Precision Physics
and
Discovery Potential
with
A Φ Factory
at LNF

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DAFNE is an e+e- storage ring

Total energy 1020 MeV – the Φ resonance

The F is produced at rest

A Φ factory (Kaons – η's)

K+K- 49%

KL-KS 34%

ρπ + π+π–π° 15.5%

η γ 1.3%

π° γ 0.13%

Total cross section for ϕ production 3 μbarn

Some basic concepts (and numbers)

Daughter particles are monochromatic,

P_{ch} **~ 125 MeV/c,** P_{neu} **~ 110 MeV/c**

Parity conservation imposes the neutral state to be

a $K_S K_L$ state

In resonant e^+e^- collisions, particles fluxes are:

1.5×10^6 $K^\pm$ pairs/pb^{-1}

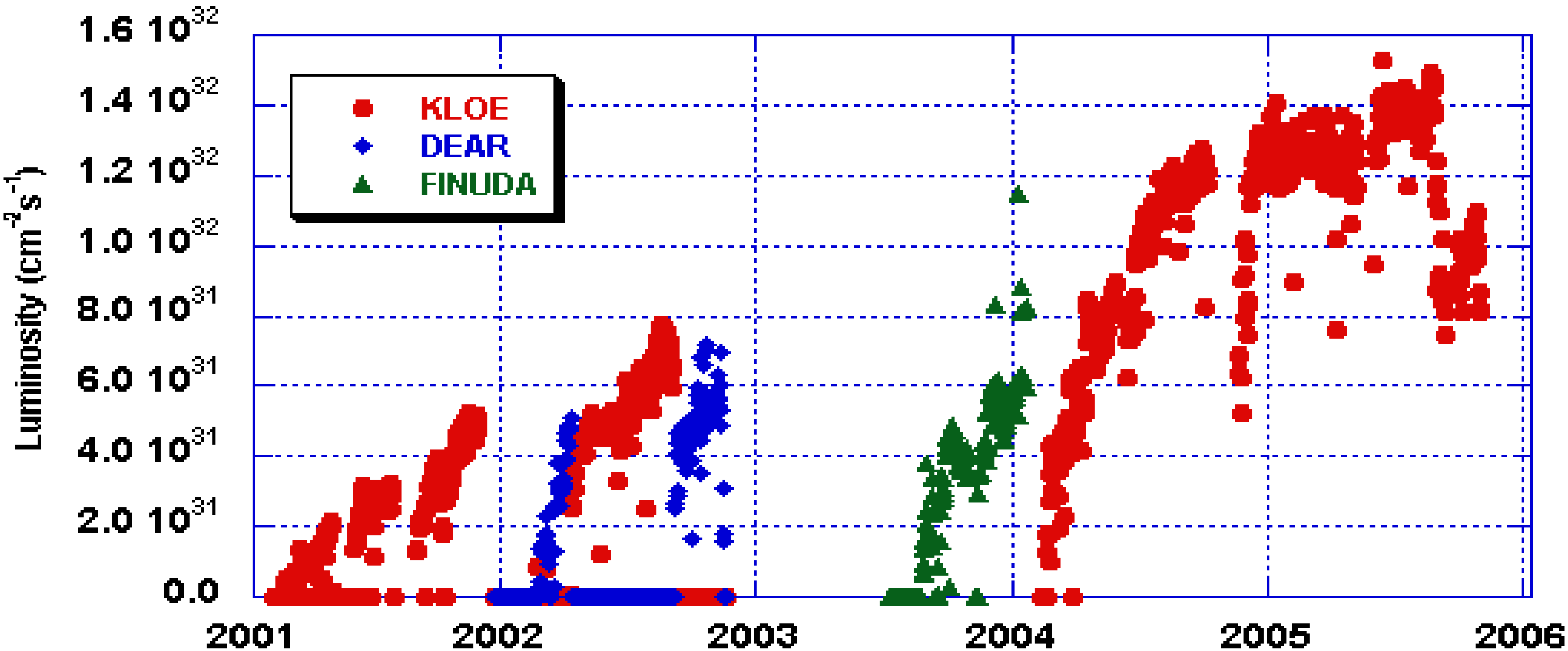
$1. \times 10^6$ $K_S K_L$ pairs/pb^{-1}

Dove siamo

KLOE @ Φ PEAK $\int L = 2.5\ fb^{-1}$ $L_{peak} = 1.5 \times 10^{32}\ cm^{-2}s^{-1}$

@ 1000 MeV $\int L = 250\ pb^{-1}$ $L_{peak} = 1.0 \times 10^{32}\ cm^{-2}s^{-1}$

DAΦNE



4x 10^9 charged kaon pairs produced

$V_{us}\, f_+(0)$ from KLOE results

	K_{Le3}	$K_{L\mu3}$	K_{Se3}	$K^{\pm}_{e3}$	$K^{\pm}_{\mu3}$
BR	**0.4007(15)**	**0.2698(15)**	**7.046(91)×10^{-4}**	**0.05047(46)**	**0.03310(40)**
τ	**50.84(23) ns**		89.58(6) ps	12.384(24) ns	

Unitarity band:

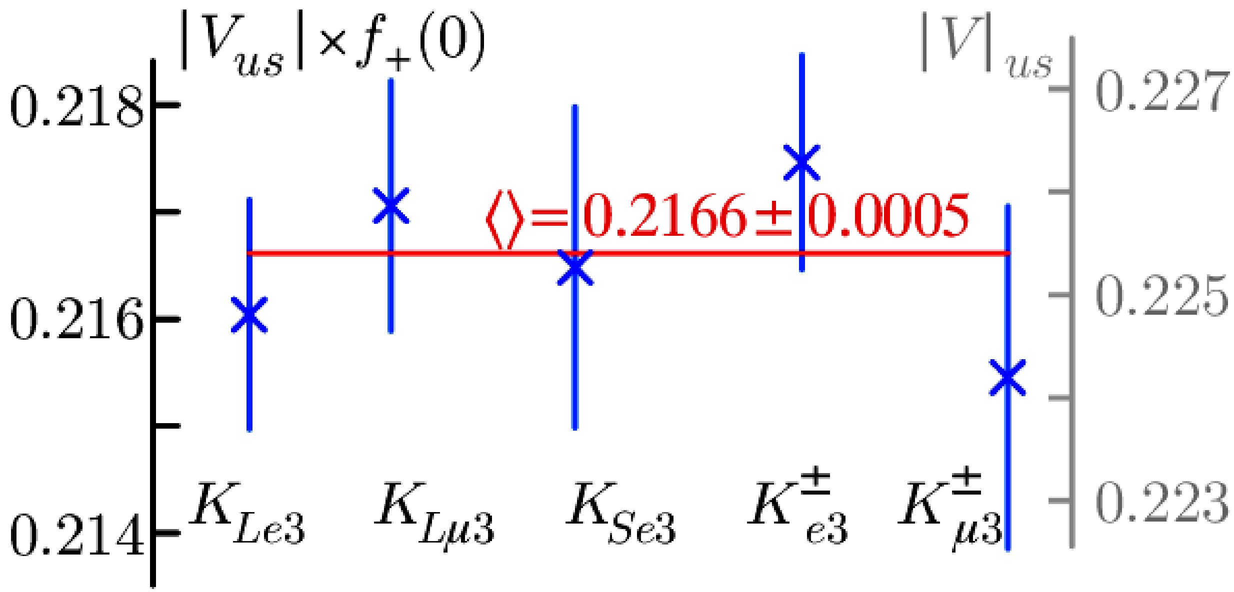
$V_{us} \times f_+(0) = 0.2187(22)$

$f_+(0)=0.961(8)$

Leutwyler and Roos 1984

$V_{ud}=0.97377(27)$

Marciano and Sirlin 2006



χ^2/dof = 1.9/4

CKM unitarity test

Δ = 0.001±0.001

…..e anche KLOE…funziona bene

KLOE papers on *K* physics

$K_S \to \pi e \nu$	PLB 535, 37 (02)
$K_S \to \pi\pi$	PLB 538, 21 (02)
$K_L \to \gamma\gamma$	PLB 566, 61 (03)
$K^\pm \to \pi^\pm\pi^0\pi^0$	PLB 597, 49 (04)
$K_S \to 3\pi^0$	PLB 619, 61 (05)
K_L *lifetime*	PLB 626, 15 (05)
K_L *main BR,* V_{us}	Accepted by PLB
$K^\pm \to \mu^\pm\nu$	Accepted by PLB

Plus (at least) as many in preparation

A possible evolution of DAΦNE

The Laboratory is now studying the possibilty for an upgrade of the present facility

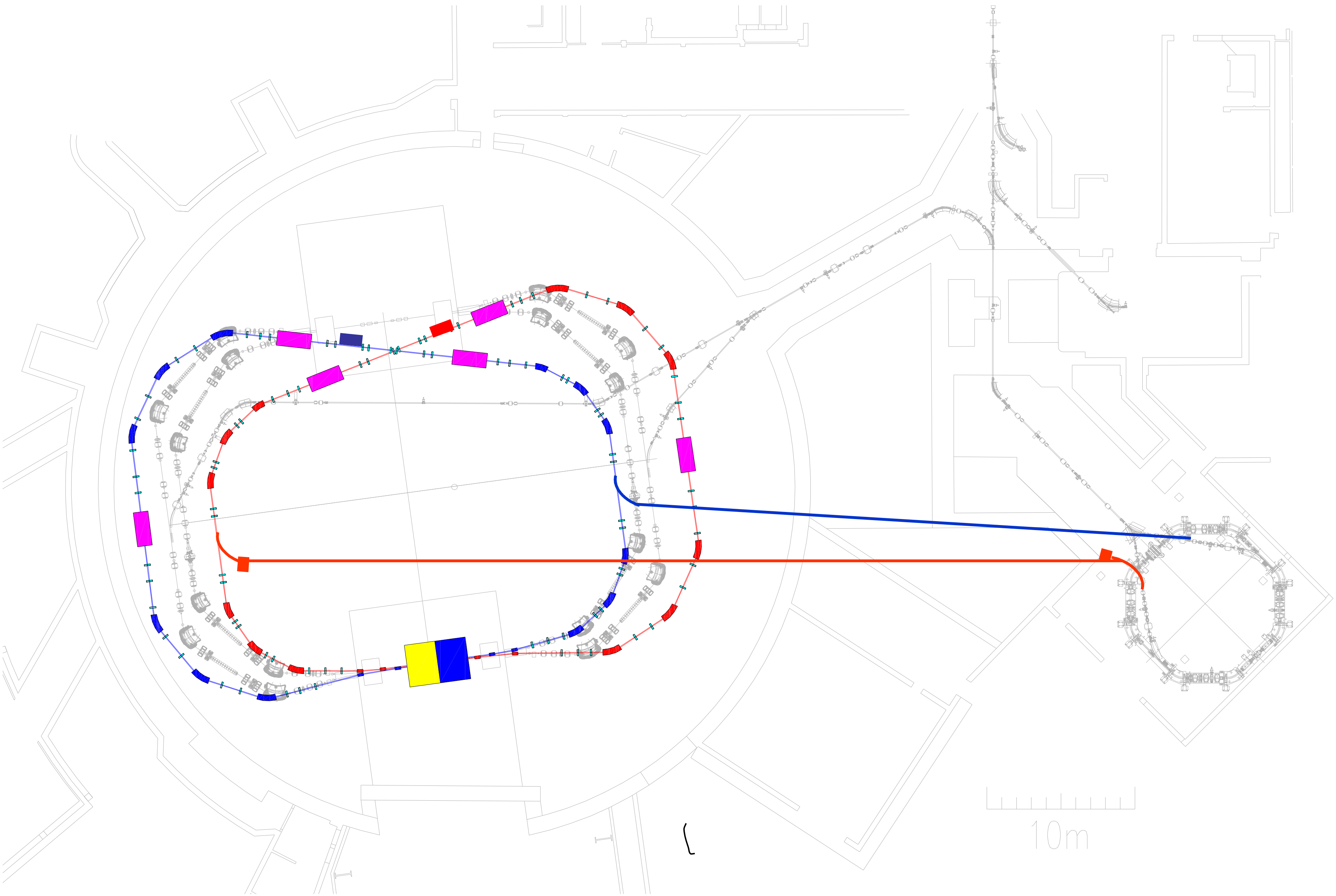
There are a few options under consideration. The one that I will discuss here, and refer to as DAΦNE-2 (DANAE) is:

A Φ-factory able to deliver 7-10 fb^{-1} in one year, i.e some

3 10^{10} kaons of all species after 2-3 years of run

The figures about detection performances

are based on measurements on real data

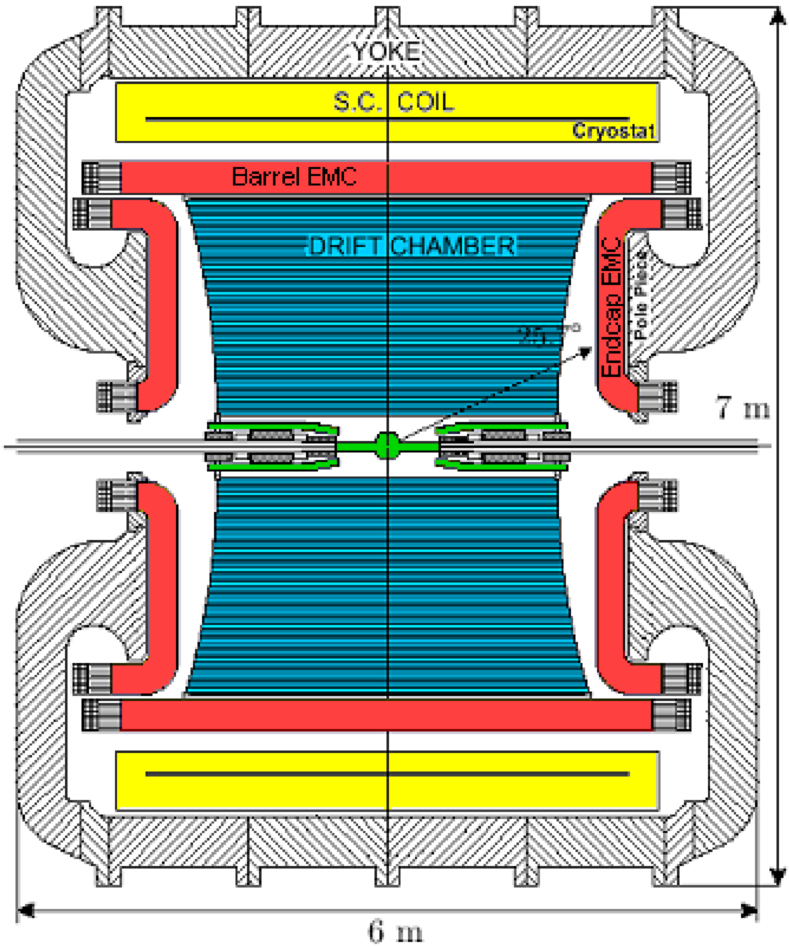


F. Sgamma

Energy and Luminosity Range

TOTAL ENERGY (GeV)	1.02	2.4
Integrated Luminosity per year (ftbarn^{-1})	8	1.5
Total integrated luminosity (5+2 years)	50	3
Peak luminosity > (cm^{-1}sec^{-2})	8 10^{32}	10^{32}

The KLOE experiment



Be beam pipe (0.5 mm thick)
Instrumented permanent magnet quadrupoles (32 PMT's)

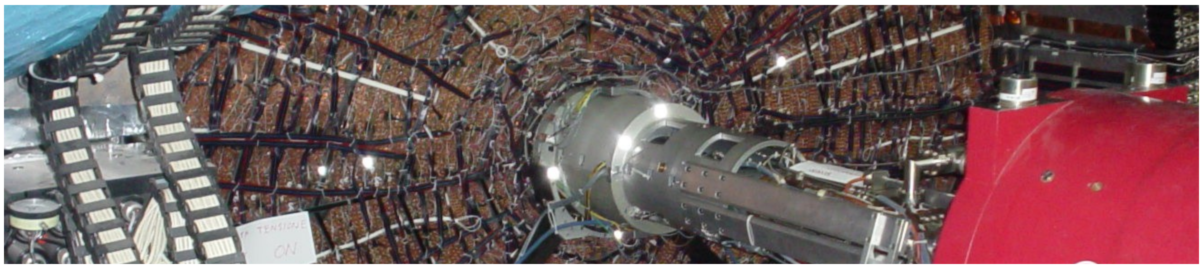
Drift chamber (4 m $\varnothing \times$ 3.3 m)
90% He + 10% IsoB, CF frame
12582 stereo sense wires

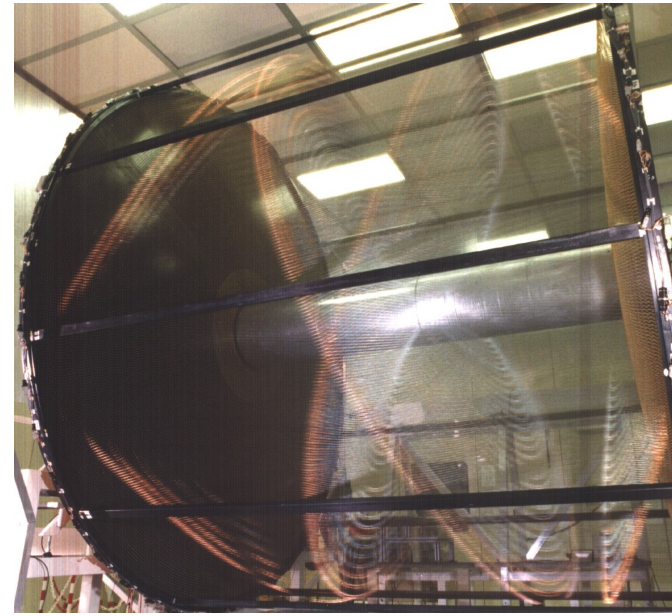
Electromagnetic calorimeter
Lead/scintillating fibers
4880 PMT's

Superconducting coil (5 m bore)
$B = 0.52$ T ($\int B\,dl = 2$ T·m)

The KLOE detector

- Large cylindrical drift chamber
- Lead/scintillating-fiber calorimeter.
- Superconducting coil: 0.52 T field.





He-IsoC_4H_{10} (90%,10%) drift chamber

4m–∅, 3.75m–length, all-stereo

$\sigma_p/p = 0.4$ % (tracks with $\theta > 45°$)

$\sigma_x^{hit} = 150\ \mu m$ (xy), 2 mm (z)

$\sigma_x^{vertex} \sim 1$ mm

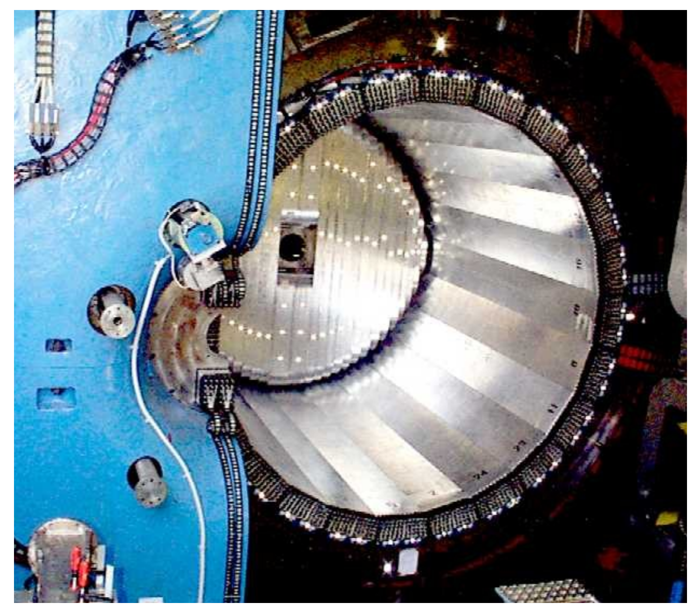
Lead-Scintillating fiber calorimeter

$\sigma_E/E = 5.7\% / \sqrt{E(GeV)}$

$\sigma_t = 54$ ps $/\sqrt{E(GeV)} \oplus 50$ ps

(relative time between clusters) PID capabilities

$\sigma_L(\gamma\gamma)$ ~ 2 cm (π^0 from $K_L \rightarrow \pi^+\pi^-\pi^0$)



K physics at KLOE - tagging

$K_S K_L$ (K^+K^-) produced from ϕ are in a pure $J^{PC} = 1^{--}$ state:

$$K_S, K^+ \longleftarrow \phi \longrightarrow K_L, K^-$$

$$\frac{1}{\sqrt{2}}\left(\left|K_L,\mathbf{p}\right\rangle\left|K_S,-\mathbf{p}\right\rangle-\left|K_L,-\mathbf{p}\right\rangle\left|K_S,\mathbf{p}\right\rangle\right)$$

ϕ decay mode	BR
K^+K^-	49.1%
$K_S K_L$	34.1%

Observation of $K_{S,L}$ signals presence of $K_{L,S}$; $K^{+,-}$ signals $K^{-,+}$

Allows precision measurement of absolute BR's

Allows interference measurements of $K_S K_L$ system

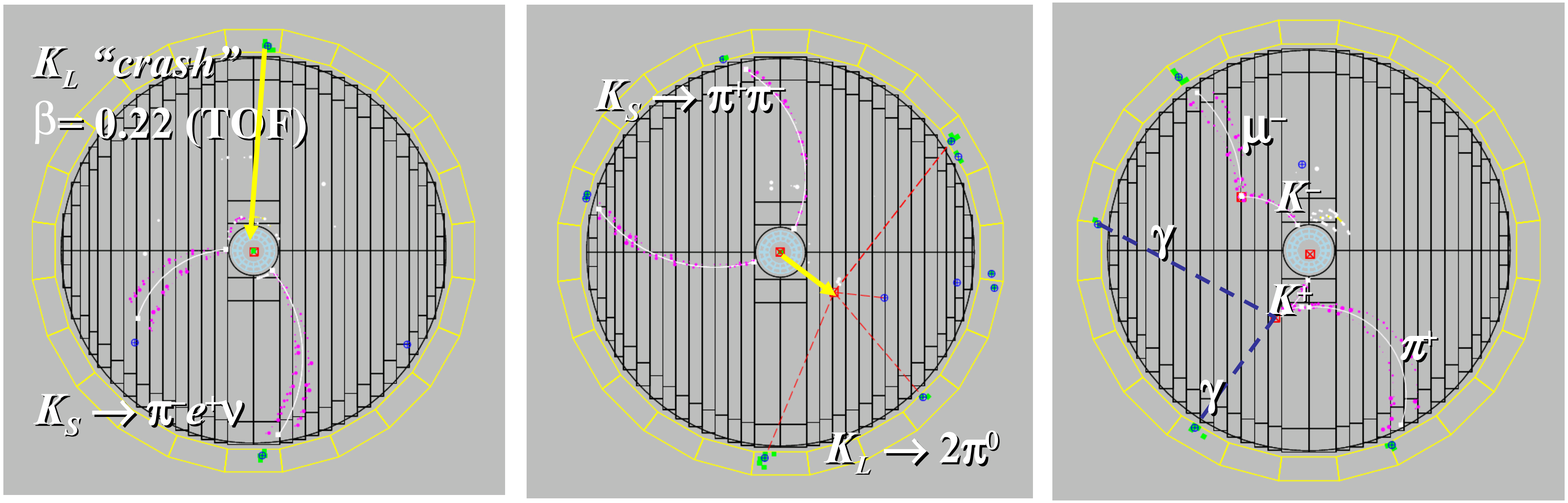
λ_S = 6 mm: K_S decays near IP in vacuum

λ_L = 3.4 m: Appreciable acceptance for K_L decays in the DC ($\sim 0.5\lambda_L$)

$\lambda_\pm$ = 0.9 m: Appreciable acceptance for $K_\pm$ decays in the DC ($\sim 0.6\lambda_\pm$)

Can efficiently tag kaons by identifying the "other charge" kaon

Measuring absolute branching ratios



- **Tagging of K_S, K_L, and $K^\pm$ beams.**

- The **absolute** branching ratio measurement:

$$\mathbf{BR = (N_{sig}/N_{tag})(1/\varepsilon_{sig})}$$

relies on the capability of selecting a tag kaon independently on the decay mode of the other.

- In fact some dependency on signal mode exists: tag bias
- **$\mathbf{BR = (N_{sig}/N_{tag})\ (1/\varepsilon_{sig})\ \alpha_{TB}}$.**
- Tag bias: carefully measured using MC, and data control samples.

Four main physics issues :

1) **Kaon physics**

2) **"High energy" physics 2.4 GeV c.m.**

3) **Time like nucleon form factors**

4) **Nuclear physics (QCD) with Strange nuclei**

With a luminosity about 10^{33} cm^{-2} s^{-1}
50 ft-1 in few years running time
Very-very high at this energy…..

Physics issues at DAΦNE-2

- Tests of **fundamental symmetries (CP, CPT)**
- Tests of prediction of **Chiral Perturbation Theory**
- Tests of prediction of **Standard Model**

1) CKM Unitarity measurements

Lattice QCD hadronic corrections to the matrix elements of the weak current operator between hadrons

measuring $|Vus|^2 / |Vud|^2$ from $\Gamma(K_{\mu 2})/\Gamma(\pi_{\mu 2})$

using |Vud| from b-decay --> |Vus|

To follow the progress of lattice QCD we need to measure rates and lifetime to 1%° accuracy.

UNITARITY OF CKM MATRIX
From 1% to
PER MIL LEVEL
PRECISION E/0 DISCOVERY PHYSICS (50 ft^{-1})

2) Lepton universality

$R = \Gamma(K^{\pm} \rightarrow e^{\pm} \nu) / \Gamma(K^{\pm} \rightarrow \mu^{\pm} \nu)$ and new physics

This ratio is a sensitive probe for new physics effects

Standard Model Prediction: $R = (2.472 \pm 0.001) \times 10^{-5}$

NA48/2 Preliminary 05: $R = (2.416 \pm 0.049) \times 10^{-5}$

NA48/2 can reach ~ 1% precision with present data

Scaling from *measured* efficiencies for K_{e3} decays
KLOE can aim at ~ 0.5% @ 20 fb^{-1}

3) $K_S \to \pi e \nu$ decays and the $\Delta S = \Delta Q$ rule

The relevant parameter here is:

$$Re\,(x^+) \sim \frac{\langle e^+\pi^-\nu \,|\, H_{wk} \,|\, \overline{K^0} \rangle}{\langle e^+\pi^-\nu \,|\, H_{wk} \,|\, K^0 \rangle}$$

~ 10^{-6} S.M.

$$1 + 4\,Re(x^+) = \frac{\Gamma_S}{\Gamma_L} = \frac{BR(K_S \to \pi e \nu)\ \tau_L}{BR(K_L \to \pi e \nu)\ \tau_S}$$

Present Uncertainties: $20\ 10^{-3}$ (Γ_S/Γ_L), $6\ 10^{-3}$ ($BR(K_S \to \pi e \nu)$), $4\ 10^{-3}$ ($BR(K_L \to \pi e \nu)$), $1\ 10^{-3}$ (τ_S)

These are KLOE measurements

@ 20 fb^{-1} one can reach ~ $2\ 10^{-3}$ in $BR(K_S \to \pi e \nu)$

4) CPT Violation in Kaon decays

A different Charge Asymmetry in semileptonic K_L and K_S decays is predicted due to CP and (possibly) CPT violation

$$\delta_L = 2\mathrm{Re}(\varepsilon_K) - \Delta$$
$$\delta_S = 2\mathrm{Re}(\varepsilon_K) + \Delta$$

CPT is violated if $\delta_S \neq \delta_L$

The most recent measurement are:

$\delta_L = (3322 \pm 58 \pm 47) \times 10^{-6}$ — **KTeV, 2002**

$\delta_S = (1.5 \pm 10 \pm 3) \times 10^{-3}$ — **KLOE, ~400 pb^{-1} (now)**

$\delta_S = (1.5 \pm 1) \times 10^{-3}$ — **KLOE-2, ~ 50 ft^{-1}**

PRECISION E/0 DISCOVERY PHYSICS (50 ft^{-1})

5) CPT and Quantum Mechanics

quantum gravity

could modify the standard QM

decoherence effects **with** **CPT violation**

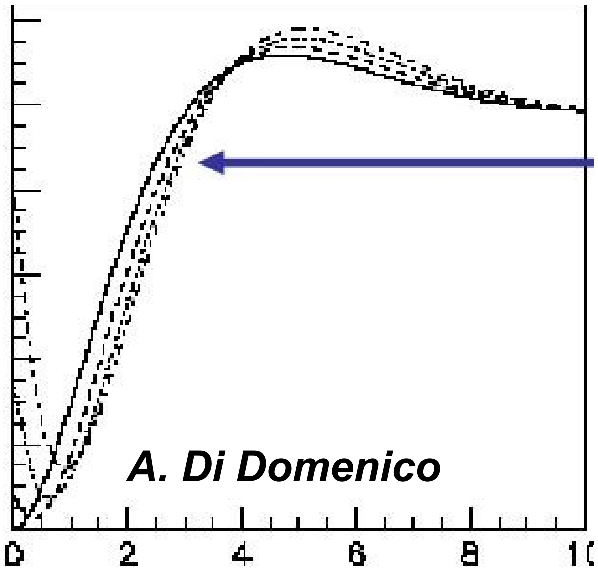
deviation of the behaviour of entagled systems

(like $K_S K_L$ from Φ decays)

from the one predicted by standard QM

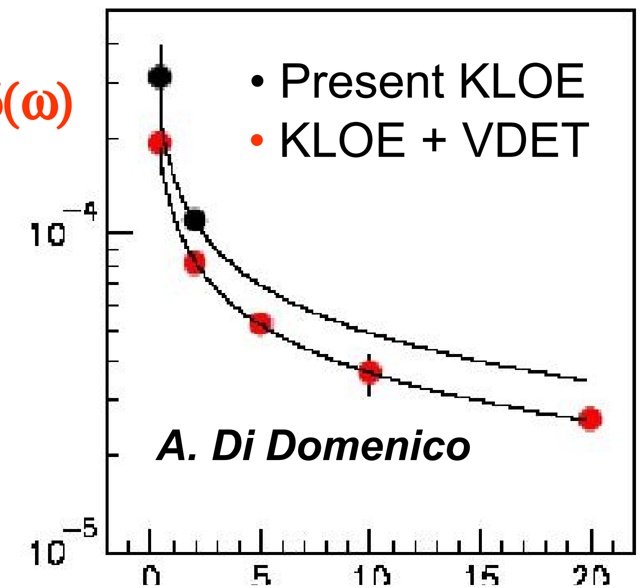
Measuring the ω parameter

The parameter **ω** can be measured by a fit to the decay time distribution of the $K_S K_L$ pair to **4π**



Δt (τ_S units)

Arg(ω) = 0,
|ω| = 1,2,3 x 10^{-3}



δ(ω)

fb^{-1}

$\pi^+\pi^-\pi^+\pi^-$ Final state

CPT and decoherence: the EHNS model

Ellis, Hagelin, Nanopoulos and (independently) ***Srednicki*** set up an evolution equation of the neutral *K* system containing three new CPT violating parameters α, β, γ with dimensions of energy

Naively, one expects $\alpha, \beta, \gamma \sim O(M_K^2 / M_{Plank}) \sim 10^{-20}$ GeV

Peskin and ***Huet*** worked out the expression of the usual double decay intensity of the $K_S K_L$ pair from Φ decays in the EHNS framework

There appear new bizarre terms in the distribution which allow to extract experimentally limits (or measurements) of these new parameters by proper fitting

Fixing the EHNS parameters

The EHNS parameters have already been constrained by CPLEAR results

$$\alpha = (-0.5 \pm 2.8) \times 10^{-17}\ \text{GeV}$$

$$\beta = (\ \ 2.5 \pm 2.3) \times 10^{-19}\ \text{GeV}$$

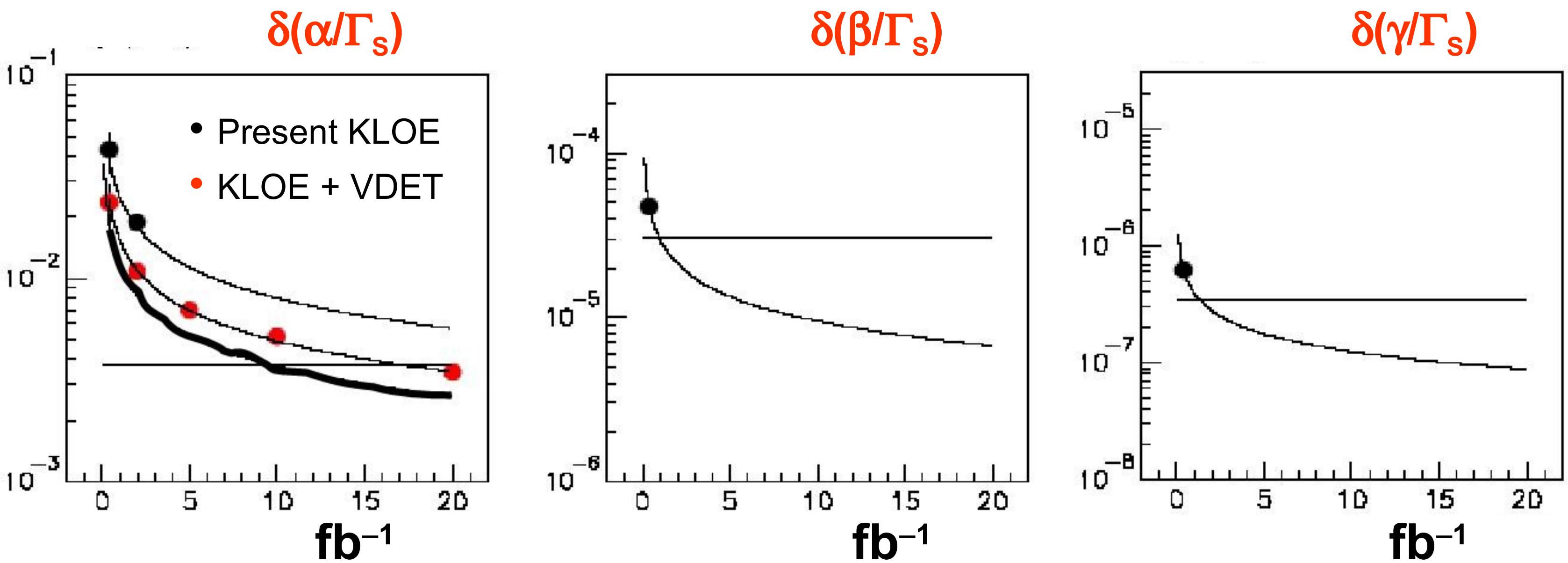
$$\gamma = (\ \ 1.1 \pm 2.5) \times 10^{-21}\ \text{GeV}$$

KLOE can reach equal sensitivity on β,γ with present data sample just with the $\pi^+\pi^-\pi^+\pi^-$ channel

Fixing the EHNS parameters

With 20 fb^{-1} one can dramatically improve, especially on β and γ

In the plots below the horizontal line is CPLEAR



CPT and Bose statistics: the BMP model

Bernabeu, Mavromatos and Pavassiliou argued that in presence of CPT violation induced by quantum gravity the **concept of antiparticle has to be modified**.

In this case the $K_S K_L$ state from Φ decays ***does not strictly obey Bose statistics***,

thus modifying the final state wave function

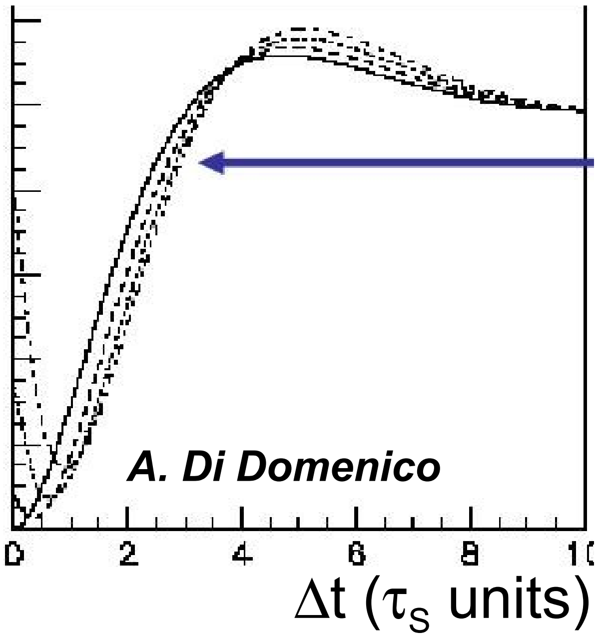
$$| i \rangle = C \{ (| K_S(+)\rangle | K_L(-)\rangle - | K_L(+)\rangle | K_S(-)\rangle) + \omega (| K_S(+)\rangle | K_S(-)\rangle - | K_L(+)\rangle | K_L(-)\rangle) \}$$

The complex parameter ω quantifies the departure from Bose statistics, in a formalism in which **the time evolution of the state is still described by the equations of standard QM**

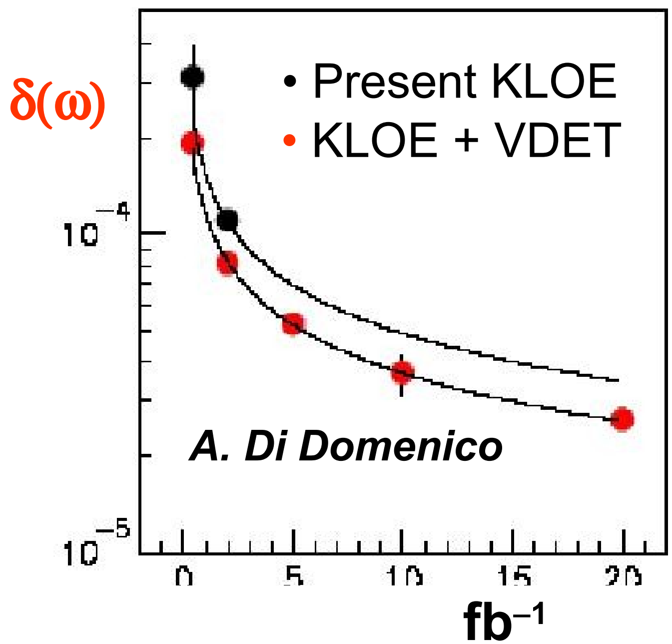
Naively, $|\omega| \sim O(M_K^2 / M_{Plank} \Delta\Gamma)^{1/2} \sim 10^{-3} \div 10^{-4}$

Measuring the ω parameter

The parameter **ω** can be measured by a fit to the decay time distribution of the $K_S K_L$ pair to 4π



Arg(ω) = 0,
|ω| = 1,2,3 x 10^{-3}



A note on the previous slides

All our estimates refer to the $\pi^+\pi^-\pi^+\pi^-$ channel only. Further information can be obtained by other decay channels, to be studied in more detail.

6) Chiral Perturbation Theory

In the limit in which u,d,s are massless the QCD lagrangian is invariant under $SU_L(3)xSU_R(3)$. The left-handed world is separate from the right-handed one: this is *chiral symmetry.*

The dynamical breaking of this (approximate) symmetry produces 8 massless Goldstone bosons to be identified with the π, K, η

One then writes down the most general lagrangian consistent with the chiral symmetry, and expands it in terms of the momentum of the involved particles. If momenta are low enough, then:

$$M(p^2) > M(p^4) > M(p^6) \dots$$

…and one can perform calculations perturbatively

This is the basic idea of *Chiral Perturbation Theory*

ChPT: the pros and the cons

The effective ChPT lagrangian leaves a number of free parameters to be determined experimentally, that increase with the order to which the lagrangian is computed

the higher you go with the power of p, the higher is the number of parameters and hence the number measurement you need to fix the theory

2 at orderd p^2, 12 at order p^4…

$K_s \rightarrow \gamma\gamma$: a test for ChPT

NA48/1 has measured BR($K_S \rightarrow \gamma\gamma$) = (2.78 ±0.06±0.04)x$10^{-6}$

This result differs from predictions of ChPT at O(p^4) by 30%

A preliminary analysis shows that KLOE can reach a statistical accuracy of ~ 4% *with the present data sample*.

A projection to 20 fb^{-1} would give an accuracy better than 1%

$K_s \to \pi^+\pi^-\pi^0$: another test for ChPT

ChPT predicts $B(K_s \to \pi^+\pi^-\pi^0) = (2.4 \pm 0.7) \times 10^{-7}$

The present experimental value $(3.3\,^{+1.1}_{-0.9}) \times 10^{-7}$ is the average of three different measurement each individually precise at ~ 40%

A preliminary KLOE analysis obtains $\varepsilon_{sig} \sim 1.3\%$, S/B ~ 2

Assuming	Error on BR @ 2 fb^{-1} (%)	Error on BR @ 20 fb^{-1} (%)
No further effort made to reduce background	~ 60%	~ 20%
Further efforts completely remove background	~ 40%	~ 12%

7) A digression in the η world

Actually, at present KLOE has the largest η statistics in the world

The η world is largely complementary with the *K* one in that it addresses most of the same physics issues.

Tests of C, CP, CPT	Tests of ChPT
$\eta \rightarrow \gamma\gamma\gamma$	$\eta \rightarrow \pi^0\gamma\gamma$
$\eta \rightarrow \pi^0 l^+ l^-$	$\eta \rightarrow 3\pi$
$\eta \rightarrow \pi\pi\gamma$	$\eta \rightarrow \pi\pi\gamma$

8) $K_s \rightarrow \pi^0\pi^0\pi^0$: perspectives

Background mostly due to photon clusters double splittings

Preliminary studies show that there is room for "algorithmic" improvements in background rejection without losses in signal efficiency

Study of the entire KLOE data set crucial for a better assessment of the real potentialities of the analysis but…

…there are hints that @ 20 fb^{-1} one can reach ~ 5×10^{-9}

With KLOE as it is now.

With 50 ft-1 it will be possible to observe this rare but expected decays in the SM

9) KS rare decays

Upgrades of the detector can likely be of importance for other important studies:

$K_S \to \pi^0 e^+ e^- \ (\pi^0 \mu^+ \mu^-)$

$K_S \to \pi^0 \gamma\gamma$

$K_S \to e^+ e^- \ (\mu^+ \mu^-)$

$K_L \to \gamma\gamma$

K_S *lifetime*

With a statistics equal to the total statistics of the previous experiments (with 50 ft-1)

“HIGH ENERGY PHYSICS”

1) Total cross section measurement :
below 1 GeV anomalous magnetic moment of the μ
between 1 e 2.5 GeV limits the calculation of the hadronic correction to α_{em}

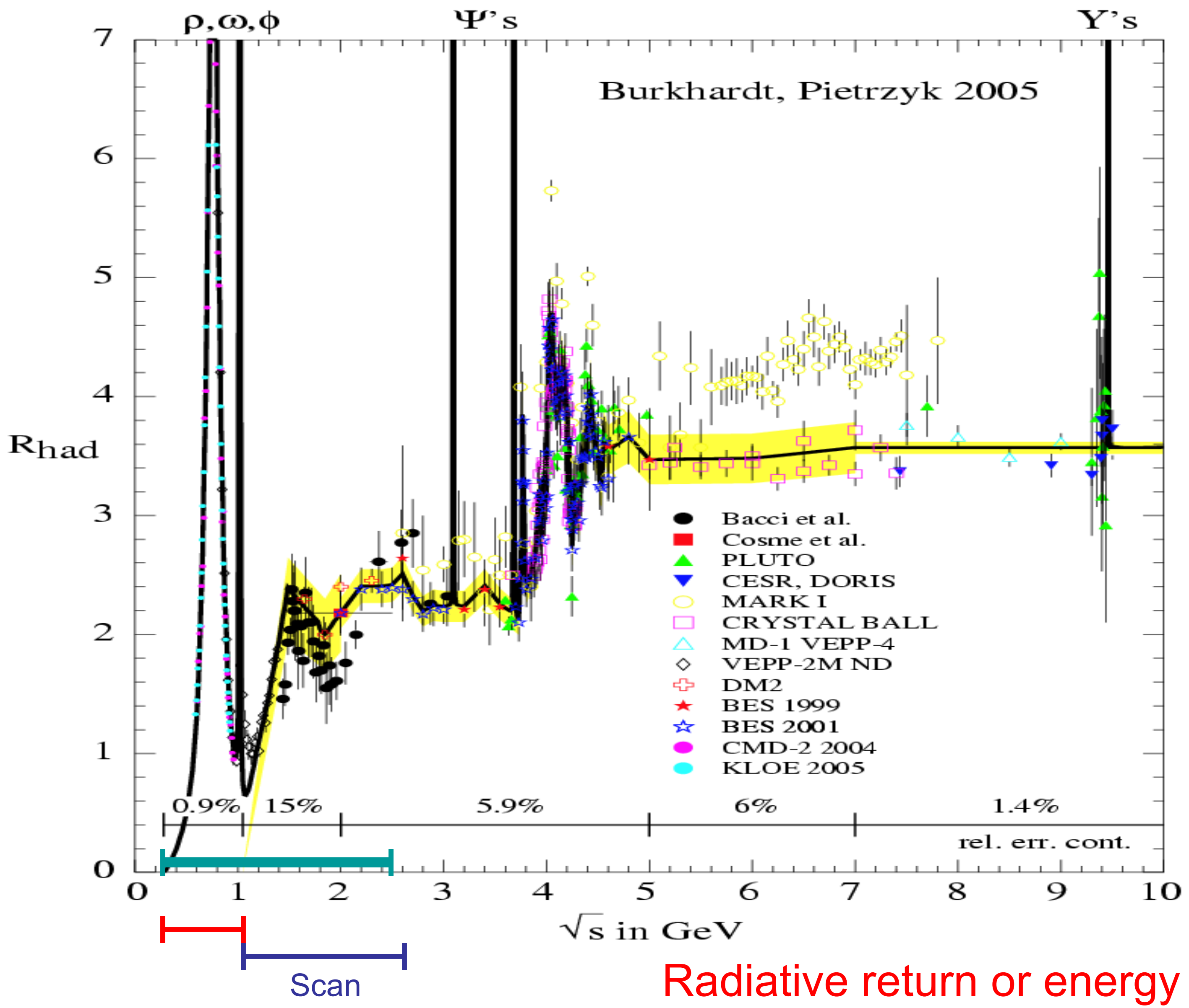
5) Meson spectroscopy 1 e 2.5 GeV:
many observed states , hybrids and glueball ?

9) Radiative decays of the Φ:
very high statistics of η e η'
scalar mesons a0(980) e f0(980), two K decays accessible

13) $\gamma\gamma$ interactions :
widths of scalar mesons and search of the σ meson

16) Measurements of the K-nucleon cross section:
sistematic study of the K-N processes, with final state identification, on many gaseous targets

10) Total cross section precision measurement - R



Radiative return or energy scan

11) R → a_μ

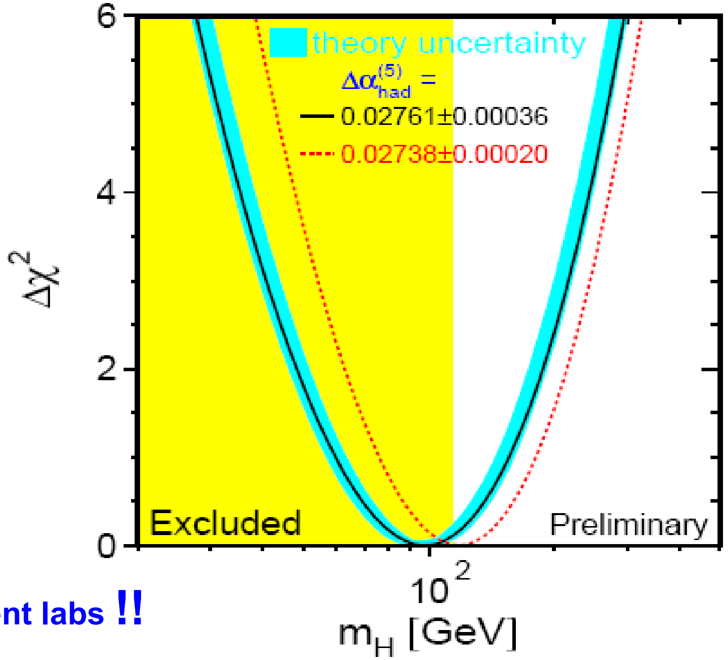
$$a_\mu = (116592080 \pm 50_{stat} \pm 40_{sys}) \times 10^{-11}$$

$a_\mu^{SM} \times 10^{11}$	$(a_\mu^{EXP} - a_\mu^{SM}) \times 10^{11}$	σ	HLO Reference
116591845 (69)	235 (91)	2.6 (3.0)	[1] (e^+e^-)
116591859 (90)	221 (108)	2.1 (2.5)	[2] (e^+e^-)
116591845 (95)	235 (113)	2.1 (2.5)	[3] (e^+e^-)
116591835 (69)	245 (91)	2.7 (3.1)	[4] (e^+e^-)
116591855 (55)	225 (81)	2.8 (3.2)	[5] (e^+e^-)
116592018 (63)	62 (87)	0.7 (1.3)	[6] (τ)
116591938 (54)	142 (81)	1.8 (2.3)	[5] (e^+e^-, τ)

12) R → $\Delta\alpha^{(5)}_{had}$

$\Delta\alpha_{had}^{(5)}(M_z^2)$ =

0.02800 (70)	Eidelman, Jegerlehner'95
0.02761 (36)	Burkhardt, Pietrzyk 2001
0.02755 (23)	Hagivara et al., 2004
0.02758 (35)	Burkhardt, Pietrzyk 6-05



Precision (and discovery?) physics, should be done by different labs !!

13) γγ–physics

***DAFNE Physics Handbook*:**

γγ→ P [π^0 , η , η’] ➔ Γ(P→γγ)

γγ→ $\pi^0\pi^0$, $\pi^+\pi^-$, ηπ ➔ Γ(S→γγ) / predizioni ChPT

→ η’, $f_0(980)$, $a_0(980)$

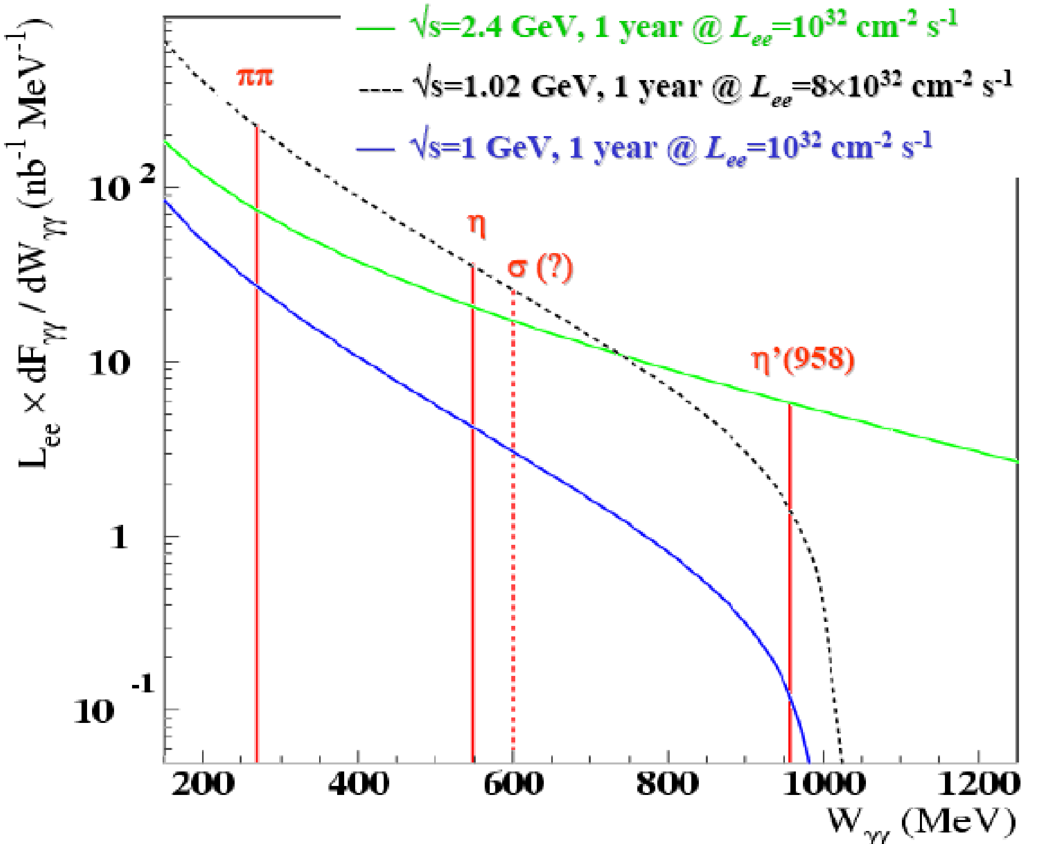
Novita’:

→ γγ → $\pi^0\pi^0$ at threshold

→ DAFNE2 ➔ alto √s

$\Gamma_{\gamma\gamma}$ di f_0 e a_0

$$N_{e+e-X} = L_{ee}\int \frac{dF_{\gamma\gamma}}{dW_{\gamma\gamma}}\sigma_{\gamma\gamma\to X}(W_{\gamma\gamma})\,dW_{\gamma\gamma}$$



NUCLEAR PHYSICS PROGRAM

AMADEUS

HIGH PRECISION - HIGH STATISTICS STUDY
OF
COLD DENSE NUCLEAR STRUCTURES

A BROAD BAND NUCLEAR PHYSICS PROGRAM
ON A UNIQUE FACILITY
IN THE WORLD

=> Explore dense nuclear states with K^- bound states

Cold and dense microscopic nuclear systems
a New Paradigm - so far untouched

Many important impacts in fundamental physics

- information concerning a ***modification of the kaon mass and of the KN interaction in the nuclear medium*** => interesting and important from the viewpoint of **spontaneous and explicit symmetry breaking of *QCD***

- information on a ***transition from the hadronic phase to a quark-gluon phase*** => changes of ***vacuum properties of QCD*** and ***quark condensate***

- **kaon condensation** in nuclear matter => implications on ***astrophysics***: ***neutron stars, strange stars***

- ***nuclear dynamics under extreme conditions*** *(nuclear compressibility, etc) could be investigated*

Kaonic Nuclei - Why so interesting?

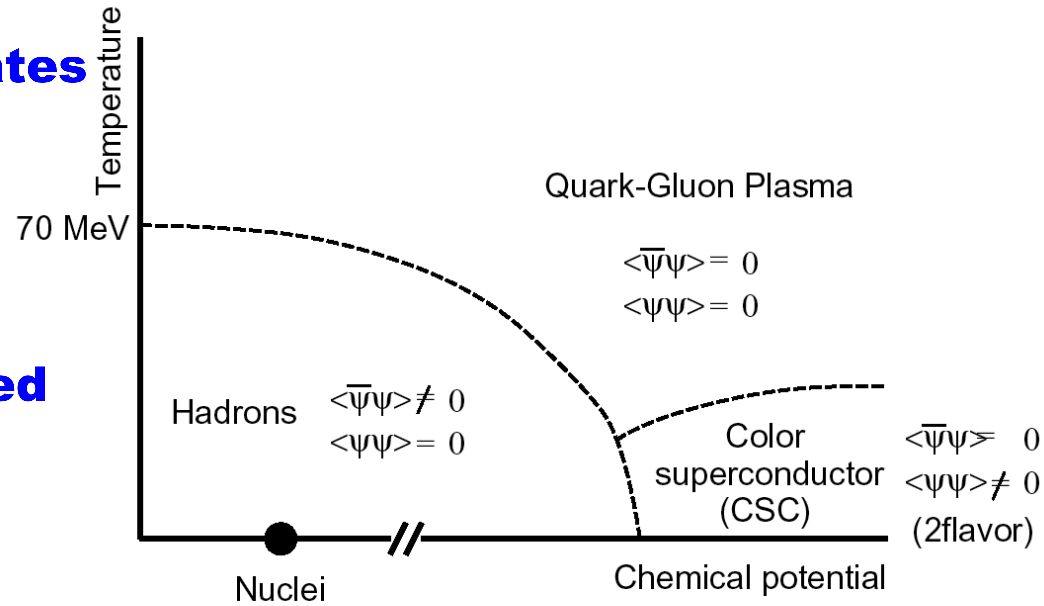
Very strong K^--p attraction

- **deep discrete bound states:**
  predicted B_K ~ 100 MeV

*** Highly excited resonance states**

*** In-medium KN interactions**
modified? chiral symmetry?

*** Dense nuclear systems formed**
Possibly, Quark-Gluon phase
at T = 0



*** Precursor to kaon condensation;**
astrophysics: neutron stars,
strange matter

*** Nuclear dynamics under extreme**
conditions

Production mechanisms:

1) Stopped K^- reactions on light nuclei, with ejection of a proton or a neutron as spectators

2) In-flight K^- reactions:

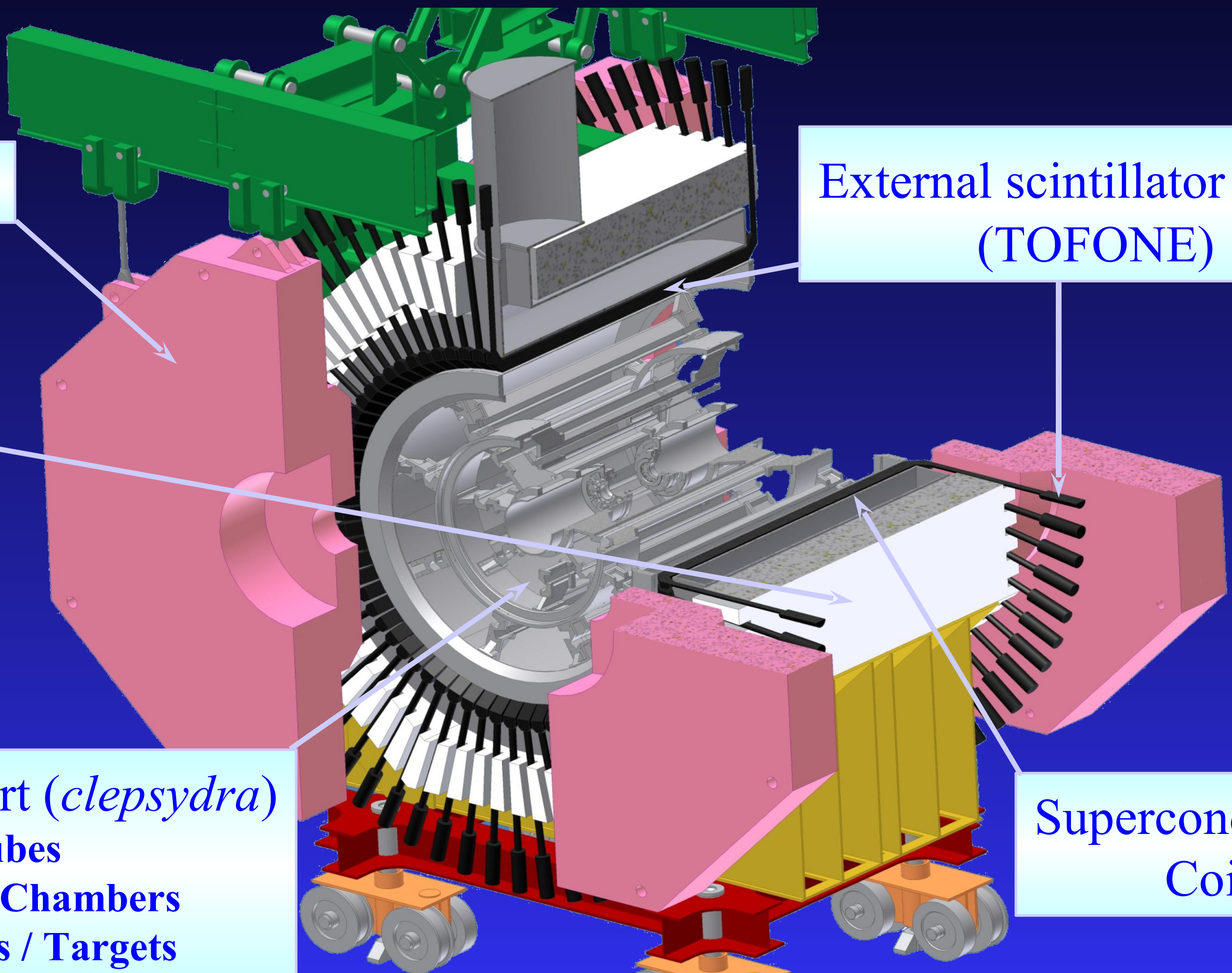
- Knock-out reactions (K^-, N) where one nucleon is knocked out in the formation stage;
- (K^-, π^-) reactions in proton-rich systems to produce exotic bound nuclear states on unbound systems.

3) Protons (3.5 – 4.5 GeV) on a deuteron target for the production of K^-pp detected in a 4π detector.

4) The identification of clusters as residual fragments ("K fragments") in heavy ion collisions via the invariant mass of their decay products.

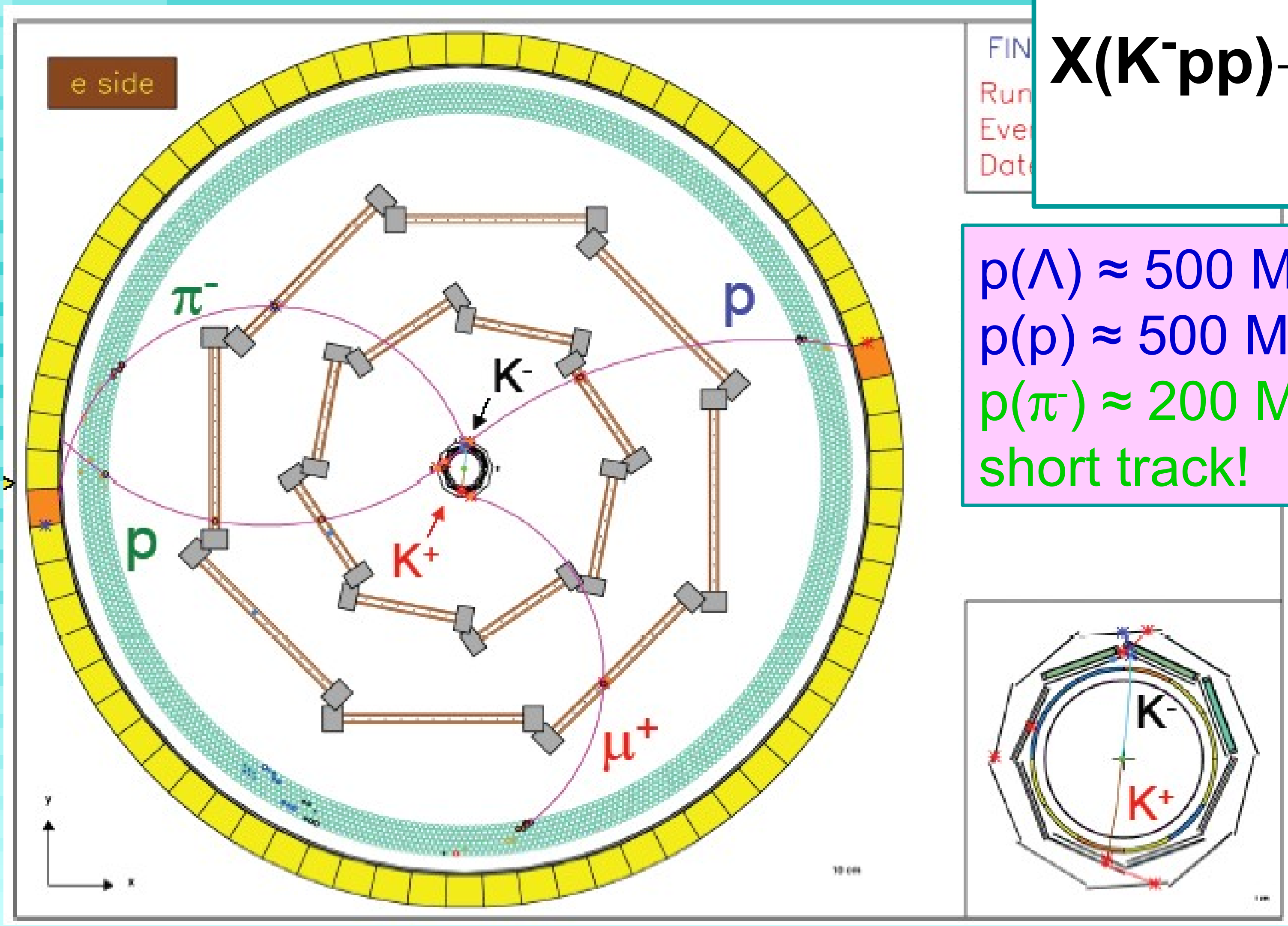
Method: Missing mass AND Invariant mass

FINUDA present apparatus



First observations III: the dibaryon

Evidences in FINUDA with the invariant mass method, 2004 data taking



$X(K^-pp) \rightarrow \Lambda p$

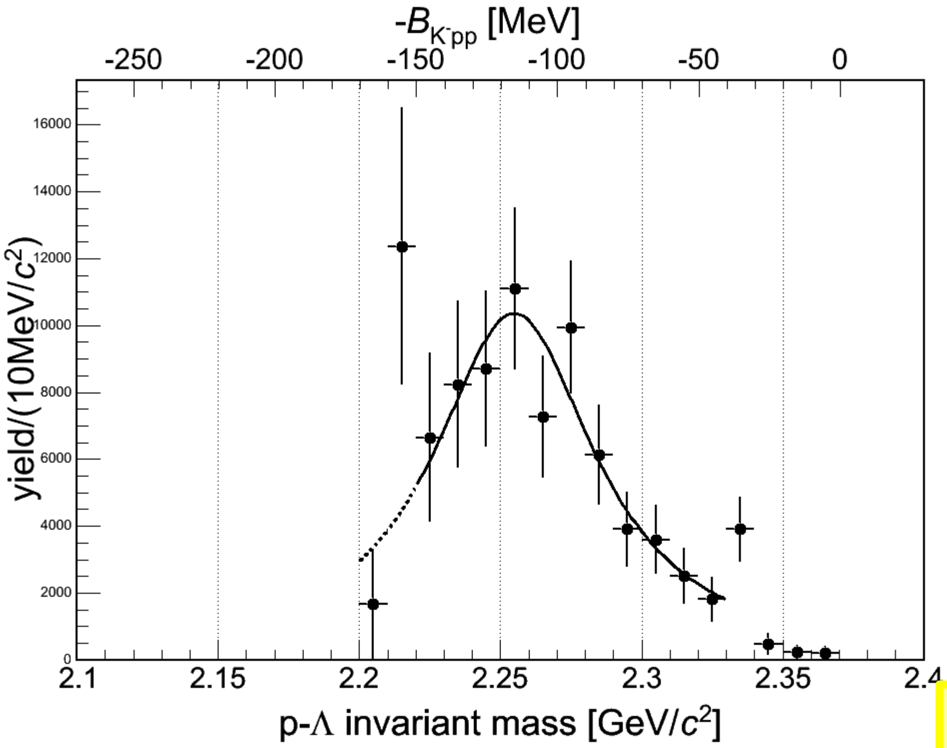
$\Lambda \rightarrow \pi^- p$

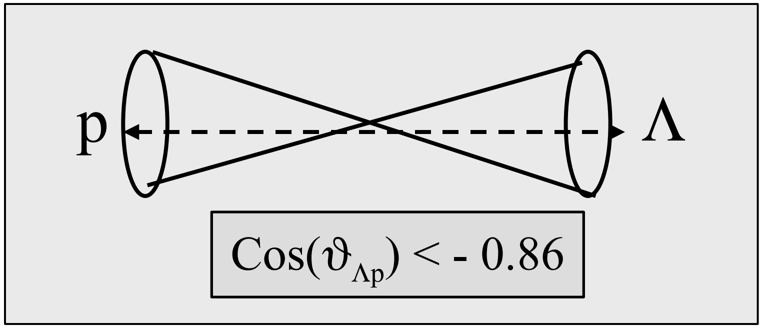
p(Λ) ≈ 500 MeV/c
p(p) ≈ 500 MeV/c
p(π⁻) ≈ 200 MeV/c
short track!

FINUDA results

$\pi^{-}pp$ Invariant Mass on ^{6}Li

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





$B = 115\ ^{+6}_{-5}(\text{stat})^{+3}_{-4}(\text{syst})$ MeV

$\Gamma = 67^{+14}_{-11}(\text{stat})^{+2}_{-3}(\text{syst})$ MeV

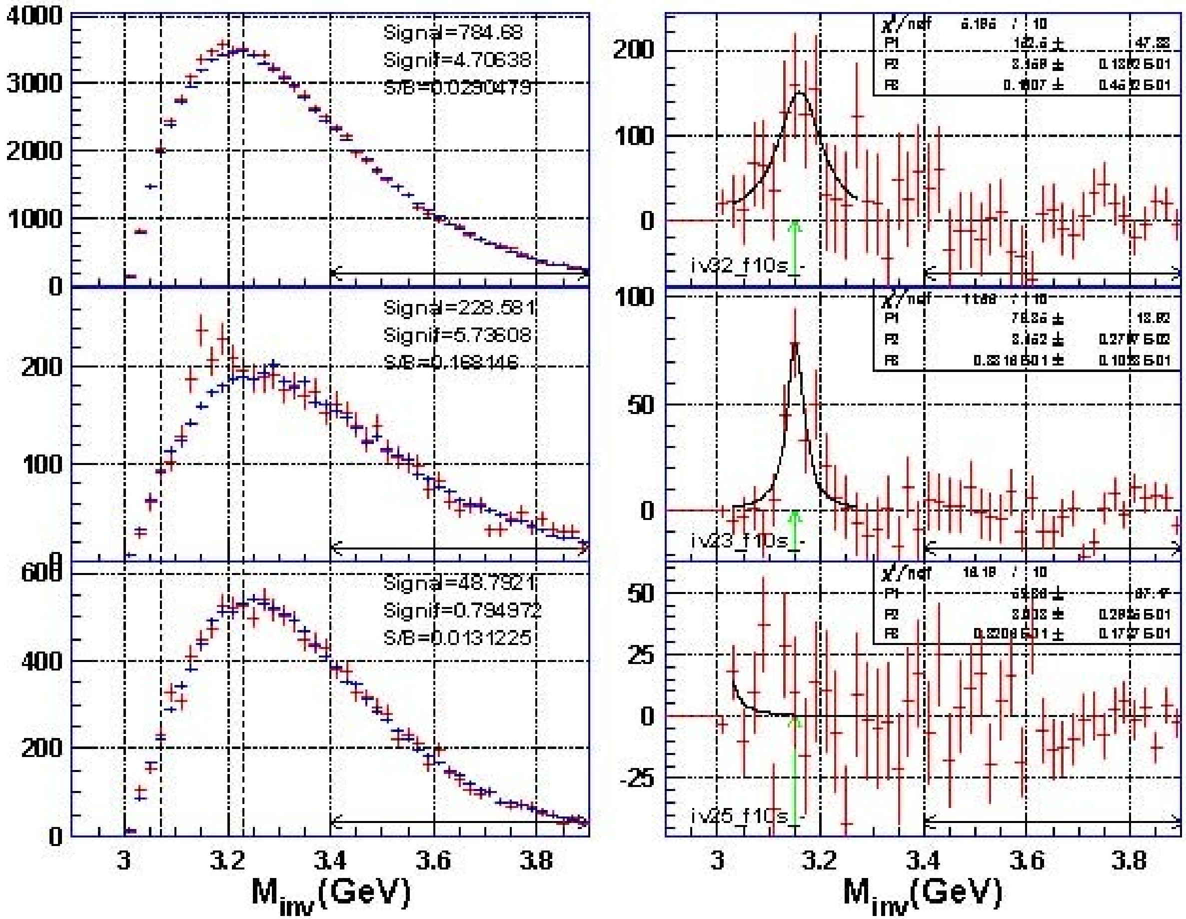
PRL 94, 212303 (2005)

In progress …

FOPI at GSI

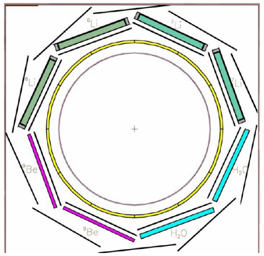
Invariant-mass spectroscopy in H. I. Reactions 1.9 GeV/u Ni + Ni

$M_{inv}(d+\Lambda) = 3160$ MeV; $\Gamma = 100$ MeV [ppnK^-]T=0



Distributions of invariant mass of Λ-d pairs in data (top), signal-MonteCarlo (middle) and background-MonteCarlo (bottom).

Next FINUDA data taking



Targets choice: 2x ^{6}Li, 2x ^{7}Li, H_2O, D_2O, 2x ^{9}Be

Expected results with ~ 1 fb^{-1}

4) **Litium targets: confirm with ~ ten fold better statistics K-pp bound states and search for K-pn and higher number of nucleons K-bound states; study of hypernuclear weak decays**

5) **high resolution and high statistic hypernuclear spectroscopy and weak decays of ^{9}Be (never done before)**

6) **high resolution and high statistic hypernuclear spectroscopy and weak decays of ^{16}O (poorly studied)**

7) **Low momentum kaon interaction on proton and neutron**

FINUDA data taking starts in September

AMADEUS

With 2 ft^{-1} (two months of data taking with DANAE)

The expected signals in the case of a ^{4}He target is

<u>45000</u> events in the (K^-, p) reaction for the S^0 (3115) neutral tribaryon

<u>12000</u> events in the (K^-, n) reaction for the S^+ (3140) charged tribaryon

<u>7000</u> events in the (K^-, n) reaction for the S^+ (3115) charged tribaryon

<u>HIGH STATISTIC STUDY !</u>

<u>High sensitivity and precision</u>

AMADEUS

precision spectroscopy studies of a number of light kaonic nuclei

to determine the quantum numbers (spin, parity, isospin)

A precise measurement of the energies of a T=1 multiplet would give its Coulomb energy difference (about 4 MeV) and thus information on the size of kaonic nuclei.

The Dalitz analysis of 3-body decays such as

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

$$pK^-pp \rightarrow \Lambda + p + p$$

$$nK^-pp \rightarrow \Lambda + p + n$$

By measuring Dalitz plots of three-body decay channels one can study the sizes, densities and quantum numbers of kaonic nuclei.

The measurement of the spin-orbit interaction by detection of p1/2 – p3/2 spin-orbit splitting which is predicted to be as large as 60 MeV for the small size of kaonic nuclei.

Total width of kaonic nuclei: 1 MeV energy resolution is necessary (KLOE)

AMADEUS

STARTING WITH GAS TARGETS

$^{3}He(K^{-}, n/p)$

Dalitz plots in 3-body channel such as $nK^{-}p \rightarrow \Lambda + p + \pi^{-}$

Similar for 3-baryon states using a *^{4}He gas target*

We plan to extend
systematically ***over a broad range of nuclear targets***
starting with
Li, B and Be.

AMADEUS : KAONIC NUCLEAR STATES

PRECISION SPECTROSCOPY STUDIES OF A NUMBER OF LIGHT KAONIC NUCLEI

THE WORLD SCIENTIFIC POLE TO STUDY KAONIC NUCLEI USING k^- INDUCED PROCESSES AT REST

Formation of an international collaboration

Work in progress

THE DANTE COLLABORATION

Measurement of the Nucleon Form Factors in the Time-Like region at DANAE

FFs are fundamental quantities describing the internal structure of the nucleon

Wavelength of the probe can be tuned by selecting momentum transfer Q^2

< 0.1 GeV^2	integral quantities (charge radius,…)
0.1-10 GeV^2	internal structure of nucleon
> 20 GeV^2	pQCD scaling

- Early interpretation based on Vector-Meson Dominance
- Good description with phenomenological dipole form factor

Proton electric and magnetic SL FFs scaling:

$G_M^p \approx \mu_p G_E^p$

$\Rightarrow$ charge and magnetization have the same distribution

- Neutron electric SL FF G_E^n smaller than the other 3 FFs
- All FFs are well described by the dipole formula:

$$G_D = \left(\frac{\Lambda^2}{\Lambda^2 + Q^2} \right)^2 \qquad \Lambda \approx 0.8\ GeV$$

$$\frac{G_i}{G_D} = 1 + \sum a_n Q^n$$

No substantial deviations from this picture were expected

How to measure Space-Like Form Factors

- **Rosenbluth separation** : Based on cross section measurement

$$\left(\frac{d\sigma}{d\Omega}\right) = \sigma_0 \left[G_E^2 + \frac{\tau}{\varepsilon} G_M^2 \right]$$

$Q^2 = |q^2|$
ε = photon polarization
$\tau = Q^2 / 4M^2$

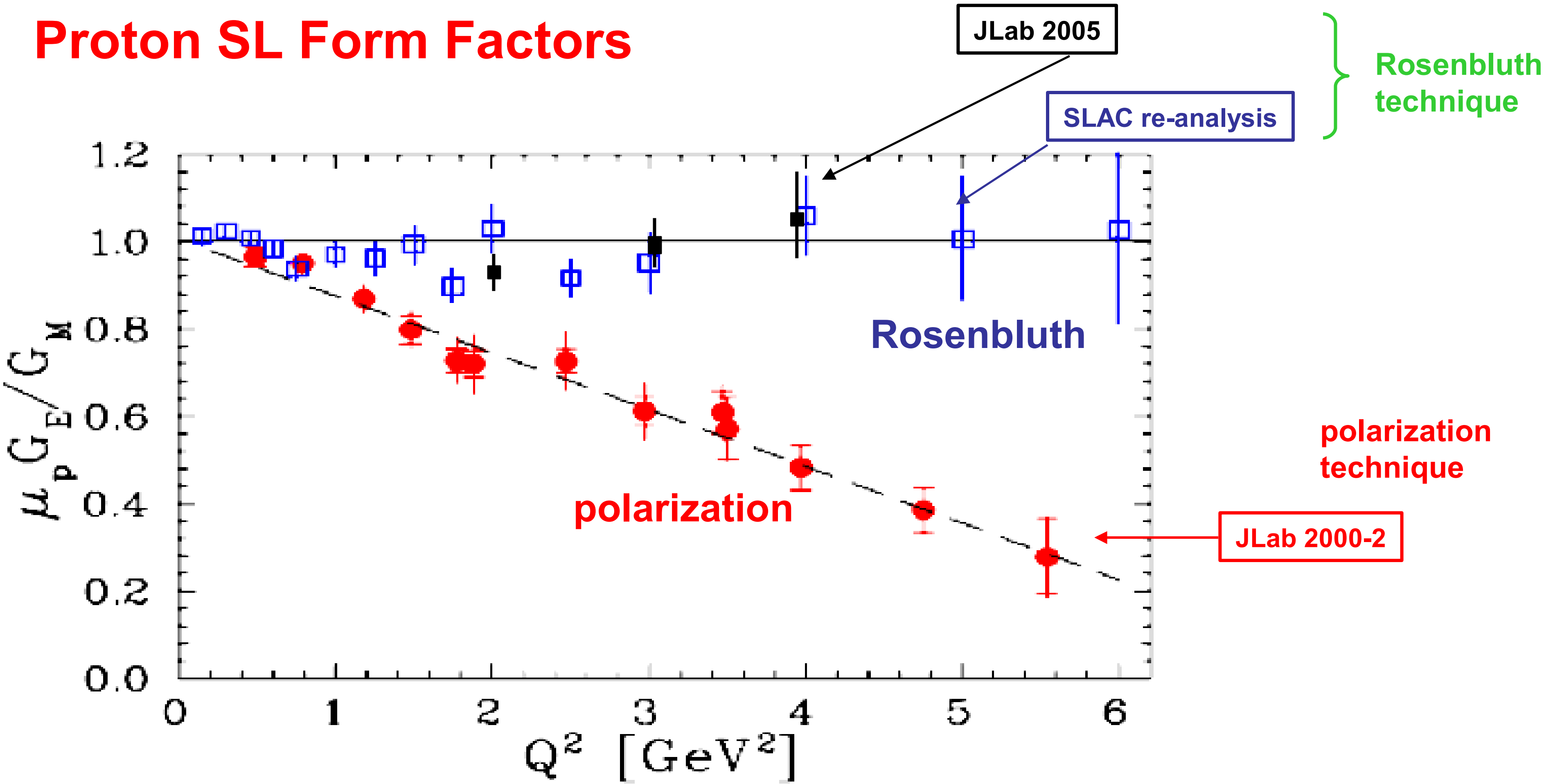
- **Polarization observables :**
  For example, electron-to-proton polarization transfer

$$\frac{G_E}{G_M} = -\frac{P_t}{P_l} \frac{E_e + E_{e'}}{2M} \tan\frac{\theta}{2}$$

Recoil polarization measurements have been proposed more than 40 years ago as the best way to reach high accuracy in the FF measurement

Akhiezer et al., Sov. Phys. Jept. 6, 588 (1958)
Arnold, Carlson, Gross, PR C23, 363 (1981)

Proton SL Form Factors



- $G_E = 0$ at some Q^2 (~8 GeV^2)?
- Asymptotic scaling: pQCD $F_2 / F_1 \sim Q^{-2}$

  pol. data $F_2 / F_1 \sim Q^{-1}$

  quark angular momentum contribution?
- radiative corrections?

Time-Like FFs measurements

FF extraction from $e^+e^- \to N\bar{N}$

$\tau = s/\,4M^2$

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 \beta C}{4s}\left\{ |G_M|^2 \left(1+\cos^2\theta\right) + \frac{1}{\tau}|G_E|^2 \sin^2\theta \right\}$$

- $|G_M| = |G_E|$ at the physical threshold $s = 4M^2 \Rightarrow$ isotropic distributions

- G_M dominates the cross section for $s >> 4M^2$

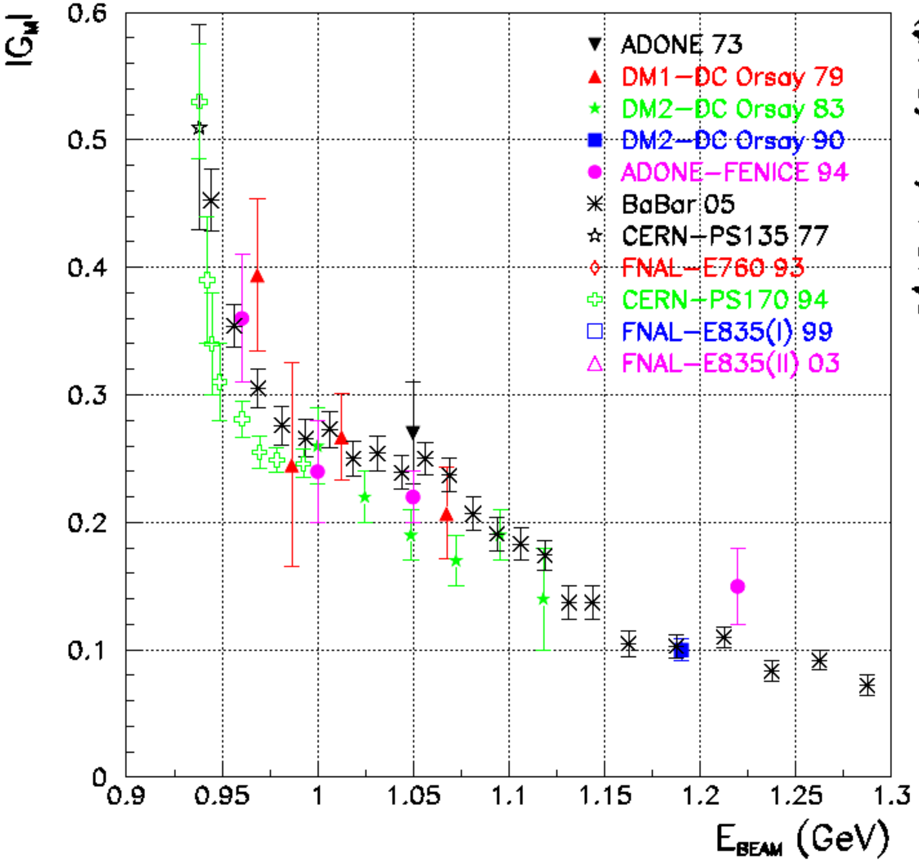
Up to now, no independent extraction of both TL FFs has been performed ($\sigma \approx 1$ nb)

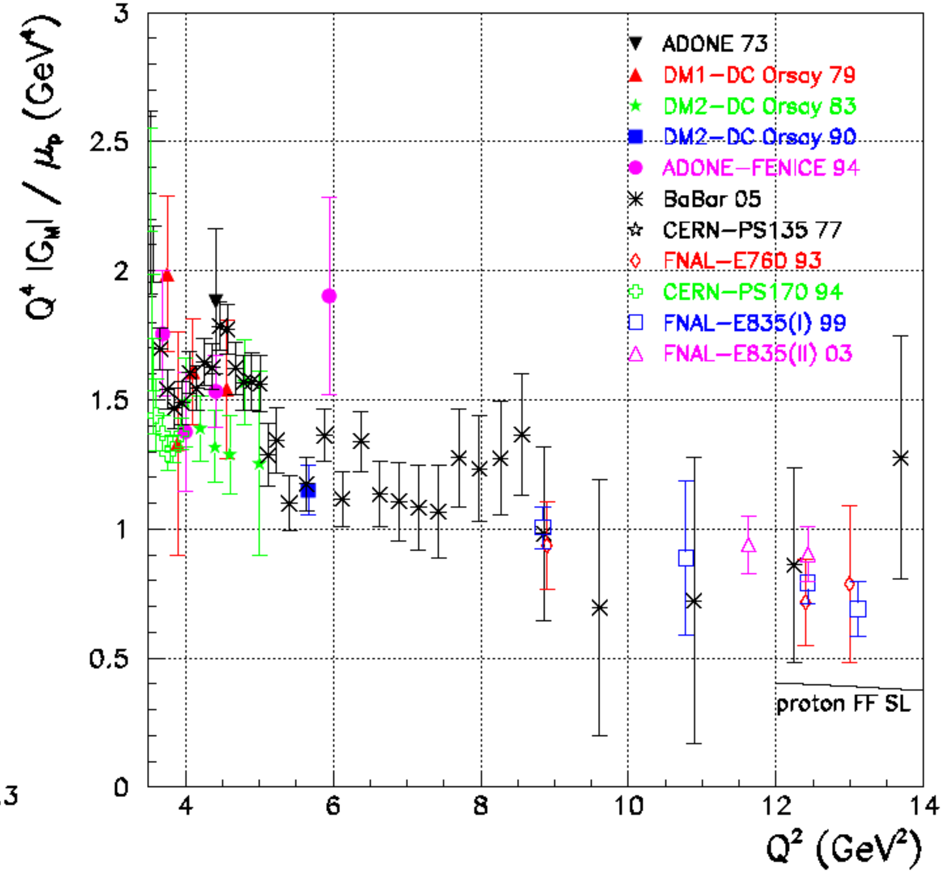
FF measurements are based on total cross section, under some theoretical assumption on their ratio

- $|G_M|$ can be more easily extracted, but it's model-dependent
- $|G_E|$ remains unmeasured

Time-Like FFs : proton data

Assuming $|G_E| = |G_M|$

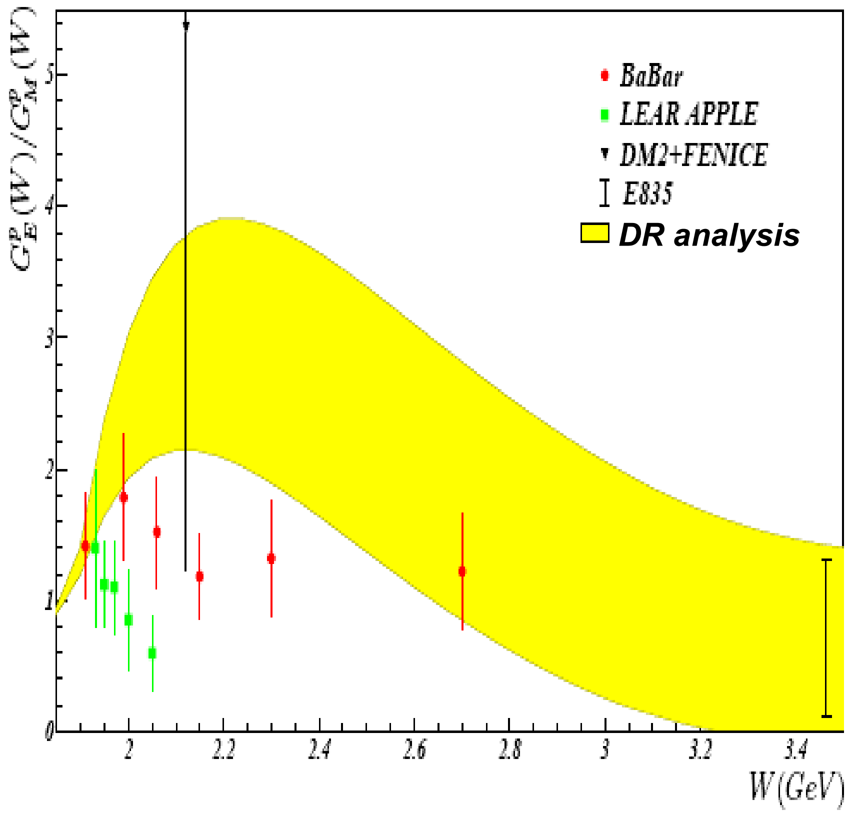




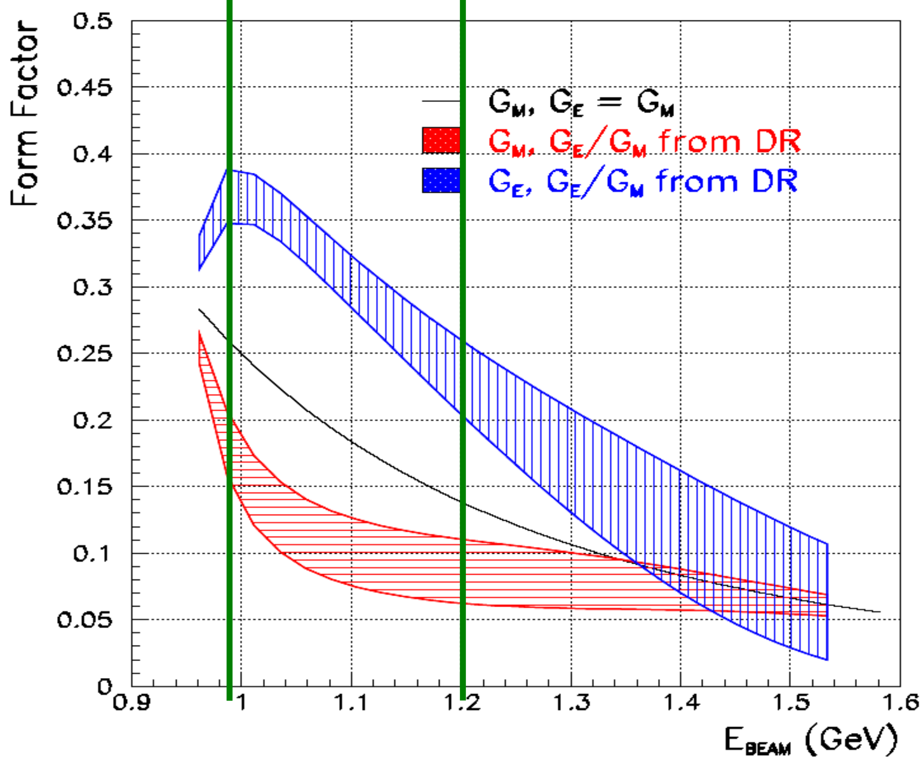
- **Early pQCD scaling $|G_M| \sim Q^{-4}$**
- **Time-like FF larger than space-like**
- **Steep behaviour close threshold**

Electric to magnetic FF ratio

Tentative extraction of FF ratio from angular distributions



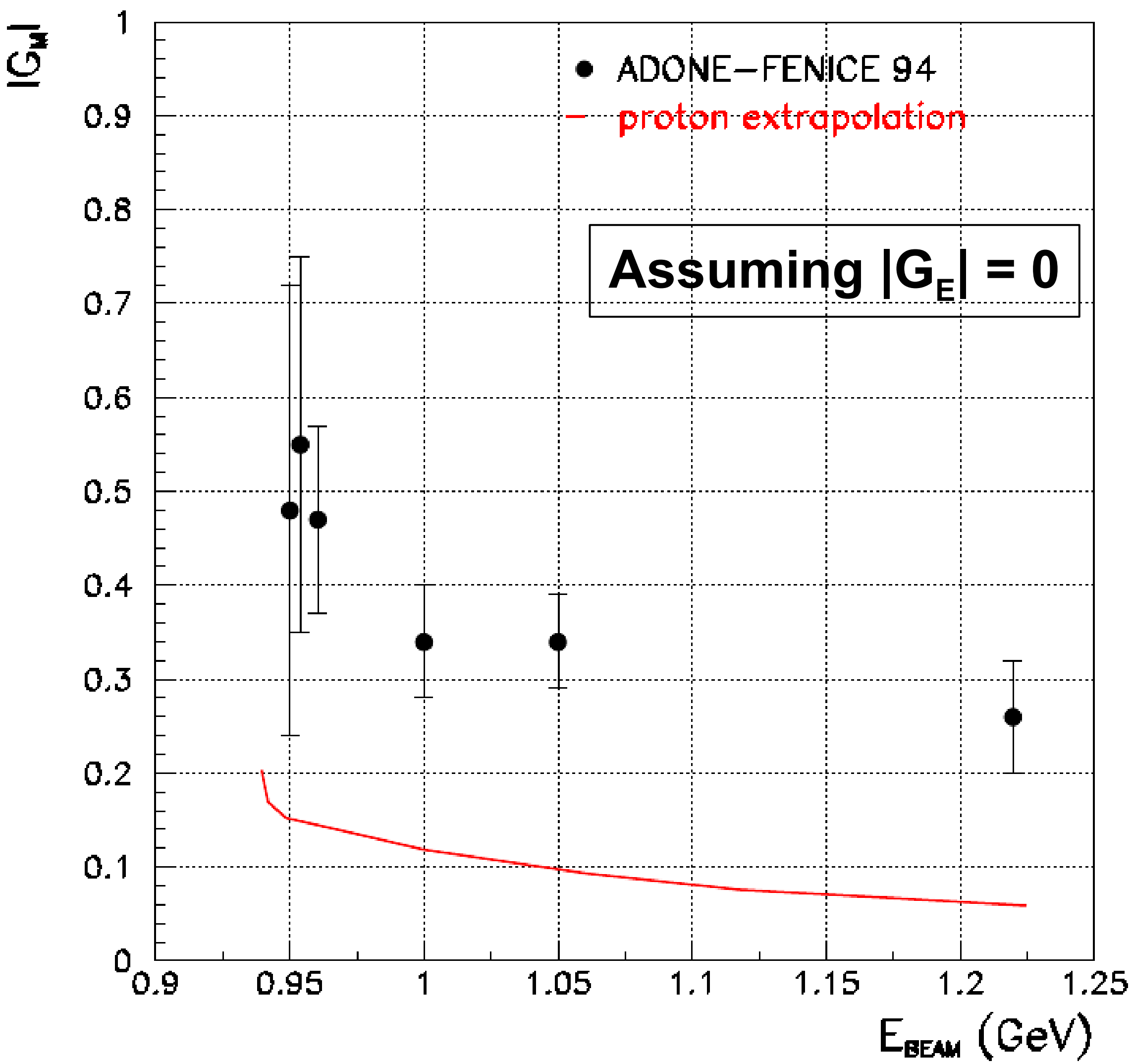
DAΦNE2



Different hypothesis on G_E/G_M strongly affect the G_M extraction mainly in the low energy region

Time-Like FFs : neutron data

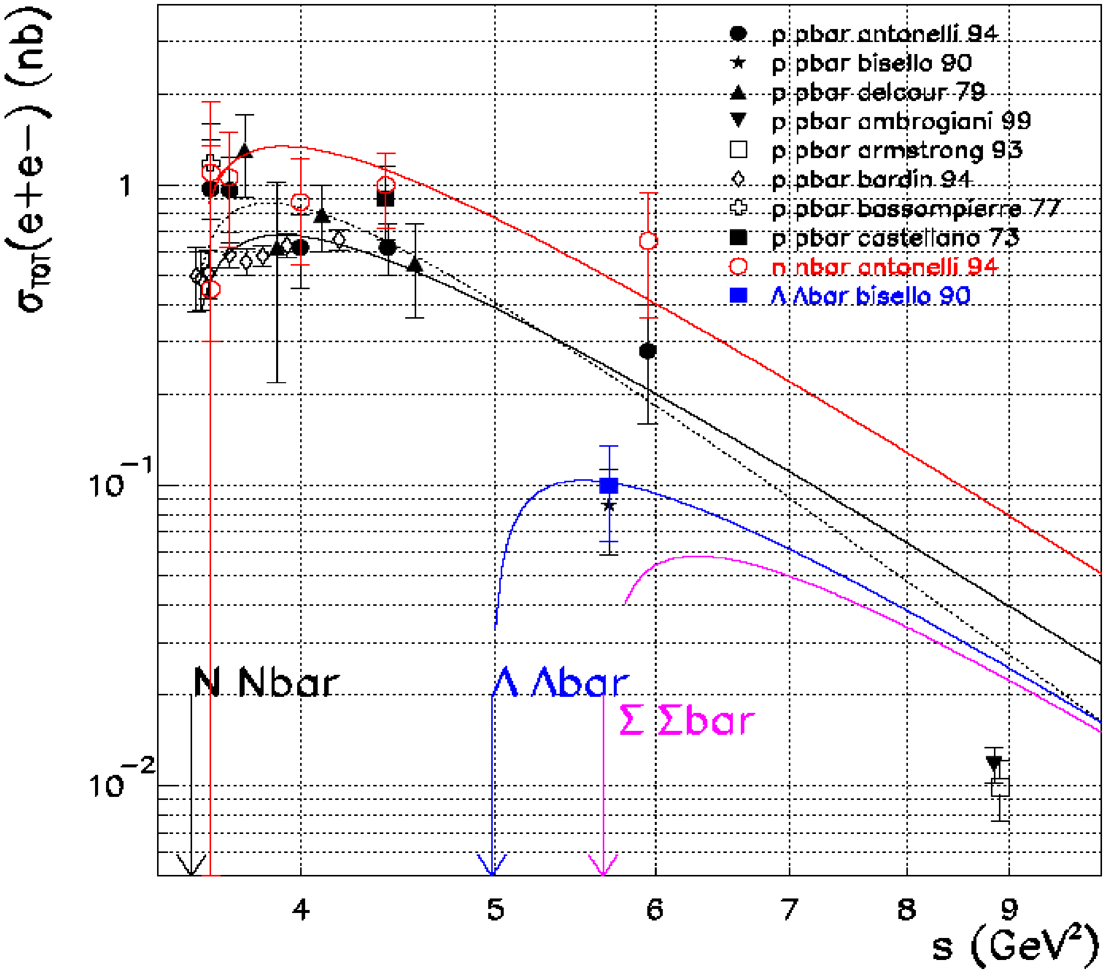
Only the FENICE data



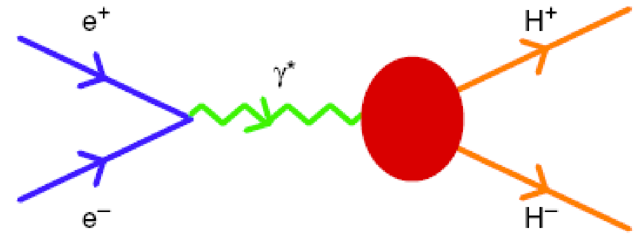
- Angular distribution $d\sigma/d\Omega \sim 1+\cos^2\theta$ compatible with $|G_E|=0$
- neutron G_M bigger than proton
- pQCD scaling?

Hyperon Form Factors

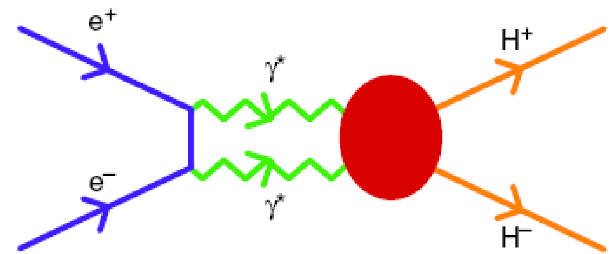
Hyperons can also be produced in $e^+ e^-$ interactions (Λ, Σ, …)
energy threshold: $\sqrt{s} \sim 2\ M_\Lambda \sim 2.23$ GeV $\Rightarrow E_{BEAM} \sim 1.12$ GeV



Two-photon contribution

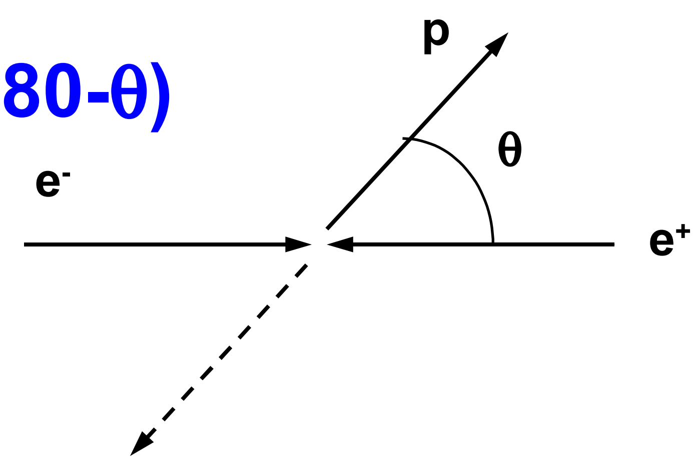


Interference between 1- and 2-γ amplitudes
Small effect (of the order of α_{em})



Some asymmetry is expected in proton (antiproton) angular distribution with respect to electron direction

$\sigma(\theta) \neq \sigma(180\text{-}\theta)$



$$A(\theta) = \frac{\sigma(\theta) - \sigma(180-\theta)}{\sigma(\theta) + \sigma(180-\theta)}$$

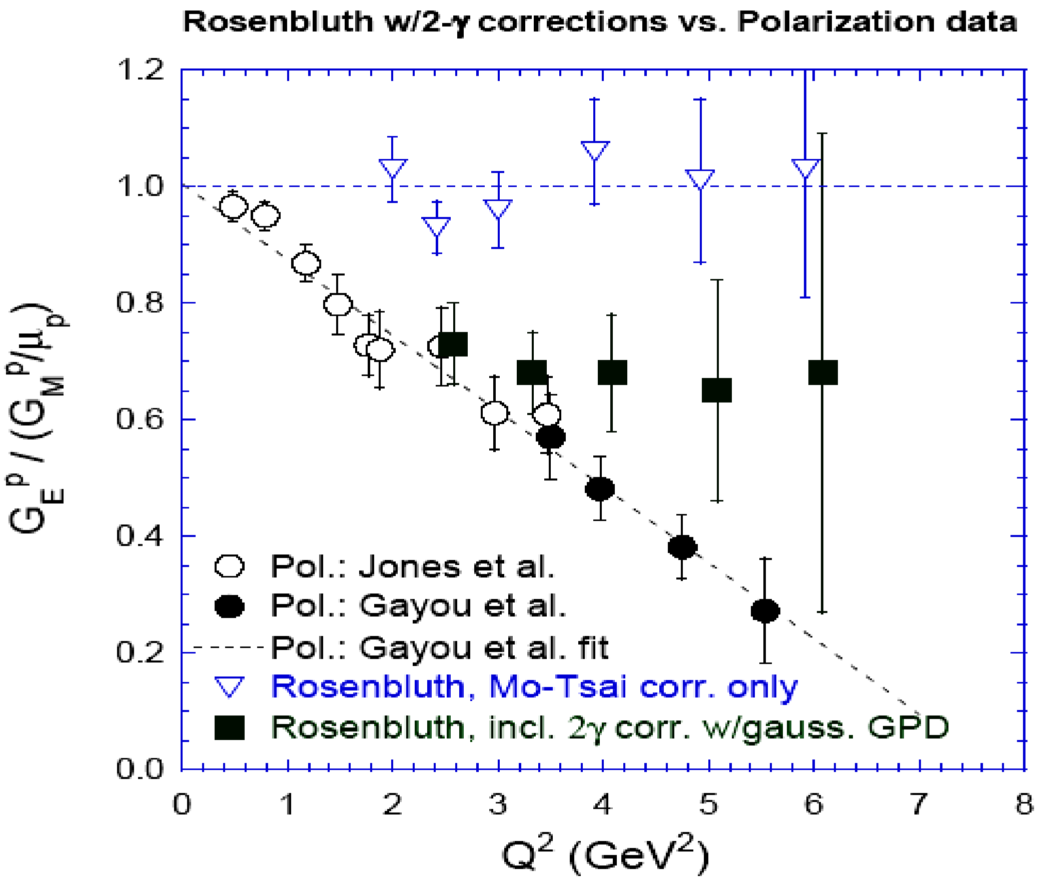
Could be estimated using:
- $\gamma\gamma \rightarrow p\bar{p}$ exp. data
- $e^+ e^- \rightarrow \gamma\gamma$ cross section

Asymmetry ~ few % ?

2-photon exchange

Afanasev et al.
hep-ph/0502013

- complex space-like FFs
- correction to the cross section are of the same order as electric contribution
- corrections to polarization observables are expected to be much smaller



Rosenbluth and polarization data could be reconciled?

- **Calculations have simple parametrization of 2- γ exchange**
- **Some authors found negligible contributions to the cross section**

With DANTE and DANAE one will produce

The FIRST accurate measurement of the proton time-like form factors $|G^p_E|$ and $|G^p_M|$

The FIRST measurement of the outgoing proton polarization, to get the relative phase between $|G^p_E|$ and $|G^p_M|$

The FIRST measurement of the two photon contribution from the proton angular distributions asymmetry

The FIRST accurate measurement of the $e^+e^- \rightarrow$ n-nbar cross section

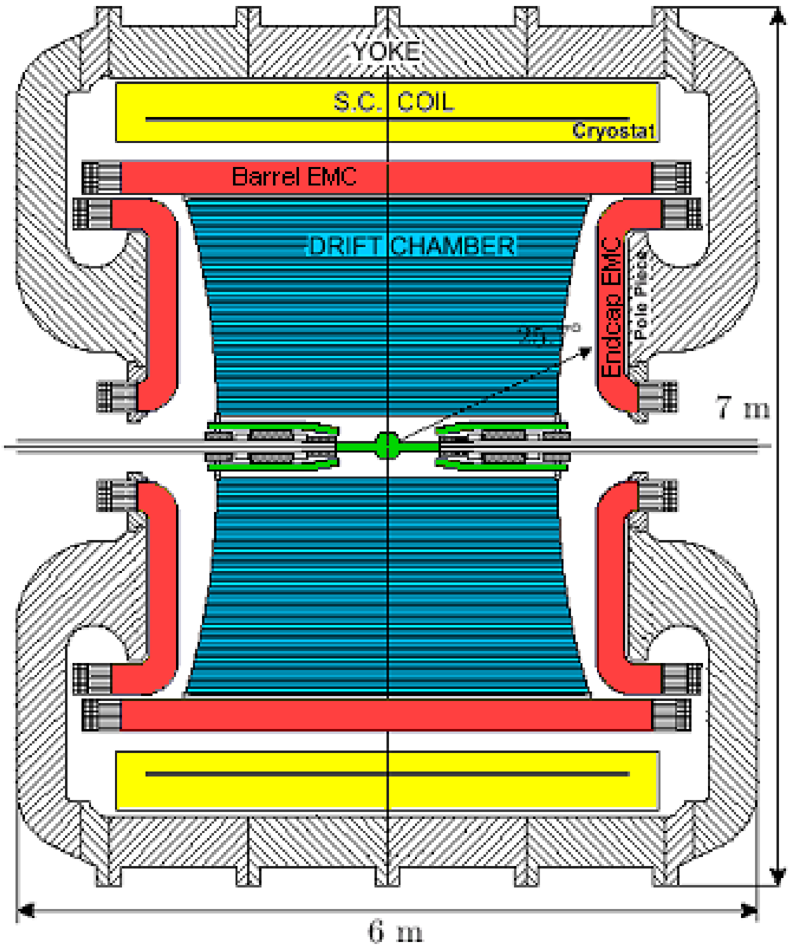
The FIRST measurement of the neutron time-like form factors $|G^n_E|$ and $|G^n_M|$

The FIRST measurement of the strange baryon form factors

An accurate measurement of the cross section of the $e^+ e^- \rightarrow$ hadrons, that provide information on possible narrow structures close to the N-Nbar threshold.

Detector Issues

The KLOE experiment



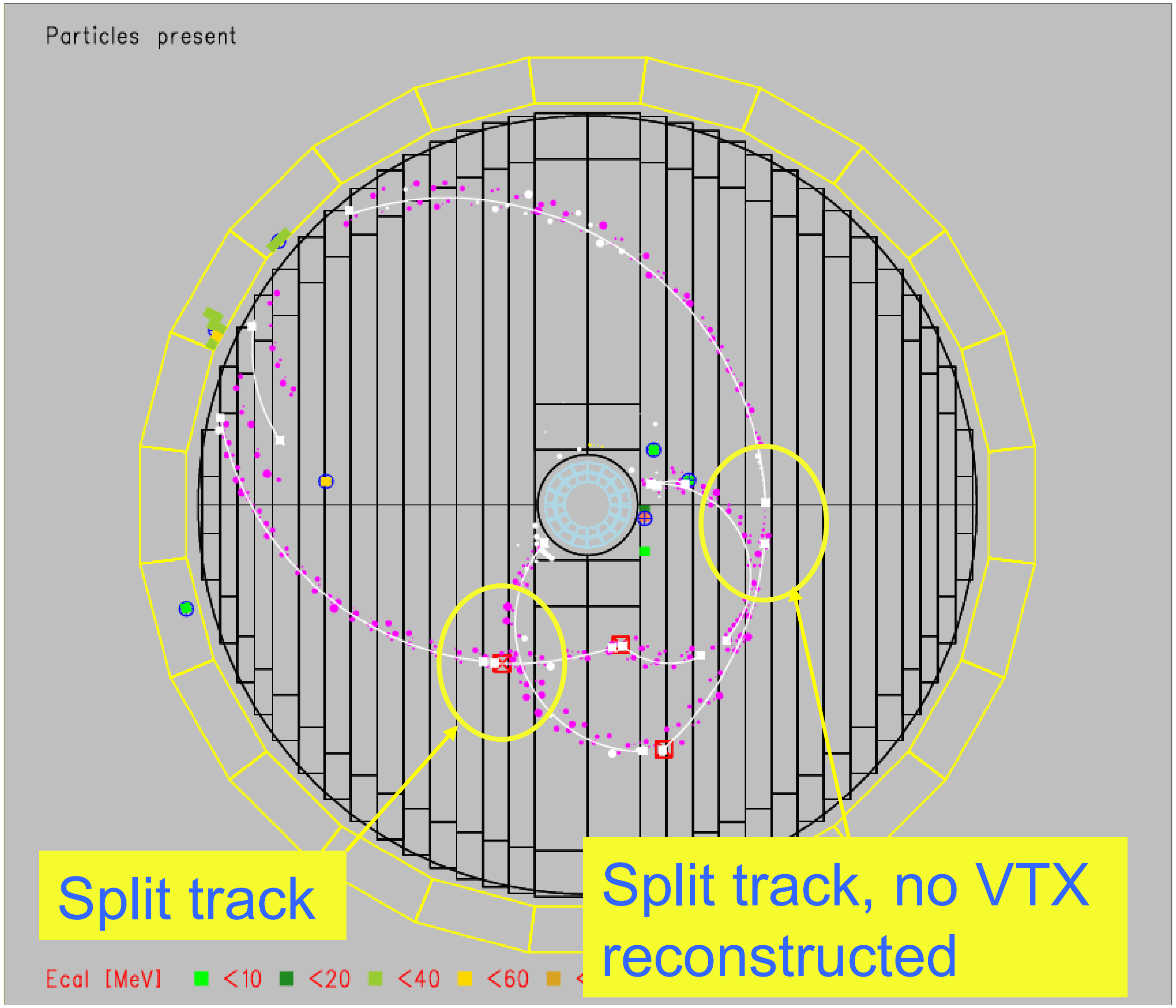
Be beam pipe (0.5 mm thick)
Instrumented permanent magnet quadrupoles (32 PMT's)

Drift chamber
90% He + 10% IsoB, CF frame
12582 stereo sense wires

Electromagnetic calorimeter
Lead/scintillating fibers
4880 PMT's

Superconducting coil (5 m bore)
$B = 0.52$ T ($\int B\, dl = 2$ T·m)

An explicative example from K^+K^-



The ingredients of KLOE

E.M: Calorimeter:

Full angular coverage

Exceptional timing capabilities

Large lever arm

Drift Chamber:

Good momentum resolution

Large tracking volume

Minimization of materials

Excellent e/π separation based on t.o.f.

Good π^0 reconstruction capabilities

Full kinematical reconstruction of events

Maximization of efficiency for long-lived particles ($K^\pm$,K_L)

There can be improvements

Still, based on our experience, some possible modifications can improve KLOE performance

- **Use of a lower magnetic field. This can increase acceptance for several of the above mentioned channels and ease pattern recognition**
- **Insertion of a vertex chamber. At present, first tracking layer is at 30 cm (*i.e. 50* τ_S) from the I.P.**
- **z coordinate reconstruction in the drift chamber. Pattern recognition would benefit of it.**
- **Increase calorimeter's readout granularity. Can improve photon counting, as well as particle identification.**

OPTIMISTIC (BUT POSSIBLE) PROGRAM

1) To have a single experiment, with variable set up, for the entire physics program, by the end of the year

3) To write the “Conceptual Design Report” of the accelerator by the end of the year

3) To be approved by INFN in the first half of 2007

4) To upgrade DAFNE adiabatically the coming three years to increase the luminosity by a factor 3 in 2009-10

5) To have an upgraded detector ready to take data in 2009-10 on a upgraded DAFNE

6) To assemble the new accelerator in 2010-2011