

# An Experiment to Search for Light Dark Matter in Low-Energy $ep$ Scattering

Sven Heinemeyer<sup>1</sup>, Yonatan Kahn<sup>2</sup>, Michael Schmitt<sup>2</sup>, Mayda Velasco<sup>2</sup>

<sup>1</sup>*Instituto de Fisica de Cantabria (CSIC-UC), Santander, Spain*

<sup>2</sup>*Northwestern University, Evanston, Illinois, USA*

December 12, 2007

## Abstract

Anomalous production of low-energy photons from the galactic center have fueled speculations on the nature and properties of dark matter particles. In particular, it has been proposed that light scalars may be responsible for the bulk of the matter density of the universe, and that they couple to ordinary matter through a light spin-1 boson. If this is the case, then such particles may be produced in the quasi-elastic low-energy scattering of electrons off protons. We present a proposal for an experiment to search for this process and assess its viability.

~ 2 MeV

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An Experiment to Search for Light Dark Matter  
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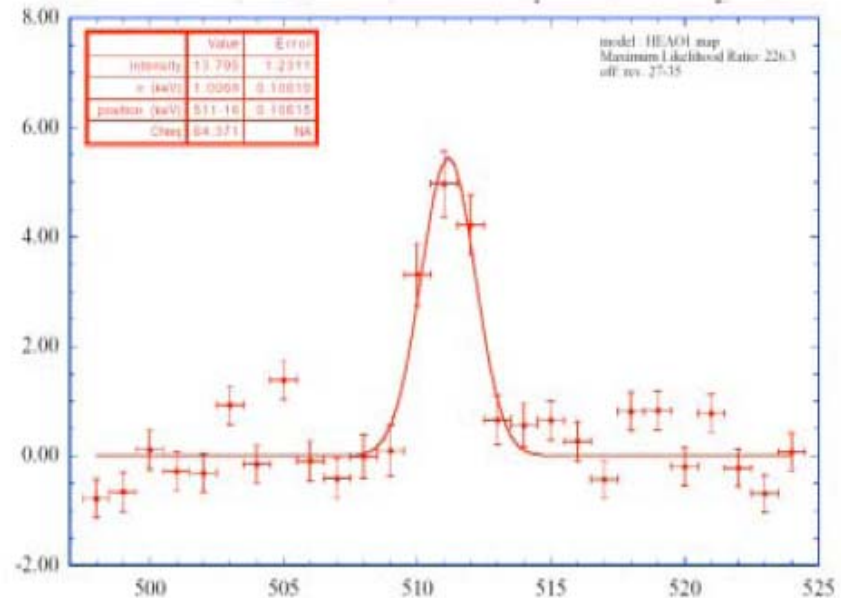
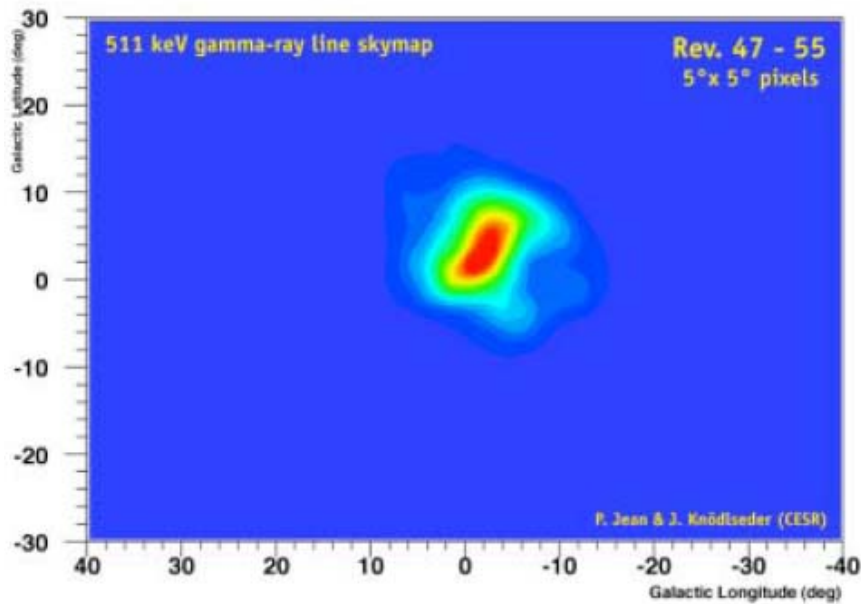
December 12, 2007

~ 50 -100 MeV

**Abstract**

Anomalous production of low-energy photons from the galactic center have fueled speculations on the nature and properties of dark matter particles. In particular, it has been proposed that light scalars may be responsible for the bulk of the matter density of the universe, and that they couple to ordinary matter through a light spin-1 boson. If this is the case, then such particles may be produced in the quasi-elastic low-energy scattering of electrons off protons. We present a proposal for an experiment to search for this process and assess its viability.

# 511 keV radiation from the Galactic Center



INTEGRAL: The International Gamma-ray Astrophysics Laboratory

# Boehm and Fayet, Nucl. Phys. B683 (2004), 219

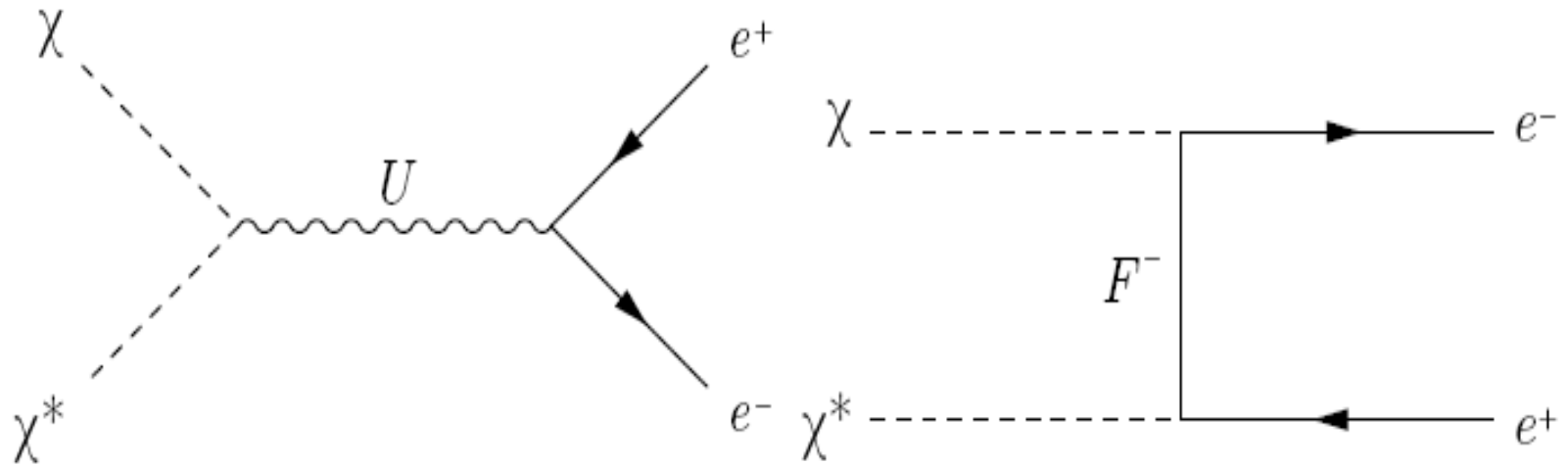


Figure 1: *dark matter annihilation into an  $e^+e^-$  pair, through  $U$ -boson exchange in the  $s$ -channel, and  $F^\pm$ -fermion exchange in the  $t$ -channel*

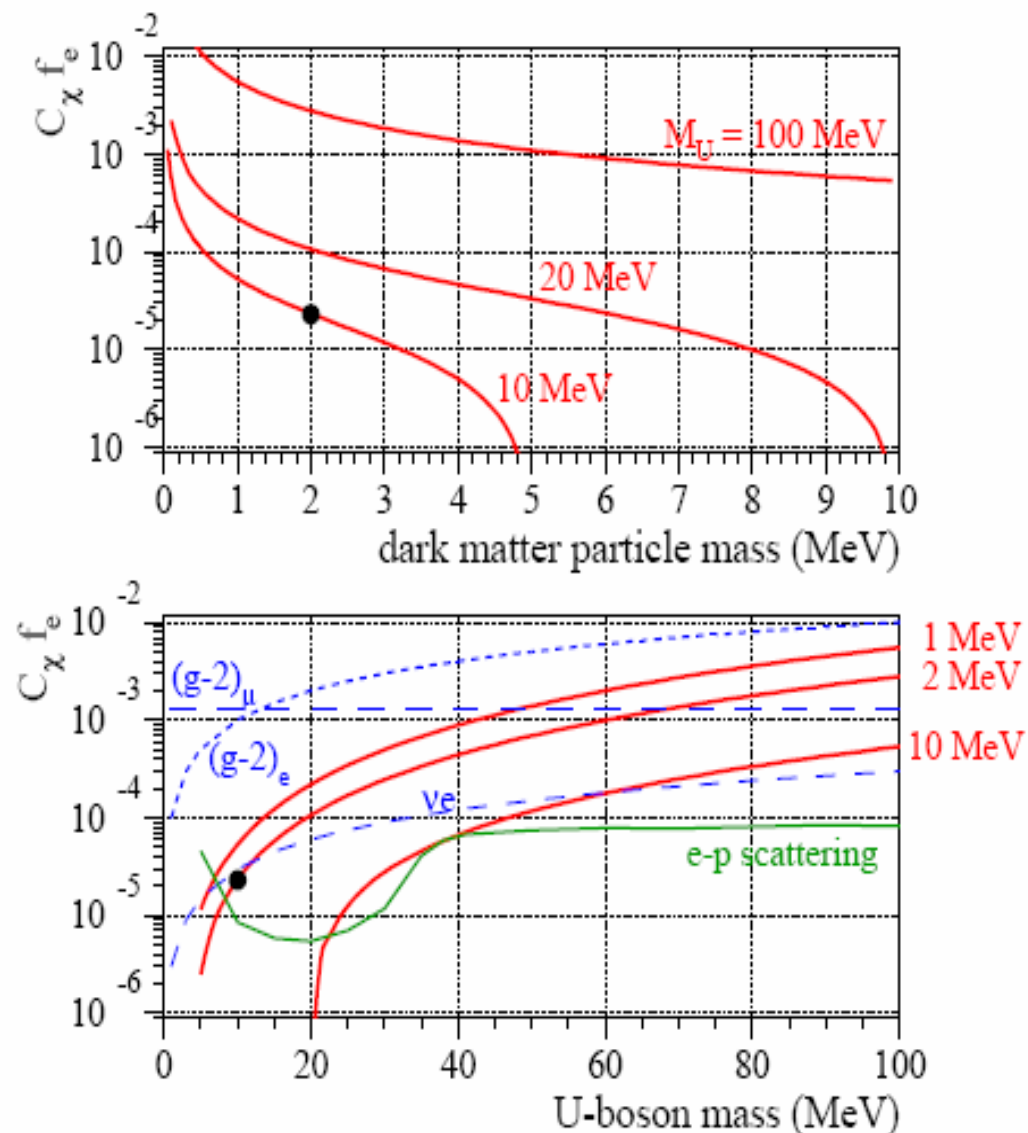


Figure 2: *TOP*: constraints on  $C_\chi f_e$  as a function of  $M_\chi$ , for three values of  $M_U$ . *BOTTOM*: heavy red lines show constraints on  $C_\chi f_e$  as a function of  $M_U$ , for three values of  $M_\chi$ . The thinner dashed blue lines show constraints coming from the measurements of  $(g-2)_\mu$ ,  $(g-2)_e$  and  $\sigma(\nu e)$  (see text), from Ref. [29], and we have set  $C_\chi = 1$ . The hook-shaped green curve indicates the sensitivity of the first experimental design, discussed in Sec. 5.1. The dots indicate our default choice for masses and couplings.

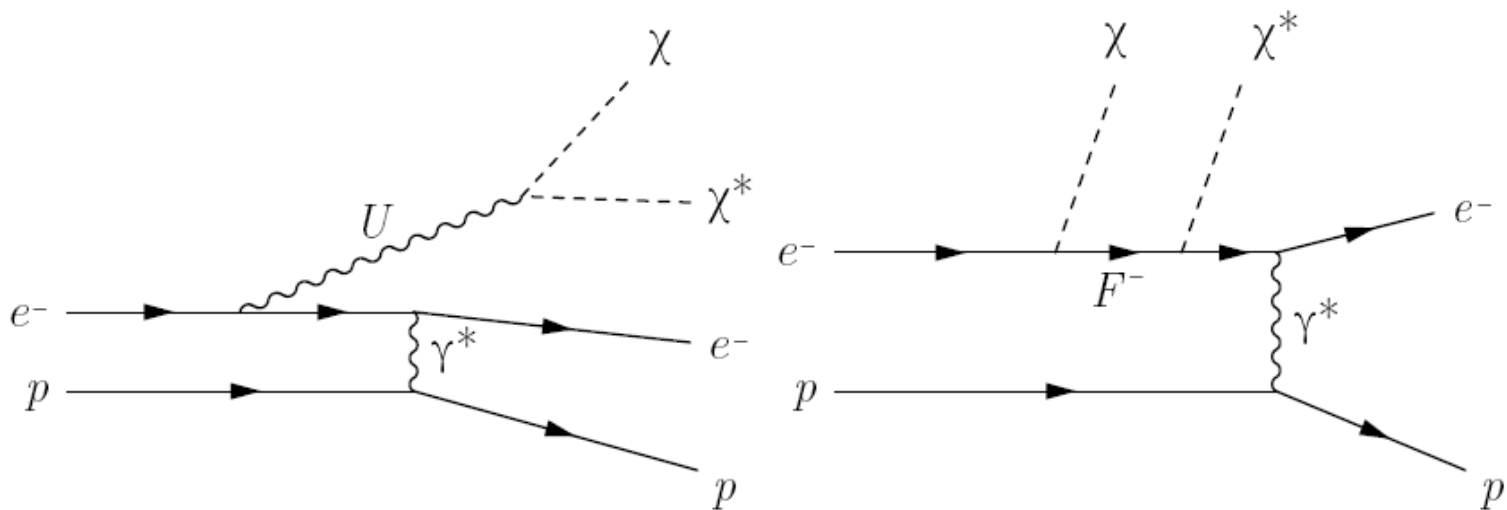


Figure 3: *example Feynman diagrams for the signal process. We consider only the  $U$ -boson diagrams in our estimates; the  $F^\pm$ -fermion diagrams can be neglected.*

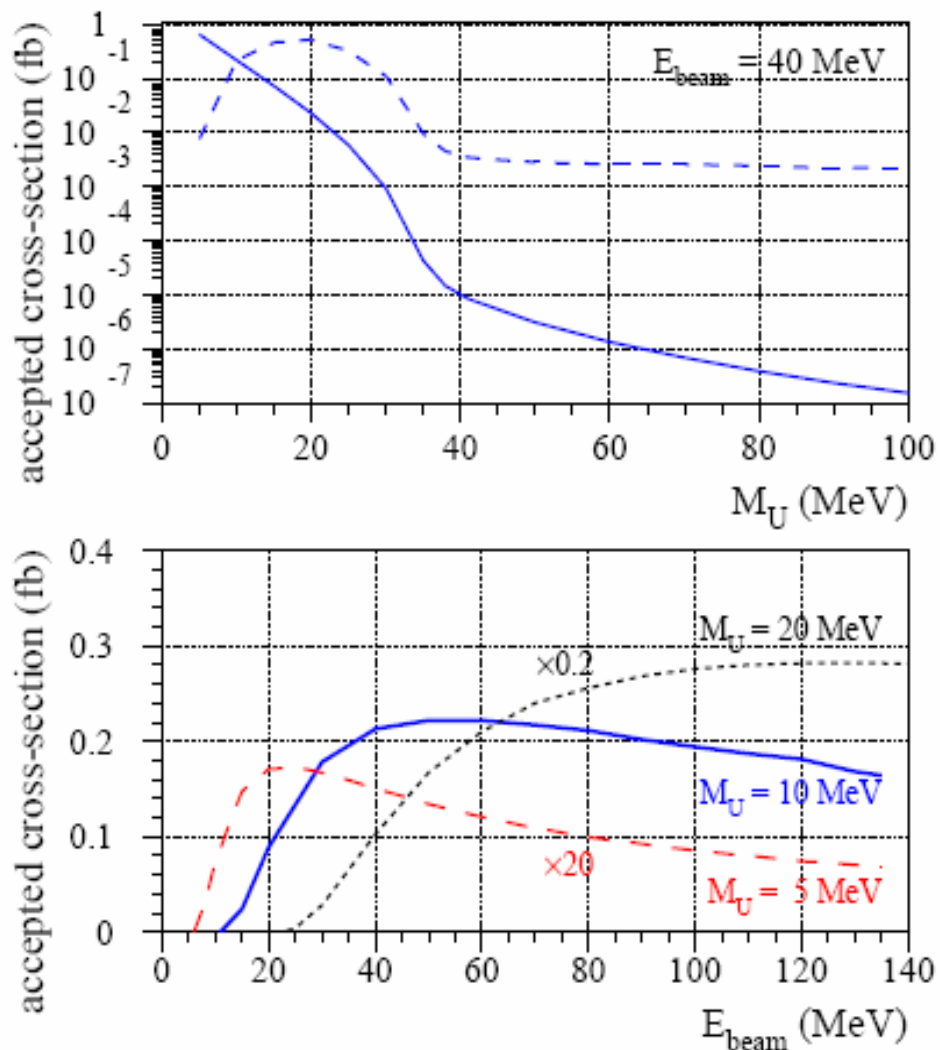


Figure 5: *signal cross-sections.* *TOP:* accepted cross-section as a function of  $M_U$ . The solid line shows the result with a fixed coupling constant, and the dashed line shows the result when the constant varies with mass according to Eq. (1). Here, “accepted” refers to a limited angular range for the scattered electron:  $89.4^\circ < \theta < 90.6^\circ$ . *BOTTOM:* cross-section as a function of the beam energy, for three values of  $M_U$ , as indicated. The curves for  $M_U = 5$  MeV and 20 MeV have been multiplied by factors of 20 and 0.2, respectively.

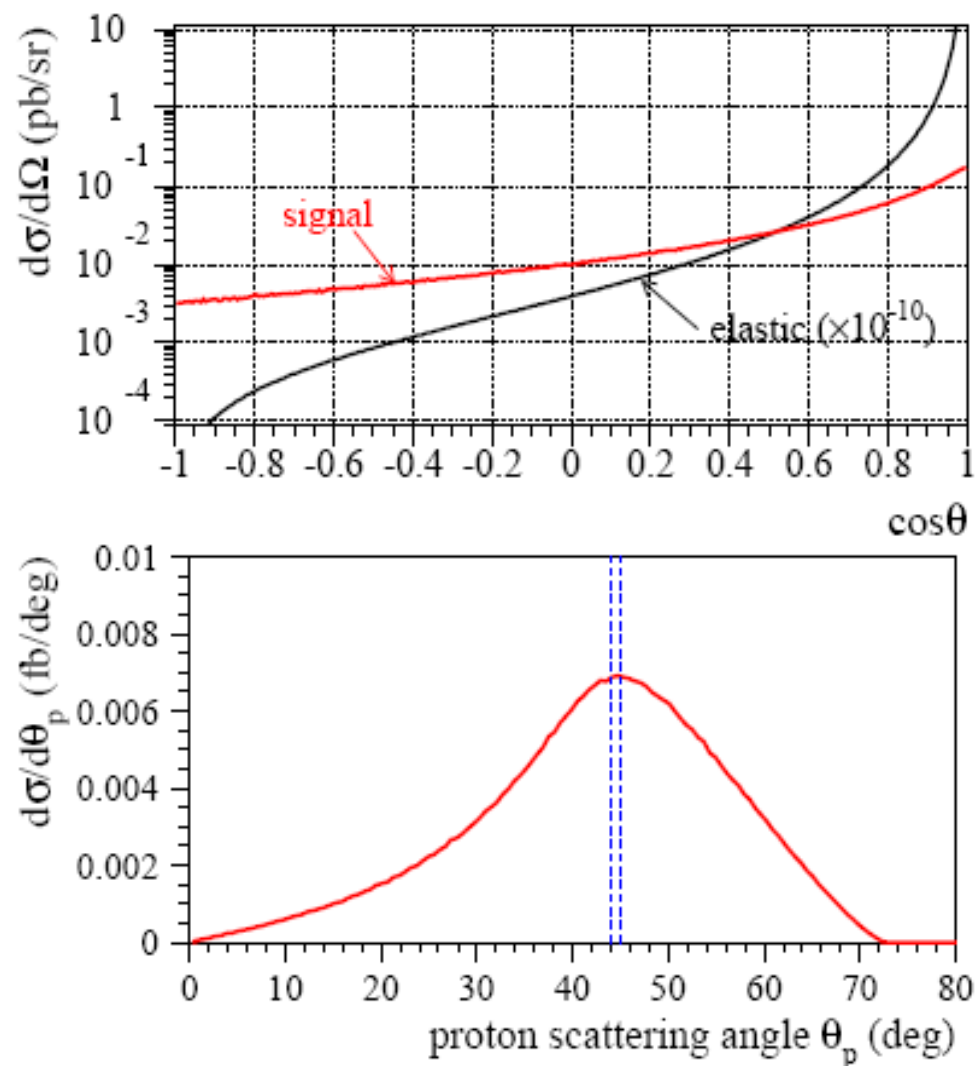


Figure 6: differential signal cross-sections as a function of angles. TOP:  $d\sigma/d\Omega$  plotted as a function of  $\cos\theta$ . The elastic scattering cross-section has been scaled down by a factor of  $10^{-10}$ . BOTTOM:  $d\sigma/d\theta_p$  showing the broad distribution expected for the signal. The vertical dashed lines show the very narrow range expected for elastic scattering even allowing for radiative processes.

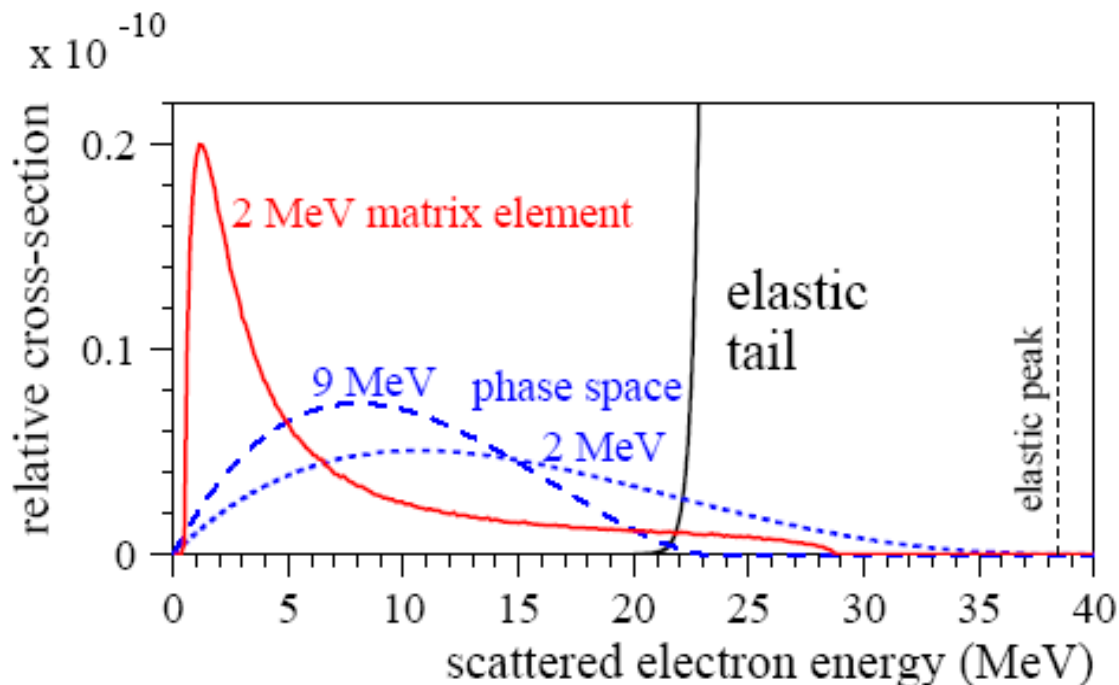


Figure 7: signal shapes compared to a Gaussian centered at  $E' = 38.4$  MeV with an r.m.s. of 6% (see text). Two examples of phase-space distributions are shown, for  $M_\chi = 2$  MeV and 9 MeV (see Sec. 4.3.1). One example of a CompHEP matrix-element calculation is shown, for  $M_\chi = 2$  MeV and  $M_U = 10$  MeV (see Sec. 4.3.2).

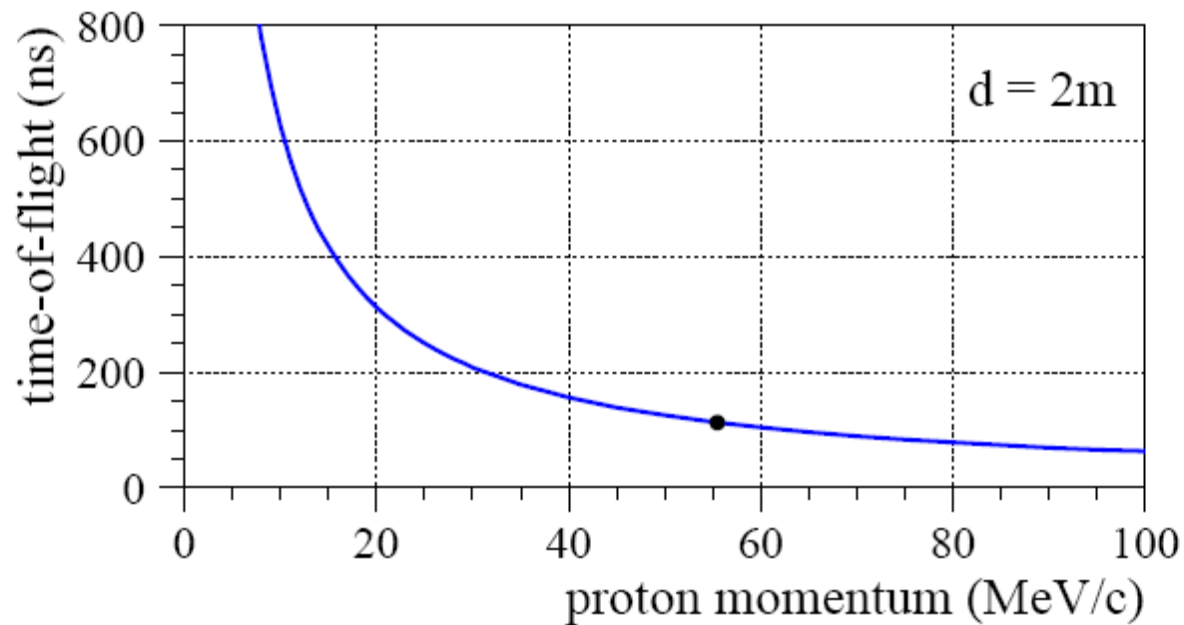


Figure 8: *time-of-flight* for the outgoing proton, when it traverses a distance of two meters. The dot marks the expected momentum for elastic scattering in experimental design I.

# Experimental concept

- Need highest luminosity – looking for rare events
- Low energy ( $\sim$  MeV KE) proton has to make it out of target – thin target
- At  $\sim$  50 MeV with 10 mA intensity – 0.5 GW!
- Energy recovery linac at JLab FEL is ideally matched to experiment
- Target  $\sim 10^{18}$  cm $^{-2}$  - supersonic nozzle
- Luminosity  $\sim 10^{35}$  cm $^{-2}$ s $^{-1}$

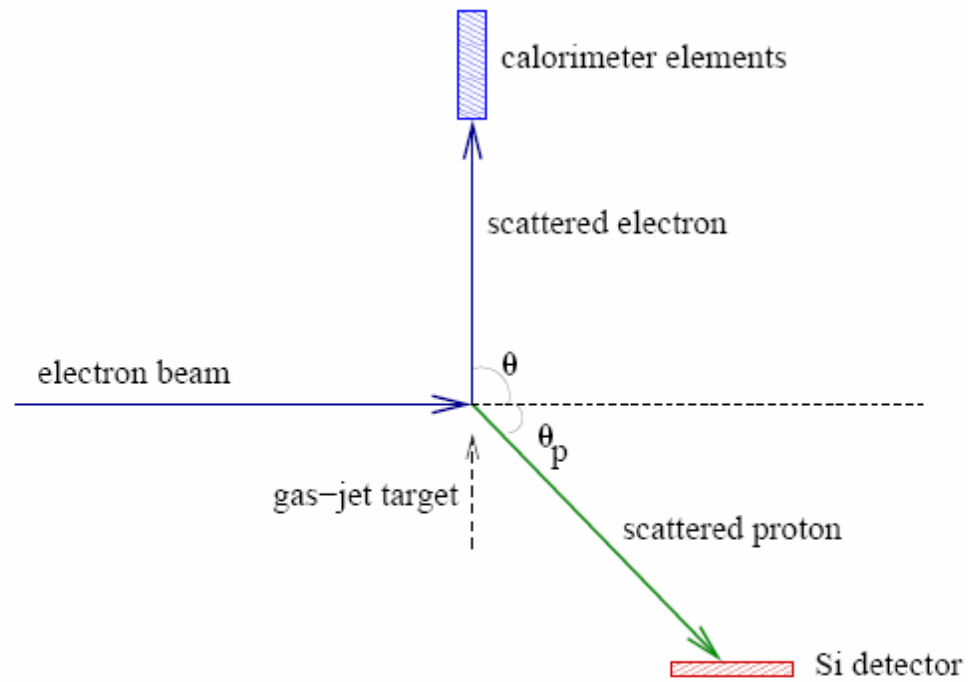


Figure 10: *experimental design I*

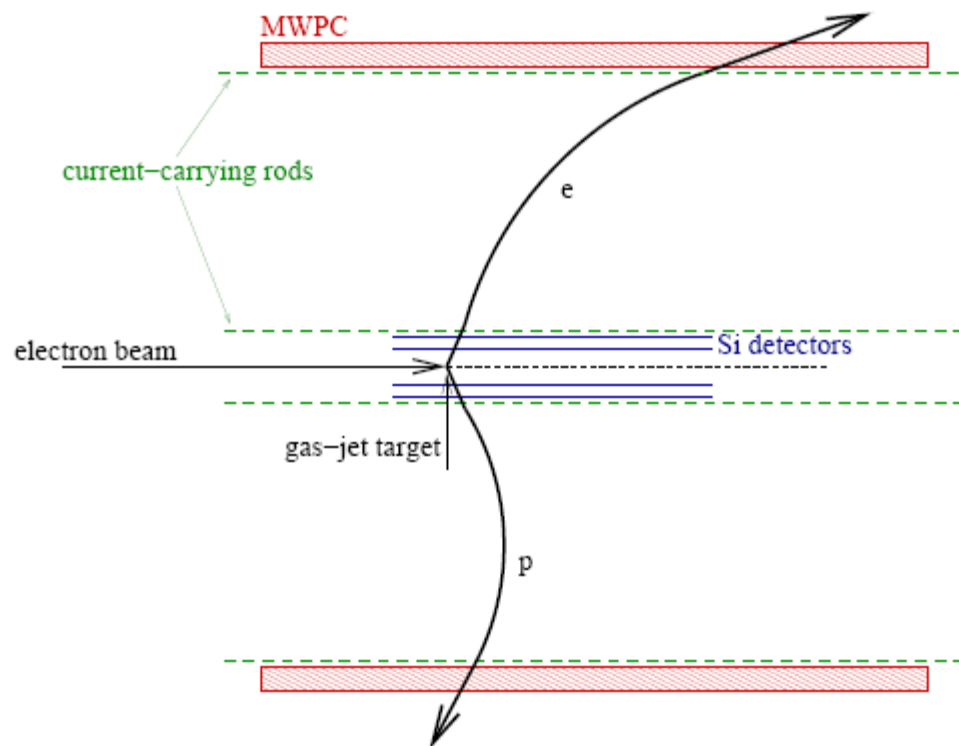
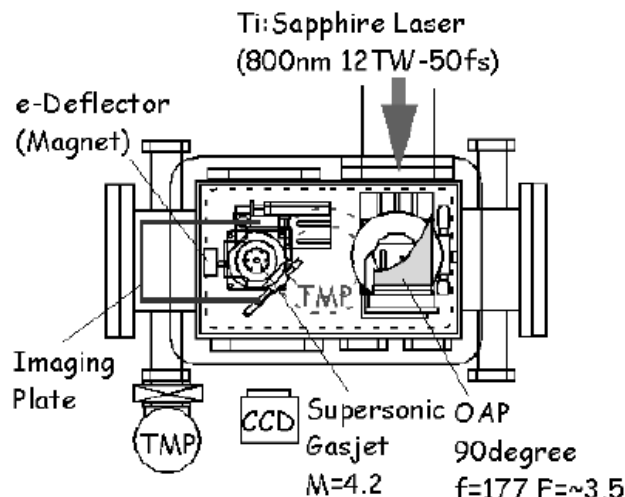


Figure 11: *experimental design II*

# SUPERSONIC GAS JET TARGET FOR GENERATION OF RELATIVISTIC ELECTRONS WITH 12TW-50fs LASER PULSE

T. Hosokai, K. Kinoshita, T. Watanabe, K. Yoshii, T. Ueda, A. Zhidokov, M. Uesaka,  
NERL, University of Tokyo, Tokai, Naka, Ibaraki, 319-1106 Japan  
K. Nakajima, KEK, Tsukuba, Ibaraki, 305-0801 Japan  
M. Kando, H. Kotaki, JAERI Kansai, 8-1Umemidai Kizu, Souraku, Kyoto, 619-0215 Japan



## 4 SUMMARY

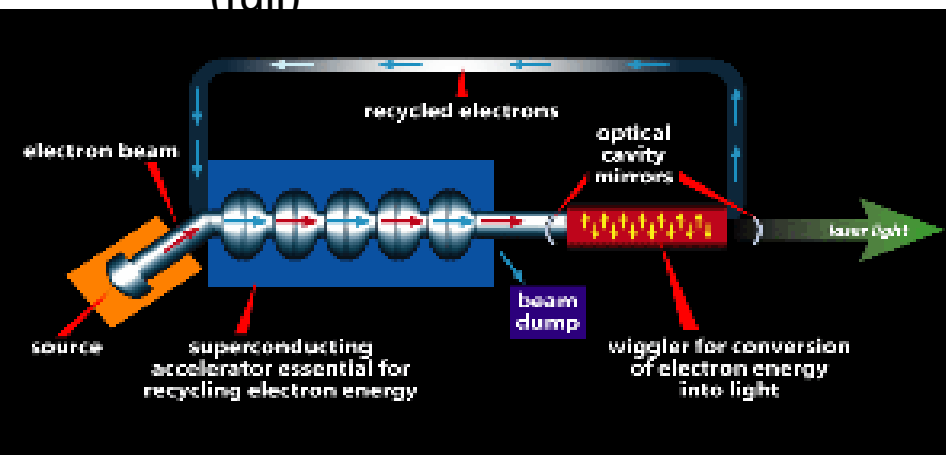
We have designed the supersonic, rapidly expanding conical *Laval* nozzle using the method of characteristics to make a well-defined gas jet target for the relativistic electron generation experiment. The ultra-short laser pulse was focused on the supersonic helium jet in the gas density range from  $7 \times 10^{18}$  to  $3 \times 10^{19} \text{ cm}^{-3}$  with the relativistic intensity of approximately  $1.5 \times 10^{19} \text{ W/cm}^2$ . The energetic electron beams (up to 40MeV) were observed in the forward direction.

Figure 4: Experimental setup for electron generation with the supersonic gas jet and ultra-short laser pulse.



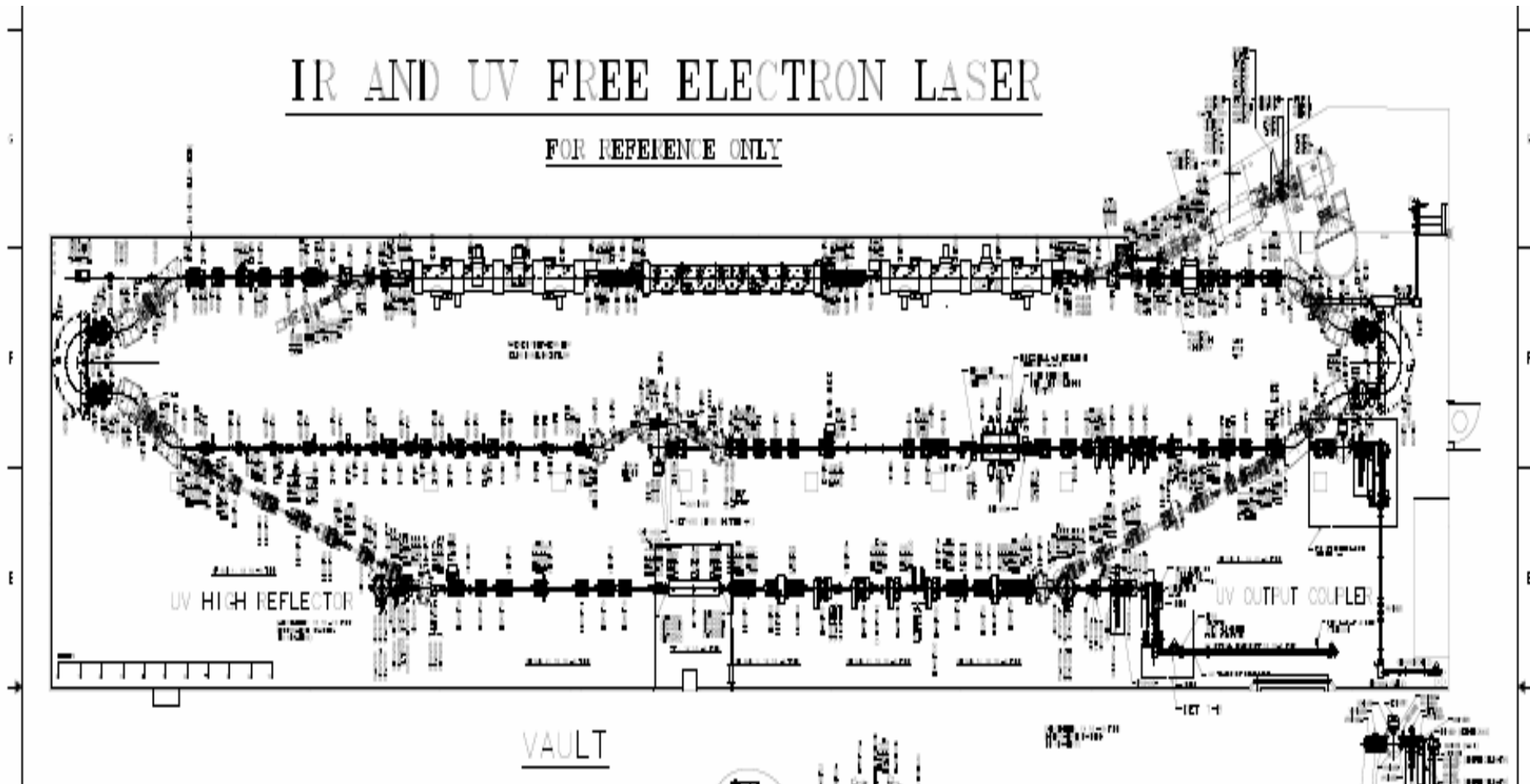
# Jefferson Lab FEL Specifications

Energy (MeV)	80-200	200
Charge per bunch (pC)	135	135
Average current (mA)	10	5
Peak Current (A)	270	270
Beam Power (kW)	2000	1000
Energy Spread (%)	0.50%	0.13%
Normalized emittance (mm-mrad)	<30	<11
Induced energy spread (full)	10%	5%

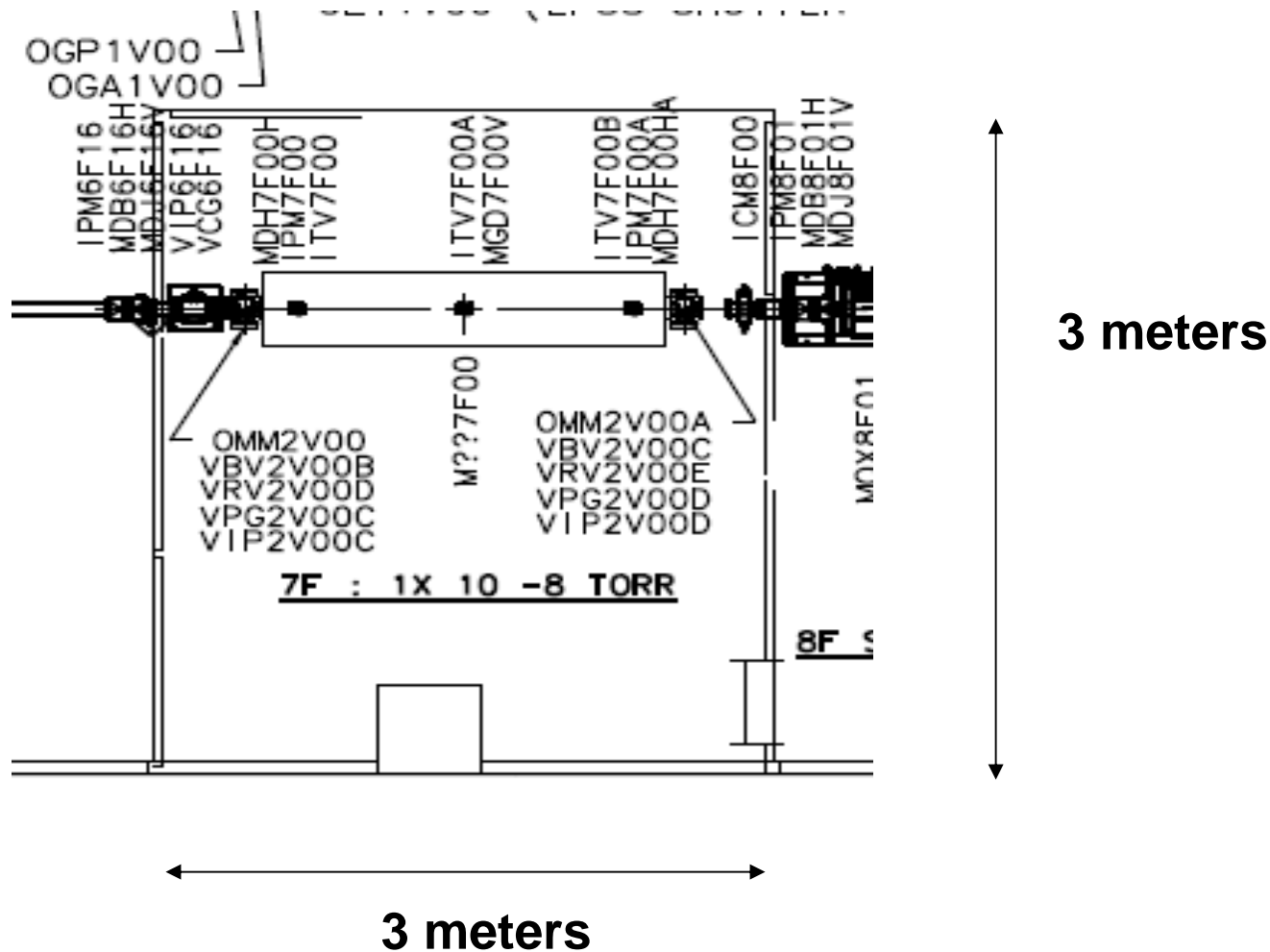


# FEL layout

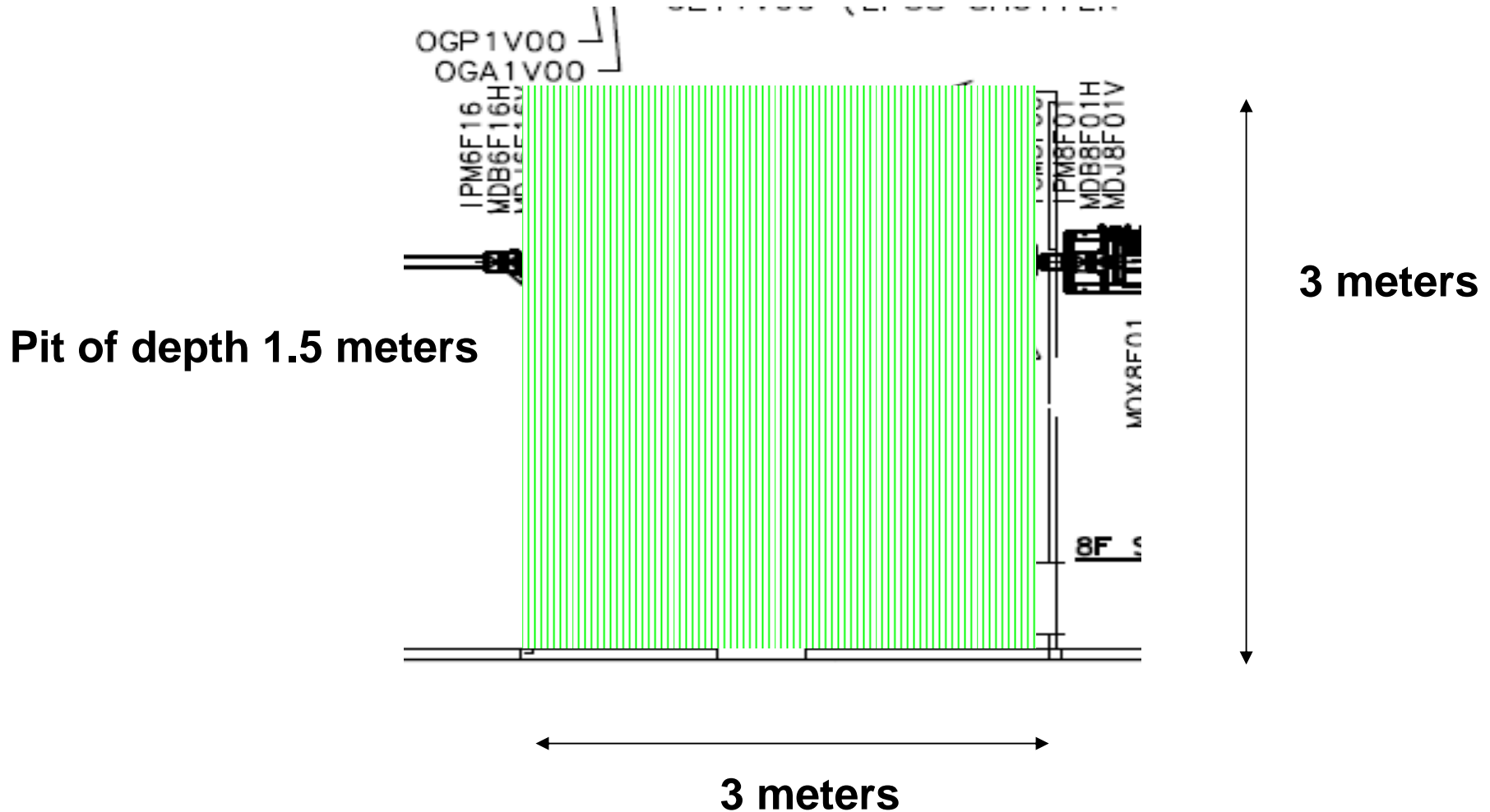
Beamline 60 cm above floor



# Possible location of experiment



# Possible location of experiment



# Summary

- JLab FEL looks like the ideal accelerator
- Experiment as proposed requires looking at cross section at 1 part in  $10^{10}$  !
- At this level, many things matter: radiative corrections,  $Z^0$  exchange etc.
- Is there a trick to amplify the sensitivity?
- Rolf Ent and I have scheduled a meeting at JLab on Tuesday May 2<sup>nd</sup> to discuss the possible experiment.