Proposal to the
University Consortium for a Linear Collider

August 28, 2002

Proposal Name

Negative Ion TPC as the LC main tracker

Classification (accelerator/detector: subsystem)

Detector: main tracker

Personnel and Institution(s) requesting funding

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Project Overview

The novel gas detector technology called Negative Ion TPC (NITPC) is a strong candidate as a main tracker for the Linear Collider. The technique utilizes a special, electronegative gas mixture to transport negative charge from track to endcap in the form of negative ions rather than electrons. The slow drift speed and strong thermalization of the drifting ions result in a number of advantages important for an NLC tracker, listed below. A 1 m^3 NITPC has been working for one year as a directional Dark Matter detector, providing proof that the concept works in practice [1].

We propose to spend one year developing and testing a small prototype, to dispel any doubt that a tracking device can be built with parameters similar to Tables 1 and 2. In year 2 and 3, we propose to advance the concept to a full design.

A NITPC solution could be considered for the so-called Large Detector option for the linear collider (LD), but we feel that it fits best the so-called Small Detector (SD) option[1]. The advantages of the SD are well known and include low cost and relatively low backgrounds. We are unaware of other gas tracker candidates for the SD. One important reasons for the fit is that the NITPC will work unaffected by magnetic fields of up to 6T.

With the slow macro-pulse structure of NLC machines, the slow drift does not incur any penalty from background tracks or track overlap relative to a conventional TPC. A comparison between a large TPC

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[1] We rename the Silicon Detector so as to accomodate the NITPC.

Parameter	Value	Comment
Electron capture cross section	80 MBarn	-
v_d(E=0.2 kV/cm)	430 cm/sec	
v_d(E=0.4 kV/cm)	860 cm/sec	
v_d(E=0.8 kV/cm)	1500 cm/sec	mobility decreasing toward saturation
Diffusion, $\sigma_l \sim \sigma_t$	$0.07\text{mm}\sqrt{L(cm)/E(kV/cm)}$	
Negative Ion stripping mean free path	$\sim 10\mu m$	At $100\mu m$ from wire center
Gain	7700	Sense wire voltage 2730 V

Table 1: He/CS$_2$ 80/20 parameters measured in a mini-NITPC with 9 mm pitch and 5 mm gap n endcap MWPC. From dE/dx to avalanche, we list electron capture probability, drift velocity and diffusion, ion stripping probability, and gain.

and a Small NITPC at TESLA remains favorable (see our NITPC webpage FAQ[2]), once the LD and SD background levels and gas density are taken into account.

We are considering drift gaps as short as 25 cm and as long as one meter and drift fields of order 1 kV/cm. Such fields are well within the E/P envelope which has been studied already in these detectors[3]. The eventual MT would have as few as one segment (radial NITPC in the SD, 50 cm drift) to as many as eight segments (axial NITPC in the LD, 25 cm drift).

In July-August 2002 we measured the properties of an atmospheric pressure electronegative gas mixture, He/CS$_2$ 80/20. The results, shown in Table 1, were so (surprisingly) good that it became immediately apparent that a NITPC could be a strong candidate for linear collider instrumentation. A paper is being prepared that discusses the physics prospects of the NITPC, based on these results.

Here we discuss in more detail the advantages of a NITPC, and why the technique ought to be studied in detail. Four major differences compared to a regular TPC are:

- the drift velocity is very slow (Table 1), allowing a much larger number of samplings along the drift direction, and increasing detector granularity. The low drift velocity also results in small or negligible Lorentz angles, so that all three drift directions (axial, radial, and azimuthal) can be freely considered to obtain the best design.
- transverse *and longitudinal* diffusion remains thermal up to high drift fields (Table 1)
- CS$_2$ is unaffected by trace amounts of other electronegative compounds (oxygen), so that long drift times can be attained.
- sparking is strongly suppressed by the photon and electron quenching properties of the gas. Drift fields of a kV/cm have been produced and maintained in test TPCs using simple, open wire field cages.

There are three aspects that need to be studied carefully in the first year.

- which TPC drift configuration (axial, azimuthal, radial) is best suited for the LC, and with what detailed parameters (drift gap, drift field)?
- which gain and readout structures are best suited for the NITPC (wire planes, GEM or Micromegas)?
- with the very small FADC occupancies we expect, can we adopt novel, low mass detector planes?

Both momentum resolution and background tolerance depend on the parameter $\sigma/\sqrt{N}$, where σ is the detector resolution and N is the number of samples along the track. σ depends on many parameters, including B-field effects (which can both increase and decrease the resolution), electronic noise, longitudinal and transverse diffusion, longitudinal and transverse sampling, multiple scattering, and pad

Parameter	Classic TPC	NITPC	Comment
z-samples(1/m)	1000	105000	NITPC low drift velocity
r-samples(1/m)	200	333	-
θ-samples(1/m)	400	333	-
N (1/m)	200	2400	r-samples for TPC, N_e for NITPC
diffusion, $< \sigma_t >$ (μm)	400	270	$< \sigma_t >= (2/3)\sigma_{max}$
diffusion, $< \sigma_l >$ (μm)	$>> 400$	270	-
Random triplets	0	?	-
TPC surface charge (nC)	0.4	5	space charge distortion par.
TPC cage	N/A	N/A	thicker in NITPC
Detector membranes	0	0.3% X_0	for perp. tracks
Endcap material	N/A	0.3% X_0	No endcaps in NITPC
NLC background density (a.u.)	1	0.05	lighter gas mixture and lower bkg. rates
TESLA background rate (a.u.)	0.05	0.03	

Table 2: A comparison of parameters of a state-of-the art TPC[5] and a preliminary design for the NITPC. For the purpose of comparison, an axial NITPC is considered with 40 cm segments. For the last two rows (background rates), the comparison is between a LD RTPC and a SD NITPC.

size. The NITPC holds an uncontroversial advantage over a RTPC in longitudinal sampling (2 orders of magnitude) and longitudinal diffusion (roughly one order of magnitude), Table 2.

N is usually the number of pads illuminated by a track. In the case of the NITPC, the low drift velocity and high gain (Table 1) conspire to make it possible to detect each ion individually[4], Table 2, effectively recovering maximal information. Note that the electronic noise contributions do not increase much, as this chamber counts electrons as opposed to measuring charge.

The introduction of detector planes inside the tracking volume would increase multiple scattering and photon conversion (both signal and background) and so it needs to be further studied. It is clear that conventional TPC pad arrays can not be used as they imply too much material (one amplifier and one cable per pad). Depending on the actual dimensions, drift field and speed, and diffusion, such planes may not in fact be required.

We stress that a novel detector plane will be a major part of the hardware R&D, as we make this powerful technology available to particle physicists. We also note that the two-layer strip detector we propose below has already been built (by a CERN-College de France collaboration) in a microstrip version[6]. With a NITPC already operating, a radial TPC already operating[7], and a double-strip plane already built, there is nothing totally untested in our idea.

As a starting point we consider an "astrophysics-style" detector planes such as that of Ref.[8]. It has the customary grid dividing the drift region from the gain region, one set of wires and one set of pickup strips. It lacks field wires (replaced by an appropriate voltage difference between strips and wires) and the electronics is located at the rim of the detector plane. There is no gating grid[2].

The system reduces detector plane material dramatically but introduces hit ambiguities. We introduce the strip system sketched in Fig. 1, with a chessboard pad pattern and daisy-chaining along the diagonals, so that a hit becomes an unambiguous triplet. The system will work due to the very low FADC occupancy we expect.

By now we have received many comments about the possible problems encountered by a NITPC at a linear collider. Please see the NITPC FAQ[2] for more details. The major ones are summarized as follows:

- **the NITPC will observe more backgrounds than a RTPC at TESLA due to the slow drift.** If the NITPC is a Small Detector, then the NITPC will see less backgrounds than a RTPC, whether at TESLA or NLC. The one difference is that at the NLC the difference is of order 20,

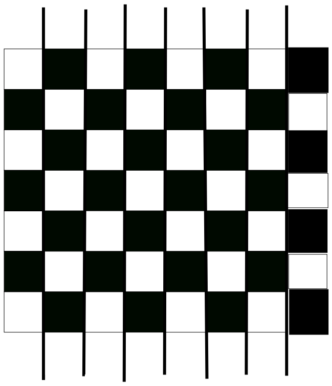

Figure 1: The detector surface layout scheme. The wires are strung vertically, and readout pads are daisy-chained to form strips. Black pads are chained along the NE-SW diagonals, and white pads are daisy-chained along the NW-SE diagonals.

at TESLA only a factor of two or less. Please see the NITPC FAQ[2]. On top of that, we expect a granularity two orders of magnitude better than a RTPC (Table 2) which will increase the background tolerance substantially.

- **the higher gain and backgrounds will result in higher space charge.** Obviously if a GEM scheme is ultimately adopted, space charge will not be a problem. But even without GEM, the NITPC is far more resistant to space charge than a RTPC, by about a factor of 30[2].
- **the NITPC has too much material.** We agree that RTPC detector planes inside the tracking volume would be unacceptable, but this device will have novel, low-mass detector planes with the two biggest offenders (pads and sense wires) removed. We note that multiple scattering errors are expected to be non-dominant at the LC, and that the excellent dE/dx resolution afforded by single electron detection will help identify pairs in dense jets (an advantage not present in silicon detectors). Most important, we expect the material in this device to compare favorably with the silicon detectors considered for the SD.

The challenges facing a NITPC (those that are certifiably harder in a NITPC than in a RTPC) include detector plane alignment and careful design of the drift and gain electric field. These will be addressed as our simulations progress.

FY2003 Project Activities and Deliverables

In Year 1 we will build a small device, of order one liter volume. The device will confirm that single electron detection, and low mass, chessboard-like detector planes can be built and operated.

FY2004-2005 Project Activities and Deliverables

In year 2 we will perform a series of tests, including operating the device in high background conditions (provided by firing a X-ray tube when a cosmic trigger is generated) and in high magnetic fields. We will also test other electronegative gases which are known to have high gain. In year 3 a full design effort will be undertaken which will address alignment issues.

Budget justification

In years 1, we will need the equipment and material money to build the mini-TPC. In Year 2, material and travel money is increased as we test the chamber extensively. In year 3, a postdoc position is requested to run design software as well as extensive simulations.

Three-year budget, in then-year K$

Institution: Wayne State University

Item	FY2003	FY2004	FY2005	Total
Other Professionals	0	0	0	0
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	0	0	0	0
Fringe Benefits	0	0	0	0
Total Salaries, Wages and Fringe Benefits	0	0	0	0
Equipment	0	0	0	0
Travel	2	2	2	6
Materials and Supplies	0	0	0	0
Other direct costs	0	0	0	0
Total direct costs	0	0	0	0
Indirect costs	1	1	1	1
Total direct and indirect costs	3	3	3	9

Institution: Temple University

Item	FY2003	FY2004	FY2005	Total
Other Professionals	0	0	46	46
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	0	0	46	46
Fringe Benefits	0	0	12	12
Total Salaries, Wages and Fringe Benefits	0	0	58	58
Equipment	18	9	0	27
Travel	2	5	2	6
Materials and Supplies	5	10	0	15
Other direct costs	0	0	0	0
Total direct costs	25	24	60	109
Indirect costs	4	8	30	42
Total direct and indirect costs	29	32	90	151

References

[1] D.P. Snowden-Ifft, C. J. Martoff and J.M. Burwell, Phys.Rev.D61:101301,2000

[2] http://motor1.physics.wayne.edu/∼schrein/science/nitpc.htm

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[4] Bonvicini, Hellaz Note 5, March 1993.

[5] D. Karlen, private communication and Tracking Group Review Talk, NLC Meeting, Santa Cruz, June 28, 2002, http://www.physics.carleton.ca/∼karlen/lc/santacruz.pdf.

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[7] G. Agakishiev *et al.*, Nucl. Phys. A661: 673, 1999.

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