

Overview of CMS experimental results

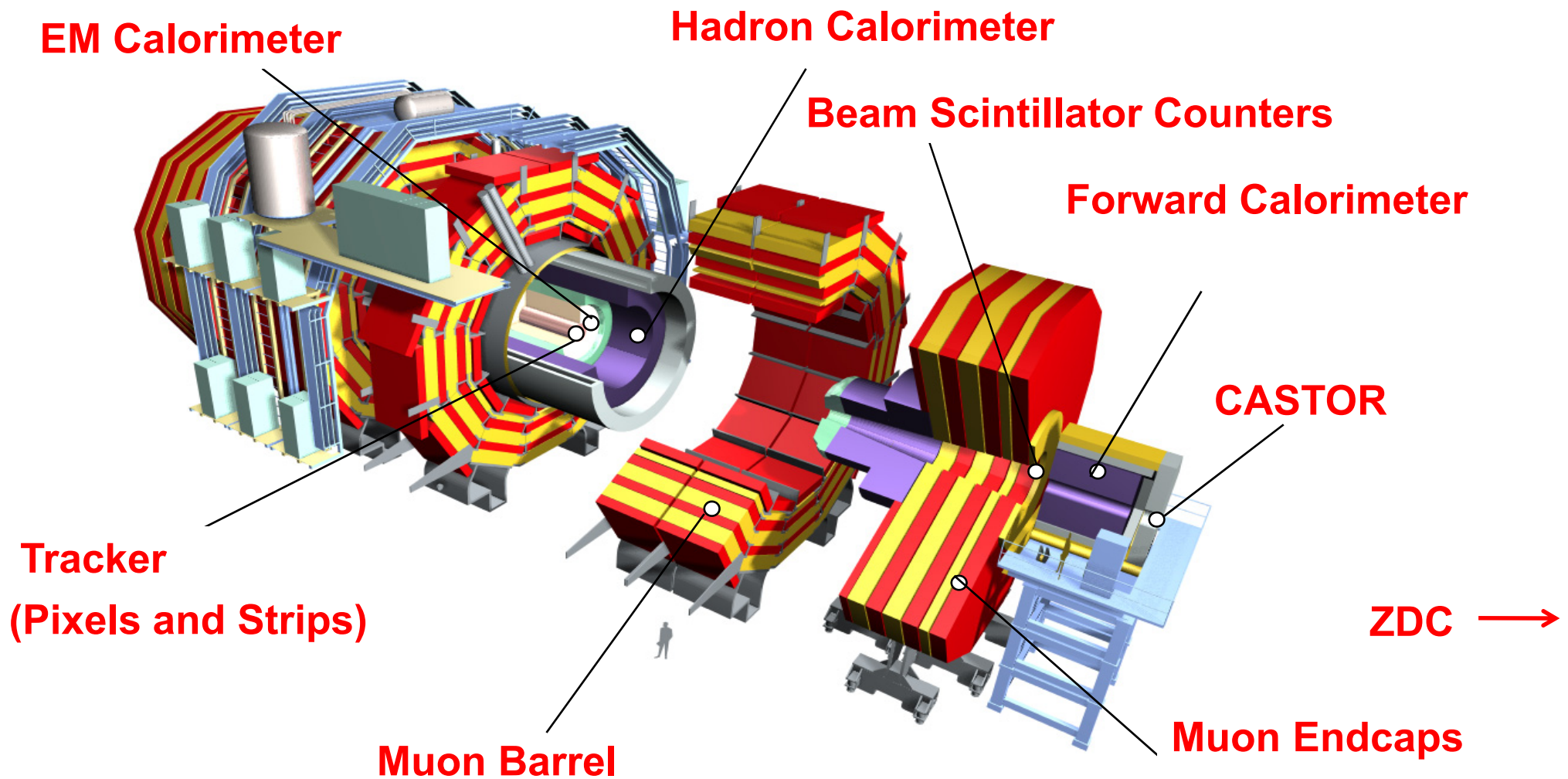
Bolek Wyslouch

École Polytechnique and MIT



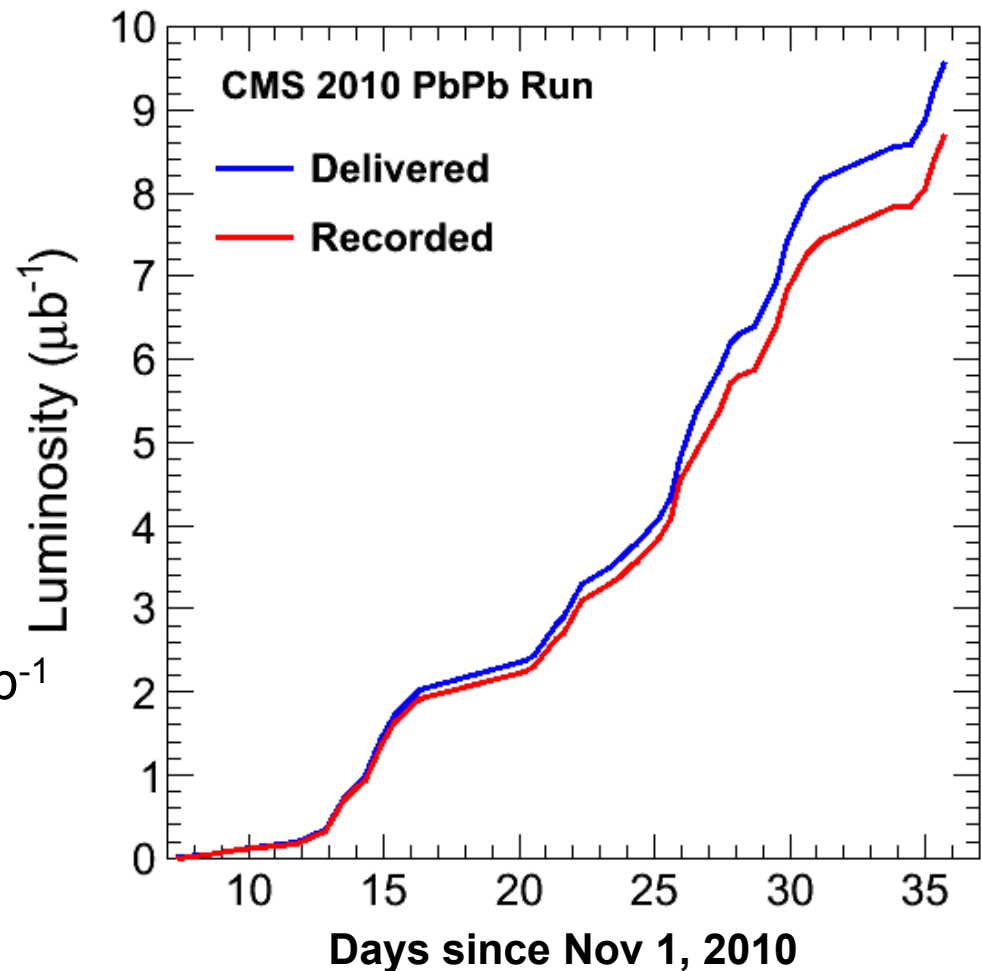
for the CMS Collaboration

CMS Experiment



Data taking during PbPb run

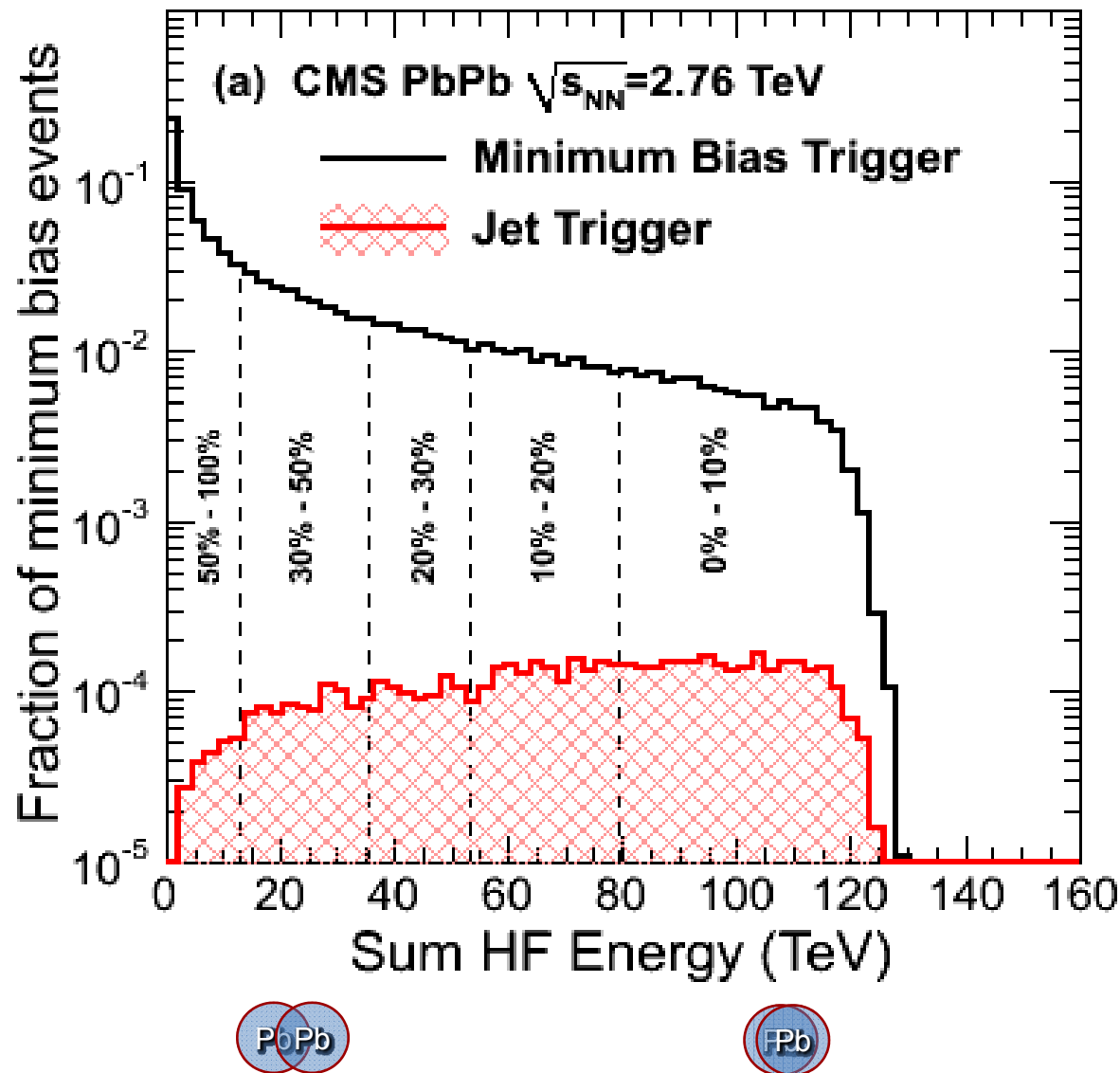
- CMS configured in a dedicated mode for heavy ions
 - Turn off zero suppression
 - Taking data at up to 220 Hz
 - 12 MB event size
- Triggering on minimum bias, jets, muons and photons
 - ALL rare probes written to tape
 - ~half of minimum bias written
- Recorded luminosity PbPb $8.7 \mu\text{b}^{-1}$
- Recorded luminosity pp@2.76 TeV 241 nb^{-1}
- Total PbPb data volume ~ 0.89 PetaByte



Note: luminosities will be rescaled by few% after complete analysis of Van der Meer scans **I.A.Cali (Poster), S.Sen (Poster)**

Centrality

- Hadron-Forward (HF) calorimeter energy deposits in $3 < |\eta| < 5$
- Notice the increase of the fraction of high- p_T triggers with centrality



I.A.Cali (Poster), S.Sen (Poster)

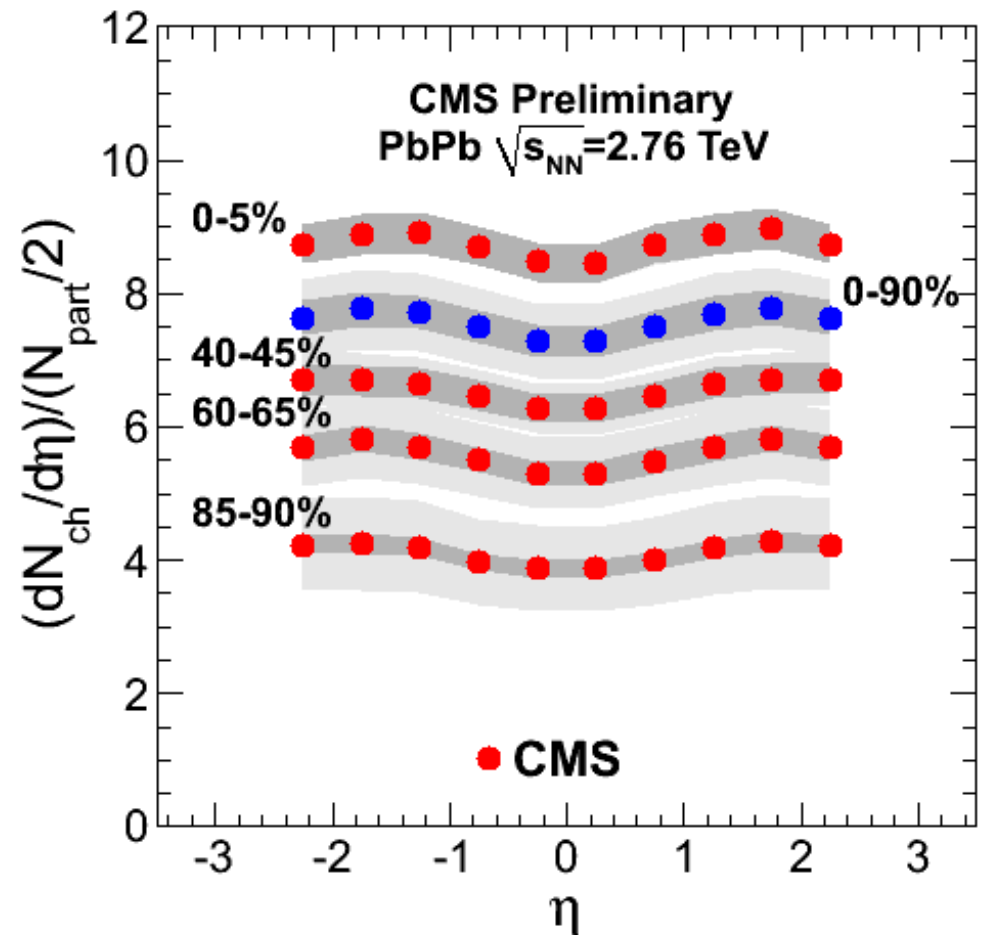
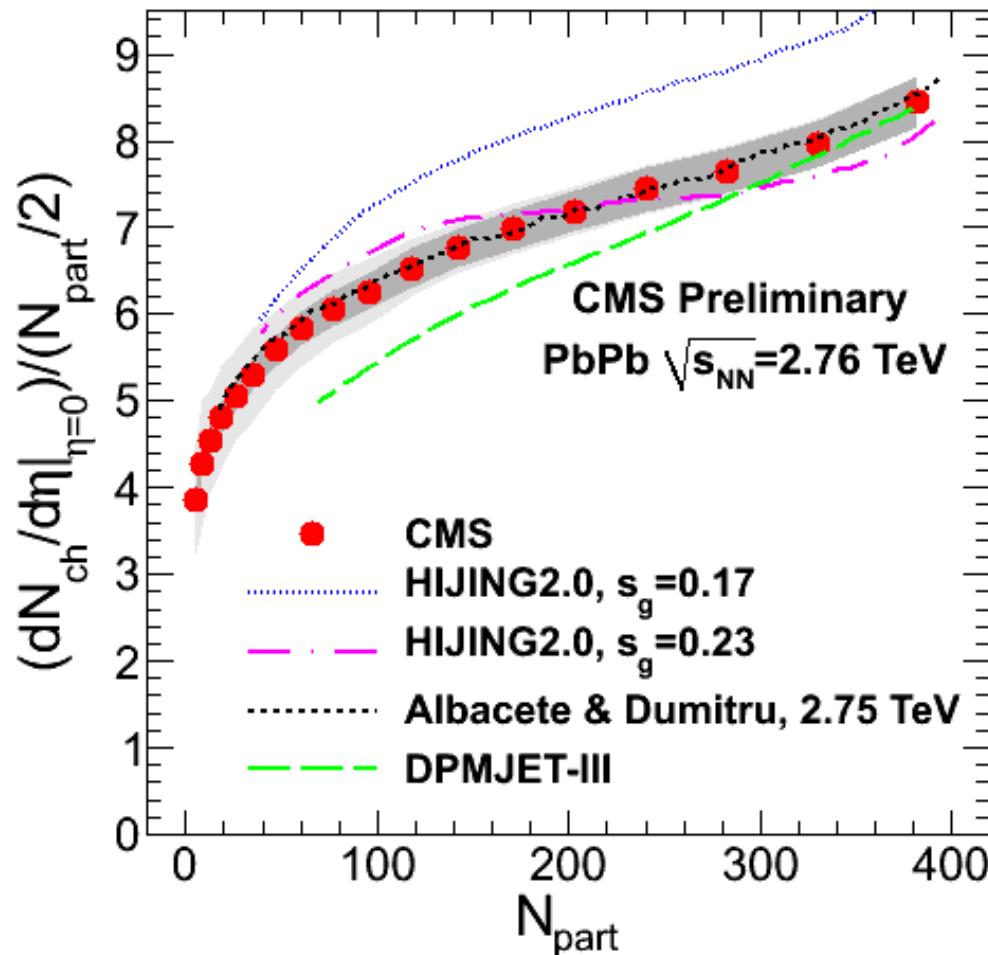
CMS results at Quark Matter 2011

- Multiplicity, E_T
 - K. Krajczar (TODAY)
 - M. Malek
- Flow and Correlations
 - W. Li (Thu)
 - J. Velkovska (Tue)
 - J. Callner (Tue)
 - S. Padula (TODAY)
 - D. Velicanu (TODAY)
 - V. Zhukova (TODAY)
 - M. Issah
- Photons, Particle Spectra
 - Y.-J. Lee (Wed)
 - Y. Kim (Fri)
 - A.Yoon (Thu)
- Jets
 - C. Roland (Wed)
 - M. Nguyen (Fri)
 - Y. Yilmaz (Fri)
 - M. Tonjes (Tue)
- Quarkonia and Heavy Flavors
 - C. Silvestre (Fri)
 - Z. Hu (TODAY)
 - T. Dahms (Tue)
 - M. Jo
 - D.H. Moon
 - H. Kim
- Weak Bosons
 - J. Robles (Thu)
 - L. Benhabib
- Detectors
 - S. Sen
 - I.A. Cali

5+1 Plenary, 13 Parallel, 8 Posters

Charged particle multiplicity

- Uses pixel tracker and two methods
- Data taken with no magnetic field, $B=0T$
- Trigger with 99% efficiency, 1% UPC contamination

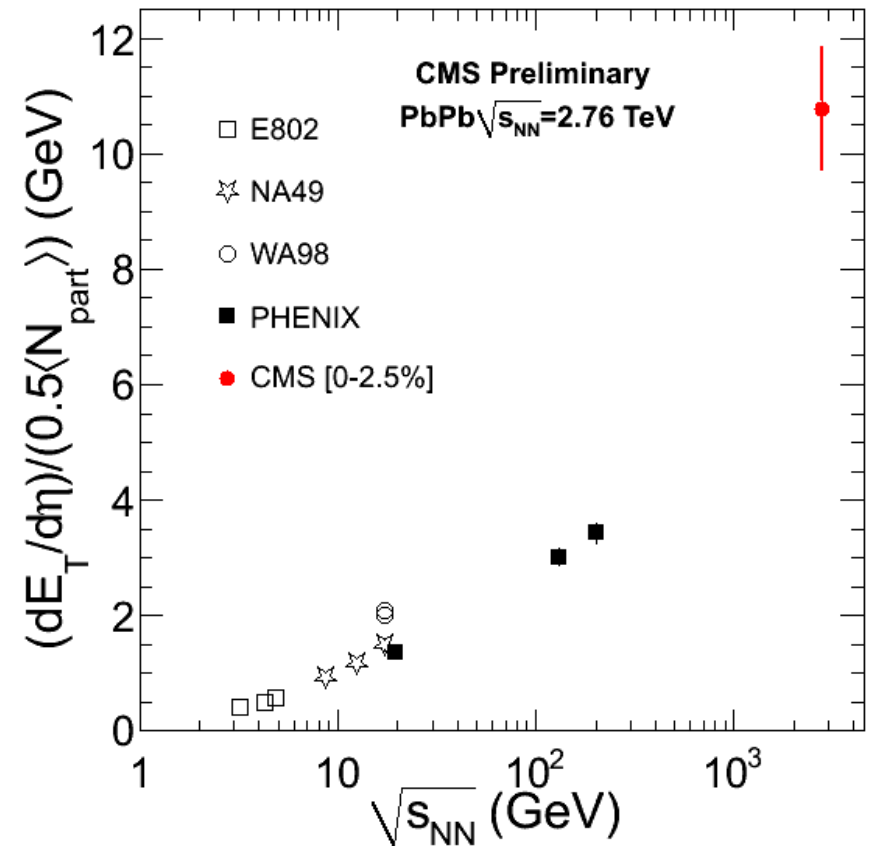
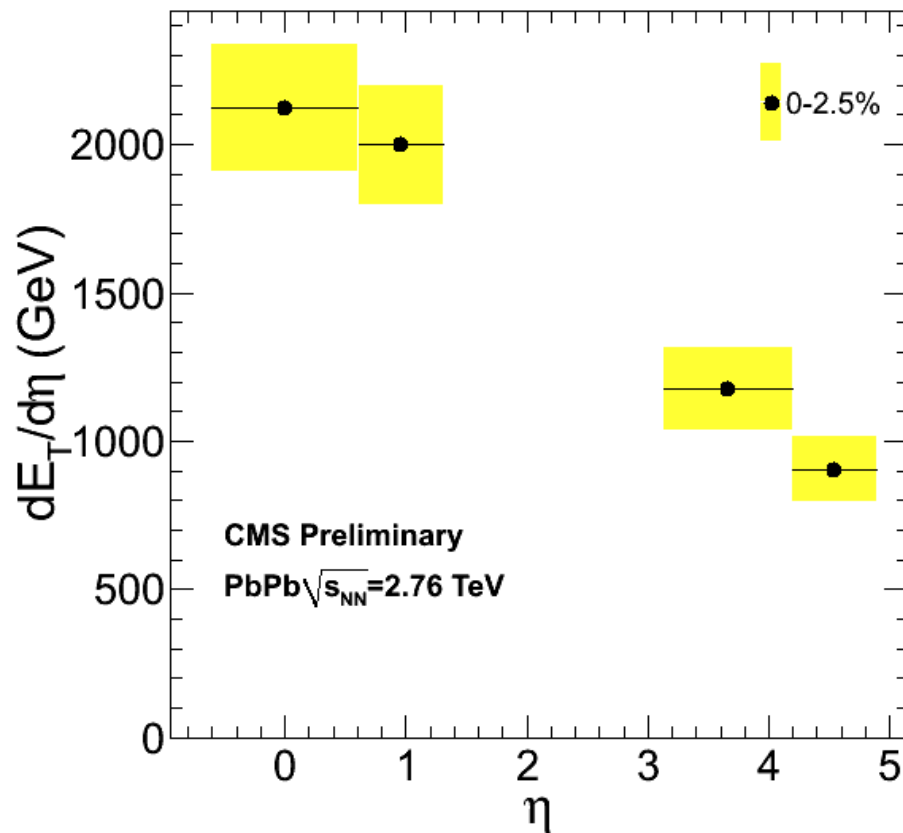


- Central multiplicity $dN_{ch}/d\eta=1610 \pm 55$ for 0–5% centrality

K. Krajczar (TODAY), M. Malek (poster)

$dE_T/d\eta$: 2 TeV at mid-rapidity

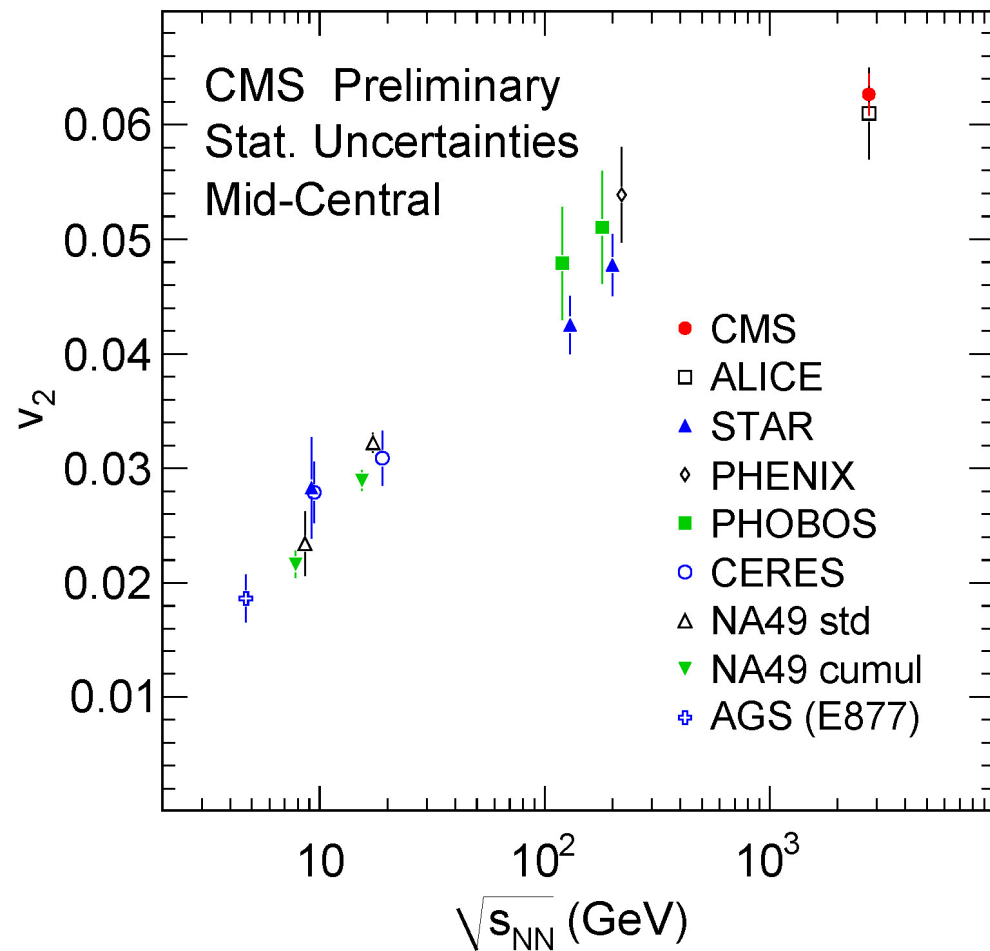
- Three times larger than at RHIC energies
- Measured over wide range of pseudorapidity



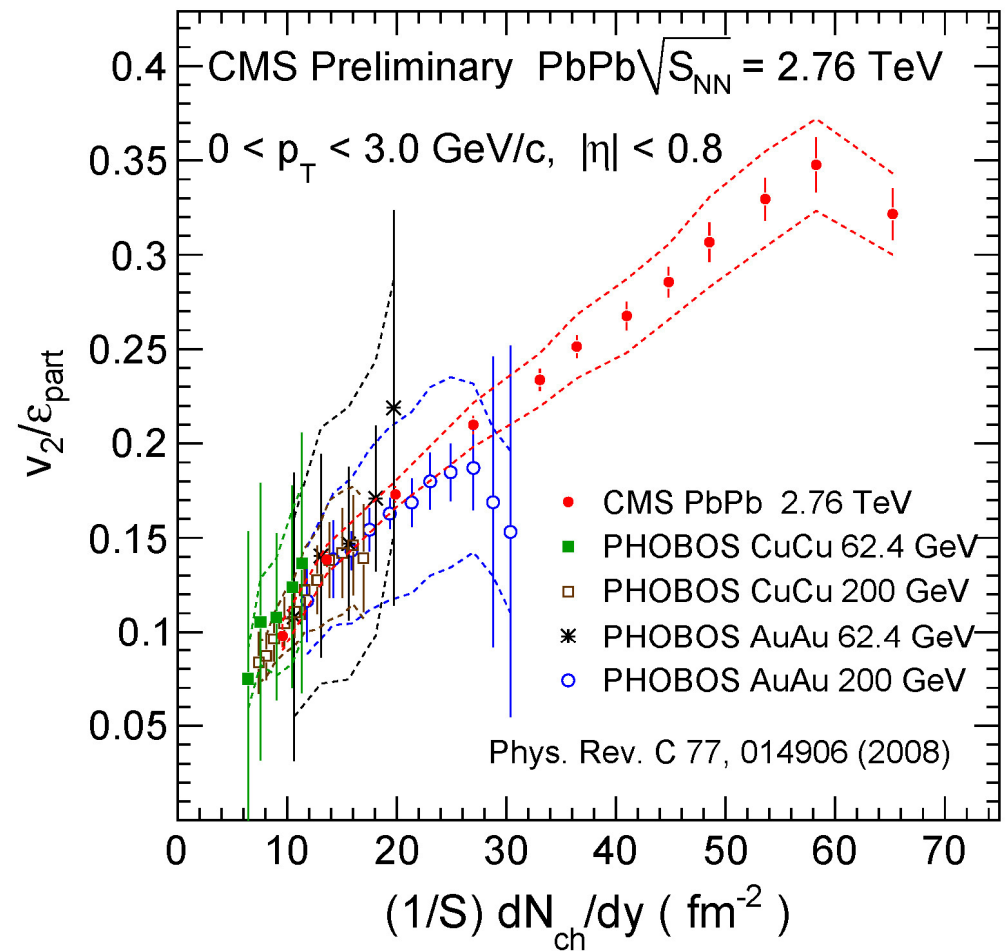
M. Malek (poster)

Increase in azimuthal anisotropy

- Energy Dependence
 - CMS: 20-30%, $v_2\{\text{LYZ}\}$
 - Extrapolated to $p_T=0$

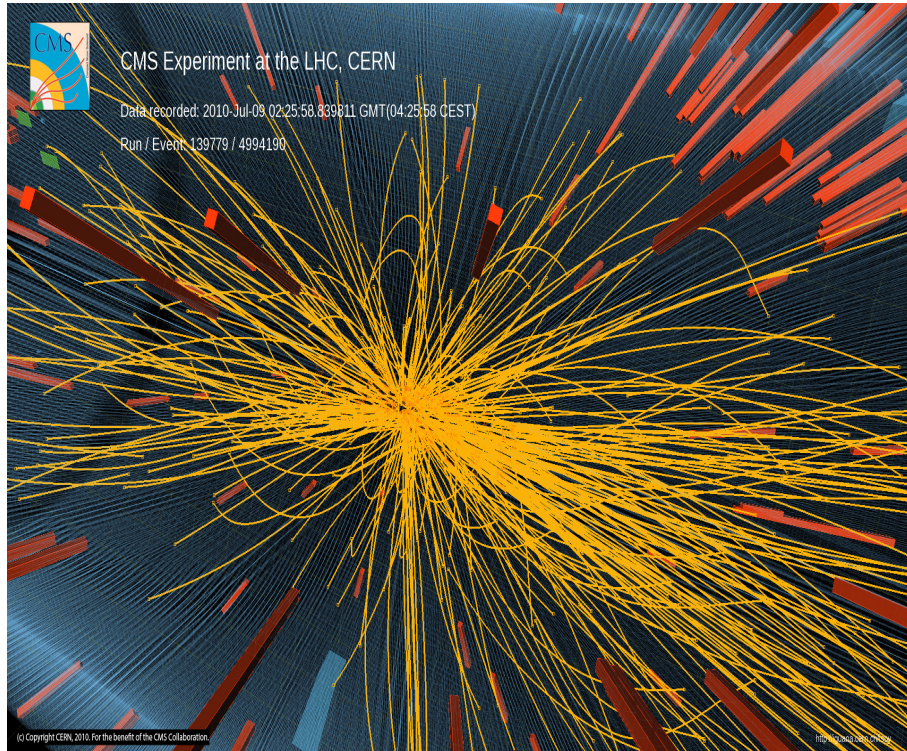


- Participant eccentricity scaling vs. transverse density



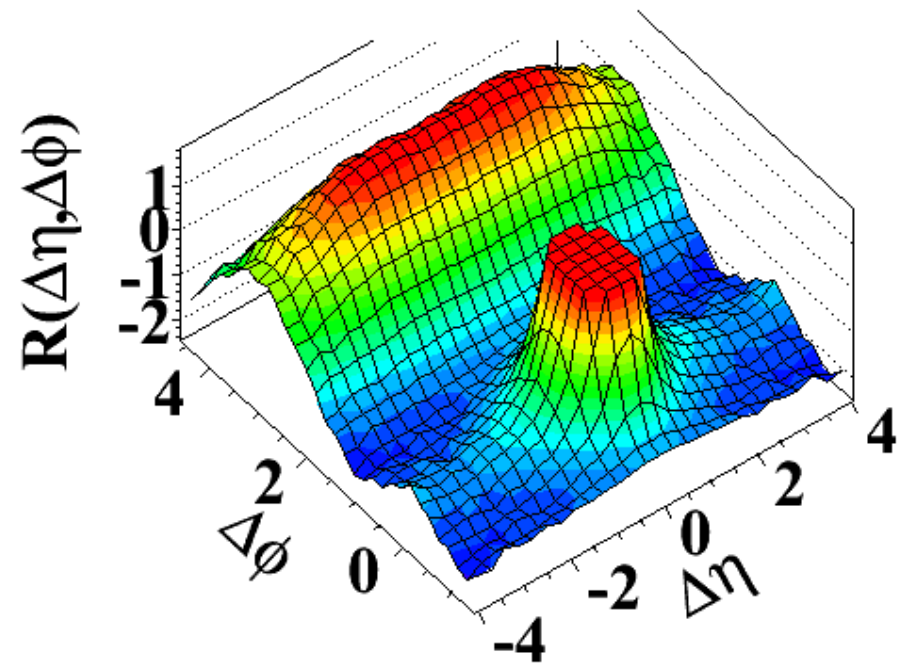
V. Zhukova (TODAY) , J. Velkovska (Tue), M. Issah (poster)

Ridge in high multiplicity pp



Intermediate p_T : 1-3 GeV/c

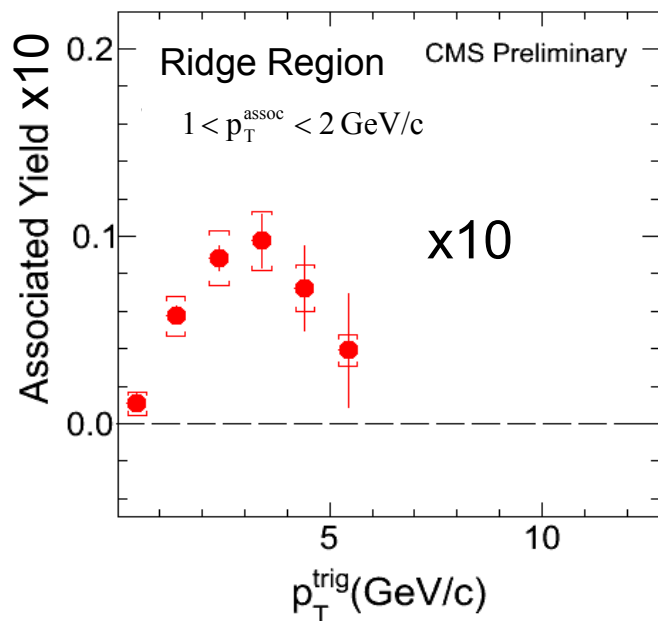
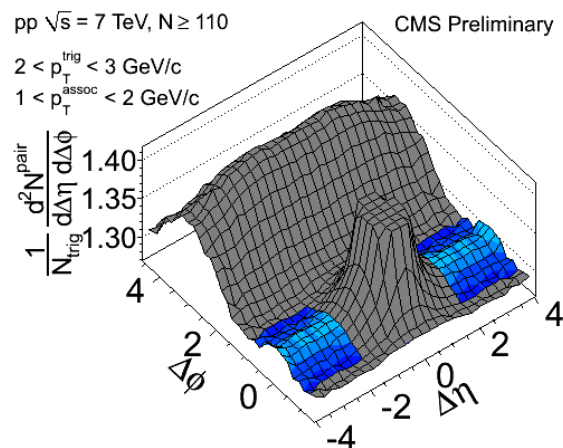
High multiplicity pp ($N \geq 110$)



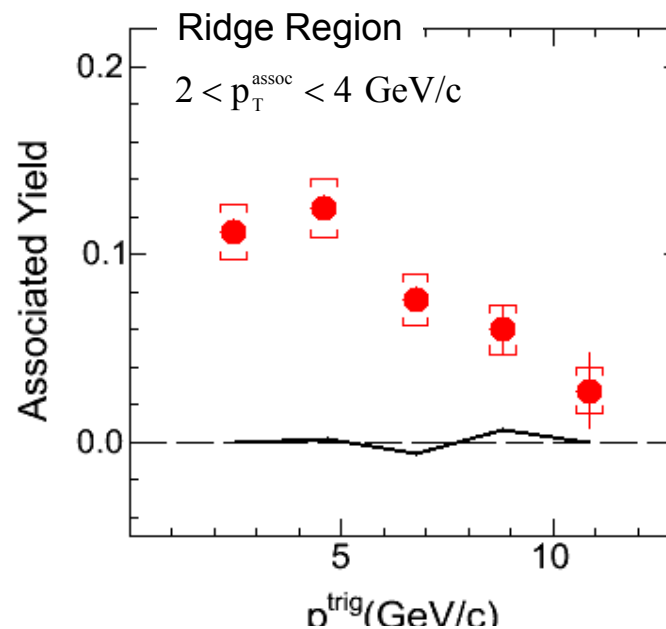
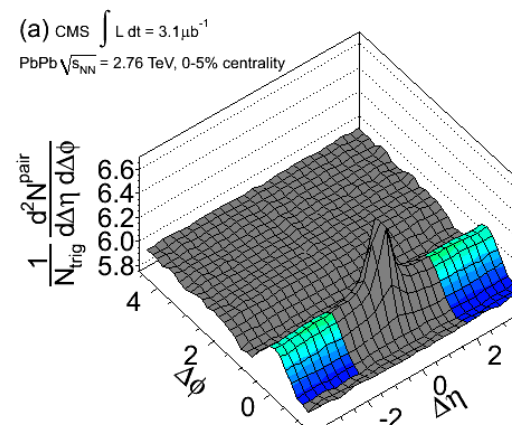
- ~350k top multiplicity events ($N > 110$) out of 50 billion collisions!
- Real-time tracking in High Level Trigger, CPU intensive
- Heavy-ion like effect in pp collisions

Ridge in pp and PbPb

CMS pp 7 TeV, $N \geq 110$



CMS PbPb 2.76 TeV, 0-5%



arXiv:1105.2438

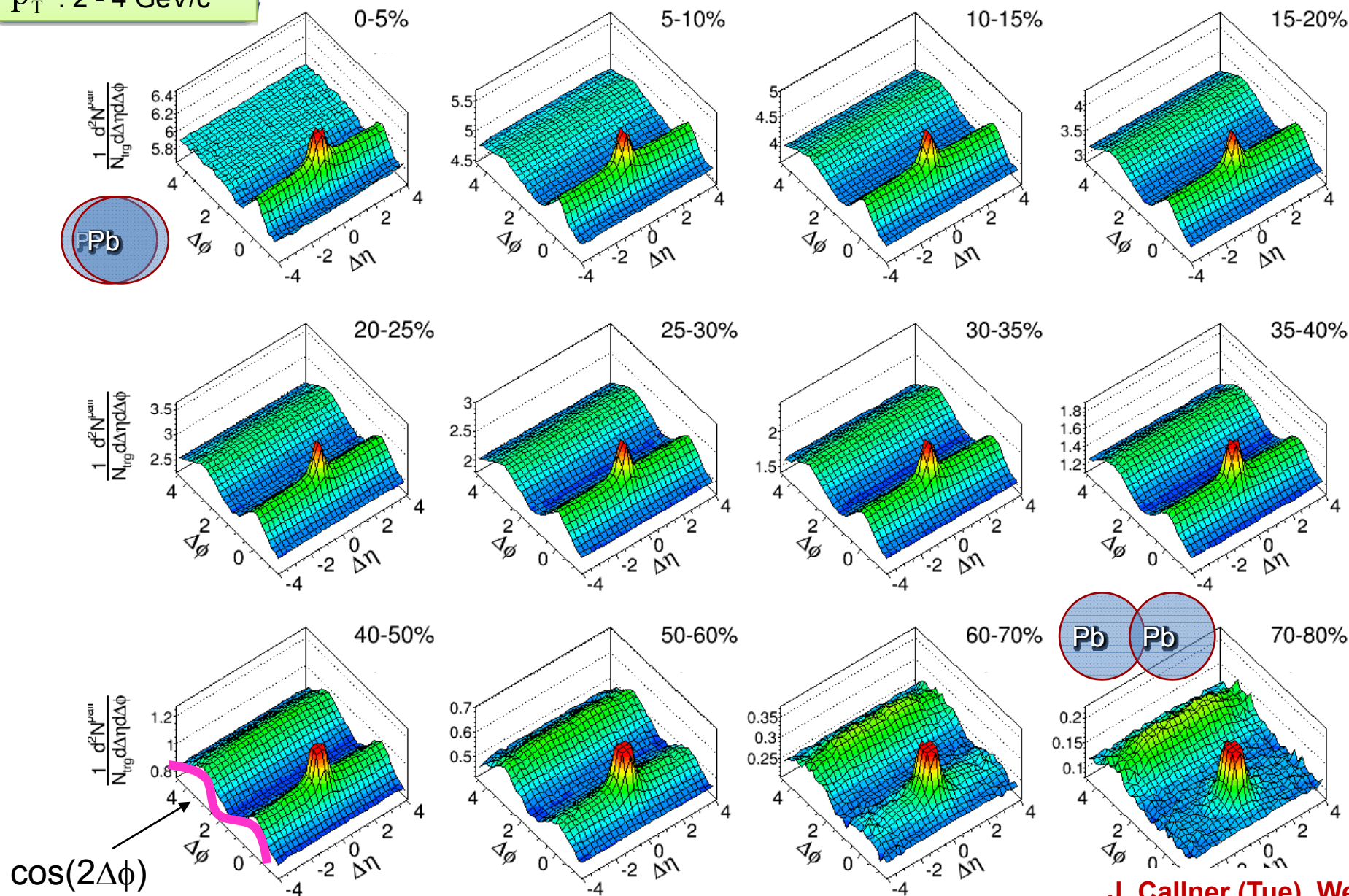
D. Velicanu (TODAY), J. Callner (Tue), Wei Li (Thu)

Triggered dihadron centrality dependence in PbPb

$p_T^{\text{trig}} : 4 - 6 \text{ GeV/c}$
 $p_T^{\text{assoc}} : 2 - 4 \text{ GeV/c}$

PbPb 2.76 TeV

CMS Preliminary

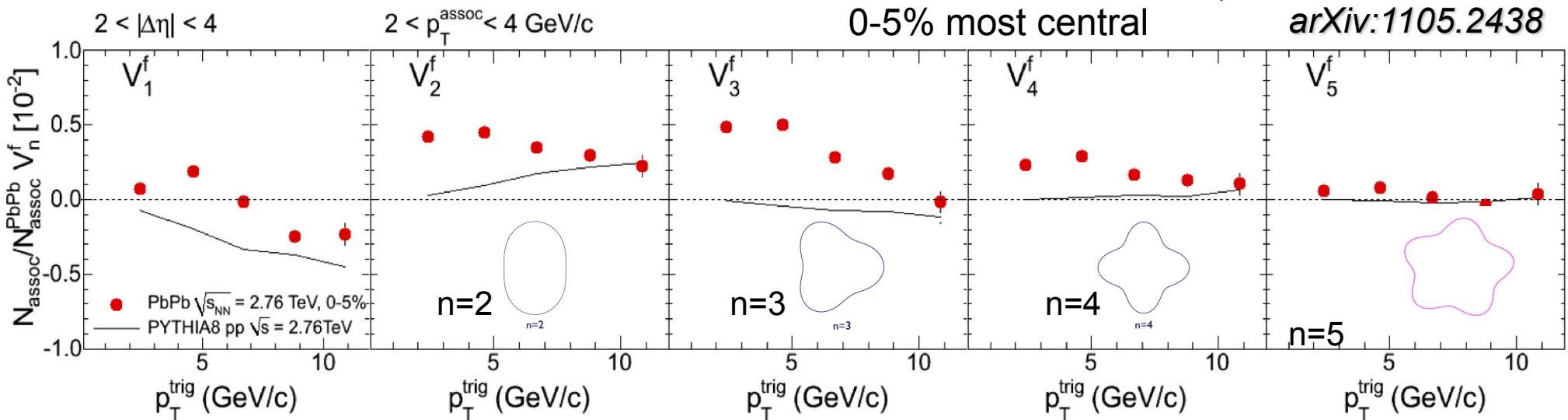
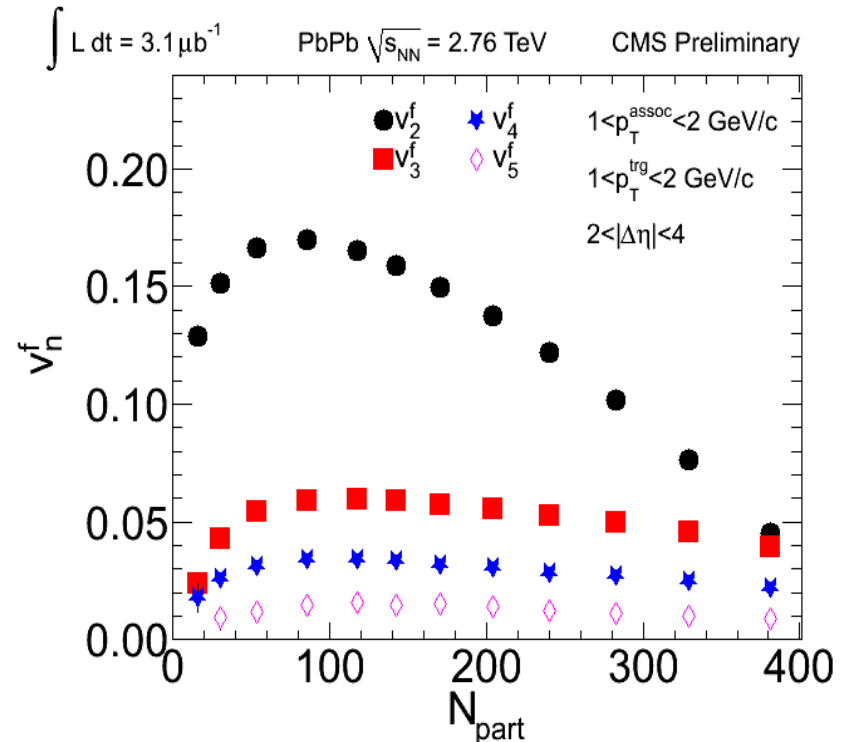
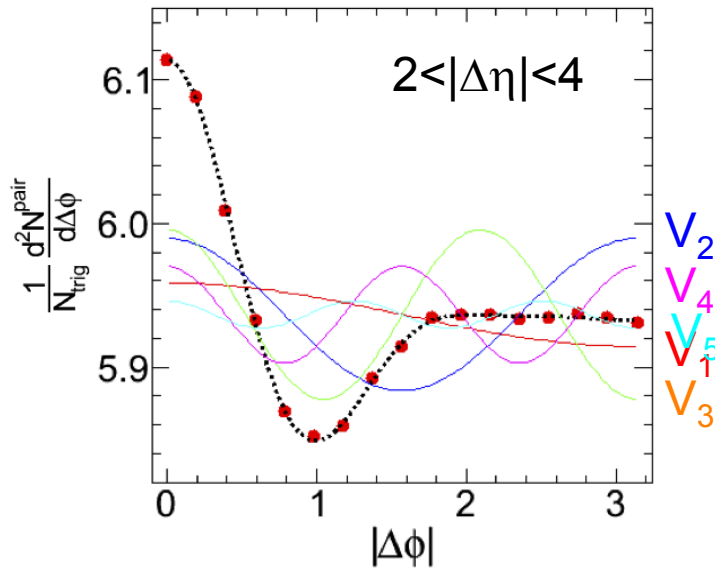


J. Callner (Tue), Wei Li (Thu)



Fourier decomposition of $\Delta\phi$ correlations

$$\frac{1}{N_{\text{trig}}} \frac{dN^{\text{pair}}}{d\Delta\phi} = \frac{N_{\text{assoc}}}{2\pi} \left(1 + 2 \sum_{n=1} V_n^f \cos(n\Delta\phi) \right)$$

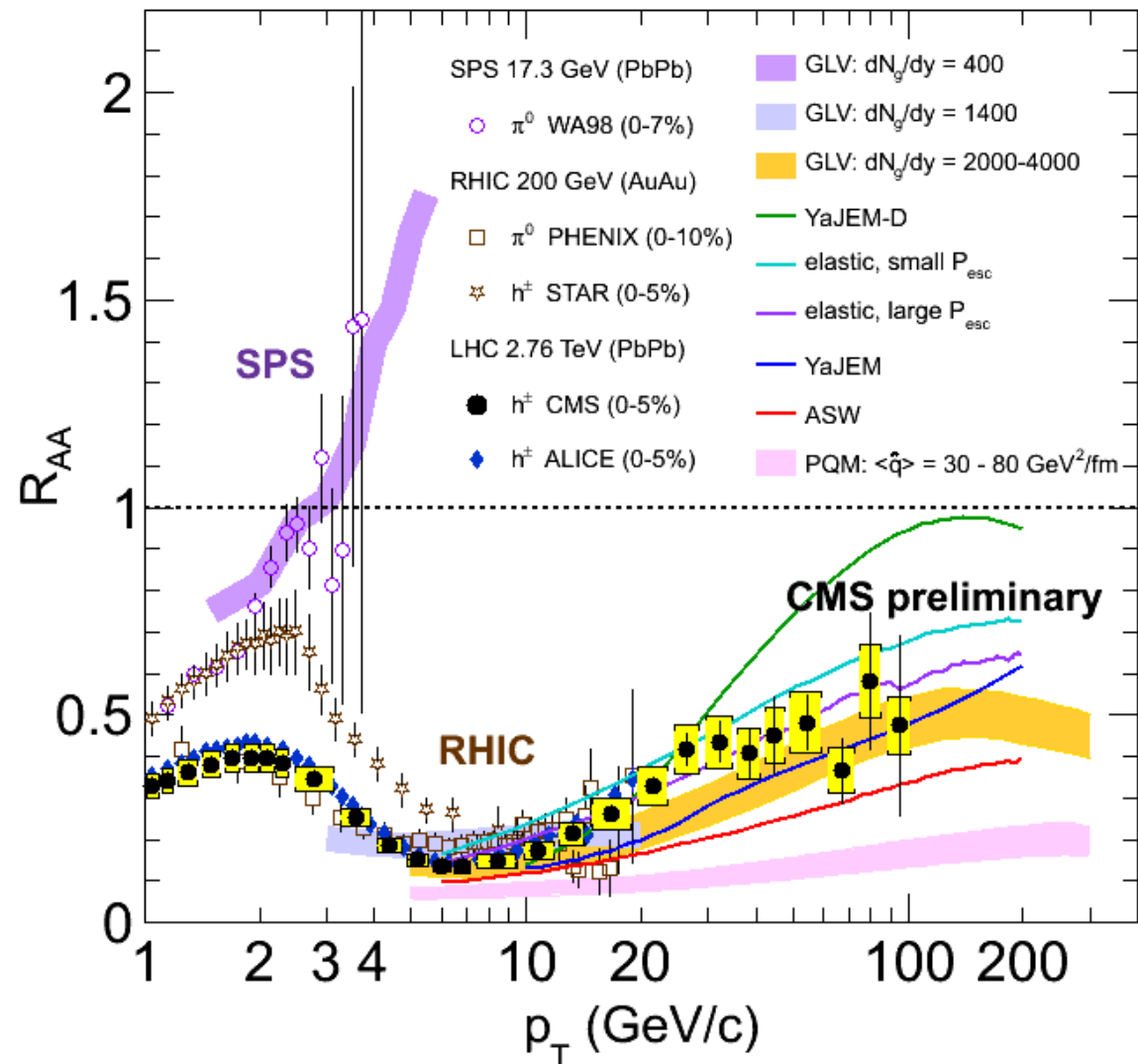
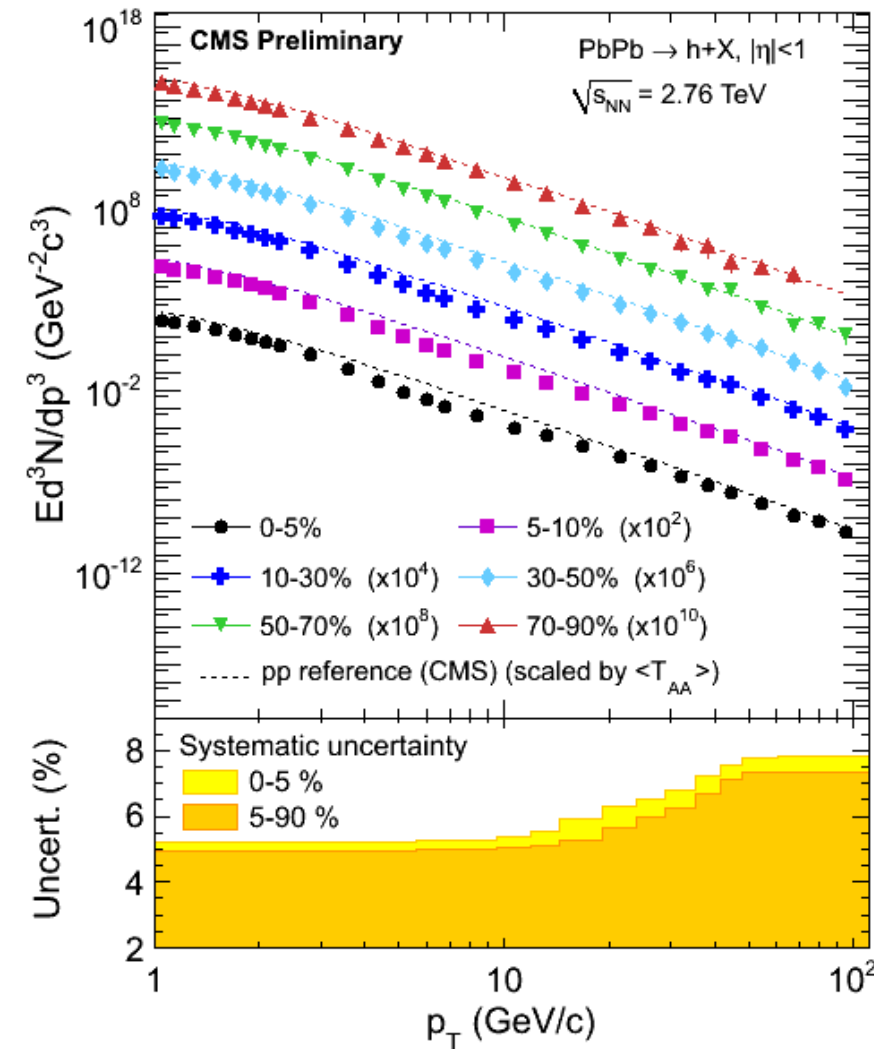


arXiv:1105.2438

J. Callner (Tue), Wei Li (Thu)

High p_T charged hadron suppression

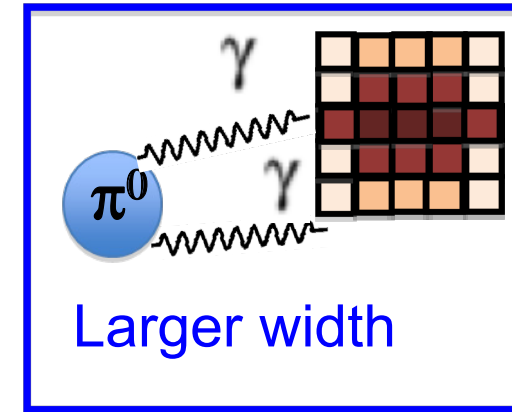
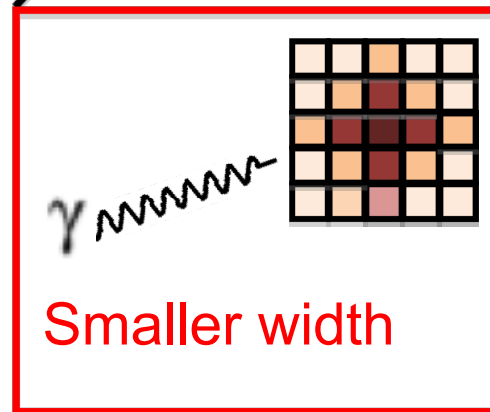
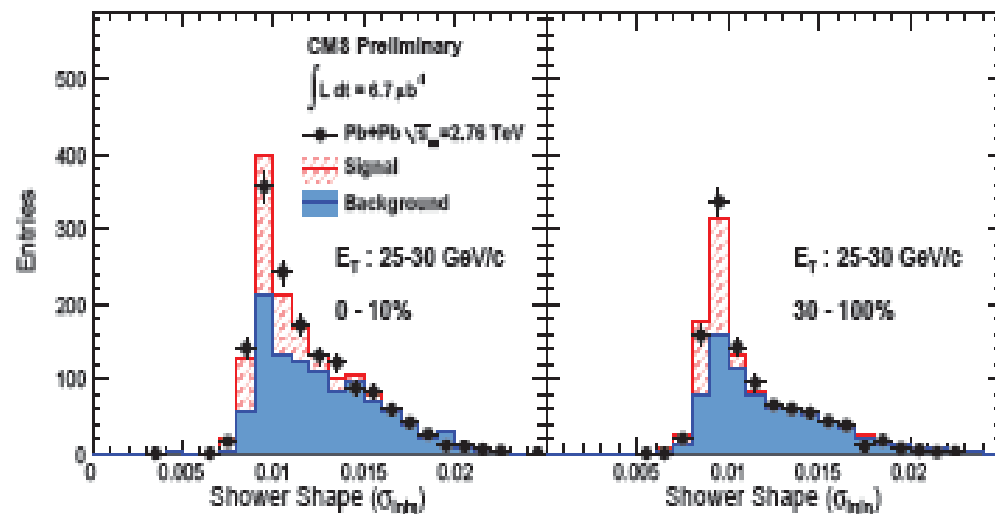
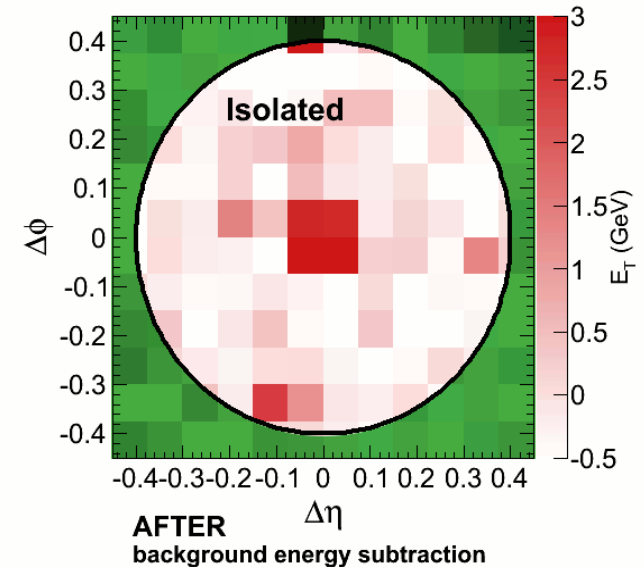
- Measuring charged tracks up to $p_T \sim 100$ GeV/c
- Using jet triggers to enhance statistics at high p_T



Y-J Lee (Wed) A. Yoon (Thu)

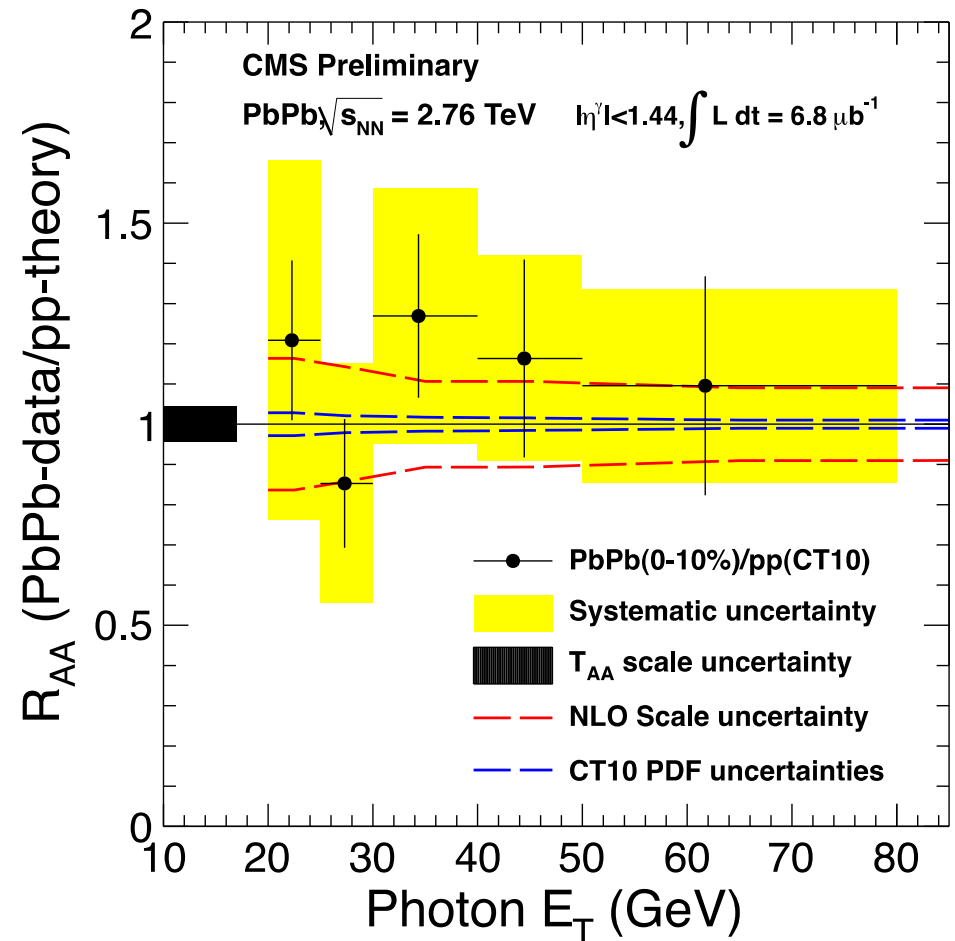
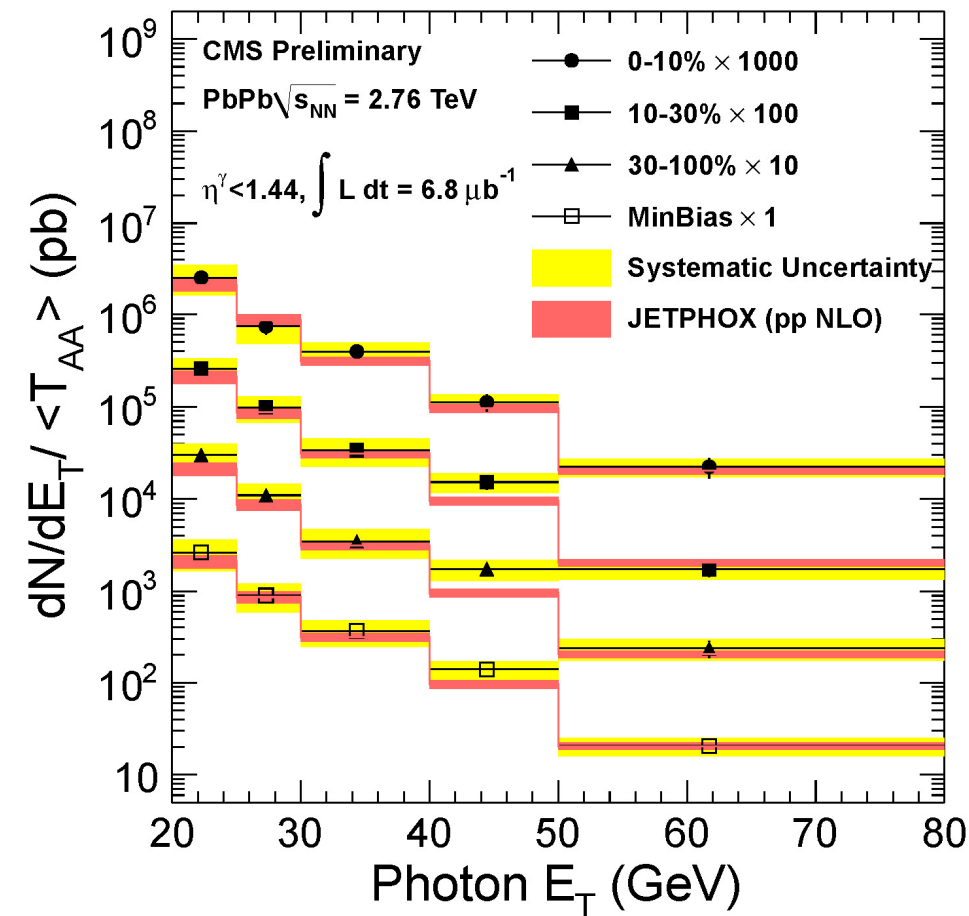
Isolated photons

- Colorless probes
 - Check suppression
 - Nuclear parton distribution function
 - Initial state
- Photon selection
 - Identify isolated electromagnetic clusters
 - $E_{\text{HCAL}}/E_{\text{ECAL}} < 0.2$
 - Energy in cone ($R < 0.4$) less than 5 GeV
 - Transverse shower shape



Y-J Lee (Thu), Y Kim (Fri)

Unsuppressed isolated high p_T photons

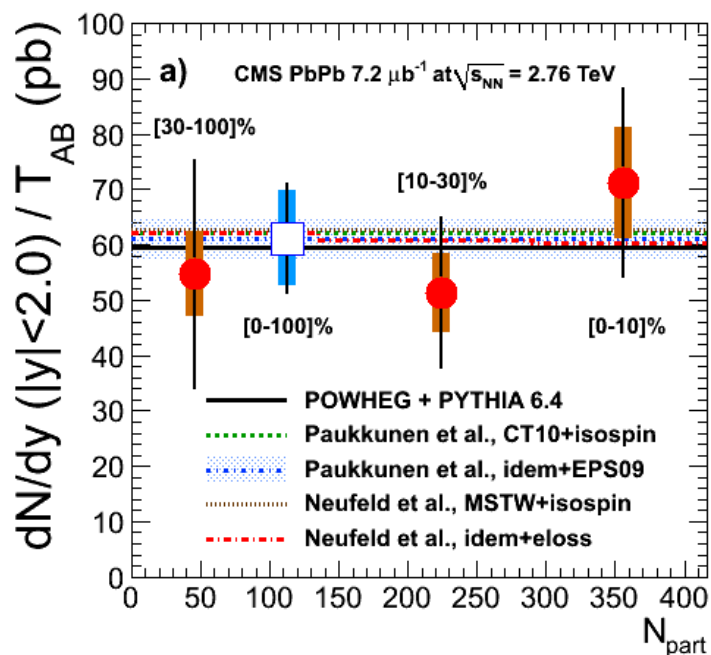
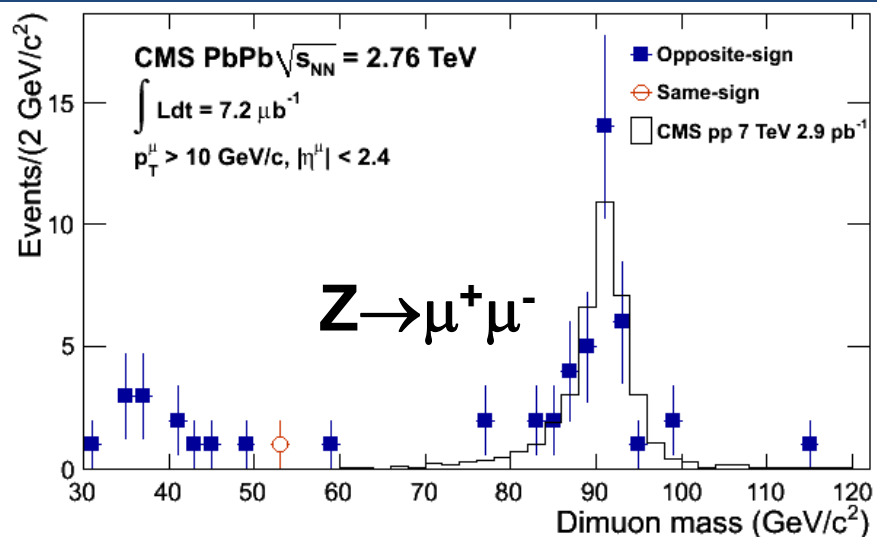


Confirmation of collisional scaling

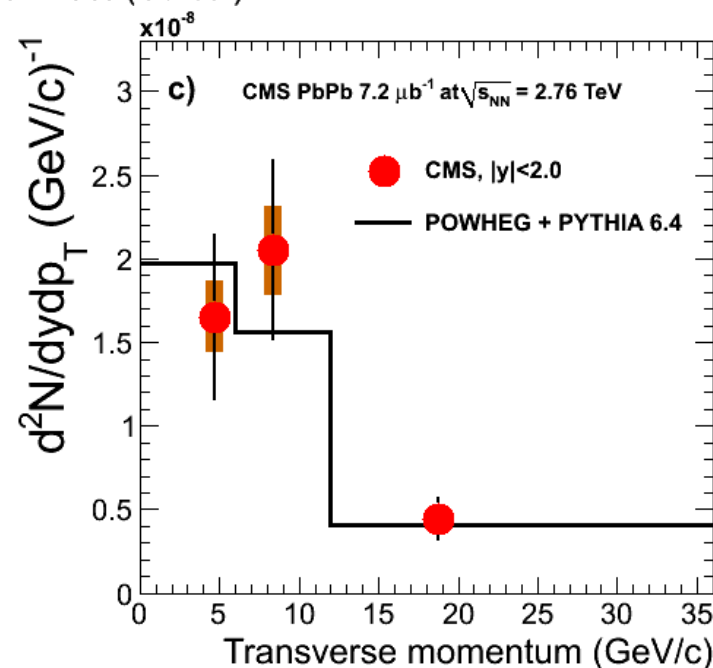
No nuclear modifications seen

Y-J Lee (Thu), Y Kim (Fri)

Z bosons show collisional scaling



No significant dependence on centrality



p_T dependence consistent with pp

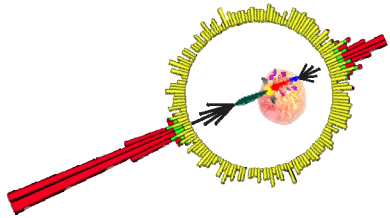
arXiv:1102.5435 accepted by PRL

J Robles (Thu)

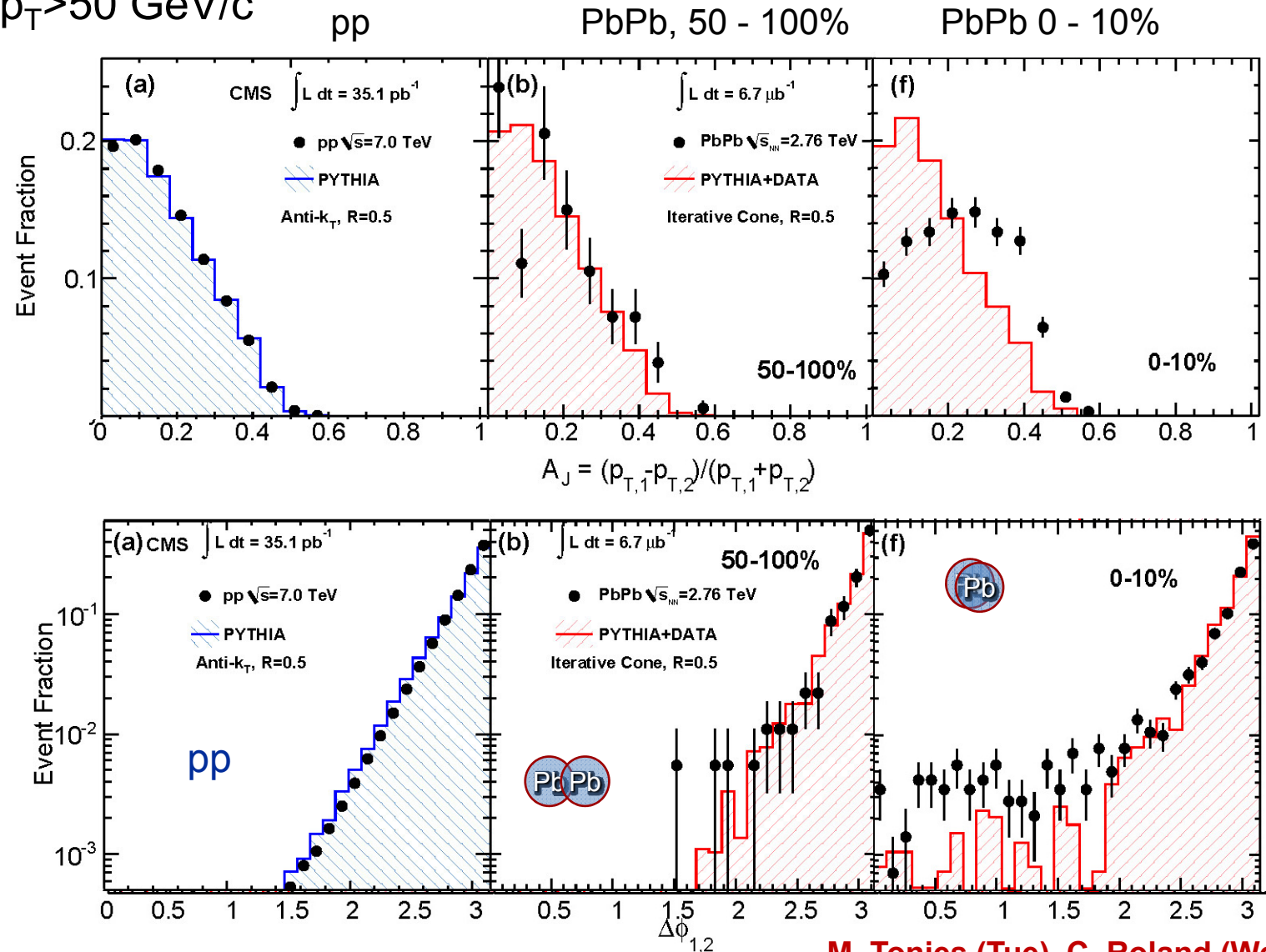
Jet quenching via large dijet energy imbalance

- Dijets, calorimeters only
 - Leading $p_T > 120$ GeV/c
 - Sub-leading $p_T > 50$ GeV/c

p_T imbalance, increasing with centrality



Back-to-back $\Delta\phi \sim \pi$ for all centralities



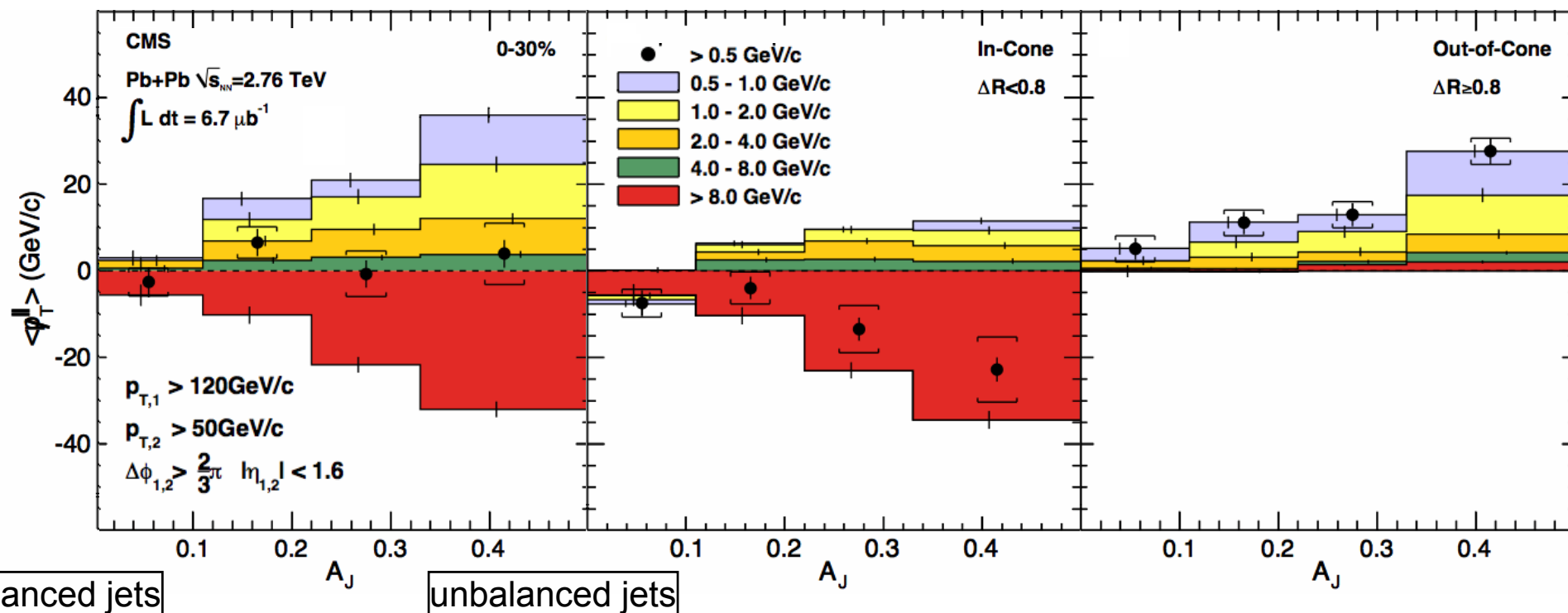
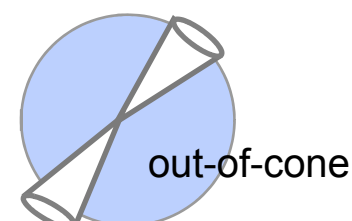
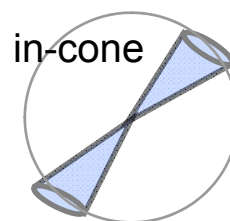
arXiv:1102.1957

M. Tonjes (Tue), C. Roland (Wed)

Where is the energy? spread out low p_T particles

$$p_T^{\parallel} = \sum_{\text{Tracks}} -p_T^{\text{Track}} \cos(\phi_{\text{Track}} - \phi_{\text{Leading Jet}})$$

0-30% Central PbPb



Low p_T , full acceptance
Momentum is balanced

In-cone large momentum
imbalance at high p_T
Consistent with calorimetry

Out-of-cone low p_T particles balance the complete event

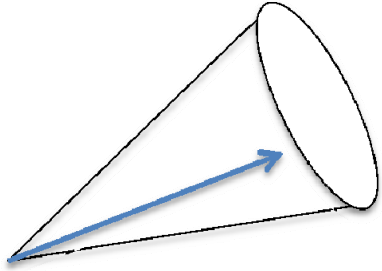
arXiv:1102.1957

M. Tonjes (Tue), C. Roland (Wed)

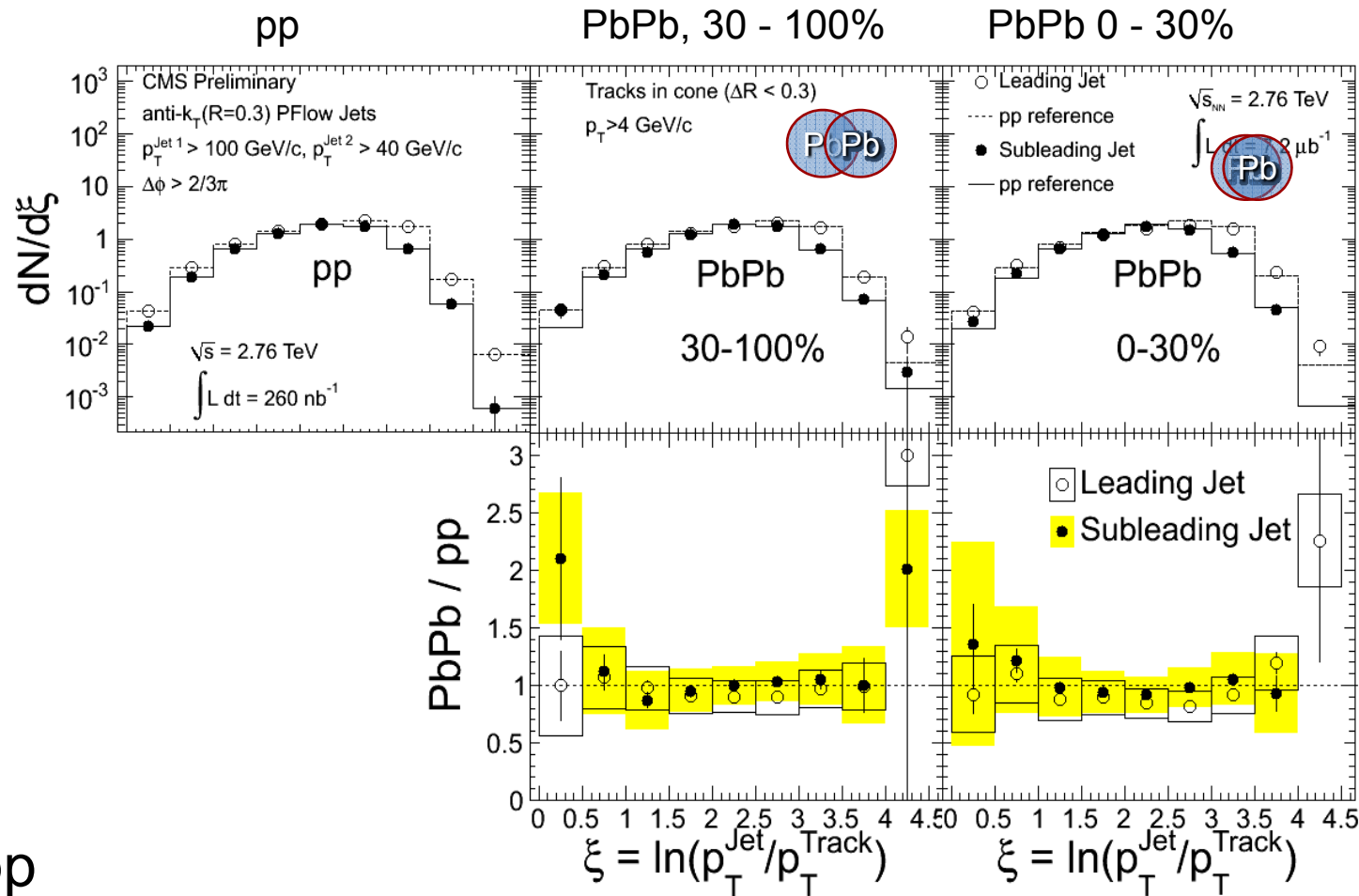


Jet fragmentation function, PbPb \approx pp

- Updated jet algorithm: Particle Flow, Anti- k_T , $R=0.3$
- Charged tracks, $p_T^{Track} > 4$ GeV/c, jets with $p_T^{Jet} = 40-300$ GeV/c



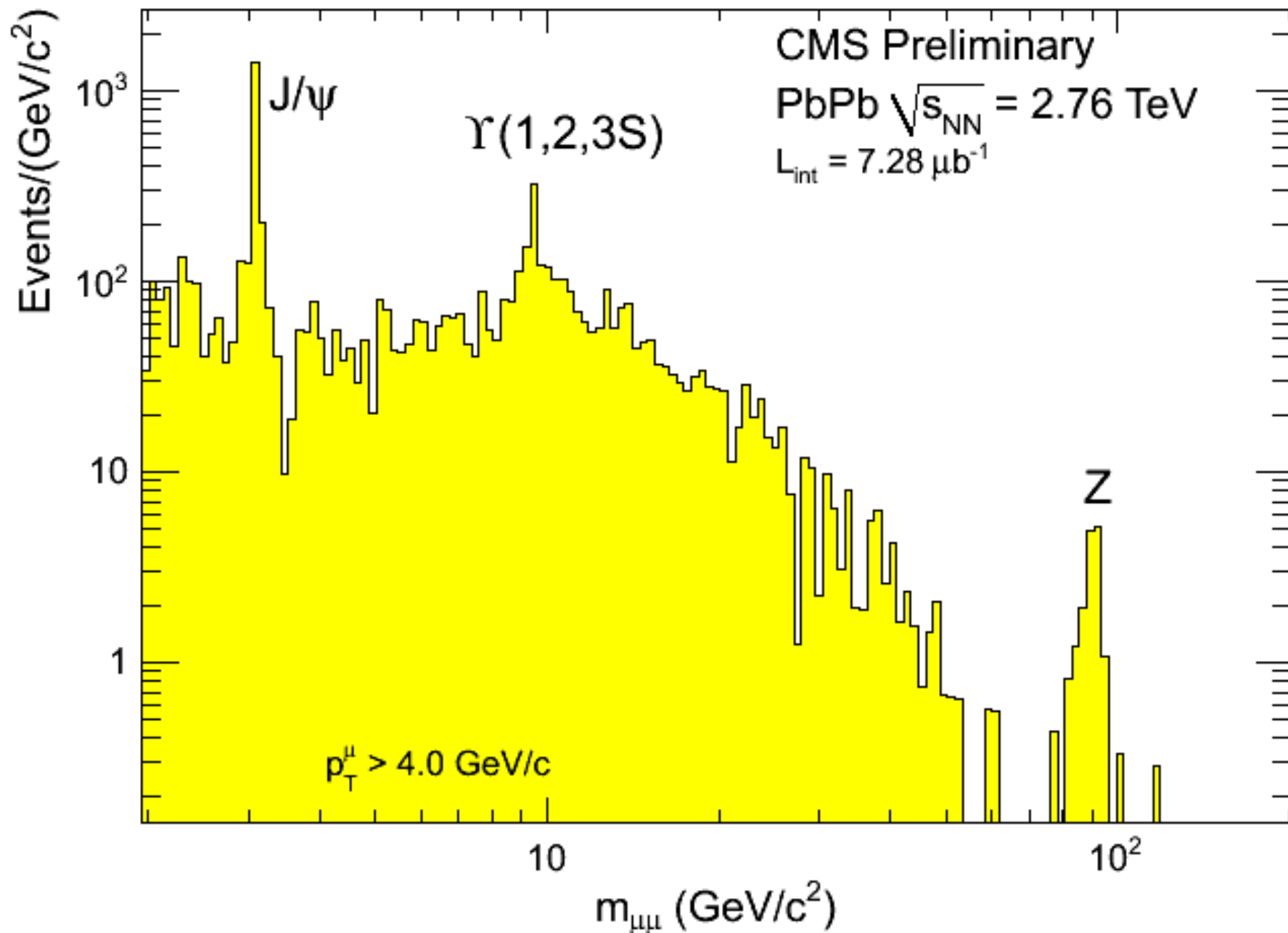
$$\xi = \ln \left(\frac{p_T^{Jet}}{p_T^{Track}} \right)$$



- Compare PbPb to pp
 - Fragmentation function similar between PbPb and pp
 - Jets fragment in the vacuum

Y. Yilmaz (Fri), C. Roland (Wed), M. Nguyen (Fri)

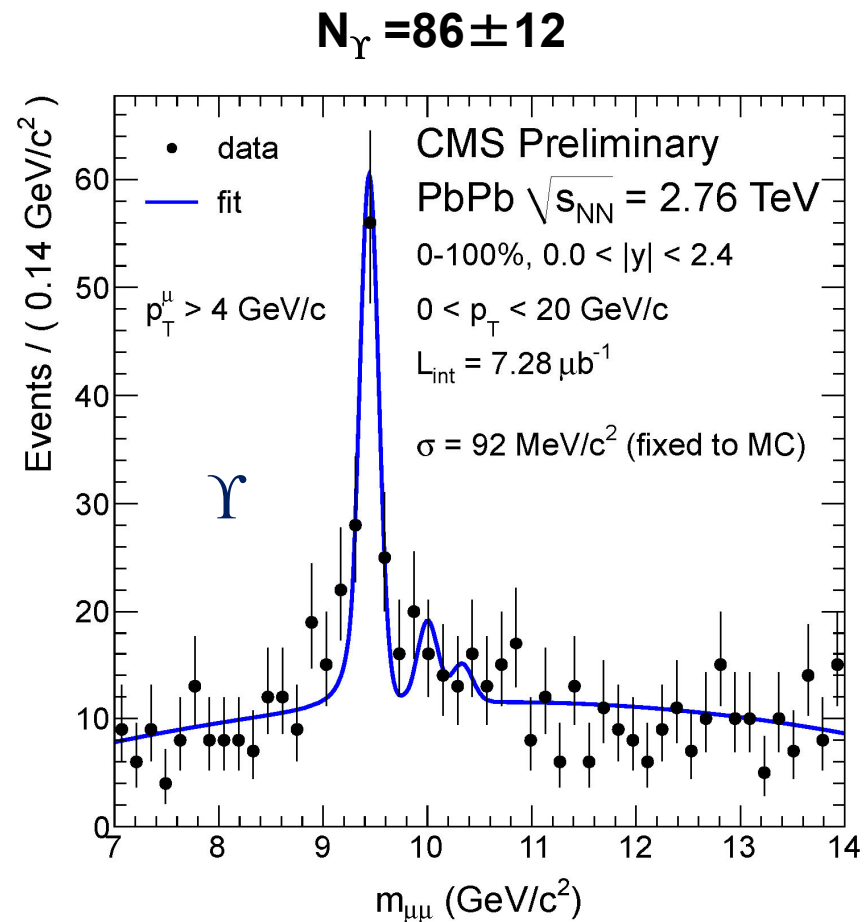
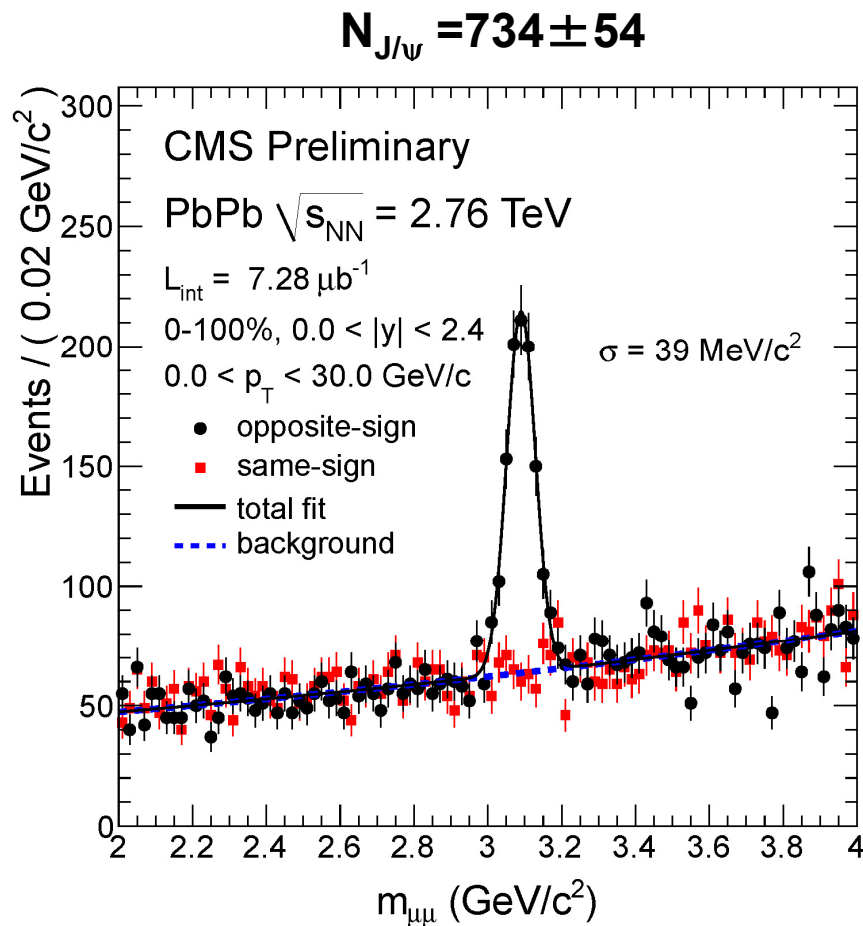
Compact Muon Solenoid: $\mu^+\mu^-$ invariant mass



Z. Hu (TODAY), T. Dahms (Tue), C. Silvestre (Fri), J. Robles (Fri), M. Jo (Poster), D.H.Moon (Poster), H. Kim (Poster)

J/ψ and Υ

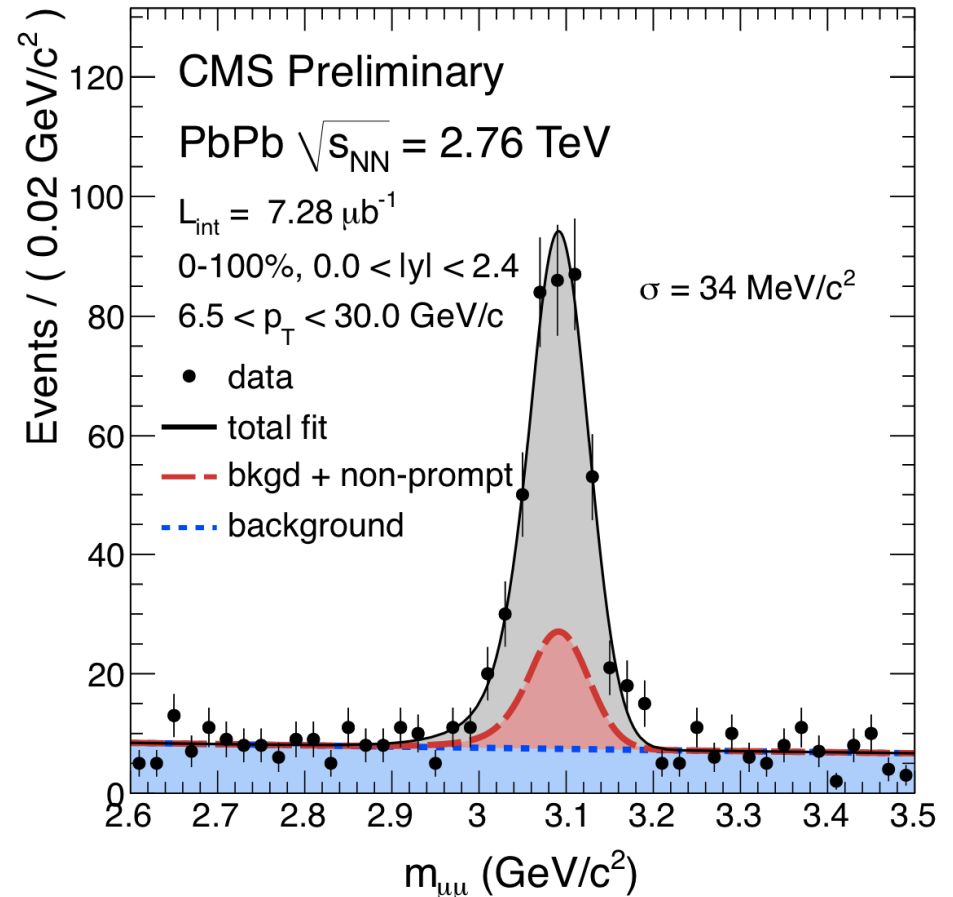
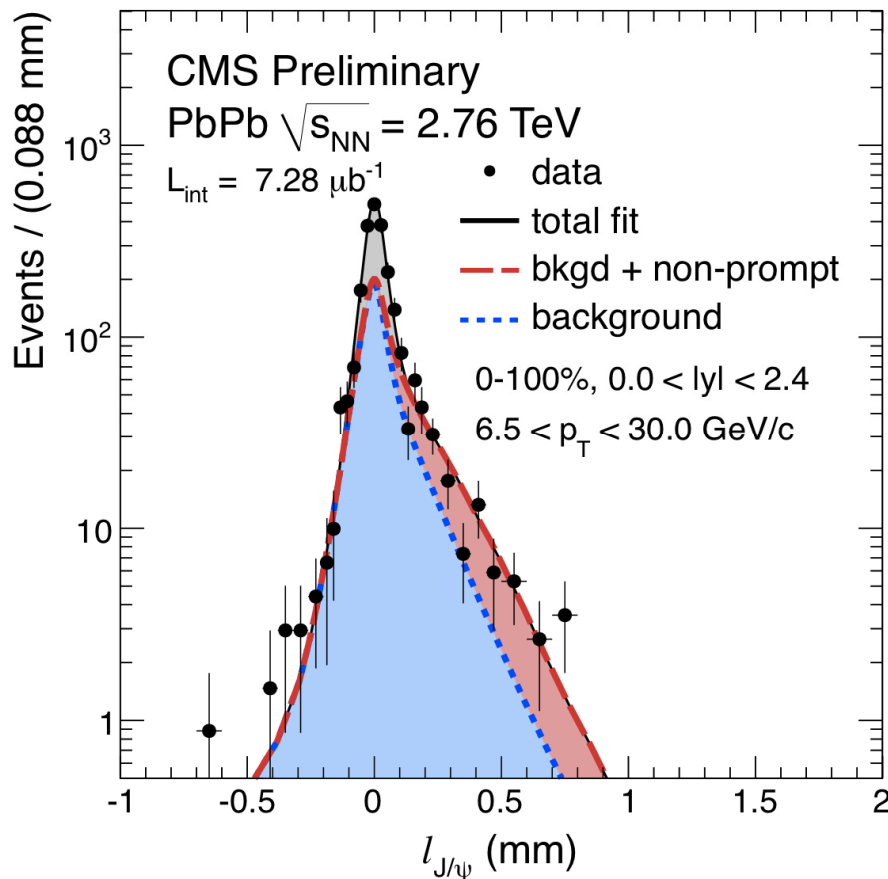
- J/ψ and Υ observed in $\mu^+\mu^-$ channel
- CMS muon acceptance $|\eta| < 2.4$, $p_{T\mu} > 2-4$ GeV/c
- Excellent mass resolution $\sim 1\%$, comparable to pp



Z. Hu (TODAY), T. Dahms (Tue), C. Silvestre (Fri)

J/ψ: prompt and from B decays

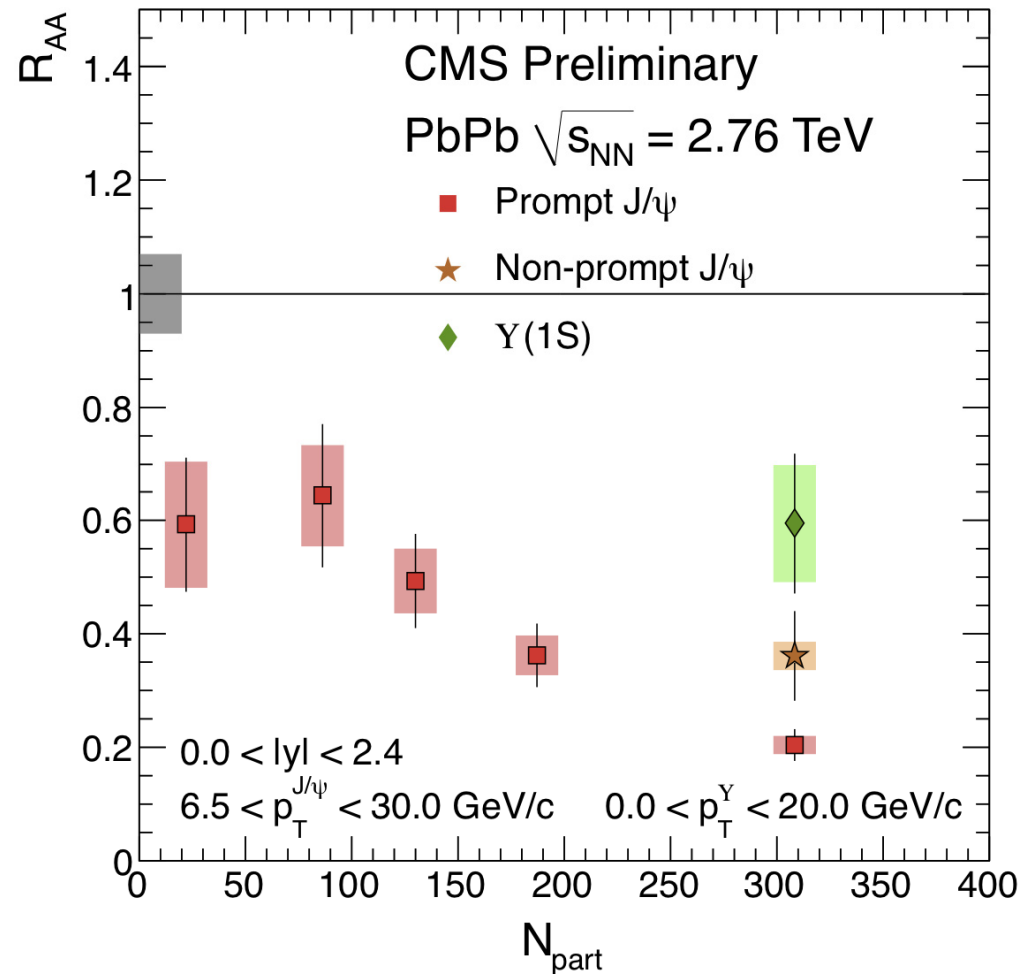
- Use separation of primary and $\mu^+\mu^-$ vertices in plane transverse to beam
- Long B decay times lead to displaced vertices
- Separate:
 - Prompt J/ψ production
 - Non-prompt J/ψ from B decays



T. Dahms (Tue), C. Silvestre (Fri)

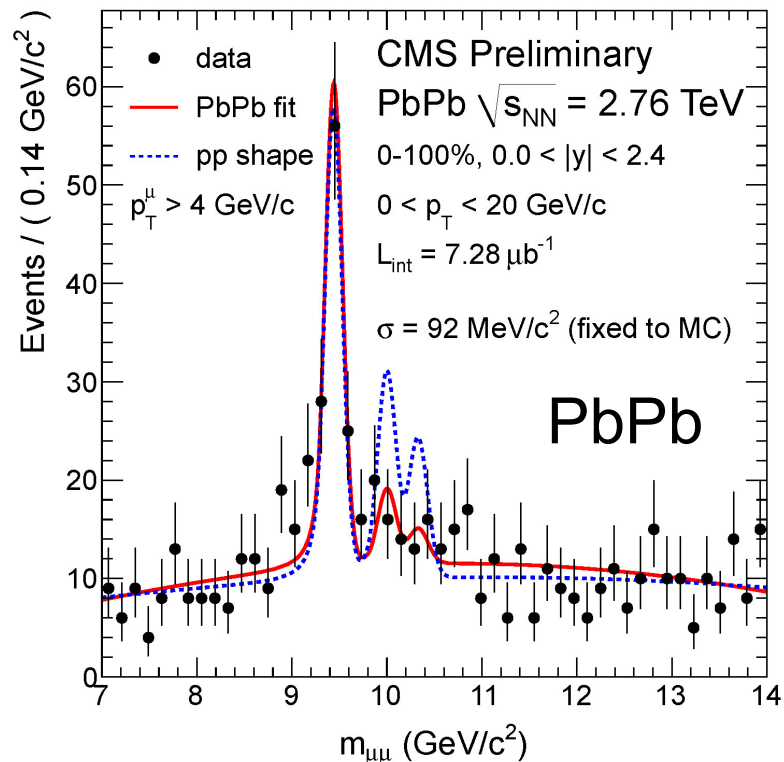
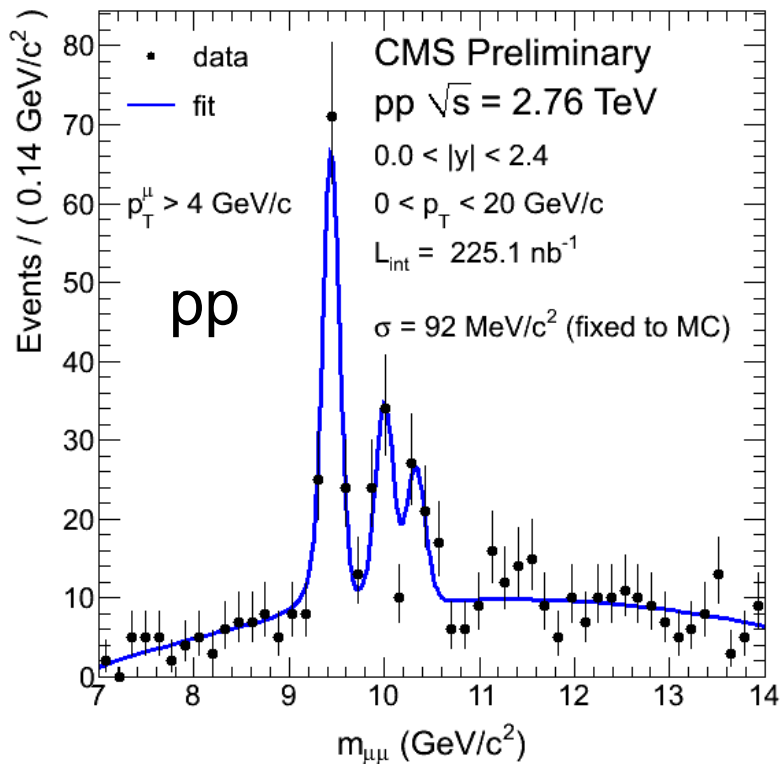
All quarkonia suppressed: R_{AA} vs. centrality

- Non-prompt J/ψ suppression is a measure of b-quark quenching
- High p_T J/ψ is strongly suppressed at the LHC
- Inclusive $\Upsilon(1S)$ is suppressed



Z. Hu (TODAY), T. Dahms (Tue), C. Silvestre (Fri)

Suppression of excited Υ states



$$\Upsilon(2S + 3S)/\Upsilon(1S)\big|_{pp} = 0.78^{+0.16}_{-0.14} \pm 0.02$$

$$\Upsilon(2S + 3S)/\Upsilon(1S)\big|_{PbPb} = 0.24^{+0.13}_{-0.12} \pm 0.02$$

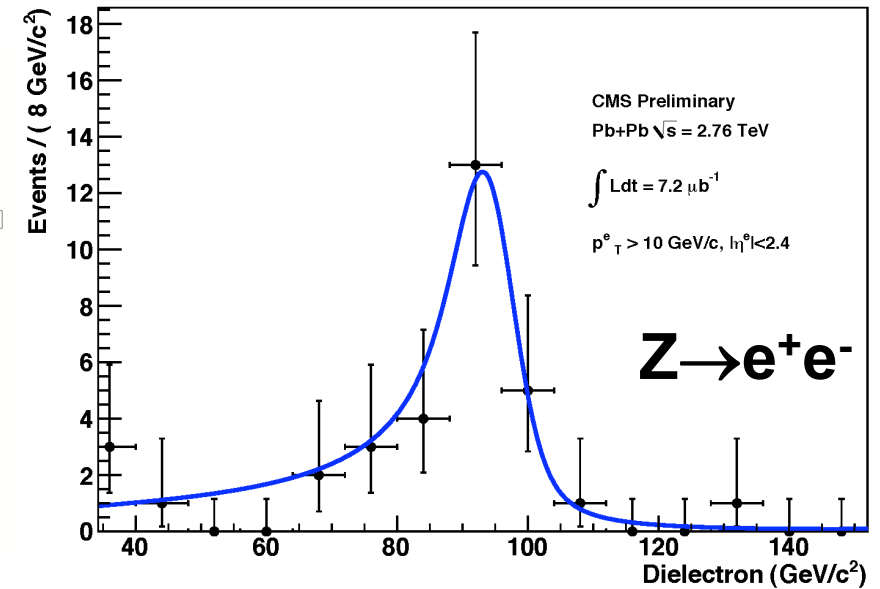
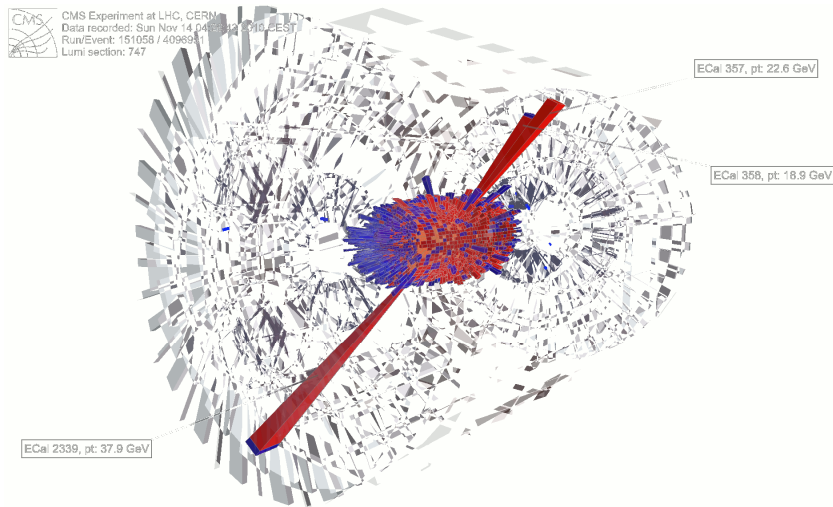
$$\frac{\Upsilon(2S + 3S)/\Upsilon(1S)\big|_{PbPb}}{\Upsilon(2S + 3S)/\Upsilon(1S)\big|_{pp}} = 0.31^{+0.19}_{-0.15} \pm 0.03$$

- Excited states $\Upsilon(2S,3S)$ relative to $\Upsilon(1S)$ are suppressed
- Probability to obtain measured value, or lower, if the real double ratio is unity, has been calculated to be less than 1%

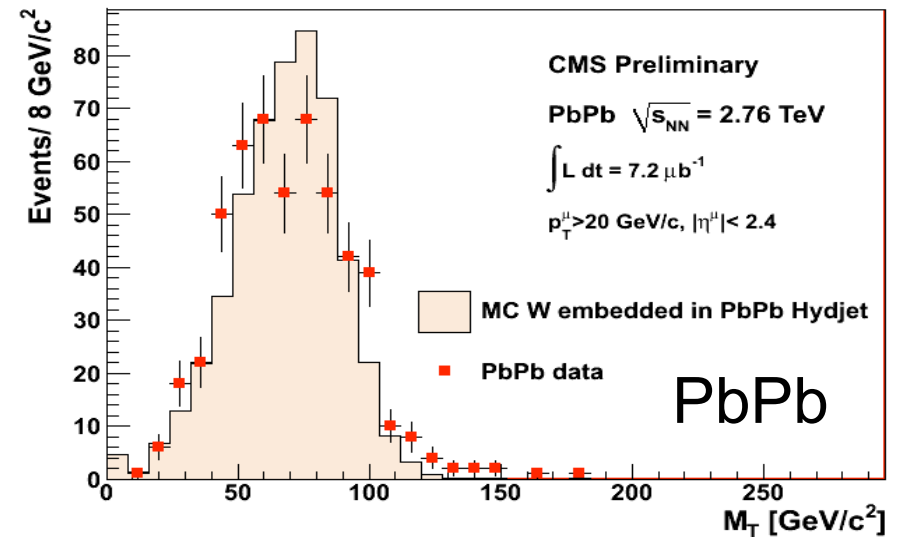
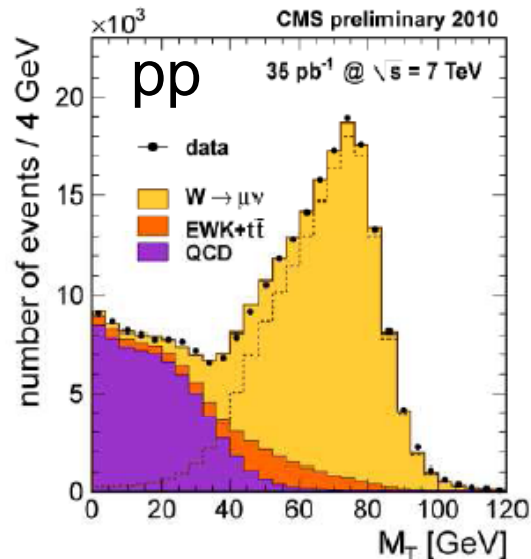
Z. Hu (TODAY), C. Silvestre (Fri)

Les desserts : $Z^0 \rightarrow e^+e^-$ and $W \rightarrow \mu\nu$

Z^0



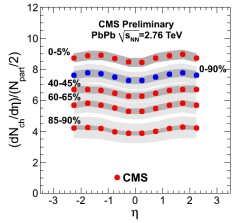
Hint of W^\pm



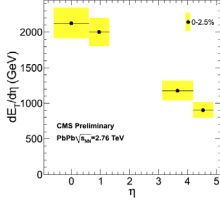
$$M_T = \sqrt{2 p_{T\mu} p_{T\nu} (1 - \cos \phi_{\mu\nu})}$$

J. Robles (Thu), L. Benhabib (Poster)

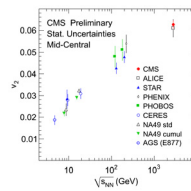
Summary of CMS experimental results



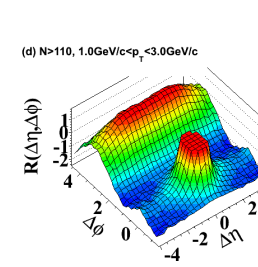
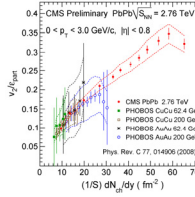
Charged hadron multiplicity



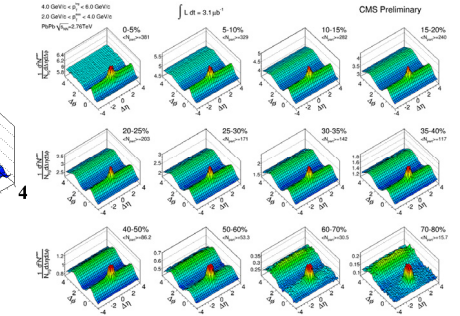
First: E_T



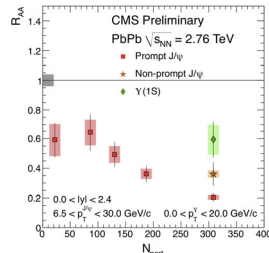
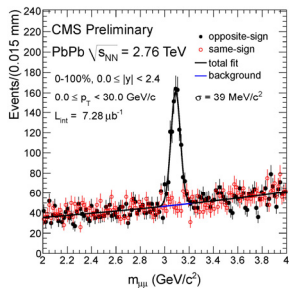
v_2 in wide acceptance



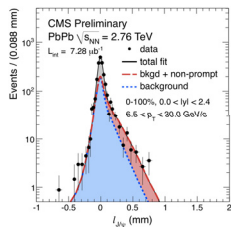
First dihadron correlations
pp and PbPb in wide acceptance



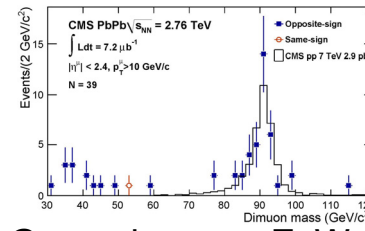
First: $h^+h^- R_{AA}$ p_T up to 100 GeV/c



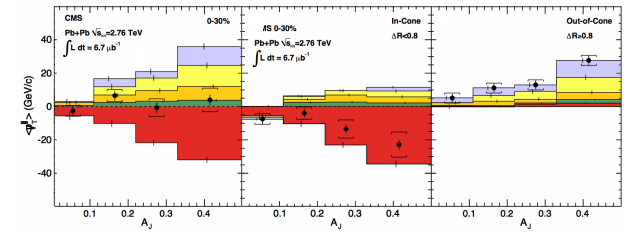
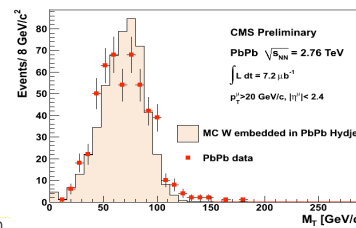
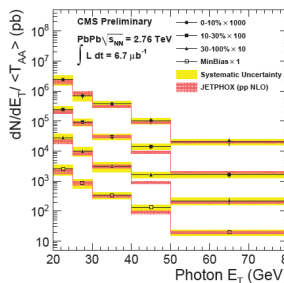
First: Prompt J/ψ and B-hadrons through non-prompt J/ψ



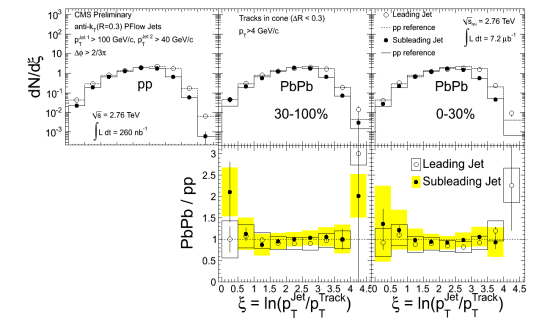
A First: Suppression of excited Υ



First: Gauge bosons: Z, W, isolated- γ



First: Jet imbalance and jet fragmentation function

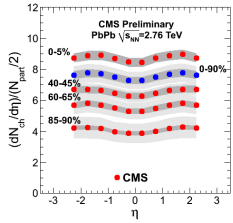


Summary

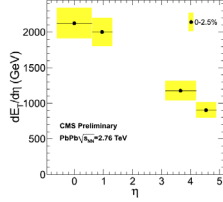
- CMS experiment performed flawlessly during the 2010 heavy ion run period at LHC
- CMS has obtained significant statistics of hard probes
- CMS conducted detailed measurements of global properties of medium in PbPb and pp collisions
- Our measurements indicate consistent view of the hot and dense medium
 - Strong collective effects in the medium
 - No quenching of weakly and electromagnetically interacting probes
 - Strong quenching of partons, including b-quarks
 - Suppression of quarkonia, including excited states of the Υ
- Thanks to CERN for fantastic LHC performance!

For more info click here: [CMS Heavy Ion Results](#)

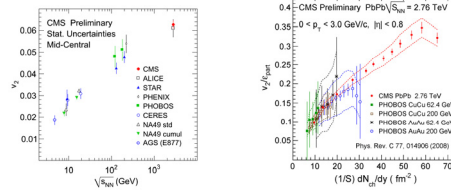
Take home messages from CMS



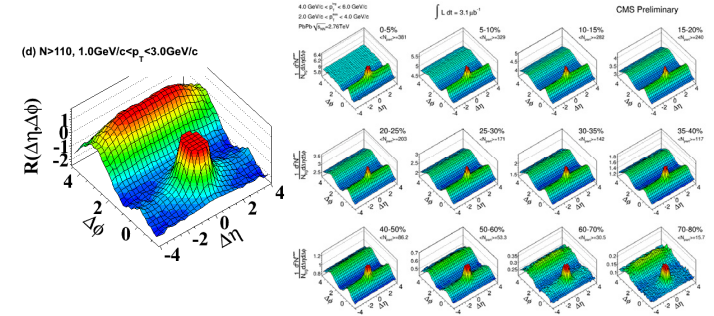
Charged hadron multiplicity



First: E_T

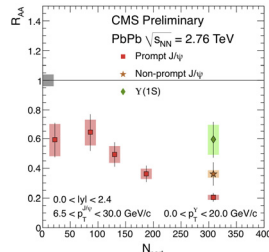
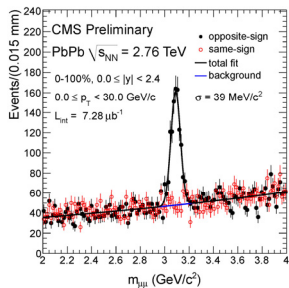


v_2 in wide acceptance

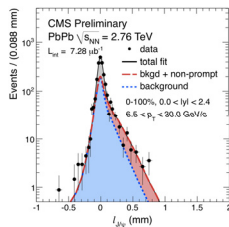


First dihadron correlations
pp and PbPb in wide
acceptance

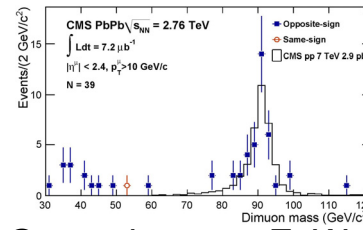
First: h^\pm R_{AA} p_T up to 100 GeV/c



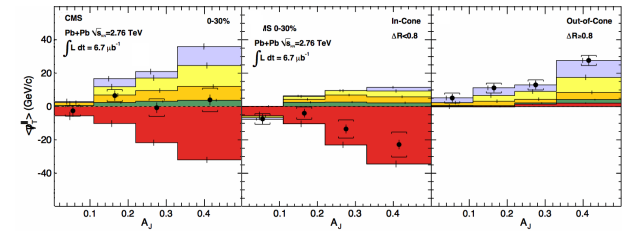
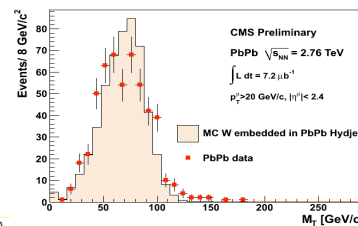
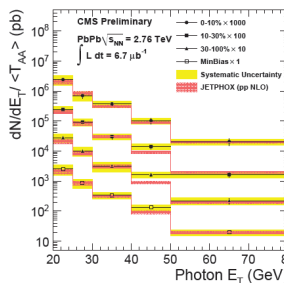
First: Prompt J/ψ and
B-hadrons through non-prompt J/ψ



A First: Suppression of excited Υ



First: Gauge bosons: Z, W, isolated- γ



First: Jet imbalance and
jet fragmentation function

