FCNC, CP violation & more at the muon collider

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Fermilab Muon Collider Workshop

(Nov10-12,'09)

Outline

- **Intro**
- **S channel physics: old & new**
- **PARTICLS @ the IR: H, t, KKZ..**
- **CP, FCNC…**
- **Summary & Outlook**

Introduction & Motivation

- CRYSTAL BALL: RS/Compositeness /strong dynamics
- Provides an extremely interesting (warped) theory of flavor…..This is the most pressing problem….Hierarchy resolution comes for FREE
- Significant deviations expected in PARTICLES @ the IR (PAIRs) Most prominent examples: Higgs, top, …KKs
- MuC provides a clean probe…   (so does LC,CLIC)
- Facilitates precision studies
- S-channel Higgs, KKZ, KKG…MuC may have advantage not just for H….….
- Potentially MuC can go up to a few TeVs…extra attraction
- Beam polarization, if possible, could be an additional asset for overcoming backgrounds as well as for CP and other studies

Crucial final states

- t t-bar pair
- t c-bar (unique FS for FCNC studies,

  Others e.g bs..and such not accessible in HE facilities even LC or MUC because of huge background problems…{That’s why for 1 thing you need SBF’s}
- Production and decay dynamics
- Rates, AFB, CP are excellent avenues

RECALL

- Naked top -> clean tedm
- Top polarimetry (also tau)
- -> decay correlations
- Analyzing power
- T_N even & odd CPV observables
- FB asymmetry
- For details: Atwood, Bar-Shalom, Eilam &AS, Phys. Reports' 01

RANDALL+SUNDRUM '99

[FIG BY H DAVOUDIASL]

Points along 5th dim correspond to diff. eff. 4d scale!

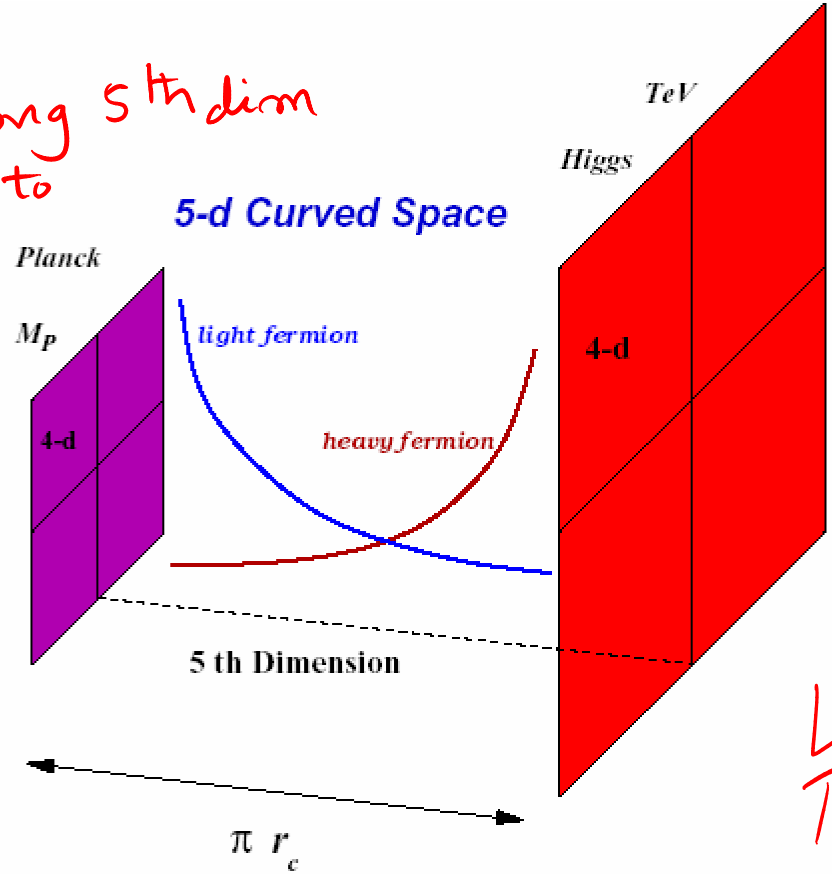


Figure 1: Warped geometry with flavor from fermion localization. The Higgs field resides on the TeV-brane. The size of the extra dimension is $\pi r_c \sim M_P^{-1}$.

$$ds^2 = e^{-2\sigma} \eta_{\mu\nu} dx^\mu dx^\nu - r_c^2 d\phi^2$$

$$\langle H_4 \rangle = e^{-\sigma} \langle H_5 \rangle$$

TeV ← → M_P

$$\sigma = k r_c \pi$$

$k r_c \sim 12$

Simultaneous resolution to hierarchy and flavor puzzles

Fermion "geography" (localization) naturally explains:

Grosman&Neubert; Gherghetta&Pomarol; Davoudiasl, Hewett & Rizzo

- **Why they are light (or heavy)**
- **FCNC for light quarks are severely suppressed**
- **RS-GIM MECHANISM (Agashe, Perez,AS'04)** **flavor changing transitions though at the *tree level* (resulting from rotation from interaction to mass basis)are suppressed roughly to the same level as the loop in SM**
- **Most flavor violations are driven by the top**

LRS

(Davoudiasl,Perez,AS,0802.0203)

- **LRS=Little Randall-Sundrum – a WARPED THEORY Of FLAVOR**
- **While the RS construction has a compelling appeal, as it allows a simultaneous resolution of SM (EW-Planck) and (EW-Flavor) puzzles, it is premised on a very strong assumption:**
- **Warping extends over many orders of magnitude w/o any basic change in physics, from the weak scale all the way to the Planck scale. Surely this assumption, no matter how appealing needs to be put to an experimental test.**
- **Is it possible, e.g. that the basic warped idea is used only for understanding EW-Flavor (~10^3 TeV) hierarchy via fermion localization, leaving open avenues for UV completion to Planck?**

EXPERIMENT Has the final say

Let’s B Modest

Table 2
Summarized comparison of constraints and predictions in the RS and the LRS scenarios. For simplicity and definiteness, the Higgs is assumed to be on the IR-brane. The constraints correspond to lower bounds on gauge KK masses, in TeV. Here, we assume a custodial symmetry for the T parameter; a left–right Z_2 symmetry is imposed to protect the $Zb\bar{b}$ coupling, unless denoted by *. The predictions in the last row correspond to a Z' of mass {2, 5} TeV, respectively

Constraint/prediction	RS	LRS
T parameter	3	3
S parameter	3	3
$Z \to b\bar{b}$	3	3*
ϵ_K	8	3
$\mathcal{S}/\mathcal{B}$ for $Z' \to l^+l^-$	{0.3, –}	{$\mathcal{O}(100)$, $\mathcal{O}(100)$}

Dilepton Little Z' Signals

Courtesy: Davoudiasl

- LRS truncation factor: $y \equiv (kr_c\pi|_{RS})/(kr_c\pi|_{LRS}) \quad (y > 1)$

- $g_{KK}|_{UV} \sim g_4/\sqrt{kr_c\pi} \quad (q, e, \ldots)$; $g_{KK}|_{IR} \sim g_4\sqrt{kr_c\pi} \quad (H, t, \ldots)$

(i) KK modes become narrower: $\Gamma \sim 1/y$ IR-coupling-dominated

(ii) Width into light states $(e^+e^-, u\bar{u}, \ldots)$ grows $\sim y$

(iii) Signal $\mathcal{S}$: $\sigma(q\bar{q} \to Z' \to \ell^+\ell^-) \propto \overbrace{\Gamma(Z' \to q\bar{q})}^{\sim y} \overbrace{\mathrm{BR}(Z' \to \ell^+\ell^-)}^{\sim y^2}$

(i) $\oplus$ (ii) $\oplus$ (iii): $\boxed{\mathcal{S} \sim y^3}$ and $\boxed{\mathcal{S}/\mathcal{B} \sim y^4}$! Background: $\mathcal{B} \sim 1/y$ (over width)

- Sensitivity to the UV-brane scale.

$y \approx 1 \Rightarrow M_5 \sim \bar{M}_P$; $y \gg 1 \Rightarrow M_5 \ll \bar{M}_P$

LRS phenomenology of Z', Z''
Explored in Davoudaisl, Gopalakrishna,AS
0908.1131

MuC is a powerful $Z'_{LRS(RS?)}$ Factory

- **FOR a few TeV Z'**

- **XS ~ 1000 fb……LRS-→10^6 events!**
- **XS ~ few fb……..RS**

- **If you can really get Lumi ~ 1/ab it could be a dream come true FACTORY!**

PROS & Cons

- **The possibilty to simultaneously address**

  EW-PI and EW-FI puzzles renders the basic warp idea extremely appealing

  BUT

- **Specific model(s) that can be used to make reliable predictions are not yet there**
- **SEEK GENERIC CLUES & TARGETS**

Gold-mines@ H&L energies

- LHC:G->Z(ll) Z(l'l'), WW
- LHC et al: t \bar t due $(G,g,Z..)_{KK}$
- LHC: Top polarization, FB-asym?
- LHC: t-> c Z…….
- t-edm
- LC(ILC,CLIC,MuC…): Some items clearly more important/relevant for these (e.g. t-edm, tcz f-B asym…); Also s-chann H, KKz's; t', L4,Nu4……
- N-edm
- D^0 mixing & CP (dir & TD)
- B_S (CP) ->ψφ,ψ η, φη, φφ….
- B_d -> (φ,η'……)$K_{S,,}$ γ K^* ….TDCP

Ultimately an experimental question

- **Analogy with Guts….expedited pushing searches for proton lifetime resulting in improvement of bounds on proton lifetime already by ~O(10^4) and possibly more in the coming years (DUSEL et al)**

Any Hints?

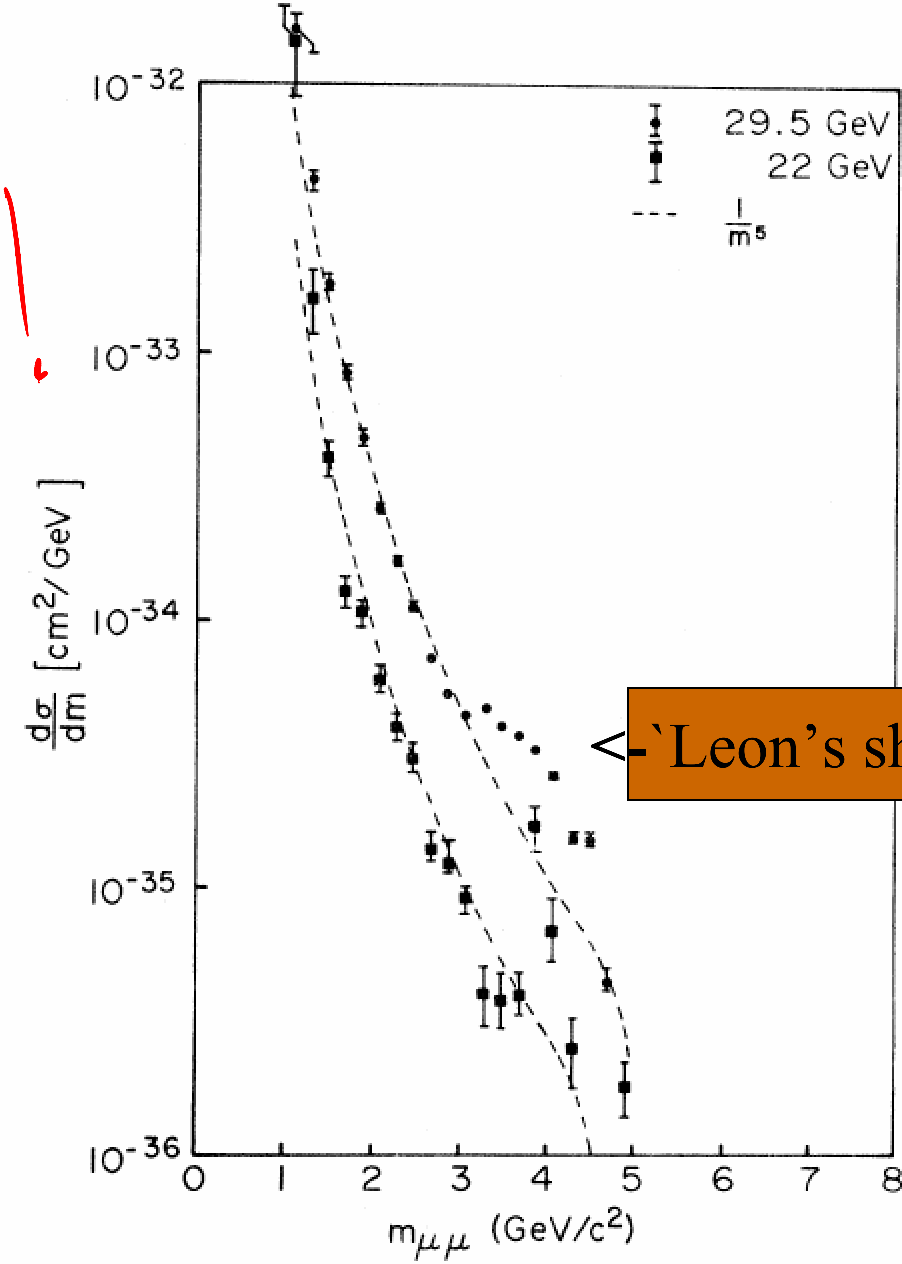
- While a compelling & conclusive evidence for breakdown of SM in flavor physics cannot be made at present, in the last few years several interesting (and possibly strong) hints have emerged.
- Although, taking too seriously every little deviation

  can be unwise and may be counterproductive; disregarding or overlooking the hints can be painfully unwise and in fact can be more damaging {LESSON(s) FROM HISTORY} . Following these up in flavor & collider physics and in theory may be a much wiser path.

{ based in part on Enrico Lunghi + A. S. 0707.0212; 0803.4340; 0903.5059; & in progress}

DRELL-YAN @ its INFANCY!

$p p \to \mu^+ \mu^- X$ @ BNL



<-`Leon's shoulder

FIG. 15. Experimental cross sections at two energies compared with a simple $1/m^5$ continuum.

2nd

Adapted from Browder

A lesson from history (I)

"A special search at Dubna was carried out by E. Okonov and his group. They did not find a single $K_L \to \pi^+ \pi^-$ event among 600 decays into charged particles [12] (Anikira et al., JETP 1962). At that stage the search was terminated by the administration of the Lab. The group was unlucky."

-Lev Okun, "The Vacuum as Seen from Moscow"

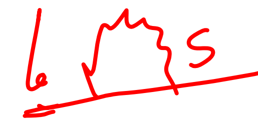
1964: BF= 2×10^{-3}

A failure of imagination ? Lack of patience ?

Summary of B-CP Anomalies

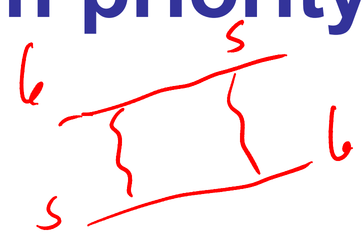
LUNGI+AS '07;08

- Fitted ("SM-predicted") value of sin 2β vs directly measured a) via tree decays
- b) via loop decays



- Dir CP in K+π- vs K+ π0
- Bs->ψφ (esp. significant since 1. Its theoretically very clean. II. It essentially follows from others…Consequently very important that Fermilab follows it up & clarifies it with very high priority).

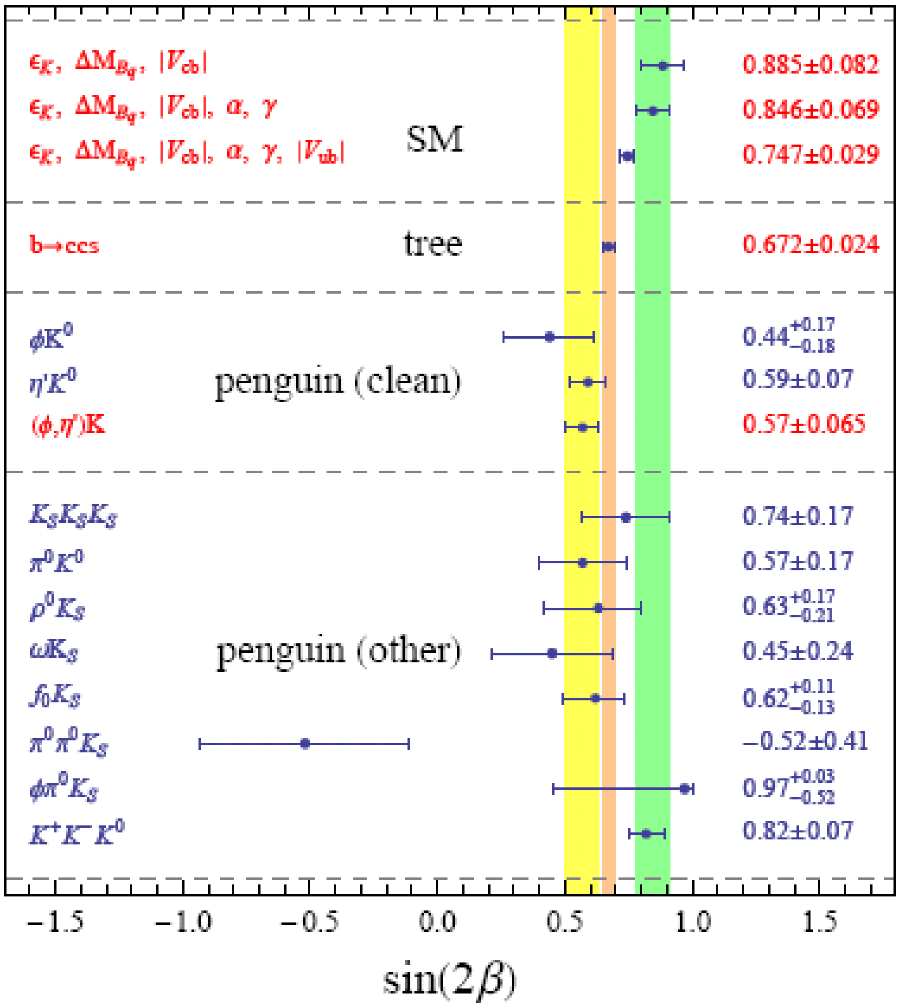
CDF & DΦ



- Each ~2 to 3.5 σ

c also MBma et al 0803.0659
LENZ+NIERSTE 0612167

Lunghi + AS, arXiv:0903.5059



mode	w/out V_{ub}	with V_{ub}
$S_{\psi K_S}$	2.4 σ	2.0 σ
$S_{\phi K_S}$	2.2 σ	1.8 σ
$S_{\eta' K_S}$	2.6 σ	2.1 σ
$S_{(\phi+\eta')K_S}$	2.9 σ	2.5 σ

If true

- What is the most interesting theoretical scenario for BSM?

HIGHLY SUBJECTIVE

WEXD

- What is the simplest scenario …?

SM4

MAY B LINKED

Contrasting B-Factory Signals from WEXD with those from SM

Agashe,Perez &AS, PRL'04
(Then for simplicity assumed Bd-mixing is SM)
O(1) uncertainties stressed. NOTE these are genuine PREDICTIONS

	Δm_{B_s}	$S_{B_s\to\psi\phi}$	$S_{B_d\to\phi K_s}$	$Br[b\to s l^+ l^-]$	$S_{B_{d,s}\to K^*,\phi\gamma}$	$S_{B_{d,s}\to\rho,K^*\gamma}$
RS1	$\Delta m_{B_s}^{SM}[1+O(1)]$	$O(1)$	$\sin 2\beta \pm O(.2)$	$Br^{SM}[1+O(1)]$	$O(1)$	$O(1)$
SM	$\Delta m_{B_s}^{SM}$	λ_c^2	$\sin 2\beta$	Br^{SM}	$\frac{m_s}{m_b}\left(\sin 2\beta, \lambda_c^2\right)$	$\frac{m_d}{m_b}\left(\lambda_c^2, \sin 2\beta\right)$

$m_{KK} \gtrsim 3$ TeV

Recently many very nice extensions (Buras,Falkowski, Perez,Weiler,Neubert)et al

HINTS

I. CPV observables are crucial; CP conserving processes seem to see hardly any effect.

II. EWP seems to have a NP component to it:

Reminiscent of the non-decoupling effects in SBGT's

III. HIERARCHY of effects due to the "New Physics" is suggestive of flavor dependence.

->This is suggestive of a "4th family"

-> 2 entirely new phases..THEREFORE NOT A PERTURBATION for CPV..NULL TESTS of SM-CKM MAY FAIL A LOT…Bs->ψφ , Bd->φ Ks are null tests whereas Brs show little effect.

-> 3 new mixing angles, 2 new masses: total of 7 parameters…

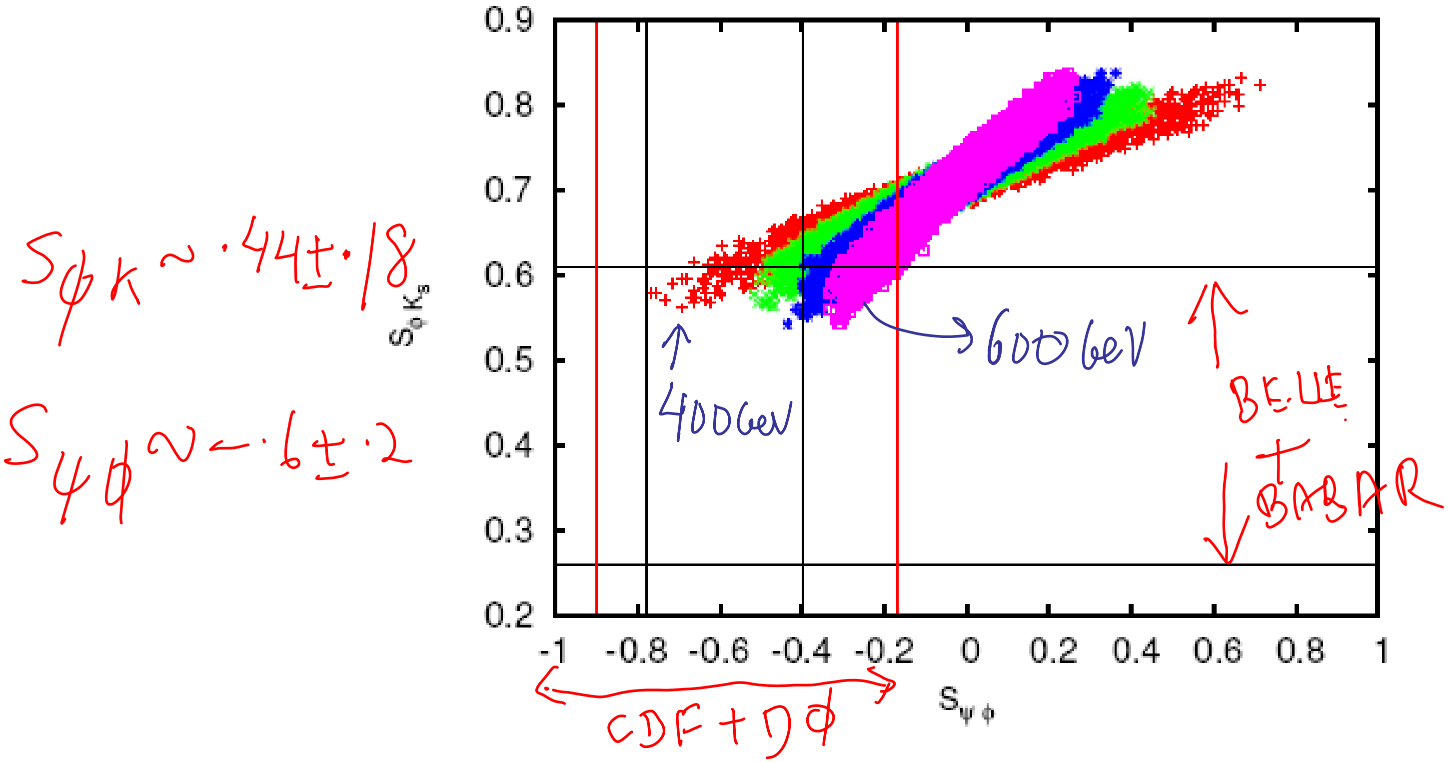


FIG. 3: Correlation between $S_{\phi K_s}$ and $S_{\psi\phi}$ for $m_{t'} = 400$ (red), 600 (green), 800 (magenta) and 1000 (blue) GeV respectively. The horizontal lines represent the experimental 1σ range for $S_{\phi K_s}$ whereas the vertical lines (Black 1-σ and red 2-σ) represent that for $S_{\psi\phi}$.

S-channel Higgs @ a MuC

Atwood&AS,PRD'95
Barger, Berger, Gunion, Han PRL'95

$$\sigma_{\mathcal{H}} = \frac{4\pi}{m_{\mathcal{H}}^2} B_\mu .$$

$$R(\mathcal{H}) = \frac{\sigma_{\mathcal{H}}}{\sigma_0} = \frac{3}{\alpha_e^2} B_\mu$$

$$\tilde{R}(\mathcal{H}) = \left[\frac{\Gamma_{\mathcal{H}}}{m_{\mathcal{H}}\delta} \arctan \frac{m_{\mathcal{H}}\delta}{\Gamma_{\mathcal{H}}}\right] R(\mathcal{H})$$

$$m_{\mathcal{H}}^2(1-\delta) < s < m_{\mathcal{H}}^2(1+\delta)$$

C also Barger, Berger, Gunion and Han, Physics Reports '96

CP violation study with transversely polarized beams @MuC

Extended Higgs Sector

Atwood +AS, PRD'95

C also Blochinger, Carena, Ellis et al '02

$$\sigma(\phi_\mu) = \left(1 - \cos 2\lambda_\mu \cos\phi_\mu + \sin 2\lambda_\mu \sin\phi_\mu\right)\sigma_0$$

CP phase cleanly

$$A_\mu \equiv \frac{\sigma(90^\circ) - \sigma(-90^\circ)}{\sigma(90^\circ) + \sigma(-90^\circ)} = \sin 2\lambda_\mu$$

Couplings to $f\bar{f}$ of non std $\mathcal{H}$

0^- or 0^+

SM Higgs

$$C_{\mathcal{H}ff} = C^0_{ff}\chi_f e^{i\gamma_5\lambda_f}$$

CP asymmetries via decay correlations (t,τ)

Let us define a coordinate system in the Higgs center-of-mass frame where the z' axis is in the direction of the f (i.e., t or τ) momentum. Let us now consider the f decays via $f \to X_i Y_i$ and the $\bar{f}$ decays $\bar{f} \to \bar{X}_j \bar{Y}_j$. We define the angle ϕ_{ij} to be the azimuthal angle between the p_{X_i} and the $p_{\bar{X}_j}$ projected into the x'-y' plane:

$$\sin(\phi_{ij}) = \frac{\vec{p}_{X_i} \times \vec{p}_{\bar{X}_j} \cdot \vec{p}_f}{|\vec{p}_{X_i}||\vec{p}_{\bar{X}_j}||\vec{p}_f|} . \quad (13)$$

CP-odd azimuthal asymmetry

$$A^f_{ij} = \frac{\Gamma(\sin\phi_{ij} > 0) - \Gamma(\sin\phi_{ij} < 0)}{\Gamma(\sin\phi_{ij} > 0) + \Gamma(\sin\phi_{ij} < 0)} .$$

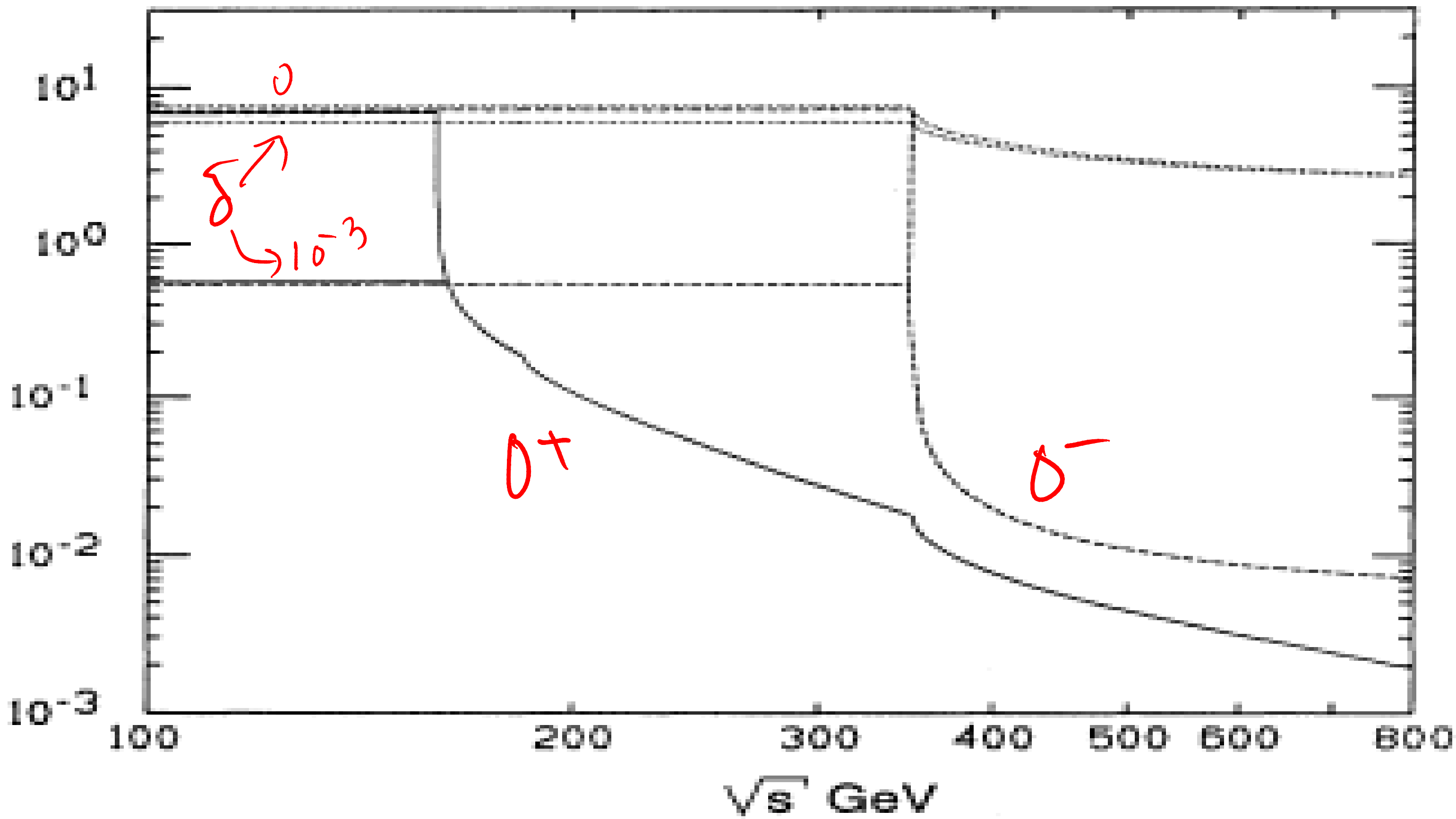


FIG. 1. The value for $R_{\mathcal{H}}$ as a function of $m_{\mathcal{H}}$ for the following three cases: (1) $\mathcal{H} = H$, $\alpha = \pi/4$, and $\chi_f = 1$ (solid); (2) $\mathcal{H} = A$ and $\chi_f = 1$ (dashes); (3) $\mathcal{H} = A$, and $\chi_l = \chi_d = 5$ and $\chi_u = \frac{1}{5}$ (dots). In each case the upper branch represents the result for $\sqrt{s} = m_{\mathcal{H}}$ while the lower branch is the result with an energy spread given by $\delta = 10^{-3}$.

(36) PRODUCTION Asymmetry for diff final states

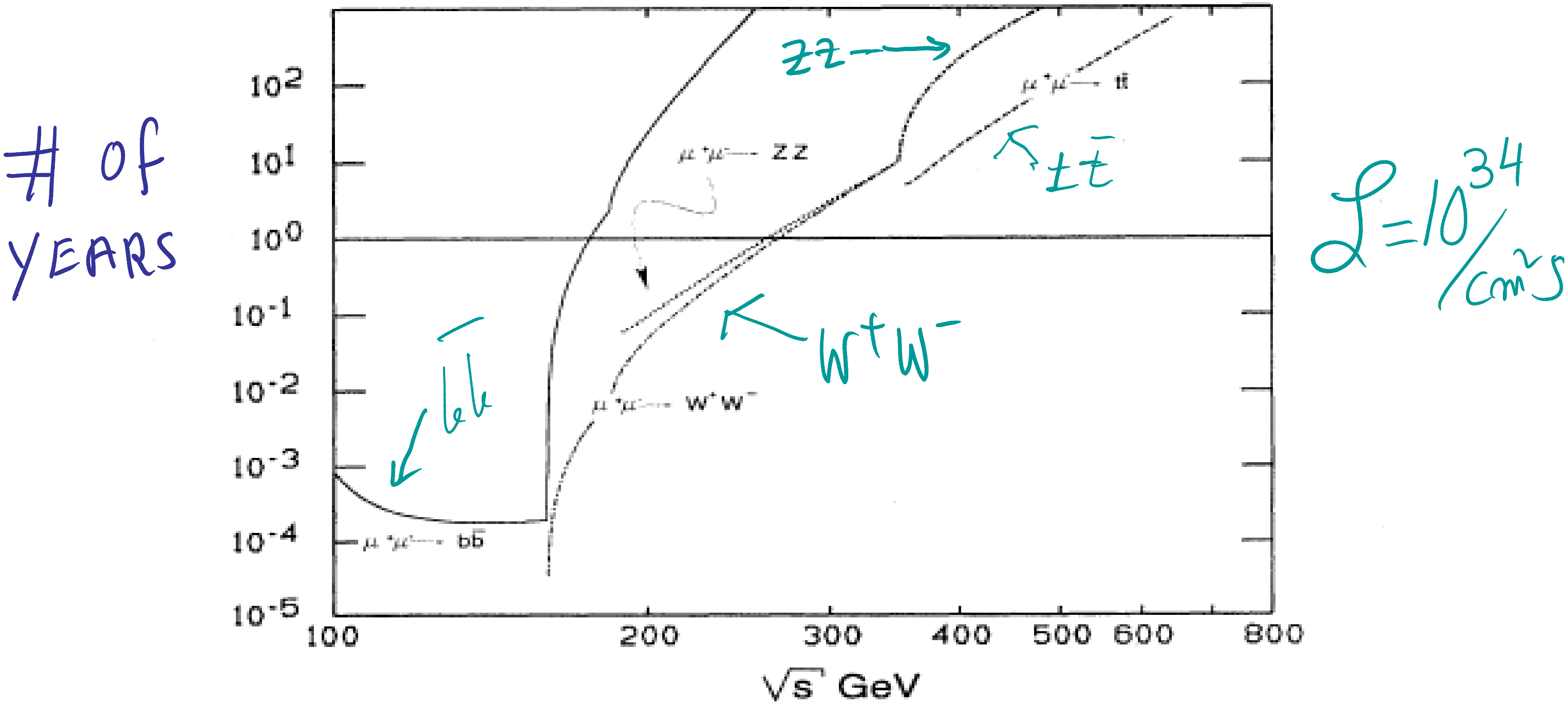


FIG. 2. The value of $y^{(3\sigma)}$ for case 1 (see caption to Fig. 1) assuming $\alpha = \pi/4 = \lambda_\mu$. $y^{(3\sigma)}_{b\bar{b}}$ is shown with the solid line, $y^{(3\sigma)}_{WW}$ with the dot-dashed line, $y^{(3\sigma)}_{ZZ}$ with the dotted line, and $y^{(3\sigma)}_{t\bar{t}}$ with the dashed line. (Note $y^{3\sigma}$ is the number of years needed to accumulate a 3σ production asymmetry. Note also that the horizontal line, $y^{3\sigma} = 1$, is drawn to serve as a point of reference.)

PRODUCTION & DECAY Asymmetries

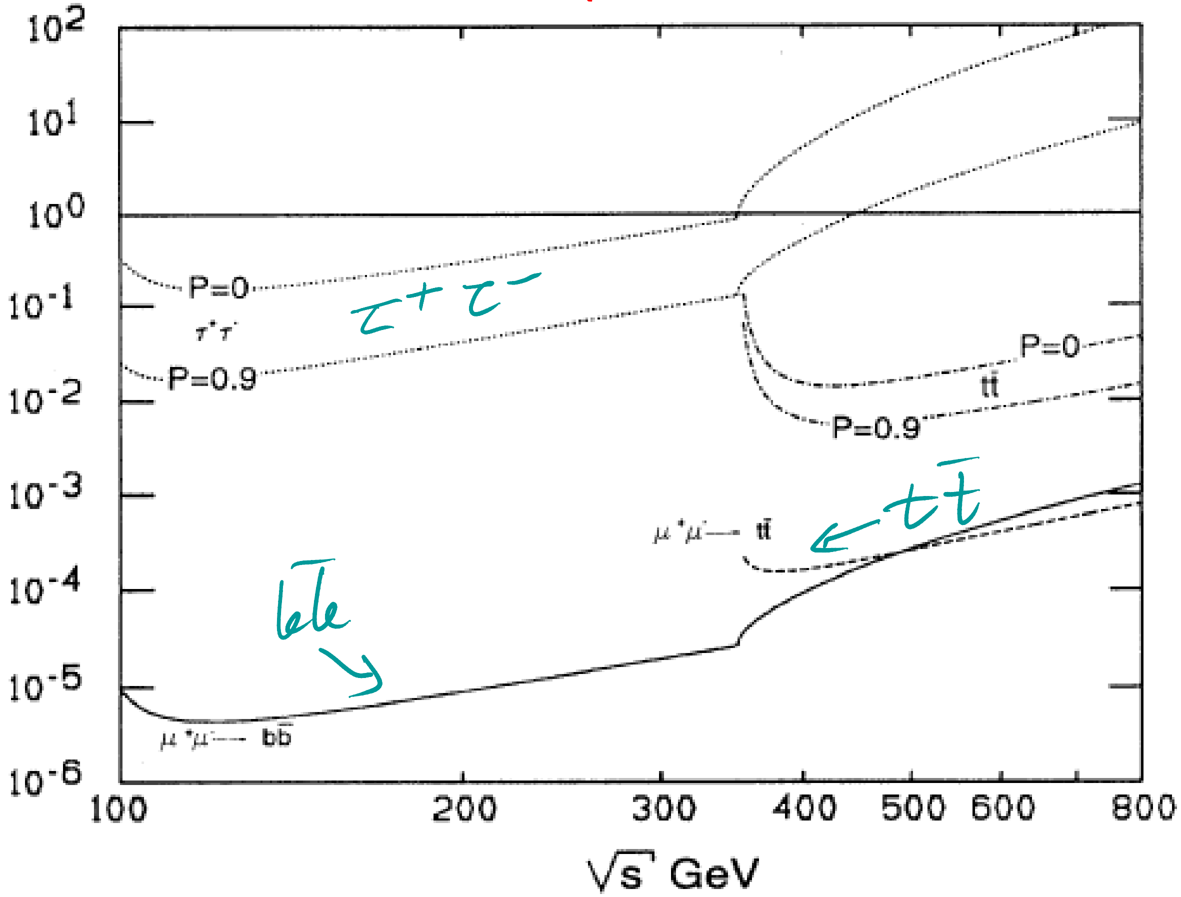


FIG. 4. The value of $y^{(3\sigma)}$ for case 3 assuming $\lambda_\mu = \lambda_\tau = \lambda_t = \pi/4$. $y^{(3\sigma)}_{b\bar{b}}$ is shown with the solid line, and $y^{(3\sigma)}_{t\bar{t}}$ with the dashed line. The results for decay asymmetries are also shown: $\hat{y}^{(3\sigma)}_{t\bar{t}}$ with the dot-dashed line and $\hat{y}^{(3\sigma)}_{\tau\tau}$ with the dotted line. Again in both of the latter cases the lower curve is for $P = 0.9$ and the upper curve is for $P = 0$. See captions to Figs. 1 and 2.

tc: a crucial final state

DISTINCTIVE HALLMARKS

of (RS) NMFV & also of SM4

$t \to cZ$ . . . . w or w/o CP

$D^0 - \bar{D}^0$ . . esp. with CP

$t \to c Z$

Effective Lagrangian from WED

Agashe,Perez,AS,PRL04

$$\mathcal{L}^t_{\rm FC} \ni \left(g_1 \bar{t}_R \gamma_\mu c_R + g_2 \bar{t}_L \gamma_\mu c_L \right) Z^\mu g_Z$$

with

$$g_{1,2} \sim \left[5 \cdot 10^{-3} \frac{(U_R)_{23}}{0.1}, 4 \cdot 10^{-4} \frac{(U_L)_{23}}{0.04} \right] \left(\frac{3\ \text{TeV}}{m_{KK}} \right)^2 ;$$

expect $O(1)$

AGASHE et al EWPT JHEP'03 $\Rightarrow m_{KK} \sim 3$ TeV

C also Aquino, Burdman, Eboli, PRL'07

Experimental signals @ the MuC

$$\mathrm{BR}\,(t \to cZ) \;\sim\; 10^{-5}\left(\frac{3\ \mathrm{TeV}}{m_{KK}}\right)^4\left(\frac{(U_R)_{23}}{0.1}\right)^2$$

≈ 1

Expect around ~10^4 t quarks, so most likely it'd be useful to Contstrain the couplings and or KKmasses but can't be sure

t->cZ in LRS

- In RS there are 2 types of distinct contributions that are roughly of the same size:
- 1) mixing of Z with Z_KK..this will be suppressed in LRS by y~6 compared to RS and therefore small
- 2)mixing between t_R and t_L^KK. This mixing is controlled by the 5D yukawa which is unchanged in LRS and therefore BR(t->cZ) is again ~10^{-5}… Correspondingly potential for relatively high Br for t->cZ, CPV (and D^0 mixing) remain good in LRS as in RS

t -> c γ,glu

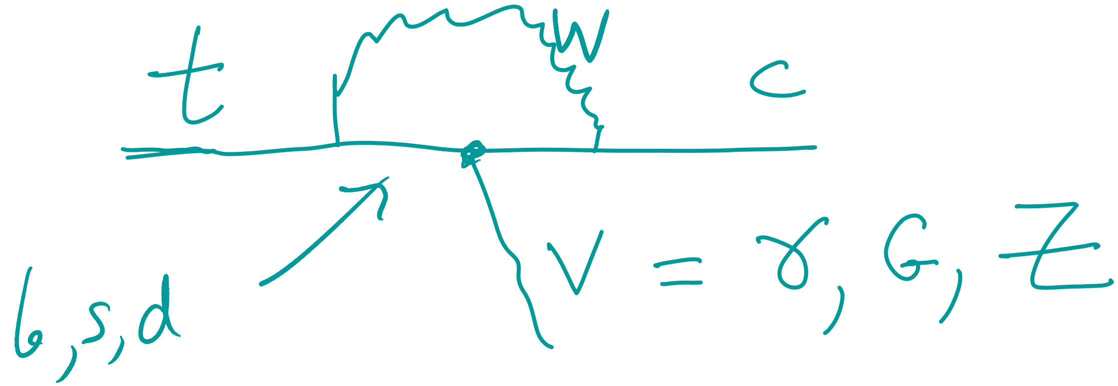
The dipole operators give

$$\mathrm{BR}\,(t \longrightarrow c\gamma, G) \;\sim\; 10^{-10,-9} \times \left(\frac{3\ \mathrm{TeV}}{m_{KK}}\right)^2 \left(\frac{(U_R)_{23}}{0.1}\right) \left(\frac{\lambda_{5D}}{4}\right)^4$$

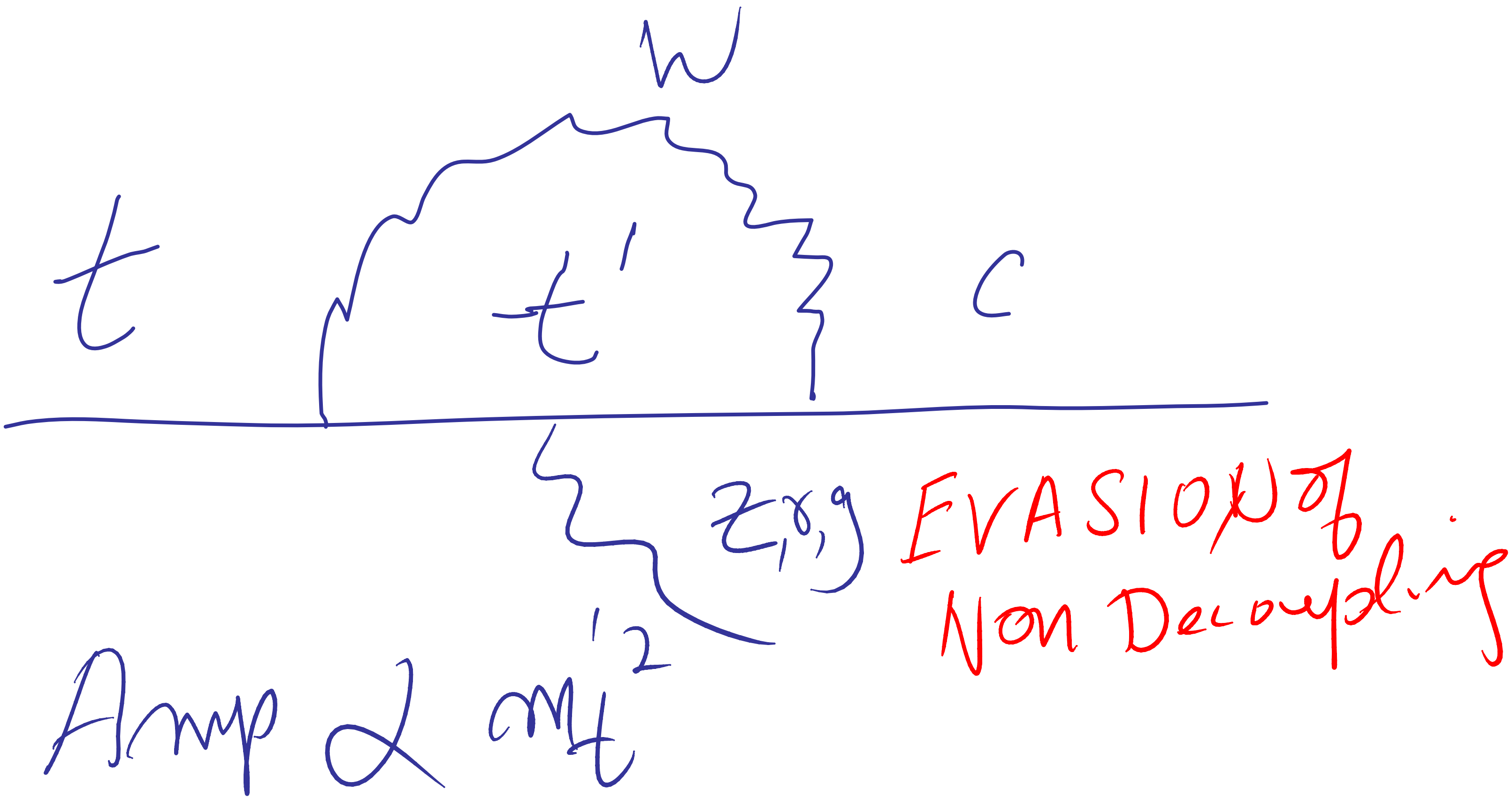
Comparison with the SM

- In SM & in 2HDM BR (t -> c V) with V= γ , G, Z computed long ago (Eilam, Hewett, A.S, PRD'91)

In the SM 1-loop graph is extremely GIM suppressed as $\{(m_b , m_s , m_d)^2 / m_t^2) \to 0 \}$



SM4 changes the tc story



COMPARISONS

	WED(1)	SM3(2)	SM4(3)	SUSY(4)
$t \to cZ$	$\lesssim 10^{-5}$	$\sim 10^{-13}$	$\lesssim 10^{-6}$	$\lesssim 10^{-6}$
$t \to c\gamma$	$\lesssim 10^{-10}$	$\sim 10^{-12}$	$\lesssim 10^{-9}$	$\leq 10^{-6}$
$t \to cg$	$\lesssim 10^{-9}$	$\sim 10^{-10}$	$\lesssim 10^{-8}$	$\leq 10^{-4}$

SIGNIFICANT DIFFERENCES

1) APS hep-ph 0606293. 2) EILAM, Hewett + AS '91
4) LIU, LI, YANG, JIN: "UNCONSTRAINED MSSM" 0406155
3) AHRIB + HOU 'JHEP '06; EILAM, MELIC, TRAMPETIC '0909.3227

Implications of tc(u)FCNC for the MuC

- $l^+ l^-$ -> t c : A unique, clean signal may be possible.

The importance of this reaction for searching fcnc was 1st stressed in Atwood, Reina & A.S, PRD'96.

Extensively studied since then, See e.g.
Bar-Shalom & Wudka, PRD'99 (eff. Lag);
J.A.Aguilar-Saavedra,PLB'01 (Exptal aspects TESLA vs LHC);
Han & Hewett, PRD'99 (eff. Lag)
Cao,Xiong & Yang, NPB'03 (SUSY)
Yue,Wang,Di & Yang,PLB'05 (littlest Higgs);
Arhrib & Hou, JHEP'06 (4th family)…….

$l^+ l^-$ -> t c: Some notable features

- fcnc searches with b s (or in general q q' , light flavors)…At LC/MuC these are extremely difficult to detect due to the overwhelming background from b b (q q) X (mis) tagging efficiency….
- CONTRAST this with tc….Here fcnc reaction can be studied simply very efficiently by staying at cm energies of about 200-335GeV. Then t t is NOT possible.

- **Thus important physcs is possible even at a low energy starting scale**

- At such energies, due to its huge mass, E_t is significantly more than Ecm/2 ….
- The opposite side is an effectively massless "charm"
  jet carrying energy appreciably less than Ecm/2
- AND IT MUST NOT CONTAIN A b-jet. So lots of handles.
- Recall also top decays are very efficient analyzers of its polarization..
  which can be a very helpful diagnostic of the underlying dynamix.

$\mu^+ \mu^- \to t\, c$ @ the MuC

Agashe, Perez, AS '04

$$R_{tc} = \frac{\zeta_{tc}(a^2_{Ztc} + b^2_{Ztc})(a^2_{Zee} + b^2_{Zee})}{[(1 - m^2_Z/s)4\pi\alpha_{em}]^2}$$

$$R_{tc} = \frac{\sigma(e^+e^- \to [t\bar{c}+c\bar{t}])}{\sigma(e^+e^- \to \gamma \to \mu^+\mu^-)} \qquad \zeta_{tc} = \frac{9}{2} y_c^2 y_t [1 + \frac{y_c}{3y_t}]$$

R_{tc} is around $2X10^{-5}$ for Ecm~200GeV and increases to ~ $2X10^{-4}$ at higher energies

Forward-Backward Asymmetry in $l^+ l^-$ -> t c, a key prediction of WEXD

For unpolarized beams:

$$A_{FB}(e^+e^- \to t\bar{c}) = \frac{2\,\zeta_{FB}\, a_{Ztc} b_{Ztc} a_{Zee} b_{Zee}}{(a^2_{Ztc} + b^2_{Ztc})(a^2_{Zee} + b^2_{Zee})}$$

$$\zeta_{FB} = \frac{1 + (y_c / y_t)}{1 + [y_c / (3 y_t)]}$$

A_{FB} is ~7% @ low energies and increases with energy to ~11%; higher with pol. beams. A distinctive feature of WED is that it predicts A_{FB} positive due to dominance of RH coupling.

Prospects for CP violation

- In general, in RS1 scenarios, the mixing coeffs. e.g. $(U_R)_{23}$ are complex ; therefore should expect new CP-odd phase(s)

- $l^+ \ l^- \to t\ c$ (with $t \to b\ W$) decay and a charm jet so FS has several momenta (inc. W Pol.) allowing construction of T_N odd observables which can be used for extracting info on new CP-odd phase(s) associated with WEXD

Possibilty of top-quark edm with WEXD

Seems DIFFICULT @ LHC

- In RS direct KK-exchanges can endow CP-odd phase(s) to flavor-diagonal processes.
- This can lead to top-quark edm: @ 1-loop

$$d_t \sim 10^{-19} \left(\frac{3 \text{ TeV}}{m_{KK}}\right)^2 \left(\frac{\lambda_{5D}}{4}\right)^2 \text{e-cm}$$

At the LC/MuC using $l^+ l^- \to t\,(b\,W^+)\,t(b\,W^-)$
edm form-factors >~ 10^{-20} - 10^{-21} e-cm seem accessible (with high lumi)
See Atwood & AS, PRD'92; Bernreuther, Ma & Schroder,PLB'92

Atwood, Bar-Shalom, Eilam & AS, Phys. Rep'01.

type of moment $(e-cm)$ ⇓	$\sqrt{s}$ (GeV) ⇓	Standard Model	neutral Higgs $m_h = 100-300$	charged Higgs $m_{H+} = 200-500$	Supersymmetry $m_{\tilde{g}} = 200-500$
$\lvert\Im\mathrm{m}(d_t^\gamma)\rvert$	500	$< 10^{-30}$	$(4.1-2.0)\times10^{-19}$	$(29.1-2.1)\times10^{-22}$	$(3.3-0.9)\times10^{-19}$
	1000		$(0.9-0.8)\times10^{-19}$	$(15.7-1.0)\times10^{-22}$	$(1.2-0.8)\times10^{-19}$
$\lvert\Re\mathrm{e}(d_t^\gamma)\rvert$	500	$< 10^{-30}$	$(0.3-0.8)\times10^{-19}$	$(33.4-1.5)\times10^{-22}$	$(0.3-0.9)\times10^{-19}$
	1000		$(0.7-0.2)\times10^{-19}$	$(0.3-2.7)\times10^{-22}$	$(1.1-0.3)\times10^{-19}$
$\lvert\Im\mathrm{m}(d_t^Z)\rvert$	500	$< 10^{-30}$	$(1.1-0.2)\times10^{-19}$	$(15.8-2.5)\times10^{-22}$	$(1.1-0.3)\times10^{-19}$
	1000		$(0.2-0.2)\times10^{-19}$	$(9.2-1.2)\times10^{-22}$	$(0.4-0.3)\times10^{-19}$
$\lvert\Re\mathrm{e}(d_t^Z)\rvert$	500	$< 10^{-30}$	$(1.6-0.2)\times10^{-19}$	$(22.9-0.8)\times10^{-22}$	$(0.1-0.3)\times10^{-19}$
	1000		$(0.2-1.4)\times10^{-19}$	$(0.6-1.9)\times10^{-22}$	$(0.4-0.1)\times10^{-19}$

Table 3: *The contribution to the top quark EDM ($d_t^\gamma(s)$) and ZEDM ($d_t^Z(s)$) form factors, in units of e-cm, at $s = (p_t + p_{\bar{t}})^2 = 500^2,\ 1000^2\ GeV^2$, for the SM (where it is a purely guess-estimate) and for some of its extensions. 4th column shows results for neutral Higgs exchanges in any MHDM's with a CP-violating htt coupling of the form $(g_W/\sqrt{2})(m_t/m_W)(a_t^h + ib_t^h\gamma_5)$, an hZZ coupling $g_W(m_Z^2/m_W^2)c^h g_{\mu\nu}$ and with $a_t^h = b_t^h = c^h = 1$. 5th column is for charged Higgs exchanges in any MHDM's of three or more doublets with a CP-violating H^+tb coupling of the form $(g_W/\sqrt{2}m_W)\left[m_t U_t(1+\gamma_5)/2 + m_b U_b(1-\gamma_5)/2\right]$ and with $\Im\mathrm{m}(U_t U_b^*) \equiv \Im\mathrm{m}(V) = 5$. Only the contribution from the lightest neutral or charged Higgs is retained. 6th column shows the results for the MSSM where only the dominant 1-loop gluino exchange diagram with gluino masses $m_{\tilde{g}} = 200-500$ GeV is considered, in which CP violation arises from $\tilde{t}_L - \tilde{t}_R$ mixing and is proportional to $\xi_{CP}^t \equiv \sin(2\theta_t)\sin(\beta_t)$, where θ_t and β_t are the angle and phase that parameterize the $\tilde{t}_L - \tilde{t}_R$ mixing matrix. The numbers are given for $\xi_{CP}^t = 1$ and for stop masses of 50 GeV (light stop) and 400 GeV (heavy stop).*

Summary

- MuC can be a very valuable "FACTORY" for S-channel resonance physics: Higgs, KKZ, KKG…
- Excellent probe for Particles @ the IR brane
- Excellent probe of the effective UV scale
- Plethora of precision studies become possible including top production and decay dynamics, CP tdm form factors, t fcnc…….
- It is a potent tool and should be vigorously explored

XTRAS

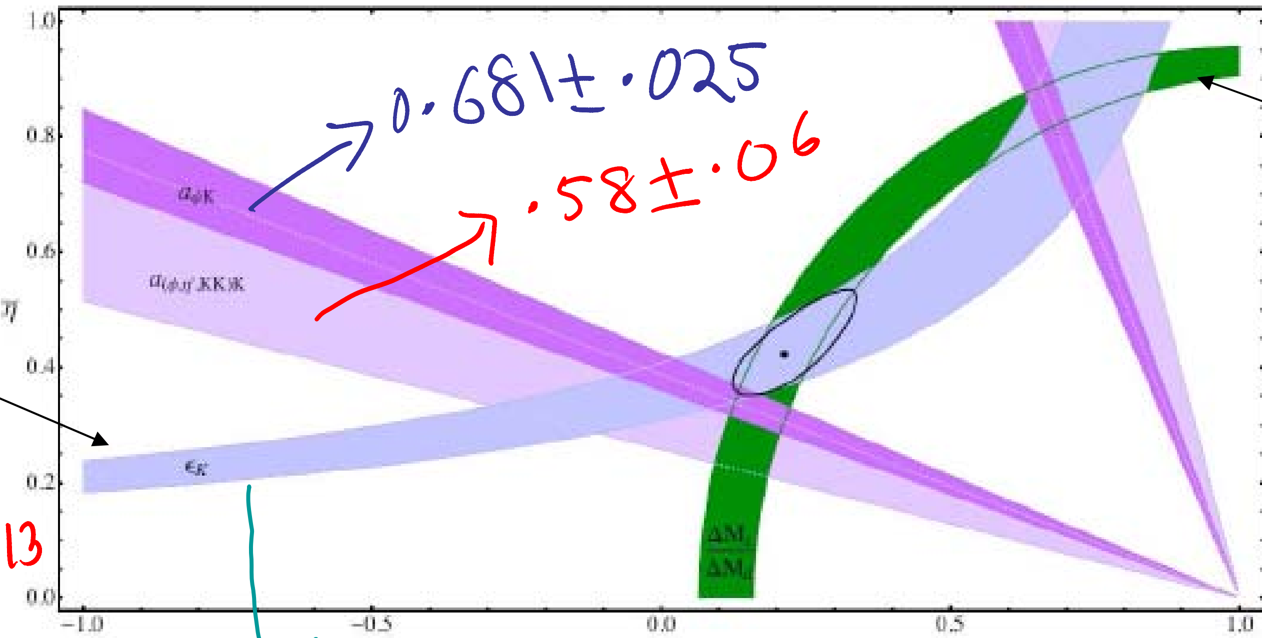
Important to Examine only DeltaF=2 observables:Leave out Vub

sin 2 β = 0.87+-.09{Lunghi+AS,hep-ph/08034340}

(became possible only due significantly reduced error in B_K)

Antonio et al (RBC-UKQCD) 0702042

Gamiz et al; Becirevic; Tantalo



$\hat{B}_K = .720 \pm .013 \pm .037$

$|V_{cb}| = 40.8 \pm .6 \times 10^{-2}$

include BURAS+GUADAGNOLI CORR. (0805.3887)

$\xi = 1.20 \pm .06$

FIG. 1: Unitarity triangle fit in the SM. All constraints are imposed at the 68% C.L.. The solid contour is obtained using the constraints from ε_K and $\Delta M_{B_s}/\Delta M_{B_d}$. The regions allowed by $a_{\psi K}$ and $a_{(\phi+\eta'+2K_s)K_s}$ are superimposed.

2.1-2.7 σ- deviation from the directly measured values of sin 2 β requires careful follow-up

B_K - Preliminary Results

C.Kelly for RBC-UKQCD @ LATTICE'09
Beijing, 7/26/09

- 24^3 paper value (*Phys. Rev. Lett.* 100:032001,2008):

$$B_K^{\overline{MS}}(2\,\text{GeV}) = 0.524(30)$$

RBC OLD (USED BY LUNGHI + AS)

- New value:

$$B_K^{\overline{MS}}(2\,\text{GeV}) = 0.537(19)$$

NEW (PRELIMINARY)

Source	24^3 Mag	New Mag.	%	Comment
stat	0.010	0.006	1.1	Stat err. from sim. fit
ChPT	0.010	0.013	2.4	analytic expansion $\sim NLO^2$ est.
FV	0.005	??	??	NLO ChPT FV corrections
NPR	0.013	0.013	2.4	Comb. stat + sys err. (mult. ex + non-ex MOM schemes)
Scaling	0.021	0	0	Scaling inc. in fits
Unphys. m_h	0.005	0	0	Reweighting
Total	0.030	0.019	3.5	Preliminary

Aubin,Laiho,VandeWater
arXiv:0905.3947

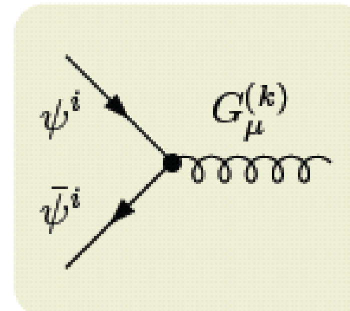
$$B_K^{\overline{MS},NDR}(2\text{GeV}) = 0.527(6)(20)$$

DIFF METHOD

RS-GIM mechanism*

COURTESY NEUBERT @ MORIOND09

- Quark-quark-gluon vertex in flavor eigenbasis:



$$\bar{\psi}^i\, G_\mu^{(k)}\, \psi^i \sim -i g_s^{4\mathrm{D}} \gamma_\mu \sqrt{L}\, F_{c_{\psi^i}}^2\,, \quad F_{c_{\psi^i}} \sim \epsilon^{-c_{\psi^i}-1/2}$$

- Quark-quark-gluon vertex in mass eigenbasis:

$$\bar{q}_L^i\, G_\mu^{(k)}\, q_L^j \sim -i g_s^{4\mathrm{D}} \gamma_\mu \sqrt{L}\, F_{c_{Q_i}} F_{c_{Q_j}}\,, \quad \bar{q}_R^i\, G_\mu^{(k)}\, q_R^j \sim -i g_s^{4\mathrm{D}} \gamma_\mu \sqrt{L}\, F_{c_{q_i}} F_{c_{q_j}}$$

Important features:

$\ln \frac{\Lambda_{UV}}{\Lambda_{IR}} = L = kr\pi \sim 35 \gg 1$

- in flavor eigenbasis KK gluon couples to quarks flavor diagonally but non-universally, so that after rotation to mass eigenstates tree-level FCNCs arise
- since FCNCs are proportional to $F_{c_{A_i}} F_{c_{A_j}}$, exponential suppression of fermion profiles $F_{c_{A_i}}$ at IR brane guarantees **flavor protection (RS-GIM)**

*Agashe *et al.*, hep-ph/0406101, hep-ph/0408134

OBLIQUE CORRECTIONS IN RS

$$S_{tree} \approx 2\pi\,(v/\kappa)^2\left[1 - \frac{1}{kr_c\pi} + \xi(c)\right],$$

$$T_{tree} \approx \frac{\pi}{2\cos\theta_W^2}(v/\kappa)^2\left[kr_c\pi - \frac{1}{kr_c\pi} + \xi(c)\right],$$

Agashe, D, M Sundrum

$$y \equiv \frac{kr_c\pi|_{RS}}{kr_c\pi|_{LRS}} \approx 6.$$

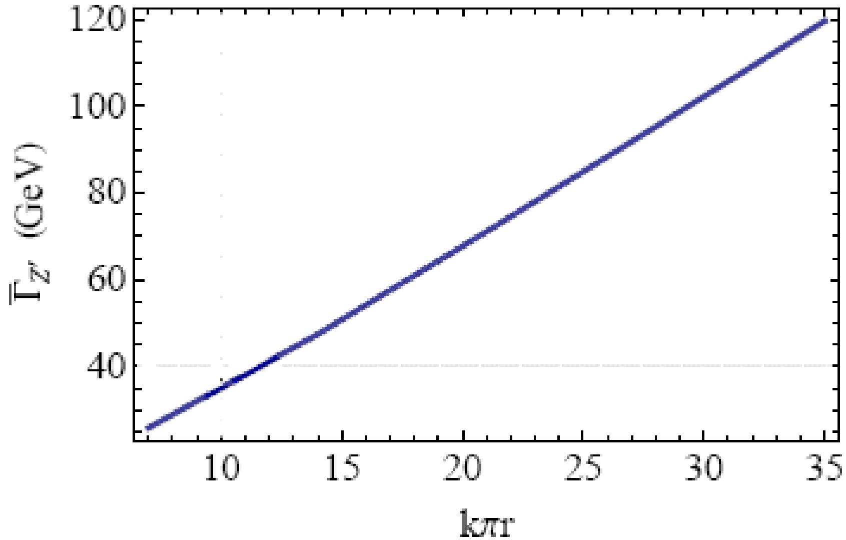


FIG. 1: The total width of a 2 TeV Z' averaged over the three neutral states.

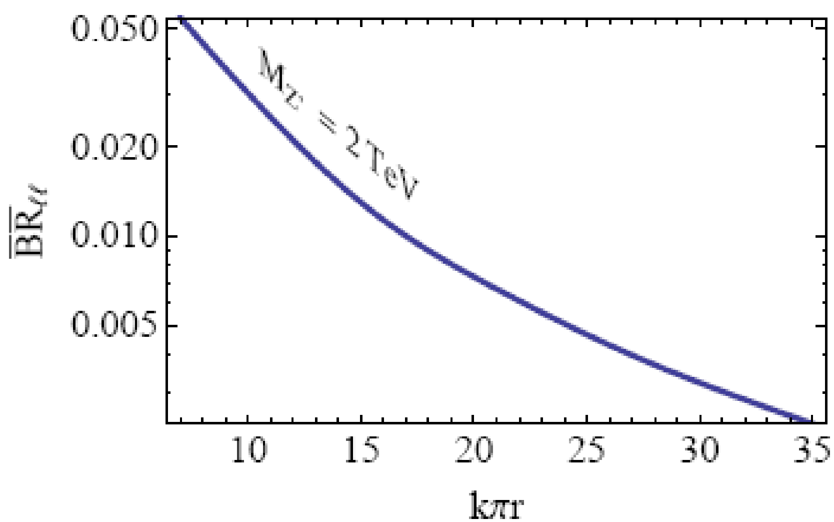


FIG. 2: The leptonic BR (into each of e or μ pairs) of a 2 TeV Z' averaged over the three neutral states.

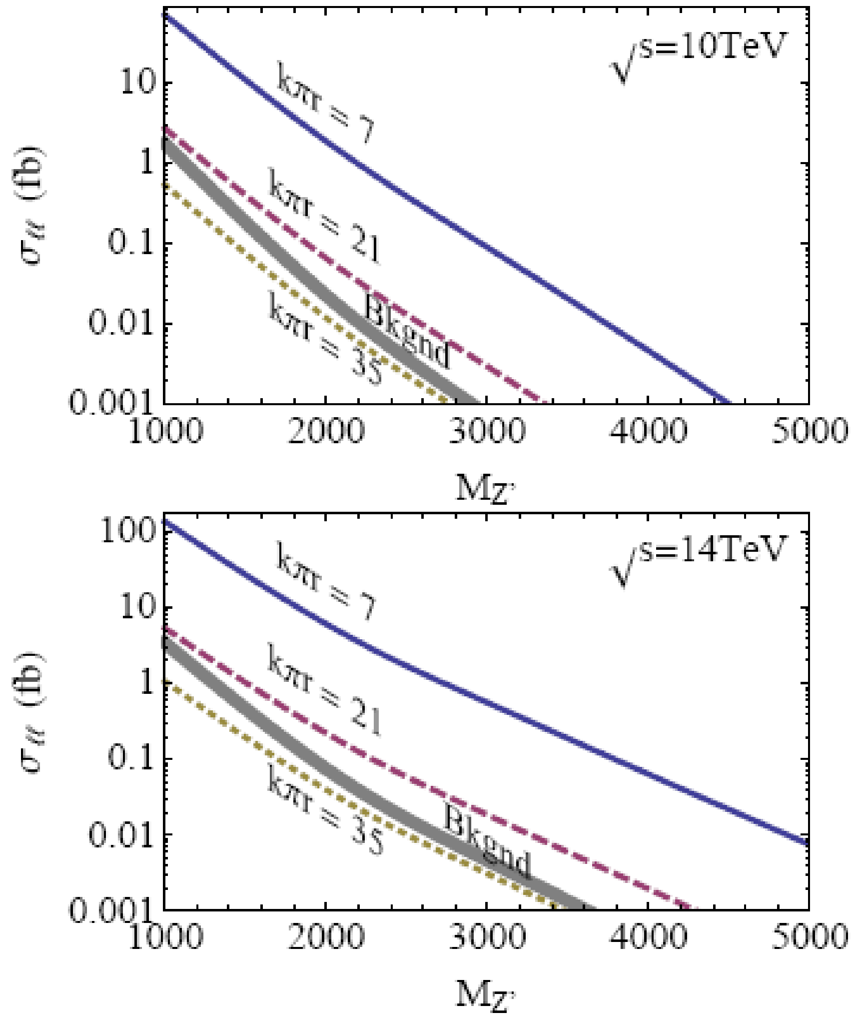
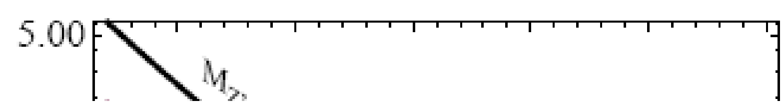


FIG. 3: The cross section $\sigma(pp \to Z' \to \ell^+\ell^-)$ versus $M_{Z'}$ at the LHC, after the cuts in Eq. (7) (for $\ell = e$ or μ, not the sum), and the SM background. The upper (lower) panel corresponds to $\sqrt{s} = 10\,(14)$ TeV.



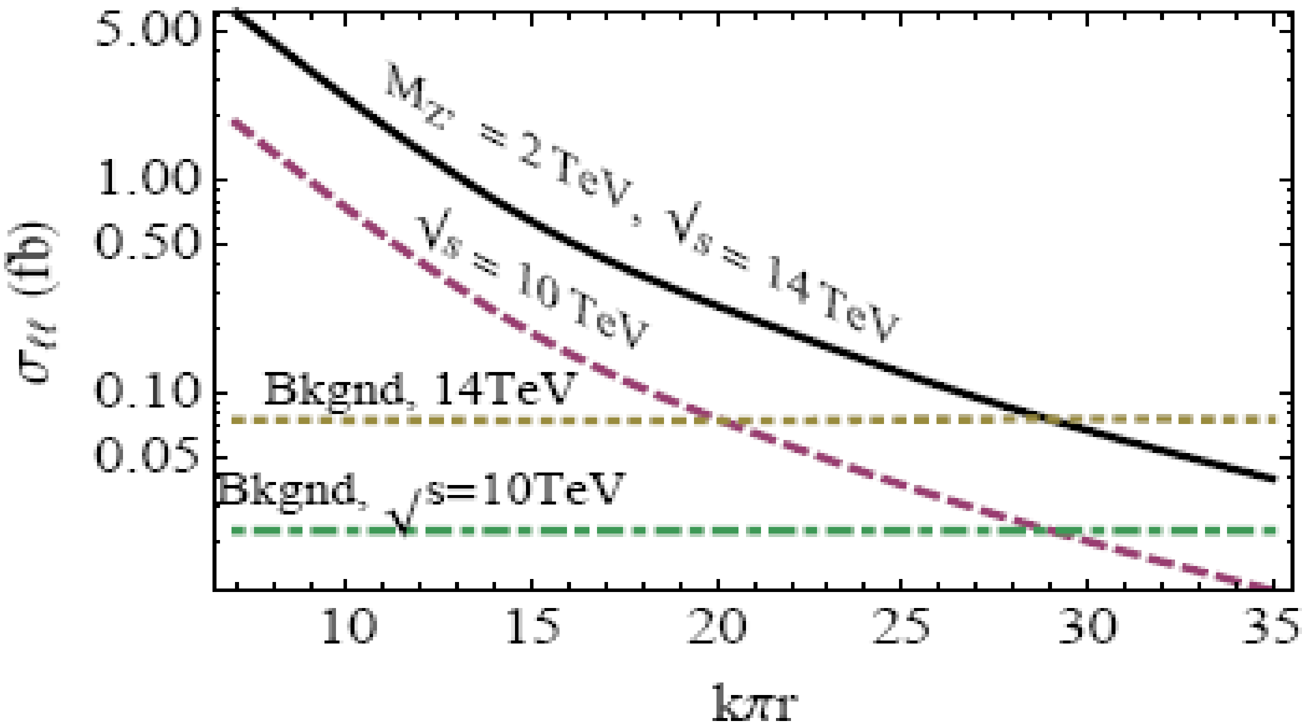


FIG. 4: The predicted $\sigma(pp \to Z' \to \ell^+\ell^-)$ at the LHC after the cuts in Eq. (7) (for $\ell = e$ or μ, not the sum), as a function of $kr_c\pi$, and the SM background. Here, we have set $M_{Z'} = 2$ TeV.

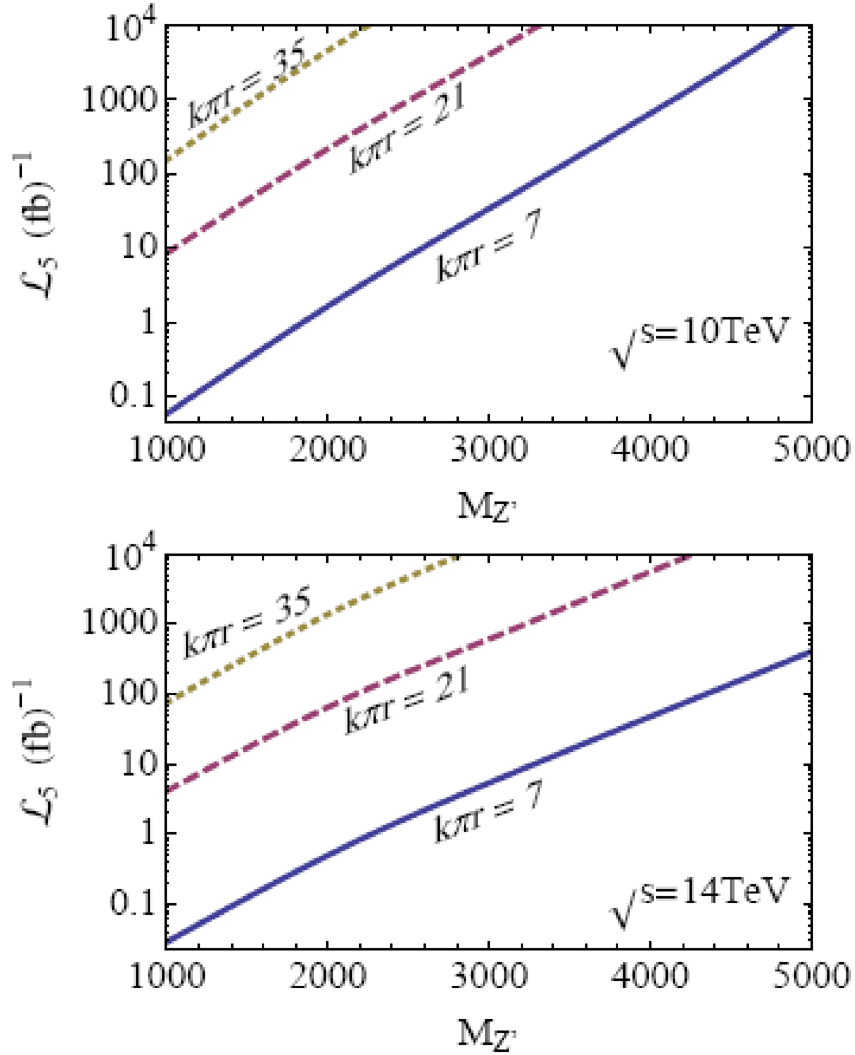


FIG. 5: The luminosity required for $5\,\sigma$ significance at the LHC in the $pp \to \ell^+\ell^-$ channel (with $\ell = e$ or μ, not the sum) requiring at least 3 events. The upper (lower) panel corresponds to $\sqrt{s} = 10\,(14)$ TeV.