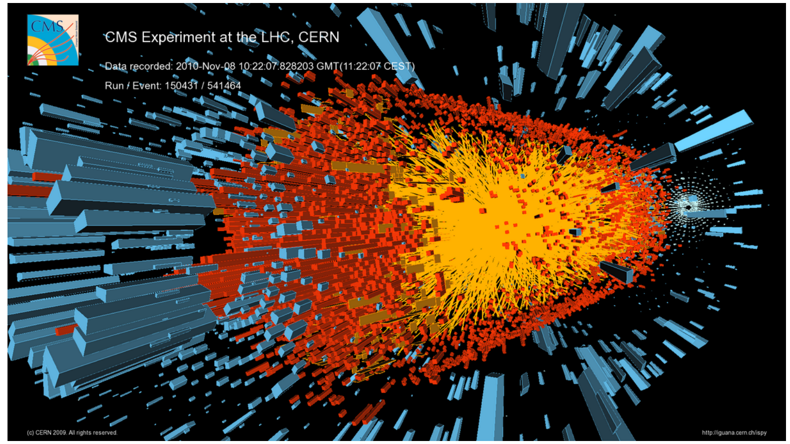
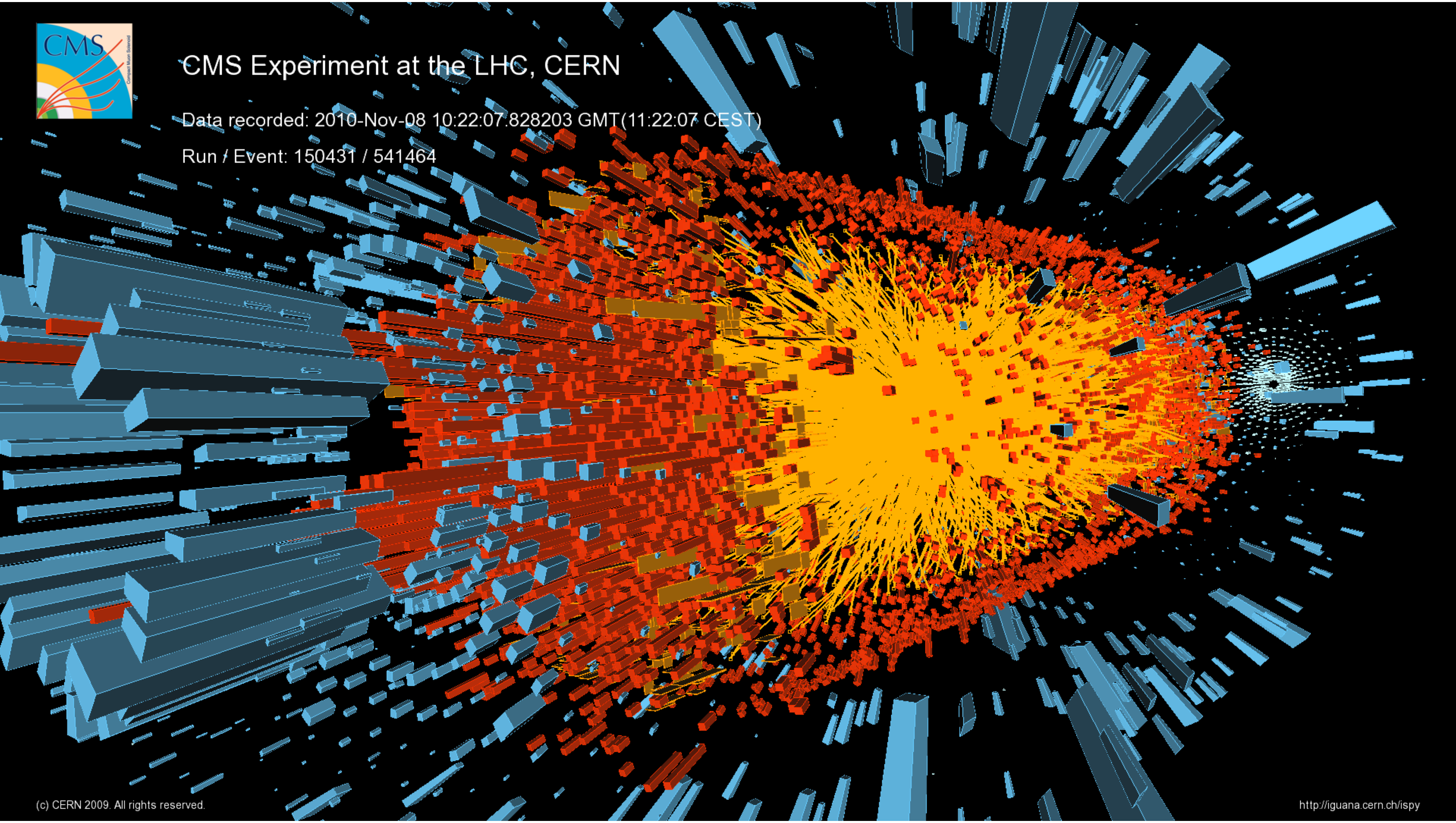


Results on global event properties of hadron and ion collisions by the CMS experiment

Gábor Veres

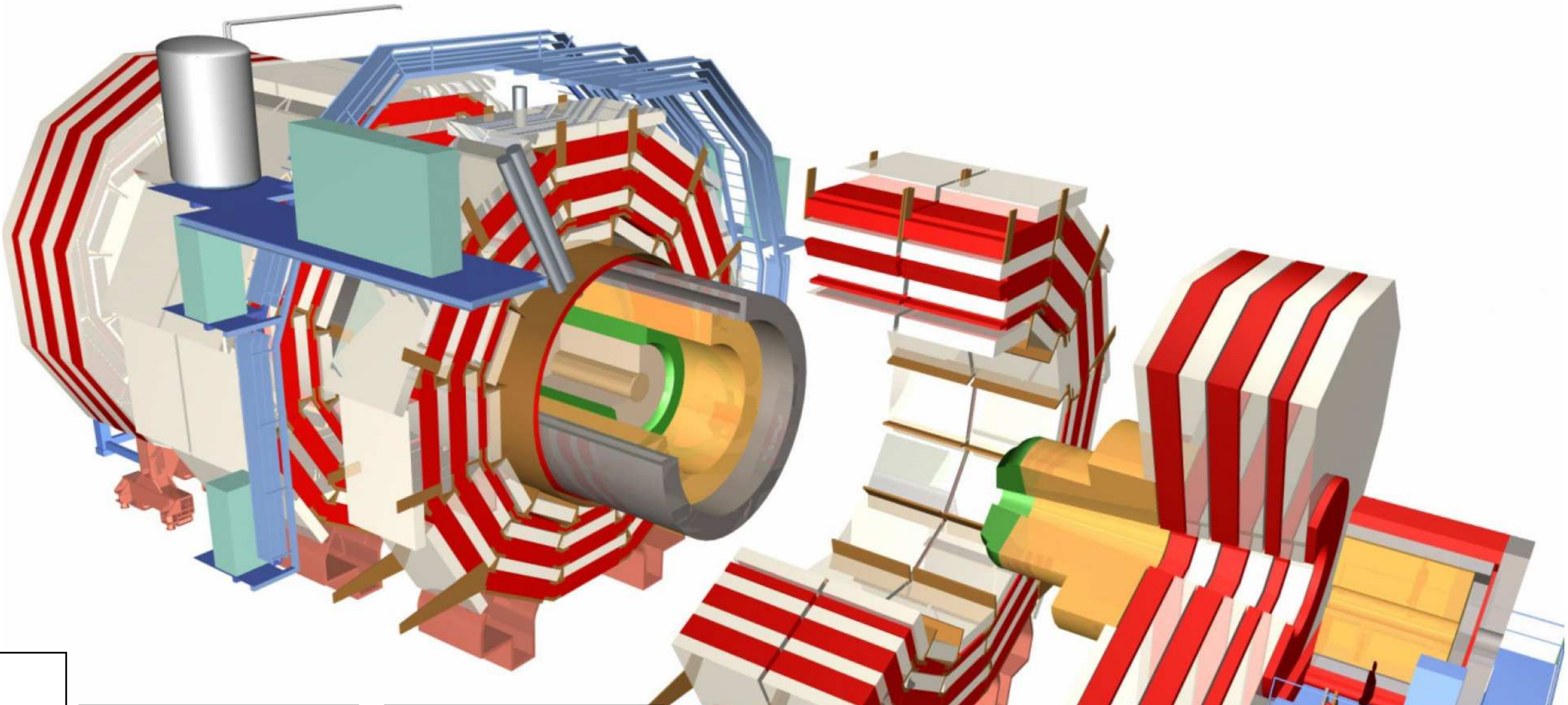
Eötvös Loránd University
Budapest, Hungary


CMS
CMS Experiment at the LHC, CERN
Data recorded: 2010-Nov-08 10:22:07.828203 GMT(11:22:07 CEST)
Run / Event: 150431 / 541464
(c) CERN 2009. All rights reserved.
http://iguana.cern.ch/ispy

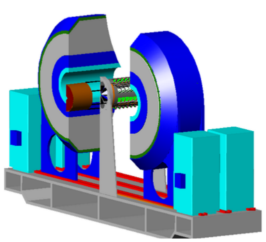
Outline

- **Historical perspective of global analysis**
  - Charged particle distributions, limiting fragmentation
- **Selected CMS results on global properties**
  - Charged particle distributions
  - Angular correlations
  - Diffraction
  - Inelastic cross section
  - Charge exchange

The CMS experiment

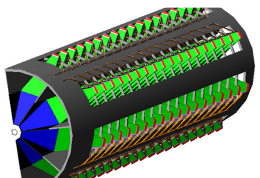


TOTEM



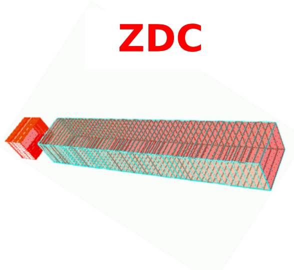
$5.3 \leq \eta \leq 6.7$

CASTOR



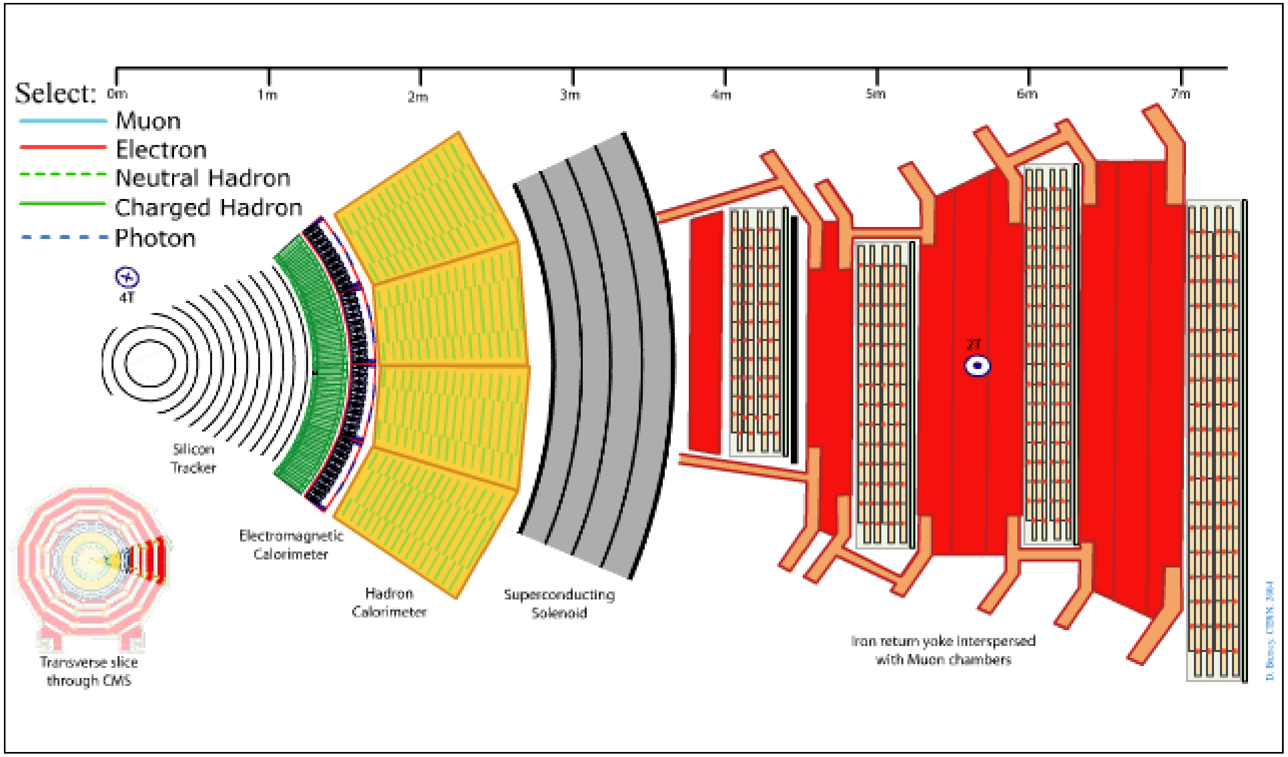
$5.2 \leq |\eta| \leq 6.6$

ZDC



$8.3 \leq |\eta|$

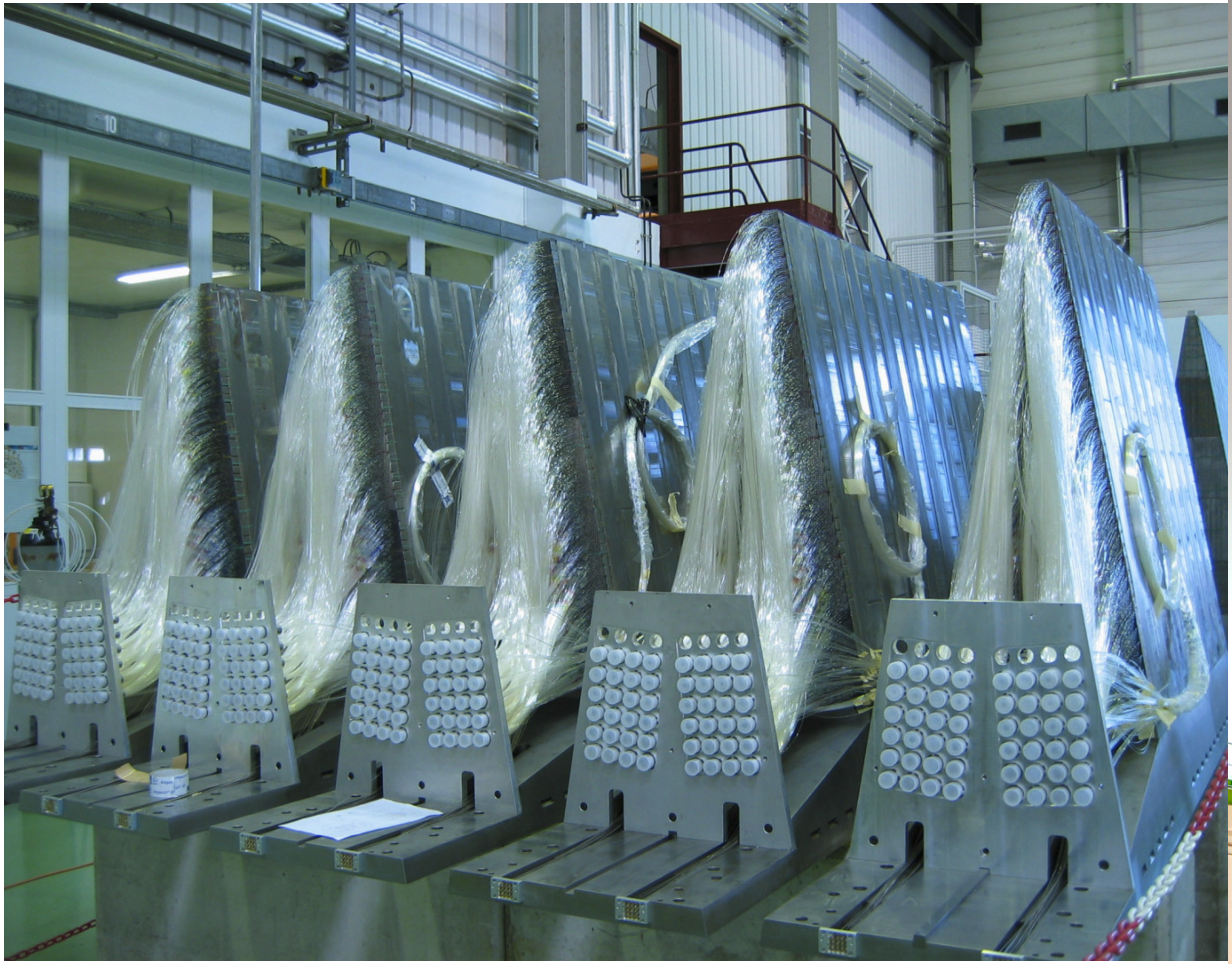
The CMS detector

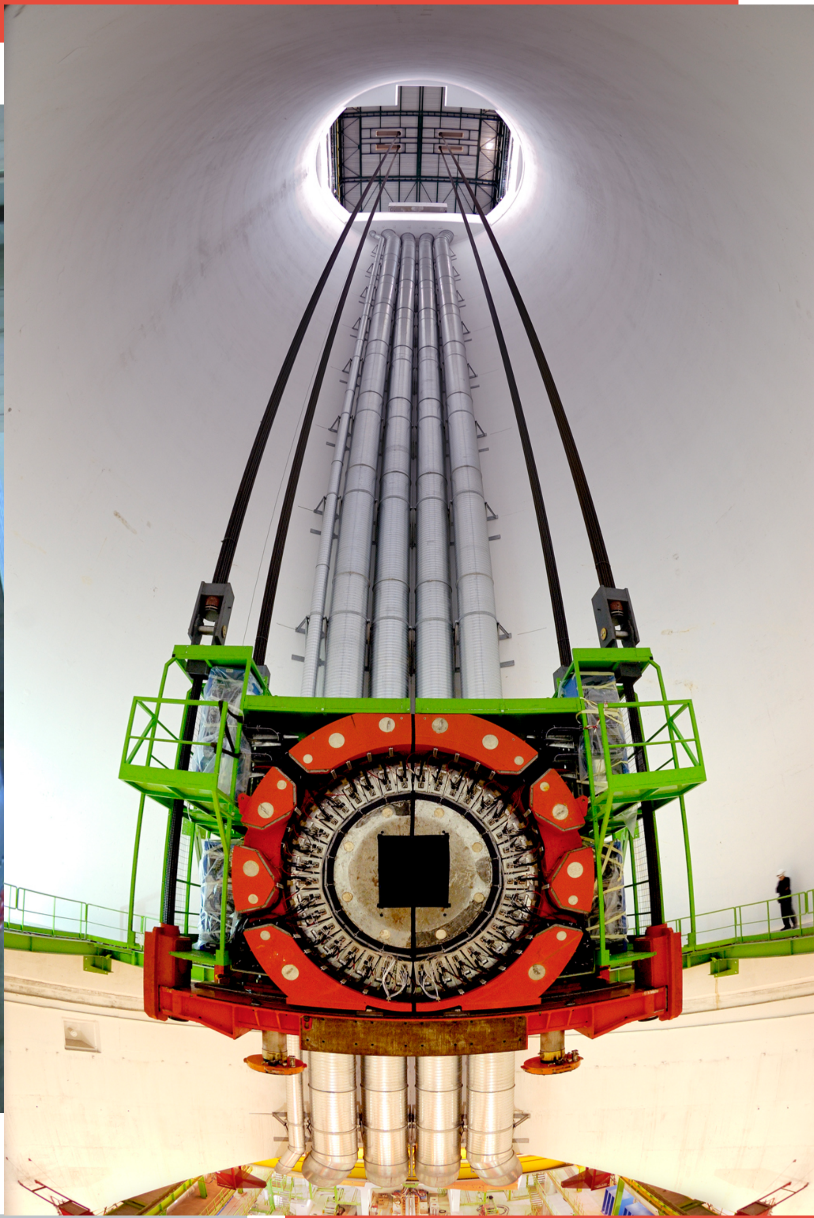


A single detector combines global characterization and specific probes

- Silicon tracker: pixels and strips ($|\eta|<2.4$)
- Electromagnetic ($|\eta|<3$) and hadronic ($|\eta|<5$) calorimeters
- Muon chambers ($|\eta|<2.4$)
- Extension with forward detectors (CASTOR $5.3<|\eta|<6.6$, ZDC $|\eta|>8.3$)

The Hadron Forward calorimeter





Global event properties – early questions

What is the energy released in a collision?

Are ions (hadrons) transparent? How much?

Are baryons stopped in a heavy ion collision?

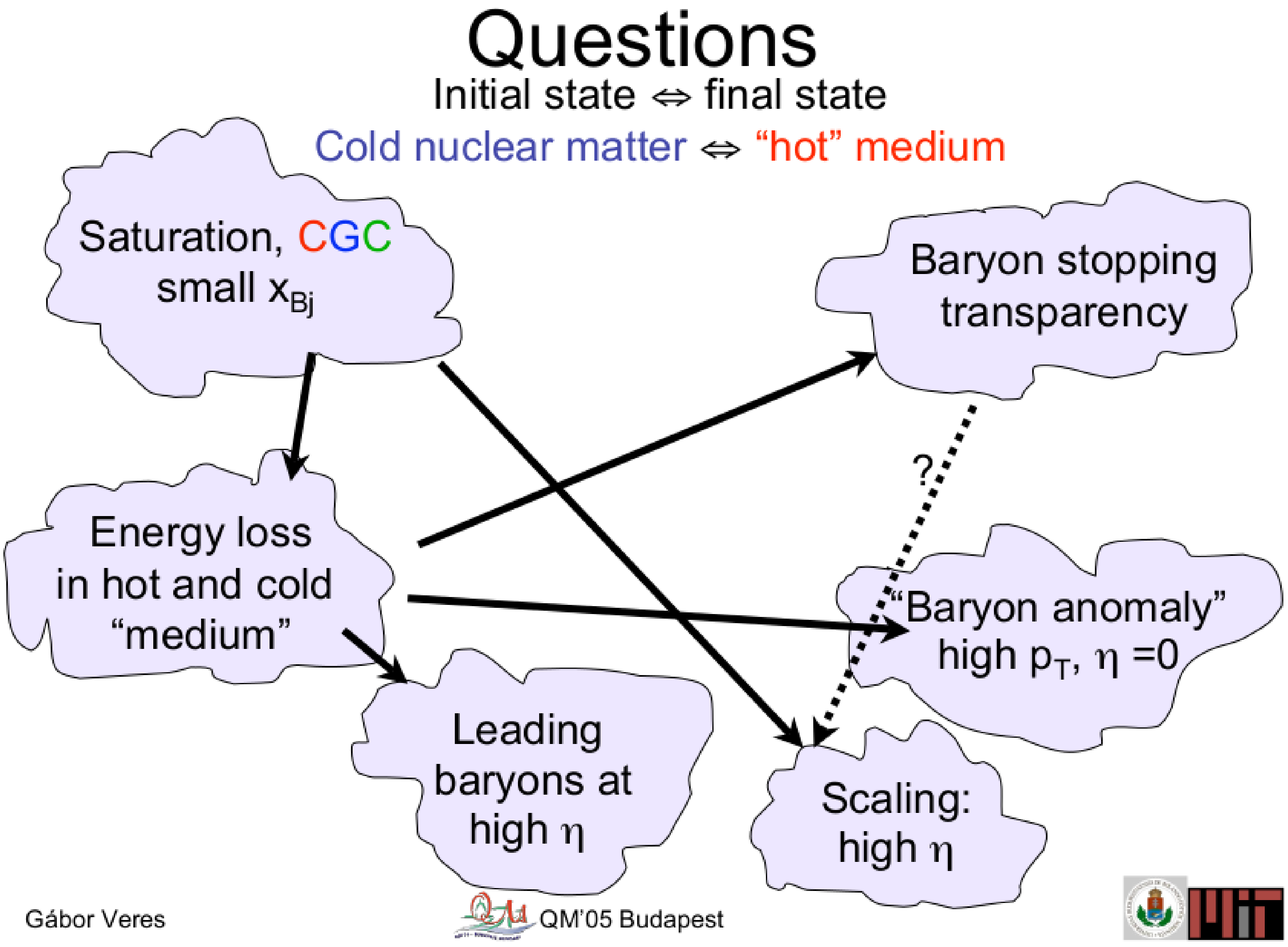
Number and momentum of final state particles?

Total, elastic, inelastic cross section, diffraction

Correlation between particles

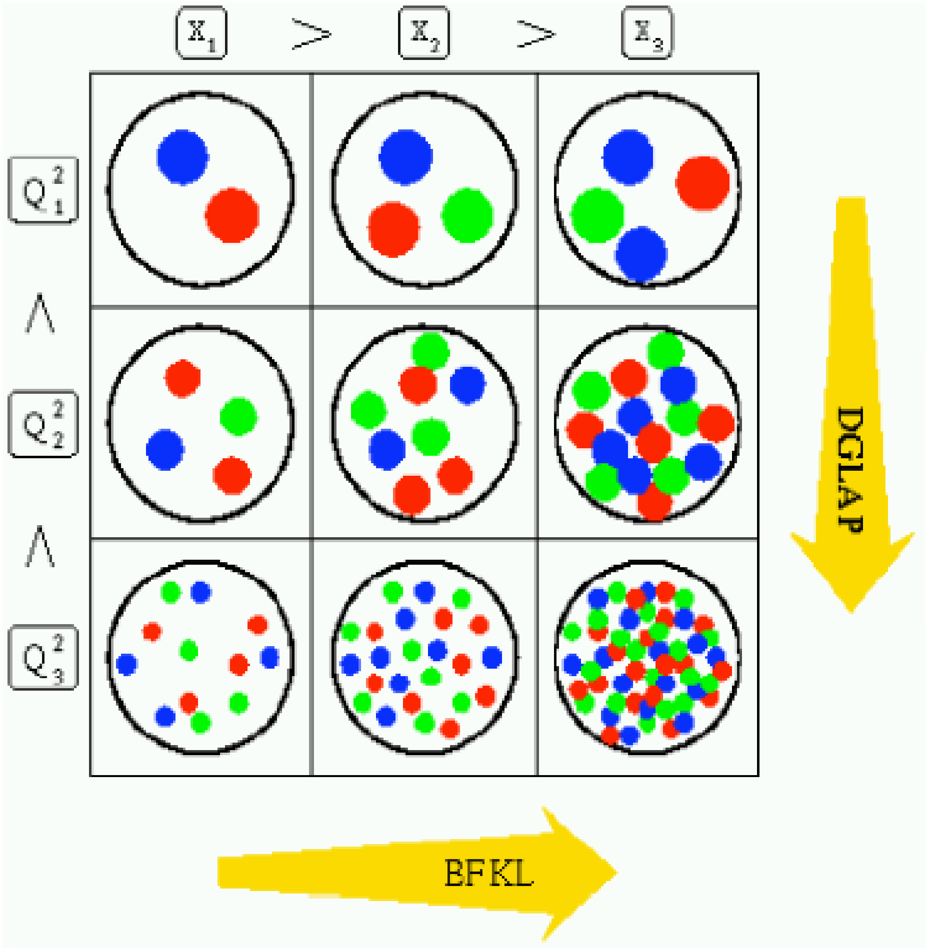
Saturation at low x (high rapidities)

Questions about high eta



Gluon saturation

Saturated initial state gluons



Kinematics

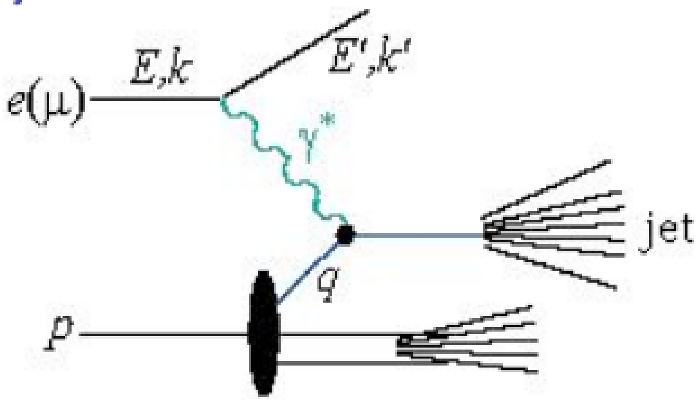
$$p_z = m_T \sinh y = p_T \sinh \eta = \frac{\sqrt{s}}{2} x_F$$

Rapidity: generalized velocity

Pseudorapidity ≈ y: easier to measure

Feynman x: $\propto p_z$

x_{Bj} : deep inelastic scattering



$$Q^2 = 2(EE' - \vec{k} \cdot \vec{k}')$$

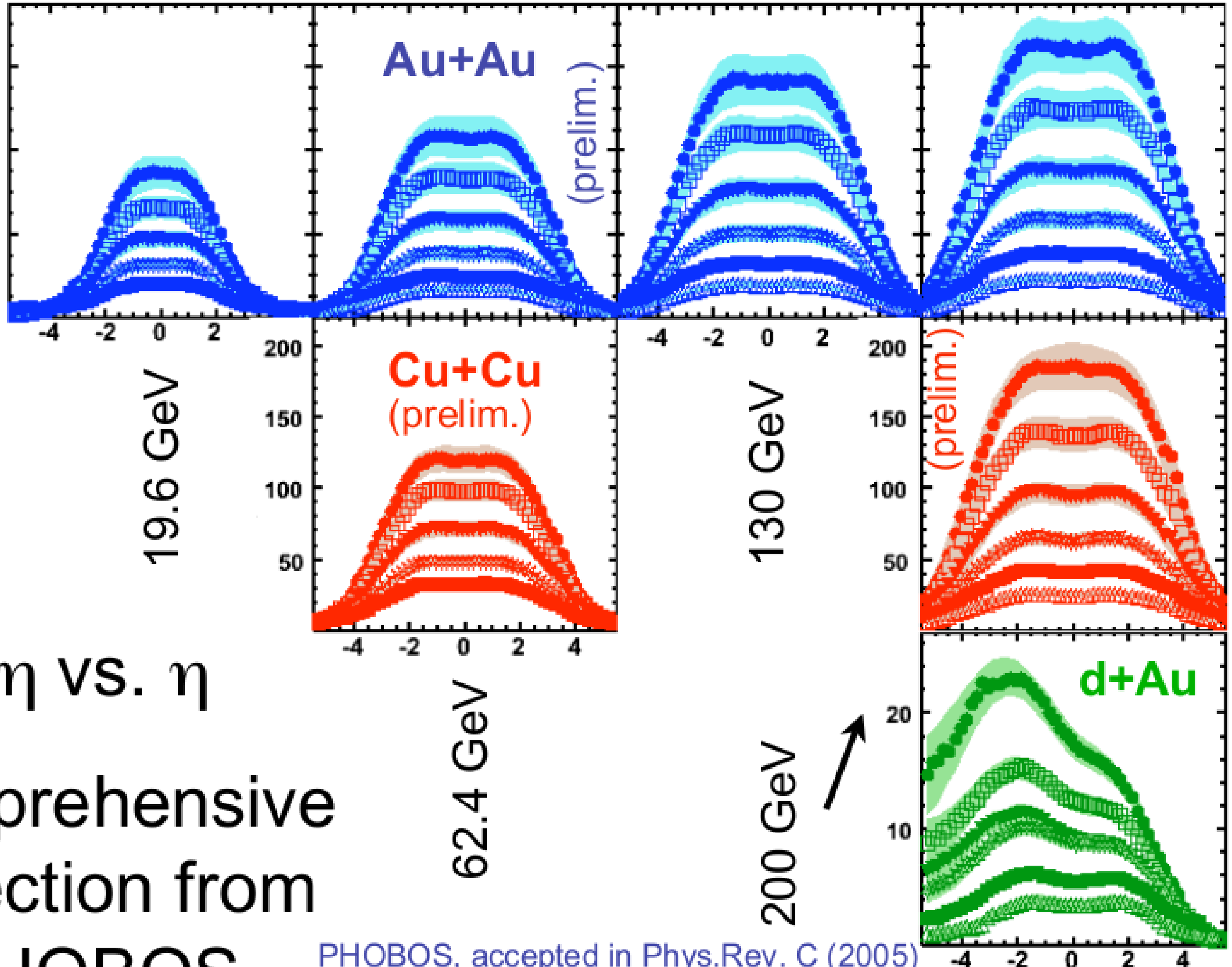
$$\nu = E - E'$$

$$x = Q^2 / 2M\nu$$

In the c.m. system:

$$x_{Bj} \approx \frac{p_T e^{-\eta}}{\sqrt{s} - p_T e^{\eta}}$$

Measurements at RHIC (PHOBOS)

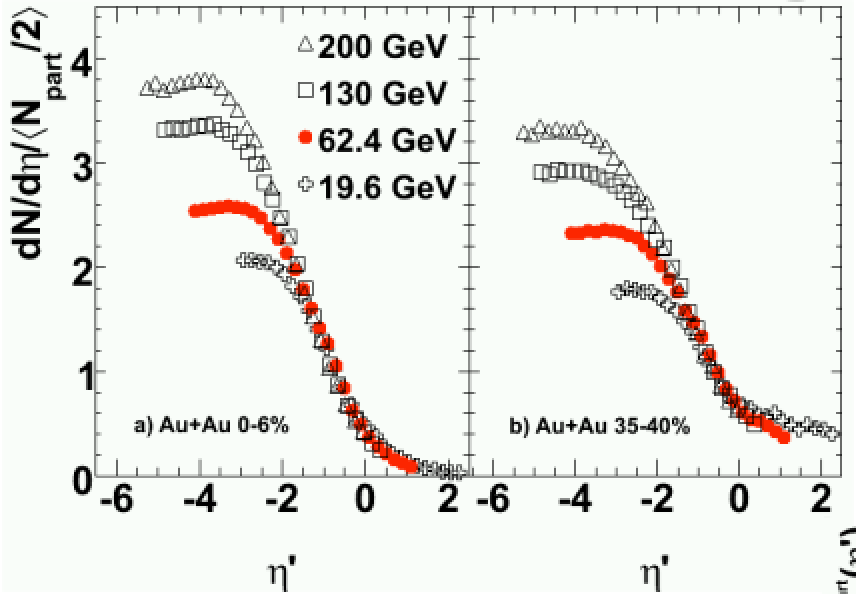


dN/dη vs. η

Comprehensive collection from PHOBOS

PHOBOS, accepted in Phys.Rev. C (2005)
Nucl. Phys. A 757 28 (2005)

Extended longitudinal scaling



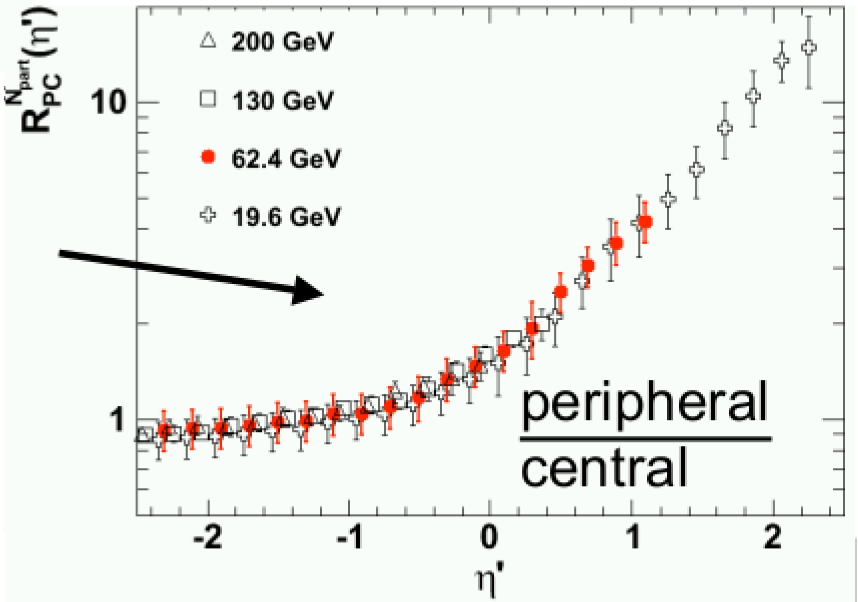
Energy independence in a large η range...

…in a centrality *dependent* way.

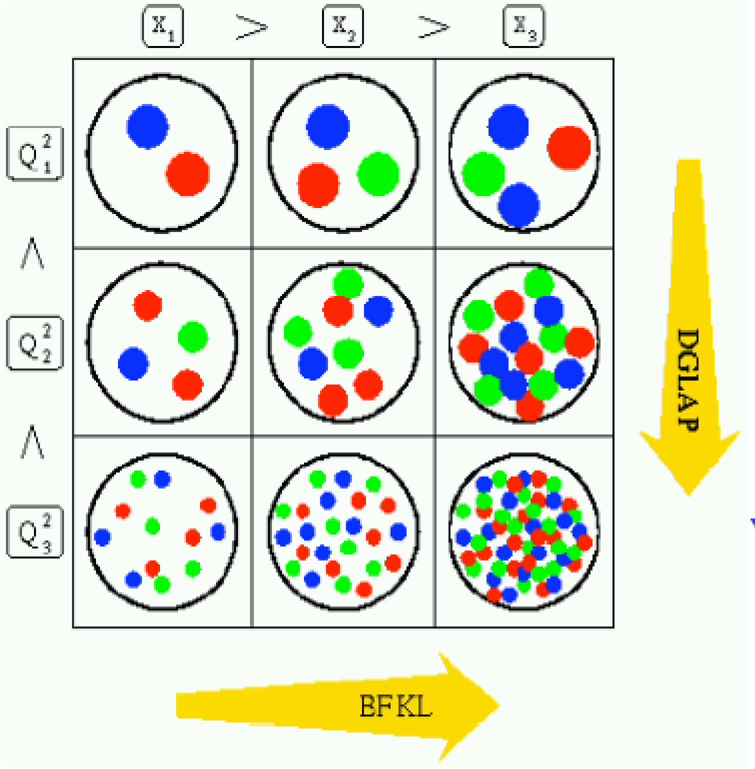
But the centrality and energy dependence factorizes!

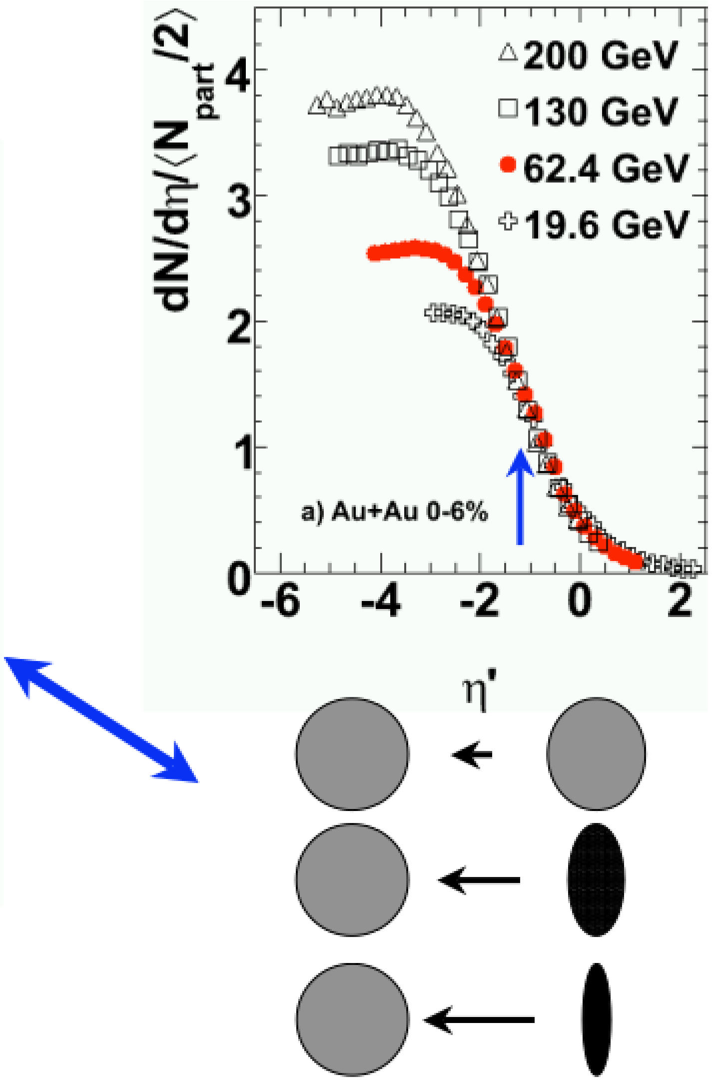
(note the precision)

Nucl. Phys. A 757 28 (2005)

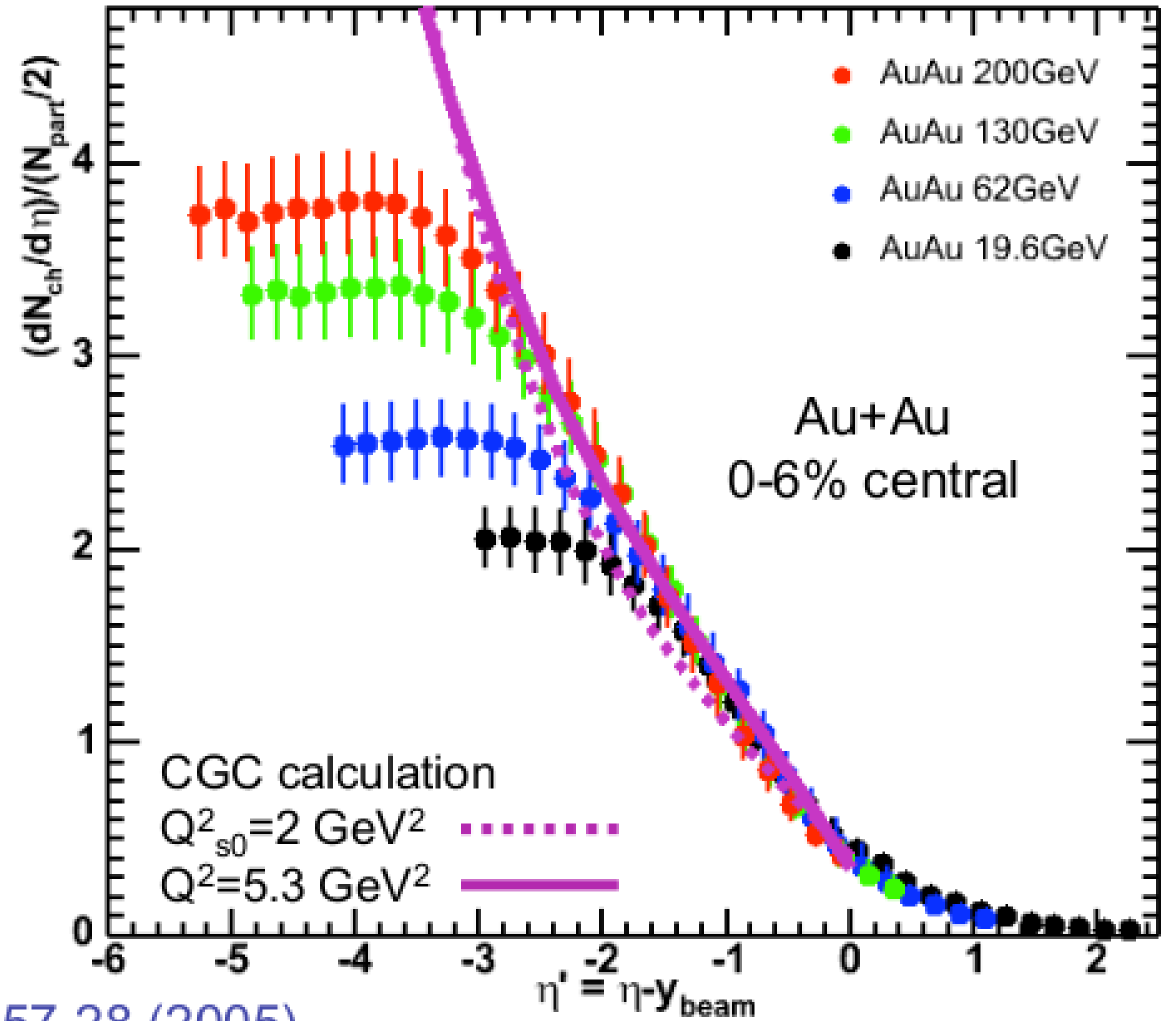


Scaling and saturation



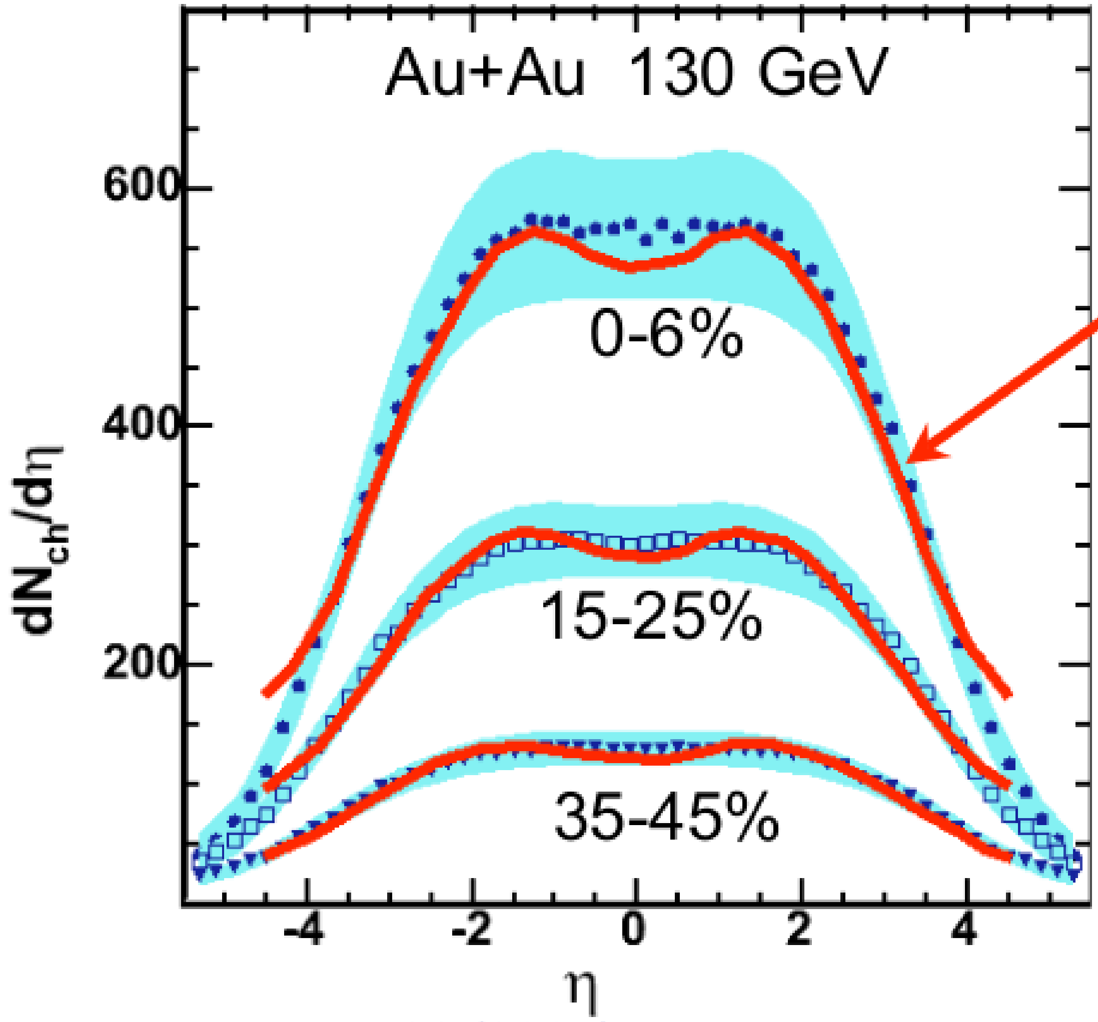


Longitudinal scaling vs. collision energy



Nucl. Phys. A 757 28 (2005)
Phys.Rev.C70 027902 (2004)

Centrality dependence: heavy ions



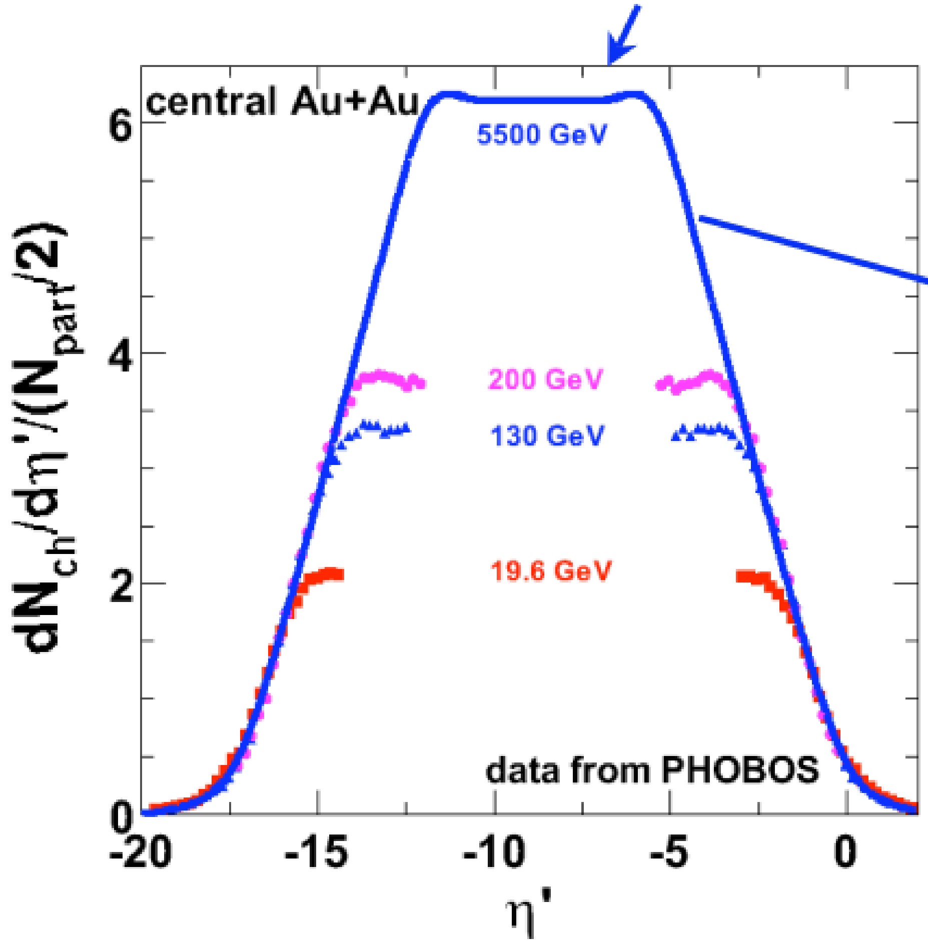
Saturation model provides a good description of the dN/dη data

Nucl. Phys. A 757 28 (2005)
J.Phys.G 30 S751(2004)

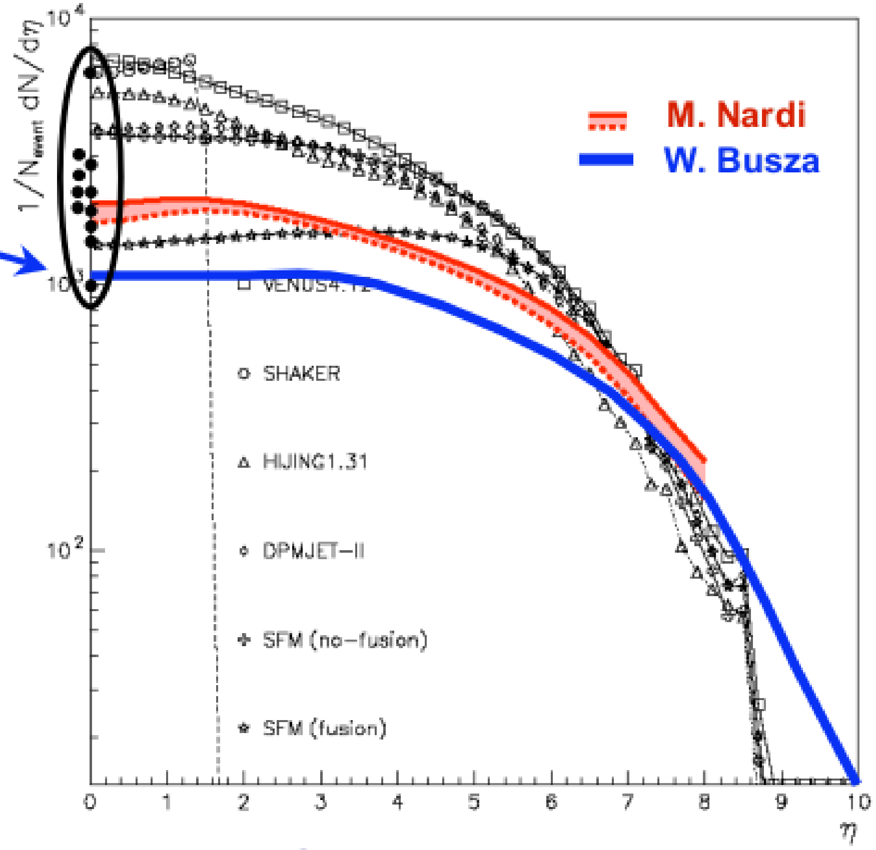
Predictions/extrapolations to LHC

Central Pb+Pb collisions at LHC energy

Assuming: dN/dη grows ∝log(s) and *linear* scaling at high η holds

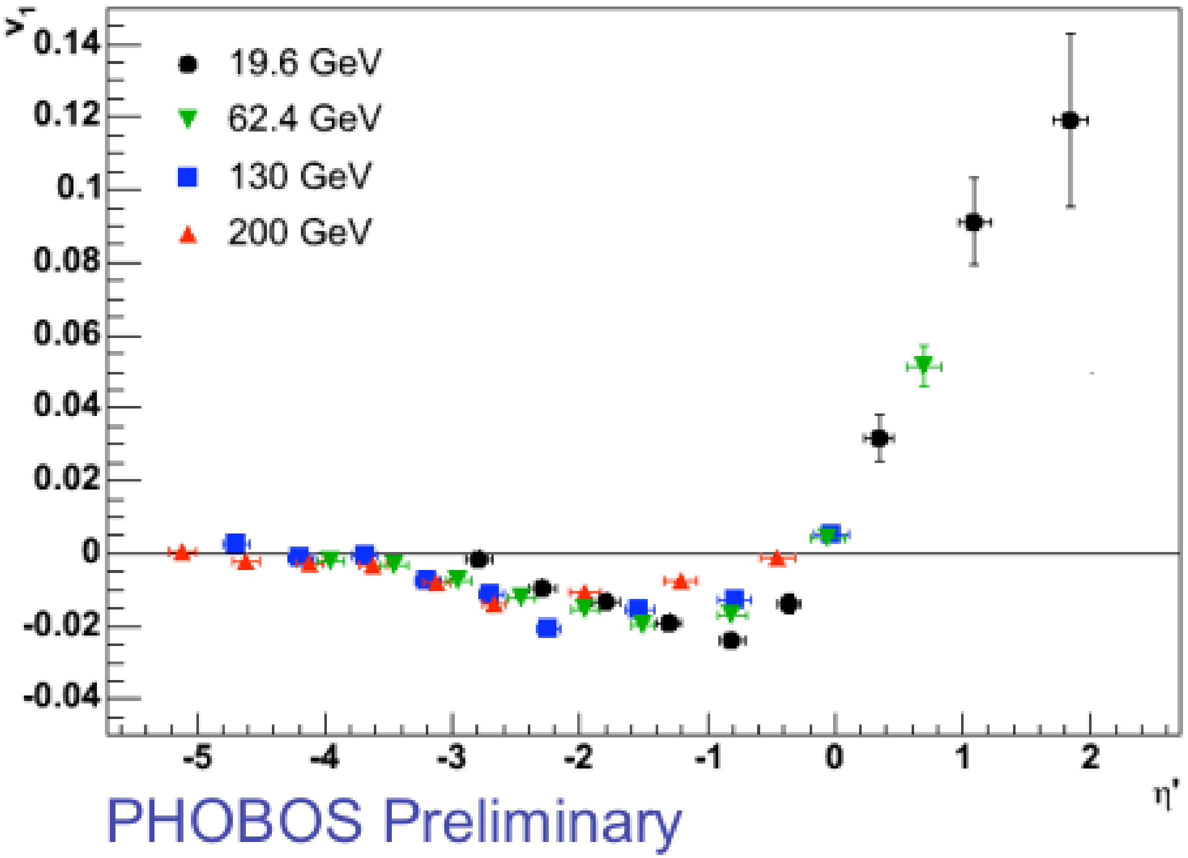


Acta Phys.Polon.B35 2873 (2004)



ALICE Tech. Proposal,
M. Nardi, various models and fits

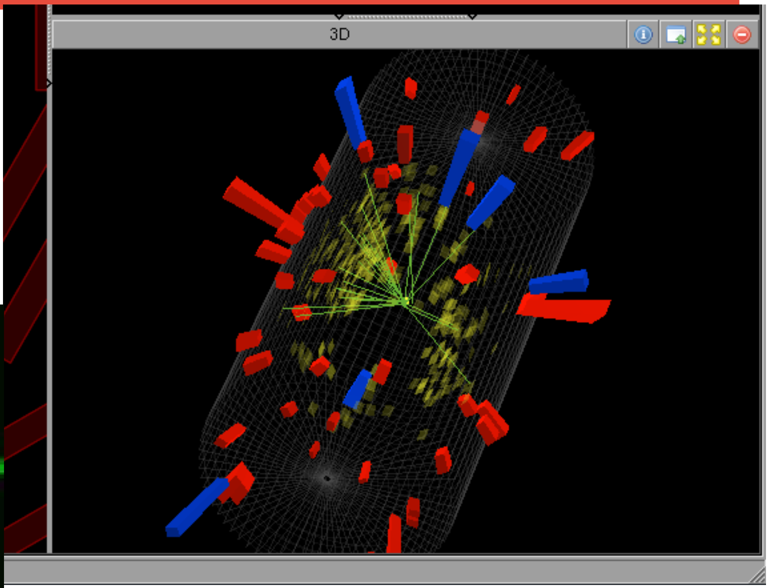
Extended longitudinal scaling: v_1

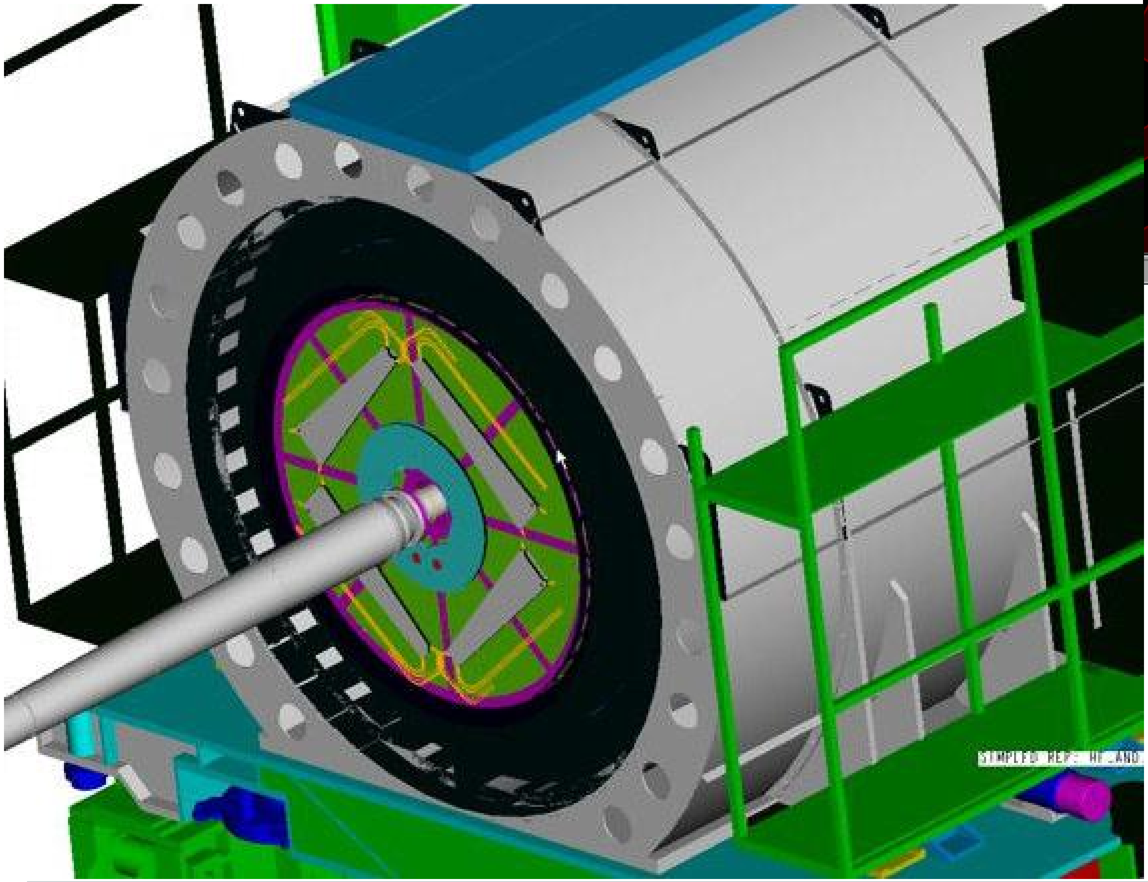


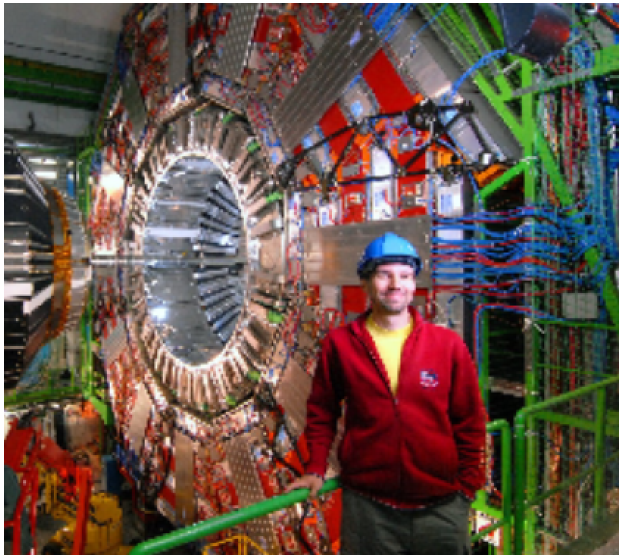
⇒ These scaling features of the bulk hadron production at high η are unexplained by initial state models alone.

The first collisions at the LHC: trigger

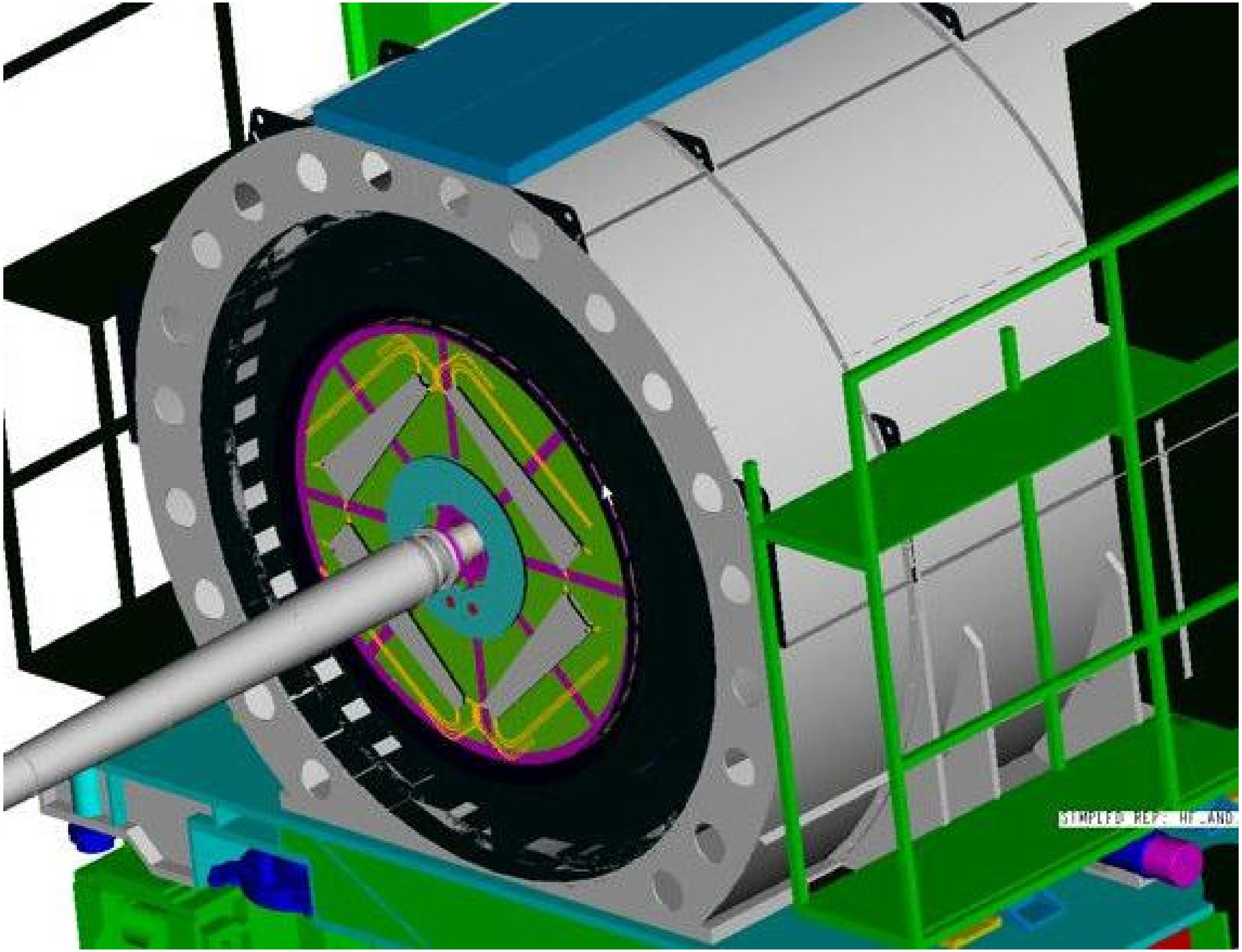
23th November, 2009, 19:20:55 CET
The first proton-proton collision
at the LHC



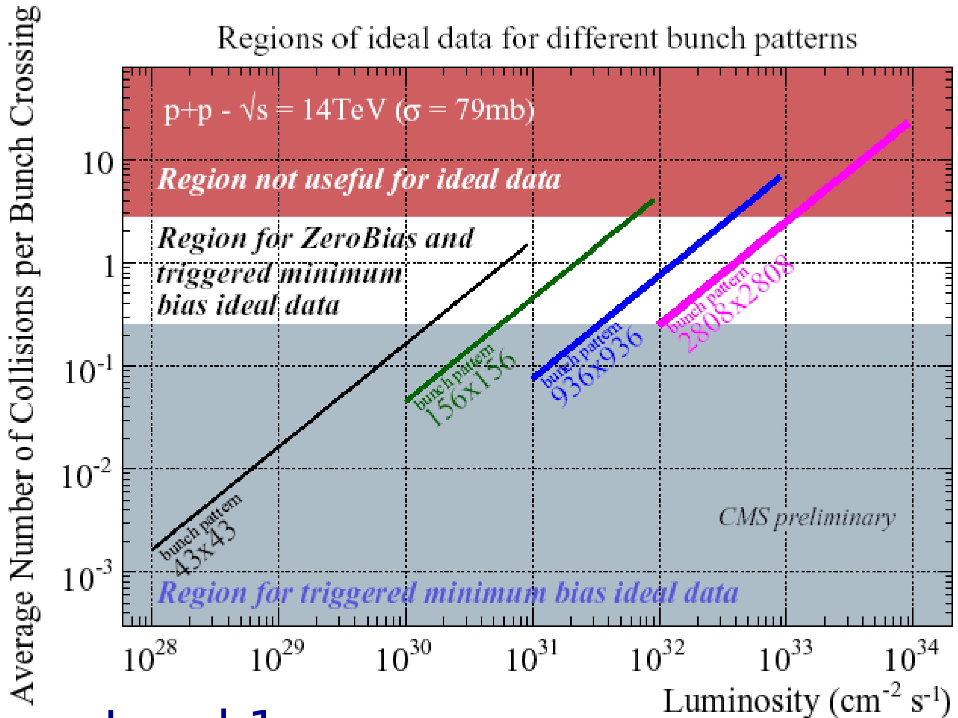




The Beam Scintillator Counters (BSC)



Trigger ideas before the LHC startup



- Random trigger, Level-1

  Zero bias: trigger on crossing of filled bunches

  Optimal for moderate intensity, heavily prescaled

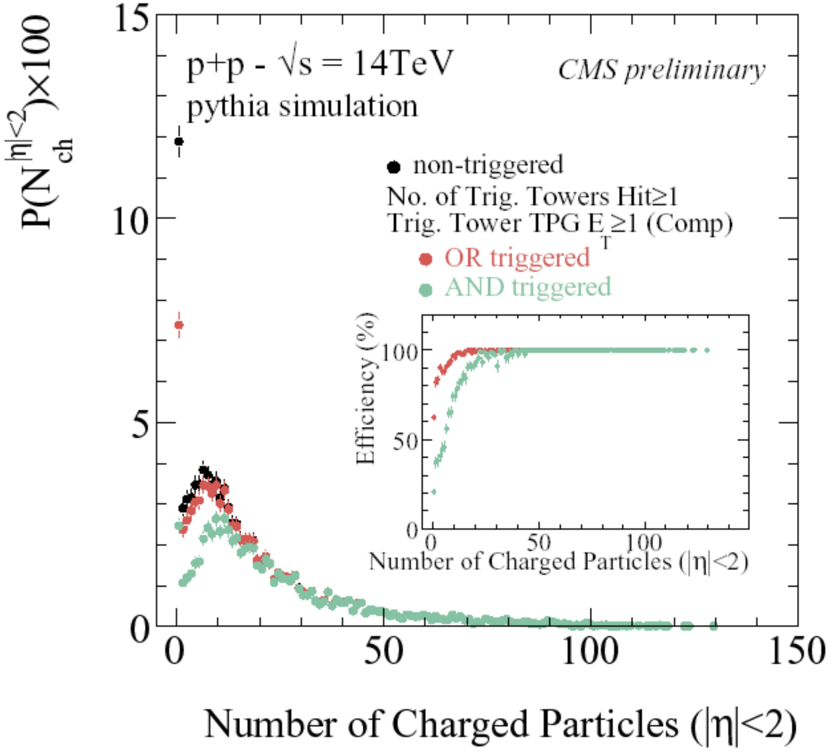
- At least one track in the pixel detector, HLT

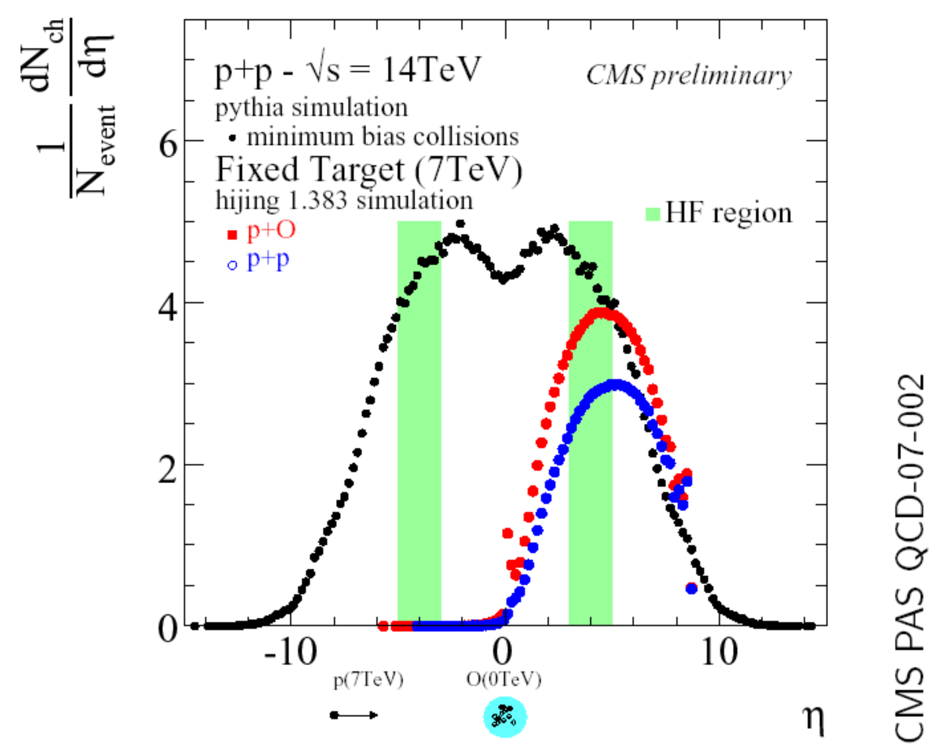
  Very low bias, optimal for very low intensity running (e.g. 900 GeV)

  Efficiency: 88% IN, 99% ND, 69% DD, 59% SD at 14 TeV

  Can be combined with offline vertex trigger

Trigger plans for minimum bias

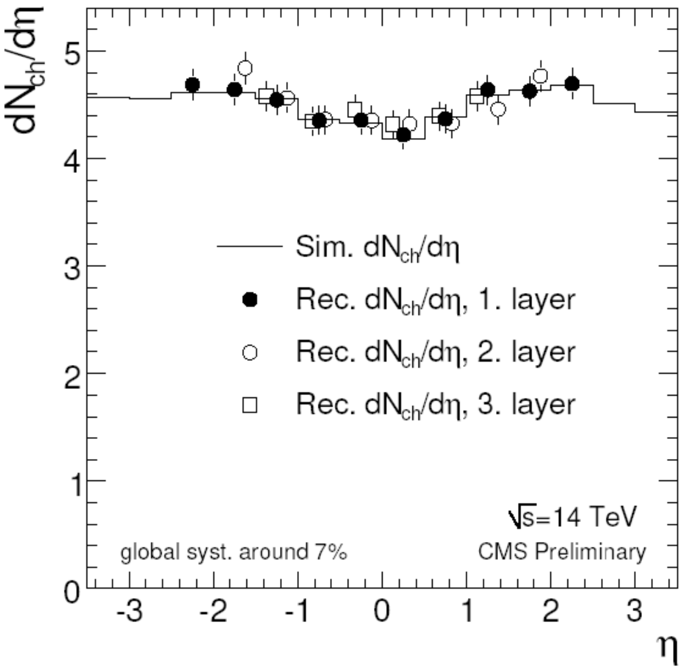


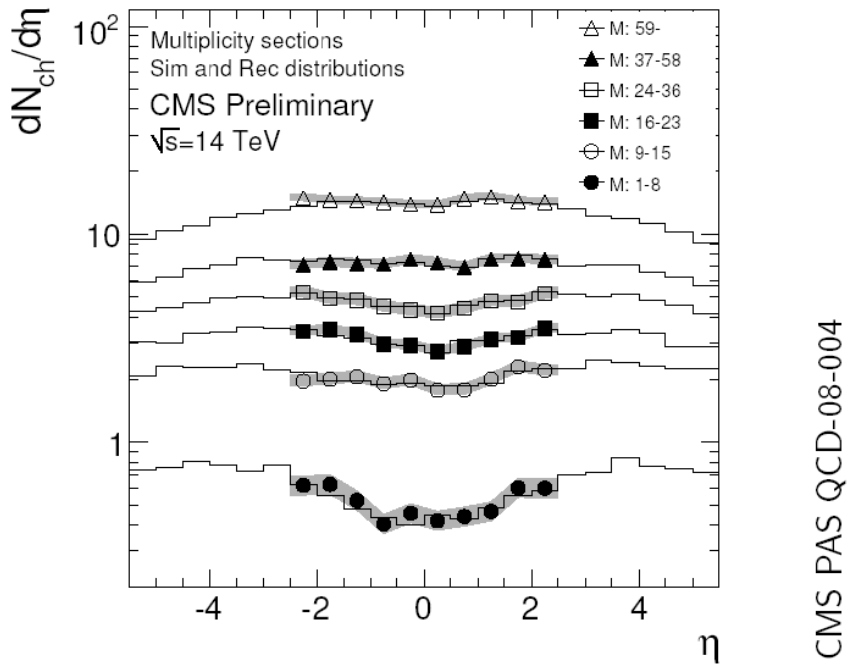


- Forward hadron calorimeters, Level-1
  - Count towers with E_T>1 GeV in the forward calorimeters (HF, 3<|η|<5)
  - Require hits on one side: 89% IN efficiency (900 GeV)
  - Require hits on both sides: 59% IN efficiency only, but insensitive to beam-gas

Usability of triggers depend on bunch pattern and luminosity

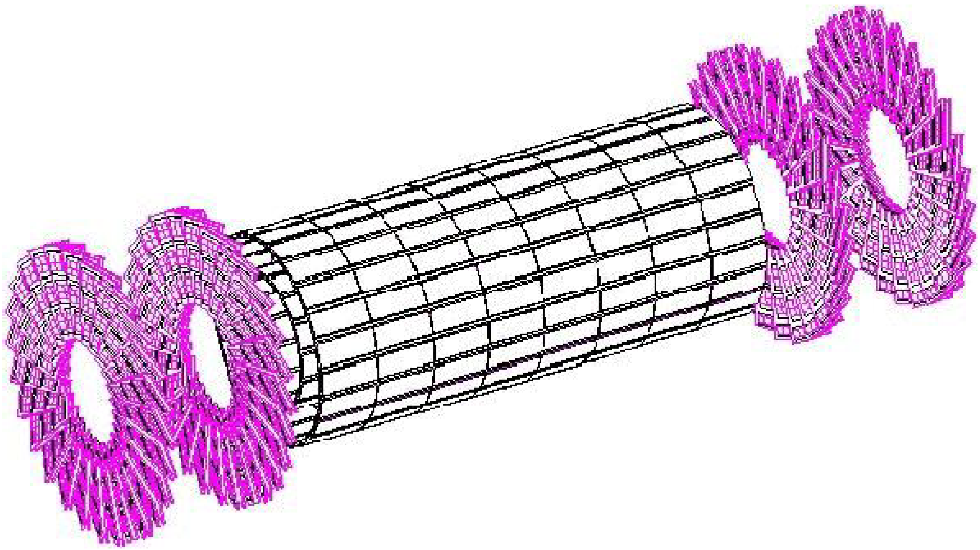
Analysis plans before LHC startup

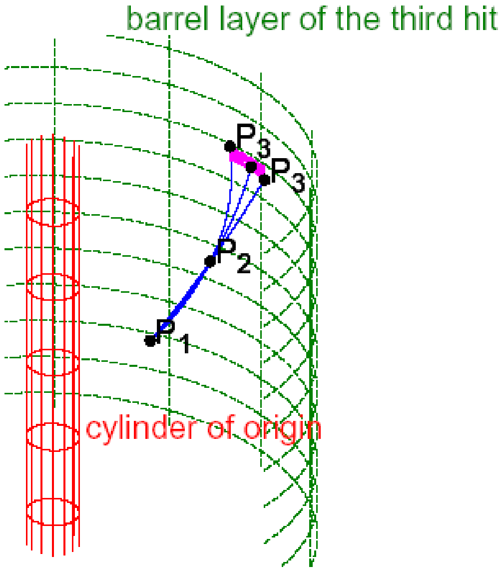




- Count clusters in the pixel barrel layers, as done in PHOBOS at RHIC
- Use pixel cluster size information to:
  - ∴ estimate the z position of the interaction vertex
  - ∴ remove hits at high η from non-primary sources
- Correction for loopers, secondaries, expected systematic error below 10%
- No need for tracking and alignment, sensitivity down to p_T of 30 MeV

Analysis plans before LHC startup





- Pixel detector

  3 barrel layers (radii: 4, 7, 10 cm) and 2 endcaps on each side
- Hit triplets

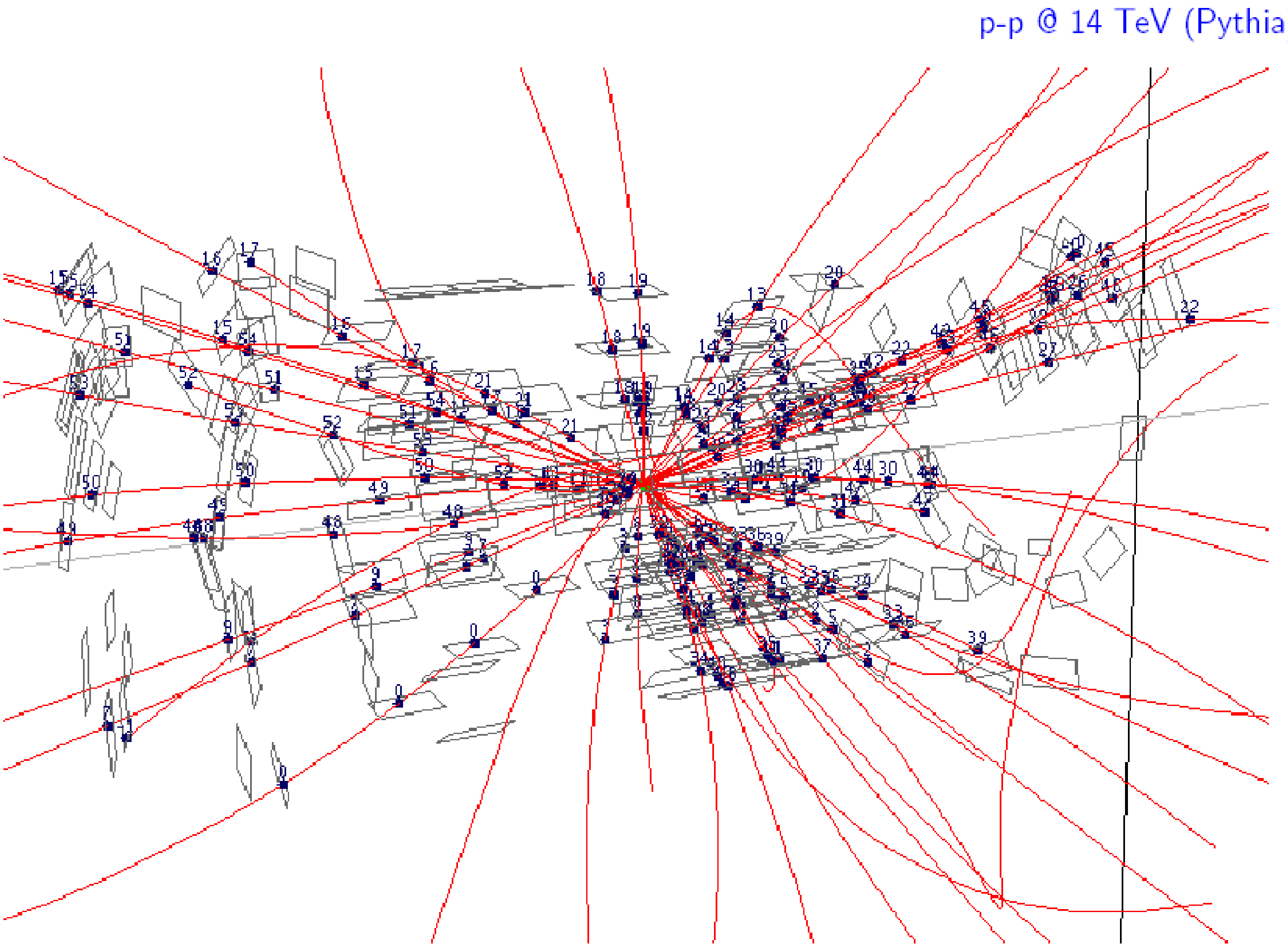
  Use pixel hit triplets instead of pairs, lower fake track rate

  modified triplet finding, reconstruction down to p_T=75 MeV/c

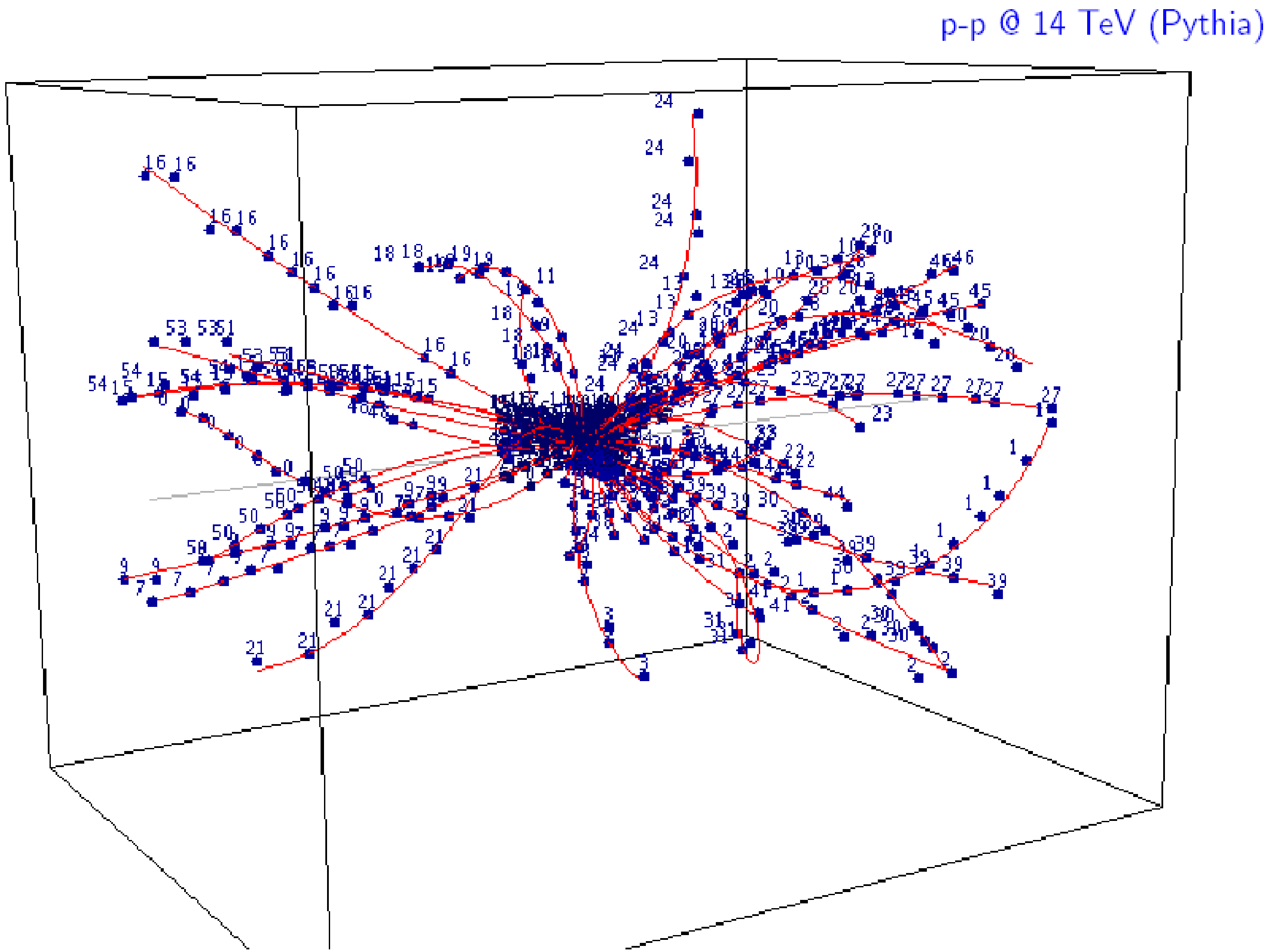
  cluster shape must match trajectory direction, very low fake track rate

Tracking optimized for all p_T

Analysis plans before LHC startup



Analysis plans before LHC startup



The first CMS paper: dN/dη distribution

Data taking: 12 and 14 Dec. (≈ 2×2 hours), ≈ 10 Hz collisions, no pileup

- Trigger: Beam Scintillator Counters (BSC) AND beam pickups (BPTX)
- Event selection:

  >3 GeV total energy on both sides in the Forward Calorimeter (HF)

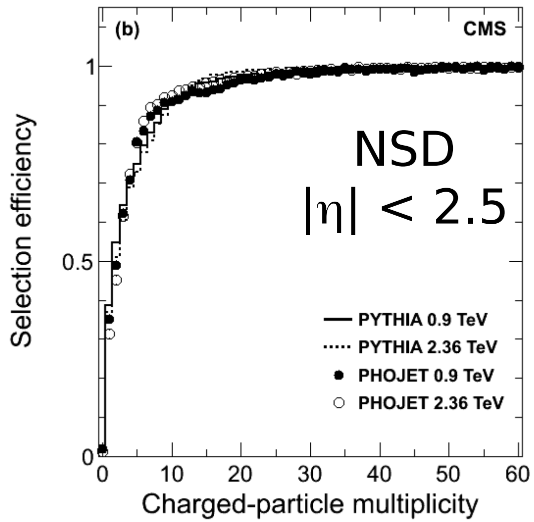
  Beam Halo rejection (BSC)

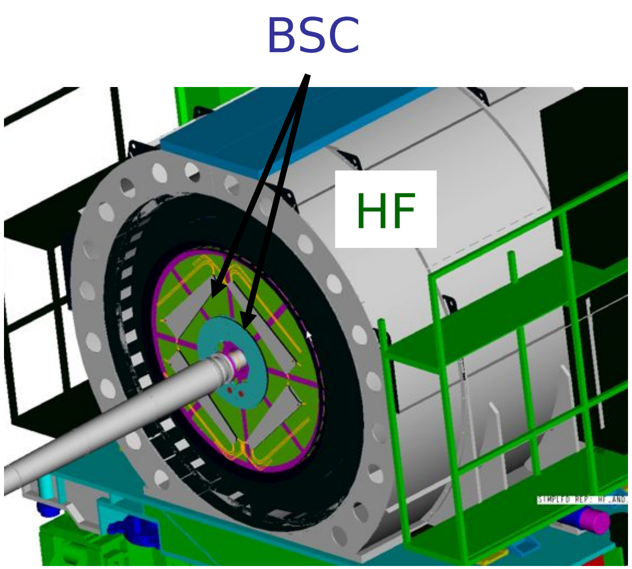
  Beam background rejection

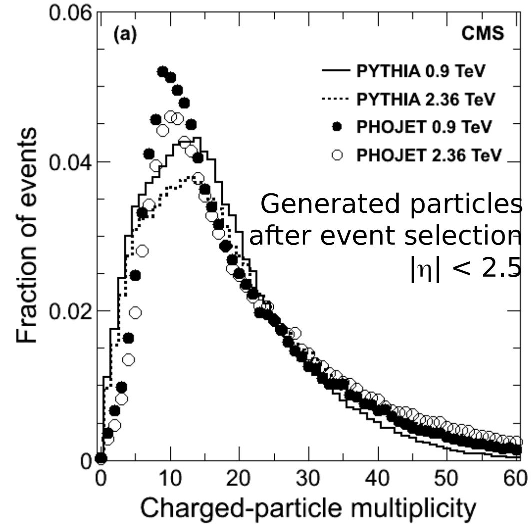
  Collision vertex

Efficiencies:

NSD:	~86 %
SD:	~19 %
DD:	~34 %

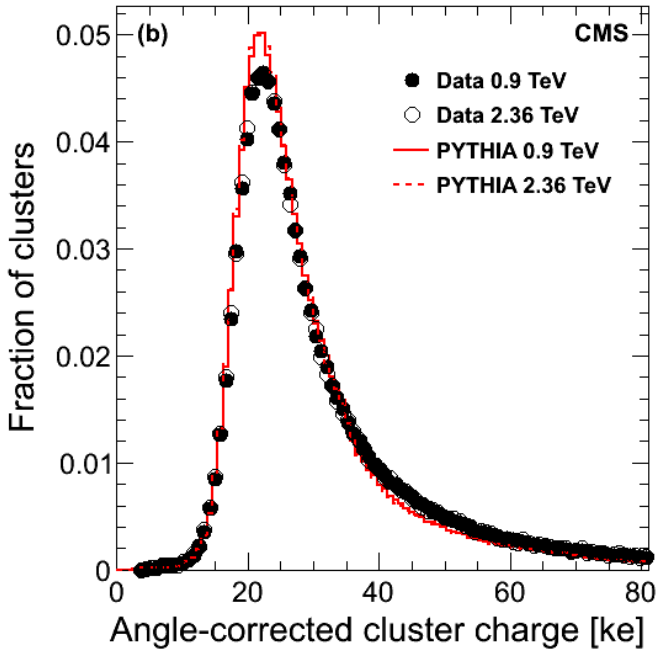




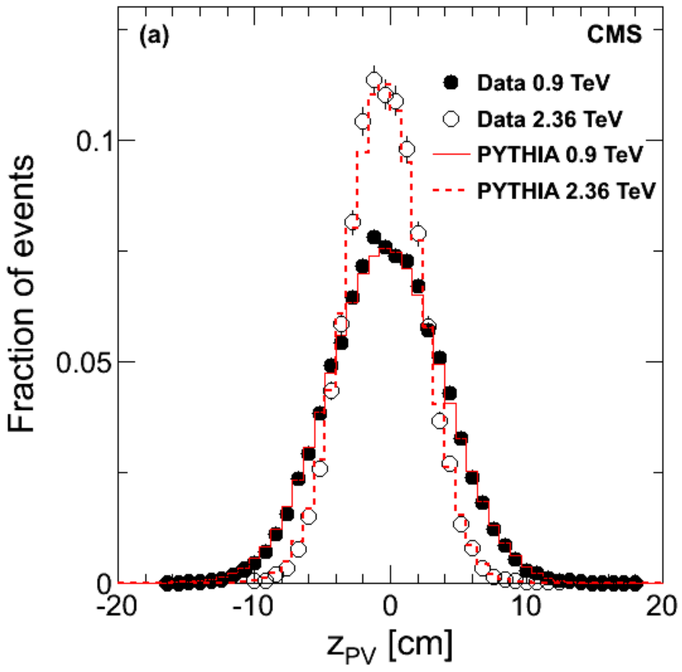


Detector performance I.

- The CMS silicon pixel and strip tracker detectors were used
- Pixels: three 53.3 cm long layers with radii 4.4, 7.3, 10.2 cm
- >97% of all channels were operational, hit efficiency optimized

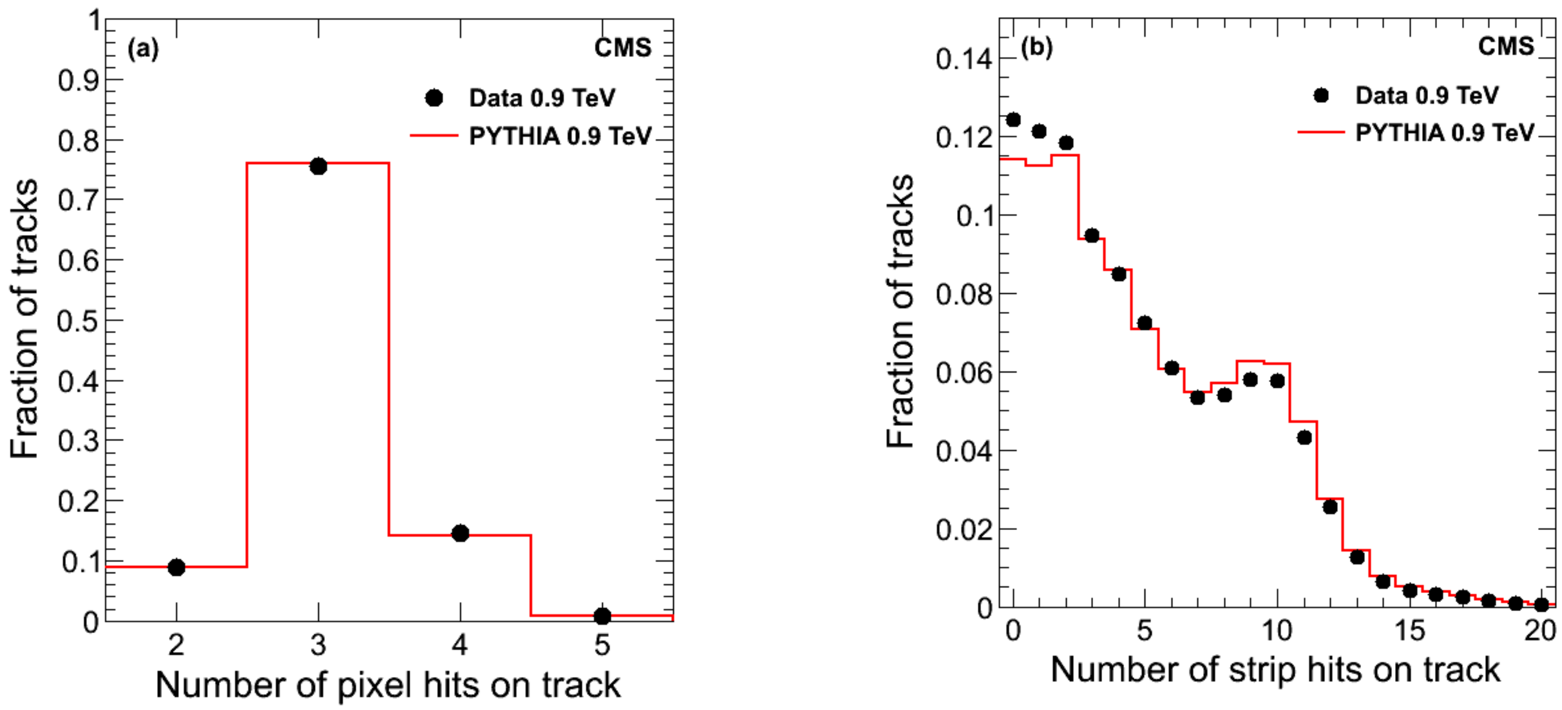


The energy loss in the tracker layers well described by MC



The vertex position distributions are clean Gaussians, with no tails

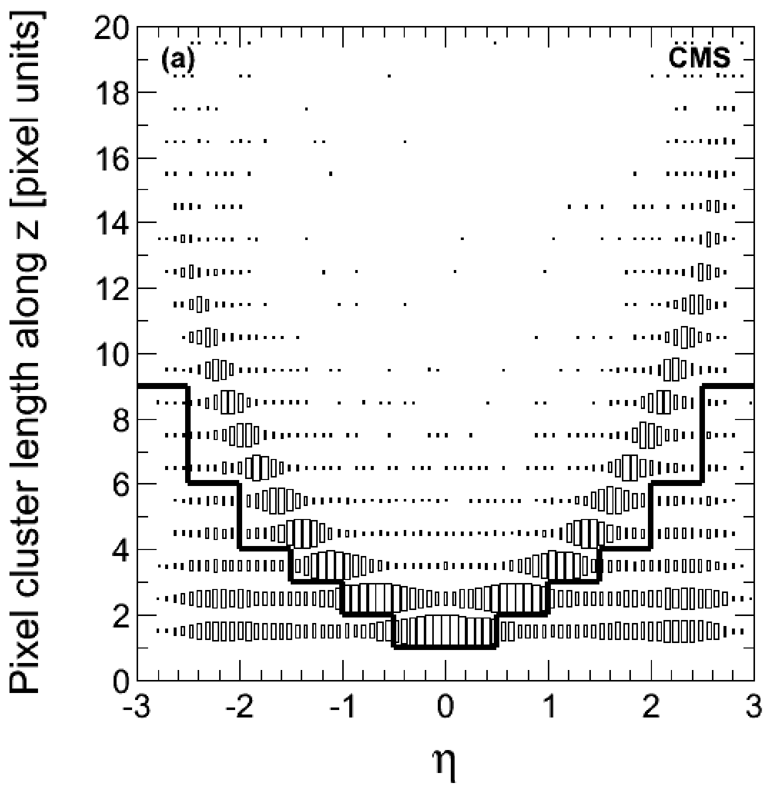
Detector performance II.

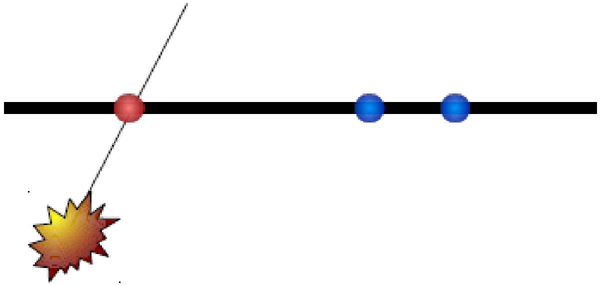


The number of hits in the pixel and strip tracker attached to tracks agrees with MC. The hit reconstruction efficiency is higher than 99%.

Cluster counting method

- Counting hits (clusters of pixels) in the pixel barrel layers
- Cluster length ~ |sinh(η)|
- Shorter clusters are eliminated (loopers, secondaries)
- Corrections for loopers, weak decays, secondaries
- Independent result for all 3 layers
- Immune to detector misalignment
- Sensitive to beam background
- Note: our detector is noise-free!

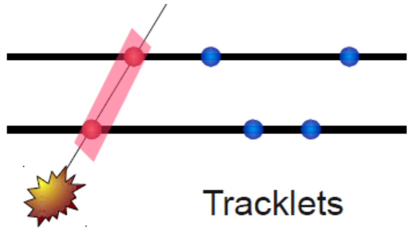


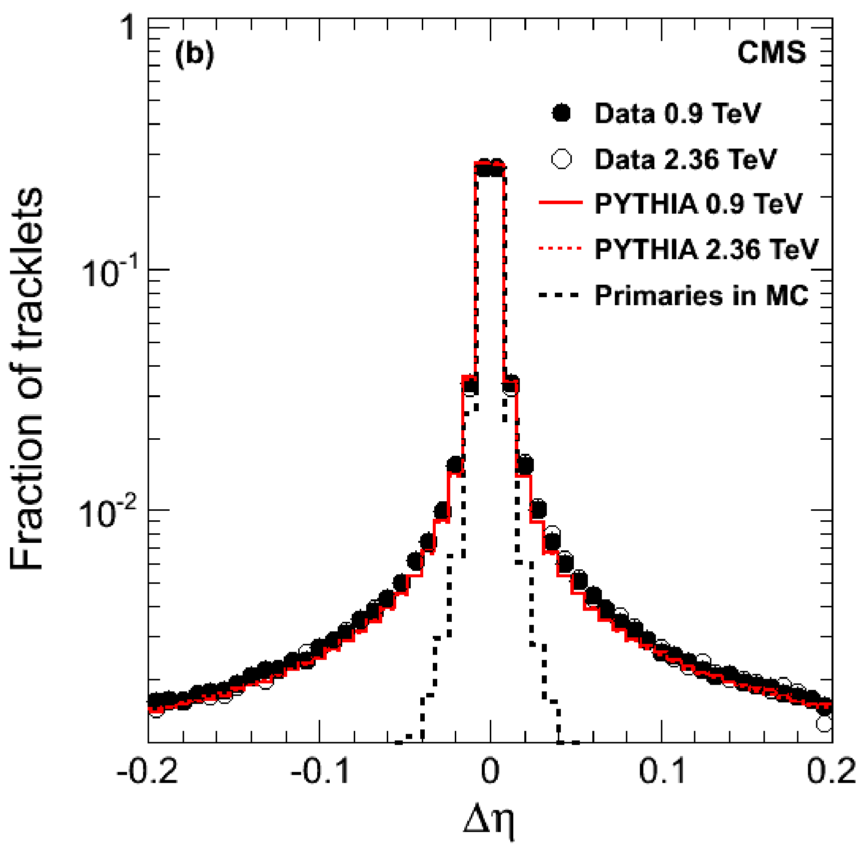


Pixel cluster length along the beam direction as a function of η. The solid line shows the cut applied.

Tracklet method

- Tracklets: pairs of clusters on different pixel barrel layers
- The $\Delta\eta$ and $\Delta\varphi$ correlations are used to separate the signal
- A side-band in $\Delta\varphi$ is used to subtract combinatorial background
- Corrections for efficiency, weak decays, secondaries
- Independent result for all 3 layer pairs
- Less sensitive to beam background





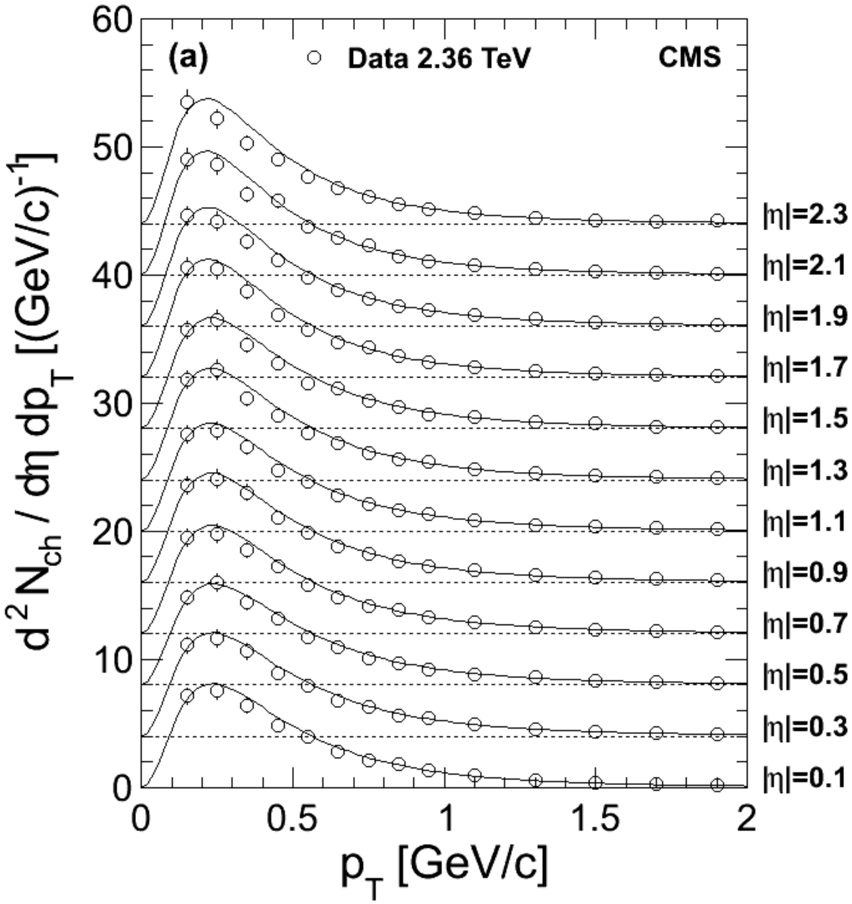
The $\Delta\eta$ distribution of the two clusters of the tracklets

Tracking method

- Uses all pixel and strip layers
- Builds particle trajectories iteratively
- Low fake rate achieved with cleaning based on cluster shapes
- Primary vertex reconstructed from tracks – agglomerative vertexing
- Compatibility with beam spot and primary vertex required
- Immune to background
- More sensitive to beam spot position and detector alignment

JHEP 02 (2010) 041

459 citations



Differential yield of charged hadrons in the range $|\eta|<2.4$ The η bins are shifted by four units vertically.

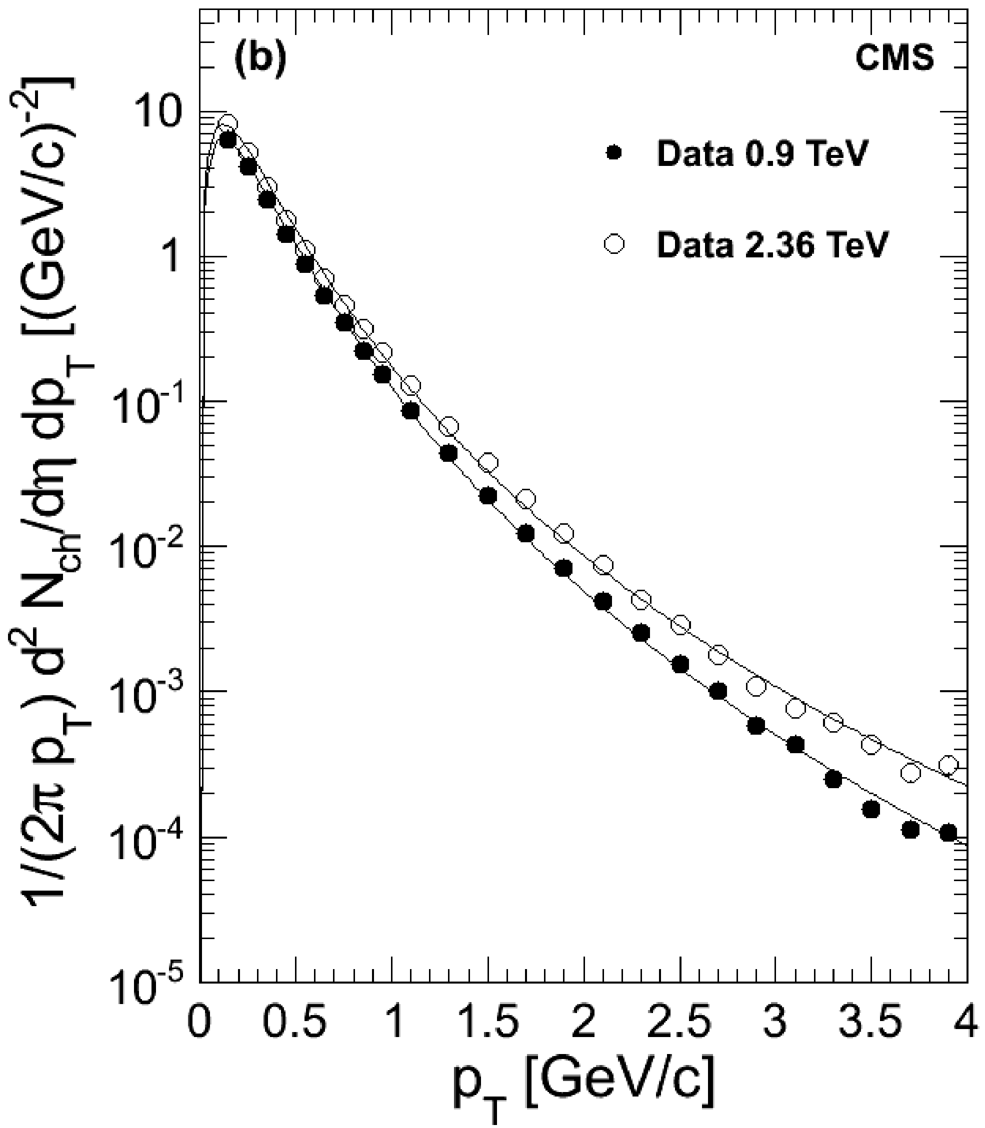
Results: p_T-distribution

- The transverse-momentum distribution of charged hadrons was measured up to 4 GeV/c.

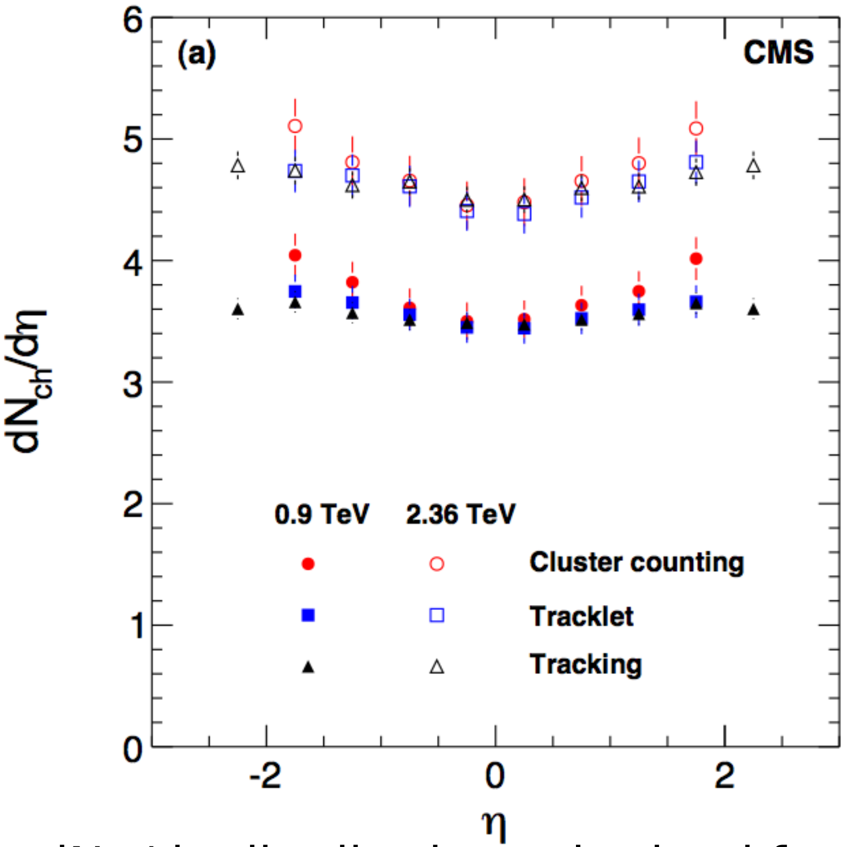
- Well described by the Tsallis-function combining a low-p_T exponential with a high-p_T tail

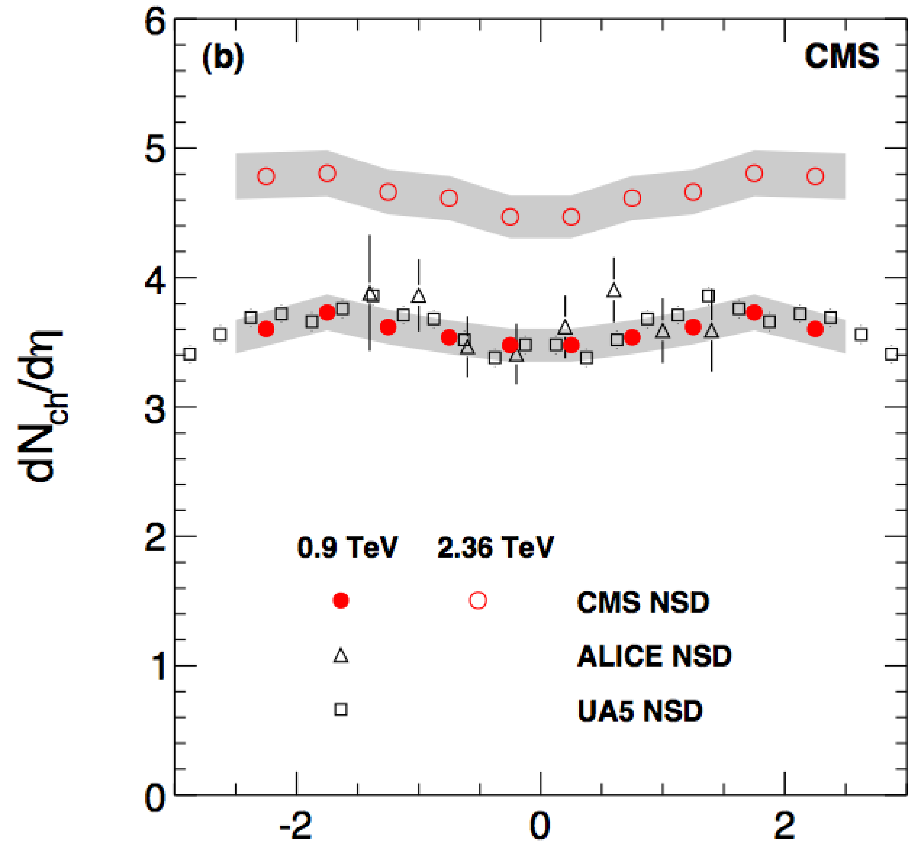
- With increasing energy, the p_T-spectrum gets "harder" (as expected)

Measured yield of charged hadrons for $|\eta| < 2.4$, fit with the Tsallis function.



Results: dN/dη

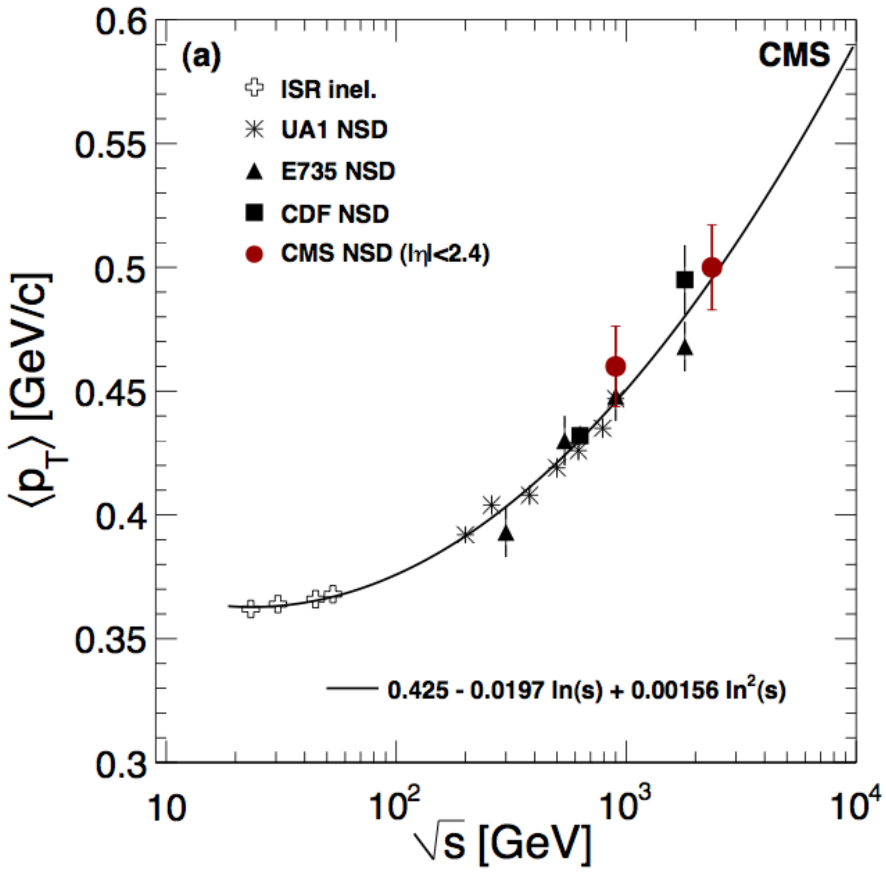


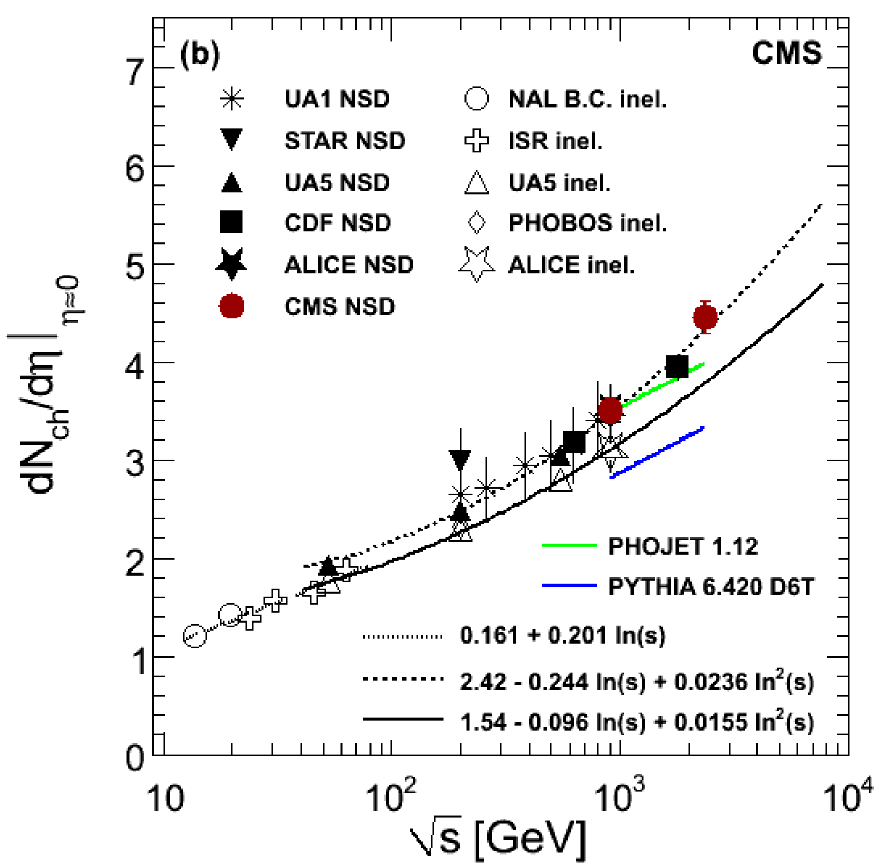


$dN_{ch}/d\eta$ distributions obtained from the three methods at 0.9 TeV and 2.36 TeV. The error bars represent systematic uncertainties excluding those common to all the methods.

$dN_{ch}/d\eta$ distributions averaged over the three methods and symmetrized in η. The shaded band represents systematic uncertainties. The error bars on the UA5 and ALICE data points are statistical only.

Results: energy dependence





Collision energy dependence of average transverse momentum.

Charged particle pseudorapidity density as a function of collision energy.

First 7 TeV paper from CMS

Collision rate ≈ 50 Hz
"pileup" ≈ 0.3% (neglected)

- Trigger: any hit in the Beam Scintillator Counters (BSC, $3.23 < |\eta| < 4.65$) AND a filled bunch passing the beam pickups (BPTX)
- Off-line event selection:

  >3 GeV total energy on both sides in the Forward Calorimeter (HF $2.9 < |\eta| < 5.2$)

  Beam Halo rejection (BSC)

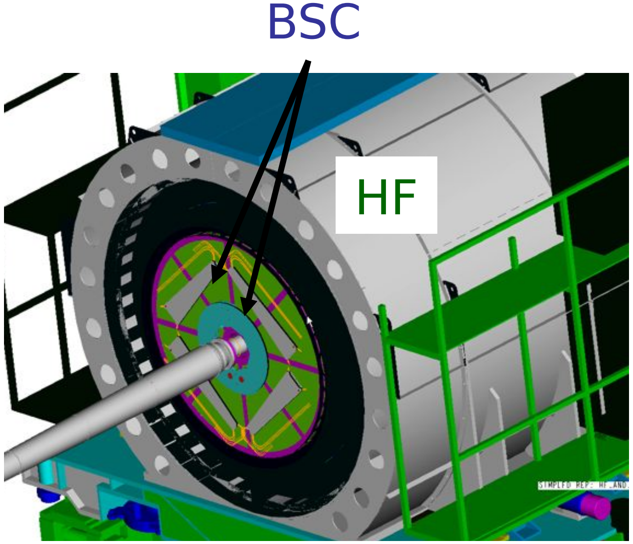
  Dedicated beam background rejection

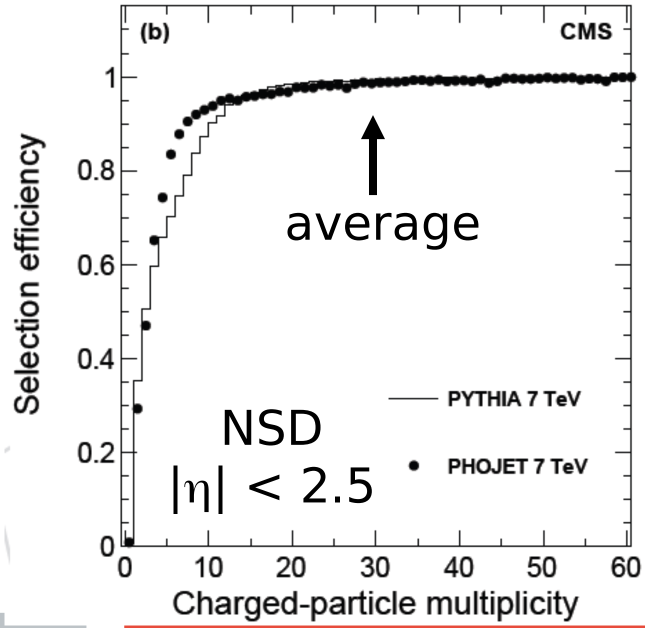
  Collision vertex

55100 events
remain after all cuts

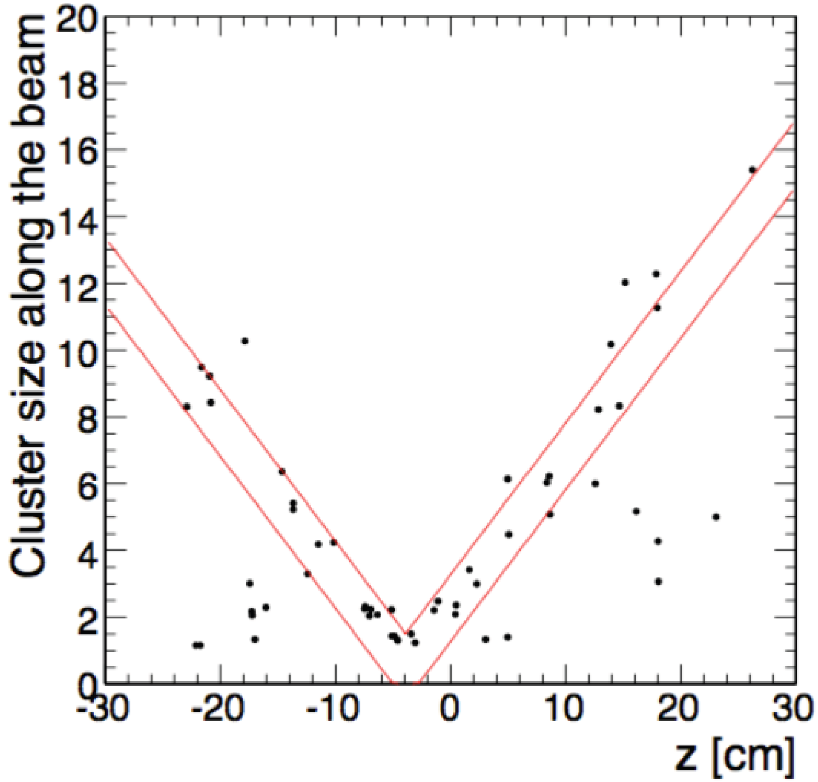
Efficiencies:

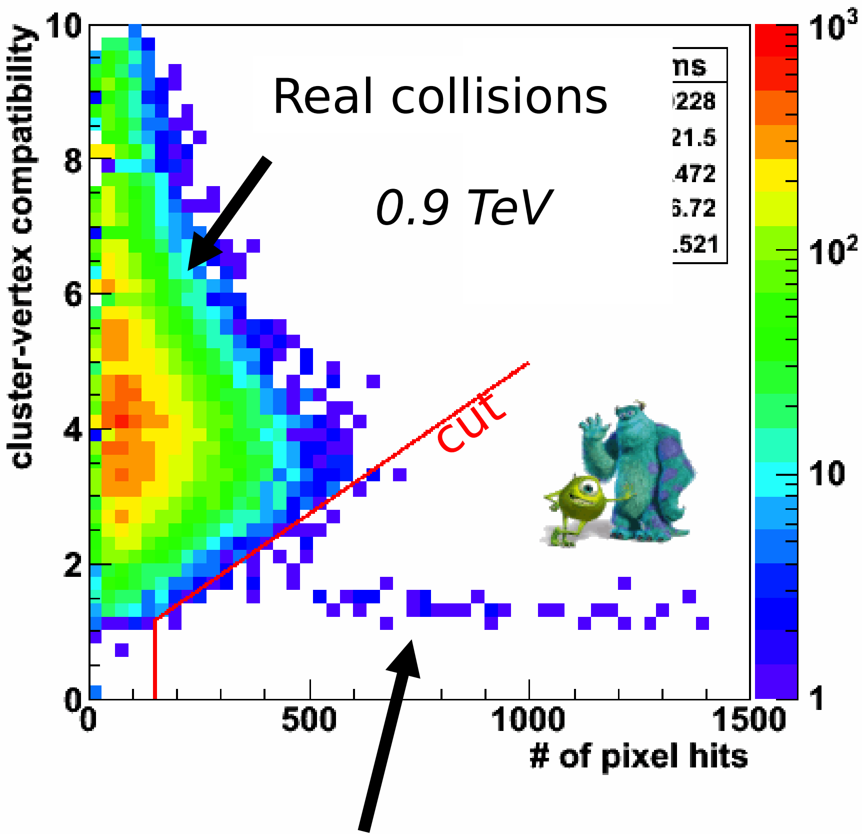
NSD:	~86 %
SD:	~27 %
DD:	~34 %





Rejecting beam-gas events





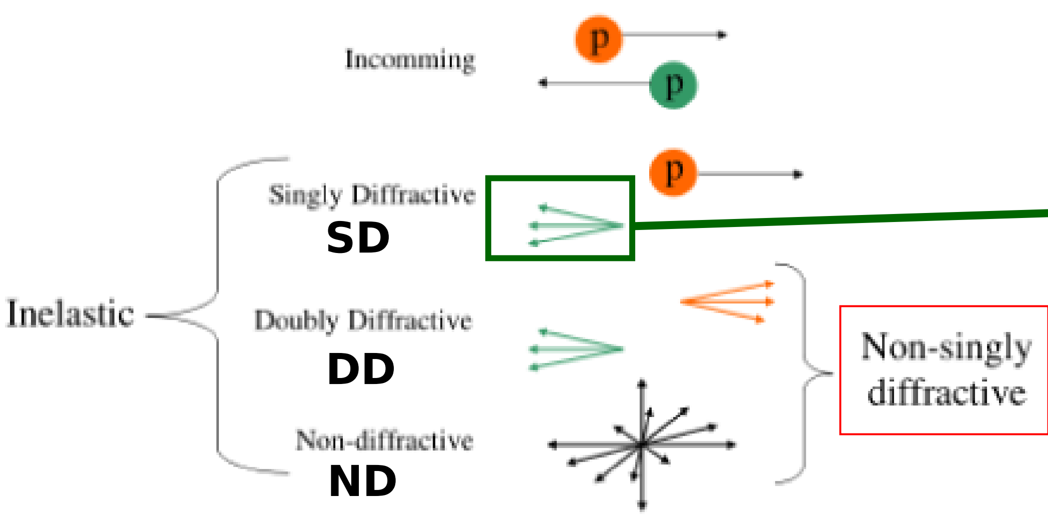
Vertex-cluster compatibility:
Ratio of #clusters in the V-shape and #clusters in the V-shape offset by ±10 cm

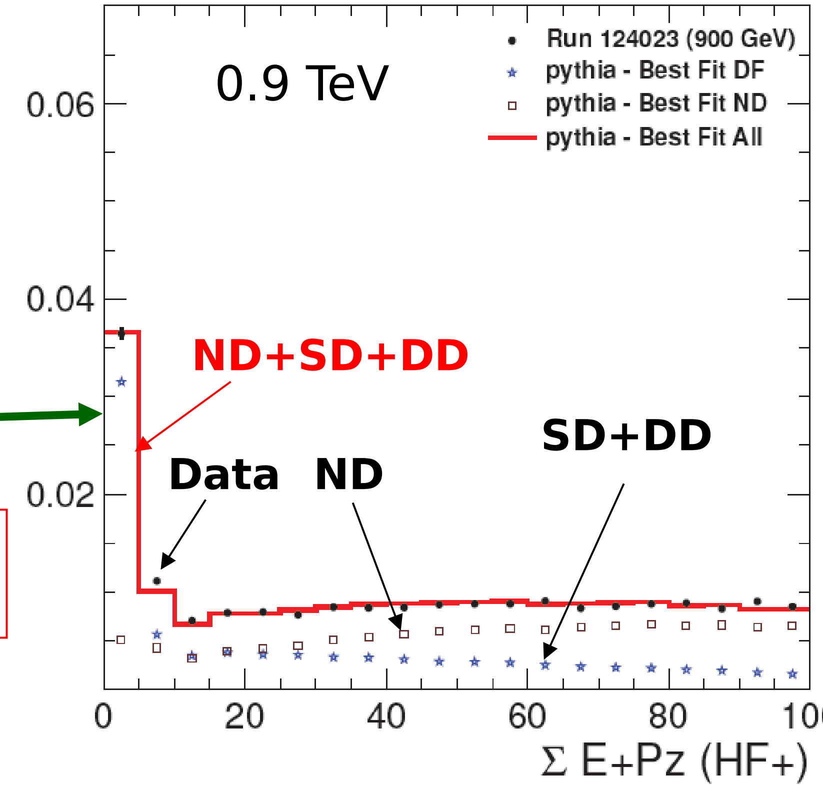
Beam-scraping events have a lot of pixel hits but ill-defined vertex

Remaining beam-gas fraction: 2×10^{-5}

Estimating diffractive fraction from data

Our measurement is corrected for inel. non-single-diffractive events!

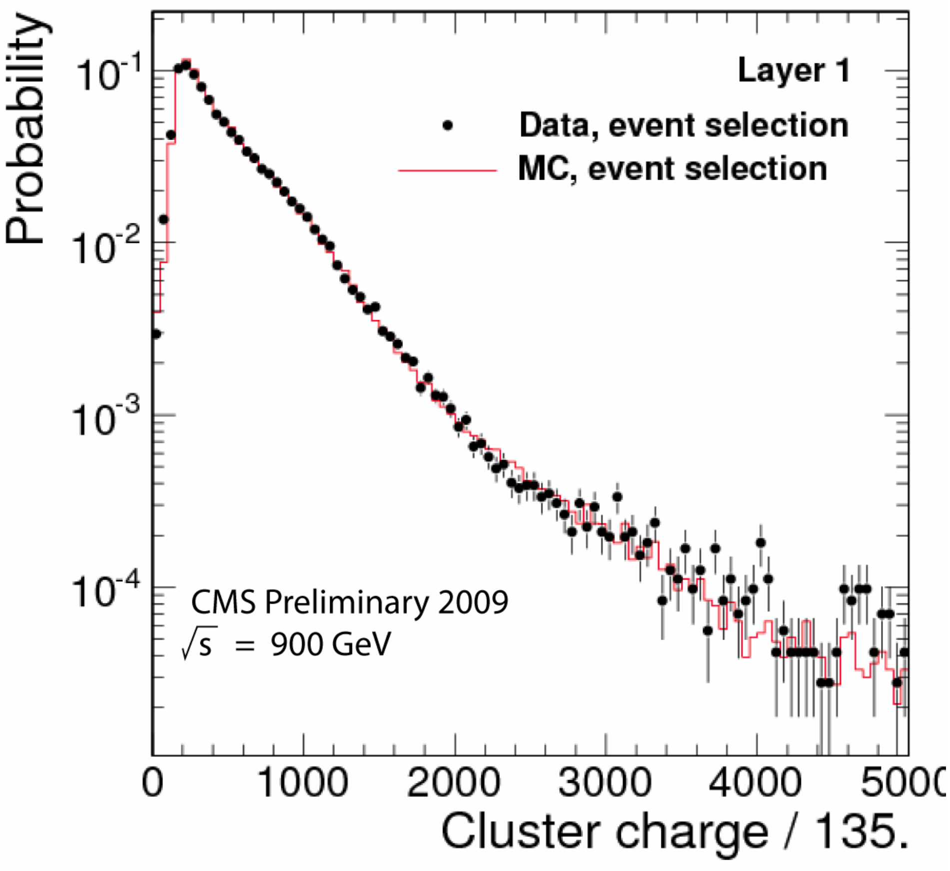




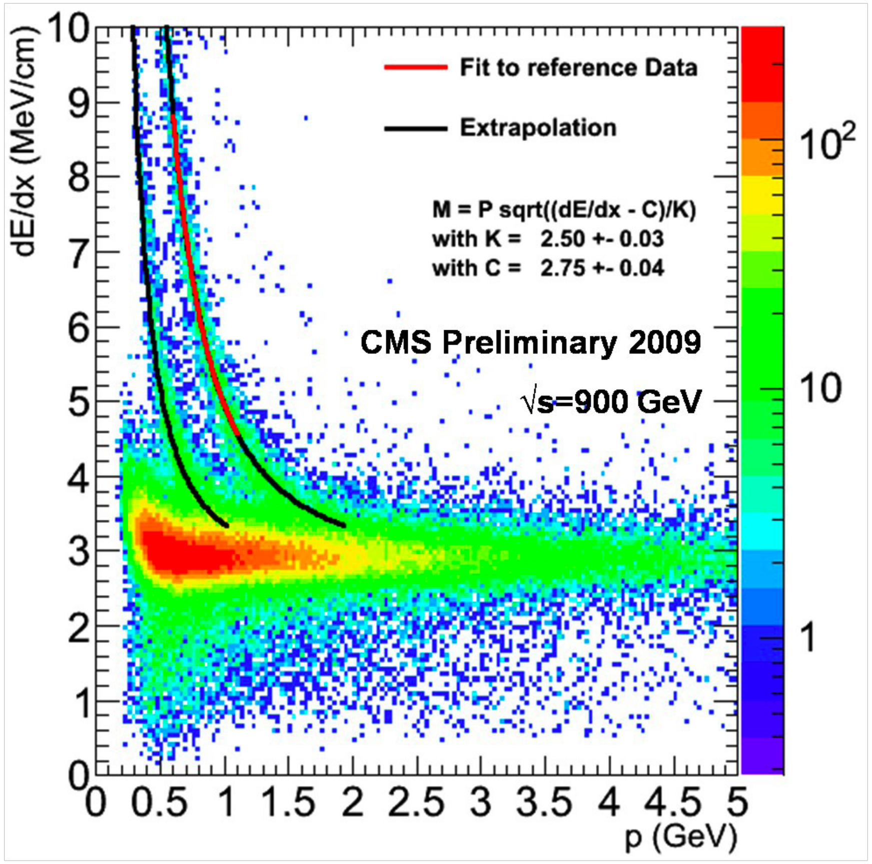
The HF calorimeter data is used to fit the SD+DD fraction in data using PYTHIA event shapes. PHOJET was also studied similarly.

dE/dx information in the silicon

Silicon pixels

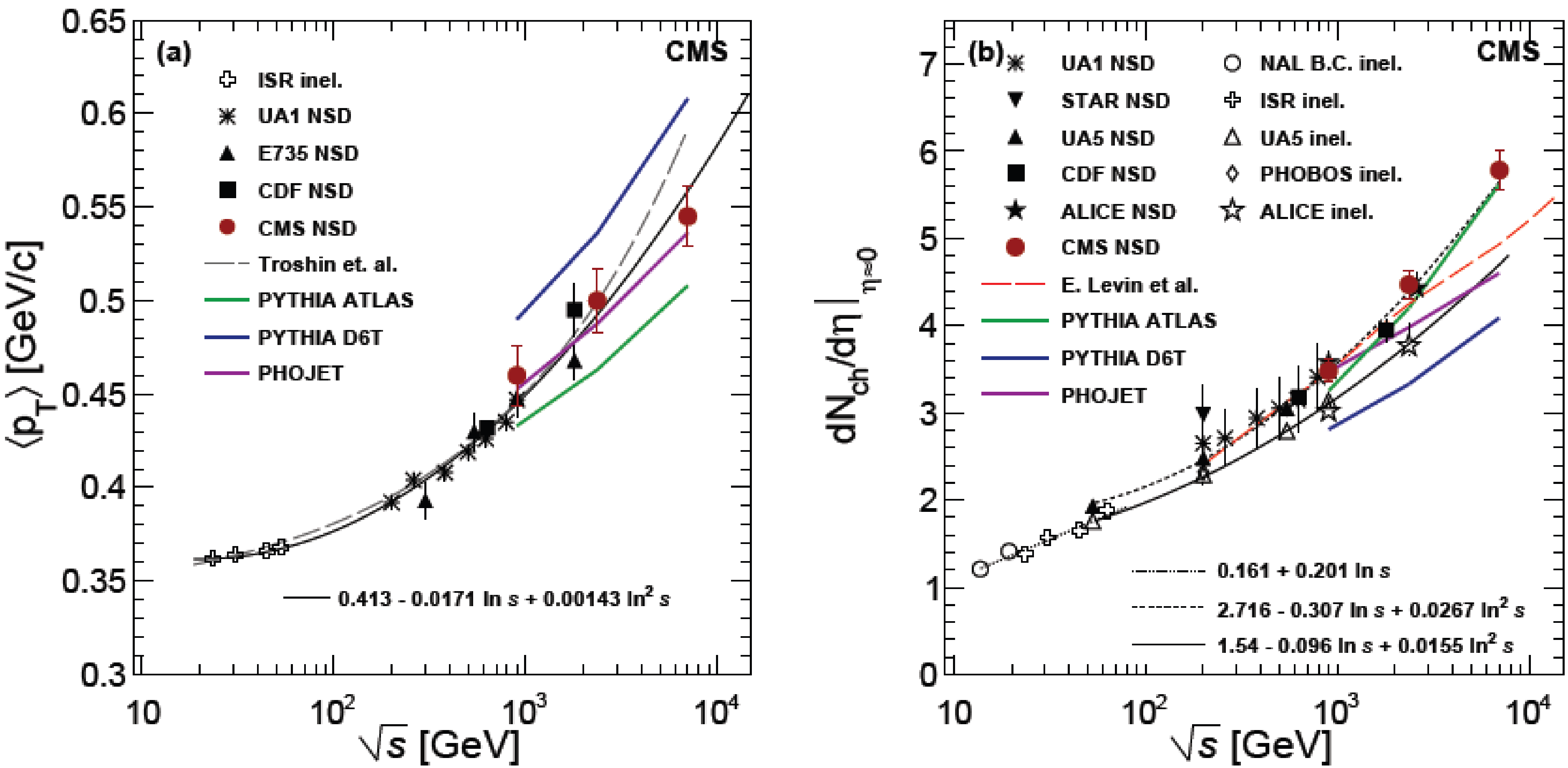


Silicon strips



Excellent agreement with simulations

Comparison with models



PHOJET describes $\langle p_T \rangle$ well

Most tunes underestimate dN/dη at 7 TeV

Observation of single diffractive events

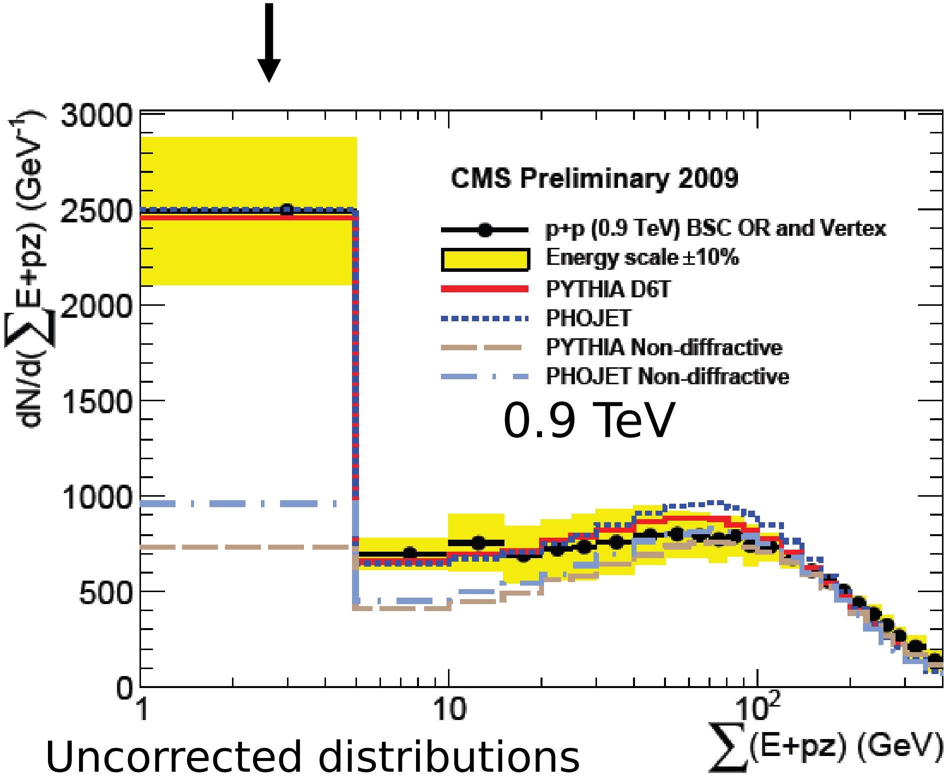
Variable used: $\Sigma(E+p_z) = \Sigma E(1+\cos\theta) = \Sigma(p_T e^{\eta})$

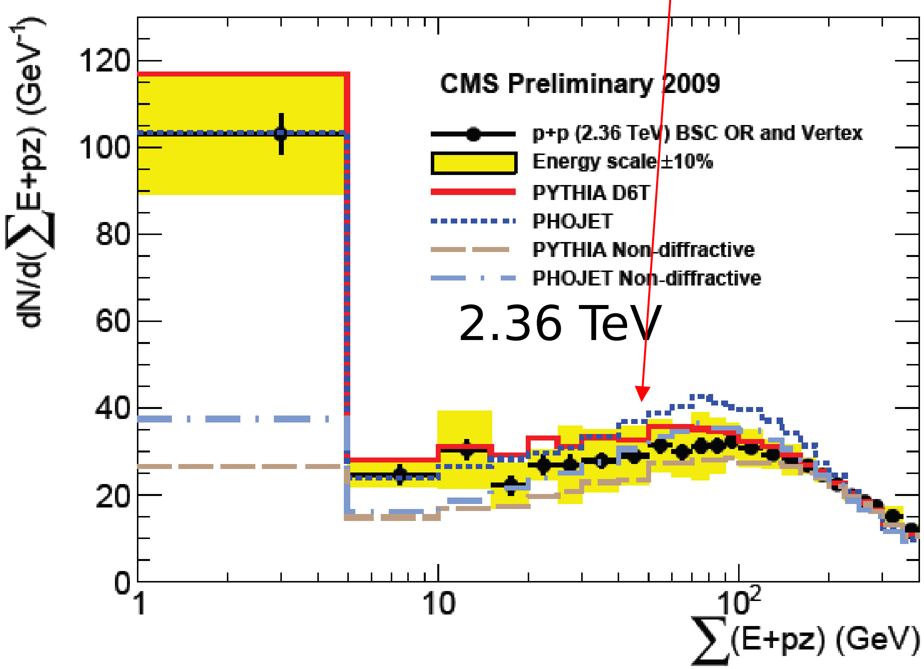
The sum runs over the full calorimeter acceptance

Events below 5 GeV are mainly single diffractive type:

almost no forward energy on the +z side

PYTHIA describes the ND part better than PHOJET





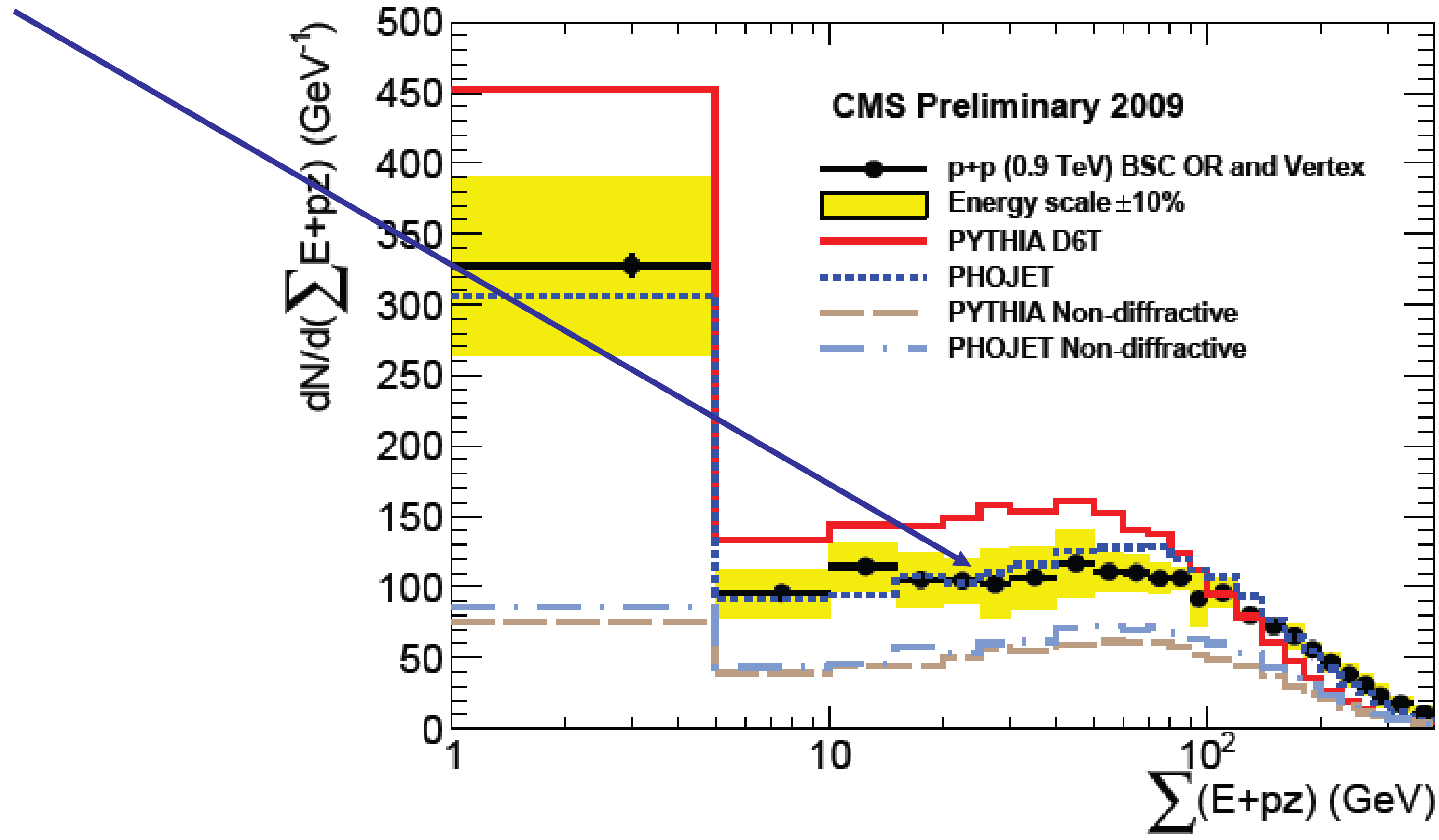
Uncorrected distributions

Observation of single diffractive events

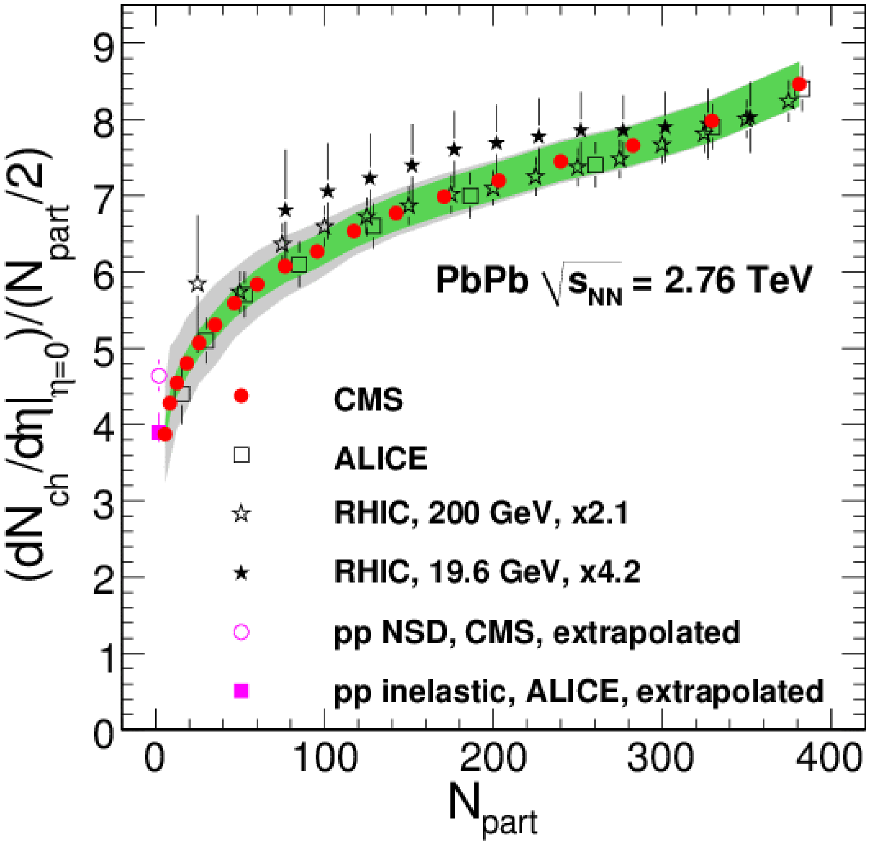
Enhancing SD events:

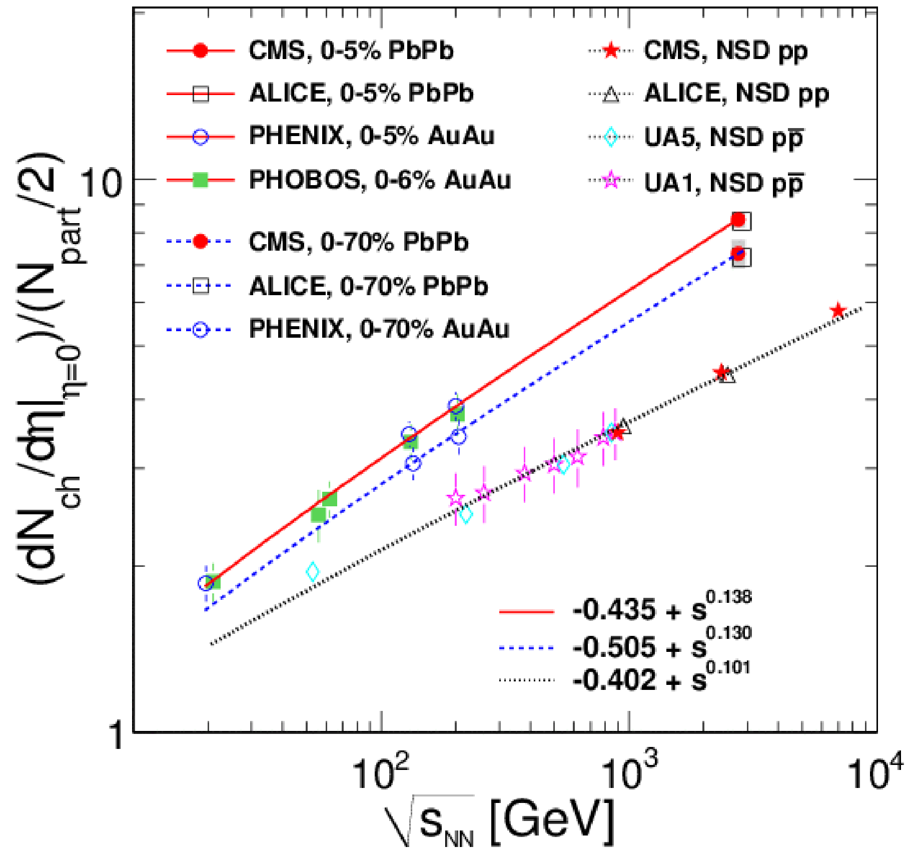
E_{HF-}<8 GeV was required (LRG over HF-)

PHOJET agrees better with the data (for high-mass SD)



Heavy ions





- Centrality dependence
  - Similar to RHIC results
  - Various experiments agree (!?)
- $\sqrt{s}$ -dependence:
  - p+p, Pb+Pb: power law

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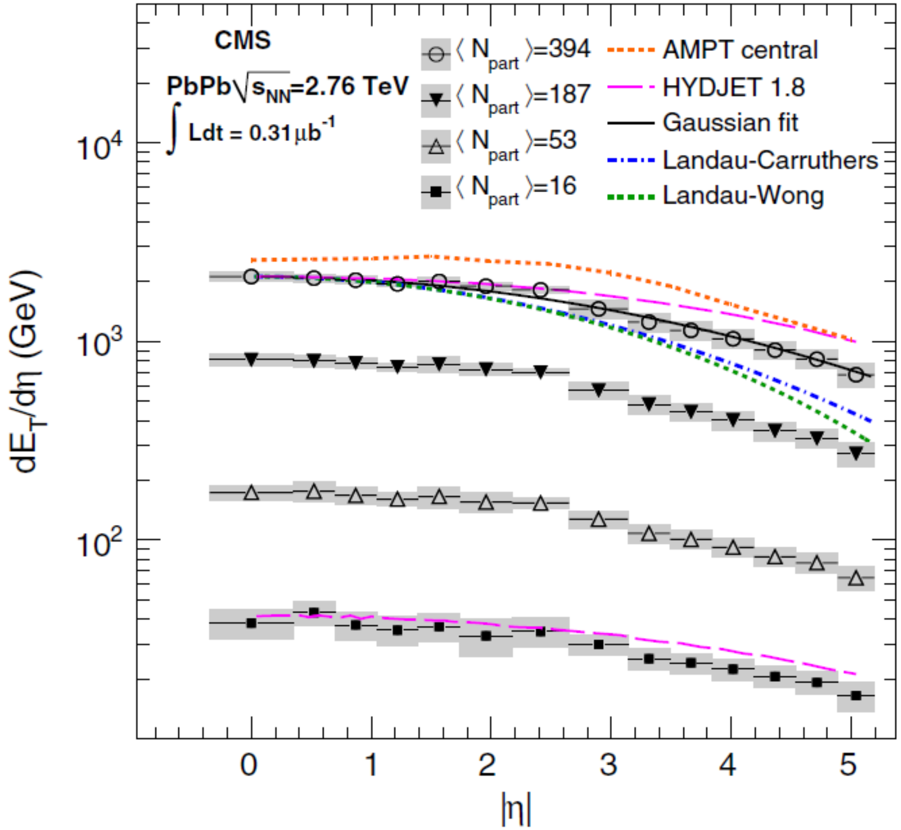
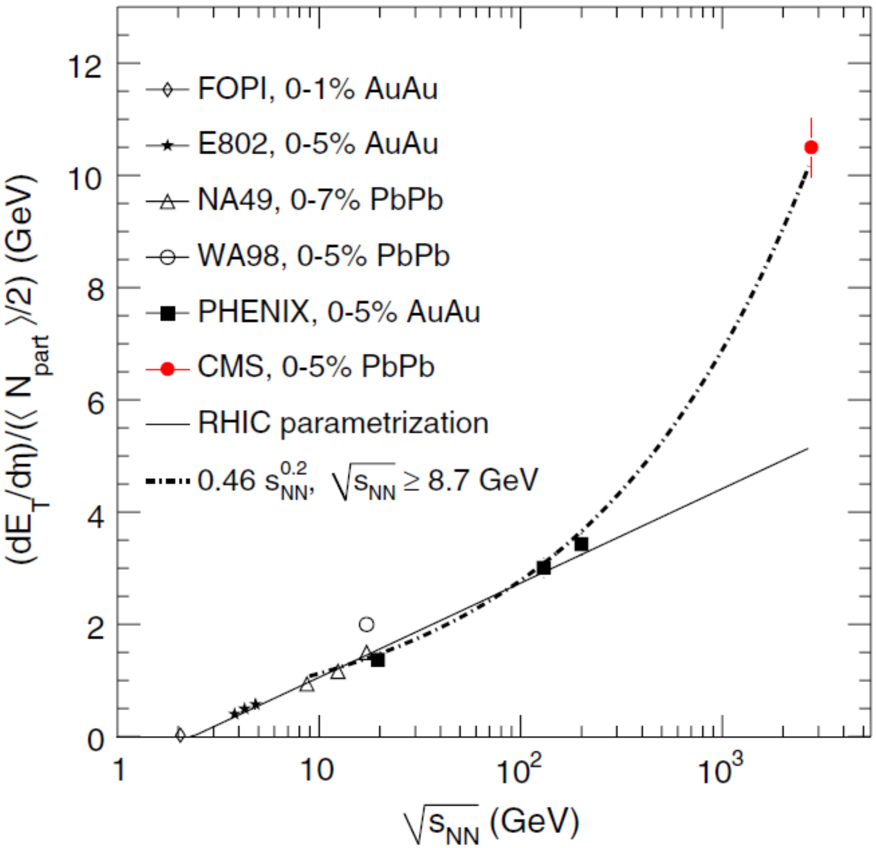
Transverse energy density



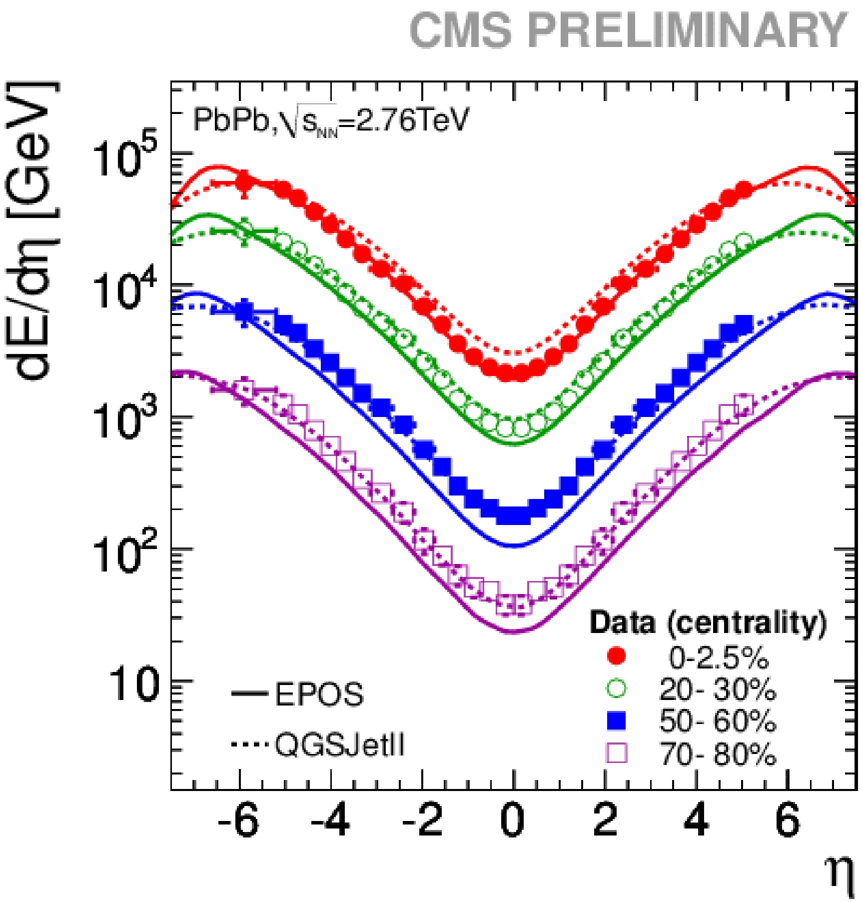


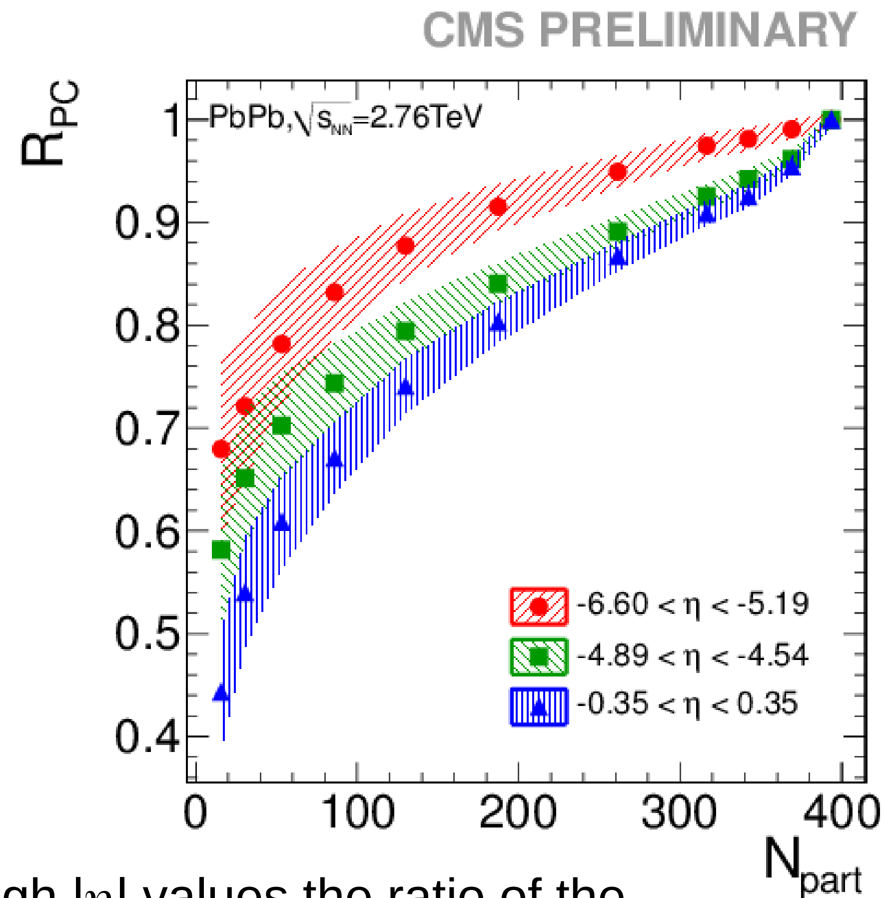
PRL 109 (2012) 152303

η-coverage: with the HF calorimeter

Related to the large energy density created in the collision
Huge increase as a function of $\sqrt{s}$

Energy release: measured up to high |η|





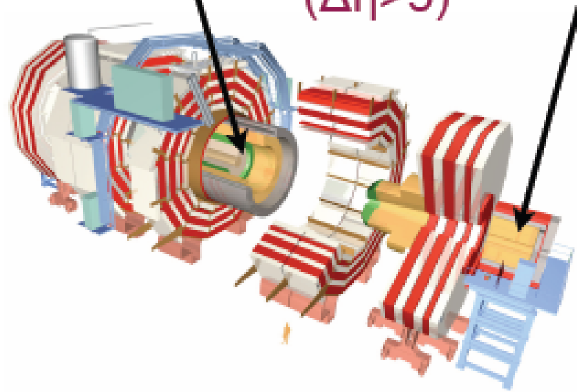
- At high |η| values the ratio of the energies measured in *central* and *peripheral* collisions is closer to 1 than at midrapidity

CMS PAS HIN-12-006

Elliptic flow

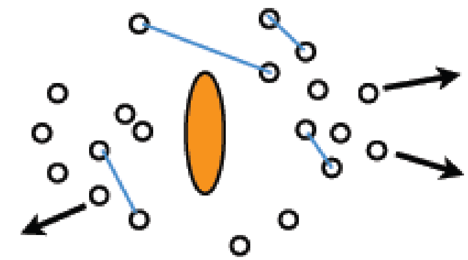
Event Plane

Correlate particles in tracker with those in HF. ($\Delta\eta>3$)



Two-particle Cumulant

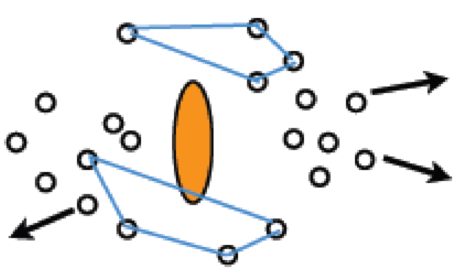
Consider all two-particle correlations.



Methods have different sensitivity to event-by-event fluctuations and non-flow effects.

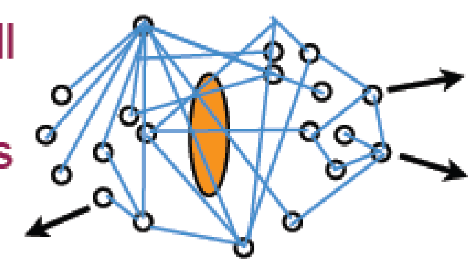
Four-particle Cumulant

Consider all four-particle correlations.



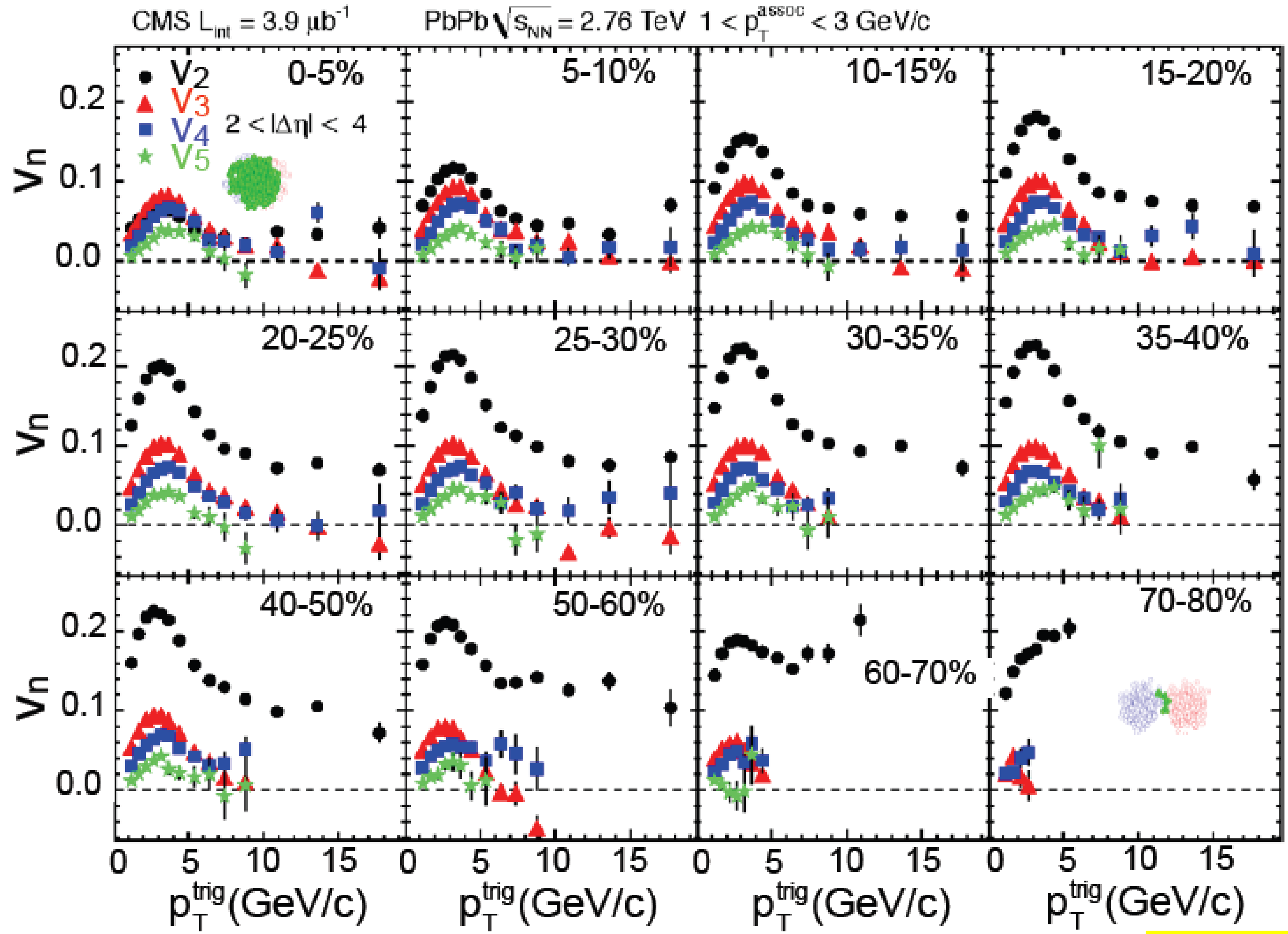
Lee-Yang Zeros

Consider all particle correlations -(Not all shown!).



Higher order Fourier components

V_n is measured from two-particle correlations at large $\Delta\eta$

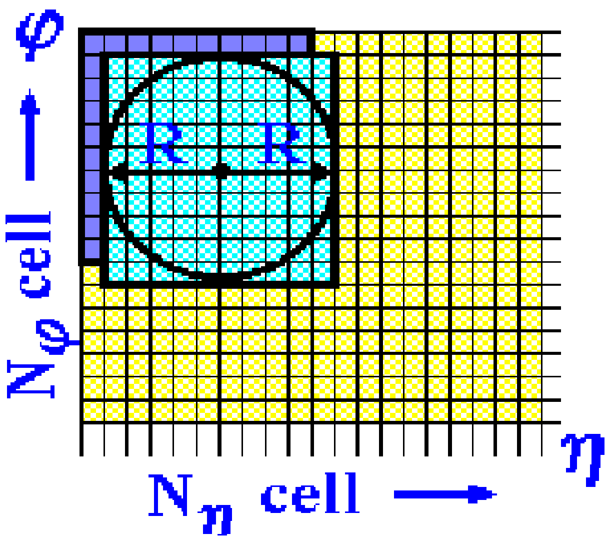


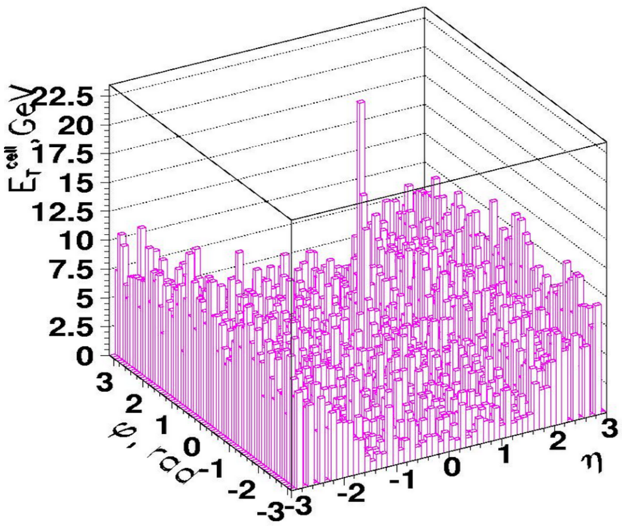
V_n (n>2) barely changes with centrality

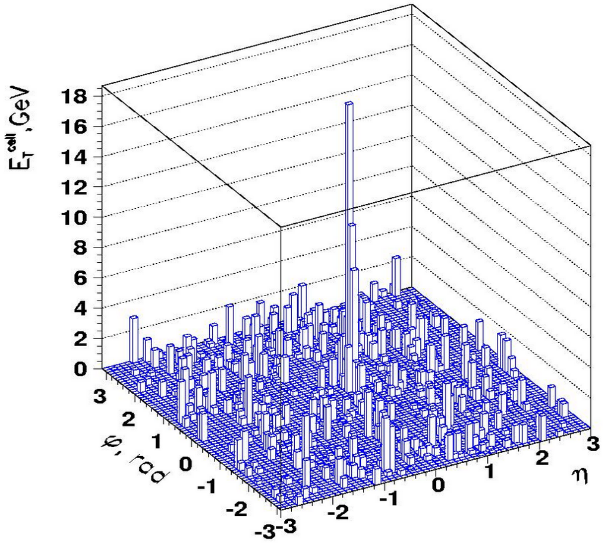
EPJC 72 (2012) 2012
PRC 87(2013) 014902

Jet reconstruction in heavy ion events?

Early idea from the Technical Design Report for Heavy Ions:

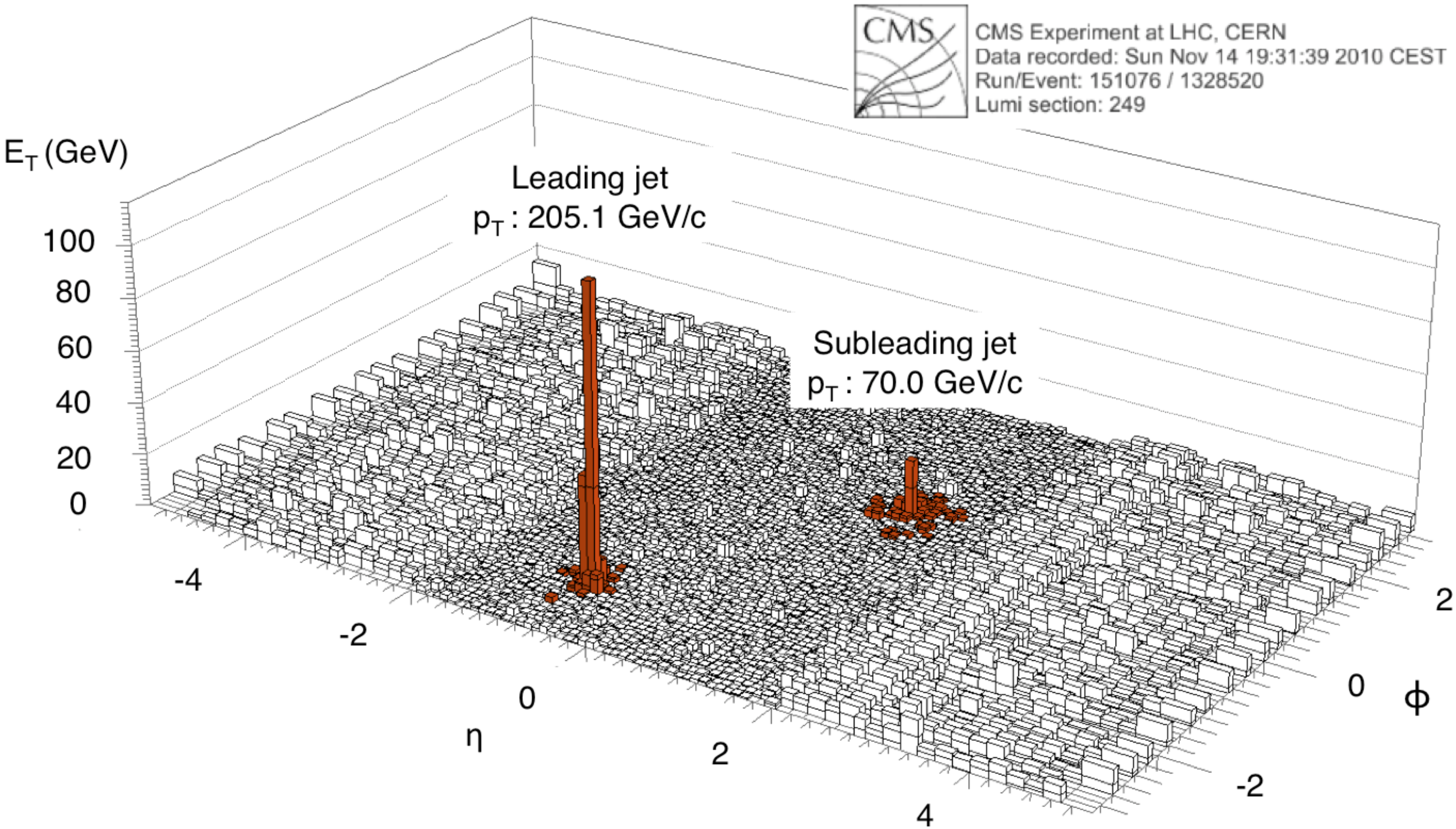






1. Subtract average pileup
2. Find jets with iterative cone algorithm
3. Recalculate pileup outside the cone
4. Recalculate jet energy

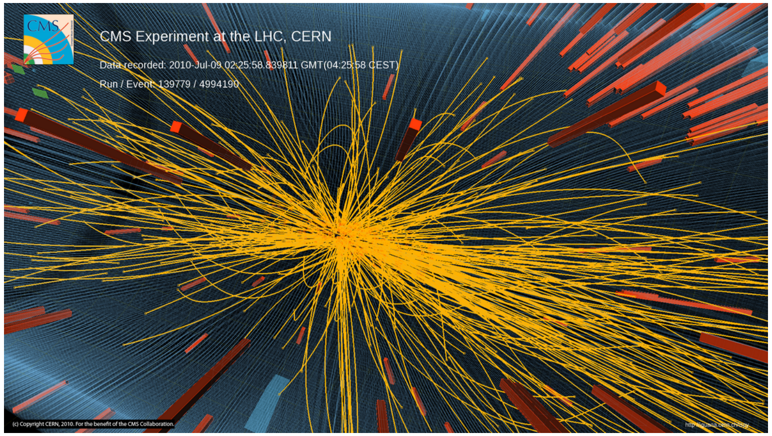
First heavy ion collisions: jet energy loss

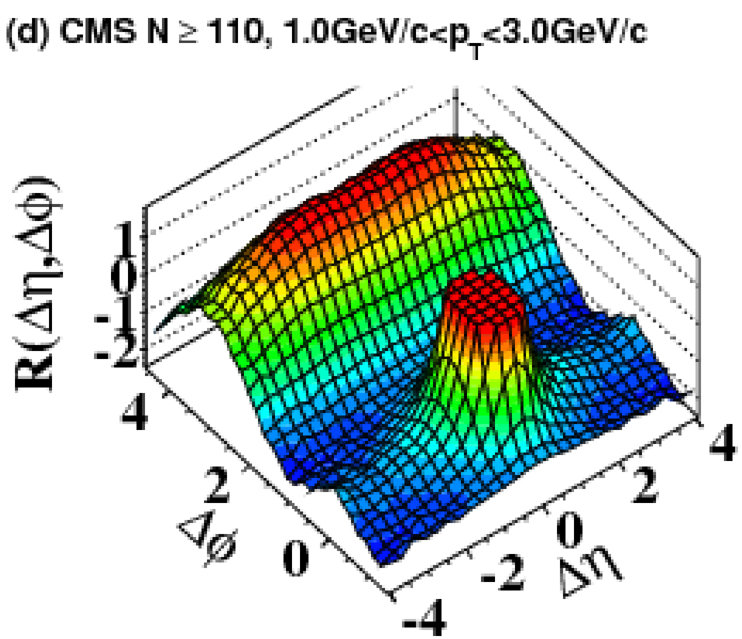


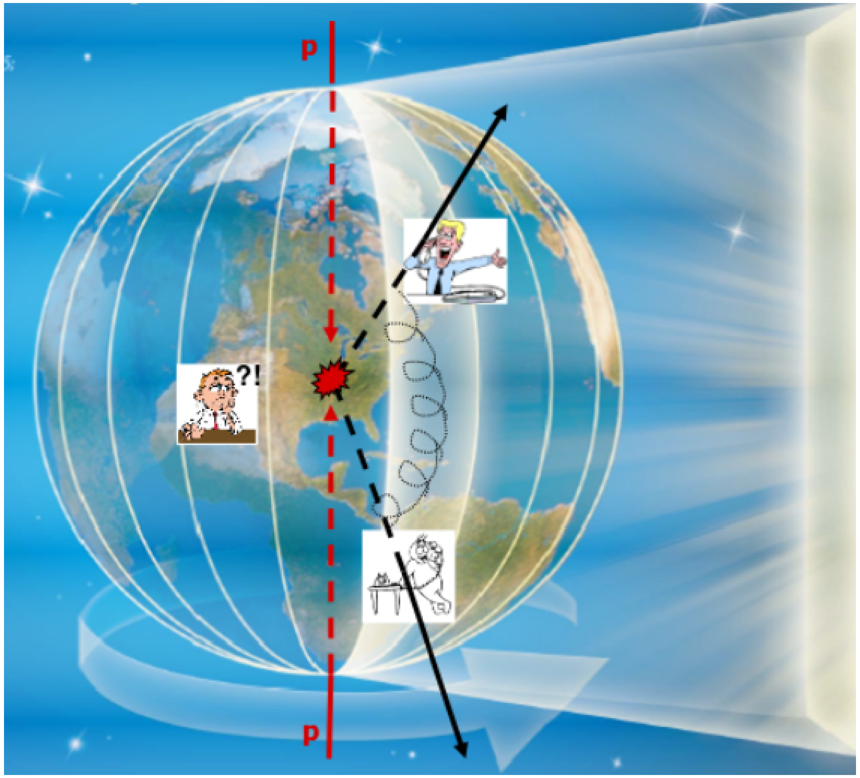
Phys.Rev. C84 (2011) 024906

890 citations

First discovery at the LHC: correlations



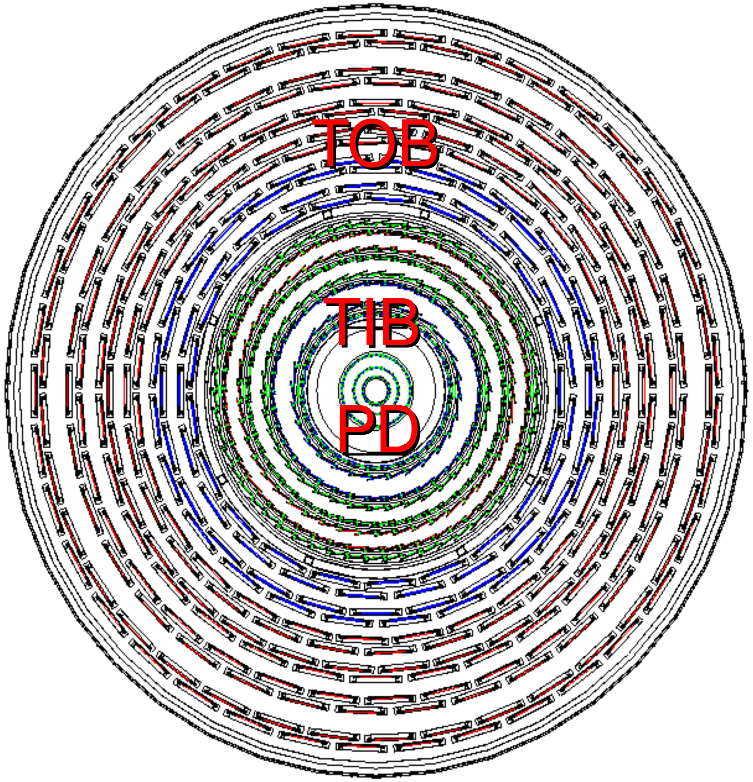


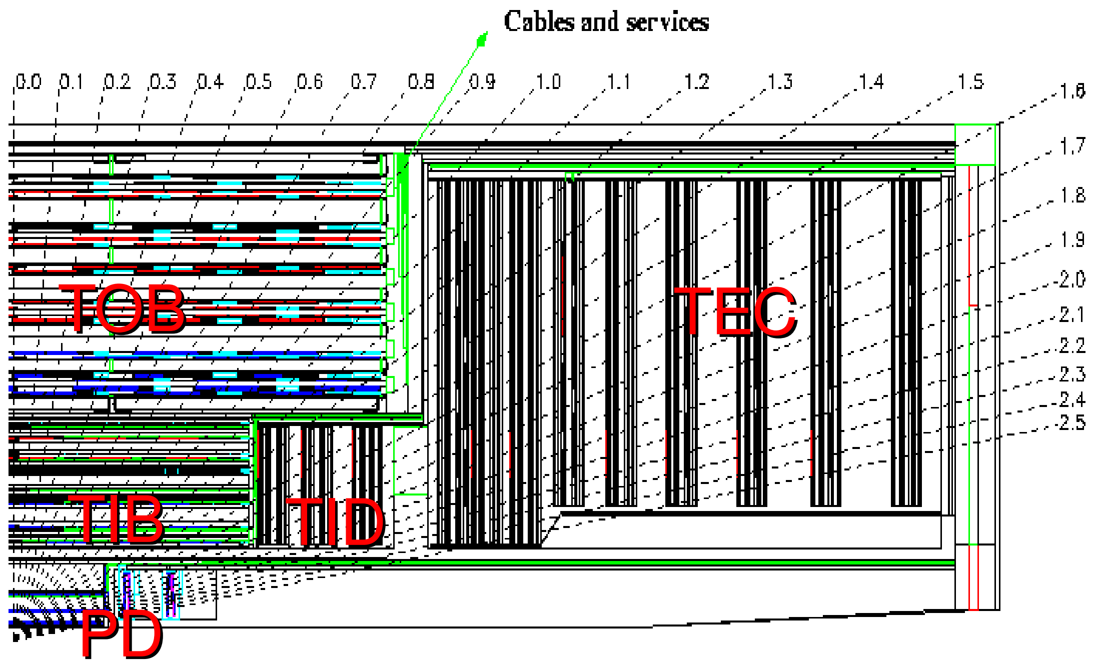


JHEP 1009 (2010) 091

1081 citations

CMS tracker: excellent for correlations





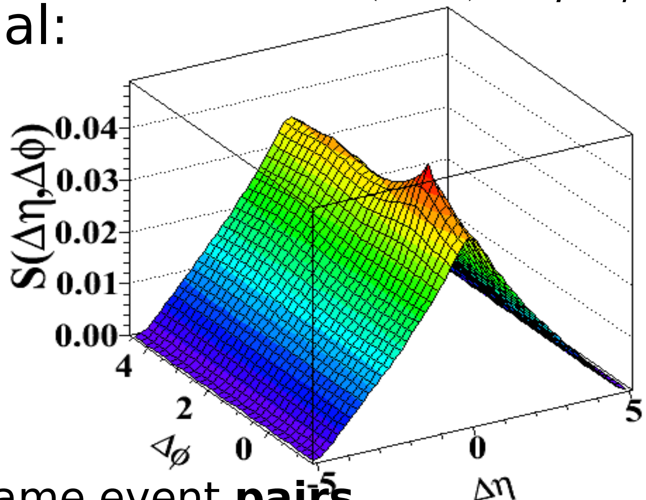
Coverage up to $|\eta|<2.5$; extremely high granularity, to keep low occupancy (~ a few%) also at LHC nominal luminosity.

Largest Silicon Tracker ever built: Strips: 9.3M channels; Pixels: 66M channels. Operational fractions: strips 98.1%; pixel 98.3%

Correlation function definition

$$S_N(\Delta\eta,\Delta\varphi) = \frac{1}{N(N-1)}\frac{d^2N^{signal}}{d\Delta\eta d\Delta\varphi}$$

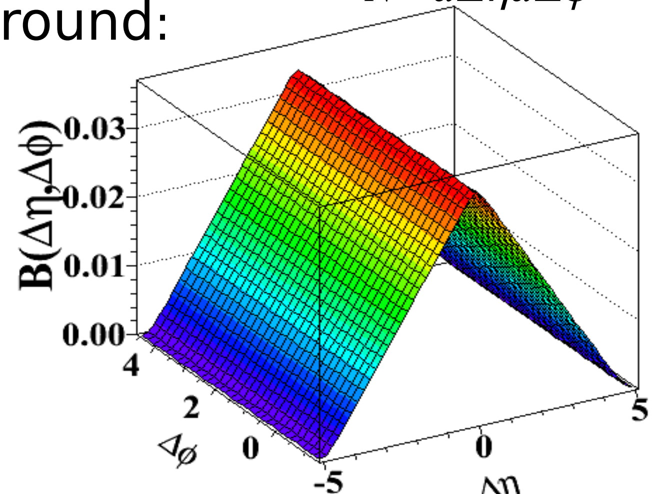
Signal:



Same event **pairs**

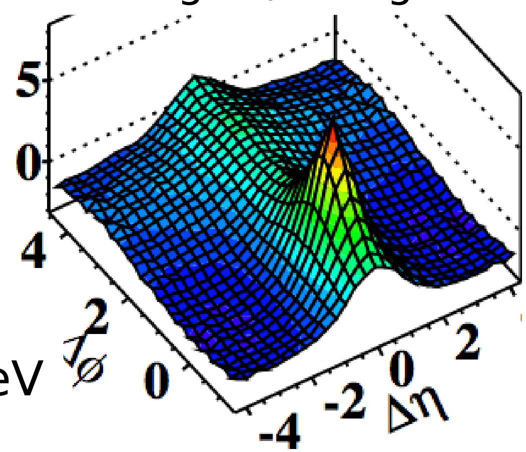
$$B_N(\Delta\eta,\Delta\varphi) = \frac{1}{N^2}\frac{d^2N^{bkg}}{d\Delta\eta d\Delta\varphi}$$

Background:



Mixed event **pairs**

Ratio Signal/Background



CMS pp 7TeV

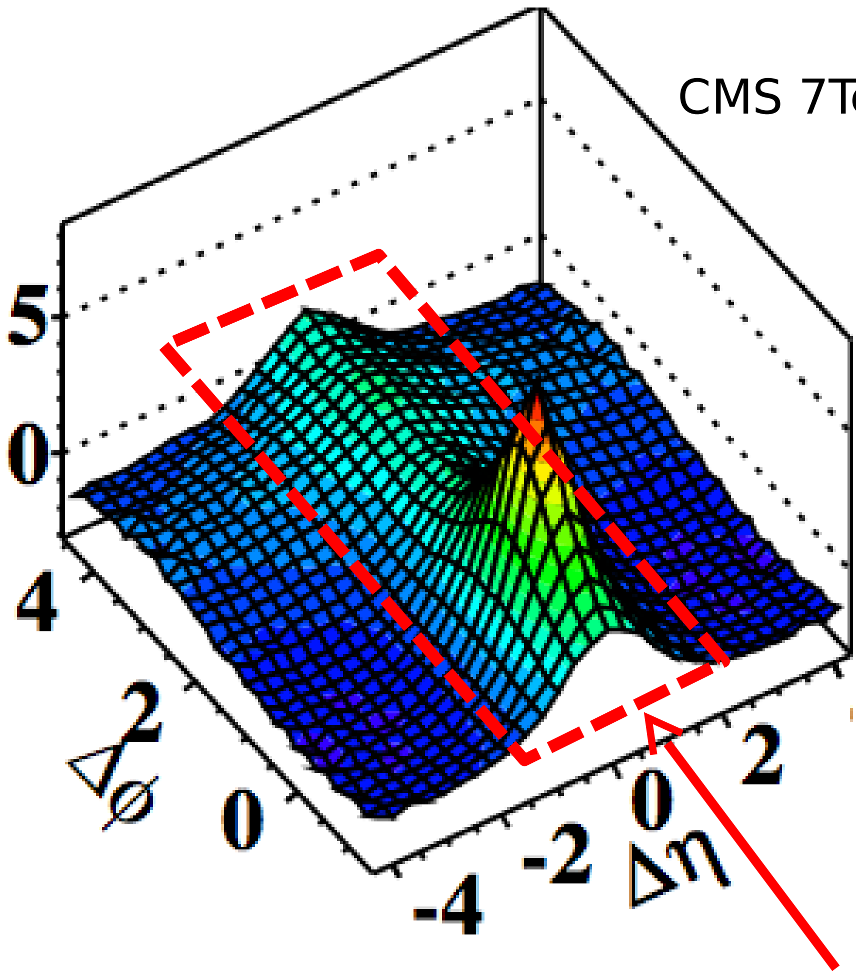
$$R(\Delta\eta,\Delta\varphi) = \left\langle (N-1)\left(\frac{S_N(\Delta\eta,\Delta\varphi)}{B_N(\Delta\eta,\Delta\varphi)} - 1\right)\right\rangle_N$$

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

p_T-inclusive two-particle angular correlations in minimum bias collisions

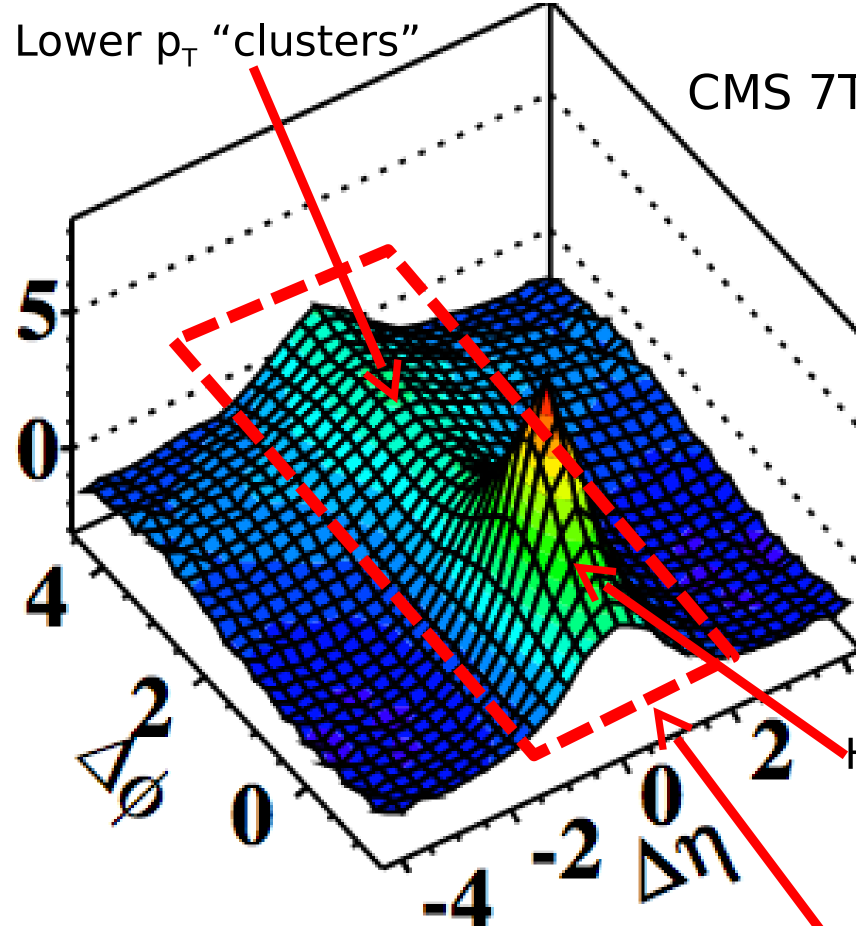
Angular correlation function

CMS 7TeV pp min bias



Short-range correlations ($\Delta\eta$ < 2):
Resonances, string fragmentation, "clusters"

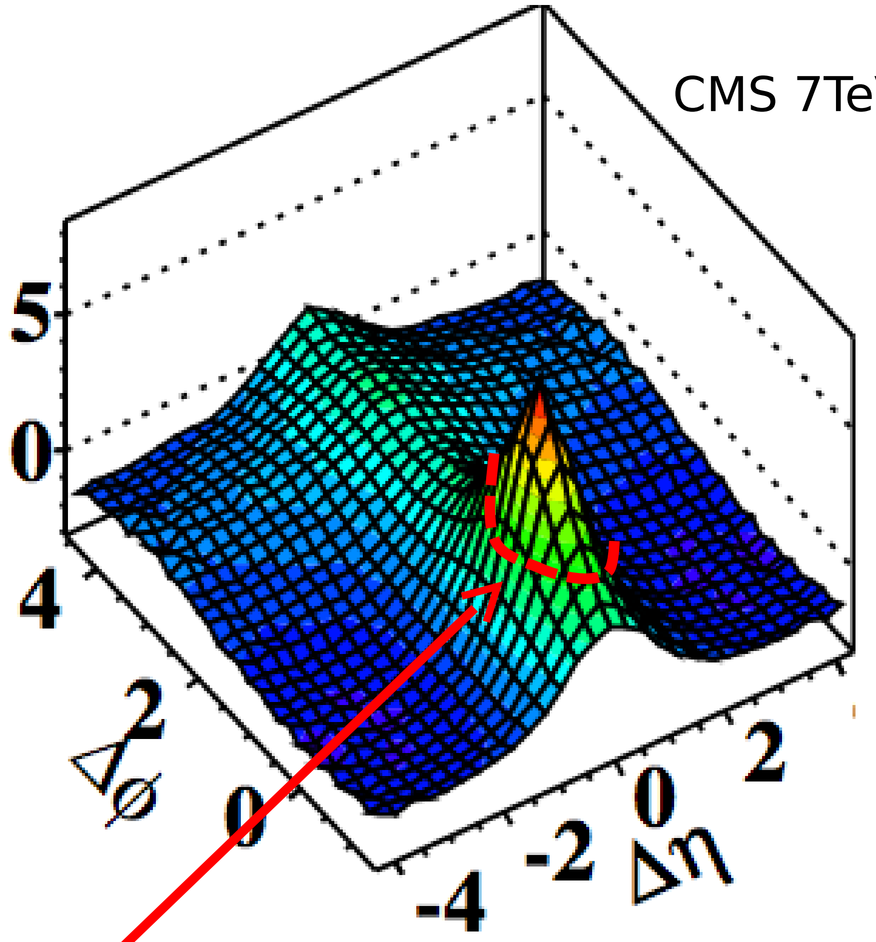
Angular correlation function



CMS 7TeV pp min bias

Short-range correlations ($\Delta\eta$ < 2):
Resonances, string fragmentation, "clusters"

Angular correlation function

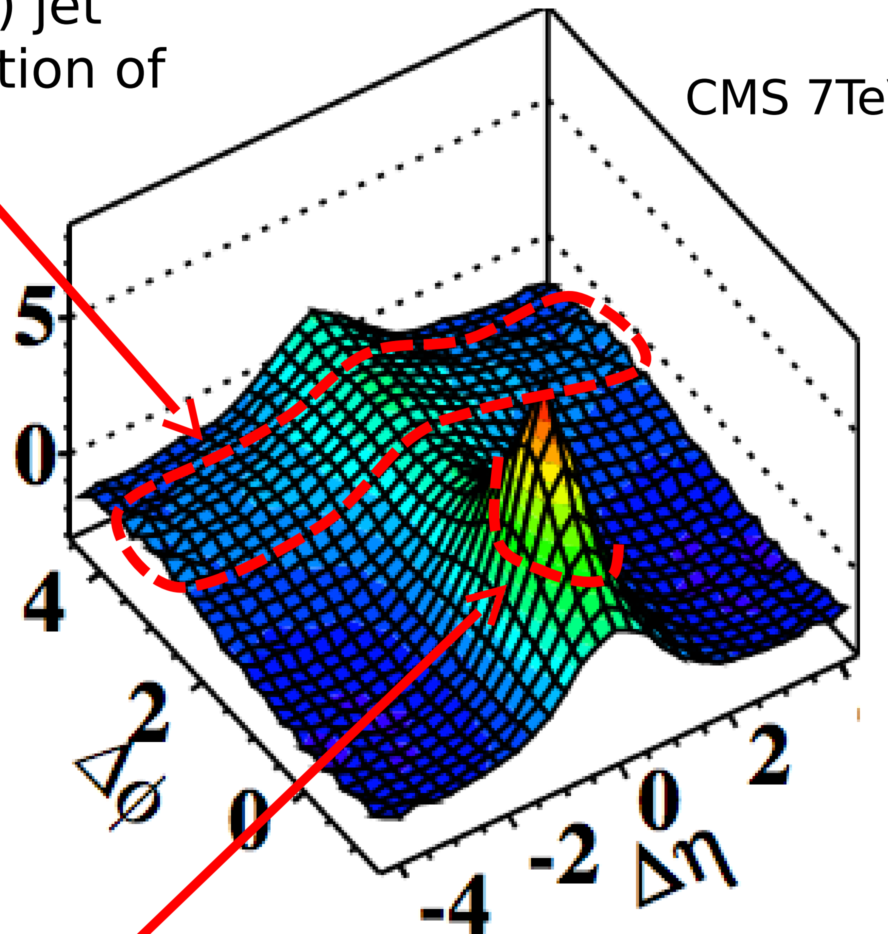


CMS 7TeV pp min bias

Near-side” (Δφ ~ 0) jet peak:
Correlation of particles
within a single jet

Angular correlation function

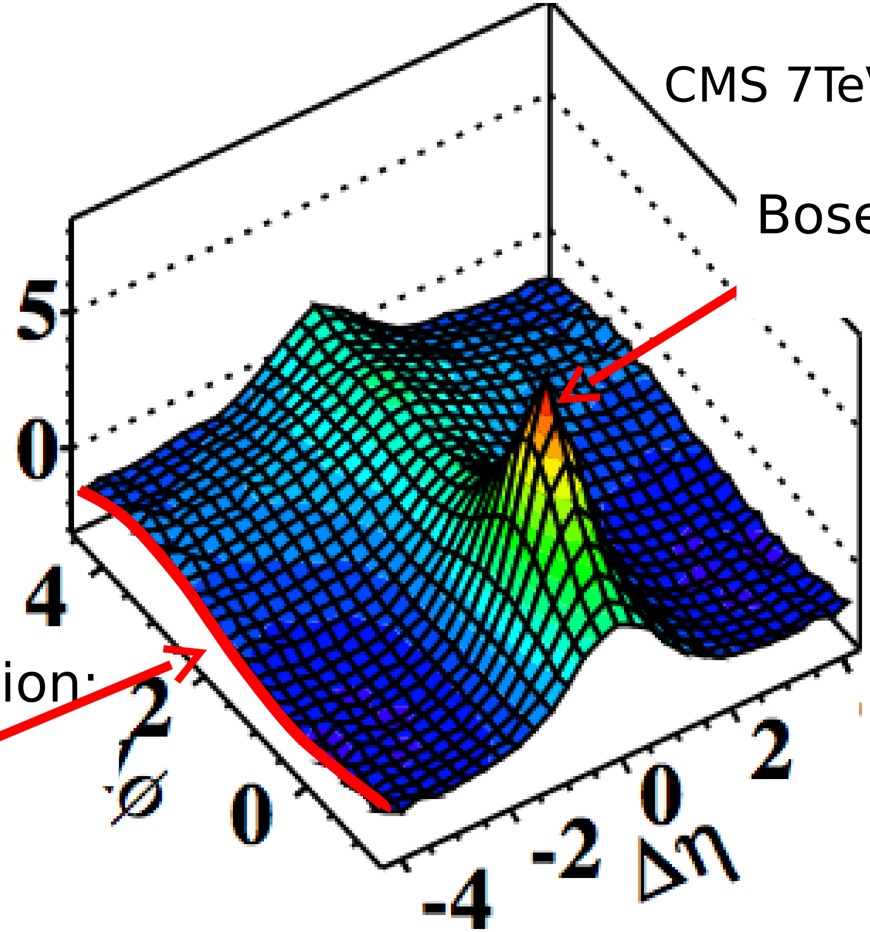
“Away-side” (Δϕ ~ π) jet correlations: Correlation of particles between back-to-back jets



CMS 7TeV pp min bias

Near-side” (Δϕ ~ 0) jet peak: Correlation of particles within a single jet

Angular correlation function



CMS 7TeV pp min bias

Bose-Einstein correlations:
$(\Delta\phi, \Delta\eta) \sim (0,0)$

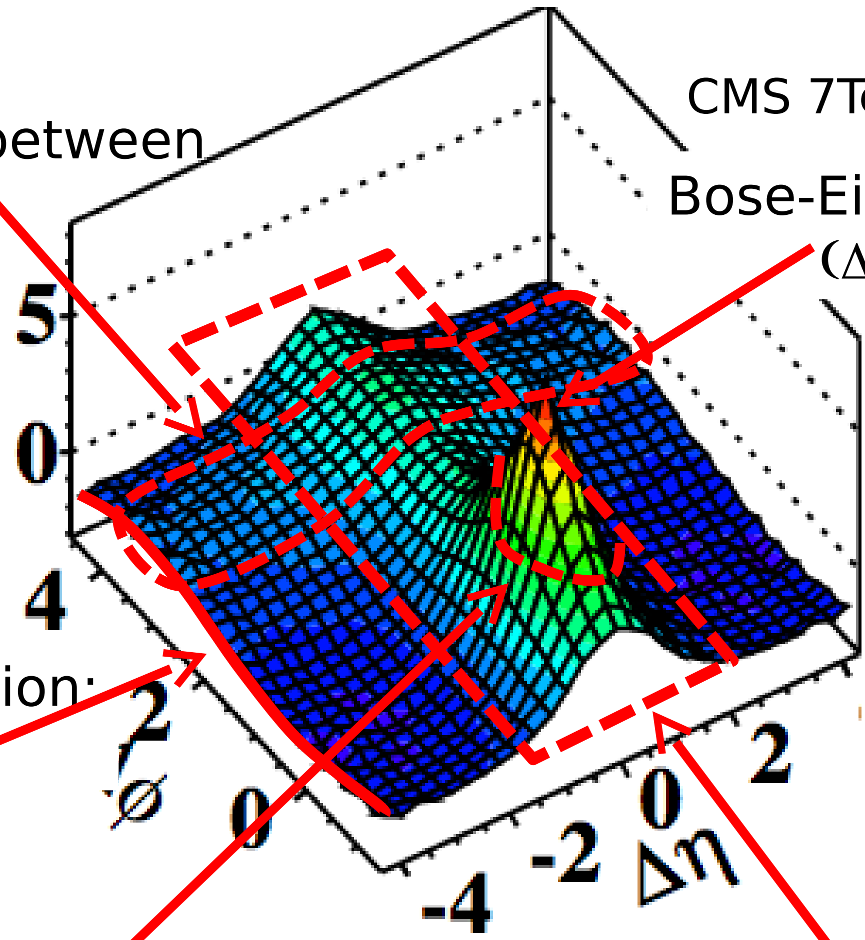
Momentum conservation:
$\sim -\cos(\Delta\phi)$

Angular correlation function

"Away-side" (Δϕ ~ π) jet correlations:
Correlation of particles between back-to-back jets

CMS 7TeV pp min bias

Bose-Einstein correlations:
(Δϕ ,Δη) ~ (0,0)



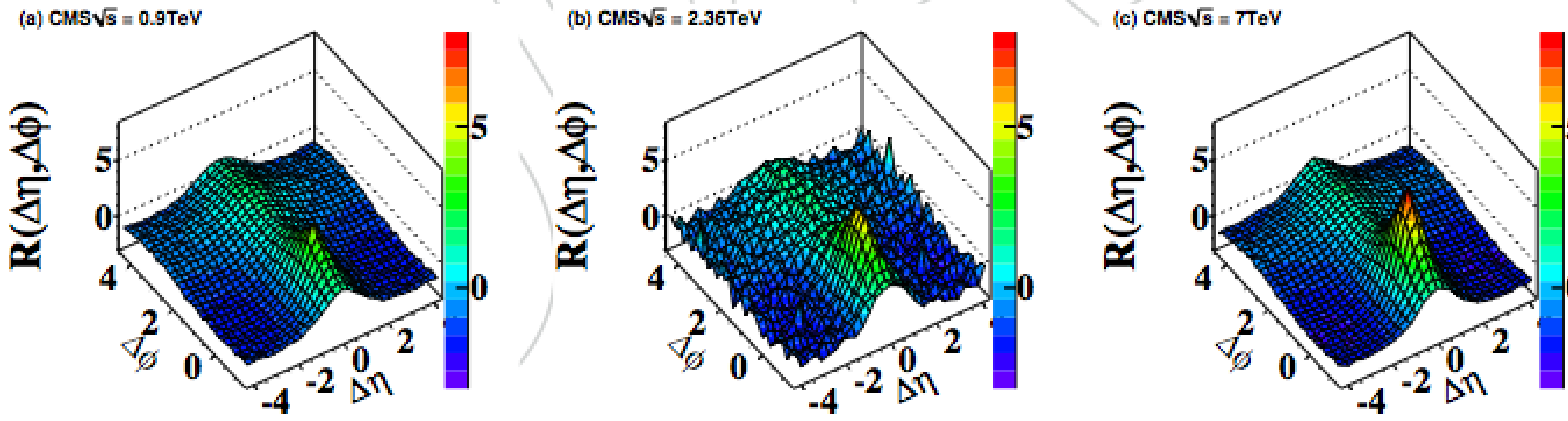
Momentum conservation:
~ -cos(Δϕ)

"Near-side" (Δϕ ~ 0) jet peak:
Correlation of particles within a single jet

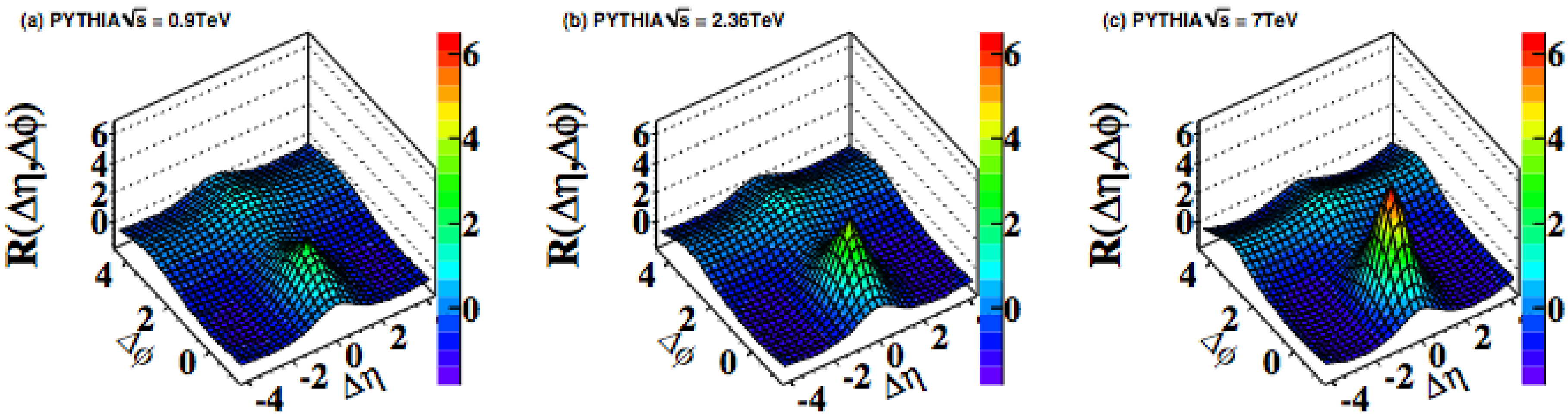
Short-range correlations (Δη < 2):
Resonances, string fragmentation, "clusters"

Correlations in minimum bias pp

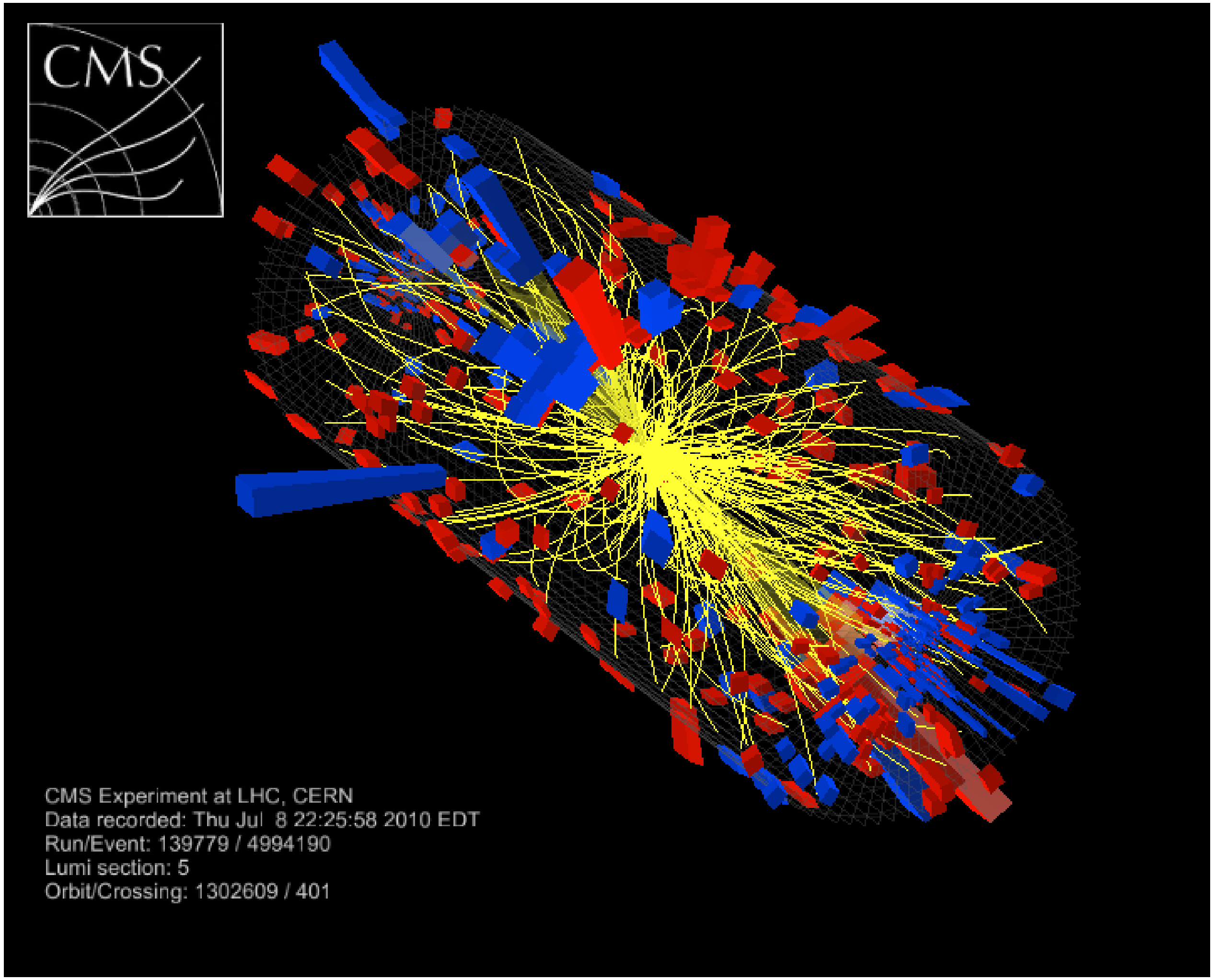
CMS pp Data



Pythia D6T

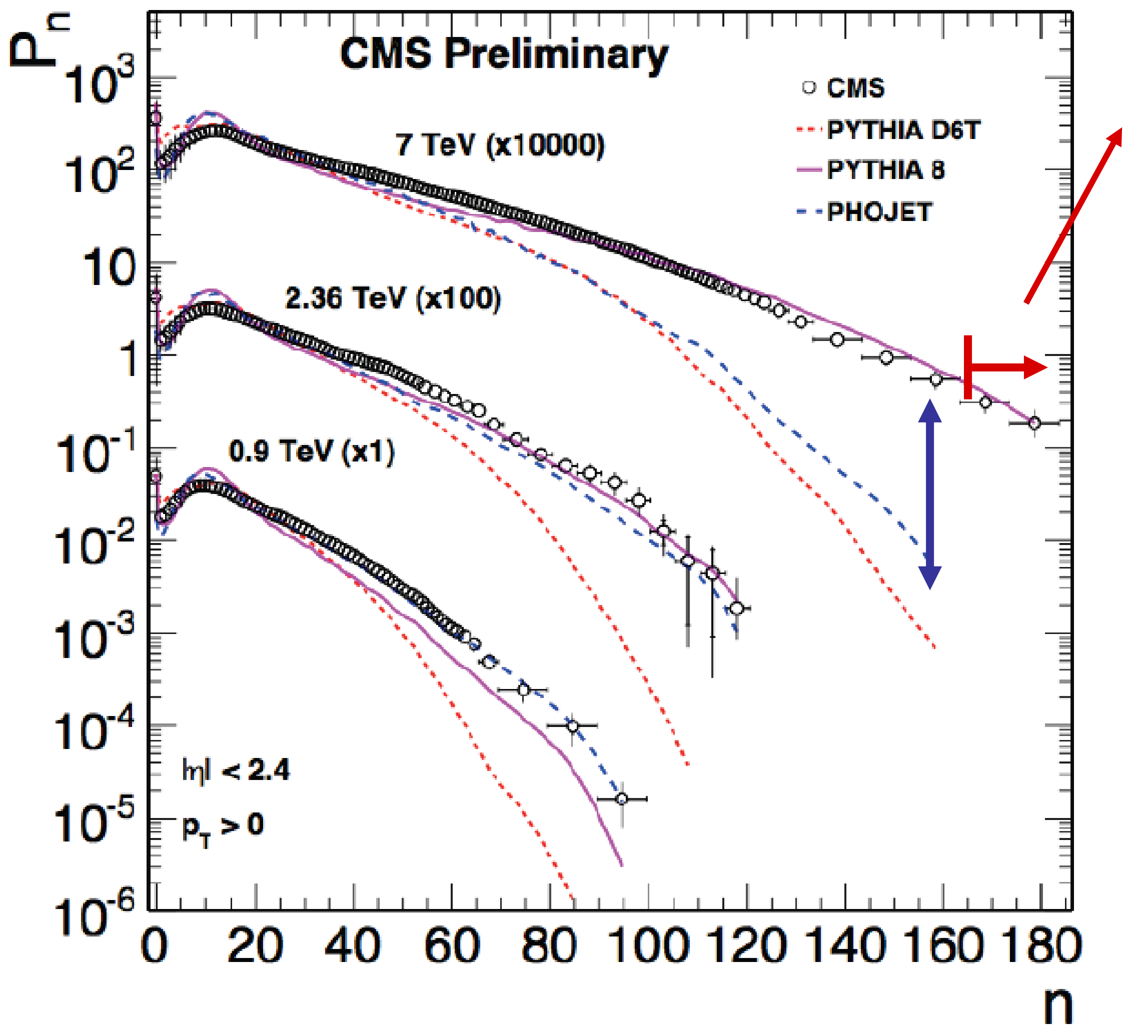


High multiplicity events



268 reconstructed particles in the tracker in a single pp collision:
the highest multiplicity event in ~70 billion inelastic events sampled (1/pb)

Extremely high multiplicities



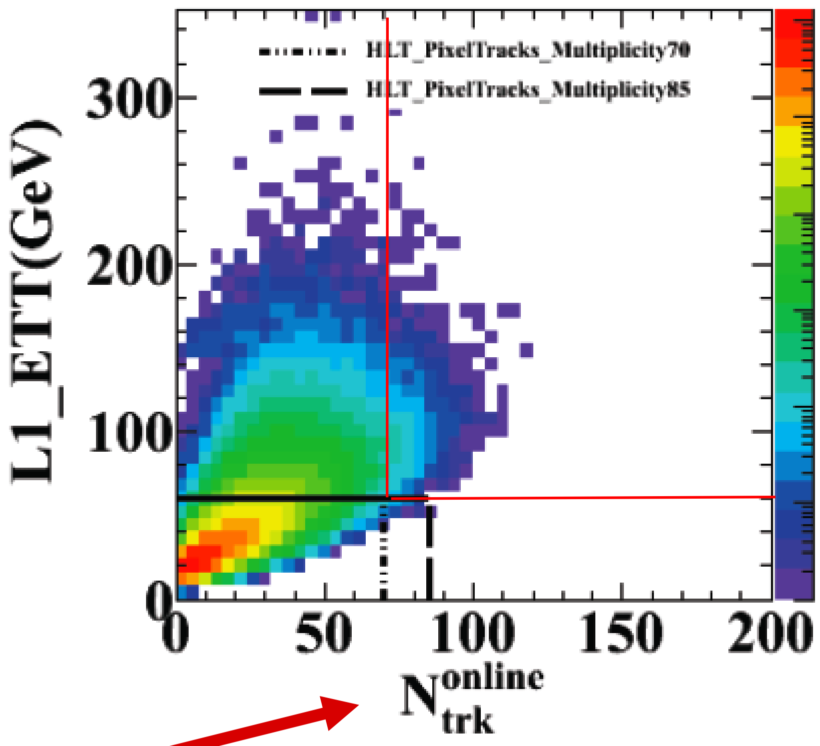
These correlation studies focus on the tail of the distribution, where various MC generators severely under-estimate the data (an exception: PYTHIA8).

Motivations:
→ Trying to find (more) **unexpected** effects in this regime
→ Learn more about (soft) QCD and particle production mechanisms with more differential measurements
→ Highest multiplicities in pp begin to approach those in **ion** collisions; can we learn something about **similarities** or **differences**?

High multiplicity trigger

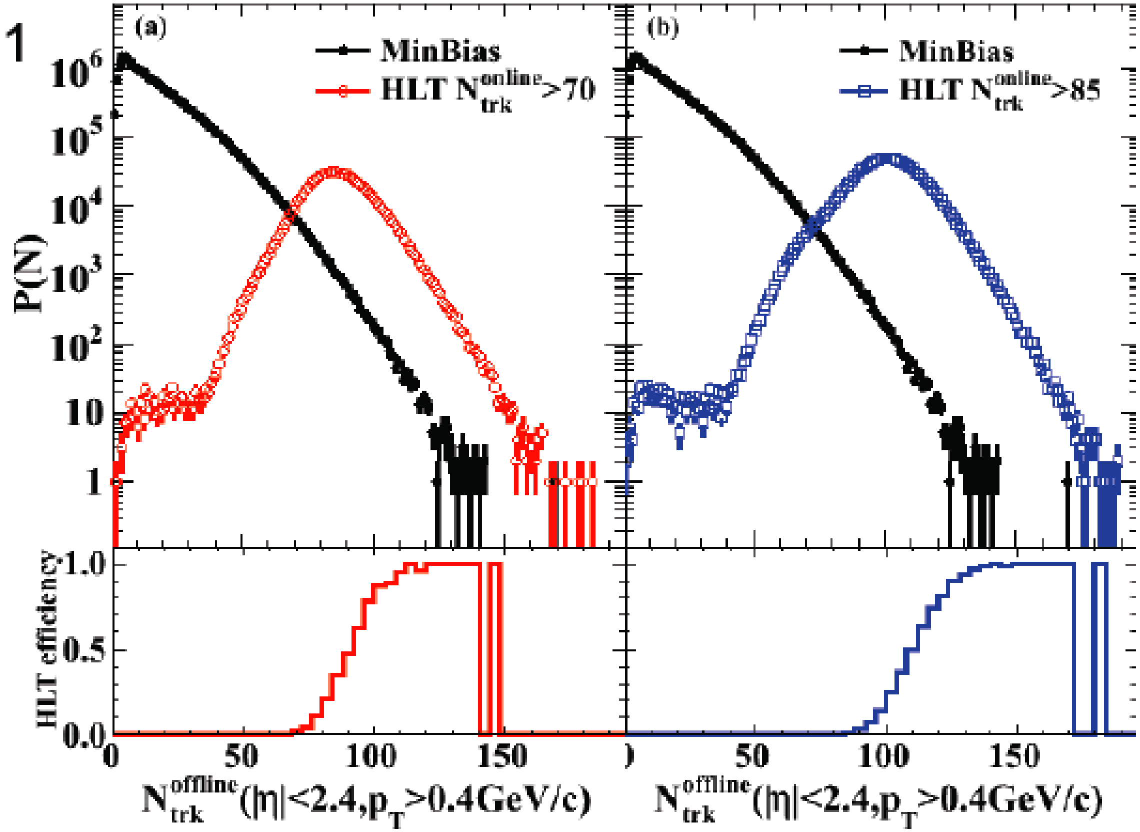
Dedicated trigger was needed to record highest multiplicities

Level-1 (hardware):
Requires E_T> 60 GeV
in calorimeters



High-Level trigger (software):
More than 70 (85) tracks with p_T > 0.4 GeV/c, $|\eta|$ < 2,
within dz < 0.12 cm of a **single** vertex with z < 10 cm.
~50% CPU usage of the HLT

High multiplicity event statistics



1000 times more high multiplicity events recorded with the trigger compared to Min. Bias

Multiplicity binning uses
p_T > 0.4 GeV/c
$|\Delta\eta|$ < 2.4

Multiplicity bin ($N_{trk}^{offline}$)	Event Count	$\langle N_{trk}^{offline} \rangle$
MinBias	21.43M	15.9
$N_{trk}^{offline} < 35$	19.36M	13.0
$35 \leq N_{trk}^{offline} < 90$	2.02M	45.3
$90 \leq N_{trk}^{offline} < 110$	302.5k	96.6
$N_{trk}^{offline} \geq 110$	354.0k	117.8

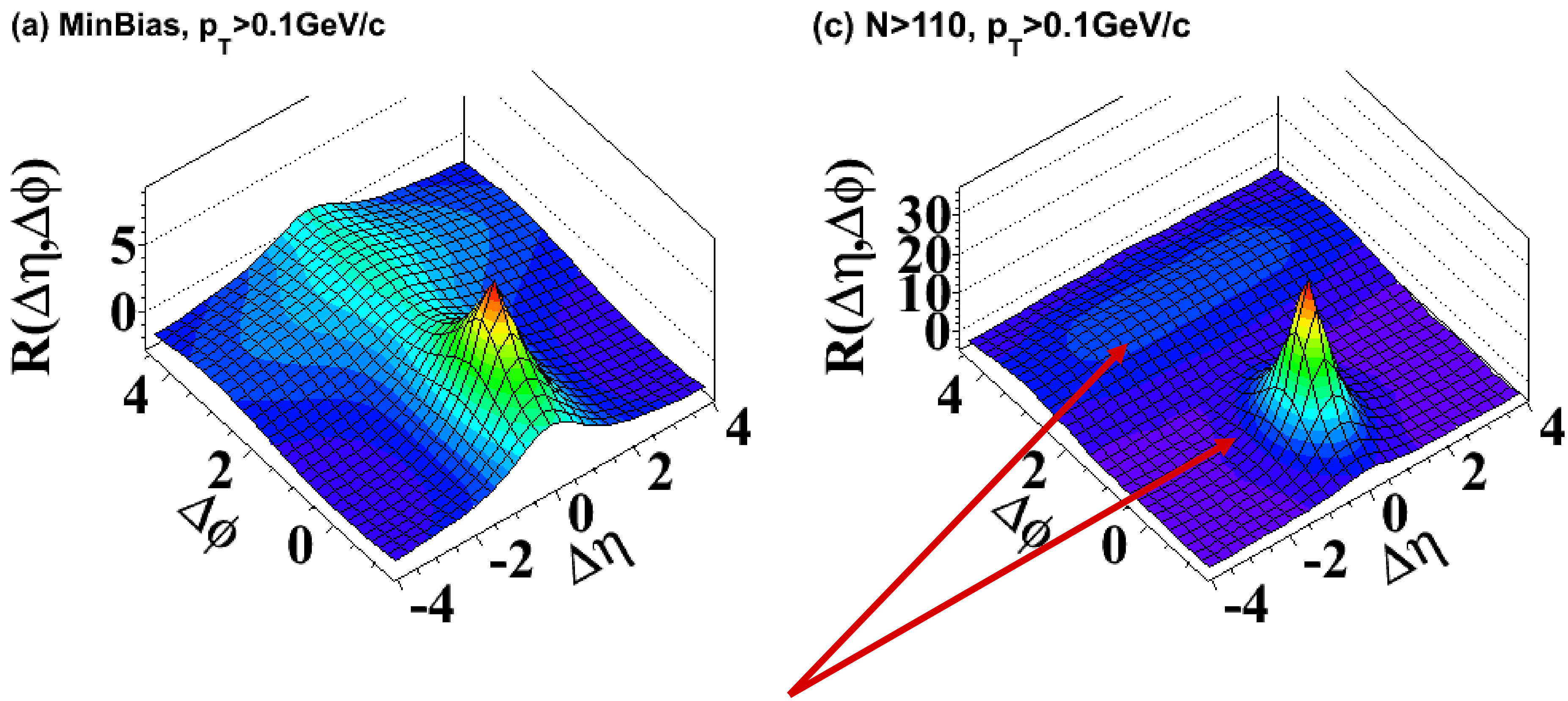
out of 5×10^{10} collisions

Two different HLT thresholds:
N^{online} > 70 and N^{online} > 85

HLT85 trigger un-prescaled
for full 980nb^{-1}

Results, inclusive p_T

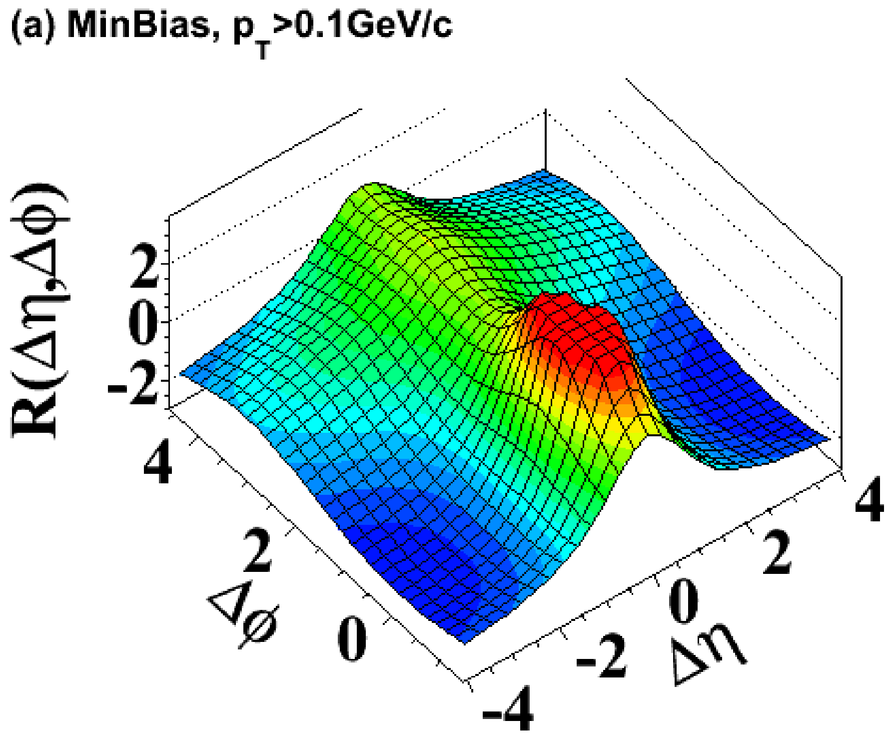
MinBias high multiplicity (N>110)

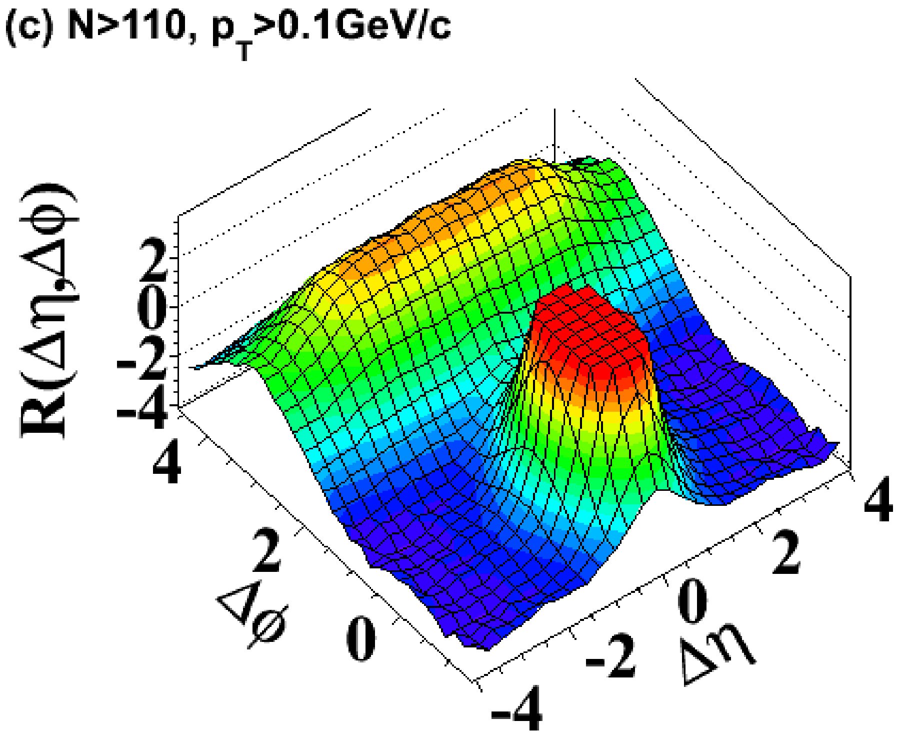


Jet peak/away-side correlations enhanced in high multiplicity events
Abundant jet production in high multiplicity sample

Results, inclusive p_T

MinBias | high multiplicity (N>110)





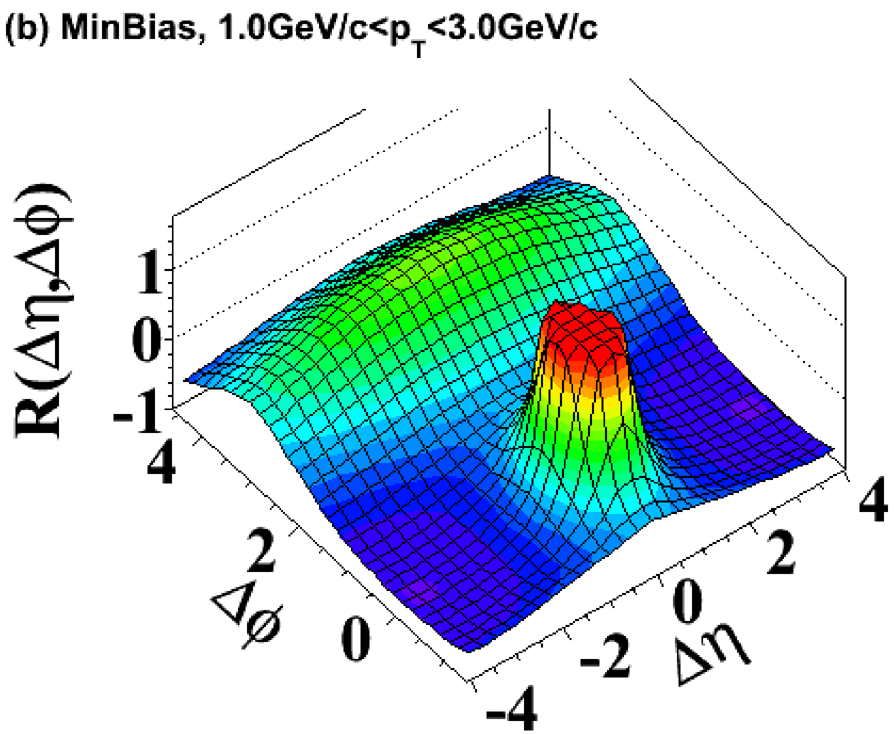
After cuting off the jet peak at (0,0) we can observe:

Structure of away-side ridge (back-to-back jets)

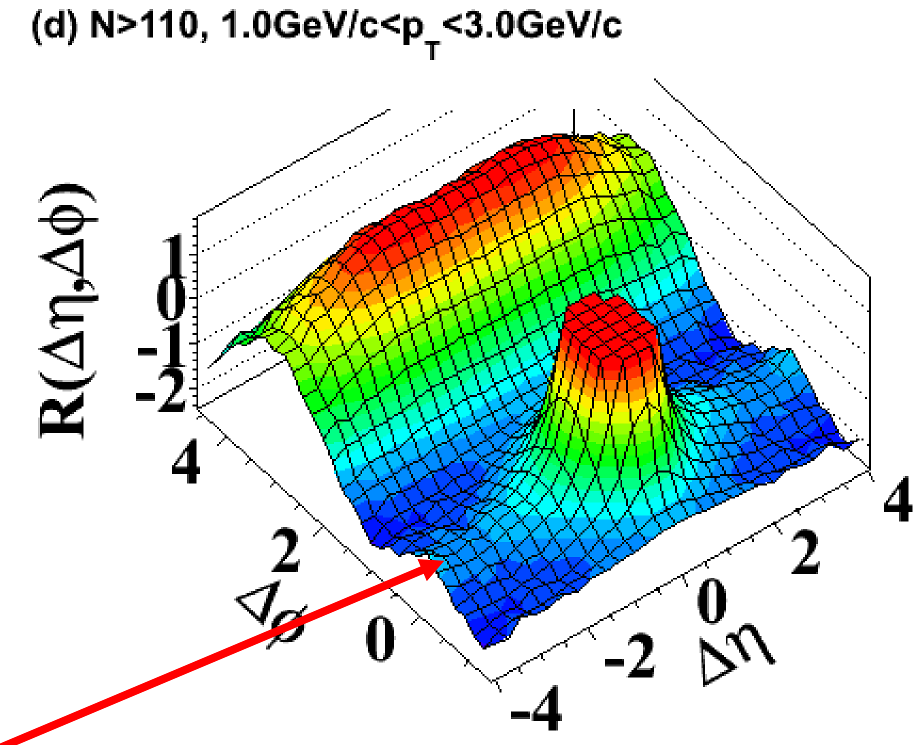
Small change for large $\Delta\eta$ around $\Delta\phi \sim 0$?

Results: $1<p_T<3$ GeV

MinBias



high multiplicity (N>110)

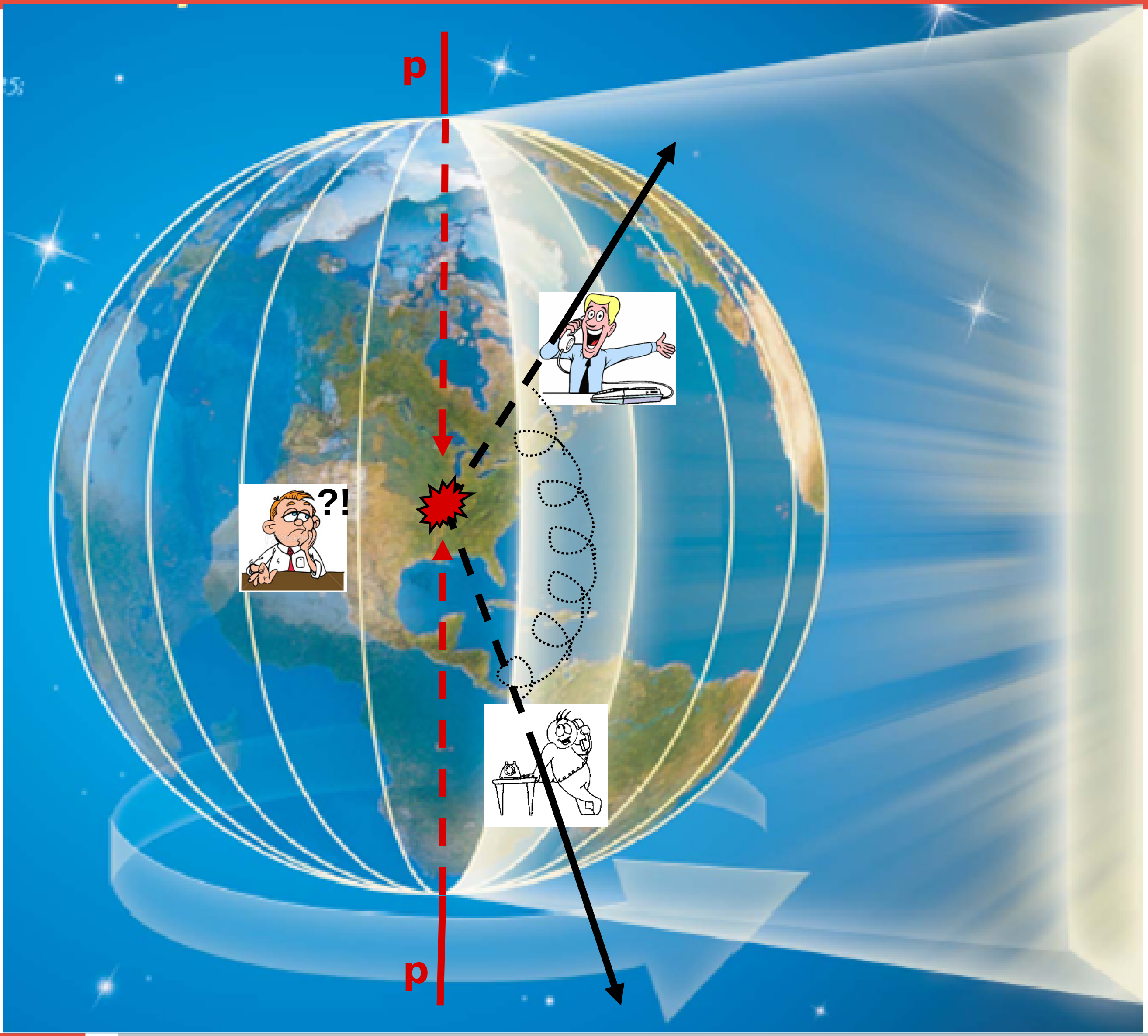


JHEP 1009 (2010) 091

Pronounced new structure
at large Δη, around Δφ ~ 0 !

1081 citations

Illustration of the effect

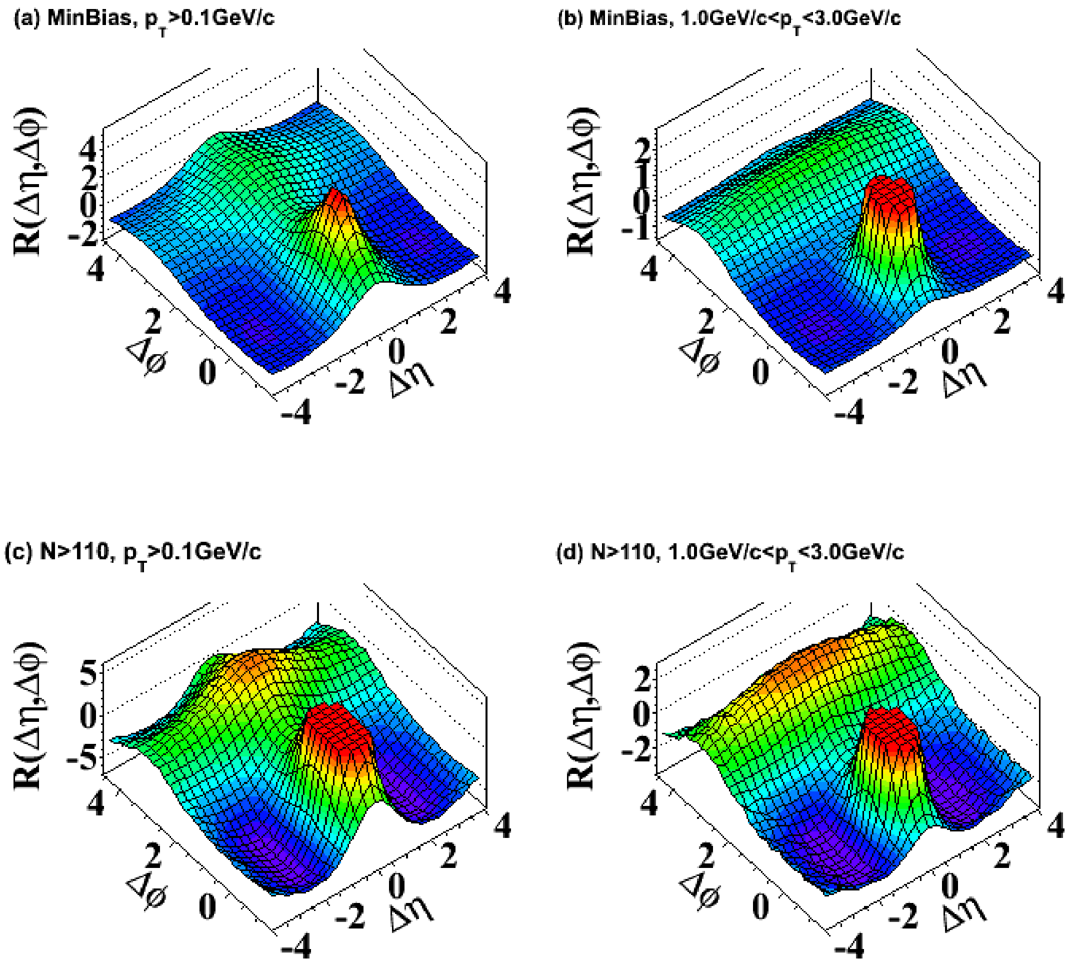


Particles surfacing in the same *time zone*, but far away in latitude, *talk to* each other…

…What mechanism is

the “telephone line”?

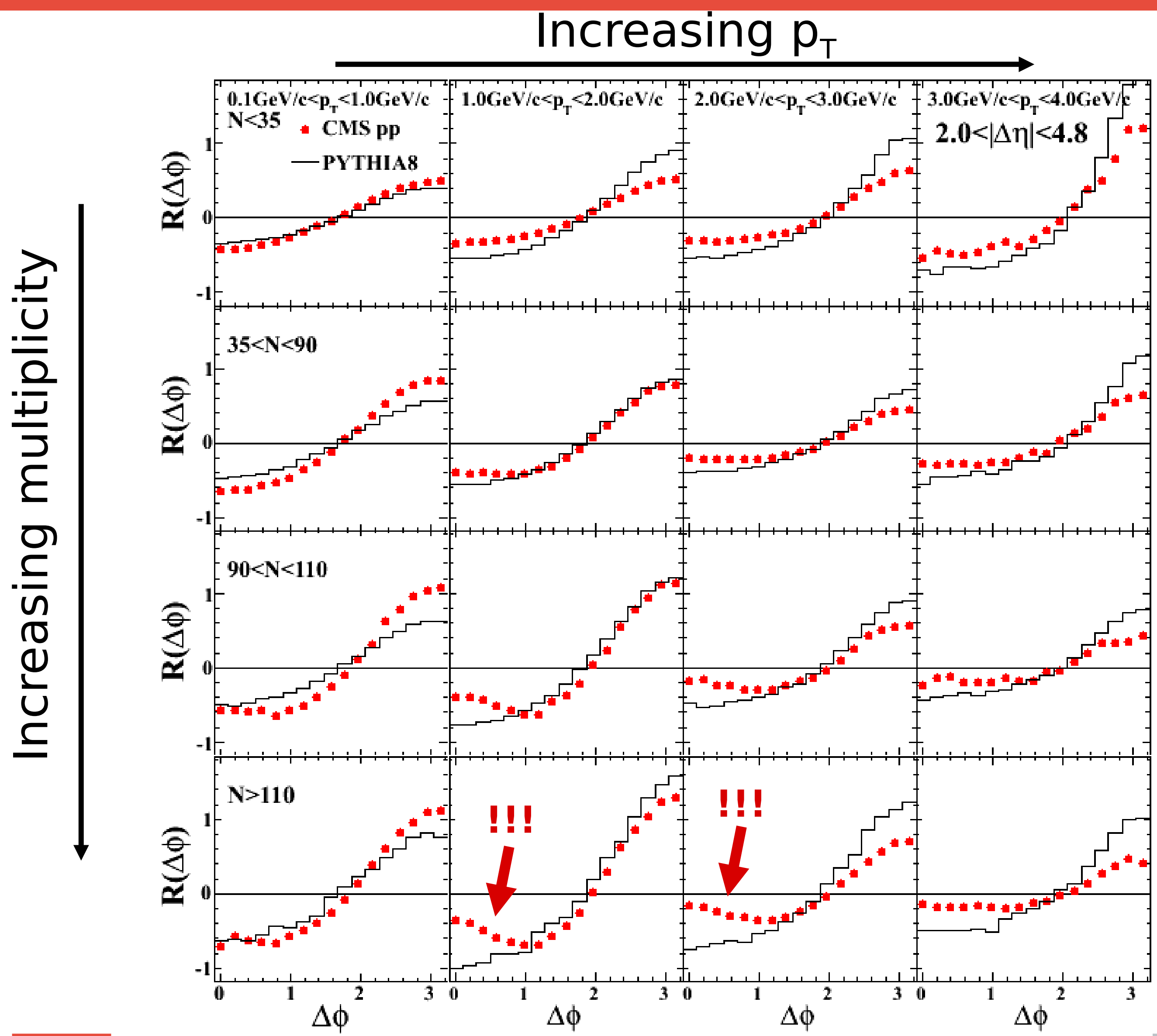
Correlations in PYTHIA8

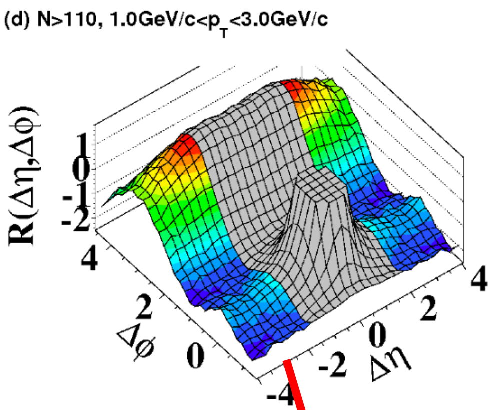


No $\Delta\phi \sim 0$ structure at large $\Delta\eta$

$\rightarrow$ Same for Herwig++, madgraph, PYTHIA6

Multiplicity and p_T-dependence



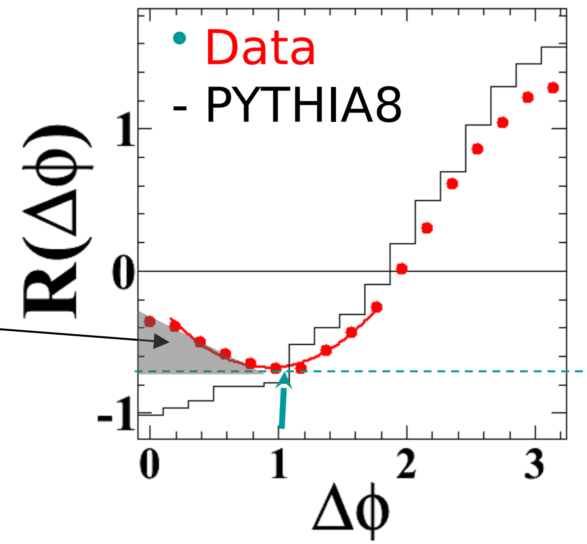


Project $|\Delta\eta| > 2$ onto $\Delta\phi$

Quantifying the associated yield

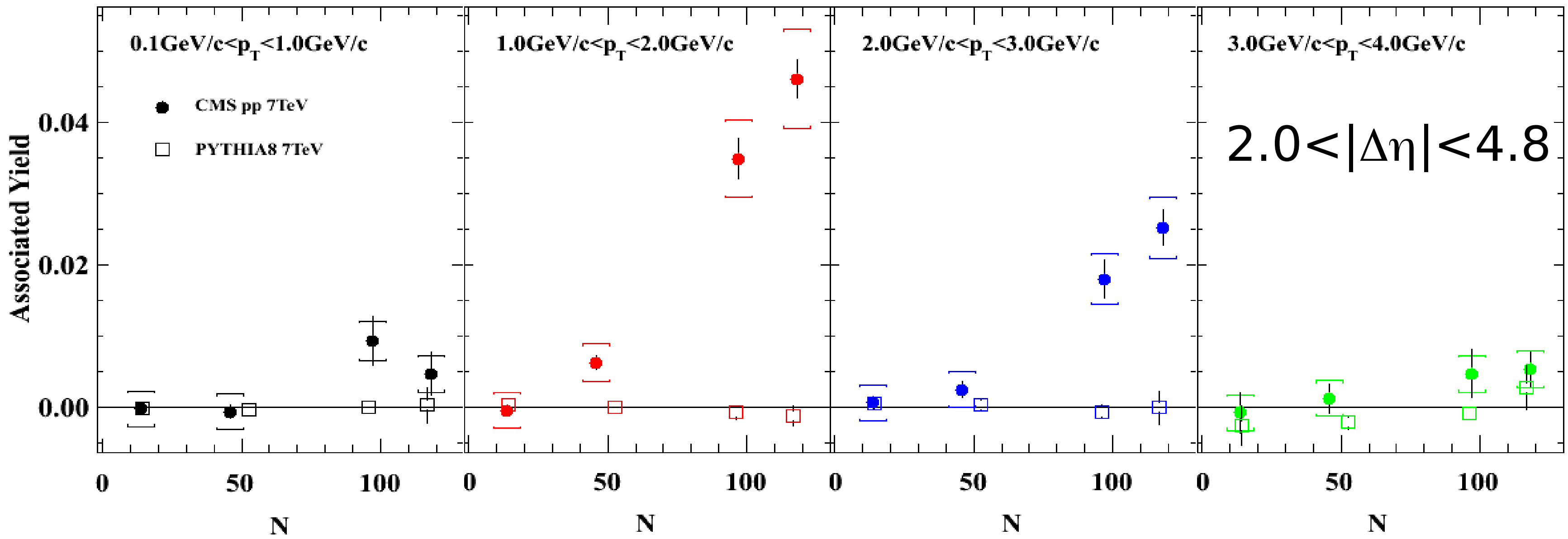
Zero Yield At Minimum (ZYAM)

Associated yield:
correlated multiplicity per particle

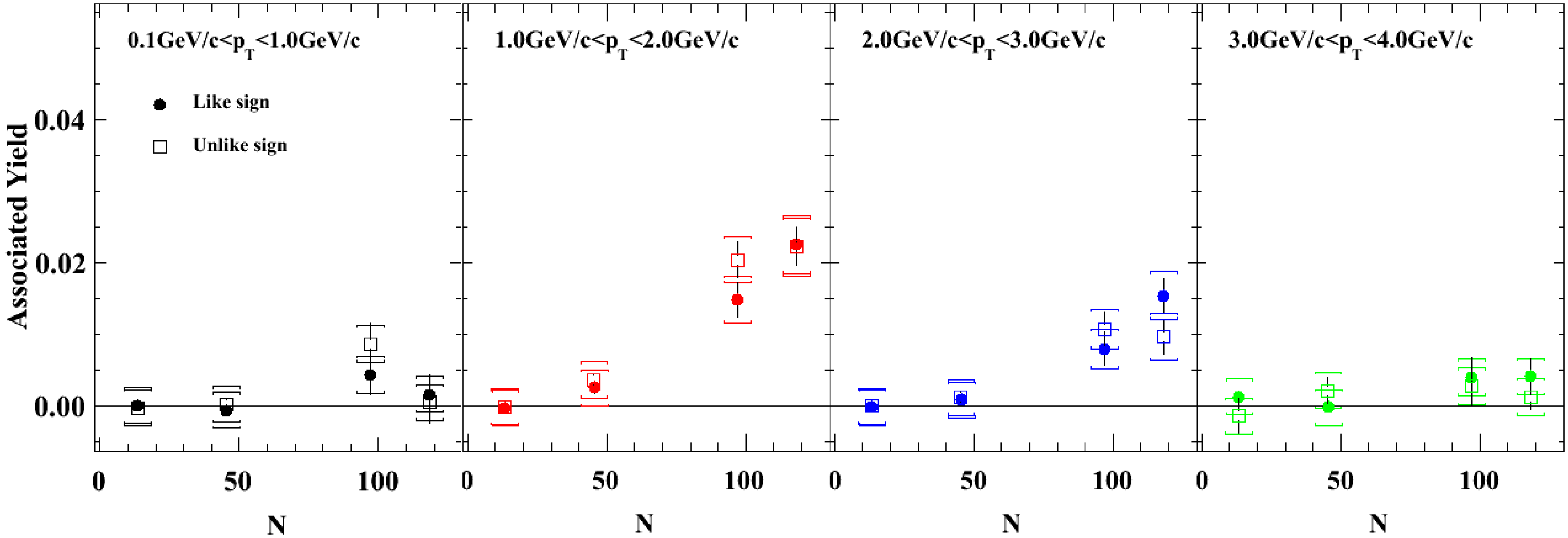


N>110
2.0<|Δη|<4.8
1GeV/c<p_T<2GeV/c

Minimum of R



Like-sign and unlike-sign pairs



No dependence on relative charge sign

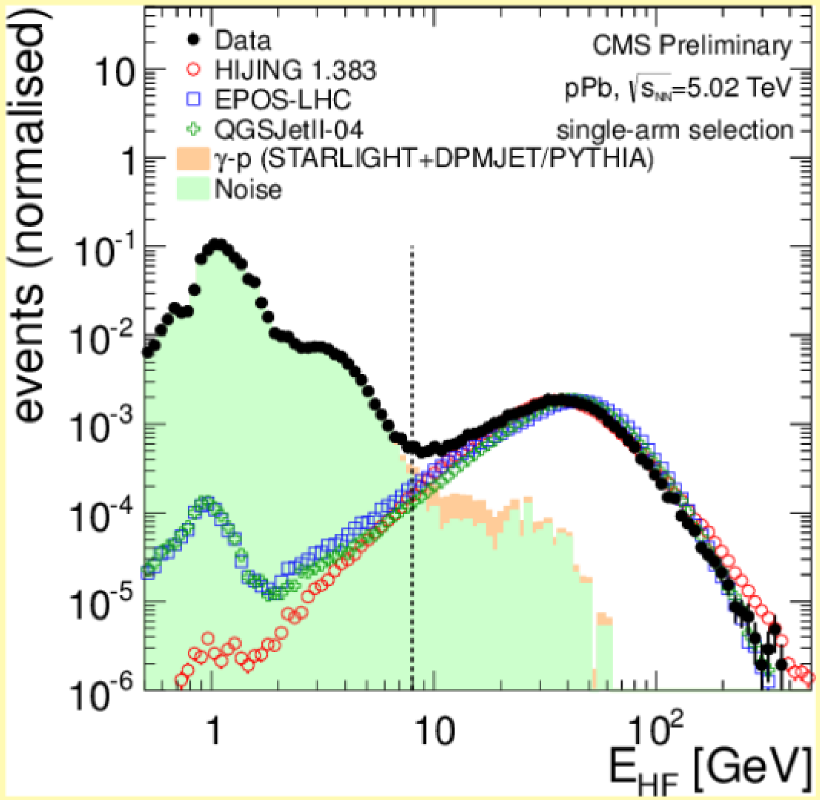
Inelastic cross section of p+Pb

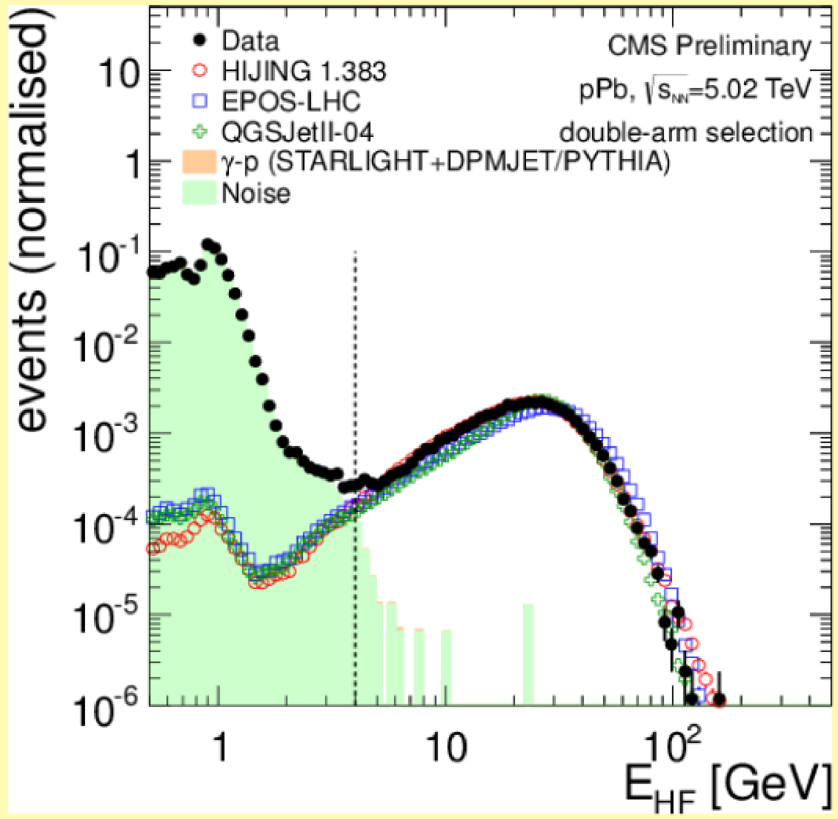
- **Events tagged using the HF calorimeters: double-sided and one-sided condition**
- **Contribution from photon-induced events**
- **Possible coherence and correlation effects (Glauber)**
- **Cosmic rays: important for proton-air xsec**

Event counting

$$E_{HF} = \begin{cases} \max(E_{HF+}, E_{HF-}) \\ \min(E_{HF+}, E_{HF-}) \end{cases}$$

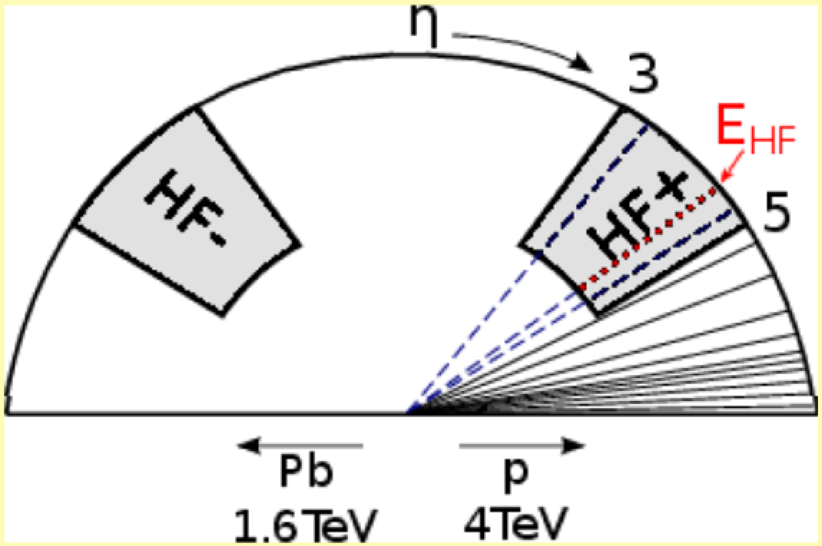
← single arm, threshold: 8 GeV
← double arm, threshold: 4 GeV



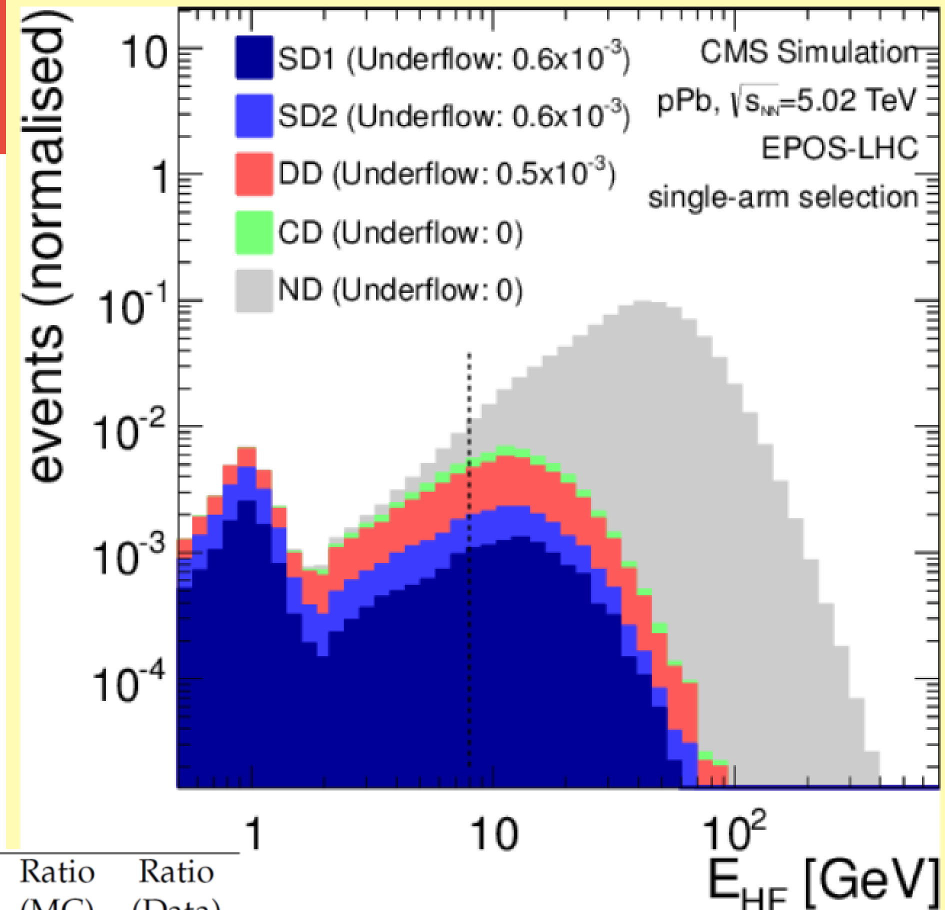


Event composition

Cartoon of a single diffractive event:



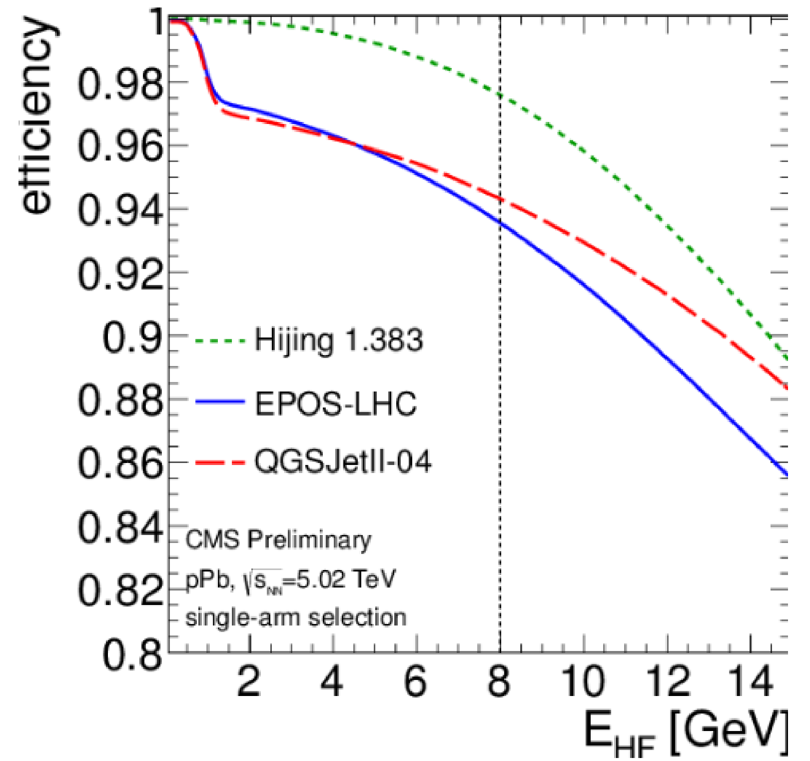
Composition of the event sample (single arm):

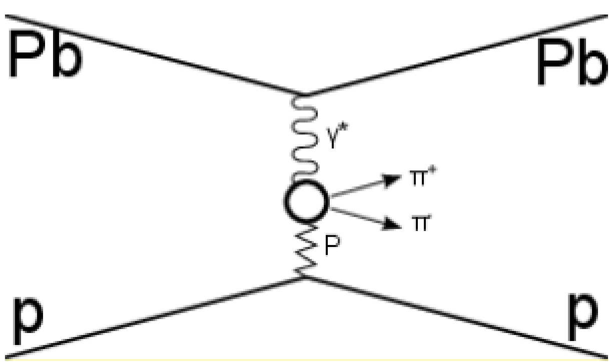


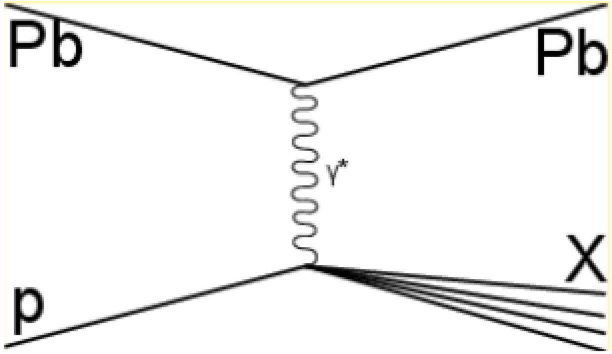
Model	Selection	SD [%]	DD [%]	CD [%]	ND [%]	∑ [%]	Ratio (MC)	Ratio (Data)
EPOS-LHC	No selection	4.5	4.5	1.1	90.0	100	-	0.966
	Single-arm	1.7	2.4	0.7	88.9	93.7	0.969	
	Double-arm	1.1	1.8	0.5	87.3	90.8		
HIJING	No selection	-	-	-	100	100	-	
	Single-arm	-	-	-	97.7	97.7	0.972	
	Double-arm	-	-	-	94.9	94.9		
QGSJETII-04	No selection	5.1	1.8	0.0	93.1	100	-	
	Single-arm	1.2	1.2	0.0	92.0	94.4	0.971	
	Double-arm	0.3	0.7	0.0	90.7	91.7		

Corrections

- **Noise from non-colliding triggers (5.4 and 0.5% for single- and double-arm selections)**
- **Contribution from γp (3.4 and 0.02%)**
- **Pileup (1.8%)**
- **Extrapolation to full phase space (9 and 6%)**
- **Electromagnetic processes from STARLIGHT**







Results

Visible cross section: σ_{vis}, all processes that pass selection cuts
Visible hadronic cross section: $\sigma_{vis,had}$, electromagnetic events subtracted from σ_{vis}
Hadronic inelastic cross section: σ_{inel}, the visible hadronic xsec extrapolated to full phase space
Systematic uncertainties: luminosity (3.5%), extrapolation to full phase space (0.5% and 1.6%), photo-nuclear contribution (0.2% and <0.1%), HF energy resolution (1.7% and 0.8%), selection cuts (0.6% and 0.2%) and variations of noise correction (1.2% and 0.2%), in total: 4.4% for both selections

Selection	σ_{vis} (b)	$\sigma_{vis,had}$ (b)	σ_{inel} (b)
$E_{HF} > 8$ GeV (single-arm)	2.003	1.938	2.063
$E_{HF} > 4$ GeV (double-arm)	1.873	1.873	2.059

Averaged result: **σ_{inel}= 2.061 ± 0.003 (stat.) ± 0.039 (syst.) ± 0.072 (lumi.) barns**

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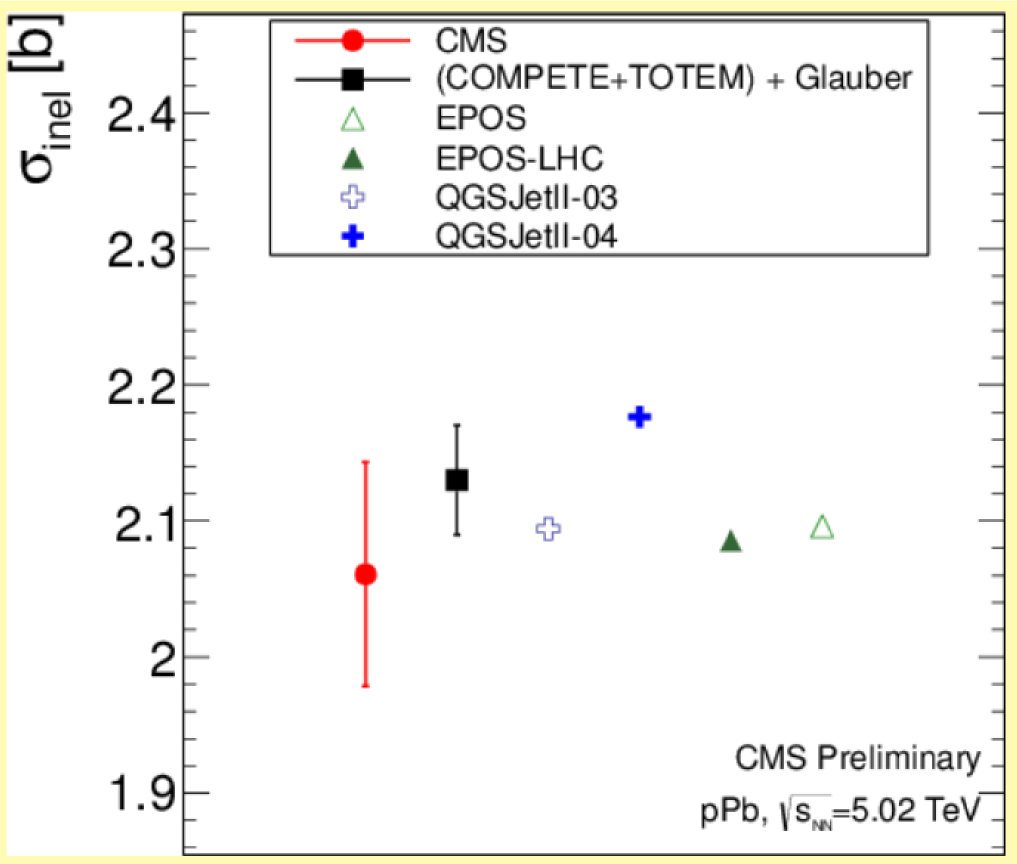
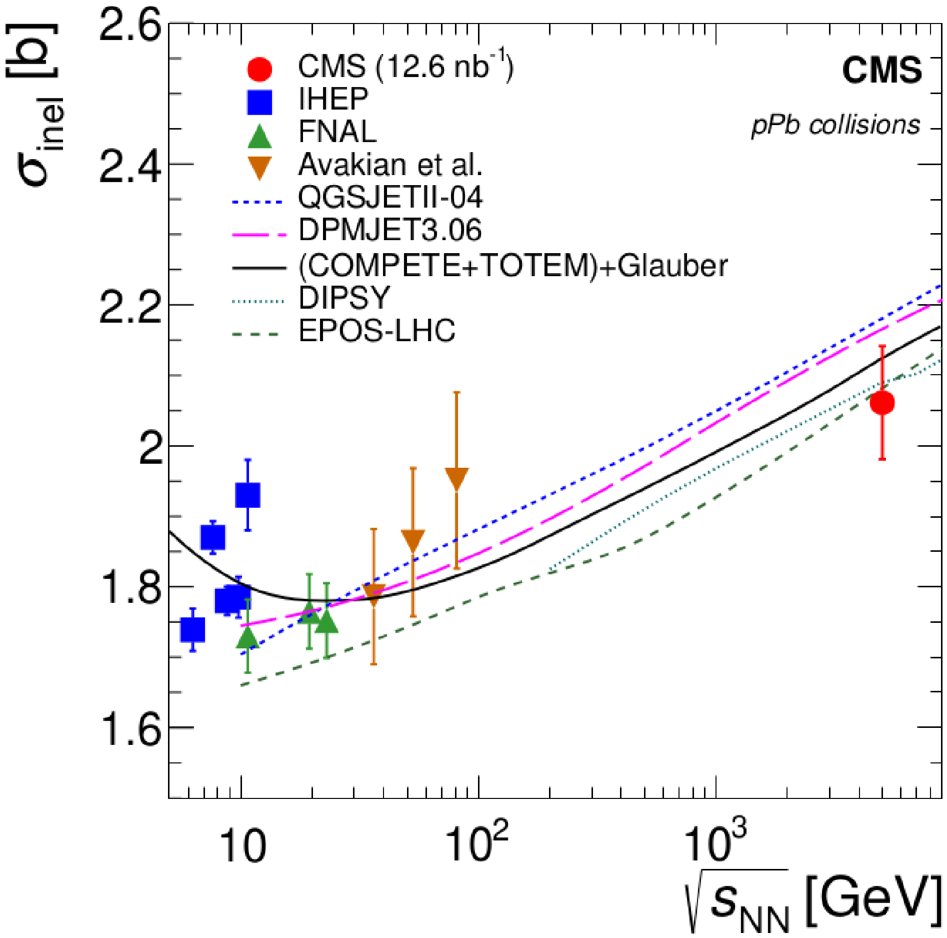
Results



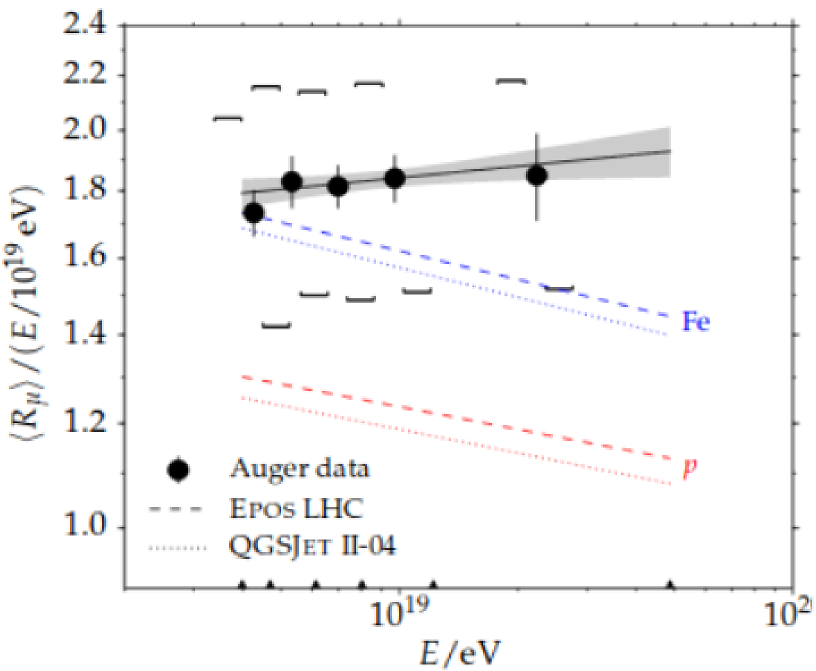
σinel [b]
2.4
2.3
2.2
2.1
2
1.9
CMS
(COMPETE+TOTEM) + Glauber
EPOS
EPOS-LHC
QGSJetII-03
QGSJetII-04
CMS Preliminary
pPb, √sNN=5.02 TeV

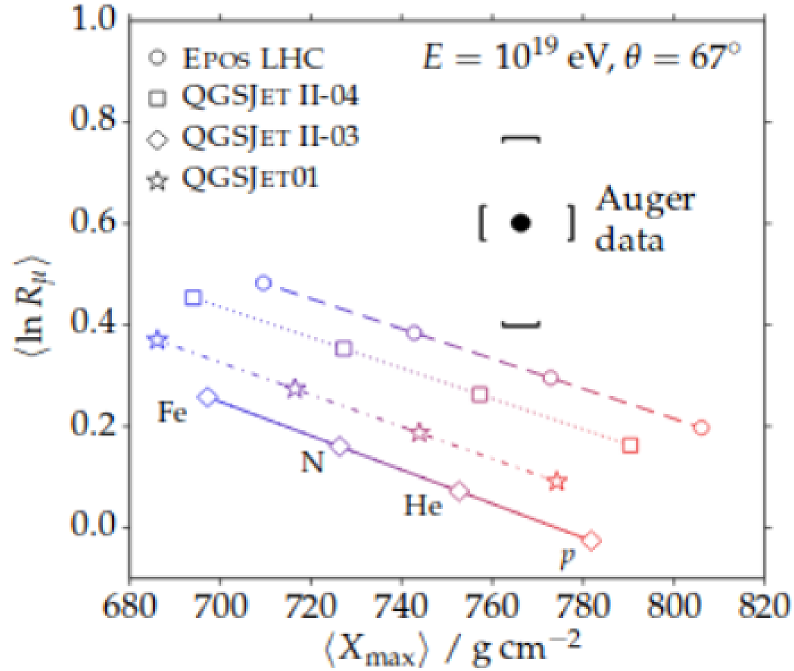


σinel [b]
2.6
2.4
2.2
2
1.8
1.6
CMS (12.6 nb-1)
IHEP
FNAL
Avakian et al.
QGSJETII-04
DPMJET3.06
(COMPETE+TOTEM)+Glauber
DIPSY
EPOS-LHC
CMS
pPb collisions
10
10²
10³
√sNN [GeV]

Charge exchange... the muon puzzle

- Measurements of ultra high energy cosmic rays (eg. at Pierre Auger Observatory)
- Muon component / shower not reproduced by simulations



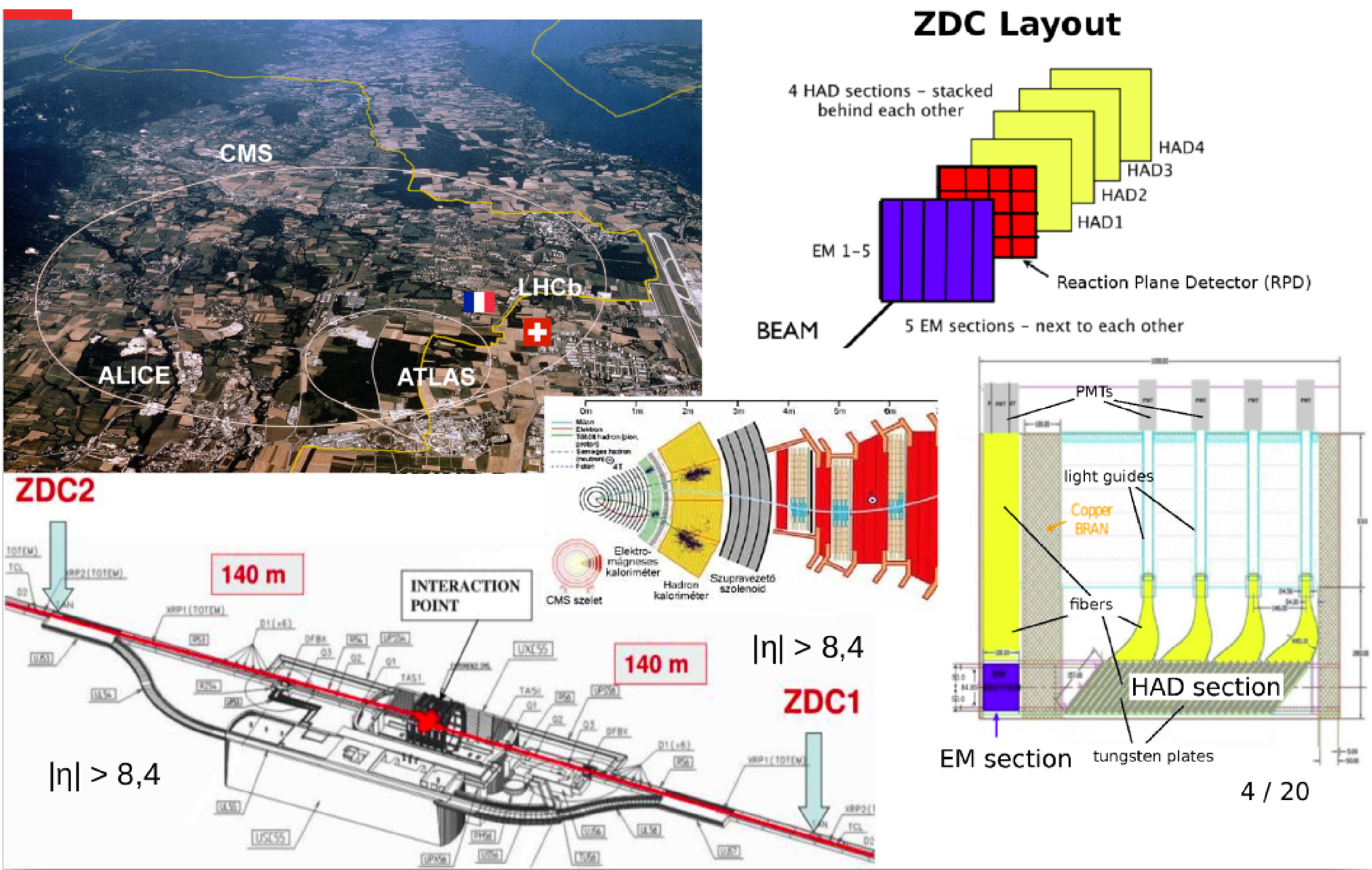


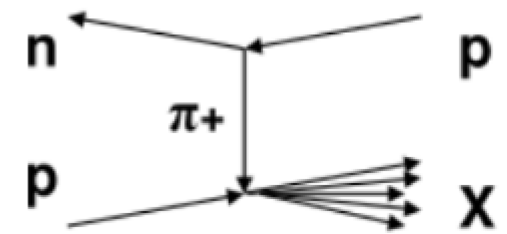
→ could this be measured in the laboratory (at LHC energies)?

- See whether simulations predict measured data well

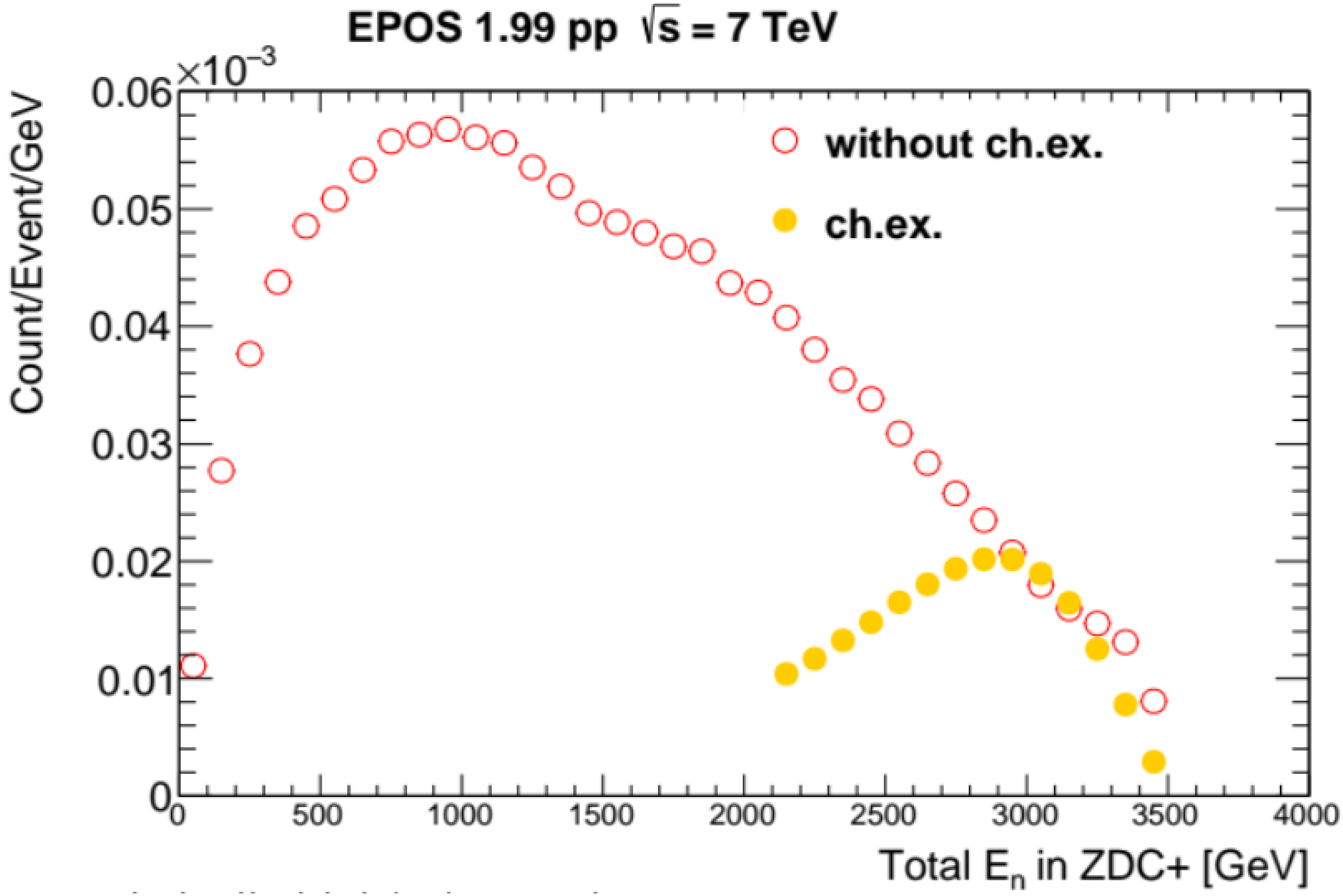
2 / 20

Charge exchange and ZDC





Energy distribution in the ZDC (MC)



Plans: charge exchange

Selection of a charge-exchange-enhanced event sample using the ZDC

Measurement of global event features:

Charged pions (charged particles), η and p_T distributions

Effectively, these are pion-proton collisions, very common in cosmic ray air showers

Muons in the showers: from charged pion decays

Top cited papers from CMS

Top cited CMS physics papers (excluding technical and tuning papers):

1) **Higgs discovery**

2) **Higgs mass (with ATLAS)**

3) **Higgs decay rates and couplings (with ATLAS)**

4) **Higgs at 7 and 8 TeV**

5) **Two-particle correlations in p+p (ridge)**

6) **Higgs mass and couplings**

7) **Higgs searches**

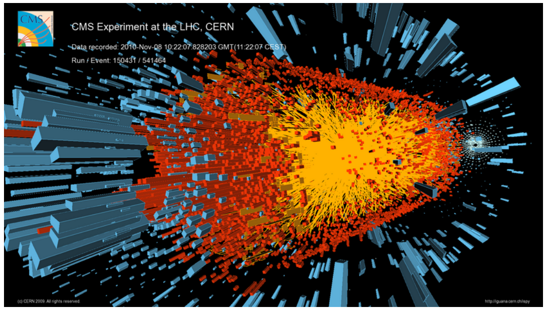
8) **Jet quenching in Pb+Pb**

9) **Two-particle correlations in p+Pb (ridge)**

10) **Higgs properties in the 4-lepton final state**

Summary

- **Global event features are important basic quantities**
- **Often have deep physical relevance**
- **These measurements attract a lot of interest**
- **They have applications in various other fields**
- **Future is still interesting for global event properties!**



THANK YOU FOR YOUR ATTENTION!