PYTHIA at RHIC

Helen Caines - Yale University

(much taken from work of PYTHIA authors and Rick Field)

PHENIX Spinfest School BNL
13th July 2009

Outline

- What is PYTHIA
- How are events modeled
- Constraining PYTHIA with data
- What's not well modeled today
- Summary

The Ancient “PYTHIA”

- Pythia: derived from Pytho, which in myth was the original name of Delphi.

- Pytho: derived from the verb pythein ("to rot") - from the decomposition of the body of the monstrous serpent “Python” after she was slain by Apollo.

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- Priestess of Oracle of Apollo (God of Widsom) at Delphi: In 8th century BC was the most prestigious and authoritative Oracle in the Greek world

- How predictions made:
  1) Believer made a sacrifice and presented his/her question to a male priest.

  2) The male priest then presented the question to the PYTHIA. (giving the PYTHIA prominence unusual for a woman in male-dominated ancient Greece)

  3) The PYTHIA went into a trance, became the voice of Apollo and announced the prophecy

Lessons to learn from original PYTHIA

- Croesus asks the PYTHIA “should he attack Persia?”.
- The Pythia answers that "Croesus will destroy a great empire."
- Encouraged Croesus invades Persia and his army is massacred.
- The Persians invade, conquered Lydia, and capture Croesus.
- Croesus bitterly denounces the Delphic oracle.
- Croesus visits, in chains, the Delphi and asks “Why did you lie to me?
- The Pythia answered that her prediction had been fulfilled.
- Croesus had destroyed a great empire--his own.

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  - You must be careful how you phrase your question
    - ambiguities will corrupt/muddle the answer
  - You must be careful how you interpret the answer
    - in particular don’t pick the answer you most want

The new PYTHIA

- PYTHIA:
  A Lund Monte Carlo program
  Models high-energy elementary particle collisions

- Contains theory and models for:
  hard and soft interactions
  parton distributions
  initial- and final-state parton showers
  multiple interactions
  fragmentation and decay

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  fragmentation and decay

- How predictions made:

  1) Believer writes interface, creates his/her own Tune, submits program to available batch queue (giving the end user a prominence unusual for experimentalists in theorist-dominated modern QCD calculations)

  2) PYTHIA runs

  3) PYTHIA "pronounces its prophecies" in a user defined format.

The Lund Model (begun in Lund theory group 1978)

- Phenomenological model of hadronization via strings (not string theory)

  Final state hadrons stem from force between partons and not from partons themselves

  Treats all but the highest-energy gluons as field lines, gluon self-interaction causes field line to “attract” each other forming narrow tubes/strings of strong color field. (Contrast to E or B field where force carrier (photon) does not self-interact, and field lines spread out).

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- String fragmentation explains many features of hadronization well.

In particular predicts that in addition to the particle jets formed along the original paths of two separating quarks, there will be a spray of hadrons produced between the jets by the string itself—which is precisely what is observed

But PYTHIA has so many parameters....

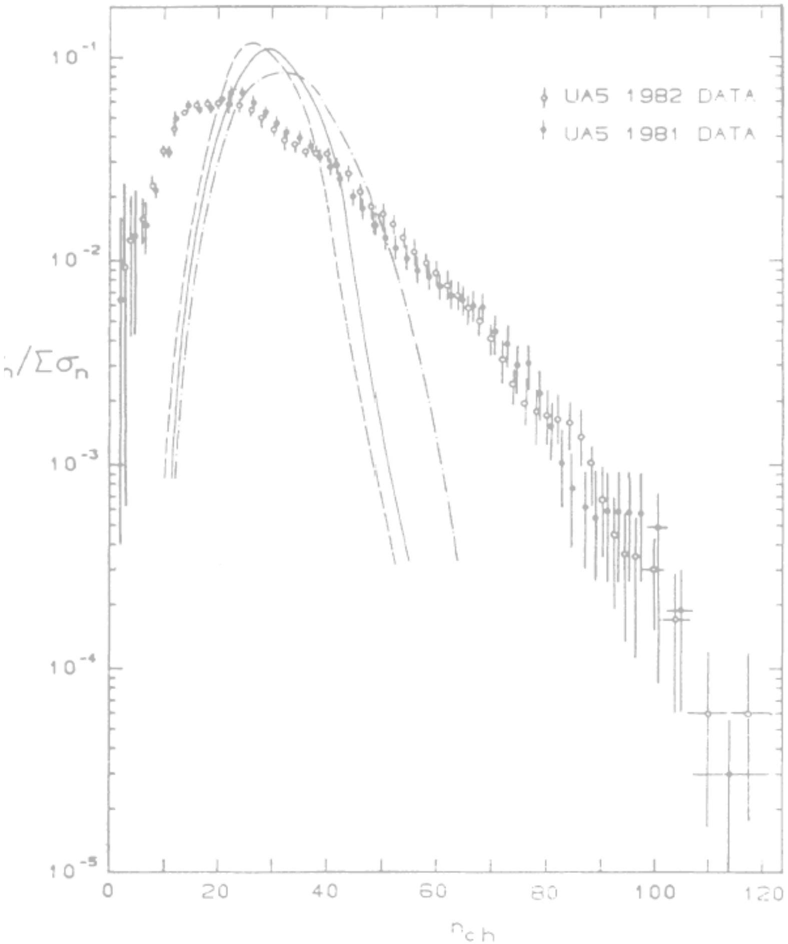
UA5 @ 540 GeV - charged multiplicity in minimum-bias events

Simple physics models

hard scattering+ ISR+FSR ~ Poisson

can tune to get average but much too small fluctuations

➔ inadequate physics model



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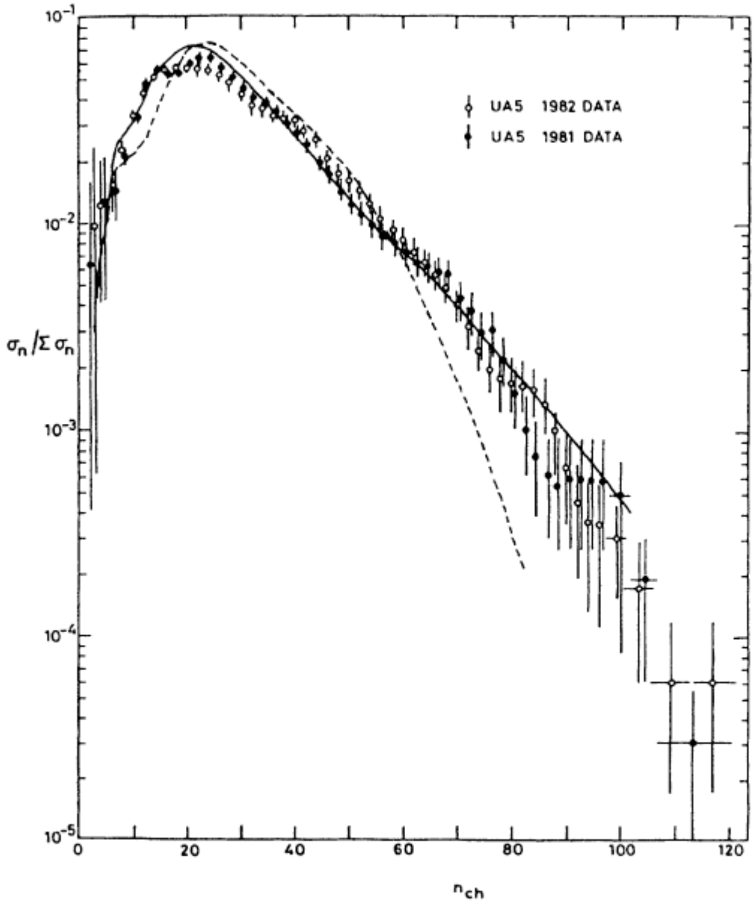
Multiple interactions + impact-parameter dependence

can now match data reasonably well



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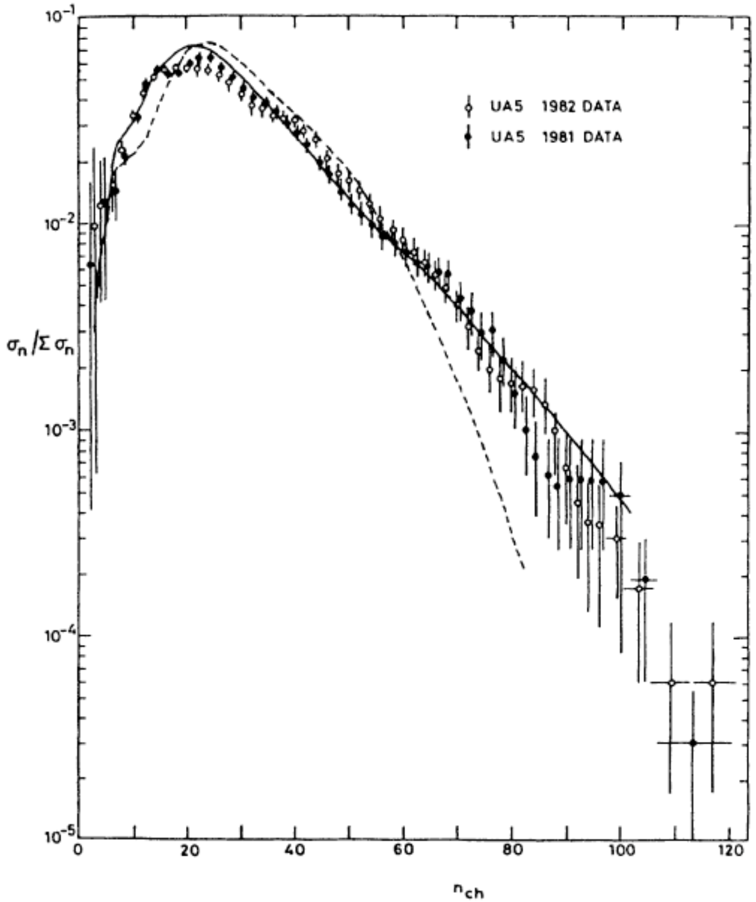


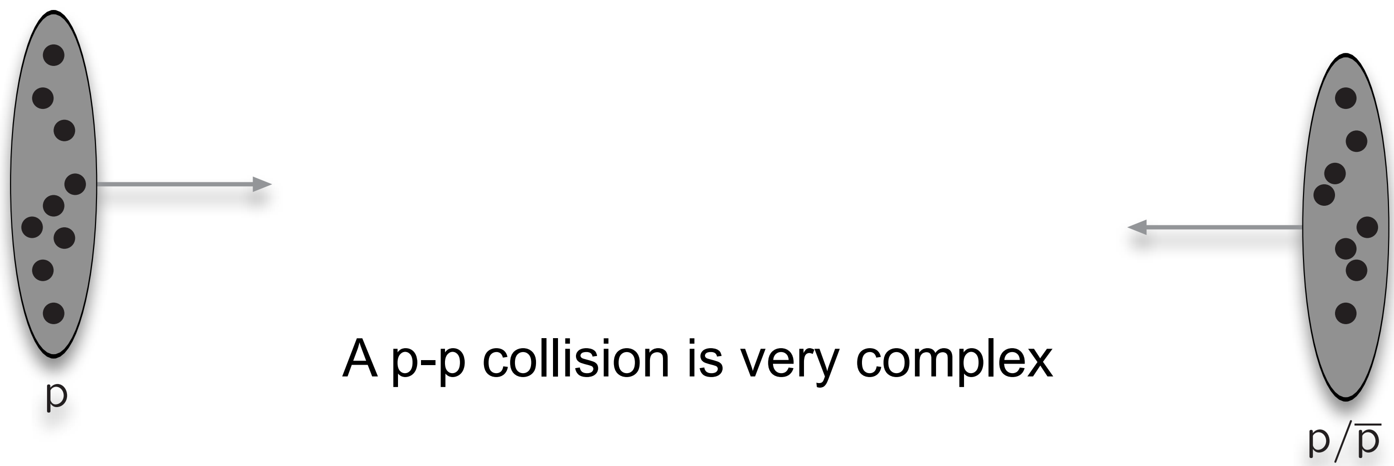
- Can only "tune" a model as well as the underlying physics allow
- Failure of a fit tells us the fit is bad

Failure in tuning a physically motivated model teaches us something

But still why so many parameters?

The structure of an event

Warning: schematic only, everything simplified, nothing to scale, . . .

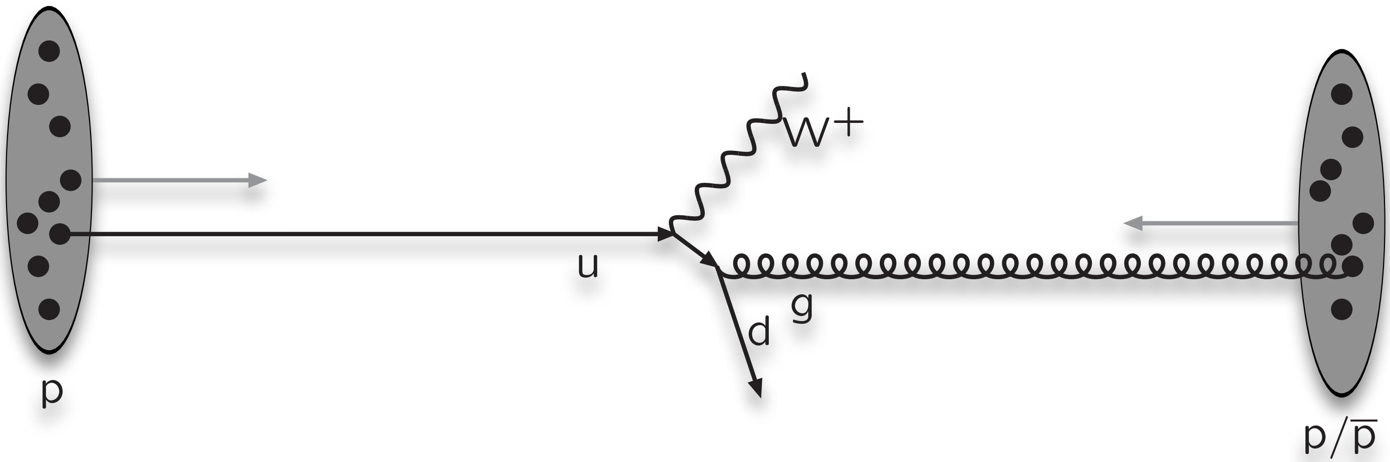


A p-p collision is very complex

Incoming beams: parton densities

From Torbjörn Sjöstrand

But still why so many parameters?



Hard subprocess: described by matrix elements

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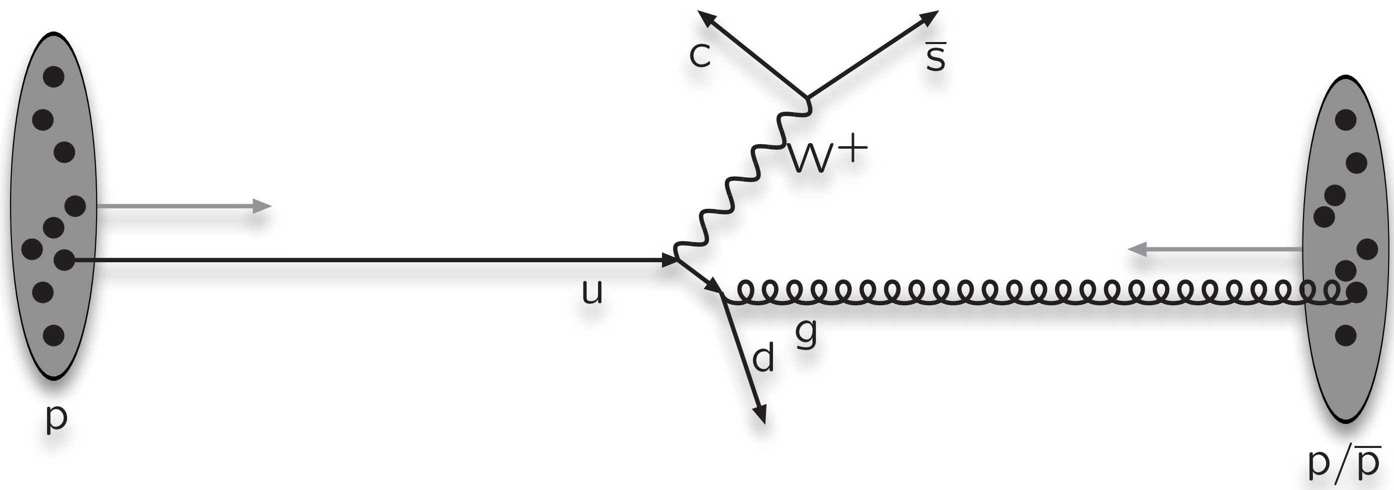

Resonance decays: correlated with hard subprocess

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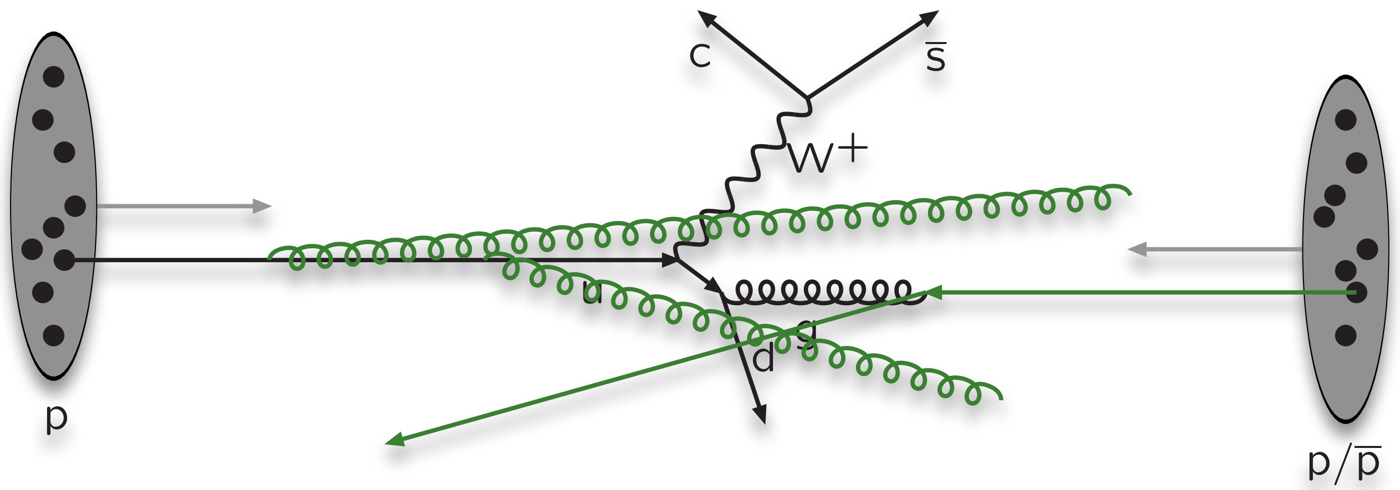

Initial-state radiation: spacelike parton showers

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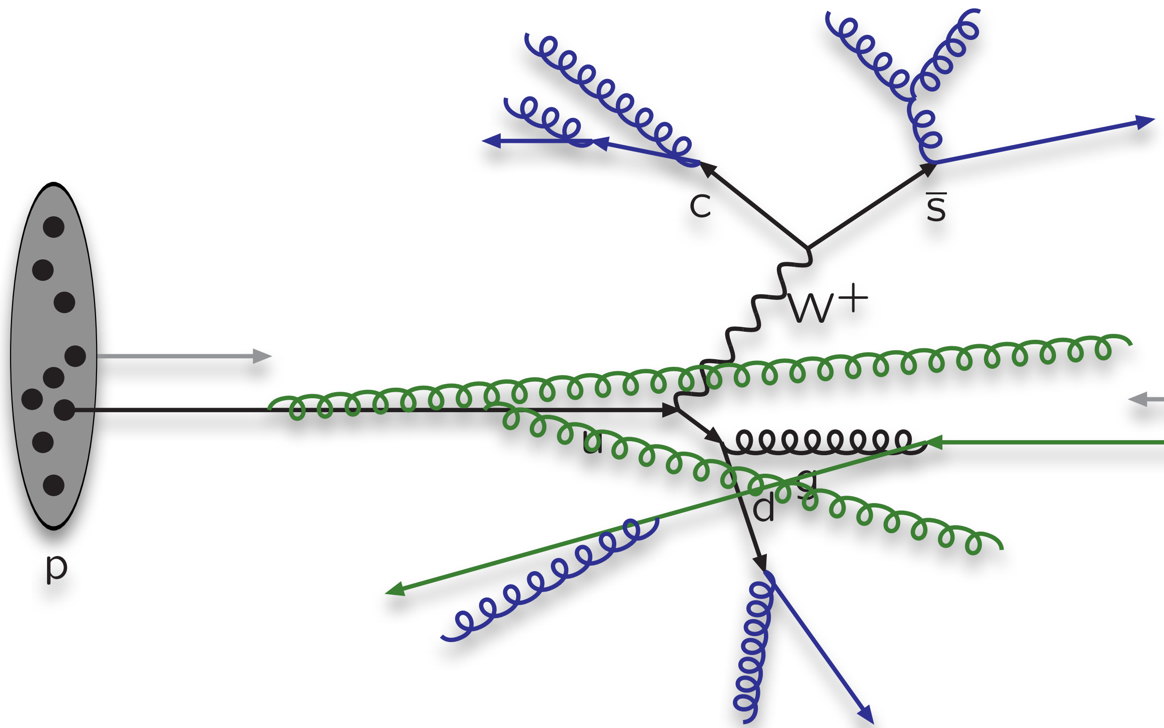

Final-state radiation: timelike parton showers

From Torbjörn Sjöstrand

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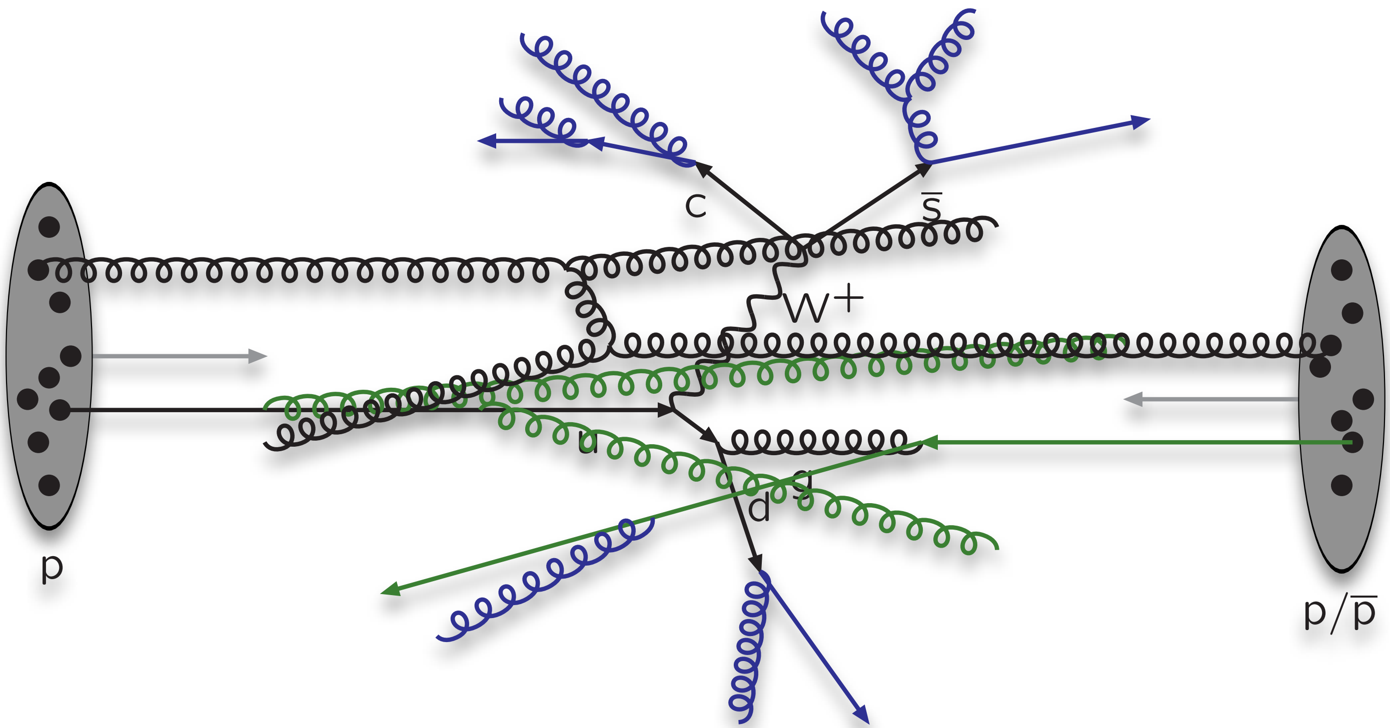

Multiple parton–parton interactions . . .

From Torbjörn Sjöstrand

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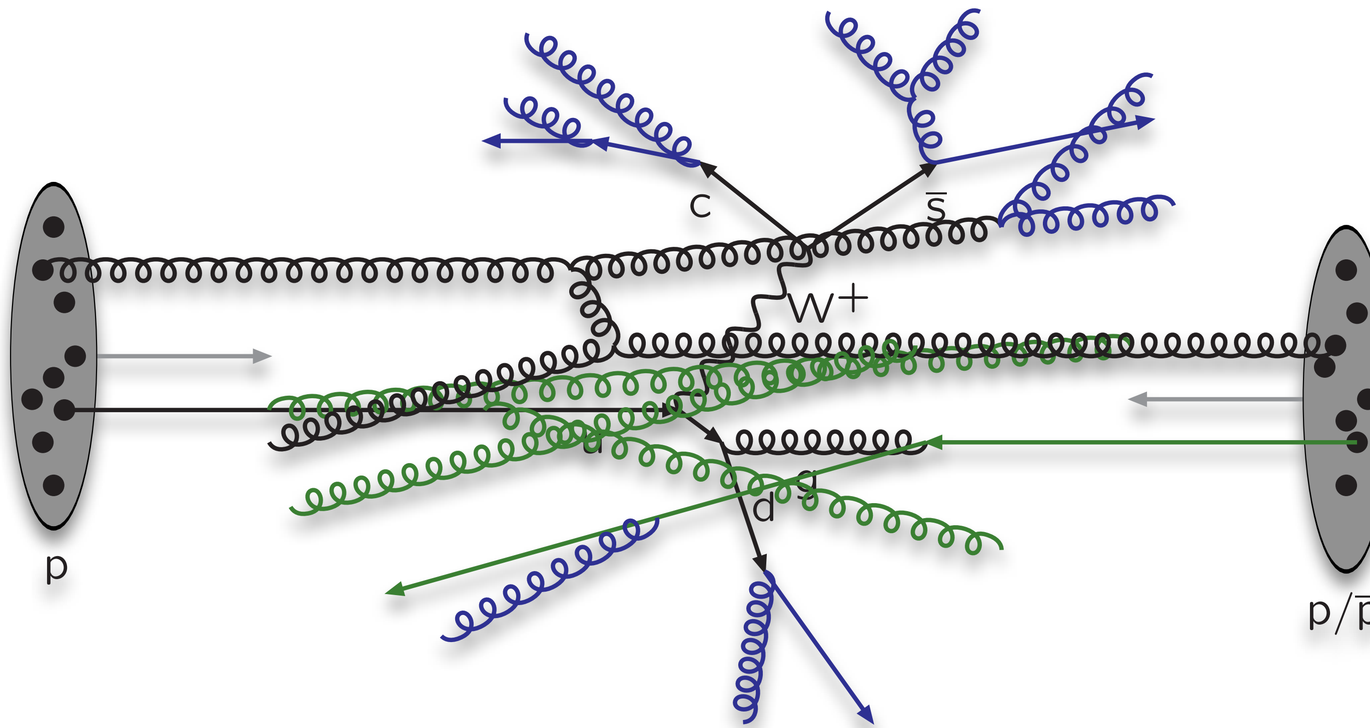

. . . with its initial- and final-state radiation

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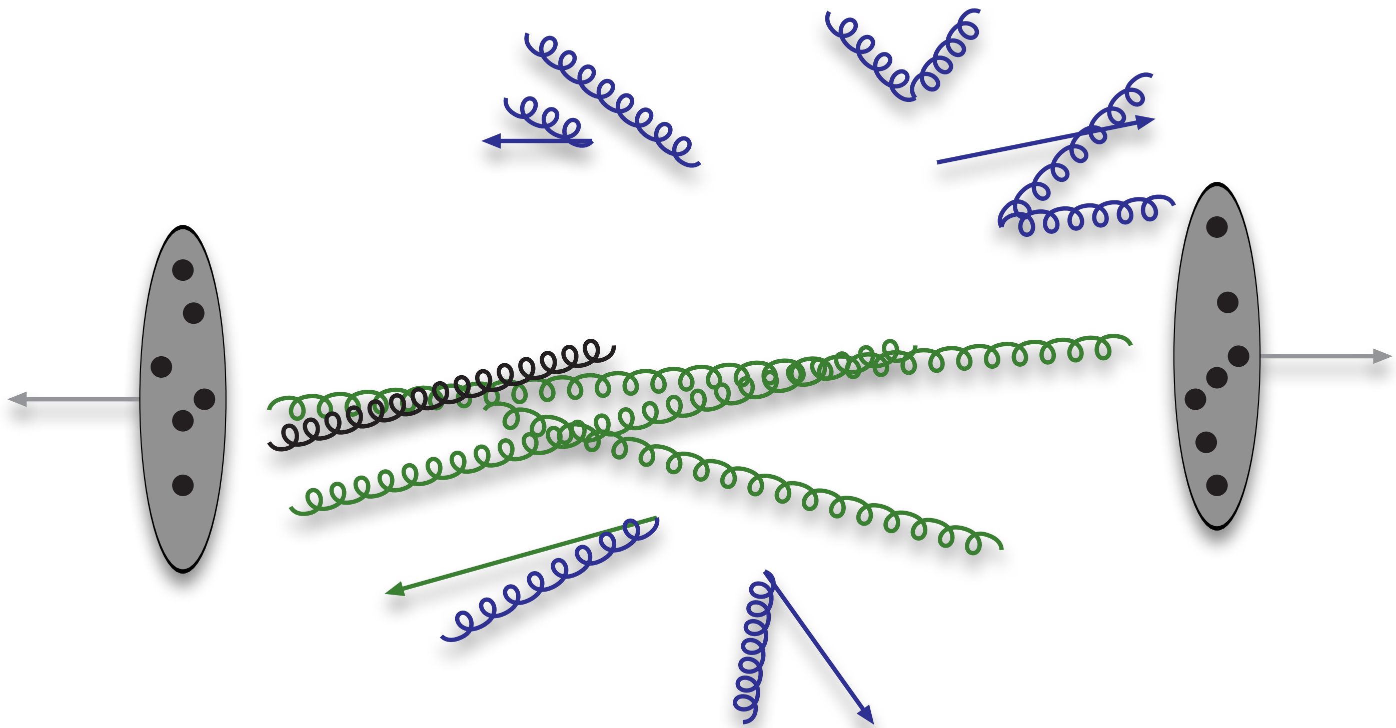

Beam remnants and other outgoing partons

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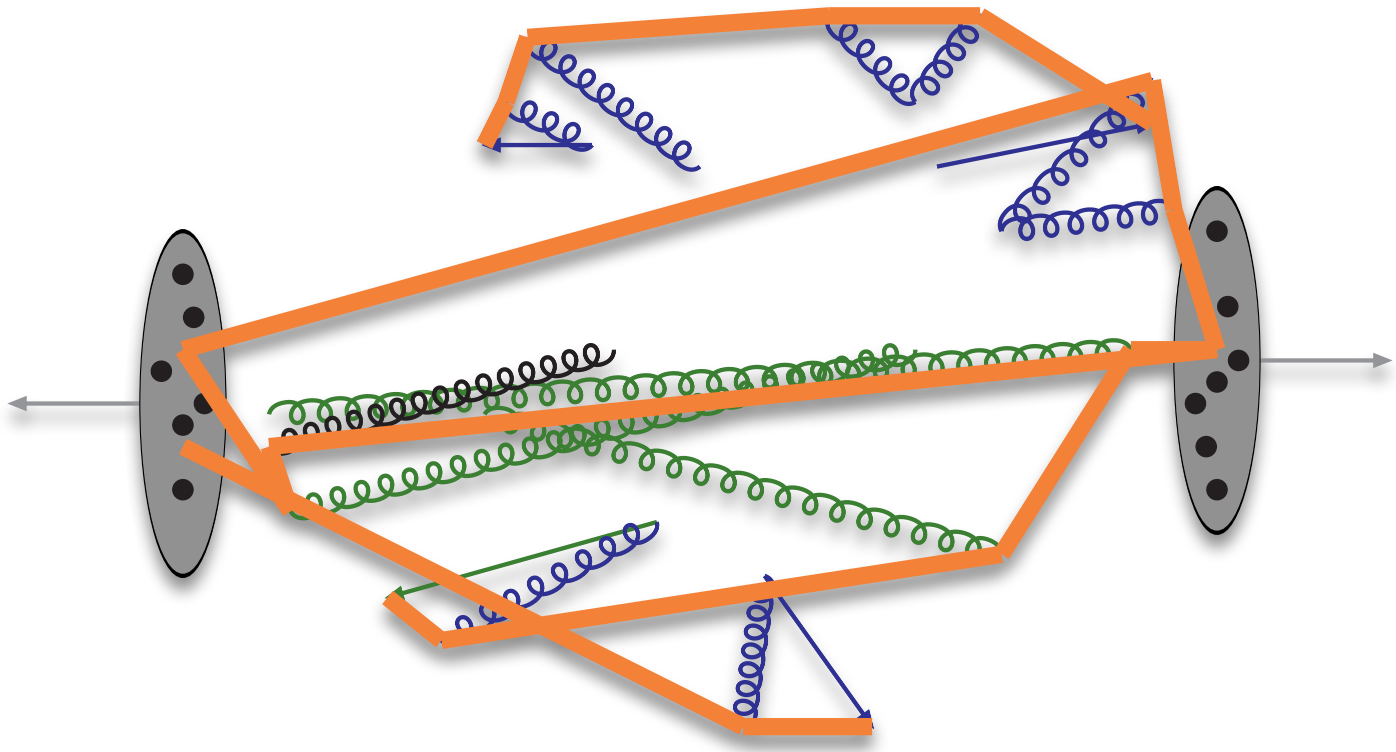

Everything is connected by colour confinement strings

Recall! Not to scale: strings are of hadronic widths

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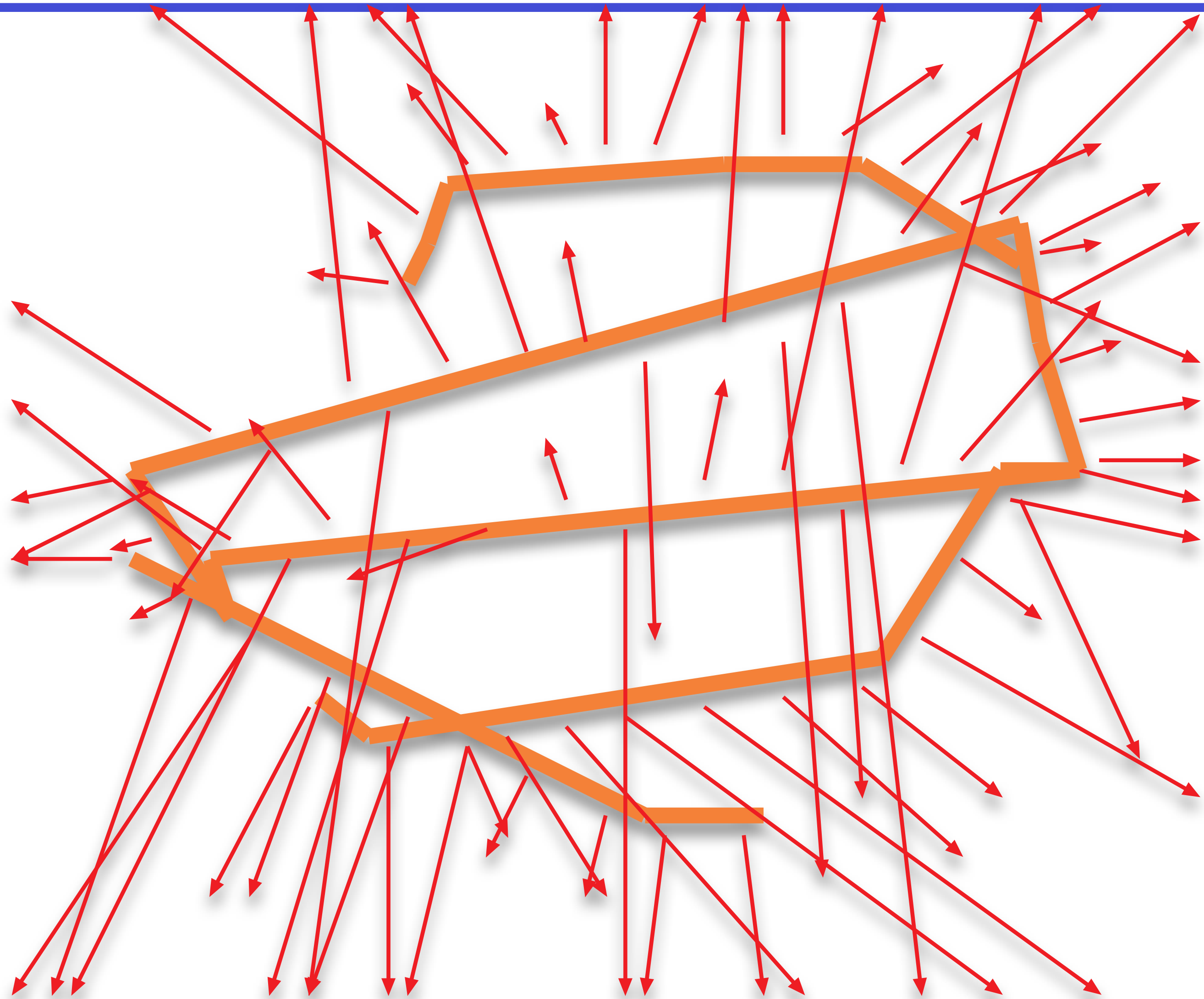

The strings fragment to produce primary hadrons

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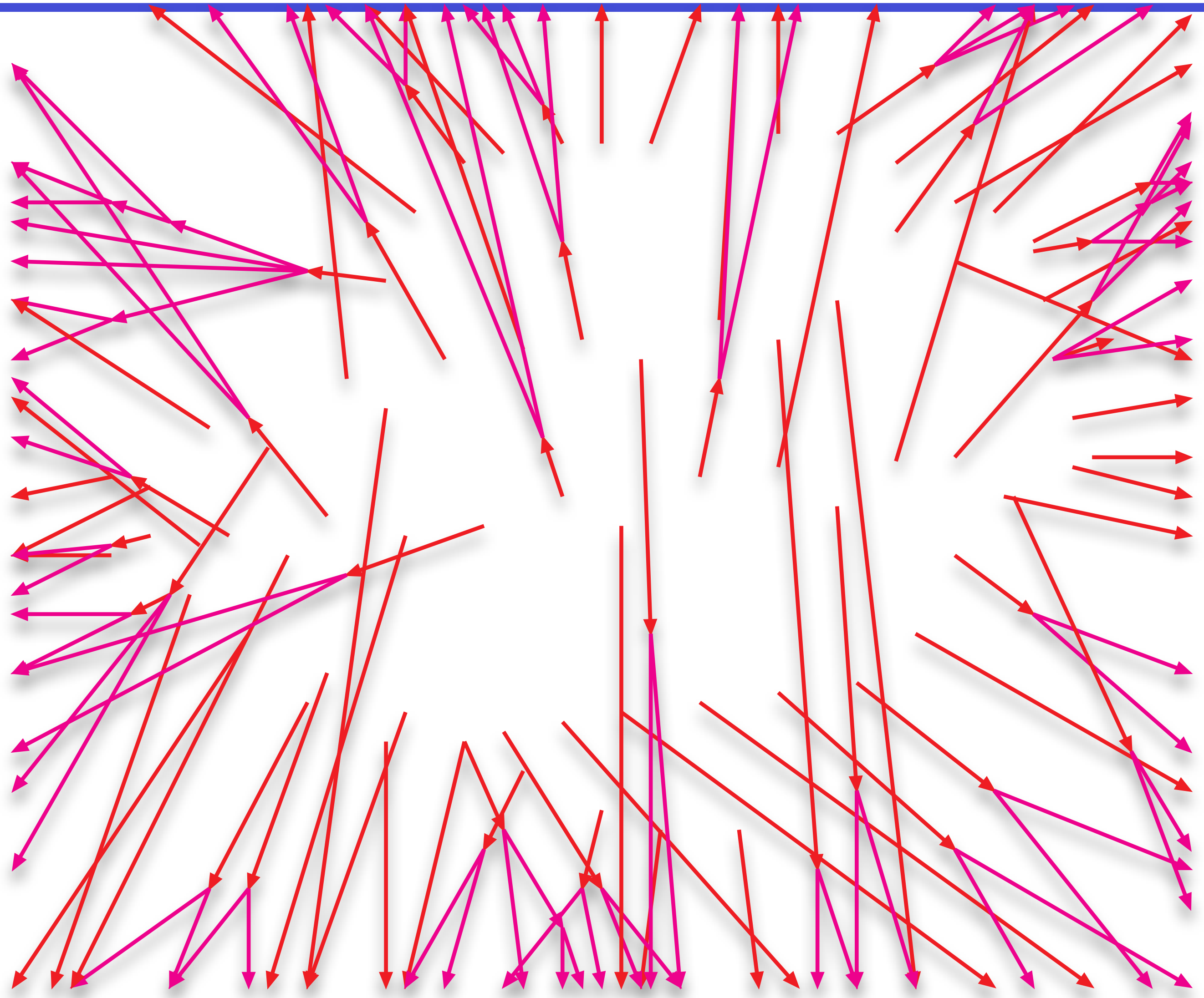

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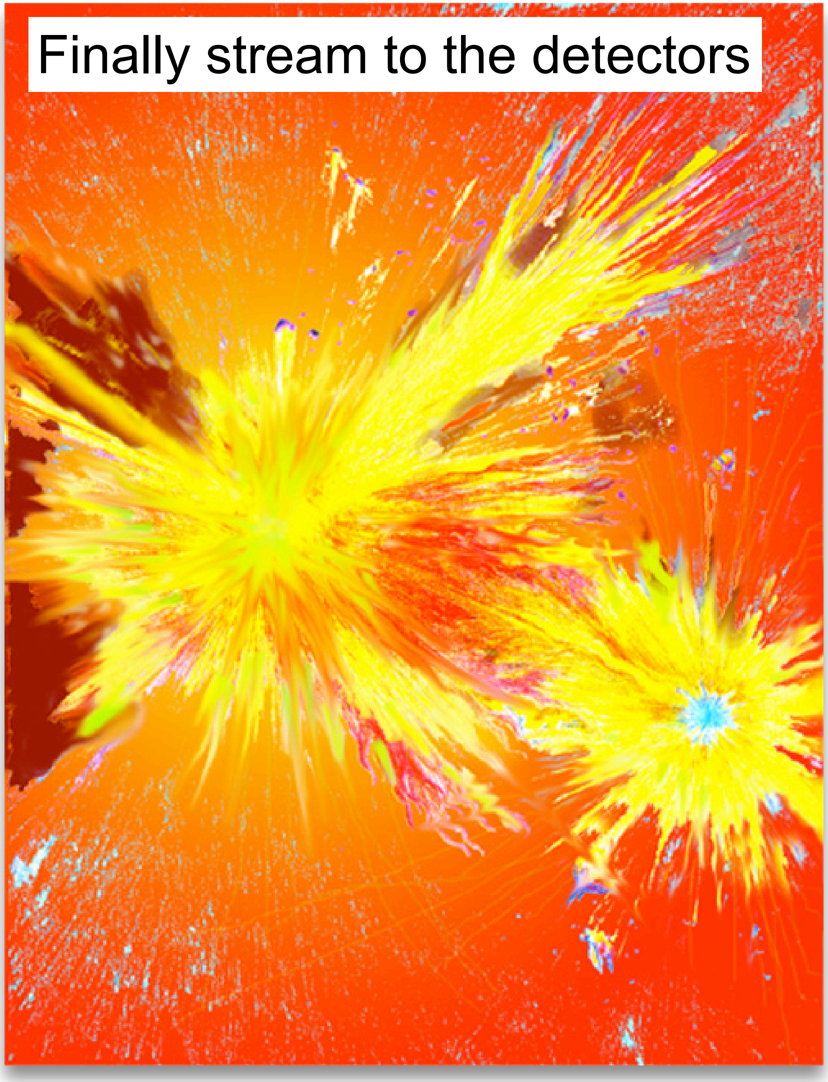


- Lots of different physics to model → a large number of parameters

- Different parameters affect different observables

- Once they are fixed via one set of measurements no freedom to move them again

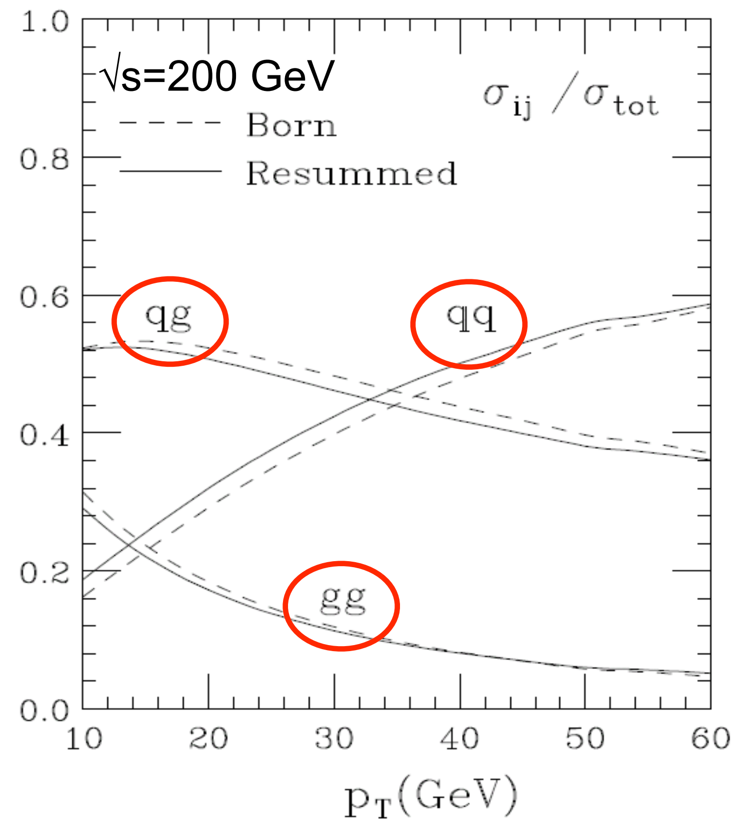
- Use e+e- data to fix a large number of parameters.

- Then turn to p-p(pbar)

- Also a number of “spare” parameters for Higgs/SUSY physics

Jets at RHIC: √s=200 GeV p+p

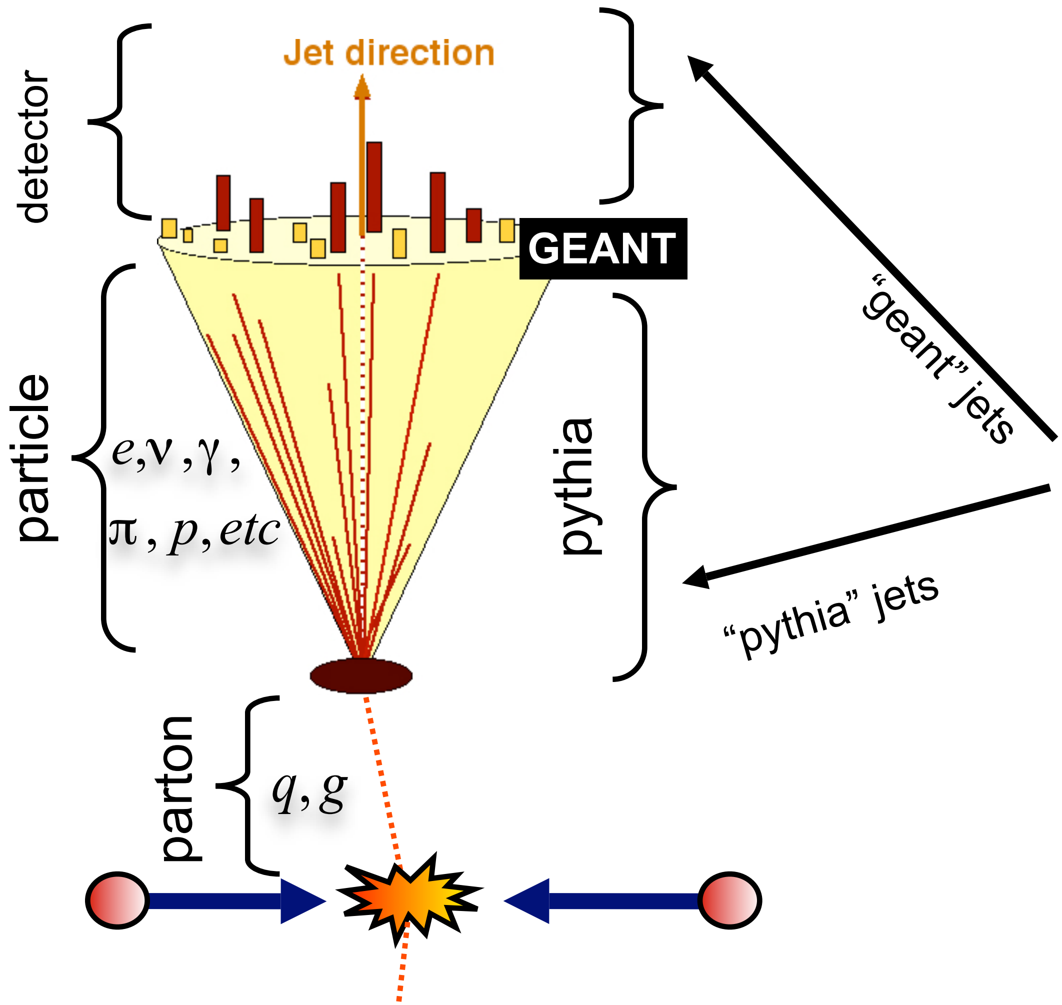
- Unpolarized measurements are a crucial part of the RHIC program
- Inclusive hadron and jet cross section measurements at RHIC add new results to existing data from other accelerators at different energies
- Constrain fragmentation functions:
  - Fits currently dominated by e^+e^- data
  - Still large uncertainties, especially in the gluon fragmentation functions



De Florian,Vogelsang, hep-ph 0704.1677

Significant contribution from gluons in the RHIC regime

STAR Jet-Finding



Use 4 fast-jetalgorithms

- Midpoint-cone
- SISCone
- K_T
- Anti-K_T

Currently Pythia+GEANT+reco compared to reconstructed real data so data at "detector" level

Jet-Finder Algorithm cuts:

p_T (track/tower) > 0.2 GeV

|vertex-z|<50 cm

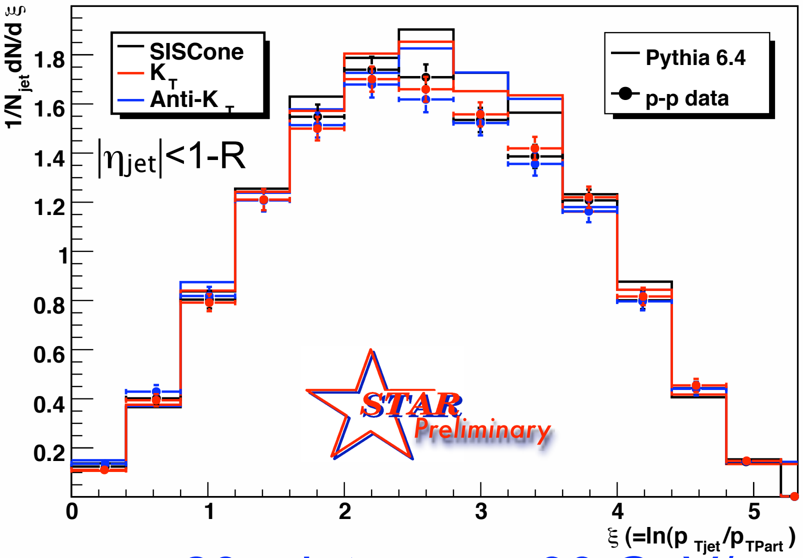
$|\eta_{jet}| < (1 - R_{jet})$

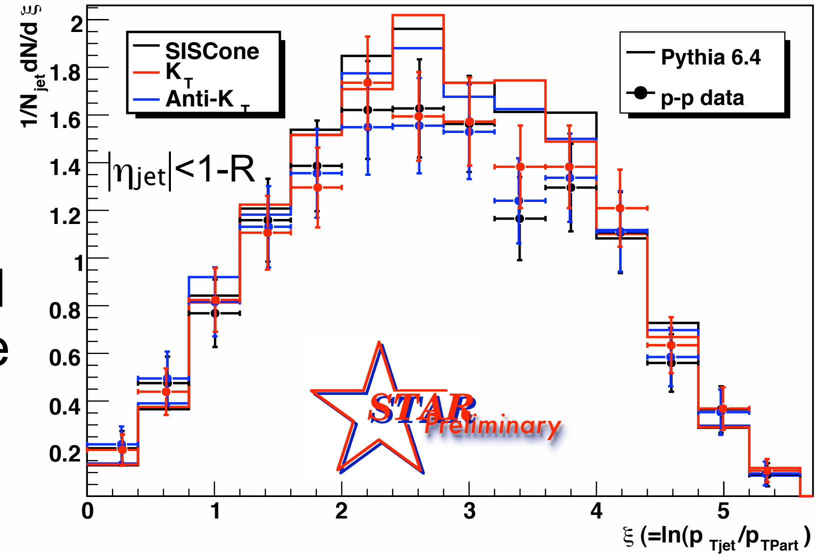
$0.05 < E_{neutral}/E_{jet}$ (NEF) < 0.85

Seed-Cut: 0.5 GeV/c (for midpoint only)

Compare results from different algorithms - estimate of systematics

ξ and z distributions for charged hadrons



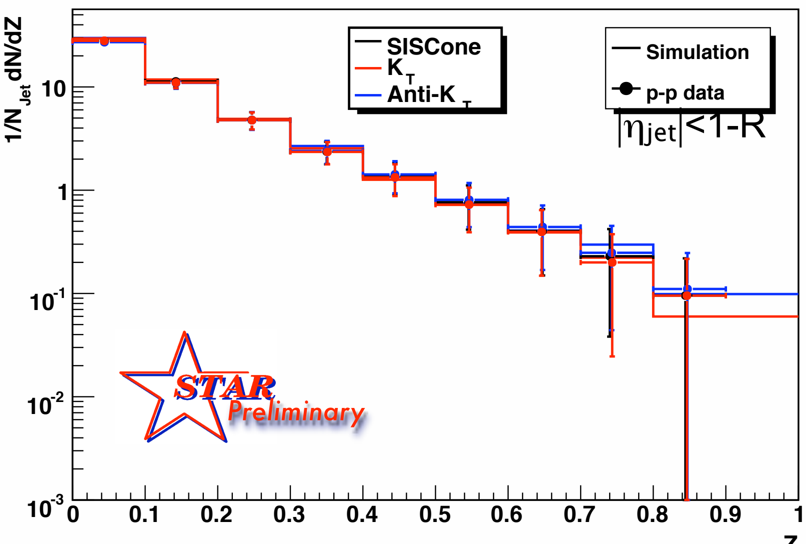


$20 < \text{Jet } p_{Treco} < 30$ GeV/c

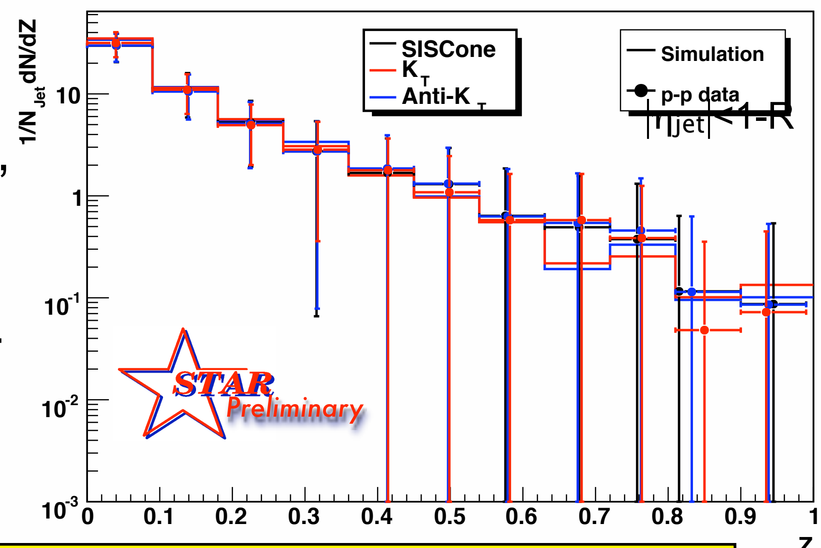
Data not corrected to particle level.

R=0.4

$30 < \text{Jet } p_{Treco} < 40$ GeV/c

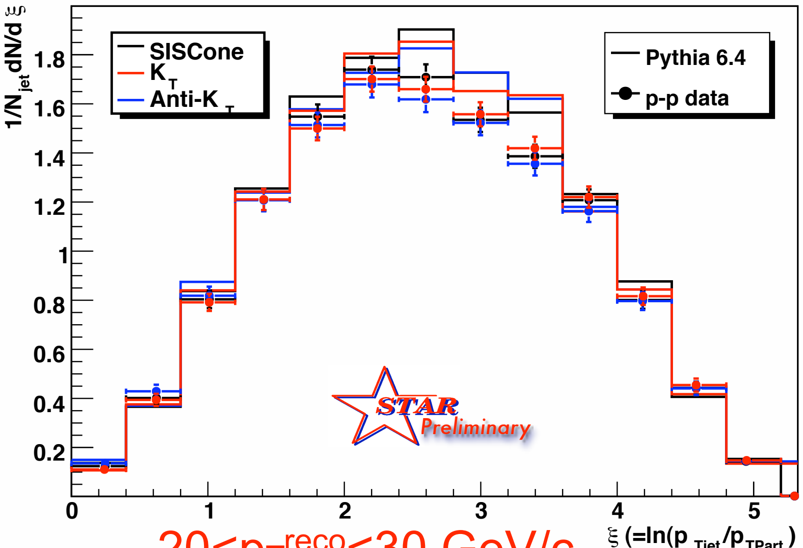


"PYTHIA" = PYTHIA +GEANT

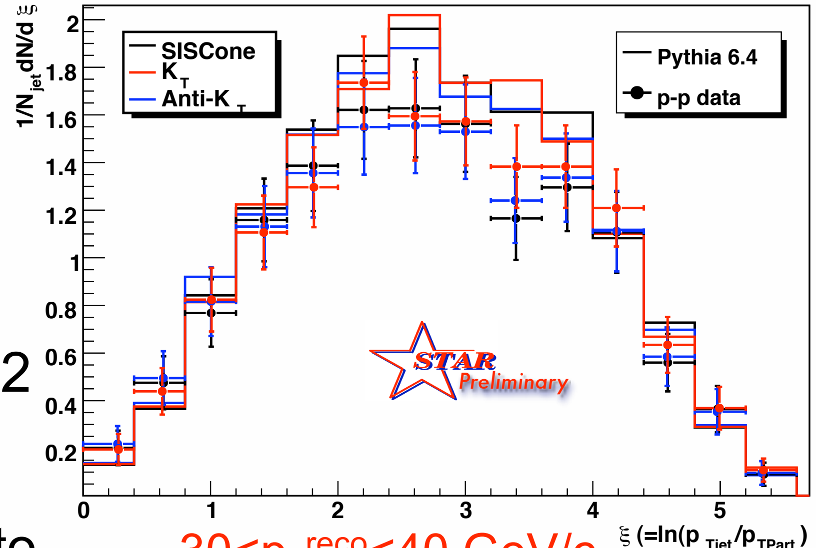


Reasonable agreement between data and PYTHIA+GEANT.

Charged hadrons ξ for different R and jet p_T



$20<p_T^{reco}<30$ GeV/c



$30<p_T^{reco}<40$ GeV/c

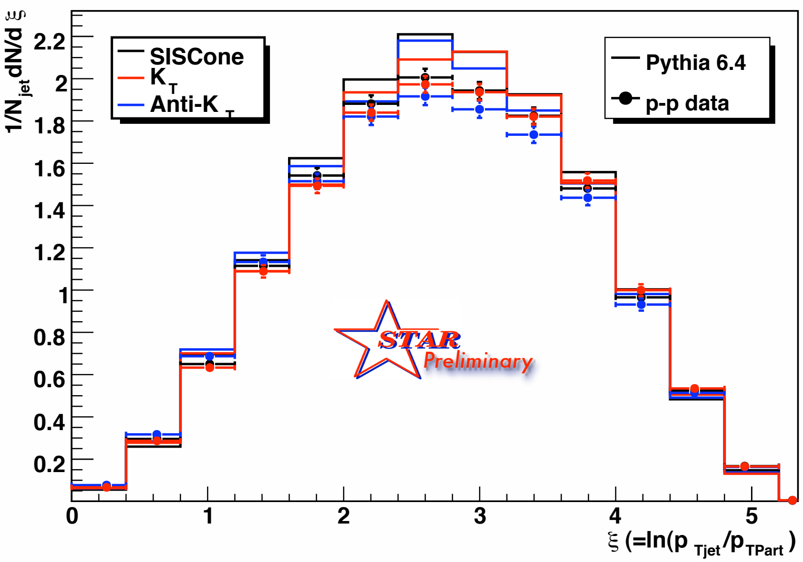
R=0.4

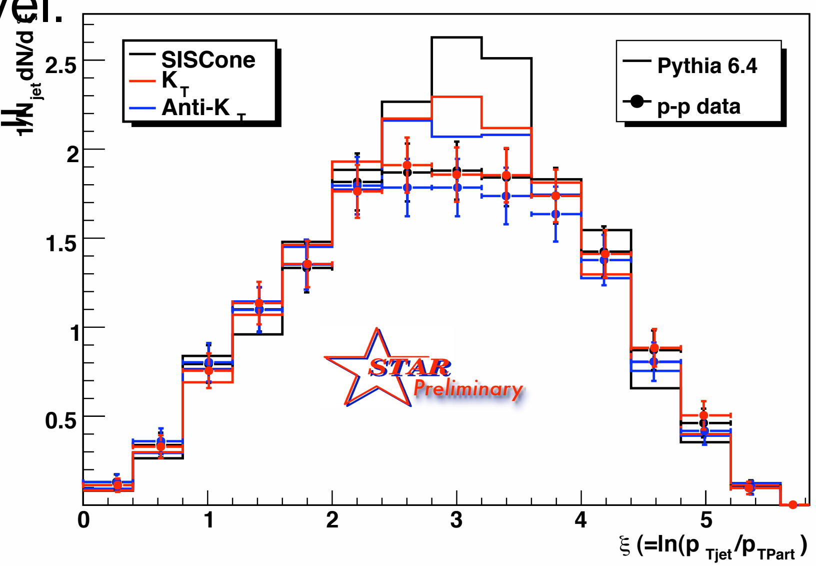
$|\eta_{jet}|<1-R$
$p_{Ttrack} > 0.2$

Data not corrected to particle level.

"PYTHIA" = PYTHIA +GEANT

R=0.7

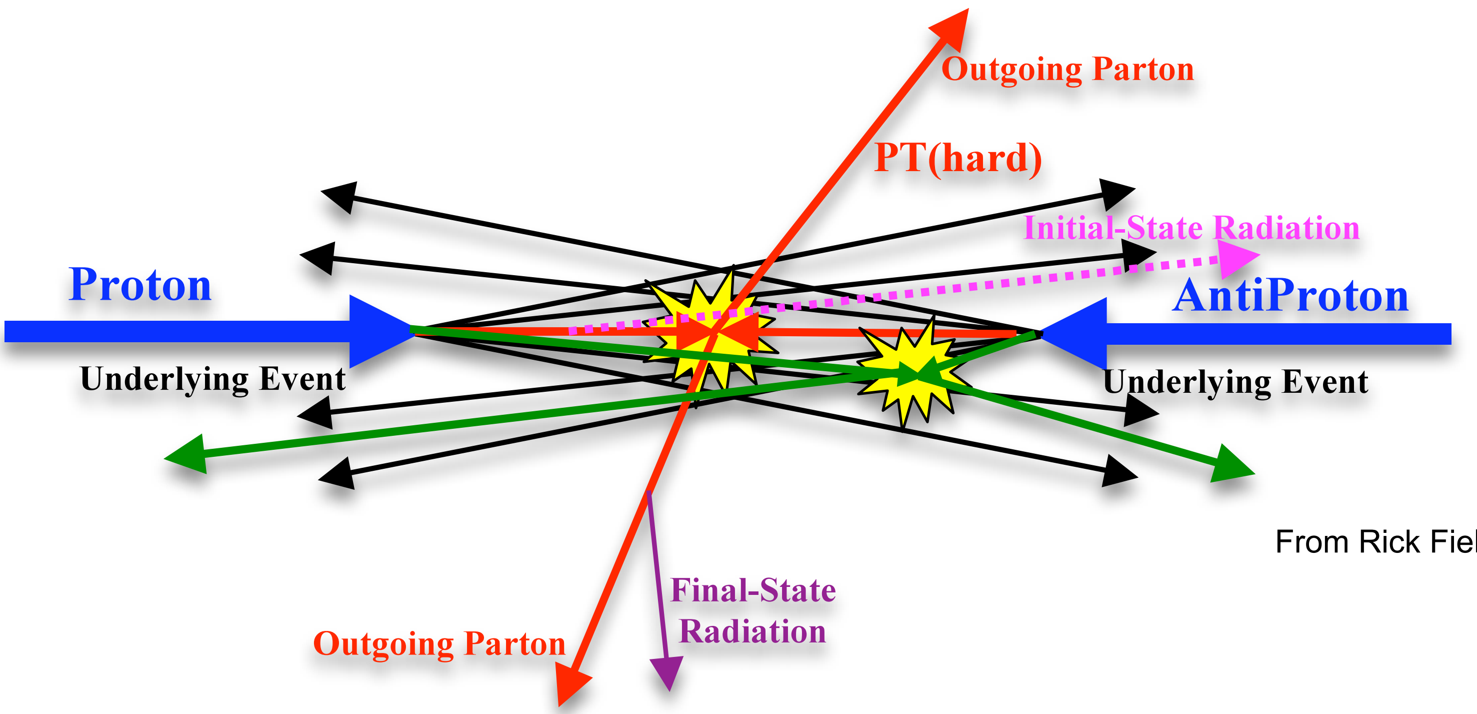




Agreement similar between PYTHIA and data for both radii.

The underlying event

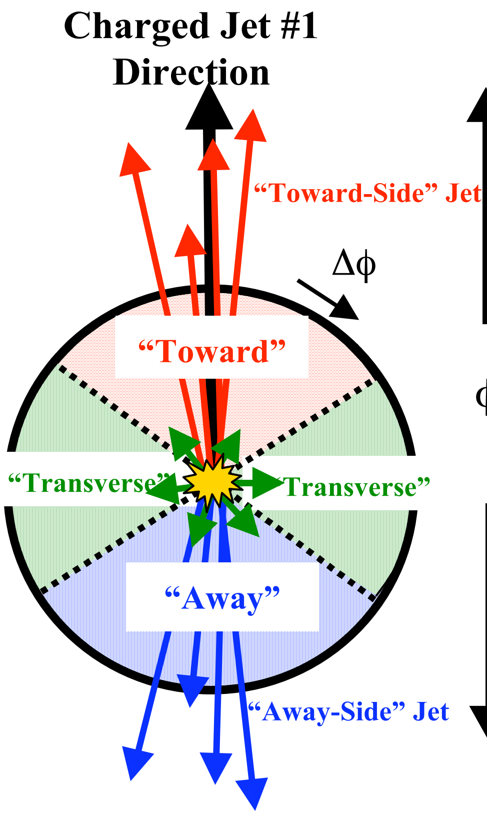
- Underlying Event: soft or semi-hard multiple parton interactions, initial & final state radiation, beam-beam remnants



From Rick Field

- Major part of PYTHIA tuned to Tevatron 1.8 TeV data
    - significant fraction done by Rick Field (Florida/CDF)
- Study min-bias and underlying event properties

Measuring the Underlying Event



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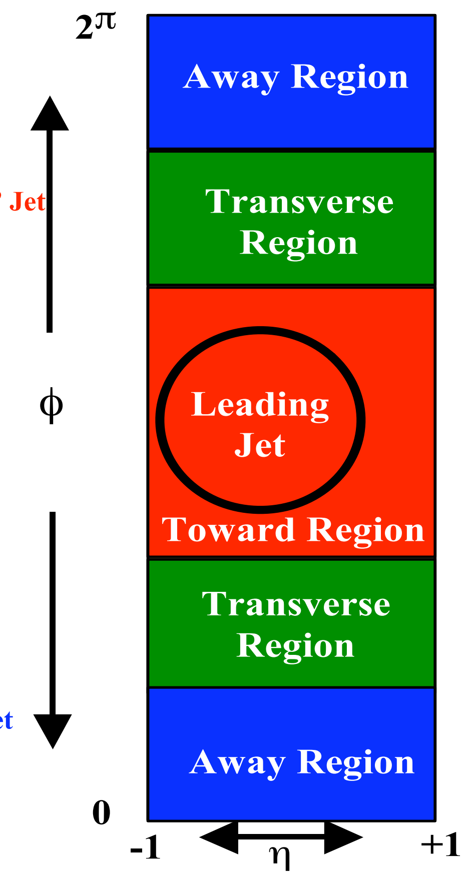

Define:

- |Δϕ| – Angle relative to leading jet
- **"Toward" |Δφ| < 60°**
- **"Away" |Δφ| > 120°.**
- **"Transverse" 60° < |Δφ| < 120°**
  - **TransMax** - Trans. region with highest Σp_T or ΣN_{track}
  - **TransMin** Trans. region with least Σp_T or ΣN_{track}

Underlying Event is the data in the Transverse regions.

Sensitivities of the variables

leading : Most basic jet cut, one jet in our acceptance.

back-to-back : Sub-set of leading jet collection.
Require $|\Delta\phi| > 150$, $p_{TAway}/p_{TLead} > 0.7$
Suppresses hard initial and final state radiation.

TransMin : Sensitive to beam-beam remnants and soft multiple parton interactions.

TransMax : Enhanced probability of containing hard initial and/or final state radiation component.

Sensitivities of the variables

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Compare TransMin and TransMax data from leading and back-to-back jet samples →

Information about large angle initial/final state radiation.

Parameters we have left to play with

Not a complete list but the key players

(often have several values that need setting themselves)

- PDF:

  MSTP(51,52) - which PDF and library to use

- ISR:

  MSTP(64) - how α_s runs in space-like parton showers

  MSTP(67) - whether to introduce color coherence effects in initial state showers (can restrict angle of the branching)

  MSTP(70) - regularization scheme for ISR when $p_T \rightarrow 0$ (sharp cut off, energy dependent smoothed cut etc)

  MSTP(72) - max. scale of radiation off FSR dipoles stretched between ISR partons

- FSR

  PARP(71) - max. parton virtuality allowed in time-like showers

  PARJ(82) - invariant mass cut-off for parton showers, below which partons do no radiate

Parameters we have to play with

- UE
  MSTP(81) - master switch for MPI
  MSTP(82) - structure of MPI (simple two string model, varying impact param. gaus, double-gaus, etc)

- Beam Remnants
  MSTP(88) - how to collapse quark-quark junctions for di-quarks and baryons
  PARP(79) - scaling factor for convert BR x to di-quark/baryon x
  PARP(80) - prob. BR joined to hard scattering by several string pieces
  MSTP(91) - Primordial k_T distribution and magnitude

- Color Reconnections
  MSTP(95) - Amount of, and how, color reconnections controlled

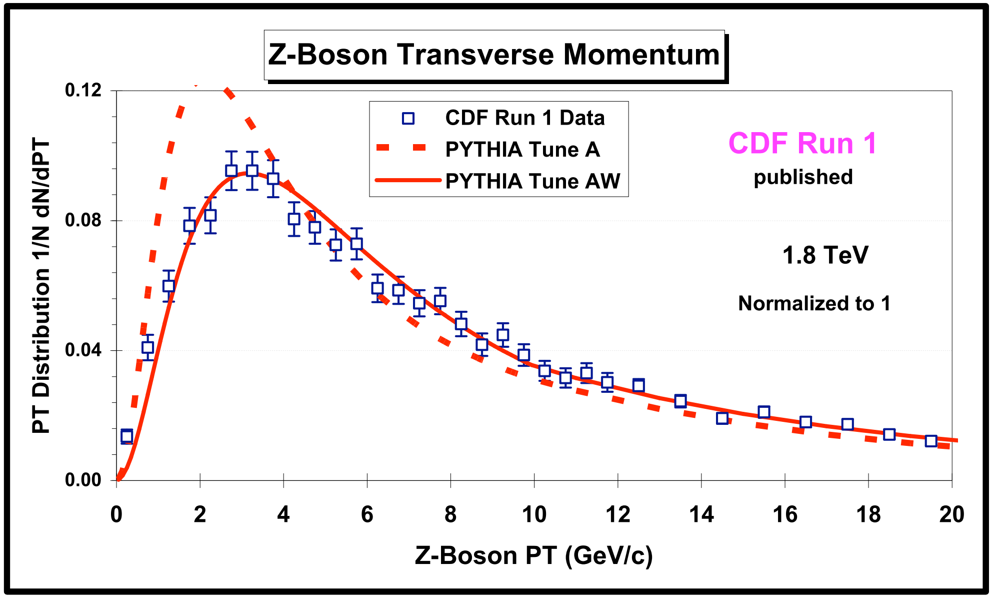
- Hadronization
  MSTJ(11) - what fraction of energy new hadron can take - LUND/Bowler/Peterson/SLAC FF can be different for heavy flavor

ISR and Intrinsic k_T

- Compare predictions of Z p_T distributions

- Sensitive to k_T and ISR

	Tune A	Tune AW
PARP(91)	1	2.1
PARP(62)	1	1.25
PARP(64)	1	0.2



From Rick Field

- PARP(91): Intrinsic k_T - needed to be sizable increased

- PARP(62): ISR - effective Q cut-off, space-like showers no longer evolved

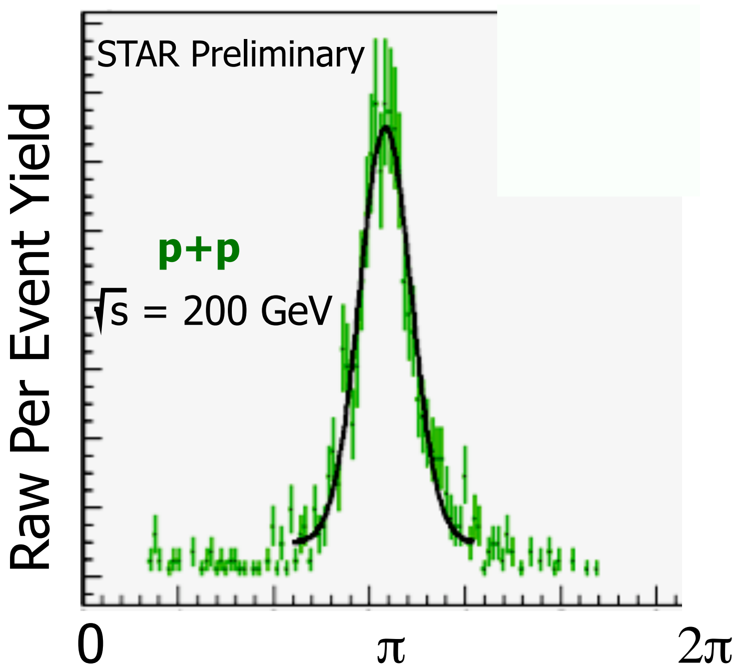
- PARP(64): ISR - Space-like shower running of α_s (k_T^2=PARP(64)(1-z)Q^2)

Need both parameter sets to give good description of data

Intrinsic k_T at RHIC

- STAR di-jet reconstruction

$\langle k_T^2 \rangle = 2.3 \pm 0.4 \pm {}^{0.67}_{1.11}$ GeV/c



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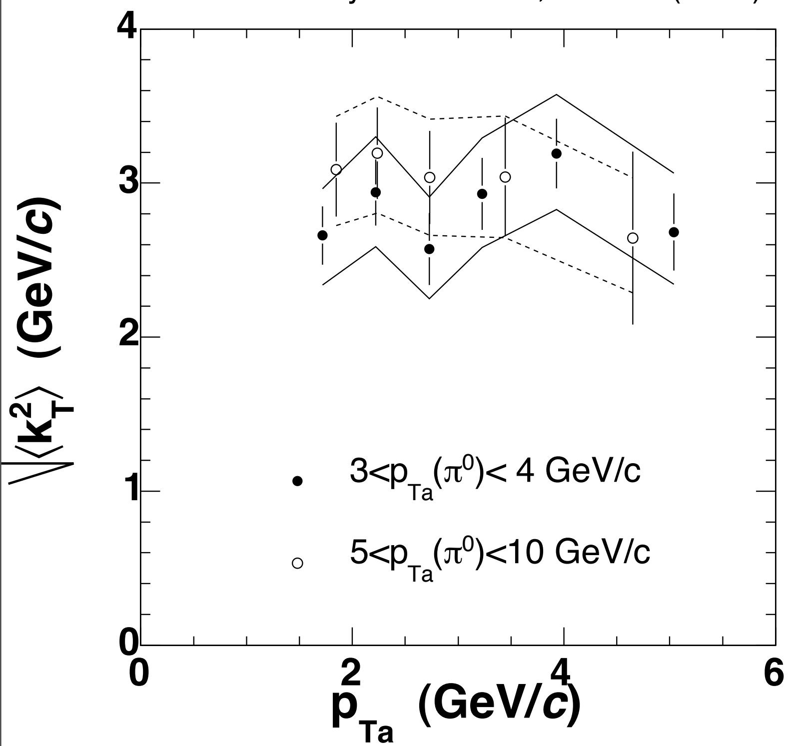
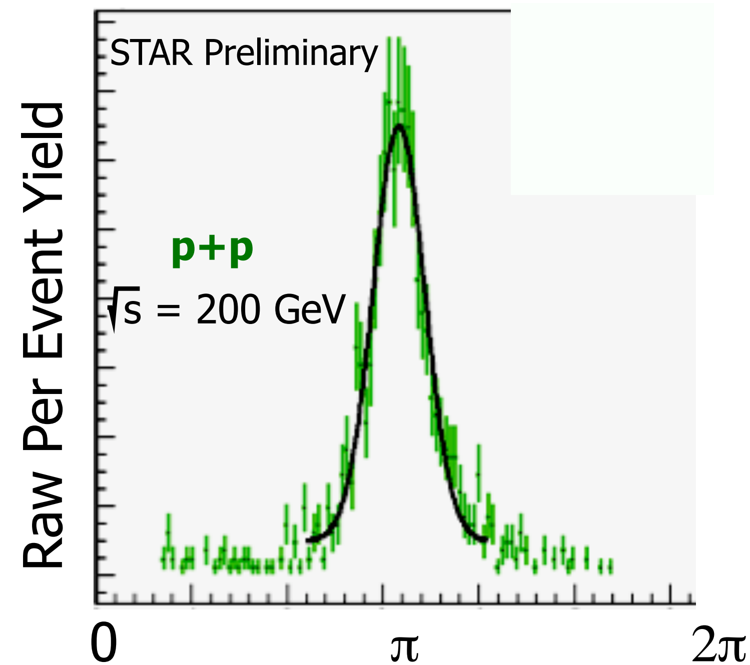




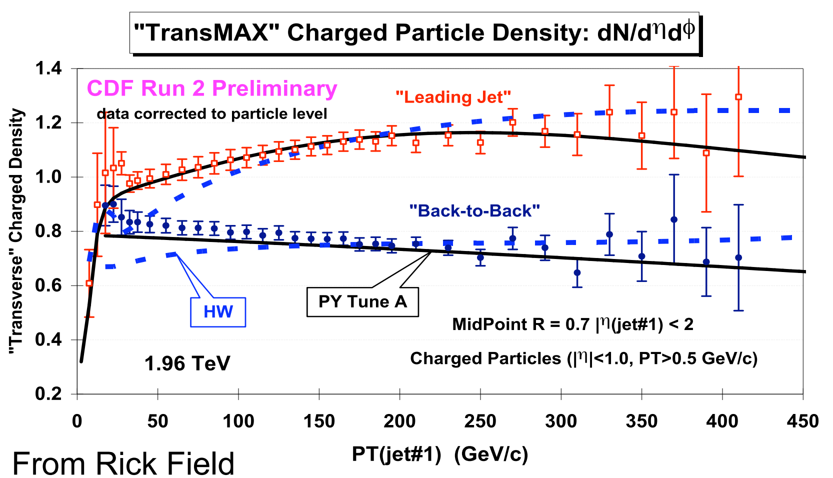
- PHENIX di-hadron correlations

p-p 200 GeV

$\langle k_T^2 \rangle = 2.68 \pm 0.04$ GeV/c

Data suggest k_T higher than PYTHIA defaults

ISR and FSR in UE regions



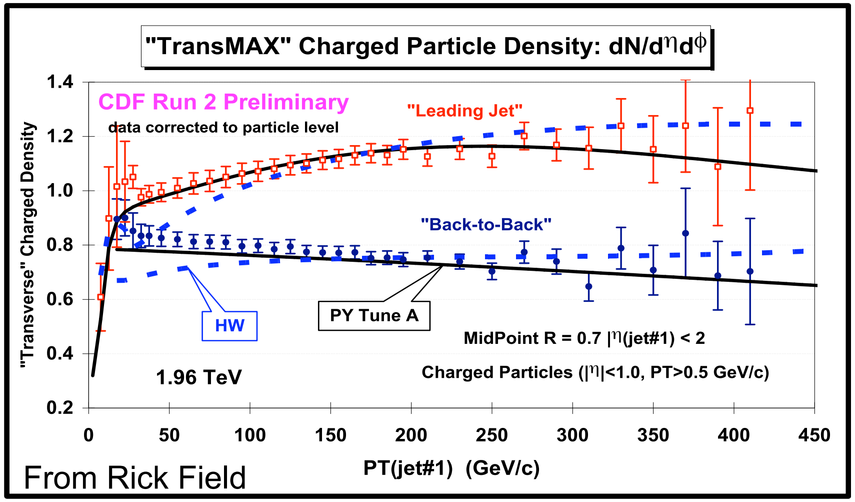
From Rick Field

CDF $\sqrt{s}$=1.96 TeV

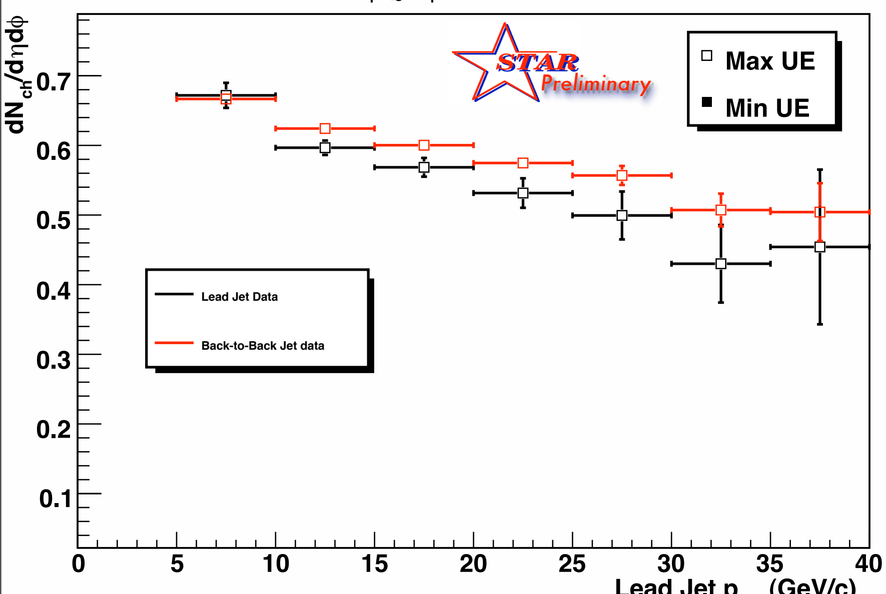
- leading TransMax > back-to-back TransMax

Significant initial/final state radiation at large angles.

ISR and FSR in UE regions



SISCone,R=0.7, $|\eta_{jet}| < 1-R$, $p_{Ttrack} > 0.2$ GeV/c



CDF $\sqrt{s}$=1.96 TeV

- leading TransMax > back-to-back TransMax

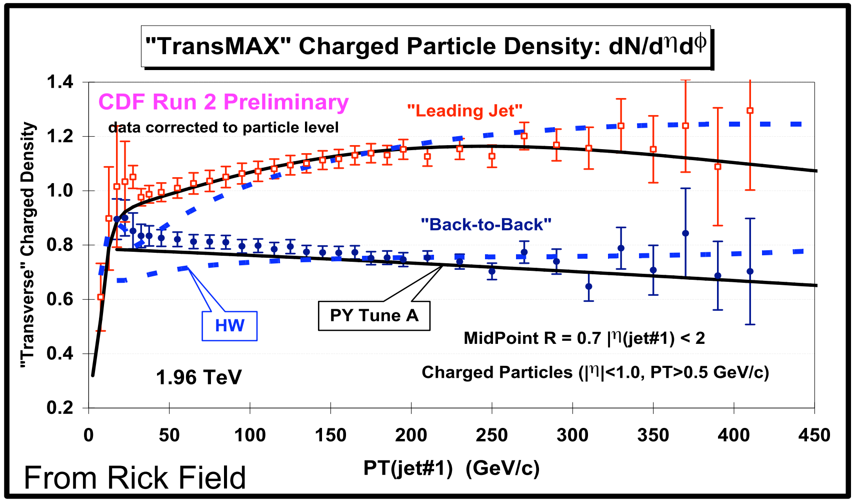
Significant initial/final state radiation at large angles.

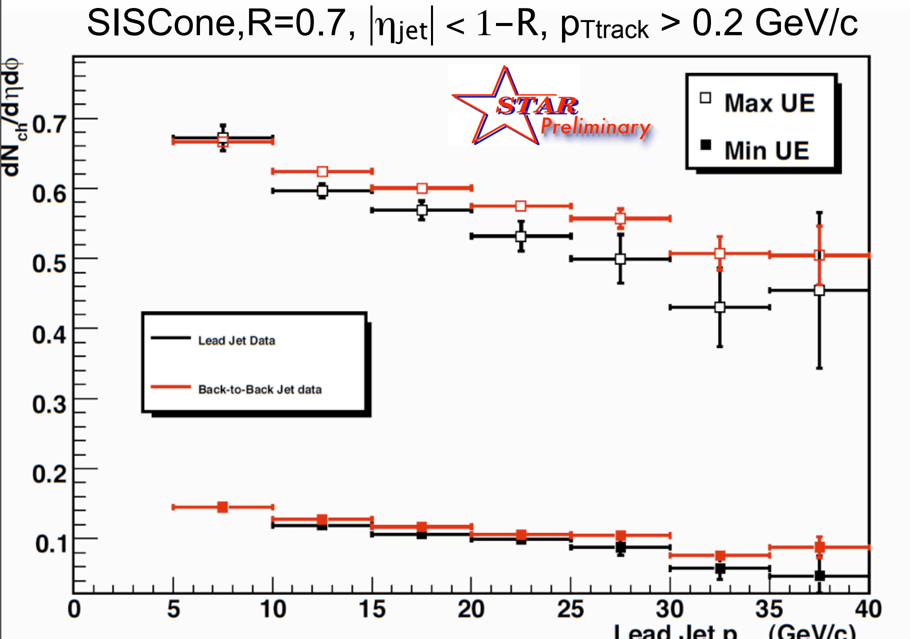
STAR $\sqrt{s}$=200 GeV

- leading TransMax ~ back-to-back TransMax

Small initial/final state radiation at large angles.

ISR and FSR in UE regions





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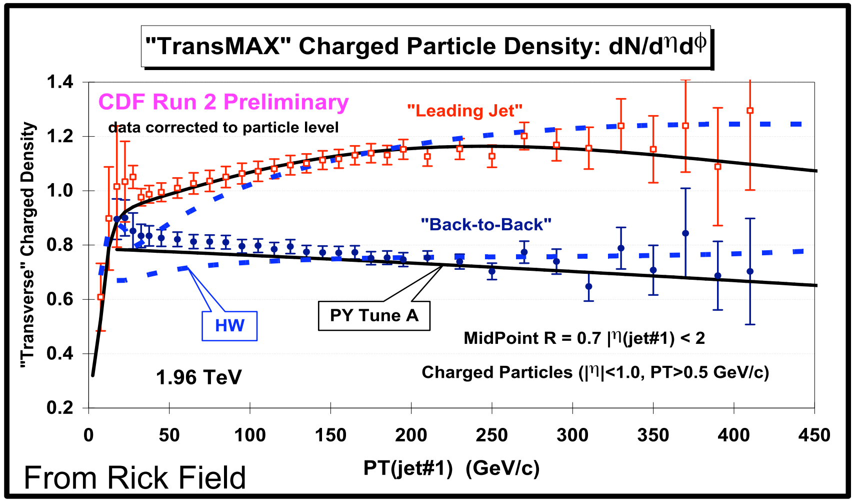
STAR $\sqrt{s}$=200 GeV

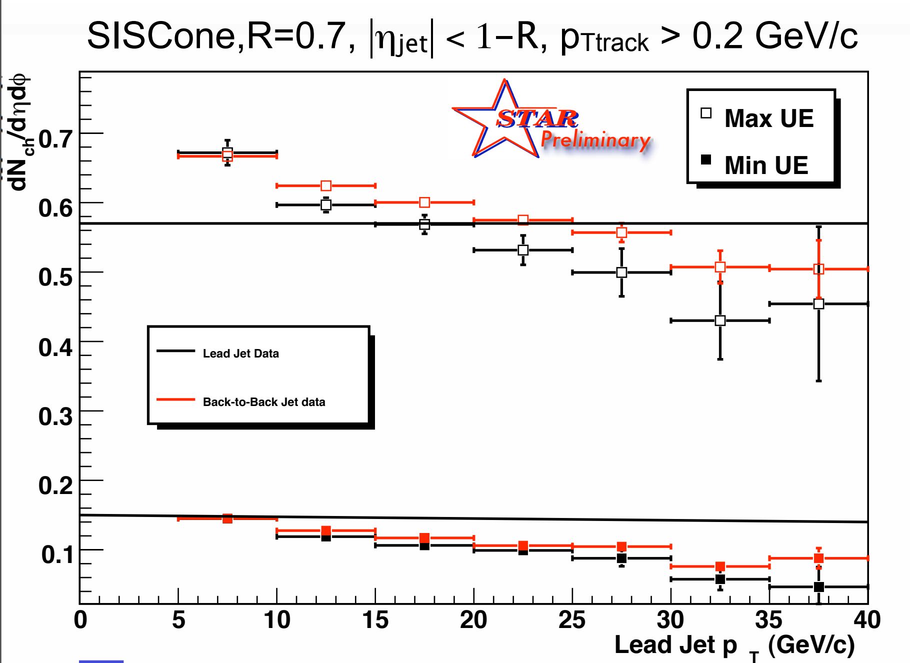
- leading TransMax ~ back-to-back TransMax

Small initial/final state radiation at large angles.

- TransMax > TransMin

ISR and FSR in UE regions





CDF $\sqrt{s}$=1.96 TeV

- leading TransMax > back-to-back TransMax

Significant initial/final state radiation at large angles.

STAR $\sqrt{s}$=200 GeV

- leading TransMax ~ back-to-back TransMax

Small initial/final state radiation at large angles.

- TransMax > TransMin

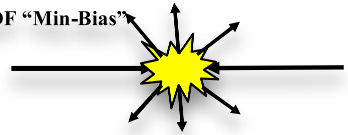
Poisson distribution with average $dN_{ch}/d\eta d\phi$ = 0.36

- UE ~independent of jet p_T.

First look at <p_T> of Min-Bias event

- Sensitive to integral of event components

From Rick Field



=

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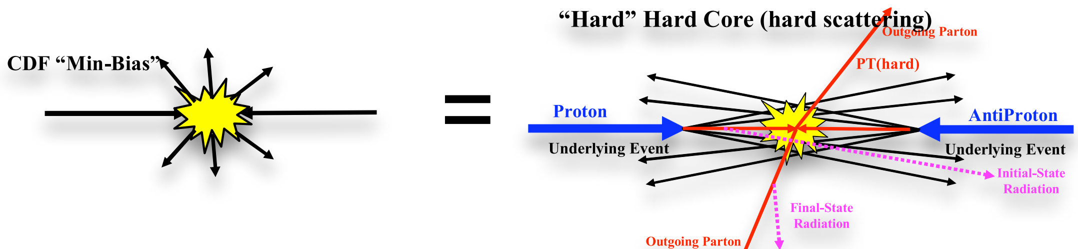
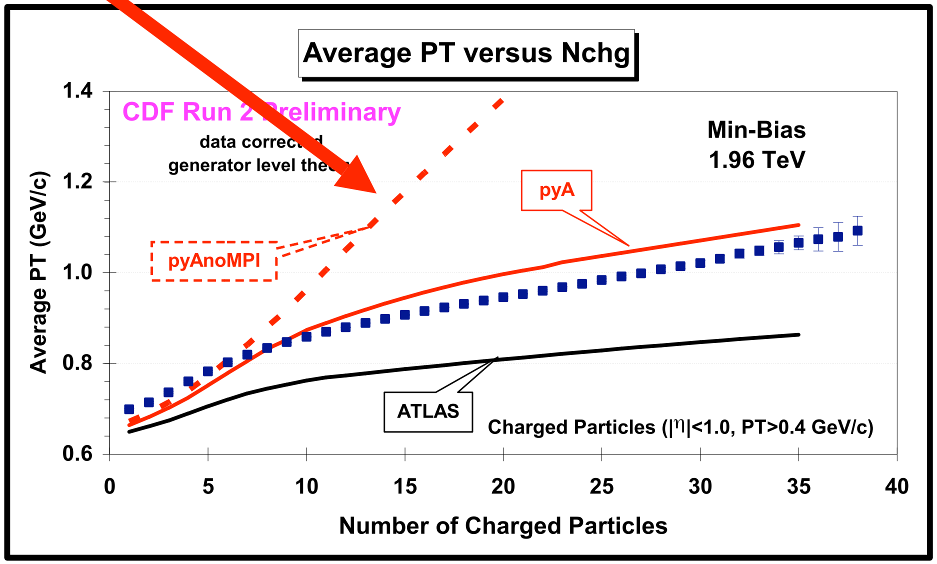


- "Hard" hard core: hard scattering: large mult, large <p_T>



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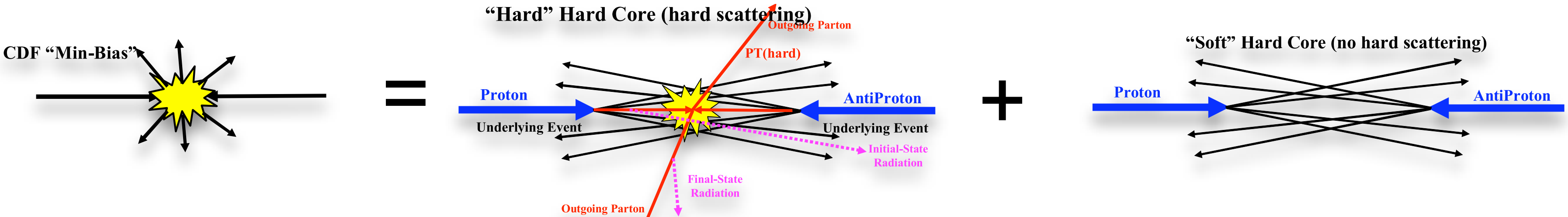
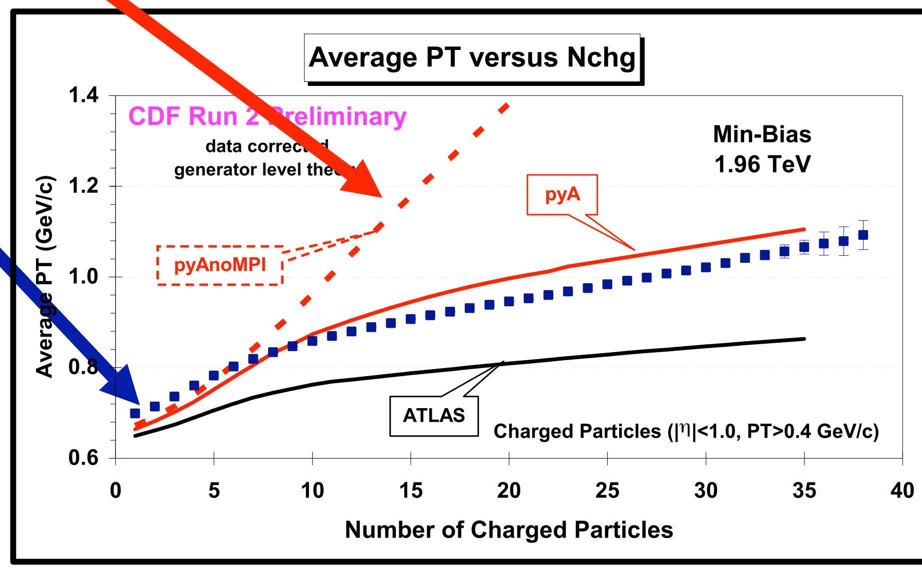


- "Hard" hard core: hard scattering: large mult, large $\langle p_T \rangle$

- "Soft" hard core: No hard scattering: Beam-Beam remnants - low mult, low $\langle p_T \rangle$, indep. of mult



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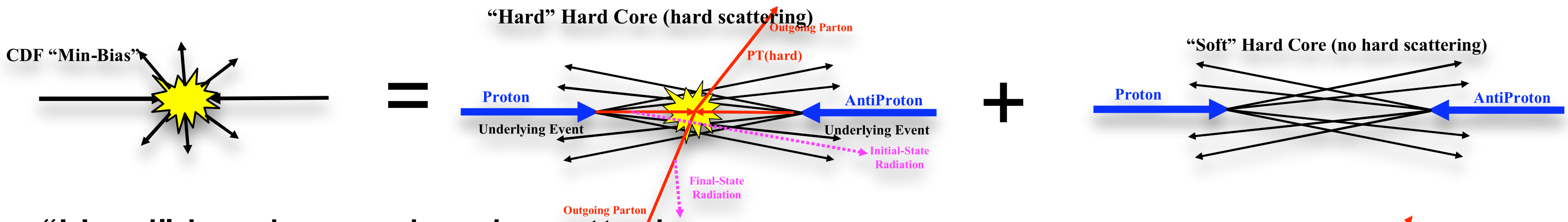

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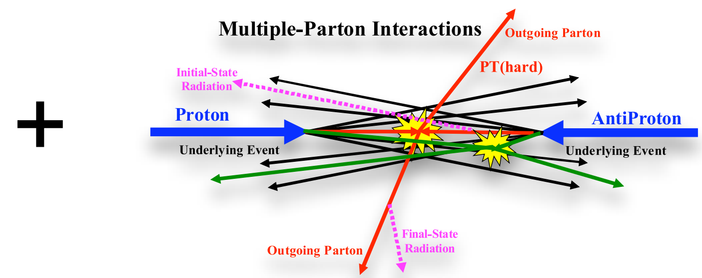

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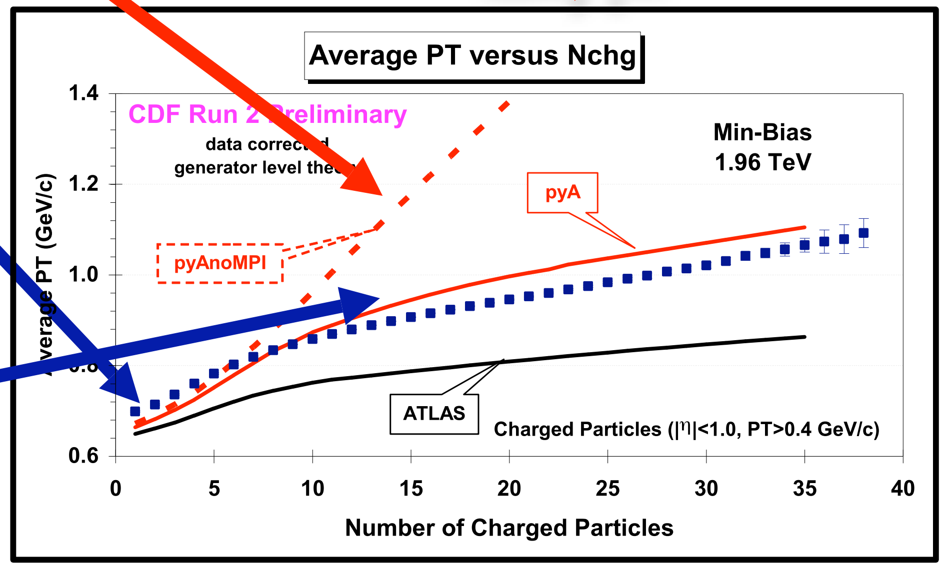
- By playing with these 2 components can nearly get the shape

- But could also include MPI



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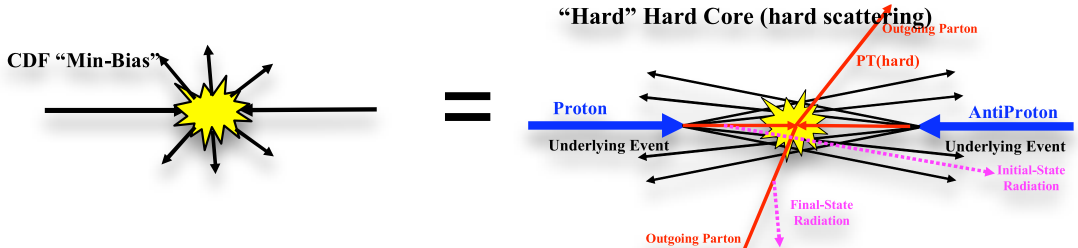

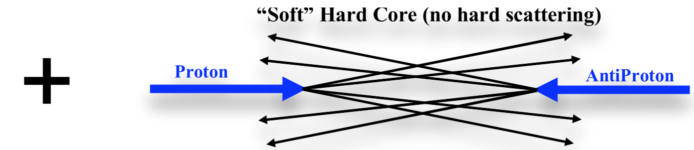

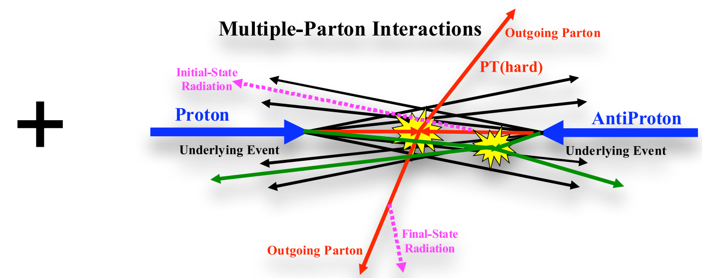

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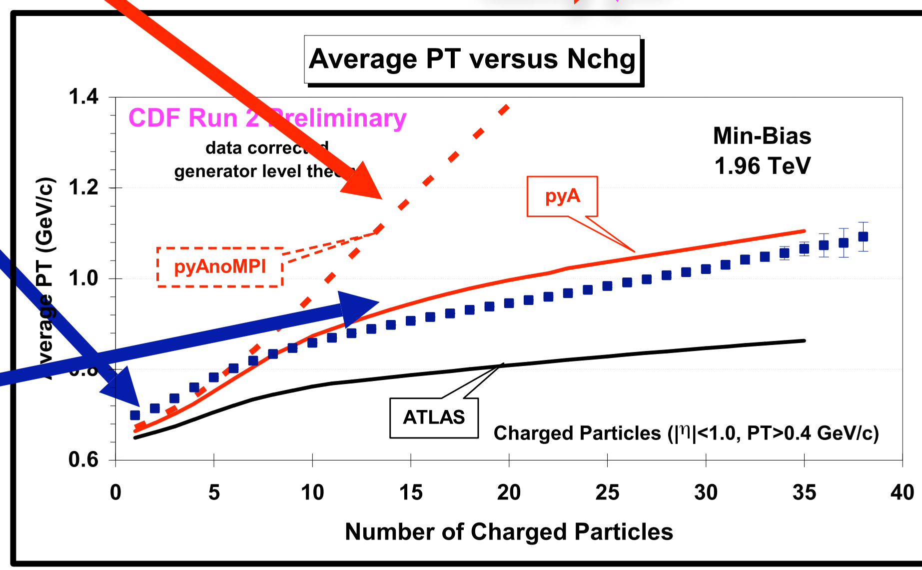
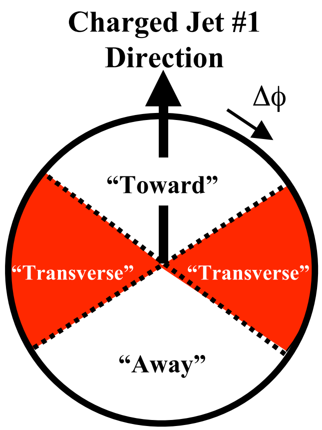
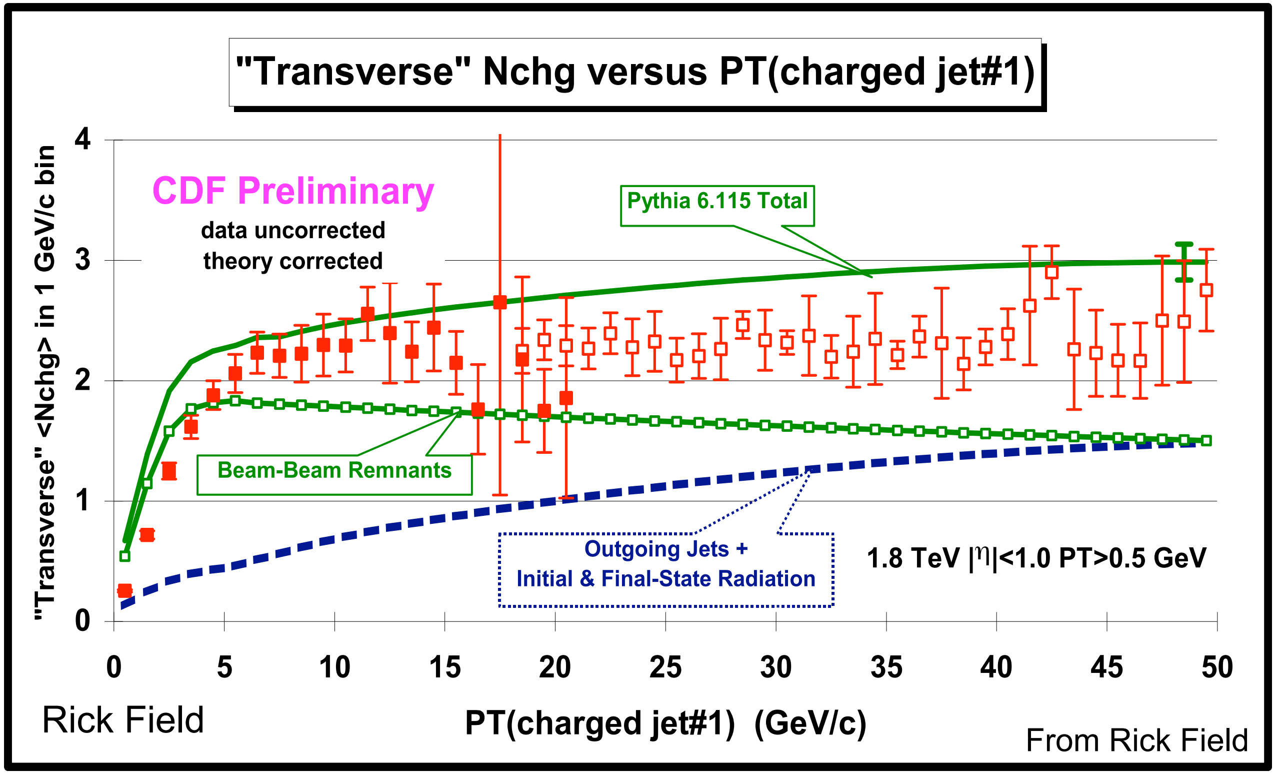


Which is correct? - need more sensitivity

The transverse region

- Initially PYTHIA divided events into only 2 categories: beam-beam remnants and outgoing jet+ISR+FSR

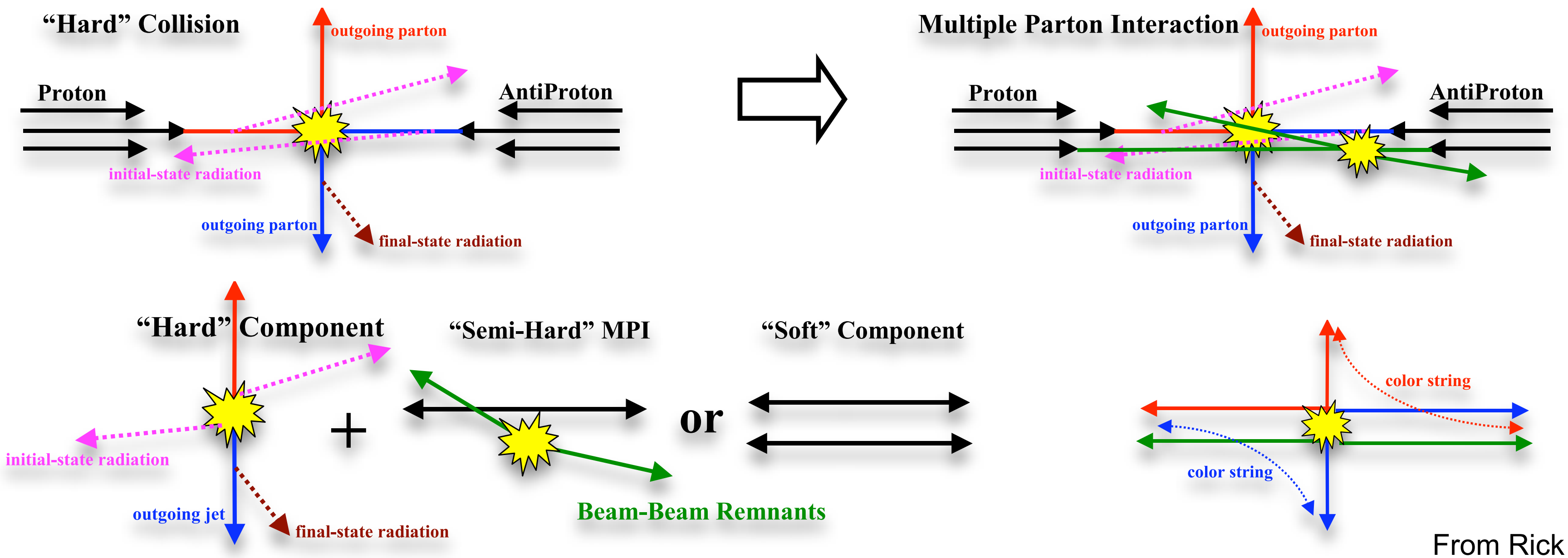




- In order to get the steep rise correct overshot the high jet p_T multiplicities

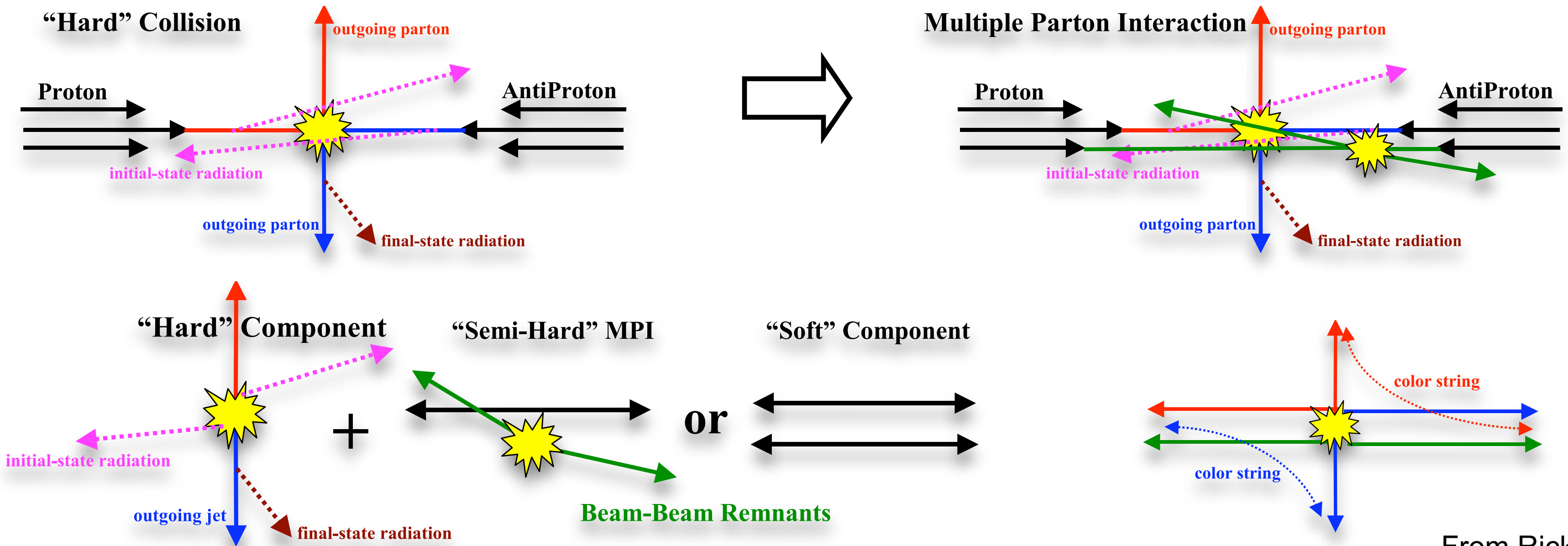
Needed something else

MPI: Multiple Parton Interactions



From Rick Field

MPI: Multiple Parton Interactions



From Rick Field

- UE: color string fragmentation - mostly soft
  + MPI - second semi-hard interaction

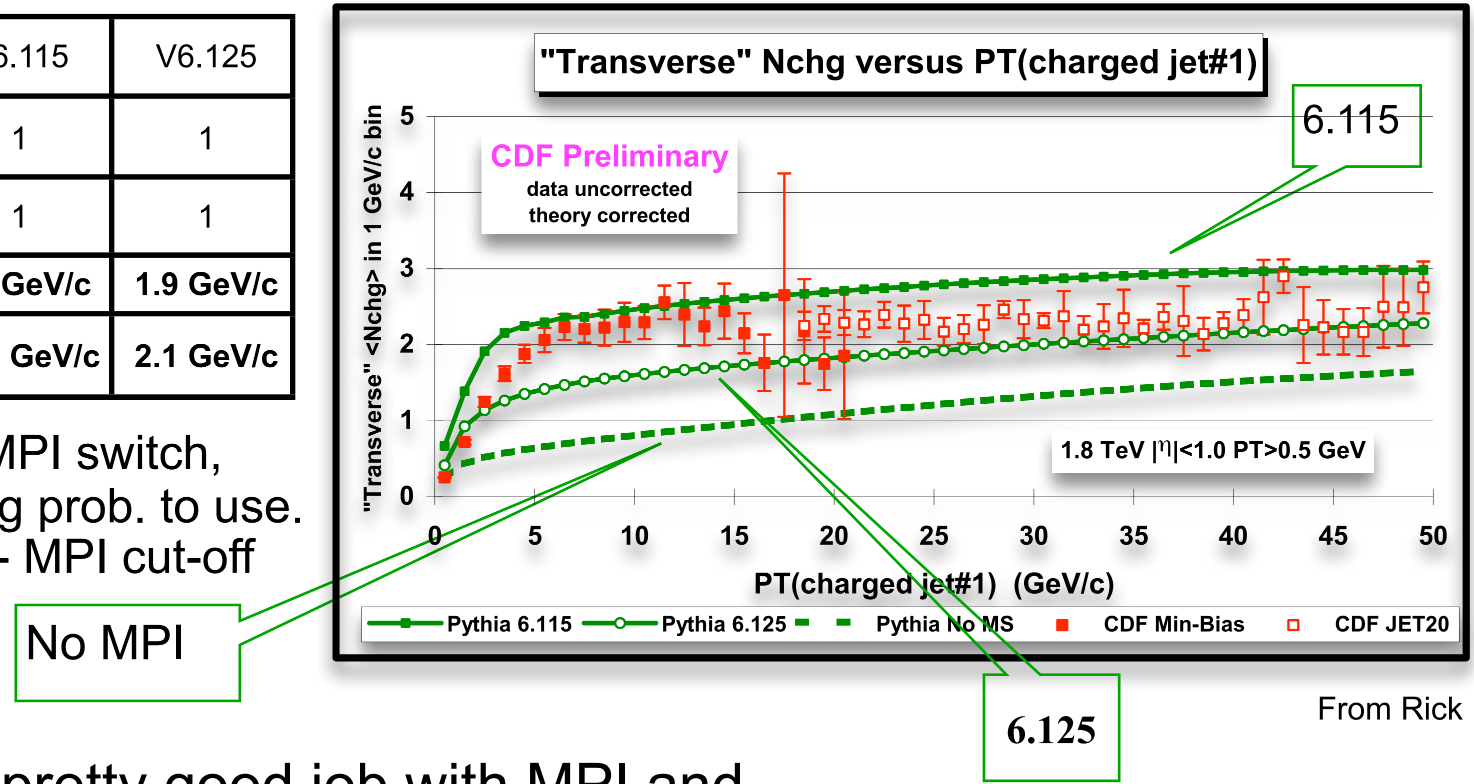
Calculations allows:

- Variation of prob. of 2nd scattering
- How/if MPI depends on p_T of hard scattering
  - X-section impact parameter dependence or const.
  - single- double- Gaussian matter distribution
- Adjustment of the color connections and flavor of MPI (singlet, nearest neighbour, q-qbar, g-g)

Determining MPI Parameters

Parameter	V6.115	V6.125
MSTP(81)	1	1
MSTP(82)	1	1
PARP(81)	1.4 GeV/c	1.9 GeV/c
PARP(82)	1.55 GeV/c	2.1 GeV/c

MSTP(81) - MPI switch, what scattering prob. to use.
PARP(81/82) - MPI cut-off



From Rick Field

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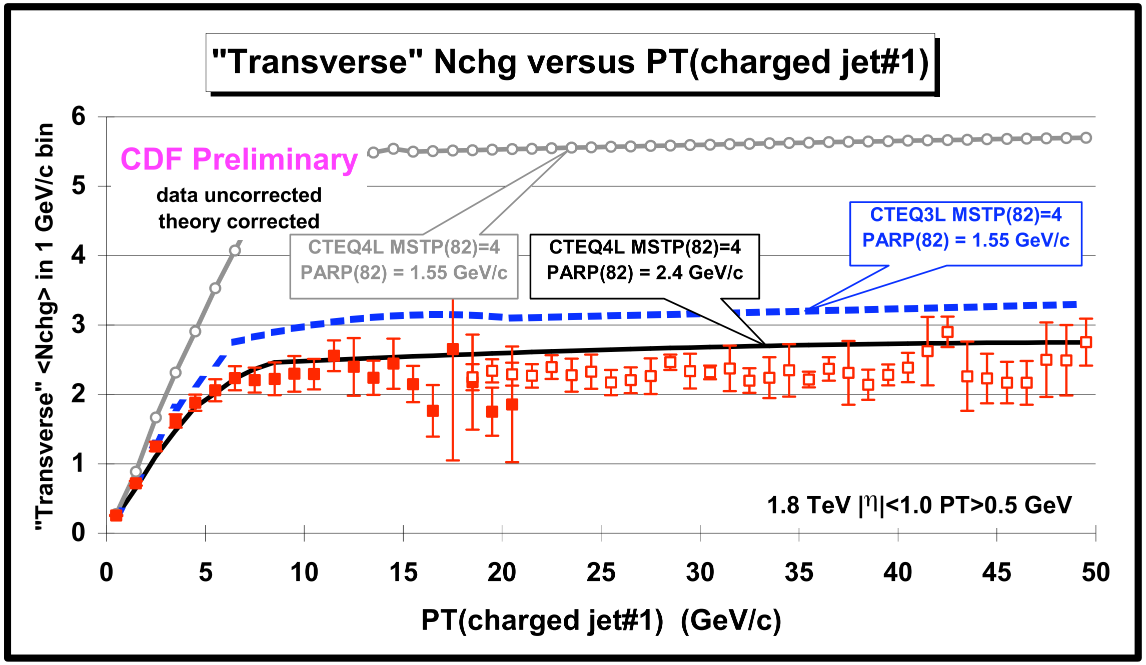

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- Note strong dependence on PDFs

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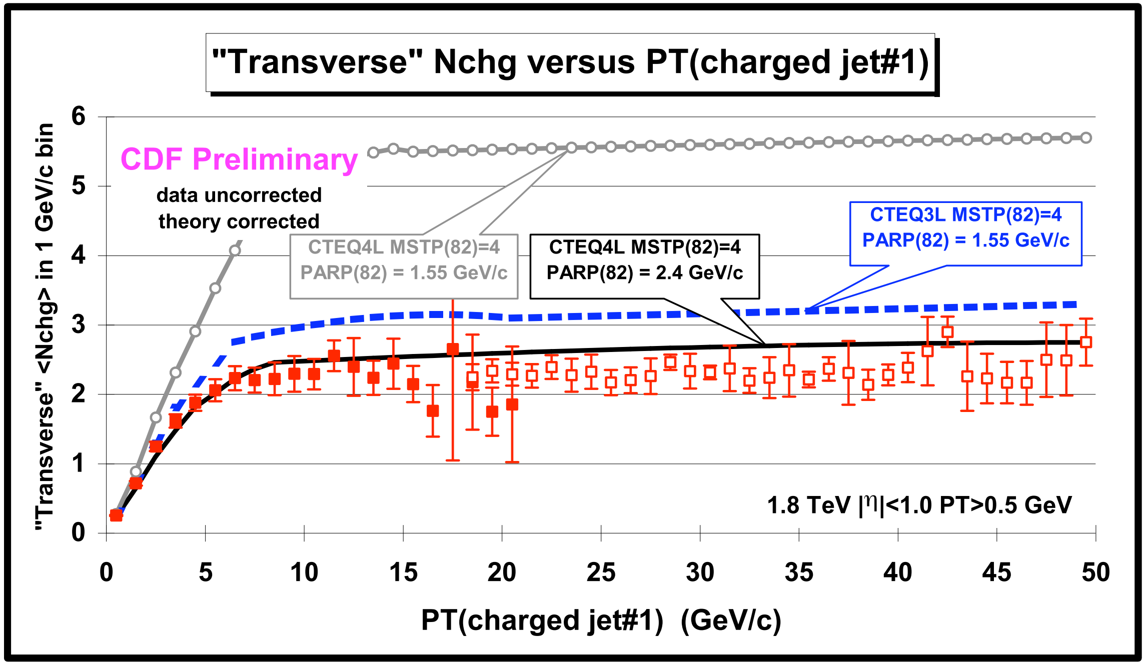

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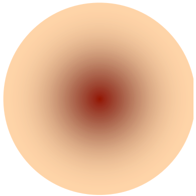
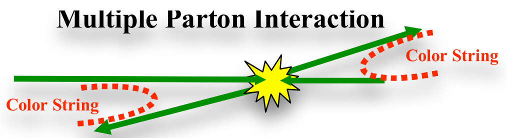


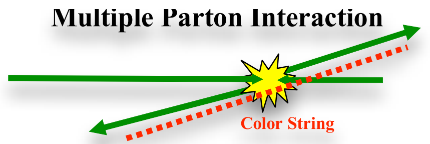
p: double Gaus hard core → collisions have impact parameter dependence

Determining the MPI Parameters

- PARP(85)= 0.33: Prob. MPI produces 2 gluons with color connections to nearest neighbour



- PARP(86)=0.66 : Prob. MPI produces 2 gluons with color connections to nearest neighbour or as a closed gluon loop. The remaining fraction a q-qbar pairs



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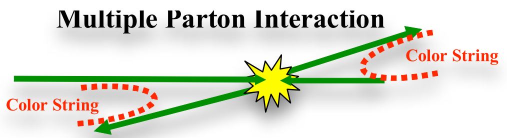

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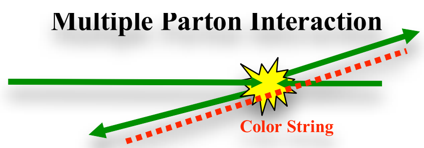

- PARP(67)=1.0: Scale factor for max. parton virtuality for space-like showers. Larger PARP(67) → larger ISR

From Rick Field

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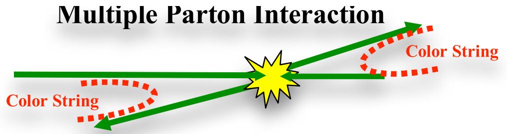

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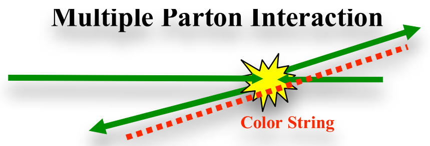

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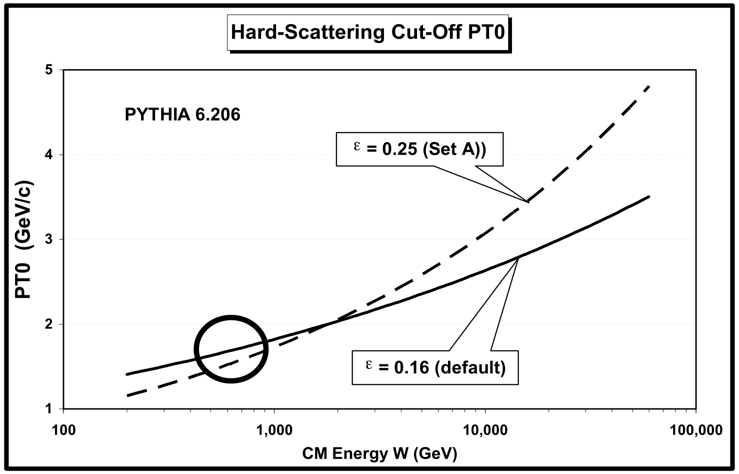
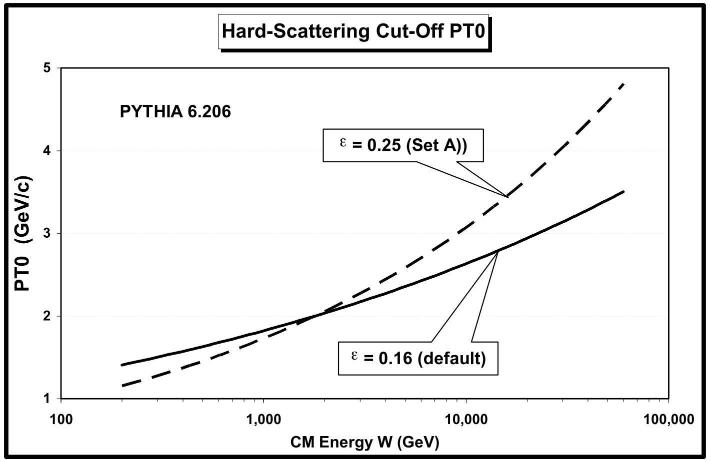
- PARP(89)=1.8 TeV: Reference E for tuning

- PARP(90)=0.16 : Hard scattering cut-off for $P_{T0}(E_{cm}) = P_{T0}(E_{cm}/E_o)^{PARP(90)=\varepsilon}$



From Rick Field

Effect of hard scattering cut-off scaling



- Increasing ε creates smaller energy dependence for UE
- remember pivot point at 1.9 TeV

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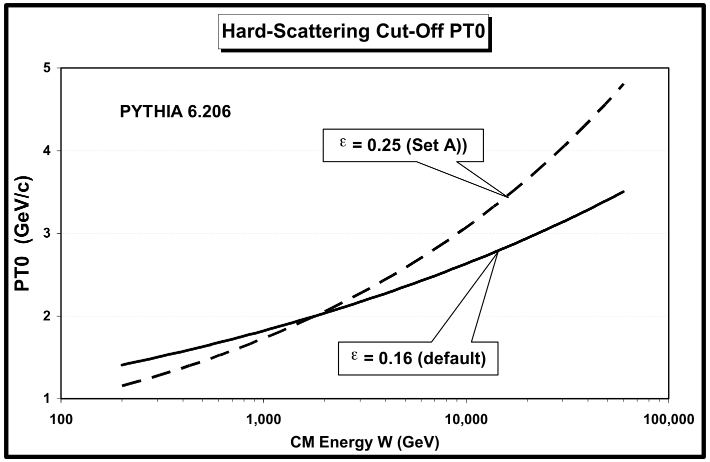
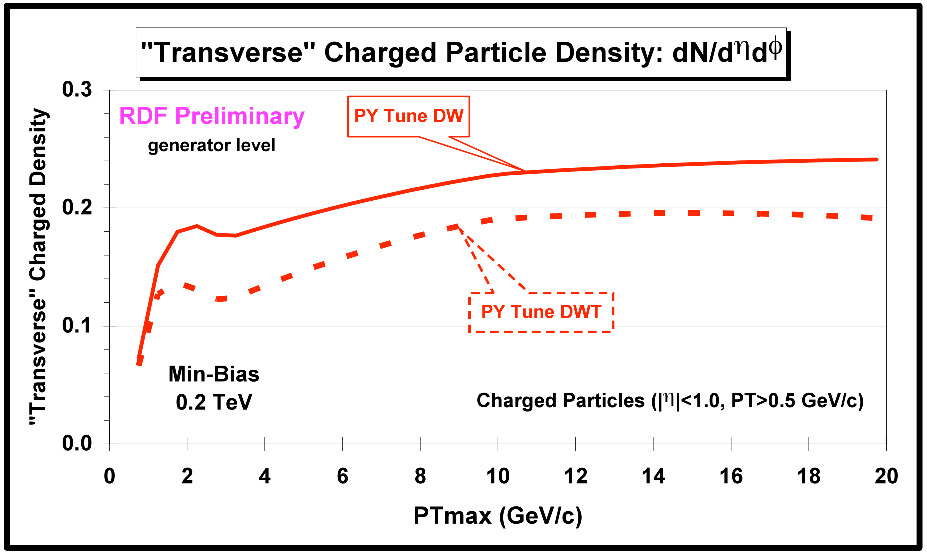
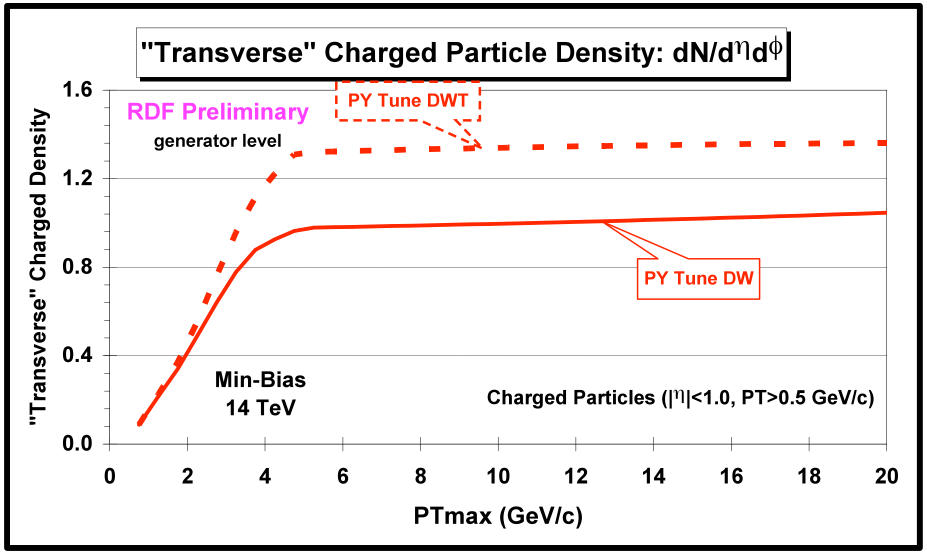
Effect of hard scattering cut-off scaling



- Increasing ε creates smaller energy dependence for UE
- remember pivot point at 1.9 TeV

- ε = 0.16 (DWT) → 0.25 (DW) (suggested by 630 GeV Tevatron) → 35% more RHIC, 26% less LHC

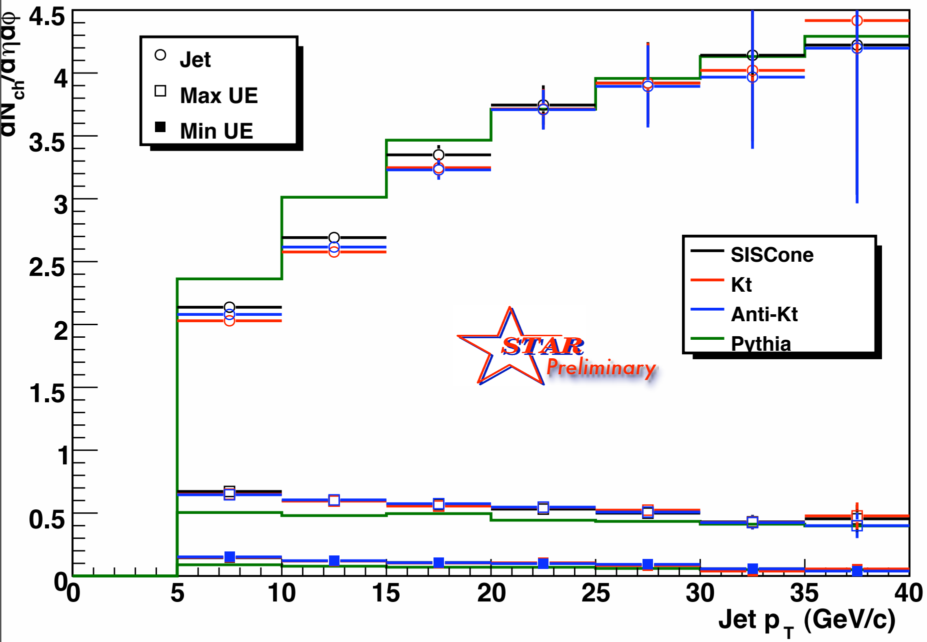


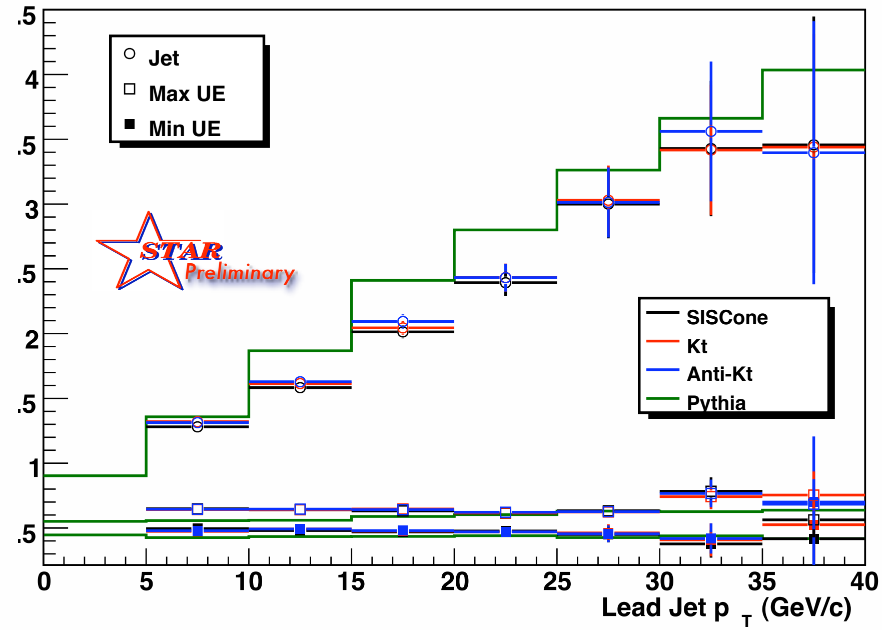


From Rick Field

Checking energy scaling at RHIC

Back-to-Back, R=0.7, $|\eta_{jet}| < 1-R$, $p_{Ttrack} > 0.2$ GeV/c

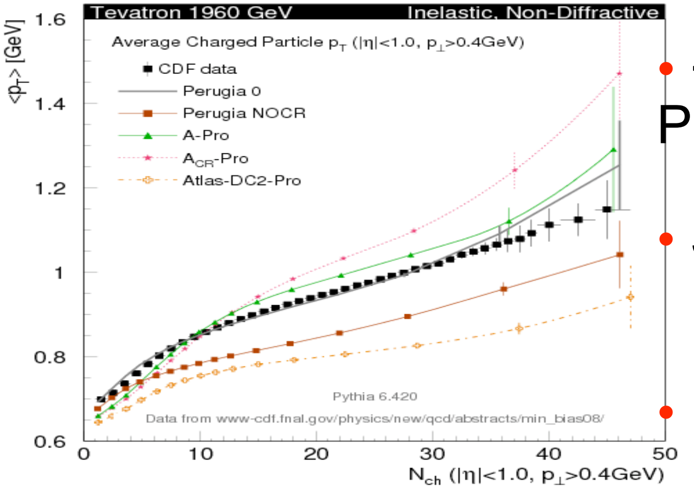




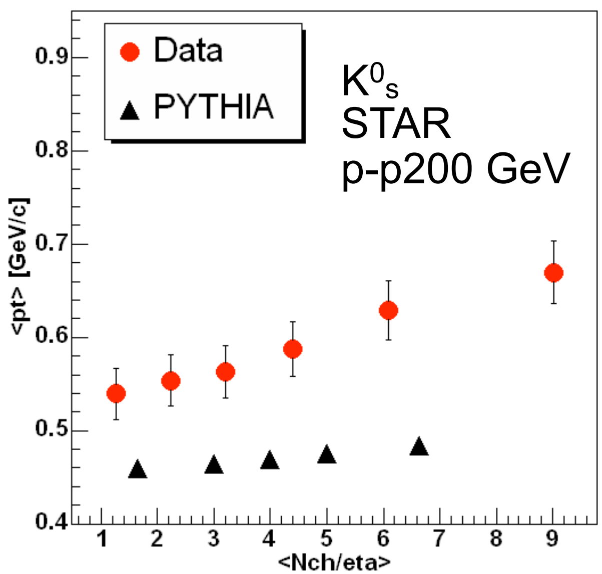
RHIC data support ε = 0.25

- Note many standard PYTHIA tunes (including those called “ATLAS”) tunes have ε = 0.16 this is INCORRECT activity in min-bias events wrong

Underlying Event and Color

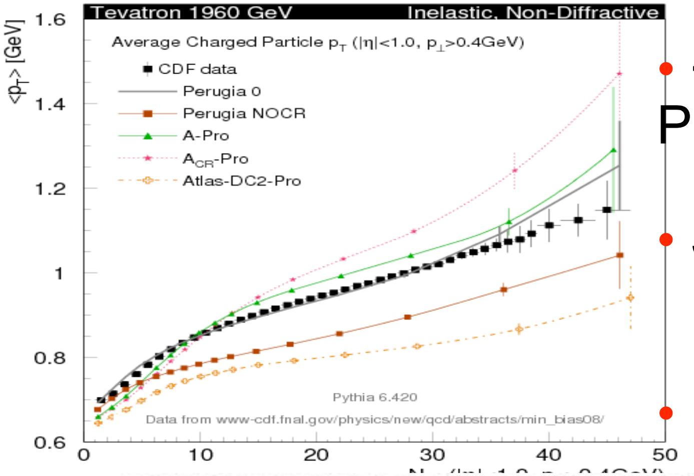


- $<p_T>$ highly correlated with event multiplicity: Problem for PYTHIA
- String frag→ Mult ~ log(m_{string})
- More strings → more Mult. but $<p_T>$ const



From Peter Skands

Underlying Event and Color



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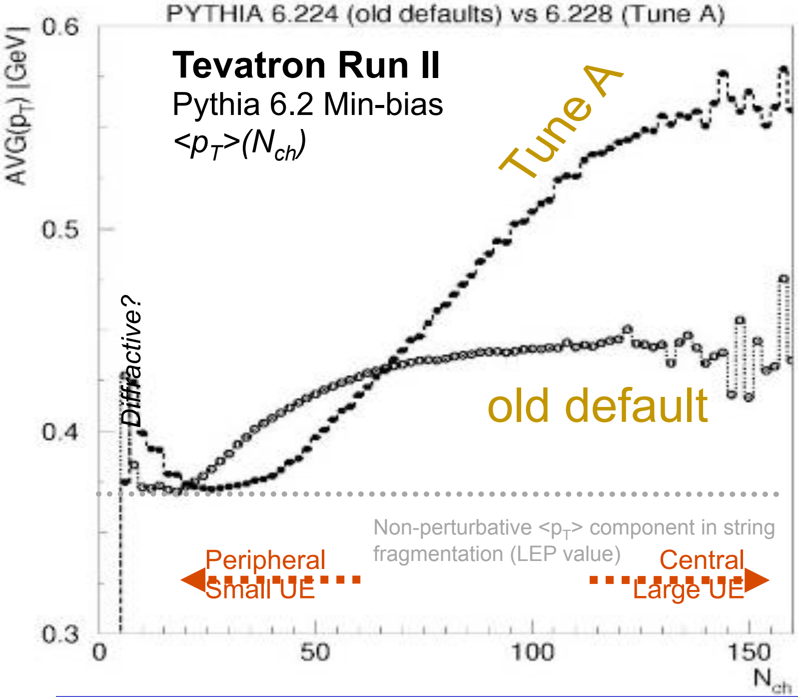


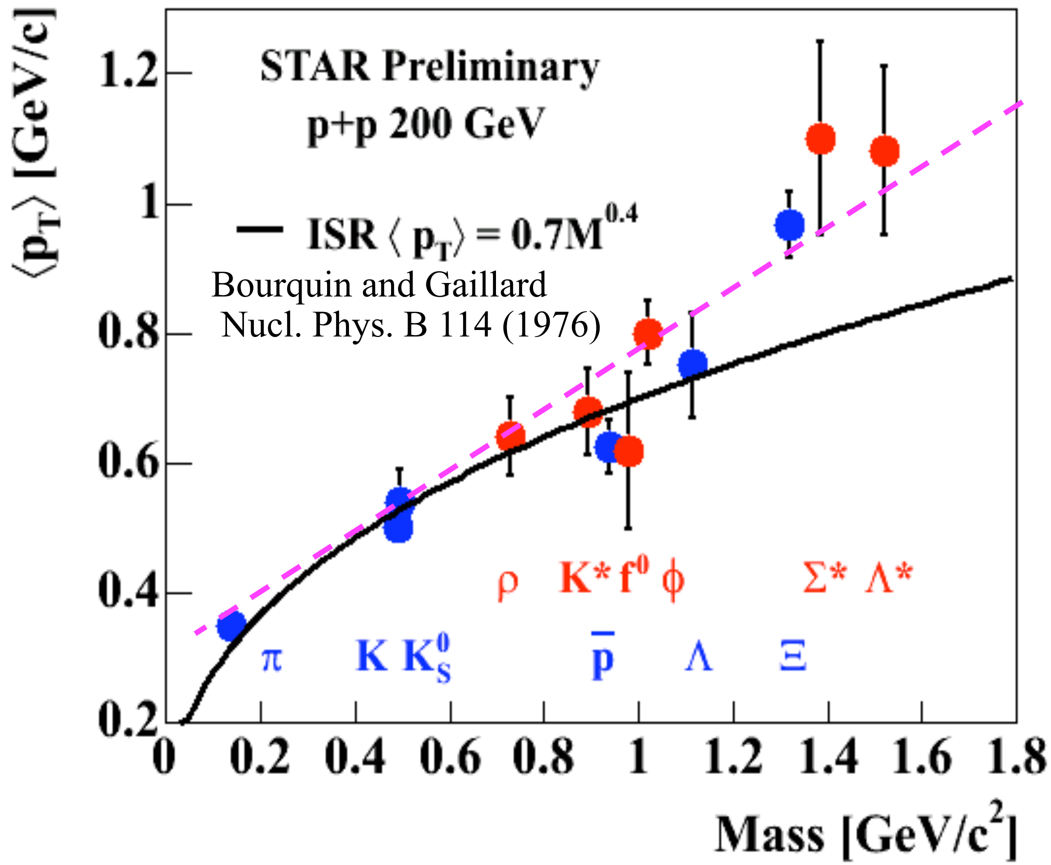
- However if MPI correlated in color → each MPI does not produce independent string → $<p_T>$ not flat dependence on Mult.
- Rick Field tried and saw good match with data but only with 100% correlation in color space between different MPI - not understood

From Peter Skands

$\langle p_T \rangle$ vs particle mass

Measured particle spectra over large mass range

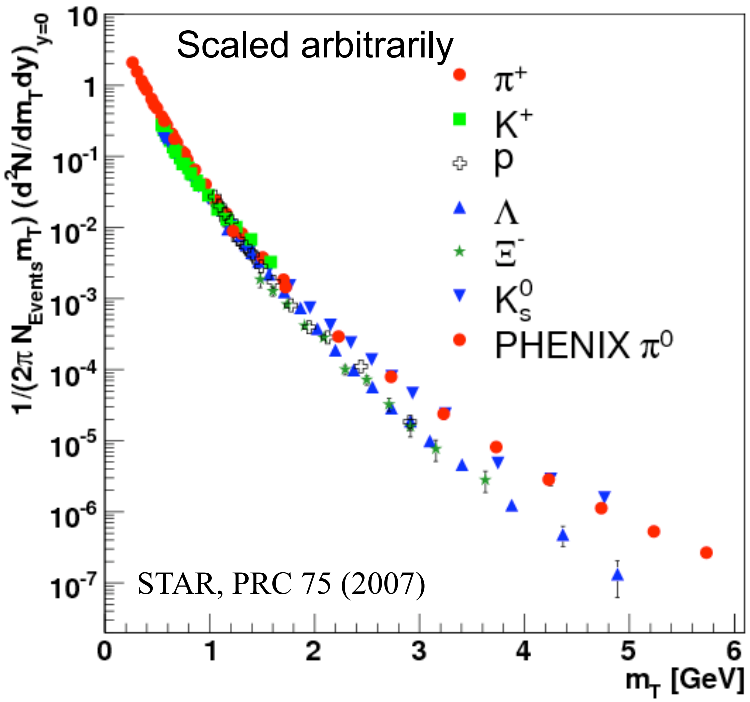
- Mass dependence, but don't expect flow in p+p
- Nice agreement with phenomenological curve established by ISR (23 GeV) for lower masses
- Strange baryons and resonances are above the curve



Linear dependence seems a better description at mid-rapidity

m_T scaling of identified particles

- First studied at ISR - In Color Glass Condensate (CGC) picture m_T-scaling would be indicative of evidence of gluon saturation
- No absolute scaling (data shown are arbitrarily normalized)
- Baryon meson splitting above m_T ~2 GeV/c



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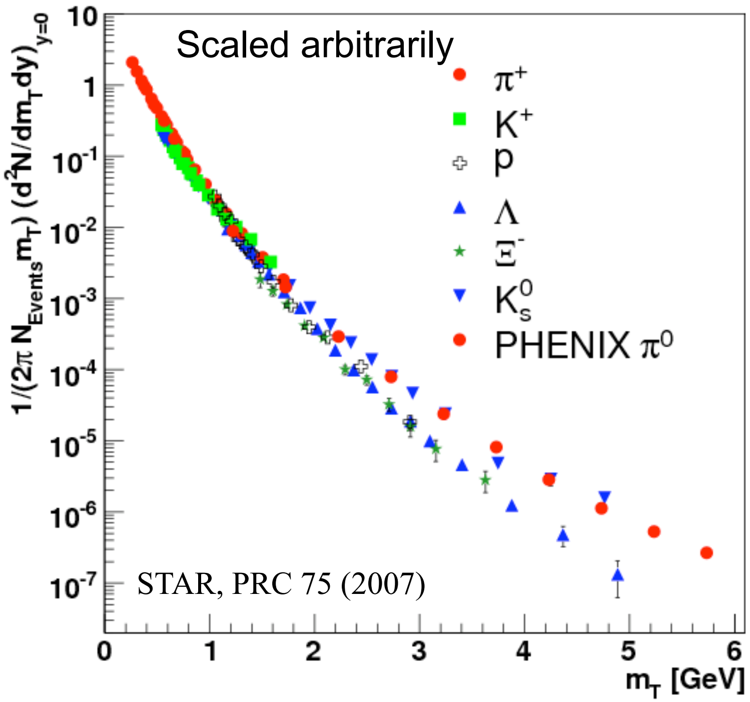

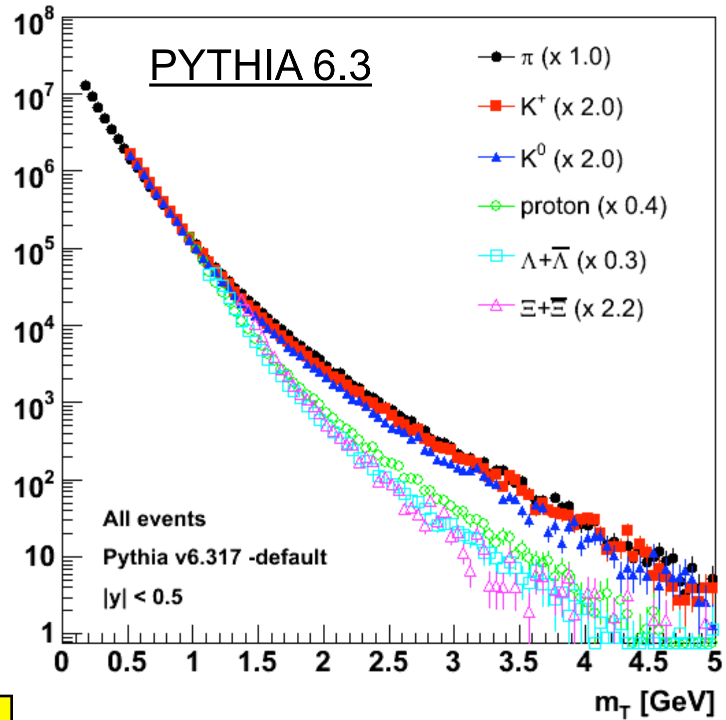

PYTHIA and data show similar trends

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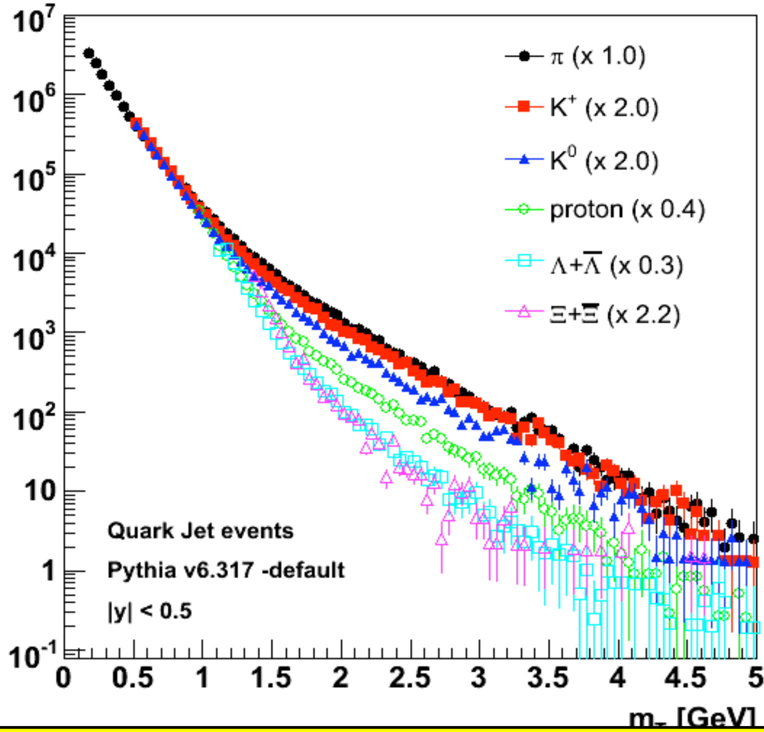
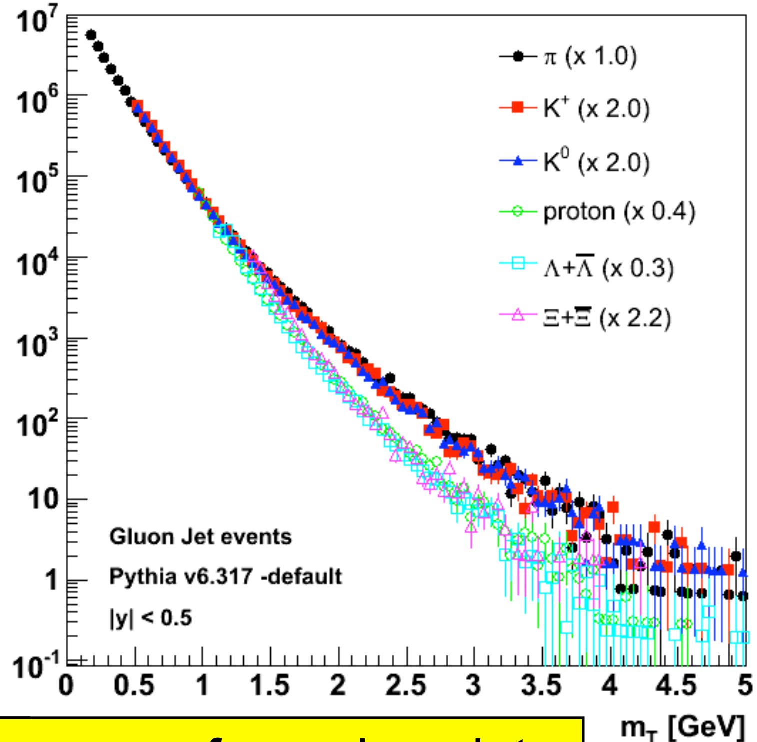
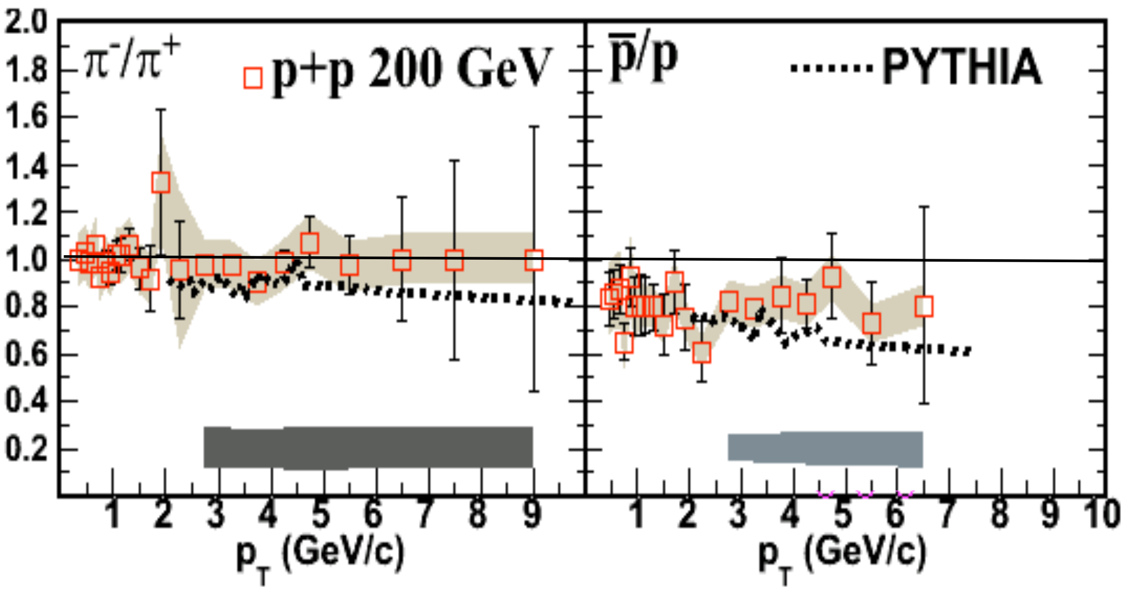




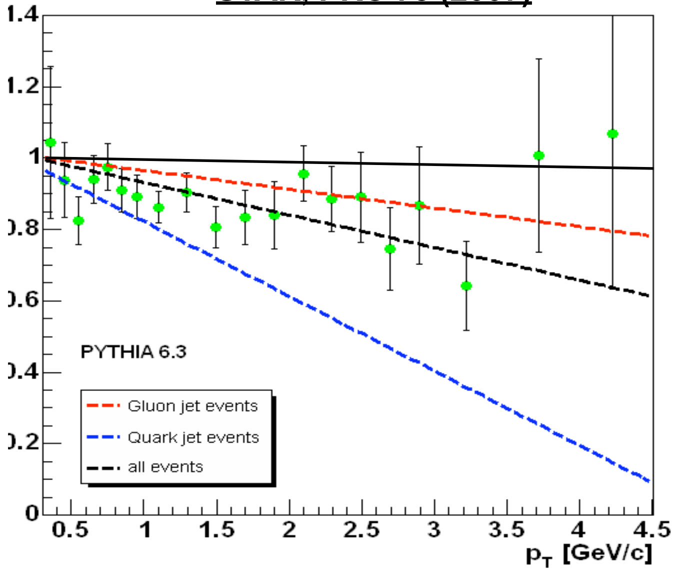
PYTHIA and data show similar trends - comes from gluon jets

Particle/Anti-particle ratios

STAR, Phys Lett B, 637 (2006) 161



STAR, PRC 75 (2007)



PYTHIA predicts:

- flat p_T dependence for π^-/π^+
- slightly more prominent p_T dependence for $\bar{p}/p$
- even stronger dependence for $\bar{\Lambda}/\Lambda$

Good agreement with current data

Data is consistent with gluon jet dominated production - but does not allow strong conclusion

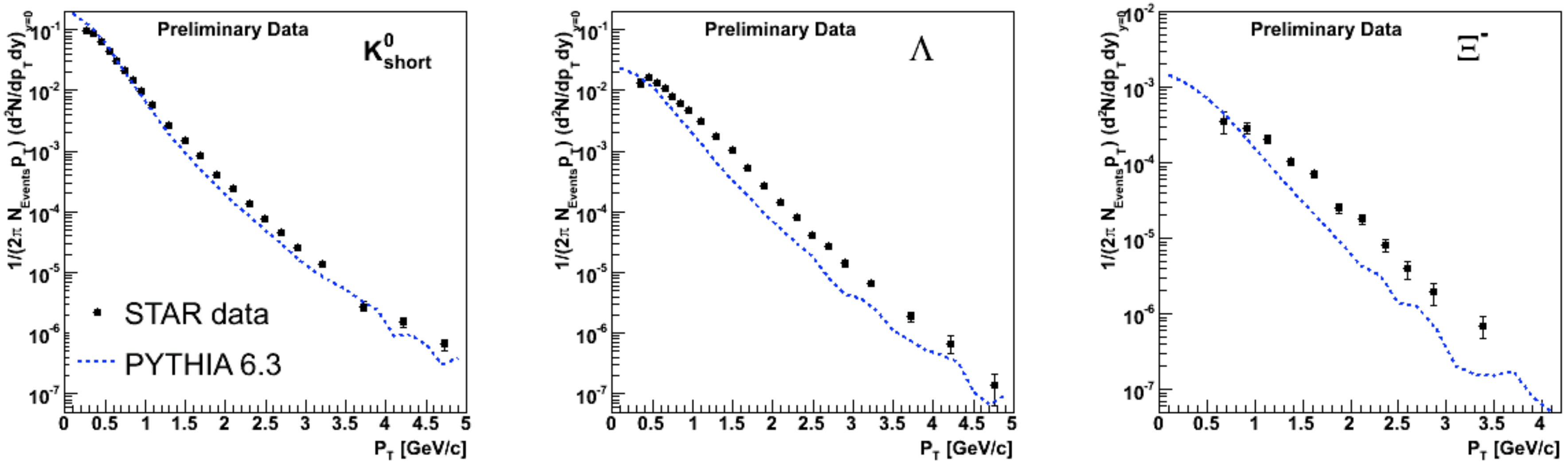
So far PYTHIA seems to be doing excellent job!

But there are problems

- Strangeness production
- Baryon transport
- Heavy flavour production

PYTHIA description of strange p_T-spectra

- PYTHIA Version 6.3
  - Incorporated parameter tunes from CDF
  - New multiple scattering and shower algorithms
- Fails to describe baryons with default parameters



From Mark Heinz

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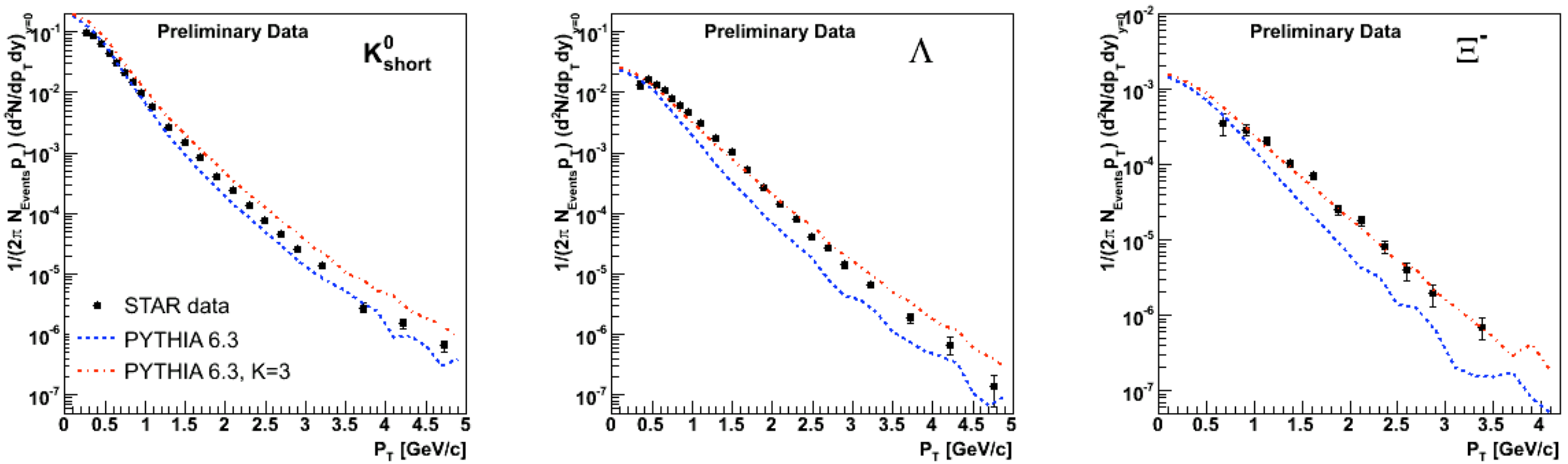
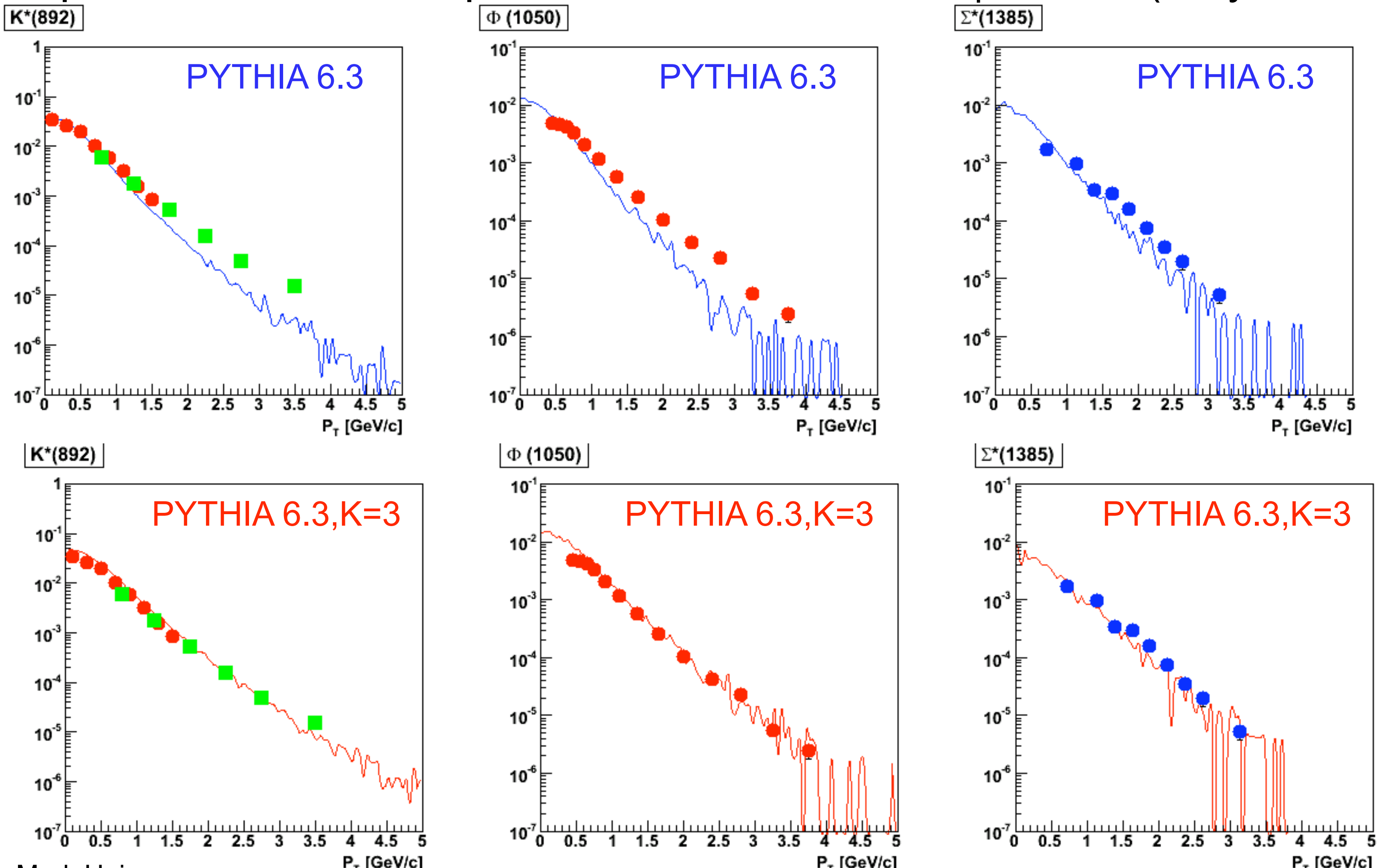


From Mark Heinz

Necessary to tune: K-Factor (accounts for NLO contribution)

What about strange resonances ?

- Compare PYTHIA 6.3 to published STAR data on ϕ, K*, Σ^* (baryon resonance)

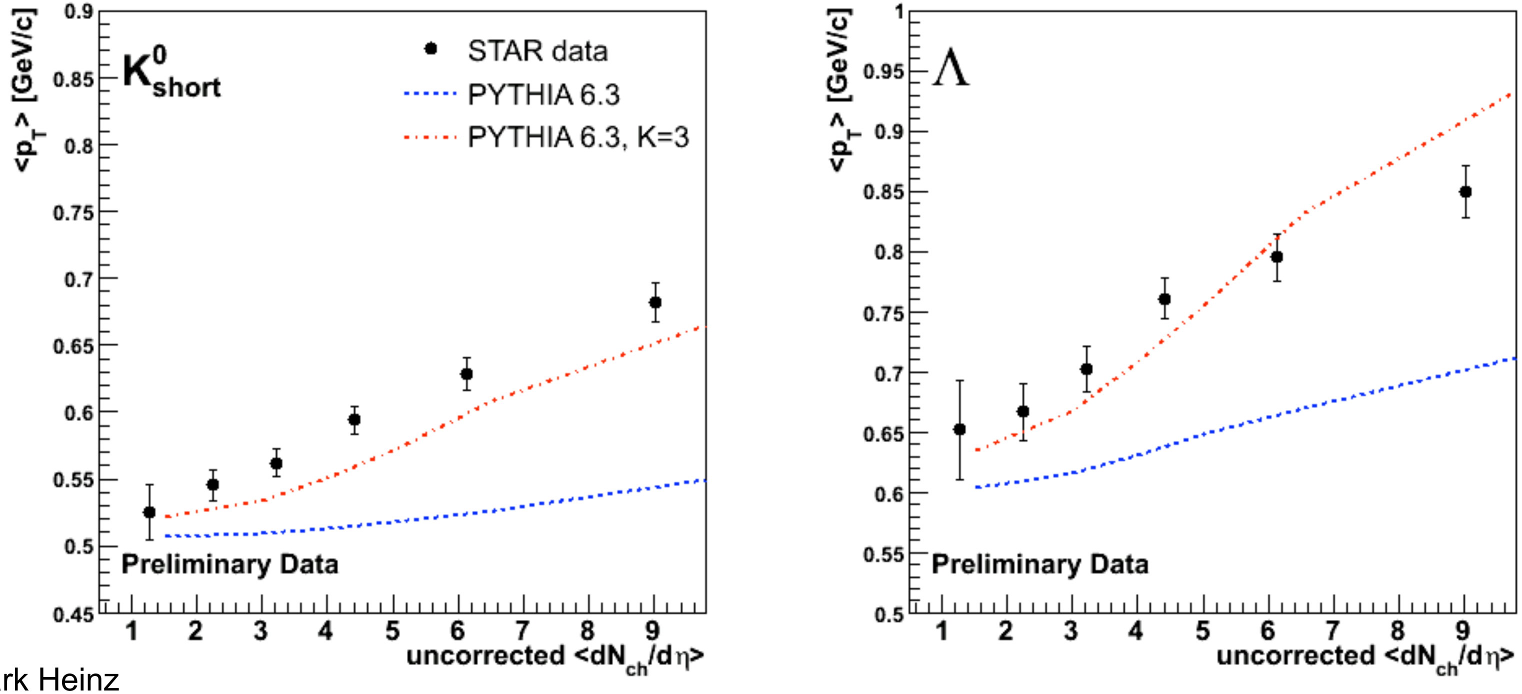


From Mark Heinz

Resonance data also need K=3 for good description

PYTHIA $<p_T>$ vs N_{ch}

- More sensitive observable to compare models to (mini-jet and/or multiple interaction implementations in models)

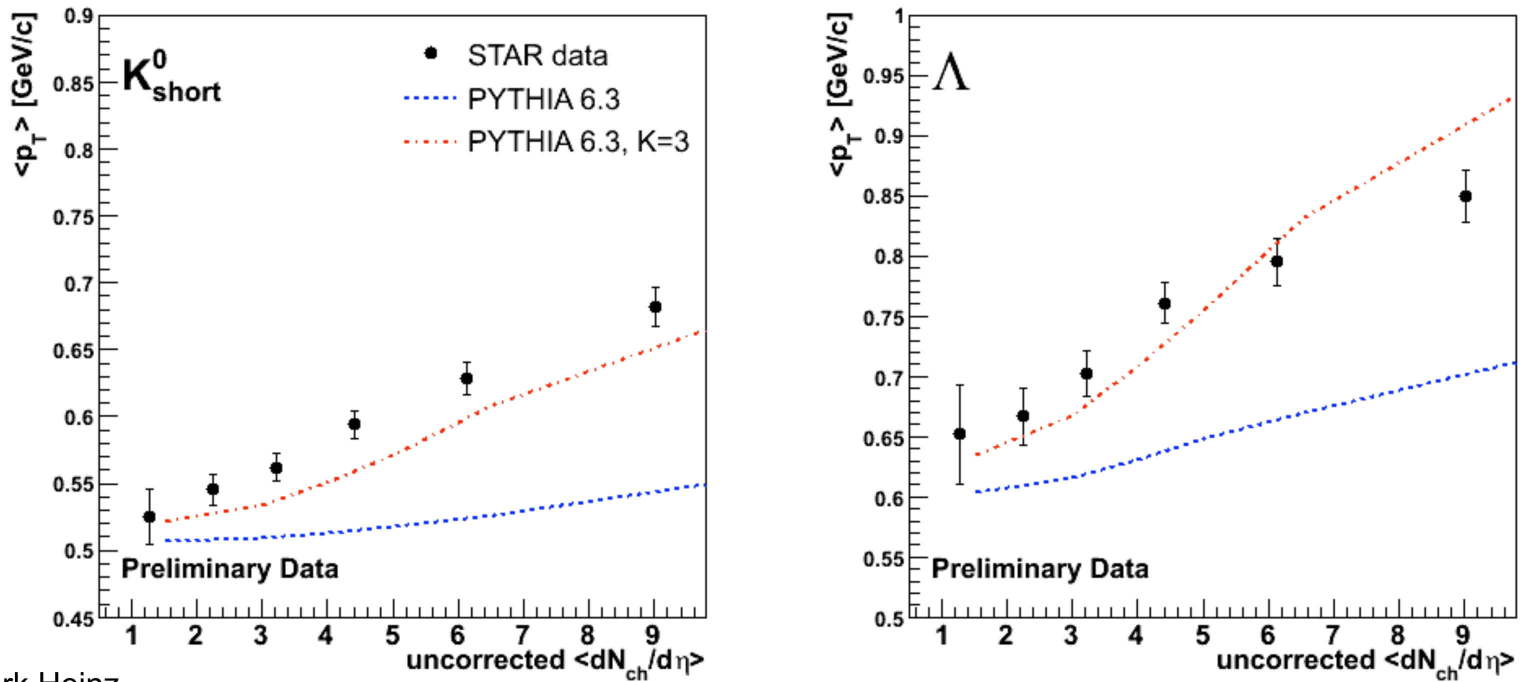


From Mark Heinz

K factor tuned PYTHIA seems to do OK job for strange hadrons

PYTHIA $<p_T>$ vs N_{ch}

- More sensitive observable to compare models to (mini-jet and/or multiple interaction implementations in models)
- K-factor accounts for increase of $<p_T>$ with charged multiplicity



From Mark Heinz

K factor tuned PYTHIA seems to do OK job for strange hadrons

K-factor in LO pQCD

- How is the K-factor defined?

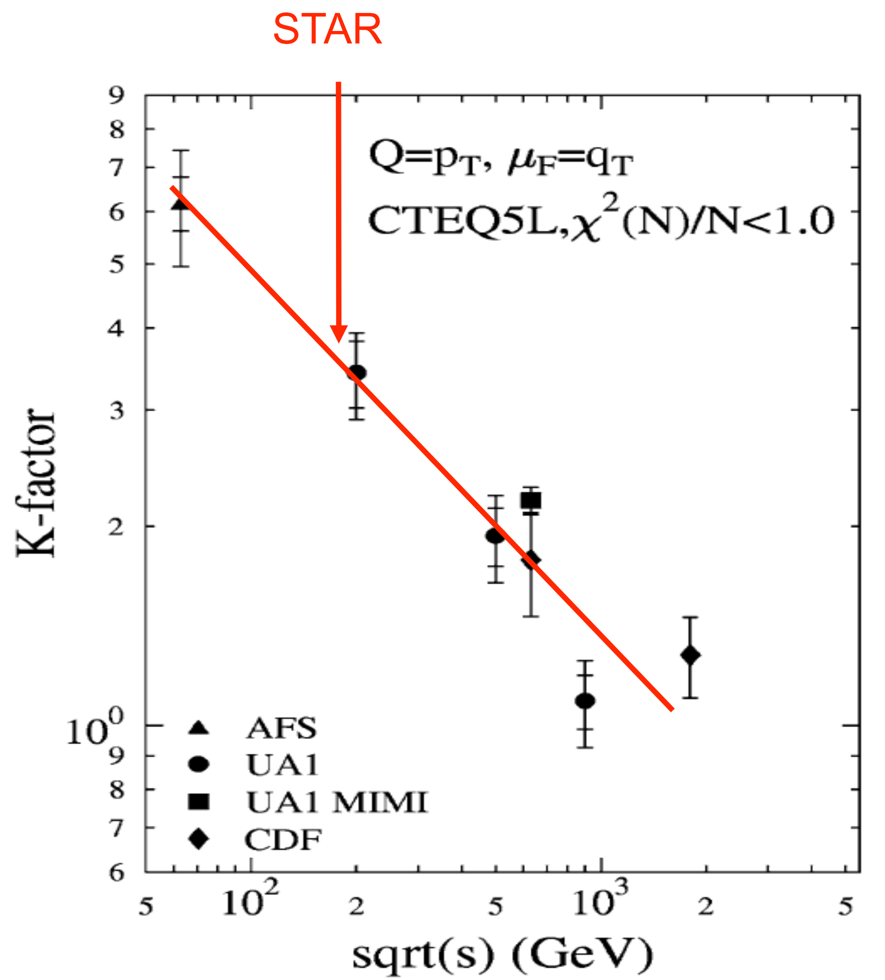
- Two definitions:

$$K_{obs} = \sigma_{exp} / \sigma_{LO}$$

$$K_{th} = \sigma_{NLO} / \sigma_{LO}$$

- Flavor dependence of K-factor, differing NLO contributions ?

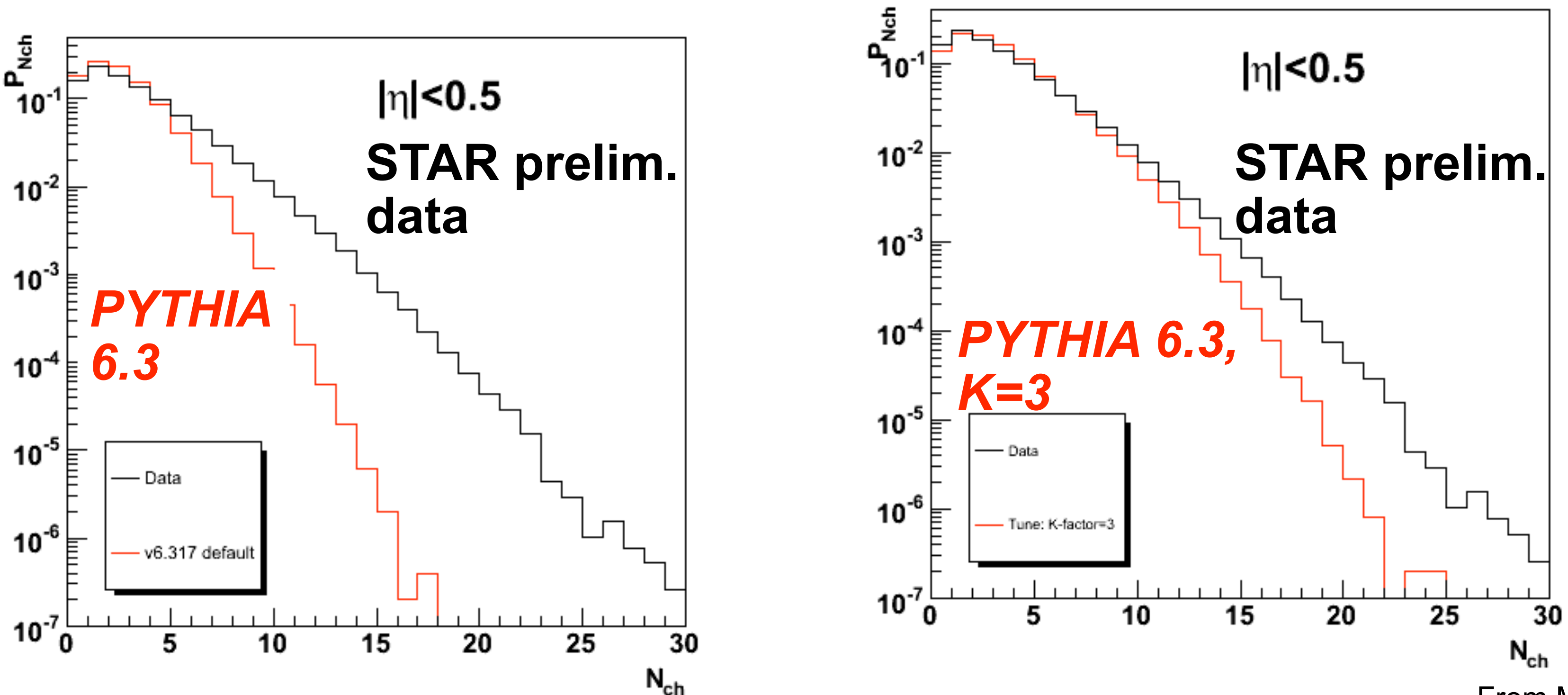
- For h^- it decreases for collision energy
  - contribution of NLO processes smaller at higher energies



Eskola et al Nucl. Phys A 713 (2003)

K factor of 3 not unreasonable

K factor - charged multiplicity distribution



From Mark Heinz

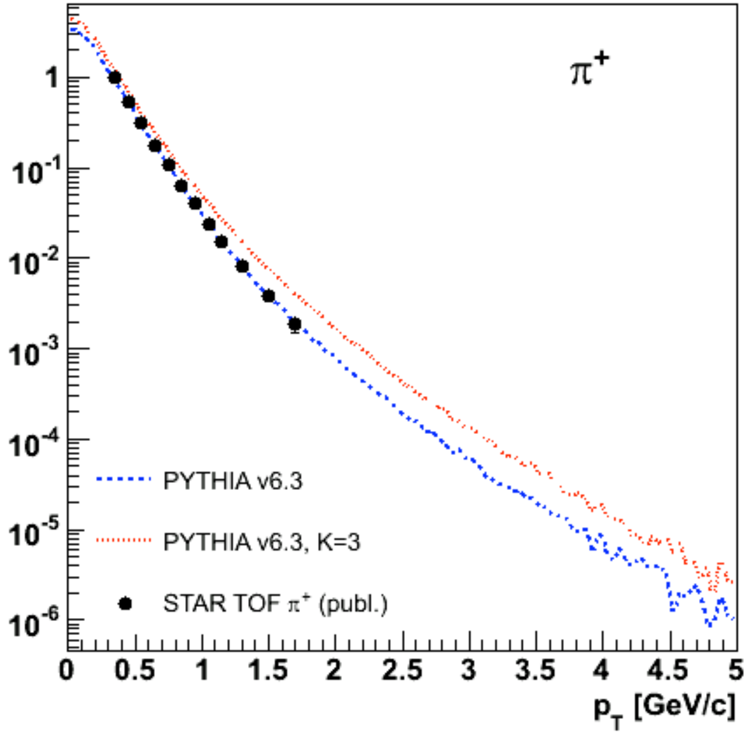
- PYTHIA + simulated trigger and detector acceptance.

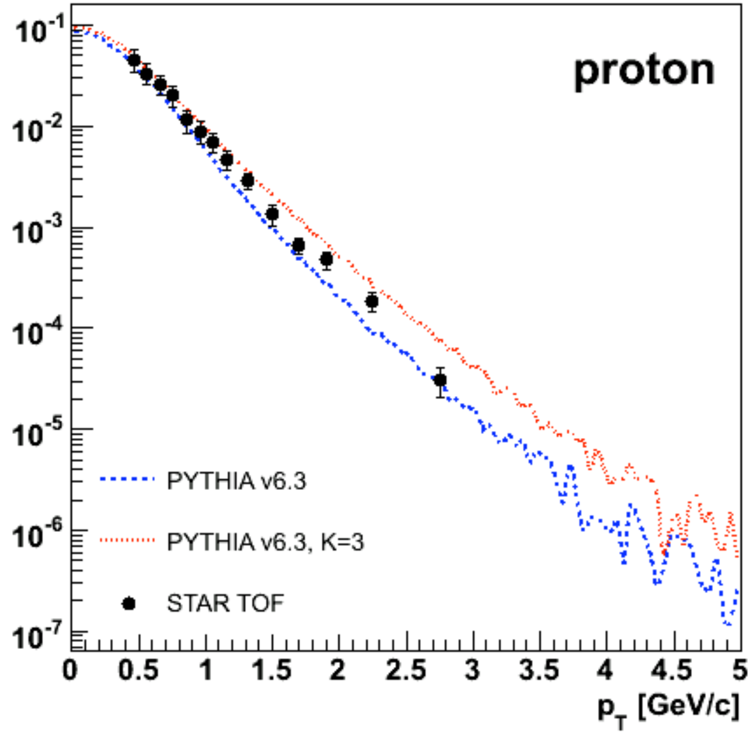
Probability of high multiplicity events very sensitive to NLO corrections

What about non-strange particles ?

- Good agreement for π with K=1 but not for K=3
- proton with 1< K <3
  - However only lower p_T region measured

From M. Heinz



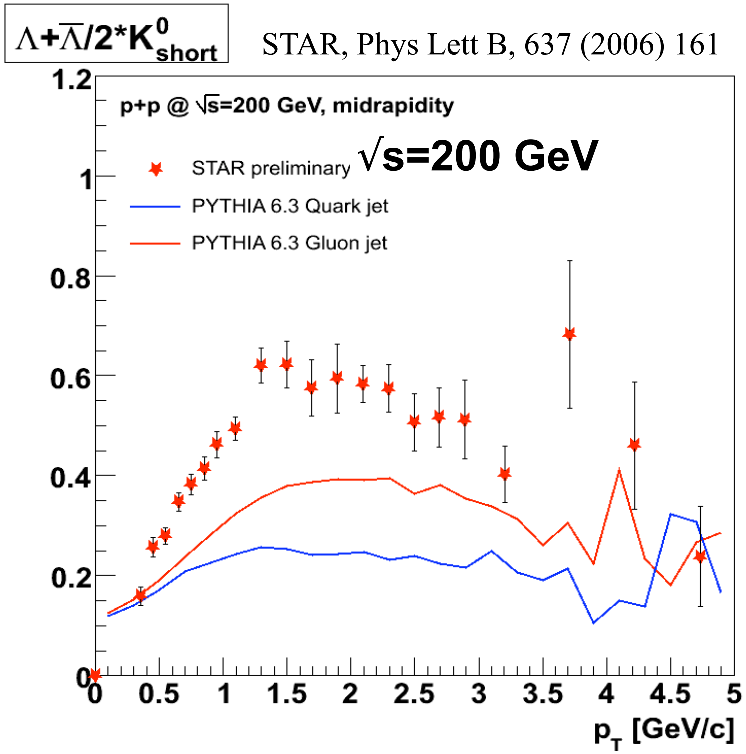


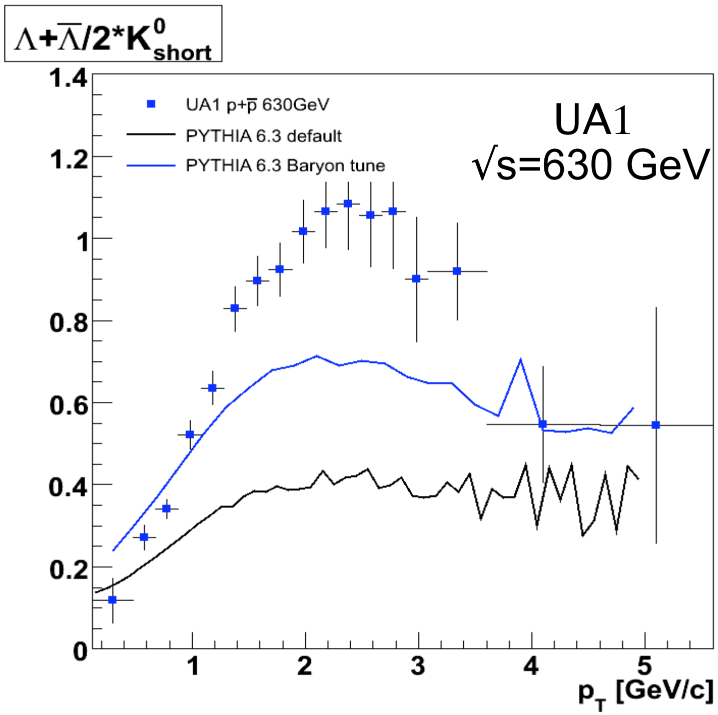
Need different K factors for different particles!

Baryon-meson ratios

- Gluon jets produce a larger Baryon/Meson ratio than quark-jets
- Cannot describe Baryon-Meson ratio at intermediate p_T even with tuned K-factors and/or di-quarks

STAR, Phys Lett B, 637 (2006) 161





Our "tuned" PYTHIA under predicts B/M ratio at 200 and 630 GeV

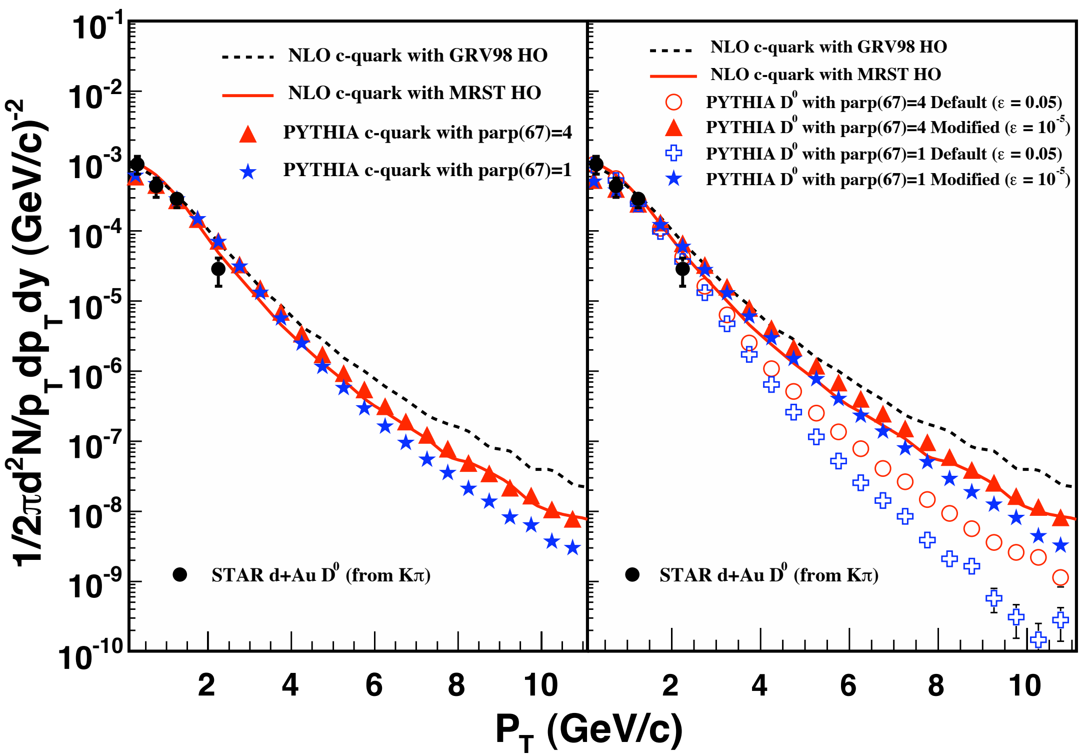
also fails for p/π at ISR and FNAL: 19-53 GeV (not shown)

Charm in PYTHIA

From X. Lin arXiv:0602067

PYTHIA **6.2** Parameters

- K = 3.5
- m_c = 1.25 GeV/c^2
- m_b = 4.8 GeV/c^2
- $<k_T>$ = 1.5 GeV/c
- MSTP(32) = 4 (Q^2 scale)
- CTEQ5L PDF
- PAR(67) = 1 or 4 (enhanced c quark production via gluon splitting - accounts for higher order effects).



With PARP(67) = 4 good match between PYTHIA and NLO

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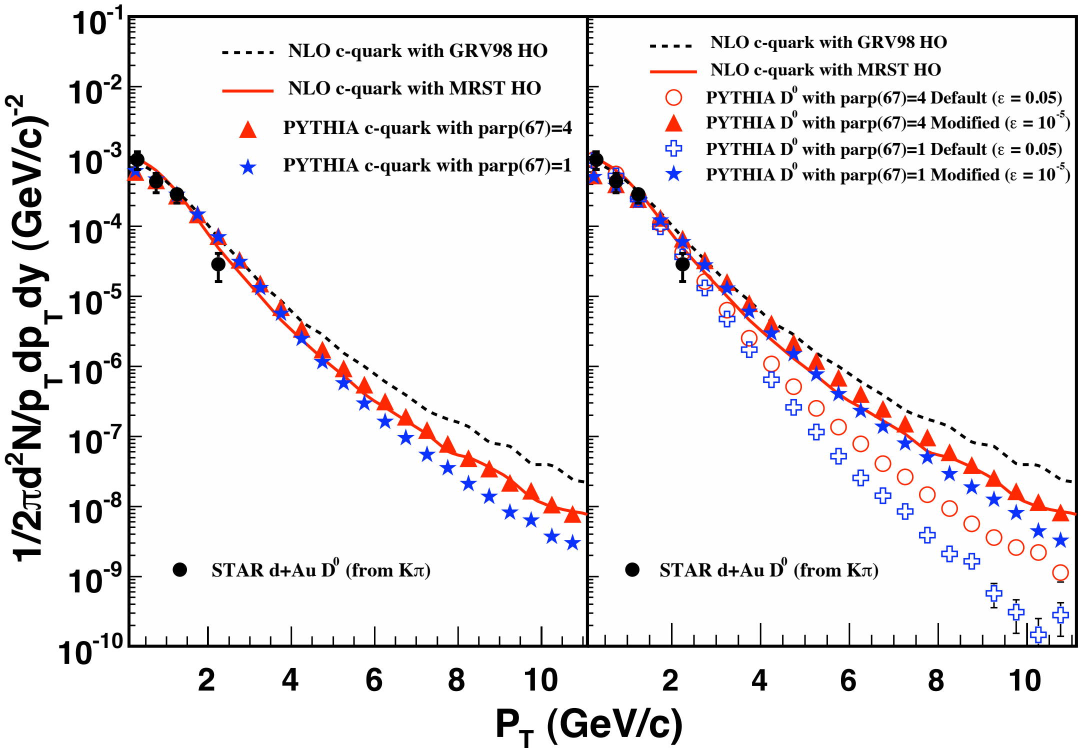

With PARP(67) = 4 good match between PYTHIA and NLO

- HF FF Peterson F^n: $D(z) \propto \frac{1}{z(1-1/z-\epsilon/(1-z))^2}$

- ε = 0.05 - Fits charm e^+e^- and γp
- ε = 10^{-5} - hadroproduction sees harder FF

STAR and PHENIX data inconclusive

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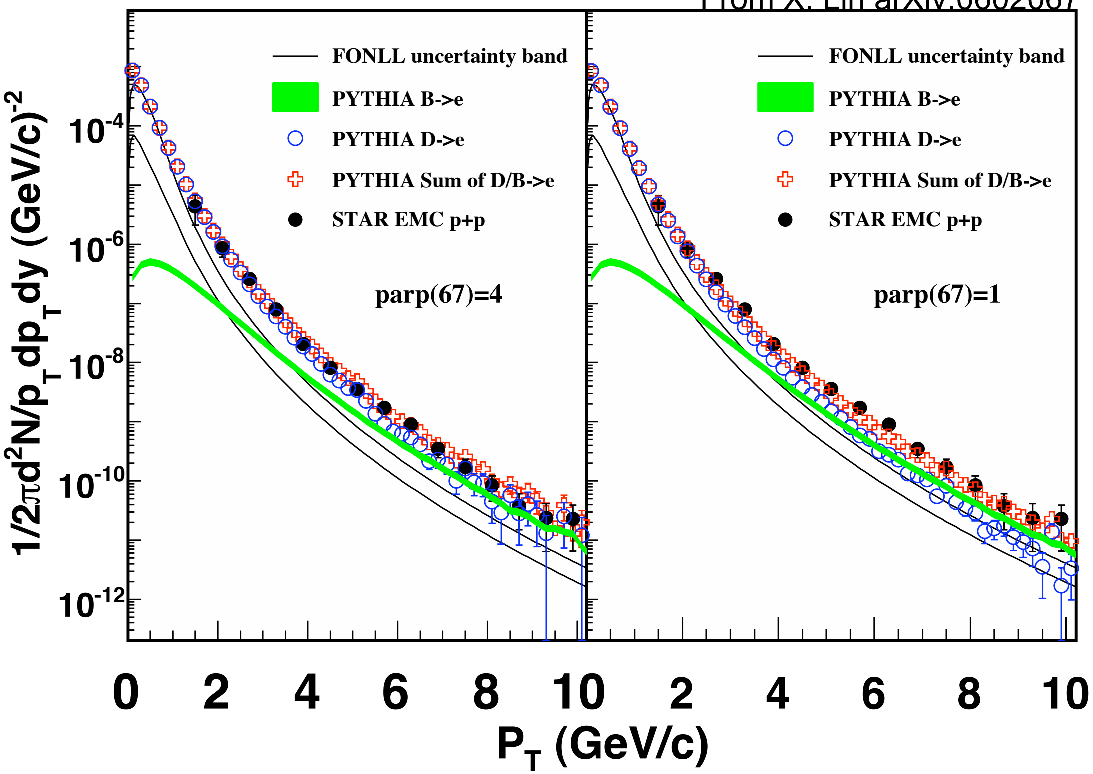

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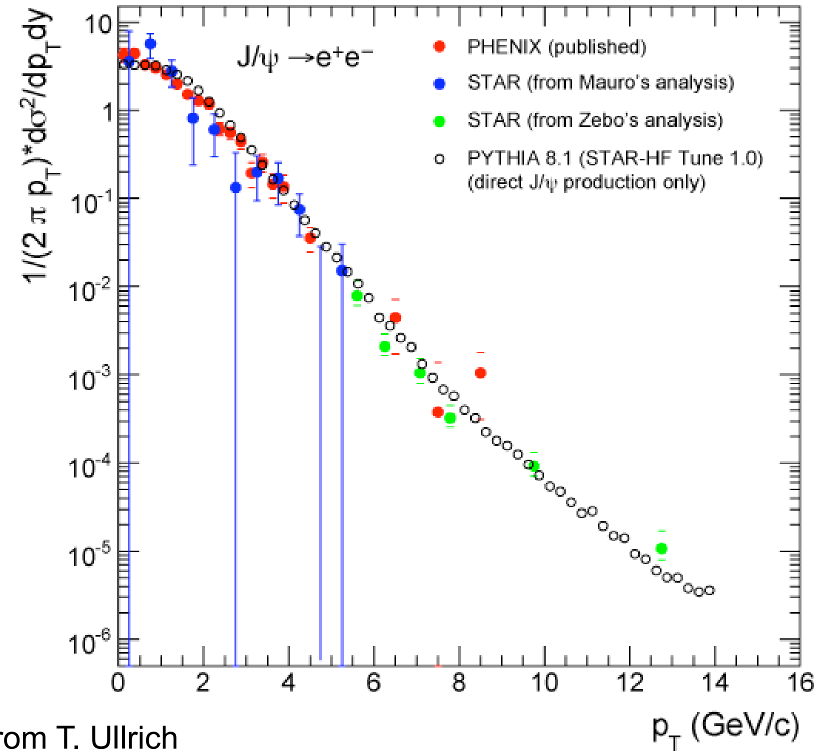
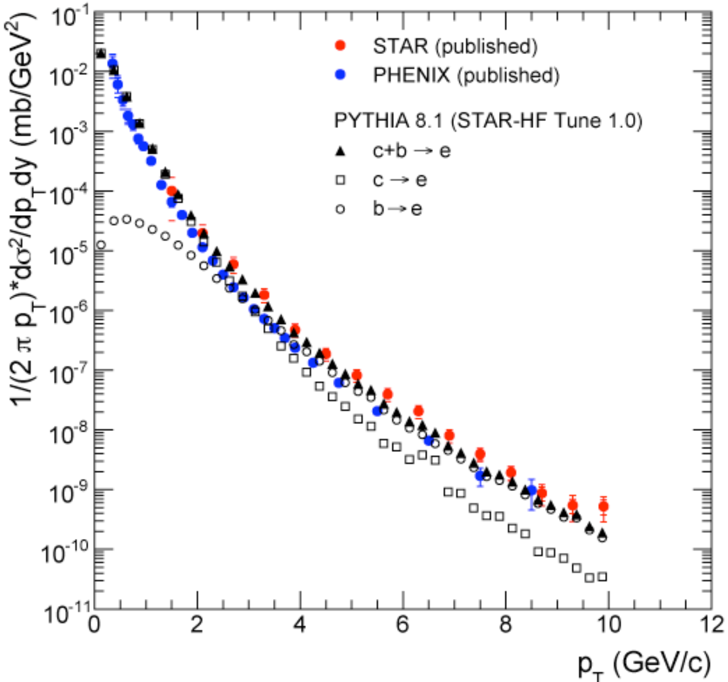
Quarkonia (PYTHIA 8)

- In this version no single tune that works for HF
- Again the K factor needs changing - caution this is for PYTHIA 8



From T. Ullrich

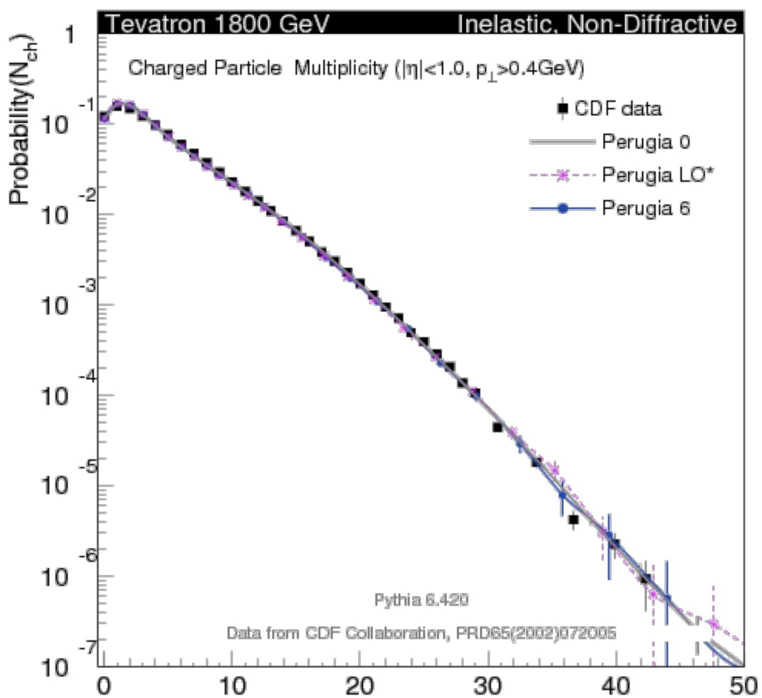


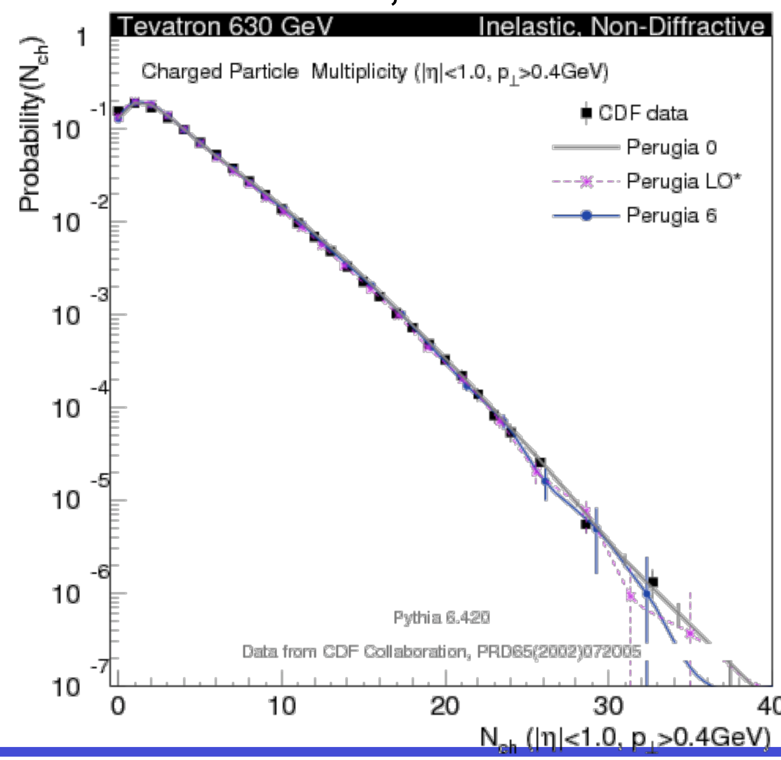
- K = 3 non-photonic e between STAR and PHENIX
- K = 0.4356 J/Psi BR*Sigma = 178 nb (PHENIX)
- K = 0.6176 Upsilon(1S) 63 pb (STAR Preliminary)

The latest and greatest tunes - Perugia

- Huge model building and tuning effort by many groups - Herwig, PYTHIA, Sherpa, Professor (MCNet)
    - Summarized at Perugia meeuing (Oct 2008)

- PYTHIA 6.4.20 now out “Perugia and “Professor” tunes available
    - Not great differences to “Tune A” - especially at RHIC
    - Better constrained energy scaling - used more data, Hard/Soft interface





From Peter Skands arXiv:0905.3418 N_{ch} ($|\eta|<1.0$, $p_\perp>0.4$GeV)

Perugia Tunes

- The major changes to PYTHIA for Perugia tunes
- arXiv:0905.3418

Parameter	Type	S0A-Pro	P-0	P-HARD	P-SOFT	P-3	P-NOCR	P-X	P-6
MSTP(51)	PDF	7	7	7	7	7	7	20650	10042
MSTP(52)	PDF	1	1	1	1	1	1	2	2
MSTP(64)	ISR	2	3	3	2	3	3	3	3
PARP(64)	ISR	1.0	1.0	0.25	2.0	1.0	1.0	2.0	1.0
MSTP(67)	ISR	2	2	2	2	2	2	2	2
PARP(67)	ISR	4.0	1.0	4.0	0.5	1.0	1.0	1.0	1.0
MSTP(70)	ISR	2	2	0	1	0	2	2	2
PARP(62)	ISR	-	-	1.25	-	1.25	-	-	-
PARP(81)	ISR	-	-	-	1.5	-	-	-	-
MSTP(72)	ISR	0	1	1	0	2	1	1	1
PARP(71)	FSR	4.0	2.0	4.0	1.0	2.0	2.0	2.0	2.0
PARJ(81)	FSR	0.257	0.257	0.3	0.2	0.257	0.257	0.257	0.257
PARJ(82)	FSR	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
MSTP(81)	UE	21	21	21	21	21	21	21	21
PARP(82)	UE	1.85	2.0	2.3	1.9	2.2	1.95	2.2	1.95
PARP(89)	UE	1800	1800	1800	1800	1800	1800	1800	1800
PARP(90)	UE	0.25	0.26	0.30	0.24	0.32	0.24	0.23	0.22
MSTP(82)	UE	5	5	5	5	5	5	5	5
PARP(83)	UE	1.6	1.7	1.7	1.5	1.7	1.8	1.7	1.7
MSTP(88)	BR	0	0	0	0	0	0	0	0
PARP(79)	BR	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
PARP(80)	BR	0.01	0.05	0.01	0.05	0.03	0.01	0.05	0.05
MSTP(91)	BR	1	1	1	1	1	1	1	1
PARP(91)	BR	2.0	2.0	1.0	2.0	1.5	2.0	2.0	2.0
PARP(93)	BR	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
MSTP(95)	CR	6	6	6	6	6	6	6	6
PARP(78)	CR	0.2	0.33	0.37	0.15	0.35	0.0	0.33	0.33
PARP(77)	CR	0.0	0.9	0.4	0.5	0.6	0.0	0.9	0.9
MSTJ(11)	HAD	5	5	5	5	5	5	5	5
PARJ(21)	HAD	0.313	0.313	0.34	0.28	0.313	0.313	0.313	0.313
PARJ(41)	HAD	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
PARJ(42)	HAD	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
PARJ(46)	HAD	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
PARJ(47)	HAD	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Summary

- Many parameters are now fixed via Tevatron data if you alter a value need to ensure don’t pull other data off. Also many parameters interconnected, changing one can affect other data due to correlations
- Does well for jet and UE unidentified particle data at Tevatron
- RHIC data being used to confirm energy scaling to allow PREdictions of LHC data
- Identified particle spectra are not yet unified into the tune - especially Strangeness and HF. Remains to be seen if a unified picture can emerge
  - Could be in part due to poorly constrained FF
  - Needs to be checked if still true with latest PYTHIA tunes

PYTHIA and MCNet authors interested in feed-back/discussions with RHIC experimentalists to include data in official tuning