Interpretation of jet quenching pattern at LHC with PYQUEN model

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PYQUEN - medium-induced partonic energy loss model (modifies PYTHIA6.4 jet event), latest version 1.5.1
http://cern.ch/lokhtin/pyquen

I. Lokhtin, A. Snigirev, Eur. Phys. J. C 46 (2006) 211

LHC data on jet quenching in PbPb collisons at $\sqrt{s}$=2.76 A TeV

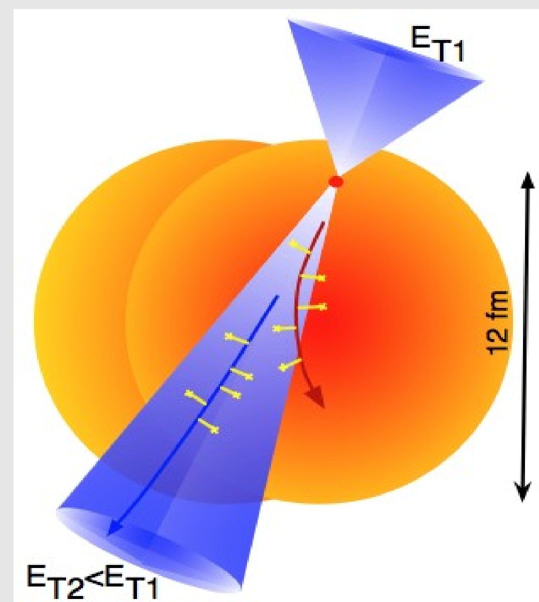
- **Nuclear modification factor for charged hadrons**

$$R_{AA} = \frac{\sigma_{pp}^{\text{inel}}}{\langle N_{\text{coll}} \rangle} \frac{d^2 N_{AA}/dp_T d\eta}{d^2 \sigma_{pp}/dp_T d\eta}$$

ALICE Coll., PLB 696 (2011) 30

- **Dijet E_T-asymmetry**

$$A_J = \frac{E_T^{j1} - E_T^{j2}}{E_T^{j1} + E_T^{j2}}$$



ATLAS Coll., PRL 105 (2010) 252303;
CMS Coll., arXiv:1102.1957, submitted to PRC

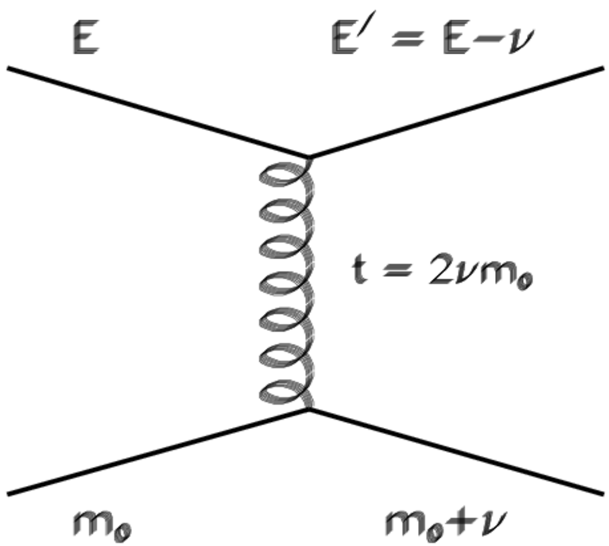
Mechanisms of partonic energy loss in PYQUEN

Collisional loss

(high momentum transfer approximation)

Radiative loss

(BDMS model, coherent radiation)



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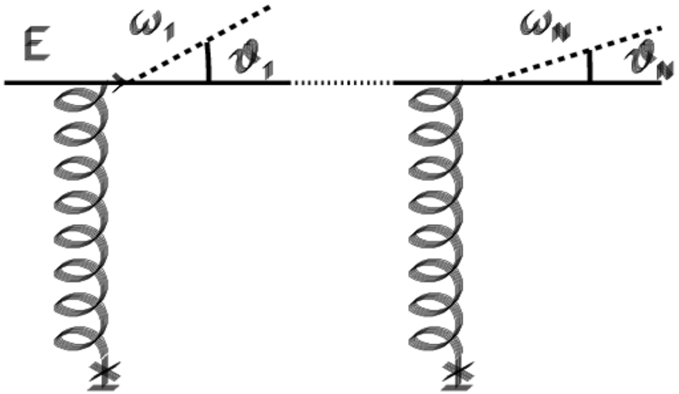


Strength of e-loss in PYQUEN is determined mainly by initial maximal temperature T0 of hot matter in central (b=0) PbPb collisions (depends also on formation time τ_0 and # of quark flavors N_f)

Angular structure of energy loss in PYQUEN

Radiative loss, two main options (simple parametrizations) for angular distribution of in-medium emitted gluons:

Small-angular radiation $$\frac{dN^g}{d\theta} \propto \sin\theta \exp\left(\frac{-(\theta-\theta_0)^2}{2\theta_0^2}\right), \quad \theta_0 \sim 5^o$$

Wide-angular radiation $$\frac{dN^g}{d\theta} \propto \frac{1}{\theta}$$

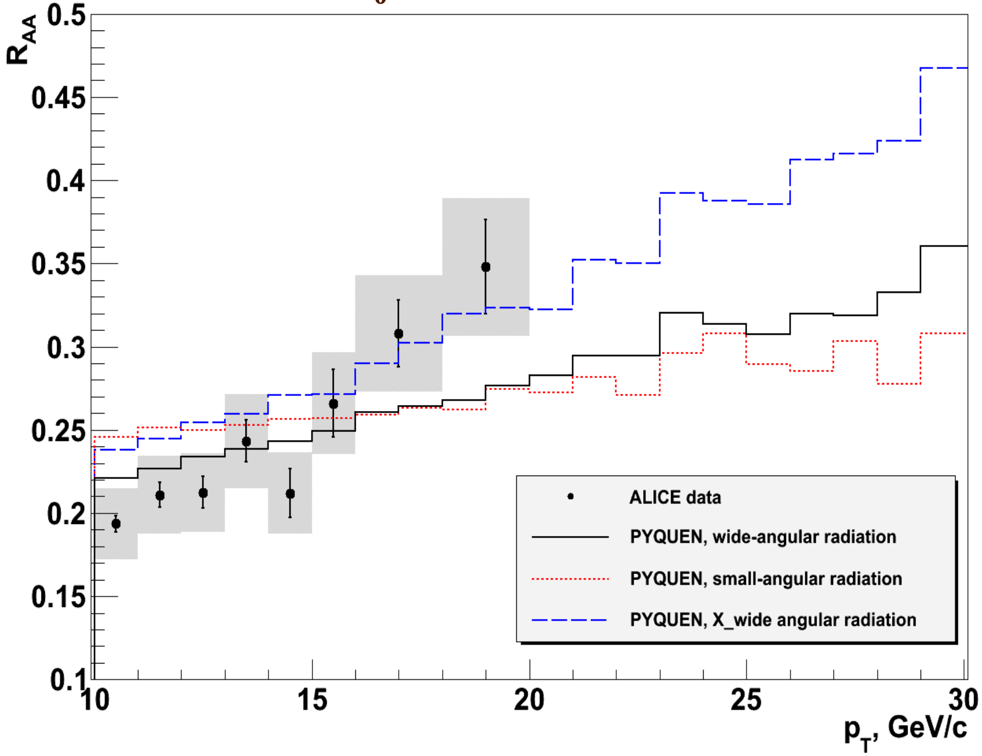
In addition, one more (rather extreme) parametrization was considered:

X_Wide-angular radiation $$\frac{dN^g}{d\theta} \propto \frac{1}{\sqrt{\theta}}$$

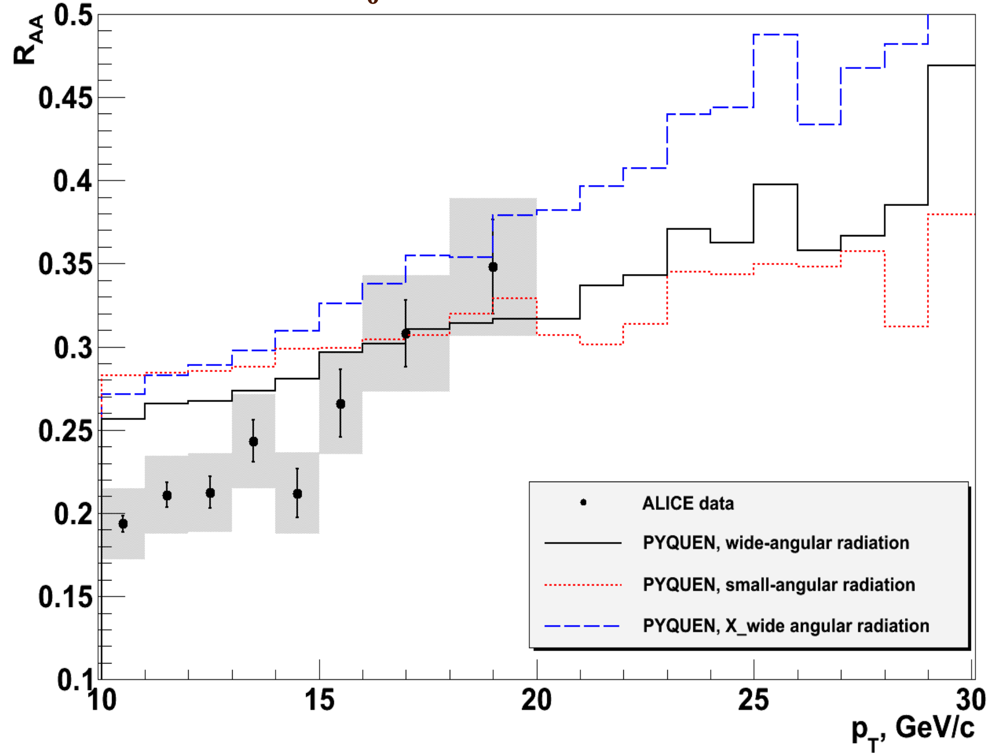
Collisional loss always "out-of-cone" (energy is absorbed by medium)

R_{AA} for charged hadrons

T_0^{max}=1 GeV



T_0^{max}=0.85 GeV

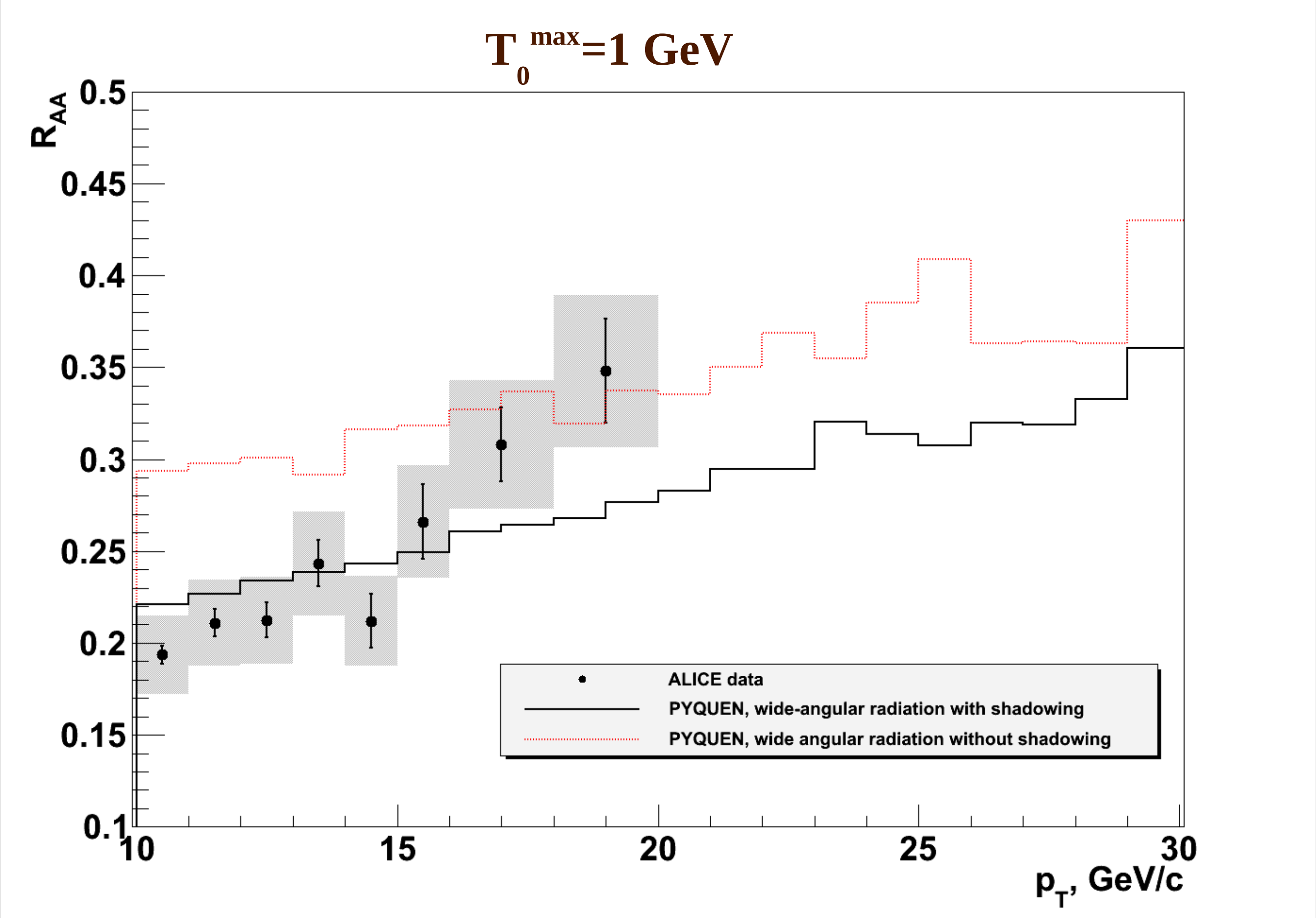


Pb+Pb, 0-5% centrality, 2.76 A TeV, $|\eta^{ch}|<0.8$

ALICE data – points, PYQUEN+NuclearShadowing (HYDJET) – histograms (τ_0=0.1 fm/c, N_f=0)

Higher initial temperature and wider angular radiation seem preferable.

R_{AA} for charged hadrons

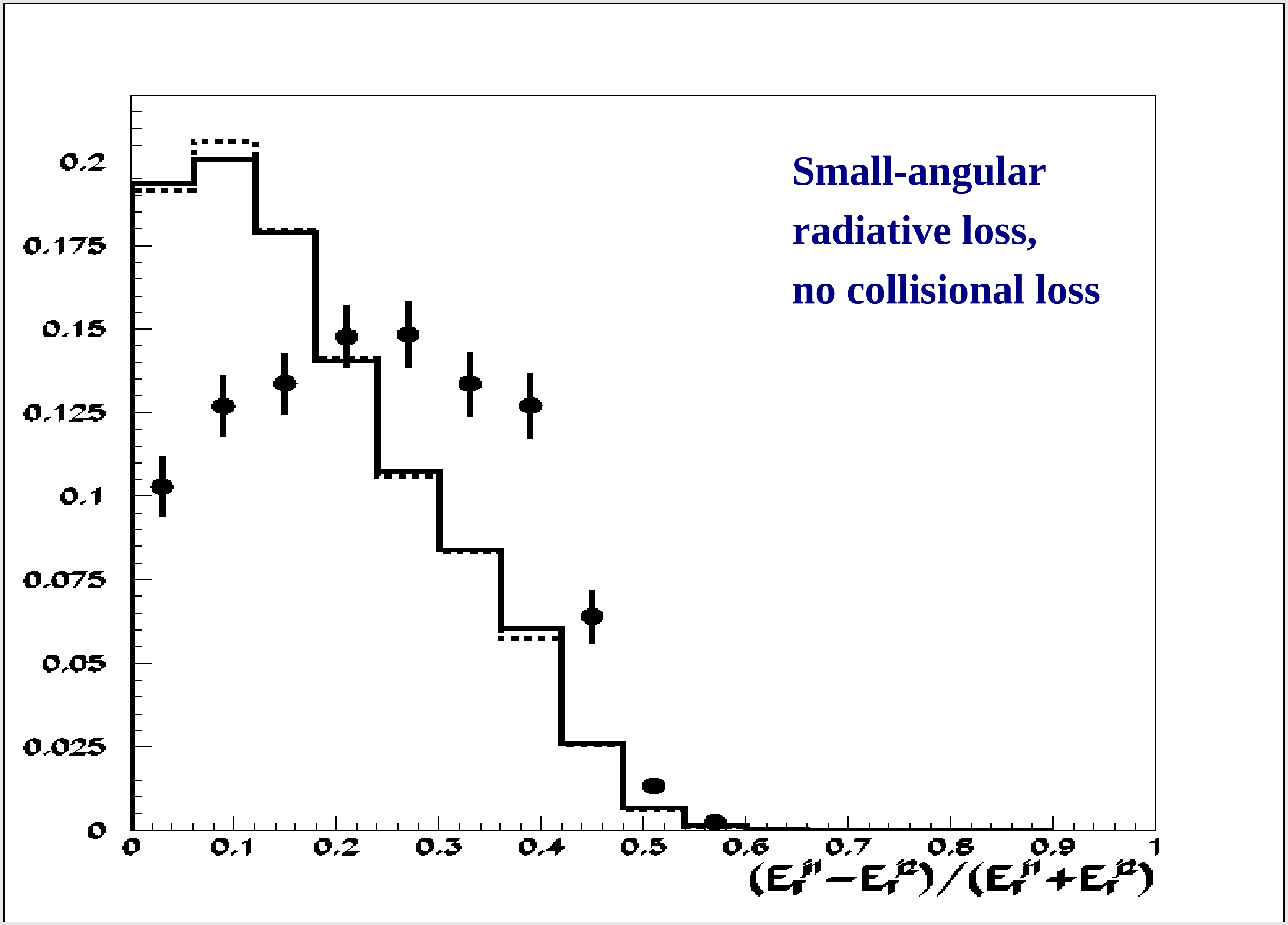


Pb+Pb, 0-5% centrality, 2.76 A TeV, $|\eta^{ch}|<0.8$

ALICE data – points, PYQUEN with and w/o shadowing – histograms

Contribution of nuclear shadowing to R_{AA} is significant (~30% at p_T=10 GeV/c).

Dijet E_T-imbalance



Pb+Pb,
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2.76 A TeV,
$|\eta|<2$, $\Delta\varphi>2.1$,
leading $E_T>120$ GeV,
sub-leading $E_T>50$ GeV
E_T(jet) is smeared,
$\sigma_{ET}=1.7\sqrt{E_T(\text{jet})}$,
R(jet)=0.5

PYQUEN — solid,
PYTHIA – dashed,
CMS data – points

PYQUEN parameters:
$T_0^{max}=1$ GeV,
$\tau_0=0.1$ fm/c, $N_f=0$

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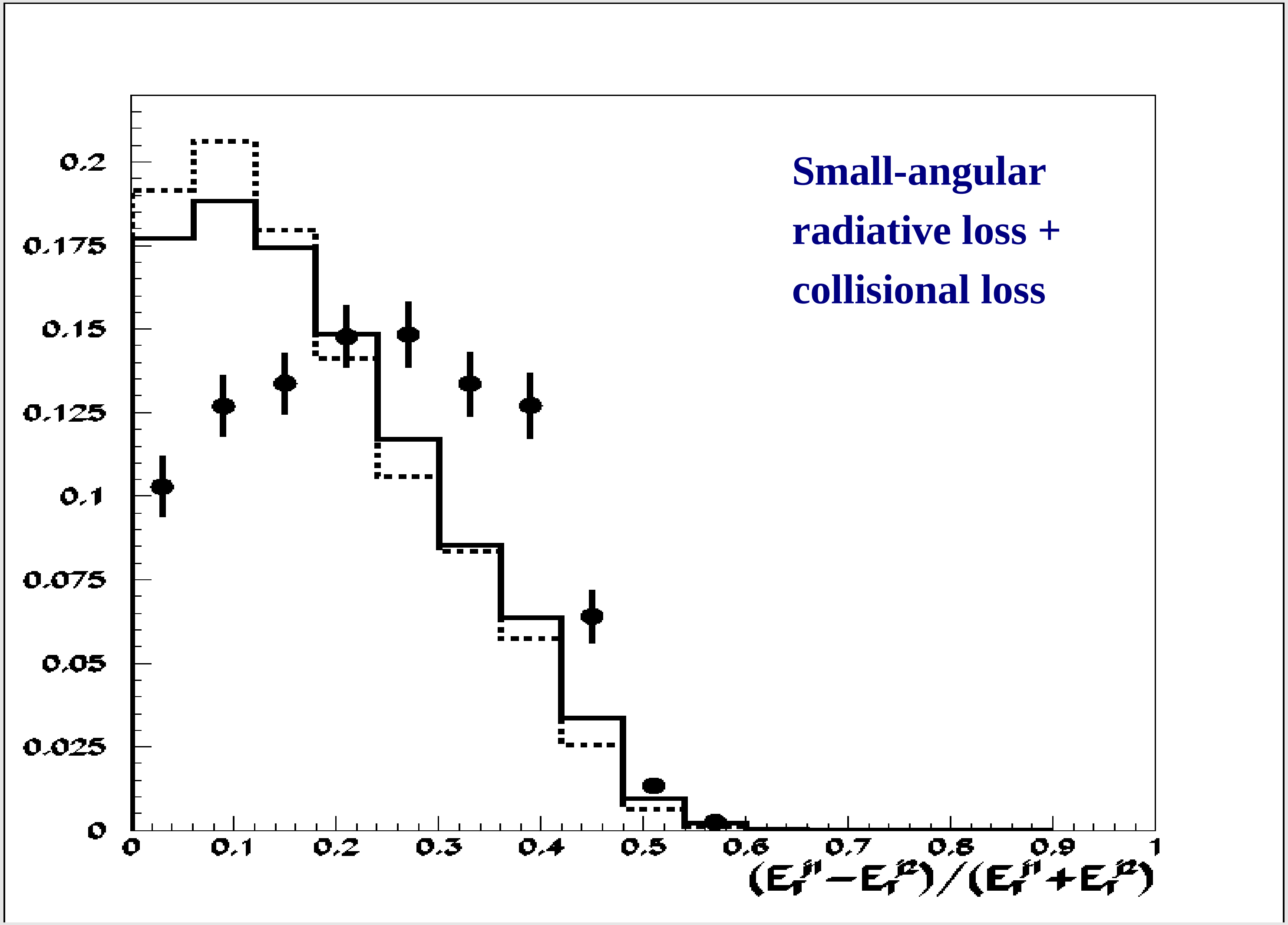

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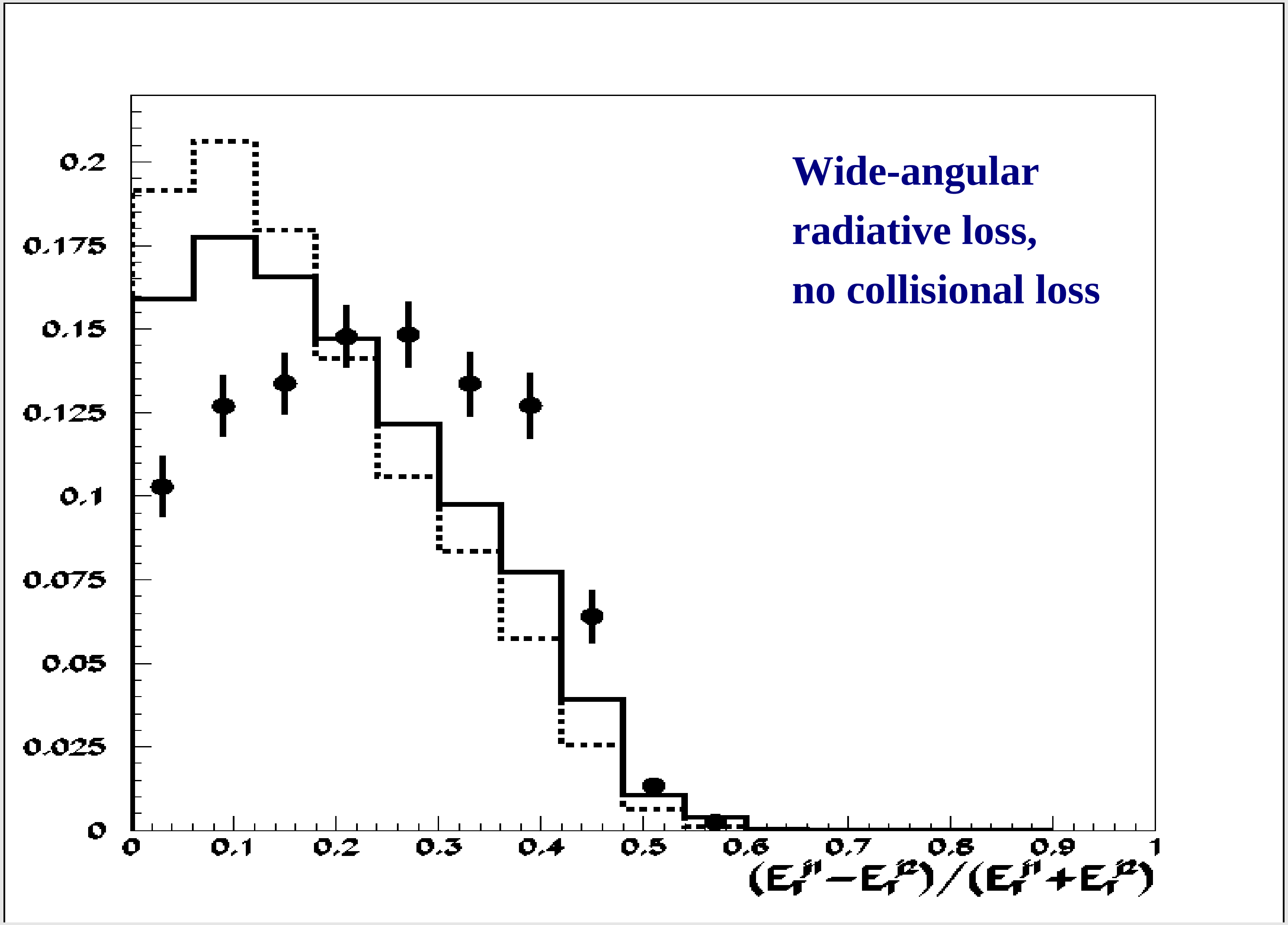

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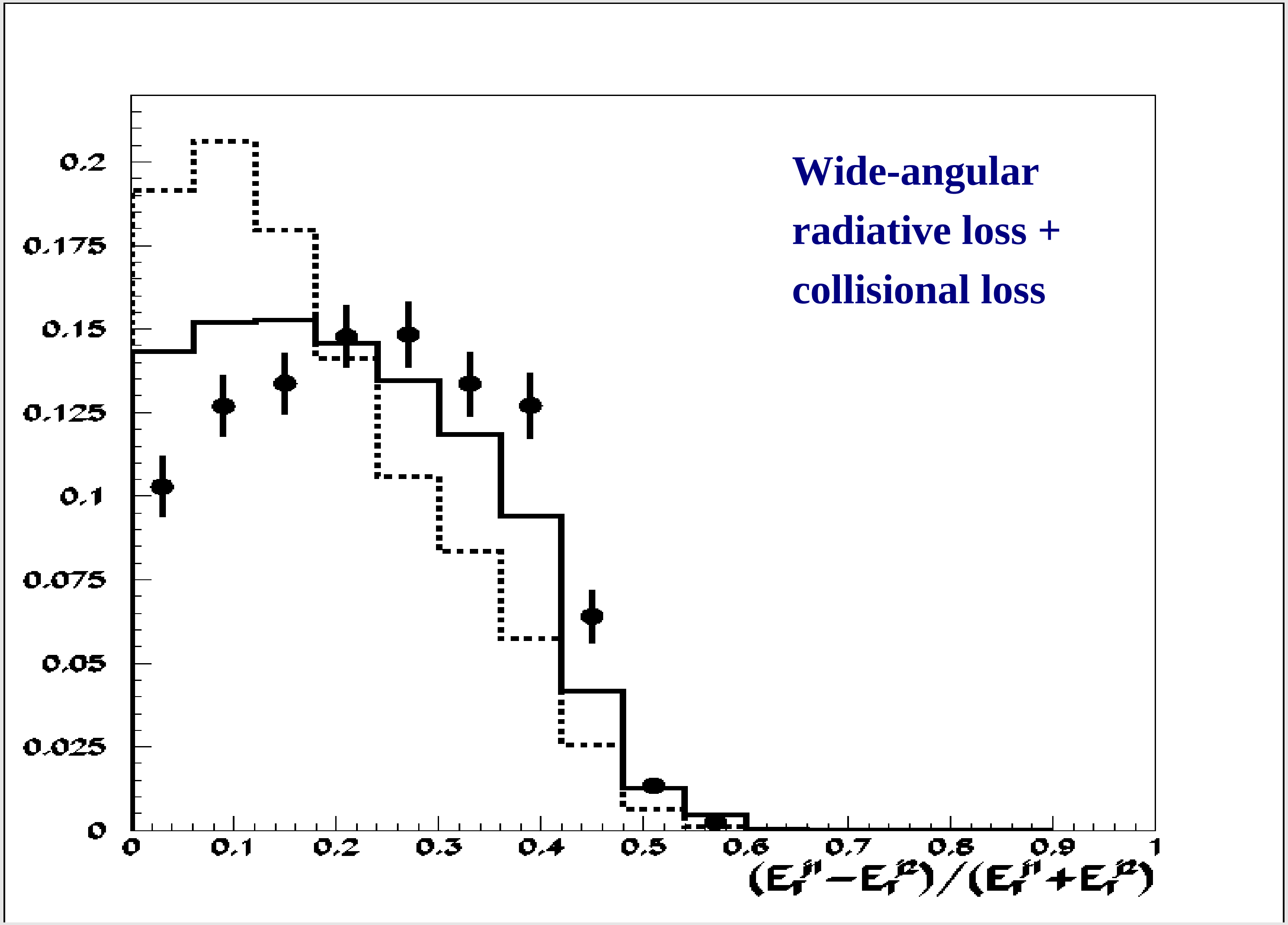

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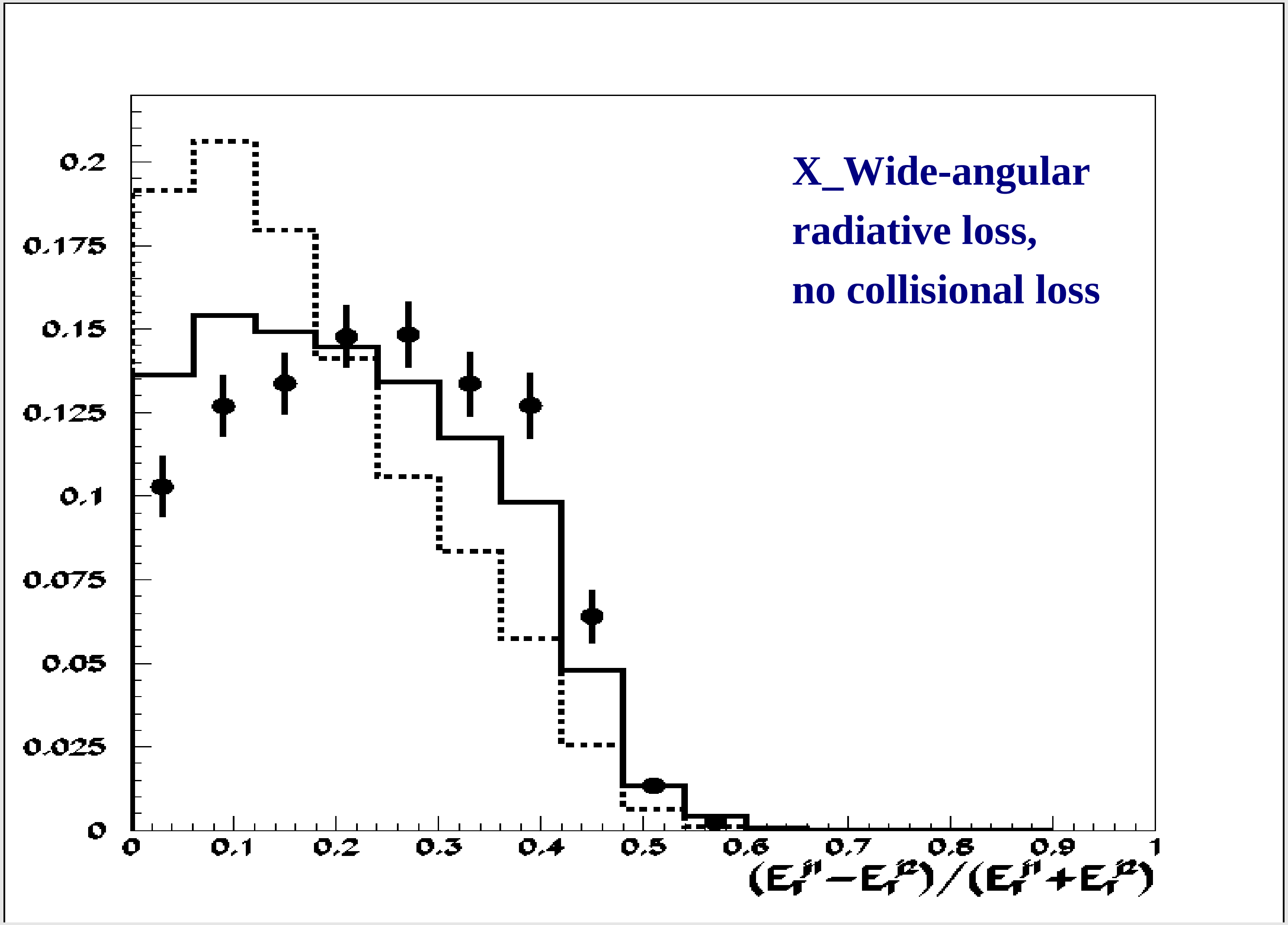

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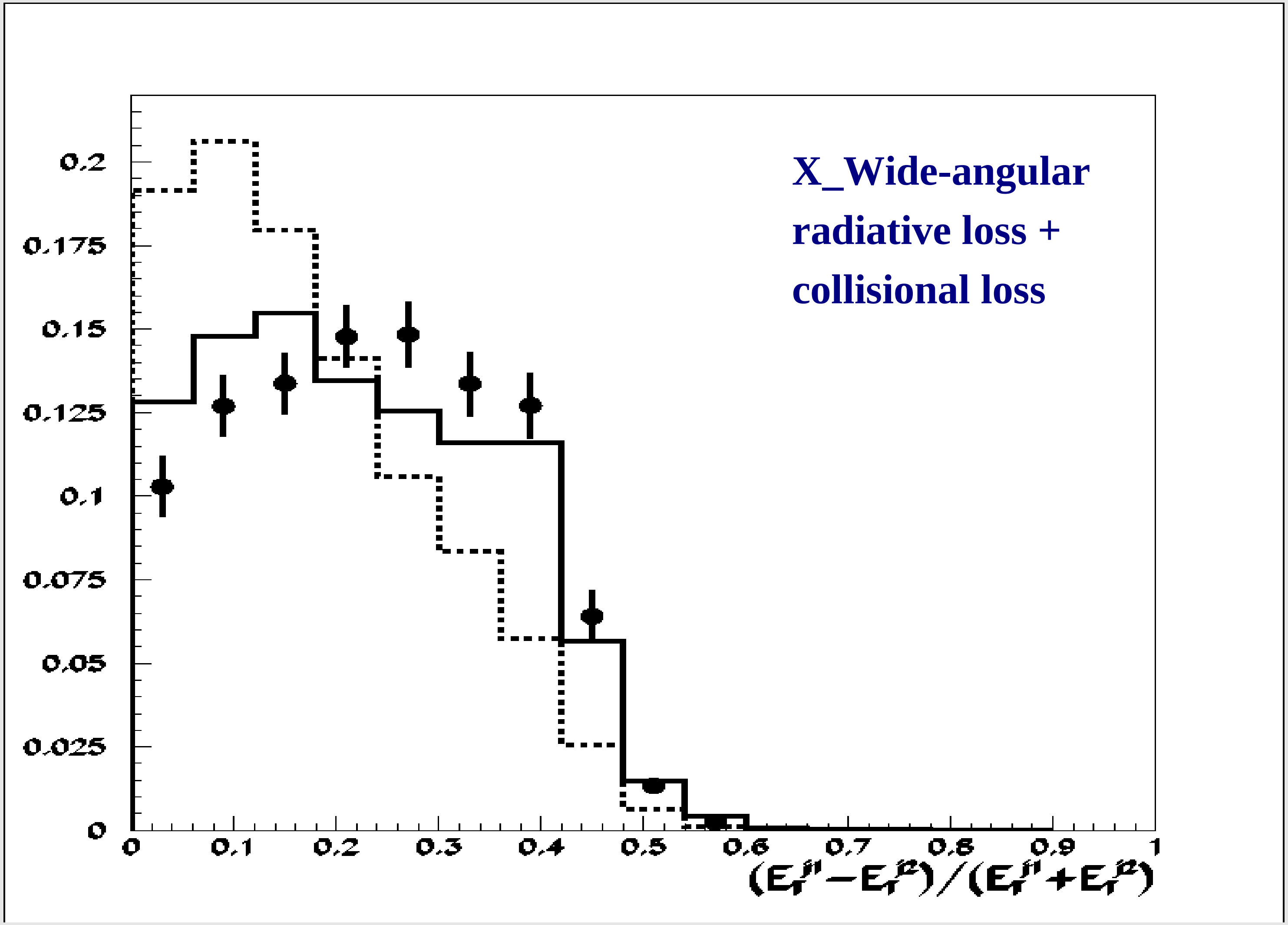

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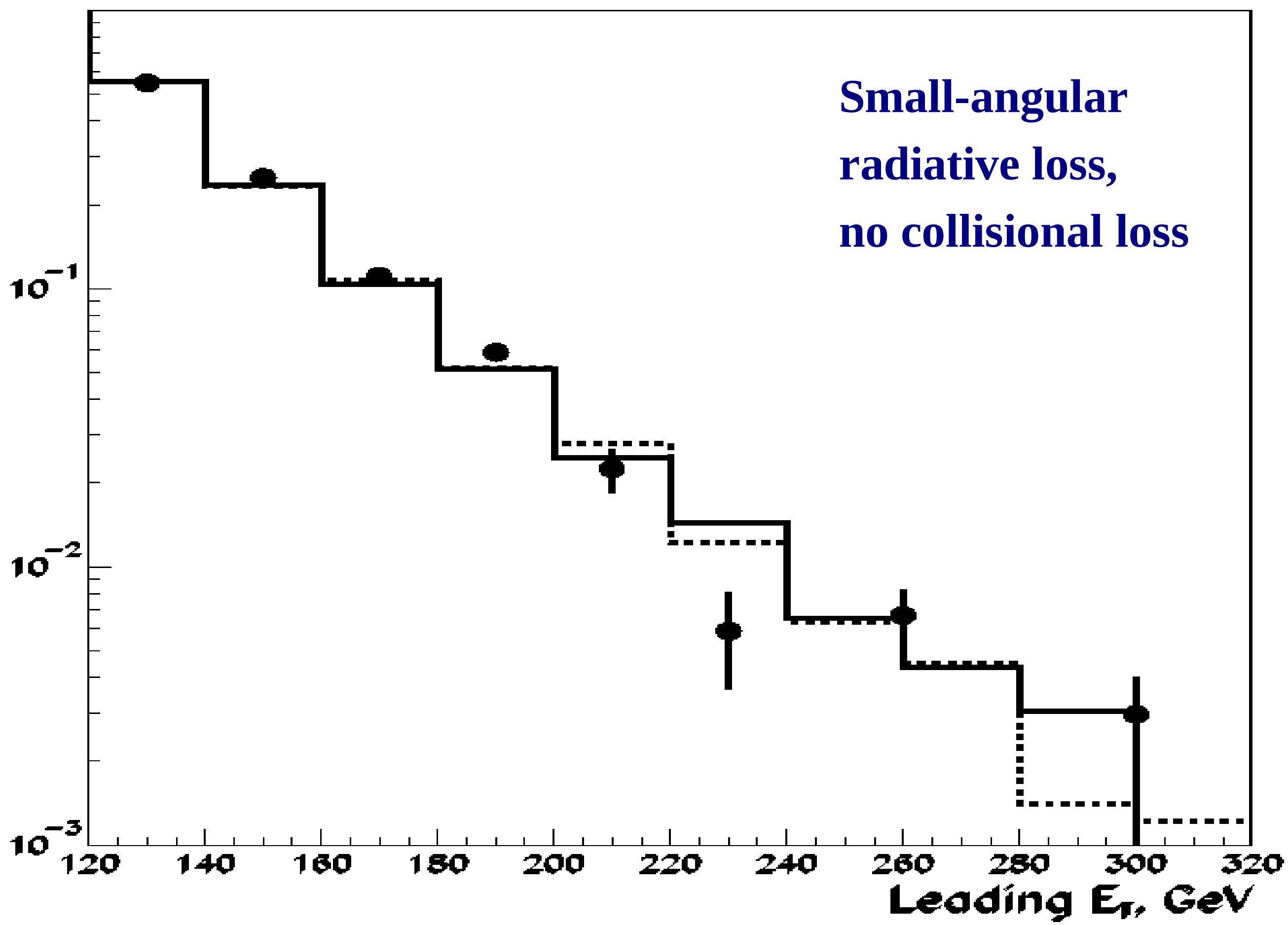
Leading jet E_T-spectrum

R_{AA}(dijet)=Ndijets(PYQUEN)/Ndijets(PYTHIA)=0.87



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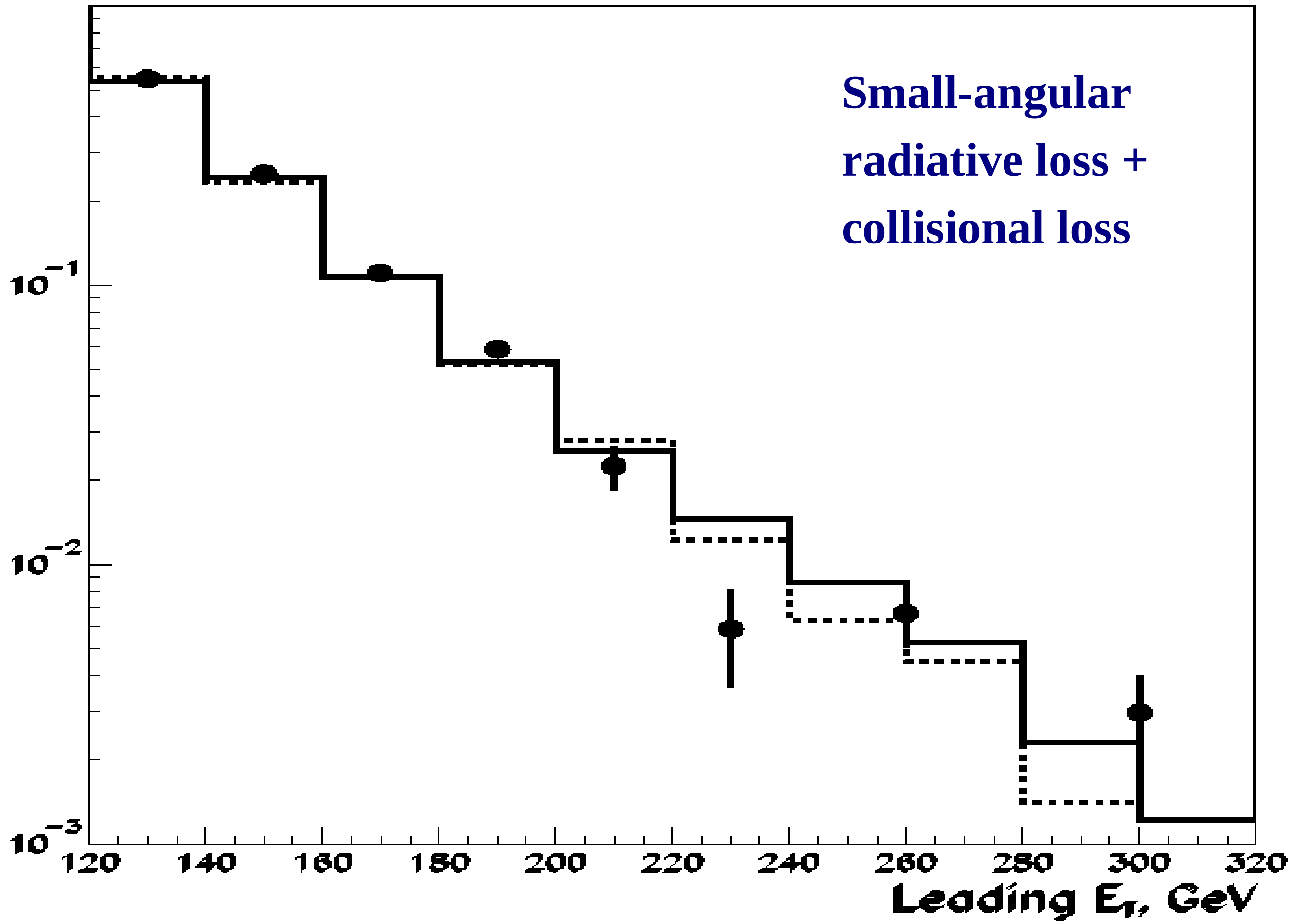
Leading jet E_T-spectrum

R_{AA}(dijet)=Ndijets(PYQUEN)/Ndijets(PYTHIA)=0.53



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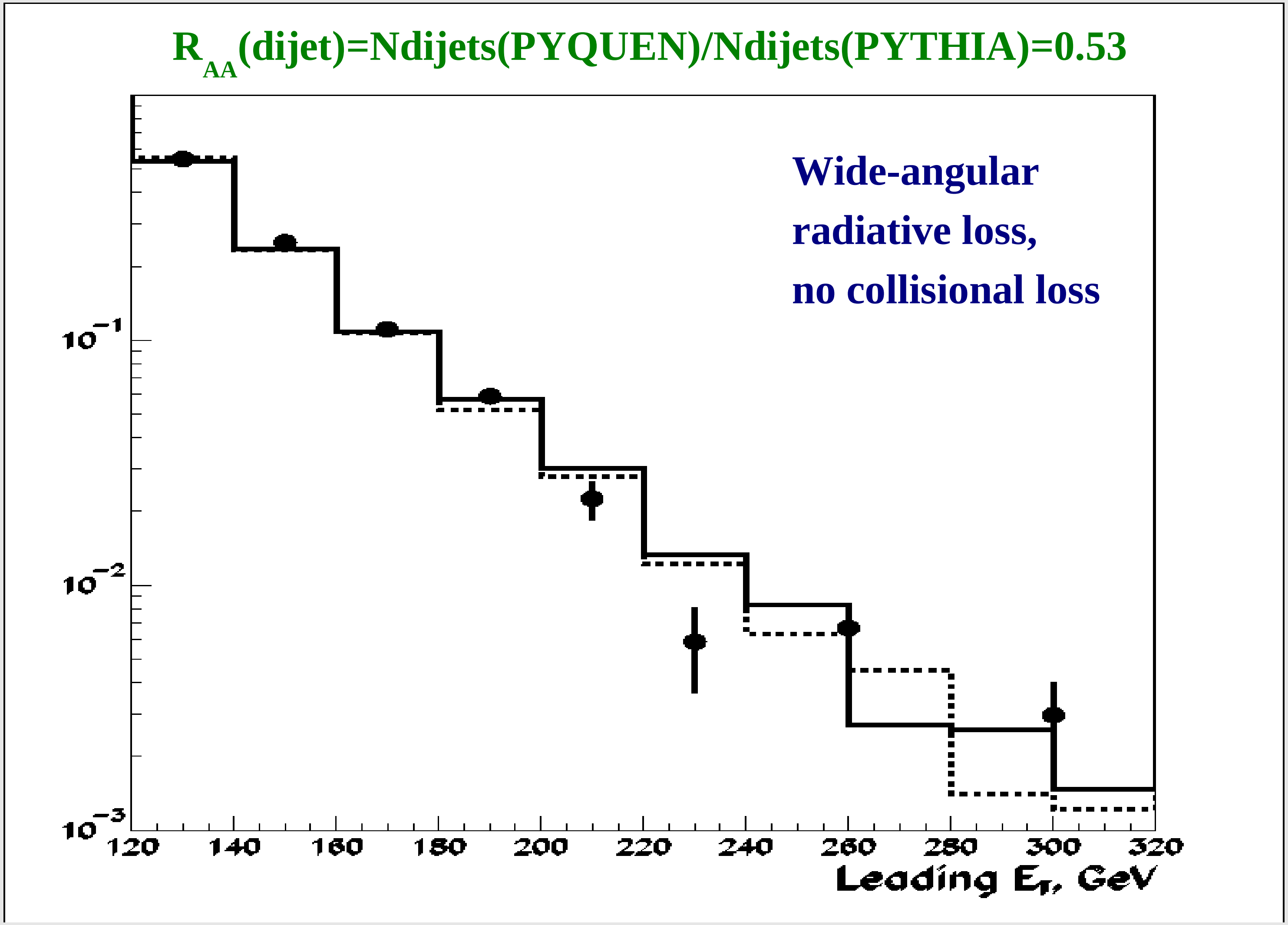

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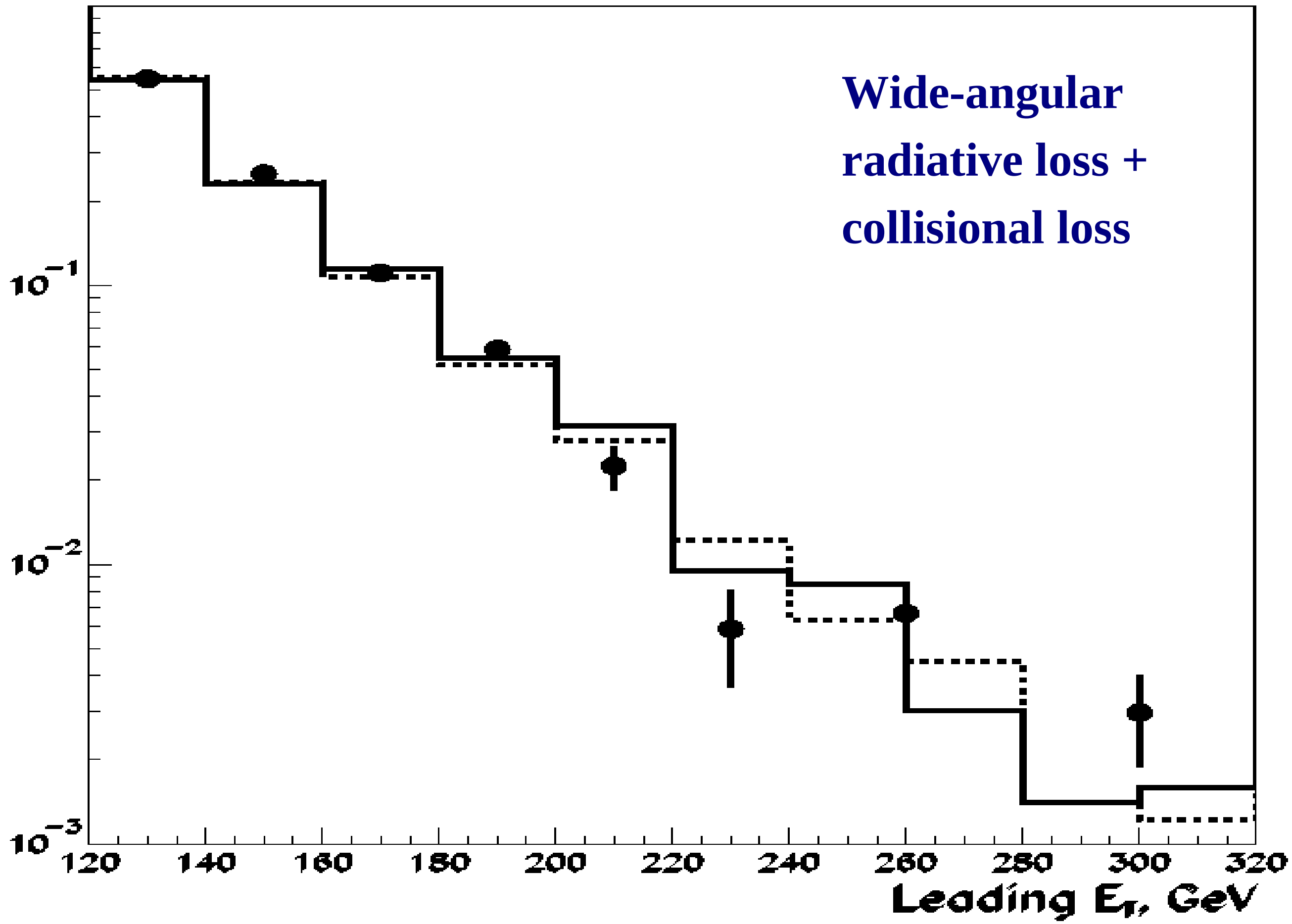
Leading jet E_T-spectrum

R_{AA}(dijet)=Ndijets(PYQUEN)/Ndijets(PYTHIA)=0.36



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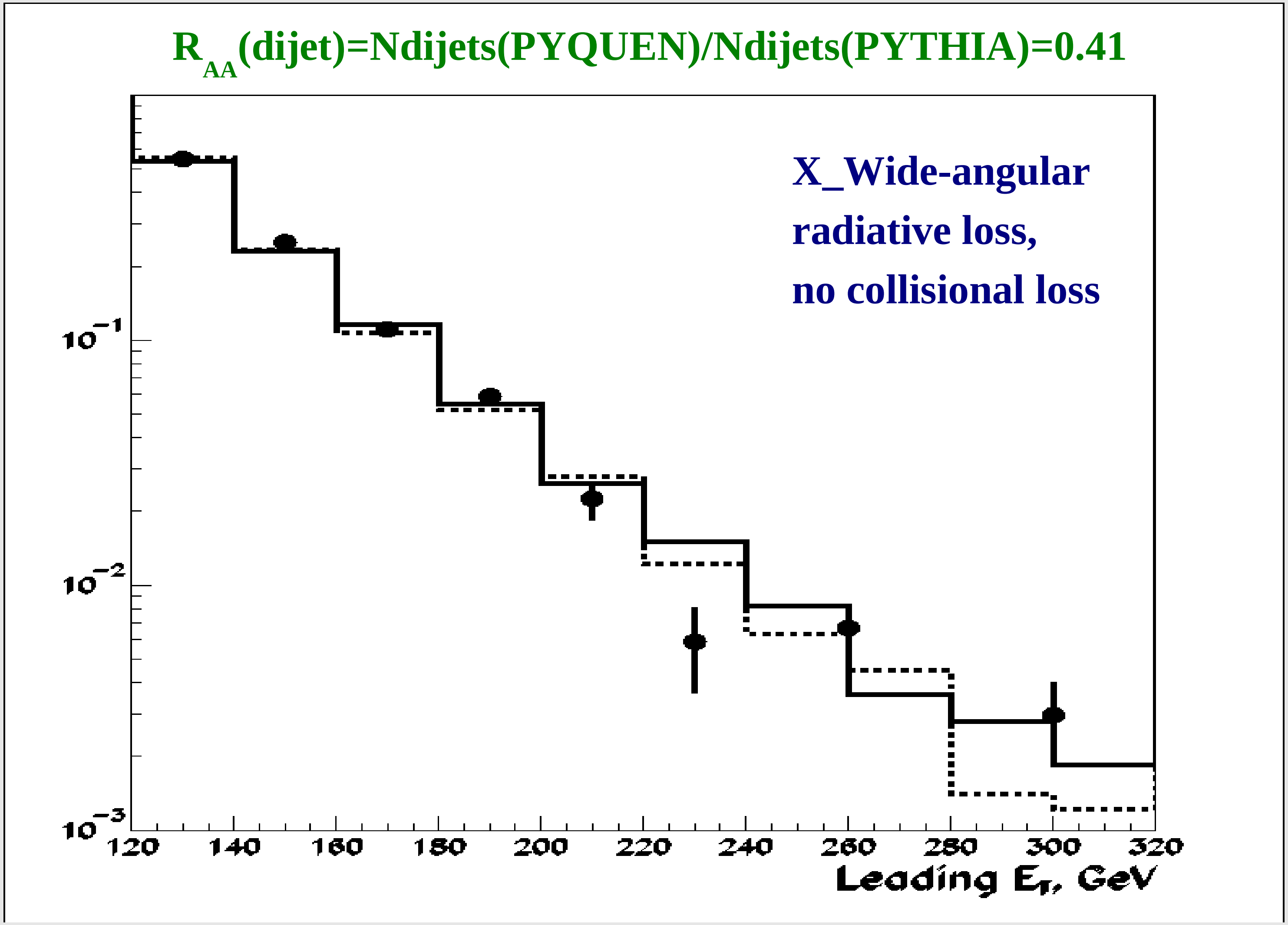
Leading jet E_T-spectrum



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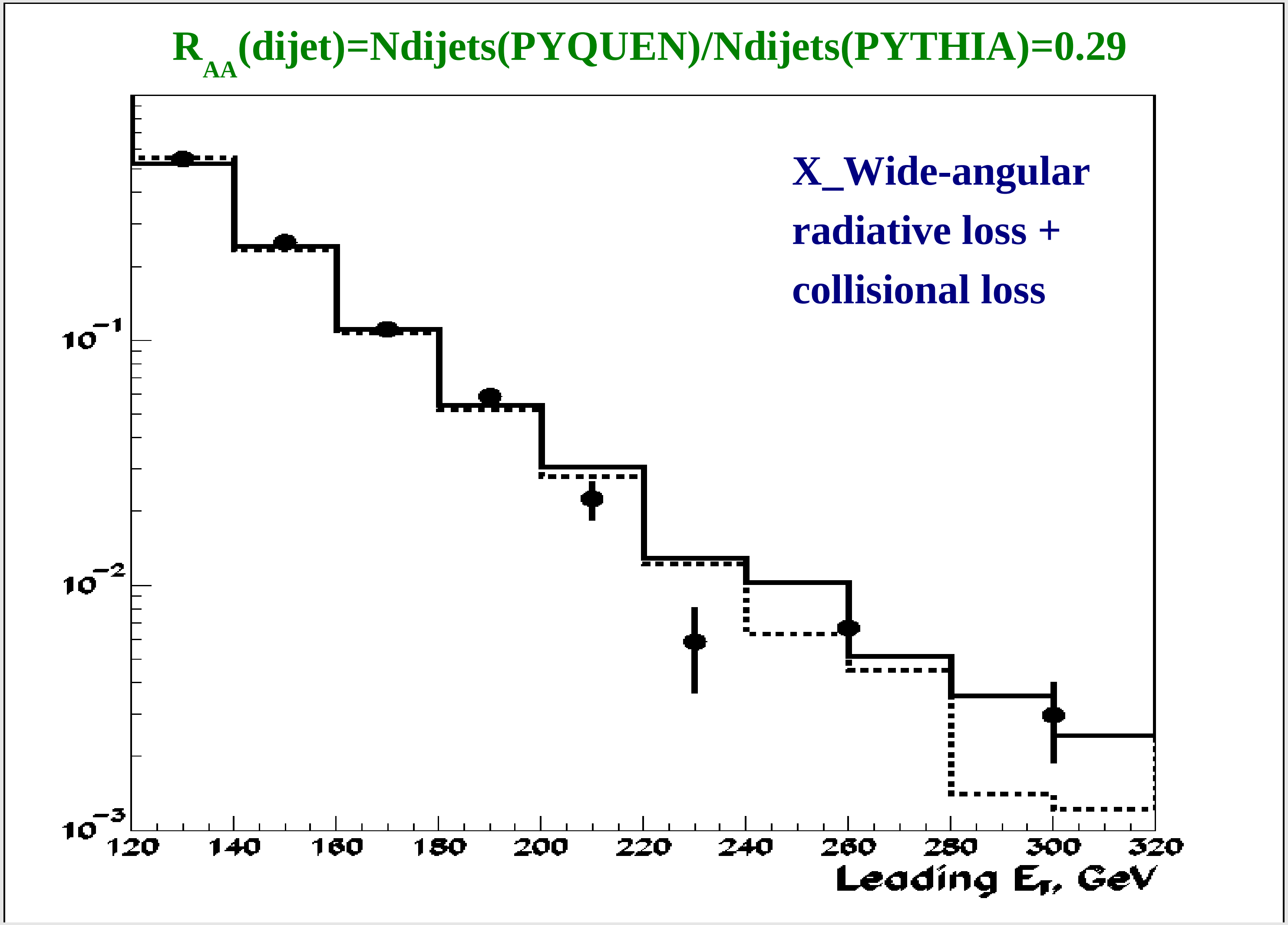

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Summary

PYQUEN studies support the supposition that the intensive wide-angular ("out-of-cone") partonic energy loss is seen in central Pb+Pb collisions at the LHC.

However, there are some complications for a more quantitative interpretation of the jet quenching pattern at the LHC.

R_{AA}@ALICE – affected by large systematic uncertainties due to the absence of pp data at the same energy. Moreover, the contribution of nuclear shadowing to R_{AA} seems significant at least up to p_T~20-25 GeV/c and should be taken into account.

A_j @CMS/ATLAS – simple generator level studies are likely not enough for the accurate comparison with the data (taking into account realistic detector effects, jet finding details and high multiplicity background may be important).

BACKUP SLIDES

PYQUEN (PYthia QUENched)

I.Lokhtin, A.Snigirev, EPJC 46 (2006) 211; http://cern.ch/lokhtin/pyquen

Initial parton configuration

PYTHIA6.4 w/o hadronization: mstp(111)=0

↓

Parton rescattering & energy loss (collisional, radiative) + emitted g

PYQUEN rearranges partons to update ns strings: ns call PYJOIN

↓

Parton hadronization and final particle formation

PYTHIA6.4 with hadronization: call PYEXEC

Three model parameters: initial maximal QGP temperature T_0 in central PbPb, QGP formation time τ_0 and number of active quark flavors in QGP N_f (+ minimal p_T of hard process Ptmin(hard) and other PYTHIA parameters)

Medium-induced partonic energy loss in PYQUEN

General kinetic integral equation:

$$\Delta E(L,E)=\int_0^L dx\,\frac{dP}{dx}(x)\,\lambda(x)\,\frac{dE}{dx}(x,E),\quad \frac{dP}{dx}(x)=\frac{1}{\lambda(x)}\exp\left(-x/\lambda(x)\right)$$

1. Collisional loss and elastic scattering cross section:

$$\frac{dE}{dx}=\frac{1}{4T\lambda\sigma}\int_{\mu_D^2}^{t_{max}} dt\,\frac{d\sigma}{dt}\,t,\quad \frac{d\sigma}{dt}\simeq C\,\frac{2\pi\alpha_s^2(t)}{t^2},\quad \alpha_s=\frac{12\pi}{(33-2N_f)\ln(t/\Lambda_{QCD}^2)},\quad C=9/4(gg),1(gq),4/9(qq)$$

2. Radiative loss (BDMS):

$$\frac{dE}{dx}(m_q=0)=\frac{2\alpha_s C_F}{\pi\tau_L}\int_{E_{LPM}\sim\lambda_g\mu_D^2}^{E} d\omega\left[1-y+\frac{y^2}{2}\right]\ln\left|\cos(\omega_1\tau_1)\right|,\quad \omega_1=\sqrt{i\left(1-y+\frac{C_F}{3}y^2\right)\bar{k}\ln\frac{16}{\bar{k}}},\quad \bar{k}=\frac{\mu_D^2\lambda_g}{\omega(1-y)},\quad \tau_1=\frac{\tau_L}{2\lambda_g},\quad y=\frac{\omega}{E},\quad C_F=\frac{4}{3}$$

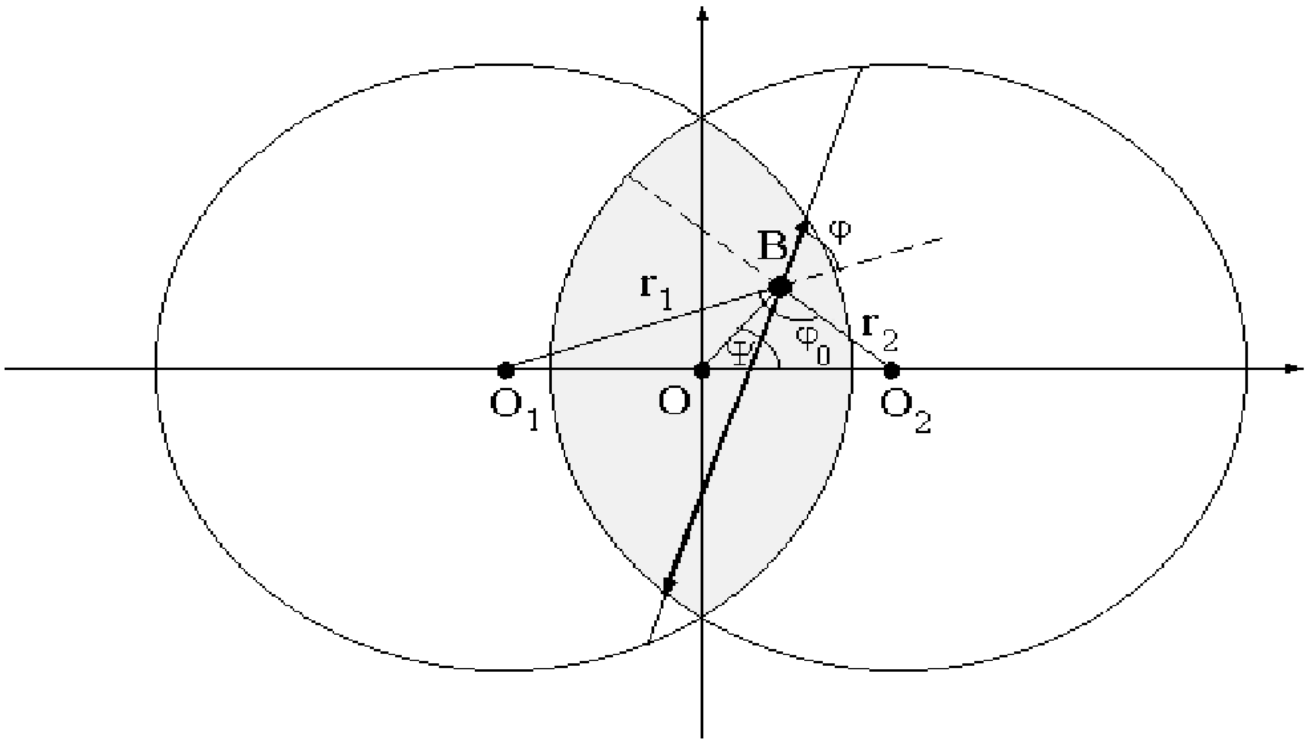
“dead cone” approximation for massive quarks:

$$\frac{dE}{dx}(m_q\neq 0)=\frac{1}{\left(1+(l\omega)^{3/2}\right)^2}\frac{dE}{dx}(m_q=0),\qquad l=\left(\frac{\lambda}{\mu_D^2}\right)^{1/3}\left(\frac{m_q}{E}\right)^{4/3}$$

Nuclear geometry and QGP evolution

impact parameter b≡ $|O_1O_2|$ - transverse distance between nucleus centers

$\varepsilon(r_1,r_2) \propto T_A(r_1) * T_A(r_2)$ (T_A(b) - nuclear thickness function)



Space-time evolution of QGP, created in region of initial overlaping of colliding nuclei, is descibed by Lorenz-invariant Bjorken's hydrodynamics J.D. Bjorken, PRD 27 (1983) 140

Monte-Carlo simulation of parton rescattering and energy loss in PYQUEN

- Distribution over jet production vertex $V(r\cos\psi, r\sin\psi)$ at im.p. b

$$\frac{dN}{d\psi\, dr}(b)=\frac{T_A(r_1)T_A(r_2)}{\int\limits_0^{2\pi} d\psi \int\limits_0^{r_{max}} r dr T_A(r_1)T_A(r_2)}$$

- Transverse distance between parton scatterings $l_i=(\tau_{i+1}-\tau_i)\, E/p_T$

$$\frac{dP}{dl_i}=\lambda^{-1}(\tau_{i+1})\exp\left(-\int\limits_0^{l_i}\lambda^{-1}(\tau_i+s)ds\right), \quad \lambda^{-1}=\sigma\rho$$

- Radiative and collisional energy loss per scattering

$$\Delta E_{tot,i}=\Delta E_{rad,i}+\Delta E_{col,i}$$

- Transverse momentum kick per scattering

$$\Delta k_{t,i}^2=\left(E-\frac{t_i}{2\mathrm{m}_{0i}}\right)^2-\left(p-\frac{E}{p}\frac{t_i}{2\mathrm{m}_{0i}}-\frac{t_i}{2\mathrm{p}}\right)^2-m_q^2$$

Monte-Carlo simulation of hard component (including nuclear shadowing) in HYDJET

- Calculating the number of hard NN sub-collisions Njet (b, Ptmin, $\sqrt{s}$) with Pt>Ptmin around its mean value according to the binomial distribution.

- Selecting the type (for each of Njet) of hard NN sub-collisions (pp, np or nn) depending on number of protons (Z) and neutrons (A-Z) in nucleus A according to the formula: $Z=A/(1.98+0.015A^{2/3})$.

- Generating the hard component by calling PYQUEN njet times.

- Correcting the PDF in nucleus by the accepting/rejecting procedure for each of Njet hard NN sub-collisions: comparision of random number generated uniformly in the interval [0,1] with shadowing factor $S(r1,r2,x1,x2,Q2) \leq 1$ taken from the adapted impact parameter dependent parameterization based on Glauber-Gribov theory *(K.Tywoniuk et al.,, Phys. Lett. B 657 (2007) 170).*