Jet reconstruction and underlying event studies in p+p and d+Au collisions from STAR

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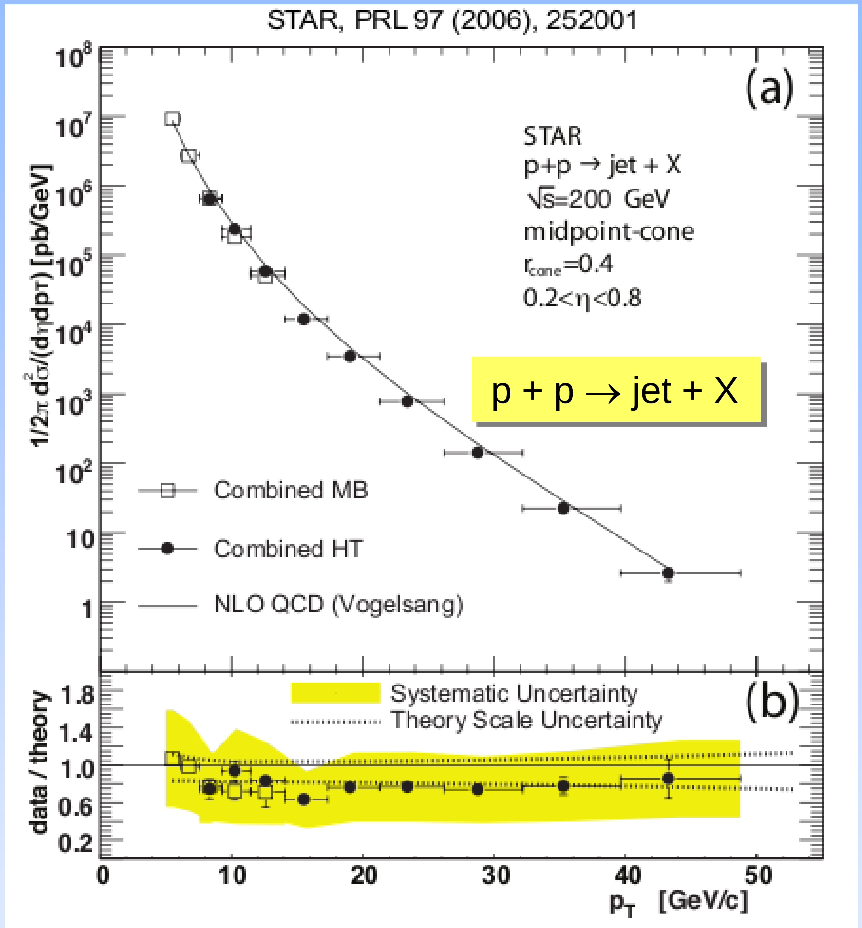
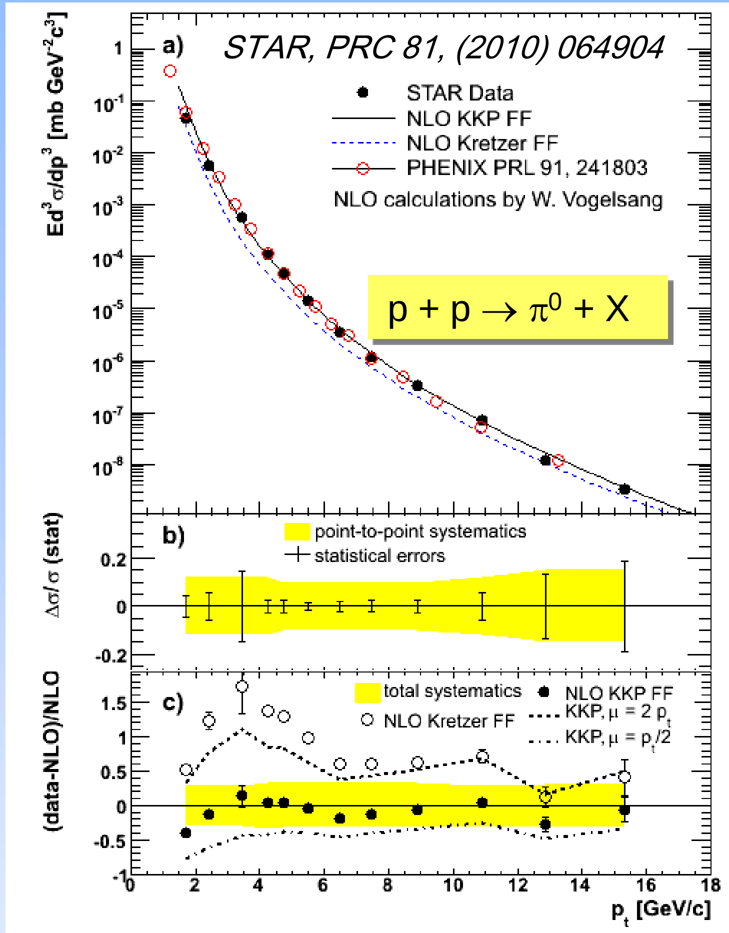
Outline:

- Introduction
- STAR experiment at RHIC
- Strange particle fragmentation functions in p+p
- Jet spectrum and k_T effect measurements in d+Au
- Underlying event studies in p+p
- Summary

Jet and high-p_T particle production in p+p@RHIC



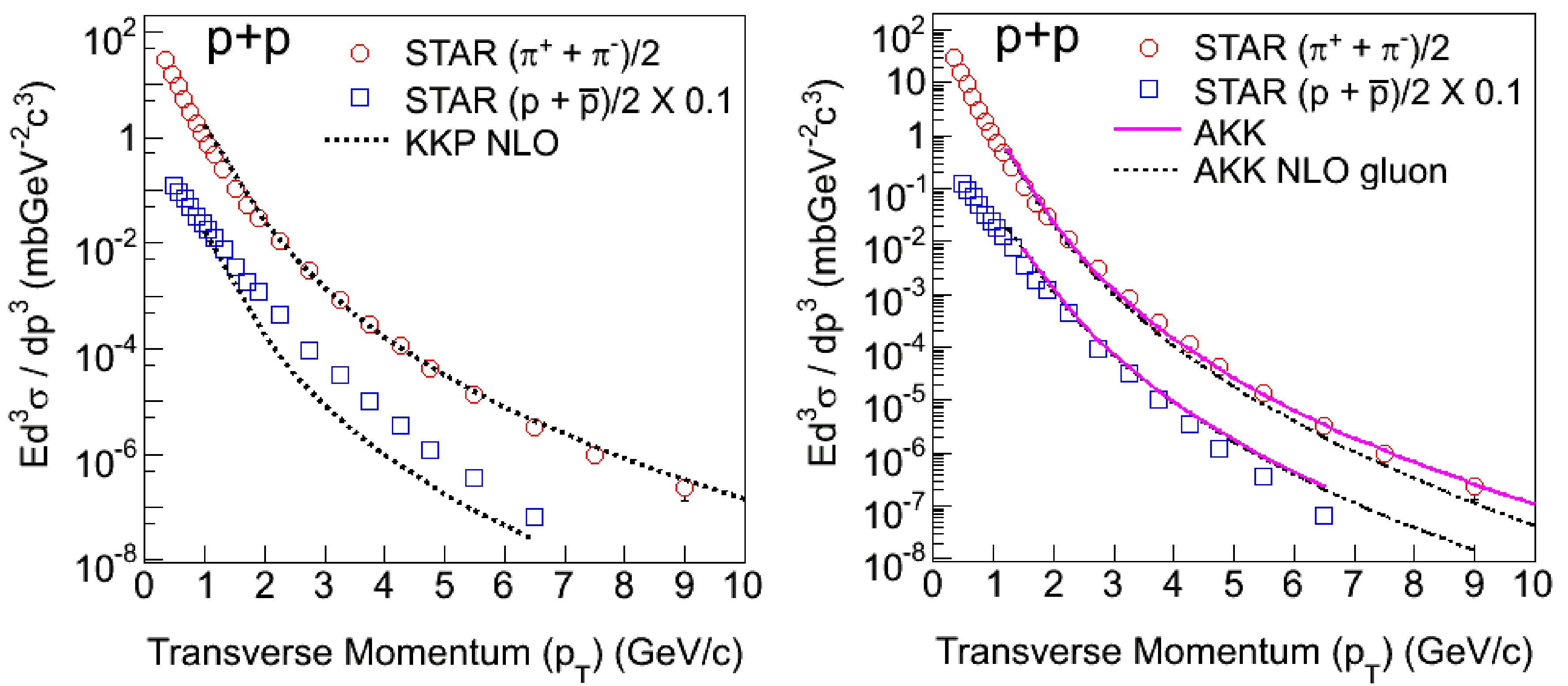


Jet cross-section and minimum bias pion production agrees well with NLO pQCD calculations over 7 orders of magnitude

What about other particle species?

How well does pQCD describe proton production?

STAR: Phys Lett B, 637 (2006) 161



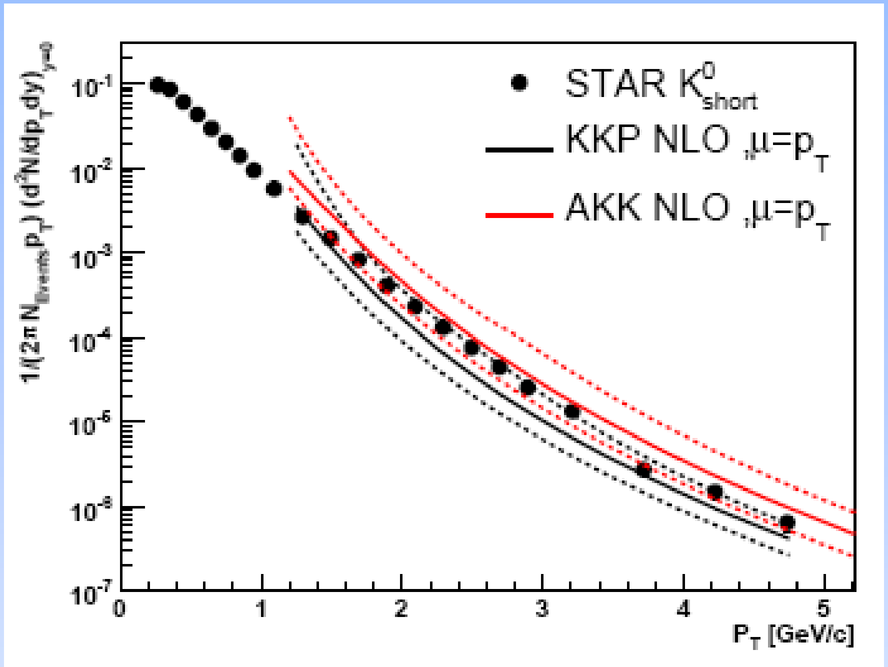
KKP: B. A. Kniehl, G. Kramer and B. Potter, Nucl. Phys. B 597 (2001) 337

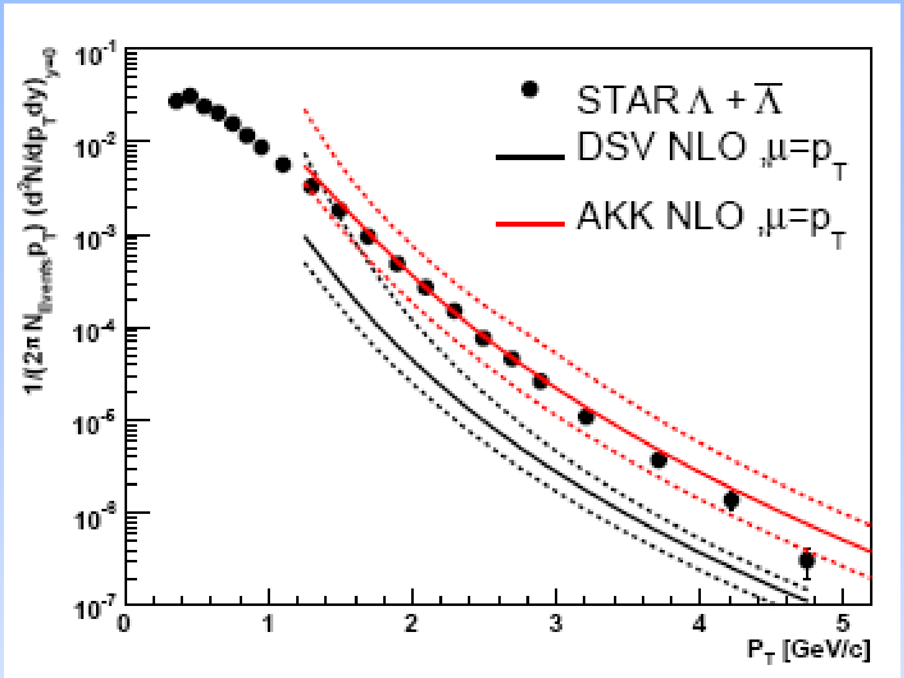
AKK : S. Albino, B. A. Kniehl, and G. Kramer, Nucl. Phys. B 725 (2005) 181

Depends on choice of fragmentation function…

Strange particle production in p+p

STAR, PRC 75 (2007)



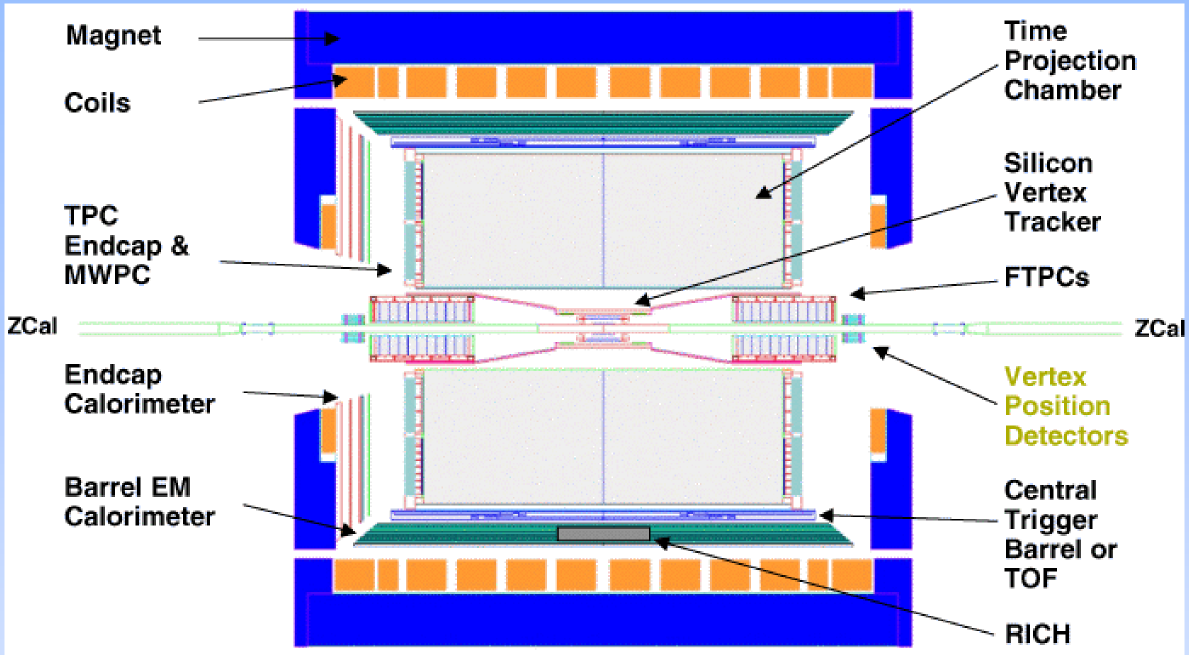


- STAR measurement of strange particles in p+p constrained AKK FF

AKK fragmentation functions agree well with both mesons and baryons at mid-rapidity.

KKP (Kniehl-Kramer-Potter): NPB 582 (200)
AKK (Albino-Kniehl-Kramer): NPB 734, 50 (2006)
DSV (DeFlorian-Stratmann-Vogelsang): PRD57, 58111 (1998)

STAR experiment at RHIC



TPC:
- charged particle tracking
- strange particle PID

BEMC:
- neutral energy contribution towers (η,ϕ) = 0.05x0.05
- trigger

- 100% hadronic correction: subtract matched track p_T off tower E_T to avoid double counting *(MIP, electrons, hadronic showers)*

Data sets:

p+p 2006: jet-patch triggers 8.7 pb^{-1} (8M events)

Jet patch trigger: BBC coincidence+BEMC

Jet-Patch (E_T>8 GeV in $\Delta\eta$x $\Delta\phi$ =1x1)

d+Au 2008: minimum bias (10M events), HT triggered events

d+Au centrality: selected 20% highest multiplicity events using East FTPC

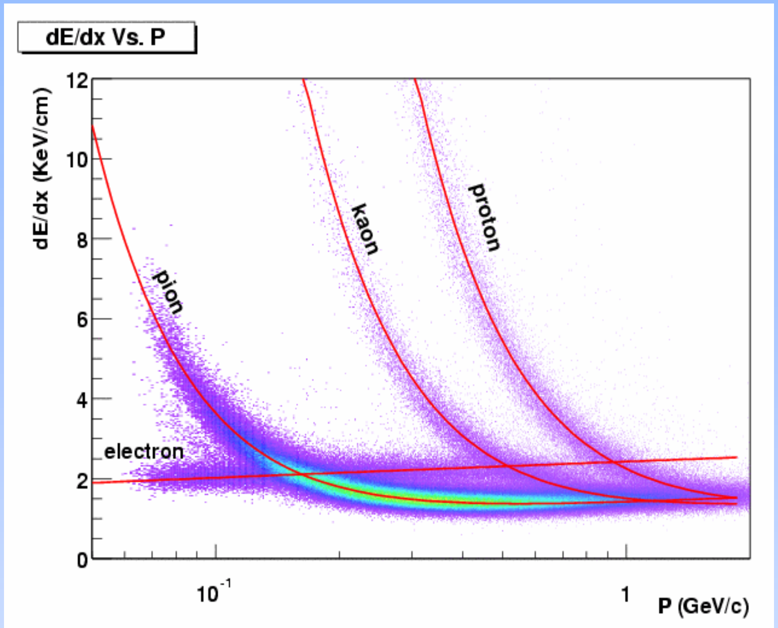
Strange particle identification in STAR

- STAR TPC offers excellent strange particle PID capabilities

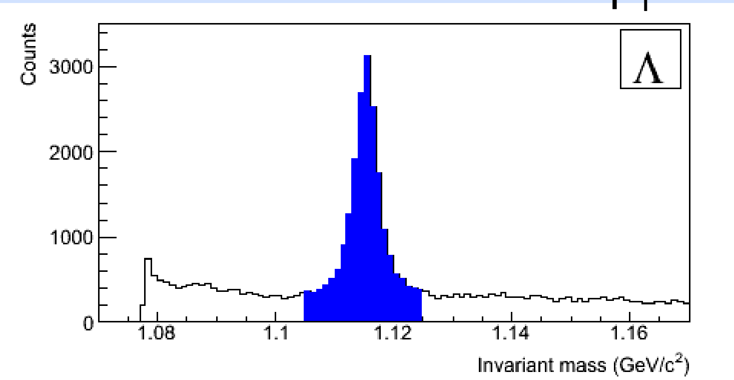
- topological reconstruction of V0 particles with small background contamination possible at p_T>1 GeV/c

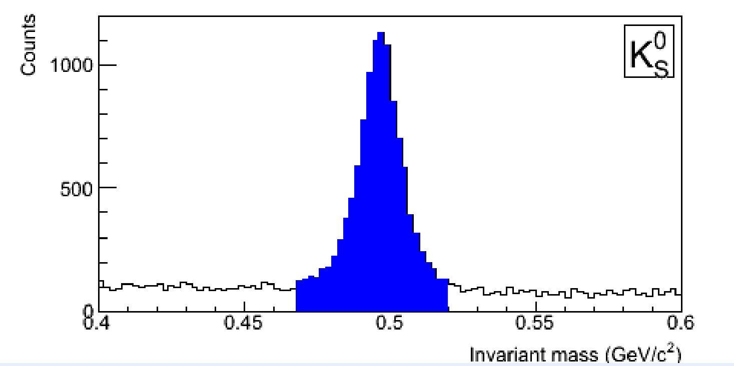
$\Lambda \rightarrow p + \pi^-$ B.R. 64%

$K^0_S \rightarrow \pi^+ + \pi^-$ B.R. 68%



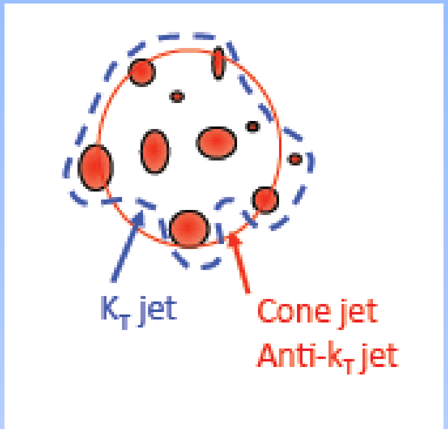
p_T>1 GeV/c





Jet reconstruction algorithms

Cone algorithms:
Midpoint Cone: merging+splitting
SISCone: insensitive to "soft" radiation
splitting does not change jets
Leading Order High Seed Cone (LOHSC)



R: cone radius/resolution parameter

Sequential recombination:

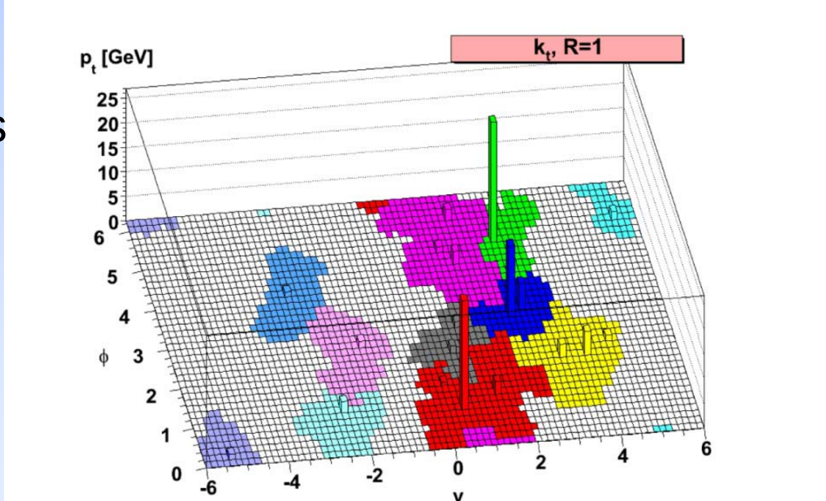
- cluster pairs of objects close in relative p_T

$d_{ij} = min(p_{Ti}^n, p_{Tj}^n)\ (\Delta\eta^2+\Delta\varphi^2)/R^2, d_i = p_{Ti}^n$
$min(d_i, d_{ij})$: d_i -> new jet, d_{ij} -> merge i,j

recombination E scheme with m=0 particles

n=2: k_T (starts from low p_T particles)
n=-2: anti-k_T (starts from high p_T particles)

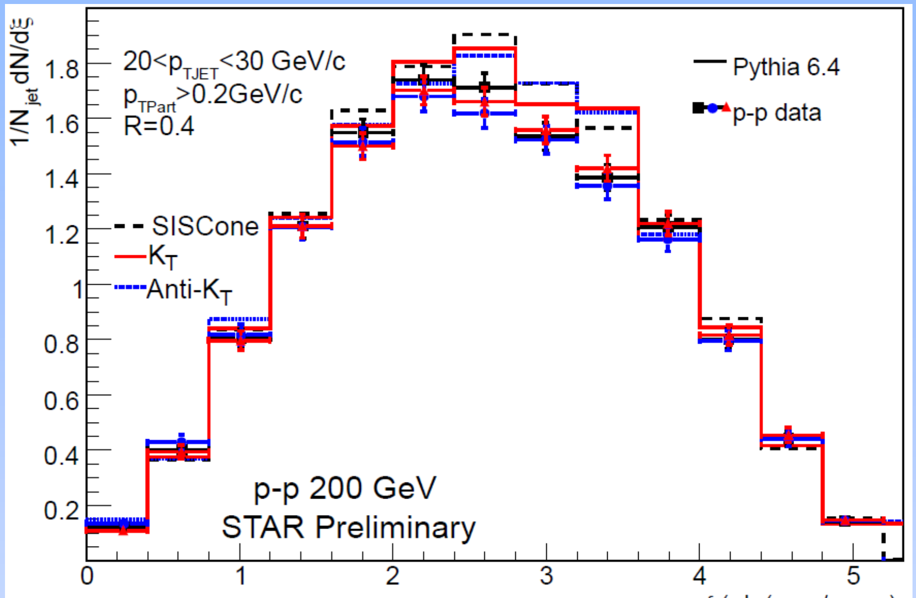
- collinear and infrared safe
- rigorous definition of jet area



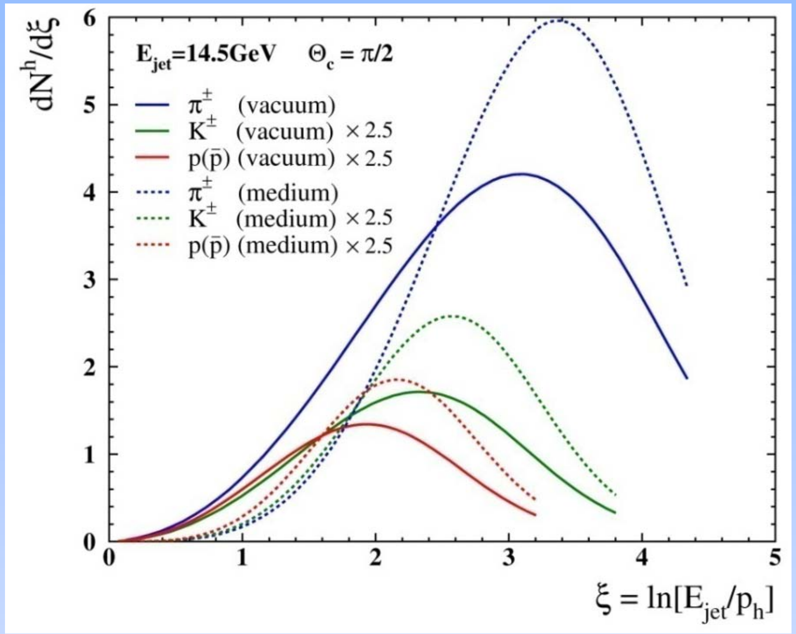
FASTJET: M. Cacciari, G.Salam and G.Soyez, JHEP0804 (2008) 005.

An important note:
Different algorithms respond differently to the underlying event.

Fragmentation functions in p+p



H.Caines (STAR), arXiv: 1012.5008



Sapeta, Wiedemann: EPJ C55 (2008) 293

- p+p data and PYTHIA simulation shown at detector level
- good agreement between different jet algorithms (k_T, anti-k_T, SISCone)

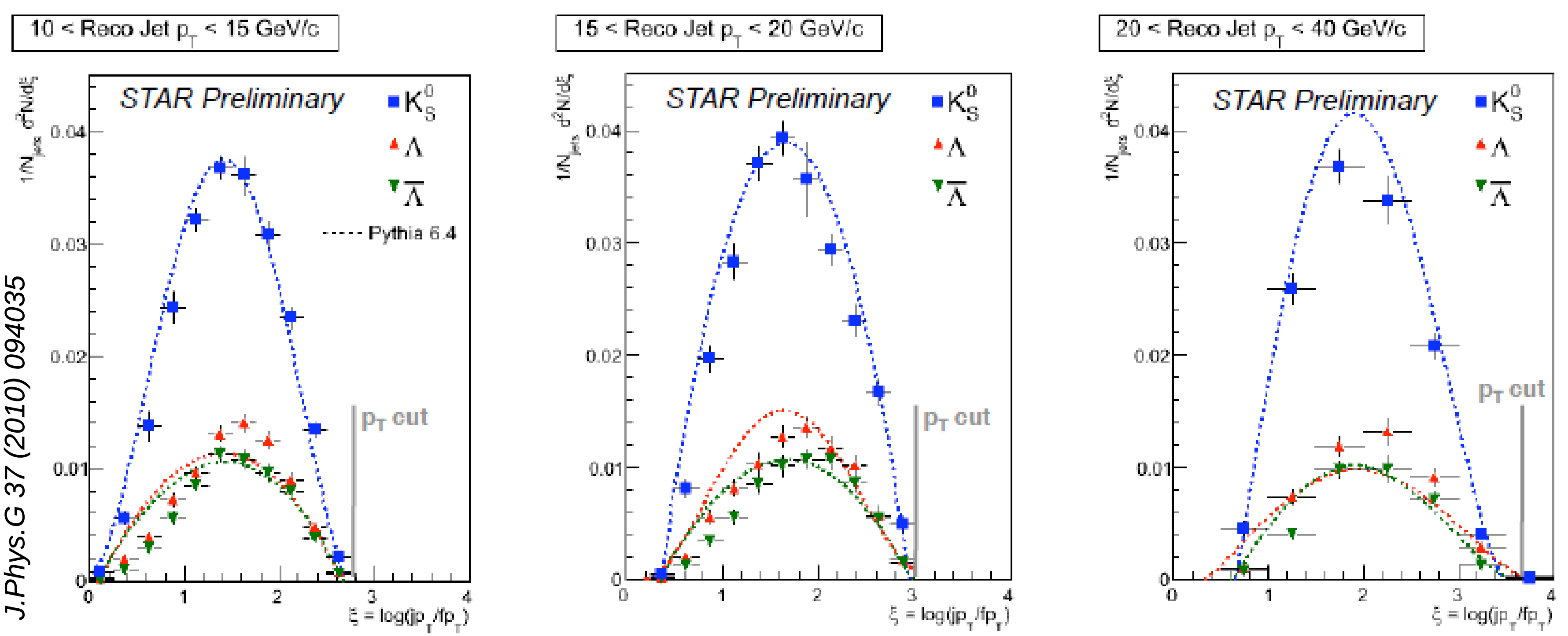
PYTHIA describes well the charged hadron fragmentation functions in p+p
→ NLO contributions at RHIC minor

- FF are species dependent but experimentally not well constrained

- a good knowledge of FF in p+p and their particle dependence is essential for their future measurements in heavy-ion collisions *(medium modification?)*

Fragmentation functions of Λ, K^0_S

$\xi = \log(1/z)$



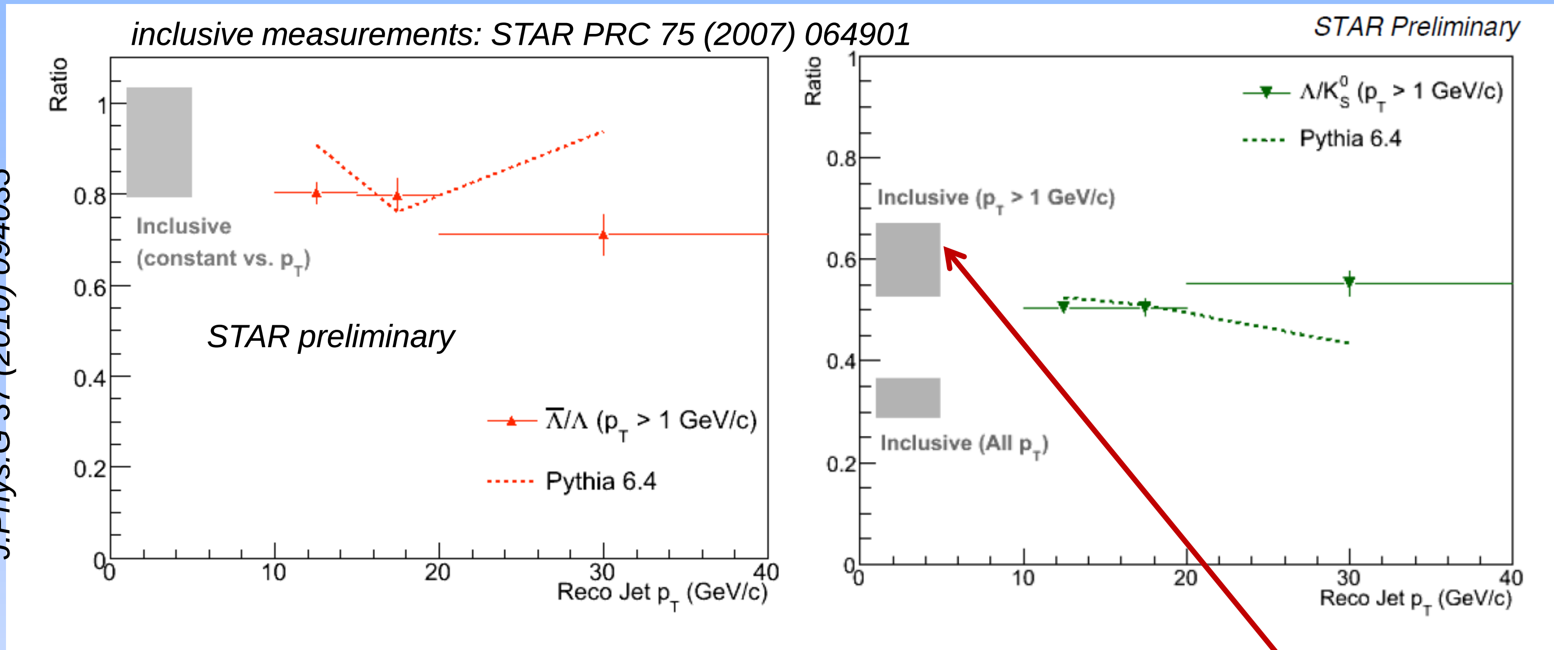
A. Timmins (STAR), J.Phys.G 37 (2010) 094035

- data shown at detector level and compared to PYTHIA 6.4 +GEANT simulation
- background under mass peaks neglected
- V0 identification: signal with low bkg for p_T>1 GeV/*c*
  → introduces artificial cut in distribution
- errors: average from k_T, anti-k_T and SISCone algorithms

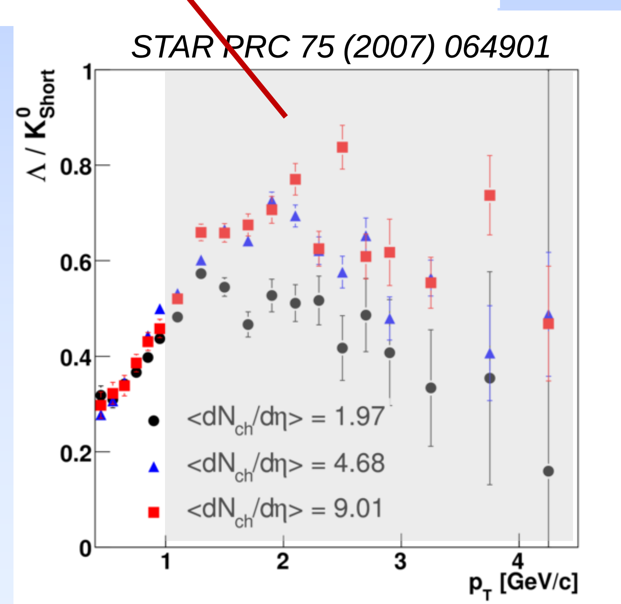
PYTHIA describes better K^0_S than Λ (as in case of p_T spectra)

Strange particle ratios in jets

A. Timmins (STAR), J.Phys.G 37 (2010) 094035



- strange baryon asymmetry observed in jets
- Λ/K^0_S ratio in jets larger than inclusive at all p_T
  BUT similar as inclusive for p_T>1 GeV/*c*



Strange particle production predominantly from jets?

d+Au collisions

look for CNM effects …

Underlying event background subtraction

- reduction: lower R, higher p_T cut on tracks/towers
- assumption: signal and background can be separated
- estimation: background density calculated on event-by-event basis:

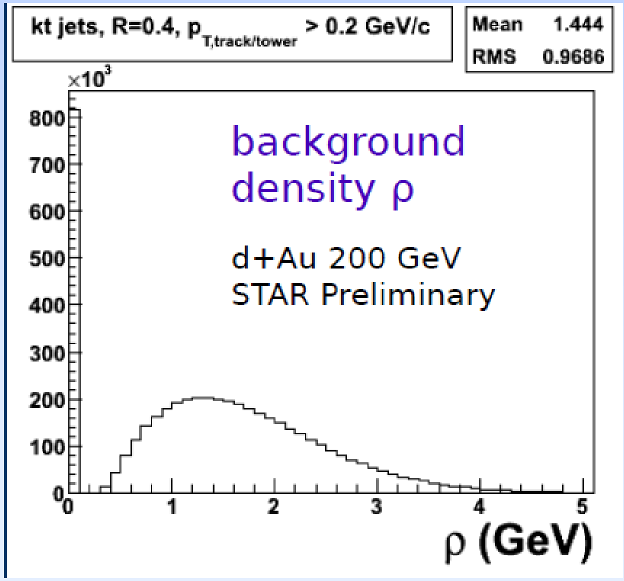
$$\rho = \text{median}\{p_T/A\} \text{ using } k_t \text{ algorithm}$$

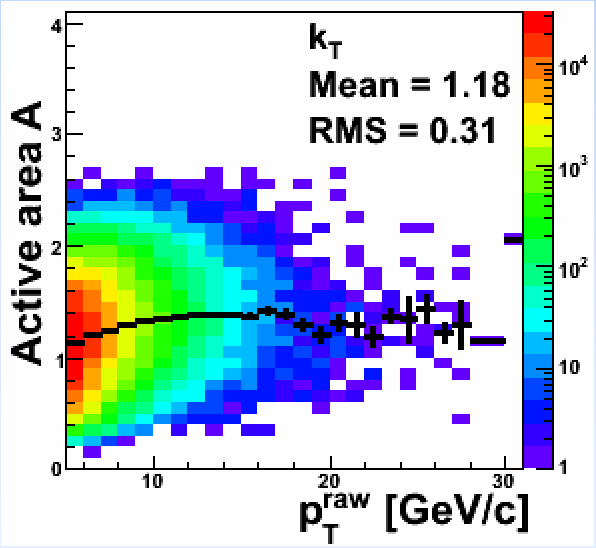
- subtraction:

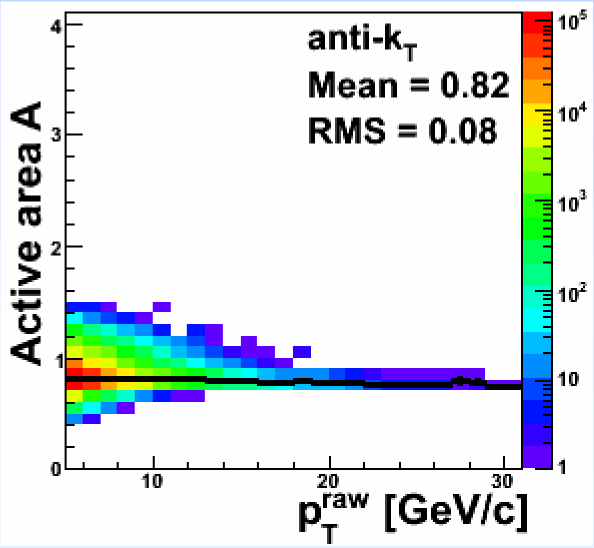
$$p_T(\text{jet true}) \sim p_T(\text{jet reco}) - \rho \times A \pm \sigma\sqrt{A}$$

A = active jet area, ρ = diffuse noise, σ = noise fluctuations

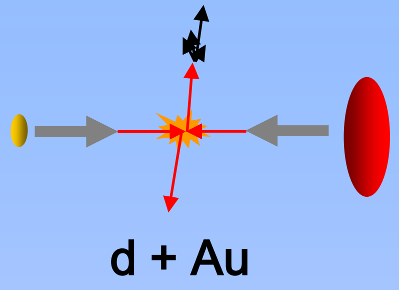
- d+Au collision asymmetric→η dependence of bkg.<2% effect on p_T spectra





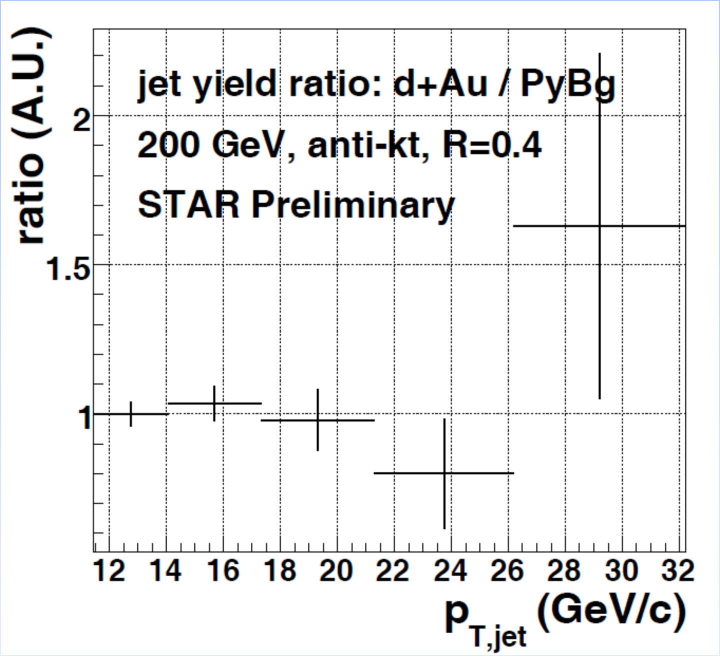


Jet p_T spectrum extraction in d+Au



Analysis:

- real data set: 20% central MB d+Au collisions at 200 GeV
- simulation data set:
  PYTHIA (PyMC)
  PYTHIA+GEANT (PyGe)
  PYTHIA+GEANT+dAu bkg (PyBg)
- anti-kt algorithm, R=0.4,
  p_T(track/tower)>0.2 GeV/*c*, $|\eta_{jet}|<0.55$

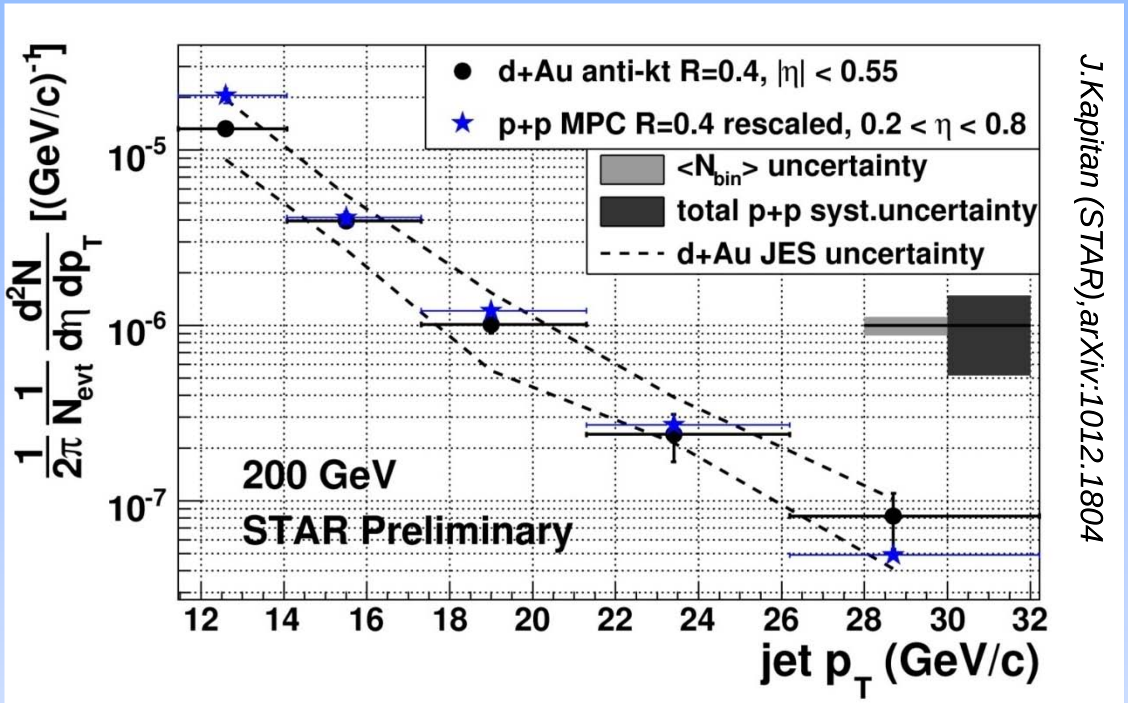


Bin-by-bin correction of the raw p_T spectrum

- ratio of jet spectra PyMC/PyBg
- generalized efficiency:
  - efficiency of jet level cuts
  - p_T resolution

Assumption: this correction method applicable
if real p_T spectrum and simulated p_T spectrum have the same shape!

Jet p_T spectrum in d+Au @ 200 GeV



Systematic uncertainties in d+Au:
Jet Energy Scale (JES)
(dashed band)
- 10% TPC tracking efficiency
- 5% BEMC calibration

In total ~ 7%

Systematic uncertainties in p+p:
(black box)
total syst. uncertainty incl. JES

$\langle N_{bin} \rangle$ scaling of p+p spectrum:
(grey box) ~12%

Note: p+p for different η range and different jet algorithm (MPC: Mid Point Cone)

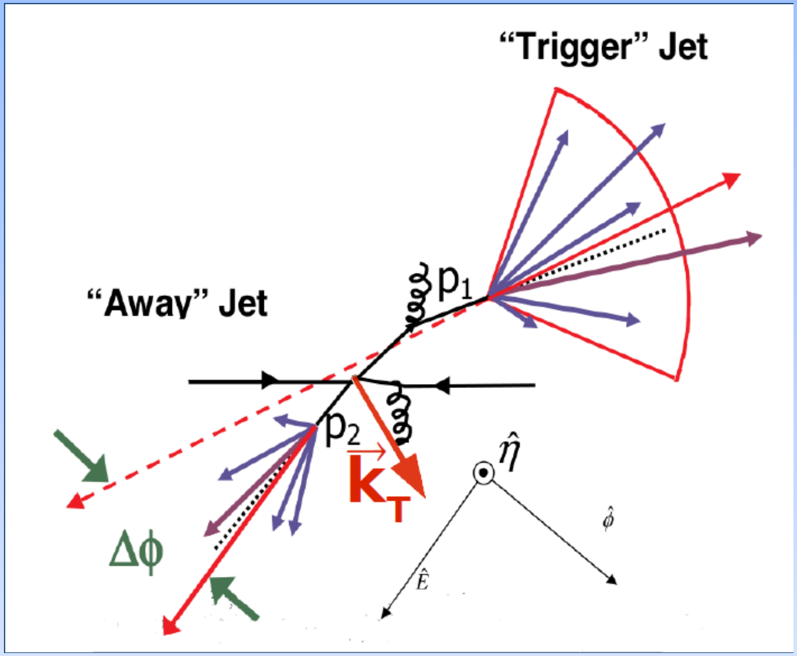
d+Au jet spectrum shows no significant deviation from N_{bin} scaled p+p jet spectrum

- further reduction of syst. uncertainties ongoing: p+p Run8 reference spectrum, jet embedding
- use of HT triggered data → reach to ~50 *GeV/c*

k_T effect in d+Au vs p+p collisions

k_T effect (di-jet broadening in $\Delta\phi$):

$\langle k_T^2 \rangle_{dA} = \langle k_T^2 \rangle_{intrinsic} + \langle k_T^2 \rangle_{vac.radiation} + \langle k_T^2 \rangle_{CNM}$



- large radiative contribution to k_T in dA

Qiu, Vitev: PLB570 (2003);
Boer,Vogelsang: PRD69 (2004)

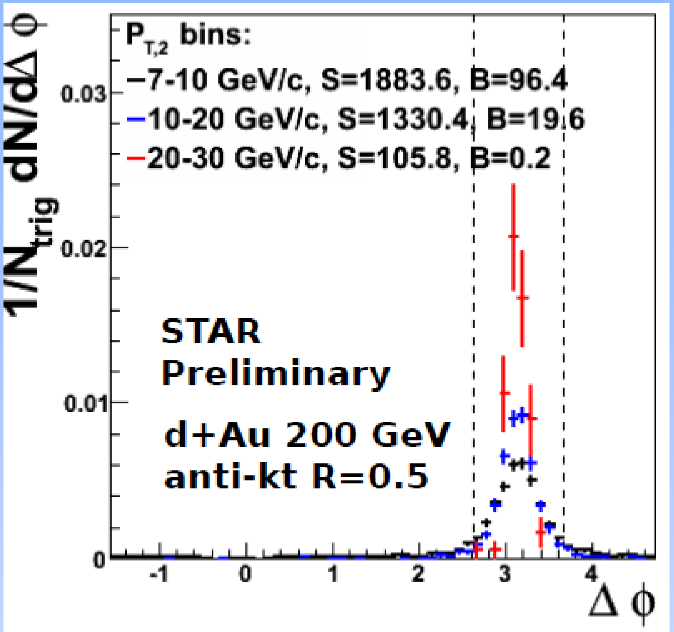
- radiation:
  soft: Gaussian shape
  hard (NLO): power-law tails

Measure azimuthal component of the k_T vector

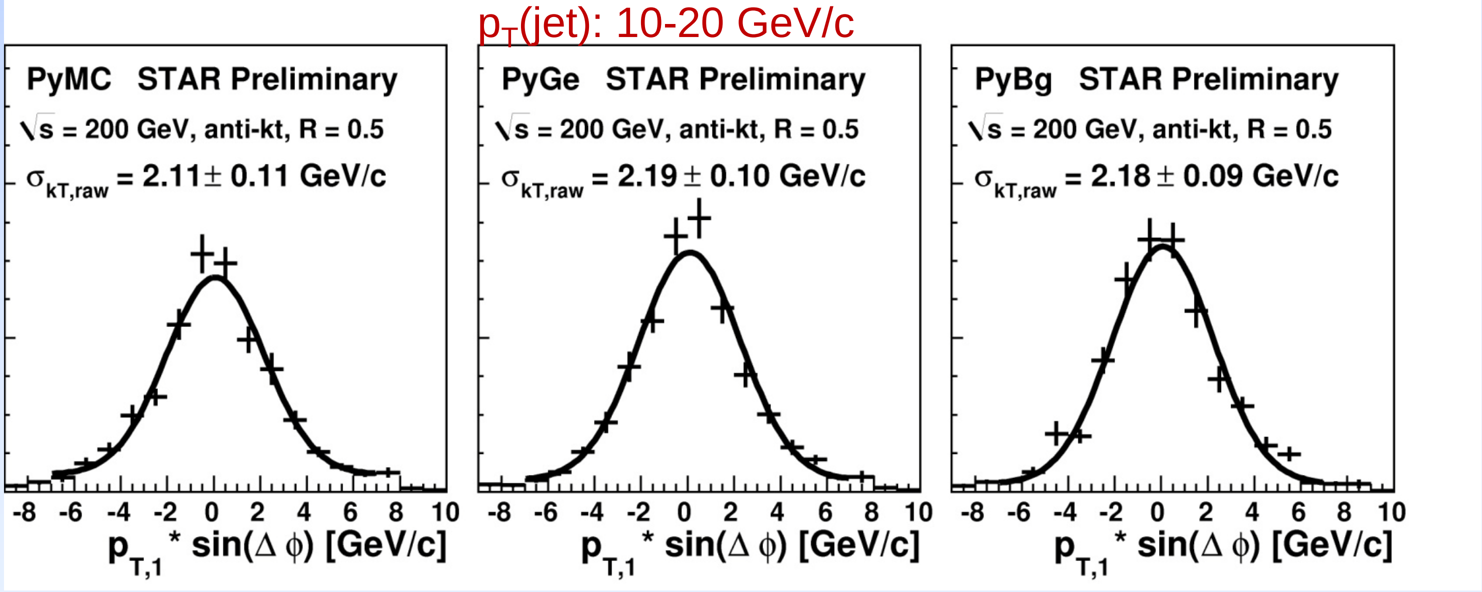
k_T effect in d+Au vs p+p collisions

Analysis:

- data: BEMC High Tower triggered data
  E_T(tower) >4.3 GeV
- anti-kt, R=0.5, p_T(track/tower)>0.5 GeV/*c*
- two highest energetic jets in event selected
  ($p_{T1}>p_{T2}$)
- calculated
  $k_{T,raw} = p_{T,1} * \sin(\Delta\phi)$, $|\sin(\Delta\phi)|<0.5$



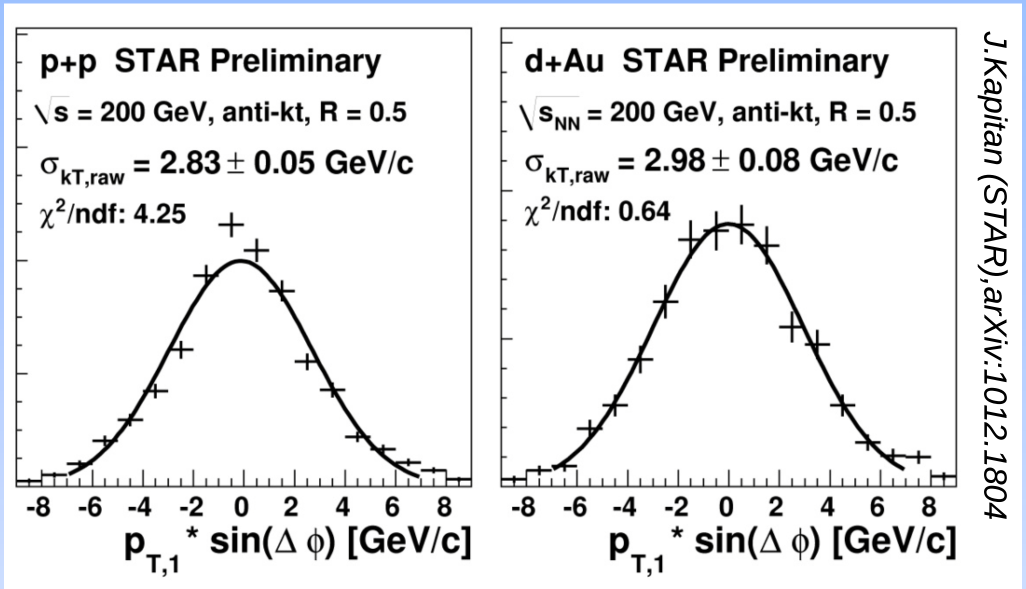
- detector effects on k_T measurement are small



J.Kapitan (STAR),arXiv:1012.1804

Do we see CNM effects on k_T in d+Au?

Run8: p+p, d+Au



Systematic uncertainties:

- detector effects neglected
- BEMC calibration
- TPC tracking efficiency

In total expected to be <10%
detailed evaluation ongoing

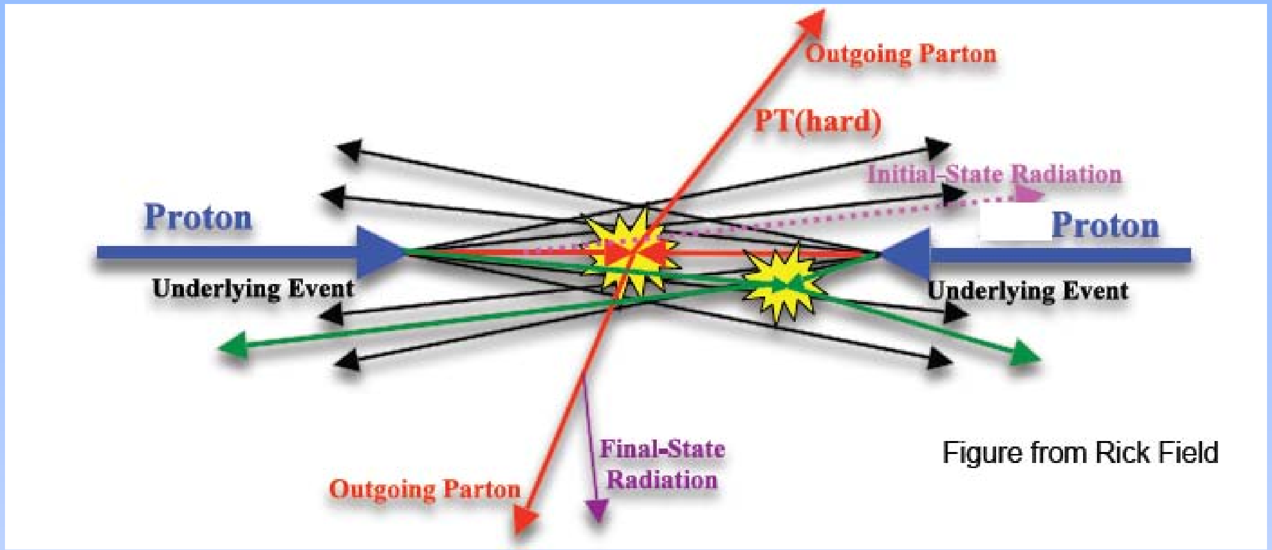
$\sigma_{kT,raw}$(p+p) =2.8±0.1 GeV/*c*
$\sigma_{kT,raw}$(d+Au)=3.0±0.1 GeV/*c*

CNM effects on nuclear k_T are found to be small.

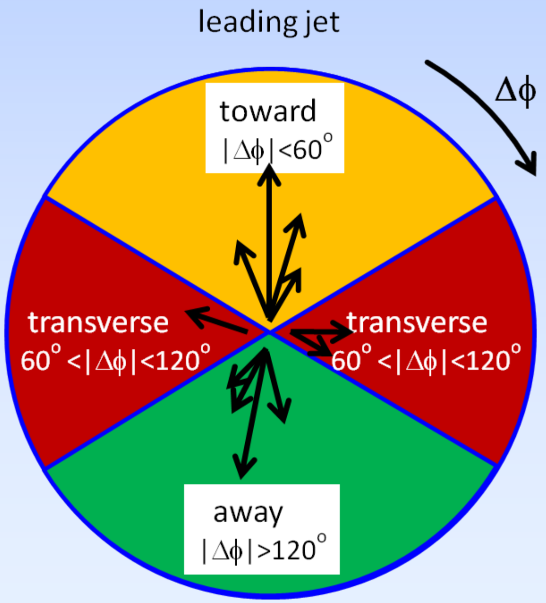
Caveat: the Gaussian fit doesn't describe the p+p data very well → studies underway

What about the underlying event?

Underlying Event studies in p+p



p+p events are more than just hard scattering …



Underlying Event (UE):

- soft/semi-hard multiple parton interactions (MPI)
- initial/final state radiation (ISR/FSR)
- beam-beam remnants

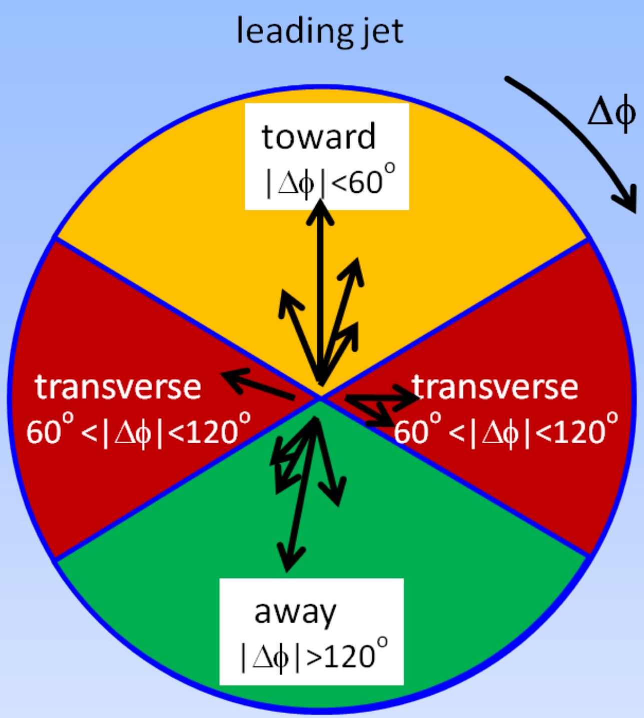
UE is everything but the hard scattering

UE contained in transverse region:

TransMax – transverse region with highest $\sum p_T, \sum N_{track}$

TransMin – transverse region with least $\sum p_T, \sum N_{track}$

Underlying Event: sensitivity of variables



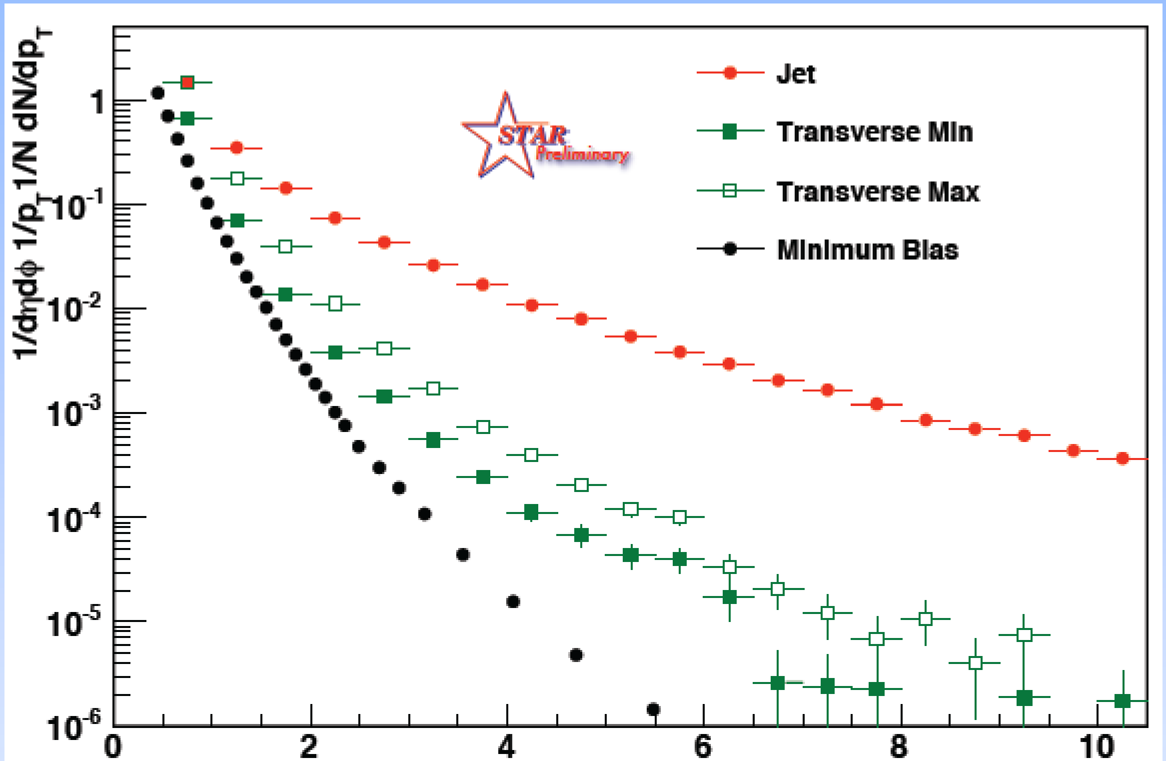
Two types of analysis:
- leading jet in the acceptance
- di-jet: $|\Delta\phi|>150^{o}$, $p_T^{away}/p_T^{leading}>0.7$
  (suppression of ISR and FSR effects)

TransMax:
enhanced probability of containing hard initial/final state radiation component

TransMin:
sensitive to beam-beam remnants and multiple parton interactions

Goal: compare "TransMin" and "TransMax" data from leading and di-jet samples
→ information about large angle ISR/FSR

Does UE p_T spectrum differ from minbias?



H.Caines (STAR), arXiv: 1012.5008

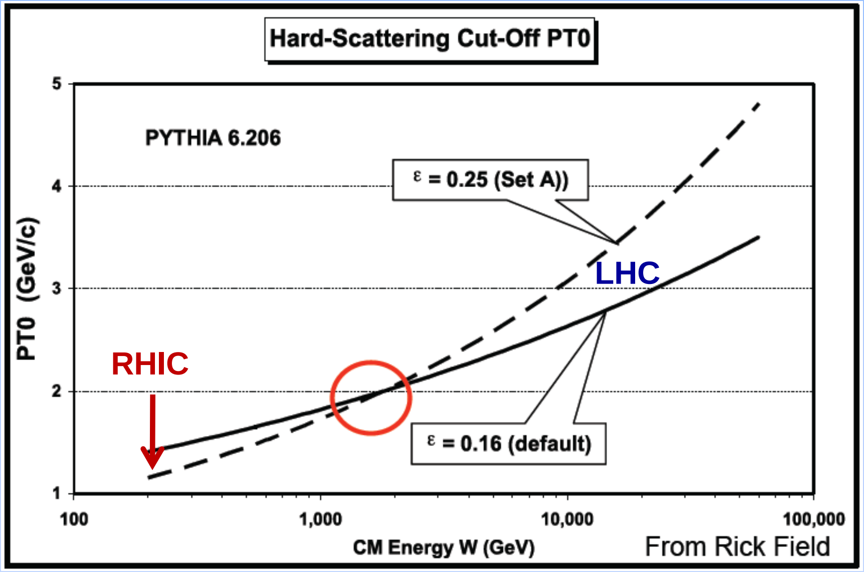
Jet:
p_T=15-30 GeV/*c*
anti-kt algorithm, R=0.7

Jet +UE:
statistical errors only

Minimum Bias (NSD) spectrum:
STAR, PRL 91 (2003) 172302

Yes, the UE spectrum is harder than NSD minimum bias spectrum and softer than that of particles in jet.

Collision energy dependence of UE



PYTHIA is tuned to 1.8 TeV

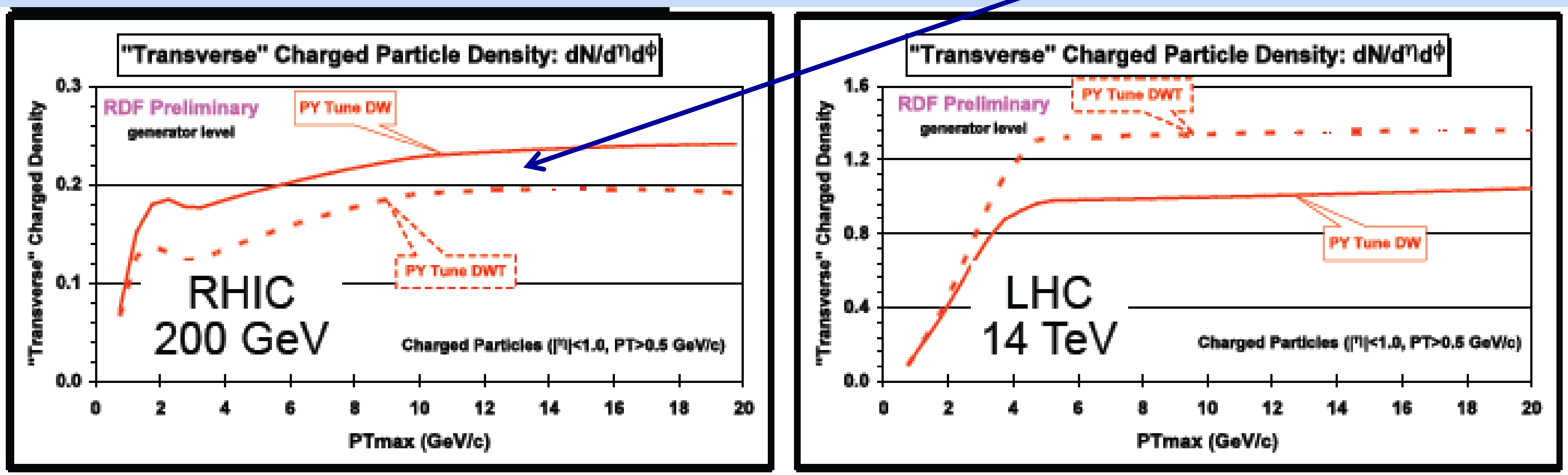
Does it describe data at other √s?

important scaling factor:
hard scattering cut-off for
the multi-parton interaction in UE:

$$P_{T0}(E_{cm})=P_{T0}(E_{cm}/E_0)^{\varepsilon}$$

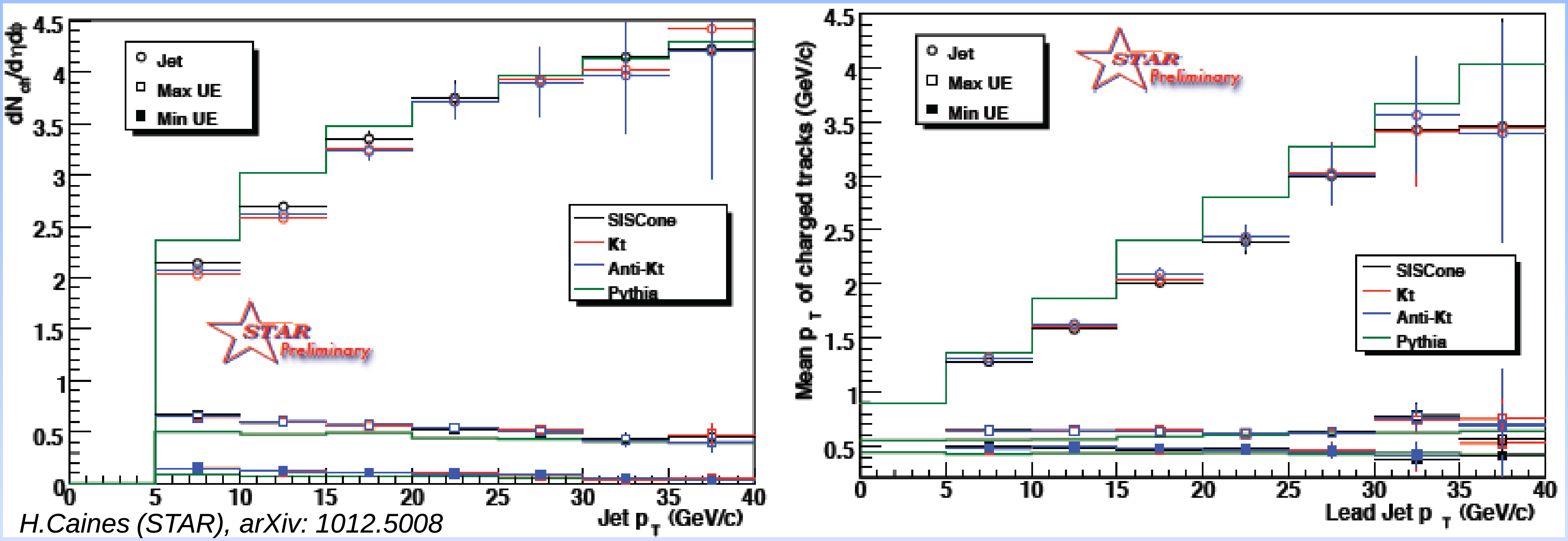
ε= 0.16 (default, DWT)
ε= 0.25 (suggested by 630 GeV data,DW)

It should be a measurable effect!



Underlying Event at RHIC energy

p+p Run6, di-jet sample, R=0.7, $|\eta_{jet}| < 1\text{-}R$, p_T(track)>0.2 GeV/c
Data shown at detector level, PYTHIA: MPI scaling factor $\varepsilon = 0.25$



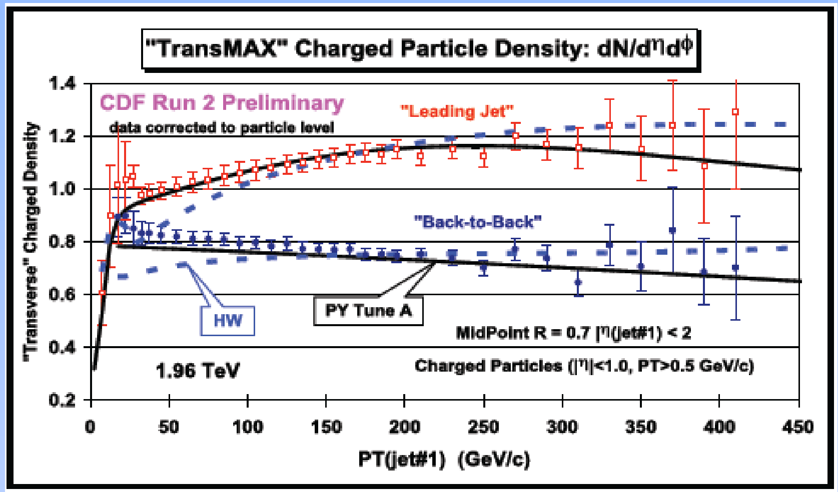
H.Caines (STAR), arXiv: 1012.5008

$dN_{ch}/d\eta d\phi$ and $\langle p_T \rangle$:
Jet: rise with jet energy as expected
UE: within errors ~ independent of jet p_T and support MPI scaling factor $\varepsilon = 0.25$.

Recent LHC UE measurements:
CMS: EPJ C70 (2010) 555.
ALICE: MPI@LHC2010, S. Vallero
ATLAS: HP2010, talk by P.K. Behera

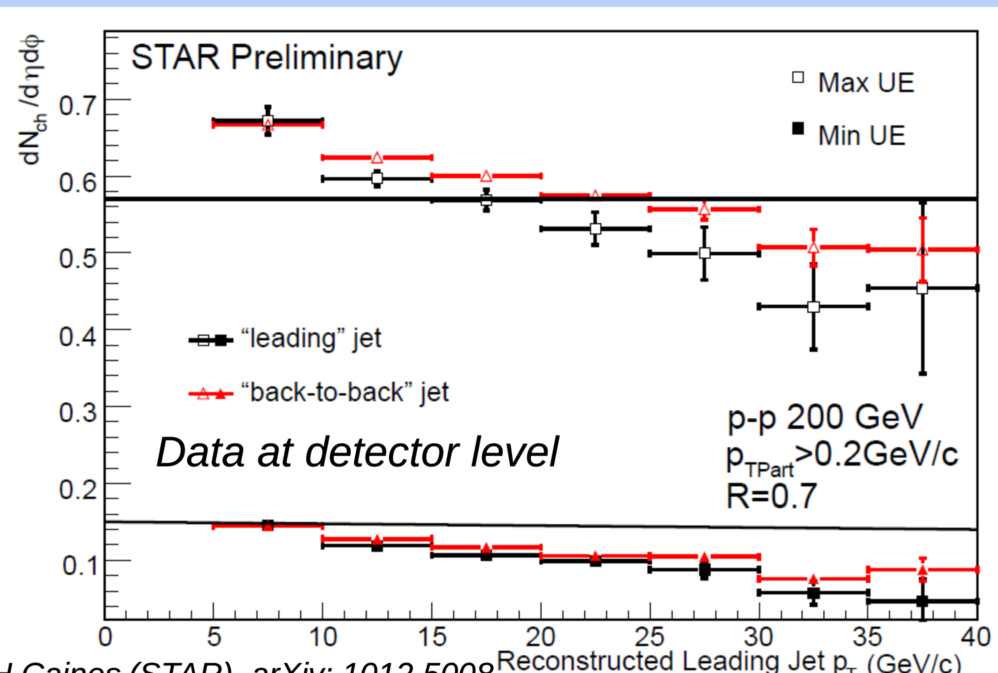
900 GeV data: support ε=0.25-0.30
7 TeV data: transverse region is more energetic than MC, near/away regions well described

ISR/FSR at RHIC vs Tevatron



Tevatron (1.96 TeV):

- leading jet TransMax > back-to-back jet TransMax
  → significant ISR/FSR at large angles



H.Caines (STAR), arXiv: 1012.5008

RHIC (200 GeV):

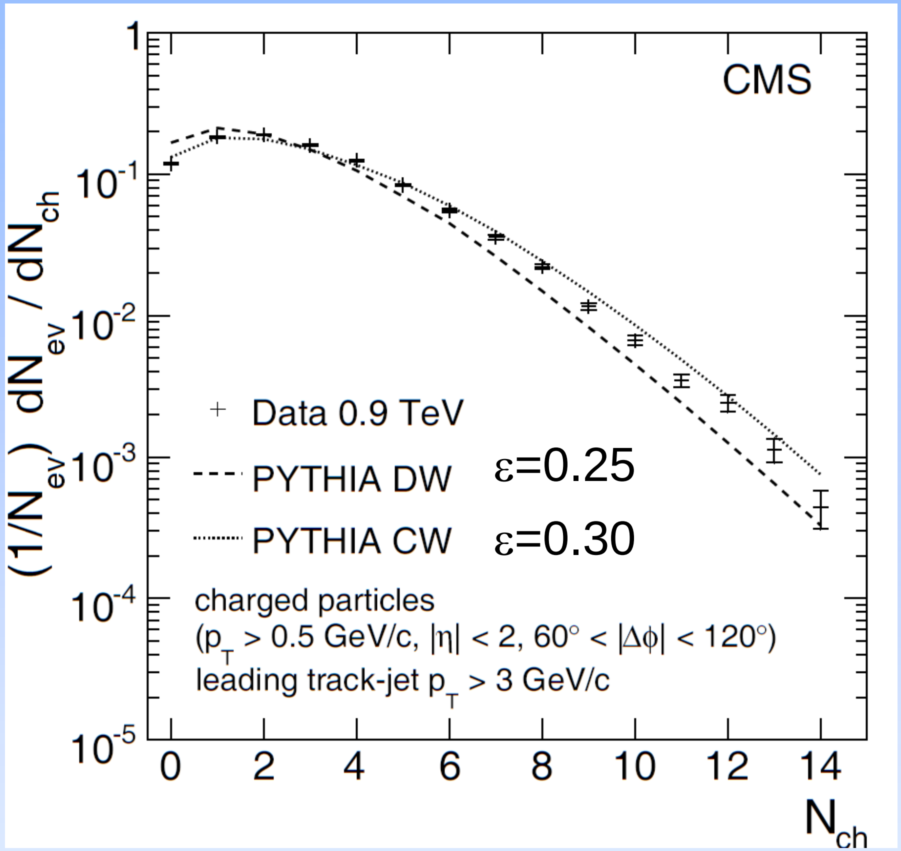
- leading jet and back-to-back jet TransMax regions similar
  → small ISR/FSR at large angles
- TransMax > TransMin
- Poisson distribution with $\langle dN_{ch}/d\eta d\phi \rangle = 0.36$
  - agreement with data → the splitting of TransMax and TransMin regions at RHIC due to sampling

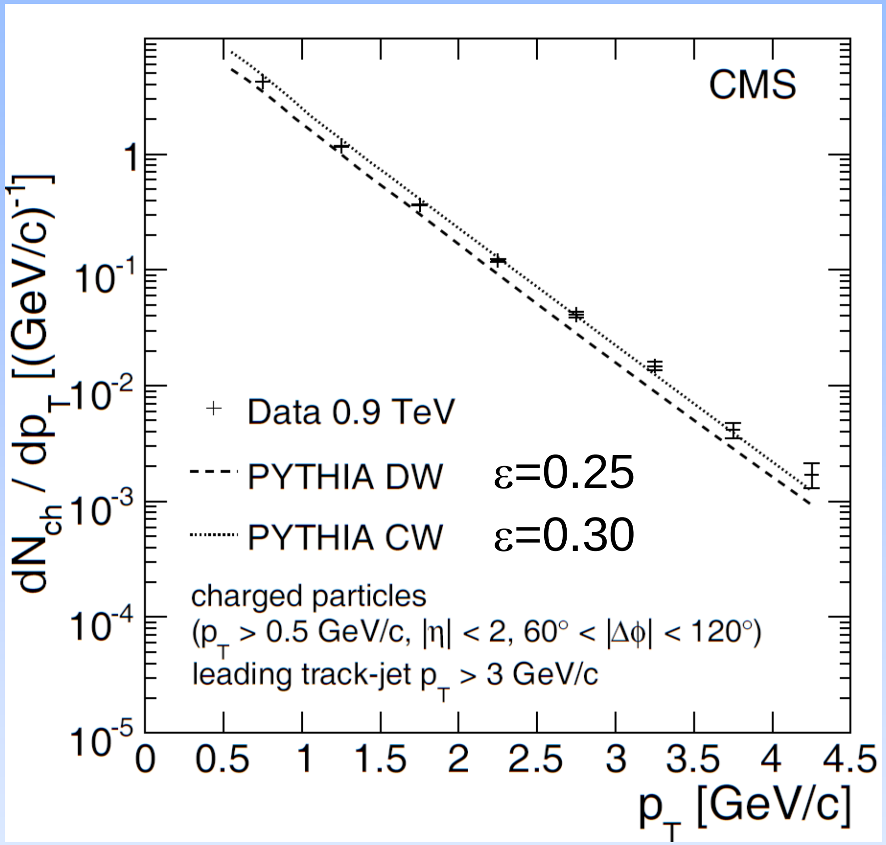
Summary

- charged particle and jet distributions well described by pQCD
- details of fragmentation functions of strange particles are being explored and will be important input to calculations
- no significant cold nuclear matter effects observed in d+Au collisions
  - further reduction of systematic errors underway + triggered data sets in Run8 p+p and d+Au → measurement of R_{dAu}
- underlying event:
  - largely decoupled from hard scattering
  - p_T spectrum softer than in the jet cone, but harder than in MB events
  - collision energy scaling for the MPI works for RHIC
  - large angle ISR/FSR is small at RHIC

BACKUP

CMS: UE studies in p+p at 900 GeV

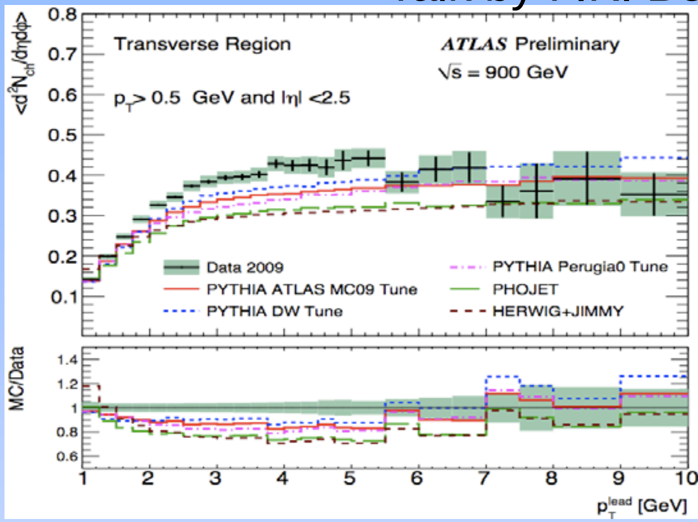


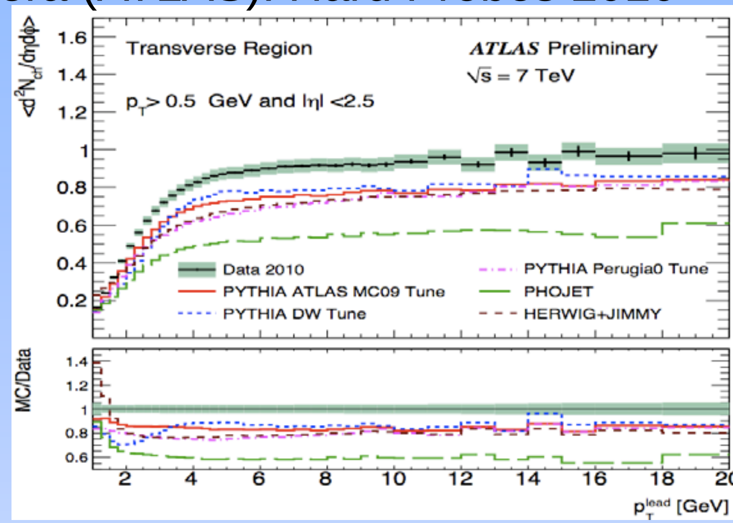


CMS, Eur.Phys.J.C70:555-572,2010

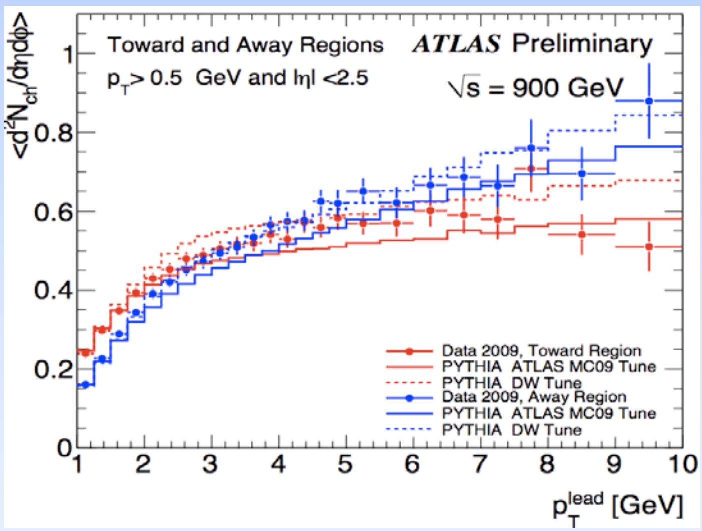
ATLAS: charged particle multiplicity

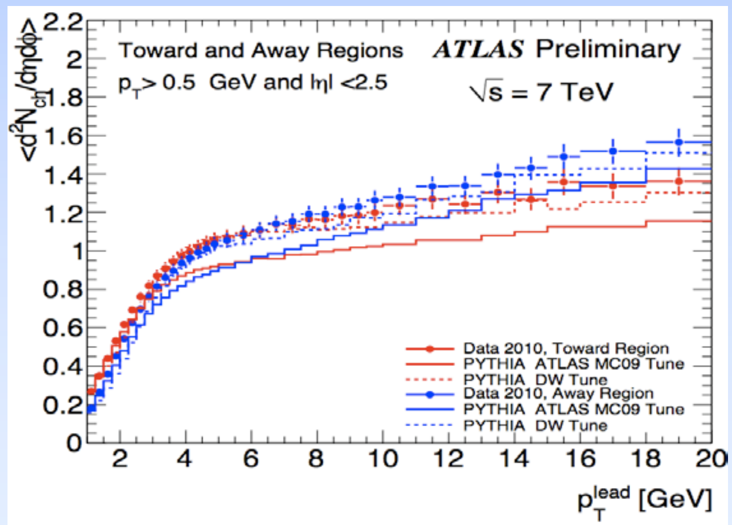
Talk by P.K. Behera (ATLAS): Hard Probes 2010





More tracks are present in UE than MC

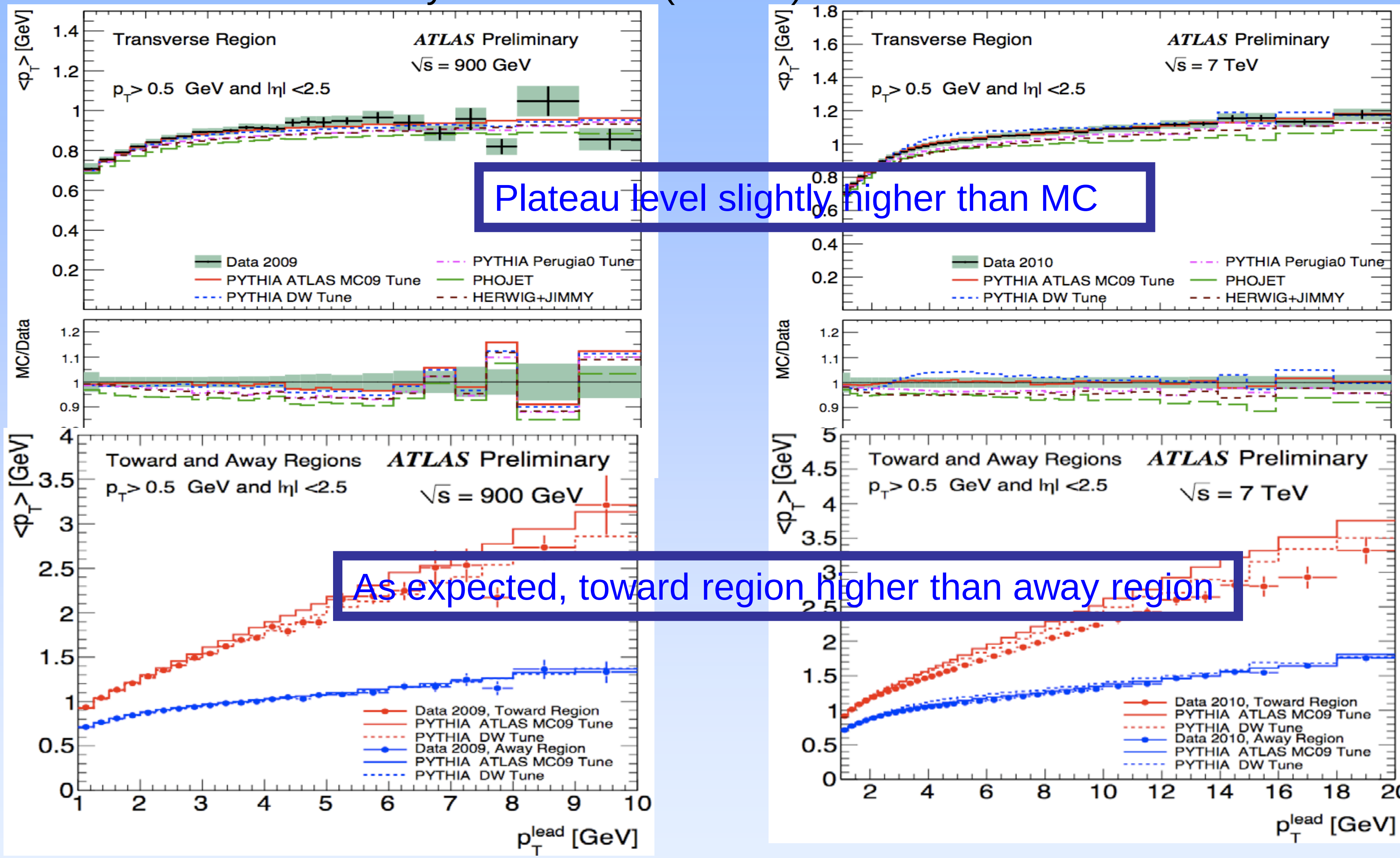




Tune DW provides good description of other regions

ATLAS: $\langle p_T \rangle$ of charged particles

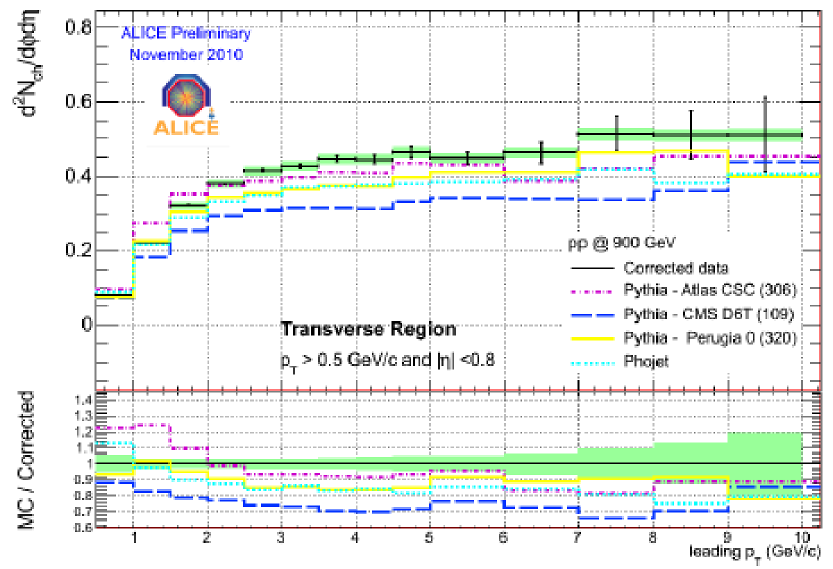
Talk by P.K. Behera (ATLAS): Hard Probes 2010

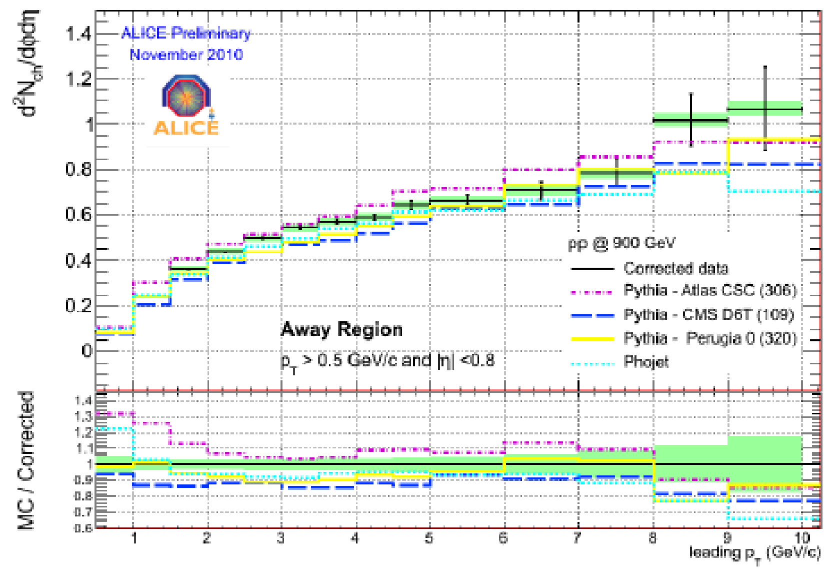


Plateau level slightly higher than MC

As expected, toward region higher than away region

ALICE: charged particle multiplicity@ 900 GeV

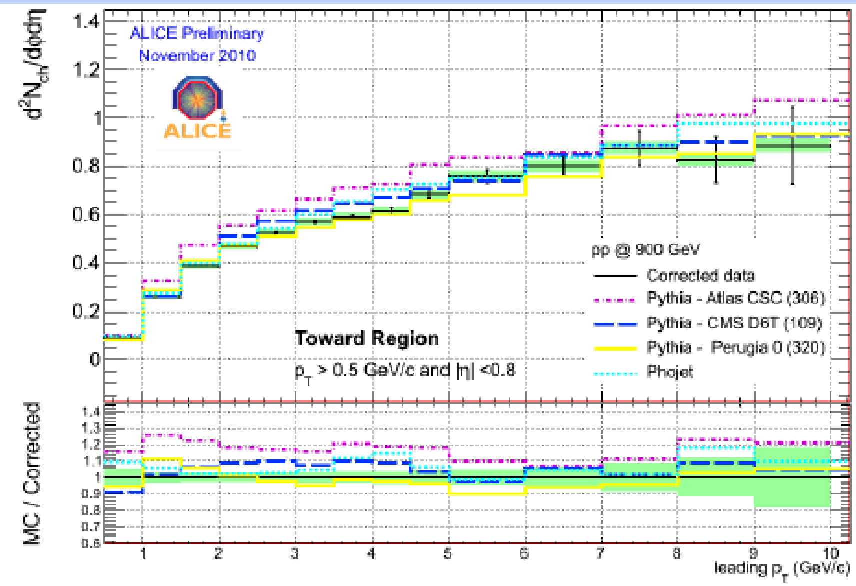




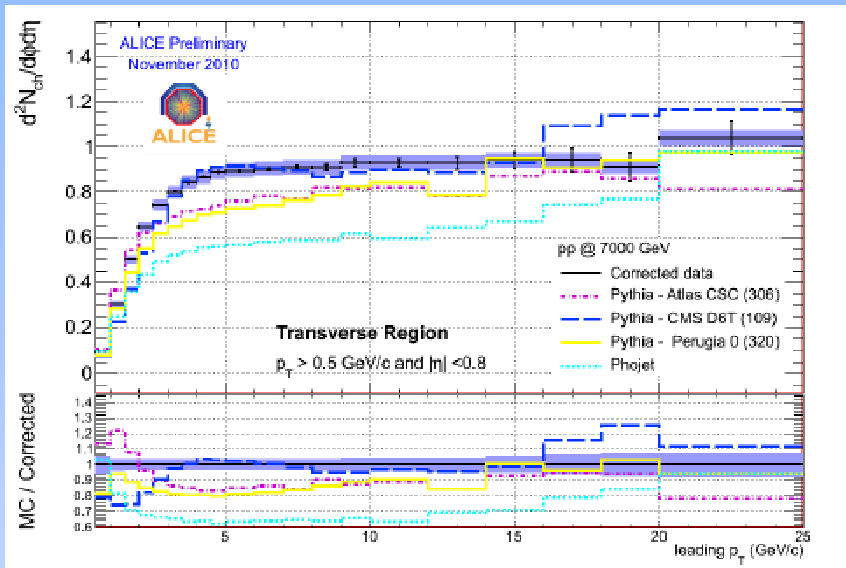
S. Vallero (ALICE), MPI@LHC 2010

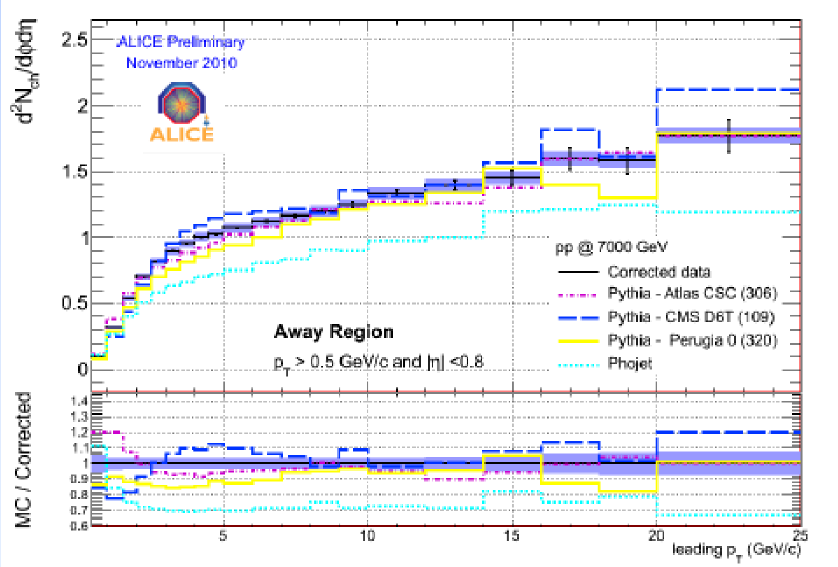
ALICE measures higher values than ATLAS

- explained by different acceptance
- ALICE excludes leading track



ALICE: charged particle multiplicity@ 7 TeV





S. Vallero (ALICE), MPI@LHC 2010

ALICE measures higher values than ATLAS

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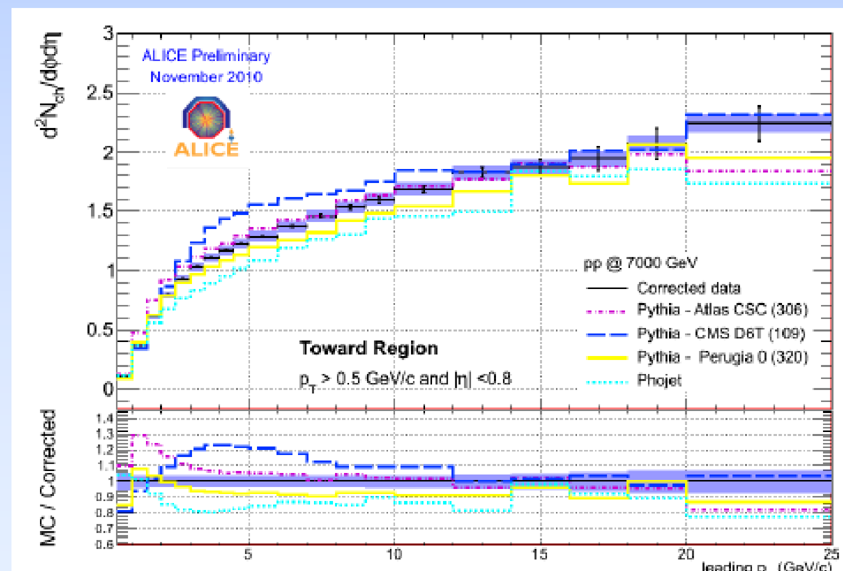
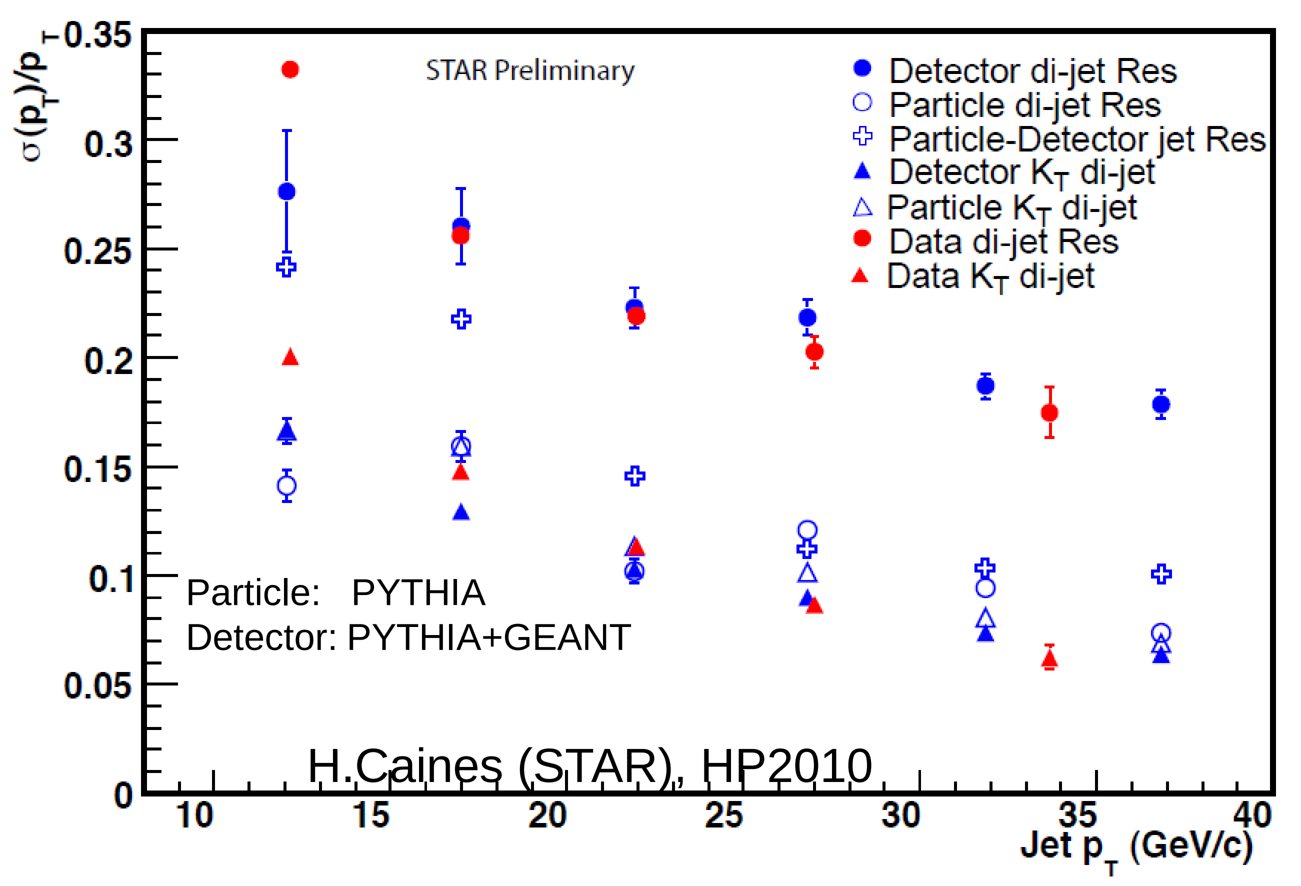
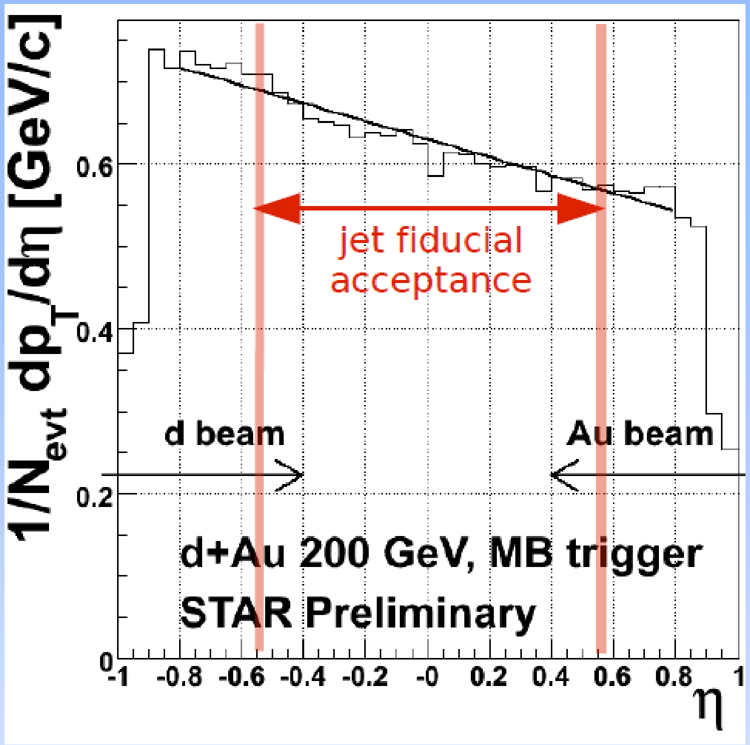


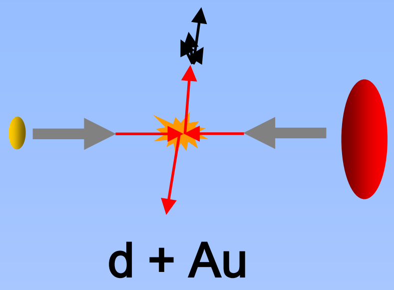
k_T and jet energy resolution



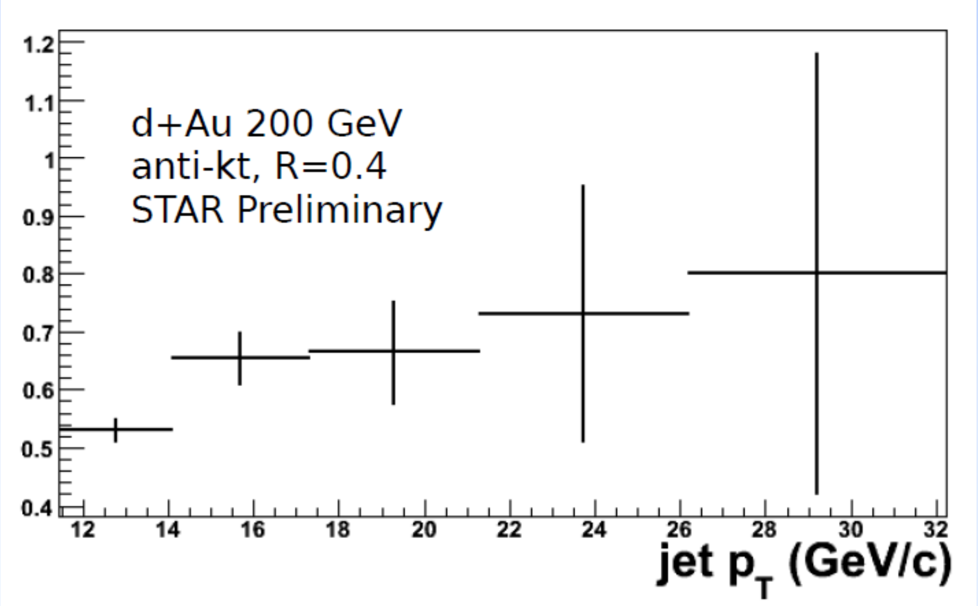
Use PYTHIA simulation to resolve detector from physics effects
JES: 15-20%, di-jet energy balance 20-30%
Data (red points) agree with PYTHIA → use PYTHIA for JES

Underlying event background subtraction





Jet p_T spectra ratio:
bkg subtracted/raw



pseudorapidity dependence
(asymmetric collision):
<2% effect on p_T spectra
negligible syst. uncertainty
• included in bkg. subtraction