p-p Correlations at $\sqrt{s}$ = 200 GeV

Jeff Porter

MIT Workshop

April, 2005

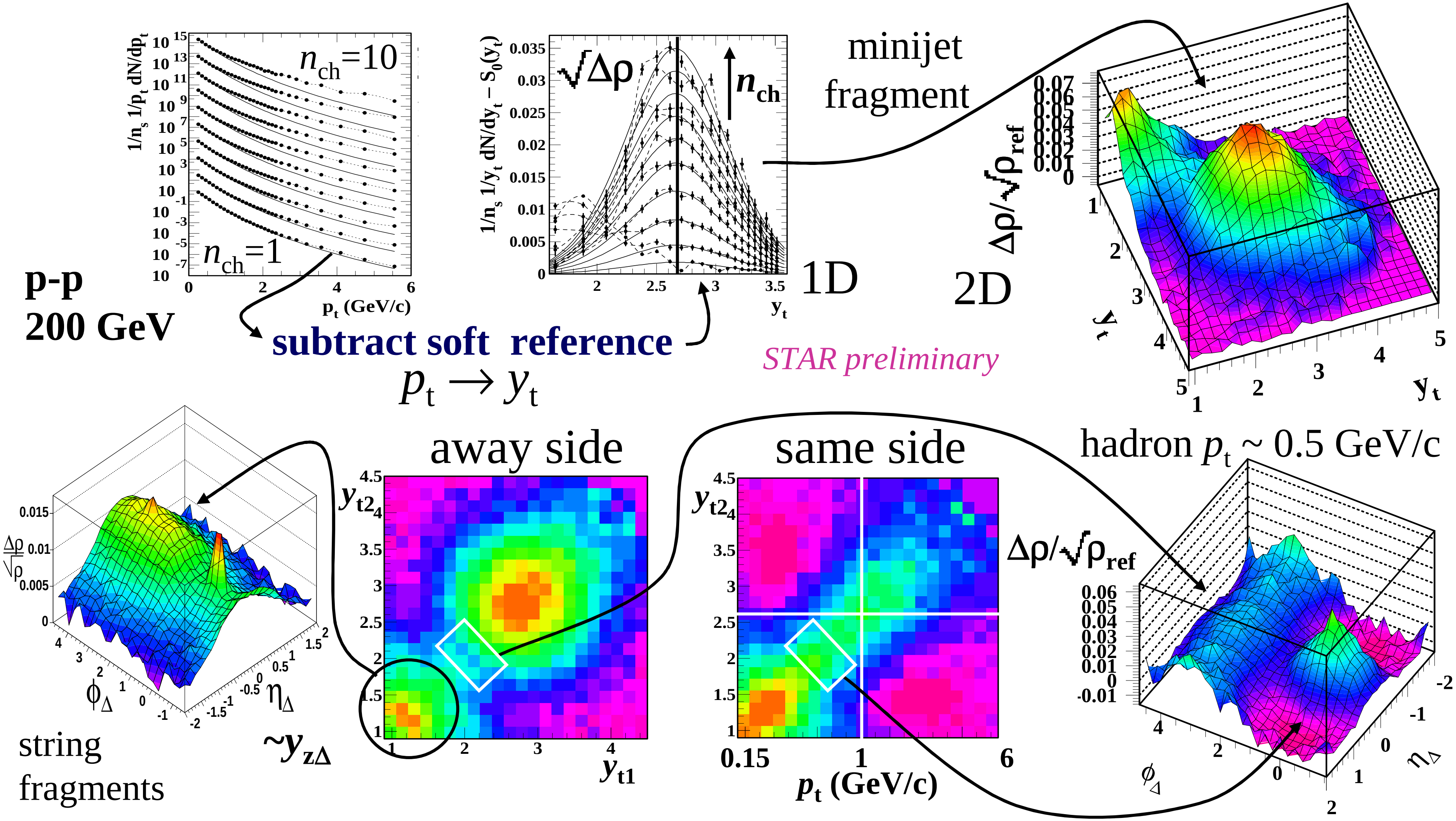
Agenda

low-Q^2 partons in p-p collisions

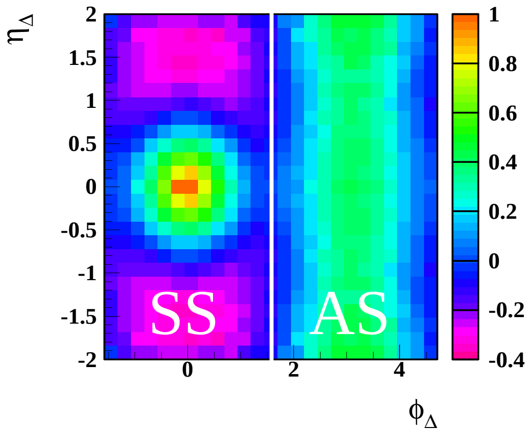
- Minimum-bias p-p correlations on (y_t, y_t) and $(\eta_\Delta, \phi_\Delta)$
- Conventional single-particle fragmentation functions
- Two-particle p-p fragment distributions on rapidity
- Low-Q^2 jet angular morphology
- Jet angular correlations at low Q^2
- j_t and k_t at low Q^2 – η,ϕ asymmetry of j_t

before we try to understand QCD in A-A collisions
we should understand it in elementary collisions

p-p Minijet Correlations on (y_{t1}, y_{t2}) and $(\eta_\Delta, \phi_\Delta)$



- p-p minijet correlations on transverse rapidity y_t like string correlations on y_z
- Minijet correlations down to hadron p_t ~ 0.35 GeV/c: probe A-A medium



p-p Correlations on (y_{t1},y_{t2})

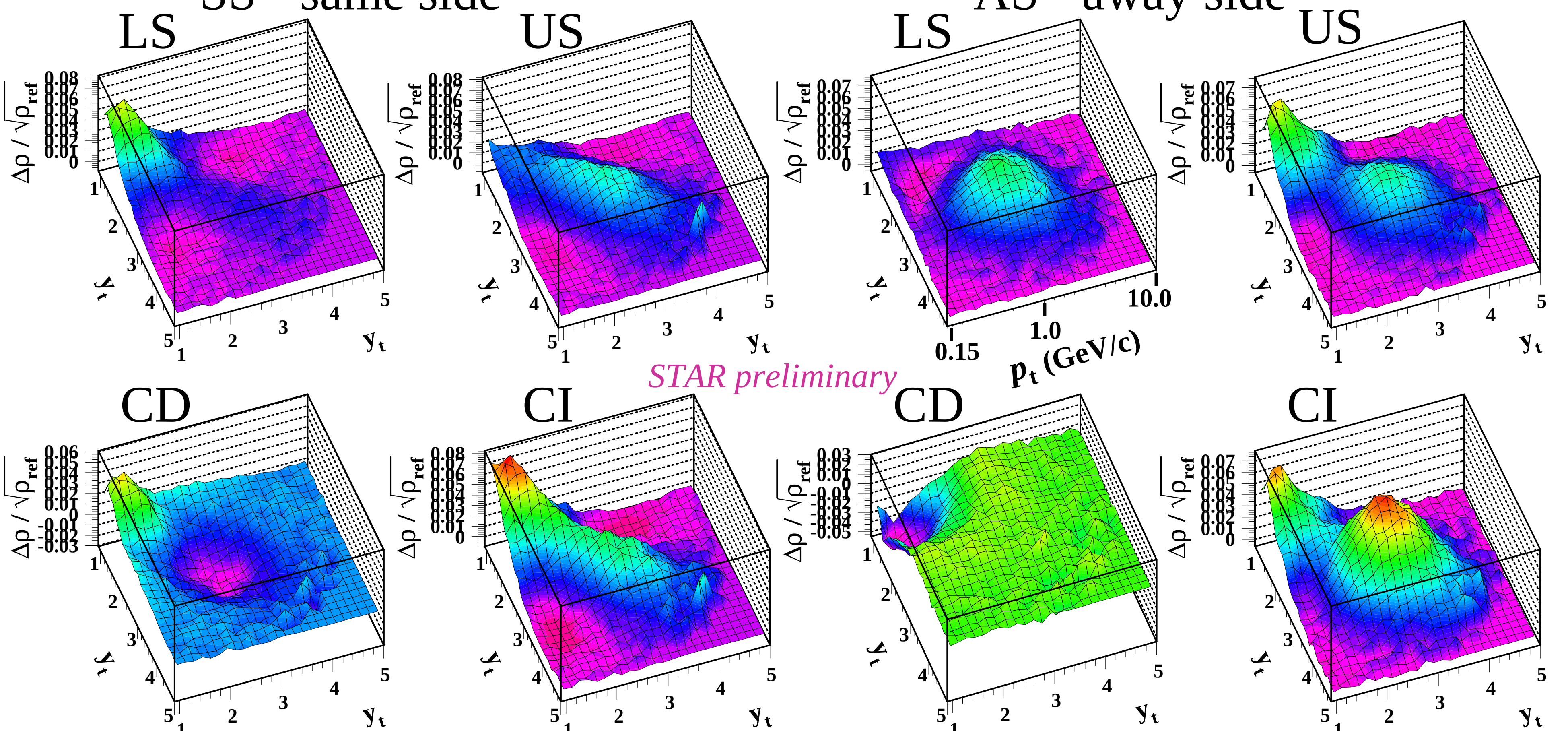
$$y_t \equiv \ln\{(m_t + p_t)/m_0\} \qquad p_t/m_0 \equiv \gamma\beta_t$$

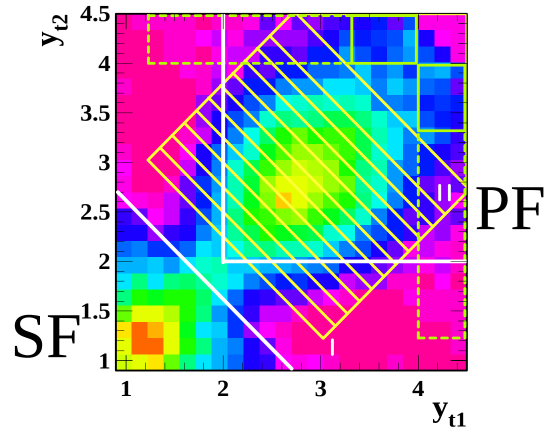
string and parton fragmentation:

two-particle *fragment distributions*

SS - same side

AS - away side

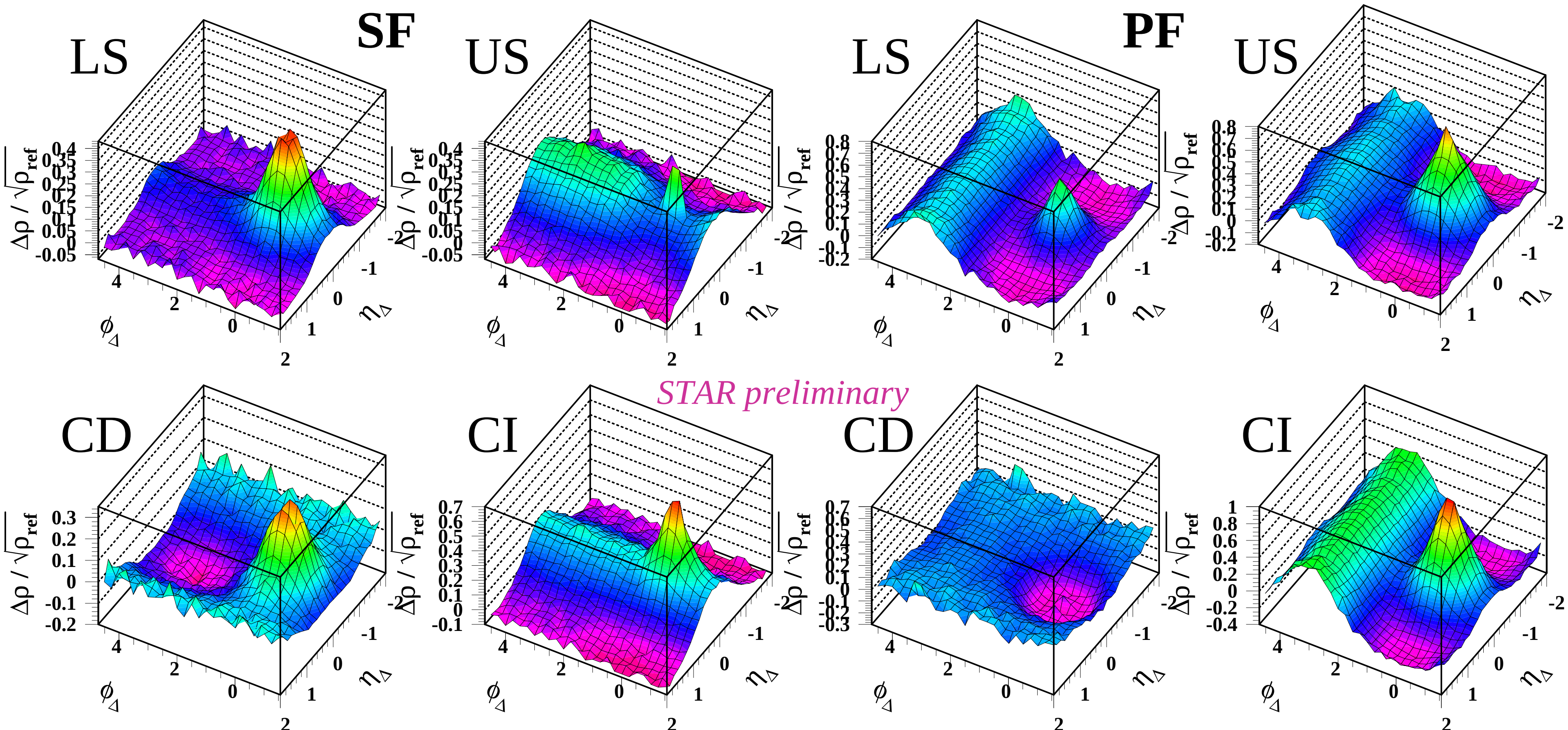




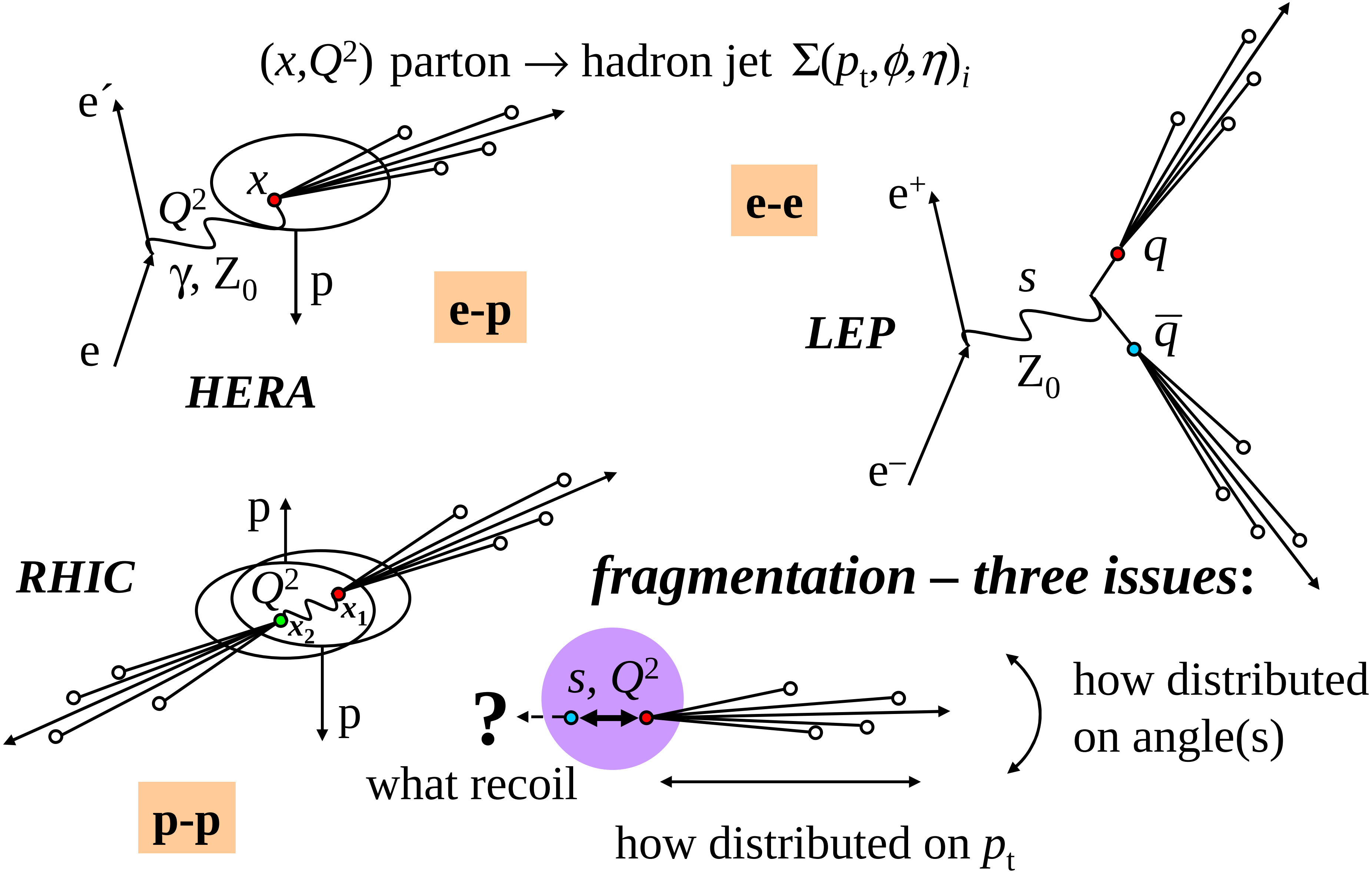
p-p Correlations on $(\eta_\Delta,\phi_\Delta)$

a study in local charge
and momentum conservation

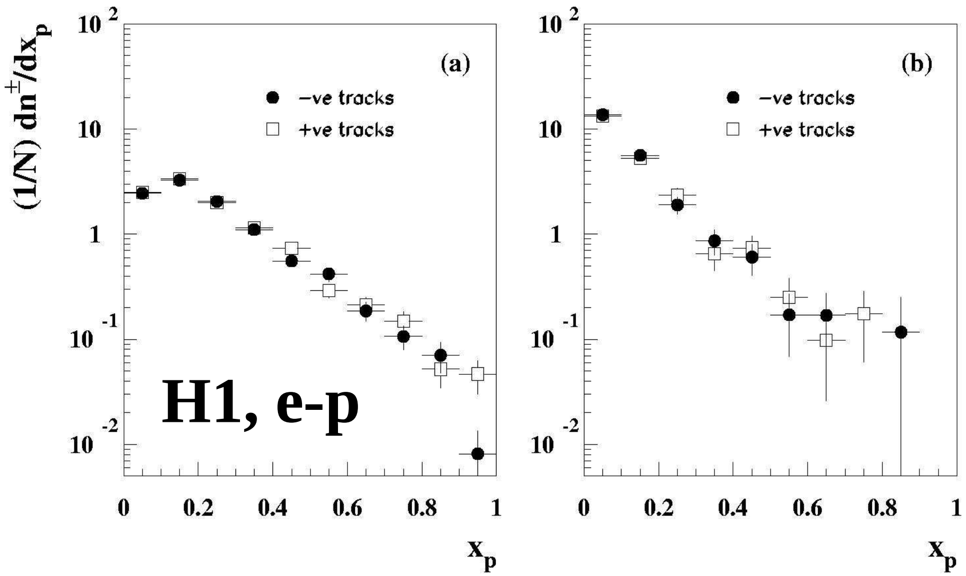
longitudinal string fragments: $\langle p_t \rangle$ transverse parton fragments: $\langle j_t \rangle, \langle k_t \rangle$

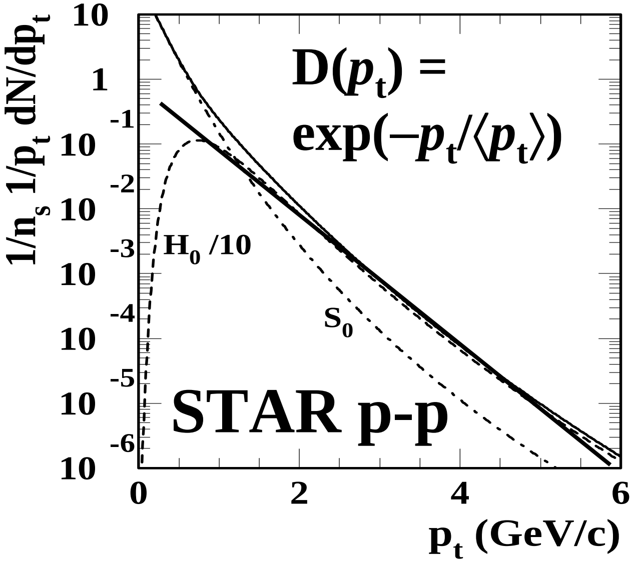


Parton Ejection and Fragmentation

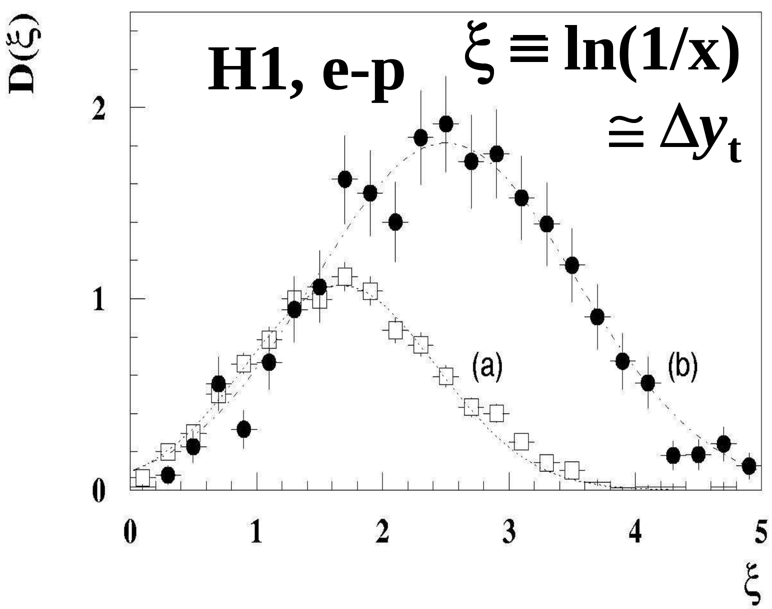


Fragmentation: Linear *vs* Logarithmic

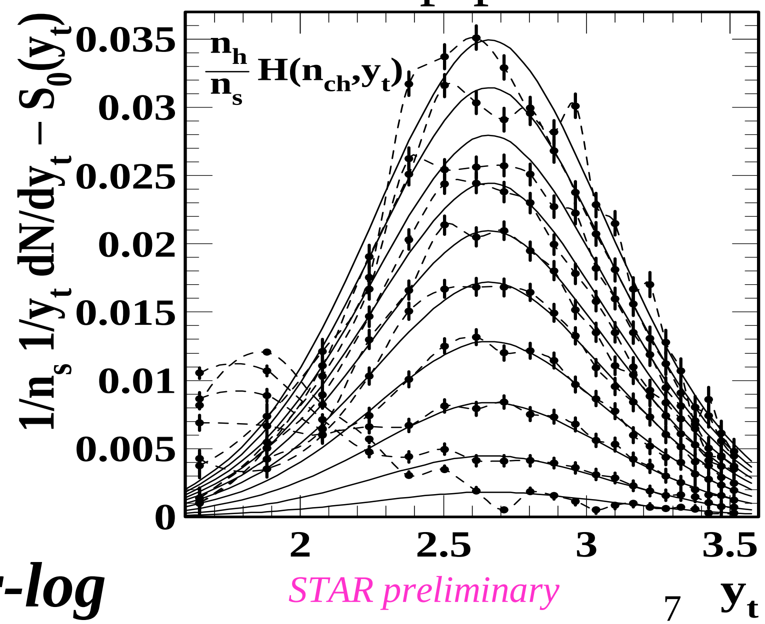




log-linear



STAR p-p



linear-log

STAR preliminary

Conventional Fragmentation Functions

***per* Jia, Rak**

trigger vs associated

$$z = p_{t,hadron} / p_{t,part}; \quad z_{trig} = p_{t,trig} / p_{t,part}$$

$$x_E = p_{t,assoc} / p_{t,trig}; \quad \langle z \rangle \approx \langle x_E \rangle \langle z_{trig} \rangle$$

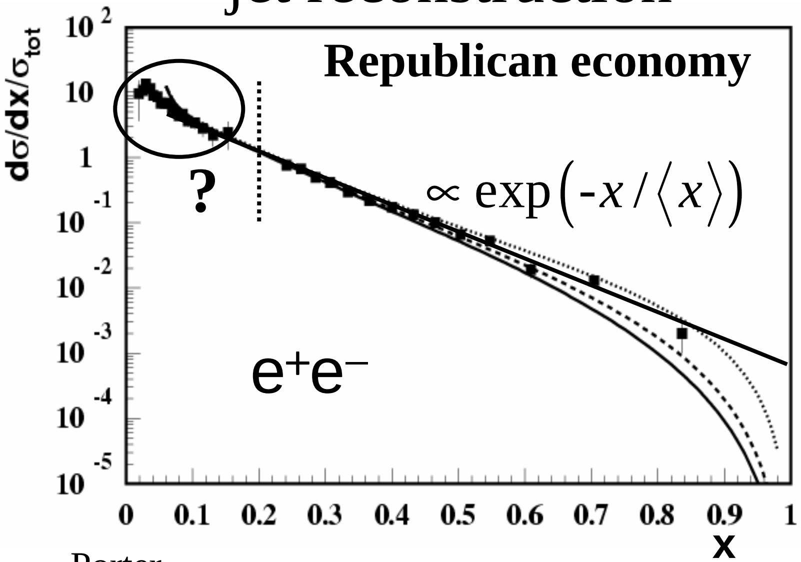
collinear approximation

symmetrize:
trigger, associated
$\rightarrow$ particles 1,2

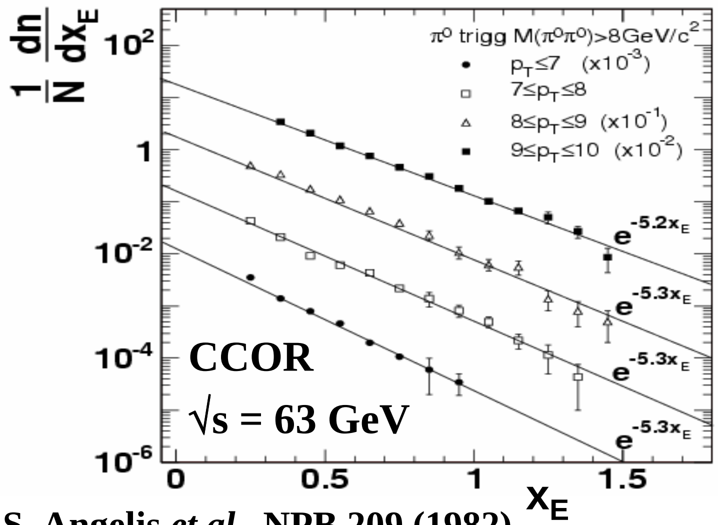
fragmentation function

$$D(x) = \frac{1}{N_{trigger}} \frac{dN_{hadron}}{dx} \propto \exp\left(-x / \langle x \rangle\right); \quad 1/\langle x \rangle \sim 6-7$$

jet reconstruction



leading particle

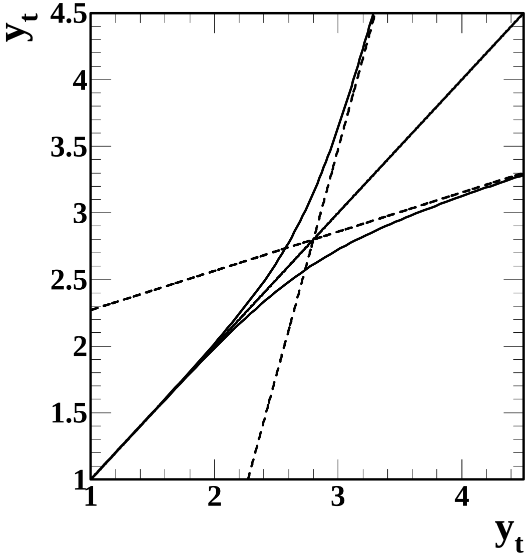


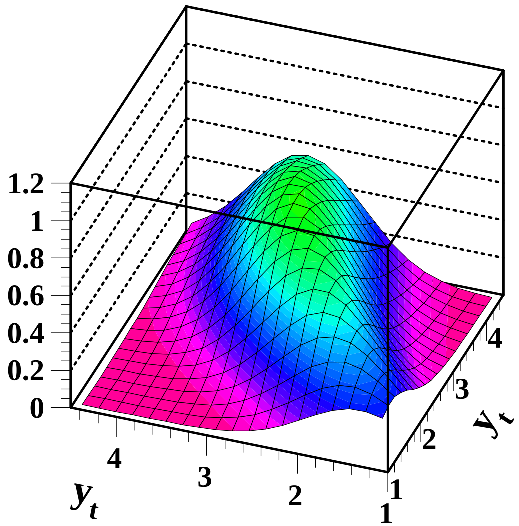
Porter

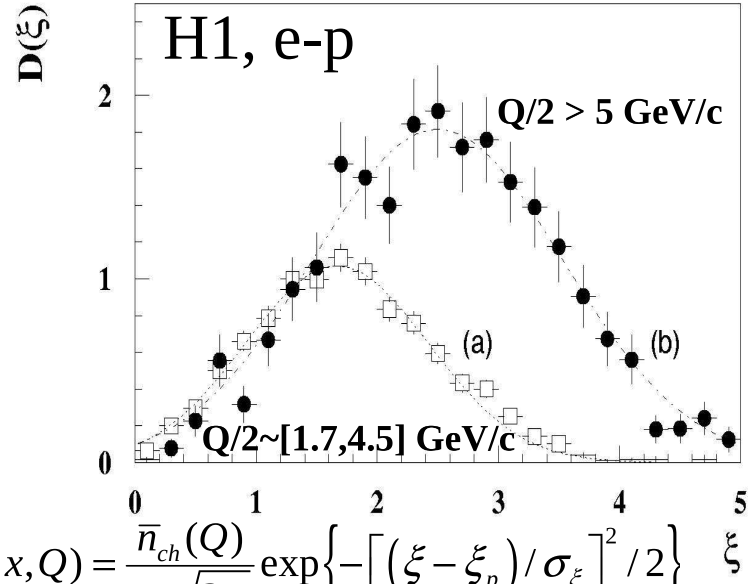
A.L.S. Angelis *et al.*, NPB 209 (1982)

Symmetrized Fragment Distributions

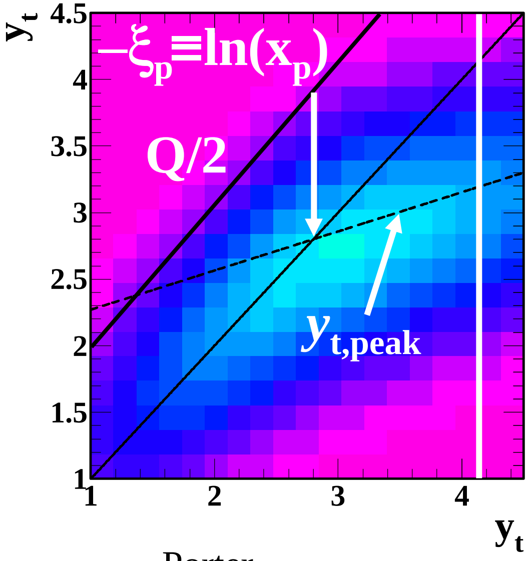
on logarithmic variables



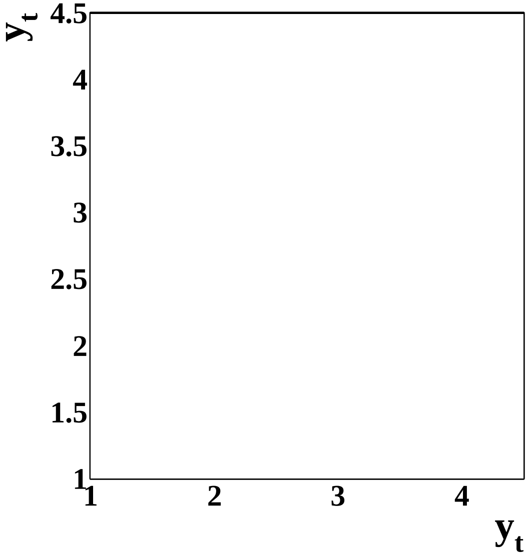




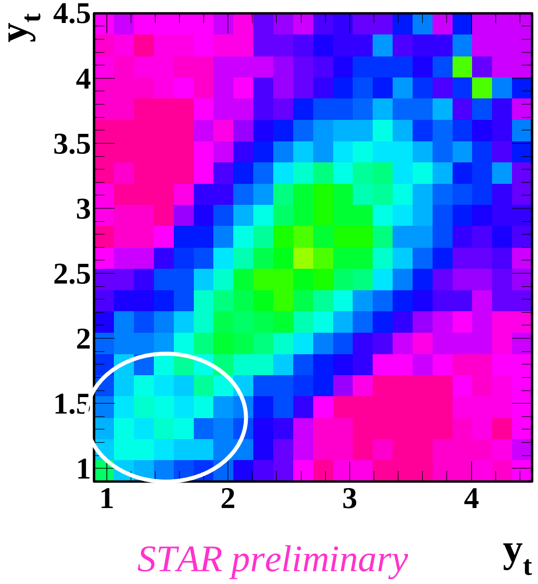
$$xF(x,Q)=\frac{\overline{n}_{ch}(Q)}{\sigma_{\xi}\sqrt{2\pi}}\exp\left\{-\left[\left(\xi-\xi_{p}\right)/\sigma_{\xi}\right]^{2}/2\right\}$$

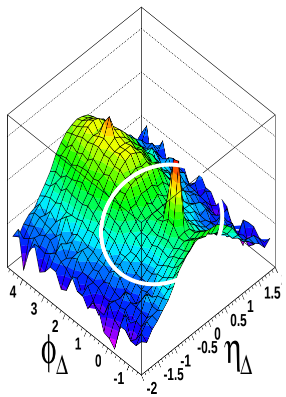


Porter

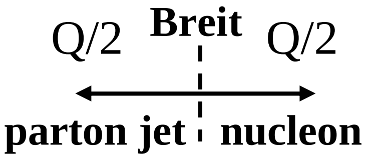


US - SS



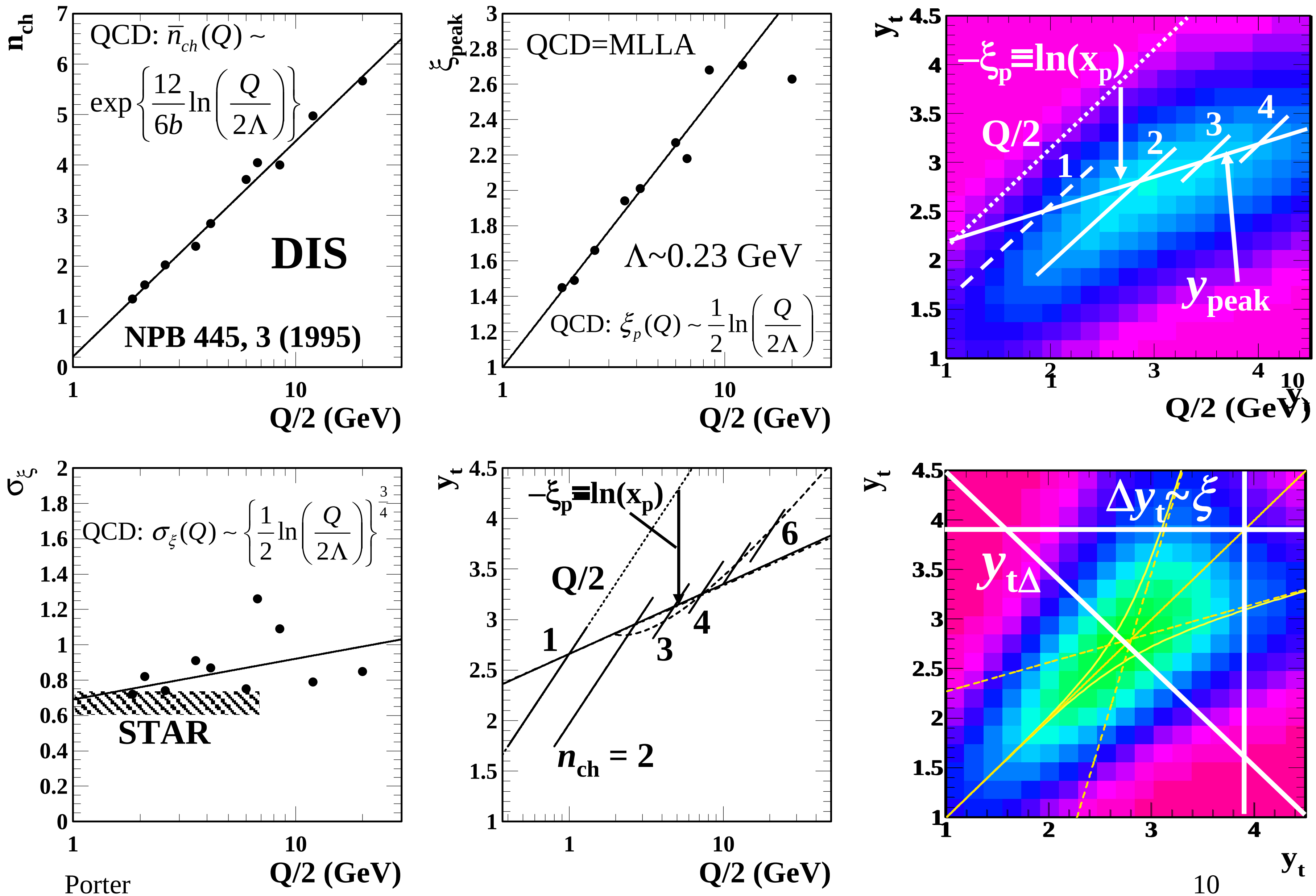


STAR preliminary



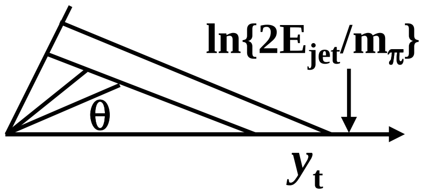
Q/2
Breit
Q/2
parton jet
nucleon

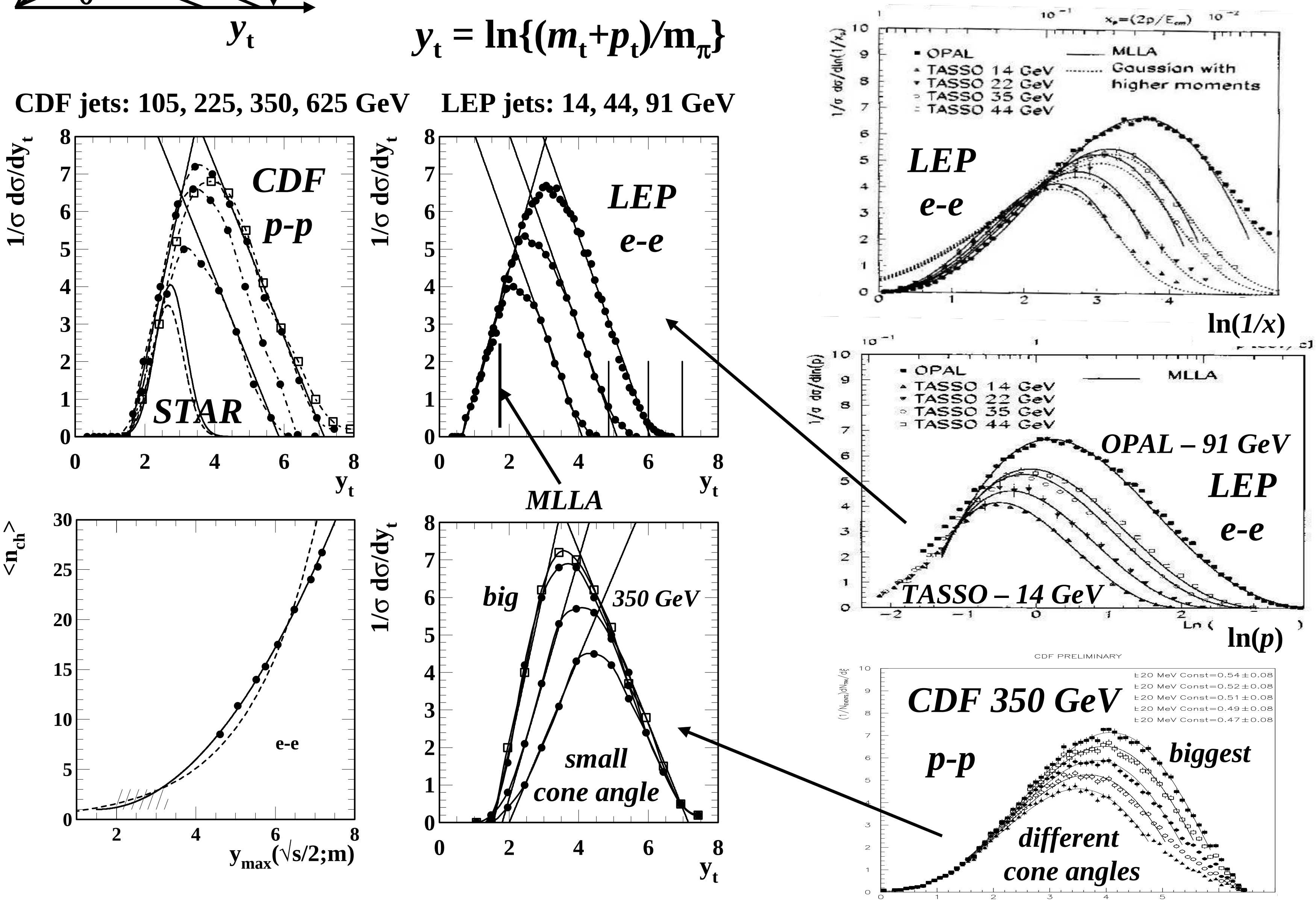
H1- Hera e-p



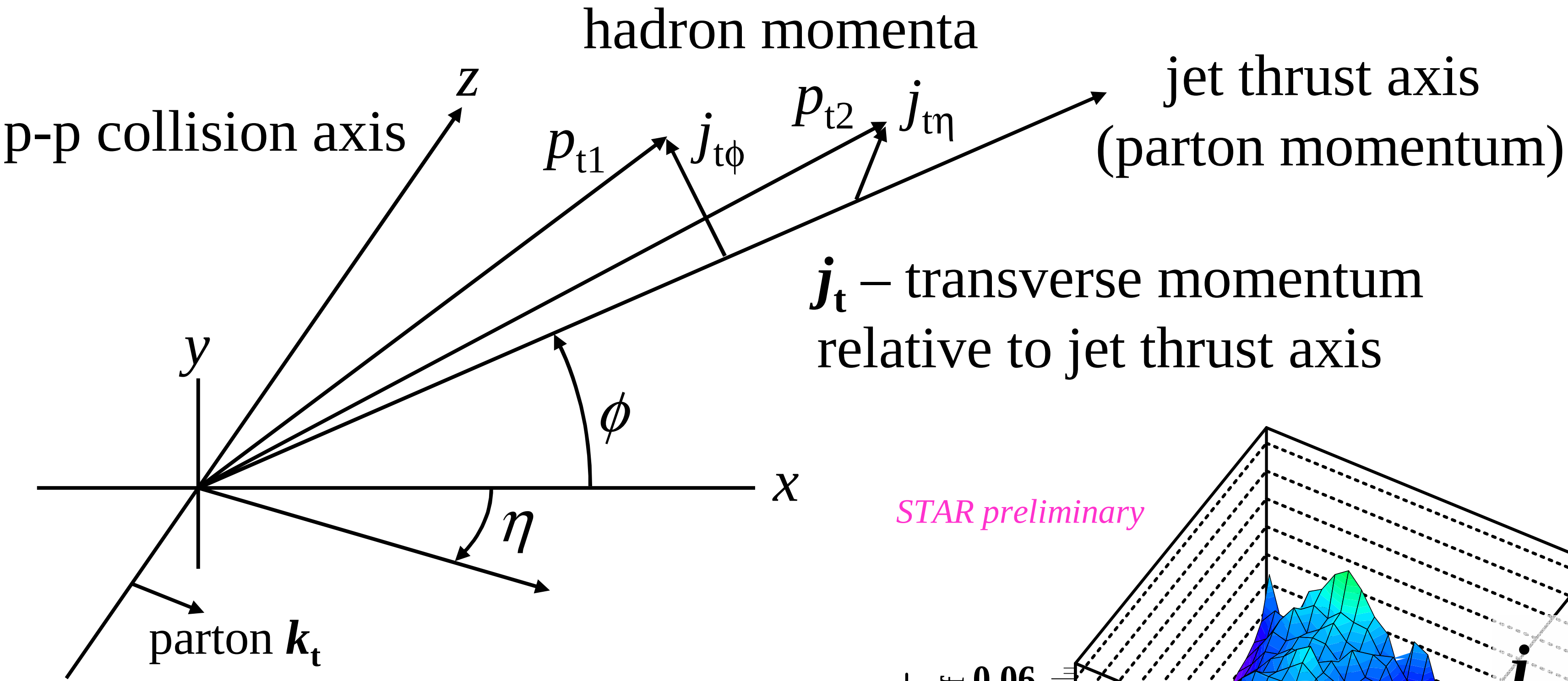
n_ch
QCD: $\bar{n}_{ch}(Q) \sim \exp\left\{\frac{12}{6b}\ln\left(\frac{Q}{2\Lambda}\right)\right\}$
DIS
NPB 445, 3 (1995)
Q/2 (GeV)
ξ_peak
QCD=MLLA
Λ~0.23 GeV
QCD: $\xi_p(Q) \sim \frac{1}{2}\ln\left(\frac{Q}{2\Lambda}\right)$
Q/2 (GeV)
y_t
$-\xi_p \equiv \ln(x_p)$
Q/2
1
2
3
4
y_peak
Q/2 (GeV)
σ_ξ
QCD: $\sigma_\xi(Q) \sim \left\{\frac{1}{2}\ln\left(\frac{Q}{2\Lambda}\right)\right\}^{\frac{3}{4}}$
STAR
Q/2 (GeV)
y_t
$-\xi_p \equiv \ln(x_p)$
Q/2
1
3
4
6
$n_{ch} = 2$
Q/2 (GeV)
y_t
$\Delta y_t \sim \xi$
$y_{t\Delta}$
y_t

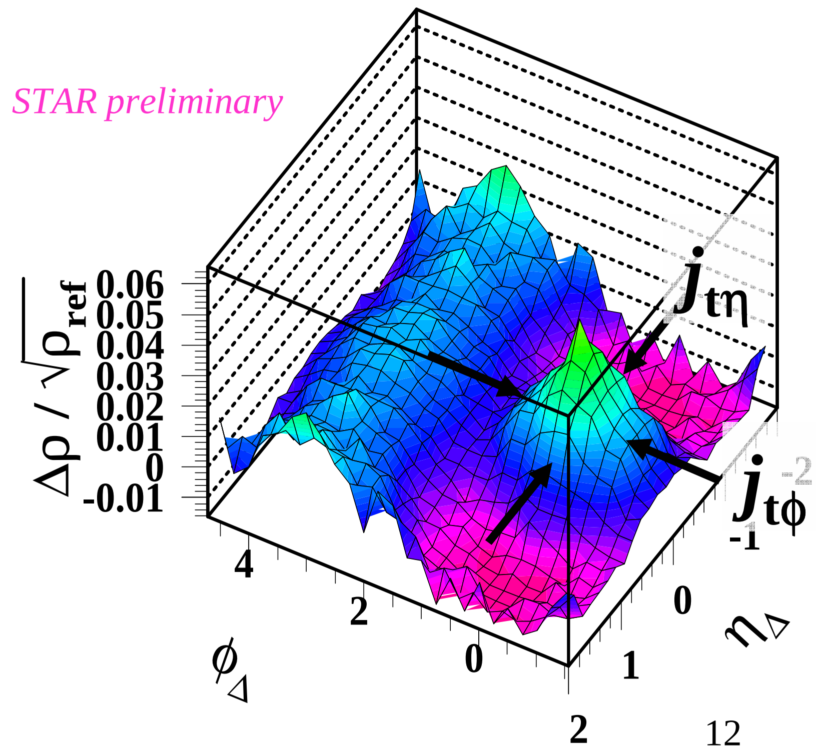
Fragmentation on y_t





Jet Morphology Relative to Thrust



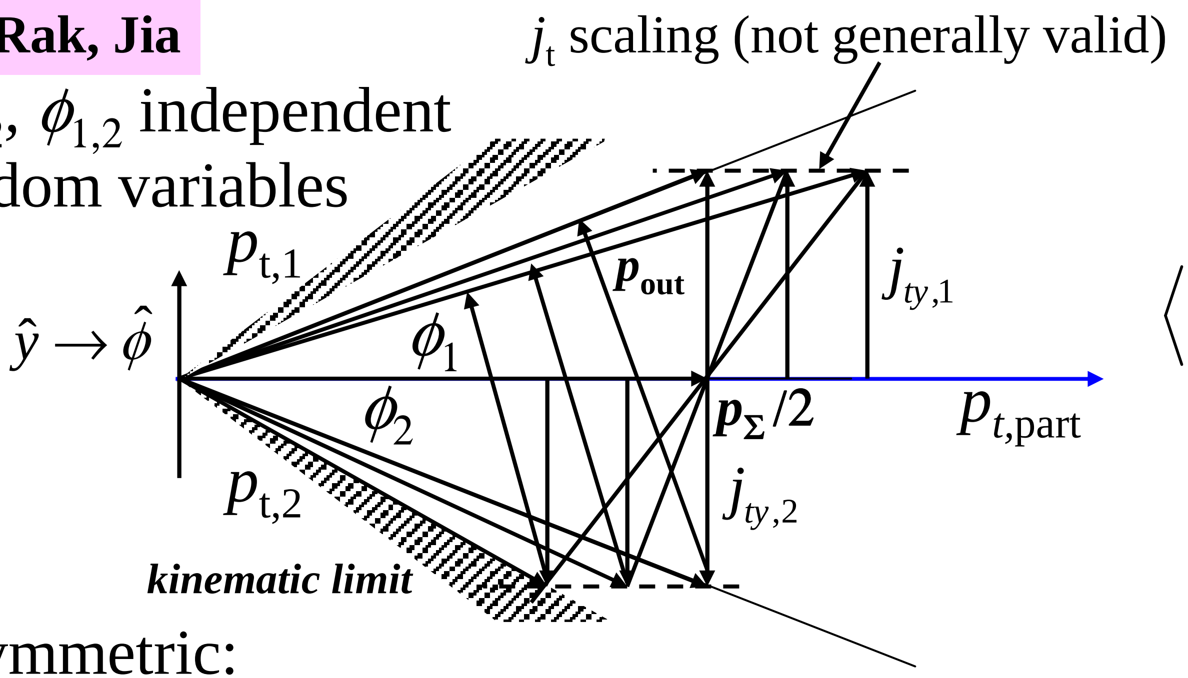


the most probable parton *Q/2* for the distribution at right is 1-2 GeV/c, *comparable to* the intrinsic parton k_t

Symmetrized Angular Kinematics

***per* Rak, Jia**

$p_{t1,2}$, $\phi_{1,2}$ independent random variables



***symmetrize*: *trigger, associated* → particles 1, 2**

$$\langle | p_y | \rangle = \langle p \rangle \langle |\sin\phi| \rangle$$

$$\langle p_{t,1}^2 \rangle \langle \sin^2\phi_1 \rangle \equiv \langle j_{ty,1}^2 \rangle$$

$$\langle p_{t,2}^2 \rangle \langle \sin^2\phi_2 \rangle \equiv \langle j_{ty,2}^2 \rangle$$

asymmetric:

$$\langle p_{out}^2 \rangle = \langle p_{t,assoc}^2 \rangle_{SS} \langle \sin^2\phi_{ta} \rangle_{SS} = \langle j_{ty,assoc}^2 \rangle_{SS} + \langle x_{at}^2 \rangle \langle j_{ty,trig}^2 \rangle \left(1 - 2\langle j_{ty,assoc}^2 \rangle_{SS} / \langle p_{t,assoc}^2 \rangle_{SS}\right)$$

we now remove the trigger/associated asymmetry

symmetric:

$$\hat{y} \rightarrow \hat{\phi}$$

$$\sqrt{\langle p_{t,1}^2 \rangle \langle p_{t,2}^2 \rangle} \langle \sin^2\phi_{12} \rangle_{SS} = \sqrt{\frac{\langle p_{t,2}^2 \rangle}{\langle p_{t,1}^2 \rangle}} \langle j_{t\phi,1}^2 \rangle + \sqrt{\frac{\langle p_{t,1}^2 \rangle}{\langle p_{t,2}^2 \rangle}} \langle j_{t\phi 2}^2 \rangle - 2\frac{\langle j_{t\phi,1}^2 \rangle \langle j_{t\phi 2}^2 \rangle}{\sqrt{\langle p_{t,1}^2 \rangle \langle p_{t,2}^2 \rangle}}$$

Symmetrize $\langle | j_{t\phi} | \rangle$ on $y_t \otimes y_t$ and $(\eta_\Delta, \phi_\Delta)$

$$\sqrt{\frac{\langle p_{t,2}^2 \rangle}{\langle p_{t,1}^2 \rangle}} \langle j_{t\phi,1}^2 \rangle + \sqrt{\frac{\langle p_{t,1}^2 \rangle}{\langle p_{t,2}^2 \rangle}} \langle j_{t\phi,2}^2 \rangle = \sqrt{\langle p_{t,1}^2 \rangle \langle p_{t,2}^2 \rangle} \left\{ \langle \sin^2 \phi_{12} \rangle_{SS} + 2 \langle \sin^2 \phi_1 \rangle \langle \sin^2 \phi_2 \rangle \right\}$$

weights

conditional $(\Delta\phi = \phi_{12})$

$$\overline{\langle j_{t\phi}^2 \rangle}_{12} \equiv \frac{\sqrt{\langle p_{t,1}^2 \rangle \langle p_{t,2}^2 \rangle} \left\{ \langle \sin^2 \Delta\phi \rangle_{SS} + 2 \langle \sin^2 \phi_1 \rangle \langle \sin^2 \phi_2 \rangle \right\}}{\sqrt{\langle p_{t,2}^2 \rangle / \langle p_{t,1}^2 \rangle} + \sqrt{\langle p_{t,1}^2 \rangle / \langle p_{t,2}^2 \rangle}}$$

weighted average

(consistent with asymmetric special case)

autocorrelation $(\phi_\Delta = \phi_{12})$

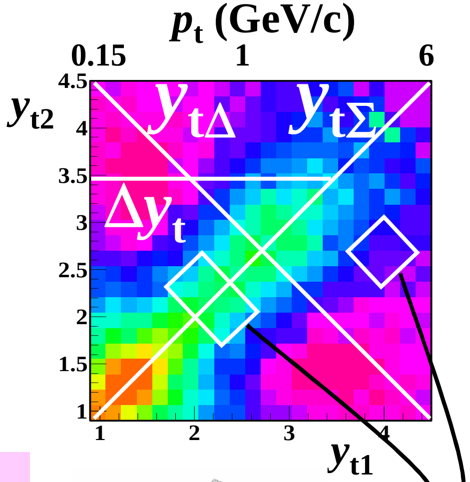
$$\approx \frac{(m_\pi / 2)^2 \exp\{y_{t\Sigma}\}}{2 \cosh\{y_{t\Delta}\}} \left\{ \langle \sin^2 (\phi_\Delta / \sqrt{2}) \rangle_{SS} + 2 \langle \sin^2 (\phi_\Delta / 2\sqrt{2}) \rangle^2 \right\}$$

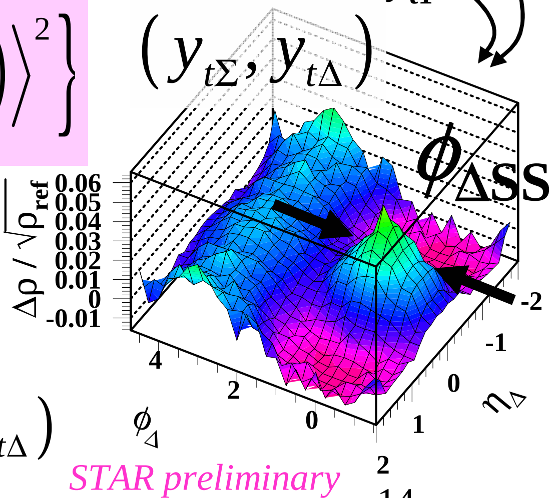
this weighted average favors the $j_{t\phi}$
of the parton fragment with smaller p_t

$$\langle \sin^2 (\phi_\Delta / \sqrt{2}) \rangle \rightarrow \sin^2 (\sigma_{\phi_\Delta} / \sqrt{\pi})$$

Porter

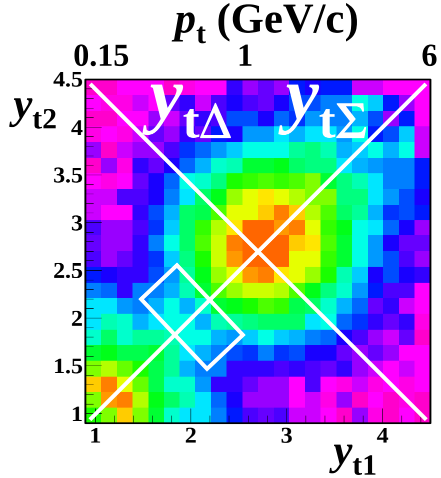
same for $\overline{\langle j_{t\eta}^2 \rangle}_{12} (y_{t\Sigma}, y_{t\Delta})$





Symmetrize $\langle |k_{t\phi}|\rangle$ on $y_t \otimes y_t$ and $(\eta_\Delta, \phi_\Delta)$

$$\sin^2\phi_{pp} \approx \frac{k_{ty,1}^2}{p_{t,part,1}^2} + \frac{k_{ty,2}^2}{p_{t,part,2}^2} \approx \frac{z_1^2 k_{ty,1}^2}{p_{t,1}^2} + \frac{z_1^2 k_{ty,2}^2}{p_{t,2}^2}, \quad z_i \equiv \frac{p_{t,i}}{p_{t,part,i}}$$

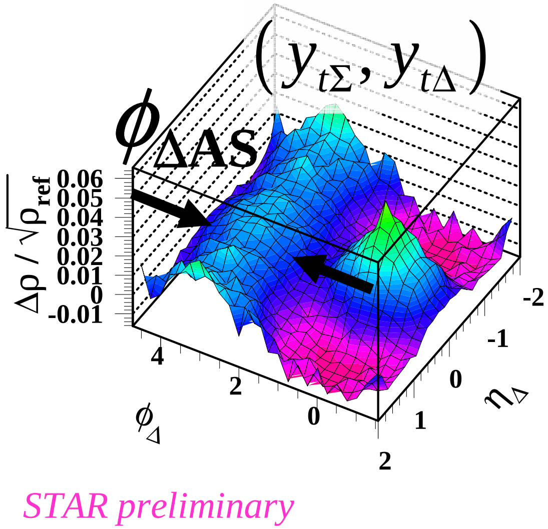


conditional $(\Delta\phi = \phi_{12})$

$$\boxed{\overline{\langle z^2\rangle\langle k_{t\phi}^2\rangle}_{12}} \equiv \frac{\sqrt{\langle p_{t,1}^2\rangle\langle p_{t,2}^2\rangle}}{\sqrt{\langle p_{t,2}^2\rangle / \langle p_{t,1}^2\rangle} + \sqrt{\langle p_{t,1}^2\rangle / \langle p_{t,2}^2\rangle}} \frac{\left\{\langle \sin^2\Delta\phi\rangle_{AS} - \langle \sin^2\Delta\phi\rangle_{SS}\right\}}{1 - 2\langle \sin^2\Delta\phi\rangle_{SS}}$$

note

(~ consistent with asymmetric special case)



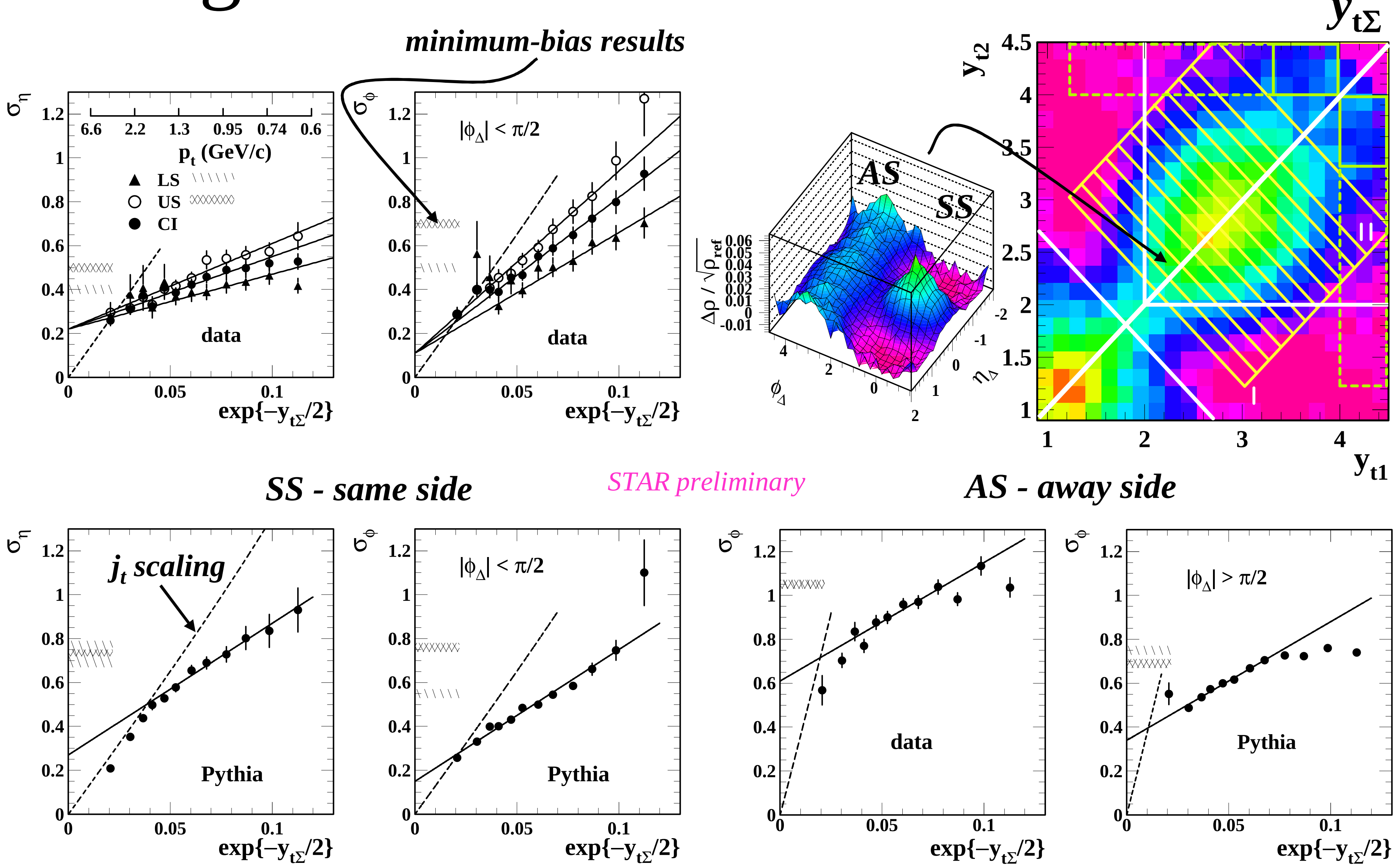
autocorrelation $(\phi_\Delta = \phi_{12})$

$$\boxed{\approx \frac{(m_\pi/2)^2 \exp\{y_{t\Sigma}\}}{2\cosh\{y_{t\Delta}\}} \frac{\left\{\langle \sin^2(\phi_\Delta/\sqrt{2})\rangle_{AS} - \langle \sin^2(\phi_\Delta/\sqrt{2})\rangle_{SS}\right\}}{1 - 2\langle \sin^2(\phi_\Delta/\sqrt{2})\rangle_{SS}}}$$

$$\langle \sin^2(\phi_\Delta/\sqrt{2})\rangle \to \sin^2(\sigma_{\phi_\Delta}/\sqrt{\pi})$$

STAR preliminary

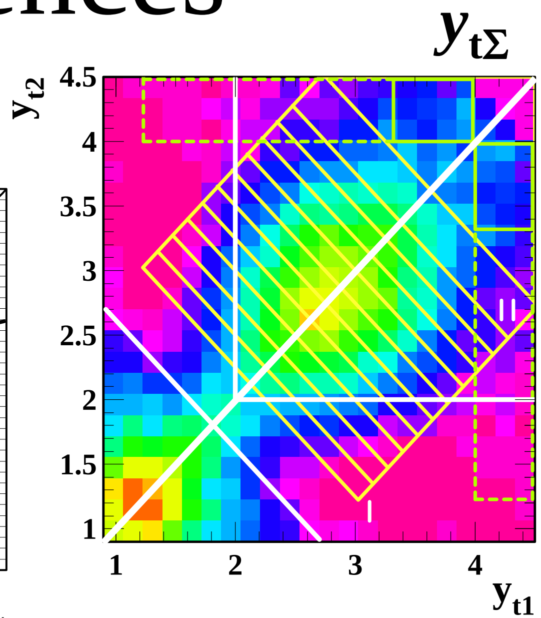
Angular Correlation Measurements

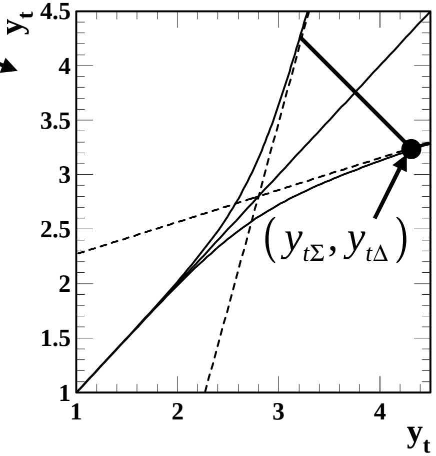


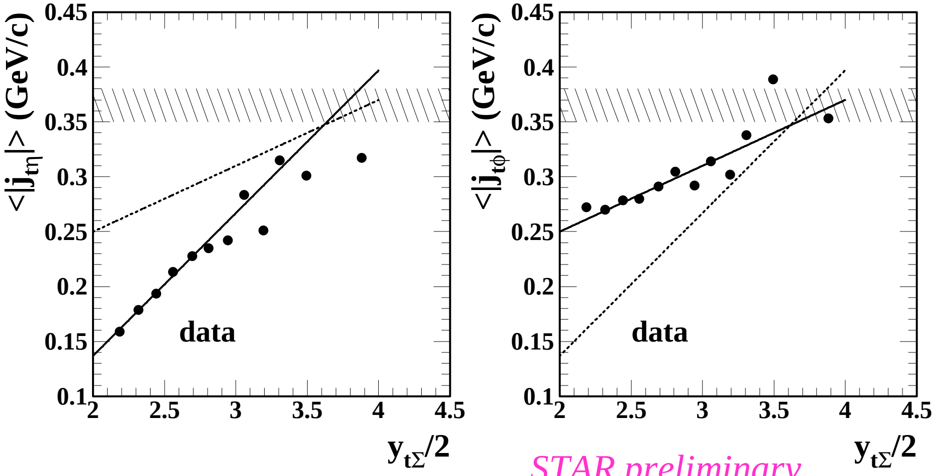
$\langle | j_{ty} | \rangle$ and $\langle |k_{ty}| \rangle$ Inferences

$$\overline{\left\langle j_{tx}^2 \right\rangle}_{12} \equiv \frac{(m_\pi/2)^2 \exp\{y_{t\Sigma}\}}{2\cosh\{y_{t\Delta}\}} \left\{ \left\langle \sin^2\left(x_\Delta/\sqrt{2}\right) \right\rangle_{SS} + 2 \left\langle \sin^2\left(x_\Delta/2\sqrt{2}\right) \right\rangle^2 \right\}$$

$x = \eta, \phi$

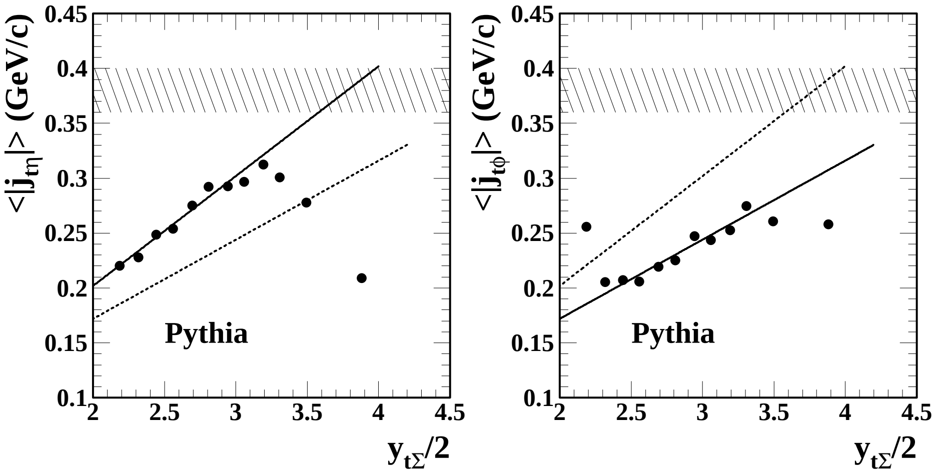


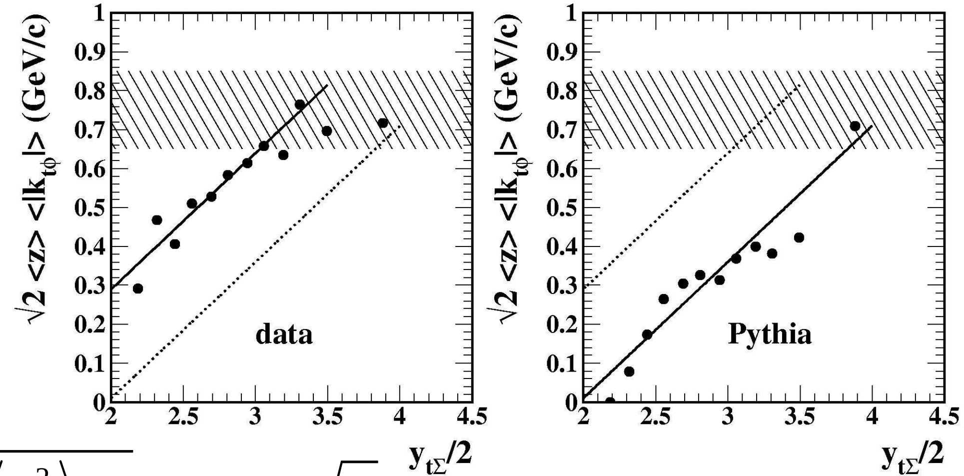




$$2\overline{\left\langle z^2\right\rangle\left\langle k_{t\phi}^2\right\rangle}_{12} \equiv \frac{(m_\pi/2)^2\exp\{y_{t\Sigma}\}}{\cosh\{y_{t\Delta}\}} \frac{\left\{\left\langle\sin^2\left(\phi_\Delta/\sqrt{2}\right)\right\rangle_{AS} - \left\langle\sin^2\left(\phi_\Delta/\sqrt{2}\right)\right\rangle_{SS}\right\}}{1-2\left\langle\sin^2\left(\phi_\Delta/\sqrt{2}\right)\right\rangle_{SS}}$$

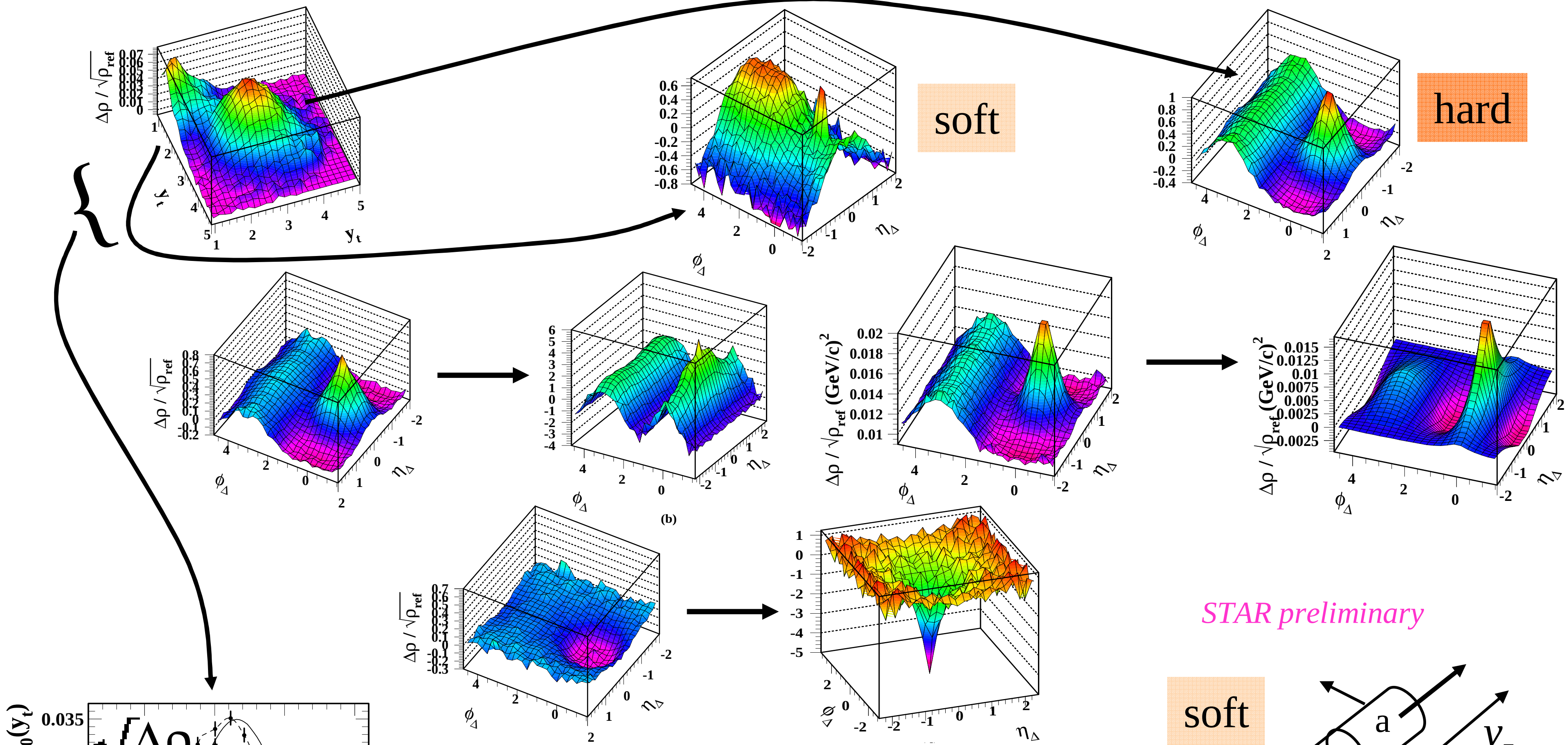
STAR preliminary

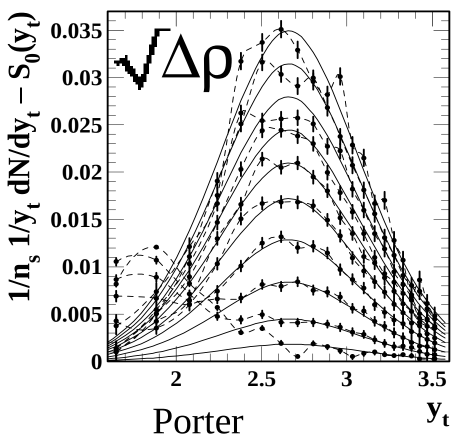




$y_{t\Sigma}/2 \sim \ln\{Q/2\Lambda\}$ $\quad \sqrt{\left\langle x_\Delta^2\right\rangle/2} \to \sigma_{x\Delta}/\sqrt{\pi}$

The p-p Reference System for A-A

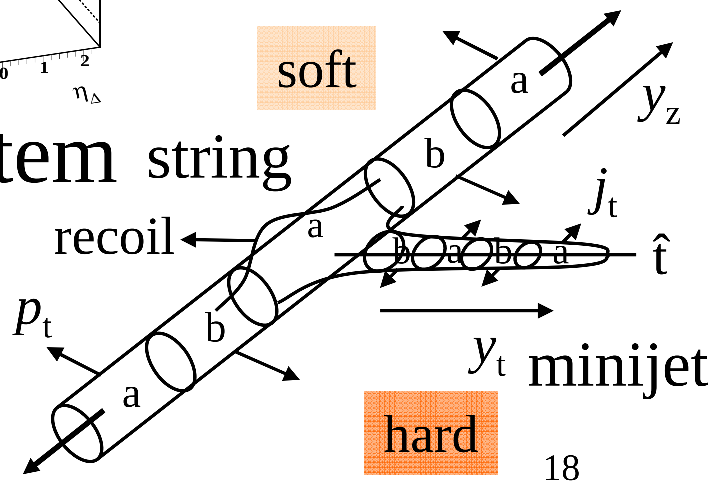




Brownian probe system
for A-A collisions

$$y_t \equiv \ln\{(m_t + p_t)/m_0\}$$

$$p_t / m_0 \equiv \gamma\beta_t$$



Summary

- Low-Q^2 parton fragmentation in p-p is precisely accessible down to hadron $p_t \cong 0.35$ GeV/c
- Jet morphology at low Q^2 requires new treatment of fragment p_t distributions, angular correlations
- Jet fragment distributions on rapidity are ‘infrared safe’ and exhibit interesting systematic behavior
- Jet angular correlations show strong asymmetry at low Q^2, possibly related to parton collision details