Trento, December 19, 2018

Glueball spectroscopy. Central diffractive production

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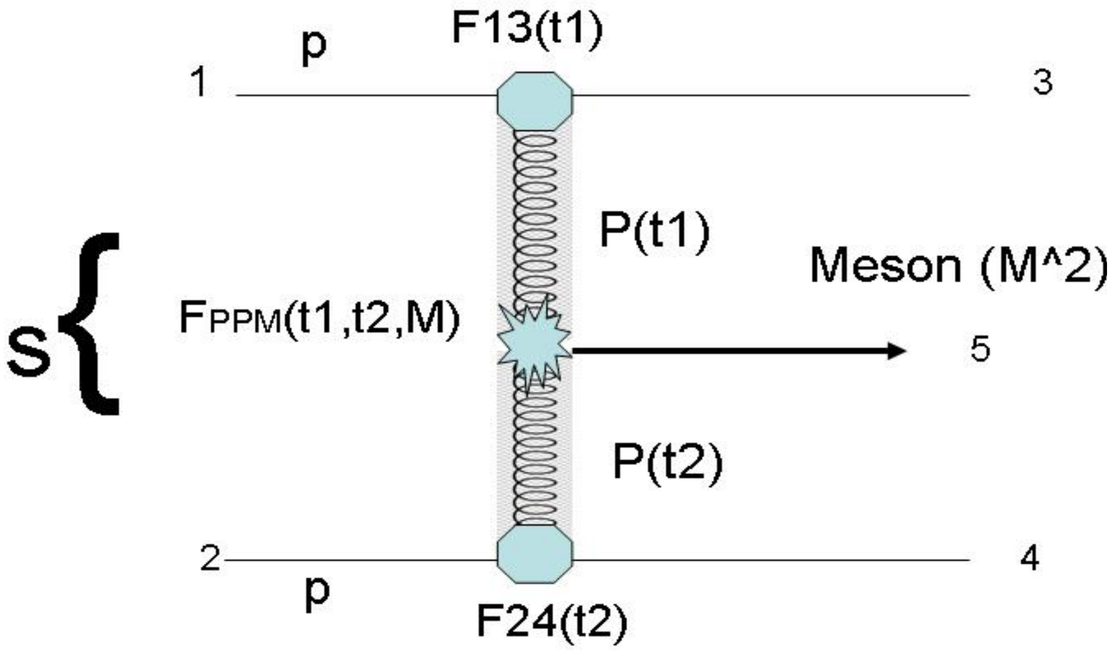
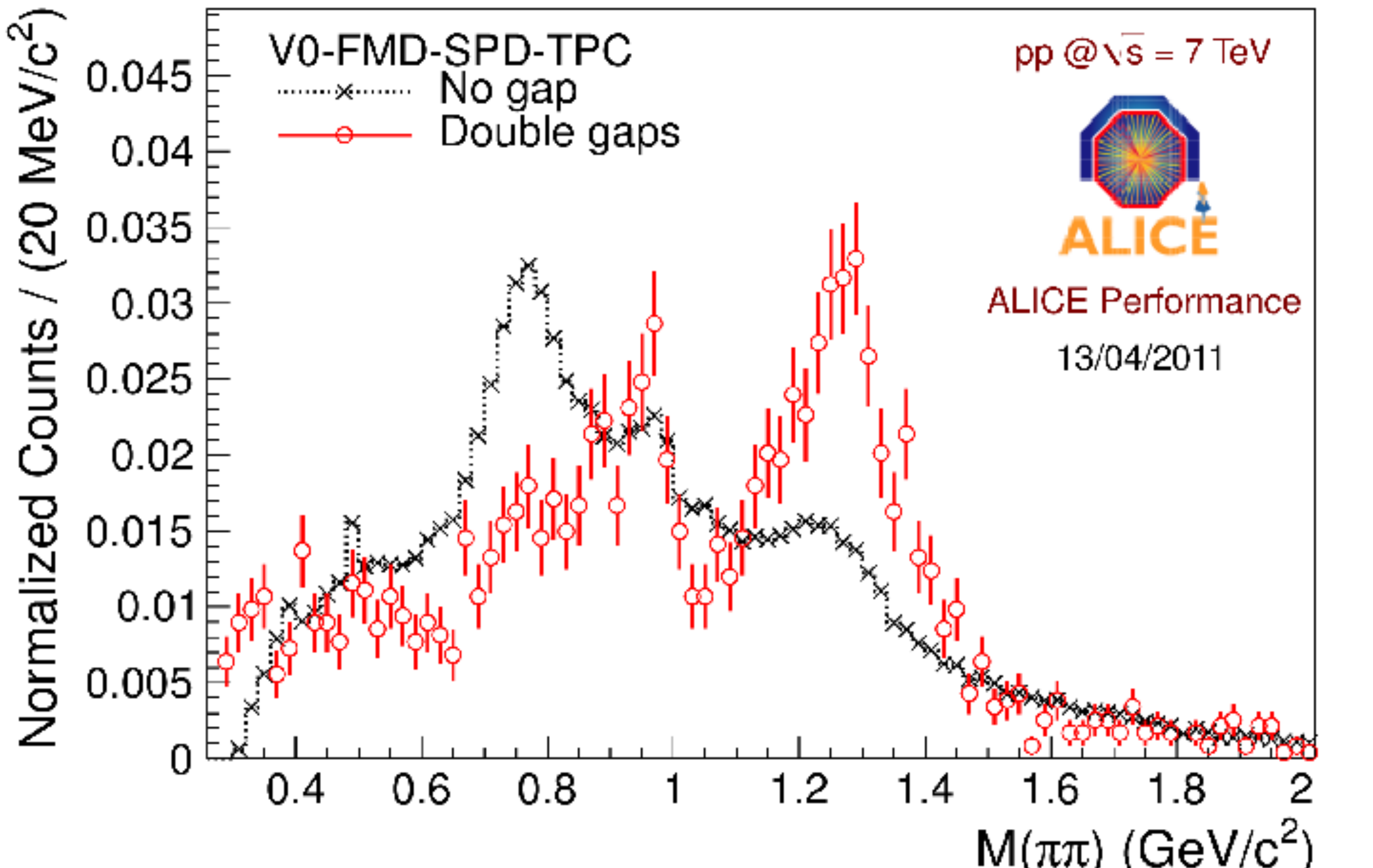
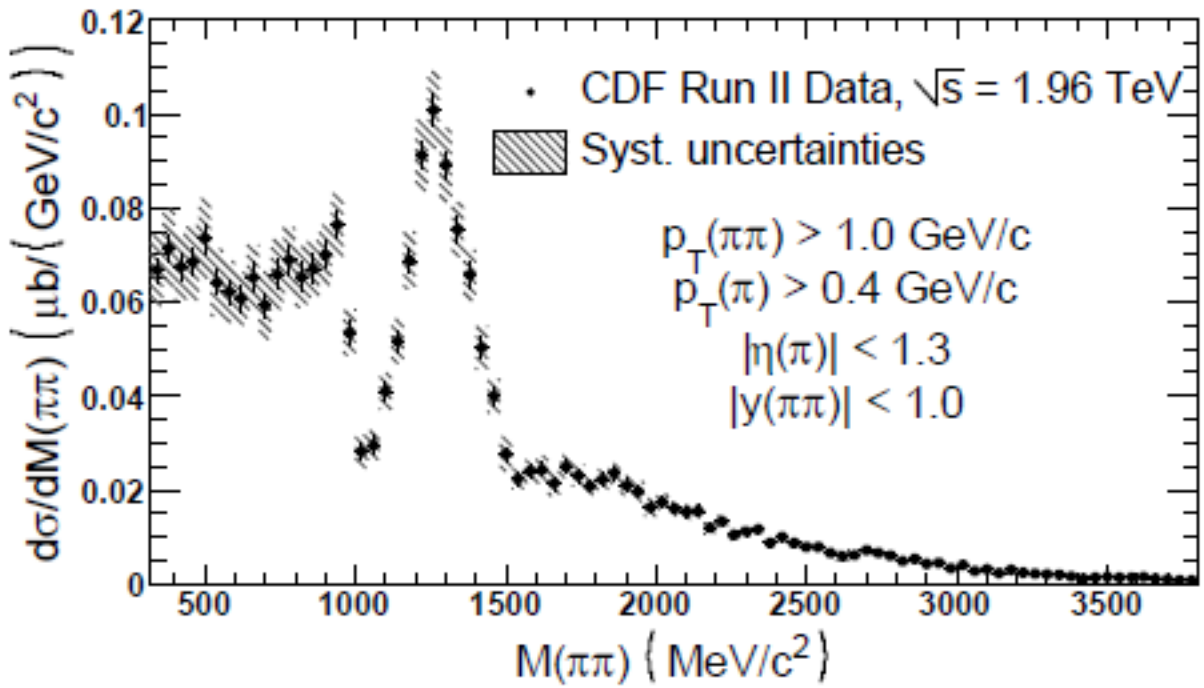
Topics

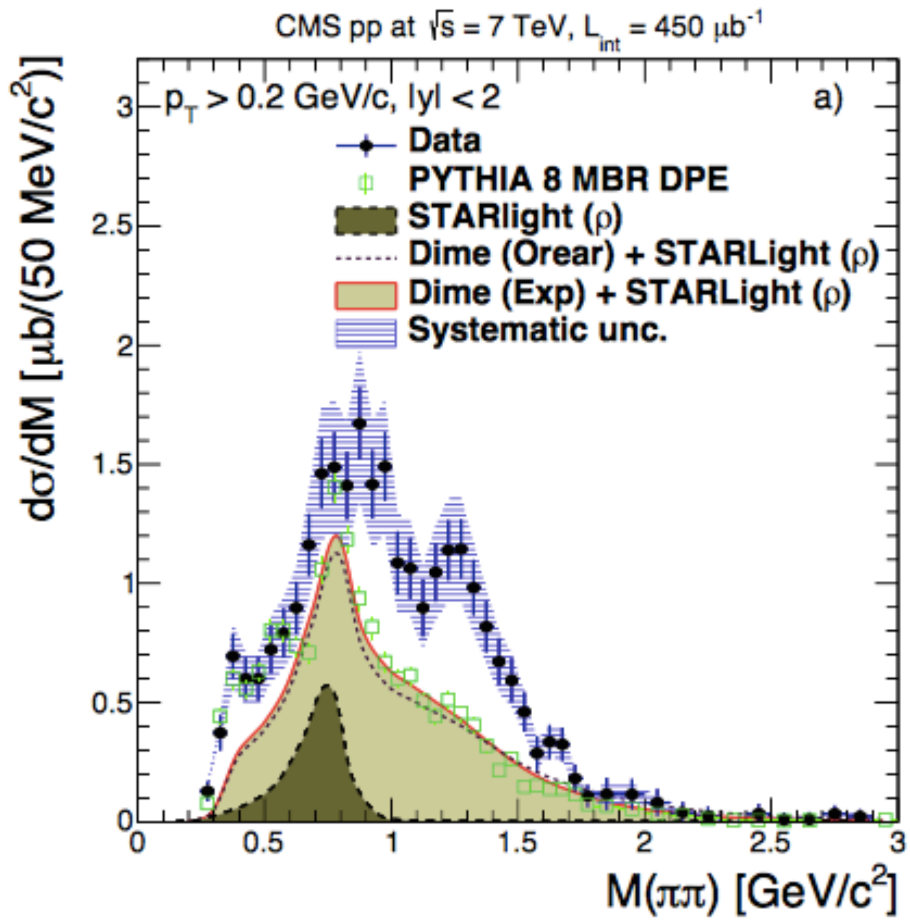
- Resonance-Regge duality, the background, two-component duality;
- The pPX vertex and DIS (HERA), triple Regge limit;
- Duality and FMSR;
-- SDD, DDD, CED, factorization relations;
- Pomeron (>95%) domination at the LHC and beyond.

Central diffractive meson production (double Pomeron exchange);

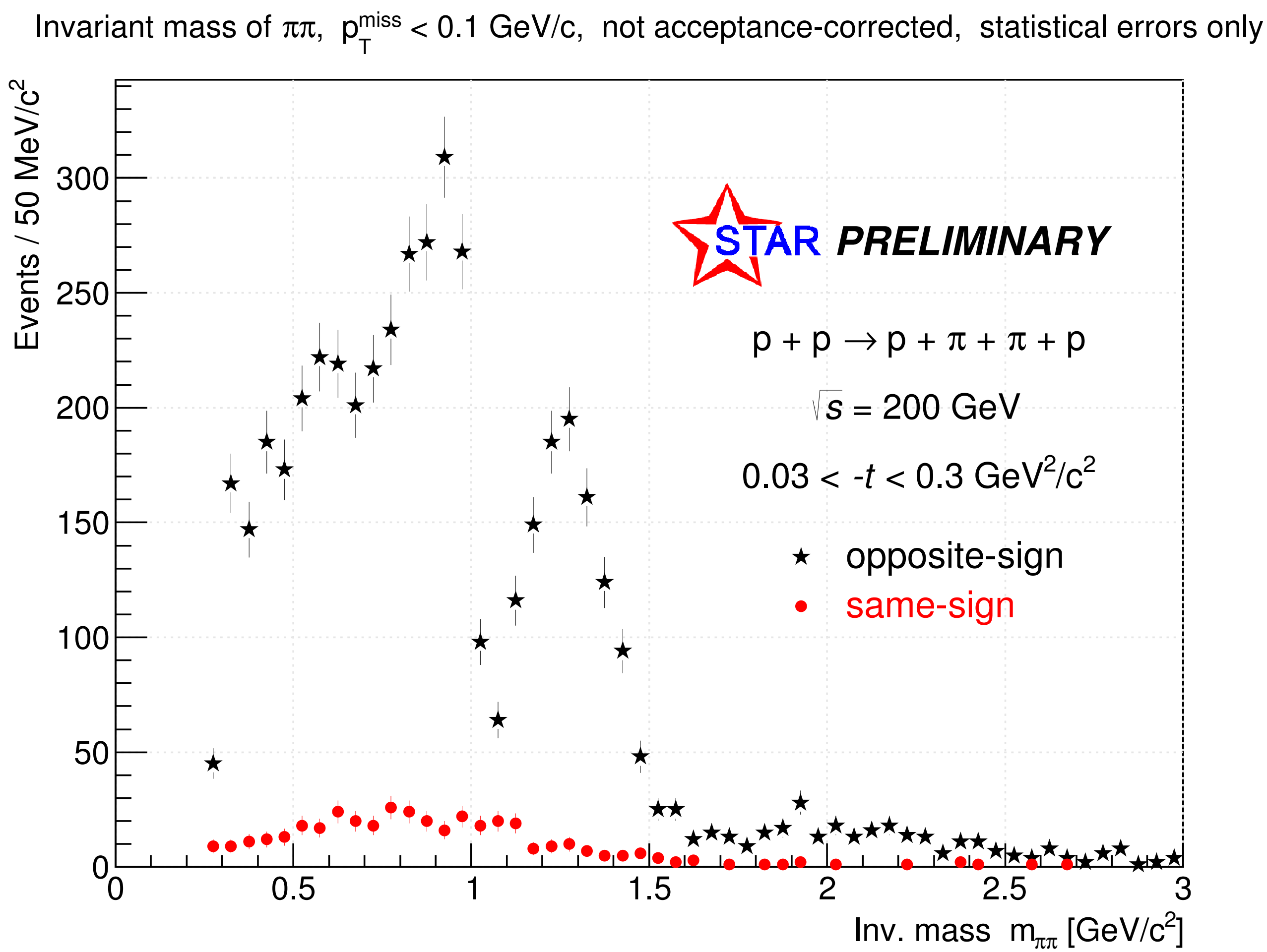


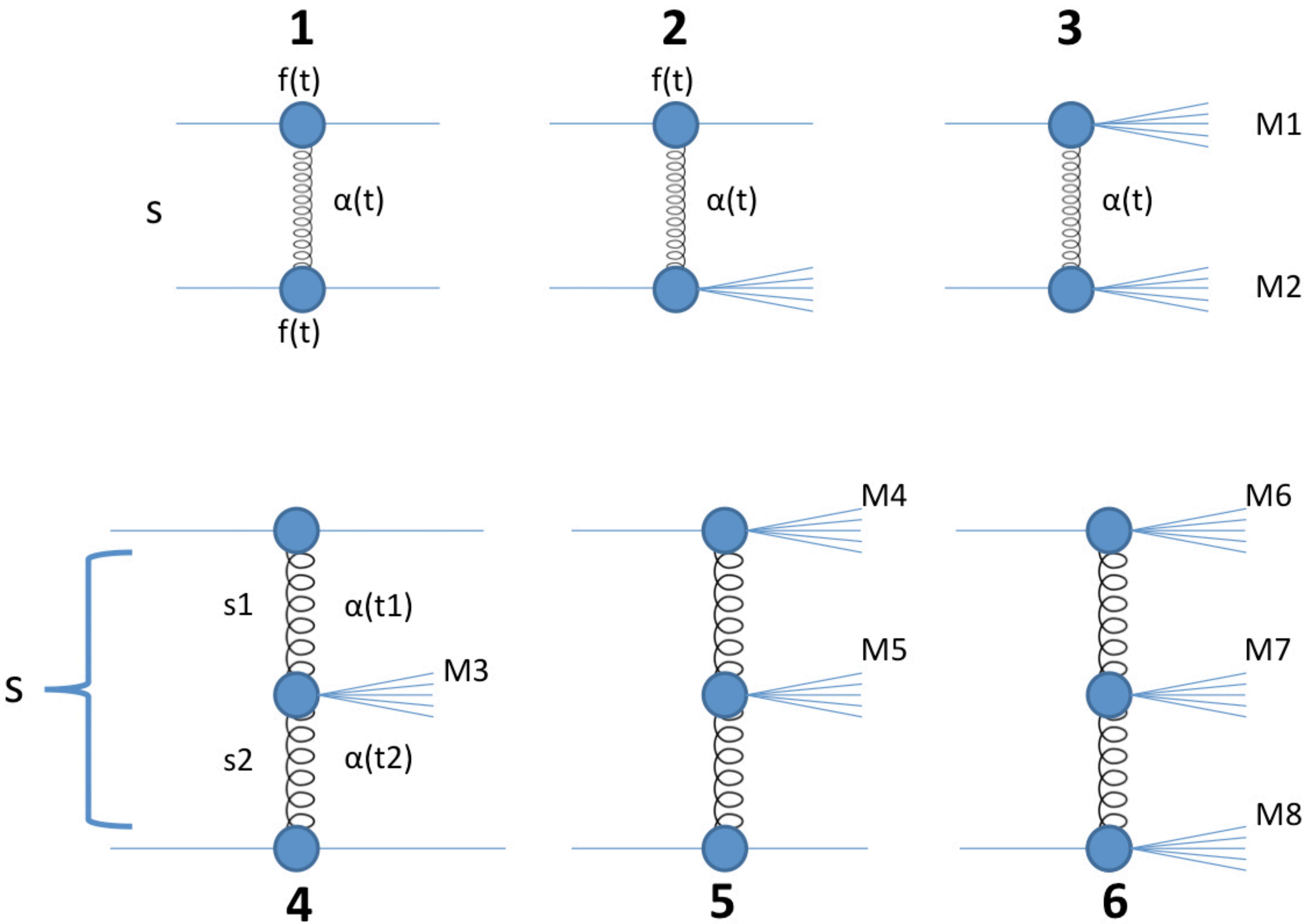

V0-FMD-SPD-TPC
No gap
Double gaps
pp @ √s = 7 TeV
ALICE
ALICE Performance
13/04/2011
Normalized Counts / (20 MeV/c²)
M(ππ) (GeV/c²)
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2


CDF Run II Data, $\sqrt{s}$ = 1.96 TeV
Syst. uncertainties
$p_T(\pi\pi) > 1.0$ GeV/c
$p_T(\pi) > 0.4$ GeV/c
$|\eta(\pi)| < 1.3$
$|y(\pi\pi)| < 1.0$
$d\sigma/dM(\pi\pi)$ (μb/(GeV/c^2))
M(ππ) (MeV/c^2)
0
0.02
0.04
0.06
0.08
0.1
0.12
500
1000
1500
2000
2500
3000
3500

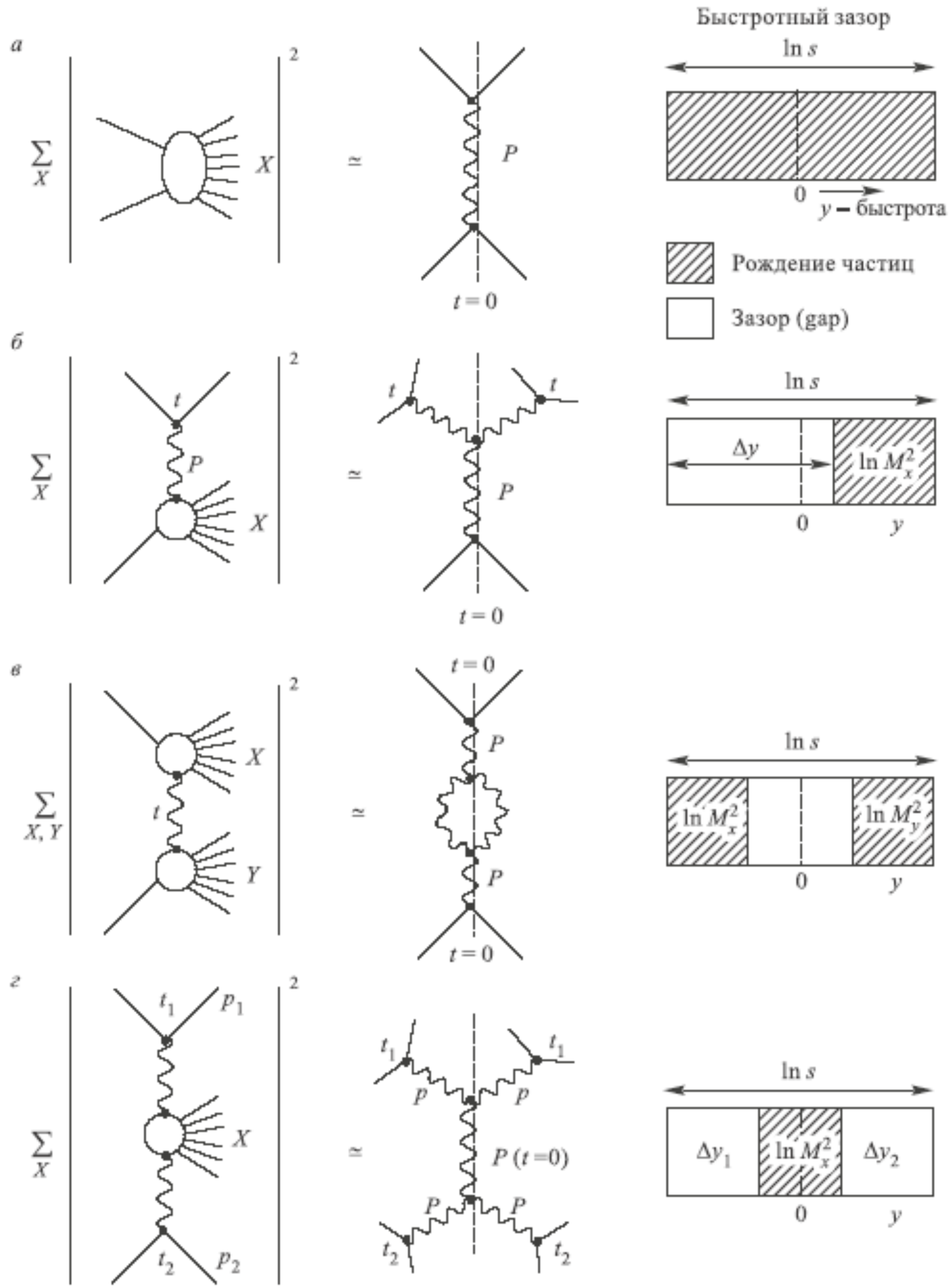


CMS pp at $\sqrt{s}$ = 7 TeV, L_{int} = 450 μb^{-1}
p_T > 0.2 GeV/c, |y| < 2
a)
Data
PYTHIA 8 MBR DPE
STARlight (ρ)
Dime (Orear) + STARLight (ρ)
Dime (Exp) + STARLight (ρ)
Systematic unc.
dσ/dM [μb/(50 MeV/c^2)]
M(ππ) [GeV/c^2]
0
0.5
1
1.5
2
2.5
3


Invariant mass of ππ, p_T^{miss} < 0.1 GeV/c, not acceptance-corrected, statistical errors only
Events / 50 MeV/c²
300
250
200
150
100
50
0
0.5
1
1.5
2
2.5
3
Inv. mass $m_{\pi\pi}$ [GeV/c²]
STAR PRELIMINARY
p + p → p + π + π + p
$\sqrt{s}$ = 200 GeV
0.03 < -t < 0.3 GeV²/c²
opposite-sign
same-sign



1
2
3
f(t)
f(t)
α(t)
α(t)
α(t)
s
f(t)
M1
M2
M4
M6
s1
α(t1)
M5
M7
M3
S
s2
α(t2)
M8
4
5
6



Быстротный зазор
а
б
в
г
ln s
0
y – быстрота
Рождение частиц
Зазор (gap)
t = 0
P
X
t
Δy
ln M_x^2
ln M_y^2
y
Y
t_1
t_2
p_1
p_2
P (t = 0)
Δy_1
Δy_2

Factorization (nearly perfect at the LHC and beyand!)

$$(g_1 g_2)^2 = \frac{(g_1 f_1)^2 (f_1 g_2)^2}{(f_1 f_2)^2}.$$

Hence

$$\frac{d^3\sigma}{dt dM_1^2 dM_2^2} = \frac{d^2\sigma_1}{dt dM_1^2} \frac{d^2\sigma_2}{dt dM_2^2} \frac{d\sigma_{el}}{dt}.$$

Assuming exponential cone, t^{bt} and integrating in t, one gets

$$\frac{d^2\sigma_{DD}}{dM_1^2 dM_2^2} = k \frac{1}{\sigma_{el}} \frac{d\sigma_1}{dM_1^2} \frac{d\sigma_2}{dM_2^2},$$

where $k = r^2/(2r-1), \quad r = b_{SD}/b_{el}.$

Further integration in M^2 yelds $\sigma_{DD} = k\frac{\sigma_{SD}^2}{\sigma_{el}}.$

$$\sigma_t(s) = \frac{4\pi}{s} Im A(s, t=0); \quad \frac{d\sigma}{dt} = \frac{\pi}{s^2}|A(s,t)|^2; \quad n(s);$$

$$\sigma_{el} = \int_{t_{min}\approx -s/2 \approx \infty}^{t_{thr.}\approx 0} \frac{d\sigma}{dt} dt; \; \sigma_{in} = \sigma_t - \sigma_{el}; \quad B(s,t) = \frac{d}{dt} \ln\left(\frac{d\sigma}{dt}\right);$$

$$A_{pp}^{p\bar{p}}(s,t) = P(s,t) \pm O(s,t) + f(s,t) \pm \omega(s,t) \rightarrow_{LHC} \approx P(s,t) \pm O(s,t),$$

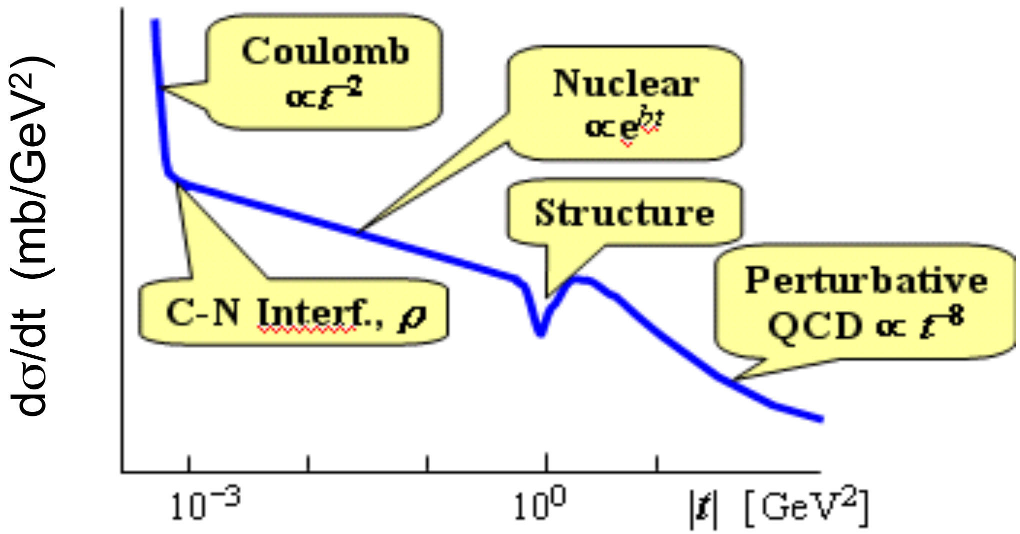
where P, O, f. ω are the Pomeron, odderon and non-leading Reggeon contributions.

α(0)\C	+	-
1	P	O
1/2	f	ω

NB: The S-matrix theory (including Regge pole) is applicable to asymptotically free states only (not to quarks and gluons)!

Elastic Scattering

$\sqrt{s}$ = 14 TeV prediction of BSW model



momentum transfer $-t \sim (p\theta)^2$

θ = beam scattering angle

p = beam momentum

$$\rho = \left.\frac{\mathrm{Re}(f_{el}(t))}{\mathrm{Im}(f_{el}(t))}\right|_{t\to 0}$$

$$\left.\frac{dN}{dt}\right|_{t=CNI} = L\pi|f_C + f_N|^2 \approx L\pi\left|-\frac{2\alpha_{\mathrm{EM}}}{|\mathrm{t}|} + \frac{\sigma_{\mathrm{tot}}}{4\pi}(i+\rho)e^{-\frac{b|t|}{2}}\right|^2$$

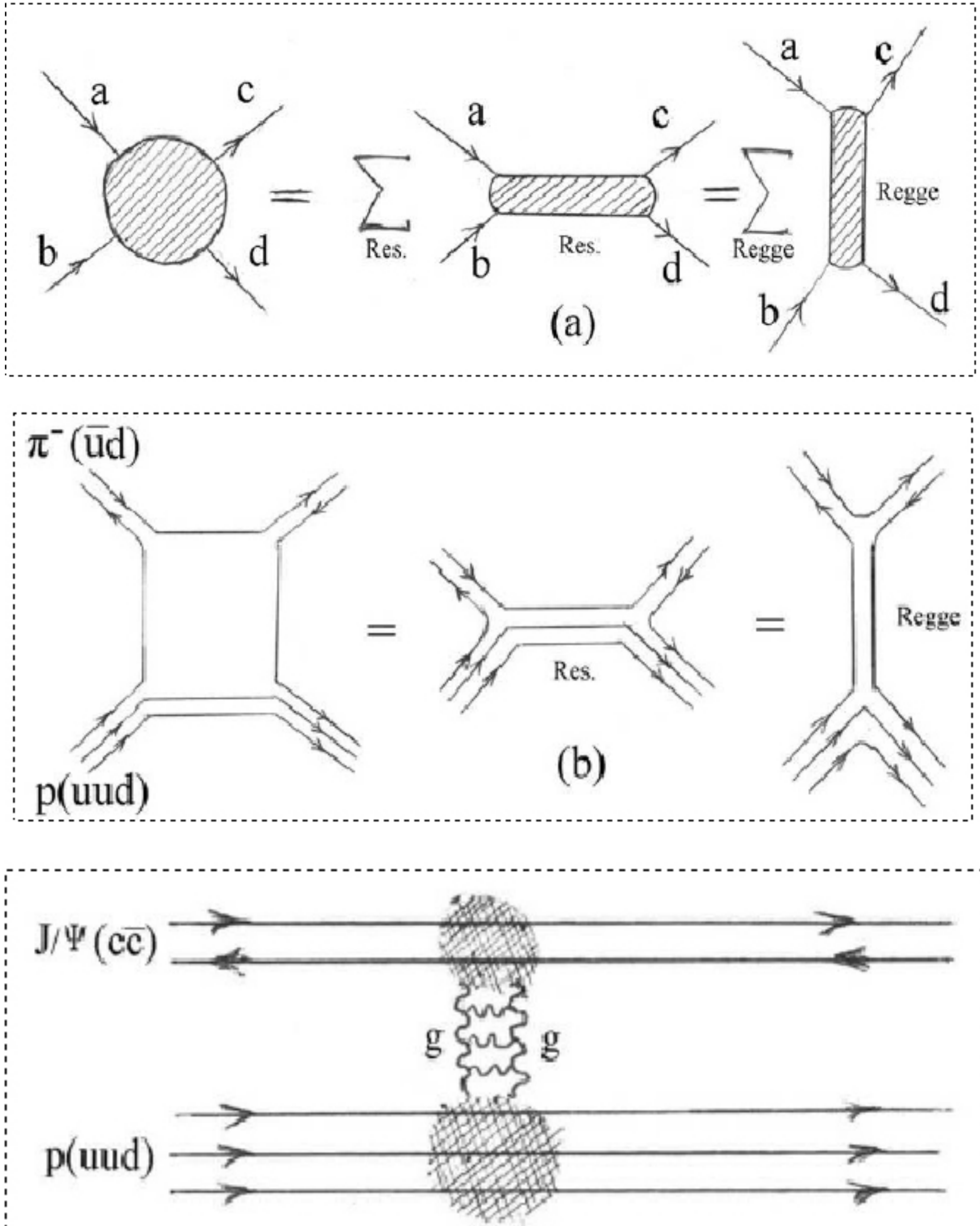
L, σ_{tot} , **b**, and ρ from FIT in CNI region (UA4)

CNI region: $|f_C| \sim |f_N|$ → @ LHC: $-t \sim 6.5\ 10^{-4}$ GeV²; θ_{min}~3.4 μrad

(θ_{min}~120 μrad @ SPS)

$$\Gamma(s = M^2) = \frac{2\Im\alpha(s)}{|\alpha'(s)|}$$

$$\sigma_t^{PP} = \frac{\sigma_0(s/s_0)^\epsilon}{\sqrt{Q_1^2 Q_2^2 \ln(s/s_0)}}.$$



a
c
b
d
Res.
Res.
Regge
Regge
(a)
$\pi^-(\bar{u}d)$
p(uud)
Res.
Regge
(b)
$J/\Psi(c\bar{c})$
g
g
p(uud)

TABLE I: Two-component duality

$\mathcal{I}mA(a+b \rightarrow c+d) =$	R	Pomeron
$s-$channel	$\sum A_{Res}$	Non-resonant background
$t-$channel	$\sum A_{Regge}$	Pomeron $(I = S = B = 0;\ C = +1)$
Duality quark diagram	Fig. 1b	Fig. 2
High energy dependence	$s^{\alpha-1},\ \alpha < 1$	$s^{\alpha-1},\ \alpha \geq 1$

The (s,t) term of a dual amplitude is

$$D(s,t) = c\int_0^1 dx\Big(\frac{x}{g_1}\Big)^{-\alpha(s')-1}\Big(\frac{1-x}{g_2}\Big)^{-\alpha(t')-1},$$

where s and t are the Mandelstam variables, and g_1, g_2 are parameters, $g_1, g_2 > 1$. For simplicity, we set $g_1 = g_2 = g_0$.

1. Regge behavior, $s \to \infty$, $t = const$: $D(s,t) \sim s^{\alpha(t)-1}$;

2. Thereshold behavior, $s \to s_0$: $D(s,t) \sim \sqrt{s_0 - s}[const + \ln(1 - s_0/s)]$;

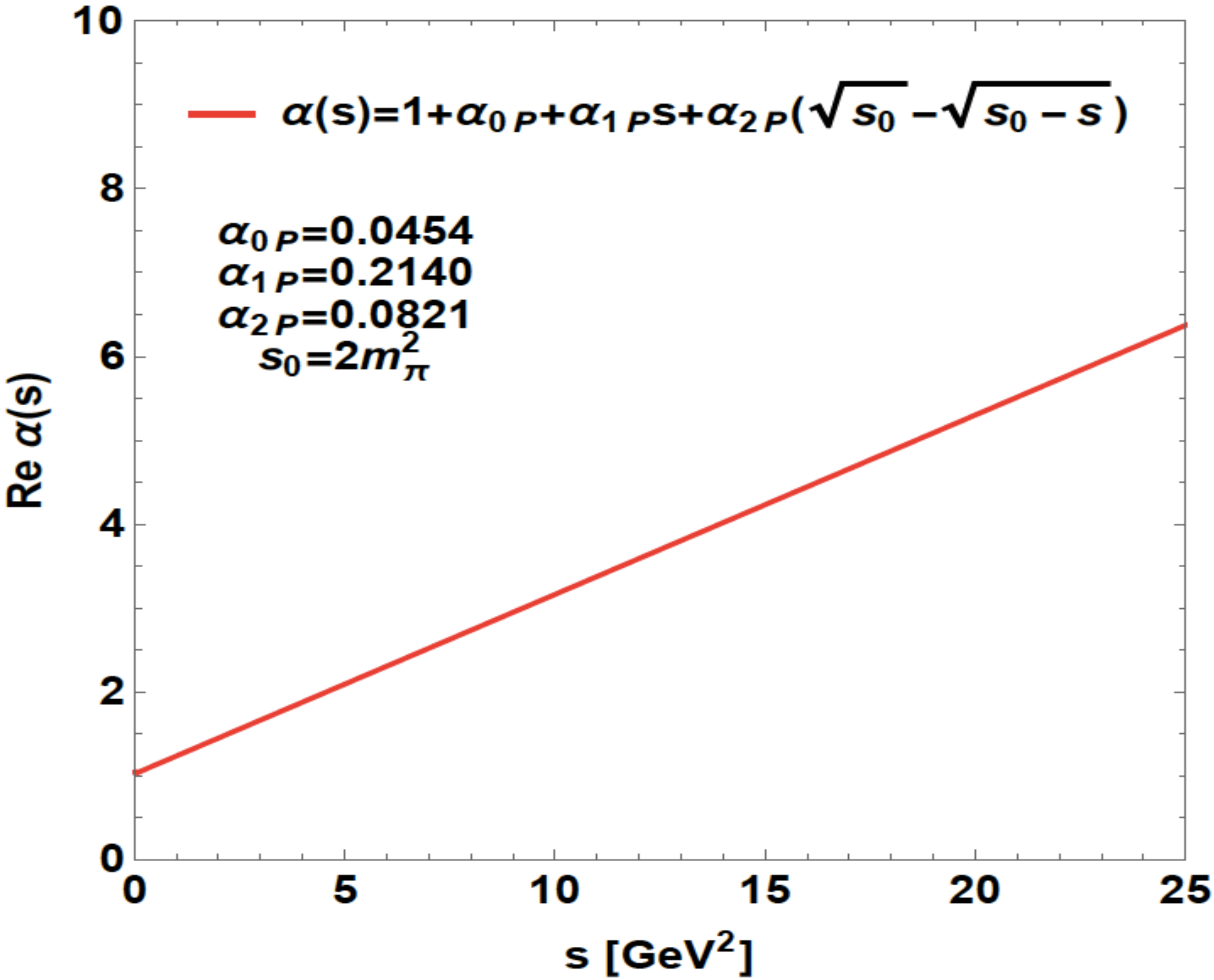
3. Direct-channel poles:

$$D(s,t)=\sum_{n=0}^{\infty} g^{n+1}\sum_{l=o}^{n}\frac{[-s\alpha'(s)]^l C_{n-l}(t)}{[n-\alpha(s)]^{l+1}}.$$

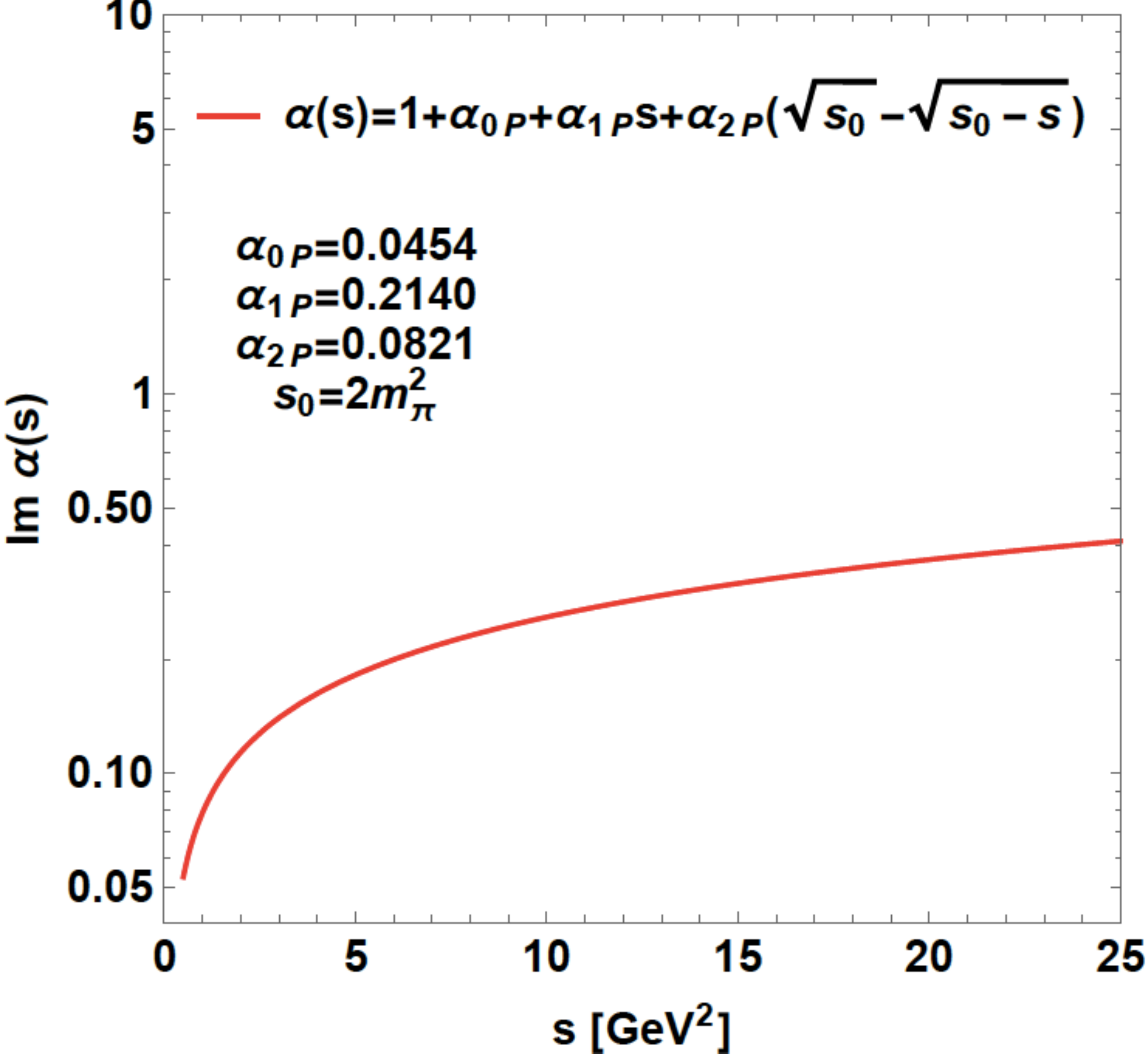
Exotic direct-channel trajectory: $\alpha(s)=\alpha(0)+\alpha_1(\sqrt{s_0}-\sqrt{s_0-s})$.

"GOLDEN" diffraction reaction: $J/\Psi p-$ scattering: By VMD, photoproduction is reduced to elastic hadron scattering:

$$D(\gamma p-Vp)=\sum\frac{e}{f_V}D(Vp-Vp).$$



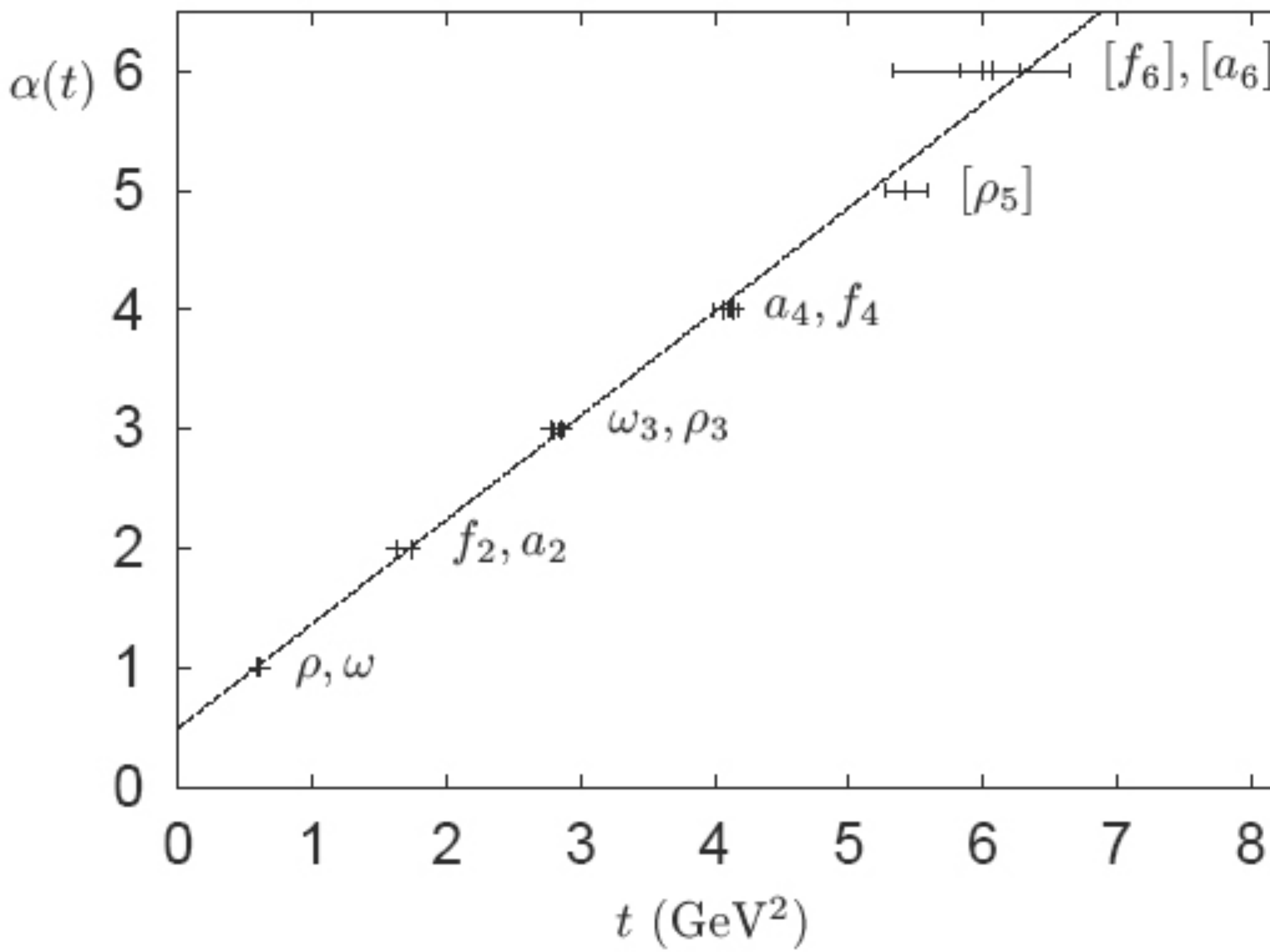
$\alpha(s)=1+\alpha_{0P}+\alpha_{1P}s+\alpha_{2P}(\sqrt{s_0}-\sqrt{s_0-s})$
$\alpha_{0P}=0.0454$
$\alpha_{1P}=0.2140$
$\alpha_{2P}=0.0821$
$s_0=2m_\pi^2$
Re $\alpha(s)$
s [GeV^2]
0
2
4
6
8
10
0
5
10
15
20
25

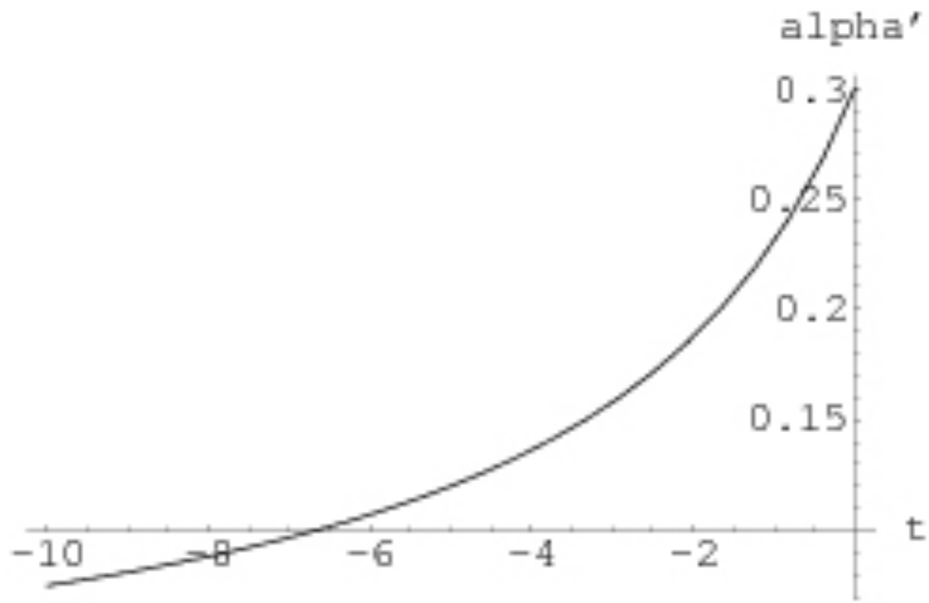


$\alpha(s)=1+\alpha_{0P}+\alpha_{1P}s+\alpha_{2P}(\sqrt{s_0}-\sqrt{s_0-s})$
$\alpha_{0P}=0.0454$
$\alpha_{1P}=0.2140$
$\alpha_{2P}=0.0821$
$s_0=2m_\pi^2$
Im $\alpha(s)$
s [GeV^2]
0.05
0.10
0.50
1
5
10
0
5
10
15
20
25

Linear particle trajectories

Plot of spins of families of particles against their squared masses:





The slope of the cone for a single pole is: $B(s,t) \sim \alpha'(t) \ln s$. The Regge residue $e^{b\alpha(t)}$ with a logarithmic trajectory $\alpha(t) = \alpha(0) - \gamma \ln(1 - \beta t)$, is identical to a form factor (geometrical model).

R. Fiore, L.L. Jenkovszky, V. Magas, F. Paccanoni, A. Papa, *Analytic model of Regge trajectories,* Eur.Phys.J. A10 (2001) 217-221; **arXiv:hep-ph/0011035**

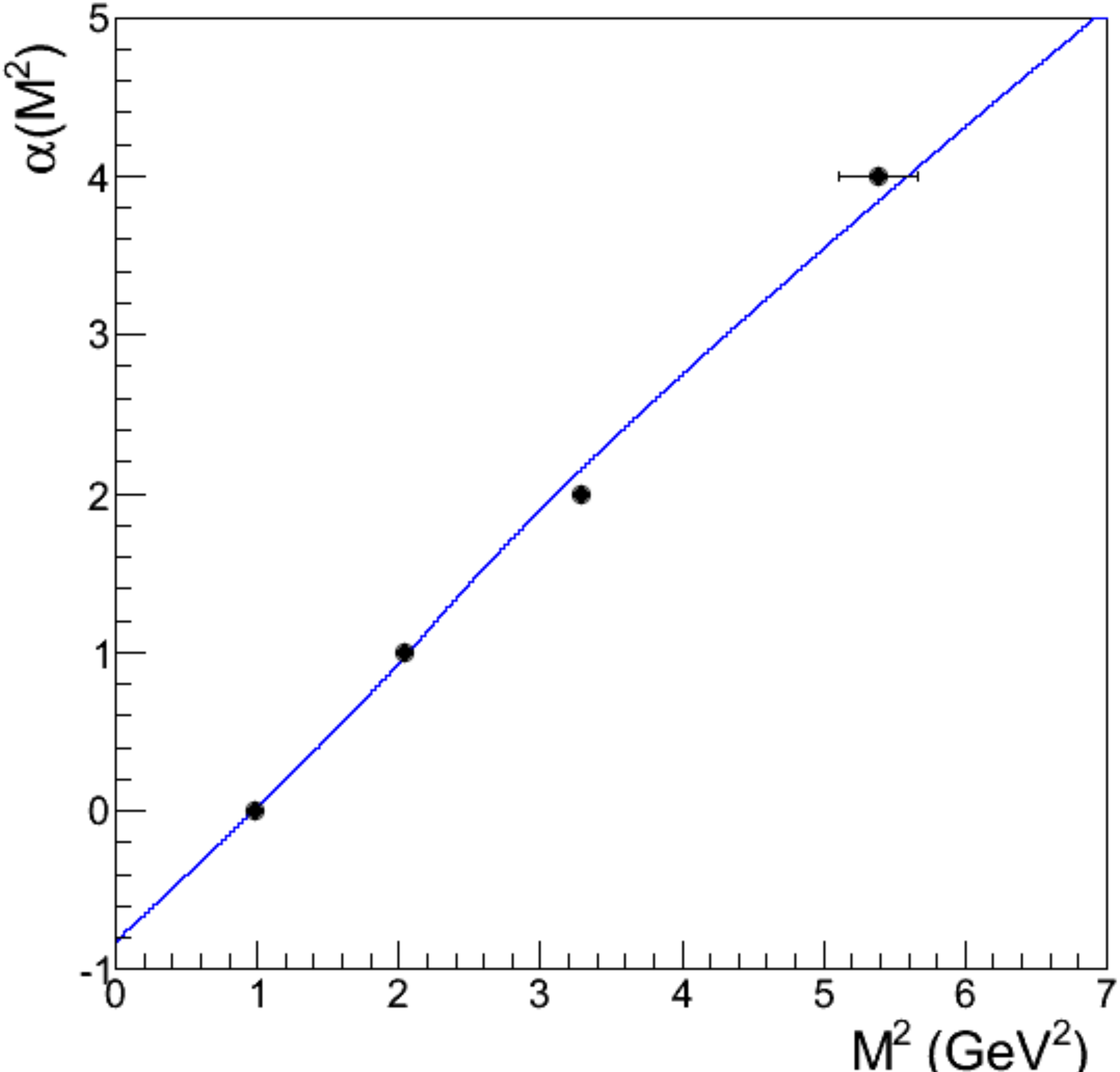
The Pomeron trajectory

The Pomeron trajectory has threshold singularities, the lowest one being due to the two-pion exchange, required by the $t-$channel unitarity. There is a constrain (Barut, Zwanziger; Gribov) from the $t-$ channel unitarity, by which

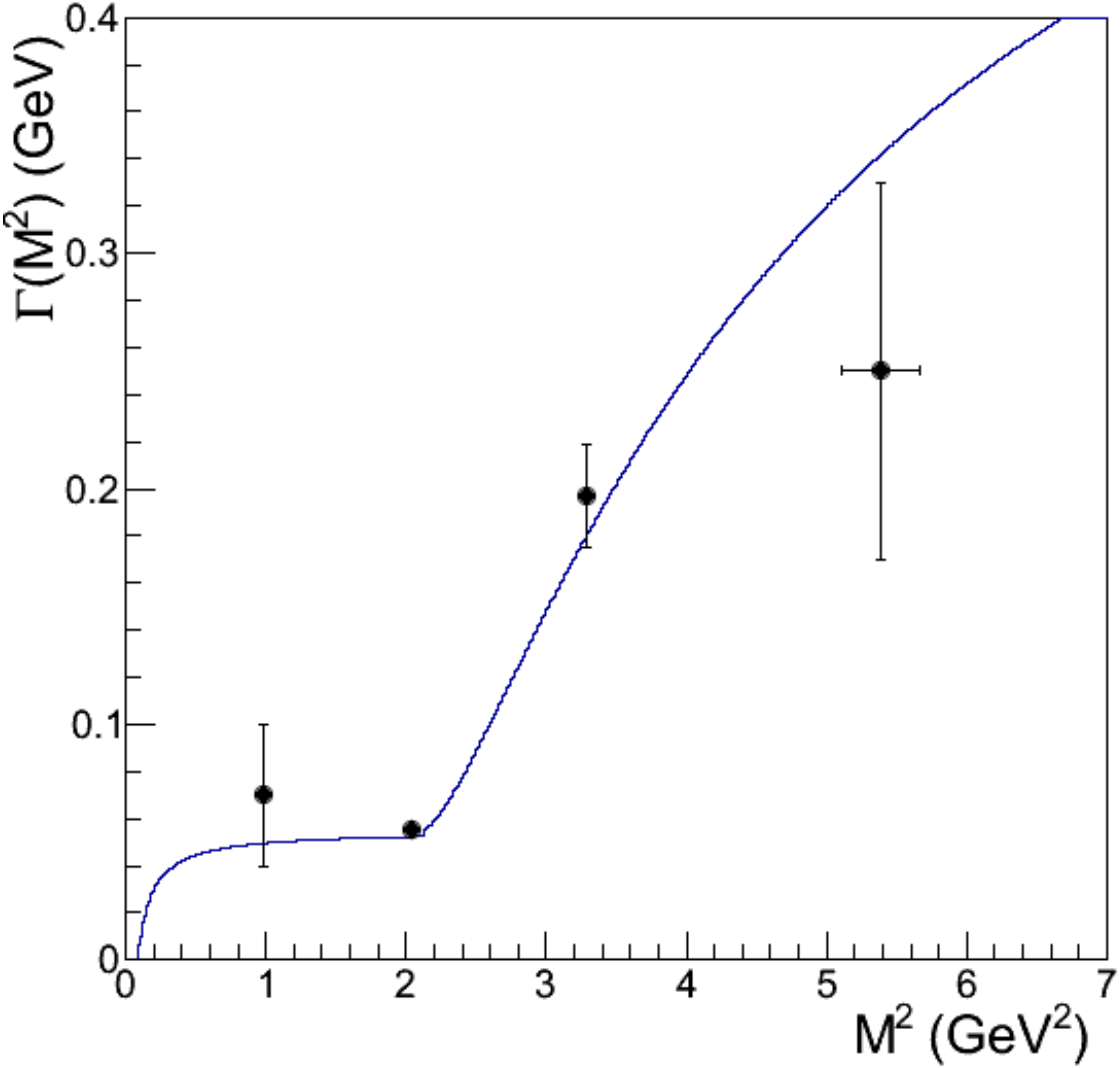
$$\Im\alpha(t) \sim (t-t_0)^{\Re\alpha(t_0)+1/2}, \quad t \to t_0,$$

where t_0 is the lightest threshold. For the Pomeron trajectory it is $t_0 = 4m_\pi^2$, and near the threshold:

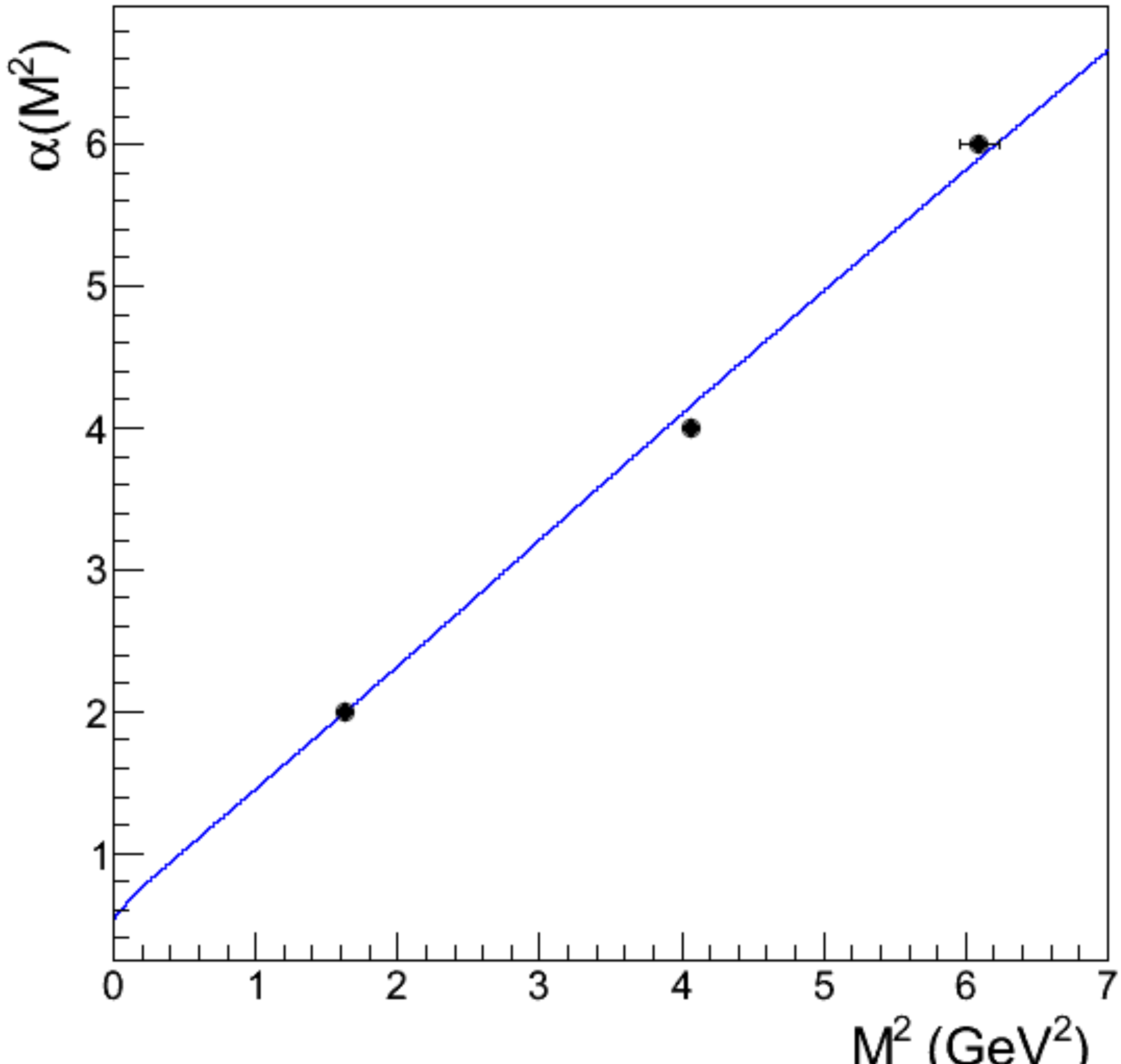
$$\alpha(t) \sim \sqrt{4m_\pi^2 - t}. \tag{1}$$



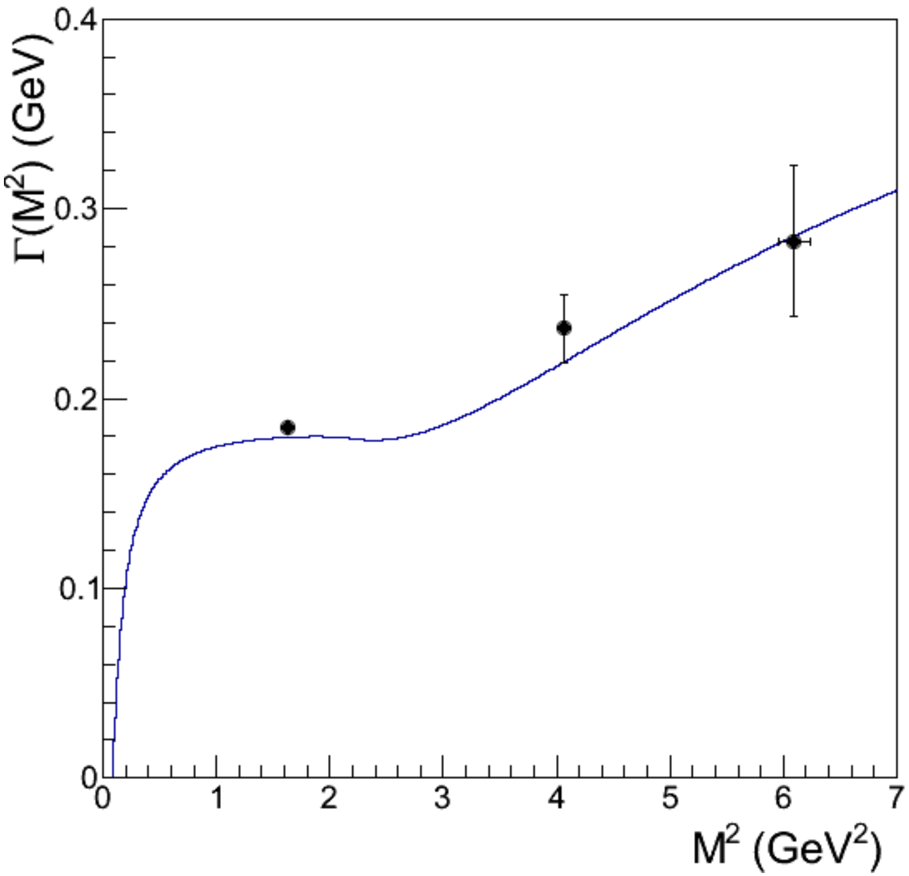
α(M²)
5
4
3
2
1
0
-1
0
1
2
3
4
5
6
7
M² (GeV²)



0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
Γ(M²) (GeV)
M² (GeV²)



α(M²)
6
5
4
3
2
1
0
1
2
3
4
5
6
7
M² (GeV²)



Γ(M²) (GeV)
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
M² (GeV²)

"Reggeized (dual) Breit-Wigner" formula:

$$\sigma_T^{Pp}(M_x^2,t) = Im\,A(M_x^2,t) = \frac{A_{N^*}}{\sum_n n - \alpha_{N^*}(M_x^2)} + Bg(t,M_x^2) =$$

$$= A_n \sum_{n=0,1,\ldots} \frac{[f(t)]^{2(n+1)}\,Im\,\alpha(M_x^2)}{(2n+0.5-Re\,\alpha(M_x^2))^2 + (Im\,\alpha(M_x^2))^2} + B_n e^{b_{in}^{bg}t}\left(M_x^2 - M_{p+\pi}^2\right)^{\epsilon}$$

$$F(x_B,t) = \frac{x_B(1-x_B)}{\left(M_x^2 - m_p^2\right)\left(1+4m_p^2 x_B^2/(-t)\right)^{3/2}}, \quad x_B = \frac{-t}{M_x^2 - m_p^2 - t}$$

$$F_p(t) = \frac{1}{1-\frac{t}{0.71}}, \quad f(t) = e^{b_{in}t}$$

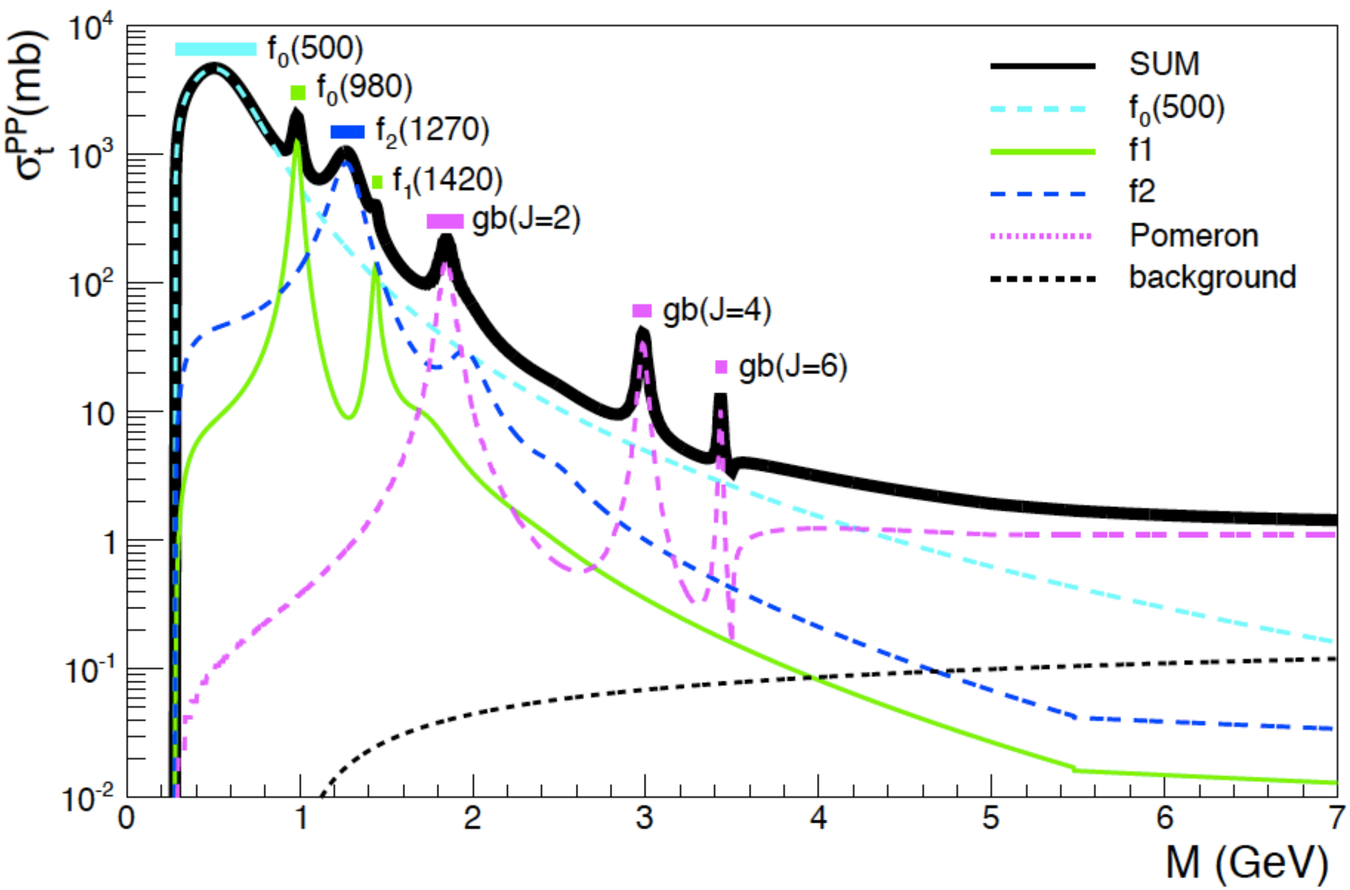
$$\alpha(t) = \alpha(0) + \alpha' t = 1.04 + 0.25t$$

Representative examples of the Pomeron trajectories: 1) Linear; 2) With a square-root threshold, required by $t-$channel unitarity and accounting for the small-t "break" as well as the possible "Orear", $e^{\sqrt{-t}}$ behavior in the second cone; and 3) A logarithmic one, anticipating possible "hard effects" at large $|t|$ $|t| < 8$ GeV^2.

$$\alpha_P \equiv \alpha_P(t) = 1 + \delta_P + \alpha_{1P} t, \tag{TR.1}$$

$$\alpha_P \equiv \alpha_P(t) = 1 + \delta_P + \alpha_{1P} t - \alpha_{2P} \left(\sqrt{4\alpha_{3P}^2 - t} - 2\alpha_{3P} \right), \tag{TR.2}$$

$$\alpha_P \equiv \alpha_P(t) = 1 + \delta_P - \alpha_{1P} \ln\left(1 - \alpha_{2P} t\right). \tag{TR.3}$$

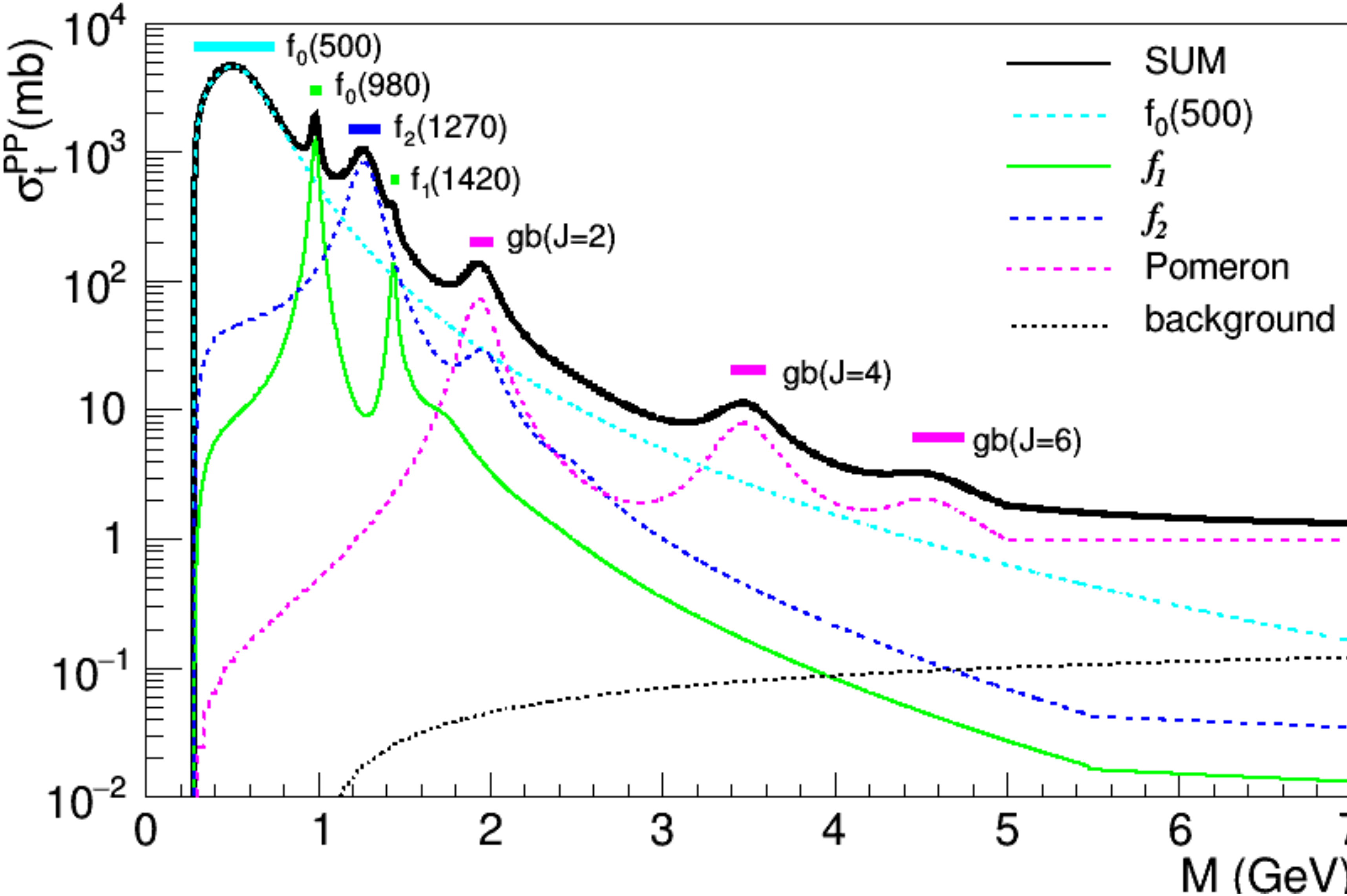


σ_t^{PP}(mb)
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
1
2
3
4
5
6
7
M (GeV)
$f_0(500)$
$f_0(980)$
$f_2(1270)$
$f_1(1420)$
gb(J=2)
gb(J=4)
gb(J=6)
SUM
$f_0(500)$
f1
f2
Pomeron
background

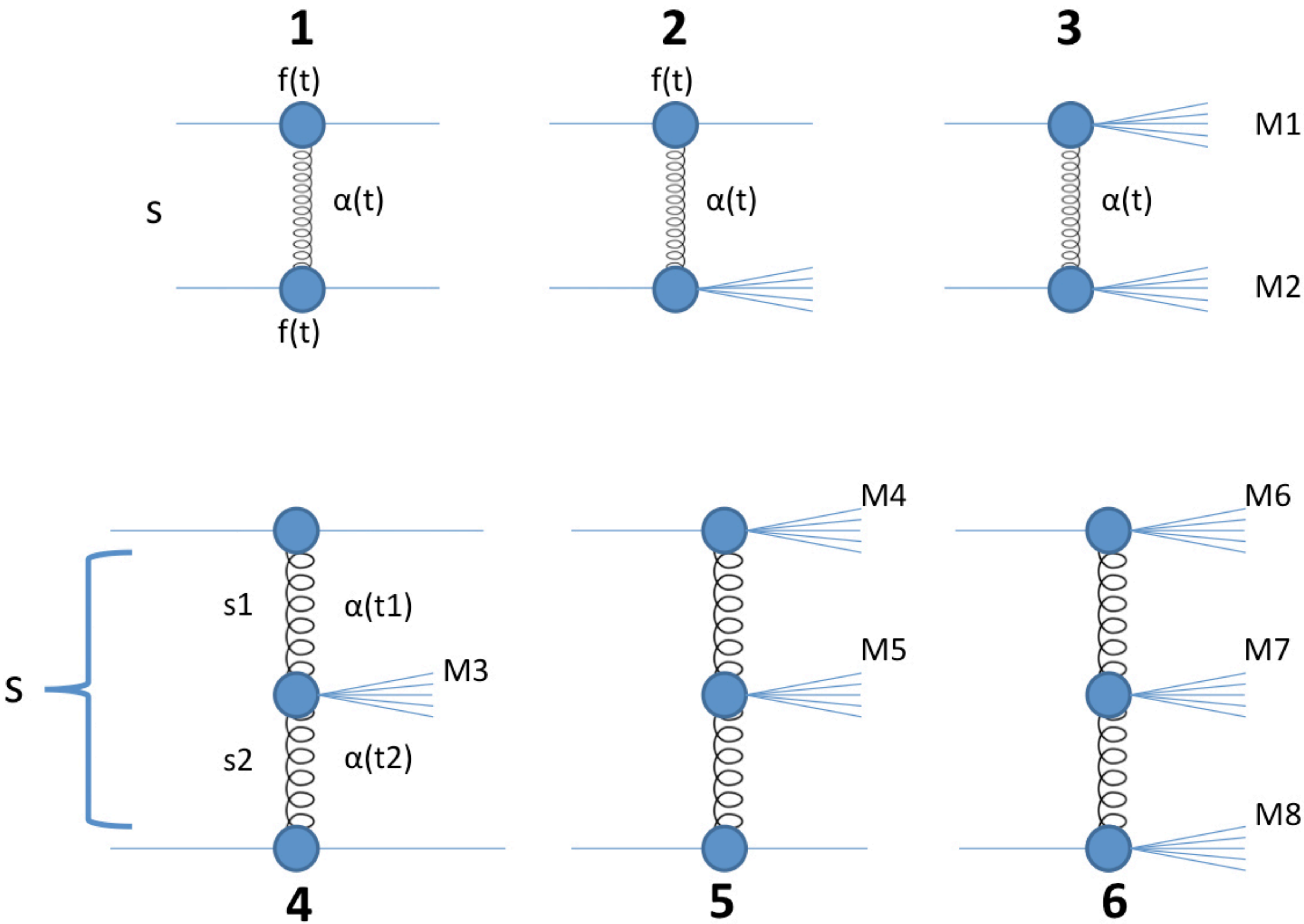
$$\alpha(s) = \alpha_0 + \alpha' s + \alpha_1 \sqrt{s_0 - s};$$

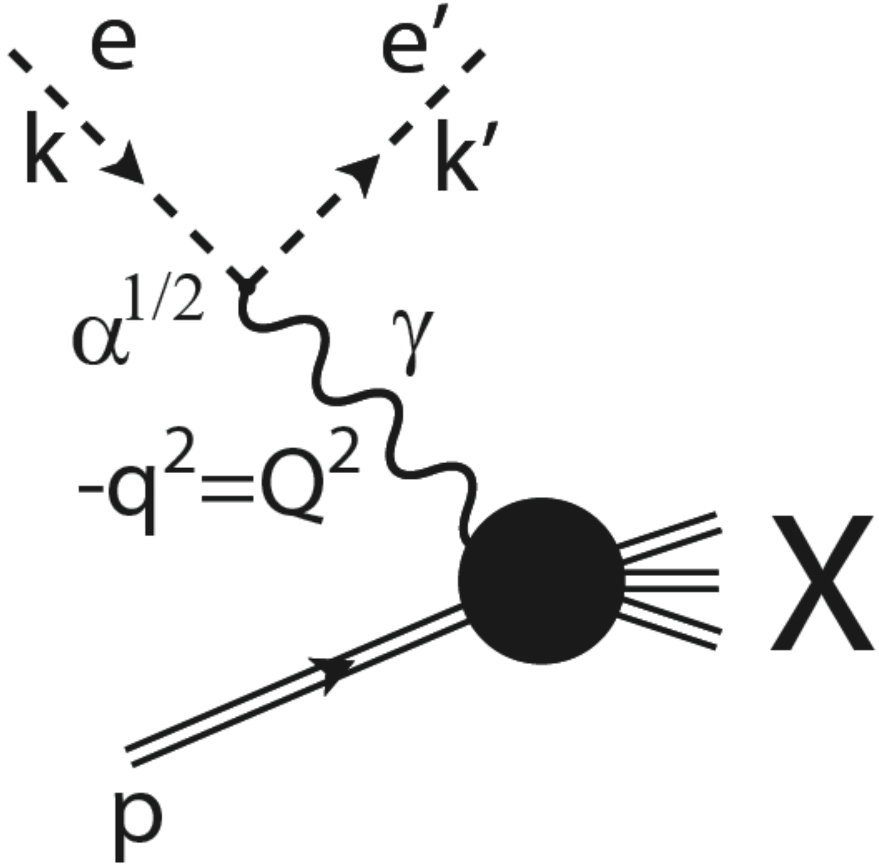
$$\alpha(s) = \alpha_0 + \alpha_2 \sqrt{s_0 - s} + \alpha_3 \sqrt{s_1 - s};$$

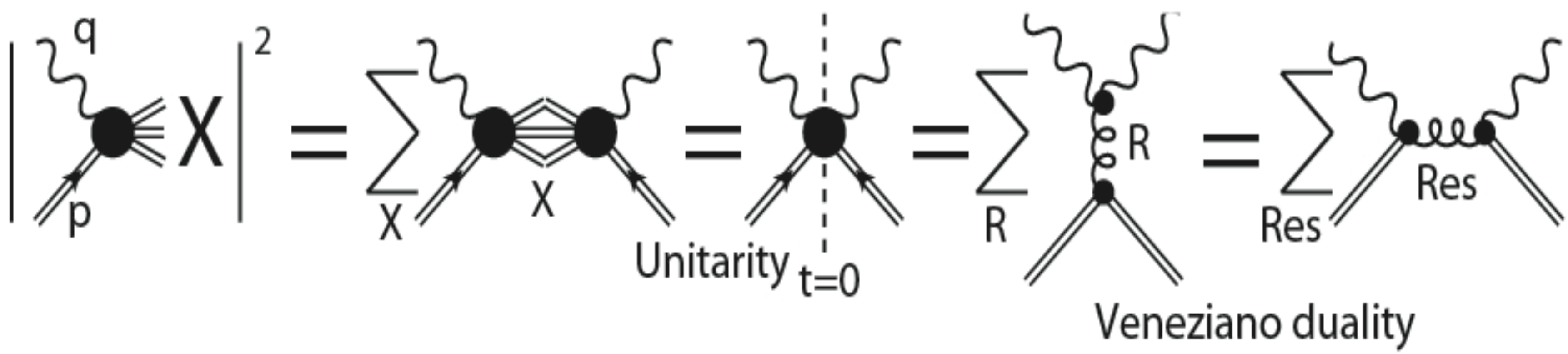
$$\alpha(s) = \frac{\alpha_0 + \alpha' s}{1 + \alpha_4 \sqrt{s_0 - s}},$$



σ_t^{PP}(mb)
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
0
1
2
3
4
5
6
7
M (GeV)
$f_0(500)$
$f_0(980)$
$f_2(1270)$
$f_1(1420)$
gb(J=2)
gb(J=4)
gb(J=6)
SUM
$f_0(500)$
f_1
f_2
Pomeron
background


1
2
3
f(t)
f(t)
f(t)
α(t)
α(t)
α(t)
s
M1
M2
f(t)
M4
M6
s1
α(t1)
M5
M7
M3
S
s2
α(t2)
M8
4
5
6


e
e′
k
k′
α1/2
γ
-q2=Q2
X
p


q
p
X
2
X
X
Unitarity
t=0
R
R
Res
Res
Veneziano duality

- R. Fiore, A. Flachi, L. Jenkovszky, A. Lengyel, and V. Magas, *A kinemetically complete analysis of the CLAS data on the proton structure function F_2 in a Regge-Dual model*, Phys.Rev. D**69** (2004) 014004; arXiv:0308178.

- Wolfgang Schäfer, Photon-Pomeron fusion…, Trento Workshop, March 2017-->
- H. Abramowicz et al. (2007)

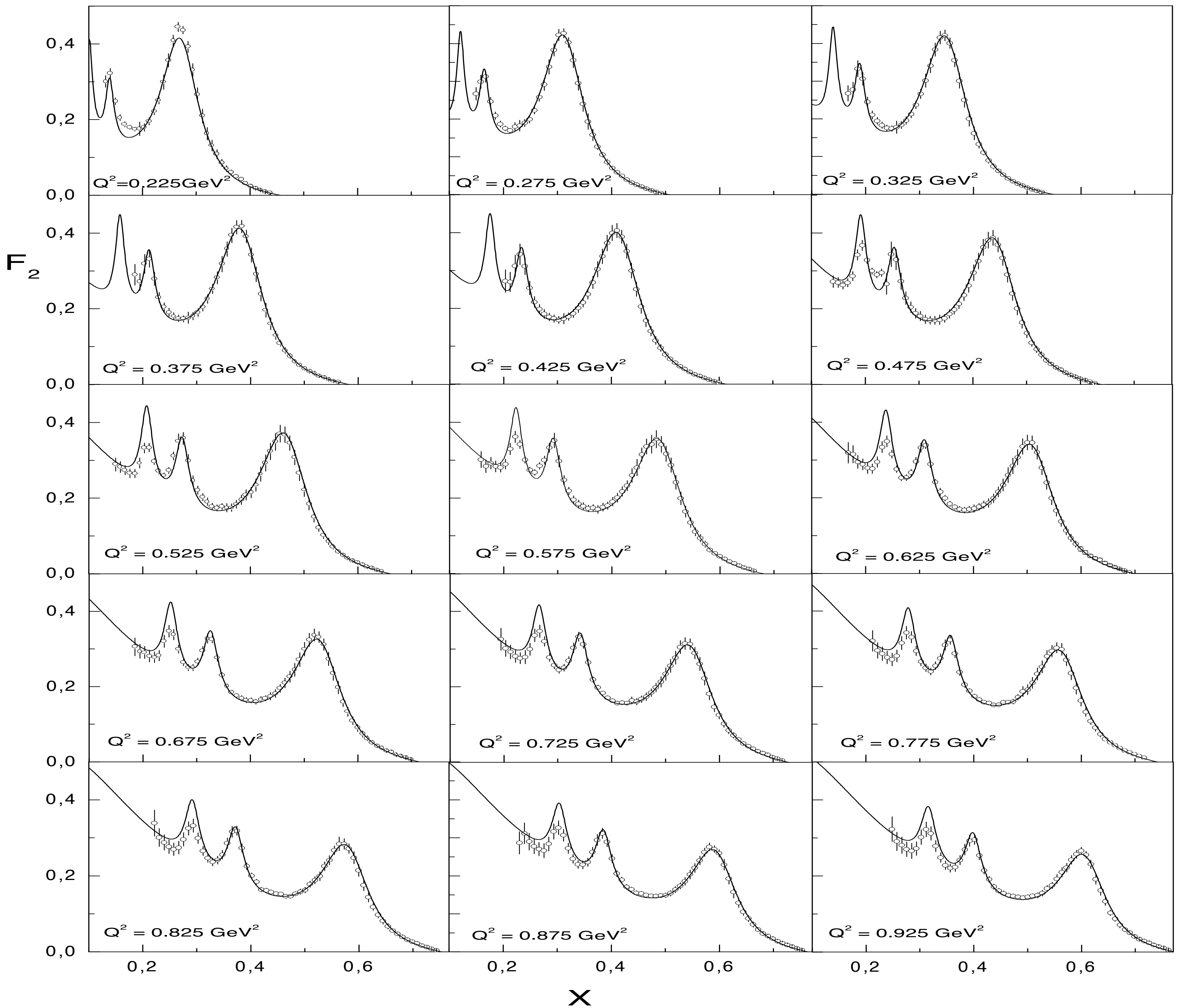
$$F_2(x,Q^2) = \frac{Q^2(1-x)}{4\pi\alpha(1+4m^2x^2/Q^2)}\sigma_t^{\gamma^* p} ,$$

with the norm

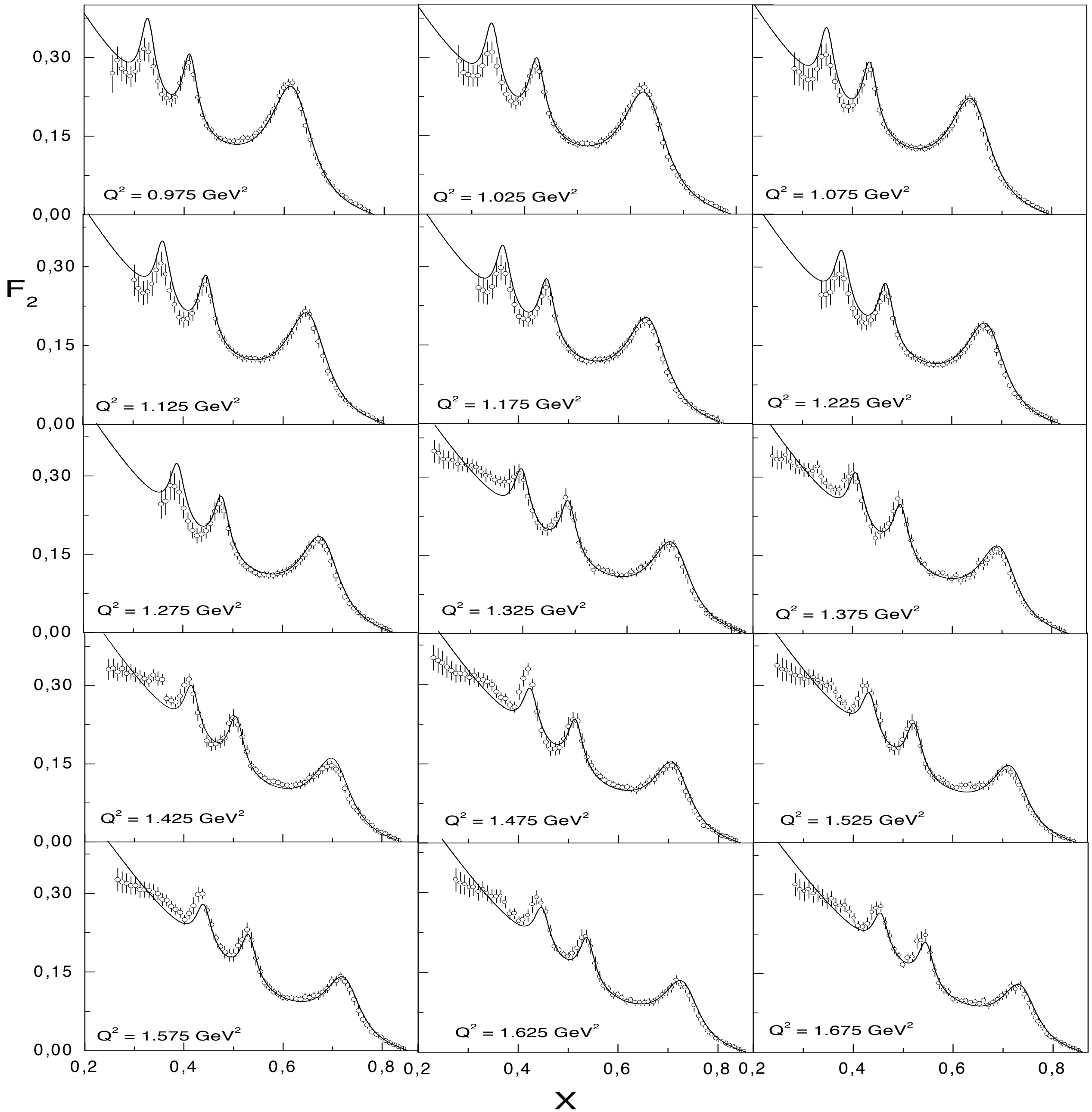
$$\sigma_t^{\gamma^* p}(s) = \mathcal{I}m \; A(s,Q^2) .$$

The center of mass energy of the $\gamma^* p$ system, the negative squared photon virtuality Q^2 and the Bjorken variable x are related by

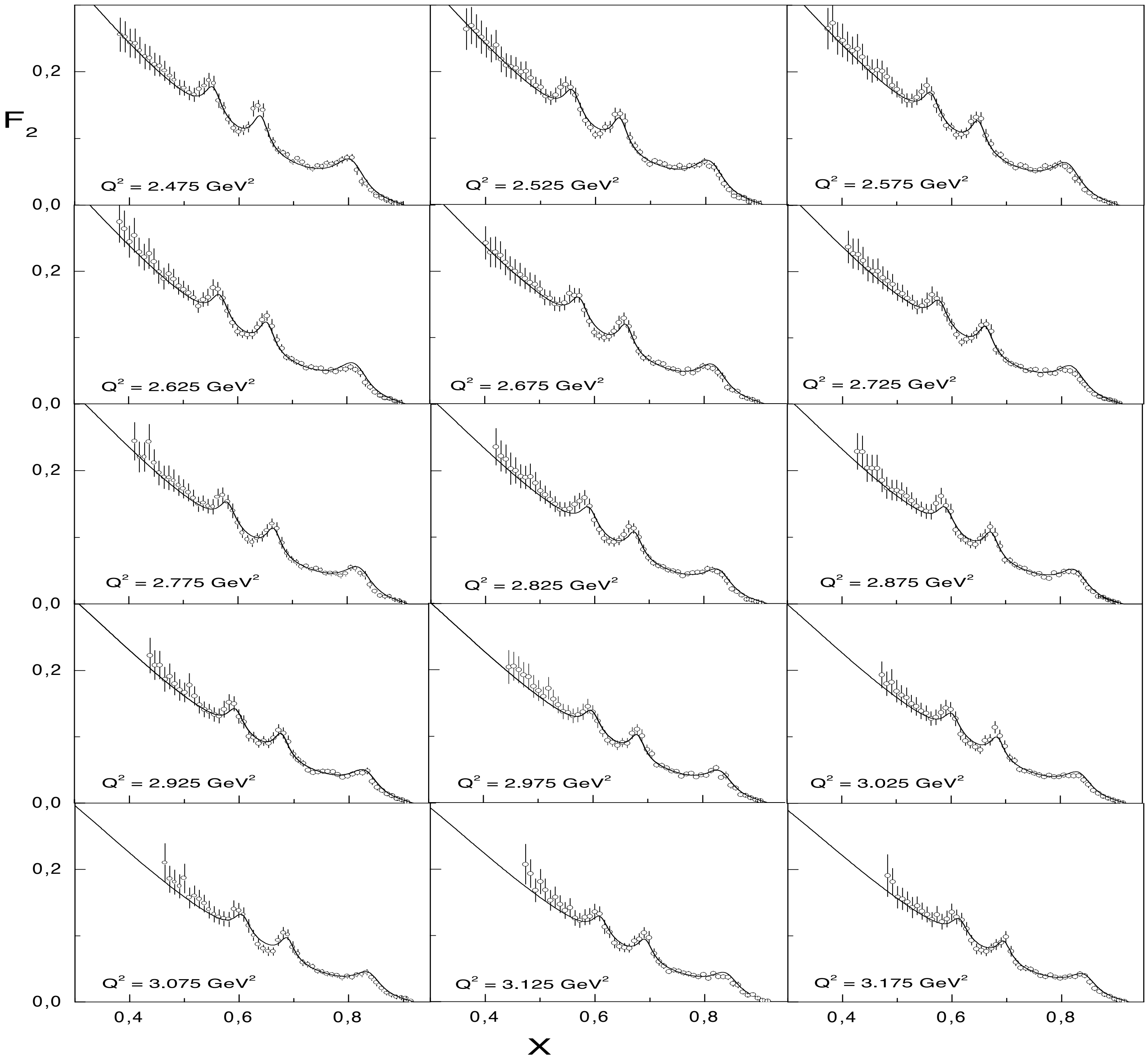
$$s = W^2 = Q^2(1-x)/x + m^2 .$$



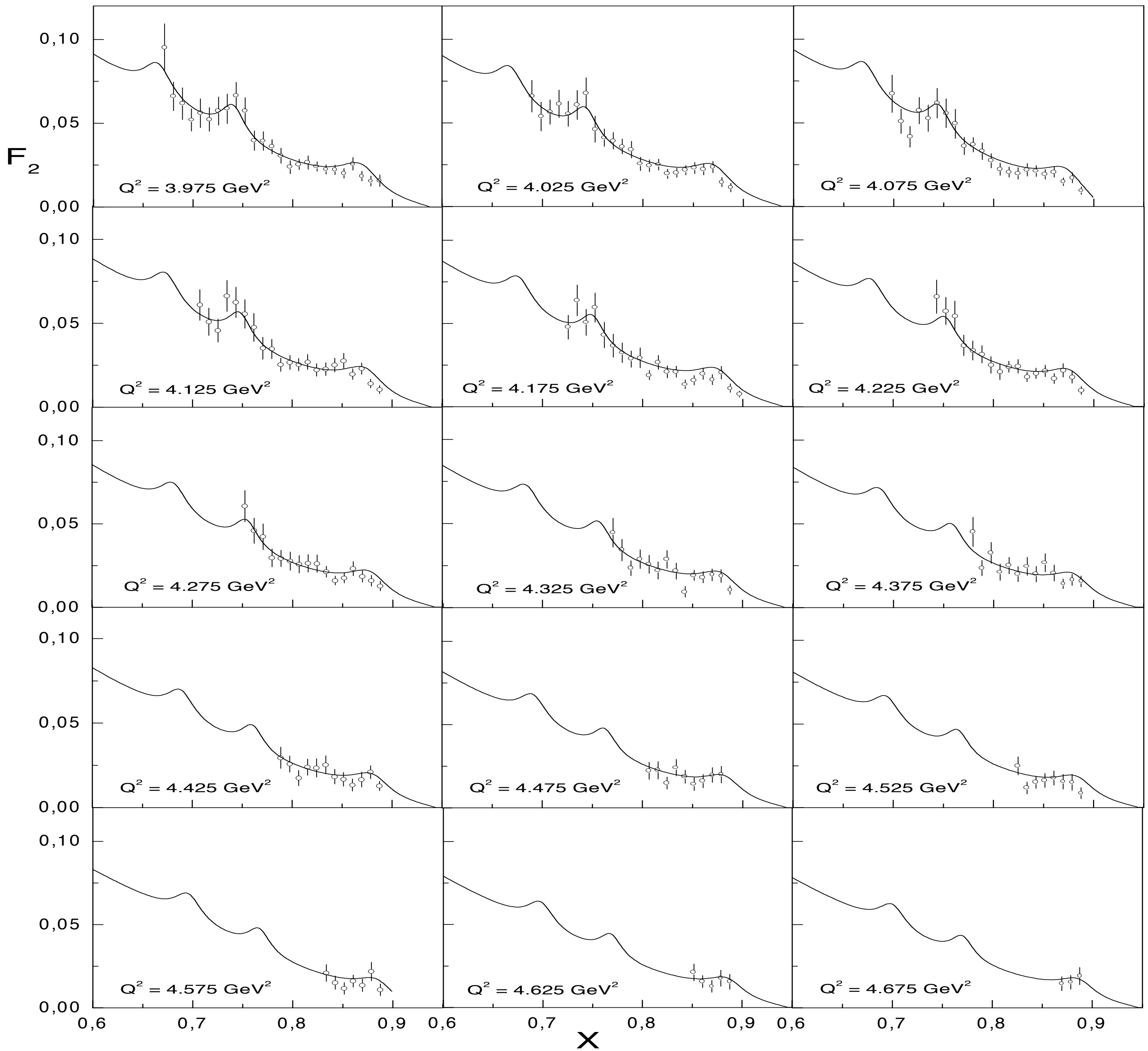
F2
x
0,0
0,2
0,4
0,6
Q2=0.225GeV2
Q2 = 0.275 GeV2
Q2 = 0.325 GeV2
Q2 = 0.375 GeV2
Q2 = 0.425 GeV2
Q2 = 0.475 GeV2
Q2 = 0.525 GeV2
Q2 = 0.575 GeV2
Q2 = 0.625 GeV2
Q2 = 0.675 GeV2
Q2 = 0.725 GeV2
Q2 = 0.775 GeV2
Q2 = 0.825 GeV2
Q2 = 0.875 GeV2
Q2 = 0.925 GeV2



F2
X
Q2 = 0.975 GeV2
Q2 = 1.025 GeV2
Q2 = 1.075 GeV2
Q2 = 1.125 GeV2
Q2 = 1.175 GeV2
Q2 = 1.225 GeV2
Q2 = 1.275 GeV2
Q2 = 1.325 GeV2
Q2 = 1.375 GeV2
Q2 = 1.425 GeV2
Q2 = 1.475 GeV2
Q2 = 1.525 GeV2
Q2 = 1.575 GeV2
Q2 = 1.625 GeV2
Q2 = 1.675 GeV2
0,00
0,15
0,30
0,2
0,4
0,6
0,8

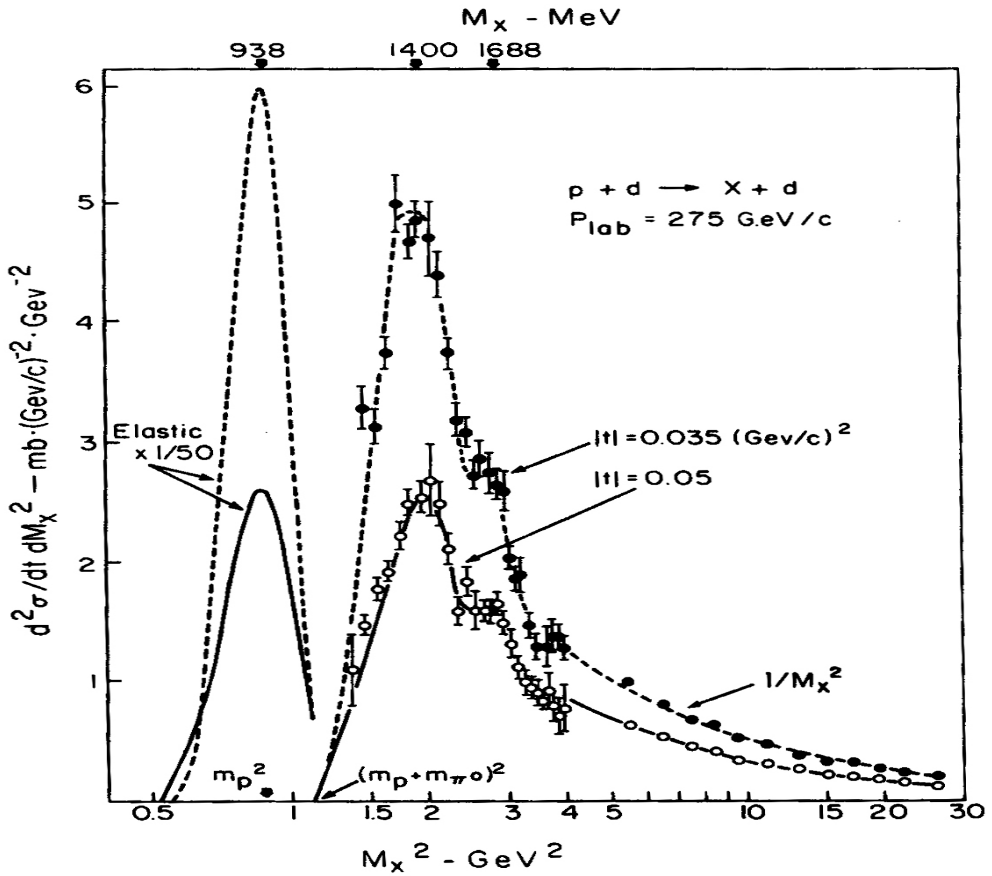


F2
0,0
0,2
Q2 = 2.475 GeV2
Q2 = 2.525 GeV2
Q2 = 2.575 GeV2
Q2 = 2.625 GeV2
Q2 = 2.675 GeV2
Q2 = 2.725 GeV2
Q2 = 2.775 GeV2
Q2 = 2.825 GeV2
Q2 = 2.875 GeV2
Q2 = 2.925 GeV2
Q2 = 2.975 GeV2
Q2 = 3.025 GeV2
Q2 = 3.075 GeV2
Q2 = 3.125 GeV2
Q2 = 3.175 GeV2
0,4
0,6
0,8
X

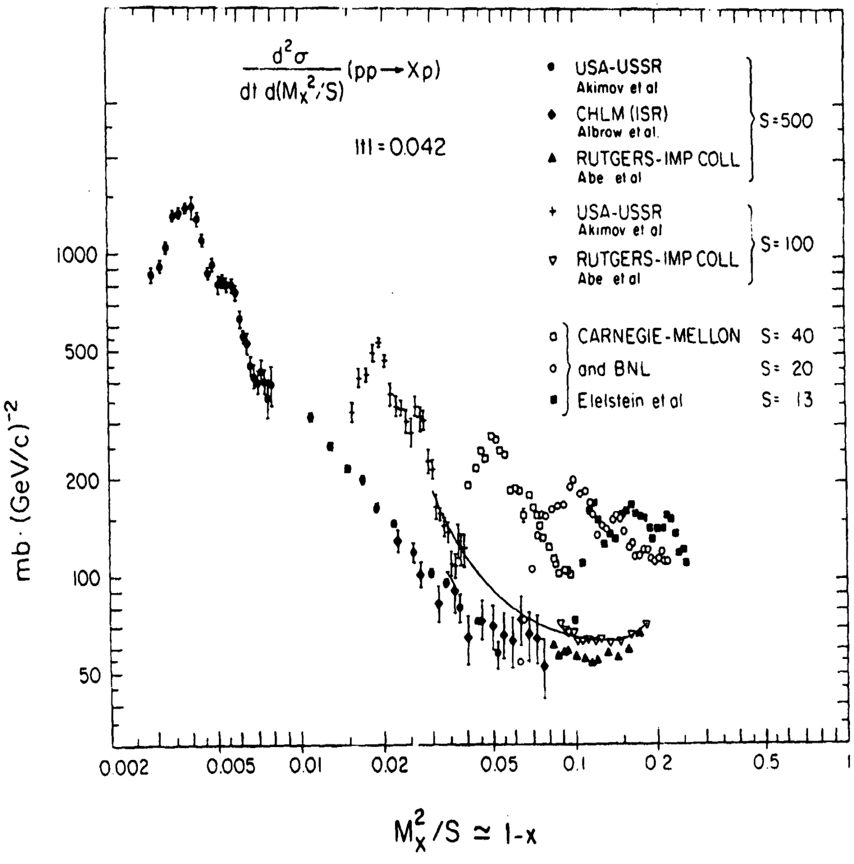


F2
0,10
0,05
0,00
Q2 = 3.975 GeV2
Q2 = 4.025 GeV2
Q2 = 4.075 GeV2
Q2 = 4.125 GeV2
Q2 = 4.175 GeV2
Q2 = 4.225 GeV2
Q2 = 4.275 GeV2
Q2 = 4.325 GeV2
Q2 = 4.375 GeV2
Q2 = 4.425 GeV2
Q2 = 4.475 GeV2
Q2 = 4.525 GeV2
Q2 = 4.575 GeV2
Q2 = 4.625 GeV2
Q2 = 4.675 GeV2
0,6
0,7
0,8
0,9
X

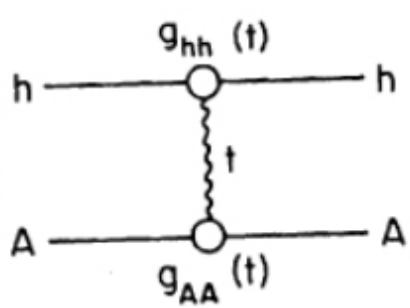
FNAL

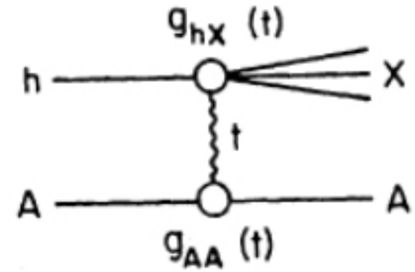


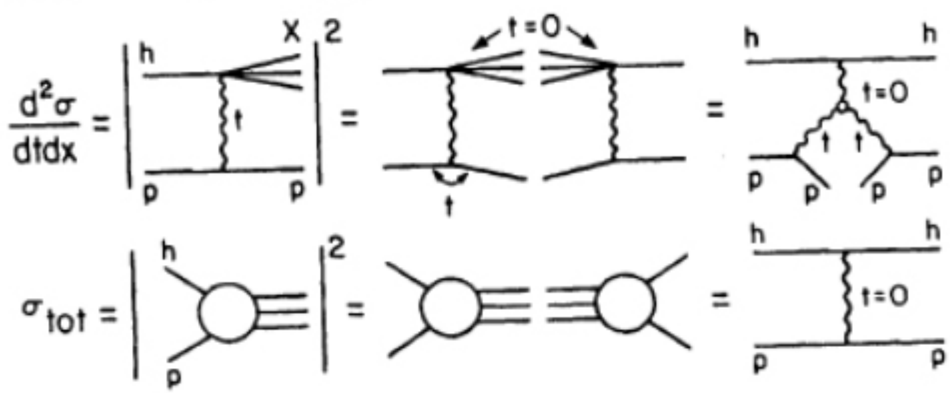
M_x - MeV
938
1400
1688
p + d → X + d
P_lab = 275 GeV/c
Elastic x 1/50
|t| = 0.035 (Gev/c)^2
|t| = 0.05
1/M_x^2
m_p^2
(m_p + m_π0)^2
d^2σ/dt dM_x^2 — mb·(Gev/c)^-2·Gev^-2
M_x^2 - GeV^2



d^2σ/dt d(M_x^2/S) (pp → Xp)
|t| = 0.042
USA-USSR Akimov et al
CHLM (ISR) Albrow et al.
RUTGERS-IMP COLL Abe et al
S=500
USA-USSR Akimov et al
RUTGERS-IMP COLL Abe et al
S=100
CARNEGIE-MELLON S= 40
and BNL S= 20
Eichstein et al S= 13
mb·(GeV/c)^-2
M_x^2/S ≃ 1-x


g_hh (t)
h
h
t
A
A
g_AA (t)


g_hX (t)
h
X
t
A
A
g_AA (t)


d²σ/dtdx =
h
X
2
t
p
p
=
t=0
t
=
h
h
t=0
t t
p
p
p
p
σ_tot =
h
p
2
=
=
h
h
t=0
p
p

Similar to the case of elastic scattering, the double differential cross section for the SDD reaction, by Regge factorization, can be written as

$$\frac{d^2\sigma}{dt dM_X^2} = \frac{9\beta^4[F^p(t)]^2}{4\pi \sin^2[\pi\alpha_P(t)/2]}(s/M_X^2)^{2\alpha_P(t)-2}\times \left[\frac{W_2}{2m}\left(1 - M_X^2/s\right) - mW_1(t+2m^2)/s^2\right], \tag{1}$$

where $W_i, \quad i = 1, 2$ are related to the structure functions of the nucleon and $W_2 \gg W_1$. For high M_X^2, the $W_{1,2}$ are Regge-behaved, while for small M_X^2 their behavior is dominated by nucleon resonances. The knowledge of the inelastic form factors (or transition amplitudes) is crucial for the calculation of low-mass diffraction dissociation.

The pp scattering amplitude

$$A(s,t)_P = \\ -\beta^2[f^u(t)+f^d(t)]^2\left(\frac{s}{s_0}\right)^{\alpha_P(t)-1}\frac{1+e^{-i\pi\alpha_P(t)}}{\sin\pi\alpha_P(t)}, \quad (1)$$

where $f^u(t)$ and $f^d(t)$ are the amplitudes for the emission of u and d valence quarks by the nucleon, β is the quark-Pomeron coupling, to be determined below; $\alpha_P(t)$ is a vacuum Regge trajectory. It is assumed that the Pomeron couples to the proton via quarks like a scalar photon.

A single-Pomeron exchange is valid at the LHC energies, however at lower energies (e.g. those of the ISR or the SPS) the contribution of non-leading Regge exchanges should be accounted for as well.

Thus, the unpolarized elastic pp differential cross section is

$$\frac{d\sigma}{dt} = \frac{[3\beta F^p(t)]^4}{4\pi\sin^2[\pi\alpha_P(t)/2]}(s/s_0)^{2\alpha_P(t)-2}. \quad (2)$$

The final expression for the double differential cross section reads:

$$\frac{d^2\sigma}{dtdM_X^2} = A_0 \left(\frac{s}{M_X^2}\right)^{2\alpha_P(t)-2} \frac{x(1-x)^2\ [F^p(t)]^2}{(M_x^2-m^2)\left(1+\frac{4m^2x^2}{-t}\right)^{3/2}} \times \sum_{n=1,3} \frac{[f(t)]^{2(n+1)}\, Im\,\alpha(M_X^2)}{(2n+0.5-Re\,\alpha(M_X^2))^2+(Im\,\alpha(M_X^2))^2}\,. \tag{1}$$

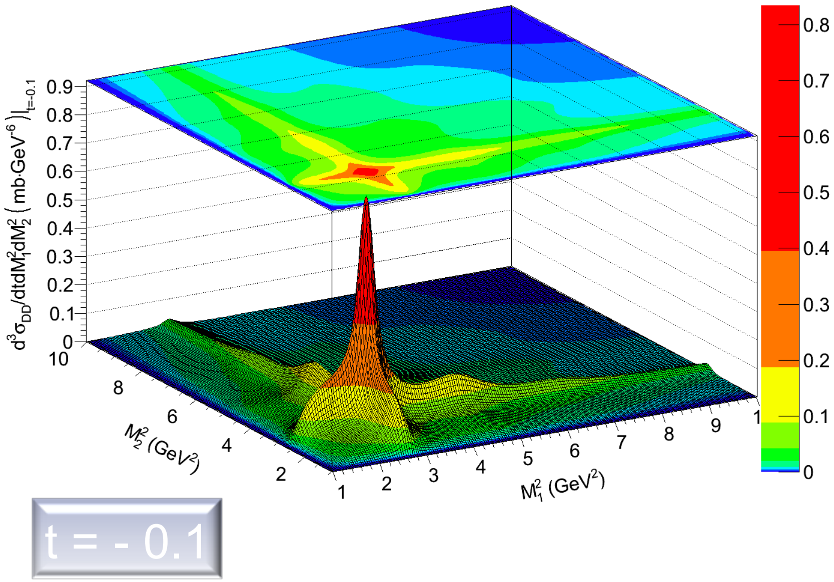
SD and DD cross sections

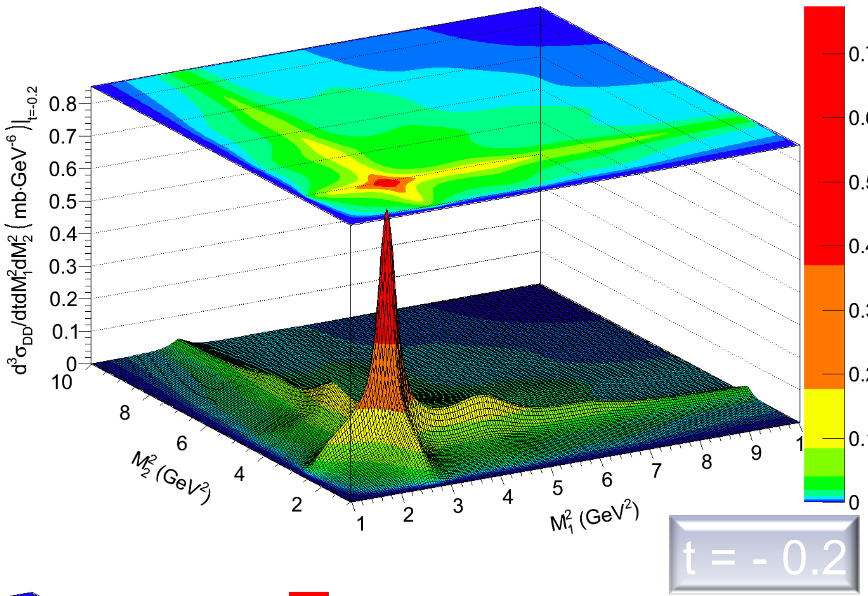
$$\frac{d^2\sigma_{SD}}{dtdM_x^2} = {F_p}^2(t)F(x_B,t)\frac{\sigma_T^{Pp}(M_x^2,t)}{2m_p}\left(\frac{s}{M_x^2}\right)^{2(\alpha(t)-1)}\ln\left(\frac{s}{M_x^2}\right)$$

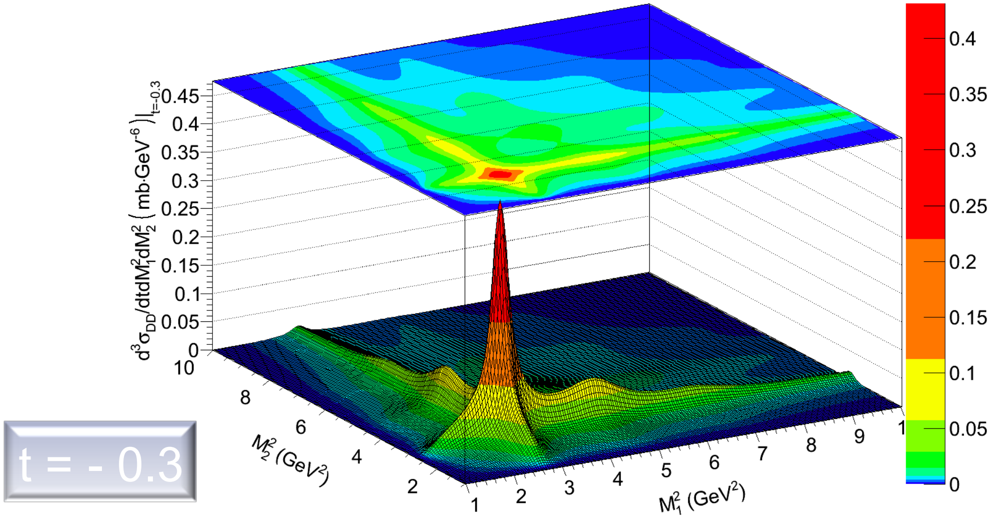
$$\frac{d^3\sigma_{DD}}{dtdM_1^2dM_2^2} = C_nF^2(x_B,t)\frac{\sigma_T^{Pp}(M_1^2,t)}{2m_p}\frac{\sigma_T^{Pp}(M_2^2,t)}{2m_p}$$

$$\times\left(\frac{s}{(M_1+M_2)^2}\right)^{2(\alpha(t)-1)}\ln\left(\frac{s}{(M_1+M_2)^2}\right)$$

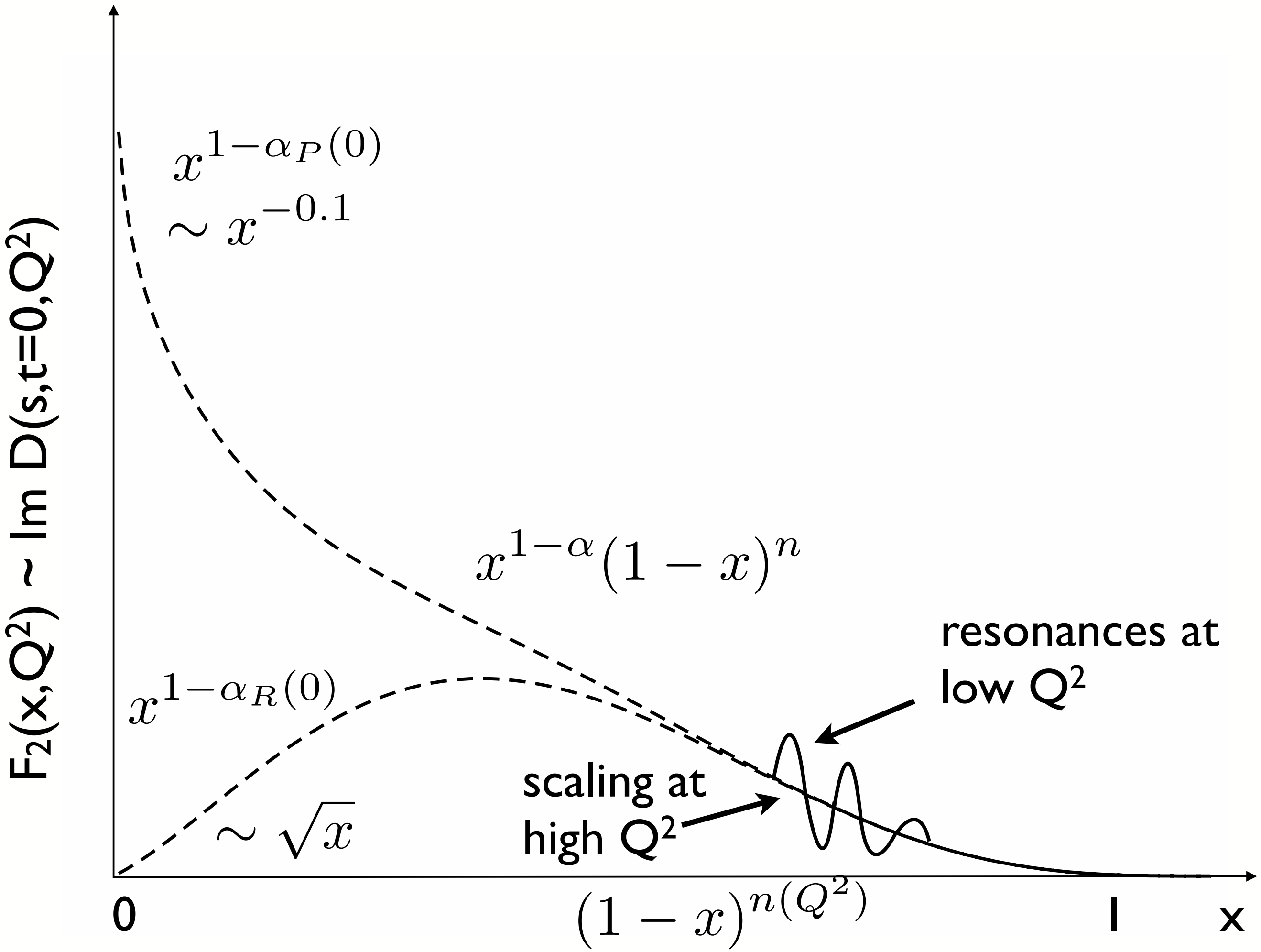
Triple differential DD cross sections

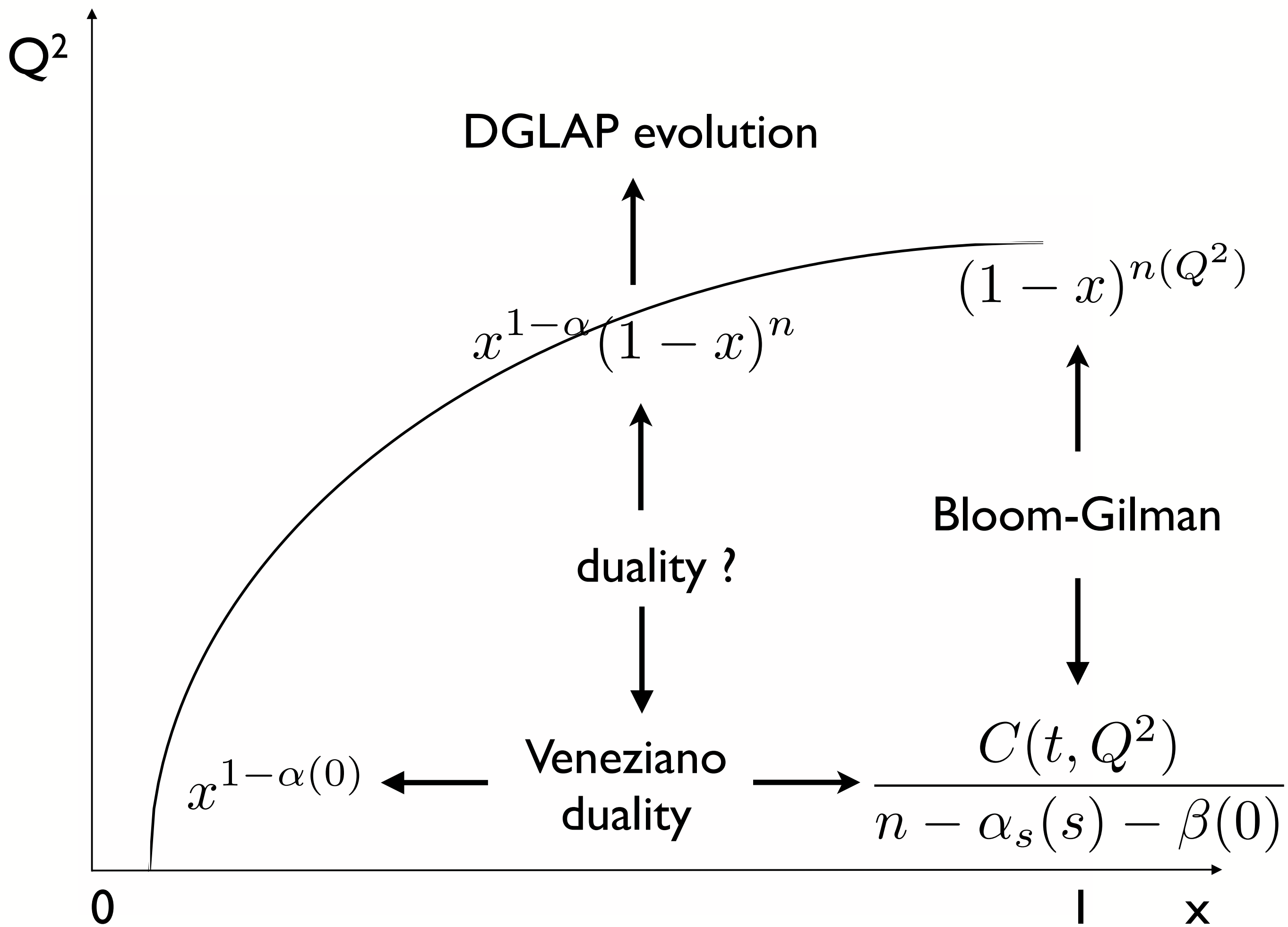






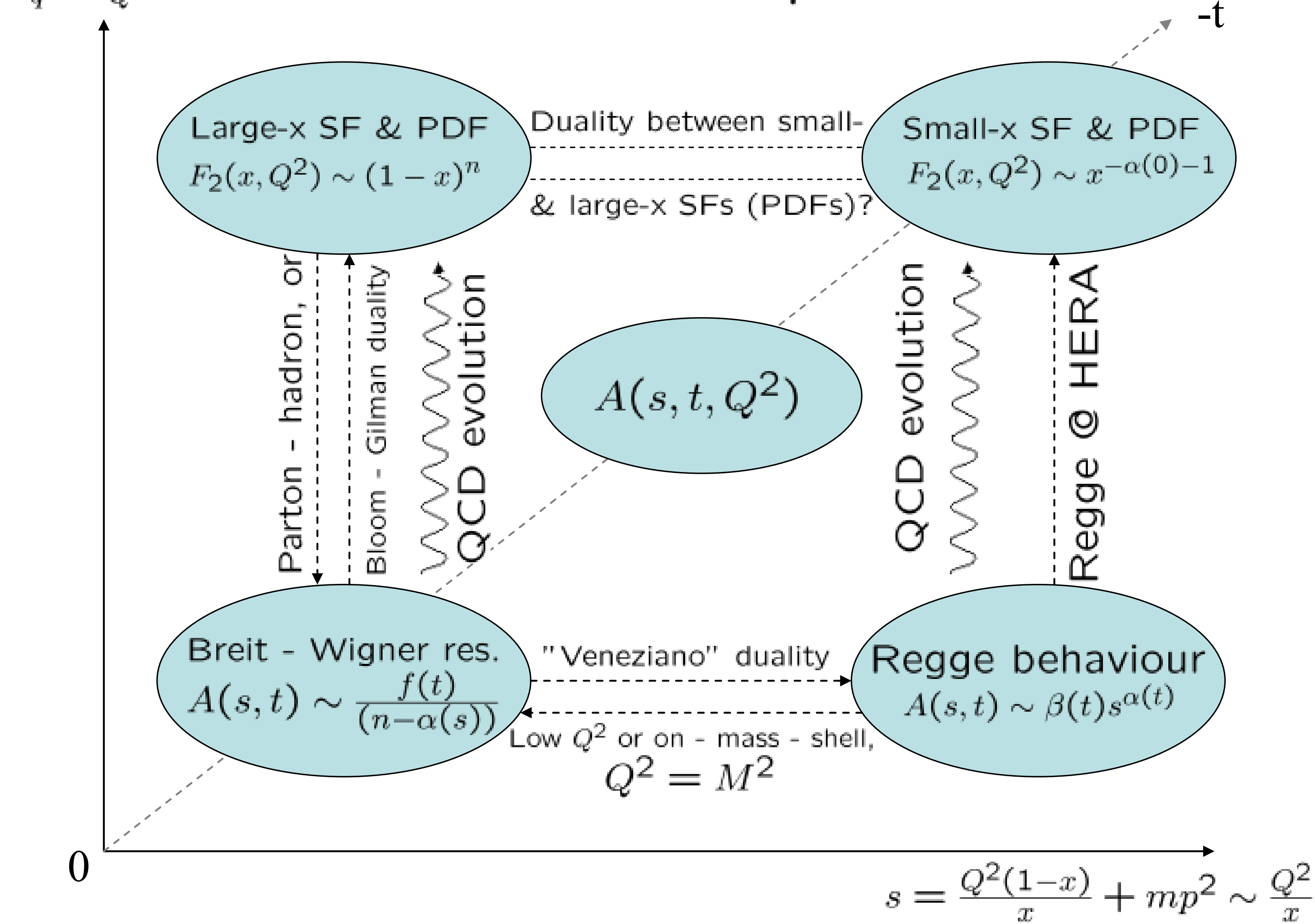
L.L. Jenkovszky, V.K. Magas, J.T. Londergan, A.P. Szczepaniak,
Model Realizing Parton-Hadron Duality,
arXiv:1204.2216





Q^2
DGLAP evolution
$x^{1-\alpha}(1-x)^n$
$(1-x)^{n(Q^2)}$
Bloom-Gilman
duality ?
Veneziano
duality
$x^{1-\alpha(0)}$
$\frac{C(t,Q^2)}{n-\alpha_s(s)-\beta(0)}$
0
1
x

Road map



$-q^2 = Q^2$
-t
Large-x SF & PDF
$F_2(x, Q^2) \sim (1-x)^n$
Duality between small-
& large-x SFs (PDFs)?
Small-x SF & PDF
$F_2(x, Q^2) \sim x^{-\alpha(0)-1}$
Parton - hadron, or
Bloom - Gilman duality
QCD evolution
$A(s, t, Q^2)$
QCD evolution
Regge @ HERA
Breit - Wigner res.
$A(s,t) \sim \frac{f(t)}{(n-\alpha(s))}$
"Veneziano" duality
Regge behaviour
$A(s,t) \sim \beta(t) s^{\alpha(t)}$
Low Q^2 or on - mass - shell,
$Q^2 = M^2$
0
$s = \frac{Q^2(1-x)}{x} + mp^2 \sim \frac{Q^2}{x}$

Thank you!

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