Gravi-Reggeons and cosmic neutrino-nucleon interactions in theory with extra dimension

Alexandre Kisselev

(IHEP, Protvino, Russia)

“From Colliders to Cosmic Rays”

Prague, Czech Republic, 7-13 September, 2005

SUMMARY

- *Warped extra dimension (ED) with the small curvature*
- *AdS5 metric vs. flat metric with one compact ED*
- *Graviton production in exclusive double diffractive event* LHC
- *Trans-Planckian scattering on the brane*
- *Neutrino-nucleon interactions at ultra-high energies* CR
- *Conclusions*

Warped Extra Dimension with the Small Curvature

Background (AdS_5) metric (Randall & Sundrum, 1999)

$$ds^2 = \gamma_{MN}(z)\, dz^M dz^N = e^{2\kappa(|y|-\pi r)}\, \eta_{\mu\nu}\, dx^\mu dx^\nu + dy^2$$

$\eta_{\mu\nu}$ - Minkowski tensor $\quad (M, N = 0,1,\ldots 4)$

r is the radius of ED $\quad (-\pi r \le y \le \pi r)$

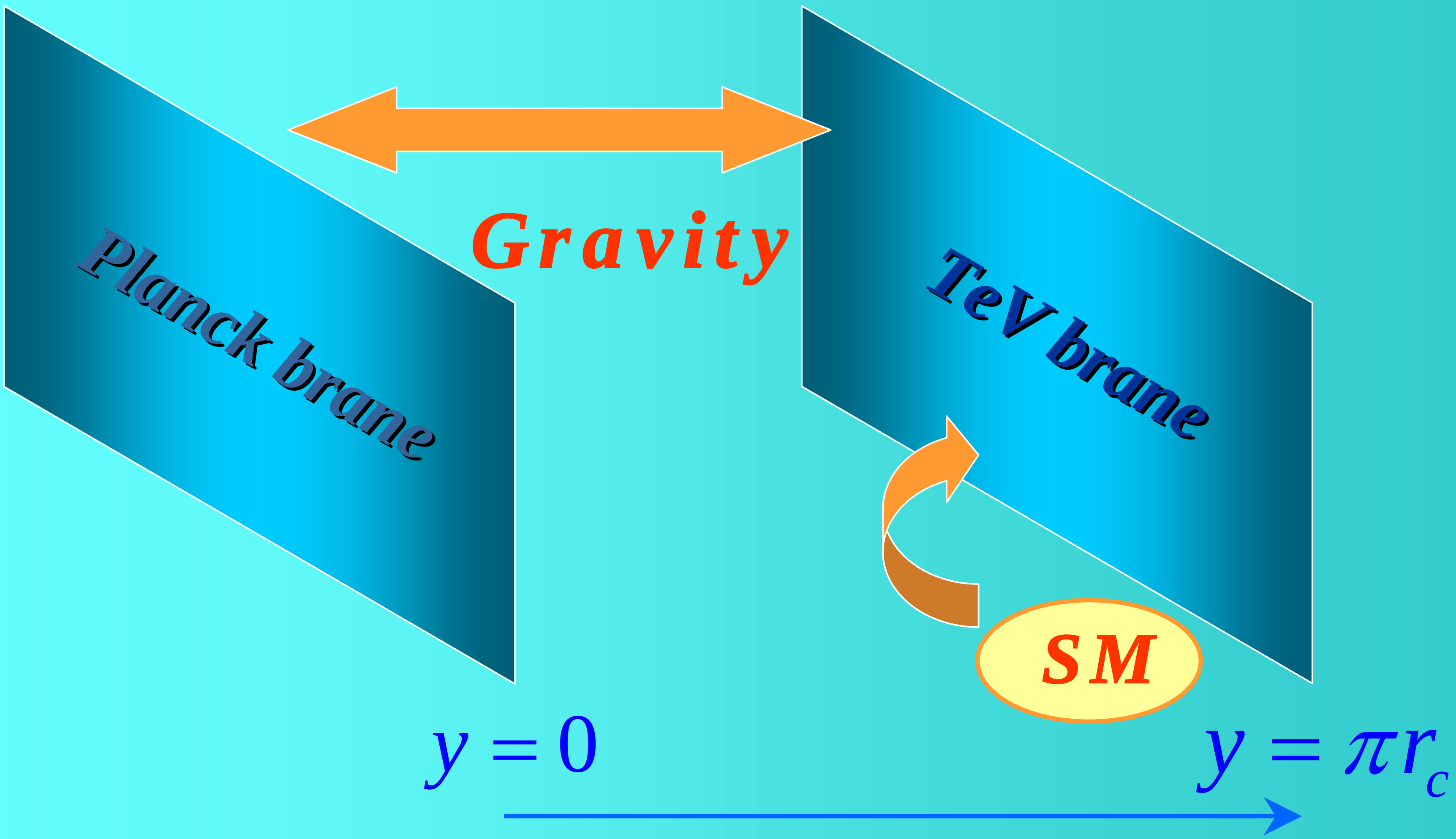
Hierarchy relation

$$M_{Pl}^2 = \frac{M_5^3}{\kappa}\left(e^{2\pi\kappa r} - 1\right) \qquad \kappa r \approx 10$$

M_{Pl} - Planck mass

M_5 - gravity scale in 5 dimensions

Gravity lives in the bulk



SM fields are confined to the TeV brane

Gravitational 5-dimensional field

$$g_{MN}(z) = \gamma_{MN}(z) + \frac{2}{M_5^{3/2}} h_{MN}(z)$$

Kaluza-Klein (KK) gravitons

$$h_{\mu\nu}(x,y) = \sum_{n=0}^{\infty} h_{\mu\nu}^{(n)}(x)\,\psi_n(y)$$

Radion (scalar) field

$$h_{44}(x,y) = \phi(x)$$

graviton masses

$$m_n = x_n \kappa$$

Interaction Lagrangian on the TeV brane

$$\mathrm{L} = -\left(\frac{1}{M_{Pl}} h^{(0)}_{\mu\nu} + \frac{1}{\Lambda_\pi}\sum_{n=1}^{\infty} h^{(n)}_{\mu\nu}\right) T^{\mu\nu} + \frac{1}{\sqrt{3}\Lambda_\pi}\phi T^{\alpha}_{\alpha}$$

physical scale $\Lambda_\pi^2 = \dfrac{M_5^3}{\kappa}$

Large curvature option

$$\kappa \approx M_5 \approx 1\,\mathrm{TeV}$$

→ ***series of massive resonances***

$$(\Lambda_\pi, m_1 \approx 1\,\mathrm{TeV})$$

Small curvature option

(Giudice et al., 2004, Kisselev & Petrov, 2005)

$$\kappa << M_5 \approx 1\,\text{TeV}$$

→ *narrow low-mass resonances with the small mass splitting* $(\Delta m \approx \pi\kappa)$

$$10^{-5} \leq \frac{\kappa}{M_5} \leq 0.1$$

Formal relation to gravity in flat space-time with one compact ED

$$\kappa \rightarrow \frac{1}{\pi R_c}, \quad \Lambda_\pi \rightarrow M_{Pl}$$

R_c *is the radius of ED*

AdS_5 Metric vs. Flat Metric with One Compact ED

RS model with the small curvature is not similar to a model with one large ED of the size $R_c^{-1} = \pi\kappa$

For instance, $R_c^{-1} = 50\ \mathrm{MeV}\,(1\ \mathrm{GeV})$
can be realized only for $d = 7\,(10)$

d ***is the number of ED's***

$d = 1$ ⇨ $R_c =$ ***solar distance***

$d = 2\,(3)$ ***- strongly limited by astrophysical bounds***

Hierarchy equation in d flat ED's (D=4+d)

$$M_{Pl}^2 = (2\pi R_c)^d \, M_D^{2+d}$$

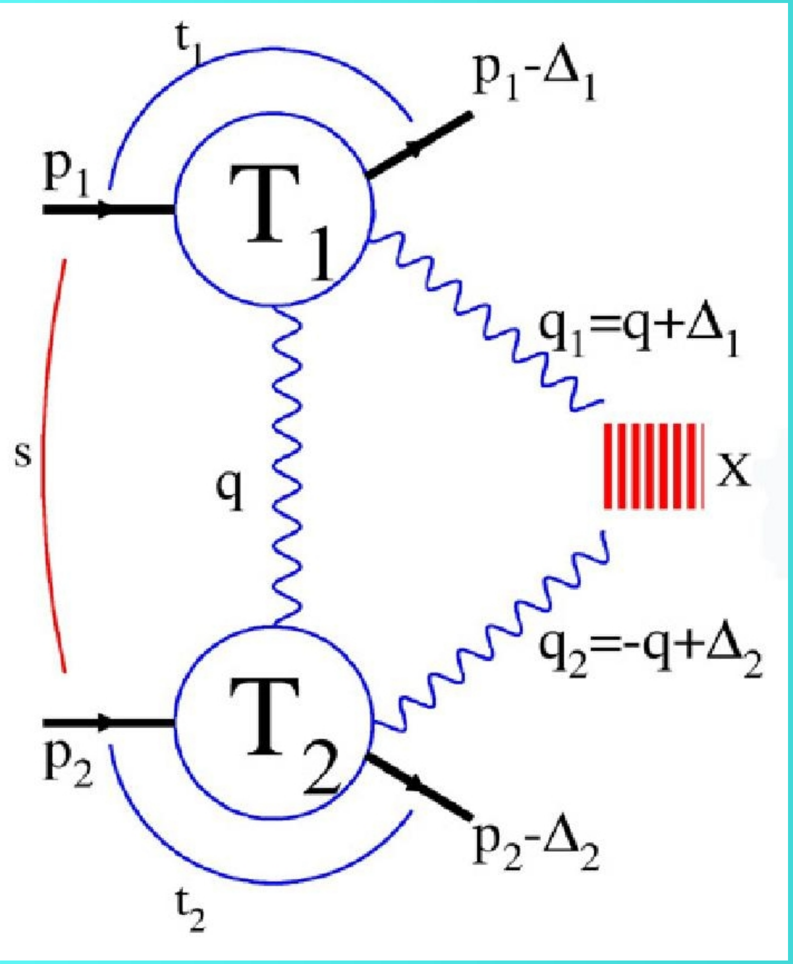
Limiting case of a similar relation for the warped metric

$$M_{Pl}^2 = \frac{M_5^3}{\kappa}\left(e^{2\pi\kappa r} - 1\right) \xrightarrow{2\pi\kappa r \ll 1} 2\pi r \, M_5^3$$

$$2\pi\kappa r \ll 1 \quad \Rightarrow \quad \frac{M_5}{\kappa} \gg \left(\frac{M_{Pl}}{M_5}\right)^2$$

(unrealistic)

Graviton production in exclusive double diffractive event (EDDE)



X = ***KK graviton***

Experimental signature at the LHC

(Kisselev, Petrov & Ryutin, 2005)

$$p + p \to p + \text{"nothing"} + p$$

(joint CMS/TOTEM experiment)

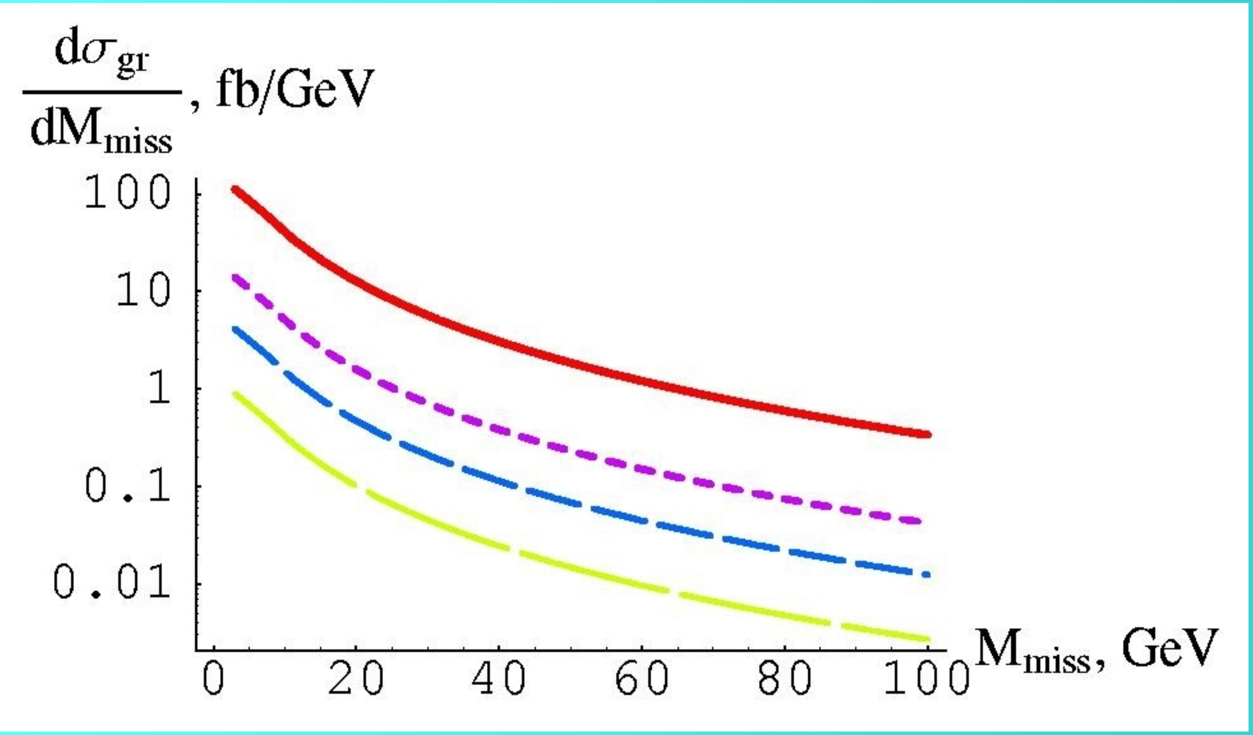
Expected number of events

Integrated luminosity: $L = 30\,(0.3)\ \text{fb}^{-1}$

$$N_{\text{ev}} = 9\,000\,(90)$$

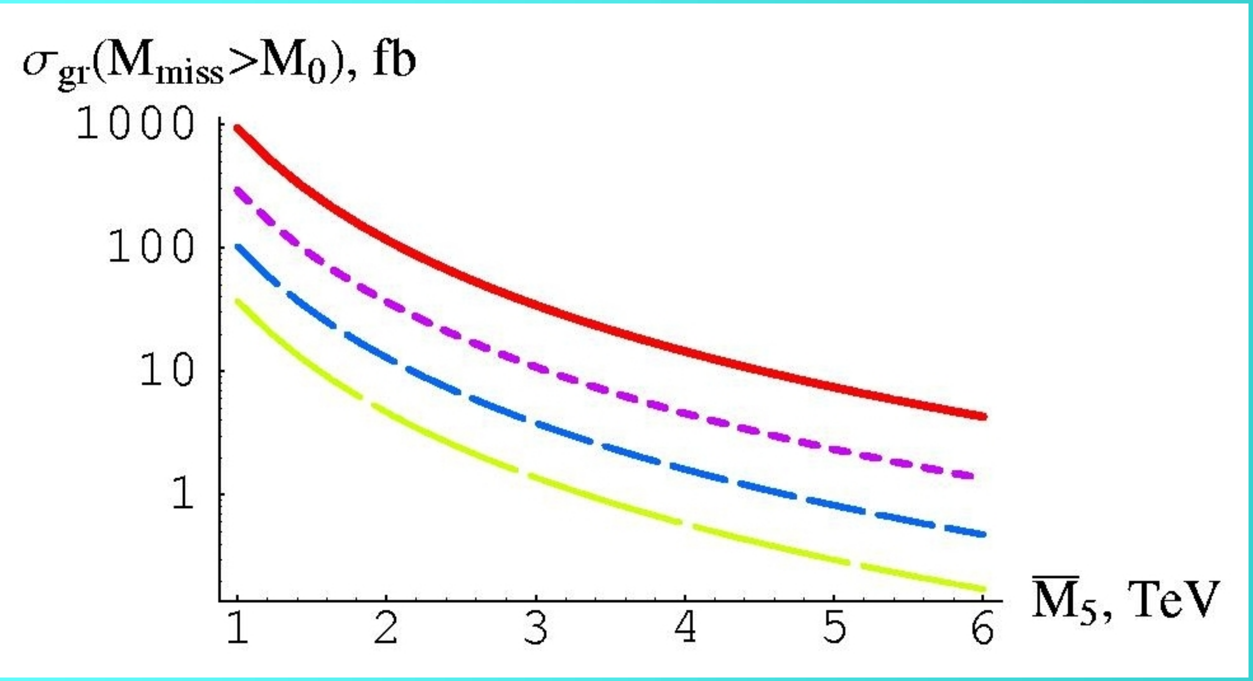
for $M_5 = 1\,\text{TeV}$ ***and*** $M_{\text{miss}} > 14\,\text{GeV}$

Distribution in the missing mass of KK gravitons in EDDE



curves (top to bottom): $M_5 = 1, 2, 3$ and 5 TeV

Cross sections for the production of KK gravitons in EDDE



curves (top to bottom): $M_0 = 3, 14, 30$ and 50 GeV

Trans-Planckian Scattering on the Brane

(Kisselev & Petrov, 2004/5)

Kinematical region — *eikonal approximation*

$$\sqrt{s} \geq M_5, \quad \sqrt{s} >> -t$$

t *is 4-momentum transfer*

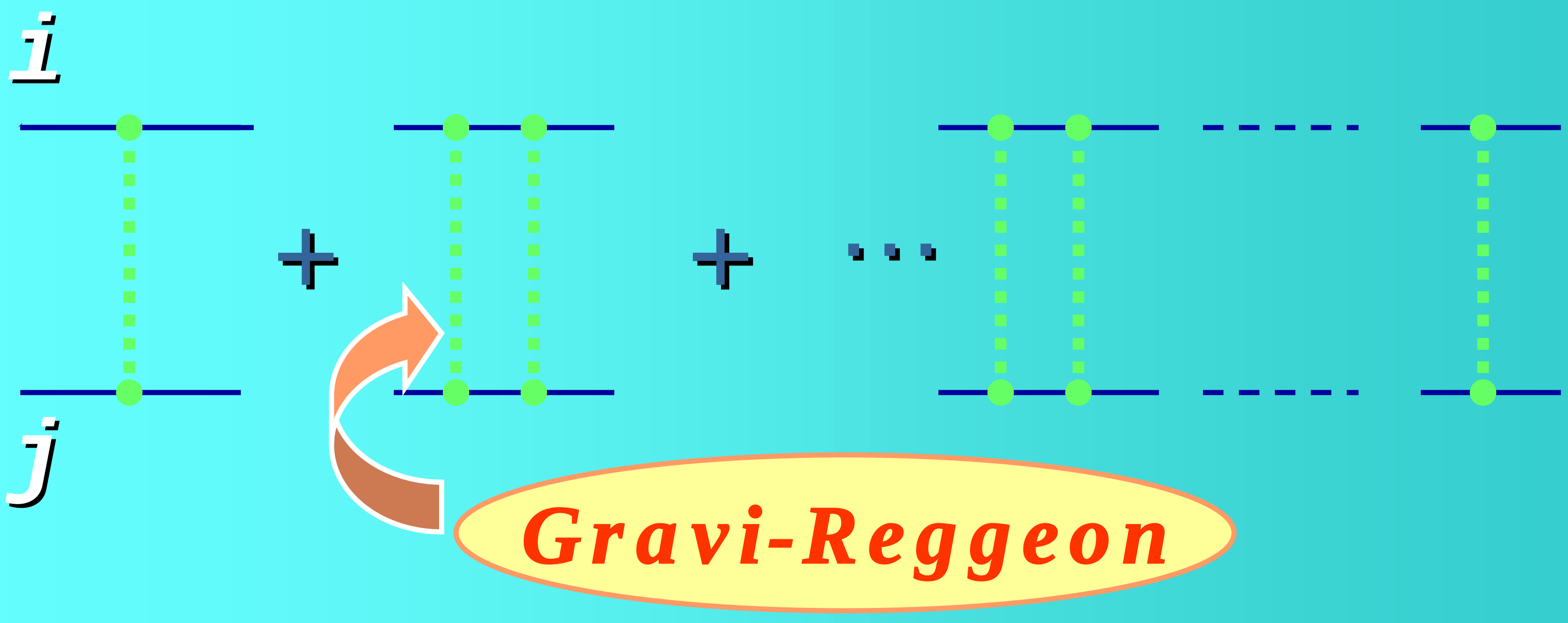
Born amplitude is the sum of the reggeized gravitons in t-channel

Gravi-Reggeons:

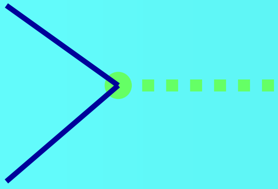
$$\alpha_n(t) = 2 + \alpha'_g t - \alpha'_g m_n^2$$

$\alpha'_g = M_s^{-2}$ *- string tension*

Gravitational amplitude



i, *j* - *SM fields (q, g, l, n…)*



$\sim \dfrac{1}{\Lambda_\pi}$ *(for all SM fields)*

Imaginary part of the eikonal

One has to calculate the sum

$$\sum_{n\neq 0} \exp\left(-\alpha_g' m_n^2 \ln s\right)$$

with $m_n \approx \pi\kappa\left(n+\frac{1}{4}\right)$

At $\kappa \ll M_5$, ***we obtain***

$$\operatorname{Im}\chi(s,b) \approx \frac{s}{M_5^2}\exp\left[-b^2/4R_g^2(s)\right]$$

$R_g(s) = \sqrt{\alpha_g' \ln s}$ ***- gravitational radius***

Fields are weakly coupled to gravity:

$$\Lambda_\pi \approx 100\left(M_5/1\,TeV\right)^{3/2}\,\mathrm{TeV}$$

for small $\kappa = 100\ \mathrm{MeV}$

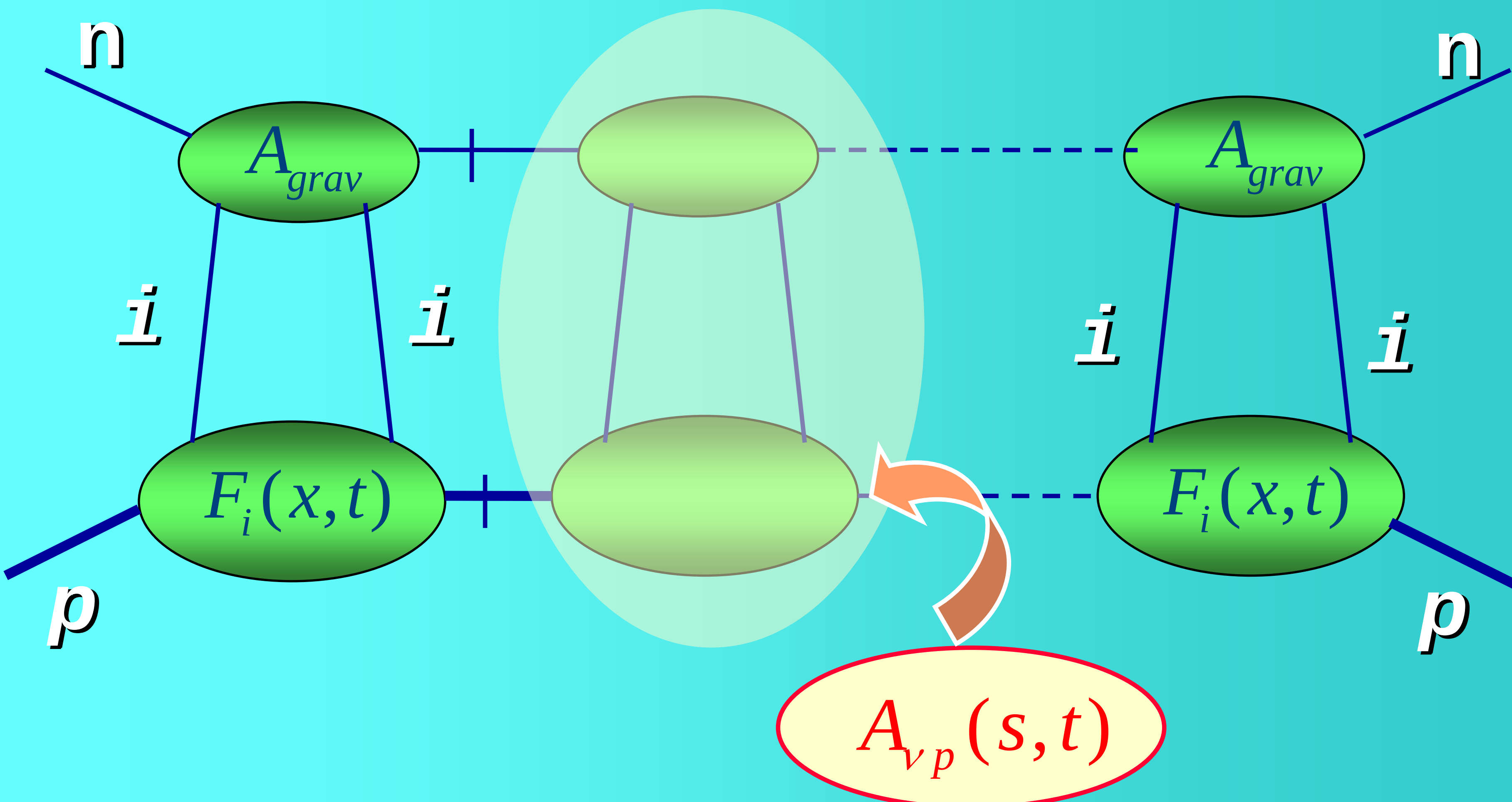
The summation of t-channel reggeized gravitons

eikonal with no explicit dependence on the brane scale and curvature

Radion production is strongly suppressed

$$\left(\Lambda_\phi = \sqrt{3}\Lambda_\pi\right)$$

Neutrino-nucleon Interactions at Ultra-high Energies



Gravitational amplitude $\left(\hat{s} = sx\right)$

$$A_{grav}\left(\hat{s}, t\right) \approx \frac{\hat{s}^2 \alpha'_g}{M_5^3 R_g\left(\hat{s}\right)} \exp\left[t\, R_g\left(\hat{s}\right)\right]$$

Skewed (t-dependent) parton distribution

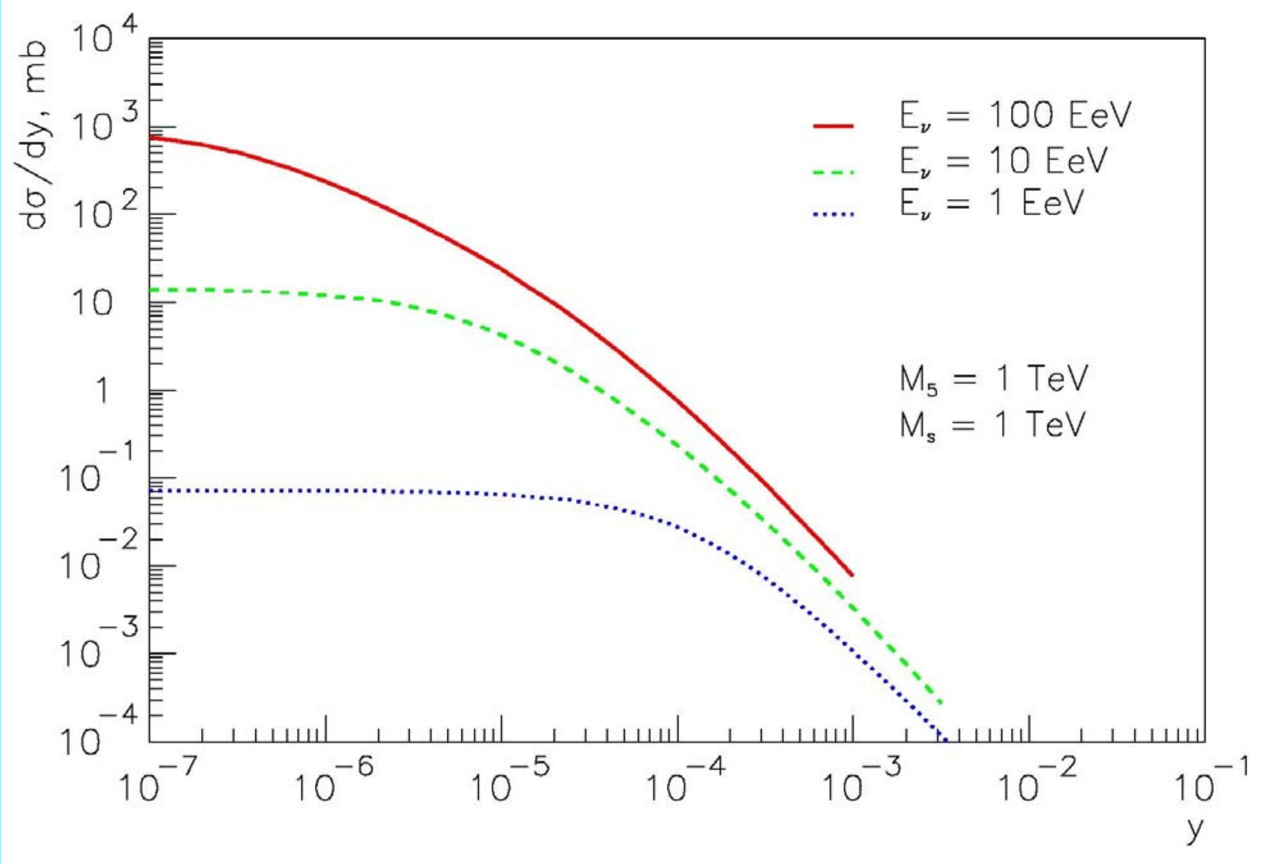
$$F_i(x,t) = f_i\left(x\right) \exp\left[t\left(b_0^2 - \alpha'_{\mathbf{P}} \ln x\right)\right]$$

$f_i\left(x\right)$ - ***standard distribution of parton i***

parameters of the hard Pomeron is used

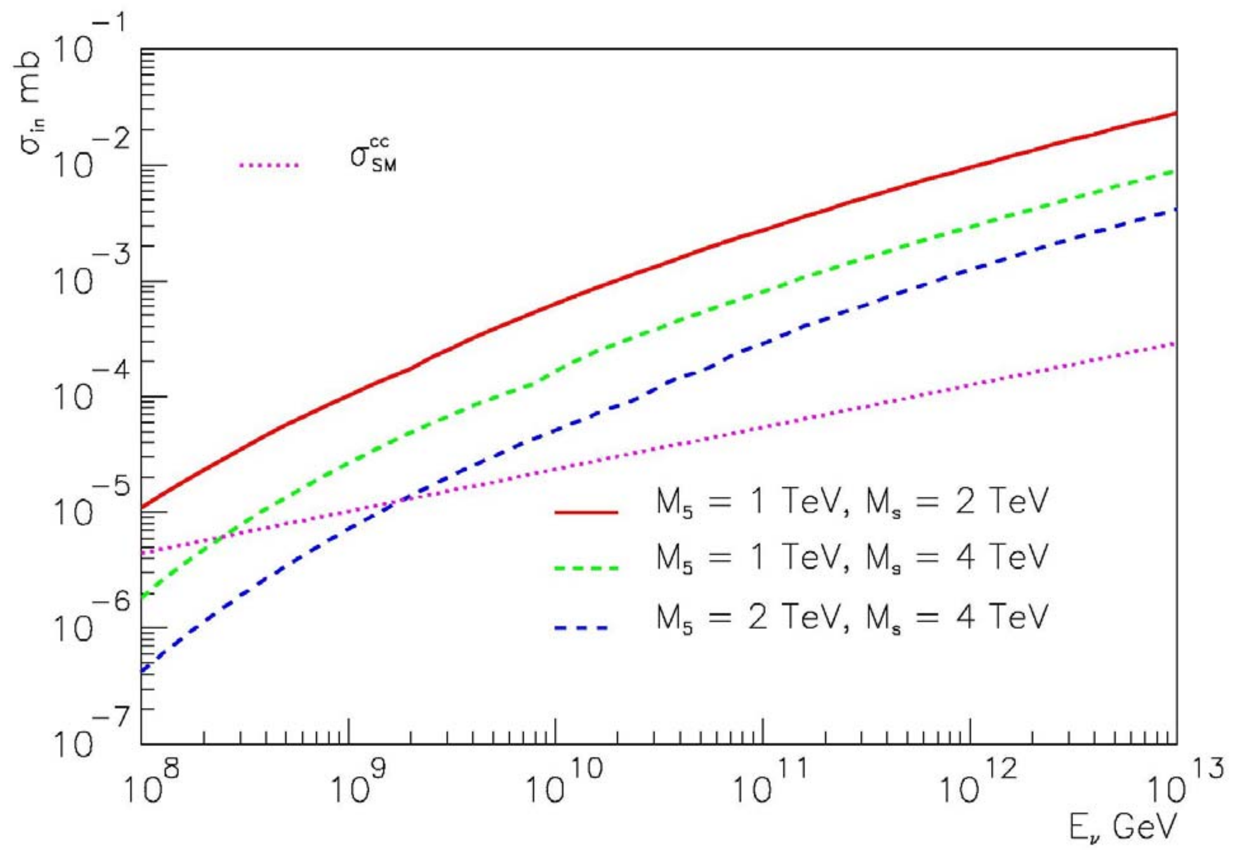
(Petrov & Prokudin, 2002)

Differential cross section



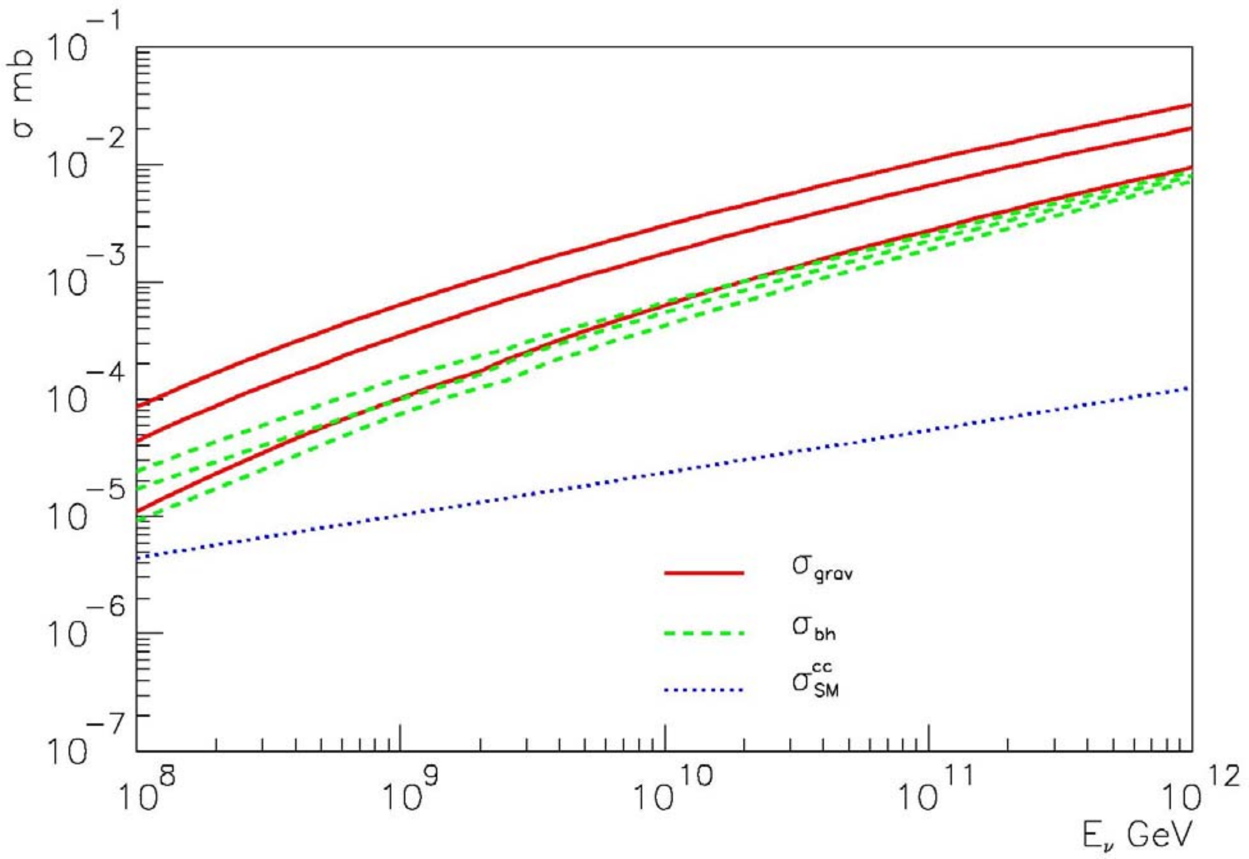
***y* - neutrino energy fraction deposited to the proton**

Inelastic neutrino-proton cross sections



dotted curve: SM (cc) cross section

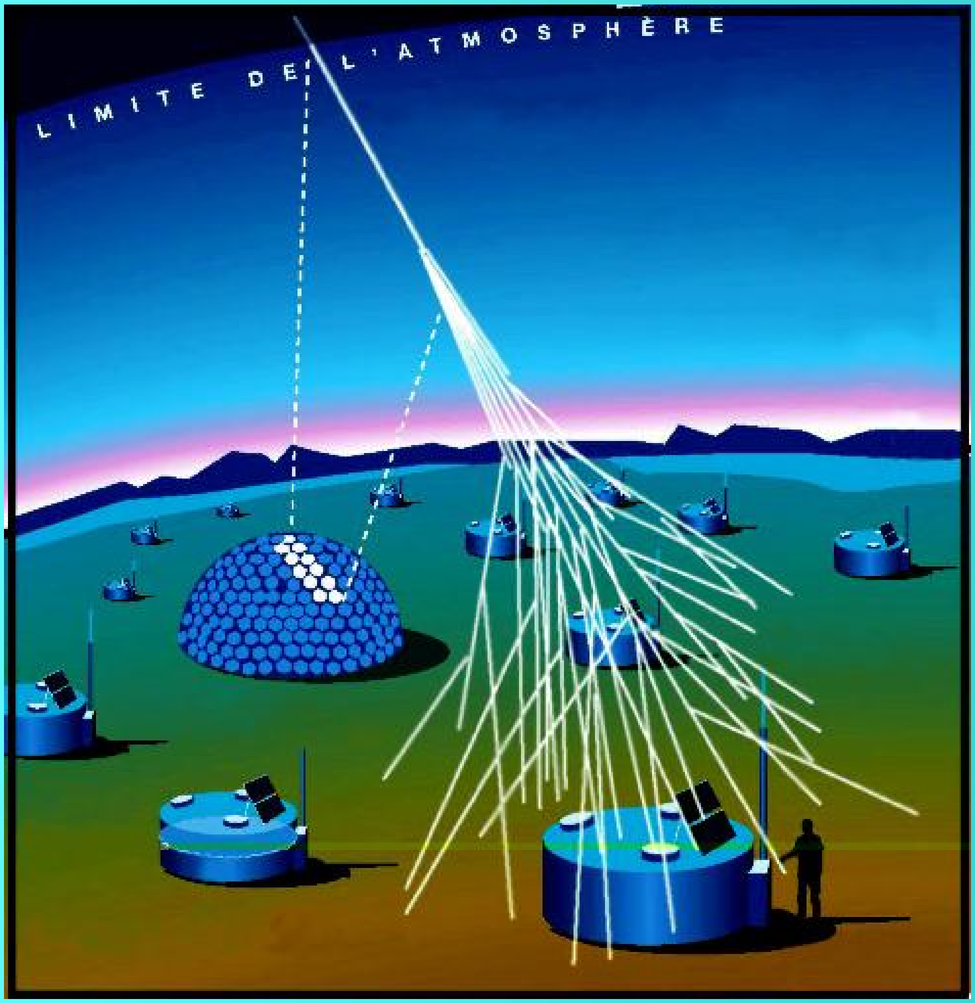
Neutrino-proton interaction vs. black hole production



solid curves: $M_5 = 0.25, 0.5, 1$ TeV

dashed curves: $M_{BH}^{min} = 0.5, 1, 2$ TeV

Detection of quasi-horizontal air showers by the Pierre Auger Observatory



(from www.auger.org)

CONCLUSIONS

- *Gravity effects from ED's may be detected in double diffractive events by the joint experiment of the CMS and TOTEM Collaborations at the LHC*

- *Trans-Planckian gravity induced scattering of the brane fields is given by an infinite sum of the t-channel reggeized gravitons (gravi-Reggeons)*

- *Gravitational part of the cross section for cosmic neutrino scattering off the nucleon is comparable with the BH production cross section*

- ***Gravity effects from ED's are large enough to be measured in ultra-high-energy neutrino-nucleon events by presently planned neutrino detectors***

Expected rate for quasi-horizontal air showers at the Auger Observatory:

4.9 per year $M_5 = 1\,\text{TeV}$

1.6 per year $M_5 = 2\,\text{TeV}$

(for Waxman-Bahcall neutrino flux)

SM: **0.08 per year**

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