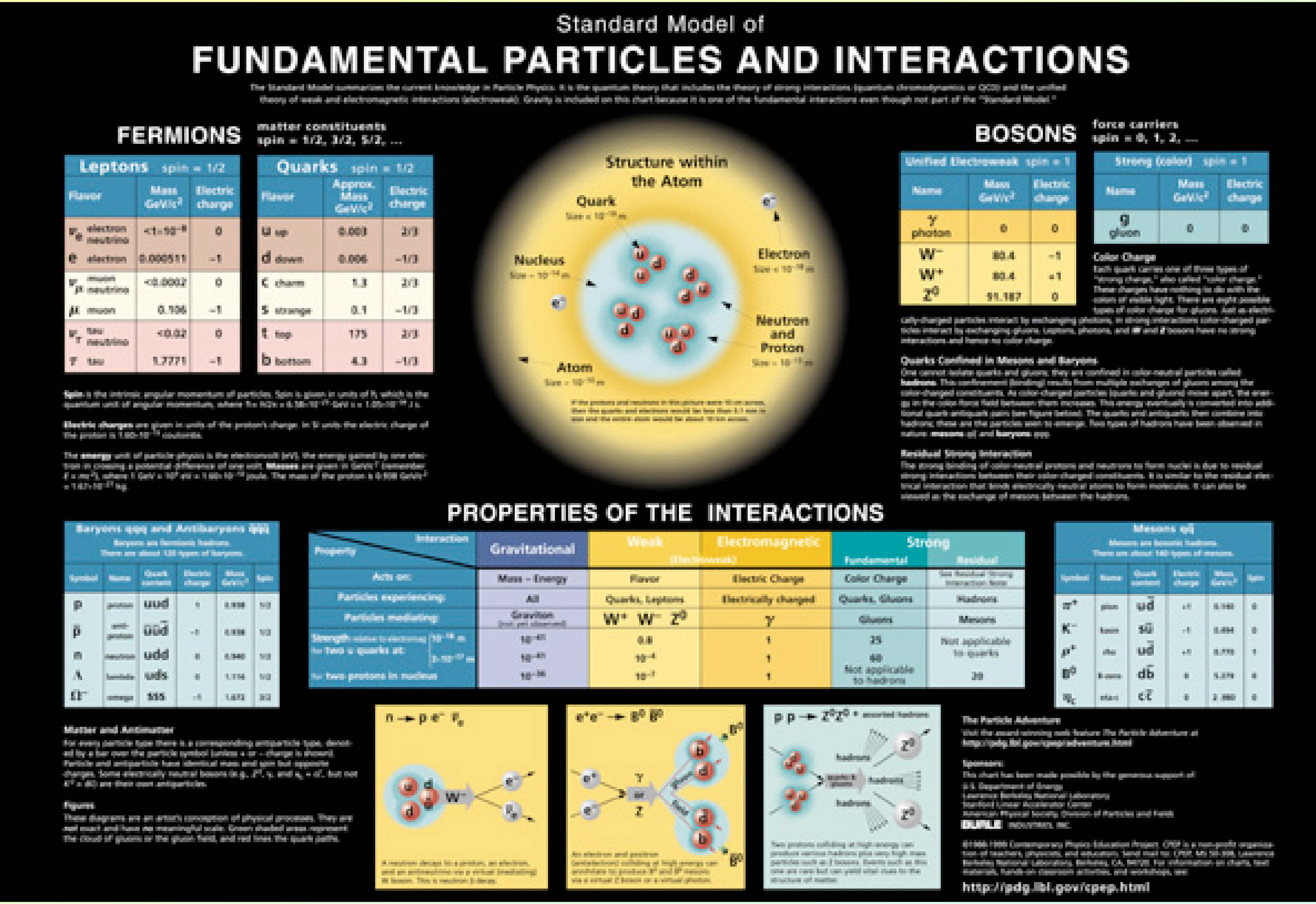


Il nucleo oggi

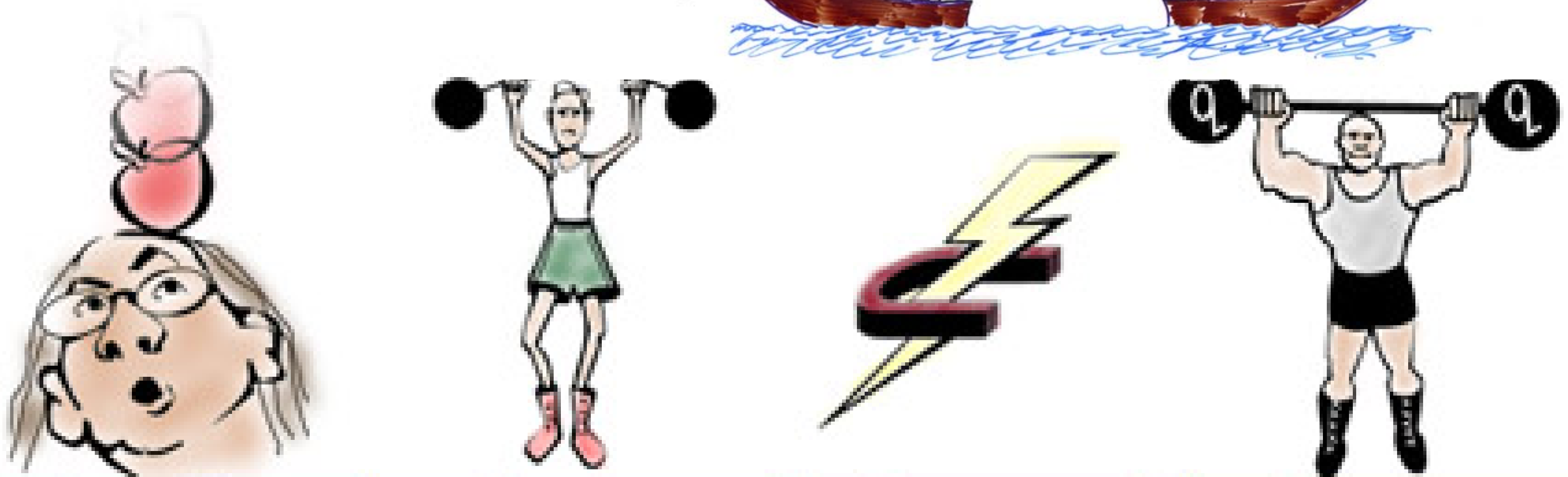
Il Modello Standard






Standard Model of
FUNDAMENTAL PARTICLES AND INTERACTIONS
FERMIONS
matter constituents spin = 1/2, 3/2, 5/2, ...
Leptons spin = 1/2
Flavor
Mass GeV/c²
Electric charge
electron neutrino
electron 0.000511 -1
muon neutrino
muon 0.106 -1
tau neutrino
tau 1.7771 -1
Quarks spin = 1/2
Approx. Mass GeV/c²
u up 0.003 2/3
d down 0.006 -1/3
c charm 1.3 2/3
s strange 0.1 -1/3
t top 175 2/3
b bottom 4.3 -1/3
Structure within the Atom
Quark
Nucleus
Electron
Neutron and Proton
Atom
BOSONS
force carriers spin = 0, 1, 2, ...
Unified Electroweak spin = 1
Name
γ photon 0 0
W⁻ 80.4 -1
W⁺ 80.4 +1
Z⁰ 91.187 0
Strong (color) spin = 1
g gluon 0 0
Color Charge
Quarks Confined in Mesons and Baryons
Residual Strong Interaction
PROPERTIES OF THE INTERACTIONS
Baryons qqq and Antibaryons q̄q̄q̄
Interaction
Property
Gravitational
Weak (Electroweak)
Electromagnetic
Strong
Fundamental
Residual
Acts on:
Mass – Energy
Flavor
Electric Charge
Color Charge
Particles experiencing:
All
Quarks, Leptons
Electrically charged
Quarks, Gluons
Hadrons
Particles mediating:
Graviton
W⁺ W⁻ Z⁰
γ
Gluons
Mesons
Not applicable to quarks
Not applicable to hadrons
Mesons qq̄
p proton uud
p̄ ūūd̄
n neutron udd
Λ lambda uds
Ω⁻ omega sss
π⁺ pion ud̄
K⁻ kaon sū
ρ⁺ rho ud̄
B⁰ db̄
ηc cc̄
Matter and Antimatter
Figures
n → p e⁻ ν̄e
W⁻
e⁺e⁻ → B⁰ B̄⁰
p p → Z⁰Z⁰ + assorted hadrons
hadrons
The Particle Adventure
Sponsors
http://pdg.lbl.gov/cpep.html

Fundamental interactions



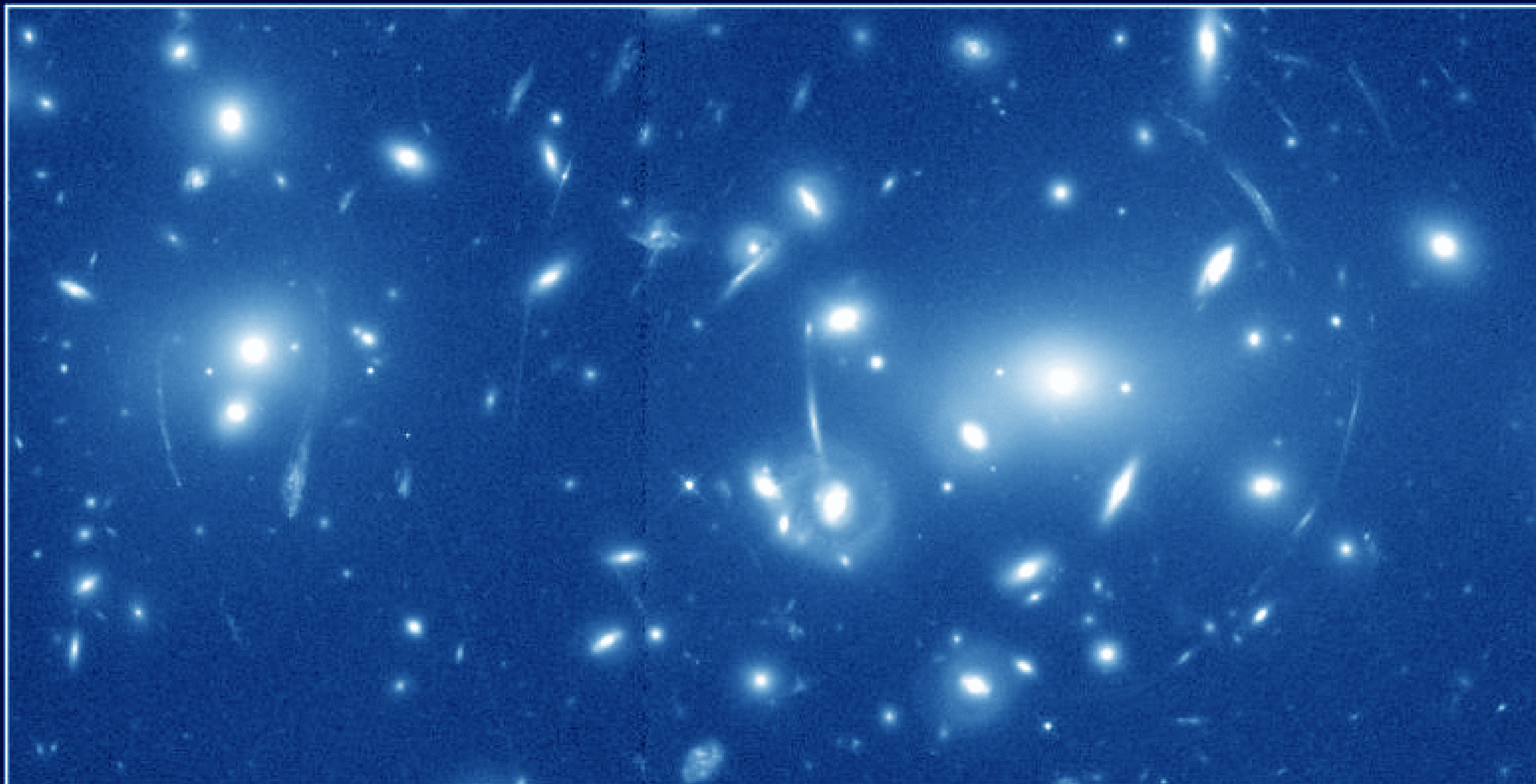
	Gravity	Weak	Electromagnetic	Strong
		(Electroweak)		
Carried By	Graviton (not yet observed)	W^+ W^- Z^0	Photon	Gluon
Acts on	All	Quarks and Leptons	Quarks and Charged Leptons and W^+ W^-	Quarks and Gluons
	1	10^{29}	10^{40}	10^{43}

Tante domande:

1. Perche 3 famiglie?
2. Da dove proviene la massa?
3. Perche 4 interazioni? (anche se la gravita’ non e’ compresa nel MS….)

……………………

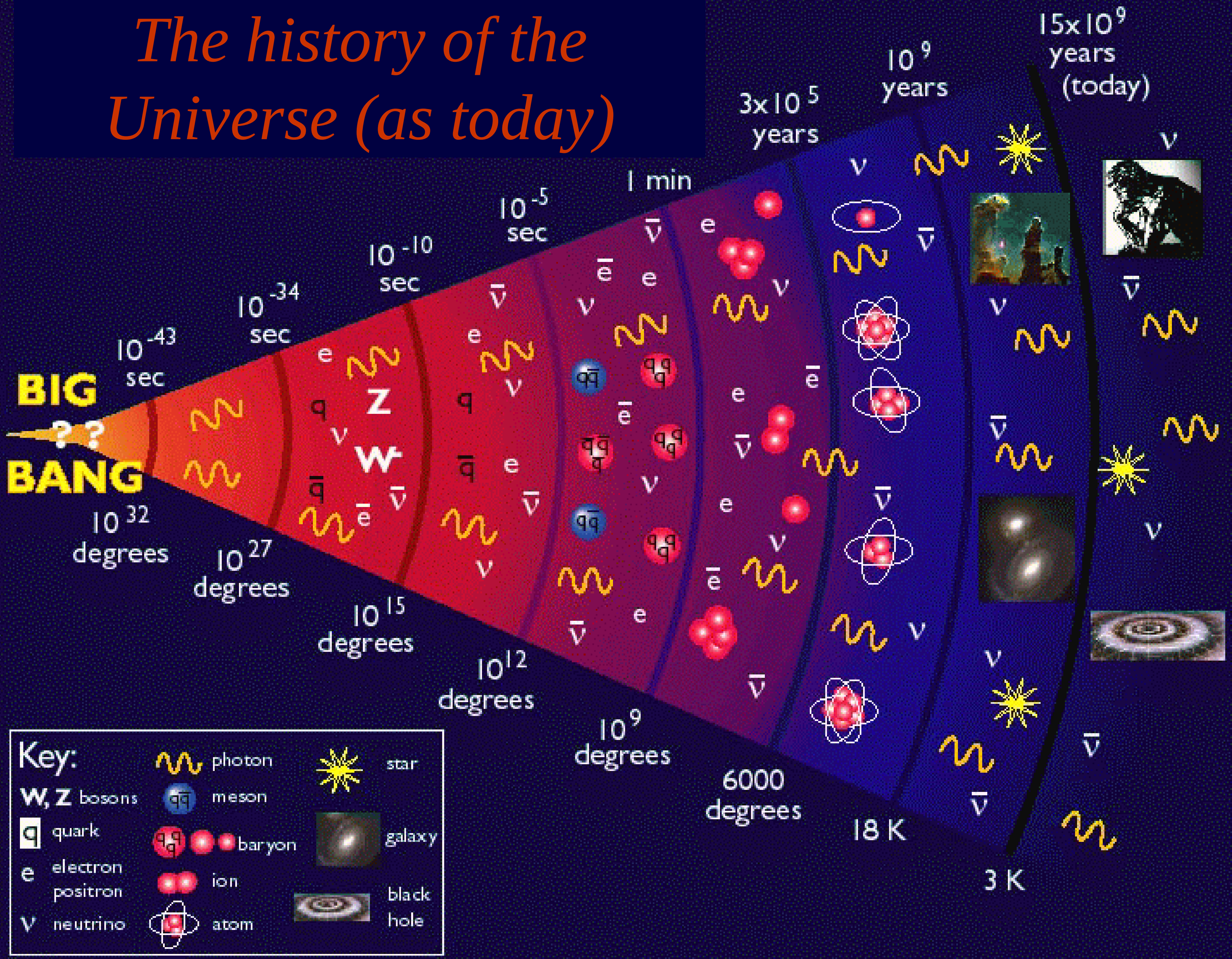
2 Com'e' composto l'Universo?



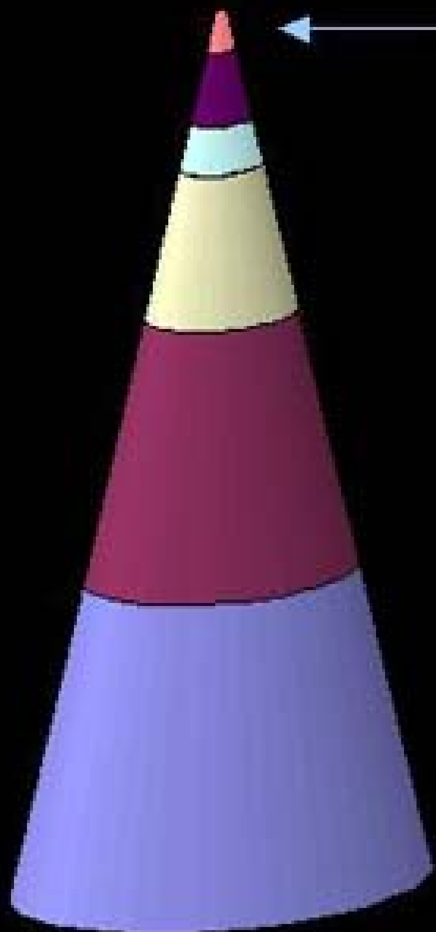
Gravitational Lens in Abell 2218 HST • WFPC2

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

The history of the Universe (as today)



Composition of the universe



← We are here

Other elements	0.03%
Neutrinos	0.3%
Stars	0.5%
Free H and He	4%
Dark matter	23%
Dark energy	72%

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

Dobbiamo capire meglio il 5% che conosciamo ...

e cosi si puo imparare qualcosa di piu'

anche sul restante 95%

3. Il problema della massa

Il problema della massa

Perche i quark hanno massa?

Higgs mechanism

Si studia attraverso lo studio della rottura della cosiddette simmetria chirale

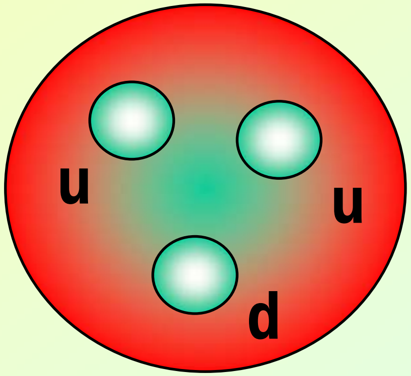
u	d	s
5 MeV	10 MeV	100 MeV

Il problema della massa

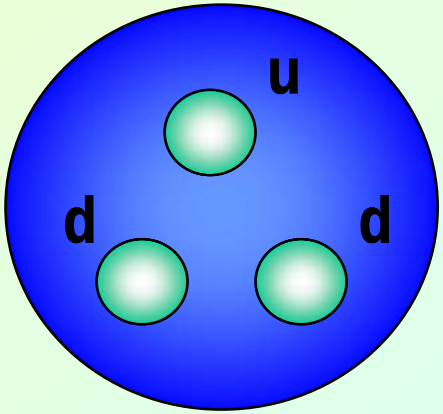
m_p non e’ uguale a

$m_u + m_u + m_d$

(ci sono contributi dai “sea quarks” e dai gluoni)



protone



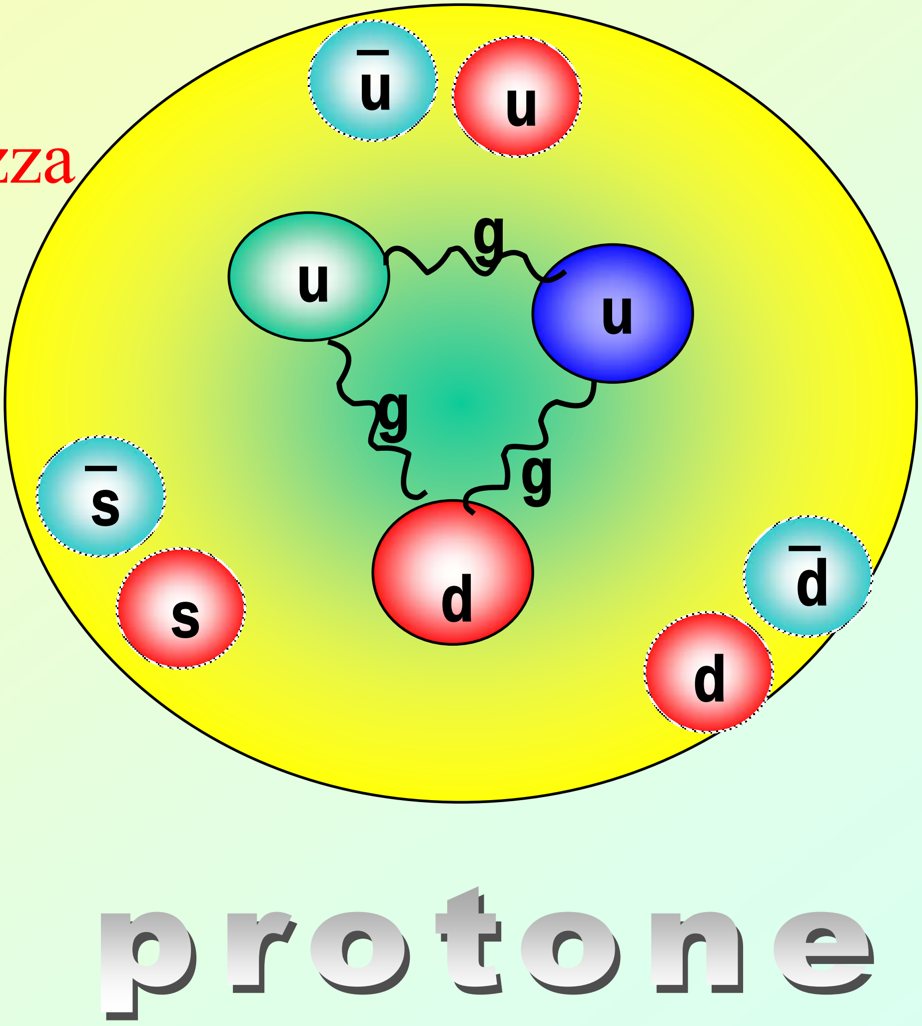
neutrone

m_n non ee uguale a

$m_u + m_d + m_d$

Il problema della massa

- Contenuto di stranezza del protone



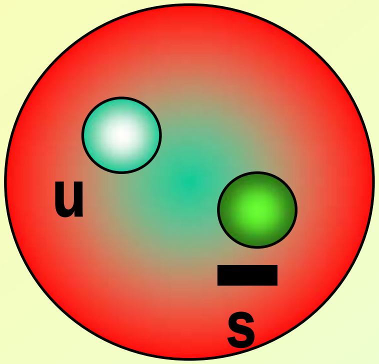
Con lo studio degli atomi kaonici

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

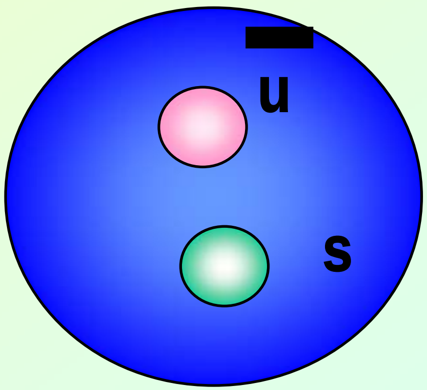
Attoraverso lo studio degli atomi kaonici si puo imparare di piu’ sul meccanismo di generazione della masa e anche sulla matteria nell’Universo

4. Atomi kaonici – cosa si impara

Il kaone carico



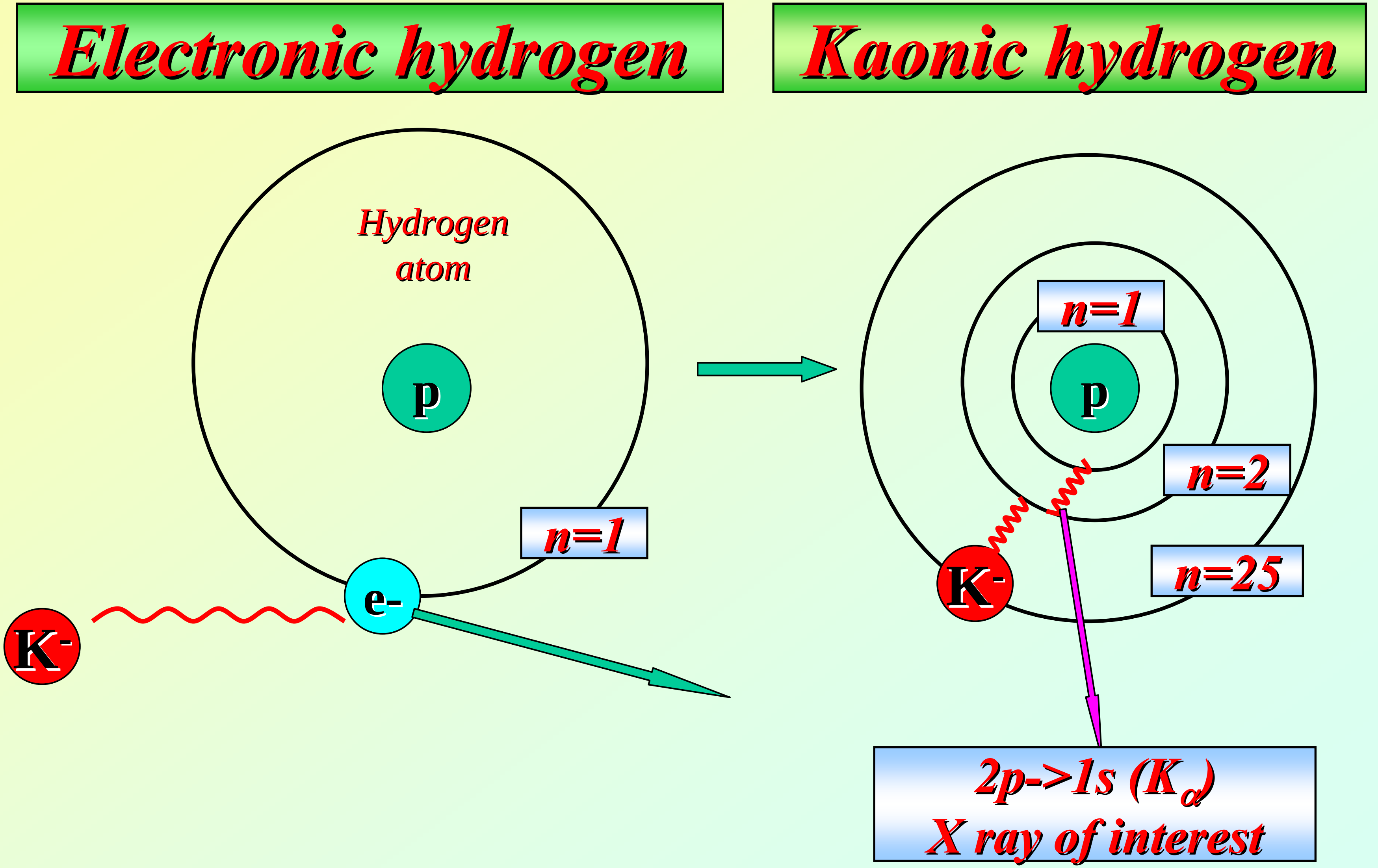
K+



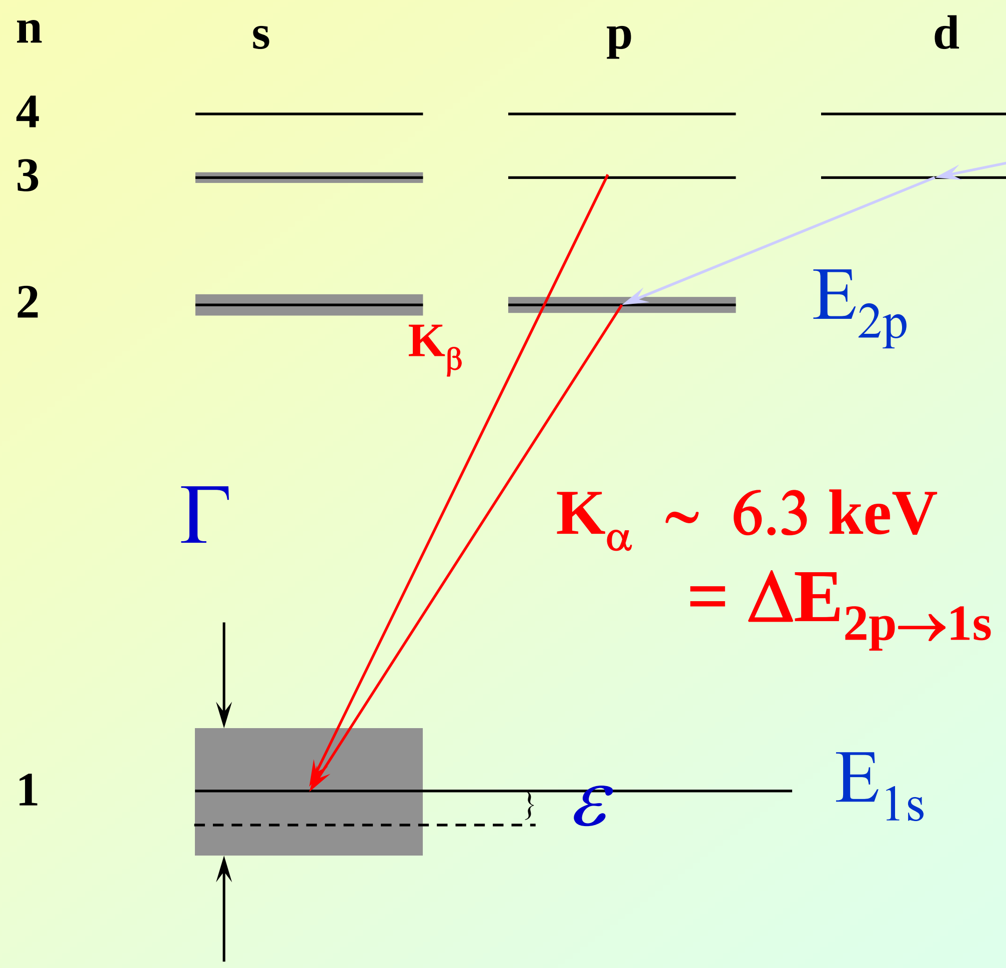
K -

DEAR =

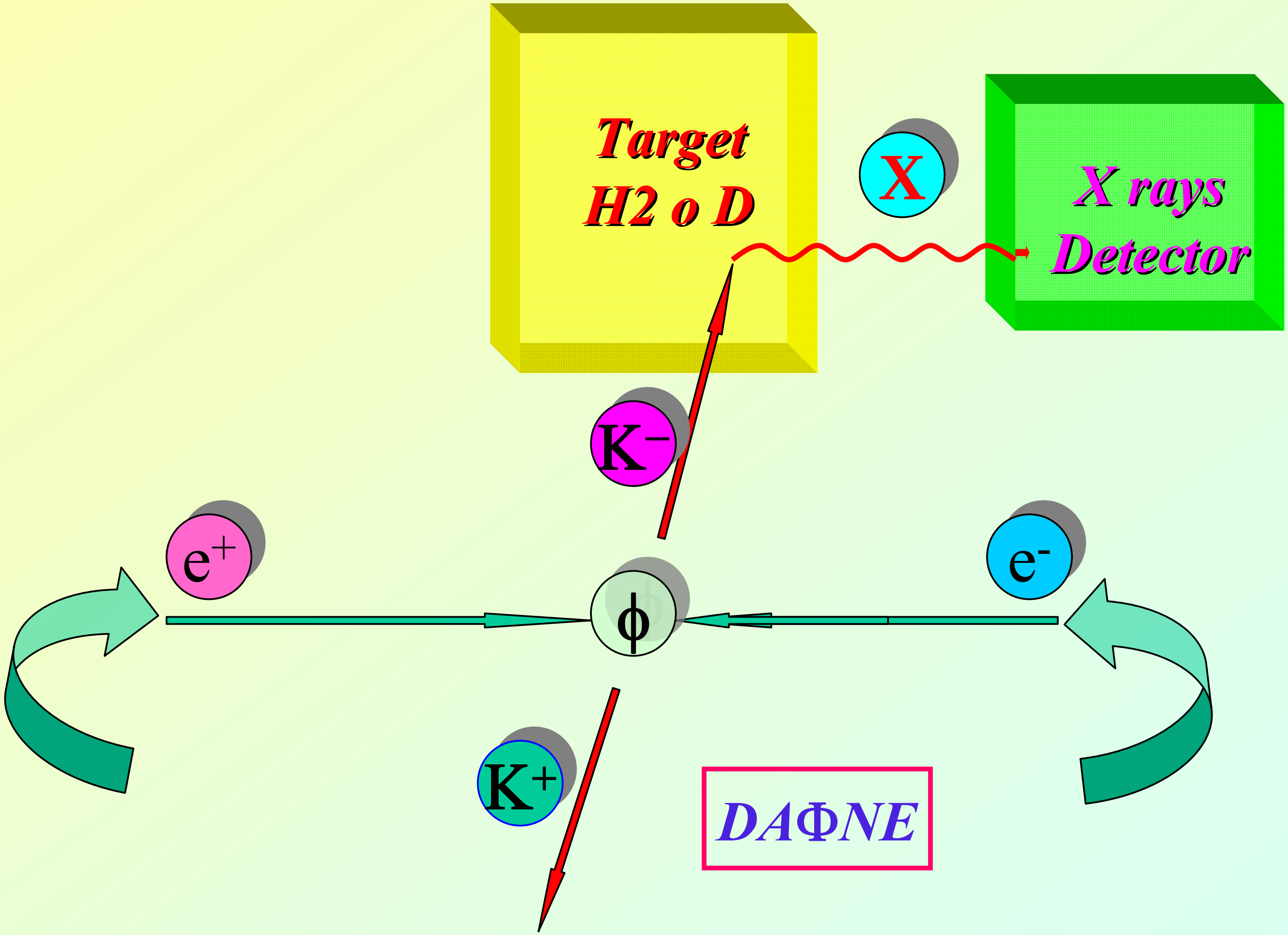
DAΦNE Exotic Atom Research



Cascata atomica e l'interazione forte



Il principio del metodo sperimentale



Lo scopo dell’esperimento

una misura di precisione (eV) dello spostamento e dell’alargamento del livello 1s nell’<u>idrogeno</u>

e

nel <u>deuterio</u> kaonici

DEAR/SIDSDHARTA Scientific program

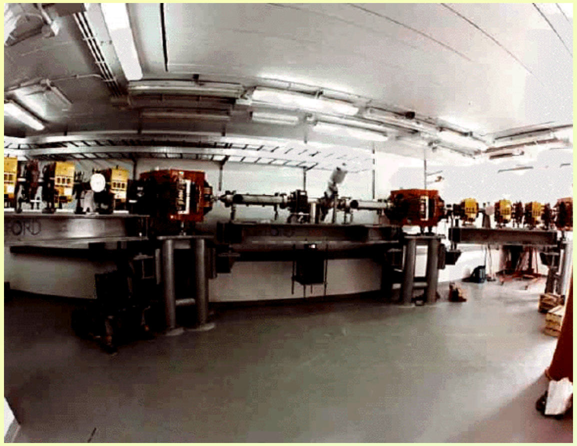
Measuring the $\bar{K}N$ scattering lengths with the precision of a few percent will drastically change the present status of low-energy $\bar{K}N$ phenomenology and also provide a clear assessment of the SU(3) chiral effective Lagrangian approach to low energy hadron interactions.

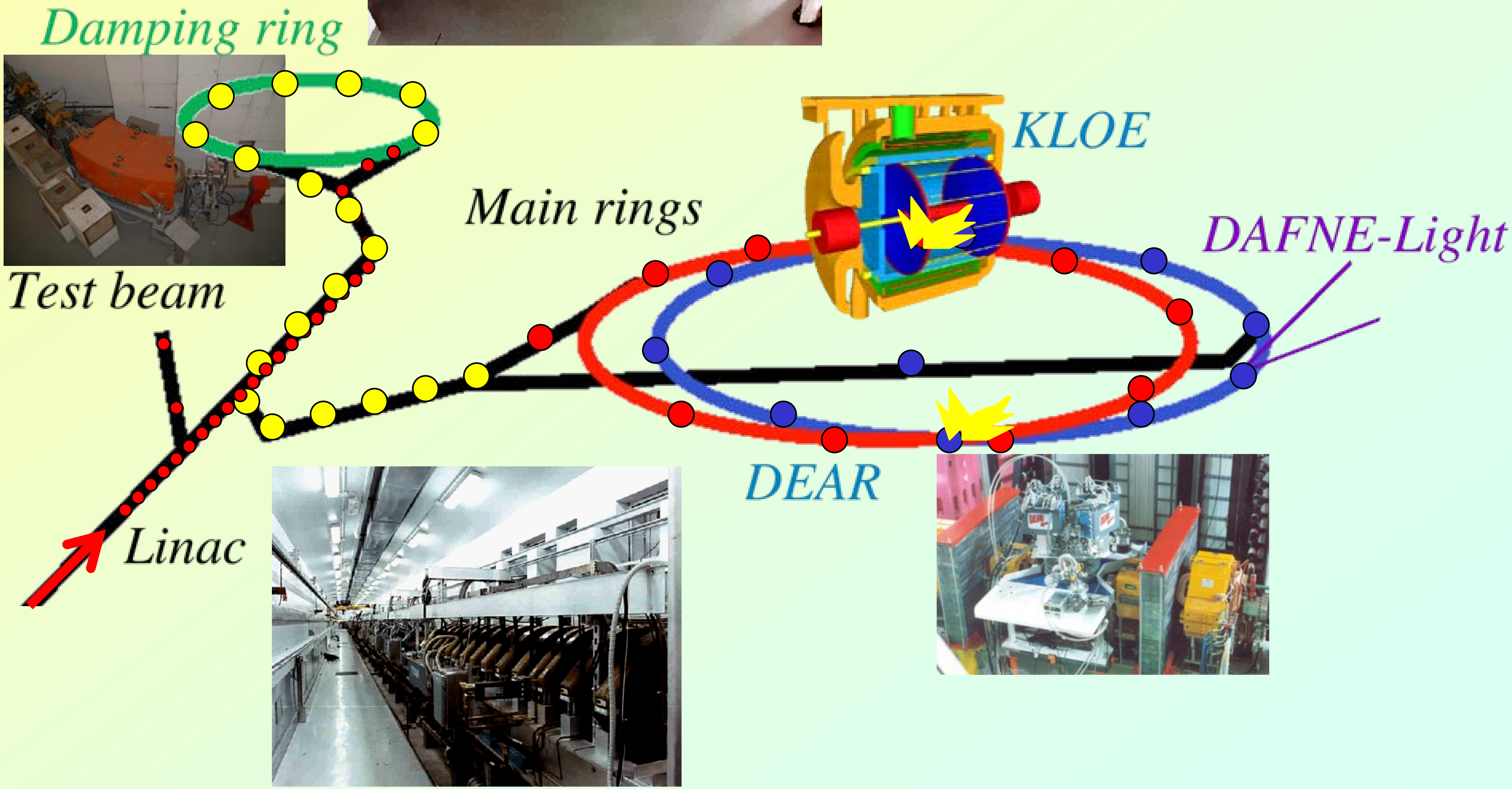
↓

1. Breakthrough in the *low-energy $\bar{K}N$ phenomenology*;
2. Threshold amplitude in QCD: Chiral 2003 (Bonn); Hadatom03 (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

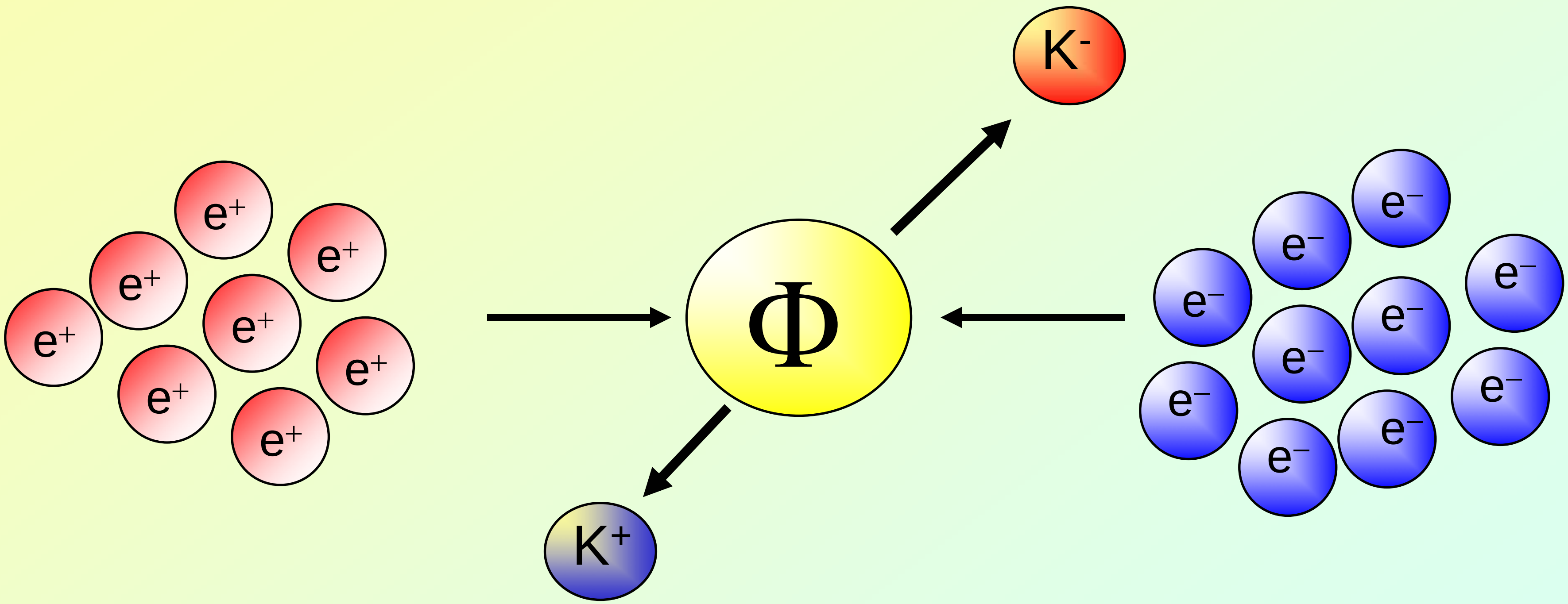



Damping ring
Main rings
KLOE
DAFNE-Light
Test beam
DEAR
Linac

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

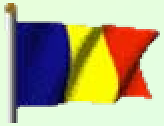
6. La situazione ad oggi

DEAR Collaboration:

LNF- INFN, Frascati, Italy

IMEP- ÖAW, Vienna, Austria

IFIN – HH, Bucharest, Romania



INFN, Trieste, Italy

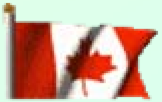
RIKEN, Japan

Univ. Fribourg, Switzerland

Univ. Neuchâtel, Switzerland

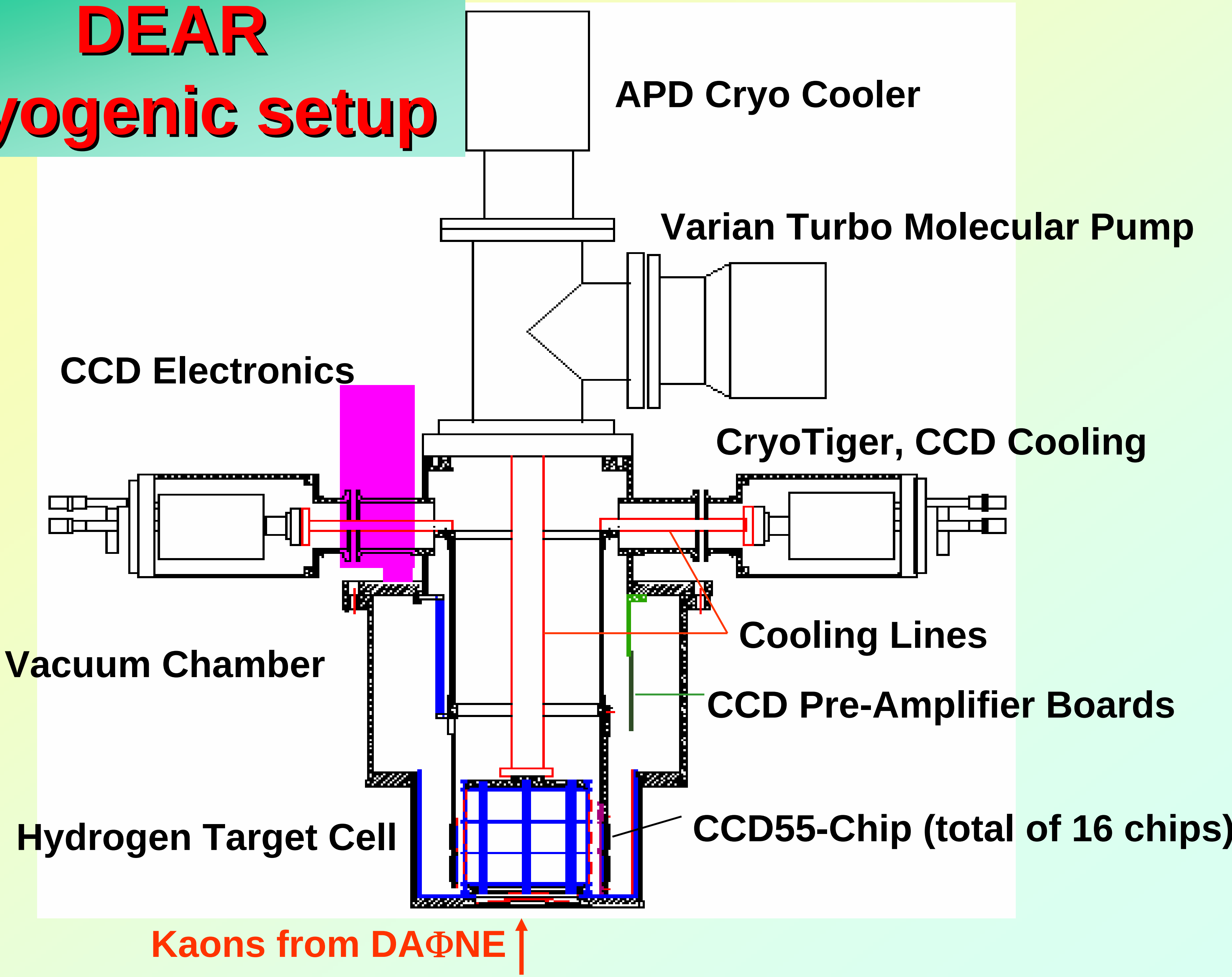
Univ. Tokyo, Japan

Univ. Victoria,Canada

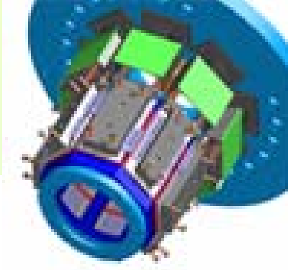


Caltech, USA

DEAR
Cryogenic setup

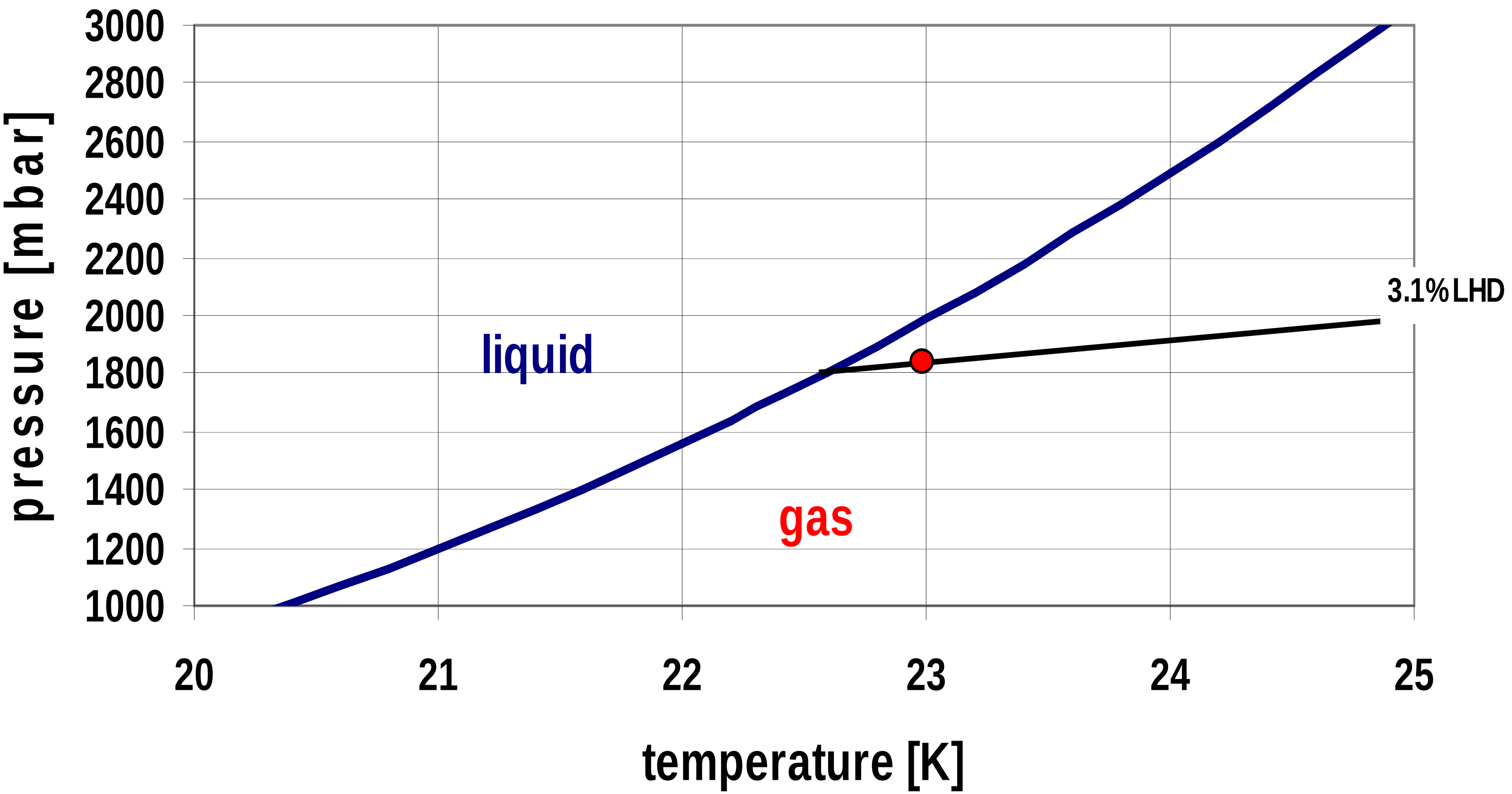


Cryogenic Hydrogen Target



working point: T = 23 K, P = 1.82 bar

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



DEAR Cryogenic Target Cell

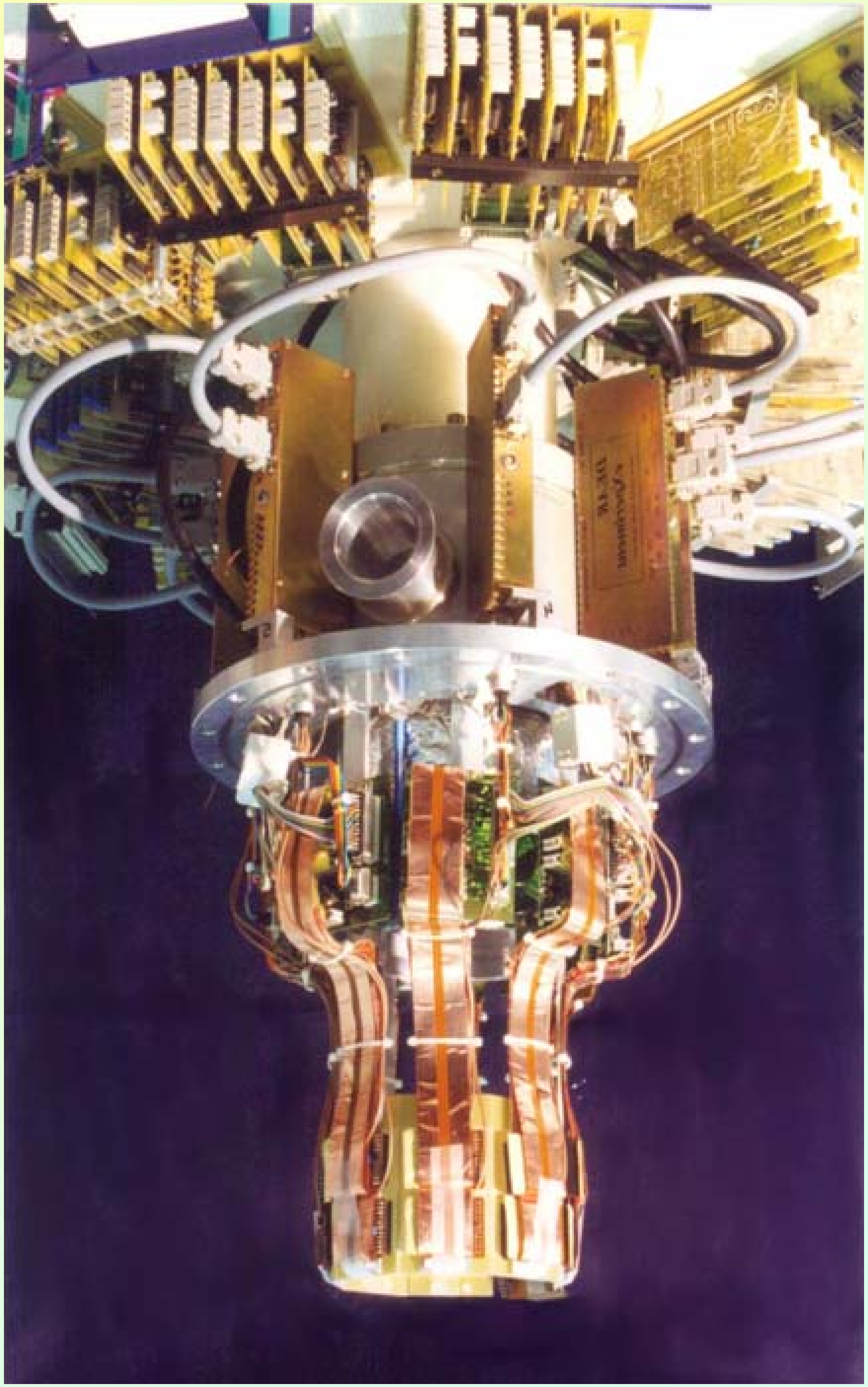
CCD mounting, cryogenics and on-cell electronics

- fiber-glass frames

- cooling system mounted on the top

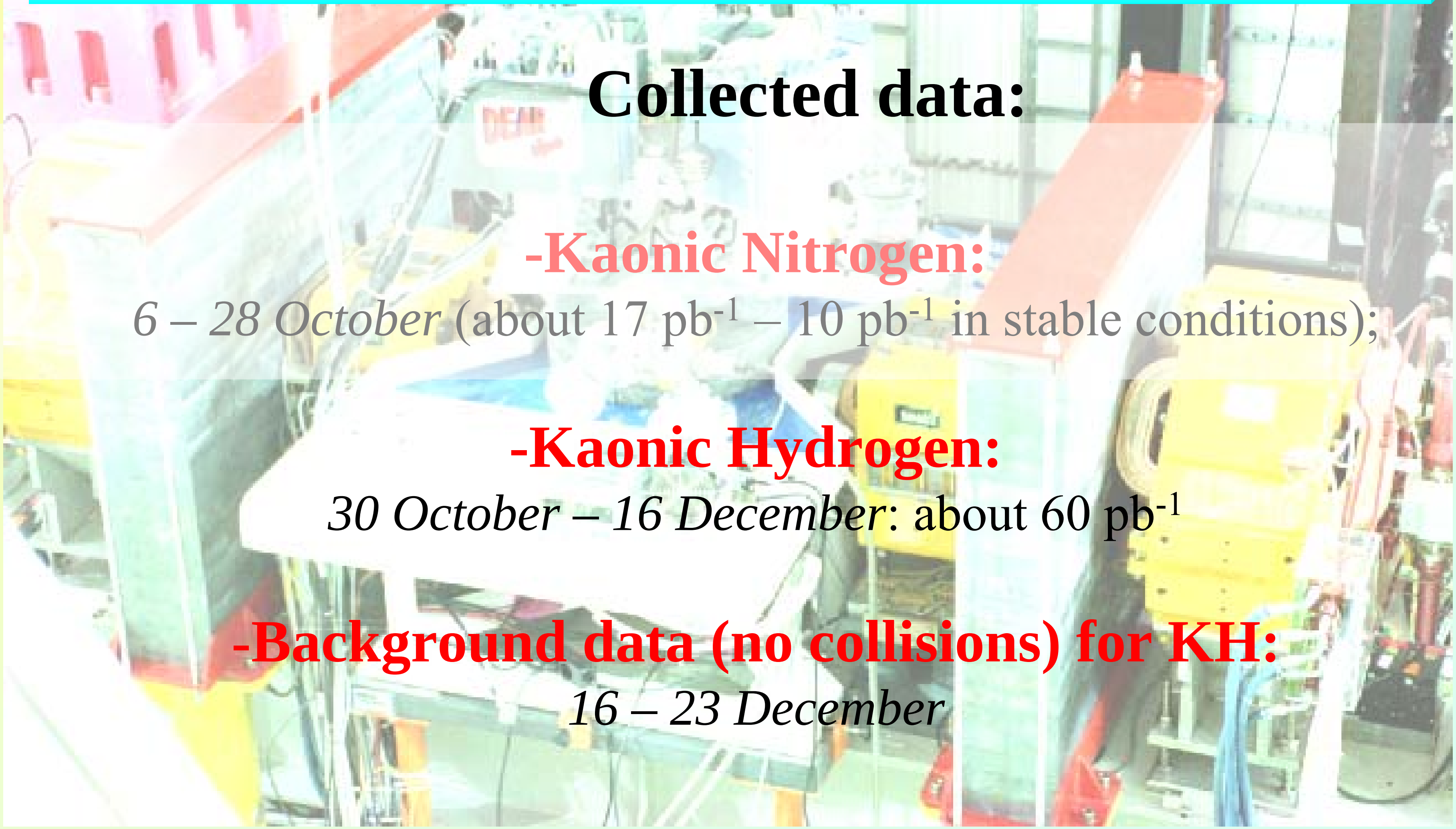
- minimized Al cold finger (behind CCDs)

- 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);

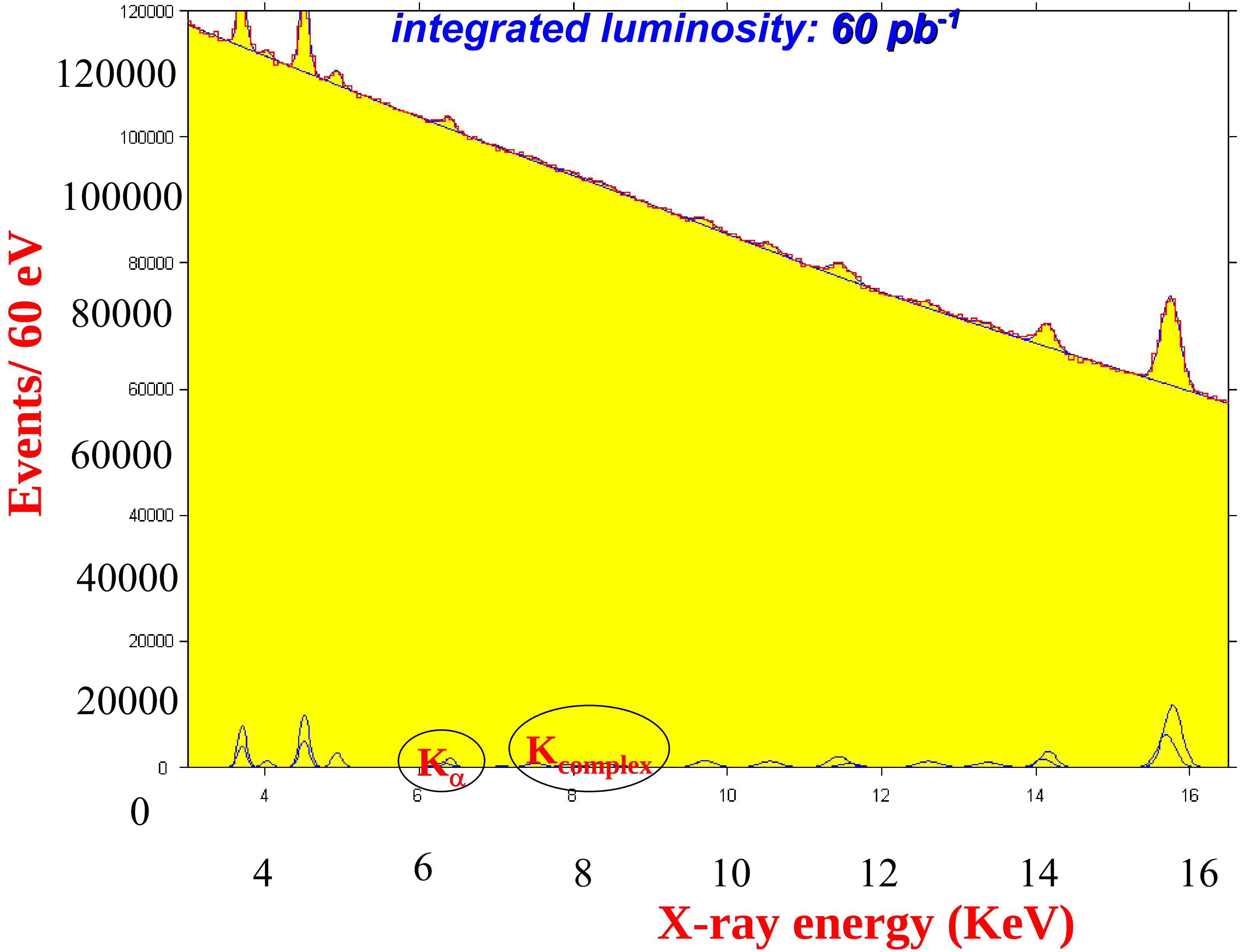
-Kaonic Hydrogen:

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

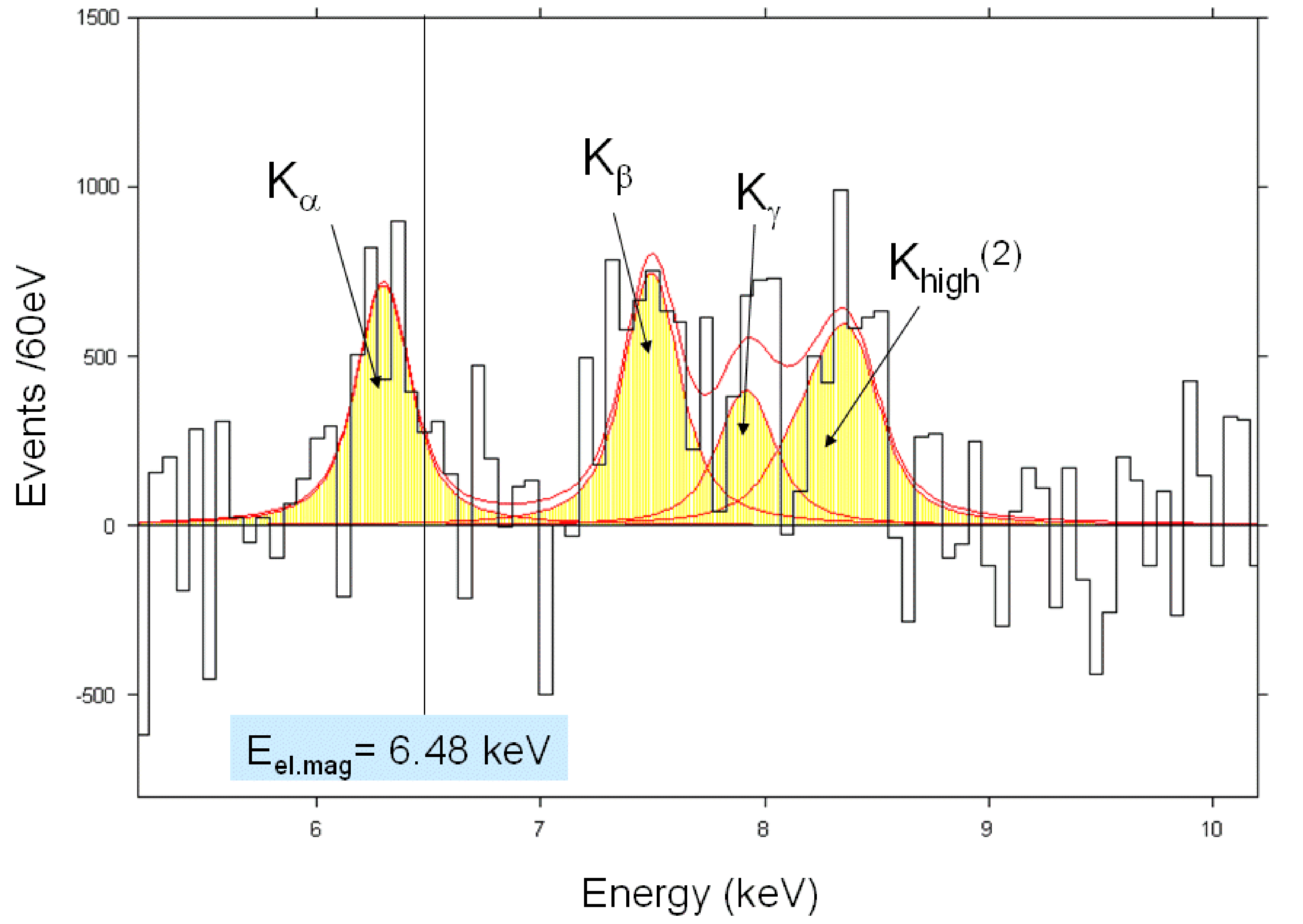
-Background data (no collisions) for KH:

16 – 23 December

Kaonic Hydrogen (2002 data)- global fit



Lo spettro di raggi X K^-p

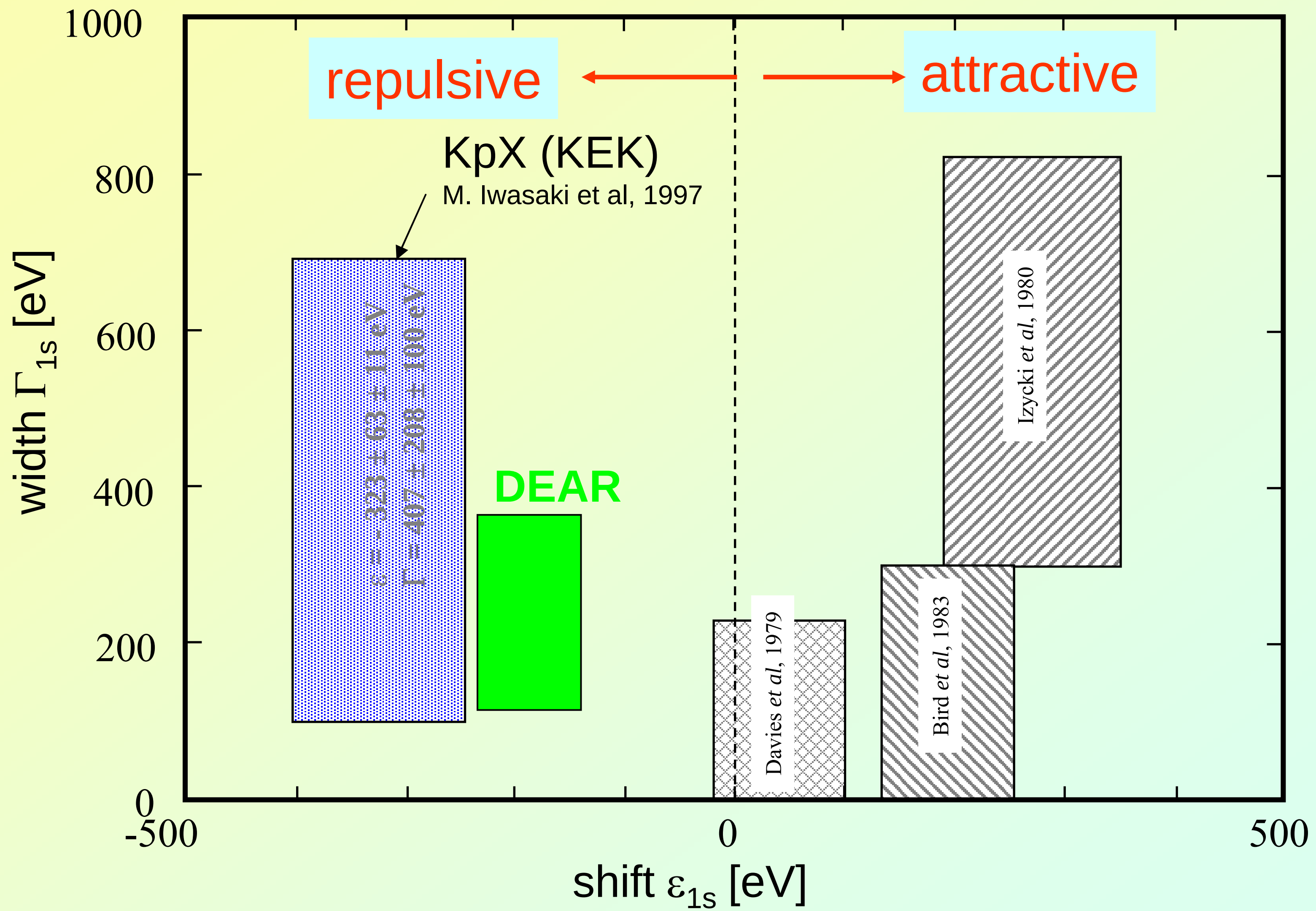


Risultati

Shift: ε_{1s} = - 194 ± 37 (stat.) ± 6 (syst.) eV

Width: Γ_{1s} = 249 ± 111 (stat.) ± 30 (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 ~ 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)

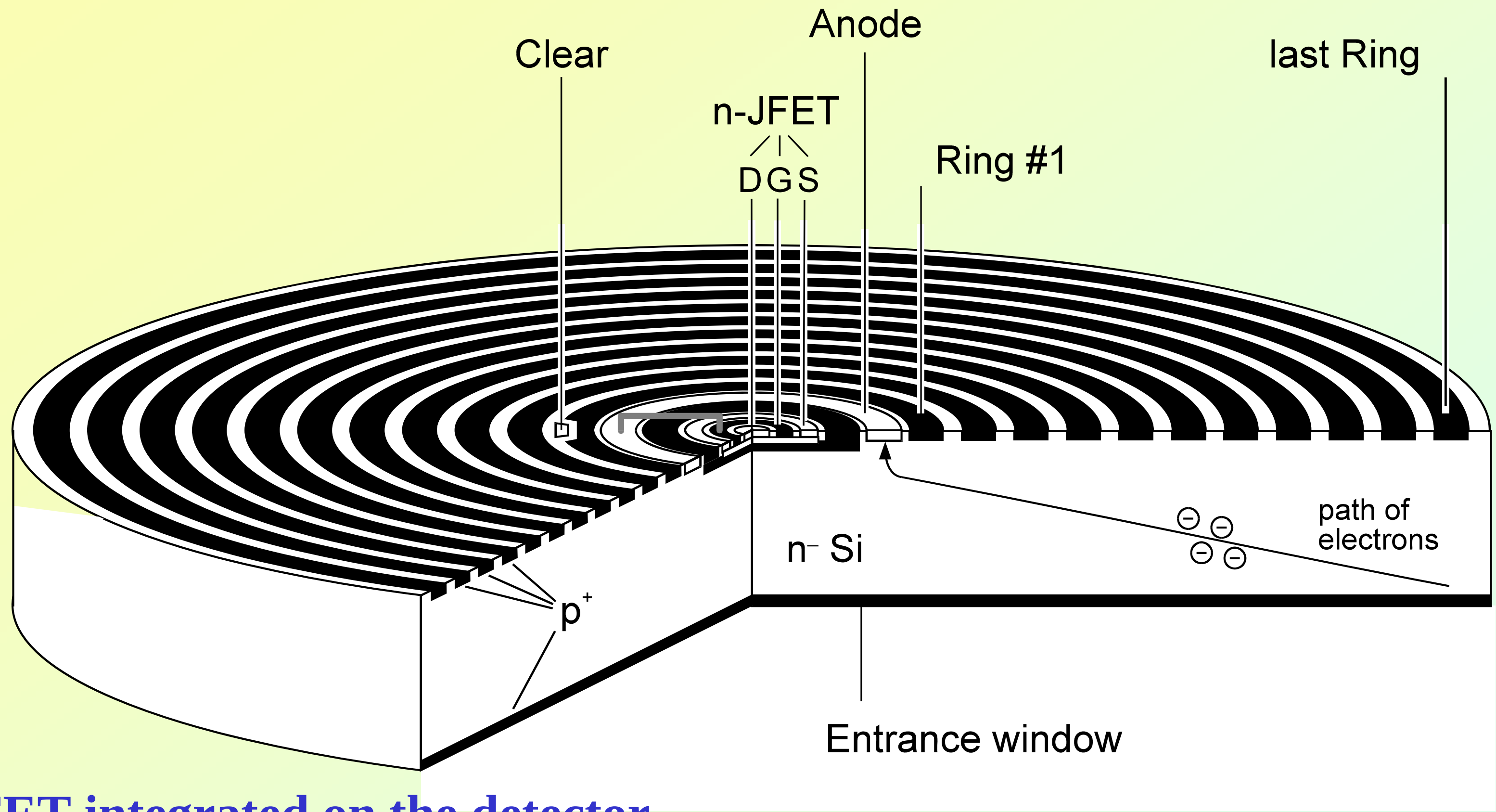
Scelta del nuovo rivelatore:

-Riproduca tutti I vantaggi delle CCD (efficienza e risoluzione in energia);

-Siano VELOCI ~ 1 μs – trigger

=> Silicon Drift Detector

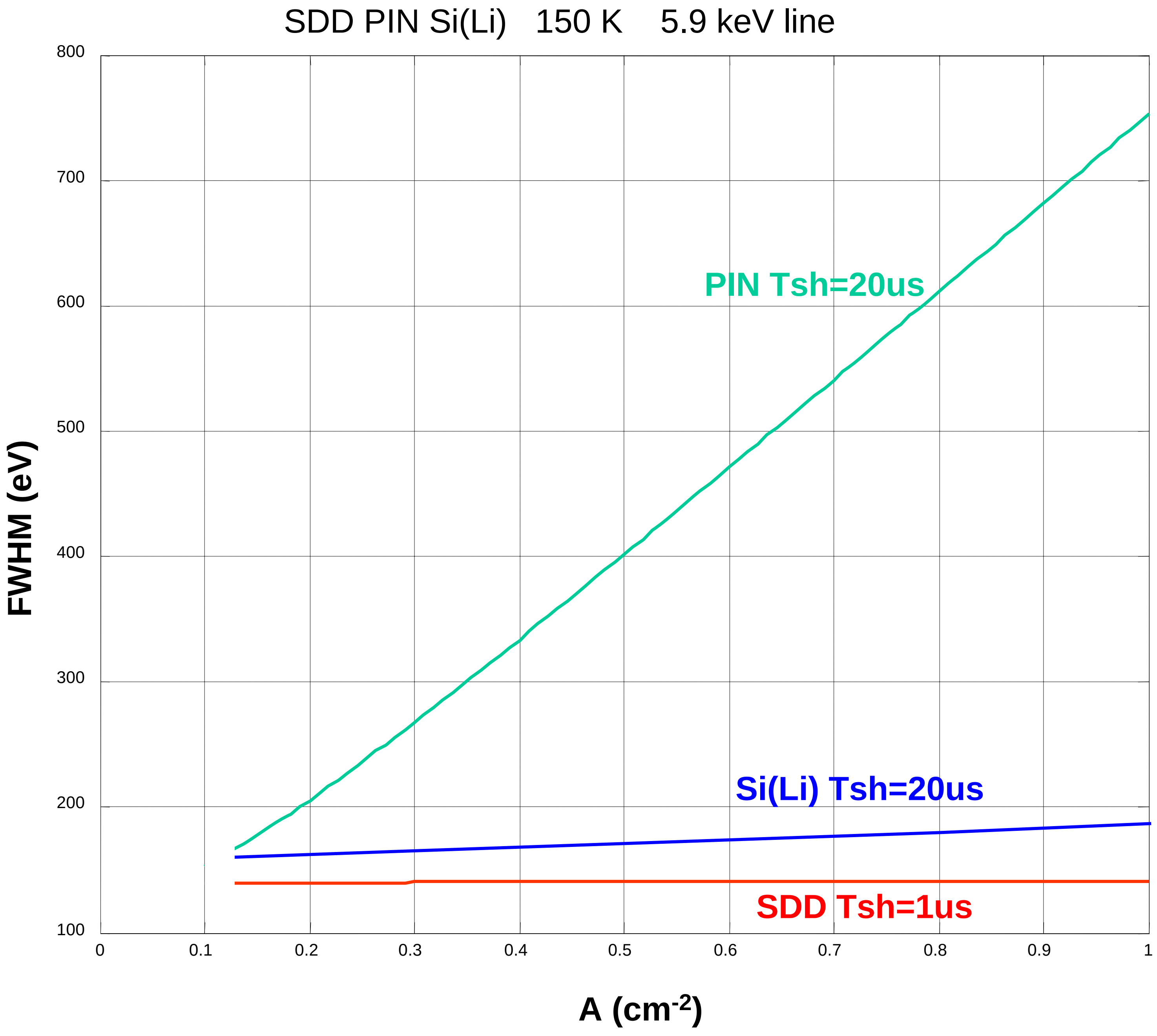
The Silicon Drift Detector with on-chip JFET



JFET integrated on the detector

- capacitive 'matching': $C_{gate} = C_{detector}$
- 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



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

HadronPhysics I3

Study of Strongly Interacting Matter

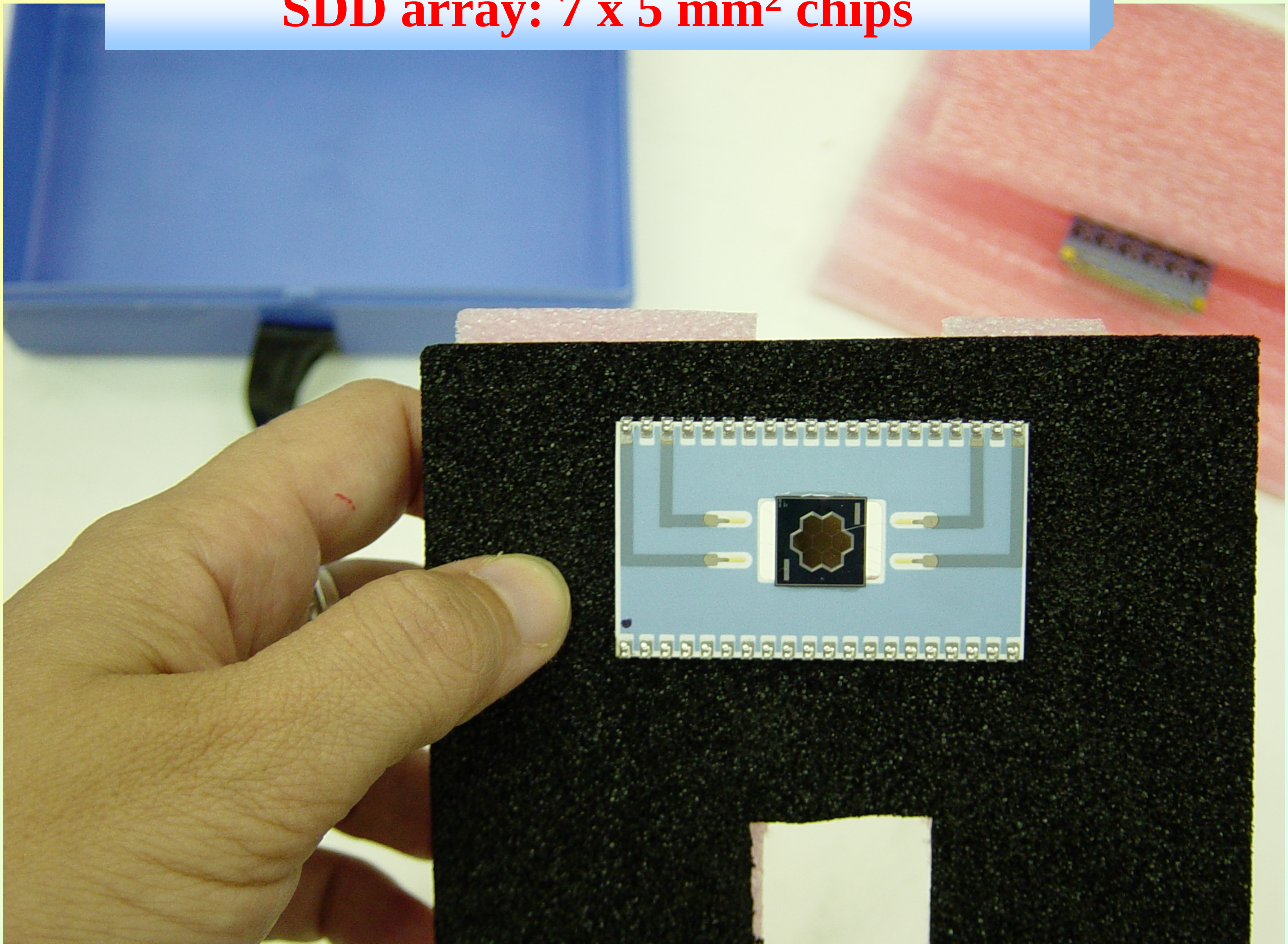
SIlicon Drift Detector for Hadronic Atom Research by Timing Applications

Transport of setup from DEAR lab to BTF

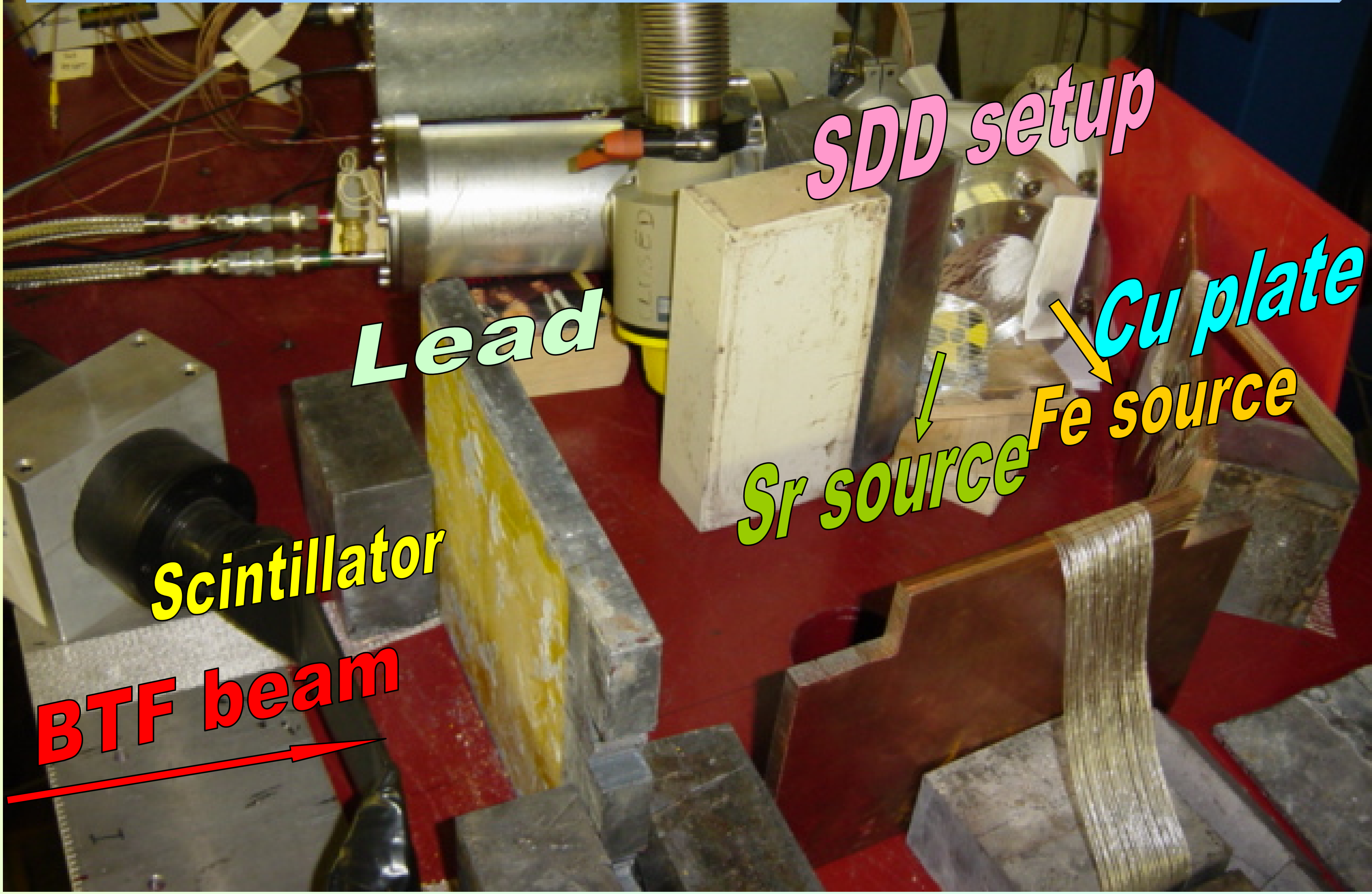
or

high-technology not always a must

SDD array: 7 x 5 mm^2 chips

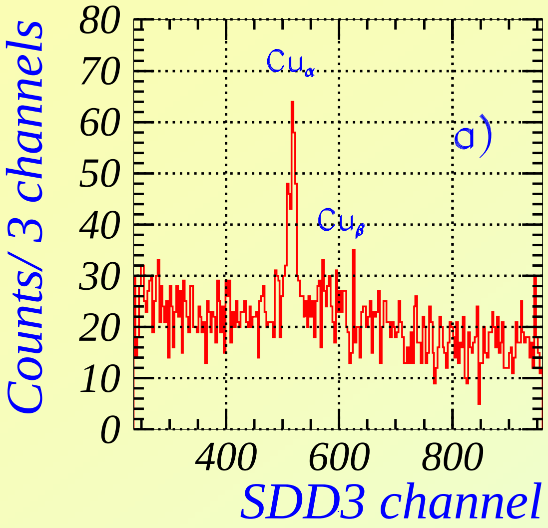


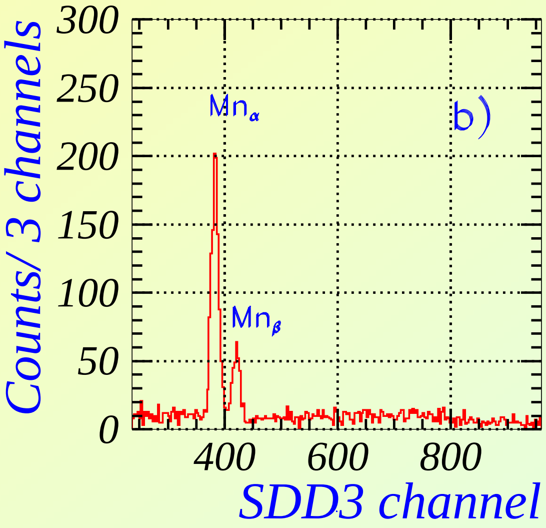
The test setup installed at BTF with the two sources (Fe and Sr) to generate asynchronous background

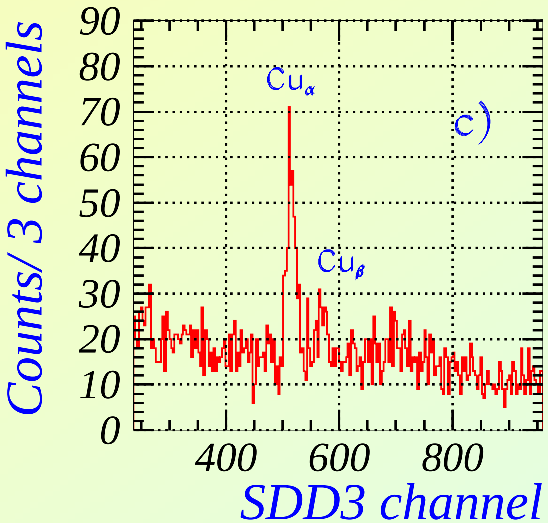


Test of SDD triggering capability

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

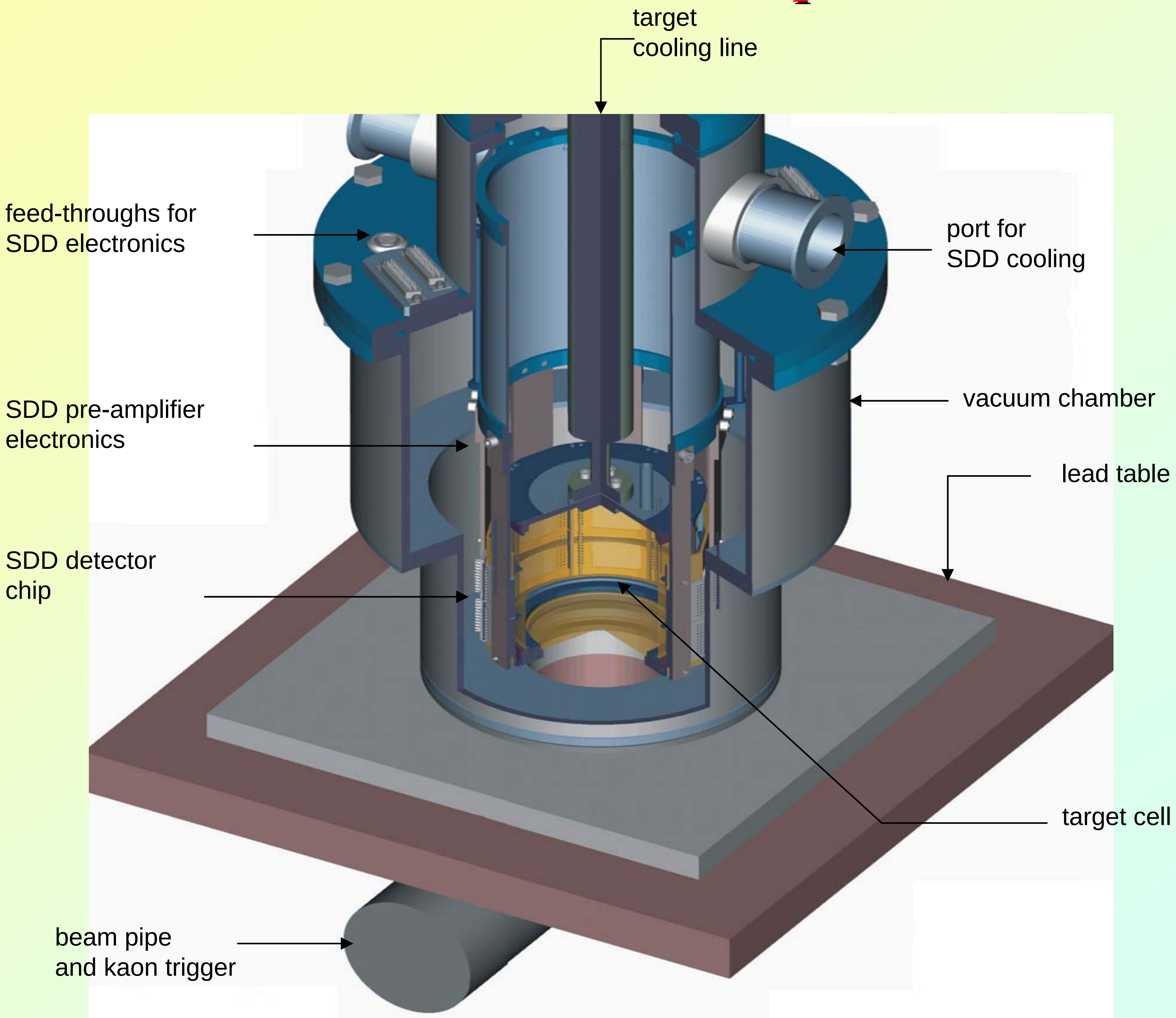
Continuous background:
- synchronous from primary beam
- asynchronous from 90 Sr source

 # 60 Hz

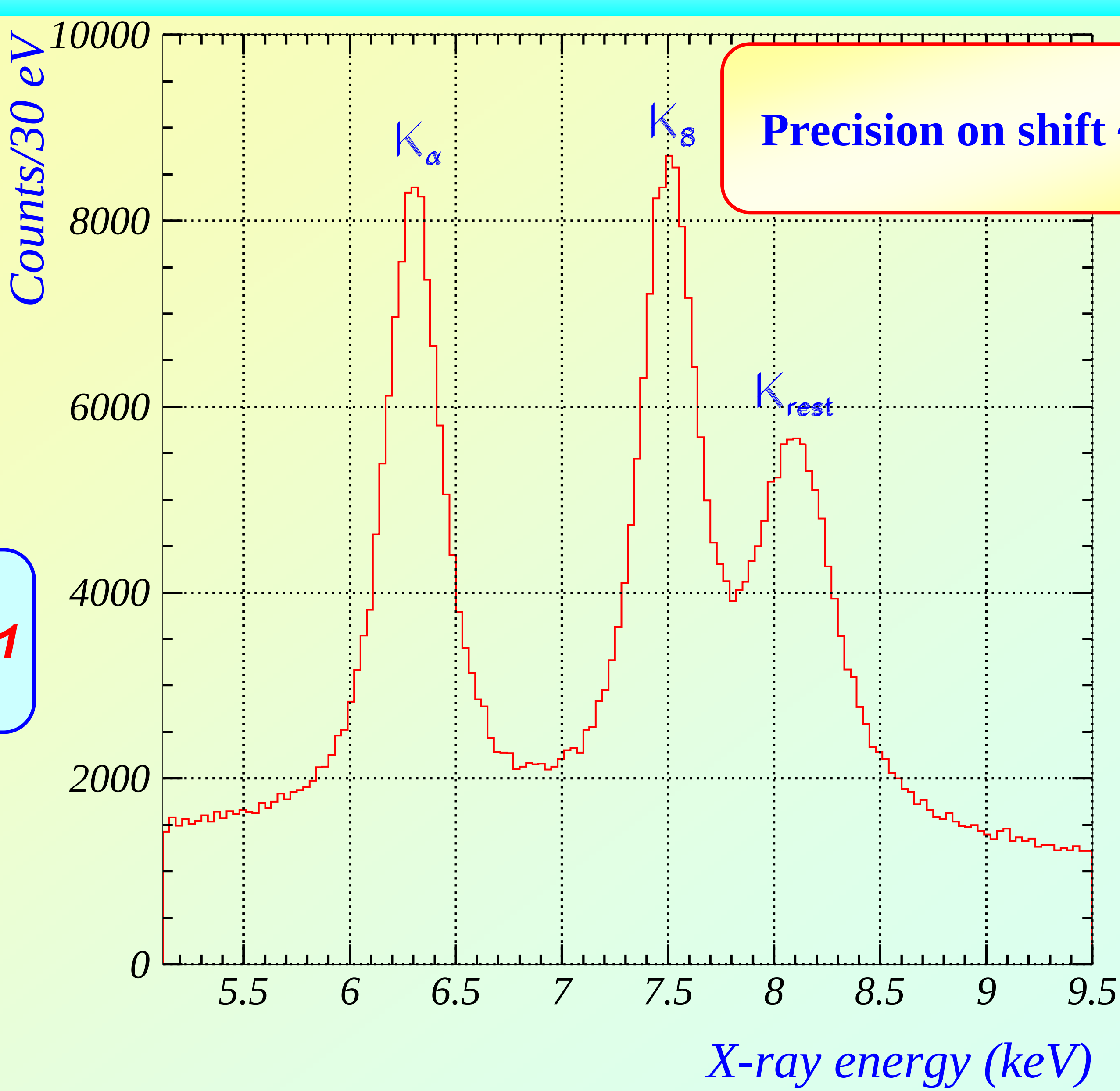
b) **# Trigger ON (~ 16 hours)**
Cu signal visible
Structured asynchronous backgr. completely cut;
Continuous background:
- synchronous from primary beam

 # 5 Hz – as a)

SIDDHARTA setup



SIDDHARTA Kaonic hydrogen simulated spectrum

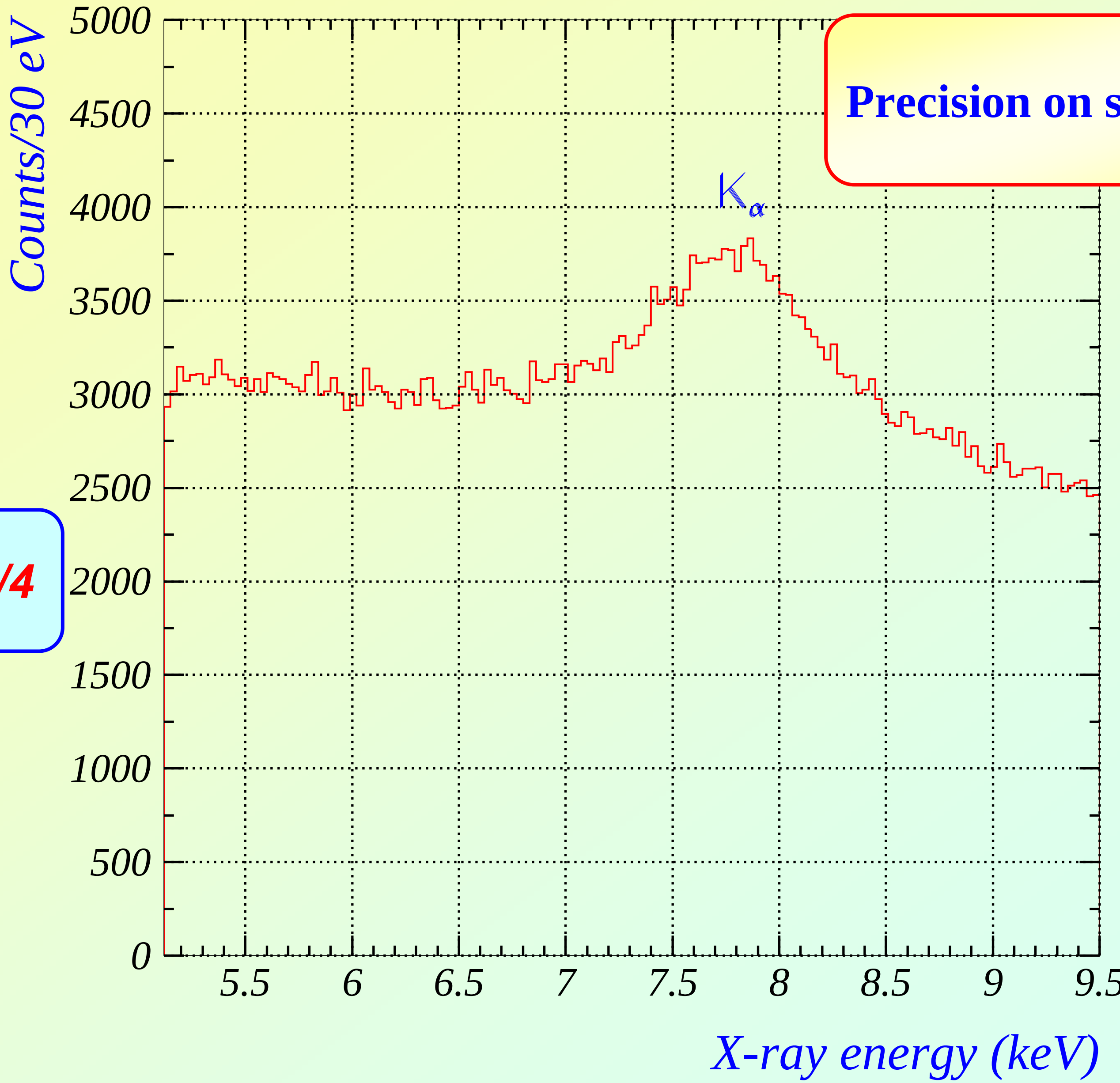


Precision on shift ~1 eV

~100 pb^{-1}

S/B = 5/1

SIDDHARTA Kaonic deuterium simulated spectrum



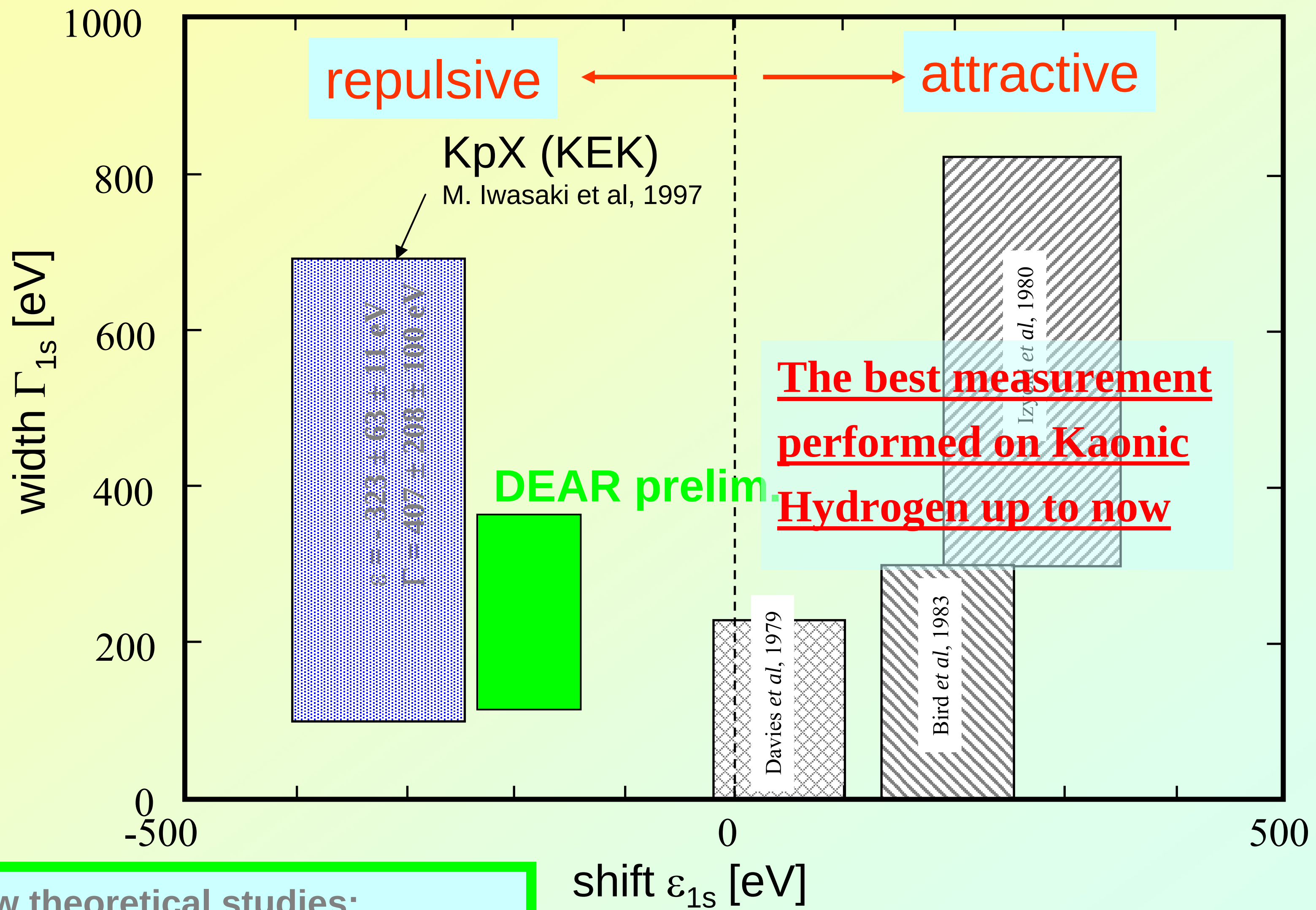
Precision on shift < 10 eV

~100 pb^{-1}

S/B = 1/4

8. Conclusioni

DEAR Results (preliminary)



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

SIDDHARTA plans (from 2007)

1) ~ 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);

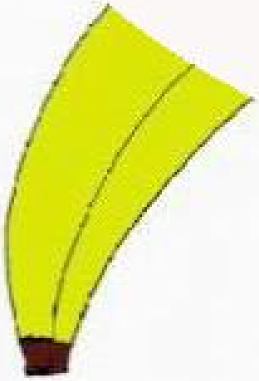
4) Kaon mass precision measurement at the level of 10 keV

5) Other light kaonic atoms measurement (Li, Be…);

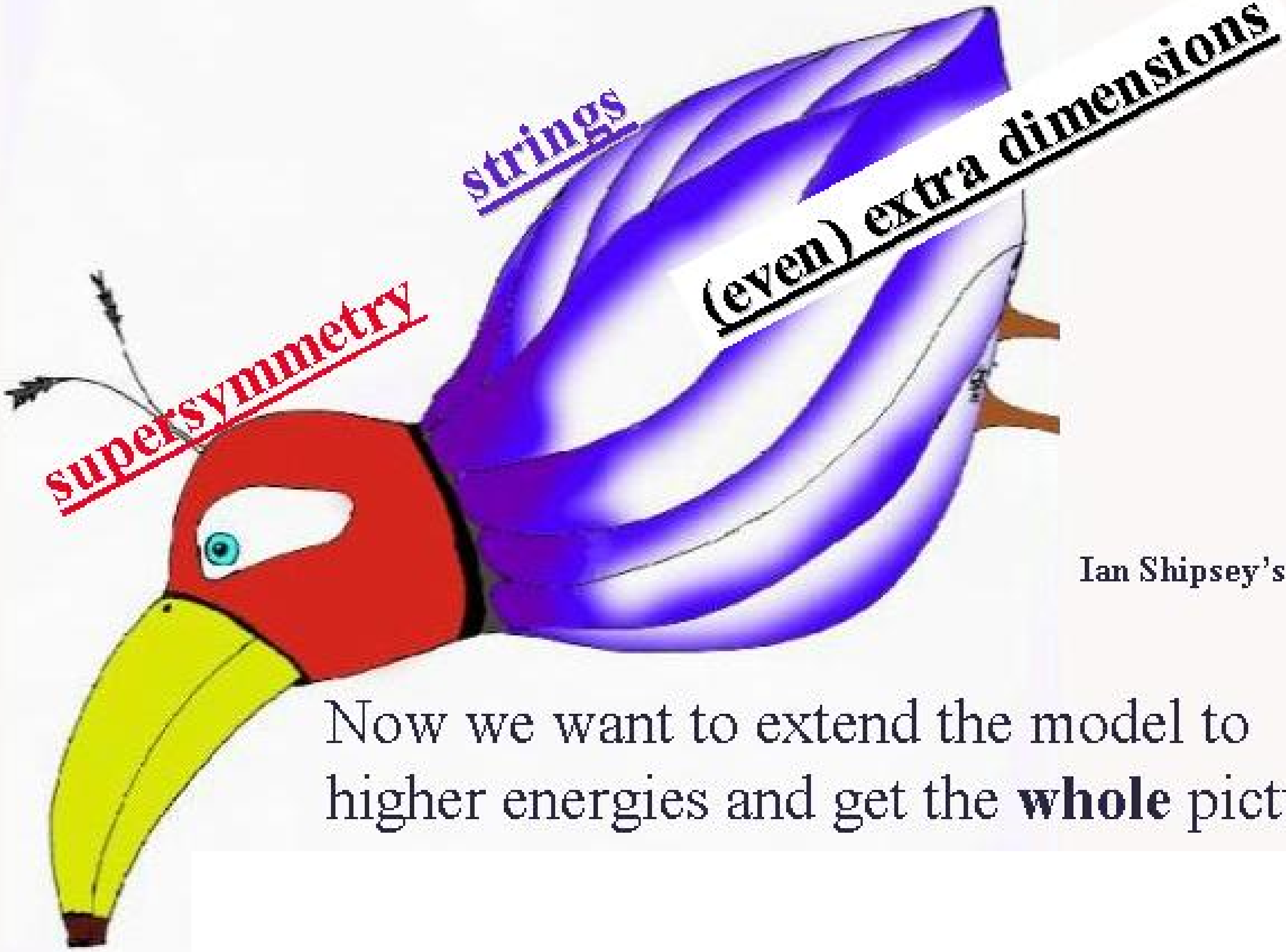
6) Investigate the possibility of the measurement of other types of hadronic exotic atoms (sigmonic hydrogen ?)

the Bigger Big picture

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

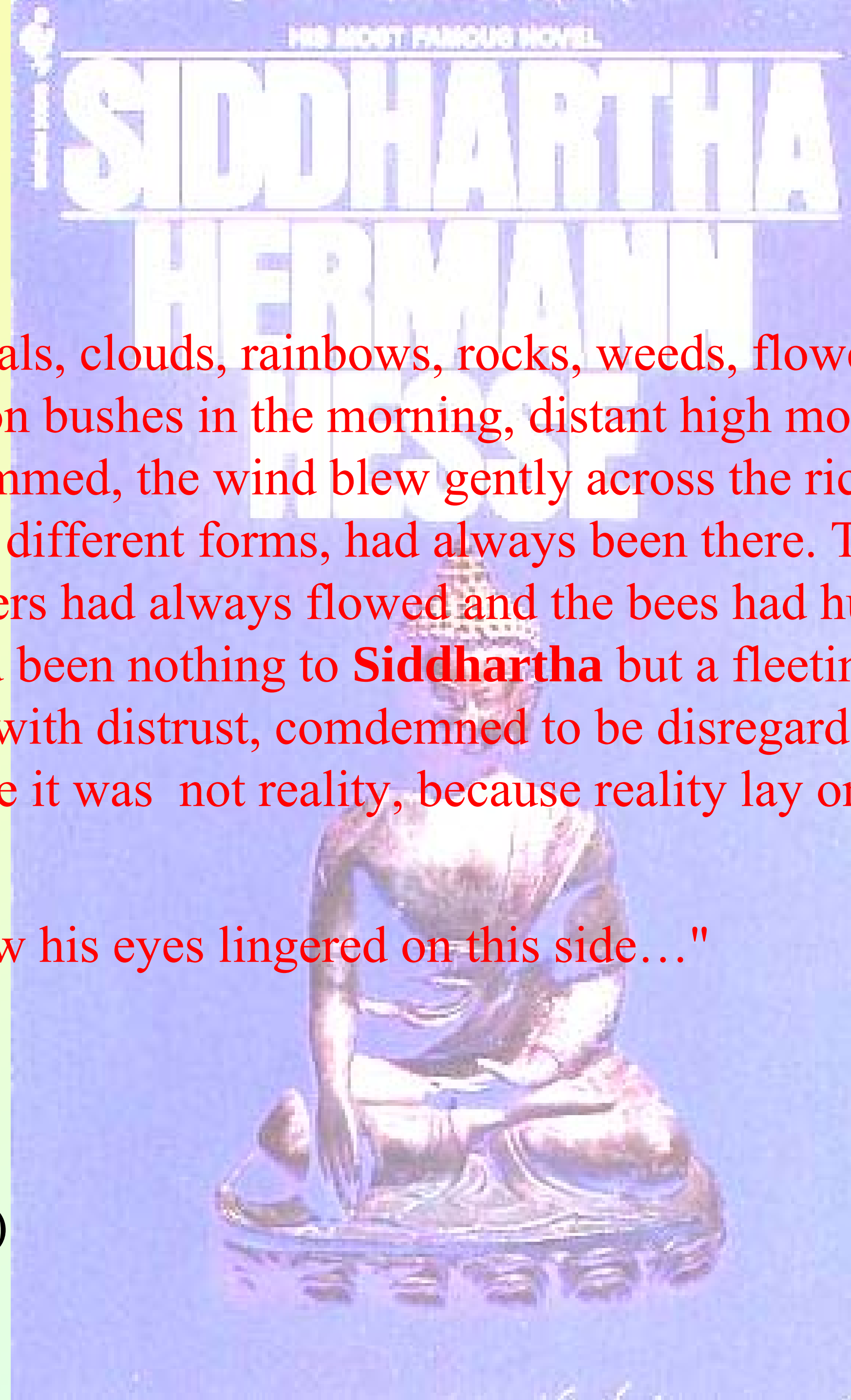


the Bigger Big picture



Ian Shipsey's bird

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



"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, comdemned 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, SIDDHARTA)