QGP tomography with direct photons and jets

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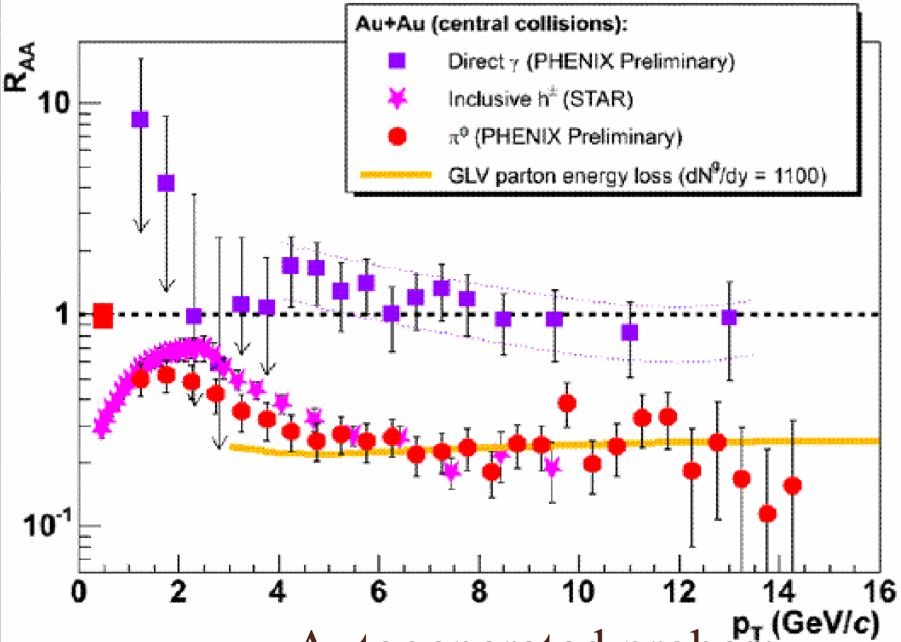
(for the ALICE collaboration)

The QCD medium

- A new state of matter is produced in heavy-ion collisions at RHIC: parton degrees of freedom with hydrodynamic properties of a liquid
- Several observations lead to this conclusion:
  - Energy densities reached exceed the critical temperature at which LQCD predics a phase transition
  - Large elliptic flow established during the early partonic phase
  - Quark scaling
  - Very low viscosity
  - Jet quenching

jet-quenching: first measurement



- The measurement:
  - Particle species spectra
    1. $\sigma(p_T^h)$
    2. $R_{AA} = \sigma_{AA}/(Norm \times \sigma_{pp})$

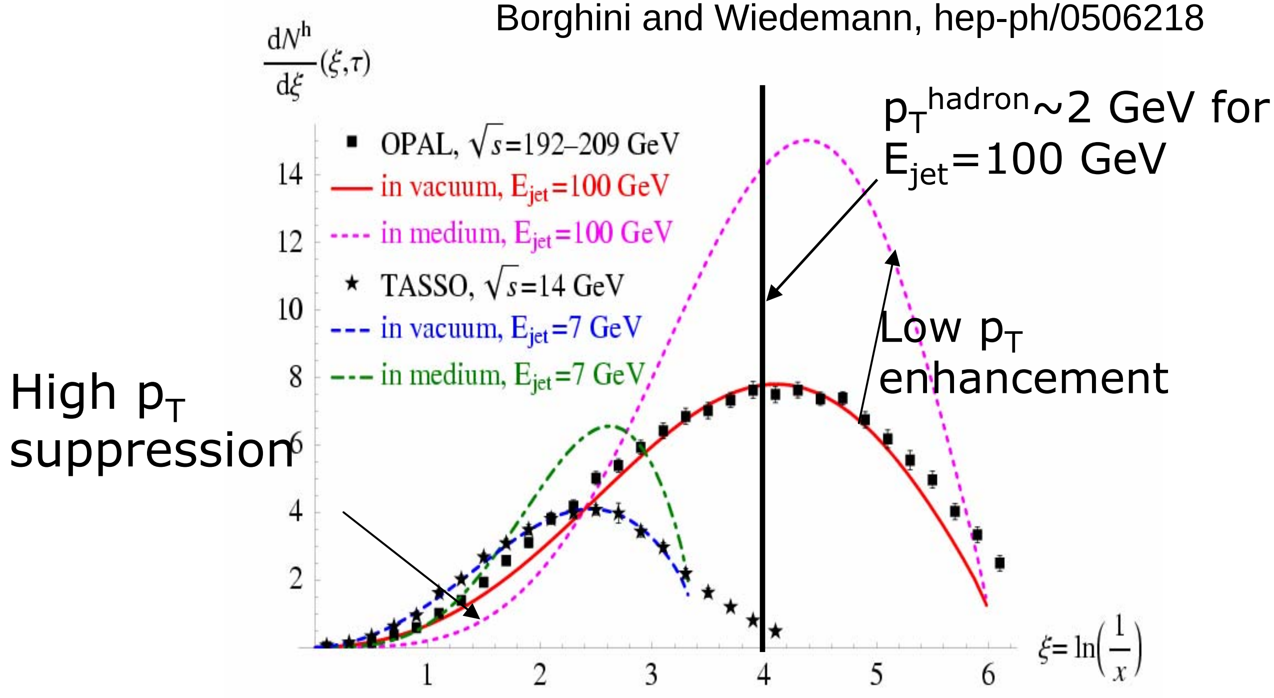
Autogenerated probes:

- hard scattered partons traversing the dense formed medium are modified → observed as reduction of high pt hadrons (jet fragments)
- direct photon traverse the medium unaffected

Measurement does not strongly constrain the interaction mechanisme or the medium properties

jet-quenching: more exclusive measurement

Borghini and Wiedemann, hep-ph/0506218



$\xi = \ln(E_{Jet}/p_{hadron})$

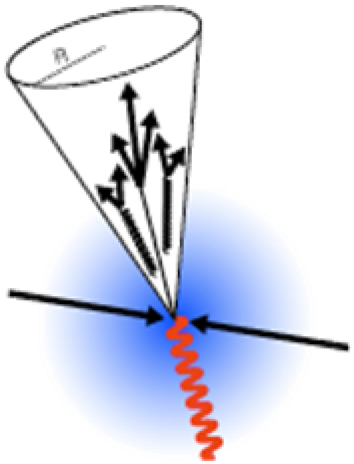
- The measurement:
  - Particle species spectra
    1. $\sigma(p_T^h)$
    2. $R_{AA} = \sigma_{AA}/(Norm \times \sigma_{pp})$
  - Fragmentation function
    1. $FF(z = p_T^h/E_{jet})$
    2. $R_{FF} = FF_{AA}/(Norm \times FF_{pp})$

$\rightarrow \hat{q}$

$$\Delta E \propto \hat{q} \cdot L^2$$
$$\frac{d\Delta E}{dz} \propto \hat{q} \cdot L$$

- Difficult to reconstruct jet in HI environment

jet-quenching: even more exclusive measurement (the golden one)



- Direct photon - jet
  - The photon 4-momentum remains unchanged while traversing the medium and sets the reference of the hard process
  - Balancing the hadron and the photon provides a measurement of the medium modification experienced by the jet
  - Allows to measure jets in an energy domain (E_{jet} < 50 GeV) where
    - The jet looses a large fraction of its energy ($\Delta E_{jet} \approx$ 20 GeV)
    - The jet cannot be reconstructed in the AA environment

Toward a true tomography measurement of QCD medium in AA (X. N. Wang)

- The azimuthally misaligned back to back jets (from a 2->2 hard process) may add to k_T, which is a measure of qhat:

$$\left\langle \Delta q_T^2 \right\rangle = \int dy \hat{q}(y,E)$$

- Triggering γ-hadrons correlation measurement with hadrons of various x_E allows to select the production point of the hard scattering:
    - large x_E, contributions to CF come mostly from hard scattering at the surface;
    - small x_E, contributions to CF are mostly from hard scattering inside the volume.
- What can be measured with ALICE?

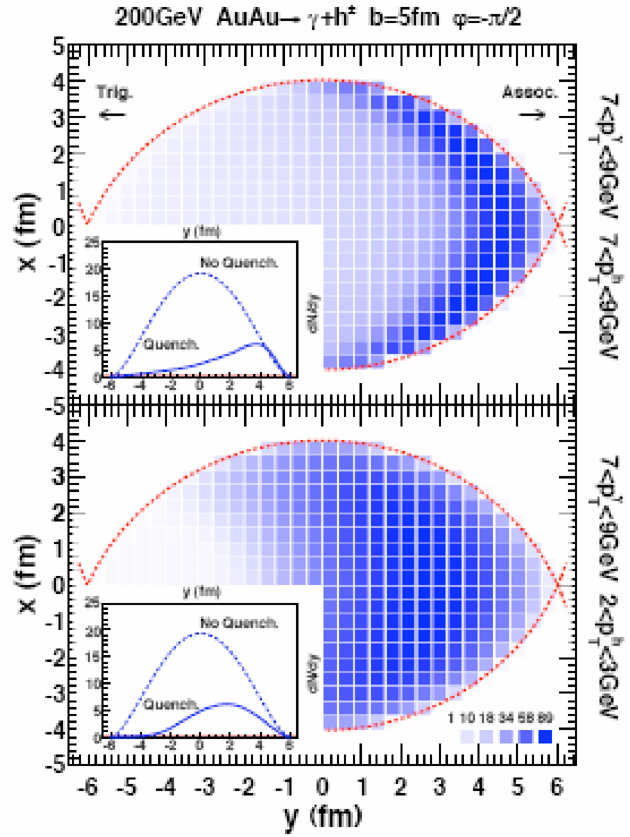
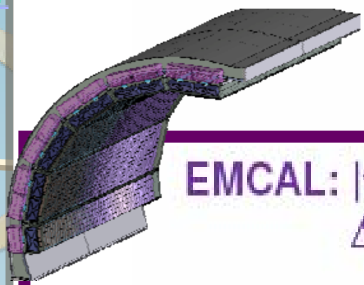
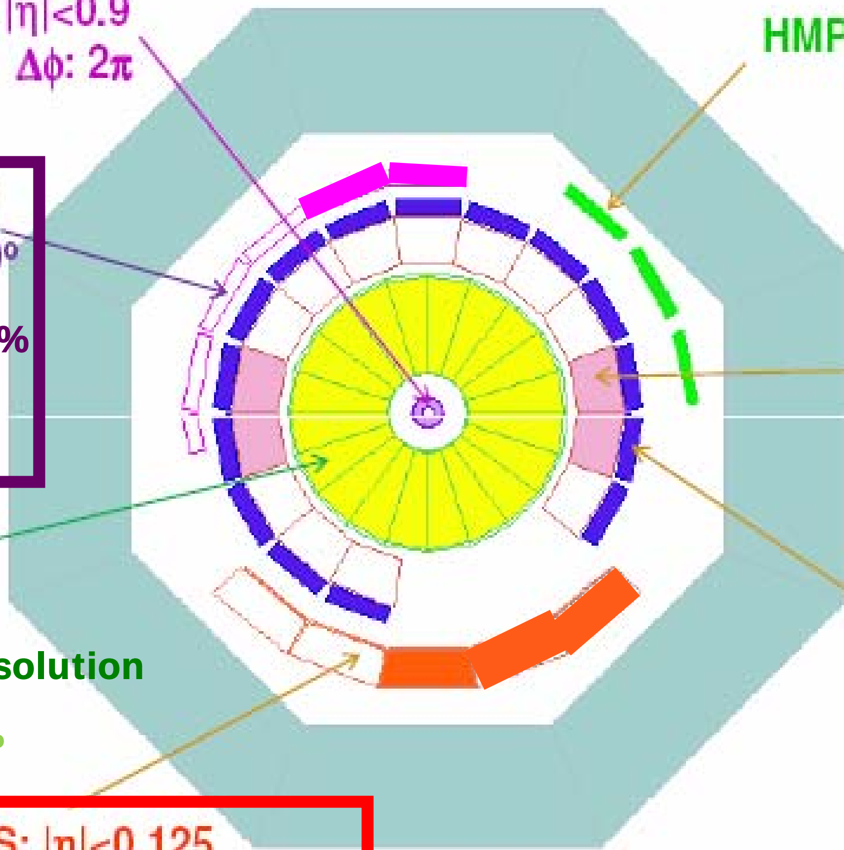


FIG. 3: (color online). Transverse spatial distributions of the initial γ-jet production vertexes that contribute to the final observed γ-hadron pairs along a given direction (arrows) with $z_T \approx 0.9$ (upper panel) and $z_T \approx 0.3$ (lower panel).

ALICE: dedicated HI Experiment





EMCAL: $|\eta|<0.7$
$\Delta\phi$: 110°

$E > 10$ GeV $\rightarrow \Delta E/E < 3\%$

$\sigma x = [3,50]$ mm

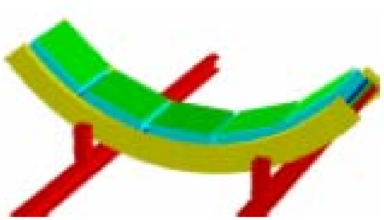
Tracking System resolution

$\Delta p/p = 2\%$, $\alpha = 1.1°$

PHOS: $|\eta|<0.125$
$\Delta\phi$: 100°

$E > 10$ GeV $\rightarrow \Delta E/E < 1.5\%$,

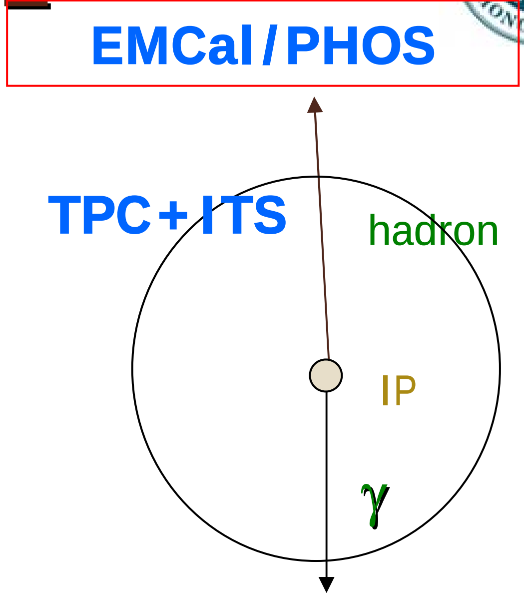
$\sigma_x = [0.5,2.5]$ mm



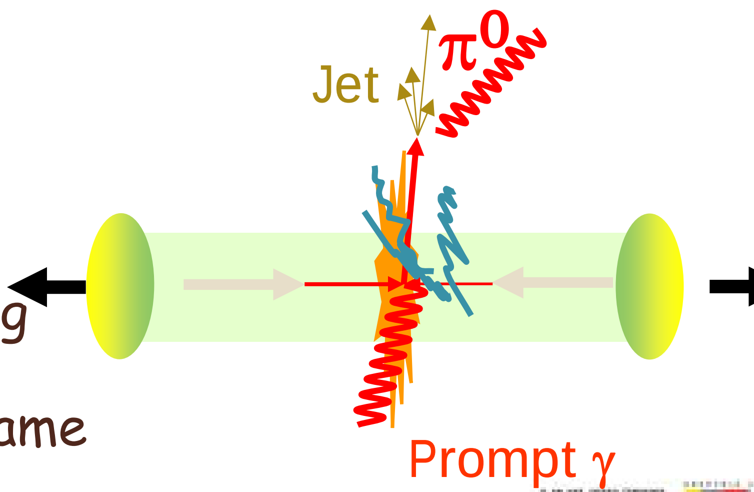
*Holes are made in front of 3 PHOS modules

γ-hadron correlations in ALICE

- Strategy (event by event):
  - Search identified prompt photon (PHOS or EMCal) with $E_\gamma > 20$ GeV
  - Search for all charged hadrons (central tracking) or neutral π^0 (EMCal or PHOS):
    - $90° < \phi_\gamma - \phi_{hadron} < 270°$



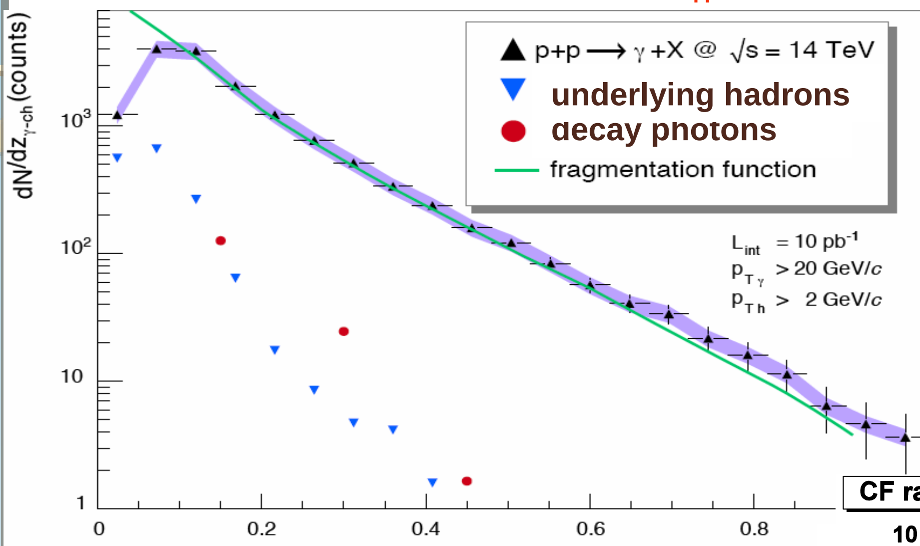
- Background:
  - Decay photons misidentified as isolated photon
  - Soft hadrons from the underlying event (UE):
    - take the hadrons from the same side of direct photons as UE



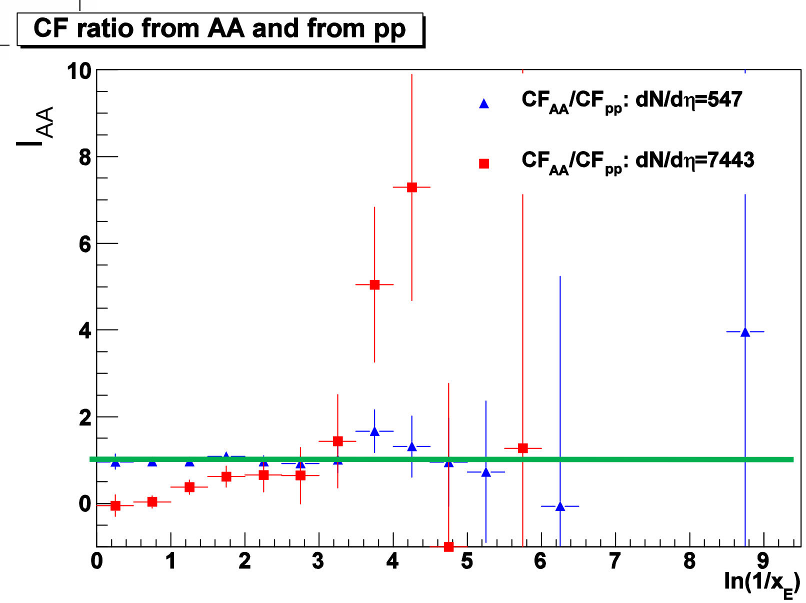
Correlation Function (CF) and I_{AA}

EPJC (2008) 57: Y. Mao

$X_E = -p_{T_h} \cdot p_{T\gamma} / |p_{T\gamma}|^2$



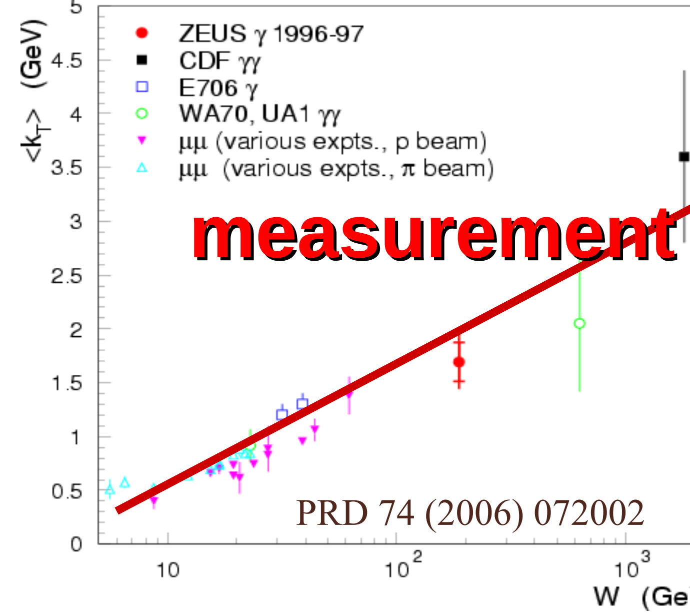
$$I_{AA} = CF_{AA}/CF_{pp}$$



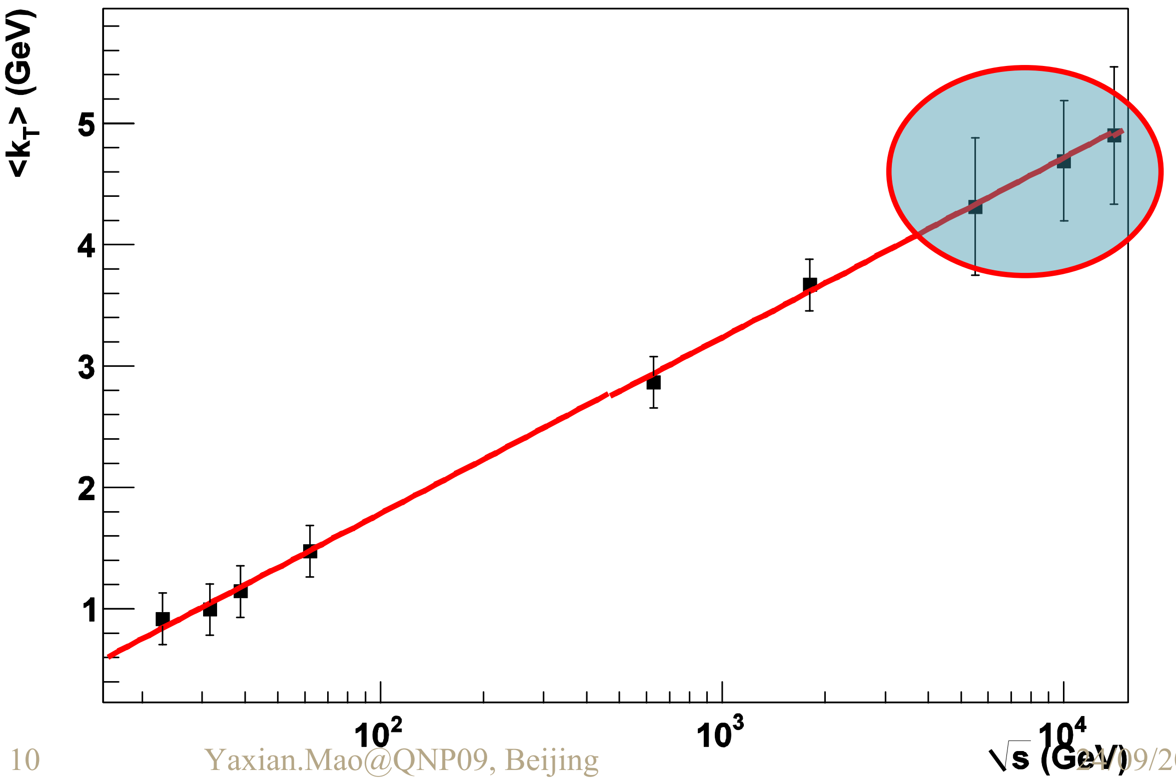
- Statistical errors correspond to one standard year of data taking with 2 PHOS modules.
- Systematic errors from decay photon contamination and hadrons from underlying events.

$<k_T>$ in γ-jet at LHC

- Extrapolated from existing measurements by PYTHIA tuning:



k_T extrappolated from existing experiments



- Intrinsic k_T (PARP(91)) and ISR/FSR on

$<p_T>_{pair} = <p_T>_{\gamma\text{-jet}}$

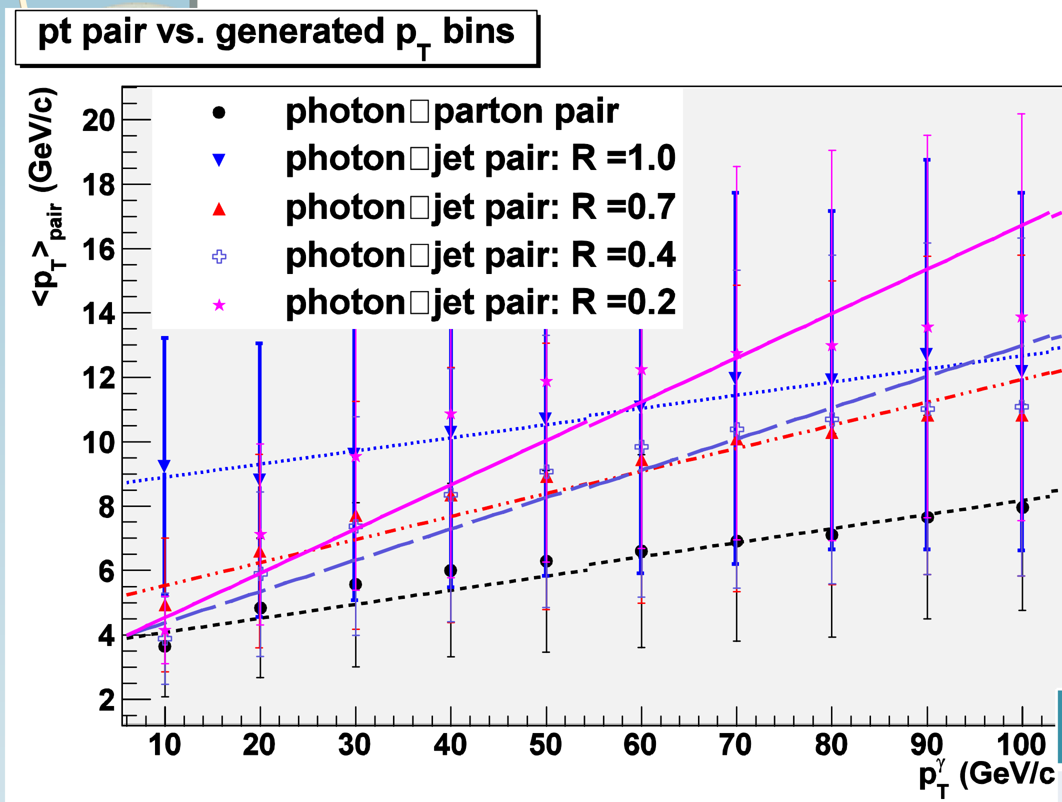
$<k_T> = <p_T>_{pair} / \sqrt{2}$

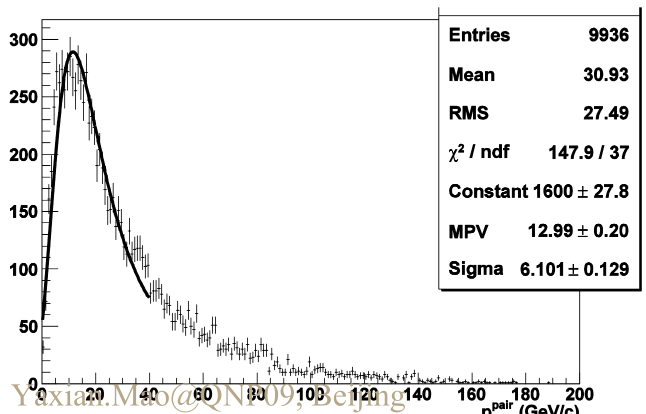
- fitting function:

$<p_T>_{pair} = A*\log_{10}(B*\sqrt{s})$

$A = 2.06 \pm 0.171$

$\langle p_T \rangle_{pair}$ dependence on p_T





Reference: γ –parton pair:

	A (GeV/c)	B $(Gev/c)^{-1}$
-----	3.63±1.40	0.05±0.03

Fitting:

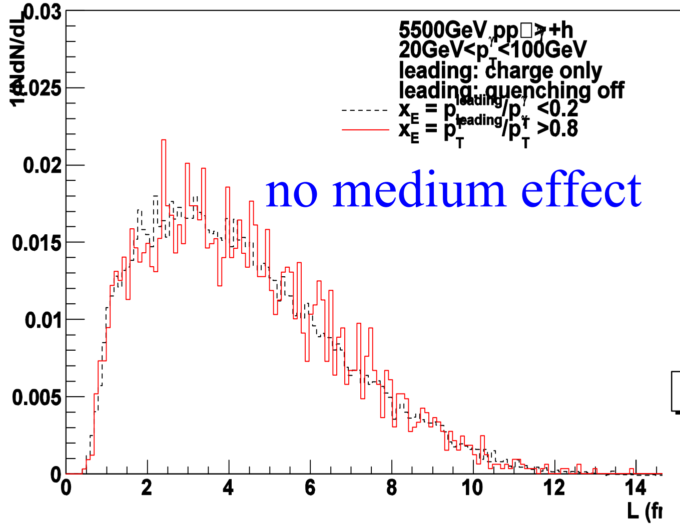
$$\langle p_T \rangle_{pair} = A + B * p_T$$

Measurement: γ –jet pair:

	A (GeV/c)	B $(Gev/c)^{-1}$
R =1	8.49±3.01	0.04±0.05
R = 0.7	4.82±1.91	0.07±0.04
R = 0.4	3.42±1.45	0.10±.0.0
R = 0.2	3.19±1.19	0.13±0.04

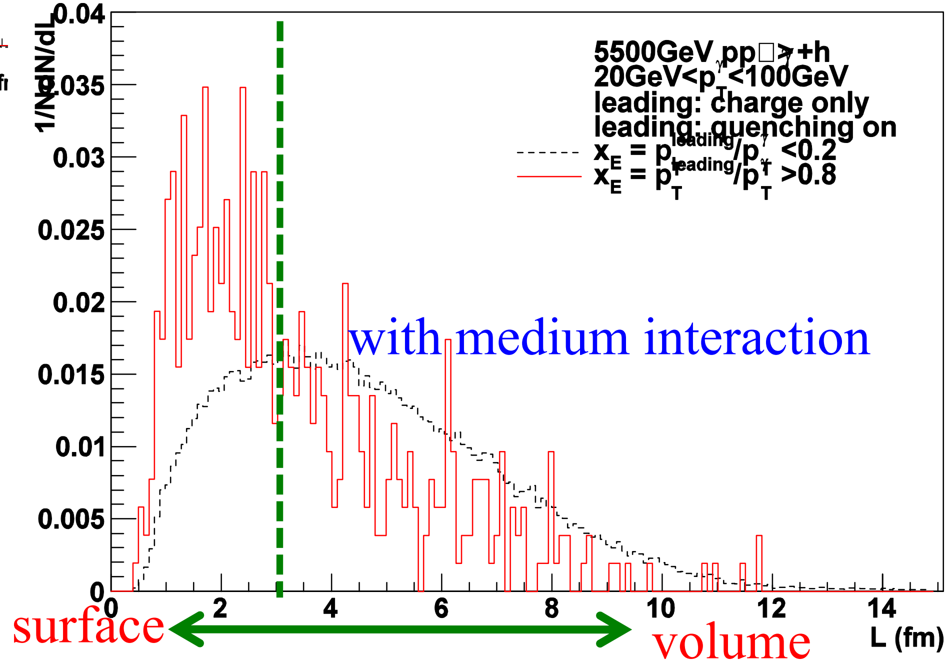
Leading particles with medium length (L) traversed

leading particle (charge only) without quenching



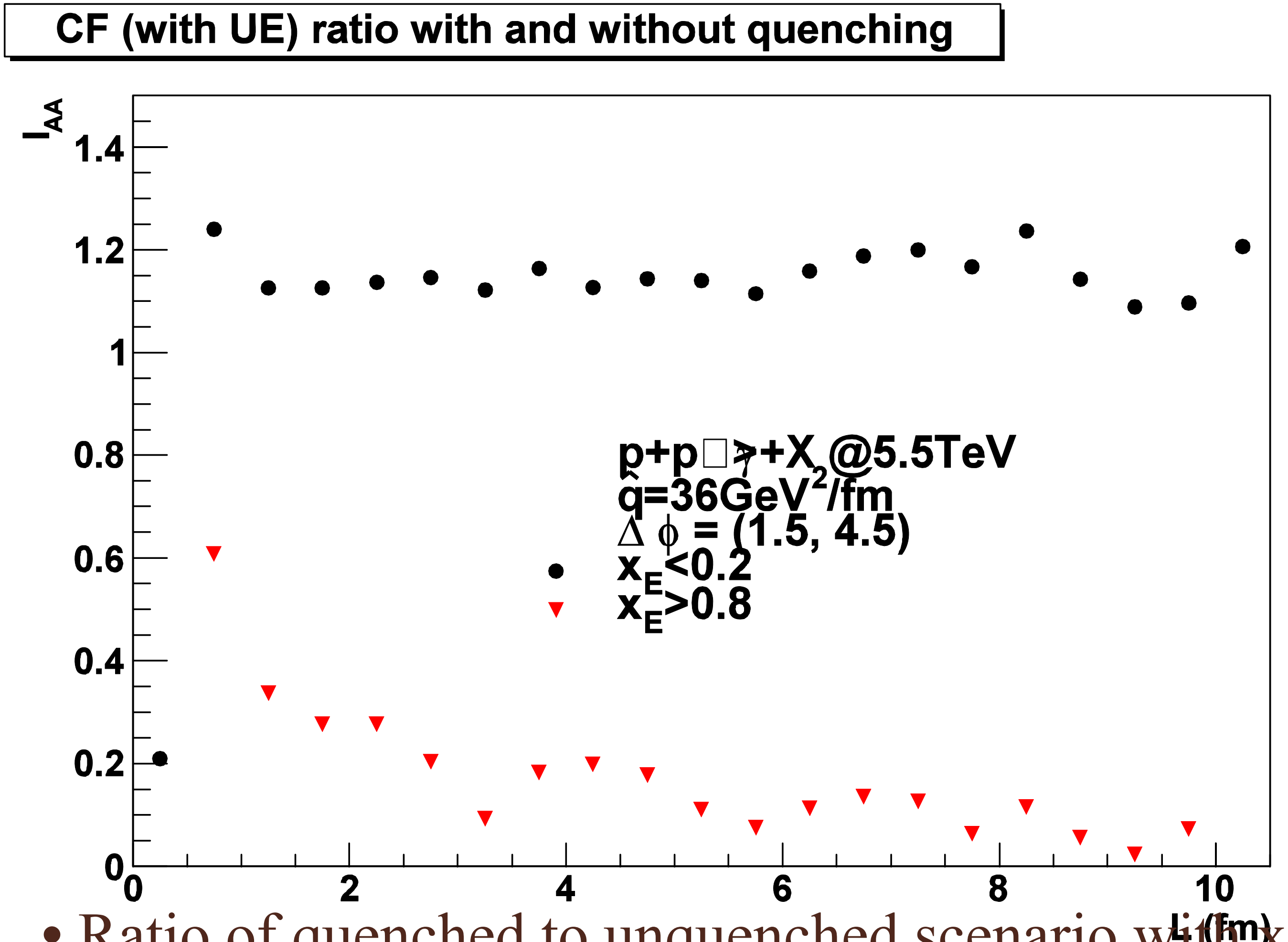
- High x leading particles come mostly from h.s. at the surface
- Low x leading particles come mostly from h.s. in the volume

leading particle (charge only) with quenching



However separation not very much pronounced!!

CF (differ x_E) dependence on L



- Ratio of quenched to unquenched scenario with x_E selection on CF

Conclusion

- Medium effect could be measured by γ-hadrons correlation:
  - Modification of the photon tagged jet fragmentation function -> medium properties
  - Detailed tomography of HI collision is in “theory” possible
  - k_T from pp to HI is an additionnal way to infer the medium property
- The measurement is challenging but worth the effort
- Let’s take a break…until LHC tell us the truth!

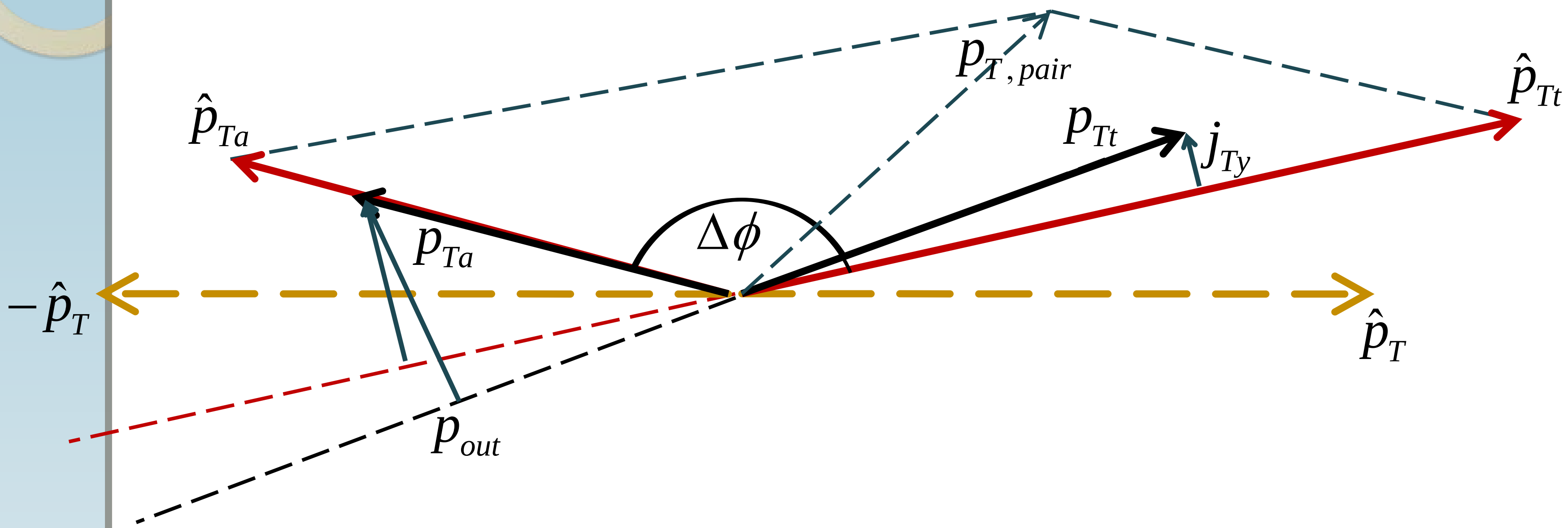
Acknowledgement

- To the organizers
- To Daicui Zhou, Yves Schutz, Xin-Nian Wang, Andreas Morsch, Peter Jacobs …for useful discussions
- To full Wuhan-ALICE group
- To full ALICE collaboration

THANKS FOR ALL!

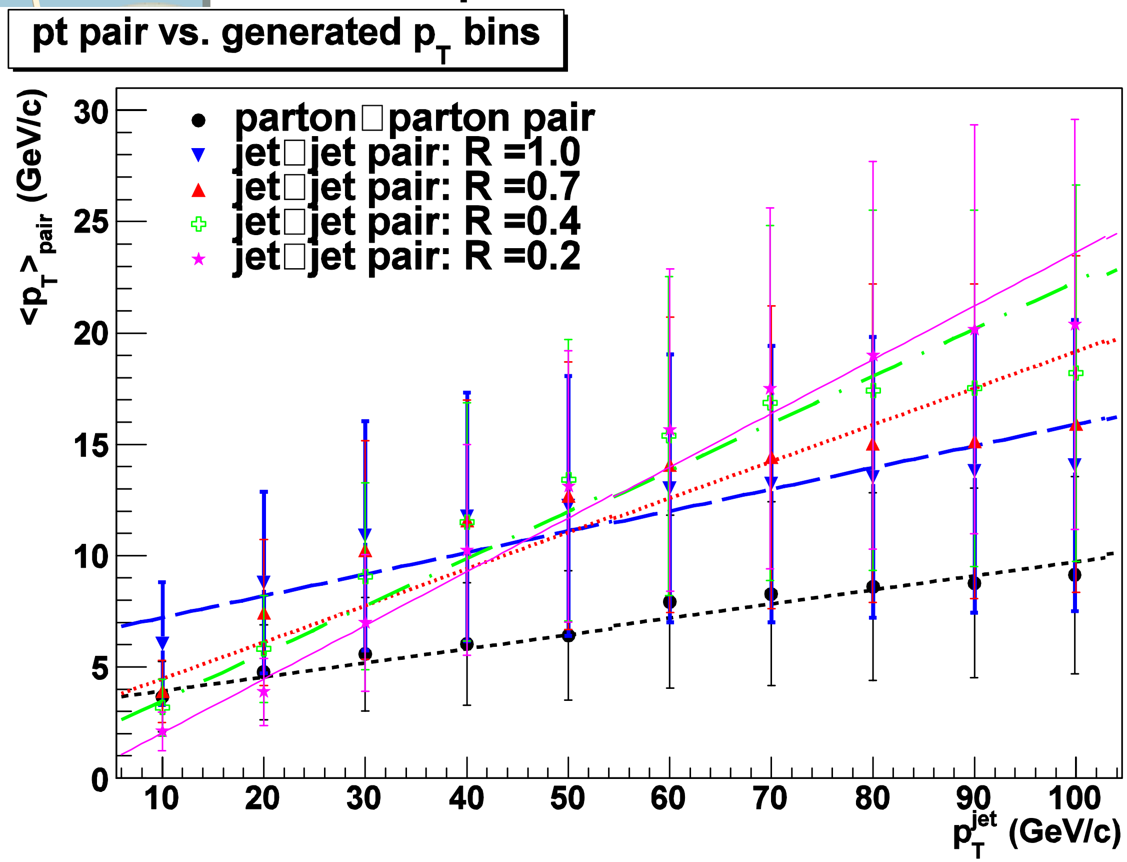
Back up

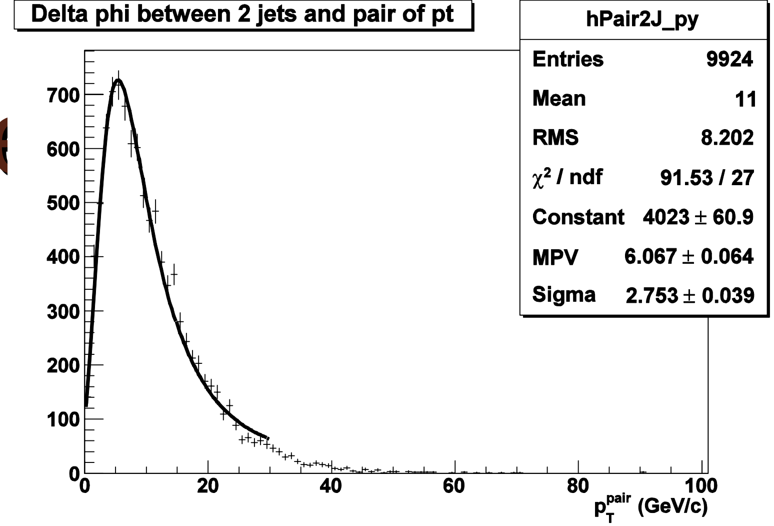
What is k_T ?



- Two partons (with hat) back to back in CM
- At an angle in lab frame due to k_T
- Fragment into final hadrons (no hat)
- $\langle k_T \rangle = \langle p_T \rangle_{pair} / \sqrt{2}$

$\langle p_T \rangle_{pair}$ in jet-jet eve





Strong dependence on jet reconstruction (R) !?

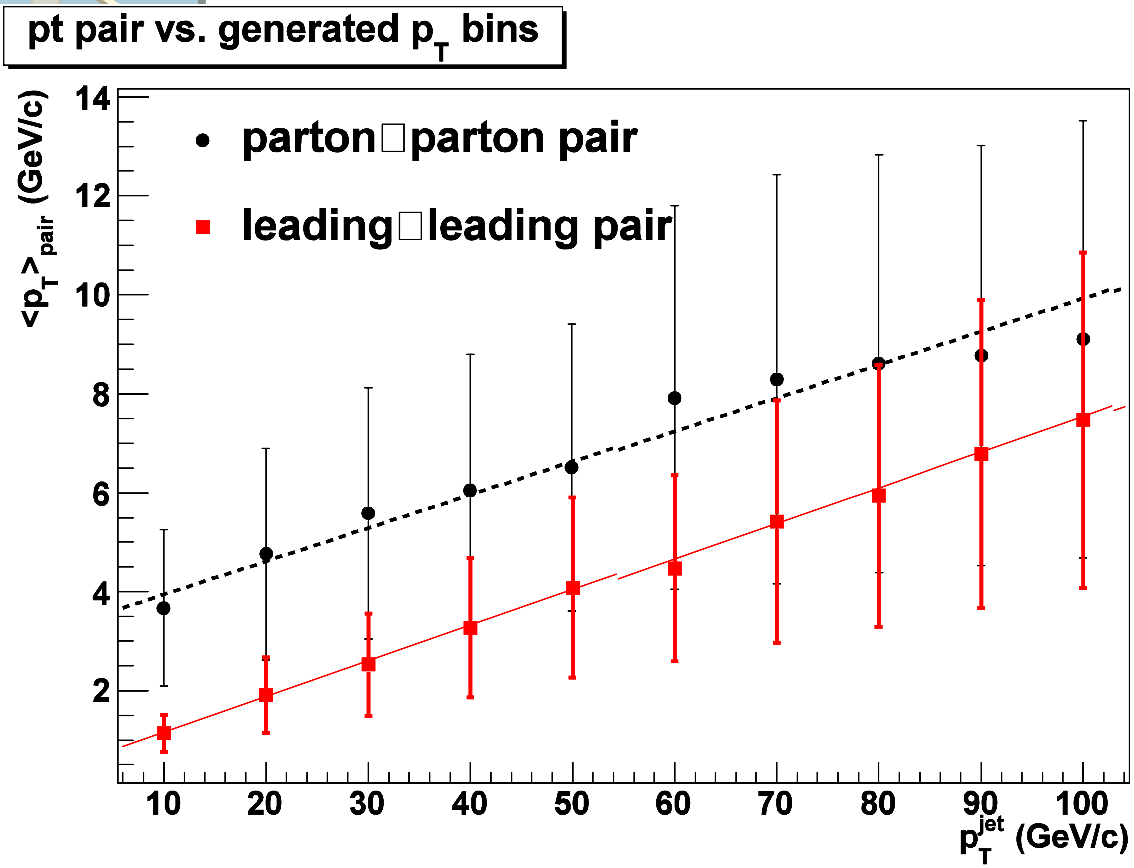
Fitting:

$\langle p_T \rangle_{pair} = A + B * p_T$

	A (GeV/c)	B (Gev/c)$^{-1}$
R =1	6.25±2.56	0.10±0.05
R = 0.7	2.84±1.56	0.16±0.05
R = 0.4	1.42±1.45	0.21±0.05
R = 0.2	- 0.36±1.08	0.24±0.05

	A (GeV/c)	B (Gev/c)$^{-1}$
-----	3.27±1.46	0.07±0.03

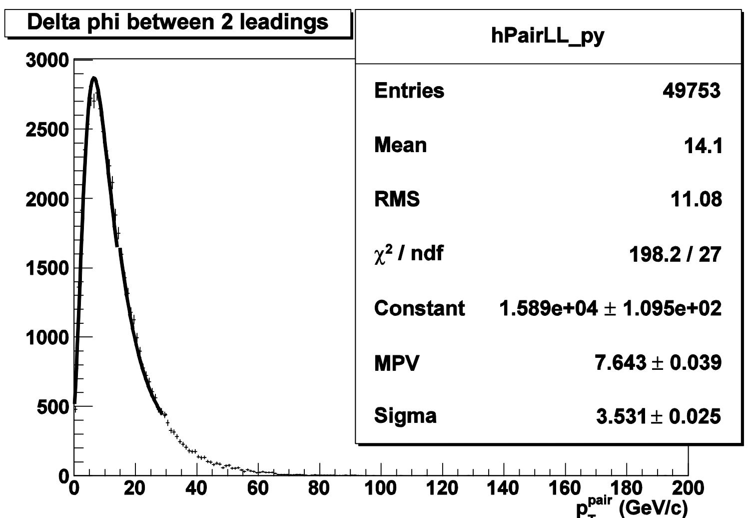
$\langle p_T \rangle_{pair}$ from leading-leading



Fitting:

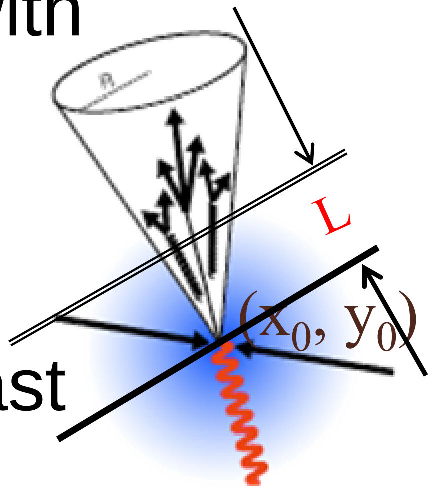
$\langle p_T \rangle_{pair} = A + B * p_T$

	A (GeV/c)	B $(Gev/c)^{-1}$
red solid line	0.45±0.44	0.07±0.02
-----	3.27±1.46	0.07±0.03

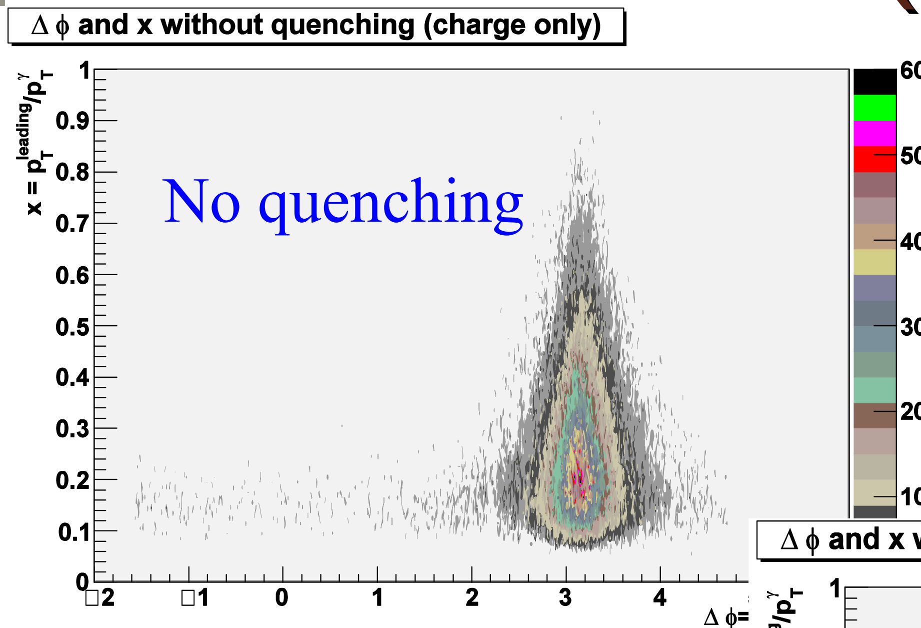


Approach to confirm…

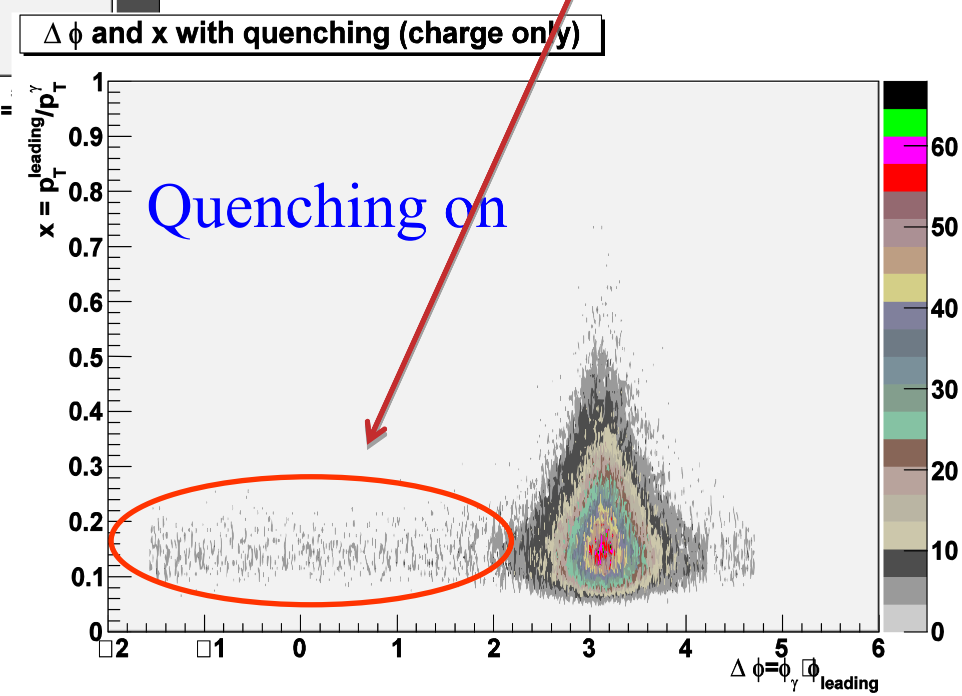
1) Generate γ-jet events (E_γ > 20 GeV) with PYTHIA generator with and without quenching (QPYTHIA)
2) Get the jet production point (x_0, y_0) inside AA geometry from Fast Glauber model
3) Calculate the traversed medium length (L) based on direction of hard scattered parton using Fast Glauber
4) Search leading hadron with the highest p_T



Phi correlation (leading and γ)



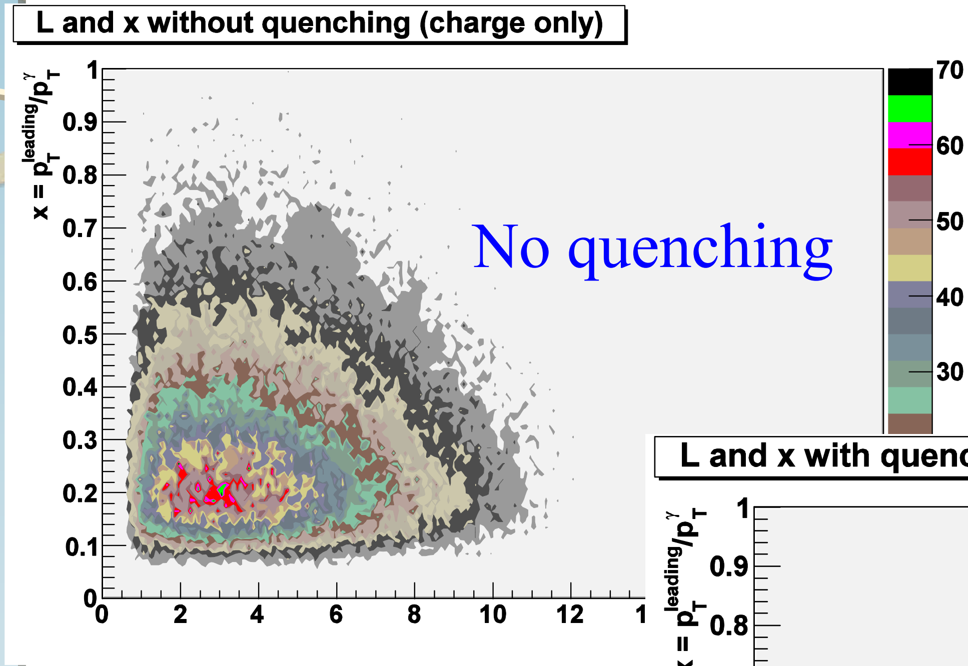
the found lp comes from the UE

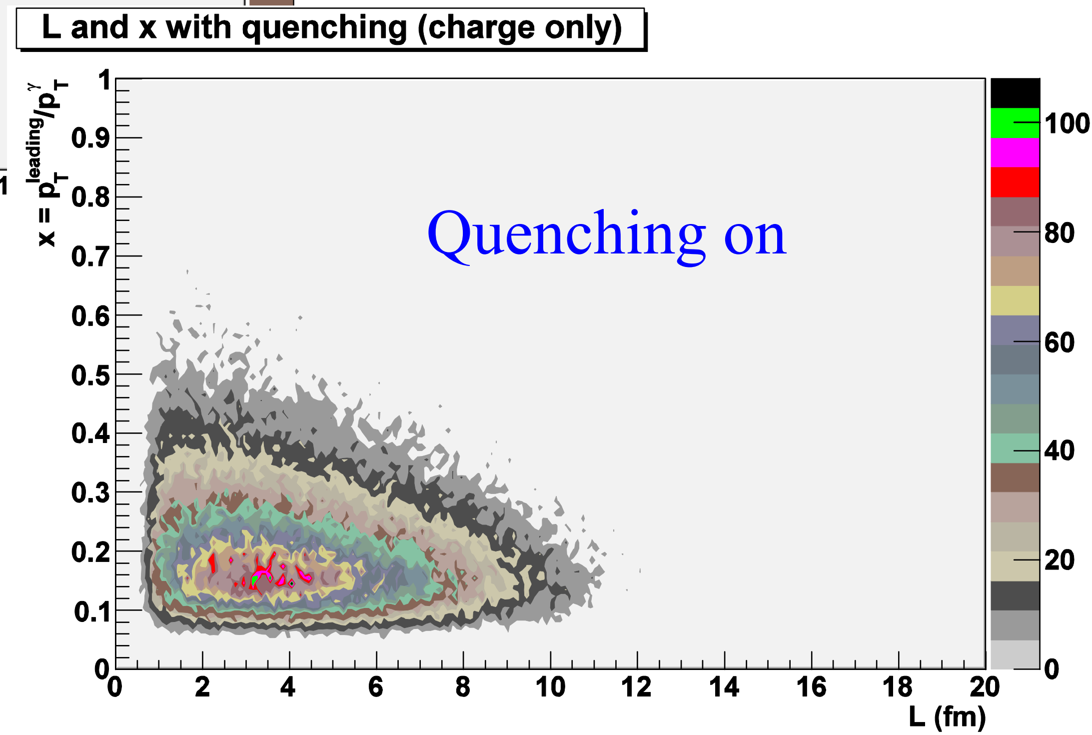


Quenching effect:

- loss of high x leading particles
- broadening of the Δ Φ correlation at low x
- x = 0.2 -> p_T ~ 4 GeV/c

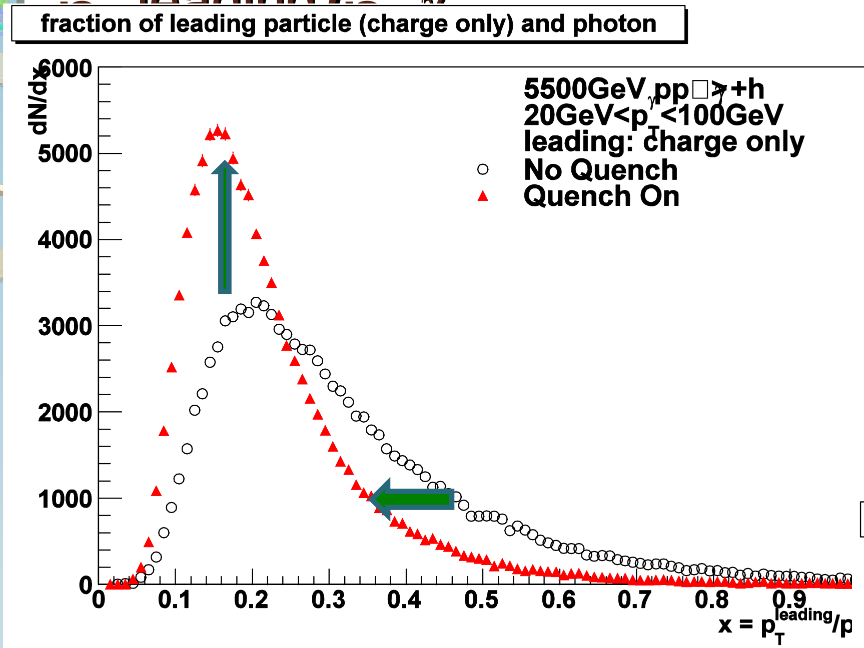
Medium length traversed by parton



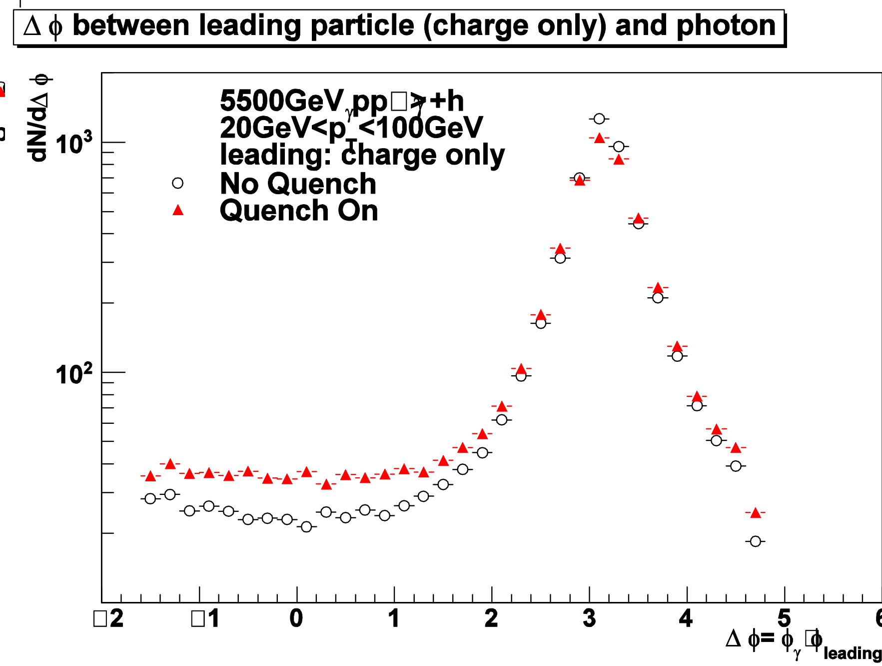


- Quenching produces more low x particles from h.s. occurring in the volume (large L)

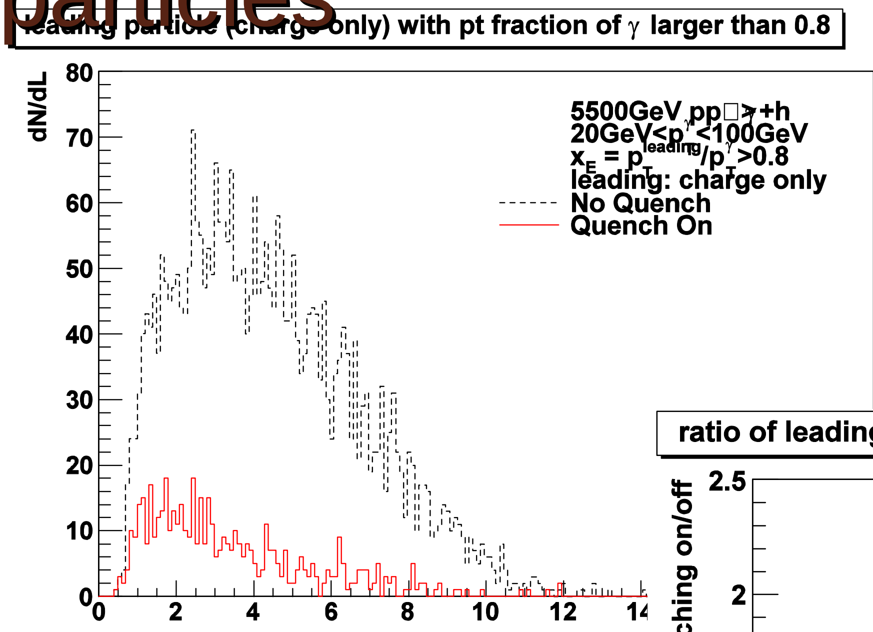
Leading particle distribution: x = $p_T^{leading}/p_T^{\gamma}$



- Quenching will generate more low x particles
- More fake leading particles from underlying events will be found due to the quenching

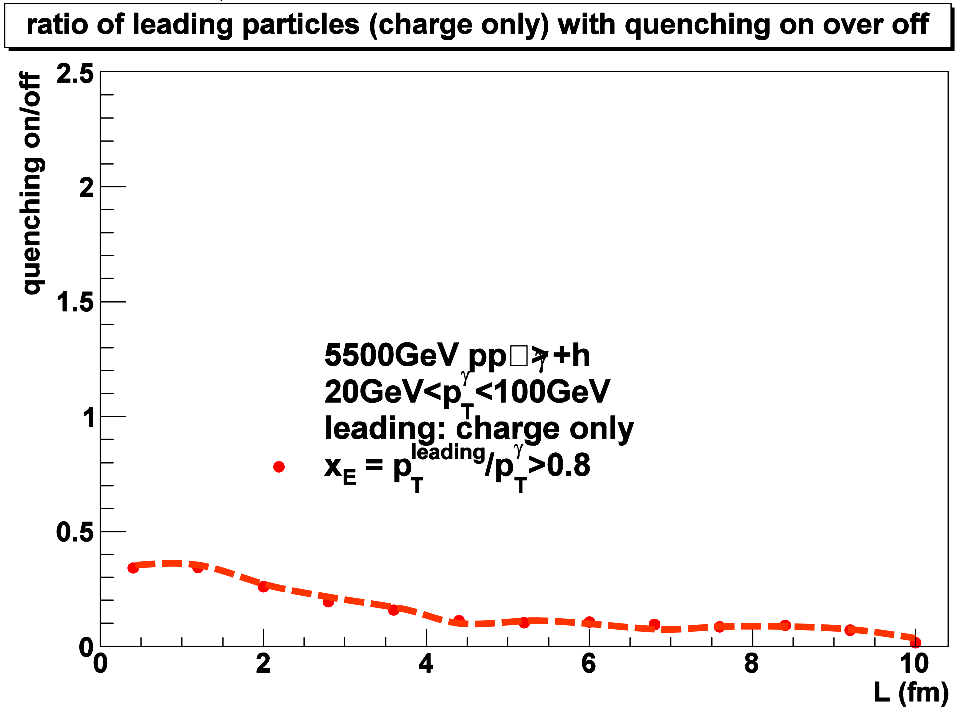


Medium effect for high p_T leading particles



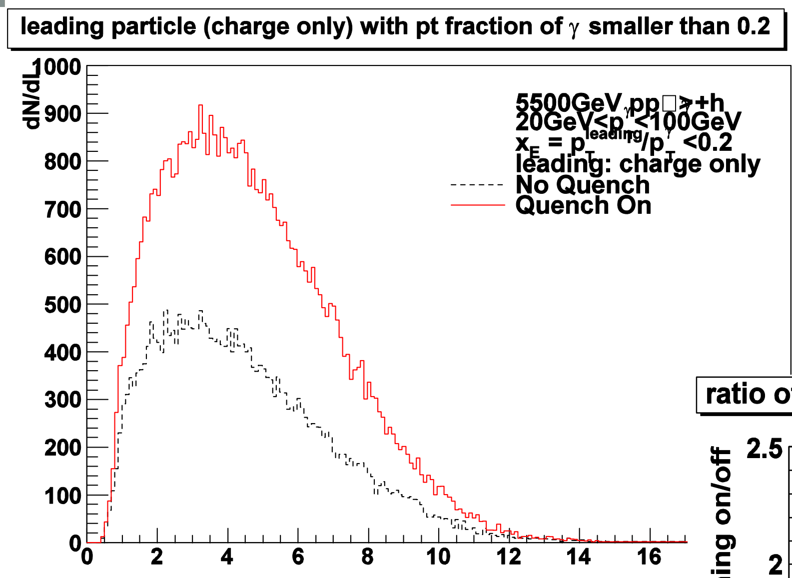
Leading particles with:

- charge only
- $x > 0.8$



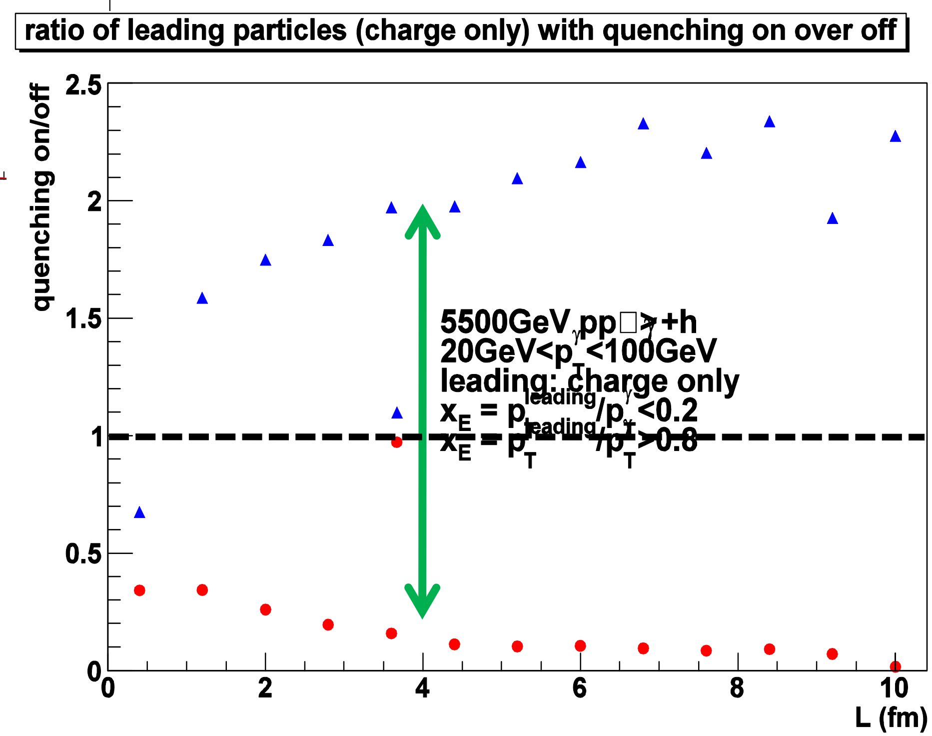
- Suppression stronger for parton traversing large L
- But L dependence is not very pronounced

Medium effect for low p_T leading particles



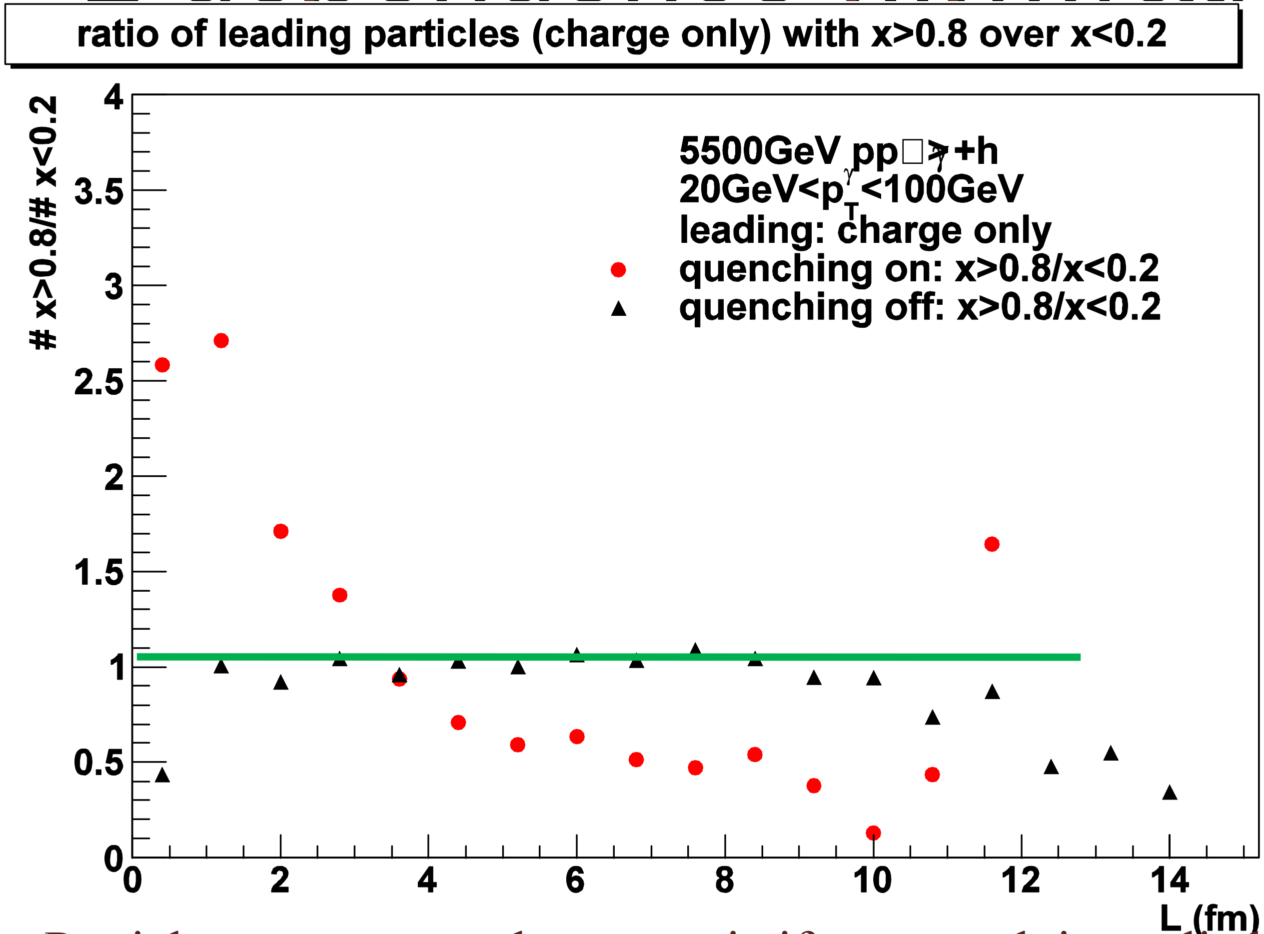
Leading particles with:

- charge only
- x < 0.2



- Opposite to before: Enhancement stronger for traversing large L
- Again L dependence is not very pronounced

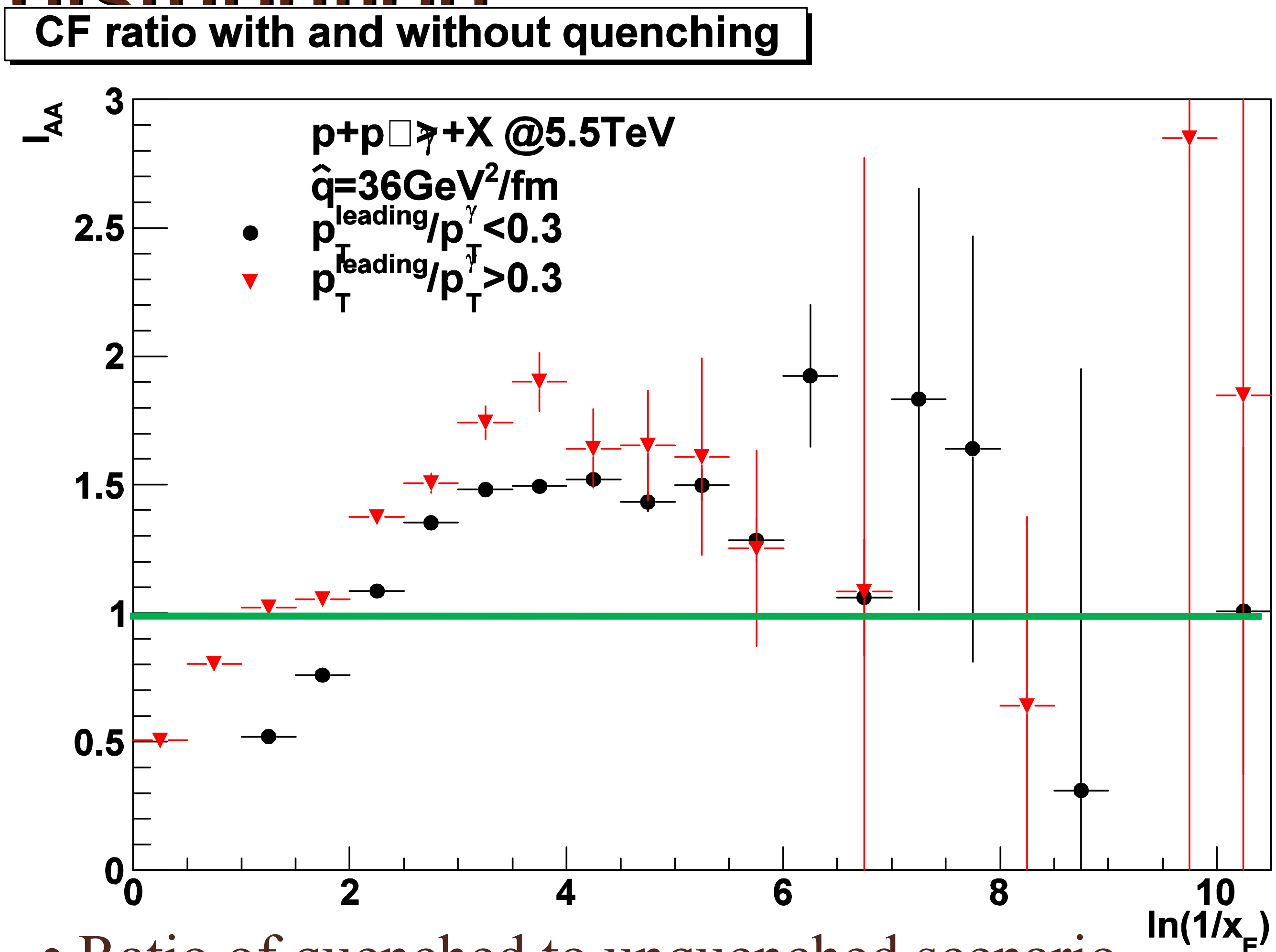
L dependence (II)…ratio



• Particles are generated symmetric if no quench is applied due to the L calculation approach

• High p_T leading particles have higher probability to come from surface than to the volume.

Gamma+lp triggered x distribution



- Ratio of quenched to unquenched scenario