# Description of fully differential Drell-Yan pair production

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HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research

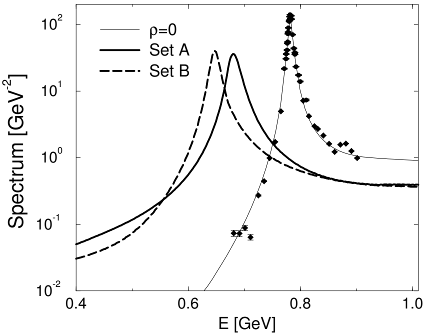
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

# Christmas party 2004

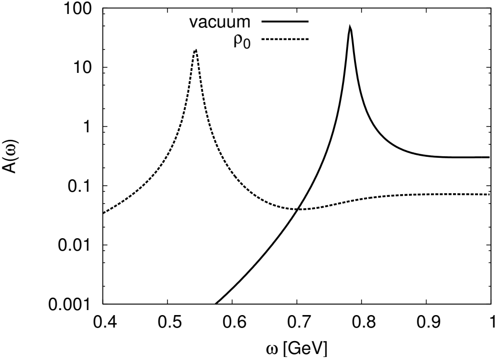
# There is no free lunch (beer)

# First try: Diploma thesis

Munich

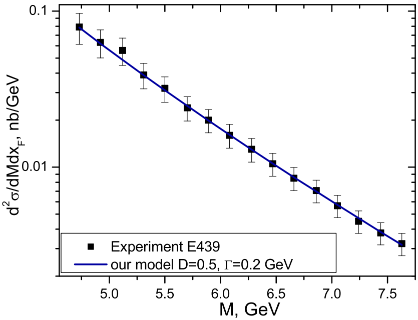



Gießen

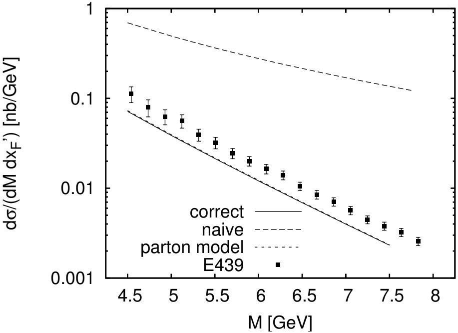


# If at first you don't succeed: PhD work

Gießen (old)




Gießen (new)

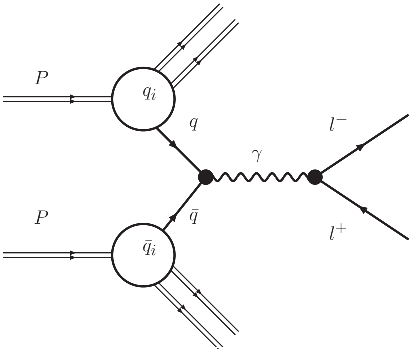


# Motivation

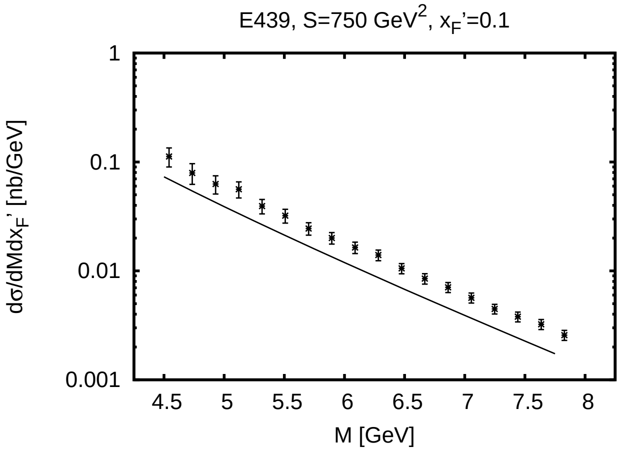
- Semi-Exclusive Drell-Yan observables give important insights into nucleon structure
- Problems:
  - Standard pQCD parton model description needs "K-factor" to reproduce data
  - $\overline{\text{P}}$ANDA @ FAIR will allow measurements of the Drell-Yan Process down to small energies
    $\Rightarrow$ non-perturbative effects become important
- Account for these shortcomings by improving standard parton model description

# The Drell-Yan Process ($pp \to l^+ l^- X$)

- Parton model:
  "Infinite momentum frame"
  $\Rightarrow$ partons collinear
  carrying momentum fraction $x$
- Factorisation:
  $d\sigma =$
  $\int \sum_i e_{q_i}^2 f_i(x_1) \bar{f}_i(x_2) d\hat{\sigma}(x_1, x_2)$
  hard subprocess ($d\hat{\sigma}$)
  parton distribution
  functions ($f_i$)
- Accessible: $d^2\sigma/(dM dx_F)$
- Not accessible:
  $p_T$ spectrum of DY-pair



# Invariant mass distribution

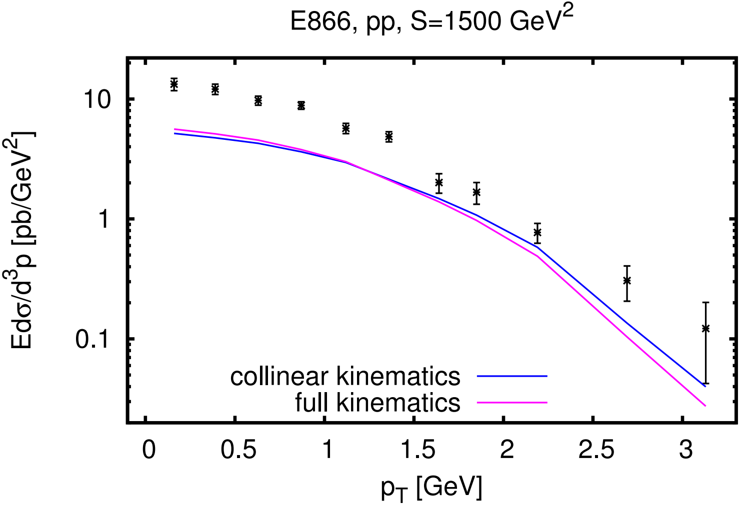



K-factor necessary to reproduce absolute values

# Quark transverse momentum

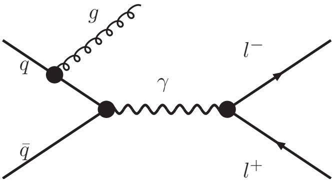
- Parton model: Neglect initial $k_T$ of quarks $\Rightarrow p_T$ spectrum of DY-pairs inaccessible in LO calculation!
- Initial $k_T$-approach: $d\sigma = \int \sum_i e_{q_i}^2 f_i(x_1)\bar{f}_i(x_2) \cdot g((\vec{k}_t)_1) \cdot g((\vec{k}_t)_2) \cdot d\hat{\sigma}(x_1, x_2)$
- Shape of $p_T$ spectrum reproduced, still K-factor needed to yield absolute values
- First improvement: Include initial transverse momentum with full kinematics: $d\hat{\sigma}(x_1, x_2, (\vec{k}_t)_1, (\vec{k}_t)_2)$
- However: Effect is small

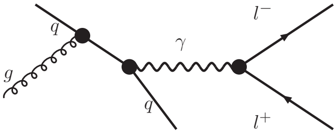
# Comparison: Simple vs. Full kinematics



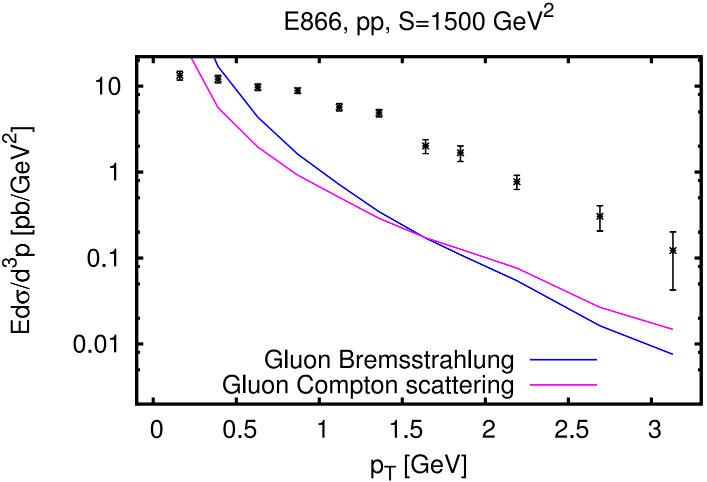
# Next to Leading Order processes

- Bremsstrahlung, Gluon-Compton-Scattering + corrections
- However: Dynamically generated $p_T$ spectrum is divergent for $p_T \to 0$ in NLO
- Reason: Massless exchange quark becomes onshell
- Exchange quark propagator: $D(k) \sim \frac{1}{u} \sim \frac{1}{p_T^2}$



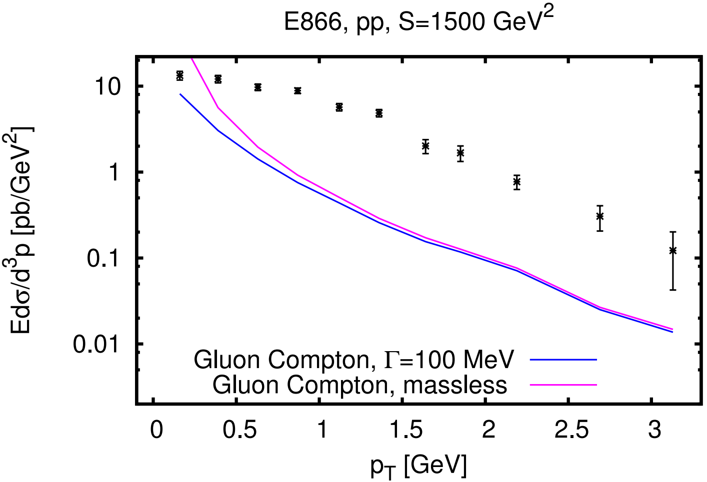
# Transverse momentum ($p_T$) spectrum



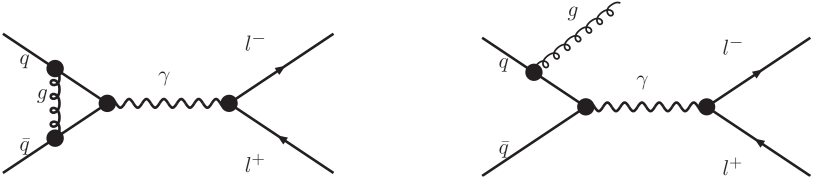
# Offshell quarks

- Distribute mass: $\frac{1}{u} \to \frac{1}{u-m^2} \cdot A(m,\Gamma)$
- Spectral function $A(m,\Gamma)$, e.g. relativistic Breit-Wigner (one parameter: width $\Gamma$)
- Motivation: interacting many-body system, compare to nucleons in nuclei
- Divergence for $p_T \to 0$ smeared out
- Effectively cutoff low $p_T$

# Gluon Compton scattering: $p_T$ spectrum

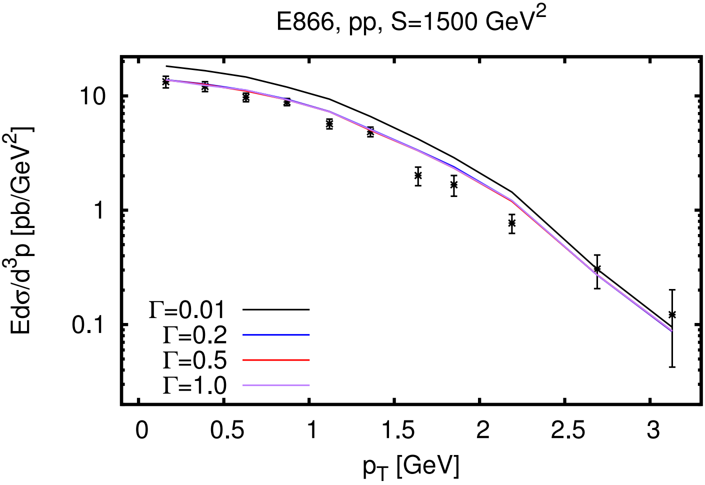


# Vertex Correction and Infrared problems

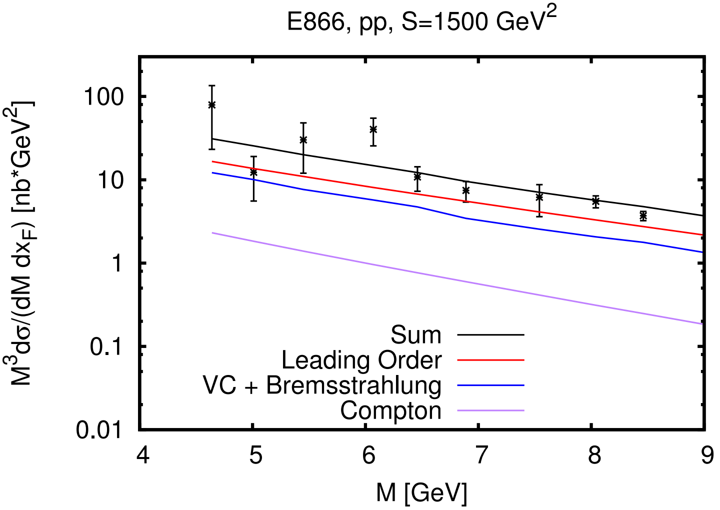



- Vertex Correction interferes with LO process
- Loop integral is infrared divergent, cancels against soft Bremsstrahlung
- $\rightarrow$ Bloch-Nordsieck mechanism

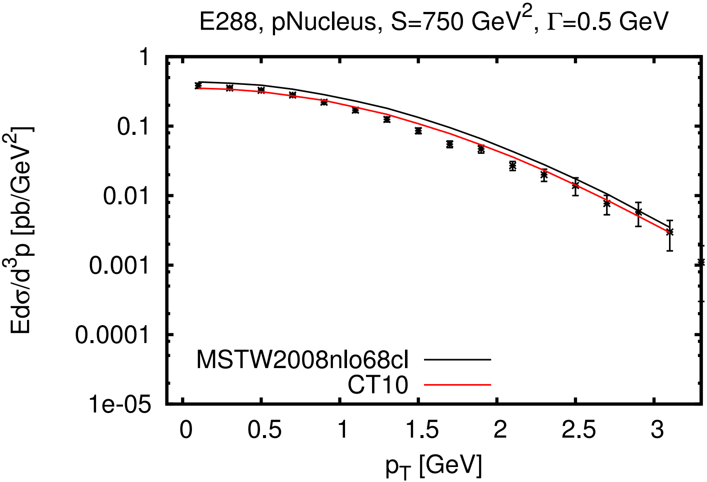
# E866 $p_T$-Spectrum



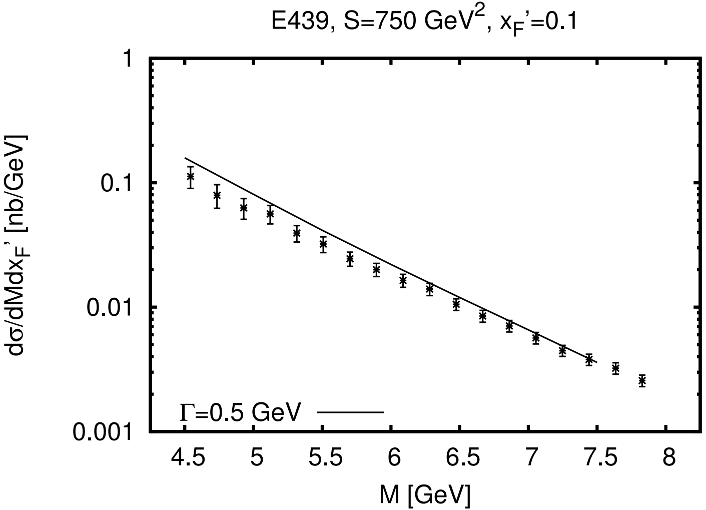
# E866 *M*-Spectrum



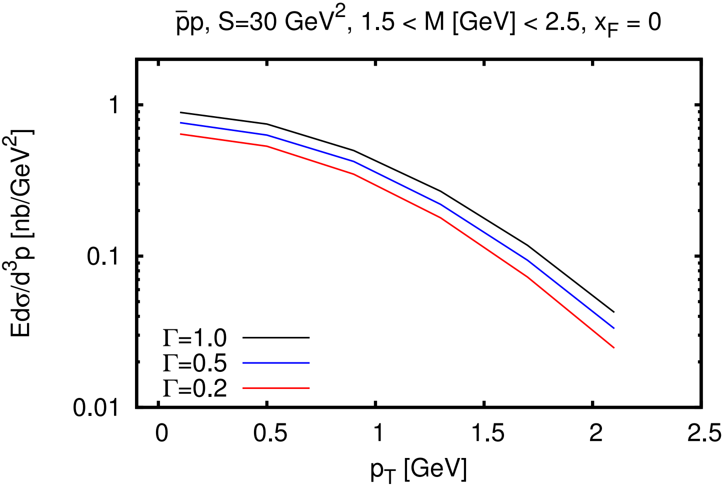
# E288 $p_T$-Spectrum



# E439 *M*-Spectrum



# $\overline{\text{P}}$ANDA prediction ($\bar{p}p$)



# Summary

- pQCD parton model has deficiencies in describing semi-exclusive DY observables
- Introduce initial parton transverse momentum distribution
- standard NLO calculation suffers from divergent $p_T$ spectrum
- Phenomenological mass distributions (width $\Gamma$) for quarks can cure this problem
- Complete model including all processes up to $O(\alpha_s)$ describes high energy data rather well, no K factor!
- Prediction for $\overline{\text{P}}$ANDA possible:

  $\Gamma$ dependence becomes more important

Many thanks to Ulrich Mosel
and happy retirement!

(But before you sail the world, please read my thesis!)