Particle Physics in Canada: Present and Future

- Who/what is the IPP
- Particle physics beyond the standard model – being done in Canada
  - Indirect searches at `BaBar`
  - The current energy frontier: `CDF`
  - The future energy frontier: `ATLAS`
- Where is Canadian particle physics headed?

William Trischuk
Director, IPP
February 23, 2005

`hep.physics.utoronto.ca/WilliamTrischuk/ipp_canada.pdf`

What is the Institute of Particle Physics

- Founded in 1971 to:
  - Coordinate, support and promote particle physics research in Canada
    - Operates a Research Scientist programme
    - Maintains long term view of particle physics being done in Canada
    - Optimises Canadian participation in international collaborations
- Operates as a non-profit corporation owned by institutional members
  - Director & Council responsible for scientific programme
  - Board of Trustees have legal & financial responsibility
- Funded by an NSERC project grant

Who is the Institute of Particle Physics

- 150 individual members from 24 Canadian institutions
- 14 institutional members:
  - Alberta, Carleton, McGill, Montreal, Perimeter, Queens, Regina, Simon Fraser, Toronto, TRIUMF, UBC, Victoria, Western & York
- Scientific programme established by
  - Director and 6 elected council members:
    - C.Burgess, A.Konaka, P.Krieger, D.O'Neil, A.Noble, M.Vincter

The IPP Research Scientists

- The IPP employs eight research scientists
  - They have the academic freedom to choose their project
  - Have a research faculty appointment at a member institution

	Projects	
	Current	Other
Corriveau (1990)	ZEUS	Linear Collider
Hearty (1994)	BaBar	T2K
Hemingway (1977)	SNO	OPAL
Krieger (2001)	ATLAS	
Martin (1980)	ZEUS	T2K
McPherson (1997)	ATLAS	
Robertson (2003)	BaBar	ATLAS
Sobie (1987)	ATLAS/BaBar	HEP Computing

IPP and Theory

- The IPP was founded by particle theorists in the 1970s
- Have played a strong role in the Institute over the years
- Currently about 50 theorists are members of the IPP
- Have benefited peripherally from the IPP
  - Through the support of workshops
  - The coordination of re-allocation submissions
- General health of subatomic physics requires theory and expt.
- With a new generation of theorists joining the IPP
  - Looking to build stronger ties with the theory community

IPP Theory Initiative

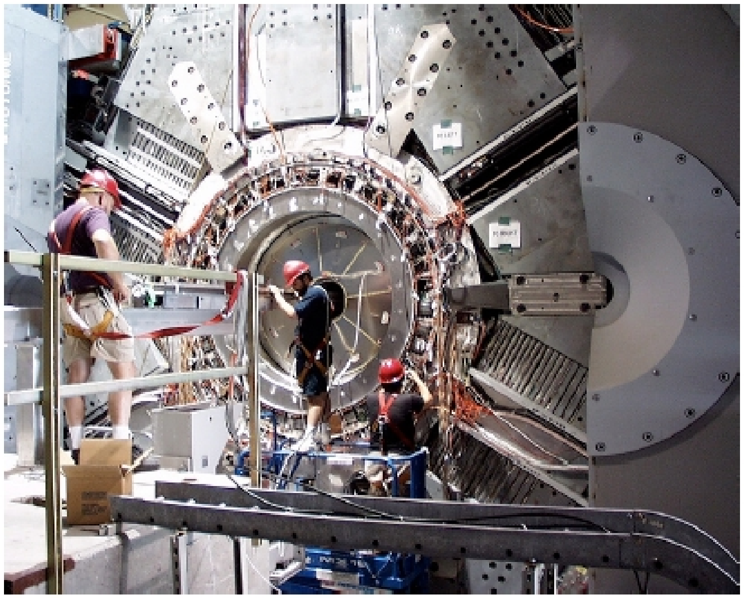
- Polled the community in 2003-04
- Setup an advisory sub-committee (Luke, Burgess, Semenov, Keeler)
- Despite GSC re-allocation efforts
  - Canadian theorists still marginally able to compete for postdocs
  - Average grants going from $40k to $50k per year
  - IPP proposal attempts to improve their financial competitiveness
  - Provide two years of matching support for theory postdocs
    - Accept applications in the fall
    - Identify postdoc recipients before Christmas
    - Hiring occurs in winter/spring
  - Requesting support for 3+3 such positions at $20k level

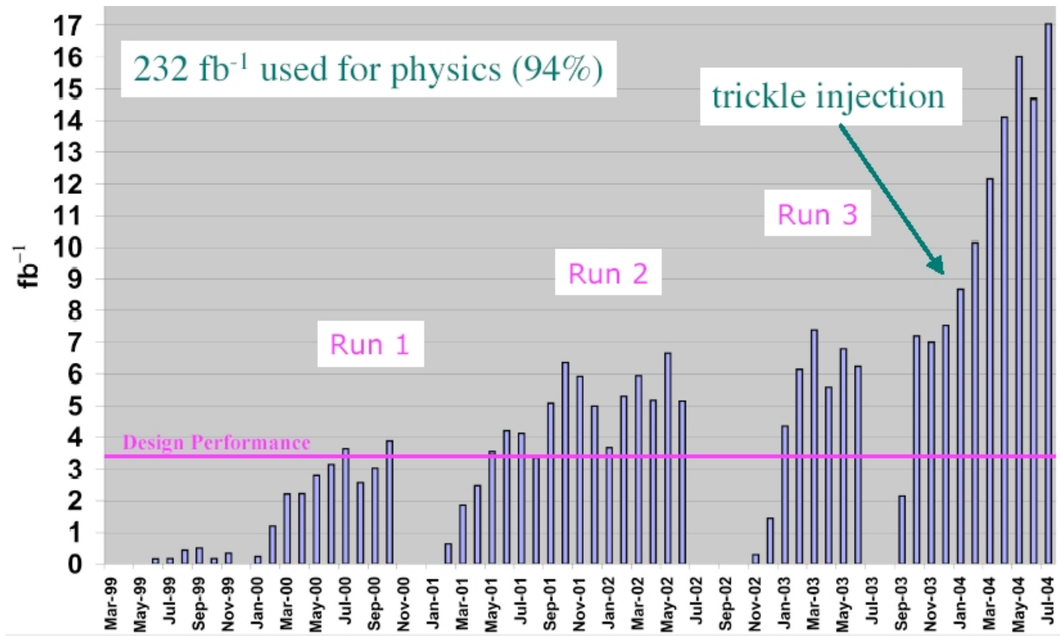
The IPP Experimental Programme

	Timescale		Investigators
Experiment	Start	End	(FTE)
ATLAS	2007	2020?	31 (22)
BaBar	1999	2009	9 (8)
CDF	1992	2008	6 (4)
SNO	1998	2007	34 (25)
T2K	2009	2015+	17 (7)
Veritas	2006	2010	2 (2)
ZEUS	1989	2007	4 (3)

- Is the IPP programme serving the community? (Yes, 70 expt FTEs)
- Are all projects currently viable?
- Look at the window on new physics from three of these:
  - BaBar
  - CDF
  - ATLAS

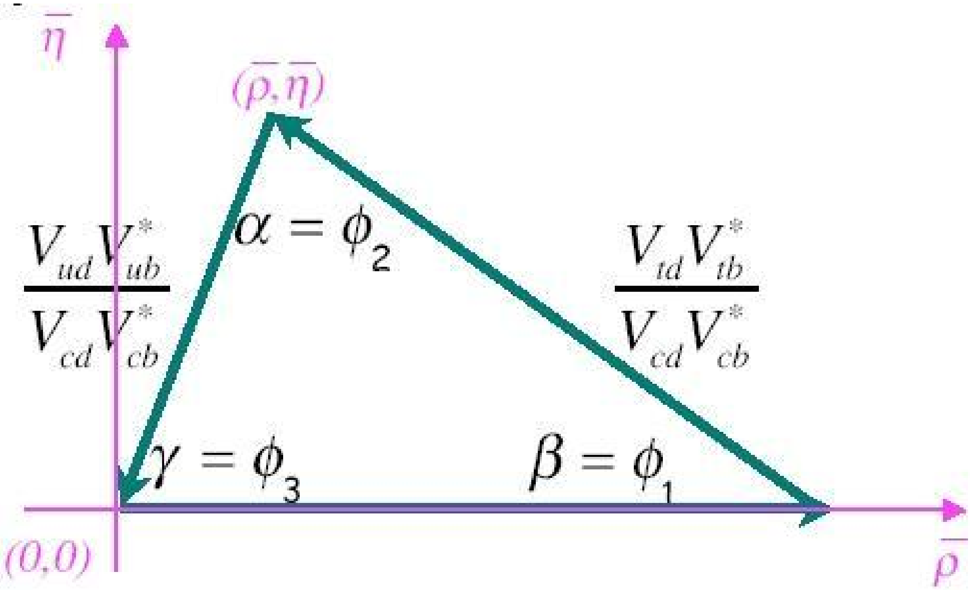
The BaBar B-factory Experiment

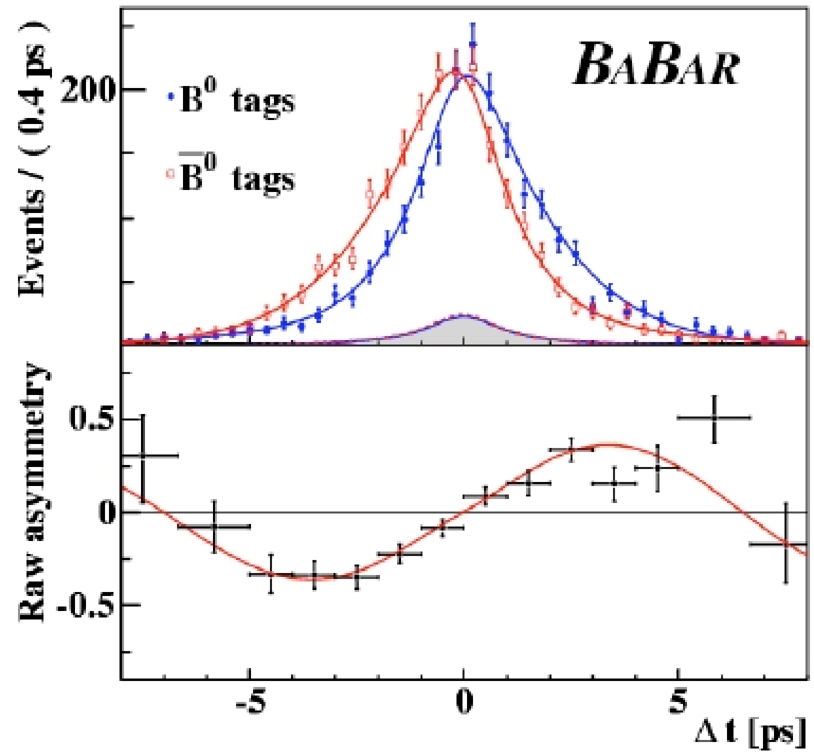




- Canadians were founding members of the experiment in 1993
- Main drift chamber was assembled and tested at TRIUMF
- Original goal was 100 million $\Upsilon(4S)$ candidates
- To pin down CP violation in B^0 meson decay
- Have been wildly successful

Precision determination of $\sin 2\beta$

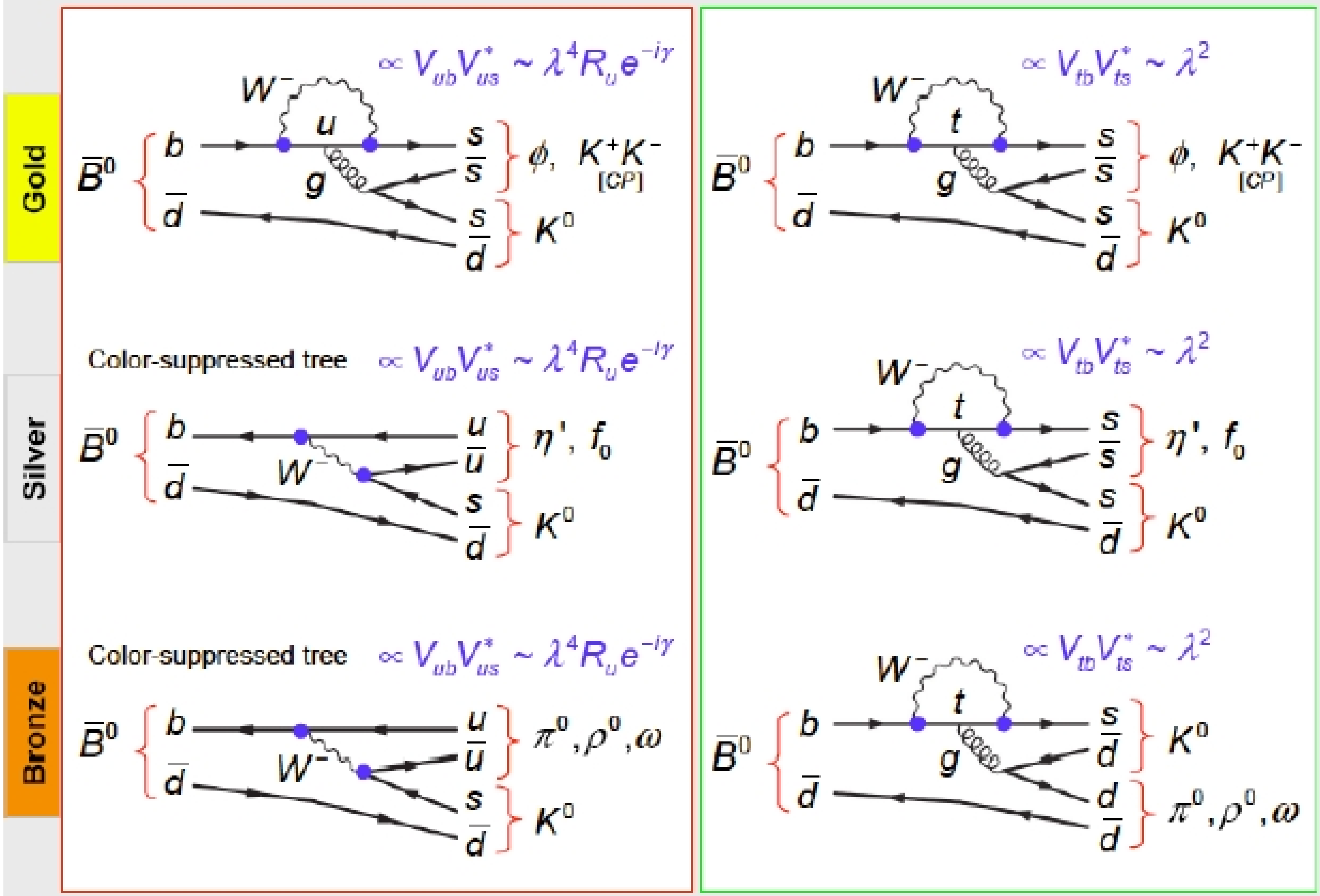




- Made first unambiguous measurement in 2001
- Now known with 5 % precision ($\sin 2\beta = 0.726 \pm 0.037$)
- Still room for improvement

CP violation in other B Meson Decay Modes?

One may identify golden, silver and bronze-plated *s*-penguin modes:



Naive (dimensional) uncertainties on sin2β

$O(\lambda^2)$
$\sim 5\%$

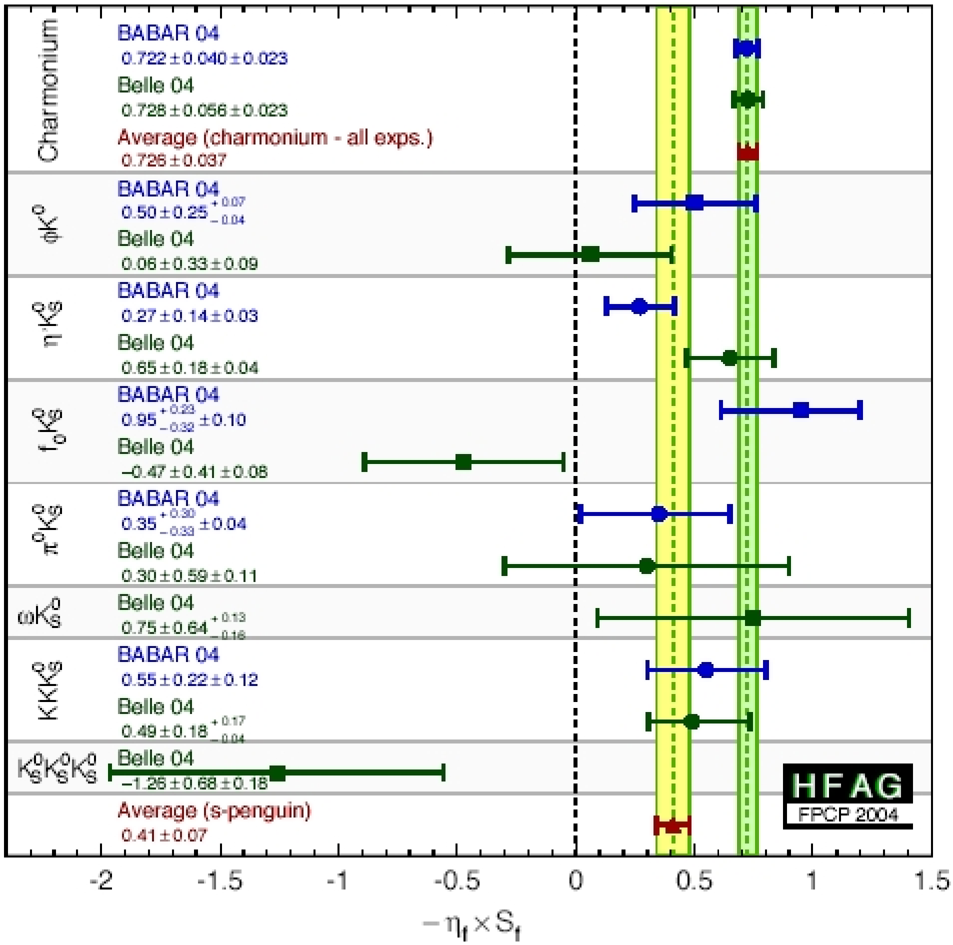
$O(\lambda^2(1+f_{qq}/\bar{\lambda}))$
$\sim 10\%$

$O(\lambda^2/\bar{\lambda})$
$\sim 20\%$

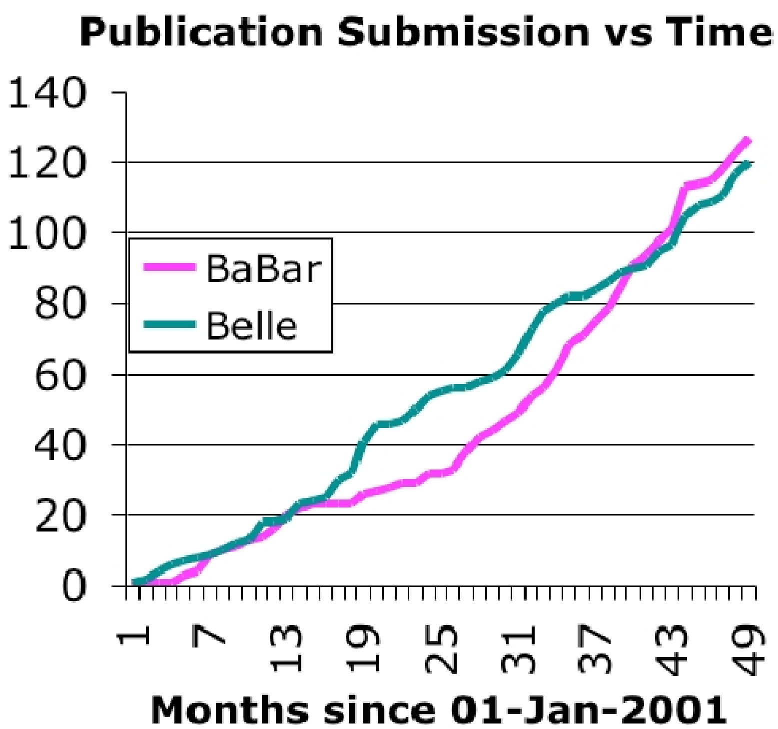
Note that within QCD Factorization these uncertainties turn out to be much smaller !

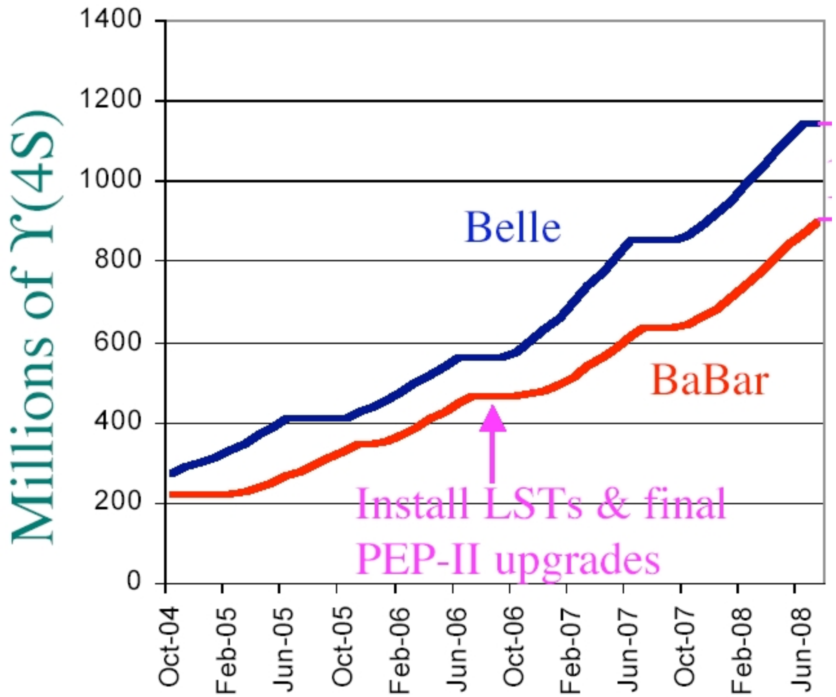
Hints for non-Standard Model CP violation

- Attention turned to other CKM angles
- Also other modes sensitive to $\sin 2\beta$
  - Modes without $b \to cX$ transition
  - Significant penguin contributions
  - Penguin loops include non-SM particles?
- For now just 2 -3 sigma hints
- But with improved precision



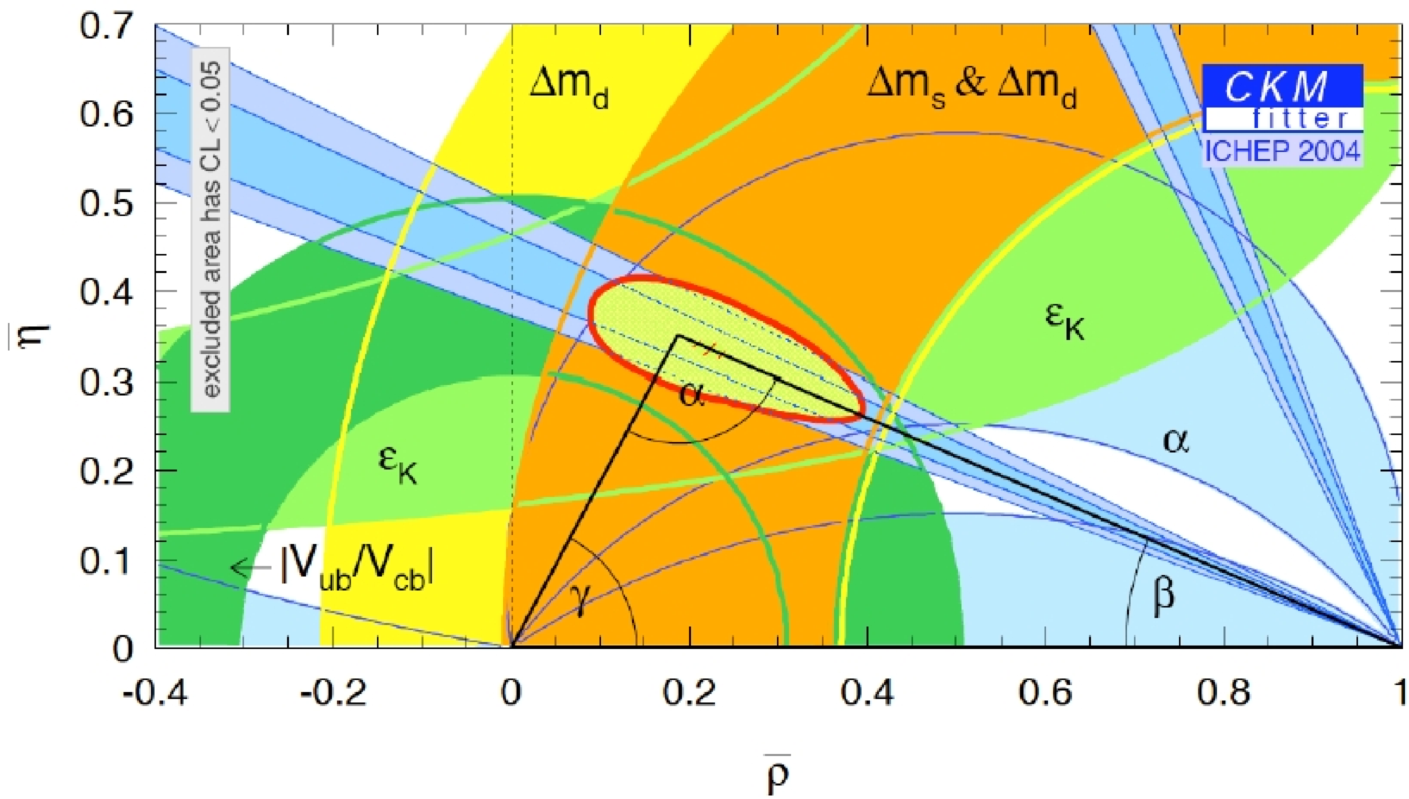
BaBar's Future Prospects





- 1000 dedicated physicists mining these datasets
- Precision on measurements sensitive to new physics will grow
- Expect four times as much data before the end
- A Super B-factory proposed to follow current experiments

Summary of CKM Parameters

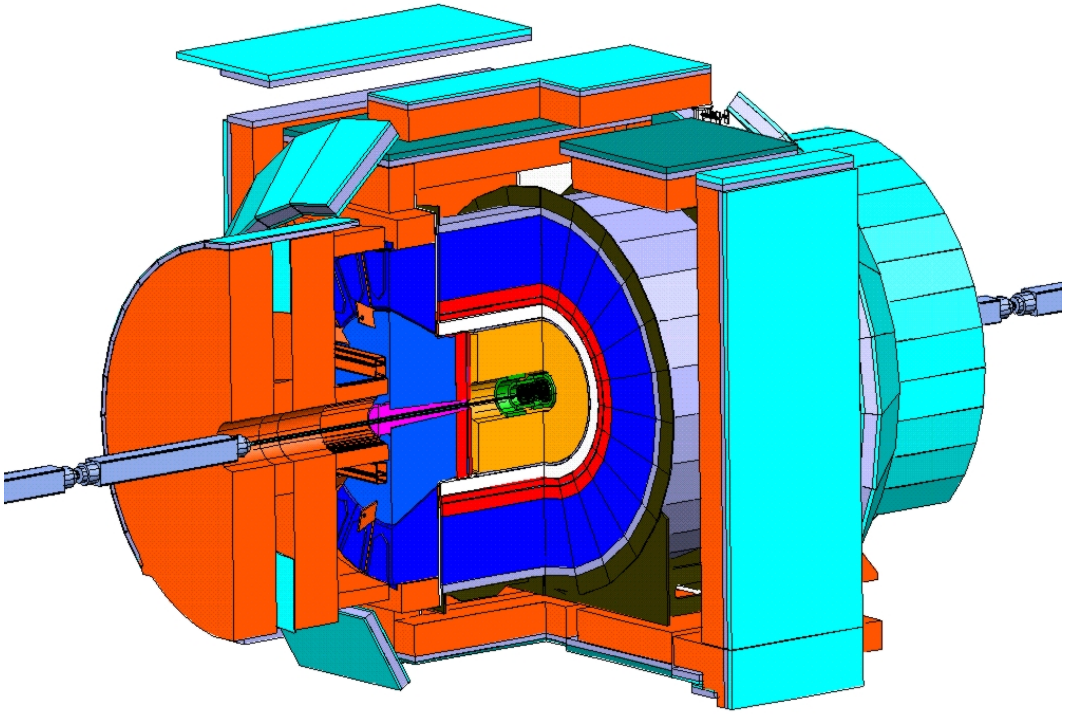


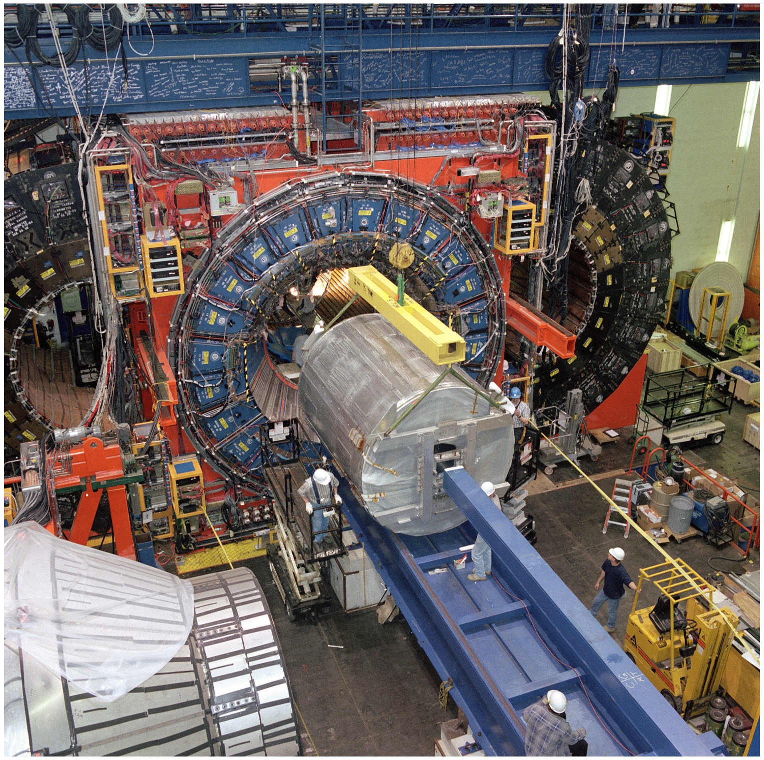
- Eagerly awaiting measurements of
  - α from $B^0 \to \pi^+\pi^-$
  - Δm_s from the Tevatron or LHC-b
  - Lattice QCD input to V_{ub}
  - γ from $b \to c$ hadronic decays

The Fermilab Collider Programme

- Luminosity
  - $10^{31} \rightarrow 10^{32}$
- Bunch spacing
  - 3.5 μs $\rightarrow$ 396 ns
- Antiproton stacking
  - Up by factor of 10
- Collision energy
  - 1.8 $\rightarrow$ 1.96 TeV
- Run started March 2001
  - One year commissioning
  - 700 pb^{-1} in three years

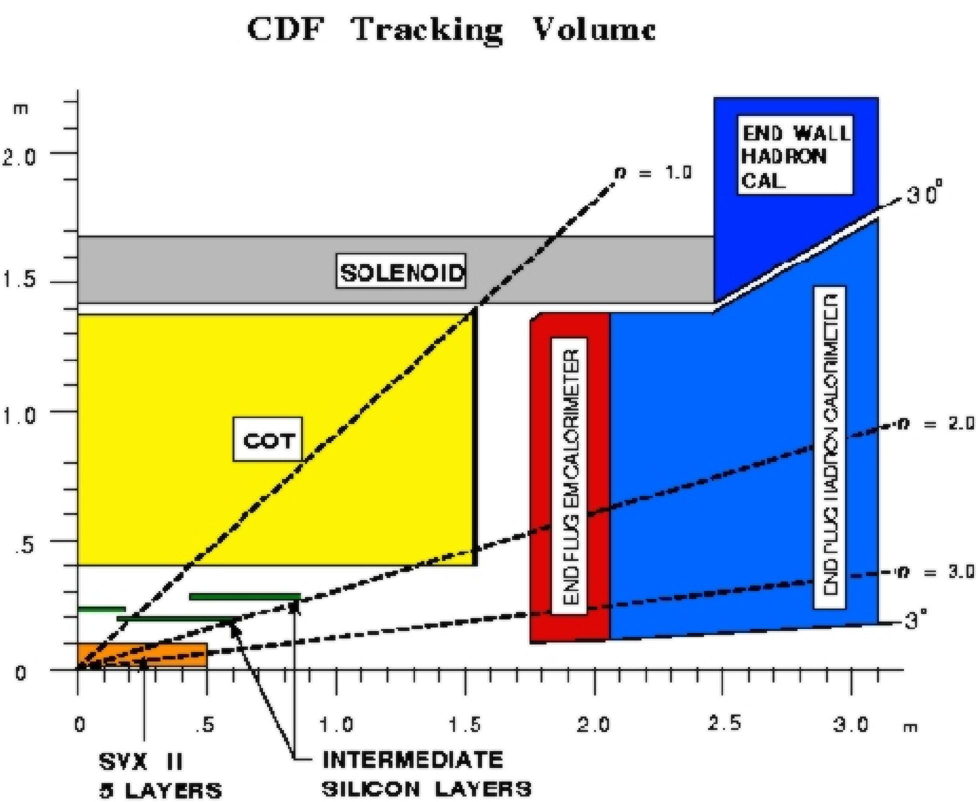
The CDFII Detector





- Completely replaced tracker
- Forward calorimetry from gas sampler to scintillator
- Filled in muon coverage to $\eta = 1.5$
- Upgraded all front-end electronics and DAQ for higher rates
- Took 5 years to complete upgrade of detector

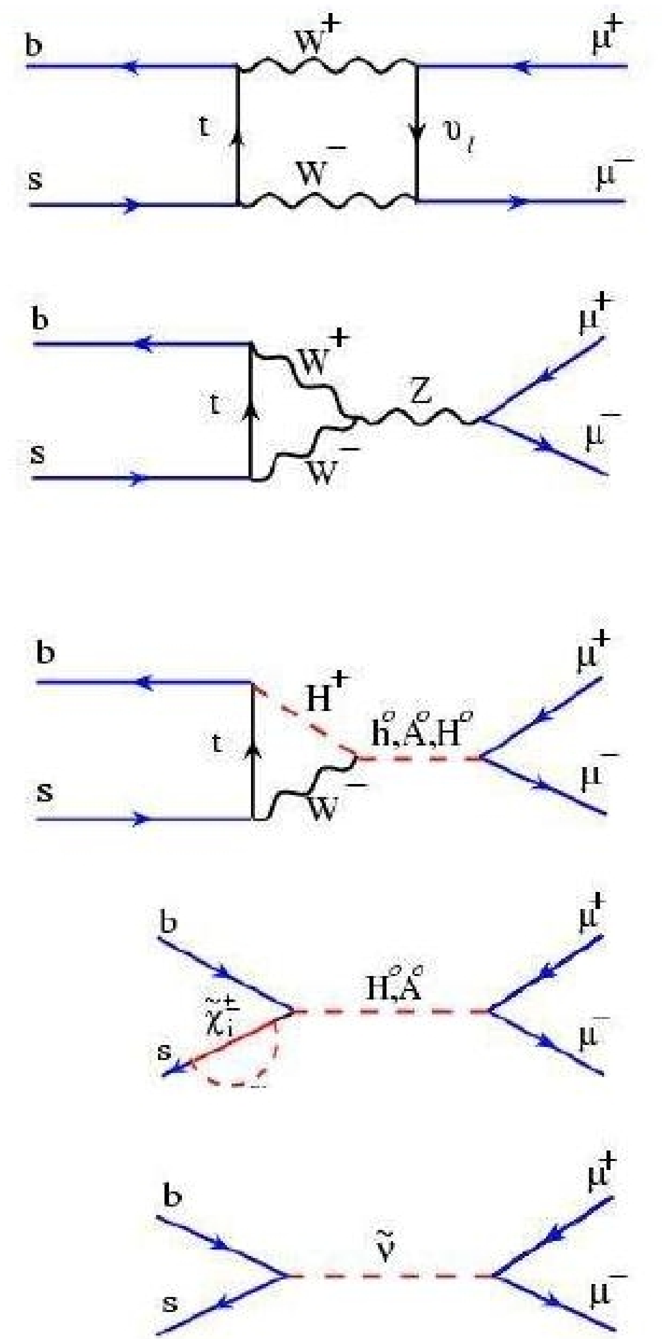
The CDF-II Tracker



- Three silicon tracking systems
  - SVXII ($r-\phi$ and $r-z$)
  - ISL (tracking into plug)
  - L00 ($r-\phi$ only at $r=1.6$ cm)
- VLSI readout chip has 42 cell pipeline
  - 50 kHz deadtimeless readout
- Wire chamber drift cells 1/2 as big
  - Drift complete between crossings
- Canadians contributed silicon support and alignment hardware

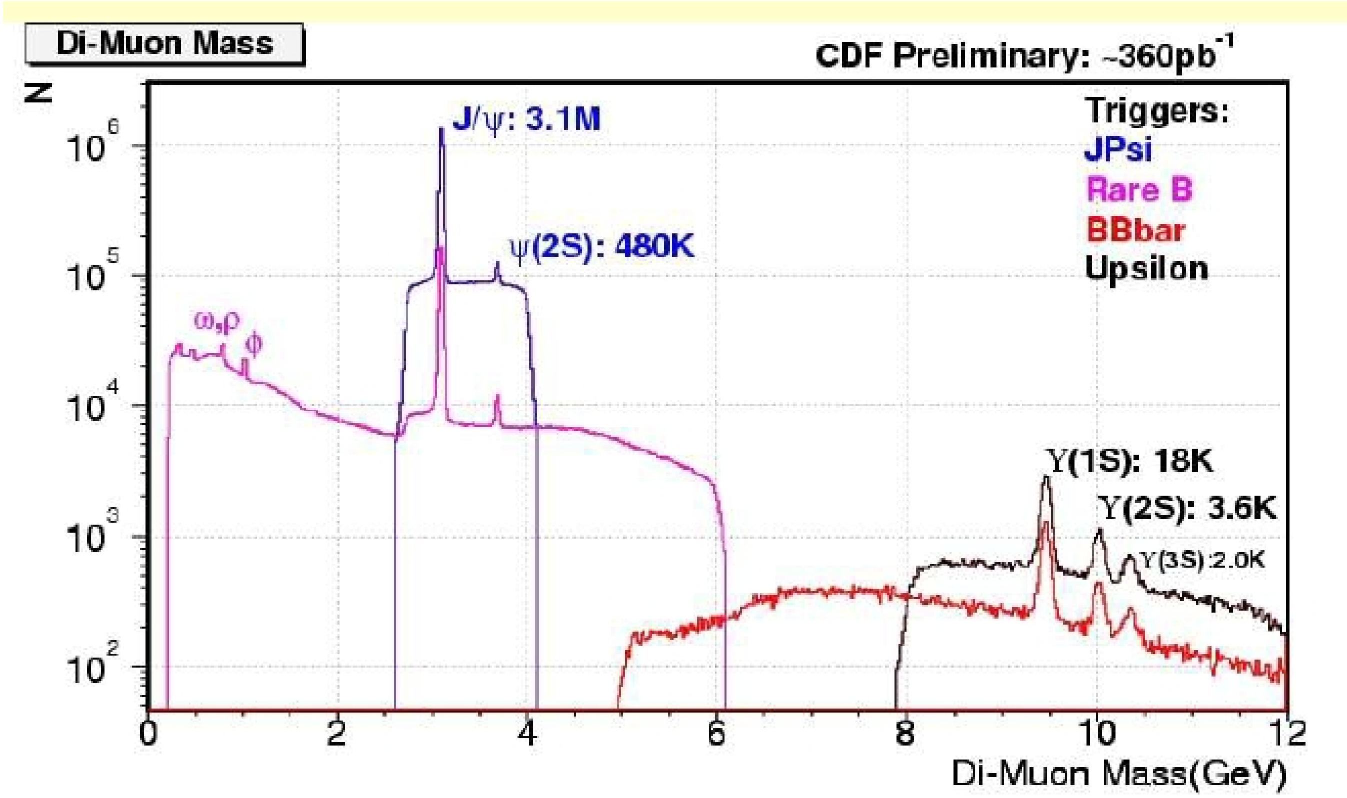
New Physics in $B_s^0 \to \mu^+\mu^-$ Decays

- Look for processes that are rare in SM
- $B^0_{s(d)} \to \mu^+\mu^-$ proceeds by box diagrams
  - No tree level FCNC to leptons
  - CKM, GIM and helicity suppressed
  - $\mathcal{B}(B_{s(d)} \to \mu^+\mu^-) = 35(1) \times 10^{-10}$
    (Buchalla et al., Nucl. Phys. **B398**, 285)
- New physics could significantly enhance this
  - Tree: R-parity violating SUSY
  - Loop: MSSM, mSugra, Higgs Doublet
    * 3 orders of magnitude enhancement
      (Babu and Kolda, Phys.Rev.Lett.**84**, 228)
    * Rate $\propto \tan^6\beta$ (lower limit if observed)
      Kane et al., hep-ph/0310042



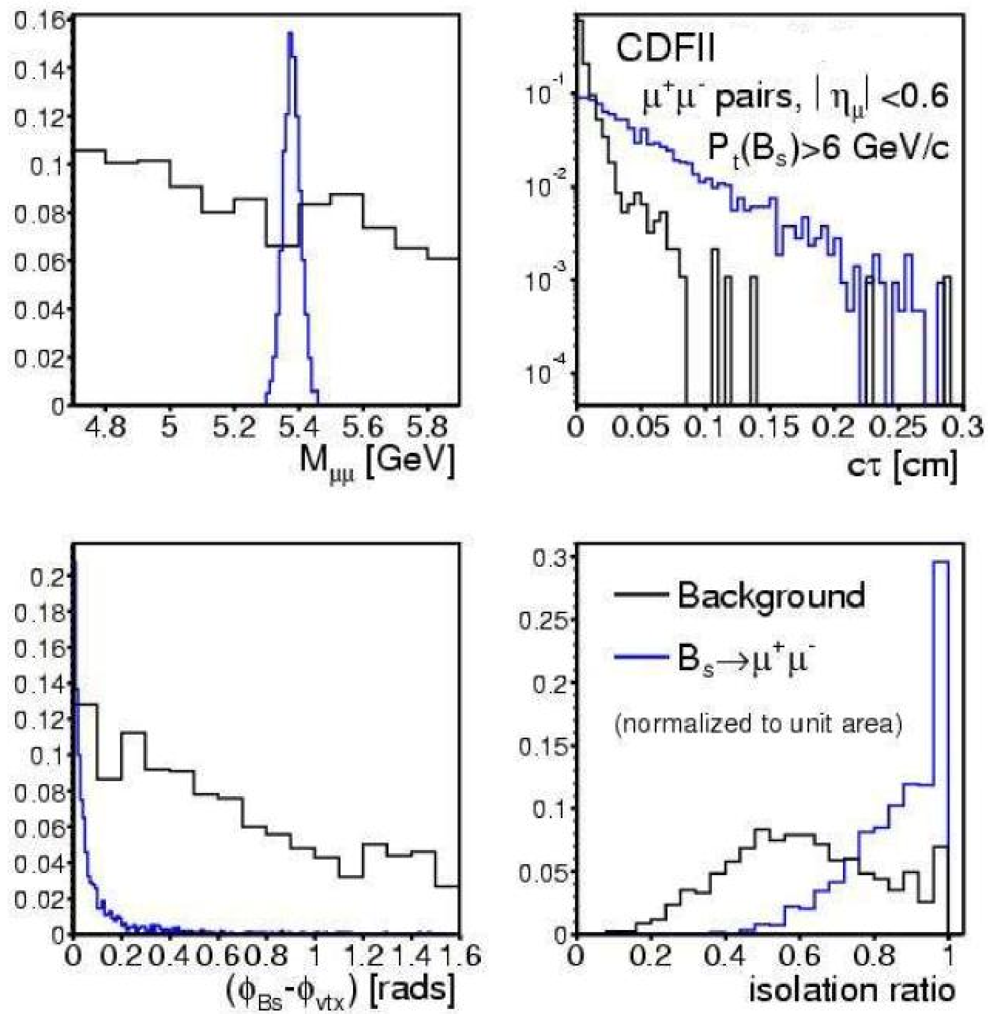
CDF's Di-Muon Datasets

- Need efficient trigger
  - Control samples
    - $J/\psi, \psi(2S)$
    - $\Upsilon(1S, 2S, 3S)$



- Must deal with large combinatoric background
  - Need to find efficient cuts to reject background
  - And determine the efficiency and correlations between cuts

$B^0_{s(d)} \to \mu^+\mu^-$ Candidates

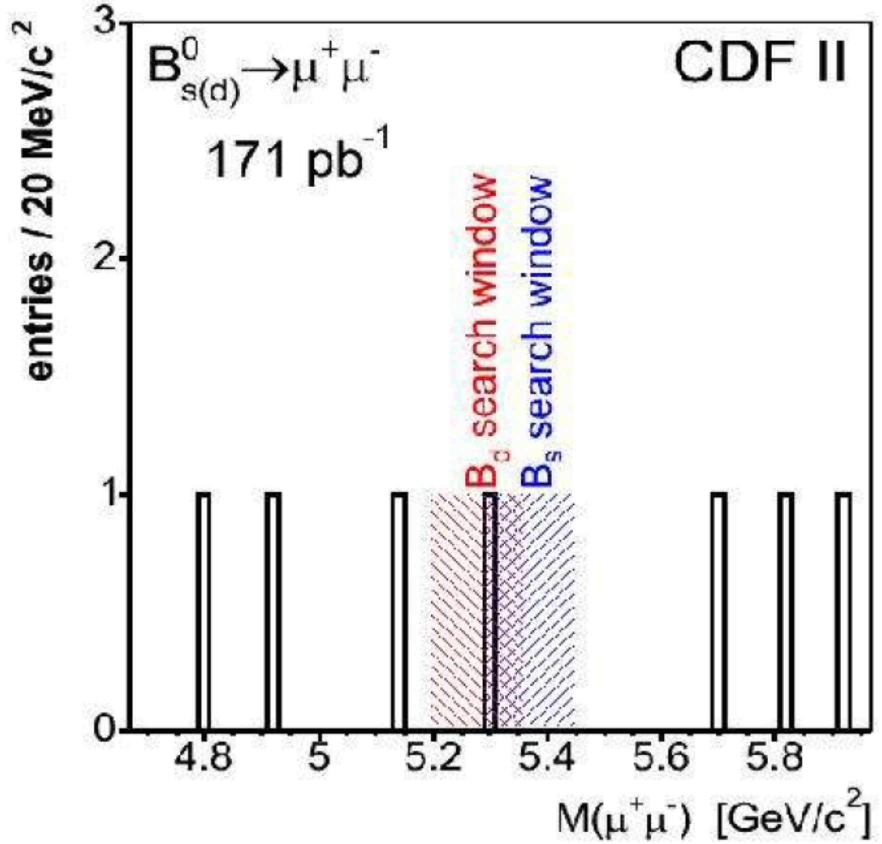


- Selection criteria
  - 3 σ mass window (27 MeV)
  - Flight distance $L_{xy} > 200\mu$m
  - Flight direction: $\Delta\phi < 0.1$ rad
  - Isolation: $p_{\mu\mu}/\Sigma p > 0.65$
- Used blind analysis technique
- Optimise using side band data and simulated signals
- Criteria factorise simplifying efficiency and background calculations
- Check backgrounds with same sign di-muons and "-cτ" samples

CDF's $B^0_{s(d)} \to \mu^+\mu^-$ Result

- Analysis achievements
  - $\alpha \times \epsilon = (2.0 \pm 0.2)\%$
  - Expect 1.1 ± 0.3 bkgd events
  - One, common, canadidate in each mass 3 σ mass window
- Set limits of:
  - $\mathcal{B}(B_s \to \mu^+\mu^-) < 5.8 \times 10^{-7}$
  - $\mathcal{B}(B_d \to \mu^+\mu^-) < 1.5 \times 10^{-7}$

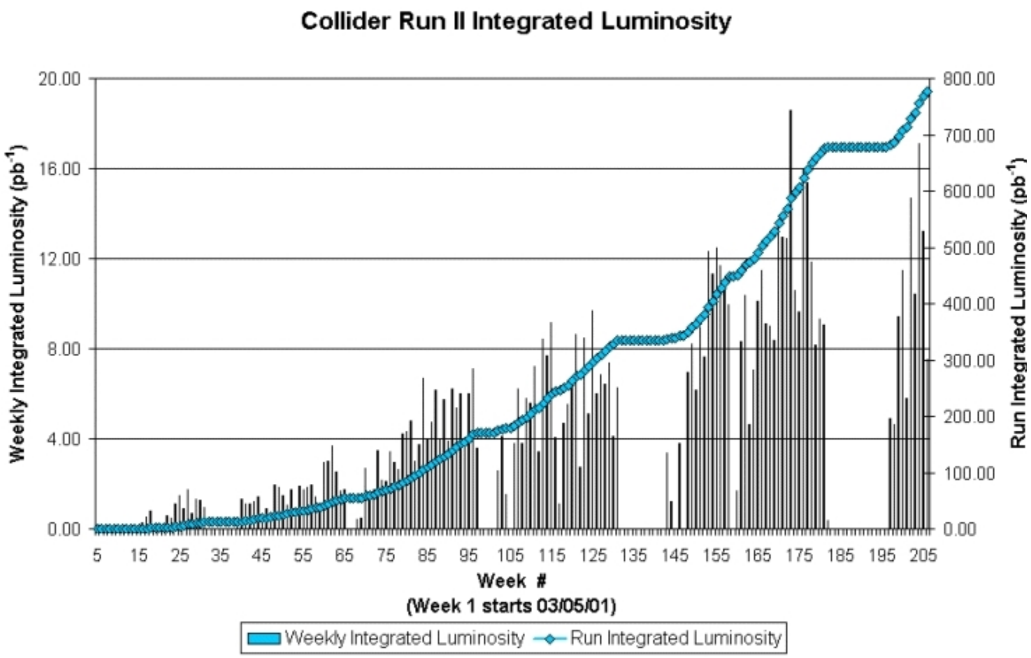
    Acosta et al., PRL **93**, 032001 (2004)



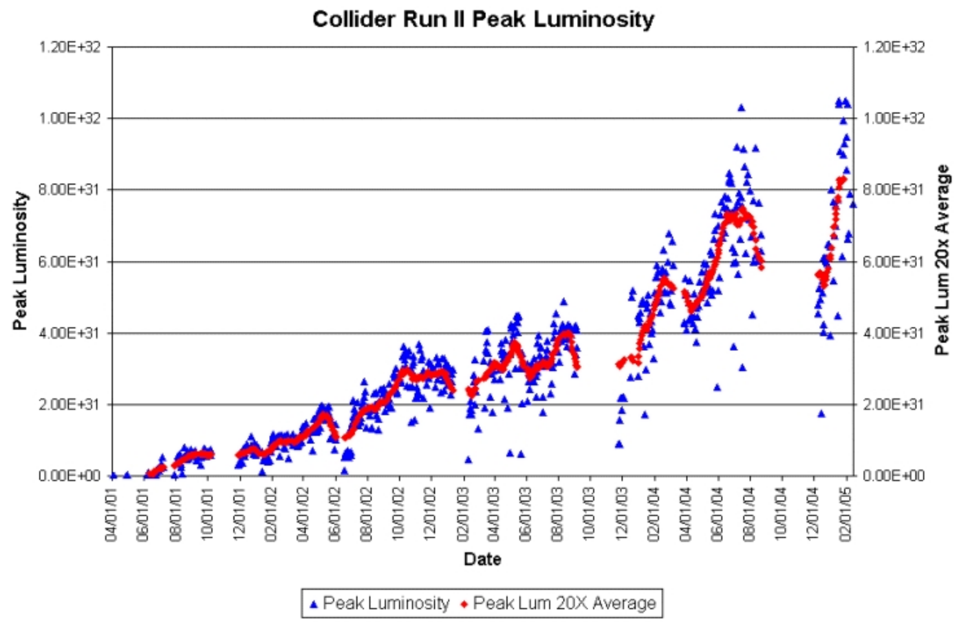
- Four times as many B_d produced than B_s
- B_s limit still constrains more models
- Most recent B factory limit $\mathcal{B}(B_d \to \mu^+\mu^-) < 0.8 \times 10^{-7}$

Tevatron Collider Luminosity

Integrated



Instantaneous

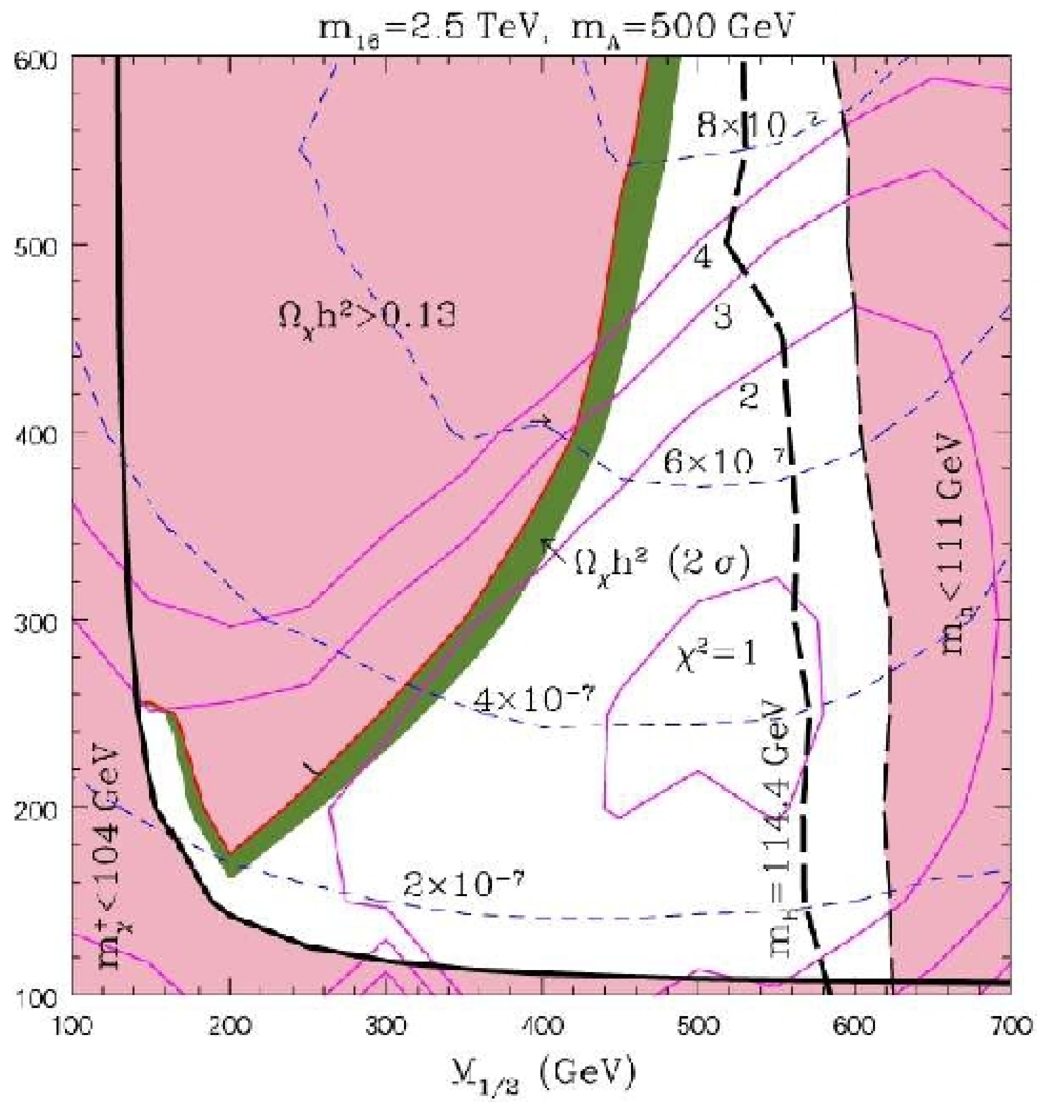


- Tevatron and CDF after three years of running
  - Have three the times the Run-I data sample for most analyses
- Still working on upgrades to further increase luminosity
  - Anti-proton recycler provides extra storage (x 1.5 now)
  - Electron cooling of anti-protons in Main Injector (x 2 by FY07)
- CDF will double its data set three more times
  - Will have 4-8 fb^{-1} before the end of the decade

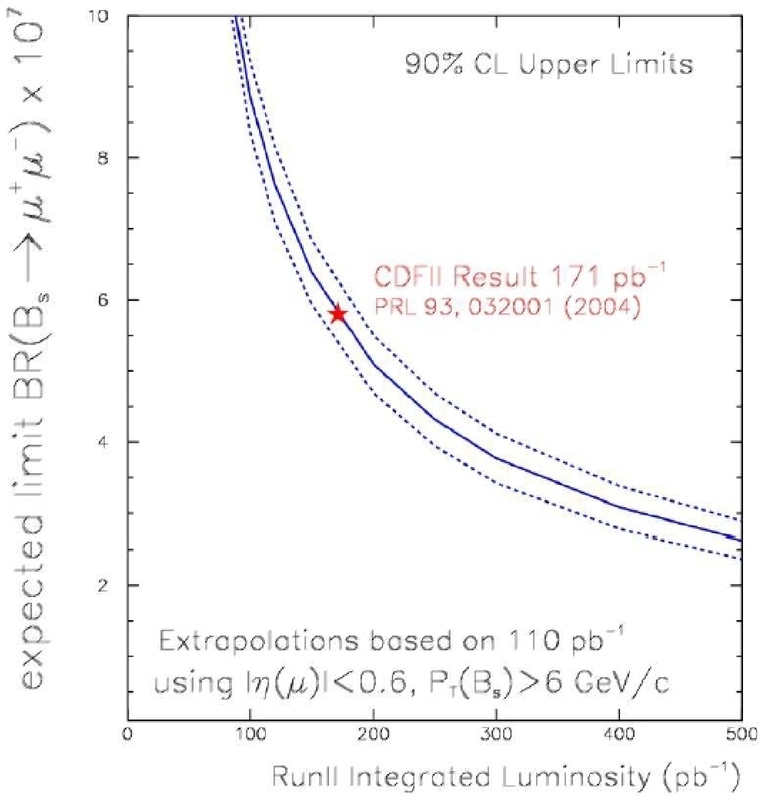
Limits on New Physics Signatures

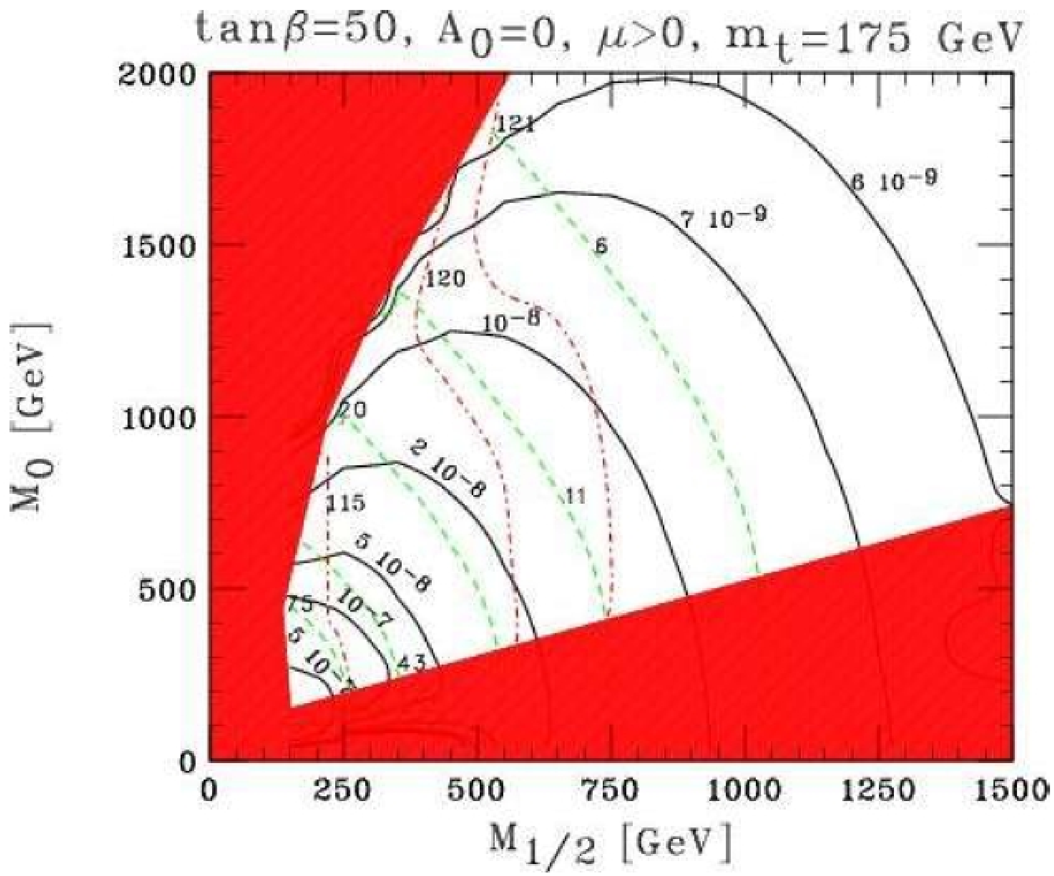
- No limit on SM prediction
  $\mathcal{B}(B_s \to \mu^+\mu^-) \approx 0.04 \times 10^{-7}$
- Limit many models beyond SM
- Example SUSY SO(10)
  - Predicts a massive neutrino
  - Possible dark matter candidate
- Exclude cases (dashed) where
  - $\tan\beta \approx 50$
  - $m_A < 450$ GeV/c^2

  R. Dermisek, hep-ph/0304101



Minimal Supersymmetry SM Limits





- Just adding new data
  - Considerably extends limit
  - 360 pb^{-1} under study

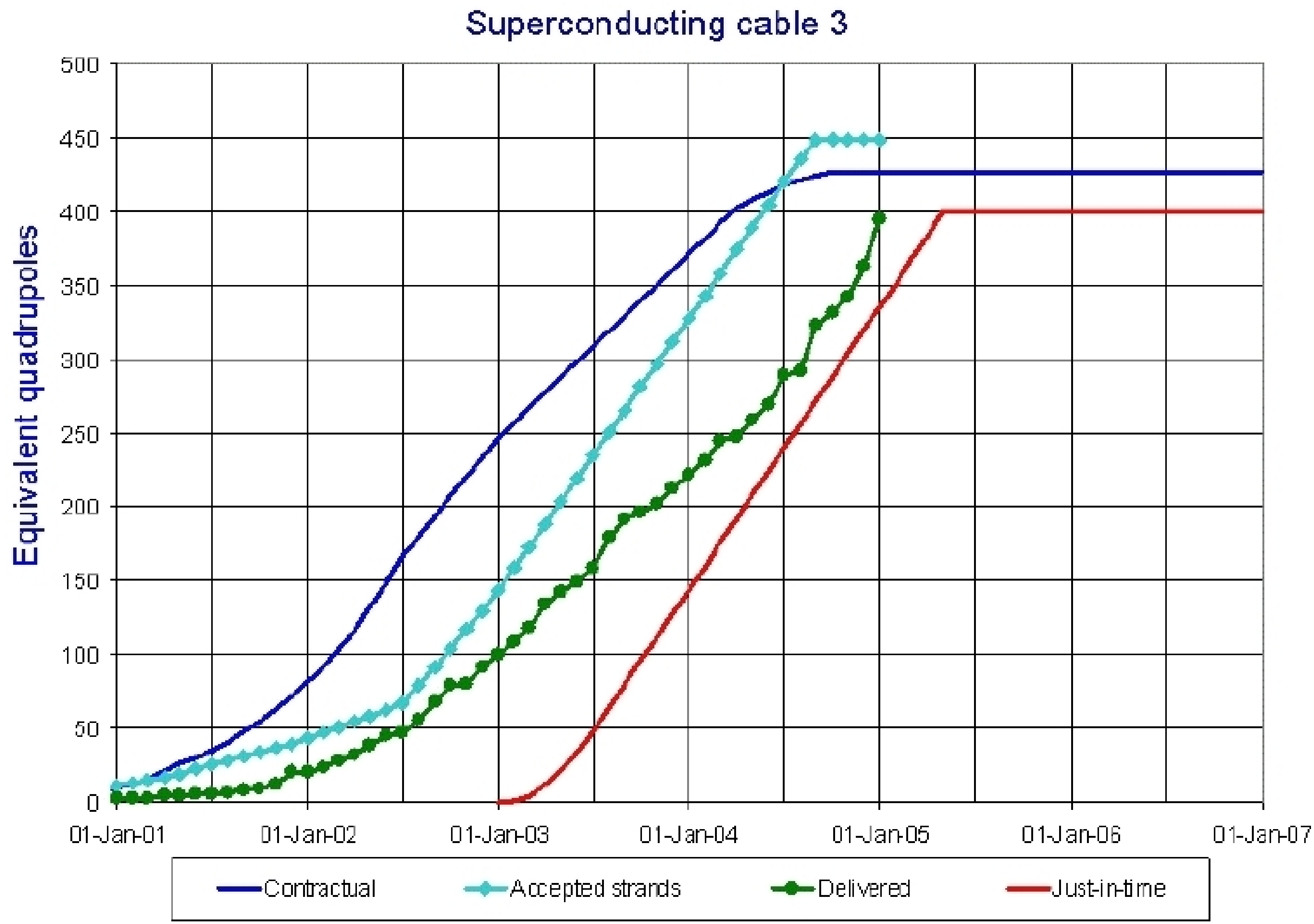
- Solid line: $\mathcal{B}(B_s \to \mu^+\mu^-)$
- Dashed line: $a_\mu \equiv (g-2)_\mu$
- Dashed line: SM Higgs limits
- Solid: Excluded by model

ATLAS and the LHC

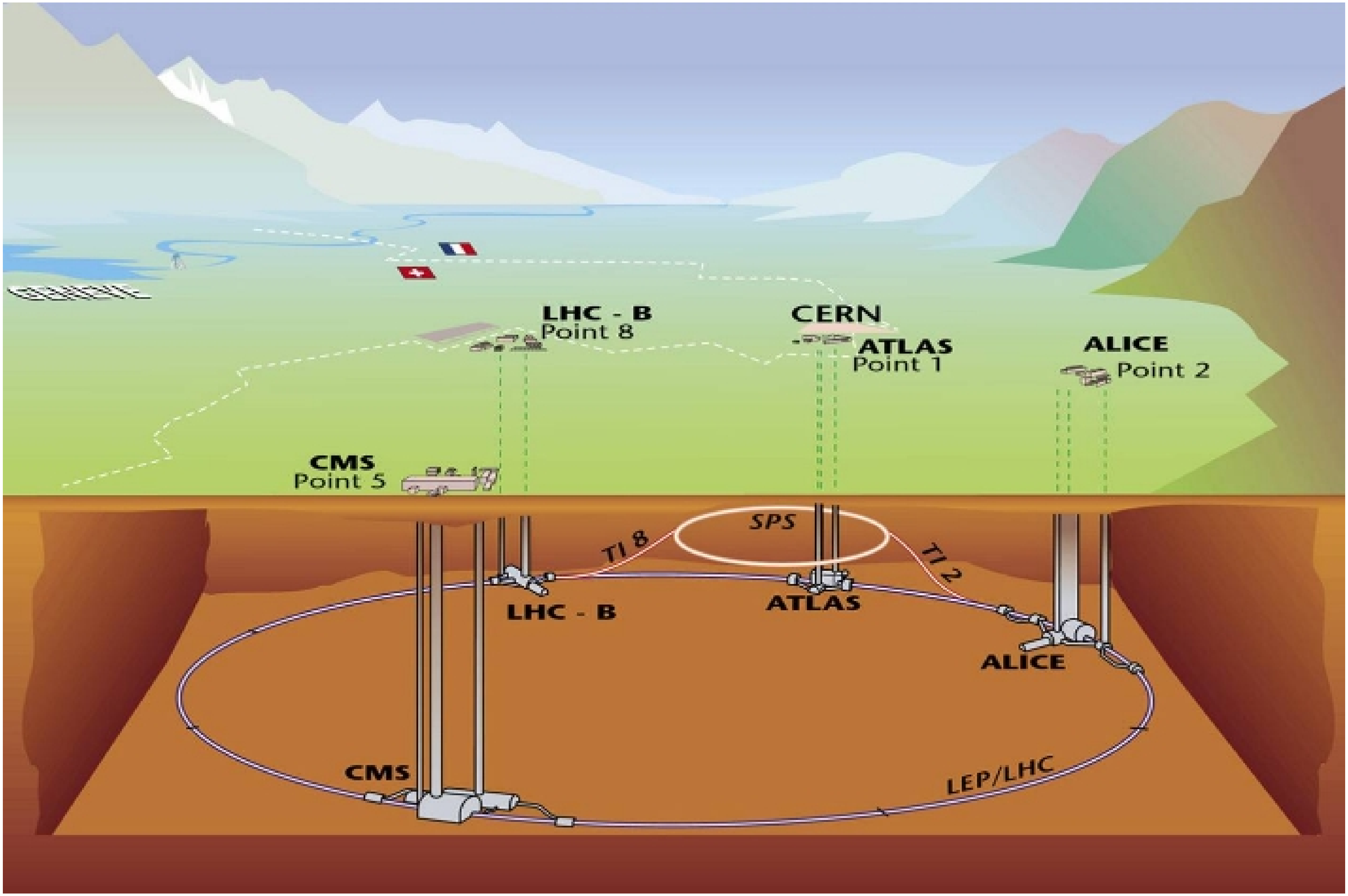
LHC machine Status

LHC Progress Dashboard

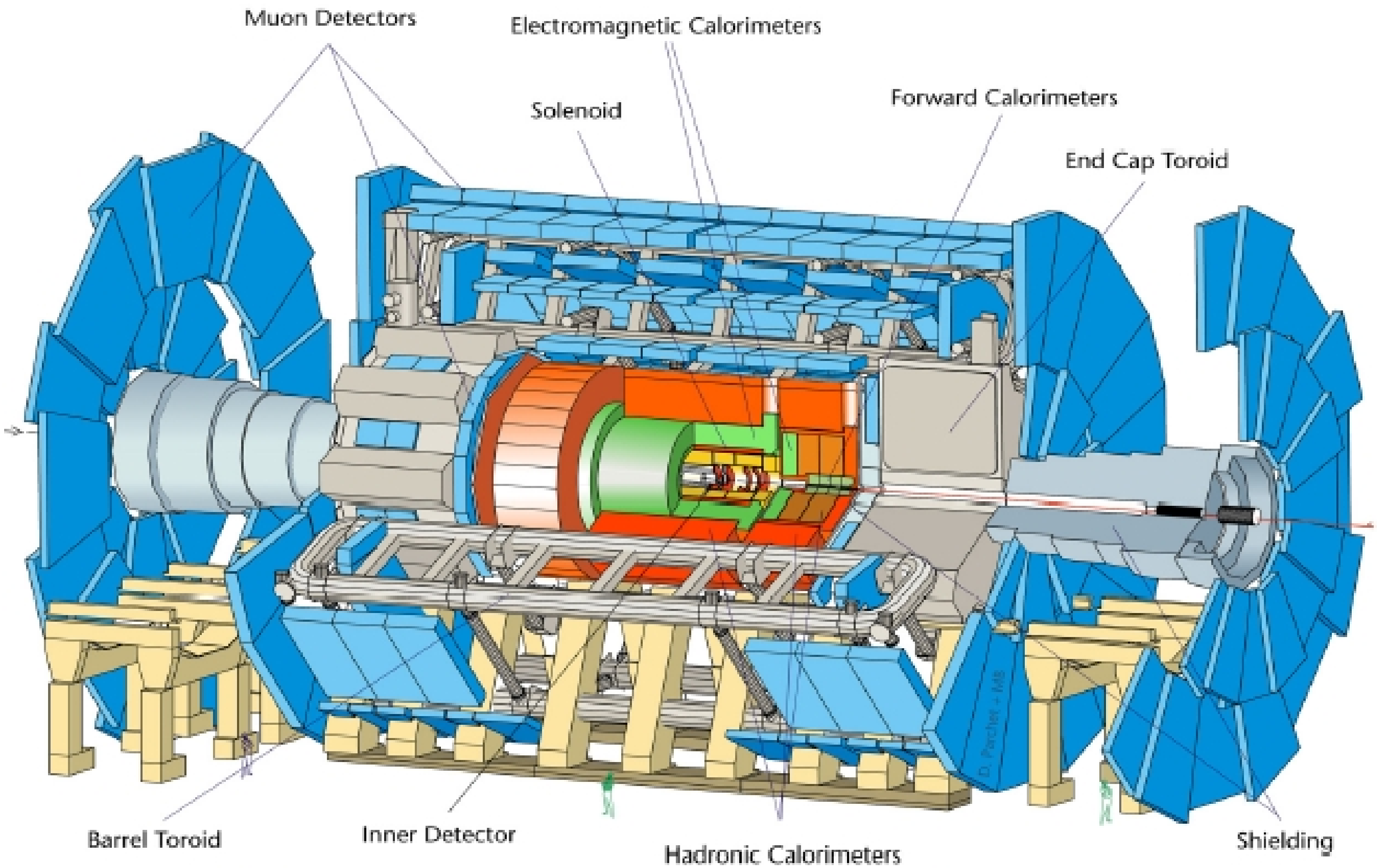
Accelerator Technology Department



The LHC Layout

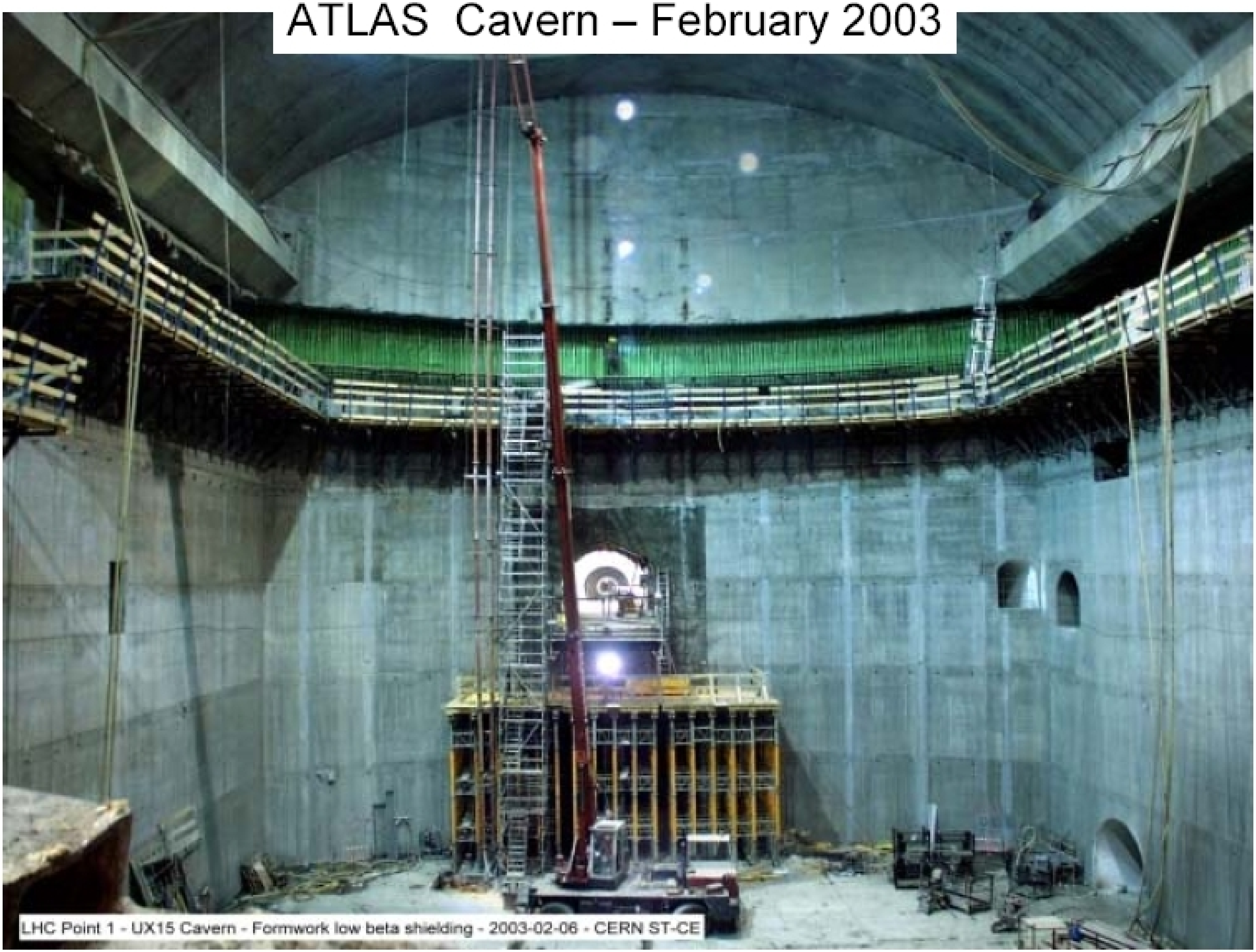


The ATLAS Detector



Diameter	*25 m*
Barrel toroid length	*26 m*
Endcap end-wall chamber span	*46 m*
Overall weight	*7000 Tons*

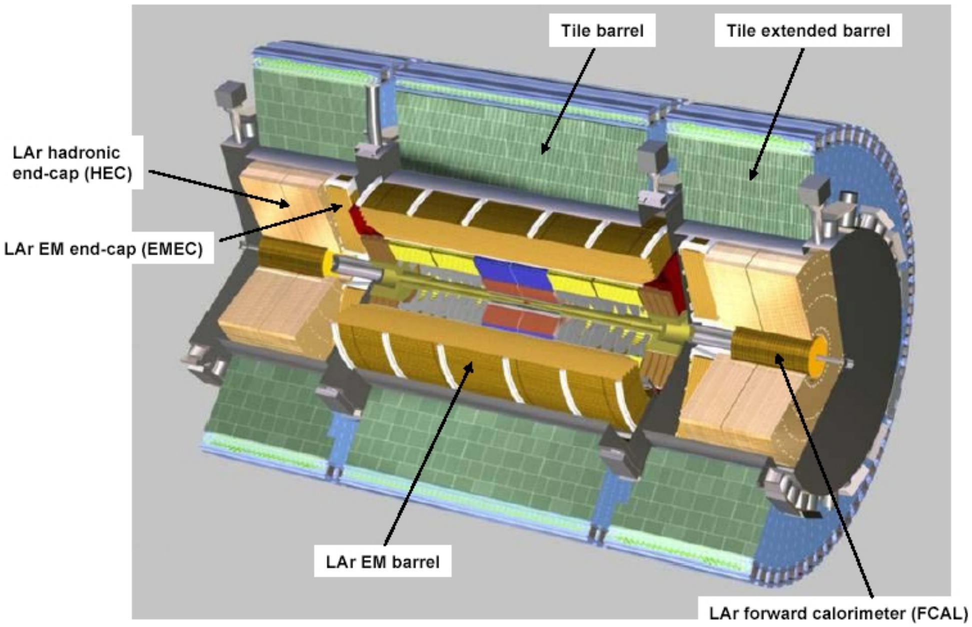
ATLAS Cavern – February 2003



ATLAS Cavern – November 2004

Installing the ATLAS Toroid Coils

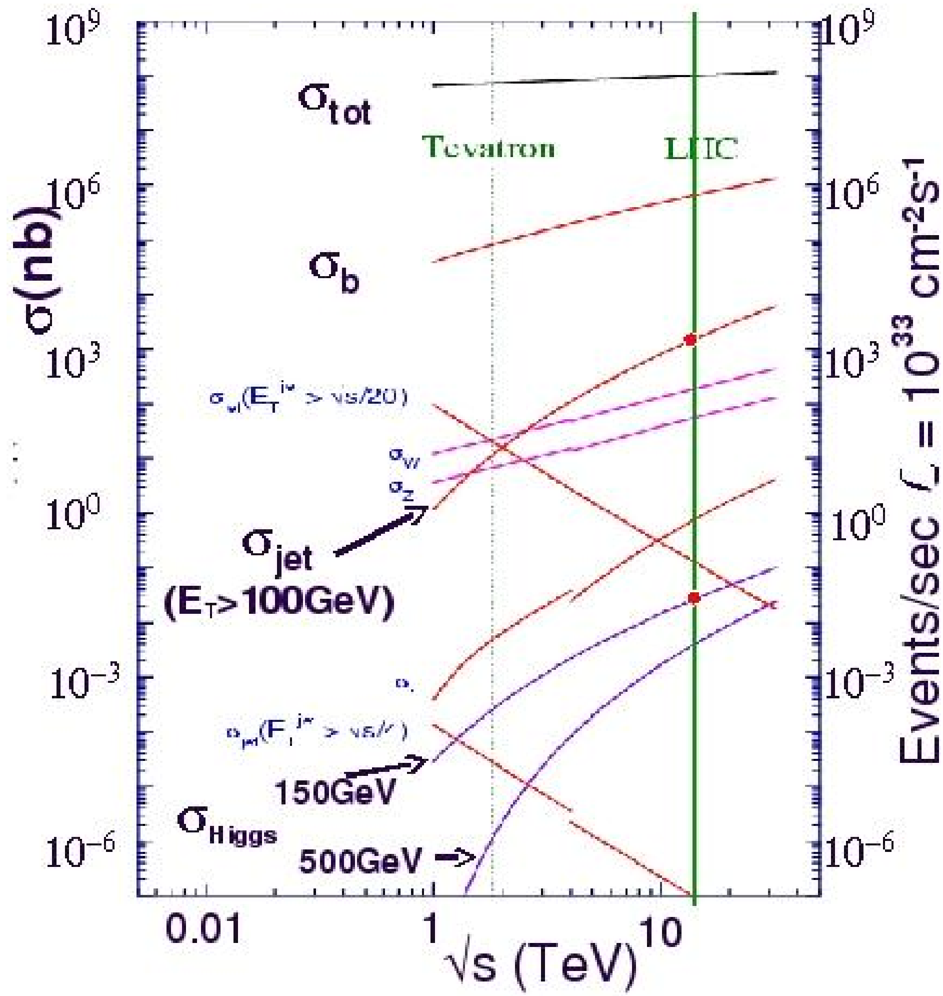
Canadian Contributions to ATLAS



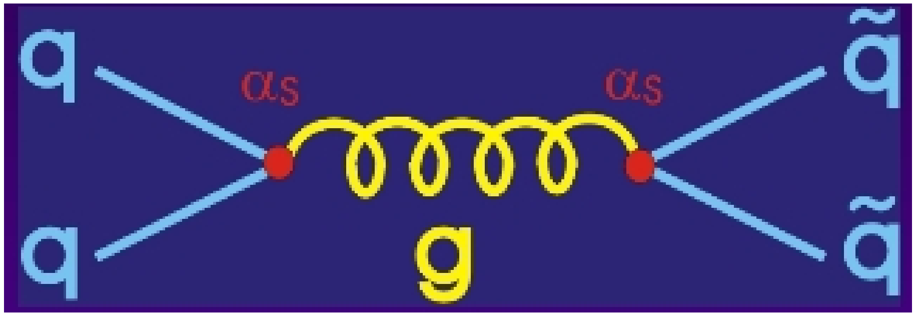
- Involved in design and prototyping of ATLAS LArg since early 90's
- TRIUMF, Victoria, Alberta built 1/2 of endcap calorimeters
- Toronto, Carleton built 2/3 of forward calorimeters
- Canada provided 4 % of the capital contribution to ATLAS

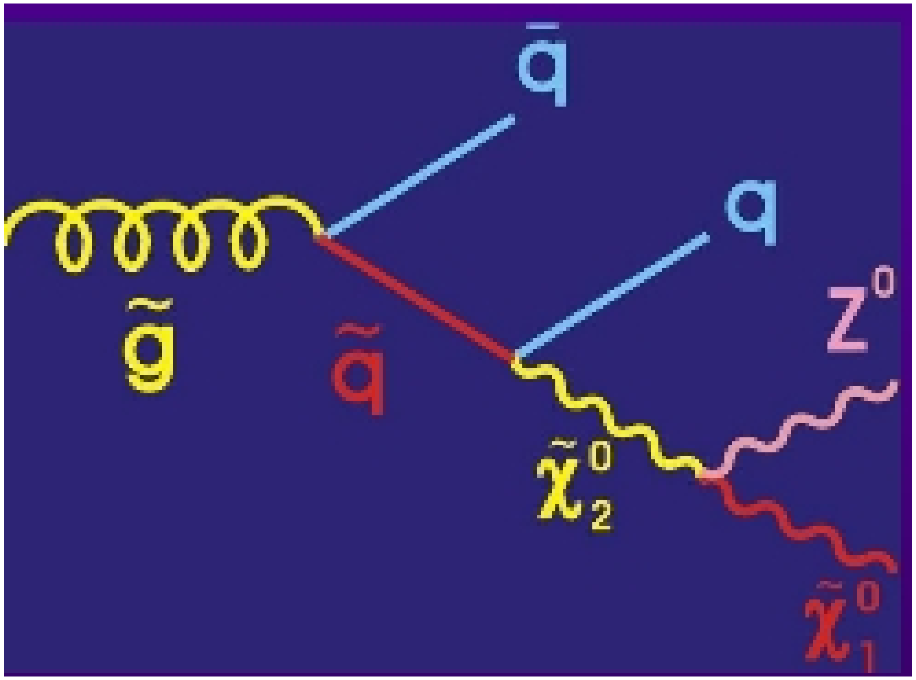
Production Cross Sections at the LHC

- Pulling physics out of LHC challenging
- Signals down by 10^{10} (or more)
  - Bunches collider occur every 25 ns
  - 20+ collisions per bunch-crossing
  - Trigger writes 5 in 10^6 to tape
    - ∗ Select events with
      - Very high energy jets
      - Electrons and muons
      - Displaced verticies
      - Missing energy



Supersymmetry Searches at the LHC





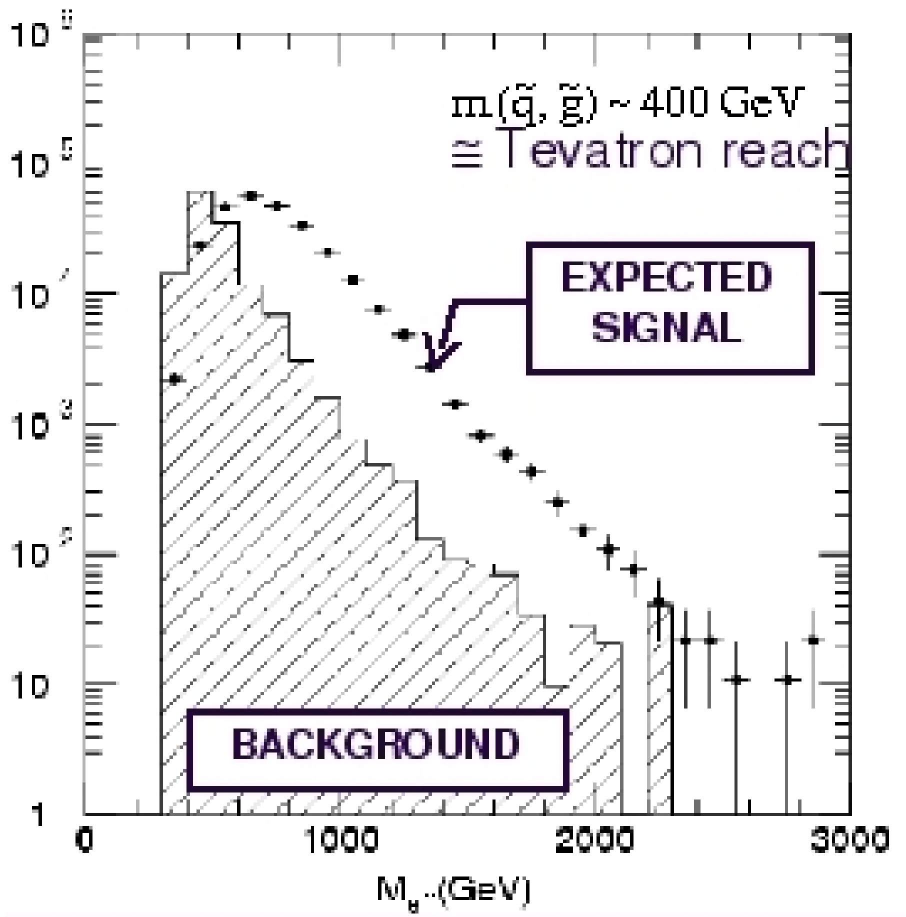
- LHC observation depends on
  - Strong production
  - Produce

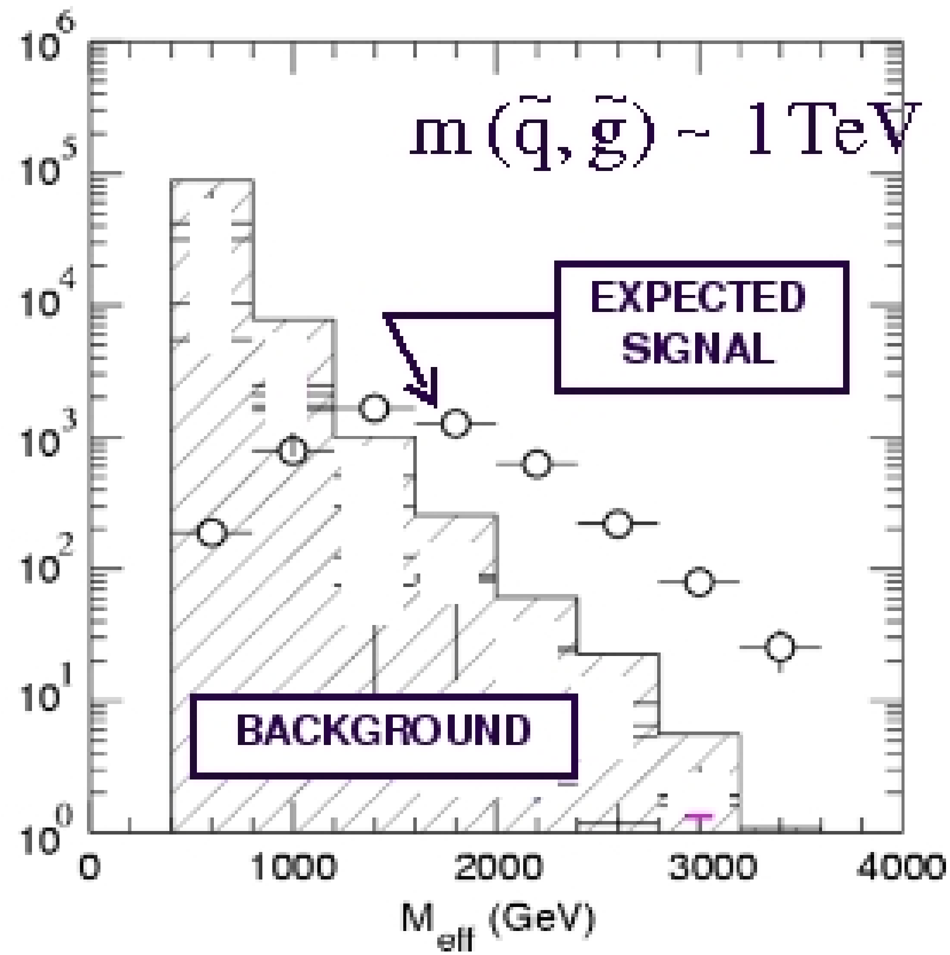
    $\tilde{q}\tilde{q}, \quad \tilde{q}\tilde{g}, \quad \tilde{g}\tilde{g}$

- Decay chain dictates final state
- Cascades with SUSY/normal particles
- Common feature
  - Missing energy from $\tilde{\chi}_1^0$
  - Good dark matter candidate

ATLAS's SUSY Signatures

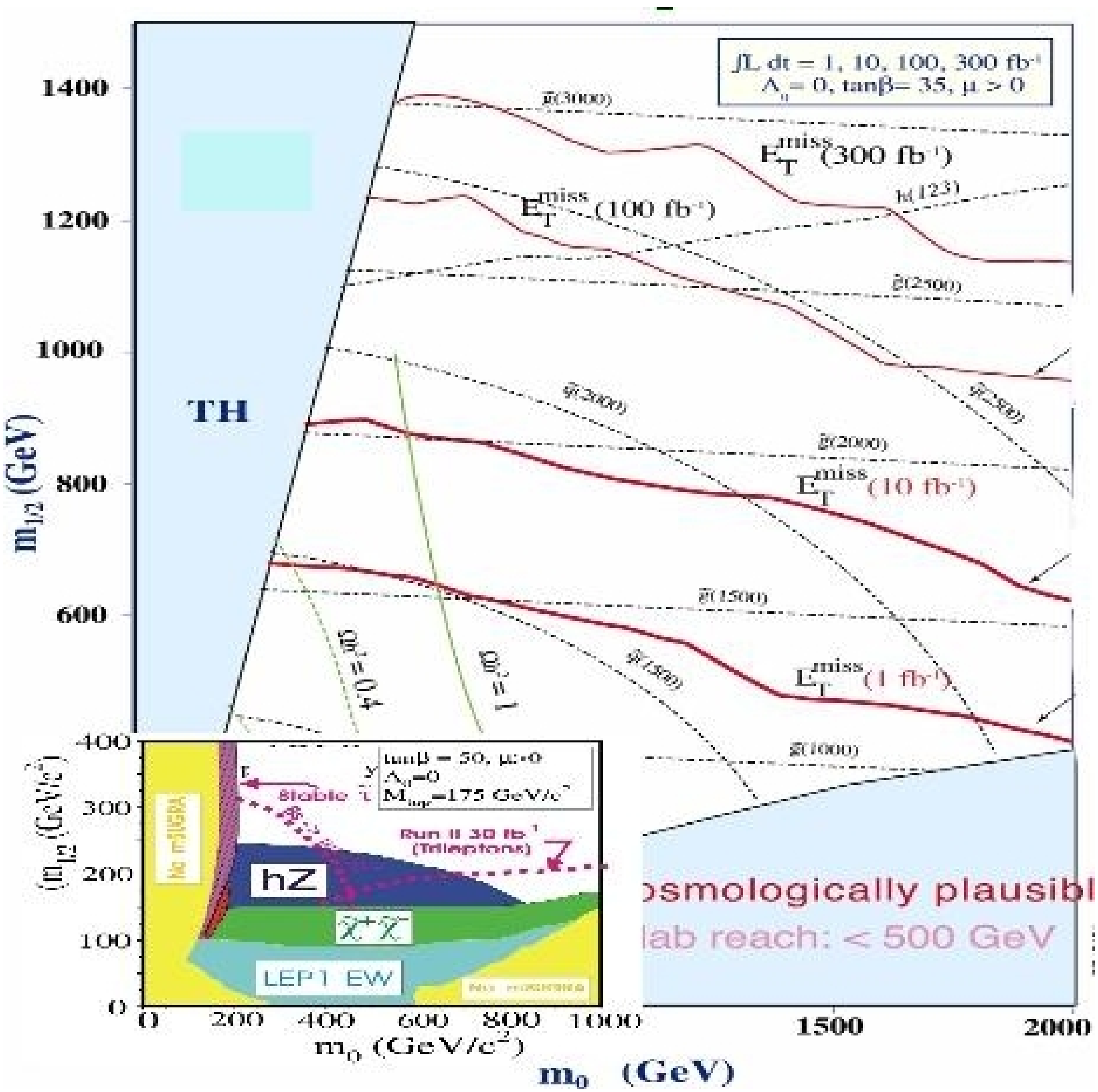
$$M_{\mathrm{eff}} = \not{E}_T + \Sigma_{i=1}^{4} p_T(\mathrm{jet})$$





- Essential for good SUSY searches
  - Good $\not{E}_T$ resolution
  - Implies hermetic calorimetry with good energy resolution
  - Canadians provided half the rapidity coverage

ATLAS SUSY Reach (5 σ)



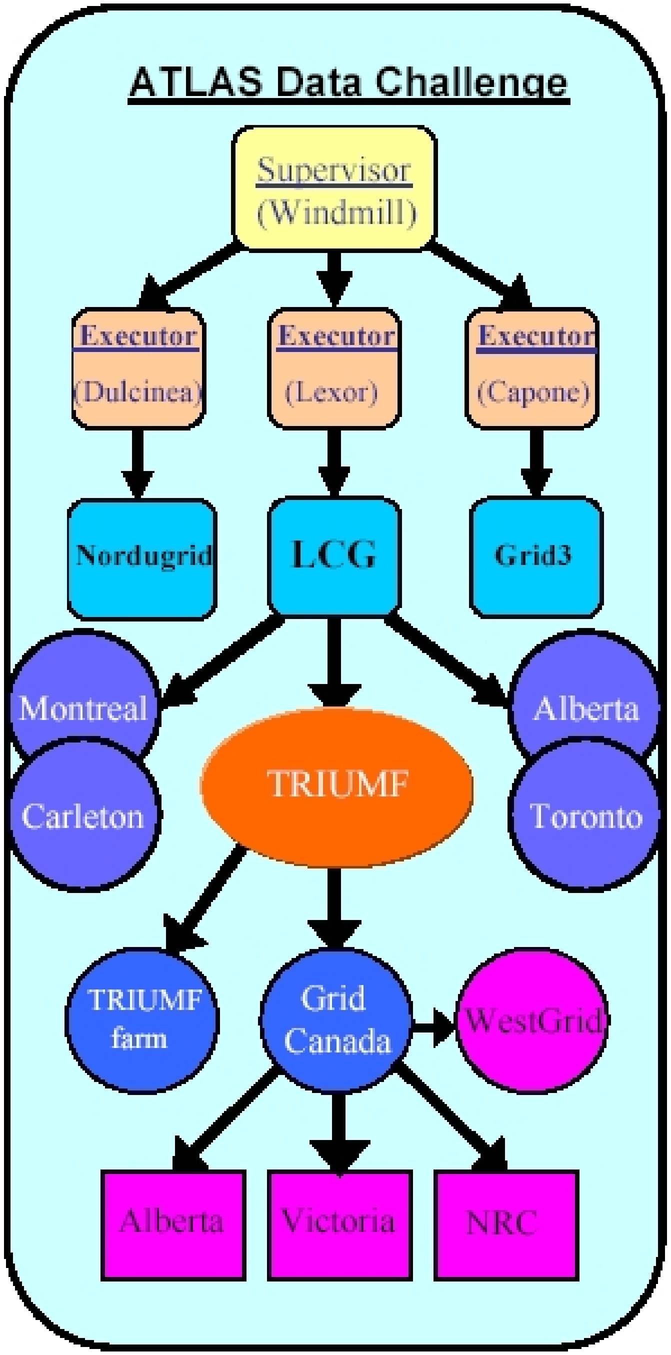
30 fb^{-1}

10 fb^{-1}

1 fb^{-1}

The LHC Computing Challenge

- In order to be able to get at this physics
  - LHC experiments need un-precedented amounts of computing
  - ATLAS will produce 3 PB of data per year
- The plan is to share this around the world
  - Already establishing GRID computing
  - Setup O(10) tier-1 computing centres
  - TRIUMF proposes to host one of these
  - Canada’s HEP investment in coming decade



The Future of the IPP Programme

	Timeline		
Experiment	Start	End	Investigators (fte)
ATLAS	2007	2020?	40 (30)
K0Pi0	2012?	2016	10 (6)
Linear Collider	2015?	2025+	30 (20)
SNO-Lab	2009	2015	30 (20)
T2K	2009	2015+	12 (8)

- How to balance large vs. small
- Any projects in the US (SLAC, FNAL, BNL)?
- In Canada ???

- NSERC sponsored SubAtomic Physics Long Range plan
  - Make recommendations for major investments over the coming decade

The International Linear Collider (ILC)

- World-wide consensus – next machine to build
- Superconducting RF technology chosen in August 2004
- Barry Barrish has accepted the position of international design director
  - Will assemble a design team and find a host site
  - Prepare technical design report in $\approx$ 2 years
  - Tender this design for host lab in three major regions of the world
- Canadians remain active in
  - Design of the ILC-detector tracking system and physics studies
  - TRIUMF investigating possible contributions to damping rings

Summary

- There are several outstanding puzzles in particle physics
  - BaBar will continue to push on hints of new CP phases
  - CDF will explore the energy frontier until the LHC turns on
  - ATLAS will thoroughly examine TeV-scale constituents
- Strong Canadian involvement in all of these (and other!) efforts
- Looking forward to new experimental observations
  - That challenge the theoretical paradigm of the Standard Model