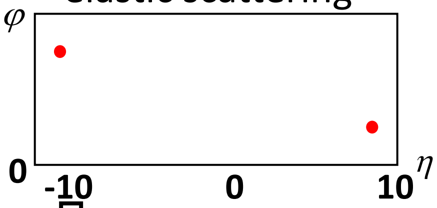
Exclusive central diffractive production of hadron pairs in the Regge eikonal model at energies from 30 Gev to 13 TeV

R.A. Ryutin

NRC “Kurchatov Institute” - IHEP

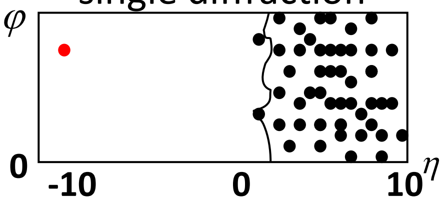
Diffractive processes

elastic scattering



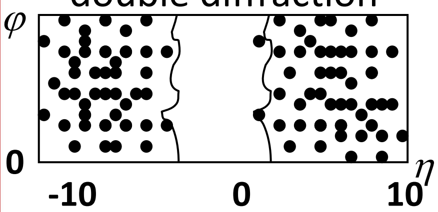
~ 100 mb

single diffraction



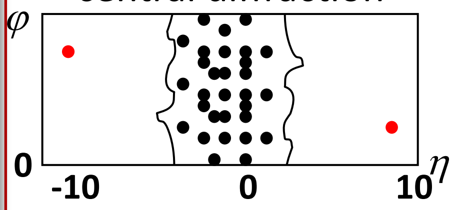
~ 10 mb

double diffraction



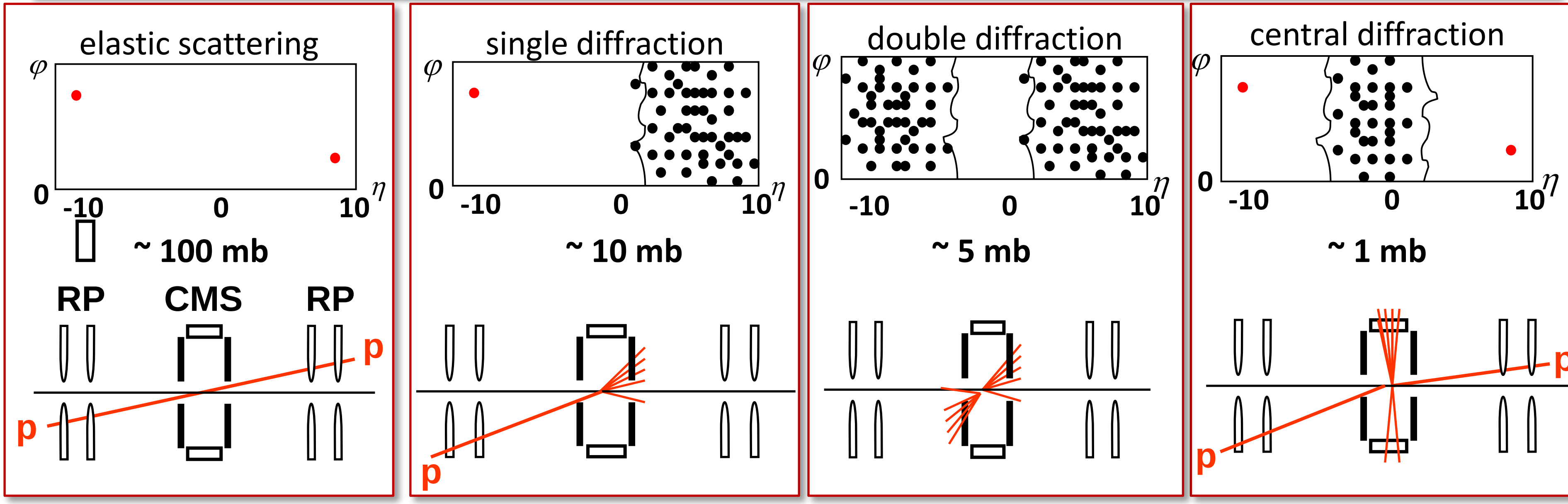
~ 5 mb

central diffraction



~ 1 mb

Diffractive processes



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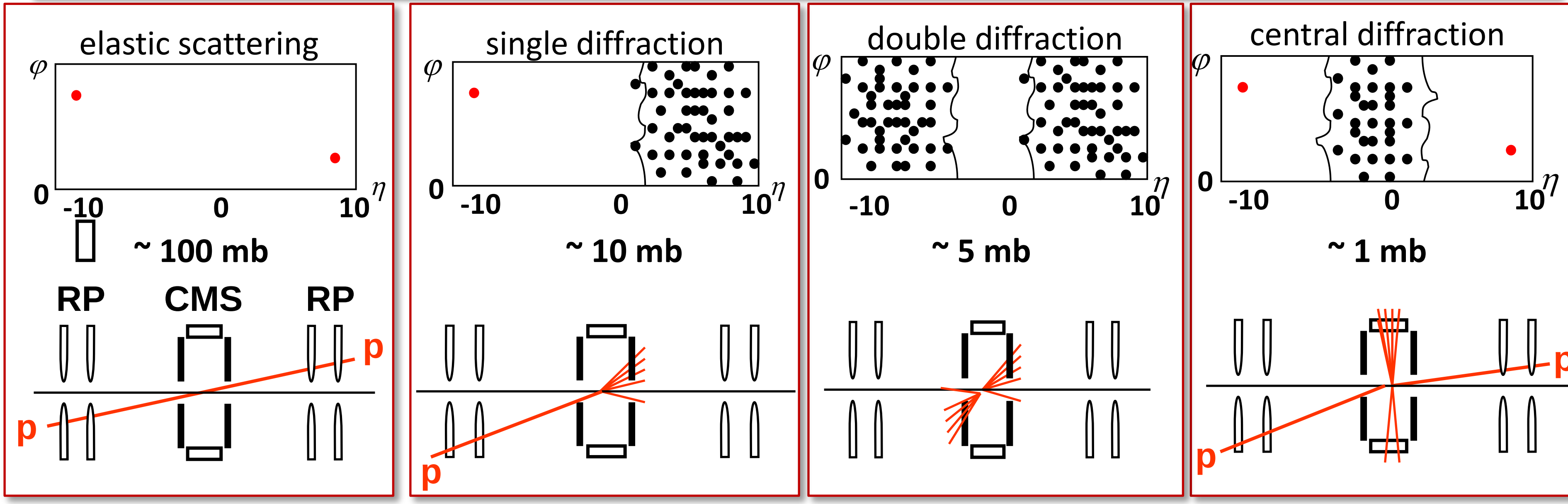
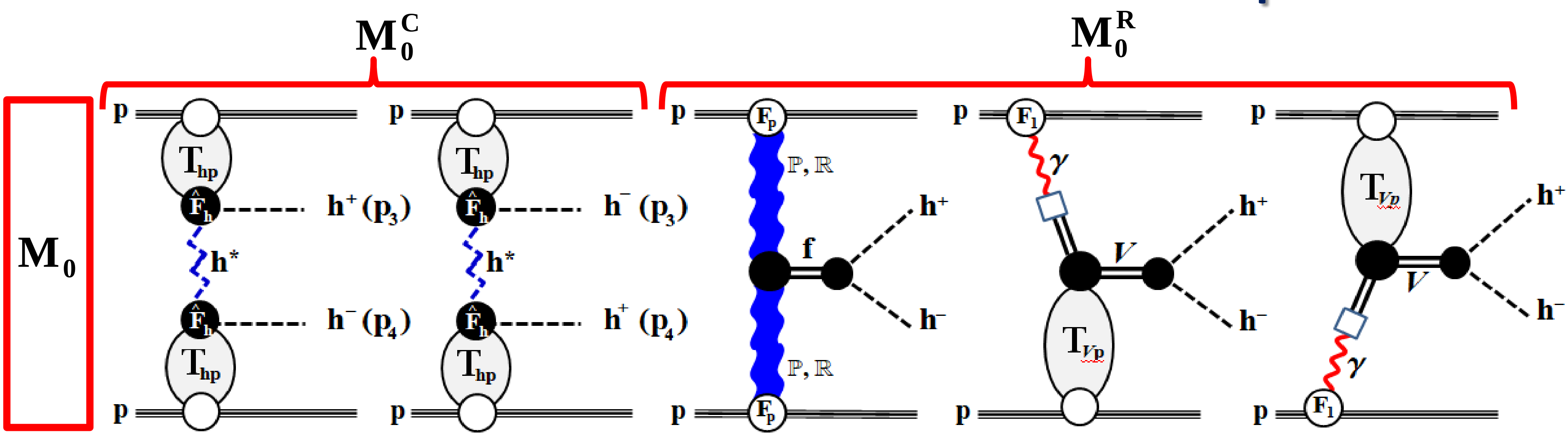
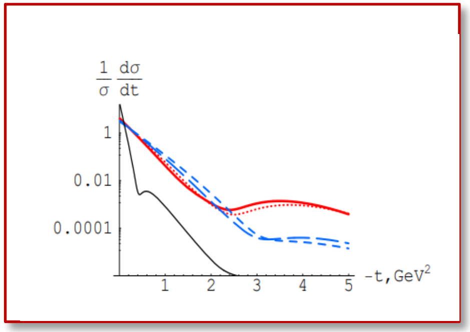


Central Exclusive Diffractive Production of hadron pairs



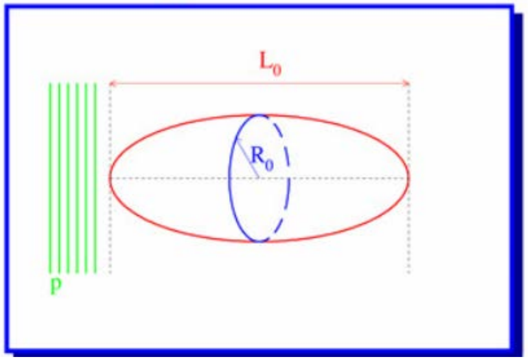
Distributions and their roles

dσ/dt



Size & shape of the Interaction region

$$L_0 \simeq \sqrt{s}/m^2 \simeq 40000\ fm \text{ at LHC}$$
$$R_0 \sim \frac{1}{m}\ln s \sim 1\ fm$$
$$p \simeq E_{LHC}$$



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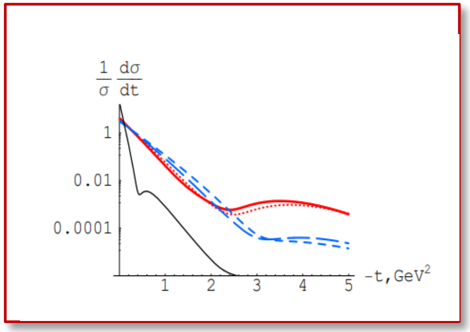

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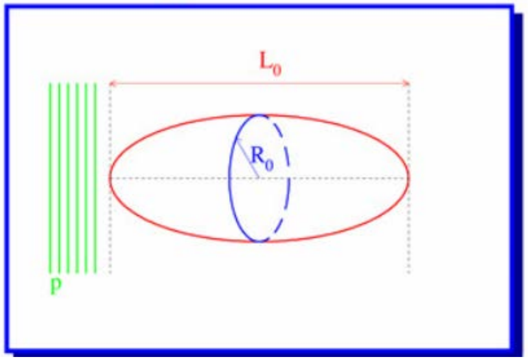
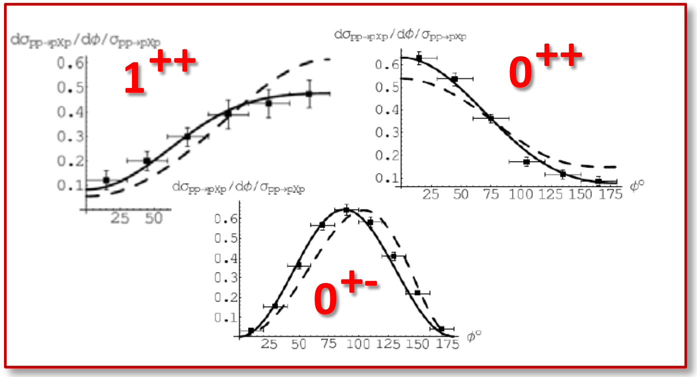


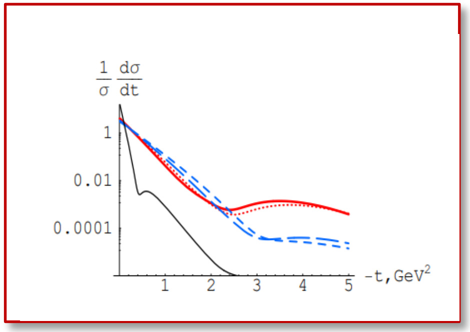
dσ/dφ (azimuthal)



Quantum numbers of central state

Distributions and their roles

dσ/dt



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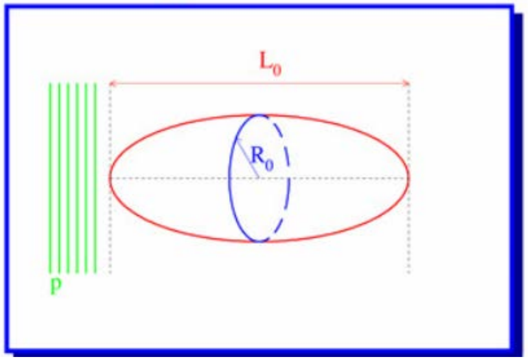

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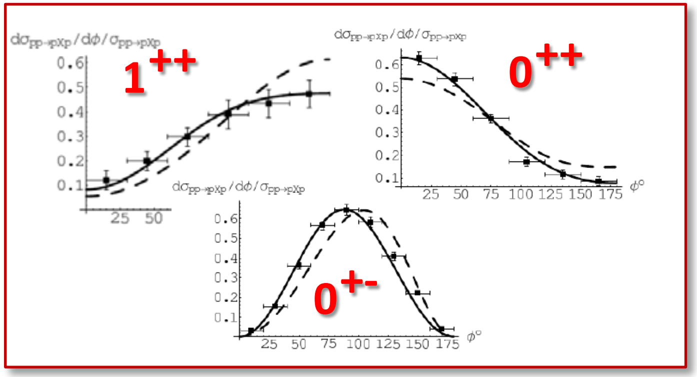
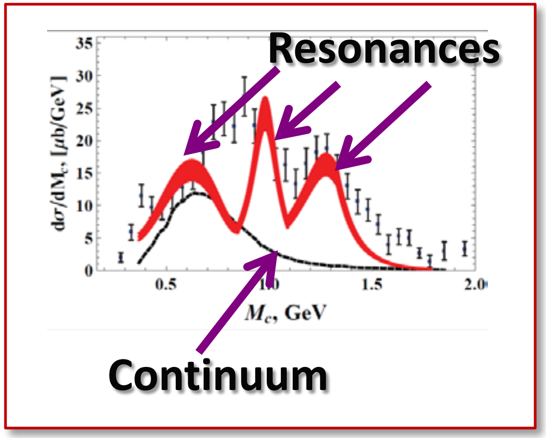


Quantum numbers of central state

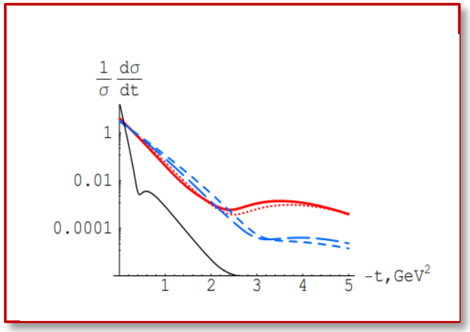
dσ/dM



Missing mass method

Distributions and their roles

dσ/dt



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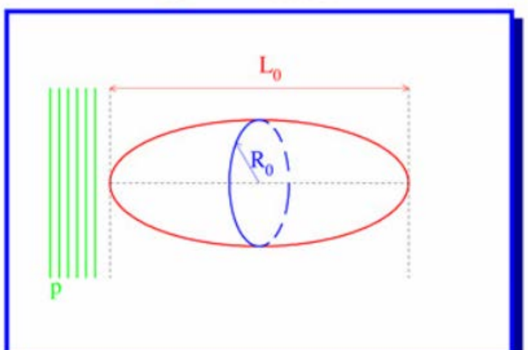
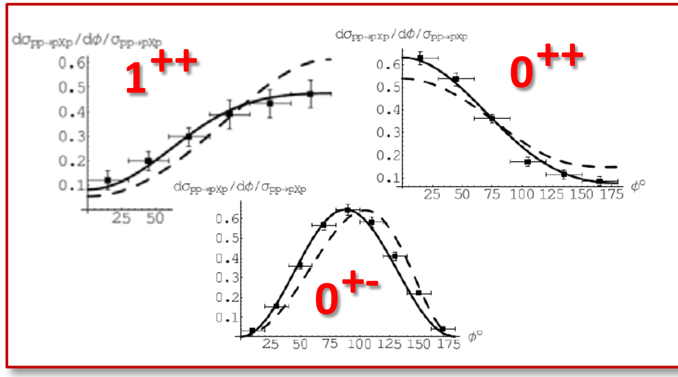
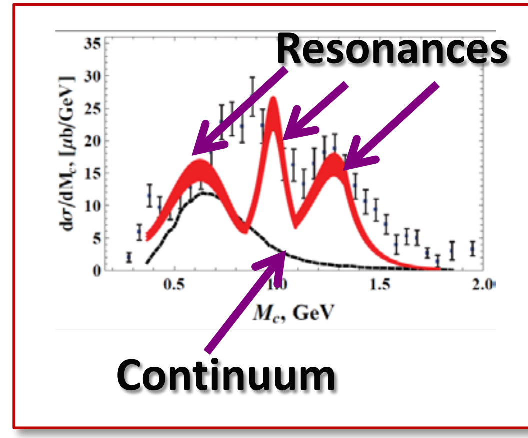


dσ/dφ (azimuthal)



Quantum numbers of central state

dσ/dM

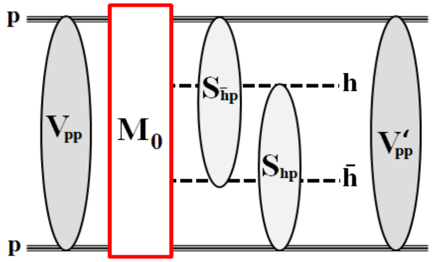


Missing mass method

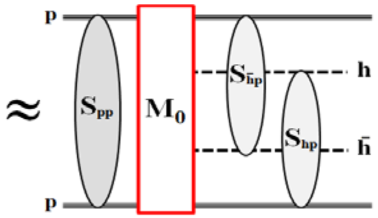
Fine tuning of diffractive models ⇒

- Form-factors
- Couplings
- Absorptive corr.
- Spin effects
- Odderon etc…

Model



$$M^U(\{p\}) =$$
$$= \int\int \frac{d^2\vec{q}}{(2\pi)^2}\frac{d^2\vec{q}'}{(2\pi)^2}\frac{d^2\vec{q}_1}{(2\pi)^2}\frac{d^2\vec{q}_2}{(2\pi)^2} V_{pp}(s,q^2)V_{pp}(s',q'^2)$$
$$\times\ \left[\left[S_{\bar{h}p}(\tilde{s}_{14},q_1^2)M_0^C(\{\tilde{p}\})\,S_{hp}(\tilde{s}_{23},q_2^2)+(3\leftrightarrow 4)\right]+M_0^R(\{\tilde{p}\})\right]$$



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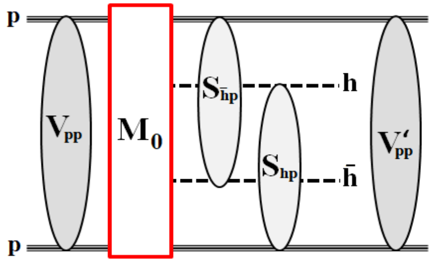
Model



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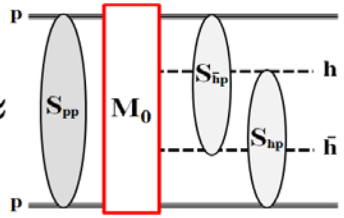
≈



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$$S_{h_1h_2}(s,q^2) = \int d^2\vec{b}\,\mathrm{e}^{\mathrm{i}\vec{q}\vec{b}}\left(1+2\mathrm{i}T^{el}_{h_1h_2}(s,b)\right) =$$
$$= \int d^2\vec{b}\,\mathrm{e}^{\mathrm{i}\vec{q}\vec{b}}\mathrm{e}^{-2\Omega^{el}_{h_1h_2}(s,b)} = (2\pi)^2\delta^2(\vec{q}) + 2\pi\bar{T}_{h_1h_2}(s,q^2),$$
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$$\tilde{T}_{h_1h_2} = \int_0^\infty b\,db\,J_0\left(b\sqrt{-q^2}\right)\left[\mathrm{e}^{-\Omega^{el}_{h_1h_2}(s,b)} - 1\right]$$

$$T^{el}_{h_1h_2}(s,b) = \frac{\mathrm{e}^{-2\Omega^{el}_{h_1h_2}(s,b)} - 1}{2\mathrm{i}},$$
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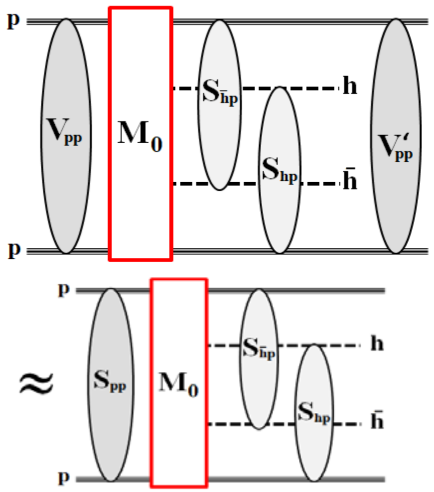
$$\delta^{el}_{h_1h_2}(s,b) = \frac{1}{16\pi s}\int_0^\infty d(-t)J_0(b\sqrt{-t})\delta^{el}_{h_1h_2}(s,t)$$

[A.A. Godizov, Eur. Phys. J. C 75, 224 (2015)]
[A.A. Godizov, Yad. Fiz. 71, 1822 (2008)]

Model



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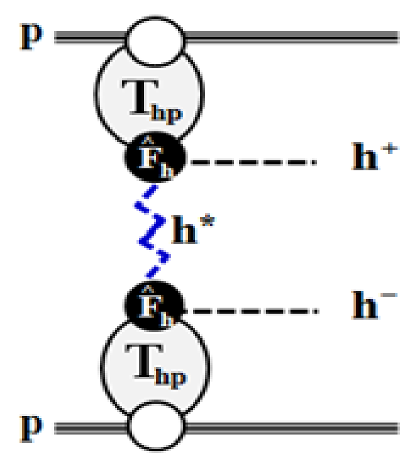

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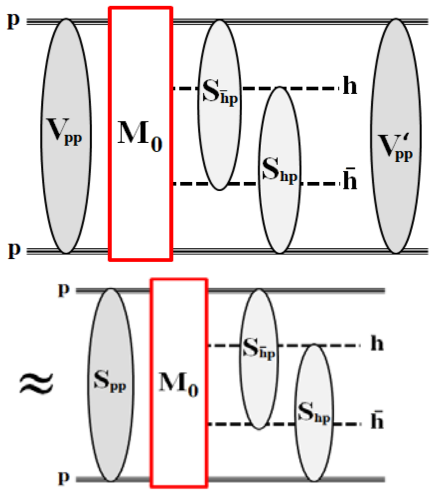
$$M_0^C(\{p\}) = T^{el}_{hp}(s_{13},t_1)\mathcal{P}_h(\hat{s},\hat{t})\left[\hat{F}_h(\hat{t})\right]^2 T^{el}_{\bar{h}p}(s_{24},t_2)$$

Model



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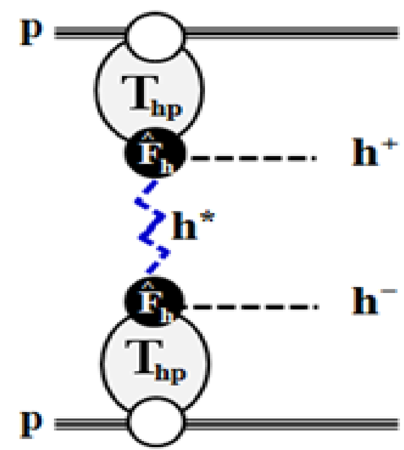

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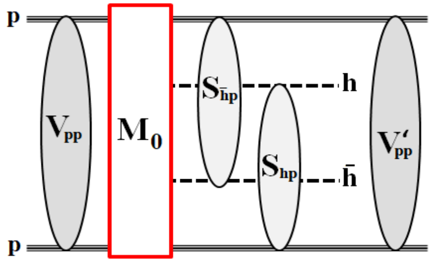
$\Lambda_h \sim 1$ **only one free parameter**

$$\hat{F}_h = \mathrm{e}^{(\hat{t}-m_h^2)/\Lambda_h^2}$$

$$M_0^C(\{p\}) = T^{el}_{hp}(s_{13},t_1)\mathcal{P}_h(\hat{s},\hat{t})\left[\hat{F}_h(\hat{t})\right]^2 T^{el}_{\bar{h}p}(s_{24},t_2)$$

[A.A. Godizov, Eur. Phys. J. C 75, 224 (2015)]
[A.A. Godizov, Yad. Fiz. 71, 1822 (2008)]

Model



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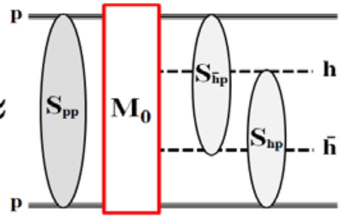
$\approx$ 

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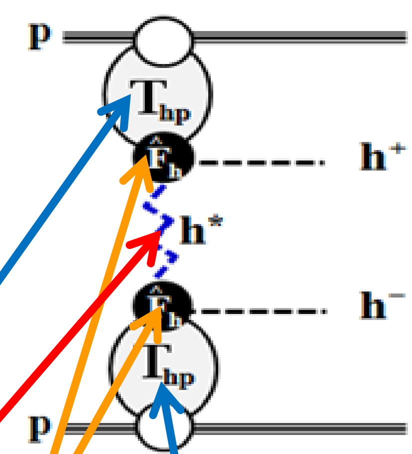
$$\tilde{T}_{h_1h_2} = \int_0^\infty b\,db\,J_0\left(b\sqrt{-q^2}\right)\left[\mathrm{e}^{-\Omega^{el}_{h_1h_2}(s,b)} - 1\right]$$

$$T^{el}_{h_1h_2}(s,b) = \frac{\mathrm{e}^{-2\Omega^{el}_{h_1h_2}(s,b)} - 1}{2\mathrm{i}},$$
$$\Omega^{el}_{h_1h_2}(s,b) = -\mathrm{i}\,\delta^{el}_{h_1h_2}(s,b),$$
$$\delta^{el}_{h_1h_2}(s,b) = \frac{1}{16\pi s}\int_0^\infty d(-t)J_0(b\sqrt{-t})\delta^{el}_{h_1h_2}(s,t)$$

$\Lambda_h \sim 1$ **only one free parameter**

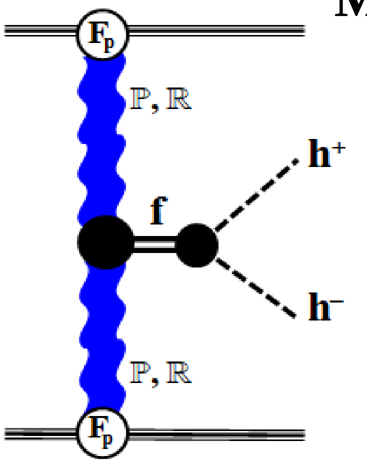
$$\hat{F}_h = \mathrm{e}^{(\hat{t}-m_h^2)/\Lambda_h^2}$$



$$M_0^C(\{p\}) = T^{el}_{hp}(s_{13},t_1)\mathcal{P}_h(\hat{s},\hat{t})\left[\hat{F}_h(\hat{t})\right]^2 T^{el}_{\bar{h}p}(s_{24},t_2)$$

[A.A. Godizov, Eur. Phys. J. C 75, 224 (2015)]
[A.A. Godizov, Yad. Fiz. 71, 1822 (2008)]

Model

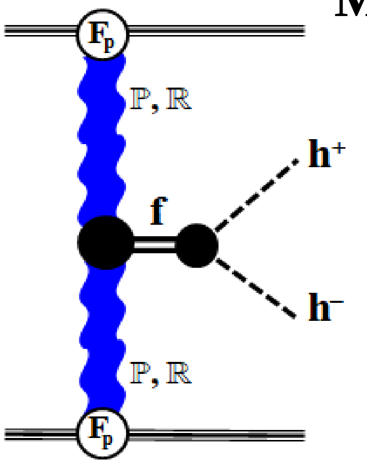


$$M_0^f = \sum_f \text{Collision part} \otimes \text{Decay part}$$

Collision part: [A. Godizov]

Decay part: [P. Lebiedowicz et al.]

Model



$M_0^f = \sum_f$ Collision part $\otimes$ Decay part

[A. Godizov] [P. Lebiedowicz et al.]

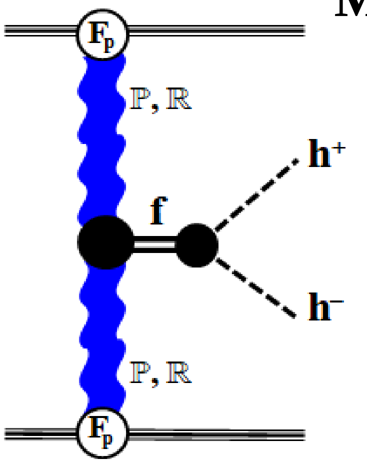
$\sqrt{s}$ > 100 GeV

Collision part =

$$F_{\mathbb{P}}(t_1,\xi_1)F_{\mathbb{P}}(t_2,\xi_2)\,g_{\mathbb{PP}f}(t_1,t_2,M_c^2) +$$
$$F_{\mathbb{P}}(t_1,\xi_1)F_{\mathbb{R}}(t_2,\xi_2)\,g_{\mathbb{PR}f}(t_1,t_2,M_c^2) + F_{\mathbb{R}}(t_1,\xi_1)F_{\mathbb{P}}(t_2,\xi_2)\,g_{\mathbb{PR}f}(t_1,t_2,M_c^2) +$$
$$F_{\mathbb{R}}(t_1,\xi_1)F_{\mathbb{R}}(t_2,\xi_2)\,g_{\mathbb{RR}f}(t_1,t_2,M_c^2)$$

$$F_{\mathbb{P}}(t,\xi) = g_{pp\mathbb{P}}(t)\left(\mathrm{i} + \tan\frac{\pi(\alpha_{\mathbb{P}}(t)-1)}{2})\right)\frac{\pi\alpha'_{\mathbb{P}}(t)}{\xi^{\alpha_{\mathbb{P}}}(t)}$$

Model



$$M_0^f = \sum_f \text{Collision part} \otimes \text{Decay part}$$

Collision part [A. Godizov]; Decay part [P. Lebiedowicz et al.]

Collision part =

$$F_{\mathbb{P}}(t_1,\xi_1)F_{\mathbb{P}}(t_2,\xi_2)\,g_{\mathbb{P}\mathbb{P}f}(t_1,t_2,M_c^2) \; +$$

$$F_{\mathbb{P}}(t_1,\xi_1)F_{\mathbb{R}}(t_2,\xi_2)\,g_{\mathbb{P}\mathbb{R}f}(t_1,t_2,M_c^2) \; + \; F_{\mathbb{R}}(t_1,\xi_1)F_{\mathbb{P}}(t_2,\xi_2)\,g_{\mathbb{P}\mathbb{R}f}(t_1,t_2,M_c^2) \; +$$

$$F_{\mathbb{R}}(t_1,\xi_1)F_{\mathbb{R}}(t_2,\xi_2)\,g_{\mathbb{R}\mathbb{R}f}(t_1,t_2,M_c^2)$$

$\sqrt{s}$ > 100 GeV

$$F_{\mathbb{P}}(t,\xi) = g_{pp\mathbb{P}}(t)\left(\mathrm{i} + \tan\frac{\pi(\alpha_{\mathbb{P}}(t)-1)}{2})\right)\frac{\pi\alpha'_{\mathbb{P}}(t)}{\xi^{\alpha_{\mathbb{P}}}(t)}$$

$$F_{\mathbb{R}}(t,\xi) = g_{pp\mathbb{R}}(t)\left(\mathrm{i} + \tan\frac{\pi(\alpha_{\mathbb{R}}(t)-1)}{2})\right)\frac{\pi\alpha'_{\mathbb{R}}(t)}{\xi^{\alpha_{\mathbb{R}}}(t)}$$

[A.A. Godizov, *Eur. Phys. J. C 76, 361 (2016)*]

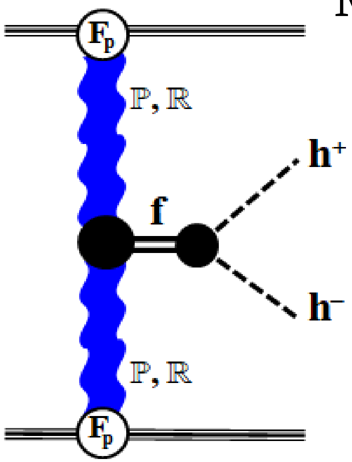
$$\alpha_{\mathbb{P}}(0) = 1.109$$

$$\alpha_{\mathbb{R}}(0) = 0.61$$

$g_{\mathbb{P}\mathbb{P}f}(t_1,t_2,M_c^2)$ $\quad$ $g_{\mathbb{P}\mathbb{R}f}(t_1,t_2,M_c^2)$ $\quad$ $g_{\mathbb{R}\mathbb{R}f}(t_1,t_2,M_c^2)$

vertex functions to fit the data

Model



$$M_0^f = \sum_f \text{Collision part} \otimes \text{Decay part}$$

[A. Godizov] [P. Lebiedowicz et al.]

Collision part =

$$F_{\mathbb{P}}(t_1,\xi_1)F_{\mathbb{P}}(t_2,\xi_2)\, g_{\mathbb{PP}f}(t_1,t_2,M_c^2) +$$
$$F_{\mathbb{P}}(t_1,\xi_1)F_{\mathbb{R}}(t_2,\xi_2)\, g_{\mathbb{PR}f}(t_1,t_2,M_c^2) + F_{\mathbb{R}}(t_1,\xi_1)F_{\mathbb{P}}(t_2,\xi_2)\, g_{\mathbb{PR}f}(t_1,t_2,M_c^2) +$$
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$\sqrt{s}$ > 100 GeV

$$F_{\mathbb{P}}(t,\xi) = g_{pp\mathbb{P}}(t)\left(\mathrm{i} + \tan\frac{\pi(\alpha_{\mathbb{P}}(t)-1)}{2}\right)\frac{\pi\alpha'_{\mathbb{P}}(t)}{\xi^{\alpha_{\mathbb{P}}(t)}}$$

$$F_{\mathbb{R}}(t,\xi) = g_{pp\mathbb{R}}(t)\left(\mathrm{i} + \tan\frac{\pi(\alpha_{\mathbb{R}}(t)-1)}{2}\right)\frac{\pi\alpha'_{\mathbb{R}}(t)}{\xi^{\alpha_{\mathbb{R}}(t)}}$$

[A.A. Godizov, *Eur. Phys. J. C 76, 361 (2016)*]

$\alpha_{\mathbb{P}}(0) = 1.109$

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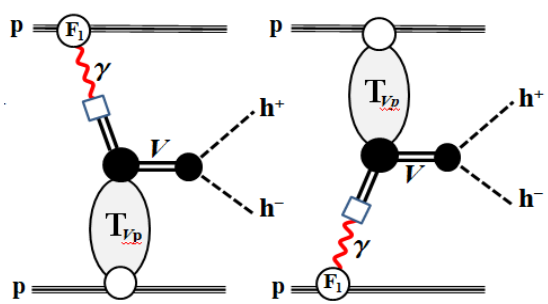
$g_{\mathbb{PP}f}(t_1,t_2,M_c^2)$ $g_{\mathbb{PR}f}(t_1,t_2,M_c^2)$ $g_{\mathbb{RR}f}(t_1,t_2,M_c^2)$

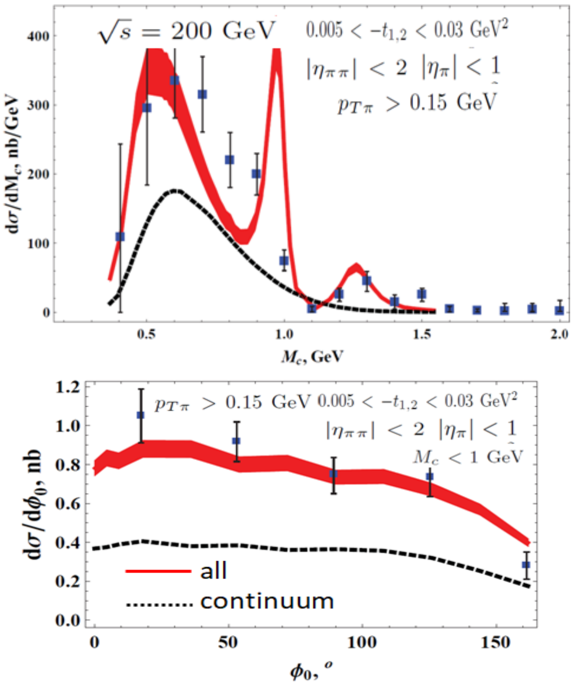
vertex functions to fit the data



$$M_0^V = \text{Photon flux} \otimes T_{Vp}^{el} \otimes \text{Decay part}$$

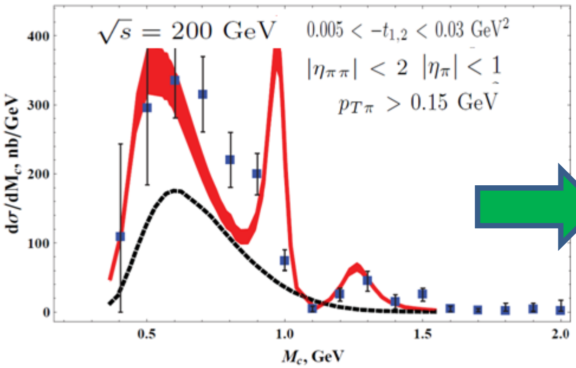
[A. Godizov] [P. Lebiedowicz et al.]

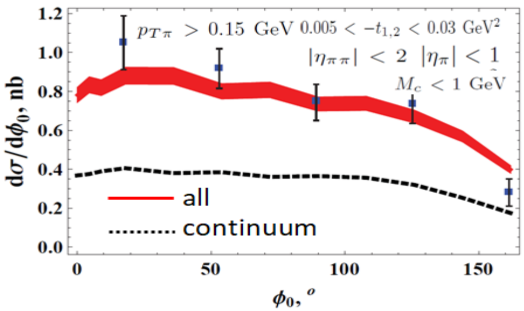
Results for di-pion production



STAR 200 GeV

Results for di-pion production





STAR 200 GeV

$$\Lambda_\pi = 1.2 \text{ GeV}$$

$$g_{\mathbb{PP}f_0(500)} = 0.88,$$

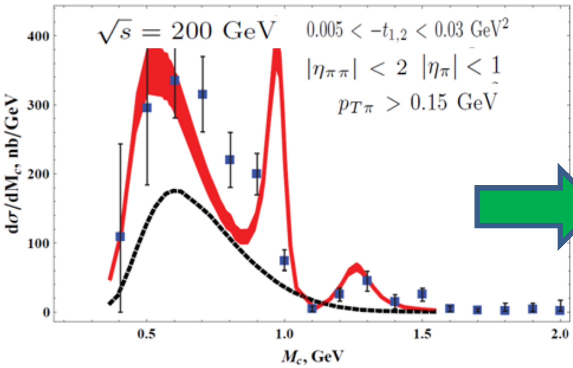
$$g_{\mathbb{PP}f_0(980)} = 0.43,$$

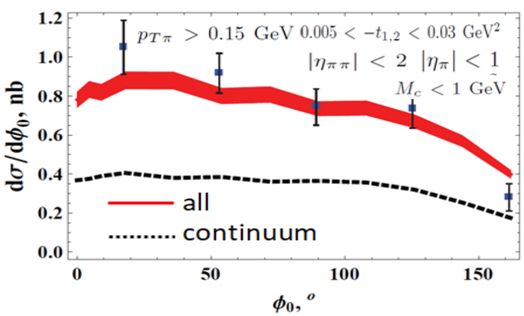
$$g_{\mathbb{PP}f_2(1270)} = 1.72.$$

0.64 (glueball) → **[A.Godizov]**

vertex functions = const

Results for di-pion production





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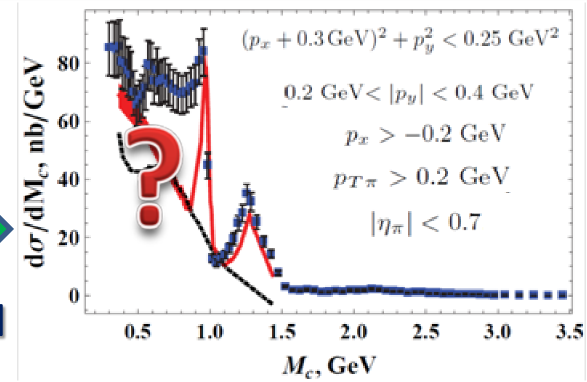
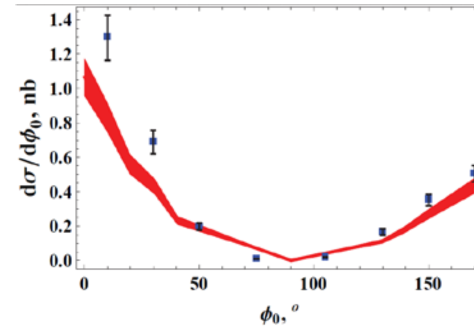
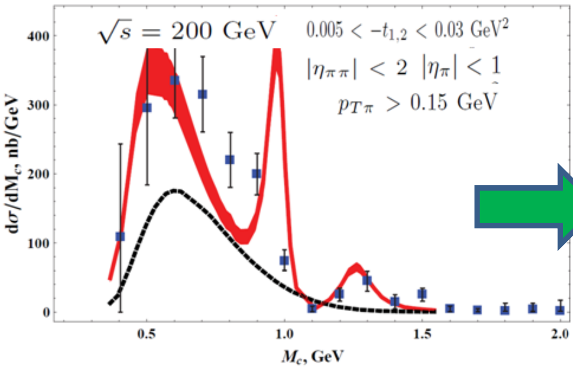
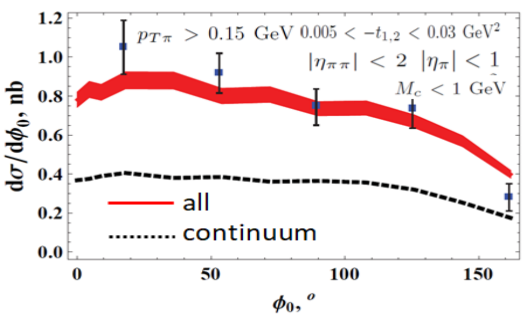




Results for di-pion production





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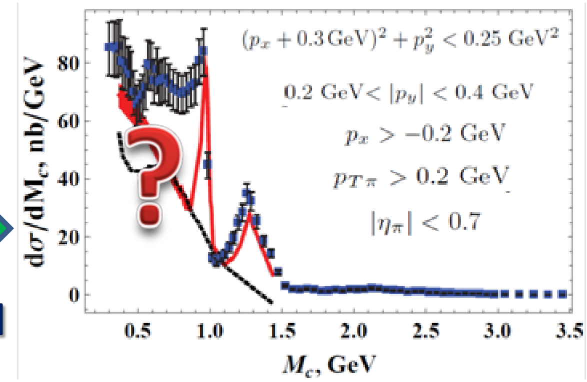
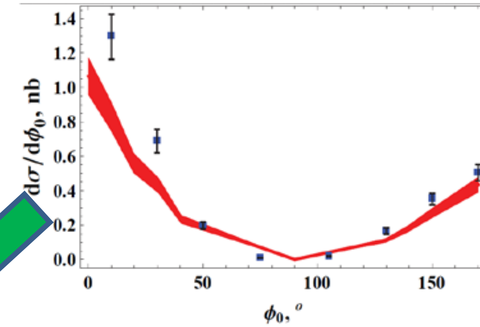
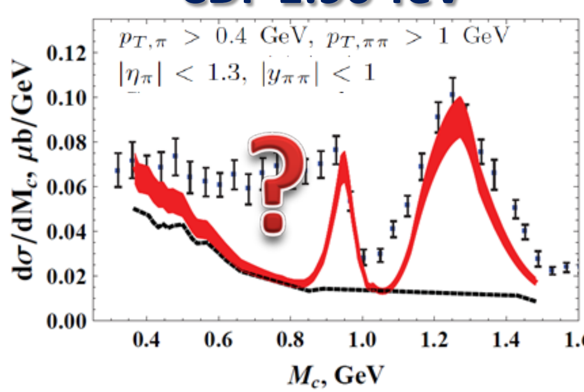
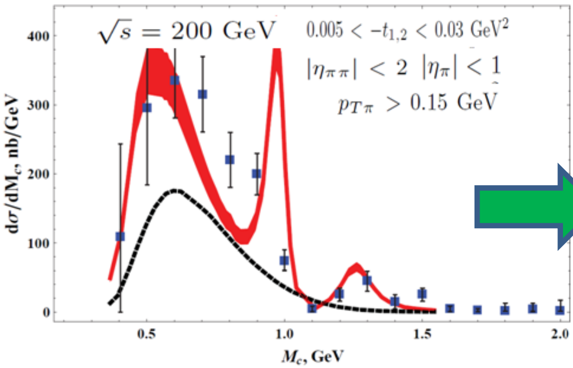


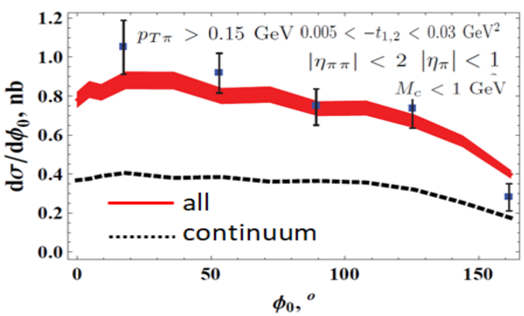


CDF 1.96 TeV



Results for di-pion production





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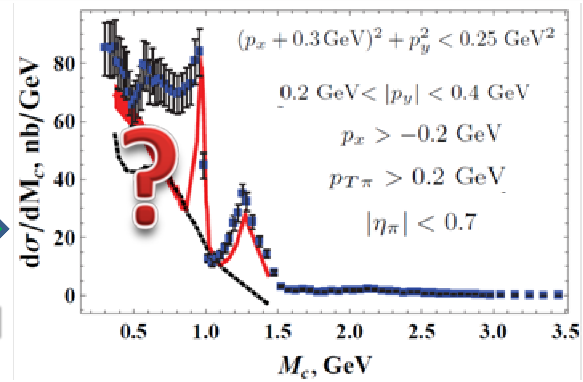
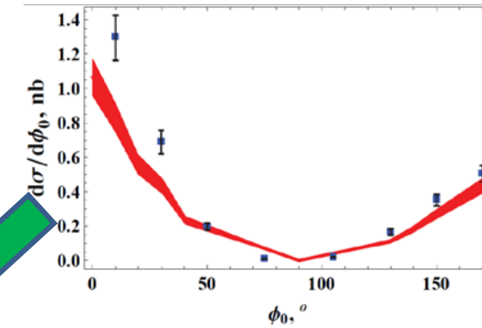
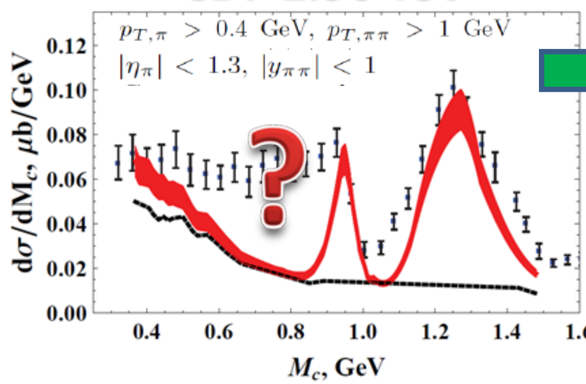
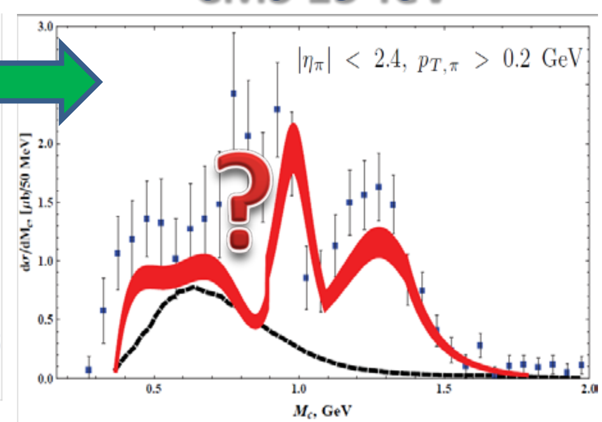




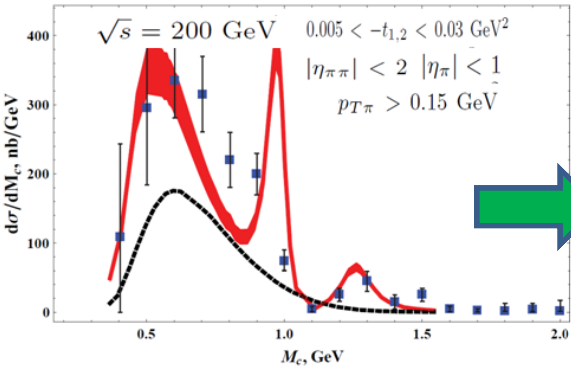
CDF 1.96 TeV



CMS 13 TeV



Results for di-pion production



STAR 200 GeV

$\Lambda_\pi = 1.2$ GeV

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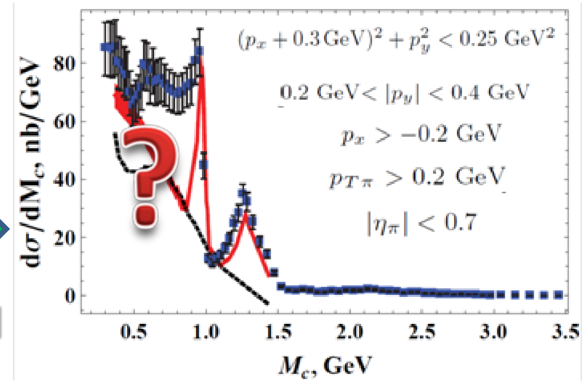
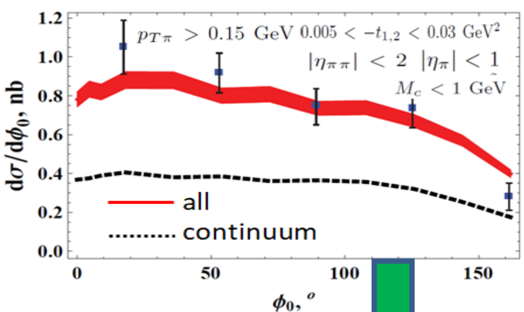
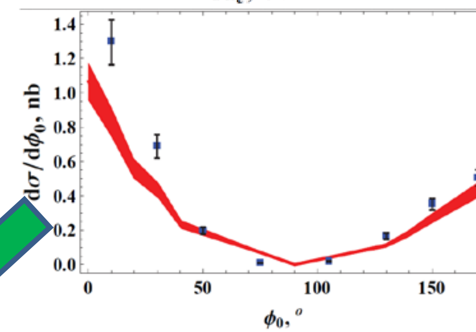
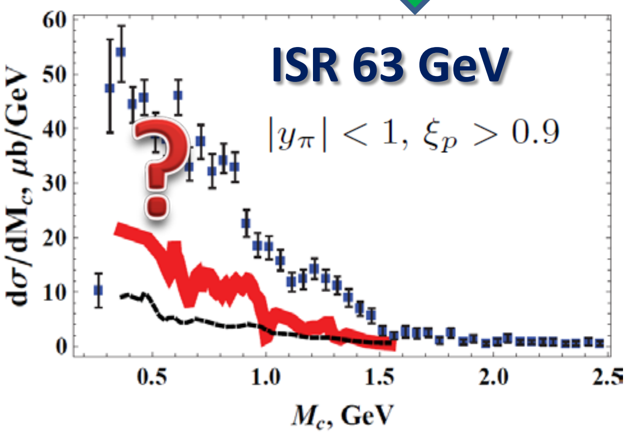
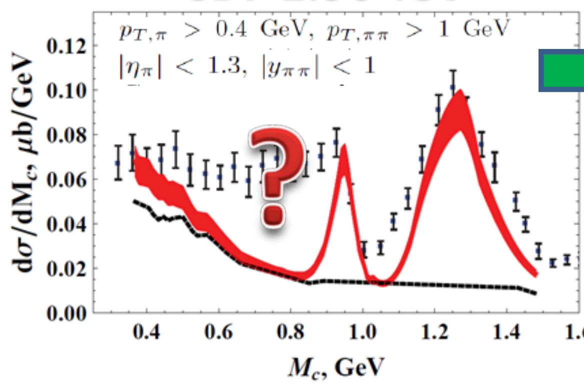




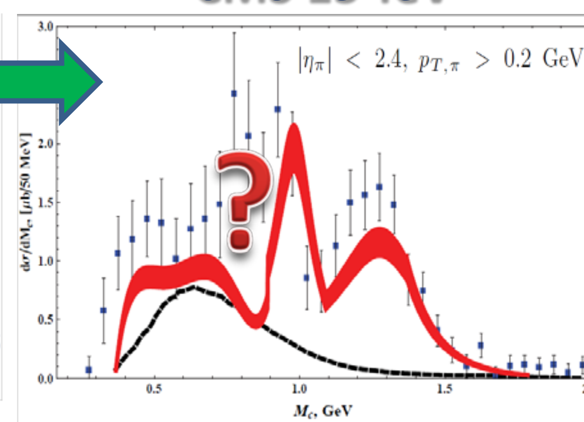




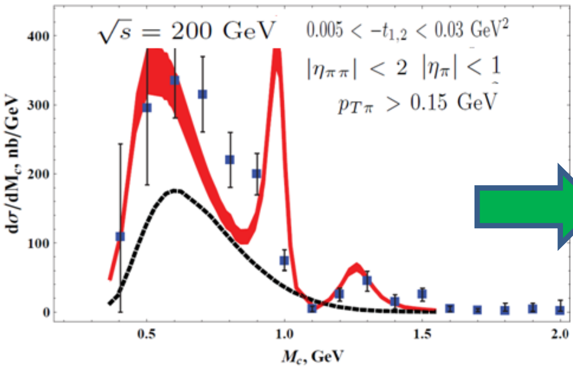
CDF 1.96 TeV



CMS 13 TeV



Results for di-pion production



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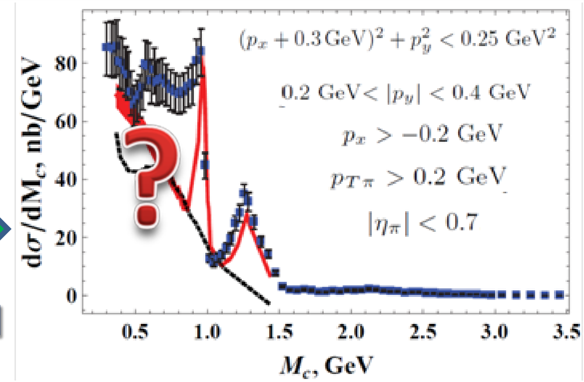
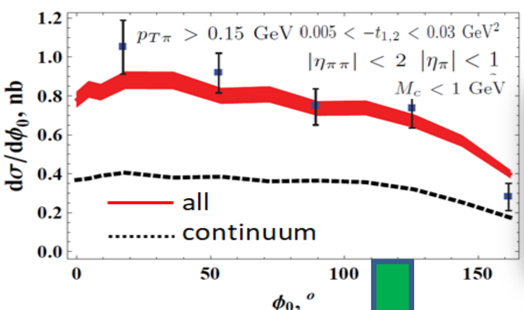
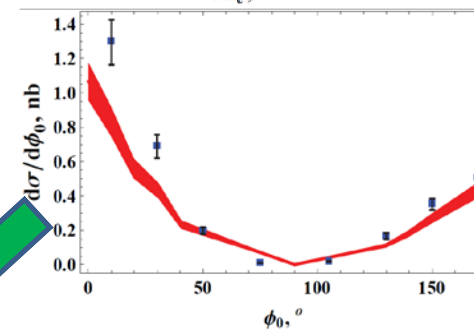


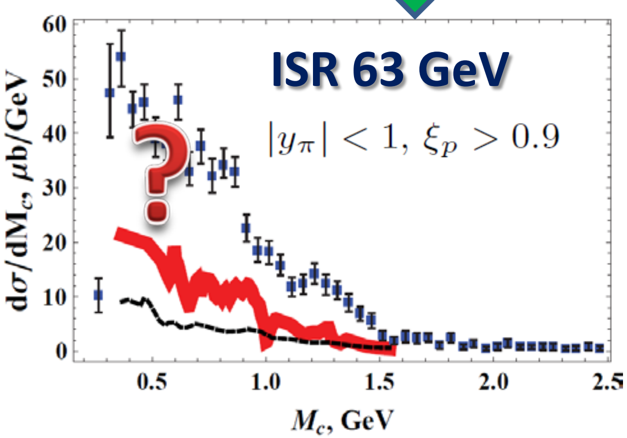
vertex functions = const



? **dσ /dM, M ~ 0.6-0.8 GeV**

ISR: Theor./Exp.~ 1/3





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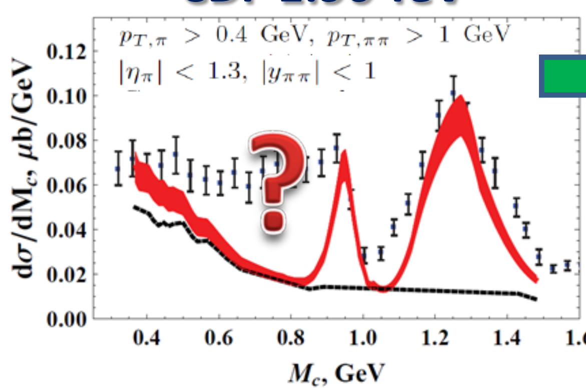
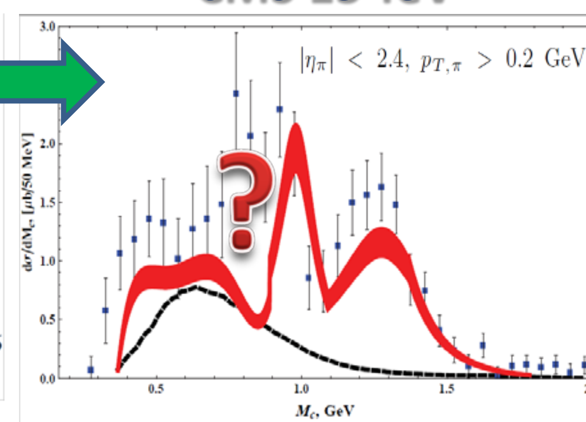
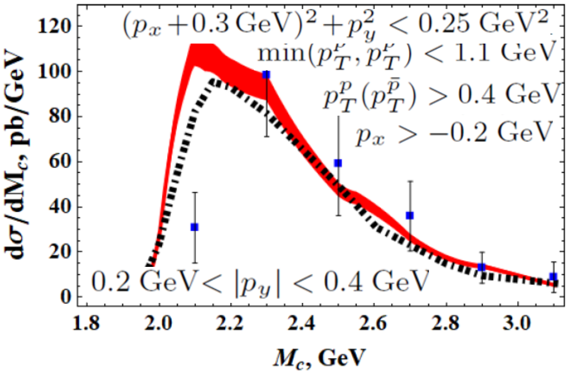


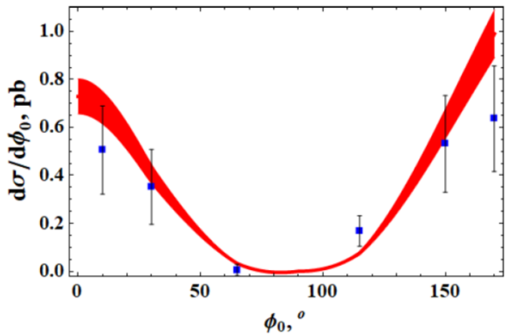
CMS 13 TeV



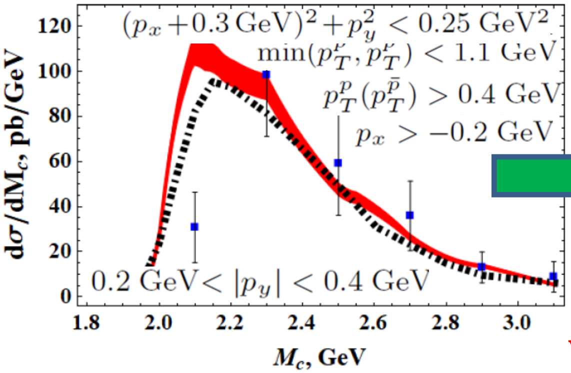
Results for p pbar production

STAR 200 GeV





Results for p pbar production

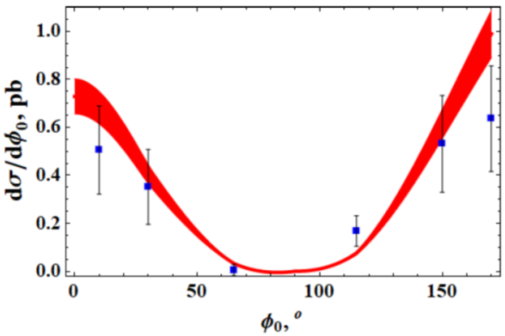


STAR 200 GeV

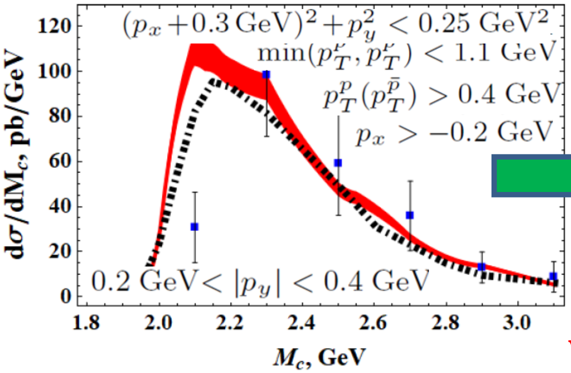
Λ_p =1.12 GeV

$$g_{\mathbb{PP}f_0(2100)} = 0.64,$$
$$g_{p\bar{p}f_0(2100)} = 3.0,$$

vertex functions = const
"scalar" proton



Results for p pbar production



STAR 200 GeV

Λ_p =1.12 GeV

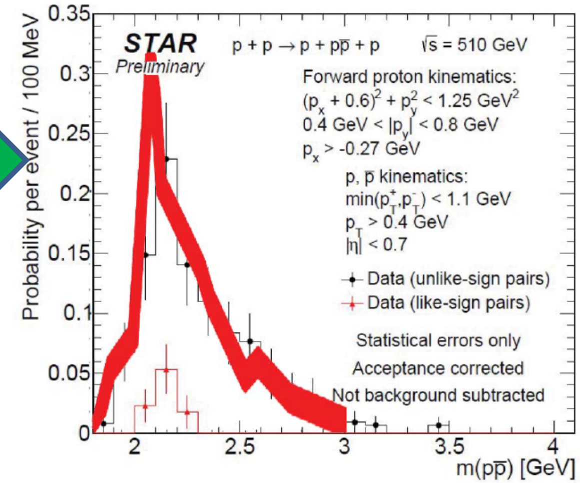
$g_{\mathbb{P}\mathbb{P}f_0(2100)}=0.64,$

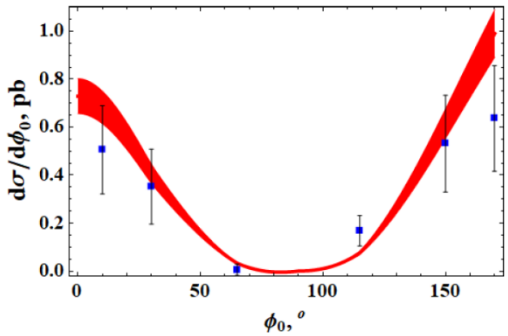
$g_{p\bar{p}f_0(2100)}=3.0,$

vertex functions = const

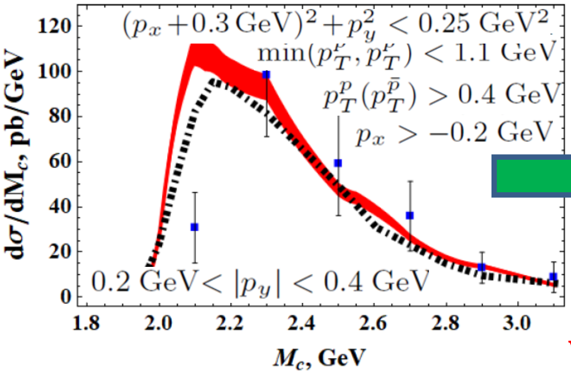
“scalar” proton

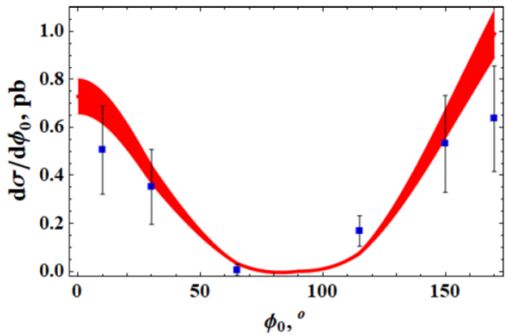
STAR 510 GeV





Results for p pbar production





STAR 200 GeV

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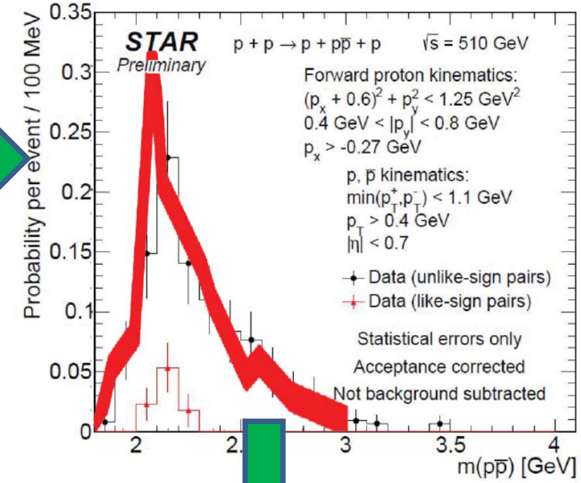
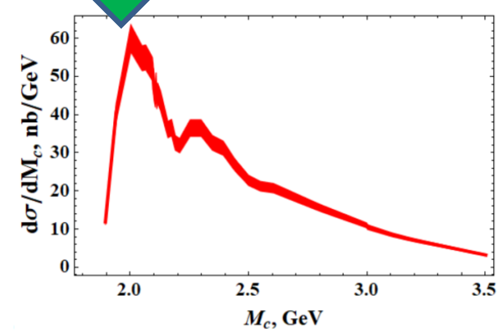
“scalar” proton

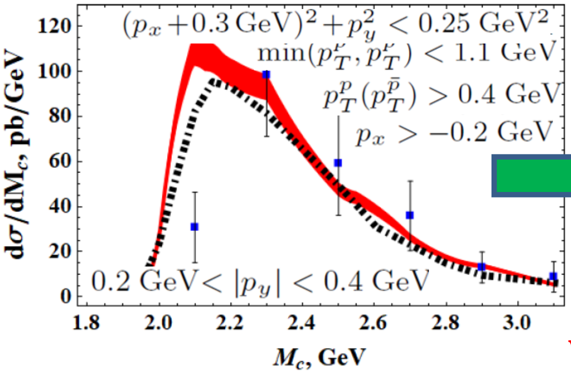
STAR 510 GeV



CMS 13 TeV



Results for p pbar production



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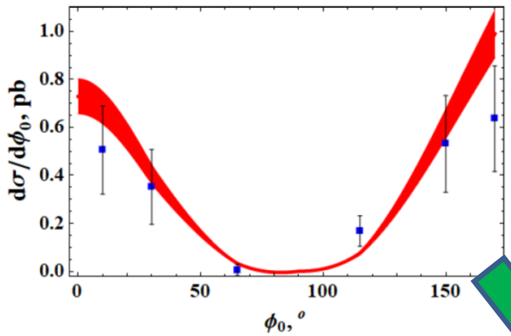
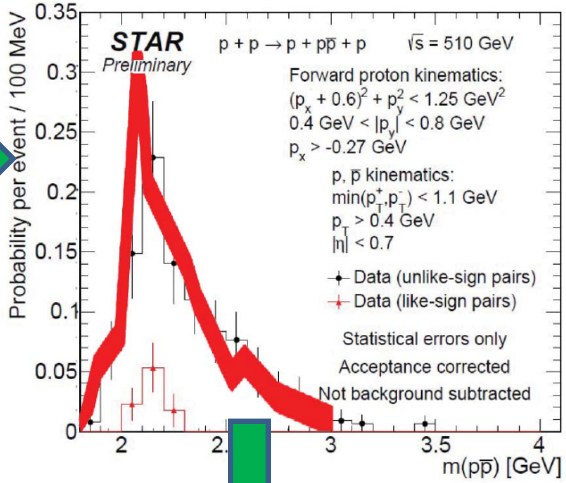


STAR 510 GeV



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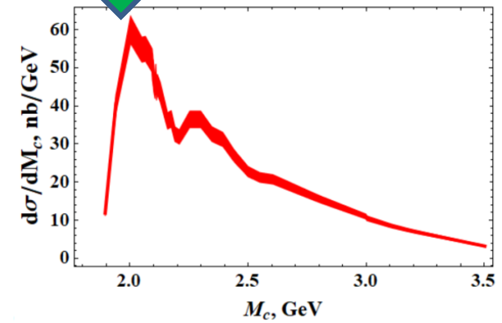
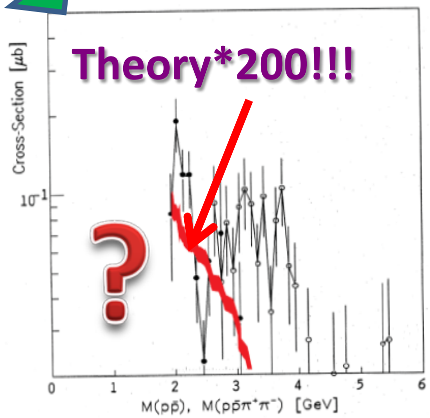


ISR 62 GeV



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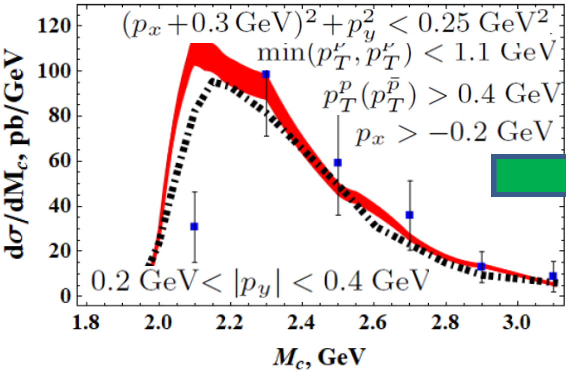

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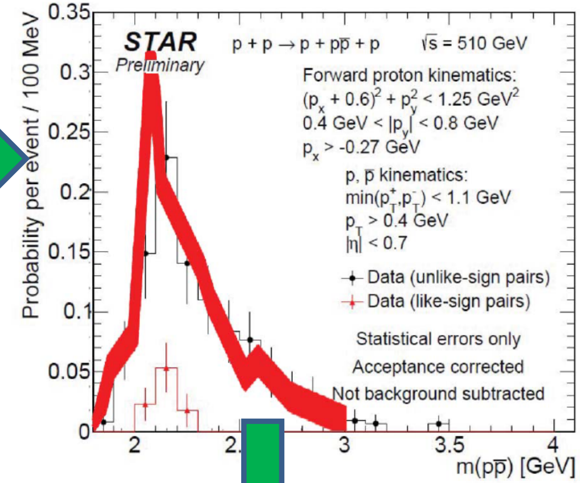

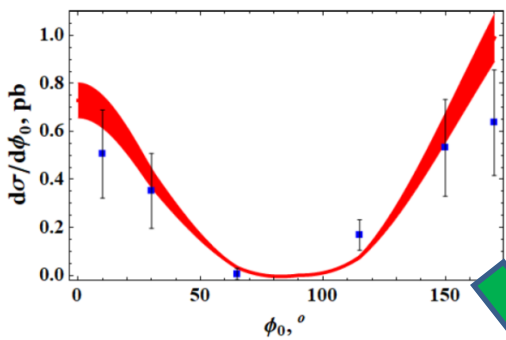

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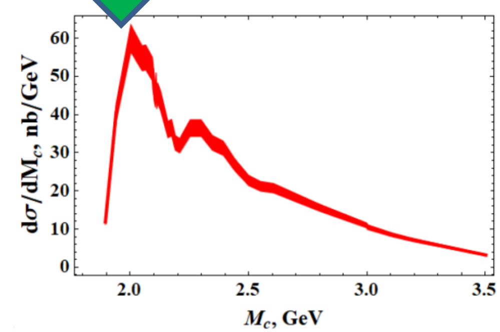
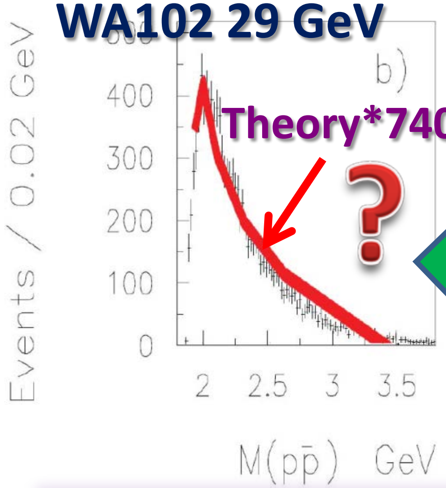


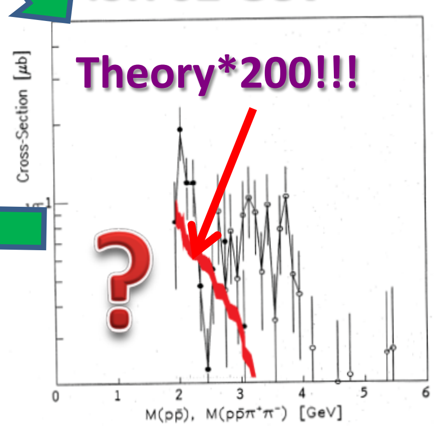
WA102 29 GeV

Theory*740!!!



ISR 62 GeV

Theory*200!!!



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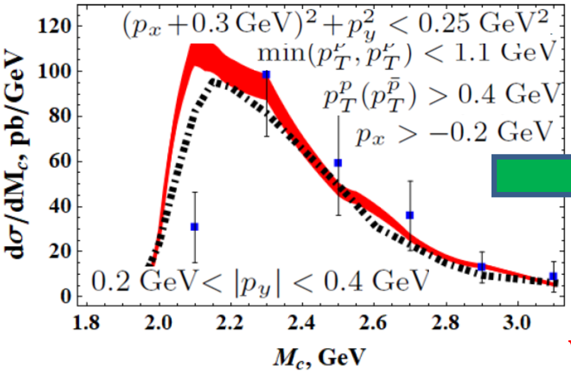

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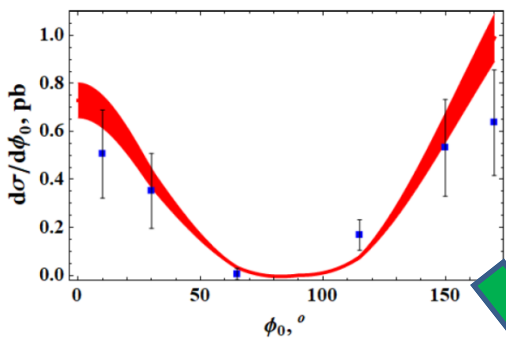

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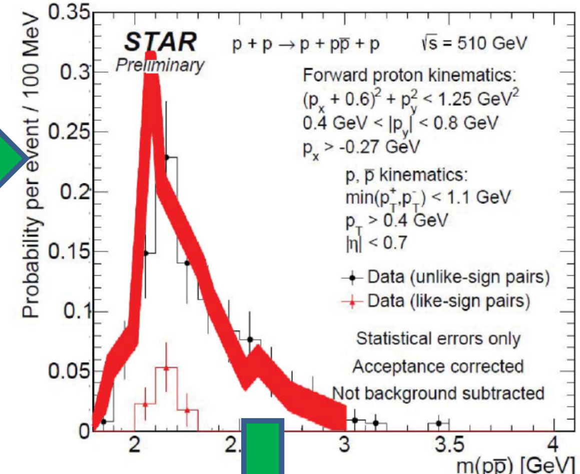

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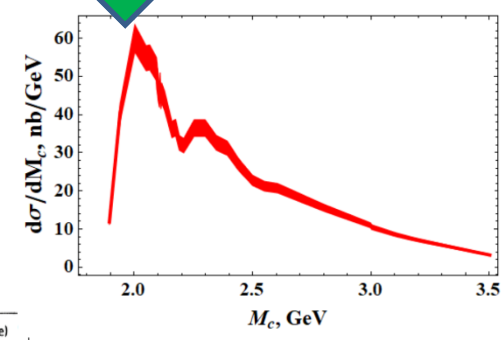

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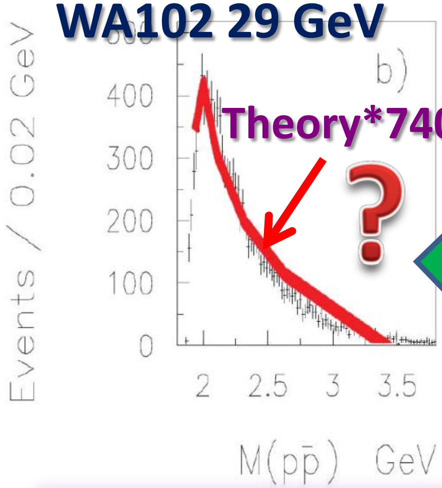

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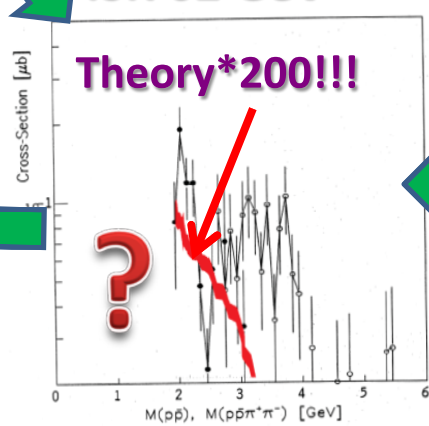

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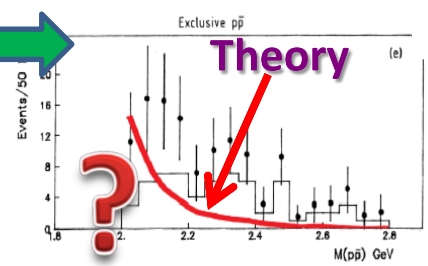

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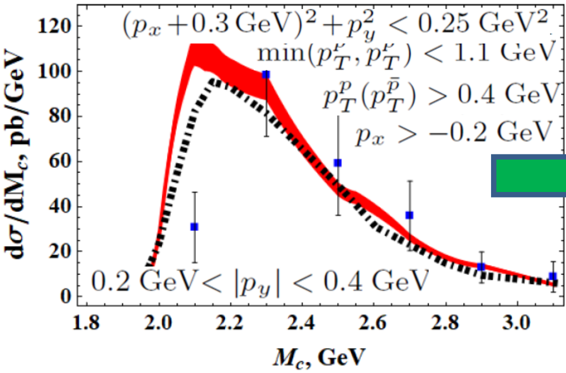

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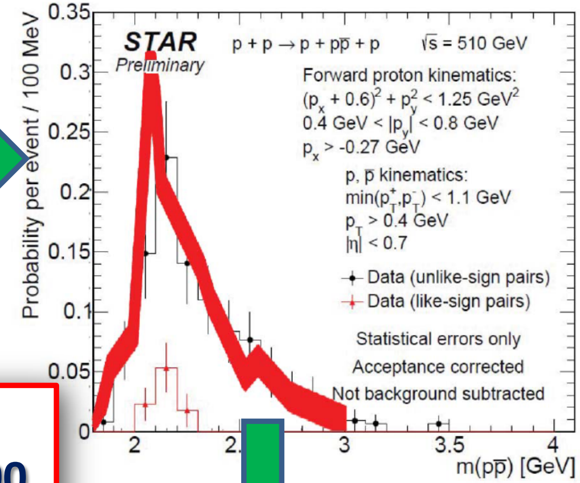

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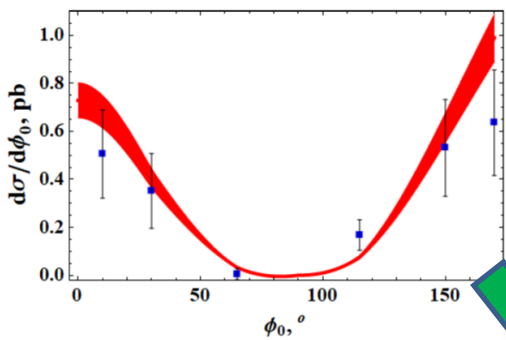

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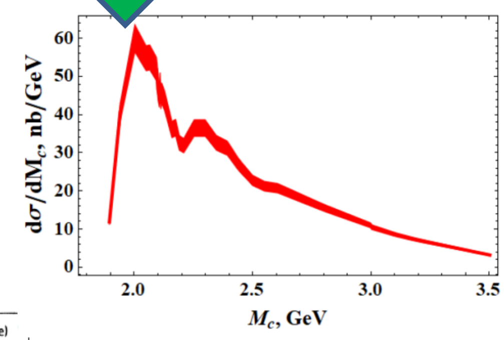
CMS 13 TeV



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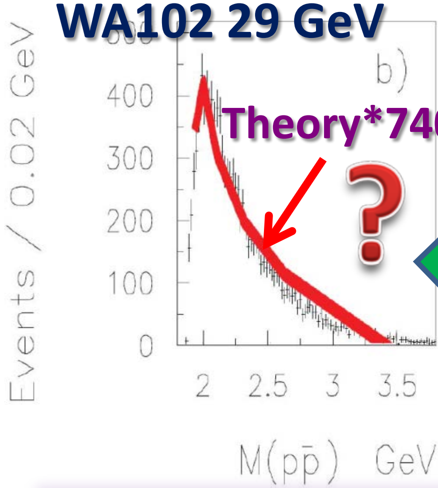

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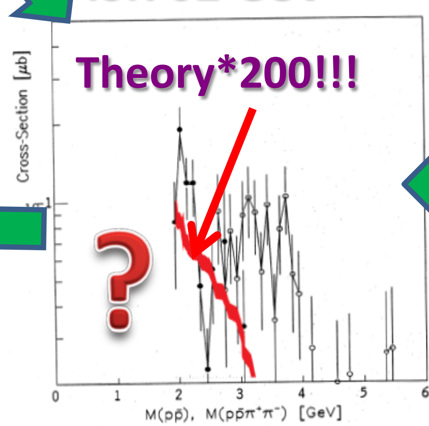

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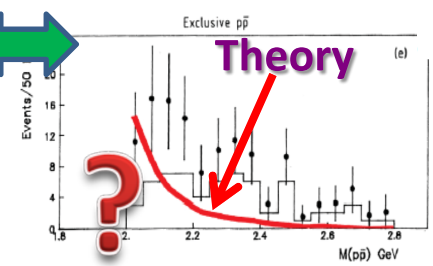

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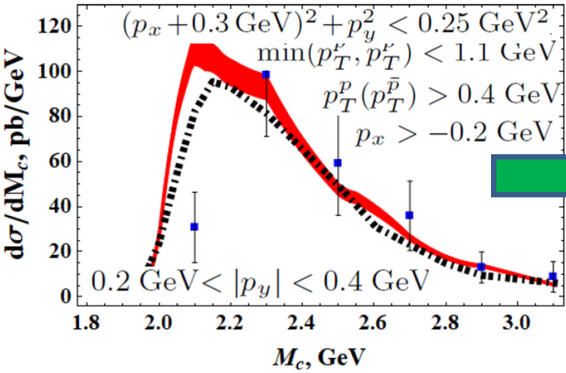

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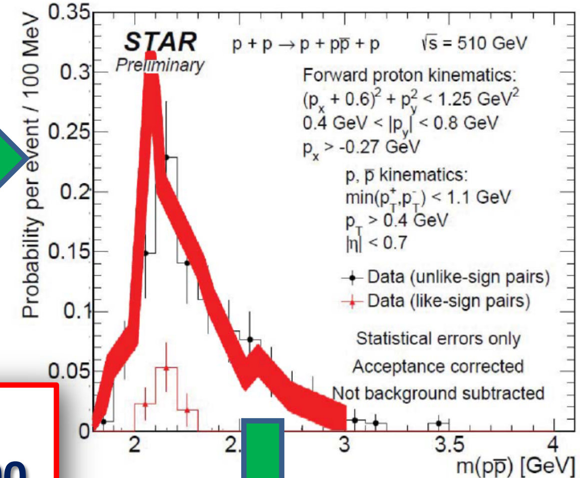

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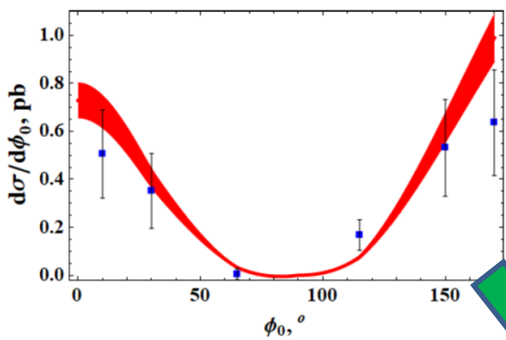

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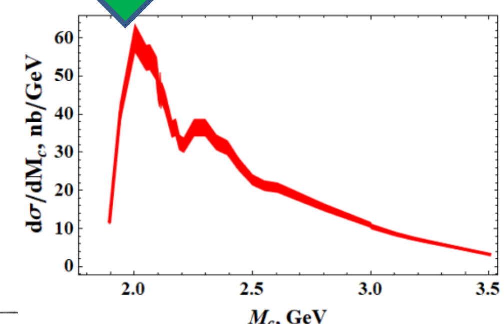

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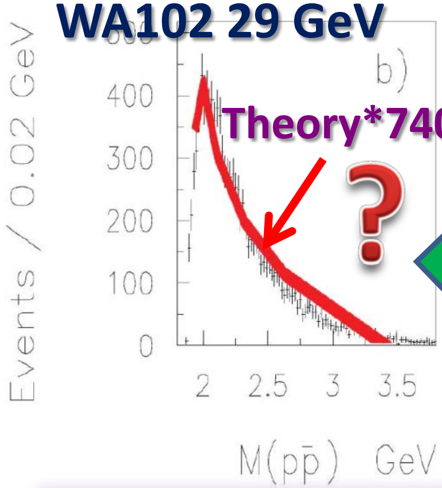

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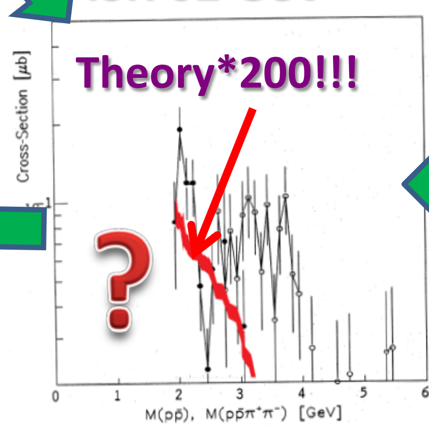

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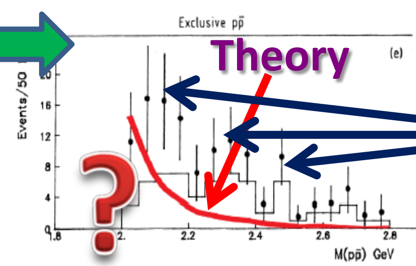

Resonances amplification?

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• *wrong normalization of the data, missed contributions from some other processes like low mass difractive dissociation, interference with gamma gamma and gamma Odderon processes*
• *effects related to the irrelevance and possible modifications of the Regge approach (off-shell hadron form-factor)*

[R.A. Ryutin, *Central exclusive diffractive production of two pions from continuum and resonance decay in the Regge-eikonal model*, **Eur. Phys. J. C 83, 172 (2023)]**
[R.A. Ryutin, *Central exclusive diffractive p pbar production in the Regge-eikonal model in the "scalar" proton approximation*, **Eur. Phys. J. C 83, 647 (2023)]**

THANK YOU!