

**An Heuristic Dual to the Standard Model:  
Stable Composite Self-Interacting Dark Matter  
*Inverting the Standard Model:***

**David R Winn  
Fairfield University**

**2025**

[winn@fairfield.edu](mailto:winn@fairfield.edu)

cell/txt: 203.984.3993\

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# Beware of the Dark Side

## Basic Conundrums:

- How can we make a particle which has no interactions with the Standard Model, but has self-interactions?
  
- How can we discover or predict particle(s) which seem to have a mass density in this universe exceeding SM by large factors?.
  
- Is there any relationship between Dark Matter and Dark Energy?
  
- What are the most basic properties that define a particle?
  1. Mass – that it interacts with the Higgs
  2. Flavor
  3. Intrinsic angular momentum/spin
  4. Couplings/Forces
  
- What dynamical properties have “Dual” natures?
  1. Electric Charge vs Magnetic Charge
  2. Color Octet: Chromoelectric vs Chromomagnetic Charges
  3. Weak Charge  $\Leftrightarrow$  Left vs Right Handedness

# In the Early epoch

- Only 1 E-M magnetic particle?  
And not in the profusion/density as electric charges?
- Why not many monopole types (Flavors/Lepton numbers)
- Chromomagnetic particles? none, zero, bupkis, nada?
- Why not tightly bound-states? (Like hadrons)
- Why not as flavor-full as in SM (mesons, baryons, leptons)?
- Say.... wouldn't or why shouldn't monopoles with large magnetic charge be made more copiously than electricity in the big banging?
- If magnetic monopoles exist, how could they be Dark?

***=> Could forces between monopole matter and Standard Model be made weak?***

**Perhaps!**

***=>Interchange or Flip SM properties to prevent SM-Dual interactions***

# Magnetic Monopole Motivation

- “almost all theoretical physicists believe in the existence of magnetic monopoles, or at least hope that there is one” - *Ed Witten*
- The existence of monopoles is “one of the safest bets that one can make about physics *not yet seen*...their existence seems inevitable in any framework that explains the quantization of electric charge. Of course their mass scale and abundance are highly uncertain.” - *Joe Polchinsky*

## Restores symmetry in Maxwell's Equations:

Maxwell's equations and Lorentz force equation with magnetic monopoles: SI units

Name	Without magnetic monopoles	With magnetic monopoles	
		Weber convention	Ampere-meter convention
Gauss's Law		$\nabla \cdot \mathbf{E} = \frac{\rho_e}{\epsilon_0}$	
Gauss's Law for magnetism	$\nabla \cdot \mathbf{B} = 0$	$\nabla \cdot \mathbf{B} = \rho_m$	$\nabla \cdot \mathbf{B} = \mu_0 \rho_m$
Faraday's Law of induction	$-\nabla \times \mathbf{E} = \frac{\partial \mathbf{B}}{\partial t}$	$-\nabla \times \mathbf{E} = \frac{\partial \mathbf{B}}{\partial t} + \mathbf{j}_m$	$-\nabla \times \mathbf{E} = \frac{\partial \mathbf{B}}{\partial t} + \mu_0 \mathbf{j}_m$
Ampère's Law (with Maxwell's extension)		$\nabla \times \mathbf{B} = \mu_0 \epsilon_0 \frac{\partial \mathbf{E}}{\partial t} + \mu_0 \mathbf{j}_e$	
Lorentz force equation	$\mathbf{F} = q_e (\mathbf{E} + \mathbf{v} \times \mathbf{B})$	$\mathbf{F} = q_e (\mathbf{E} + \mathbf{v} \times \mathbf{B}) + \frac{q_m}{\mu_0} \left( \mathbf{B} - \mathbf{v} \times \frac{\mathbf{E}}{c^2} \right)$	$\mathbf{F} = q_e (\mathbf{E} + \mathbf{v} \times \mathbf{B}) + q_m \left( \mathbf{B} - \mathbf{v} \times \frac{\mathbf{E}}{c^2} \right)$

- **Dirac:** If  $g$  exists,  $eg = \text{constant}$  *both* quantized,  $g = (e/\alpha) \sim 137e$ ,  $\Leftrightarrow \mathbf{E} \times \mathbf{B}$  angular momentum +  $\mathbf{L}$  conserved, quantized;  $g$  *integer*
- **Dirac String:** “infinitesimal line solenoid ending at a point, and the location of the solenoid is the singular part of the solution” – leads to monopole-monopole  $\sim$  linear potential piece’
- **GUT Monopoles:** Any GUT  $\Rightarrow$  U(1) at long distance  $\Rightarrow$  magnetic monopoles.. (’t Hooft-Polyakov)  $r_{\text{GUT}} \sim 10^{-18} \text{ m} \sim W \lambda_{\text{Compton}}$

$F^{\alpha\beta}$  is the electromagnetic tensor,  $\tilde{F}^{\alpha\beta} = \frac{1}{2} \epsilon^{\alpha\beta\gamma\delta} F_{\gamma\delta}$  is the dual electromagnetic tensor

**Dual tensor must be contracted in SM coupling to monopoles  
 $\Rightarrow$  monopole contributions ( $g-2$ ) for Example**

## A Seldom Used Symmetry

### 1. Photons and electric and magnetic charges: 2 classes



- **Photon Coupling to Magnet Monopoles:**

- Photon from Electric Charge couples to Magnetic Charge:  $\sim \beta g$   
(Schwinger:  $\beta g$  charge<sub>effective</sub> restores Rutherford Scattering)

*=> Photons emitted from e vs g charges treated symmetrically*  
 *$\beta g$  from electric  $\gamma_e$  to magnetic poles,*

□  *$\beta e$  from magnetic  $\gamma_m$  to electric poles.'*

### Interesting consequences:

*Cosmic Monopoles =>  $\gamma_m$  detected on earth => dim source...!*

- $\gamma_m + e \Rightarrow e + \gamma_e$ :  $\beta_{cms} \sim Q/(Q+M) \sim 10^{-5}$

- interacts rarely (scatter, absorb, reflect,  $\Delta n$ ) -w/ mirror, glass, Si pixel, nuclear charge =>  $\gamma_e$  and then has normal optics

- => Dim Galaxies, Dim Stars – since only 1 per 100k  $\gamma_m$ 's detected

- Possible explanation for dim objects that appear much brighter in x-ray/gamma than would be expected based on Vis-IR brightness..

*=> High Energy Cosmic Rays from from apparently empty sky...?!*

*Test: Image dim part of sky. Then cover aperture with thin optical density >3 film. If image only slightly reduced,  $\gamma_m$ . Alternatively, back the image camera with a stack of multiple detectors.*

# A Dual to the Standard Model

## yielding

### Neutral Stable Composite Scalar Self-Interacting Dark Matter

- **Flavors/Lepton numbers remain the same**
- **Bare masses remain the same** at tree level - up to field energy

*Specify a mass and you have specified a flavor and vice-versa  $\Leftrightarrow$  Higgs*

*Now Flip/Exchange the properties that affect the dynamics*

- **Spin:** spin changed by  $\frac{1}{2} \Rightarrow$  **SUSY-lite – Unbroken Masses**  
 $\Rightarrow$  Use SUSY names – squark, slepton, photino, wino etc.. **Convenient**
- **E-M Charge:** Exchange **Charge  $e \Rightarrow$  Magnetic Charge  $g$**   
–  $\mathbf{E} \times \mathbf{B} \Rightarrow$  angular momentum  $\Rightarrow \mathbf{L} \Rightarrow$  quantized  $\mathbf{E}, \mathbf{B}$  charges
  - **Dirac prescription**  $\Rightarrow g \sim e/\alpha$  **small  $e \rightarrow$  large  $g$**  (Preskill, t’Hooft)
  - **- Integer multiples of  $g = 2e/\alpha$  - integer charges in dual**  
 $-1/3 q \Rightarrow -6g$  squark;  $+2/3 q \Rightarrow +3g$  squark;  $\pm 2g$  Slepton+Wino
- **Chromocharges:** Chromoelectric Charge  $\Rightarrow$  Chromomagnetic Charge  
– **Chromo Charge:** Chromoelectric x Chromomagnetic  $\Rightarrow \mathbf{L} \Rightarrow$  quantized chromocharges
  - Implies  $\alpha_{m(\text{Chromomagnetic})} \sim 1/\alpha_s < 1$  as  $q^2 \Rightarrow 0$
  - Reasonable: no 3-gluino vertex = no chromomagnetic confinement
  - Assume running of  $\alpha_m$  is more like running of e-m  $\alpha$  than  $\alpha_s$
- **$L \Leftrightarrow R$ : Handedness exchange** – electro-weak hypercharge  $\Rightarrow \text{SU}(2)_R$ 
  - Are (pseudo)scalar sneutrinos RH still Majorana? (no)
  - Prevents Z decays to sneutrinos thus keeping width of Z same. 6

# Dual Forces

*In effect, the force-strengths are inverted:*

- *Magnetic force plays role of chromoelectric force*

## Lattice Strongly Coupled U(1) - Confining Phases => N-S Pairs Confined

- J. Kogut et al: Strong Coupling Gauge Theories and Beyond (World Scientific, Singapore, 1991) p. 309; V-A Miransky, Dynamical symmetry breaking in quantum field theories, (World Sci, Si

$$V_{MM}^{(b)}(r) = -\frac{g^2}{4\pi R} + \frac{\ln(2g^2)}{a^2}r \quad (\text{for } r > R)$$

constant  $a \rightarrow 0$ , blows up – introduce arbitrary cutoff at  $R$

- Others suggest  $V \sim -g^2 \frac{e^{-\alpha m r}}{r}$  with a range  $r \approx \frac{1}{\alpha m}$

$$E_{\text{bind}}(r) = -\frac{\mu_0}{4\pi} \frac{g_1 g_2}{r} = \frac{g^2 \alpha \hbar c}{4\pi r} \quad \alpha_g \leftrightarrow \mu_0 g^2 / (4\pi \hbar c)$$

- *$r = r_0$  – pole forming distance or pole size crucial*
- *assume Compton  $\lambda_W \sim$  t'Hooft Polyakov  $r \sim r_{\text{max}} [\sim e \sim 10^{-18}\text{m}]$*
- *10's of TeV binding energy*

- *Chromomagnetic force plays role of electric force*  
– *following slides*

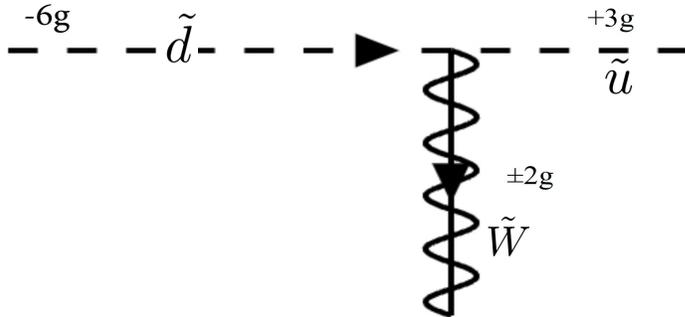
- *A Dual to ordinary matter – Consequences? Yes.*
- *Composite  $g=0$  Dark Matter Candidates? Yes.*
- *DM self-interacting? Yes.*
- *How would magnetically neutral bound states interact with ordinary matter? Only at highest  $q^2$  – resolve constituents*
- *$N \Leftrightarrow e^-$   $S \Leftrightarrow e^+$ . If reversed  $\Leftrightarrow$  consequences.*

**Inputs into Composite DM yielding neutral Dual composites:  
Stability, small SM interaction, Self-Interaction,  
Forbidden forces limit connection to SM**

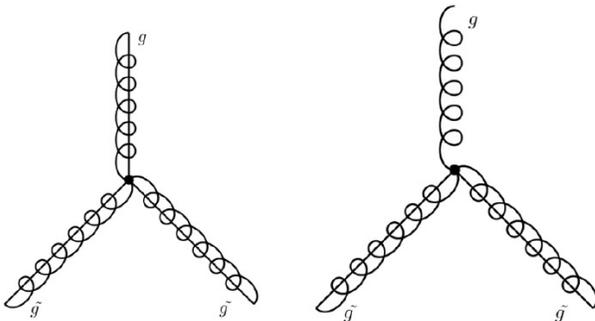
**FORBIDDEN:**

**NO Flavor-Changing (Magnetic) Charged Current of squarks.**

*Example: squark  $g = +3g$  to different flavor charged  $g = -6g$  squark by a charge  $g = \pm 2m$  is forbidden by magnetic charge, angular momentum conservation.*



**Weak Magnetic Charge Current Turned Off in Squark Sector!**



**FORBIDDEN:**

**Chromomagnetic gluino  $\leftrightarrow$  gluon:**

**No gluino-gluon-gluon**

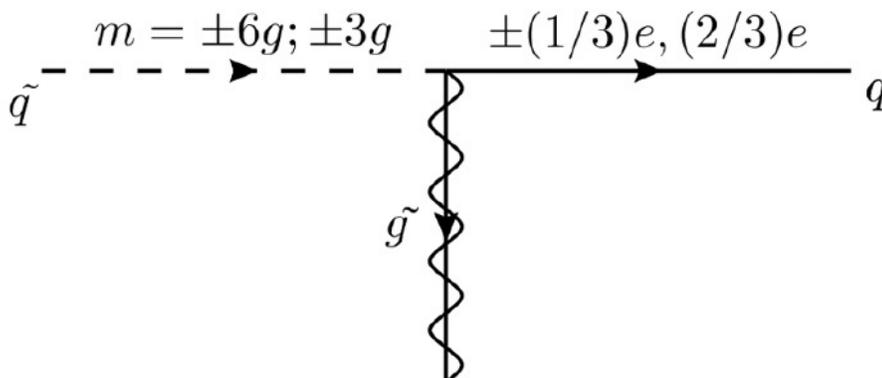
**No gluino-gluino-gluon**

**No gluino-gluino-gluino**

**Chromocharges, angular momentum not conserved**

**FORBIDDEN:**

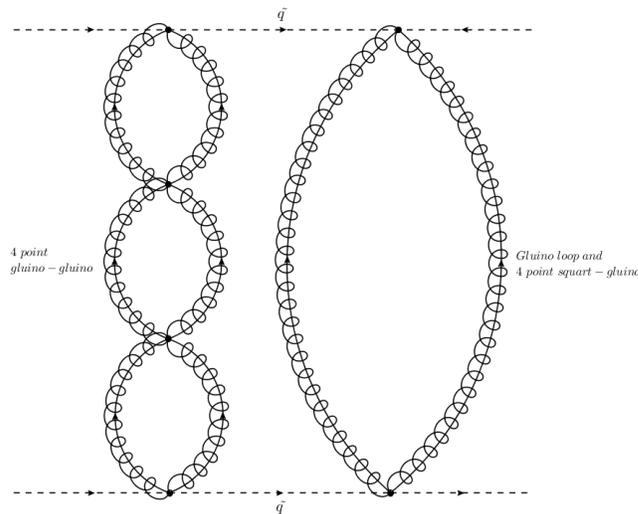
**Magnetic squark converting to quark by gluino emission: charge not conserved.**



# Chromomagnetic Interactions

## *Dual Shadrons:*

- Loops of spinor Di-gluino-gluino(scalar) connect **spin 0** squarks or shadrons
- Yukawa-like interaction; range  $\sim 1/m_{\text{monopolium}}$
  - Effective mass **m**: bound smeson or gluino-gluino  $\Rightarrow$  in sub-0.1 KeV range.
  - Dual: up/down squark bare masses **small** – *u, d squarks (3-6 MeV).*



## *Interaction with SM hadrons:*

### *Moving/fluctuating chromo-electric charges in hadrons*

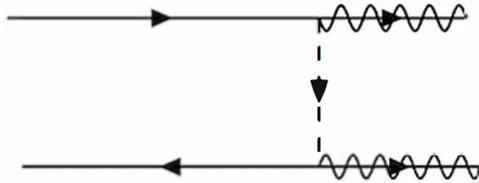
Create effective chromo-magnetic/electric fields and charge densities  
 $\Rightarrow$  effective chromomagnetic charge densities **within SM hadrons**

- Chromocharge densities fluctuate - damped by small masses. ‘
- *Effective Monopole Couplings* –fluctuating chromoelectric/magnetic field densities at  $r > 1/m_{\text{squark}}$  -limited at low energy (as in dark matter experiments);
- *Resolving monopoles bound in stable monopolium* requires high energy probes.

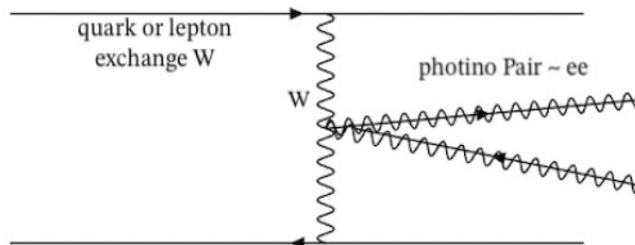
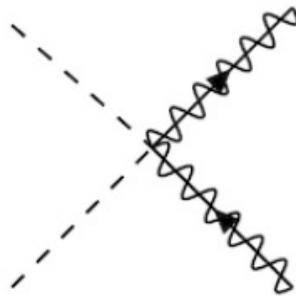
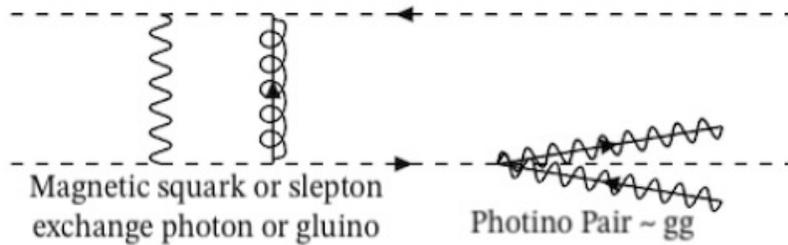
# Photino Production

**FORBIDDEN in SM:**

*Photino production in SM* - no electric charge selectron fermion-fermion  $\rightarrow$  2 photinos absent



## Photino Production in Dual



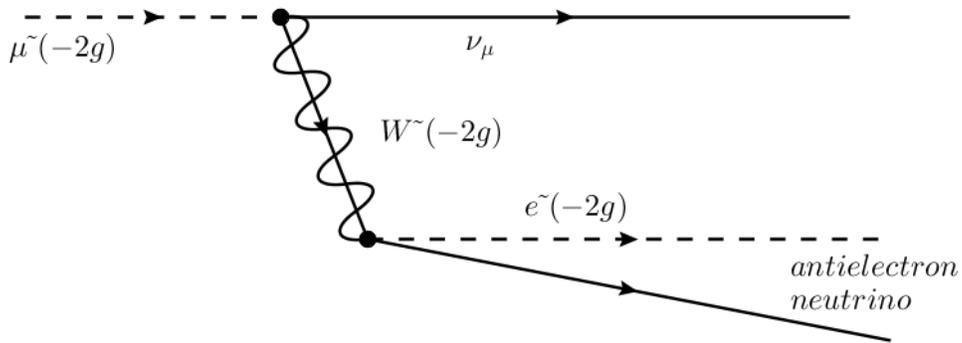
Dimension 5

# Sleptons

## Connections of DM to SM (also *time reversed!*)

### Charged Slepton → Lepton Decay

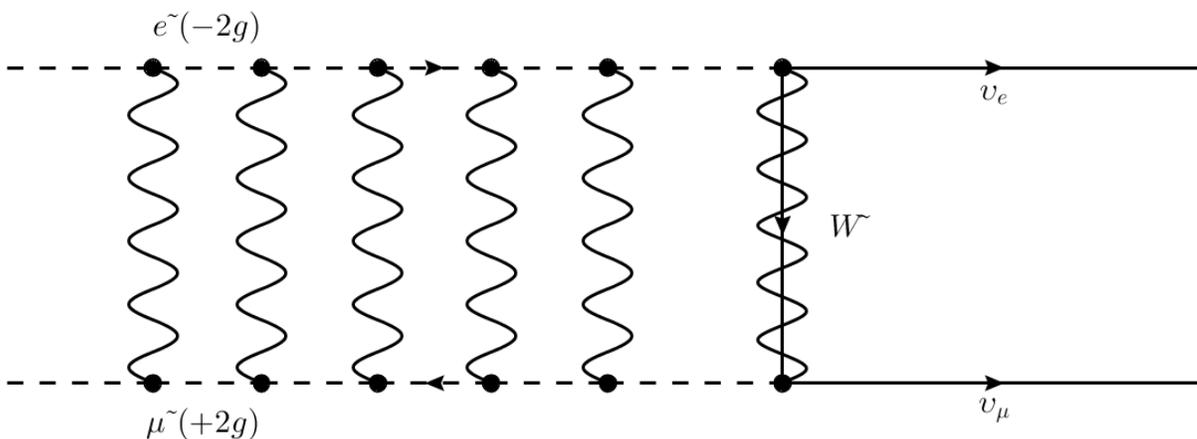
$g=\pm 2$  slepton can decay via the Wino to corresponding SM sneutrino (Handedness?)



**Sleptonium:** **bound state of 2 different flavor** magnetic charged sleptons – Exchange magnetic photons (ladder diagram) between a charged  $-2g$  scalar slepton + different lepton number charged scalar  $+2g$  anti-sleptom decays to corresponding SM Neutrinos through the fermion Wino: There are 3 types of sleptoniums + 3 “antisleptoniums”. .... Unless bound state mass < neutrino masses .. Binding energy  $\sim 500$  GeV.

The di-slepton state sleptonium has *the same Quantum numbers as a coherent neutrino pair* – **implications for neu-oscillations?** neutrino+antineutrino can create sleptoniums....

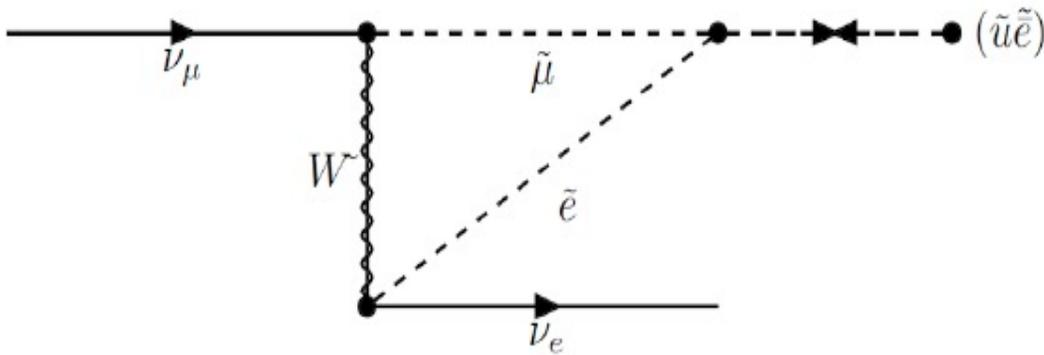
### Sleptonium



$M_{\text{monopolium}} \Rightarrow$  Very Large Binding Energies...  $M \rightarrow 0$   
**What do we do with Binding Energy  $>$  Mass??**

**Neutrino Decay if  $m_{\text{monople}} < m_\nu$ ??**

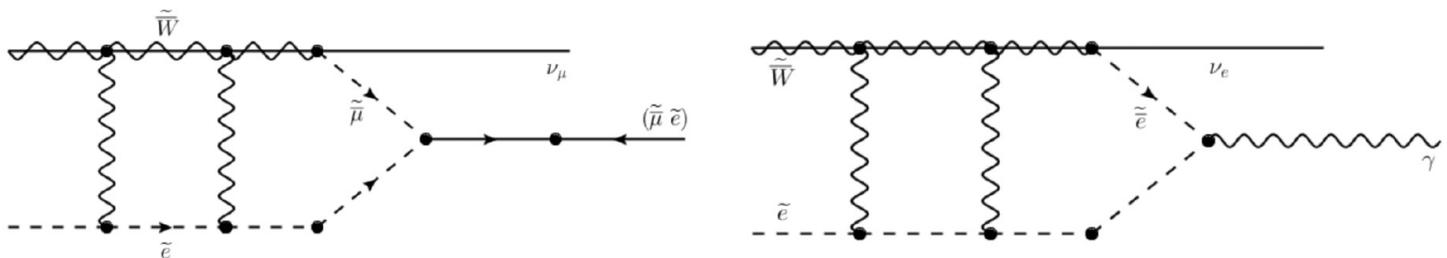
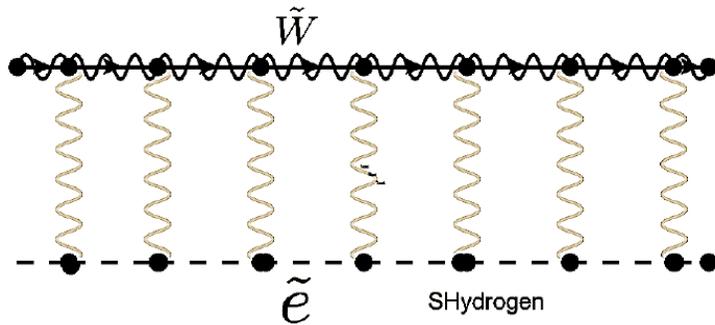
Can  $\nu$  be off mass-shell? – ex:  $\pi \rightarrow \mu\nu$



**$\nu$ -Sector:** Decay changes flavor. **Charged Sector:** flavor conserved.  
**Implications for Oscillations? Anomalies?**

**sHydrogen– Spin 1/2 - Satom?**

Energy levels + Binding Energy  $r_0 = \text{Compton } \lambda_{W^-} \sim -24 \text{ TeV}$



Plus  $\tilde{\nu}$  is a (pseudo) scalar right-handed particle....

$\Rightarrow$  Implications for neutrino oscillation and anomaly interpretations?<sup>2</sup>

*Shadronic Matter: from bound squarks-squarks=> low masses.*

**Glueinos not confining**

**Yet squark composites from magnetic photon exchange**

- low mass, with small radii-

- Binding energies truly prodigious  $\sim(3g)^4$  or  $(6g)^4 \sim 1-10$ 's TeV

=>low mass composites

- *To probe shadrons with SM particles requires high energy.*

- **Stable Spin 0 Neutral Smesons** – Flavor-changing charged current Wino charge  $g=2$  shut off => Thus: Analogs:

- *2x3=6 neutral spinless smesons – QM quantized excited energy levels??*

weak hypercharge=0 => *No Z coupling ⇔ Connection to SM is Higgs exchange.*

$$K^0: [\tilde{d}\tilde{s}], D^0: [\tilde{u}\tilde{c}], B^0: [\tilde{b}\tilde{d}]$$

- **Stable Neutral sbaryons:** Analog of neutral baryons: example: proton but neutral (sproton=sneutron), 1 of  $3 \times 3 \times 3 = 27$  **neutral sbaryons.**

$$\text{sProton} \quad [\tilde{u}\tilde{d}\tilde{d}] = 3g + 3g - 6g = 0$$

- **Stable Neutral di-Smesons:** Two  $(+3g + -3g)$  smesons, as shown – or re-arranged as 2 neutral smesons – **36 such neutrals.** (no Z coupling)

$$[\tilde{u}\tilde{d}\tilde{c}\tilde{s}]$$

- **Stable Neutral tri-Smesons: 36 variants**

$$[\tilde{u}\tilde{u}\tilde{c}\tilde{t}\tilde{d}\tilde{d}\tilde{c}\tilde{t}]$$

$\tilde{u}$

**105 "ground-state" sHadrons!**

- **Satoms:** Posit: multi-*s*Quark and *s*Lepton systems:  
weakly bound neutral mesons/sbaryons ~in contact

1. ~Ionic, Van der Waals, covalent bond via magnetic photon field exchanges, enabling shared monopoles.
2. Chromomagnetic gluino loops exchange:
  1. relatively weak + **Yukawa-like range**
  2. chromomagnetic dipolar force not confining –
  3. no 3 gluino vertices, no string-like component.

- **Shatoms:** atom-like states in contact - *s*Chemistry

3 6g squarks + 9 2g selectrons => g=0

- spinless neutral boson chromomagnetic charge = 0 bound state with chromomagnetic charge=0.
- The 3 -6g squarks with differing flavors? - chromomagnetic neutral system (like sbaryons) – **a shatom of *s*Lithium**, with 36 "shisotopes" – of different mass/flavor squarks.

**Satoms 'n' Shatoms:** bosons comprised of bosons

- Excited-deexcited arbitrary energies above ground state
- Likely could be decomposed

**100's-100's of Dark *s*Particles!**

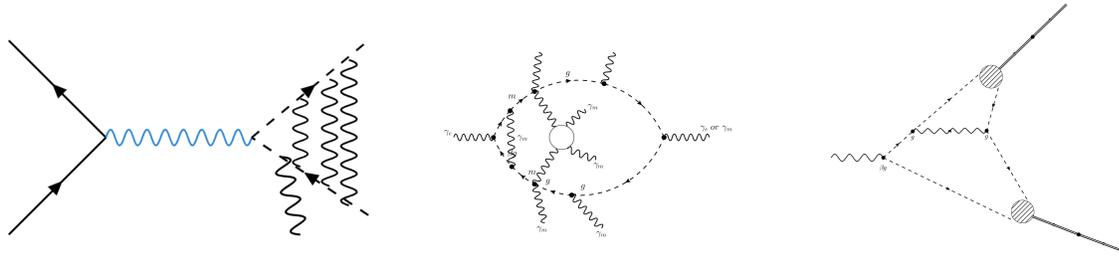
- **Beyond** – Schemistry => .....*s*Humans .... *s*AI *s*Supremacy

- **Satoms:** Posit: stabile multi-squark systems weakly bound neutral smesons/ sbaryons *similar to atoms*,
- forces similar to ionic or Van der Waals bonding can occur via magnetic photon exchanges, and exchange of (near) massless chromomagnetic gluino-loops -  $2\tilde{g}$  (spin 0) between systems composed of multi-squark states.
- **Chromomagnetic Gluino-Loop Exchange** -relatively weak + Yukawa-range, chromomagnetic force not confining – no 3 gluino vertices, no string-like component.
- **Satoms: atom-like states:** Example:  $3g = -6g$  squarks +  $9\tilde{e}$   $g = +2g$  => bind to  $g=0$  spinless neutral boson - states bound by magnetic charge and by gluino-gluino semi-weak couplings - bound state with chromomagnetic charge=0.  $+3g$  -  $-6g$  squarks may have differing flavors - chromomagnetic neutral system (like sbaryons) – here, *a shat  $\tilde{q}$  of sLithium*, with 36 "shisotopes" - different mass/flavor .
- **Shatoms/sChem:** scalars comprised of scalars - no specific energy levels except bosonic levels –excited/deexcited arbitrary energies by  $\gamma_m$ . Decomposedable.
- **Beyond** => magnetic physicists at a "SUSY" Conference<sup>15</sup>

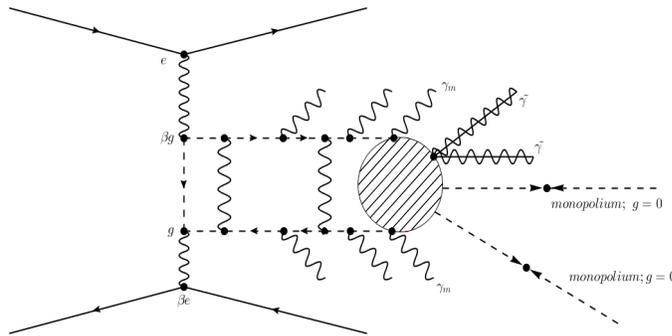
# Strongly Coupled Magnetic Monopole SM Pair Production

## s-channel Scalar Monopole Pair Production

1. **Forbidden: CP conservation:  $\gamma$   $J^{PC}=1^{--}$  N-S:  $CP = -1$ ; CP-Veto!**  
no  $1^-$  - nor  $1^{++}$  states; true even if P,C do not conserve separately but CP does.
2. **Amplitude accounting for Dirac String vanishes if direction averaged**
3. **Even if the photon couples as  $\beta g$ , in the rest frame of the heavy virtual photon the monopoles are produced at rest ie  $\beta=0$**



## t-Channel Photon Fusion Monopole Pair Production =>



monopole pair production=Inner-Bremsstrahlung=>neutralized pair  
 monopoliums escape – coupling chain  $e-\beta g-g-\beta e$ . Fraction of event energy given to poles  $f_{MM}$ .

$$\langle f_{M\bar{M}} \rangle \sim \mathcal{O}\left(\frac{m}{\sqrt{s}}\right) \times (\log/\text{acceptance factors})$$

- $e^+e^-$  at  $\sqrt{s} = 10 \text{ GeV}$ ,  $m = 10 \text{ MeV}$ :  $m/\sqrt{s} \sim 10^{-3}$ . Expect  $\sim 0.1\%$  of the total energy in  $M\bar{M}$
- ILC-like  $\sqrt{s} = 250 \text{ GeV}$ , same  $m$ :  $m/\sqrt{s} \sim 4 \times 10^{-5} \Rightarrow$  tens of ppm to the monopoles on average.
- LHC  $pp$  at  $\sqrt{s} = 14 \text{ TeV}$ , same  $m$ :  $m/\sqrt{s} \sim 7 \times 10^{-7} \Rightarrow$  sub-ppm central energy fraction.

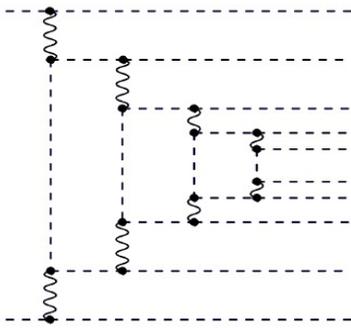
$\Rightarrow$  Low mass squarks, slepton w:  $g \geq 274e$ , pair energy far too small to escape.  
 $U \sim g^2/r$ .

$\Rightarrow 100 \text{ GeV}/100 \text{ TeV} \sim 10^{-3} \Rightarrow$  not nearly enough to escape at  $r \sim 10^{-18} \text{ m}$

# Shedding Energy of Escape

## 1. Inner Production of Monopole Pairs – uses up $E_{\text{escape}}$ *t-channel “Nest” or “Telescope”*

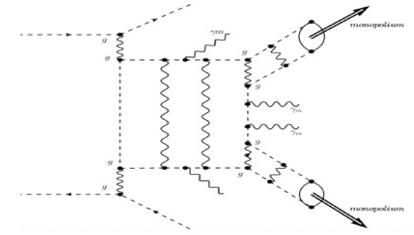
*A pair generated by SM process undergoes repeated light-by-light monopole pair production until up  $E_{\text{escape}} \rightarrow 0$*



**Coupling: g-g-g-g**

3 generation= 8 monopoles  
Annihilate or Recombine

Not Shown: Non-Perturbatives



*Escaping monopoliums Shed Energy and Hide Monopoles*

## 2. Inner Bremsstrahlung: shedding soft magnetic Photons

$\mathbf{a} = d\boldsymbol{\beta}/dt \sim g^2/(mr^2)$ , r separation distance;  $q \Rightarrow g$ ;

$$\text{Lienart relativistic Power } P = \frac{q^2 a^2 \gamma^6}{3c^3}$$

Assume  $\gamma \sim \text{constant}$ , express  $r(t)$  and integrate

$$E_{\text{brems}} \sim \frac{g^6}{m^2 c r_0^3}$$

$$E_{\text{escape}} = \frac{\mu_0 c^2 g^2}{4\pi r_0}$$

$$\frac{E_{\text{brems}}}{E_{\text{escape}}} \propto \frac{g^4}{m^2 c r_0^2}$$

**Small m, large g, small formation radius**

$\Rightarrow E_{\text{brems}}$  can overwhelm escape:

$r_0 \sim \text{Compton } W \sim 10^{-18} \text{m}$ : Confines all m.

### 3. Hard Bremsstrahlung of monopole pairs

Probability monopole pair m  
 w/ energy loss  $\Delta E$  10 MeV, 3g  
 squark  $\Rightarrow \Delta E \sim 20$  MeV

$$\exp \left[ - \left( \frac{8g^2}{3\pi\hbar c} \right) \ln \left( \frac{mc^2}{\Delta E} \right) \right]$$

### 4. Schwinger Process – Large **B** between pairs

$$B_{\text{total}}(r) = \frac{\mu_0}{4\pi} \frac{8g}{r^2} \quad \Gamma_M = \frac{g^2 B^2}{8\pi^3} \exp \left( -\frac{\pi M^2}{gB} + \frac{g}{4} \right)$$

For  $r \sim 10^{-18} - 10^{-21}$  m monopoles/fm<sup>-3</sup>/zs  $\sim 10^3 - 10^{15}$

*If magnetic mass small,  $r_0$  small: energy shed per time/distance by Nesting and bremsstrahlung is faster than the force between the poles decreases per unit time.*

*Lowest Dual masses for secondary/screen pair production  $m \sim 0.5-6$  MeV*

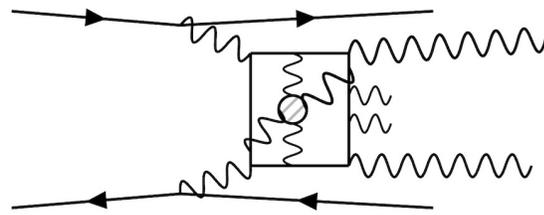
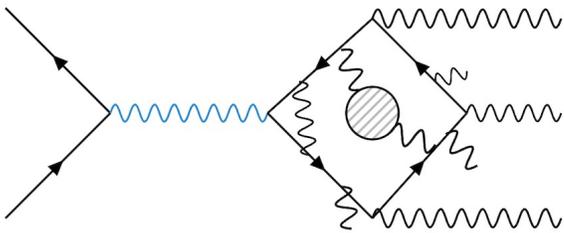
*Leads to Re-annihilation or*

*Escaping neutral flavored monopoliums*

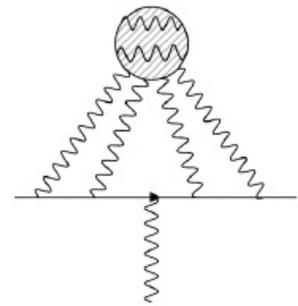
## Monopole Mass/Existence limits:

- **Light-by-Light  $\Rightarrow$  2 or 3-photons** monopole loop

- Calculations of limits violate Unitarity
- Uncontrollably larger higher order diagrams- *increase the amplitude*
- Production crosssections essentially analytically impossible... (like QCD)



- **$[(g^2-4)/(g+2)]$  likely not affected** – *CP-Veto* -strong coupled boson made of bound scalars – likely cannot generate a dipole —requires non-perturbative analysis



- **$R$  in  $e+e-$**  not affected– numerator & denominator roughly equally affected – *coupling in s-channel vanishes for pseudo scalar monopole pairs*. t-channel not counted. Monopoliums produced in either numerator or denominator will escape - not change the crosssection ratio

- **Lamb Shift** – *electric field* – Not affected

- **$H \rightarrow \gamma\gamma$  rate as detected** not affected via a top-squark loop –  $(\text{rate multi-}\gamma_m)/(\text{rate 2 isolated } \gamma_m) \gg 1$  from magnetic triangle loop – would not reconstruct  $H$  as a single  $\gamma_m + \gamma_m \gamma_m$  will interact more weakly in calorimeter depending on  $\beta$ .<sup>19</sup> However, the width would be larger than predicted by  $SM^b$  – perhaps  $\times 2 \Rightarrow$  smoking gun...

## Anomalous Soft Photon Mysteries: Production in Accelerator Experiments – Monopolium?

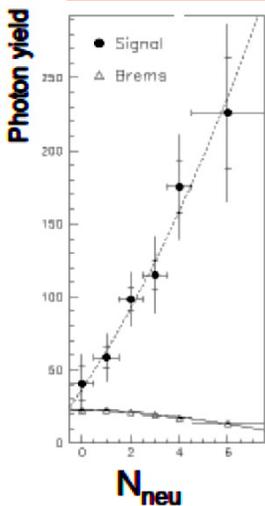
- **Soft photons, low transverse momenta**  $\sim 10$ 's MeV, in high-energy p-p and  $e^+e^-$  annihilation produced in excess of prediction of electromagnetic bremsstrahlung by x4–x8 when hadrons are produced, *but agree with electromagnetic bremsstrahlung predictions (Low theorem) in absence of hadron production.*

- Anomalous soft photons associated with hadron production implies a) presence of additional QED soft photon sources in QCD hadron production, *or some anomalous hitherto undetected process.* **Proposed Model:** oscillation of the color charge densities  $\Leftrightarrow$  oscillation of electric charge densities - **fails.**

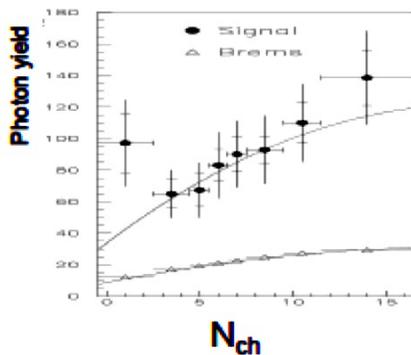
- Cheuk-Yin Wong, *An Overview of the Anomalous Soft Photons in Hadron Production; arXiv:1404.0040v1 [hep-ph]*
- V.Peripelitsa (for DELPHI) *Proc;XXXIX Int Sympo Multiparticle Dynamics, Nonlin.Phenom Complex Syst.,12,343(2009)*

Experiment	Collision Energy	Photon $k_T$	Photon/Brem Ratio
$K^+p$ , CERN,WA27, BEBC (1984)	70 GeV/c	$k_T < 60$ MeV/c	$4.0 \pm 0.8$
$K^+p$ , CERN,NA22, EHS (1993)	250 GeV/c	$k_T < 40$ MeV/c	$6.4 \pm 1.6$
$\pi^+p$ , CERN,NA22, EHS (1997)	250 GeV/c	$k_T < 40$ MeV/c	$6.9 \pm 1.3$
$\pi^-p$ , CERN,WA83,OMEGA (1997)	280 GeV/c	$k_T < 10$ MeV/c	$7.9 \pm 1.4$
$\pi^+p$ , CERN,WA91,OMEGA (2002)	280 GeV/c	$k_T < 20$ MeV/c	$5.3 \pm 0.9$
$pp$ , CERN,WA102,OMEGA (2002)	450 GeV/c	$k_T < 20$ MeV/c	$4.1 \pm 0.8$
$e^+e^- \rightarrow$ hadrons, CERN,DELPHI with hadron production (2010)	$\sim 91$ GeV(CM)	$k_T < 60$ MeV/c	4.0
$e^+e^- \rightarrow \mu^+\mu^-$ , CERN,DELPHI with no hadron production (2008)	$\sim 91$ GeV(CM)	$k_T < 60$ MeV/c	1.0

$$\frac{\text{Soft photon yield}}{N_{neu}} \gg \frac{\text{Soft photon yield}}{N_{ch}}$$



**$e^+e^-$  annihilation at Z0 decay ( $\sim 91$  GeV)**



Hypothesis: chromomagnetic charge oscillations radiate  $\gamma_m$  at high rates.

- A check of the total energy in  $e^+e^-$  is crucial.
- $\gamma_m$  coupling deposits less e-m energy in typical calorimeters

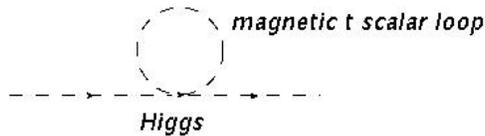
## Hint of Monopolium in Cosmic Rays

**Multi- $\gamma$  events.** Five peculiar photon shower events were found in nuclear plates exposed to high-altitude cosmic rays<sup>40</sup>. The five events are characterized by a very energetic narrow cone of tens of photons, without any incident charged particle. The total energy in the photons is of the order of  $10^{11}$  GeV. The radial spread of photons ( $10^{-3} \div 10^{-4}$  rad) suggests a c.m. velocity corresponding to  $\gamma > 10^3$ . The energies of the photons in the overall c.m. system are very small, orders of magnitude too low to have  $\pi^0$  decays as their source. One of the possible explanations of these events could be the following: a high-energy  $\gamma$ -ray, with energy larger than  $10^{12}$  eV, produces in the plate a pole-antipole pair, which then suffers bremsstrahlung and annihilation producing the final multi- $\gamma$  events. M.Schein, D.M. Haskins, R.G.Glasser, Phys.Rev99,643(1955)

- *Alternate interpretation:* high energy neutral hadron monopolium interacts with an emulsion nucleus, excites/de-excites w/  $g_m$  emission.
- *Cosmic Ray Monopolium Evade GZK Limit*
  - a. Monopolium neutral,  $g$  confined.
  - b.  $M < m_{\text{proton}}$interact weakly w/ cosmic background photons + cms energy available for  $\pi^0$  insufficient until well above the GZK limit.
- Longitudinal and transverse development of event-showers above  $10^{20}$  eV not well explained by proton-initiated Monte Carlo
- Hypotheses that the events are initiated by neutrinos or photons seem inconsistent.
- $\sim 100$ 's cosmic ray events evade the GZK cutoff, and  $\sim 10$ 's exceed  $10^{20}$  eV. Acceleration of free poles in magnetar fields which recombine in the plasma surrounding them may explain these energies, which are difficult to explain either the energy, the rates or the propagation in the SM  
[arXiv:2307.15667v2](https://arxiv.org/abs/2307.15667v2) [astro-ph.HE] 11 Jan 2024 ; [arXiv:astro-ph/9605156v1](https://arxiv.org/abs/astro-ph/9605156v1)

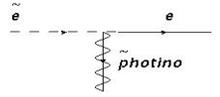
# Consequences of a Magnetic Dual

- **Higgs mass** is naturally Stabilized.



- **R-parity**: Not needed to prevent p-decay (aka prot-rot)- no diagrams for conserving both electric magnetic charges in proton decay.

- **Squarks** cannot decay/convert by charged current weak interaction.



- **Sleptons: slepton-lepton-photino**: Charge, L-R SU(2)<sub>R</sub>

$$\tilde{\mu} \rightarrow \tilde{e} + \bar{\nu}_e + \nu_\mu \quad \nu + \bar{\nu} \rightarrow \tilde{l} + \bar{l}$$

- **Dark Matter** is effectively a Hidden Sector – magnetic charged slepton/squark cannot convert to lepton/quark via photino/gluino emission:

- **Neutral Boson Dark Matter Shadrons**:

- **Smesons**(weak charge & hypercharge=0)neutral meson stable!



- **Sbaryons** – 27 neutral baryons – neutral sproton aka sneutron

- higher order neutral **di- and tri- smesons**

- **Satoms** involving charged smesons or baryons and selectrons

**100's-1,000's Dark Matter – Possible Soln Baryon/Antimatter?**

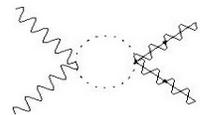
- **v-Sector**: Decay changes flavor. **Charged Sector**: flavor conserved.

## Implications for Oscillations? Anomalies?

- **Production of chromomagnetic monopoles**  $\alpha_{sm} \sim 1/\alpha_s$  No triple chromomagnetic “gluino” vertex- not confining,  $1/\alpha_s$  runs differently?

- **Full Chromoelectric/Chromomagnetic Lagrangian**: –  $\theta_{CP} \rightarrow 0??$

- **Photon-photino coupling** via Dual magnetic scalar bubble



- **Photinos are a massless fermion gas** in this model- generates Fermi-pressure in the universe as frequencies  $\rightarrow 0$

A component of **Dark Energy**.

**Photon-Photon  $\Leftrightarrow$  Photino-Photino**

- **Other Anomalies: X17 boson? Cosmic Ray Phenomena**

*Can we - and is it worth it -  
exploring soft photon showers (LHC, e<sup>+</sup>e<sup>-</sup>)*

- *Clusters of many soft photons:  $\sim 10-100$  MeV  $p_T$  wrt an axis?*
- *Overlapping cluster of soft photons look like a very early starting e-m shower, and be detectable?*
- *high photon multiplicity vs missing energies, neutral/charged multiplicity, particle type multiplicity, ...?*
- *Sub-radiation length thick longitudinal segmentation e-m calorimeters to look for the  $\beta_e$  coupling.*
- *The “no-lose”: Soft photons as seen in other experiments in cosmic rays, hadron and e<sup>+</sup>e<sup>-</sup> are not well-studied, in need of quantitative explanation, **monopoles or not**. Need quantitative predictions/“smoking guns” for monopoliums, **or in ruling this out**.*

*Searches for the Stable Dark Monopoliums/Monopoles*

- **Electric Dipole Field:** Neutron-like star with a strong Electric Dipole field – created by circulating monopole currents (**inverse Magnetar – an Electrotar**) – a smoking gun...
- **Bohr “electroton”**
- **Induced Magnetic Moment** and acceleration in the diverging field of a Magnetar
- **Radiation Length:** Detecting low=>high energy photons from highest energy physics collisions (pp in colliders and fixed target) that *appear* to have longer radiation lengths in finely segmented tracking calorimeters than normal photons.
- **Timing:** With timing precision in high energy collisions, detect photons that appear to travel at light speed through otherwise transparent or low-Z opaque materials.
- **Missing Total Observed Energy:** e<sup>+</sup>e<sup>-</sup> high multiplicity of low energy photons and missing total energy
- **UV-Vis-IR- $\mu$ Wave photons:** from atmospheric cosmic rays or cosmic sources (stars, galaxies) have a smaller cross-section with photon detectors/cameras
- **Cosmic Air Showers:** Unusual shower development unlike simulations/data for p or nuclei cosmic rays.
- **Cosmos:** light through strong magnetic fields : changes in light polarization or energy distribution due to induced magnetic dipoles in monopolium.
- **Orbiting cosmic ray telescope:** high orbit or L5 – panels many square meters with x-y resolutions, separated by  $\sim$ km’s to detect cosmic interactions with dark matter.
- **Lepton disappearance:** e, $\mu$  beams disappearing
- **$\nu$  Oscillations:** Differences between accelerator vs source/reactor  $\nu$ -oscillations

# Extra Slides

## Non-perturbative strong-coupled U(1) (Dirac String)

- $g$  integer multiples of  $e/\alpha$
- QMD  $\beta$ -function runs like  $\alpha$  (Schwinger)? Or inversely like  $\alpha_s$  (Coleman)?
- Lower bounds? Assume  $r_{\text{Monopole}} \sim r_e$  or  $W$  Compton  $\lambda$
- $m_{\text{Monopole}} \sim (m_e \text{ or } m_{\text{up-quark}}) < 10\text{MeV}$
- **Lattice Strongly Coupled U(1) - Confining Phases  $\Rightarrow$  N-S Pairs Confined**
  - J. Kogut et al: Strong Coupling Gauge Theories and Beyond (World Scientific, Singapore, 1991) p. 299; S. Love, ibid p. 309; V-A Miransky, Dynamical symmetry breaking in quantum field theories, (World Sci, Singapore, 1993).

$$V_{MM}^{(b)}(r) = -\frac{g^2}{4\pi R} + \frac{\ln(2g^2)}{a^2} r \quad (\text{for } r > R)$$

- constant  $a \rightarrow 0$ , blows up – introduce arbitrary cutoff at  $R$

- Others suggest  $V \sim -g^2 \frac{e^{-\alpha m r}}{r}$  with a range  $r \approx \frac{1}{\alpha m}$

### Indirect Monopole Mass limits: light-by-light producing 3-photons via monopole box, g-2, ...

- Theory calculations used for limits violate Unitarity
- Unjustified application of electromagnetic duality to QED Lagrangians
- *Uncontrollably larger higher order diagrams- extra photon legs increase the amplitude*
- If monopoles are (pseudo)scalars, monopole mass limits lower.
- *Production estimates essentially analytically impossible....*
- **See references:** *L.Gamberg, G.R. Kalbfleisch, and K.A. Milton, Difficulties with Photonic Searches for Magnetic Monopoles, arXiv:hep-ph/9805365v1, -Kimball A Milton, Status of magnetic monopoles, 2006 Rep. Prog. Phys. 69 1637*

# Monopolium/Monopole Pair Fate

*Can monopole pairs separate if produced by SM? Controversial!*

- **Linear term in potential?** => if so, likely **Confinement**
  - **Internal Bremsstrahlung+2ndary Pairs in monopole Pair Production Processes**  
 $q=g$ ;  $a = \text{acceleration} \sim g^2/m$ :  $\mathbf{a} = d\boldsymbol{\beta}/dt \sim g^2/(mr^2)$ ,  $r$  separation distance
    - Radiated Power  $P$  when  $\mathbf{a} \parallel \mathbf{v}$ :  $\frac{q^2 a^2 \gamma^6}{3c^3}$   $E = mc^2 \Rightarrow \mathbf{P} \sim \gamma^2 g^6 m^{-6} \Rightarrow$
  - *If magnetic mass sufficiently small, energy shed by bremsstrahlung and by separation per unit time is **faster than the force between the poles decreases per unit time**. Lowest Dual masses screen pair production  $\sim 0.5-6 \text{ MeV}$* 
    - Monopole pairs re-annihilate and/or hide by screening with secondary produced low mass pairs (*akin to quark hadronization*) –
    - **Basic Requirement for Dual: low mass monopoles < few MeV, produced by off-mass bremsstrahlung photons from primary pair, yielding secondary pairs that neutralize/screen magnetic-chromomagnetic charges of pair produced primaries.**
    - lowest mass monopoles re-annihilate - Energy radiated away as SOFT PHOTONS (Brems Spectra) – magnetic photons with low absorption in SM matter.
    - **Magnetic Photon Multiplicity** Estimate from Brem:  $2\pi g^2/hc \sim 100$ 's
- The Fates of a produced  $\pm g$  pair:***
- *Re-annihilates* immediately back to photon(s) or Z(s) ..... or even gluons
  - *Binds to form Monopolium* ( $r_0 < 1F!$ ) -orbital de-excitation “ground state”=>annihilates
    - Naïve Binding/Rydberg energy for  $g=2 \times 137e$ :  **$\sim 50 \text{ GeV}$  for  $r > 1F$**
    - *How to interpret  $E_{\text{binding}} > M$ ?*
  - “Dirac String” “snaps” forms another  $\pm g$  pair/monopolium? *Much like hadronization?* =>
    - ***A monopole mass  $\sim m_e, m_q$  makes it difficult to find monopoles.***
- Quarks hide via 3-gluon vertex – Monopoles hide by shedding photons*
- **How would stable monopolium interact? Exchange of chromomagnetic scalars** made as photino pairs, 2-gluino or 4 gluino loops with 4-point vertices.

# Strongly Coupled U(1) and Neutral Monopoliium

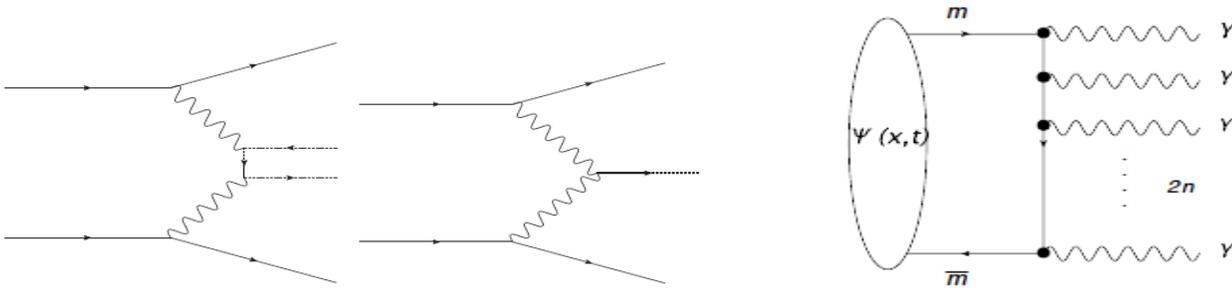
- Non-perturbative strong-coupled U(1) (Dirac String)
- $g$  integer multiples of  $e/\alpha$  (Preskill et al)
- The QED beta function increases with energy
- Lower bounds? Assume  $r_{\text{Monopole}} \sim r_e$ :  $m_{\text{Monopole}} \sim (g/e)^2(m_e \text{ or } m_{\text{up-quark}}) \sim <10 \text{ GeV}$
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*Light-by-light/photon fusion leads to a nonperturbative bound monopole* emitting large numbers of magnetic photons. Similar light-by-light schemes simply replacing electric charge with magnetic charge have uncontrollably uncalculable corrections.

$$\tilde{g} \quad \tilde{\nu} \quad \tilde{e} \quad \tilde{W} \quad \tilde{q}$$