Summary and Outlook

Forward

Much of this talk is my personal view – where we stand and where we want to go. Be aware that I am an experimentalist with biasses and blinders as appropriate. You don't get the erudite theorist view of the world here. And you get a non-expert view of many of the topics.

Figures and plots are borrowed from many talks and friends, not always with complete attribution. My thanks to my colleagues!

My thanks to all the speakers at the conference – exceptionally high quality. And to the organizers for the good choices made.

This talk is my mostly my personal perspective, not that of the DOE where I am on leave this year. For those things with DOE hat on, I'll denote with the green background.

So often we feel at the end of a conference that there was little new. But think back 5-10 years and gauge the progress that has been made.

- Unitarity triangle then and now. From despairing control of penguin loops to exploiting them to shine light on new physics.
- Pinning down the EW SM – precision Z, W, top measurements have constrained the nature of EWSB mechanisms.
- Finding and verifying the existence of dark energy through cosmic microwave background and supernovae maps.
- Progress from understanding that neutrinos must oscillate, to quite precise measurement of mass squared differences and mixing angles.
- Knowledge of proton structure – and extension to spin structure, low x, high Q^2, heavy quarks.
- Idea of QGP as ideal gas of free colors is replaced by what seems to be a very rapidly equilibrated nearly ideal liquid.
- Learn to calculate on the lattice and change the landscape for flavor and QCD physics.

HEP is incremental – each new piece of understanding or technical advance raises the vantage point. And despite the lack of SM departures, the foundation we have built has become steadily more solid.

Summarize?? ~50 talks on very diverse topics

2006 Aspen Winter Conference on Particle Physics Program, v1.8

"Particle Physics at the Verge of Discovery"

	12-Feb Sunday	13-Feb Monday	14-Feb Tuesday	15-Feb Wednesday	16-Feb Thursday	17-Feb Friday	18-Feb Saturday
Morning	**Arrival**	**Chair: John Womersley**	**Chair: Matthias Neubert**	**Chair: Marcela Carena**	**Chair: Sally Dawson**	**Chair: Estia Eichten**	**Chair: Greg Landsberg**
8:00-8:30am		First Results from Pierre Auger Aaron Chou	New Physics in B-Decays Gudrun Hiller	Panel "Funding Future Findings" Dawson, Dorfan, Oddone, Roe, Ruchti, Shochet	LHC Phenomenology Steve Mrenna	Models of EW Symmetry Breaking Maxim Perelstein	New Ideas Gia Dvali
8:30-9:00am		Tevatron Searches Qizhong Li	Rare B-Decays and New Physics Klaus Honscheid		Extra Dimensions: Phenomenology Eduardo Ponton	Electroweak Baryogenesis Mariano Quiros	
9:00-9:30am		Top + EW Physics Theory Laura Reina	Rare B-Decays from B-Factories Henning Flaecher		Split SUSY & New Ideas Nima Arkani-Hamed	SUSY Dark Matter Csaba Balazs	Summary and Outlook Paul Grannis
9:30-10:00am		**Coffee Break**					
10:00-10:30am		Tevatron Top Physics Andrew Ivanov	CP-Violation from B-Factories Hiro Aihara	Tevatron for LHC Michael Schmitt	On the Way to ILC Shekhar Mishra	Searches for Dark Matter Rick Gaitskell	**End of the conference!**
10:30-11:00am		Tevatron EW/QCD Physics Heidi Schellman	Progress in Heavy Flavor Theory Thomas Becher	LHC - Status of the Machine Roger Bailey	Physics at the ILC Graham Wilson	Dark Matter: Lighting up the Stars Alex Kusenko	
11:00am-4:30pm		**Free time/skiing**					
Afternoon		**Chair: Paul Grannis**	**Chair: Klaus Honscheid**	**Chair: Fred Gilman**	**Chair: Syd Meshkov**	**Chair: Mirjam Cvetic**	
4:30-5:00pm		New Results from HERA Andrew Mehta	Status of CLEOc Ian Shipsey	LHC - Status of the Detectors James Rohlf	Neutrinos: Global Fits & Model Bldg. Paul Langacker	Dark Energy: Obs. & Theory Rachel Bean	
5:00-5:30pm		HERA for LHC Roberto Carlin	New States Above Charm Threshold Estia Eichten	LHC Physics with 1 fb^{-1} Robert McPherson	MiniBoone Results Ion Stancu	Braneworld Gravity Jose Santiago	
5:30-6:00pm		**Coffee Break**					
6:00-6:30pm		LHC: Total Cross Section Martin Block	RHIC - Theory Dmitry Kharzeev	Progress in Lattice QCD Howard Trottier	First Results from MINOS Niki Saoulidou	CMB Measurements Jonathan Sievers	
6:30-7:00pm		Gamma-Ray Astrophysics Loic Rolland	RHIC - STAR James Dunlop	**Dinner (6:30-7:15)** **Walk to Wheeler Auditorium**	Reactor Experiments David Reyna	String-Inspired Methods in QCD Marcus Spradlin	
7:00-7:30pm	**Reception**	Tevatron Heavy Flavors Cheng-Ju Lin	RHIC - PHENIX Brian Cole		LHCb Experiment & Physics Sheldon Stone	The Landsape Shamit Kachru	
7:30-8:30pm		**Dinner**	**Dinner**		**Banquet** **Tango Evening**	**Dinner in Aspen**	
				7:30 - Public Lecture "The Quantum Universe" John Womersley			

Instead, I will show a few highlights that captured something important for me.

The Energy Frontier

The Tevatron is working very well. Recent improvements in accumulating antiprotons have shown that 6 fb^{-1} by 2009 can be reached. Another equivalent improvement would allow reaching 8 fb^{-1}.

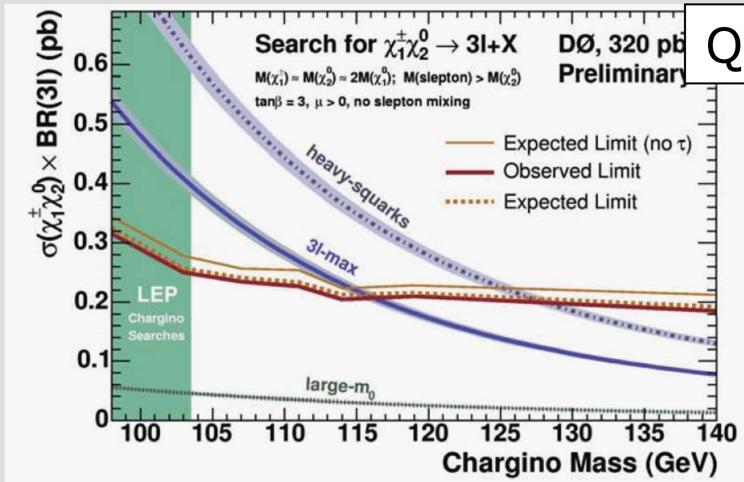
At the least, the Tevatron physics analyses and detector operations are teaching us how to work at the LHC. At the best, indications of new physics will emerge. In the middle range, measurements (m_{top} & m_W refining the constraints on Higgs, tt production properties, heavy flavor production, B_s mixing, rare B decays, and the closure of allowed ranges for new physics will occur.

M. Schmitt’s and S. Mrenna’s talks showed many ways in which the experience – and data – from the Tevatron will inform the way LHC experiments can smooth their way to early physics results.

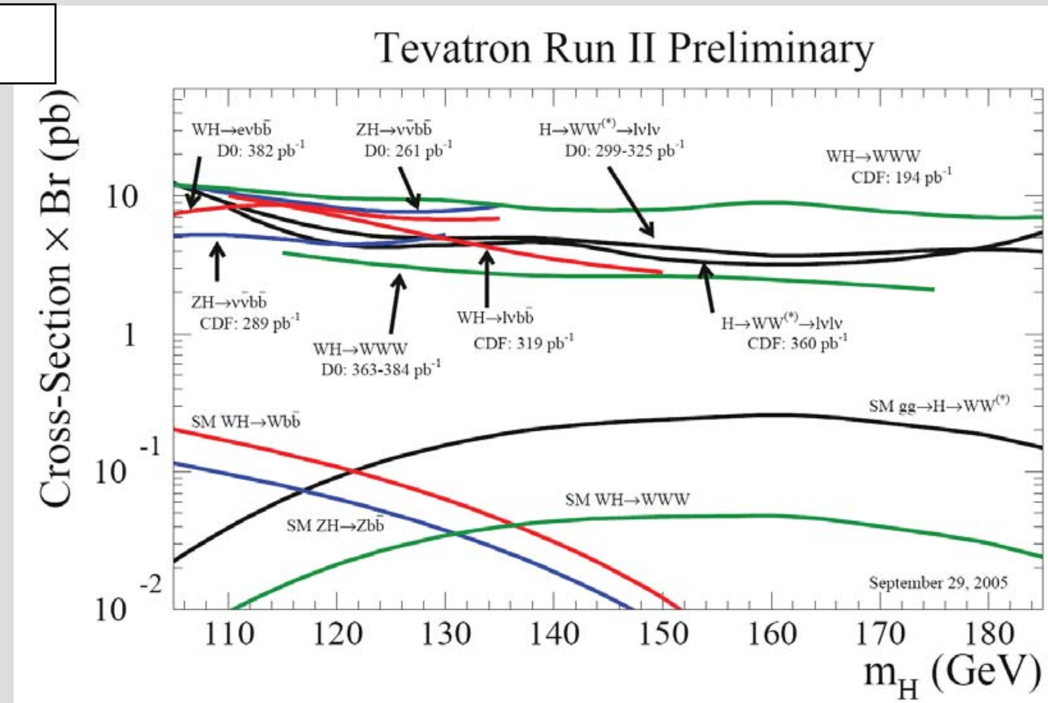
A large part of the story is becoming more clever when you have data.

The Tevatron experiments learned much from UA1 and UA2; the Atlas and CMS can profit enormously from the knowledge of CDF and DØ.

Q. Li

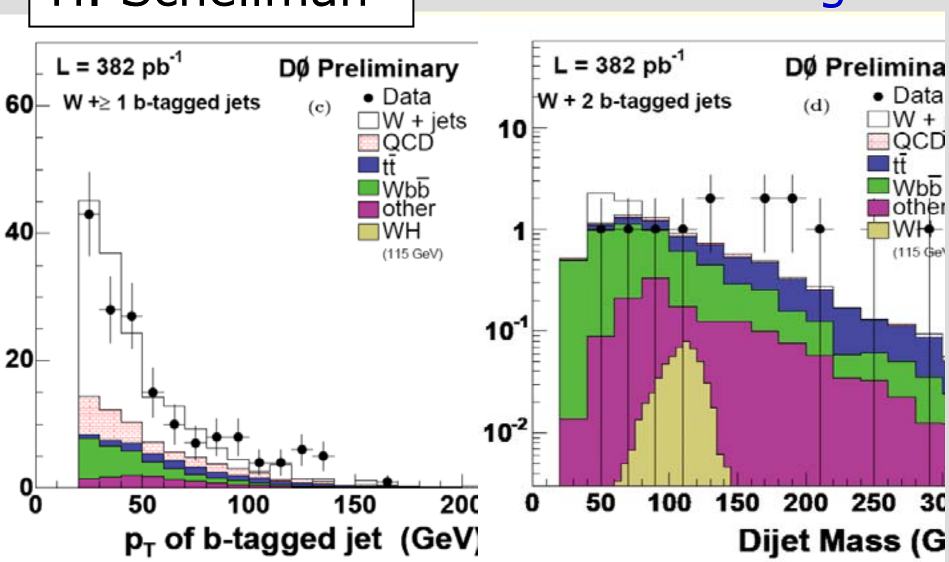


Susy searches are extended (chargino-neutralino via 3 lepton final states)

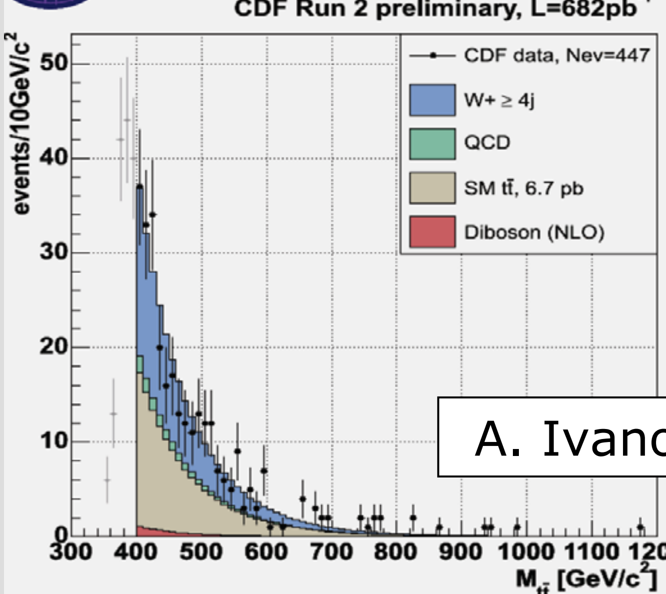


SM Higgs – many channels. With about 1/25 of expected final data sample, still a long way to go. Improvements seem plausible but are still to be demonstrated.

H. Schellman

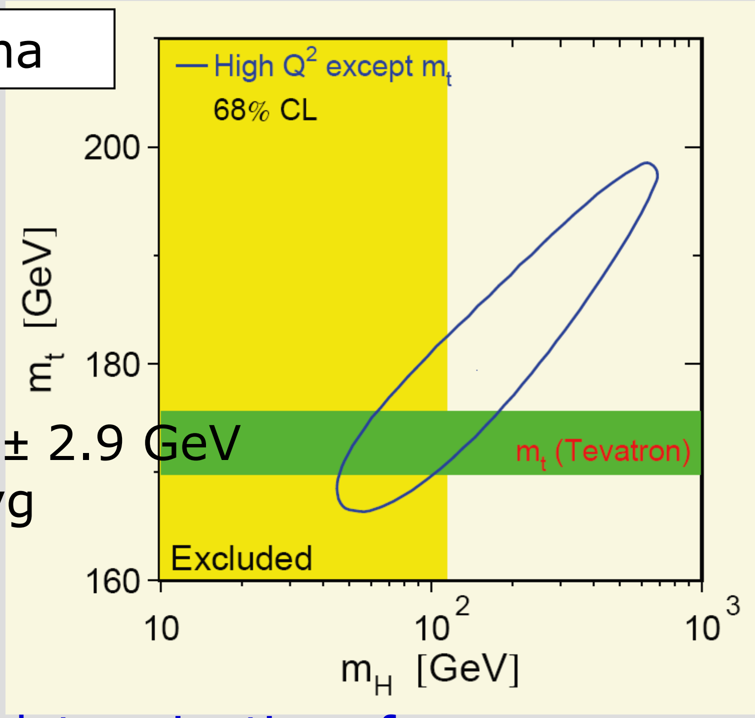


Measurements of W/Z + 1,2 b jets are now being made. Important for pQCD and for calibrating backgrounds to searches.



A. Ivanov

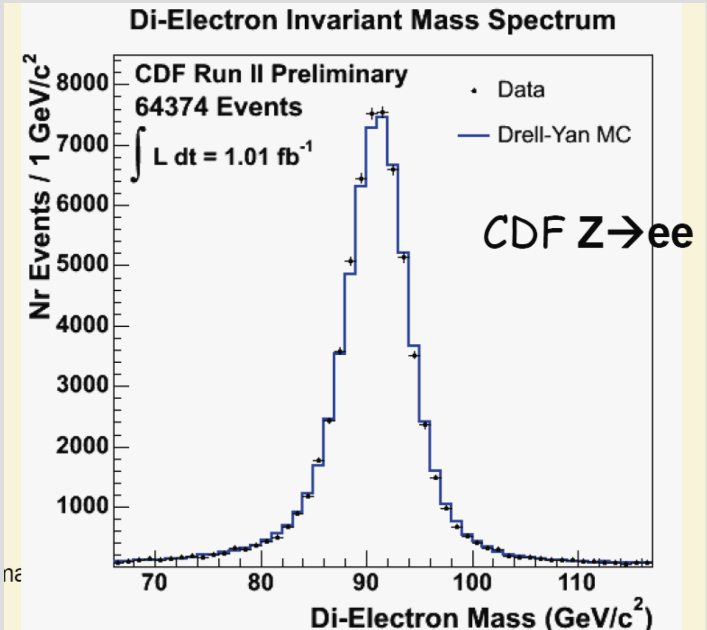
L. Reina



M_t = 172.7 ± 2.9 GeV
Tevatron avg

tt resonances? Not this year.
But string models would like.

Top mass determinations from many channels, matrix element analyses, improved jet energy scales – giving tight constraints on SM Higgs. Need to get the new M_W analyses.

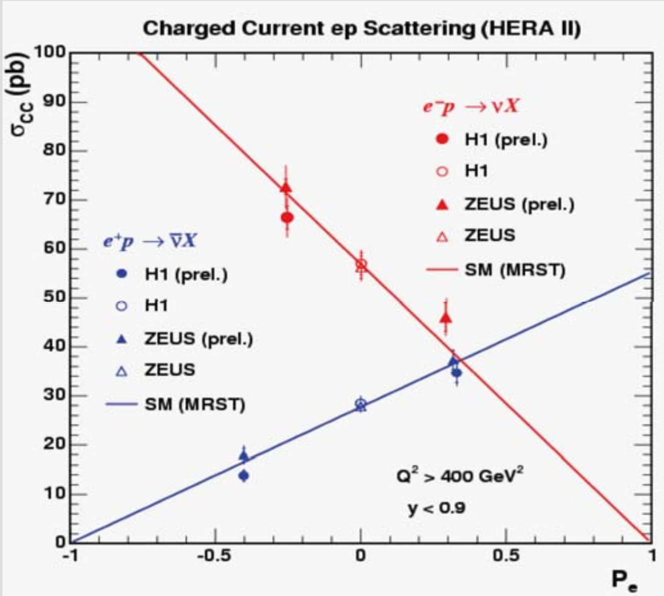


CDF Z→ee

First data plot with > 1 fb^{-1} ; three more doublings of data will give exciting new opportunities.

A. Mehta

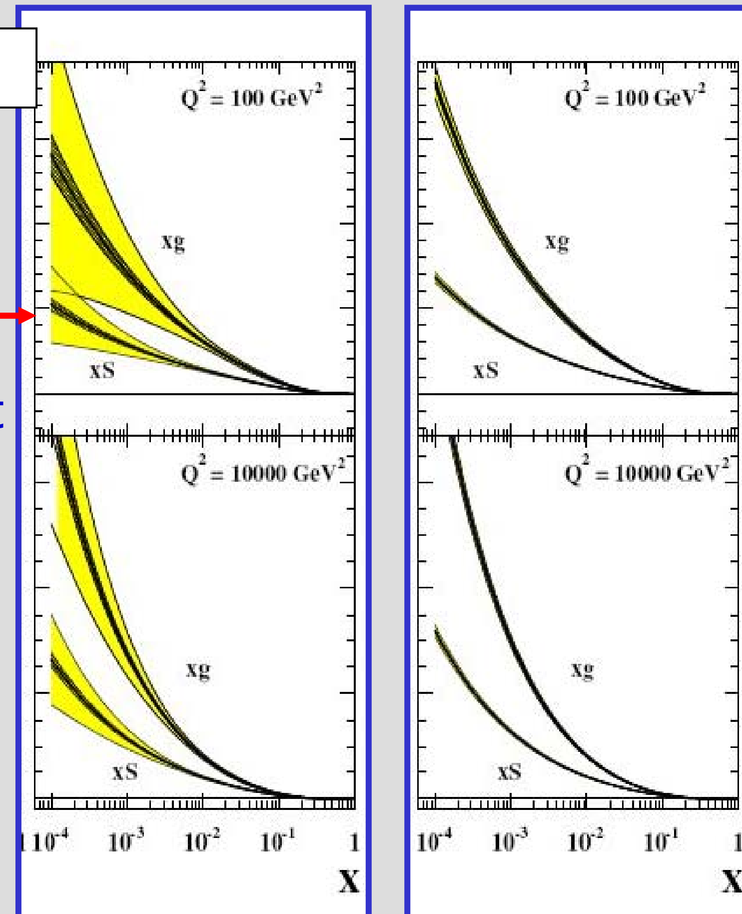
HERA



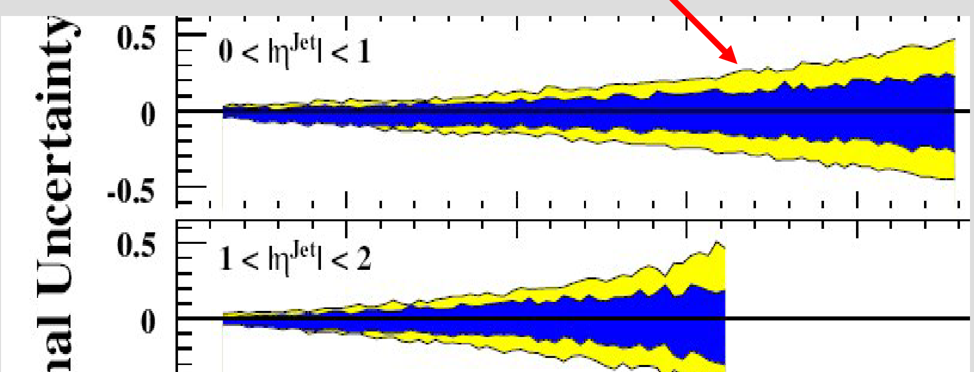
H1 and ZEUS results over 12 years on proton structure are seminal advances. The beautiful structure functions are for the textbooks.

HERA is now running with polarized electrons. Experiments demonstrate RH charged current directly.

R. Carlin



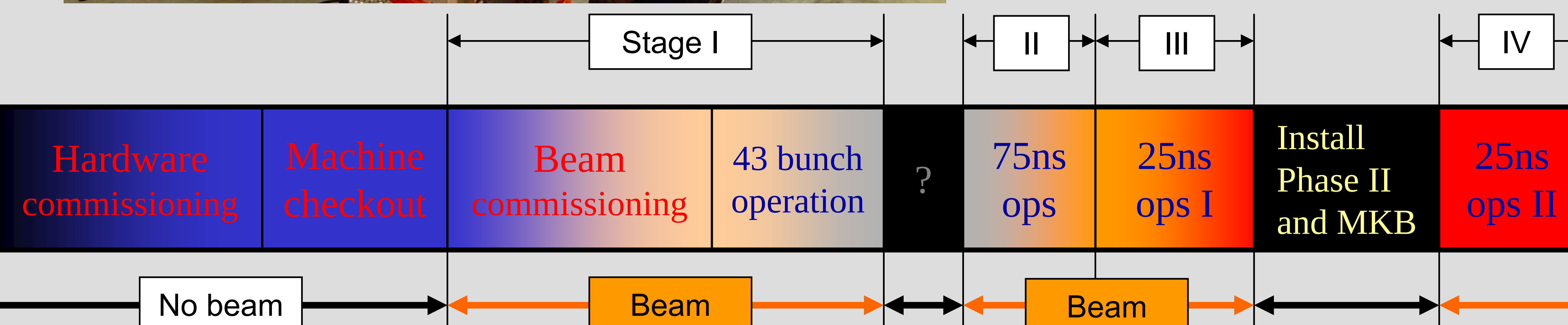
What has HERA done for our understanding of the PDFs – the engineering input for all measurements at a hadron collider? The yellow bands indicate what we would know without HERA. In turn, the effect on LHC jet cross section uncertainty is dramatic.



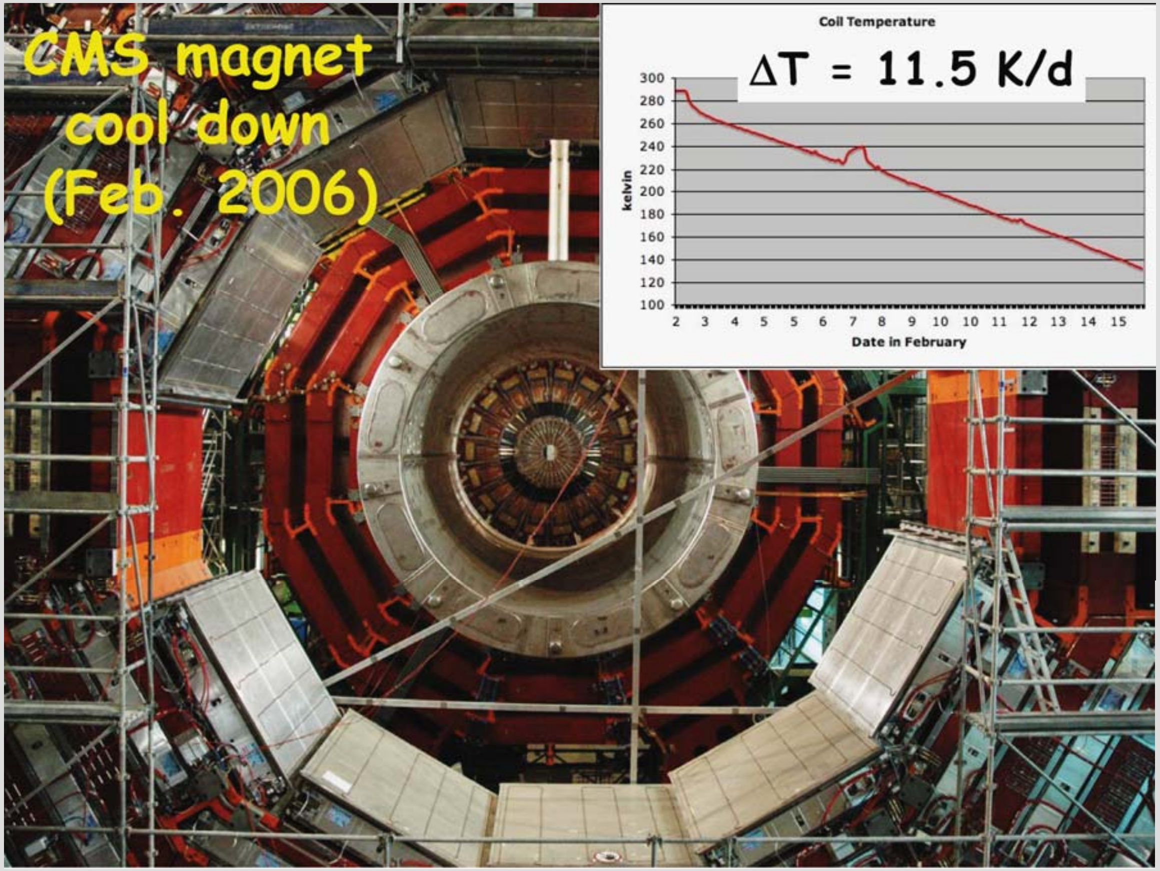
The advent of the LHC

R. Bailey outlined the LHC machine installation and commissioning plans. The former is aggressive. The latter looks sensible and should give O(1 fb^{-1}) samples by ~2008-9. Shutdowns, MD, special runs will limit high ***L*** data collection to <50%.

LHC is now taking form in the tunnel! Good to see.



ATLAS and CMS are being installed and tested with cosmic rays; the experiments are coming into being – magnets, calorimeters, muon systems, tracking are all coming into place (**J. Rohlf**).



The experiments as physics instruments are becoming real – understanding how to commission, calibrate, analyse the first data (**R. McPherson**)

The path for the next 3 years will be frustrating, exhausting, and exhilarating. The LHC program carries our field for next decade; we cannot allow this program to flounder.

The prospect of the ILC

S. Mishra reported on the good progress by GDE in establishing the ILC baseline design, the basis for Reference Design and costing by end 2006. A broad R&D program worldwide, with particular emphasis on SC cavities and cryomodules, rf power and distribution.

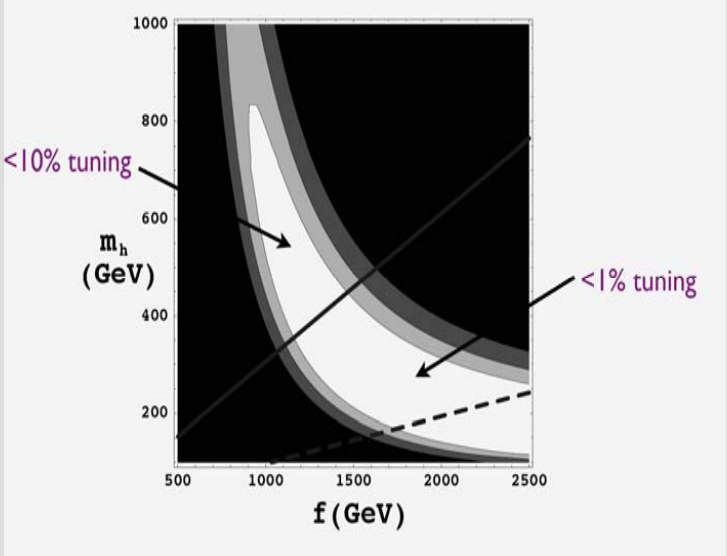
Currently envision a technically limited schedule that could start construction early in next decade. The decisions on site and construction approval by governments, ILC organization are being addressed and are at least as hard as the technical issues.

G. Wilson emphasized the complementarity of the ILC and LHC physics capabilities. For a wide variety of possible physics chosen by Nature, the two programs together are much more than either alone.

EWSB mechanisms

M. Perelstein

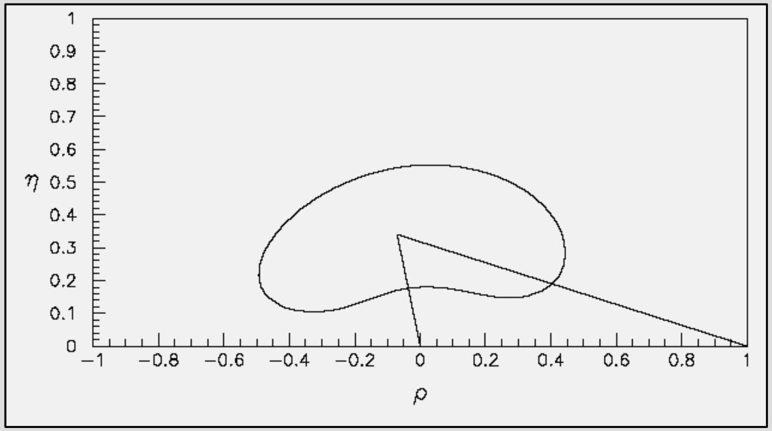
We know we need new physics to explain EW symmetry breaking. In addition to our old friends Susy, Technicolor we now have Littlest Higgs (bringing in heavy Top T, new gauge particles, scalar triplet), and extension with T parity – giving new negative parity Q# to new particles. Lightests T-odd is DM candidate. The Higgs may be heavy.

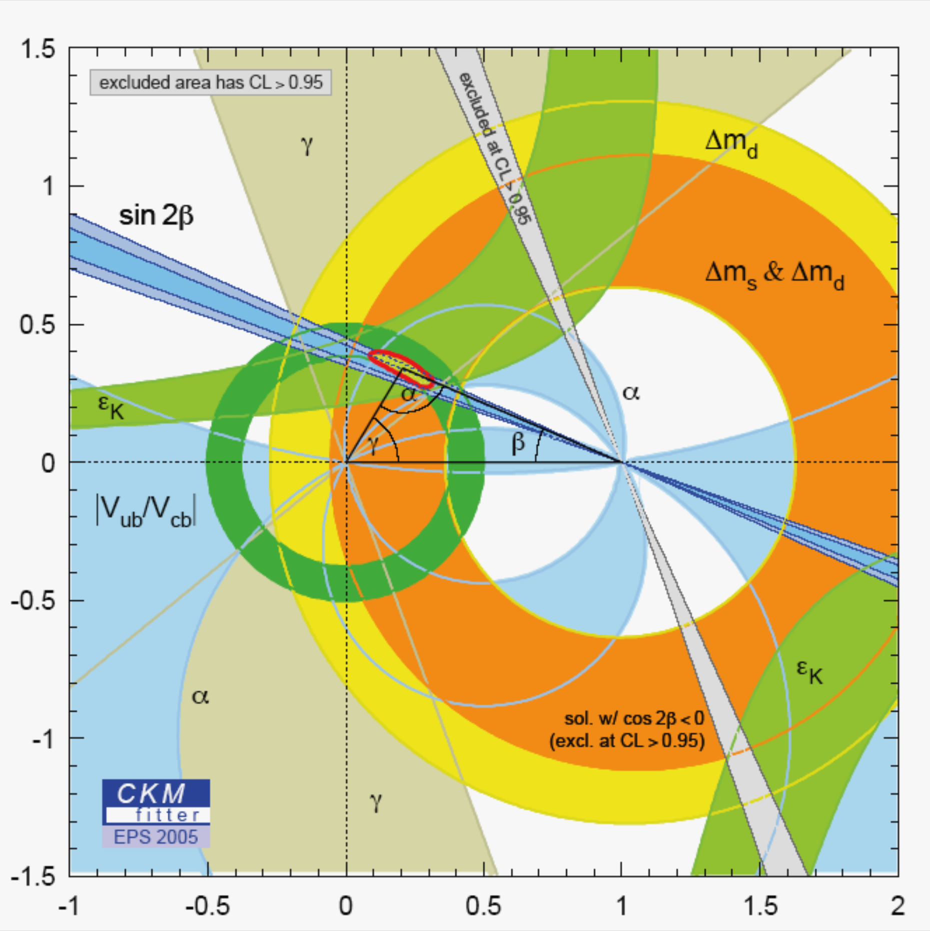


E. Ponton

Many variations on extra dimension models – number, size, metric. Discussion here on universal extra dimensions with all fields in bulk; 6-dim. model has nice phenomenology. Modulo 3 generations; RH ν's; suppress proton decay. Predict observable tt resonances at Tevatron or LHC.

The Precision Flavor Frontier



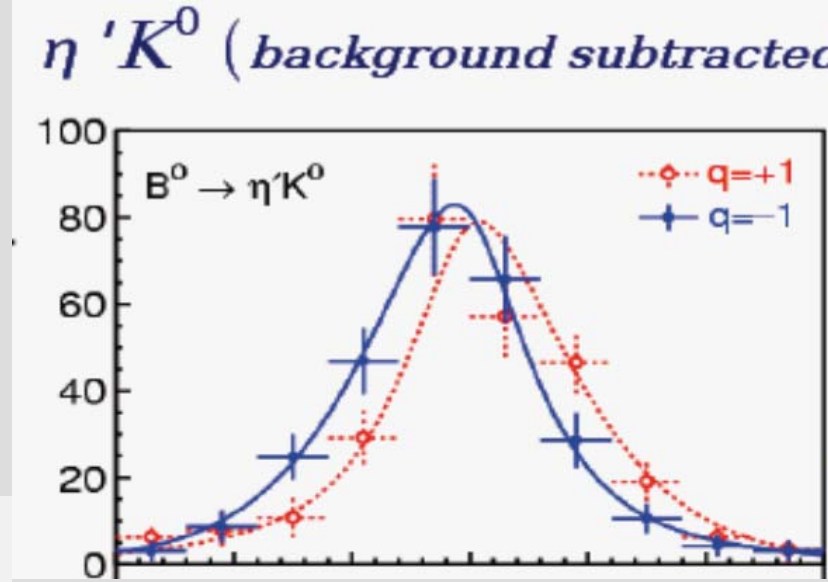


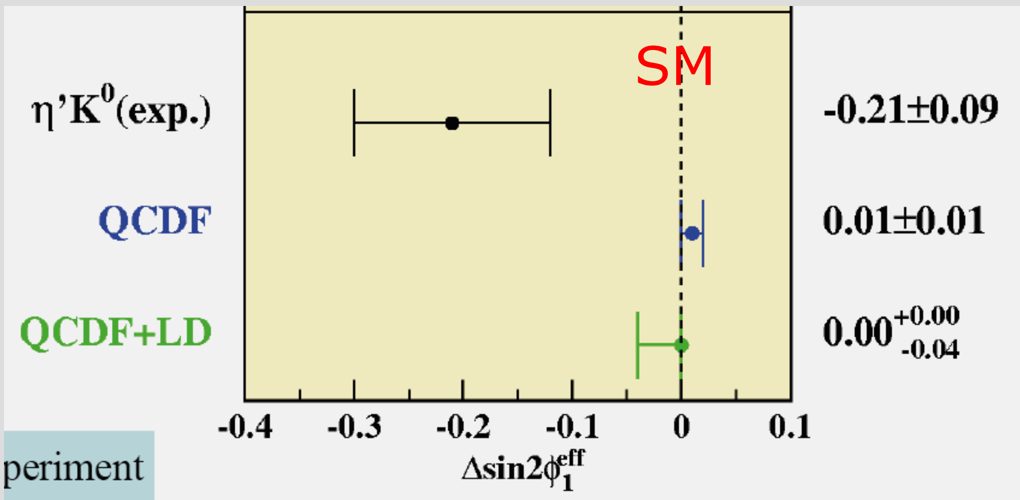
1995 → 2005

The triangle seems to close; we now have many constraints on sides, angles. (and the plots have become more colorful!)

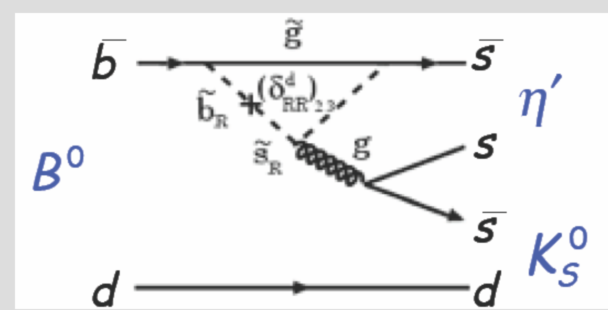
Talks by C-J Lin, G. Hiller, K. Honschied, H. Flaecher, H. Aihara, T. Becher, I. Shipsey, S. Stone

Sin2β measurements in decays where loops contribute continue to show a hint of deviation from the tree b → ccs processes. The largest deviation is in η'Kº (2.3σ). Calculations show SM corrections are unlikely to be the cause.



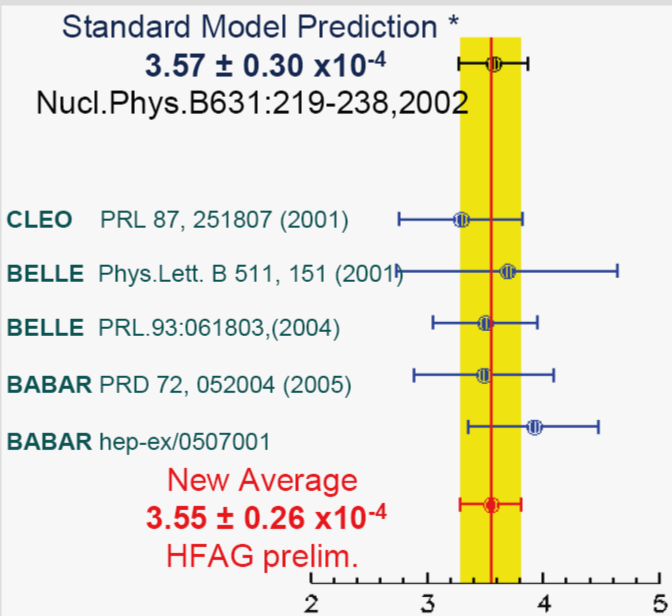


If the deviation is real, we will sense BSM physics. Though we can't distinguish the cause from such measurements, combining information from LHC/ILC with the precision measurements of B factories will give added insight on couplings.

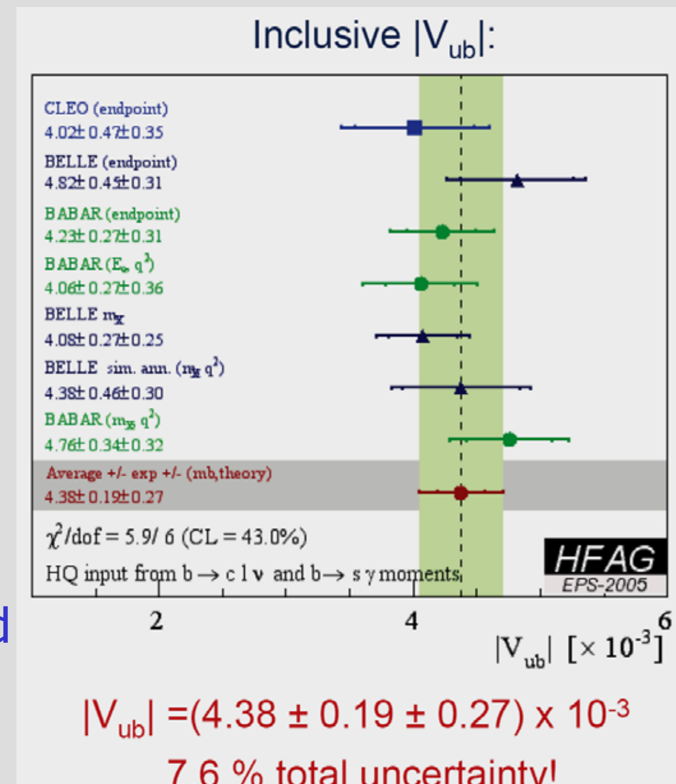


With the help of new techniques, complementary information on penguin parameters and lattice QCD, the CKM parameters are being understood. Angles α and γ are now measured. Rare decays are becoming accurately determined.

Experiment reaches SM theory level for $b \to s\,\gamma$

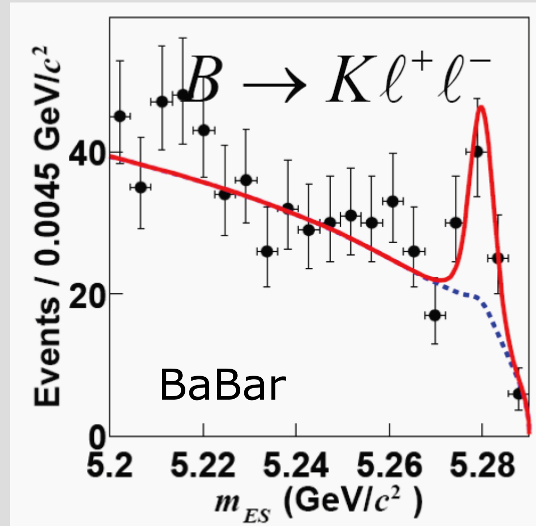


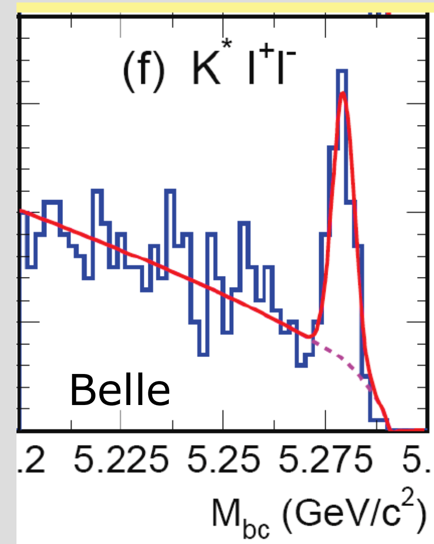
Inclusive and exclusive $b \to u$ decays give Vub and agree, with complementary errors.

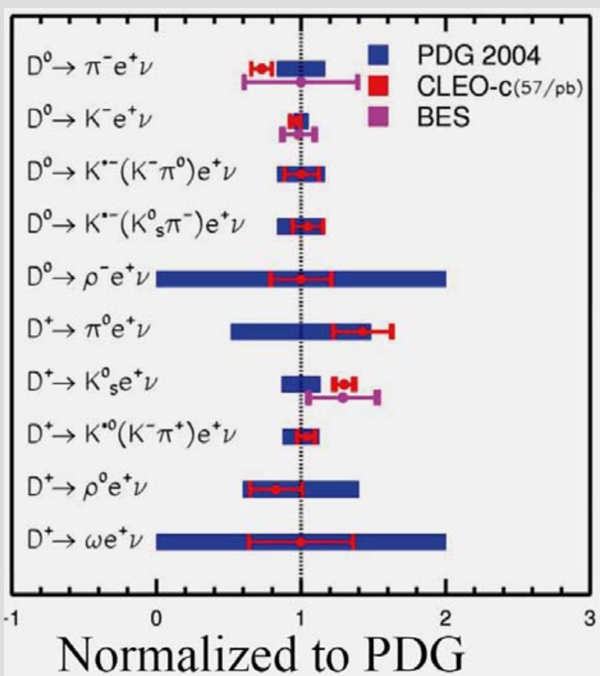


State of the art calculations required involving NNLO higher order loops.

EW penguin processes are cleanly observed in BaBar and Belle. The rates and forward backward asymmetries are sensitive to new physics.

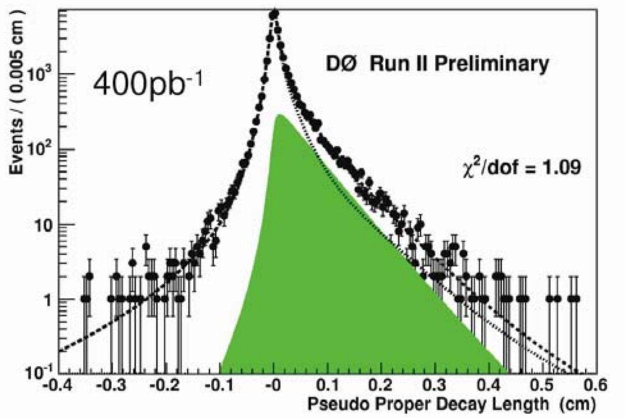




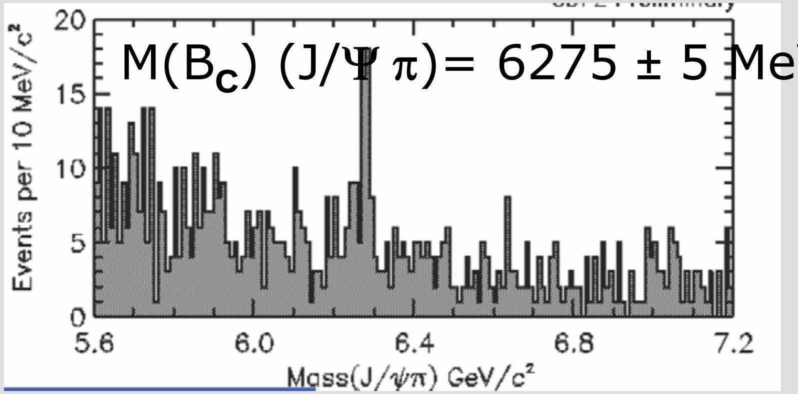


Precision measurements in charm decays (CLEO-c, BES) constrain non-perturbative QCD effects, seek evidence for new physics and allow form-factor calibrations for many CKM measurements.

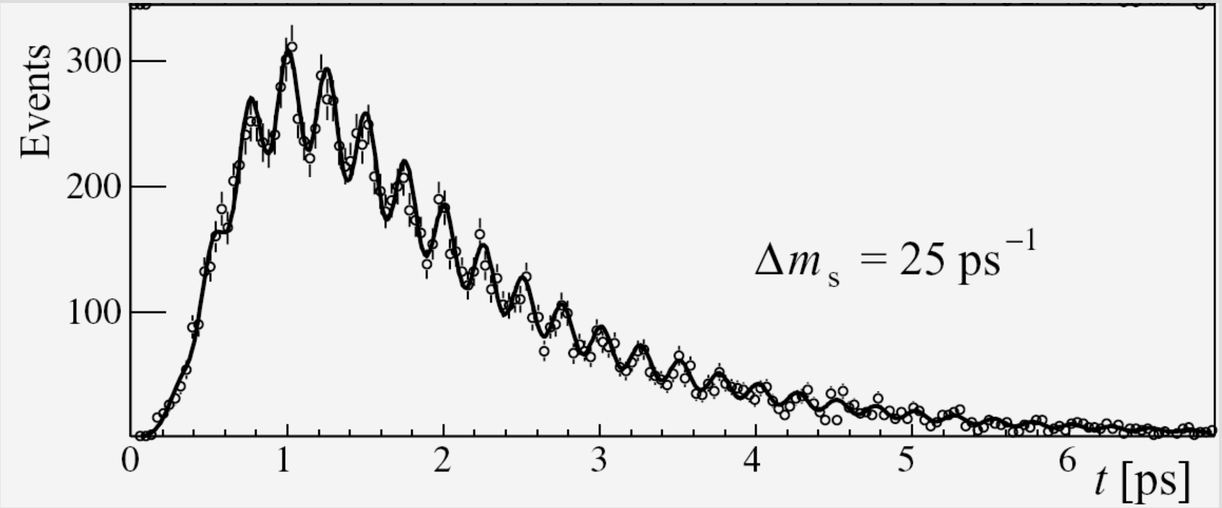
Hadronic beauty production



D0:
$\tau(B_s)$=1.420±0.043(stat) ±0.057(syst)
(Best in the world)



Tevatron is making impressive progress in measuring properties of heavy B states.

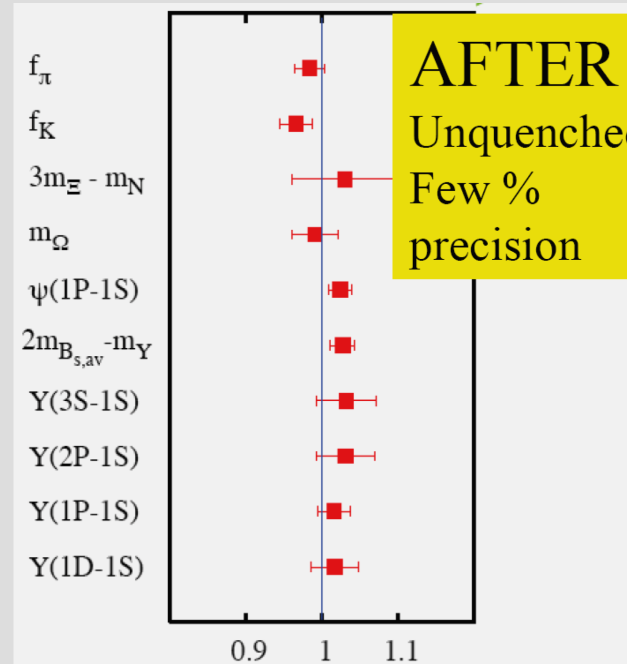


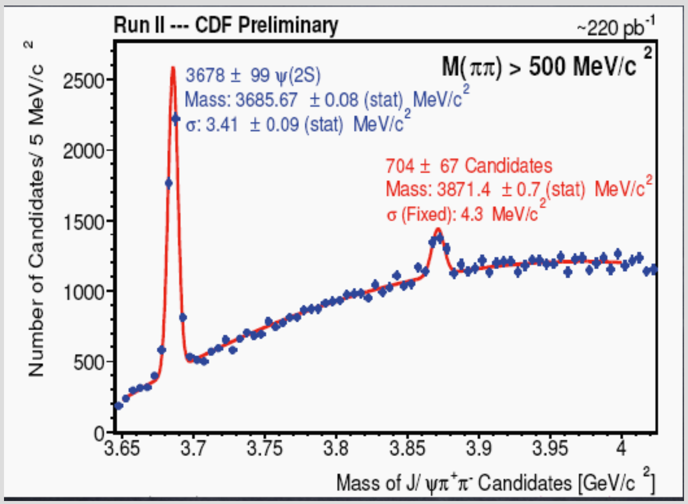
LHCb will provide exquisite precision on properties of all b-quark states.

Δm_s observed to 68 ps^{-1} in 2 fb^{-1}

H. Trottier

Lattice QCD determinations of hadron properties below strong decay thresholds have matured dramatically – new techniques to speed up unquenched lattice calculations are giving very accurate <u>predictions</u>.





E. Eichten

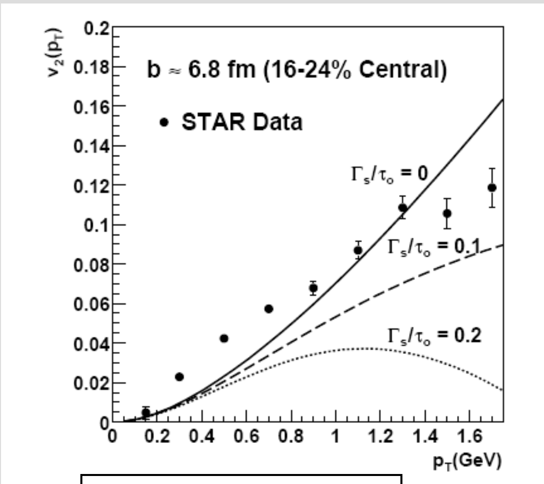
New channels, high statistics e+e- and pp experiments are finding exotic new states that reflect the full complexity of QCD – excited charmonium, molecular quark states, hybrids …

M. Quiros

The SM fails to provide sufficient CP violation to give baryon-antibaryon asymmetry. Minimal Supersymmetric Symmetry Breaking models may be feasible, but constrained by WMAP. If Higgs > 120 GeV, split supersymmetry may do the job.

New QCD phase at high temperature – RHIC results

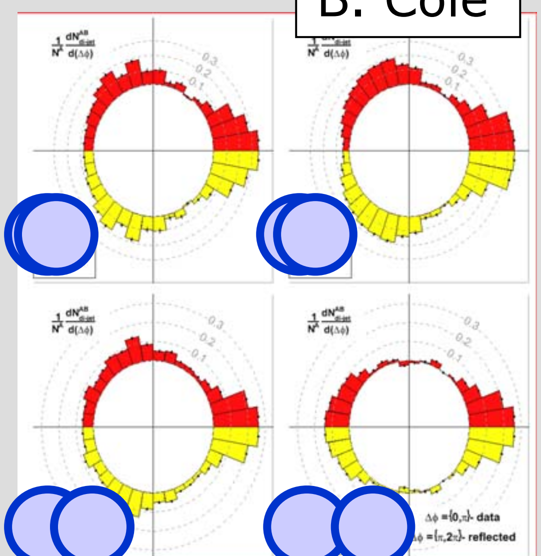
Picture is emerging of a rapid formation of a new phase of deconfined color which equilibrates very rapidly. The speed of equilibration seems to require new processes. **Very different from prejudices before RHIC turn-on – a great success for experiments.**



J. Dunlop

v2 measures the transverse momentum anisotropy (reflecting the elliptical partially overlapped early stage Au Au collision). Elliptic flow reduces the anisotropy. Large v2 indicates the QGP is a hydrodynamic medium with essentially zero viscosity (not an ideal gas!)

B. Cole



Jets traversing the QGP are quenched by the strongly interacting medium – lose the away side jet. But PHENIX evidence for a cone of particle flow at 120º relative to away jet, at intermediate overlap – Cherenkov-like effect?

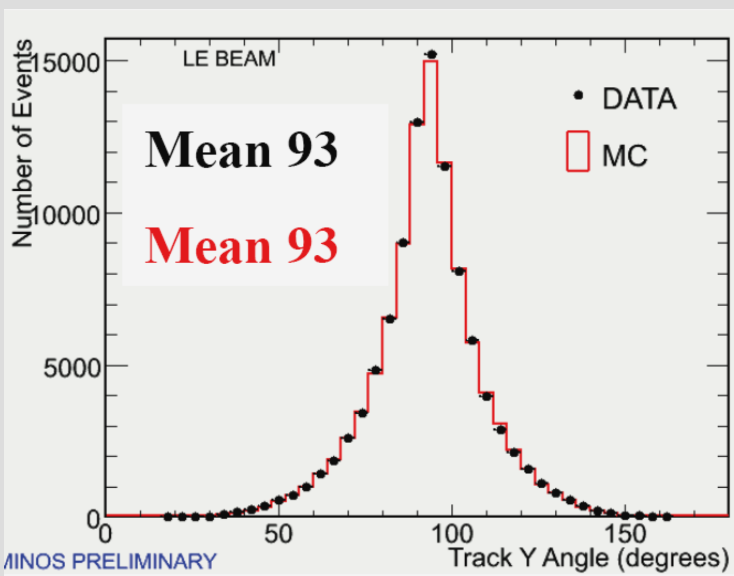
Neutrinos today

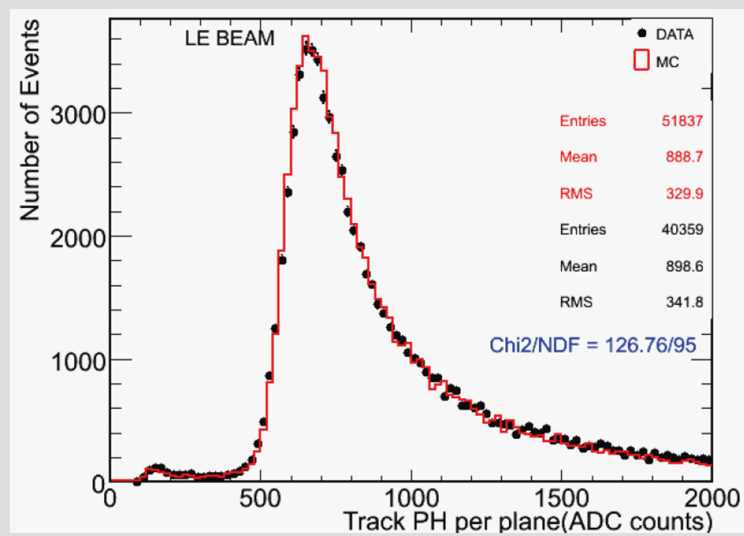
MiniBoone: Is the LSND evidence for a sterile neutrino true? A hard experiment (no independent flux measurement) that is nearly ready to open the blind box.

I. Stancu

MINOS: Very impressive turn-on. The first result on ν_μ disappearance, with K2K sensitivity, is expected very soon.

N. Saoulidou





MINOS has demonstrated excellent understanding of the beam and detector – look forward to many good results in near term.

Neutrinos in future

Reactor neutrinos offer the cleanest way to extract θ_{13} without entanglements of hierarchy and other angles. Double Chooz will come on line ~2007. Five other possible experiments are being discussed (China, US, Brazil, Korea, Japan).

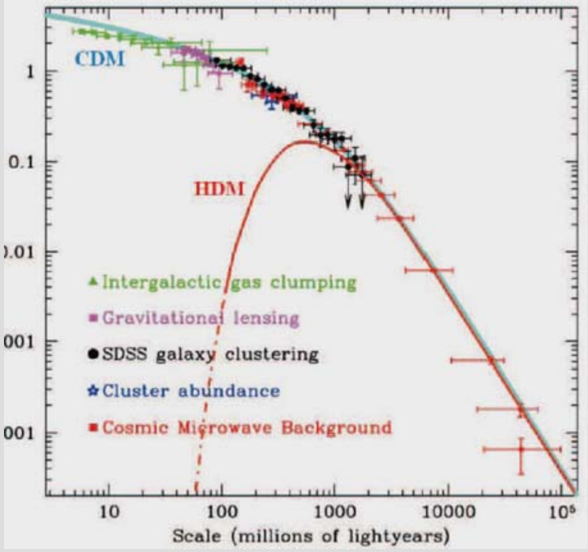
D. Reyna

Off axis ν beams from accelerators and long baseline allow direct observation of ν_e. Need massive fine grained detectors. **T2K** is JHF to SuperK; **NOνA** is FNAL to Minnesota. Should determine the mass hierarchy and get to $\sin^2\theta_{13} \sim 0.01$.

String theories can inform neutrino properties. Current indications are that see saw is difficult to incorporate, and that ν's may be Dirac.

P. Langacker

Physics of the universe – Dark Matter



C. Balazs

Stable supersymmetric particles remain a good candidate for dark matter. Many model classes within Susy – and many other possibilities as well! Ordinary matter making up 5% of universe comes in many types – why not DM as well?

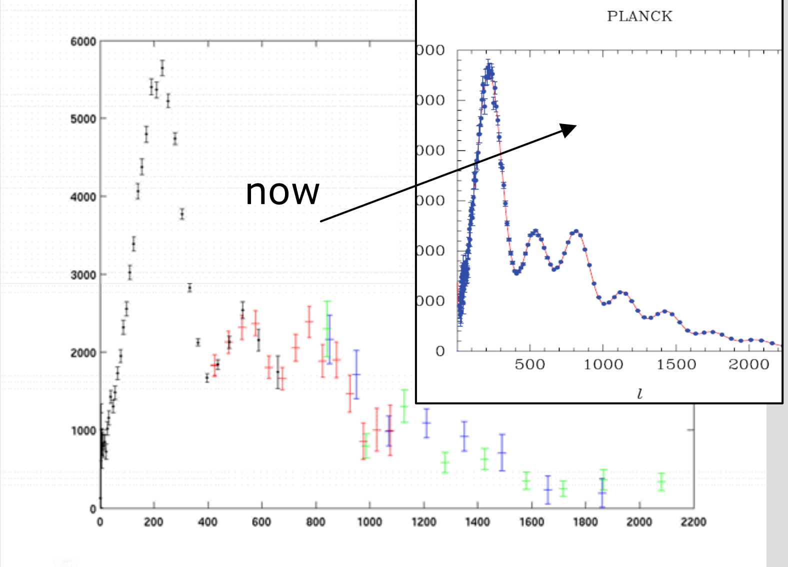
A. Kusenko

Is it possible that dark matter is due to keV scale sterile neutrinos? This possibility also solve the problem of large proper motions of pulsars, seed the early galactic structure formation and place cutoffs on small scale structure near galaxies. With 3 of them, it could generate the baryon asymmetry. (These ν_s are not the LSND object.)

R. Gaitskell

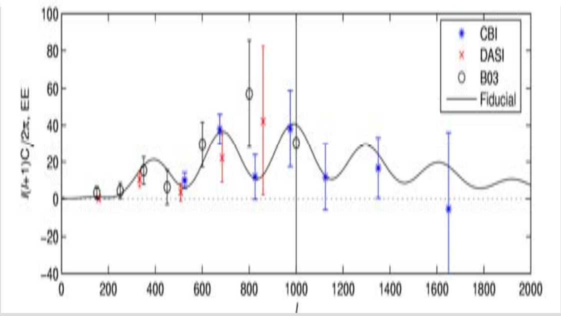
Underground searches for DM – cryogenic phonon detectors, ionization detectors (Ge, LXe, LAr). CDMS now into the interesting SUSY region but need another 4 orders of magnitude in event rate. Large challenges with cosmic ray, radioactive backgrounds.

Cosmology and Dark Energy



J. Sievers

CMB power spectrum: Constrained consistent fit to curvature, Ω_{DM}, Ω_{B}, tilt, optical depth. Polarization due to Thomson scattering on co-moving electrons agrees with intensity power spectrum – well correlated with intensity.



Hope to learn of tensor perturbations from inflation – hard measurements to be addressed by Planck, Spider, …

R. Bean

Job is to characterize Dark Energy and distinguish among models – cosmological constant, modification of Einstein field equations, new dynamical fields – we need to measure the equation of state (w = p/r). The tools are studies of density fluctuations, L vs. z, angular diameters vs. z using supernovae, galactic clustering, weak lensing, CMB. We are still mapping the morphology of Dark Energy.

Strings, non-perturbative processes

On which I report without comment!

M. Spradlin

Using string methods to calculate QCD in 4 dimensional processes where there would be Avogadro's number of Feymnan diagrams. Amazing! It sounds like great progress.

J. Santiago

Seeking a unified framework for evaluating braneworld gravity and extra dimension models and their physical viability.

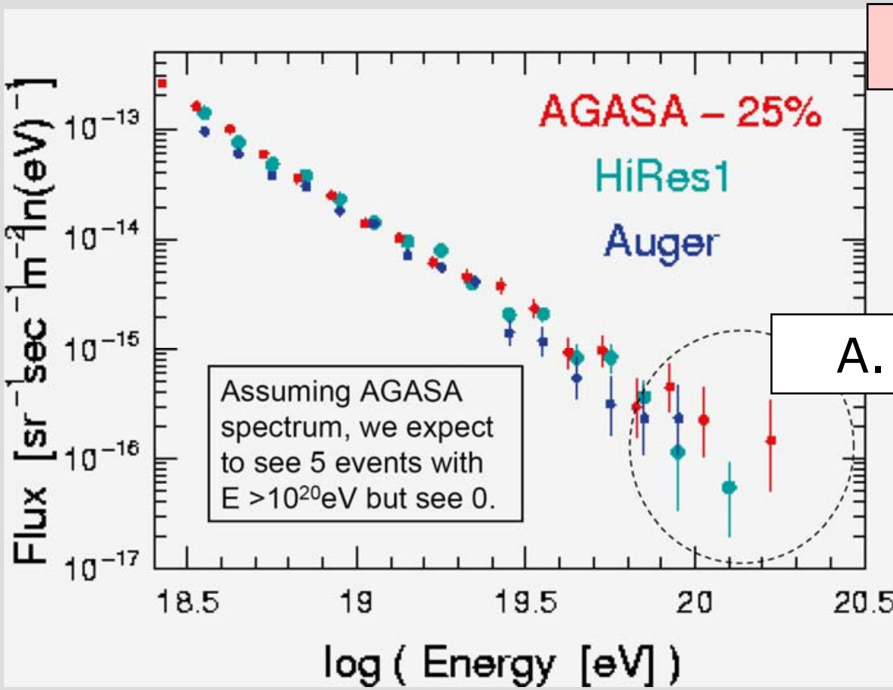
D. Kharzeev

Exploring the effects of non perturbative QCD in the high density and temperature regime of heavy ion collisions.

M. Block

An old non-perturbative problem: Does the high energy extrapolation of total cross sections obey the Froissart bound? Filtering out outlier measurements (risky) and using analytic matching to low energy data (good) suggests the answer is yes. And a prediction of σ_{TOT}(pp) at LHC = 107.3 ± 1.2 mb .

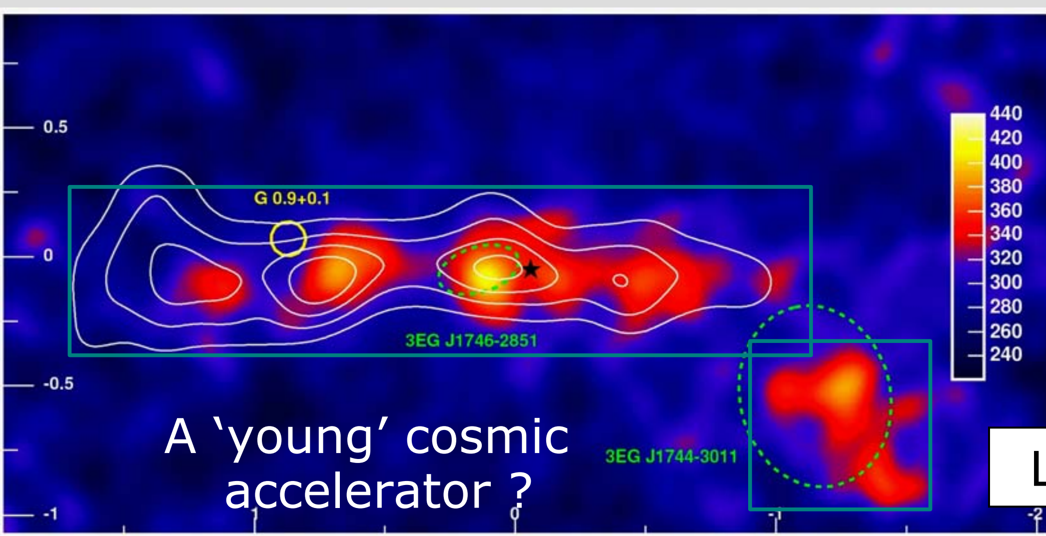
New astroparticle experiments



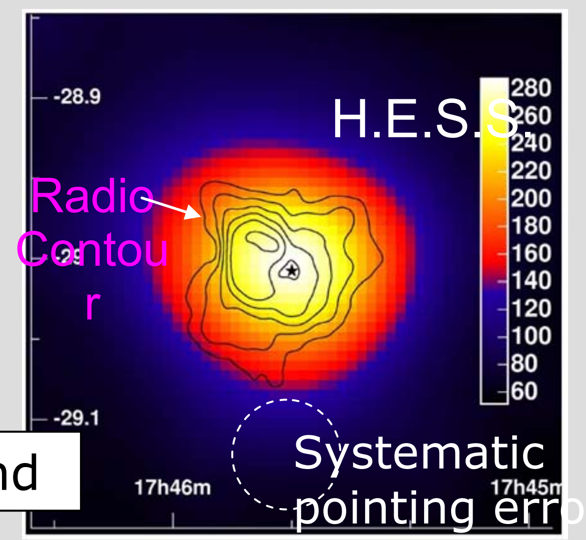
Pierre Auger partially installed, operating. Not yet seeing events beyond the GZK cutoff.

A. Chou

γ ray experiments study diffuse and point sources in galaxy and beyond. HESS sees both at center of Milky Way. γ's help pin down cosmic ray acceleration mechanism (favor proton acceleration – Fermi mechanism).



L. Rolland



A personal outlook

The nature of HEP: Traditionally we have focussed on the inner space frontier, pursuing the questions of the construction of matter and the fundamental forces at the smallest scale accessible.

Today we have also pressing questions from the Universe. The understanding of the microworld and our tools are invaluable in investigating the universe at large. And cosmic phenomena effect microphysics.

While there has always been pragmatic (and sometimes even dramatic) study of the detailed properties of complex systems (glueballs, nucleon structure, production cross sections etc.), I believe that what draws us to HEP are the big questions – what are the ultimate structures of matter; what is the role of symmetries in its construction; what underlies the apparent unification of the forces; how has the universe evolved?

These ideas are what drew us into this field; our future depends on keeping them firmly in our sights.

We owe much to those who, over the past 35 years, have assembled our Standard Model. It has withstood thousands of experimental tests. It is highly predictive. It is sufficiently well defined that the next phase of exploration *Beyond the SM* is now very well formulated.

It has been frustrating that we have not found significant chinks in the SM yet (I take the point of view that seeing neutrino mass and mixing, and concomitant lepton number violation is exciting and strictly speaking a SM departure – but is qualitatively similar to what has been seen in the quark sector).

But it is a common conviction that the SM is fundamentally incomplete & flawed, and that big new physics is lurking. Though we don't know much about the character of the new physics, we do have good evidence that it should start to emerge at the TeV scale.

And we will know its there when we see it.

Why we believe in Beyond the Standard Model:

- The miracle of fine tuning – what stabilizes the hierarchy disparity between EW and GUT or Planck scales?
- The arbitrariness of the 26 mass, mixing, coupling and phase parameters; is there a deeper reason for these?
- We need new ideas to generate dark energy
- We need new particles to provide dark matter, dark galaxies.
- Why is the neutrino mass so small and why are its mixings so different from the quarks?
- Unification of Strong, Electromagnetic and Weak forces is a tantalizing near miss: can new ingredients salvage it?
- How do we formulate gravity as a quantum force?
- Baryon-antibaryon asymmetry in the universe requires new undiscovered CP violation mechanisms.

With all of these reservations, why is the SM so good?

There are many theoretical suggestions for solving these questions:

- TeV scale supersymmetry
- Large extra dimensions
- Technicolor, strong coupling
- Little Higgs
- New scalar fields … and so on …

All of these models have many variants; Each can explain some of our puzzles. Not all (or maybe even not any) of them will be true.

For each, the probability that there are observable phenomena in TeV scale parton collisions is very high. The LHC and ILC are very well suited to explore the new terrain.

This is an experimentalist’s dream! We have identified the playing field, but have no idea of who are the players or what game they are playing.

GO THERE !

Experimentally, it is almost always worth doing new experiments if ≥2 orders of magnitude improvement in precision is possible.

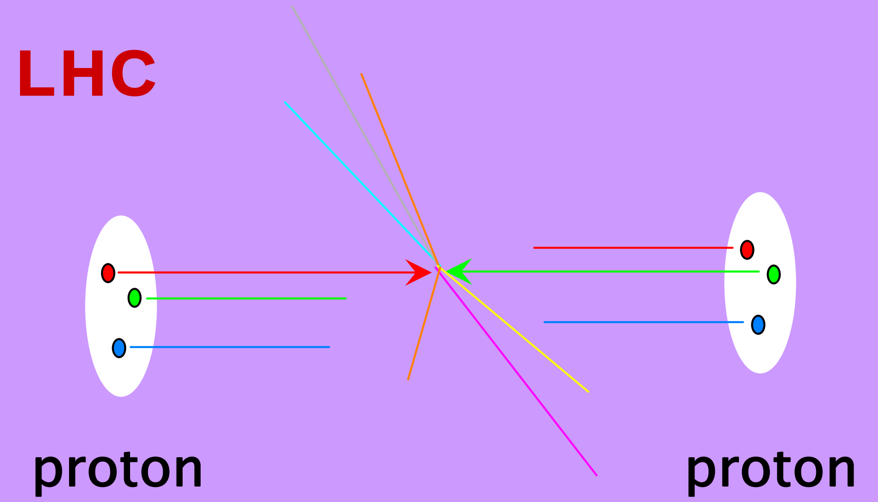
But failing that opportunity, it seems to me that new initiatives on quark flavor physics are not good bets for the near future – we could measure CKM parameters better, but will this bring fundamental understanding of the big underlying questions? Effects of new physics could show up in the flavor sector but it's hard to pinpoint the root source. We are likely to learn more by producing the new states directly at the energy frontier.

There can still be surprises in ν's. Measuring the ν properties and MNS matrix elements more precisely may reveal if CP is violated and if ν's are connected to a high E scale. But mapping the MNS matrix may be like the CKM studies. The big payoff here is not yet firmly assured, so proceeding stepwise seems appropriate.

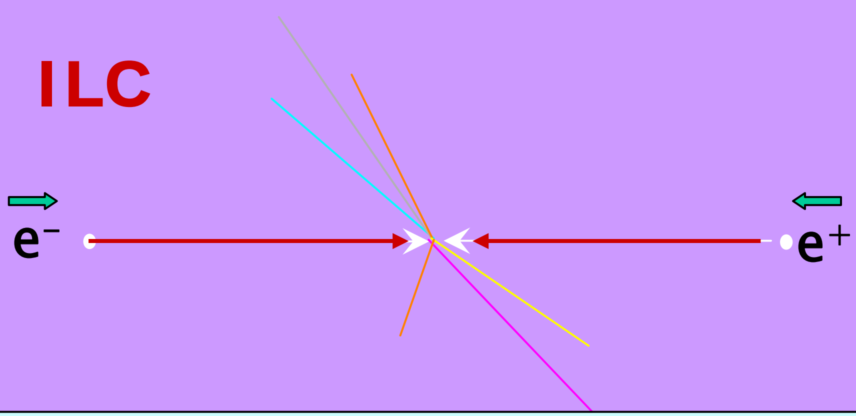
Pursuing understanding of the Dark World is imperative. We suspect they bring new fields and particles. We are still in the phase of characterizing DM and DE. So an incremental program, planning each step in sequence, seems wise.

1. At the energy frontier

- ✓ High energy reach, subject to PDFs
- ✓ Broad CM energy spectrum
- ✓ Large event rate
- ❖ Large QCD backgrounds
- ❖ Pileup – spectator quarks & other pp collisions
- ❖ Radiation damage issues



- ✓ Know initial quantum state
- ✓ Well-defined E_{CM} and pol'zn
- ✓ low bkgd → ambitious experimental techniques
- ❖ Event rates low; need sequential runs at different E_{CM} and polarization
- ❖ Complex machine detector interface; need exquisite control of beam optics

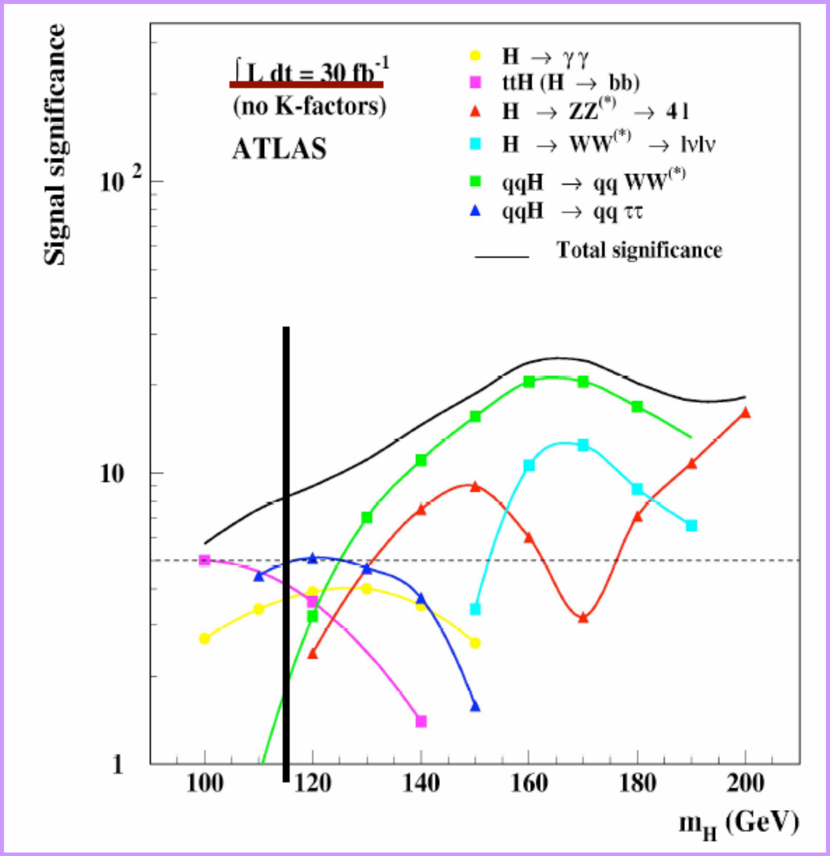


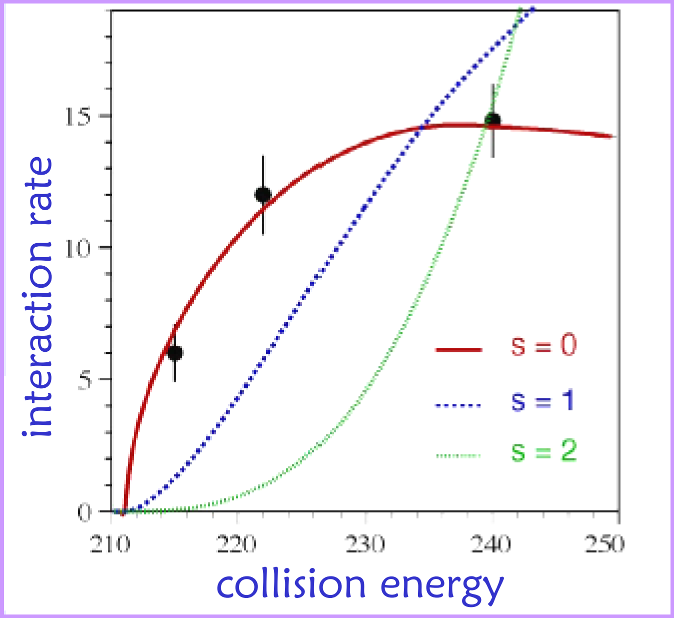
LHC & ILC collider characteristics are highly complementary

Steps of the campaign: The Higgs issue

Does the SM or surrogate Higgs exist?

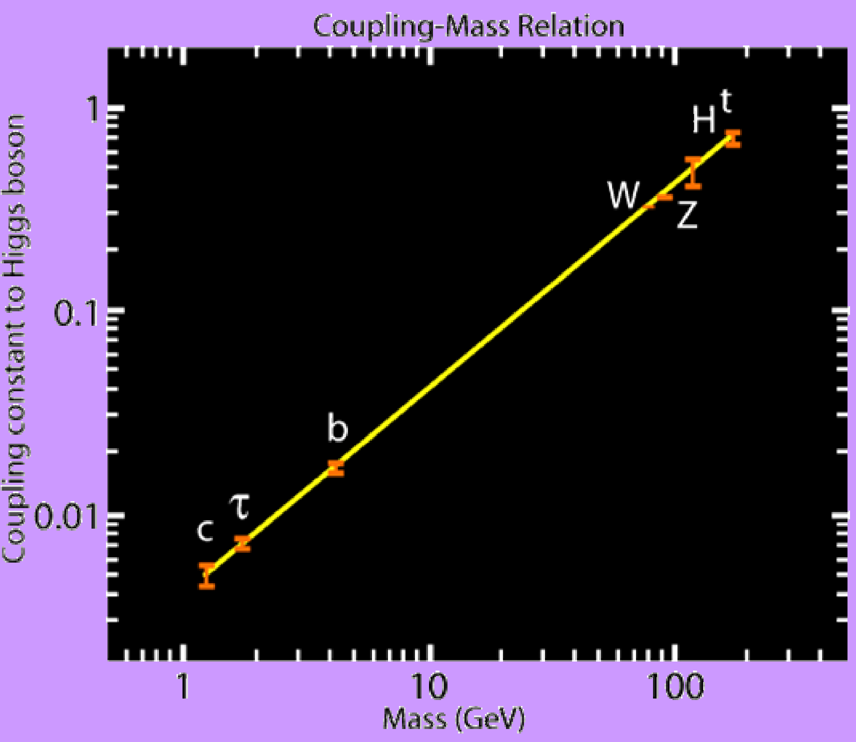
Tevatron has a narrow but important window for low mass Higgs. LHC will almost surely discover, but it could take a while if mass is below 130 GeV.





ILC makes Higgs without bias, recoiling against Z. Invisible modes are observable. Angular distributions and threshold curve tell us the quantum numbers.

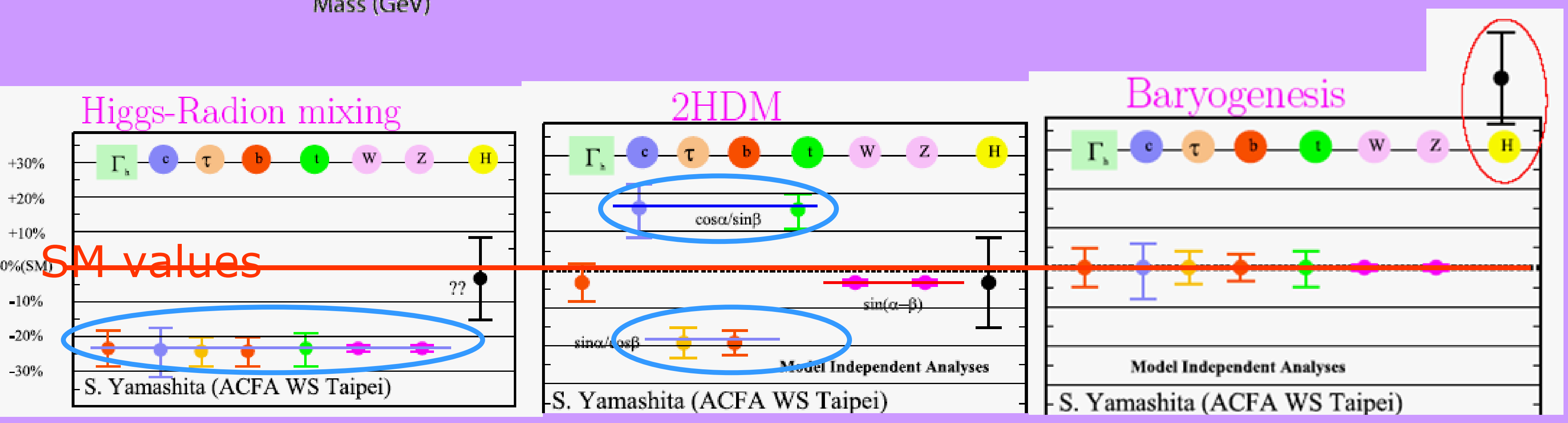
Is it SM or something else?



SM Higgs couplings are proportional to mass. LHC will make rough measurements of some couplings; ILC will measure to several % level.

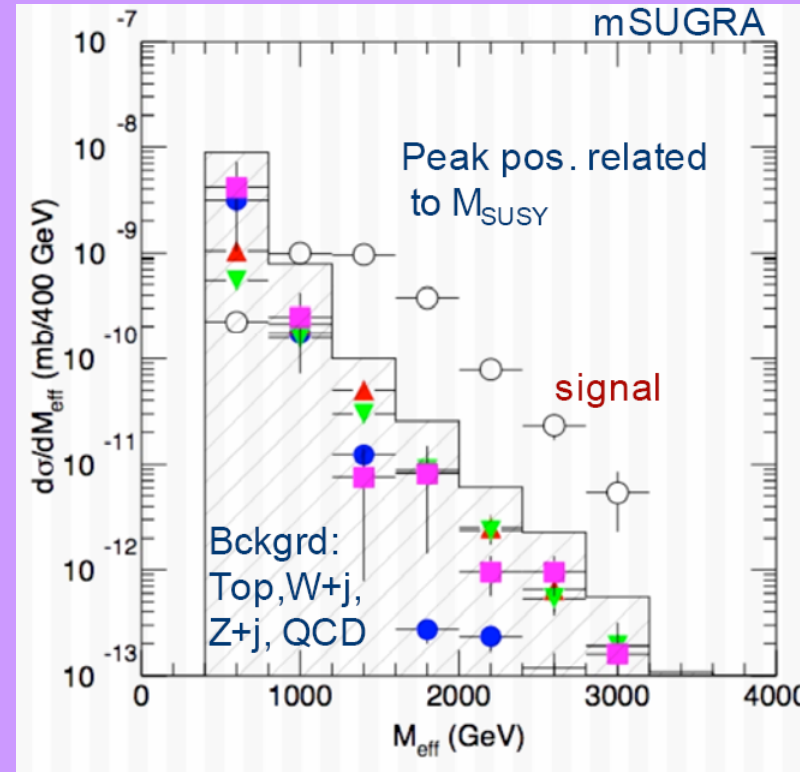
If the Higgs is non-SM, these couplings change in distinctive ways, so we have an insight into the new physics. Deviations from SM are at O(10%) level.

ILC can measure Higgs self-coupling



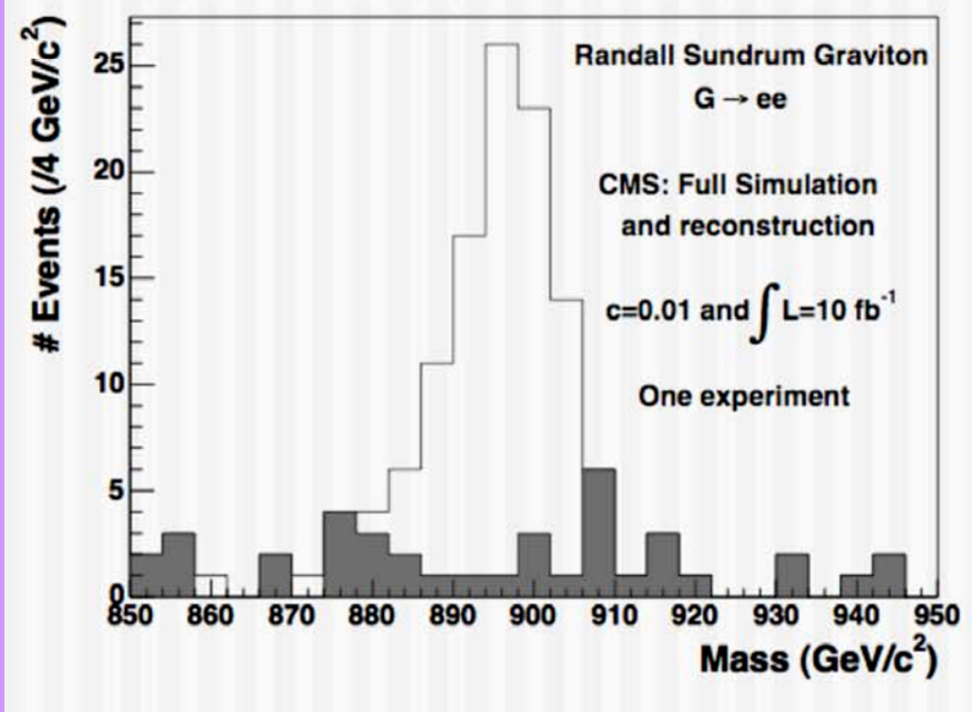
Can you sense the new physics at LHC?

Easy cases …



Sensing SUSY high E_T excess is easy.

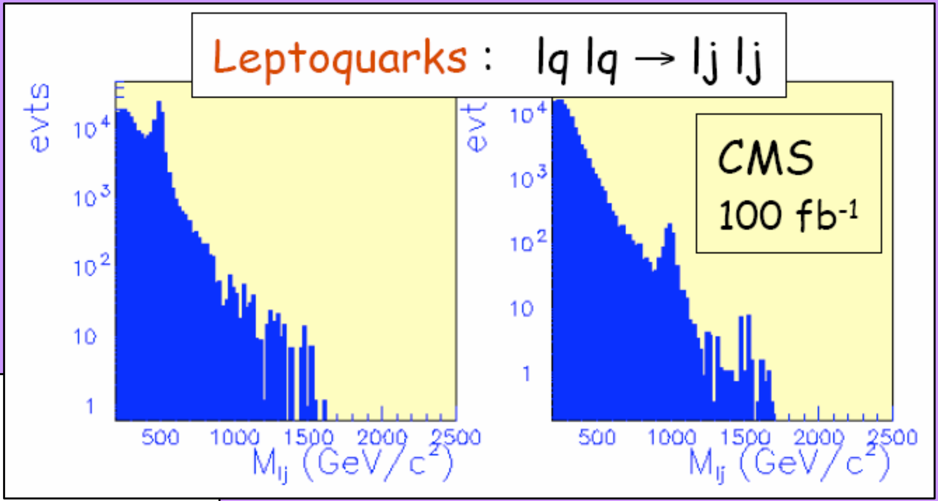
- Massive Kaluza-Klein excitations, eg. Gravitons

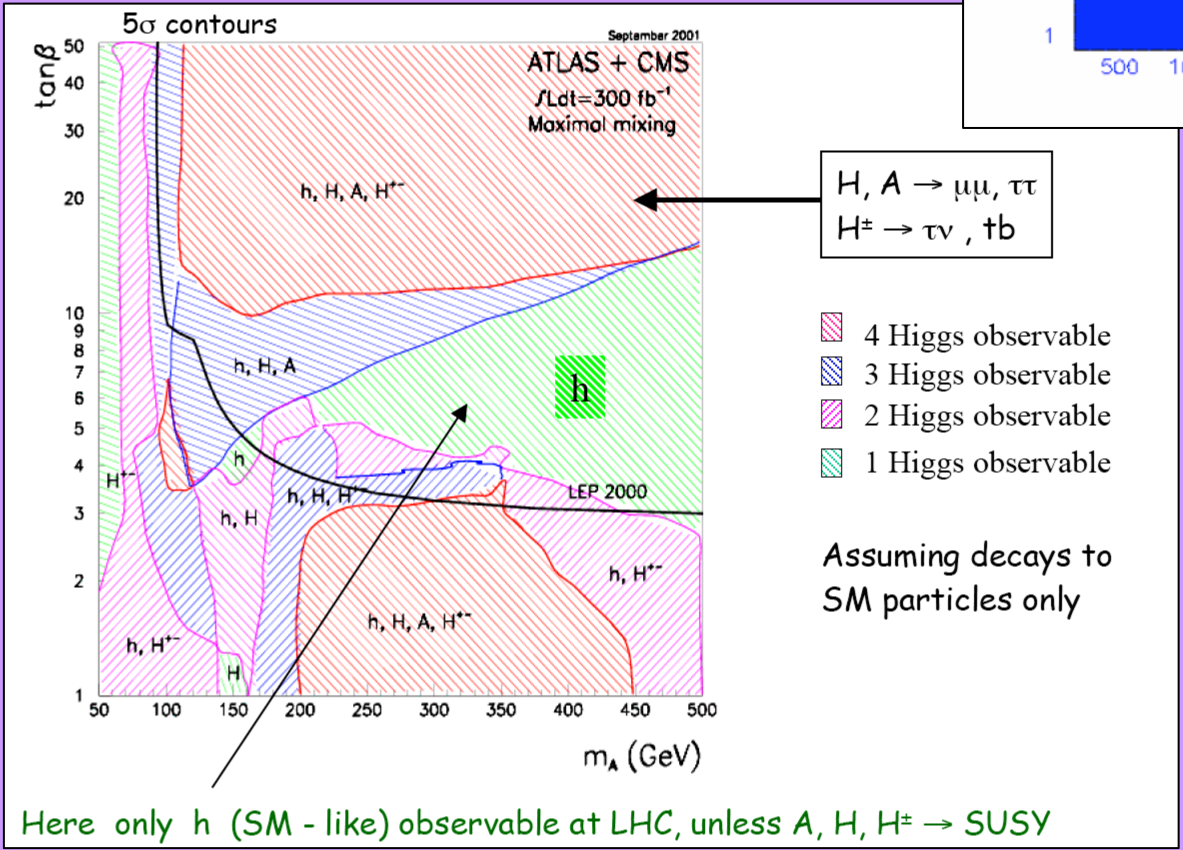


Seeing new dilepton resonances is straightforward.

Can you sense the new physics at LHC? harder cases …

Discovering and mapping a strongly coupled world will be a challenge.

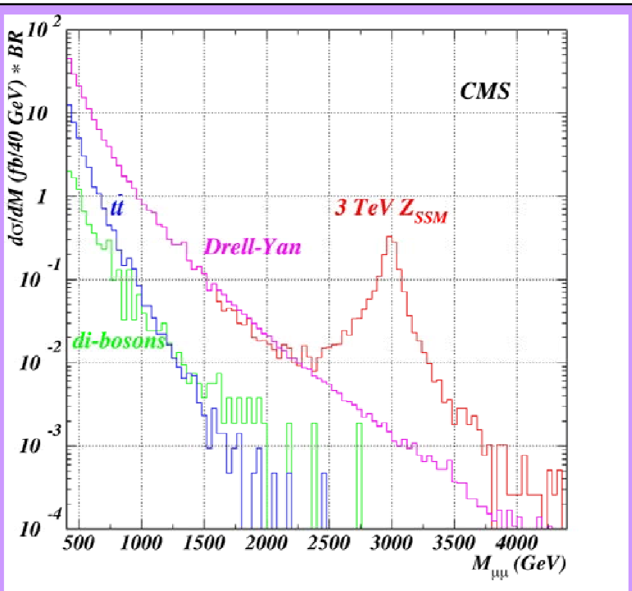


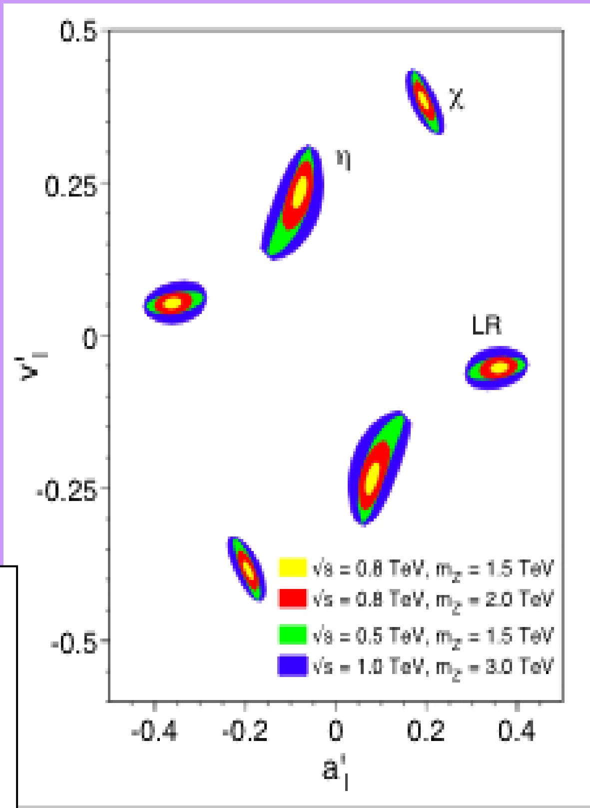


Delineating a two-Higgs doublet world will be a challenge.

Do you understand what the new LHC physics is?

We saw examples where the ILC was needed to give the full portrait of the Higgs boson (Q#s, BRs, self-couplings …).
For most of the new physics possibilities, this question is even larger.





e.g. For a new massive e^+e^- state at LHC – is it a KK resonance, strong coupling, extra Higgs doublets, … ?

Using polarized beams, ILC measures its axial & vector couplings and tells us the origin.

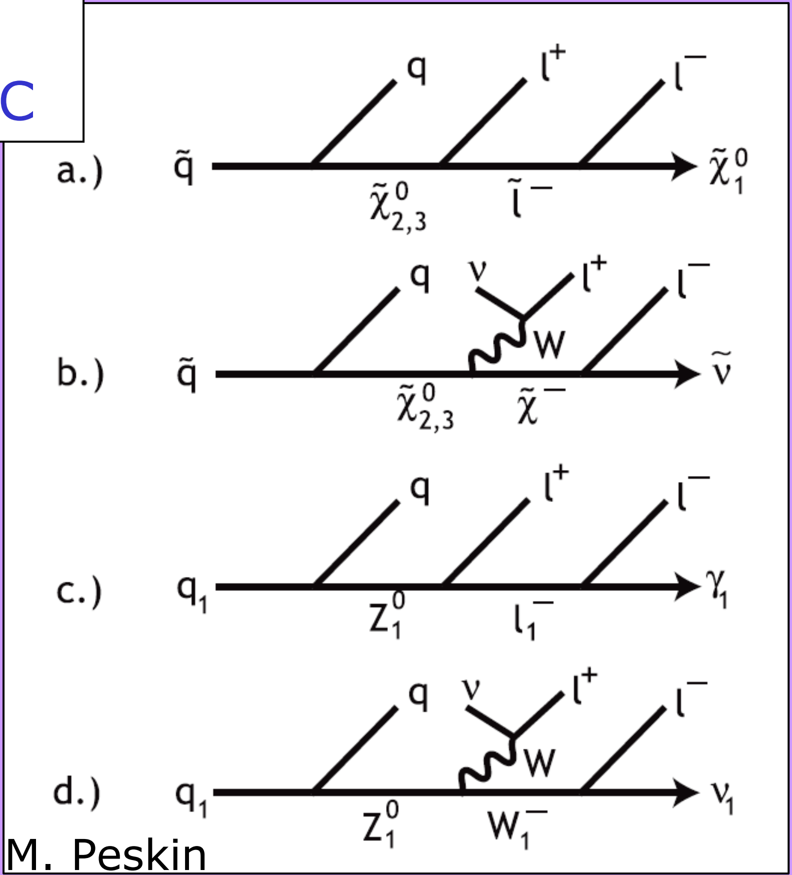
Do you understand what the new physics is?

Four ways to produce a 'signal' in jet $l^+\ l^-\ \not{E}_T$ (dark matter signature) at LHC

a) Susy LSP = neutralino

b) Susy LSP = sneutrino

c) & d) Extra Dim model variants

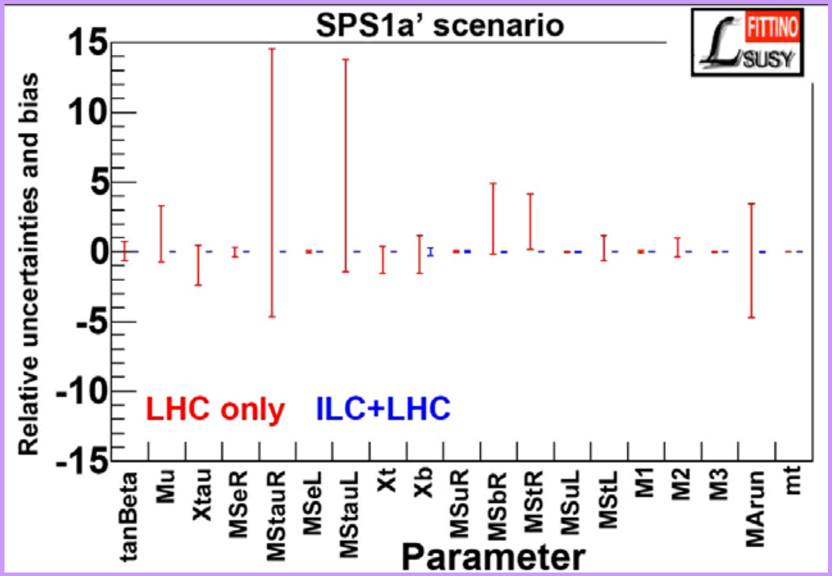


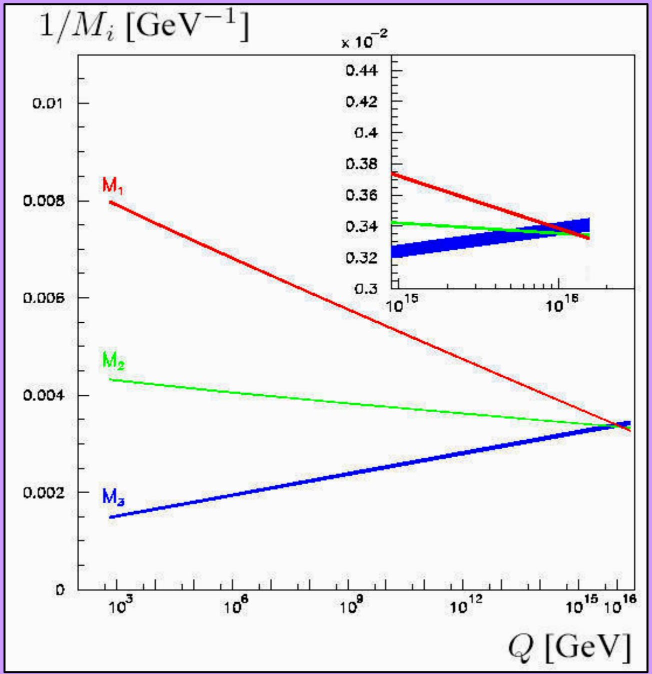
LHC can't distinguish these interpretations. At ILC, the cross-sections and angular distributions for different initial state polarizations tell us which is happening.

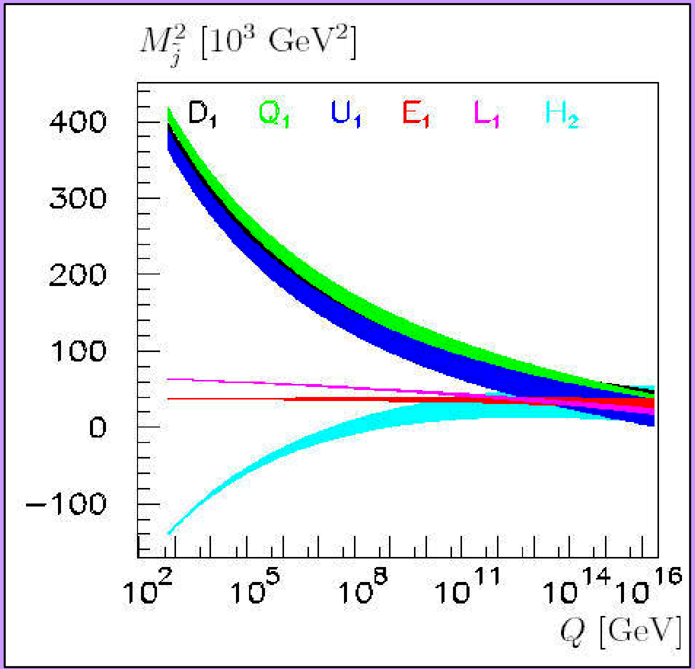
In turn can be used by LHC to measure the heavy particle masses.

Precision matters

ILC measures masses, couplings, mixings of accessible Susy spectrum much more precisely than LHC. This in turn allows renormalization group extrapolation of gauge couplings and matter parameters to demonstrate (or not) unification and illuminate the Susy breaking mechanism.

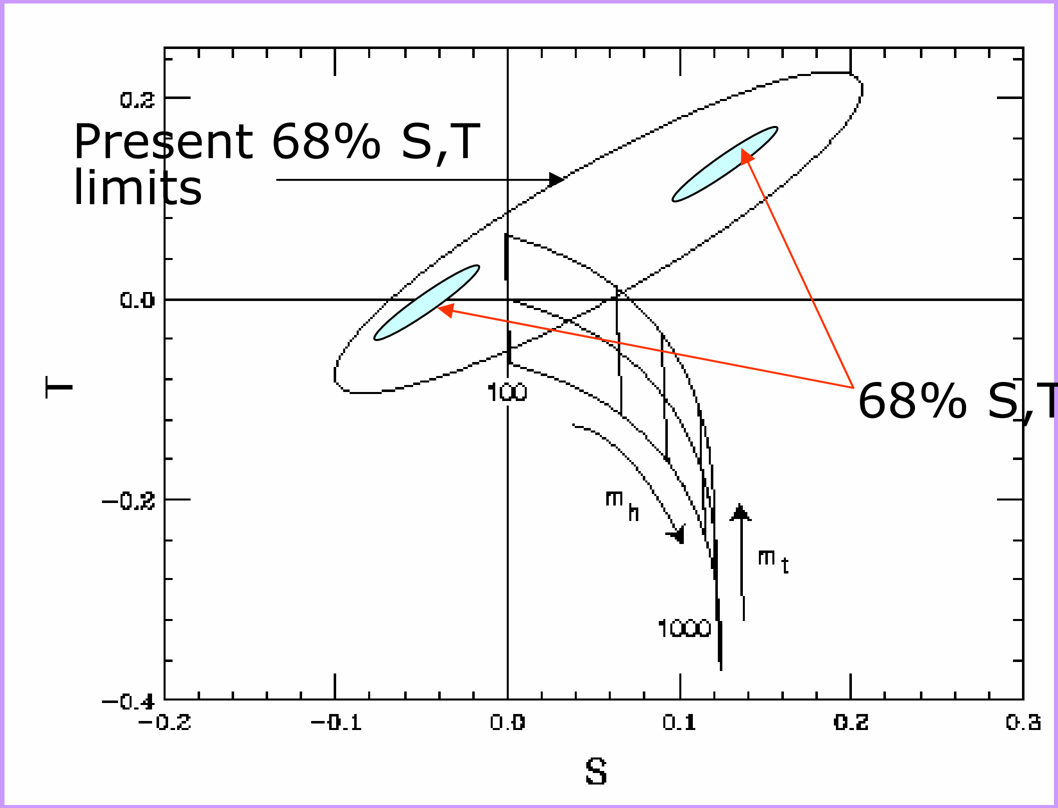






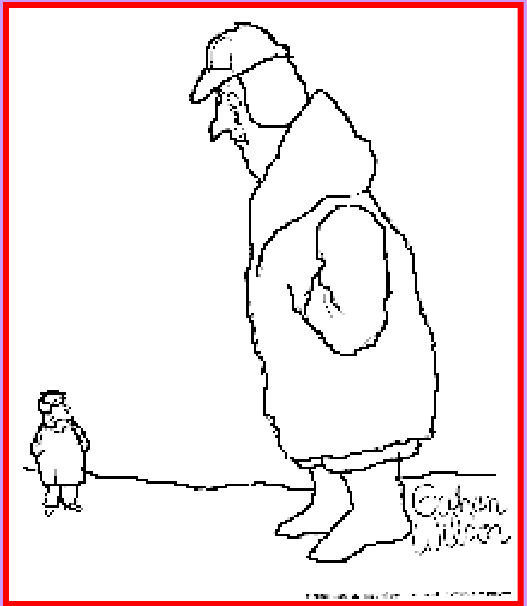
Precision matters

In a scenario where the new measurements are puzzling, precision EW measurements may give us valuable guidance. ILC return to Z-pole, WW threshold, top pair threshold will measure the radiative correction parameters S,T accurately. Where they lie tells us what type of theory is at work.



ILC and LHC make a dynamic duo

Either LHC and ILC alone gives an incomplete view of the new physics. Acting together, like binocular vision, they give a depth of view that can tell us much more than either alone.



“Pardon me, I thought you were much farther away”

We have seen at LEP, SLC, Tevatron, HERA that the experiments become much more incisive than was predicted before turn-on. Having data (and competition) stimulates new ideas. Using data to understand backgrounds and calibrate detectors empowers more incisive analyses.

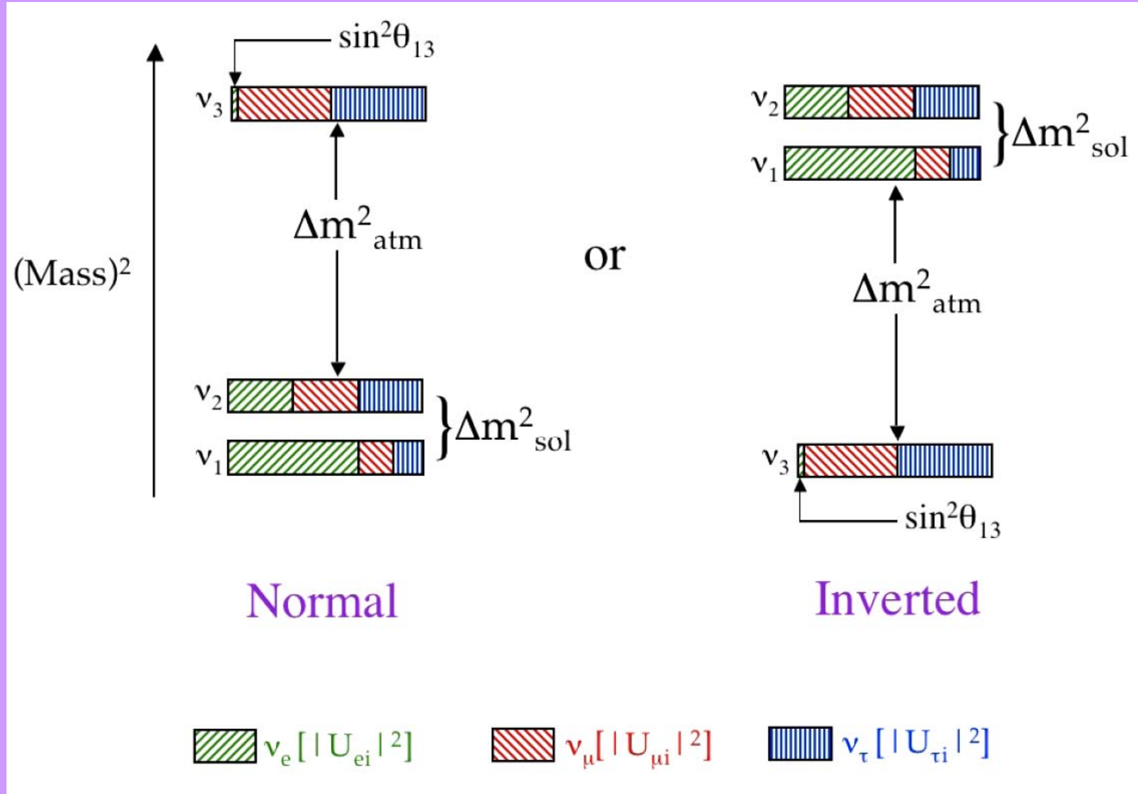
Expect more from the LHC and ILC experiments than they predict now!

2. The neutrino campaign

Neutrinos have mass, and the flavors mix (oscillations). As for the 3 generations of quarks, CP violation is possible. These facts require the SM to be extended (lepton number violation).

The main issues:

- What are the absolute masses and what is their ordering?
- Why are the angles θ_{12} and θ_{23} so large (and θ_{13} so small)?
- Are neutrinos their own antiparticles?
- Is there CP violation?



The larger question is whether ν experiments can shed light on fundamental questions of GUT scale physics or baryon-antibaryon asymmetry.

The neutrino mixing matrix:

$$U = \underbrace{\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix}}_{\text{Atmospheric}} \times \underbrace{\begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{bmatrix}}_{\text{Cross-Mixing}} \times \underbrace{\begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}}_{\text{Solar}}$$

Atmospheric neutrino oscillations → $\Delta m^2_{atm} \approx 2.4\times10^{-3}$ eV^2

$37^o \leq \theta_{23} \leq 53^o$ ($\theta_{23} = 45^o$ is maximal mixing; if this is the case, would expect a new symmetry to make it so.)

Solar neutrino oscillations → $\Delta m^2_{sol} \approx 8.0\times10^{-5}$ eV^2

$31.7^o \leq \theta_{12} \leq 36.4^o$

Observing the CP violating phase δ requires $\theta_{13} \neq 0$. We know from reactor experiments that $\sin^2\theta_{13} < 0.3$. Why is θ_{13} so different from θ_{12} and θ_{23}?

Unscrambling the unknowns requires several experiments – each depends on all the matrix elements.

The path– the absolute mass and Majorana/Dirac character

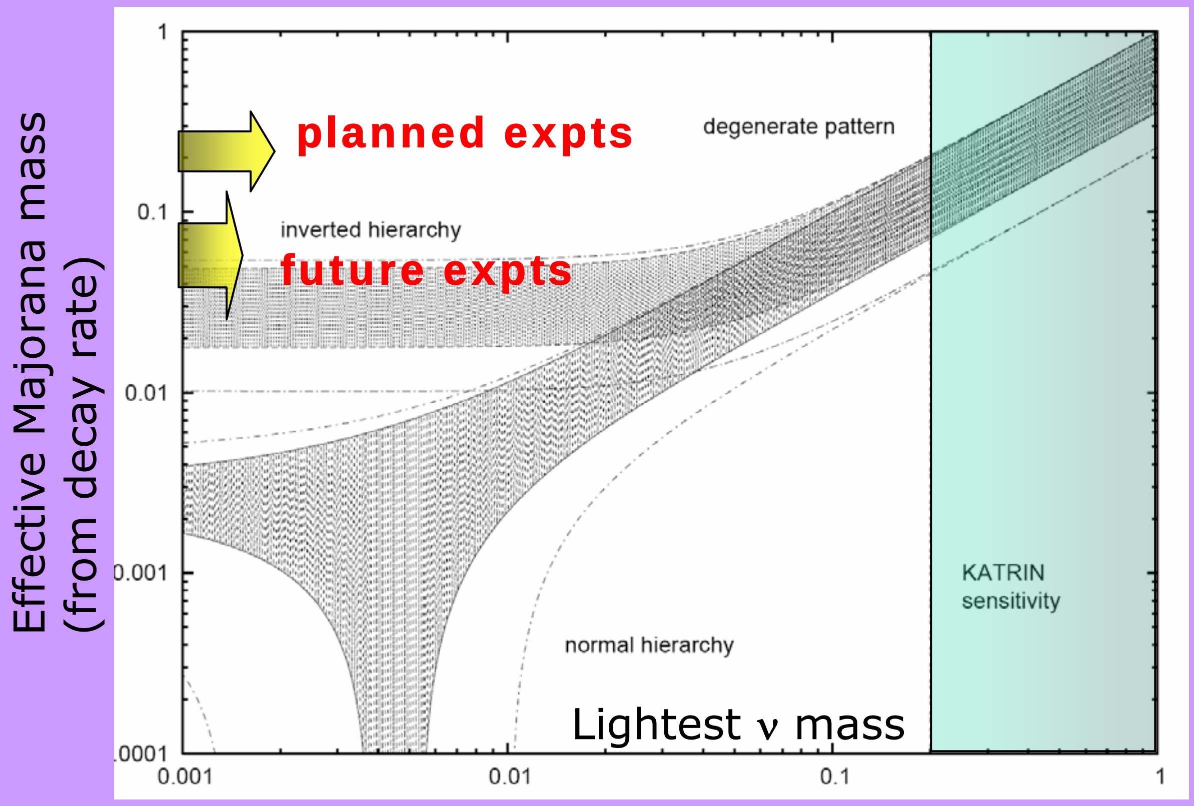
H^3 β decay (KATRIN) would see $m(\nu_e) \sim 0.2$ eV

Observing neutrino-less double β decay would demonstrate lepton # violation, that ν's are Majorana, and give information on the absolute masses.

Bands are due to unknown Majorana phases.

Dotted lines are from current errors in mixing, Δm^2.

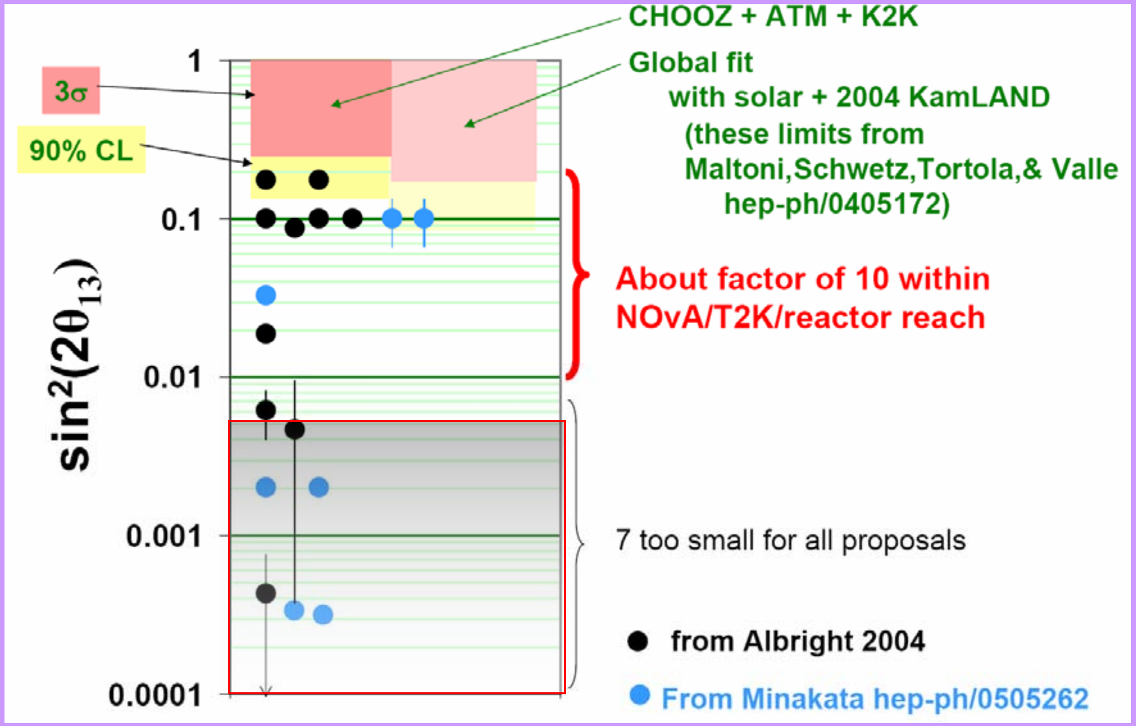
At low masses, need to know hierarchy.



The path – hierarchy, $\sin^2\theta_{13}$ and CP violation

Knowing $\sin^2\theta_{13}$ is the gateway. Reactor ν_e disappearance will get us to 0.02 (Double Chooz) in the near term; future proposals (Daya Bay or Braidwood) can get to ~0.005. This covers the range of many, but not all theoretical possibilities.

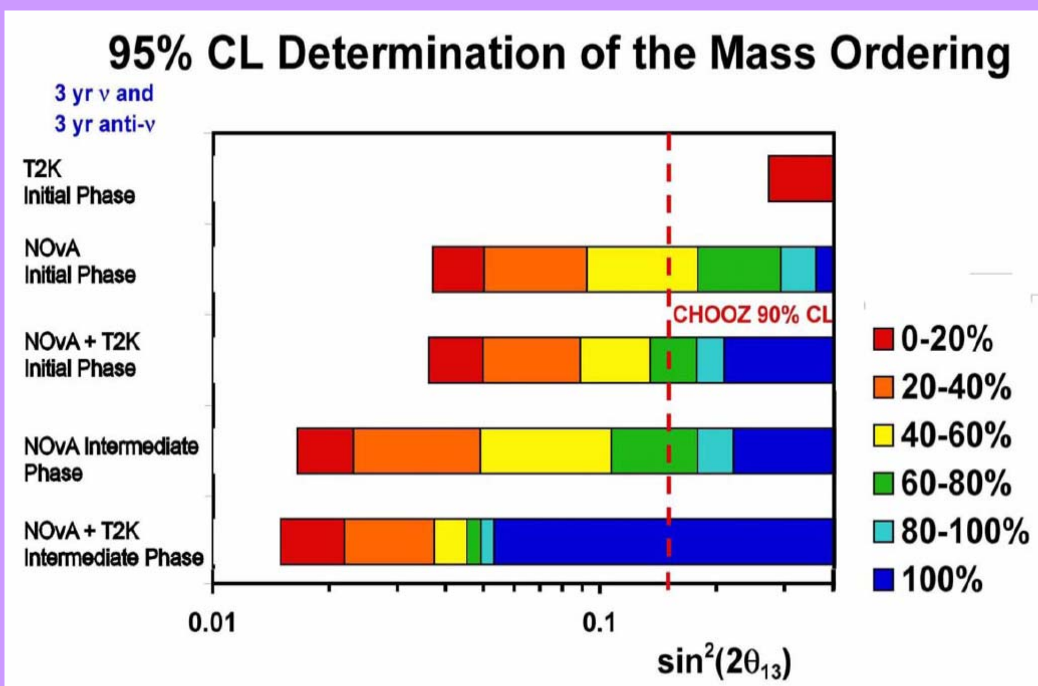
Reactor experiments set limits on $\sin^2\theta_{13}$ independently of other parameters.

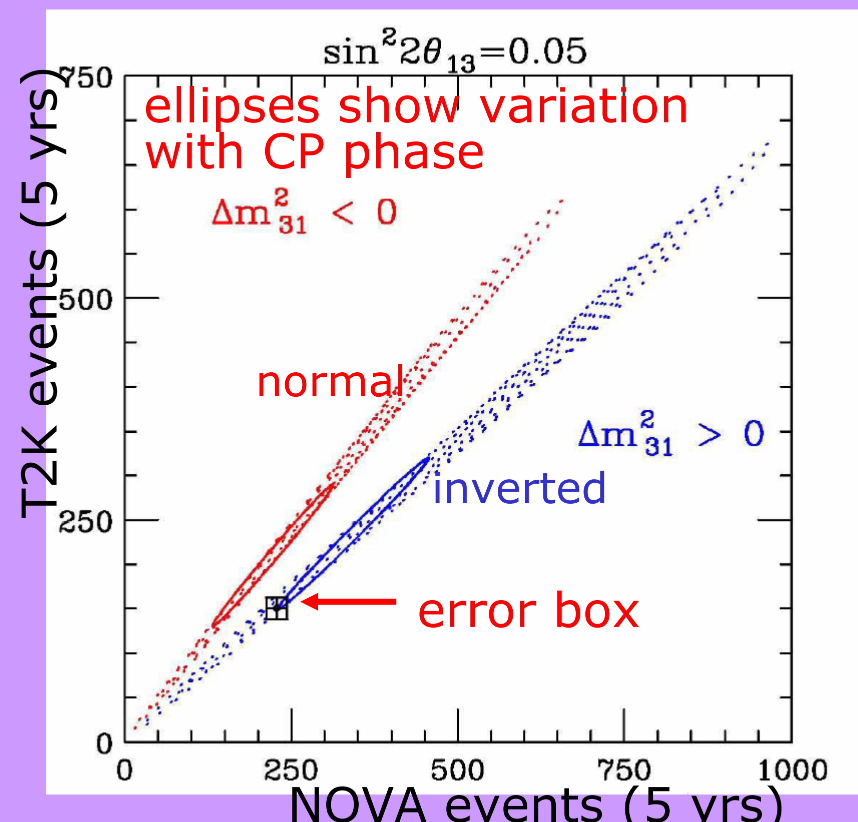


The path – hierarchy, $\sin^2\theta_{13}$

Accelerator ν_μ and $\bar{\nu}_\mu$ experiments seeking ν_e appearance :

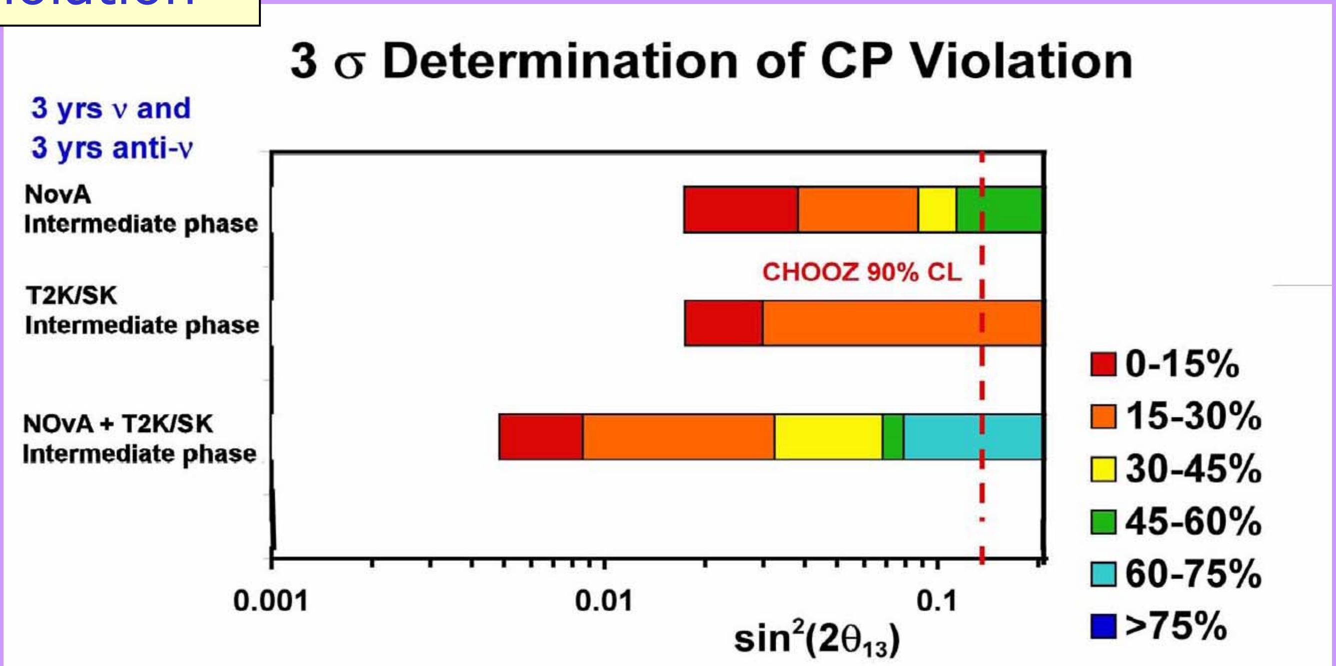
NOVA (~1.8 GeV, 810 km) and T2K (~0.65 GeV, 295 km) can measure $\sin^2\theta_{13}$ to ≤ 0.01, and can distinguish the normal and inverted hierarchy.





The path– CP violation

T2K and NOVA together have a (small) chance to see CP violation.



With luck, the planned program will map the neutrino parameter space. But if $\sin^2\theta_{13}$ is small, higher power ν sources will be needed (proton driver, long baseline, larger detectors).

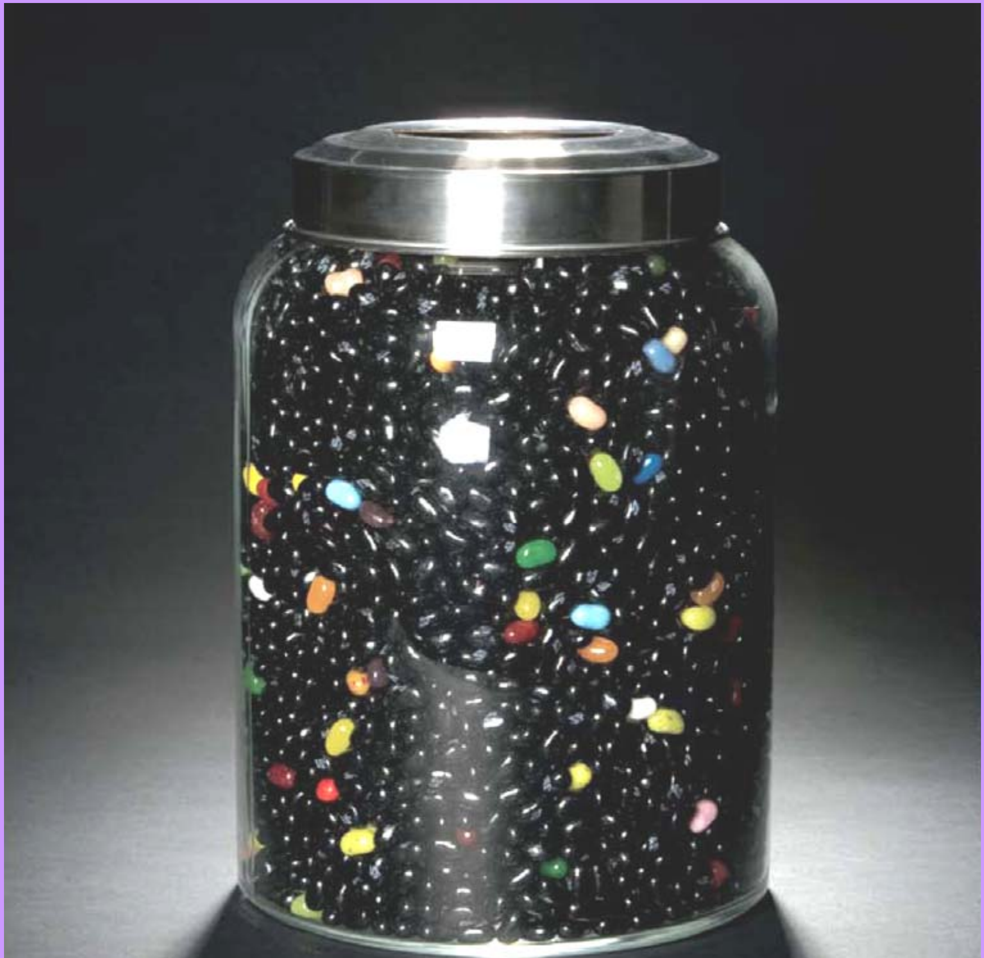
Will we make headway on the really fundamental issues (GUT scale physics, baryon asymmetry etc.) by measuring the ν matrix? It is a gamble. The corresponding quark matrix studies have not yet illuminated the big issues. But the next stage ν experiments are surely needed.

3. Particle physics in the universe
– cosmology and astroparticles

We ‘understand’ about 5% of the matter/energy content of the universe.

Elucidating the character of dark matter and dark energy are among the top questions in physical science today.

Particle physics, as the science of matter, energy, space and time, must help to explain the dark world.

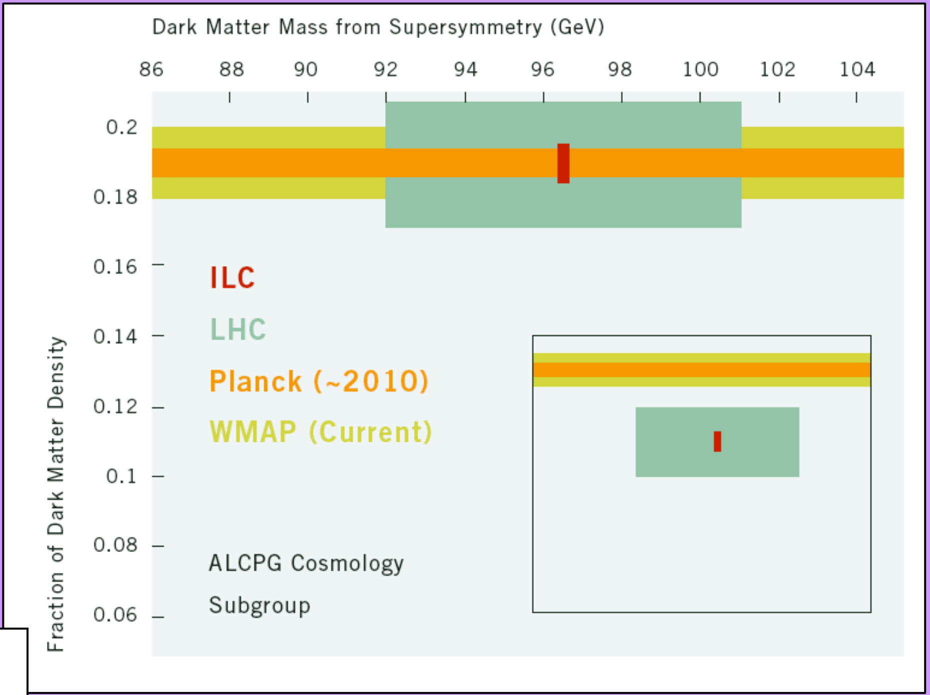

from Discovering the Quantum Universe

Dark matter

There is a consensus that dark matter is cold (massive, weakly-interacting particles). Direct detection in non-accelerator experiments looking at recoil energy from DM scattering is important. Inferring its presence from cosmic microwave background measurements gives the average density in the universe. Astronomical studies (e.g. dark matter galaxies) will continue to add information.

But collider experiments are needed to identify the particle(s). The ILC/LHC can discover the LSP of SUSY or other contributors.

Non-accelerator experiments often make use of techniques from HEP.



Particle physics, astronomy and cosmology work hand in hand

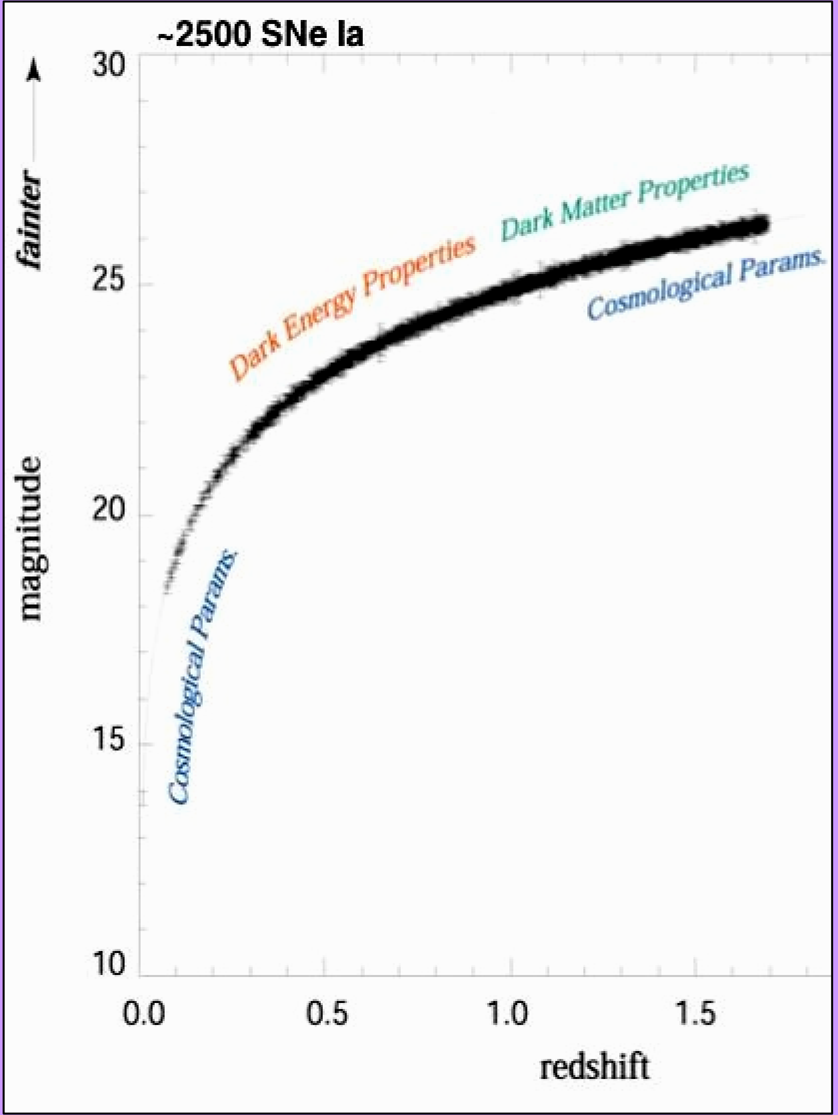
Dark energy

The character of dark energy is unknown – is it a new quantum field? It is likely that DE impinges on our understanding of the particle world.

Perhaps study of scalar fields (Higgs) will give us a some insight.

Some of the techniques of particle physics may assist new dark energy studies, but astronomical observations are central to this exploration.

Incisive dark energy research should be a component of our effort, but HEP is not well-suited to do it alone. The main techniques are astronomical.



Astroparticle studies

There are many examples of interesting astrophysical objects where particles are the messengers.

- High energy gamma rays from γ ray bursters, AGNs, binary mergers, black hole accretion disks, etc.
- Neutrinos from supernovae, coalescing black hole binaries
- Very energetic cosmic ray hadrons and nuclei
- Gravitational waves from black hole formation

These open windows on very interesting astronomical phenomena, and particle physics techniques can be successfully applied.

But they are not really ‘particle physics’, and astroparticle experiments will not carry our field.

Cosmology & Astroparticle vs. Accelerator experiments

I believe we should be wary in making astroparticle and cosmology the central thrust for the future of particle physics. Traditional particle physics experiments still have much to teach cosmology.

Accelerator based experiments are now poised to explore some truly fundamental new physics and give us a dramatic new paradigm. Experiments at the energy frontier are usually rewarding, and now we know where the frontier begins. We have some urgent business at hand.

The cosmological questions are so important that we must take part in these experiments. But it is not time yet to abandon our roots of the accelerator based study of the microworld – what we learn will continue to enlighten many of the macroscale studies of the universe.

The Outlook for 2007

DOE Office of Science budget request up 14% (by $505M); DOE HEP up 8%; NSF PHY up 6.6%

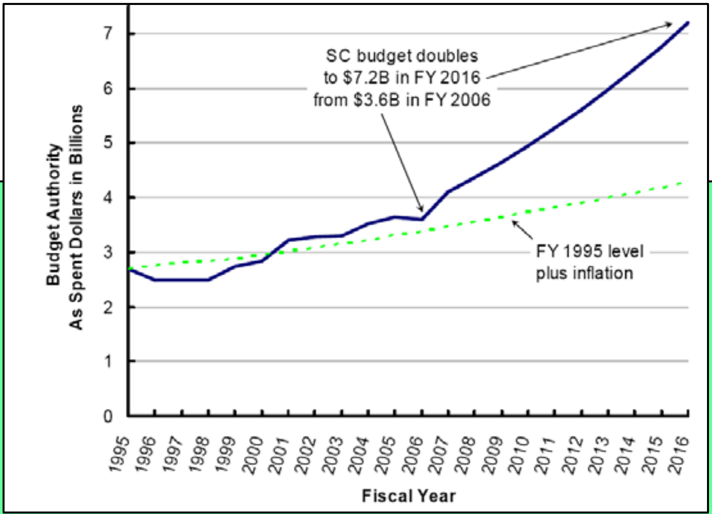
President's request calls for doubling physical science in 10 years (DOE SC, NSF, NIST) This would be average of 7.2% per year. (Inflation is about 3% per year.)

Both houses of Congress have shown support for doubling.

NAS Panel report "Rising Above the Gathering Storm" called for doubling in 7 years.

The President's budget request now goes to Congress where much can happen before passage. There are many other calls on discretionary funding

But this request has to be seen as good news!



The DOE SC program in FY 2007

In $M

	FY 2005 Approp.	FY 2006 Approp.	FY 2007 President's Request	FY 2007 Request vs FY 2006 Appropriation	
Basic Energy Sciences	**1,084**	**1,134**	**1,421**	**+286**	**+25%**
Advanced Scientific Computing Res.	**226**	**235**	**319**	**+84**	**+36%**
Biological & Environmental Research	**567**	**580**	**510**	**-70**	**-12%**
High Energy Physics	**723**	**717**	**775**	**+58**	**+8%**
Nuclear Physics	**394**	**367**	**454**	**+87**	**+24%**
Fusion Energy Sciences	**267**	**288**	**319**	**+31**	**+11%**
Other	**375**	**275**	**304**	**+29**	**+11%**
Total, Science	**3,636**	**3,596**	**4,102**	**+505**	**+14%**

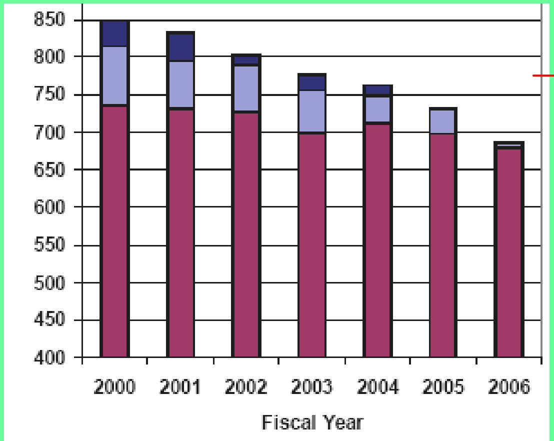
The DOE HEP FY07 budget

		FY05 Actual	FY06 Approp.	FY07 Request	FY07 - FY06
Facility ops	Tevatron	234	215	215	0
	B-factory	108	93	93	0
	LHC (construction+ops)	62	60	60	0
	LBNL and BNL infrastructure	6	6	6	0
Other Projects	Construction and non-LHC MIEs	17	2	13	11
Subtotal ops & projects		**427**	**376**	**387**	**11**
core research	University physics research	104	104	110	6
	Laboratory physics research	85	83	85	2
	Accelerator Science (univ + lab)	28	28	33	5
	SciDAC & Lattice QCD	7	7	7	0
Subtotal core research		**224**	**222**	**235**	**13**
	Accelerator Development	24	28	28	0
	Detector R&D	14	20	14	-6
	ILC R&D	24	30	60	30
	Dark Energy R&D	3	3	13	10
	Neutrino R&D	0	9	4	-5
Subtotal R&D and new initiatives		**65**	**90**	**119**	**29**
Others (incl. SBIR/STTR in 06 and 07)		**7**	**29**	**34**	**5**
Total as shown in FY07 budget		**723**	**717**	**775**	**58**
SBIR/STTR in FY 2005		17			
	Grand Total incl SBIR/STTR	**740**	**717**	**775**	**58**

The DOE HEP program in FY 2007

Overall HEP budget and priorities in FY 2007:

- Tevatron and B-factory supported for full scheduled Ops
- LHC Support (Operations and Computing) up 8% as construction completes
- Core research program increased at the universities (6%) and laboratories (2%)
- Initiatives for the future of HEP:
  - Double ILC R&D to $60M (but bring detector R&D into ILC budget)
  - Start NOVA
  - Start reactor ν experiment (need to choose)
  - Long-term accelerator R&D increased +$5M



FY2007 Requested amount

Other initiatives

Subject to HEPAP advice, plan to:

- Reactor Neutrino Detector. NuSAG recommends either Daya Bay (China) or Braidwood (Illinois) for scientific reasons. Selection by DOE in 2006.
- Electron Neutrino Appearance (NOVA) experiment scintillator detector to observe ν_e appearance in off-axis NuMI beam.
- Technical evaluation of high intensity neutrino beam for neutrino CP-violation experiments R&D continues
- A neutrinoless double-beta decay experiment – 200kg Xenon experiment in operation by 2007. R&D for ~1000kg experiments (with DOE NP, maybe NSF)
- R&D for next-generation DM experiments, with NSF (DM SAG)
- Ground-based DE expt(s) R&D (with NSF, DETF advice)
- Space-based dark energy experiment(s): SNAP conceptual design R&D for JDEM with NASA and R&D on other approaches will be considered

Outlook

We are blessed with well defined questions for which we have the necessary tools for incisive experiments. New understanding in the next decade seems assured.

We have made choices over the past several years that help us define our priorities.

The government is recognizing that basic science must be supported in a healthy society. Doubling the basic science budget is now a priority in the Executive and Legislative branches.

It is our job not only to develop the new experimental tools and theoretical structures, but also to explain to the public why this enterprise is needed.

Lets give the organizers our thanks for an excellent conference.

- Greg Landsberg
- Marcela Carena
- Matthias Neubert
- (Gudrid Moortgat-Pick)