Evolution and flavor effects in $e^+e^- \to h_1 h_2 X$

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Breaking news

arXiv.org > hep-ph > arXiv:1508.00402

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High Energy Physics – Phenomenology

Effects of TMD evolution and partonic flavor on e^+e^- annihilation into hadrons

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(Submitted on 3 Aug 2015)

We calculate the transverse momentum dependence in the production of two back-to-back hadrons in electron-positron annihilations at the medium/large energy scales of BES-III and BELLE experiments. We use the parameters of the transverse-momentum-dependent (TMD) fragmentation functions that were recently extracted from the semi-inclusive deep-inelastic-scattering multiplicities at low energy from HERMES. TMD evolution is applied according to different approaches and using different parameters for the nonperturbative part of the evolution kernel, thus exploring the sensitivity of our results to these different choices and to the flavor dependence of parton fragmentation functions. We discuss how experimental measurements could discriminate among the various scenarios.

Comments:	33 pages, 10 composite figures, JHEP style file
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Report number:	NIKHEF preprint number 2014-035
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	(or arXiv:1508.00402v1 **[hep-ph]** for this version)

Impact of QCD evolution
with flavor dependent
TMD input distributions

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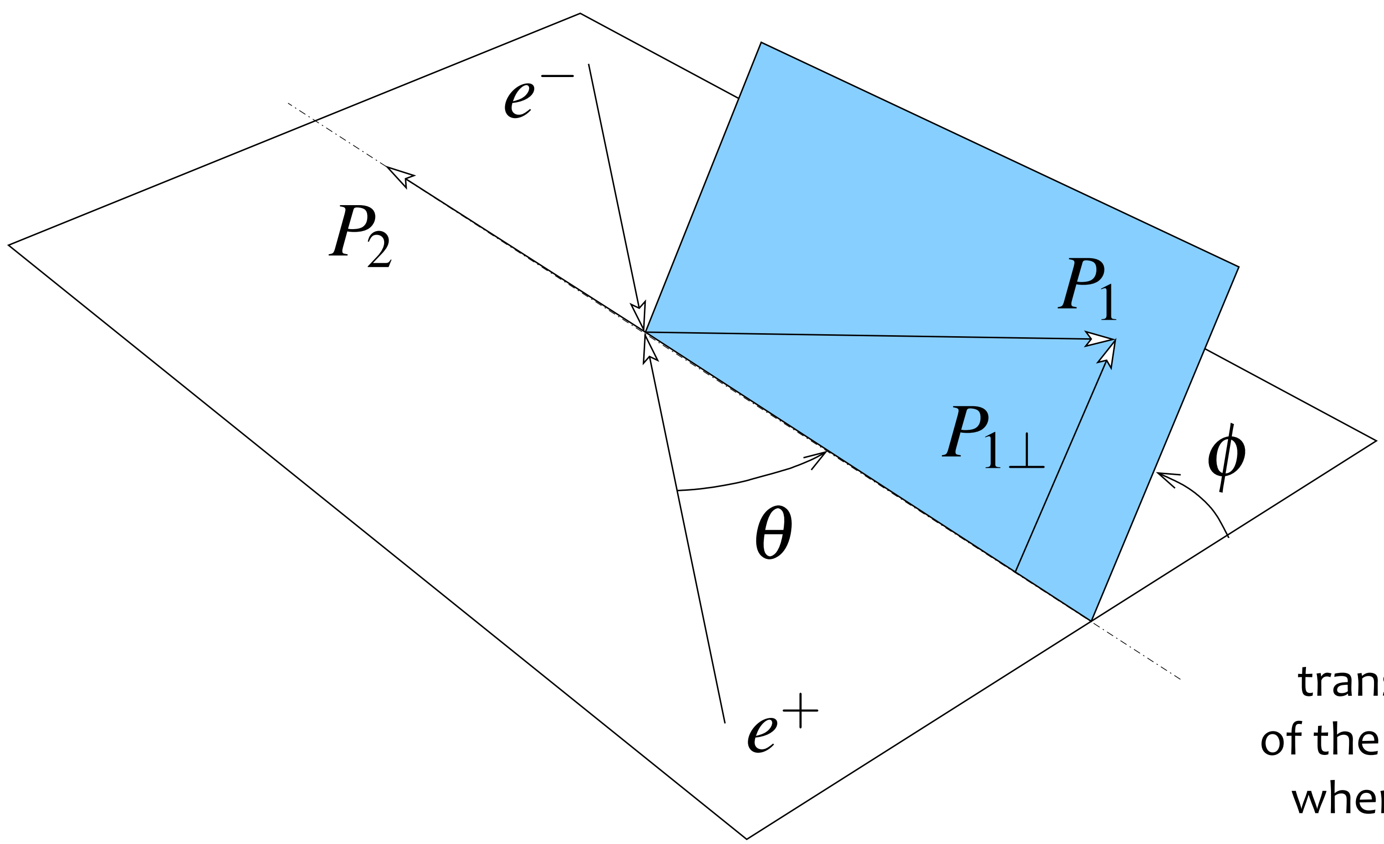
Kinematics and observables



e+e- CM frame:
production of two back-to-back jets
with leading hadrons h1 and h2

h1 only has transverse momentum wrt to z

$$q_T^\mu = -\frac{P_{1\perp}^\mu}{z_1} + O\left(\frac{M^2}{Q^2}\right)$$

transverse momentum of the photon in the frame where h1,2 are collinear

transverse momentum of h1 wrt photon

Our observable: normalized multiplicity,
poorly sensitive to perturbative corrections

$$M^{h_1 h_2}(z_1, z_2, q_T^2, y)/M^{h_1 h_2}(z_1, z_2, 0, y)$$

Multiplicity,
defined as in SIDIS

$$M^{h_1 h_2}(z_1, z_2, q_T^2, y) = \frac{d\sigma^{h_1 h_2}}{dz_1\ dz_2\ dq_T^2\ dy} \Big/ \frac{d\sigma^{h_1}}{dz_1\ dy}$$

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Implementation of evolution

$$\frac{d\sigma^{h_1 h_2}}{dz_1 dz_2 dq_T^2 dy} \sim H(Q^2,\mu) \longrightarrow \text{1, no alpha corrections}$$

$$\times \sum_q e_q^2 \int_0^\infty db_T b_T \; J_0(q_T b_T) \left[z_1^2 D_1^{q\to h_1}(z_1, b_T;\mu,\zeta_1) z_2^2 D_1^{\bar{q}\to h_2}(z_2, b_T;\mu,\zeta_2) + (q \leftrightarrow \bar{q}) \right]$$

$$+ \cancel{Y(q_T^2/Q^2)} + \cancel{\mathcal{O}(M^2/Q^2)}$$

no high qT tail
(collinear factorization)

no higher twist

$$D_1^{q\to h}(z, b_T;\mu,\zeta) = \underbrace{[C \otimes d_1^{q\to h}](z, b_T;\mu,\zeta)}_{\text{small } b_T/\text{medium } k_T} + \underbrace{\mathcal{O}(b_T \Lambda_{\rm QCD})}_{\text{high } b_T/\text{small } k_T} \longrightarrow$$

flavor and kinematic dependent Gaussian model (JHEP 1311 (2013) 194)

$$e^{-\frac{\langle k_T^2\rangle_{q/h}(z)}{4} b_T^2}$$

LO and NLL
pert. Sudakov
quark form factor

OPE coefficients
are delta on the
flavors

models for
non-pert.
Sudakov quark f.f.

$$g_{\rm np}^{\rm lin/log}(b_T^2; g_2)$$

models for
the small/high bT
separation

$$\hat{b}_T(b_T; b_{\max}) = \{b_T^* \; , b_T^\dagger\}$$

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Implementation of evolution

$$b_T^* = \frac{b_T}{\sqrt{1 + \frac{b_T^2}{b_{\max}^2}}} \xrightarrow[b_T \to \infty]{} b_{\max}$$

$$b_T^\dagger = b_{\max} \left\{ 1 - \exp\left[- \frac{b_T^4}{b_{\max}^4} \right] \right\}^{\frac{1}{4}} \xrightarrow[b_T \to \infty]{} b_{\max}$$

two different ways
to approach bmax,
the point where we stop
trusting the perturbative result

for b larger than bmax
a model is needed
also in the evolution

$$g_{\mathrm{np}}^{\mathrm{lin}}(b_T^2; g_2) = \frac{g_2}{4} b_T^2$$

$$g_{\mathrm{np}}^{\log}(b_T^2; g_2) = g_2 \ln\left(1 + \frac{b_T^2}{4}\right)$$

bmax and g2
are anticorrelated
parameters

see also PhysRevD.91.074020
(Collins, Rogers)

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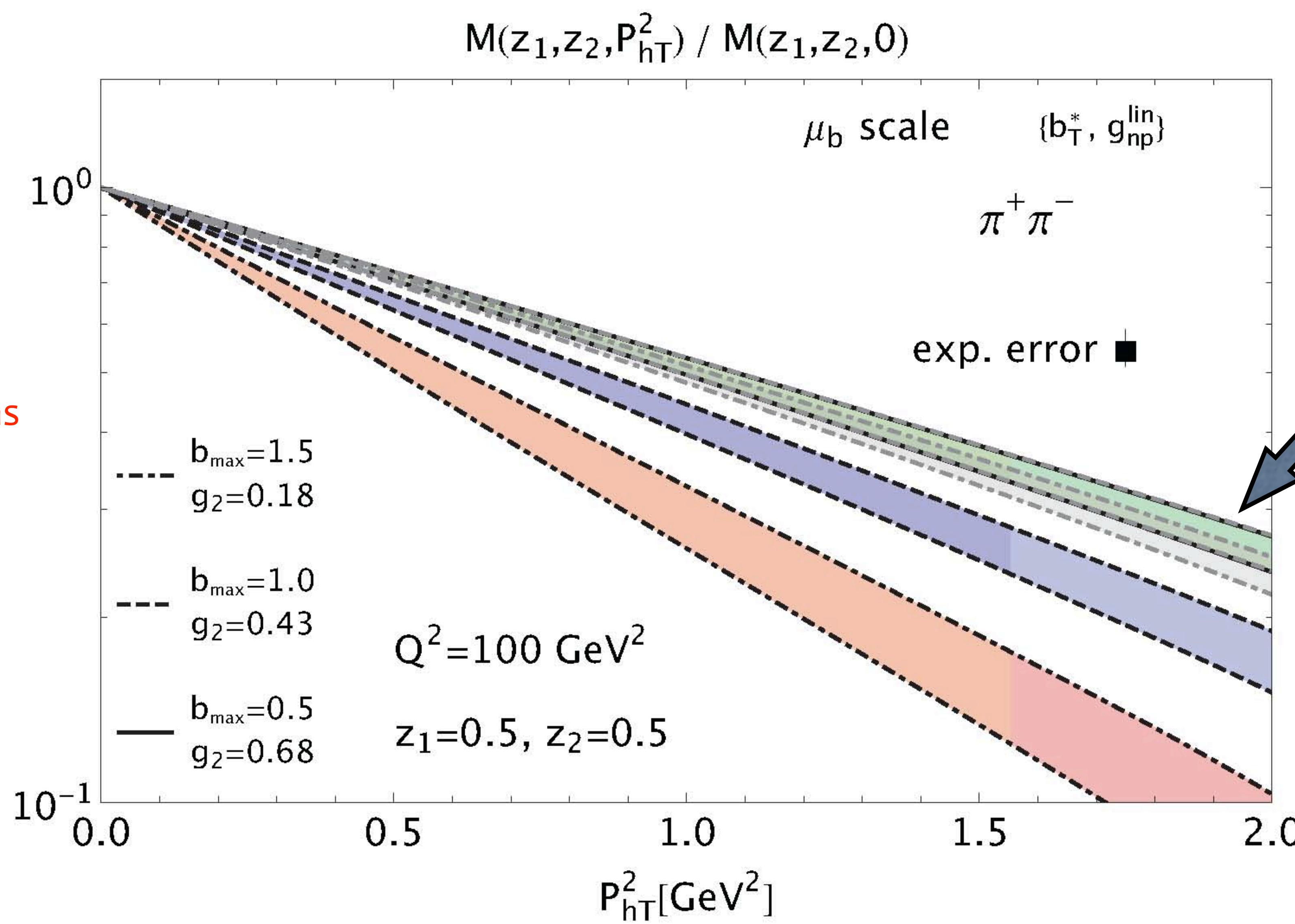
Sensitivity to …

Only a selection of results

… non-perturbative evolution



different values
produce
different predictions

theoretical uncertainty
(grey) is much smaller
wrt the NP effects (rgb)

assuming 7% uncertainty
we can discriminate
among different NP scenarios

the results are stable upon variations
of the renormalization scale

$$\mu = \{\mu_b/2,\ \mu_b,\ 2\mu_b\}$$

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... factorization scale (evolution scheme)

$$\sigma^{\mathrm{F.O.}} \sim \ln \frac{Q}{q_T} \xrightarrow[\text{at scale } \mu]{\text{factorization}} \ln \frac{Q}{\mu} \cdot \frac{\mu}{\mu_b} = \ln \frac{Q}{\mu} + \ln \frac{\mu}{\mu_b}$$

factorization in a nutshell

$\ln \frac{Q}{\mu}$: hard part H

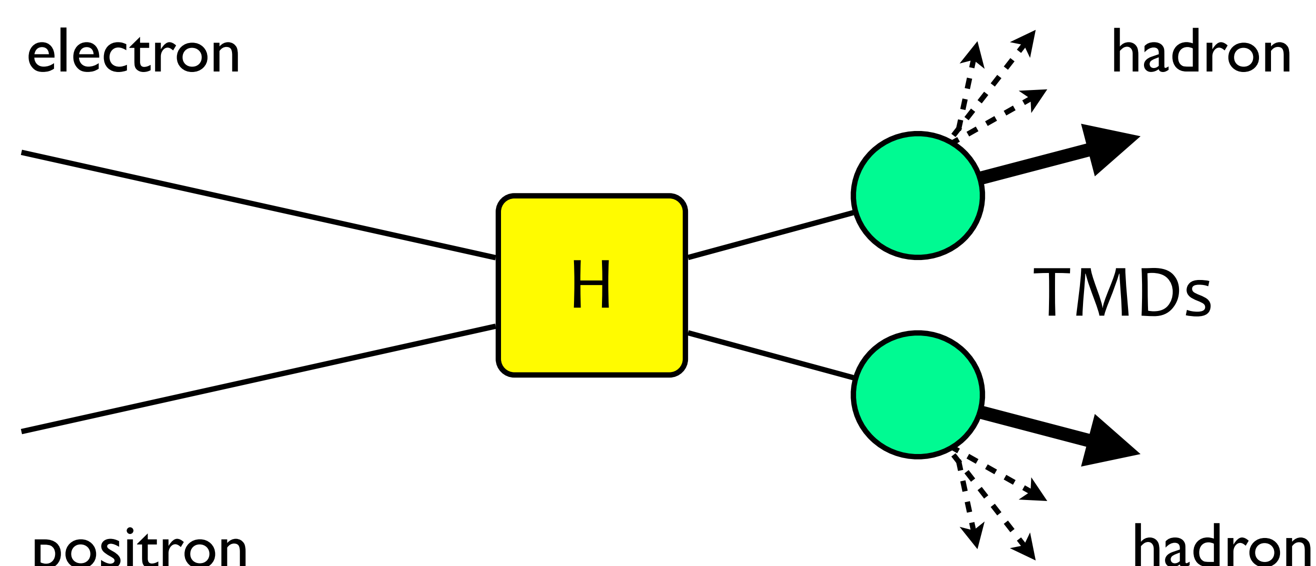
$\ln \frac{\mu}{\mu_b}$: perturbative part of W term (TMDs)

Different choices are possible for the factorization scale, with different implications:

resumming these logarithms we get a finite cross section at low qT

$\mu \to \mu_b \sim 1/b\ , q_T$ minimize logs in W

$\mu \to Q$ minimize logs in H



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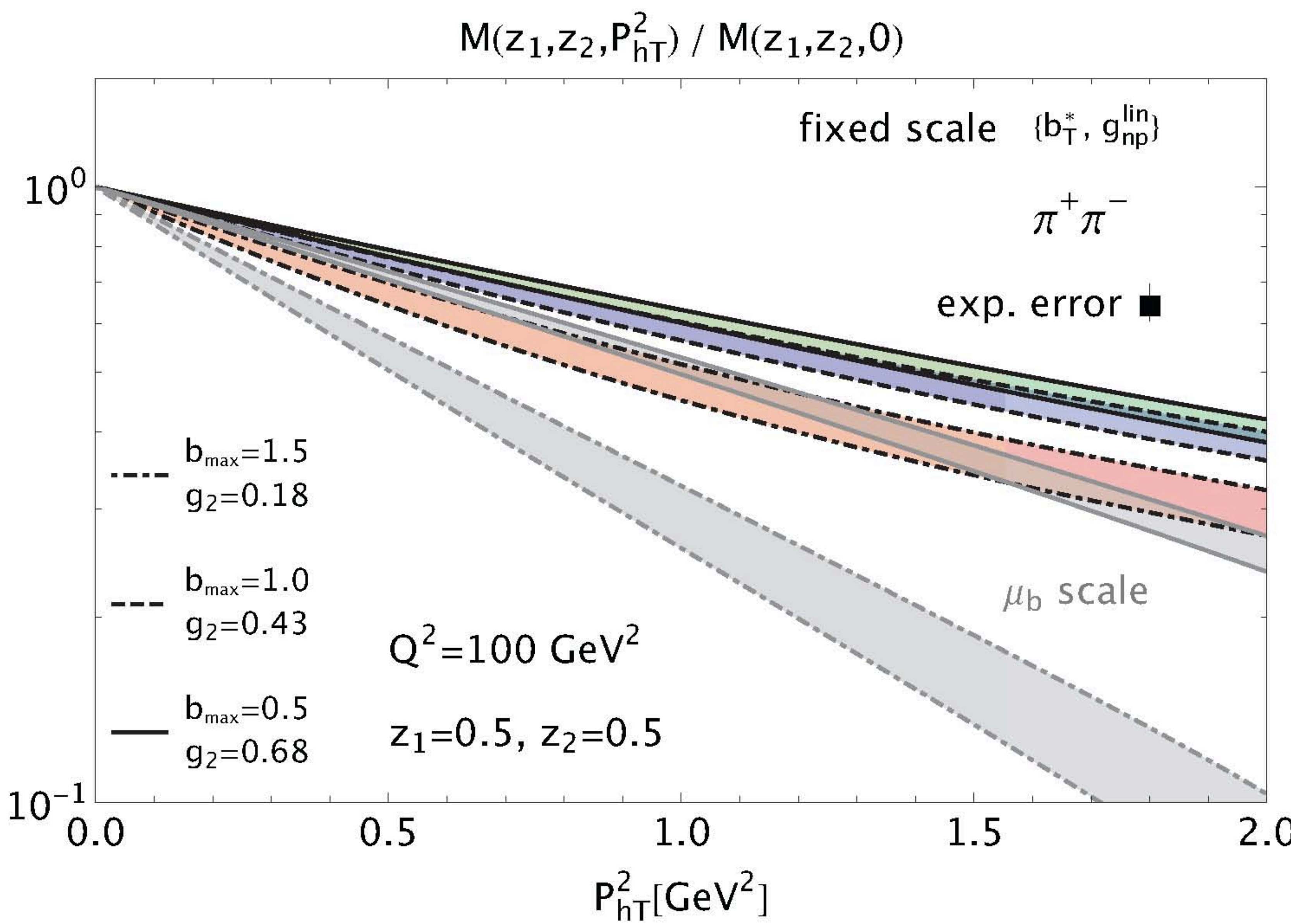
… factorization scale (evolution scheme)



Q enhances the logs in the evolved TMDs, mub minimizes them:

$$\ln Q/\mu_b$$

$$\ln \mu_b/\mu_b = 0$$

using Q rather than mub
we get very different predictions

overall effect: larger distributions,
more perturbative content

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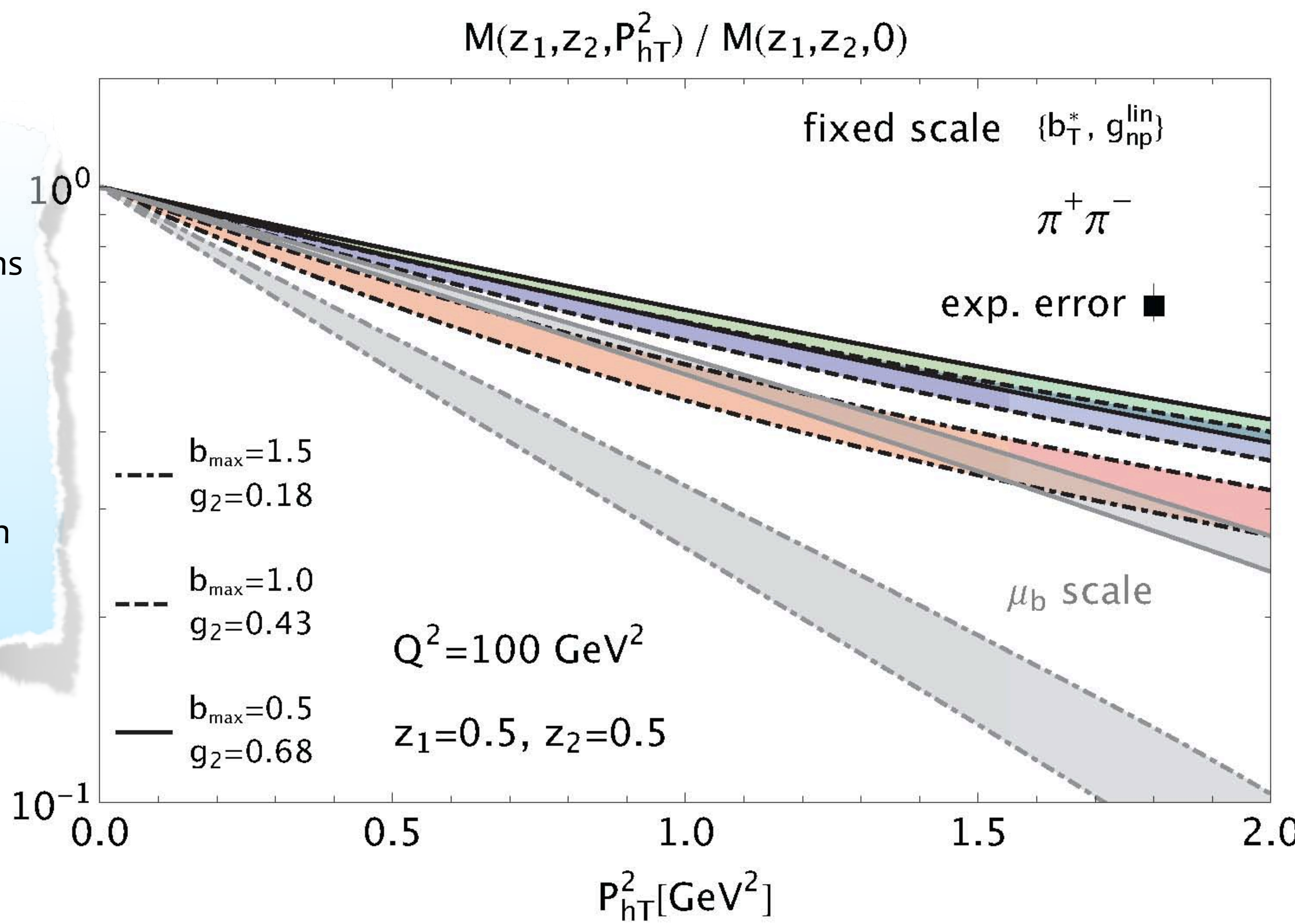
... factorization scale (evolution scheme)

overlap between the two prescriptions for different NP parameters

can't we distinguish them ?



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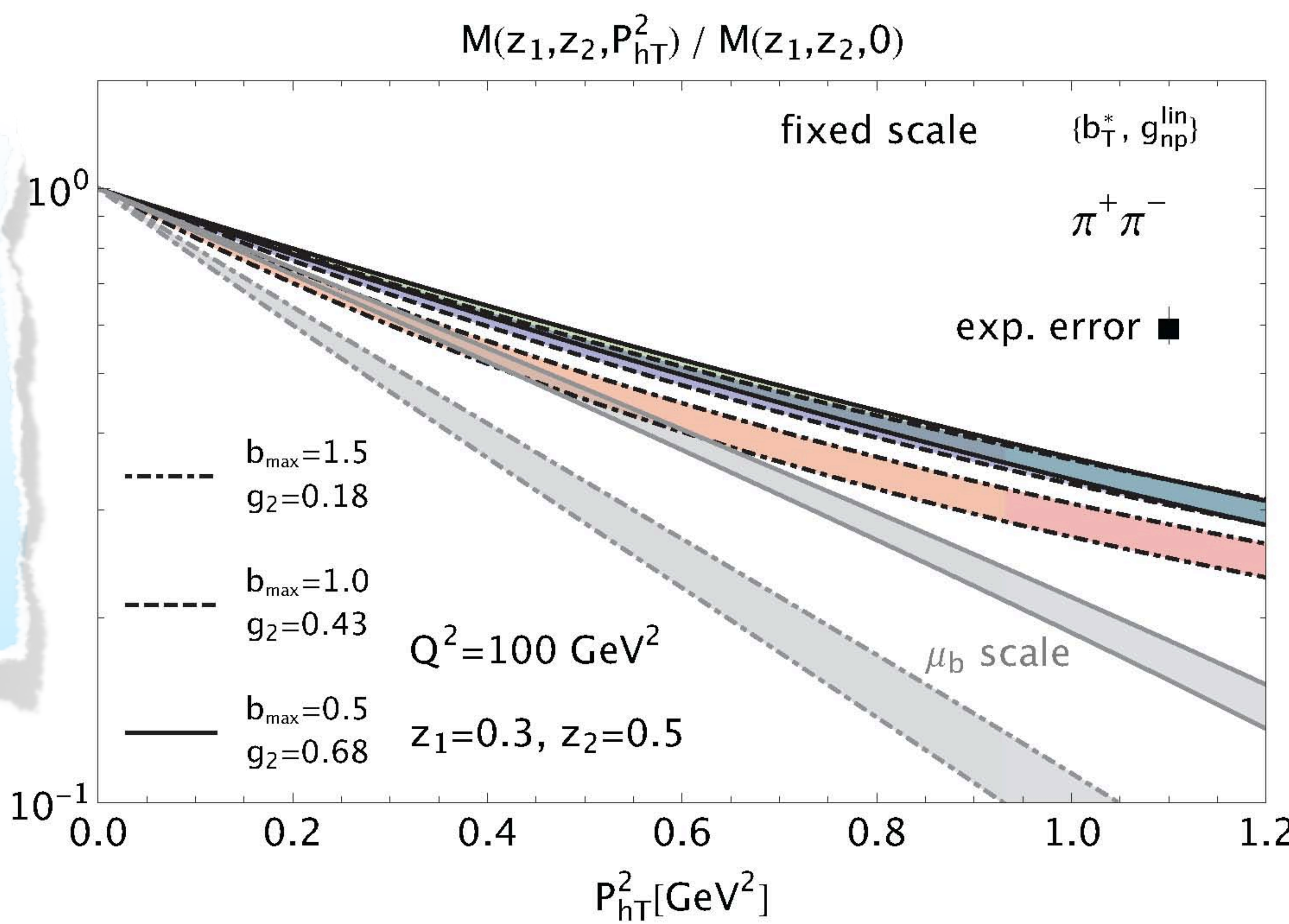
... factorization scale (evolution scheme)

Yes, but only taking into account the z dependence too!

it requires combined information on P1\perp and z1, z2



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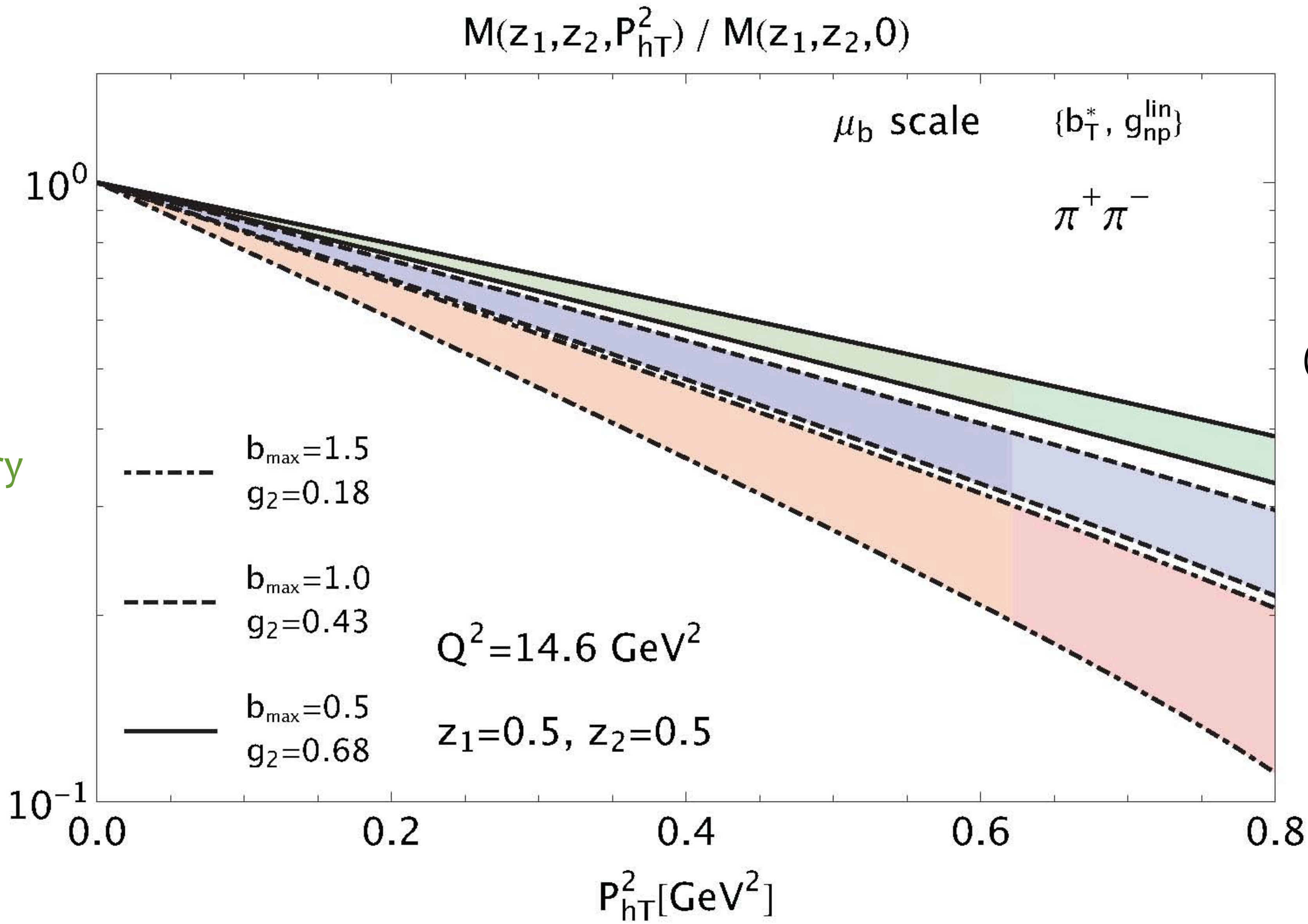
… hard scale Q (Belle vs BES-III)

low and high Q
are
complementary



not useful
to discrimante
among different
scenarios
(the bands are too large)

useful
to select some of
the replicas within
the NP bands

Belle $Q^2 = 100\ \mathrm{GeV}^2$ or $Q^2 = 14.6\ \mathrm{GeV}^2$? BES-III

it depends on the goal !

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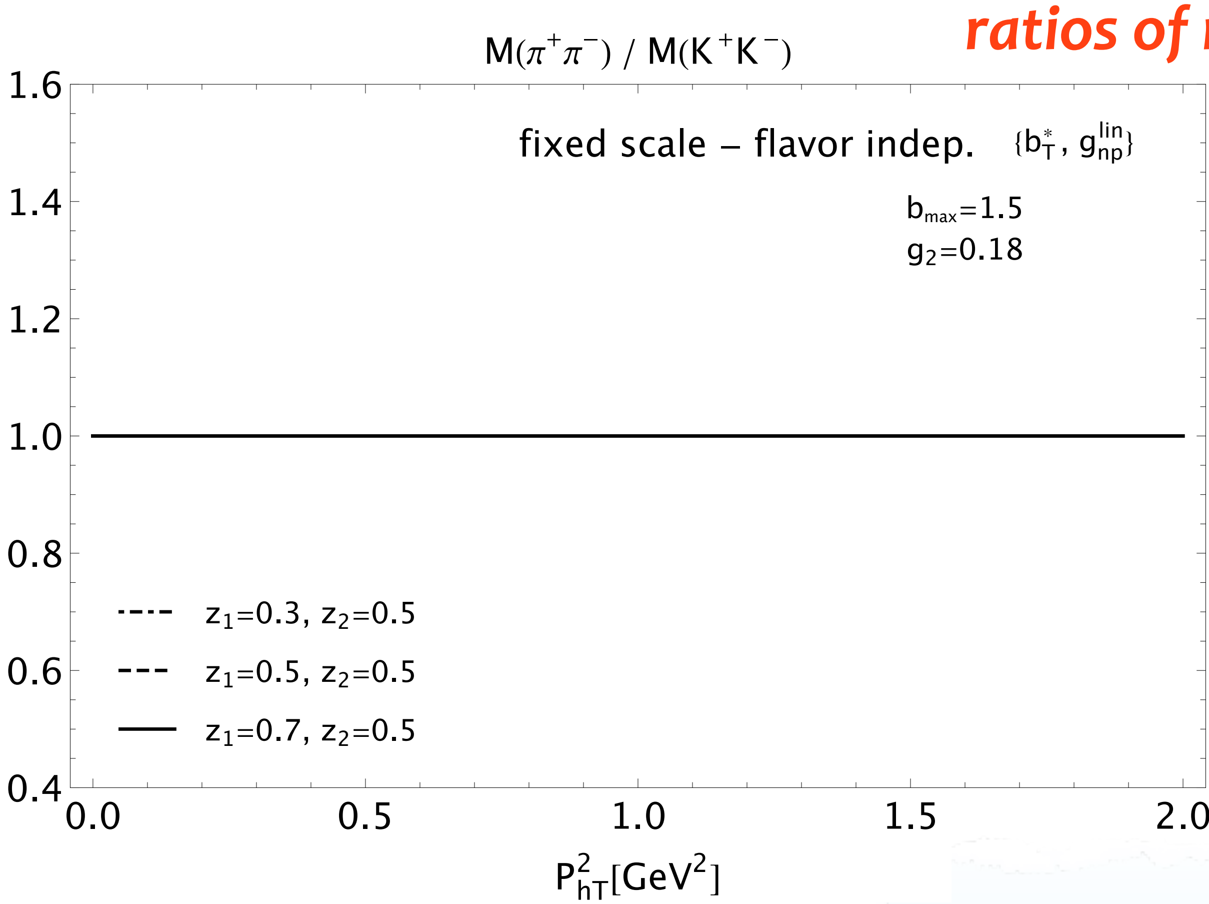
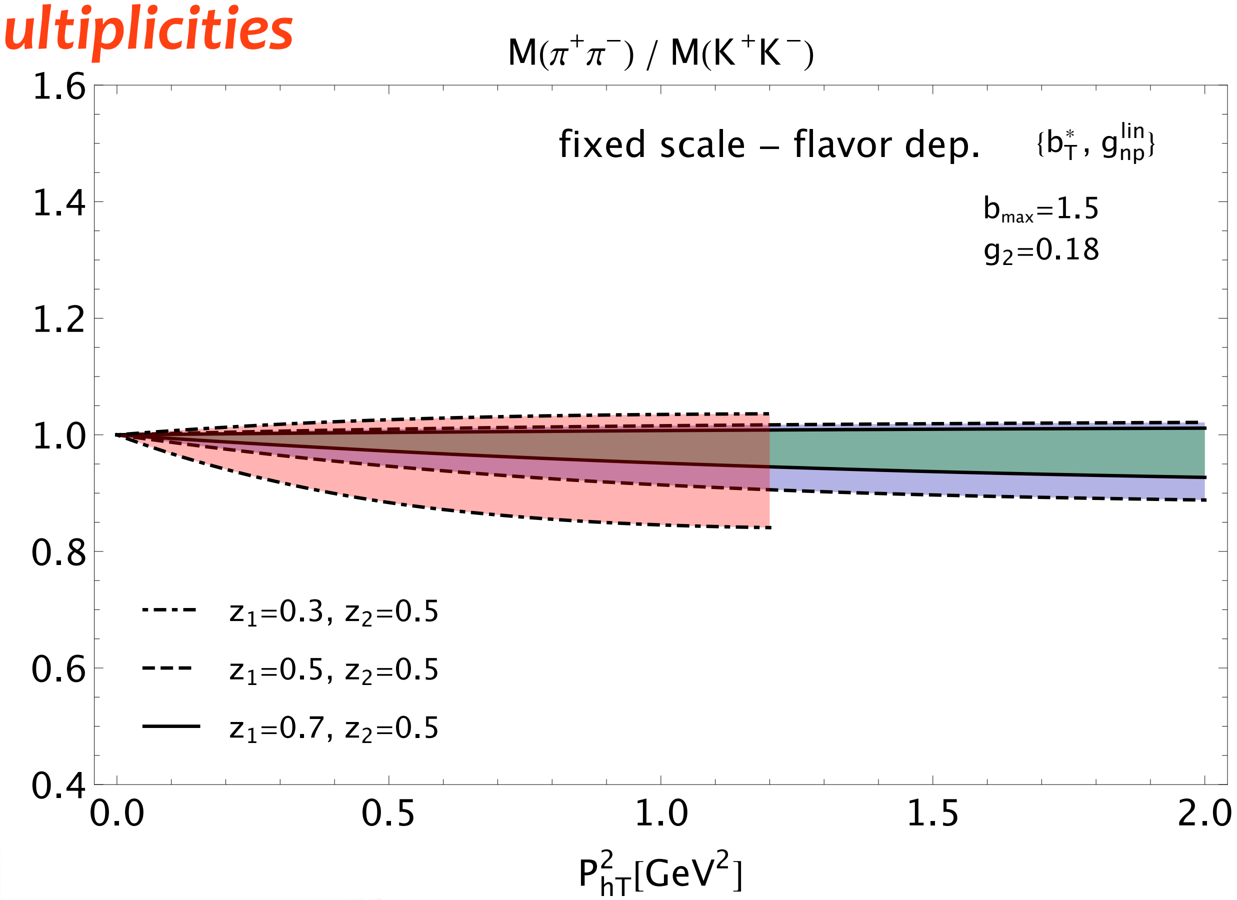
… partonic flavor

fixed scale evolution

ratios of multiplicities





being flavor independent
they factor out and cancel:

no qT dependence is left

the transverse momentum
dependence is described
ONLY by the input NP
Gaussian distributions

$$d_1^{q\to h}(z, Q_i)e^{-\frac{\langle k_T^2\rangle_{q\to h}(z)}{4}b_T^2}$$

being flavor dependent
they combine and give a
specific qT dependence

band width result from
intrinsic flavor dependence

~ lower than 1 because the kaon TMDFFs are larger than pion ones

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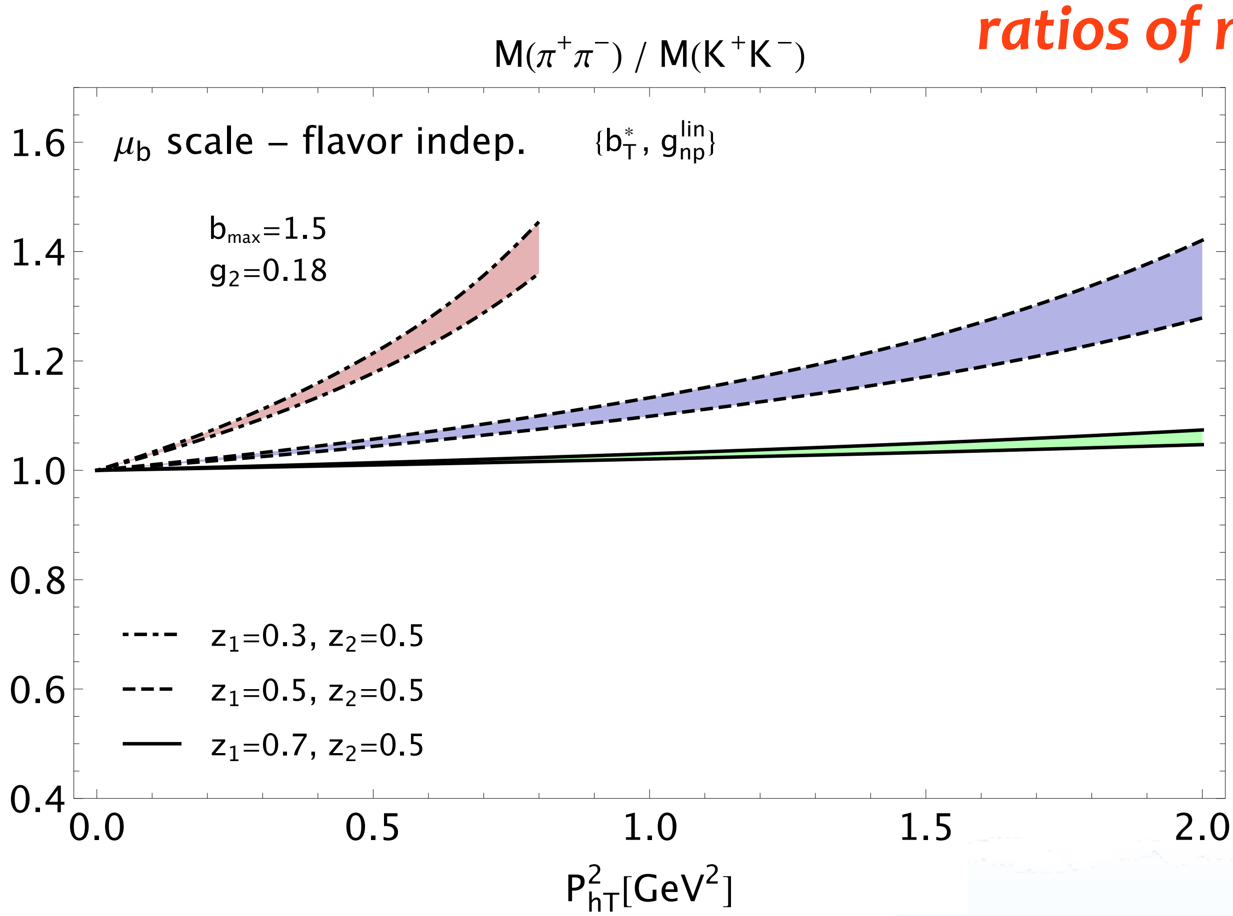
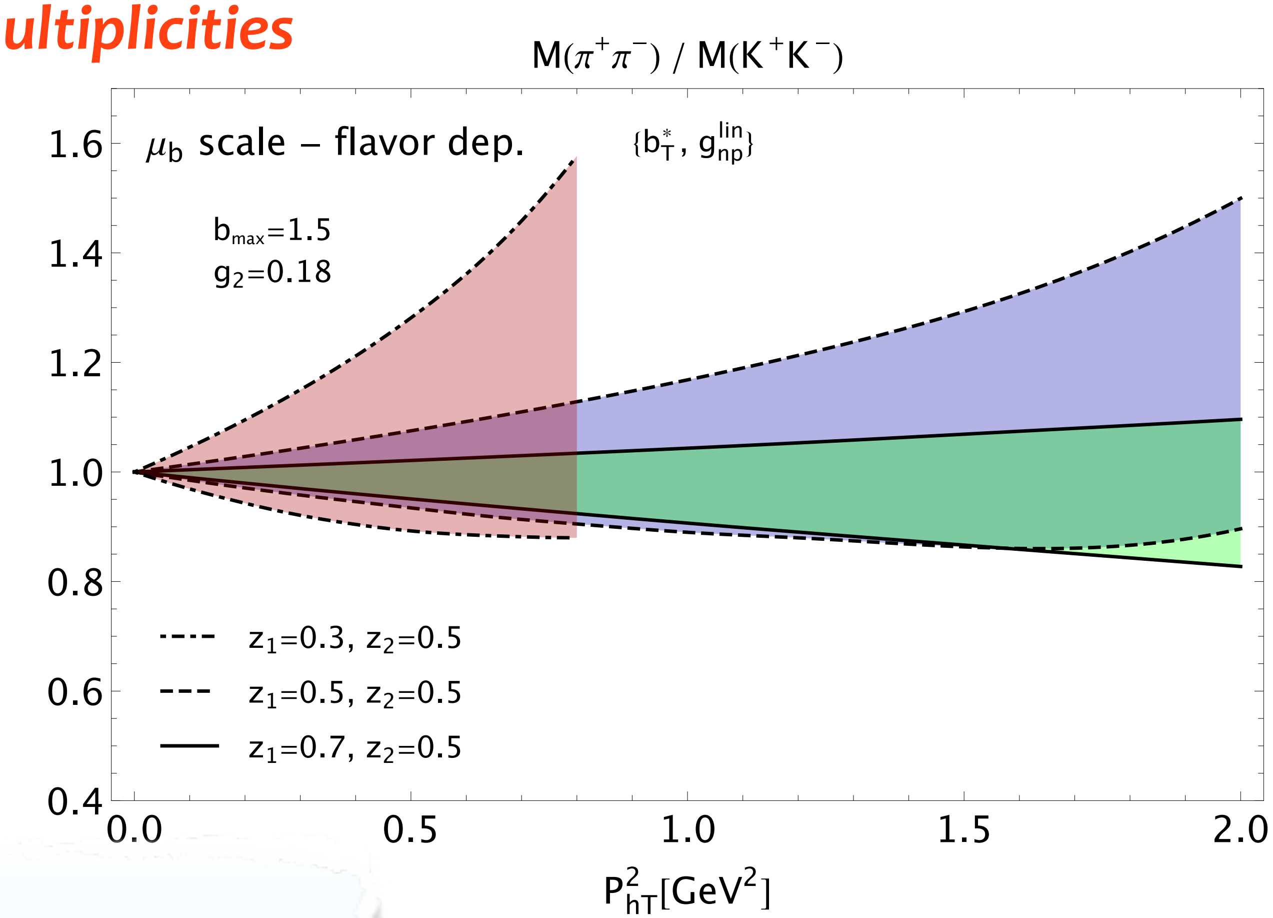
… partonic flavor

mu_b scale evolution

ratios of multiplicities





this is the effect of the
perturbative flavor dependence ONLY:

it is induced by RGE equations
with flavor dependent
initial conditions (collinear FF)

the transverse momentum
dependence is described
BOTH by the input NP
Gaussian distributions
and the collinear FF

$$d_1^{q\to h}(z, \mu_b(b_T))e^{-\frac{\langle k_T^2\rangle_{q\to h}(z)}{4}b_T^2}$$

larger effect,
combination of
perturbative and NP
flavor dependence

but the two are
difficult to disentangle!

exp. data may be useful
to discriminate among the replicas

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Conclusions

Five take-home messages :

0) The way we implement QCD evolution affects the extraction of non-perturbative information - [*very important*]

1) At Belle scale (100 GeV^2) we can discriminate evolution schemes and pin down non-perturbative evolution parameters (g2, bmax)

2) Annihilations at BES scale (14.6 GeV^2) can be very useful to select non-perturbative intrinsic parameters of TMD FFs

3) Annihilations to different final states {π, K} can be useful to constrain flavor dependence of TMD FFs

4) knowledge of unpolarized TMD FFs helps in constraining both (un)polarized TMD PDFs and polarized TMD FFs

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Backup slides

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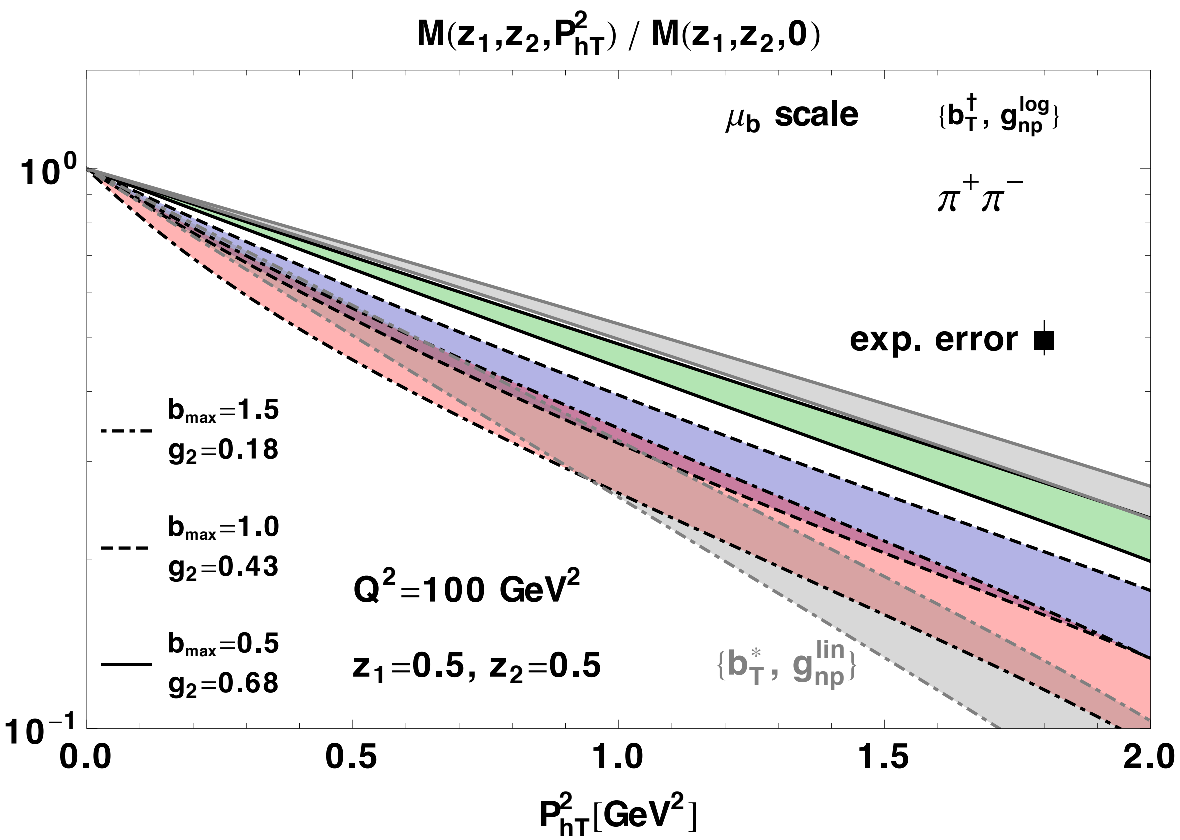
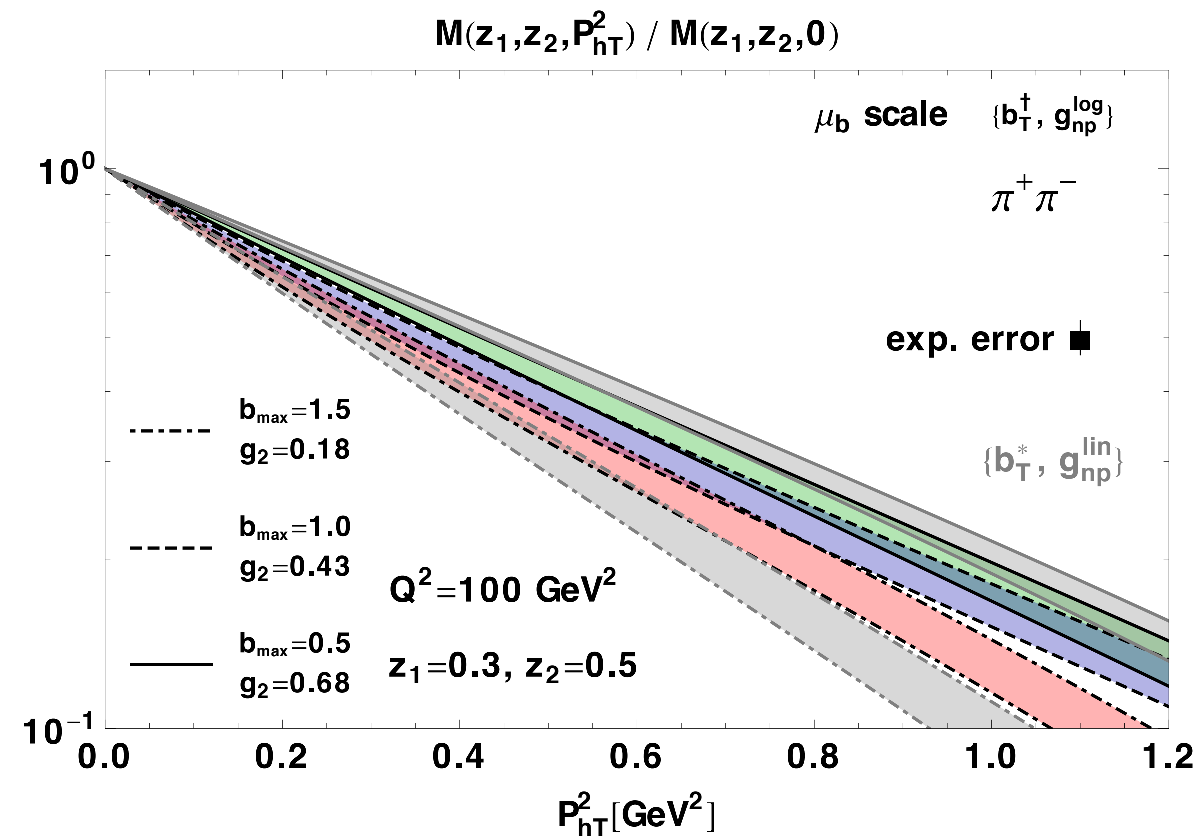
… transition low/medium qT





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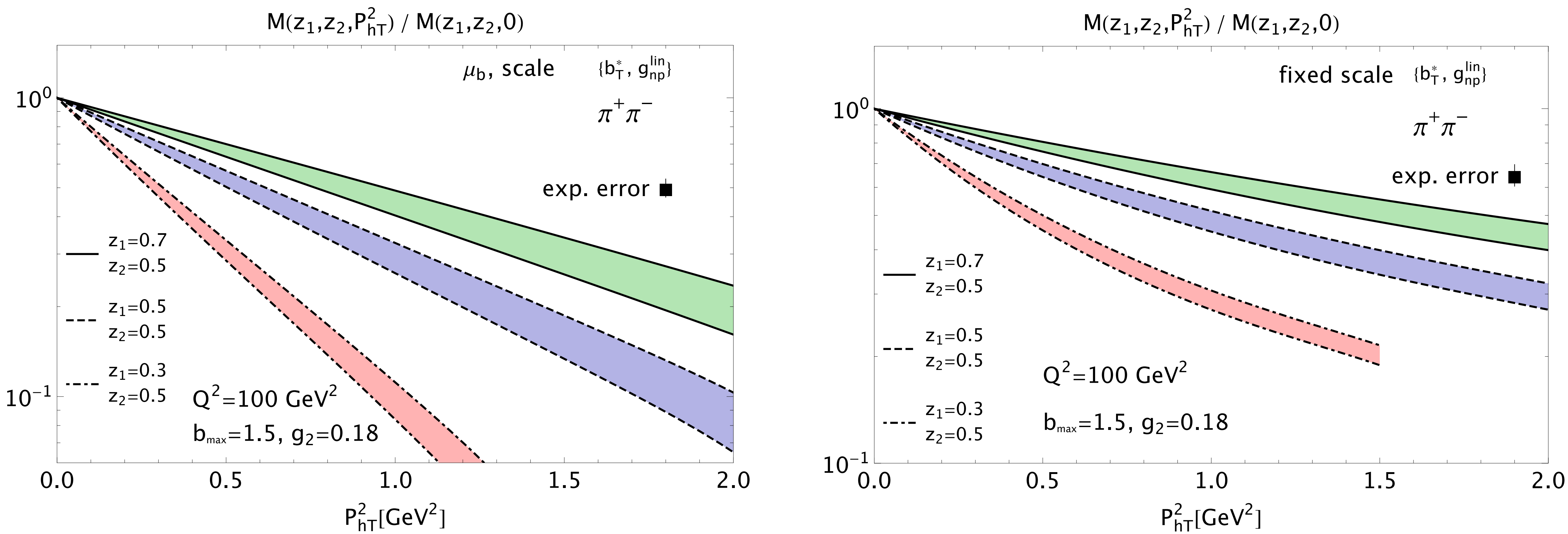
... collinear energy fractions $z_{1,2}$



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