Aspen Winter Physics Conference 2007

Theory (Summary) Talk

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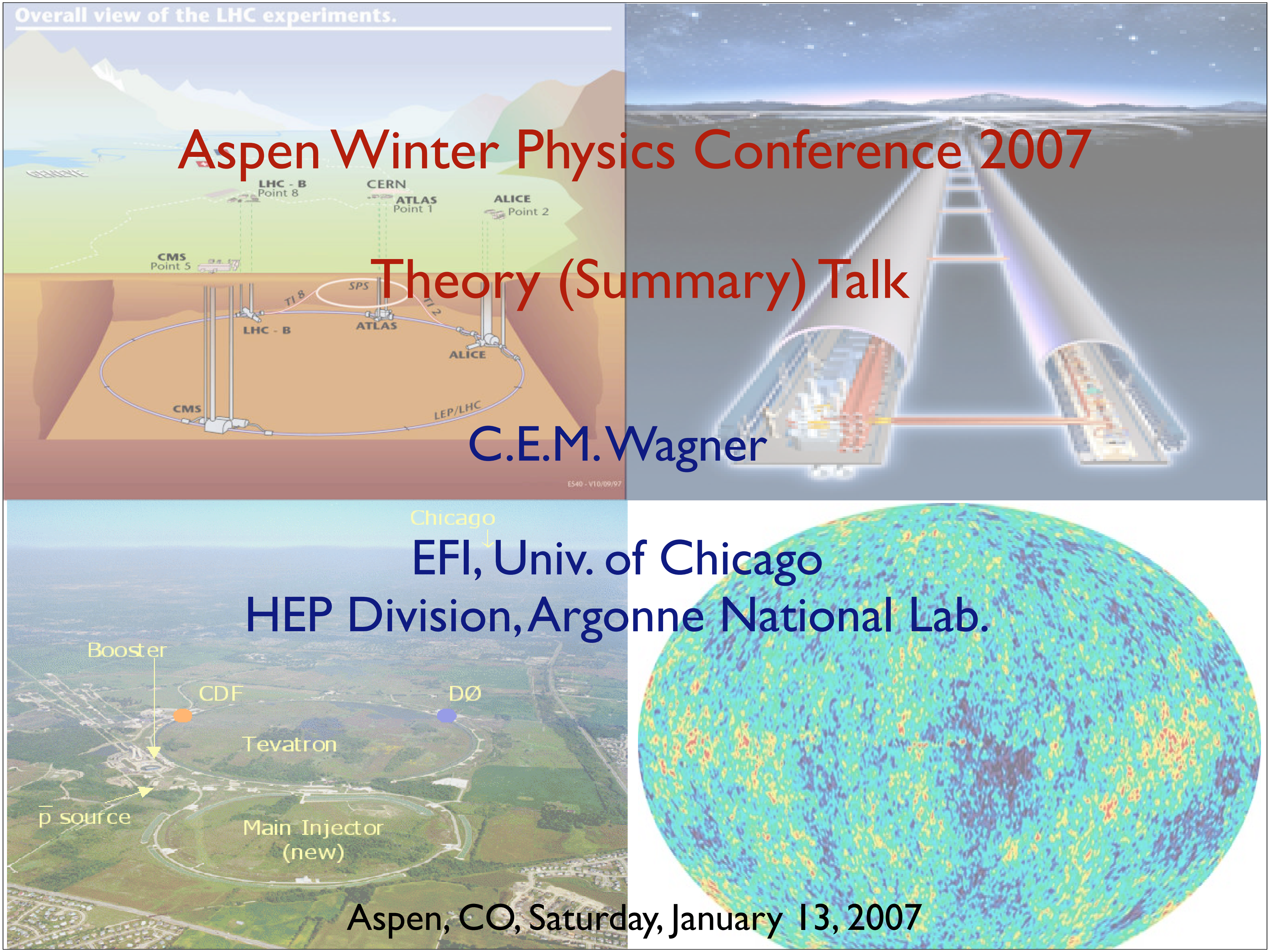
Aspen, CO, Saturday, January 13, 2007



The new High Energy Physics Framework

- High Energy Physics has provided an understanding of all data collected in low and high energy collider experiments

- Contrary to expectations, no signature of physics beyond the SM was observed at the LEP electron-positron collider and no large deviation is being observed at the Tevatron.

- However, there are two reasons to believe that there is new physics around the corner. One is related to particle physics, and the other to cosmology:

- Electroweak Symmetry Breaking

- Origin of Dark Matter

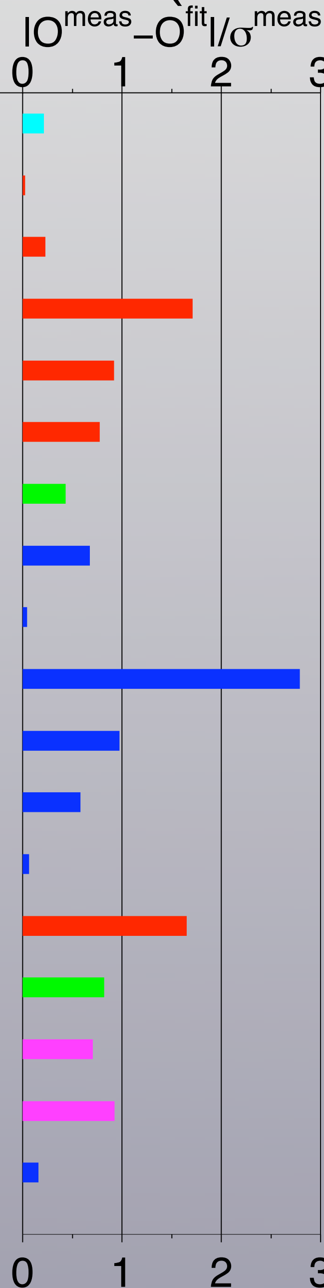
- The aim of high energy physics experiments is, in great part, to contribute to the understanding of these two questions. But of course, physics at the TeV scale may be there for unexpected reasons, which may look completely unmotivated based on what we know today.

Modern HEP Theory

- The main emphasis of these conference has been on hadron collider physics.
- On the theory side, mainly on the tools to comfront the new LHC era, which is about to start
- Topics included precision measurements, Higgs physics, QCD, top-quark physics, event generators as well as some specific signatures of well motivated models, as well as some apparently unmotivated ones
- The SM, which constitutes the basics for our understanding of physics (together with GR), reached maturity in the 1990's, with the precision tests on the electroweak observables

(from W. Skiba's talk)

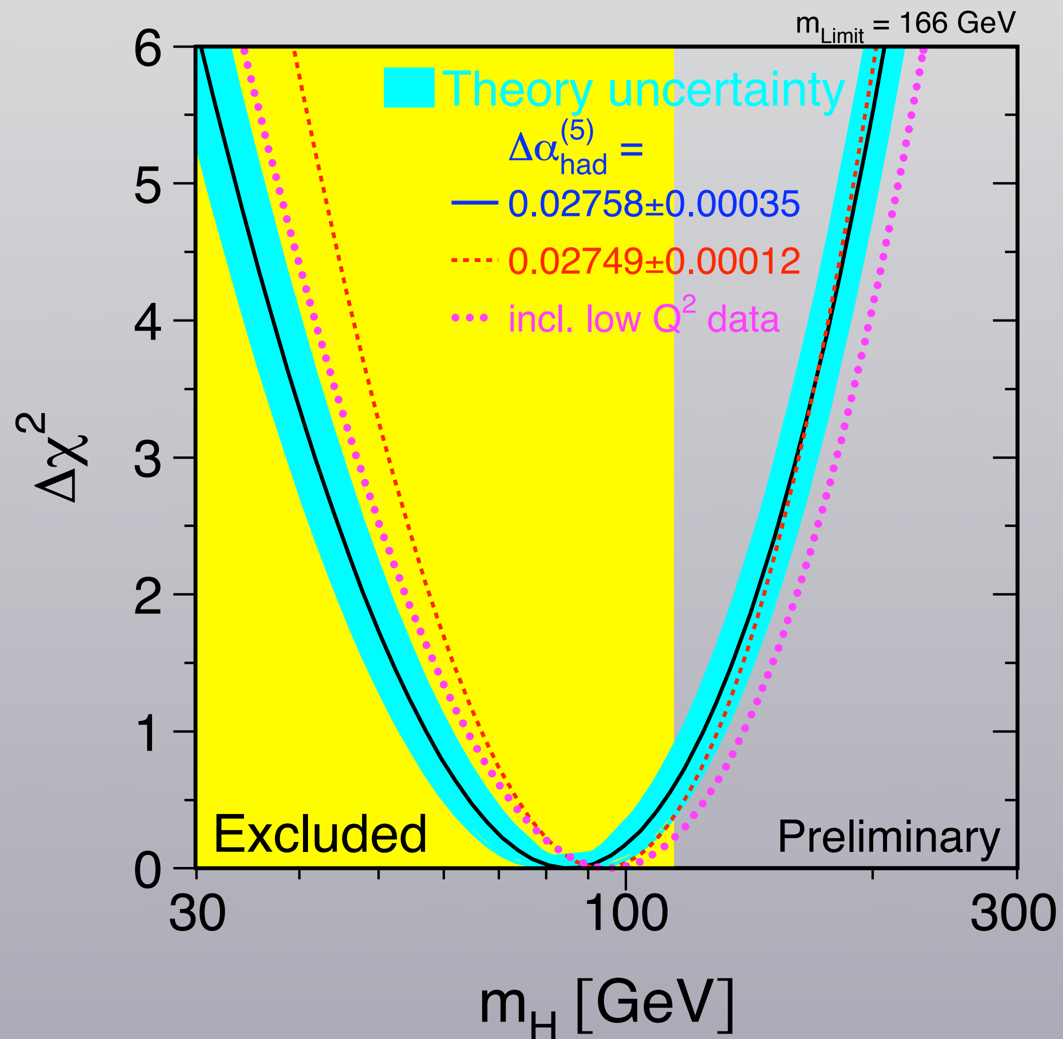
	Measurement	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02766
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957
σ_{had}^0 [nb]	41.540 ± 0.037	41.477
R_l	20.767 ± 0.025	20.744
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01640
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1479
R_b	0.21629 ± 0.00066	0.21585
R_c	0.1721 ± 0.0030	0.1722
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1037
$A_{fb}^{0,c}$	0.0707 ± 0.0035	0.0741
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1479
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.392 ± 0.029	80.371
Γ_W [GeV]	2.147 ± 0.060	2.091
m_t [GeV]	171.4 ± 2.1	171.7



Standard Model agrees with the data better than we hoped it would.

Two discrepancies larger than 2 sigma are F-B asymmetry in b production and NuTeV result for the weak angle.

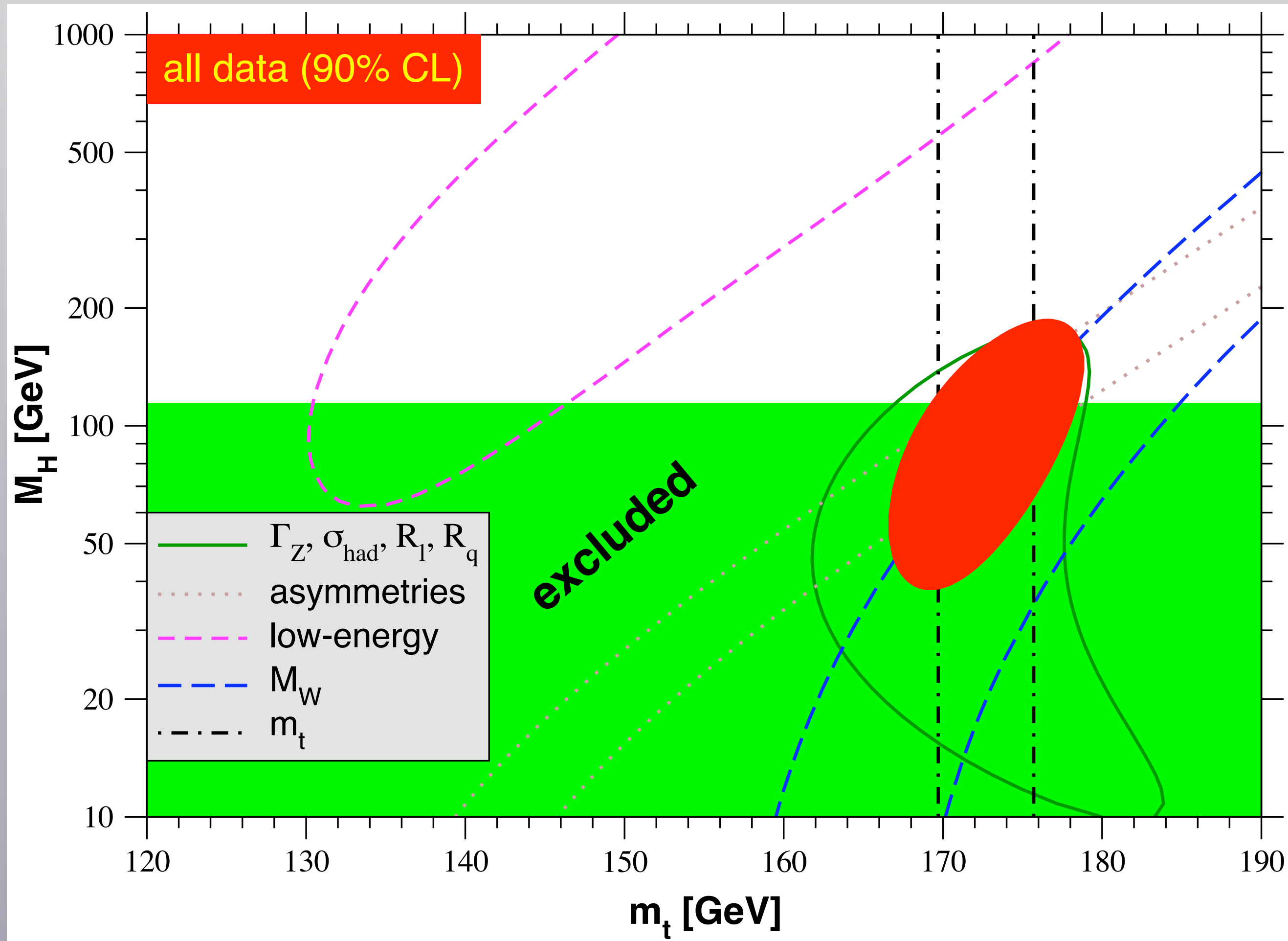
LEP Electroweak Working Group Summer '06



Assuming no new physics !

LEP Electroweak
Working Group
Summer '06

1) Light SM Higgs from Z line shape and cross sections alone
2) The NuTeV result pulls the fit towards larger Higgs mass



Erler, Langacker
PDG '06

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_i a_i O_i$$

- The coefficients a_i encode the dependence on the masses and couplings of the heavy fields.
- The operators O_i contain SM field only and are consistent with SM gauge symmetries and some global symmetries.

Buchmuller & Wyler, Nucl. Phys. B268 (1986) 621:
all operators of dimension 6 that preserve B, L
(80 such operators)

a) Higgs and gauge fields (2)

$$O_{WB} = (h^\dagger \sigma^a h) W^a_{\mu\nu} B^{\mu\nu} \quad O_h = |h^\dagger D_\mu h|^2$$

$$S = \frac{4scv^2}{\alpha} a_{WB} \qquad T = -\frac{v^2}{2\alpha} a_h$$

b) 4 fermions (11+10)

$$O_{ff} = (\bar{f} \gamma^\mu f)(\bar{f} \gamma_\mu f)$$

e.g. $O^s_{lq} = (\bar{l} \gamma^\mu l)(\bar{q} \gamma_\mu q)$ $O^t_{lq} = (\bar{l} \gamma^\mu \sigma^a l)(\bar{q} \gamma_\mu \sigma^a q)$

c) 2 fermions, Higgs, and gauge fields (7+6)

$$O_{hq} = i(h^\dagger D^\mu h)(\bar{f} \gamma_\mu f) + \text{h.c.}$$

e.g. $O^t_{hl} = i(h^\dagger \sigma^a D^\mu h)(\bar{f} \gamma_\mu \sigma^a f) + \text{h.c.}$

d) gauge fields only (1)

$$O_W = \epsilon^{abc} W^{a\nu}_\mu W^{b\lambda}_\nu W^{c\mu}_\lambda$$

$$\chi^2 = \chi^2_{min} + (a_i - \hat{a}_i)\mathcal{M}_{ij}(a_j - \hat{a}_j)$$

$\mathcal{M}_{ij}$ only depends on the experimental errors, and would change if precision of the data improves

$\hat{a}_i$ depend on the SM predictions, central values of observables, and experimental errors

This provides a generaliztion of the S, T, U framework and is easy to use in any BSM theory.

Application to Gauge-Higgs Unification models

M. Carena, E. Ponton, J. Santiago, C.W. '07

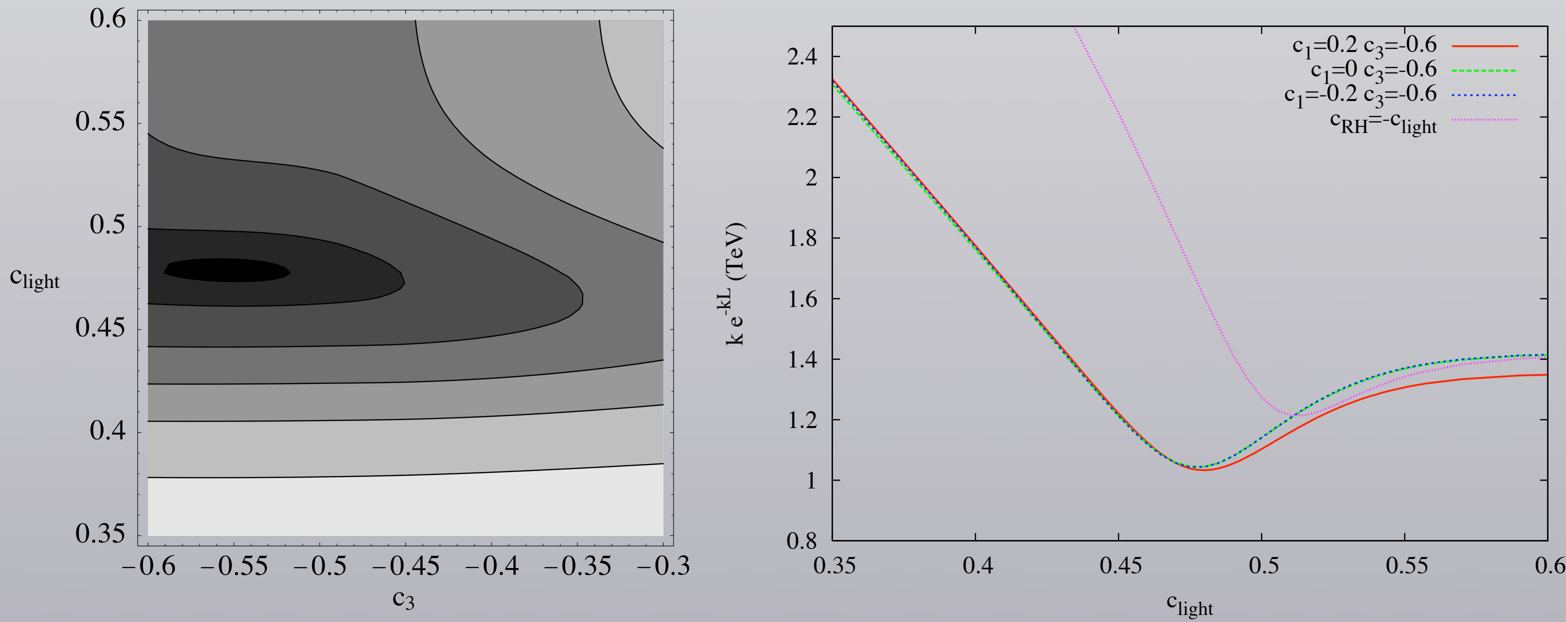


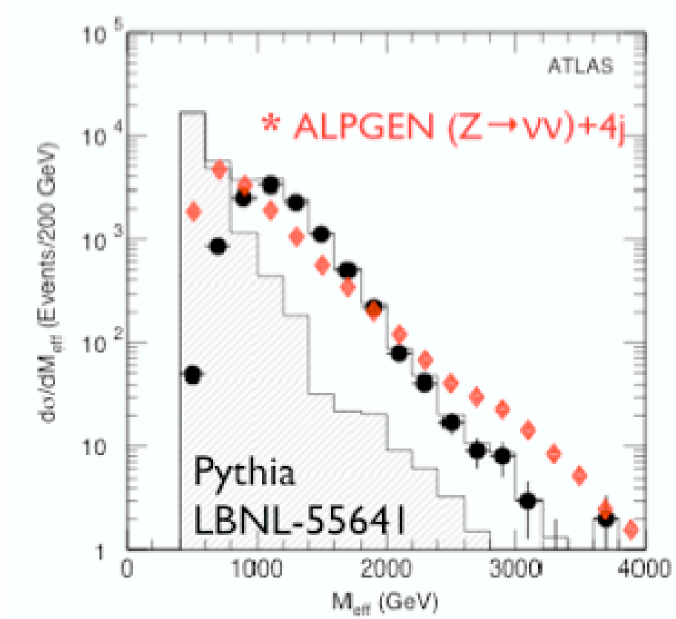
FIG. 2: Lower bound on $\tilde{k} = k\,e^{-kL}$ as a function of c_3 and $c_{\rm light}$ for fixed $c_1 = 0.2$ and $c_{\rm RH} = -0.6$ (left panel). The different contours, from dark to light, correspond to $\tilde{k} = 1030, 1100, 1300, 1500, 1700$ and 2000 GeV, respectively. The minimum is $\tilde{k}_{\rm min} = 1$ TeV, corresponding to $c_3 \approx -0.55$ and $c_{\rm light} \approx 0.48$. In the right panel we show the lower bound on $\tilde{k}$ as a function of $c_{\rm light}$ for fixed $c_{RH} = c_3 = -0.6$ and three values of c_1. We also show the lower bound on $\tilde{k}$ for $c_1 = 0.2$ and $c_3 = -0.6$, assuming $c_{\rm RH} = -c_{\rm light}$. The mass of the first gauge KK modes is $m^{\rm gauge} \approx 2.5\,\tilde{k}$.

QCD

Frank Petriello's message:

- Need more work on QCD tools for LHC physics!
  - Need fixed order QCD+resummation to verify, improve MC generators
  - Must accurately quantify, reduce uncertainties; test at HERA, Tevatron
- Highlights:
  - Test of ME+PS merging on Tevatron Z+jets
  - $pp \to WW$ background shows importance of NLO signal, background calculations $\Rightarrow$ also interplay between higher orders and experimental cuts
  - Theory progress on automated NLO coming! First result: $pp \to Hjj$ for HWW coupling determination
  - Di-photon results from Tevatron show importance of careful QCD analysis: resummation, fragmentation needed to describe all regions of phase-space
  - Differential W, Z result at NNLO with spin correlations for acceptances
    - Tested on Tevatron data, potential pdf implications
    - Tevatron luminosity analysis?
- Challenging and important work to do!

SUSY searches and PYTHIA



Mangano et al. hep-ph/0504221

- $\mathrm{M_{eff}} = \sum_j p_\perp^j + E_\perp^{\mathrm{miss}}$: standard SUSY discriminator
- ALPGEN: exact LO matrix elements, correct hard emissions
- PYTHIA: extra jets generated via parton shower

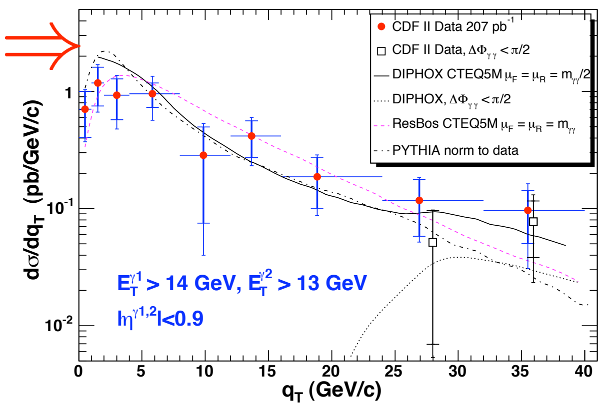
⇒ Without tuning, PYTHIA does not describe multiple hard emissions well

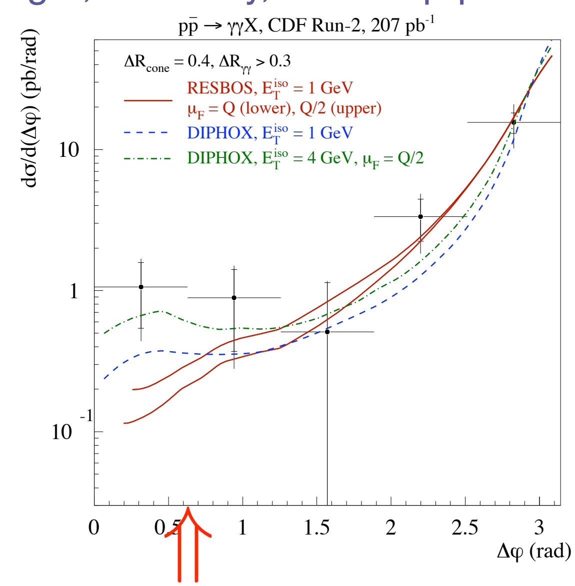
Moral

- Moral: need systematic, controlled QCD expansion
  - pQCD expansion in α_s augmented with necessary resummation
  - Verify and improve Monte Carlo tools
- Issues to consider:
  - Is the kinematics described correctly? Hard jets, azimuthal correlations require matrix elements; multiple soft/collinear emissions better described by parton showers
    $\Rightarrow$ full phase-space coverage requires merging parton-shower with multi-parton tree-level (CKKW)
  - What is the correct normalization, and what is its uncertainty?
    $\Rightarrow$ requires $\mathrm{N^nLO}$ fixed-order calculations
  - Do new qualitative effects like the gluon pdf (large at the LHC) appear at higher orders?
  - Have kinematic boundaries where resummation may be required been considered?

Di-photon production

- $pp \to \gamma\gamma$ important for Higgs discovery and measurements
  - Many subtle effects to include in background calculation:
    - $gg \to \gamma\gamma$ subprocess formally NNLO but large
    - Resummation for low $q_T^{\gamma\gamma}$ (Balazs, E. Berger, Nadolsky, Yuan hep-ph/0603037)
    - Fragmentation $q \to \gamma$ important at $q_T^{\gamma\gamma} > Q$, low $\Delta\phi$

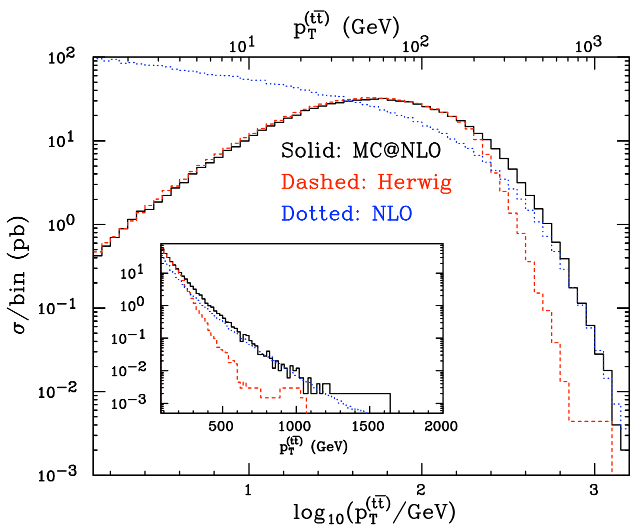




  - Resummation only in RESBOS; large sensitivity to tuneable parameters in DIPHOX fragmentation $\Rightarrow$ do we really understand low $\Delta\phi$ region?
  - Need better understanding, especially when $1\ \mathrm{fb}^{-1}$ is analyzed

Combining NLO with parton showers

- Fixed order, parton showers complimentary
  - PS: universal, hadronization,detector simulation
  - FO: correct rates, hard emissions, reduced and quantifiable errors
  - ⇒ want the advantages of both approaches!



- MC@NLO (Frixione, Webber)
- Smoothly matches soft/collinear (MC) and hard (NLO) regions
- Unweighted events, NLO normalization
- Available for $W, Z, H, \gamma^*, b\bar{b}, t\bar{t}, WW, ZZ, WZ, tb$

- Recent detailed study for LHC top production (Mangano et al. hep-ph/0611129)
- Work on alternate implementations (Giele, Skands; Bauer, Schwartz)

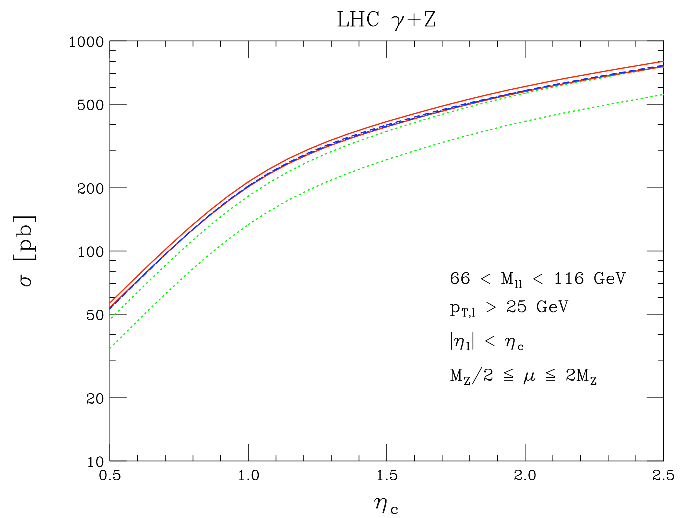
Status of NNLO calculations

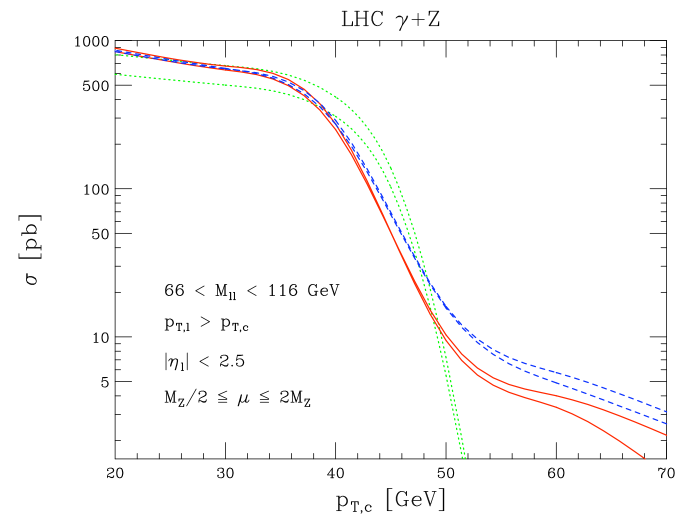
- When is NNLO needed?
  - When corrections are large (H production, fixed target energies for pdfs)
  - For benchmark measurements, where expected errors are small ($W, Z, t\bar{t}$ production)
- What is known?
  - Several inclusive $2 \to 1$ processes (W, Z, H production)
    (van Neerven, Harlander, 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)

$\Rightarrow$ Generalization to $2 \to 1$ processes ($pp \to jj, t\bar{t}$) very difficult

Results at NNLO

- NNLO QCD result for W, Z production (Melnikov, FP hep-ph/0609070)
  - Contains spin correlations, finite-width effects, $\gamma - Z$ interference, all kinematics





  - Residual scale dependences $< 1\%$ for standard cuts
  - Comparison with recent CDF result for forward W production; take ratio of $|\eta_e| < 1$ over $1 < |\eta_e| < 2.8$
    $R^{CDF}_{c/f} = 0.925(33)$; $R^{NLO}_{c/f} = 0.940(12)$; $R^{NNLO}_{c/f} = 0.927(2)$

$\Rightarrow$ potential stringent constraint on pdfs with more data

Modern Event Generators

(from P. Skanks presentation)

BR: Beam Remnant

CR: Colour Reconnection

FSR: Final-State Radiation

ISR: Initial-State Radiation

Matching: Combining PS & ME consistently (e.g. CKKW, MLM)

ME: Matrix Element

MI: Multiple parton-parton Interactions (not pile-up)

PS: Parton Shower

PT: Perturbation Theory

Tune: A set of generator parameters

UE: Underlying Event

– Specialized tools for calculating higher fixed orders (and BSM processes) plus **matching techniques**

➔ hard subprocess (and to some extent resonance decays) increasingly handled by separate codes (LO … N^nLO)

➔ Need universal interfaces and standards

[e.g. the Les Houches Accords **(Les Houches 2007: Jun 11-29, France)**]

MC4LHC `06: "A standard format for Les Houches Event Files" - **hep-ph/0609017**

➔ Entering era of precision event generators for hadron colliders

– **Beyond fixed order**

Better understanding of PS uncertainties – À LA ERROR PDF'S?

Improved PS formulations – MORE CONSISTENT, MATCHING TO N^nLO, RESUMMATION OF HIGHER LOGS & SMALL-X EFFECTS (BFKL), …

Better understanding of the underlying event and non-perturbative effects - ESPECIALLY IN THE BUSY ENVIRONMENT OFFERED BY LHC

Matching

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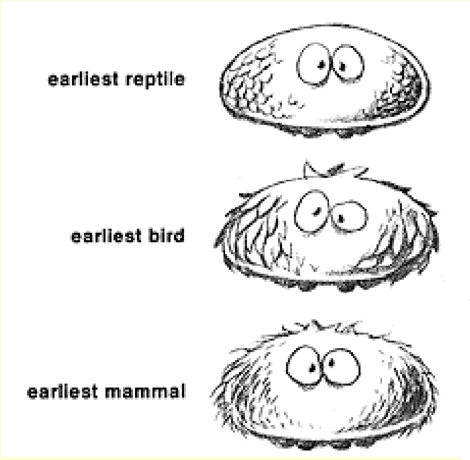
– Matching of up to one hard additional jet
  - PYTHIA-style (reweight shower)
  - HERWIG-style (add separate events from ME: weight = ME-PS)
  - MC@NLO-style (ME-PS subtraction similar to HERWIG, but NLO)

– Matching of generic (multijet) topologies:
  - ALPGEN-style (MLM)
  - SHERPA-style (CKKW)
  - ARIADNE-style (Lönnblad-CKKW)
  - PATRIOT-style (Mrenna & Richardson)

– Brand new approaches (still in the oven)
  - Refinements of MC@NLO (Nason)
  - CKKW-style at NLO (Nagy, Soper)
  - SCET approach (based on SCET – Bauer, Schwarz, SEE BAUER'S TA
  - VINCIA (based on QCD antennae – Giele, Kosower, PS, THIS TALK)



Evolution

C++ Players

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– **HERWIG++: complete reimplementation**
  - Improved PS and decay algorithms
  - Eventually to include CKKW-style matching ?
  - B.R. Webber; S. Gieseke, D. Grellscheid, A. Ribon, P. Richardson, M. Seymour, P. Stephens, . . .

– **SHERPA: complete implementation, has CKKW**
  - ME generator + wrappers to / adaptations of PYTHIA, HERWIG
  - F. Krauss; T. Fischer, T. Gleisberg, S. Hoeche, T. Laubrich, A. Schaelicke, S. Schumann, C. Semmling, J. Winter

– **PYTHIA8: selective reimplementation**
  - Improved PS and UE, limited number of hard subprocesses
  - Many obsolete features not carried over → simpler, less parameters
  - T. Sjöstrand, S. Mrenna, P. Skands

PYTHIA 8

[BR:]{.underline} Beam Remnant

CR: Colour Reconnection

FSR: Final-State Radiation

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Matching: Combining PS & ME consistently (e.g. CKKW, MLM)

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UE: Underlying Event

Basic generator already there

Includes a few processes (+ full Pythia6 library), new p_T-ordered showers, new UE, Les Houches interfaces, and more

You are invited to try it out

Click /future/ on the Pythia homepage, download pythia8070.tgz, follow instructions in readme (./configure, ./make, and have fun)

Still not advised for production runs

If you have suggestions, *now* is the time!

Timeline:

Spring 2007: QED showers, LHAPDF, interleaved FSR, beam remnants, colour reconnections → useful

Fall-Winter 2007: resonance decays, GUI, **official release?**

Particle Distribution Functions

Saturation of the Froissart bound

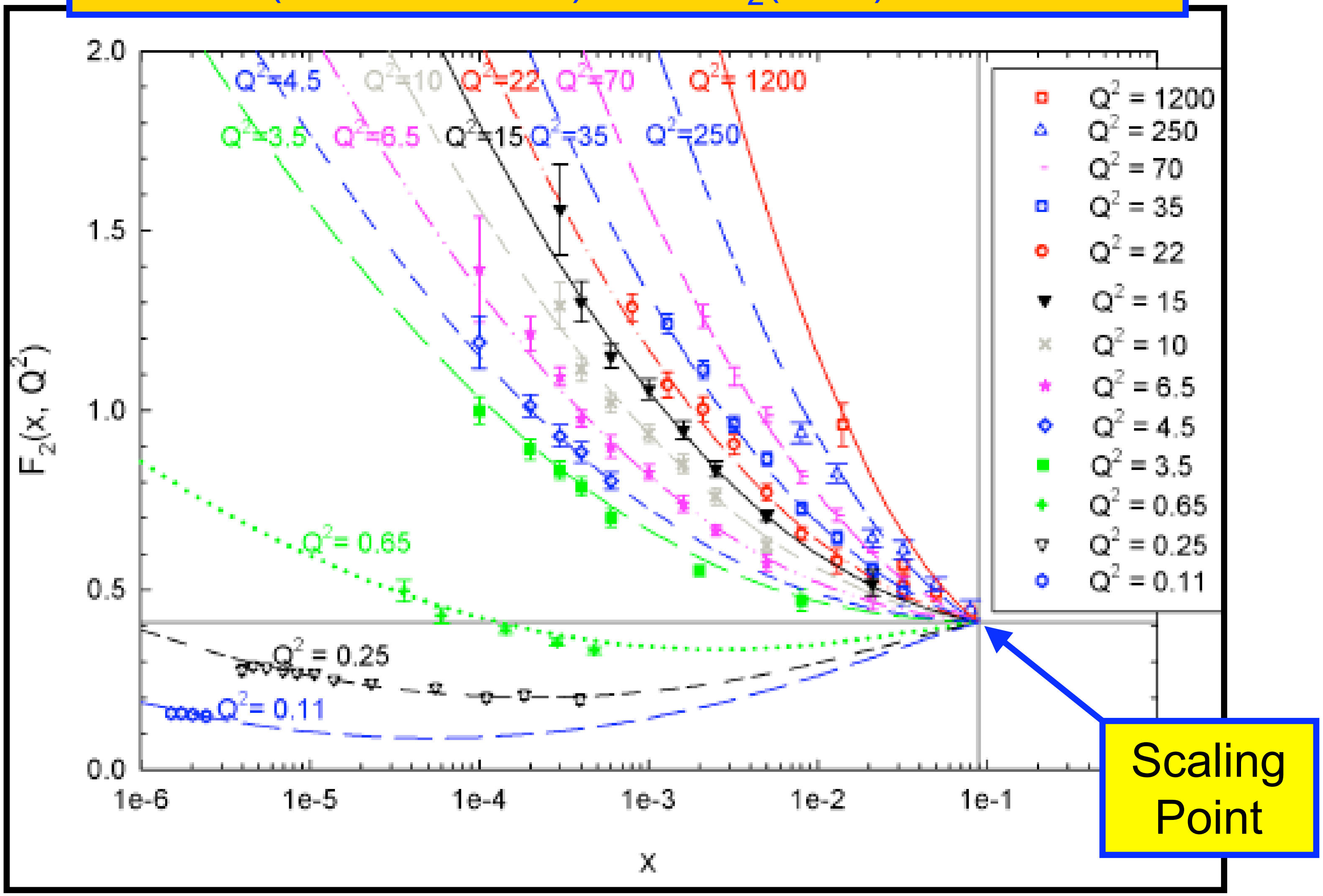
We choose to work in terms of a dimensionless "reduced" $\gamma^* p$ cross section, $\sigma^{\rm tot}_{\gamma^* p}(W, Q^2)/\kappa$, where $\kappa \equiv 4\pi^2\alpha/Q^2$. We write the reduced cross section as

$$\sigma^{\rm tot}_{\gamma^* p}(W, Q^2)/\kappa = A + \beta \ln^2 \frac{s}{s_0} + cs^{-0.5}.$$

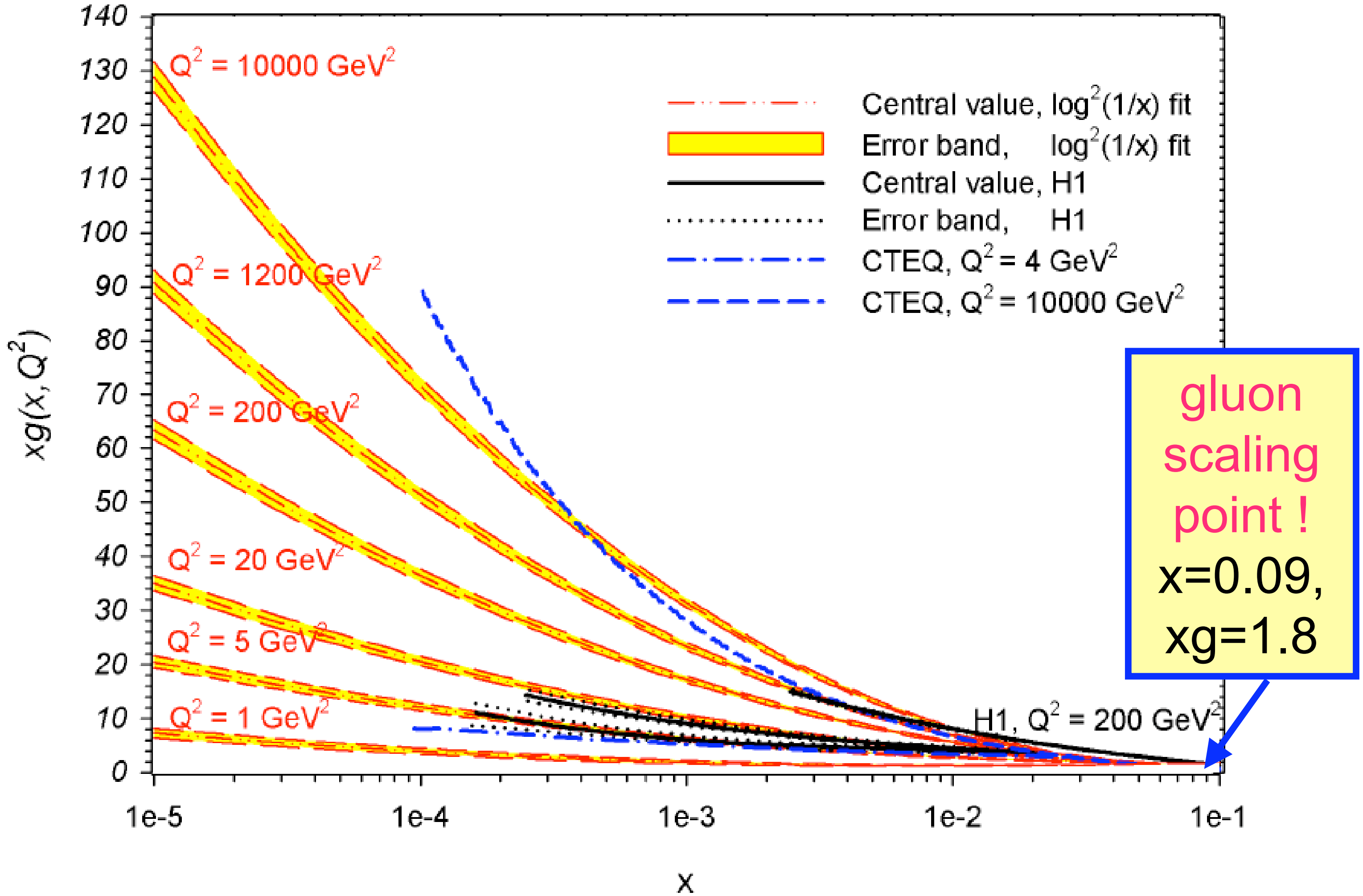
The 4 coefficients A, β, s_0, and c are functions of Q^2. We present fits to 29 data sets published by the ZEUS collaboration , for $Q^2 = 0.11$, 0.20, 0.25, 0.65, 2.7, 3.5, 4.5, 6.5, 8.5, 10, 12, 15, 18, 22, 27, 35, 45, 60, 70, 90, 120, 150, 200, 250, 350, 450, 650, 800, and 1200 GeV^2.

In order to avoid possible normalization differences, we have not included H1 data in our analysis, although preliminary examination of the combined data sets leads us to identical physics conclusions.

Global (Simultaneous) Fit of $F_2(x,Q^2)$ to x and Q^2



NLO Gluon Distributions, $xg(x,Q^2)$



Higgs

Sally Dawson emphasizes:

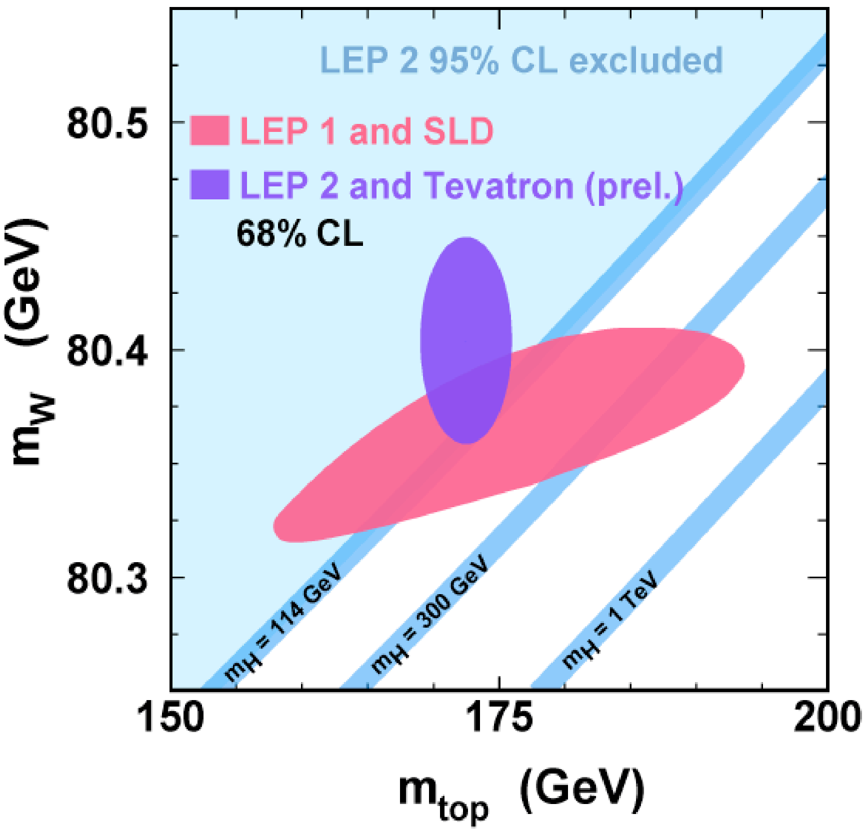
Standard Model is Incomplete Without Something like a Higgs boson

- Requires physical, scalar particle, h, with unknown mass
  - M_h is ***ONLY*** unknown parameter of EW sector
- Observables predicted in terms of:
  - M_Z=91.1875 ± .0021 GeV
  - G_F=1.16639(1) x 10^{-5} GeV^{-2}
  - α=1/137.0359895(61)
  - M_h
- Higgs and top quark masses enter into quantum corrections
  - $\approx M_t^2$, log (M_h)

Everything is calculable….***testable theory***

Quantum Corrections Sensitive to Higgs Mass

- Direct observation of W boson and top quark (blue)
- Inferred values from precision measurements (pink)

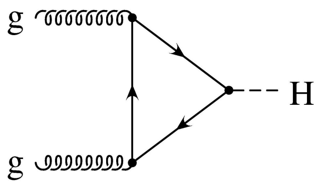


New from ICHEP, 2006

Production can be very different from SM

- Example #1: Generalized operators
  - Dimension 6 operator:

$$L_{6g} = \frac{f_g}{\Lambda^2} \Phi^+ \Phi G_{\mu\nu}{}^a G^{\mu\nu\, a}$$



  - Expand around vacuum: $\phi^0 \to \frac{(h+v)}{\sqrt{2}}$
  - Generate interaction

$$L_{6g} = \frac{f_g v}{\Lambda^2} h G_{\mu\nu}{}^a G^{\mu\nu\, a}$$

  - For heavy top quark, the SM hGG interaction is well approximated by

$$L_{6g} = \frac{\alpha_s}{x\pi v}\left(1 + \frac{11\alpha_s}{4\pi}\right) h G_{\mu\nu}{}^a G^{\mu\nu\, a}$$

  - New operator is just arbitrary enhancement or suppression of gg→h production rate

$$\sigma \to \sigma_{SM}\left(1 + \frac{36\pi}{\alpha_s} f_g \left(\frac{v}{\Lambda}\right)^2\right)$$

eg. Manohar and Wise, hep-ph/0601212

Higgs Production can be suppressed

- Example #3
  - Add a single real scalar *S* to the standard model
  - *S* carries no charge and couples to nothing except the Higgs, through the potential

    $$V(H,S) = -\mu^2|H|^2 + \lambda|H|^4 + \eta S^2 H^2 + m_s^2 S^2 + \kappa S^4$$
  - Physical particles are linear combination of h, s

    $$\phi_1 = h\cos\gamma + s\sin\gamma \; ; \phi_2 = s\cos\gamma - h\sin\gamma$$
  - Higgs branching ratios are $BR_{SM} \cdot \sin^2\gamma$
  - If $m_1 > 2\, m_2$, new decay channel:

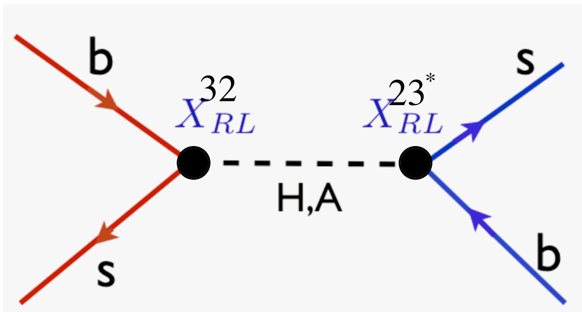
    $\varphi_1 \rightarrow \varphi_2\, \varphi_2 \rightarrow$ (bb)(bb), (bb)($\tau^+\tau^-$), ($\tau^+\tau^-$)($\tau^+\tau^-$)

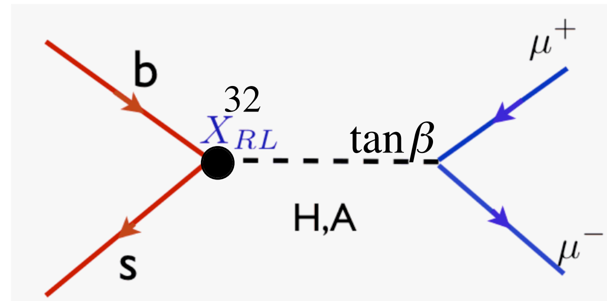
Some examples of Higgs physics beyond the SM and its experimental consequences

MSSM-- from M. Carena's talk

Correction between Bs mixing and $\mathrm{BR}(B_S \to \mu^+\mu^-)$

due to $\tan\beta$ enhanced Higgs mediated flavor violating effects





$$\left(\Delta M_{B_S}\right)^{SUSY} \propto \ominus \frac{X_{RL}^{32} X_{LR}^{32}}{m_A^2}$$

Negative sign with respect to SM

$$BR(B_S \to \mu^+\mu^-)^{SUSY} \propto \frac{\left|X_{RL}^{32}\right|^2 \tan\beta^2}{m_A^4}$$

- SUSY contributions strongly correlated, and for Minimal Flavor Violation

$$\frac{\Delta M_{B_S}}{BR(B_S \to \mu^+\mu^-)} \propto \frac{m_A^2}{\tan\beta^2}$$

to maximize $\Delta M_{B_S}^{DP}$ for a given value of $\mathrm{BR}(B_S \to \mu^+\mu^-)$ $\Leftrightarrow$ minimize $\tan\beta$ (for fixed m_A)

$\Rightarrow$ choose large, negative values of ε_0 and ε_Y (large implies $\mu \approx M_{\tilde{g}} \approx 2M_{\tilde{q}} \approx \frac{2}{3}A_t$)

What can we learn from Bs-mixing?

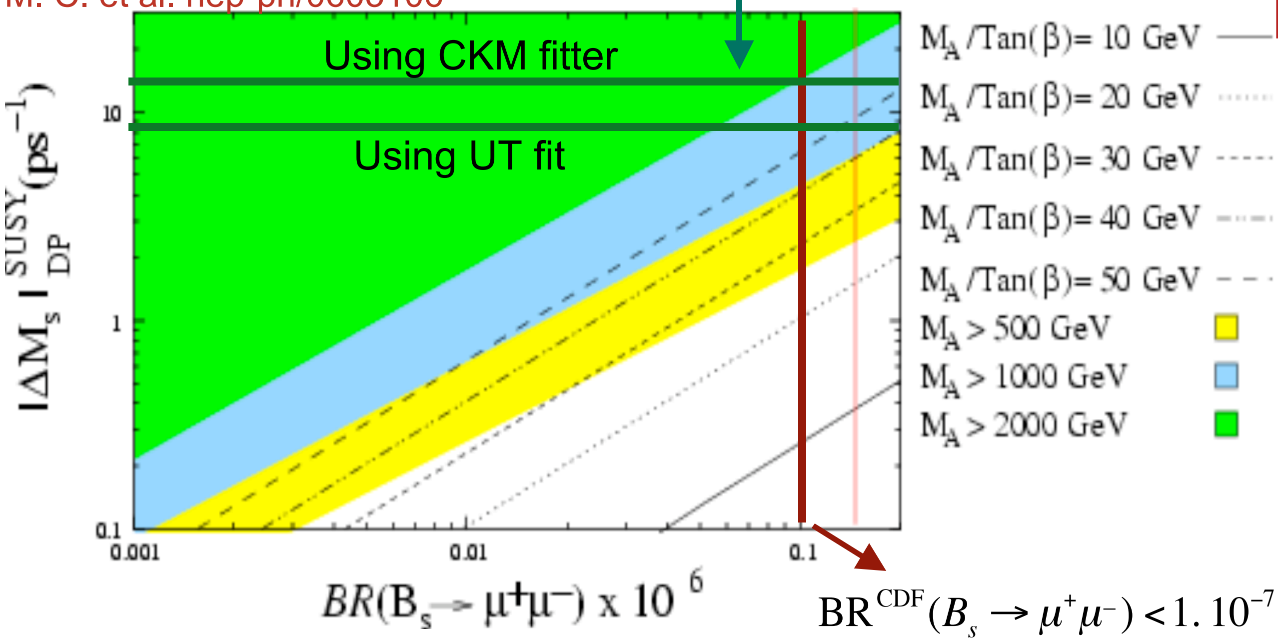
How strong is the bound on $\mathrm{BR}(B_s \to \mu^+\mu^-)$?

Upper bound on NP from CDF ==> $\Delta M_S = 17.7 \pm 0.10 \pm 0.07\, ps^{-1}$

$\Delta M_S^{CKM} = 18.9^{+12.2}_{-5.5}\, ps^{-1}$

$\Delta M_S^{UT} = 20.9 \pm 5.2\, ps^{-1}$

M. C. et al. hep-ph/0603106



$\mathrm{BR}^{\mathrm{CDF}}(B_s \to \mu^+\mu^-) < 1.\,10^{-7}$

$\mathrm{BR}(B_s \to \mu^+\mu^-)_{SM}$ of order 10^{-9}

at the reach of LHC with about $10 fb^{-1}$

SUSY corrections can enhance it by 2 orders of magnitude.

For natural values of $m_A < 1000$ GeV ==> largest contributions at most a few ps-1

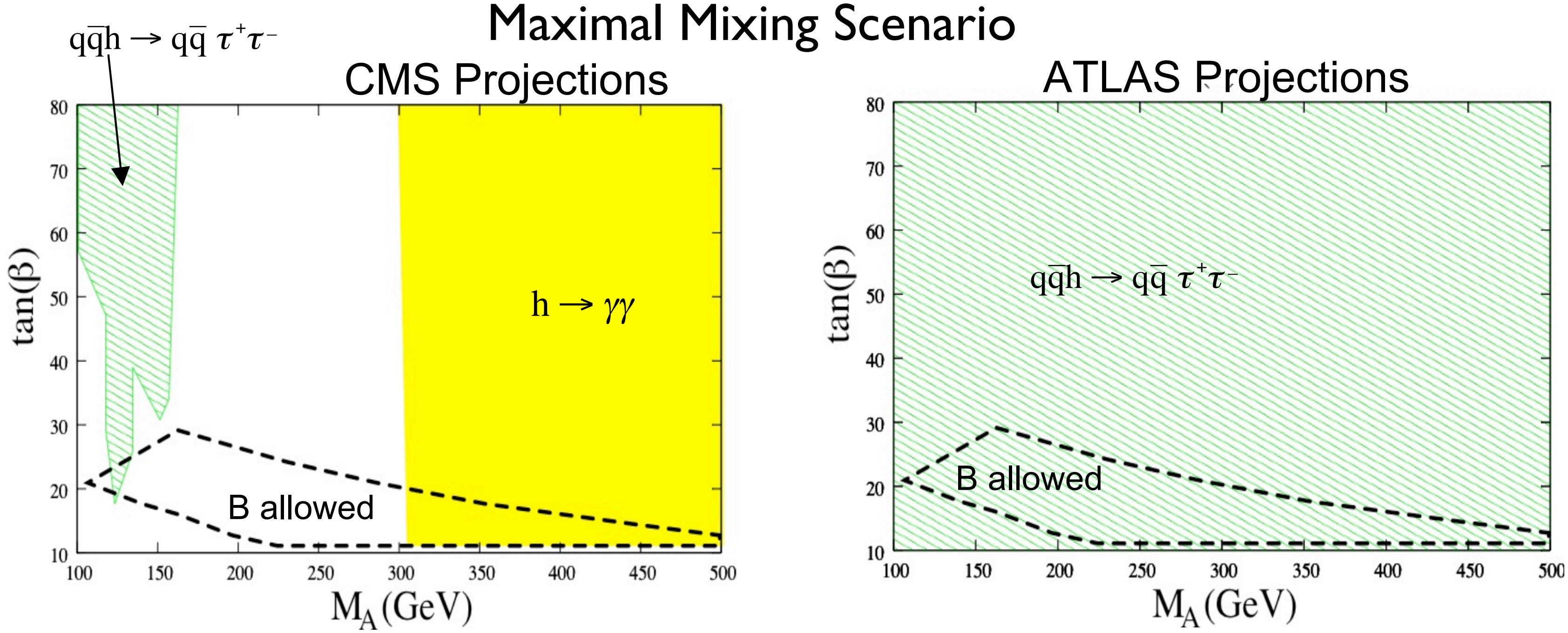
A/H at the reach of the Tevatron or the LHC <==> strong constraints on $|\Delta M_S|^{\mathrm{SUSY}}_{\mathrm{DP}}$

Discovery reach for SM-like MSSM Higgs at the LHC with 30 fb-1

•The m_h^{max} scenario: $M_S = 1$ TeV ; $X_t = 2.4\ M_S$; $m_{\tilde{g}} = 0.8\ M_S$; $M_2 = -\mu = 200$GeV; $A_t = A_b$

Production and decay channels: $t\bar{t}h\ (h \to b\bar{b})$; $q\bar{q}h \to q\bar{q}\ \tau^+\tau^-$ and $h \to \gamma\gamma$ inclusive

Maximal Mixing Scenario



M.C., A. Menon, C. Wagner' 07

CMS: First, full simulation analysis of qqH, H->ττ->l+jet Nikitenko, ICHEP 06

Optimized ==>NN with kinematics and γ isolation as input

ATLAS: re-doing the Higgs studies at present

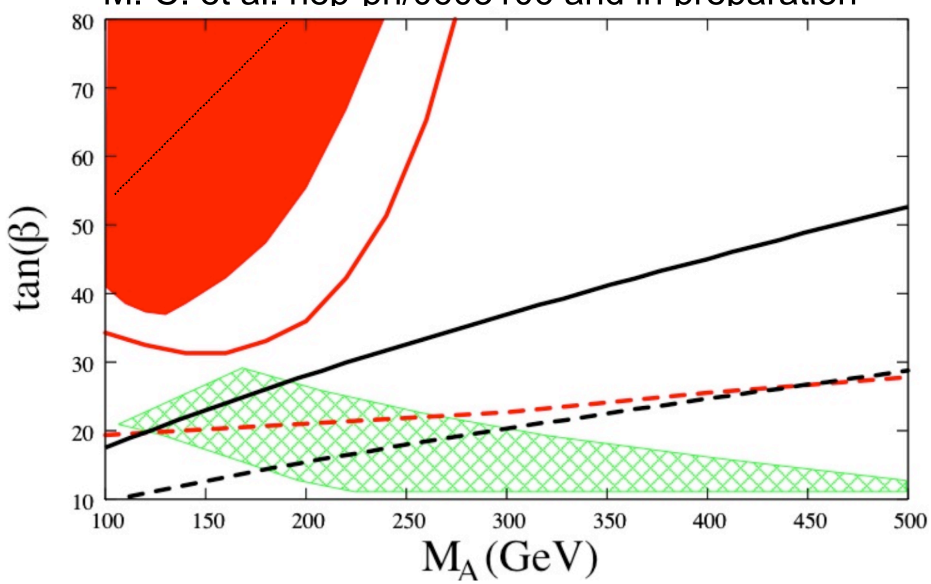
Non-SM-like Higgs and B Physics Searches

<u>Large to moderate values of X_t</u> ==> SM like Higgs heavier than 120 GeV

$BR(B_S \to \mu^+\mu^-) \propto |\mu A_t|^2 \Rightarrow$ Experimental bound ==> small μ

Small $\mu < 0$ ==> $\cong$ constant H^+ and enhanced negative $\chi^+ - \tilde{t}$ contributions to $BR(b \to s\gamma)$

M. C. et al. hep-ph/0603106 and in preparation



Red: $p\bar{p}, pp \to H/A \to \tau^+\tau^-$
with 1 and 4 fb^{-1} at the Tevatron
with 30 fb^{-1} at the LHC

black lines: $BR(B_s \to \mu^-\mu^+)$ reach:

Tevatron: 2×10^{-8} ($8 fb^{-1}$)

LHC: 5.5×10^{-9} ($10 fb^{-1}$)

Hatched Area: presently allowed
$BR(B_u \to \tau\nu)$, $BR(b \to s\gamma)$
and $BR(B_S \to \mu^+\mu^-)$ regions

M.C., A. Menon, C.Wagner' 07

- Sizeable LR stop mixing <==> small/moderate mu

  ==> **B searches more powerful than Non-SM like Higgs searches**

- **SM-like Higgs:** small Tevatron coverage; with 30fb^{-1}: CMS can cover some parts, with $h \to \tau\tau$ and $h \to \gamma\gamma$; ATLAS tau tau channel seems to have full coverage

Jack Gunion told us

My bias:
The combination of:

1. **the precision electroweak preference for a SM-like Higgs with $m_h \sim 100$ GeV,**
2. **the old LEP excess (at reduced rate) at this mass in the $b\bar{b}$ channel,**
3. **the fact that supersymmetric models evolved to the GUT scale have minimal fine-tuning for such a mass**

all combine to suggest that $h \to pp$ where p then decays in some way that evades the LEP $m_h > 114$ GeV bound may be what LHC should be looking for.

There are many possibilities for p and how it decays with $p =$ a pseudoscalar and $p =$ a neutralino or other light SUSY particle being prominent on the list.

p decays can be constructed in both cases to avoid LEP limits and make LHC discovery very difficult.

- **The NMSSM** allows you to have your cake and eat it too.

  Recall that the NMSSM introduces a singlet superfield that leads to an extra CP-even Higgs and an extra CP-odd Higgs: we end up with the mixed states $h_{1,2,3}$ and $a_{1,2}$.

  The NMSSM has the following wonderful properties:

  - Gauge coupling unification is preserved under singlet addition.
  - RGE breaking of electroweak symmetry is preserved.
  - An effective $\mu \widehat{H}_d \widehat{H}_u$ superpotential term is automatically from the $\lambda \widehat{S} \widehat{H}_d \widehat{H}_u$ NMSSM superpotential term: $\mu_{\rm eff} = \lambda \langle S \rangle$.
    There is also a $\frac{1}{3} \kappa \widehat{S}^3$ superpotential term.
  - Once again minimal fine-tuning is achieved for a SM-like h_1 with $m_{h_1} \sim 100~{\rm GeV}$, but now this is LEP allowed provided $h_1 \to a_1 a_1$ with $m_{a_1} < 2m_b$ is the dominant decay. If $m_{a_1} > 2m_b$, then $h_1 \to a_1 a_1$ also feeds the $Z + b's$ channel that is strongly constrained by LEP data.
    In fact, large $B(h_1 \to a_1 a_1)$ with small m_{a_1} can be arranged without significant tuning of the A_λ and A_κ soft parameters. Some preference is shown for $m_{a_1} > 2m_\tau$ for this. (R. Dermisek and J. F. Gunion, arXiv:hep-ph/0611142.)

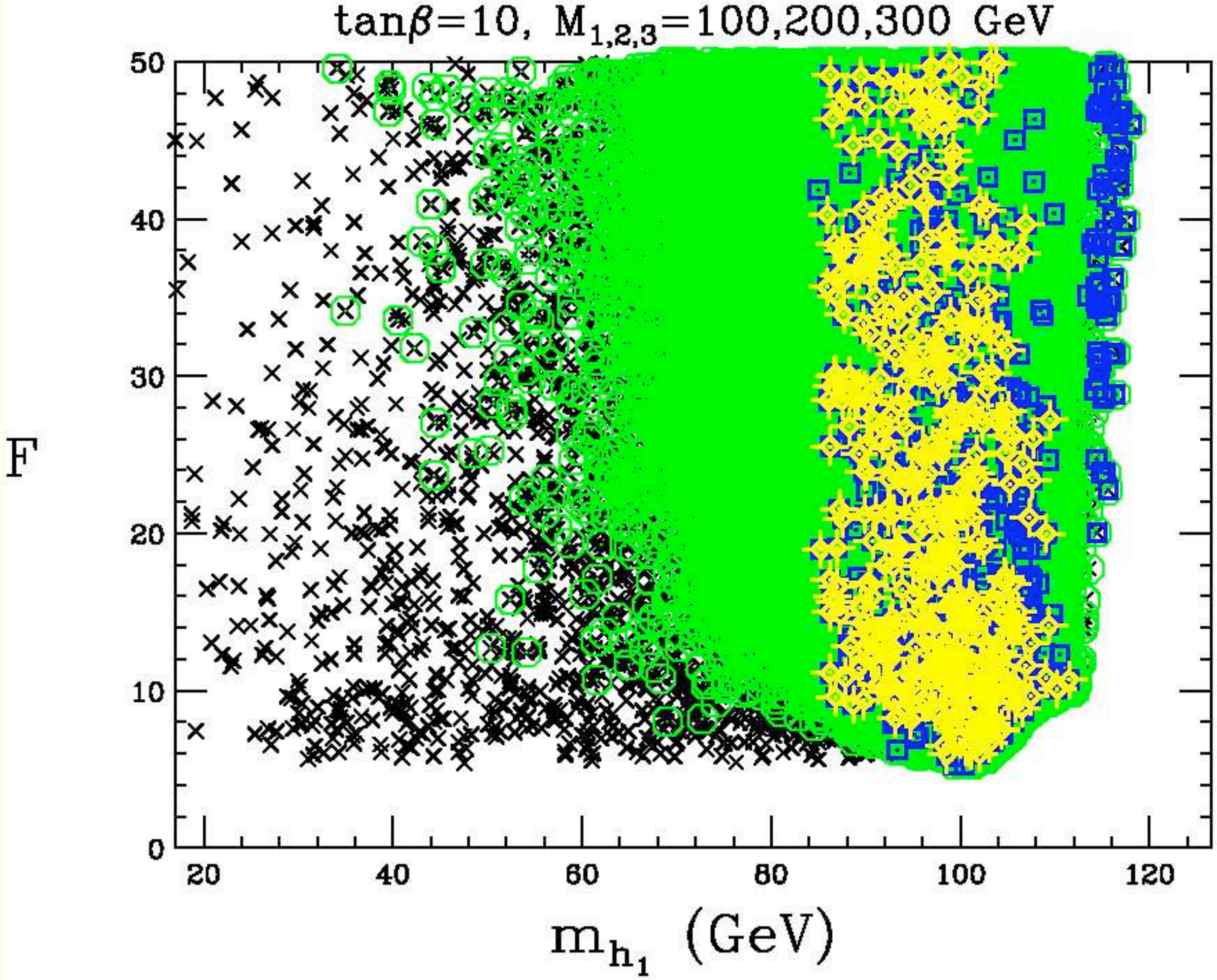


Figure 9: *F vs. m_{h^0} in the NMSSM for $\tan\beta = 10$, $M_{1,2,3}(m_Z) = 100, 200, 300$ GeV. Large yellow crosses are fully consistent with LEP constraints. See earlier Dermisek + JFG refs.*

– **A large majority of the yellow crosses have $B(h_1 \to b\bar{b}) \sim 0.1$ or so**

There are two more sets of two Higgs doublets, but these are chosen to decouple. Also the singlinos are chosen to decouple.

A different limit of the model might lead to a lot of complexity.

- **MSSM with R-parity Violation**

I will mention two models of this type. Both are designed to allow the PEW preferred value of $m_{h^0} \sim 100~\mathrm{GeV}$, which you have also seen is preferred by fine-tuning in the MSSM, while escaping LEP limits through unusual decays, much in the spirit of $h_1 \to a_1 a_1$.

1. First there is the model of M. Carena, S. Heinemeyer, C. E. M. Wagner and G. Weiglein, Phys. Rev. Lett. 86, 4463 (2001) [arXiv:hep-ph/0008023]. Here, they argue in favor of a light sbottom quark of mass about $7.5~\mathrm{GeV}$. The Higgs boson would decay mainly into $\widetilde{b}\widetilde{b}$.
   Normally, $\widetilde{b} \to b\widetilde{\chi}_1^0$, in which case $h^0 \to 2b + \not{E}_T$. Would this have been picked by LEP search?
   With baryonic R-parity violation $\widetilde{b} \to 2j$ is possible, and the Higgs signal is $h^0 \to 4j$ with no missing energy. LEP would have missed this signal for $m_{h^0} \sim 100~\mathrm{GeV}$.

2. The second model I mention is that of L. M. Carpenter, D. E. Kaplan and E. J. Rhee, arXiv:hep-ph/0607204.
   They find parts of MSSM parameter space in which $m_{h^0} \sim 100~\mathrm{GeV}$ and $h^0 \to \widetilde{\chi}_1^0 \widetilde{\chi}_1^0$ is dominant.
   If R-parity is conserved this is equivalent to $h^0 \to invisible$ and LEP excludes this channel at such a low m_{h^0}.
   However, if there is baryonic R-parity violation, then $\widetilde{\chi}_1^0 \to 3j$ and therefore $h^0 \to 6j$. This channel not excluded by LEP for $m_{h^0} \sim 100~\mathrm{GeV}$.
   The $\widetilde{\chi}_1^0$ decays could be slightly non-prompt and still have effectively the same LEP signal. In this case, one would want to search for $6j$ events with a somewhat displaced vertex.

Spencer Chang added:

- Lighter Higgs mass (below LEP2 limit)
  - Alleviates SUSY Little Hierarchy
  - Improves Precision Electroweak Fit (esp. as top mass central value continues to decrease)
- For e.g., adding a new scalar *a* adds new dominant nonstandard Higgs decays; $h \to 2a \to 4\tau$ allows Higgs mass < 100 GeV (LEP2)

Dermisek, Gunion
Chang, Fox, Weiner
Graham, Pierce, Wacker

SUSY Example

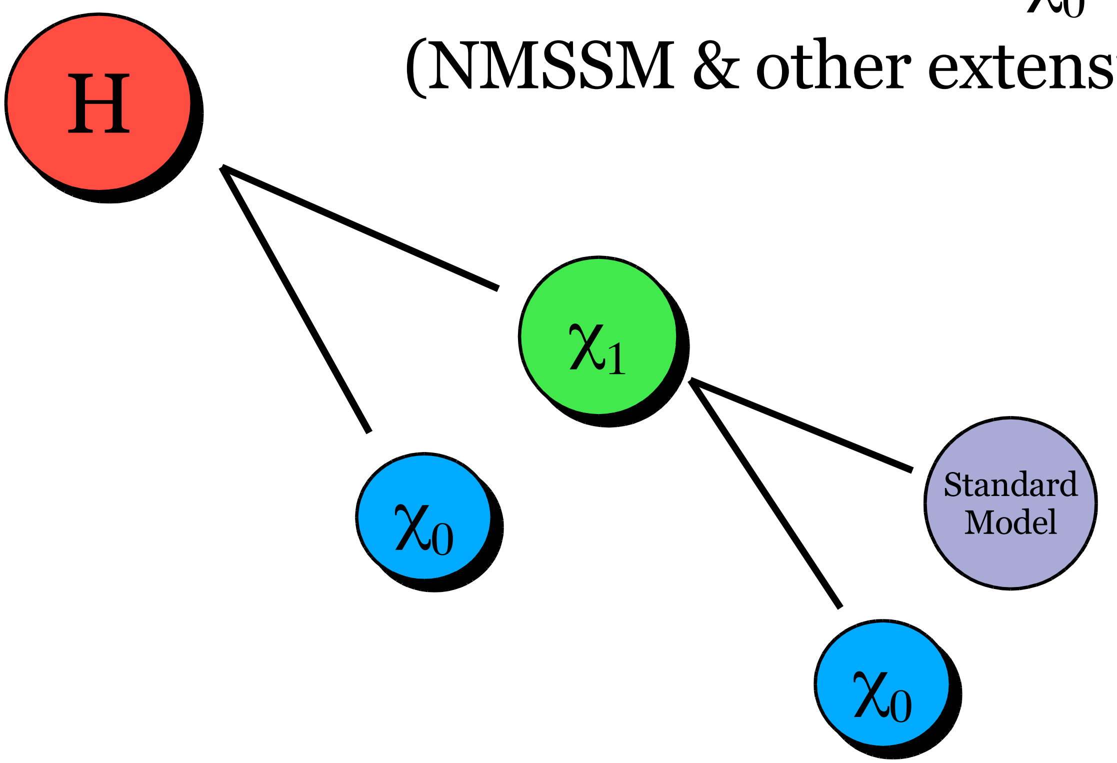
MSSM

+

new neutralino χ_0

(NMSSM & other extensions)

Barger, Langacker, Shaughnessy



Invisible $2\chi_0$ decay strongly constrained

Higgs allowed below 114.4 GeV?

However, with RPV see Kaplan et.al.

Higgs Limit

100 GeV Higgs seems allowed for

$BR(\chi_1 \chi_0) \sim 1$ for decays into light quarks, leptons

$BR(\chi_1 \chi_0) \sim .3$ for all modes

Neutralino Properties

h	90-110 GeV	χ_1	40-60 GeV	χ_0	1-20 GeV

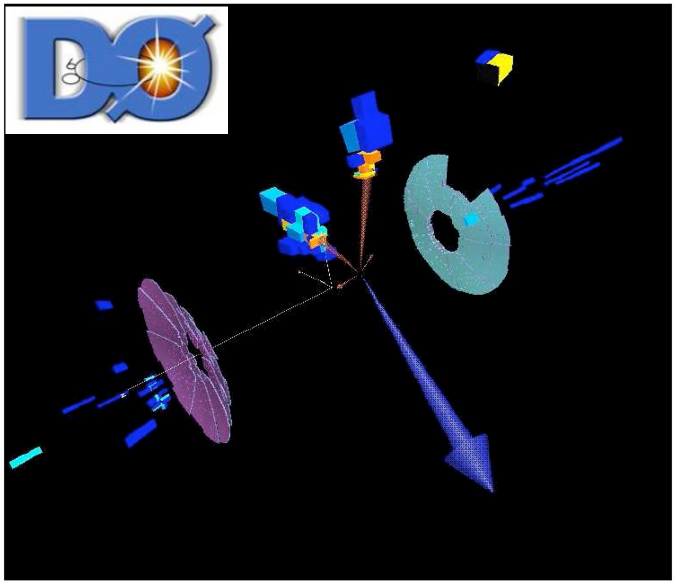
- Chargino search constraint, > 100 GeV
  - Requires a new singlet Weyl Fermion (Singlino) → NMSSM?
- Z Invisible Width and Neutralino Production at LEP
  - If tan $\beta > 1$, χ_1 is mostly bino and χ_0 is mostly singlino   Barger et.al.
- Dark Matter Abundance: No Overclosure
  - A new light scalar of mass about $2m_{\chi_0}$

Belanger et.al.
Gunion et.al.
Barger et.al.

Impact on SUSY Pheno

Ellwanger,Hugonie
Strassler

- Dominant singlino LSP implies longer cascades, potentially displaced vertices
- Longer cascades mean more visible energy (jets, leptons) and reduced missing energy
- Searches normally expect:
  - Squark→ jet + MET
  - Gluino→ 2jets + MET
- Effects degrade search esp. with optimized MET cuts



Top Quarks

Argonne NATIONAL LABORATORY

THE UNIVERSITY OF CHICAGO

Perspectives on single-top-quark production

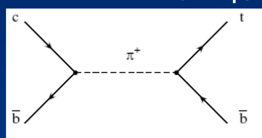
Zack Sullivan

Aspen Winter Conference 2007

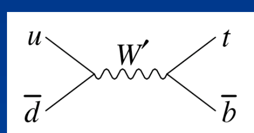
New phenomena affect *s*- and *t*-channel separately

Resonances

Scalars (π^+_T)

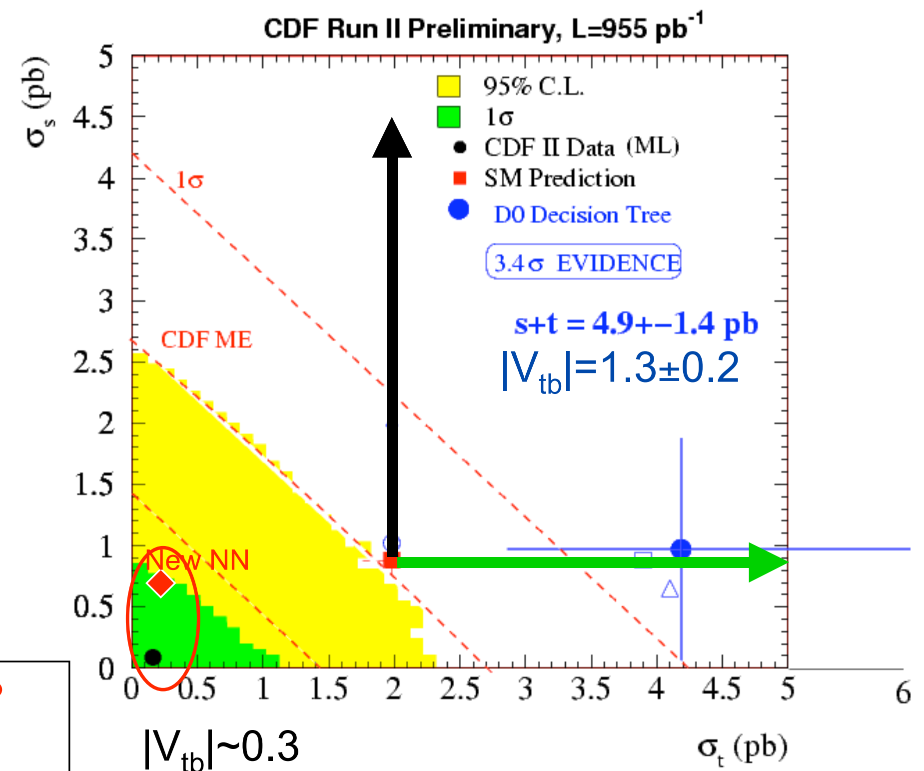


Vector currents



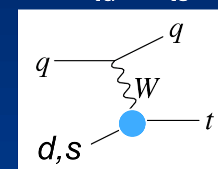
KK-modes
etc.

4th generation?
t-*T* mixing?
Suppress *t* not *s*?

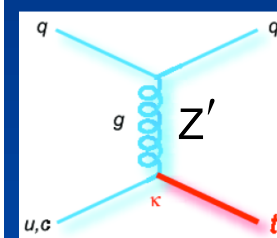


New *q*-*t*-*X* verticies

V_{td}, V_{ts}



FCNC



BR(t→Zc)<0.33
CDF, PRL80,2525(98)
will soon change

Fully exclusive NLO calculations

D0 w&c

Source	2 jets	3 jets	jets
	Event Yields in 0.9 fb^{-1} Data Electron+muon, 1tag+2tags combined		
tb	16 ± 3	8 ± 2	2 ± 1
tqb	20 ± 4	12 ± 3	4 ± 1
$t\bar{t} \to ll$	39 ± 9	32 ± 7	11 ± 3
$t\bar{t} \to l$+jets	20 ± 5	103 ± 25	143 ± 33
$W+b\bar{b}$	261 ± 55	120 ± 24	35 ± 7
$W+c\bar{c}$	151 ± 31	85 ± 17	23 ± 5
$W+jj$ HUGE	119 ± 25	43 ± 9	12 ± 2
Multijets	95 ± 19	77 ± 15	29 ± 6
Total background	686 ± 131	460 ± 75	253 ± 42
Data	697	455	246

Required new methods to calculate fully exclusive cross sections with massive states

- Phase space slicing method with 2 cutoffs.
  L.J. Bergmann, Ph.D. Thesis, FSU (89)
  cf. H. Baer, J. Ohnemus, J.F. Owens, PRD 40, 2844 (89)
  B.W. Harris, J.F. Owens, PRD 65, 094032 (02)
- Phase space slicing method with 1 cutoff.
  W.T. Giele, E.W.N. Glover, PRD 46, 1980 (92)
  cf. W.T. Giele, E.W.N. Glover, D.A. Kosower, NPB 403, 633 (93)
  E. Laenen, S. Keller, PRD 59, 114004 (99)
- Massive dipole formalism (a subtraction method) coupled with a helicity-spinor calculation. Invented to solve single-top production.
  cf. L. Phaf, S. Weinzierl, JHEP 0104, 006 (01)
  S. Catani, S. Dittmaier, M. Seymour, Z. Trocsanyi, NPB 627,189 (02)

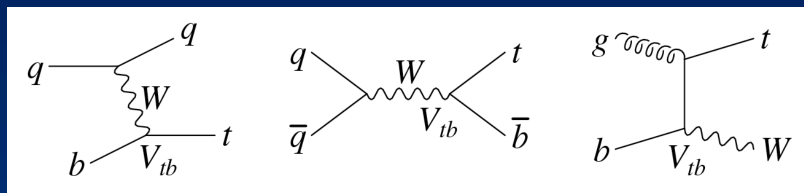
# *b*-jets	*t j (W j j)*	*t j j (W j j j)*
s-channel = 2	0.620 pb	0.168 pb
= 1	0.022 pb	(NNLO)
t-channel = 1	0.950 pb	0.152 pb
= 2	0.146 pb	0.278 pb

Cuts: E_{Tj}>15 GeV, $|\eta_j|$<2.5, no cuts on *t*

- Worked out analytically in
  Harris, Laenen, Phaf, ZS, Weinzierl, PRD 66, 054024 (02)
- Numerically studied using ZTOP
  ZS, PRD 70, 114012 (04)
- Now in MCFM 5.1+
  Campbell, K. Ellis

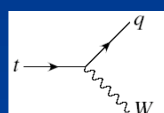
New baseline NLO standard

Zack would summarize the current situation like this



Single-top-quark production forces us to reconsider our intuitions and develop new technologies that push the frontiers of perturbative QCD:

- We will have precision measurements of weak interaction structure.



$$-i\frac{g}{\sqrt{2}}V_{tq}\gamma^{\mu}\frac{1}{2}(1-\gamma_5)$$

- Single-top has changed how we think about the cross section.

$$\sigma_{\mathrm{obs.}} = \int f_1(x_1,\mu_1) f_2(x_2,\mu_2) \otimes |M|^2 \otimes d\mathrm{P.S.} \otimes D_i(p_i)\ldots D_n(p_n)$$

Things not covered

- 1st PDF uncertainties
- "Modifed Tolerance Method" (what you use for PDF errors)

$$\delta O_{+} = \sqrt{\sum_{i=1}^{20}\left(\max\left[O(z_i^0+t)-O(z_i^0), O(z_i^0-t)-O(z_i^0), 0\right]\right)^2}$$

$$\delta O_{-} = \sqrt{\sum_{i=1}^{20}\left(\max\left[O(z_i^0)-O(z_i^0+t), O(z_i^0)-O(z_i^0-t), 0\right]\right)^2}$$

Z.S., PRD 66, 075011 (2002);
Z.S., P. Nadolsky, eConf C010630, P511 (2002);
eConf C010630, P510 (2002)

- Kinematic uncertainties
- Push for "NN" b-tags and clever uses

…

It will be vital to the success of the LHC to develop close interactions between theory and experiment of the type single-top-quark production has enjoyed.

Tops from decays of new particles

Lian Tao Wang told us two important examples:

- Case 1: $t\ \bar{t} + \not{E}_T$

Highly motivated from naturalness problem

Top partner typically has SM quantum numbers, couples to top.

Additional ingredient:

discrete symmetry $\rightarrow$ removal of unwanted operators

EWPT, dark matter, proton decay...

$\longrightarrow$ End product of NP decay is stable, e.q., A_H.

$\longrightarrow t\ \bar{t} + \not{E}_T$

Typical Examples:

1. $\tilde{t}$ in low energy supersymmetry

$$\tilde{t} \rightarrow t + \text{LSP}$$

2. T' (odd under T-parity) in Little Higgs models*.

$$T' \rightarrow t + \text{LTP}(A_H)$$

Similar signature, KK-top in UED†.

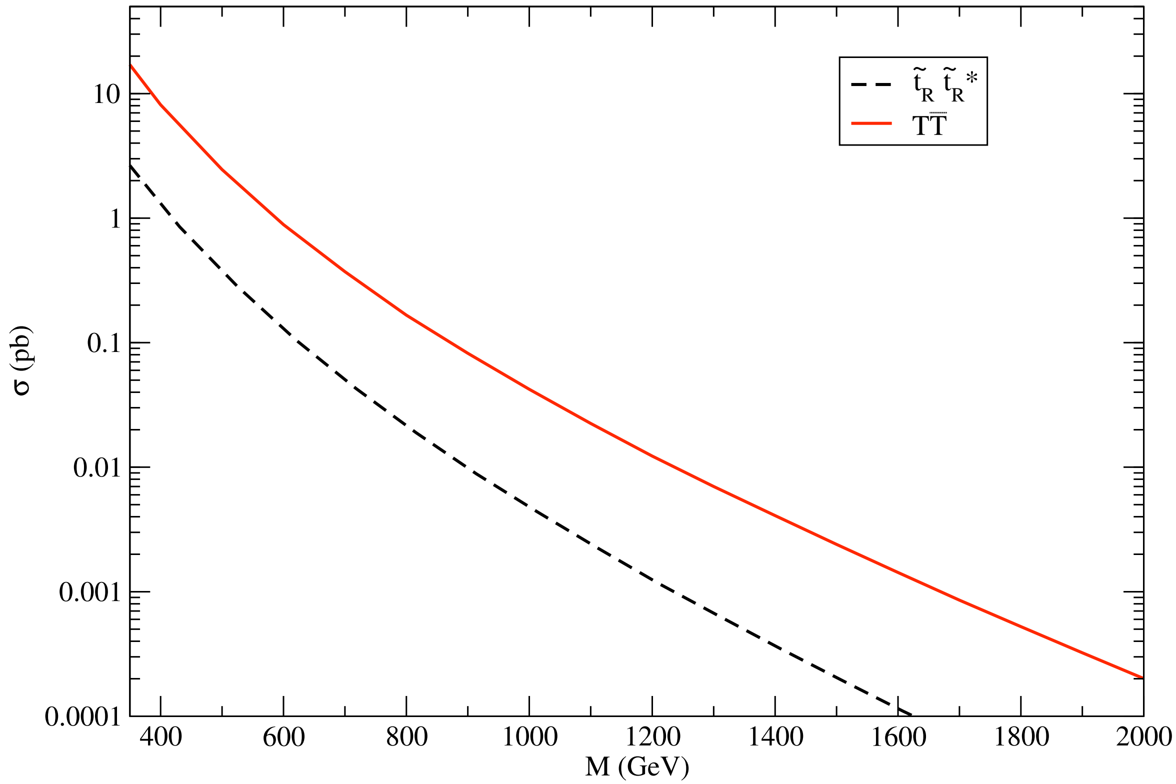
Pair production of $\tilde{t}$ or $T' \longrightarrow t\bar{t} + \not{E}_T$

*H. C. Cheng, I. Low, LW hep-ph/0510225

†T. Appelquist, H. C. Cheng and B. A. Dobrescu, hep-ph/0012100

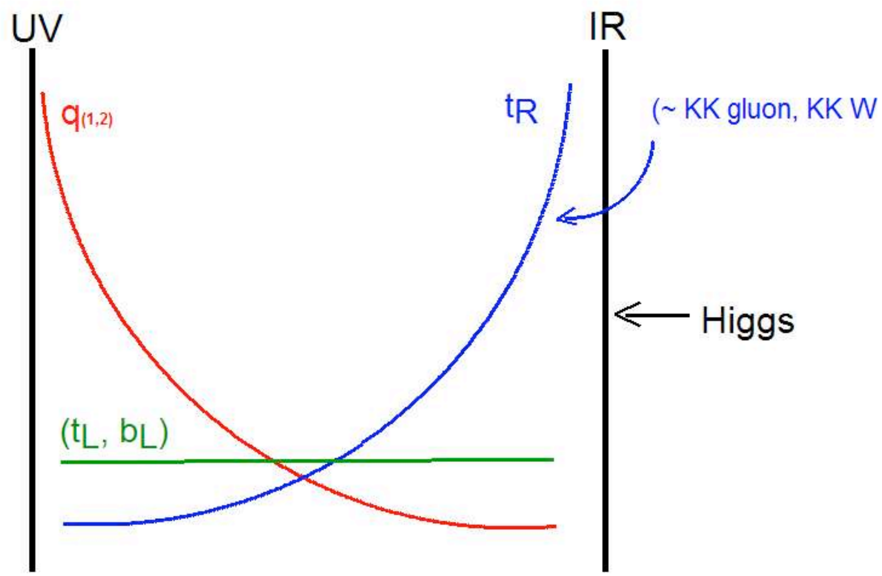
Rate*

After studying the signal and background, it seems TeV masses are accessible, particularly using top reconstruction. Simlar studies are being performed by other groups, Meade et al, Burdman et al, Matsumoto et al, ...



*H. C. Cheng, I. Low, LW hep-ph/0510225

Case 2: NP resonances $\rightarrow$ $t\ \bar{t}$*



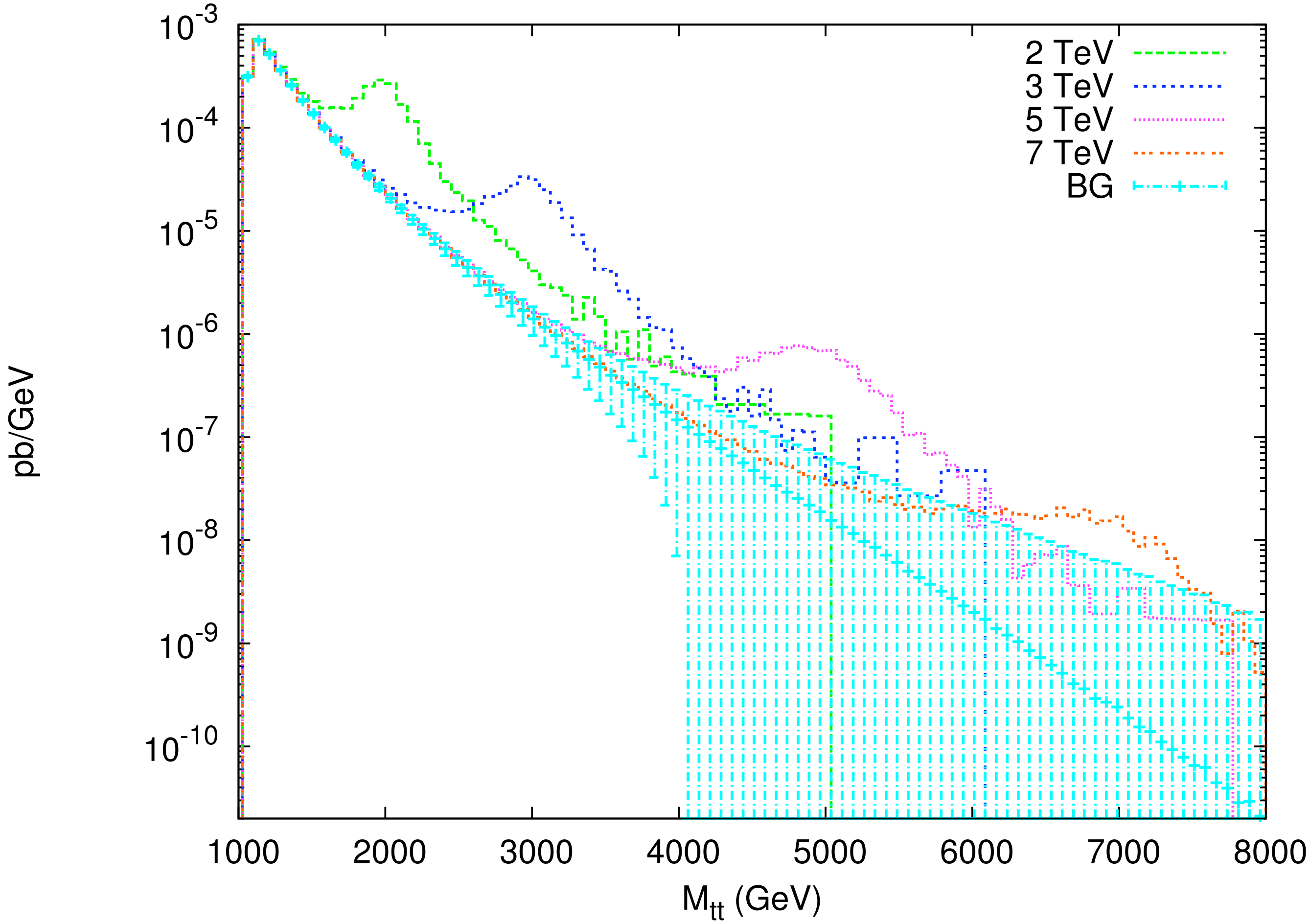
top is composite $\longrightarrow$ top is heavy

Other composite states (KK gluon, KK W) dominantly decay into $t\bar{t}$.

Bump searching.

*K. Agashe, A. Delgado, M. May, R. Sundrum, hep-ph/0308036

Singal vs SM $t\bar{t}$, $\sqrt{N}$ error bar



B. Lillie, L. Randall and L.T. Wang, in preparation

Challenges

1. SM $t\bar{t}$ has long tail in $m_{t\bar{t}}$.

2. Wider resonances, $\Gamma \sim 0.2M$. PDF distorts the shape of resonances.

3. EWPT typically constrains the composites to be quite heavy $\geq$ 3TeV*.

$$\longrightarrow \text{ Very energetic tops}$$

Reconstruction of tops based on isolated objects is likely to fail.

*K. Agashe, A. Delgado, M. May, R. Sundrum, hep-ph/0308036

J. Wacker told us about the search for gluinos

Scenarios discussed motivated by Split SUSY.

Two scenarios:

Scenario with large mu parameter and Bino masses close to gluino masses (induced by RG evolution). Challenging because of soft jets

Quasi-stable gluino. Very interesting possibility of gluino stopping

Let me concentrate on the second one.

At the LHC very large production cross section

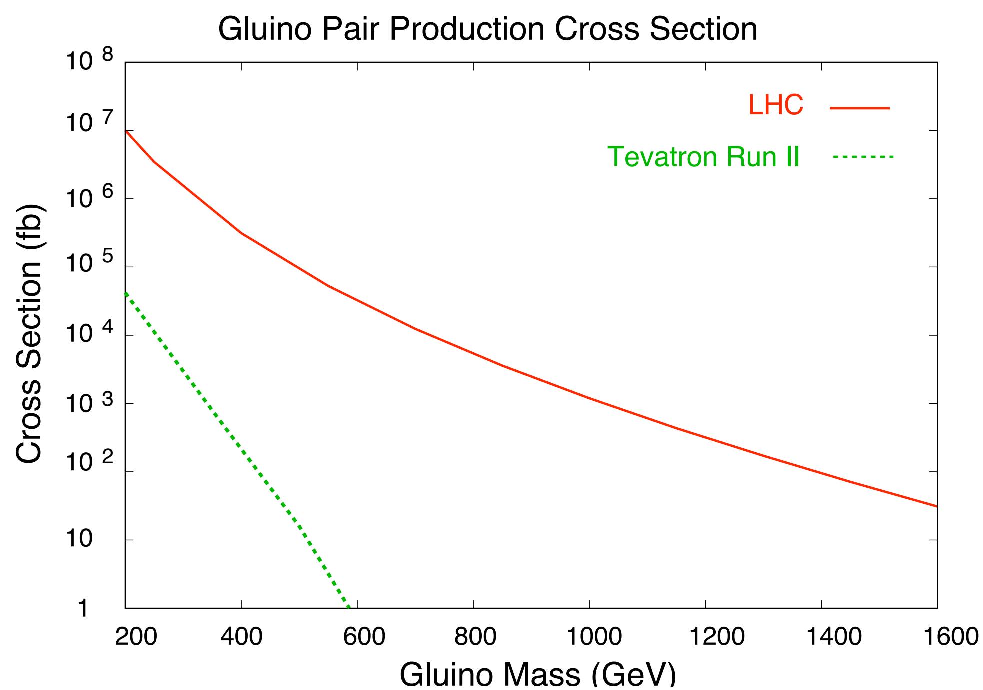


Figure 1: The gluino production cross section as a function of mass at the LHC (red solid) and Tevatron Run II (green dashed).

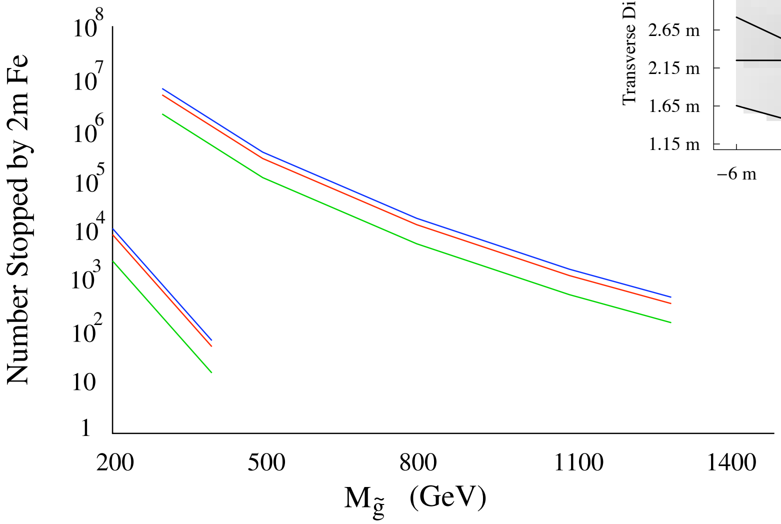
Four distinct ways to look for quasi-stable gluinos:

1) Looking for monojet signatures in gluino-gluino-jet production

2) Slowly moving particles in tracking chamber. Look for charged R-hadrons may lead to reach of 1.2 TeV at the LHC

3) Search for charge oscillation events (flippers) in the chambers, thing that proves to be difficult

4) Stopped gluinos, and their late decay. Exciting possibility !



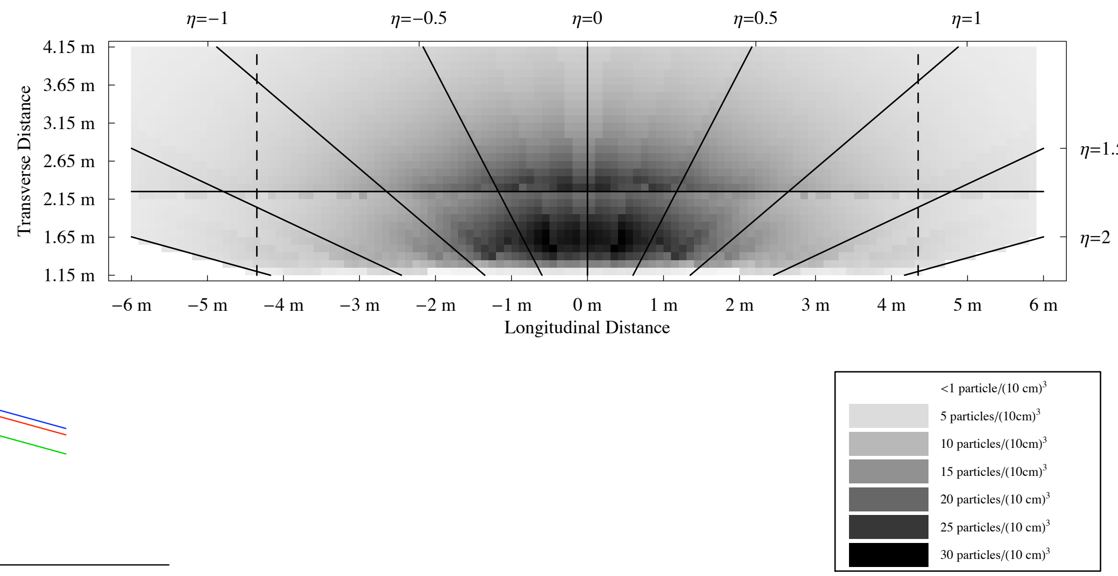
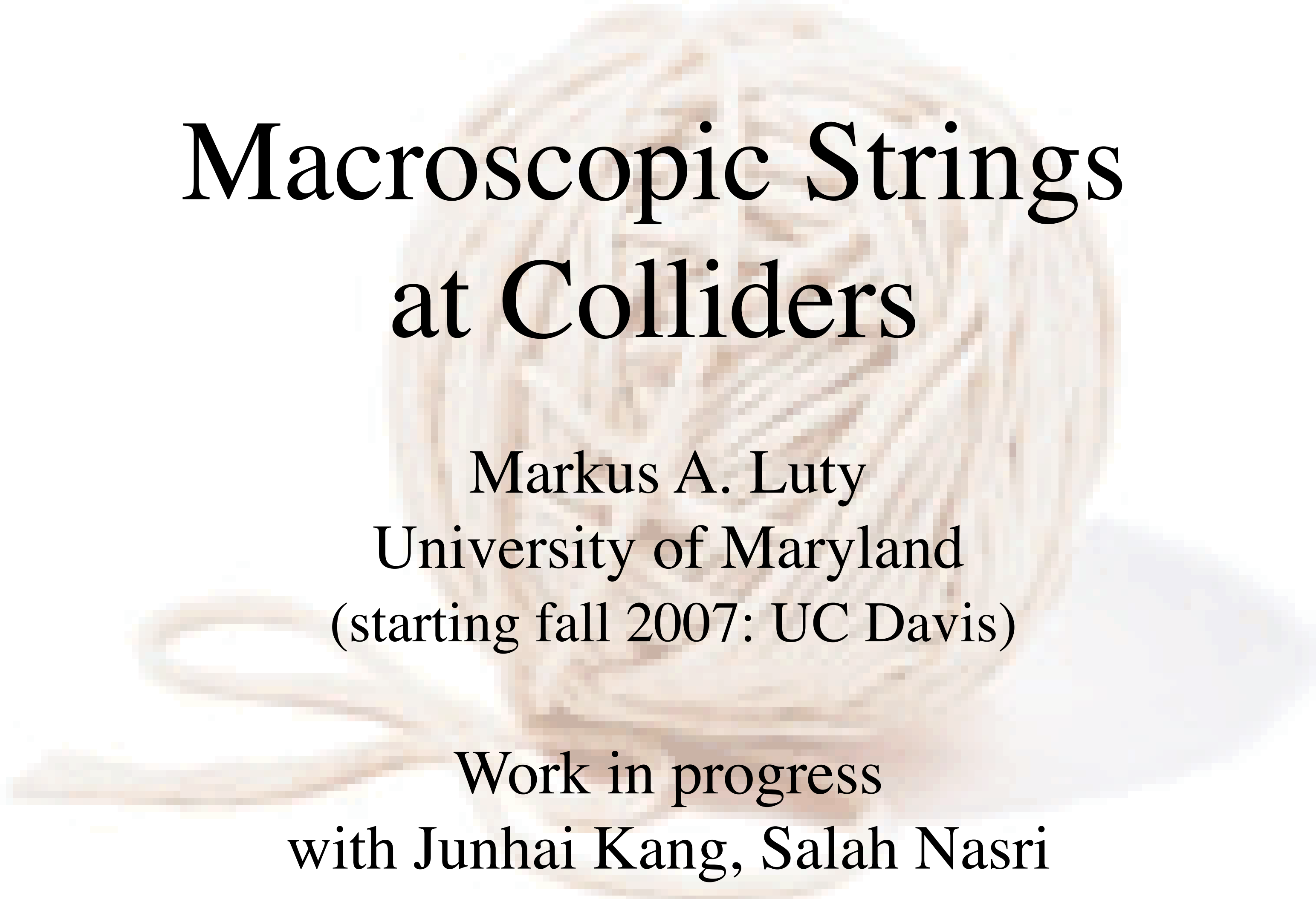


Figure 4: The number of R-hadrons stopped after two meters of iron in Mass Region 1. This plot convolutes the velocity distribution at production with conversion processes and matter and ionization losses. The upper set of curves is for the LHC for a total accumulated luminosity of 100 fb^{-1}, equivalent to a year of running at high luminosity. The lower set is for the Tevatron Run II, assuming a total of 2 fb^{-1}. In each set the curves correspond to a meson to baryon conversion cross section, $\sigma_0 = 30$ mb, 3 mb, and 0.3 mb from top to bottom.

Observing the signature of stopped gluinos, and be sure that is not due to event fluctuation, or cosmic ray will allow us to be sure of the existence of quasi-stable particle

“Unmotivated”, but yet exciting physics



Macroscopic Strings at Colliders

Markus A. Luty
University of Maryland
(starting fall 2007: UC Davis)

Work in progress
with Junhai Kang, Salah Nasri

The model

$$SU(3)_{\mathrm{C}} \times SU(2)_{\mathrm{W}} \times U(1)_Y \times SU(N)$$

$$q \sim (\mathbf{3}, \mathbf{2})_{\frac{1}{6}} \times \mathbf{1}$$
$$u^c \sim (\bar{\mathbf{3}}, \mathbf{1})_{-\frac{2}{3}} \times \mathbf{1}$$
$$d^c \sim (\bar{\mathbf{3}}, \mathbf{1})_{\frac{1}{3}} \times \mathbf{1}$$
$$\ell \sim (\bar{\mathbf{1}}, \mathbf{2})_{-\frac{1}{2}} \times \mathbf{1}$$
$$e^c \sim (\bar{\mathbf{1}}, \mathbf{1})_{1} \times \mathbf{1}$$

$$Q \sim (\bar{\mathbf{3}}, \mathbf{1})_{\frac{1}{3}} \times \mathbf{N}$$
$$\bar{Q} \sim (\bar{\mathbf{3}}, \mathbf{1})_{-\frac{1}{3}} \times \overline{\mathbf{N}}$$
$$L \sim (\bar{\mathbf{1}}, \mathbf{2})_{-\frac{1}{2}} \times \mathbf{N}$$
$$\bar{L} \sim (\bar{\mathbf{1}}, \mathbf{2})_{\frac{1}{2}} \times \overline{\mathbf{N}}$$

$$m_Q, m_L \sim 100 \text{ GeV–TeV}$$

Assume Q's long lived

$SU(N)$ sector

$SU(N)$ unbroken $\Rightarrow$ 2 parameters

$$\Lambda = \text{scale of } SU(N) \text{ confinement}$$

$$= M_{\rm GUT} e^{-8\pi^2/b g^2_{\rm GUT}}$$

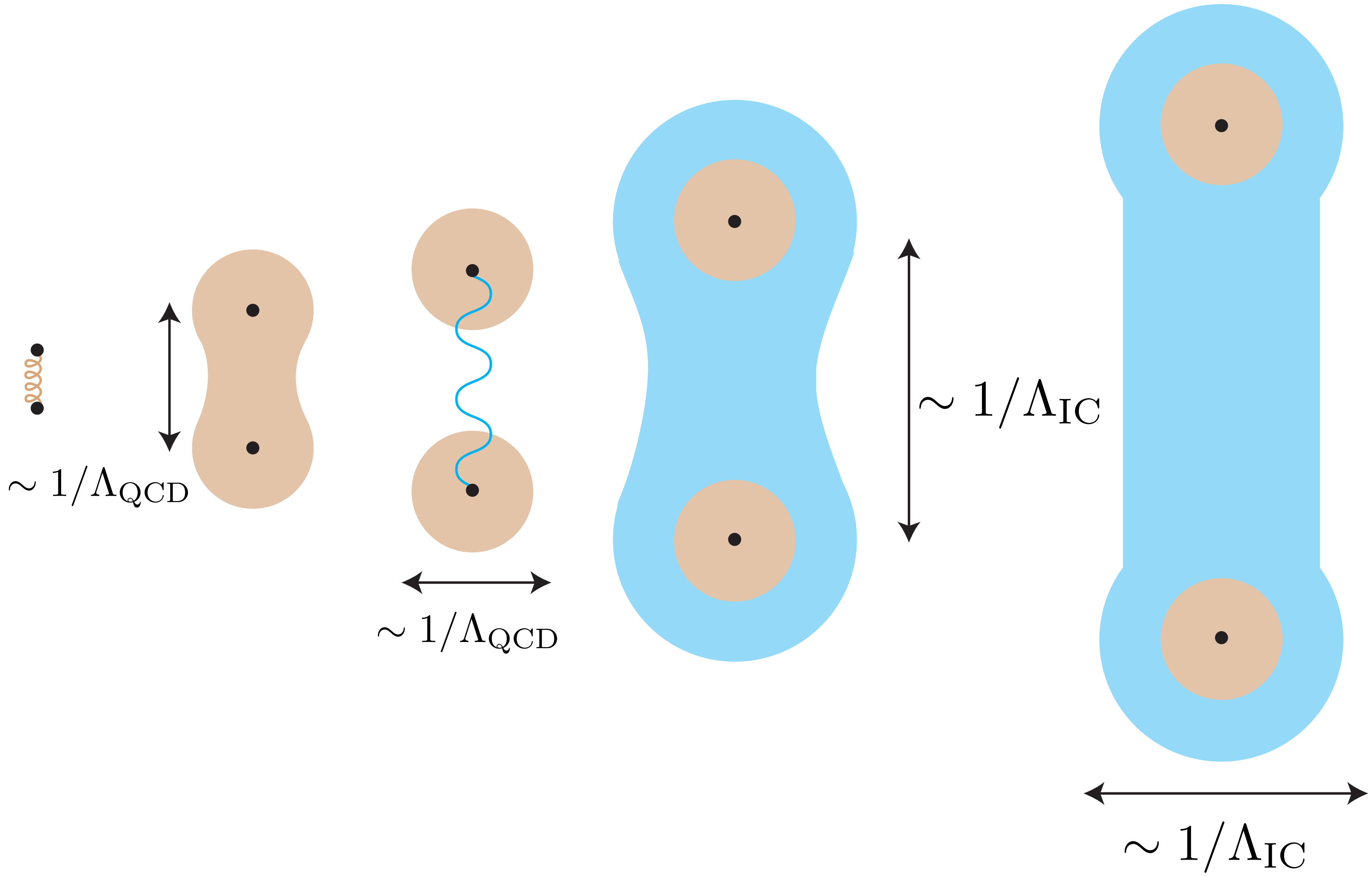
$\Rightarrow$ every decade of energy "equally likely"

m = mass of fermions $\sim$ electroweak scale,

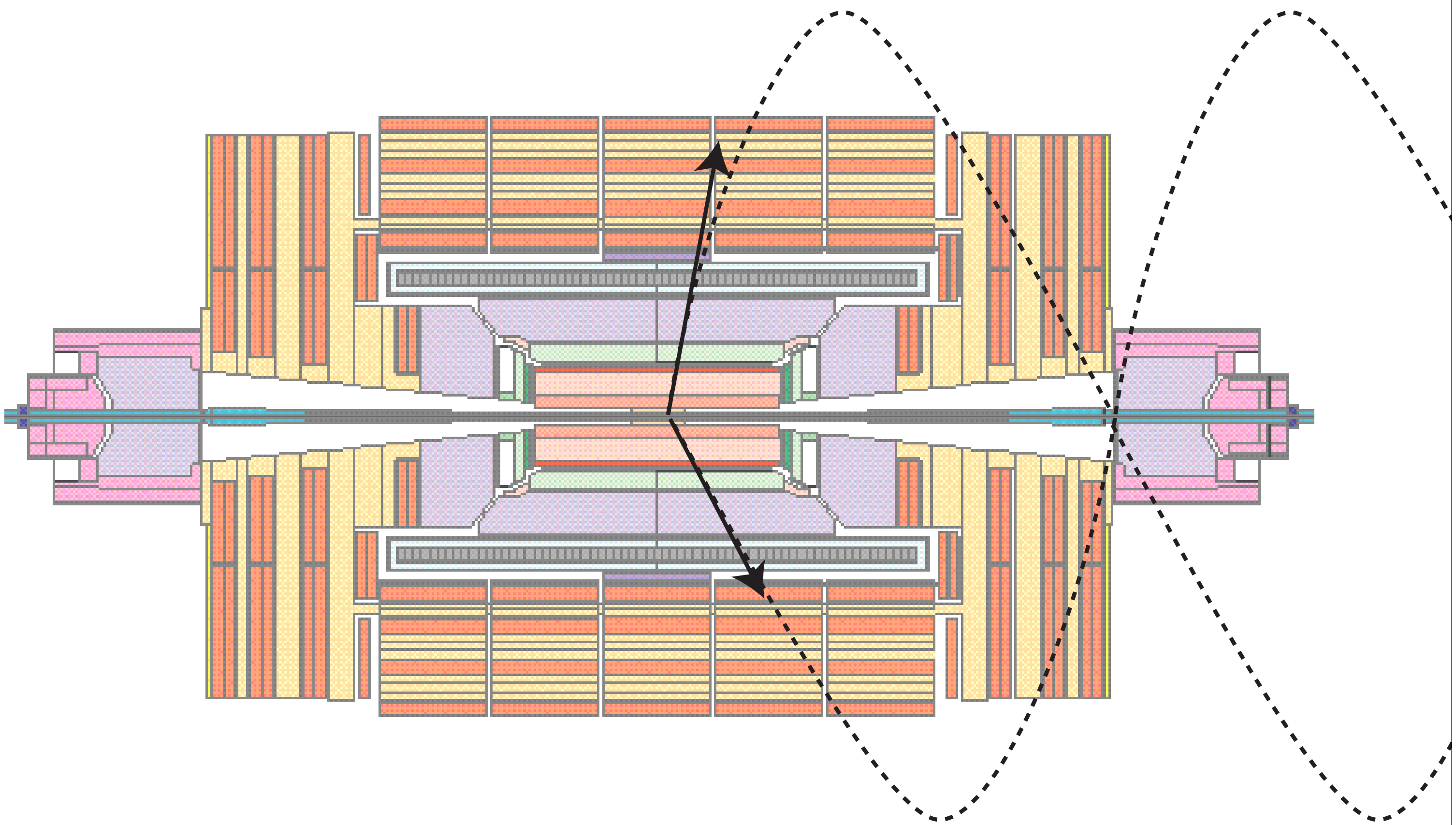
preserves electroweak symmetry

(like SUSY "μ term")

Hadronization: $\Lambda_{\mathrm{QCD}} \gg \Lambda_{\mathrm{IC}}$



$\Lambda_{IC} \lesssim$ keV: Anomalous curvature



Exciting signature at the LHC !

Summary

- The work presented in this conference gives a global, although by far not complete, picture of the efforts of HEP Theorists in preparation to the LHC era.
- Many topics have been omitted, in part due to the lack of capability of this reviewer of covering them in a coherent way. In particular, neutrino physics has been ignored, due to time limitations, but I recommend you to look at the excellent talk by A. de Gouvea.
- An important topic, not discussed in depth in this conference, is the growing and important connection between particle physics and astrophysics and cosmology. This is bound to provide complementary information to our understanding of physics in the coming years
- Most importantly, the LHC is starting to run in a few months from now, and will start doing physics, hopefully, by 2009. I am persuaded we are preparing well (although perhaps not we are not well prepared) for the challenge.
- The Tevatron is still running and may lead to surprises. The LHC is starting quite soon. The ILC is in the horizon. We are living an exciting era, and things are bound to improve in the very near future !