The Strange Essence in KLOE
or
My Last Chapter on Strangeness
or
How I Came to Toil for 14 Years at an Italian ϕ–factory

Juliet Lee-Franzini

LNF, 20 May 2005

OUTLINE

A peek into JLF's scrapbook:

http://www.lnf.infn.it/~juliet/

1957: Nuclear Emulsions

1972: Triggered Spark Chambers

1979: Electromagnetic Calorimeters

1991: Design and Construction of KLOE

2000: Optimize Exploitation of KLOE

2005: $|V_{us}|$

Objects Lessons for Future

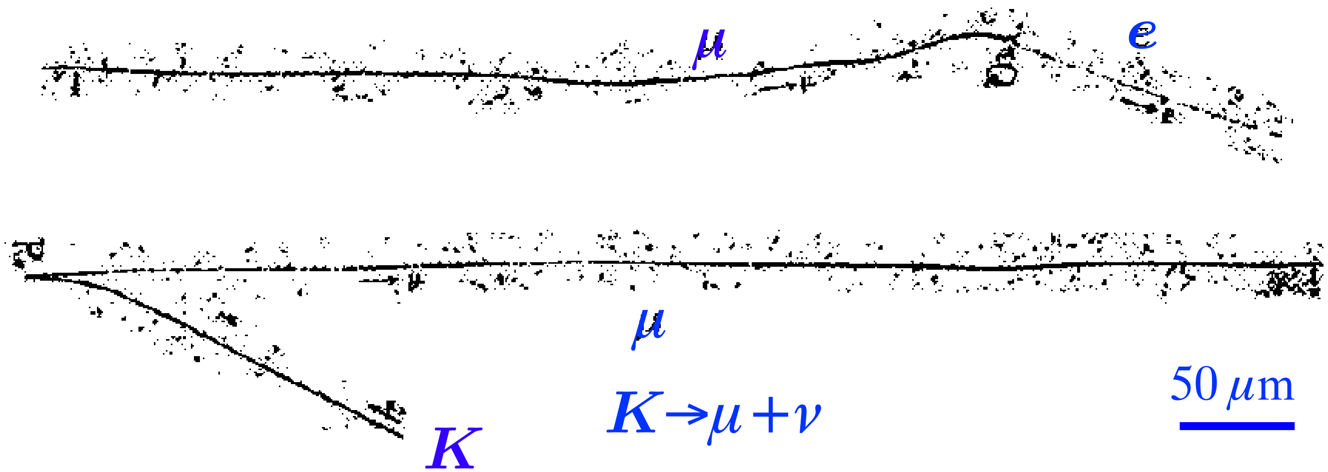
This is the last lecture of this LNFSS (X)

Present: You've just heard 3 young (about 24 years old) KLOE researchers report new results on Open and Hidden Strangeness (in kaons and η's)

Future: Prior to that you've heard Bob Tschirhart's lectures urging large expenditures in efforts(dollars) to search for Rare Decays

Past: So I thought to give some anecdotal account of how we got here (as it could also tell us what it takes to go forward).

Since the early days of kaon's discovery, Nuclear Emulsions was a favorite medium for studying kaon properties. For example, it played a key role in the discovery of Parity Violation in Weak Interactions: namely, the $\tau - \theta$ puzzle.



I'm going to tell you about my first Physics Publication, Phys. Rev. 108, pp.1561, 1957, an unexpected bonus from the $\tau - \theta$ stack, because it demonstrates NucEmul's forte and weakness (grain-count: 13-tracks per manday: gap-count-analysis: two-weeks per event).

ANOMALOUS K^+ DECAY

Out of 5000 kaon endings examined, their single charged secondaries all have ranges consistent with the known two body θ^+, K_{μ_2}, three body τ' and K_{μ_3} decays, except for one:

IT HAD A RANGE OF 4.8 cm!!! and then decayed into a muon.

What could it be??

(1) $K^+ \to \pi^+ + \pi^0 + \gamma$? Dipole transition

(2) or $K^+ \to \pi^+ + 2\gamma$? 1×10^{-6}

(3) or $K^+ \to \pi^+ + \nu + \bar{\nu}$? no charged lepton

Much agitation, discussions with "young" theory colleague R. Dalitz, calculations on mechanical machine...

Assuming mode (1), one pion with energy of about 60 MeV (γ energy between 55-158 MeV) out of 5000 is consistent with expected rate. (PDG $(1.8 \pm 0.4) \times 10^{-5}$).

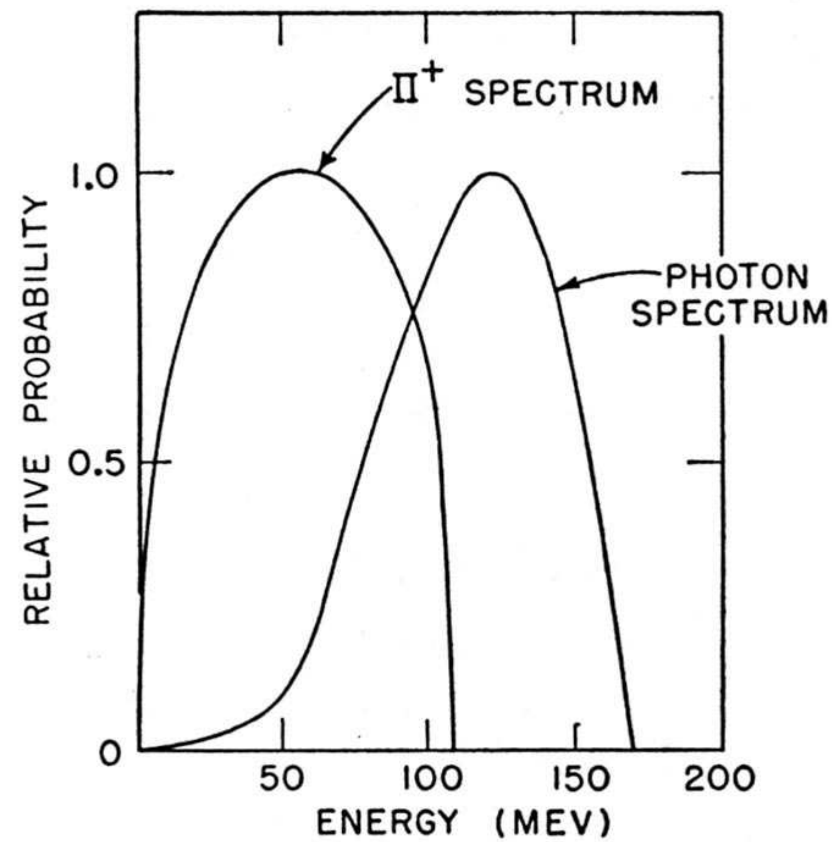


FIG. 1. Photon and π^+ energy spectra for the decay mode $K^+ \to \pi^+ + \pi^0 + \gamma$ using the dipole matrix element in the paper of Dalitz.[4]

Now fast forward: $\Delta I = 1/2$ RULE

Recall that there are two neutral kaons which were antiparticles of each other and belonged to two different isospin doublets which have opposite strangeness S

In order to explain why the neutral kaon decay into 2 pions is much faster (about 700$\times$) than the charged kaon into 2 pions, Gell-Mann and Pais in 1954 proposed an empirical rule, $\Delta I = 1/2$ in non leptonic decays, still unexplained, which also implied that the ratio R of kaon decaying into a pair of charged pions over into a pair of neutral ones should be $\sim$2.

So we, the Chair and I, with about five students, designed a precision, dedicated, fixed-target experiment to measure R.

A 1 GeV π^- beam hitting a polyethelene target produces ΛK pairs in association.

The trigger is based on the disappearance of the π^- and the appearance of a proton, 3$\times$mimimum ionizing, in a 10x10 element hodoscope, 10 cm downstream.

The 40 layer spark chamber C_3, in a 14 KG field, records the decay products. Subsequent analyses yield their momenta, position and energy. Photons are recognized by spark clusters w/o a beginning track.

One of the first measurements of R which accounts correctly for systematic uncertainties, with high statics, was performed in an optical spark chamber in 1972 at the PPA.

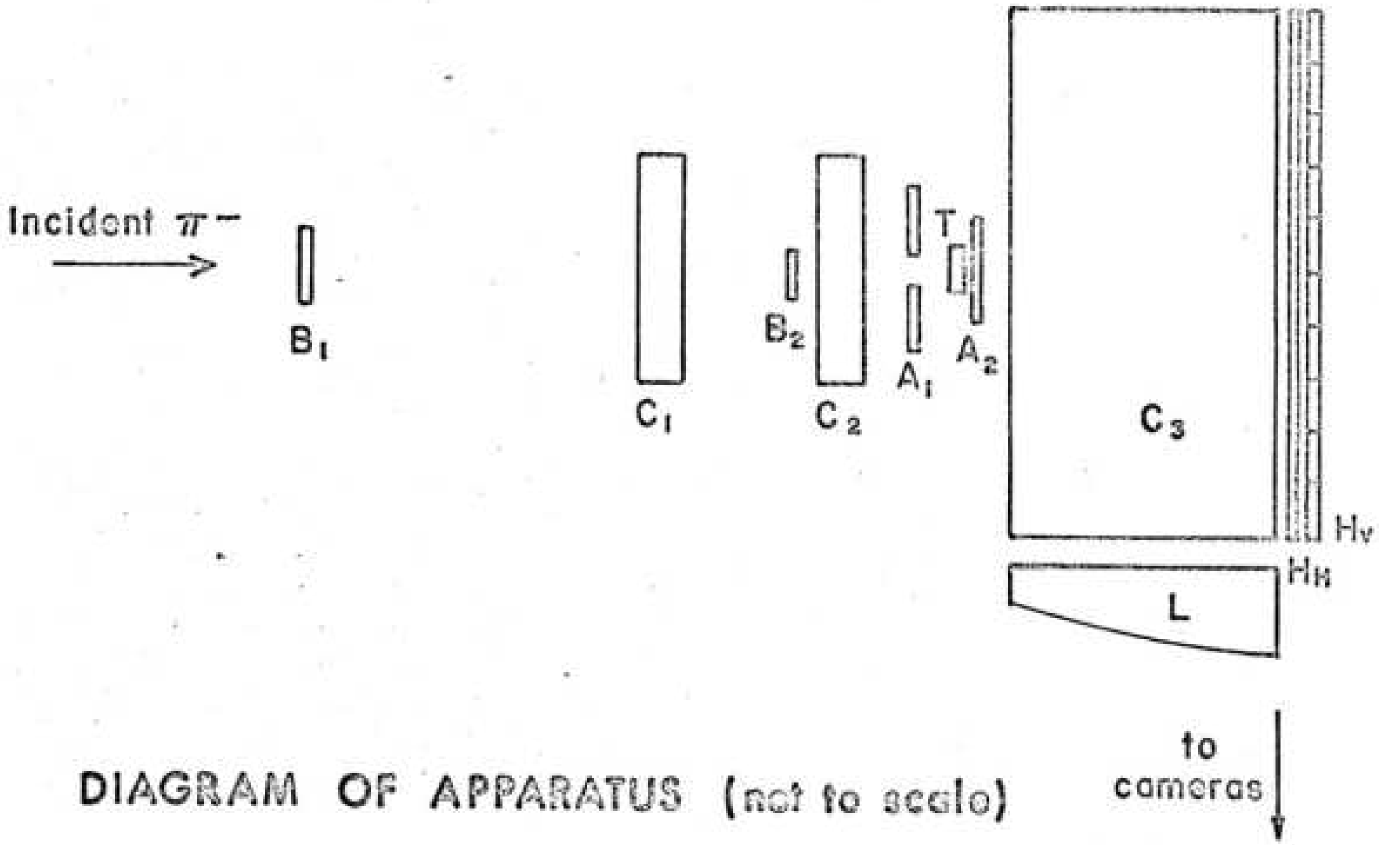


DIAGRAM OF APPARATUS (not to scale)

65,000 Λ decays were observed, together with 16,000 $K^0 \to \pi^+\pi^-$ decays, resulting in R = 2.165 $\pm$ 0.098.

A MODERN GIANT, THE KLOE CHAMBER

52,000 wires - Al + W.

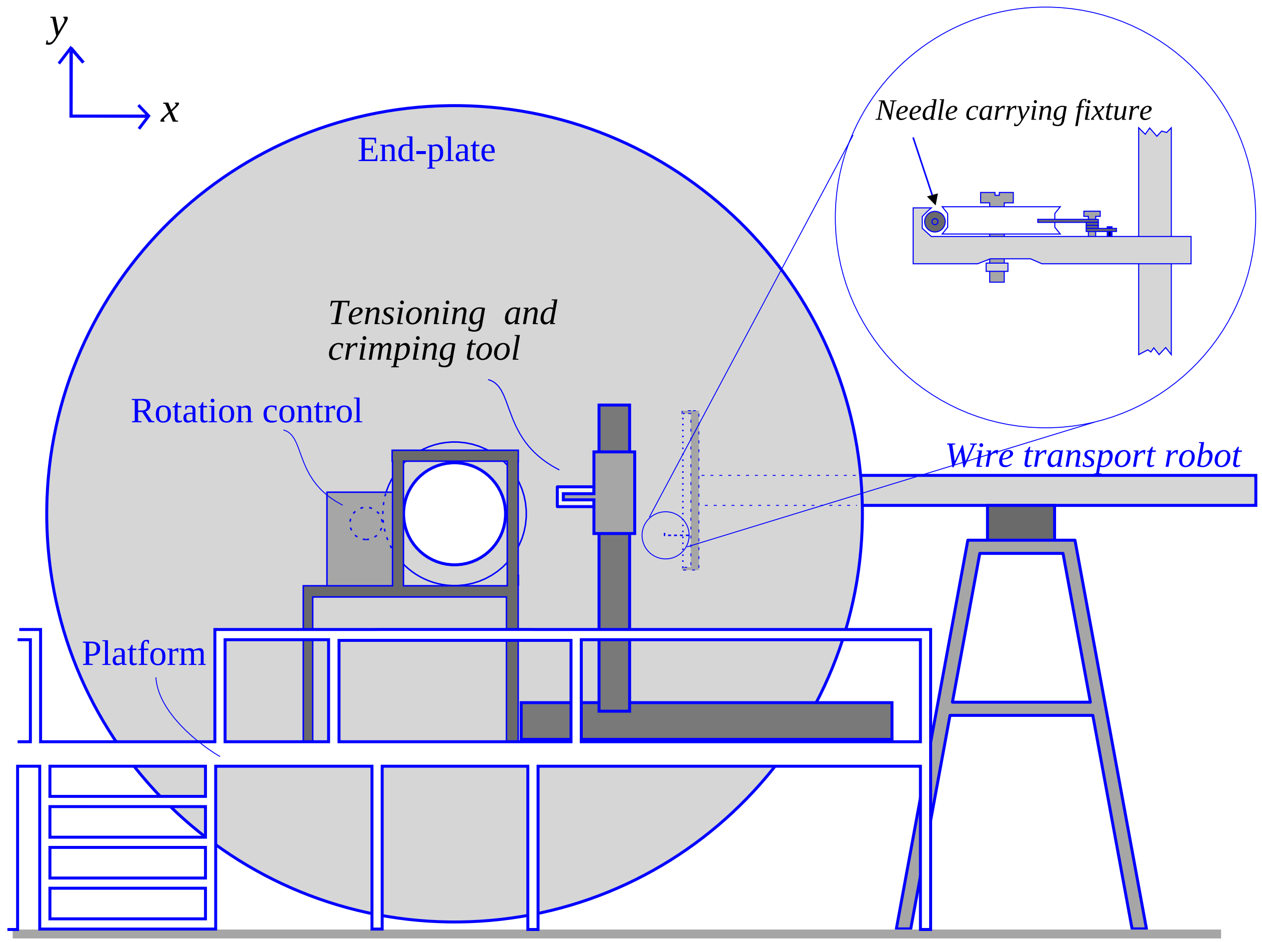
All C-fiber construction.

Spherical end-plates tensioned while stringing.

He + 10% iso-C_4H_{10}+ water 0.5%.

Wire tension measured electrostatically.

New techniques were invented to build such objects, for. ex. how to string the thousands of wires? The KLOE solution was later used also to build the BABAR Chamber



Karlsruhe - Fall 2002 *Juliet Lee- Franzini* - Spark Chambers

1979 Electron-Positron Colliders at Resonance

$$\mathcal{M}_V = M - i\Gamma/2$$

$$\sigma_{\mathrm{res},(q\bar{q})} = \frac{12\pi}{s}\frac{\Gamma_{ee}\Gamma M^2}{(M^2-s)^2+M^2\Gamma^2}$$

$$= \frac{12\pi}{s}B_{ee}\frac{M^2\Gamma^2}{(M^2-s)^2+M^2\Gamma^2}$$

ϕ: $s\bar{s}$, ${}^3\mathrm{S}_1$ bound state with $J^{PC}{=}1^{--}$

$$\sigma(e^+e^- \to \phi, s = (1.02)^2\ \mathrm{GeV}^2) \sim \frac{12\pi}{s}B_{ee}$$

$$= 36.2\times(1.37/4430) = 0.011\ \mathrm{GeV}^{-2} \sim 4000\ \mathrm{nb},$$

$$\sigma(\mathrm{hadr}){\sim}(5/3)\times 87{\sim}100\mathrm{nb}.$$

In 1979 we were given at CESR a tiny interaction region in a pit for detecting the neutral products of the Upsilon decays.

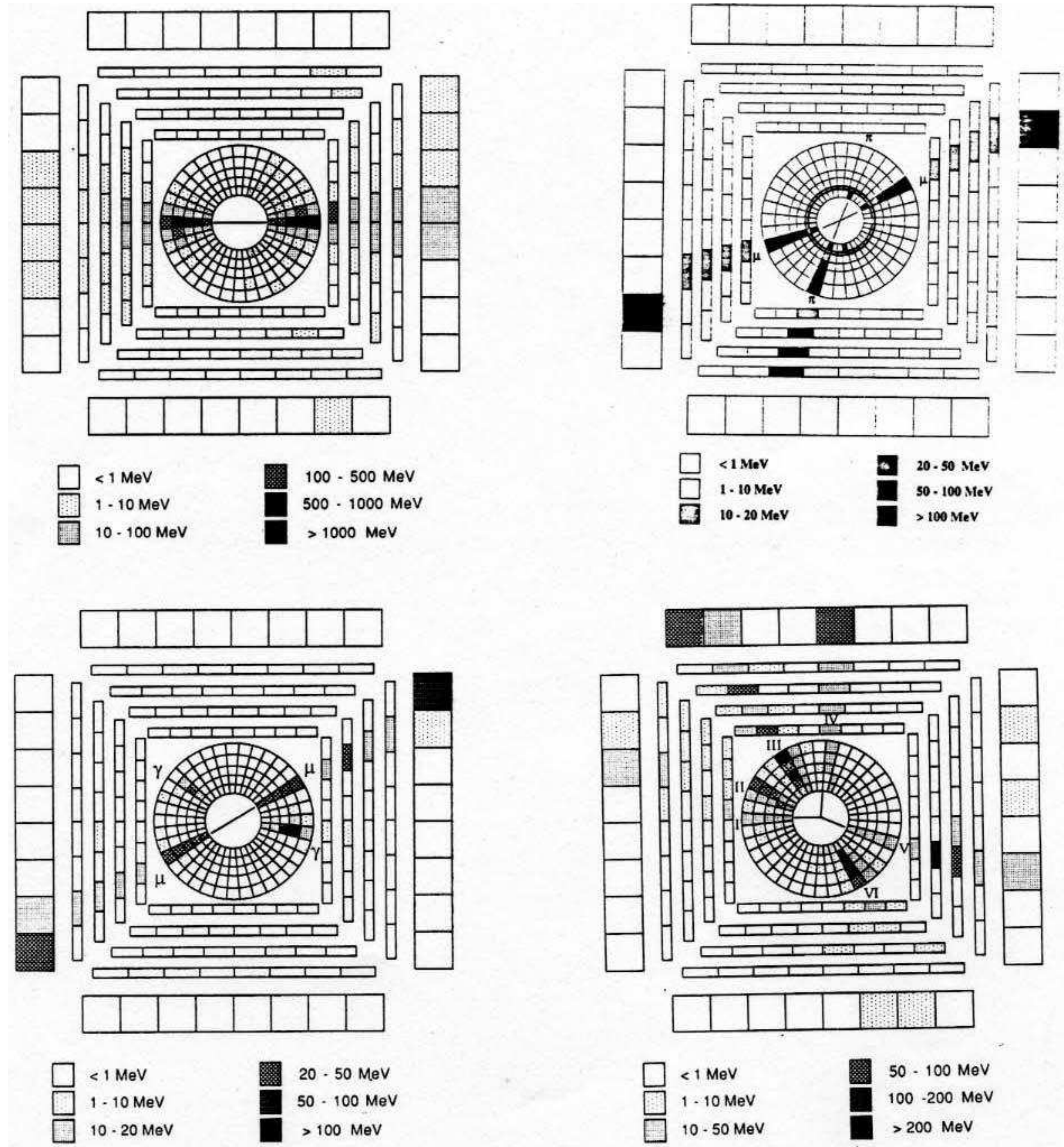
HOMOGENEOUS CALORIMETERS

By homogeneous we mean that the whole detector is made of the same active material, inorganic scintillators, usually NaI, BGO or CsI crystals.

In order to measure the energy contained in the shower, the calorimeter is composed ideally of truncated pyramidal crystals whose apex points to the interaction region.

Since the shower may not be contained within one crystal, one has to add the energy depositions from adjacent towers as well.

Event Displays in CUSB-II: top-left: Bhabha, top-right: $\pi\pi\mu\mu$, bottom-left $\mu\mu\gamma\gamma$, bottom-right hadronic event



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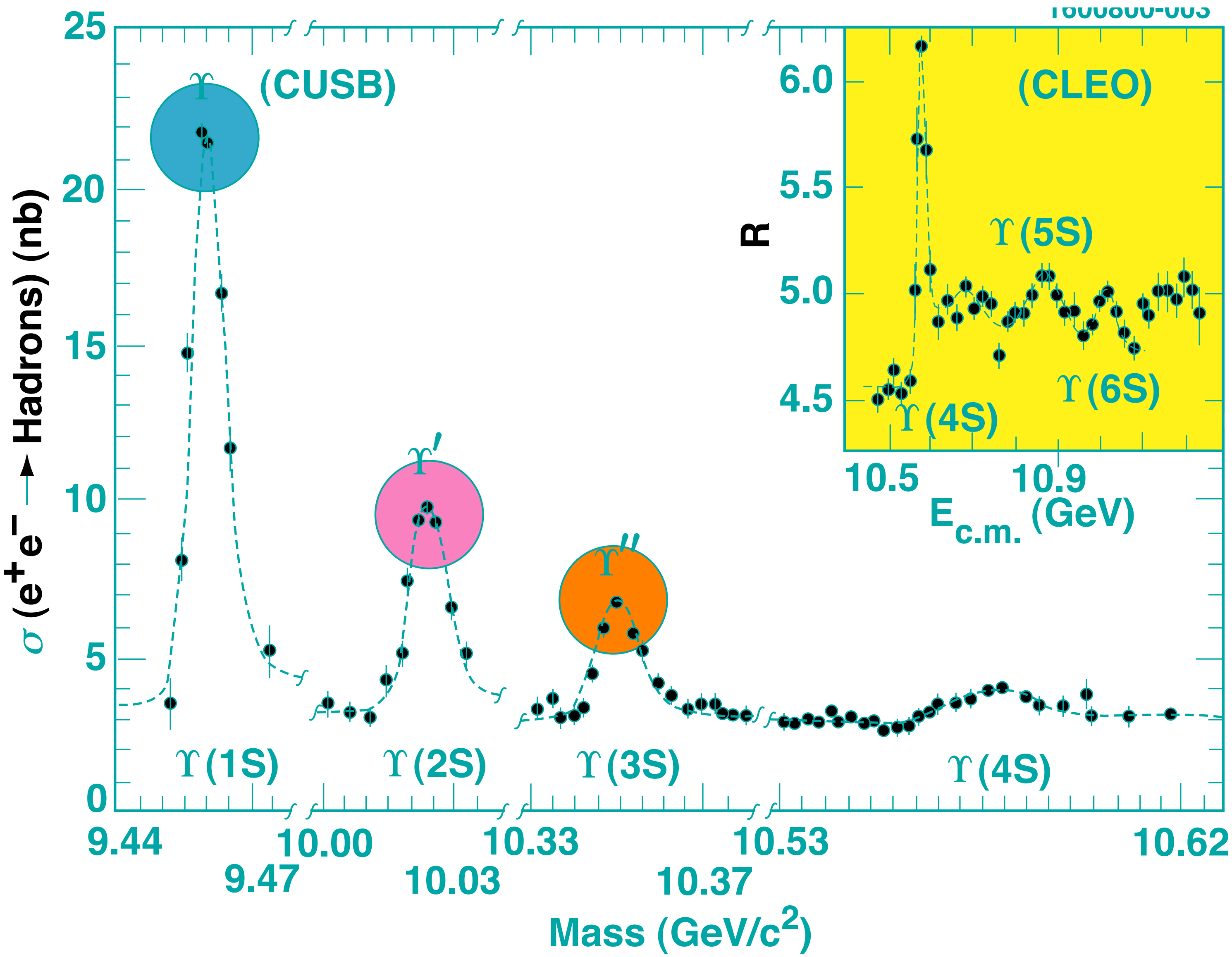


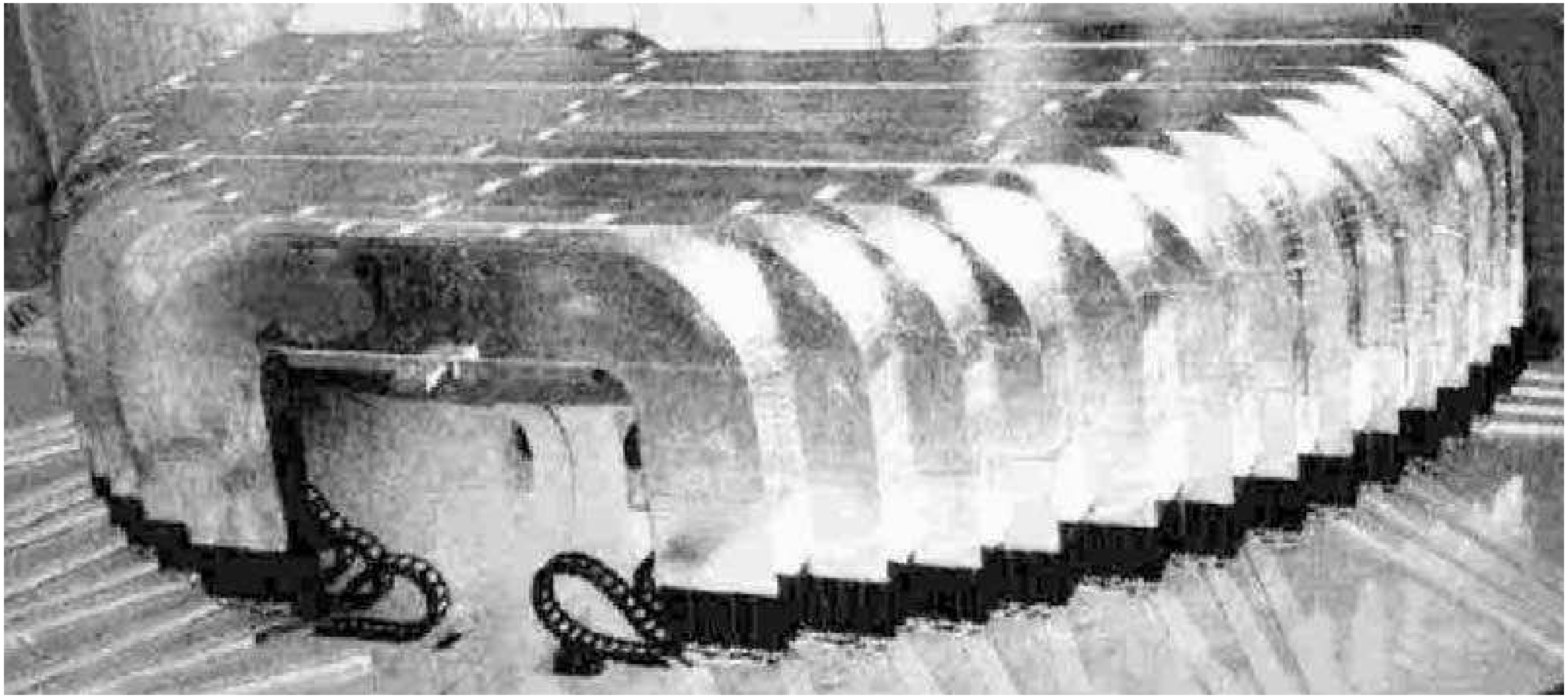
Karlsruhe - 2003 *Juliet Lee- Franzini* - Emcal-Spectroscopy. . .

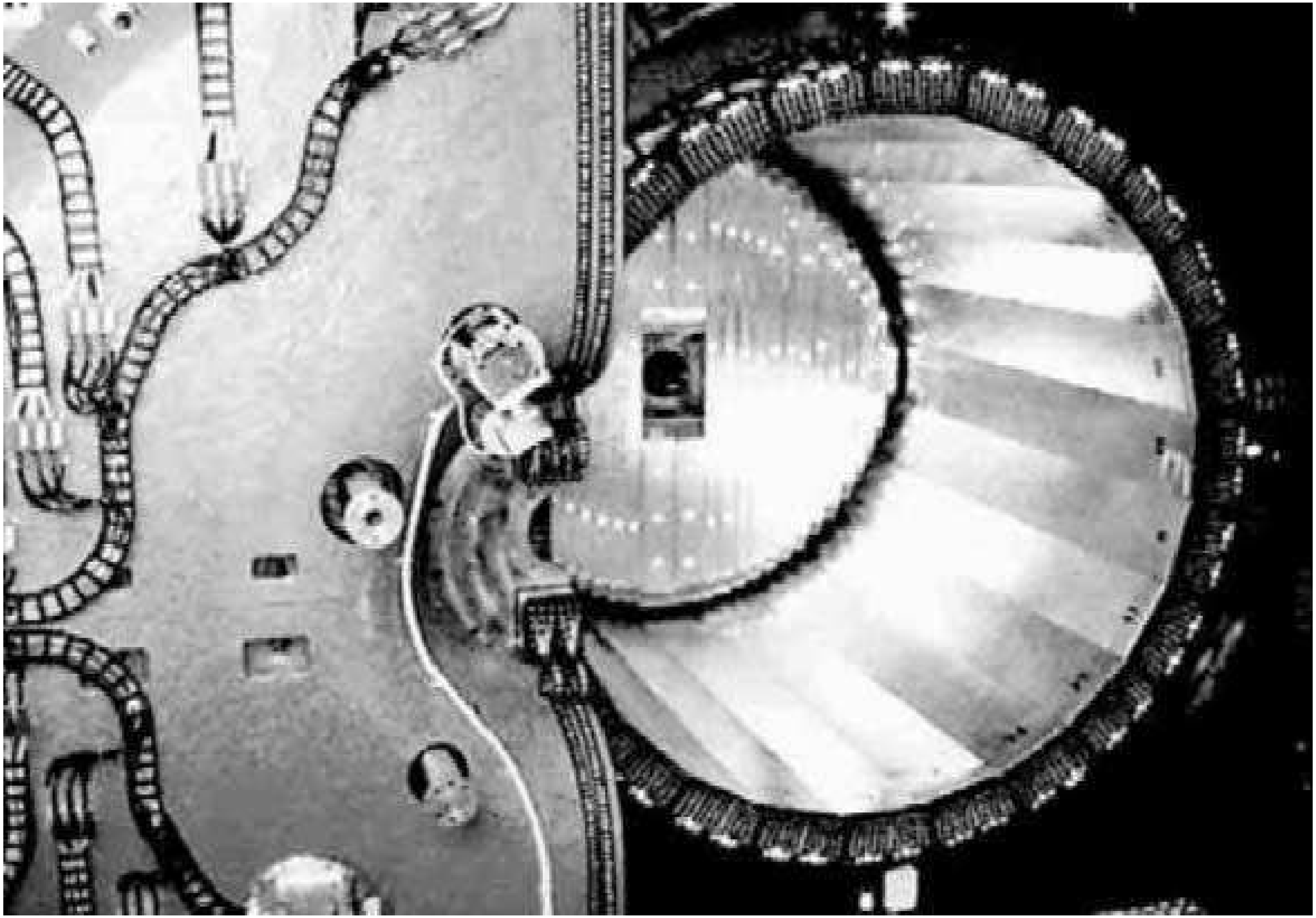
We did discover a dozen $b\bar{b}$ bound states and the first semileptonic B decays.

THE MEANEST and FASTEST CALORIMETER IN THE WEST

The calorimeter is made of grooved lead layers rolled out from a spaghetti machine, into whose grooves 1mm scintillating fibers are laid. The lead to scintillating fibers ratio is such that the lead is not even visible to the naked eye.

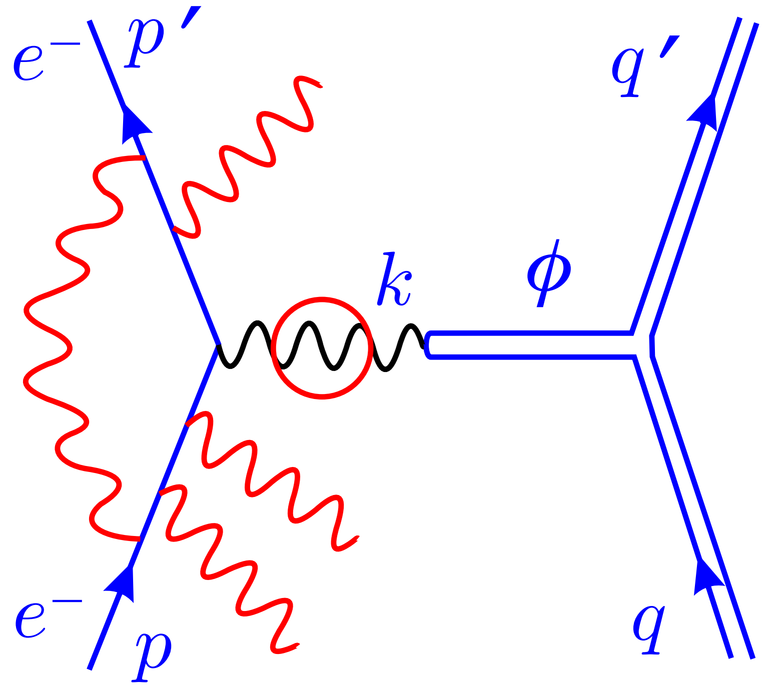
BEND TWO ENDS TO FORM ENDCAPS
wrapped around the iron yoke pole pieces





Karlsruhe - 2003 *Juliet Lee- Franzini* - Emcal-Spectroscopy. . . 53

1991: Direct CP Violation at DAFNE



$$\sigma_0 = 4\ \mu\text{b}$$

$$\sigma(e^+e^- \to \phi, s = (1.02)^2\ \text{GeV}^2) \sim 3\ \mu\text{b}$$

To Measure Real Part of (ϵ'/ϵ) to $\sim 10^{-4}$ requires ideally about 12 fb^{-1}, collected in about one (two?) year.

$$\gamma\beta c\tau_L = 3.4 \text{ m}$$

Drives detector size

$$\gamma\beta c\tau_S = 5.6 \text{ mm}$$

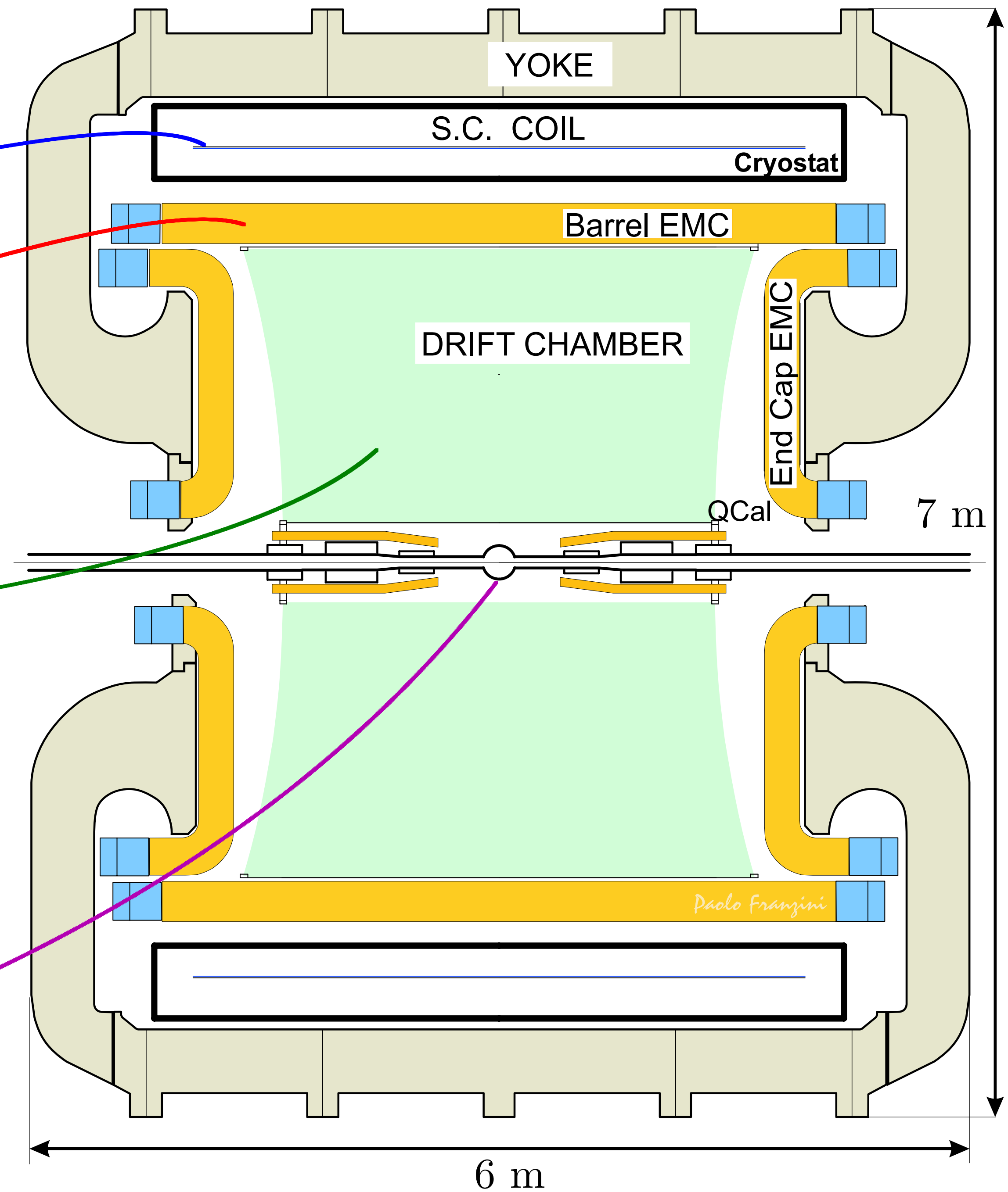
Drives IP surroundings

Magnet
SC Coil, B=0.6 T

EM Calor.
Pb–scint fiber
4880 pm

Drift Ch.
12582 sense wires
52140 tot wires
dE/dx

Al-Be beam pipe
r=10 cm, 0.5 mm thick



Yields for KLOE

From 2000-2002 collected about $\sim$400 pb^{-1}
From $\sim$400 pb^{-1} of integrated $\mathcal{L}$ we get:

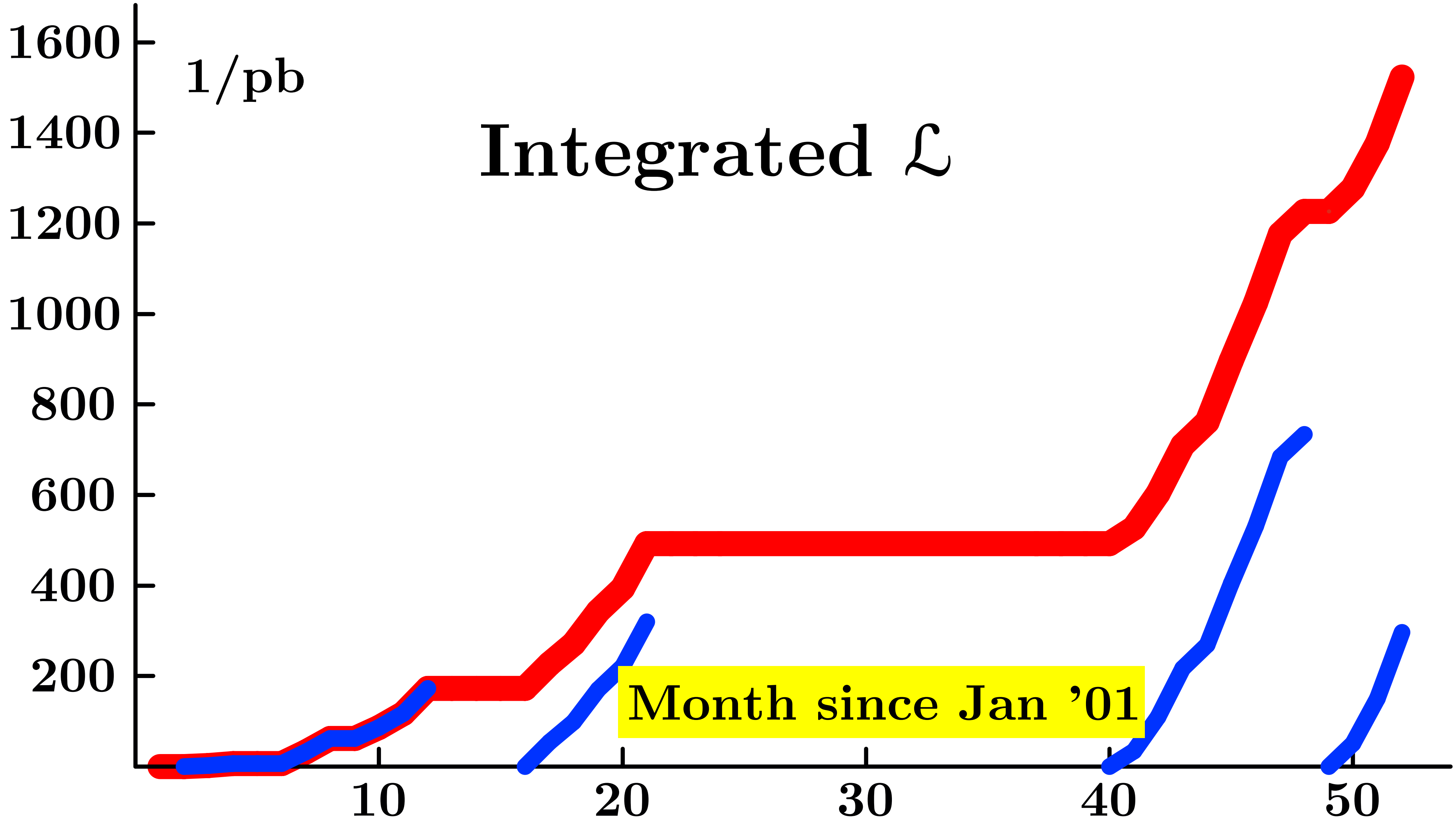
ch.	yield
ϕ	1.2×10^9
K_S,K_L	4×10^8
K^+, K^-	6×10^8

ch.	yield
tag'd K_L	1.3×10^8
tag'd K_S	2×10^7
tag'd K^+, K^-	2×10^8

decays	yield
${K^0}_{e3}$	2.8×10^6
${K^0}_{\mu 3}$	1.9×10^6
${K^\pm}_{e3}$	1.8×10^6
${K^\pm}_{\mu 3}$	1.2×10^6

Today we have 3 times as much so KLOE is in excellent position for carrying all Kaon parameters except rare decays.

KLOE. 2001 through 2005



$\phi \rightarrow K^0 \overline{K^0}$

$$|\, i \,\rangle = \frac{|\, K^0, \mathbf{p} \,\rangle |\, \overline{K^0}, -\mathbf{p} \,\rangle - |\, \overline{K^0}, \mathbf{p} \,\rangle |\, K^0, -\mathbf{p} \,\rangle}{\sqrt{2}}$$

$$|\, K_S \,\rangle \equiv p' |\, K^0 \,\rangle + q' |\, \overline{K^0} \,\rangle \qquad |p'|^2 + |q'|^2 = 1$$

$$|\, K_L \,\rangle \equiv p |\, K^0 \,\rangle - q |\, \overline{K^0} \,\rangle \qquad |p|^2 + |q|^2 = 1$$

$$|\, i \,\rangle = \frac{|\, K_S, \mathbf{p} \,\rangle |\, K_L, -\mathbf{p} \,\rangle - |\, K_L, \mathbf{p} \,\rangle |\, K_S, -\mathbf{p} \,\rangle}{\sqrt{2(qp' + q'p)}}$$

CPT invariance requires $p' = p$ and $q' = q$

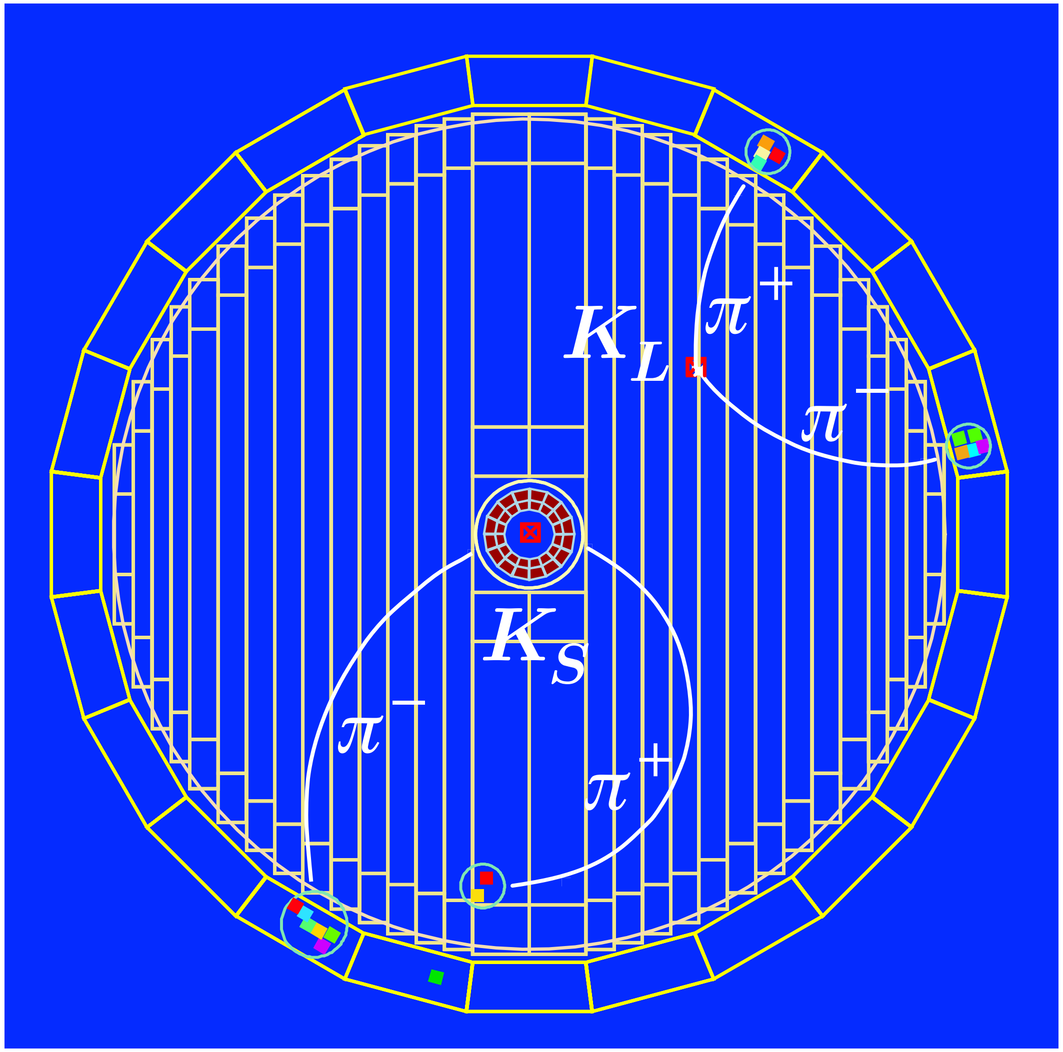
1. Pure, K_L, K_S, K^0, $\overline{K}^0$ beams
2. Kaon interferometry

From unitarity and $\sigma(\gamma\gamma \to K^0\overline{K}^0, J^P = 0^+)$

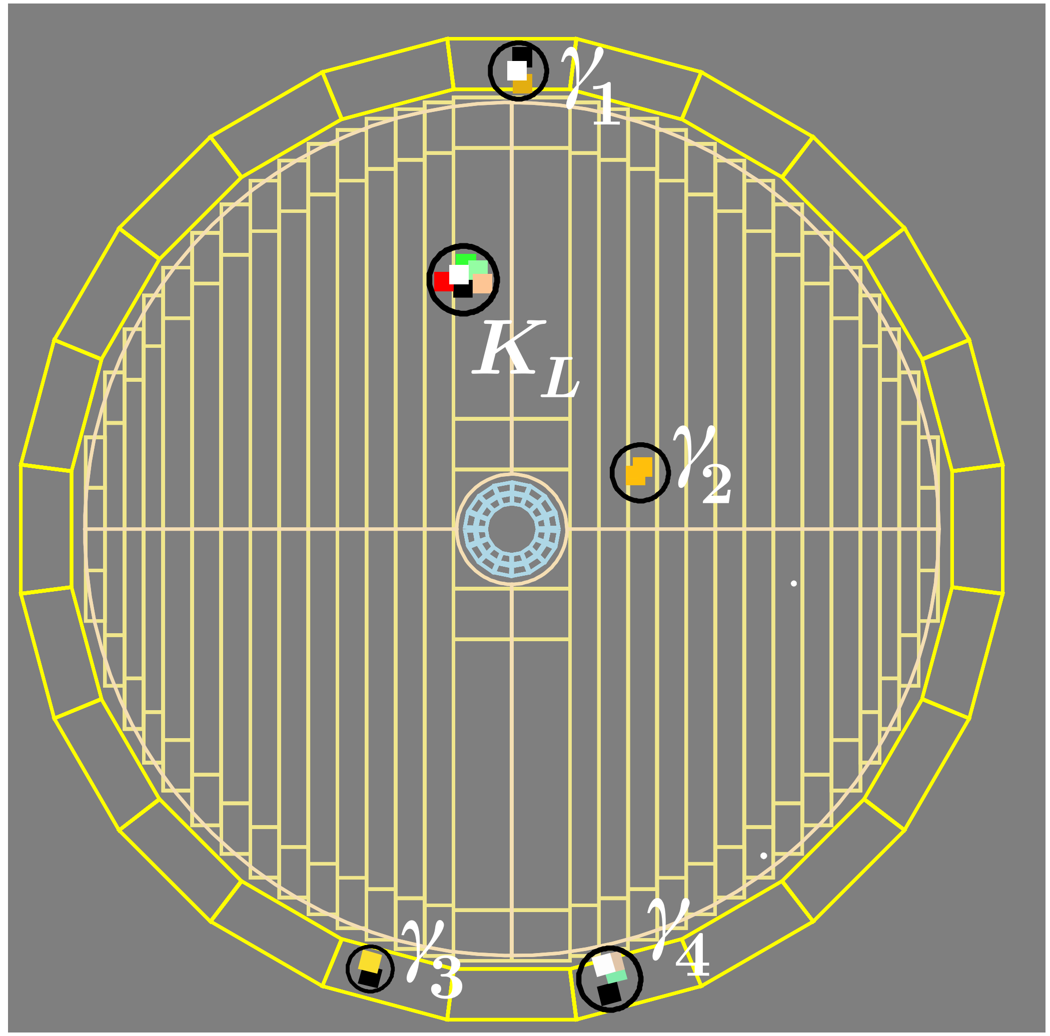
$$\frac{e^+e^- \to K_S K_S \text{ or } K_L K_L}{e^+e^- \to \phi \to K_S K_L} \sim \text{few} \times 10^{-9}$$

Unique opportunity to study:
K_S BR's to high accuracy
K_S Rare decays: $K_S \to \pi\ell\nu$, $\to \pi^0\pi^0\pi^0$, $\to \pi^+\pi^-\pi^0$
in addition to CP and CPT studies,
the original mission of KLOE.

The first events, April '99

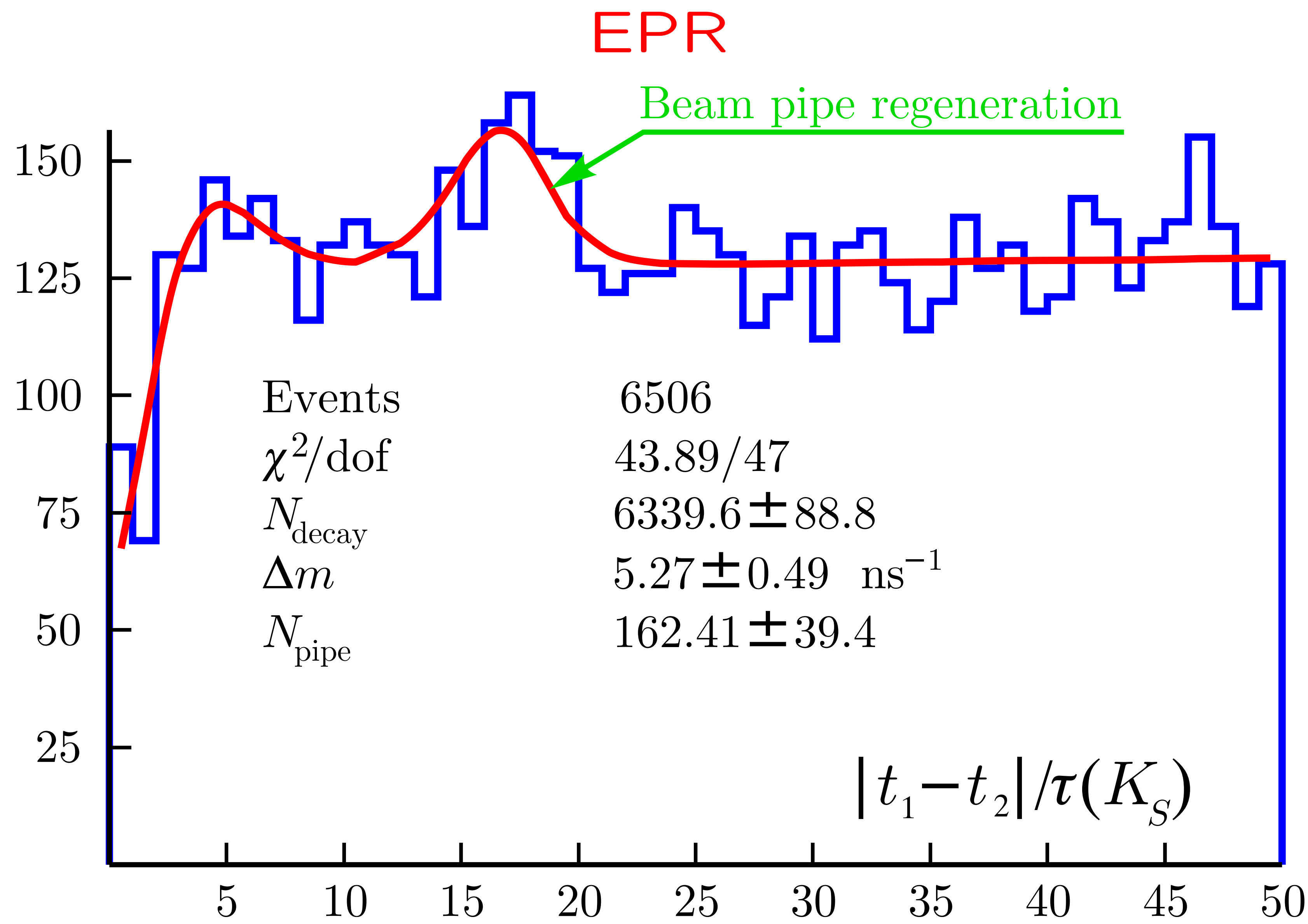


$K_S \rightarrow \pi^+\pi^-$, $K_L \rightarrow \pi^+\pi^-$

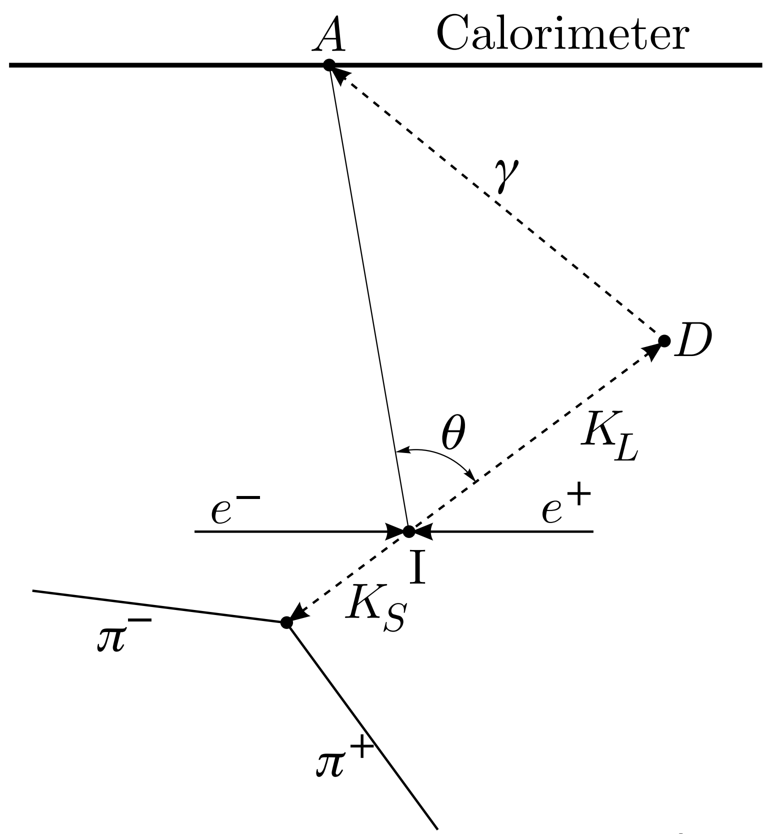


$K_S \rightarrow \pi^0\pi^0$, K_L interacts in ECal

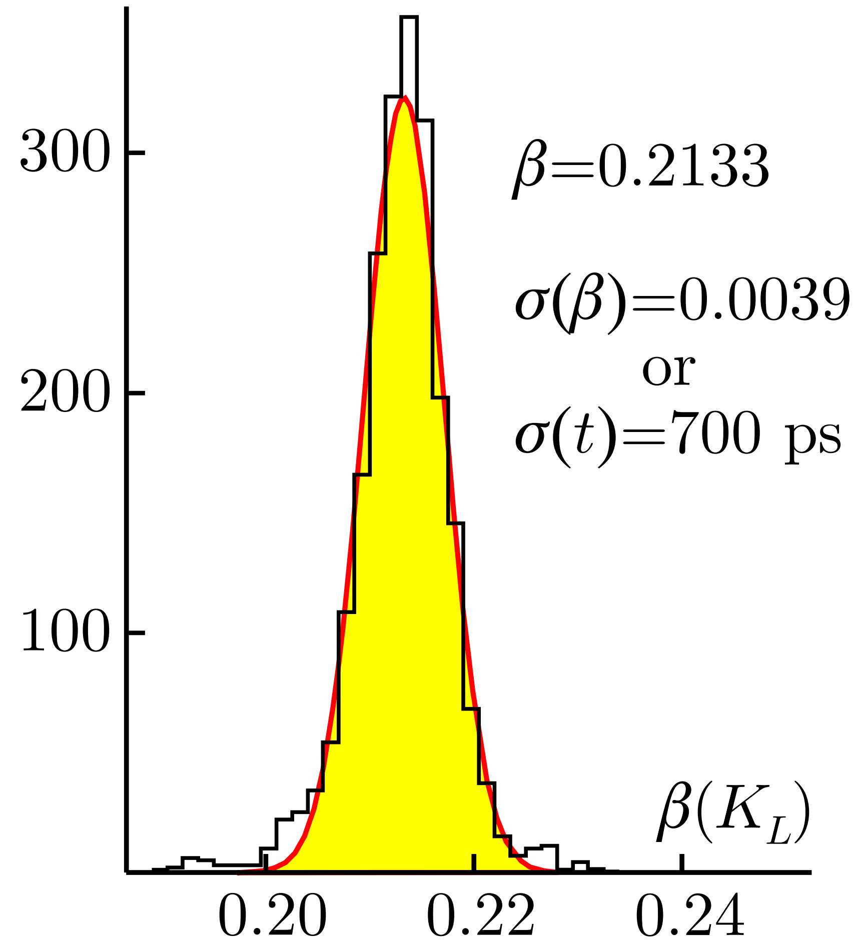
First observation ever of coherence in two kaon system



KLOE performance



Measure K_L path by $t(I \to A)$
and K_S direction
Tag K_S from "K_L-*crash*"



δW(DAΦNE)=1 MeV
gives $\delta\beta$=0.004

Measuring BR

We intend to measure "absolute" BR, *i.e.* Γ_i/Γ, not ratios of partial rates. In general we have three ways to proceed:

1. Measure single BR's
2. Inclusive measurements
3. Direct partial rate measurements

In all cases we always use tagged kaons to find a BR. Trigger must not depend on decay mode of tagged kaon. For every event, the trigger must be verified as due to the tagging kaon.

Response of all trigger elements is available for each event.

There is a fundamental difference between $K^{\pm}$ and K_L:

$K_L \rightarrow 2$ charged particles $\quad K^{\pm} \rightarrow 1$ charged particle

Single BR

Used mostly for rare decays or special channels (e.g. 3π).
Tag as apprpriate

Analysis steps:

1. Validate the trigger
2. Tag provides kaon count: N_K
3. Extract signal, N_S. BR=N_S/N_K
4. Estimate efficiencies, bckgnds, etc

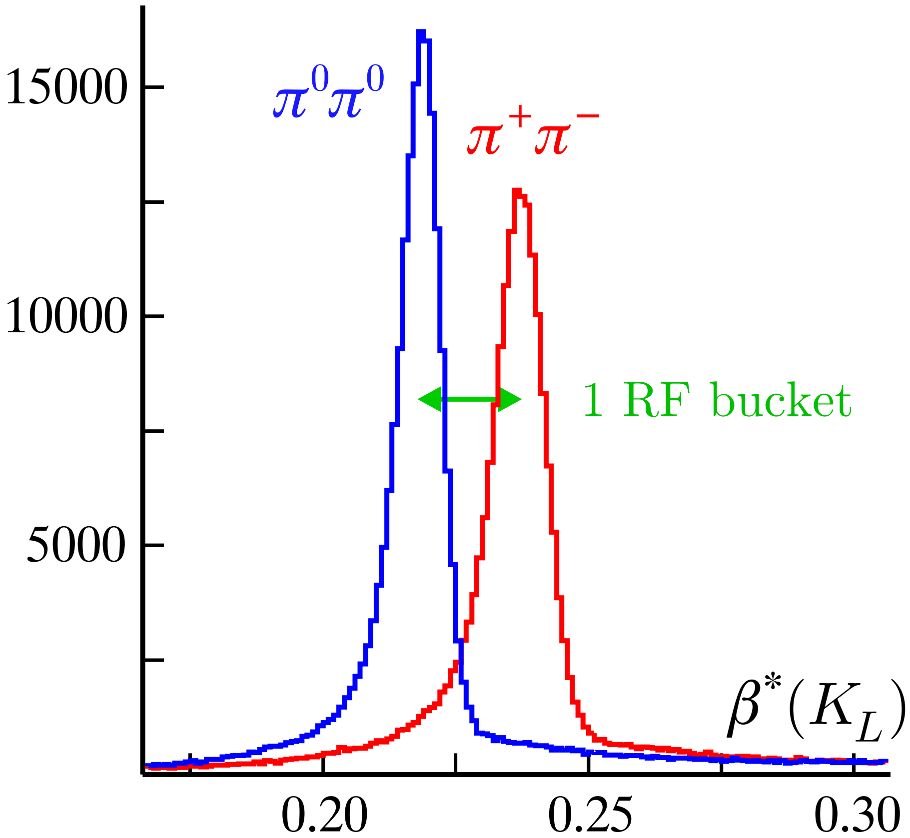
Corrections:

1. Estimate trigger mistakes, other side dependence
2. Estimate corrections, systematics, etc by data and MC.

Typically $\sim$1% each effects

K_S-decays

$\Delta I = 1/2$
Chiral expansion parameters
Calculation of $\Re(\epsilon'/\epsilon)$
BR's for K_S decays (and K_L)



K_L interacting in the calorimeter gives an ideal K_S tag, almost independent of K_S decay mode

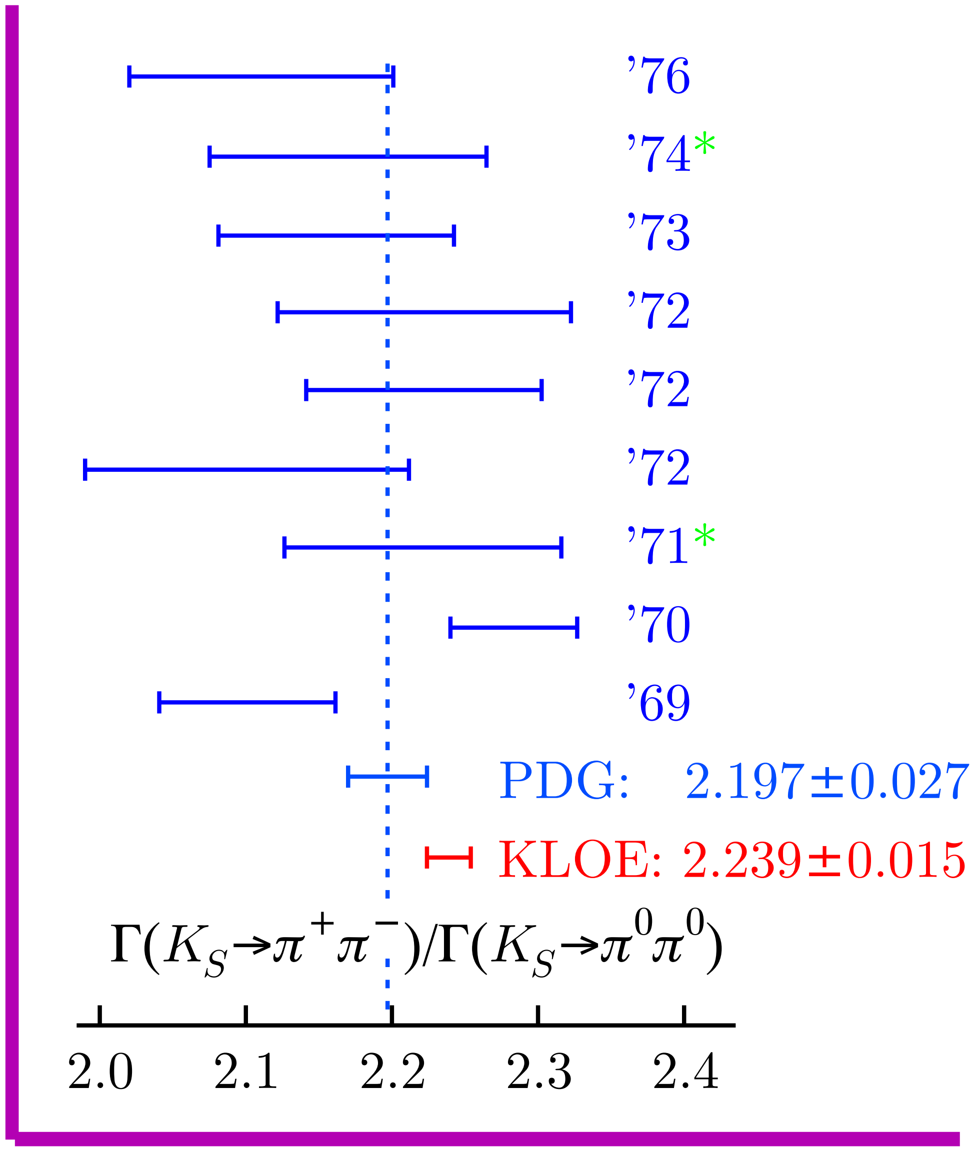
Trigger eff >96.5%

Overall accept. ~57%

ALL FROM DATA ⇓

Systematic errors

Source	Error, %
Tracking	0.2
Cluster count	0.5
Trigger	0.06
Cosmic-r. veto	0.35
Tagging	0.4
Total	0.76

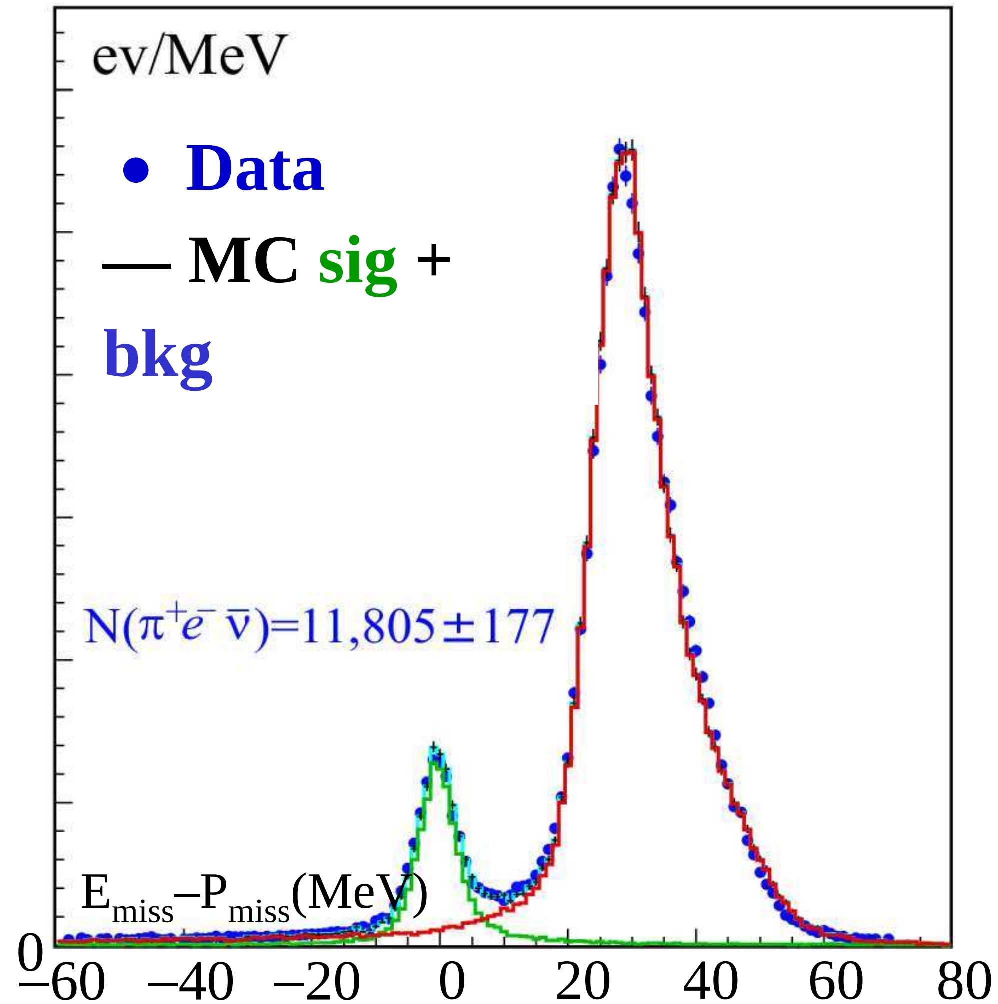


$R = 2.239 \pm 0.003$(stat.)± 0.015(syst.)

KLOE includes all $K_S\to\pi^+\pi^-\gamma$, others inc. unknown fraction.

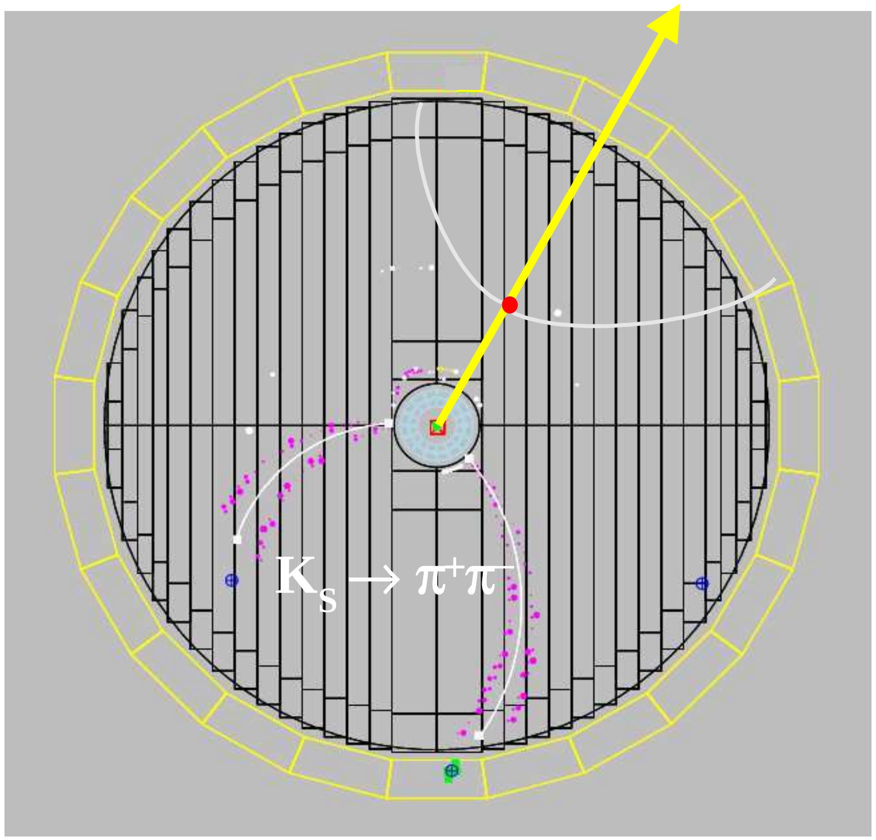
K_S semileptonic decay

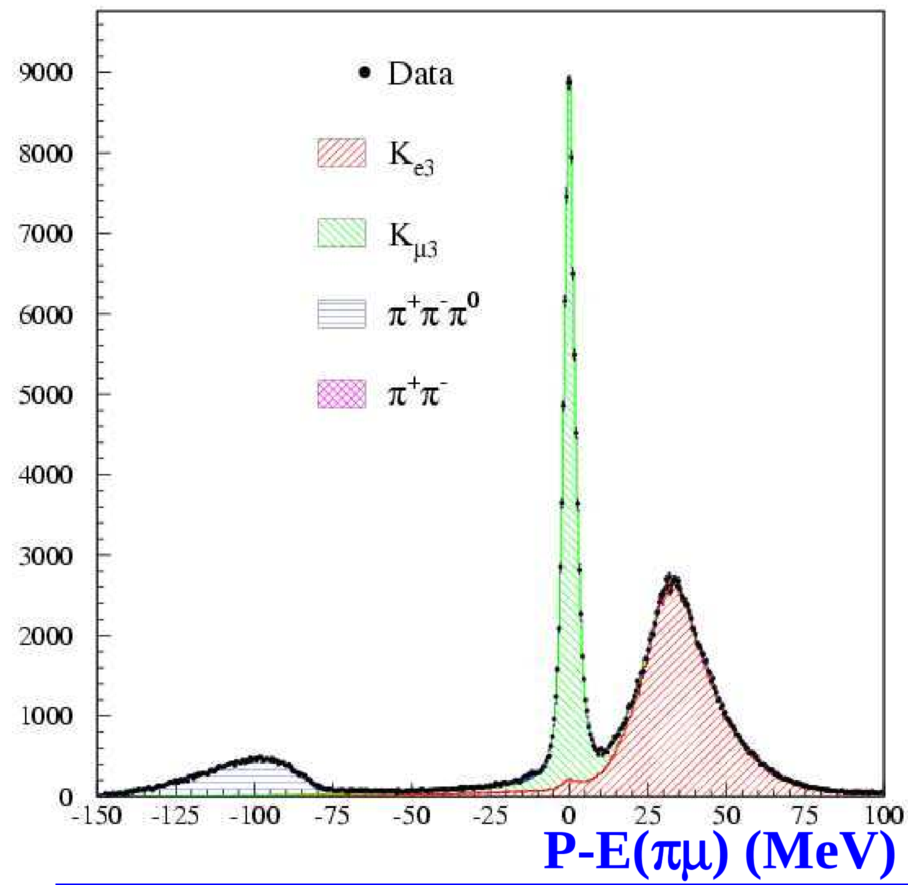
- Selected using Tof technique
- Event counting obtained by fitting the E(πe)-P distribution
- The two charge modes are measured independently
- selected ~10^4 signal events per charge in the 2001-2002 data sample.



$$\mathrm{BR}(K_S \to \pi e \nu) = (7.09 \pm 0.07_{stat} \pm 0.08_{syst})\ 10^{-4}$$

$K_L \rightarrow$charged





2 tracks forming a vertex along the K_L direction.
Vertex and tracking efficiency ~55% for Kl3 and 40% for 3π

Events counted by fitting missing momentum minus missing energy in the pion-muon hypothesis

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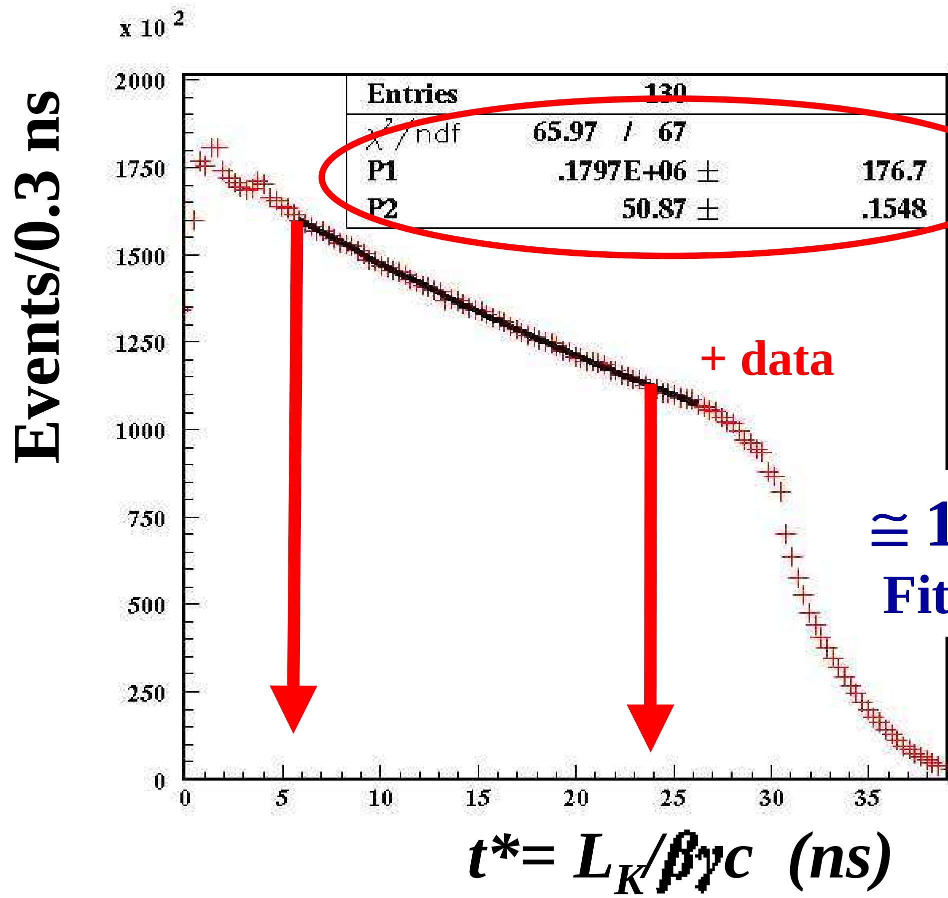
K_L lifetime from $K_L \to 3\pi^0$



$\simeq$ 14 x 10^6 events

Fit region = 6 -26 ns (40% τ_L)

τ (PDG) (fit) = (51.7 ± 0.4) ns

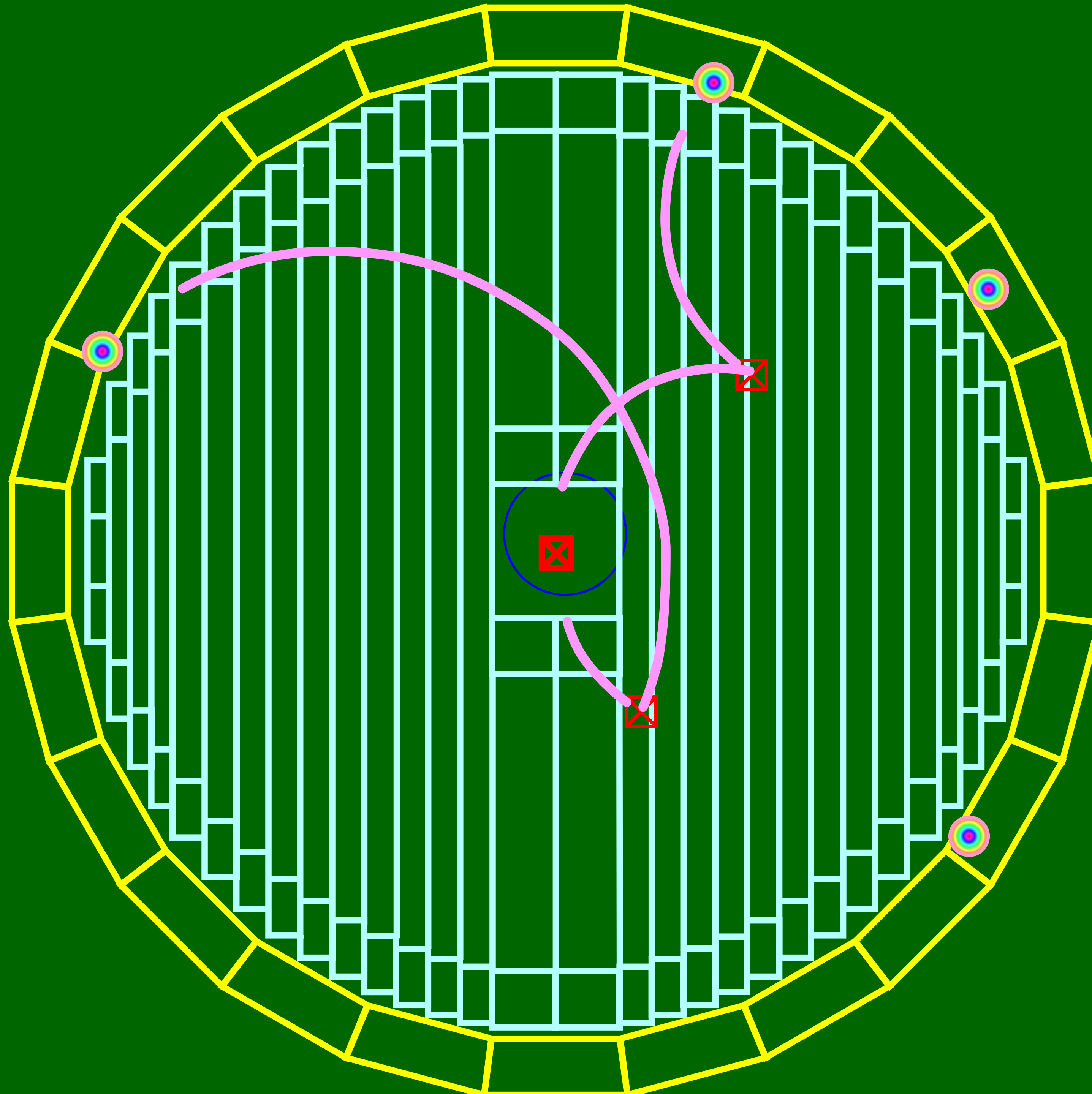
τ (Vosburg, 1972) = (51.54 ± 0.44) ns - 0.4 Mevents

τ_L (KLOE) = (50.87 ± 0.16 ± 0.26) ns - 14.5 Mevents – 440 pb^{-1}

$$\phi \to K^+ K^-$$

$$K^+ \to l^+ \pi^0 \nu$$

$$K^- \to \mu^- \overline{\nu}$$



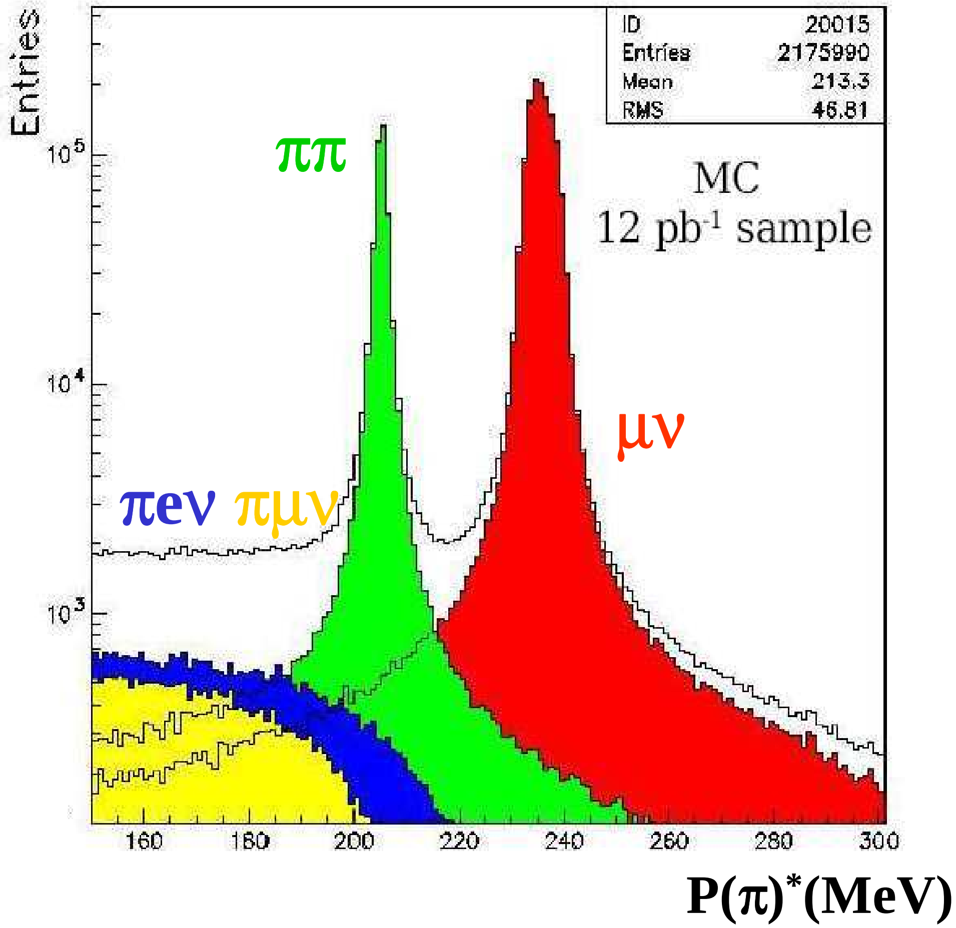
Measurement of BR($K^+ \to \mu\nu(\gamma)$)

Combining the experimental value of
$\Gamma(K\to\mu\nu(\gamma))/\Gamma(\pi\to\mu\nu(\gamma))$
with the ratio
f_K/f_π obtained from lattice calculations
we can extract the ratio $|V_{us}|/|V_{ud}|$
(Marciano hep-ph/0406324)

Selection

- **Negative self-triggering $\mu\nu$-Tag**
- **2002 data ~175 pb^{-1} (2/3 is used as efficiency sample)**
- **Background events identifyied by the presence of a neutral pion.**

Particle momentum in K rest frame



Conclusion

With the data collected in the year 2001-2002 KLOE has measured:

- **The dominant K_L BR's with 0.5% accuracy**
- **The K_L lifetime with 0.6% accuracy**
- **BR($K_S \to \pi e \nu$) with 1% accuracy**
- **BR($K^+ \to \mu^+ \nu$) with 0.2% accuracy**
- **All BR's are inclusive of the radiation**

Final papers are under review by the Collaboration

A large number of $K^\pm$ semileptonic decays has been collected and identified allowing us to measure all the BR's with better than 1% accuracy

KLOE is now measuring:

- **$K^\pm$ lifetime**
- **Kl3 form factor**
- **$K_S \to \pi \mu \nu$ BR**

Coming soon the update of $\Gamma(K_S \to \pi^+ \pi^- (\gamma))/\Gamma(K_S \to \pi^0 \pi^0)$ measurement

We expect to collect 2fb^{-1} for the end of December 2005

Claudio Gatti **CKM2005 San Diego March 2005**

$\boxed{\text{1963}}$

UNITARY SYMMETRY AND LEPTONIC DECAYS

Nicola Cabibbo
CERN, Geneva, Switzerland

(Received 29 April 1963)

From $\dfrac{\Gamma(K_{\mu}2)}{\Gamma(\pi_{\mu}2)}$ $V_{us} = 0.25$

$\boxed{\text{1980-2002}}$

Mostly from $K_{\ell 3}$ decays, $V_{us} \cong 0.220$

1st row unitarity: $\Delta = 1 - |V_{ud}|^2 - |V_{us}|^2 = 0.003.$

The 0.003 could be due, for instance, to a 3% mistake in $|V_{us}|$ or 6% in $\Gamma(K_{\ell 3})$.

2004-05

$V_{us} \cong 0.226$ From K_L!!

$$\Delta = 1 - |V_{ud}|^2 - |V_{us}|^2 = 0.0002$$

(equivalent to $\delta|V_{us}| \sim 0.2\%$) due to

1. BR's up few %
2. $\int$ over phase space down because of FF, 1%
3. $\Gamma(K_L)$ up or lifetime down 1%

We can begin to hope for better than 1% knowledge of $|V_{us}|$

58 or 42 years later!

$\boxed{\text{From BR and } \tau \text{ to } |V_{us}|}$

$$\Gamma_i = \frac{\mathrm{BR}_i}{\tau} = \frac{G_\mathrm{F}^2\, M_K^5\, |V_{us}|^2\, C_K^2}{768\,\pi^3}\left(\int_i \rho\,\mathrm{d}y\,\mathrm{d}z\right) \times [1 + \delta + \ldots]$$

$\Uparrow$ Gino

For K_{e3}

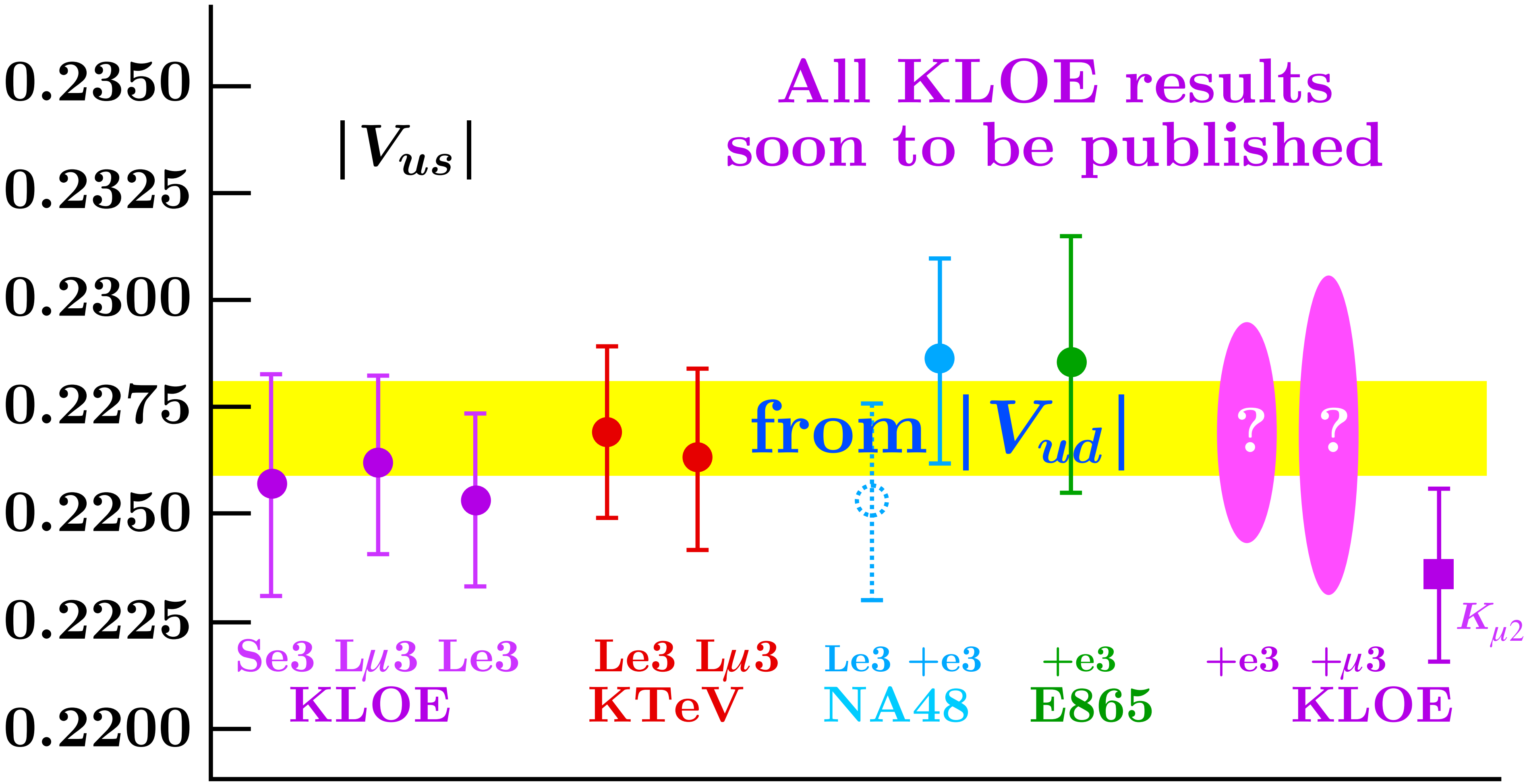
$$\rho(y,z) = 24((z+y-1)(1-y)-\alpha)|f_+(t)|^2$$

$$f_+(t) = 1 + \lambda'_+ \frac{1+a-z}{\alpha} + \frac{\lambda''_+}{2}\left(\frac{1+a-z}{\alpha}\right)^2$$

$$\alpha = \frac{m}{M} \qquad y = \frac{2E_e}{M} \qquad z = \frac{2E_\pi}{M}$$

$$I_{e3} = 0.563402 + 1.94706\,\lambda' + 2.69077\,(\lambda'^2 + \lambda'')\ldots$$

2004-05


0.2350
0.2325
0.2300
0.2275
0.2250
0.2225
0.2200
$|V_{us}|$
All KLOE results
soon to be published
from $|V_{ud}|$
?
?
$K_{\mu 2}$
Se3 Lμ3 Le3
KLOE
Le3 Lμ3
KTeV
Le3 +e3
NA48
+e3
E865
+e3 +μ3
KLOE

ADVICE FOR STRANGENESS HUNTERS

BE PATIENT. KLOE took 1991 thru 1993

for the Experiment to be Approved

BE INNOVATIVE. KLOE during 1993 -1995

Design State-of-Art EMCAL, DC, TRIGGER, DAQ,

BE INDUSTRIOUS. All Components Built, Assembled,

Tested and Detector Rolled onto Beamline by Xmas 1998

BE BRAVE From 1995 to date

The Most Powerful Computational Facilities in the INFN.

Be ADAPTIVE. Be Ready to Change Goal

when Faced with Constraints:

in Luminosity, Time, Money, Human-Power...