PPA Strategy and Challenges

David MacFarlane
Associate Laboratory Director for PPA
May 7, 2010
Fundamental Questions

• What are the ultimate Laws of Nature?
  – Are there new forces, beyond what we see today? Do the forces unify? At what scale? Why is gravity so different from the other forces?
  – What lies beyond the quarks and leptons? What completes the Standard Model? How do the neutrinos fit in the picture?

• What is the structure of space and time?
  – Why are there four spacetime dimensions? Are there more? What are their shapes and sizes? What is the quantum theory of gravity?
  – What is the state of the vacuum? What is the origin of mass?

• How did the Universe come to be?
  – What is the dark matter and dark energy? What happened to antimatter? What powered the big bang?
  – What is the fate of the Universe?
Rich science opportunities and a rich toolkit
Frontiers of particle physics and cosmology

From the P-5 HEPAP Subpanel Report, May 2008

PPA Strategy and Challenges

- Guidance also from PASAG
- Report coming in September from ASTRO2010
PASAG Guidance

• Prioritization criteria for Particle Astrophysics (PA)
  – Science addressed is a significant step towards HEP goals
  – Particle physics participation adds significant value/feasibility
  – Scale matters, particularly at the boundary between particle physics and astrophysics, & small effective projects ensure physics breadth

• Guidance
  – Dark matter & dark energy both remain high priorities
  – Dark energy funding recommended for largest fraction of PA budget, but should not compromise US leadership in dark matter, where discovery could be imminent
  – Dark energy and dark matter together should not completely zero-out other important activities, e.g., AGIS/CTA and CMB

PASAG = Particle Astrophysics Scientific Assessment Group
Outline

• Overview of current PPA program
• Future initiatives
  – Energy Frontier: ATLAS & Linear Collider
  – Intensity Frontier: SuperB and EXO
  – Cosmic Frontier: LSST, SuperCDMS, AGIS & CMB
• Concluding remarks
Core research program breakdown by FTEs

FY2010, 288 FTEs, $73M core [$95M total + FACET]

Includes faculty, staff, postdocs, and students
Planning criteria

- Importance and impact of science opportunity
  - Includes long-term goals as a laboratory HEP effort
- Alignment with national priorities: HEPAP, P-5, PASAG, ASTRO2010, etc
- Coherence of overall PPA plan
- Match to current or future capabilities
- Availability of core research staff and/or faculty
- Responding to and supporting user community
Energy Frontier

Science Directions

Future energy-frontier accelerators

Accelerator research: ILC, high-gradient, plasma-wakefield, laser

Nonaccelerator physics: EXO-200, CDMS

Accelerator-based particle physics: ATLAS & BABAR

Higgs, SUSY, discovery physics

Astrophysics & Cosmology: Fermi GST, DES

PPA: Strategy and Challenges
ATLAS and the LHC

• National planning constraints
  – OHEP does not intend to grow LHC program beyond present levels
  – Growth plans at SLAC sharply curtailed as well, reduced even from FY2009 levels

• Revised timeline for the LHC and upgrades
  – Upgrade timeline unknown, CERN still evaluating options
  – No major DOE investments for coming 5 years at least

• Present focus
  – Bringing detector into operation, computing support through Tier 2 center, initial physics exploitation, and minimal upgrade R&D
LHC Timeline (Very Preliminary)

S. Myers, HEPAP presentation March 11, 2010

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Start of 2 year cycle

3.5 TeV per beam

Goal end of 2011: 1 fb⁻¹

Repair splices

High Energy Possible

Higher Intensity from injectors?

12-14 TeV CMS

PPA Strategy and Challenges
Physics opportunities at the LHC

Integrated Luminosity (fb⁻¹)

- H → 4l, m_H = 180 GeV
- H → e⁺e⁻, m_H = 115 GeV
- Extra-dimensions G → e⁺e⁻, m = 1 TeV
- m = 1 TeV SUSY (g, q̄)
- Z' → e⁺e⁻, m = 1 TeV
- t̄t - First top quarks observed in Europe!
- m = 2.5 TeV SUSY (g, q̄)
- TeV-scale resonances from WW scattering
- m = 3 TeV SUSY
- Z', m ≈ 6.5 TeV Compositeness, Λ ≈ 60 TeV

Current planning

Year

Not yet known

SLHC

Gianotti / Nessi 2007
Next Energy Frontier machine: ILC

• International Linear Collider (ILC) R&D
  – Capable of 0.5-1 TeV
  – GDE plan for R&D and TDR development by 2012
  – Unlikely physics needs will be defined by then, nor is there an obvious host country
  – Reduced longer-term R&D effort thereafter, unless project launched

• Strengths: Mature design, proven technology
• Risks: High construction cost, limited energy reach
Next Energy Frontier machine: CLIC

- Compact Linear Collider (CLIC) R&D
  - Capable of multi-TeV energies
  - Collaboration with GDE on many systems & ILC detector community
  - CTF3 and CDR aimed at spring 2011
  - Further R&D and development of a TDR by 2016
  - May need large-scale systems test thereafter

- Strengths: Multi-TeV energy reach, lower construction cost
- Risks: Emittance preservation, two-beam rf source technology, high operating costs at multi-TeV
The Alternative LC Program

• Provide a lower-cost expandable LC option
  – Develop a linear collider design aiming at 50% of ILC cost but with lower risk than CLIC design
  – 300~500 GeV LC option expandable to multi-TeV CLIC-like design

• Develop technology with broad application across OS
  – Low cost compact acceleration applications such as storage ring injectors, light source drivers, compact linacs for security, industry and medicine

• Core capability in rf and linac design
  – SLAC provides Office of Science (and the world) with a core capability in normal conducting rf linac design and fabrication

• Strengths: Understood rf source, lower construction cost
• Risks: Emittance preservation
Next Energy Frontier machine: Muon collider

• Enlarged R&D program proposed by Fermilab
  – Part of a long-term strategy building on high-power proton sources: Project-X, neutrino factory, and muon collider

• Major technical challenges to be addressed
  – Source: 8 GeV x 4 MW proton driver to create $10^{14}$ muons/s
  – Cooling: Muon capture and 6-D phase space cool by more than $10^6$
  – Acceleration: Collective effects due to bunch structure and muon decays
  – BDS: High-field superconducting focusing magnets and detector shielding

• Strengths: Reduced construction costs, multi-TeV energy reach, lower operating costs at multi-TeV

• Risks: Significant technology challenges, loss of precision physics capability
One of several possible scenarios

- **ILC**
  - TDR
  - Extended R&D

- **CLIC**
  - CDR
  - TDR
  - Systems test

- **ALC**
  - R&D & CDR development
  - Physics requirements: both 500 GeV and multi-TeV
  - Technology strategy
  - International project development
  - 500 GeV ALC construction

- **Muon collider**
  - R&D & CDR development
  - TDR & systems tests
  - Neutrino Factory

- **3 TeV CLIC extension**

**My supposition**
Lepton Collider strategy

- Broaden technology options beyond cold-rf for ILC
  - Pursue ALC warm x-band rf technologies of benefit to both HEP and other applications
  - Enlarge partnerships with CERN, KEK to position US program for foreign hosted LC based on broad range of technologies

- Engage in muon collider R&D program
  - Help US community explore viability of this pathway for next generation energy frontier machine

- Pursue detector R&D and support benchmark capability for LC experiments
  - LC is a precision instrument and options need to be evaluated in a common physics and simulation framework
Science Directions

Intensity Frontier

Expand accelerator luminosity frontiers

New physics properties from flavor sector

Nature of the neutrino

Accelerator research: ILC, high-gradient, plasma-wakefield, laser

Accelerator-based particle physics: ATLAS & BABAR

Nonaccelerator physics: EXO-200, CDMS

Astrophysics & Cosmology: Fermi GST, DES

PPA: Strategy and Challenges
The SuperB Project

• Opportunity to pursue discovery science complementing the LHC energy frontier explorations:
  – Measurements of the flavor couplings will allow a deeper understanding of the nature of any New Physics
  – Same measurements are sensitive to New Physics at energy scales 5-10 times direct production at the LHC

• Two projects under development: SuperKEKB in Japan & SuperB in Italy

• Opportunity to broaden the scope of the US experimental HEP program

• DOE & SLAC would have major enabling role for the SuperB project with in-kind contributions of PEP II & BABAR components

• Participation in an offshore Super B Factory was recommended in all but lowest budget scenario of the P-5 Report
Current SuperB approval status & next steps

• Assessment requested by DOE/OHEP on possible US involvement in the INFN-hosted SuperB project
  – SLAC-led task force developed scenarios for new detector and new collider contributions beyond reuse of PEP-II/BABAR hardware

• Decision by the Italian government on approval of the SuperB project is expected imminently
  – SuperB designated as high priority for funding under new National Research Plan announced by Ministry of Education & Science

• OHEP conducting comparative review of SuperB, SuperKEKB and g-2 flavor physics options this summer
  – Potential flavor physics investments for inclusion in FY2012 budget
Challenges

• Issues:
  – Development of a SuperB project team for an ambitious and technically challenging machine
  – Limited new investment being considered by OHEP, perhaps below a level with enough impact on project success
  – Size of SLAC effort would be comparatively modest, leaving overall accelerator-based particle physics relatively small
  – Cannot sustain SLAC effort beyond FY2010 without a decision
  – Could consider SuperKEKB should SuperB fail to materialize, but no benefit from reuse of PEP-II & BABAR components in this case
Enriched Xenon Observatory (EXO-200)

- Search for neutrinoless double beta decay in 200 kg of $^{136}$Xe
  - Occurs if neutrinos are Majorana & lepton number violated
  - Rate is proportional to $<m_\nu>^2$
- EXO-200 currently being set up at WIPP
  - TPC is in its cryostat
  - Should be taking data with natural xenon by late summer of 2010
Development of full EXO

• Results from EXO-200 critical in guiding strategy for ton-scale full EXO at DUSEL
  – No signal would lead to further work on liquid options
  – Observation of a signal would strongly push the design towards a gaseous detector

• Challenges
  – DOE/NP recently designated as the steward for DUSEL neutrinoless double beta decay experiments
  – Costs and technical risks of scaling to ton-sized liquid or gaseous underground detector
  – Other competing technologies may be adopted for next generation experiment
Science Directions

Cosmic Frontier

- Accelerator research: ILC, high-gradient, plasma-wakefield, laser
- Accelerator-based particle physics: ATLAS & BABAR
- Nonaccelerator physics: EXO-200, CDMS
- Astrophysics & Cosmology: Fermi GST, DES

- Direct dark matter searches
- Cosmic dark matter & cosmic rays
- Dark Energy
- Inflation
Large Synoptic Survey Telescope

- LSST is planned as a collaborative NSF and DOE-HEP project
  - NSF provides the telescope & data system
  - DOE the 3.2 Gigapixel camera
- SLAC led consortium developing the key camera technologies
LSST Science Goals

- Provide a sensitive survey of the entire sky at visible wavelengths every few nights
  - Comprehensive map of Dark Matter in the Universe through gravitational lensing
  - Resulting in tight constraints on the cosmic expansion history, and thus on the nature of Dark Energy

0.64-m diameter, 3.2 Gigapixel

Broad program of astronomy & astrophysics, LSST Science Book
**Future: LSST simulation**

- **Cosmic shear (growth of structure + cosmic geometry)**
- **Counts of massive structures vs redshift (growth of structure)**
- **Baryon acoustic oscillations (angular diameter distance)**
- **Measurements of Type 1a SNe (luminosity distance)**
- **Mass power spectrum on very large scales tests CDM paradigm**
- **Shortest scales of dark matter clumping tests models of dark matter particle physics**

**LSST probes Dark Energy in multiple ways**

**Dark Energy Equation of state**

\[
 w = w_0 + (1-a)w_a \\
a = (1+z)^{-1}
\]

**2800 galaxies i<25 mag**
LSST evolution & challenges

- Challenges:
  - LSST may not emerge with highest priority from ASTRO2010
  - Developing multiagency international funding for camera system
  - Building up sufficient scientific and technical team
  - Technical challenges in the camera and data management areas
Evolution of dark matter program: SuperCDMS

- SuperCDMS at the Soudan Mine: 15 kg
  - Joint NSF-DOE project
  - Currently discussing deployment of improved Germanium sensors (iZIP)
- SuperCDMS at SNOLAB: ~100 kg
  - Currently in the R&D Phase, expecting a CD-0 this year
  - SLAC plans to play a major role in the project
- GEODM at DUSEL: ~1000 kg
  - Currently in R&D Phase: S4 award from NSF for preliminary studies
- PASAG recommended direct dark matter experiments with high priority
  - Two 2nd generation experiments and the 100kg SuperCDMS SNOLAB experiment should be started as soon as possible
Search for Relic Dark Matter: SuperCDMS
CDMS timeline

- 2010
  - Fabrication & assembly of SuperCDMS at Soudan (15kg)
  - Operation
  - R&D for SuperCDMS at SNOLab (100kg)
  - Fabrication & assembly
  - Operation
  - Concept for GeoDM at DUSEL (1T)
  - R&D
  - Sensor fabrication
  - Assembly
  - Operation

PPA Strategy and Challenges
Challenges

• Issues:
  – Other competing technologies could prove more effective at ton scale
  – Limited SLAC experience with germanium sensors, cryogenic systems, underground construction
  – CDMS Collaboration transitioning from University-style R&D efforts to full-scale projects
  – Fermilab has managed CDMS, SuperCDMS at Soudan; SLAC project management role uncertain
Snapshot in 5 years

Energy Frontier
Intensity Frontier
Cosmic Frontier

Accelerator research:
SuperB, LC, high-gradient, plasma-wakefield, laser

Nonaccelerator physics:
EXO-200, SuperCDMS

Accelerator-based particle physics:
ATLAS, SuperB

Astrophysics & Cosmology:
Fermi GST, LSST
Snapshot in 5 years

**Energy Frontier**
- Intensity Frontier
- Cosmic Frontier

**LHC upgrades, Project-X**

**EXO**
- Non-accelerator physics: EXO-200, SuperCDMS
- GeoDM
- AGIS
- CMB

**Accelerator research:**
- SuperB, LC, high-gradient, plasma-wakefield, laser

**ATLAS upgrades**
- ATLAS, SuperB

**Accelerator-based particle physics:**
- ATLAS, SuperB

**Astrophysics & Cosmology:**
- Fermi GST, LSST

**LC demo, FACET phase II**
Tied together by forefront science goals & world-class accelerator capability, enhanced by cross fertilization of ideas & techniques.
What ifs?

- What if ALC x-band program is not pursued?
  - Future of x-band core competency threatened
- What if LSST is not pursued?
  - Other Dark Energy projects will be pursued, e.g., JDEM, Big BOSS, Euclid,…
- What if SuperB is not pursued in Italy?
  - Consider SuperKEKB, enhance LSST, SuperCDMS efforts, advance AGIS earlier
  - Accelerator-based particle physics focused only on ATLAS
- What if CDMS is not pursued beyond SNOLab?
  - Will have established a dark matter science group well positioned for PASAG-recommended next generation experiment
Parting questions

- Are the science questions being addressed appropriate?
- Is this program ambitious enough for Stanford and SLAC?
  - Challenging times for HEP as a field and discovery science generally in the US
- Will this program provide sufficient long-term direction?
  - Many projects are proposed but not yet funded
- Are planning assumptions sound?
  - Timescales, national priorities, and technical directions and trends
- Is the lack of a Project-X science engagement a problem?
- Do we have the staff to execute the plan? or can we attract the necessary talent?
Backup
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## 4 ACCELERATOR & DETECTOR R&D

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**KEY**
- R&D: Research and Development
- Construction
- Operation
Upcoming Reviews

• Electron-based research program review in June
  – Currently BABAR, ILC detector R&D, and SuperB R&D
  – Proposed SuperB, lepton-collider detector R&D, dark photon searches

• Nonaccelerator lab program review in late September
  – Scheduled shortly after public release of ASTRO2010 report
  – Focus on themes:
    • Dark energy through astrophysical measurements
    • Direct and indirect dark matter searches
    • Neutrinoless double-beta decay searches
    • Properties of CMB
    • Study of nature’s highest energy particles
    • KIPAC as an integrating intellectual environment
  – Coordination with Fermilab, LBNL, ANL, and BNL essential
Accelerator-based particle physics

• Playing a significant role in the Large Hadron Collider & ATLAS
  – Potentially discover origins of mass, new symmetries of nature, dark matter candidates, or hidden dimensions of quantum gravity

• Pursuing full exploitation of the unique dataset from the SLAC B Factory

Discovery of CP violation underpins 2008 Nobel Prize to Kobayashi & Maskawa

BABAR = PhD factory as well
Accelerator science and development

- World-class accelerator research program:
  - Playing enabling role in technology development for the ILC & leading high-gradient X-band research in the US

Warm technology rf structure developed with KEK & CERN with 5x SLAC linac gradient
Astrophysics and Cosmology

- Leading particle-astrophysics and cosmology:
  - Operating the Fermi Gamma-Ray Space Telescope and continuing scientific discoveries with this unique observatory.
Nonaccelerator physics & detector R&D

- Understanding the nature of the neutrino and search for relic dark matter
  - Novel technologies for low-activity underground experiments

Low-activity liquid xenon TPC with readout during assembly
Kavli Institute for Particle Astrophysics and Cosmology

- Founded 2003 as bridge between:
  - Physics and astrophysics
  - SLAC and Stanford campus
  - DOE, NASA, NSF, and private sector
- Major commitment by partners
  - 10 faculty billets, 2 buildings
- KIPAC today
  - ~40 full members, 20 postdocs, 35 students, 10 visitors
  - ~200 papers per year, ~10 active projects
  - Instrumentation, data analysis, particle astrophysics, relativity, computational astrophysics, observational cosmology, theoretical cosmology…

SLAC
NATIONAL ACCELERATOR LABORATORY

PPA Strategy and Challenges
Experimental core competencies

- **Electronics engineering**
  - System architecture, analog and digital front-end design, ASICs, high-performance DAQ systems, high-reliability systems, mechanical integration, hardware and software trigger systems, control systems

- **Mechanical engineering**
  - Low background materials & design, systems design, project management

- **Computing**
  - Online and offline systems, large-scale data management, detector simulations, state-of-the-art database systems

- **Detector R&D**
  - Silicon device design and fabrication, tracking systems, photodetectors and Cherenkov systems
ARD core competencies

- Beam theory
- Advanced acceleration R&D
- rf design and fabrication
- Accelerator design
  - Presently have world class programs in beam delivery system design; polarized e-source design; low emittance ring design; linac systems design; FEL design; & diagnostics
  - Working on designs for future SLAC facilities (LCLS-II, PEP-X) and facilities worldwide (ILC, CLIC, PS2, Super-B)
- Accelerator commissioning – LCLS, SPEAR-III, LHC
Camera technical challenges

• Detector requirements:
  – Stringent requirements individually available, but not simultaneously in one detector
• Focal plane position precision of order 3 μm
• Package large number of detectors, with integrated readout electronics, with high fill factor and serviceable design
• Large diameter filter coatings
• Constrained volume (camera in beam)
  – Makes shutter, filter exchange mechanisms challenging
• Constrained power dissipation to ambient
  – To limit thermal gradients in optical beam
  – Requires conductive cooling with low vibration
SuperCDMS R&D at SLAC

• Key areas of investigation include:
  – Procurement of crystals of large diameter (4 and/or 6 inch)
  – Optimization of fabrication process for large diameter sensors
  – Modification of laboratory equipment for large diameter sensors
  – Sensor development and quality control
  – Streamline testing with new cryogenic set-up
  – Support develop of tower mechanical structures
  – Develop scalable software framework
    • System architecture, data access, data processing and database middleware
  – Develop Ge Crystal Monte Carlo simulations within Geant4
  – Support deployment of test facility at SNOLAB capable of testing large diameter sensors
  – Systems engineering and management
Dark matter detector: cryogenic Ge detectors

Current sensors

Next generation: 100mm diameter x 33mm thick

charge fiducial volume
Advanced Gamma-ray Imaging System (AGIS)

- **Next-generation ground-based $\gamma$-ray observatory**
  - Based on an array of Atmospheric Cherenkov Telescopes
- **10x increase in sensitivity** versus current experiments
  - Large area, fine angular resolution, improved background rejection
- **Timeline**
  - R&D and prototype ~2015
B-mode polarization of CMB background

• Probe energy scale of inflation; constrain sum of neutrino masses
  – Still need 1-2 orders of magnitude improvement in sensitivity

• Next-generation ground-based CMB arrays
  – BICEP/BICEP-II → Keck array → POLAR-1/POLAR array bolometer-based detection
  – QUaD → QUIET-1/QUIET-2 radiometry-based detection

• Timeline
  – Will likely remain small scale projects through ~2015