New Strong Dynamics at the μ-collider

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Outline

- Why new Tev-scale strong dynamics?
- features of models: cast of characters
- signals of strong dynamics at μ-collider

Why new Tev-scale strong dynamics?

- don't need a Higgs boson for EWSB

add in some new fermions:

"techni-fermions"

chiral EW charges

$$T_{iL} = (N_{TC}, 2)_0$$
$$T_{iR} = (N_{TC}, 1)_{\pm 1/2}$$

new strong gauge interaction "technicolor"

- dynamical symmetry breaking has precedents in nature (QCD, superconductivity)

... but requires strong interactions

new Tev-scale strong dynamics

many different names & slightly different mechanisms

multi-scale technicolor

topcolor-assisted technicolor

topcolor

top-seesaw

Technicolor

composite Higgs

warped extra dimensions/RS

Extended Technicolor

Bosonic technicolor

deconstructed models/(D)BESS

Why not Tev–scale strong dynamics?

usual arguments:

- Precision electroweak: S,T,U too large

assumes a particular model for TeV-scale dynamics = rescaled QCD

should not exclude other models based on this

New dynamics could easily be very different (i.e. 'walking coupling') (interesting lattice progress.. see talk by George)

Also: $\sin^2\theta_W$ not totally settled: 3 sig variation among 'best' measurements: S = 0.45 preferred by LEP alone

(Chanowitz, Marciano)

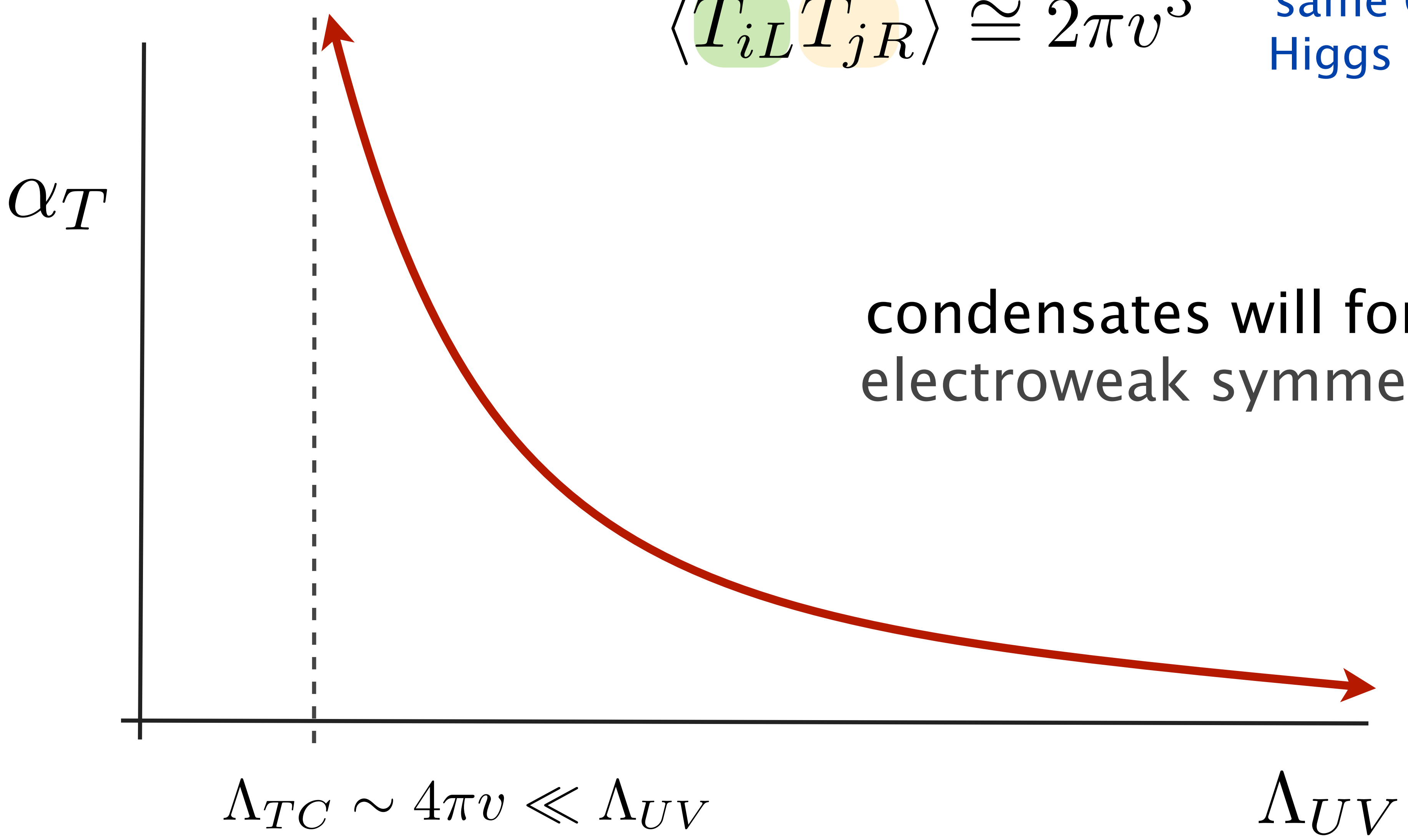
Why new Tev-scale strong dynamics?

ONLY natural way to generate exponentially large hierarchies

if technicolor becomes confining at ~ TeV ...

$$\langle \bar{T}_{iL} T_{jR} \rangle \cong 2\pi v^3$$

same Q# as a Higgs doublet



condensates will form, causing electroweak symmetry to break

Why new Tev-scale strong dynamics?

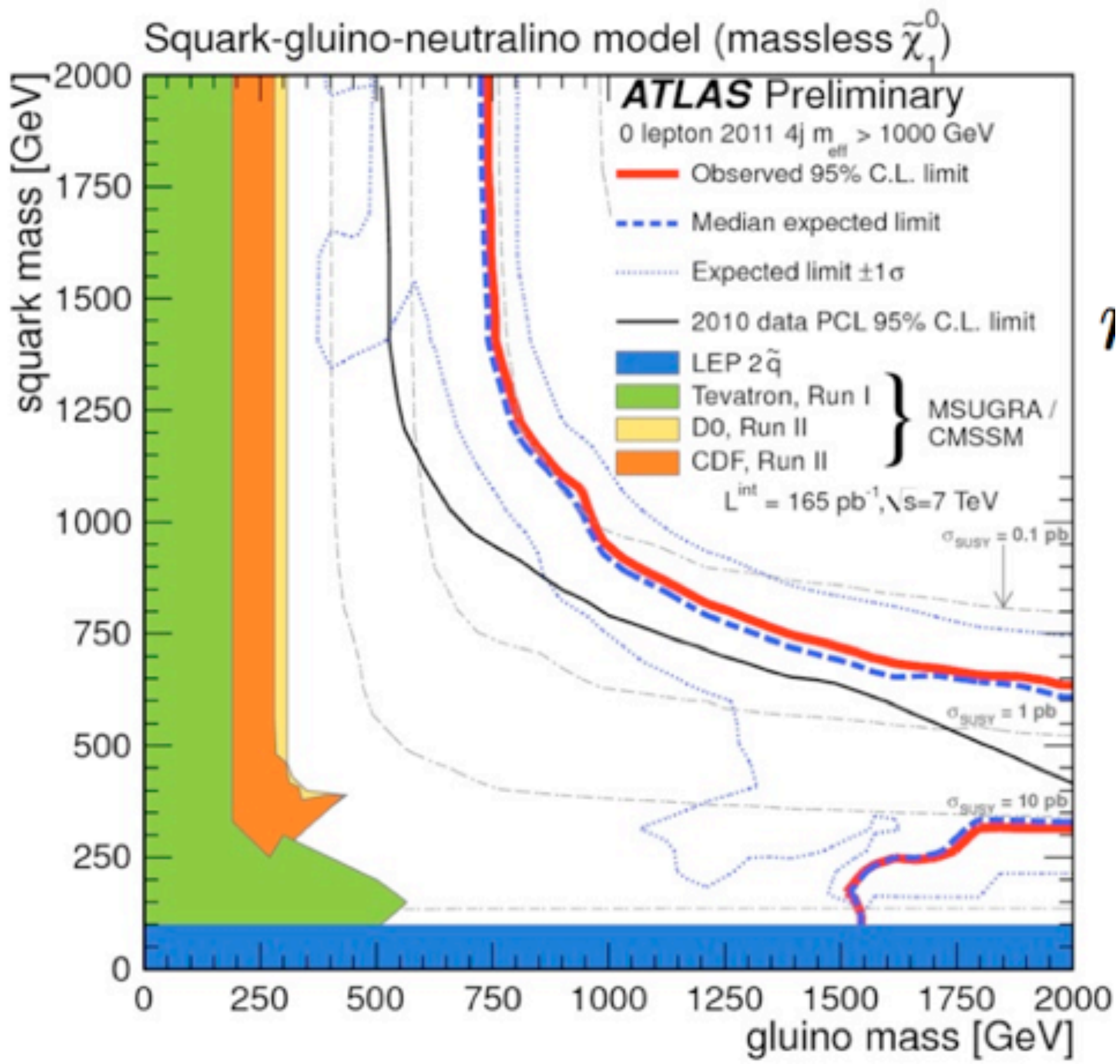
TeV-scale strong dynamics different than most BSM scenarios

No light colored states:
not squeezed by LHC (yet...), all EW produced

No light Higgs...

Not tied to Z_2 dark matter...
instead: techni-baryons

(more from Graham)

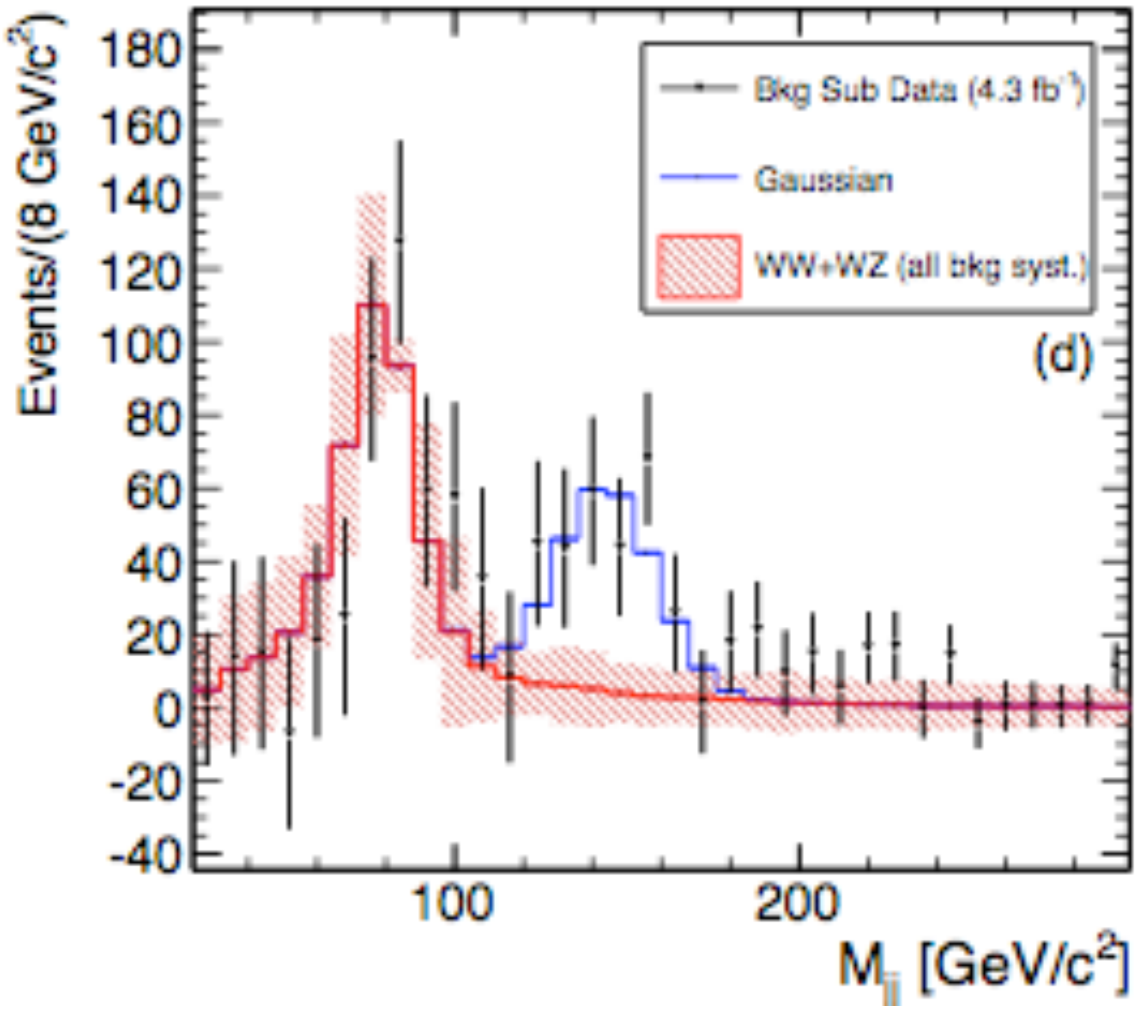


Why new Tev-scale strong dynamics?

TeV-scale strong dynamics fits several recent, interesting collider results

A^{tt}_{FB} : fit naturally in topcolor/top-seesaw models (Cui, Han, Schwartz)

Wjj: fit by light techni-resonances, as in multi-scale TC (Eichten, Lane, AM)



Cast of Characters:

exactly which states are lurking at the TeV scale depends somewhat from model to model

present in **all** models (wide range of masses)

- spin-1, EW resonances: ρ_T, Z', W_{KK}

model dependent

- spin-0, pseudoscalars: "technipions", "top-pions"
- spin-0, scalars: "top-Higgs"
- spin-1, colored resonances: "colorons", "axigluons"
- heavy fermions: ψ_{KK}, "techni-baryons"
- more.. (spin-2, spin-3/2..)?

Signals at μ-collider, spin-0:

"techni-pions": present whenever there are multiple sources of EWSB (TC2, multi-scale TC, etc.) or large techni-chiral symmetry

ex: $\langle \bar{T}_{1L} T_{1R} \rangle \sim v_1^3 e^{i\pi_{T1}/v_1} \qquad \langle \bar{T}_{2L} T_{2R} \rangle \sim v_2^3 e^{i\pi_{T2}/v_2}$

- one combination of π_{T1}, π_{T2} eaten by $W^{\pm}/Z$
- other combination remains, receive mass from explicit breaking of chiral symmetry of constituents

important features:

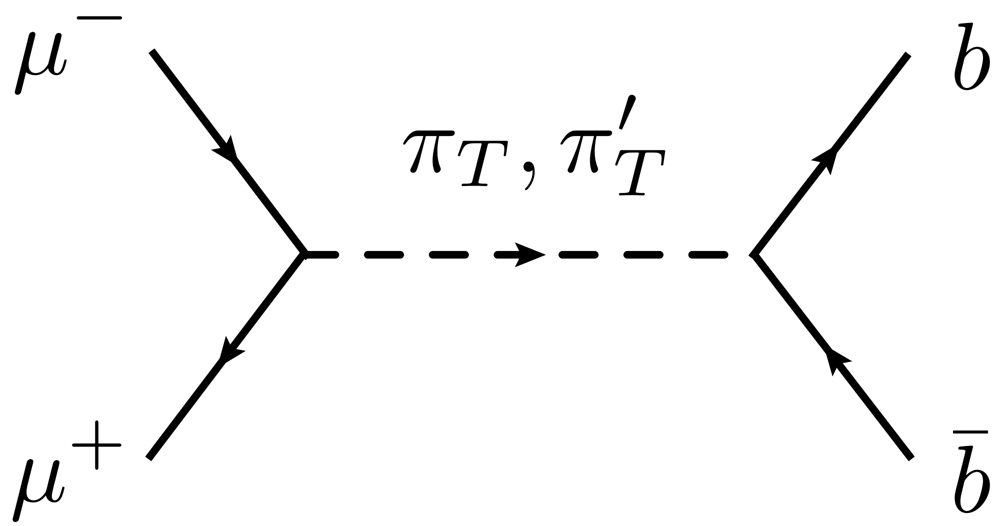
- PNGBs -> often the lightest new state around
- usually couple to SM fermions w/ strength ~ m_f

$$\frac{1}{\Lambda^2} \langle \bar{T}_{1L} T_{1R} \rangle \bar{f}_L f_R \quad \longrightarrow \quad m_f \Big(+ i \frac{\pi_T}{v} + \cdots \Big) \bar{f}_L f_R$$

Signals at μ-collider, spin-0:

as coupling ~ m_f, enhanced at MuC by $(m_\mu/m_e)^2$

at MuC can be produced in the s-channel, decays back into quarks/leptons, possibly to gluons



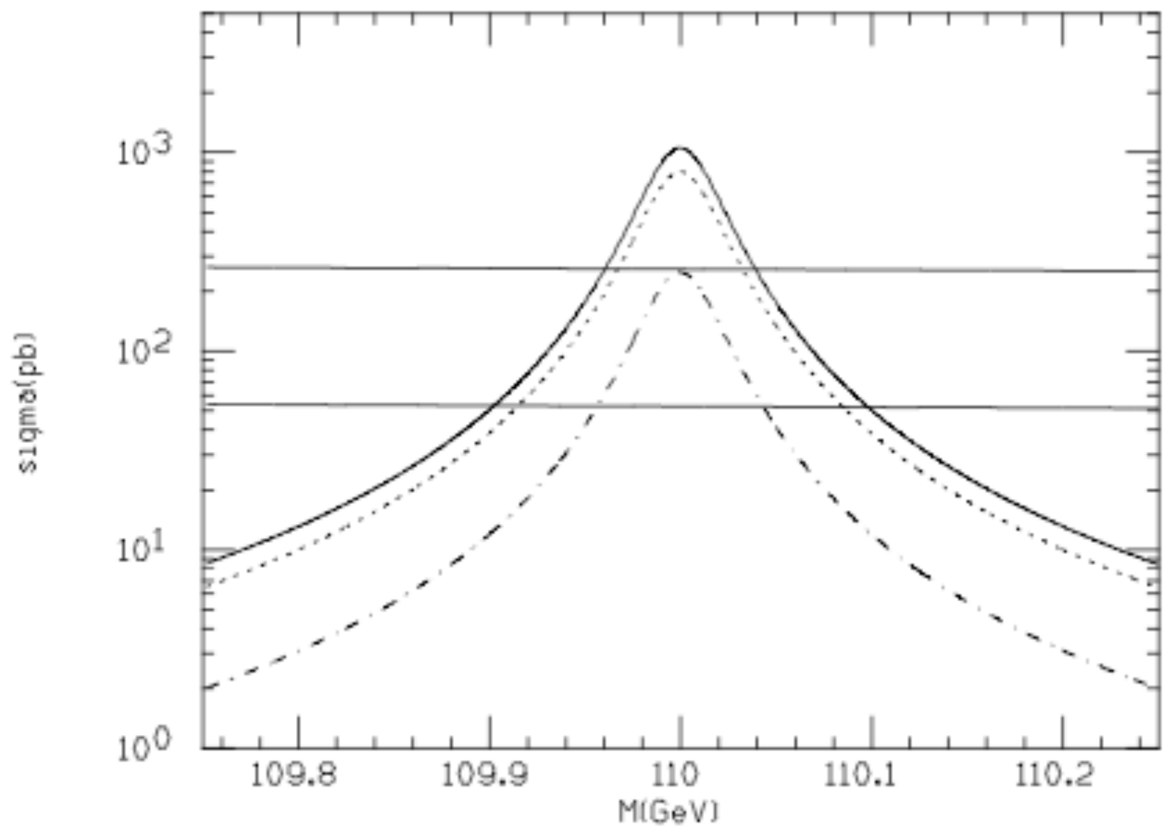
(or to $\bar{t}$ c in topcolor models)

current limits (LEP/Tevatron) ~150 GeV, but depend on production assumptions

LHC discovery likely to come from $\rho_T \to \pi_T + W$ quite tricky if heavy ρ_T

Signals at μ-collider, spin-0:

from hep-ph/9802368



$$\frac{d\sigma(\mu^+\mu^- \to \pi_T^0 \text{ or } \pi_T^{0\prime} \to \bar{f}f)}{dz} = \frac{N_f}{2\pi}\left(\frac{C_\mu C_f m_\mu m_f}{F_T^2}\right)^2 \frac{s}{(s-M_{\pi_T}^2)^2 + s\,\Gamma_{\pi_T}^2},$$

$$\frac{d\sigma(\mu^+\mu^- \to \pi_T^{0\prime} \to gg)}{dz} = \frac{C_{\pi_T}}{32\pi^3}\left(\frac{C_\mu m_\mu \alpha_S N_{TC}}{F_T^2}\right)^2 \frac{s^2}{(s-M_{\pi_T}^2)^2 + s\,\Gamma_{\pi_T}^2}.$$

for light π_T, extremely narrow (as light Higgs), therefore benefits from fine beam energy resolution at MuC

Signals at μ-collider, spin-1:

electroweak, color-neutral resonances

go by many names: ρ_T, Z', W_{KK} but **always** present

- isospin representation, mass hierarchy somewhat model dependent

- weak, usually flavor-universal coupling to SM fermions

- strong coupling to $W^{\pm}_L/Z^0_L$, techni-pions if present.. can become relatively wide if heavy

will appear @ LHC as WZ, WW, or perhaps di-lepton resonances

Signals at μ-collider, spin-1:

Mass of spin-1 resonances is model dependent:

light resonances: show up when multiple sources of EWSB

(TC2, multi-scale TC) $v_1^2 + v_2^2 = v^2$, $M_{res,i} \sim 4\pi v_i$

can be as light as ~200 GeV and still consistent with Tevatron/LEP data if coupling to fermions is ~0.1 g_{SM}

$$g_{ff\rho_{T1}} \sim g\frac{M_W}{M_{\rho_{T1}}}\left(\frac{v_1}{v}\right)$$

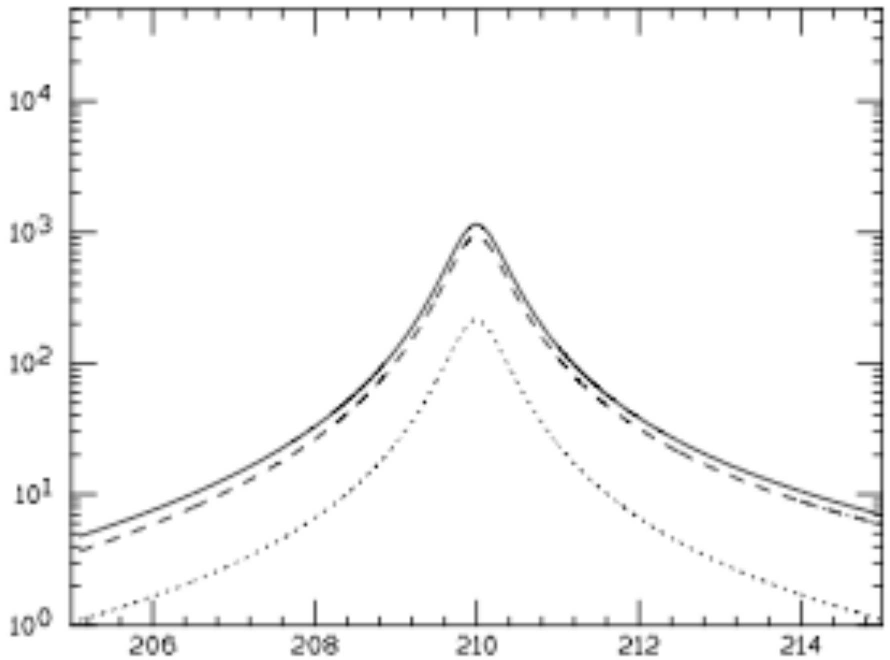
when light (M_ρ not >> $2M_W$, $2M_\pi$), resonances are narrow
Can be produced with phenomenal rate at low-energy MuC

Signals at μ-collider, spin-1:

ex: from hep-ph/9802368

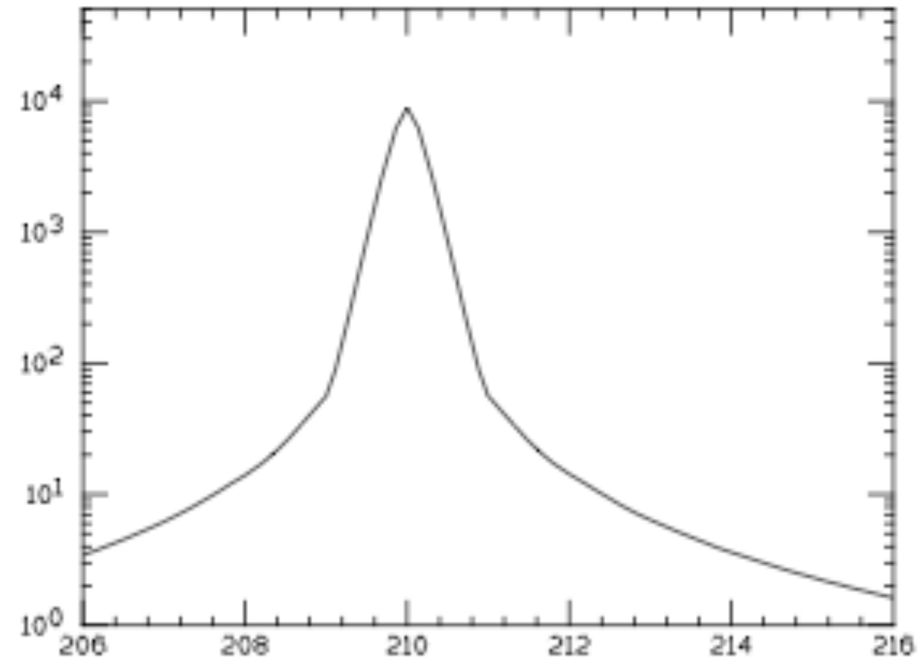
Γ_ρ ~ GeV, Γ_ω even smaller

peak σ (pb) $\rho_T \to W\pi_T$



M_{ρ_T}

peak σ (pb) $\omega_T \to \gamma\pi_T$



M_{ω_T}

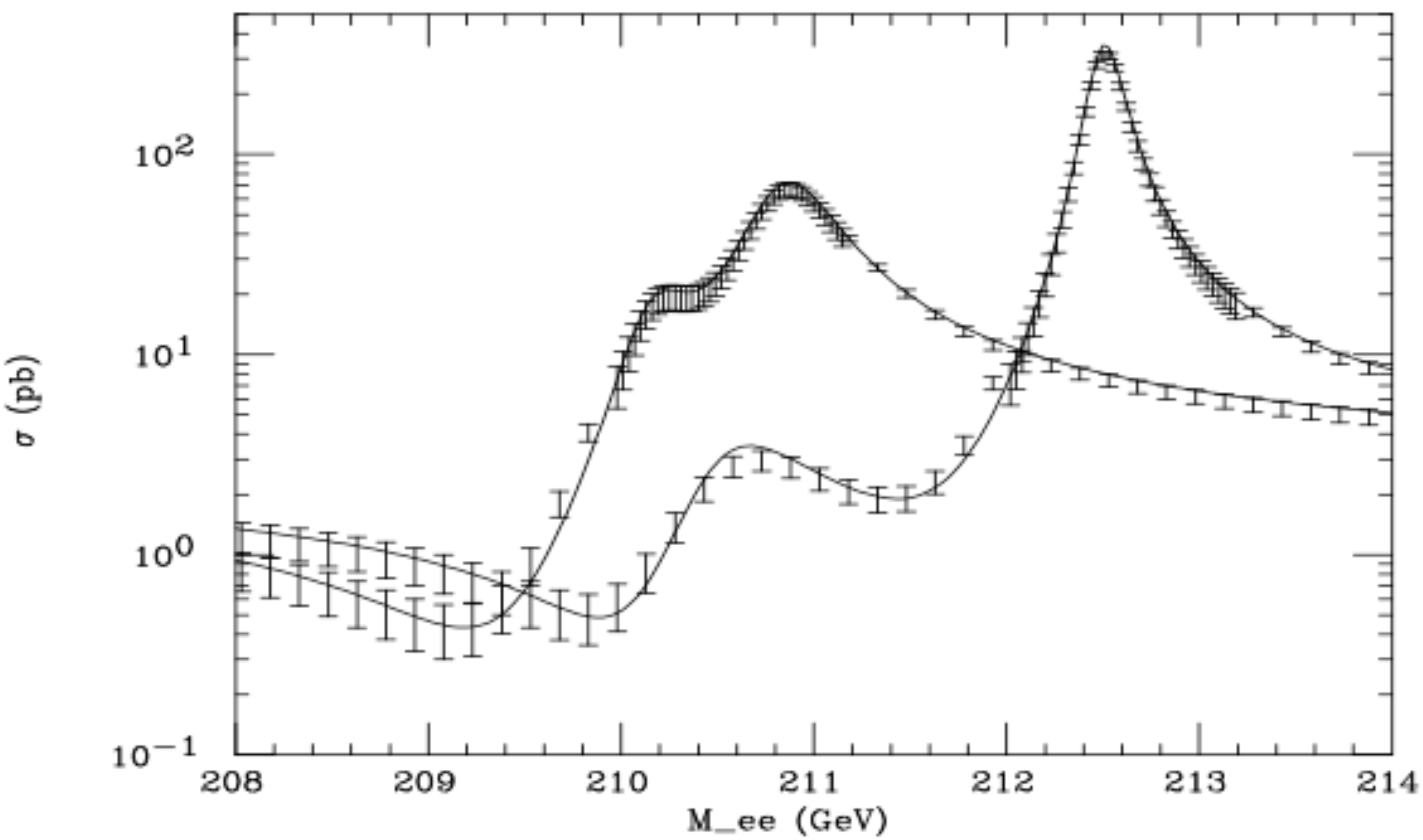
O(nb) cross section, allows study of charged π

- can also look in dilepton modes
- VBF production also a possibility
- as with Z', polarization useful

Signals at μ-collider, spin-1:

Often there are several (neutral) resonances that are nearly degenerate (ρ^0_T, ω^0_T even a^0_T in multi-scale TC, A_{KK}, Z_{KK} in several 5D models)

Look in dilepton modes -- fine energy resolution is necessary to disentangle these states & observe interference

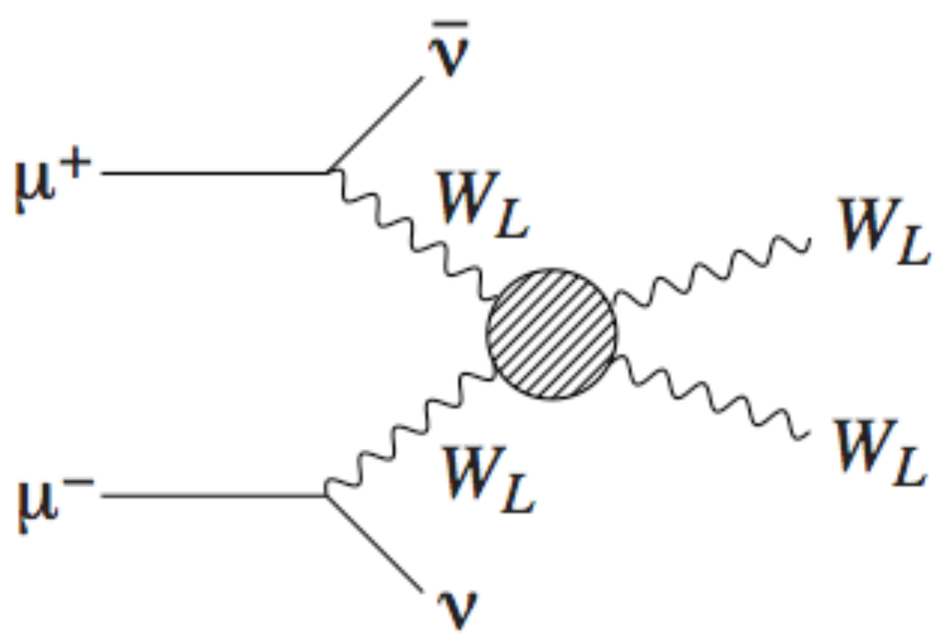


Signals at μ-collider, spin-1:

increasing mass of spin-1 .. much of story remains same

heavy spin-1 (~few TeV): become broad, quite difficult to see at LHC (decay to WW, WZ, ttbar), but may be the only hint of underlying EWSB mechanism around

best chance to study this is high energy MuC



(see Jack's talk)

Signals at μ-collider, spin-1/2:

new strong dynamics nicely generates W/Z masses, but what about fermions?

have to attach SM fermions to strong dynamics in a way that allows sizable masses, CKM, etc. but avoids flavor constraints

couple of different ideas, with different implications at colliders

Signals at μ-collider, spin-1/2:

Extended Technicolor

$$\frac{1}{\Lambda^2}\langle \bar{T}_{1L} T_{1R} \rangle \bar{f}_L f_R$$

large Λ makes flavor okay, but then very difficult to generate sufficient mass

but easy to model build in 4D

composite fermions? depends on N_{TC}

partial compositeness

$$\lambda_L f_L \mathcal{O}_L + \lambda_R f_R \mathcal{O}_R$$

by dialing dimension of O_L, O_R, can make operators relevant -> irrelevant.

easy to get fermion mass hierarchy

flavor can still be controlled

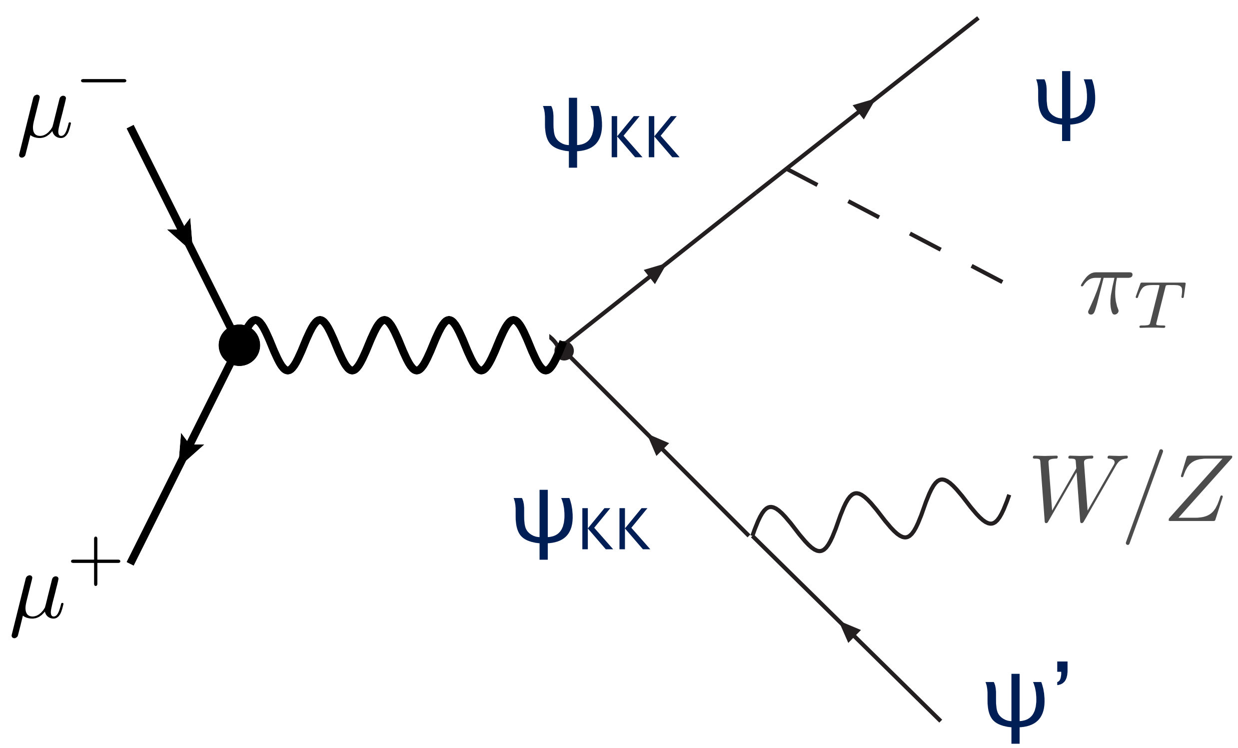
4D modeling hard, often done in 5D

must be composite fermions nearby

Signals at μ-collider, spin-1/2:

composite colored fermions would be easily pair-produced at LHC, color-singlets harder to make

ex:



different decays than 4th generation

MuC can play an important role in precision study, or even discovery

Conclusions

EW-scale strong dynamics is an exciting possibility for BSM physics

Many signals w/ s-channel resonances, O(EW) production, well suited for lepton collider

Cast of characters:

similar to existing 'benchmarks' ($\pi_T \sim H$, $\rho^0_T \sim Z'$, $\psi_{KK} \sim$4th gen), but there are important differences