High Energy Scattering and Search for Extra Dimensions at the LHC

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Outline

I N T R O D U C T I O N

- **Main tasks for LHC**

  Higgs, Susy, extra-dimensions

- **Reasons to think about extra dimensions**
  - Kaluza-Klein,
  - Strings
  - D-branes
  - TeV-gravity scenario

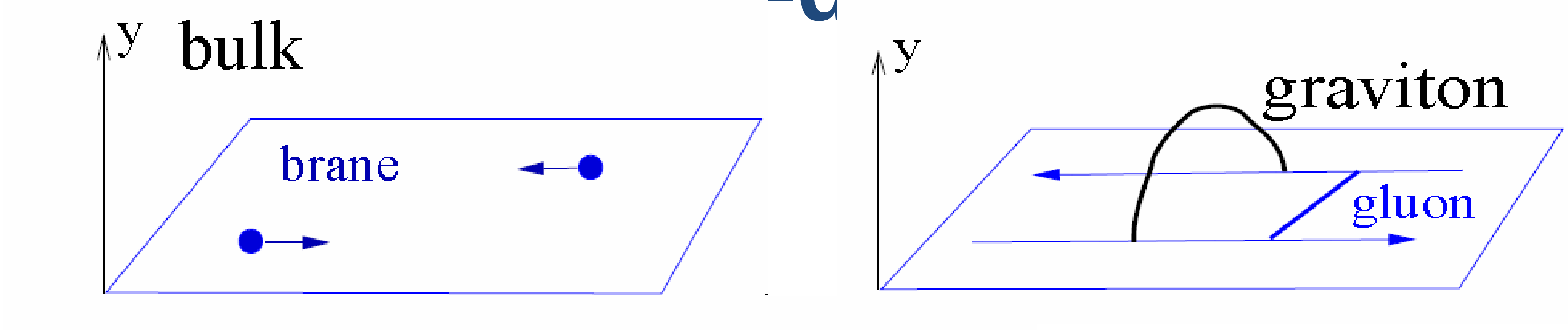
- **Possible manifestations of Extra Dimensions**
  - **KK modes**
  - **Black Hole/Wormhole production**
  - **Signs of strong quantum gravity**

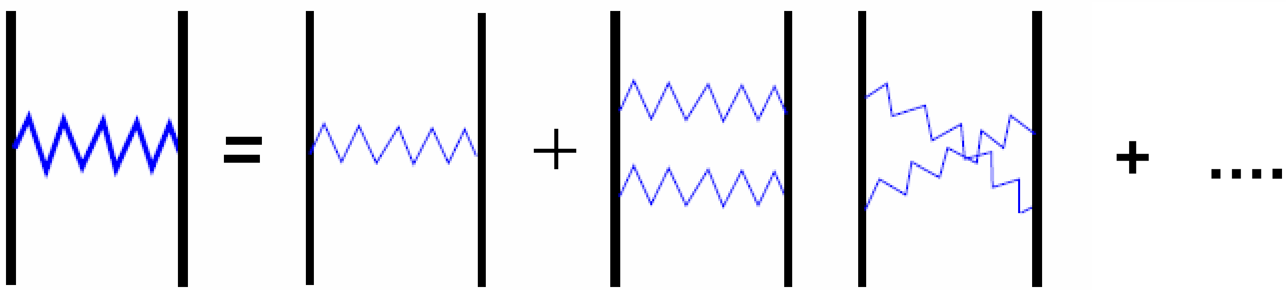
Signs of strong quantum gravity

- Eikonal approximation in the case of extra-dimensions

- Hardon membrane (***Colliding Hadron as Cosmic Membrane***)

Eikonal approximation in the case of extra-dimensions





Guidice, Rattazzi,Well, hep-ph/0112161, Lodone, Rychkov, 0909.3519

Barbashov, Kuleshov,Matveev, Sissakian, TMP,1970

Kadyshevskii at al, TMP,1971

$2 \to 2$ *small angle T-scattering amplitude*

$$\mathcal{A}_{\rm eik}(\mathbf{q}) = \mathcal{A}_{\rm Born} + \mathcal{A}_{\text{1-loop}} + \ldots = -2is \int d^2\mathbf{b}\, e^{-i\mathbf{q}.\mathbf{b}}(e^{i\chi} - 1)$$

$$\chi(\mathbf{b}) = \frac{1}{2s} \int \frac{d^2\mathbf{q}}{(2\pi)^2} e^{i\mathbf{q}.\mathbf{b}} A_{\rm Born}(\mathbf{q}) \qquad \mathcal{A}_{Born}(\mathbf{q}) = \frac{-s^2}{M_D^{n+2}} \int \frac{d^n l}{q_\perp^2 + l^2}$$

Eikonal approximation in the case of extra-dimensions

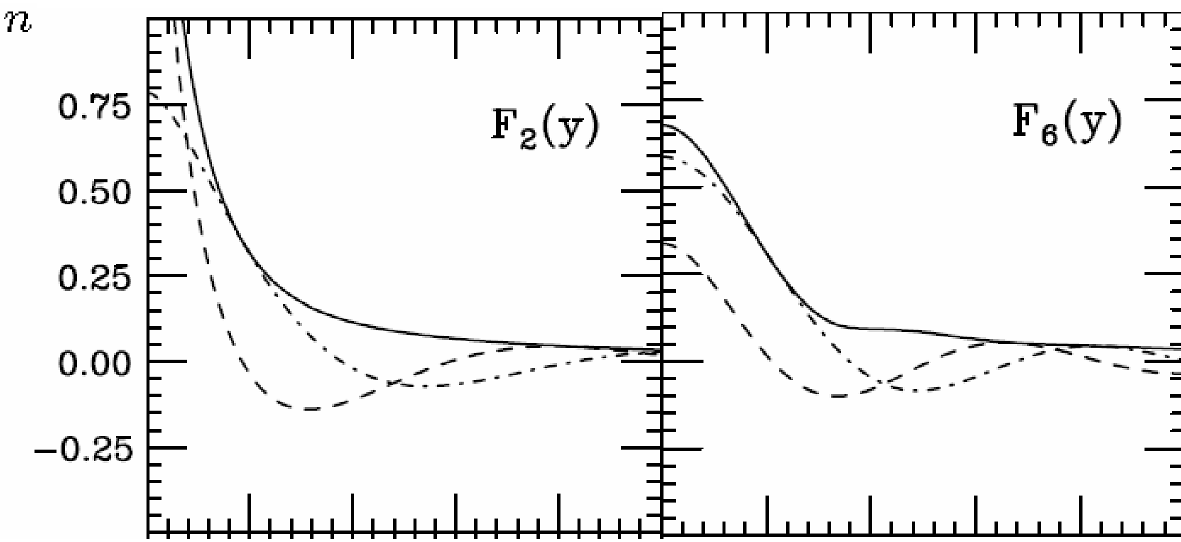
$$2 \rightarrow 2 \ \textit{small angle T-scattering amplitude}$$

$$\mathcal{A}_{Born}(\mathbf{q}) = \frac{-s^2}{M_D^{n+2}} \int \frac{d^n l}{q_\perp^2 + l^2} = \pi^{\frac{n}{2}} \Gamma(1 - \frac{n}{2}) (\frac{q^2}{M_D^2})^{\frac{n}{2}-1} (\frac{s}{M_D^2})^2$$

$$\mathcal{A}_{\text{eik}} = 4\pi s b_c^2 F_n(b_c q)$$

$$F_n(y) = -i \int_0^\infty dx\, x J_0(xy) \left(e^{ix^{-n}} - 1 \right)$$

$$b_c \equiv \left[\frac{(4\pi)^{\frac{n}{2}-1} s \Gamma(n/2)}{2 M_D^{n+2}} \right]^{1/n}$$



From **hep-ph/0112161**

BH Formation and the Eikonal Approximation

Real eikonal phase satisfies the unitarity and cannot describe BH formation

$$\sigma_{\rm eik} = \frac{1}{16\pi^2 s^2}\int d^2q_\perp\,|\mathcal{A}_{\rm eik}|^2 = \frac{{\rm Im}\mathcal{A}_{\rm eik}(0)}{s}$$

$$\mathcal{A}^{(2\to 2)}_{eik}(\mathbf{q}) = -2s\int_{|\mathbf{b}|>b_c} d^2\mathbf{b}\,e^{-i\mathbf{q}.\mathbf{b}}(e^{i\chi}-1) - 2s\int_{|\mathbf{b}|<b_c} d^2\mathbf{b}\,e^{-i\mathbf{q}.\mathbf{b}}(e^{-\delta+i\chi}-1)$$

$$\sigma_{BH} = \sigma_{total} - \sigma_{el} = \int_{|\mathbf{b}|<b_c} d^2\mathbf{b}\,[1-e^{-2\delta}]$$

Corrections in b/R_S

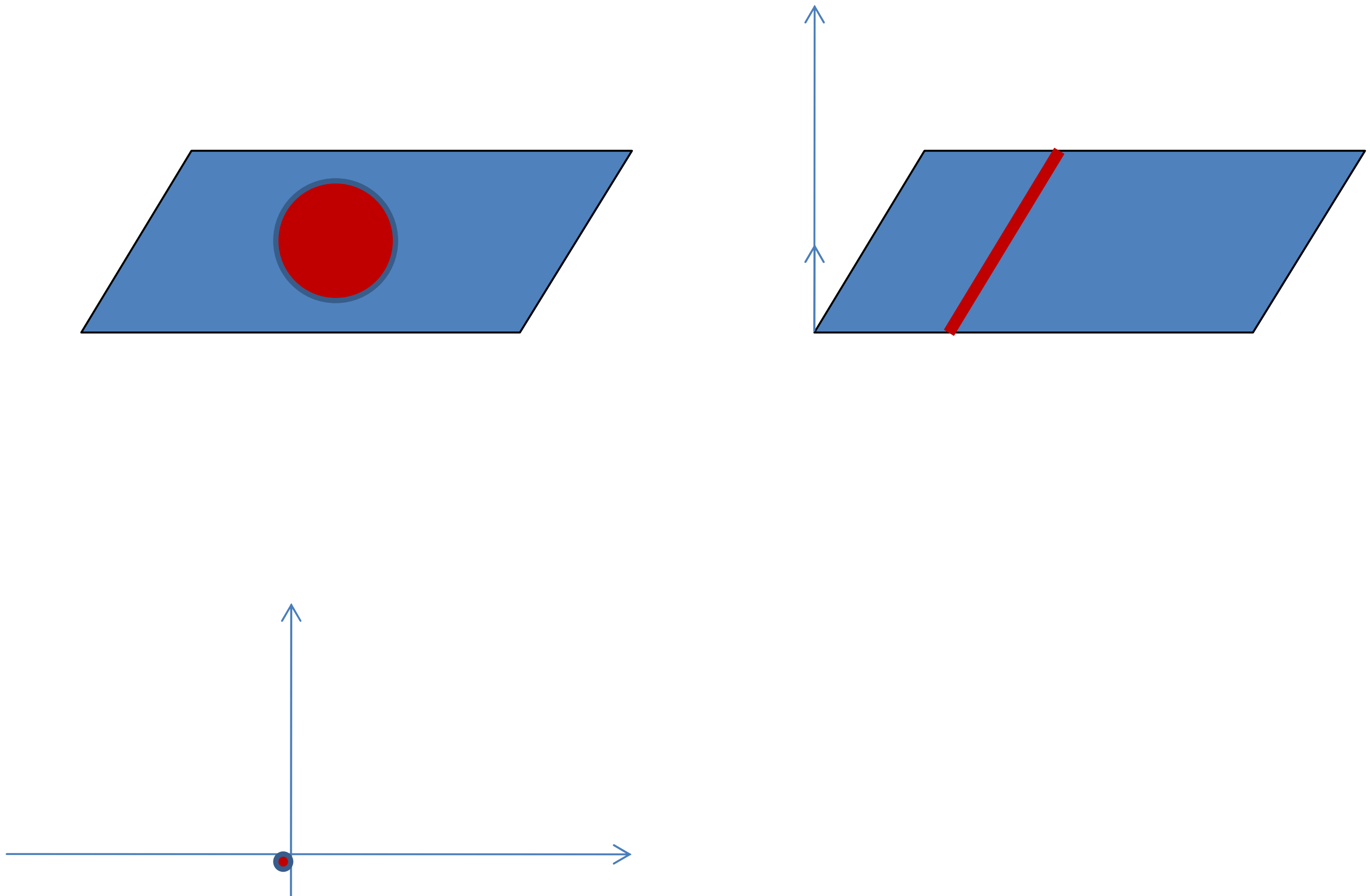
Analogy with Sin-Gordon

$$2\ \text{particles} \ \rightarrow\ \text{breather}$$

Veneziano, Wolsek, 0804.3321
Ciafaloni, Colferi, 0807.2117,
I.A.,0912.5481

Colliding Hadron as Cosmic Membrane

I.A.1007.4777

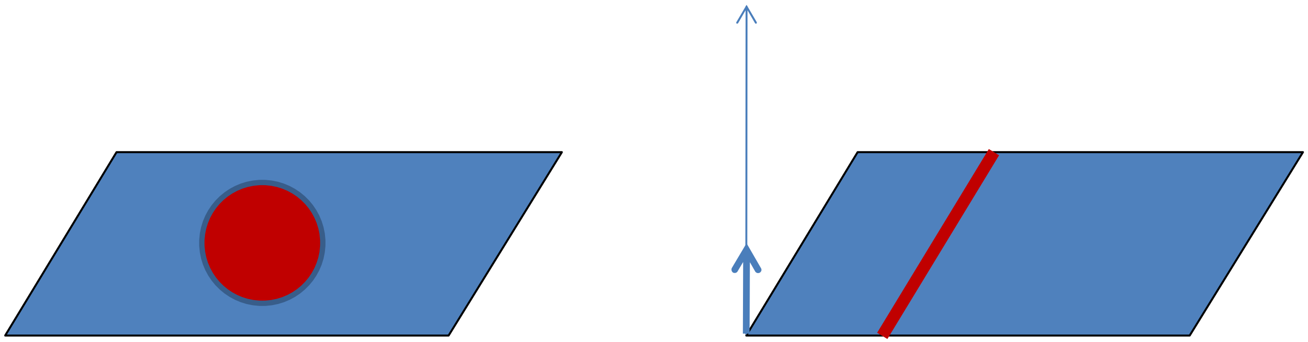


Colliding Hadron as Cosmic Membrane

- **Hight-energy hadrons colliding on the 3-brane embedding in the 5-dim spacetime with 5th dim smaller than the hadrons size are considered as colliding cosmic membranes.**

- **This consideration leads to the 3-dim effective model of high energy collisions of hadrons and the model is similar to cosmic strings in the 4-dim world.**

Colliding Hadron as Cosmic Membrane



Colliding Hadron as Cosmic Membrane

- **These membranes are located on our 3-brane. Since 5-gravity is strong enough we can expect that hadrons membranes modified the 5-dim spacetime metric.**

$$l_{hadron} > l_5 \Longrightarrow$$

ADD $$M_{Pl,5} \sim 10^3 TeV$$

RS2 $$M_{Pl,5} \sim TeV$$

Colliding Hadron as Cosmic Membrane

- **Due to the presence of the hadron membrane the gravitational background is nontrivial and describes a flat spacetime with a conical singularity located on the hadron membrane.**

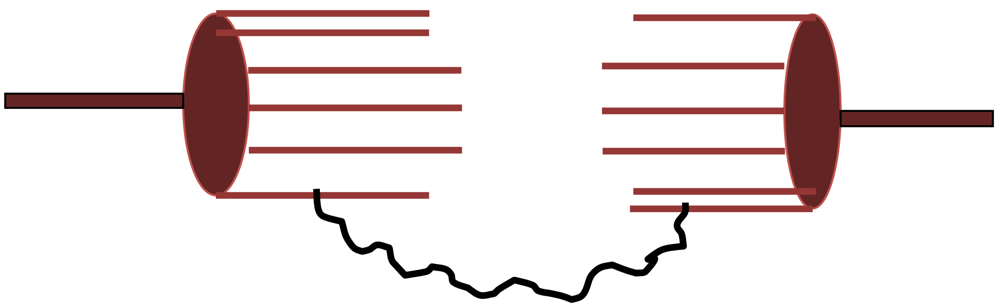
- **The angle deficit**

$$\delta = G_5\,\mu, \quad [G_5] = M^{-3}, [\mu] = M / S = M^3$$

Colliding Hadron as Cosmic Membrane

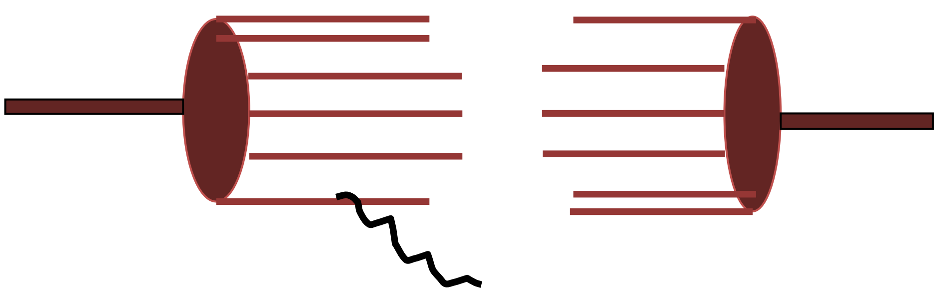
- **Two types of effects of the angle deficit :**

corrections to the graviton propagation;



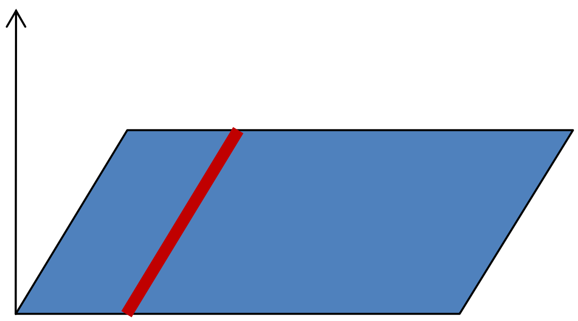
$$\delta = G_5 \, \mu,$$

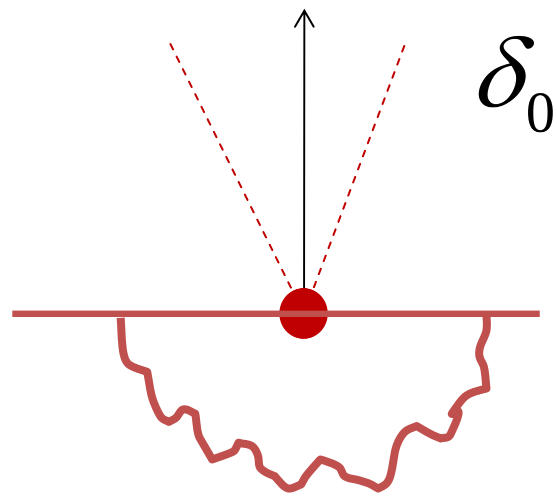
new channels of decays



Colliding Hadron as Cosmic Membrane

Corrections to the graviton propagation;





$$\delta_0 = G_5\,\mu,$$

$$\delta_0 \approx \frac{1}{10^{3\cdot 3}} \cdot \frac{1}{1^2} = 10^{-9},$$

$$\delta = 10^4\,\delta_0 = 10^{-5},$$

New channels of decays

Toy model: **if we neglect brane, light particle m→2M**

$$\sigma_l \approx 10^{-7}\,\frac{g^2}{M^3} \quad for \quad k >> M\,\delta^{-1}$$

k – momentum of m particle

Propagators for 2-dim space with a deficit angle

$$K_\alpha(z,0;z',0;\tau) = \frac{i}{2\alpha}\int_\gamma dw\,\mathrm{ctg}\left(\frac{\pi w}{\alpha}\right)\,\mathcal{K}_w(z,z';\tau)$$

$$\mathcal{K}_w(z,z';\tau) \equiv \frac{1}{4\pi\tau}\exp\{-\frac{z^2+z'^2-2zz'\cos w}{4\tau}\}$$

$$\mathcal{D}(r,v) = \int\int e^{ir(z-z')+iv(z+z')}e^{-m^2\tau}\mathcal{K}_w(z,z';\tau)dzdz'\frac{d\tau}{4\pi\tau}$$

$$\mathcal{D}(r,v) = \frac{2}{\sin w}\frac{1}{\frac{r^2}{\sin^2\frac{w}{2}}+\frac{v^2}{\cos^2\frac{w}{2}}+m^2}$$

Amplitude

$$S_\alpha = i(2\pi)^3\delta^3\left((p_1+p_2-p_3-p_4)_{\check{\mu}}\right)\mathcal{M}_\alpha,$$

$$\mathcal{M}_\alpha = \frac{i}{2\alpha}\int_\gamma dw\,\mathrm{ctg}\left(\frac{\pi w}{\alpha}\right)\frac{2}{\sin w}\frac{1}{\frac{Q^2}{\sin^2\frac{w}{2}}+\frac{P^2}{\cos^2\frac{w}{2}}+q_{\check{\mu}}^2+m^2},$$

$$q_{\check{\mu}} = (q_0, q_1, q_2),\ \check{\mu} = 0,1,2,\quad q = (q_{\check{\mu}}, q_z),\ q_\perp = (q_1, q_2),$$

$$Q = \frac{1}{2}(p_1-p_2-p_3+p_4)_z,\quad P = \frac{1}{2}(p_1+p_2-p_3-p_4)_z,\quad q_{\check{\mu}} = (p_1-p_3)_{\check{\mu}}.$$

In the eikonal regime $Q \approx -P$

$$\mathcal{M}_\alpha \approx \frac{i}{2\alpha}\int_\gamma dw\,\mathrm{ctg}\left(\frac{\pi w}{\alpha}\right)\mathcal{B}_w(q_\perp, P),$$

$$\mathcal{B}_w(q_\perp, P) = \frac{2}{\sin w}\frac{1}{q_\perp^2+m^2+\frac{4P^2}{\sin^2 w}}.$$

Amplitude

w-eikonal phase χ

$$\mathcal{X}_w(\mathbf{b}, P) = \frac{1}{2s} \int \frac{d^2\mathbf{q}}{(2\pi)^2} e^{i\mathbf{q}.\mathbf{b}} \mathcal{B}_w(q_\perp, P)$$

The total eikonal phase is given by the integral over the contour γ

$$\chi_\alpha(\mathbf{b}, P) = \frac{i}{2\alpha} \int_\gamma dw \,\mathrm{ctg}\left(\frac{\pi w}{\alpha}\right) \mathcal{X}_w(\mathbf{b}, P)$$

$$\begin{aligned} \mathcal{S}_{\mathrm{eik},\alpha}(p_1, p_2, p_3, p_4) &= i(2\pi)^4 \delta^4(p_1 + p_2 - p_3 - p_4) \mathcal{A}_{\mathrm{eik,flat}} \\ &+ i(2\pi)^3 \delta^3 \left((p_1 + p_2 - p_3 - p_4)_{\check{\mu}}\right) \mathcal{M}_{\mathrm{eik},\alpha} \end{aligned}$$

Lost momentum

To conclude

- **Main tasks for LHC**

  Higgs, Susy, extra-dimensions

- **Reasons to think about extra dimensions**
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  - Strings
  - D-branes
  - **TeV-gravity scenario**
- **Possible manifestations of Extra Dimensions**
  - **KK modes**
  - **Black Hole /Wormhole production (Technical results)**
  - **Signs of strong quantum gravity (Hadron membrane and a change of the eikonal amplitude)**

Technical results

- Modified Thorn's conjecture is confirmed for several examples;
- Results of trapped surface calculations are confirmed

Catalysts:

- **A particular "dilaton" acts as a catalyst**
- **Lambda<0 acts as a catalyst**