

# HIN PAG Status and Plans



Gábor Veres (CERN)  
*for the HIN group*

*Conveners: Julia Velkovska*  
*Gabor Veres (outgoing)*  
*Christof Roland (incoming)*

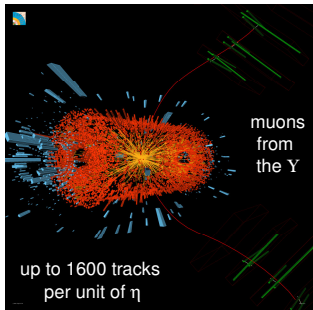
**CMS Week, CERN**

**14 December, 2012**



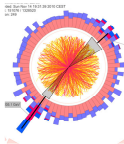
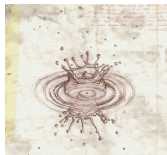
# The CMS Heavy Ion PAG

- About 110 people in total, from 20 institutes
- Two-fold responsibilities:
  - **Physics** analysis, publications, conference talks, etc.
  - Various tasks connected to CMS **operations** and **offline**, in PbPb and pPb collisions
    - Trigger concepts, special triggers, menu preparation, validation
    - Special operation parameters, NZS in some cases, baseline algorithms
    - Heavy-ion related software, objects, etc.



# Physics topics and tools

- Strong interaction under extreme conditions
  - High density, temperature, pressure, collective phenomena (described by near-perfect-fluid hydrodynamics)
  - Phase transition to deconfined quark-gluon matter
  - Parton saturation and low-x physics
  - Nuclear parton distribution functions...
- Analysis methods adapted to these goals:
  - ‘bulk observables’: created number of particles, energy, azimuthal asymmetry of particle production, two-particle correlations
  - Quarkonium states ( $J/\Psi$ ,  $\Upsilon$ ) to measure dissociation related to Debye-screening, temperature,...
  - ‘hard probes’ established in HEP, to study the ‘medium’:
    - Strongly interacting probes: jets, charged particles, b-jets
    - Penetrating probes: Z, W, photons

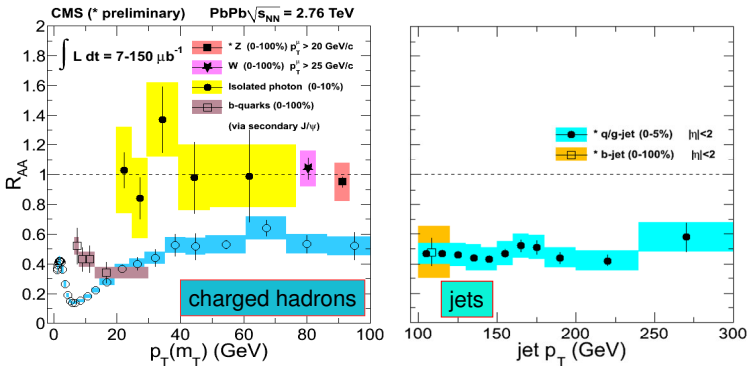


CMS has excellent capabilities for these studies!

# Milestones – timeline

- **Sept 12, 2012:** pPb test run, at  $\sqrt{s_{NN}}=5$  TeV
  - ~one fill at low luminosity, 2 million collisions
- **14 Jan – 10 Feb, 2013:** ion run
  - Requests: pPb@5 TeV (30/nb) to match the 2011 PbPb statistics;  
pp@2.76 TeV (6/pb) to match the 2011 PbPb stats,  $\sqrt{s}$   
[pp@5 TeV (6/pb) to match the 2013 pPb stats and  $\sqrt{s}$ ]
- **2013-14:** New analyses (pPb); finishing the QM12 papers
  - more elaborate and detailed analyses on:  
jet modification, quarkonia, W and Z, photons, UPC,...
  - Preparations for the high-luminosity PbPb runs: L1 upgrade
- **May 19-24, 2014:** Quark Matter'14 conference, Darmstadt

# Highlights: Nuclear modification factors



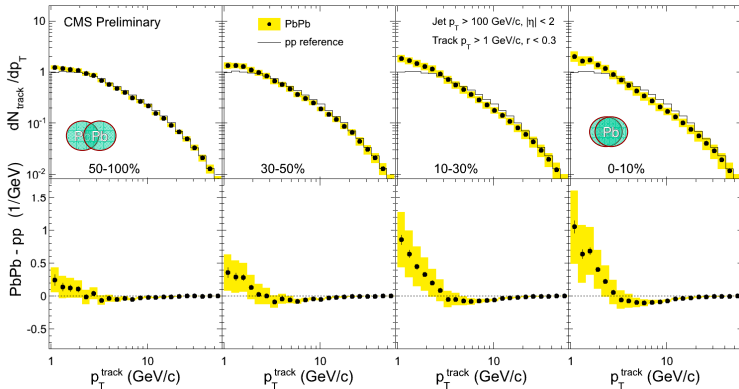
Factor of 2 higher  
 $p_T$  reach than ALICE

Sampling the ~same parton  $p_T$  range

100 GeV higher  
 $p_T$  reach than ATLAS

**Note:** jets fragment into high- $p_T$  particles in pp and PbPb the same way

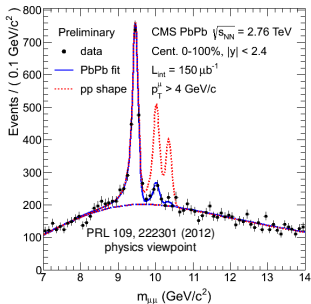
# Highlights: track $p_T$ distributions in jets



High  $p_T$ : **no change** compared to track distributions in pp jets  
Low  $p_T$ : excess of charged particles in central PbPb (quenched jets)

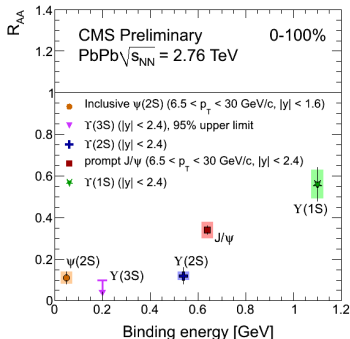
# Highlights: quarkonia suppression

2011 data



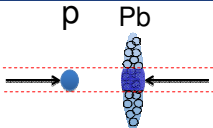
Observation of sequential  
suppression of Y family  
Detailed studies

Note:  $6.5 < p_T < 30$  GeV for J/ $\psi$  and  $\psi(2s)$



Expected in terms of  
binding energy

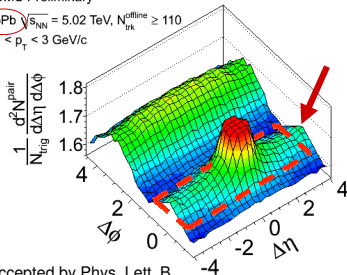
# Highlights: 'ridge' in pPb (and in pp, PbPb)



Unexplained features  
in two-particle correlations

CMS Preliminary

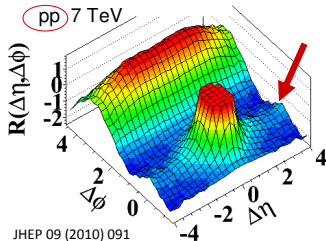
pPb  $\sqrt{s_{NN}} = 5.02$  TeV,  $N_{trk}^{offline} \geq 110$   
 $1 < p_T < 3$  GeV/c



accepted by Phys. Lett. B

(d)  $N > 110$ ,  $1.0 \text{ GeV}/c < p_T < 3.0 \text{ GeV}/c$

pp 7 TeV



JHEP 09 (2010) 091



# Submitted papers (the first ~2 years)

- |                                     |                       |                             |                         |
|-------------------------------------|-----------------------|-----------------------------|-------------------------|
| 1. HIN-10-004 (dijet imbalance):    | PRC 84 (2011) 024906  | <a href="#">[182 cites]</a> |                         |
| 2. HIN-11-007 (Y2s/Y1s ratio):      | PRL 107 (2011) 052302 | <a href="#">[65 cites]</a>  | * physics synopsis      |
| 3. HIN-10-005 ( $R_{AA}$ ):         | EPJC 72 (2012) 1945   | <a href="#">[55 cites]</a>  | on the cover of issue 3 |
| 4. HIN-10-006 (quarkonia):          | JHEP 05 (2012) 063    | <a href="#">[52 cites]</a>  |                         |
| 5. HIN-10-001 ( $dN_{ch}/d\eta$ ):  | JHEP 08 (2011) 141    | <a href="#">[42 cites]</a>  |                         |
| 6. HIN-11-001 (correlations):       | JHEP 07 (2011) 076    | <a href="#">[33 cites]</a>  |                         |
| 7. HIN-10-003 (Z):                  | PRL 106 (2011) 212301 | <a href="#">[30 cites]</a>  | *                       |
| 8. HIN-11-006 (correlations):       | EPJC 72 (2012) 2012   | <a href="#">[29 cites]</a>  |                         |
| 9. HIN-11-013 (dijets):             | PLB 712 (2012) 176    | <a href="#">[29 cites]</a>  |                         |
| 10. HIN-11-010 ( $\gamma$ -jet):    | PLB                   | <a href="#">[23 cites]</a>  | *                       |
| 11. HIN-11-012 (high $p_T$ $v_2$ ): | PRL 109 (2012) 022301 | <a href="#">[21 cites]</a>  | *                       |
| 12. HIN-10-002 ( $v_2$ flow):       | PRC                   | <a href="#">[18 cites]</a>  |                         |
| 13. HIN-11-002 (photons):           | PLB 710 (2012) 256    | <a href="#">[18 cites]</a>  | *                       |
| 14. HIN-11-004 (jet FF):            | JHEP 10 (2012) 087    | <a href="#">[15 cites]</a>  | *                       |
| 15. HIN-11-011 (Y):                 | PRL 109 (2012) 222301 | <a href="#">[9 cites]</a>   | * physics viewpoint     |
| 16. HIN-11-003 ( $dE_T/d\eta$ ):    | PRL 109 (2012) 152303 | <a href="#">[6 cites]</a>   | * physics viewpoint     |
| 17. HIN-11-008 (W):                 | PLB 715 (2012) 66     | <a href="#">[6 cites]</a>   | *                       |
| 18. HIN-12-015 (pPb ridge):         | PLB                   | <a href="#">[2 cites]</a>   | *                       |
| 19. HIN-11-009 ( $\pi^0$ $v_2$ ):   | PRL                   | <a href="#">[0 cites]</a>   | *                       |

~0.8 papers/month

**published  
accepted**

\* first-ever  
measurements  
in heavy ions at LHC

# Publications: comparison

## TOPICS

## CMS

1. dijet imbalance
2. Y2s/Y1s ratio
3. Charged  $R_{AA}$
4. Quarkonia
5.  $dN_{ch}/d\eta$
6. two-particle correl.
7. Z
8. Correlations
9. Dijets
10.  $\gamma$ -jet
11. high  $p_T$   $v_2$
12.  $v_2$  flow
13. Photons
14. jet FF
15. Y
16.  $dE_T/d\eta$
17. W
18. pPb ridge
19.  $\pi^0$   $v_2$

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CMS

Published,  
accepted,  
submitted

# Publications: comparison

	TOPICS	CMS	ALICE	ATLAS
1.	dijet imbalance	CMS		ATLAS
2.	Y2s/Y1s ratio	CMS		
3.	Charged $R_{AA}$	CMS	central	
4.	Quarkonia	CMS	fwd J/psi	ATLAS
5.	$dN_{ch}/d\eta$	CMS	central + all	ATLAS
6.	two-particle correl.	CMS	Jet-like corr.	
7.	Z	CMS		ATLAS
8.	Correlations	CMS	ALICE	
9.	Dijets	CMS		
10.	$\gamma$ -jet	CMS		
11.	high $p_T$ $v_2$	CMS		
12.	$v_2$ flow	CMS	ALICE	ATLAS (2 papers)
13.	Photons	CMS		
14.	jet FF	CMS		
15.	Y	CMS		
16.	$dE_T/d\eta$	CMS		
17.	W	CMS		
18.	pPb ridge	CMS	ALICE	
19.	$\pi^0$ $v_2$	CMS		
20.	D suppression		ALICE	
21.	Muons from heavy flavour		ALICE	
22.	Event bg fluctuations		ALICE	
23.	Higher order flow		ALICE	
24.	BEC		ALICE	
25.	UPC J/ $\Psi$		ALICE	
26.	Charge fluctuations		ALICE	
27.	PID spectra		central	
28.	UPC xsec		ALICE	
29.	pPb $R_{AA}$		ALICE	
30.	pPb $dN/d\eta$		ALICE	
31.	PID and non-PID flow at high $p_T$		ALICE	
32.	Jet $R_{AA}$			ATLAS

Published,  
accepted,  
submitted

# Publications: comparison

	TOPICS	CMS	ALICE	ATLAS
1.	dijet imbalance	CMS		ATLAS
2.	Y2s/Y1s ratio	CMS		
3.	Charged $R_{AA}$	CMS	central	
4.	Quarkonia	CMS	fwd J/psi	ATLAS
5.	$dN_{ch}/d\eta$	CMS	central + all	ATLAS
6.	two-particle correl.	CMS	Jet-like corr.	
7.	Z	CMS		ATLAS
8.	Correlations	CMS	ALICE	
9.	Dijets	CMS		
10.	$\gamma$ -jet	CMS		
11.	high $p_T$ $v_2$	CMS		
12.	$v_2$ flow	CMS	ALICE	ATLAS (2 papers)
13.	Photons	CMS		
14.	jet FF	CMS		
15.	Y	CMS		
16.	$dE_T/d\eta$	CMS		
17.	W	CMS		
18.	pPb ridge	CMS	ALICE	
19.	$\pi^0$ $v_2$	CMS		
20.	D suppression		ALICE	
21.	Muons from heavy flavour		ALICE	
22.	Event bg fluctuations		ALICE	
23.	Higher order flow	(approved)	ALICE	
24.	BEC	(planned)	ALICE	
25.	UPC J/ $\Psi$	(ongoing)	ALICE	
26.	Charge fluctuations		ALICE	
27.	PID spectra	(preapp in pPb)	central	
28.	UPC xsec		ALICE	
29.	pPb $R_{AA}$	(ongoing)	ALICE	
30.	pPb $dN/d\eta$		ALICE	
31.	PID and non-PID flow at high $p_T$		ALICE	
32.	Jet $R_{AA}$	(approved)		ATLAS

Published,  
accepted,  
submitted

# Publications: summary

- Number of publications on PbPb and pPb collisions by LHC experiment:

	Submitted	Accepted	Published	Total
<b>CMS</b>		<b>4</b>	<b>15</b>	<b>19</b>
ALICE	4	4	12	20
ATLAS	2		5	7

CMS plays an important role in the global Heavy Ion community

# Analyses in progress

- |   |                   |
|---|-------------------|
| • HIN-12-007 ( $\Psi(2S)$ ):                  | CWR 2013          |
| • HIN-12-008 (Z in 2011):                     | CWR 2013          |
| • HIN-12-014 ( $J/\Psi$ with 2011 data):      | CWR 2013          |
| • HIN-11-005 ( $v_n$ flow):                   | CWR early 2013    |
| • HIN-12-011 (UCC flow):                      | CWR March 2013    |
| • HIN-12-010 (high- $p_T$ dihadron corr):     | CWR April 2013    |
| • HIN-12-006 (CASTOR energy flow)             | CWR early 2013    |
| • HIN-12-003 (b-jets):                        | CWR mid-2013      |
| • HIN-12-013 (jet fragmentation):             | CWR Dec 2012      |
| • HIN-12-002 (jet shapes):                    | CWR Dec 2012      |
| • HIN-12-004 (jet $R_{AA}$ ):                 | CWR Dec 2012      |
|   |                   |
| • HIN-12-009 (UPC $J/\Psi$ ):                 | PAS early 2013    |
| • HIN-12-001 ( $J/\Psi$ flow):                | PAS early 2013    |
| • HIN-12-012 ( $\gamma$ -track correlations): | PAS early 2013    |
| • HIN-12-005 ( $R_{AA}$ $p_T > 100$ GeV):     | PAS 2013          |
| • HIN-12-016 (PID spectra in pPb):            | CWR Dec--Jan 2013 |
| • HIN-12-017 ( $R_{pPb}$ ):                   | PAS early 2013    |

+ many more analyses in pPb!

Approved,  
pre-approved,  
not yet preapproved

# pPb run schedule

ML

## 2013 LHC & Injector Schedule

Draft

July 31, 2012

V1.1

Recommission  
injectors & LHC  
(protons & ions)

PS open

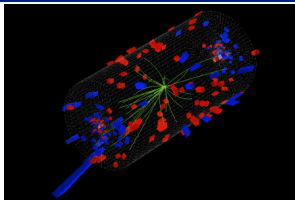
	Jan			Feb			Mar							
Wk	1	2	3	4	5	6	7	8	9	10	11	12	13	
Mo	31	7	14	21	28	4	Quench tests	11	18	25	4	11	18	25
Tu	STANDBY													
We														
Th														
Fr														
Sa														
Su														

LHC PROTON-ION RUN  
IONS TO NORTH AREA

Powering tests

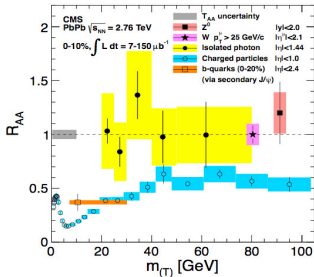
SHUTDOWN  
LS1

G. Friday



# Goals of the pPb run

- HI observables often studied in terms of the **nuclear modification factors**:  $R_{AA}$ 
  - Compares PbPb to suitably scaled pp spectra
  - Combines **initial** state effects (PDF's) with **final** state effects induced by the passage of partons through the created QGP
- pPb collisions provide a means to **distinguish initial** state effects from plasma-induced effects
  - Nuclear PDF's
  - Gluon saturation effects
  - Color Glass Condensate (CGC)
  - Cold Nuclear Matter effects
- Also relevant for generator tuning used in **cosmic ray** physics



$$R_{AA} = \frac{dN^{AA}/dp_T}{\langle T_{AA} \rangle d\sigma^{pp}/dp_T}$$

$$\langle T_{AA} \rangle = \frac{\langle N_{coll} \rangle}{\sigma_{inel}^{NN}}$$

pA workshop at CERN: <https://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=182223>



# CMS beam request for 2013

- In 2011 CMS has collected  $150 \mu\text{b}^{-1}$  of PbPb data
  - Want to get equivalent-statistics reference-data
    - benchmark: **same number of high  $p_T$  probes** (e.g. Z bosons) as observed in the 2011 PbPb run
- CMS Beam request:
  - pPb data at 5.02 TeV  $\sim 30 \text{ nb}^{-1}$ 
    - Could take anywhere from 7 to 24 days of running
  - pp data at 2.76 TeV  $\sim 6 \text{ pb}^{-1}$ 
    - Important; lack of pp statistics currently dominates the systematic uncertainty in most PbPb measurements that use pp as a reference
    - Takes 3-4 days of running

# p+Pb run: preparations

- **Trigger** preparations
  - Trigger optimized for: very low  $p_T$  for charged particles, photons, jets, dileptons with very low  $p_T$  thresholds; efficient minimum bias triggering; special triggers from TOTEM; Zero Bias
  - L1: Need to lower the thresholds of some L1 Algorithms
  - HLT: Single Object triggers based on current pp reco algorithms
- **Readout**, DAQ: close to pp default: zero-suppressed tracker, no zero-suppression at HLT needed
- A few **reconstruction** steps will be added to the workflow
  - event centrality, objects necessary for event plane studies
- **Forward**: ZDC, BSC, CASTOR, and synch with TOTEM

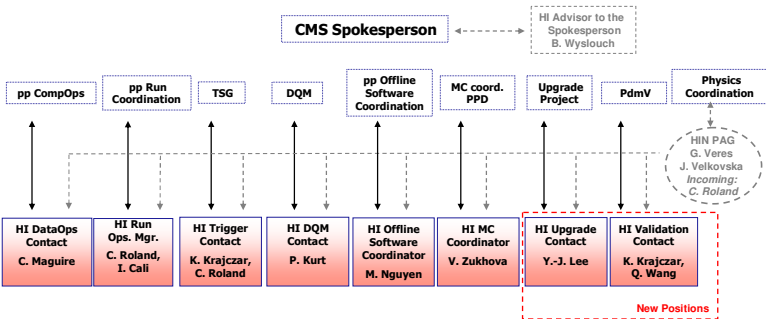
# Trigger setup for the pPb run

- The trigger setup needs to be optimized for:
  - Spectra measurements to **low  $p_T$**  for charged particles, photons, jets, dileptons
  - Efficient **minimum bias** triggering
    - Keep a significant contribution of Zero Bias events
  - Special triggers from TOTEM
- L1 Menu
  - Need to lower the thresholds of some L1 Algorithms
  - Receive TOTEM L1 trigger signal and send selected CMS L1 triggers to TOTEM
- HLT Menu
  - Mostly Single Object triggers, like in the 2011 PbPb menu
  - Based on current pp reconstruction algorithms
- Data grouped into 3 Primary Datasets
  - Up to 350 Hz per PD
- Trigger menus are ready for 200 kHz and 2 MHz interaction rate
  - Validation of the menus on MC and pilot run data currently ongoing

# Preparations for high lumi: L1 upgrade

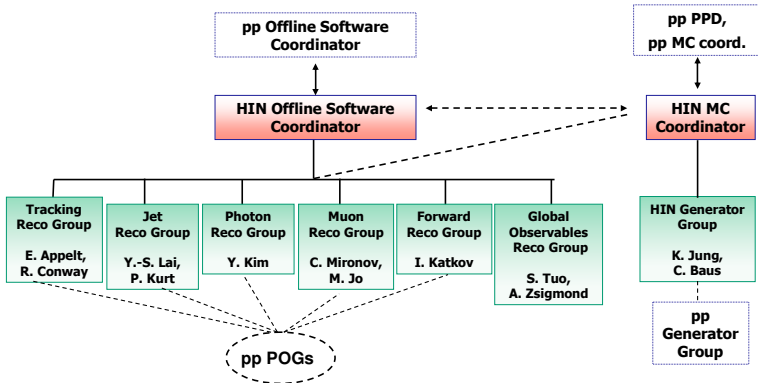
- **Selectivity** of L1 for high-energy jets is only ~50%, due to the large underlying event
- At the 2011 run, we were **at the edge** of our L1 rate capabilities, almost lost some high-energy jets
- **Underlying** event **subtraction** must be implemented at L1 to maintain our physics potential for high luminosity PbPb
- Therefore, we need the **L1 upgrade before** the next PbPb run (Nov 2015)

# Changes in the HIN group coordination



**HIN Contact to the pp projects  $\Leftrightarrow$  Coordinator within the HI group**  
**Support layer of HIN experts embedded in pp projects**

# HIN extension to Offline Software/PPD



- This structure has been presented to the Management Board
- The MB has taken note of this proposal and supports it
- Will be handed to the Collaboration Board for final endorsement

# Summary

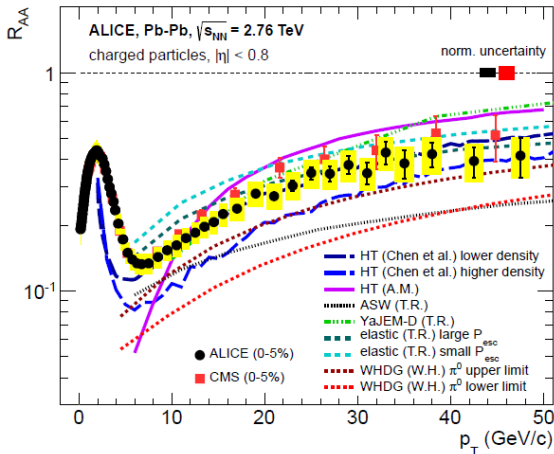
- CMS has a very strong and competitive Heavy Ion program
  - Several highly cited and featured papers, many ‘first’ measurements@LHC
- The Heavy Ion group has many **more** ideas/topics for new analyses (and interesting technical challenges) **than** manpower/time
- **We already have a full program planned until 2014/15!**
- **BUT**: there is still a lot of room for **creativity**, and for your own individual ideas!
- Large [conference talk/person] and [**paper/person**] ratios
- Friendly and collegial atmosphere ☺

→ You are welcome to join our PAG!

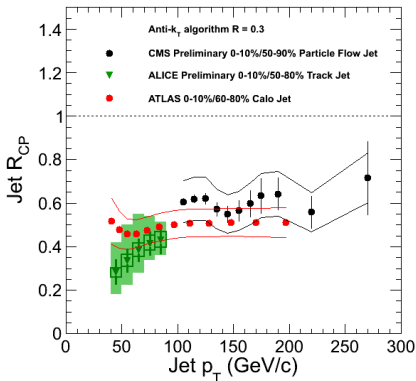
# BACKUPS



# Charged hadron $R_{AA}$ : ALICE and CMS

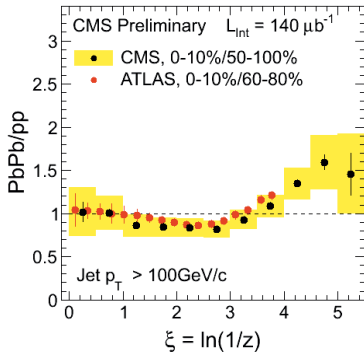
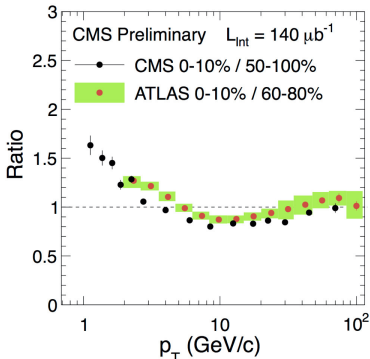


# Jet $R_{CP}$ : ATLAS, CMS and ALICE



Reasonable agreement, raising  $R_{AA}$  as a function of jet  $p_T$ ?

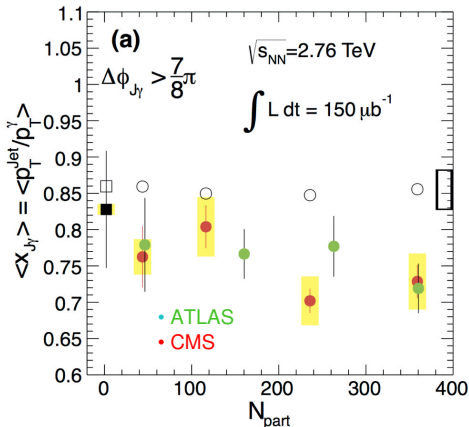
# Jet fragmentation: CMS and ATLAS



Good agreement!

Are all jets modified a bit, or just a few jets modified a lot?

# Gamma-jet: CMS and ATLAS

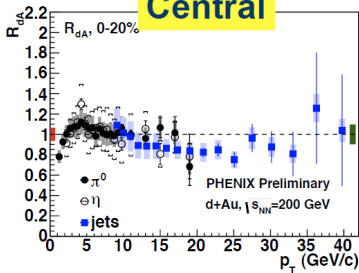


Good agreement, but slightly different selections

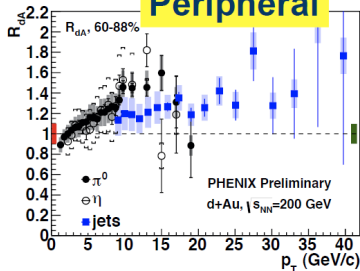
# pPb: prepare for strange results?!

PHENIX  $R_{dA}$  results

**Central**



**Peripheral**



???

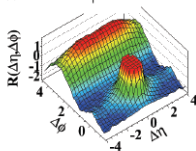
# Rige: theory predictions competing

## Plan of pPb analysis

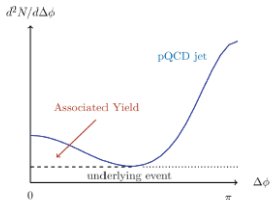
### (1) Search for ridge in high multiplicity pPb:

- With special triggers, up to  $10^{-5}$  top multiplicity events can be explored (few 100K events)
- Interaction probability of 5% requires online tracking
- Trigger status: ready

(d)  $N > 110$ ,  $1.0 \text{ GeV}/c < p_T < 3.0 \text{ GeV}/c$

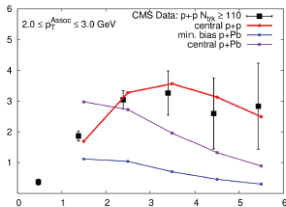


### Glasma prediction in pPb:



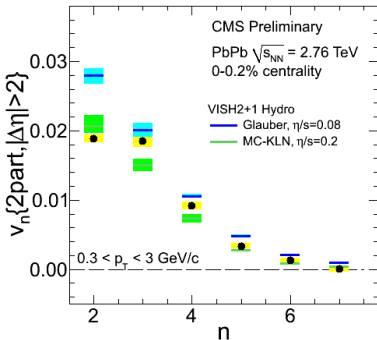
Away-side jet structure can also be calculated and compared to the data

### Ridge yield

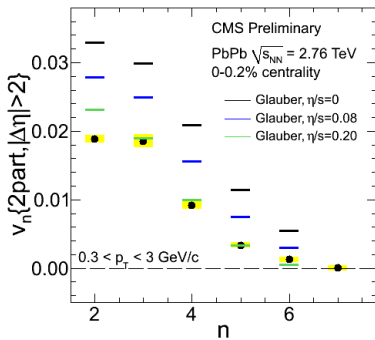


# From ultra-central flow to viscosity

C. Shen, Z. Qiu, and U. Heinz.



M. Luzum and J. Ollitrault.



# Analysis plans for 2012-13: jets

- **Publish** QM2012 results (see previous slides)
- Jet **fragmentation** with  $\gamma$ -jet pairs with and without jet reconstruction
- Jet **medium response**: search for structures in jet-track correlations
- Jet **structure**, shape: from high  $p_T$  to low  $p_T$ 
  - Can we learn about the shower development as a function of time? “color decoherence”? “jet collimation”?
- **Flavour** dependence of jet quenching: b-jet and three-jet events
  - Do we see different amounts of quenching with gluons and quarks?
  - Improve b-jet reconstruction by using secondary tracks
- **Path-length** dependence of energy loss: jet quenching vs. event shape
  - Event-by-event  $v_n$  reconstruction. Event-shape “engineering”.
- pPb run: dijet asymmetry, jet  $R_{pA}$ 
  - puzzling PHENIX results on high  $p_T$  jet anti-suppression



# Analysis plans for 2012-13: quarkonia

- Azimuthal asymmetry ( $v_2$ ) of  $J/\Psi$  (HIN-12-001)
  - publish  $J/\Psi$   $R_{AA}$  (HIN-12-014)
  - publish  $\Psi(2S)$  double ratio (HIN-12-007, may wait for more pp data)
  - $R_{AA}$  vs.  $p_T$  and  $y$ , as we get more pp data
  - $Y$ -hadron correlations in pp and PbPb
- 
- pPb: Measure the  $Y$  double ratio and check if it is 1
  - pPb: prompt and non-prompt  $J/\Psi$

# Analysis plans for 2012-13: **EWK** bosons

- Analyzing the  $Z \rightarrow e^+e^-$  channel
- Increasing **tracking** efficiency w/ improved tracking
- **publish**  $Z$  boson  $R_{AA}$  with improved tracking (HIN-12-008)
- $W^\pm$  bosons based on  $150/\mu\text{b}$  with improved tracking
- Isolated **photons** with the 2011 data (full statistics)
- pPb:  $W$  and  $Z$  and isolated photons ( $|\eta| < 2$ )

# Analysis plans for 2012-13: correlations

- Publish the  $v_2$  and  $v_n$  papers with several analysis methods
  - Finalizing high- $p_T$  triggered correlations
  - Finalizing the flow measurements in ultra-central collisions
  - Directed flow ( $v_1$ ) at midrapidity up to very high  $p_T$ : has not been measured yet and can be uniquely explored at CMS.
  - Event-by-event  $v_n$  measurement (shown by ATLAS at QM)
  - Correlations among different orders of  $v_n$  and event plane
  - Further optimizing the tracking including large impact parameter tracking
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- pPb: “ridge” in high multiplicity pPb events.
  - pPb: high- $p_T$  dihadron correlations and comparison to PbPb

# Analysis plans for 2012-13: spectra, fwd

- Extending the charged **hadron**  $p_T$  spectrum and  $R_{AA}$  above 100 GeV/c
  - Approving the PbPb data points
  - Extending the  $p_T$ -reach in pp, which is presently limiting us
  - Including  $R_{pA}$ , i.e. using the pPb data set and interpolated pp reference
- **Exotic** searches with CASTOR
- **Quarkonia** in **ultra-peripheral** events
- pPb: energy flow including CASTOR
- pPb: quarkonia in ultra-peripheral events
- pPb:  $\sigma_{inel}$  and direct test of (extended) Glauber model
- pPb:  $dN_{ch}/d\eta$  together with TOTEM
- pPb: forward jets (in HF and CASTOR) and then extension to TOTEM+CMS