Tevatron and Run II
Status and Plans

John Womersley

IOP HEPP Group Meeting – Recent Results from the Tevatron
Imperial College
21 September 2005

CCLRC

Outline

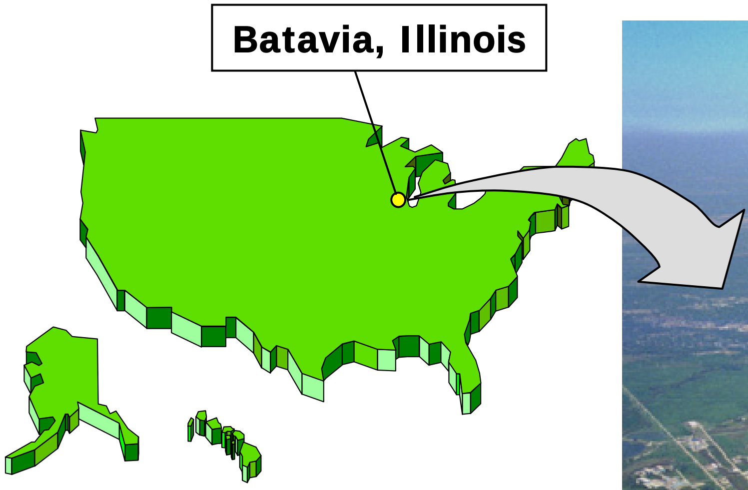
- Status and prospects of the Tevatron accelerator
- Brief status of the CDF and DØ detectors
- A few words about P5
- Introduce and motivate the major physics goals of the Tevatron

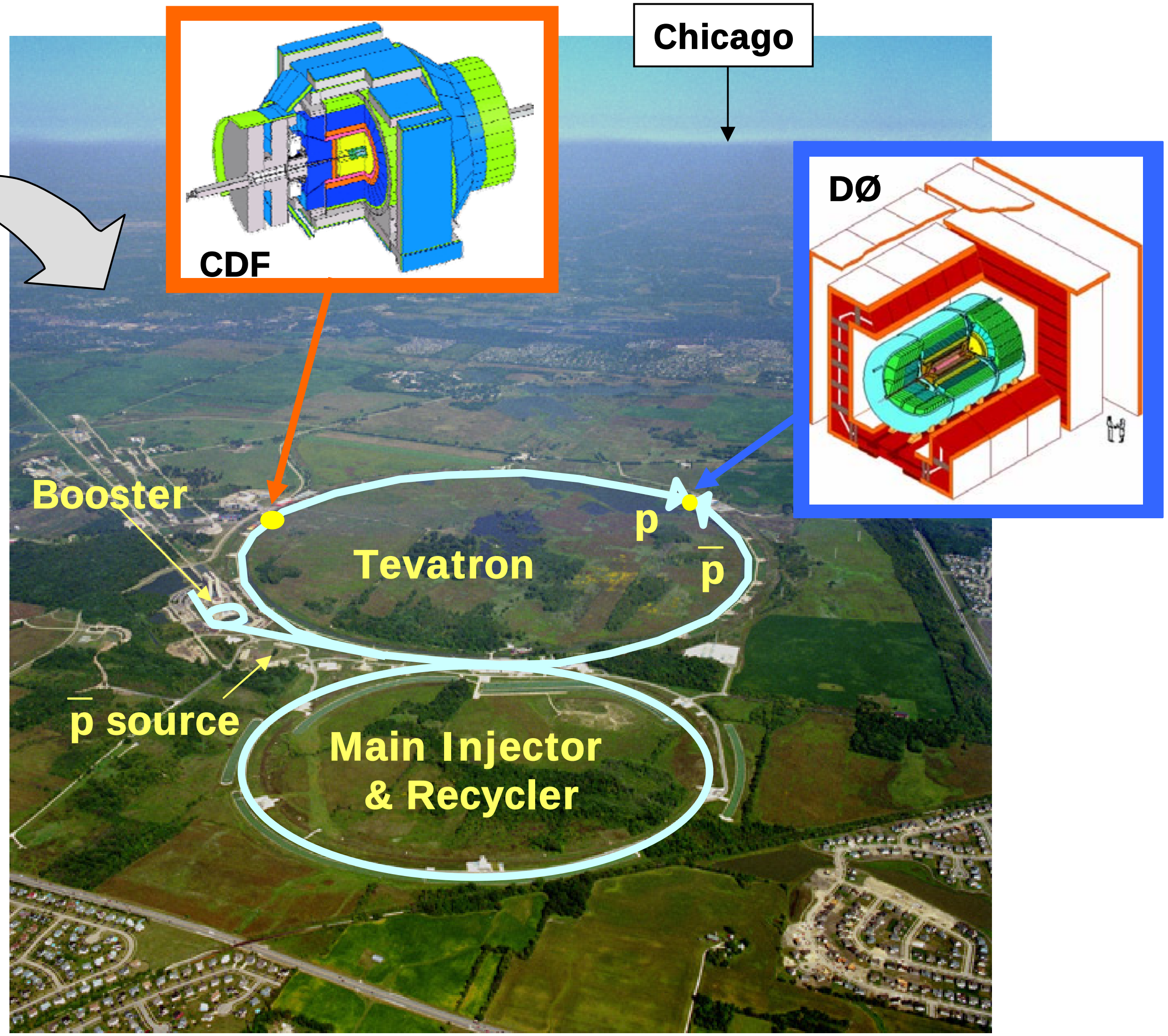
What is the universe made of?

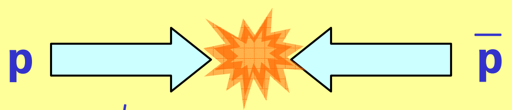
- A very old question, and one that has been approached in many ways
  - The only <u>reliable</u> way to answer this question is by directly enquiring of nature, through experiments
- We live in a cold and empty universe: only the stable relics and leftovers of the big bang remain. The unstable particles have decayed away with time, and the symmetries have been broken as the universe has cooled.

  But every kind of particle that ever existed is still there, in the quantum fluctuations of the vacuum. The vacuum "knows" about all the degrees of freedom and all the symmetries.
- We use colliders to pump sufficient energy into the vacuum to re-create the particles and uncover the symmetries that existed in the earliest universe.
- Accelerators, which were invented to study the structure of matter, are also tools to study the structure of the vacuum – the space-time fabric of the universe itself

Fermilab





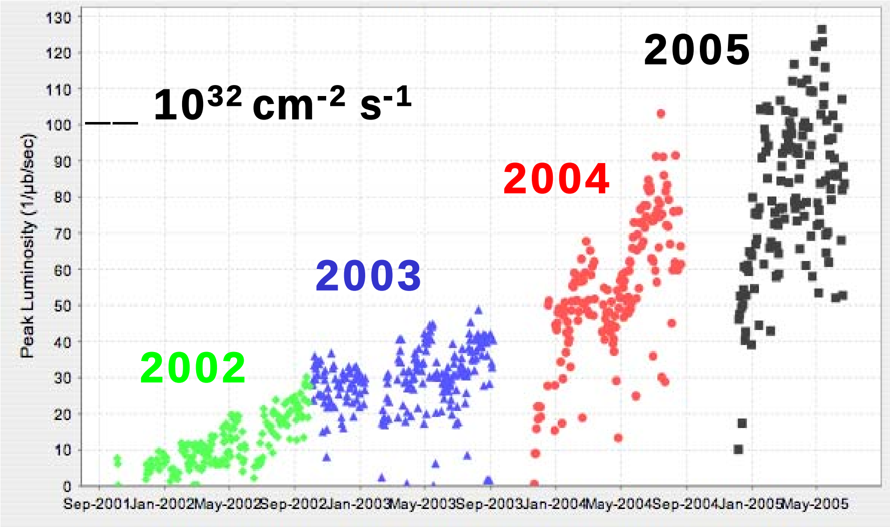


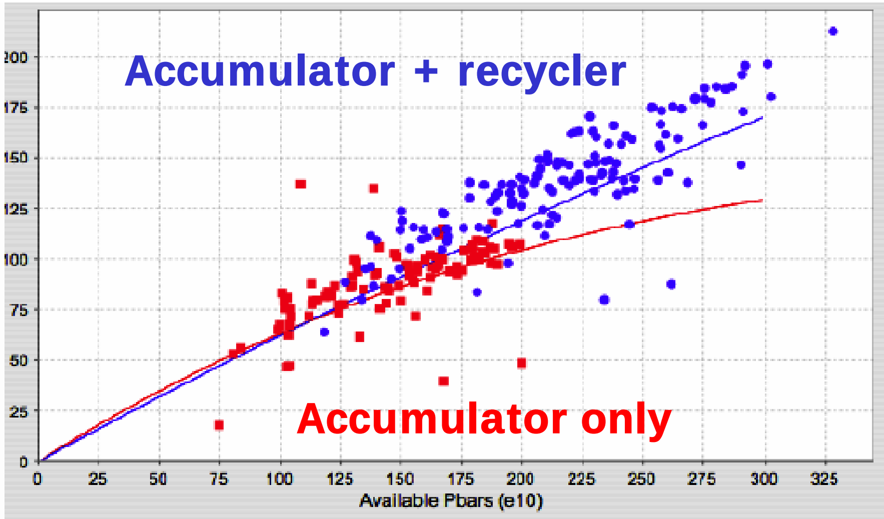
$\sqrt{s}$ = 1.96 TeV
Δt = 396 ns

Run I 1992-96
Run II 2001-09

50 × larger dataset
at increased energy

Tevatron Status

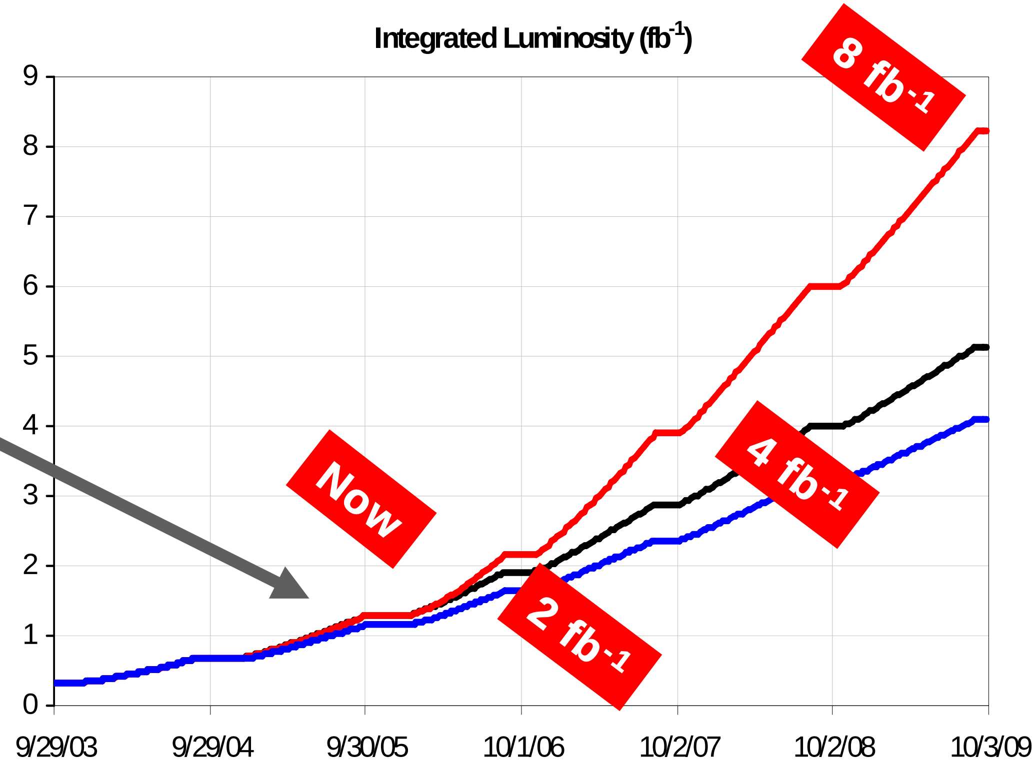




- Luminosity increase since 2004 is due to
  - Improved performance of injector chain
  - Realignment of Tevatron magnets
  - Integration of recycler ring into operations
  - Adoption of a rigorous approach to operations and upgrades
- Continued improvements require more antiprotons
  - Improved production
  - Greater cooling
  - Better transfer efficiency

Upgrades

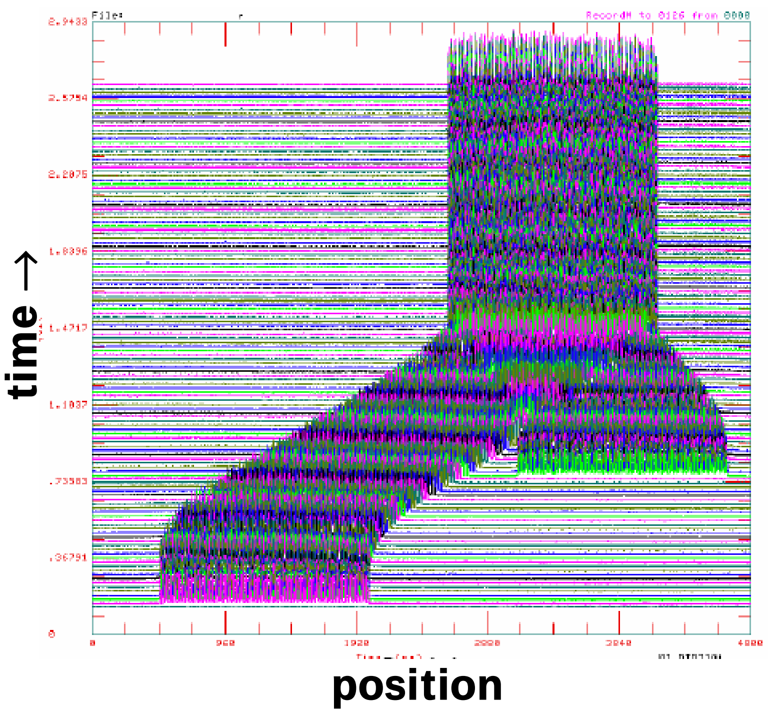
Champagne for 1 fb^{-1}

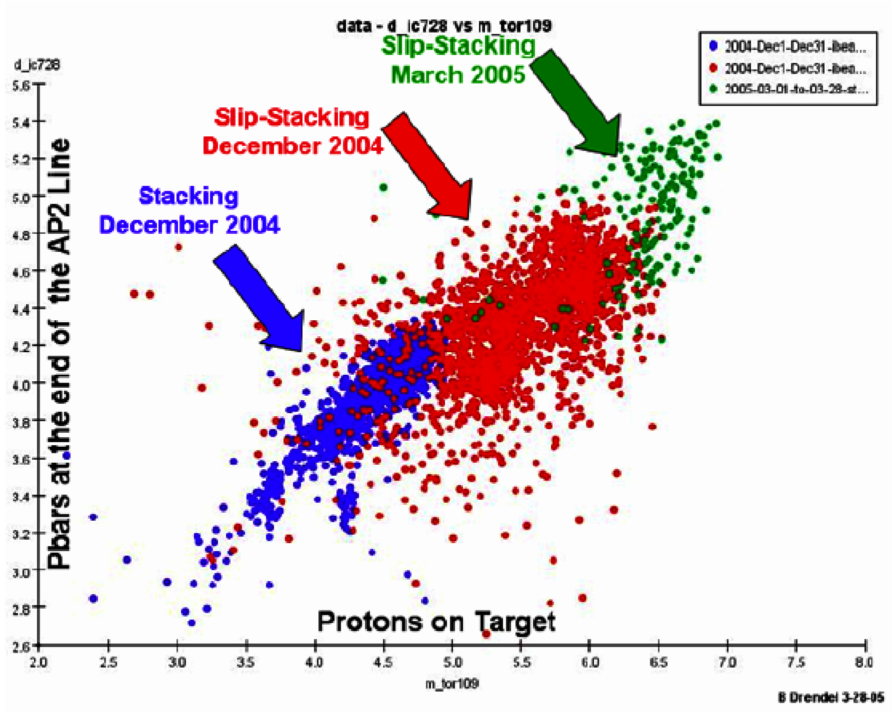


- **Autumn 2005 is the time when a significant increase in luminosity is foreseen, and many of the upgrades for the Tevatron should come online**
  - **How are we doing?**

Antiproton Production

- Slip stacking: a way of merging multiple booster batches into the Main Injector to get more protons on to the antiproton production target

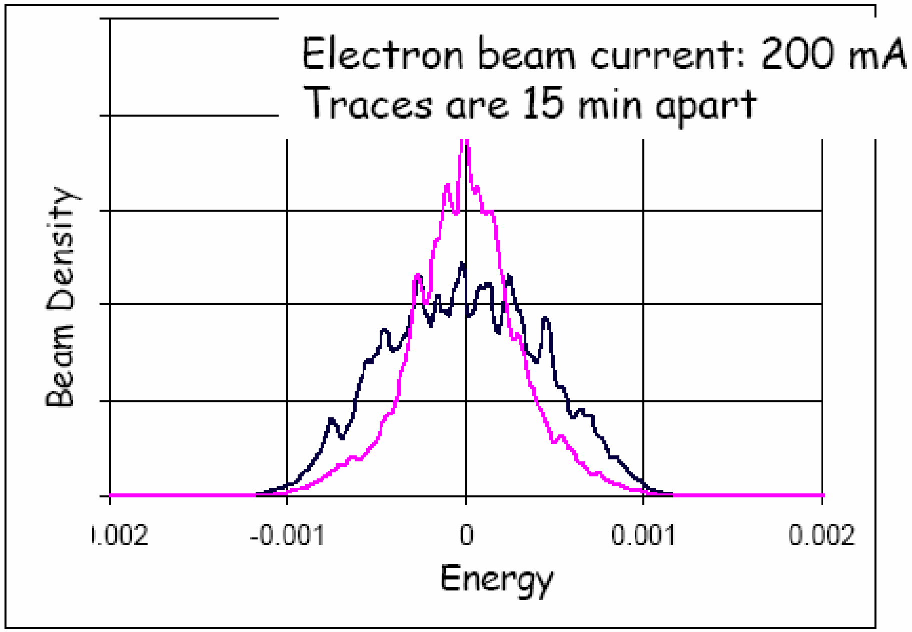




- Working!

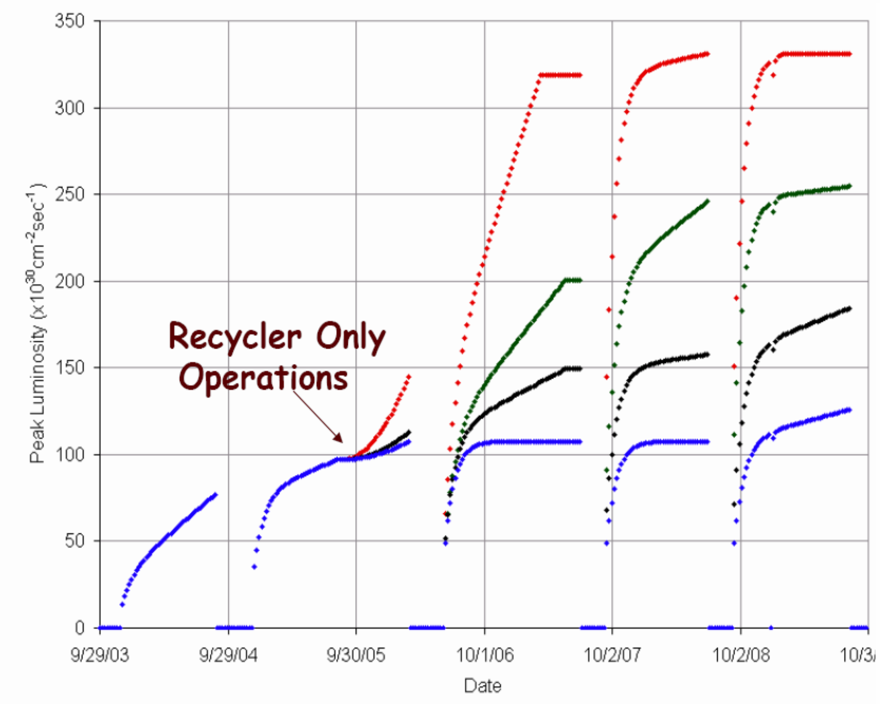
Electron Cooling

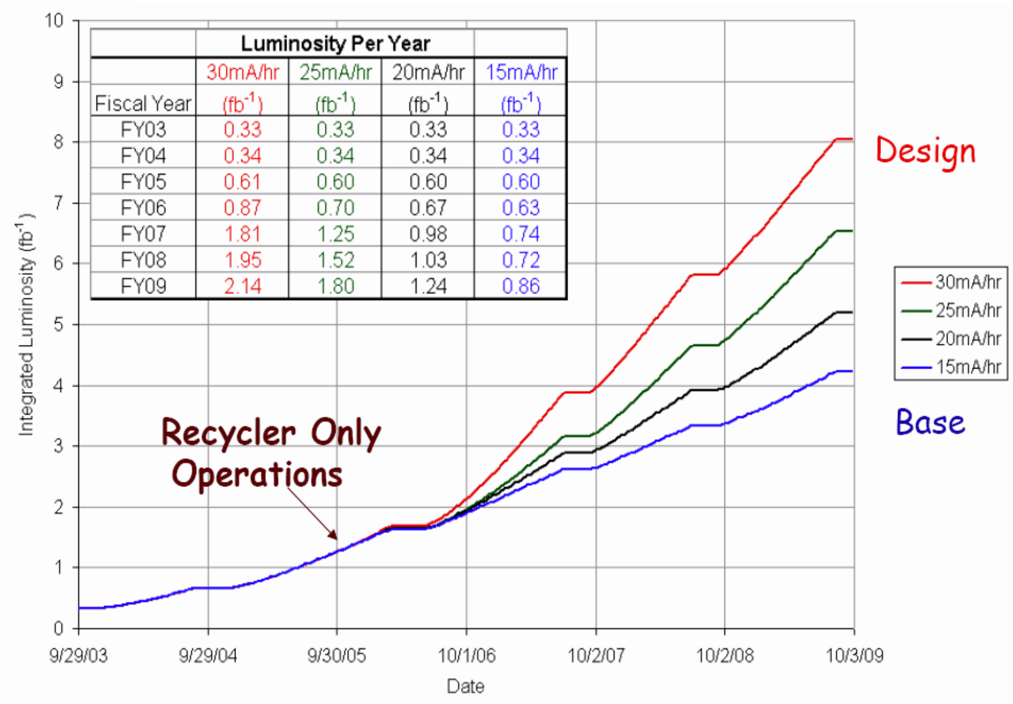
- Electron cooling in the Recycler is installed and working!



- Will transition to Recycler-only operations by November 1

Luminosity Prospects



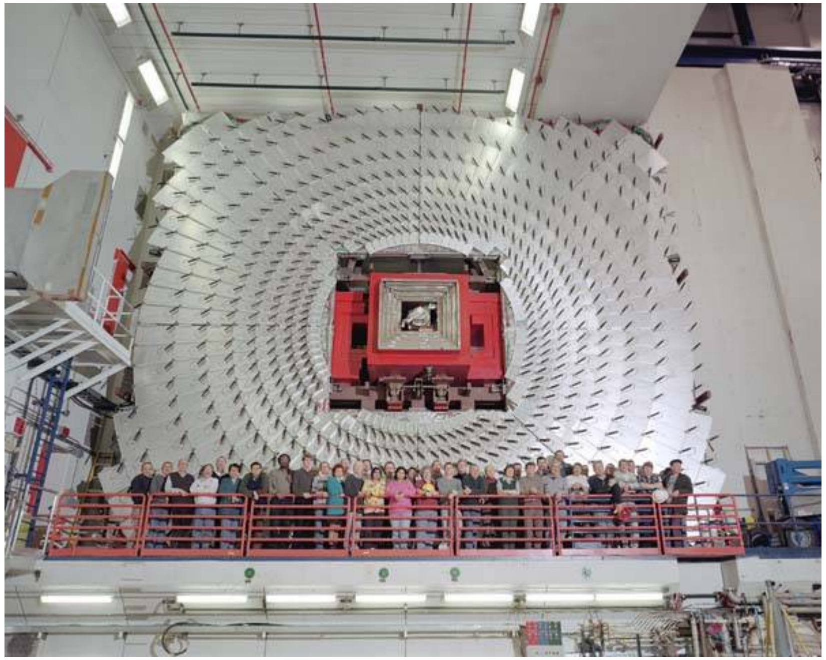


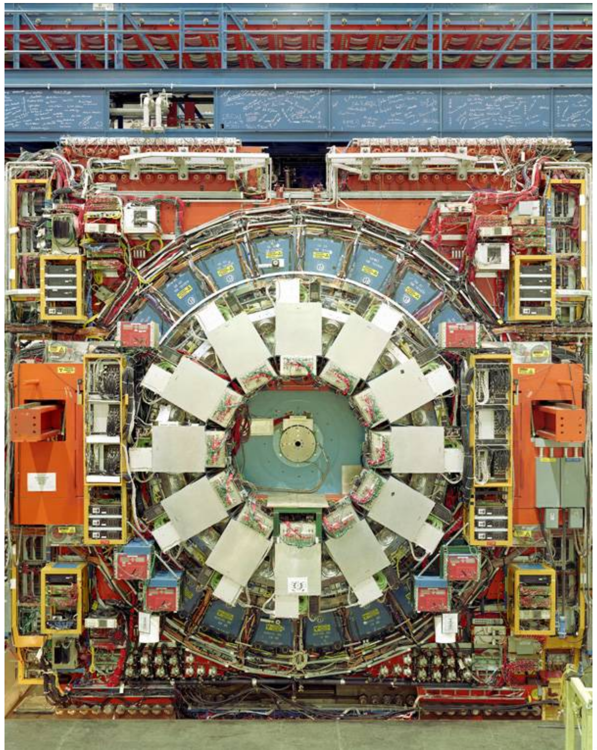
Fiscal Year	30mA/hr (fb^{-1})	25mA/hr (fb^{-1})	20mA/hr (fb^{-1})	15mA/hr (fb^{-1})
FY03	0.33	0.33	0.33	0.33
FY04	0.34	0.34	0.34	0.34
FY05	0.61	0.60	0.60	0.60
FY06	0.87	0.70	0.67	0.63
FY07	1.81	1.25	0.98	0.74
FY08	1.95	1.52	1.03	0.72
FY09	2.14	1.80	1.24	0.86

- **The only remaining uncertainty is the antiproton stacking rate that can be achieved**
  - **Best so far is 17 mA/h, design needs 30 mA/h**
- **A dedicated task force has been set up**
  - **Define a study plan, specify the instrumentation needed, and execute plan by March 2006**

CDF

DØ





Detector status

- Both detectors are running well
  - Recording 85-90% of delivered luminosity
  - Reconstructing all data in a timely manner
  - Increasing use of offsite computing resources (includes UK)
  - Little if any degradation of detector performance seen
    - Inner layer silicon lifetime estimated at 5—7, 8 fb^{-1} (DØ, CDF)
- Publishing results at an accelerating rate
  - CDF+DØ 2003/04/05: 4/19/48 submitted or published
- Upgrades
  - CDF: Central preshower, EM timing (installed autumn 2004)
  - DØ: new inner silicon layer (ready to install)
  - Both detectors: DAQ and triggers for higher luminosity
- The path forward
  - Algorithms still being improved (jet resolution, b-tagging…)
  - Developing trigger lists for few $\times 10^{32}$
  - Understand manpower needs for running to 2009 and how to streamline and automate operations

P5

- The Particle Physics Project Prioritization Panel was asked to advise on what factors might lead to a cessation of Tevatron operations one or two years earlier than planned, or to running longer than planned

- Panel met at Fermilab last week, heard presentations from lab management and from the experiments.
  - They seemed pleased with what they heard.

- Panel's report not yet written; will be at SLAC next week for PEP-II; <u>but</u> they seem to be heading towards something like this:
  - It is too early to judge the physics and the luminosity promise of the Tevatron.
  - Similarly, too early to judge the LHC schedule.
  - Recommend to review the program again in **early 2007**.
  - Given US budget timescale, this can really only affect running in **FY 2009** and later.
  - Want to find a way to involve (not just inform) **non-US stakeholders** in the eventual decision.

Revolution is coming

- The standard model makes precise and accurate predictions
- It provides an understanding of what nucleons, atoms, stars, you and me are made of
- But (like capitalism!) it contains the seeds of its own destruction

- Its spectacular success in describing phenomena at energy scales below 1 TeV is based on
  - At least one unobserved ingredient
    - the SM Higgs
  - Whose mass is unstable to loop corrections
    - requires something like supersymmetry to fix
  - And which has an energy density 10^{60} times too great to exist in the universe we live in

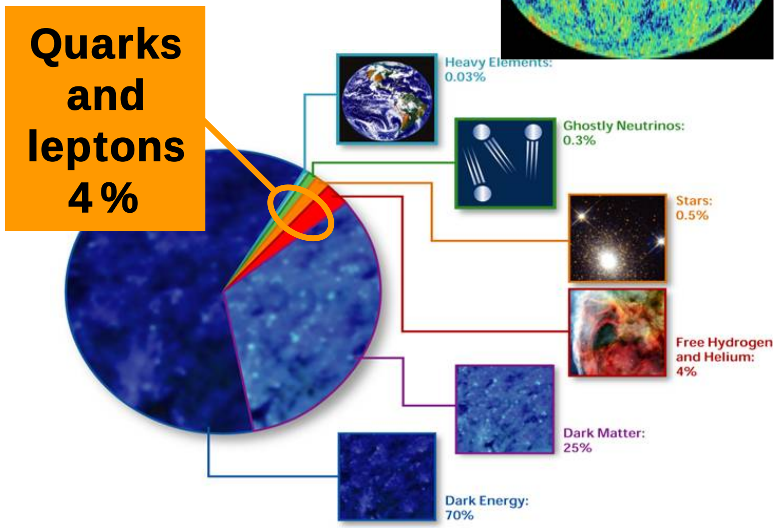
- The way forward is through experiment (and only experiment)
  - tantalizing – we know the answers are accessible
  - frustrating – we have known this for 20 years…

We went to Texas

... and we came back

Meanwhile, back in the universe ...

- What shapes the cosmos?
  - Old answer: the mass it contains, through gravity
- But we now know
  - There is much more mass than we'd expect from the stars we see, or from the amount of helium formed in the early universe
    - Dark matter
  - The velocity of distant galaxies shows there is some kind of energy driving the expansion of the universe, as well as mass slowing it down
    - Dark Energy
- We do not know what 96 % of the universe is made of!



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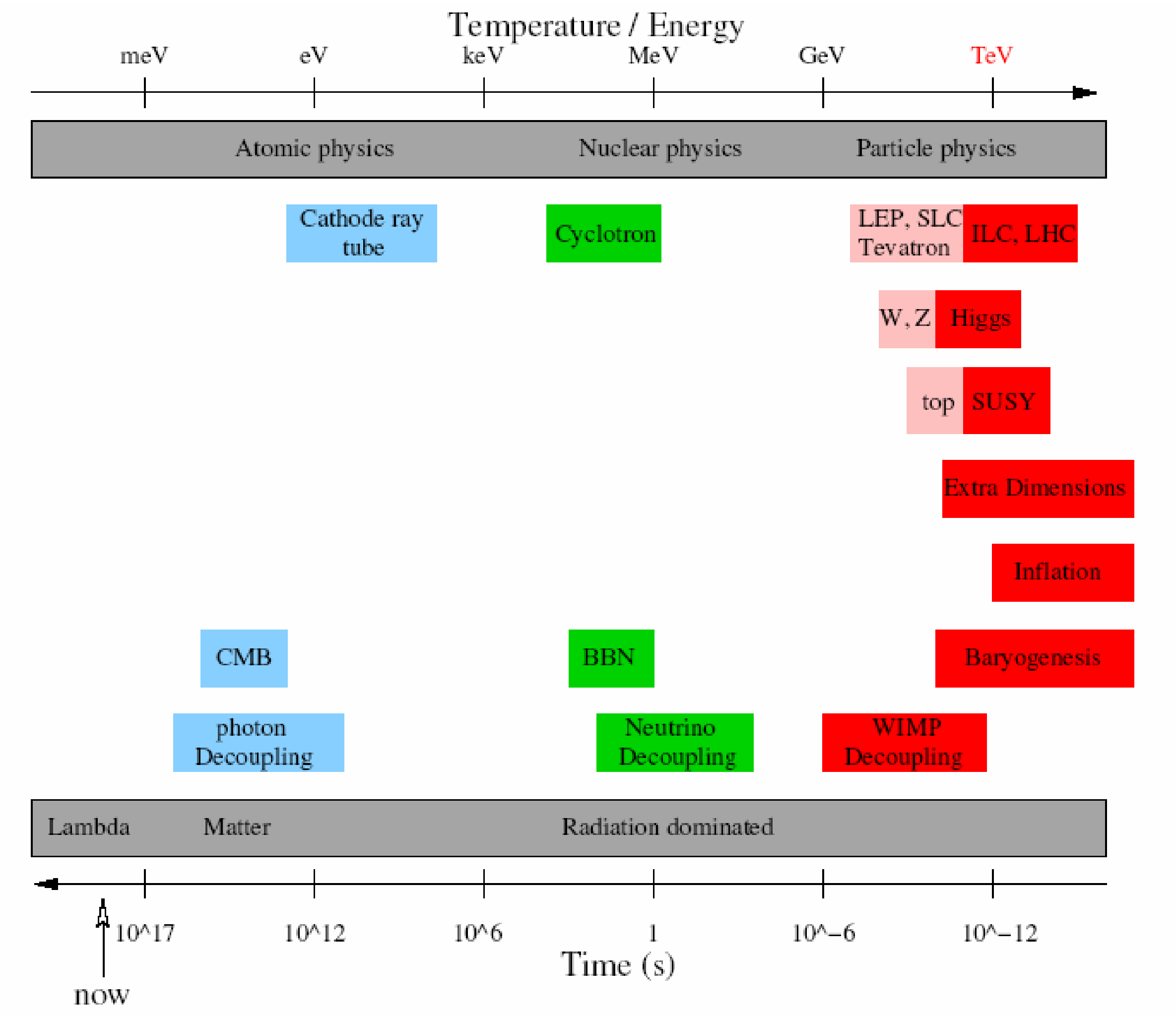
These questions come together at the TeV scale



We are exploring what the universe contained ~ 1ps after the big bang!

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Particle
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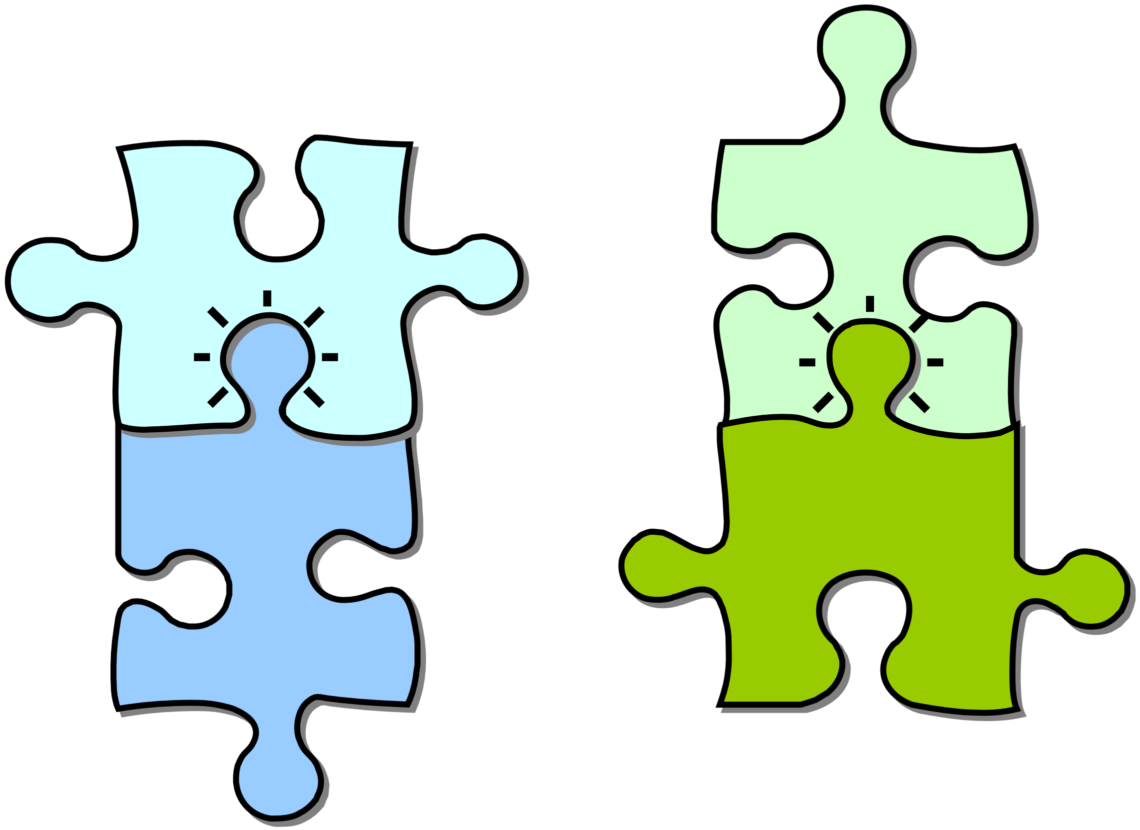
Experiments
Accelerators
Underground

Quantum
Field
Theory
(Standard
Model)



Astronomy
Experiments
Telescopes
Satellites

Standard
Cosmology
Model

10^{-18} m

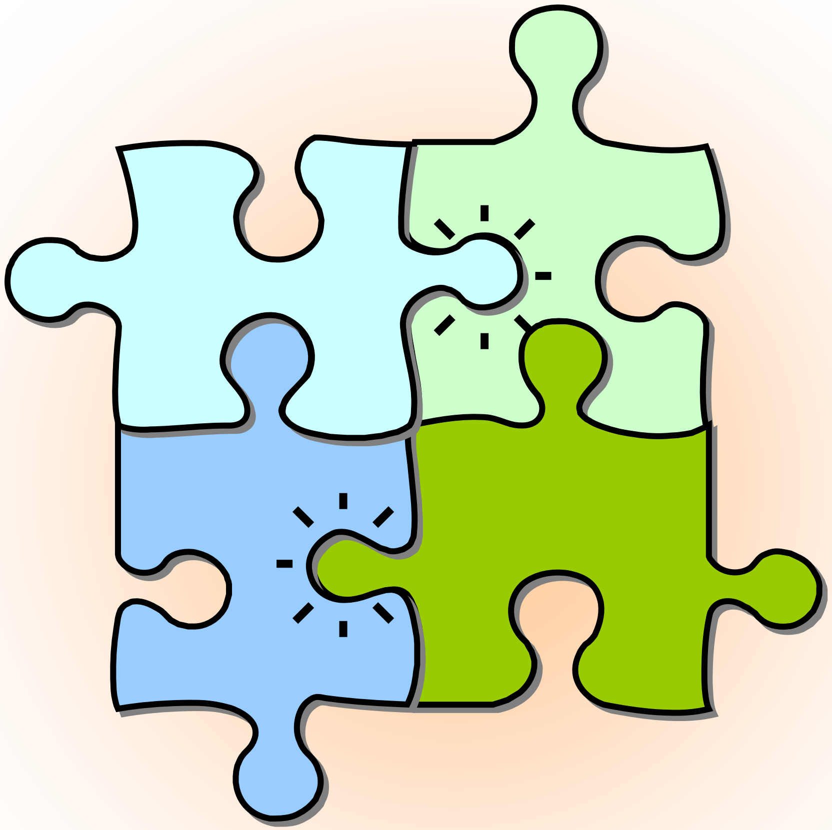
10^{26} m

Describing the Universe

Describing the Universe

Particle Physics Experiments Accelerators Underground

Quantum Field Theory (Standard Model)



Astronomy Experiments Telescopes Satellites

Standard Cosmology Model

Consistent understanding?

10^{-18} m ←

→ **10^{26} m**

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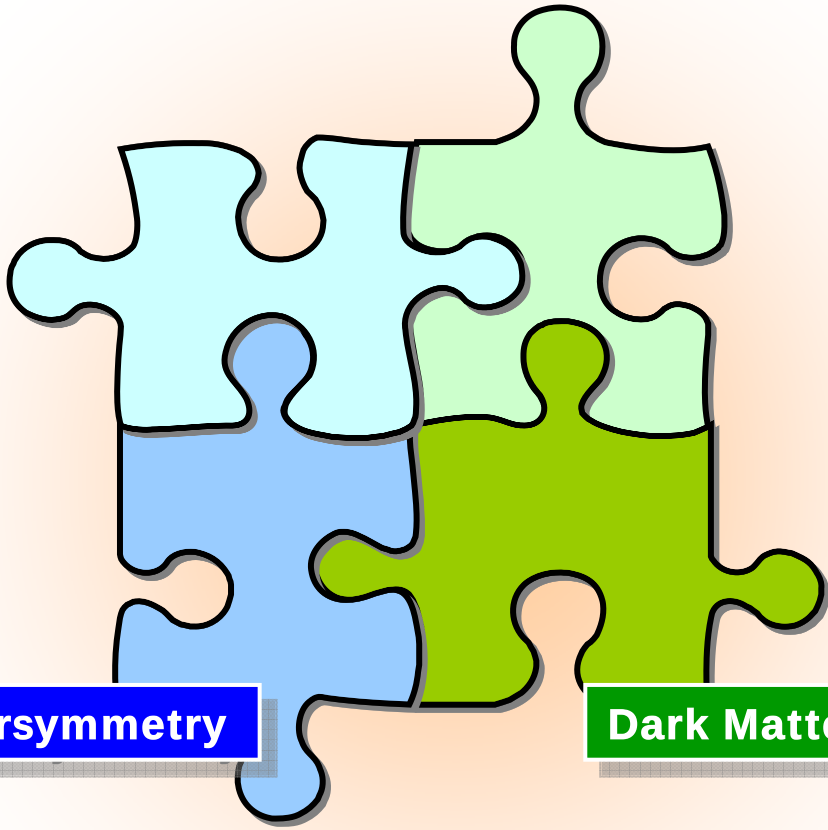
Quantum Field Theory (Standard Model)



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Standard Cosmology Model

Consistent understanding?

?

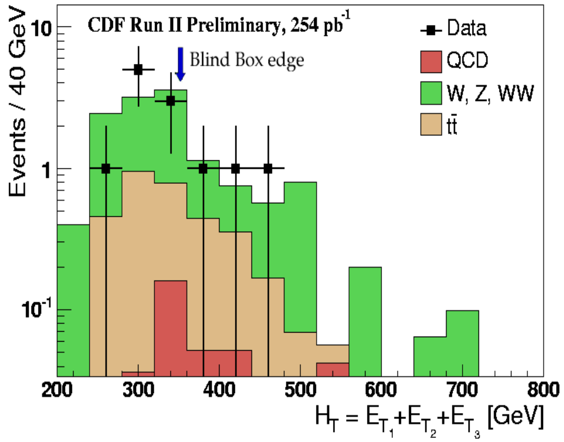
Goals for hadron colliders

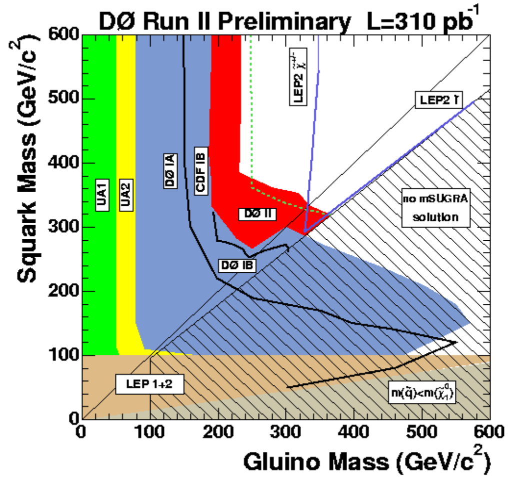
- **can we discover supersymmetry? Something else?**
- **is it consistent with cosmic dark matter?**

Tevatron supersymmetry searches

Two classic search modes:

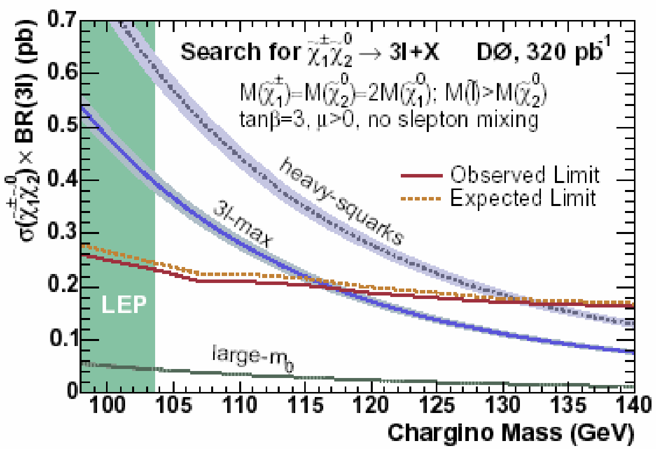
1. Squarks / Gluinos → jets + missing E_T

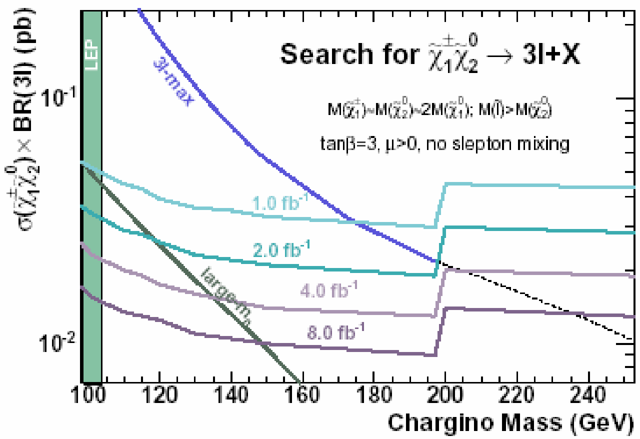




2. Chargino + Neutralino → trileptons + missing E_T signature

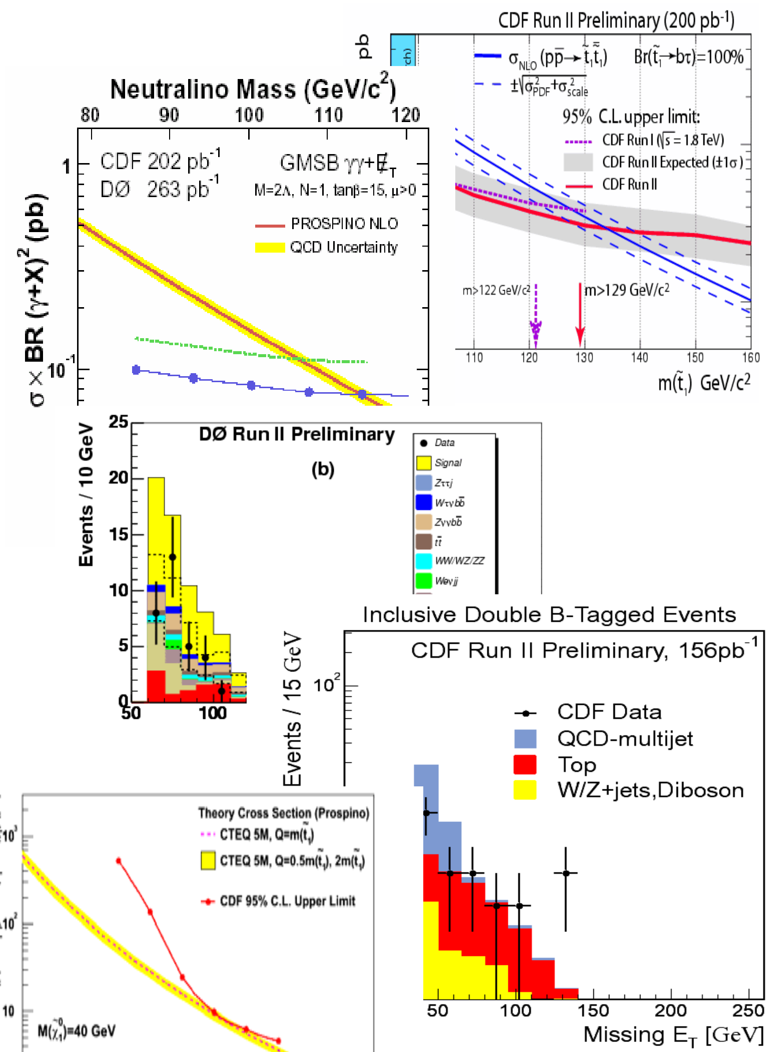
Sensitivity now beyond LEP… … discovery potential

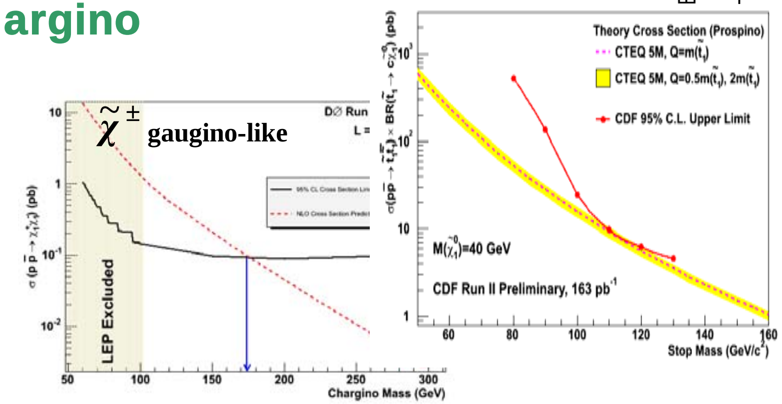




Many other SUSY searches ongoing…

- gluino $\rightarrow$ sbottom + bottom
- sbottom pair production
- stop pair production
- gauge mediated SUSY
  - photons + missing E_T signature
- R-parity violation
  - multileptons from LLE coupling
  - jets + muons from LQD coupling
  - neutralino $\rightarrow$ eμ, ee, $\mu\mu$, $\tau\tau$
  - stop pairs $\rightarrow$ bτ bτ
- charged massive (quasi-)stable particles
  - e.g. stau or chargino





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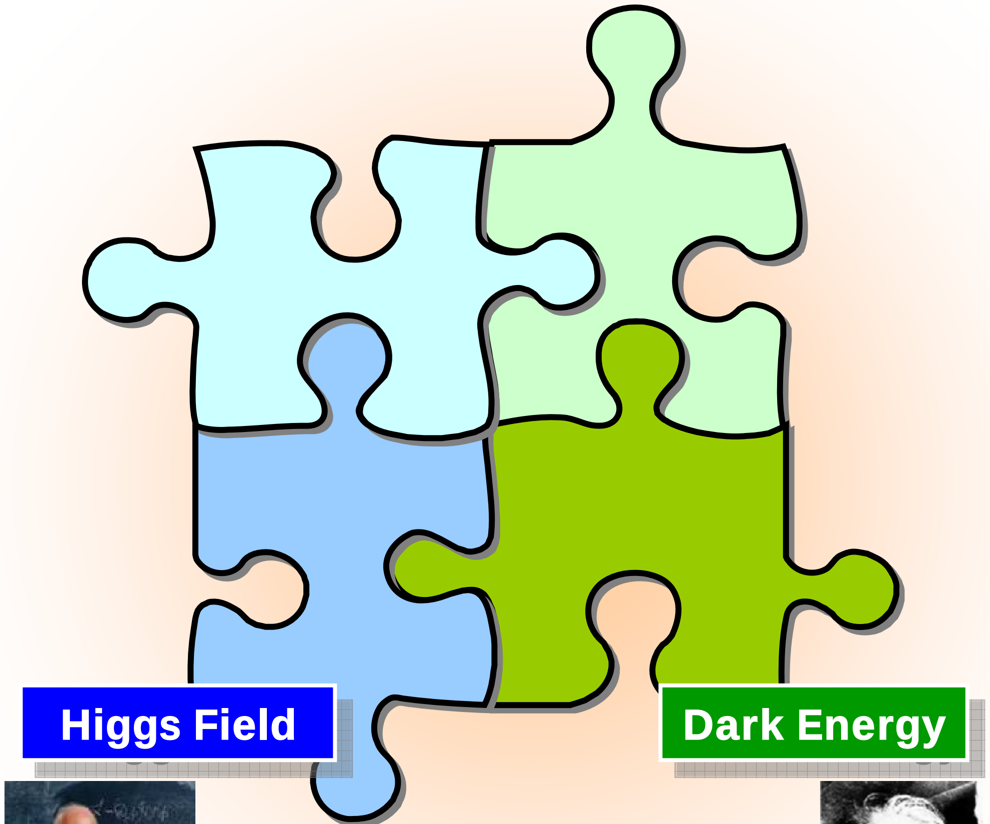
Quantum Field Theory (Standard Model)



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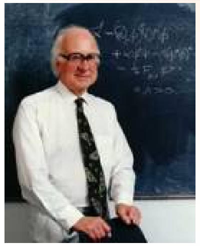
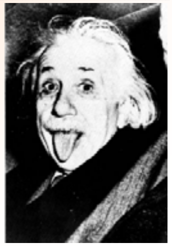
Standard Cosmology Model



Consistent understanding?

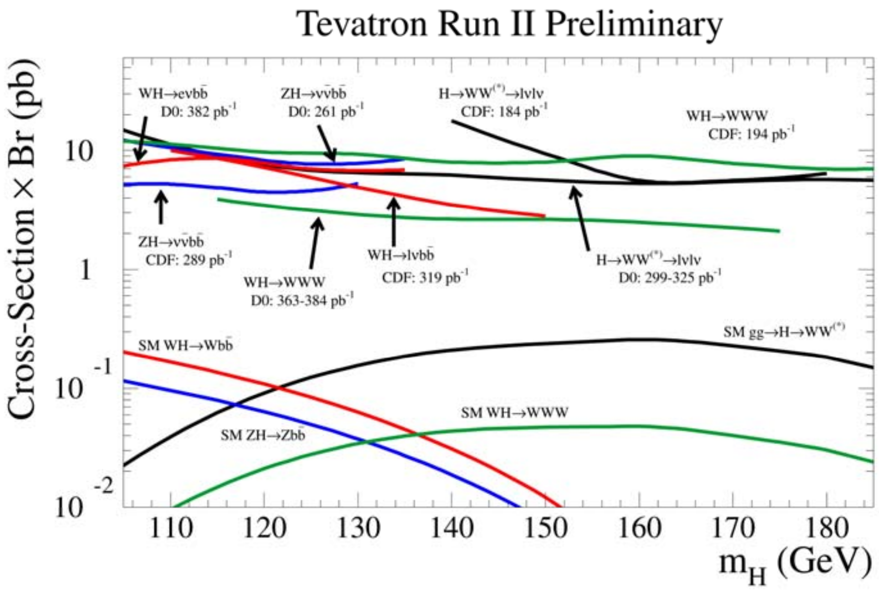
NO! > 10^{60}

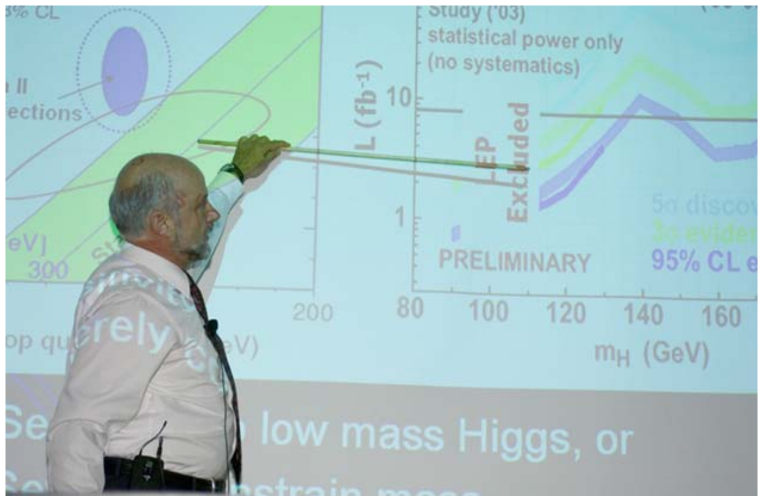


Goals for hadron colliders
- **what can we learn about the Higgs field?**
- **from direct searches, and indirectly from the top quark?**

Higgs at the Tevatron

- **Many analyses being carried out**
- **Limits obtained with ~300pb^{-1} are 20-100 times higher than SM cross section**
- **Experiments have quantified the improvements in sensitivity needed to reach projections**
  - **EM coverage**
  - **EM efficiency**
  - **Dijet mass resolution**
  - **b-tagging**
  - **…**
- **No one said this would be easy!**

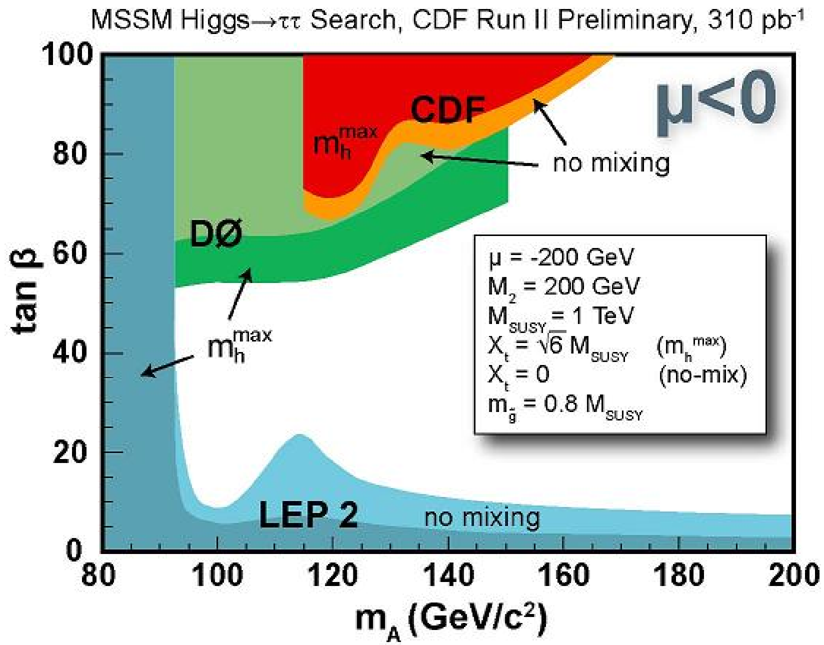


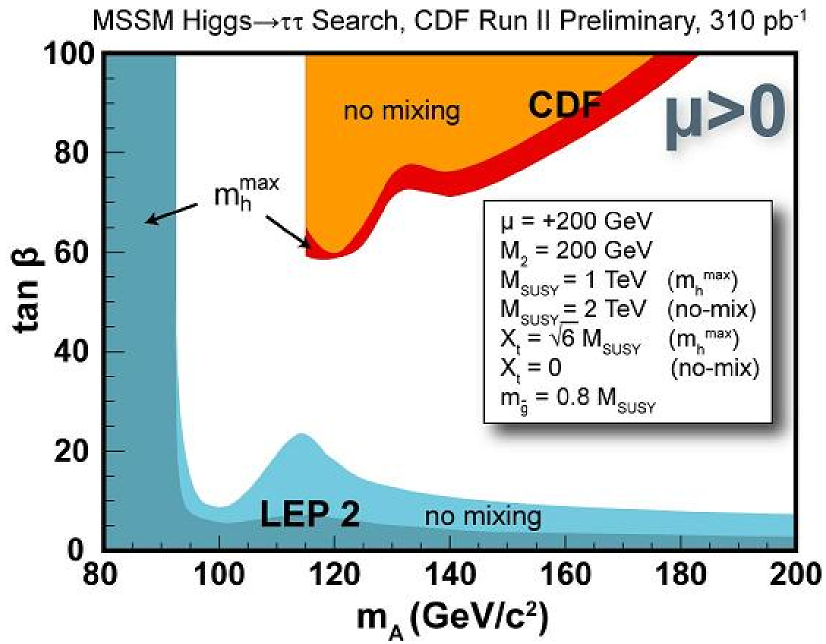


Pier Oddone at National Academies EPP2010 Panel
May 2005

Supersymmetric Higgs at the Tevatron

- **H / h / A → $\tau\tau$ and $b\bar{b}$**

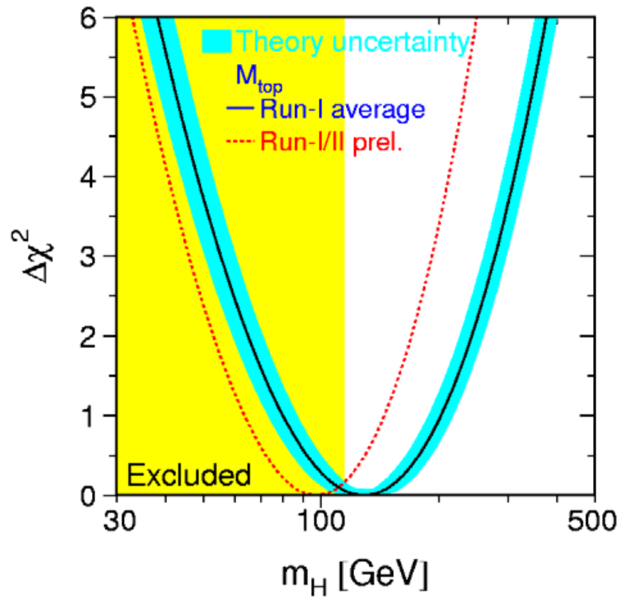


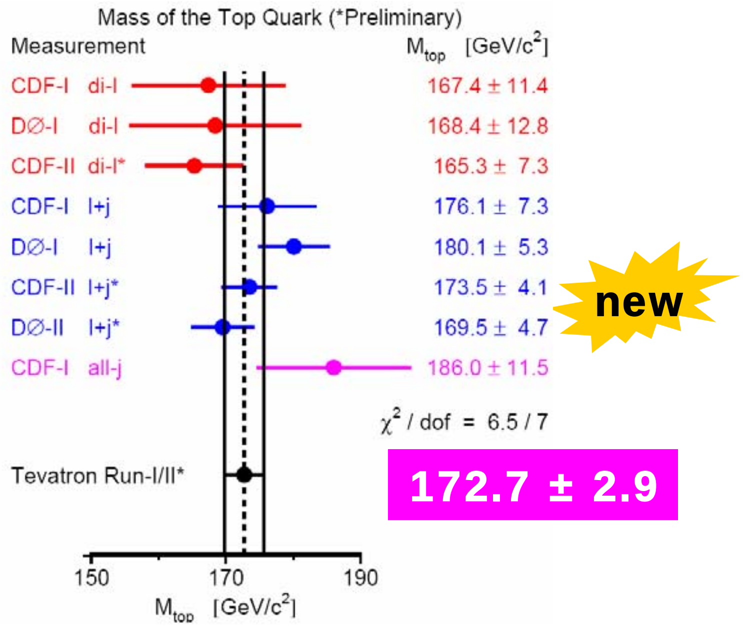


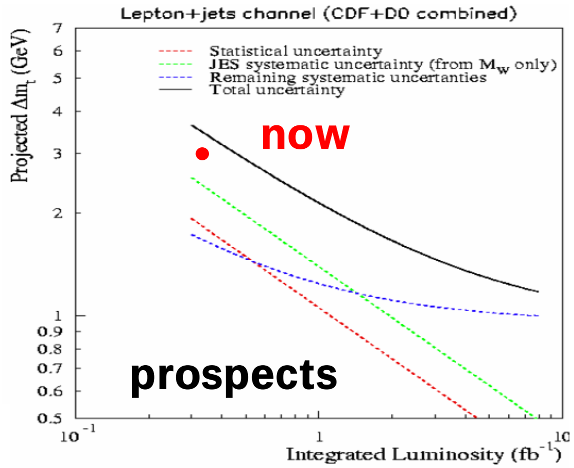
- **Already constraining models at large tan β**

Top Mass

- **New Run II masses (lepton + jets)**
  - **TEV EWWWG hep-ex/0507091**



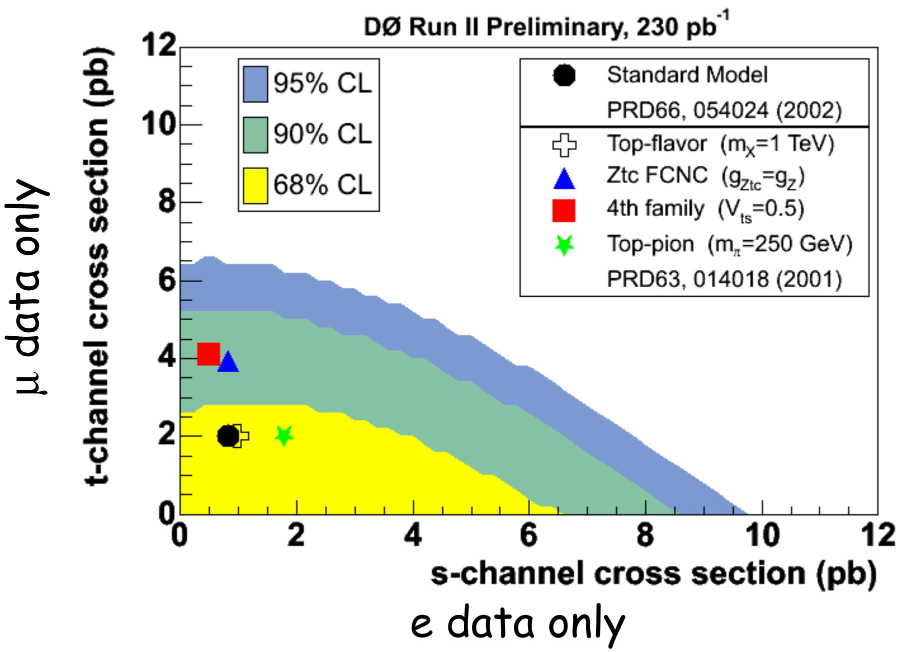




- **$m_H \lesssim 220$ GeV (95% of m_H > 114 GeV)**
- **Δm_t < 2 GeV with a few fb^{-1}**

Single Top

- Probes the electroweak properties of top
- Good place to look for new physics connected with top
  - Desirable to separate s and t-channel production



Channel	CDF (162 pb^{-1})	DØ (230 pb^{-1})
s+t	<17.8 (13.6)	
s	<13.6 (12.1)	<6.4 (4.5)
t	<10.1 (11.2)	<5.8 (5.0)

95% CL observed (expected)

- Not yet sensitive to SM, but starting to be sensitive to some models
- With current DØ analysis, would require ~ 2.5fb^{-1} for a 3σ signal in the t-channel
  - So it will happen in Run II – but improvements still desirable!

Particle
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Quantum
Field
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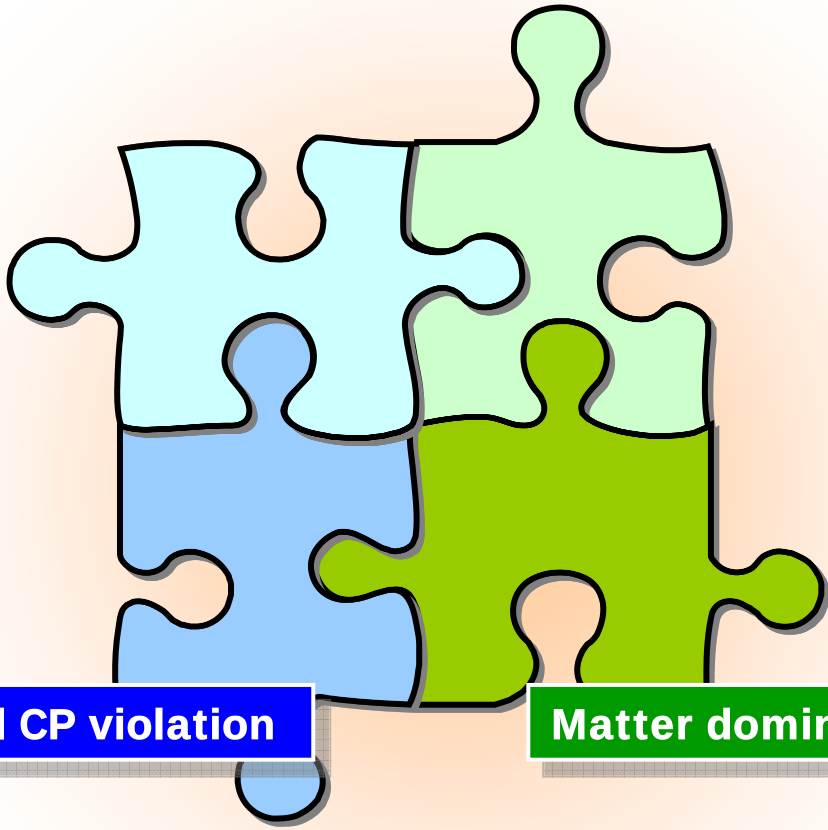

Astronomy
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Cosmology
Model

Small CP violation

Matter dominates

Consistent understanding?

Not really

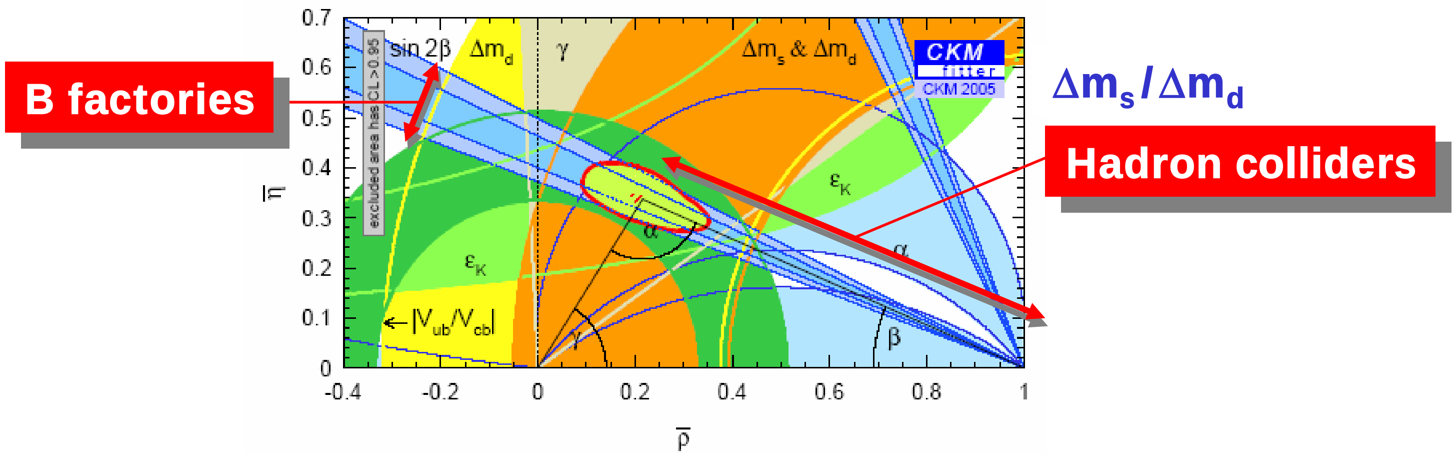
Goals for hadron colliders
- complement the B-factories in exploring CP violation
- search for new sources and use B as probe of new physics

B physics at hadron colliders

If quark mixing is described by a unitary 3×3 matrix, we can parametrize the phases and magnitudes by a triangle.

Hadron colliders confront this unitarity triangle in ways that complement measurements at the e^+e^- B-factories

e.g. through the B^0_s system . . .

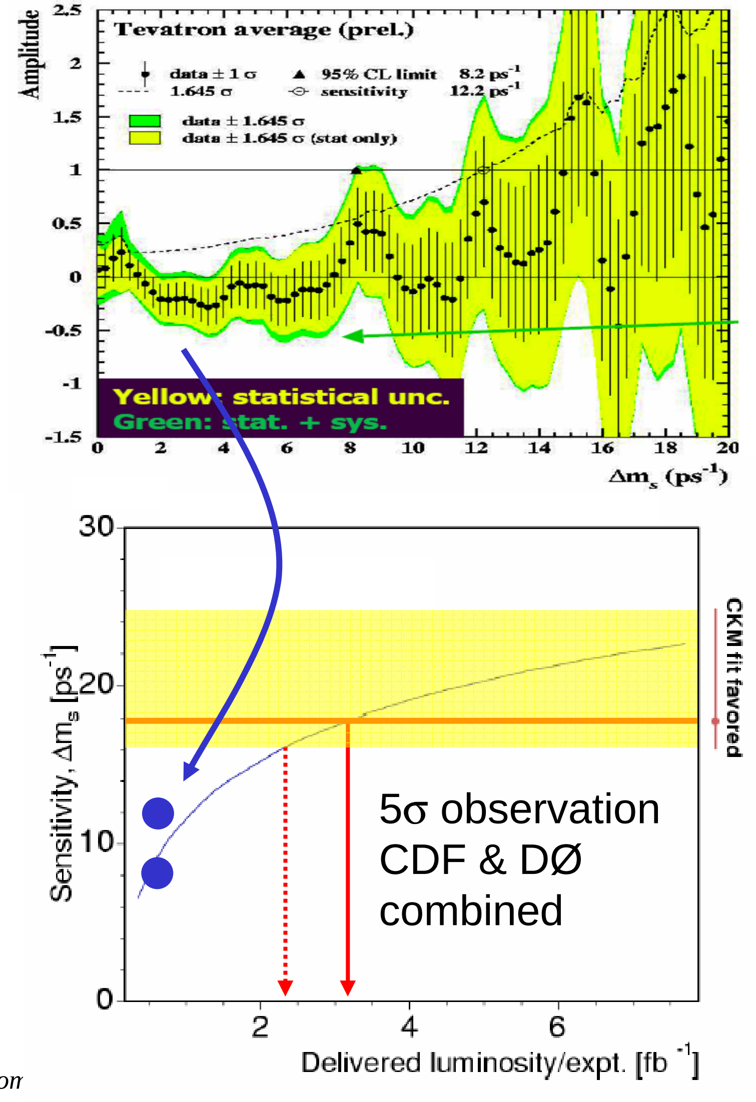


A good way to see indirect effects of new physics not detectable at B-factories

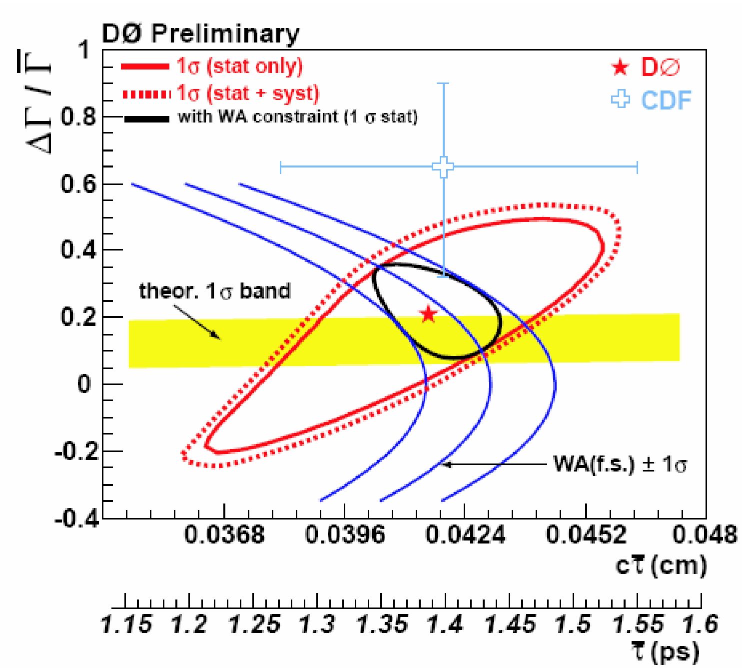
B-factory tease: 2.6σ discrepancy between sin 2β measured in tree diagram modes and strange quark penguins…

B^0_s oscillations and width difference

- Δm_s > 8.2 ps^{-1} (12.2 expected)



- $\Delta\Gamma_s/\Gamma$ from CDF larger than expected; central value would imply large Δm_s (and new physics?)



- Combined DØ + CDF consistent with SM

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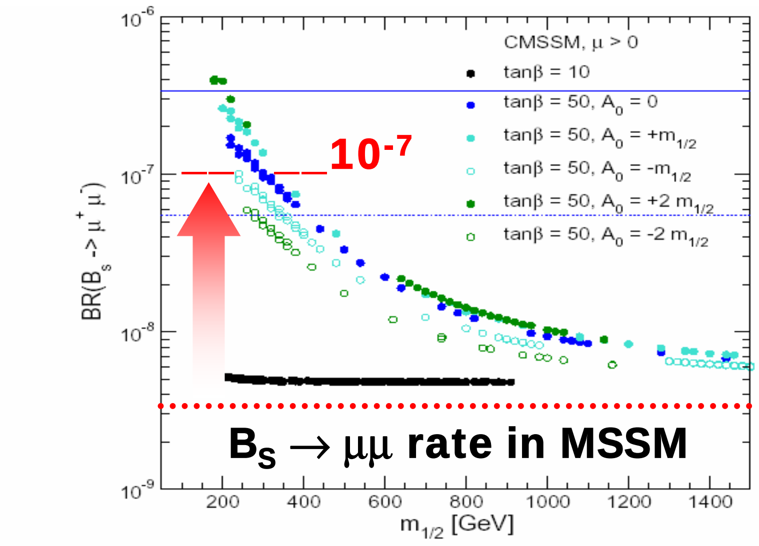
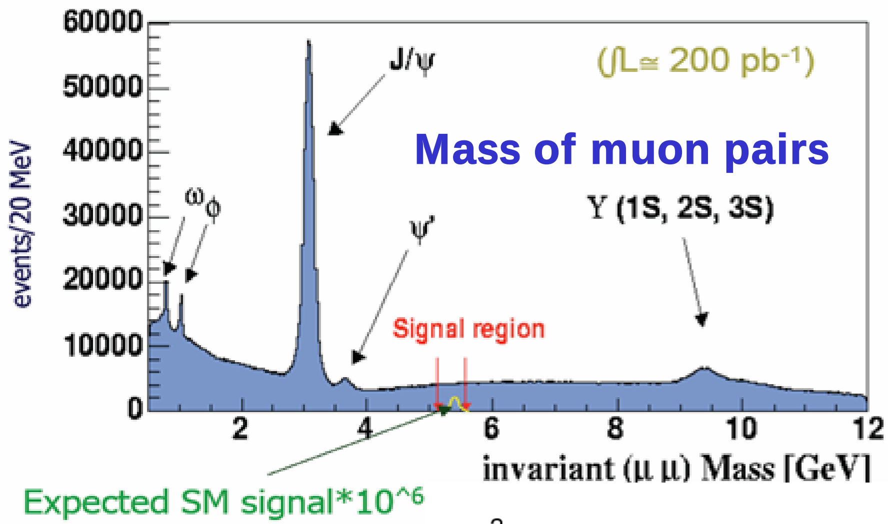
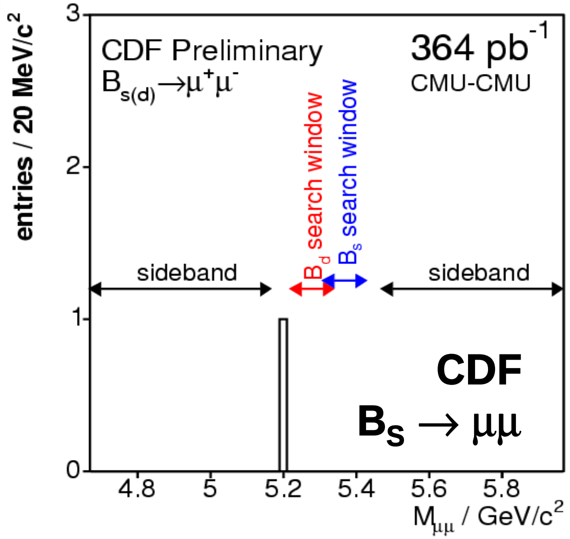
Indirect searches for new physics

- New particles (e.g. SUSY) can substantially increase branching ratios of rare B decays





Decay Mode	CDF (364/336pb^{-1})	DØ (300 pb^{-1})	SM Prediction
$B_s \to \mu^+ \mu^-$	**< 2.0 × 10^{-7}**	**< 3.7 × 10^{-7}**	3.4 ± 0.4 × 10^{-9}
$B_d \to \mu^+ \mu^-$	**< 4.9 × 10^{-8}**	—	1.5 ± 0.9 × 10^{-10}
$B_s \to \mu^+ \mu^- \phi$	—	**< 4.1 × 10^{-6}**	1.6 ± 0.5 × 10^{-6}
	(95% CL)	(95% CL)	



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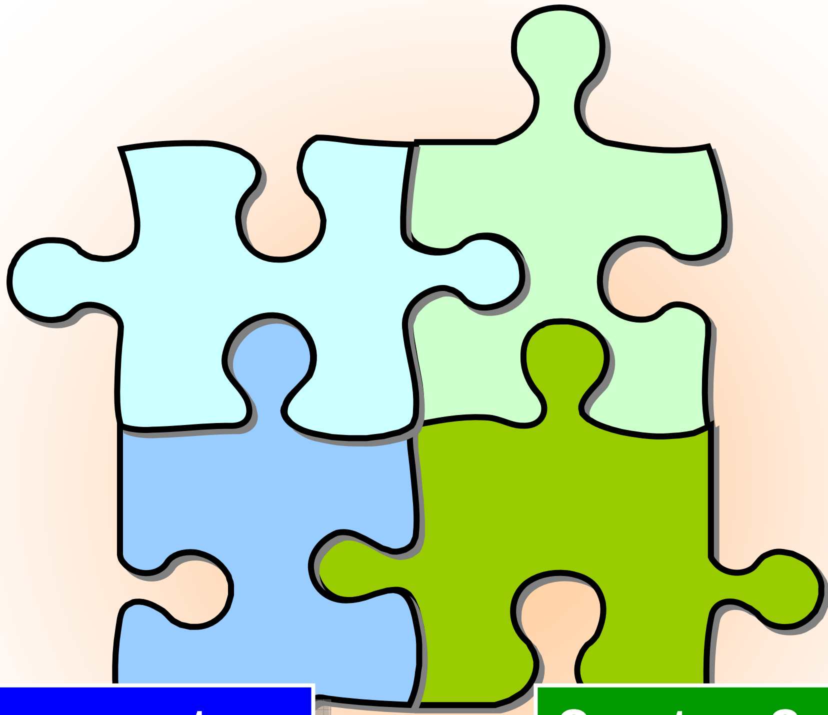

Astronomy
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Standard
Cosmology
Model

Supersymmetry
Extra Dimensions

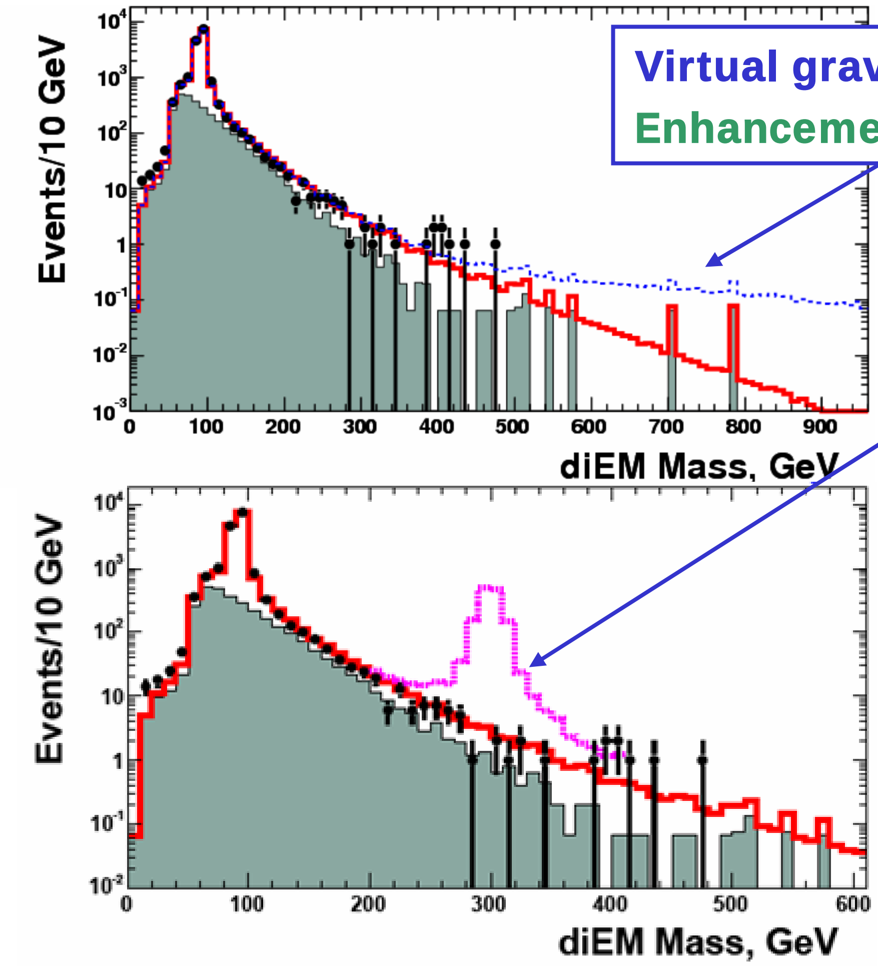
Quantum Gravity
Inflation

Consistent understanding?

Superstrings!

Goals for hadron colliders
– can we see evidence of extra dimensions?

Measuring the shape of space-time

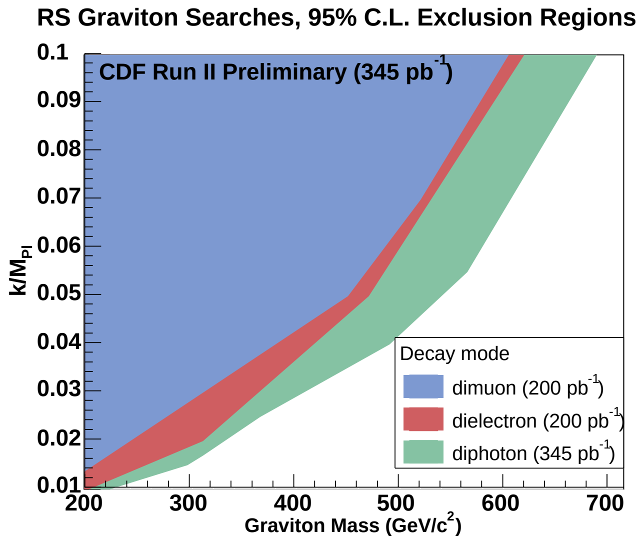


Virtual graviton exchange, e.g. in ADD framework

Enhancement to photon / electron-pair production

KK excitation of the graviton, e.g. in Randall-Sundrum framework

Assumed to couple to γγ, ee, μμ



- **See no deviation from 3+1 dimensions**
- **Set limits on the size and properties of extra dimensions**

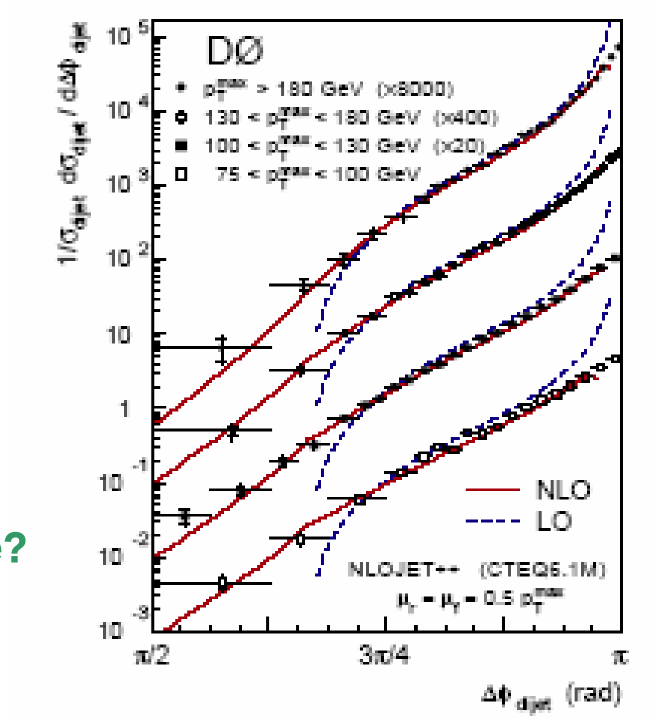
QCD

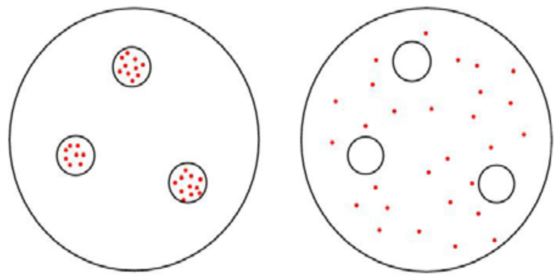
- Underlies everything we do with hadron colliders
- Contains its own puzzles

Pretty much everyone believes that QCD is the correct theory of the strong interaction – but this is not the same as having detailed predictions of the behavior of quarks and gluons under all conditions

QCD questions

- At high momentum transfer, things pretty much do what we expect
  - … but perturbative calculations must continue to confront data if we are to improve our understanding of signals and backgrounds
  - Can use Tevatron data to reduce undertainties on PDF’s
- At lower momentum transfers, QCD enters the “non-intuitive” regime
  - What is the right way to think/calculate?
    - DGLAP vs. BFKL?
  - Hard diffraction
    - Why does it happen so often (1%)?
    - How can it happen at all?
    - What is/are the exchanged particle(s)?
    - Is it some kind of collective behaviour?





a) b)

Conclusions

- The Tevatron physics program is broad and important
- It is based on the detailed understanding of Standard Model particles and forces that we have obtained over the last few decades
- With that basis we can address some very big questions about the universe, for example
  - What is the cosmic dark matter? is it Supersymmetry? Or…?
  - Is the universe filled with a Higgs Field? How does this relate to dark energy?
  - What is the structure of spacetime? Are there extra dimensions?

The Tevatron is the only operating facility that can do all this

We are sailing in unexplored territory — who knows what we will find!