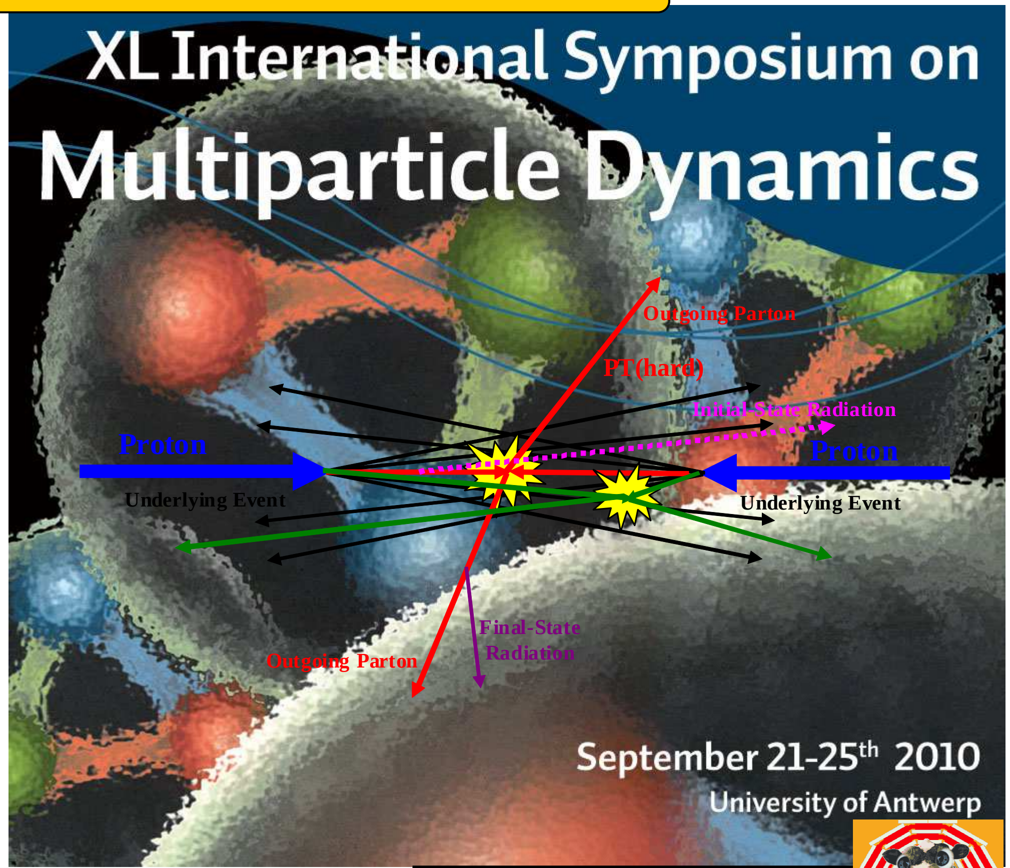
ISMD 2010

The Quest to Find New Physics

Rick Field
University of Florida

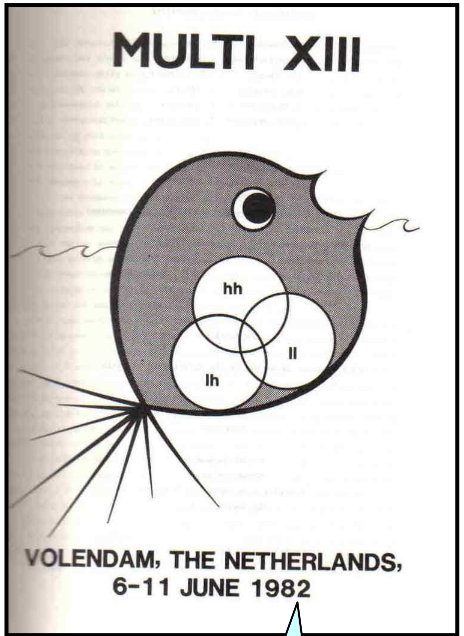
Outline of Talk

- **"New physics" in 1977.**
- **"New physics" in high multiplicity "min-bias" events at the LHC!**
- **We hope much more "new physics" is soon to come from the LHC.**
- **Why expect "new physics"?**
- **What "new physics"?**
- **When "new physics"?**
- **How to find "new physics"?**



UE&MB@CMS

International Symposium on Multiparticle Dynamics

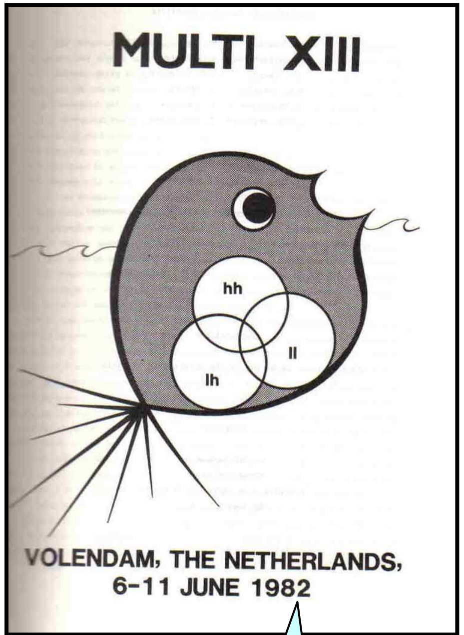


22 Years!

<u>Rick Field (theorist?)</u>
"Jet Formation in QCD"

<u>Rick Field (experimenter?)</u>
"Min Bias and the Underlying Events in Run 2 at CDF"

International Symposium on Multiparticle Dynamics



28 Years!

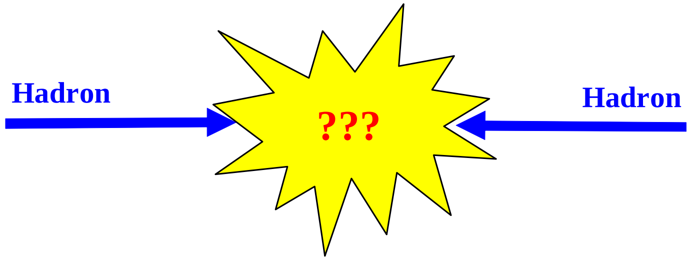
Rick Field (theorist?)
"Jet Formation in QCD"

Rick Field (phenomenologist?)
"The Quest to Find New Physics"

"New Physics" 1977

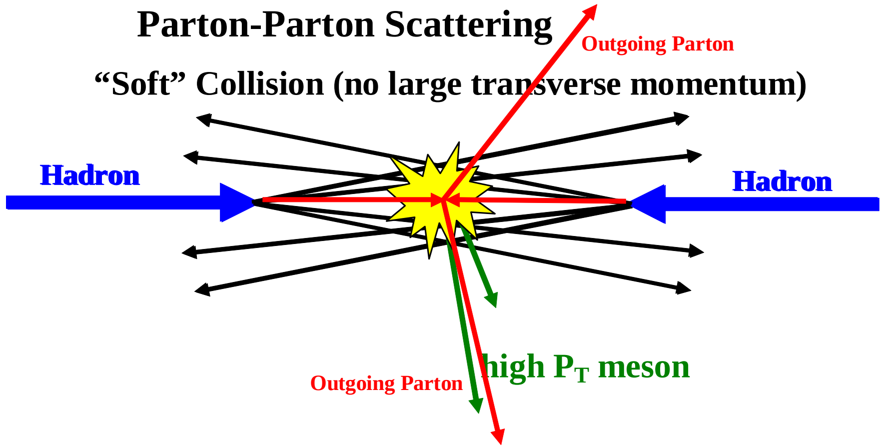
FF1 1977

- **What happens when two hadrons collide at high energy?**



- **Most of the time the hadrons ooze through each other and fall apart (*i.e.* no hard scattering). The outgoing particles continue in roughly the same direction as initial proton and antiproton.**
- **Occasionally there will be a large transverse momentum meson. Question: Where did it come from?**
- **We assumed it came from quark-quark elastic scattering, but we did not know how to calculate it!**

"Black-Box Model"



"New Physics" 1977

FF1 1977

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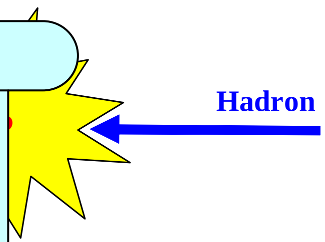
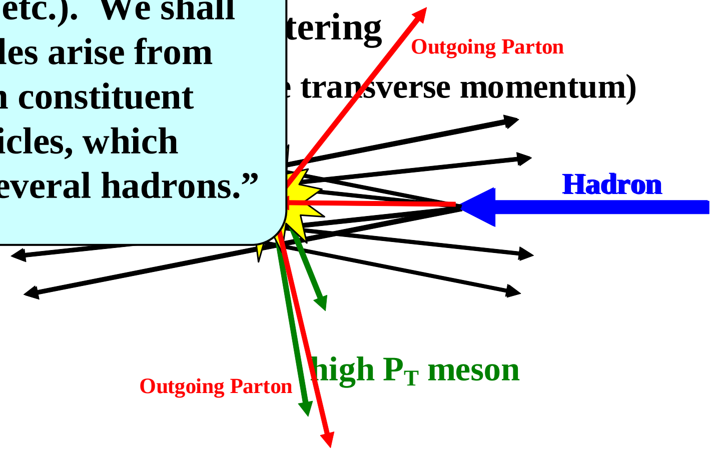


Feynman quote from FF1

"The model we shall choose is not a popular one, so that we will not duplicate too much of the work of others who are similarly analyzing various models (e.g. constituent interchange model, multiperipheral models, etc.). We shall assume that the high P_T particles arise from direct hard collisions between constituent quarks in the incoming particles, which fragment or cascade down into several hadrons."

- Occasionally th
  transverse mom
  Question: Where did it come from?



- We assumed it came from quark-quark elastic scattering, but we did not know how to calculate it!

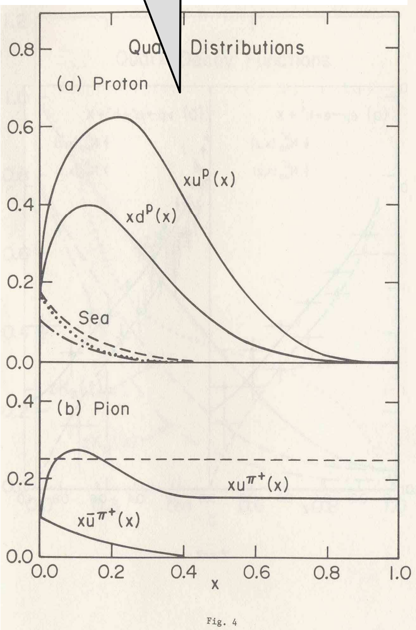
"Black-Box Model"

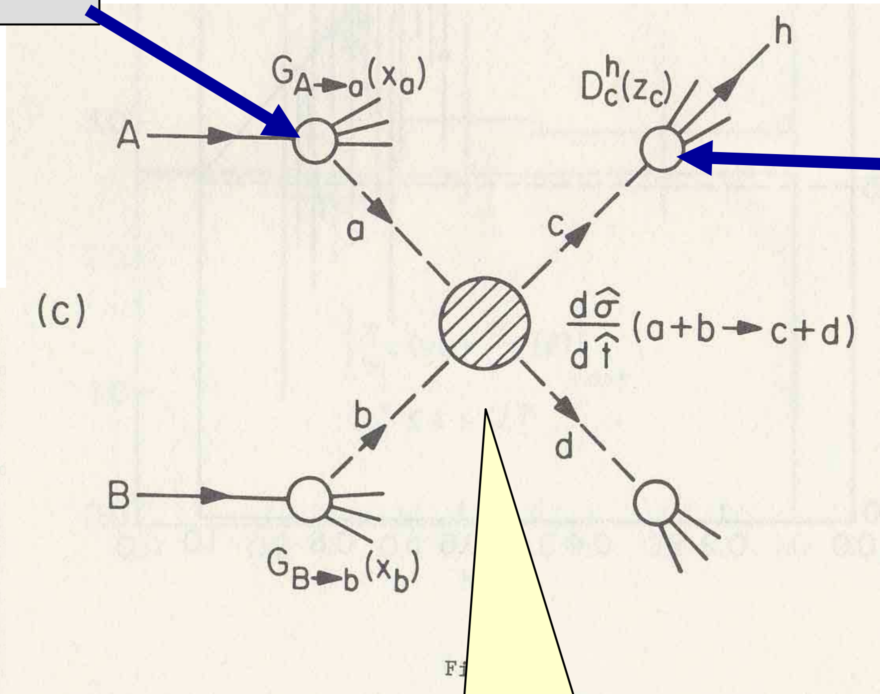
Quark-Quark Black-Box Model

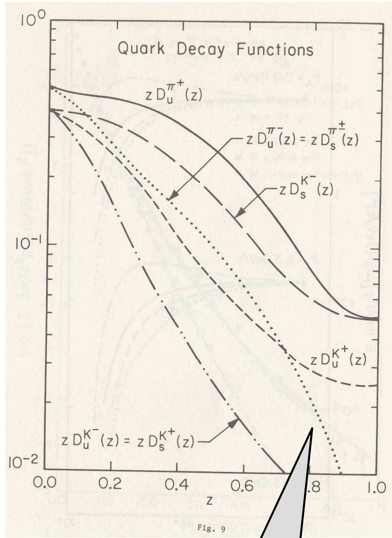
FF1 1977

No gluons!

Quark Distribution Functions
determined from deep-inelastic lepton-hadron collisions







Quark-Quark Cross-Section
Unknown! Deteremined from hadron-hadron collisions.

Quark Fragmentation Functions
determined from e^+e^- annihilations

Quark-Quark Black-Box Model

FF1 1977

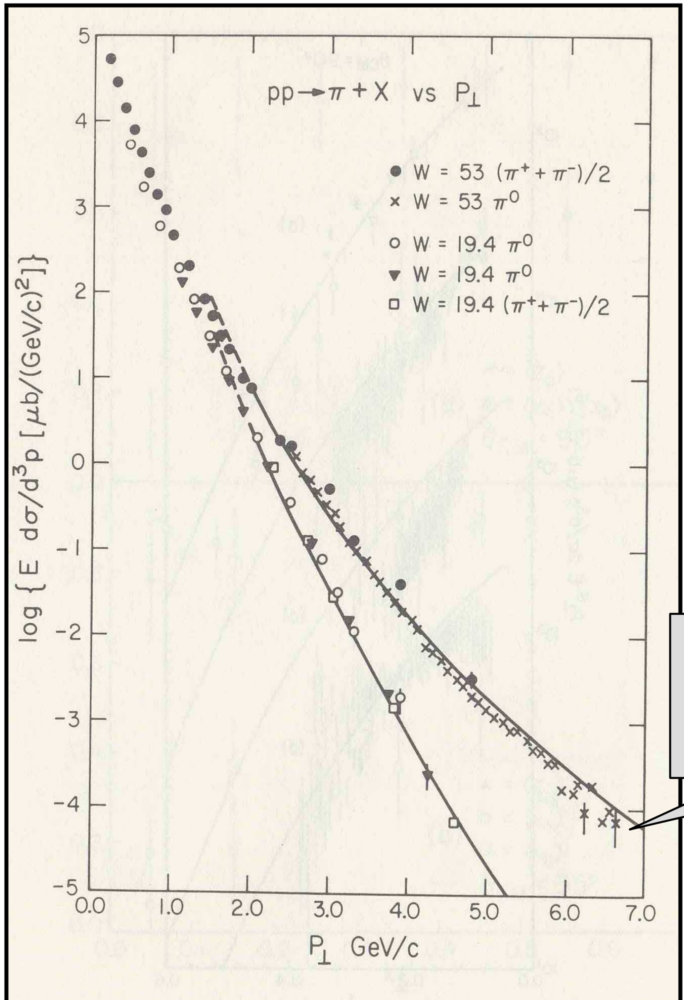
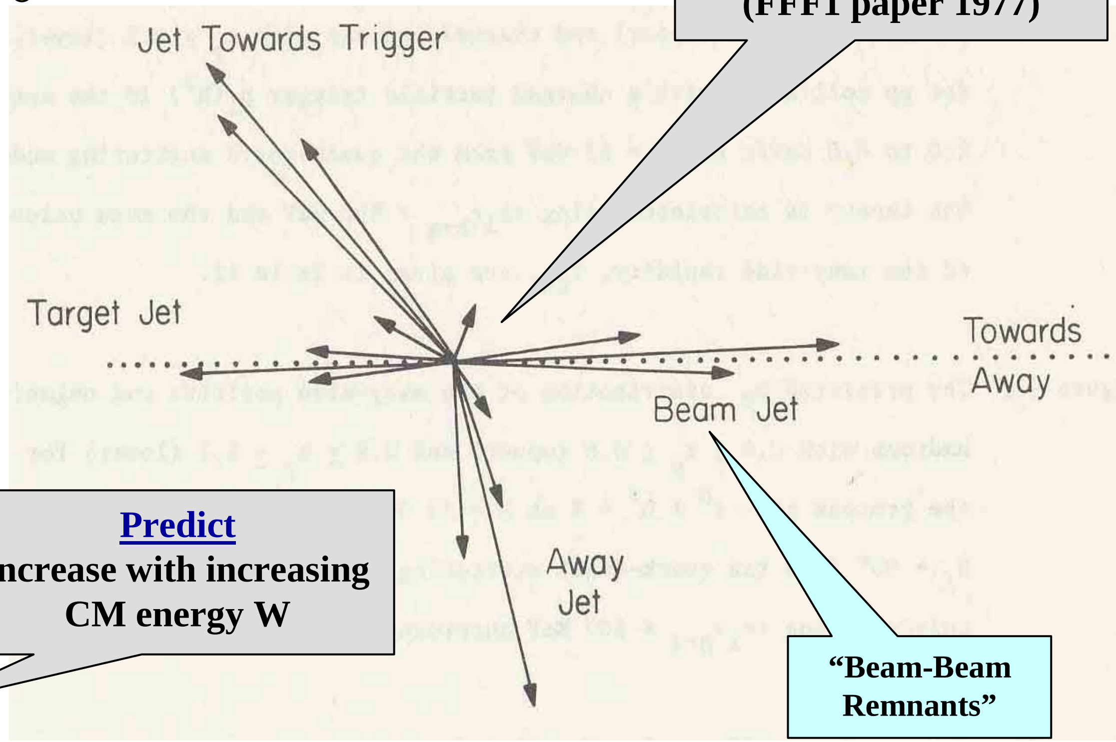


Fig. 13

Predict
increase with increasing CM energy W

Predict
overall event topology (FFF1 paper 1977)



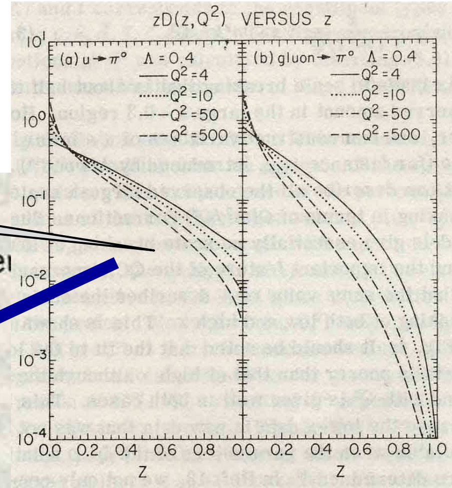
"Beam-Beam Remnants"

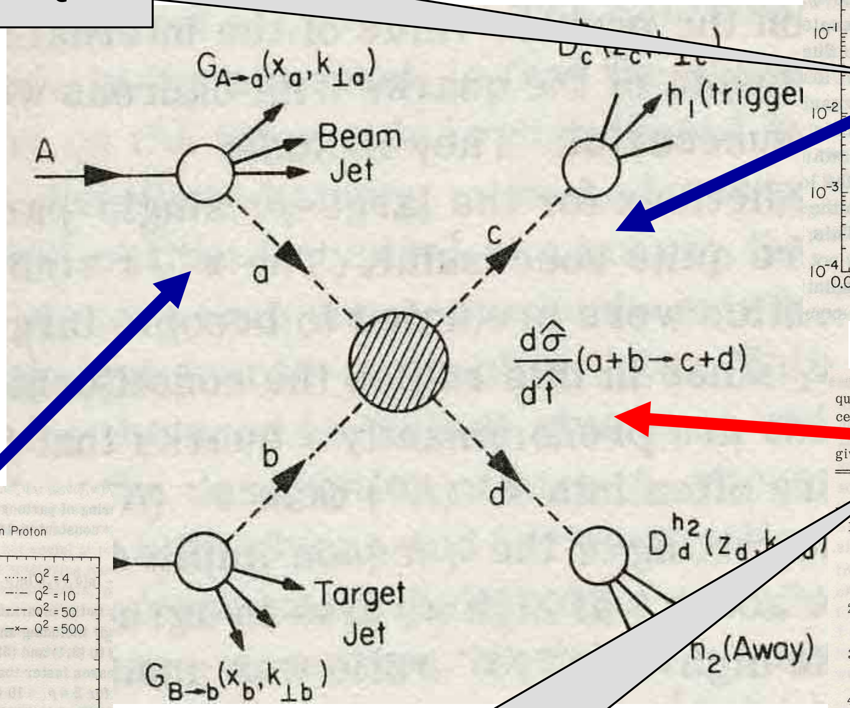
QCD Approach: Quarks & Gluons

FFF2 1978

Quark & Gluon Fragmentation Functions
Q^2 dependence predicted from QCD

Parton Distribution Functions
Q^2 dependence predicted from QCD





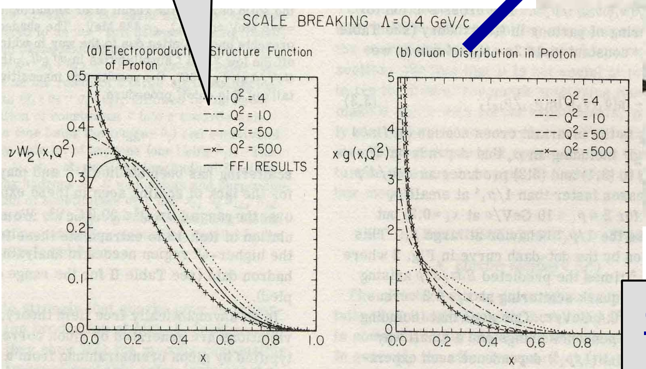


TABLE I. Cross sections for the various constituent quark-quark, quark-gluon, and gluon-gluon subprocesses.[a] The differential cross section is given by $d\hat\sigma/d\hat t$ = $\pi\alpha_s^2(Q^2)|A|^2/\hat s^2$, where $\alpha_s(Q^2)$ is the effective coupling given by Eq. (3.1).

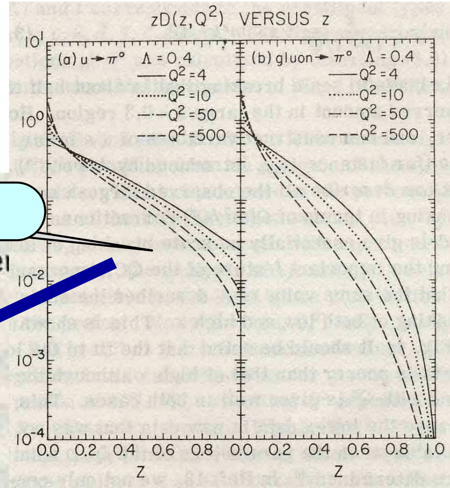
	Subprocess	$\lvert A\rvert^2$
1.	$q_iq_j \to q_iq_j$ $q_i\bar q_j \to q_i\bar q_j$ $(i \neq j)$	$\frac{4}{9}\frac{\hat s^2+\hat u^2}{\hat t^2}$
2.	$q_iq_i \to q_iq_i$	$\frac{4}{9}\left(\frac{\hat s^2+\hat u^2}{\hat t^2}+\frac{\hat s^2+\hat t^2}{\hat u^2}\right)-\frac{8}{27}\frac{\hat s^2}{\hat u\hat t}$
3.	$q_i\bar q_i \to q_i\bar q_i$	$\frac{4}{9}\left(\frac{\hat s^2+\hat u^2}{\hat t^2}+\frac{\hat t^2+\hat u^2}{\hat s^2}\right)-\frac{8}{27}\frac{\hat u^2}{\hat s\hat t}$
4.	$q_i\bar q_i \to gg$	$\frac{32}{27}\left(\frac{\hat u^2+\hat t^2}{\hat u\hat t}\right)-\frac{8}{3}\left(\frac{\hat u^2+\hat t^2}{\hat s^2}\right)$
5.	$gg \to q_i\bar q_i$	$\frac{1}{6}\left(\frac{\hat u^2+\hat t^2}{\hat u\hat t}\right)-\frac{3}{8}\left(\frac{\hat u^2+\hat t^2}{\hat s^2}\right)$
6.	$q_ig \to q_ig$	$-\frac{4}{9}\left(\frac{\hat u^2+\hat s^2}{\hat u\hat s}\right)+\left(\frac{\hat u^2+\hat s^2}{\hat t^2}\right)$
7.	$gg \to gg$	$\frac{9}{2}\left(3-\frac{\hat u\hat t}{\hat s^2}-\frac{\hat u\hat s}{\hat t^2}-\frac{\hat s\hat t}{\hat u^2}\right)$

Quark & Gluon Cross-Sections
Calculated from QCD

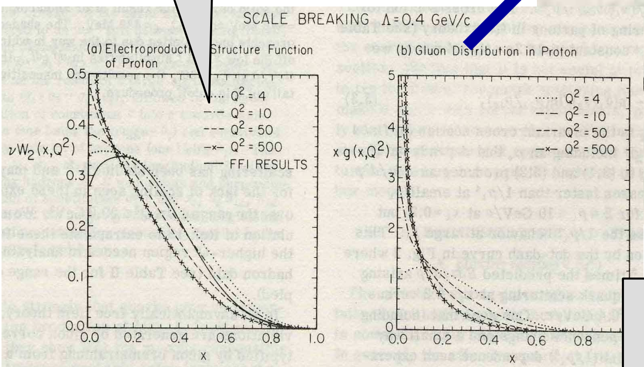
QCD Approach: Quarks & Gluons

FFF2 1978

Quark & Gluon Fragmentation Functions
Q^2 dependence predicted from QCD

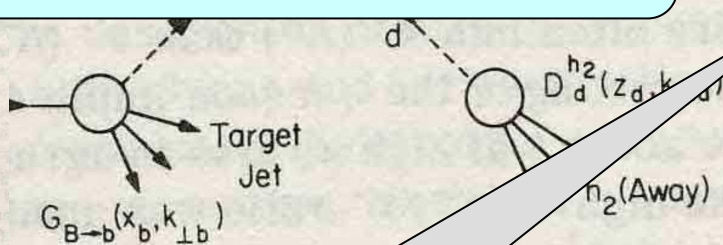


Parton Distribution Functions
Q^2 dependence predicted from QCD



Feynman quote from FFF2

"We investigate whether the present experimental behavior of mesons with large transverse momentum in hadron-hadron collisions is consistent with the theory of quantum-chromodynamics (QCD) with asymptotic freedom, at least as the theory is now partially understood."



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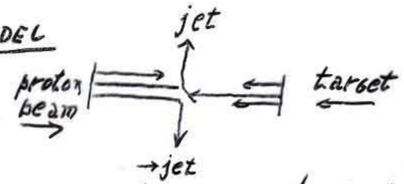
Quark & Gluon Cross-Sections
Calculated from QCD

Feynman Talk at Coral Gables (December 1976)

1st transparency

Field & Feynman CALT-68-565
Fox (Brookhaven APS) CALT-68-573

MODEL



Quark - Quark Collision.
But $P_\perp^{-8}$ Not $P_\perp^{-4}$?

Need: (a) Quark distribution in hadron. (Pion?)
(b) The way quark makes hadron jet.
FROM EXPERIMENTS WITH LEPTONS.
(c) Quark-Quark scattering x-section.

$$\frac{d\hat{\sigma}}{dt} = \frac{2300\,mb}{s(-t)^3}$$

Try to fit all correlation experiments with no new parameters.

Last transparency

WORK IN PROGRESS

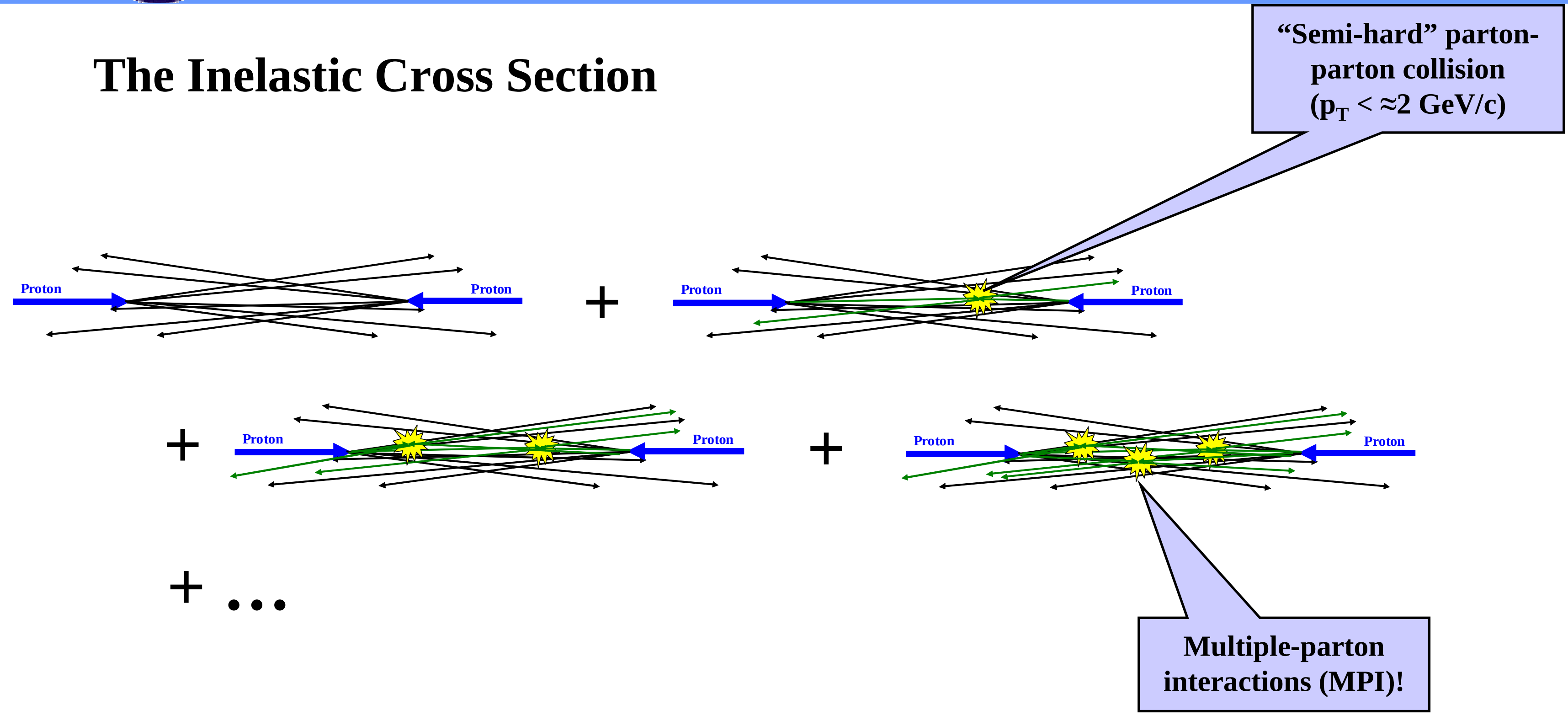
a) More detailed Calculations
b) Theory of q → hadron cascade

"Feynman-Field Jet Model"

FUTURE.
Protons & baryons at high $P_\perp$.
Single γ's at high $P_\perp$.
Nuclear targets.
Are we really in trouble from $P_\perp$ transverse of quarks?
Unify theory to that of main collision at low $P_\perp$.

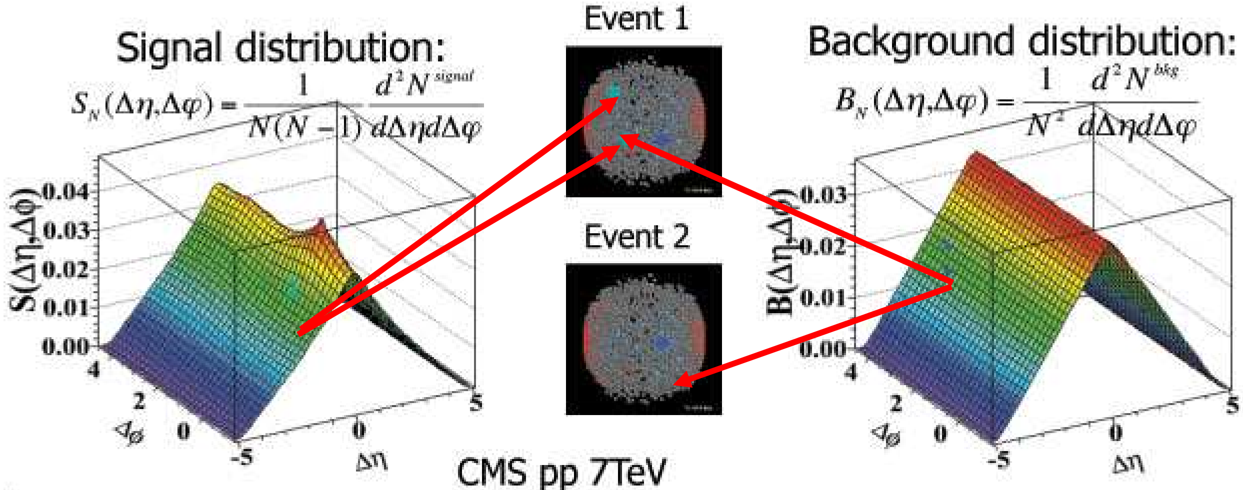
New Physics in "Min-Bias"?

The Inelastic Cross Section



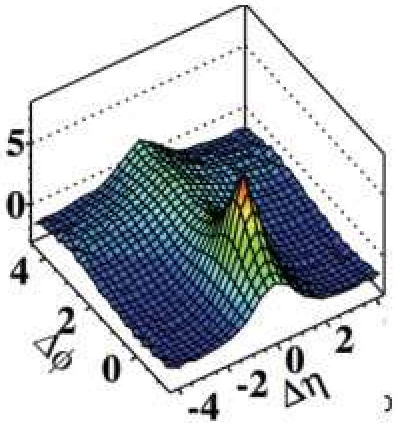
➡ **CMS Two-Particle Correlations at 7 TeV.**

Two Particle Angular Correlations



CMS pp 7TeV

$$\Delta\eta = \eta_1 - \eta_2$$
$$\Delta\varphi = \varphi_1 - \varphi_2$$



$$R(\Delta\eta,\Delta\varphi) = \left\langle (N-1)\left(\frac{S_N(\Delta\eta,\Delta\varphi)}{B_N(\Delta\eta,\Delta\varphi)} - 1\right)\right\rangle,$$

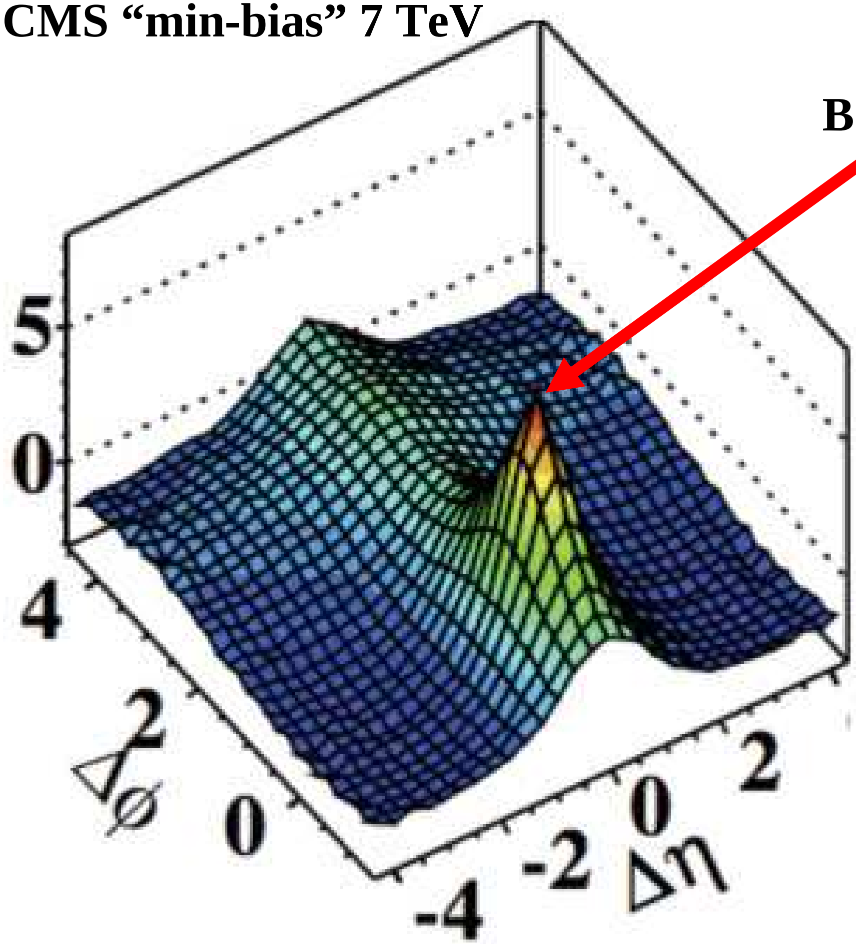
p_T-inclusive two-particle angular correlations in MinBias collisions

- **Signal, S, is two particles in the same event. Background, B, is two particles in two different events.**
- **Correlation, R, is ~(S-B)/B.**

See the very nice talk by Xavier Janssen at this meeting for more details!

Two Particle Angular Correlations

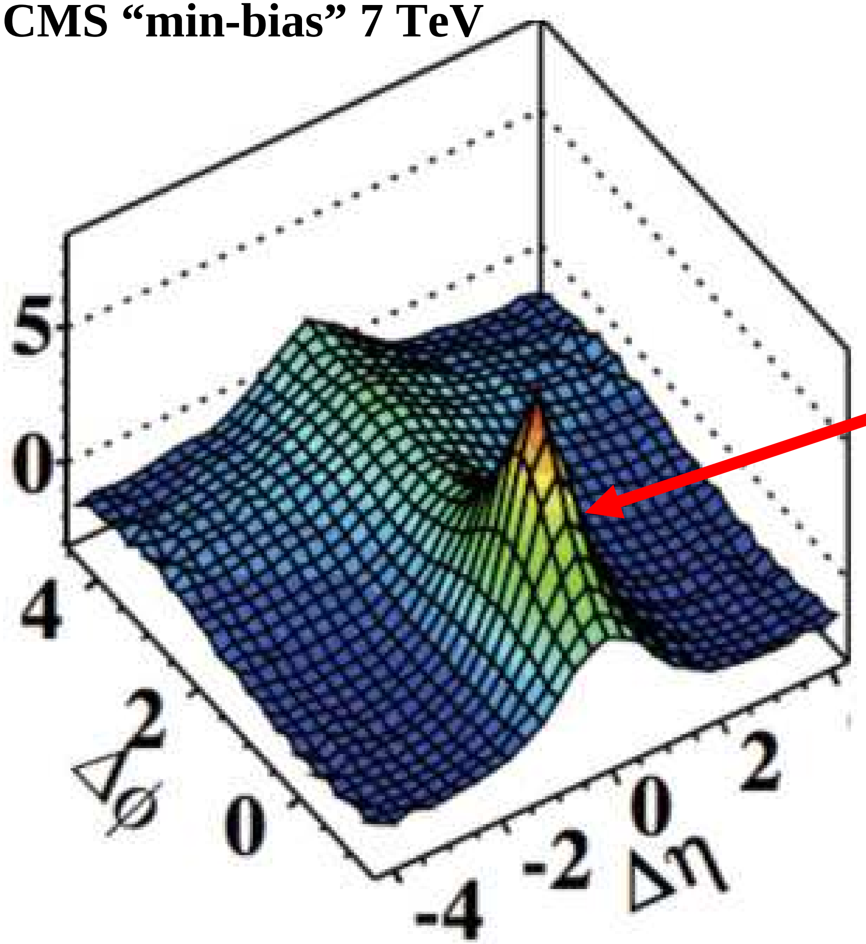
CMS "min-bias" 7 TeV

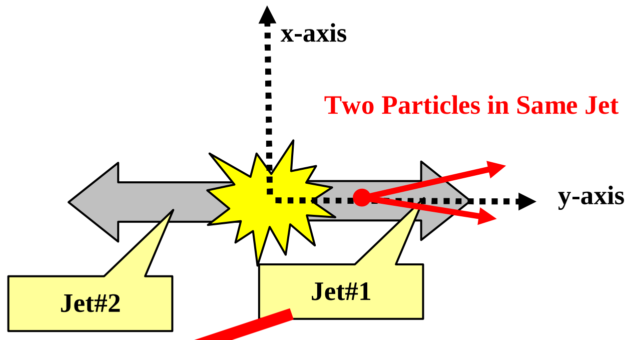


Bose-Einstein

Two Particle Angular Correlations

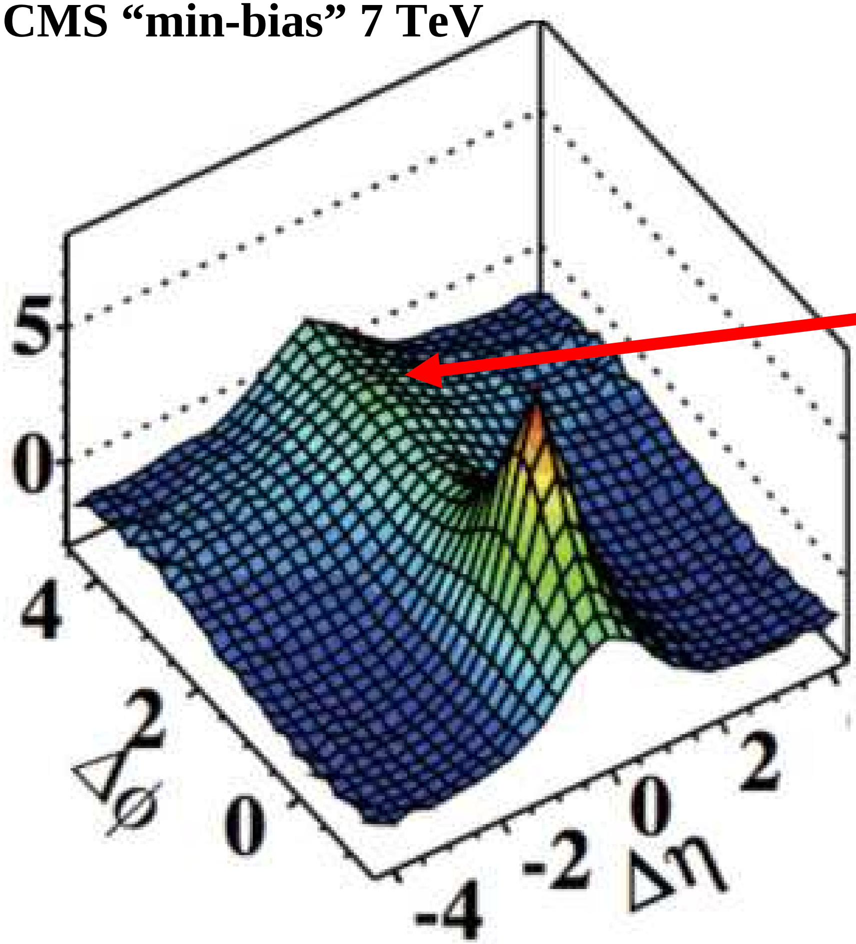
CMS “min-bias” 7 TeV

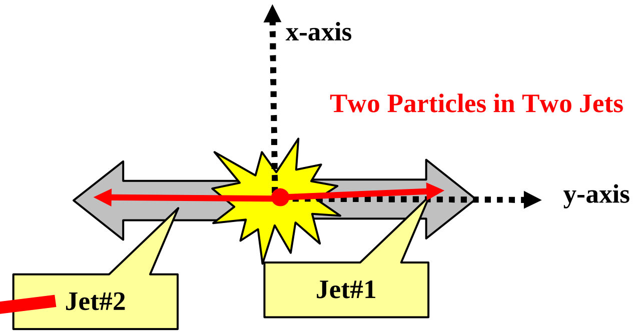




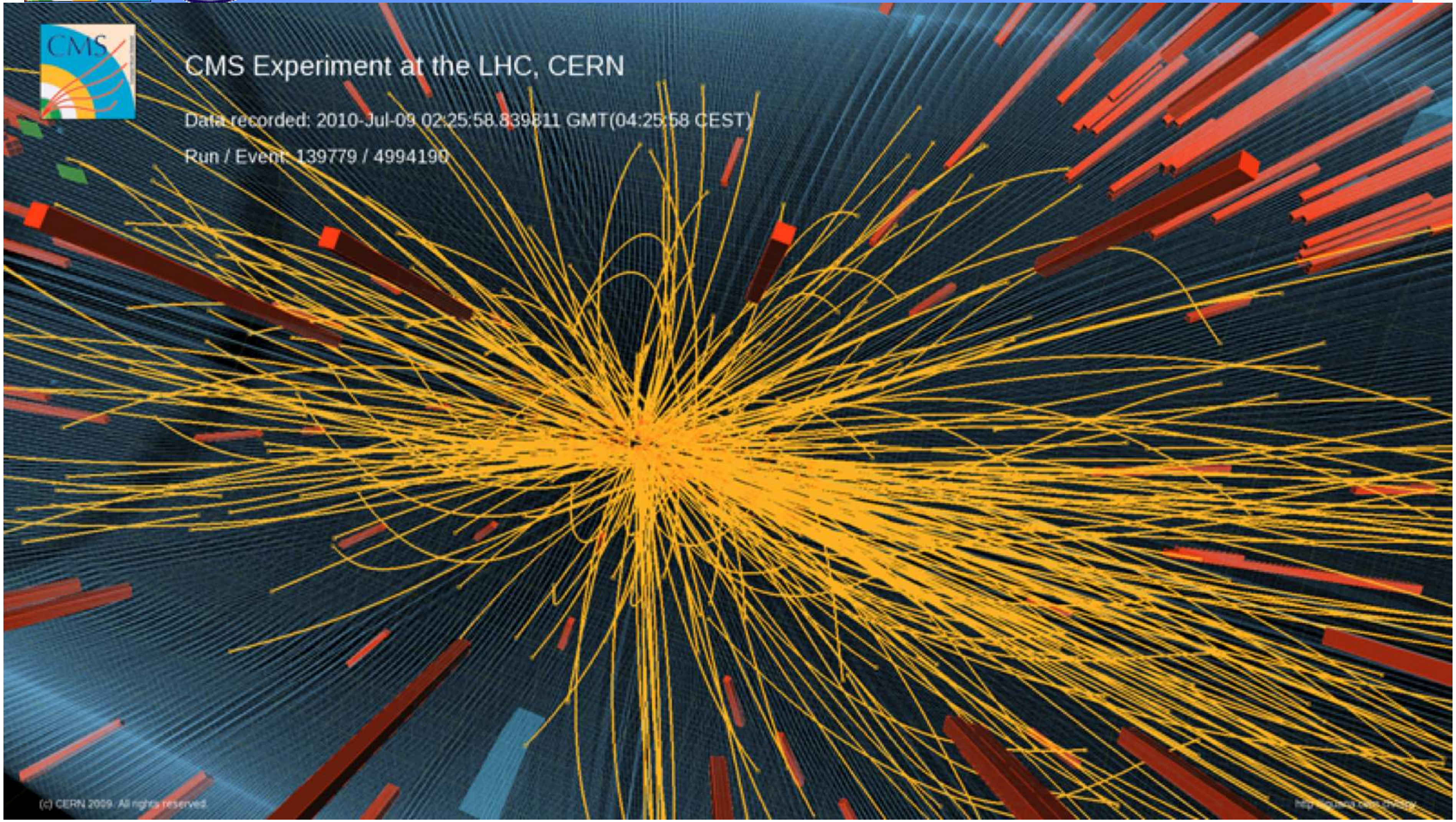
Two Particle Angular Correlations

CMS "min-bias" 7 TeV

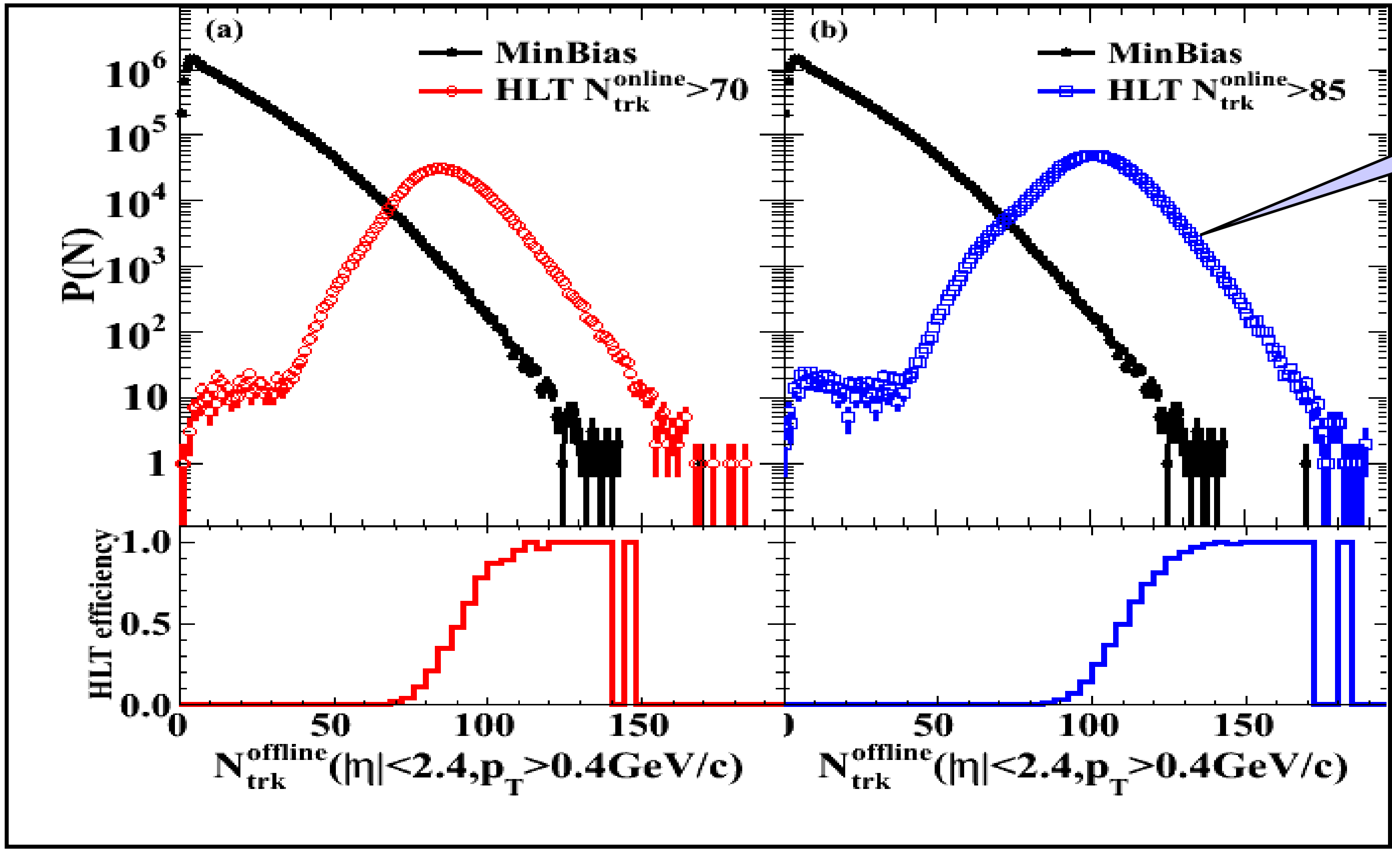




High Multiplicity at 7 TeV



CMS High Multiplicity Trigger

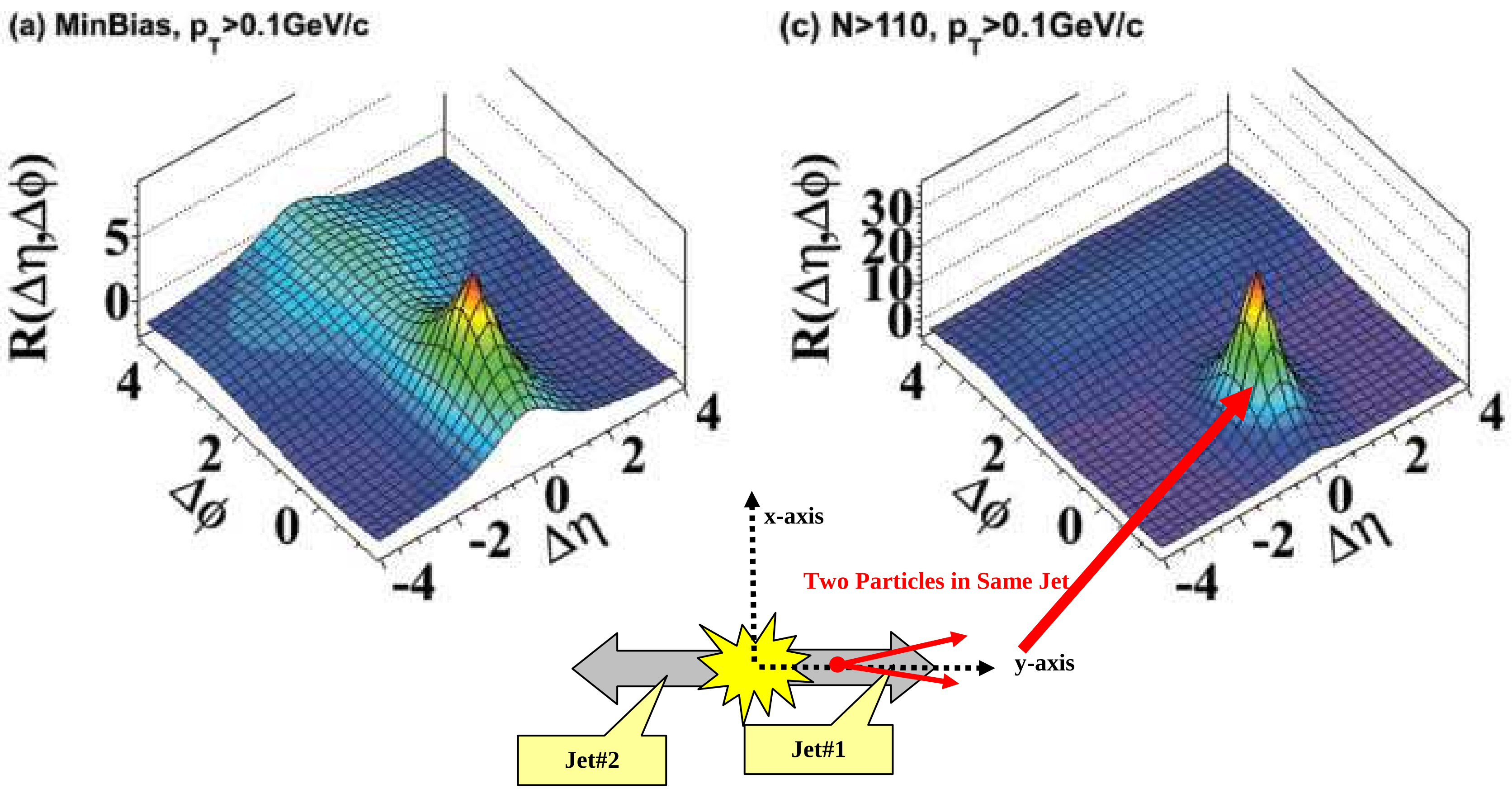


Statistics for high multiplicity enhanced by ~1,000!

- A dedicated high multiplicity trigger was implemented in the two levels of the CMS trigger system. Level 1 (L1): Sum of the total ET (ECAL, HCAL, and HF) > 60 GeV.
- High-level trigger (HLT): number of online tracks built from the three layers of pixel detectors >70 (85).

Two Particle Angular Correlations

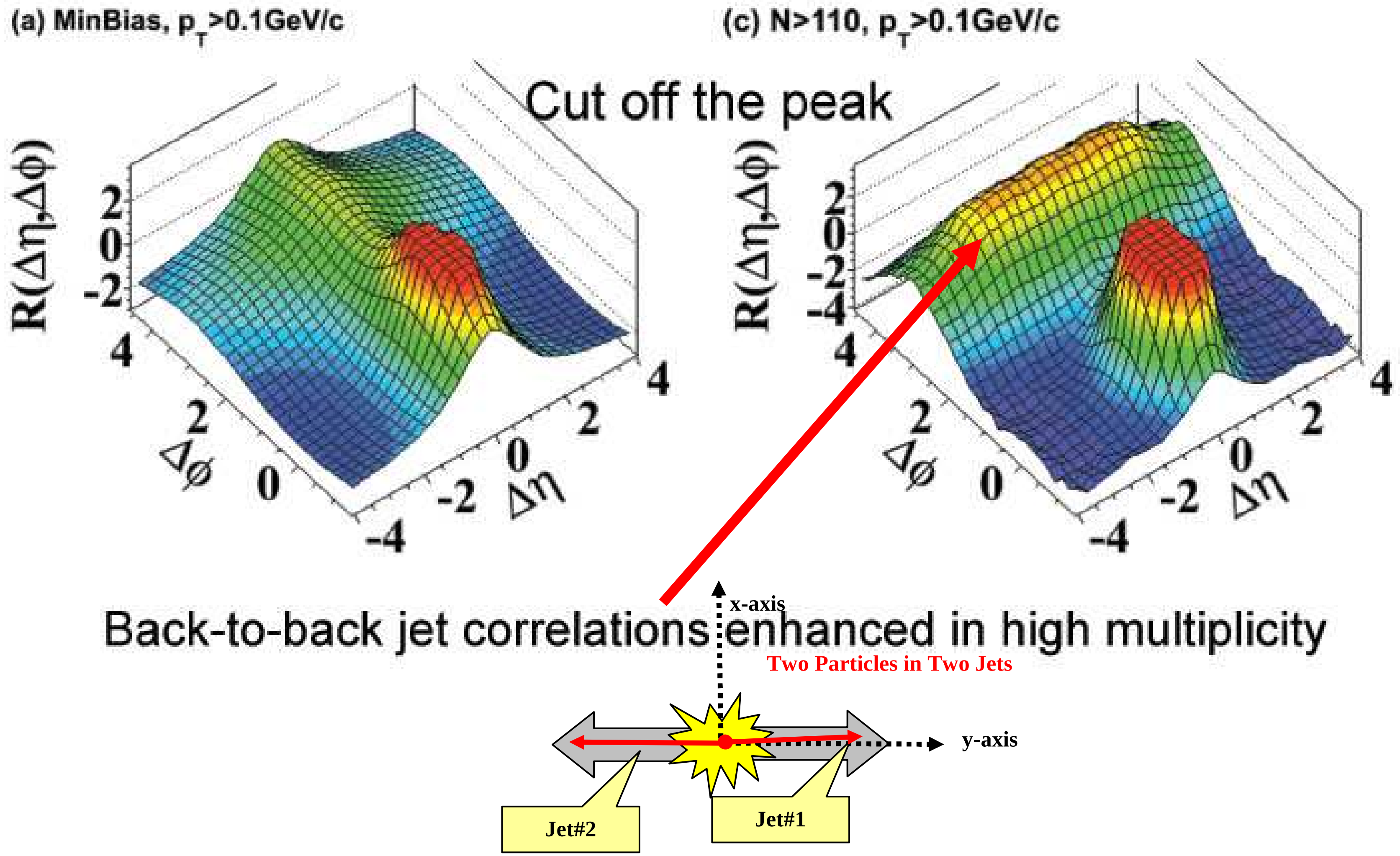
Average "Min-Bias" **High Multiplicity "Min-Bias"**



➡ **Lots of jets at high multiplicity!**

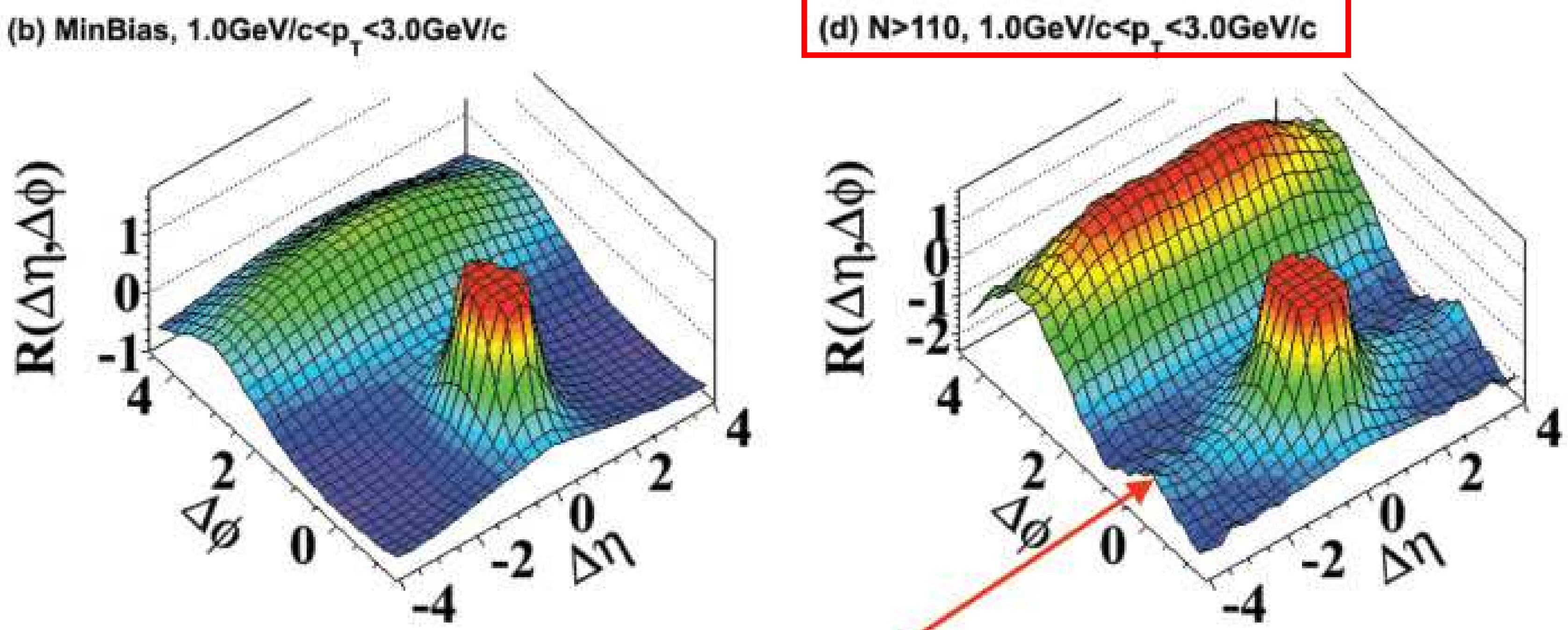
Two Particle Angular Correlations

Average "Min-Bias" **High Multiplicity "Min-Bias"**



Two Particle Angular Correlations

Average "Min-Bias" | **High Multiplicity "Min-Bias"**

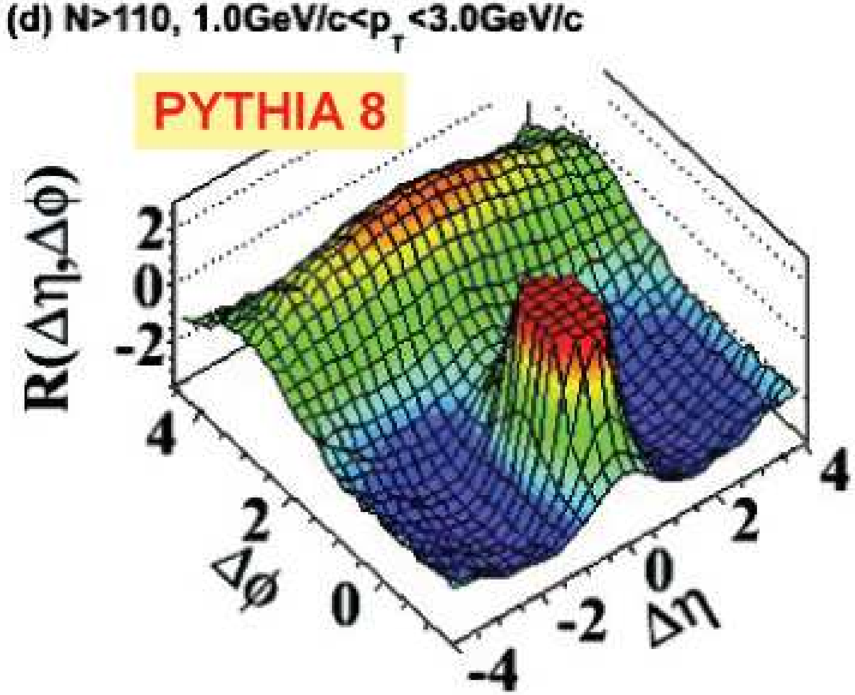


Striking "ridge" structure extending to large Δη at Δφ ~ 0

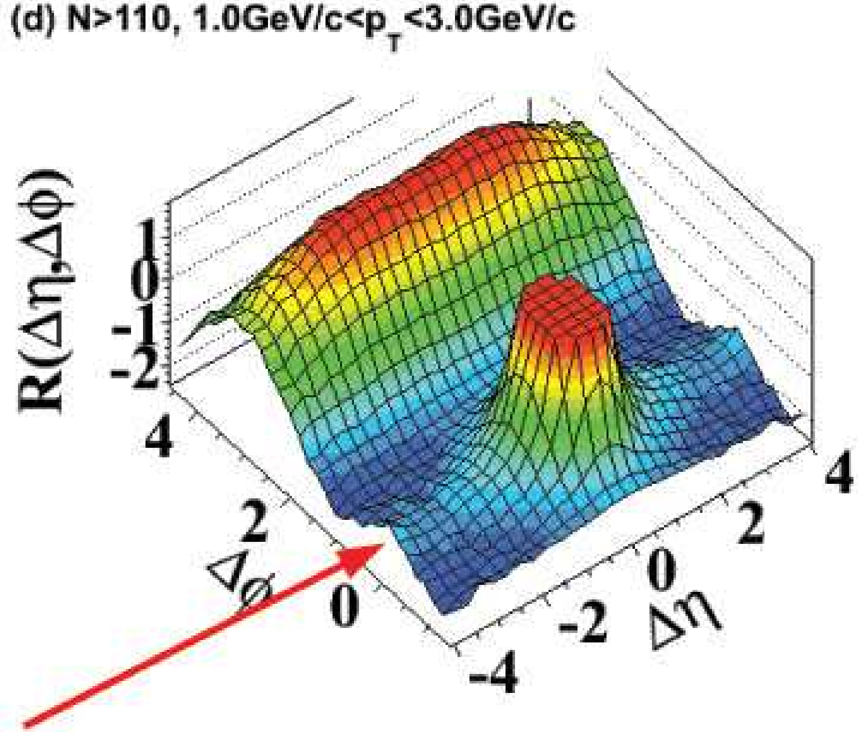
➡**Long range (in Δη) same side correlations!** **What is this?**

Long-Range Same-Side Correlations

High Multiplicity "Min-Bias"



High Multiplicity "Min-Bias"

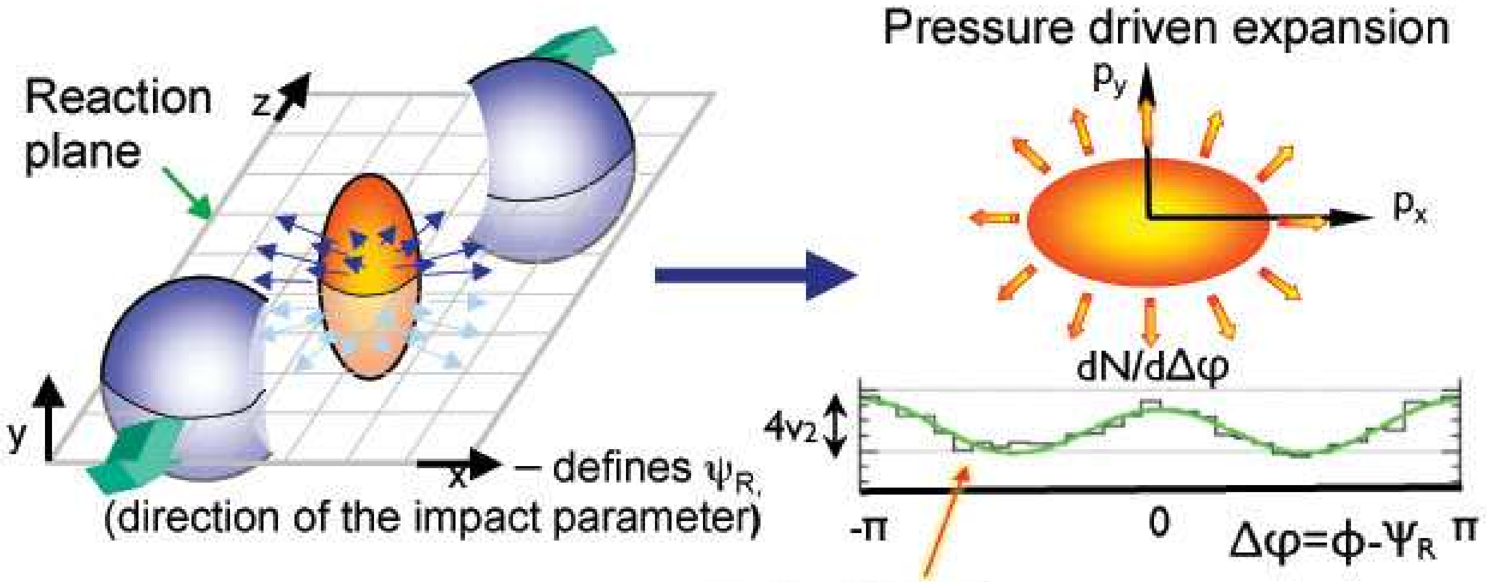


→ Observation of a Long-Range, Near-Side angular correlations at high multiplicity in pp events at intermediate p_T (Ridge at $\Delta\phi \sim 0$)

Not there in PYTHIA8! Also not there in PYTHIA 6 and HERWIG++!

Correlation in Heavy Ion Collisions

Collective flow phenomena:



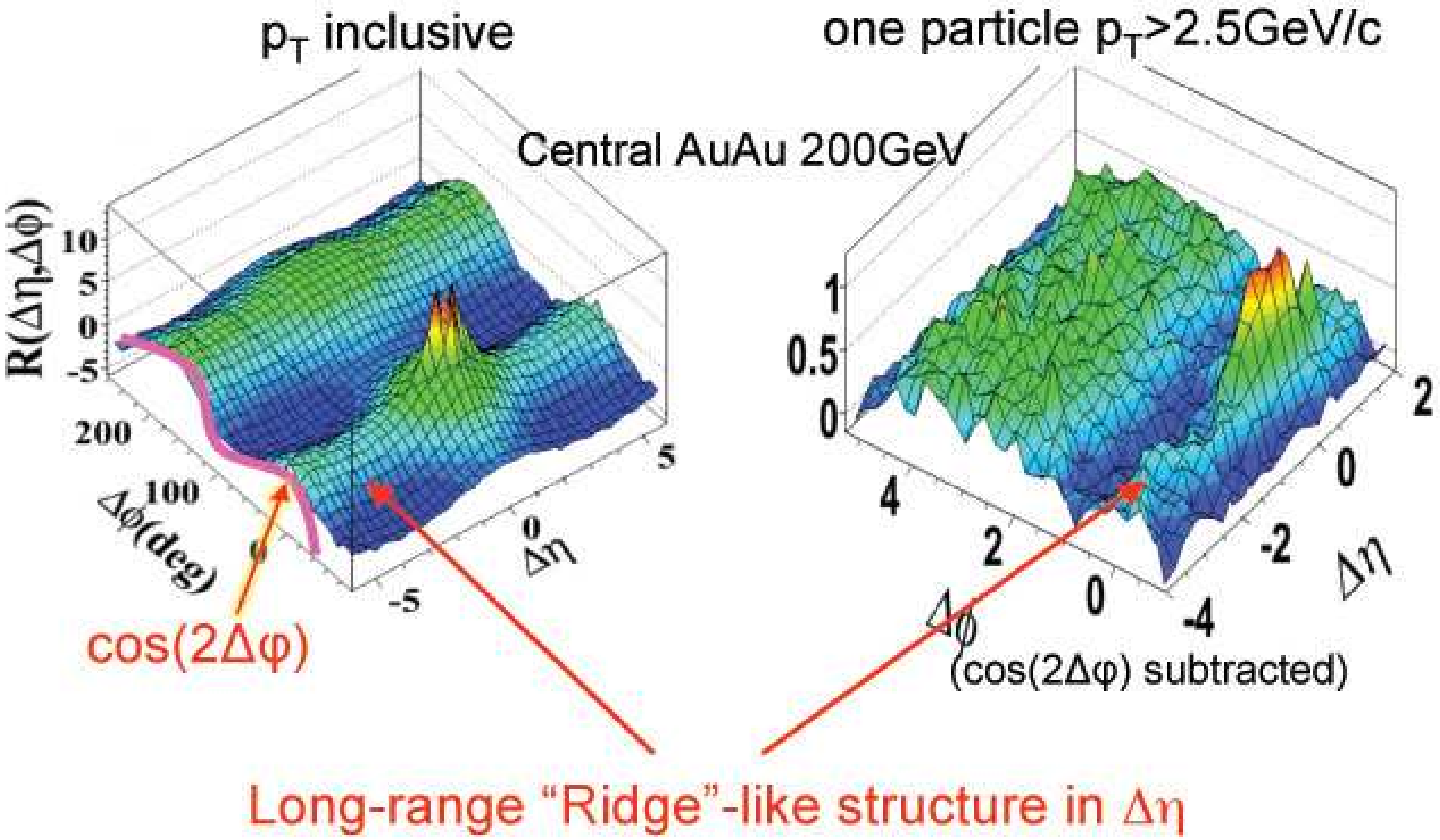
~ cos(2Δφ) (long-range in η)

Extracted shear viscosity of the medium found to be close to theoretical lower bound 1/4π

Most convincing evidence of "Perfect liquid" at RHIC!

➡**Long range correlations expected in "collective flow" in heavy ion collisions.**

Correlation in Heavy Ion Collisions

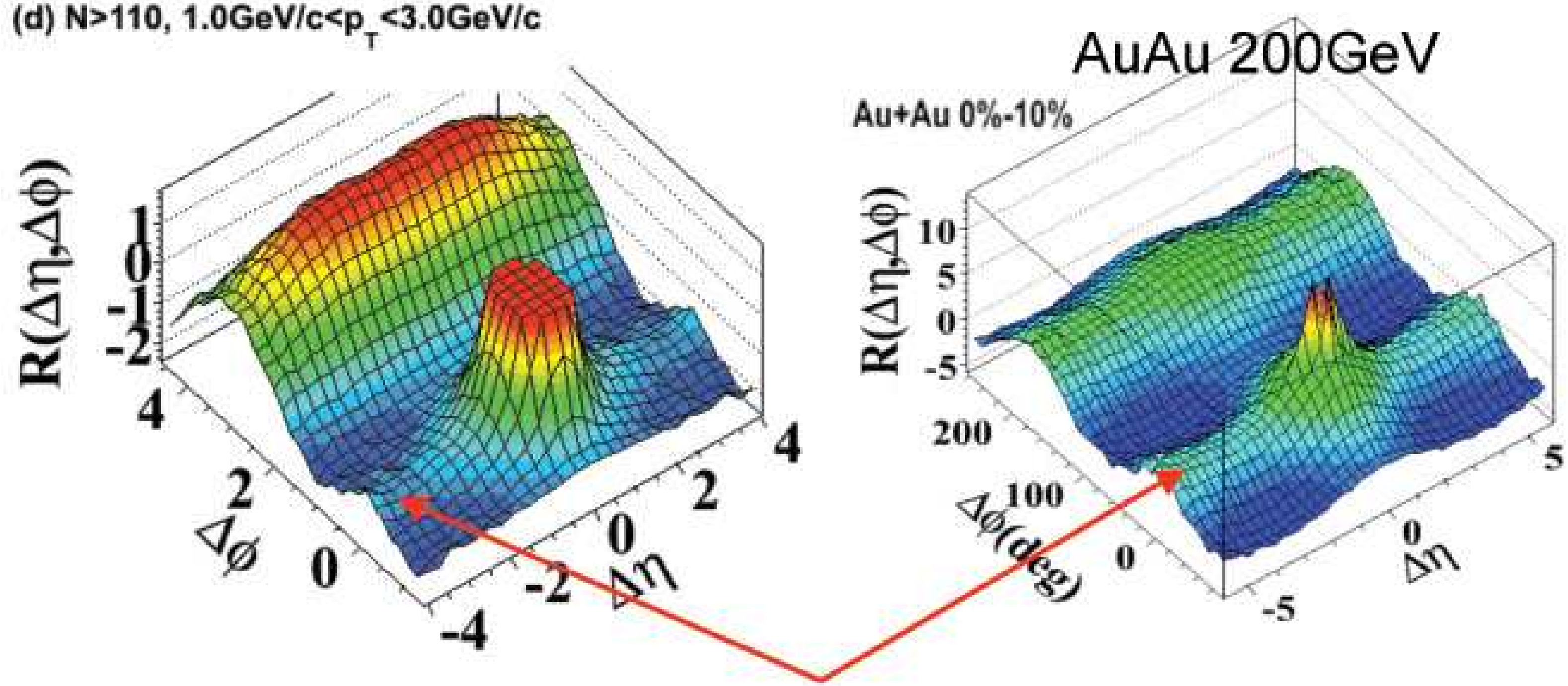


➡ **Long-range "Ridge"-like structure in Δη at Δϕ ≈ 0!**

Proton-Proton vs Au-Au

Proton-Proton Collisions 7 TeV

Gold-Gold Collisions 200 GeV



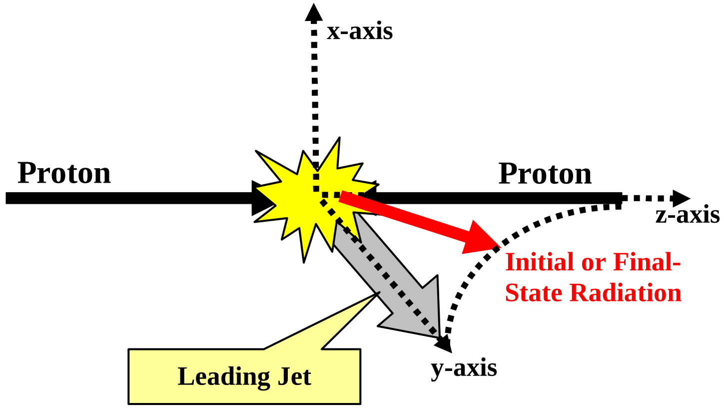
Similar "ridge" in high multiplicity pp
(even similar p_T dependence)

➡ **I am not ready to jump on the quark-gluon plasma bandwagon quite yet!**

Jet-Jet Correlations

- Are the "leading-log" or "modified leading-log" QCD Monte-Carlo Models missing an important QCD correlation?

- The leading jet and the incident protons form a plane (yz-plane in the figure). This is the plane of the hard scattering.

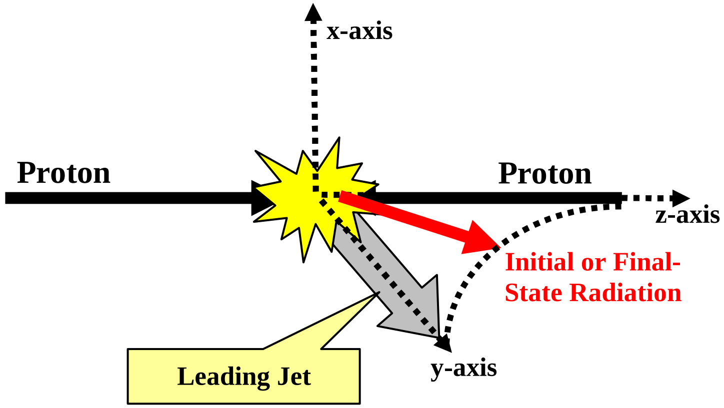


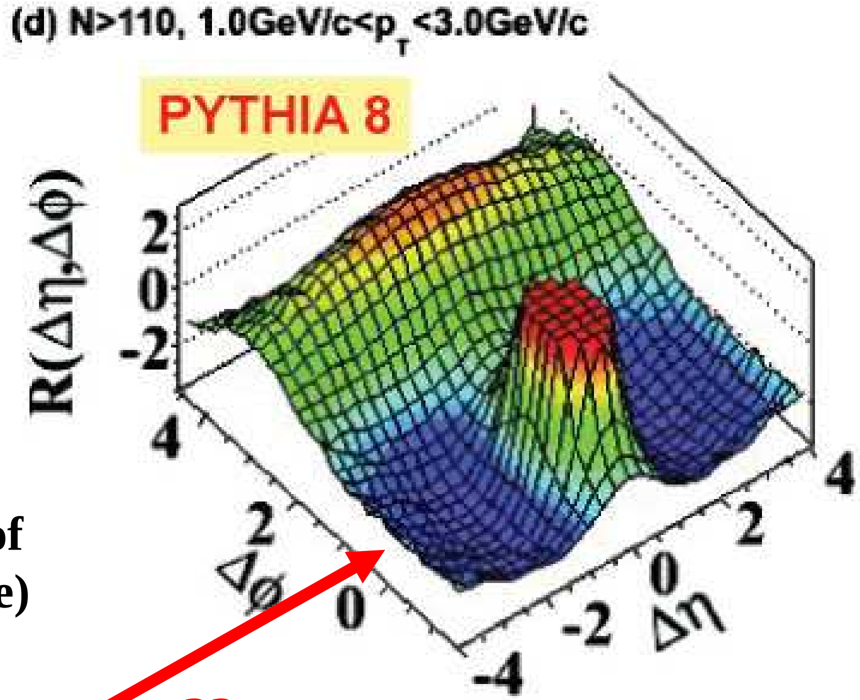
- Initial & final-state radiation prefers to lie in this plane. This is a higher order effect that you can see in the 2→3 or 2→4 matrix elements, but it is not there if you do 2→2 matrix elements and then add radiation using a naïve leading log approximation (*i.e.* independent emission).

- I do not know to what extent this higher order jet-jet correlation is incorporated in the QCD Monte-Carlo models.

- I would think that this jet-jet correlation would produce a long range (in $\Delta\eta$) correlation with $\Delta\phi \approx 0$ from two particles with one in the leading jet and one in the radiated jet. Why don't we see this in the Monte-Carlo models?

Jet-Jet Correlations





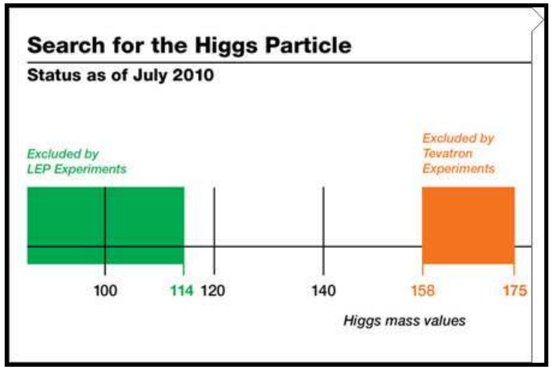
- **Initial & Final-State Radiation:** **There should be more particles "in-the-plane" of the hard scattering (yz-plane in the figure) than "out-of –the-plane".**

- **I do not understand why this does not result in a long-range same-side correlation?**

??

Why Expect "New Physics"?

➡ **Unitarity:** **Fermi contact interaction is tamed at high energies through an intermediate Massive Vector Boson (W). However, massive vectors develop a longitudinal component and unitarity is lost at high energies!**



Violates Unitarity ! **Restored via Goldstone Bosons!** ➡ **"New Physics"**

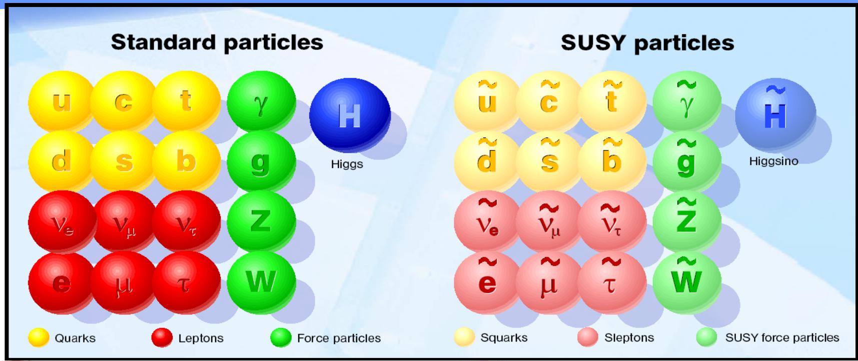
➡ **Dark Matter:** **If gravity is described by Einstein's equations, the Universe we observe cannot be explained without sizeable "dark components".**

No Dark Matter candidate in Standard Model ! ➡ **"New Physics"**

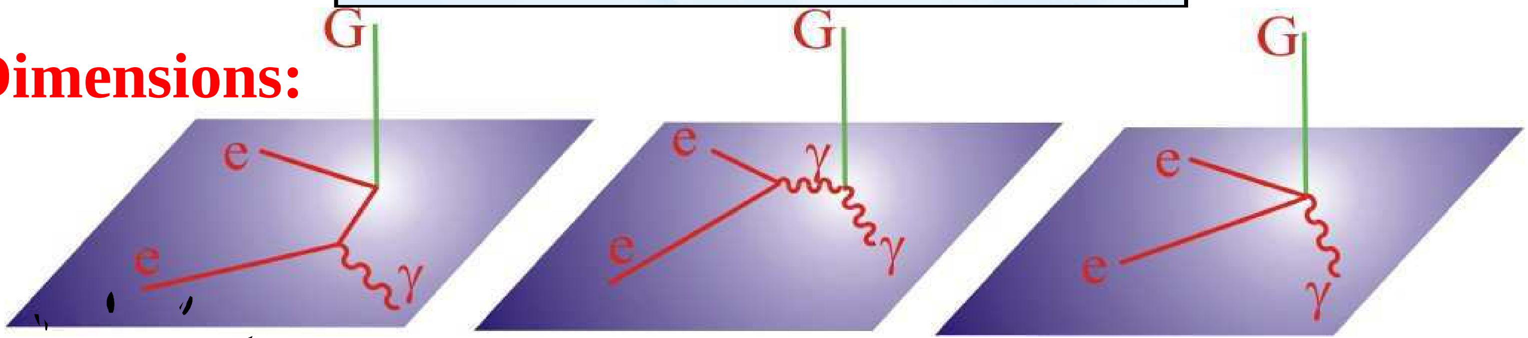
Neutralinos, Gravitinos, Axinos, Scalar Neutrinos, KK Photons, KK Neutrinos, 4th Gen. Neutrinos, Mirror Photons, Mirror Nuclei, Stable States from Technicolor, Sterile Neutrinos, Light scalars, Q-balls, D-matter, Braneworld Matter, Primordial Black Holes, Axions, …

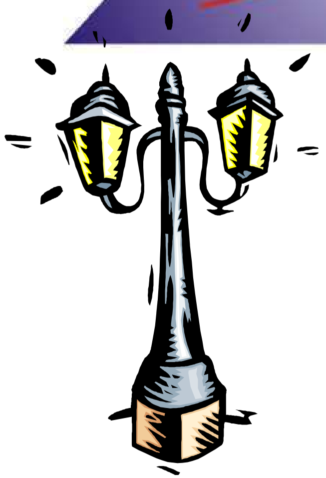
What "New Physics"?

➡Supersymmetry:



➡Extra Dimensions:



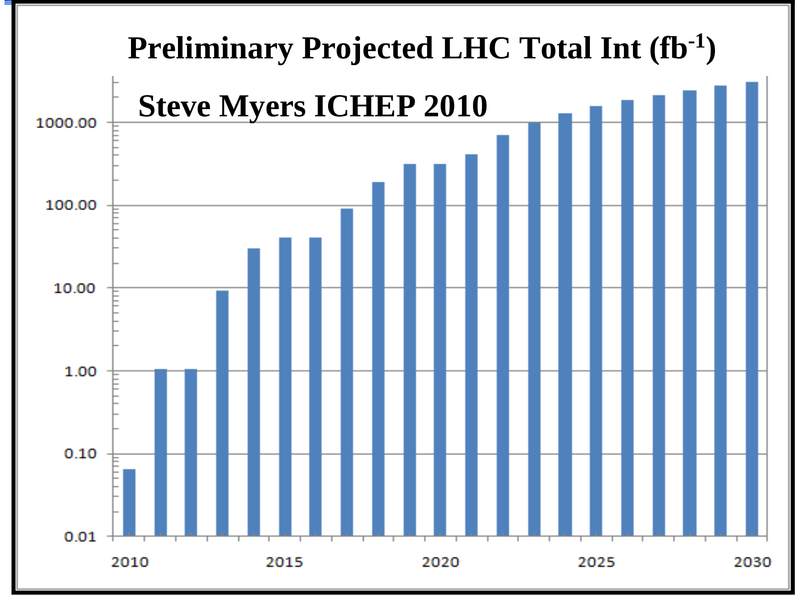


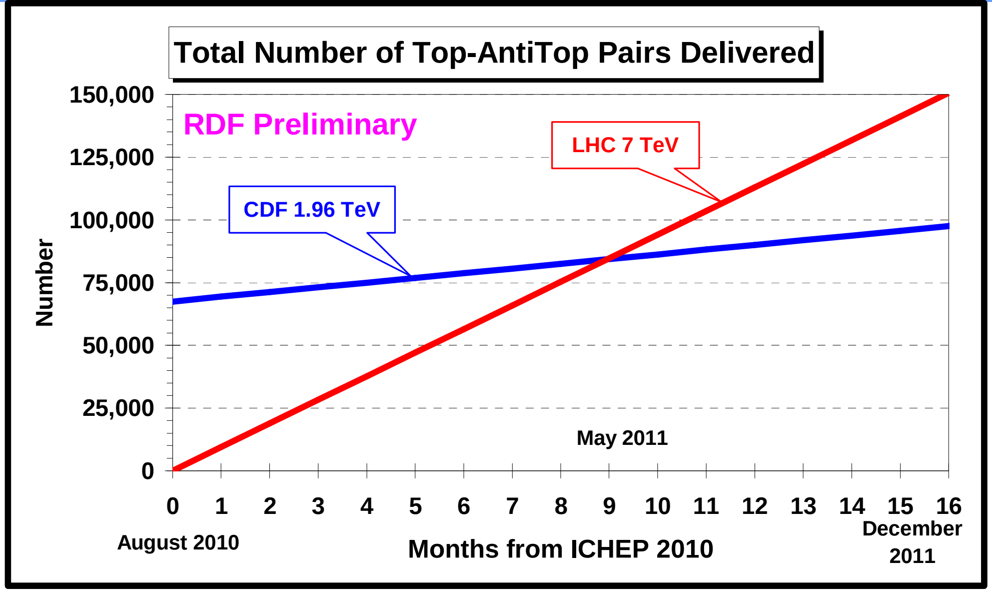
LHC Street Lamp

*Hidden Sectors (Y. Xie ICHEP talk)
*Exotic particles of Various Spin and Gauge permutations (Berger ICHEP talk)
*Quirks (Y. Xie ICHEP talk)
*Supermodels At Early LHC (Ligeti ICHEP talk)
*Exotic Higgs Decays (Several ICHEP talks)
*Many Others

From James Wells (ICHEP 2010)

When "New Physics"?

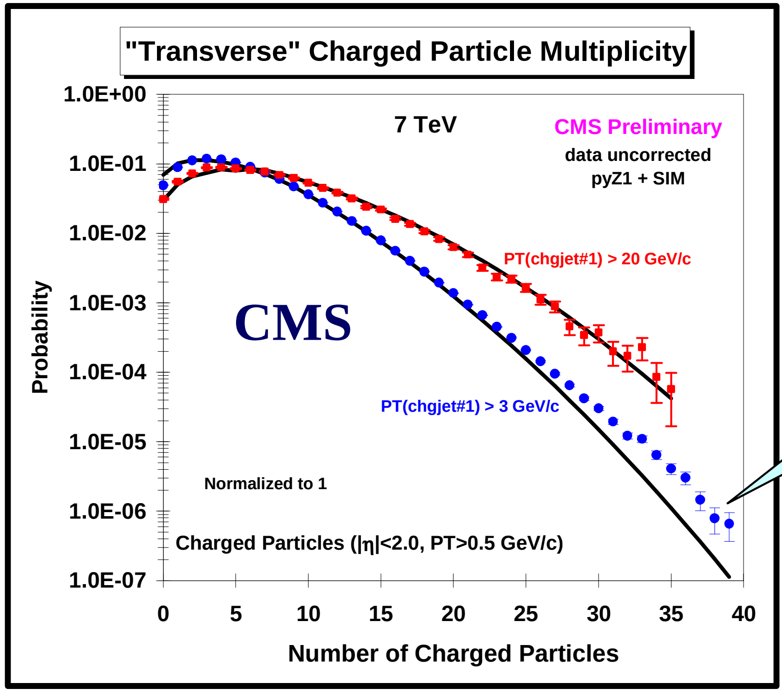




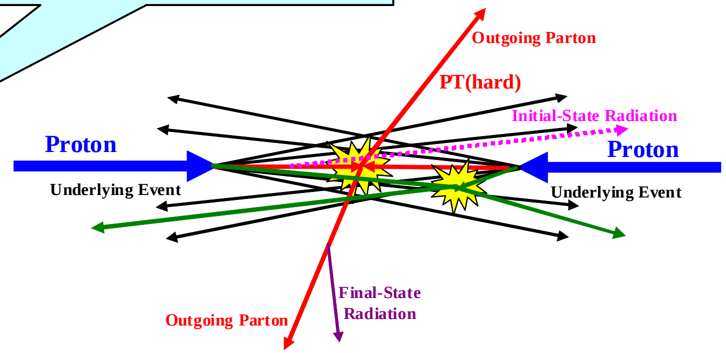
- Expect more new LHC physics in 2011 (if Steve Myers' integrated luminosity projections are correct)!
- Also might see new physics at the Tevatron (*e.g.* A_{FB}(top))!
- I think the Tevatron and LHC programs complement each other nicely and I would like to see the Tevatron continue to run over the next several years!

CDF has a high multiplicity min-bias trigger.
They should look for long-range same-side correlations!
If it is a QCD effect, it should be there at 1.96 TeV.

How to Find "New Physics"?



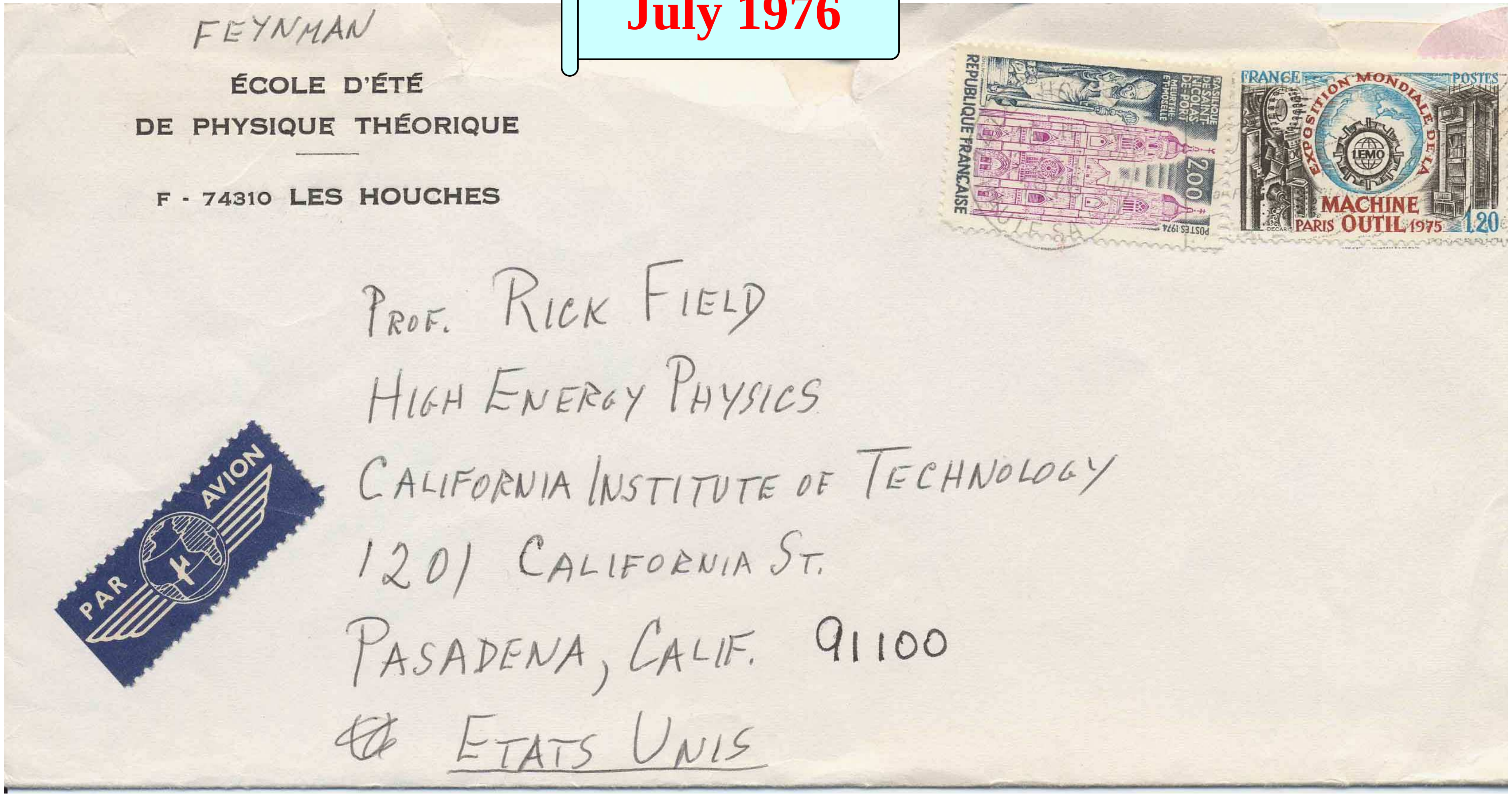
Difficult to produce enough events with large "transverse" multiplicity at a low hard scale!

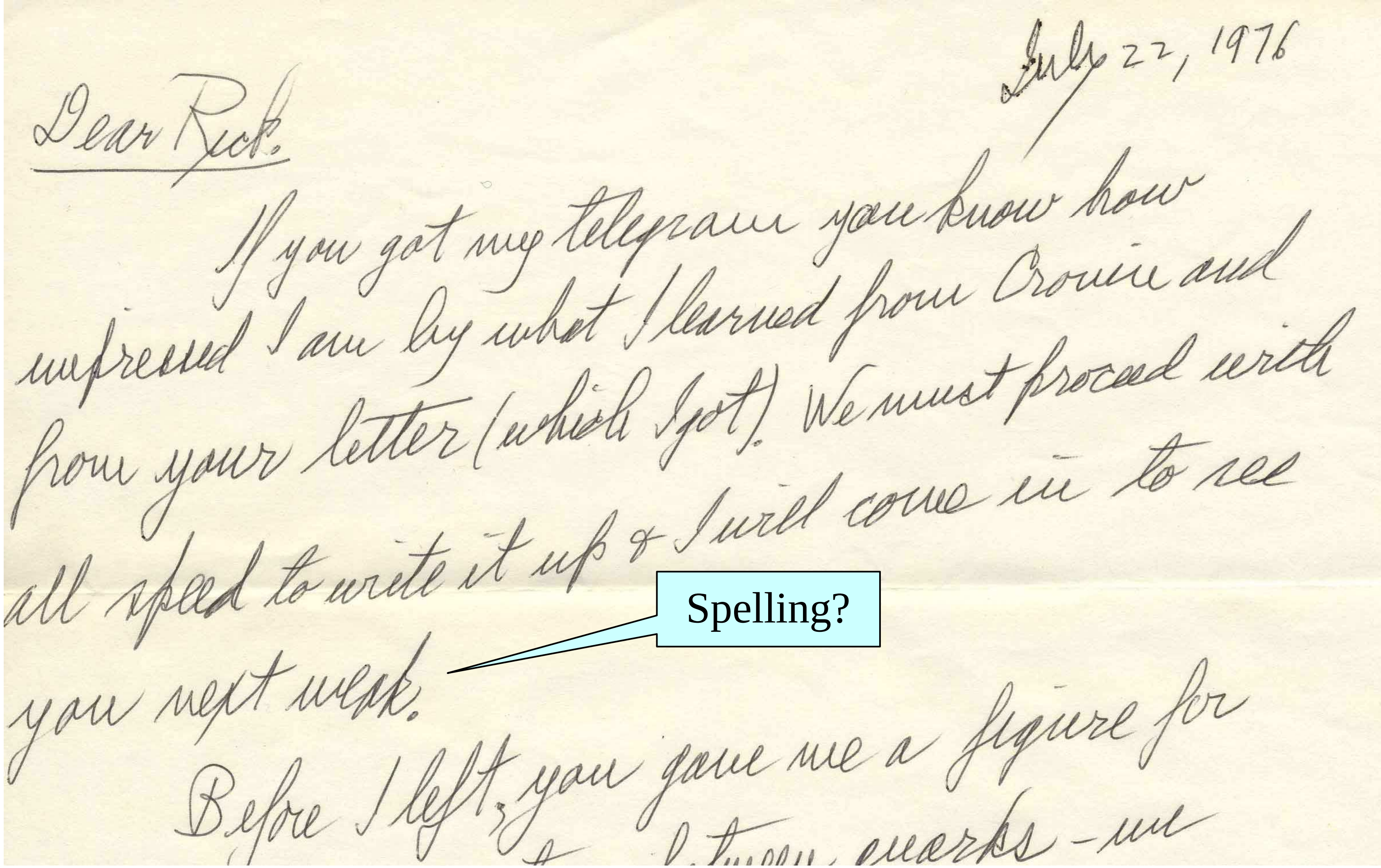


Calculate the Standard Model and QCD as accurately as possible and look for deviations from these predictions in the data!

Letter from Feynman

July 1976





July 22, 1976

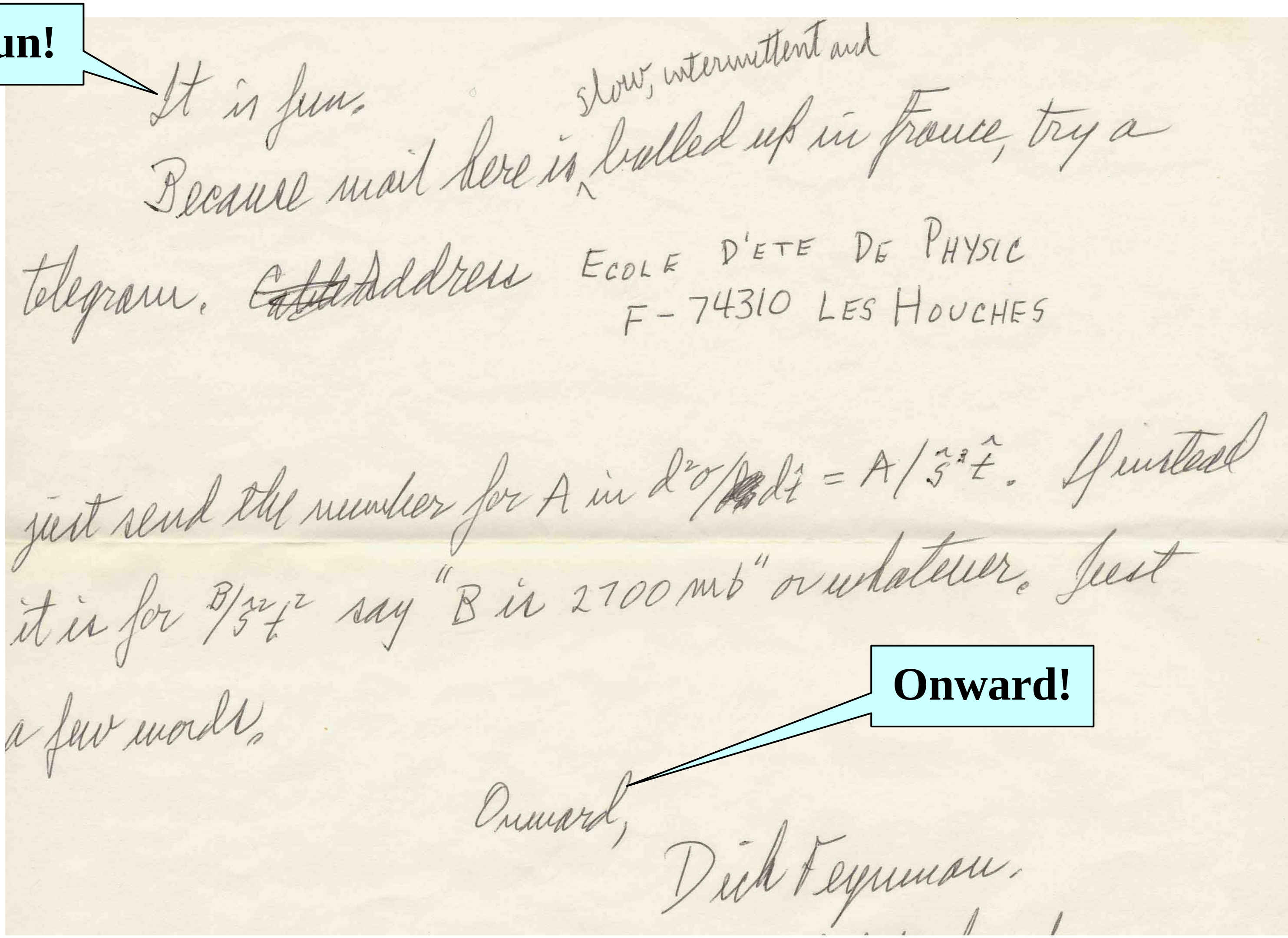
Dear Rick.

If you got my telegram you know how impressed I am by what I learned from Cronin and from your letter (which I got). We must proceed with all speed to write it up & I will come in to see you next weak.

Before I left, you gave me a figure for

Letter from Feynman Page 3

It is fun!



It is fun.

Because mail here is slow, intermittent and balled up in France, try a telegram. Address ECOLE D'ETE DE PHYSIC
F-74310 LES HOUCHES

just send the number for A in $d^2\sigma/d\hat{t} = A/\hat{s}^3\hat{t}$. If instead it is for $B/\hat{s}^2\hat{t}^2$ say "B is 2700 mb" or whatever. Just a few words.

Onward,

Dick Feynman.

Onward!