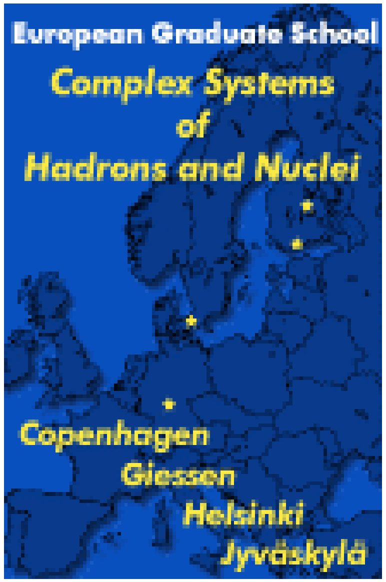
Lecture week “Strangeness, Spin and QGP” Torino, Oct 8-15, 2005



Transverse momentum of Drell-Yan pairs in perturbative QCD and beyond

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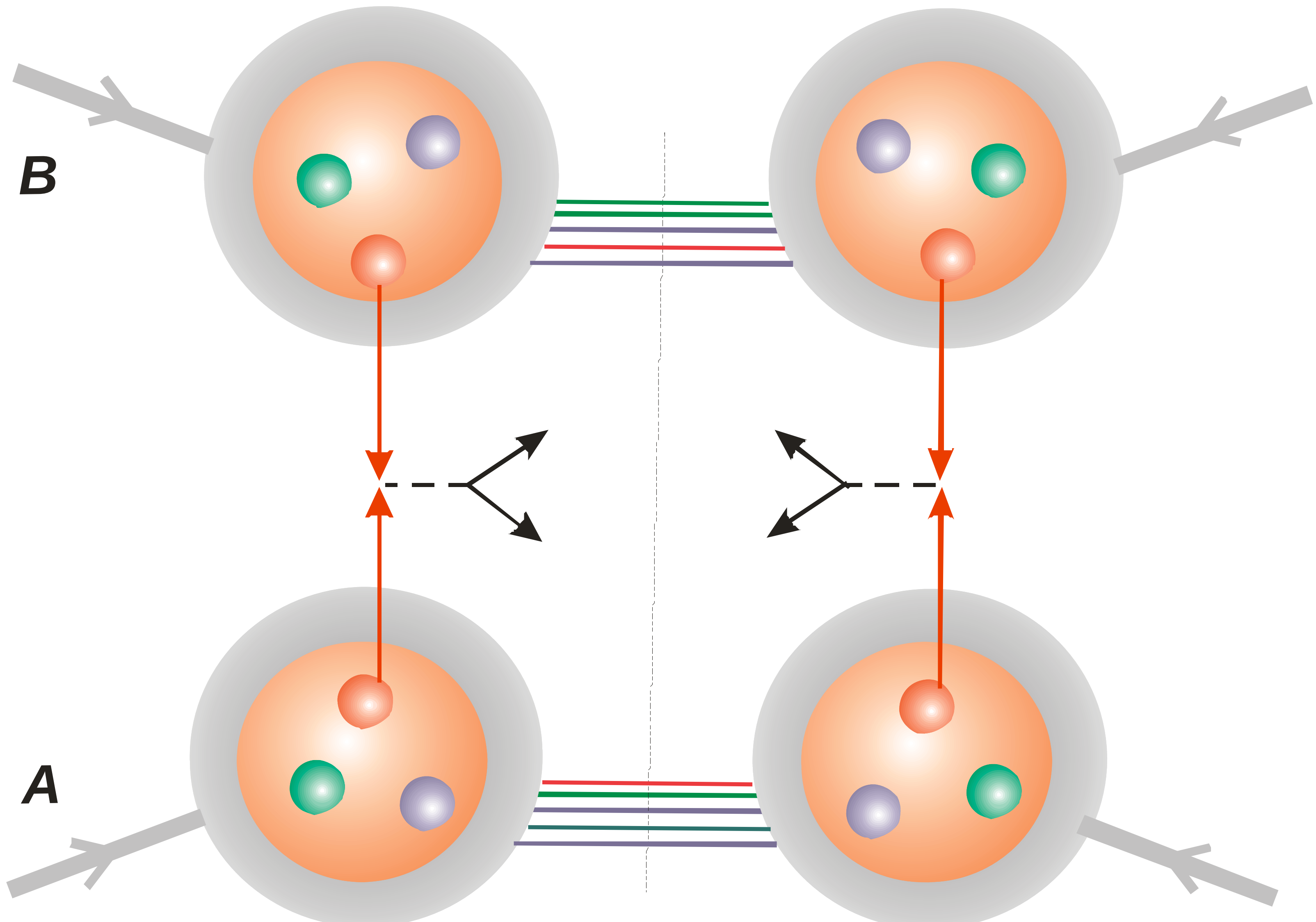
p_T spectrum of Drell-Yan pairs

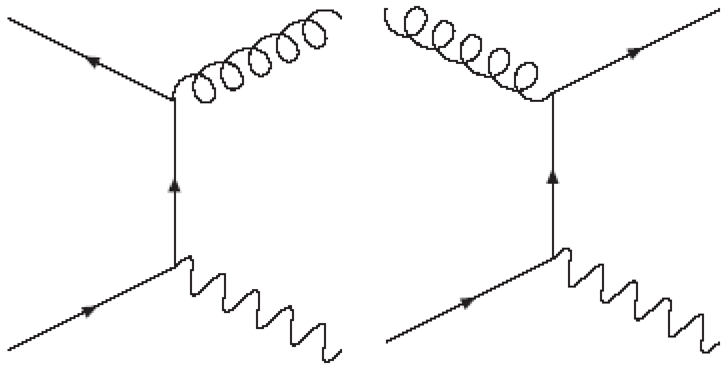
Plan

- Generation of p_T in the next-to-leading order of collinear perturbative QCD
- Beyond the approximation of collinear on-shell quarks
- Wigner function of quark inside the proton
- Description of existing data (experiment E866 at Fermilab)
- Predictions for PANDA


B
A

At the leading order of pQCD, the p_T spectrum of ~ g(p_T)

NLO

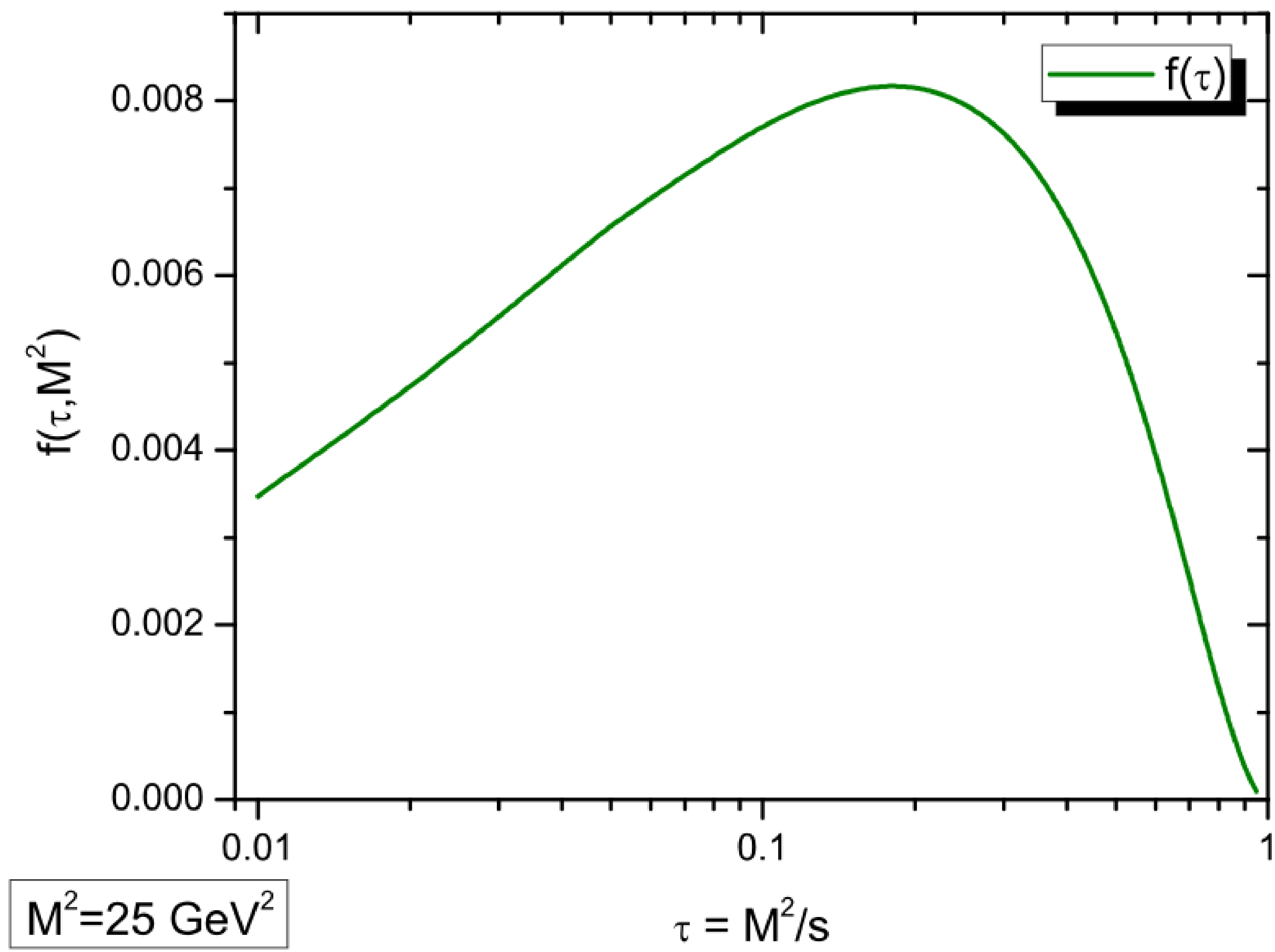


$$p_T^2 = \frac{(\hat{s} - M^2)^2}{4\hat{s}} \sin^2 \Theta.$$

The hadronic cross section at NLO is singular at p_T=0, but there is a method to extract mean <p_T>. Result:

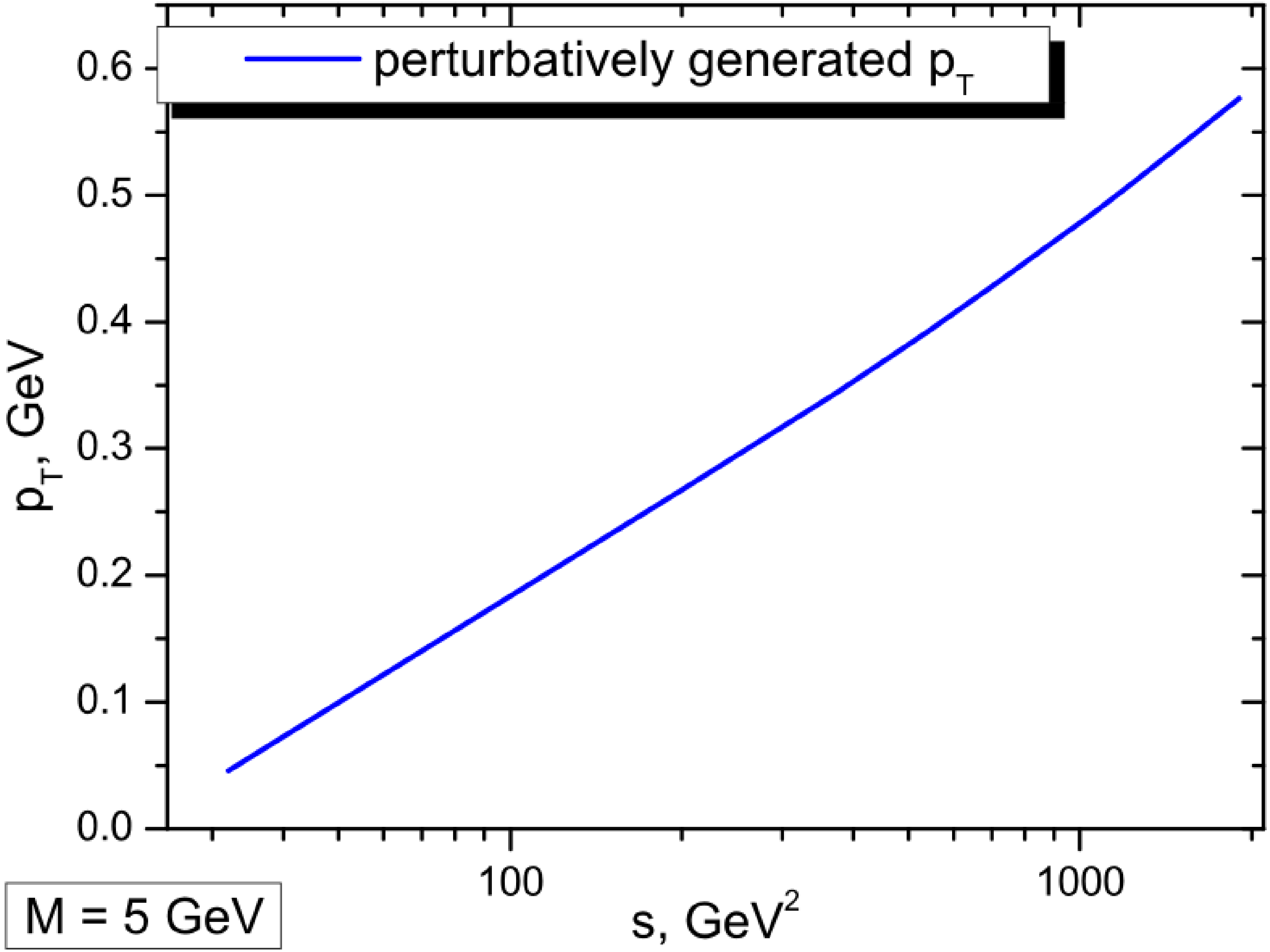
$$\boxed{\langle p_T^2 \rangle = \alpha_S(Q^2) s f(\tau, \alpha_S(Q^2)) + \ldots}$$

where the function *f* can be calcualted, using PDFs.

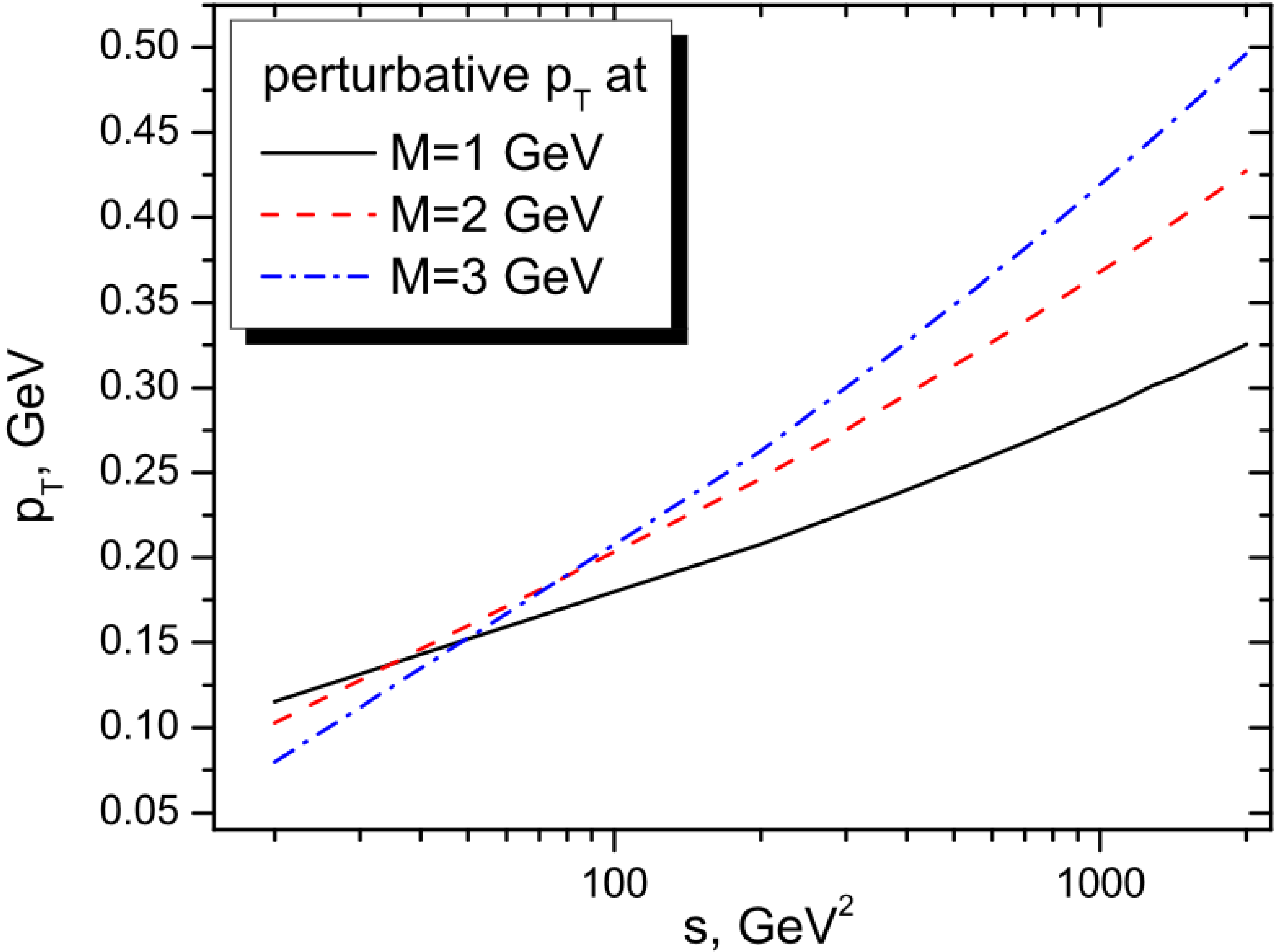


f(τ)
0.008
0.006
0.004
0.002
0.000
f(τ,M²)
0.01
0.1
1
τ = M²/s
M²=25 GeV²

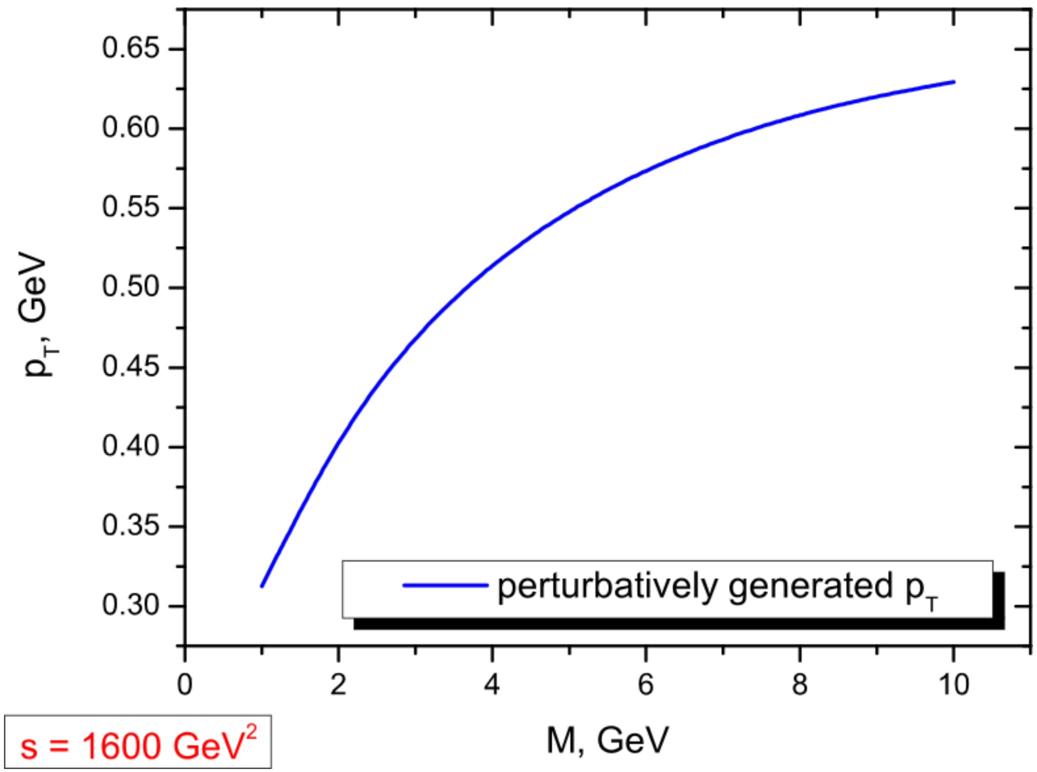
Perturbative <p_T>



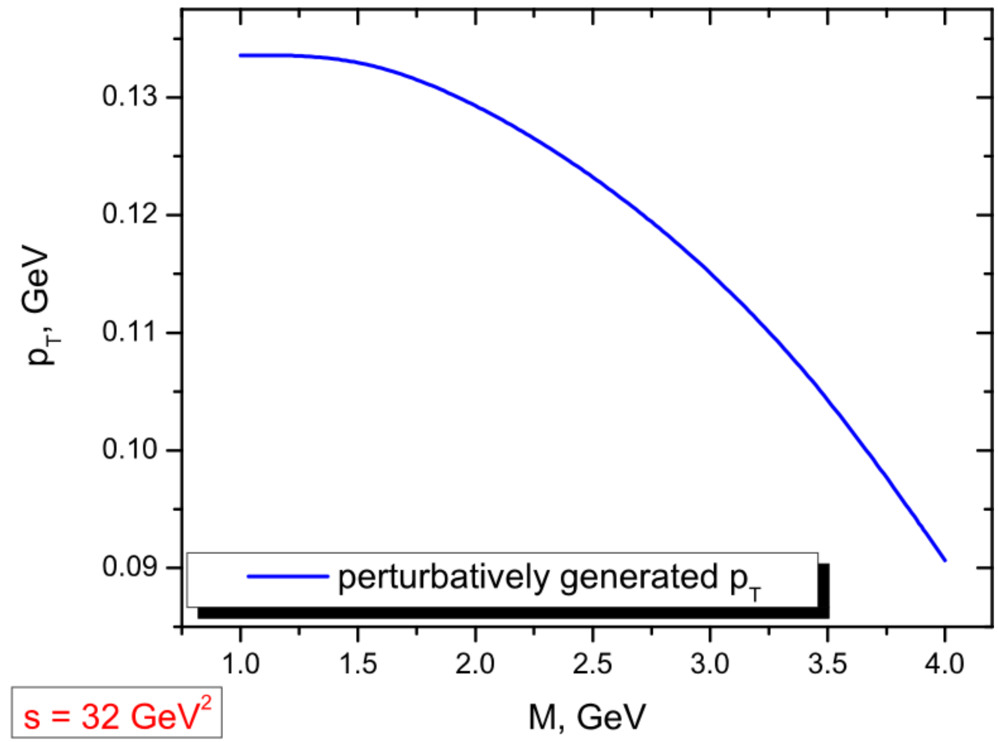
M = 5 GeV



perturbative p_T at
M=1 GeV
M=2 GeV
M=3 GeV
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
p_T, GeV
100
1000
s, GeV^2



Perturbative pT at Fermilab energy



Perturbative pT PANDA energy

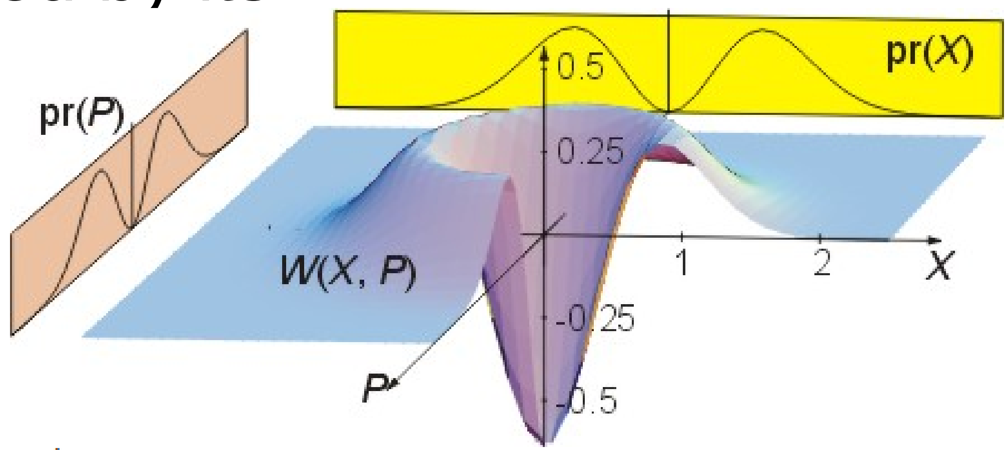
But measured mean $p_T > 1$ GeV

Wigner function

Quantum system is described by its wave function

$$\psi(r)$$

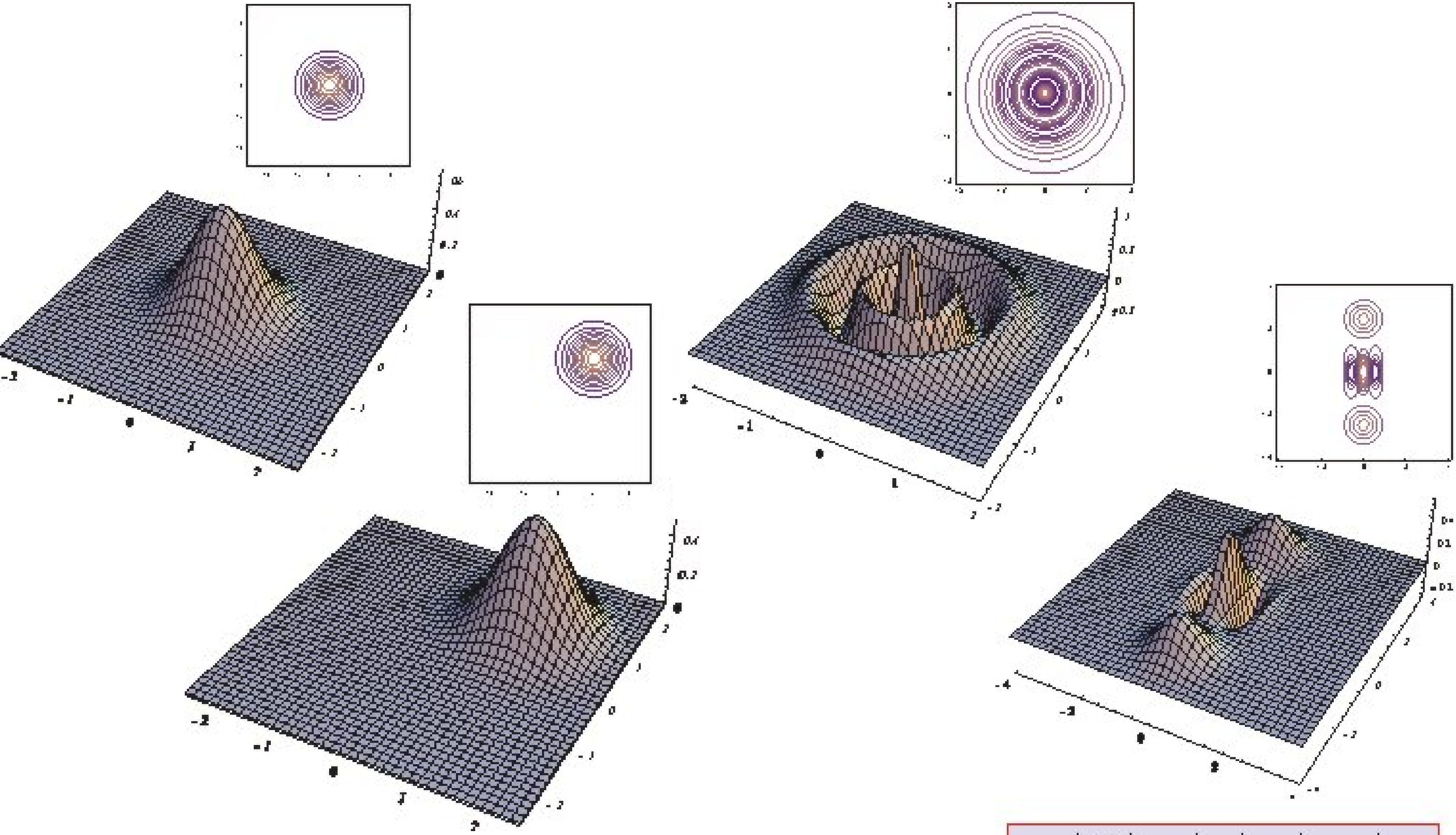
or by the Wigner function



$$\hat{W}_\Gamma(\vec{r},k) \equiv \int d^4\eta\, e^{i\eta\cdot k}\, \bar{\psi}(\vec{r}-\eta/2)\, \mathcal{L}^\dagger\, \Gamma\, \mathcal{L}\, \psi(\vec{r}+\eta/2)$$

which is especially useful for mixed systems, like in the Einstein-Podolsky-Rosen paradox.

Wigner function $W(k_p, x_p)$



$$\left|\Psi\right\rangle = \left|\alpha\right\rangle + \left|-\alpha\right\rangle$$

Wigner function $W(k_p, x_p)$

- Complete information on the system! ☺
- No explicit time dependence
  - → 7 variables.
- Uncertainty principle
  - → Maximum 4 variables can be determined in a single measurement.
- Choose measurements to access interesting variables.

Parton Distribution Function

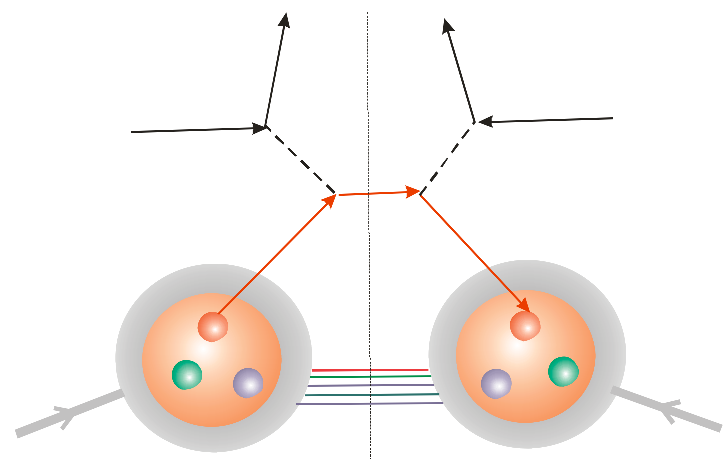
quark (light-cone) momentum distribution

$$q(x) = \int \frac{d^2 k_T}{(2\pi)^2} \int \frac{d^3 r}{(2\pi)^3} \int \frac{dk^-}{(2\pi)} W_{\gamma^+}(\vec{r}, k)$$

$$q(x) = \int \frac{d\xi^-}{4\pi}\, e^{ixp^+\xi^-} \, \langle PS|\bar{\psi}(0)\gamma^+\psi(0,\xi^-,\vec{0}_T)|PS\rangle$$

Deep Inelastic Scattering

j$^-$p 0A j$^-$X



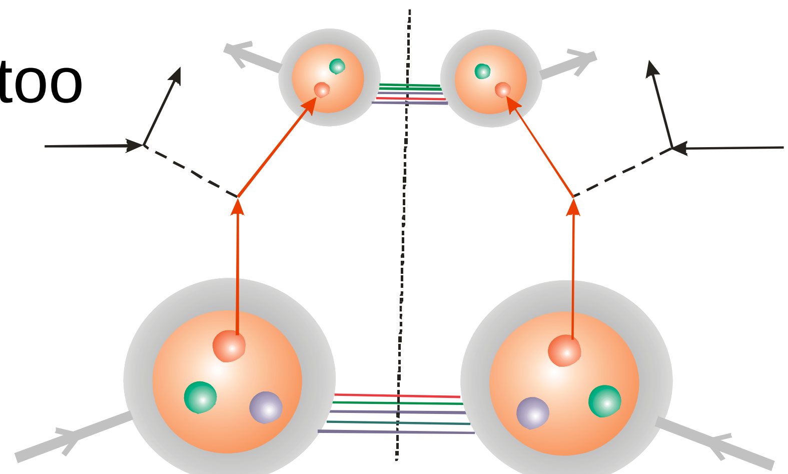
Unintegrated (non-collinear) parton distributions

$$q(x, k_T) = \int \frac{d^3r}{(2\pi)^3} \int \frac{dk^-}{(2\pi)} W_{\gamma^+}(\vec{r}, k)$$

$$q(x, \vec{k}_T) = \int \frac{d\xi^-}{4\pi} \int \frac{d\vec{\xi}_T}{(4\pi)^2}\, e^{i(xp^+\xi^- + \vec{k}_T\cdot\vec{\xi}_T)}\, \langle P|\bar{\psi}(0)\gamma^+\psi(0, \xi^-, \vec{\xi}_T)|P\rangle$$

DIS (polarized as well as unpolarized) is too inclusive to access this distribution

Measurable in SIDIS and Drell-Yan

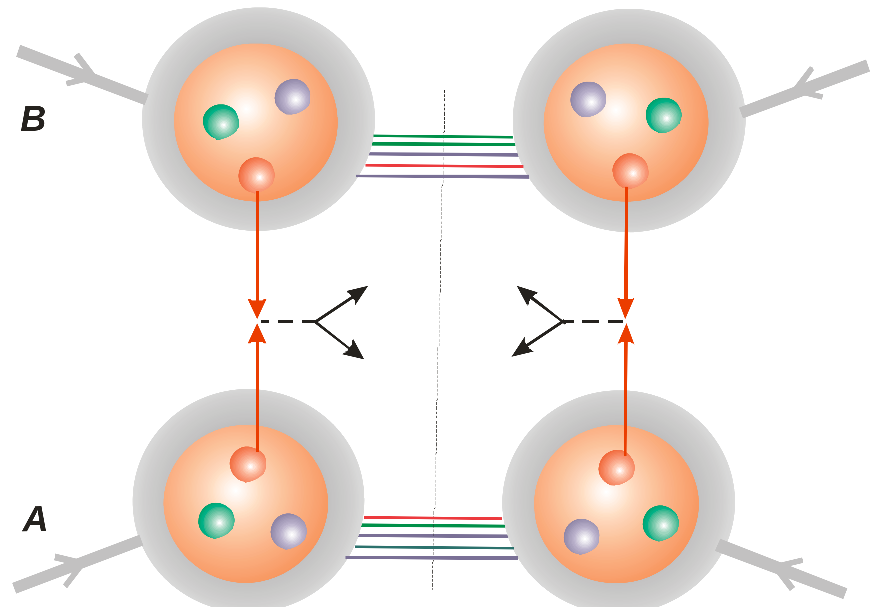


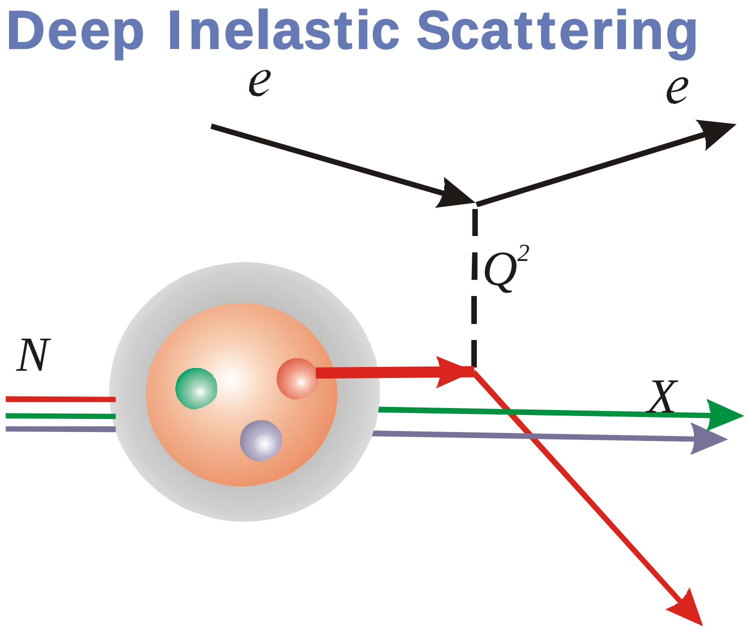
Unintegrated (non-collinear) off-shell distribution

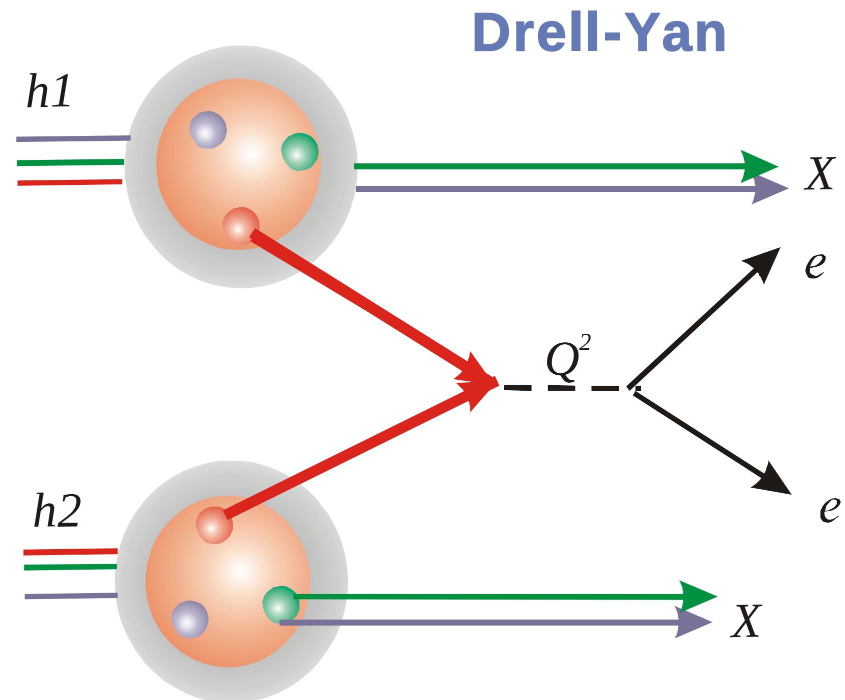
$$q(x, k_T, k^-) = \int \frac{d^3r}{(2\pi)^3} W_{\gamma^+}(\vec{r}, k)$$

We claim that one can access this 4-dimensional distribution in unpolarized Drell-Yan,

by measuring the p_T spectrum of the lepton pairs







$$d\sigma = f(Q^2, p_T, \xi) \otimes d\hat{\sigma}(\xi, m) \otimes Sp(m, \Gamma),$$

$d\hat{\sigma}(\xi, m)$ - off-shell partonic cross section,

$Sp(m, \Gamma)$ - quark spectral function,

$f(Q^2, p_T, \xi)$ - unintegrated quark distributions.

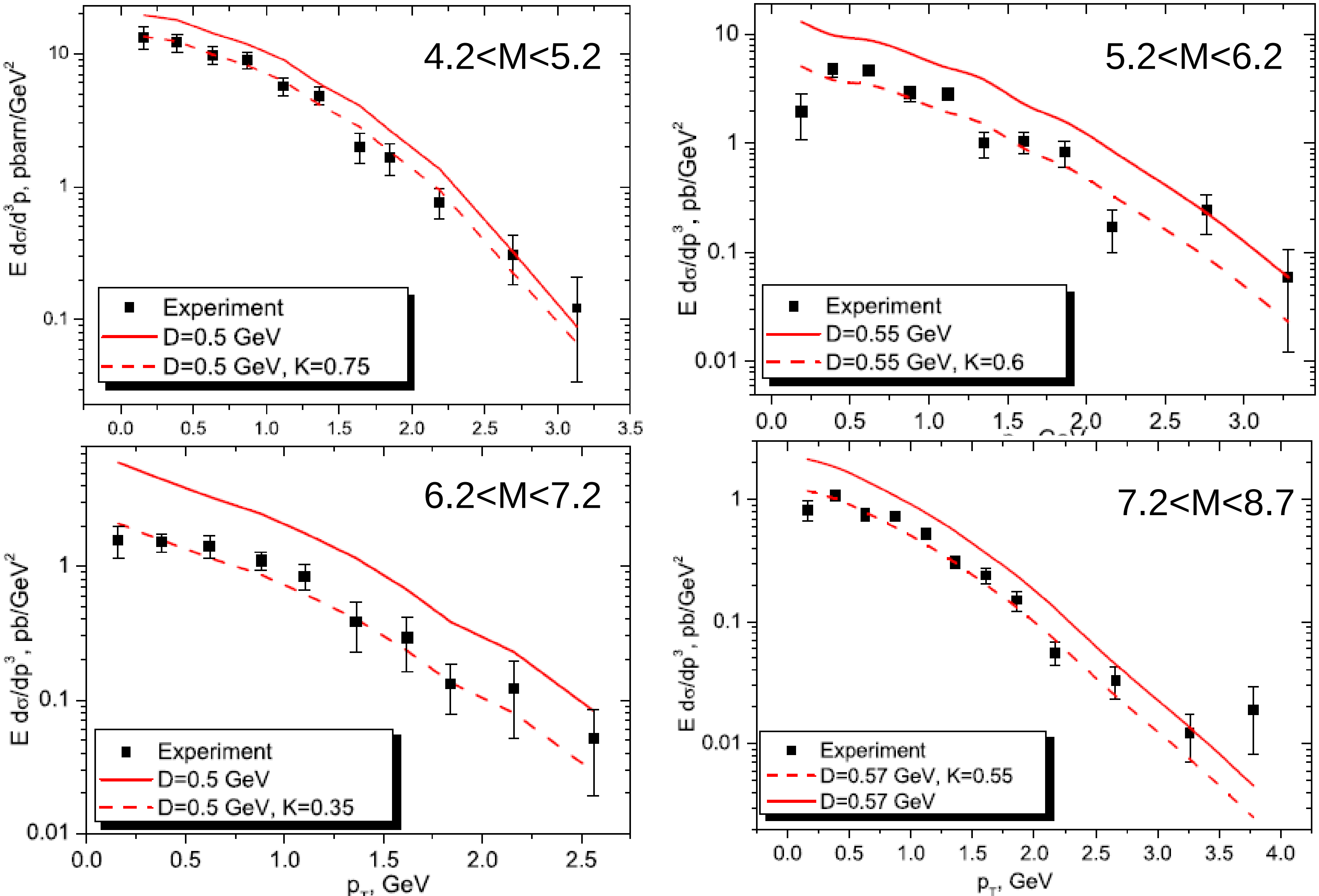
Model assumption: $f(Q^2, p_T, \xi) = f(p_T)q(Q^2, \xi)$,

where $f(p_T)$ - Gaussian, $q(Q^2, \xi)$ - conventional parton distribution functions.

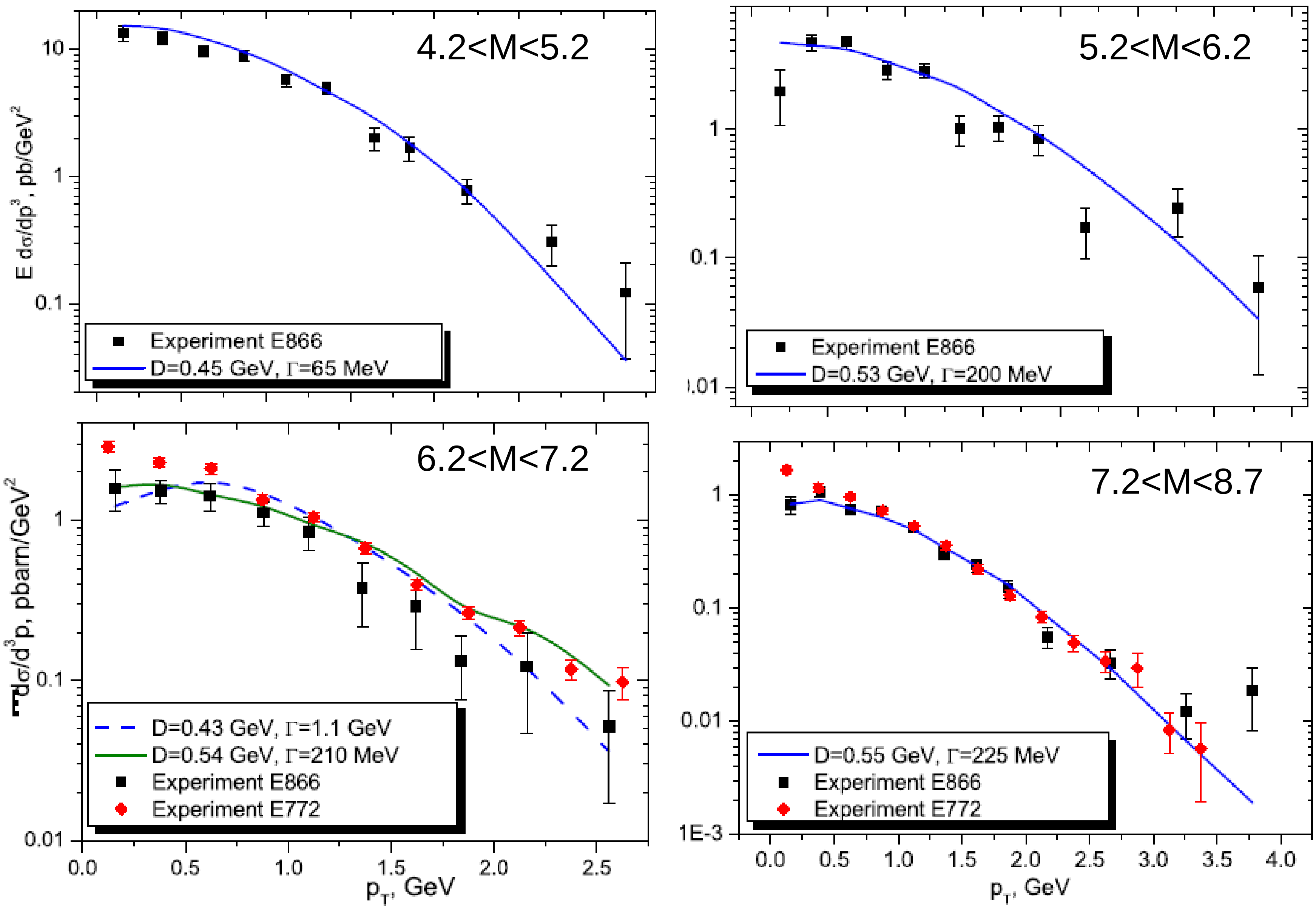
p_T-distribution of dileptons in the intrinsic-k_T approach as compared to the data of E866 at Fermilab on Drell-Yan in *pp* collision at s=1600 GeV^2.

We fitted the quark transverse momentum dispersion *D* to obtain the solid lines.

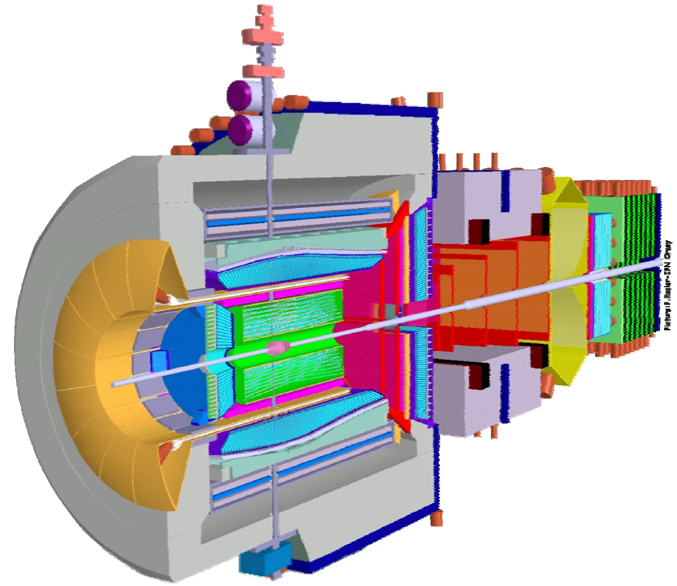
A K-factor is necessary to reproduce the data (dashed lines).



The same cross section as calculated in our model (solid line) is compared to the data of E866 (pp → l+l-X) and E772 (pd → l+l-X). No more need for a K-factor.



PANDA is a multipurpose detector to be installed at the future GSI facility, at FAIR.



One of the processes to be studied:

$$\bar{p}p \rightarrow l^+ l^- X$$

S up to 32 GeV^2.

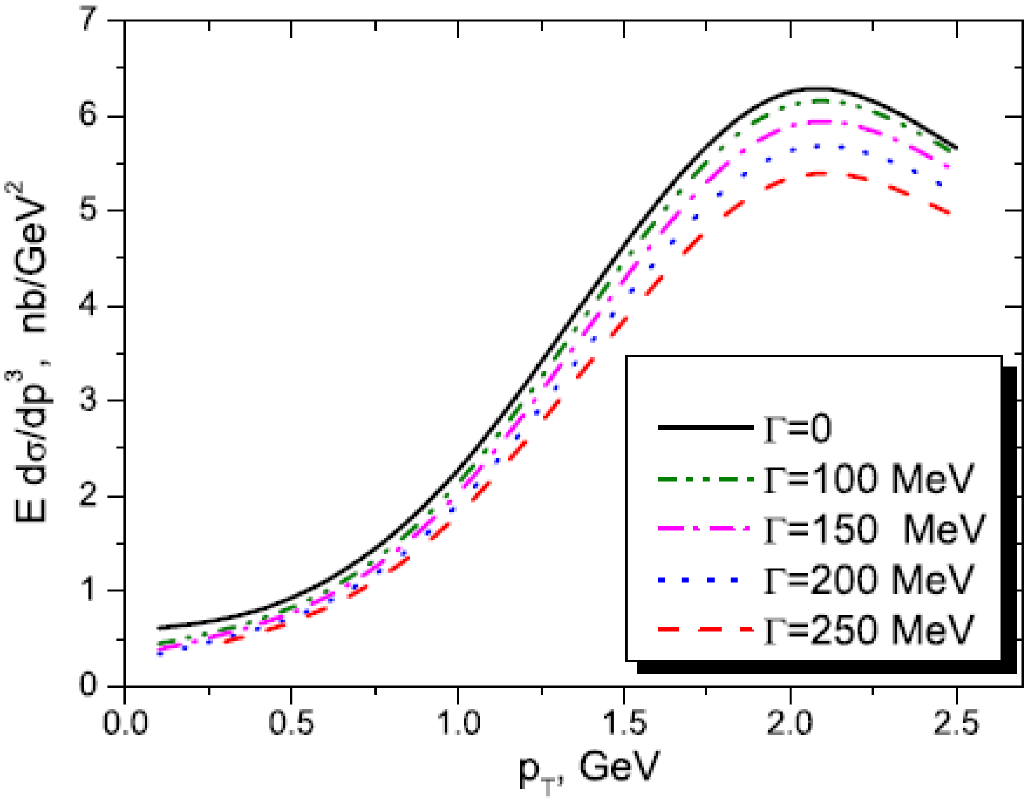
Recent plans – PAX at FLAIR.

One of the processes to be studied:

transversely polarized $\bar{p}p \rightarrow l^+ l^- X$

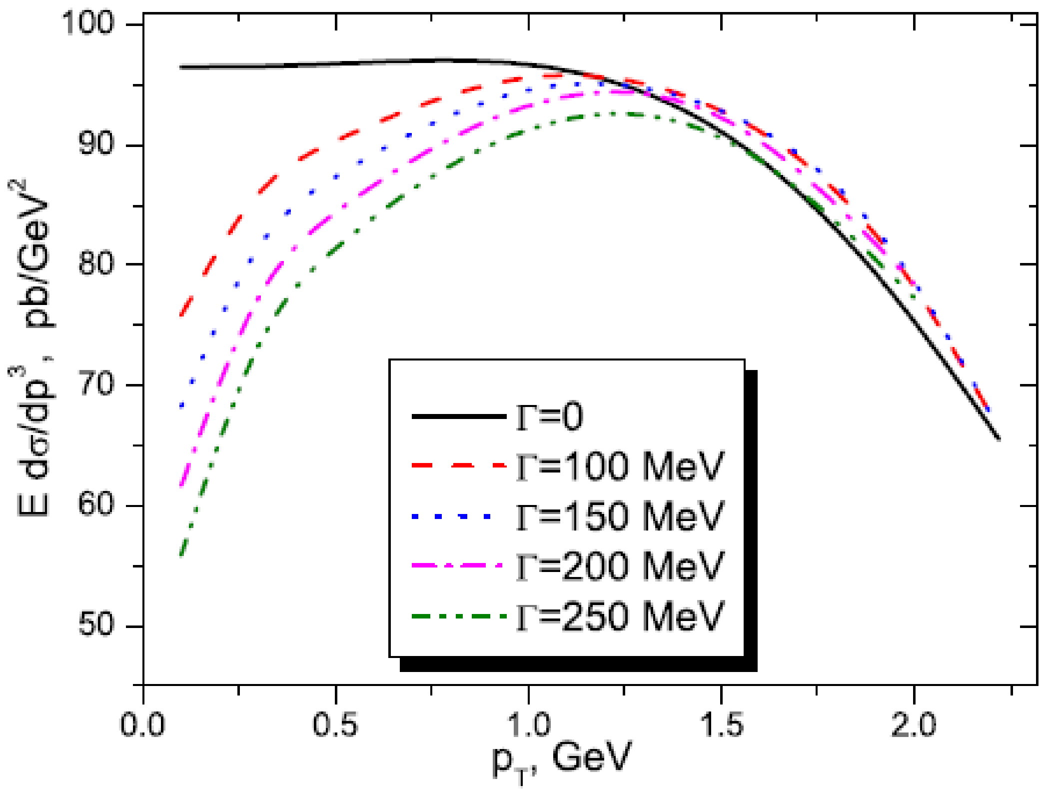
S up to 200 GeV^2.

Prediction for the p_T-distribution of the Drell-Yan pairs at PANDA. The quark average transverse momentum is 1 GeV. The quark width is 100-250 MeV.

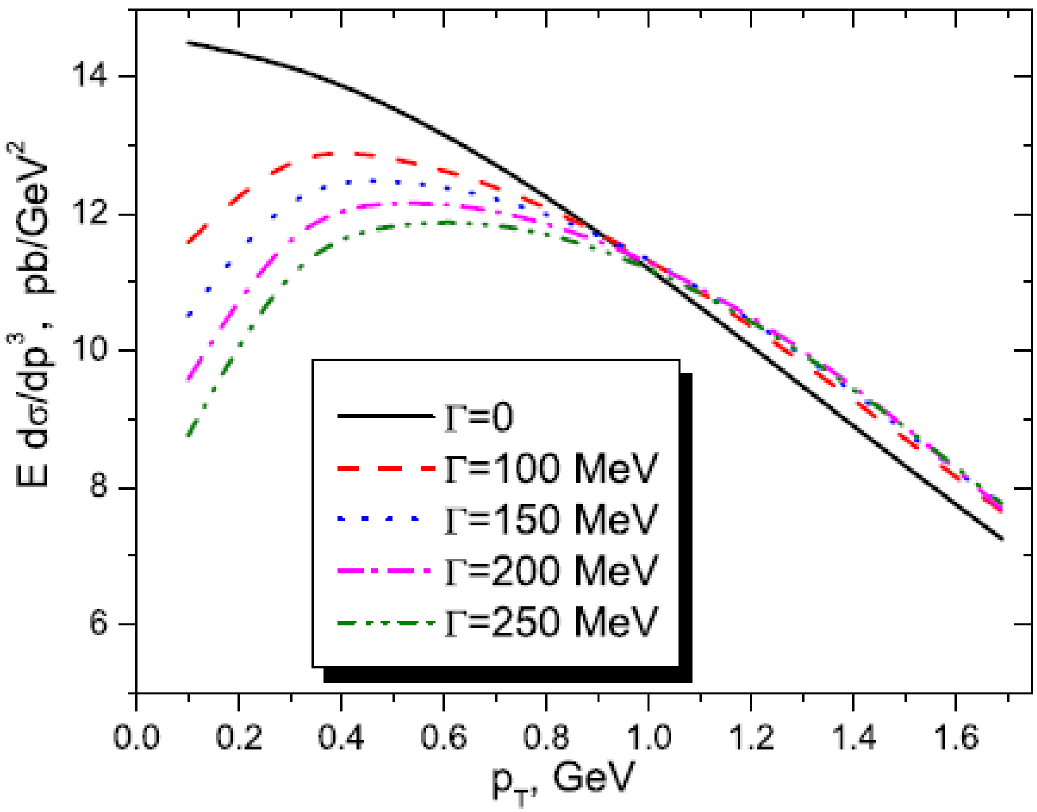


M=1 GeV
x_F=0.1

M=2 GeV
x_F=0.1

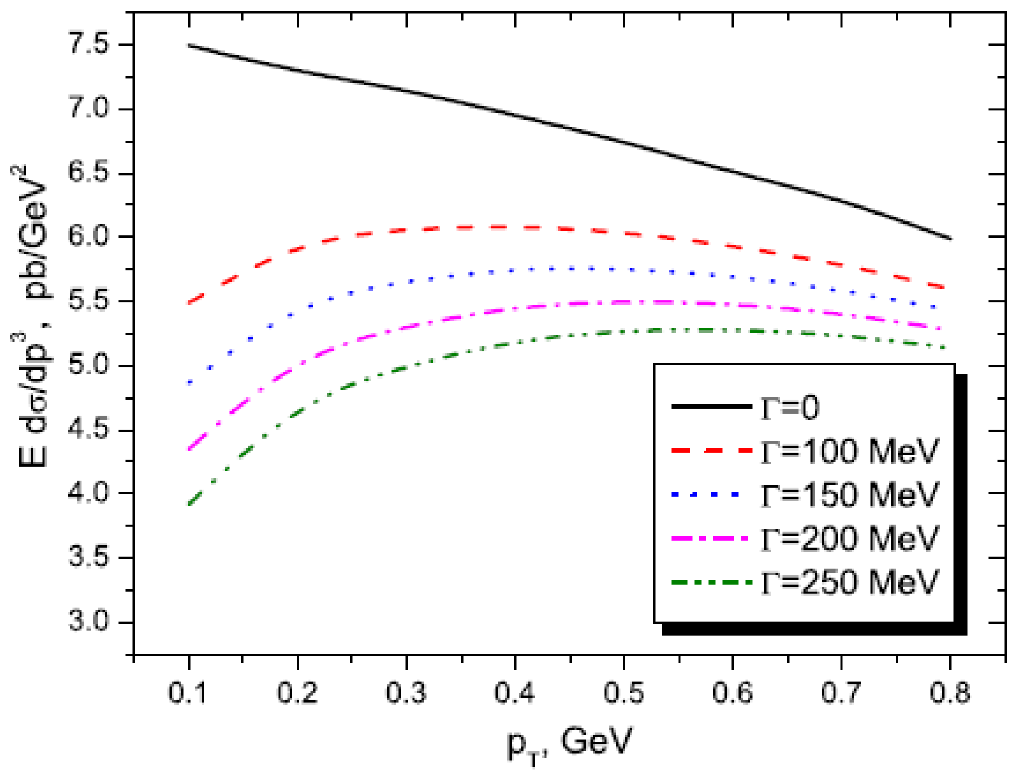


Prediction for the p_T-distribution of the Drell-Yan pairs at PANDA. The quark average transverse momentum is 1 GeV. The quark width is 100-250 MeV.

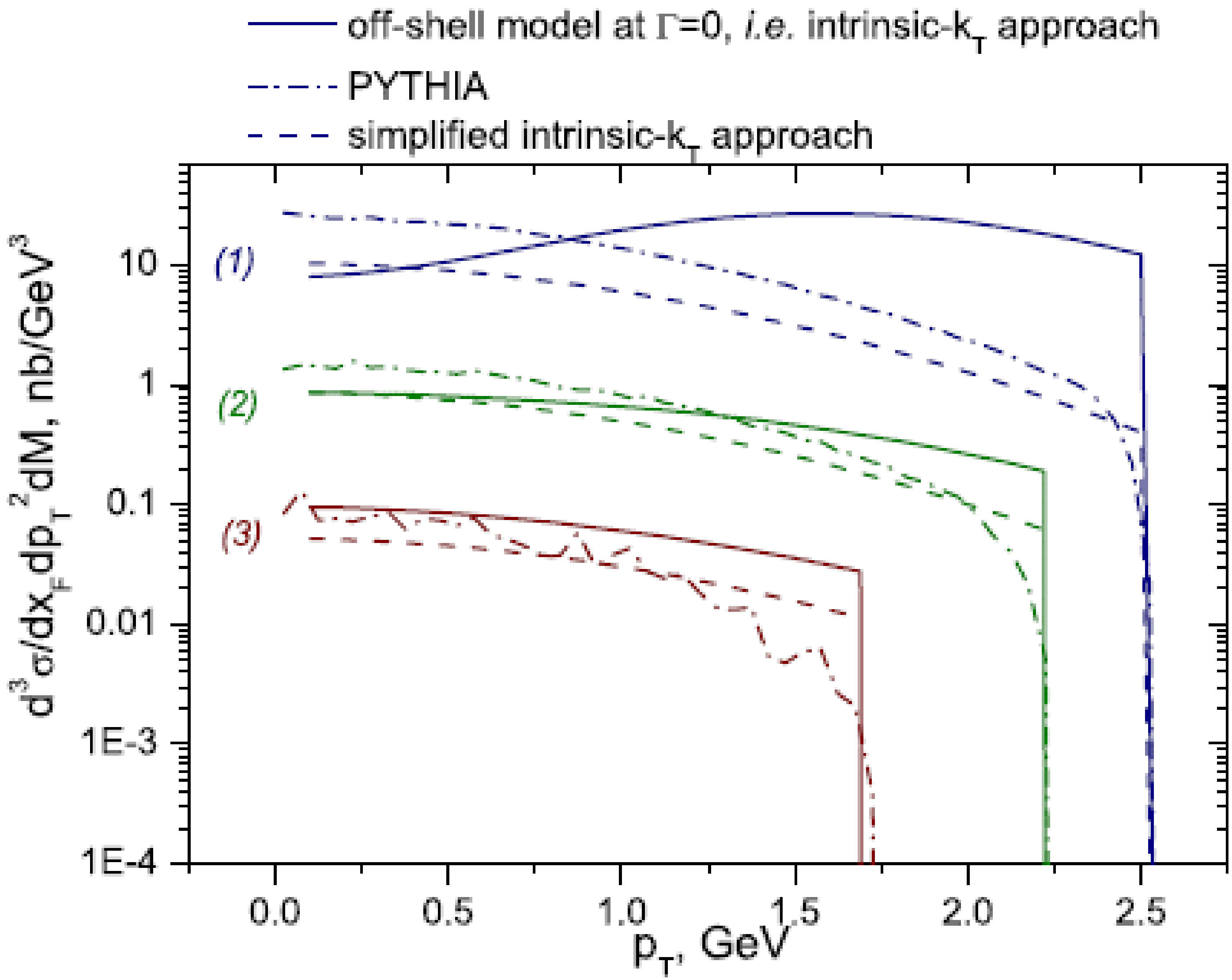


M=3 GeV
x_F=0.1

M=4 GeV
x_F=0.1



PANDA predictions in three models



(1) M=1 GeV
(2) M=2 GeV
(3) M=3 GeV

Summary

* The structure of the proton is encoded in quark Wigner function, integrals of which can be measured.

* Collinear pQCD does not reproduce measured p_T of Drell-Yan pairs. Resummation and modelling needed.

* p_T spectrum of Drell-Yan pairs is sensitive to quark
  * intrinsic transverse momentum, and
  * off-shellness.

* For more information, see hep-ph/0412138, hep-ph/0506134

Thank you!

Processes

$$q(x) = \int \frac{d^2k_T}{(2\pi)^2} \int \frac{d^3r}{(2\pi)^3} \int \frac{dk^-}{(2\pi)} W_{\gamma^+}(\vec{r}, k)$$

j p 0A j- X

$$q(x, k_T) = \int \frac{d^3r}{(2\pi)^3} \int \frac{dk^-}{(2\pi)} W_{\gamma^+}(\vec{r}, k)$$

$\bar{p}$ p 0A j- X

vs. transverse momentum of j-

$$f(r, x) = \int \frac{d^2k_T}{(2\pi)^2} \int \frac{dk^-}{(2\pi)} W_{\gamma^+}(\vec{r}, k)$$

j- p 0A j p

$\bar{p}$ p 0> j- j

$$f(b_\perp, x, k_T) = \int \frac{dz}{(2\pi)} \int \frac{dk^-}{(2\pi)} W_{\gamma^+}(\vec{r}, k)$$

j- p 0A V_1 V_2 p

vs. relative transverse momentum of V_i

$$q(x, k_T, k^-) = \int \frac{d^3r}{(2\pi)^3} W_{\gamma^+}(\vec{r}, k)$$

$\bar{p}$ p 0A j- X

vs. transverse momentum of j-