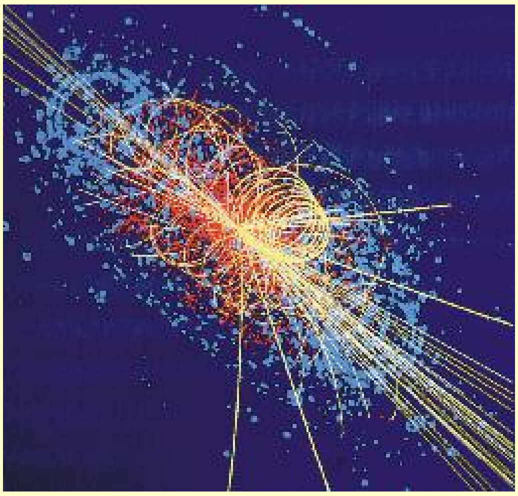
Hadron Collider Physics

-Where are we, where do we go ? -

Conference Summary and Perspectives



Karl Jakobs
Physikalisches Institut
Universität Freiburg / Germany

Instead of an Outline……

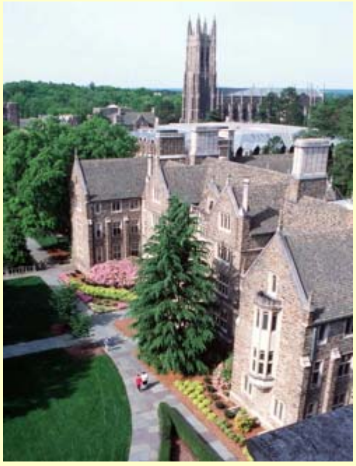
- The previous talk by Michael Harrison had ID=57
- Impossible to summarize all results in detail ……
  (available time = 40 sec / talk)
- Instead: Use the Organizer's invitation and talk about

"Summary and Perspectives"

⇒ discuss the global picture and the present and future role of Hadron Colliders

- I therefore had to make a selection of results
- My apologies to those speakers whose results I have omitted
  (it is not intended as a reflection of the relative importance)

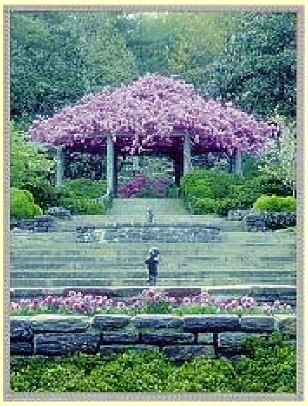
Where are we ?

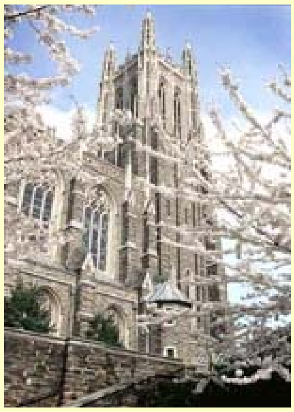


- We have spent one week in a wonderful place

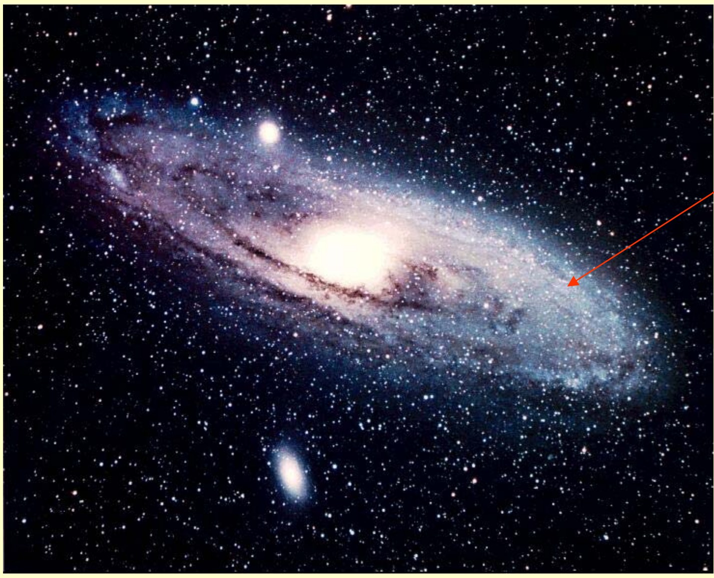
- in an enthusiastic atmosphere

- were presented many new results by excellent speakers
  ⇒ demonstrated the wealth of Hadron Collider Physics





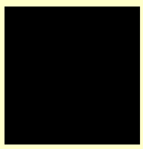
Where are we in the Universe ?



We are here

Surrounded by

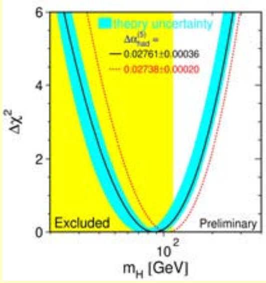
- Mass
  (planets, stars, ….,hydrogen gas)
- **Dark Matter**
- **Dark Energy**



© Rocky Kolb

Key Questions of Particle Physics

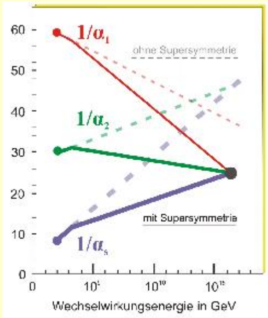
1. **Mass:** What is the origin of mass?
   - How is the electroweak symmetry broken ?
   - Does the Higgs boson exist ?



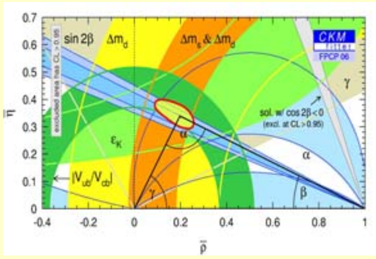
2. **Unification:** What is the underlying fundamental theory ?

   Motivation: Gravity not yet included;
   Standard Model as a low energy approximation

   - Is our world supersymmetric ?
   - Are there extra space time dimensions ?
   - Other extensions ?



3. **Flavour:** or the generation problem
   - Why are there three families of matter?
   - Neutrino masses and mixing?
   - What is the origin of CP violation?

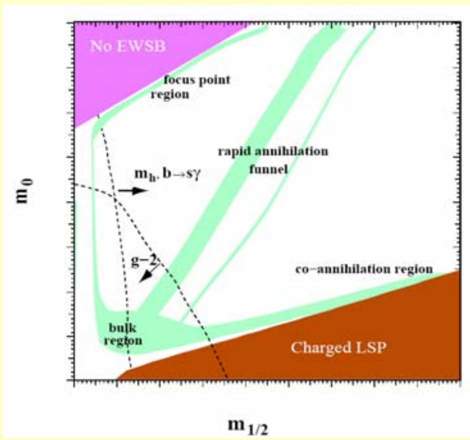


The role of Hadron Colliders

1. **Mass**
   - Search for the Higgs boson

2. **Unification**
   - Test of the Standard Model
   - Search for Supersymmetry
   - Search for other Physics Beyond the SM

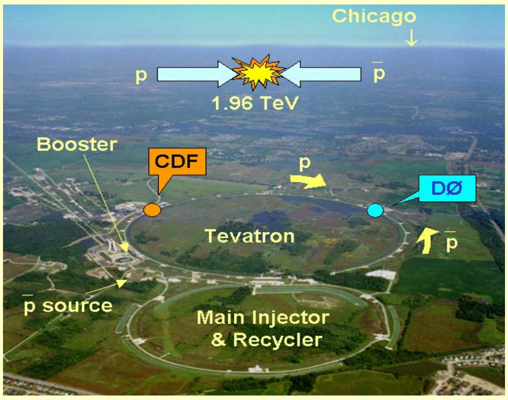
The link between SUSY and Dark Matter ?

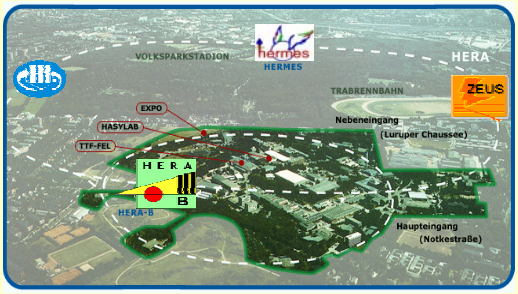


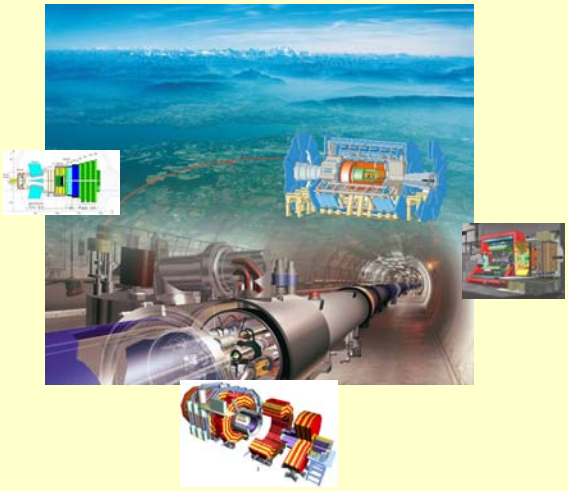
M. Battaglia, I. Hinchliffe, D.Tovey, hep-ph/0406147

3. **Flavour**
   - B hadron masses and lifetimes
   - Mixing of neutral B mesons
   - CP violation

Accelerators
and
Detectors

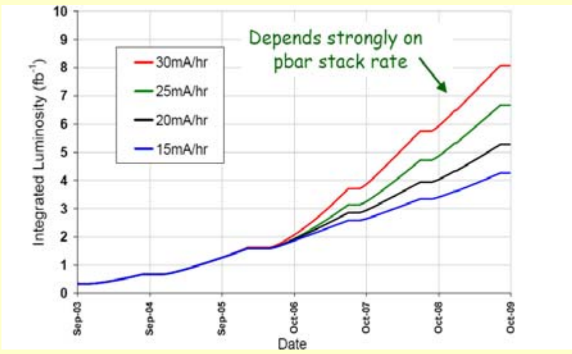






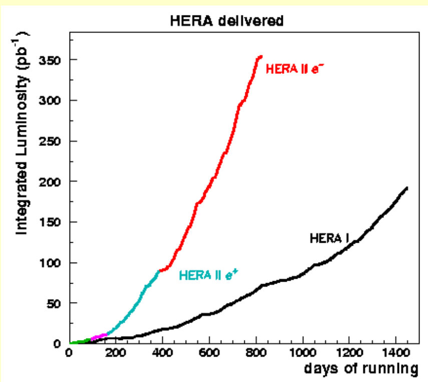
Tevatron

K. Gollwitzer



- very good performance during the past years
- Jan. 2006: luminosity record,
  new record: 1.71 10^{32} cm^{-2} sec^{-1}
- improvements due to electron cooling in the recycler;
  final performance depends on pbar stacking rate in accumulator
  (at present 20 mA/h = 0.2 · 10^{12} pbar /h)

and HERA



- similar to Fermilab…
  good performance after a slow start-up
- Polarized lepton beam,
  May 2006: L = 350 pb^{-1}
- Stop operation in June 2007,
  expected L = 700 pb^{-1}

Status of the LHC machine

L. Evans

Beam energy	7 TeV
Luminosity	10^{33} - 10^{34} cm^{-2}s^{-1}
Bunch spacing	25 ns
Particles/Bunch	$1.15 \cdot 10^{11}$
SC Dipoles	1232, 15 m, 8.33T
Stored Energy	362 MJ/Beam

- Key components available
- Installation progressing in parallel and at high speed; aim to finish by end March 2007
- "Every effort is being made to have first collisions by end of 2007"

<u>A "likely" startup scenario</u>:

Late 2007: Proton run ~ 10 - 100 pb^{-1} (for 10 pb^{-1}: number of tt events comparable to Tevatron with 1 fb^{-1})

→ detector and trigger commissioning, calibration, early physics

By end 2008: Physics runs: ~ 1 – 10 fb^{-1}

Installation work, underground

Preparation for installation, Hall SMI2

LHC Detector Installation and Commissioning

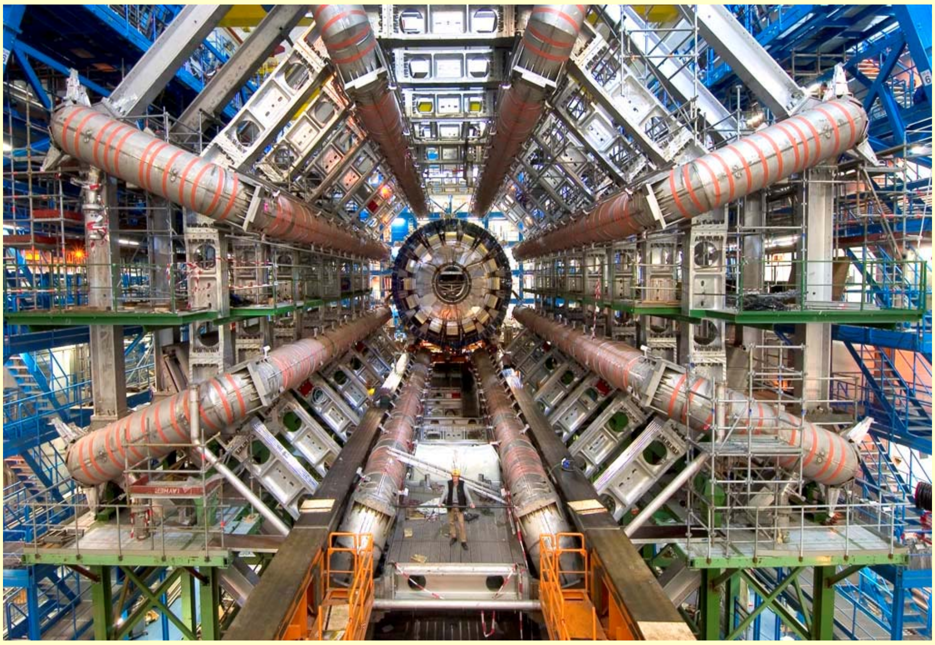
There was consensus among the experiments about the following:

- Most of the detector components are in hands;
- Enormous progress during the past 1-2 years, installation and commissioning are proceeding very well;
- Infrastructure and service work underestimated;
- Installation is time critical, more work than originally anticipated has to be done in parallel;

- A detector setup to take first collisions will be there in 2007.

ATLAS Installation

M. Nessi



November 2005

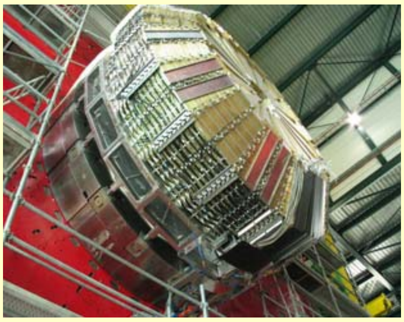
- Impressive progress! Nearly all detector components at CERN;
- Installation in the pit proceeding well, although time delays, work in parallel to catch up;
- On critical path: Installation of Inner detector services and forward muon wheels (time);
- ATLAS expected to be ready in August 2007 … one more tough year ...

CMS Installation

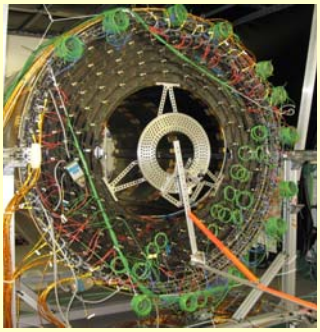
J. Incandela

Coil inserted, 14. September

Cathode Strip chambers and yoke endcaps



Hadronic calorimeter, endcap

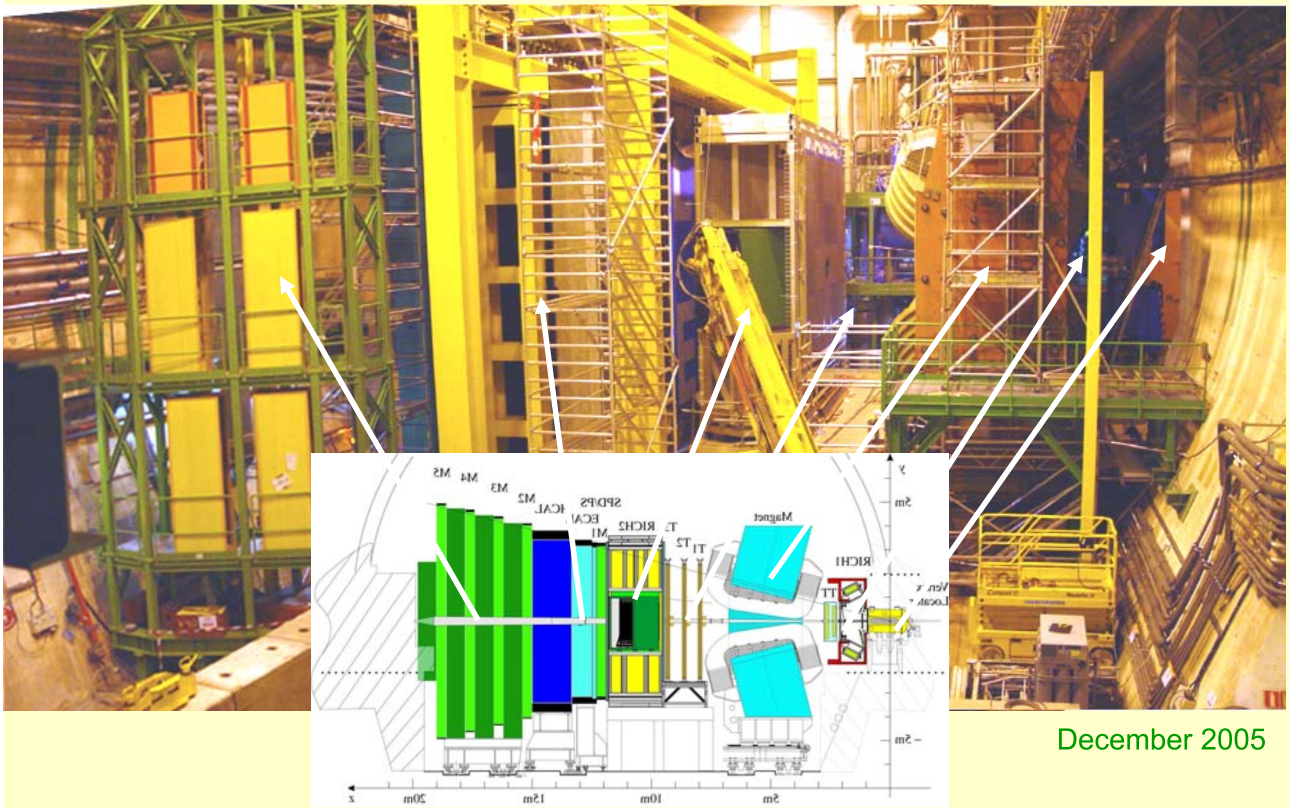


Tracker, outer barrel

On critical path: ECAL crystal delivery (Barrel: Feb. 07, Endcaps: Jan. 08)
Pixel installation for 2008 physics run.

LHCb Detector Status

B. Pietrzyk



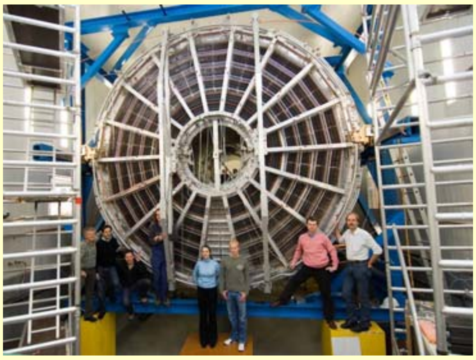
December 2005

- Detector construction and commissioning progressing efficiently
- Tight schedule, ready for collisions in 2007

ALICE Detector Status

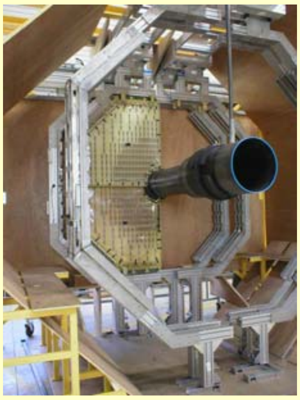
H. Gustafsson

Space frame installed in L3 magnet



ALICE TPC

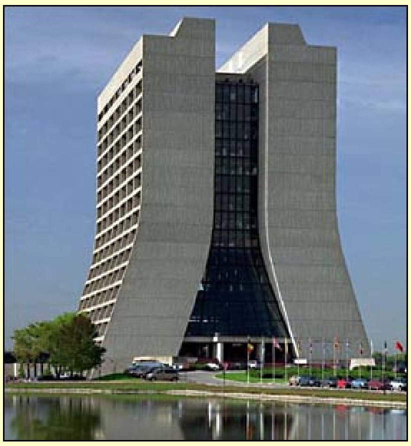
Photon detector,
crystals



Muon detector

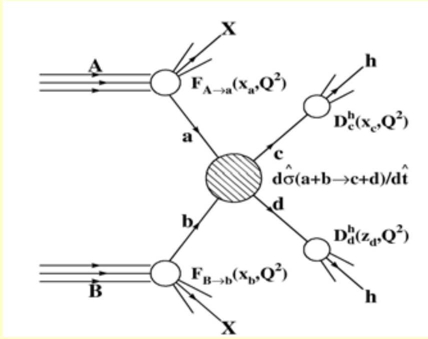
- All large structures installed
- Service installation still to be done
- Commissioning of several subsystems has started;
- Tight time schedule

Tests of the Standard Model



- Quantum Chromodynamics
- Electroweak Parameters
  - W mass
  - Top Quark Mass & Properties

QCD



QCD underlies everything we are doing at hadron colliders
$\Rightarrow$

(i) Test of the theory
(ii) Reliable background predictions;

Both require the calculation of challenging higher order corrections
(huge theoretical effort)

+ their implementation in Monte Carlo event generators

(Provides for a good collaboration between theorists and experimentalists)

Status of NLO and NNLO Calculations:

F. Petriello

Parton-level results available for all $2 \to 2$ and some $2 \to 3$ processes:

- AYLEN/EMILIA (de Florian et al.): $pp \to (W,Z) + (W,Z,\gamma)$
- DIPHOX (Aurenche et al.): $pp \to \gamma j, \gamma\gamma, \gamma^* p \to \gamma j$
- HQQB (Dawson et al.): $pp \to t\bar{t}H, b\bar{b}H$
- MCFM (Campbell, Ellis): $pp \to (W,Z) + (0,1,2)\,j,\ (W,Z) + b\bar{b}, V_1V_2, \ldots$
- NLOJET++ (Nagy): $pp \to (2,3)\,j,\ ep \to (3,4)\,j,\ \gamma^* p \to (2,3)\,j$
- VBFNLO (Figy et al.): $pp \to (W,Z,H) + 2\,j$
- $\ldots$

- Several inclusive $2 \to 1$ processes (W, Z, H production) (van Neerven, Harlander, Kilgore, Anastasiou, Melnikov, Ravindran, Smith)
- A few "semi-inclusive" $2 \to 1$ distributions (W, Z rapidity distributions) (Anastasiou, Dixon, Melnikov, FP)
- Fully differential $2 \to 1$ result ($pp \to H, W, Z + X$) (Anastasiou, Melnikov, FP)
- DGLAP splitting kernels (Moch, Vermaseran, Vogt)
- Various approximate results (soft approximations)

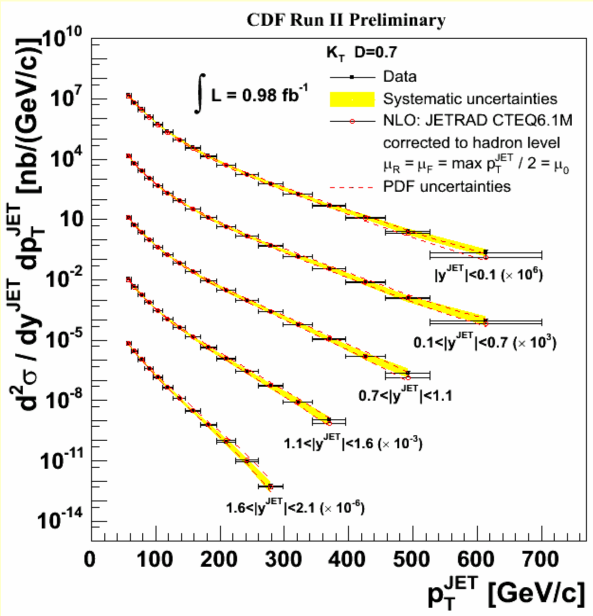
- New approaches to match parton showers and matrix elements:
  (some based on algorithm developed by Catani, Krauss, Kuhn and Webber (CKKW))
  - ALPGEN Monte Carlo + MLM matching, M. Mangano et al.
  - PYTHIA, adapted by S. Mrenna
  - SHERPA Monte Carlo, F. Krauss et al.
  - …….

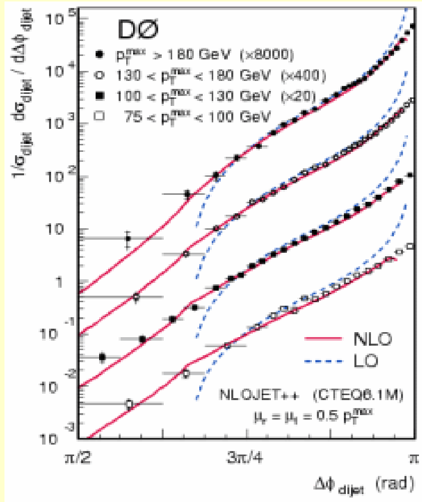
- Very important role of the Tevatron:

  Validation of the present Monte Carlos / simulation approaches….
  ("before the big flood comes" (D. Rainwater))

(i) High P_T Jet production

M. Convery



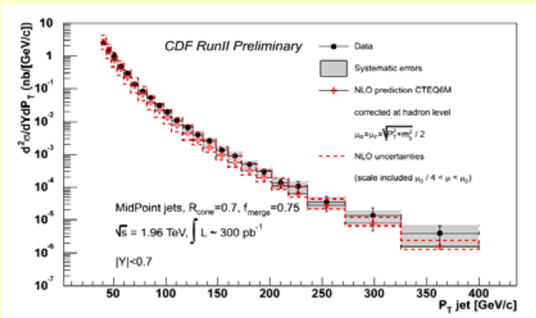


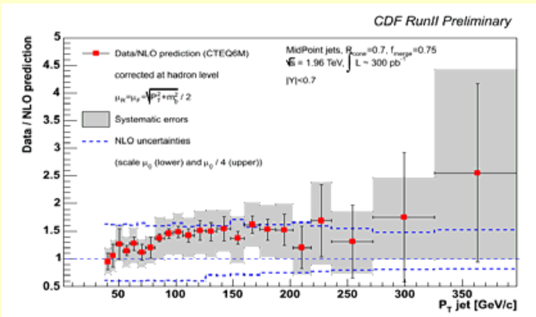
Good agreement with NLO calculations….. over the full pseudorapidity range
(angular correlations less sensitive to exp. systematics)

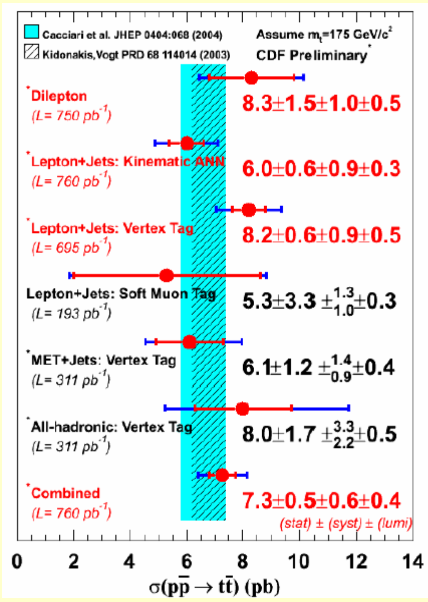
No evidence for deviations from the Standard Model

Heavy flavours (b- and t-quarks)

M. Convery,
F. Petriello
M. Weber



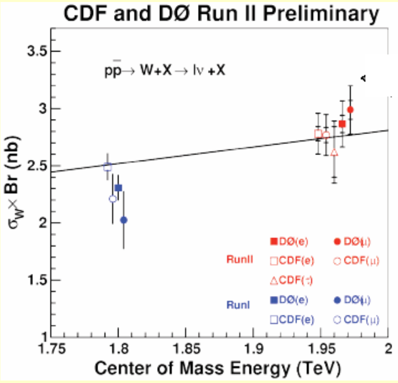


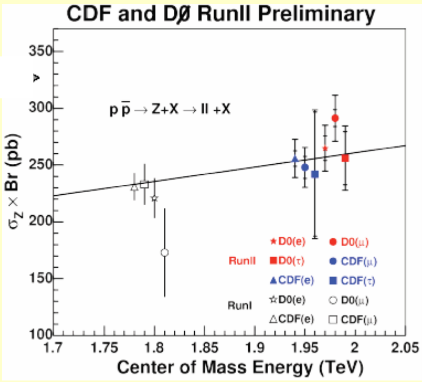


Run I discrepancy has disappeared
(consistent treatment of fragmentation functions,
resummation, improved pdfs)

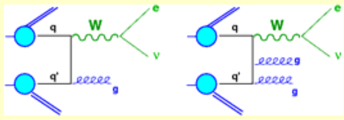
W/Z (+jet) production:

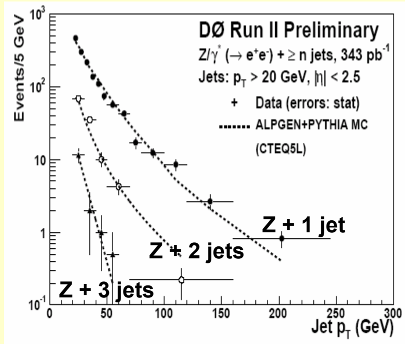
M. Convery,
F. Petriello,
D. Waters





QCD at work ….





Good agreement with NNLO QCD calculations
C.R.Hamberg et al (1991)
Anastasiou et al. (2004)

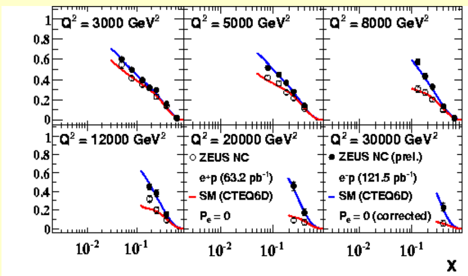
Precision is limited by systematic effects
(uncertainties on luminosity, parton densities,...)

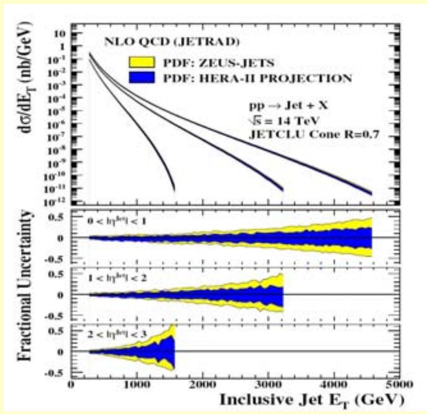
QCD at HERA

K. Wichmann

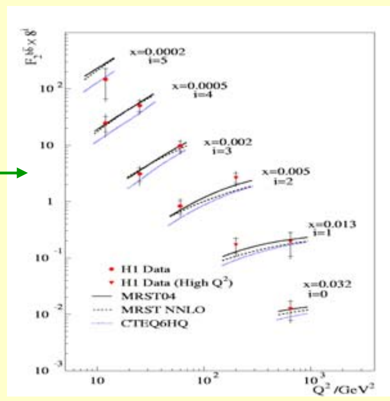
- More precise measurements of parton distributions;
  First QCD fits with HERA-II (2004/05) polarized e^-p data
  (important for LHC cross section uncertainties)

- σ_{NC} differs significantly for e^+p ane e^-p
  $\Rightarrow$ extract xF_3





- Also at HERA: QCD provides a reasonable description of heavy flavor production
  (no b-crisis anymore ?)



- Impressive α_s measurement from jet rates and scaling violations:

$$\alpha_s(M_Z) = 0.1196 \pm 0.0011\,(\text{stat.})\,^{+0.0019}_{-0.0025}\,(\text{exp})\,^{+0.0029}_{-0.0017}\,(\text{theo})$$

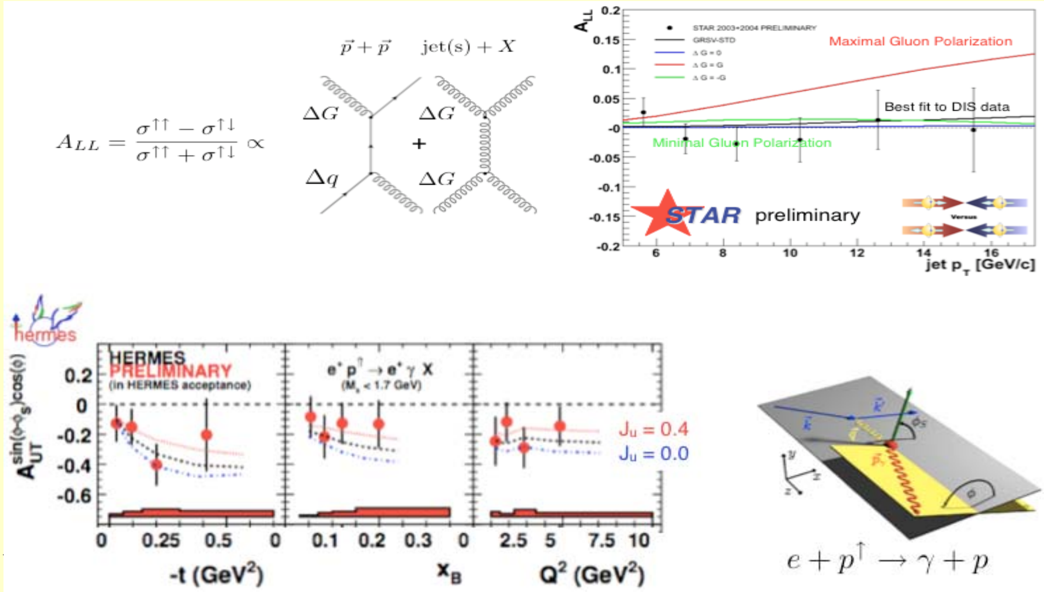
E. Sichtermann

Nucleon Spin Structure

~ 20 years after the European Muon Collaboration found that Quark Spins contribute little to the proton spin,

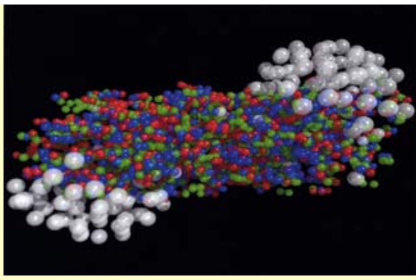
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

experiments at CERN, DESY, JLAB and RHIC are closing in on the gluon polarisation and orbital momentum.

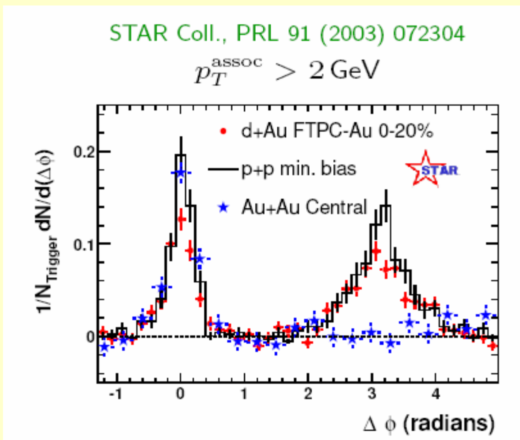


The Quark-Gluon Plasma

- non-expert's impressions -



- Evidence for a „New State of Matter“ discovered at CERN SPS in the 1990th
- Evidence for a „New State of Matter“ re-discovered at RHIC in a different form in 200x
- Very strong experimental programme and very important results



- The matter is
  - strongly coupled
  - quenches jets
  - behaves like a nearly ideal fluid.
- Lot of theoretical work;
- Many complementary measurements (RHIC, LHC,..) needed for a detailed understanding.

Precision measurements of m_W and m_{top}

Motivation:

m_W and m_{top} are fundamental parameters of the Standard Model;

Well defined relations between m_W, m_{top} and m_H

Electromagnetic constant measured in atomic transitions, e^+e^- machines, etc.

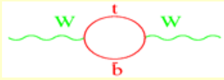
$$m_W = \left(\frac{\pi \alpha_{EM}}{\sqrt{2} G_F} \right)^{1/2} \frac{1}{\sin\theta_W \sqrt{1-\Delta r}}$$

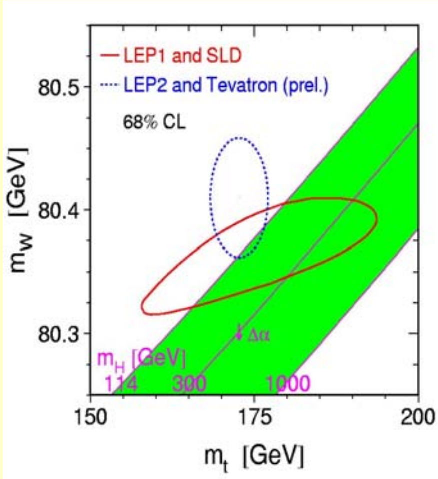
Fermi constant measured in muon decay

weak mixing angle measured at LEP/SLC

radiative corrections

$\Delta r \sim f(m_{top}^2, \log m_H)$





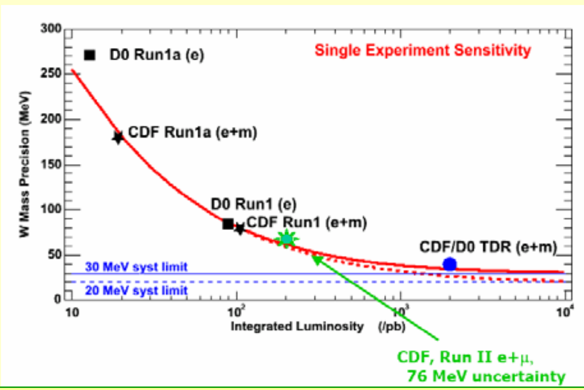
Ultimate test of the SM: Comparison between the (hopefully) observed Higgs boson mass and radiative corrections

D. Wackeroth

$\delta m_H / m_H$ = 47% (today) → 18% (LHC)

W mass measurement

D. Waters
C. Buttar



Goals: ± 20 MeV (TeV) → ± 15 MeV (LHC)

- QCD radiative corrections to W/Z production: exact up to $\mathcal{O}(\alpha_s^2)$ (total cross sections) and soft gluon resummation ($p_T(W,Z)$ distributions).
  R.Hamberg *et al.*, NPB359 (1991); W.L.van Neerven *et al*, NBP382 (1992) ; W.T.Giele *et al*, NPB403 (1993); C.Balazs *et al*, PRD56 (1997) (RESBOS)
  Fully differential distributions to W boson production and Z rapidity distribution up to $\mathcal{O}(\alpha_s^2)$
  K.Melnikov, F.Petriello, hep-ph/0603182; L.Dixon *et al.*, hep-ph/031226
- Electroweak (EW) corrections to Z and W boson production: complete EW $\mathcal{O}(\alpha)$ contribution and multiple final state photon radiation.
  U.Baur *et al*, PRD65 (2002); C.M.Carloni Calame *et al*, JHEP05 (2005) and U.Baur, D.W., PRD70 (2004); S.Dittmaier, M.Krämer, PRD65 (2002); A.Andonov *et al*, hep-ph/0506110, L.Akhushevich *et al*(2003); W.Placzek *et al*, EPJC29 (2003); C.M.Carloni Calame *et al*, PRD69 (2004)

Hadron Collider Symposium

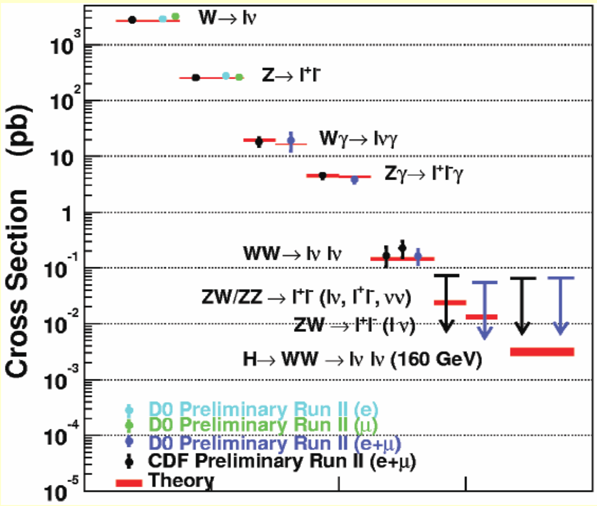
On the theoretical side:

D. Wackeroth

- Very good progress in providing theoretical predictions (QCD and el. Weak) for W / Z physics at NLO, NNLO and higher (leading log)
- Many Monte Carlos available
  ⇒ Experimentalists highly appreciate the efforts to implement electroweak and QCD corrections within one Monte Carlo generator

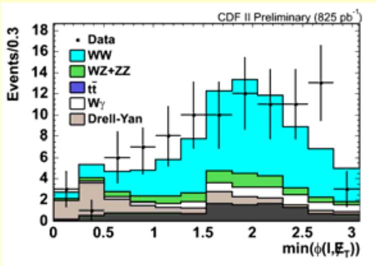
Summary of results of di-boson searches

A. Stone /
S. Protopopescu

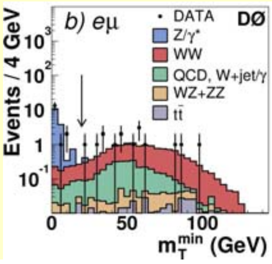


- Cross sections for di-boson production of Wγ, Zγ and WW have been measured (leptonic final states + ℓν jj)
- First indications for WZ production
- Good agreement with Standard Model predictions
- First limits on anomalous couplings

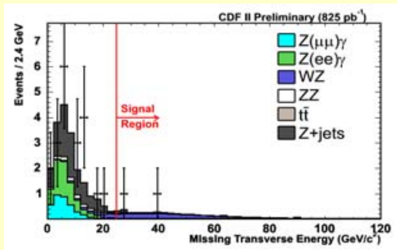
CDF: WW



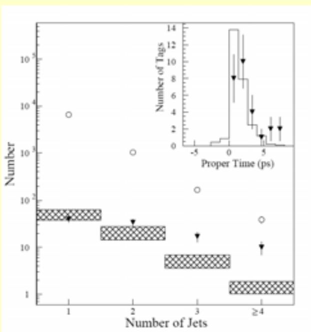
DØ: WW

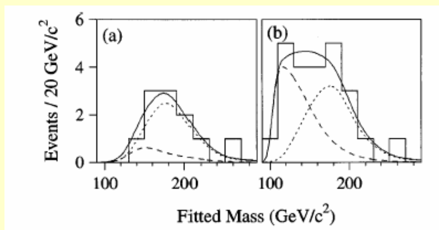


CDF: WZ



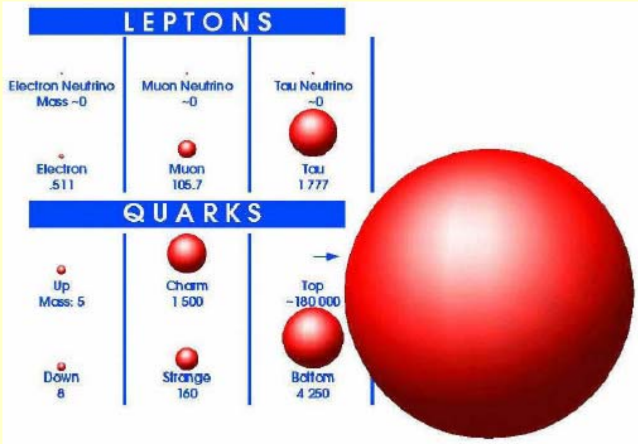
The Top Quark: ~ 10 years ago





Why is Top-Quark so important ?

D. Rainwater



- The top quark may serve as a window to ***New Physics*** related to the electroweak symmetry breaking;
  Why is its Yukawa coupling ~ 1 ??

$$M_t = \frac{1}{\sqrt{2}} \lambda_t v$$

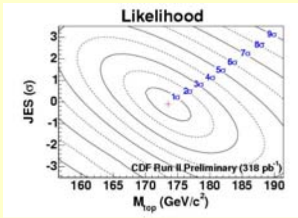
$$\Rightarrow \lambda_t = \frac{M_t}{173.9\,\mathrm{GeV}/c^2}$$

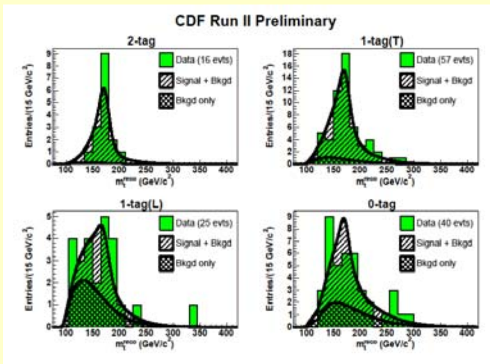
- We still know little about the properties of the top quark:
  mass, spin, charge, lifetime, decay properties (rare decays), gauge couplings, Yukawa coupling,…

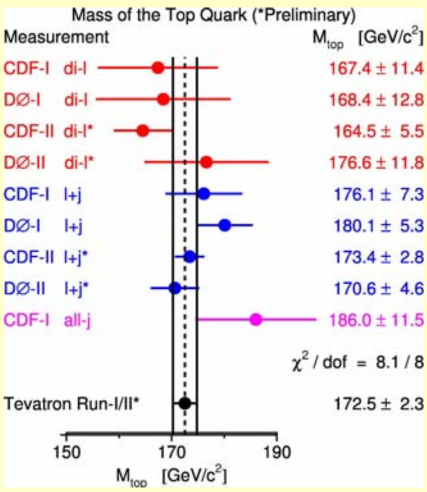
Tevatron results on the top quark mass

Un-ki Yang

- Impressive results on top mass measurement
  - increased statistics (600- 800 pb^{-1})
  - in situ Jet Energy Scale calibration, W → qq
  - improved methods: matrix element, templates,…
- Run II goal on $\delta\, m_{top}$ surpassed
  dominant errors: b-jet scale, MC modelling,….
  Where are the limits ? Probably we need to use better theory models soon….







<u>Most precise single measurements</u>:

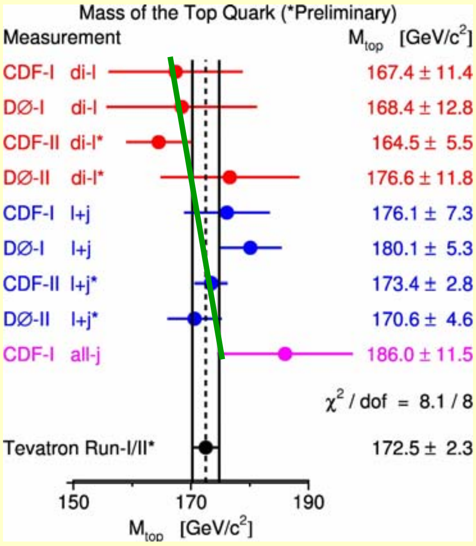
m_{top} = 173.4 ±3.5 (stat+JES) ± 1.3 (syst) GeV/c^2 (CDF)

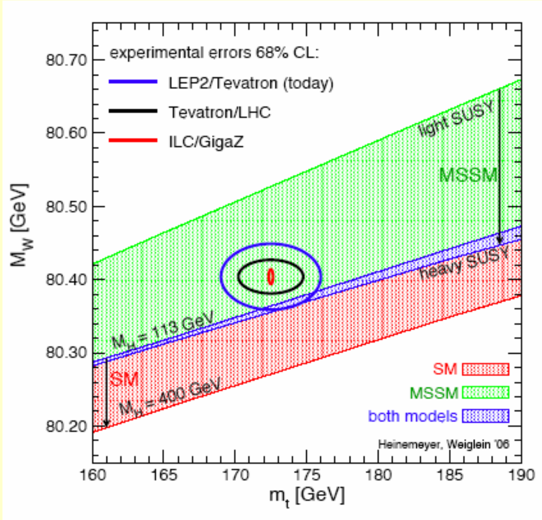
m_{top} = 170.6 ±4.4 (stat+JES) ±1.4 (syst) GeV/c^2 (DØ)

m_{top} = 172.5 ± 2.3 GeV/c^2

Un-ki Yang
J. D‘Hondt
C. Buttar

Future Prospects for the top quark mass measurement

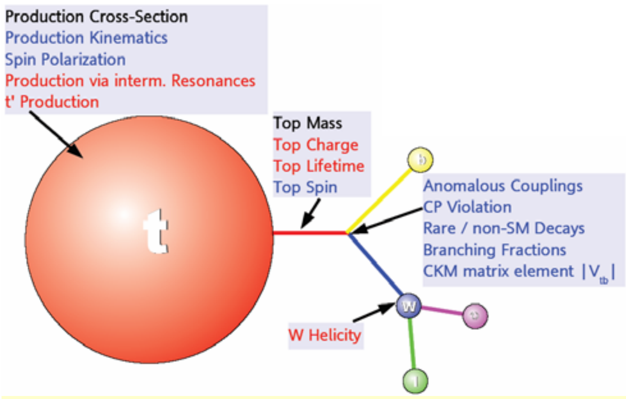




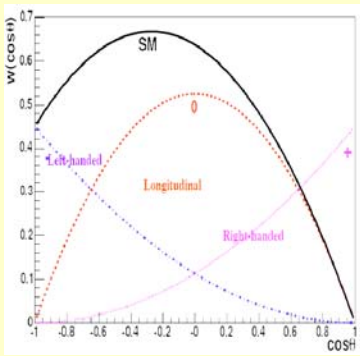
1. Channel dependence ? still statistically consistent results;
2. Expected Tevatron precision (full data set): ± 1.5 GeV/c^2
3. Expected LHC precision for 10 fb^{-1}: < ~ 1 GeV/c^2
   (Combination of several methods, maybe somewhat conservative)

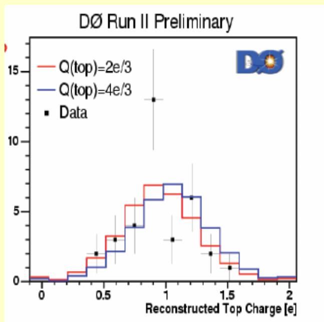
M. Weber

Other top properties



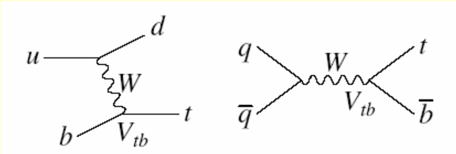
	Tevatron Result	luminosity (fb^{-1})
Mass	172.5 ± 2.5 GeV	0.6 – 0.8
W helicity	f_0 = 0.74 (+0.22) (-0.34) f_+ = 0.08 ± 0.10	0.16 0.37
Charge Lifetime V_{tb} BR(t→Wb) / BR(W→Wq)	rule out Q = +4/3 (93.7% CL) cτ < 53 μm (95% CL) awaiting single top 1.03 (+0.19) (-0.17)	0.23 0.32 0.23
Search for: Resonances X_0 → tt 4th generator t‘ quark	 M(X_0) > 725 GeV (95% CL) m(t‘) > 258 GeV (95% CL)	 0.68 0.76





Single Top Production ?

D. Rainwater
M. Weber

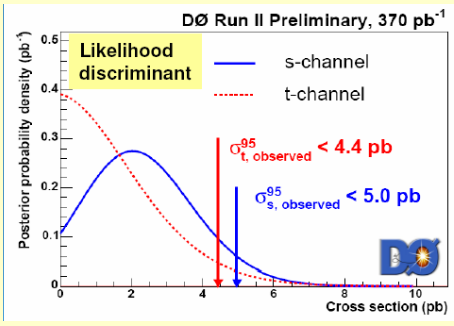


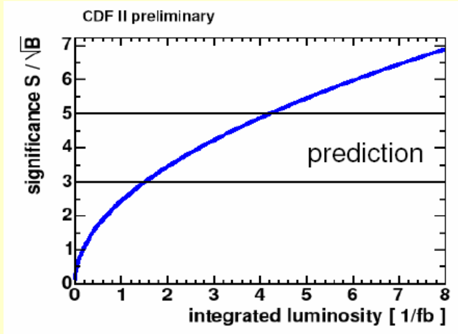
Latest results (370/pb) likelihood
s: < 5.0 pb @ 95% C.L.
t: < 4.4 pb @ 95% C.L.

Earlier limits published in
PLB 622, 265 (2005)

Latest CDF results (695/pb) NN
s: <3.2 pb @ 95% C.L.
t: <3.1 pb @ 95% C.L.
s+t: <3.4 pb @ 95% C.L.

Earlier limits published in
PRD 71 012005





Could be the next “expected” Tevatron discovery

The Top Quark at the LHC

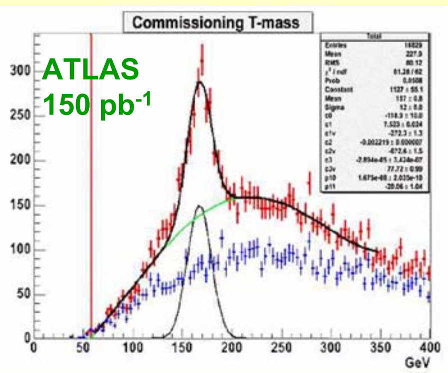
J. D‘ Hondt

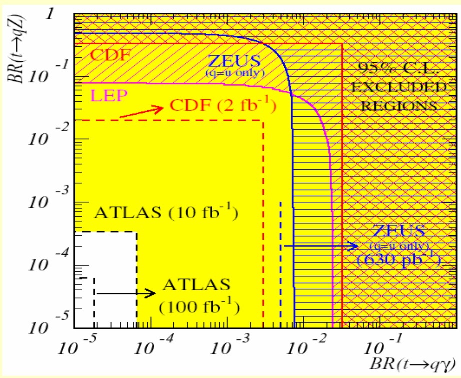
The role of the top quark at the LHC is defined by its huge production rate:
σ(tt) ~ 800 pb (NLO) ⇒ expect 1 event per second in the tt → ℓνb qqb mode

1. **Background** in Searches for New Physics
   Top events are omnipresent at the LHC !

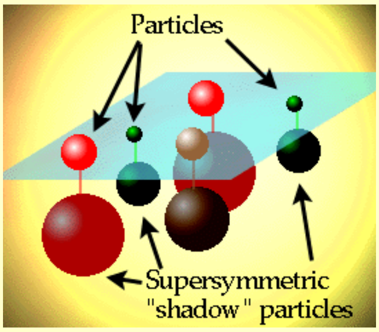
2. **Calibration** signal (b-tag, jet energy scale,…)

3. **Physics Signal** (- Test of the Standard Model with better precision,
   - Search for physics beyond the SM,
   e.g., FCNC decays, t → qZ, qγ, qg)





The Search for

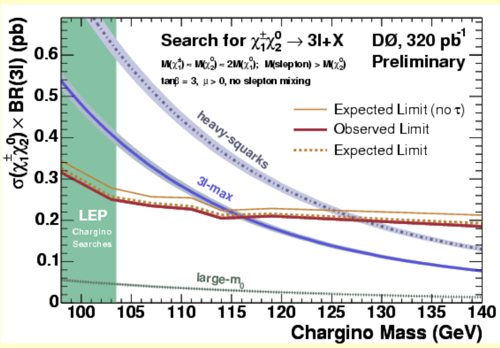


Supersymmetry

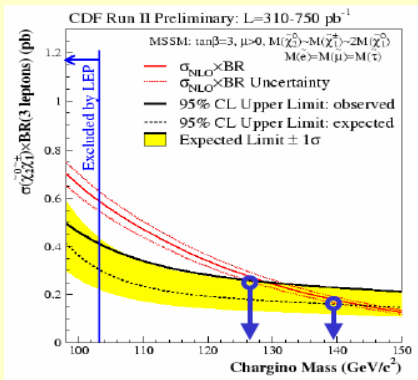
Search for SUSY at the Tevatron, the classical channels

(i) Charginos and Neutralinos in 3-ℓ final states: $\tilde{\chi}_2^0 \tilde{\chi}_1^\pm \rightarrow l^\pm l^\mp l^\pm \tilde{\chi}_1^0 \tilde{\chi}_1^0 X$

X. Portell



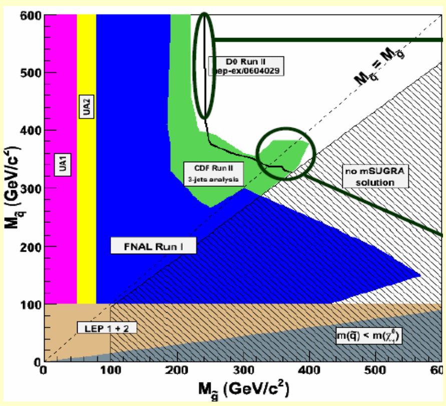
Limits beyond LEP limits (for specific scenarios)



(ii) Squarks and Gluinos

copiously produced, QCD production,
Run I limits significantly extended

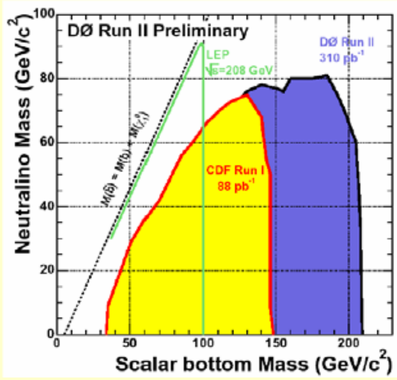
beyond LEP- mSUGRA limits

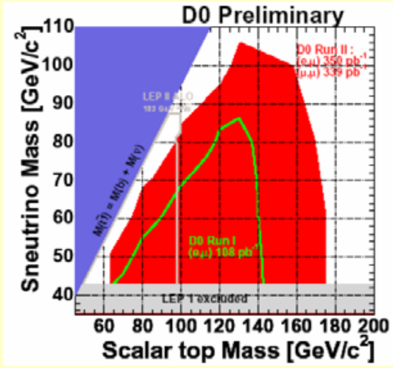


Many other SUSY Searches going on….

X. Portell

- Search for 3rd generation squarks
- Gauge mediated SUSY searches
  - $\gamma\gamma$ + E_T^{miss} signature
  - …….
- R-parity violating SUSY
  - multileptons from LLE coupling
  - stops
  - …..
- Charged massive, quasi stable particles



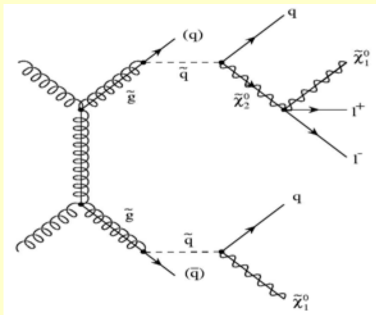


Search for Supersymmetry at the LHC

D. Acosta

- If SUSY exists at the electroweak scale, a discovery at the LHC should be easy
- Squarks and Gluinos are strongly produced

  They decay through cascades to the lightest SUSY particle (LSP)



$\Rightarrow$ combination of
Jets, Leptons, E_T^{miss}

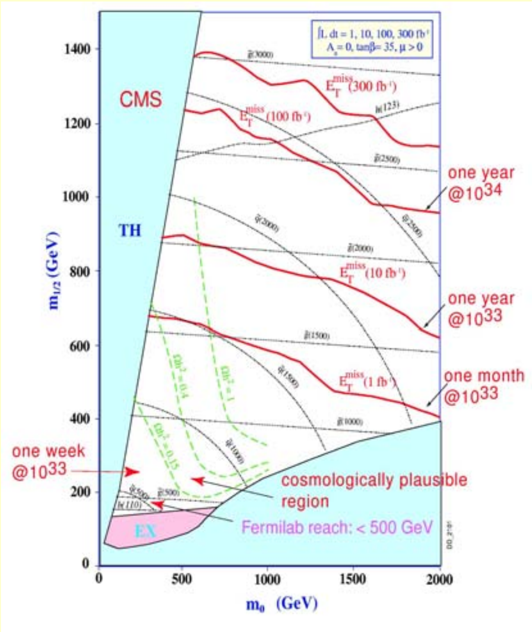
1. Step: Look for deviations from the Standard Model
   Example: Multijet + E_T^{miss} signature

2. Step: Establish the SUSY mass scale use inclusive variables, e.g. effective mass distribution

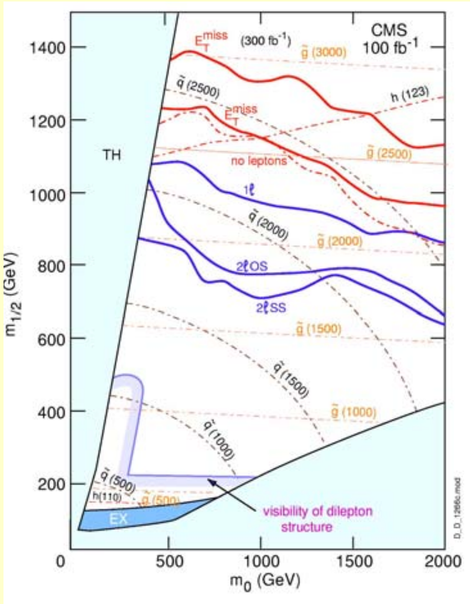
3. Step: Determine model parameters (difficult)
   Strategy: select particular decay chains and use kinematics to determine mass combinations

LHC reach in the m_0 - $m_{1/2}$ mSUGRA plane:

Multijet + E_T^{miss} signature



SUSY cascade decays give also rise to many other inclusive signatures: **leptons, b-jets, τ's**



Expect multiple signatures for TeV-scale SUSY

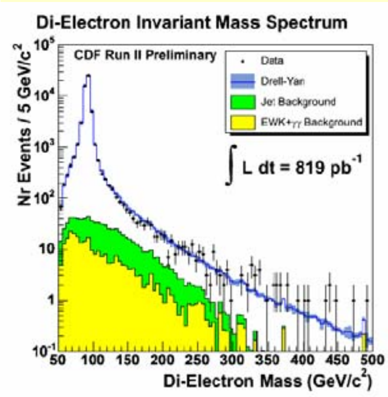
Search for Exotics at the Tevatron

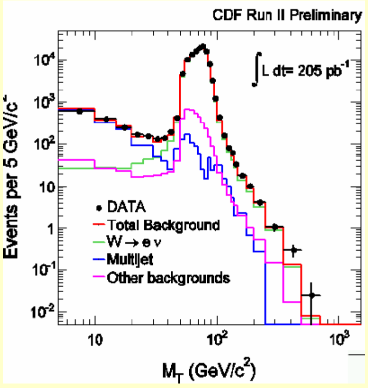
G. Brooijmans

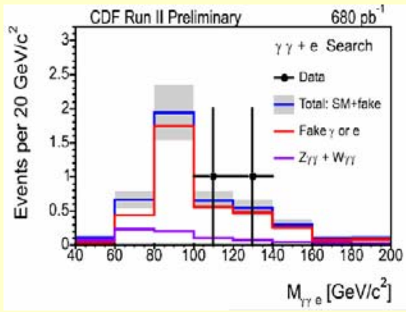
- Many papers
- Many searches
- Nothing found !
- Frustration increased….
- …and previous excesses disappeared

Summary of recent results:

	Present limits (95%CL)
Excited Quarks Q* → q Z	M (q*) ~ 520 GeV
Leptoquarks (qν qν) Vector-LQ3 → bτ	M (LQ) ~ 136 GeV ~ 340 GeV
Z‘ → ee W‘→ eν	M (Z‘) > 850 GeV M (W‘) ~ 788 GeV





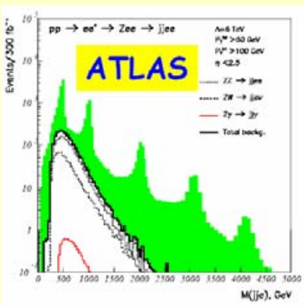


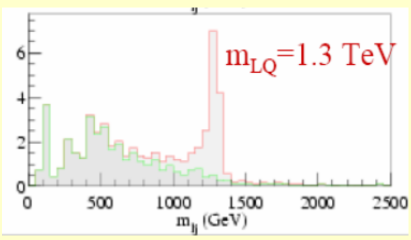
LHC reach for other BSM Scenarios

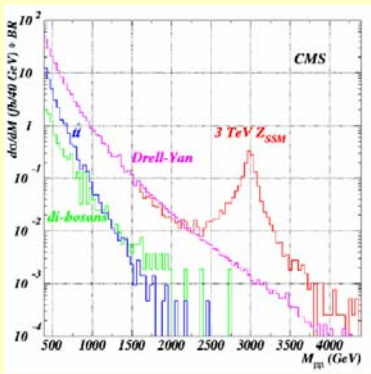
(a few examples for 30 and 100 fb^{-1})

K. Benslama

	30 fb $^{-1}$	300 fb $^{-1}$
Excited Quarks & Lept. Q* → q γ	M (q*) ~ 3.5 TeV	M (q*) ~ 6 TeV M (ℓ*) ~ 3-4 TeV
Leptoquarks	M (LQ) ~ 1 TeV	M (LQ) ~ 1.5 TeV
Z‘ → ℓℓ, jj W‘→ ℓ ν	M (Z‘) ~ 3 TeV M (W‘) ~ 4 TeV	M (Z‘) ~ 5 TeV M (W‘) ~ 6 TeV
Compositeness (from Di-jet)	Λ ~ 25 TeV	Λ ~ 40 TeV





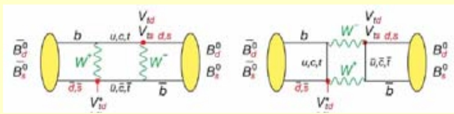


A few highlights on

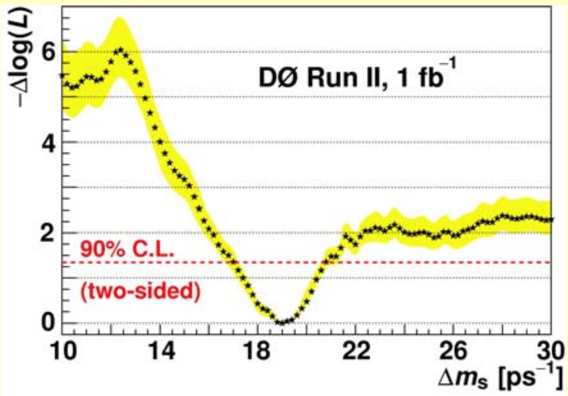
B-Physics

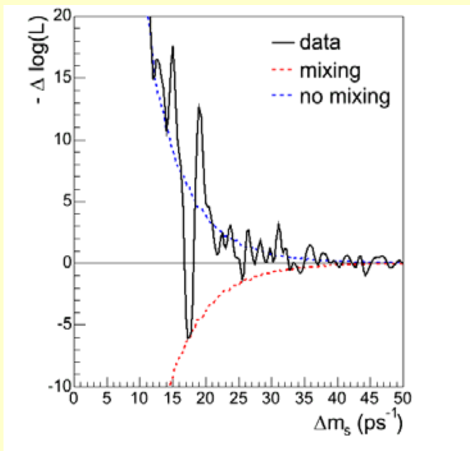
- Impressive results from the B-factories / BaBar and Belle — G. Leder
- **Evidence for B^0_s mixing from the DØ and CDF experiments** — S. Burdin
- Precise lifetime and mass measurements of B hadrons at the Tevatron — S. Uozumi
- Impressive physics potential of LHCb — C. Lazzeroni
- Interesting limits on rare decays from the Tevatron and good perspectives for ATLAS and CMS — V. Krutelyov, S. Tarem

B_s mixing



S. Burdin
C. Lazzeroni





March 2006: two-sided limit from DØ:
$17 < \Delta m_s < 21$ ps^{-1} @ 90% C.L.

April 2006: Measurement from CDF

$\Delta m_s = 17.33\ (+0.42)(-0.21)$ (stat.) ± 0.07 (syst.) ps^{-1}

$17.00 < \Delta m_s < 17.91$ ps^{-1} @ 90% C.L.

Congratulations to both collaborations for these impressive results !

LHCb expectations: $\delta\, \Delta m_s$ (stat) = 0.01 ps^{-1} (after 1 year of data taking)

Rare decays: $B_s \to \mu\mu$

V. Krutelyov
S. Tarem

- Standard Model branching ratio is very small:

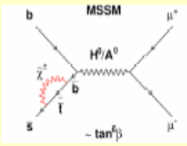
$$BR(B_s \to \mu^+\mu^-) = (3.5 \pm 0.9) \times 10^{-9}$$

(Buchalla & Buras, Misiak & Urban)

- Large enhancement possible in SUSY:

$$B(B_s \to \mu^+\mu^-) \propto \tan^6\beta / m_A^4$$

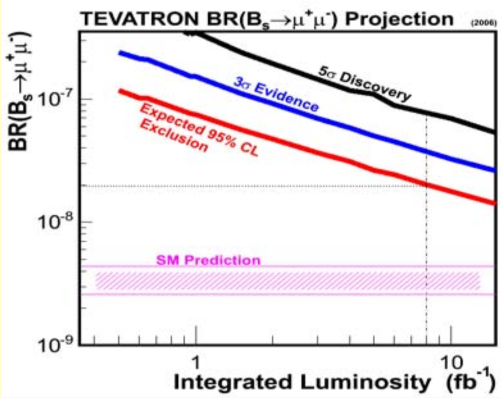
(Babu, Kolda: hep-ph/9909476+ many more)



- Present 95% CL limits on BR:

CDF (171 pb^{-1}): BR < $5.8 \cdot 10^{-7}$
DØ (240 pb^{-1}): BR < $4.1 \cdot 10^{-7}$
DØ (300 pb^{-1}): BR < $3.0 \cdot 10^{-7}$

CDF (780 pb^{-1}): BR < $1.0 \cdot 10^{-7}$



- Future Tevatron limits will start to severely constrain the mSUGRA parameter space
  (see e.g. B. Allanach, C. Lester, hep-ph/0507283)

- ATLAS and CMS have the potential to probe the Standard Model values after a couple of years of running

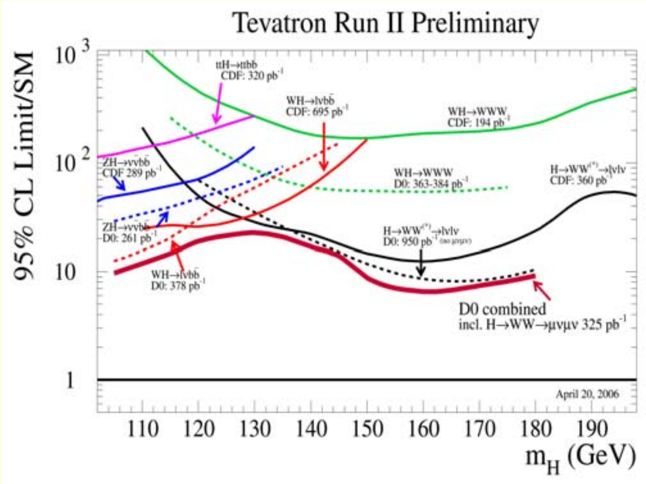
Where is the

Higgs Boson ?

Higgs boson searches at the Tevatron

L. Sonnenschein

- Many analyses (in many different channels) presented
- No excess above SM background $\Rightarrow$ Limits extracted



Combination of current analyses (DØ): for ~325 pb^{-1}

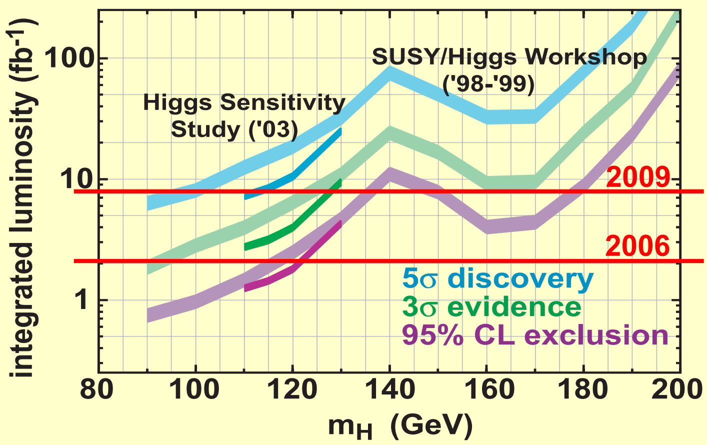
- upper limit about ~ 15 times larger than SM prediction at 115 GeV/c^2
- for L = 2 fb^{-1}: $\rightarrow$ gain = $\sqrt{L / 0.325}$ $\rightarrow$ still a factor 6.1 missing

- Can the missing factors be gained ??

Anticipated improvements:

L. Sonnenschein

- increase acceptance (forward leptons, forward b-tagging)
- improvements in b-tagging (neural network)
- improvements in selection efficiencies (track-only leptons, neural networks)
- improved di-jet mass resolution
- ....



- *hard piece of work…*
- *Improvement factors suspiciously close to the required values to get to the nominal performance*

95% CL exclusion:	~ 2 fb^{-1}:	115 GeV/c^2
	8 fb^{-1}:	135 GeV/c^2
3 σ evidence:	5 fb^{-1}:	115 GeV/c^2

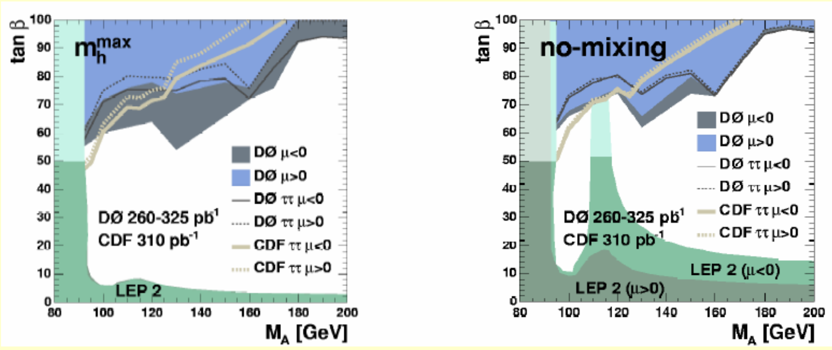
Updated Sensitivity Estimates (assumes all factors can be reached)

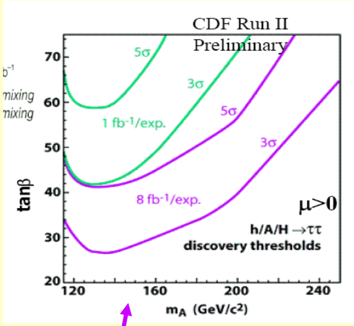
improvements not demonstrated yet, no guarantee, but there is a chance....

MSSM Higgs boson searches at the Tevatron

L. Sonnenschein

Search for A/H → bb and A/H → ττ



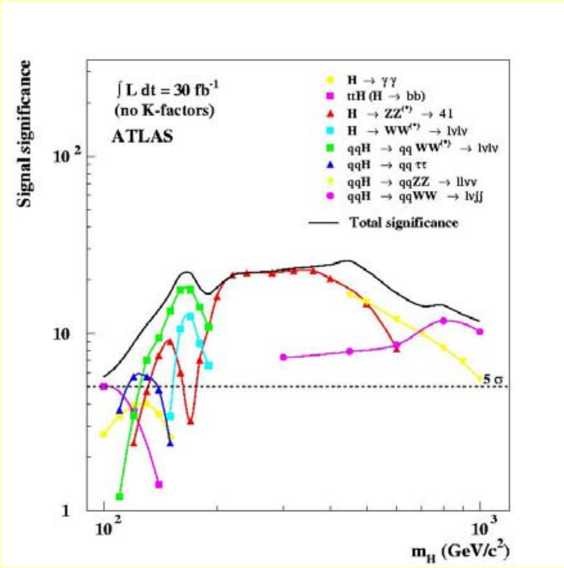


Start to access interesting regions of parameter space and to constrain models at large tan β;
(however, beware of large radiative corrections !)

Good prospects for discovery of MSSM Higgs bosons in the (large tanβ–small m_A) region, if $8 fb^{-1}$ can be achieved.

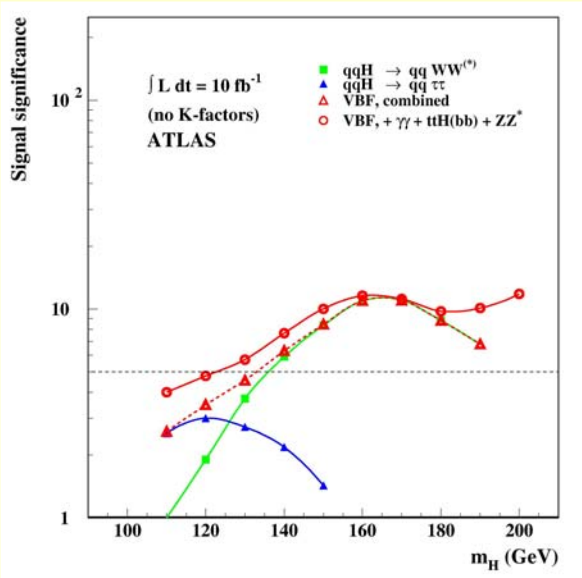
LHC Higgs boson discovery potential for 30 fb^{-1}

A. Korytov



- **Full mass range can already be covered after a few years at low luminosity (several channels available)**
- **Vector boson fusion channels play an important role**
- **Conservative estimates, but, the low mass region around 115 GeV/c^2 will not be easy**

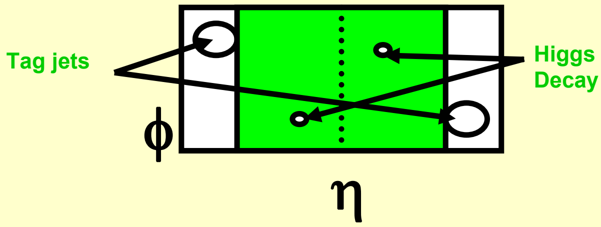
Combined significance of vector boson fusion (VBF) channels for 10 fb^{-1}



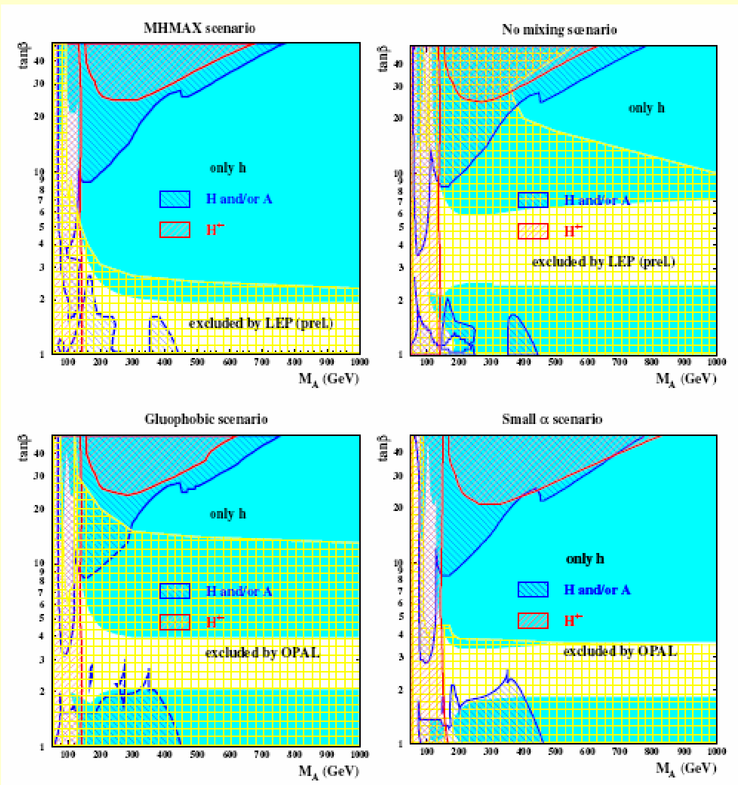
For 10 fb^{-1} in a single experiement (1 year -after t_0- at low luminosity):

5 σ significance for $120 \leq m_H \leq 190$ GeV/c^2

However: channels rely on
- forward jet tagging
- jet vetos in central detector region



MSSM discovery potential for various benchmark scenarios



A. Korytov

- Full parameter range can be covered with modest luminosity, 30 fb^{-1}, for all benchmark scenarios !
- Only one Higgs boson, h, in some regions (moderate tanβ – large m_A wedge)

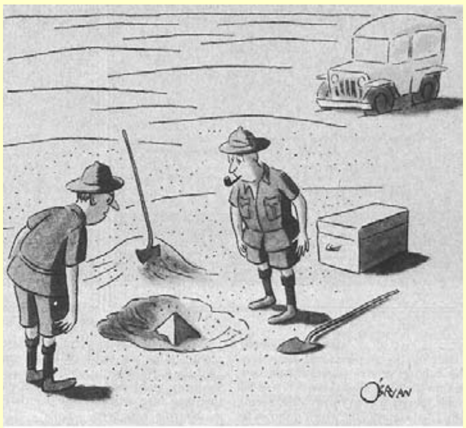
- valid if CP is conserved -

From the Tevatron to the LHC

In addition to measuring top quark properties, testing the Standard Model and making discoveries the Tevatron has a key role in:

Testing and validation of Monte Carlos
Transfer of knowledge on Object ID and Computing

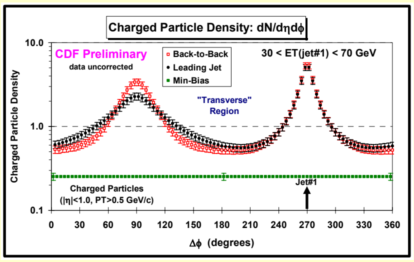
Certified Monte Carlos + reliable theoretical calculations at NLO, NNLO++….
will allow to minimize uncertainties on the backgrounds at the LHC



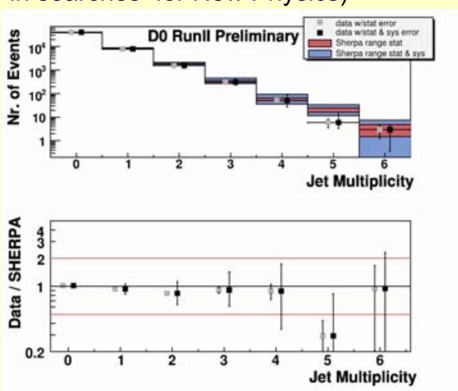
"This could be the discovery of the century. Depending, of course, on how far down it goes."

A few examples:

(i) Study of Minimum Bias Events
(important for LHC simulations, pile-up,…….)



(ii) Study of CKKW matching procedures
(important application: description of jet vetos in searches for New Physics)



(iii) Particle ID + analysis methods

- E/γ, μ identification
- Tau identification
- b tagging
- Jet energy scale calibration
- ………

numerous talks at this conference

(iv) Computing model

numerous talks at this conference

Changing Prospects for Higgs and SUSY ?

1985: No – Lose theorem
LHC will discover a Higgs boson and/or a Supersymmetric World

1995: Maybe SUSY will not be realized in its minimal version ….
(maybe there is NMSSM, no h with m_h below 130 GeV)

…. but we believe in SUSY (see e.g. J. Ellis, hep-ph 9503426)

negligible in this range. Similar sensitivity is to be expected in the CMS experiment [14]. Thus essentially all the parameter space of the MSSM allowed by naturalness arguments will be covered. If the LHC does not discover supersymmetry, we theorists will have to eat our collective hat.

2006: No discoveries at LEP-II and Tevatron (so far), Standard Model still rules !
Maybe SUSY is not realized as a *Low Energy SUSY* …..

"The SUSY-train is already a bit late….." (G. Altarelli)

New models: extra space time dimensions, …… including dark Higgs scenarios !
(e.g. J.van der Bij et al., Higgs boson coupled to a higher dimensional singlet scalar, hep-ph/0605008)

in the range $s^{1/2} > 100\,\mathrm{GeV}$. The data show a slight preference for a five-dimensional over a six-dimensional field. This Higgs boson cannot be seen at the LHC, but can be studied at the ILC.

Prospects for Higgs and SUSY (cont.)

LHC data are coming soon !

Do they want to escape ?

We are still here

United States Capitol Building, (Murals), Washington, DC

Let us follow "experimentalists saying":
"Never trust a theorist."

…. exploit the Tevatron and HERA

…. bring up the LHC
(still a huge experimental and theoretical effort)

…. *explore Terra Incognita*
which for us is the Tera-scale

…. *Let Nature speak*
and give guidance to theory

and give guidance to future experiments.

Before I really conclude,

I would like to thank
- our experimental and theory colleagues for producing such a wealth of material
- all speakers for the excellent talks

In addition, also on behalf of all speakers:

- Ashutosh Kotwal and the local organizing committee
  (Douglas Benjamin, Andrea Bocci, Mircea Coca, Al Goshaw, Mark Kruse, Berndt Mueller, Tom Phillips, Kate Scholberg, Chris Walter)
- Manuela Damian (conference secretariat)
- The scientific program committee
- Brookhaven, CERN, Duke University and Fermilab
- The US funding agencies DoE and NSF

for making this well-organized and high-quality meeting.

Conclusions

Hadron Colliders will play a crucial role in physics over the forthcoming years:

They can say the final word about

- The Standard Model Higgs mechanism

  and

- Low-energy SUSY and other TeV-scale predictions

and they will allow for huge progress in the flavour area (LHCb).

The results will most likely modify our understanding of Nature