OUTLINE

I. SCIENTIFIC MOTIVATIONS

II. SUBGROUP PLANS

[ DISCUSSION ]
I. SCIENTIFIC MOTIVATIONS

• We are privileged to work at a time when this cartoon is not so far-fetched.

• How did we get here?
A Tale of Two Standard Models

Particle Physics

Cosmology

\[ \Omega_i = \frac{\rho_i}{\rho_{\text{CRITICAL}}} \]
\[ \Omega_{\text{TOTAL}} = 1 \]

~ 10^{-17} \text{ cm} \quad \sim 10^{28} \text{ cm}

(Cf. 1998: \( \Omega_{\Lambda} = 0? \quad \Omega_{\text{CDM}} = 0.2 - 0.6 \))
Synthesis

• Together these Standard Models pose grand fundamental questions:
  What is dark energy?  What is dark matter?
  Why is there a matter/anti-matter asymmetry?

• These enhance and sharpen the search for the Higgs boson, supersymmetry, extra dimensions…

• Both particle physics and cosmology are required to find the answers.

• We seek to explore what a Linear Collider will bring to this enterprise. Some examples…
Dark Matter

• Dark matter $\rightarrow$ a new stable particle $\chi$. Number density $n$ determined by

$$\frac{dn}{dt} = -3Hn - \langle \sigma v \rangle \left[ n^2 - n_{eq}^2 \right]$$

Dilution from expansion

\[ \chi\chi \rightarrow f\bar{f} \quad f\bar{f} \rightarrow \chi\chi \]

• Initially, $\langle \sigma v \rangle$ term dominates, so $n \approx n_{eq}$.

• Eventually, $n$ becomes so small that the dilution term dominates and the co-moving number density is fixed (freeze out).
WIMPs

- Weakly-interacting particles with weak-scale masses give observed $\Omega_{\text{DM}}$

- Either
  - a devious coincidence,
  or
  - a strong, fundamental, and completely independent motivation for new physics at the electroweak scale

- Universe cools, leaves a residue of dark matter with $\Omega_{\text{DM}} \sim 0.1 \left(\frac{\sigma_{\text{Weak}}}{\sigma}\right)$
LC as Dark Matter Laboratory

- The LHC and LC will discover WIMPs and determine their properties.

- Consistency of

  WIMP properties (particle physics)
  WIMP abundance (cosmology)

leads to an understanding of our Universe at

\[ T = 10 \text{ GeV}, \quad t = 10^{-8} \text{ s.} \]
Big Bang Nucleosynthesis

- We’ve seen this before:
  - Consistency of light element properties (nuclear physics) and light element abundances (astrophysics) leads to an understanding of our Universe at $T = 1 \text{ MeV}, t = 1 \text{ s.}$
- Dark matter studies may extend our knowledge by 8 orders of magnitude in time.
Particle/Cosmo Interface

Collider Inputs

Weak-scale Parameters

$\chi \chi$ Annihilation
$\chi N$ Interaction

Relic Density
Indirect Detection
Direct Detection

Astrophysical and Cosmological Inputs
An example: Neutralinos

In more detail: Pandora’s box! Neutralino annihilation is sensitive to many processes. For example:

\[
\chi \rightarrow f \bar{f}, \quad \chi \rightarrow W^- W^+, \quad \chi \rightarrow \tau \gamma
\]

Requires precise knowledge of \( \chi \) mass and Sfermion masses, \( \chi \) gaugino-ness, and \( \Delta m \) to ~ few GeV.
Neutralinos at Colliders

- $\chi$ mass measured through kinematics.

- $\chi$ gaugino-ness measured through polarized cross sections.

- Model-independent determination of $\Omega_\chi$ to a few %: challenging but possible at LHC/LC.
Questions

• Axions will escape the LC.

• Superheavy candidates will escape the LC.

• But can the LC carry out this program for all WIMPy candidates (and distinguish the various possibilities)?
  Neutralino dark matter
  Kaluza-Klein dark matter
  Scalar dark matter
  SuperWIMP dark matter
  Branon dark matter
  …
Baryogenesis

- BBN and CMB have now determined the baryon content of the Universe:

\[ \Omega_B h^2 = 0.024 \pm 0.001 \]

- The observed matter/anti-matter asymmetry requires

  Baryon number violation
  CP violation
  Out-of-equilibrium period

- The Standard Model of particle physics cannot generate the observed asymmetry; new physics is required.
Electroweak Baryogenesis

- Many scenarios for baryogenesis rely on physics at the GUT scale. In these cases the LC will have little to add.

- However, an attractive and testable possibility is that the asymmetry is generated at the weak scale.

- E.g., in supersymmetry, sufficient asymmetry is generated for
  - light Higgs
  - Light top squark
  - large CP phases.
  Promising for LC!

Quiros (2001)
Baryogenesis Parameters at the LC

- Top squark parameter constraints for 10 fb$^{-1}$ using $e^{-}_{R,L} e^{+}$ → stop pairs

- CP phase constraints using chargino/neutralino masses and cross sections

Bartl et al. (1997)

Barger et al. (2001)
Questions

• How well can we determine $\Omega_B$ in this scenarios?

• Are there other weak-scale scenarios the LC can explore?

• Does the LC have anything to say about GUT-scale baryogenesis/leptogenesis?
Cosmic Rays

- Cosmic rays observed with energies $\sim 10^{19}$ eV imply $E_{\text{CM}} \sim 100$ TeV in collisions with nucleons.

- $E_{\text{CM}}$ higher than any man-made collider.

- Cosmic rays are already exploring energies above the weak scale!
Cosmic Rays

**Drawbacks:**

- Miniscule luminosities.
- Event reconstruction sparse and indirect.
- Colliders may help interpret upcoming ultrahigh energy data.

Event starts here
The GZK Paradox

• Protons with $\sim 10^{20}$ eV energies quickly lose energy through
  $$p \gamma_{\text{CMB}} \rightarrow n \pi^+$$
  so must be emitted from nearby, but no local sources found.

• Solutions:
  
  Bottom-up: e.g., CRs are gluino-hadrons.

  Top-down: CRs result from topological defect decays, should
  produce up-going cosmic neutralinos if SUSY exists.

• Many testable predictions for colliders.
Dark Energy, Inflation

- Without a single plausible solution to the cosmological constant problem, it is hard to be concrete.

- Nevertheless, thorough exploration of the Higgs boson(s) and Higgs potential may give insights into scalar particles, vacuum energy.

- Ideas welcome!
II. SUBGROUP PLANS

The charge from Jim Brau and Mark Oreglia:

1. Form working group in ALCPG framework

2. Determine and prioritize topics with potential connections

3. Produce white paper on 1 year time scale
Group Organization

Editorial Committee: Marco Battaglia, Jonathan Feng*, Norman Graf, Michael Peskin, Mark Trodden*

*Co-chairs

- We have personally contacted all respondents to the initial announcement and are inviting many others to join the effort (~ 60 so far).

- International participation encouraged.

- We anticipate an author list consisting of active participants.
Questionnaire

• If you would like to participate, please fill out the following questionnaire (available at http://www.physics.syr.edu/~trodden/lc-cosmology) and send it to us.

• About the LC and astrophysics/cosmology study:
  __ I am interested in receiving email. I don't promise to do any work.
  __ I have done work relevant to this topic. Please read it! (list:)
  __ I would like to start a project on ...
  __ I would like to give a talk (maybe only with speculative or preliminary results) at the ALCWG meeting at SLAC in January.
  __ I cannot make it to SLAC in January, but I would like to give a talk at a future meeting.
Topics and Meetings

• Dark matter, baryogenesis, cosmic rays, dark energy and inflation. Others? We are actively soliciting advice regarding relevant topics and papers.

• We expect studies to include LHC and other experiments as relevant for LC prospects.

• 1st meeting: SLAC ALCPG Meeting, 7-10 January 2004, with ~10 parallel talks and a brief organizational session.

• All talks welcome, even if on preliminary results. In addition, we plan to assign some speakers thorny topics (e.g., “The LC and Dark Energy”).
White Paper

• The particle physics/cosmology connection is of growing interest to researchers, policy makers, and the general public. (See www.interactions.org, “Hot Topics”.)

• The Turner report, *Connecting Quarks with the Cosmos*, received a lot of attention.

• This role of all accelerators in exploring this connection is worth highlighting. A new HEPAP Committee, chaired by Persis Drell, will do exactly this.

• We aim to produce a white paper focused on the LC that states this case in a clear and balanced way. We expect this document to be ~ 50 pages long, summarize both old and new work, and target an audience of particle physicists, astrophysicists, cosmologists, and astronomers.
Timeline

• November, December 2003: solicit contributors, define topics.

• January 2004: Parallel sessions at ALCPG Meeting, SLAC. Main topics defined, most of the active contributors on board.

[April 2004: Possible meeting at LCWS 04, Paris.]

• July 2004: Parallel sessions at ALCPG Meeting, Victoria. Contributions finalized.

• September 2004: White paper submitted to ALCPG Executive Committee.
Contact Information

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