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?


X [μ m]
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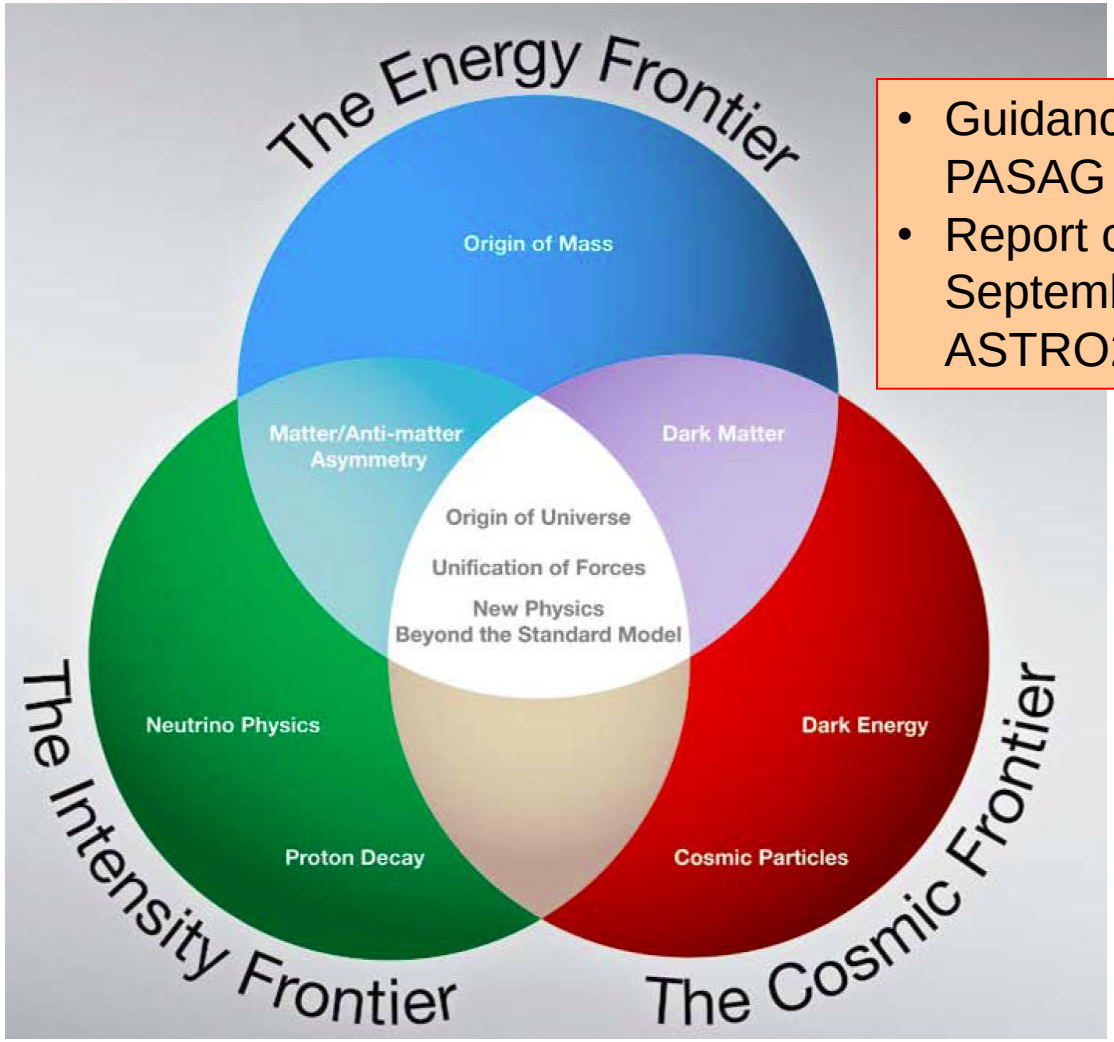
Rich science opportunities
and a rich toolkit

Frontiers of particle physics and cosmology



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

From the P-5 HEPAP Subpanel Report, May 2008

PASAG Guidance

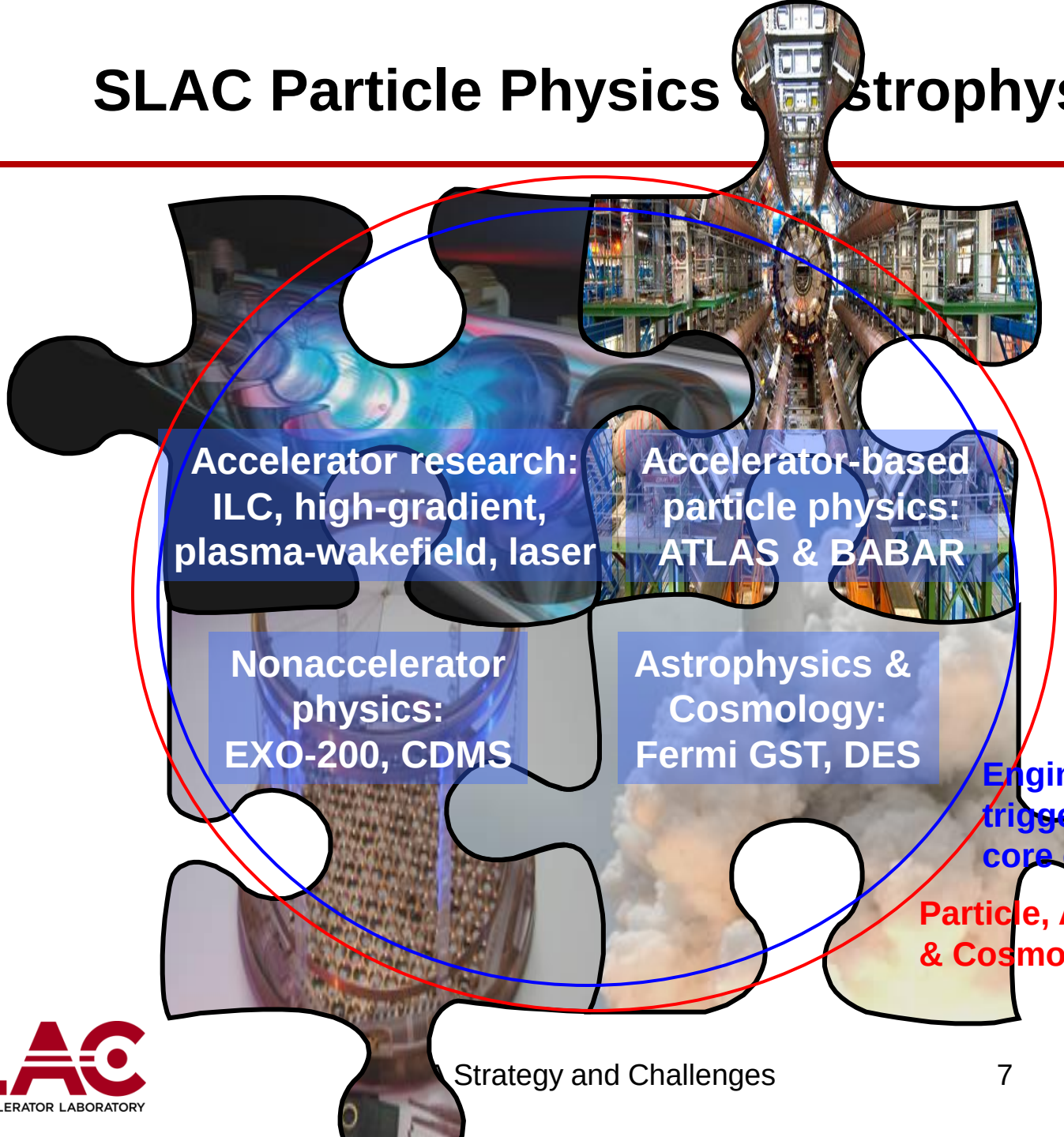
- Prioritization criteria for Particle Astrophysics (PA)
  - Science addressed is a significant step towards HEP goals
  - Particle physics participation adds significant value/feasibility
  - Scale matters, particularly at the boundary between particle physics and astrophysics, & small effective projects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

SLAC Particle Physics & Astrophysics

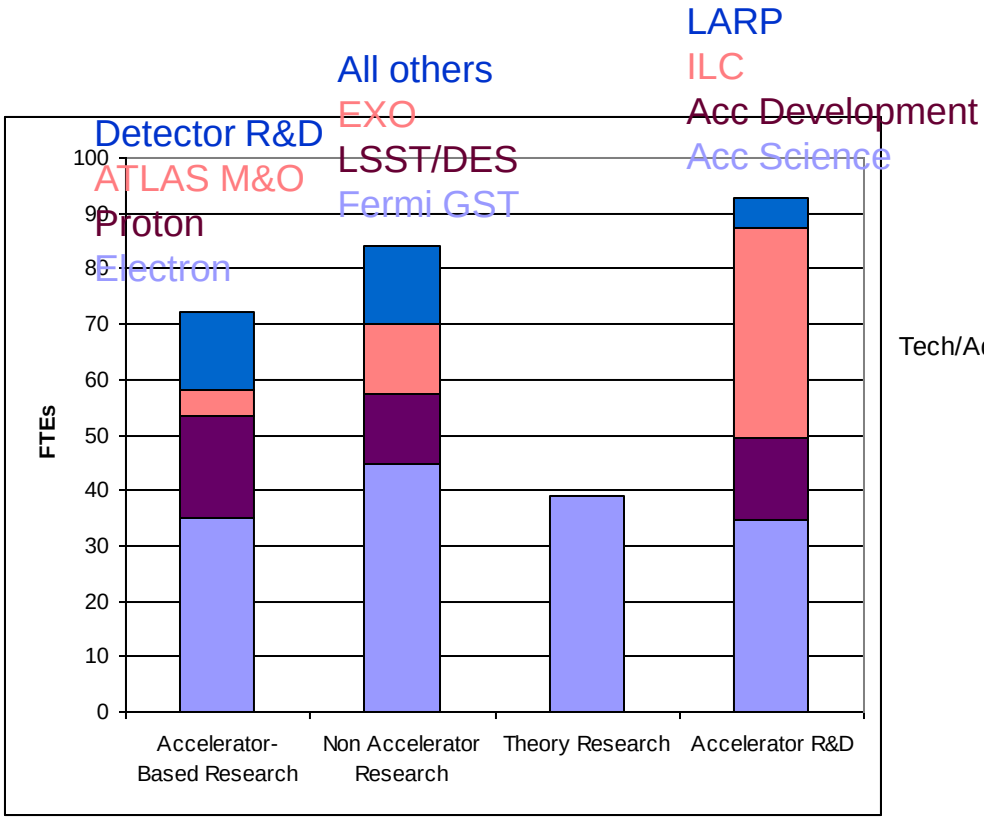


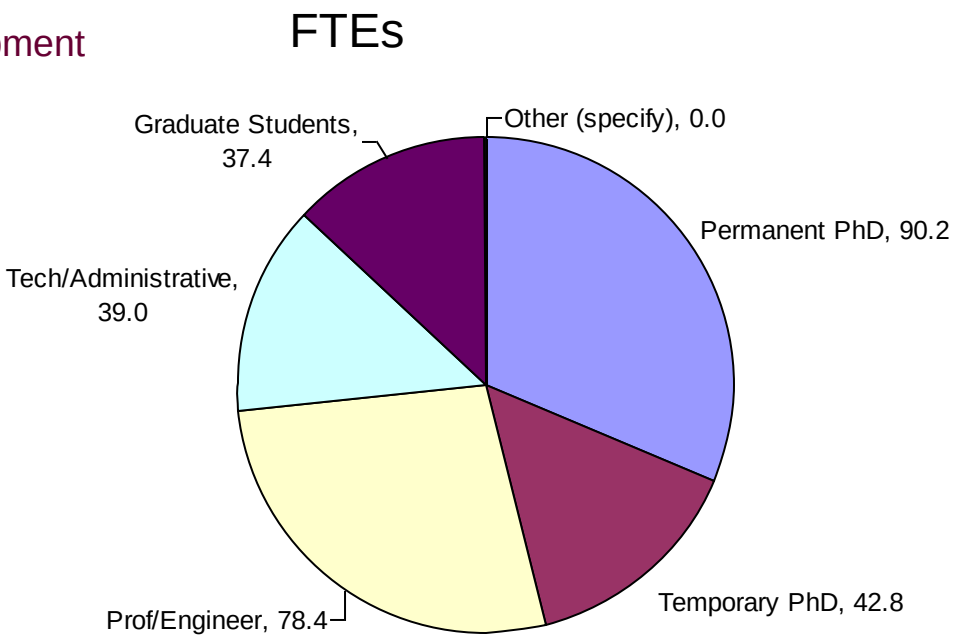
Engineering, DAQ, trigger & computing core capabilities

Particle, Astrophysics, & Cosmology Theory

Core research program breakdown by FTEs

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



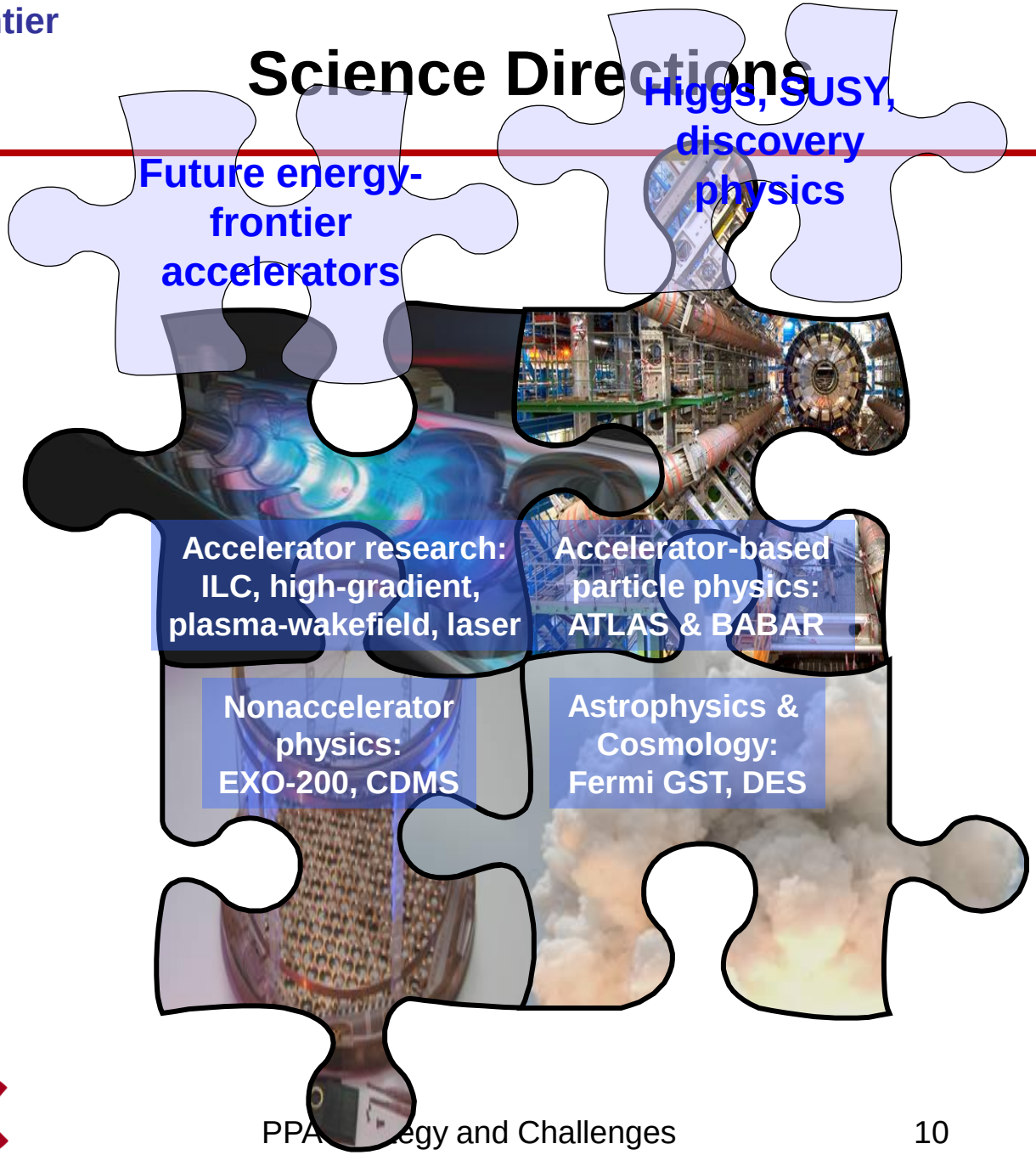


Includes faculty, staff, postdocs, and students

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

Science Directions

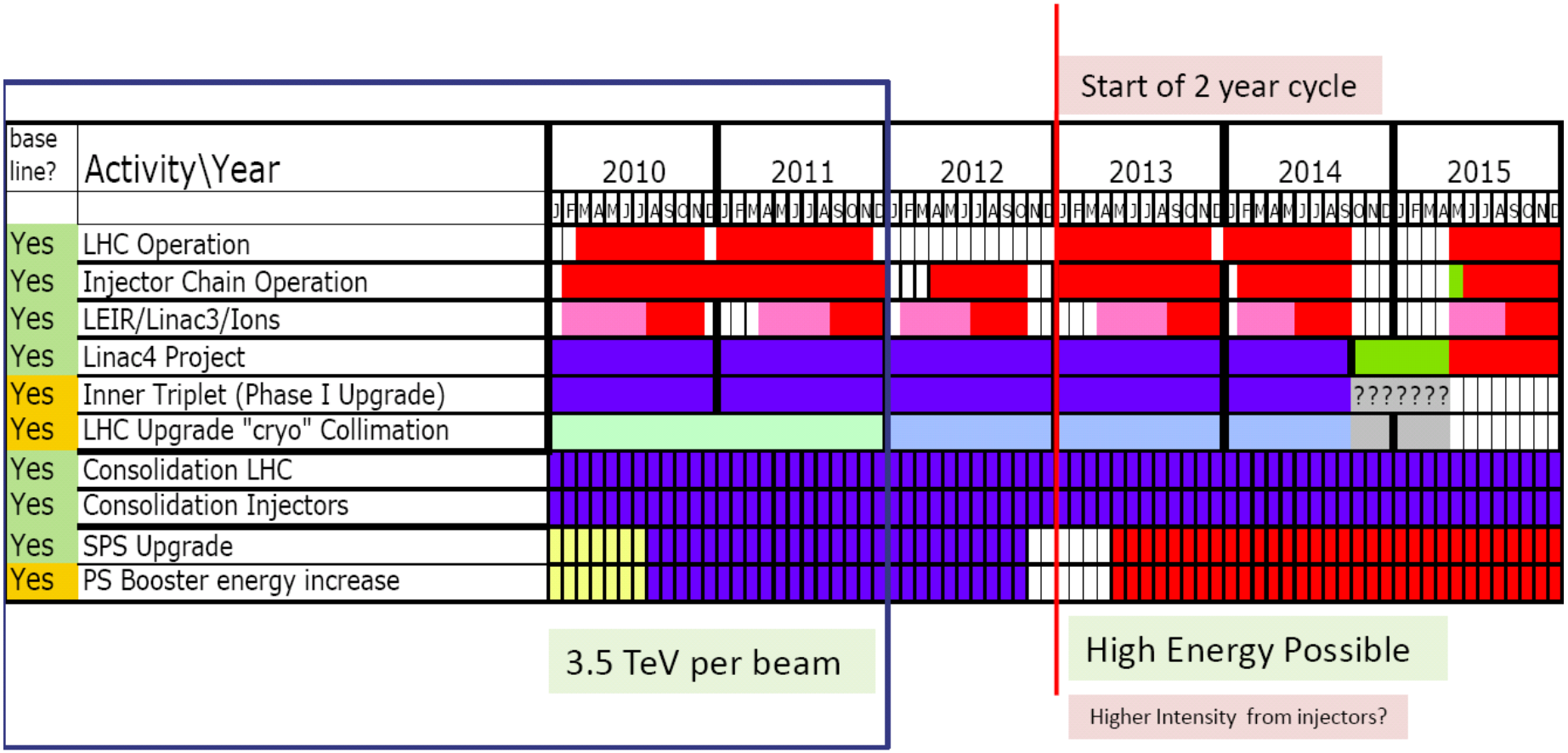


ATLAS and the LHC

- 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

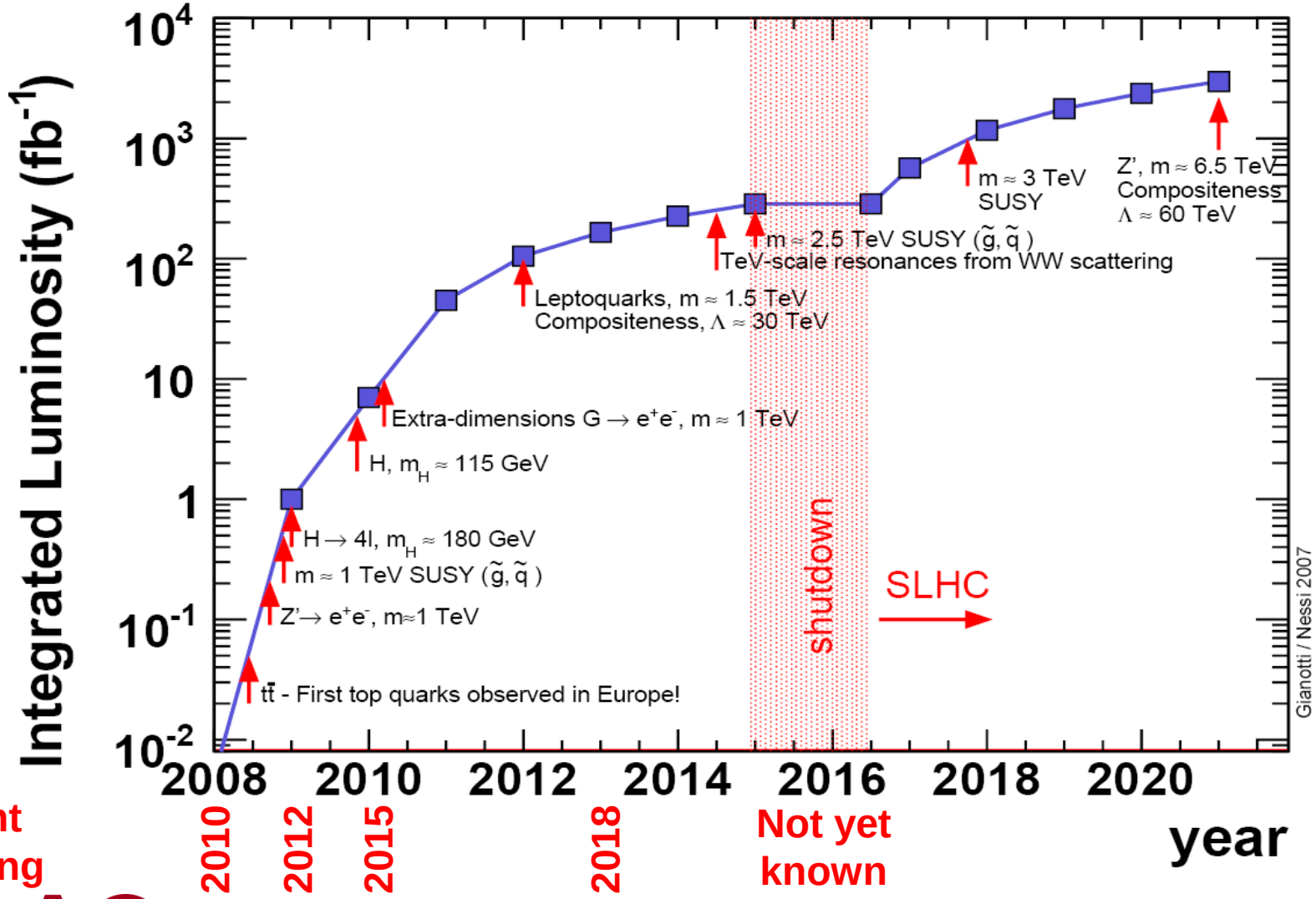


Goal end of 2011: 1 fb^{-1}

Repair splices

12-14 TeV CMS

Physics opportunities at the LHC



Current planning

2010 2012 2015 2018

Not yet known

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

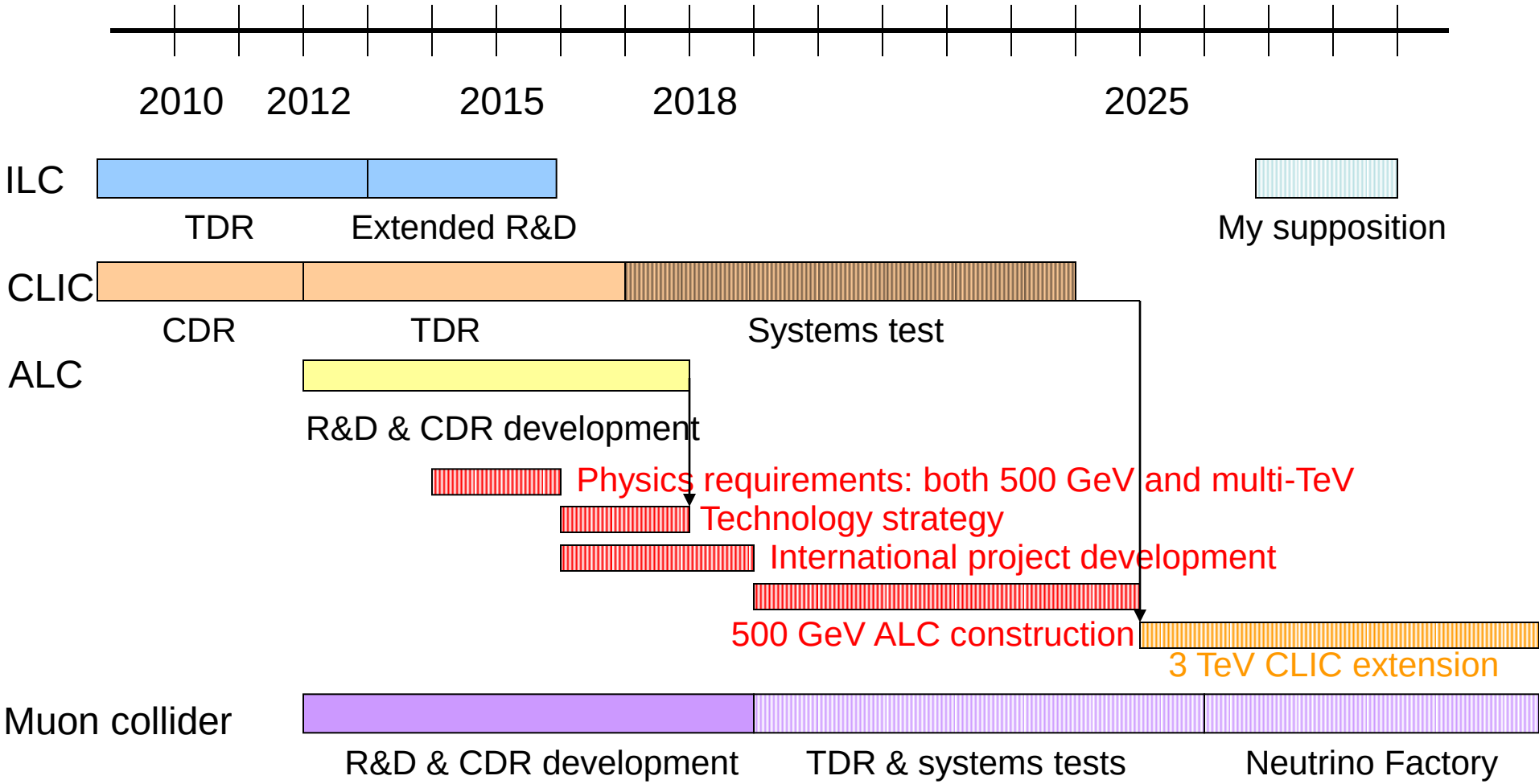
The Alternative LC Program

- 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



Lepton Collider strategy

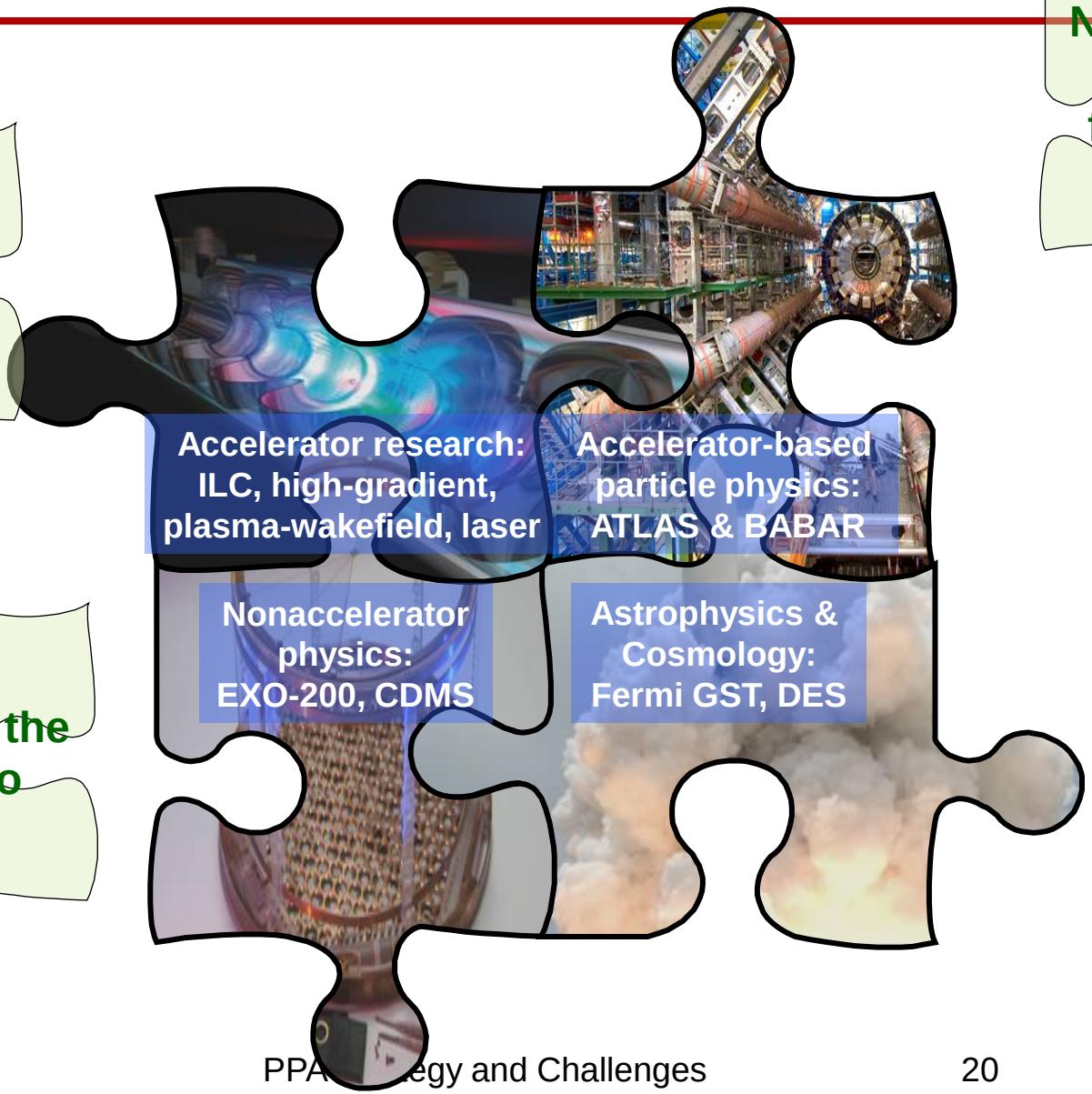
- Broaden technology options beyond cold-rf for ILC
  - Pursue ALC warm x-band rf technologies of benefit to both HEP and other applications
  - Enlarge partnerships with CERN, KEK to position US program for foreign hosted LC based on broad range of technologies
- Engage in muon collider R&D program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

Intensity Frontier

Science Directions

New physics properties from flavor sector

Expand accelerator luminosity frontiers



Nature of the neutrino

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

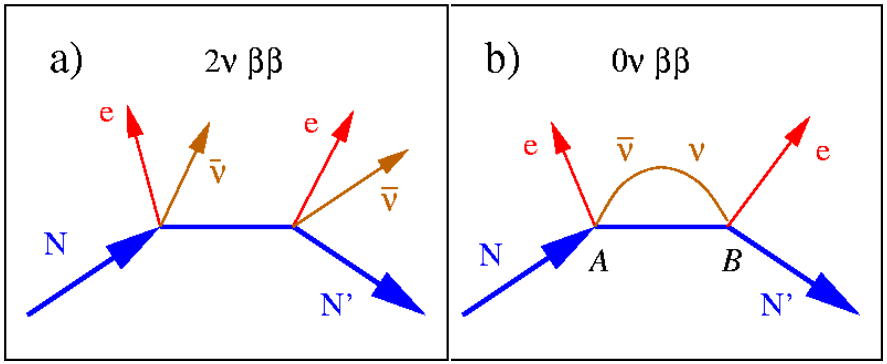
- Assessment requested by DOE/OHEP on possible US involvement in the INFN-hosted SuperB project
  - SLAC-led task force developed scenarios for new detector and new collider contributions beyond reuse of PEP-II/BABAR hardware
- Decision by the Italian government on approval of the SuperB project is expected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

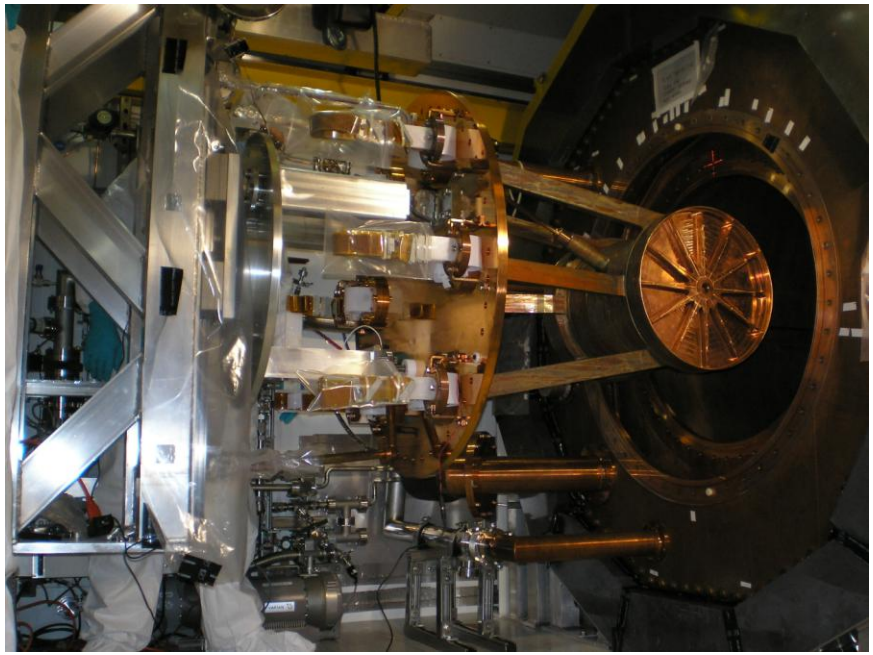
Challenges

- 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

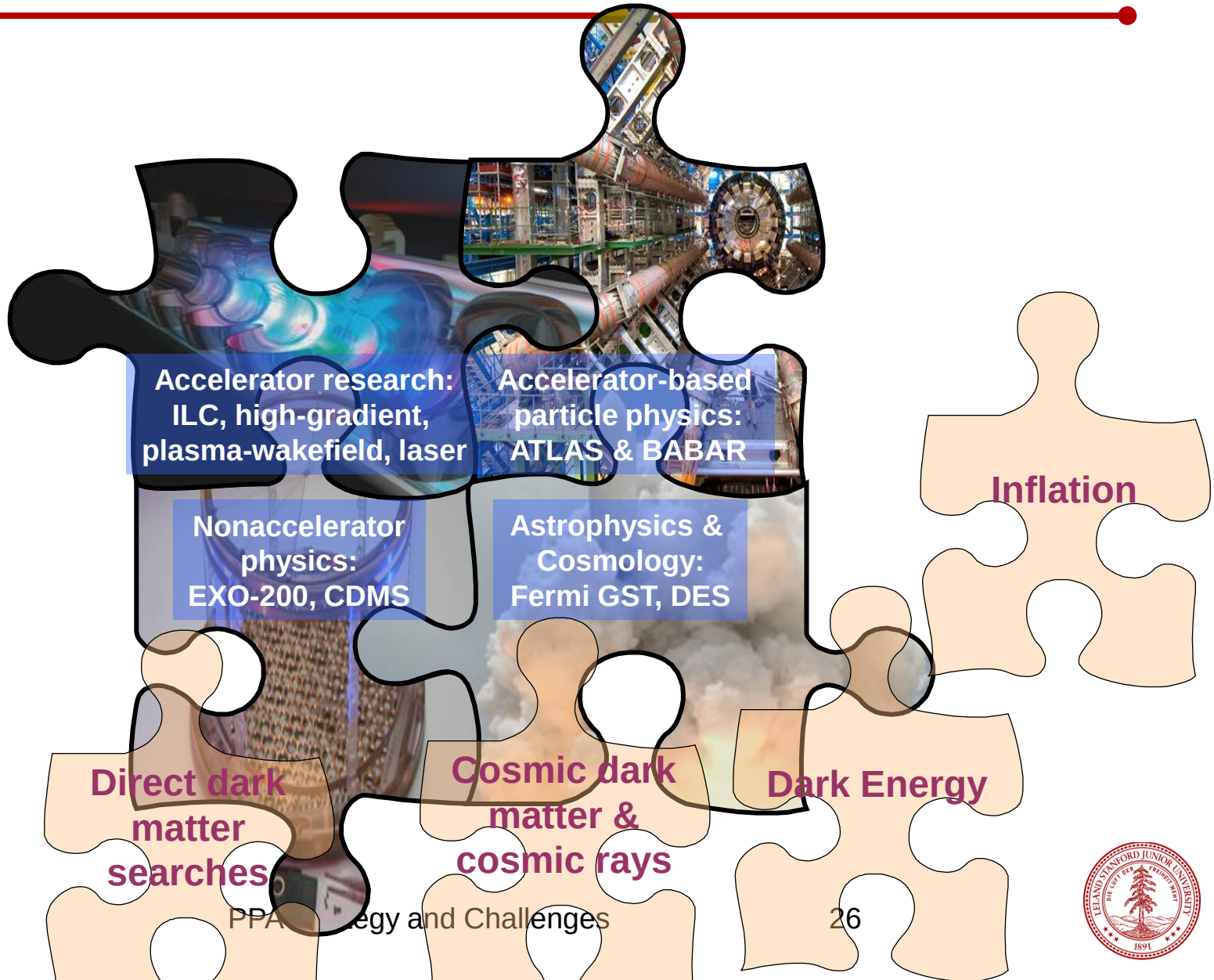




Development of full EXO

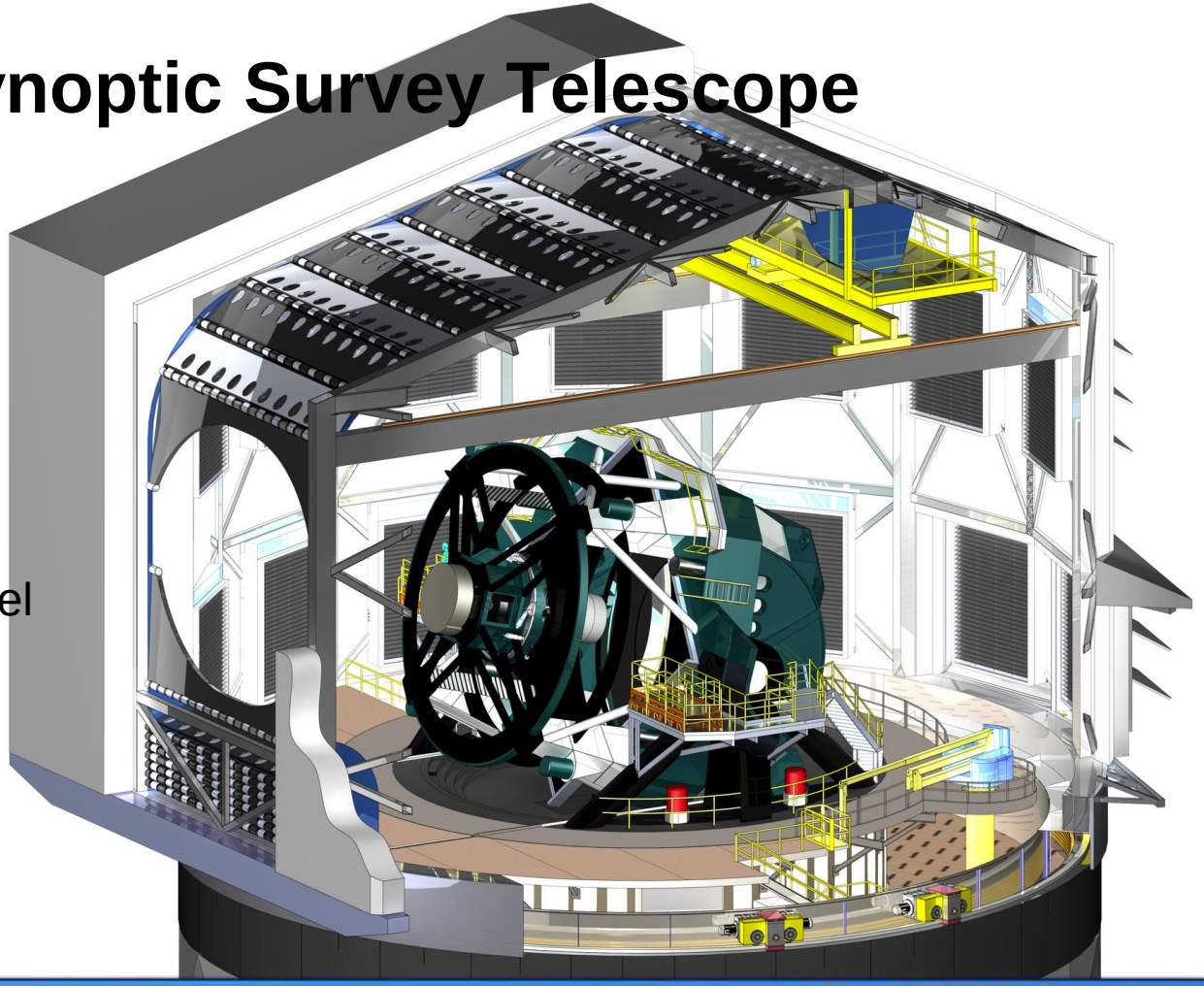
- Results from EXO-200 critical in guiding strategy for ton-scale full EXO at DUSEL
  - No signal would lead to further work on liquid options
  - Observation of a signal would strongly push the design towards a gaseous detector
- Challenges
  - DOE/NP recently designated as the steward for DUSEL neutrinoless 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



Large Synoptic Survey Telescope

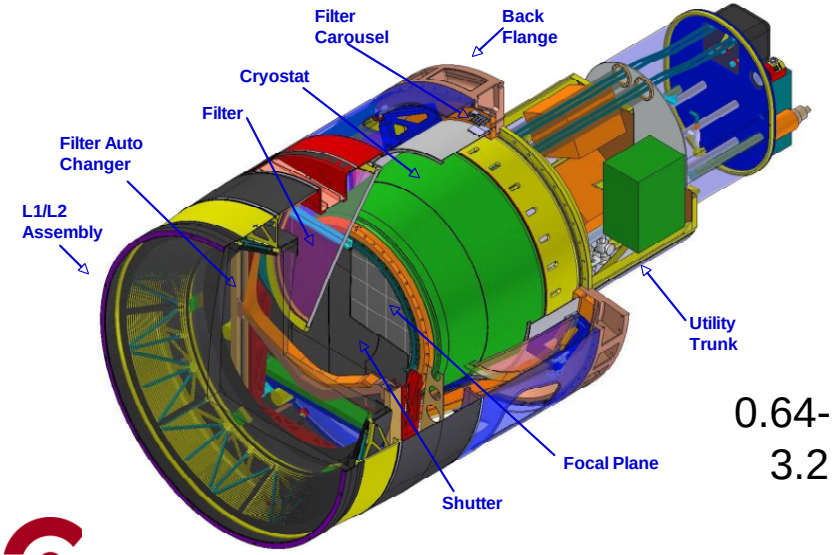
- LSST is planned as a collaborative NSF and DOE-HEP project
  - NSF provides the telescope & data system
  - DOE the 3.2 Gigapixel camera
- SLAC led consortium developing the key camera technologies



LSST Science Goals

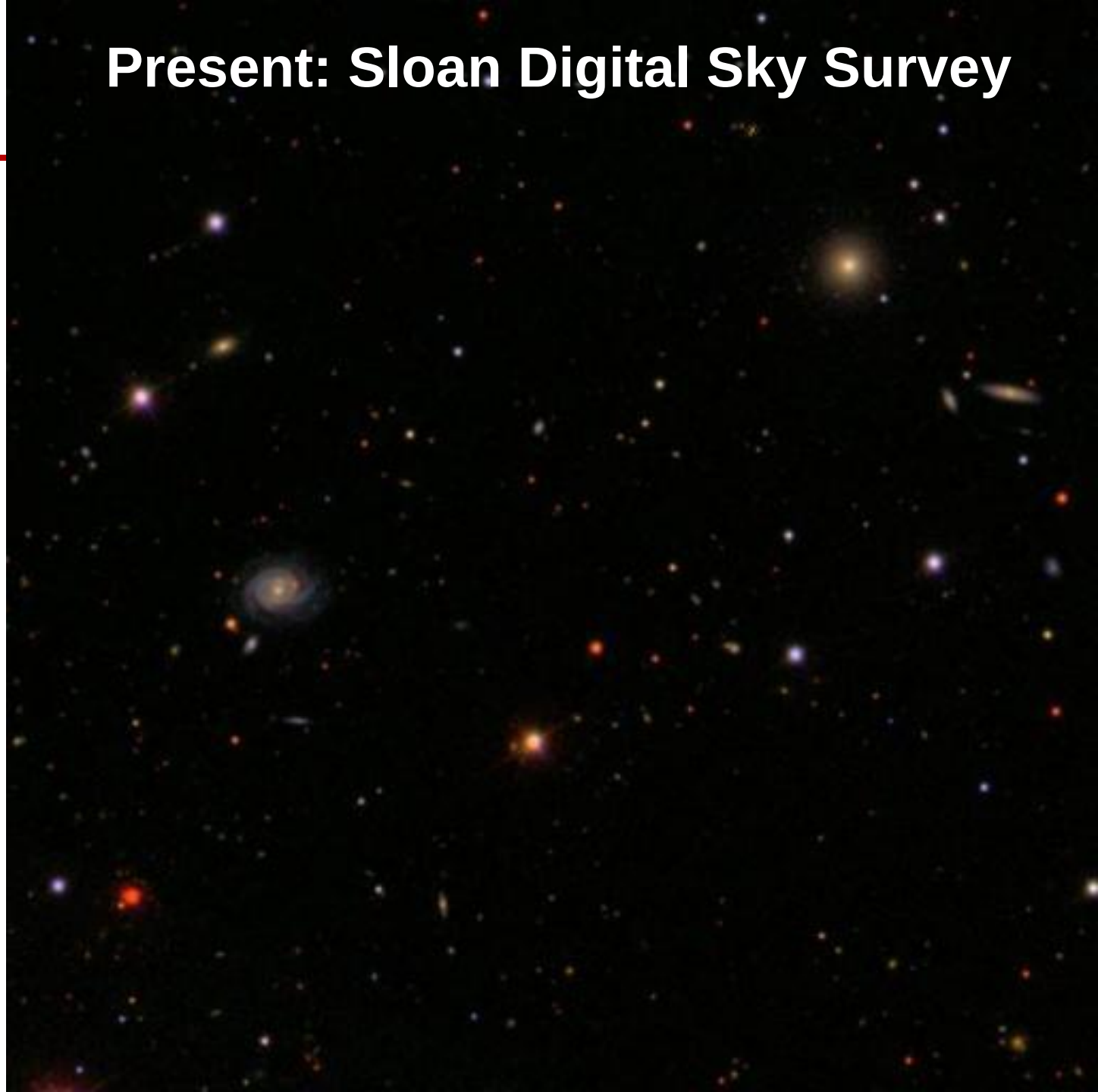
- Provide a sensitive survey of the entire sky at visible wavelengths every few nights
  - Comprehensive map of Dark Matter in the Universe through gravitational lensing
  - Resulting in tight constraints on the cosmic expansion history, and thus on the nature of Dark Energy

Broad program of astronomy & astrophysics, LSST Science Book



0.64-m diameter,
3.2 Gigapixel

Present: Sloan Digital Sky Survey



7.5 arcminutes

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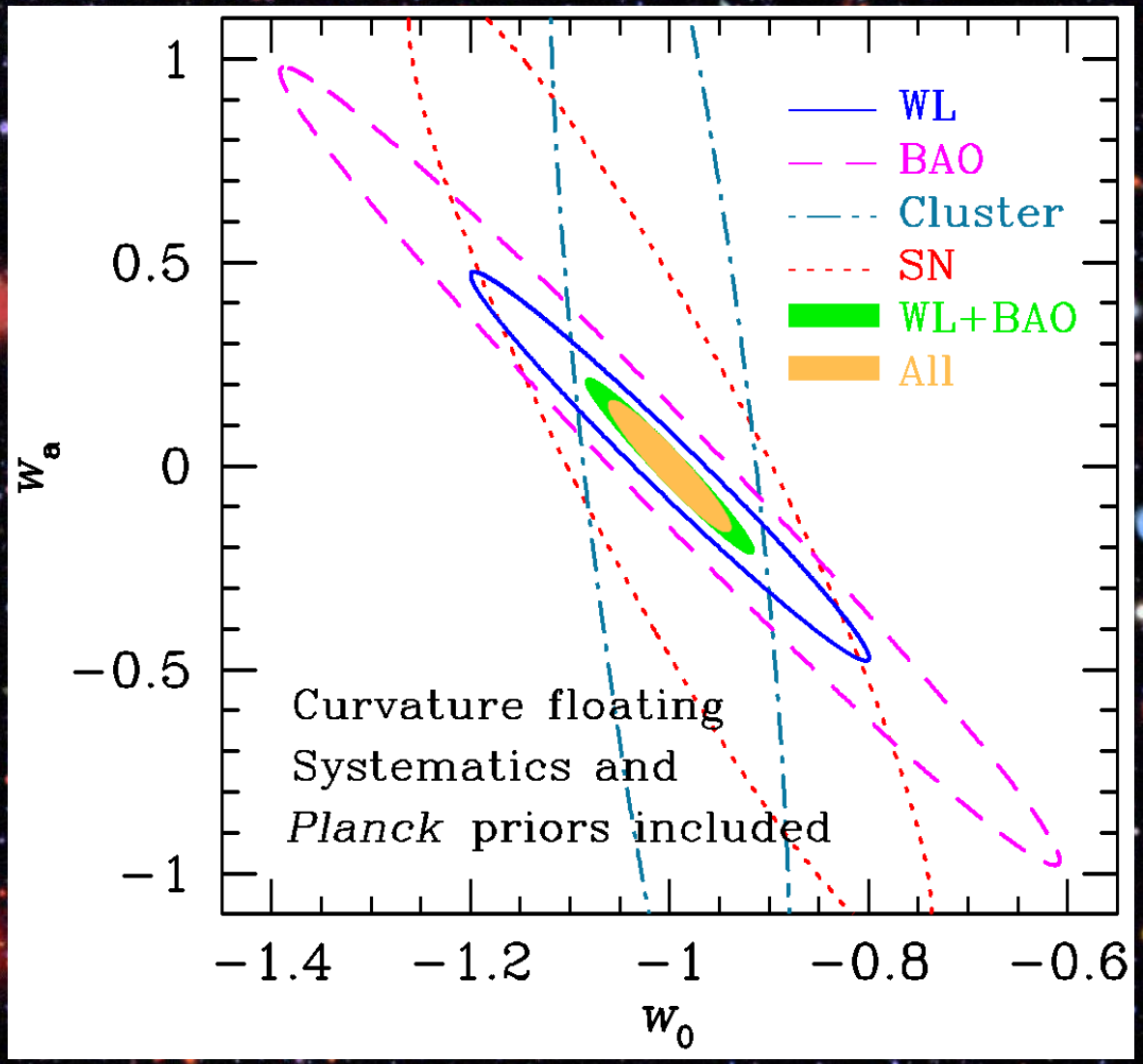
Future: LSST simulation

7.5 arcminutes

Dark Energy
Equation of state

$w = w_0 + (1-a)w_a$
$a = (1+z)^{-1}$



2800 galaxies i<25 mag

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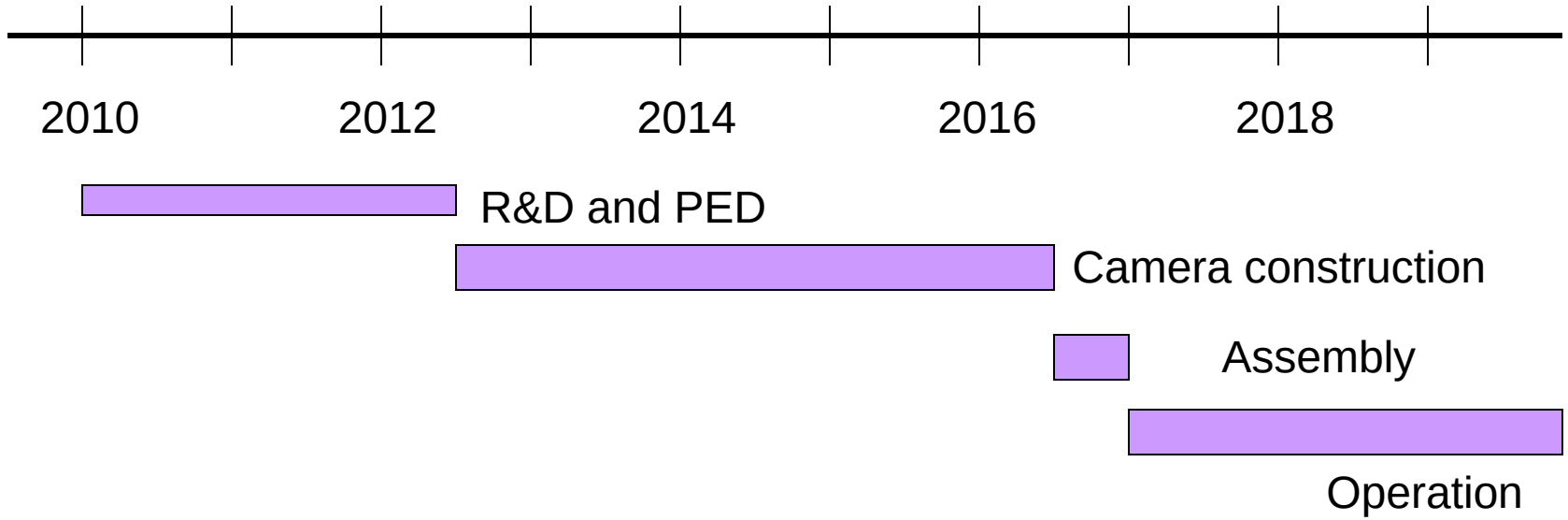
LSST evolution & challenges

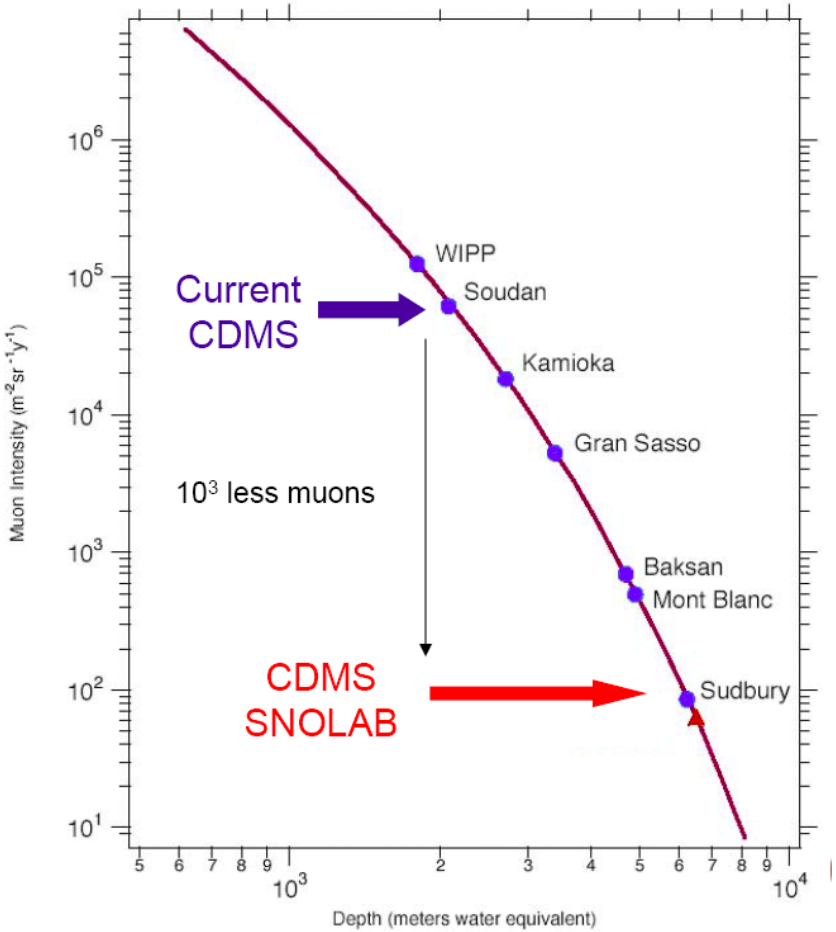


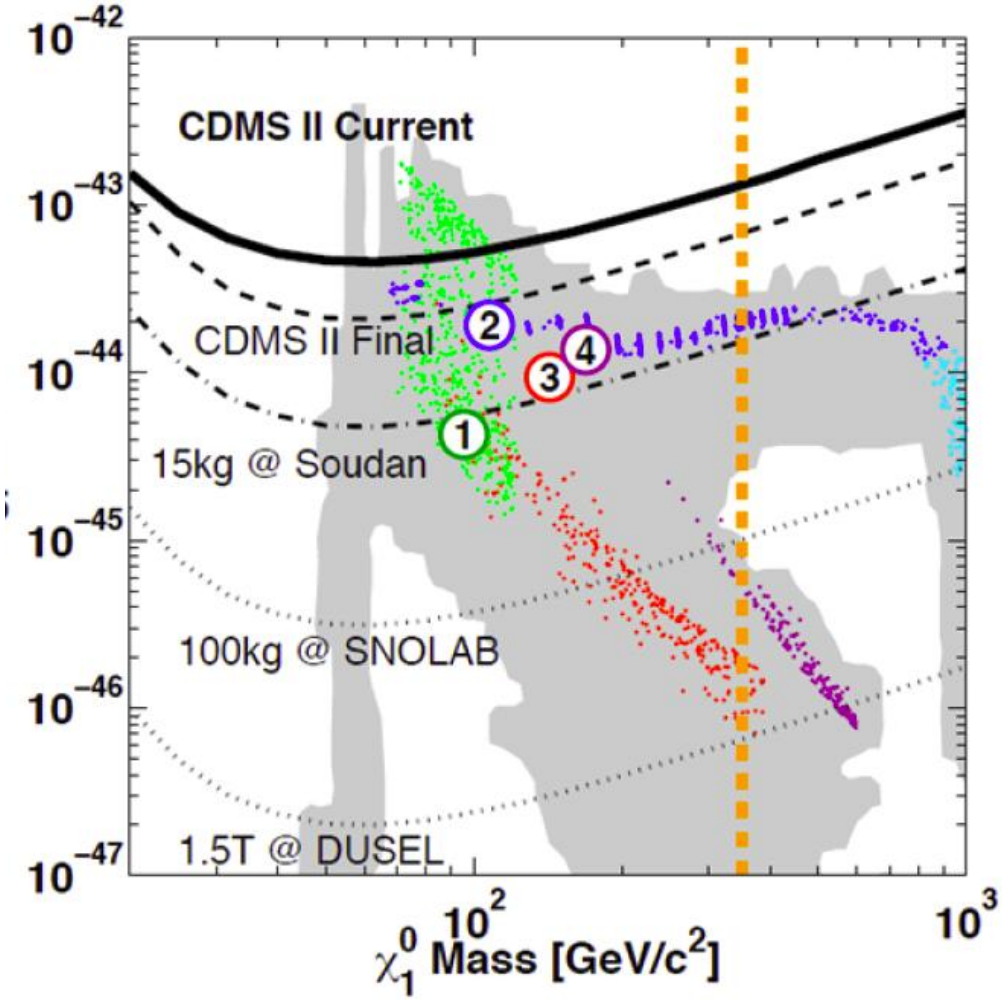
- Challenges:
  - LSST may not emerge with highest priority from ASTRO2010
  - Developing multiagency international funding for camera system
  - Building up sufficient scientific and technical team
  - Technical challenges in the camera and data management areas

Evolution of dark matter program: SuperCDMS

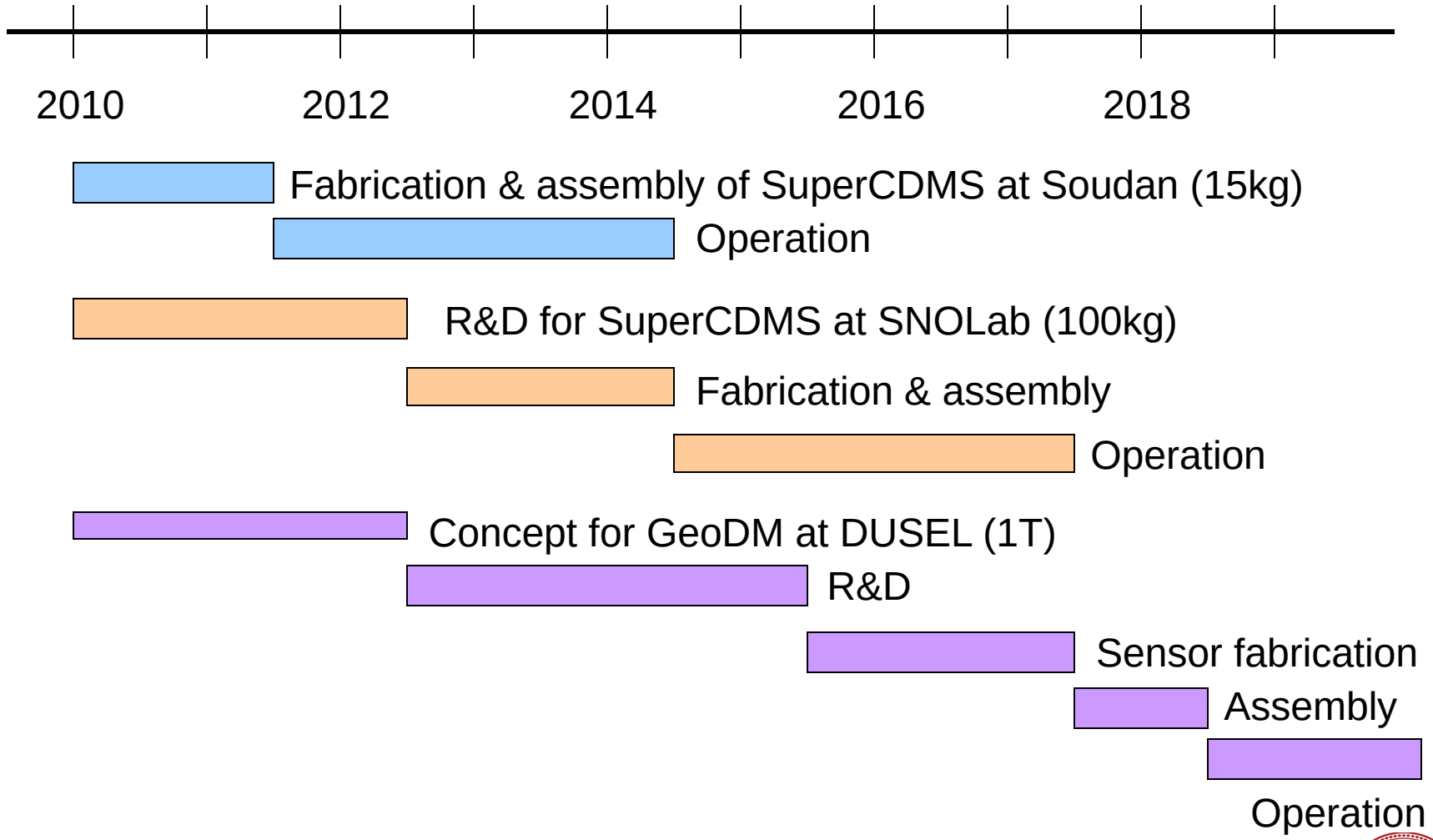
- SuperCDMS at the Soudan Mine: 15 kg
  - Joint NSF-DOE project
  - Currently discussing deployment of improved Germanium sensors (iZIP)
- SuperCDMS at SNOLAB: ~100 kg
  - Currently in the R&D Phase, expecting a CD-0 this year
  - SLAC plans to play a major role in the project
- GEODM at DUSEL: ~1000 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

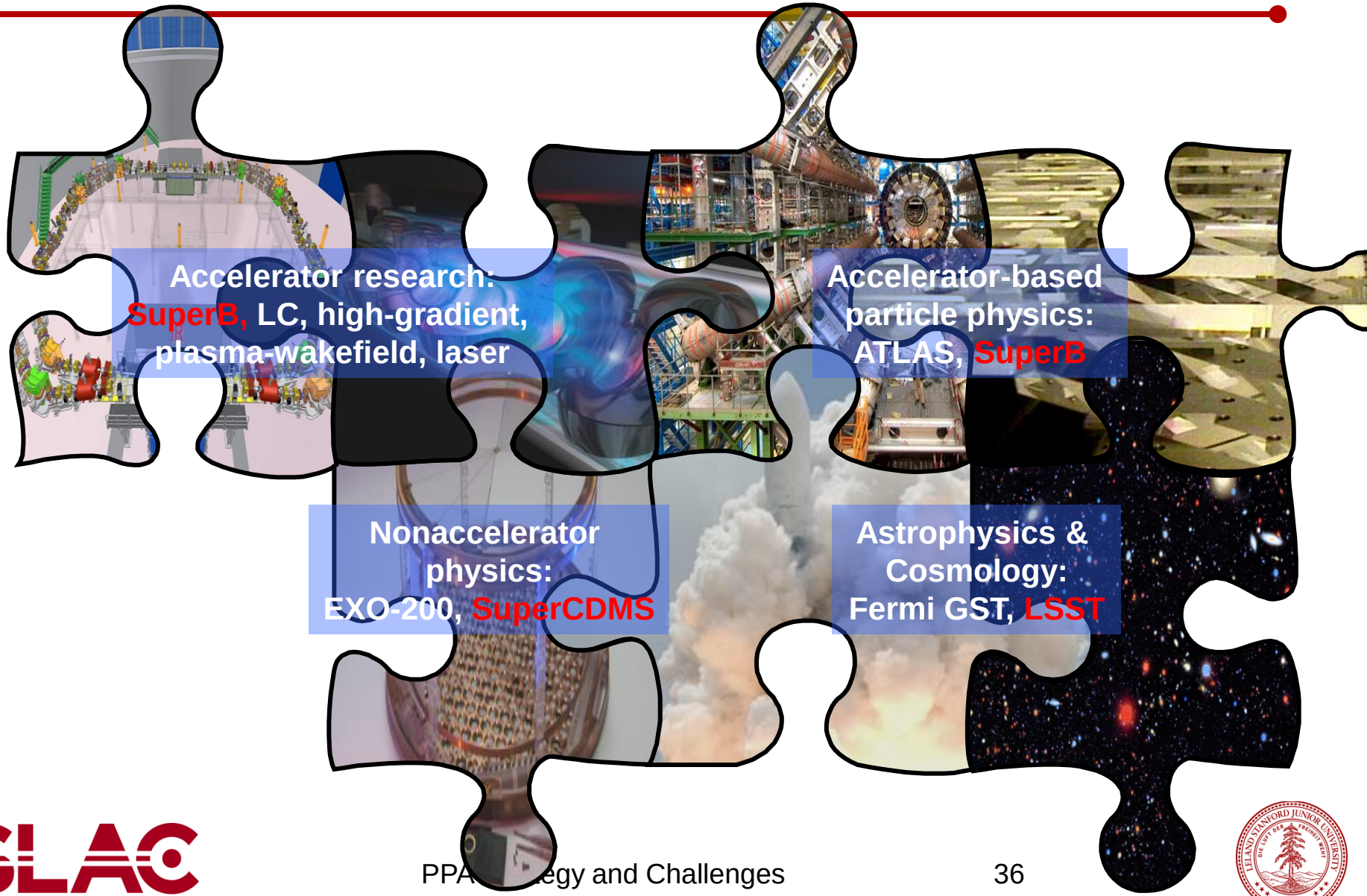


Challenges

- 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

Energy Frontier
Intensity Frontier
Cosmic Frontier

Snapshot in 5 years



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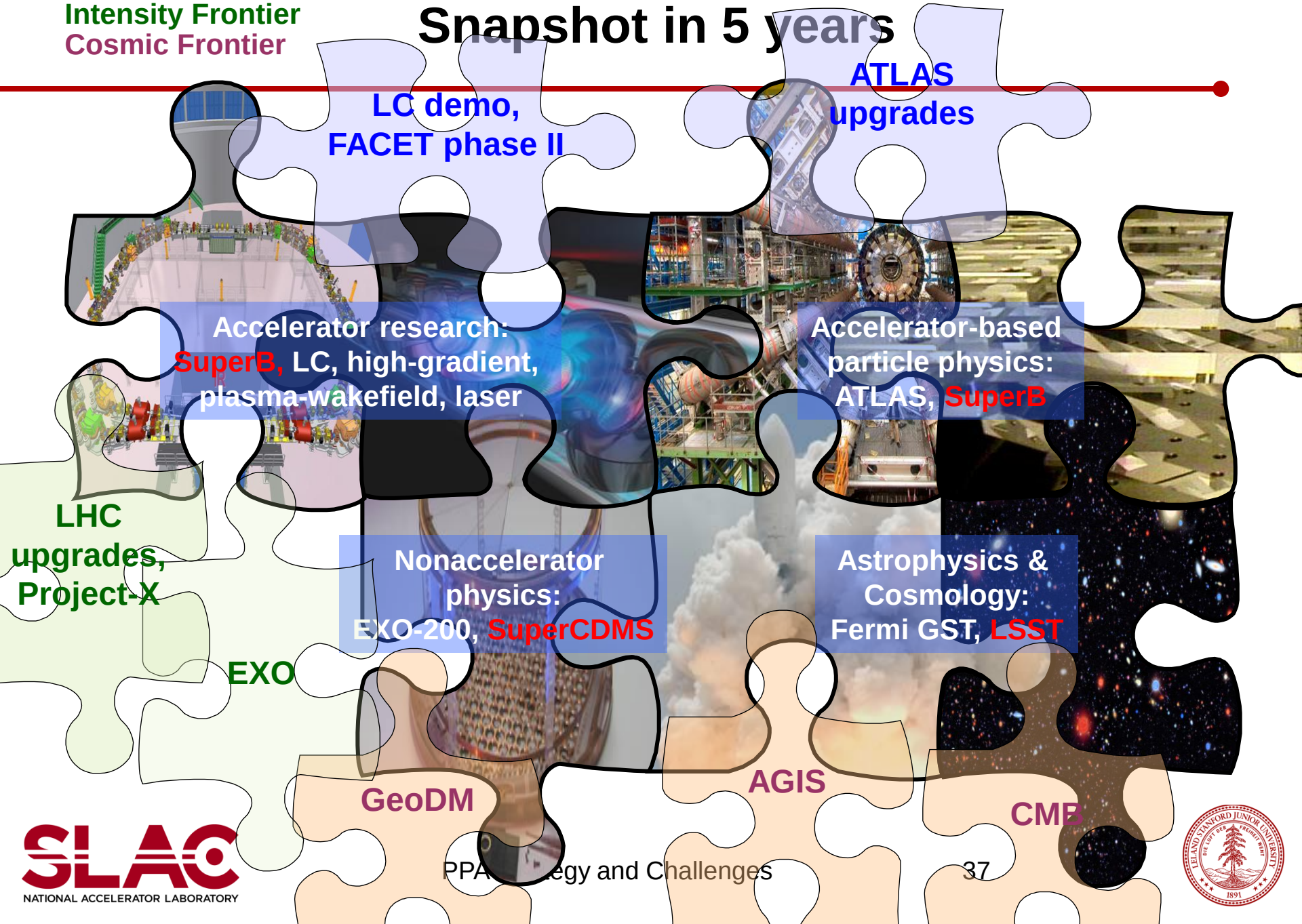
Energy Frontier
Intensity Frontier
Cosmic Frontier

Snapshot in 5 years



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SLAC Science Opportunities and Future Directions

Tied together by forefront science goals & world-class accelerator capability, enhanced by cross fertilization of ideas & techniques

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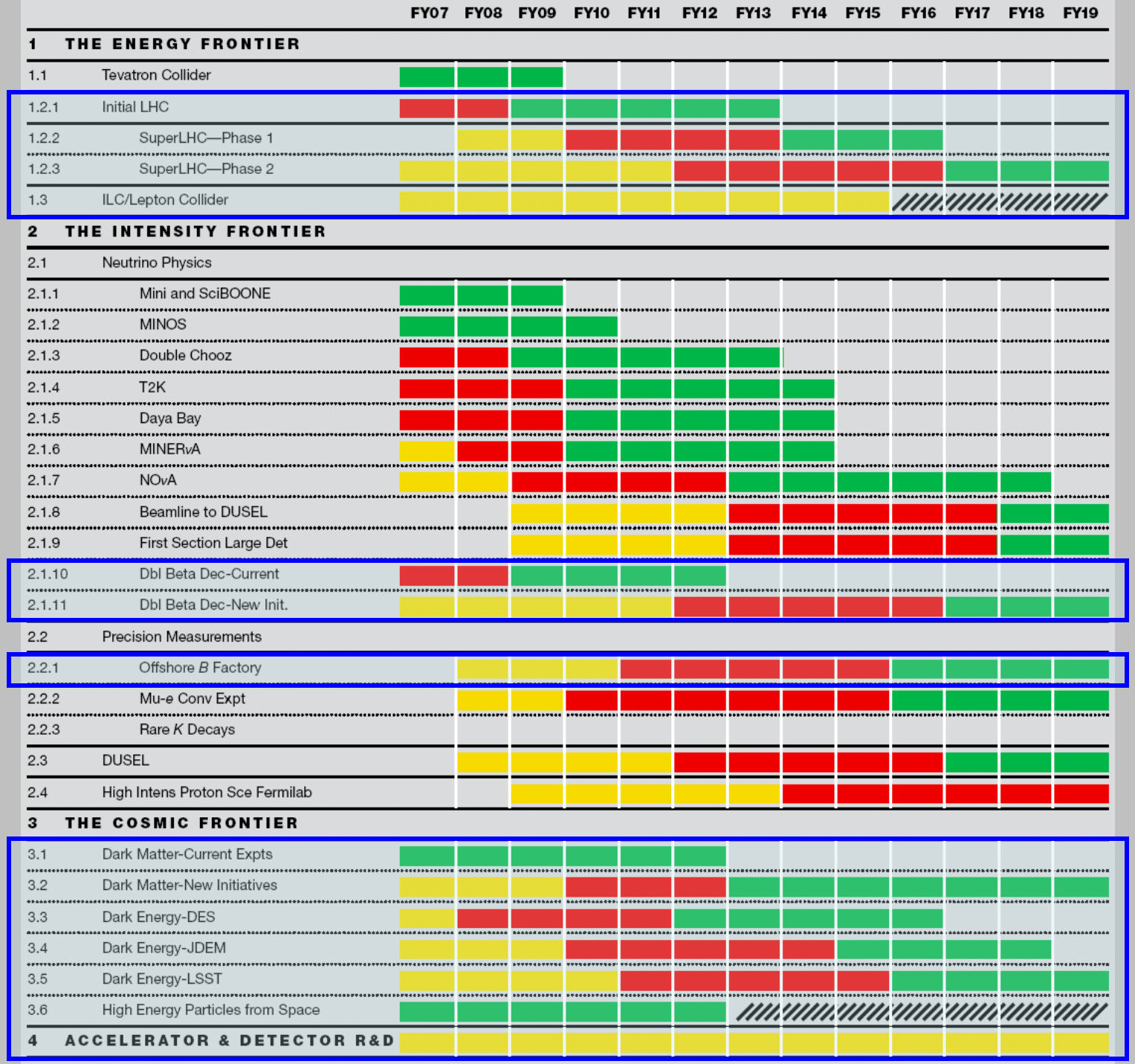
What ifs?

- 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



SLAC program

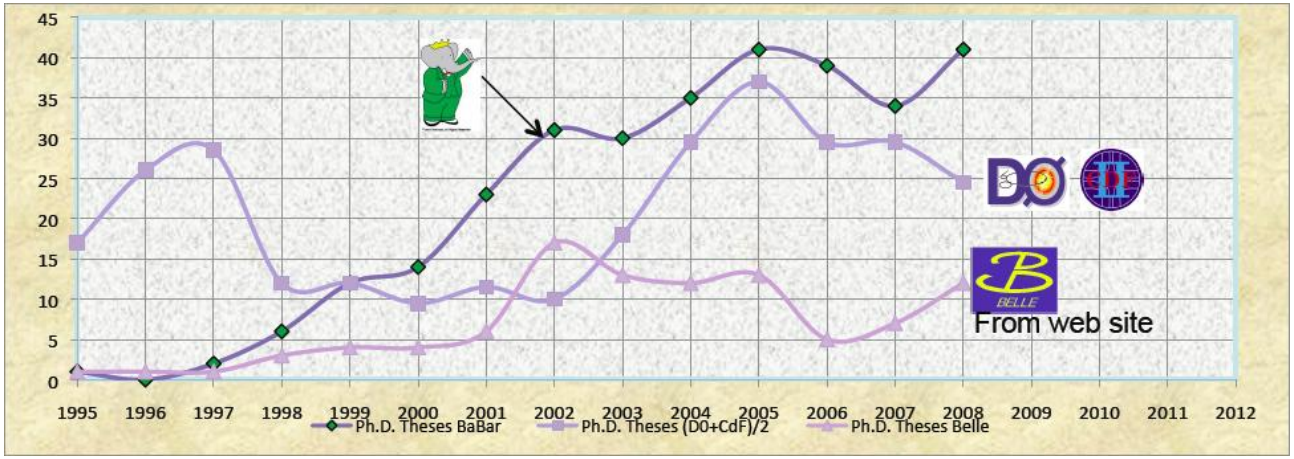
P-5 Roadmap

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

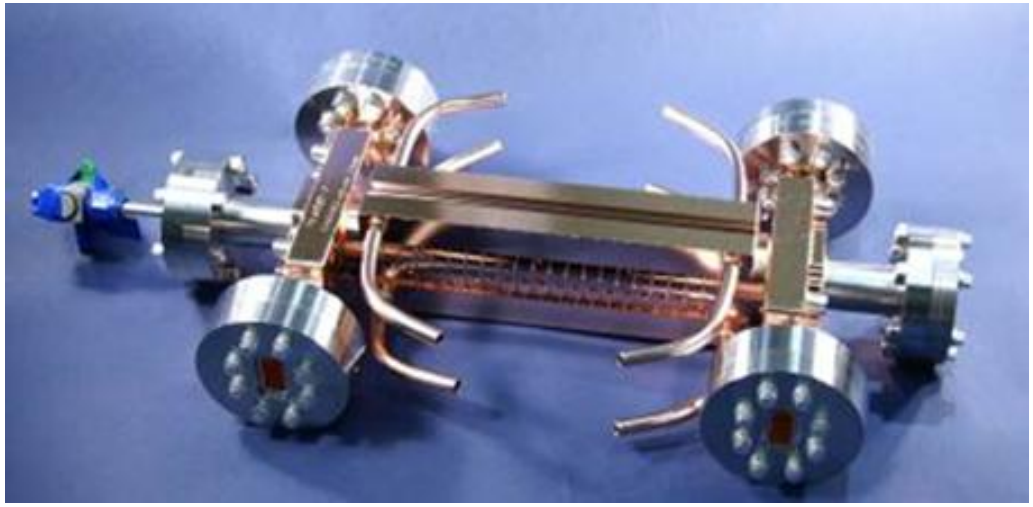


Discovery of CP violation underpins 2008 Nobel Prize to Kobayashi & Maskawa

BABAR = PhD factory as well

Accelerator science and development

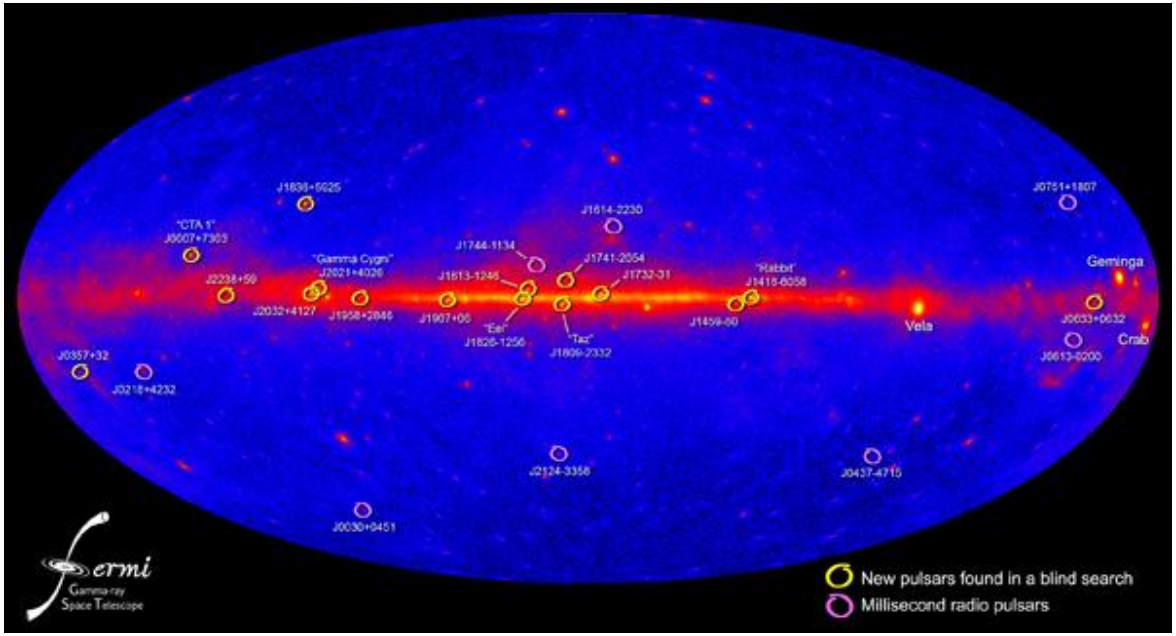
- World-class accelerator research program:
  - Playing enabling role in technology development for the ILC & leading high-gradient X-band research in the US



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

Astrophysics and Cosmology

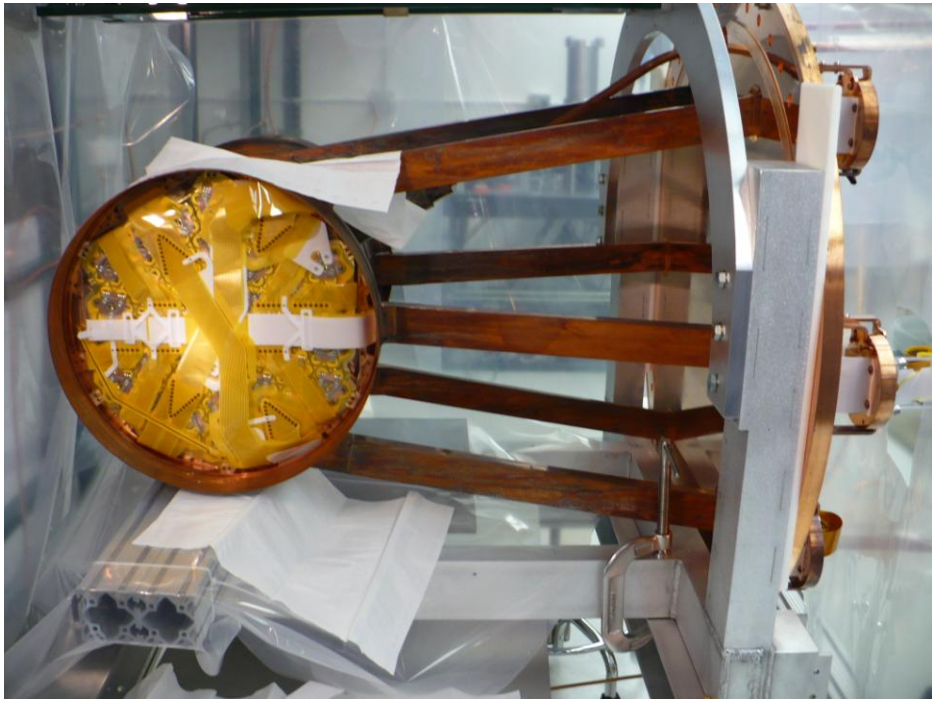
- Leading particle-astrophysics and cosmology:
  - Operating the Fermi Gamma-Ray Space Telescope and continuing scientific discoveries with this unique observatory

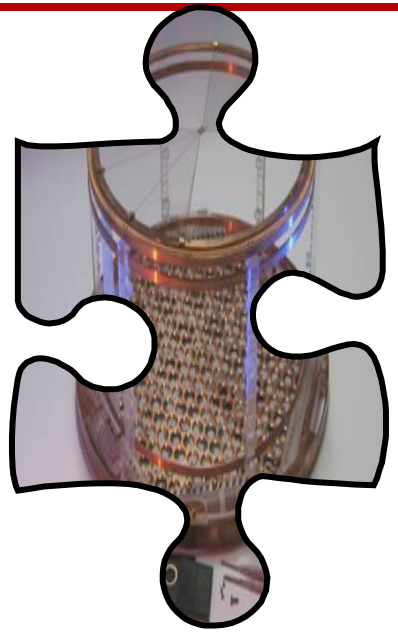


Mapping the high-energy gamma-ray universe with exquisite precision

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…

Physics-Astrophysics Building

FKB Inauguration
March 17 2006

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

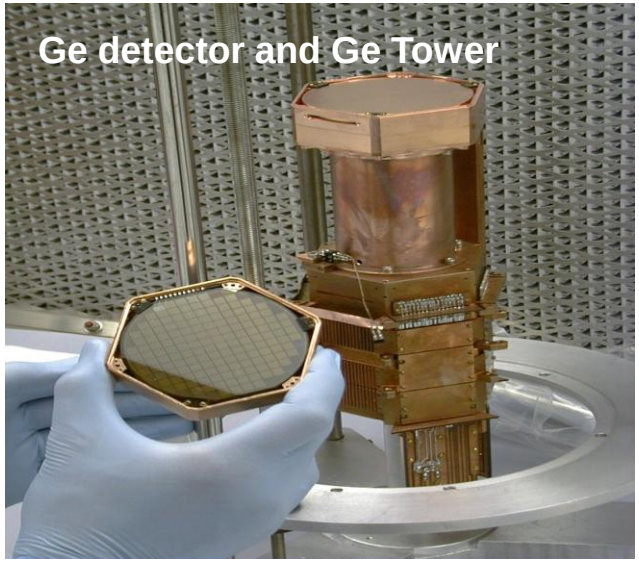
Camera technical challenges

- 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

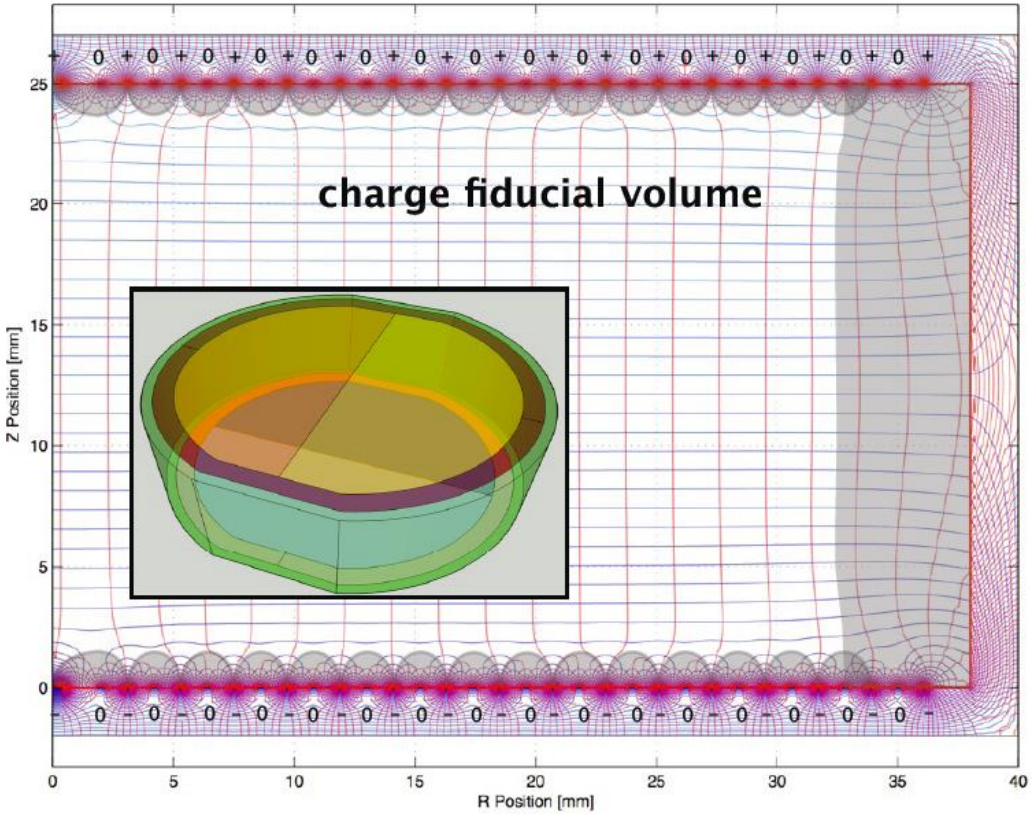
- Key areas of investigation include:
  - Procurement of crystals of large diameter (4 and/or 6 inch)
  - Optimization of fabrication process for large diameter sensors
  - Modification of laboratory equipment for large diameter sensors
  - Sensor development and quality control
  - Streamline testing 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



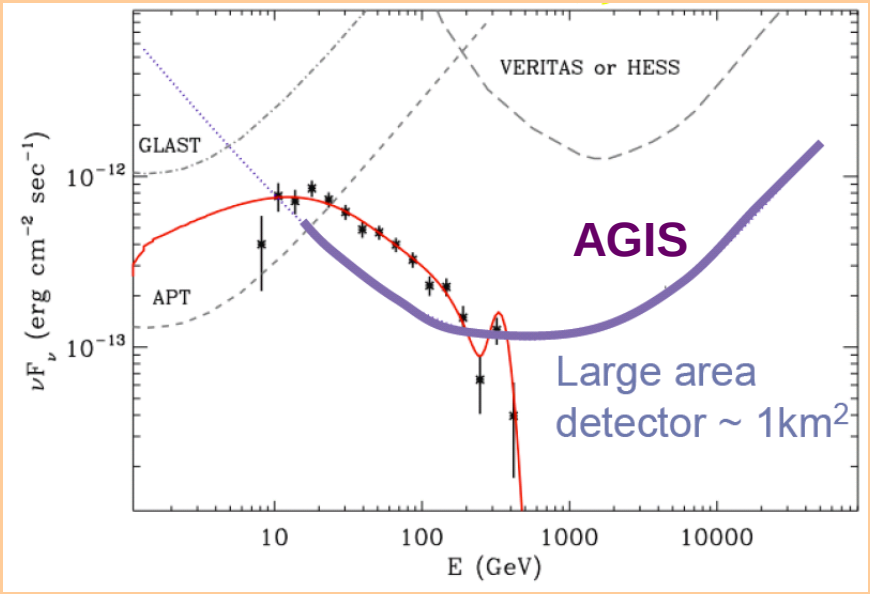
Current sensors

Next generation: 100mm diameter x 33mm thick



Advanced Gamma-ray Imaging System (AGIS)

- Next-generation ground-based γ-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



Sensitivity to annihilation cross-section

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