Connections to Astrophysics and Cosmology

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Linear Collider Seminar
Thursday, 6 November 2003
blueox.uoregon.edu/~lc/alcpg/webcast/

images: NASA, N.Graf

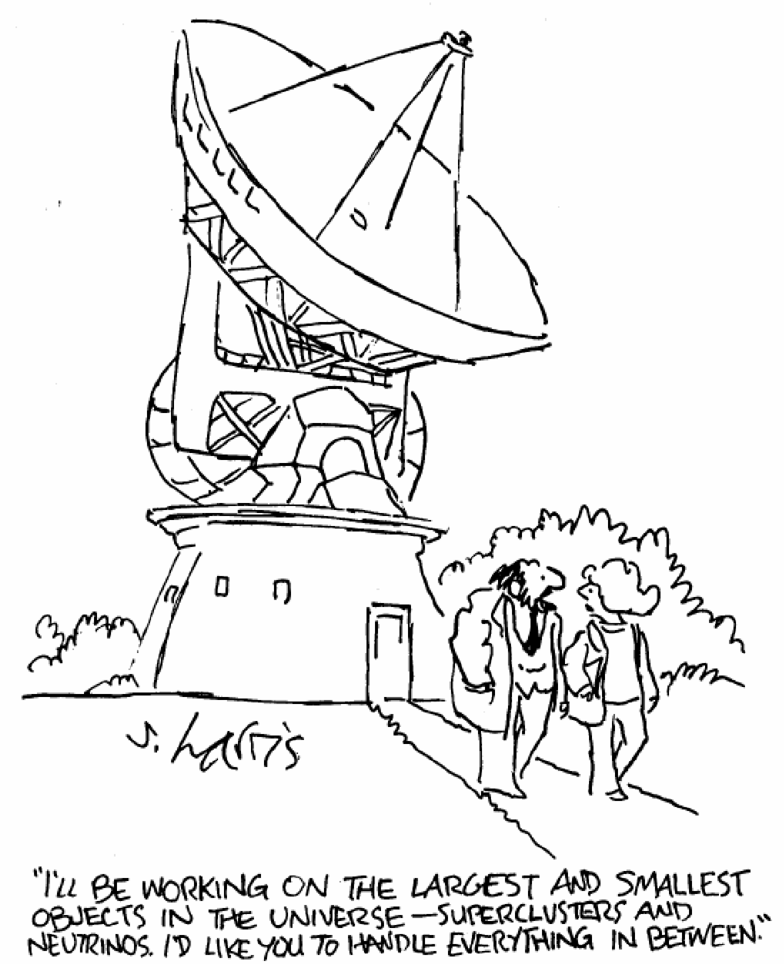
OUTLINE

I. SCIENTIFIC MOTIVATIONS

II. SUBGROUP PLANS

[DISCUSSION]

I. SCIENTIFIC MOTIVATIONS

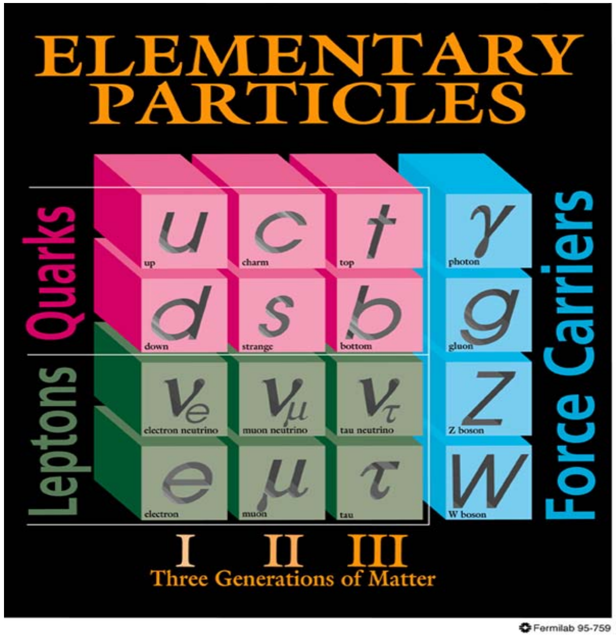


- We are privileged to work at a time when this cartoon is not so far-fetched.

- How did we get here?

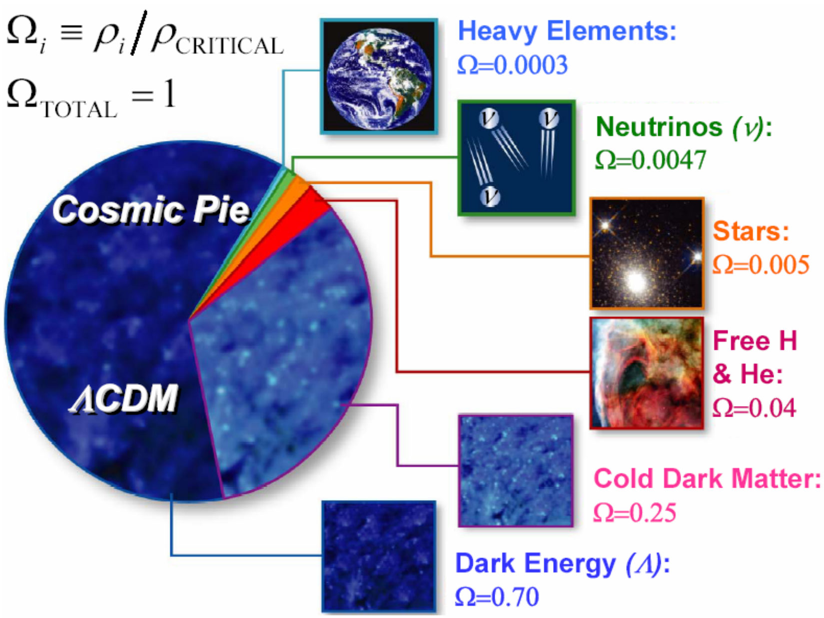
A Tale of Two Standard Models

Particle Physics



~ 10^{-17} cm

Cosmology



~ 10^{28} cm

(Cf. 1998: $\Omega_\Lambda = 0$? $\Omega_{\mathrm{CDM}} = 0.2 – 0.6$)

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

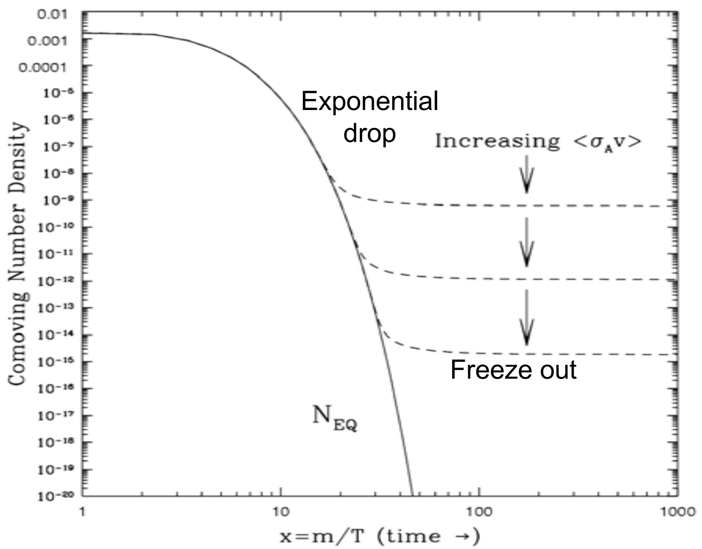
- Dark matter → a new stable particle χ.
  Number density *n* determined by

$$\frac{dn}{dt} = \underbrace{-3Hn}_{\text{Dilution from expansion}} - \langle \sigma v \rangle \left[\underbrace{n^2}_{\chi\chi \to f\bar{f}} - \underbrace{n_{\text{eq}}^2}_{f\bar{f} \to \chi\chi} \right]$$

- Initially, <σ*v*> 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



- Universe cools, leaves a residue of dark matter with $\Omega_{DM} \sim 0.1\ (\sigma_{Weak}/\sigma)$

- Weakly-interacting particles with weak-scale masses give observed Ω_{DM}

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

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 GeV, t = 10^{-8} s.

Big Bang Nucleosynthesis

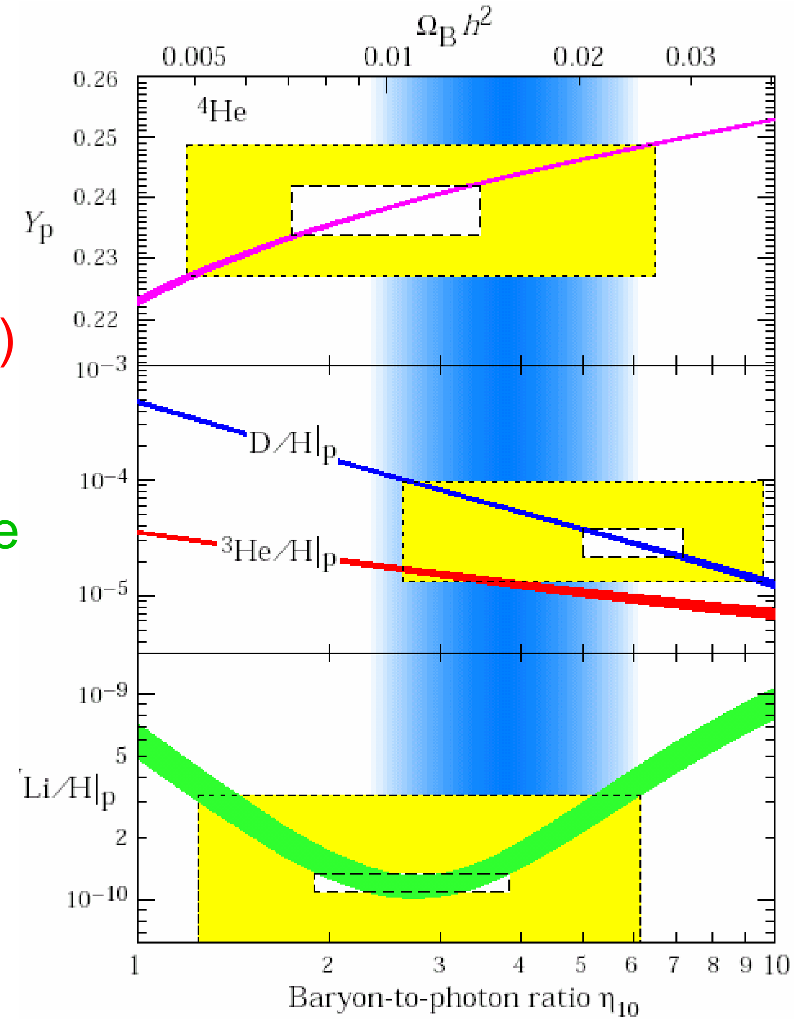
- We've seen this before:

  Consistency of

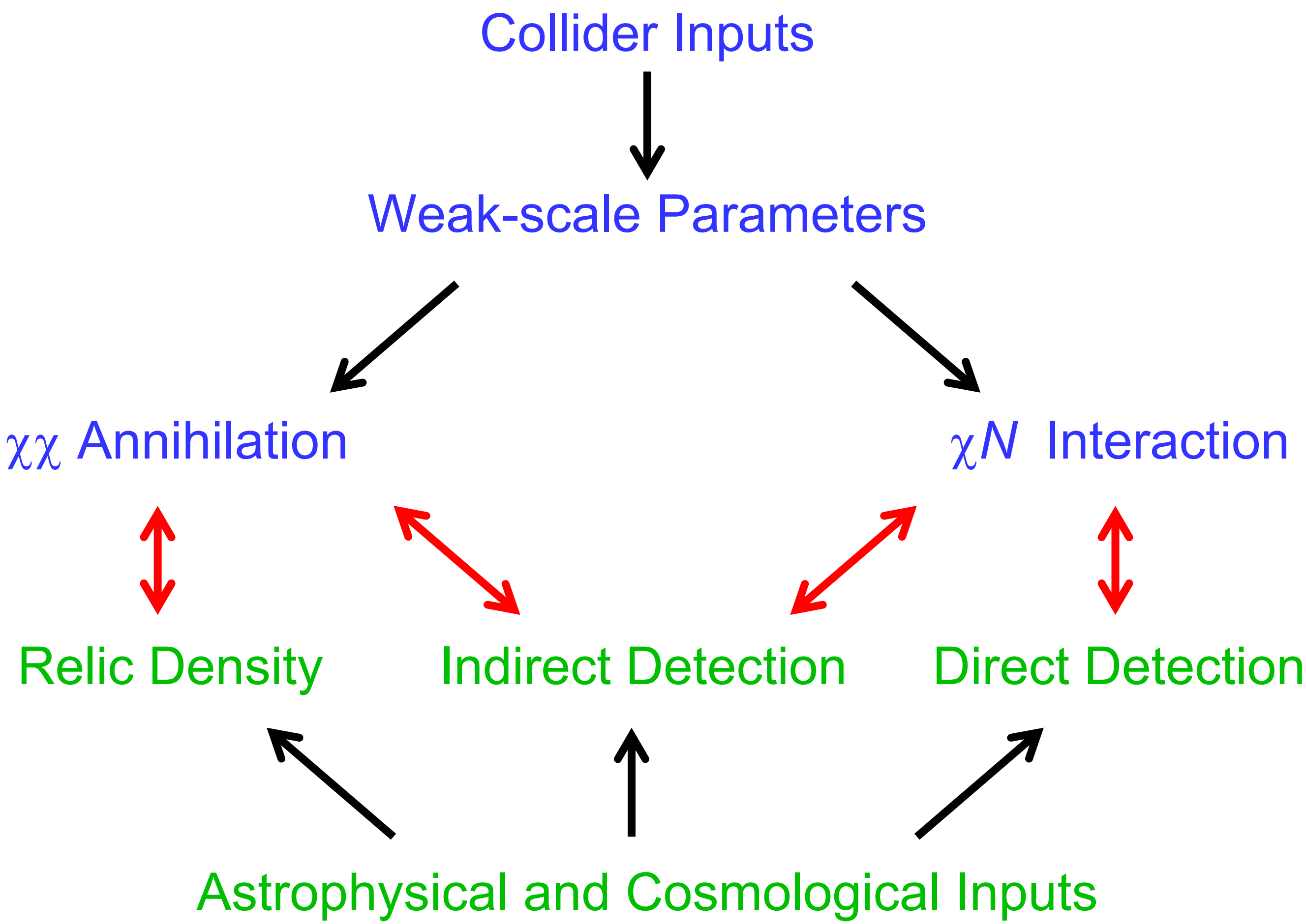
  light element properties (nuclear physics)
  light element abundances (astrophysics)

  leads to an understanding of our Universe at
  T = 1 MeV, t = 1 s.

- Dark matter studies may extend our knowledge by 8 orders of magnitude in time.

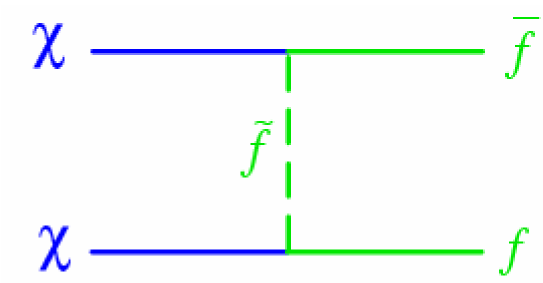


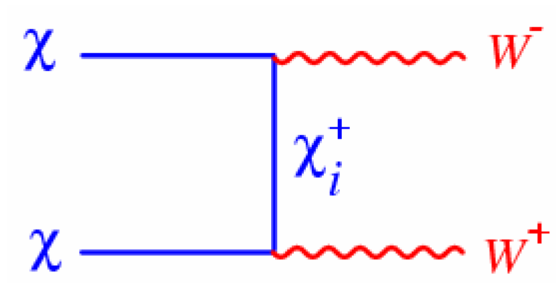
Particle/Cosmo Interface

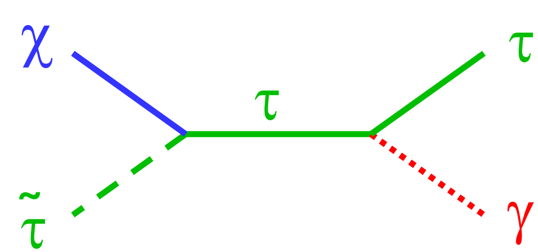


An example: Neutralinos

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





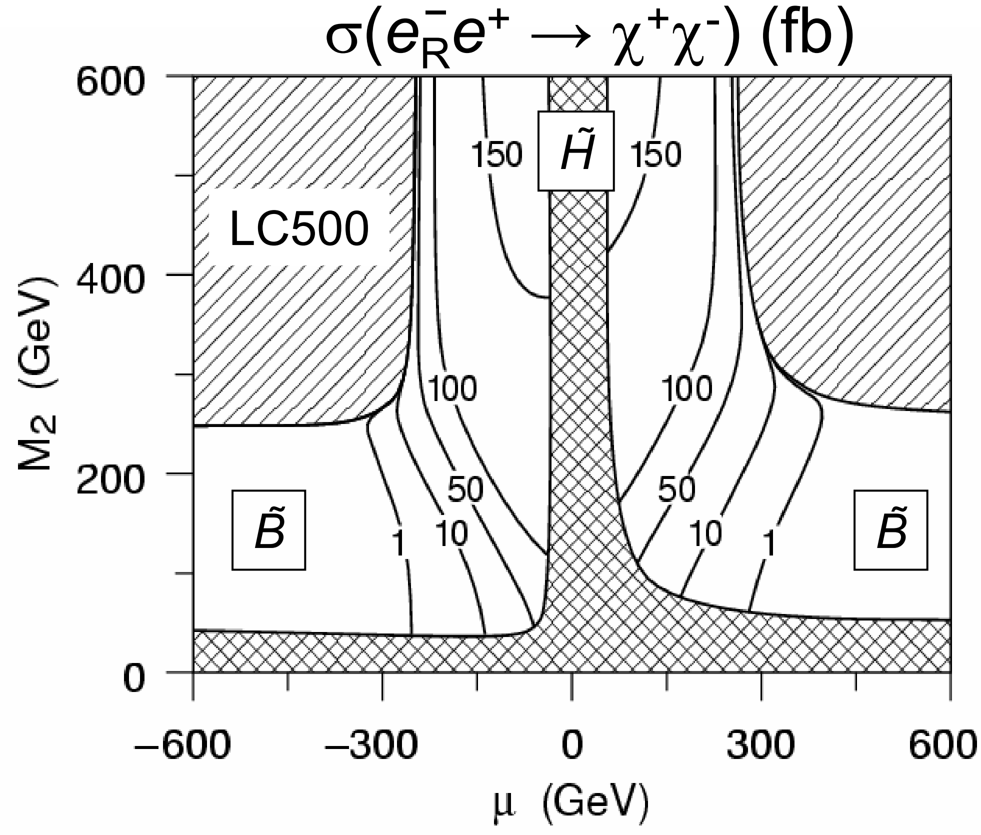


Requires precise knowledge of χ mass and

Sfermion masses | χ gaugino-ness | Δm to ~ few GeV

Neutralinos at Colliders

- χ mass measured through kinematics.
- χ gaugino-ness measured through polarized cross sections.
- Model-independent determination of Ω_χ to a few %: challenging but possible at LHC/LC.



Feng, Murayama, Peskin, Tata (1995)

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.

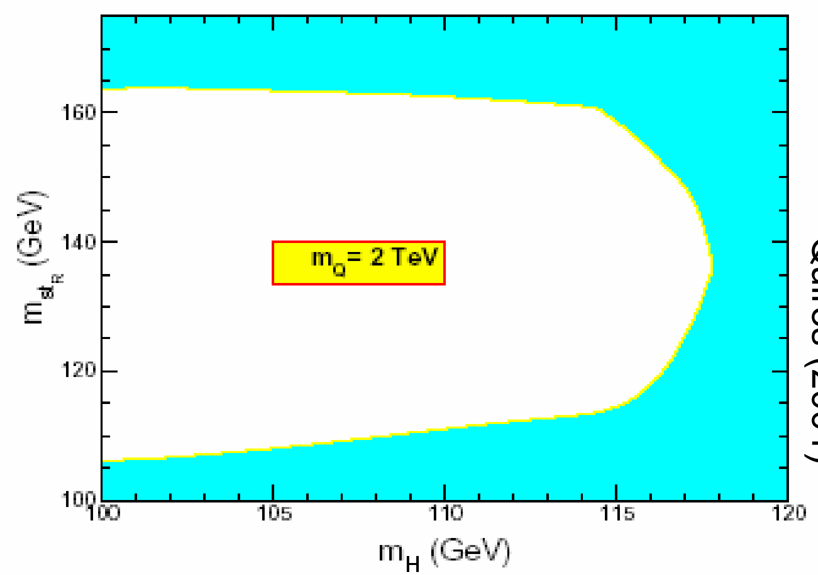
Electroweak Baryogenesis

- 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.

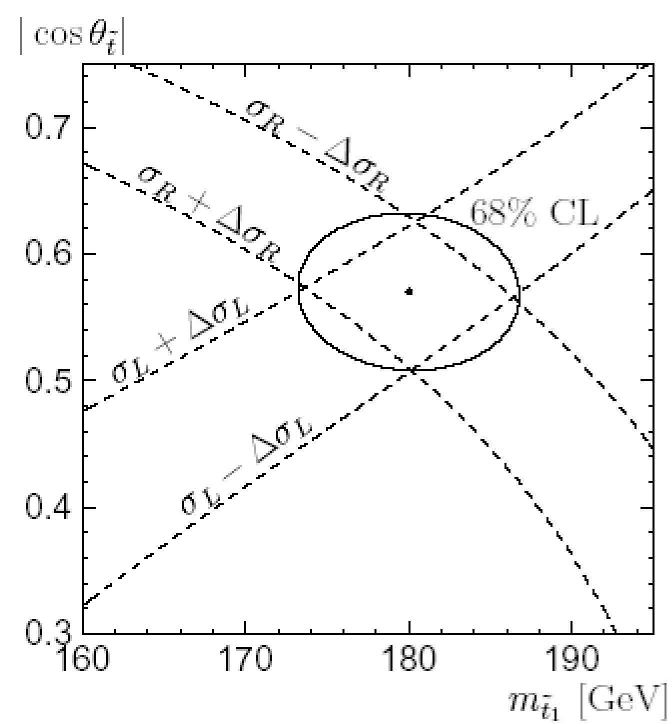
  Promising for LC!



Quiros (2001)

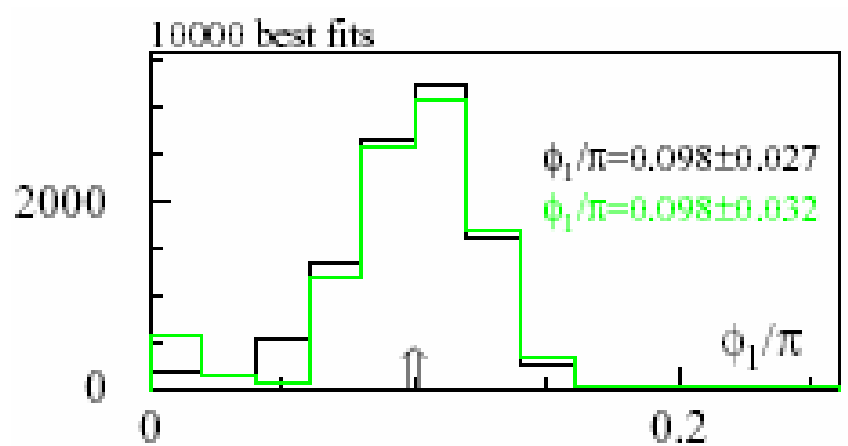
Baryogenesis Parameters at the LC

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



Bartl et al. (1997)

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



Barger et al. (2001)

Questions

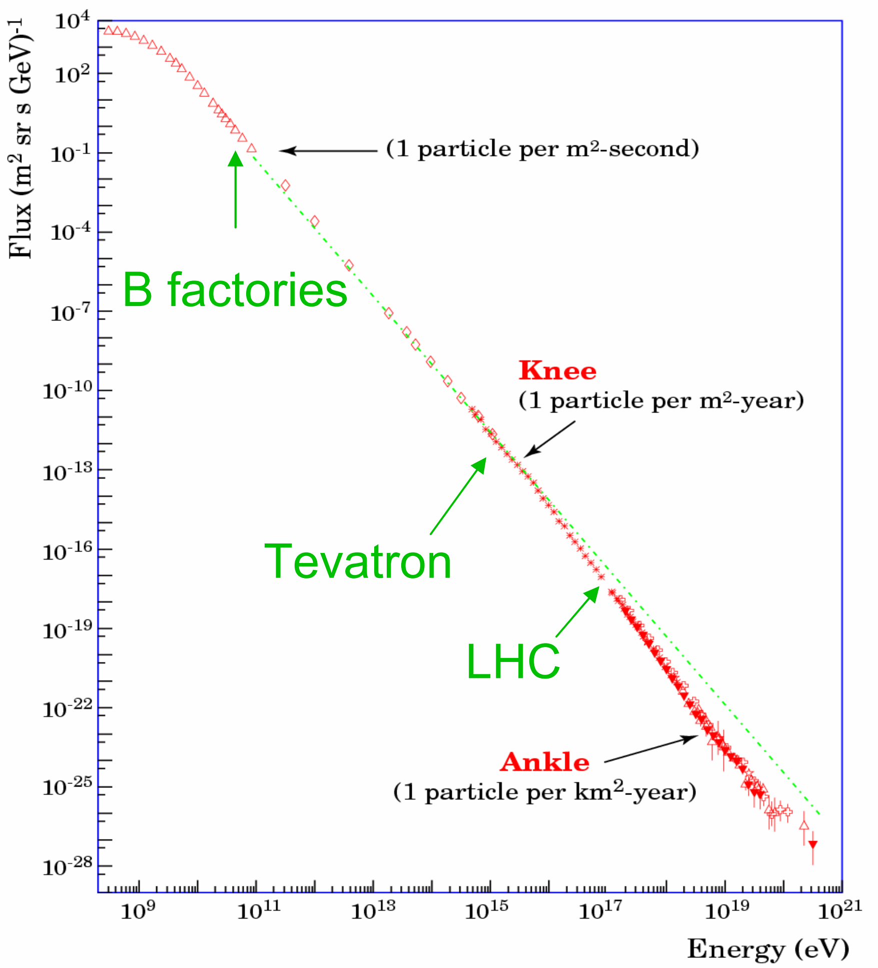
- How well can we determine Ω_B in this scenarios?
- Are there other weak-scale scenarios the LC can explore?
- Does the LC have anything to say about GUT-scale baryogenesis/leptogenesis?

Cosmic Rays

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

- E_{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.

Event starts here

- Colliders may help interpret upcoming ultrahigh energy data.

The GZK Paradox

- Protons with ~10^{20} eV energies quickly lose energy through

  $$p\,\gamma_{\mathrm{CMB}} \rightarrow n\,\pi^{+}$$

  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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  http://www.physics.syr.edu/~trodden/lc-cosmology

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