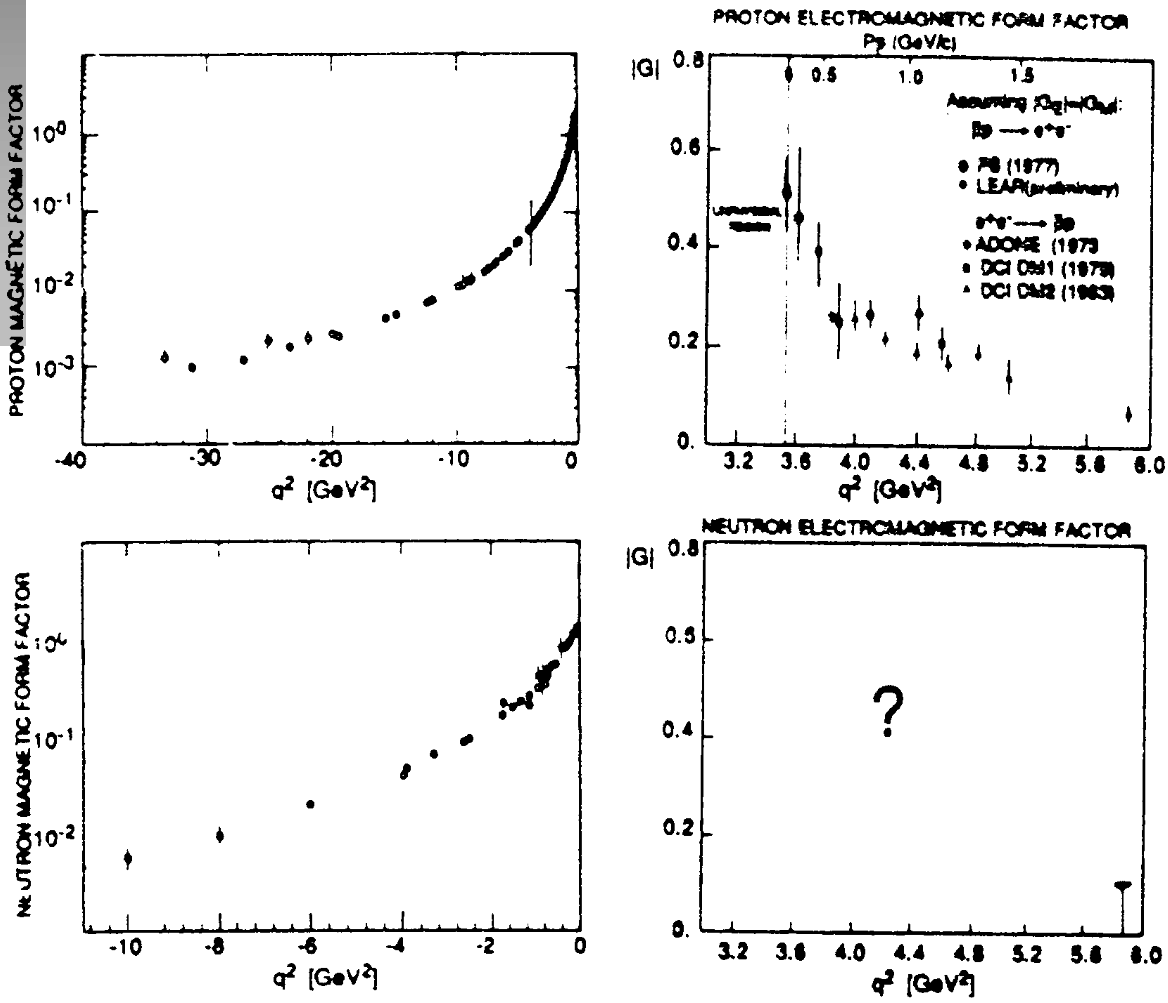
Recent results and future programs on nucleon and nuclear structure in Frascati

Hadron Structure ‘96
Stará Lesná
Slovak Republic
February 12 -16, 1996

A. Feliciello / I.N.F.N. - Sezione di Torino

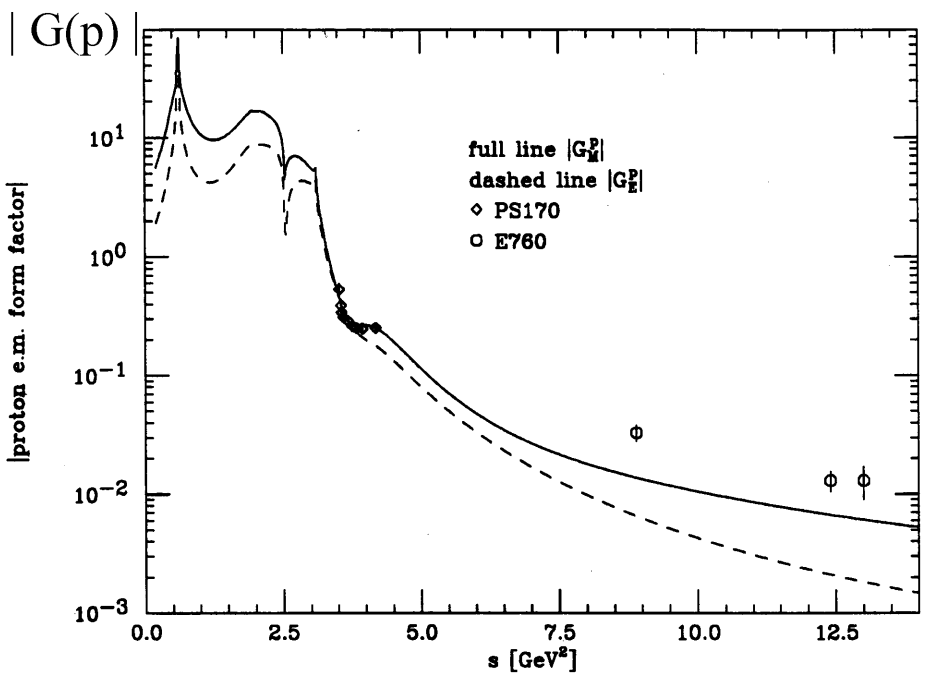
... before *FENICE*

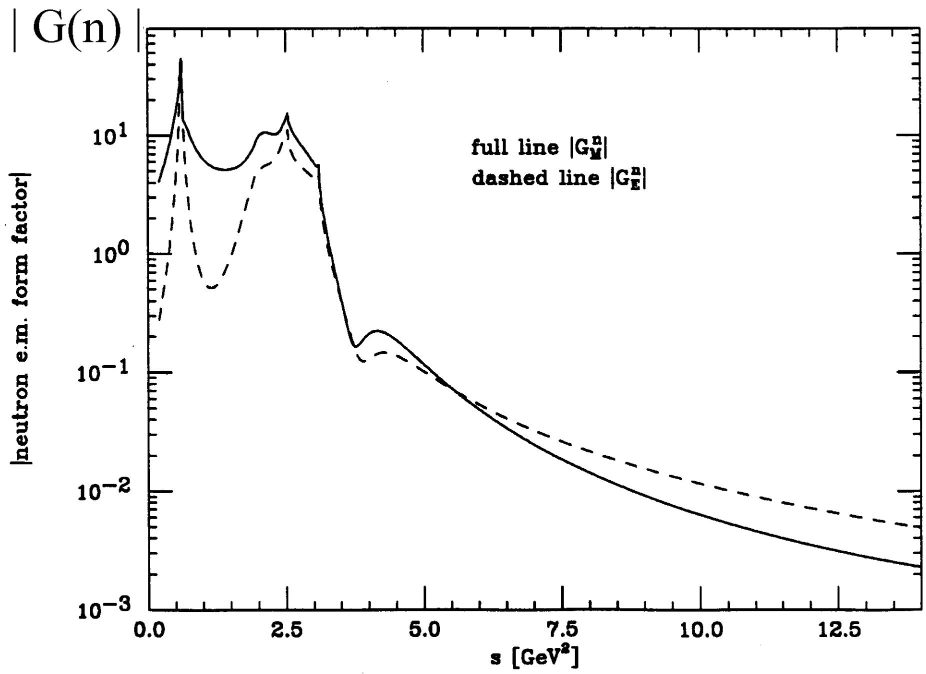


Theoretical expectations for $r = \frac{\sigma(e^+e^- \to n\bar{n})}{\sigma(e^+e^- \to p\bar{p})}$

threshold < q^2 < 10 GeV^2

- **QCD sum rules** (Brodsky 72) $r \sim \frac{q_d^2}{q_u^2} \sim 0.25$
  baryon = lead. quark (Chernjak 83)
  + diquark (Hyer 92) $r \sim 0.06$
  @ q^2 = 25 GeV^2
- **EVDM:**
  $\rho + \omega$ (Cabibbo 61) $r \sim 14$
  Veneziano Rec. (Körner 77) $r \sim 2$
  PDG Rec. (Voci 82) $r \sim 100$
  + Unit. Ampl. (Dubnicka 88) $r \sim 25$
  (Dubnicka 92) $r < 1$
- + $N\bar{N}$ strong final state interaction (Dalkarov 92) (Meshcheryakov 93) $r \leq 1$ @ threshold
- U spin invariance (Biagini 91) $r > 1$
  @ $q^2 \sim 4 - 5$ GeV^2

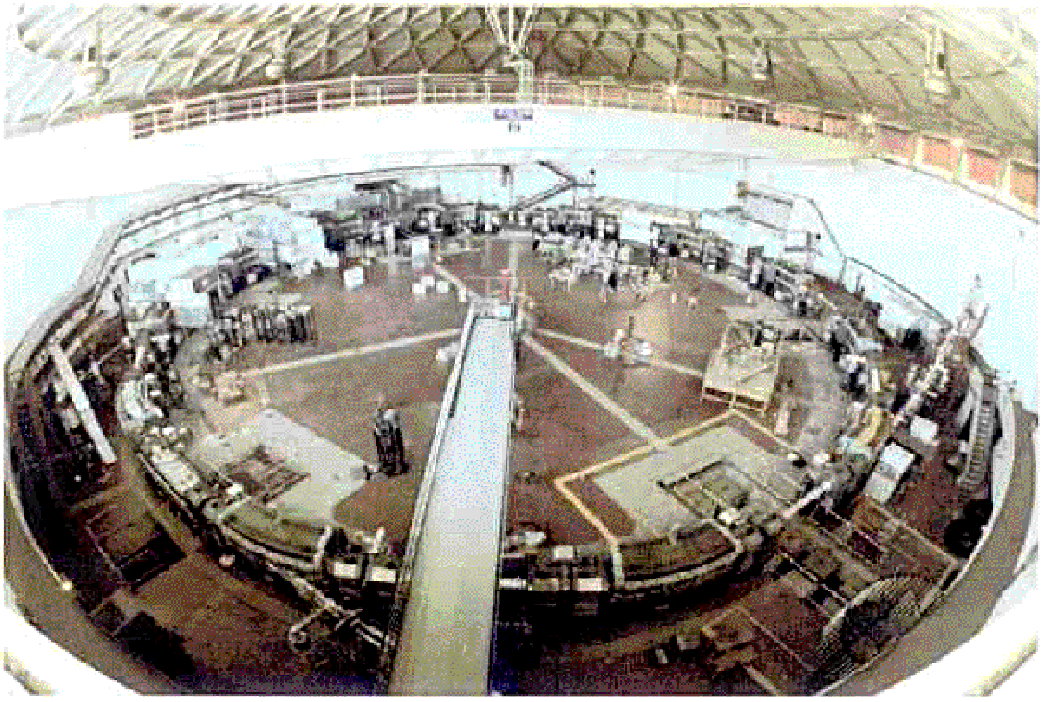

| G(p) |
full line $|G_M^p|$
dashed line $|G_E^p|$
◇ PS170
○ E760
|proton e.m. form factor|
s [GeV²]


| G(n) |
full line $|G_M^n|$
dashed line $|G_E^n|$
|neutron e.m. form factor|
s [GeV²]

The FENICE experiment

- Cagliari University and INFN
- Ferrara University and INFN
- INFN National Laboratories of Frascati
- Padova University and INFN
- Roma “La Sapienza” University and INFN
- Roma “Tor Vergata” University and INFN
- Torino University and INFN
- Trieste University
- Udine University and INFN

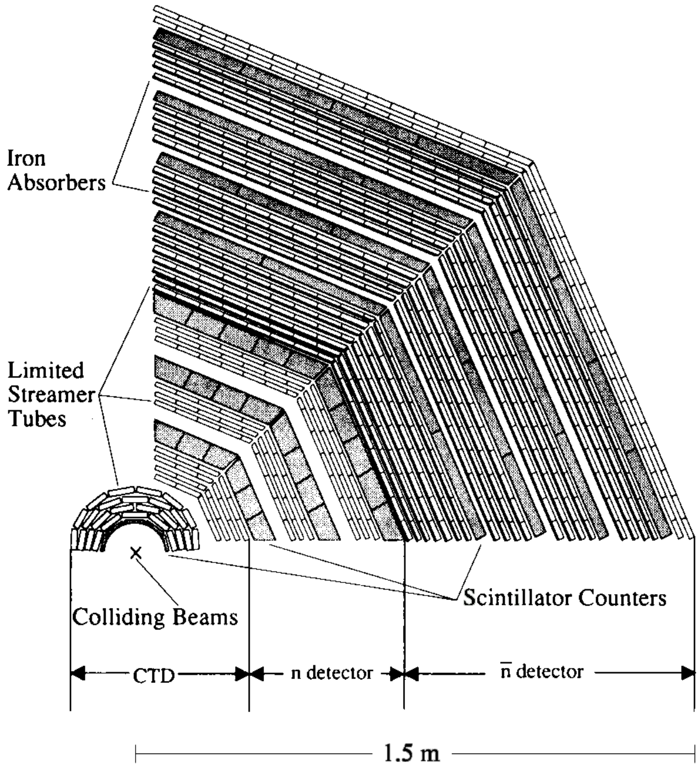
ADONE
(1969 -1993)

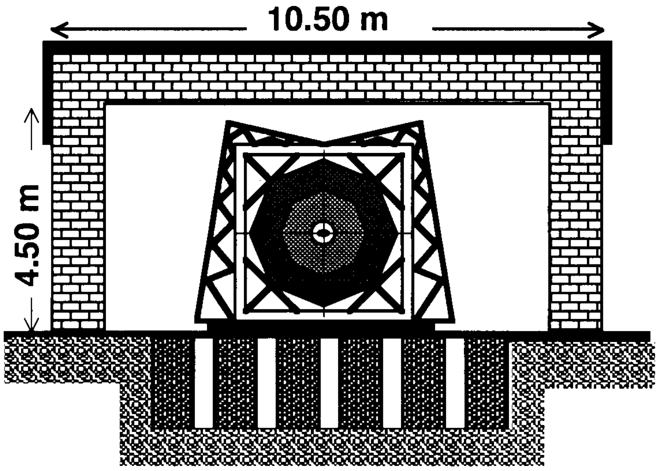


- single bunch operation
- β value: 4.5 m (horizontal), 0.8 m (vertical)
- beam-beam tune shift at 2 GeV ($\Delta\nu \cong 0.035$)
- luminosity measured by single beam-beam bremsstrahlung: gas bremsstrahlung is subtracted by separating the beams at the i.p.

☛ c.m. energy (max)	2.0 (3.1) GeV
☛ peak luminosity	1.0×10^{29} $cm^{-2}s^{-1}$
■ particles/bunch	2.0×10^{10}
■ crossing frequency	2.8×10^{6} Hz
■ emittance	0.14 mm rad
■ r.m.s. energy spread	3.8×10^{-4}
■ horizontal r.m.s. beam size	1.15 mm
■ vertical r.m.s. beam size	0.08 mm
■ r.m.s. source lenght	6.0 cm

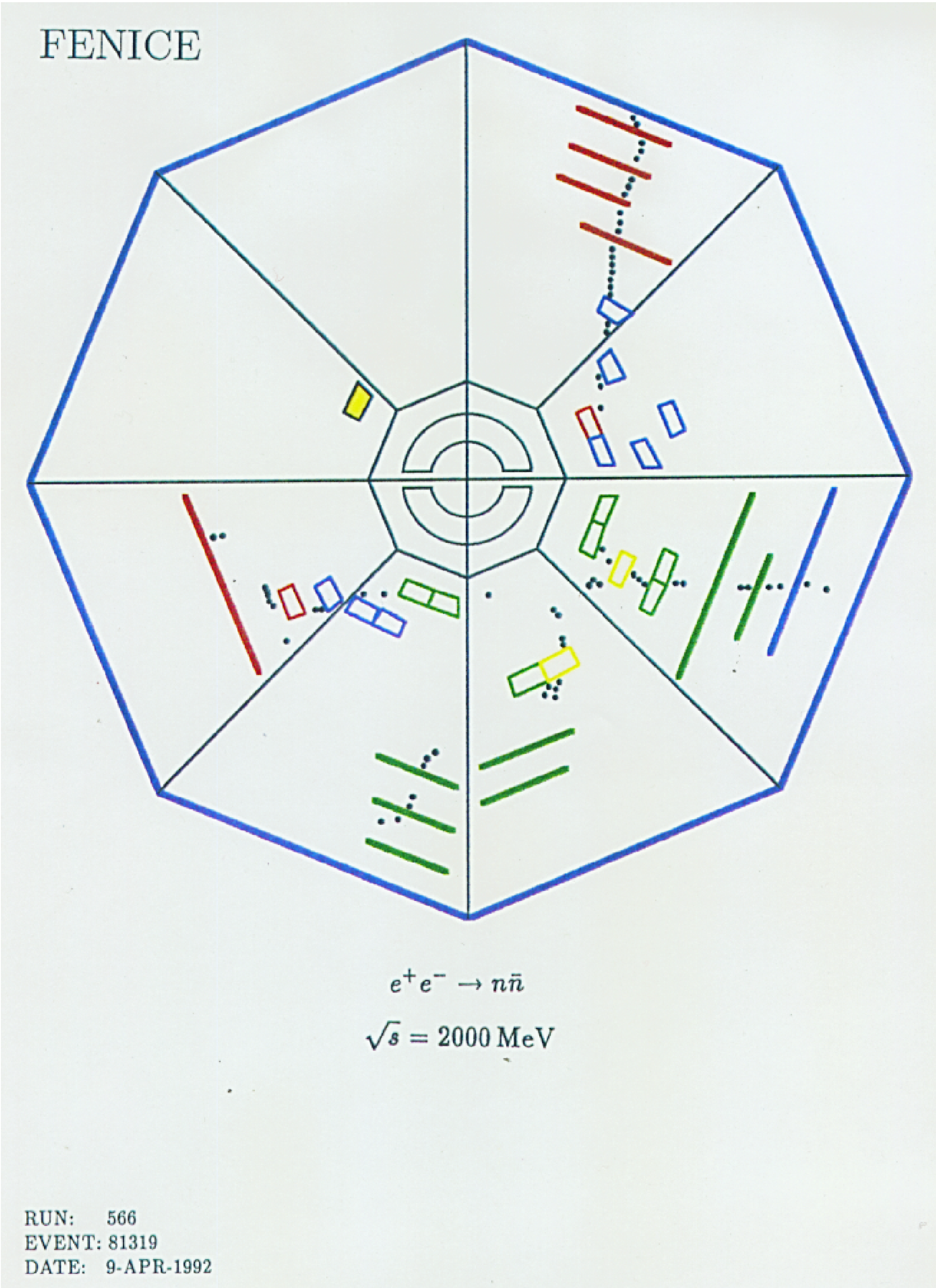
The *FENICE* apparatus



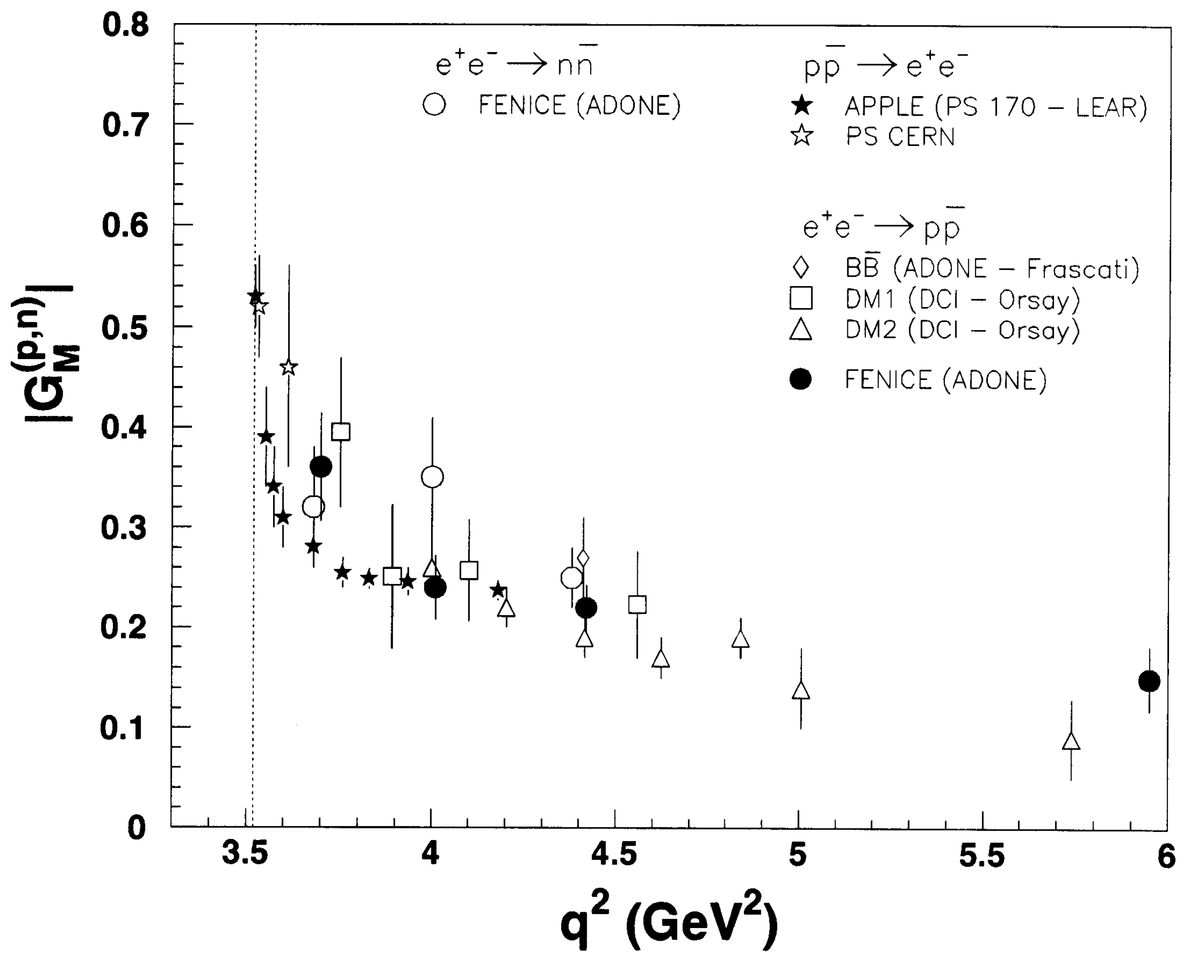


FENICE in numbers

- ~ 40000 channels Limited Streamer Tubes
- ~ 400 photomultipliers
- Acceptance:
  - ~ 76% 4π sr for collinear tracks
- Energy resolution:
  - 25 % / $\sqrt{E}$ e.m. (8 X_0)
  - 60 % / $\sqrt{E}$ hadronic (1.5 Λ)
- TOF resolution:
  - 600 ps
- Neutral trigger efficiency
  - 80 % @ 2 GeV
  - 60 % @ 3 GeV
- Neutron detection efficiency
  - 10 % @ 2 GeV
  - 40 % @ 3 GeV
- Luminosity measurement via Bhabha scattering:
  - in agreement with ADONE staff


FENICE
$e^+e^- \to n\bar{n}$
$\sqrt{s} = 2000\,\mathrm{MeV}$
RUN: 566
EVENT: 81319
DATE: 9-APR-1992

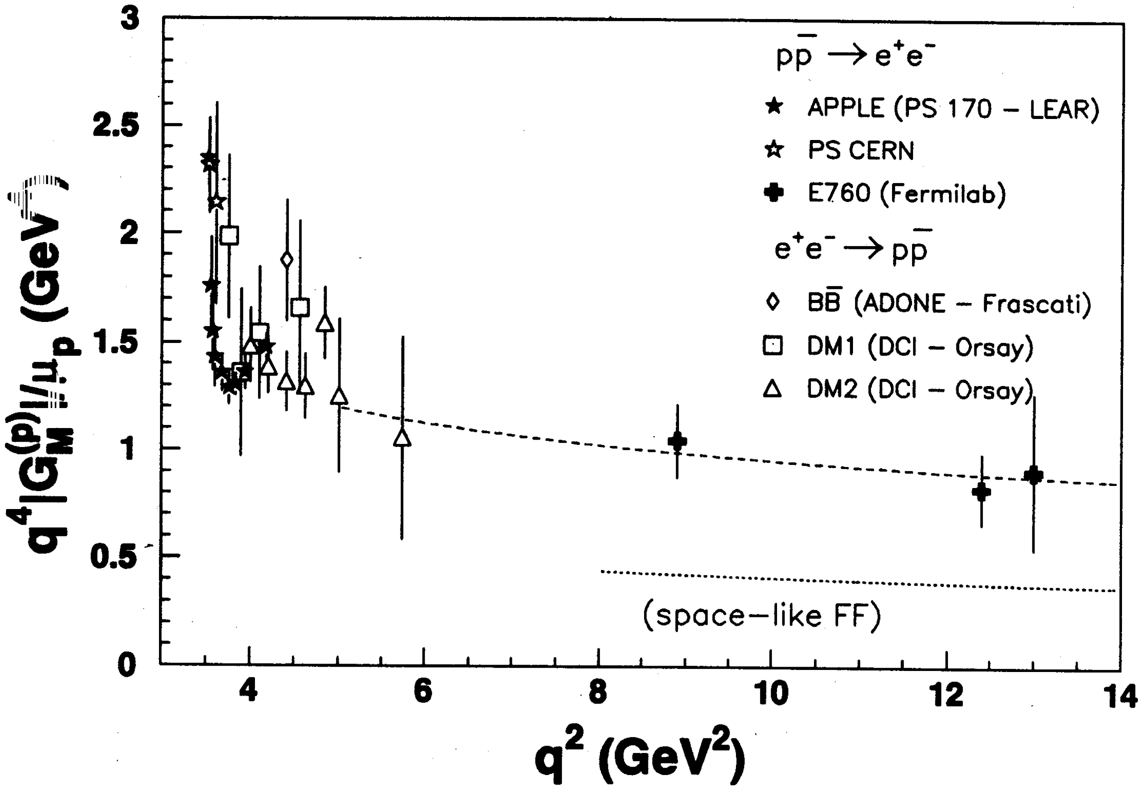
Nucleon time-like F.F.



neutron (preliminary)

q^2 [GeV^2]	$\mathcal{L}$ [nb^{-1}]	$\sigma(e^+e^- \to n\bar{n})$ [nb]	$\lvert G_M \rvert$
3.69	79	1.3 ± 0.3	0.32 ± 0.06
4.00	92	1.3 ± 0.4	0.35 ± 0.06
4.41	98	0.76 ± 0.13	0.25 ± 0.03

Proton time-like F.F. (high q^2)



- *Asymptotic from $q^2 \approx 5$ GeV^2*

  but $G_{time\text{-}like} \approx 2\, G_{space\text{-}like}$

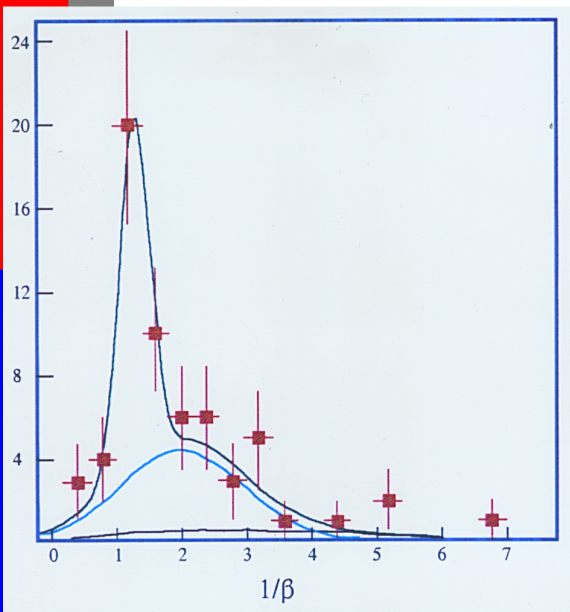
- *Same situation for the π FF*

  (Milana et al. PRL 71 (1993))

  $|\, F_\pi(q^2 = M^2_{J/\psi})\,| \approx 2\, F_\pi\, (q^2 = -9.6$ GeV$^2)$

- *Diquark model (Kroll) and some PQCD calculation (Gousset-Pire P.R. D51 (1995)) ➡ slow approach to the asymptotic behaviour in the time-like region*

A comment on J/ψ decay



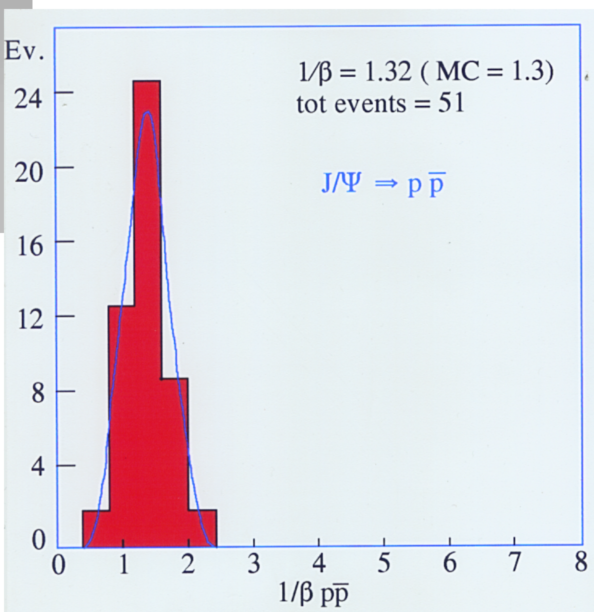
$J/\psi \rightarrow n\bar{n}$

FENICE (PL B301 (1993) 317)

$BR(e^+e^- \rightarrow n\bar{n}) = (1.9 \pm 0.5)\ 10^{-3}$

BONANZA (PL B78 (1978) 374)

$BR(e^+e^- \rightarrow n\bar{n}) = (1.8 \pm 0.9)\ 10^{-3}$



$J/\psi \rightarrow p\bar{p}$

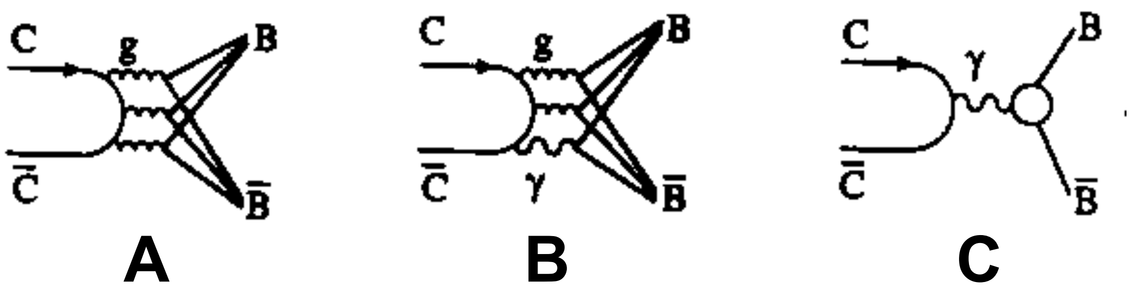
FENICE

$BR(e^+e^- \rightarrow p\bar{p}) = (2.03 \pm 0.32)\ 10^{-3}$

PDG

$BR(e^+e^- \rightarrow p\bar{p}) = (2.16 \pm 0.11)\ 10^{-3}$

A comment on J/ψ decay



A real

PQCD: $B_p = -0.03\, A$ ($B_n = 0$) *(Glashow-Wise 83)*

$C_n \sim -C_p$, C real *(Disp. relations)*

E760: $G_M^p(9.6\text{ GeV}) = 0.029 \pm 0.03$

PDG: $BR(J/\psi \rightarrow p\bar{p}) = (2.1 \pm 0.1)\, 10^{-3}$

Expected: $C_p/A = (16.8 \pm 2.0)\%$

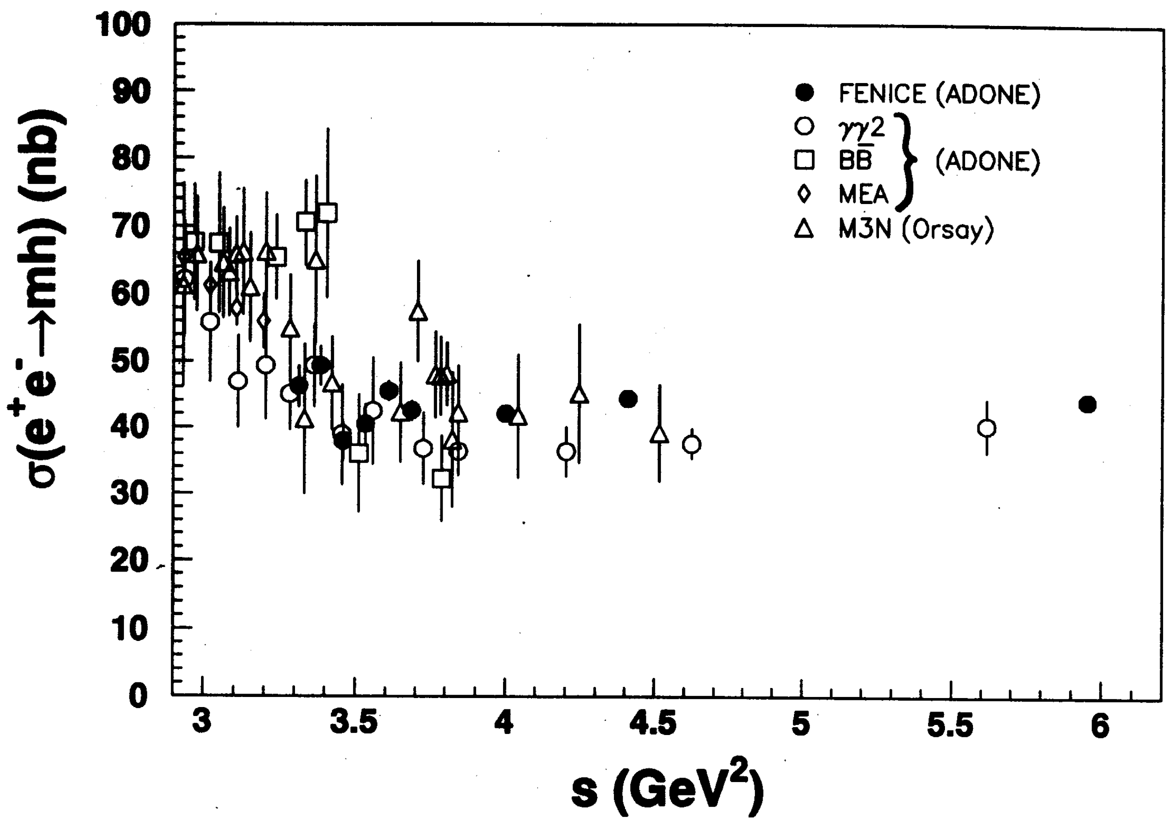
$BR(J/\psi \rightarrow n\bar{n}) = (1.2 \pm 0.2)\, 10^{-3}$

Experimentally:

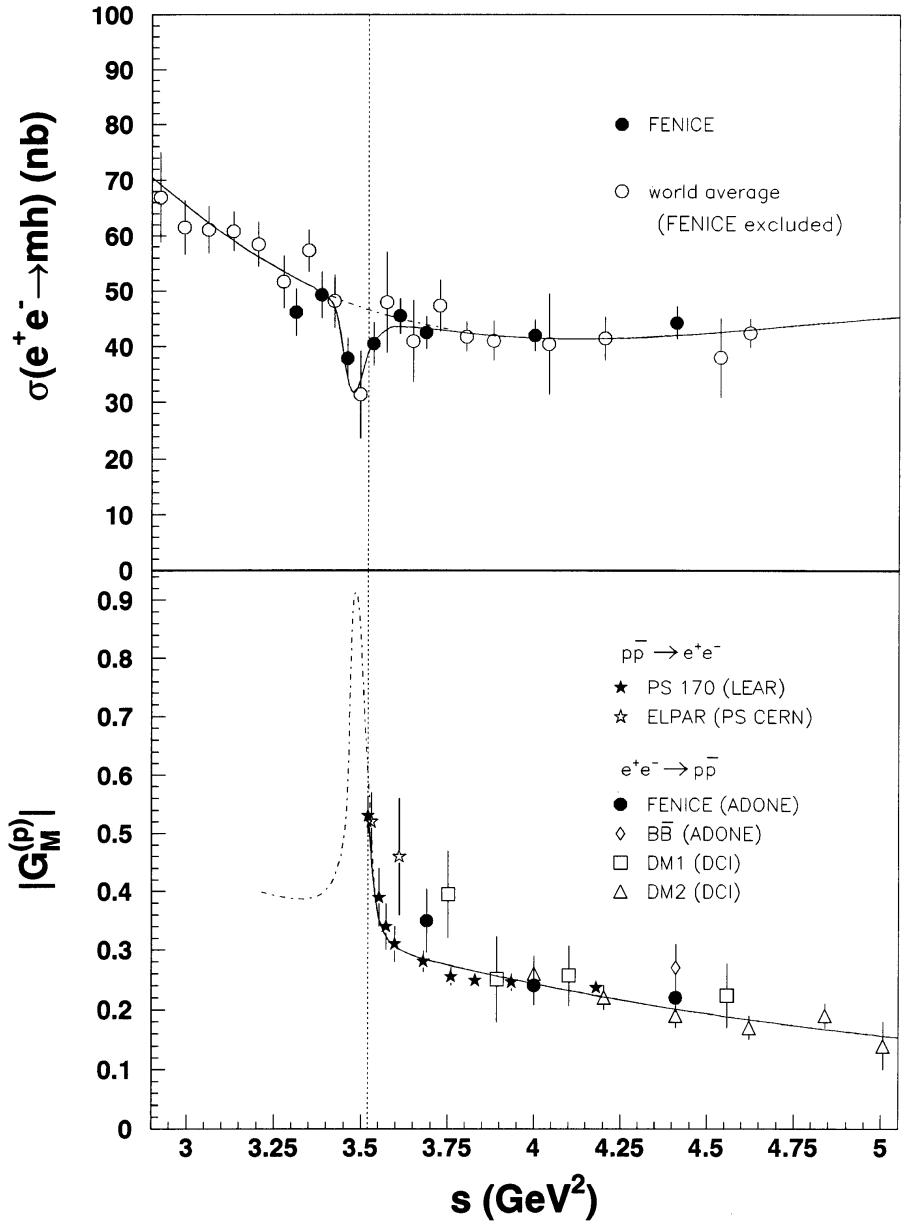
FENICE $BR(J/\psi \rightarrow n\bar{n}) = (1.9 \pm 0.5)\, 10^{-3}$

Speculation: A or G_M imaginary?

$e^+e^- \rightarrow hadrons$



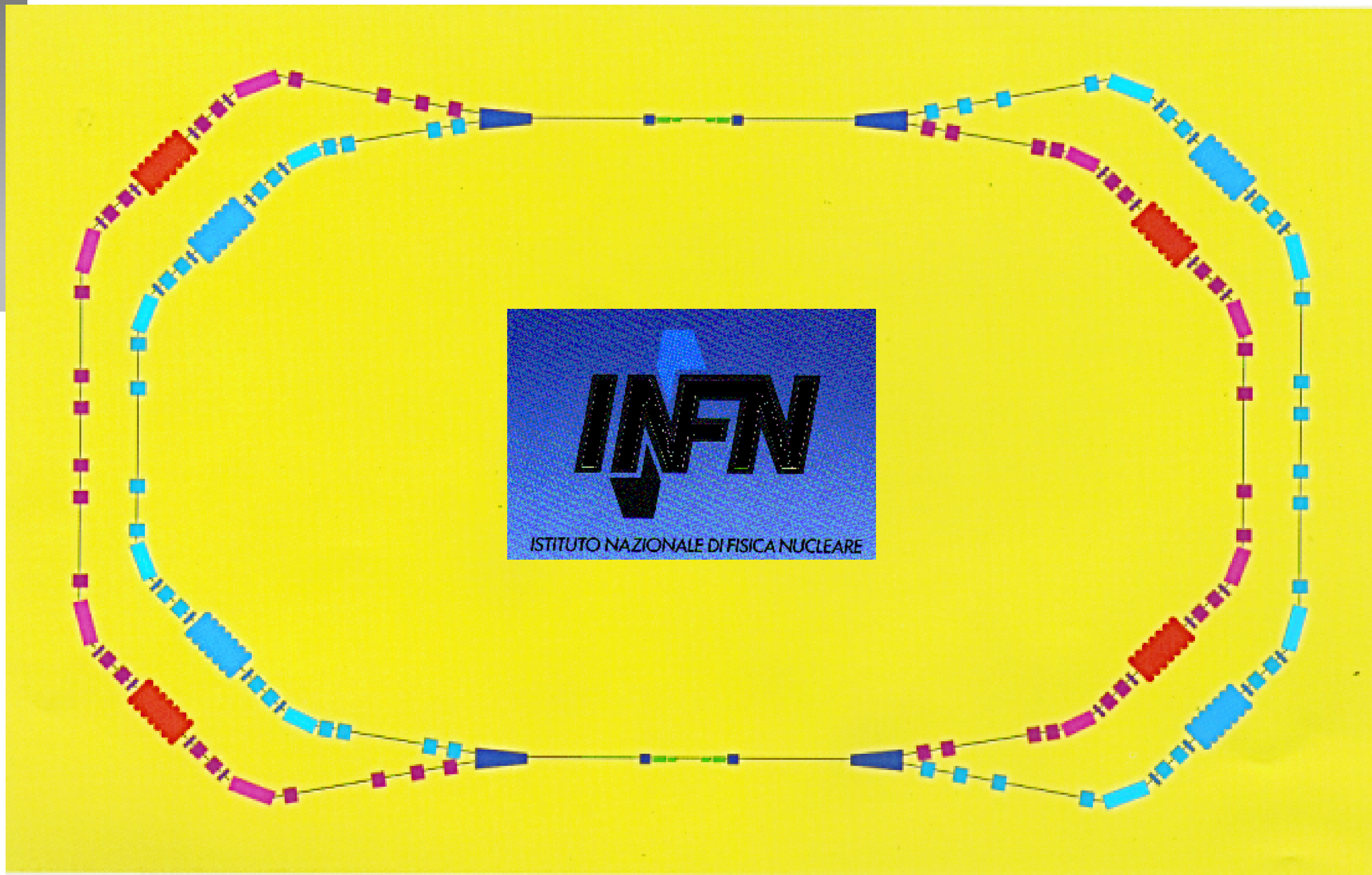
$e^+e^- \rightarrow hadrons$



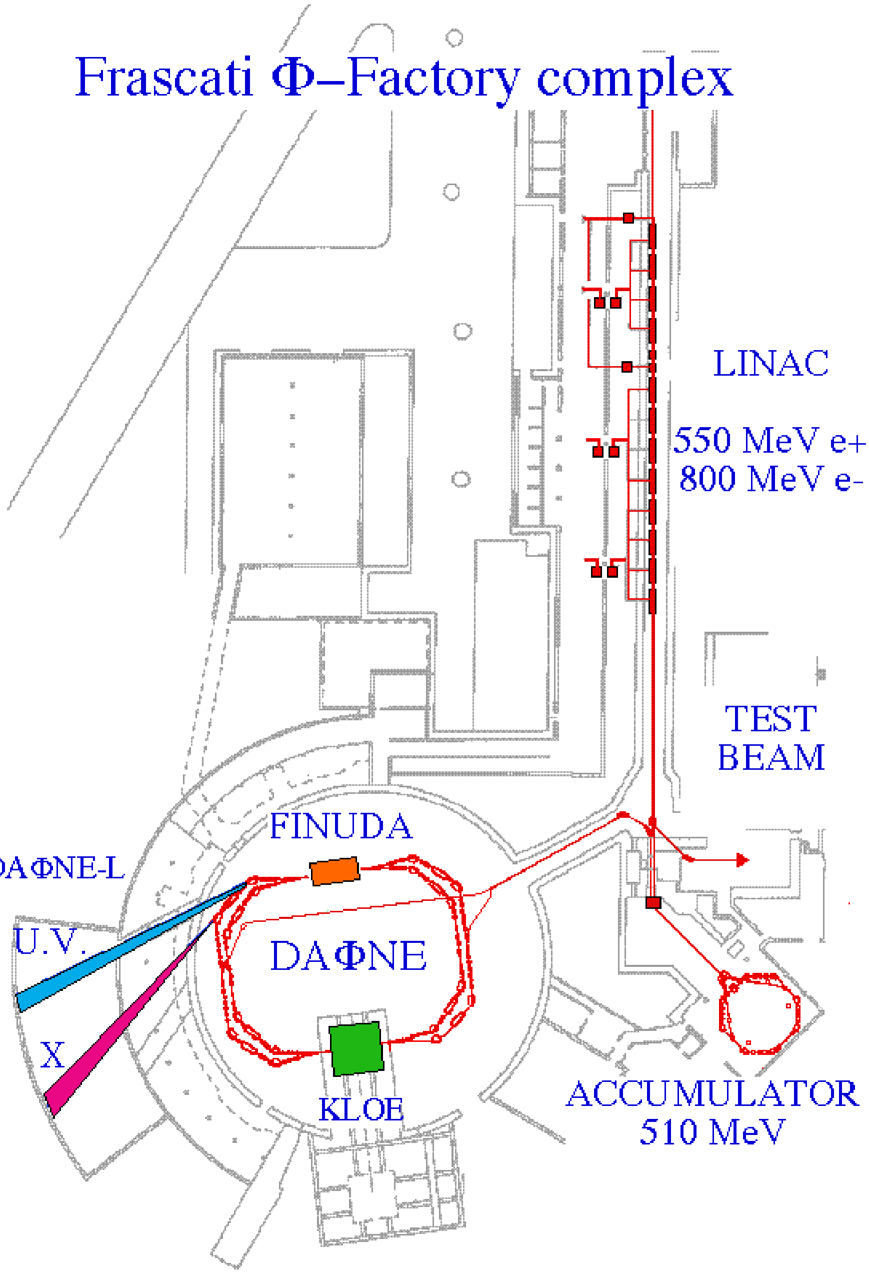
$M = (1.87 \pm 0.01)$ GeV

$\Gamma = (10 \pm 5)$ MeV

The DAΦNE project



The DAΦNE machine complex



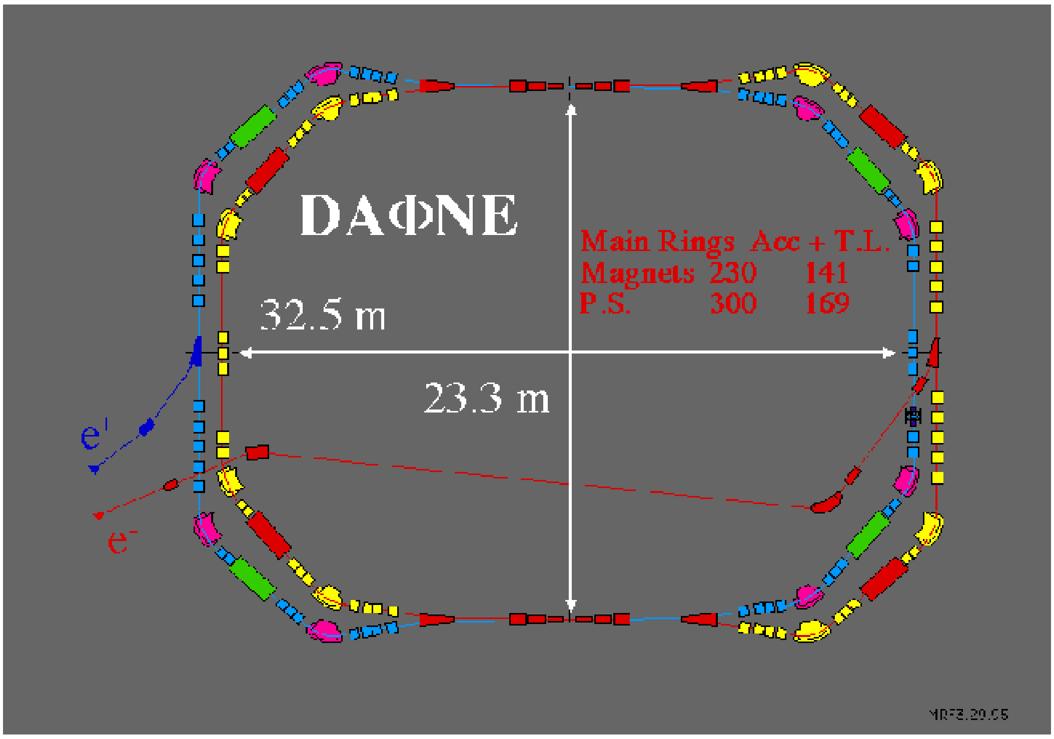
How to reach the goal luminosity

$\mathcal{L} \approx 10^{33}\ cm^{-2}s^{-1}$

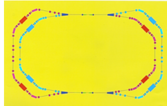
2 basic alternatives:

- small ring footprint and few bunches
  - ▲ attractive from the accelerator physics point of view
  - ▲ lower cost
  - ▼ very high single bunch luminosity (!?!)

- large ring footprint and many bunches
  - ▲ conventional technologies
  - ▲ more reliable



DAΦNE features



- e^+ and e^- circulate in 2 separate rings, ~ 100 m long, and collide at a horizontal half-angle

  $\vartheta_x = 10 - 15$ mrad

- high collision frequency

  without parasitic crossing

- 4-period modified Chasman-Green type lattice

- crab-crossing option

- low β insertions carefully designed, because of 2 constraints:
  - large, unencumbered solid angle around the interaction points (IP)
  - horizontal separation required at a short distance from IP, to allow for short bunch-to-bunch longitudinal distance

DAΦNE
potentialities

At $\mathcal{L} = 5 \times 10^{32}\ cm^{-2}s^{-1}$
in a 10^7 s year we will have
a production of ~ $22 \times 10^9\ \phi$

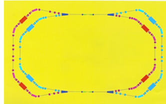
Considering the ϕ decays,
with their branching ratios, we will obtain:

decay mode	B.R.	events per year
$\phi \rightarrow K^+K^-$	0.495	1.1×10^{10}
$\phi \rightarrow K_L K_S$	0.344	7.6×10^9
$\phi \rightarrow \gamma\eta$	0.012	2.8×10^8
$\phi \rightarrow \gamma\eta'$	$< 10^{-3}$	—

Hence DAΦNE can be regarded also as:

- *a remarkably good K-factory*
- *a good η-factory*
- *an interesting source of η' and gluons (hopefully)*

Possible high-statistics and high-precision "nice experiments"



- *CP, CPT physics*
- *hypernuclear physics*
- *K decays*
- *ϕ decays and quantum mechanics*
- *one photon processes*
- *photon-photon processes*
- *radiative ϕ decays*
- *spectroscopy issues above ϕ*

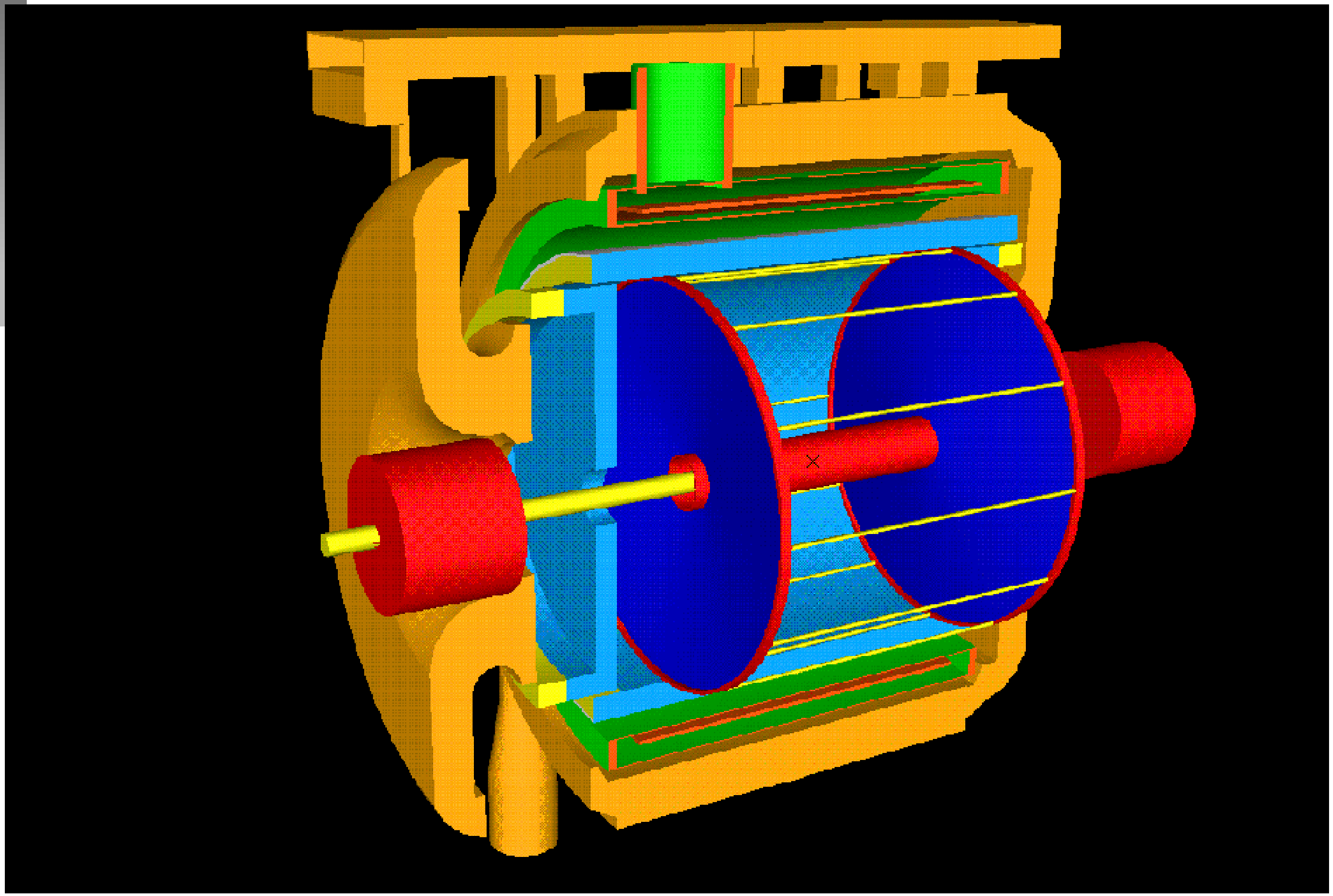
  (in the prospect of an energy upgrade of the machine)
- *low energy K-$\mathcal{N}$ interactions*

Double
Annular
Φ-factory for
Nice
Experiments

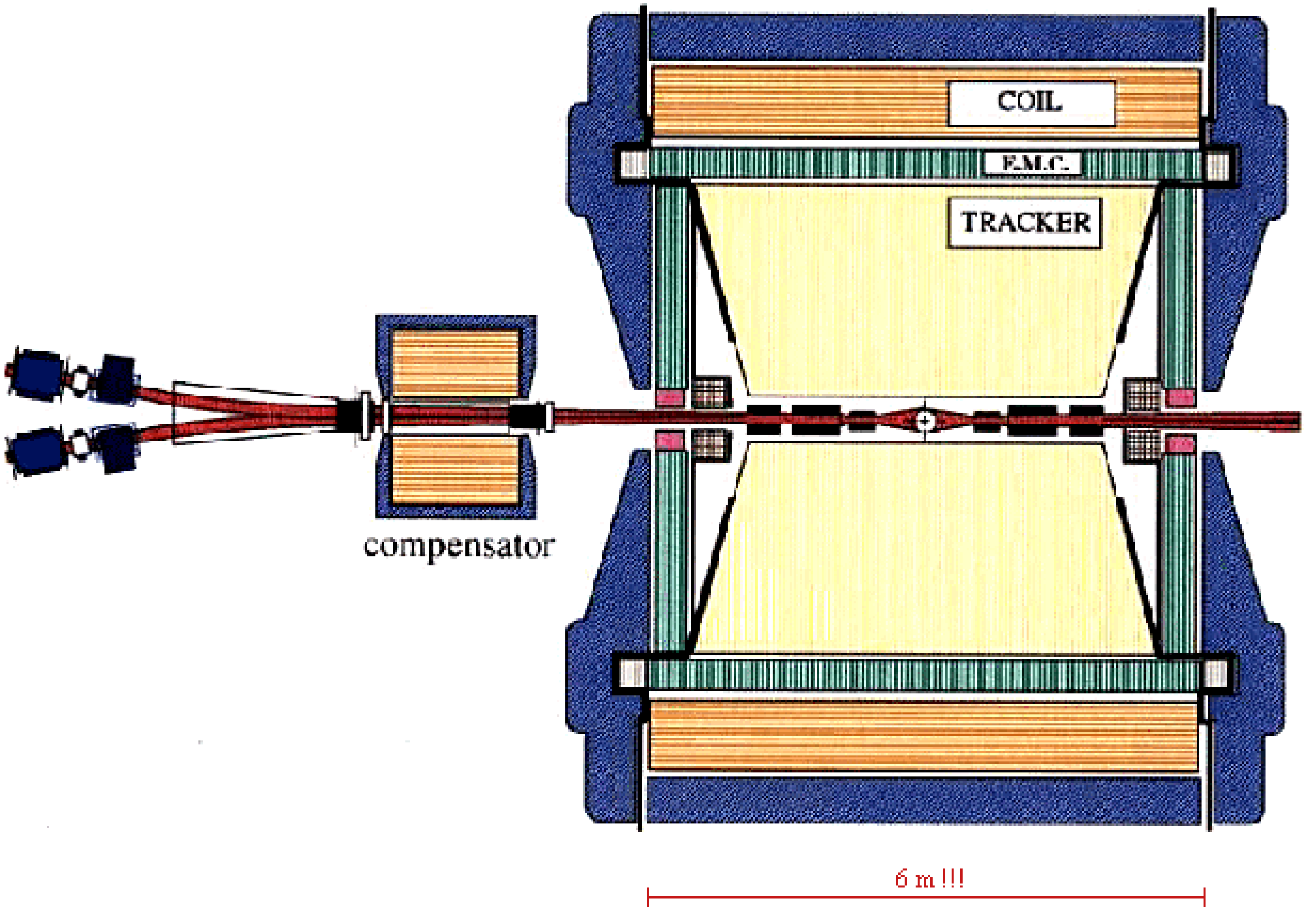
The KLOE experiment

- Bari University and INFN
- Roma Istituto Superiore di Sanità and INFN
- INFN National Laboratories of Frascati
- Lecce University and INFN
- Napoli University and INFN
- Pisa University and INFN
- Roma “La Sapienza” University and INFN
- Roma “Tor Vergata” University and INFN
- Roma III University and INFN
- Trieste University and INFN
- Udine University and INFN
- Columbia University, New York
- IEKP, Universitat Karlruhe
- IHEP, Institute of High Energy Physics, Academia Sinica
- ITEP, Institute of Theoretical and Experimental Physics, Moscow
- SUNY at Stony Brook
- Tel Aviv University, School of Physics and Astronomy
- Ben Gurion University

The KLOE apparatus



The KLOE apparatus



The KLOE detector

standard 4π, general purpose collider's apparatus

- large ($\sim 6 \times 6 \times 6$ m^3) cylindrical structure
- high resolution
- mininimum bias

tracking device ➨ drift chamber ($\varnothing$ = 4m, L = 3.5 m)

- large fiducial volume for K_L decays

  30 cm < r < 150 cm   -150 cm < z 150 cm

  (35% of all K_L are expected to decay in it)
- very light mechanical structure:
  8 mm Carbon fiber
- operated with a Helium-based gas mixture
- high p resolution: $\Delta p_t/p_t \approx 2.5\ 10^{-3}$
  (at 220 MeV/c)
- high reconstruction efficiency: $\geq$ 98%

The KLOE detector

e.m. calorimeter ➨ lead-scintillator sampling

- exceptional timing ability: $\sigma_t = 50\ ps/\sqrt{E_{[GeV]}}$
- good efficiency (> 99%) and
  good resolution $\sigma_E/E = 4.5\ \%/\sqrt{E_{[GeV]}}$ for γ
  down to 20 MeV
- true hermetic device: $\Delta\Omega/4\pi = 0.99$
- good particle identification

magnetic field ➨ superconducting solenoid

- 0.6 T uniform field in a ~ 76 m^3 volume

beam pipe ➨ beryllium (0.5 mm)

- low-mass to minimize multiple scattering
  $K^\pm$ energy loss
  K regeneration
- proper design to define a fiducial region for
  K_S decays

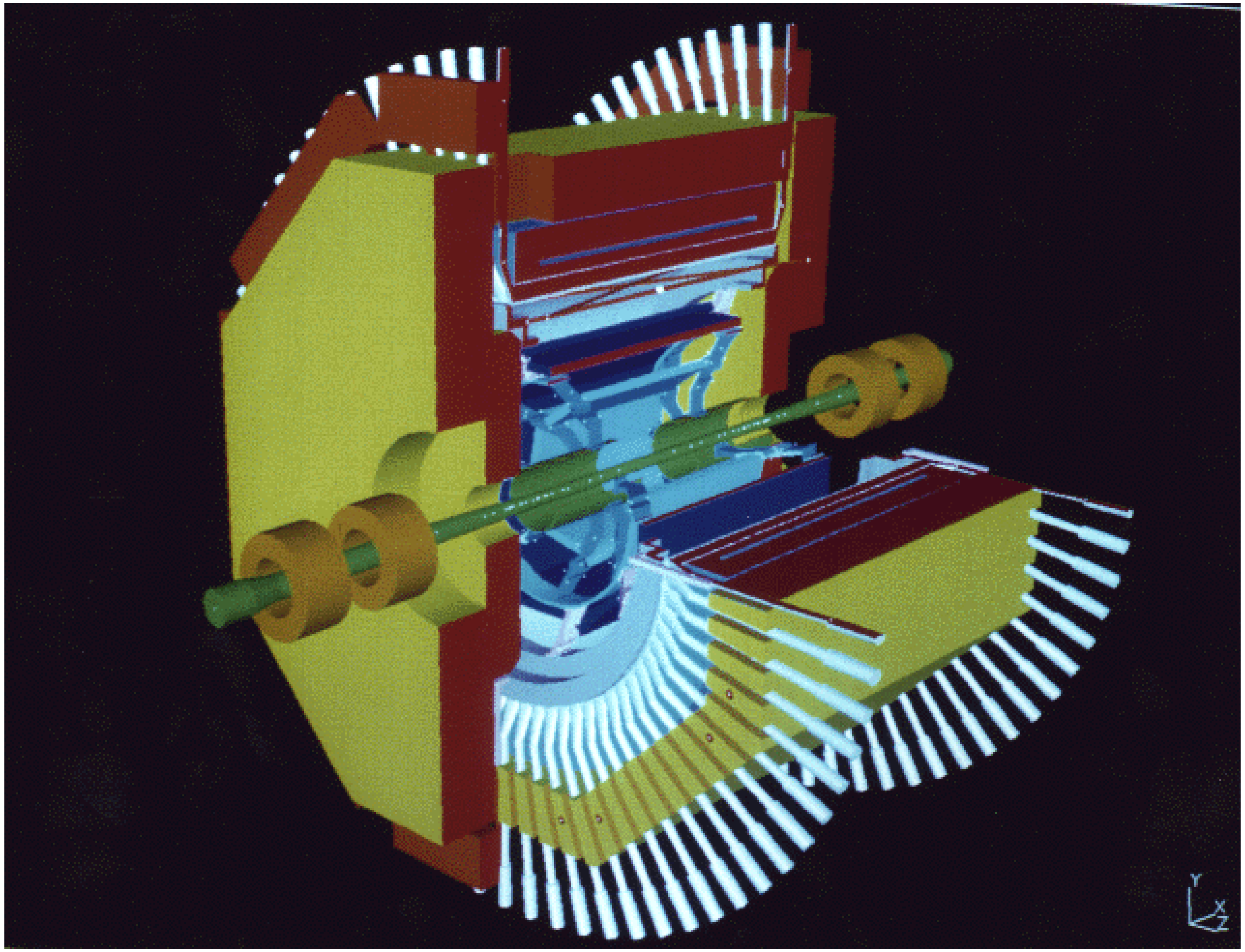
… other physics topics

- searches for CP violation in $K_S \to 3\,\pi^0$
- radiative ϕ decays
  ($a_0(980)$ and $f_0(970)$ puzzle)
- e^+e^- annihilations into hadrons
  from threshold to 1.5 GeV
- rare K decays
- K-mesons and the Chiral Lagrangian
- rare η and π^0 decays
- test of Quantum Mechanics

The FINUDA experiment

- Bari University and INFN
- Brescia University
- INFN National Laboratories of Frascati
- Pavia University and INFN
- Torino University, Polytechnic and INFN
- Trieste University and INFN
- TRIUMF, Vancouver

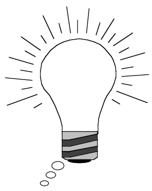
The FINUDA apparatus



Why a nuclear physics experiment at a collider?

The K^- from ϕ decay present a series of unique properties

- nearly monochromatism (~ 16 MeV)
- no contamination
- low energy ➡ range ~ 1 g/cm^2
  straggling on range ~ 50 mg/cm^2
- possibility of tagging by means of K^+



They represent an ideal tool for high-resolution hypernuclear spectroscopy with stopped K^-

Hypernuclei production

- *Strangeness exchange reaction (hystorical)*

$$K^- + n \rightarrow \Lambda + \pi^- \qquad ①$$

▲ *high cross section (~ mb/sr)*
▼ *K "beam" problems (π contamination, energy spread)*
▼ *very small momentum transfer to Λ (0 at the "magic momentum" of 505 MeV/c)*
▼ *reduced number of final states (Λ and n with the same spin and orbital wave function)*

- *Associated production reaction*

$$\pi^+ + n \rightarrow \Lambda + K^+ \qquad ②$$

▲ *large momentum transfer to Λ (~ 250 MeV/c)*
▲ *large spectrum of final states*
▲ *good intensity and quality π beams*
▼ *low cross section (2 order of magnitude lower than that of ①)*

Hypernuclei production

- *The way of combining the advantages of ① and ② is that of exploting the formation reaction*

$$K^-_{stop} + {}^{A}X_Z \rightarrow {}^{A}_{\Lambda}X_Z + \pi^-$$

(250 MeV/c ≤ p_π *≤ 280 MeV/c)*

▲ *same momentum transfer to Λ of ②*

▼ *moderate hypernuclear final states rate production:* 10^{-3}*/stopped* K^-

The FINUDA apparatus

It is a non focusing magnetic spectrometer with the following design features:

- cylindrical geometry
- large solid angle (> 2π sr)
- large momentum acceptance (100 - 300 MeV/c)
- excellent momentum resolution (~ 3‰ at 270 MeV/c)
- capability of detecting secondary charged particles: π and p from hypernuclear states decay
- capability of detecting n from non-mesonic decay of hypernuclei

It consist basically of:

1. an interaction/target region
2. a compound tracking system
3. an outer scintillator array

It is immersed into a 1.1 T solenoidal magnetic field, uniform within 1% over the tracking volume

The FINUDA physics program

- High resolution Λ-hypernuclei spectroscopy
- Study of hypernuclei decays and possible violation of the $\Delta I = \frac{1}{2}$ rule
- Production of Λ-hypernuclei with a large neutron excess
- Search for π^+decay mode of hypernuclei
- Study of the puzzle of Σ- hypernuclei
- Measurement of K^+- $\mathcal{N}$ total cross section
- Study of K^-- $\mathcal{N}$ scattering at low energies

Test of $\Delta I = \frac{1}{2}$ rule validity

Λ free weak decay ($\tau \approx 2.63\ 10^{-10}$ s)

$$\Lambda \rightarrow \begin{cases} p + \pi^- + \sim 40\ \text{MeV} & (\sim 64\ \%) \\ n + \pi^0 + \sim 40\ \text{MeV} & (\sim 36\ \%) \end{cases} \quad ①$$

Λ-hypernuclei, in their ground state, also decay via weak interaction mechhanism,

but when Λ is embedded in nucleus...

- *Λ can be bound up to 25 MeV ➡ phase space reduction for mesonic decay ①*
- *final state nucleon in ① has a very low momentum ➡ further suppression of mesonic decay mode due to Pauli blocking effect*

$\Downarrow$

Test of $\Delta I = ½$ rule validity

⇓

New non-mesonic decay mode for Λ–hypernuclei

$$\Lambda + \mathcal{N} \rightarrow \mathcal{N} + \mathcal{N} + \sim 176\ \text{MeV} \qquad ②$$

- final state nucleons have a momentum of ~ 417 MeV/c ➡ they are no more Pauli blocked

⇓

Accurate measurements of the

$$\Lambda + n \rightarrow n + n$$

and of

$$\Lambda + p \rightarrow n + p$$

relative branching ratios may confirm a possible violation of the $\Delta I = ½$ rule for weak process

[Shumacher, NP A547 (1992)]