Dilepton pair production at the LHC

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Introduction: Overview

Aspect of e^+e^- (and $\mu^+\mu^-$) pair production at relativistic heavy ion collisions

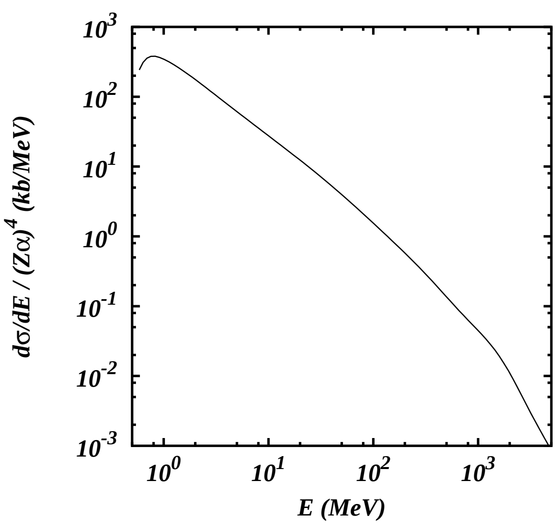
- Total cross sections for pair production.
- Behavior of probability at small b.
- Strong field effects: Multiple pair production, unitarity corrections, Coulomb corrections.
- Measurement at RHIC: Pair production at small b.
- Inelastic pair production: Loss process and Probing ions with virtual photons.

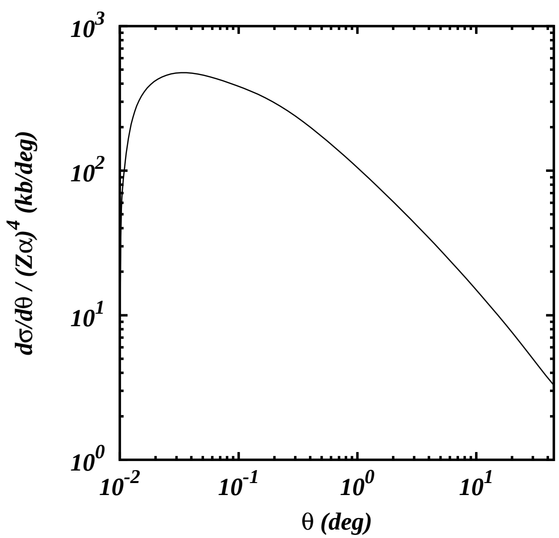
Pair Production at RHI Collisions

- Cross section for e^+e^- large for relativistic HI collisions.
- Using Racah formula (Racah 1937)

$$\sigma = \frac{Z^4\alpha^4}{\pi m^2}\frac{28}{27}\left(\ln^3\gamma^2 - 2.19\ln^2\gamma^2 + \cdots\right)$$

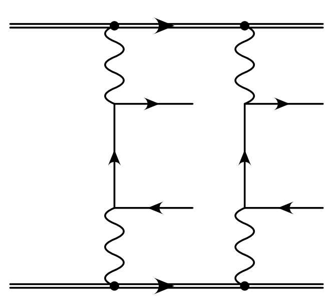
  200kbarn for PbPb at LHC, 700 barn for CaCa at LHC, 30kbarn for AuAu collision.
- 10^7 pairs/s for Pb-Pb. 10^9 pairs/s for Ca-Ca.
- Due to strong electromagnetic field and small mass.
- Differential cross section peaks at forward direction, moderate invariant masses.

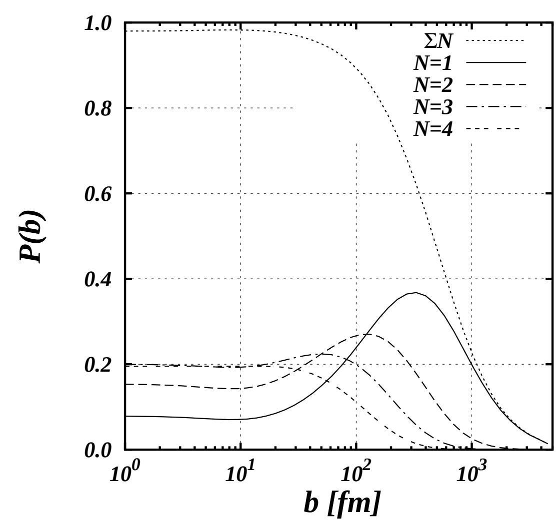




Application of pair production

- Potential background to detectors.
- Studied for ALICE for the internal trigger system:
  K. Hencken , S. Sadovsky, Yu. Kharlov, ALICE-INT-2002-27
- ITS most sensitive due to sensitivity to small pt and curling of the pairs.
- Of interest as a possible luminosity measurement both in central and forward region. Telnov et al., Piotrzkowski et al.
- Theoretical interest: Multiple pair production, Coulomb corrections.
- Lowest order results violate unitarity: $P(b) > 1$: Multiple pair production.





- General overview: G. Baur et al., Physics Report 364, 359 (2002).

Analytic expression of P(b) for small b

Work done together with V. Serbo (U Novosibirsk)

- Find analytic expression for $P(b)$ at small b.
- For $b > \lambda_c \approx 400$fm EPA suggests:
  For $1 \ll m\rho = b/m_e \leq \gamma$:

$$P(\rho) = \frac{28}{9\pi^2} \frac{(Z_1 \alpha Z_2 \alpha)^2}{(m\rho)^2} \left[2 \ln \gamma^2 - 3 \ln (m\rho)\right] \ln (m\rho) \,,$$

and for $\gamma \leq m\rho \ll \gamma^2$,

$$P_{\mathrm{B}}(\rho) = \frac{28}{9\pi^2} \frac{(Z_1 \alpha Z_2 \alpha)^2}{(m\rho)^2} \left(\ln \frac{\gamma^2}{m\rho} \right)^2 \,.$$

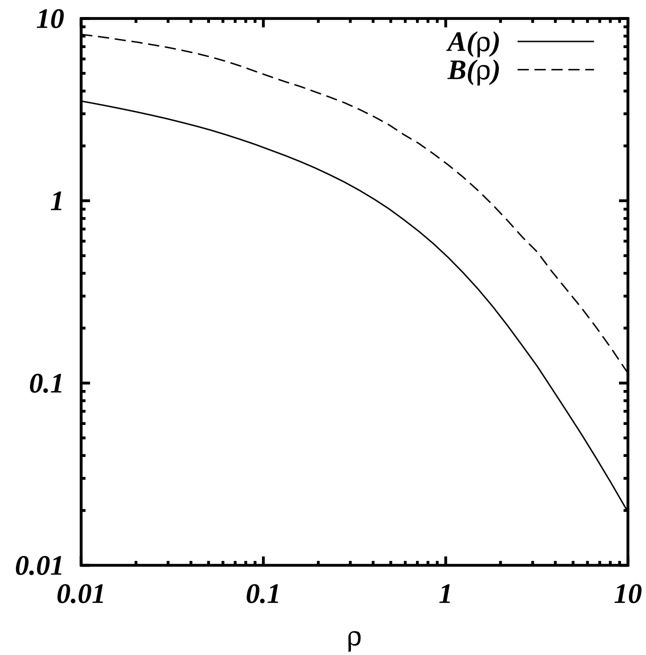
- For $b < 1/m_2$, $\rho < 1$, $P(b)$ was calculated numerically in lowest order QED.

Parameterization of $P(\rho)$

- To get a general parameterization of $P(b)$ for arbitrary b, use form suggested by EPA

$$P(\rho) = (Z_1\alpha Z_2\alpha)^2 (A(b) \ln(\gamma)^2 - B(b))$$

- Fit $A(b)$, $B(b)$ to number of different values for γ



Can be used to calculate multiple pair production cross sections as well as unitarity corrections via

$$C(n) = \frac{1}{n!} \int_{\rho_m in}^{\infty} A(\rho)^n d^2\rho$$

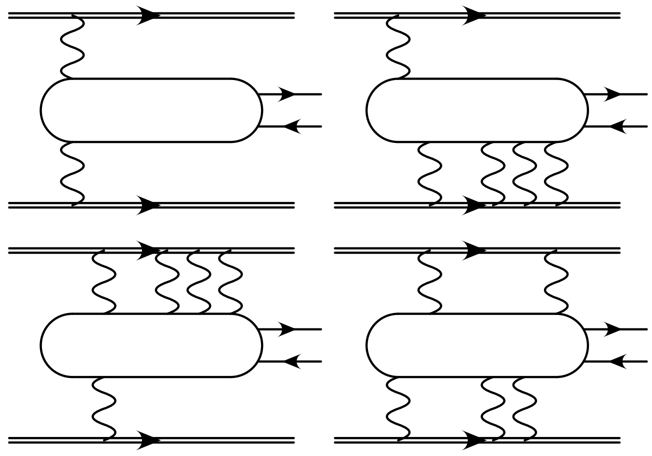
via

$$\sigma(n) = C_n \frac{(Z_1\alpha Z_2\alpha)^{2n}}{m_e^2} \ln(\gamma^2)^n \qquad \sigma_{unit} = -2C_2 \frac{(Z_1\alpha Z_2\alpha)^4}{m_e^2} \ln(\gamma^2)^2$$

Muon Pair Production/Coulomb correction

- Work in progress also on muon pair production.
- Form factor plays important role.
- Total cross section also studied in this way.
- New Ideas:
  Double muon pair production.
  Muon pair production together with e^+e^-

- Coulomb corrections due to strong field:
- Correction to the total cross section known.
- Based on BMD results:



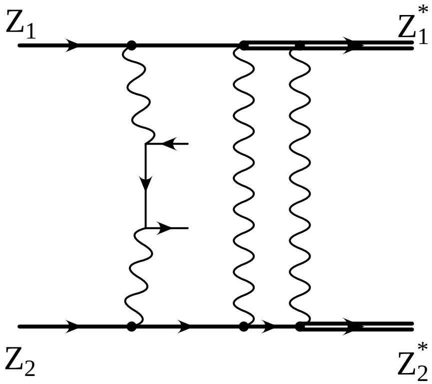
- Based on different importance of different diagrams
- Still open question: Coulomb corrections at small b.

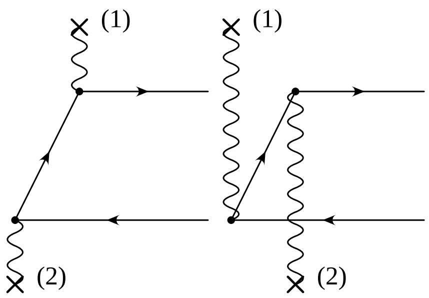
Pair production at small b

- Experiment at RHIC: Pairs produced at small b.
- Tagging for mutual excited ions: few neutrons emitted into the ZDC.
- Average impact parameter:

$$\bar{b} = \frac{\int d^2b \, bP(b)}{\int d^2bP(b)} \approx \frac{8R_a}{3} \approx 19 \text{ fm},$$

- Rather severe restriction on phase space:
  trans. momenta of $e^+e^- > 60MeV$,
  rapidity < 1.15.
- Calculation done in lowest order external field QED.
- Comparison with data and also EPA approach.





K. Hencken, G. Baur, D. Trautmann, Phys. Rev. C69 (2004) 054902
J. Adams et al. (STAR collaboration), nucl-ex/0404012, to appear in PRL ’04

Calculation in external field approach

- In external field approximation different processes factorize:

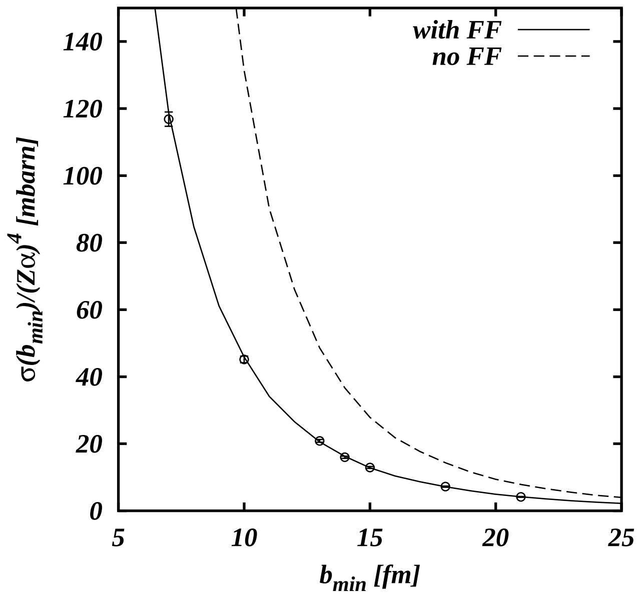
$$\frac{d^6\sigma_{e^+e^-,2GDR}}{d^3p_+d^3p_-} = 2\pi \int_{b_{min}}^{\infty} bdbP^2_{GDR}(b)\frac{d^6P(b)}{d^3p_+d^3p_-}.$$

- $b_{min} \approx 2R_A$ to avoid hadronic interactions.
- Assume $P^2(GDR,b) \sim S^2/b^4$, S from TRK sum rule.

$$S \approx 5.45 \times 10^{-5} Z^3 N A^{-2/3} \text{fm}^2.$$

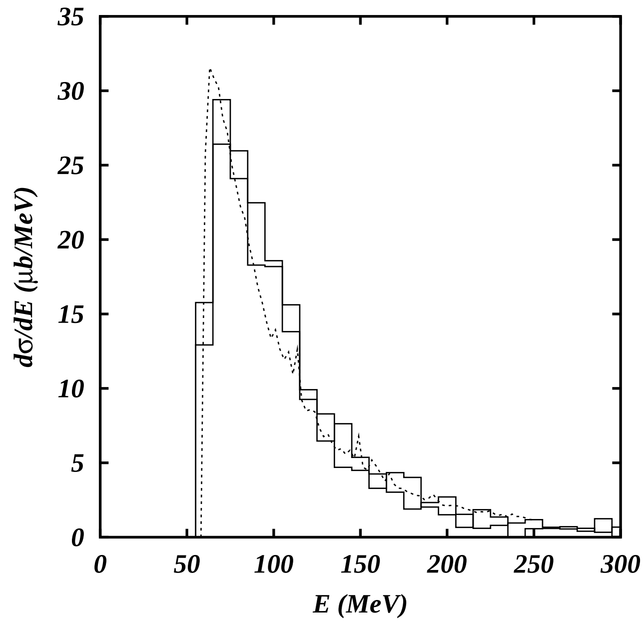
- Can be generalized to arbitrary $1/b^n$ behavior.
- Study also differential distributions.

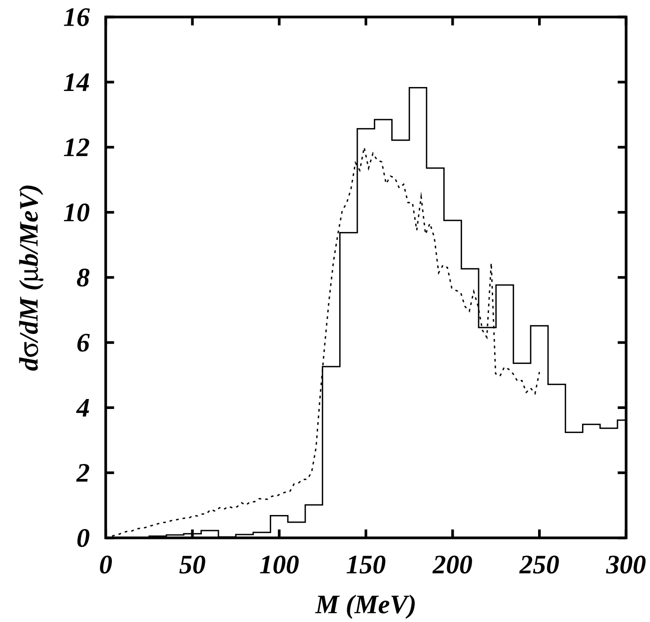
As a function of b_{min}:



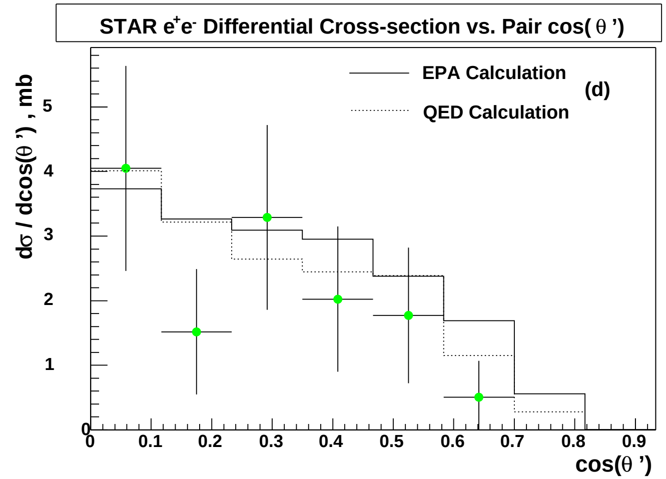
Differential distributions

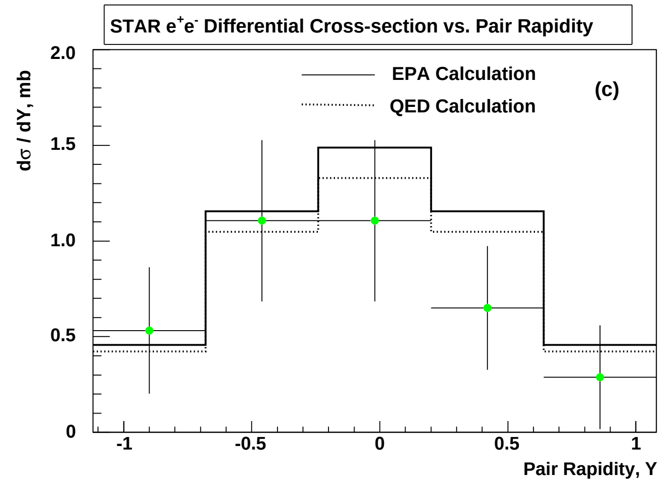
Comparison also with distribution of unrestricted cross section (without GDR excitation):





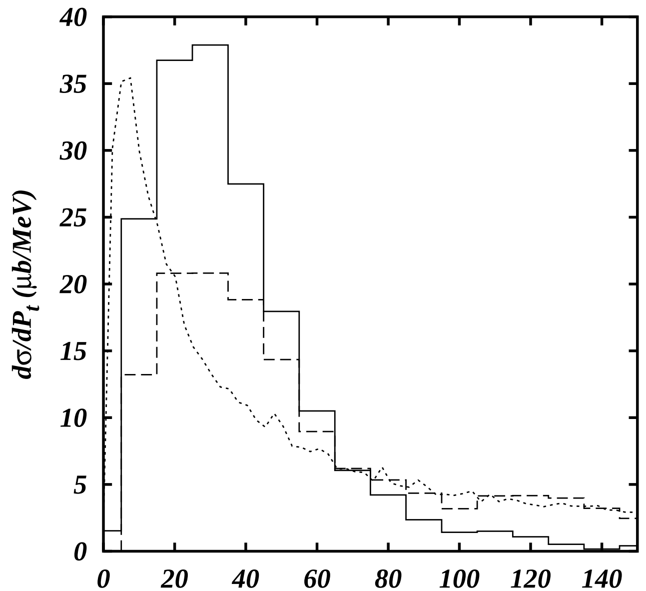
Comparison with experimental results at STAR, EPA calculation:

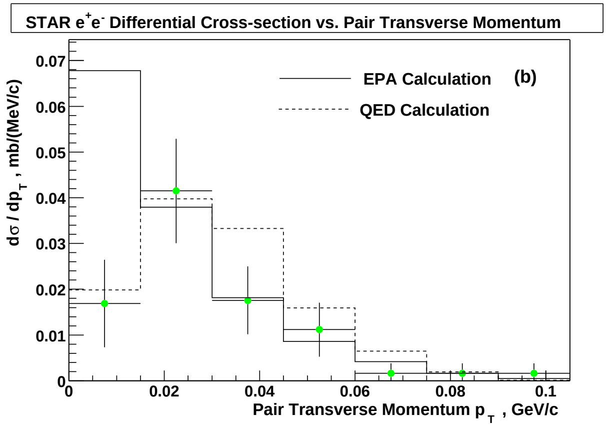




Distribution of pair-Pt

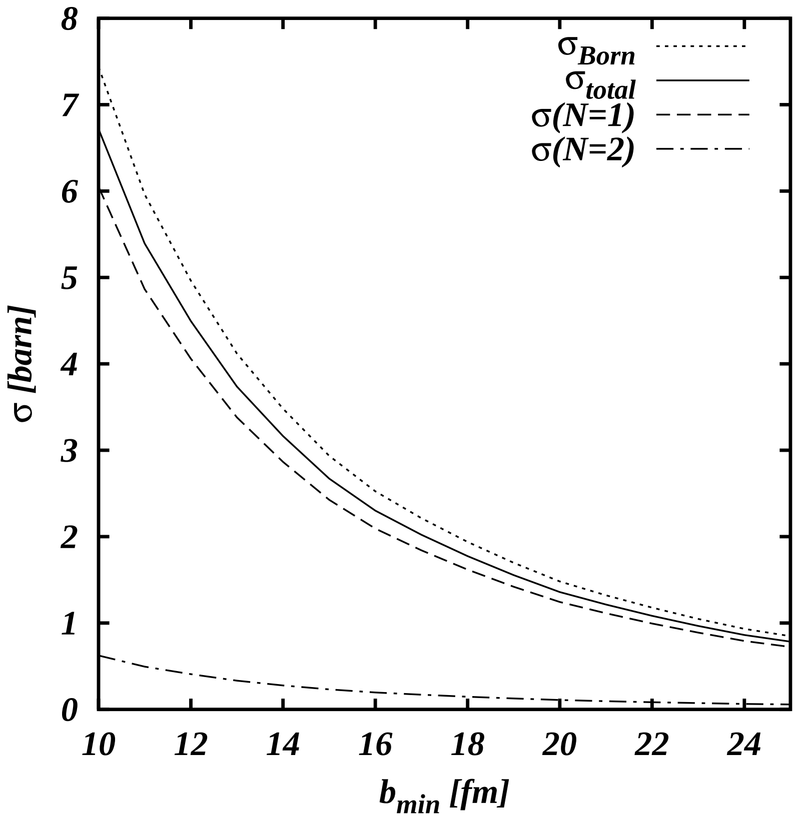
- Main difference seen in P_t of the pair.
- untagged and GDR tagged cross have different form.
- Also EPA calculation by Morozov et al. has different Pt behavior.
- Experiment in better agreement with full calculation.
- Explanation: Photon-k_t distribution is b dependent.
  For small b, distribution is wider.
- At the moment no evidence for Coulomb effects.
- Multiple pair effects are small.





Pair production at ALICE/LHC

- Can use Internal Trigger System (ITS) of ALICE to detect electrons and positrons.
- Cut in phase space on $p_t > 2.6$MeV, $|Y| < 1.5$.
- Distributions of less importance, as no tracking possible.
- Probability in this region is rather large.
- Multiple pair production could be seen at LHC.
- Two-pair production contributes to 10% of total cross section.
- To be studied: pair production into CASTOR.



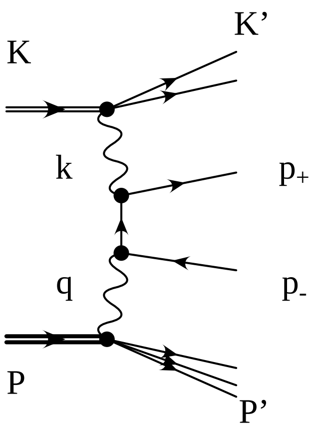
Inelastic pair production

Work done together with U. Dreyer (U Basel)

U. Dreyer et al., to be submitted 2004

- Cross section for (elastic) pair production is large: 200kbarn for PbPb@LHC.
- Inelastic pair production might still give reasonable cross section:
  Z^2 enhancement reduces to Z (A).
  range of q^2 extended considerably.

- Emphasis on two effects:
- Additional loss process: GDR excitation, quasifree knockout.
- Probing the ions with virtual photons: Avoiding restriction of quasireal photons.
- Not comparable with dedicated eRHIC machine.
- Calculated in Plane wave approach.



Calculation of the cross section

- Inclusive cross section given as

$$\sigma = \frac{(2\pi)^4(4\pi\alpha)^4 2M_K 2M_P (2\pi)^2}{8E_K E_P (2\pi)^8} \int \delta(q+k-p_+-p_-) \left(M^{\mu\mu'\nu\nu'} W^K_{\mu\mu'} W^P_{\nu\nu'} \right)$$
$$\frac{1}{q^4 k^4} \frac{d^3 p_+}{(2\pi)^3 2\epsilon_+} \frac{d^3 p_-}{(2\pi)^3 2\epsilon_-} d^4 q d^4 k$$

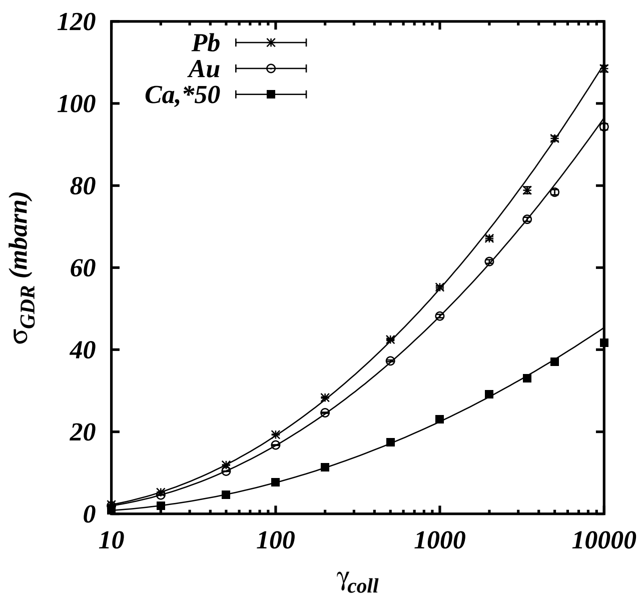
- Electromagnetic tensors determined by W_1 and W_2:

$$W_i^{\mu\mu'} = \left(-g^{\mu\mu'} + \frac{q_i^\mu q_i^{\mu'}}{q_i^2} \right) W_{i,1}$$
$$+ \left(p_i^\mu - \frac{p_i \cdot q_i}{q_i^2} q_i^\mu \right) \left(p_i^{\mu'} - \frac{p_i \cdot q_i}{q_i^2} q_i^{\mu'} \right) \frac{W_{i,2}}{M^2}$$

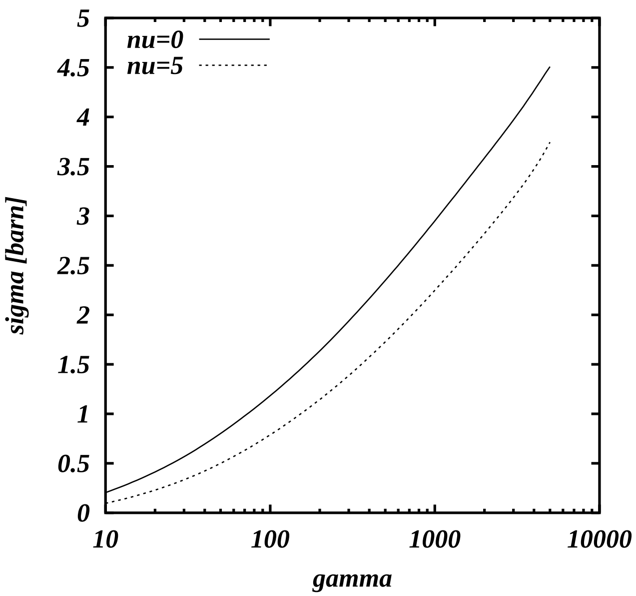
- Elastic process on one vertex: $W_1 = 0$, $W_2 = \delta(\nu) Z^2 F_{el}(q^2)$.
- Inelastic process W_1 and W_2 selected for process of interest.

Contribution to beam loss

- Beam loss and therefore total beam lifetime limited by electromagnetic processes:
  Electron capture from Pair Production = Bound-free Pair production.
  Electromagnetic excitation of the ions.
- Dominant nuclear excitation to the GDR.



- Alternative scenario: Quasielastic nucleon knockout.
- Also leads to change in Z/A ratio.
- Deexcitation via multiple neutron emission.
- Use simple Fermi gas model.
- Depends on average excitation energy for the nucleon.



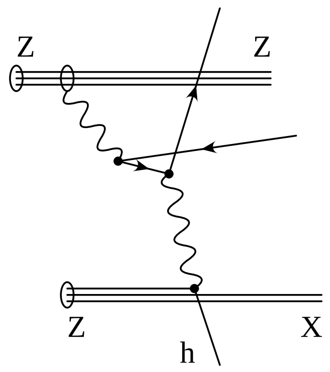
- Open question: Contribution to mutual excitation for luminosity measurement.

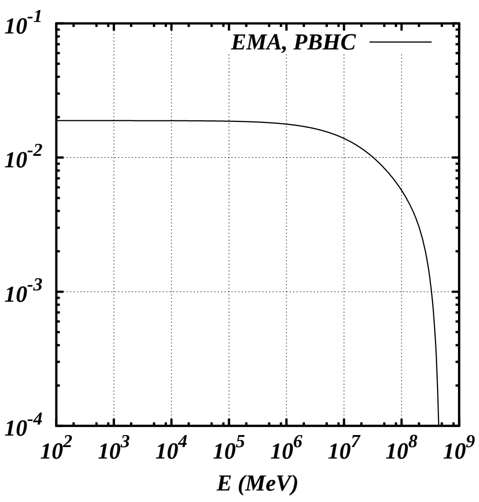
Deep inelastic scattering in inel. pair production

- Inelastic pair production allows to go from quasireal photons to virtual photons.
- Picture: Equivalent Lepton Approximation:

$$f_{l|A}(x) \approx \int \frac{du}{u} f_{\gamma|A}(u) f_{l|\gamma}(x/u)$$

- At high q^2: Study quark pdf in the nucleus.
- Estimate cross sections with no medium modification.
- Compare EPA, ELA with full calculation.
- Both electron and muon pair production studied.

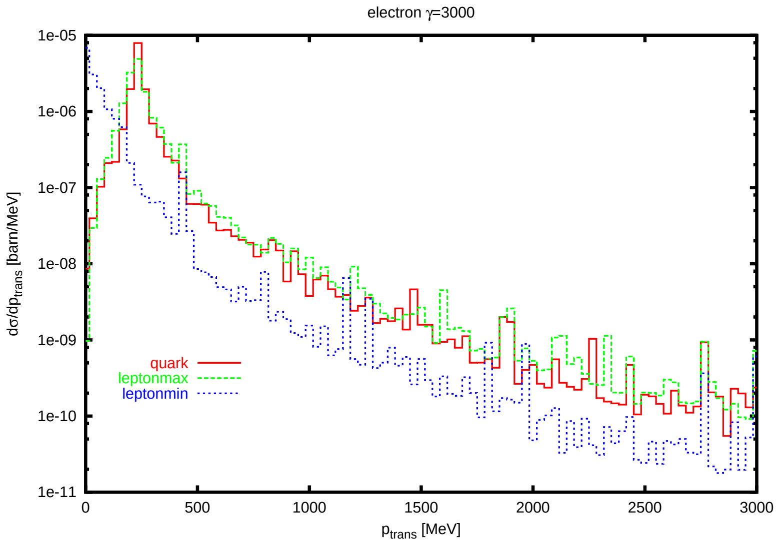


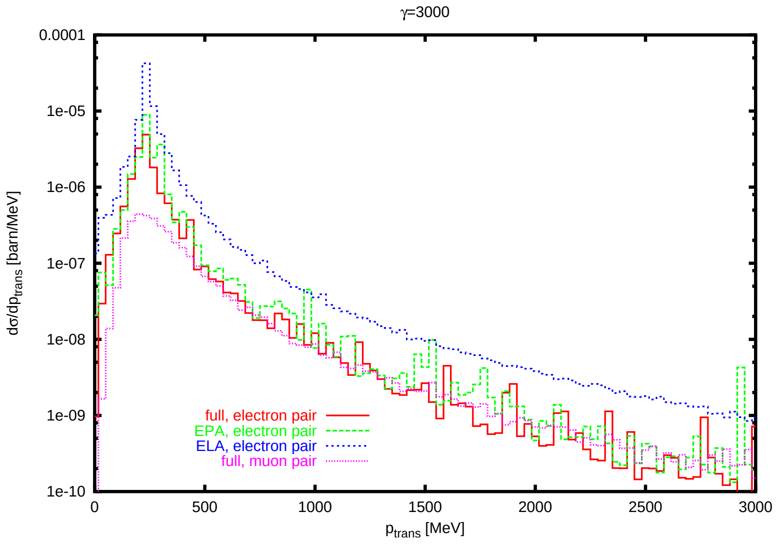


$$W_1 = \frac{1}{2Mx} F_2(x), \quad W_2 = \frac{2Mx}{Q^2} F_2(x), \quad F_2(x) = \sum_i e_i^2 x f_i(x)$$

Transverse momentum distribution

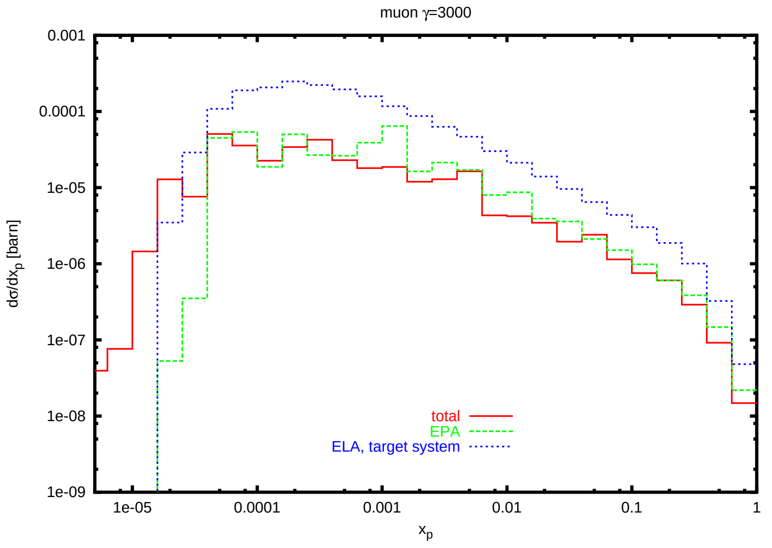
- Identify the two leptons via their transverse momenta:
- Smaller p_t (ptmin) $\leftrightarrow$ spectator lepton.
- Larger p_t (ptmax) $\leftrightarrow$ inelastic scattered lepton.
- ptmax-distribution coincides with "quark" ptrans-distribution
- Comparison between EPA, ELA, full approach:
  EPA reproduces differential and total cross section reliably.
  ELA overestimates up to a factor of four.
- Explanation: pt of intermediate muon ($=$ spectator muon) can get large.
- Muon cross section only differ slightly compared to electron.

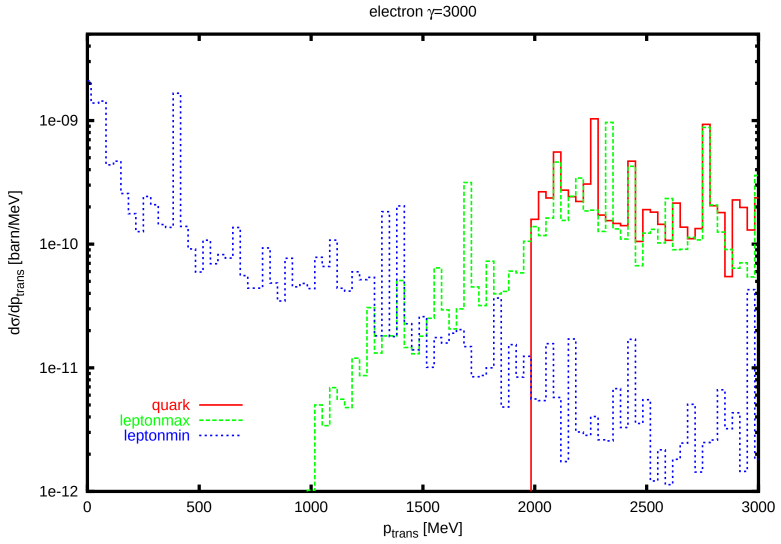


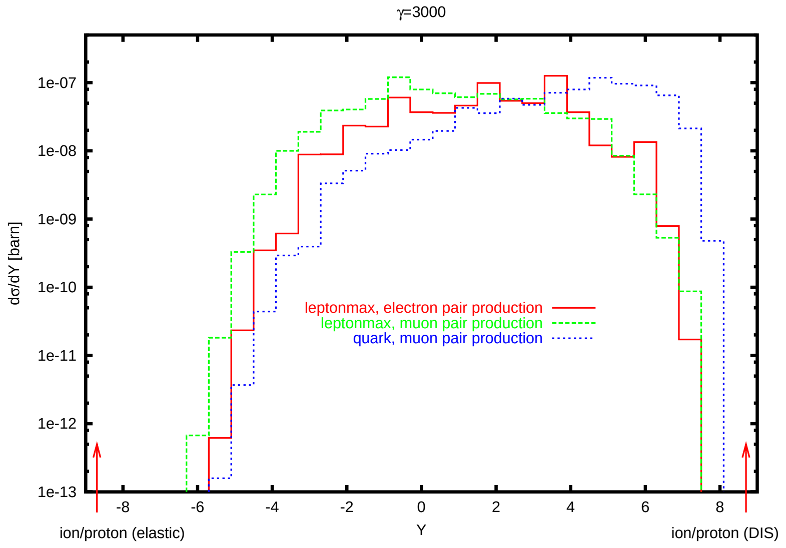


Jet transverse momenta of 2GeV

- Restrict cross section to transverse momentum transfer > 2GeV.
- Naive expectation: ELA should agree better.
- Important also to be able to detect/reconstruct jet.







Future work

- Calculate in-medium modification effects for moderate q^2 and x.
- Study cross section including experimental acceptance (especially of ALICE, CMS)
- Especially: accuracy that can be reached.
- Reconstruction of the muon energy.
- q^2 dependence of exclusive (coherent) vector meson production.

Summary and Outlook

- Large cross section for e^+e^- both a possible background and an interesting signal.
- Impact parameter dependence and cross sections of corrections well understood.
- Analytic expression for γ dependence, universal parameterization available.
- Coulomb corrections at small b still an open question.
- Experimental results at RHIC in good agreement with calculation.
  But: Phase space rather restricted.
- Interesting question: Effect at small b in CASTOR.
- Inelastic pair production:
- Correction to elmgn. excitation of ions, loss process
- Deep inelastic scattering possible approach to study quark pdfs in nuclei at LHC.

Work done together with:

A. Aste, T. Baier, G. Baur, U. Dreyer, Yu. Kharlov, S. Sadovsky, V. Serbo, D. Trautmann