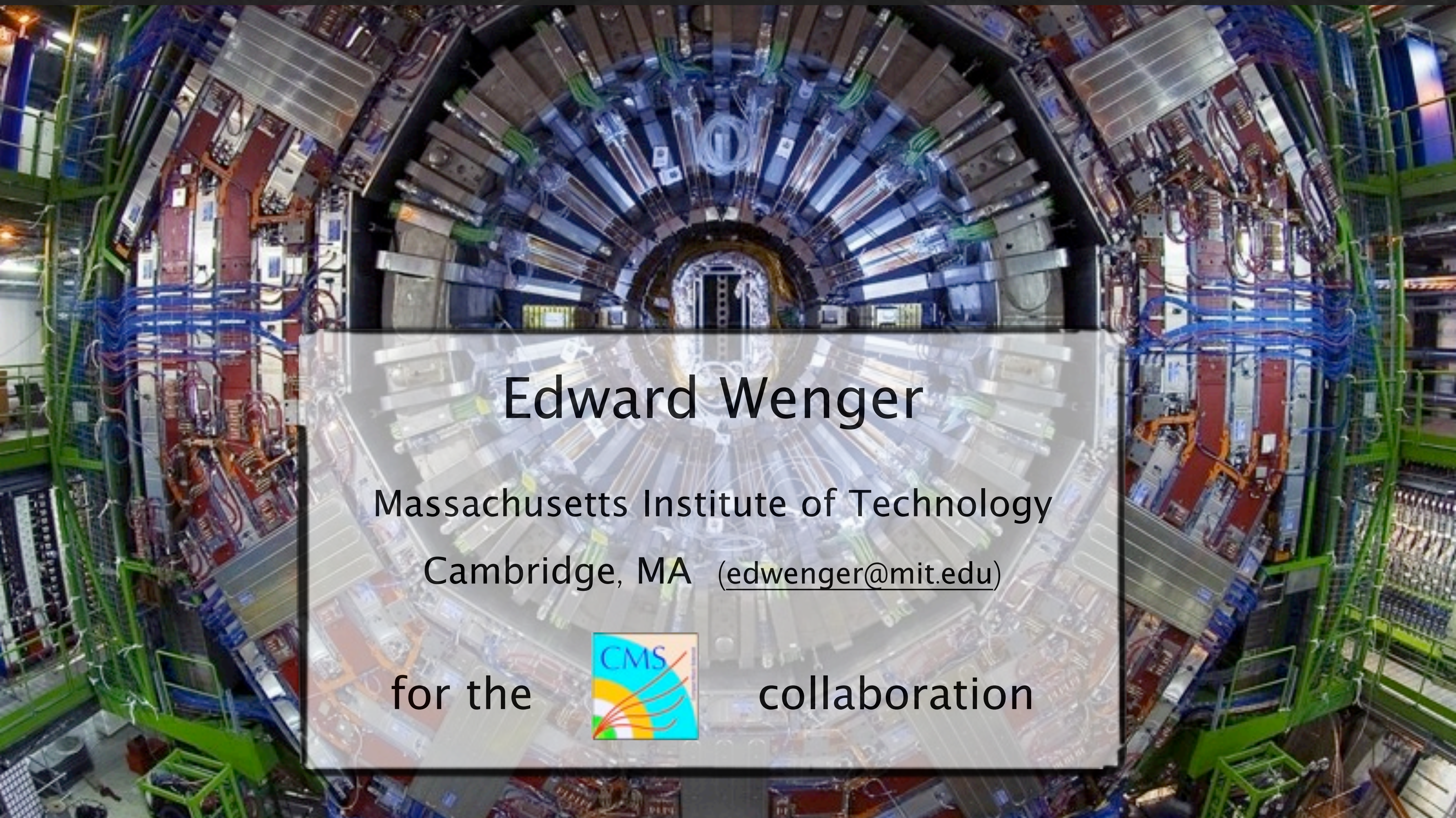
First Results from CMS and Perspectives for Heavy Ions



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for the CMS collaboration

Outline

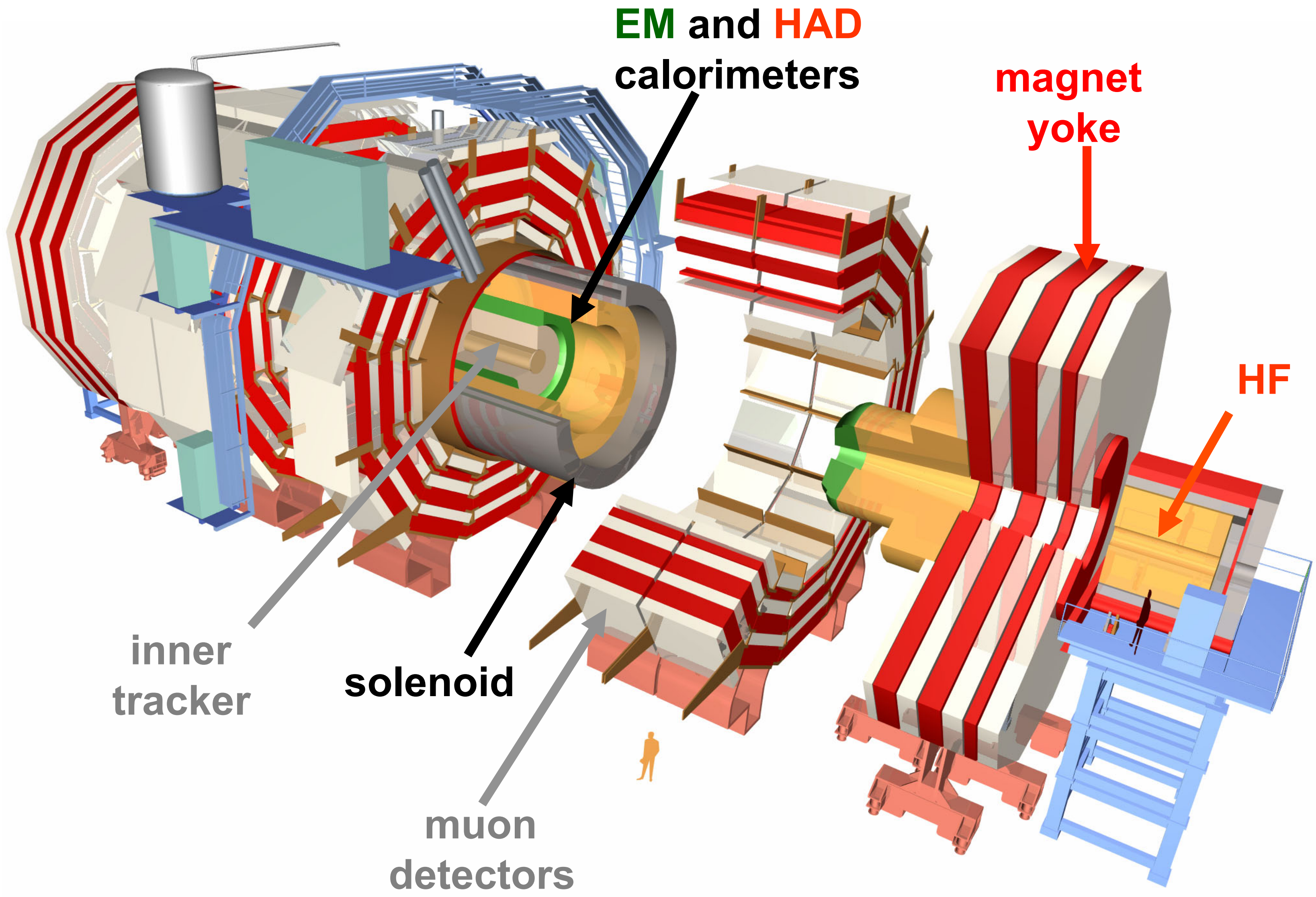
- Exciting QGP properties accessible from first Pb+Pb collisions (0.2 ➔ 2.76 TeV)

Multiplicity *Spectra*

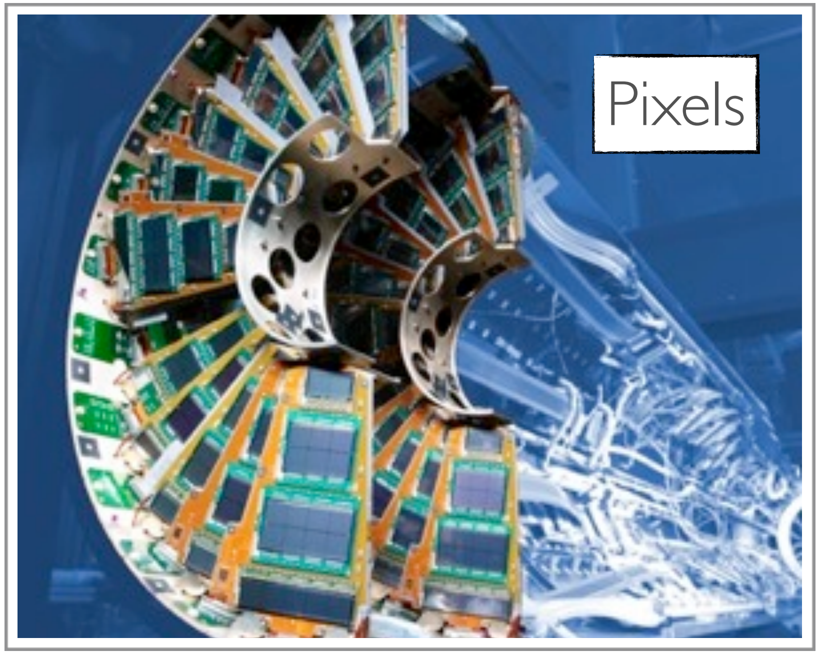
Correlations *Dimuons* *Jets*

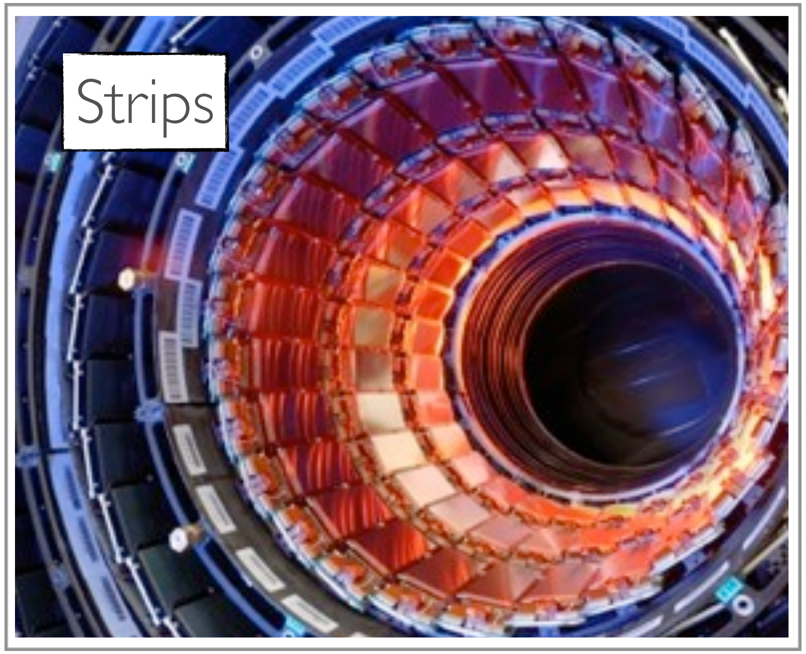
- Analysis of p+p reference measurements
- Capabilities for Pb+Pb measurements

CMS Detector



CMS Tracking System

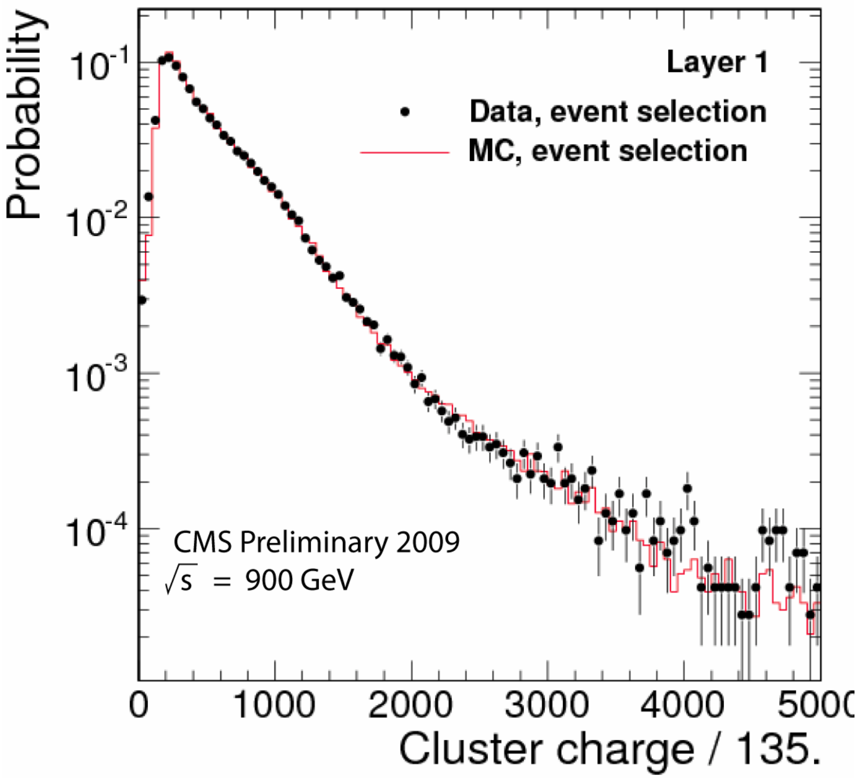




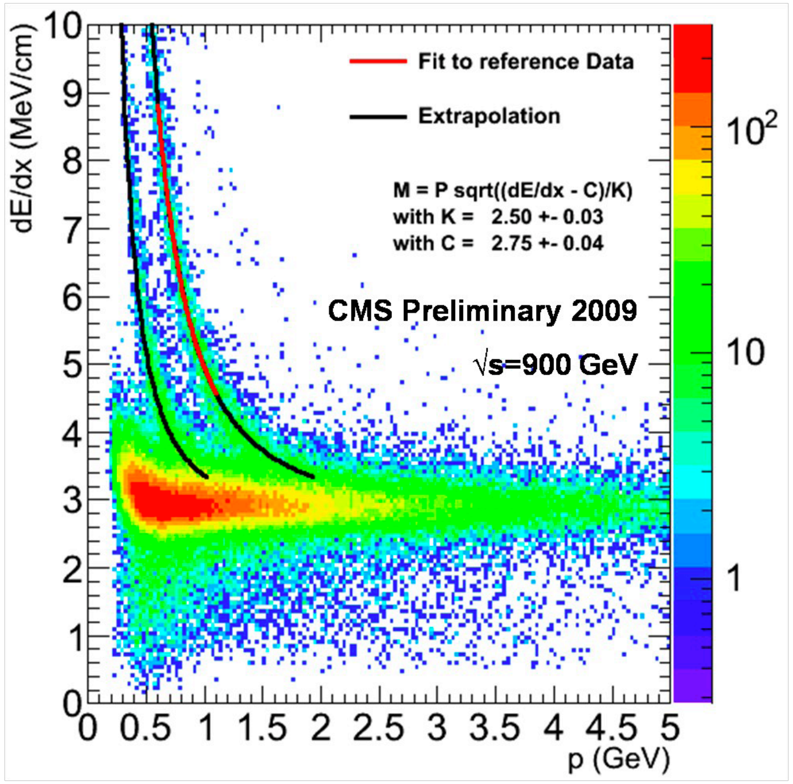
- Inside 3.8T field
- Hit reconstruction efficiency above 99%
- >97% of channels operational
- Coverage over $|\eta| < 2.4$ with ≥ 3 pixel and ≥ 10 strip hits

Tracker Performance

Pixel charge



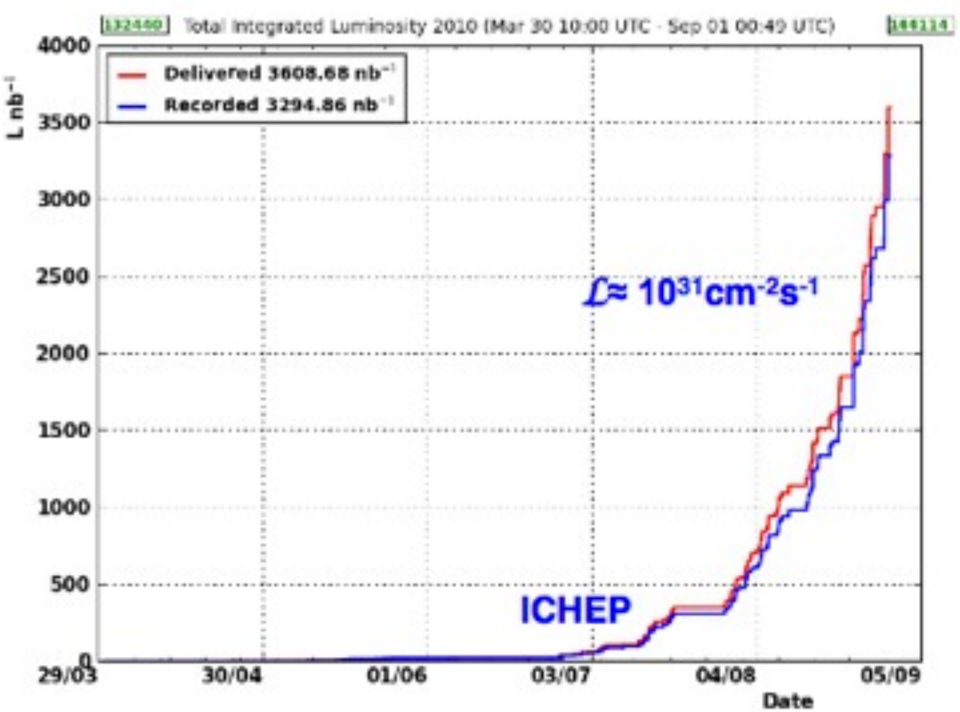
Silicon strip PID



- CMS tracker well-understood after first collisions, showing excellent agreement with simulations.

QCD studies with CMS

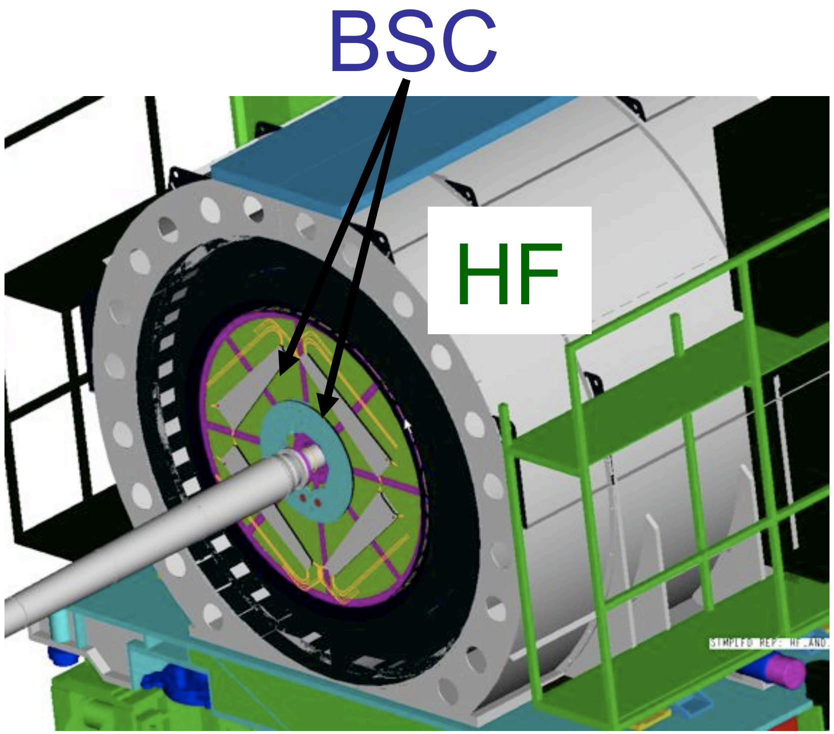
Integrated luminosity at 7 TeV ~ 3.3 pb^{-1}



- p+p collisions at 0.9, 2.36, and 7 TeV
- First measurements performed with 10,000 - 200,000 minimum bias events

Minimum bias event selection

- Trigger:
  - Single hit BSC
  - In-time with BPTX
- Offline:
  - 1 tower with >3 GeV in each HF (forward calo)
  - Beam-halo rejection from BSC timing
  - Vertex from pixel track(s)

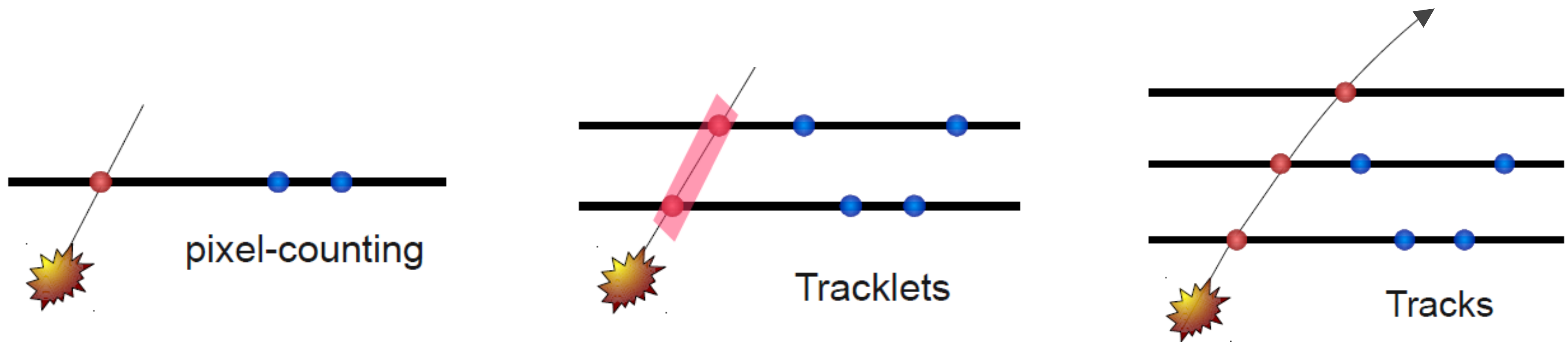


BSC: $3.23 < |\eta| < 4.65$

HF: $2.9 < |\eta| < 5.2$

1. Charged multiplicity

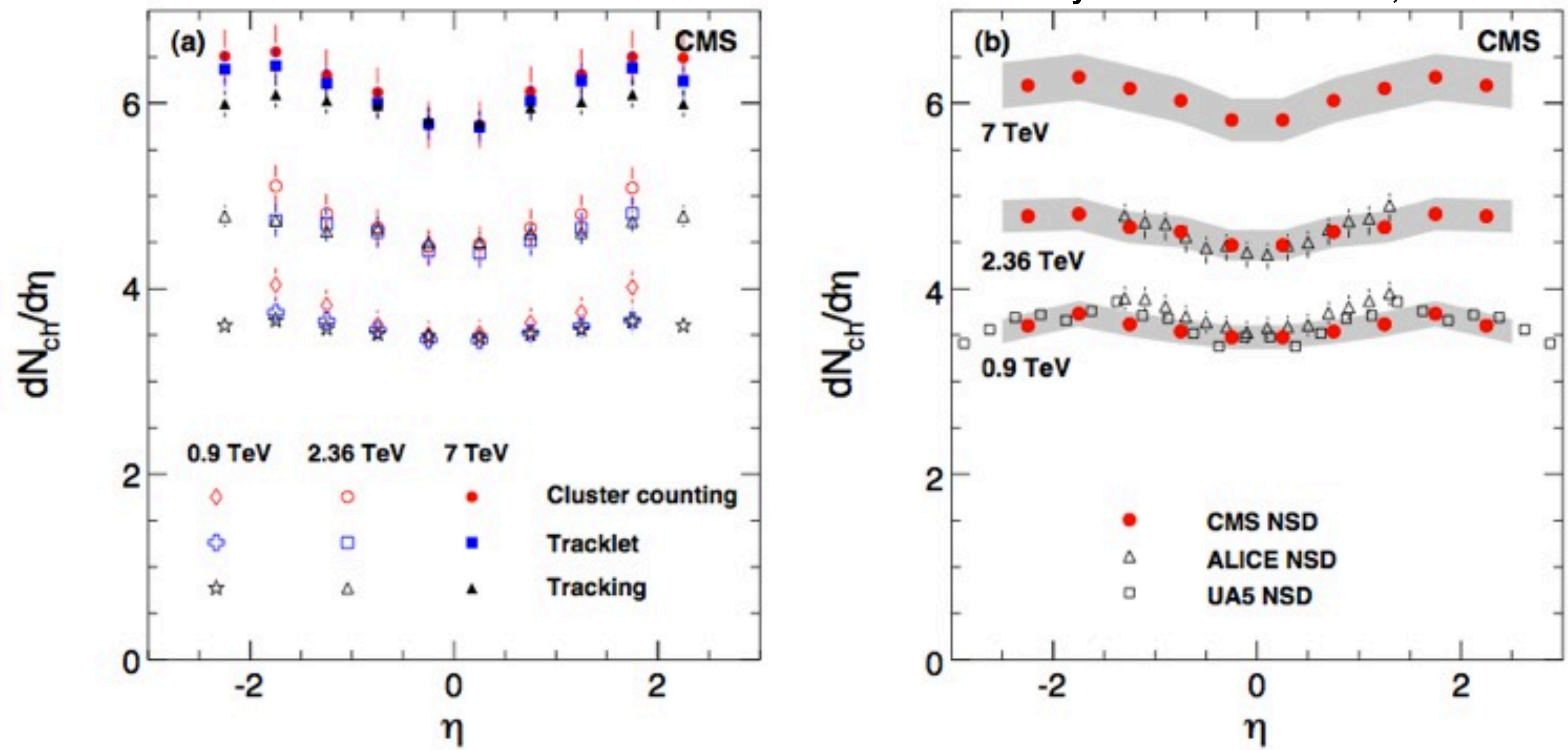
- Three analysis techniques:



- Sensitive to different systematic effects

$dN_{ch}/d\eta$ results

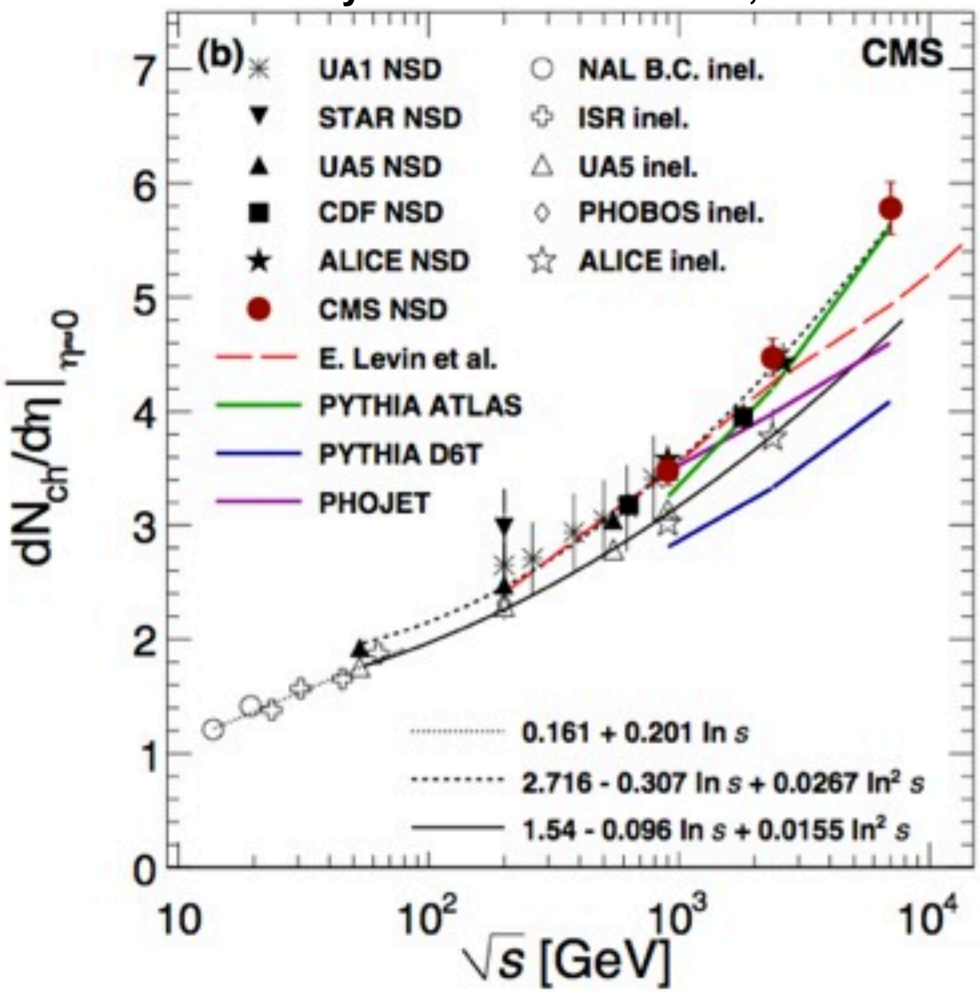
Phys.Rev.Lett.105:022002,2010

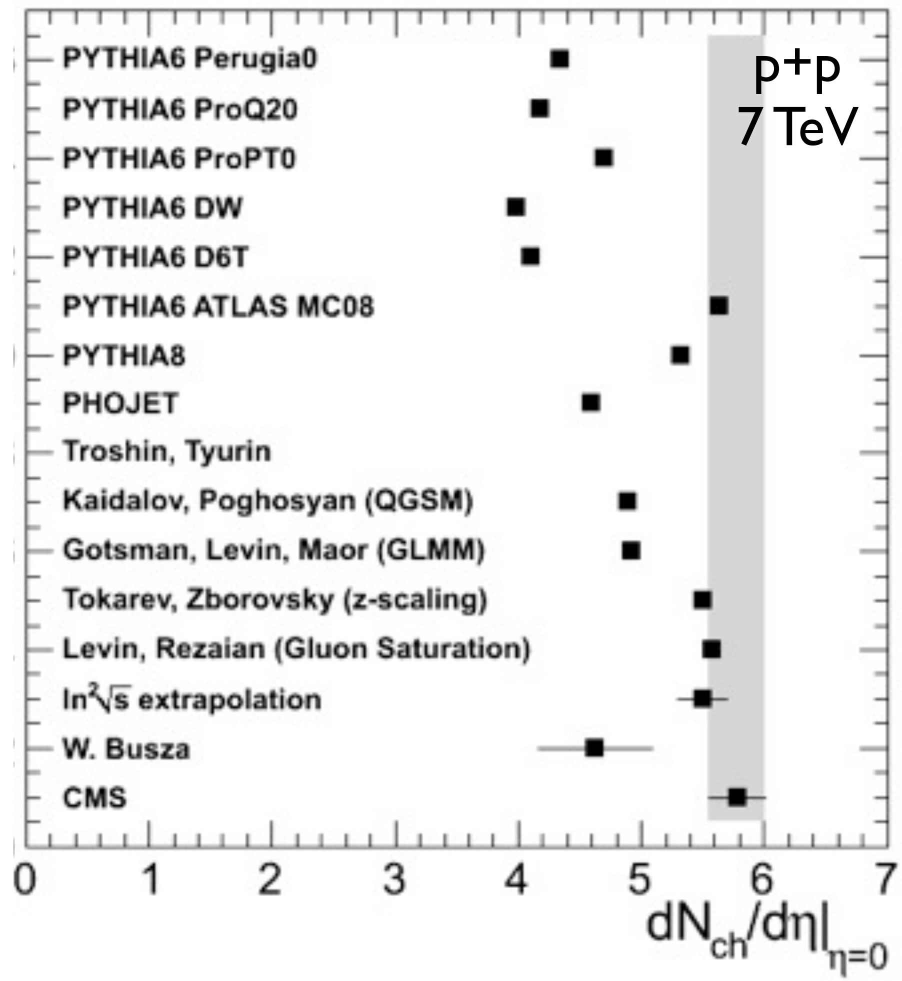


Results from three methods weighted by uncorrelated errors, averaged, and symmetrized

Collision energy dependence

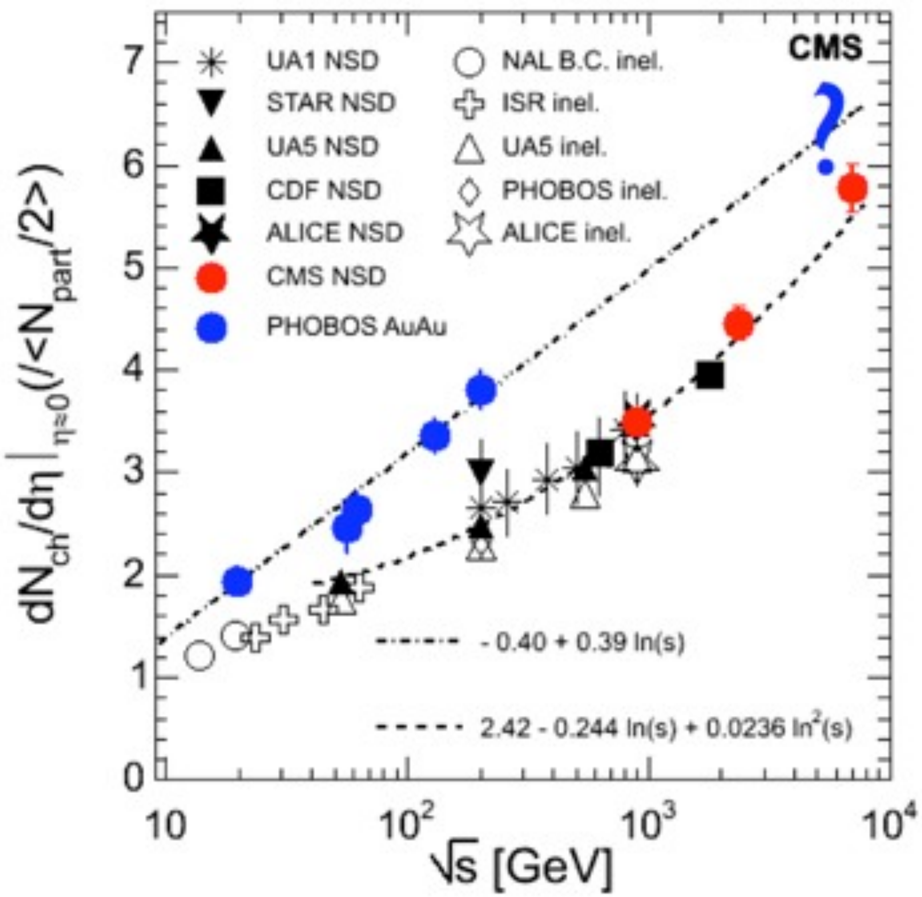
Phys.Rev.Lett.105:022002,2010

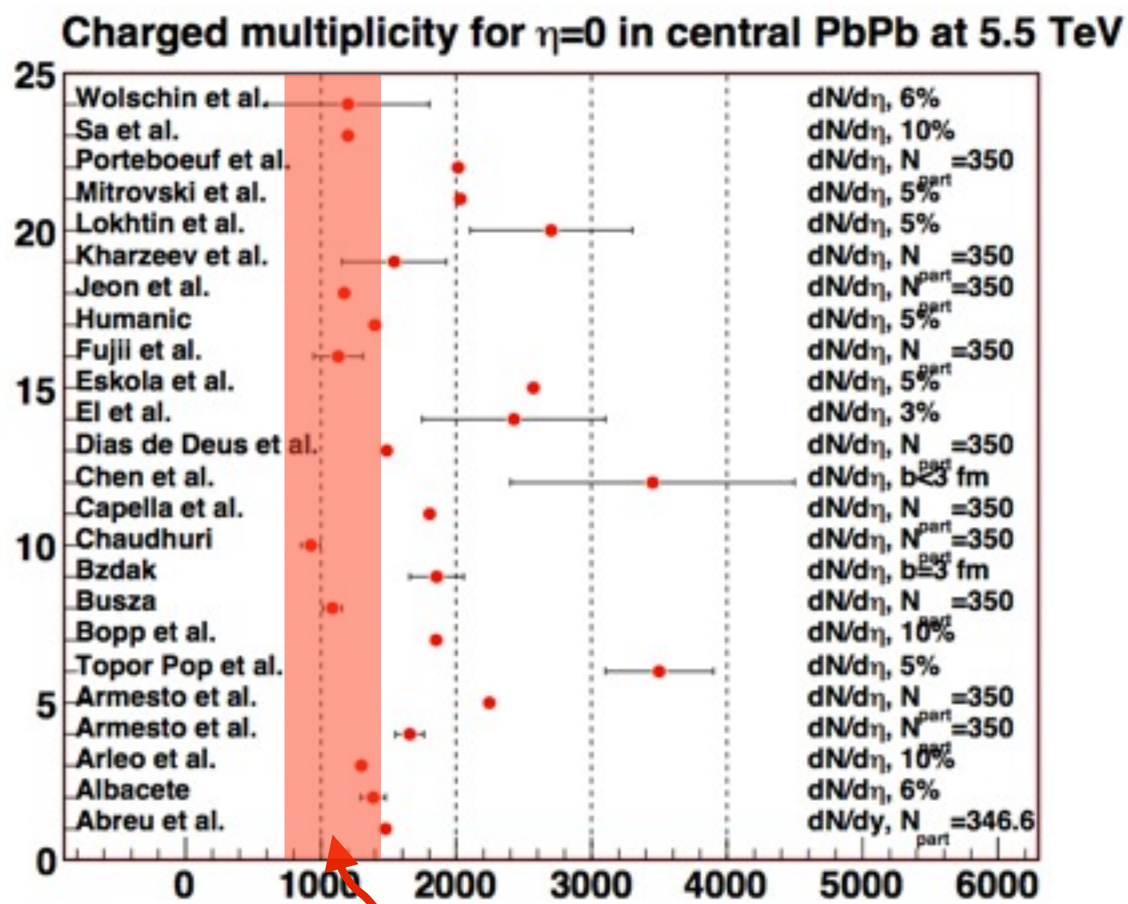




- Charged multiplicity grows more quickly with energy than predicted by most models.

Implications for Pb+Pb

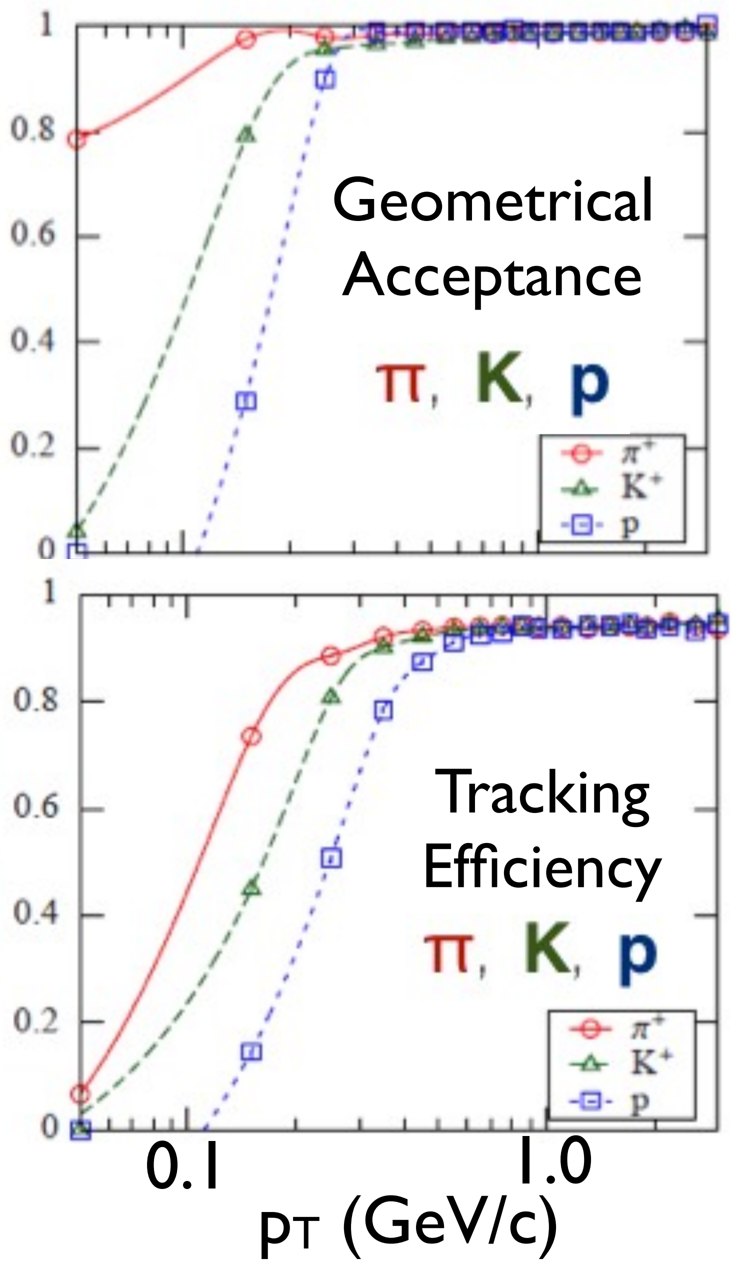




N. Armesto (arxiv:0903.1330)

- Steeper-than-expected energy dependence in p+p suggests that lowest Pb+Pb estimates are unlikely.

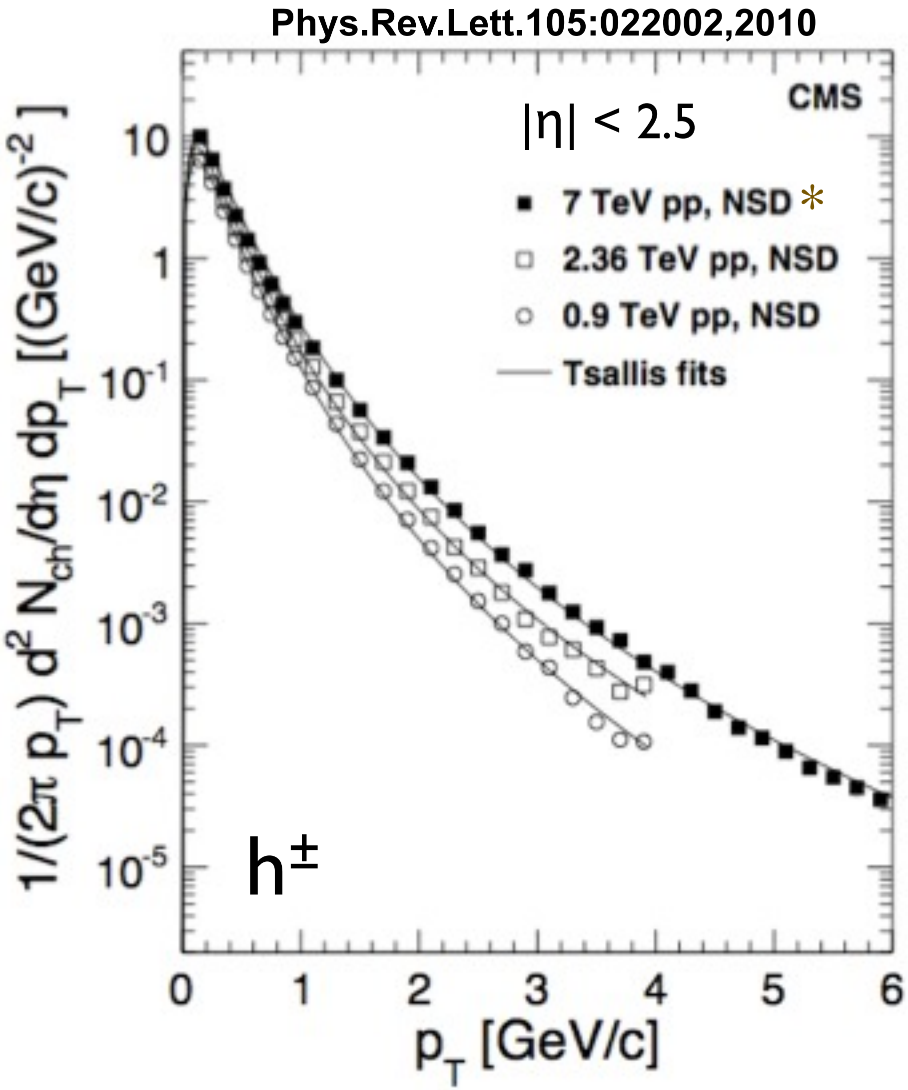
2. Charged p_T spectra



p+p tracking
Excellent performance
even at very low momentum
p_T ~ 150 MeV/c

Pb+Pb tracking
Combination of pixel triplet tracks (p_T=0.2-3.0 GeV/c) and full tracks including the strip layers (p_T=0.9-100s of GeV/c)

Charged hadron dN/dp_T results



- Results well-described by Tsallis fit function
  - Exponential (low-p_T)
  - Power-law (high-p_T)
- As expected, spectrum is "harder" at higher energy

* New preliminary CMS result out to 140 GeV/c !!

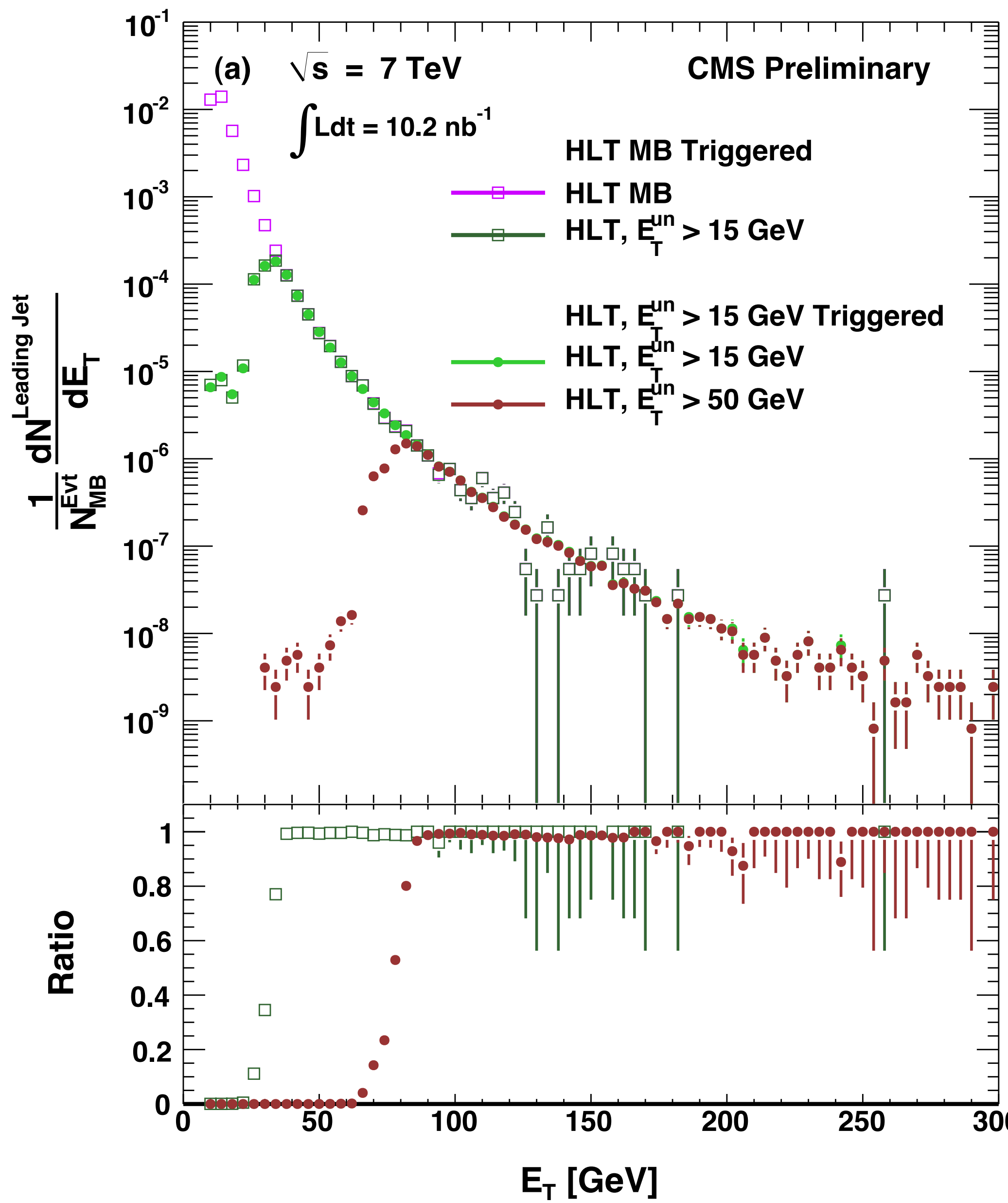
Strategy for high-p_T spectra

- Events are classified by the E_T of the leading anti-k_T calojet (R=0.5) using MC-based jet energy corrections
- Extend p_T-reach of spectra with HLT_Jet15U sample.
- Determine normalization with respect to pre-scaled MinimumBias sample

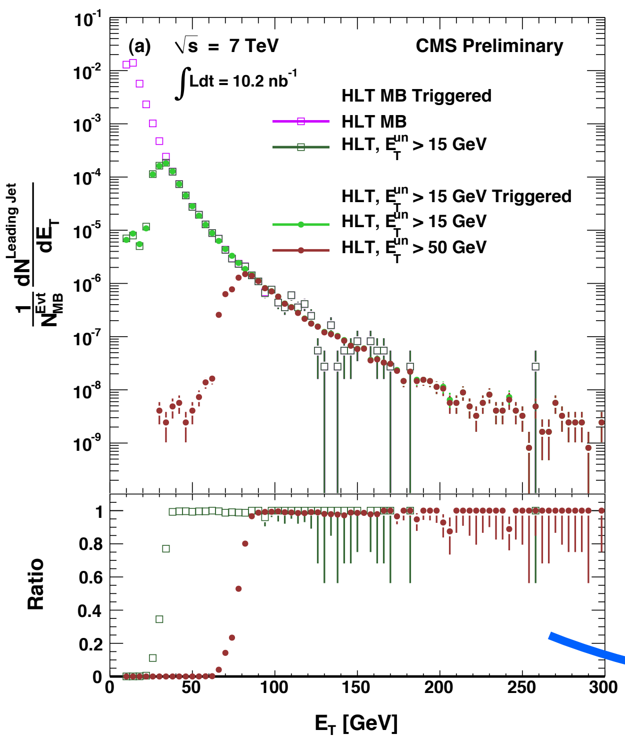
Leading-jet E_T Distribution

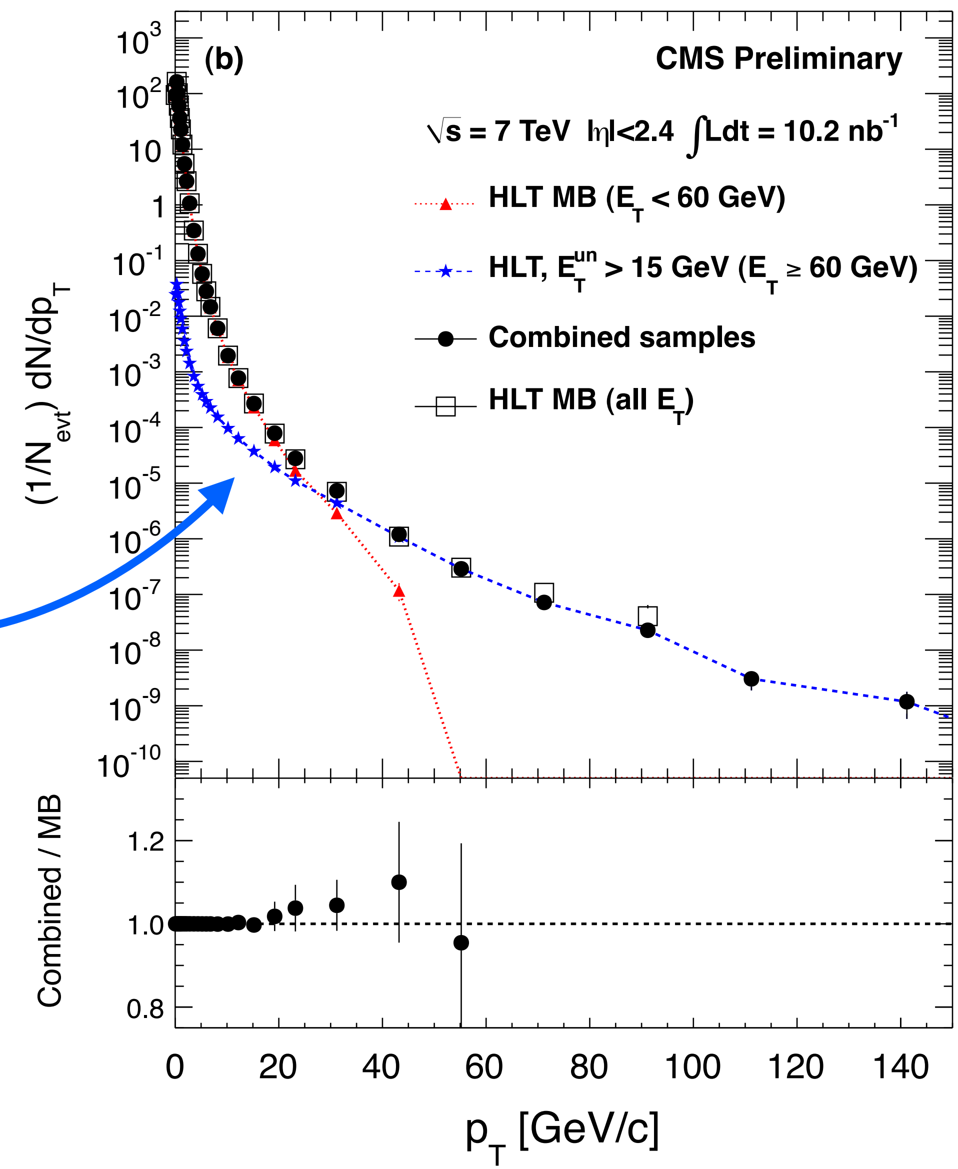
The leading-jet distribution for the Jet15U-triggered sample is normalized per MB event by matching the integral above E_T=60 GeV with the distribution for the pre-scaled MinBias sample.

HLT_Jet15U is >99% efficient above ~40 GeV



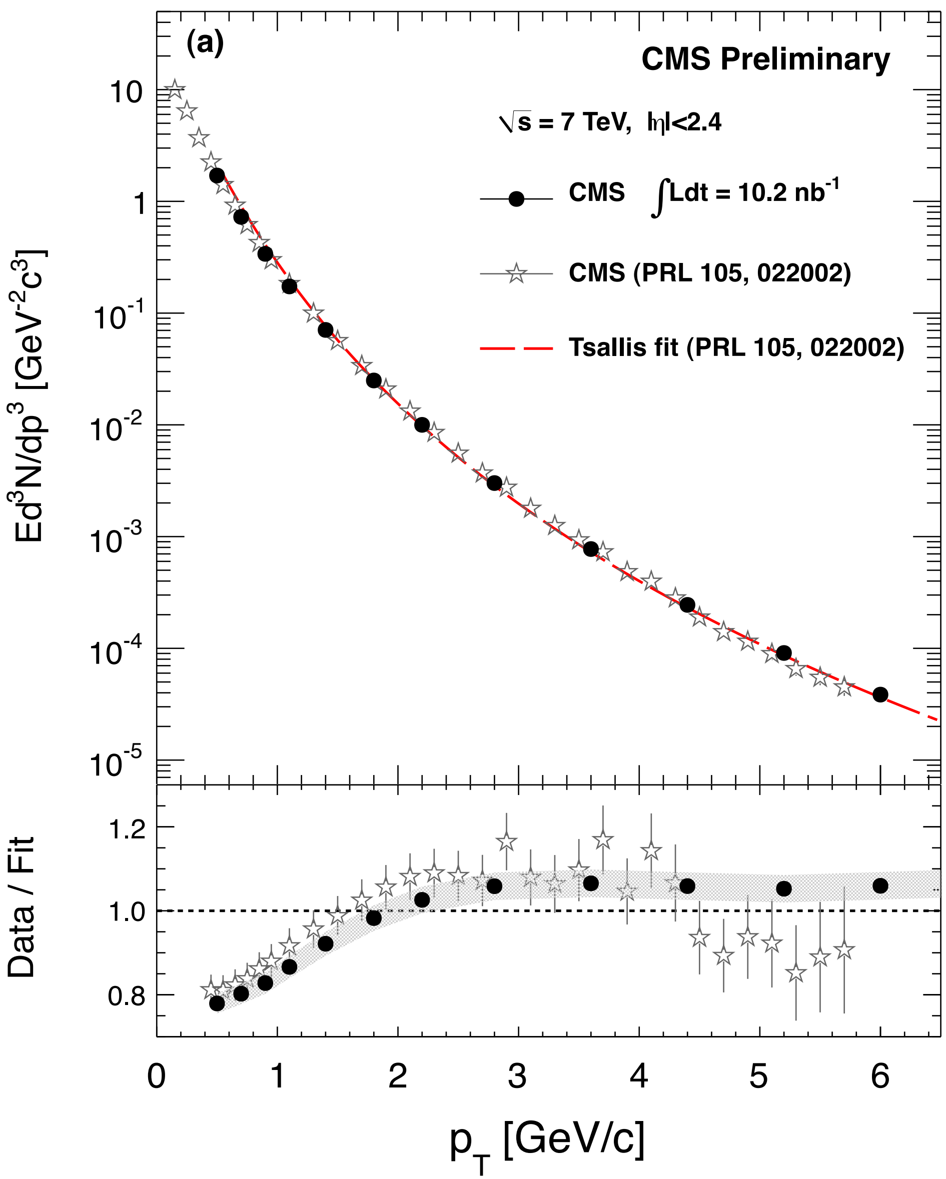
Extending Reach with Jet Trigger





Same normalization applied to p_T spectra from HLT_Jet15U triggered sample

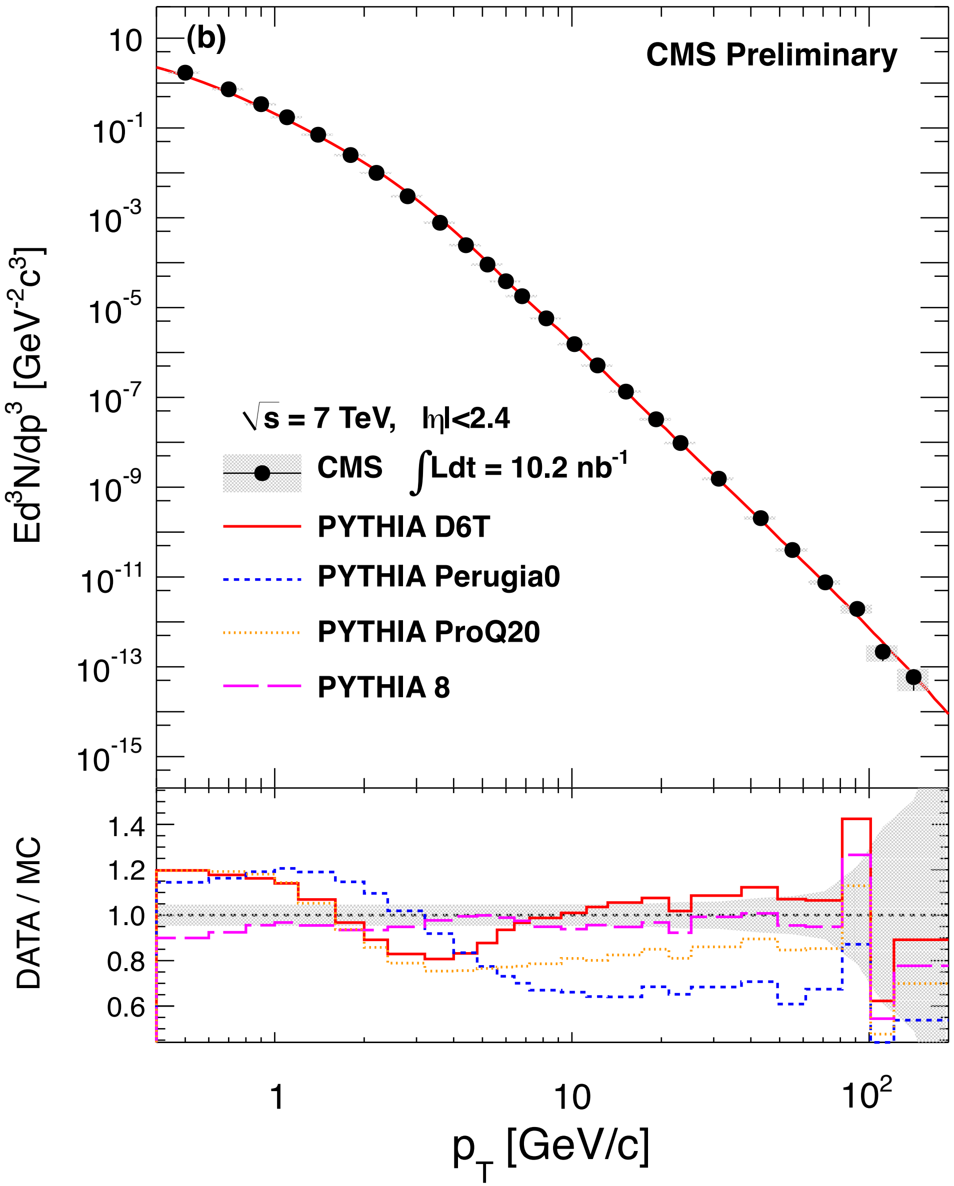
Comparison to published result



Consistent within statistical + systematic errors

3.1% band excludes the contribution from the common event selection

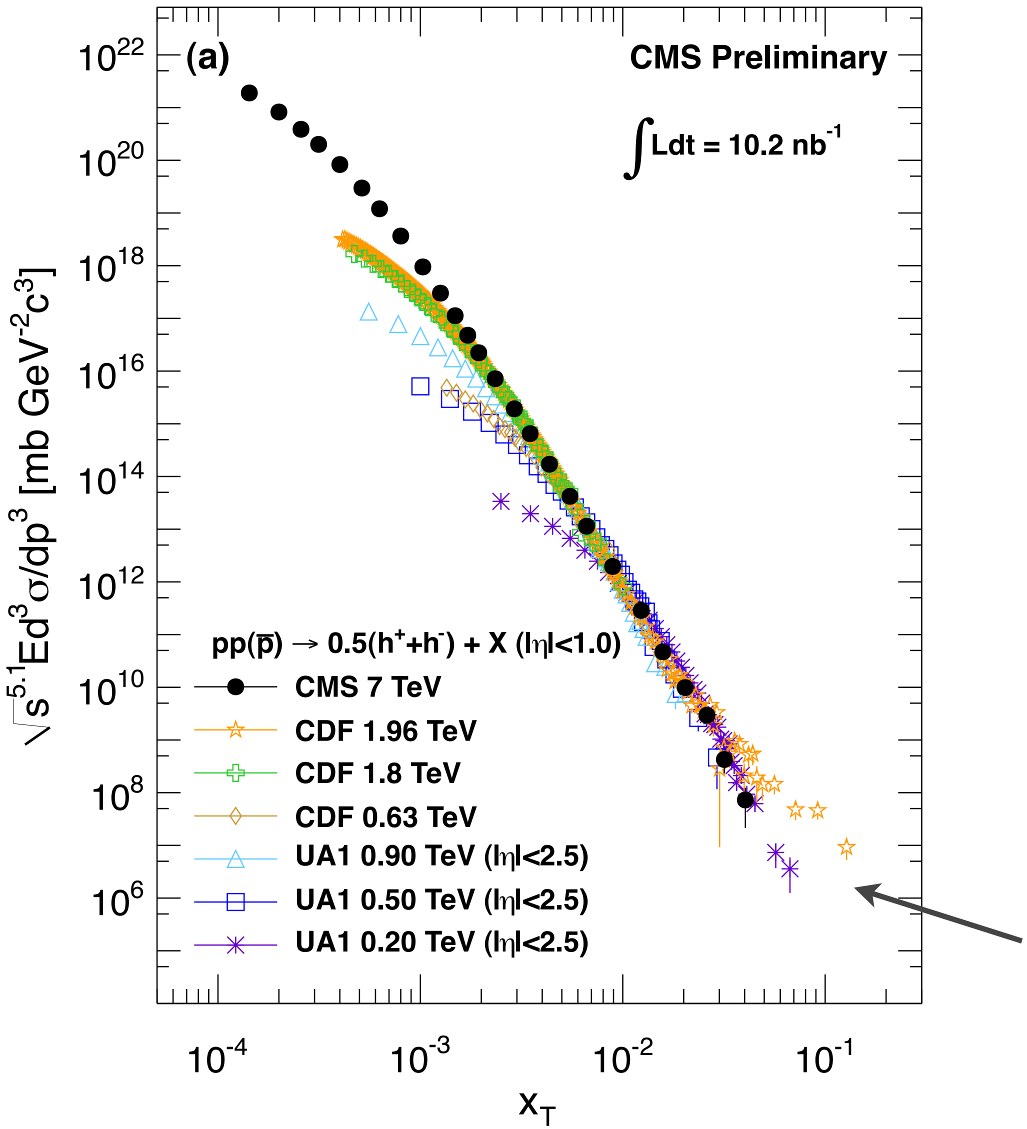
Comparison to generator tunes



Factor of ~2 between different generator tunes at high p_T.

Most consistent with PYTHIA-8 over the full p_T range

2.76 TeV Reference



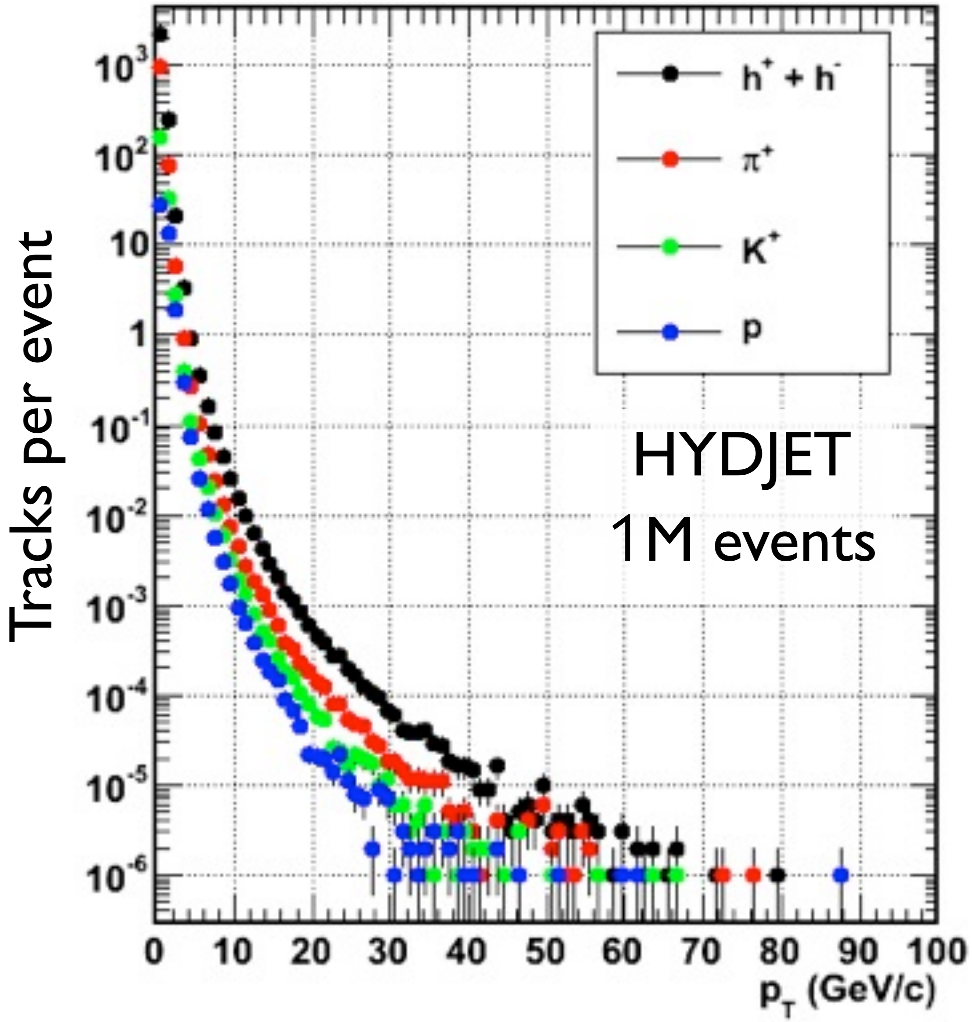
Extend 0.9 TeV measurement to p_T ~ 20 GeV

Direct interpolation between three energies at low p_T

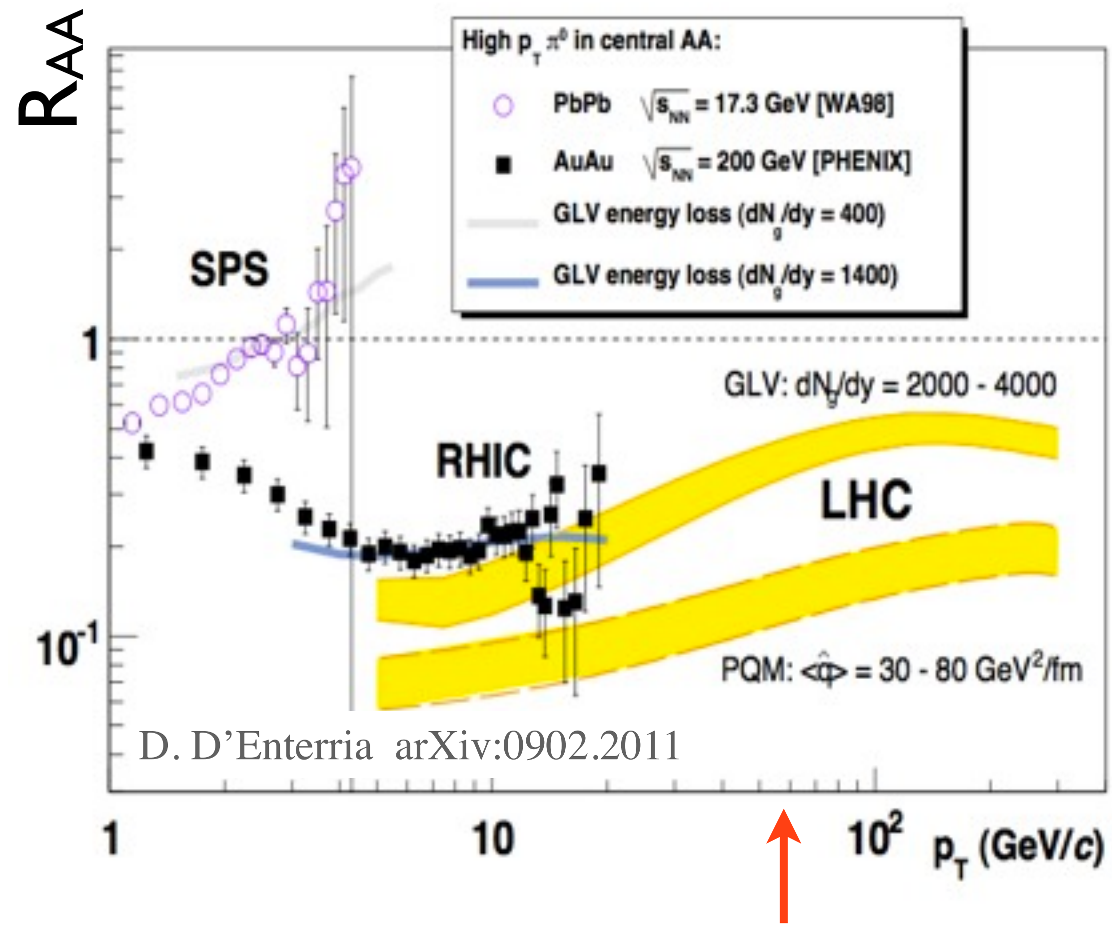
x_T-scaling and/or tuned NLO for high-p_T 2.76 TeV spectra interpolation

How to control 'fakes' down by 14 orders of magnitude? Verify calo energy deposit.

Predictions for Pb+Pb Run-1



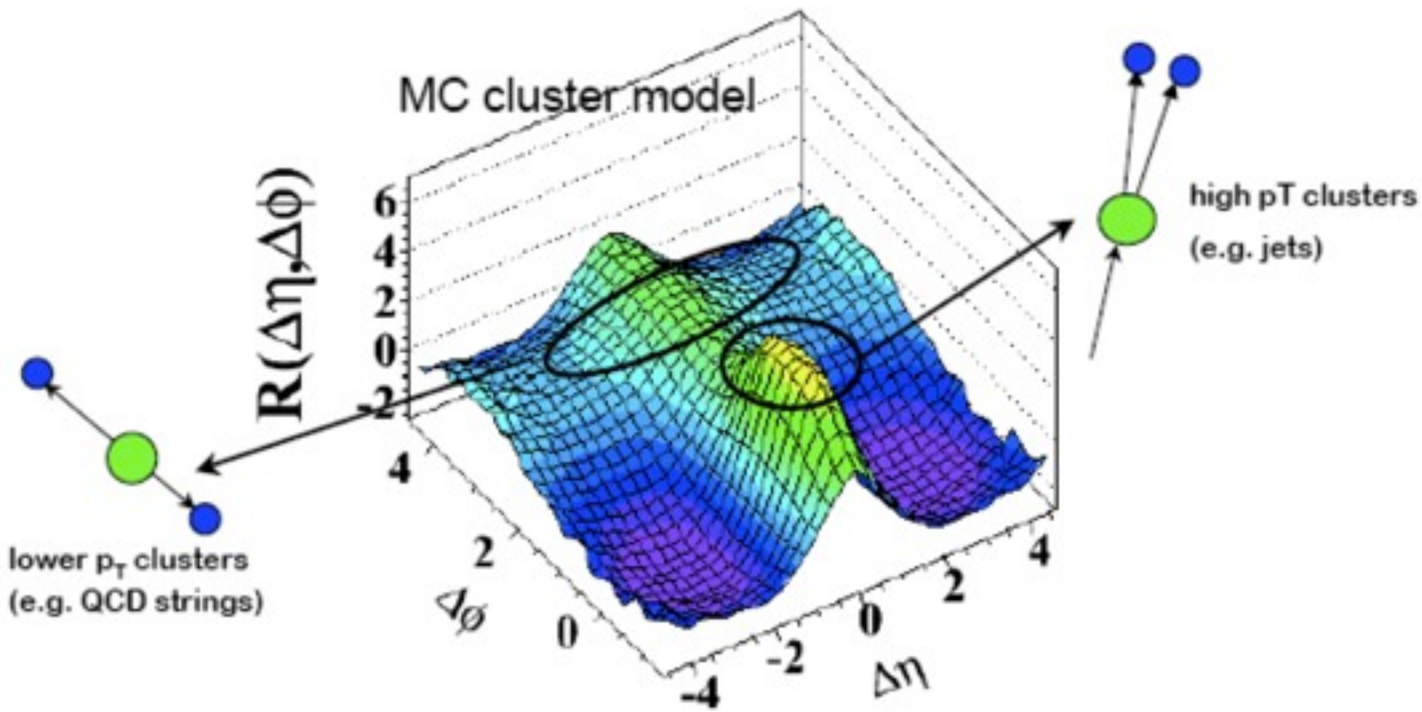
High-p_T suppression predictions



Run-1 p_T-reach: ~0.2-50 GeV/c with ~25M events

3. Two-particle correlations

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

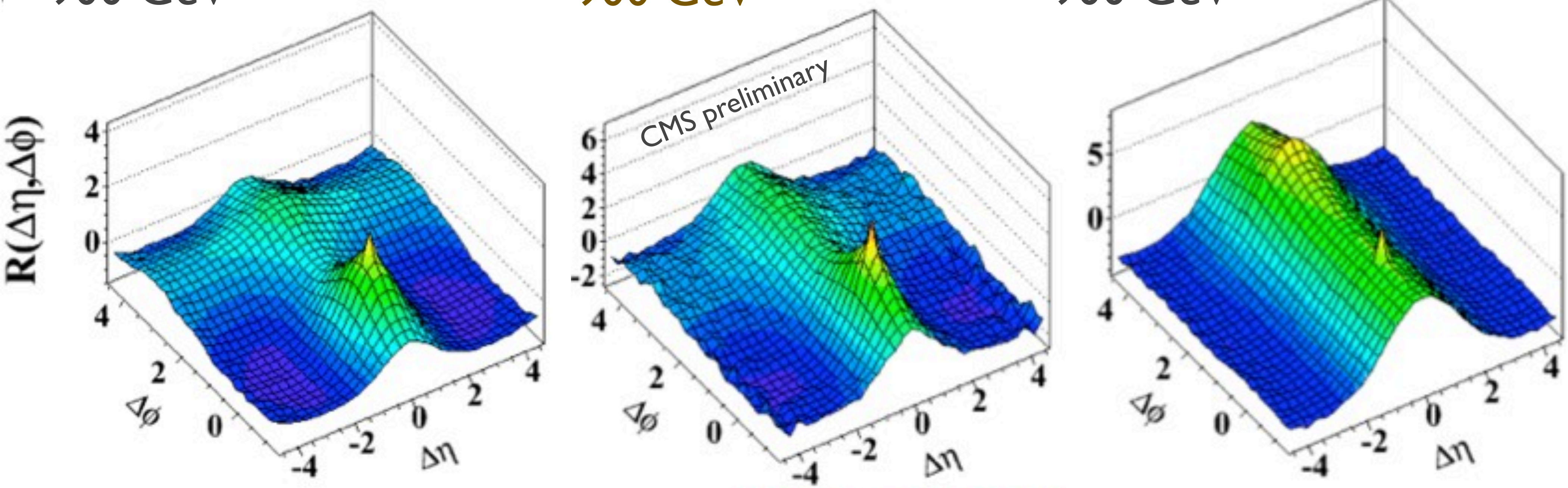


Correlations in particle production related to hadronization process

Comparison to models

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

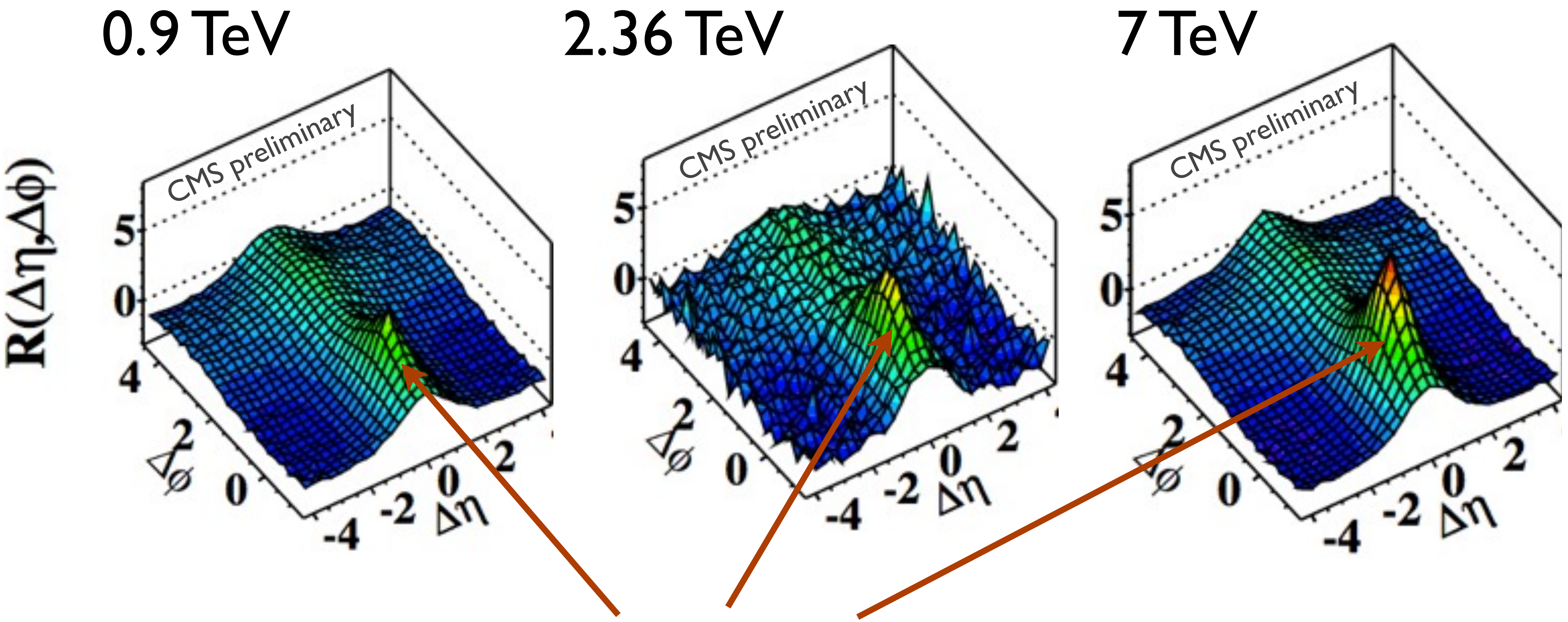
PYTHIA 900 GeV | CMS data 900 GeV | HERWIG++ 900 GeV



"jet-like" ⟷ "string-like"

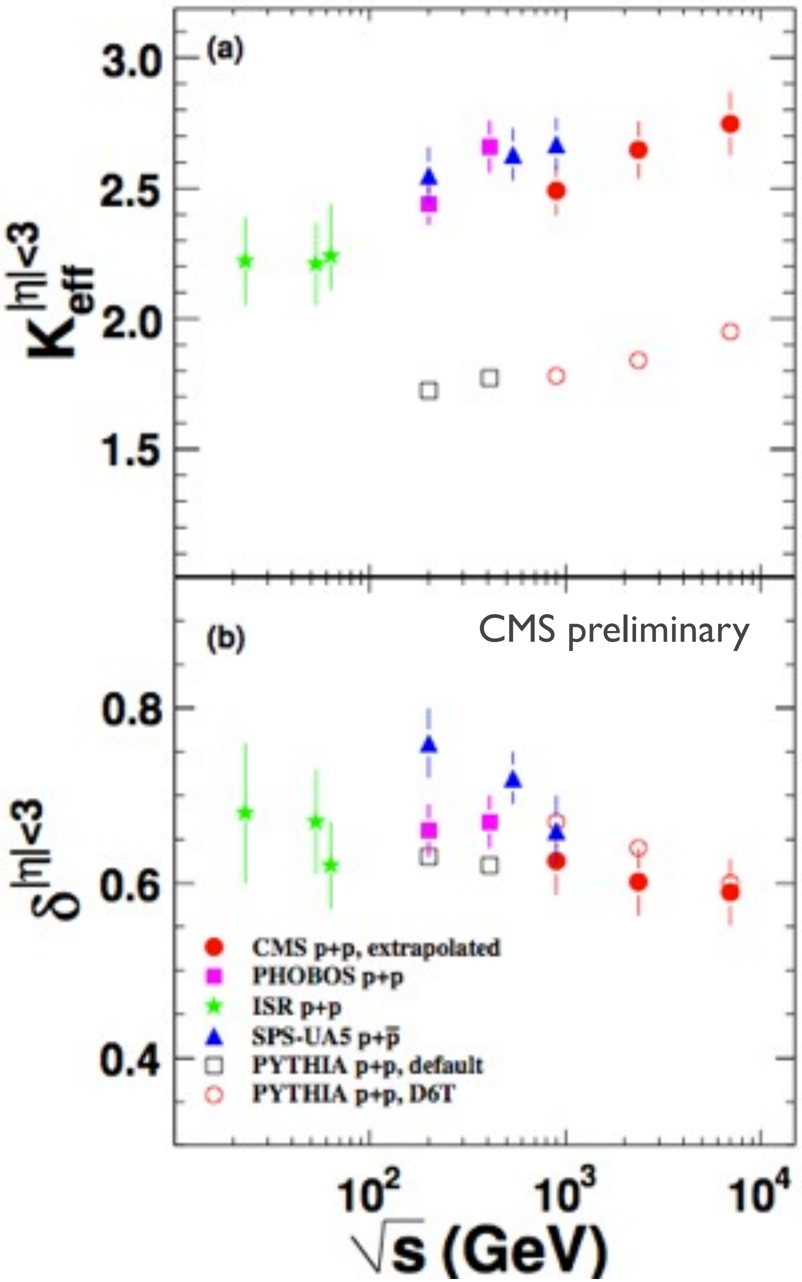
Collision energy dependence

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



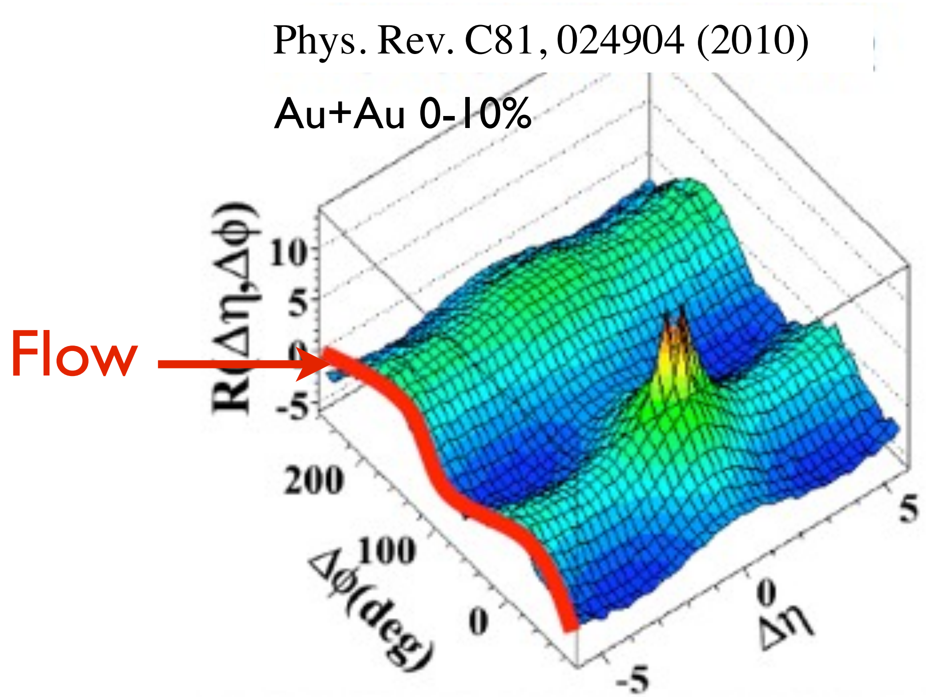
Rapid growth of "jet-like" component with $\sqrt{s}$

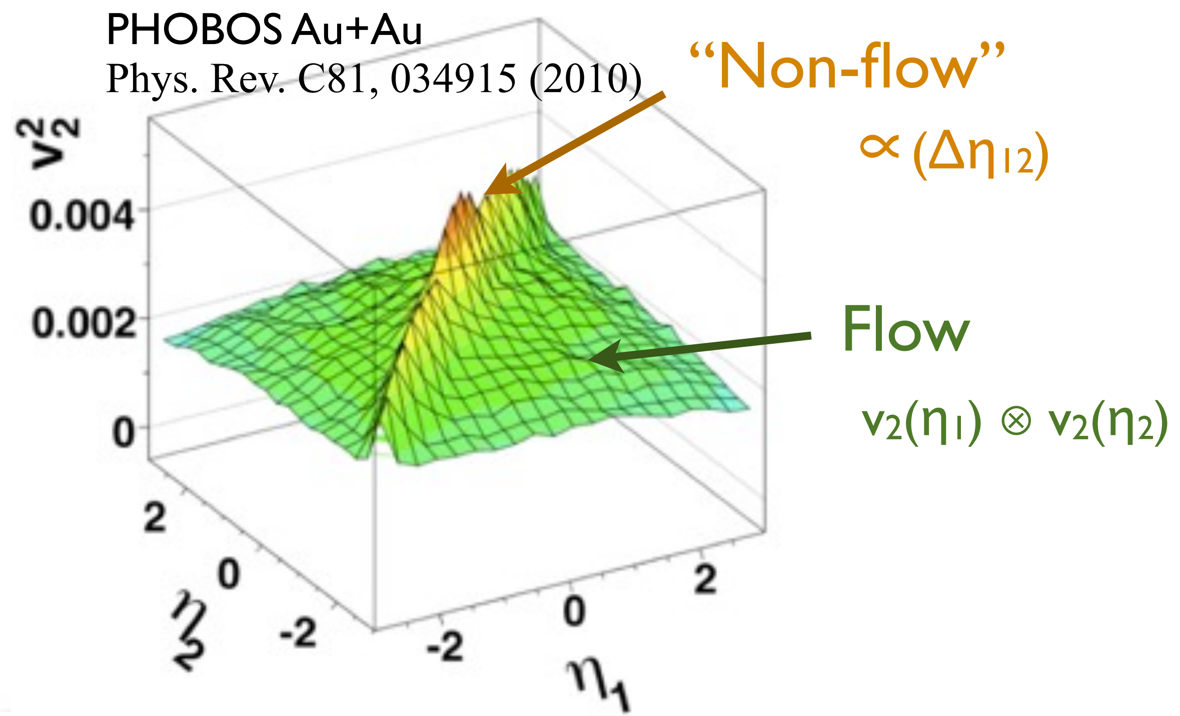
Energy dependence (cont'd)



- Effective "cluster size" consistent with trend, significantly in excess of PYTHIA
- "Cluster width" similar to lower energy measurements

Correlations in Pb+Pb

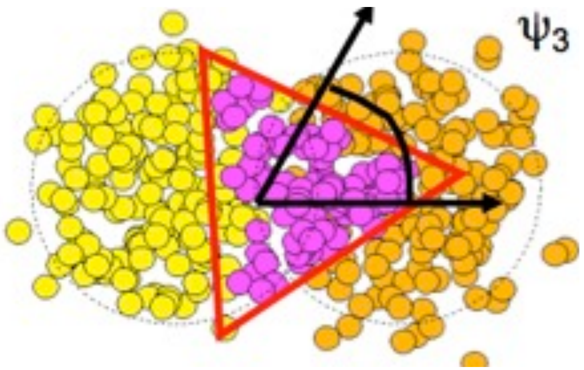




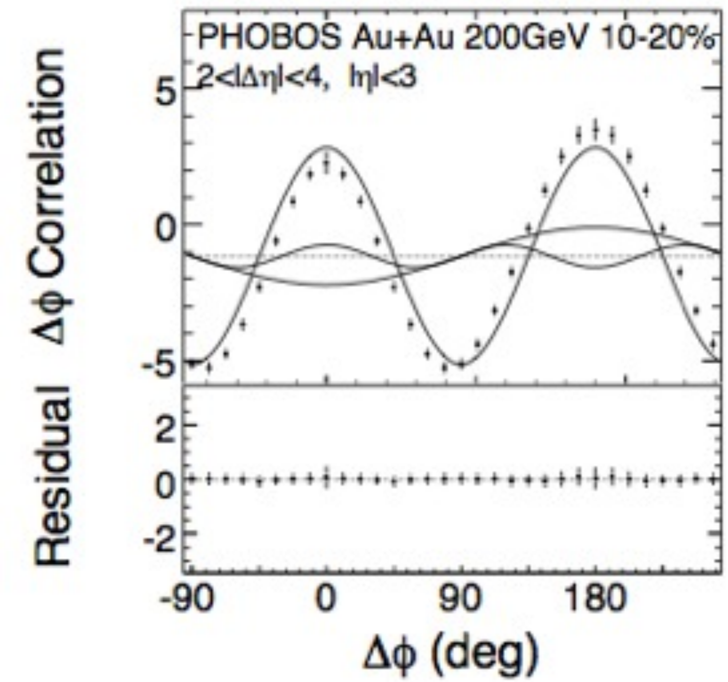
- Large Δη acceptance of CMS tracker advantageous for exploring HI physics
- Away from the jet peak, Fourier decomposition easier

Fourier decomposition

Initial State Fluctuations

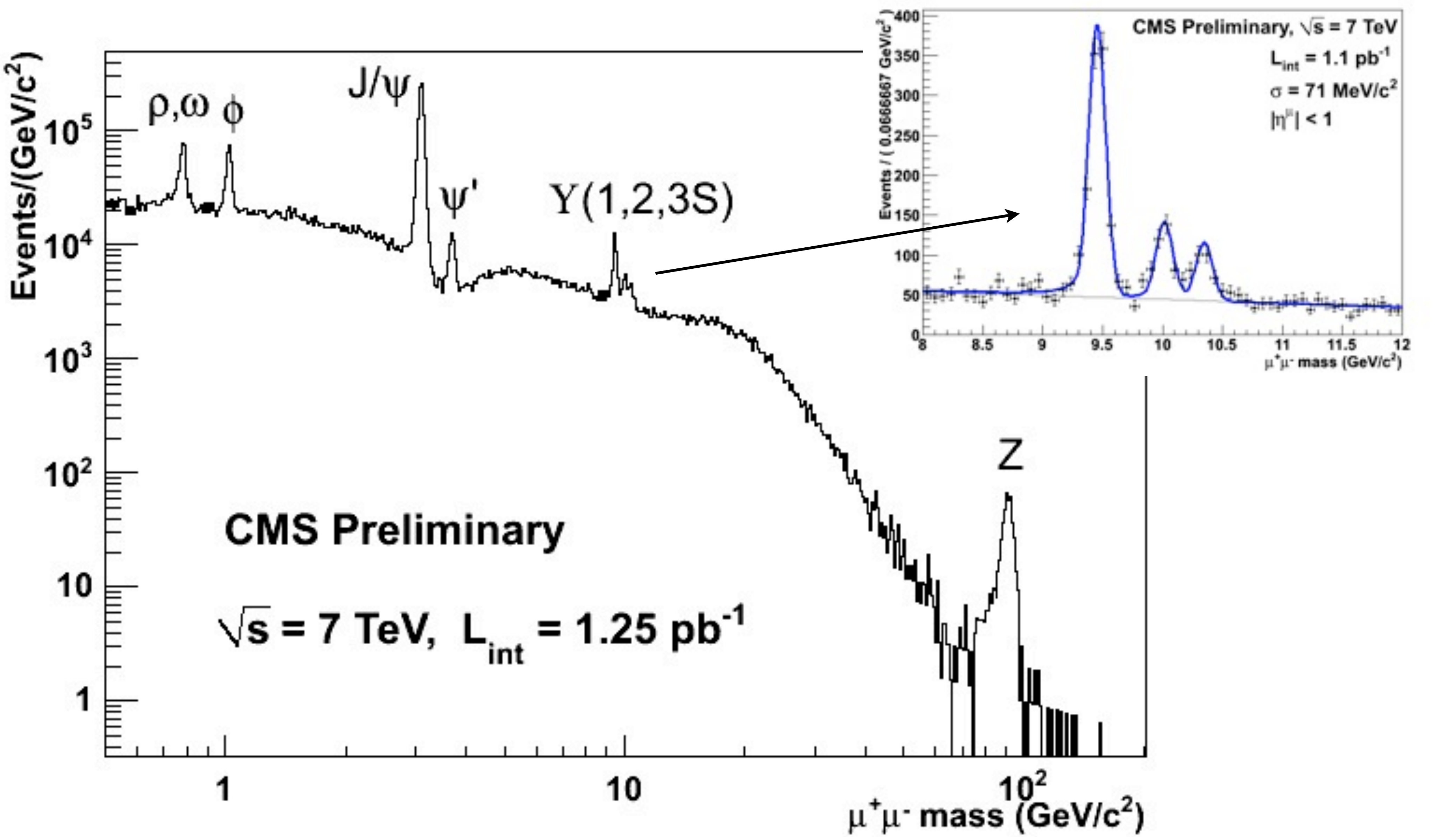


Alver and Roland. PRC 81, 054905 (2010)



- Combination of good track reconstruction and large rapidity coverage will enable more detailed studies of e.g. triangular flow vs. p_T

4. Dimuons in CMS



Expected Statistics

For 1-10 μb^{-1} in Run-1:

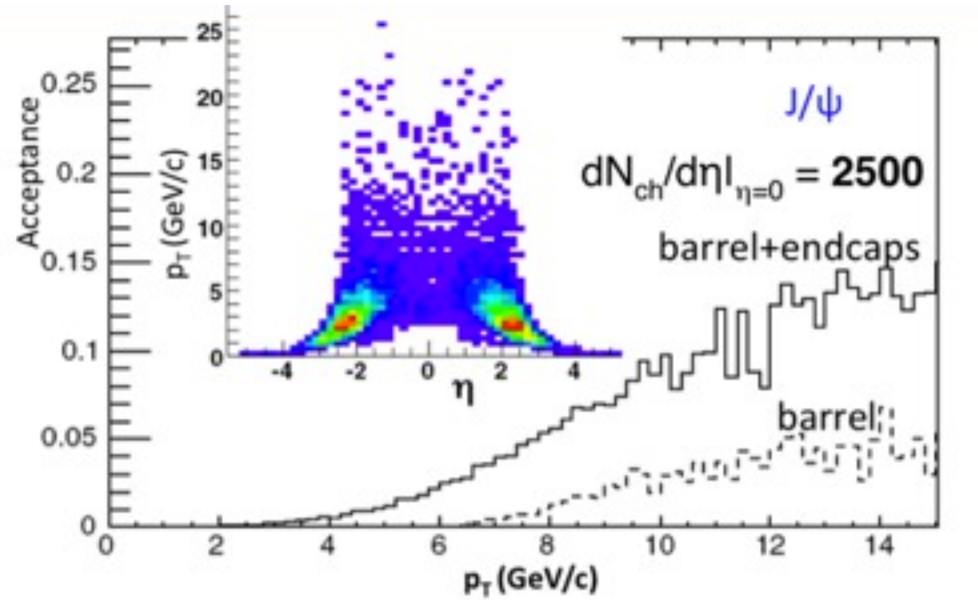
250(2500) J/ψ, S/B ~1.12, S/√(S+B) ~10 (to 30)
- Suppressed at RHIC but understanding is not clean. Regeneration?

30(300)Υ, but S/B ~ 0.12, S/√(S+B) ~1 (to 4)
- CMS resolution allows separation of the bound states
- Sensitivity to different melting temperatures?

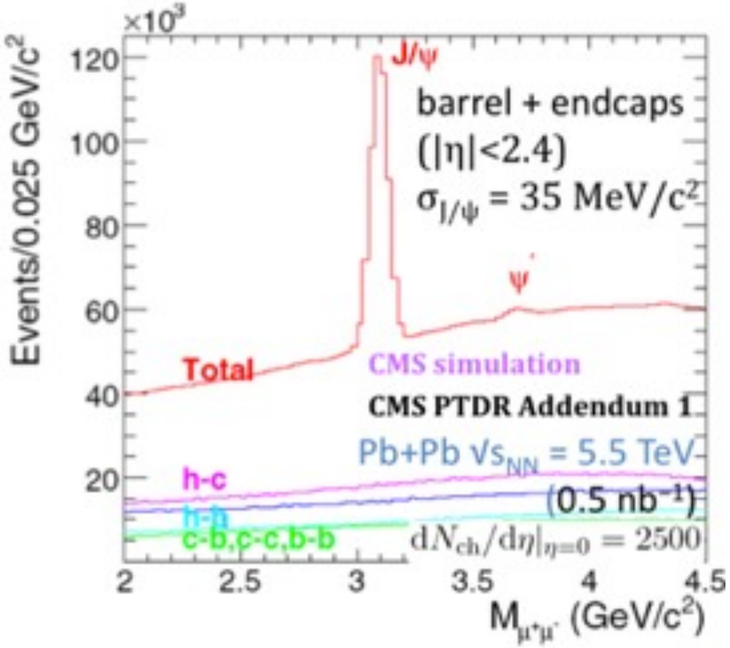
$|\eta| \approx 0$, $\sigma_{mass(\Upsilon)} \approx 54$ MeV
$|\eta| < 2.4$, $\sigma_{mass(\Upsilon)} \approx 90$ MeV

10(100) Z^0 expected, **S/B~20**, S/(√S+B) ~ 3 (to 10)
- First weak boson measurement in heavy ion !
- Easiest in terms of S/B. Sensitive to PDF. Towards a Z-jet analysis

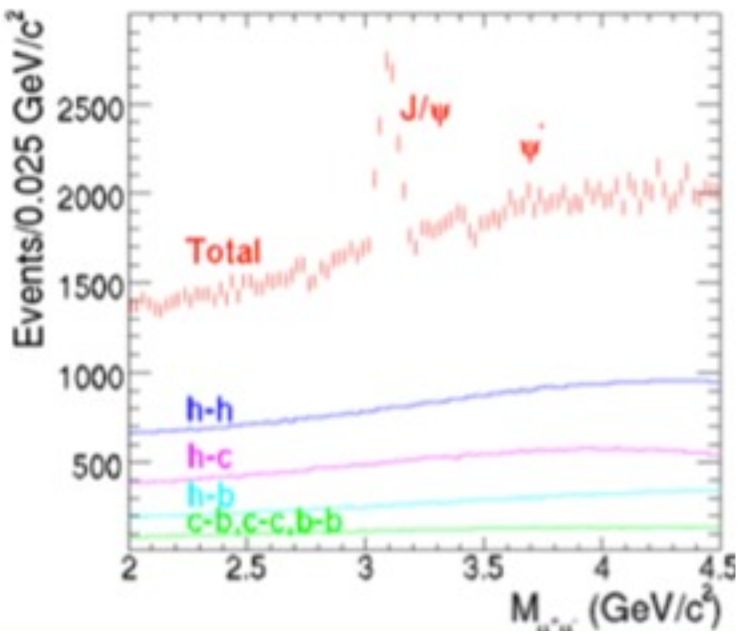
J/psi acceptance



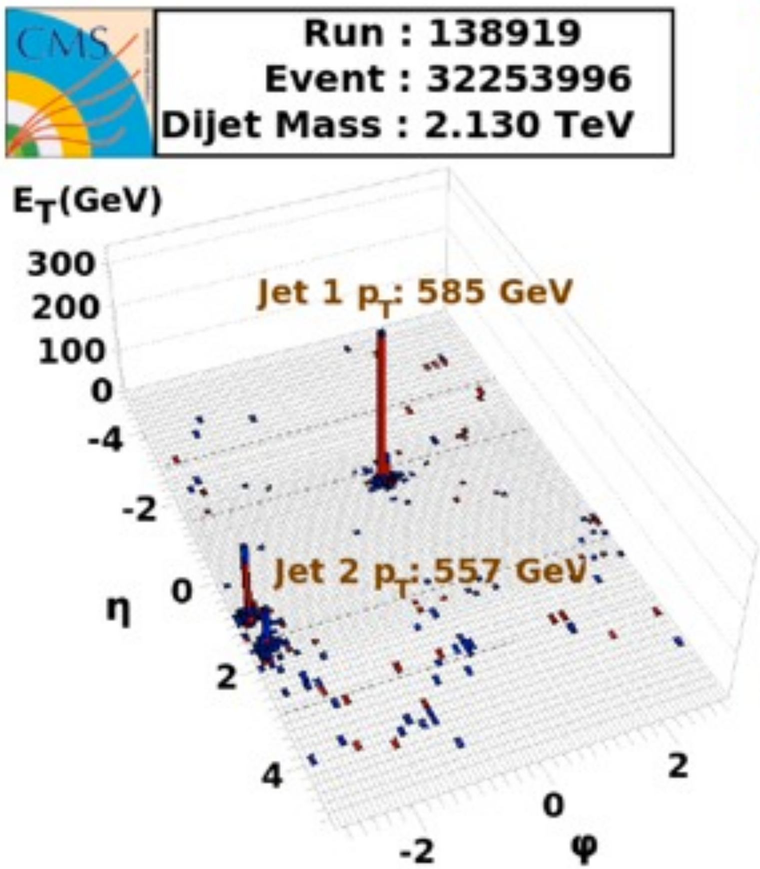
Nominal Run

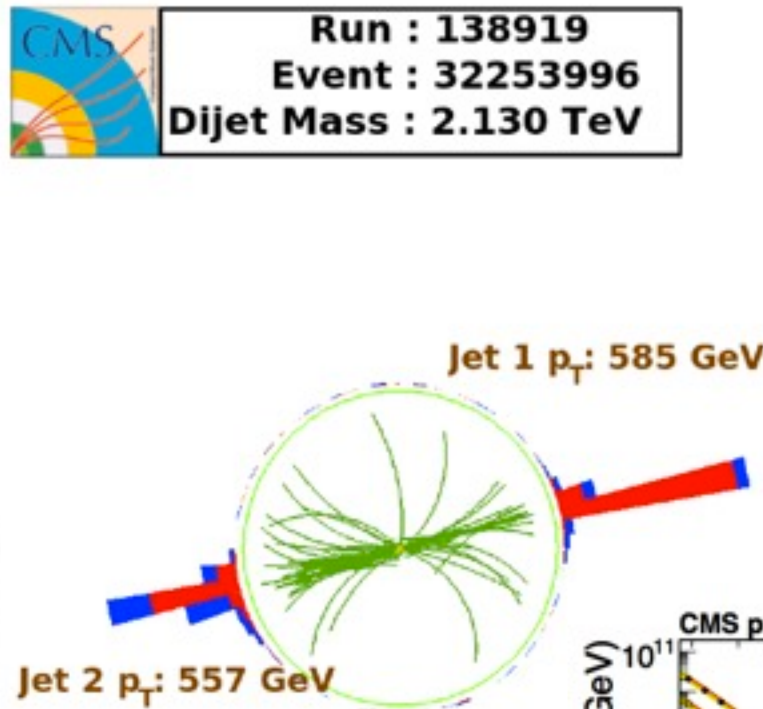


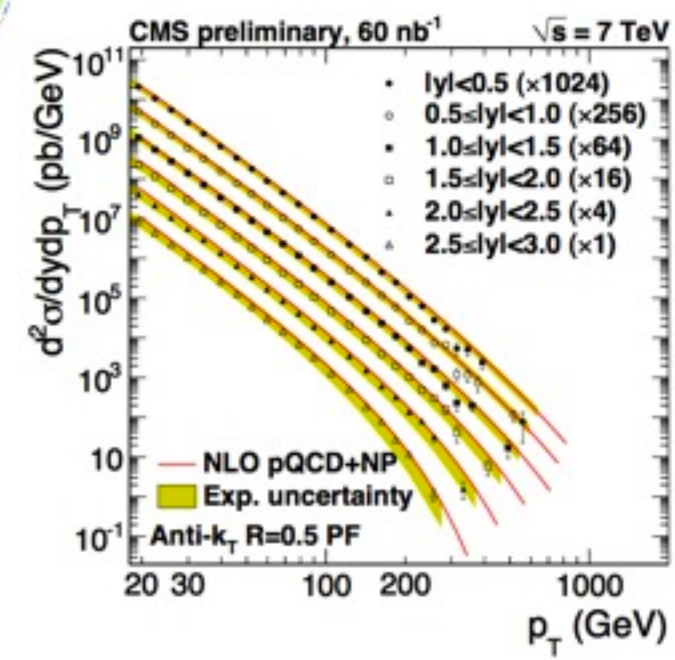
First-year
Low estimate



5. But wait, there's more.... Jets!



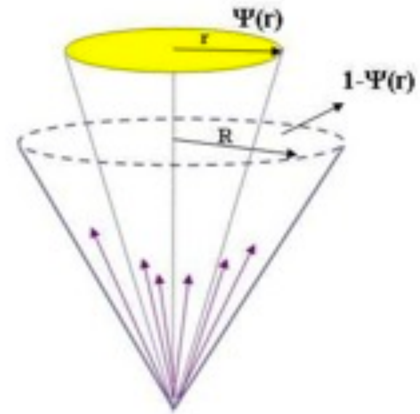




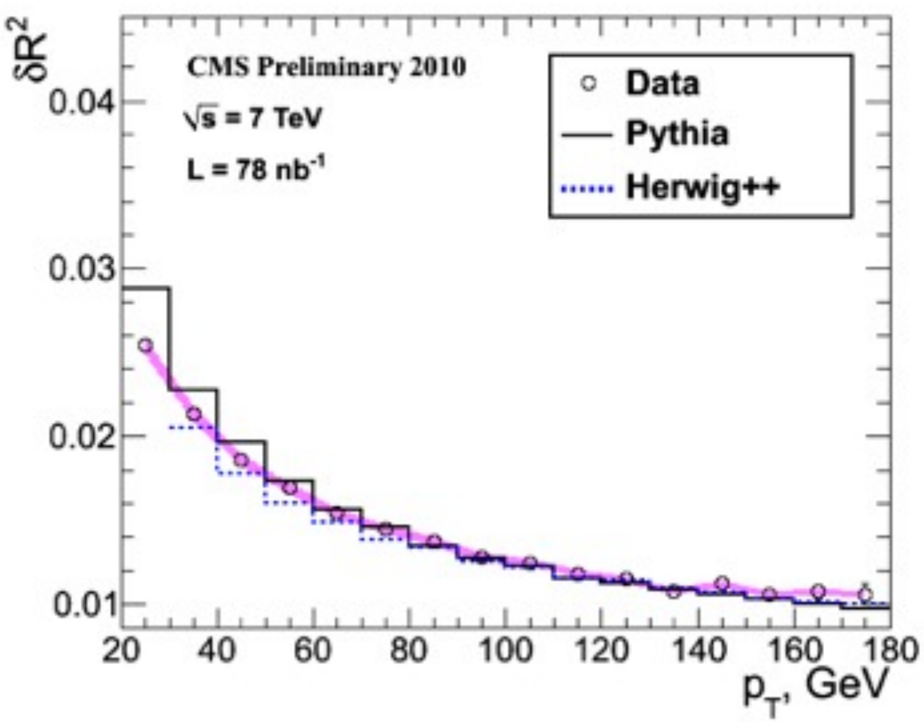
Of course we don't expect 600 GeV dijets in 2010, but we should see a couple thousand with $E_T > 100$ GeV

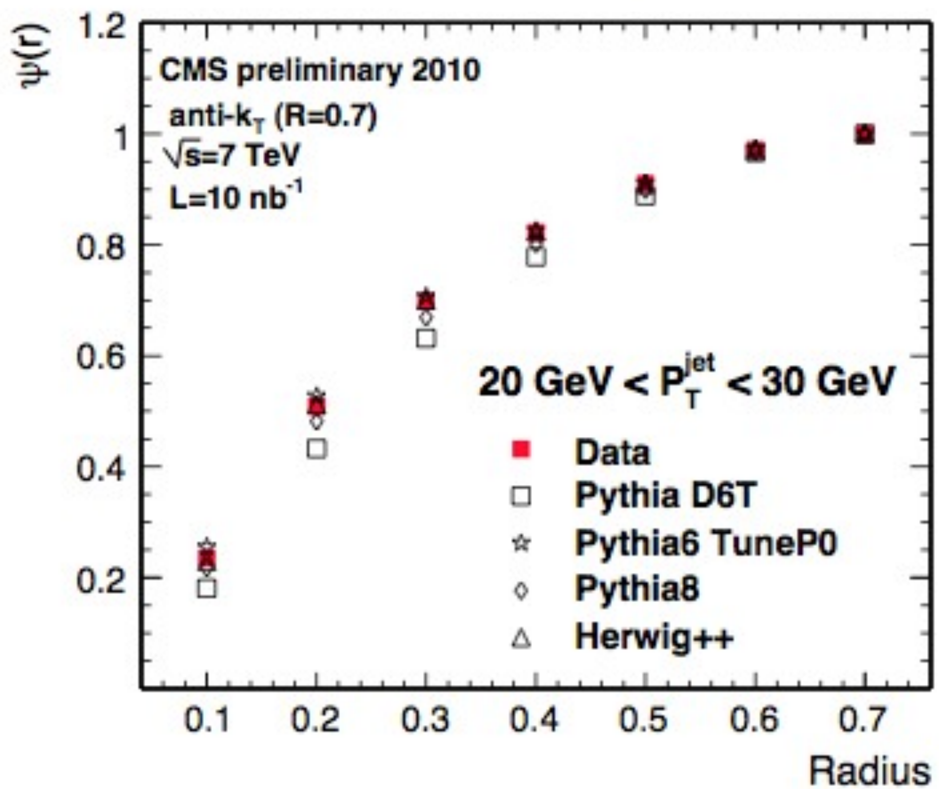
Jet properties

1. Jet shapes (p+p result shown)
2. Jet fragmentation functions (next slide)



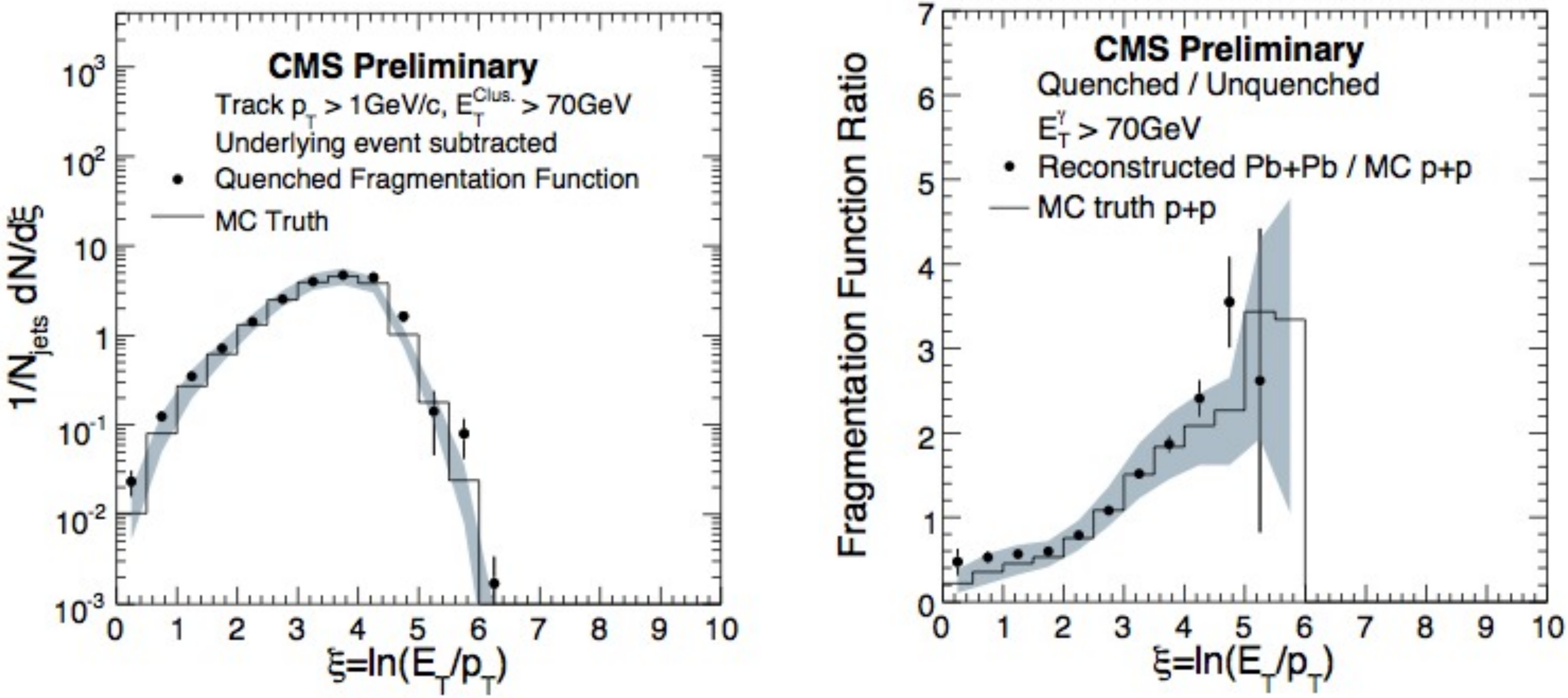
p_T-weighted width





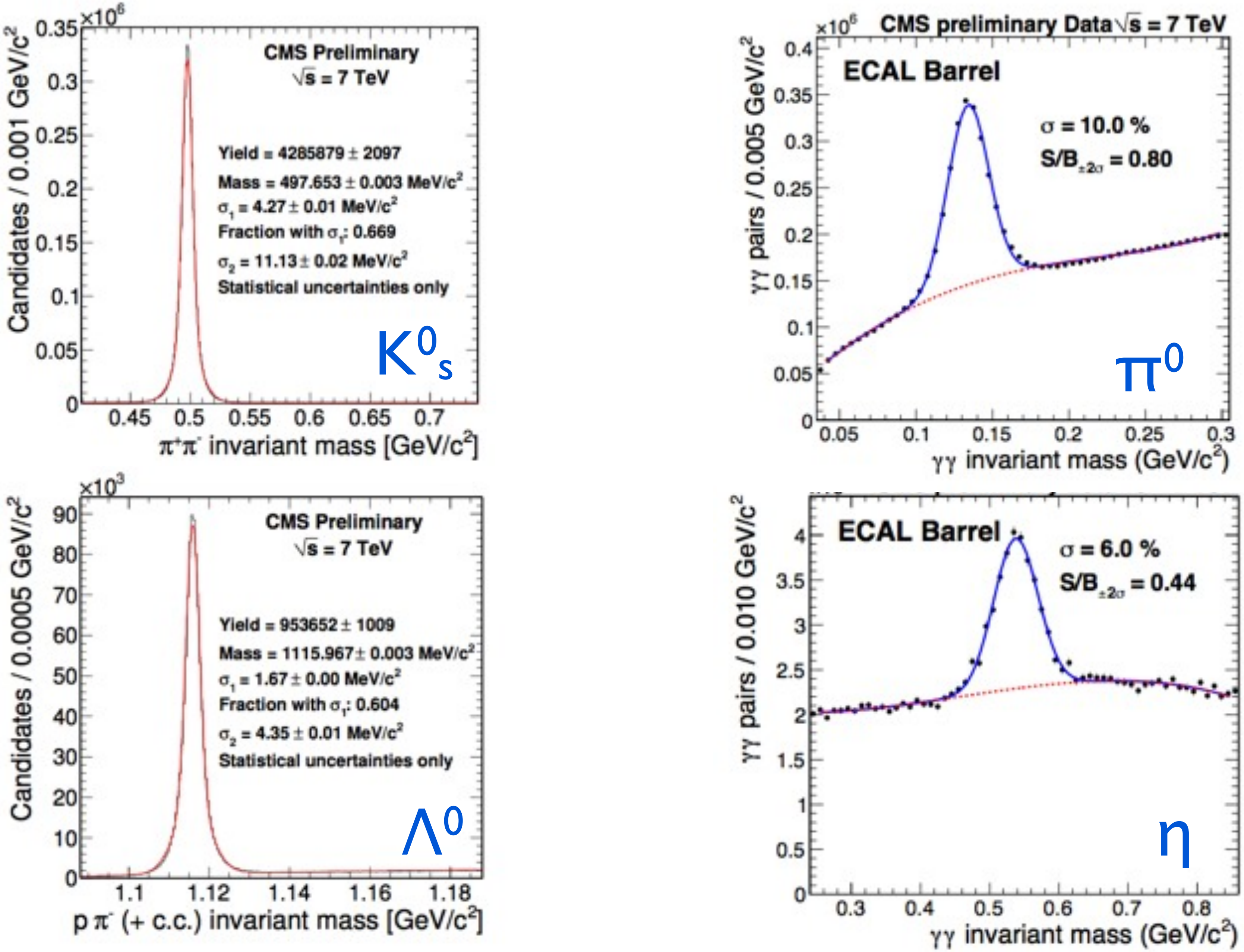
Fragmentation functions

Simulations Nominal Run 5.5 TeV



- Not too many γ-jets in Run-1 (event displays not FF)
- Dijet fragmentation functions sensitive to quenching.
- More complicated without photon ➔ initial parton energy.

And finally … PID!



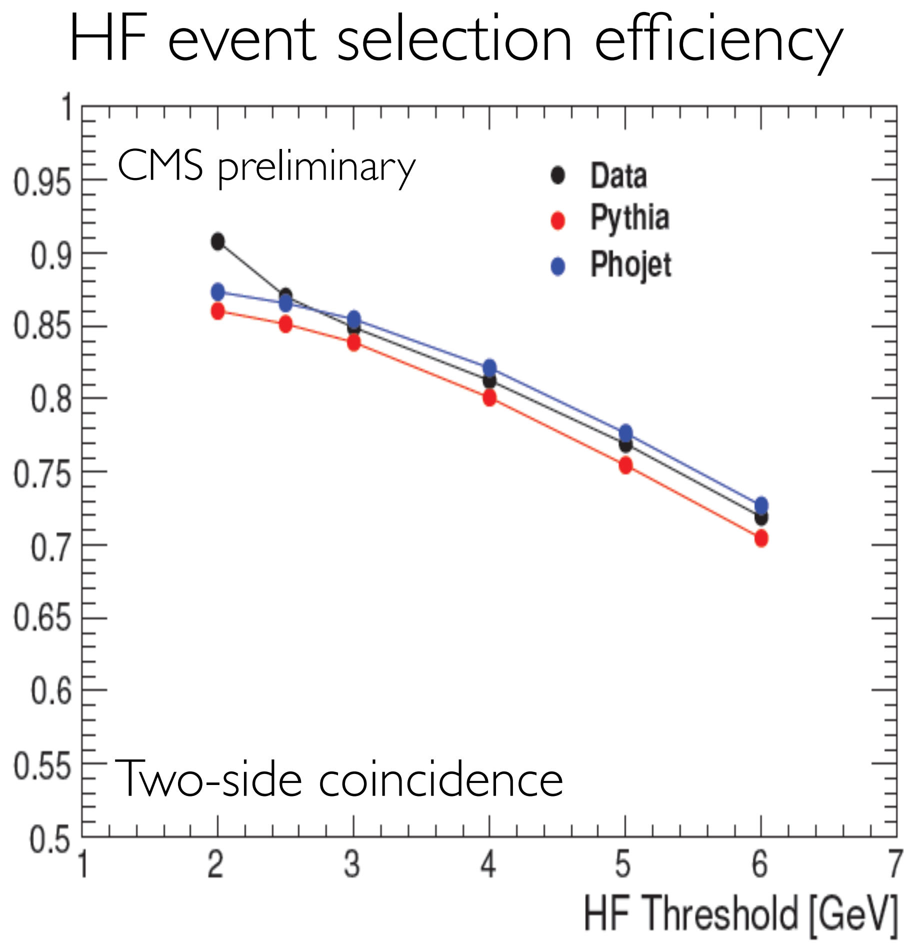
Summary

- CMS is a remarkable instrument for studying QCD physics in p+p and Pb+Pb
- First p+p results published at 0.9, 2.36, and 7 TeV. Important references for HI.
- Precision measurements of rare probes now appearing
- Exciting prospects for early* Pb+Pb physics in Run-1 in 8 weeks!

* 50,000 events ~ 10 minutes of colliding beams

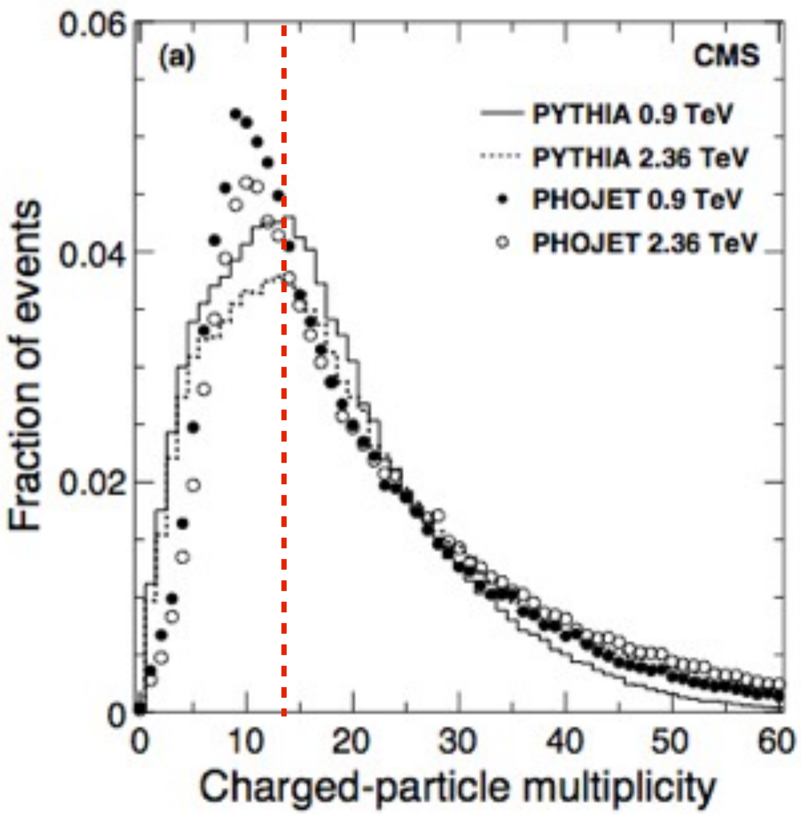
Backup Slides

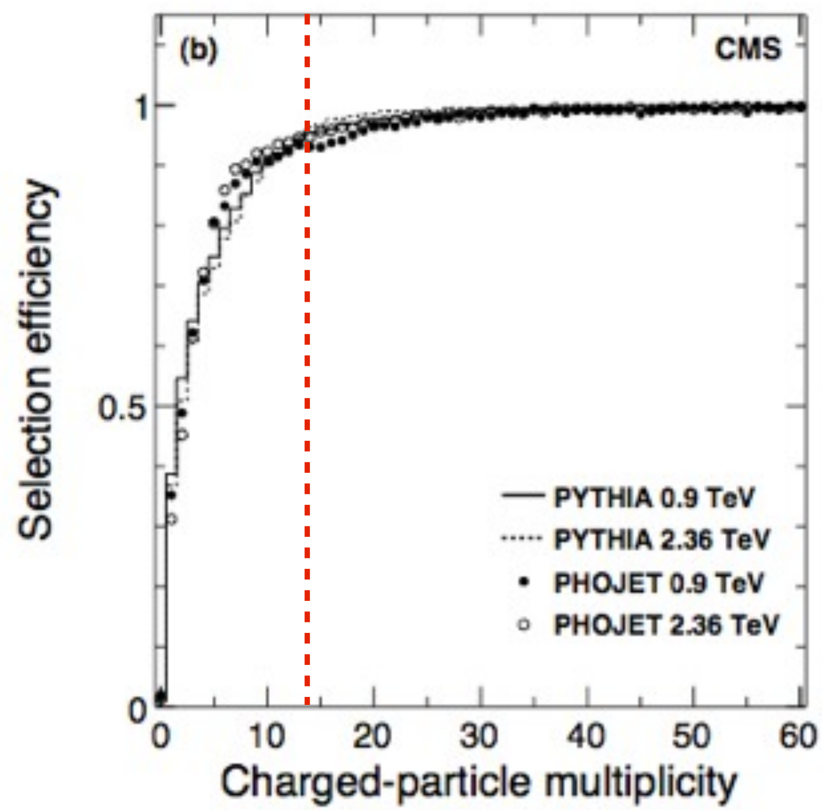
HF event selection efficiency



Based on ZeroBias data + 1 pixel track

Event selection efficiency

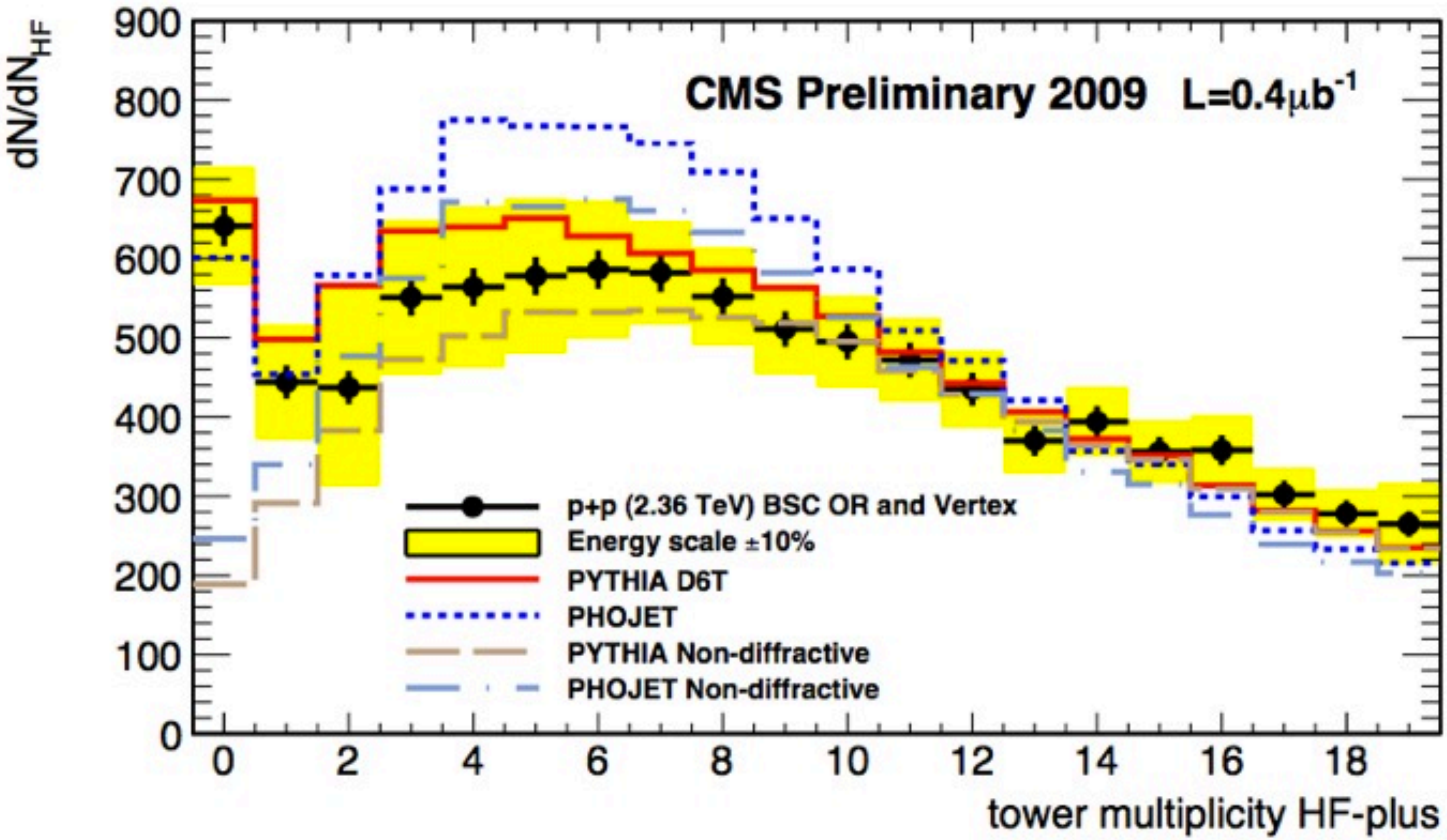




Generated particles after event selection $|\eta| < 2.5$

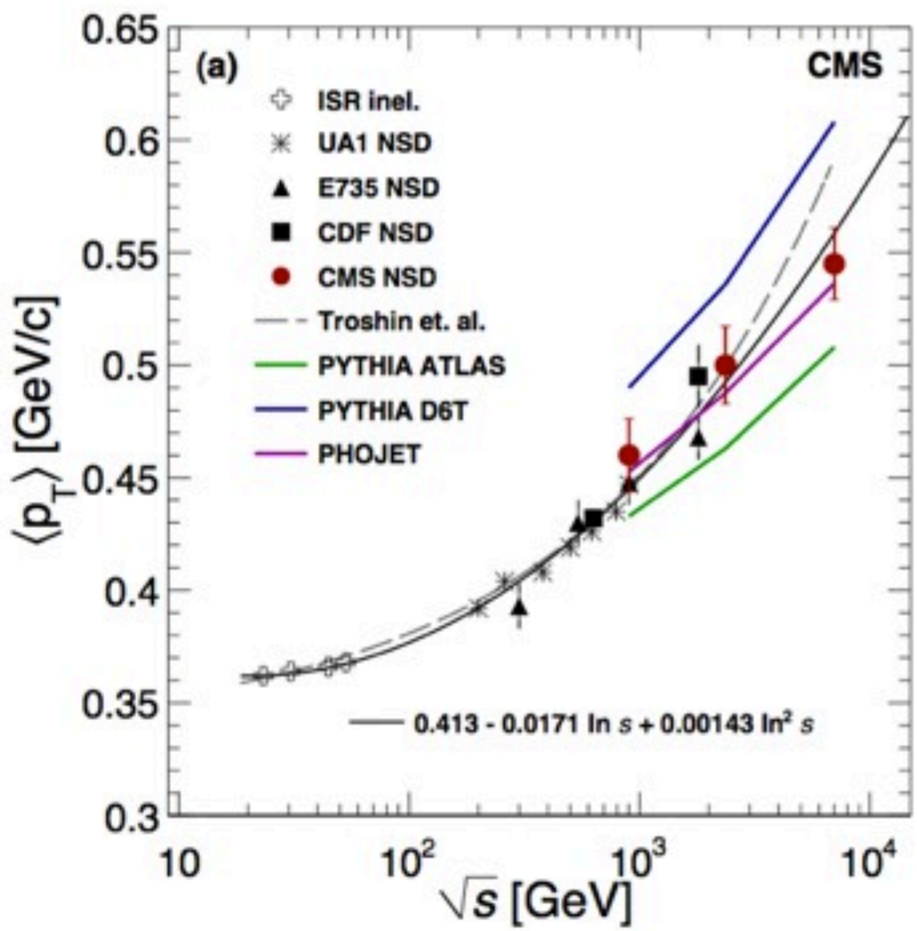
Non-single diffractive (NSD) selection efficiency $|\eta| < 2.5$

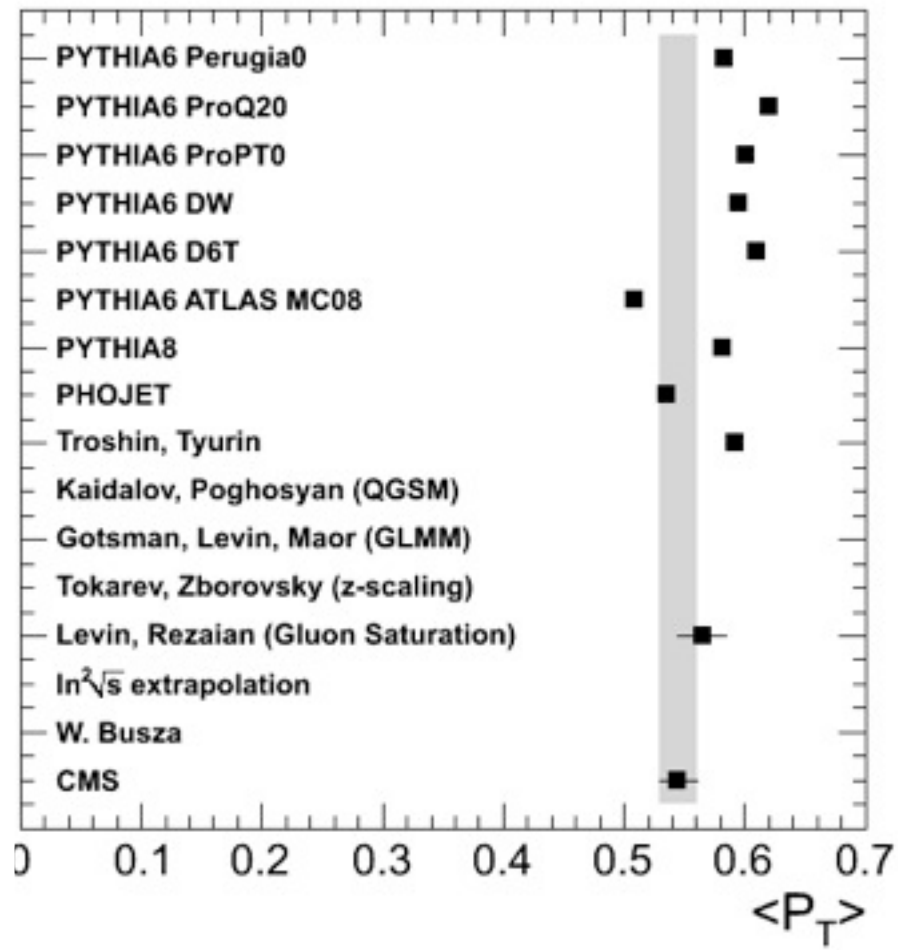
Diffractive Components



PAS-FWD-10-001

Energy dependence of ⟨p_T⟩



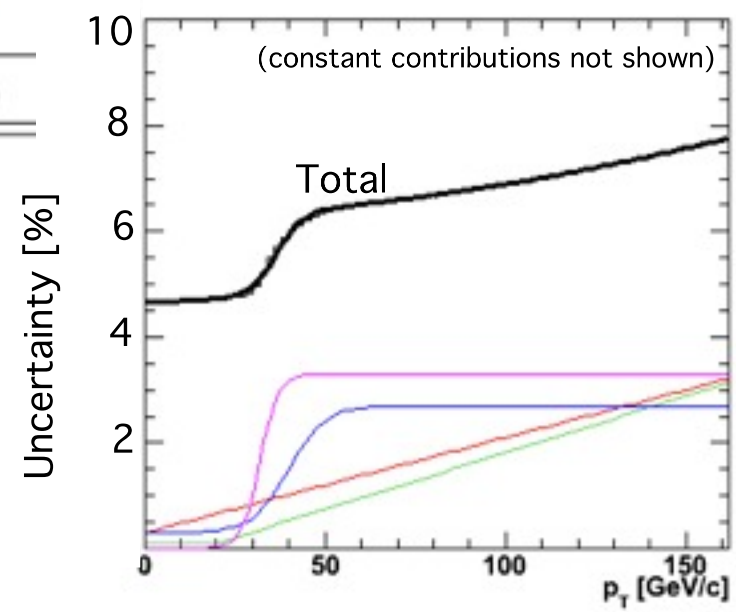


High-p_T Spectra Systematics

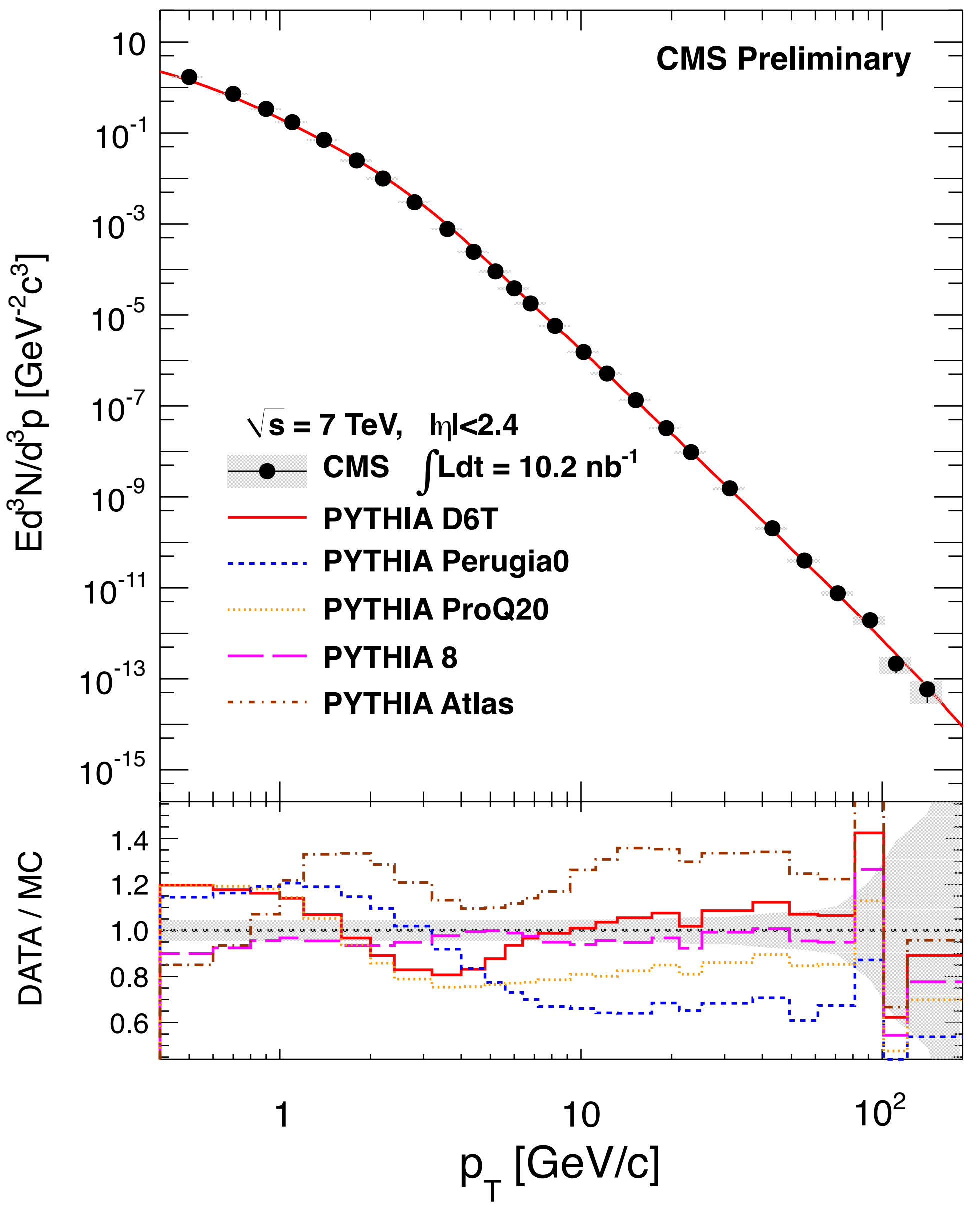
Source	Uncertainty [%]
Event selection uncertainty	3.5
Pileup effect on vertexing	1.2
Acceptance uncertainty	1.5
Reconstruction efficiency	2.2
Occupancy effect on efficiency	0.0 - 2.8
Fake track rate	0.3 - 3.0
Correction for secondary particles	1.0
Momentum resolution and binning	0.3 - 2.7
Normalization of jet-triggered spectra	0.0 - 3.3
Total	4.7 - 7.5

Contributions are added in quadrature

Systematic errors vs. p_T



Including ATLAS tune



x_T scaling: empirical expectation

$$E\frac{d^3\sigma}{d^3p} = F(x_T)/p_T^{n(x_T,\sqrt{s})} = F'(x_T)/\sqrt{s}^{n(x_T,\sqrt{s})}$$

slow evolution of exponent: n~5-6

- running α_s, FFs, PDFs

$x_T = 2p_T/\sqrt{s}$

Fit this quantity: $\sqrt{s}^{n(x_T,\sqrt{s})} \; E\frac{d^3\sigma}{d^3p}$

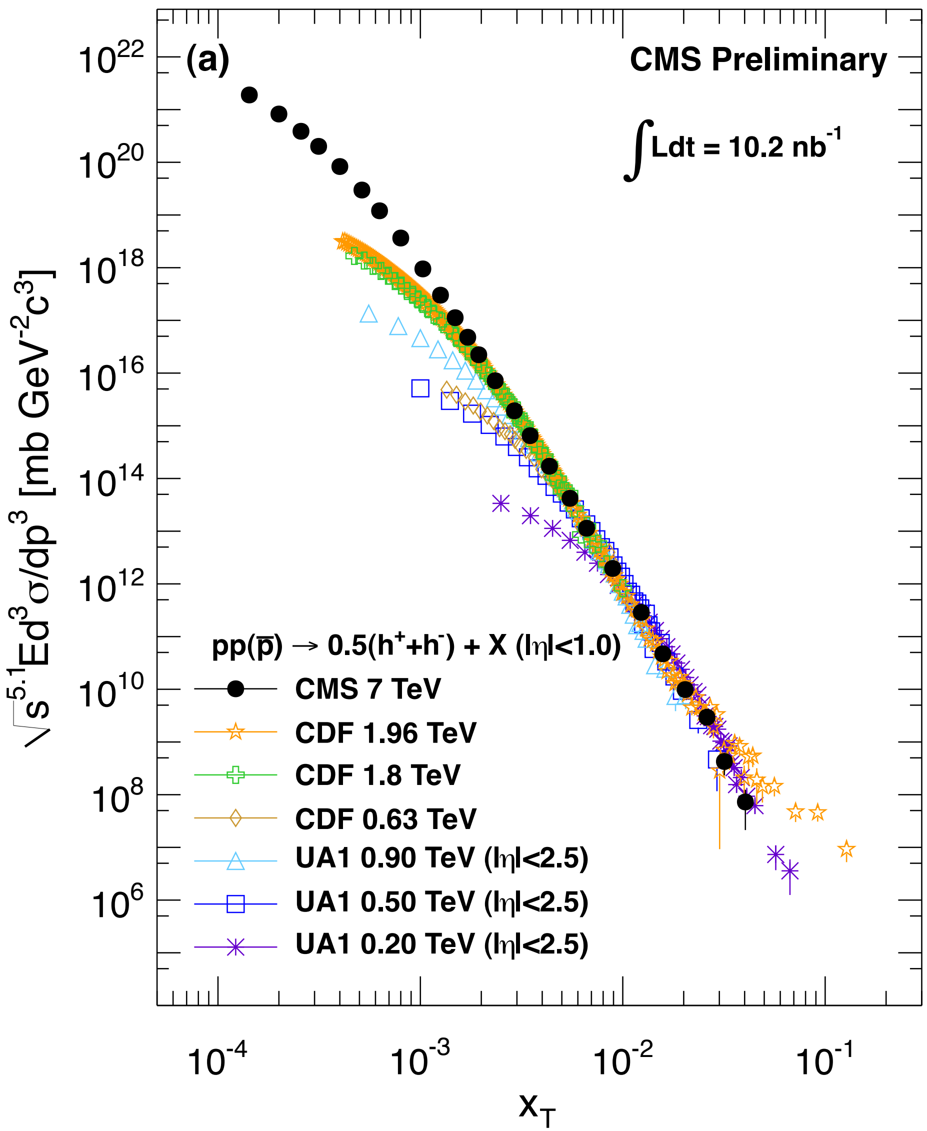
with a power-law: $p_0 \cdot [1 + (x_T/p_1)]^{p_2}$

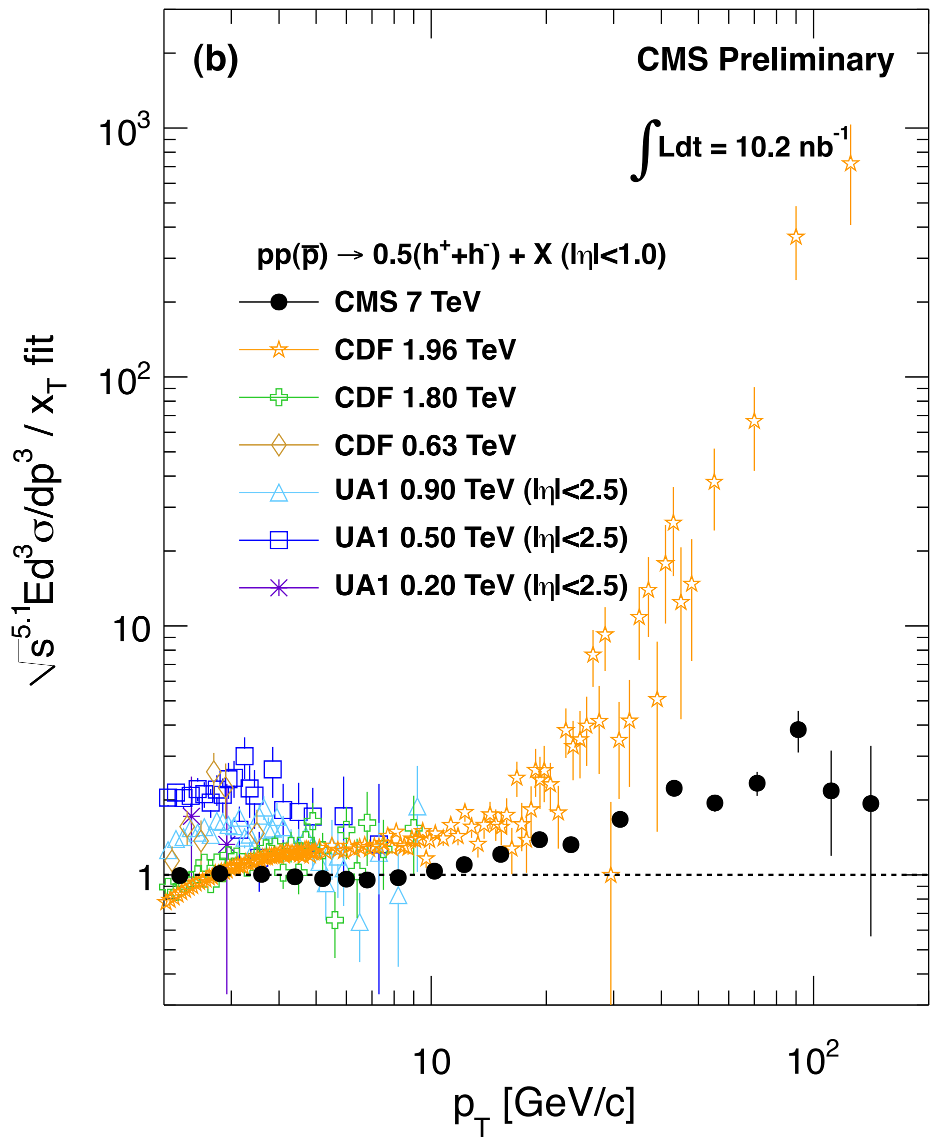
for p_T > 2 GeV/c and various values of n.

minimum χ^2 for n=5.1 including all results

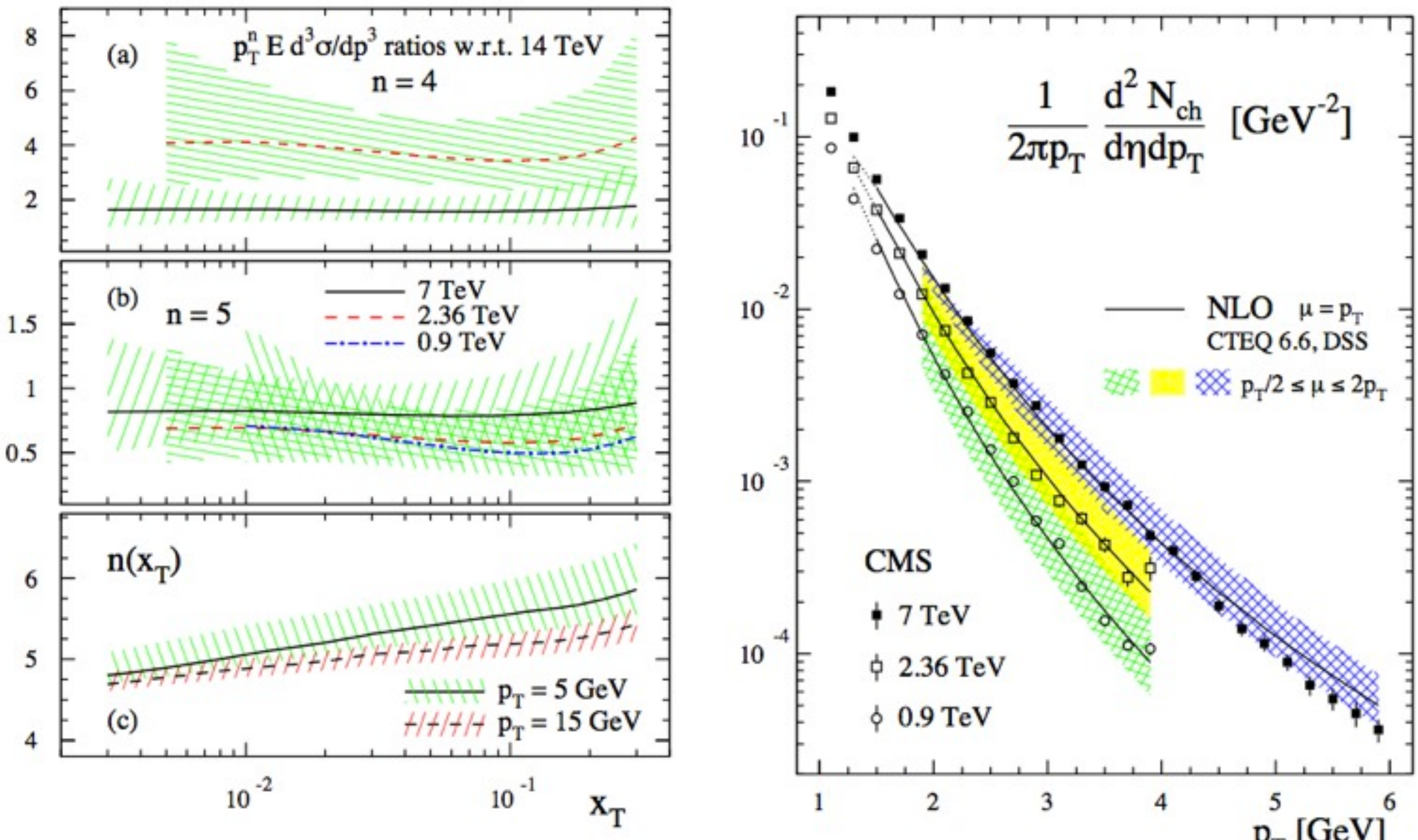
(n=5.5 for all results excluding CMS 7 TeV)

x_T scaling: empirical expectation



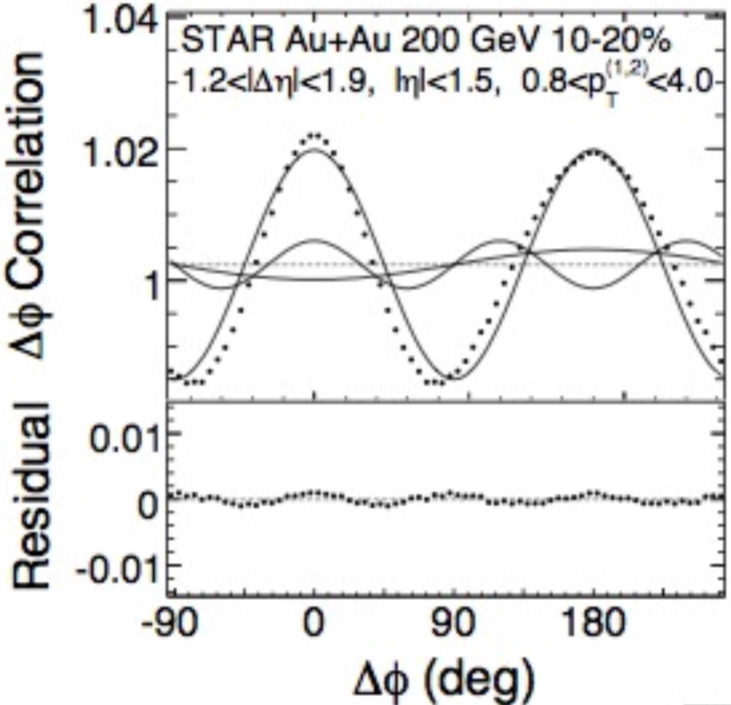


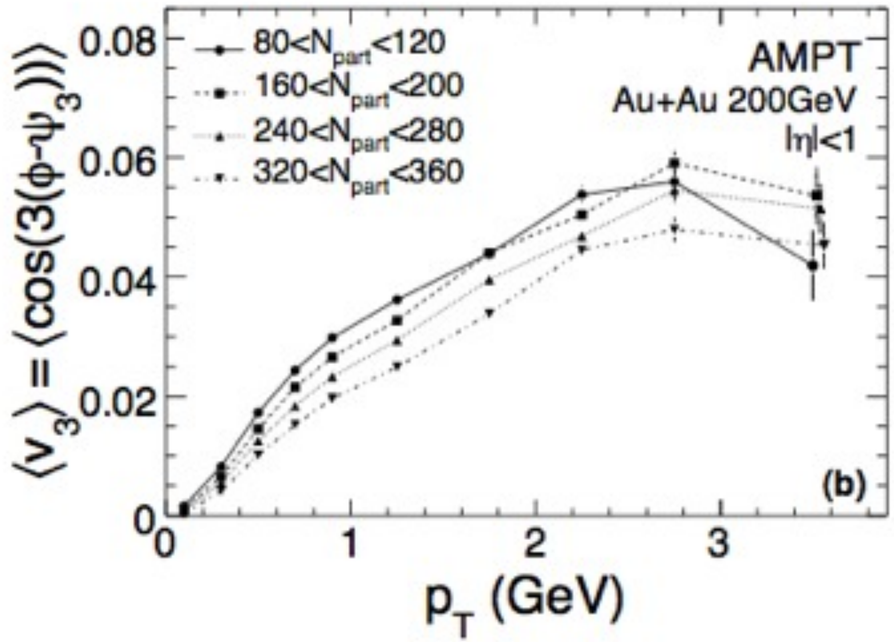
NLO

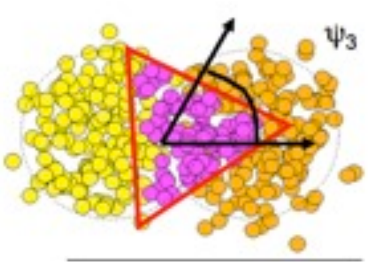


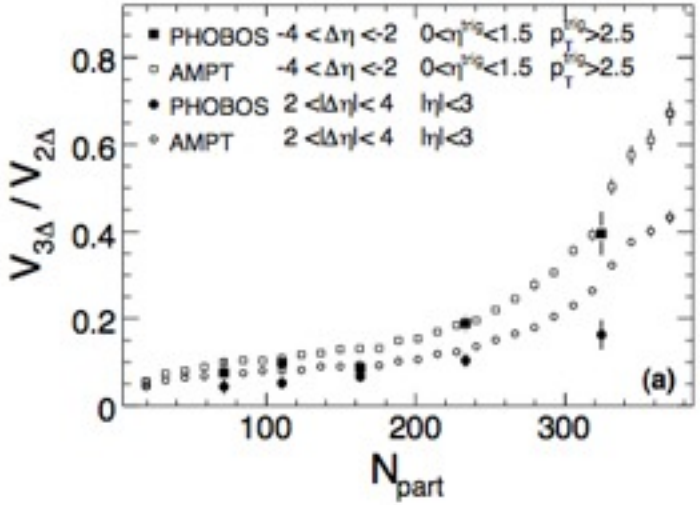
Sassot, Zurita, Stratmann, arXiv:1008.0540v1

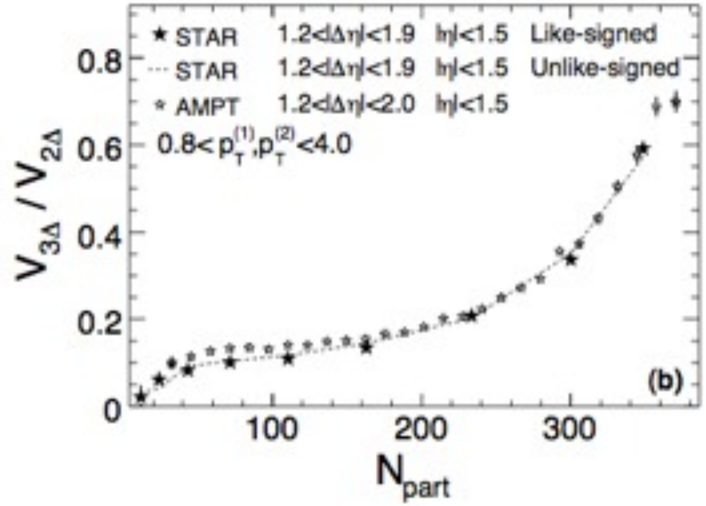
More on triangular flow





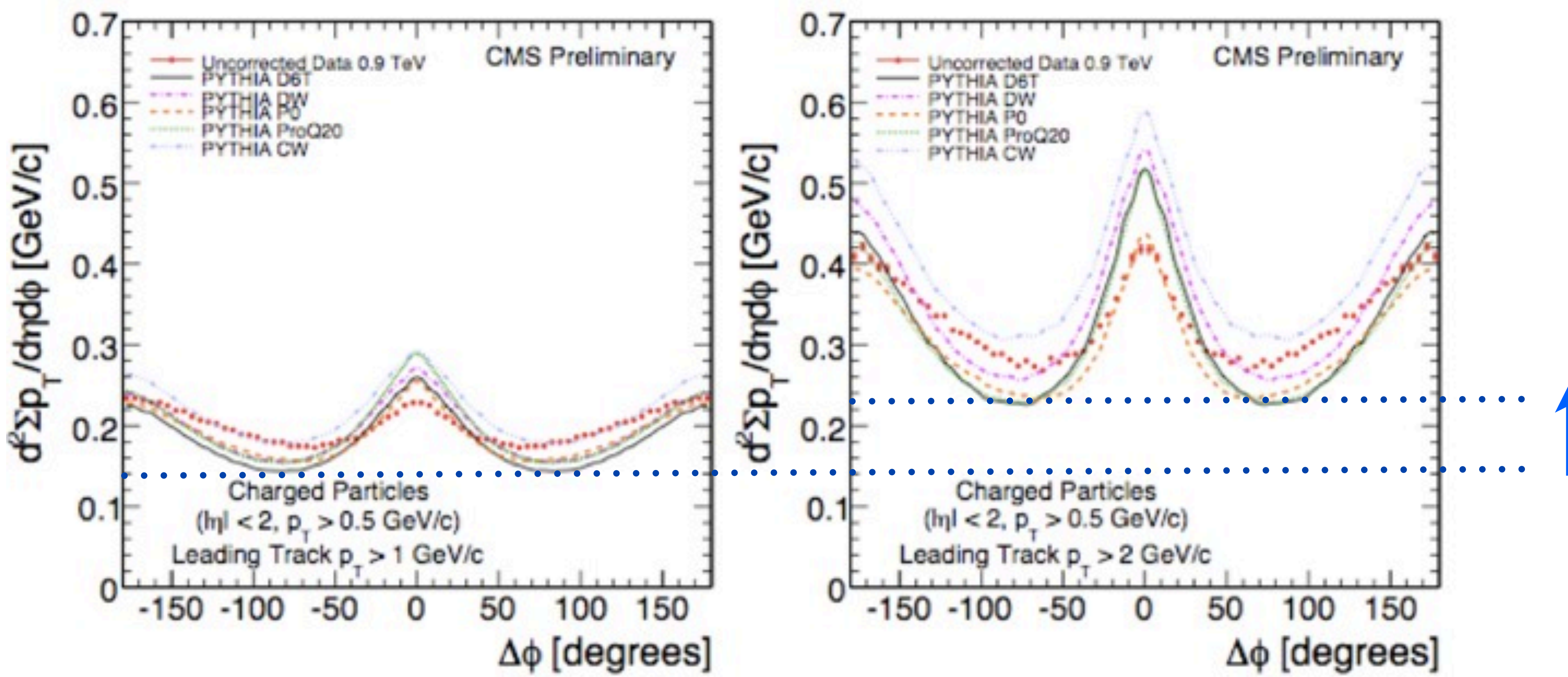






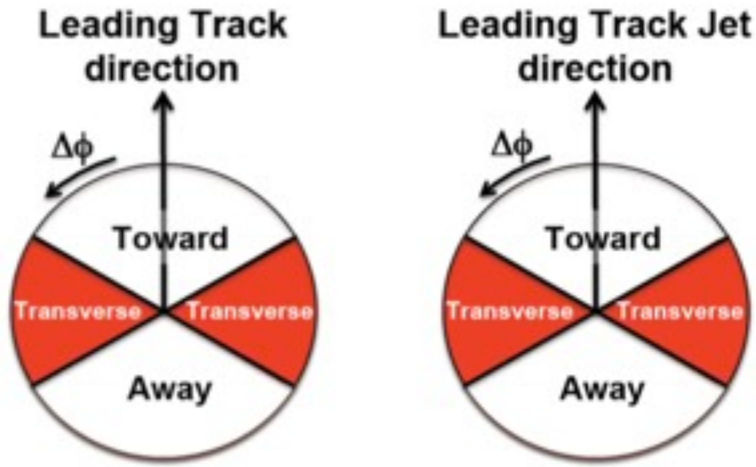
Triggered correlations

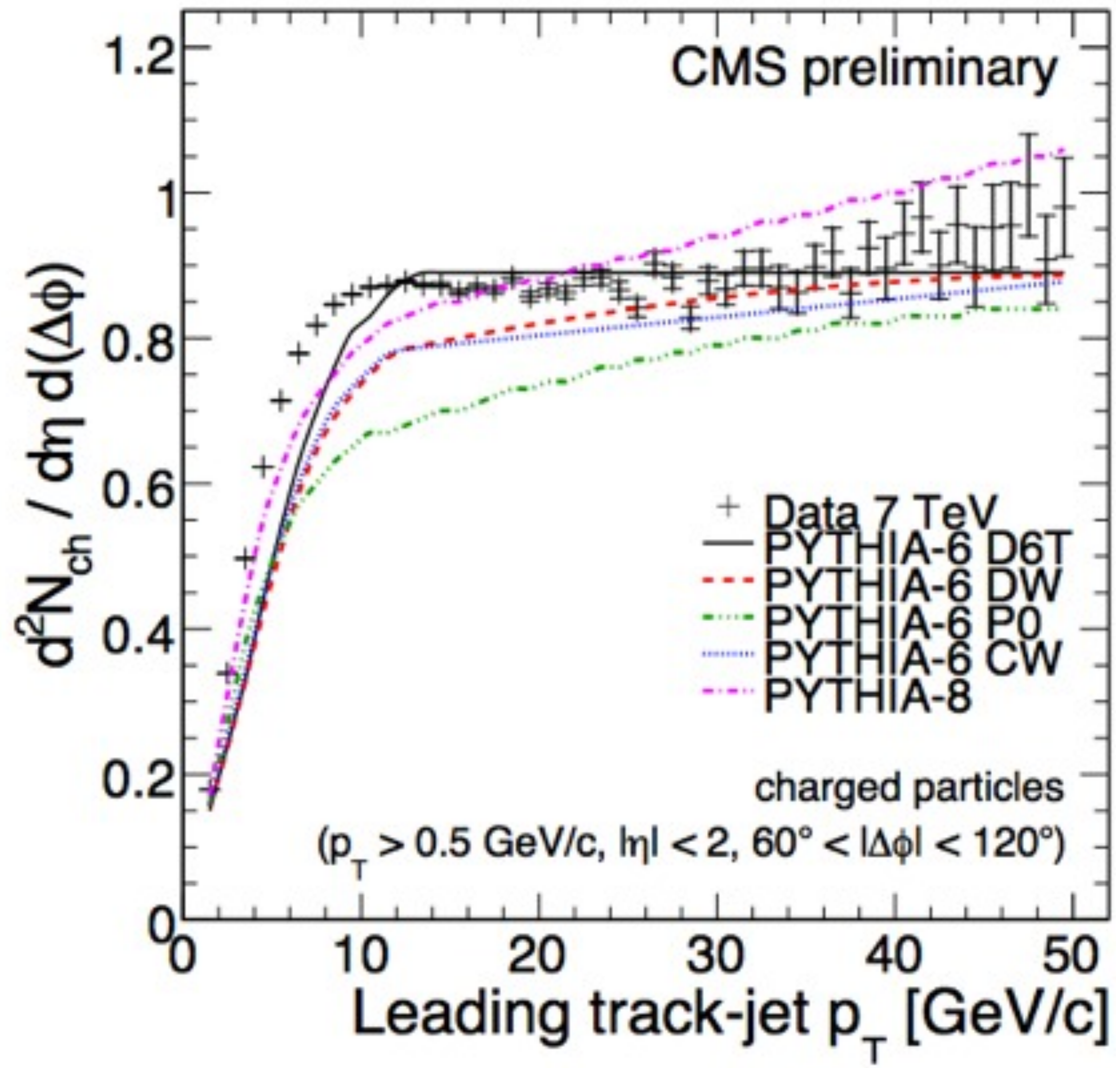
Leading track: 1 GeV/c → 2 GeV/c



What is a correlated yield? Underlying event intimately tied to presence of high-p_T track (or jet)

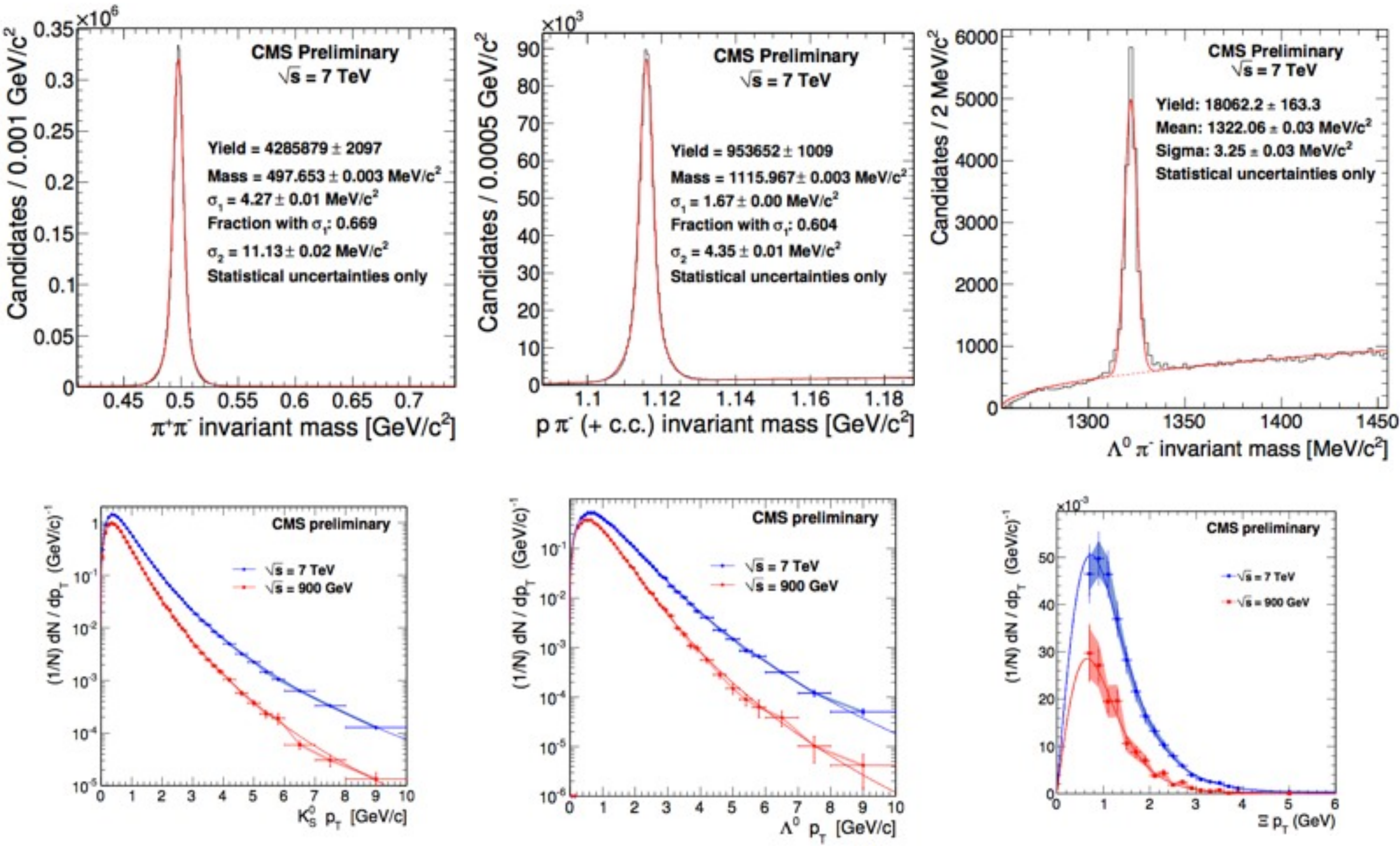
Underlying event activity





Strong turn-on of particle production in transverse region as a function of track-jet p_T

Strange Particle Spectra



More on jet shapes