SUSY 2011

Quirks from Tevatron to LHC

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in collaboration with { Fok (U Oregon -> York U)
Harnik, Martin (Fermilab)

Outline

- Quirks, infracolor, and quirkonia
- Wjj arising from (s)quirk production
  - Idea -> Strategy
  - Model -> Calculations
  - Associated processes (esp. WWjj)
- Summary

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Quirks

"Quirks" -- New particles transforming under a new strong force "infracolor"

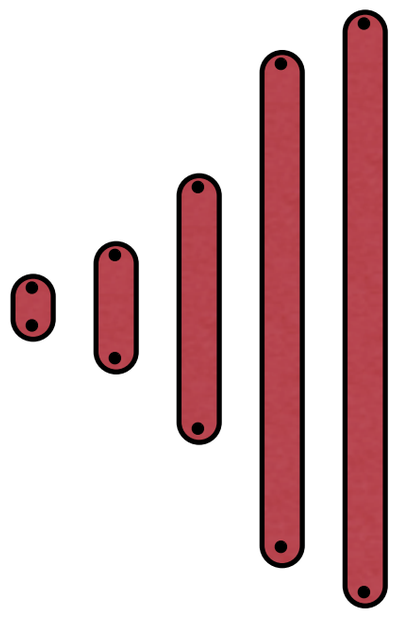
$\Lambda_{IC} << M_Q$

as well as (part of) SM group.

Kang & Luty 0805.4642

$\Lambda_{IC} << M_Q$

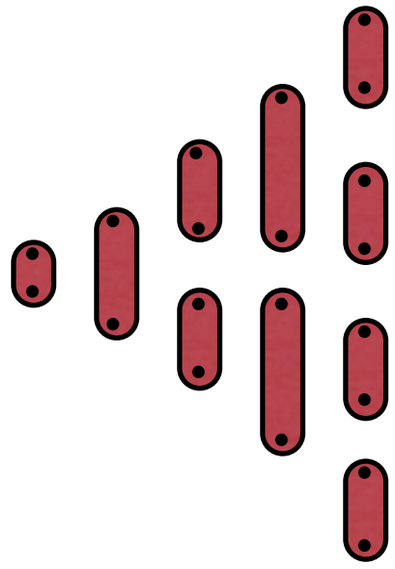
Infracolor strings don't break -- no fragmentation.



bound quirks

$\Lambda_{QCD} > M_{u,d}$

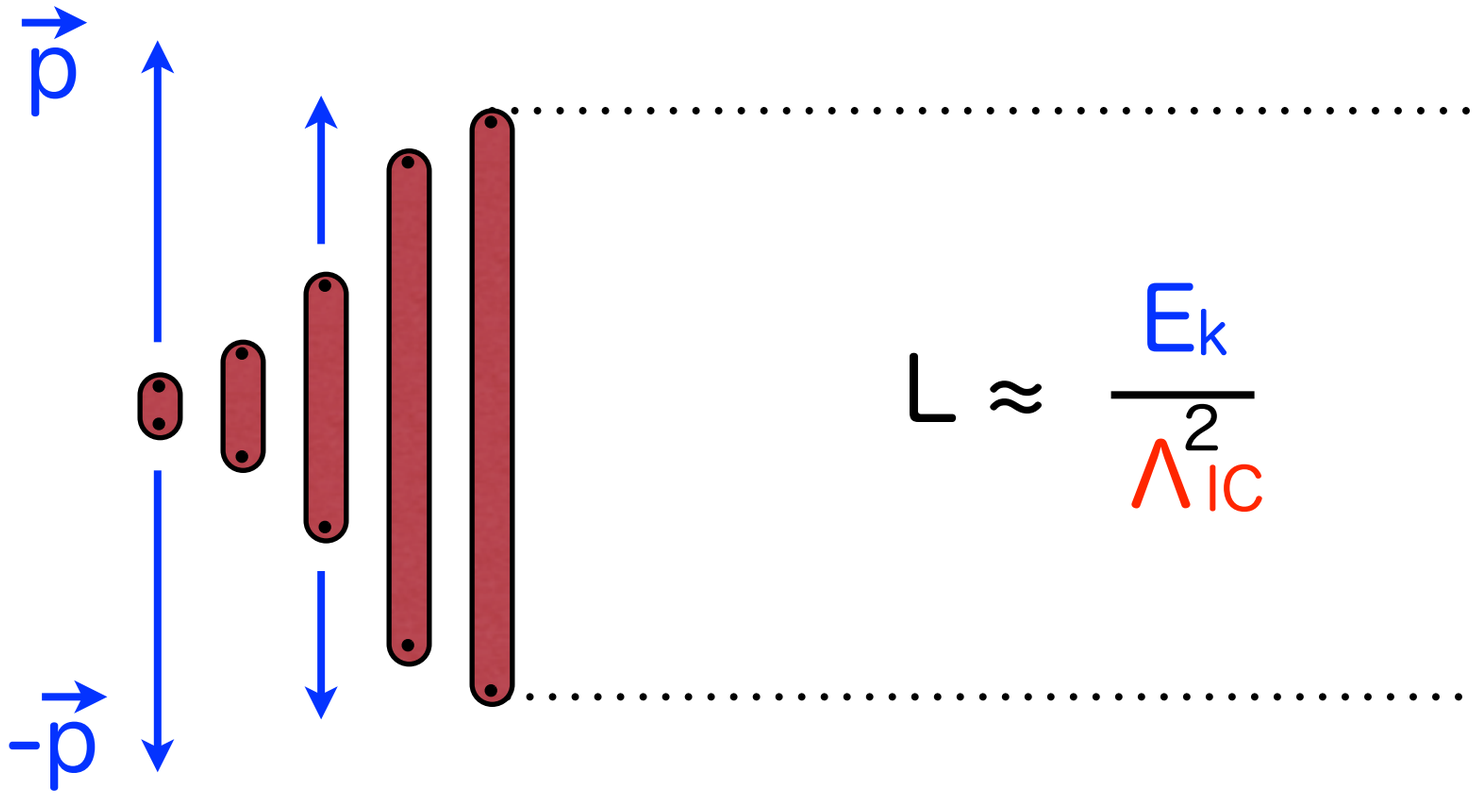
QCD strings break -- fragmentation.



pions

Stretched Infracolor String

Infracolor strings can stretch until energy in infracolor flux tube is $\approx \sigma L \approx \Lambda_{IC}^2 L$



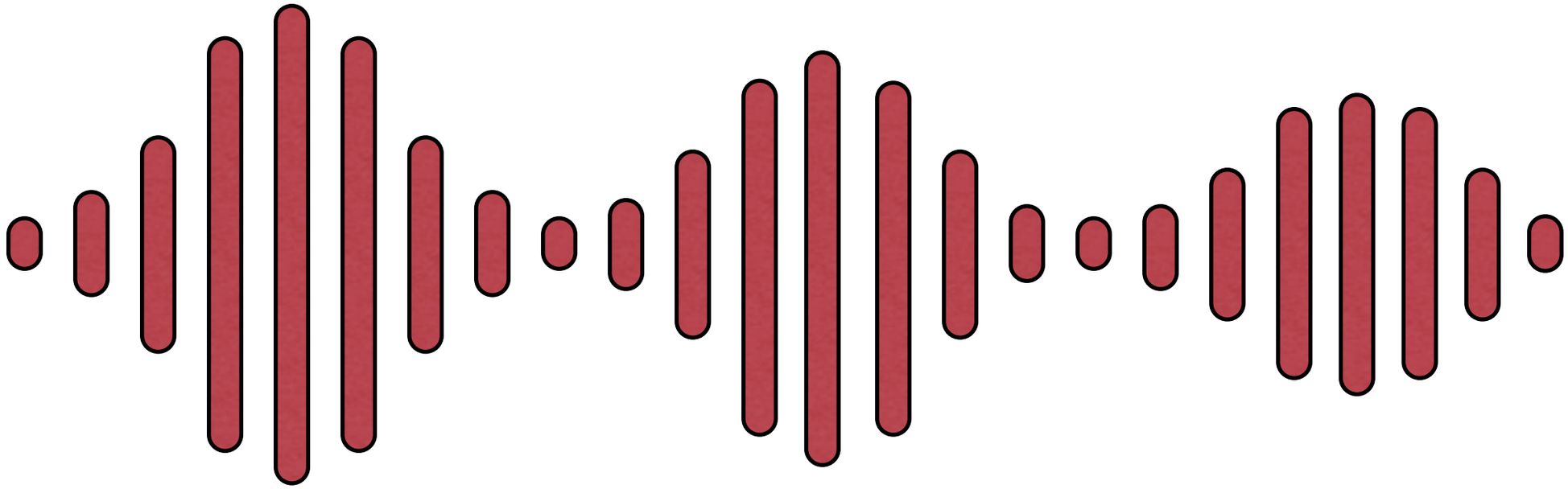
$|\vec{p}| = E_k \approx \sqrt{s} - 2M_Q$

$$L \approx \frac{E_k}{\Lambda_{IC}^2}$$

$$L \approx (0.1\ \text{mm}) \frac{E_k}{100\ \text{GeV}} \frac{(10\ \text{keV})^2}{\Lambda_{IC}^2}$$

Wonga Wonga

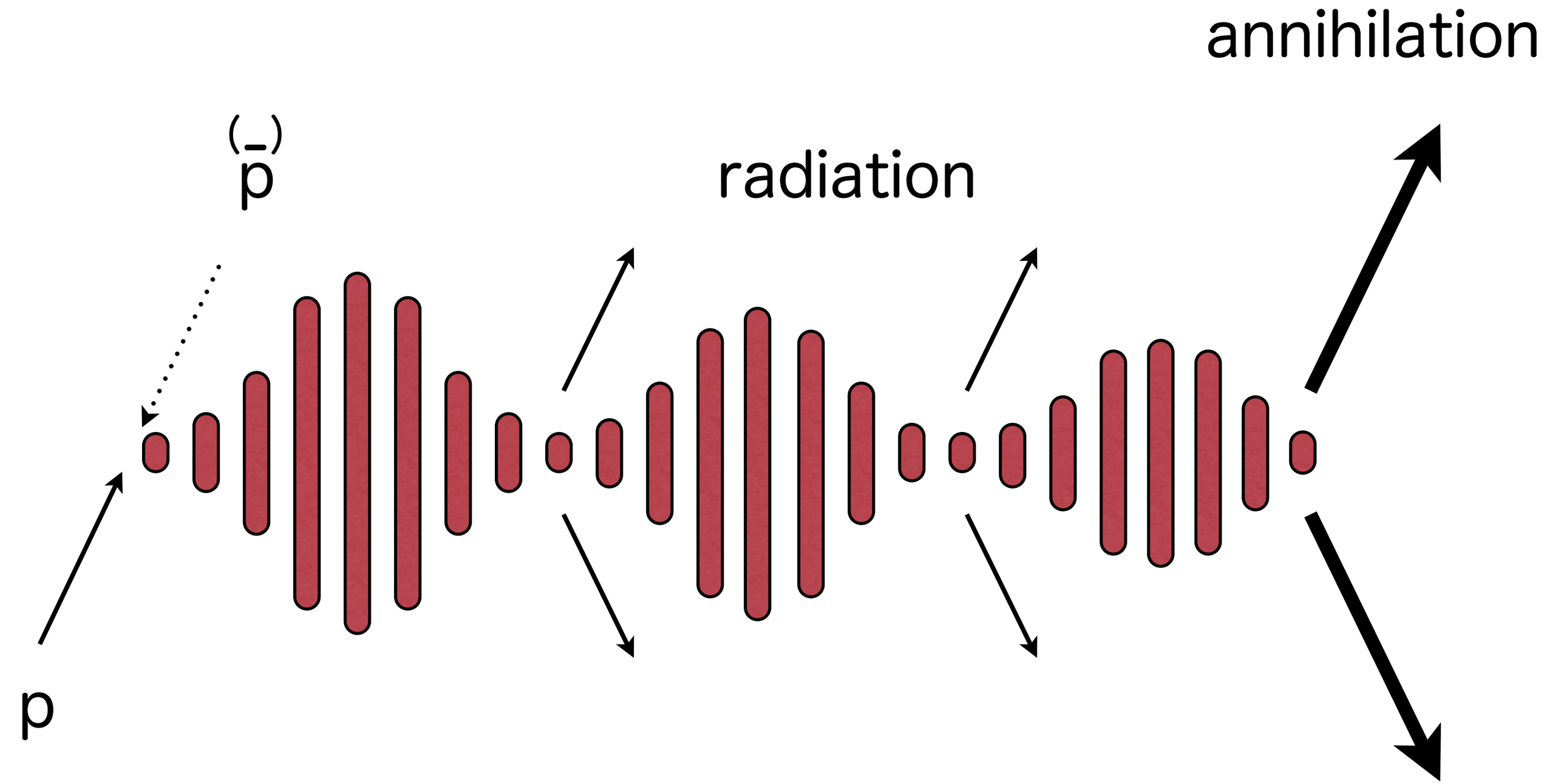
Collider signal qualitatively distinct for
macroscopic versus microscopic



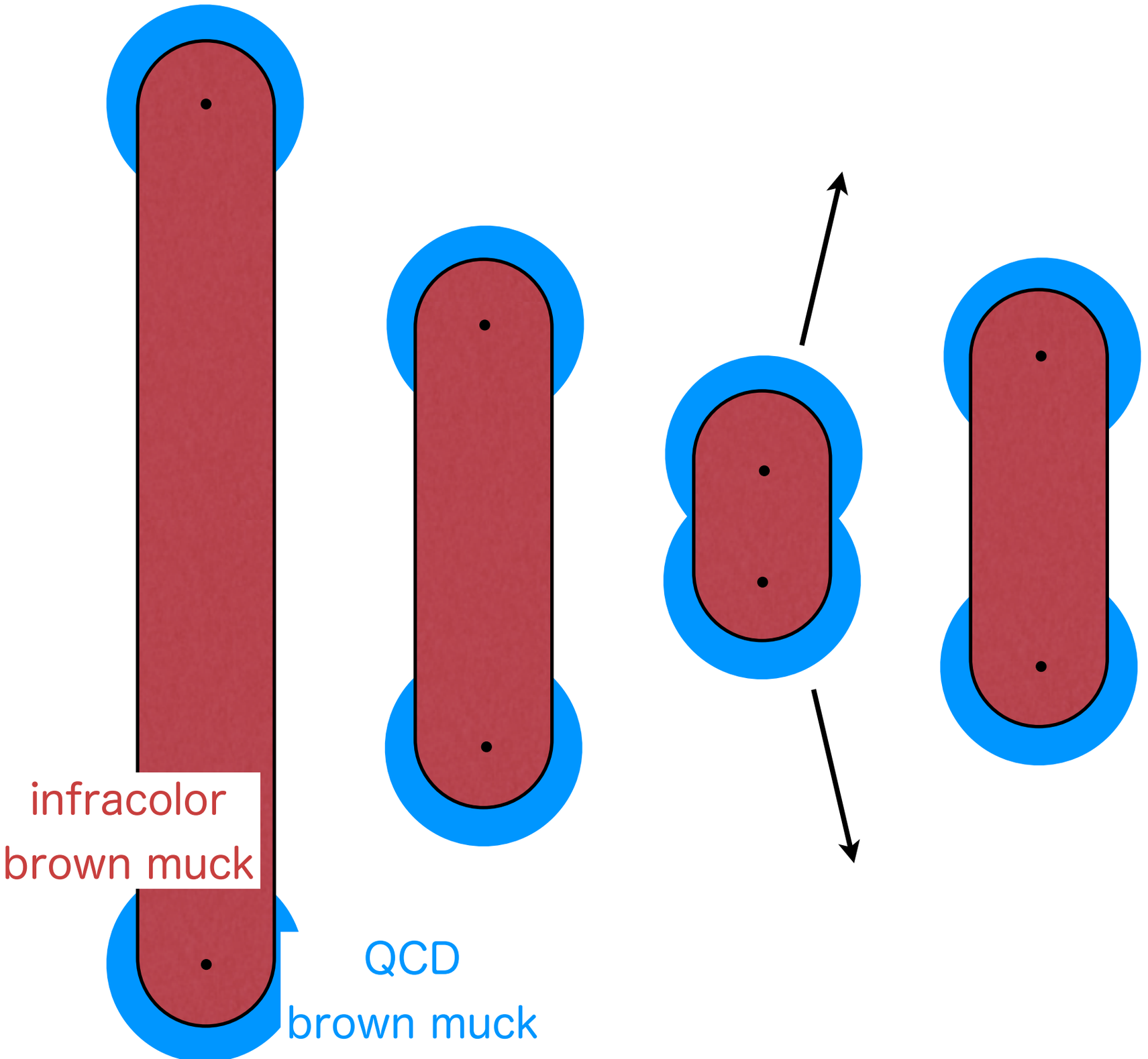
Our interest is microscopic:

10 keV << Λ_{IC} << M_Q

Energy loss, spin-down, annihilation



Energy Loss Assumption



Release:

$\approx \Lambda_{IC}$ energy

and/or

$\approx \Lambda_{QCD}$ energy

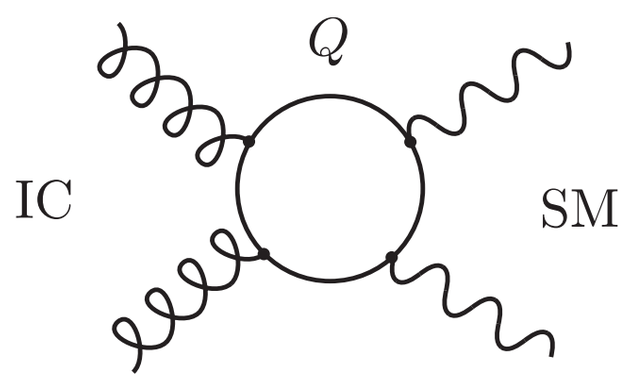
at each crossing.

Kang & Luty 0805.4642

Infragluelball Emission

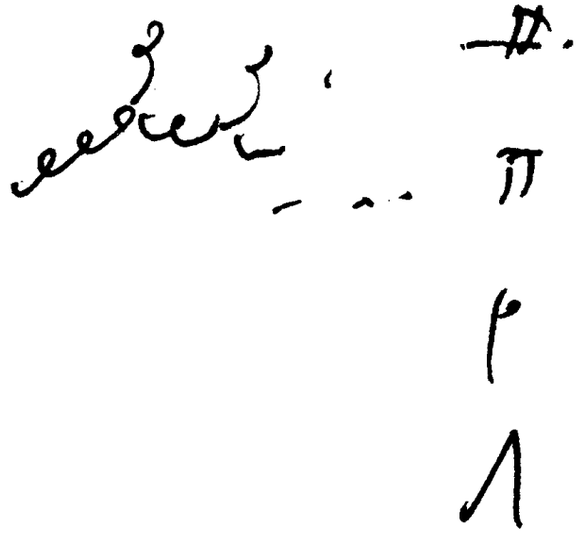
For $\Lambda_{IC} \ll M_Q$, infragluelballs (g'g') escape detector as missing energy

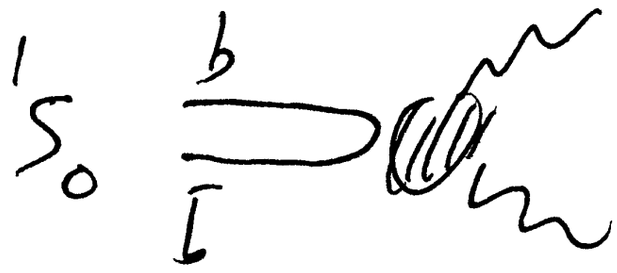
(glueball decay rate suppressed by $\frac{\Lambda_{IC}^9}{M_Q^8}$)



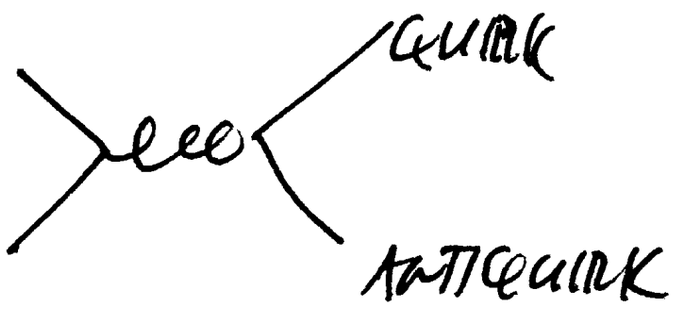
Quirky Calculability

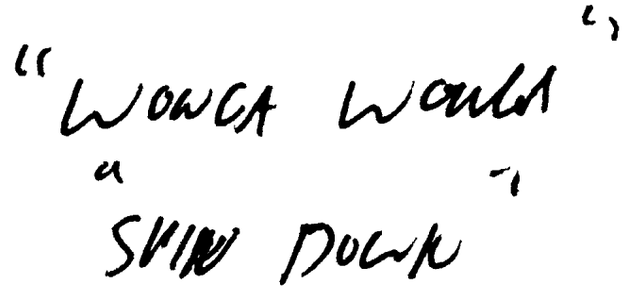
QCD

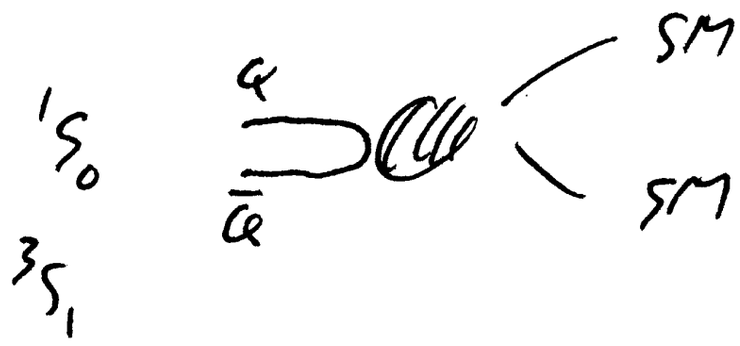




Quirks







calculable

estimatable

calculable

(Quirkonium Decays)

Depending on whether quirks are
chiral versus non-chiral,
the relative quirkonia decay rates
are qualitatively distinct and interesting!

See talk by Ricky Fok later this session.

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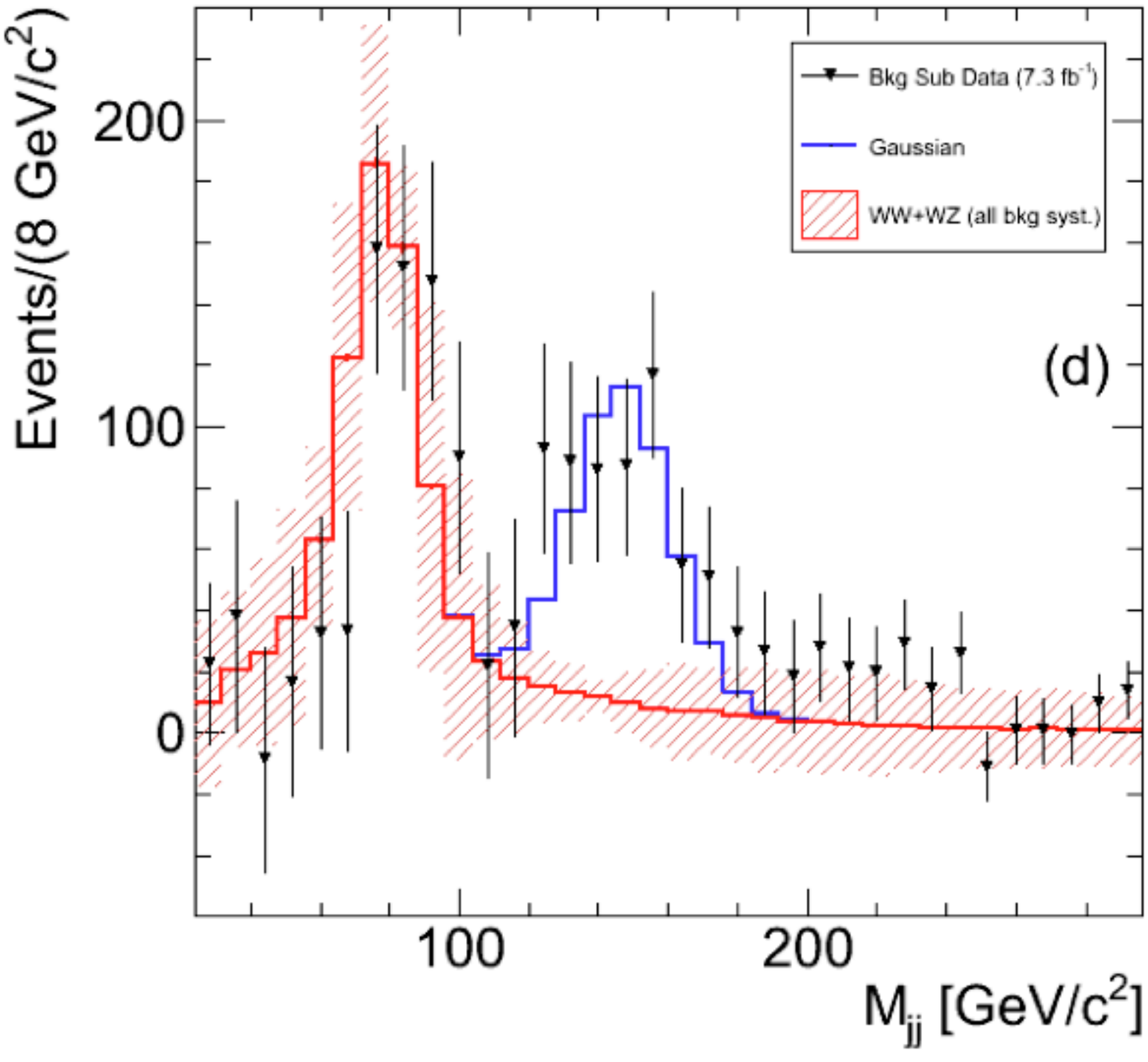
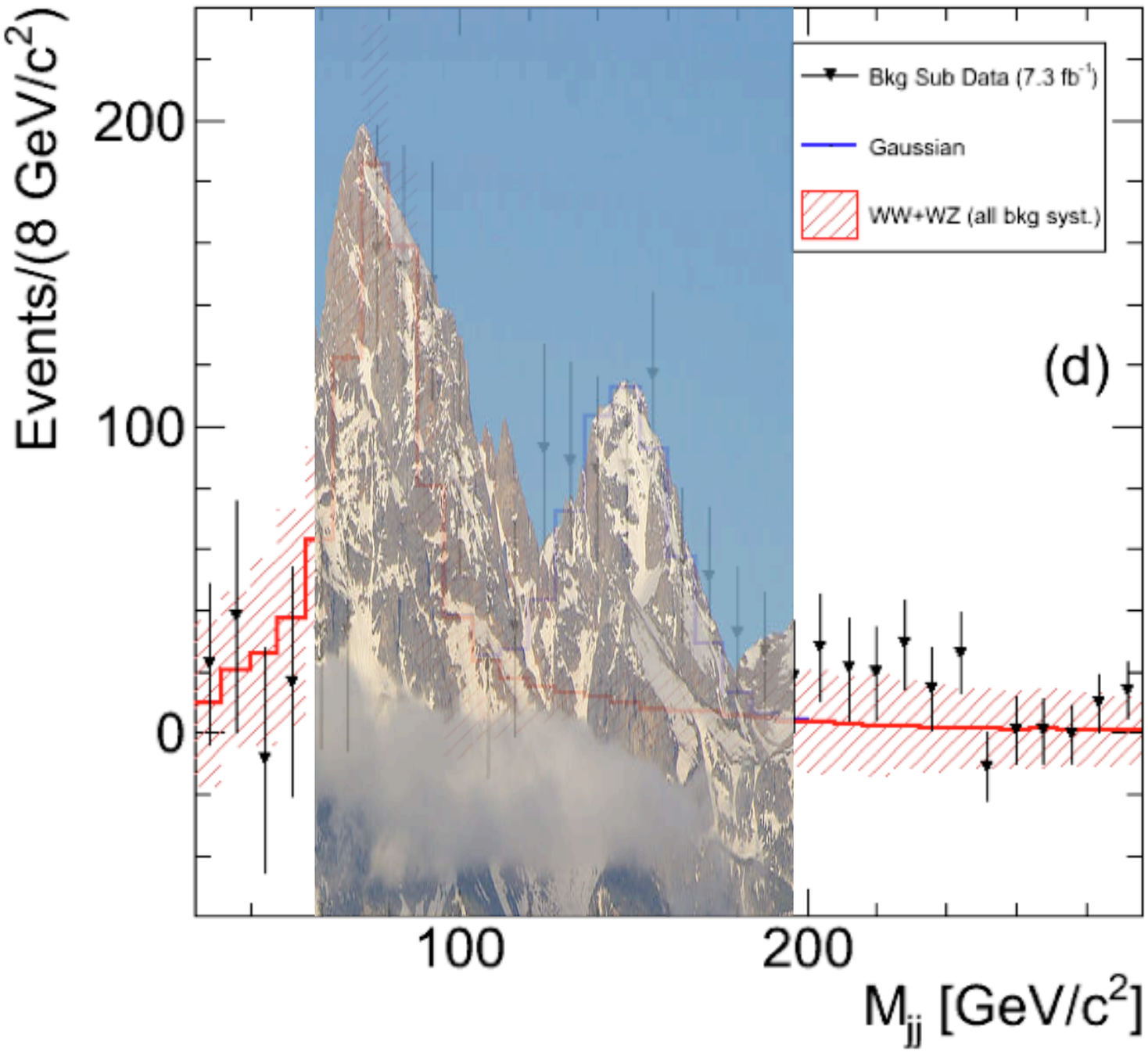
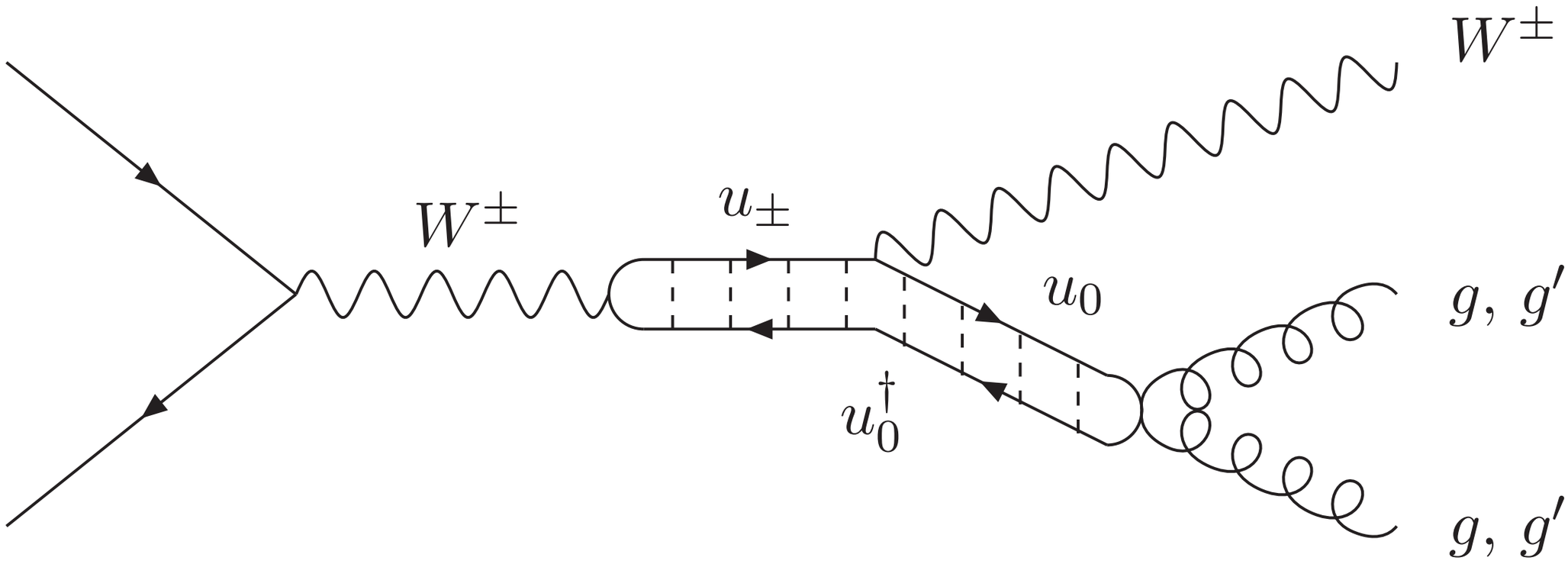
CDF Wjj excess



CDF: http://www-cdf.fnal.gov/physics/ewk/2011/wjj/7_3.html

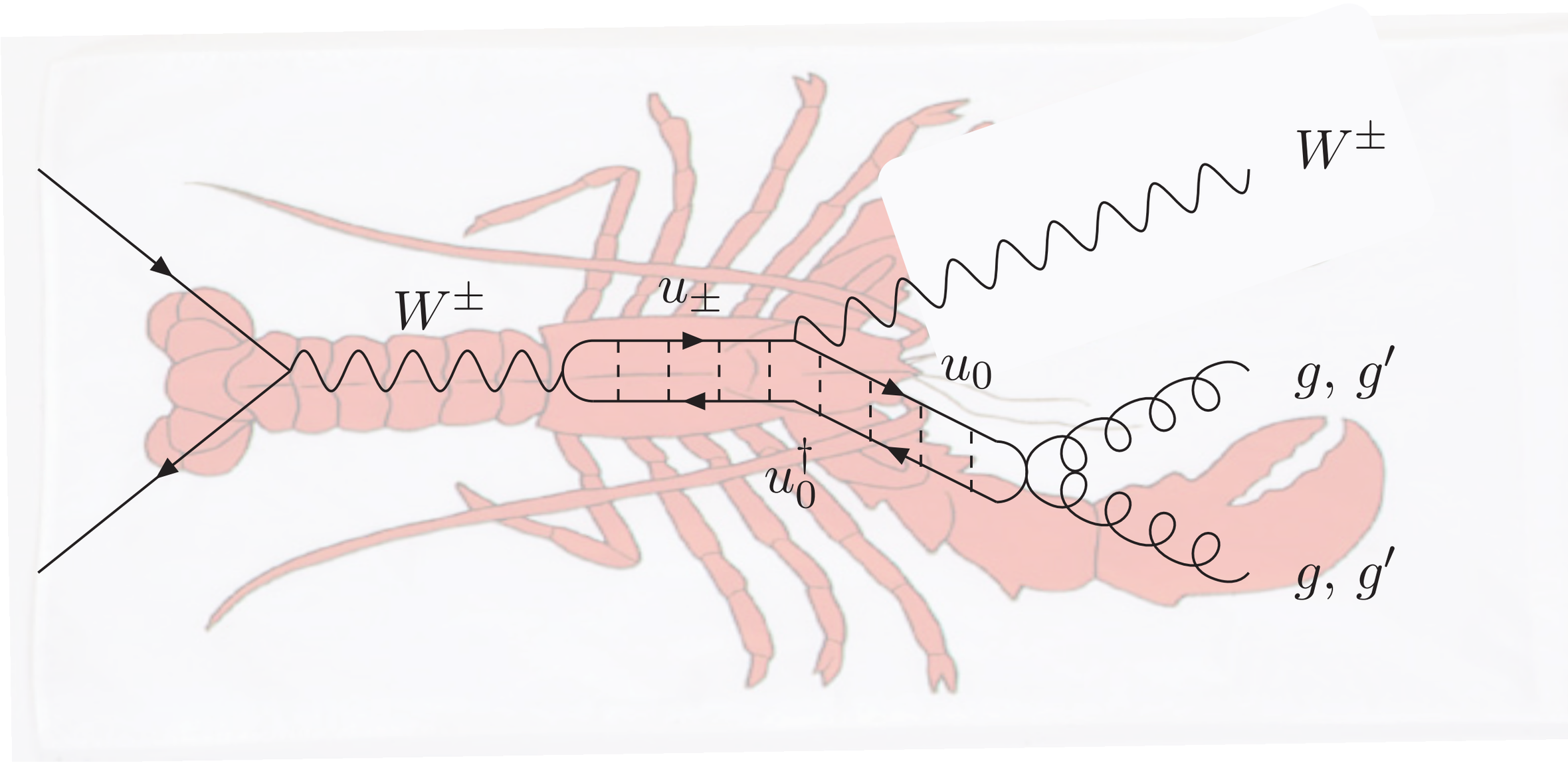

Events/(8 GeV/c^2)
200
100
0
Bkg Sub Data (7.3 fb^{-1})
Gaussian
WW+WZ (all bkg syst.)
(d)
100
200
M$_{jj}$ [GeV/c^2]

Quirky Idea:



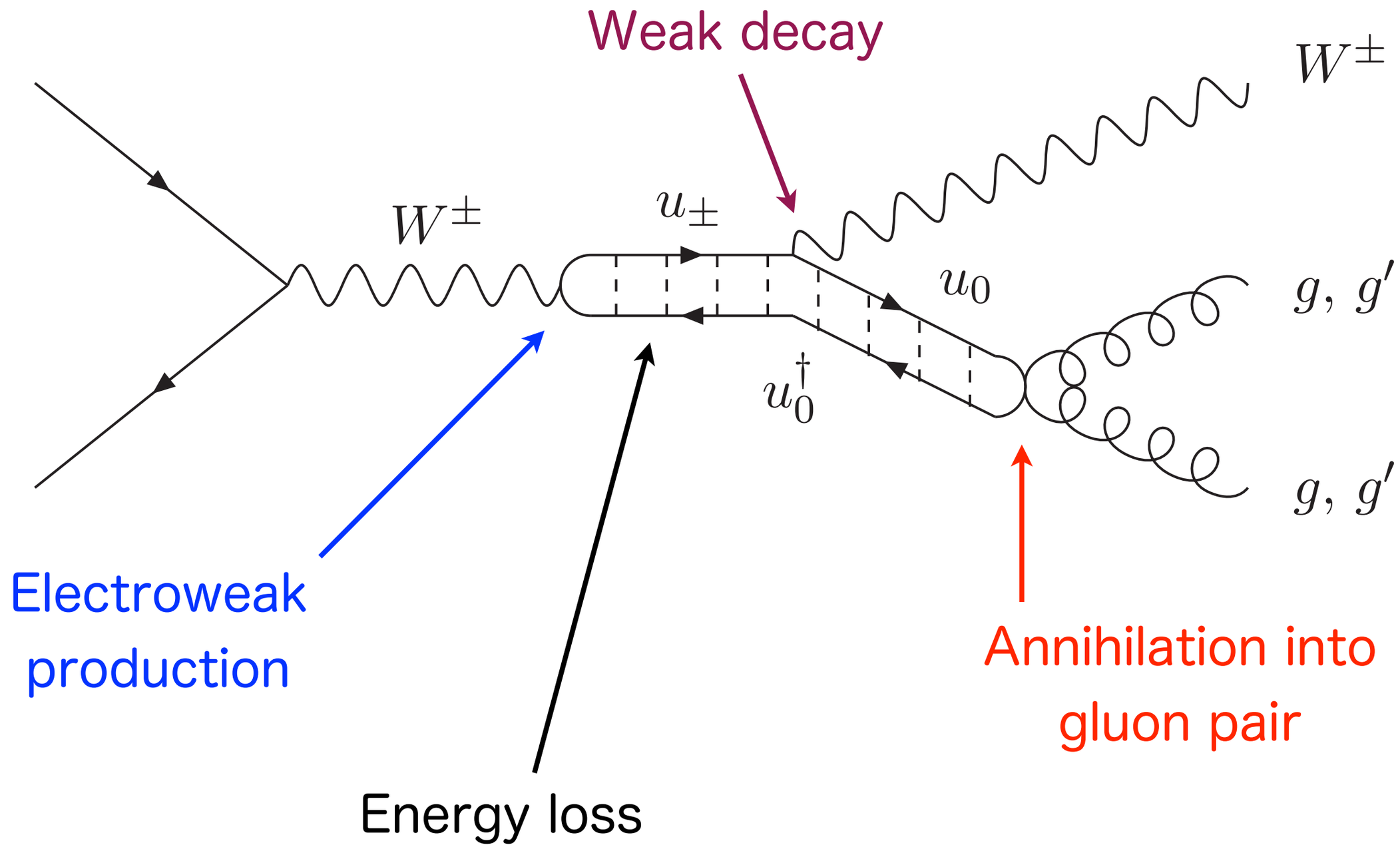
"One-armed lobster diagram"

Quirky Idea:

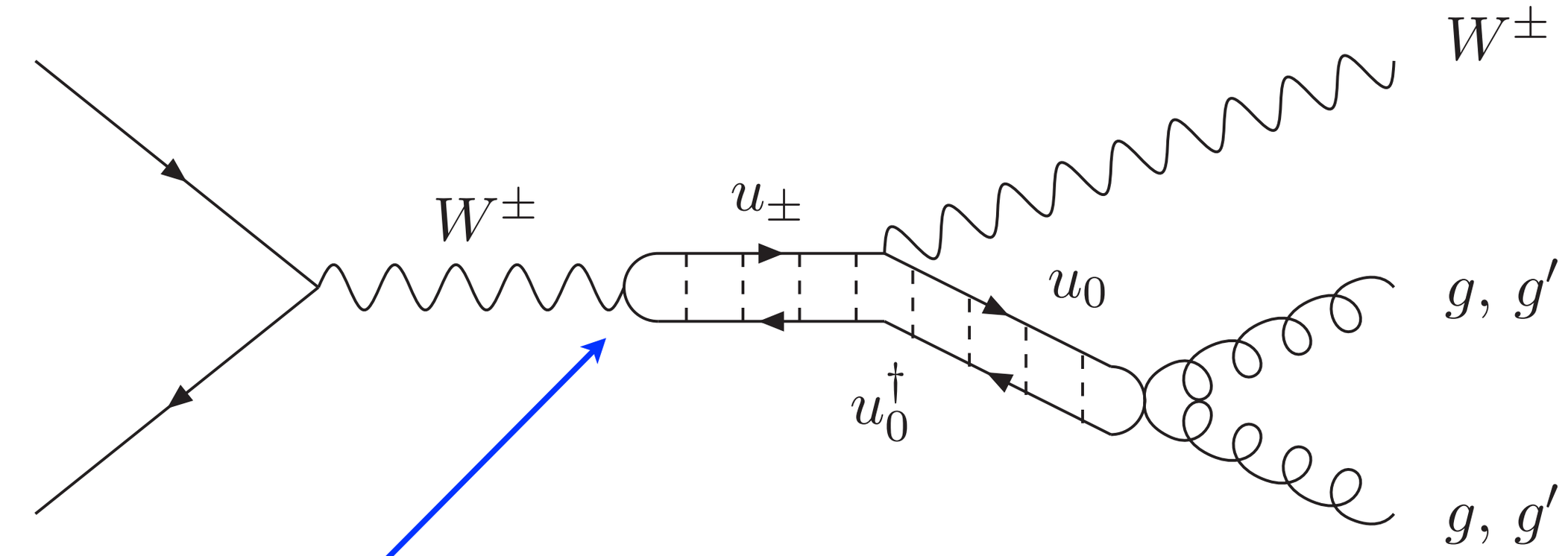


"One-armed lobster diagram"

Quirky Idea:


Weak decay
$W^\pm$
$u_\pm$
$W^\pm$
u_0
$u_0^\dagger$
$g,\ g'$
$g,\ g'$
Electroweak production
Energy loss
Annihilation into gluon pair

Strategy

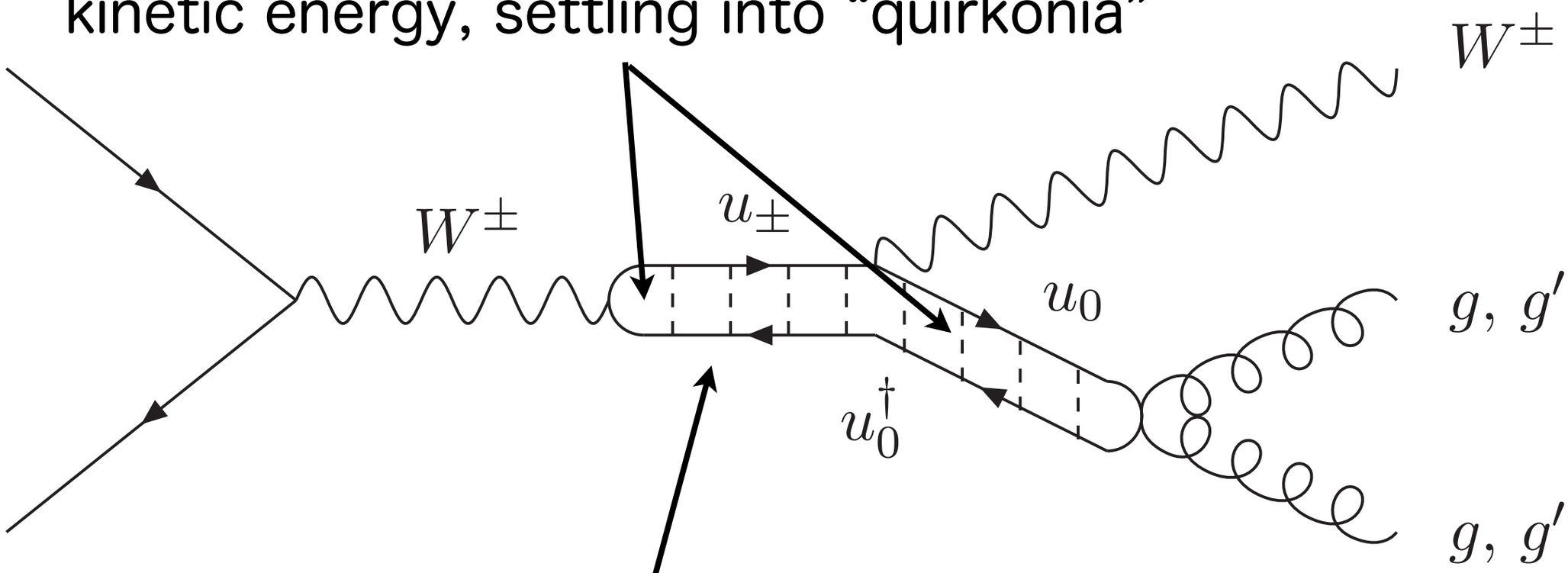


Electroweak production

Quirks transform as triplet under $SU(2)_L$ (with Y=0)

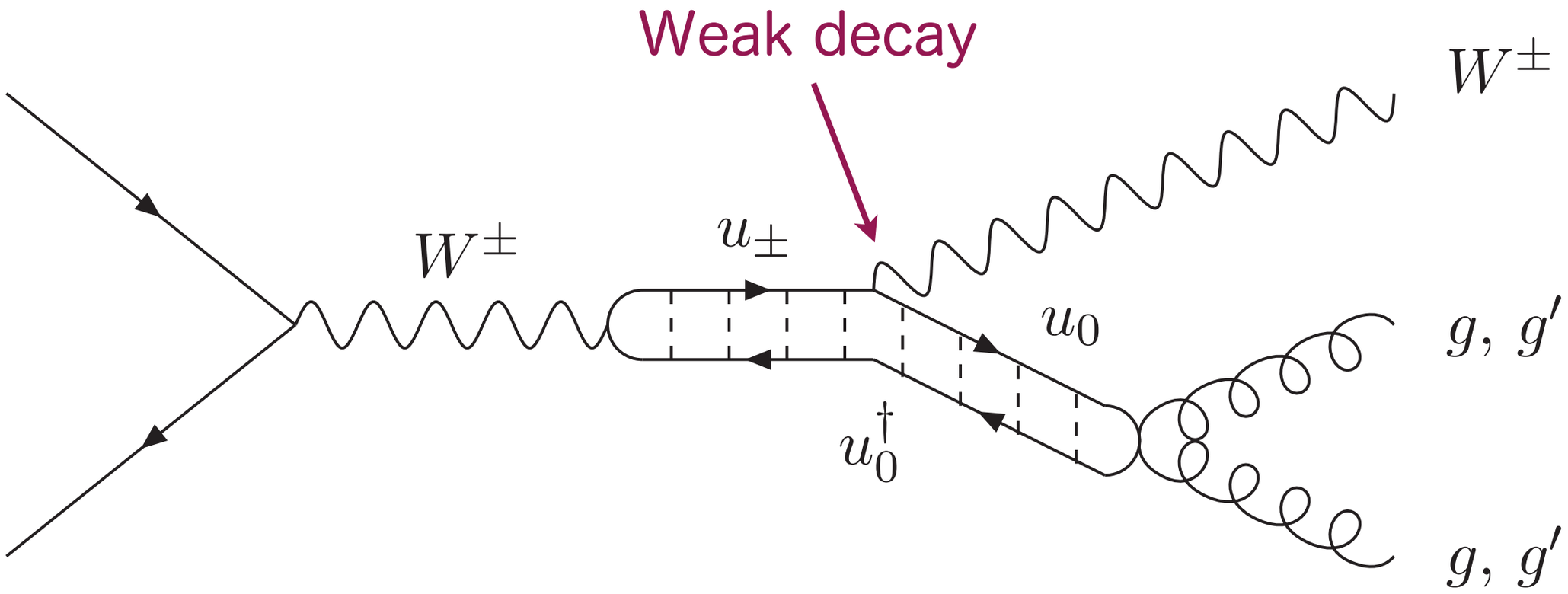
Strategy

Quirks are bound by infracolor; they lose kinetic energy, settling into “quirkonia”



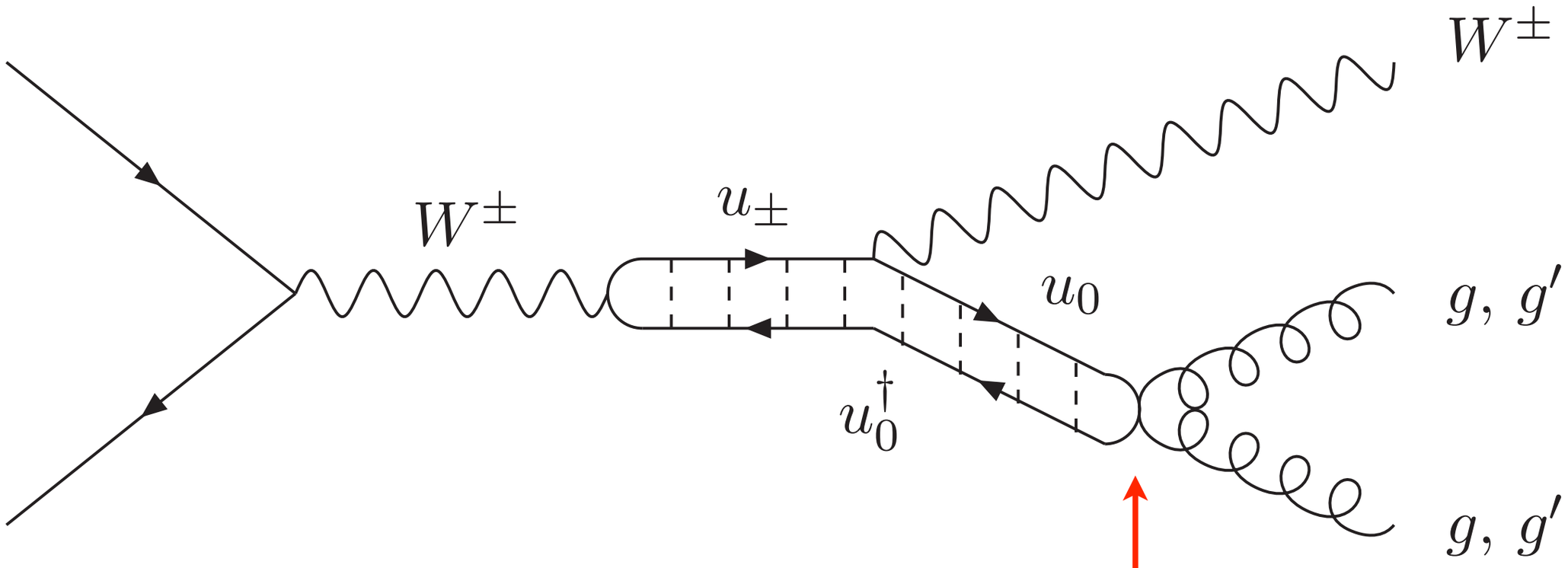
Energy loss into QCD and/or infracolor brown muck; events may have additional underlying event and/or unusual kinematics

Strategy



Engineer quirk spectrum such that
$\Delta m = m(u_\pm) - m(u_0) \approx 40\text{-}80$ GeV;
large enough for β-decay prior to
direct annihilation $u_\pm u_0$ -> SM

Strategy



Quirks carry QCD color such that lightest electrically neutral quirk dominantly decays into gg

Annihilation into gluon pair

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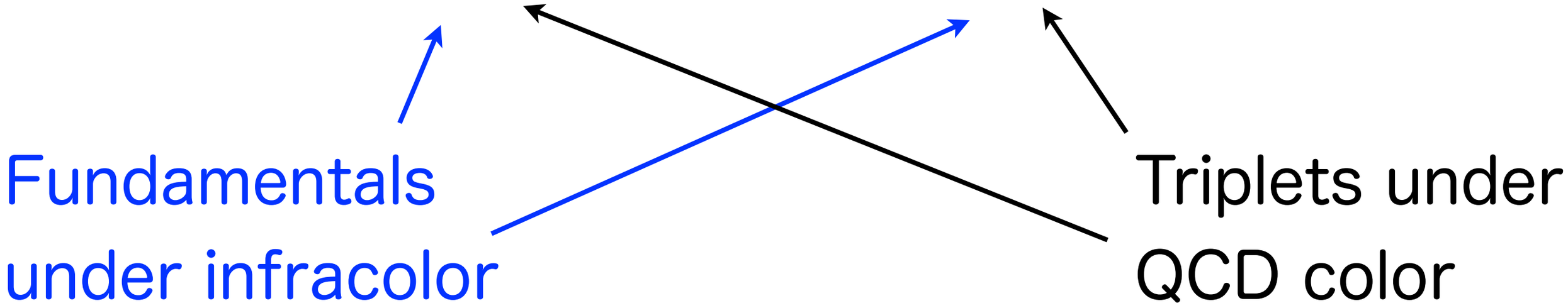
Model

Scalar quirks “squirks” transforming under $[SU(N)_{IC}, SU(3)_C, SU(2)_L, U(1)_Y]$:

$U[N,3,3,0]$ and $S[N,3,1,0]$



Model

Scalar quirks "squirks" transforming under $[SU(N)_{IC}, SU(3)_c, SU(2)_L, U(1)_Y]$:

$U[N,3,3,0]$ and $S[N,3,1,0]$

$SU(2)_L$ triplet; $Y=0$ — $SU(2)_L$ singlet; $Y=0$

$$U \begin{pmatrix} u_+ \\ u_3 \\ u_- \end{pmatrix} \qquad S$$

Squirk Interactions of $U\begin{pmatrix} u_+ \\ u_3 \\ u_- \end{pmatrix}, S$

Renormalizable interactions include:

$\frac{1}{2}M_U^2 U^\dagger U + \frac{1}{2}M_S^2 S^\dagger S$	masses
$+ \lambda_{U4}(U^\dagger U)^2 + \lambda_{S4}(S^\dagger S)^2$	quartics
$+ \lambda_U (H^\dagger H)(U^\dagger U) + \lambda_S (H^\dagger H)(S^\dagger S)$	Higgs portal
$\lambda_4 (S^\dagger S)(U^\dagger U)$	“double wonga wonga”
$\kappa (H^\dagger \tau^a H)(S^\dagger U_a) + \text{h.c.}$	isospin splitting

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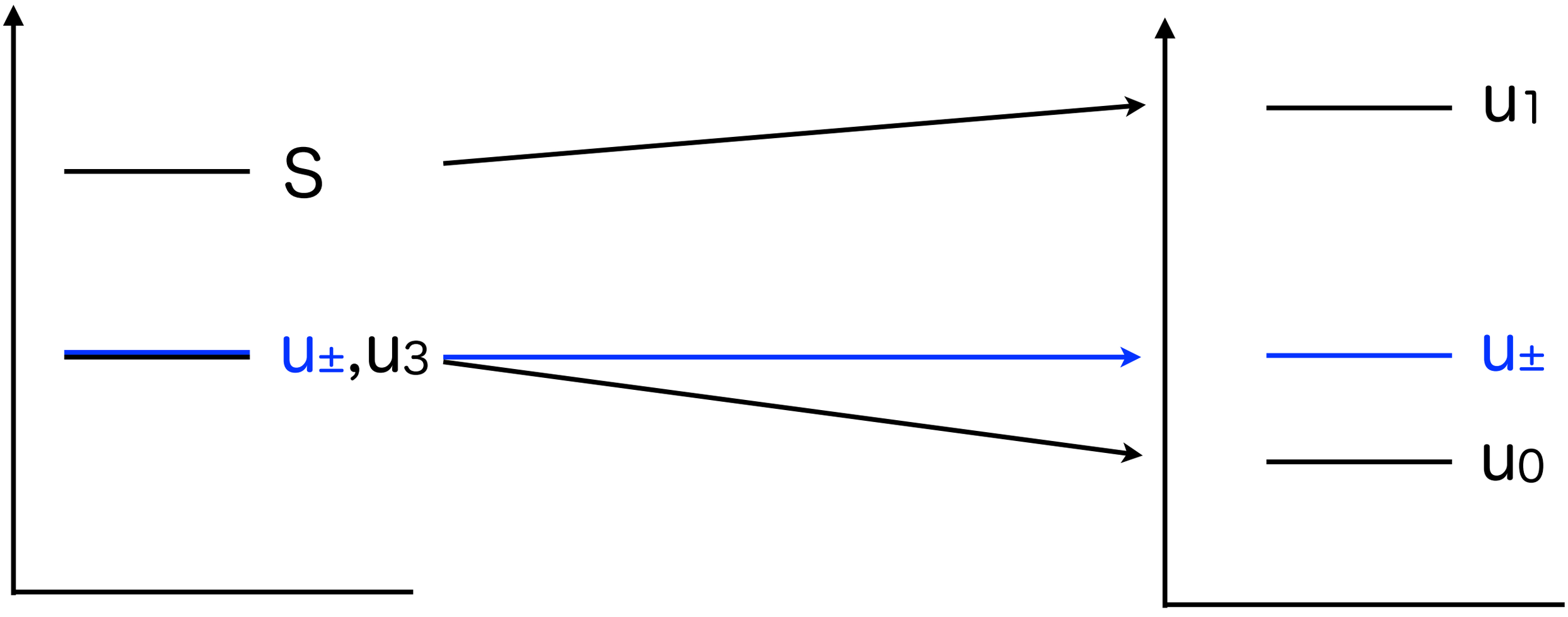
Isospin Splitting

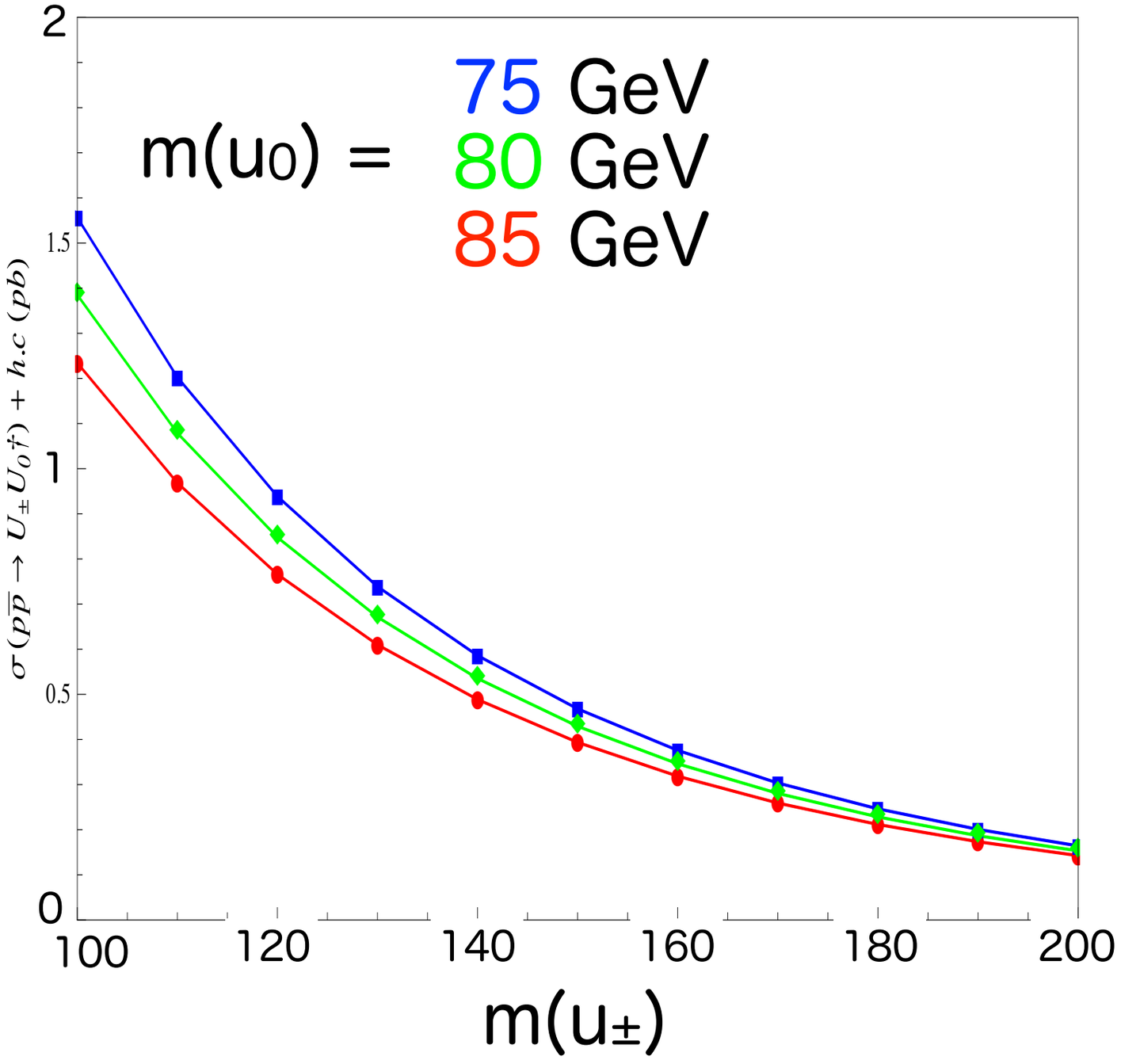
$$\kappa(H^\dagger \tau^a H)(S^\dagger U_a) + \text{h.c.}$$

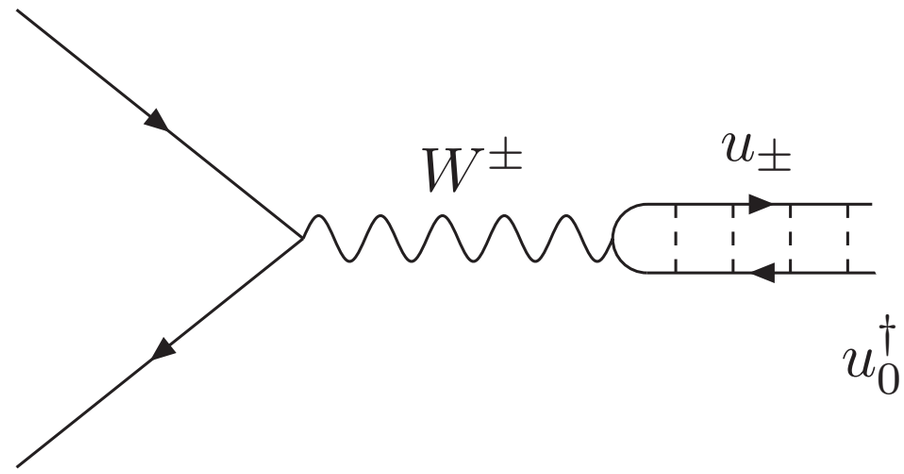
After EWSB, this leads to mass mixing among the q=0 squirks:



This is the main reason for squirks (instead of quirks)

Tevatron EW Production: $u_\pm u_0^\dagger + u_\pm^\dagger u_0$





σ per infracolor!

Harnik, GK, Martin; 1106.2569

$SU(N)_{IC}$ with $N \approx 3$ or 4,

would appear to be sufficient!

BUT!! Dynamics more subtle;

several other production processes;

(some highly constrained,

others can *add* to our signal)

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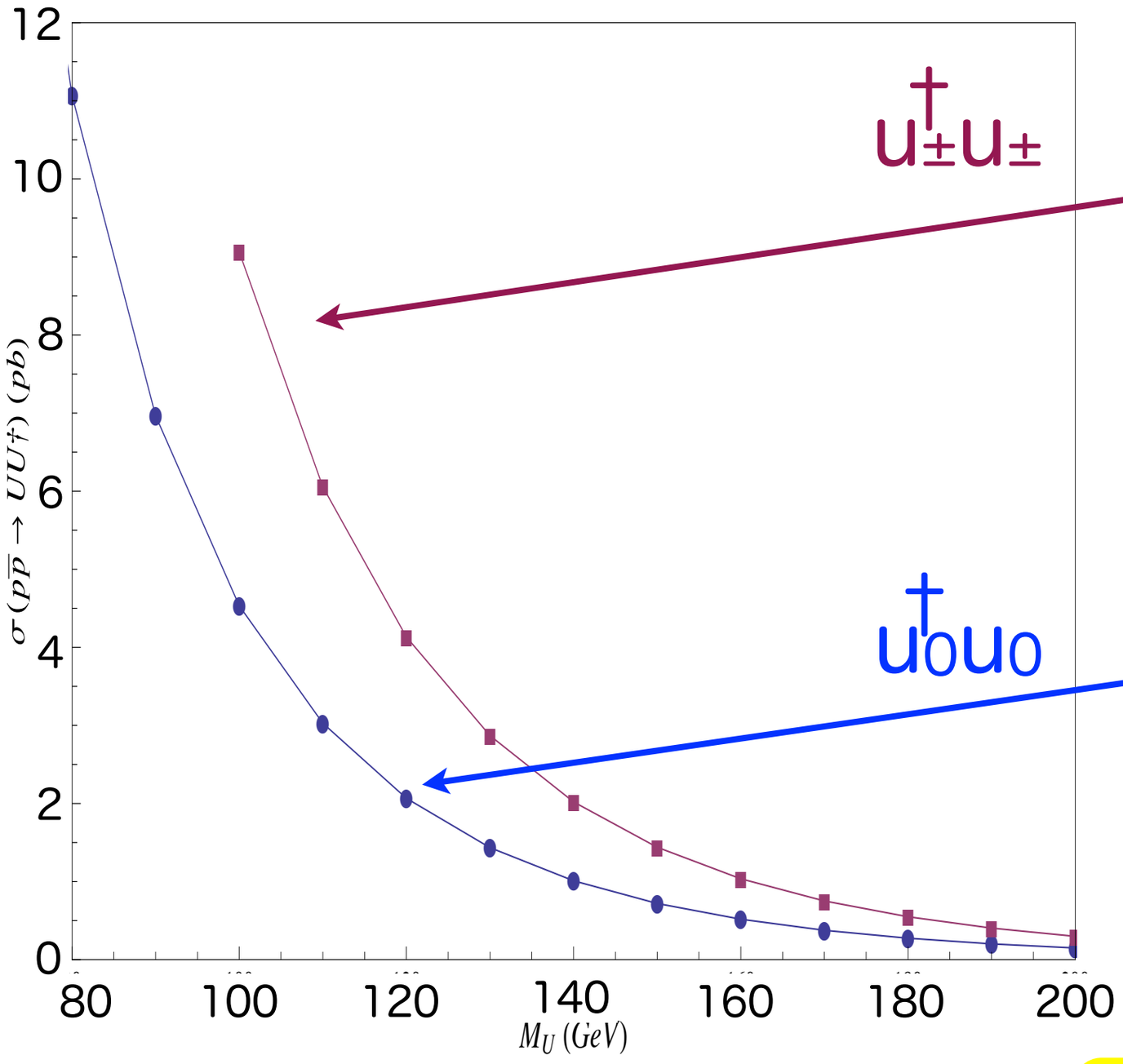
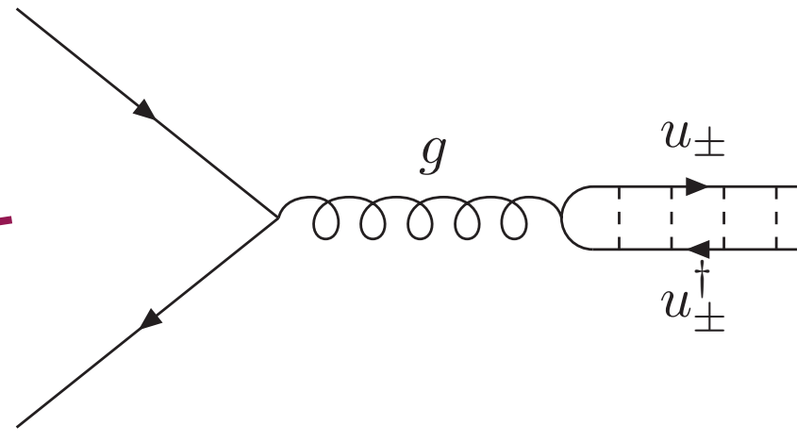
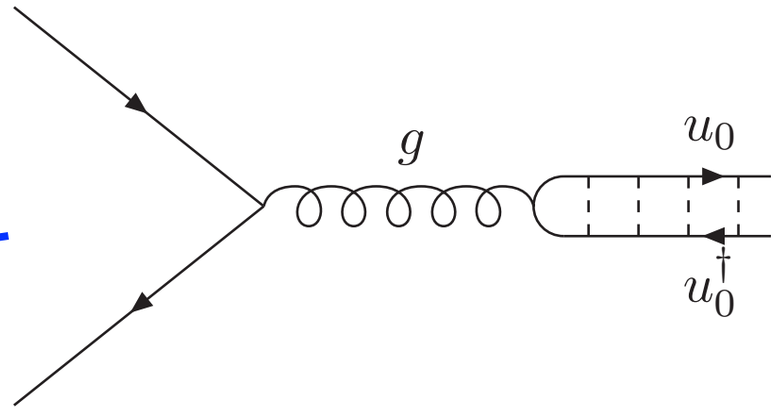
Tevatron Colored Squirk Production







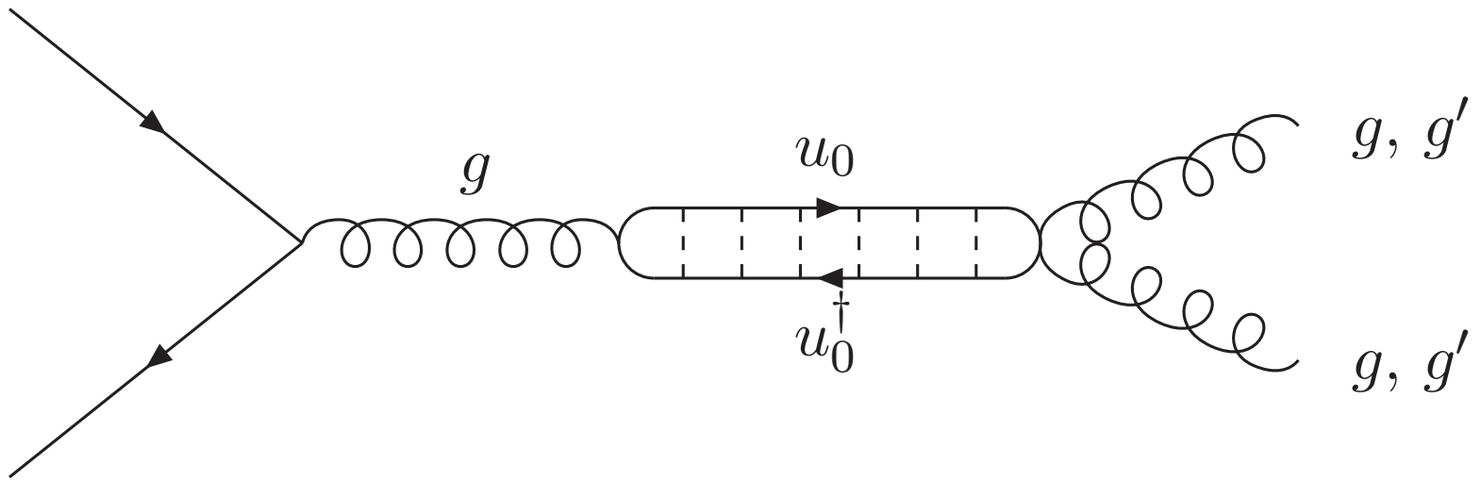
Harnik, GK, Martin; 1106.2569

σ per infracolor!

$u_0^\dagger u_0$

LEP production zero (u_0: T_3=0; Y=0).

Typical hadron collider production and annihilation:

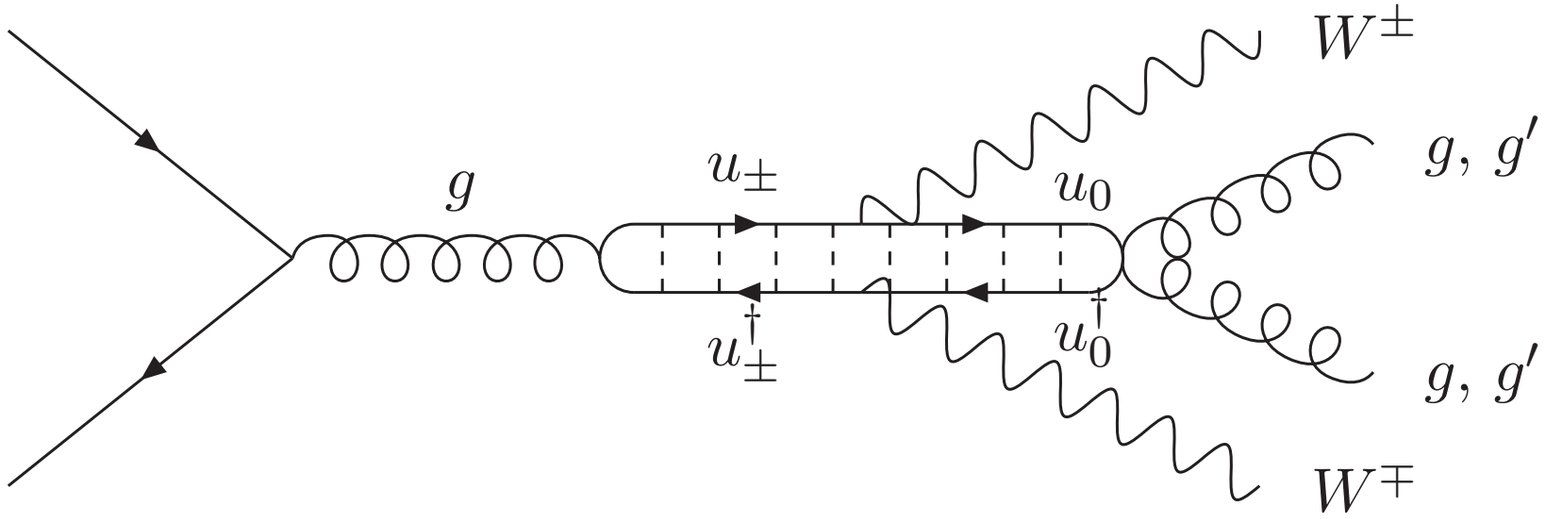


- gg: Resonance in dijets near $M_{jj} \approx$ 150-160 GeV; super-safe from UA2 and Tevatron bounds

- g'g': Annihilation to infraglue weakly constrained by monojet search (radiate extra g)

$u^{\dagger}_{\pm}u_{\pm}$

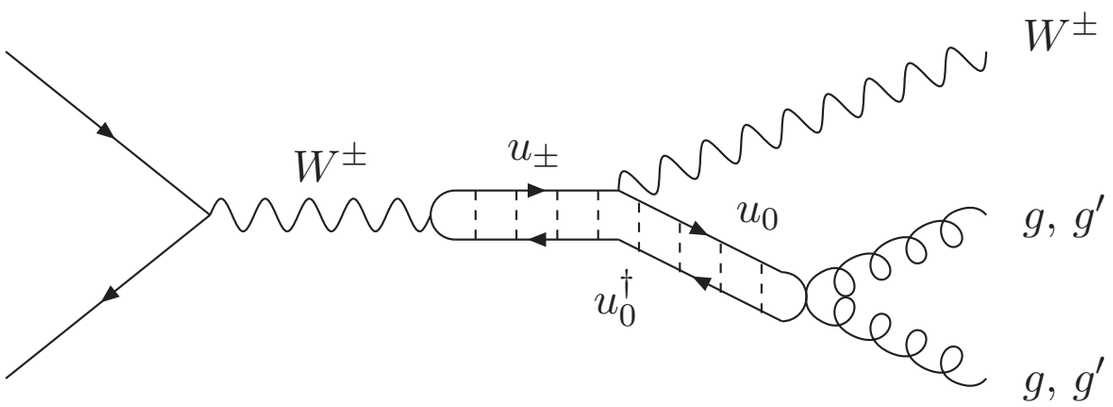
One possibility of production and annihilation:

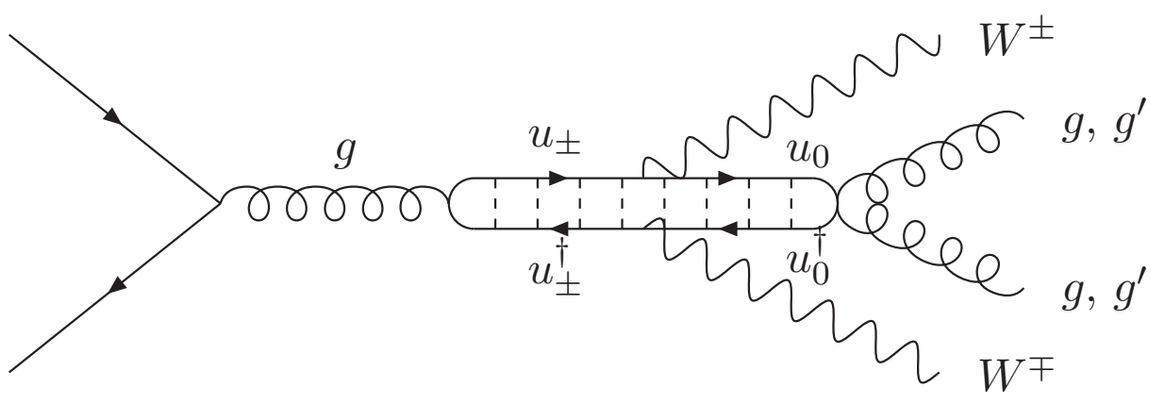


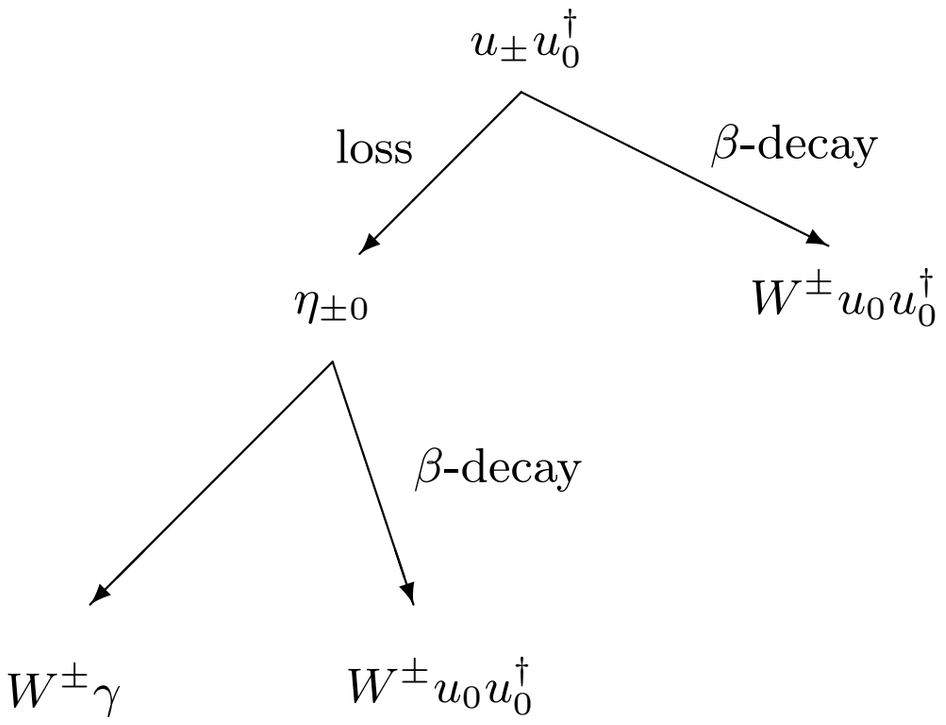
- If β-decay proceeds rapidly, get several pb of WWjj

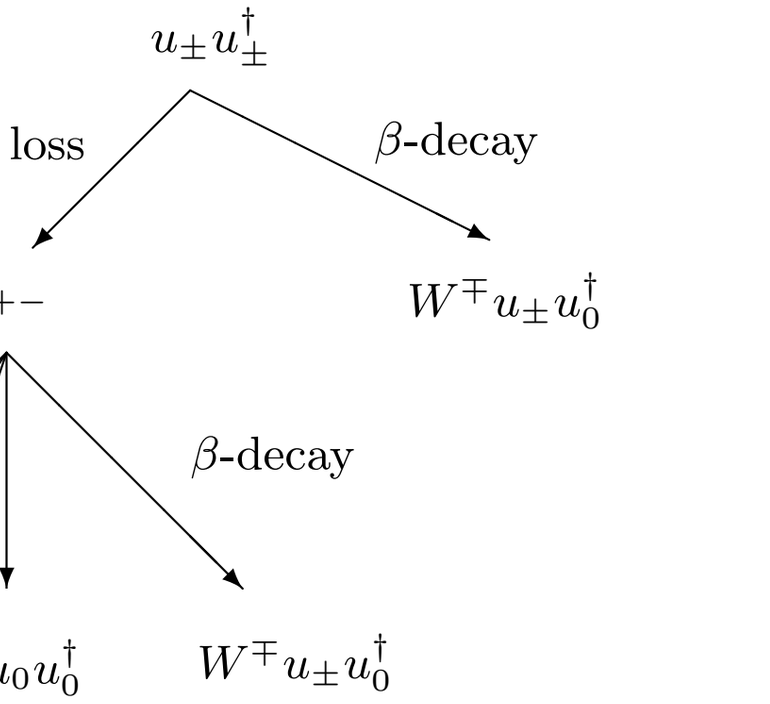
- If β-decay not so rapid, can have direct annihilation
  $u^{\dagger}_{\pm}u_{\pm}$ -> gg; g'g'; $\gamma\,\gamma$; $u^{\dagger}_0u_0$

Horserace





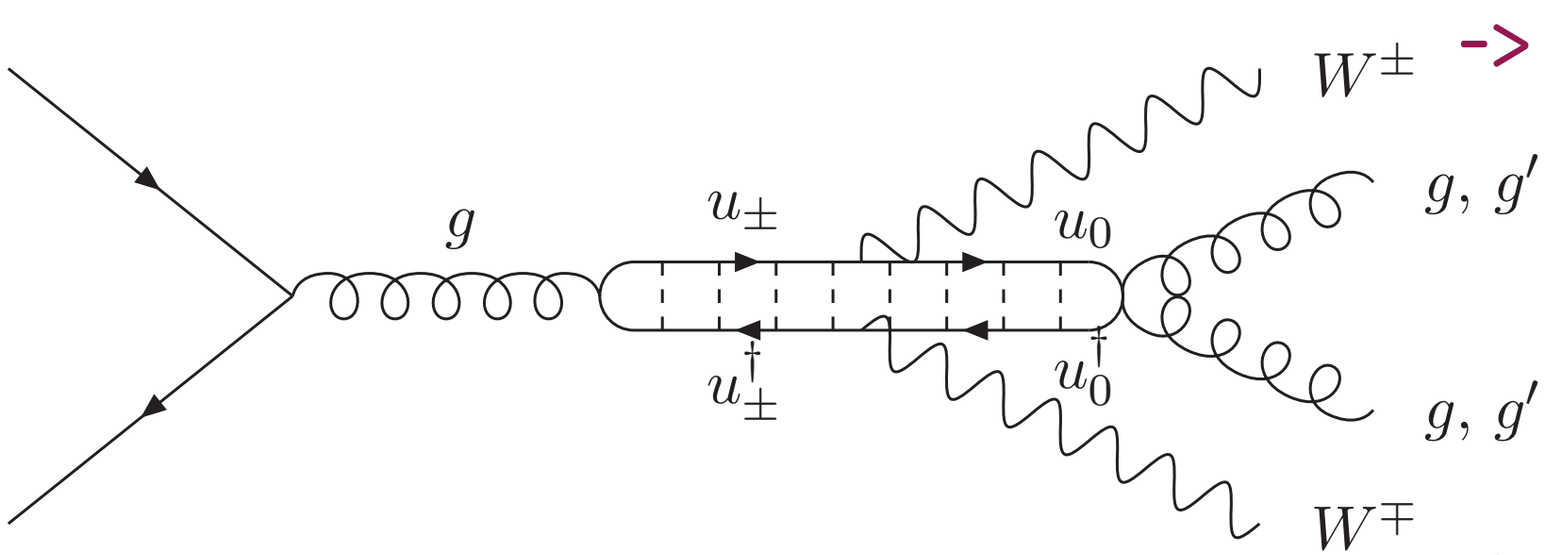




We calculated β-decay and estimated energy loss to arrive at "net" WWjj, Wjj, $\gamma\,\gamma$ signals from the various paths.

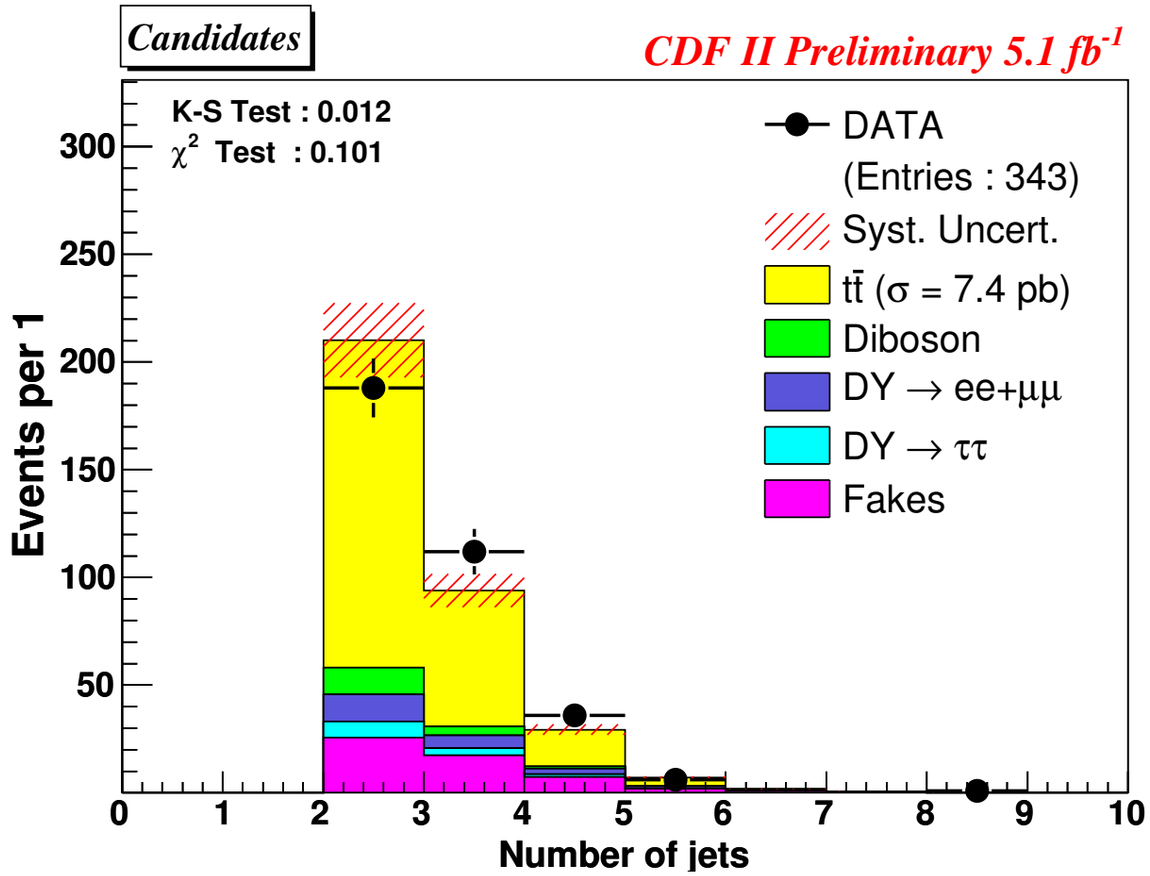
Incorporating crude estimates of kinematics with cuts, we find Wjj can just as easily arise from WWjj, esp when W decay off-shell.

WWjj in Dileptonic Top Sample



-> leptonic

-> leptonic



CDF "pre-tag" constrains

$\sigma(WWjj) < 2$ pb @ 95% CL

Actual constraint on squirk production weaker when β-decay off-shell.

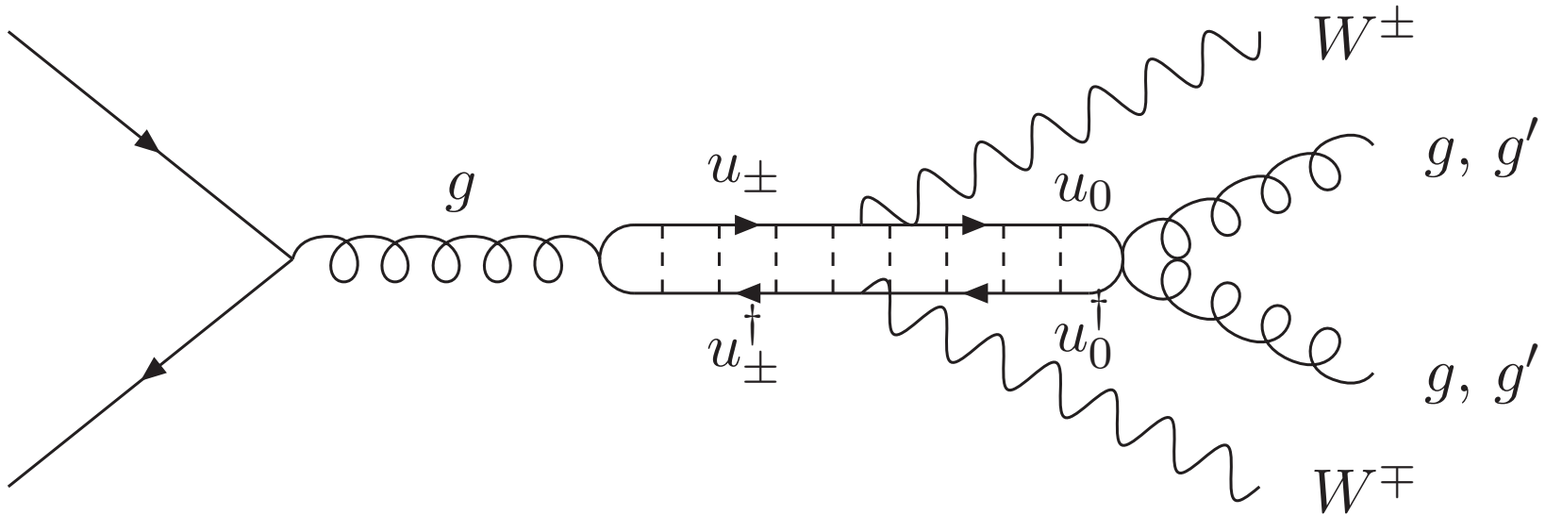
Benchmarks

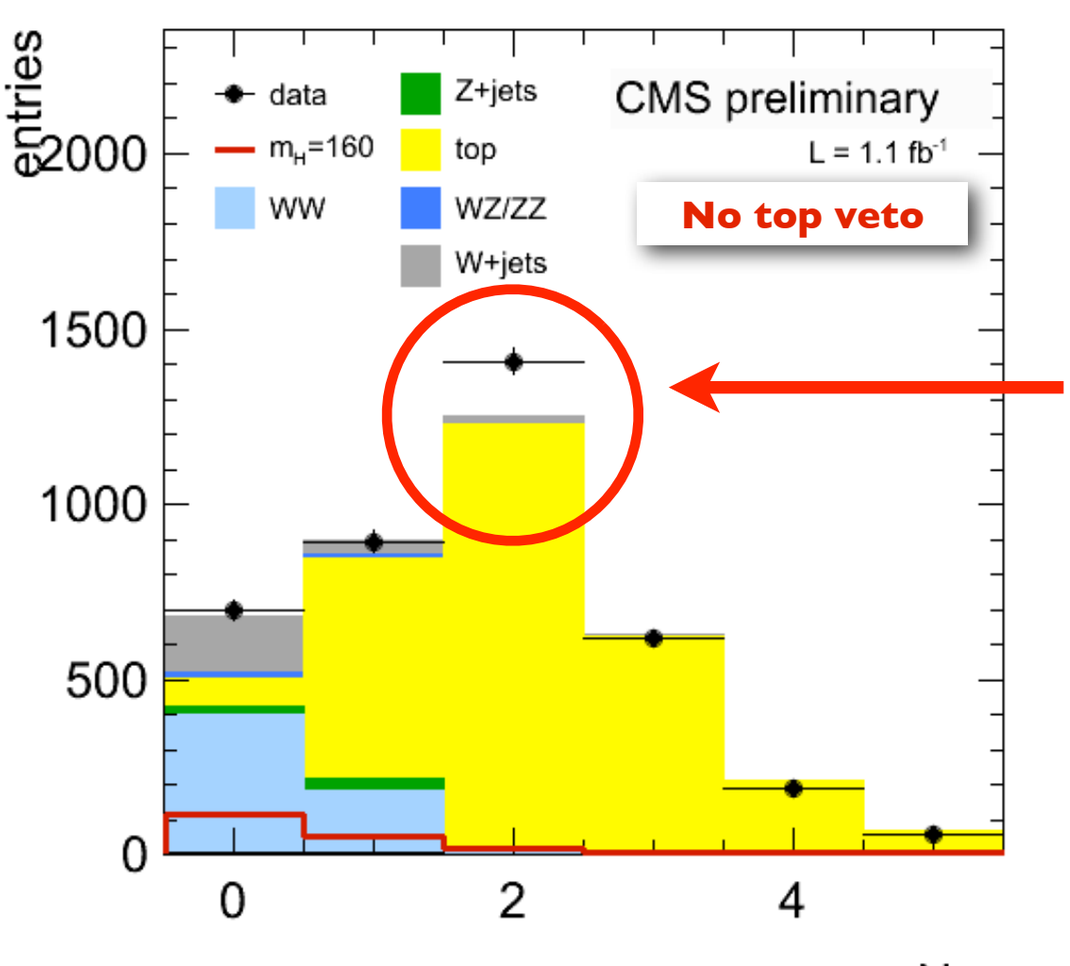
	Bench 1	Bench 2	Exp't Bound
N_{ic}	3	4	-
Λ_{ic}	1.6	6.2	-
M_V	120	145	-
M_S	150	250	-
δ	106.5	172	-
λ_4	2	1	-
m_0	80	75	-
$m_\pm$	120	145	$\gtrsim 100$
m_1	175	279	-
s_θ	0.82	0.89	-
$\sigma(u_0 u_0^\dagger)$	33	42	-
$\sigma(u_\pm u_0^\dagger + u_0 u_\mp^\dagger)$	2.5	1.9	-
$\sigma(u_\pm u_\pm^\dagger)$	6.2	3.5	-
$BR(u_0 u_0^\dagger \to gg)$	0.51	0.48	-
$BR(u_0 u_0^\dagger \to g'g')$	0.49	0.52	-
$\sigma_{\rm UA2}(u_0 u_0^\dagger \to gg)$	0.3	0.6	$\lesssim 90$
$\sigma_{\pm 0}(Wjj)$	0.72	0.84	-
$\sigma_{+-}(WWjj)$	2.4	2.4	-
$\sigma(\ell^+\ell^{-(\prime)}jj) \times$ eff	1.6	2.0	$\lesssim 2$
$\sigma(Wjj) \times$ eff	1.3-2.0	1.0-1.5	$\lesssim 1.9$
$WWjj/Wjj_{\rm total}$	$\sim 85\%$	$\sim 69\%$	-
$\sigma_{+-}(\gamma\gamma)$	0.006	0.004	$\lesssim$ 0.01-0.04
$\sigma_{\pm 0}(W\gamma)$	1.1	0.2	$\lesssim$ 8-14
ΔT	0.02	0.01	$-0.05 \to 0.2$
$\sigma_{\rm LHC7}(u_0 u_0^\dagger)$	480	430	-
$\sigma_{\rm LHC7}(u_\pm u_\pm^\dagger)$	200	130	-

Harnik, GK, Martin; 1106.2569

Specific parameters satisfying our estimates of all constraints.

WWjj @ CMS?





In searching for dileptonic h -> WW + jets, intriguing discrepency in +2 jet bin.

Summary

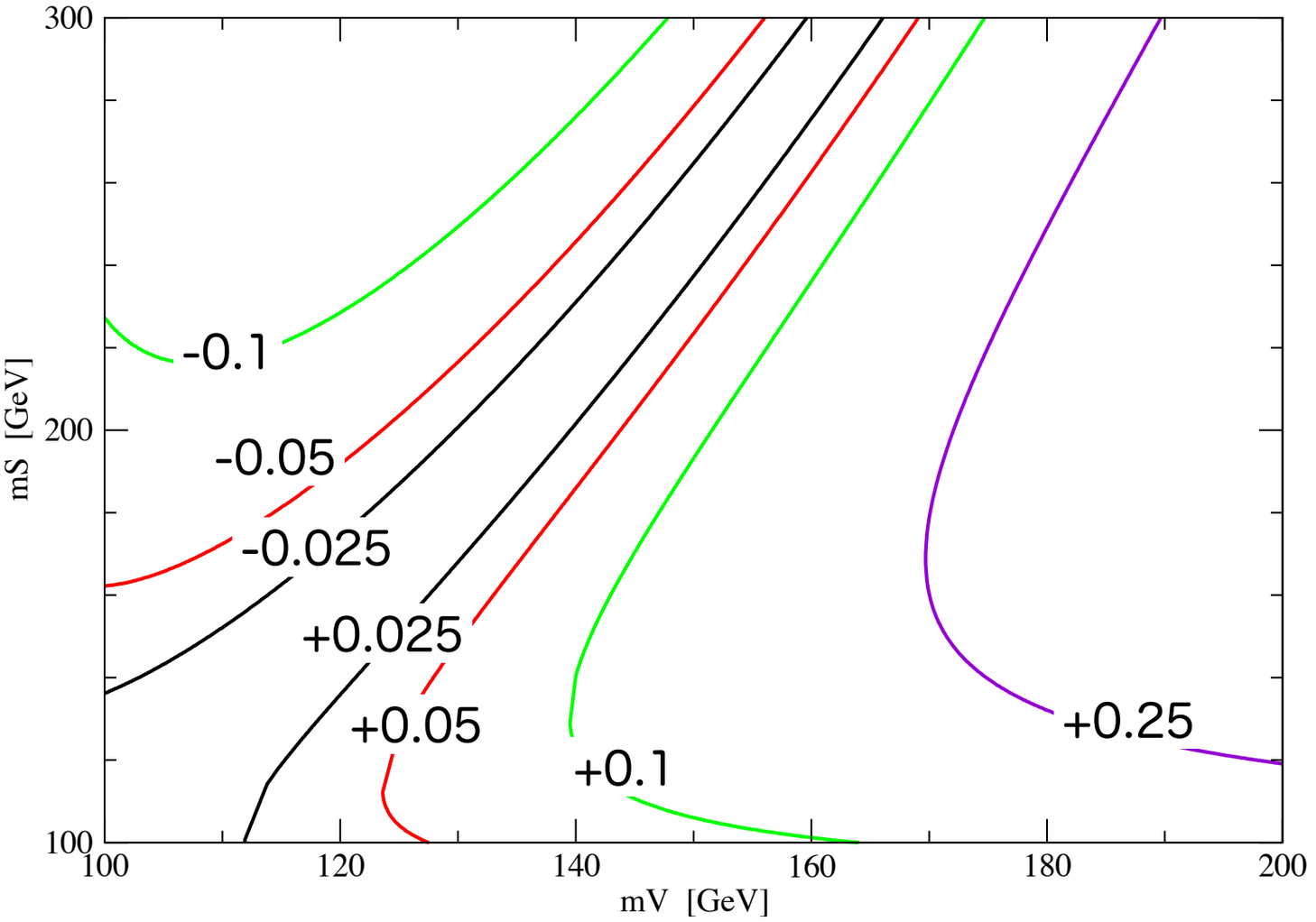
- New non-Abelian infracolor force + (s)quirks

- "Even" microscropic quirks have surprisingly interesting collider signals

- Wjj as squirk production
  -- no associated Zjj or γjj signal
  -- WWjj feeding into top sample
  -- $\gamma\gamma$ resonance (small?) from $u_{\pm}u_{\pm}$ annih
  -- underlying event? unusual kinematics?

Extra

T Parameter



$$\Delta T = \frac{N_c N_{ic}}{16\pi s_w^2 M_W^2}\left[c_\theta^2 f(m_0, m_\pm) - s_\theta^2 f(m_1, m_\pm)\right]$$

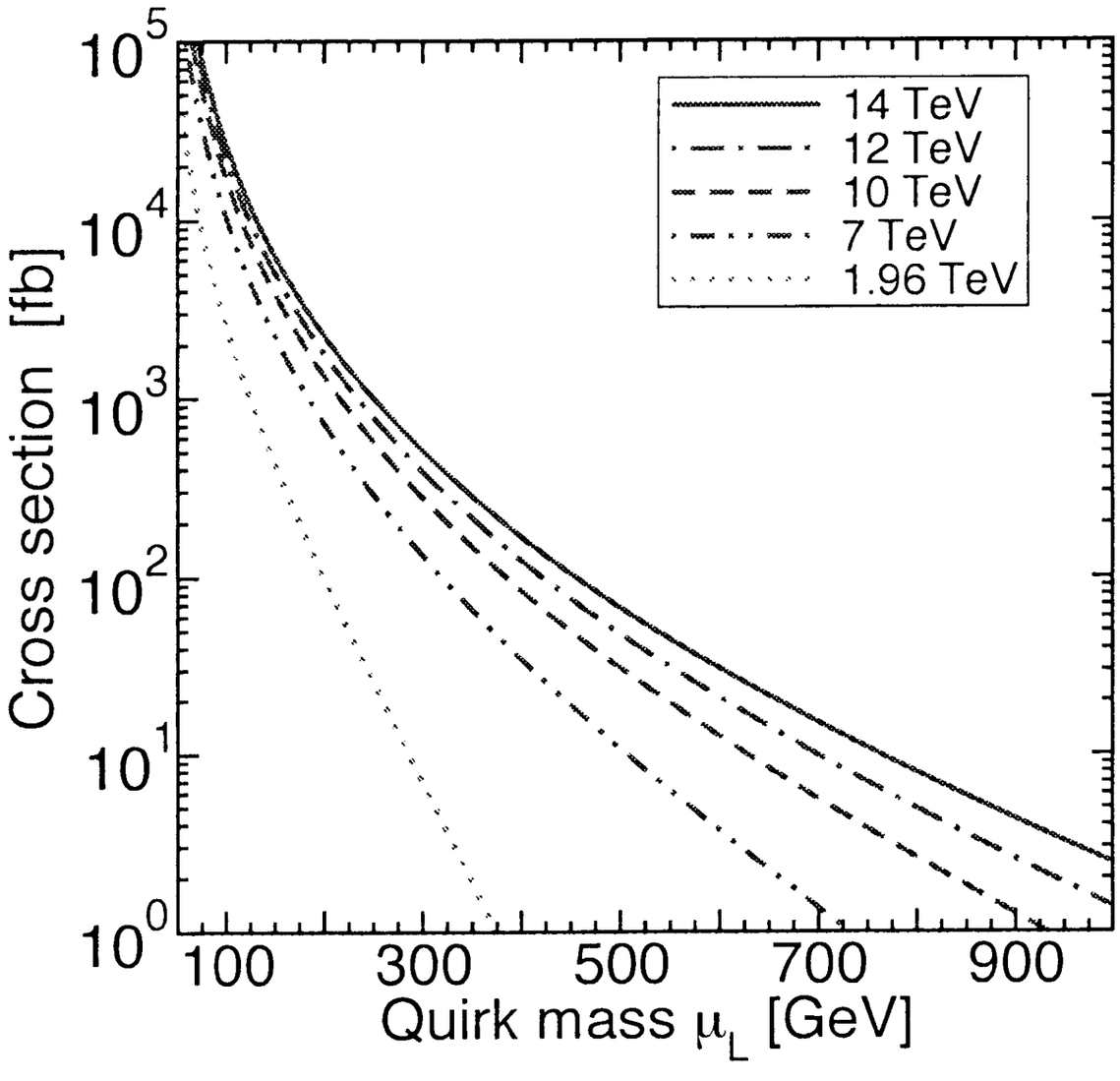
$$f(m_a, m_b) = m_a^2 + m_b^2 - \frac{2m_a^2 m_b^2}{m_a^2 - m_b^2}\log\frac{m_a^2}{m_b^2}$$

ΔT per infracolor!

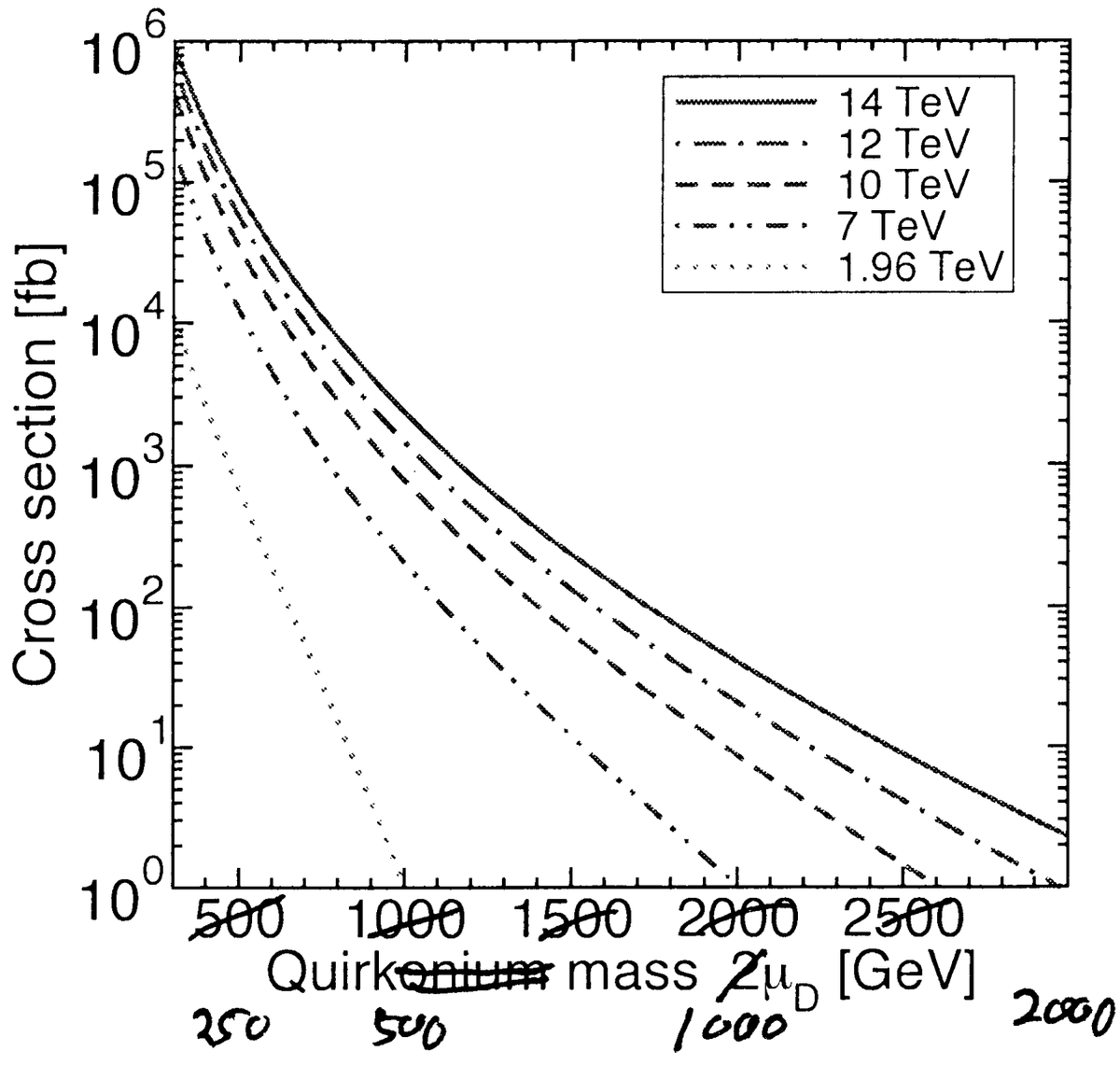
Harnik, GK, Martin; 1106.2569

Typical Production Cross Sections

electroweak



colored



Martin 1012.2072