Ideas for Future Measurements

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for the CMS Collaboration

Jet Workshop in HI Collisions

UPMC, Paris, France

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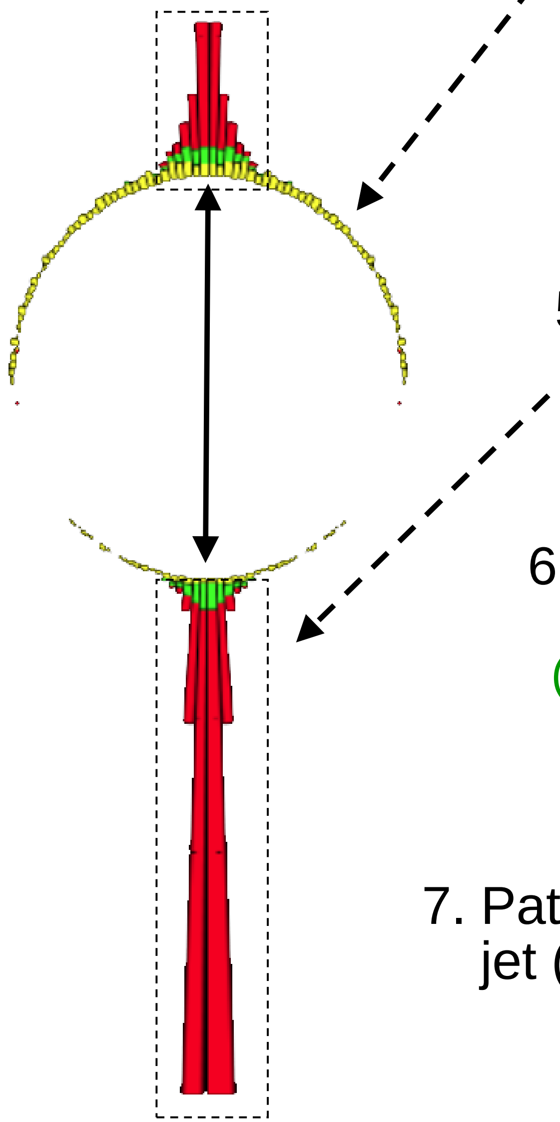
What we have learned so far

1. Jet $R_{AA(CP)}$: High p_T jet suppression
→ΔR = 0.2 — 0.5 doesn't capture all the radiated energy

2. Large average dijet and photon-jet p_T imbalance

No jet quenching in pPb MB p_T ratio difference < 2% in the highest multiplicity pPb events

3. Angular correlation of jets not largely modified



4. p_T difference found at low p_T particles far away from the jets

5. Observation of modified FF and jet shape

6. Indication of b-jet quenching via b→J/ψ, b-jet tagging (and high p_T muon suppression)

7. Path length dependence of jet (very high p_T track) v_2

Heavy ion program timeline

2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025

 LS1 ~0.3-1.5 nb^{-1} PbPb LS2 ~2-4 nb^{-1} PbPb LS3 ~10 nb^{-1} PbPb

Also corresponding pp reference

Also corresponding pp reference

CMS request

PbPb 5.1TeV | PbPb 5.1TeV | pPb? 8.2TeV

ArAr pPb PbPb 5-8 TeV

PbPb pp (?) 5.5 TeV

L1 trigger upgrade

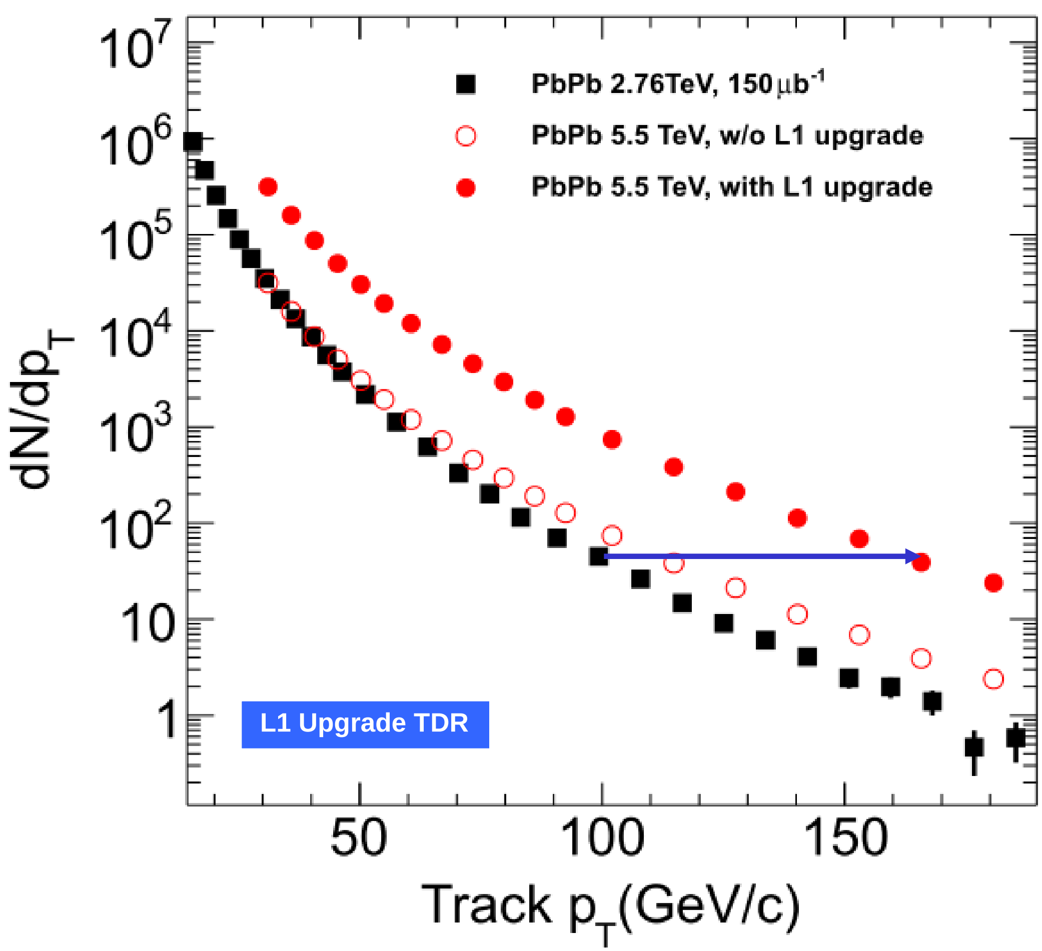
Pixel detector upgrade

3 layers → 4 layers

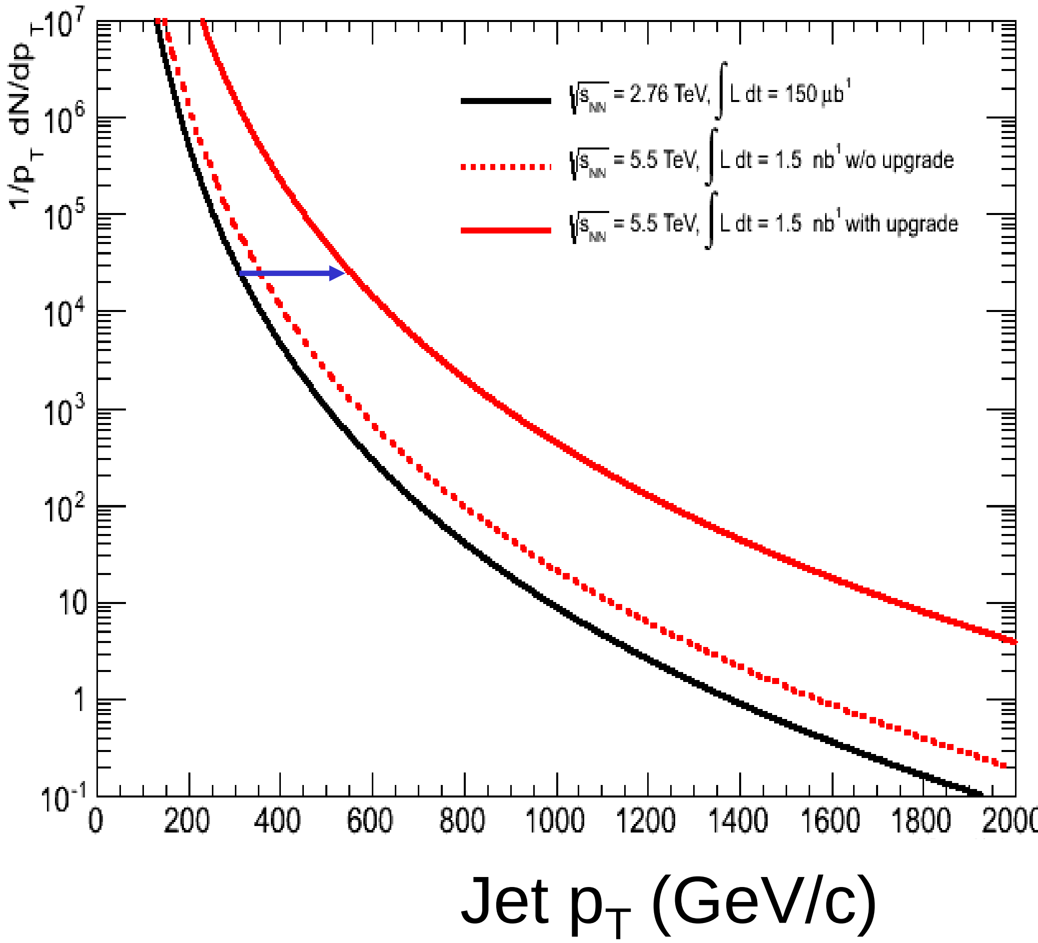
Extended tracker coverage $|\eta|<4$ (?)

Kinematic reach

High p_T track



High p_T Jet (Anti-k_T R =0.3)



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O(1k) b-jet (p_T>120GeV/c)	~4k-21k	~28k-56k	~140k

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1.5k	Isolated photon-jet ($p_{T\gamma}$>60 GeV/c)	~9k-45k	~60k-120k	~300k
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	($p_{T\gamma}$>120 GeV/c)	~300-1.5k	~2k-4k	~10k
~100	W (pT>50 GeV/c)	~600-3000	~4k-8k	~20k
~10	Z (p_T>50 GeV/c)	~60-300	~400-800	~2k
7-10	ttbar→llbb MET	~90	~200	~600

Possible future measurements

- (1) Extended analysis with dijet, photon-jet, Z(W)-jet
- (2) Flavor dependence of jet quenching
- (3) Path length dependence of jet energy loss
- (4) nPDF measurement & dijet η shift

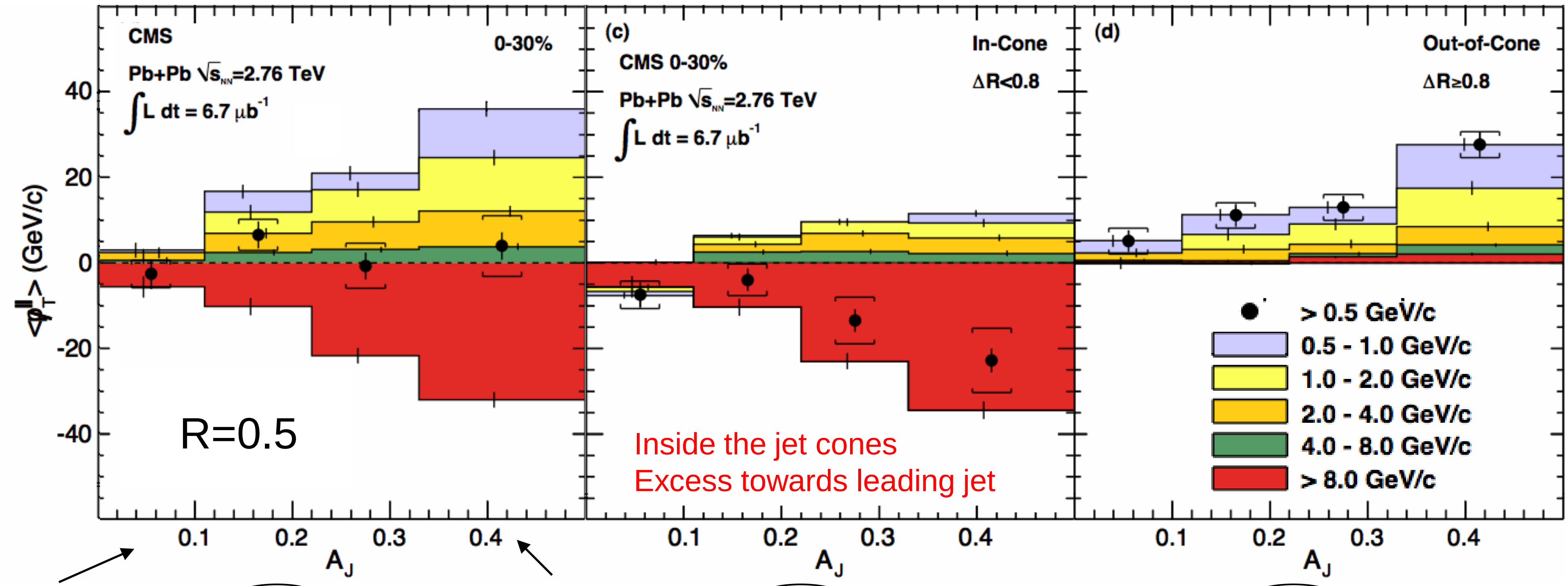
- (1) Extended analysis with dijet, photon-jet, Z(W)-jet
  - Turn on of the jet quenching in PbPb (pPb?)
  - Detailed map of the radiated energy
    - Missing p_T, associated yield
  - Jet shape and fragmentation function (moment)
  - Select on quenched jet

Missing-$p_T^{||}$

Missing $p_T^{||}$: $$\not{p}_T^{\parallel} = \sum_{\text{Tracks}} -p_T^{\text{Track}} \cos\left(\phi_{\text{Track}} - \phi_{\text{Leading Jet}}\right)$$

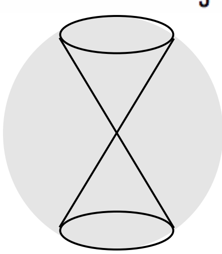
0-30% Central PbPb

Out of the jet cones
Excess towards sub-leading jet

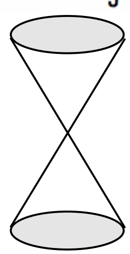


balanced jets

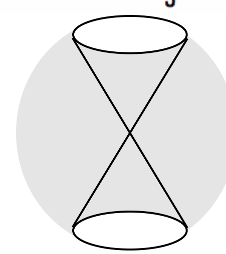
unbalanced jets



All tracks



Tracks in
the jet cone
ΔR<0.8

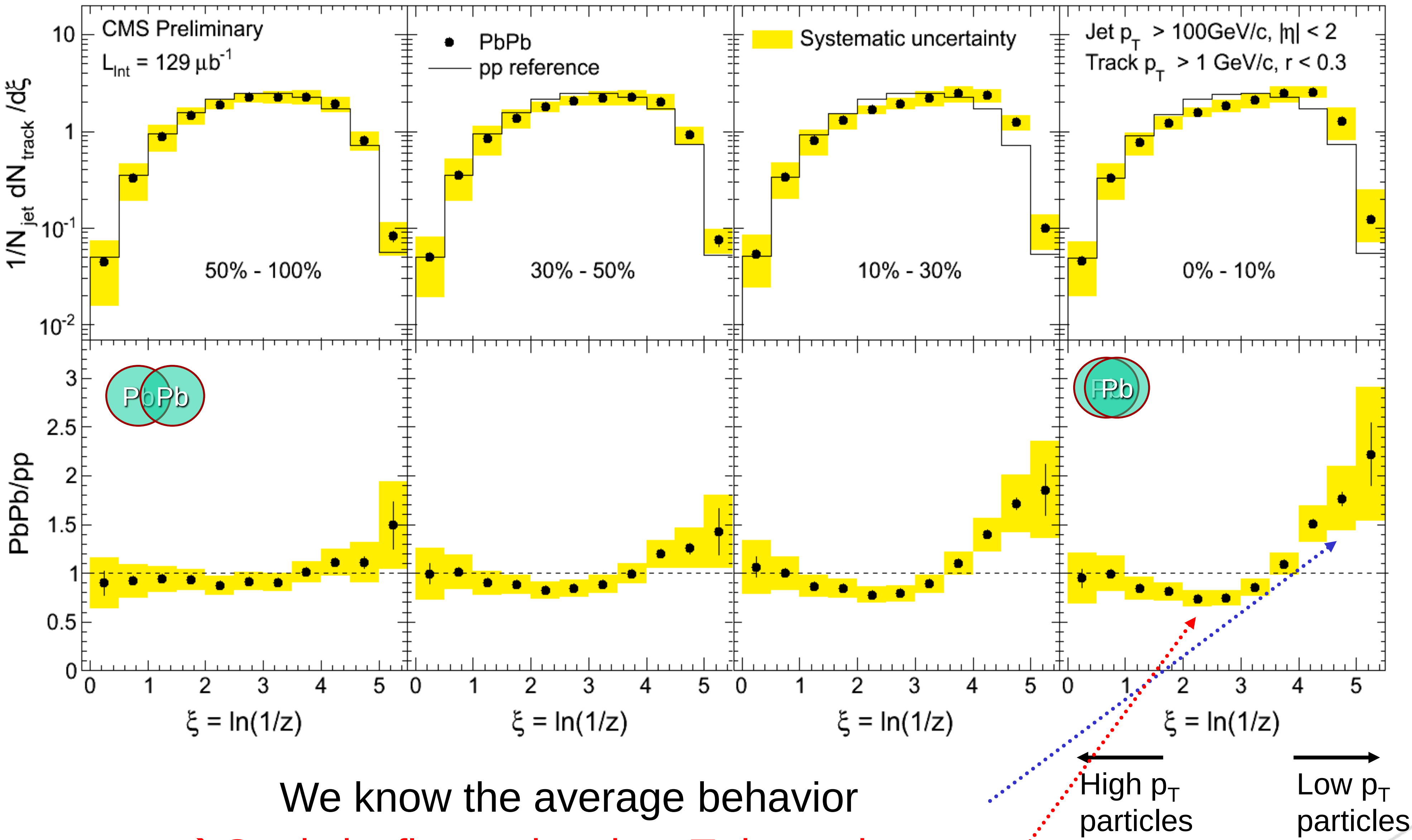


Tracks out of
the jet cone
ΔR>0.8

Possible extension: more differential in cone size

Study photon(Z)-track missing $p_T^{||}$

Jet fragmentation functions



$$\xi = \ln \frac{1}{z} \quad ; \quad z = \frac{p_{\parallel}^{track}}{p^{jet}},$$

We know the average behavior

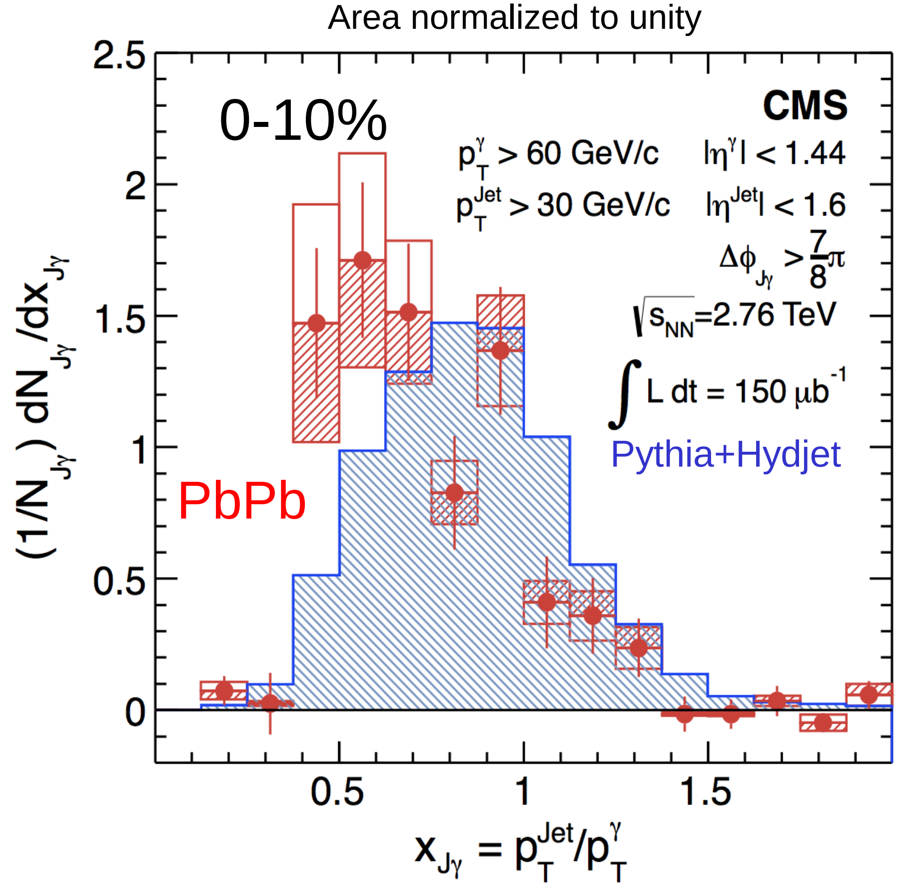
→Study its fluctuation, jet pT dependence

→Use photon-jet

Select on quenched jets

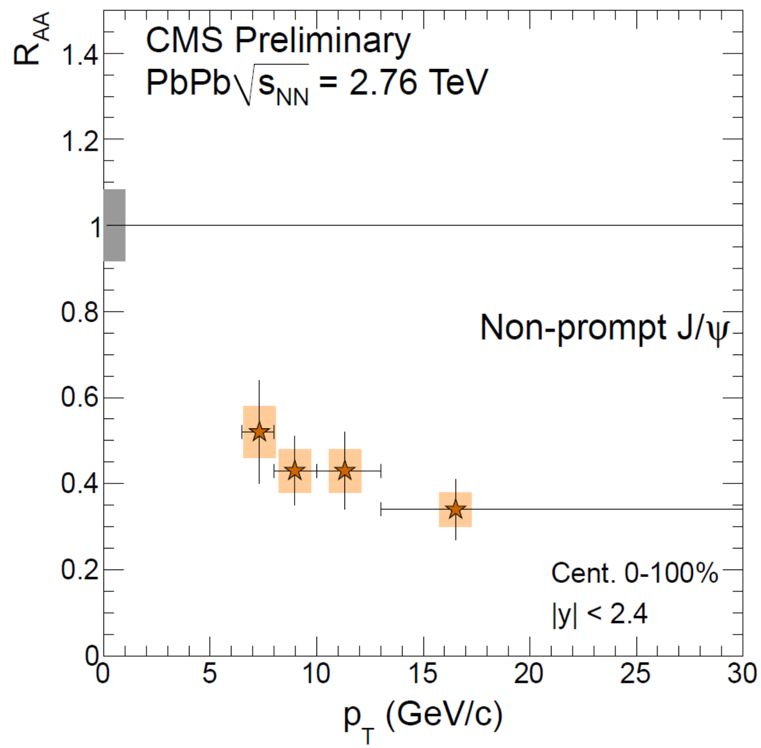
- $X_{j\gamma}$ as a proxy
  - Selecting on jets originated from partons passing different in-medium path length
  - Jet shapes, fragmentation function (moment) v.s. $X_{j\gamma}$
- Can we "unfold" the $X_{j\gamma}$ distribution to get P(ΔE)?

PLB 718 (2013) 773



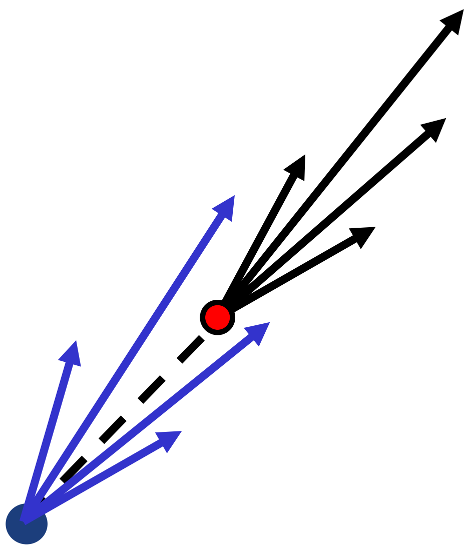
(2) Flavor dependence

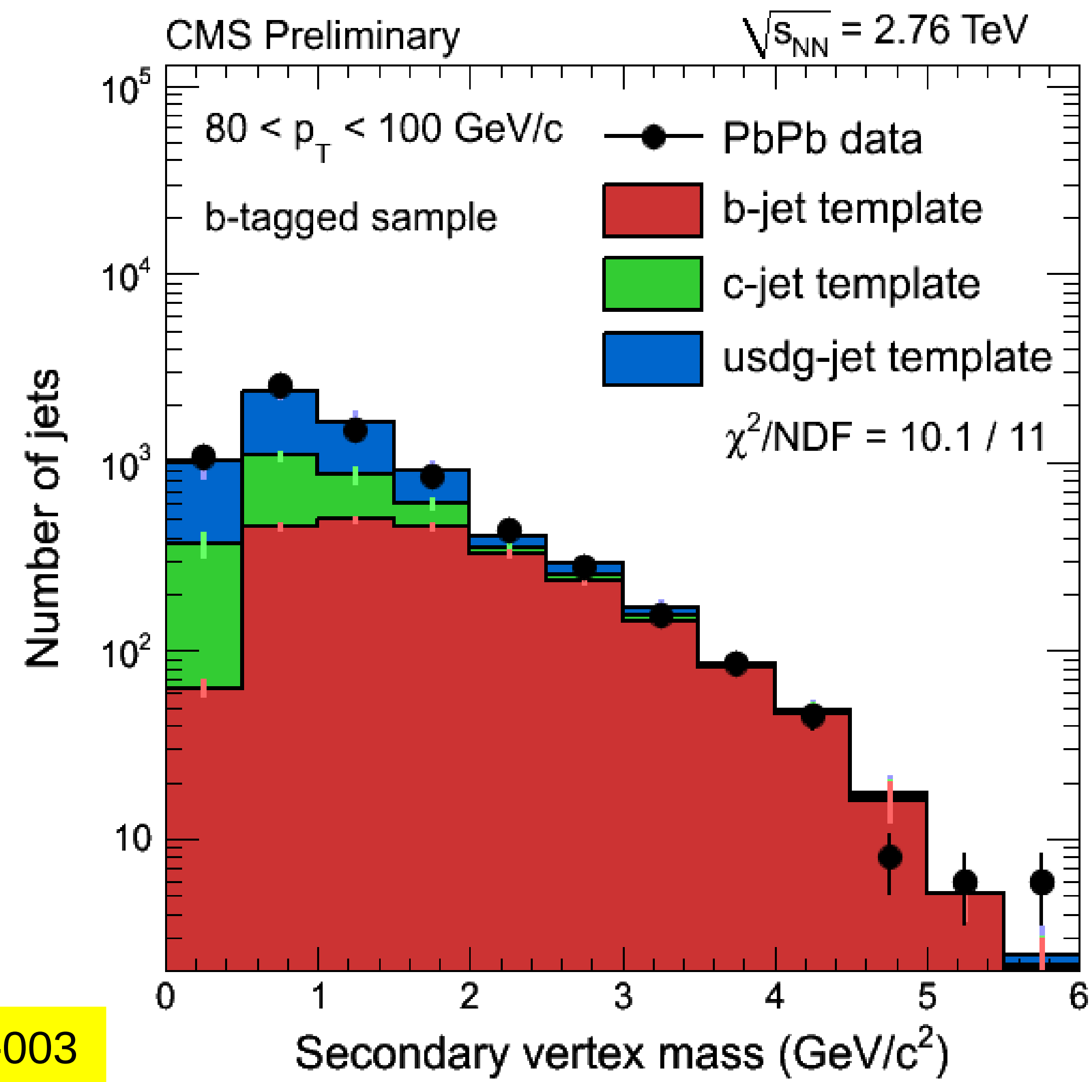
- Flavor dependent jet quenching
  - b-jet tagging (gluon-jet tagging?)
  - 3jet/2jet ratio
  - Non-prompt J/ψ
  - Open heavy flavor meson (D, B)



Tagging and counting b-quark jets

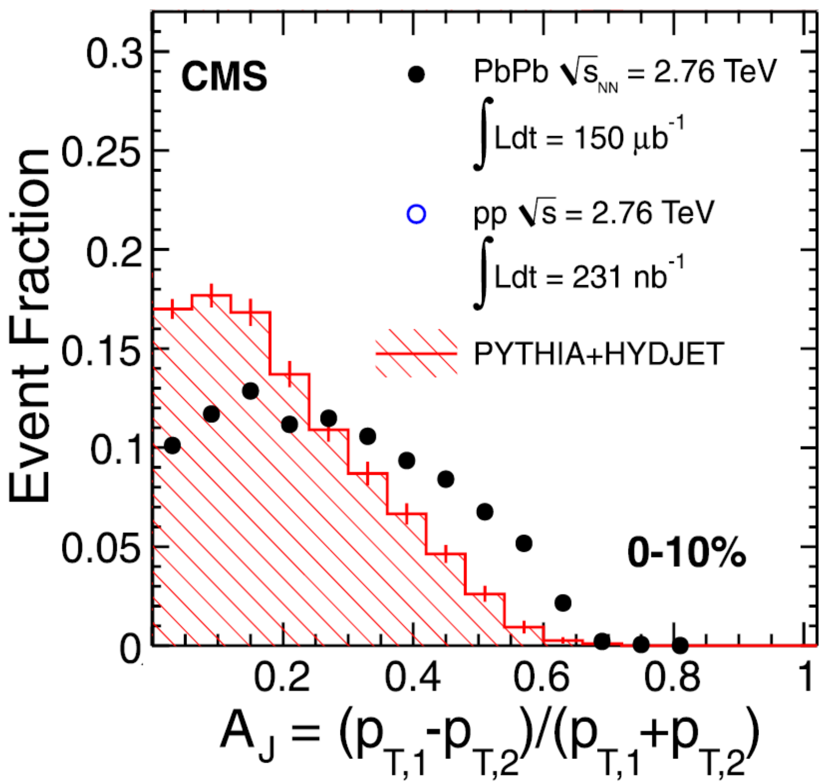
Secondary vertex tagged using flight distance significance

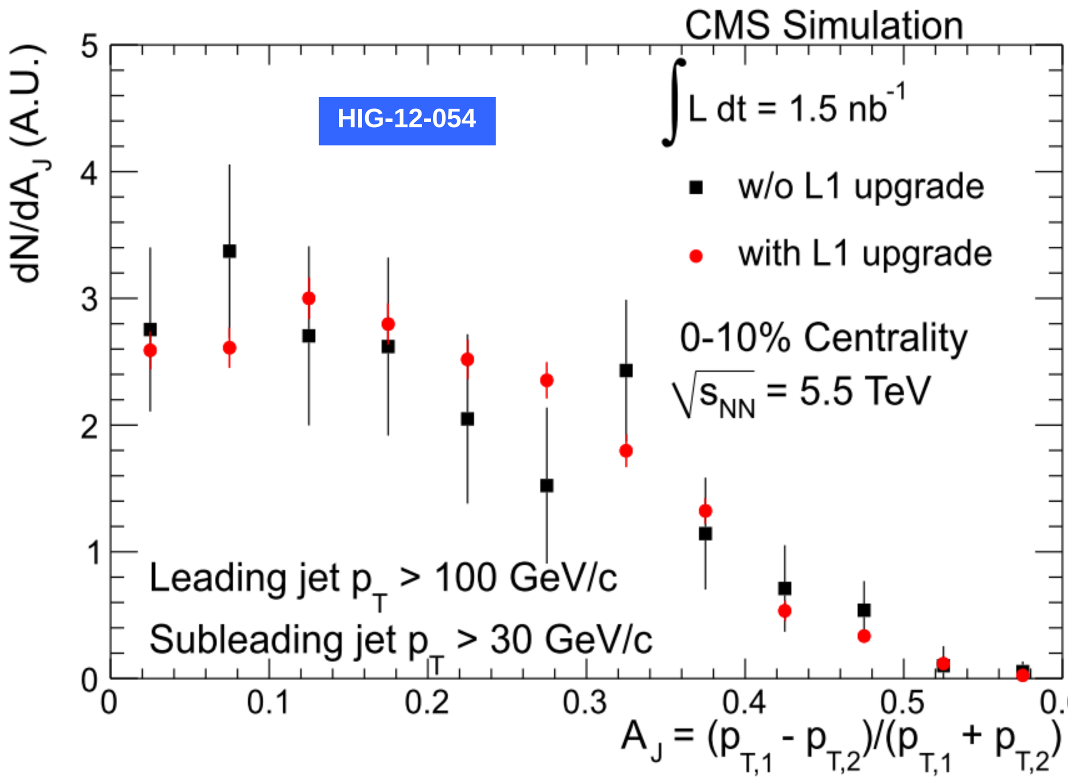




CMS PAS HIN-12-003

b-jet physics performance

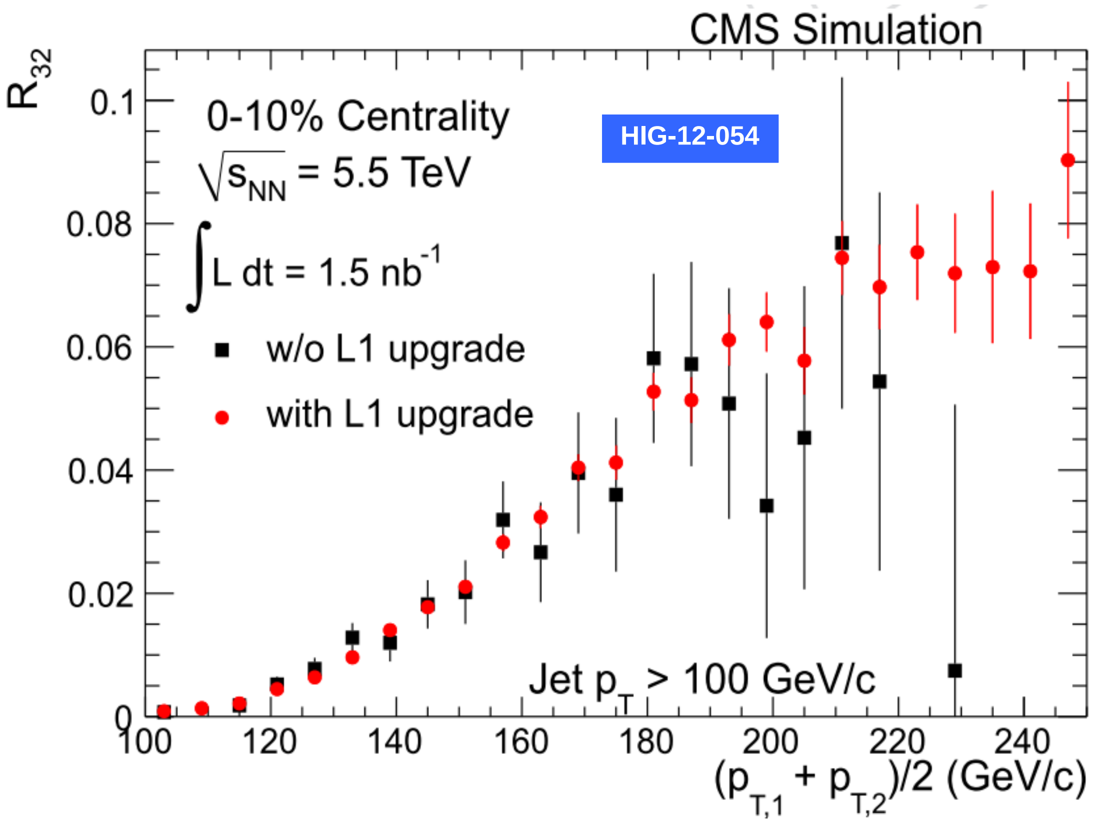




- Goal: di-b-jet asymmetry as done for inclusive jets in HIN-10-004 and HIN-11-013
- Proposed observable:
    - Dijet asymmetry (A_J) & R_B (fraction of balanced di-b-jet)
- Expect similar systematics as light jets + (b tagging uncertainty & light jet contamination)
- Use 2011 kinematic cuts: $p_{T,1}$ > 100 GeV/c and $p_{T,2}$ > 30 GeV/c

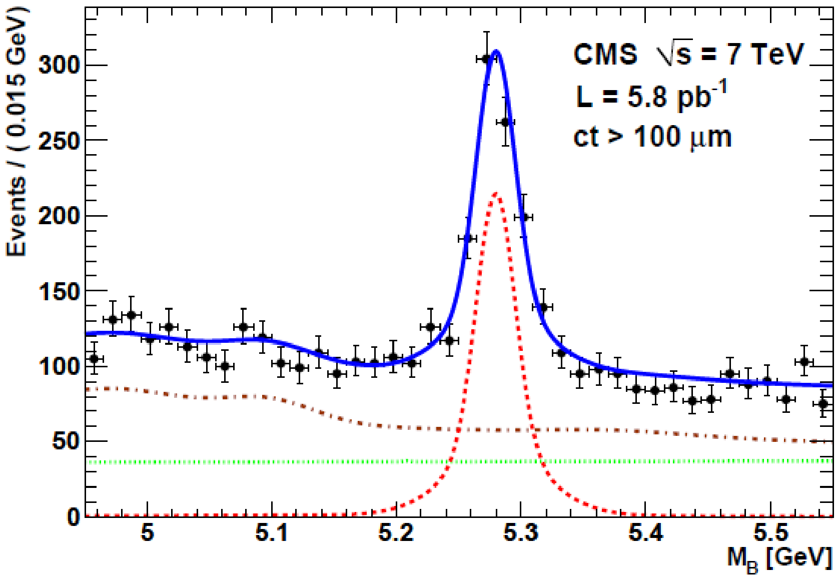
Physics performance of 3-jet events

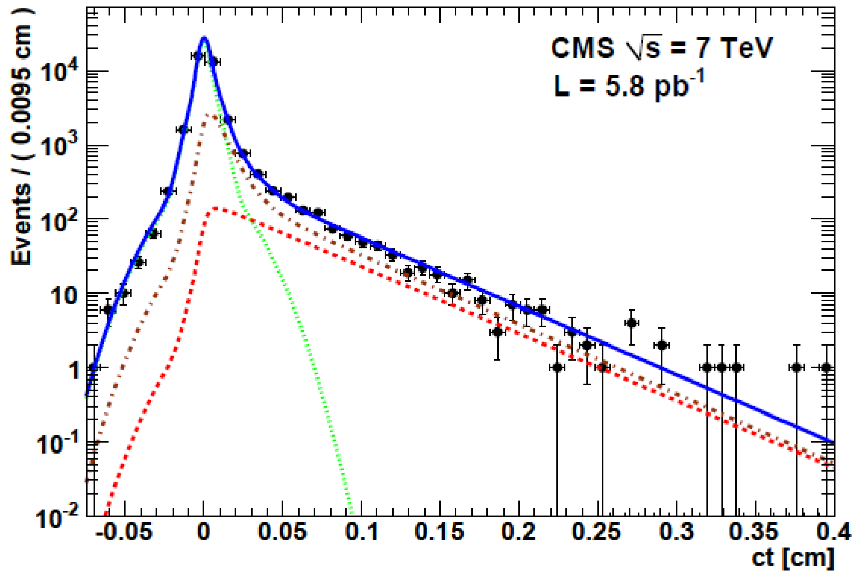
- Access to gluon jets: three jet events
  - R_{32} may be modified due to jet quenching
- Similar study as QCD-10-012
  - All jet p_T threshold > 100 GeV/c
- No existing experimental measurements in heavy ion collision
- Simulated with PYTHIA at 5.5 TeV



B and D meson

PP 7 TeV





$$p_T^B > 5\,\mathrm{GeV} \text{ and } |y^B| < 2.4$$

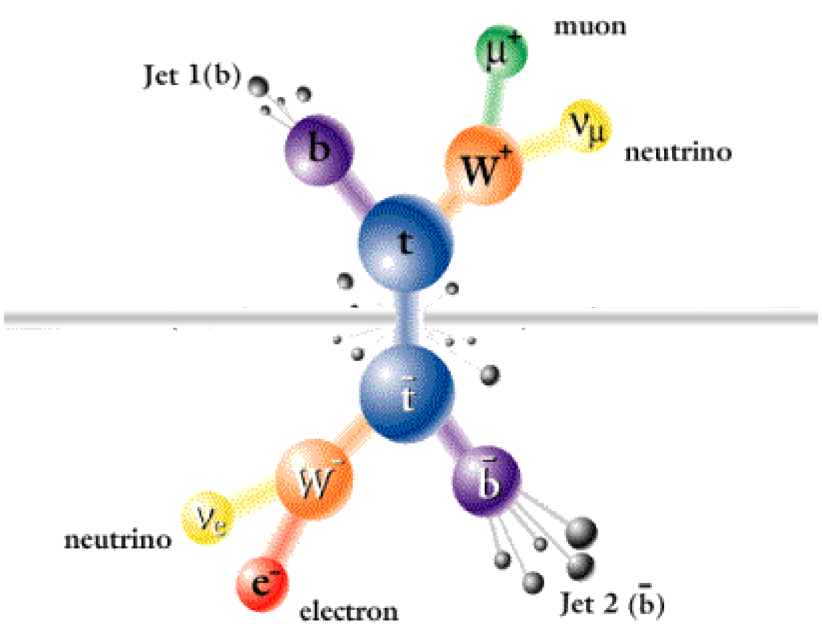
CMS is capable of reconstructing $B^+ \rightarrow J/\psi K^+$, $B^0 \rightarrow J/\psi K_s$, $B_s \rightarrow J/\psi \phi$…

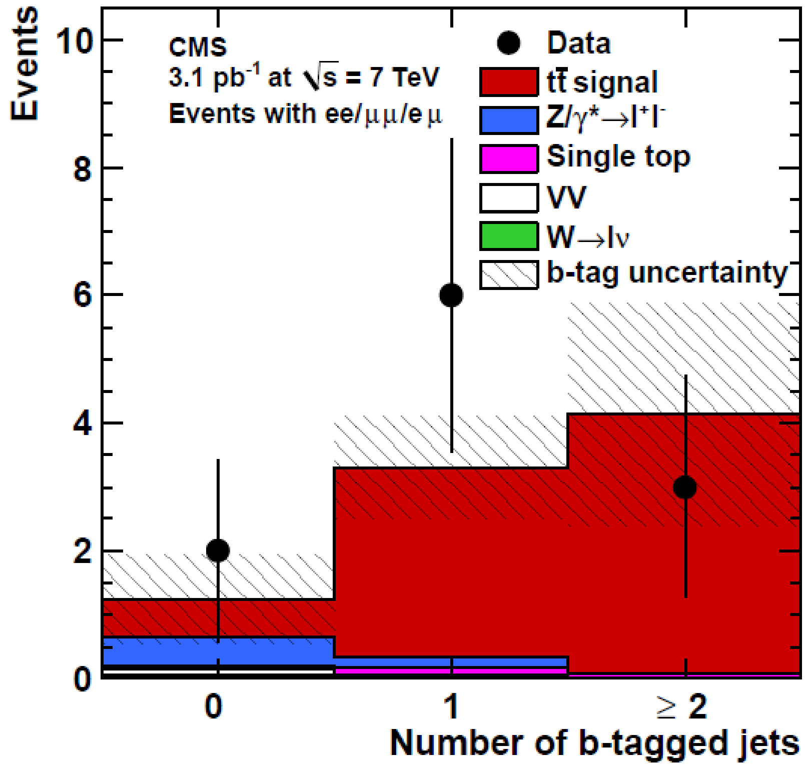
Requires high p_T D*, B meson trigger

Top production in pp collisions

Decay channels:

- ll+bb+MET 10%:
  "observation channel"
- l+bb+2jet+MET 44%
- bb+4jet 46%





Number of bjets with p_T > 30 GeV/c

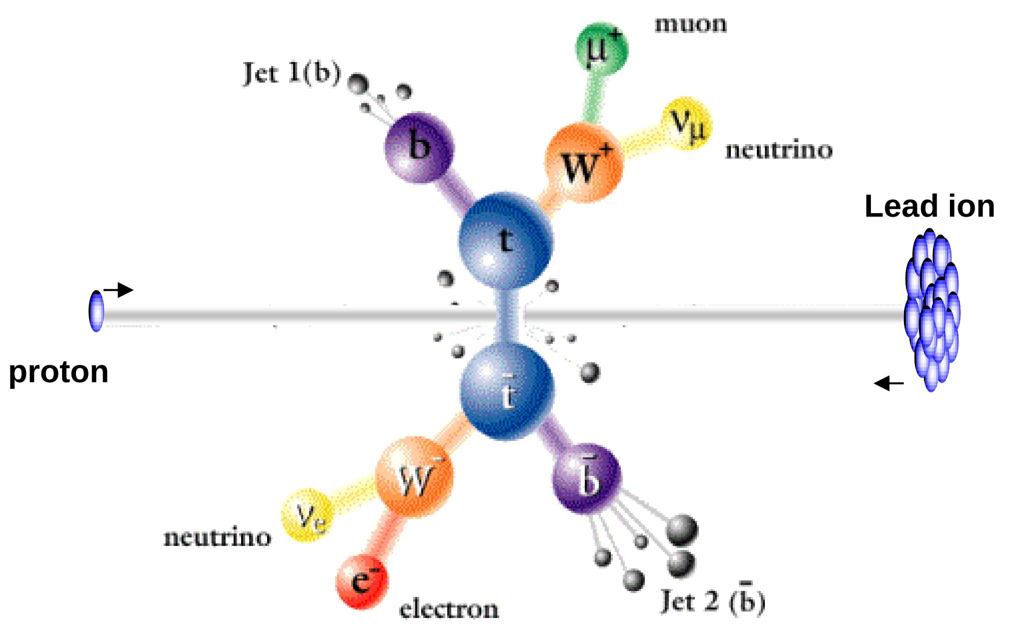
PLB 695 424-443,2011

ttbar production in pPb

- Observation of ttbar production in heavy ion collisions. Cross-section measurement.

- Expected statistics
  - 30/nb → ~400 ttbar pair
  - 300/nb → ~4000 ttbar pair

- Eff*Acc of ll+jet channel ~ 1.5-2.5%
  - 30/nb → ~10 ll+jet candidates
  - 300/nb → ~100 ll+jet candidates



Top production in PbPb collisions

Assuming 1/nb at 5.5 TeV

Ttbar cross-section:

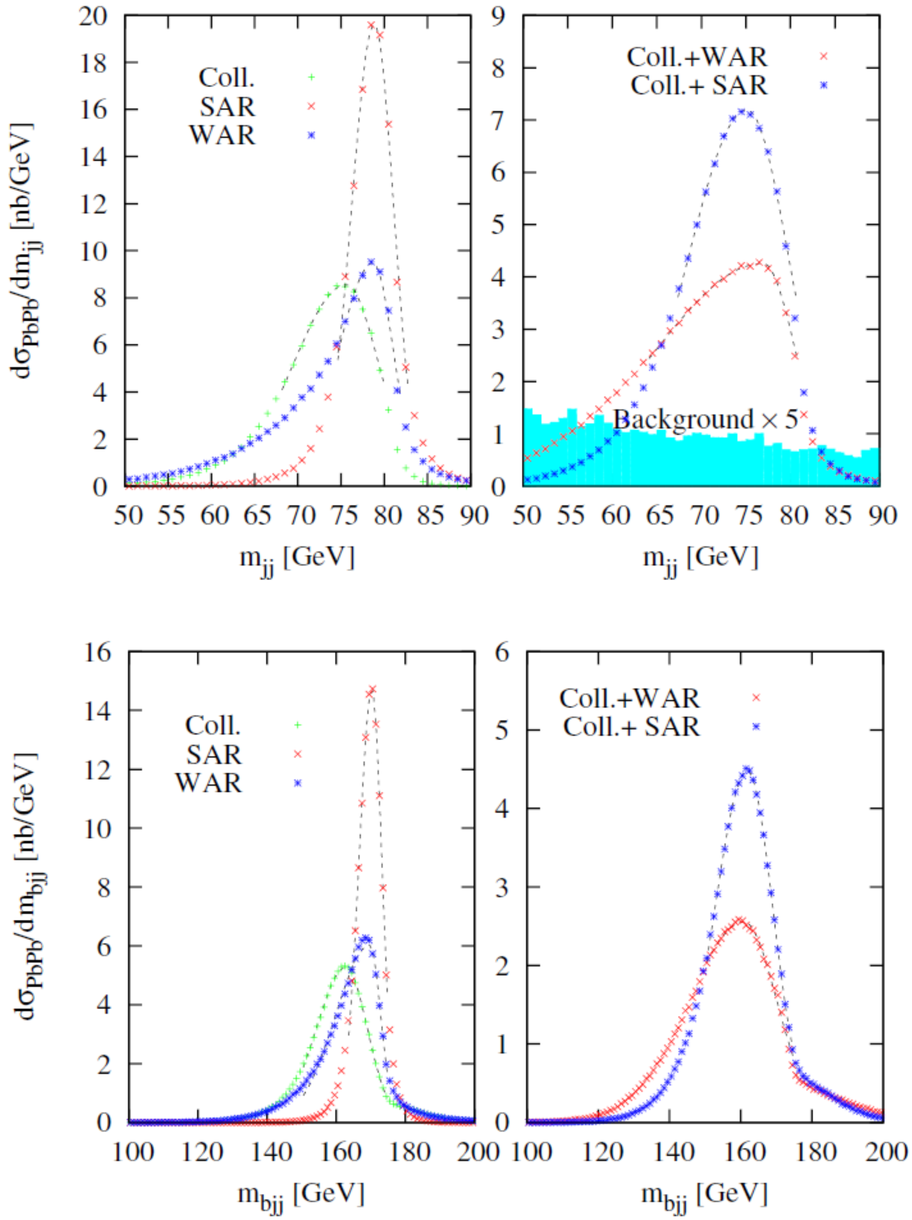
~ 3.5 μb

→~3500 ttbar pairs per 1/nb

→~50-90 ll+jet per 1/nb

- Decay channels:
  - ll+bb+MET 10%: "observation channel"
  - l+bb+2jet+MET 44%
  - bb+4jet 46%

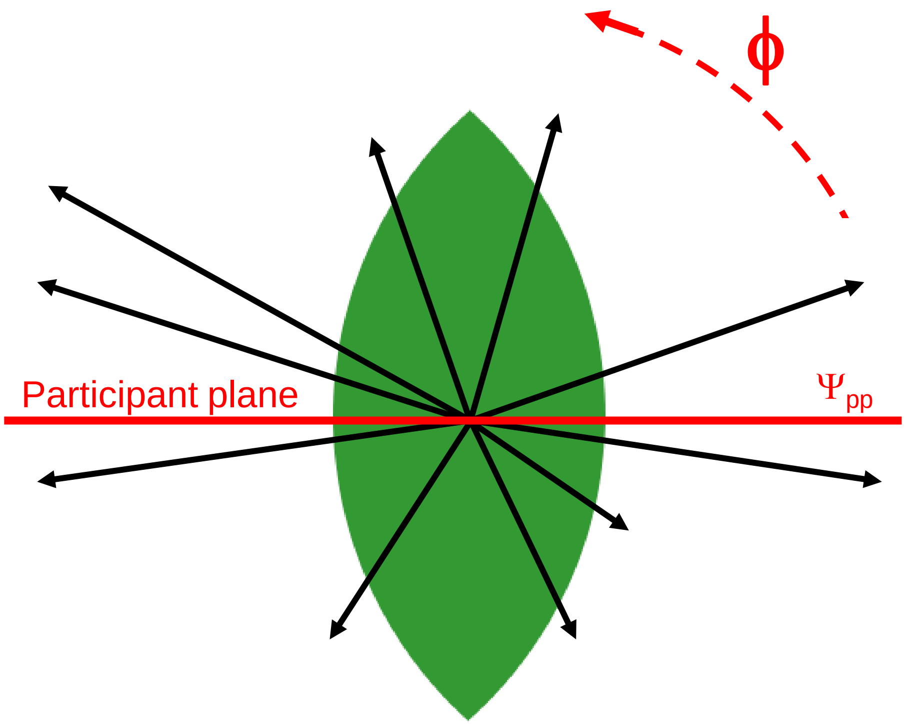
"modification of top mass" (M_{bjj})



Arxiv 1210.0116

- (3) Path length dependence
  - Jet observables v.s. centrality
  - Jet observables v.s. $\Delta\psi_{EP}$
  - Jet observables v.s. v_N
  - Biased selection (leading hadron / sub-jet selection)

Path length dependence of jet energy loss?



Overlap zone is almond-shaped

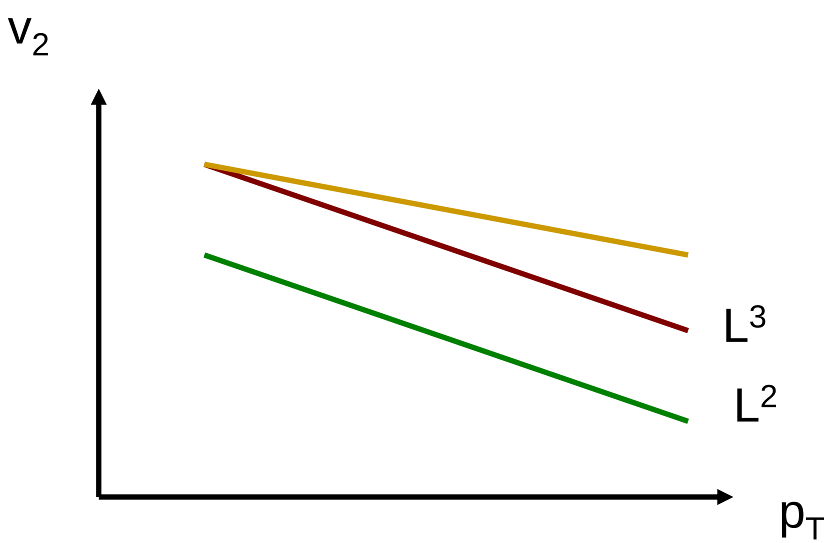
→ Parton energy loss is smaller along the short axis

→ More high-p_T tracks and jets closer to the event plane

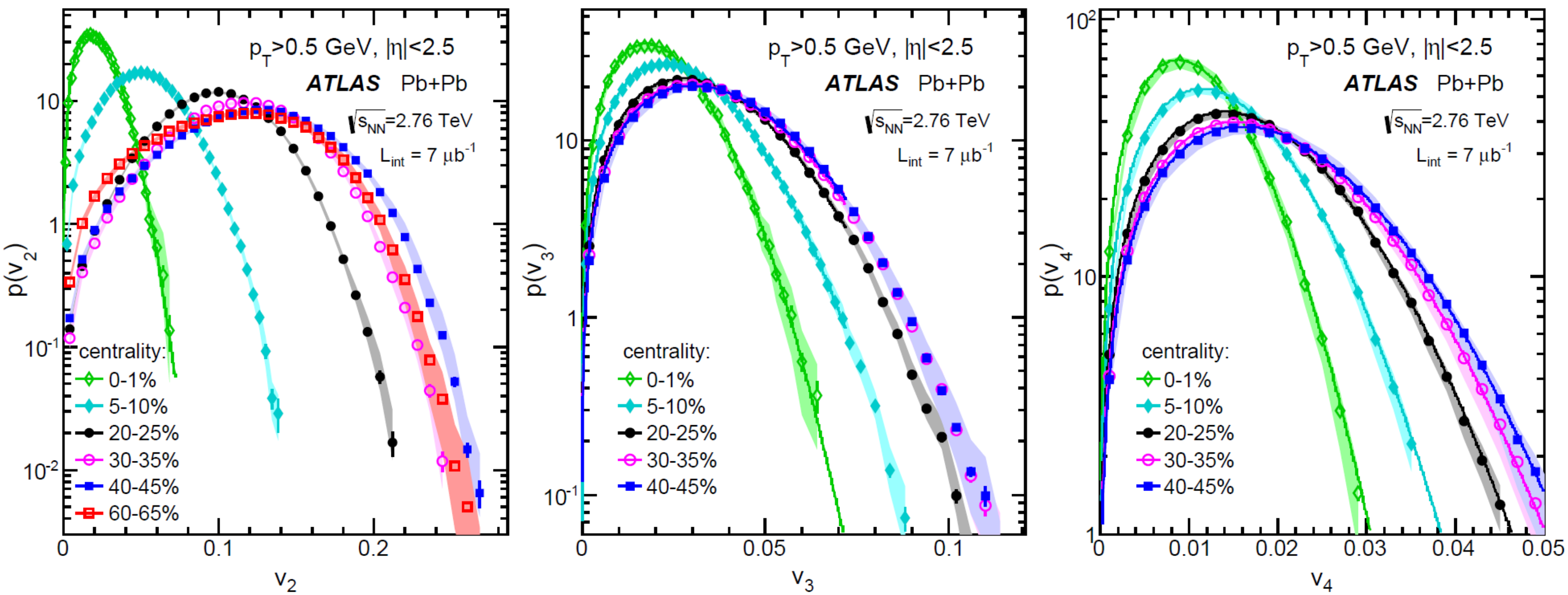
→ Azimuthal asymmetry (v_2):

$$dN/d\phi \propto 1 + 2v_2 \cos(2(\phi - \Psi_{EP}))$$

→ v2 is sensitive to the path-length dependence of the energy loss



Event shape engineering



(4) Dijet η shift

- What is the origin of the dijet η shift?
  - Study of dijet η v.s. jet p_T selection, dijet mass v.s. forward calorimeter energy
  - Study of photon-jet η v.s. forward calorimeter energy
  - W & Z boson v.s. forward calorimeter energy?

nPDF measurement

- nPDF measurements in pPb & PbPb:
  - Study of dijet η v.s. jet p_T selection, dijet mass
    - Vary the Q^2 and x we are probing
  - Inclusive isolated photon measurement
    - Sensitive to gluon PDF
    - 20-300 GeV
  - W and Z boson pseudorapidity
  - Study of jet production with large cone size (R=0.5,0.7)

Backup