Searching for an extra neutral gauge boson from muon pair production at LHC

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Motivações

- Modelo Padrão $SU(3)_c x SU(2)_L x U(1)_{em}$
- Afinidade das previsões do MP com os experimentos

  redução das incertezas nas medidas dos observáveis
- Validade testada para energias $\approx$ GeV

mas...

A conferir

- Mecanismo de geração das massas (Higgs / algo equivalente),
- espectro das massas,
- número de famílias (= 3),
- matéria escura **(80% Universo)**
- supersimetria

Dados experimentais

- UA1/UA2 (p anti p) $\sqrt{s} \approx 550$ GeV
- SLD ($e^+ e^-$) polarizados $\sqrt{s} \approx 90$ GeV
- LEP ($e^+ e^-$) 90 GeV < $\sqrt{s}$ < 200 GeV
- Tevatron (p anti p) 1.0 TeV < $\sqrt{s}$ < 1.9 TeV
- DESY (e^-/e^+ p) $\sqrt{s} \approx 300$ GeV

(27.5 GeV & 920 GeV)

PDG [1] dados experimentais das propriedades da particulas: massa, spin, ...

Z

$J = 1$

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Z MASS

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The Z boson" and ref. LEP-SLC 06). The fit is performed using the Z mass and width, the Z hadronic pole cross section, the ratios of hadronic to leptonic partial widths, and the Z pole forward-backward lepton asymmetries. This set is believed to be most free of correlations.

The Z-boson mass listed here corresponds to the mass parameter in a Breit-Wigner distribution with mass dependent width. The value is 34 MeV greater than the real part of the position of the pole (in the energy-squared plane) in the Z-boson propagator. Also the LEP experiments have generally assumed a fixed value of the $\gamma - Z$ interferences term based on the standard model. Keeping this term as free parameter leads to a somewhat larger error on the fitted Z mass. See ACCIARRI 00Q and ABBIENDI 04G for a detailed investigation of both these issues.

VALUE (GeV)	EVTS	DOCUMENT ID		TECN	COMMENT
91.1876±0.0021 OUR FIT					
91.1852±0.0030	4.57M	[1] ABBIENDI	01A	OPAL	E^{ee}_{cm}= 88–94 GeV
91.1863±0.0028	4.08M	[2] ABREU	00F	DLPH	E^{ee}_{cm}= 88–94 GeV
91.1898±0.0031	3.96M	[3] ACCIARRI	00C	L3	E^{ee}_{cm}= 88–94 GeV
91.1885±0.0031	4.57M	[4] BARATE	00C	ALEP	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
91.1872±0.0033		[5] ABBIENDI	04G	OPAL	E^{ee}_{cm}= LEP1 + 130–209 GeV
91.272 ±0.032 ±0.033		[6] ACHARD	04C	L3	E^{ee}_{cm}= 183–209 GeV
91.1875±0.0039	3.97M	[7] ACCIARRI	00Q	L3	E^{ee}_{cm}= LEP1 + 130–189 GeV
91.151 ±0.008		[8] MIYABAYASHI	95	TOPZ	E^{ee}_{cm}= 57.8 GeV
91.74 ±0.28 ±0.93	156	[9] ALITTI	92B	UA2	$E^{p\bar{p}}_{cm}$= 630 GeV
90.9 ±0.3 ±0.2	188	[10] ABE	89C	CDF	$E^{p\bar{p}}_{cm}$= 1.8 TeV
91.14 ±0.12	480	[11] ABRAMS	89B	MRK2	E^{ee}_{cm}= 89–93 GeV
93.1 ±1.0 ±3.0	24	[12] ALBAJAR	89	UA1	$E^{p\bar{p}}_{cm}$= 546,630 GeV

[1] ABBIENDI 01A error includes approximately 2.3 MeV due to statistics and 1.8 MeV due to LEP energy uncertainty.
[2] The error includes 1.6 MeV due to LEP energy uncertainty.
[3] The error includes 1.8 MeV due to LEP energy uncertainty.
[4] BARATE 00C error includes approximately 2.4 MeV due to statistics, 0.2 MeV due to experimental systematics, and 1.7 MeV due to LEP energy uncertainty.
[5] ABBIENDI 04G obtain this result using the S–matrix formalism for a combined fit to their cross section and asymmetry data at the Z peak and their data at 130–209 GeV. The authors have corrected the measurement for the 34 MeV shift with respect to the Breit–Wigner fits.

Nova Física

- Um novo Z'
- Novos Higgs's (neutros, carregados,...)
- Novos bosons carregados
- Oscilação de neutrinos (Dirac/Majorana)
- Processo com violação de números leptônicos (Majorana)
- Energia escura & matéria escura
- Aumento do regime de energia → 2010/2011

PDG reserva espaço para a Nova Física

Nos experimentos extraimos limites de observáveis associados às partículas, que ainda não foram observadas ...

Higgs Bosons — H^0 and $H^\pm$, Searches for

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STANDARD MODEL H^0 (Higgs Boson) MASS LIMITS

These limits apply to the Higgs boson of the three-generation Standard Model with the minimal Higgs sector. For a review and a bibliography, see the Note above on "Searches for Higgs Bosons."

H^0 Direct Search Limits

Limits on the Standard Model Higgs obtained from the study of Z^0 decays rule out conclusively its existence in the whole mass region $m_{H^0} \lesssim 60$ GeV. These limits, as well as stronger limits obtained from e^+e^- collisions at LEP at energies up to 202 GeV, and weaker limits obtained from other sources, have been superseded by the more recent data of LEP. They have been removed from this compilation, and are documented in previous editions of this Review of Particle Physics. The same holds for limits obtained from $p\overline{p}$ collisions at the Tevatron that have been superseded by more recent results incorporating a larger integrated luminosity.

In this Section, unless otherwise stated, limits from the four LEP experiments (ALEPH, DELPHI, L3, and OPAL) are obtained from the study of the $e^+e^- \to H^0 Z$ process, at center-of-mass energies reported in the comment lines.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
>114.1	95	[1] ABDALLAH	04	DLPH	$E_{cm} \leq 209$ GeV
>112.7	95	[1] ABBIENDI	03B	OPAL	$E_{cm} \leq 209$ GeV
>114.4	95	[1,2] HEISTER	03D	LEP	$E_{cm} \leq 209$ GeV
>111.5	95	[1,3] HEISTER	02	ALEP	$E_{cm} \leq 209$ GeV
>112.0	95	[1] ACHARD	01C	L3	$E_{cm} \leq 209$ GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
		[4] AALTONEN	09A	CDF	$p\overline{p} \to H^0 X$, $H^0 \to W W^{(*)}$
		[5] ABAZOV	09C	D0	$p\overline{p} \to H^0 W X$
		[6] AALTONEN	08AF	CDF	$p\overline{p} \to H^0 Z X$
		[7] AALTONEN	08V	CDF	$p\overline{p} \to H^0 W X$
		[8] AALTONEN	08X	CDF	$p\overline{p} \to H^0 Z X$, $H^0 W X$
		[9] ABAZOV	08AO	D0	$p\overline{p} \to H^0 Z X$, $H^0 W X$
		[10] ABAZOV	08Y	D0	$p\overline{p} \to H^0 W X$
		[11] ABAZOV	07X	D0	$p\overline{p} \to H^0 Z X$
		[12] ABAZOV	06	D0	$p\overline{p} \to H^0 X$, $H^0 \to W W^*$
		[13] ABAZOV	06O	D0	$p\overline{p} \to H^0 W X$, $H^0 \to W W^*$

[1] Search for $e^+e^- \to H^0 Z$ in the final states $H^0 \to b\overline{b}$ with $Z \to \ell\overline{\ell}, \nu\overline{\nu}, q\overline{q}, \tau^+\tau^-$ and $H^0 \to \tau^+\tau^-$ with $Z \to q\overline{q}$.

[2] Combination of the results of all LEP experiments.

[3] A 3σ excess of candidate events compatible with m_{H^0} near 114 GeV is observed in the combined channels $q\overline{q}q\overline{q}$, $q\overline{q}\ell\overline{\ell}$, $q\overline{q}\tau^+\tau^-$.

[46] AQUINO 91 limits obtained from neutron lifetime and asymmetries together with unitarity of the CKM matrix. Manifest left-right asymmetry is assumed.
[47] BARBIERI 89B limit holds for $m_{\nu_R} \leq 10$ MeV.
[48] First JODIDIO 86 result assumes $m_{W_R}=\infty$, second is for unconstrained m_{W_R}.

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MASS LIMITS for Z' (Heavy Neutral Vector Boson Other Than Z)

Limits for Z'_{SM}

Z'_{SM} is assumed to have couplings with quarks and leptons which are identical to those of Z, and decays only to known fermions.

VALUE (GeV)	CL%	DOCUMENT ID		TECN	COMMENT
> 923	95	[49] AALTONEN	07H	CDF	$p\overline{p}$, $Z'_{SM} \rightarrow e^+e^-$
>1305	95	[50] ABDALLAH	06C	DLPH	e^+e^-
>1500	95	[51] CHEUNG	01B	RVUE	Electroweak
• • • We do not use the following data for averages, fits, limits, etc. • • •					
> 850		[52] ABULENCIA	06L	CDF	Repl. by AALTONEN 07H
> 825	95	[53] ABULENCIA	05A	CDF	$p\overline{p}$; $Z'_{SM} \rightarrow e^+e^-$, $\mu^+\mu^-$
> 399	95	[54] ACOSTA	05R	CDF	$\overline{p}p$: $Z'_{SM} \rightarrow \tau^+\tau^-$
none 400–640	95	ABAZOV	04C	D0	$p\overline{p}$: $Z'_{SM} \rightarrow q\overline{q}$
>1018	95	[55] ABBIENDI	04G	OPAL	e^+e^-
> 670	95	[56] ABAZOV	01B	D0	$p\overline{p}$, $Z'_{SM} \rightarrow e^+e^-$
> 710	95	[57] ABREU	00S	DLPH	e^+e^-
> 898	95	[58] BARATE	00I	ALEP	e^+e^-
> 809	95	[59] ERLER	99	RVUE	Electroweak
> 690	95	[60] ABE	97S	CDF	$p\overline{p}$; $Z'_{SM} \rightarrow e^+e^-$, $\mu^+\mu^-$
> 490	95	ABACHI	96D	D0	$p\overline{p}$; $Z'_{SM} \rightarrow e^+e^-$
> 398	95	[61] VILAIN	94B	CHM2	$\nu_\mu e \rightarrow \nu_\mu e$ and $\overline{\nu}_\mu e \rightarrow \overline{\nu}_\mu e$
> 237	90	[62] ALITTI	93	UA2	$p\overline{p}$; $Z'_{SM} \rightarrow q\overline{q}$
none 260–600	95	[63] RIZZO	93	RVUE	$p\overline{p}$; $Z'_{SM} \rightarrow q\overline{q}$
> 426	90	[64] ABE	90F	VNS	e^+e^-

[49] AALTONEN 07H search for resonances decaying to e^+e^- in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV.
[50] ABDALLAH 06C use data $\sqrt{s}$ = 130–207 GeV.
[51] CHEUNG 01B limit is derived from bounds on contact interactions in a global electroweak analysis.
[52] ABULENCIA 06L search for resonances decaying to e^+e^- in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV.
[53] ABULENCIA 05A search for resonances decaying to electron or muon pairs in $p\overline{p}$ collisions at $\sqrt{s}$ = 1.96 TeV.
[54] ACOSTA 05R search for resonances decaying to tau lepton pairs in $\overline{p}p$ collisions at $\sqrt{s}$ = 1.96 TeV.
[55] ABBIENDI 04G give 95% CL limit on Z-Z' mixing $-0.00422 < \theta < 0.00091$. $\sqrt{s}$ = 91 to 207 GeV.
[56] ABAZOV 01B search for resonances in $p\overline{p} \rightarrow e^+e^-$ at $\sqrt{s}$=1.8 TeV. They find $\sigma \cdot$ B($Z' \rightarrow ee$)< 0.06 pb for $M_{Z'} >$ 500 GeV.

Z prime

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Extra gauge bosons

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Transição da era do MP

- LHC (Large Hadron Collider)

  colisões entre feixes de protons

  detectores: ATLAS, CMS, LHCb, ALICE

  2010 $E_{CM} \rightarrow$ 7 TeV (3.5 x 3.5) & 1 $fb^{-1} \leftarrow$ *Luminosidade*

  2014 $E_{CM} \rightarrow$ 14 TeV (7 x 7) & 100 $fb^{-1} \leftarrow$ *Luminosidade*

- Linear collider ILC (2013) / CLIC (2017)

  colisões entre electrons e positrons

  $E_{CM} \rightarrow$ 500 GeV a 2 TeV & 100 $fb^{-1} \leftarrow$ *Luminosidade*

- confirmação da existência Z' (efeitos interferência)
- medidas mais precisas

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Antes dos dados experimentais do LHC

- Continuar a testar o MP
- Formular modelos alternativos ou extensões.

⇩

aumento dos grupos → mais estados físicos, misturas entre eles … (Nova Física / Exótica)

Modelos contendo Z'

- 3-3-1 models [2]
- Little Higgs model [3]
- Left-right symmetric models [4]
- Superstring inspired E_6 [5]
- Modelos com dimensões extra (excitações Kaluza-Klein de bosons de gauge neutros) [6]

com a fenomenologia ≈ a do MP na escala GeV

Características Z'

- Massa > 600 GeV
- Largura (2 GeV < Γ< .... GeV)

  → par de leptons, quarks, bosons de gauge,...
- Leptofóbico ou leptofílico
- Assimetrias (natureza axial)
- Distribuições dos produtos finais (influências do Z')

$$\mathcal{L}^{NC} = -\frac{g}{2\cos\theta_W}\sum_f \left[\bar{f}\,\gamma^\mu\,(g_V + g_A\gamma^5) f\, Z_\mu + \bar{f}\,\gamma^\mu\,(g'_V + g'_A\gamma^5) f\, Z'_\mu\right]$$

	3-3-1 MIN		3-3-1 RHN	
	g'_V	g'_A	g'_V	g'_A
$Z'\bar{l}l$	$-\frac{\sqrt{3}}{2}\sqrt{1-4\sin^2\theta_W}$	$\frac{\sqrt{3}}{6}\sqrt{1-4\sin^2\theta_W}$	$\frac{-1+4\sin^2\theta_W}{2\sqrt{3-4\sin^2\theta_W}}$	$-\frac{1}{2\sqrt{3-4\sin^2\theta_W}}$
$Z'\bar{u}u$	$-\frac{1+4\sin^2\theta_W}{2\sqrt{3-12\sin^2\theta_W}}$	$\frac{1}{\sqrt{3-12\sin^2\theta_W}}$	$\frac{3-8\sin^2\theta_W}{6\sqrt{3-4\sin^2\theta_W}}$	$-\frac{1}{2\sqrt{3-4\sin^2\theta_W}}$
$Z'\bar{d}d$	$\frac{1-2\sin^2\theta_W}{2\sqrt{3-12\sin^2\theta_W}}$	$-\frac{1+2\sin^2\theta_W}{2\sqrt{3-12\sin^2\theta_W}}$	$\frac{3-2\sin^2\theta_W}{6\sqrt{3-4\sin^2\theta_W}}$	$-\frac{\sqrt{3-4\sin^2\theta_W}}{6}$

	Sym L-R		$E_6-\chi$	
	g'_V	g'_A	g'_V	g'_A
$Z'\bar{l}l$	$\frac{-1+4\sin^2\theta_W}{2\sqrt{\cos^2\theta_W-\sin^2\theta_W}}$	$\frac{\sqrt{\cos^2\theta_W-\sin^2\theta_W}}{2}$	$\frac{2\sin\theta_W}{\sqrt{6}}$	$\frac{\sin\theta_W}{\sqrt{6}}$
$Z'\bar{u}u$	$\frac{3-8\sin^2\theta_W}{6\sqrt{\cos^2\theta_W-\sin^2\theta_W}}$	$-\frac{\sqrt{\cos^2\theta_W-\sin^2\theta_W}}{2}$	0	$\frac{\sin\theta_W}{\sqrt{6}}$
$Z'\bar{d}d$	$\frac{-3+4\sin^2\theta_W}{6\sqrt{\cos^2\theta_W-\sin^2\theta_W}}$	$\frac{\sqrt{\cos^2\theta_W-\sin^2\theta_W}}{2}$	$-\frac{2\sin\theta_W}{\sqrt{6}}$	$-\frac{\sin\theta_W}{\sqrt{6}}$

Fenomenologia do Z'

- Explorada no momento para a energia do LHC
- Indícios indiretos → decaimentos / efeitos interferência
- Dados de precisão (no polo /fora do polo de Z')
- Observação em processos com $\sqrt{s} > M_{Z'}$
- Decaimentos comparados com "background" do MP
- OBJETIVOS: limites nos parâmetros, separação de modelos, potencial de descoberta, ...

Trabalho

$p + p \rightarrow \mu^+ + \mu^- + X$

800 GeV < $M_{Z'}$ < 1200 GeV

Desempenho dos detetores / eliminação “background”

$\rightarrow$ cortes em variáveis

Cortes (CMS):
- massa invariante $M_{\mu\mu} > 500$ GeV
- pseudo rapidity $|\eta_\mu| \leq 2.5$
- $p_t > 20$ GeV

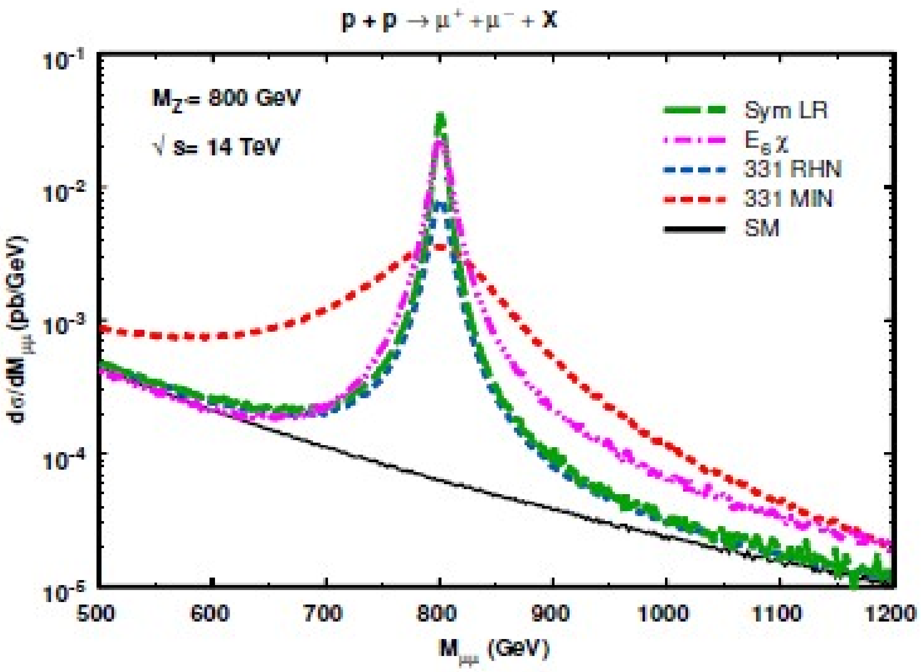
Comparação observáveis entre modelos (sensíveis à Nova Física):

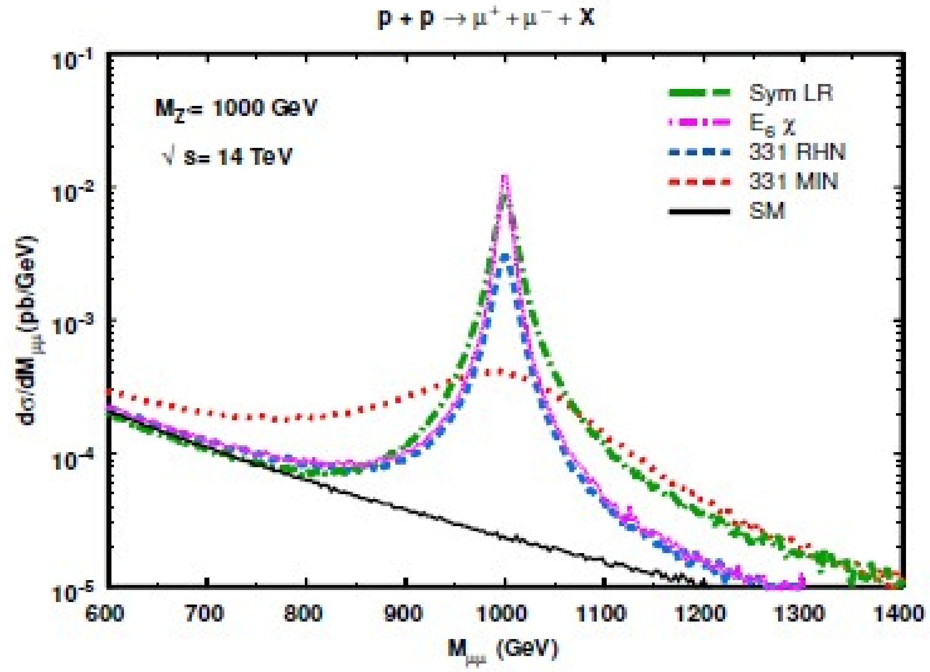
1- Distribuição em massa invariante

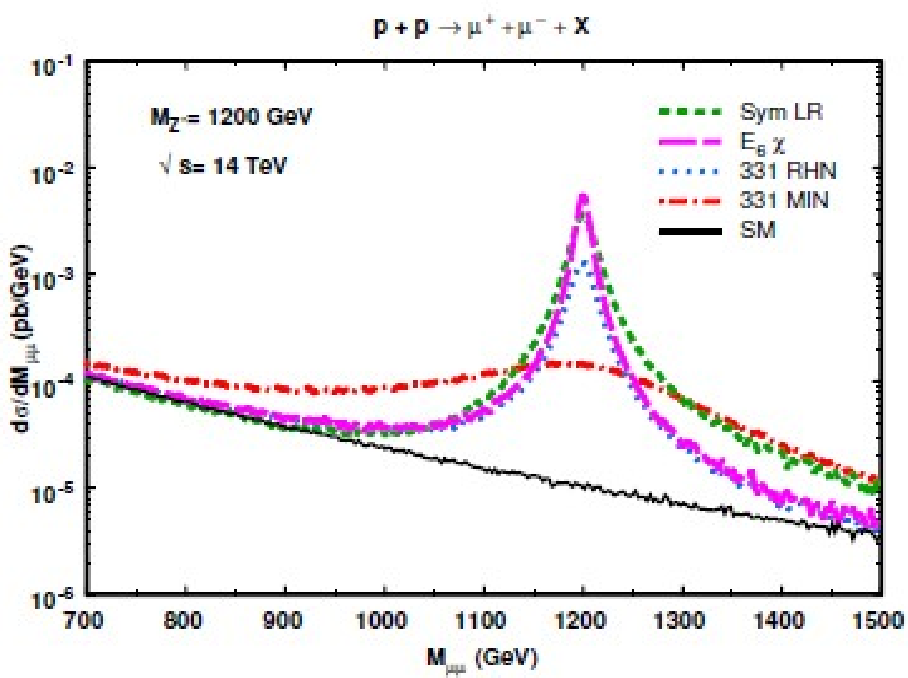
2- A_{FB}

3-Distribuição em momento transverso

(1–3: Comphep)







Massa invariante

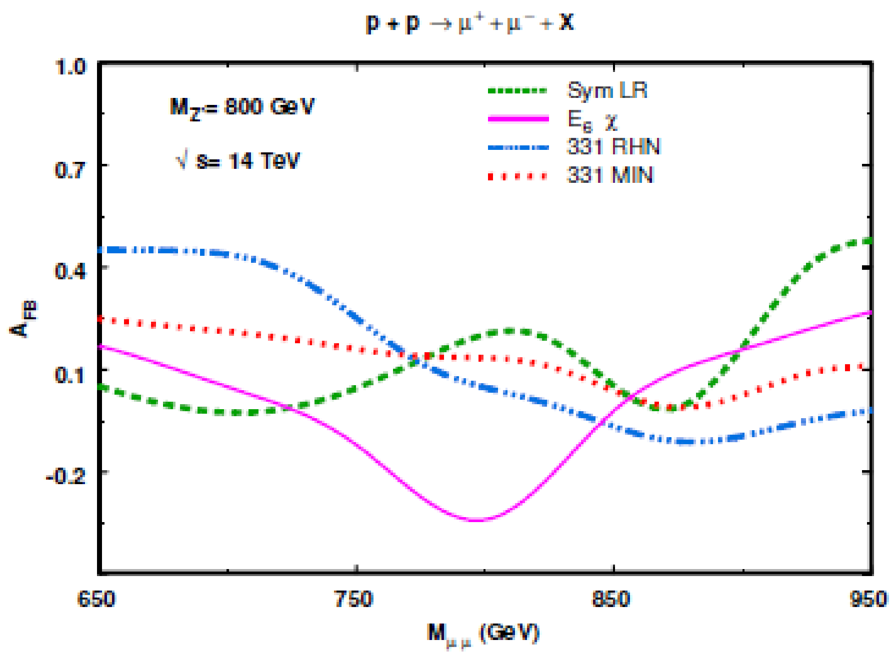
A_{FB}

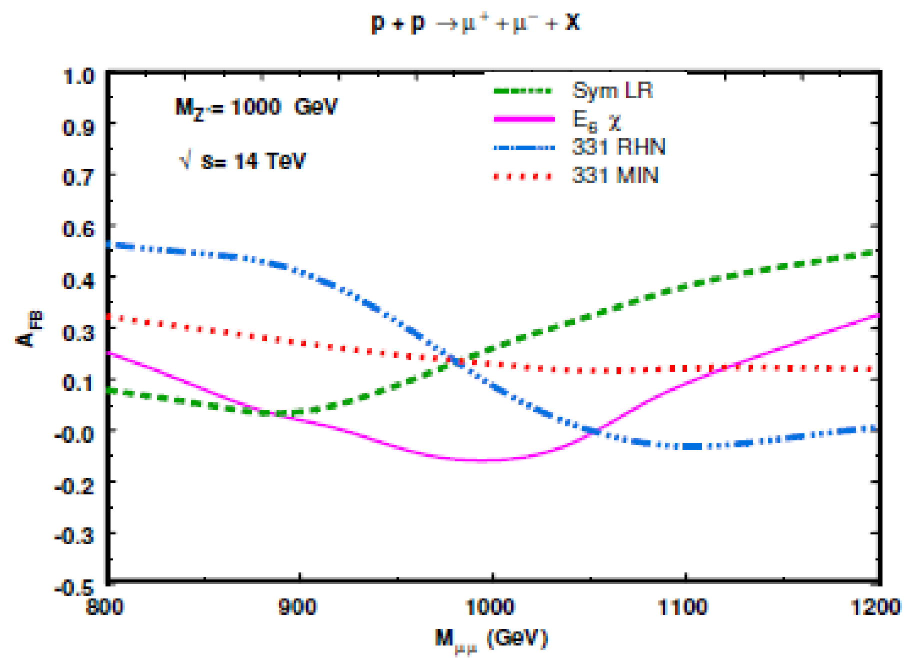
- Em colisões hadrônicas as direções originais dos quarks não são conhecidas
- As direções são extraidas da cinemática do par leptons, assim

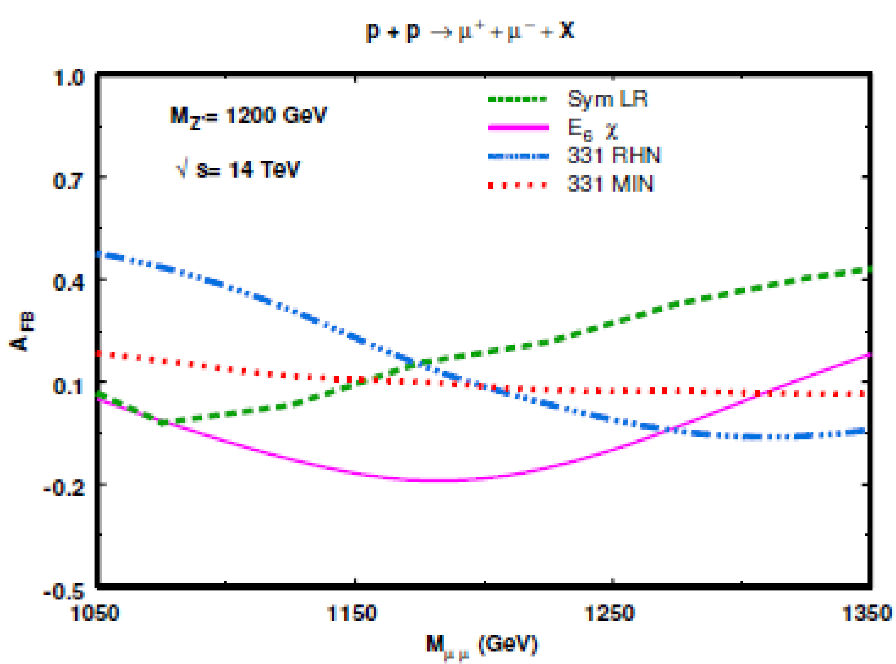
  a direção do quark $\approx$ direção do “boost” que conecta o sistema dimuon e o eixo do feixe

$\Longrightarrow$ Selecionamos dimuons com rapidity $|y_{\mu\mu}| > 0.8$

- A_{FB} (SM) $\approx$ 0.6
- A_{FB} x $M_{\mu\mu}$







A_{FB}

$|y_{\mu\mu}| > 0.8$

direção parton

Inicial

Distribuição de momento transverso

Dois polos na s_{elem} em M_Z e $M_{Z'}$ (ressonâncias)

Na mudança variável momento fermion → momento transverso fermion, o Jacobiano introduz o fator

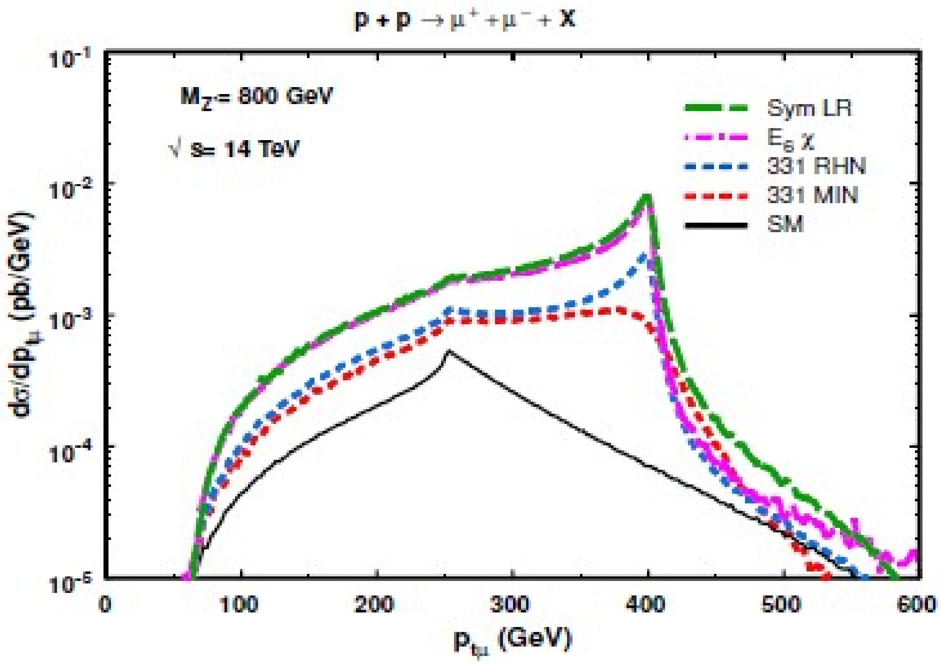
$$\sqrt{s/(s-p_T^2)}$$

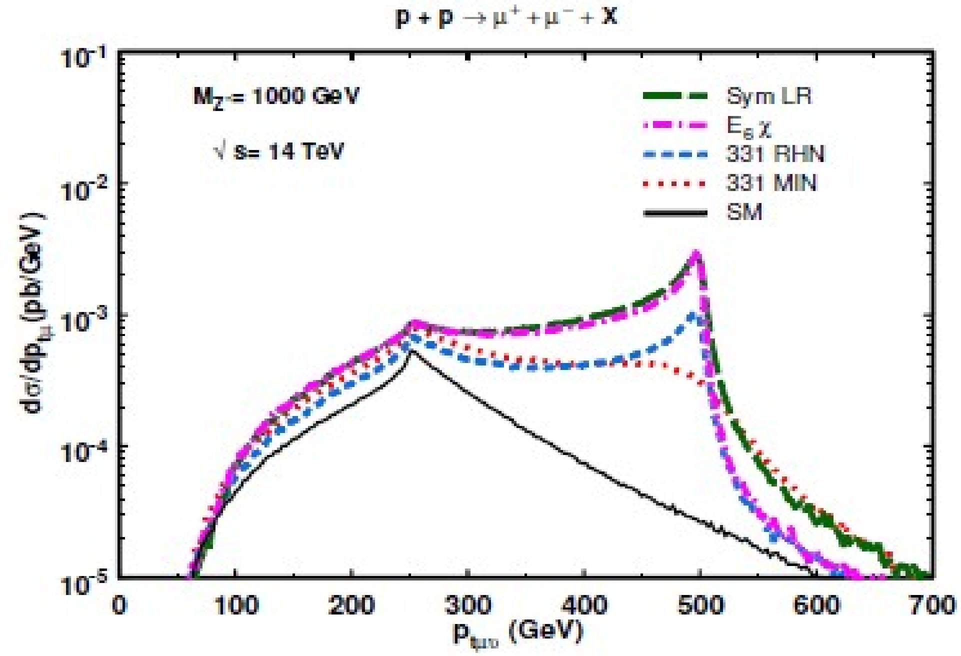
maior contribuição para distribuição p_t

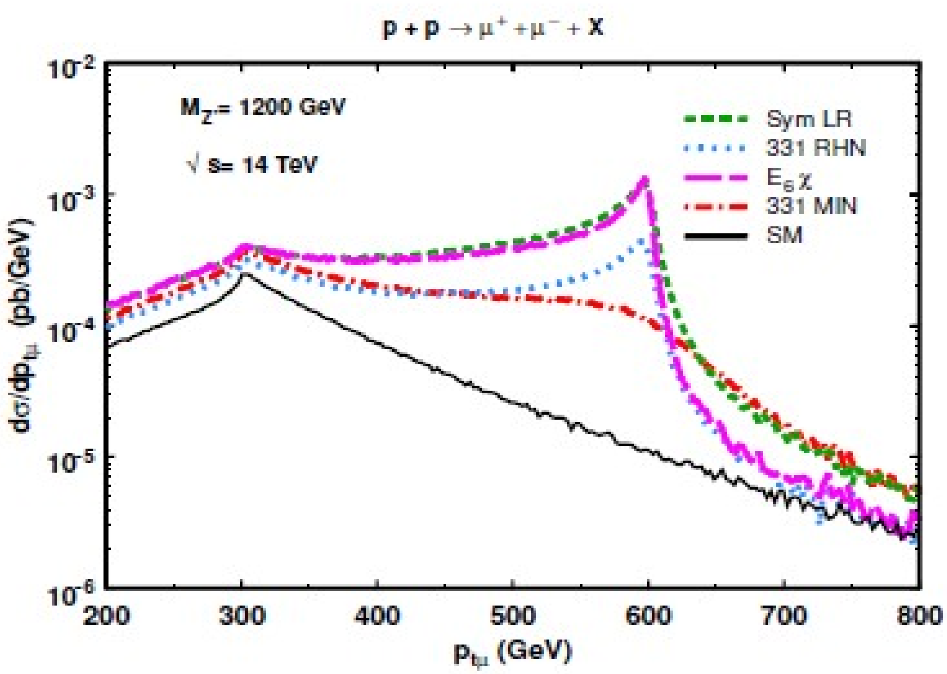
$$\sqrt{s_{elem}} \approx M_{Z,Z'}$$

máximo da distribuição em $p_t \approx M_{Z,Z'}/2$

® determinação da massa das ressonâncias

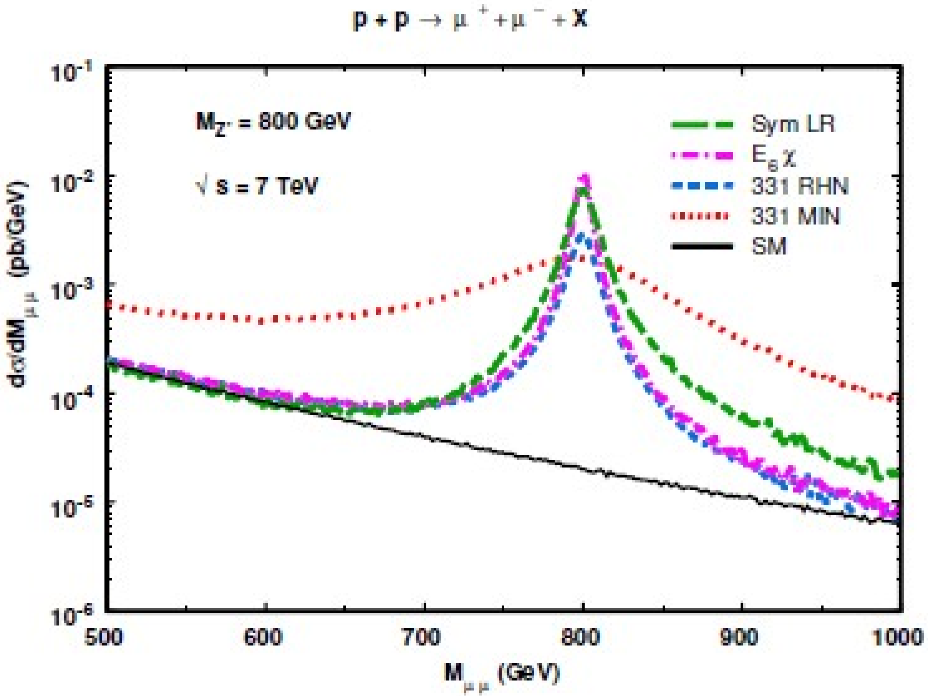


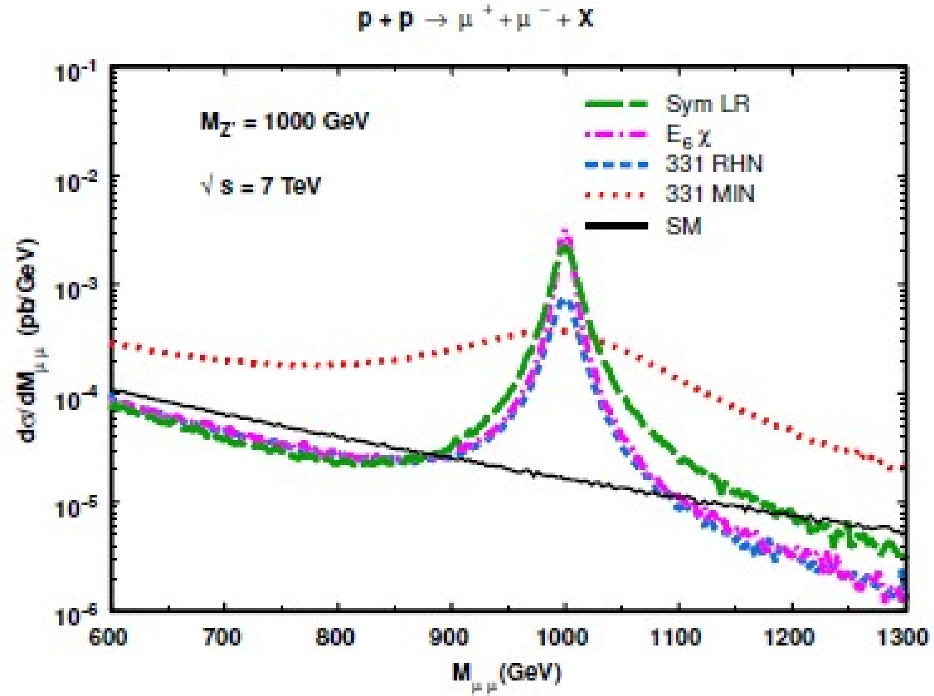


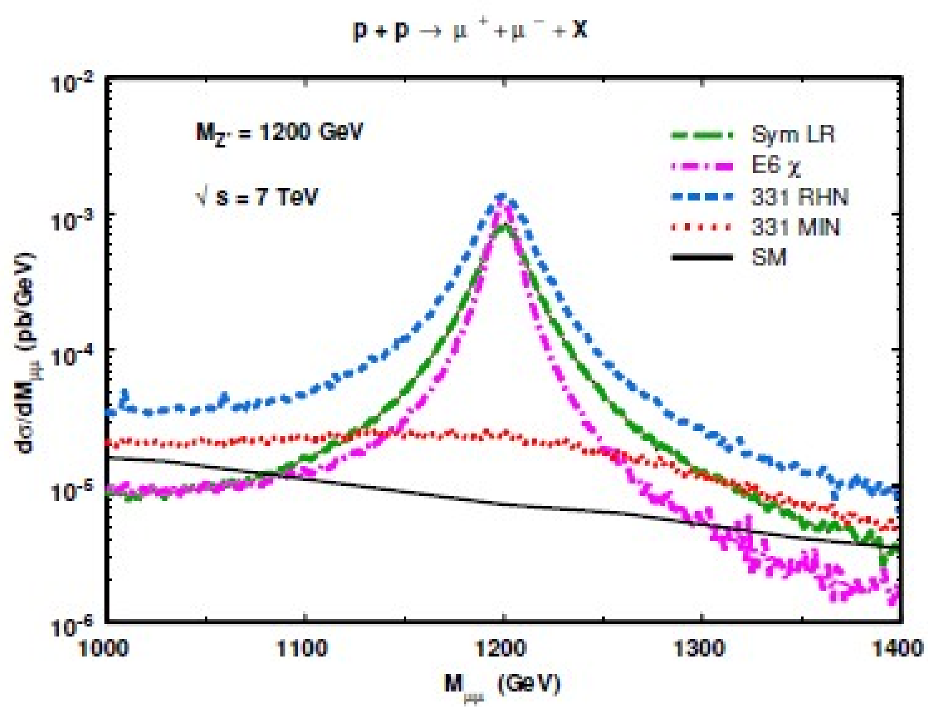


p_t

Pico do Jacobiano

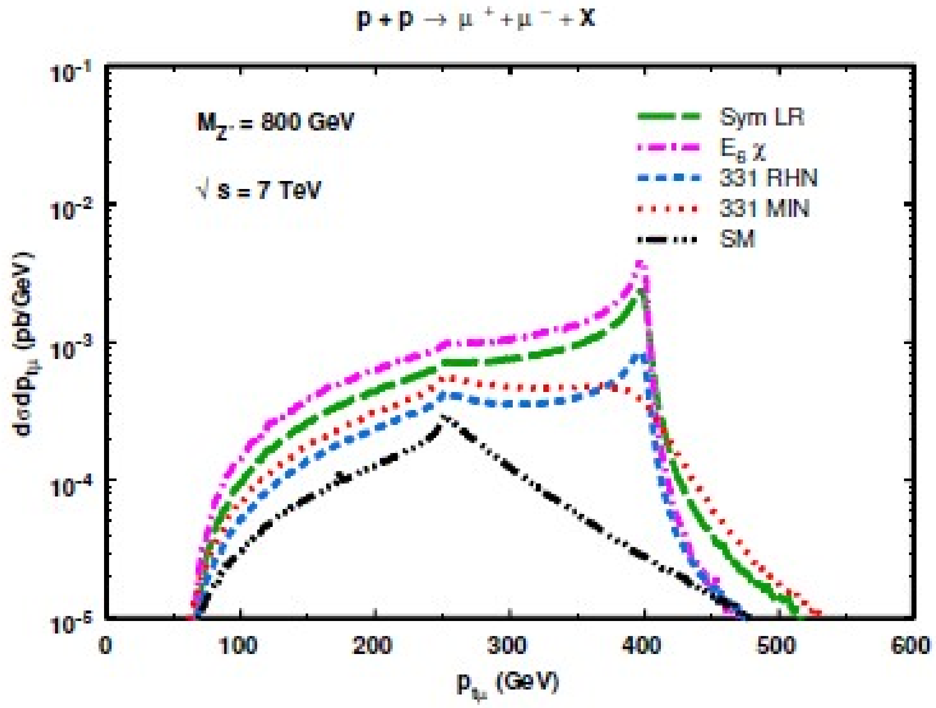


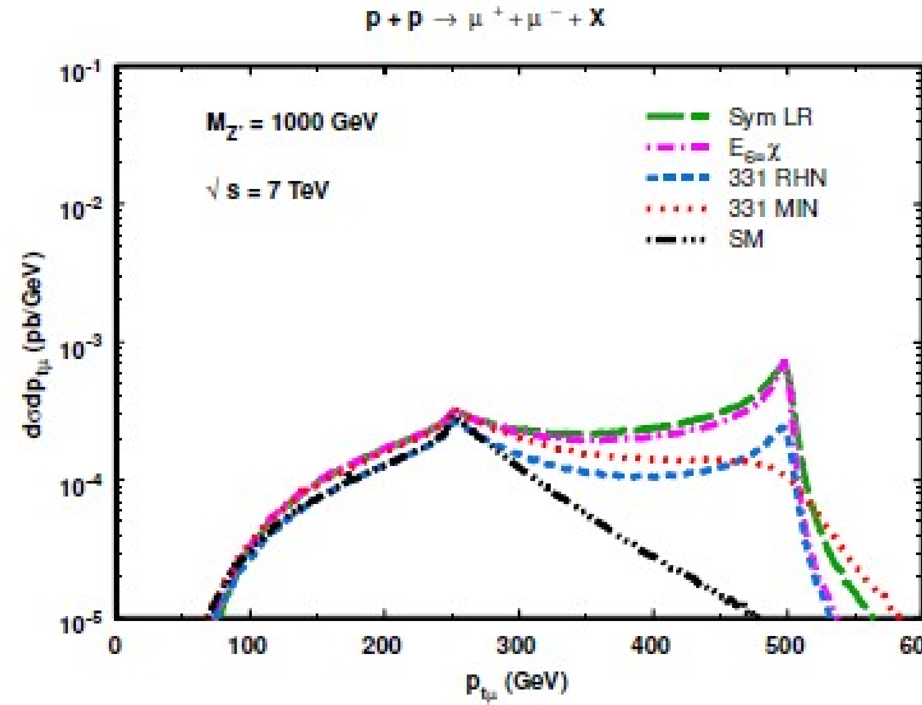


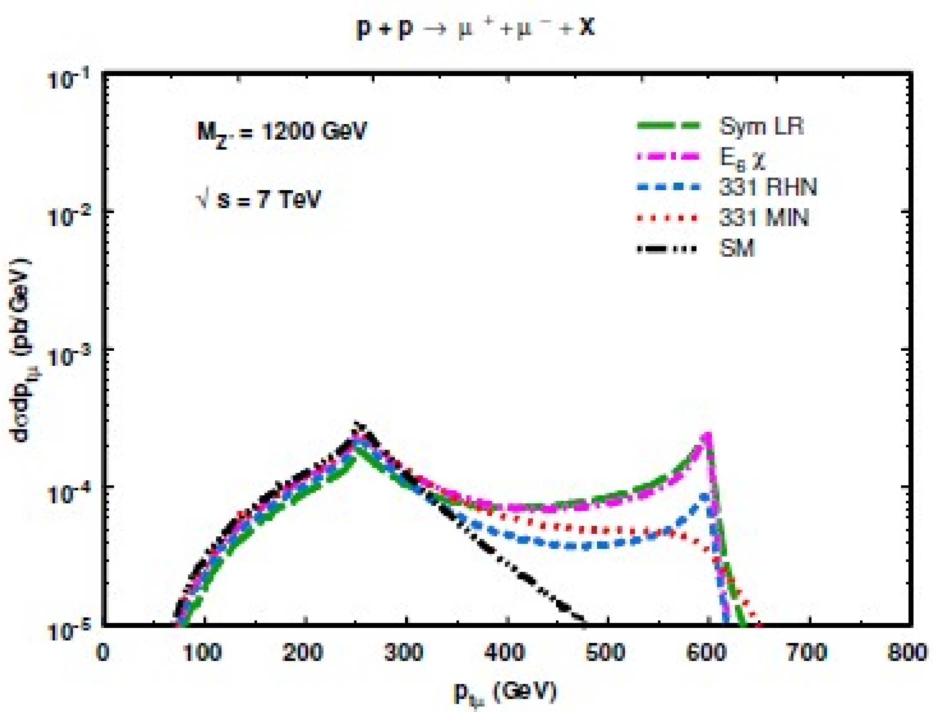


$M_{\mu\mu}$

E_{cm} = 7 TeV


p + p → μ⁺ + μ⁻ + X
M_Z' = 800 GeV
√ s = 7 TeV
Sym LR
E6 χ
331 RHN
331 MIN
SM
dσdp_tμ (pb/GeV)
p_tμ (GeV)


p + p → μ⁺ + μ⁻ + X
M_Z' = 1000 GeV
√ s = 7 TeV
Sym LR
E6 χ
331 RHN
331 MIN
SM
dσdp_tμ (pb/GeV)
p_tμ (GeV)


p + p → μ⁺ + μ⁻ + X
M_Z' = 1200 GeV
√ s = 7 TeV
Sym LR
E6 χ
331 RHN
331 MIN
SM
dσdp_tμ (pb/GeV)
p_tμ (GeV)

p_t

E_{cm} = 7 TeV

Conclusões e perspectivas

- A_{FB} parece separar os modelos
- p_t fornece assinatura para o pico do Jacobiano associado ao Z'

eventos $3x10^4$ - $12x10^4$

$E_{CM} \rightarrow$ 14 TeV (7 x 7) & 100 $fb^{-1} \leftarrow$ *Luminosidade*

eventos 40 - 140

- $E_{CM} \rightarrow$ 7 TeV (3.5 x 3.5) & 1 $fb^{-1} \leftarrow$ *Luminosidade*

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Importante: comparação entre as previsões dos modelos,

escolha de observáveis que levam a discriminação entre modelos


15 1 2008