Extra dimension searches in central exclusive production

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II Workshop on Diffractive Physics at the LHC
CBPF - 2011

Summary

Motivations

- BSM physics searches in LHC (ATLAS & CMS)
- **Extra dimensions** (ED) as solution of hierarchy problem
- Different scenarios: RS & ADD
- Central Exclusive production (CEP): clear sign in colliders with 2 rapidity gaps, projectiles outside of central region; low background
- CEP mechanisms:
  - gluon fusion
  - photon fusion

This talk:

CEP of gravitons, radions and ZZ in LHC hadron collisions

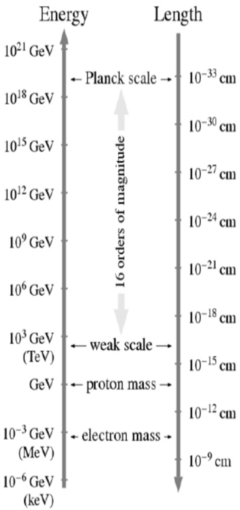
- pp
- pPb & $PbPb \Rightarrow$ nuclear effects

$$h_1 h_2 \to h_1 \oplus \{G_n, \Phi, ZZ\} \oplus h_2$$

Hierarchy solution

The hypothesis:

Many dimensions universe: we are in a *"brane"* embedded in the *"bulk"*
The gravity is weak in the brane because is dilute in the bulk



ED scenarios

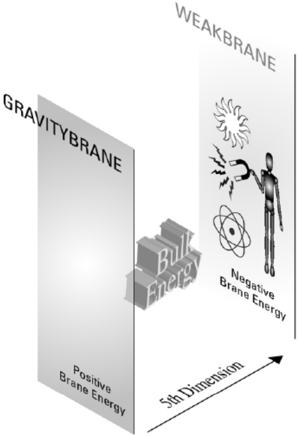
Arkani-Hamed, Dimopoulos e Dvali;

- Two D-branes separate by n flat especial dimensions (torus)
- Standart Model particles in our brane. Only the graviton “see” the other brane
- Rescales the unification scale in TeV order
- Kalusta-Klein tower of graviton states: very close ones
- Introduces an another hierarchy scale

ED scenarios

Randall & Sundrum

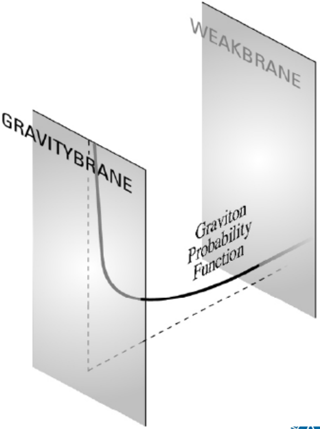
- Two (3+1) branes separate by one ED
- Pentadimensional anti-De Sitter space time
- *"Warped"* bulk depends on the distance from our brane



ED scenarios

Randall & Sundrum

- Two (3+1) branes separate by one ED
- Pentadimensional anti-De Sitter space time
- *"Warped"* bulk depends on the distance from our brane
- Gravitons away from our brane = weak gravity; KK states tower with defined mass values
- Radion: excited state of metric tensor, gravi-scalar, signal similar to the Higgs boson



CEP Models

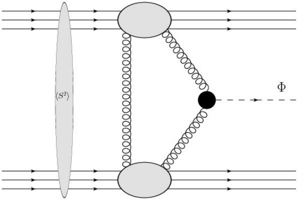
In the literature:

1. gluon fusion:
   - Khoze, Martin, Ryskin (KMR or *“Durham Model”*);
   - Bialas, Landshoff *et al.* (*“Saclay Model”*);
   - Cudell *et al.*
   - Szczurek *et al.*
2. photon fusion:
   - Equivalent photon approximation (Weisäker/Williams);

Gluon fusion: Durham model

Total cross section:

$$\sigma_{tot} = \int dy \langle \mathcal{S}^2 \rangle \mathcal{L}_{excl} \frac{2\pi^2}{m_R^3} \Gamma(\Phi, G \to gg)$$



- $\langle \mathcal{S}^2 \rangle$: survival probability gap (SPG);
- $\mathcal{L}_{excl}$ effective luminosity
- Γ ressonance decay width in two gluons

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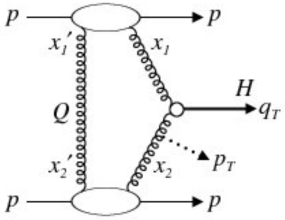


$$\mathcal{L}_{excl} = \left[\frac{\pi}{8b} \int_{Q_0^2}^{\infty} \frac{dQ_T^2}{Q_T^4} f_g(x_1, x_1', Q_T^2, m_R^2/4) f_g(x_2, x_2', Q_T^2, m_R^2/4) \right]^2$$

Gluon fusion: Durham model

- f_g: non-integrated, non-diagonal, skewed gluon density in the nucleon

$$f_g(x, x', Q_T^2, \mu^2) = R_g \frac{\partial}{\partial \ln Q_T^2} \left[\sqrt{T(Q_T,\mu)} xg(x, Q_T^2) \right]$$

- $R_g \simeq 1.2$: skewness
- $xg(x, Q_T^2)$: integrated gluon distribution (CTEQ6L)
- $T(Q_T,\mu)$: Sudakov factor (suppression of hard emissions)

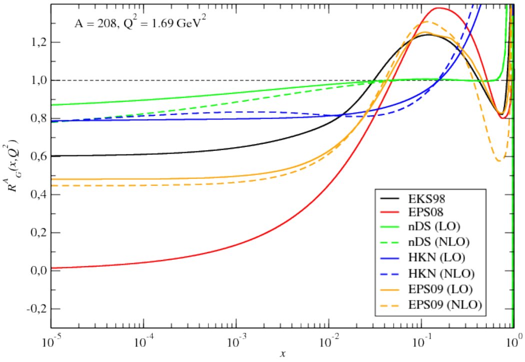
$$T(Q_T,\mu) = \exp\left\{ - \int_{Q_T^2}^{\mu^2} \frac{dk_t^2}{k_t^2} \frac{\alpha_S(k_t^2)}{2\pi} \int_0^{1-\Delta} dz \left[zP_{gg}(z) + \sum_q P_{qg} \right] \right\}$$

- $P_{ij}(z)$: splitting functions
- $$\Delta = \frac{k_t}{k_t + \beta}$$

Gluon fusion: nuclear effects

Gluons distribution:

We using $xg(x,Q_T^2) \rightarrow xg_A(x,Q_T^2) = AR_g^A(x,Q_T^2)xg_p(x,Q_T^2)$



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Gluon fusion: SPG & Γ

SPG:

- SPG is a open question; process dependent
- Estimatives for nuclear SPG;
  - Conservative choice $\Rightarrow$ 3% for pp LHC energies
  - Levin/Miller: $\langle \mathcal{S}^2 \rangle = 8 \times 10^{-4}$ (8.16×10^{-7}) for pAu $(AuAu)$;
  - “Naïve” nuclear model : $\langle \mathcal{S}^2 \rangle_{A_1 A_2} = \langle \mathcal{S}^2 \rangle_{pp} / (A_1 A_2)$.

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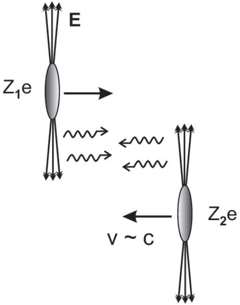
Decay Width:

$$\Gamma[\Phi \to gg] = \frac{\alpha_s^2 m_\Phi^3}{32\pi^3 \Lambda_\phi^2} \left| \frac{15}{3} + x_t [1 + (1 - x_t) f(x_t))] \right|^2 .$$

$$\Gamma[G \to gg] = \frac{1}{10\pi} x_1^2 \left(\frac{k}{\bar{M}_{\rm Pl}} \right)^2 m_G$$

Photon fusion

- large impact parameters and ultrarelativistic energies
- electromagnetic interactions
- factorization $\Rightarrow$ EPA



$$\sigma_{AB\rightarrow ARB} = \int_0^\infty \frac{d\omega_A}{\omega_A} \int_0^\infty \frac{d\omega_B}{\omega_B} F(\omega_A, \omega_B)\sigma_{\gamma\gamma R}(\omega_A, \omega_B) \qquad (1)$$

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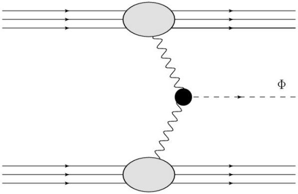

$$\sigma_{AB\to ARB} = \int_0^\infty \frac{d\omega_A}{\omega_A} \int_0^\infty \frac{d\omega_B}{\omega_B} F(\omega_A,\omega_B)\sigma_{\gamma\gamma R}(\omega_A,\omega_B) \qquad (1)$$

- $F(\omega_1,\omega_2)$ is the photon “folded” spectrum,

$$F(\omega_A,\omega_B) = 2\pi \int_{R_A}^\infty b_1 db_1 \int_{R_B}^\infty b_2 db_2 \int_0^{2\pi} d\phi\, N_A(\omega_A,b_1)N_B(\omega_B,b_2) \times\Theta(b-R_A-R_B),$$

with $b^2 = b_1^2 + b_2^2 - 2b_1b_2\cos\phi$; $R_{A,B} = 1{,}2\,\text{fm}\;A^{1/3}$ ($R_p = 0{,}7\,\text{fm}$).

Photon fusion

- Weizsäcker-Williams photon spectrum:

$$N(\omega) = \frac{2\alpha_{em} Z^2}{\pi \omega \beta^2} \left\{ \xi K_0(\xi) K_1(\xi) - \frac{1}{2}\beta^2 \xi^2 \left[K_1^2(\xi) - K_0^2(\xi) \right] \right\}, \quad (2)$$

$\xi = \omega b_{\min}/\gamma\beta$, β is hadron speed, γ is Lorentz factor, $b_{\min}$ minimum impact parameter

- Sub-process cross section

$$\sigma_{\gamma\gamma R}(\omega_A, \omega_B) = \int ds\, \delta(4\omega_A \omega_B - s) \times \frac{8\pi^2}{m_R} \Gamma_{R\to\gamma\gamma} \delta(s - m_R^2)$$

- Decay width (radion):

$$\Gamma(\Phi \to \gamma\gamma) = \frac{\alpha_{em}^2 m_\Phi^3}{256\pi^3 \Lambda_\Phi^2} \left| \frac{19}{6} - \frac{41}{6} - [2 + 3x_W + 3x_W(2 - x_W) f(x_W)] + \frac{8}{3} x_t [1 + (1 - x_t) f(x_t)] \right|^2, \quad x_{W,t} = \frac{4m_{W,t}^2}{m_\Phi^2}$$

Photon fusion

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- Decay width (graviton):

$$\Gamma(G_n \to \gamma\gamma) = \frac{1}{80\pi} x_1^2 \left(\frac{k}{\bar{M}_{\rm Pl}} \right)^2 m_G$$

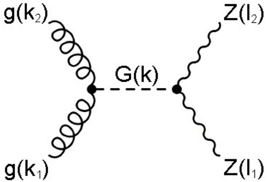
Double Z boson

- Suppressed in SM: two electroweak couplings, large ZZ production threshold ; gluon fusion, in one loop level
- Angular distribution $\Leftrightarrow$ resonance spin
- Gluon fusion (KMR)

$$\sigma_{tot} = \int dy \int \frac{dM^2}{M^2} \langle \mathcal{S}^2 \rangle \mathcal{L}_{excl} \hat{\sigma}(gg \to ZZ)$$

- Virtual graviton exchange in ADD scenario (Kober *et al.*); tree level

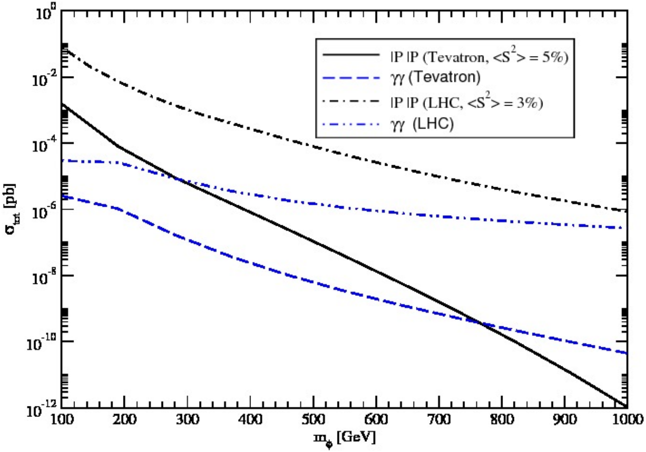
$$\hat{\sigma}(gg \to ZZ) = \frac{\sqrt{\hat{s}(\hat{s} - 4m_Z^2)} P(\hat{s}, m_Z)}{120\pi^{1-d} m_Z^4 M_D^4 \Gamma^2(d/2)}$$



Radion

Mass dependence

pp



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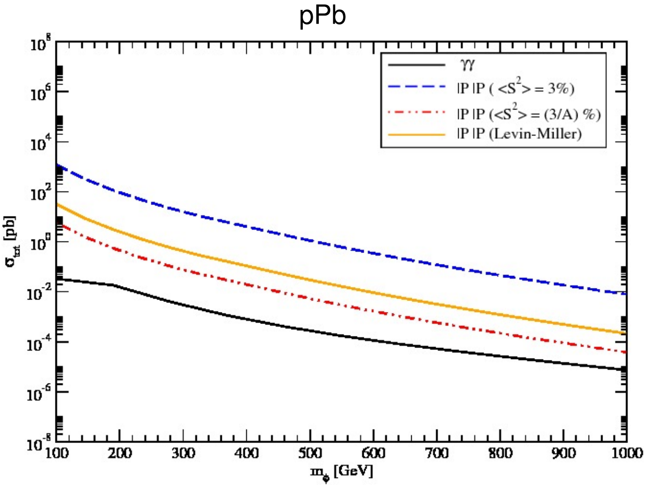

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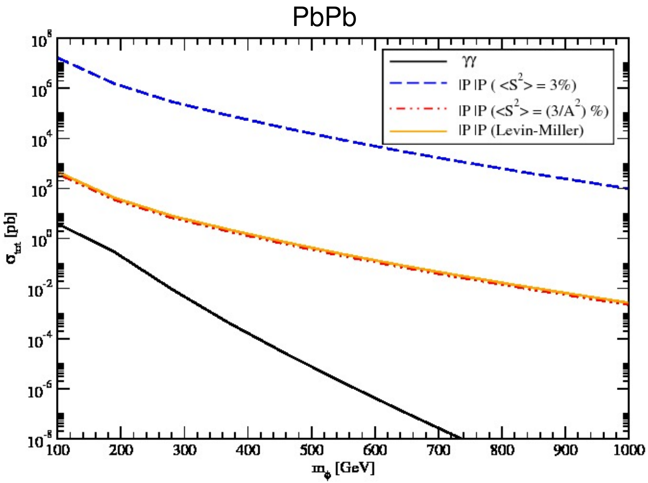


Radion & Graviton

One year number of events, LHC energies

	$\gamma\gamma$	gg
pp	3.0	700
pPb	4.5×10^{-3} 3	9×10^{-2} 60
$PbPb$	2.5×10^{-4}	3.5×10^{-1}

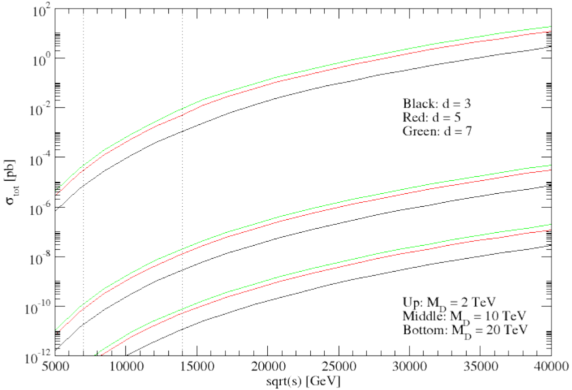
Graviton:

$k/\overline{M}_{\text{Planck}} \sim 0{,}01$, $m_G = 1{,}0\,\text{TeV}$, LHC energies:

σ_{tot}	$\gamma\gamma$	$\langle \mathcal{S}^2 \rangle$	gg
pp ($\sqrt{s} = 14{,}0\,\text{TeV}$)	$1{,}2 \times 10^{-9}$ pb	3%	$3{,}7 \times 10^{-7}$ pb
pPb ($\sqrt{s} = 8{,}8\,\text{TeV}$)	$2{,}1 \times 10^{-4}$ pb	3% $3\%/A^2$	$3{,}3 \times 10^{-3}$ pb $1{,}6 \times 10^{-5}$ pb
$PbPb$ ($\sqrt{s} = 5{,}5\,\text{TeV}$)	$2{,}2 \times 10^{-10}$ pb	3% $3\%/A^2$	$1{,}5 \times 10^{+1}$ pb $3{,}4 \times 10^{-4}$ pb

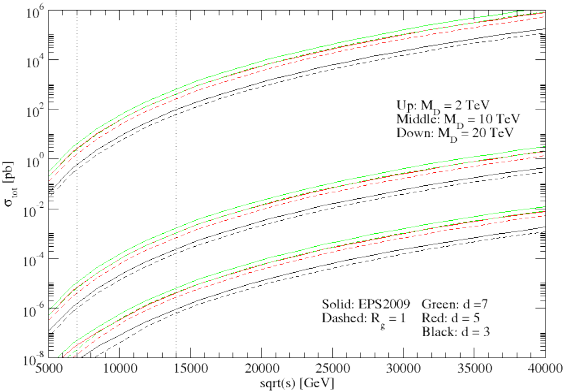
Double Z boson

$$pp \rightarrow p\ ZZ\ p$$



Double Z boson

$$PbPb \to Pb\, ZZ\, Pb$$



Conclusions:

- Due the trace anomaly $\Rightarrow$ radion $\sigma_{\rm tot} \sim 8$ times large than Higgs in the mass interval in gluon fusion
- photon fusion as lower limit production; Z^2 improvement in ion collisions
- gluon production dominant in all scenarios. A^2 or A^4 improvement. Sensitivity in SPG.
- Crucial dependence on mass and Λ_Φ.
- low number of events in nuclear collisions, reasonable in pp
- small sign than inclusive production, but clean due the process topology
- pile-up in exclusive production

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- First RS graviton state: small number of events

- Double Z production: an enhancement above the SM; feasible measurement in heavy ion case in a low M_D scale

Forthcoming issues

- diphotons / dileptons
- graviton in ADD scenario
- monojet production (missing energy)