A new e+e- facility at SLAC in the c.m. energy range 1.2 ÷ 3.1 GeV

Diego Bettoni

INFN - Ferrara

Commissione I - 21/05/2001

e^+e^- physics at INTERMEDIATE ENERGIES workshop

STANFORD LINEAR ACCELERATOR CENTER • Stanford, California • April 30 – May 2, 2001

To Explore the Physics Potential of an Asymmetric High Luminosity e^+e^- Collider of Energy $M_\phi < E_{CM} < M_{J/\psi}$

DISCUSSION topics:

- R Measurements with Application to Hadronic Corrections to g-2 and Higgs Mass Prediction
- Baryon and Meson Time-Like Form Factors
- Precision QCD Tests
- Vector Meson Spectroscopy
- Two-Photon Physics
- Potential Uses of Initial-State Polarization
- Dimuonium and Ditauonium Formation and Detection
- Accelerator/Detector Requirements

CONTACT Information:

Maura Chatwell
Workshop Coordinator
SLAC, MS 81
PO Box 4349
Stanford, California, USA 94309-4349
Telephone: 650-926-4931
Fax: 650-926-2525
maura@slac.stanford.edu
www-project.slac.stanford.edu/pep-n/

ADVISORY committee:

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This is the second workshop in a series, following the meeting held at the Budker Institute of Nuclear Physics, Novosibirsk, Russia, March 1–5, 1999.

OUTLINE

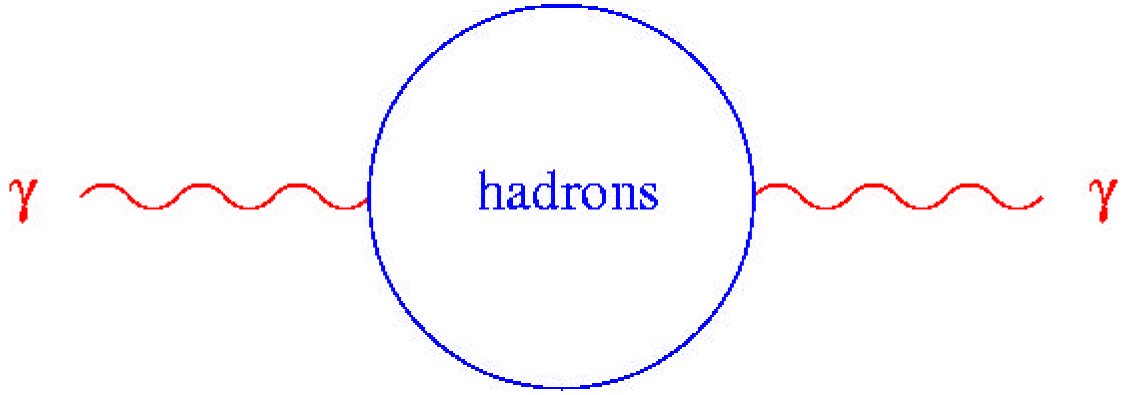
- Introduction
- Physics motivations
- Detector Requirements
- Detector Layout
- Conclusions

Physics Motivations

- R measurement
  - evolution of α_{EM}
  - hadronic contribution to g_{μ}-2
- Nucleon form factors
- Other baryon form factors
- Meson form factors
- Vector meson spectroscopy
- Multihadron channels
- $\gamma\gamma^*$ interactions

R measurements

The hadronic vacuum polarization diagram



contributes significantly to the *evolution of* $a_{EM}(M_Z^2)$ and to $g_m - 2$.

The vacuum polarization diagram can be determined directly by measuring the ratio R

$$R = \frac{s\,(e^+e^- \to hadrons)}{s\,(e^+e^- \to m^+m^-)}$$

Evolution of α_{EM}

The evolution of α_{EM} is given by:

$$a_{EM}(s)^{-1} = \left[1 - \Delta a_{lep}(s) - \Delta a^{5}_{had}(s) - \Delta a^{top}(s)\right] a_{EM}(0)^{-1}$$

the hadronic term can be calculated using:

$$\Delta a^{5}_{had}(s) = -\frac{a_{EM}(0)s}{3p} P\int_{4m_p^2}^{\infty} \frac{R(s')}{s'(s'-s)} ds'$$

with $a^{-1}_{EM}(0) = 137.0359895(61)$.

Various calculations of $\Delta a^{5}_{had}(M^{2}_{Z})$ exist. With recent data from VEPP-2M, BES and BESII:

$\Delta a^{5}_{had}(M^{2}_{Z}) = 0.02755 \pm 0.00046$ *(Pietrzyk, experiment only)*

$\Delta a^{5}_{had}(M^{2}_{Z}) = 0.02742 \pm 0.00025$ *(Martin, data + QCD models)*

$\Delta a^{5}_{had}(M^{2}_{Z}) = 0.02770 \pm 0.00029$

Energy	$\Delta\alpha^{5}_{had}(M^{2}_{Z})$	$\delta\Delta\alpha^{5}_{had}$
< 1.4 GeV	0.0048	0.00006
1.4 – 2.1	0.0010	0.00015
2.1 - M_{Υ}	0.0134	0.00025
> M_{Υ}	0.0092	0.00030
Total	0.02755	0.00046

A measurement of R with 2 % accuracy for would yield

$$d\Delta a^{5}_{had}(M^{2}_{Z}) \approx \pm 0.00028$$

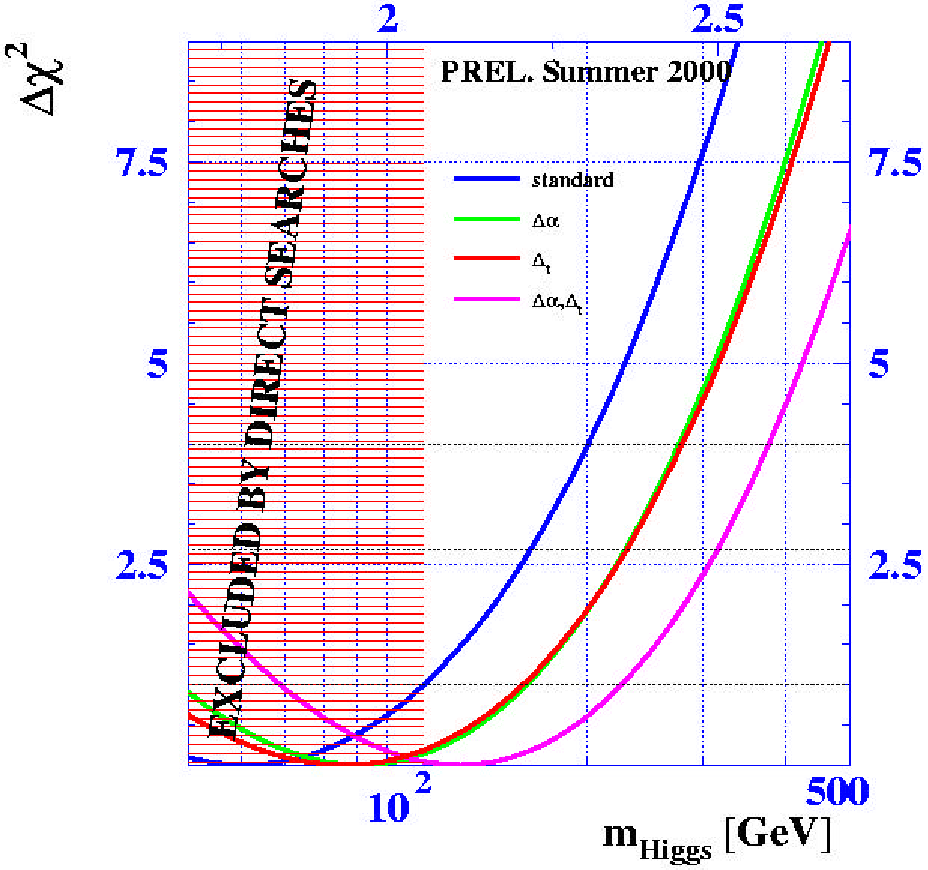
$$dM_{H} \approx 10\,GeV$$

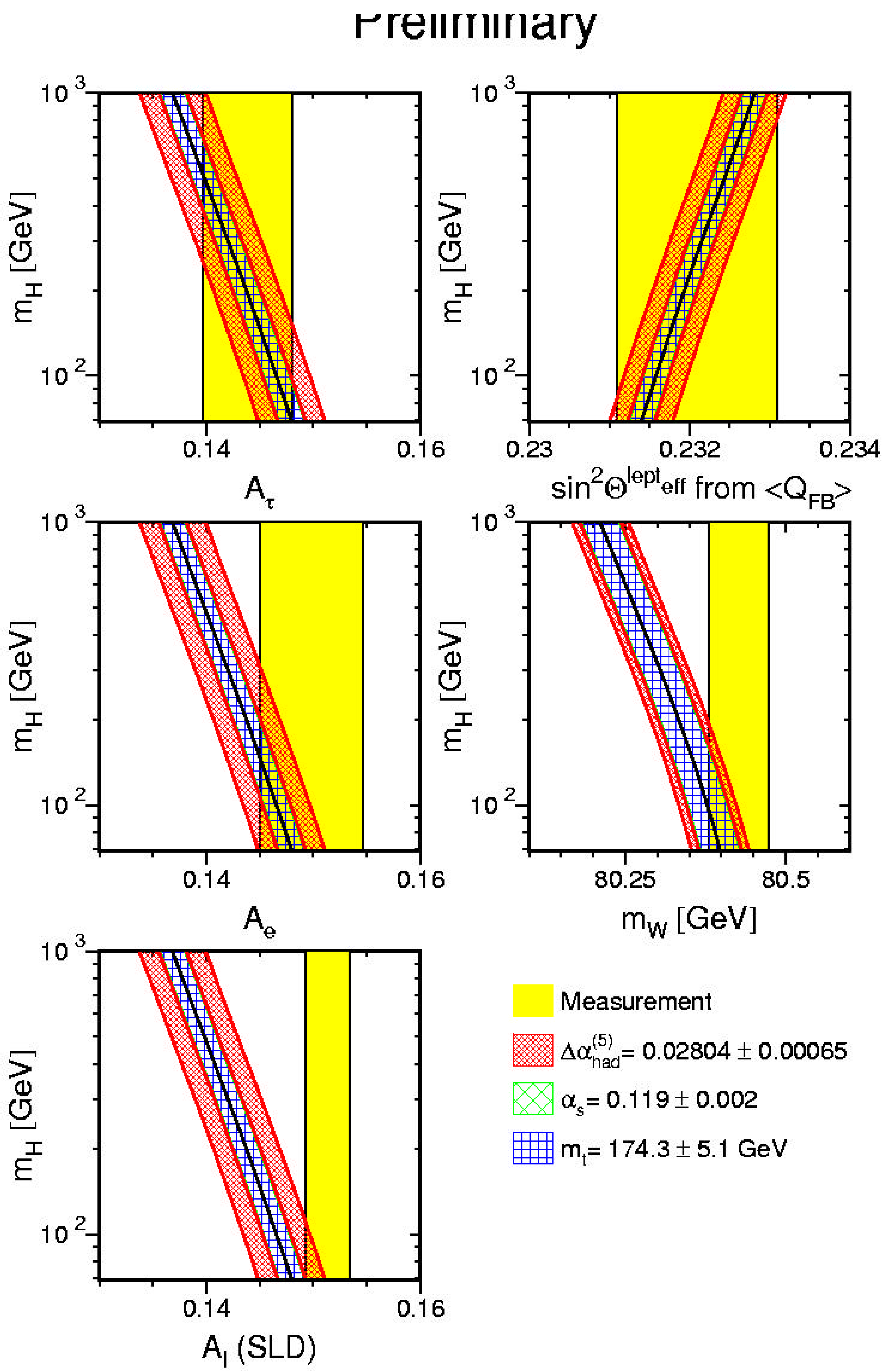
Sensitivity to $\Delta\alpha$ and Δ m$_t$

$$\Delta a^{5}_{had}(M_Z^2) = 0.02804 \pm 0.00065$$

$$m_t = 174.3 \pm 5.1 GeV$$

$$dM_H(d\Delta a^{5}_{had}(M_Z^2) = \pm 0.00065) = 30\, GeV$$




Preliminary
10^3
10^2
m_H [GeV]
0.14
0.16
A_τ
0.23
0.232
0.234
$\sin^2\Theta^{lept}_{eff}$ from $<Q_{FB}>$
A_e
80.25
80.5
m_W [GeV]
A_l (SLD)
Measurement
$\Delta\alpha^{(5)}_{had} = 0.02804 \pm 0.00065$
$\alpha_s = 0.119 \pm 0.002$
$m_t = 174.3 \pm 5.1$ GeV

Hadronic contribution to (g_μ-2)

$$a_m \equiv \frac{g_m - 2}{2} = a_m^{QED} + a_m^{weak} + a_m^{had}$$

$$a_m^{had} = \frac{a^2(0)}{3p^2} \int_{4m_p^2}^{\infty} ds \frac{K(s)}{s} R(s)$$

$$K(s) = x^2\left(1 - \frac{x^2}{2}\right) + (1+x)^2\left(1 + \frac{1}{x^2}\right)\left(\ln(1+x) - x + \frac{x^2}{2}\right) + \frac{1+x}{1-x} x^2 \ln x$$

$$x = \frac{1 - b_m}{1 + b_m}$$

$$b_m = \sqrt{1 - \frac{4m_m^2}{s}}$$

The greatest contribution comes from the low energy part of the integral, with 92 % coming from $\sqrt{s} < 1.8\,GeV$

The QED and the weak contributions are known to a few parts in 10^{-11}. The most recent measurement of the muon anomaly has been carried out by BNL-E821:

$$a_m^{\exp} = (116592020 \pm 160) \times 10^{-11}$$

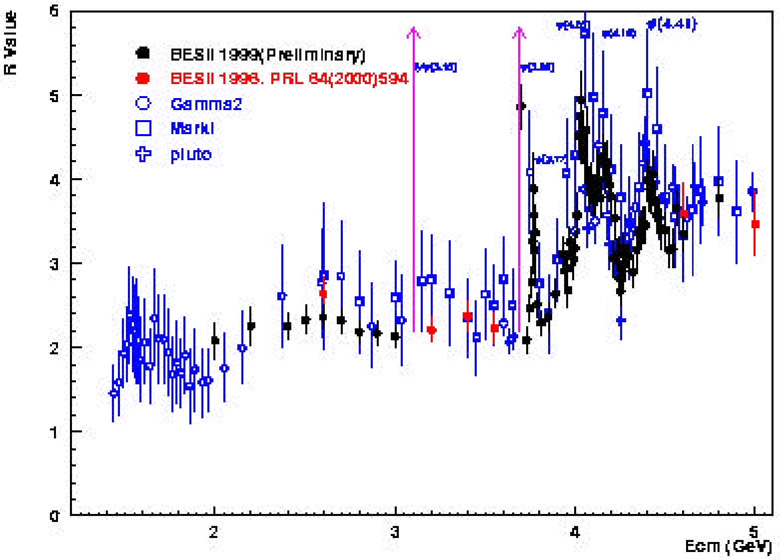
The authors claim a 2.6 σ discrepancy between their results and SM calculations which use e^+e^- data, hadronic τ decays, perturbative QCD and sum rules to minimize the uncertainty.

The final goal of BNL-E821 is $\pm 40 \times 10^{-11}$ or 0.34 ppm.

R measurements at low energy

Precision Tests of the EW Gauge Theory, ICHEP2000, Osaka

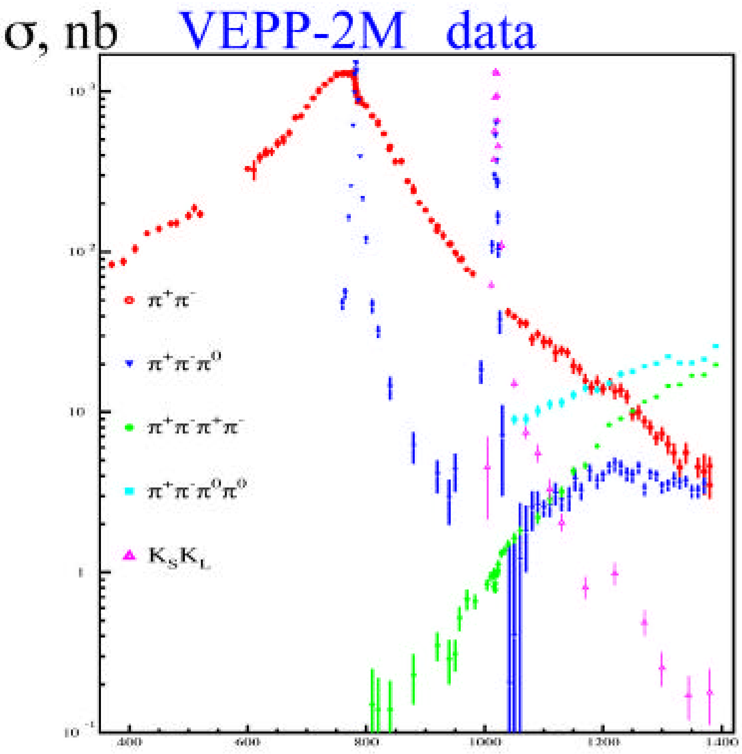
A. Gurtu



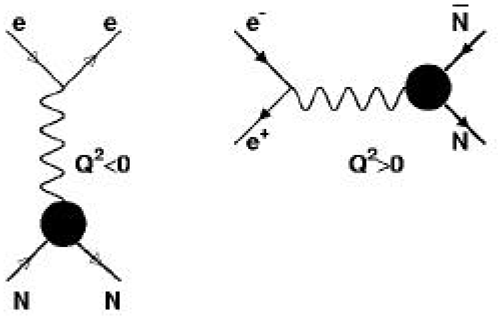
Global Fit to EW data

Expected (red) progress in a_μ^{had} (ppm)
(direct e^+e^- experimental data only)

channel	a_μ^{had}	δ,%	δ a_μ
$\pi^+\pi^-$	43.19	2(0.6)	1.0(0.26)
$\pi^+\pi^-\pi^0$	3.88	1.5	0.06
K^+K^-	1.81	5.2	0.09
K_SK_L	1.12	1.9	0.02
$\pi^+\pi^-\pi^0\pi^0$	0.77	7	0.05
$\pi^+\pi^-\pi^+\pi^-$	0.53	7	0.04
$\pi^0\gamma,\eta\gamma$	0.31	6	0.02
Total<1.4	51.6	2(0.6)	1.0(0.29)
1.5-2.5	3.8	10	0.4
Total>2.5	4.8	15(5-7)	0.4(0.2)



Nucleon Form Factors



$$e^+ + e^- \rightarrow \overline{N} + N \qquad (Q^2 = s > 0)$$

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

G_E and G_M electric and magnetic form factors.

The form factors describe the distribution of charge and magnetization current within the nucleons at **low Q^2**; at **high Q^2** they probe the valence quark distribution functions at high relative momentum.

Nucleon form factor data are crucial as a test of QCD from the non-perturbative regime near threshold to the perturbative regime at high Q^2.

Predictions of nucleon form factors are applicable up to high Q^2 in both the spacelike and timelike regions.

- Perturbative QCD and analyticity relate timelike and spacelike form factors, predicting a continuous transition and spacelike-timelike equalitity at high Q^2.
- At high Q^2 PQCD predicts:

$$F_1(Q^2) \propto \frac{a_s^2(Q^2)}{Q^4} \qquad F_2(Q^2) \propto \frac{a_s^2(Q^2)}{Q^6}$$

F_1 and F_2 are the Dirac and Pauli form factors respectively.

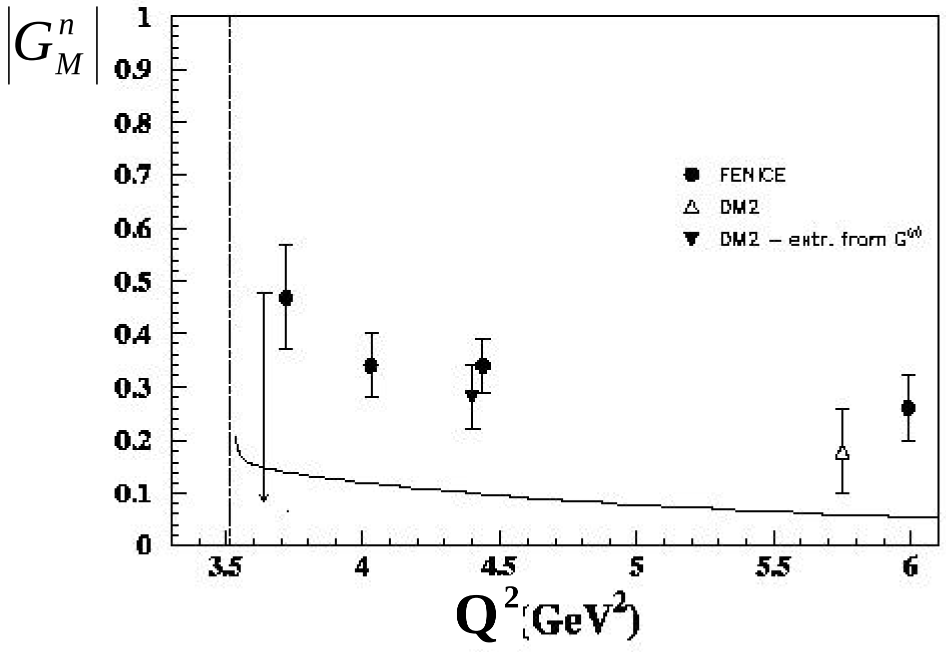
- PQCD and analyticity predict:

$$\left|\frac{G_M^n}{G_M^p}\right|^2 \approx \left(\frac{q_d}{q_u}\right)^2 = 0.25$$

There are several unexpected features in the existing data which deserve further experimental investigation:

- Ratio between neutron and proton form factors.
- Threshold Q^2 dependence.
- High Q^2 predictions.
- Resonant structures.

Ratio between neutron and proton form factors

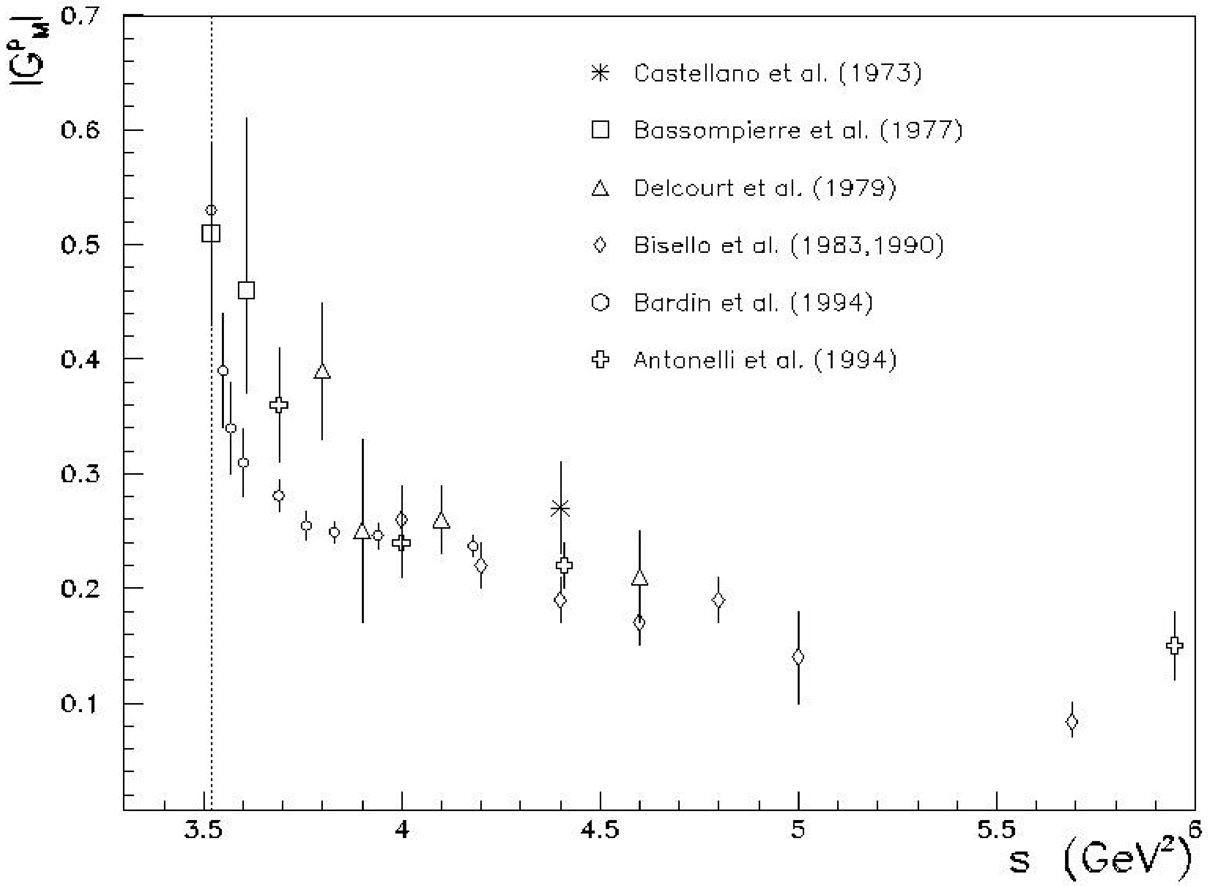


Data obtained primarily by the FENICE experiment (Adone, Frascati). $\int L dt = 0.4\ pb^{-1}$ 80 events.

The neutron form factor is bigger than that of the proton !!!

Assumes $G_E = G_M$ near threshold for both proton and neutron. New, high-statistics measurement needed to separate electric and magnetic form factors.

Threshold Q^2 dependence

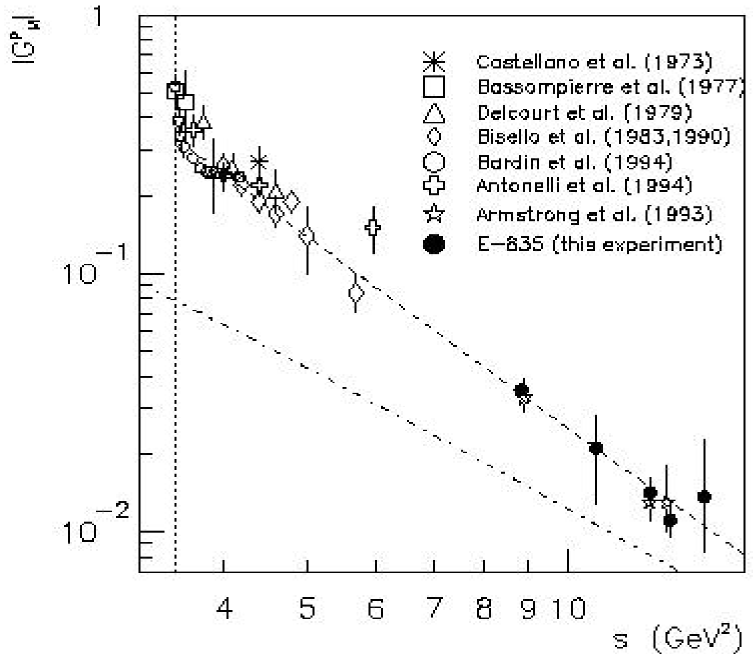


Steep behaviour near threshold observed by PS 170 at LEAR (about 2000 events).

Does the neutron have a similar behaviour ?

The existing FENICE data (statistics limited) suggest $G_M^n >> G_E^n$ which might imply a rapid decrease of G_E^n with increasing Q^2.

High Q^2 predictions

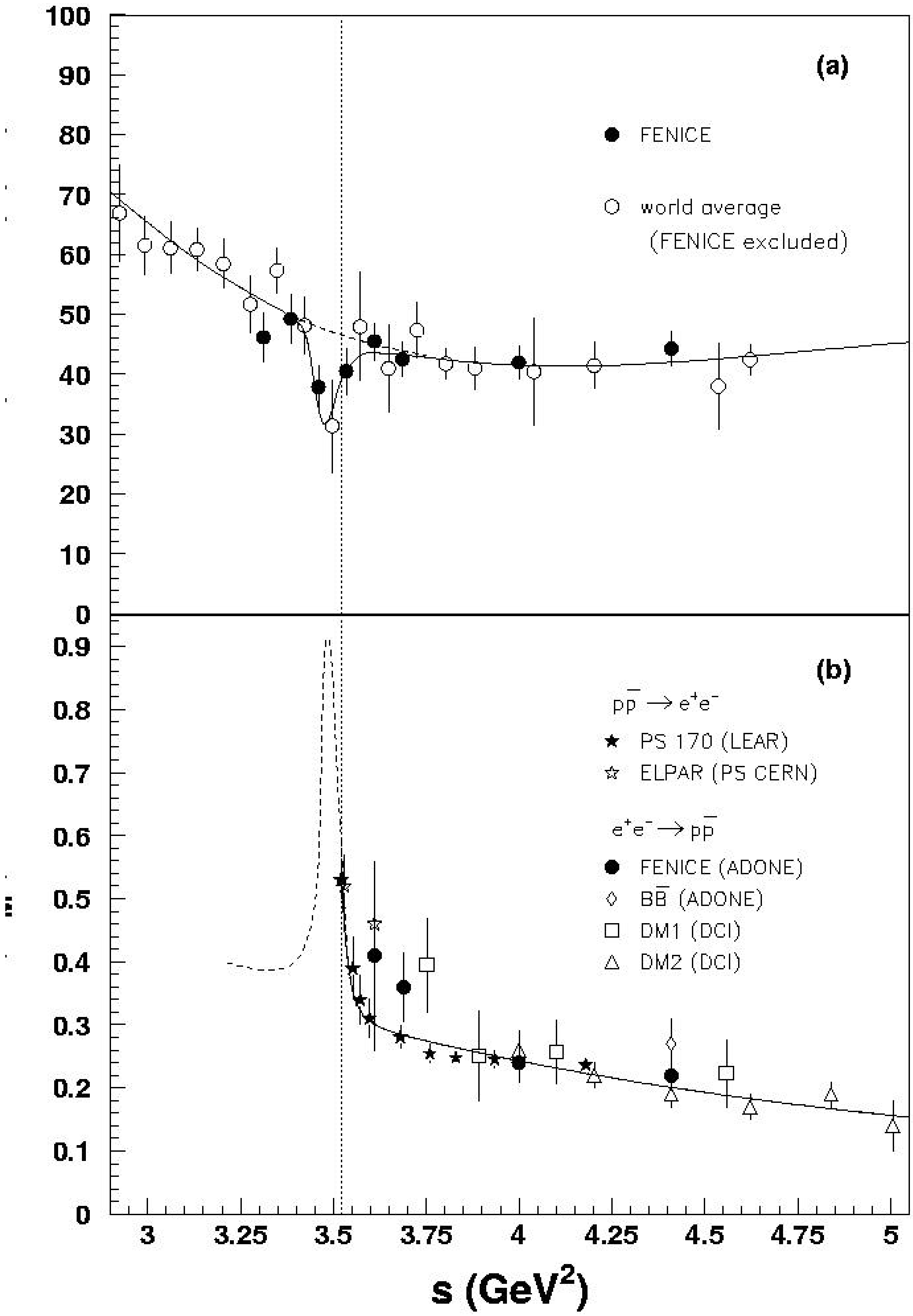


The dashed line is the PQCD fit.

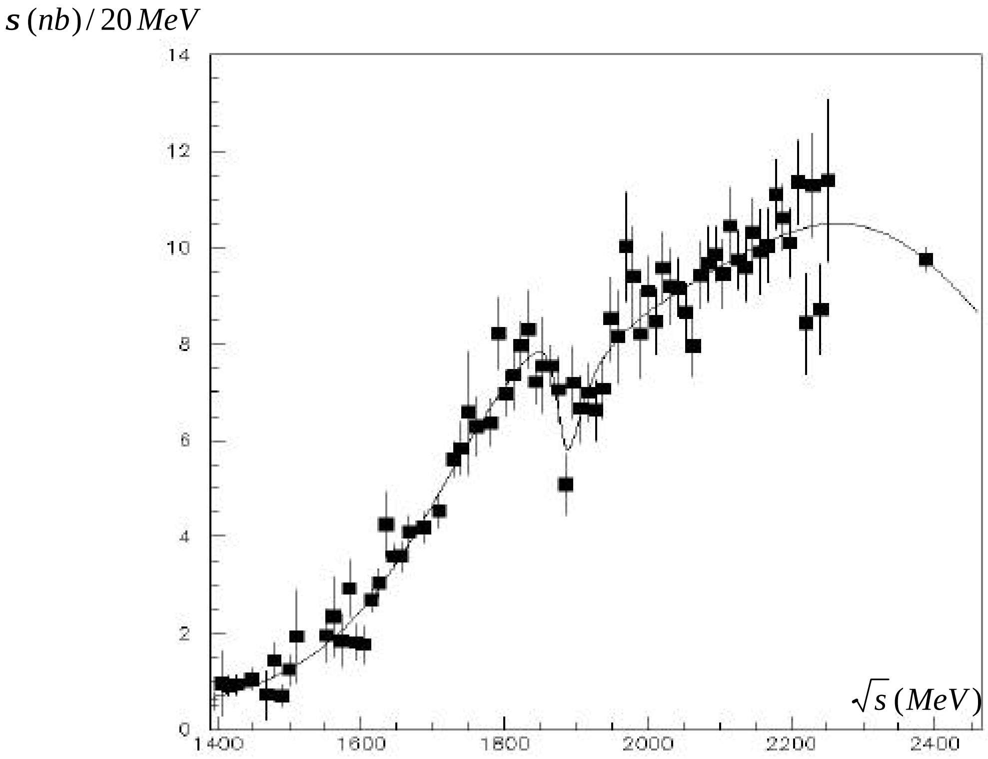
The dot-dashed line represents the dipole behaviour of the form factor in the spacelike region for the same values of $|Q|^2$.

The expected Q^2 behaviour is reached quite early, however there is a factor of two between timelike and spacelike data measured at the same $|Q|^2$.

Resonant Structures

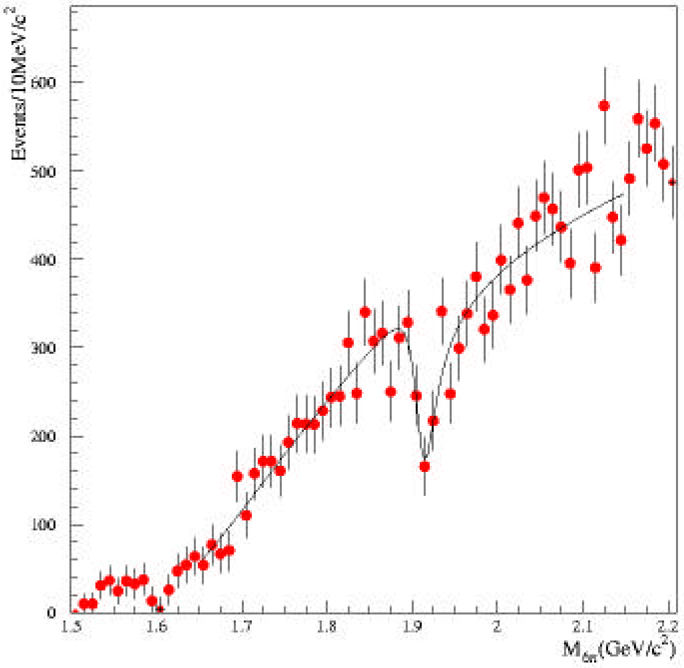


Multihadron channels



$e^+e^- \to 3p^+3p^-$

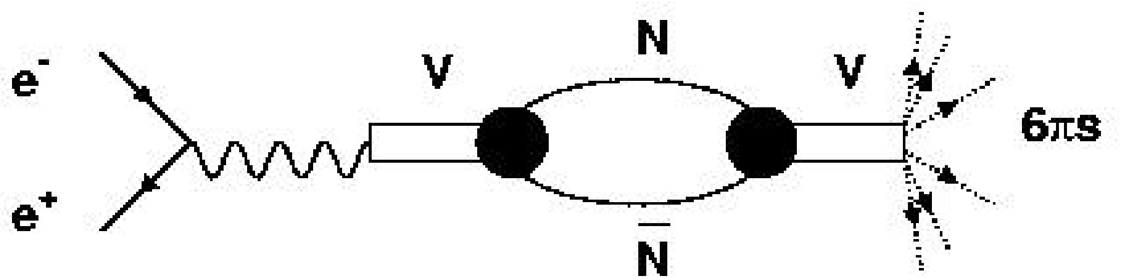
DM2 data



FNAL E687

$3p^+3p^-$ inv. mass distribution in high energy photoproduction

The dip in the total multihadronic cross section and the steep variation of the proton form factor near threshold may be fitted with a narrow vector meson resonance, with a mass M ~ 1.87 GeV and a width Γ ~ 10-20 MeV, consistent with an N $\bar{N}$ bound state.



These considerations strongly support the importance of a new measurement of the neutron and proton timelike form factors with much higher statistics than previous work and with the capability of separately determining the electric and magnetic form factors.

Near and below the threshold a measurement of the various multihadronic e^+e^- channels is also of great importance to understand if there are indeed N `N bound states.

Vector Meson Spectroscopy

The $1.4 < \sqrt{s} < 2.5\,GeV$ is the region of the ρ, ω, ϕ radial excitations. 8 states accepted by PDG:

ρ(1450), ρ(1690), ρ(1700)

ω(1420), ω(1600)

ϕ(1680), ϕ_3(1850)

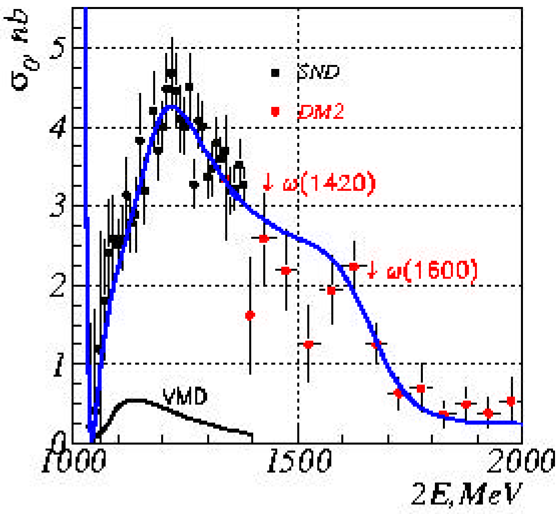
The masses, widths and branching ratios of these states are poorly known, and improved determinations are possible at PEP-N.

Better measurements of exclusive decay channels are needed to determine if these states are members of SU(3) multiplets or exotics.

$$e^+e^- \to p^+p^-p^0$$

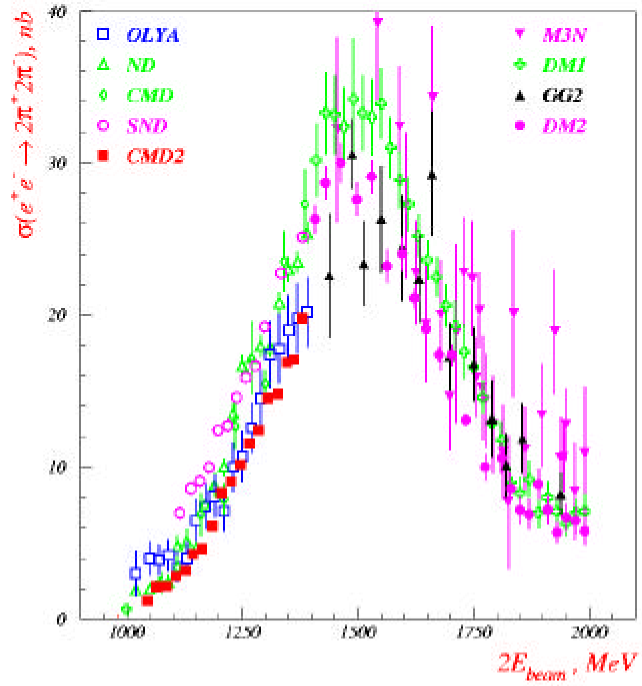
$$M_{w'} \approx 1200 - 1500\,MeV$$

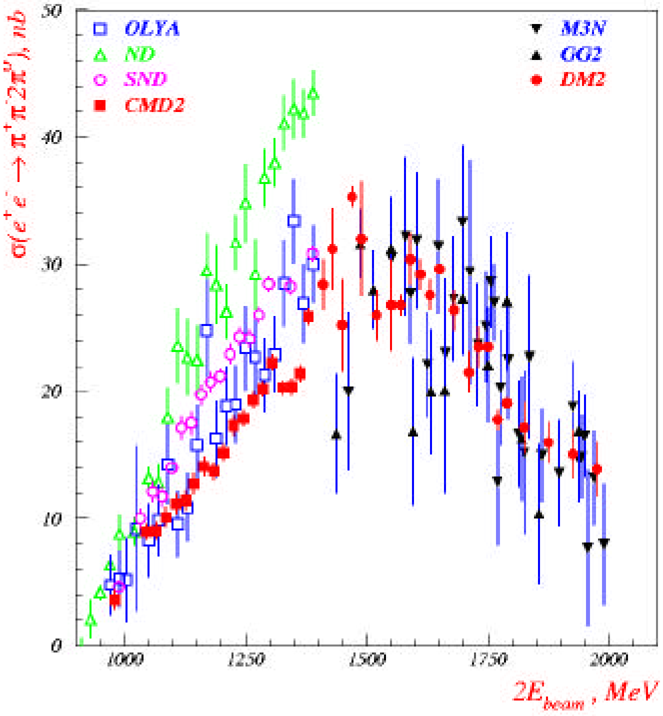
$$\Gamma_{w'} \approx 200 - 900\,MeV$$



Vector Meson Spectroscopy

$e^+e^- \to p^+p^-p^+p^-$

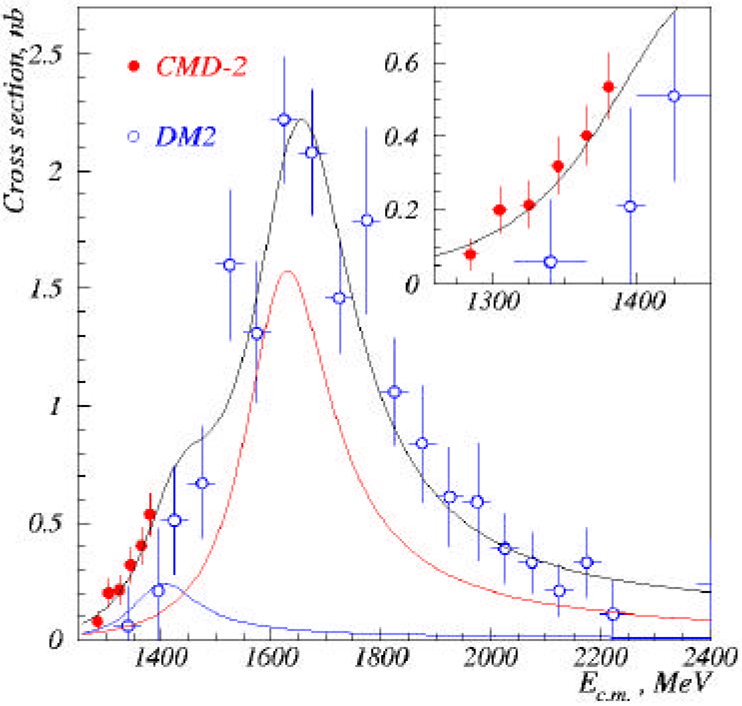


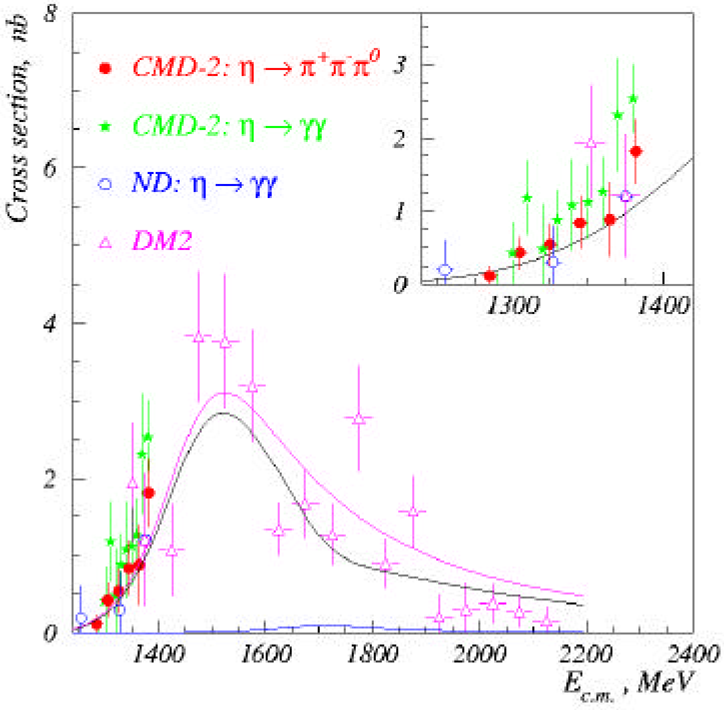


$e^+e^- \to p^+p^-p^0p^0$

Vector Meson Spectroscopy

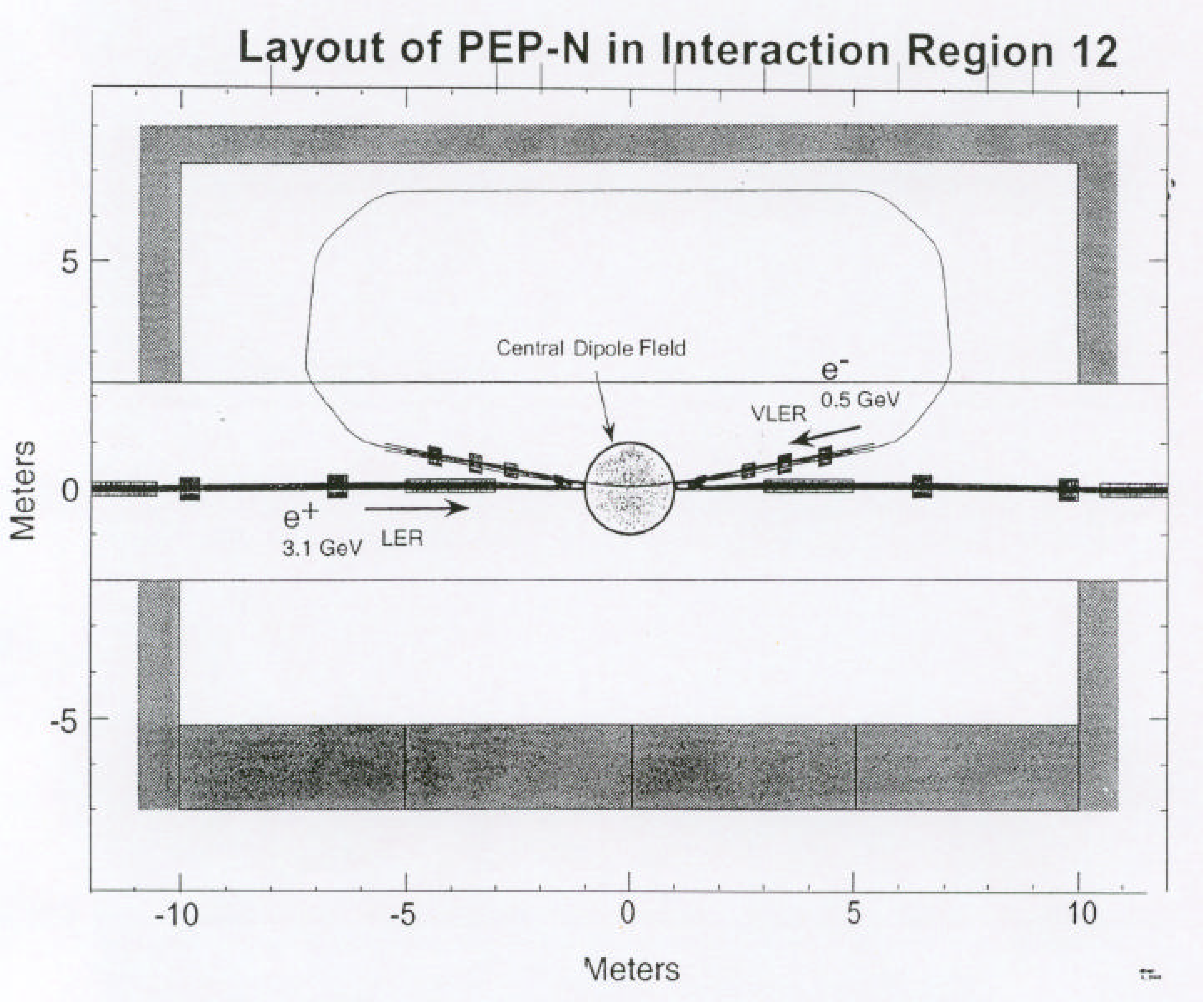
$e^+e^- \to wp^+p^-$





$e^+e^- \to hp^+p^-$

PEP-N Collider



e⁻ energy: variable 0.1 to 0.8 GeV at < 80 mA
e⁺ energy: fixed 3.1 GeV at 2140 mA (from LER)
Luminosity: 10^{31} at 0.8 GeV e⁻
VLER: **new** e⁻ ring 0.1 to 0.8 GeV

Experimental Requirements

- For the measurement of **R** one would want ideally a hermetic detector. Hadronic events can be defined inclusively by requiring a minimum number of particles within the detector acceptance, e.g.:
  - 3 charged particles, or
  - 2 charged particles and 1 γ at large angle, or
  - 1 charged particles and 2 γ reconstructing a π^0.

Potentially large systematic errors associated with calculation of overall acceptance.

Reconstruct the event completely and measure the cross section of each individual channel contributing to **R**.

- The study of exclusive final states (e.g. vector meson spectroscopy, multihadronic channels) will also require the ability to reconstruct the event completely.
- The study of nucleon form factors requires the additional capability to detect neutrons and antineutrons.

Detector Requirements

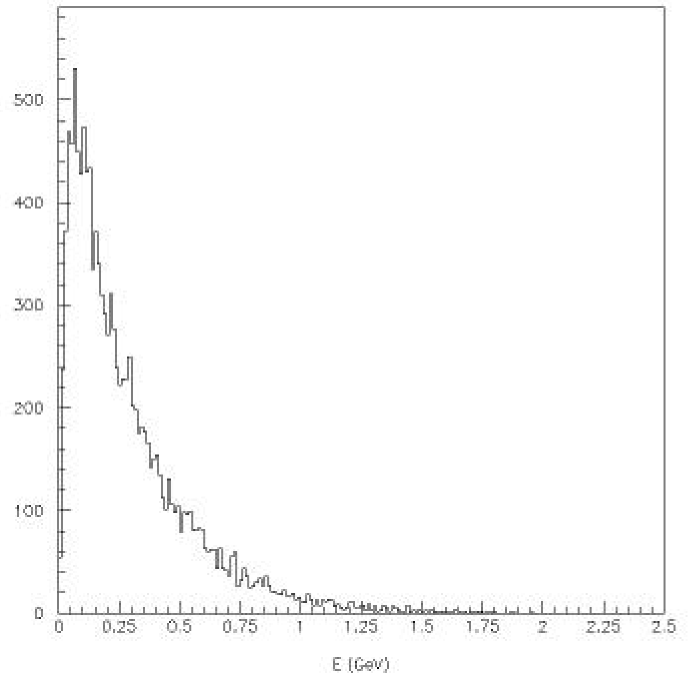
- low mass tracking
- momentum measurement with good precision
- EM calorimetry
- luminosity measurement
- $N \bar{N}$ detector
- particle ID
- modest cost

Some important characteristics

- magnet: 0.1-0.3 T vertical B field (must NOT disturb LER and HER)
- The contribution of multiple scattering to the momentum resolution as high as 2 %.
- $b_{cm} \approx 0.8$
- event rate: < 1 Hz

$e^+e^- \to hadrons$

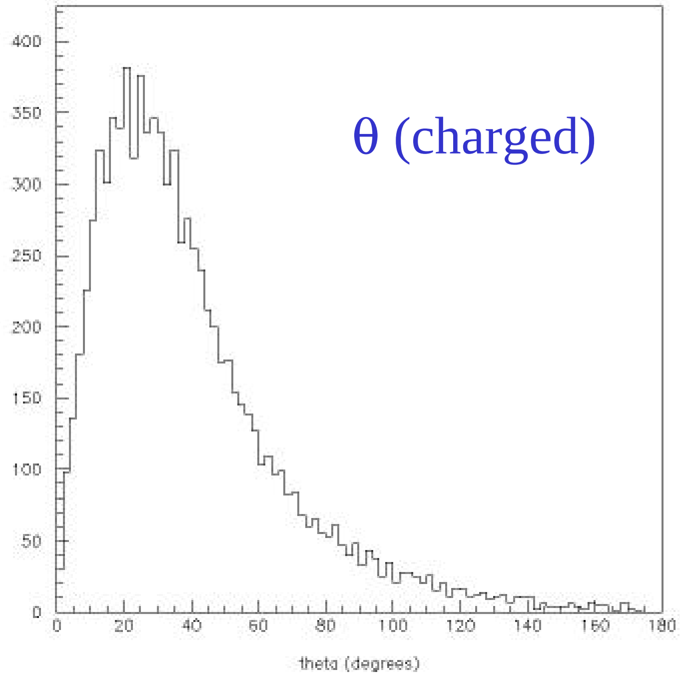
Photon energy distribution

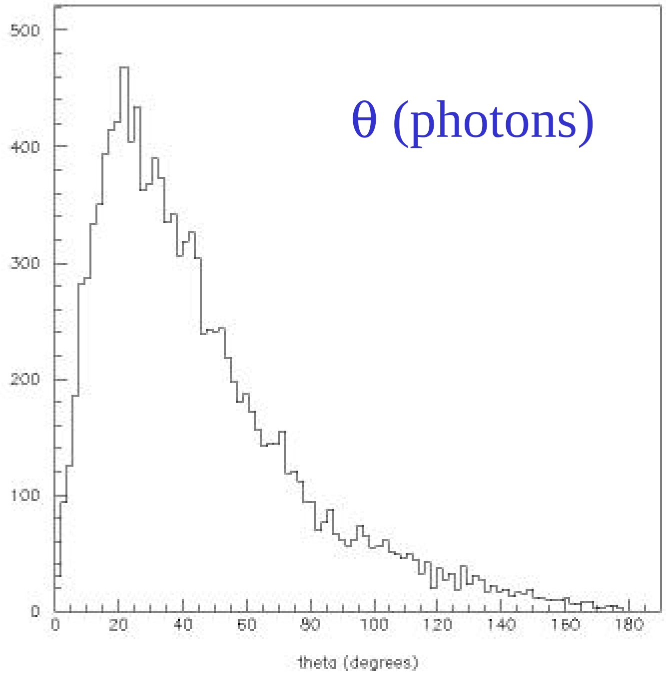


Full efficiency and good energy resolution needed down to very low energies (<100 MeV)

$e^+e^- \to hadrons$

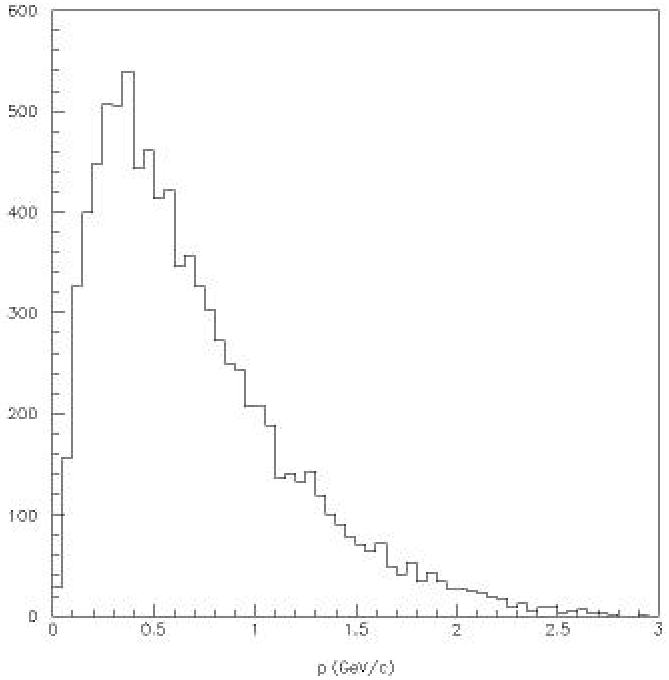
Acceptance





$$e^+e^- \rightarrow hadrons$$

Charged particle momentum distribution



Event Rate

The cross-sections for the processes we wish to study vary over a significant range.

$$s_{mm}(\sqrt{s} = 2\,GeV) = 21.7\,nb$$

$$s_{had}(\sqrt{s} = 2\,GeV) \approx 43\,nb \quad (R = 2)$$

$$s_{\bar{p}p} \approx s_{\bar{n}n} \approx 1\,nb$$

Rates	μμ	0.22 Hz
	had	0.43 Hz
	p $\bar{\text{p}}$	0.01 Hz
	n $\bar{\text{n}}$	0.01 Hz

Taking a maximum total cross-section of 100 nb and a maximum possible instantaneous luminosity of 10^{31}cm^{-2}s^{-1}, the **maximum rate is 1 Hz**.

Data Taking

Average instantaneous luminosity: 5×10^{30}cm^{-2}s^{-1}
(≈ 0.5 pb^{-1}/day)

Measurement of R

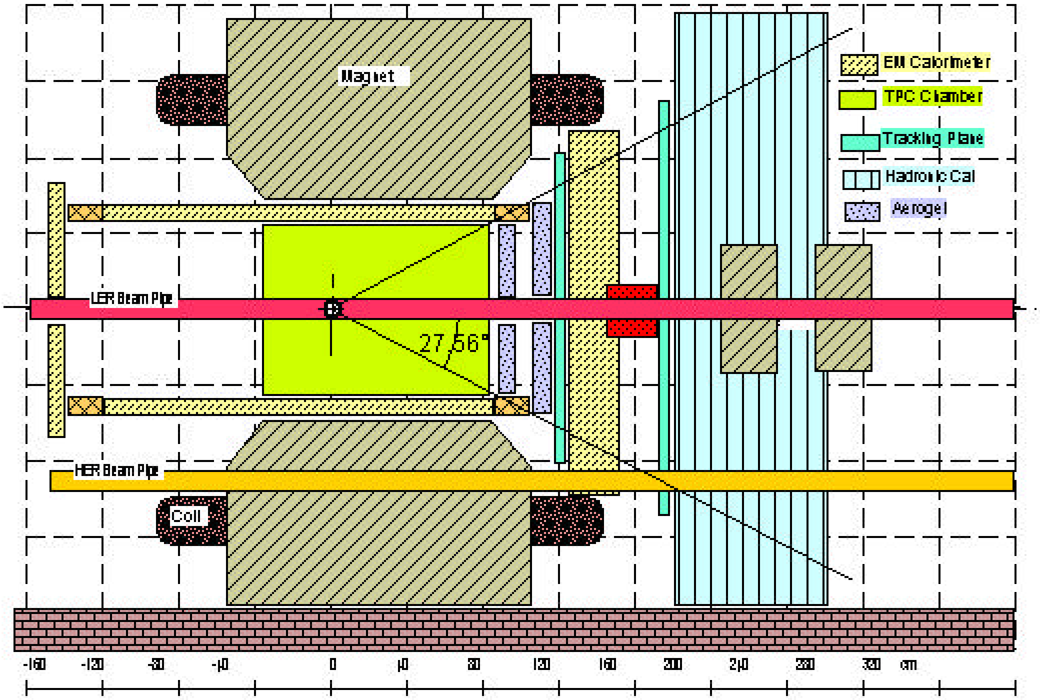
Event Rate: ≈ 0.25 Hz   10000/day
(assuming a detection efficiency of 50 %).
i.e. 1 point/day
assuming 200 points in 10 MeV intervals
200 days data taking.

Nucleon Form Factors

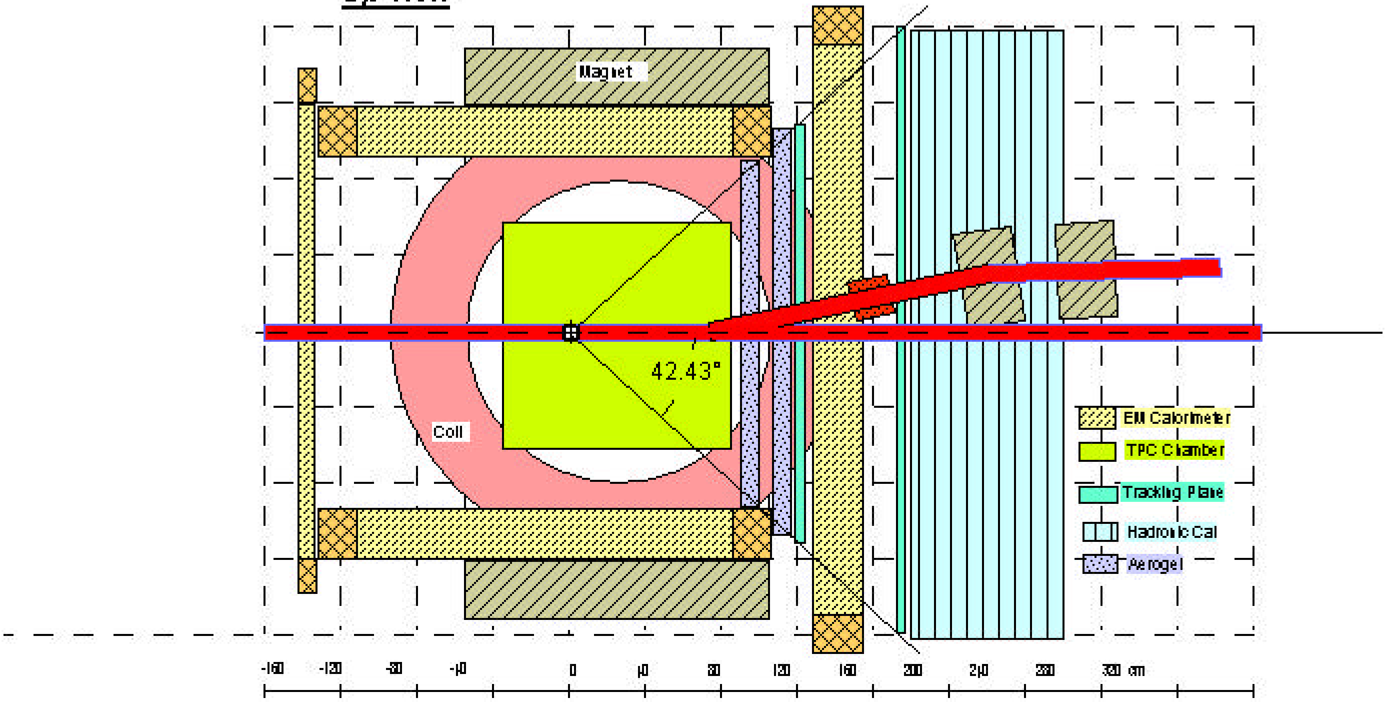
≈ 200 events/day (more than the total statistics of FENICE)
10 days/point

Detector Layout

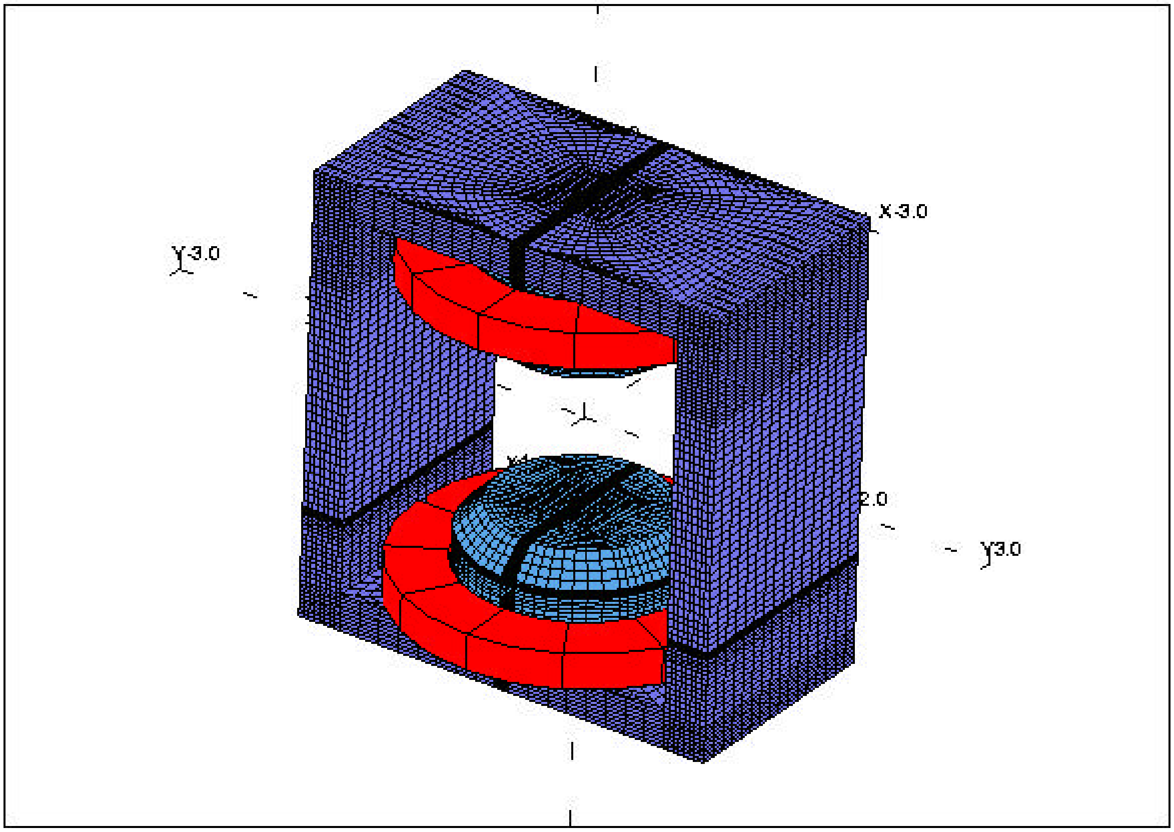
Side view



Up view

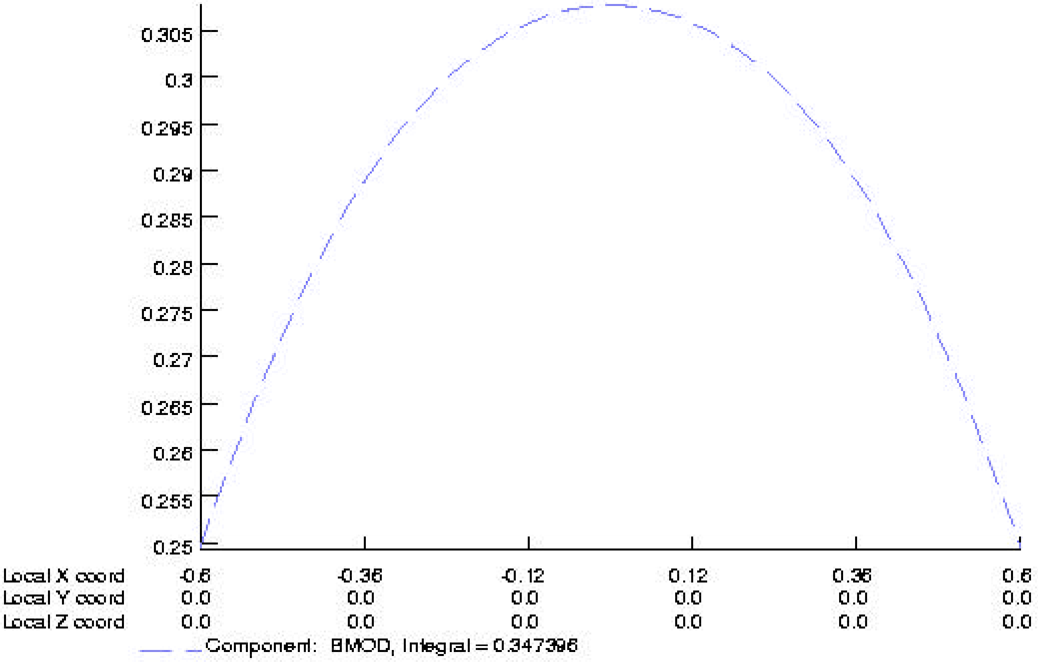


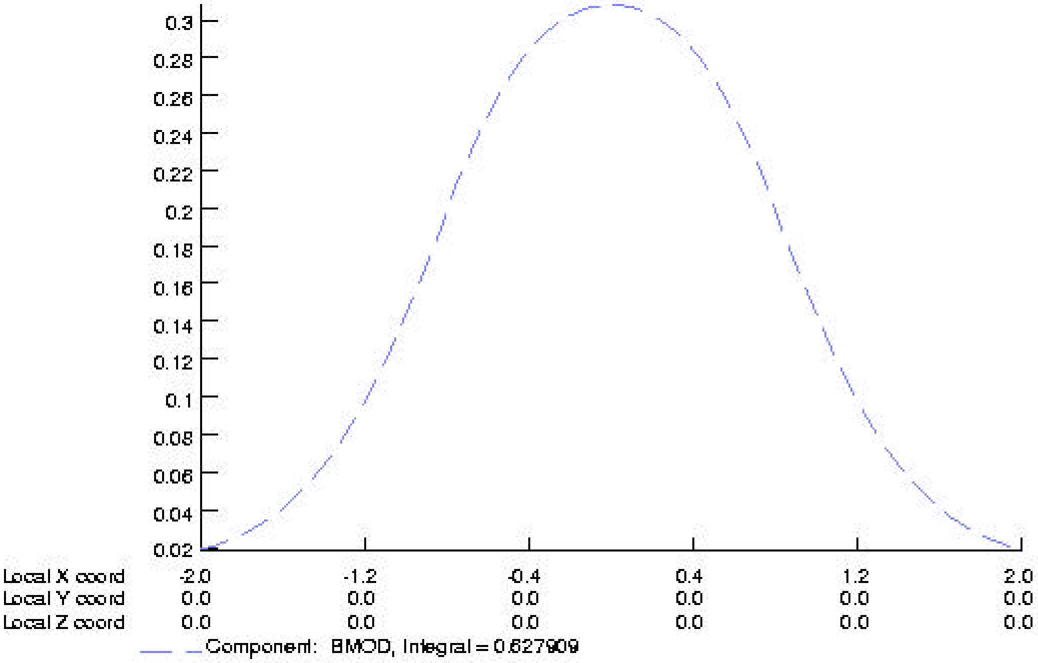
PEP-N Dipole Magnet



distance between poles (y)	1.2 m
pole diameter	1.56 m
horizontal thickness (x)	1.6 m
coil internal diameter	1.6 m
coil external diameter	2.4 m
height (z)	3.1 m
current density	1.58 A/mm^2

Magnetic field along the beam line





Tracking

Requirements:

- Good space resolution: σ = 200÷300 μm
- dE/dx capability for particle ID
- low mass (to minimize multiple scattering)
- minimize dead spaces (frames, supports etc)

TPC with slow He-based gas

(to minimize distortions due to magnetic field non-uniformity).

Forward tracking:

- helps correct distortions in TPC
- veto for neutrons
- help with muon identification

E.M. Calorimeter

Requirements:

- high acceptance
- good efficiency and good energy resolution (few %) down to low energy (< 100 MeV)
- good time resolution

Lead and scintillating fibers calorimeter

(à la KLOE).

KLOE calorimeter

99 % efficiency for 20 Mev < E_γ < 500 MeV

$$\frac{s(E)}{E} = \frac{5.7\%}{\sqrt{E(GeV)}}$$

$$s_z = \frac{1.24\ cm}{\sqrt{E(GeV)}}$$

$$s_t = \frac{54\ ps}{\sqrt{E(GeV)}} + 110\ ps$$

Particle ID

Particle identification is achieved by means of two aerogel counters, each 10 cm thick (total thickness 0.15 r.l.), which can achieve 4s p-K separation in the momentum range 0.6÷1.5 GeV.

Below 0.6 GeV particle ID will be based on dE/dx in the tracking chamber and on TOF in the forward EM calorimeter.

Hadron Calorimeter

It is the main n $\bar{n}$ detector and thus it should:

- be efficient for neutrons
- allow antineutrons to interact
- provide TOF and position of both n and $\bar{n}$.

The hadron calorimeter will be used also for muon ID.

Luminosity Measurement

Online

Required for machine tuning and monitoring. PEP-II monitor, based on single Bremsstrahlung at zero degrees, seems appropriate.

Offline

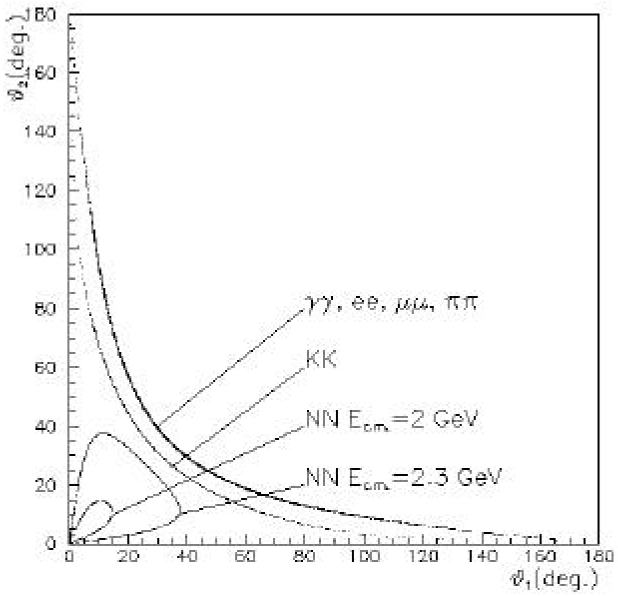
The necessary 1 % accuracy in the integrated luminosity measurement can be achieved using Bhabhas.

Muon pairs will be useful as a check.

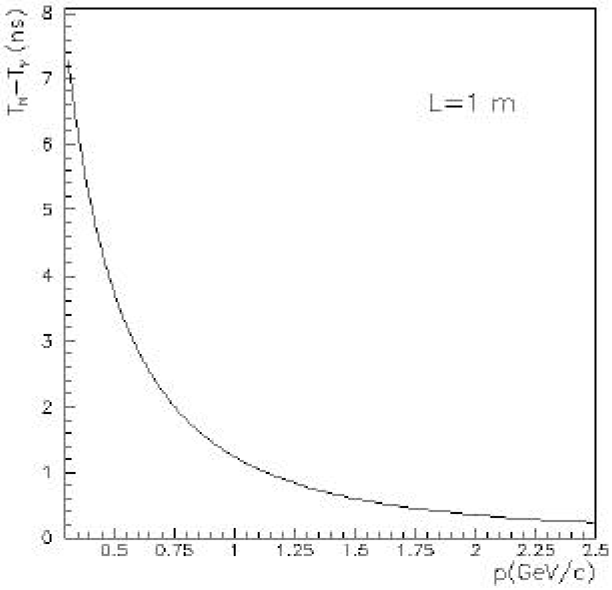
$N\bar{N}$ Identification and measurement

- Angular Correlation

-good angular resolution
-difficult at small E_{cm}.



- Time-of-flight to identify events and reject prompt photons and other fast backgrounds.



- Momentum analysis for $\bar{p}p$
- Calorimetric measurement

Monday, 4/30

D.Bettoni Detector Layout

M.E.Biagini Interaction Region and Lattice Design

M.Negrini Simulation and Detection Efficiencies

M.Placidi Magnet Design

J.Va'vra Tracking Design

Tuesday,5/1

J.Seeman Accelerator Layout

M.Sullivan More on Interaction Region

L.Keller Background

M.Mandelkern Luminosity Monitor

A.Onuchin Aerogel and Particle ID

P.Patteri Electromagnetic Calorimeter

E.Pasqualucci Trigger

Wednesday, 5/2

P.Bosted Baryon Form Factor Measurement at PEP-N

D.Michael Hadron Calorimetry with MINOS technique

S.Rock Nucleon Polarization Measurement

D.Bettoni Detector Design Summary

V.Blinov, S.I.Eidelman, V.Golubev, B. Khazin, V.N.Ivanchenko,
E.Onuchin, S.I.Serednyakov, E.P.Solodov
Budker Institute of Nuclear Physics – Novosibirsk Russia
M.Mandelkern, C.Munger, J.Schultz
University of California, Irvine USA
D.Michael
California Insititute of Technology, Pasadena USA
M.Placidi
CERN – Geneva Switzerland
V.Azzolini, W.Baldini, D.Bettoni, R.Calabrese, G.Ciullo, P.Dalpiaz, P.F.Dalpiaz,
P.Lenisa, E.Luppi, M.Martini, M.Negrini, F.Petrucci, M.Savrie'
Ferrara University and INFN – Ferrara Italy
R.Baldini, S.Bellucci, M.Bertani, M.Ferrer, P.LeviSandri, P.Patteri,A.Zallo
INFN Laboratori Nazionali di Frascati Italy
M.Schioppa
Calabria University and INFN, Rende Italy
U.Mallik
The University of Iowa, Iowa City USA
R.Arnold, P.Bosted, G.Peterson, S.Rock
University of Massachussets, Amherst USA
P.Paolucci, D.Piccolo
Napoli University and INFN, Napoli Italy
M.Morandin, M.Posocco, P.Sartori, R.Stroili, C.Voci
Padova University and INFN, Padova Italy
G.Bonneaud
Ecole Polytechnique, Paris, France
C.Bini, P.Gauzzi, E.Pasqualucci
University of Roma “La Sapienza” and INFN, Roma Italy
V.Bidoli, R.Messi, L.Paoluzi
University of Roma “Tor Vergata” and INFN, Roma Italy
G.Godfrey, L.Keller, M.Perl, J.Va’vra
SLAC, Stanford USA
S.Conetti, D.B.Day, B.E.Norum
University of Virginia, Charlottesville USA