Jet-Quenching in pp collisions at LHC

Quark Matter Studies by **PrET** (**Pr**oton-**E**xpansion-**T**omography) at LHC pp in collisions

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ZIMANYI Winter School

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OUTLINES

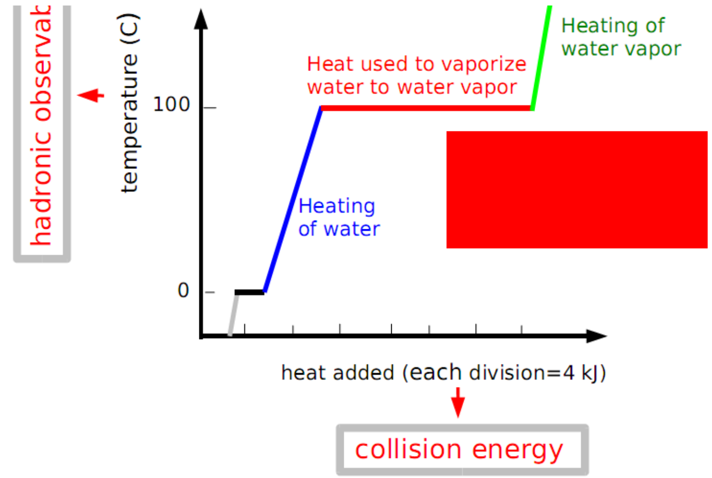
- Historical remark
- Flattening effect
- KNO-scaling
- Bose-Einstein correlations versus multiplicity
- A naive model: dressed quarks
- PET + CT principle
- PrET
- Multiplicity effects
- Dark Matter
- Summary
- Appendix

Thus when scanning the phase diagram a maximum of fluctuations located in a domain close to the critical point (the increase of fluctuations can be expected over a region $\Delta T \approx 15$ MeV and $\Delta\mu_B \approx 50$ MeV [82]) or the critical line should signal the second order phase transition. The position of the critical region is uncertain, but the best theoretical estimates based on lattice QCD calculations locate it at $T \approx 158$ MeV and $\mu_B \approx 360$ MeV [83, 84] as indicated in Fig. 17. It is thus in the vicinity of the chemical freeze-out points of central Pb+Pb collisions at the CERN SPS energies.

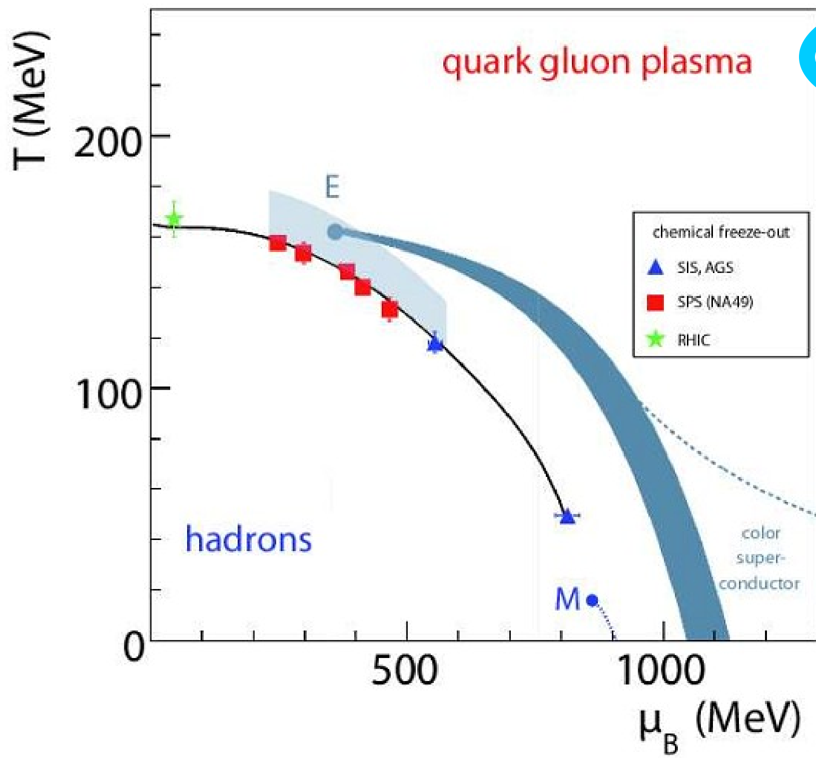
[82] Y. Hatta and T. Ikeda, Phys. Rev. D **67**, 014028 (2003) [arXiv:hep-ph/0210284].

[83] Z. Fodor and S. D. Katz, JHEP **0404**, 050 (2004) [arXiv:hep-lat/0402006].

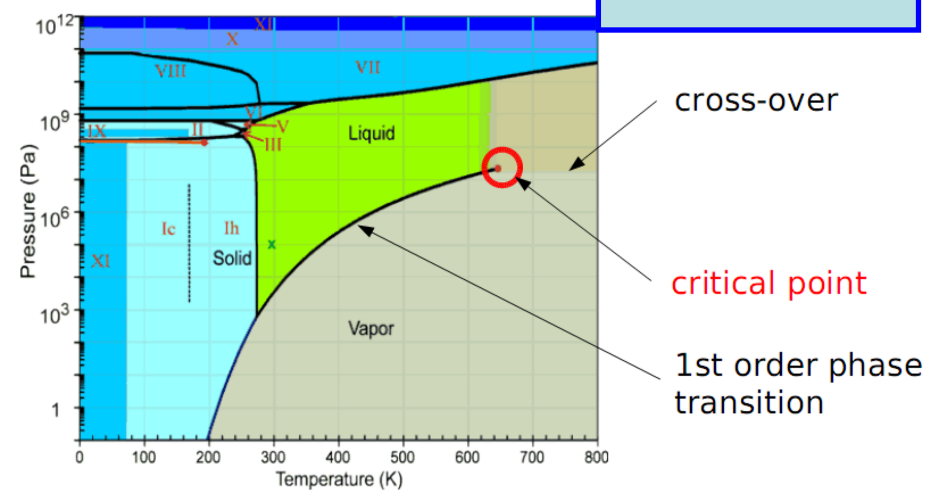
Zoltán FODOR(ELTE)



Water analogy for QGP phase transition



Phase diagram of water



the end point of a 1st order line = a critical point of the 2nd order
(at the critical point the phases start to be indistinguishable)

Volume 118B, number 1, 2, 3 PHYSICS LETTERS 2 December 1982

MULTIPLICITY DEPENDENCE OF p_t SPECTRUM AS A POSSIBLE SIGNAL FOR A PHASE TRANSITION IN HADRONIC COLLISIONS

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Received 25 August 1982

It is argued that the flattening of the transverse momentum (p_t) spectrum for increasing multiplicity n, observed at the CERN proton–antiproton collider for charged particles in the central rapidity region, may serve as a probe for the equation of state of hot hadronic matter. We discuss the possibility that this p_t versus n correlation could provide a signal for the deconfinement transition of hadronic matter.

1. Experiments at the CERN $p\bar{p}$ collider (c.m. energy $\sqrt{s}$ = 540 GeV) have shown that the charged particles produced in the central region of rapidity ($|y| \leqslant y_0 = 2.5$) have the following properties:

(a) The multiplicity per unit of rapidity, dn/dy, continues to grow above ISR energies ($\sqrt{s}$ = 30–60 GeV) [1,2].

(b) There is a clear dependence of the p_t spectrum on the central multiplicity

When plotted for successive intervals of n, the p_t spectrum (in the interval 0.3 GeV/$c < p_t <$ 6 GeV/c) becomes flatter as n increases [3]. This flattening corresponds to an increase of the mean $\langle p_t \rangle$ at constant shape of the spectrum. The flattening slows down around $dn/dy \sim 8$ ($n \sim 40$) and seems to stop around $dn/dy \sim 15$; this could be a kinematic effect due to lack of available energy [3]. The increase of $\langle p_t \rangle$ is from ~0.33 to ~0.5 GeV/c.

E735 Collaboration / Physics Letters B 353 (1995) 155–160

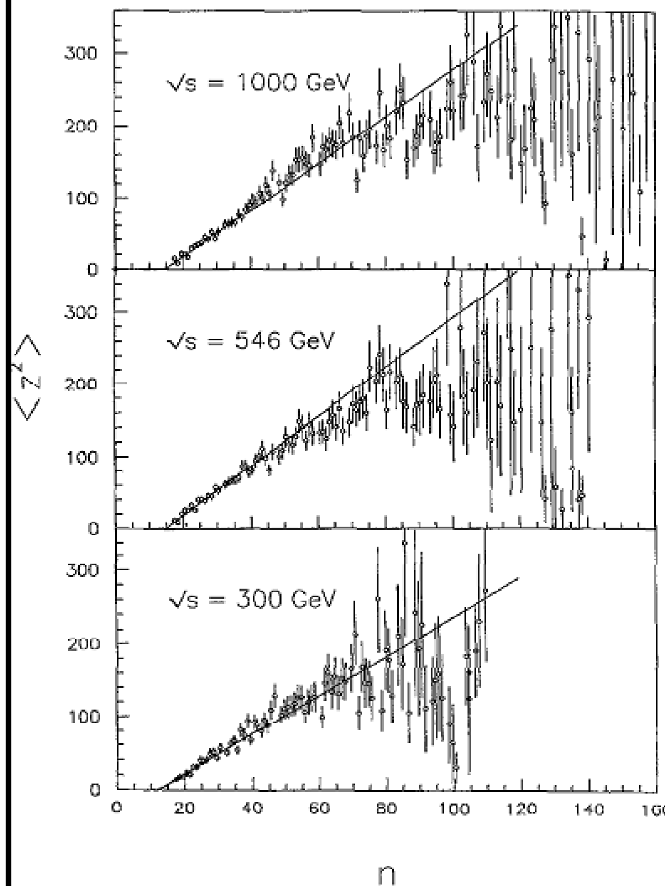


Fig. 5. Variance of the asymmetry distribution as a function of the total charged multiplicity at the listed energies for $|\eta| < 3.25$. The solid line is a fit up to $n \approx 40$. The data at high multiplicities have not been corrected for hodoscope resolution.

Flattening effect in E735

KNO-scaling as function of C.M. energy

T. Alexopoulos et al. / Physics Letters B 435 (1998) 453–457

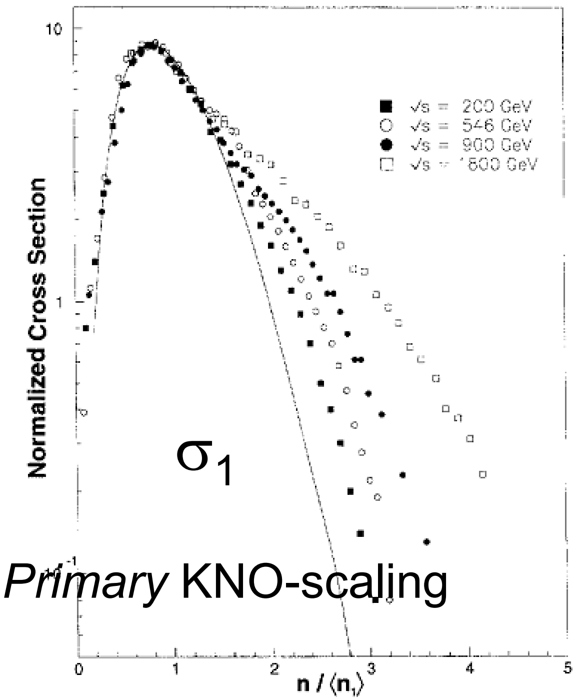


Fig. 2. A comparison of multiplicity distributions at different values of $\sqrt{s}$. The distributions have been normalized at the maximum value of $d\sigma/dx$ where $x = n/\langle n_1 \rangle$. The solid curve is the KNO distribution from the ISR data. The actual cross section $d\sigma/dx$ may be obtained by integrating the overall curves as presented in the figure and equating the result to the measured value of σ_{NSD} to determine the scale constant.

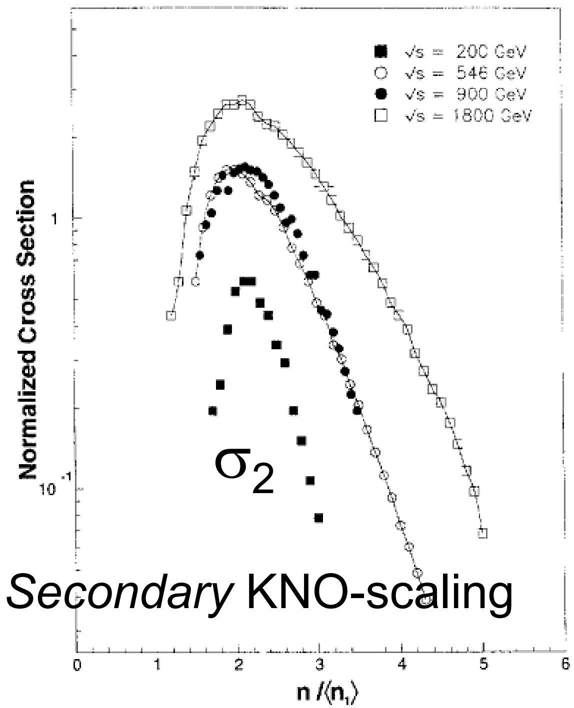


Fig. 3. The derived multiplicity distributions were obtained by taking the difference between the $p-\bar{p}$ collider data and the KNO curve.

Physics Letters B 528 (2002) 43–48

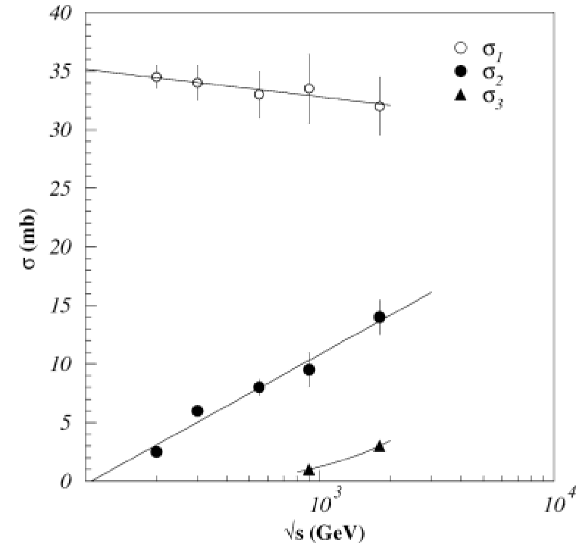


Fig. 1. Comparison of the cross-sections for single, double, and triple encounter collisions which increase σ_{NSD} above 32 mb as a function of $\sqrt{s}$.

New components are emerging at higher energies in E735

Subtracting lower energy KNO-curve, new KNO appears

3 components at highest energies

Bose-Einstein interference versus multiplicity

Higher multiplicity means higher source radii both at E735 and CMS

Physics Letters B 528 (2002) 43–48

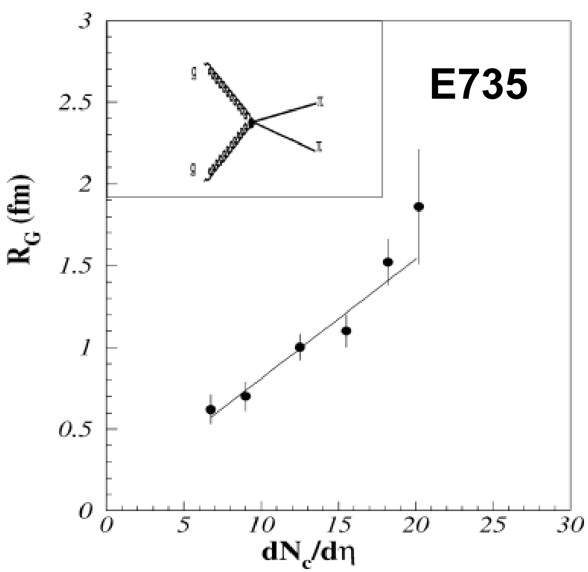


Fig. 2. Dependence of the Gaussian radius R_G on $dN_c/d\eta$. The gluon diagram indicates that two gluons are required to form two pions.

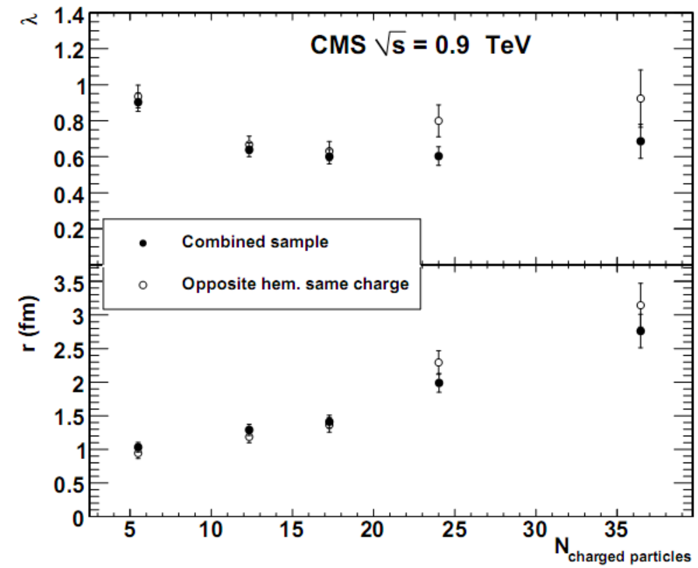
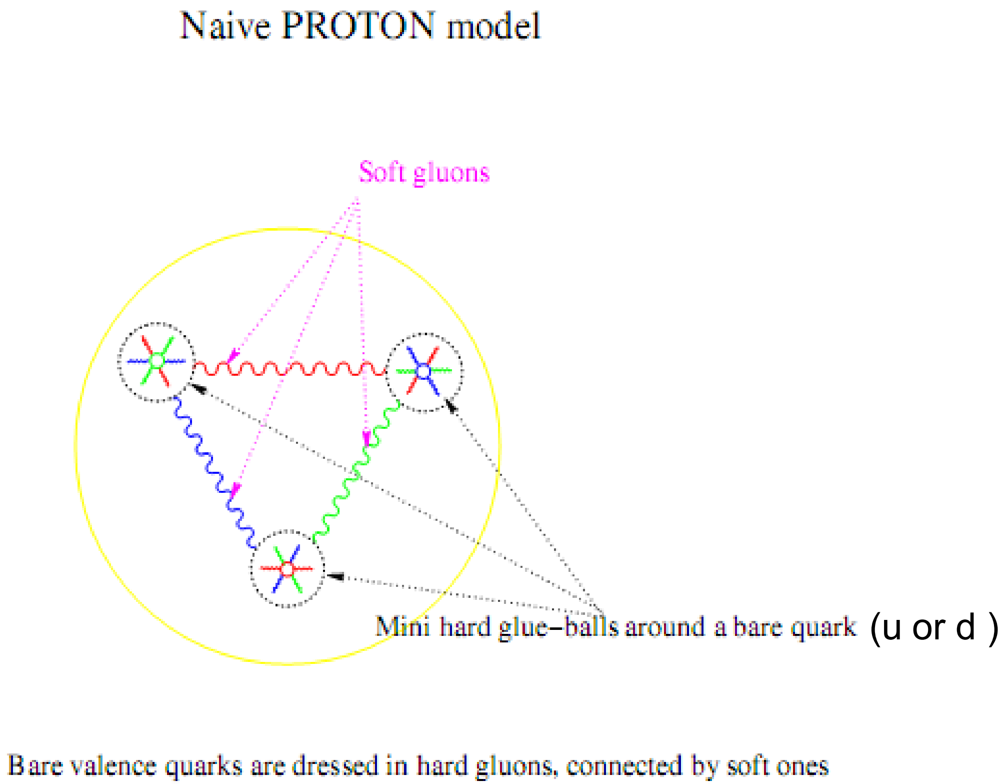


Figure 4: Values of the λ (top) and r (bottom) parameters as a function of the charged-particle multiplicity in the event for combined (dots) and opposite-hemisphere, same-charge (open circles) reference samples, at 0.9 TeV. The errors shown are statistical only. The points are placed on the horizontal scale at the average of the multiplicity distribution in the corresponding bin.

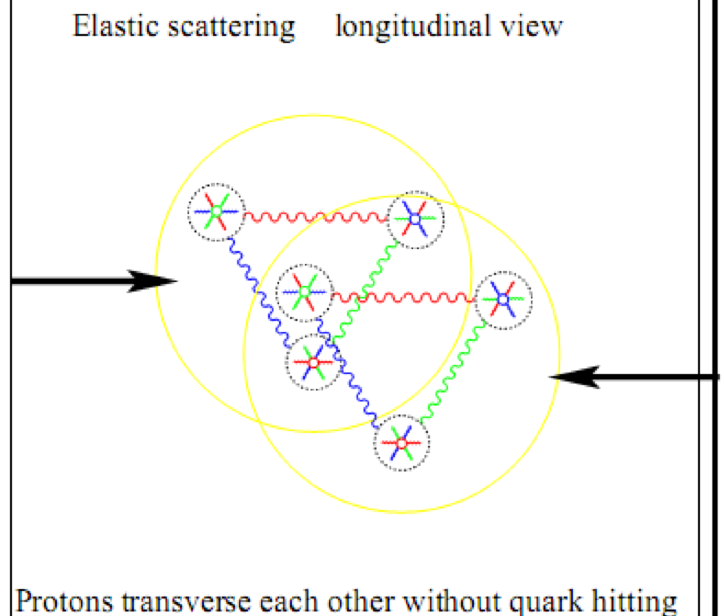
Remark: Quark Matter is observed in **larger expanding volumes** in correlation with the violance of the collision.

Naive „dressed” quark-model



Heavy quarks are created by exciting the mini glue-ball

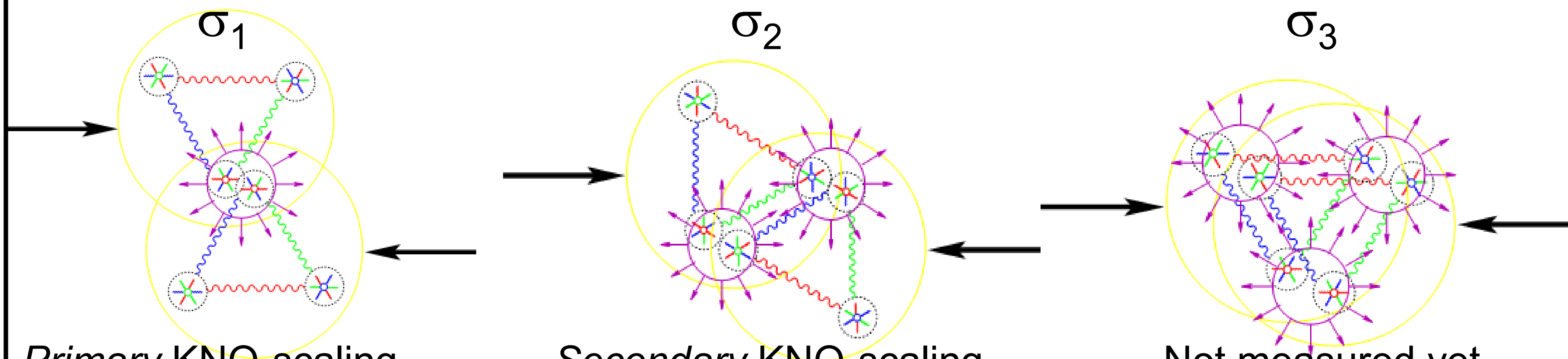
Resonance states without flavour change are produced by exciting soft gluons



„HADRON-TRANSPERENCY”

SOFT COLLISIONS

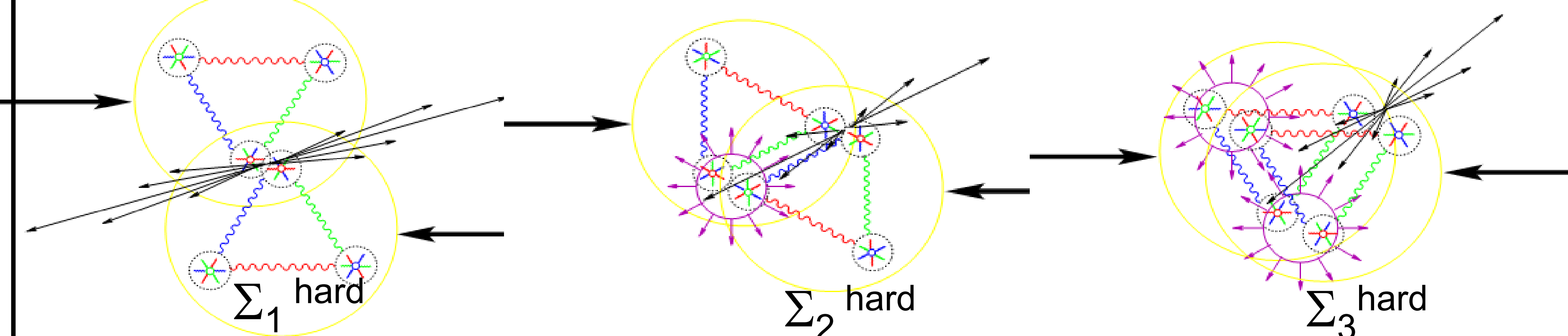
Single soft collision longitudinal view | Double soft collision longitudinal view | Triple soft collision longitudinal view



Primary KNO-scaling | *Secondary* KNO-scaling | Not measured yet

HARD + SOFT COLLISIONS

Single hard collision longitudinal view | Single soft + hard collision longitudinal view | Double soft + hard collision longitudinal view

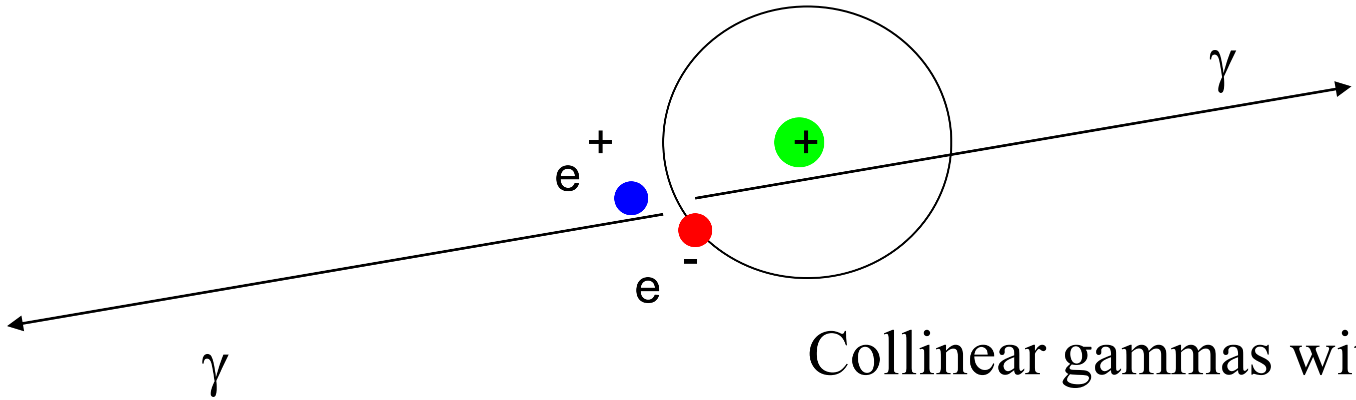


The aim of this study is to identify these processes

PET principle

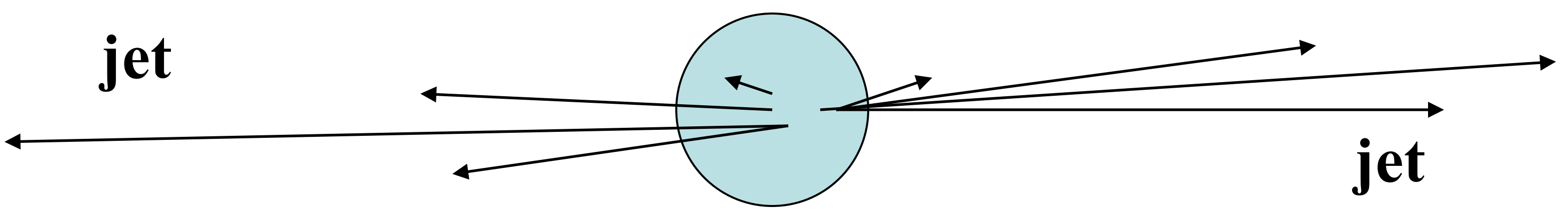
In inhomogenous medium the positron annihilation

gamma-gamma pair emission provides space-time structure



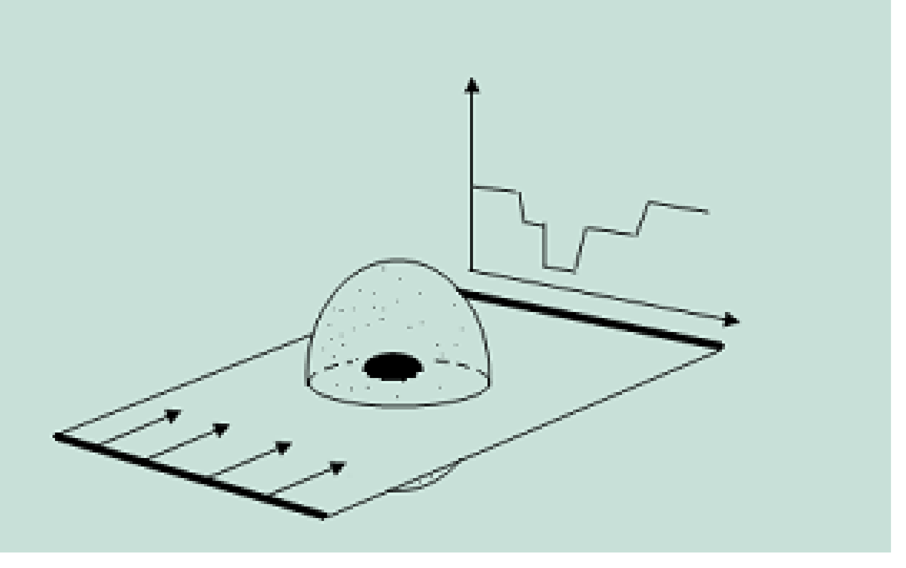
Collinear gammas with fixed energy

Jet-jet pair emission space-time structure inside nucleus

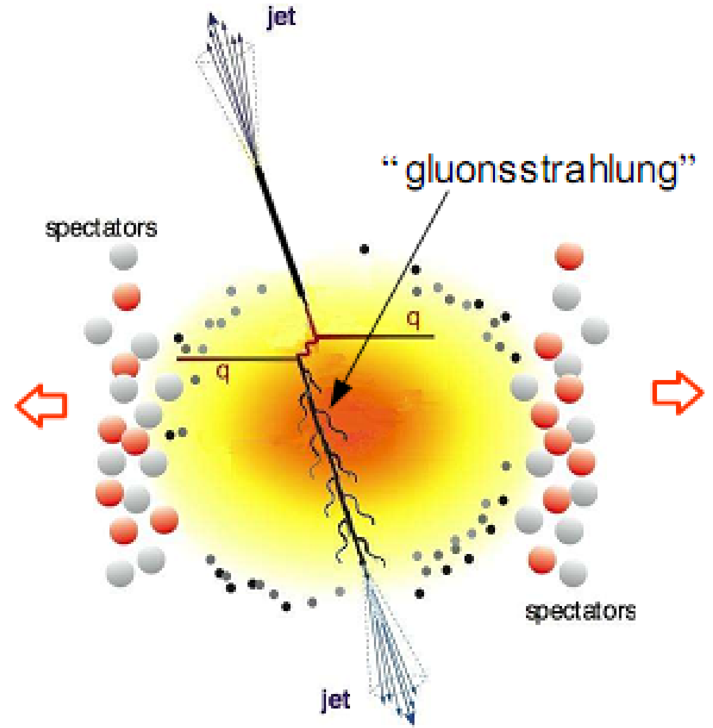


Unknown energies

A komputertomográfia a hagyományos Röntgen-átvilágítási technika szellemes továbbfejlesztése. A tomográfiás felvétel esetében vékony, síkszerű röntgensugár-nyalábbal világítják át a vizsgált objektumot.
Az objektum mögött elhelyezett detektor egy vonal mentén érzékeli, hogy a sugárnyalábból hol és mennyi nyelődött el. Az 1. ábrán egy tojásdad, kisebb áteresztőképességű maggal bíró testet világít át a síkszerű röntgensugár-nyaláb.
A háttérben a detektor által észlelt intenzitás görbéje látható. A sugárnyalábbal ugyanebben a síkban több irányból is átvilágítják a testet, és a mért Intenzitásgörbékből kibontakozik az adott síkban (szeletben) elhelyezkedő részletek rajza. A síkot ezután arrébb tolják és újra körbeforgatják. Az eljárás befejeztével a vizsgált test térbeli szerkezete feltérképezhető. „Szerkezeten” itt a röntgensugáráteresztő-képesség szempontjából megkülönböztethető részletek elrendeződése értendő.



"Jet quenching" as a QGP signal



- Multiple final-state non-Abelian (gluon) radiation off the produced hard parton induced by the dense QCD medium
- Parton energy loss ∝ medium properties:

GLV: $\Delta E \propto \alpha_S^3 C_R \frac{1}{A_\perp} \frac{dN^g}{dy} L$ ∝ (g density, L)

BDMPS Wiedemann: $\langle \Delta E \rangle \propto \alpha_S C_R \langle \hat{q} \rangle L^2$ ∝ ($\hat{q}$ coeffic., L^2)

- Flavor dependent energy losses:

$\Delta E_{loss}(g) > \Delta E_{loss}(q) > \Delta E_{loss}(Q)$

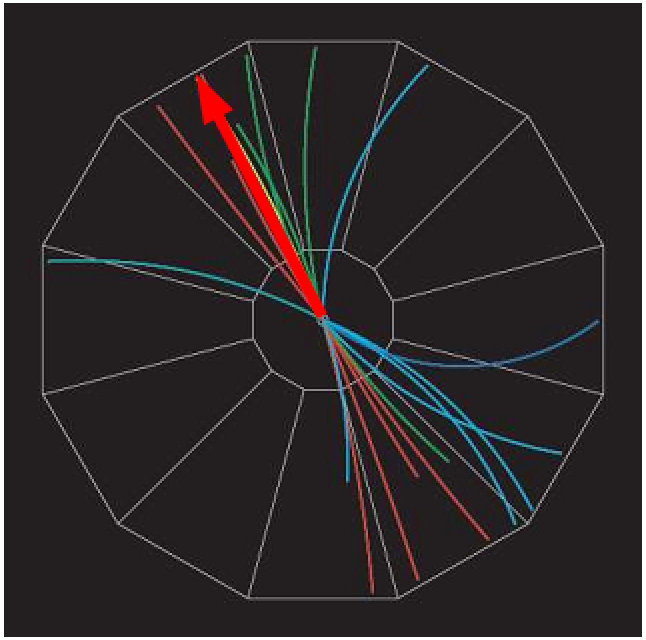
(color factor) (mass effect)

- Energy is carried away by gluons emittted inside (broader) jet cone: $dE/dx \sim \alpha_s \langle k_T^2 \rangle$

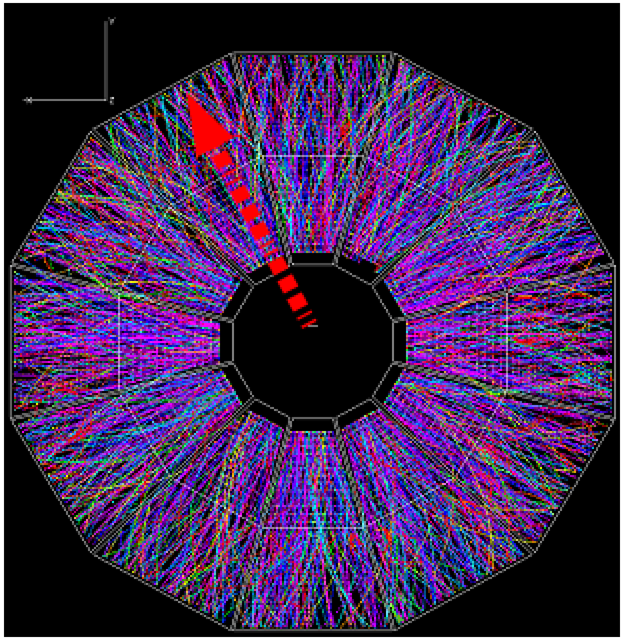
- Prediction I: Suppression of high p_T leading hadrons: dN/dp_T ◄ SPS,RHIC,LHC
- Prediction II: Modification of (di)jet correlations: $d^2N_{pair}/d\varphi d\eta$ ◄ RHIC,LHC
- Predition III: Modified energy- & particle- flow within full jet ◄ LHC

„Jet physics" at heavy ions: Single inclusive high pT spectra

- Alternative I : Study the energy modifications suffered by the highest p_T hadron in the event ("leading" hadron of the jet) in AA (compared to pp):



p+p → h+ X [$\sqrt{s}$ = 200 GeV]



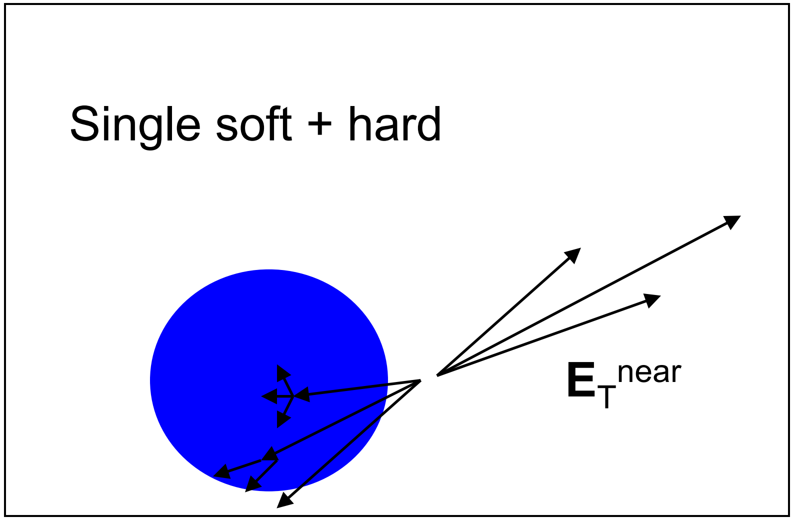
Au+Au → h+X [$\sqrt{s_{NN}}$ = 200 GeV]

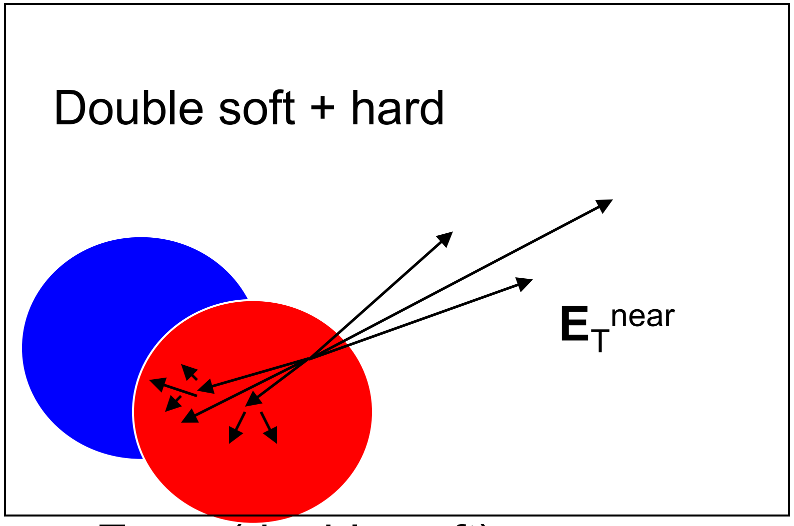
- Many interesting results obtained from this "first-order" approach !

IN pp INTERACTIONS both TRACK and JET methods are possible!!!

HARD + SOFT COLLISIONS

Transversal view

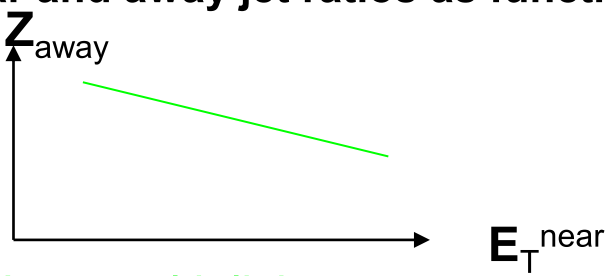




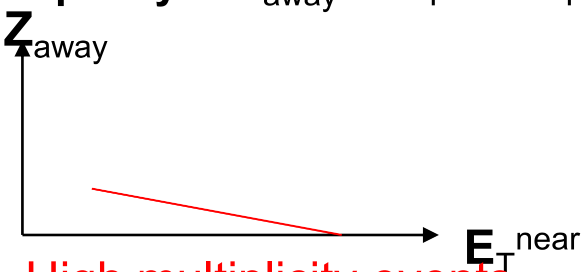
E_T^{away} (single soft) >> E_T^{away} (double soft)

Away jet must traverse more excited Quark Matter in case of double soft interaction

Near and away jet ratios as function of multiplicity: $Z_{away} = E_T^{away}/E_T^{near}$



Low multiplicity events

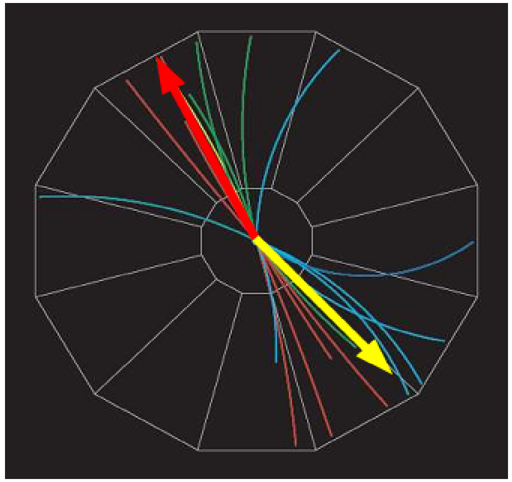


High multiplicity events

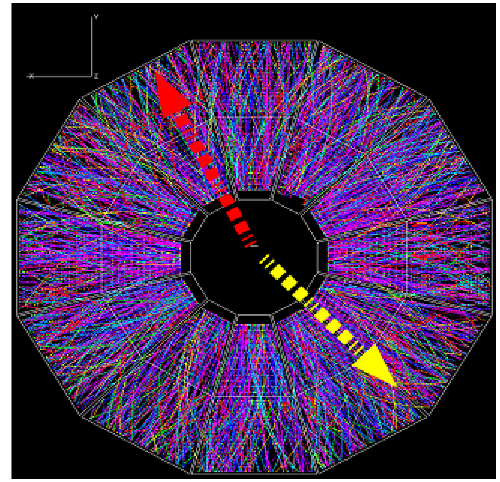
One expects similar results if highest p_T tracks are used instead of jets

"Jet physics" at RHIC (II): di-hadron azimuthal correlations

- Study the azimuthal correlations in AA relative to pp between the highest p_T hadron ("trigger") & any other "associated" hadron:



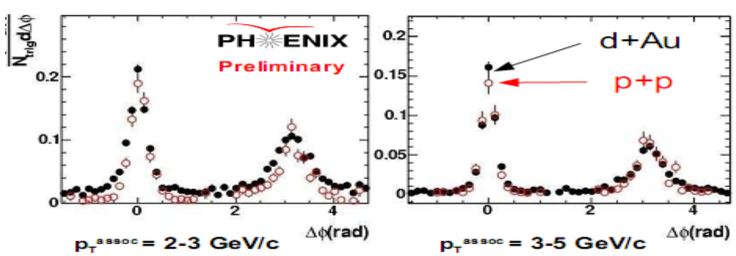
$p+p \rightarrow h_1+h_2+X$ [$\sqrt{s}$ = 200 GeV]

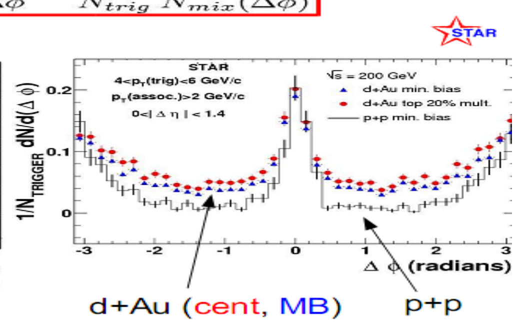


Au+Au $\rightarrow h_1+h_2+X$ [$\sqrt{s_{NN}}$ = 200 GeV]

Dijets via high p_T di-hadron ϕ correlations: pp, dAu

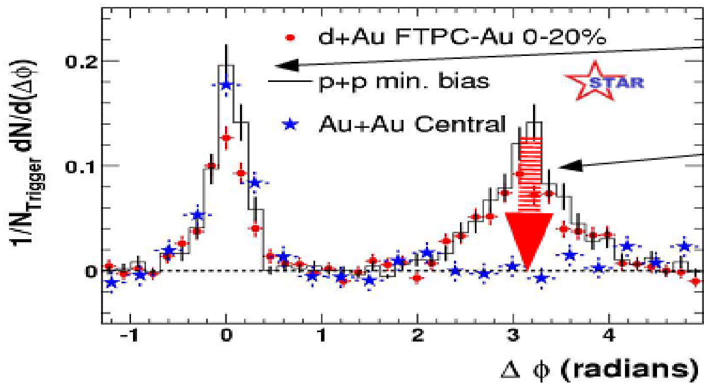
- Two-particle correlations: $h^{\pm} - h^{\pm}$, $\pi^{0,\pm} - h^{\pm}$. Trigger: highest p_T (leading) hadron.
- Associated $\Delta\phi$ distribution (e.g. "assorted": 2 GeV/c < p_T^{assoc} < $p_T^{trigger}$)
- Normalized to number of triggers: $\frac{1}{N_{trig}}\frac{dN}{d\Delta\phi} = \frac{1}{N_{trig}}\frac{N_{cor}(\Delta\phi)}{N_{mix}(\Delta\phi)}$





- Clear near- ($\Delta\phi \sim 0$) and away- ($\Delta\phi \sim \pi$) side jet signals

Di-hadron AuAu Δφ correlations: Results at high p_T



- Near-side jet-like Gaussian peak unmodified (AuAu ~ dAu ~ pp)
- Away-side peak disappearance: "monojet"-like topologies in central AuAu.

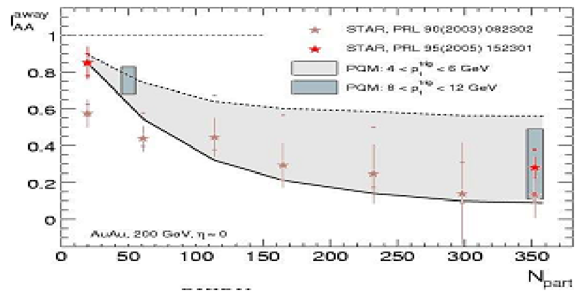
$p_{T\,trigg}$ = 4 – 6 GeV/c
$p_{T\,assoc}$ > 2 GeV/c

STAR, PRL 90, 082302 (2003)

- Centrality dependence of away-side disappearance globally described by parton energy loss models (increasing medium traversed):

$$I_{AA} = \left(\frac{N^{assoc}}{N^{trig}}\right)_{AA} \Big/ \left(\frac{N^{assoc}}{N^{trig}}\right)_{pp}$$

PQM – A. Dainese, C. Loizides, G. Paic
EPJ C 38, 461(2005)



Compare near-away correlations at different multiplicities in LHC pp

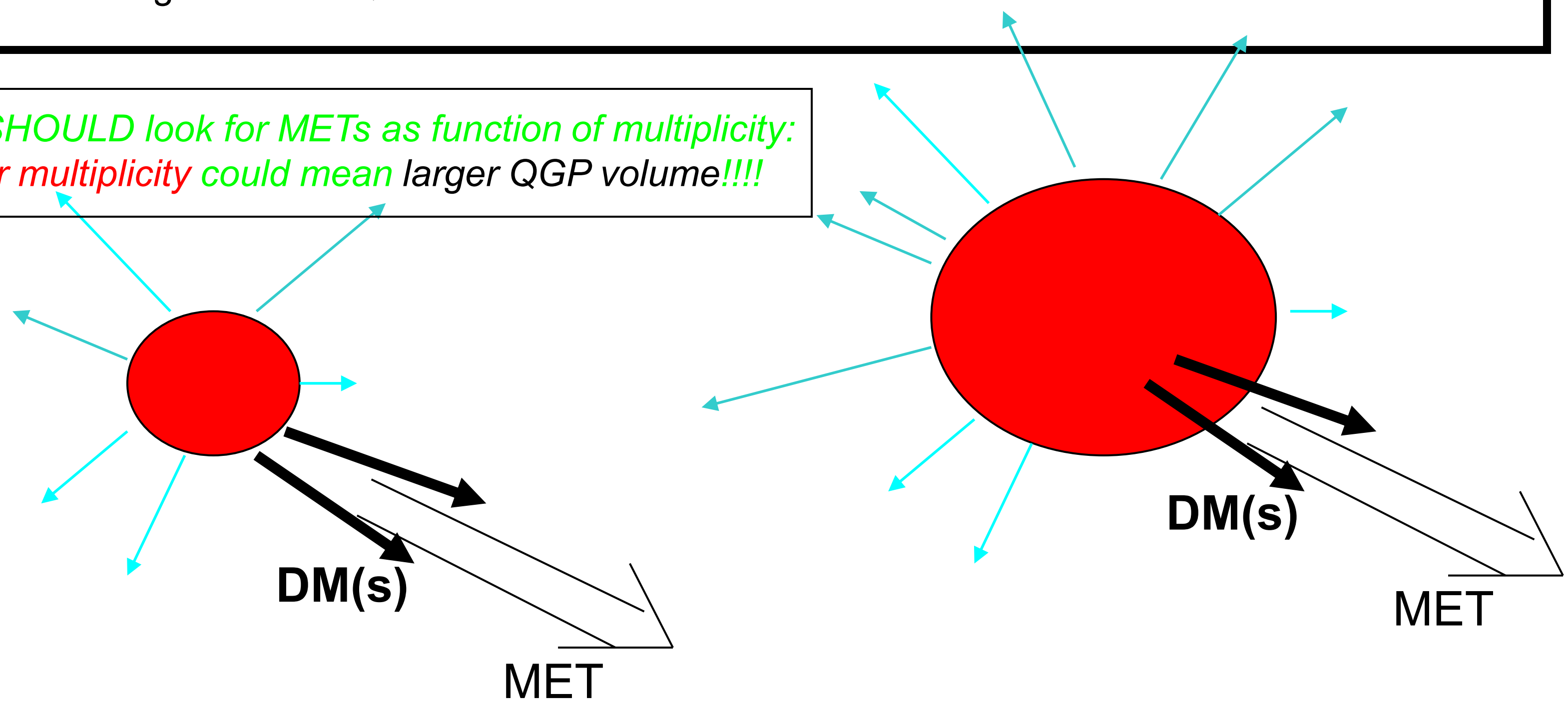
One expects that higher multiplicity will have similar effect as larger nucleus size

DARK MATTER (DM) versus QGP

At the Big-Bang the Dark Matter was produced with **Prob$_{DM}$** probability and Baryonic Matter with **Prob$_{BM}$**=1- **Prob$_{DM}$** . But most of the BM annihilated and there remained only 1 out of 10^{9}. At present we have about 10 times more DM than BM, therefore one expects about **Prob$_{DM}$** = 10^{-8} .

At LHC Dark Matter will be produced with similar probability, therefore one expects very rarely escaping DM particles. One needs large luminosity, but there can be a considerable enhancement if there is a larger volume QGP at the start.

ONE SHOULD look for METs as function of multiplicity:
Higher multiplicity could mean larger QGP volume!!!!



In **larger volume** one expects DM particles (e.g. black-hole or pair of SUSY with considerable momentum) *with* higher probability .
If the radius for double collisions is 2-3 times greater than for single, then one expects 8-27 times more DM due to the volume effect.

SUMMARY

One expects jet quenching measured in near-away jet-jet

and track-track correlations due to change of QGP volume

implied by multiplicity dependence

Missing ET as function of multiplicity can indicate dark matter

APPENDIX or appendicitis

ADDENDUM: QCD theory

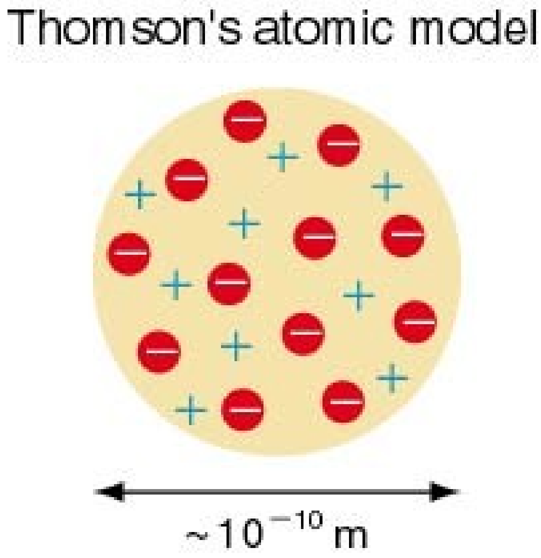
The main symptom of *appendicitis* is abdominal pain.
Symptoms of *appendicitis* may take 4-48 hours to develop.
Other symptoms include: **...**
www.medicinenet.com › ..

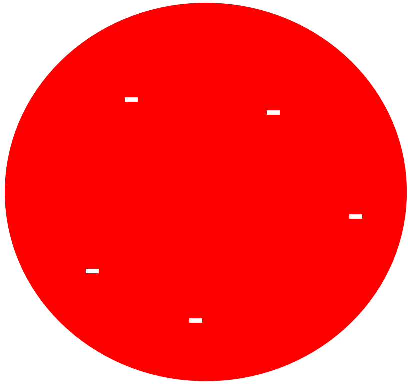
Thomson   vs Rutherford

The plum pudding *model* of the *atom* by *J. J. Thomson*, who discovered the electron in 1897, was proposed in 1904 before the discovery of the *atomic* nucleus. **...**

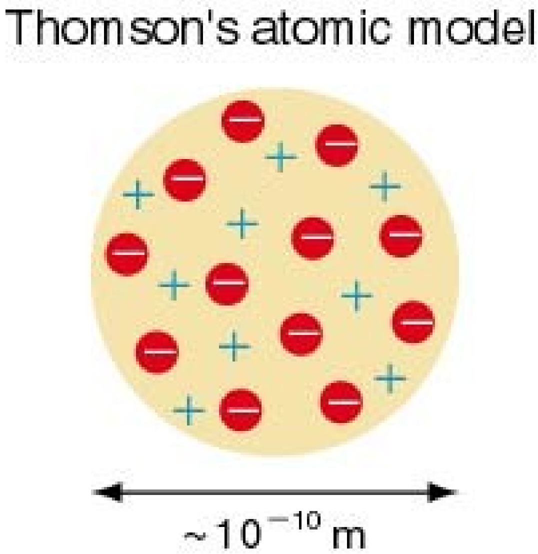
—*J. J. Thomson*. Thomson imagined the *atom* as being made up of these corpuscles swarming in a sea of positive charge; this was his plum pudding *model*. **...**
*en.wikipedia.org/wiki/J._J._**Thomson*** -

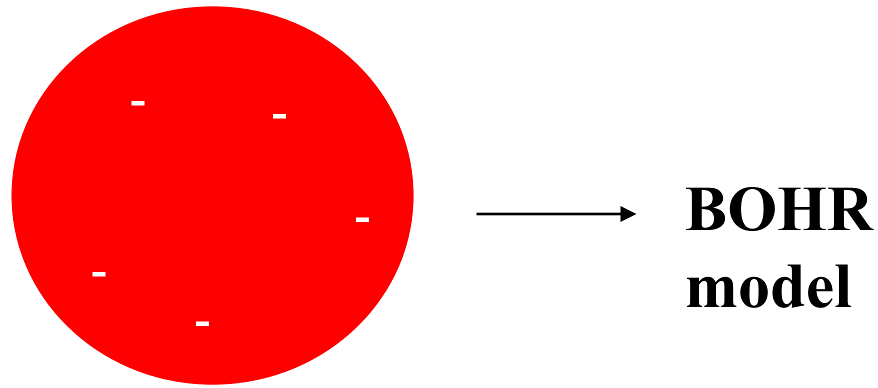
J. J. Thomson considered that the structure of an *atom* is something like a raisin bread, so that his *atomic model* is sometimes called the raisin bread *model* **...**
*www.kutl.kyushu-u.ac.jp/.../**Thomson_model**_E.htm*



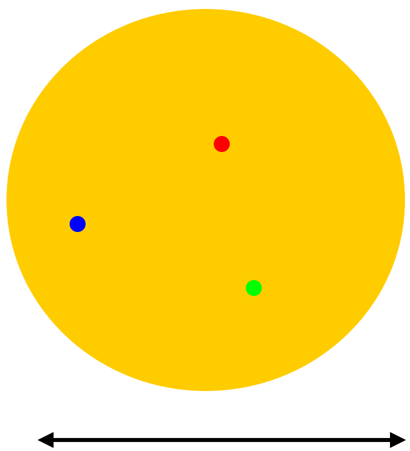


Rutherford model
Mini Solar system



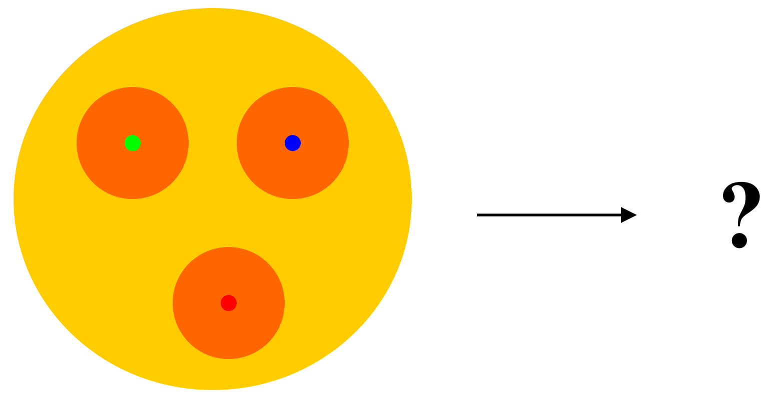


Rutherford model



10^{-15} m

Atom:Homogen pozitiv sea
Parton: homogen gluon sea



Atom: Inhomogen postive distribution
Dressed q: inhomogen gluon-sea