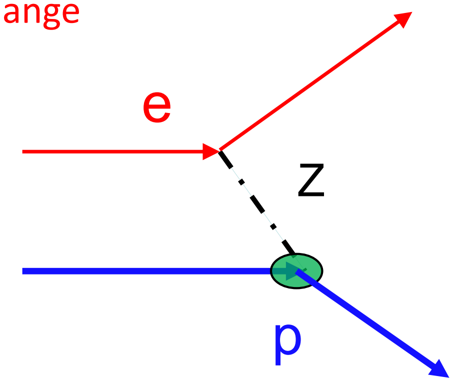
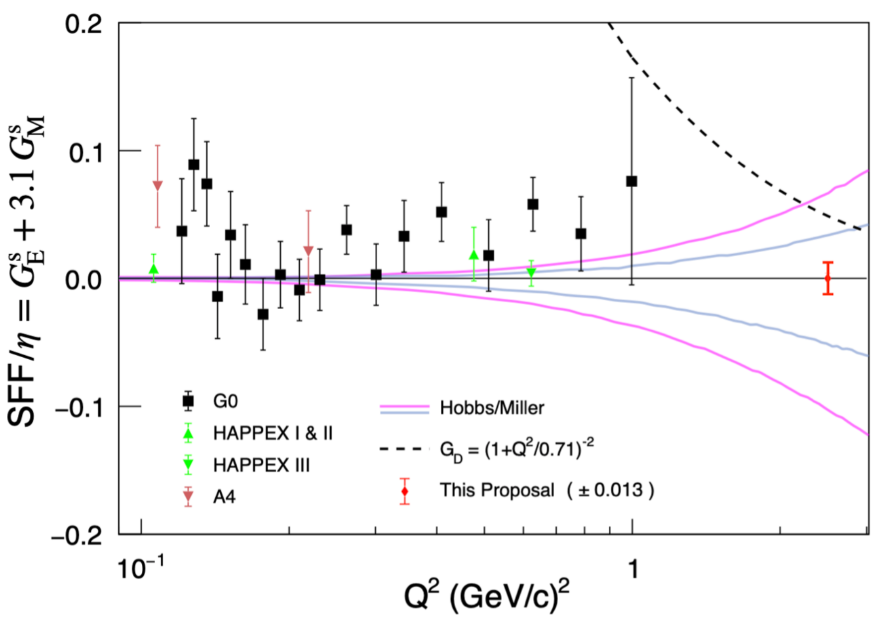
The proton weak form factor (Z exchange) - E12-23-004

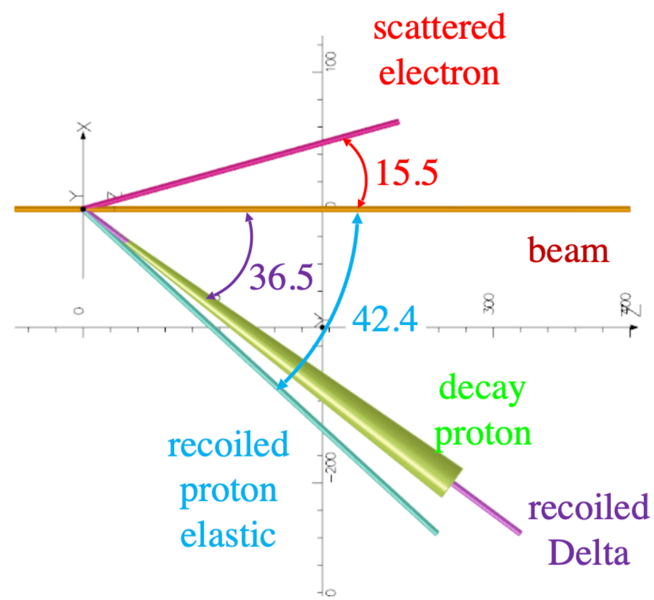
Z exchange



γ-Z interference –> PV !

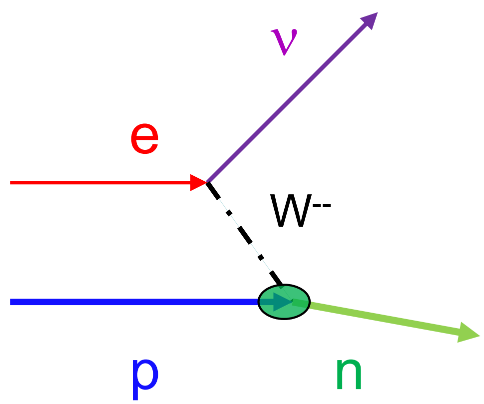
R.Beminiwattha
D.Hamilton
C.Palatchi
K.Paschke
B.Wojtsekhowski





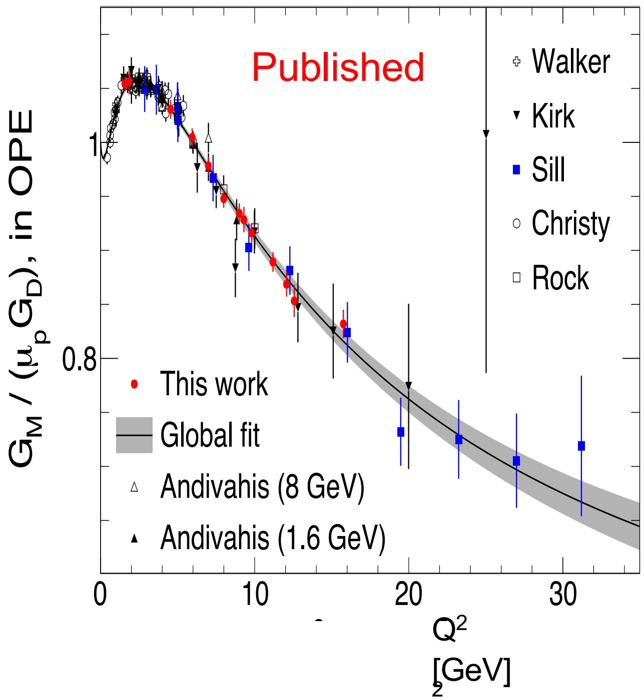
“Another weak FF experiment” (slides in July SBS-2023 meeting):

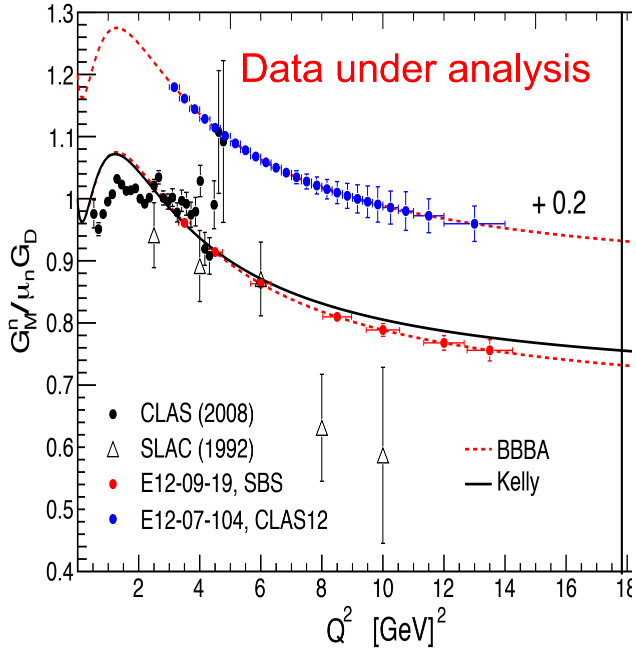
The proton weak form factor (W exchange)

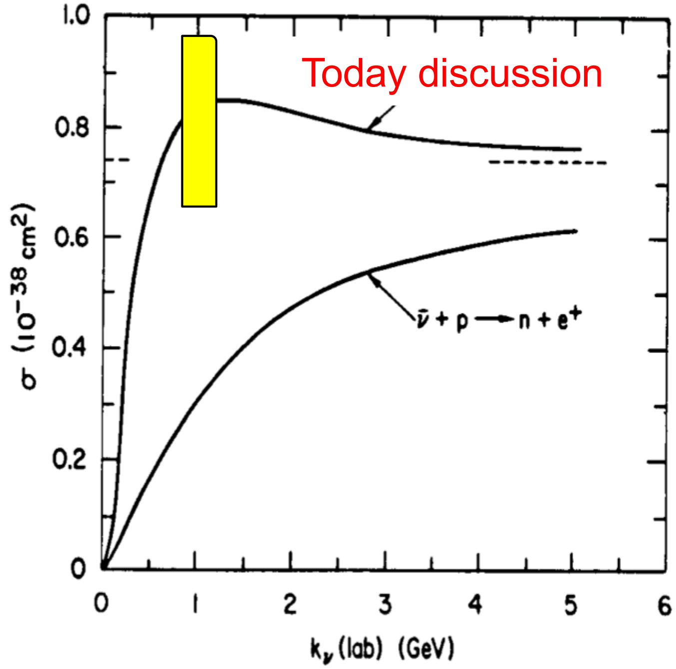


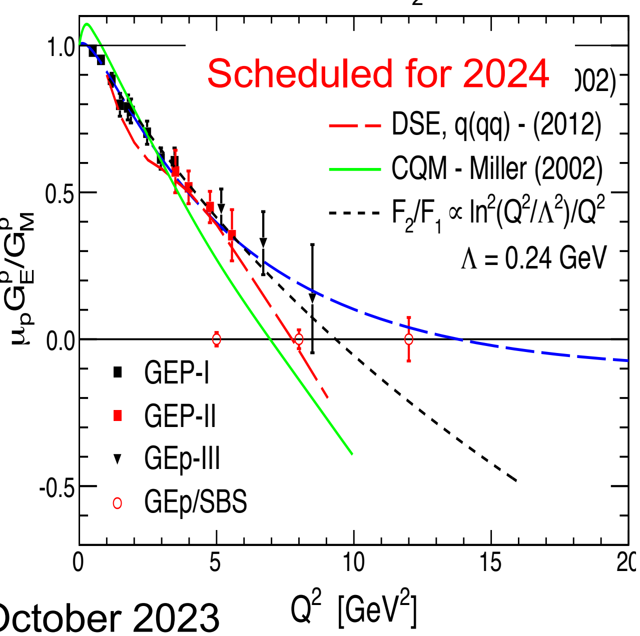
W exchange

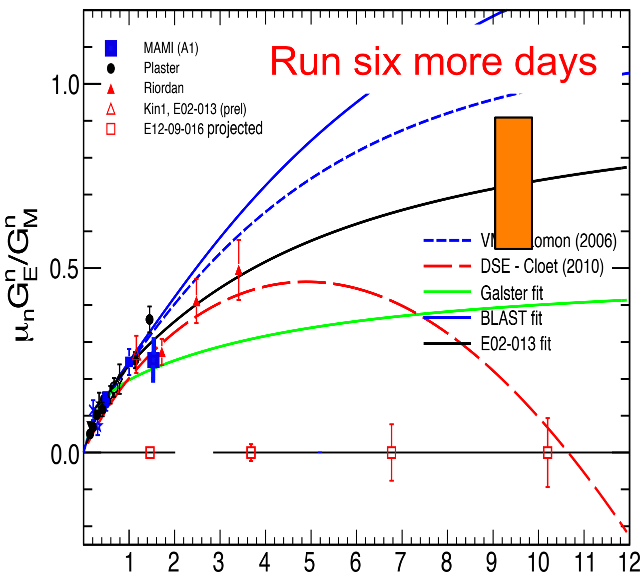
The nucleon FFs

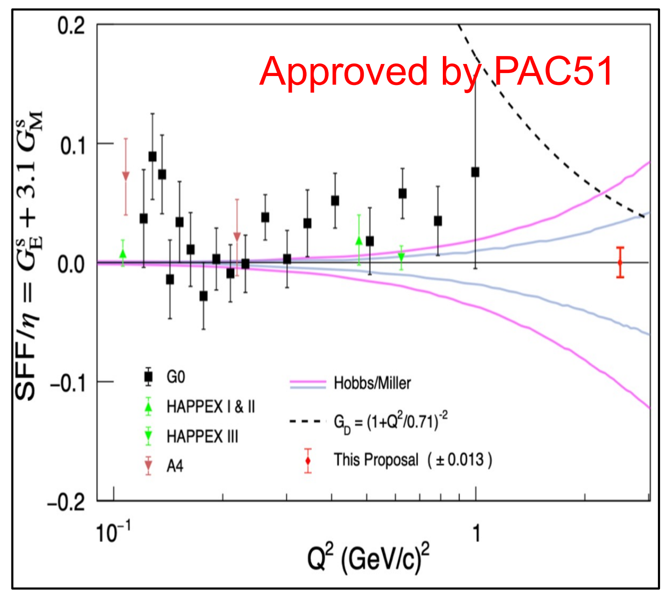












1988 LOI by J. Napolitano

Nov 14, 1988 : this probably is impossible.

$\gamma + p \to \pi^+ + n$

Measurement of the Nucleon Weak Axial Vector Form Factor

A CEBAF Letter of Intent

Oct 31, 1988

J. Napolitano*, ~~S.J. Freedman,~~ D.F. Geesaman, R.J. Holt, H.E. Jackson, ~~B. Zeidman~~

Argonne National Laboratory

R. Carlini

CEBAF and The College of William and Mary

M. Finn and R. Siegel

The College of William and Mary

*Present Address: CEBAF and The College of William and Mary

Abstract

It may be possible to carry out direct measurements of the weak axial vector form factor $F_A(Q^2)$ at CEBAF by detecting the neutron in the reaction $p(e^-,n)\nu_e$ as a function of energy and angle. Such a direct measurement is not complicated by the usual assumptions and experimental uncertainties in neutrino reaction measurments. In addition, it may be possible to extend the present range of Q^2. However, the viability of the experiment depends crucially on background rates in the neutron detector. It appears that the beam microstructure of the accelerator, as well as the availability of longitudinally polarized beam, can be used to reduce the dependence on these background rates. We also discuss the possibility of using the data to search for right handed weak currents.

Experimental Hall A
Experimental Hall B
Experimental Hall C
Experimental Hall D
Experiment Research
Experiment Schedule
Program Advisory Committee

2010 Proposals
2009 Proposals
2008 Proposals
2007 Proposals
2006 Proposals
2005 Proposals
2004 Proposals
2003 Proposals
2002 Proposals
2001 Proposals
2000 Proposals
1999 Proposals
1998 Proposals
1997 Proposals
1996 Proposals
1995 Proposals
1994 Proposals
1993 Proposals
1991 Proposals
1990 Proposals
1989 Proposals

2003 LOI to PAC25 by A.Deur
2023 LOIs to PAC51: one by A.Deur and a second by D.Datta

In LOI 2003 the focus was on $Q^2 \sim 1\text{-}3\ GeV^2$. Interest is large, some questions about how to proceed

In LOI 2023 AD made focus on low Q^2, low beam energy so the pion can not be produced

DD proposed a different idea (also for low Q^2) based on TDIS proton detector and the reaction with a positron beam:
$e^+ + d \to p + p + \nu$

Reference papers

NEUTRINO REACTIONS AT ACCELERATOR ENERGIES

C.H.LLEWELLYN SMITH

Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305, USA

1972

The reaction e- + p ---> nu/e + n at intermediate-energies

S.L. Mintz (Florida Intl. U.), M.A. Barnett (Florida Intl. U.), G.M. Gerstner (Florida Intl. U.), M. Pourkaviani (MP Consulting, Altamonte Springs)

Mar, 1997

9 pages

Published in: *Int.J.Mod.Phys.E* 6 (1997) 111-119

1996

At first glance the reaction $e^- + p \to \nu_e + n$ might seem an unlikely one for calculation in support of possible experimental work. Because both final state particle, the neutrino and the neutron, are neutral, the reaction on the face of it would seem to be very difficult to observe. However we have been assured by experimentalists[1] that it is now very possible to observe this reaction by detecting the outgoing neutron. The reaction itself offers a number of advantages over other weak electron scattering reactions[2–4] which have been proposed for possible experiments at facilities such as CEBAF.

Cross section calculation

Paper by L-Smith

$$\frac{d\sigma}{d|q^2|}\begin{pmatrix}\nu n \to \ell^- p \\ \bar{\nu} p \to \ell^+ n\end{pmatrix} = \frac{M^2 G^2 \cos^2\theta_c}{8\pi E_\nu^2}\left[A(q^2) \mp B(q^2)\frac{(s-u)}{M^2} + \frac{C(q^2)(s-u)^2}{M^4}\right]$$

$$(s-u = 4ME_\nu + q^2 - m^2)\,.$$

C.H. Llewellyn Smith, Neutrino reactions at accelerator energies 303

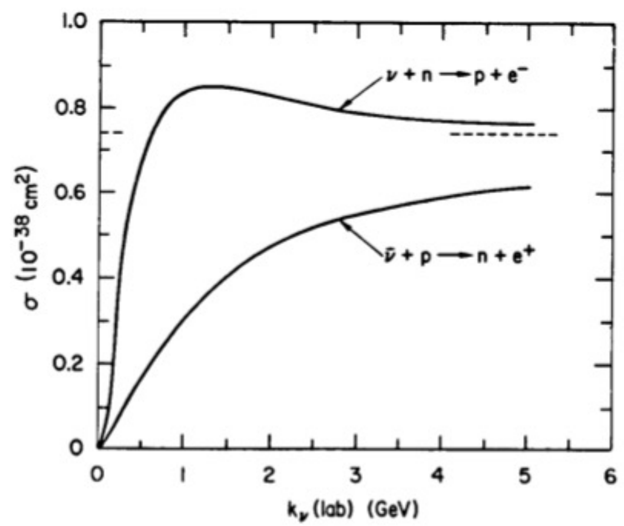


Fig. 10. Cross sections for the quasielastic process in the conventional theory with $m = 0$ and dipole forms $F(0)/(1 - q^2/0.73\ \mathrm{GeV}^2)^2$ for the form factors F_A and $F_V^{1,2}$ [L12] (the dotted line is the limit for σ_ν and $\sigma_{\bar{\nu}}$ as $E \to \infty$).

Cross section calculation

In LOI by Alex Deur

$$\frac{d\sigma}{d\omega'} = M\frac{G^2\cos^2\theta_c}{\pi}\frac{\omega'}{\omega}\left[\cos^2(\theta_l/2)f_2 + \left(2f_1 + \frac{\omega+\omega'}{M}f_3\right)\sin^2(\theta_l/2)\right]$$

Last month I got a code from Jacek Golak
also see PRC **107**, 024617 (2023)

```
In[1]:= << FeynCalc`
```

FeynCalc 9.3.1 (stable version). For help, use the documentation center, check out the wiki or visit the forum.

To save your and our time, please check our FAQ for answers to some common FeynCalc questions.

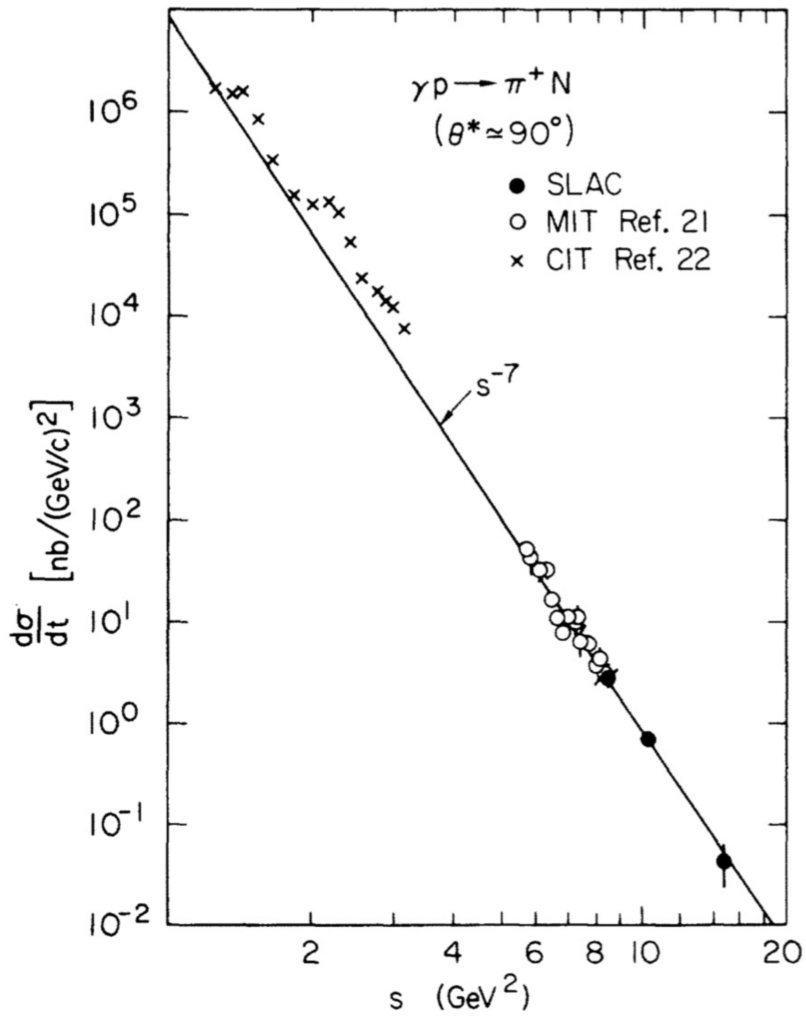
See also the supplied examples. If you use FeynCalc in your research, please cite

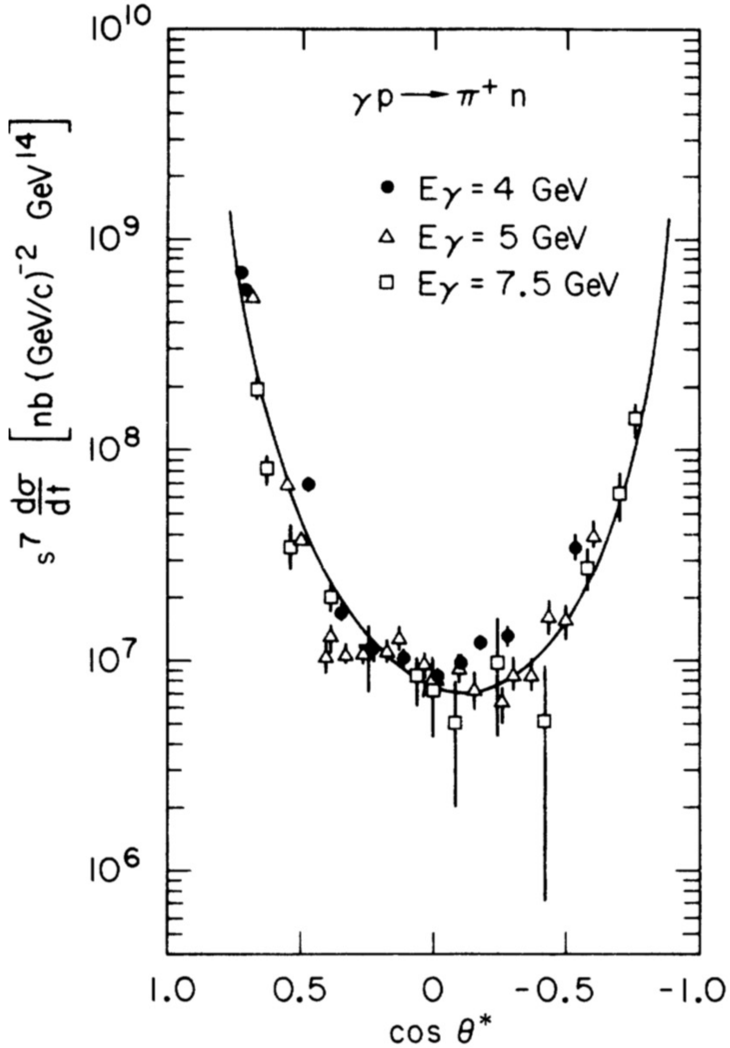
- V. Shtabovenko, R. Mertig and F. Orellana, Comput.Phys.Commun. 256 (2020) 107478, arXiv:2001.04407.

Big challenges in the study of $e + p \rightarrow \nu + n$ process

- Cross section for the weak process is of a few 10^{-40} cm^2/sr
- Pion photo-production cross section ~ 10^8 of the weak one
- Proton rate from electron elastic e-p ~ 10^6 of the weak one

Pion photo production cross section





Proposed solution for the e + p --> ν + n experiment

1. High momentum resolution neutron detector
2. High angular resolution neutron detector
3. Reconstruction of the incident lepton energy to 1%
4. High efficiency of the charge particle rejection in BB
5. Analysis of the distribution (3.) shape for tagged events
6. Determination of the extra rate at the elastic “peak”

Weak Proton Form Factor at 1 GeV^2

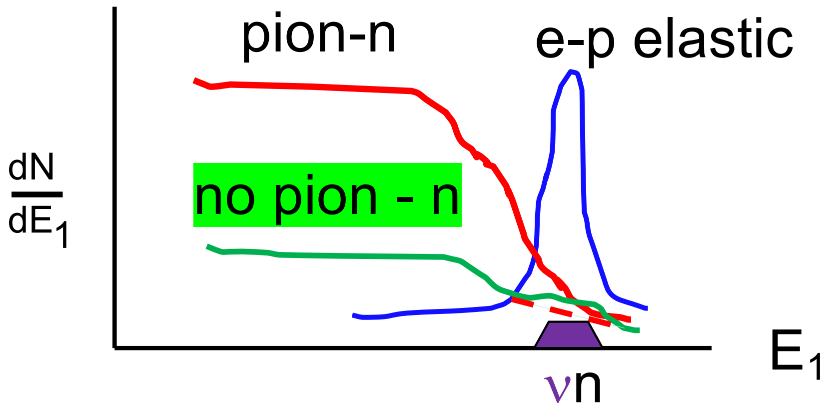
Estimation of the experiment parameters:

- Beam energy 2.2 GeV with a LH2 target
- Electron/pion/neutrino angle 54 degrees
- Recoil proton/neutron 30 degrees, p_n = 1 GeV/c
- π+ in BigBite; efficiency ~ 95%+4% (μ are forward)
- Electron in BigBite: efficiency 99.9%; solid angle 60 msr
- Neutron in LND: 1m x1m, solid angle 40 msr; $\delta\theta$ ~ 1mrad
- Initial lepton momentum reconstruction accuracy ~1%
- Photon flux 0.02 x 1/100 x ¼ => $0.5/10^4$ per electron
- Electron-proton luminosity 10 cm LH2 x 100 uA = 3×10^{38}
- Rate of elastic ep events 6 kHz
- Rate of \no(e)p events 6 Hz, \no(e)n < 0.6 Hz or ~ 2k per hour
- Rate of π^+n events 15 Hz
- Rate of \no(π^+)n events 500 per hour
- Rate of "weak" neutrons 110 per hour
- Signal/Background 1/20 at location of the elastic "peak"
- 100 hours, 10% neutron efficiency (free protons only):

S/B = 0.050 +/- 0.01

Lepton initial energy

$$E_1 = (E_n - m) / \left[1 + \frac{P_n \cos\theta_n - E_n}{m}\right]$$



- Signal/Background 1/20 at location of the elastic “peak”
- 100 hours, 10% neutron efficiency (free protons only):

S/B = 0.050 +/- 0.01

Time-of-Flight resolution

$$\frac{\sigma_p}{p} = \gamma^2 \times \frac{\sigma_\beta}{\beta}$$

$$\frac{\sigma_\beta}{\beta} = \frac{\sigma_{ToF}}{ToF}$$

for 10 m path and 0.12 ns time resolution

using Q^2=1 GeV^2 (γ=1.5)

$$\frac{\sigma_p}{p} = \gamma^2 \times 1/275 \sim 0.4\%$$

0.12 ns time resolution is hard

Traditional ToF system

Number of channels ~ 25 x (1m x 1m) x 0.5m
using 5 cm x 5 cm x 100 cm bars -> 5000 bars

With 25 m distance it will allow 40 msr solid angle

Angular resolution ~ 1 mrad

Cost per bar ~ $2k for 2 PMT + scintillator
Cost of HV+DAQ per bar ~ $2k

CH, aver. density 0.79 g/cm^3

1 m long detector with 0.25 ns resolution

Cost is high ~ $20M

Scintillator fiber systems

Scintillating fiber detectors for the HypHI project at GSI

D. Nakajima [a,b,*], B. Özel-Tashenov [a,c,**], S. Bianchin [a], O. Borodina [a,d], V. Bc
M. Kavatsyuk [e], S. Minami [a], C. Rappold [a,f], T.R. Saito [a,d], P. Achenbach [d], S. A
T. Fukuda [h], Y. Hayashi [i], T. Hiraiwa [i], J. Hoffmann [a], K. Koch [a], N. Kurz [a], O. I
Y. Mizoi [h], T. Mochizuki [k], M. Moritsu [i], T. Nagae [i], L. Nungesser [d], A. Okamu
A. Sakaguchi [k], M. Sako [i], C.J. Schmidt [a], H. Sugimura [i], K. Tanida [l], M. Träger

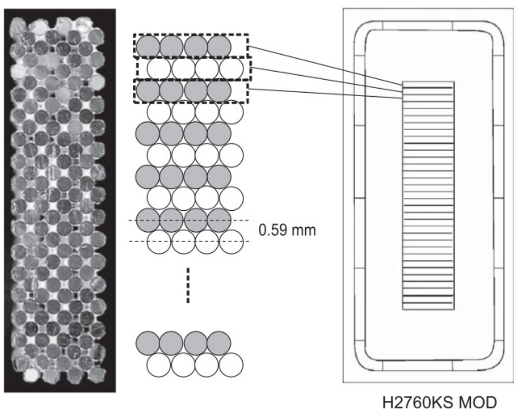
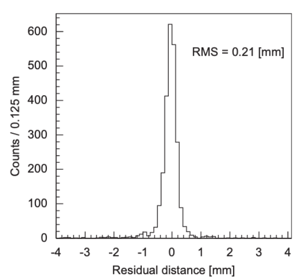


Fig. 2. (a) Cross-section of a 32-channel fiber bundle and (b) corresponding enlarged schematic drawing. The panel (c) shows a scheme of the surface of PMT H7260KS MOD.



A two-dimensional scintillation-based neutron detector with wavelength-shifting fibers and incorporating an interpolation method

T. Nakamura [a,*], K. Toh [a], T. Kawasaki [a], M. Ebine [b], A. Birumachi [b], K. Sakasai [a], K. Soyama [a]

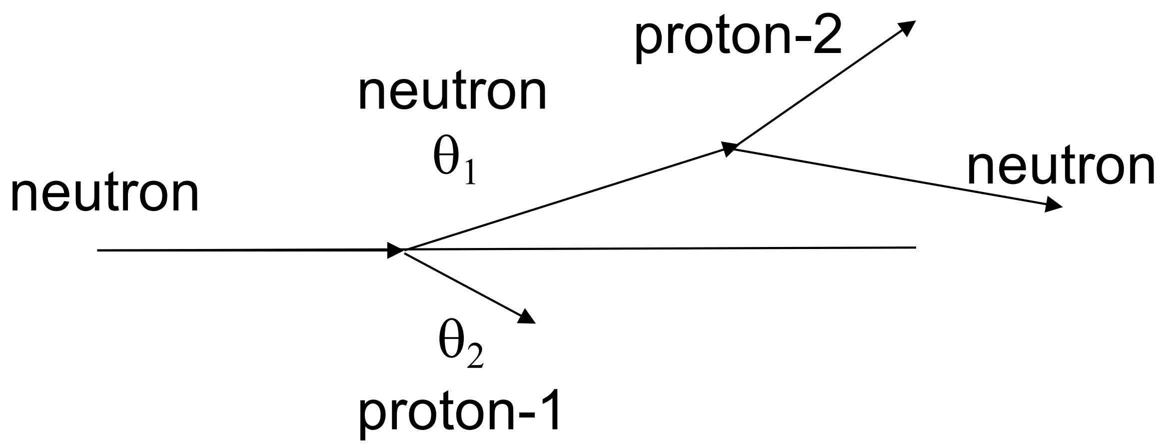
3.3. Spatial resolution

Fig. 7 shows the spatial resolution measured while scanning the collimated beam over the detector. The spatial responses were fitted with a Gaussian function to extract the variance (σ) for each incidence position. The spatial resolution, which was calculated as the full width at half maximum (FWHM) by 2.35σ, was better when the neutron beam was incident on top or near the WLS fiber than when it was incident between the fibers. Measurements made over a distance of 10 mm revealed a periodicity in the spatial resolution of 2.5 mm for all of the MPC logics, which reflected the pitch of the WLS fibers. These observations were consistent with the spatial responses shown in Figs. 4 and 5.

The average FWHM spatial resolutions were 3.3 ± 0.3, 2.7 ± 0.1, and 2.5 ± 0.1 mm for standard-, half-, and quarter-pitch logics, respectively. The spatial resolution improved from 1.2- to 1.3-fold

noise. At a single photon threshold the SiPM suffers from the same problems as a GAPD. Current state of the art SiPMs have thermal noise rates[6] at $\mathcal{O}(100\,\text{kHz})$[7] at single photon level. This value depends on the temperature and the bias voltage. The typical pixel sizes of SiPMs are between $25 \times 25\,\mu\text{m}^2$ and $100 \times 100\,\mu\text{m}^2$. One single device can cover active areas up to $6 \times 6\,\text{mm}^2$ (fig. 3.9).

Neutron/proton tracking detector



$$E = \frac{2mc^2}{\tan\theta_1 \tan\theta_2} - mc^2$$

Mostly sensitive to the sum $(\theta_1+\theta_2)$

for $\mathrm{E} = 1.5\ \mathrm{mc}^2$

$$\frac{\sigma_p}{p} = 8 \times \sigma_\theta [\mathrm{rad}]$$

=> 0.8% with 1 mrad angular resolution

Neutron/proton tracking detector

Preliminary results on the feasibility of a liquid methane detector for fast neutrons

G. Bressi [a], M. Cambiaghi [a], G. Carugno [b], S. Centro [c], E. Conti [c], B. Dainese [c], G. Prete [b] and N. Toniolo [b]

[a] *INFN, Sezioni di Pavia, Via A. Bassi, 6 Pavia, Italy*
[b] *INFN, Laboratori Nazionali di Legnaro, Via Romea 4, Legnaro PD, Italy*
[c] *INFN, Sezioni di Padova, Via Marzolo, 8 Padova, Italy*

Received 11 May 1990 and in revised form 10 September 1990

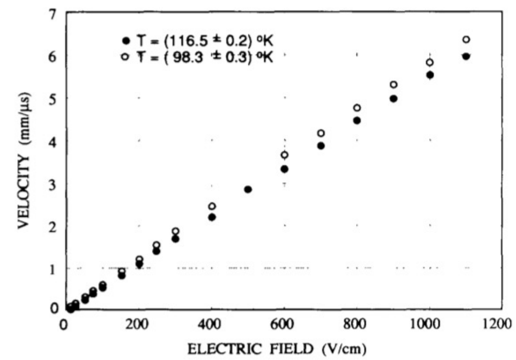


Fig. 7. Electron drift velocity vs electric field for two different liquid temperatures.

Study of the liquid-methane ionization chamber

Hiroki Tanaka[a,*,1], Tetsuya Ariyoshi[a], Takeshi Uemura[a], Hidehiko Arima[a], Keisuke Maehata[a], Kenji Ishibashi[a], Yuzuru Matsumoto[b]

[a] *Department of Applied Quantum Physics and Nuclear Engineering, Kyushu University, Hakozaki, Higshi-ku, Fukuoka 812-8581, Japan*
[b] *Teikyou University Fukuoka Junior College, Omuta, Fukuoka 836-8505, Japan*

Received 13 August 2004; received in revised form 27 October 2004; accepted 30 October 2004
Available online 8 December 2004

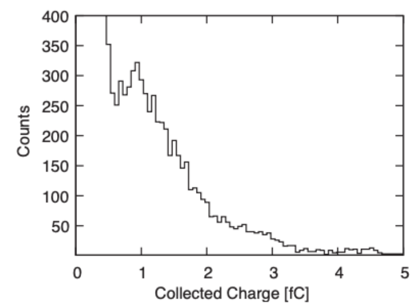
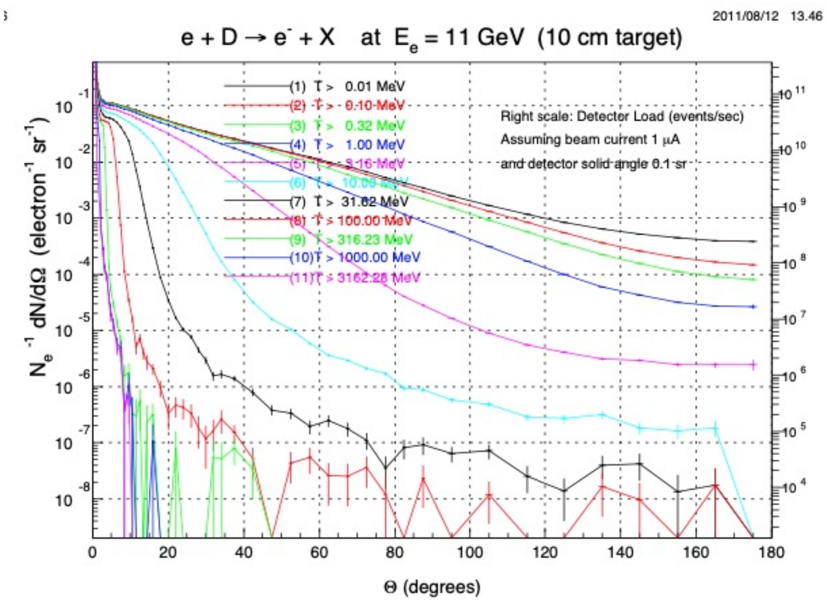


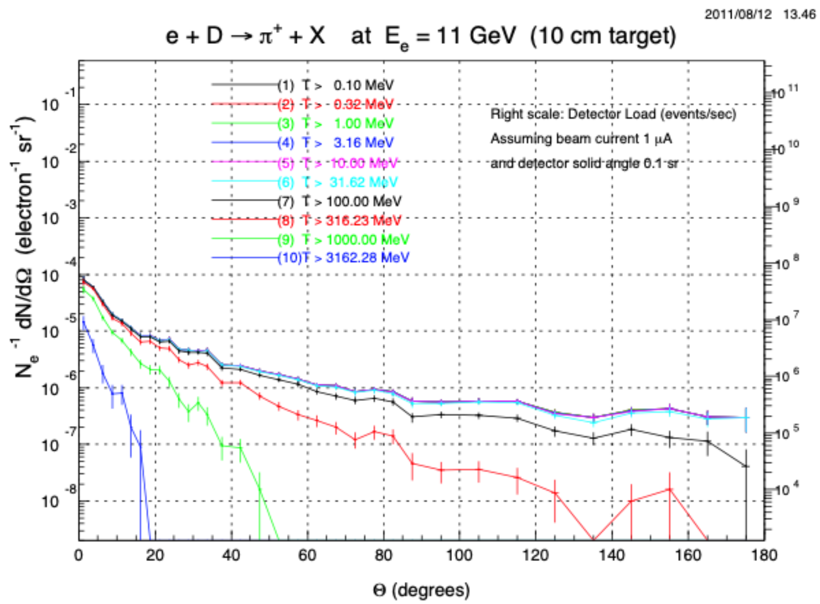
Fig. 8. Collected charge distribution at 10 kV/cm.

60 mm /us with 2 mm wire spacing => 25 ns time window

Rate in detector

40 msr at 30 degrees for 3 x 10^{38} luminosity

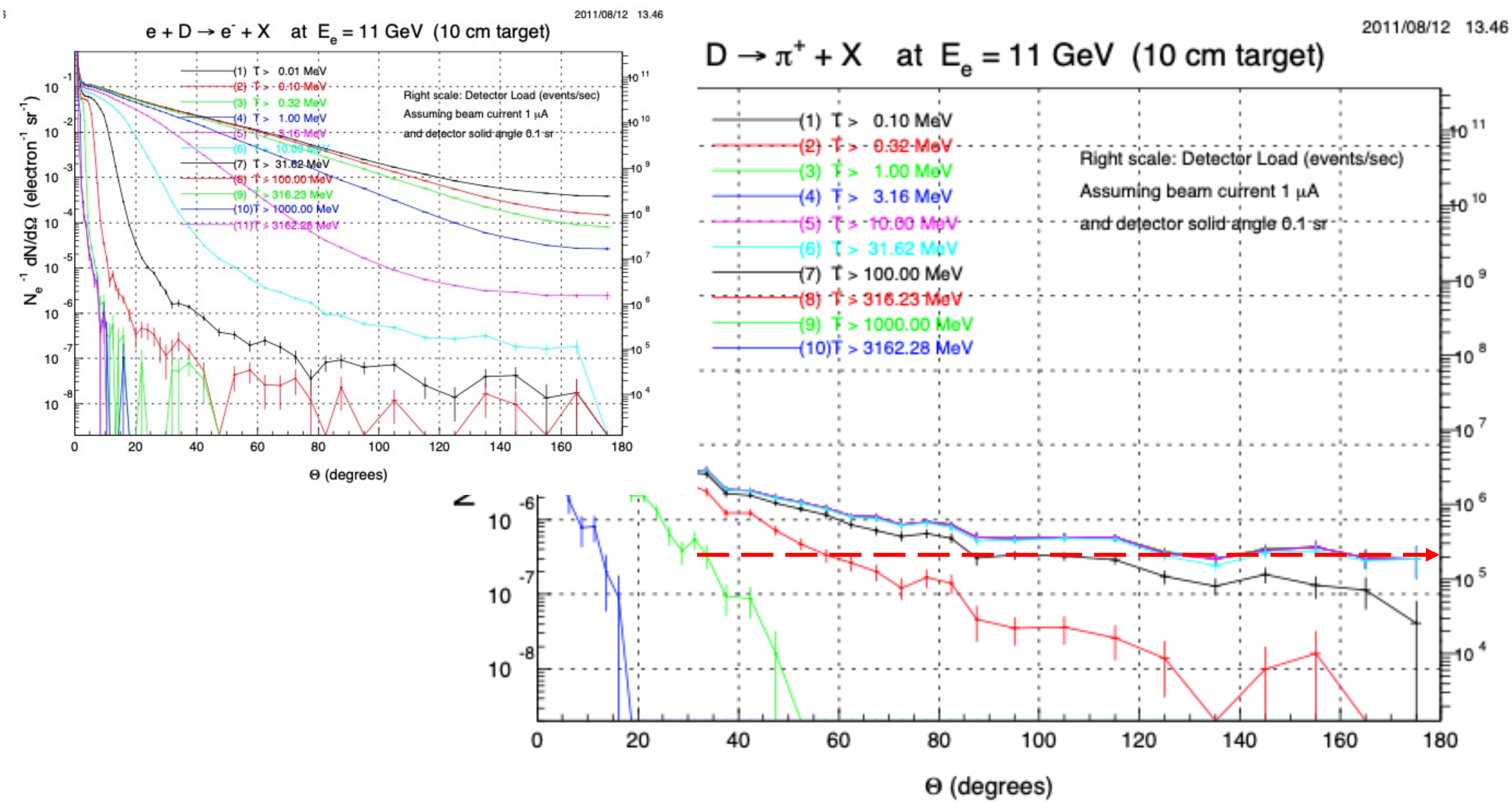




A magnetic sweeper to keep p < 1 GeV/c out of detector

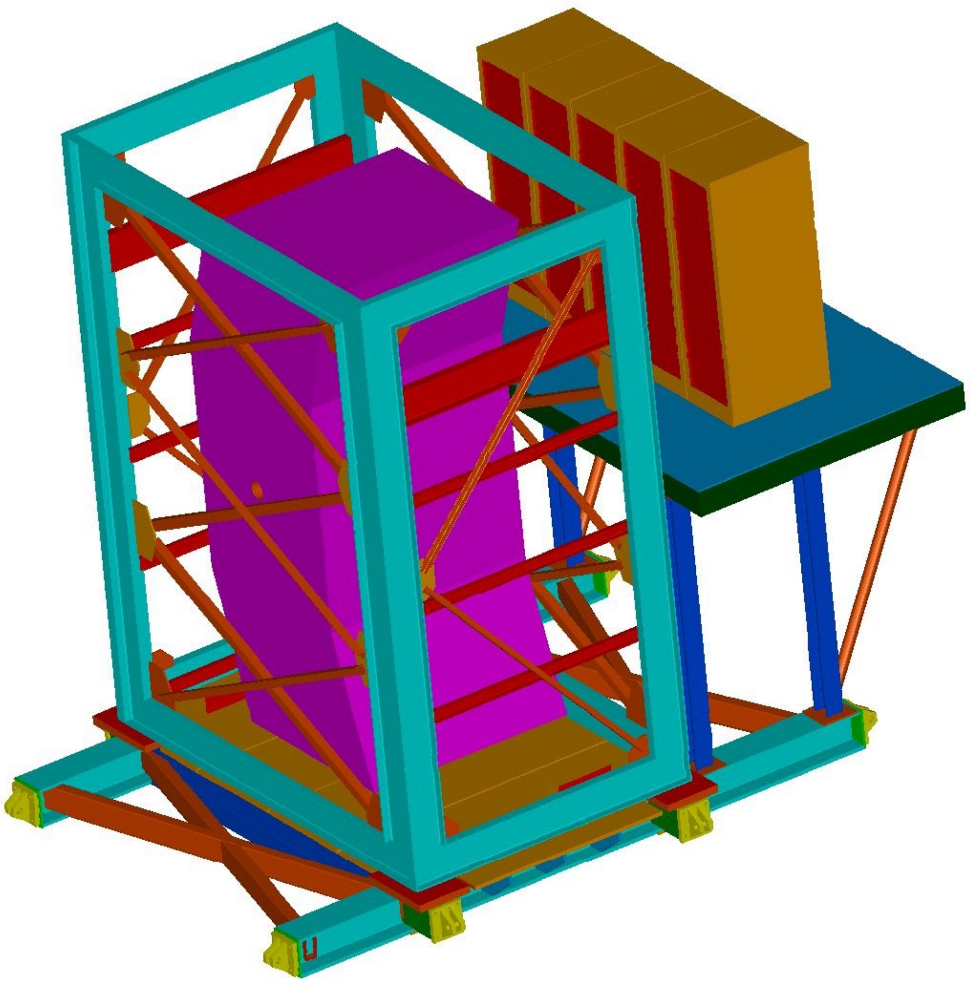
Rate in detector

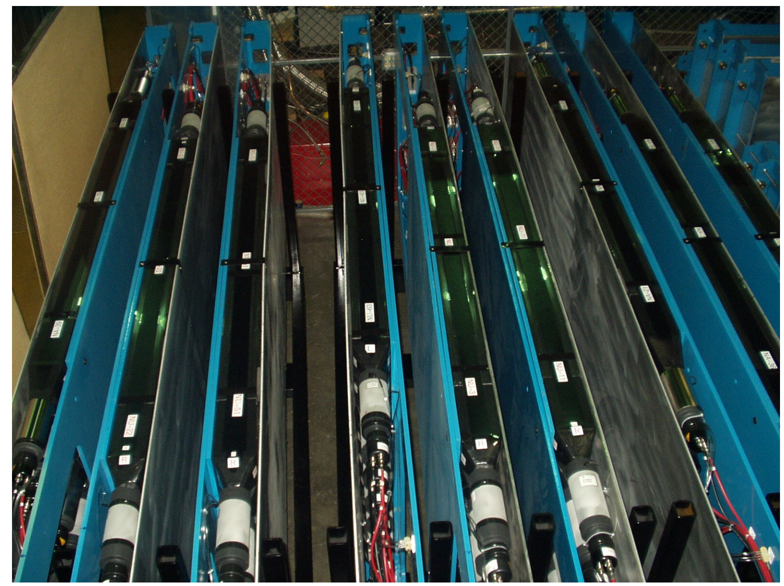
40 msr at 30 degrees for 3 x 10^{38} luminosity



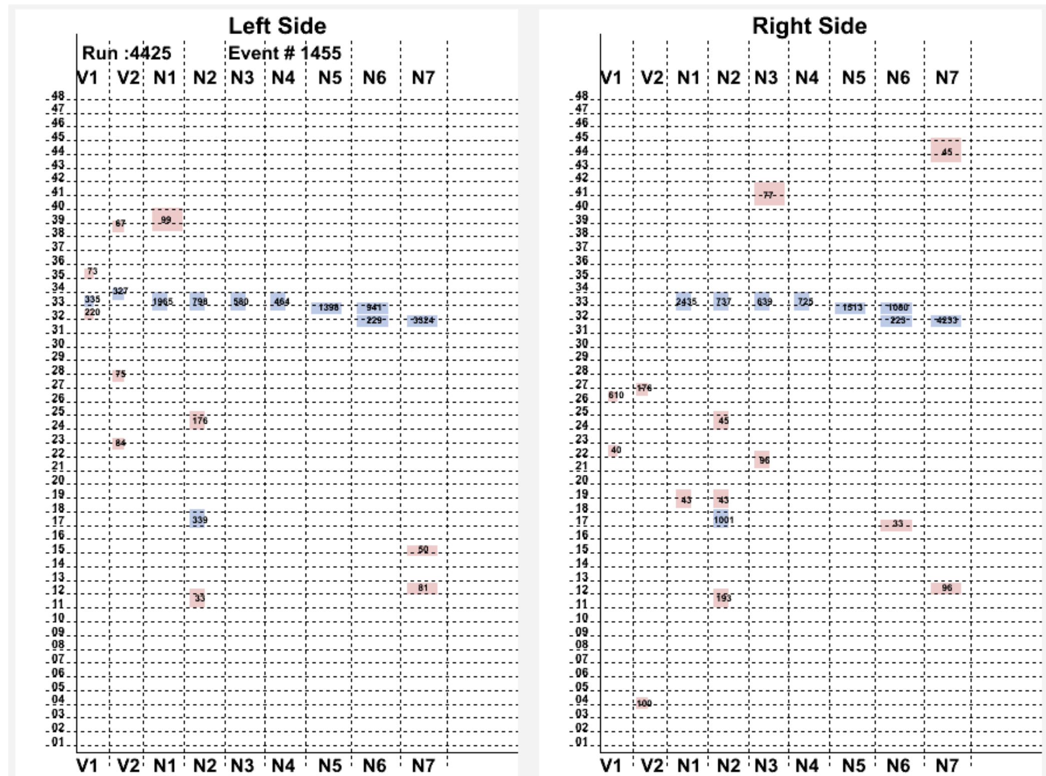
Backup slides

Neutron arm in GEn-I



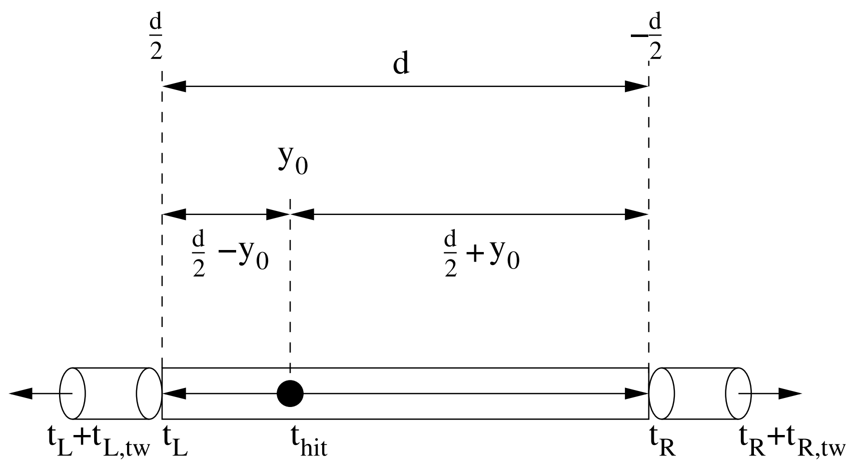


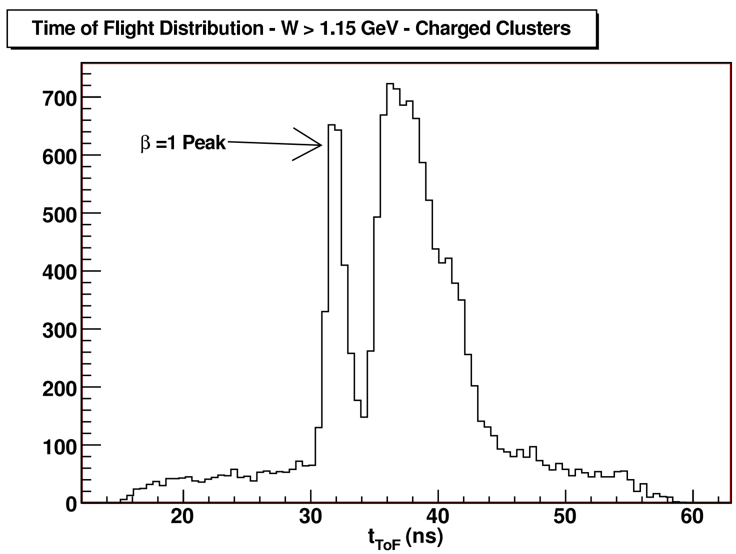
GEn-I neutron arm

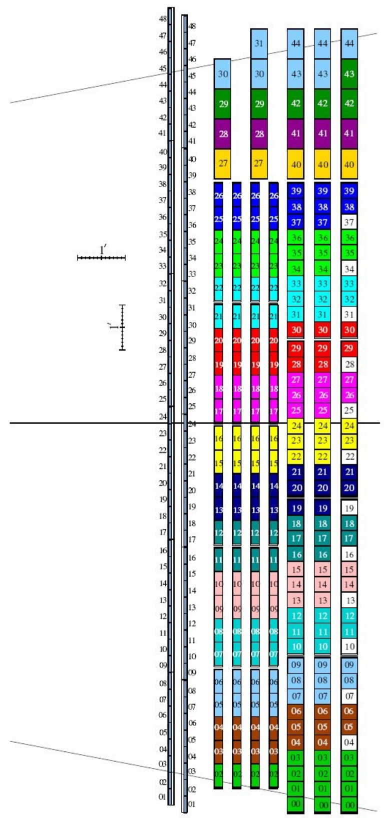


200 veto counters, ~300 neutron bars; ~800 PMTs

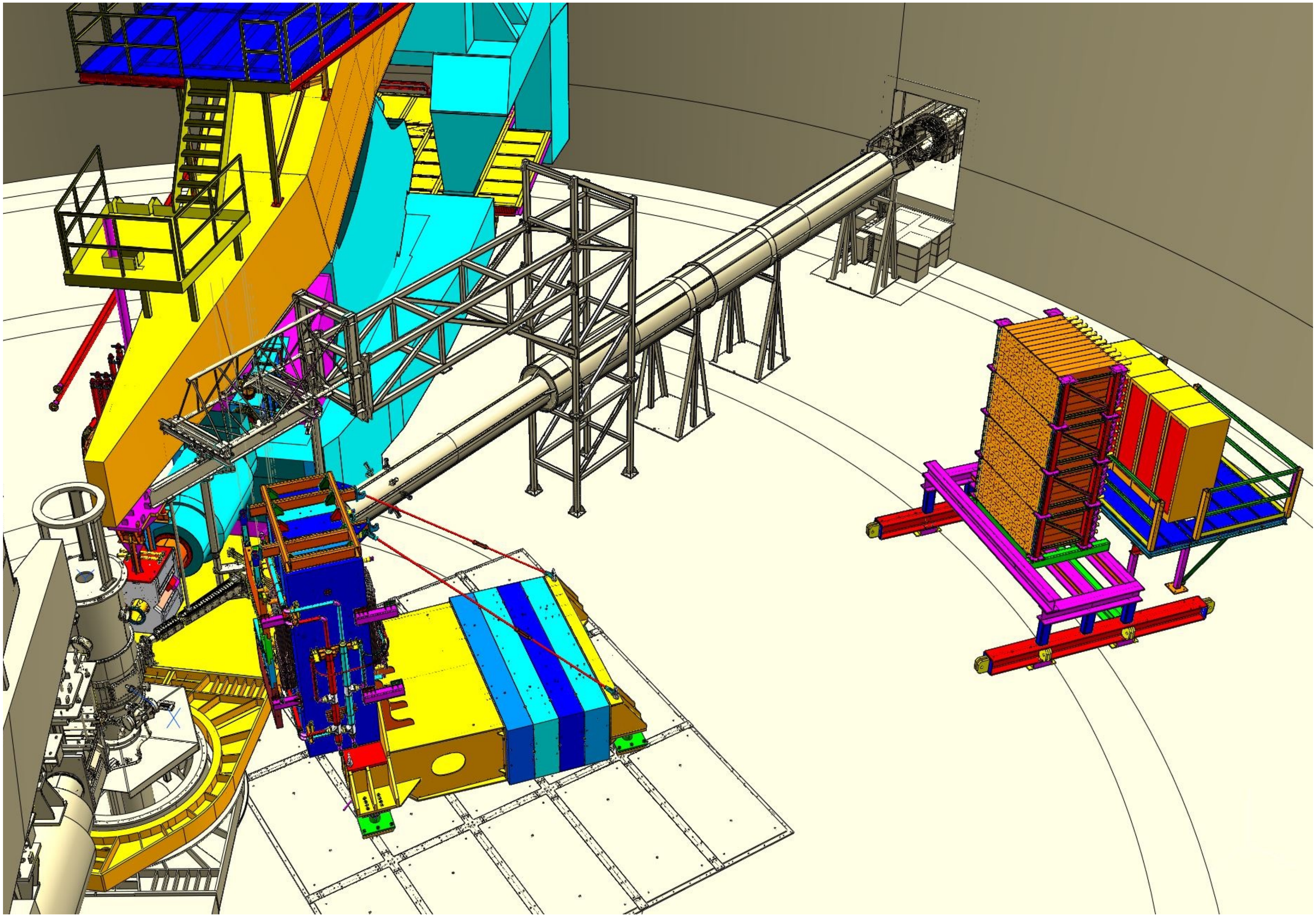
Time-of-flight







SBS neutron arm



SBS neutron arm