Search for new effects to see extra dimensions

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Outline

- Introduction
- Cosmic membrane
- Possible effects
- Technical details
- Conclusion

Introduction

- **Search for extra-dimensions is one of 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**
  - **Hardon membrane effects**

Transplanckian energy

- Within TeV-gravity scenario collisions of hadrons at the LHC are transplanckian processes.

Transplanckian energy $\mathrm{M_{Pl,D}} < \mathrm{E}$

$$\mathrm{M_{Pl}} = \sqrt{\frac{\hbar c}{\mathrm{G}_{Newton}}}$$

D=4 $\mathrm{M_{Pl,4}} \cong 10^{19} Gev$

$$c = 1, \quad \hbar = 1$$

$$G_4 \equiv G_{Newton}$$

D > 4 $M_{Pl,D} \approx 1\, TeV$

$$G_D = \frac{1}{M_D^{D-2}}$$

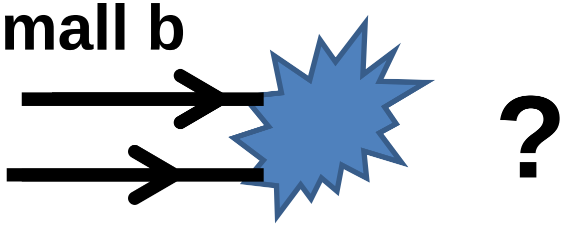
Transplanckian scattering

In recent years the study of transplanckian scattering within the TeV-gravity scenario has attracted significant theoretical and phenomenological interest.

Different physical pictures are expected for different ranges of impact parameters b.

Transplanckian scattering

Small b

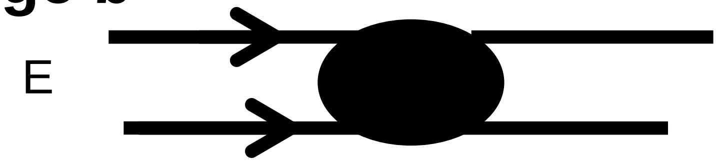


For impact parameters b of the order of the Schwarzschild radius R_{sh} of a black hole of mass E, microscopic black hole formation and its subsequent evaporation is expected

. Banks, Fischler, hep-th/9906038
I.A., hep-th/9910269,
Giddings, hep-ph/0106219,
Dimopolos, Landsberg, hep-ph/0106295,……

Proposals concerning the production of more complicated objects such as wormholes/time machines *I.A., I.Volovich*, 2007

Large b



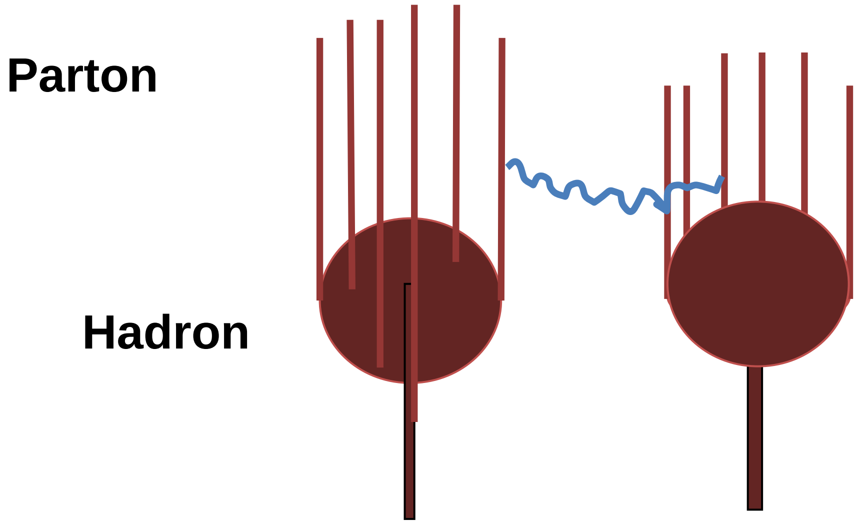
For large impact parameters $b \gg R_{sh}$ the eikonal picture given by eikonalized single-graviton exchange is expected

Giuduce, Rattazzi, Wells, hep-ph/0112161

Corrections in R_{sh}/b to the elastic eikonal scattering have been studied, Lodone, Rychkov, 0909.3519,…..

High-energy scattering

To study high-energy scattering of the hadrons one usually deals with the parton picture.



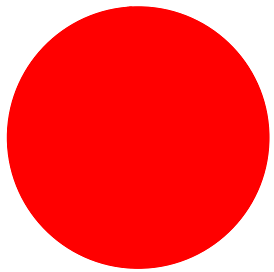
Graviton is supposed to be propagated freely

Since D-dimensional gravity is strong it would be interesting to calculate the modification of the graviton propagator due to a presence of matter.

***This is difficult problem, however, it can be solved in particular cases*.**

Colliding hadrons as gravitational membranes

According to Fermi-Landau hydrodynamical model hadron is a ball



- **Due to Lorentz contraction we can treat colliding hadrons in the laboratory frame as membranes with the transversal characteristic scale of order of the hadron and a negligible thickness.**

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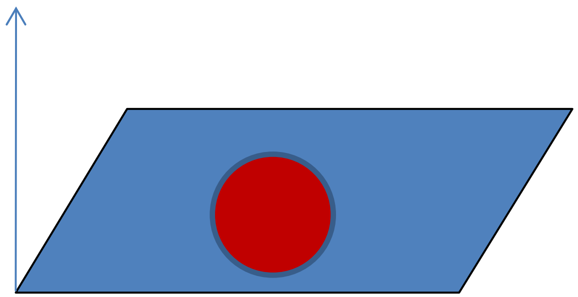
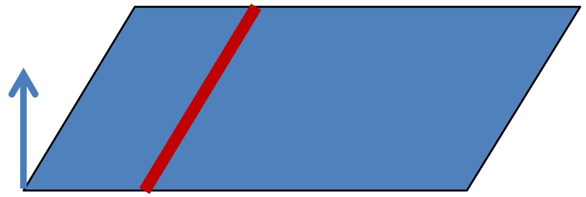
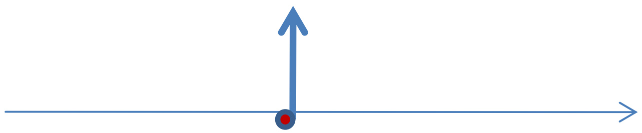
Colliding Hadron as Gravitational Membrane

These membranes are located on our 3-brane







Since 4+n gravity is strong enough we can expect that hadron membranes modify the 4+n-spacetime metric.

Colliding hadrons as Gravitational membranes

Only for the case of n=1 we know explicitly the modified metric and we can estimate explicitly the influence of this modification on the parton and other particle scattering.

Remarks

- It is known that the 5-dimensional ADD model with the Planck mass about few TeV is not phenomenologically acceptable and we can deal with the RS2 model or with the DGP model .
- **In all these cases we treat a moving hadron as an infinite moving membrane in the 5-dimensional world with location on the**

  3-brane (our world).

Colliding Hadrons as Gravitational Membranes

- **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 Hadrons as Gravitational Membranes

n=1, ADD, flat bulk

$$ds^2 = -dt^2 + d\vec{x}_\perp^2 + dx_\parallel^2 + dy^2$$

$$(t, \vec{x}_\perp, \vec{y}) \quad , \vec{y} = (x_\parallel, y) \qquad T_{00} = \mu\,\delta(\vec{y}),$$

$$R_{MN} - \frac{1}{2} g_{MN} R = G_5 T_{MN}, \qquad \vec{y} \Rightarrow (\rho, \varphi)$$

Solution

$$ds^2 = -dt^2 + d\vec{x}_\perp^2 + \rho^{-G_5\mu/\pi}(d\rho^2 + \rho^2)d\varphi^2$$

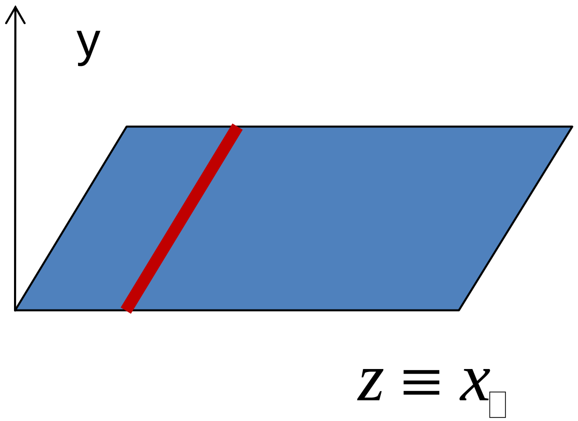
Change of variables

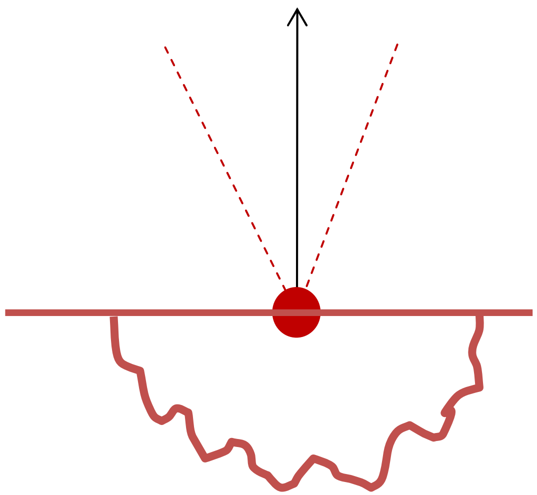
$$r = \frac{\rho^\beta}{\beta}, \quad \beta = 1 - \frac{G_5\mu}{2\pi},$$

$$ds^2 = -dt^2 + d\vec{x}_\perp^2 + dr^2 + \beta^2 r^2 d\varphi^2 = -dt^2 + d\vec{x}_\perp^2 + dr^2 + r^2 d\theta^2$$

$$\theta = \beta\varphi, \quad 0 \le \theta \le 2\pi\beta \equiv 2\pi - \delta, \quad \delta = G_5\mu$$

Colliding Hadrons as Gravitational Membranes





Colliding Hadrons as *Gravitational* Membranes

- **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.**

- **This picture is a generalization of the cosmological string picture in the 4-dimensional world to the 5-dimensional world.**

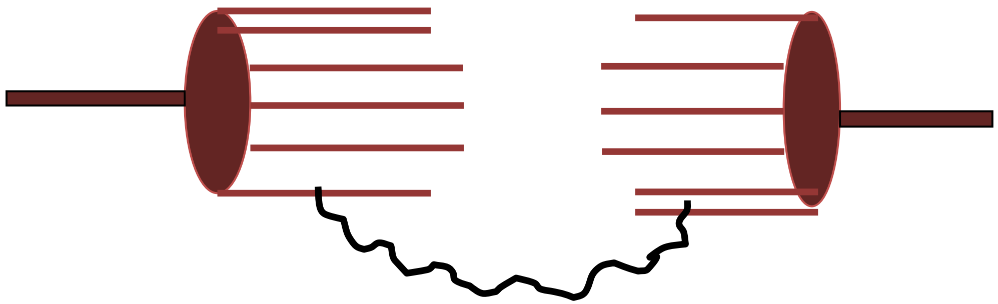
- **The deficit angle**

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

Colliding Hadrons as Gravitational Membranes

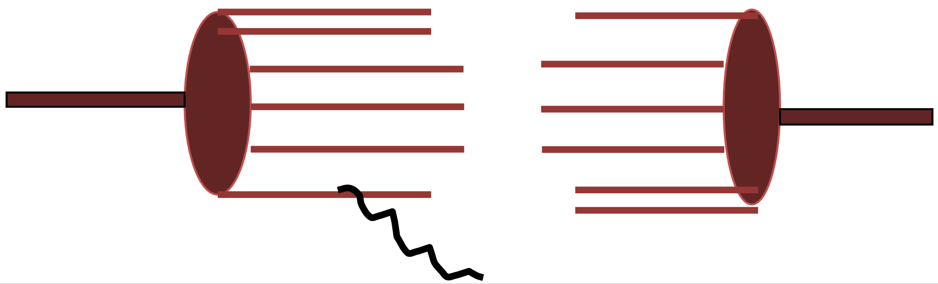
- **Two types of effects of the deficit angle:**

  corrections to the graviton   propagation



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

new channels of decays



Deficit angle. Numbers

RS2 $M_{Pl,5} \sim TeV$ $\delta_0 = G_5 \mu,$

$$\delta_0 \approx \frac{1}{10^3 \cdot 10^{3\cdot 2}} = 10^{-9}, \qquad \delta = 10^4 \delta_0 = 10^{-5},$$

One can compare this number with an estimate of the deficit angle

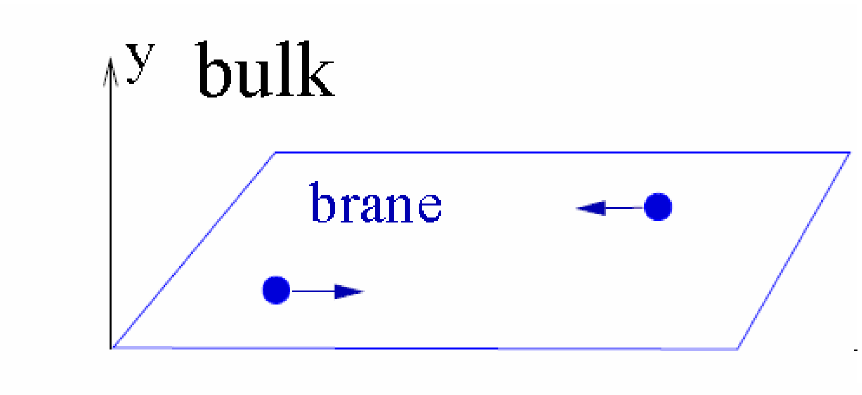
$$\delta_{cs} \approx 10^{-6}$$

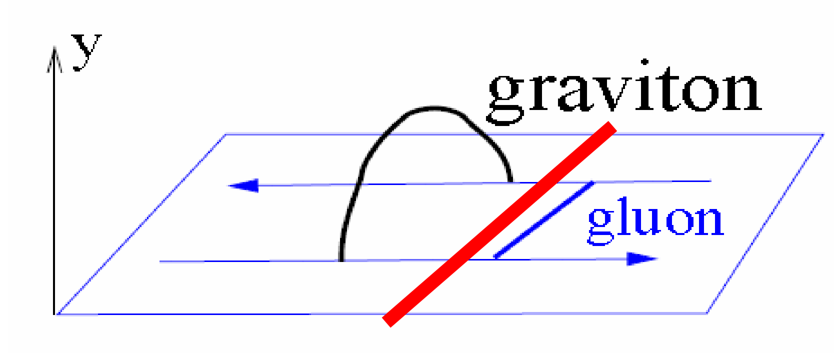
for a cosmic string in 4-dimensional spacetime with the Newtonian gravitational constant G and the density

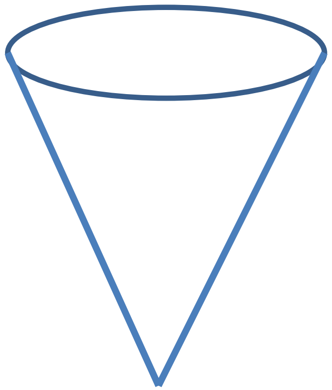
$$\rho = \frac{m}{l} = 10^{33} GeV^2$$

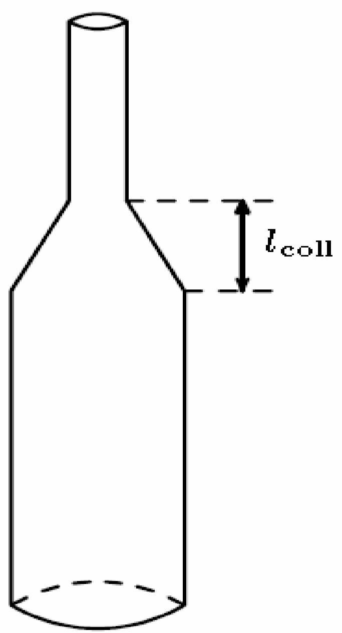
that corresponds to the Earth mass distributed on a length of about l=9km

Corrections to the graviton propagation









D.V.Shirkov, *Coupling Running through The Looking-Glass of dimensional Reduction,* 1004.1510

Propagators for 2-dim space with a deficit angle

**A.Sommerfeld,1897;J.S.Dowker, 1972;
Deser,Jackiw, 1988**

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

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

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

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

Born's Amplitude in a space with a membrane

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

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

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

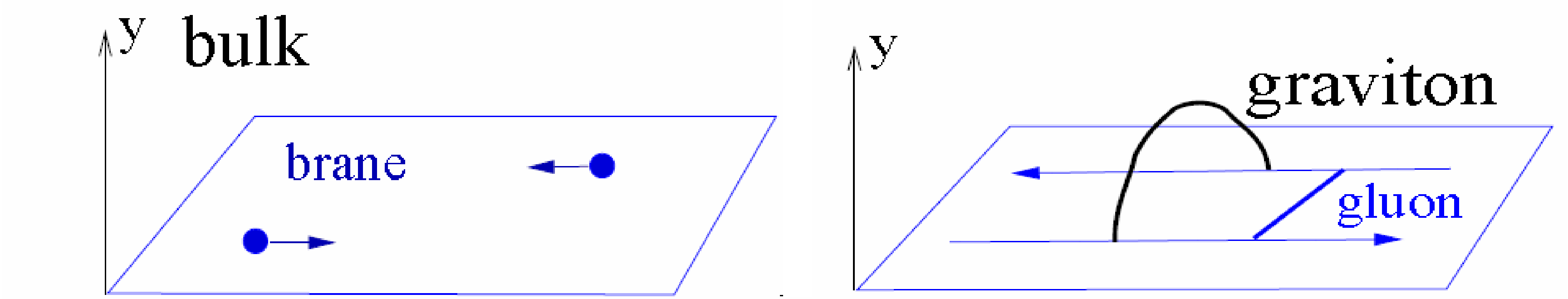
$$Q=\frac{1}{2}(p_1-p_2-p_3+p_4)_z,\quad P=\frac{1}{2}(p_1+p_2-p_3-p_4)_z,\quad q_{\check{\mu}}=(p_1-p_3)_{\check{\mu}}.$$

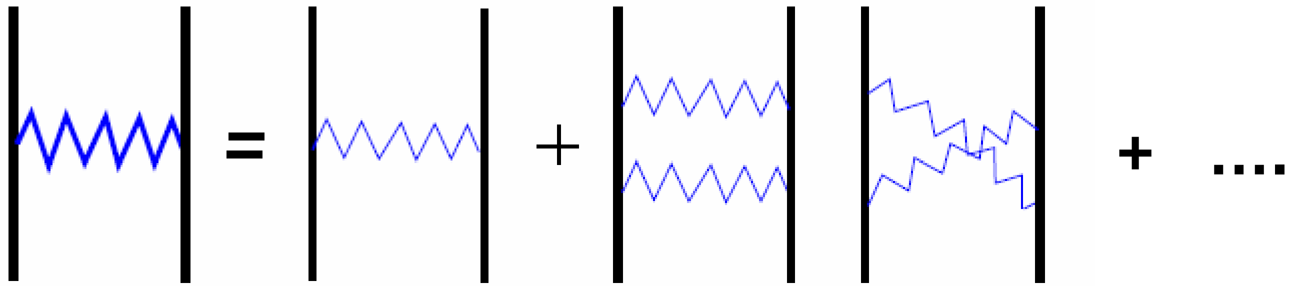
In the eikonal regime $Q\approx -P$

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

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

Eikonal approximation. Flat extra-dimensions





Guidice, Rattazzi,Well, hep-ph/0112161

Barbashov, Kuleshov,Matveev, Sissakian, TMP,1970

Kadyshevsky at al, TMP,1971

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

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

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

Eikonal approximation. The deficit angle corrections

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

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

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

Lost momentum

Eikonal approximation.   Flat extra-dimensions

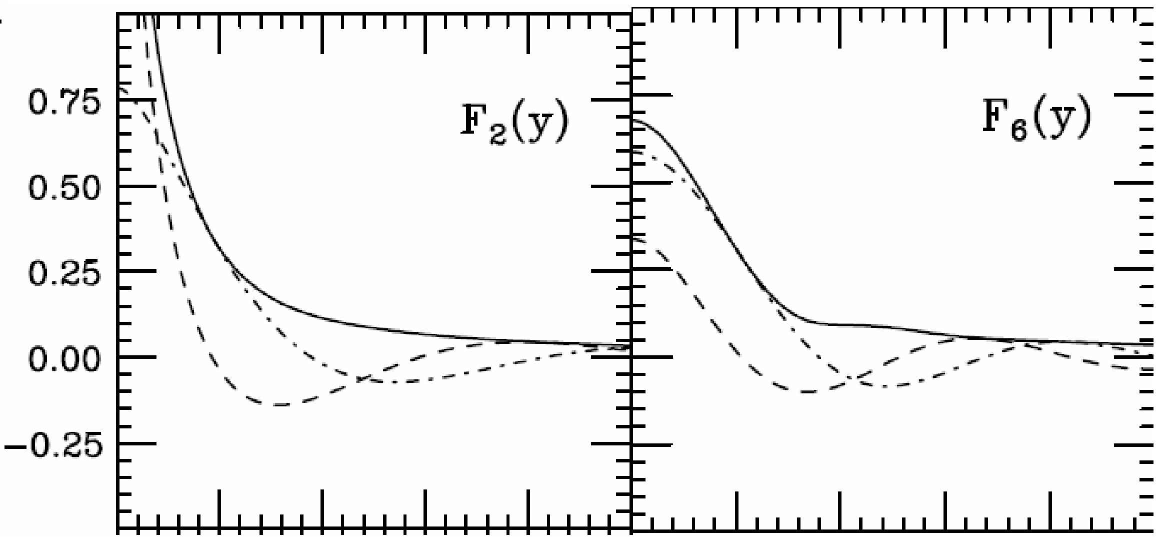
2 → 2 small angle T-scattering amplitude

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

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

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

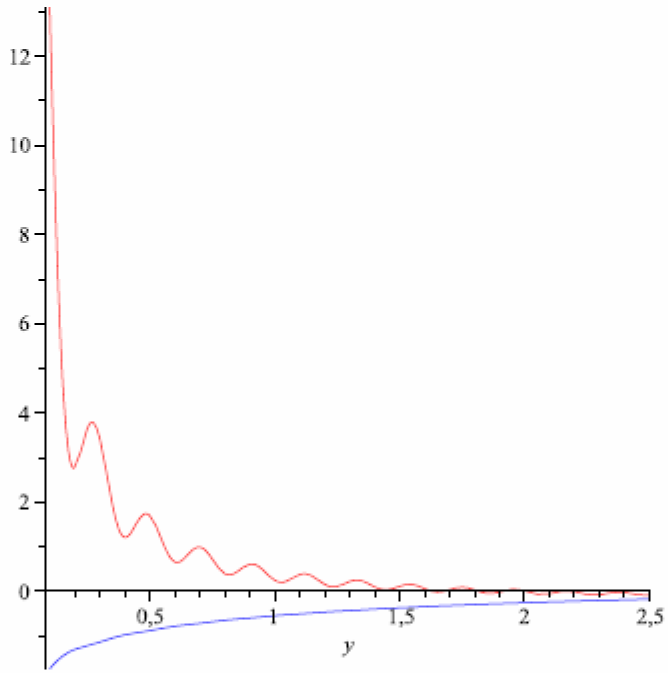
$$b_c \equiv \left[\frac{(4\pi)^{\frac{n}{2}-1} s \Gamma(n/2)}{2 M_D^{n+2}} \right]^{1/n}$$



From hep-ph/0112161

Corrections to the eikonal amplitude

Toy model with the deficit angle equal to π



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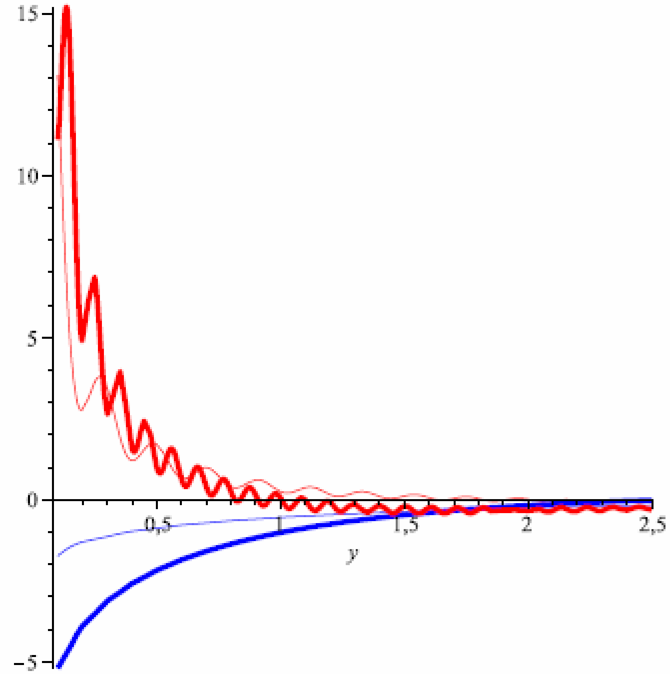

B

New channels of decays.

Toy model: **if we neglect brane, light particle → 2 heavy particles**

m → 2M

For large longitudinal momentum of the light particle,

$$k_z >> 2M\delta^{-1} \qquad *$$

the cross-section does not depend on k_z and is defied only by the cubic coupling g of these 3 particles and heavy mass M

$$\sigma_l \approx \frac{g^2}{M^3}$$

To realize the condition * it is enough to take k_z about 1 TeV and M of the order of the few MeV's.

To conclude

- **High-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.**

Main message:

Colliding Hadron as Gravitational Membrane

Colliding hadrons as cosmic membranes

I.A.1007.4777

- **Due to Lorentz contraction we can treat colliding hadrons in the laboratory frame as membranes**

  with the transversal characteristic scale of order of the hadron and a negligible thickness.
- **These membranes are located on our 3-brane.**
- **Since 4+n gravity is strong enough we can expect that hadron membranes modify the 4+n-spacetime metric.**
- **n=1 we can perform explicit calculation**

2-merization vs 3-merization

- In other words, we deal with an effective 3-dimensional picture in the high-energy scattering (compare with the usual effective 2-dimensional picture in 4-dimensional spacetime).