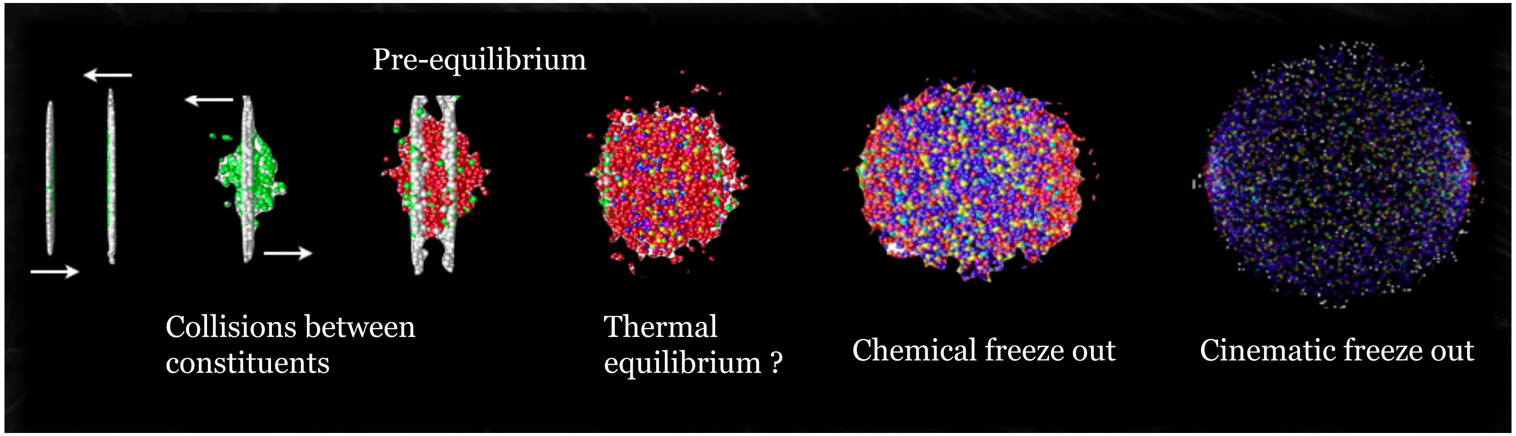
Hard probes in Heavy-Ion collisions with CMS (by Alice)

But only Electroweak bosons

LHC France 2013, Annecy

Alice Florent
On behalf of the CMS collaboration

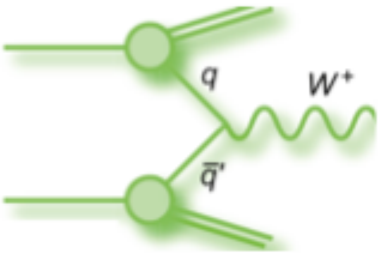
Evolution of Heavy-Ion collisions

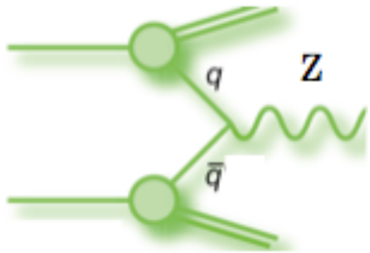


- Hard processes (High Q^2)
- **Production of hard probes**

Quarkonia
Jets
Z,W,γ

Weak bosons are formed before QGP due to their large mass t ≅ 1/M ≅ 0.003 fm/c

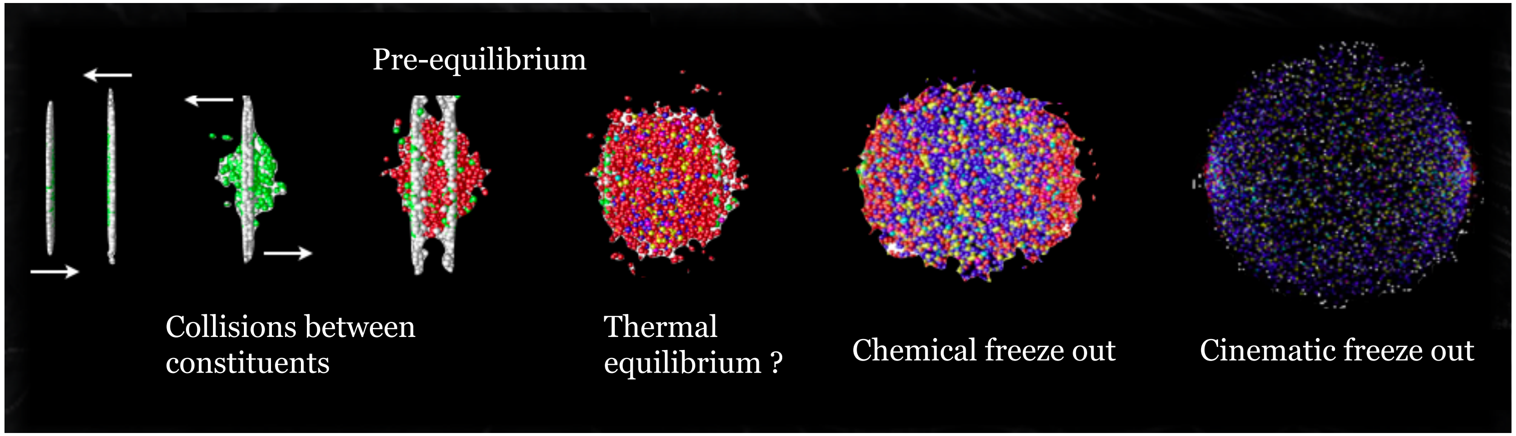




t(Z→X) ≈ 0.08 fm/c
t(W→X) ≈ 0.09 fm/c

W and Z decay before QGP

Evolution of Heavy-Ion collisions

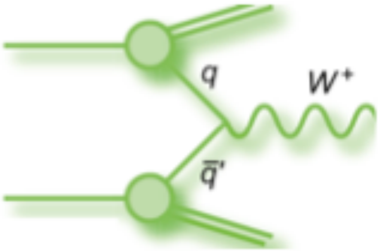


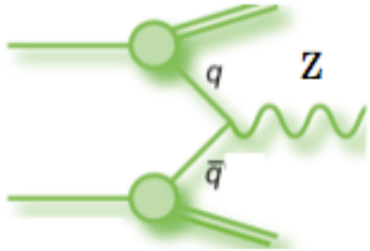
QGP formation
1 fm/c
10^{-15} m
$T_c \approx 190$ MeV

- Hard processes (High Q^2)
- **Production of hard probes**

Quarkonia
Jets
Z,W,γ

Weak bosons are formed before QGP due to their large mass t ≅ 1/M ≅ 0.003 fm/c

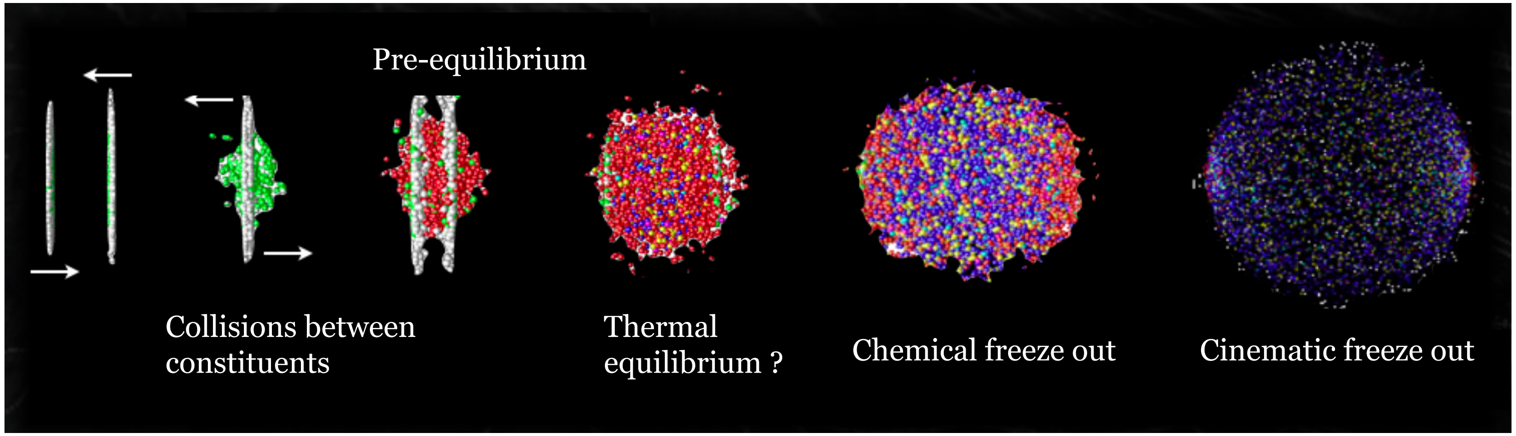




$t(Z \rightarrow X) \approx 0.08$ fm/c
$t(W \rightarrow X) \approx 0.09$ fm/c

W and Z decay before QGP

Evolution of Heavy-Ion collisions

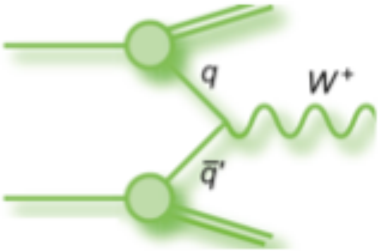


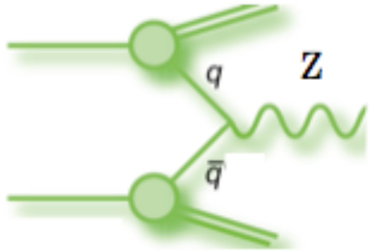
- Hard processes (High Q^2)
- **Production of hard probes**
  Quarkonia
  Jets
  Z,W,γ

QGP formation
1 fm/c
10^{-15} m
$T_c \approx 190$ MeV

- **Hadronization**
- Number of particles is set

Weak bosons are formed before QGP due to their large mass t ≅ 1/M ≅ 0.003 fm/c

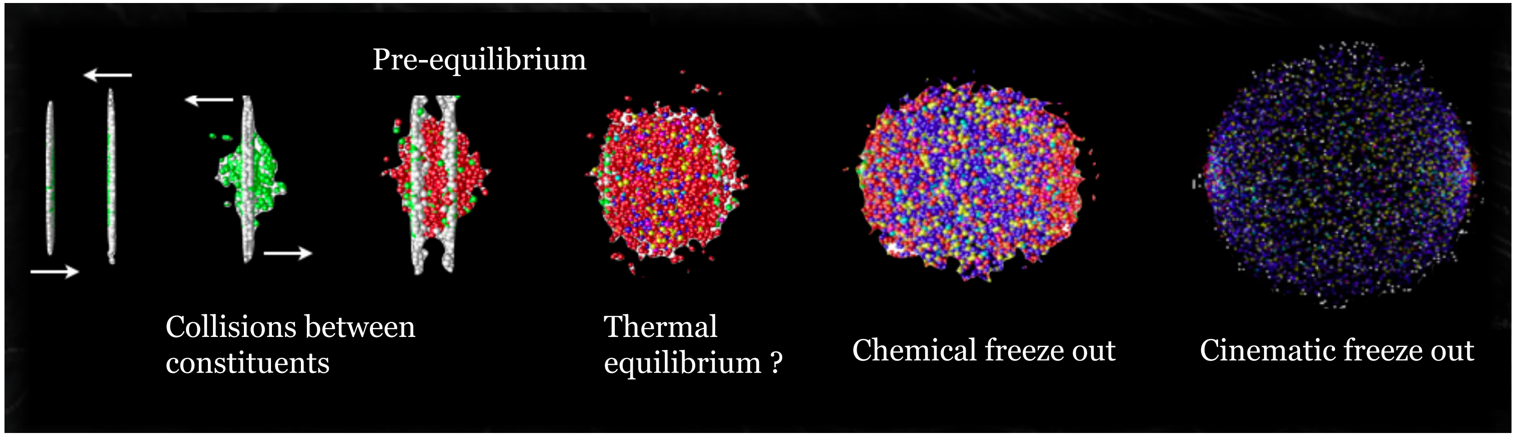




$t(Z \rightarrow X) \approx 0.08$ fm/c
$t(W \rightarrow X) \approx 0.09$ fm/c

W and Z decay before QGP

Evolution of Heavy-Ion collisions



- Hard processes (High Q^2)
- **Production of hard probes**

Quarkonia
Jets
Z,W,γ

QGP formation
1 fm/c
10^{-15} m
$T_c \approx 190$ MeV

- **Hadronization**
- Number of particles is set

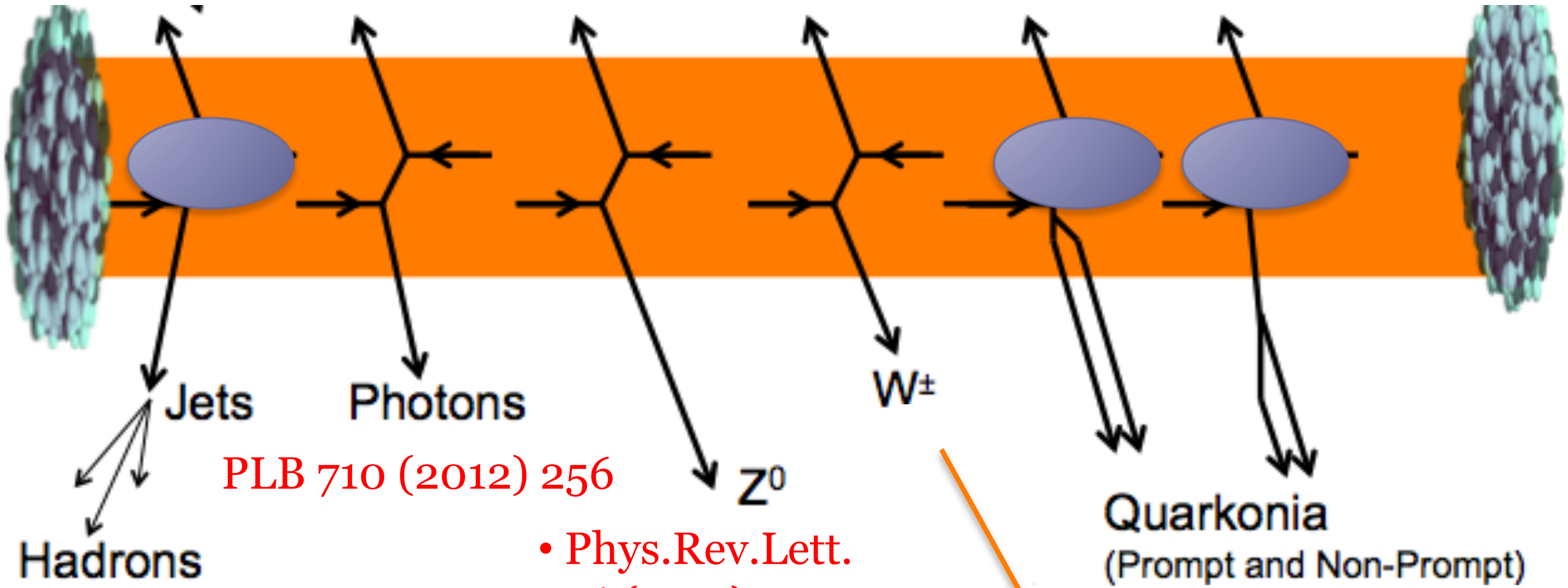
- **Final state**
- Detection

Weak bosons are formed before QGP due to their large mass t ≅ 1/M ≅ 0.003 fm/c

$t(Z \rightarrow X) \approx 0.08$ fm/c
$t(W \rightarrow X) \approx 0.09$ fm/c

W and Z decay before QGP

Hard processes in QCD medium



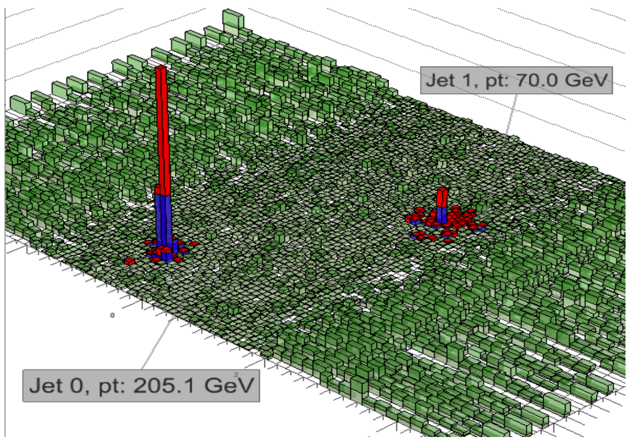
PLB 710 (2012) 256

PLB 718 (2013) 773

- Phys.Rev.Lett. 106 (2011) 212301
- PAS-**HIN-12-008**

N.Filipovic's talk

PLB 715 (2012) 66



The CMS unmodified talk

Electro + weak bosons (through their leptonic decays) are **medium-blind**

- References for modified processes
- Help to constrain initial state

Which ones can we detect in heavy-ion collisions with CMS?

All of them!!!

The CMS unmodified talk

Electro + weak bosons (through their leptonic decays) are **medium-blind**

- References for modified processes
- Help to constrain initial state

Which ones can we detect in heavy-ion collisions with CMS?

All of them!!!

$Z \rightarrow \mu^{+} \mu^{-}$ 1
PAS-**HIN-12-008**

The CMS unmodified talk

Electro + weak bosons (through their leptonic decays) are **medium-blind**

- References for modified processes
- Help to constrain initial state

Which ones can we detect in heavy-ion collisions with CMS?

All of them!!!

$Z \rightarrow \mu^+ \mu^-$ 1
PAS-**HIN-12-008**

$W \rightarrow \mu^\pm \nu$ 2
PLB 715 (2012) 66

The CMS unmodified talk

Electro + weak bosons (through their leptonic decays) are **medium-blind**

- References for modified processes
- Help to constrain initial state

Which ones can we detect in heavy-ion collisions with CMS?

All of them!!!

$Z \rightarrow \mu^+ \mu^-$ 1
PAS-**HIN-12-008**

$W \rightarrow \mu^\pm \nu$ 2
PLB 715 (2012) 66

Isolated γ 3
PLB 710 (2012) 256

The CMS unmodified talk

Electro + weak bosons (through their leptonic decays) are **medium-blind**

- References for modified processes
- Help to constrain initial state

Which ones can we detect in heavy-ion collisions with CMS?

All of them!!!

$Z \rightarrow \mu^+ \mu^-$ 1
PAS-**HIN-12-008**

$Z \rightarrow e^+ e^-$
On going

$W \rightarrow \mu^\pm \nu$ 2
PLB 715 (2012) 66

Isolated γ 3
PLB 710 (2012) 256

The CMS unmodified talk

Electro + weak bosons (through their leptonic decays) are **medium-blind**

- References for modified processes
- Help to constrain initial state

Which ones can we detect in heavy-ion collisions with CMS?

All of them!!!

$Z \rightarrow \mu^+ \mu^-$ 1
PAS-**HIN-12-008**

$W \rightarrow e^\pm \nu$
possible

$W \rightarrow \mu^\pm \nu$ 2
PLB 715 (2012) 66

$Z \rightarrow e^+ e^-$
On going

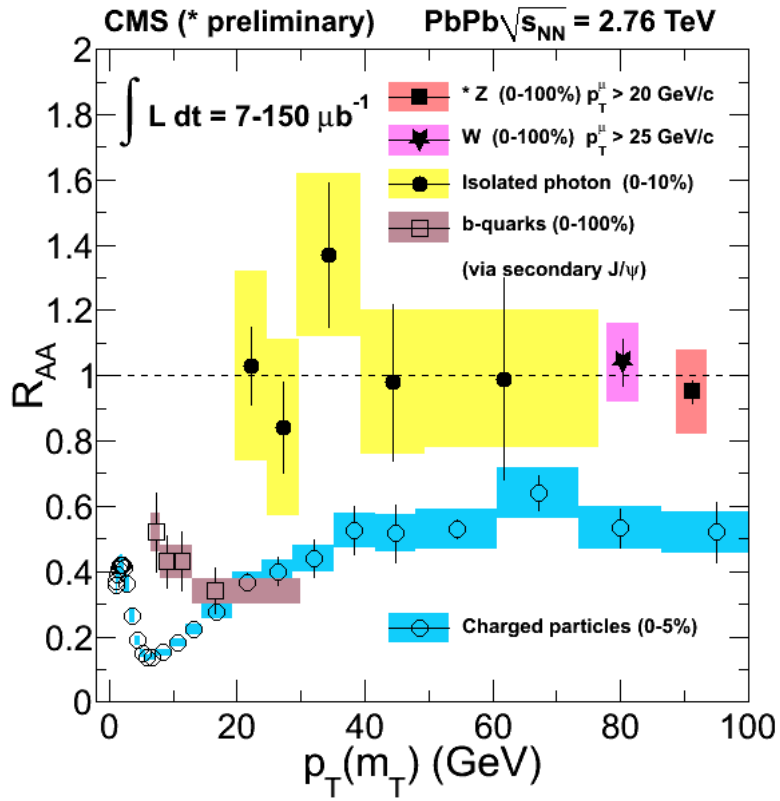
Isolated γ 3
PLB 710 (2012) 256

How to measure if a probe is affected by the medium?

R_{AA} = ratio between the production yield in PbPb and the production yield in pp, normalized by the number elementary collisions

$$R_{AA} = \frac{N_{AA}}{N_{pp} \times N_{coll}}$$

N_{coll} = number of elementary collisions



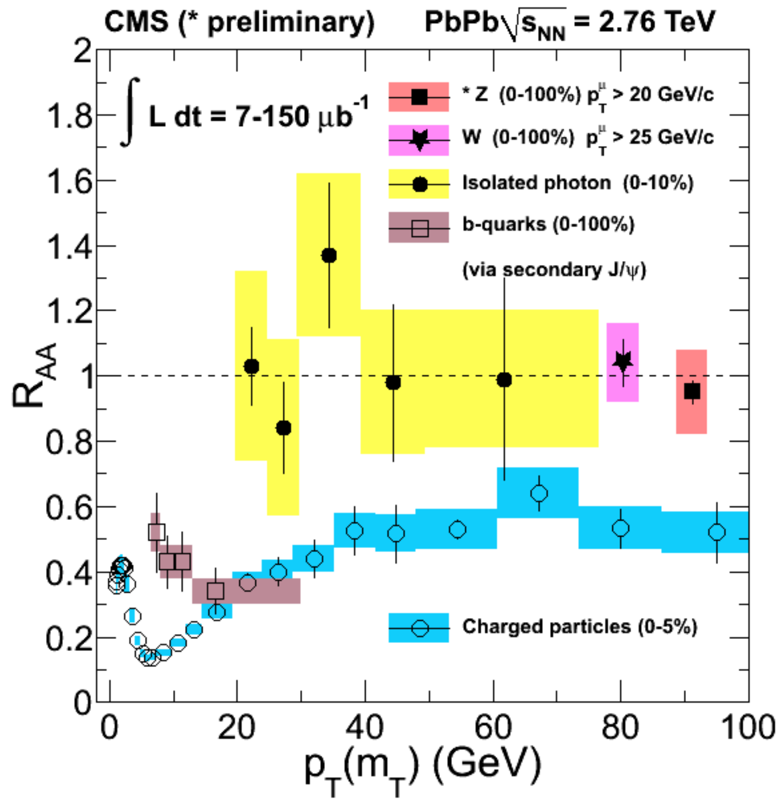
How to measure if a probe is affected by the medium?

R_{AA} = ratio between the production yield in PbPb and the production yield in pp, normalized by the number elementary collisions

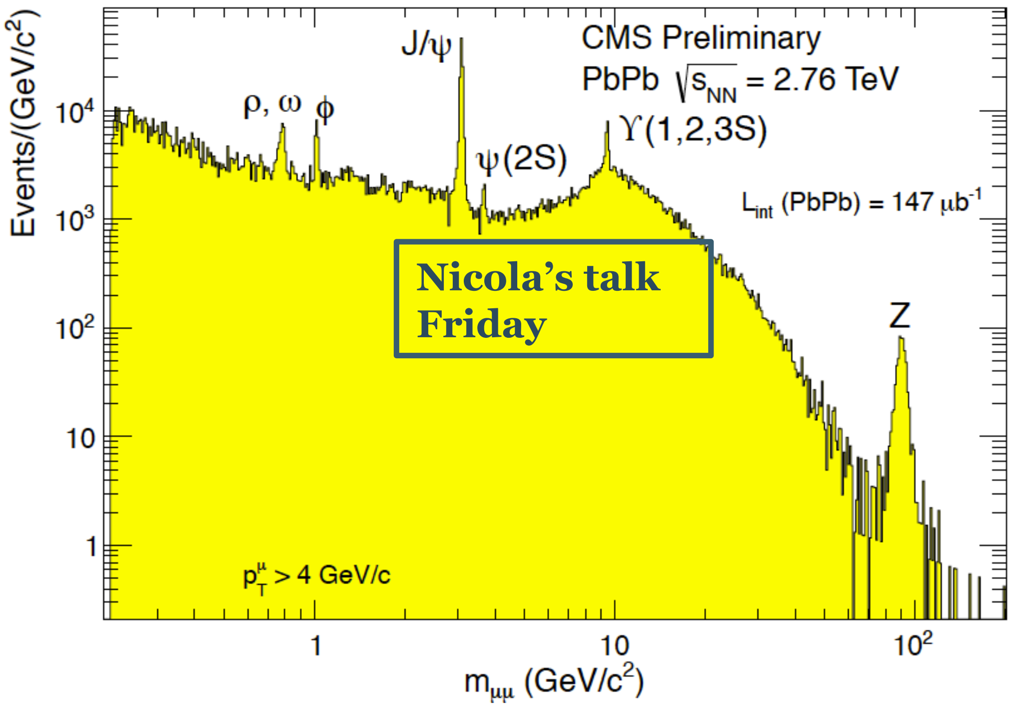
$$R_{AA} = \frac{N_{AA}}{N_{pp} \times N_{coll}}$$

N_{coll} = number of elementary collisions

$R_{AA} \sim 1$ Non-modified

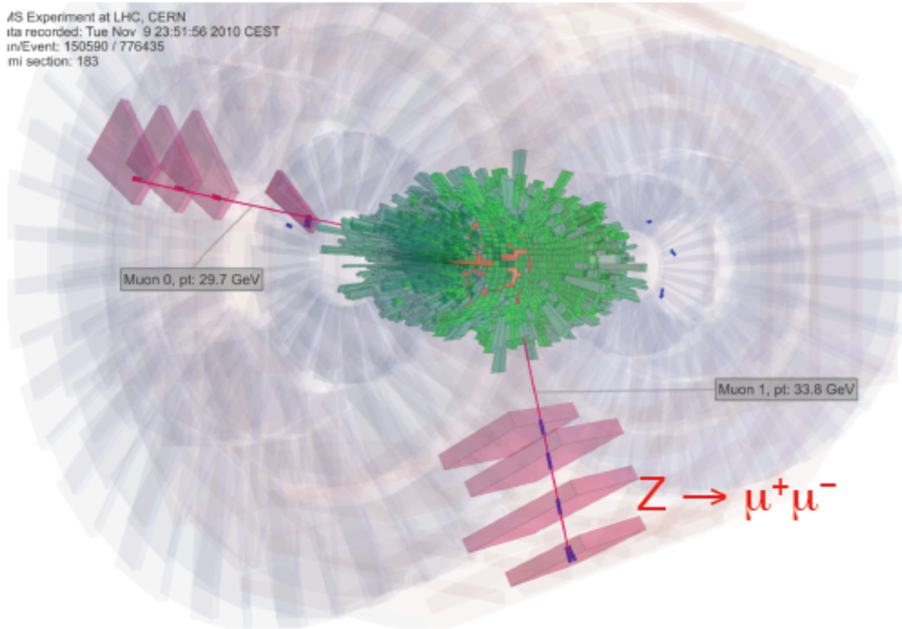


1. Z → $\mu^+ \mu^-$



Dimuon invariant mass spectrum

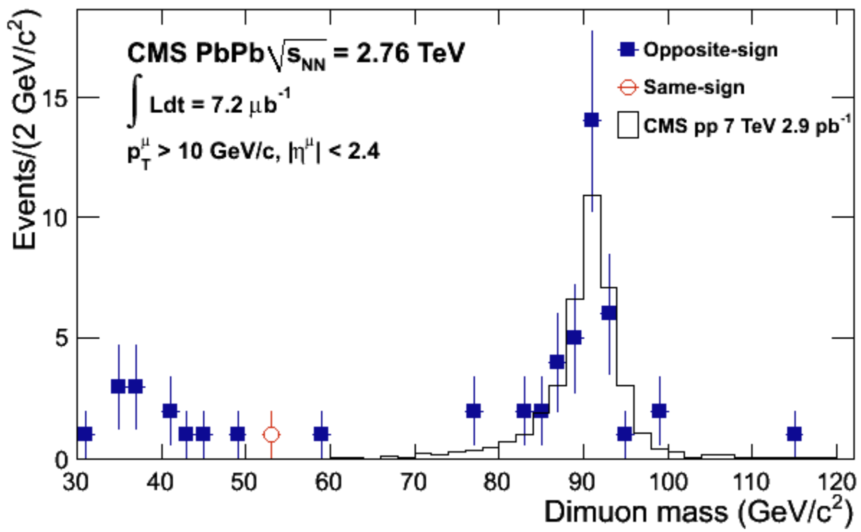
Z boson picture



Invariant mass

Data sample Pb+Pb collisions @ **√s = 2.76 TeV**

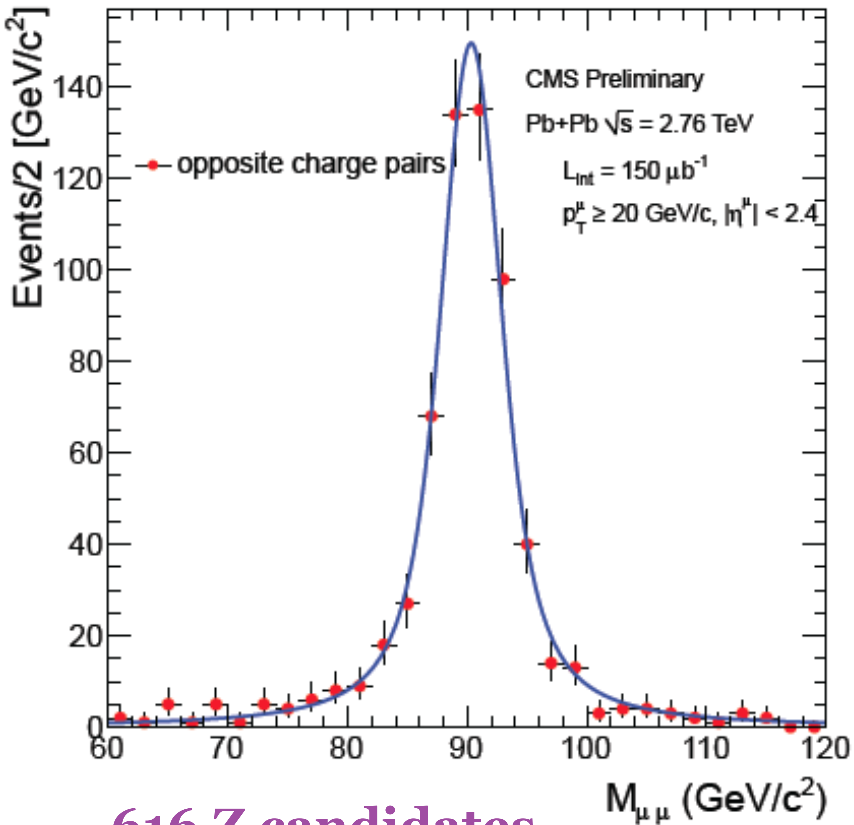
2010: $L_{int} = 7.2\ \mu b^{-1}$



39 Z candidates

$P_T^{\mu} > 10$ GeV/c

2011: $L_{int} = 150\ \mu b^{-1}$

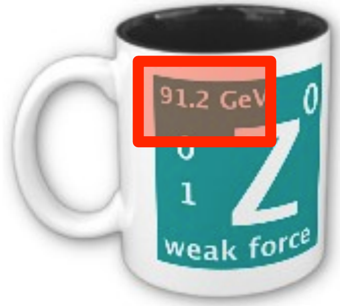


616 Z candidates

$p_T^{\mu} > 20$ GeV/c

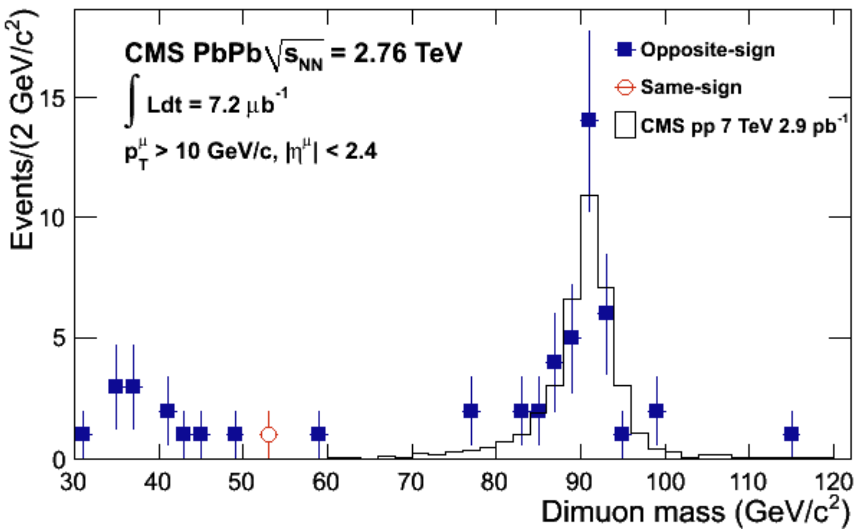
CMS-PAS-HIN-12-008

Invariant mass



Data sample Pb+Pb collisions @ **√s = 2.76 TeV**

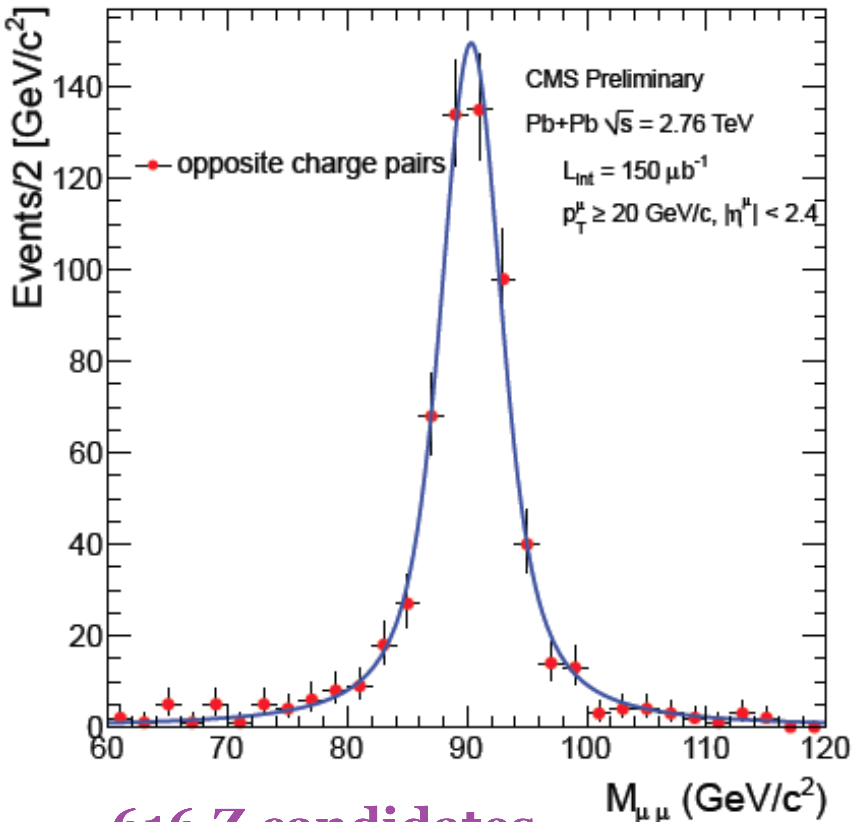
2010: L_{int} = 7.2 μb^{-1}



39 Z candidates

P_T^{μ} > 10 GeV/c

2011: L_{int} = 150 μb^{-1}



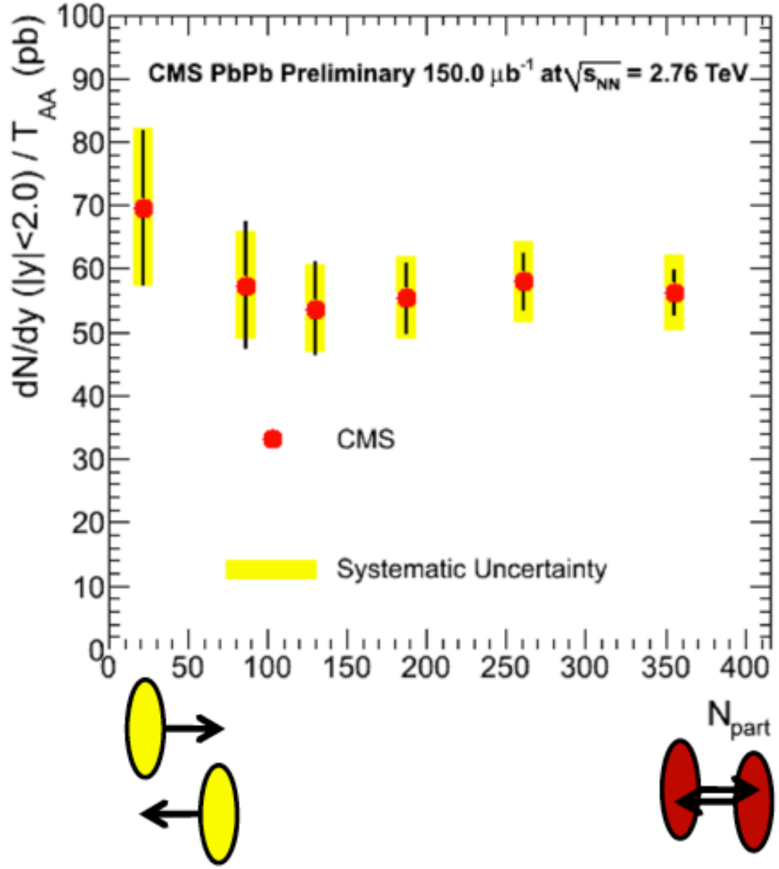
616 Z candidates

p_T^{μ} > 20 GeV/c

CMS-PAS-HIN-12-008

R_{AA} deduce from powheg

CMS-PAS-HIN-12-008

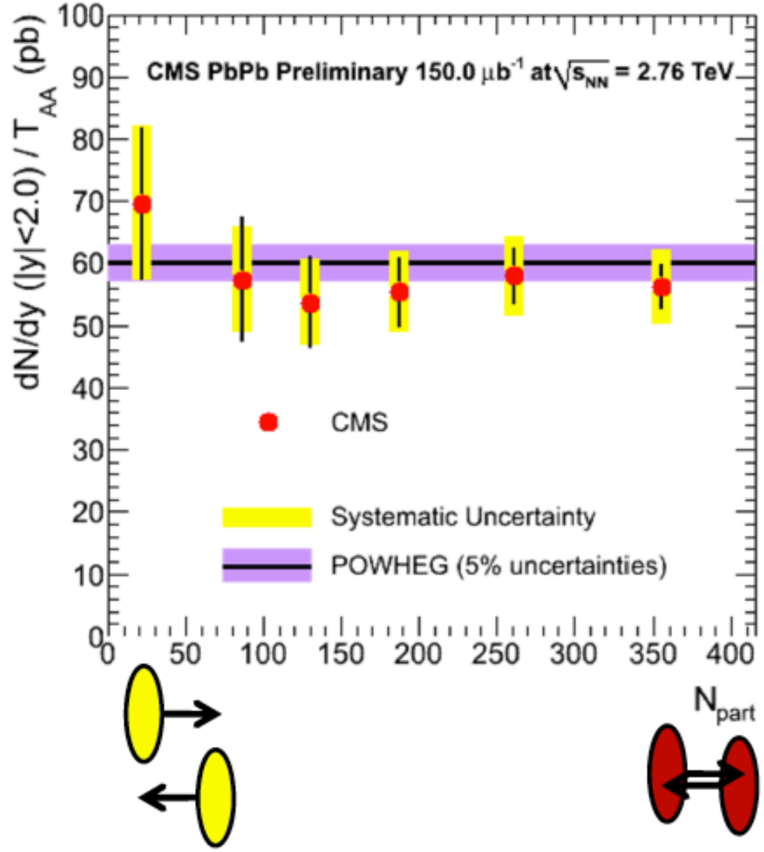


Centrality independence

dN_{AA}/T_{AA}

R_{AA} deduce from powheg

CMS-PAS-HIN-12-008

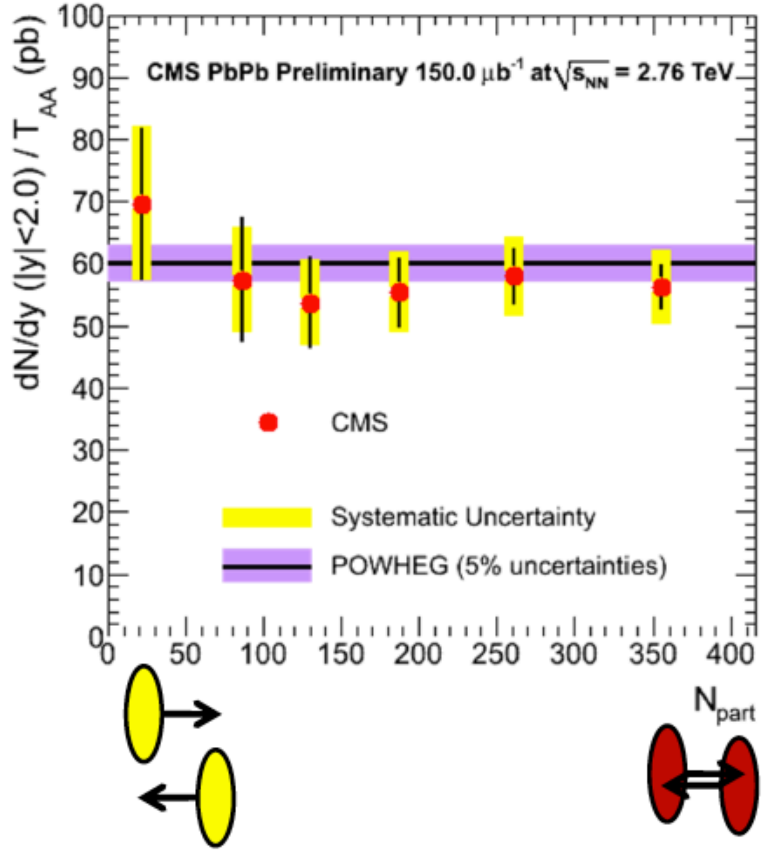


Centrality independence

$$dN_{AA}/T_{AA} = d\sigma_{pp} \times dN_{AA}/dN_{pp} \times N_{coll}$$

R_{AA} deduce from powheg

CMS-PAS-HIN-12-008



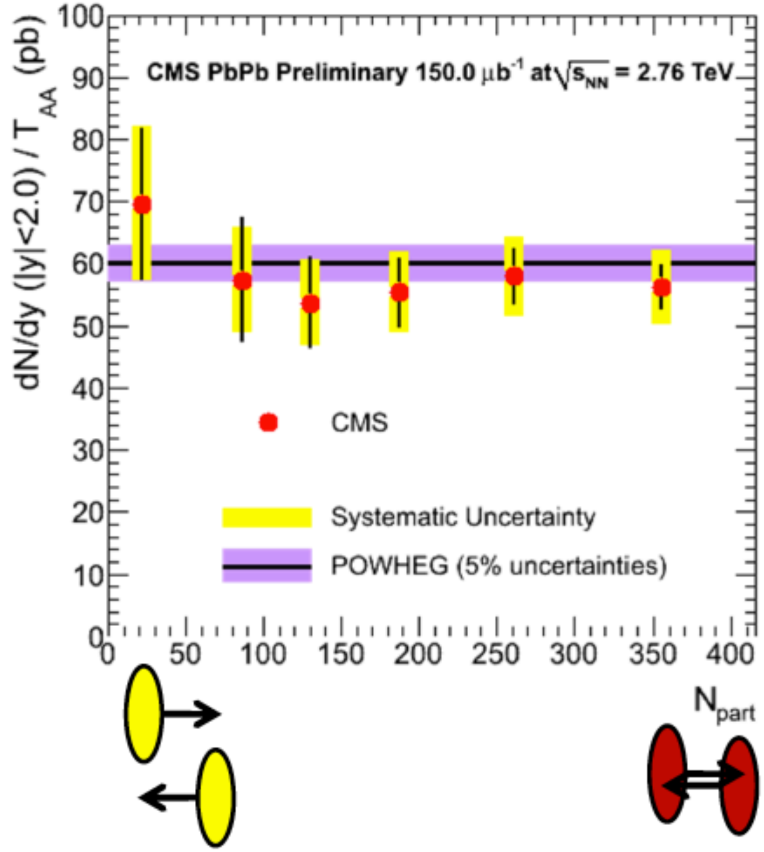
Centrality independence

$$dN_{AA}/T_{AA} = d\sigma_{pp} \times dN_{AA}/dN_{pp} \times N_{coll}$$

$$dN_{AA} / T_{AA} = d\sigma_{pp} \text{ x } R_{AA}$$

R_{AA} deduce from powheg

CMS-PAS-HIN-12-008



Centrality independence

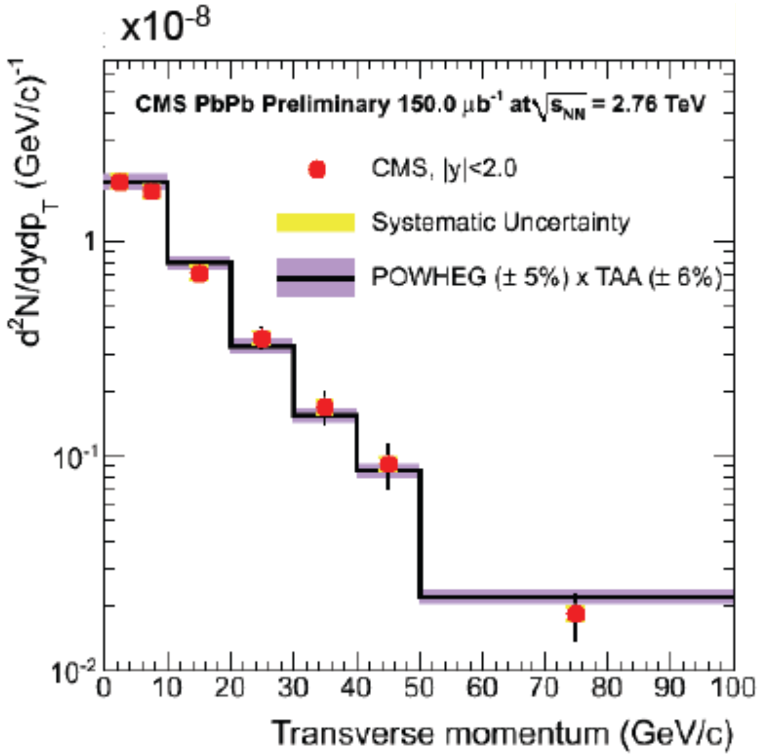
$$dN_{AA}/T_{AA} = d\sigma_{pp} \times dN_{AA}/dN_{pp} \times N_{coll}$$

$$dN_{AA} / T_{AA} = d\sigma_{pp} \times R_{AA}$$

$$R_{AA} = 0.95 \pm 0.03 \pm 0.13$$

Additional Insights

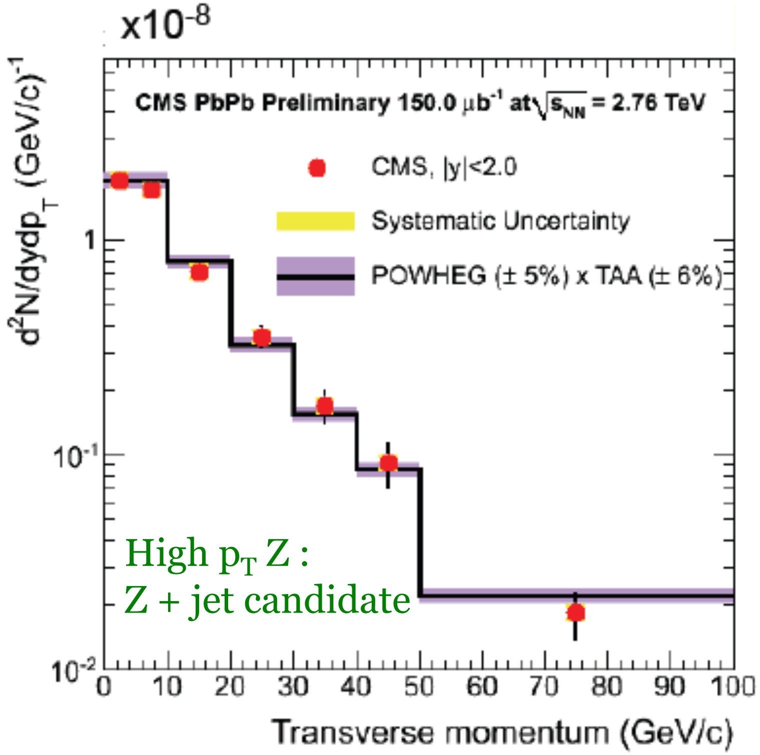
Yield of Z as a function of transverse momentum



Distribution matches POWHEG
No deviation from pp

Additional Insights

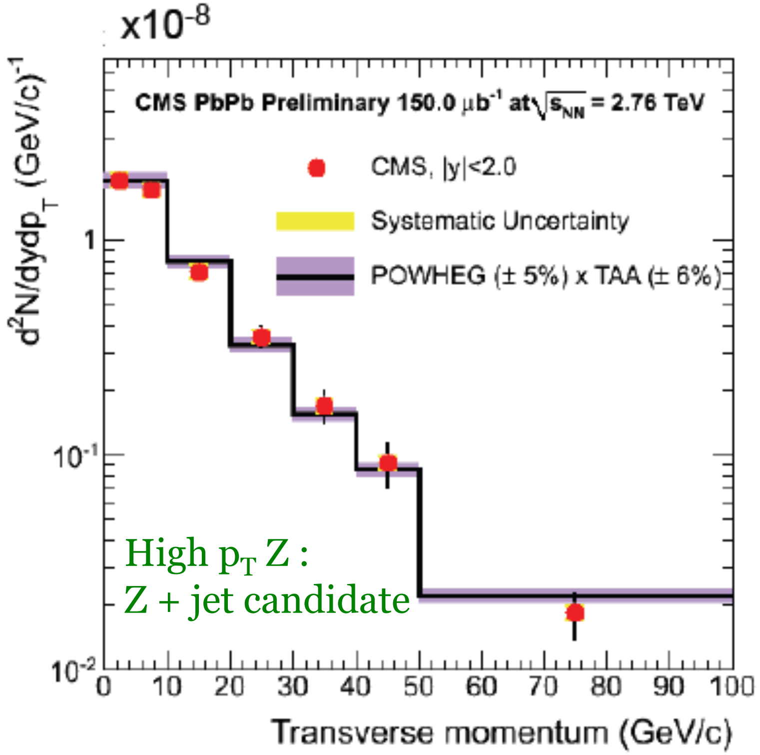
Yield of Z as a function of transverse momentum

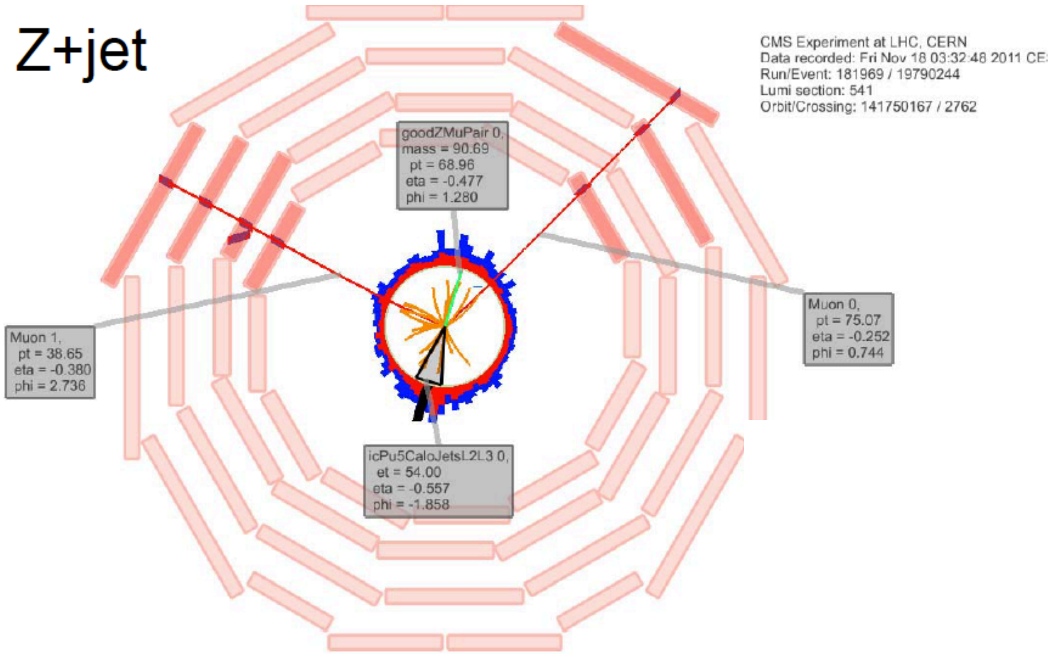


Distribution matches POWHEG
No deviation from pp

Additional Insights

Yield of Z as a function of transverse momentum



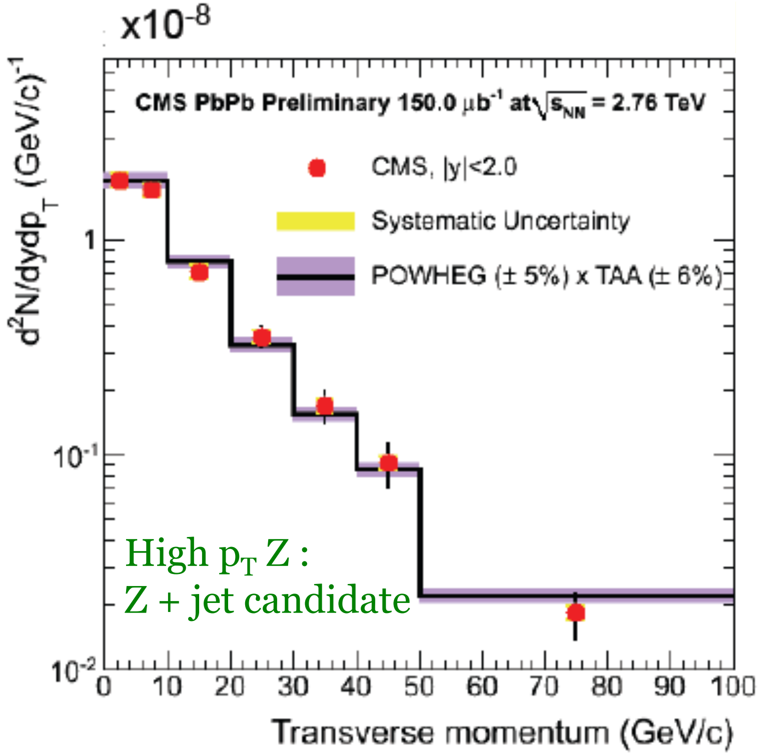


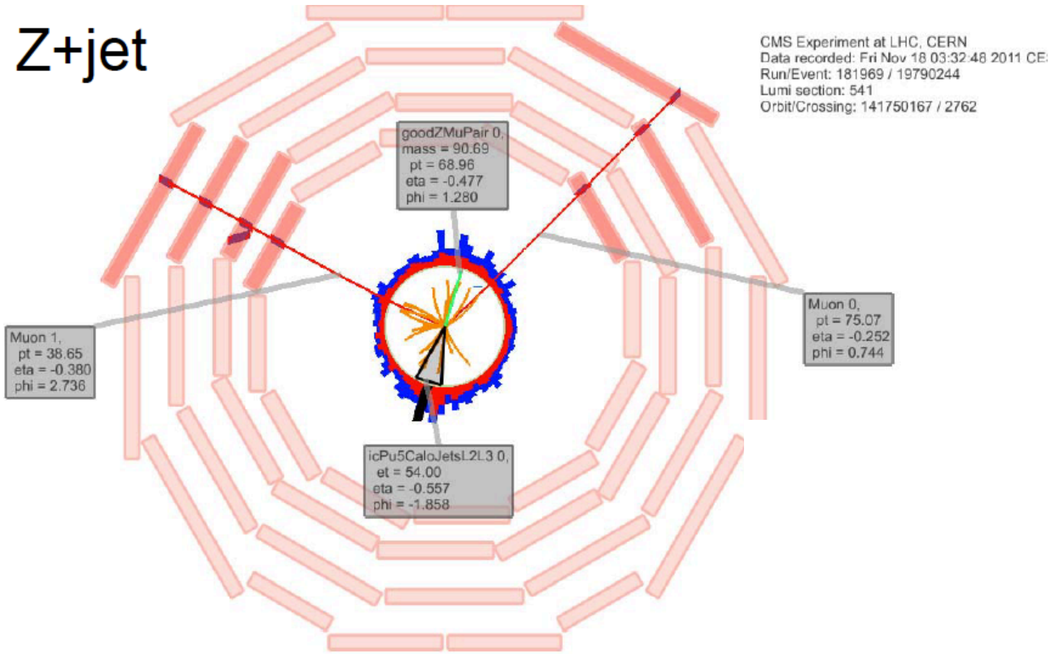
Distribution matches POWHEG

No deviation from pp

Additional Insights

Yield of Z as a function of transverse momentum





Distribution matches POWHEG
No deviation from pp

Z p_T used as estimate of the jet p_T
Cleaner (no fragmentation) than γ + jet but less statistics

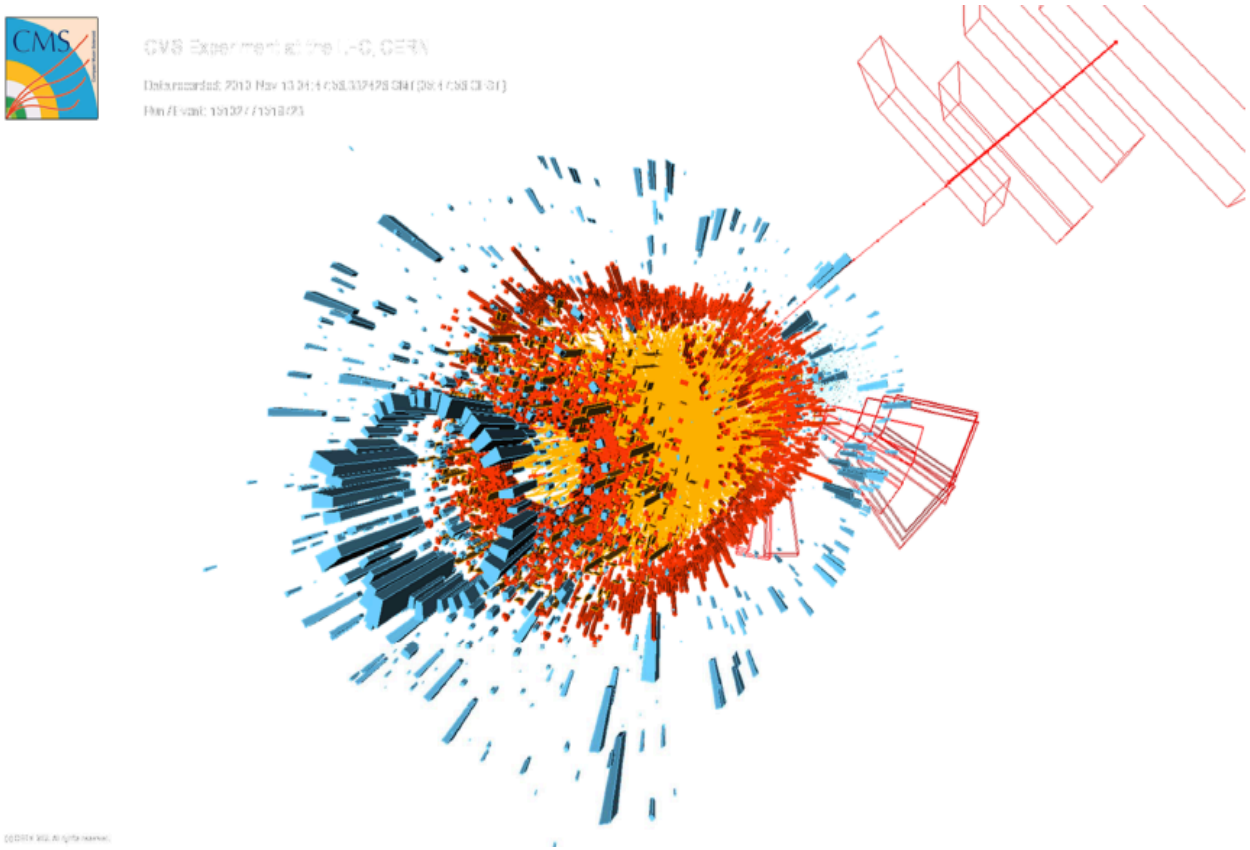
Conclusion 1/3

1. $Z \rightarrow \mu^{+} \mu^{-}$

- Proportional to binary collisions
- Independent of centrality collision
- Could serve to estimate the initial energy of the away-side parton

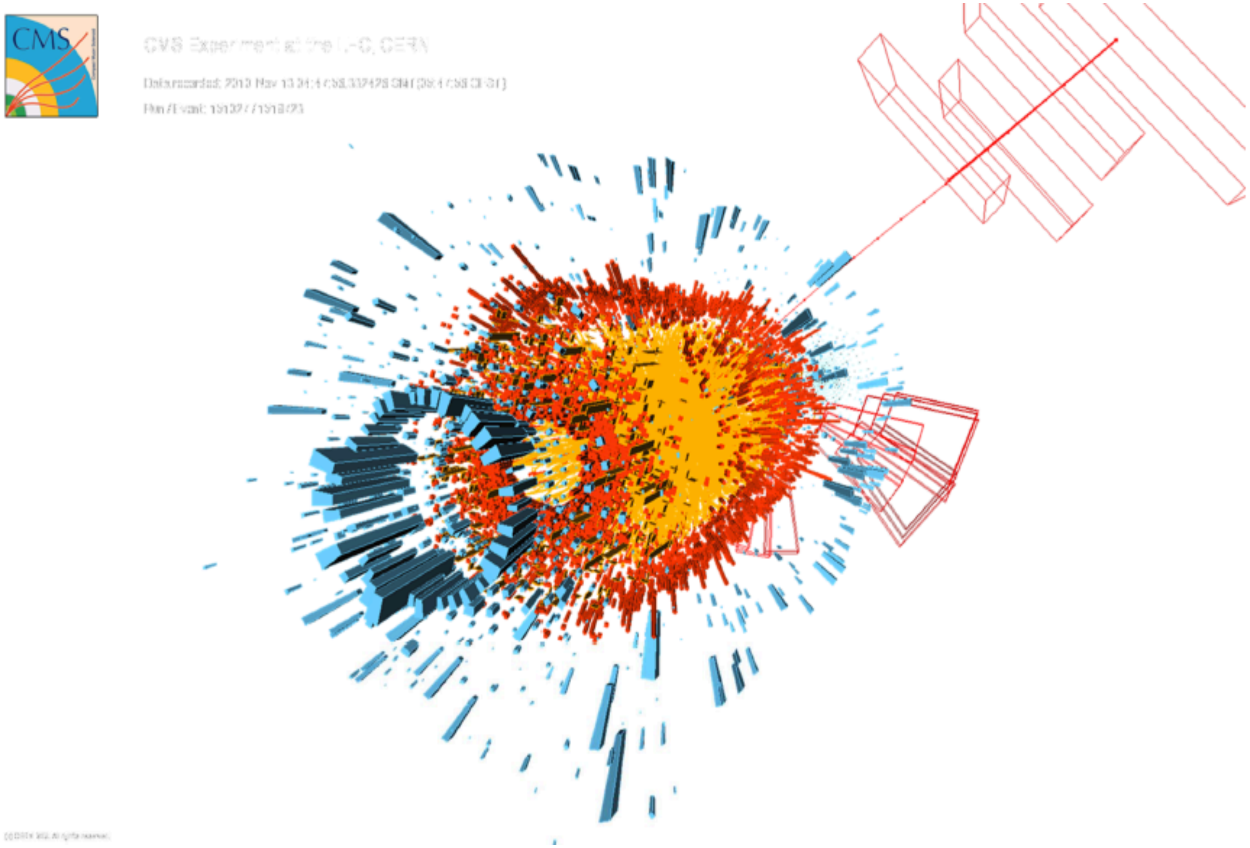
2. W $\rightarrow \mu^{\pm} \nu$

Official picture



2. W →μ± ν

Official picture

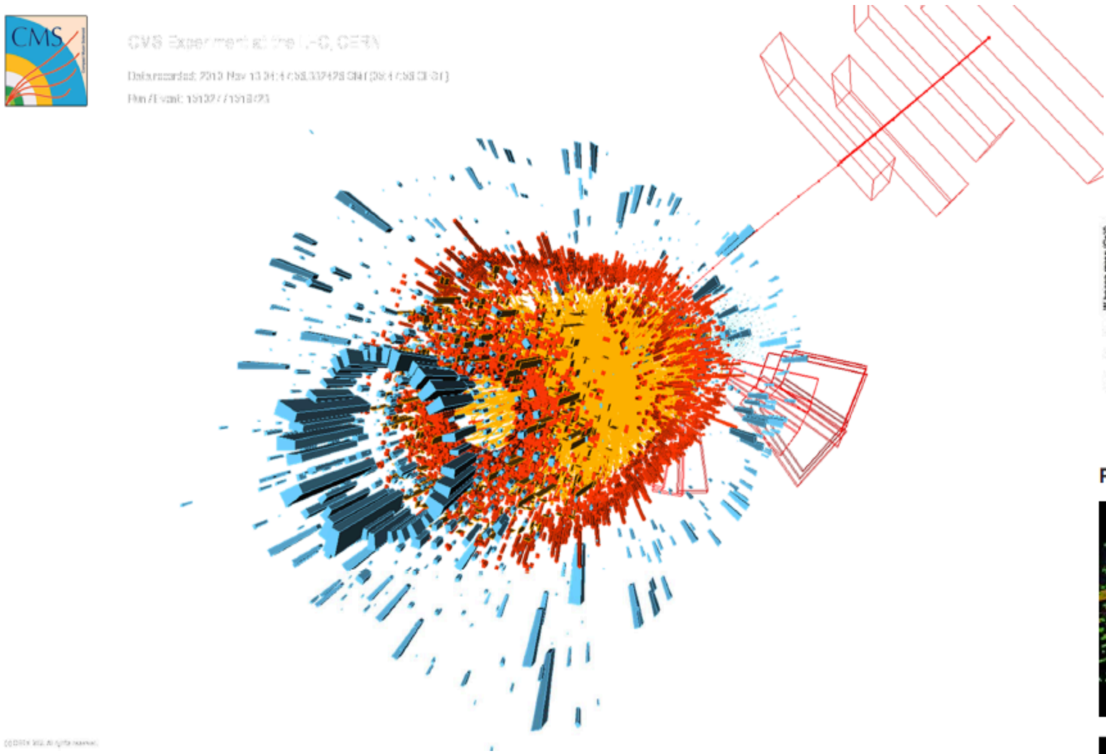


Non-official picture

when you google "W boson" you get :

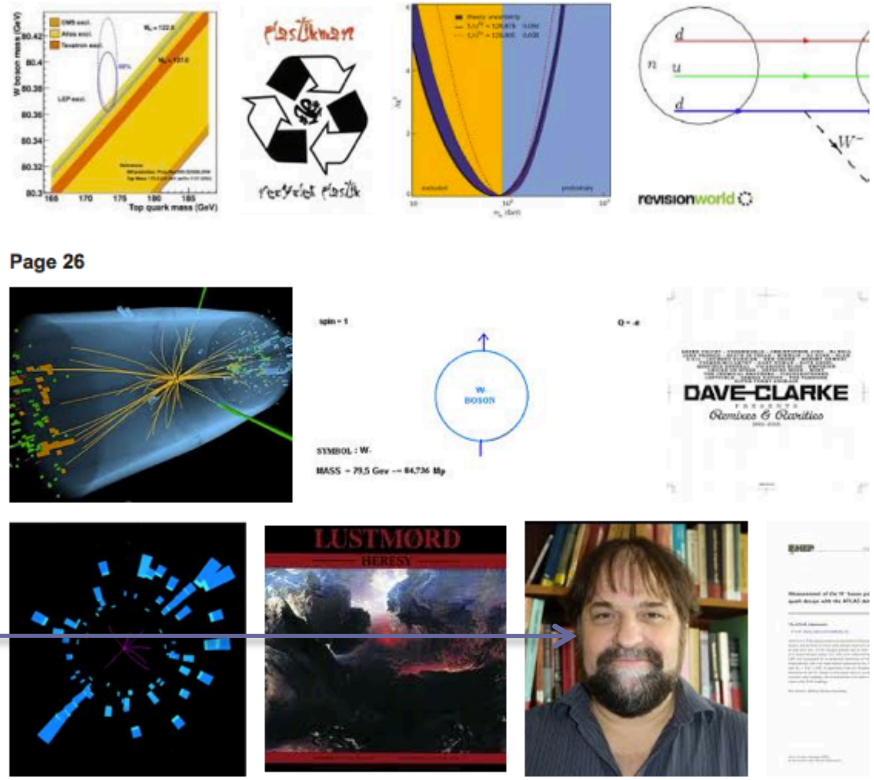
2. W → μ± ν

Official picture



Non-official picture

when you google “W boson” you get :



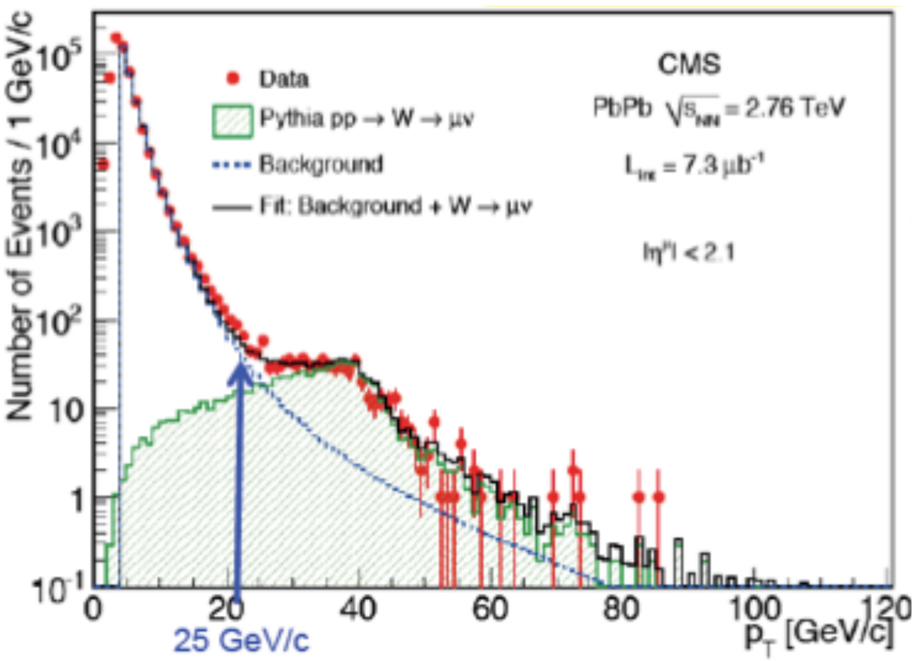
Yves Sirois

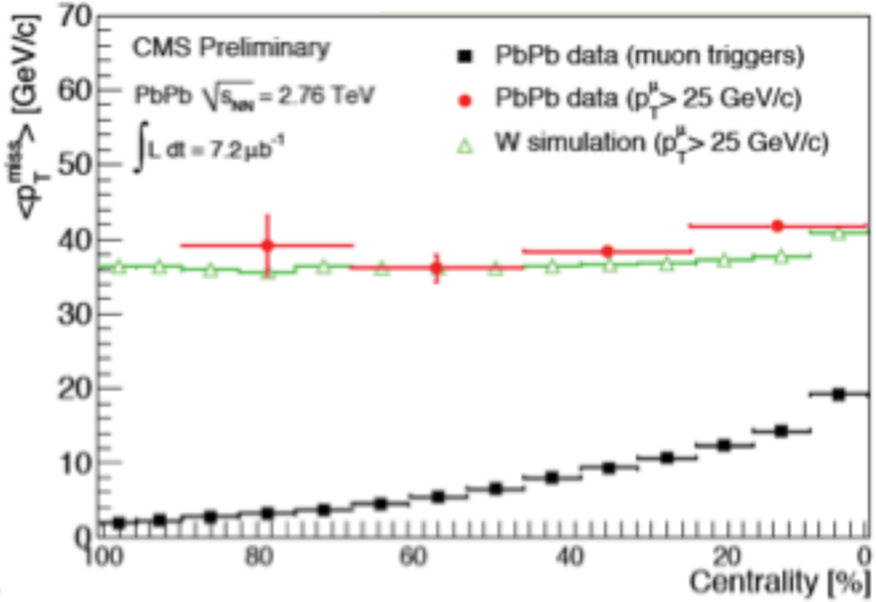
μ and ν

μ p_T

$$\not{p}_T = -\sum \vec{p}_T$$

PLB 715 (2012) 66

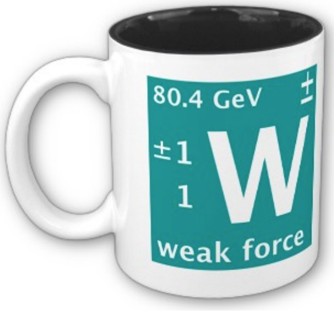




Signal already visible in muon P_T spectrum

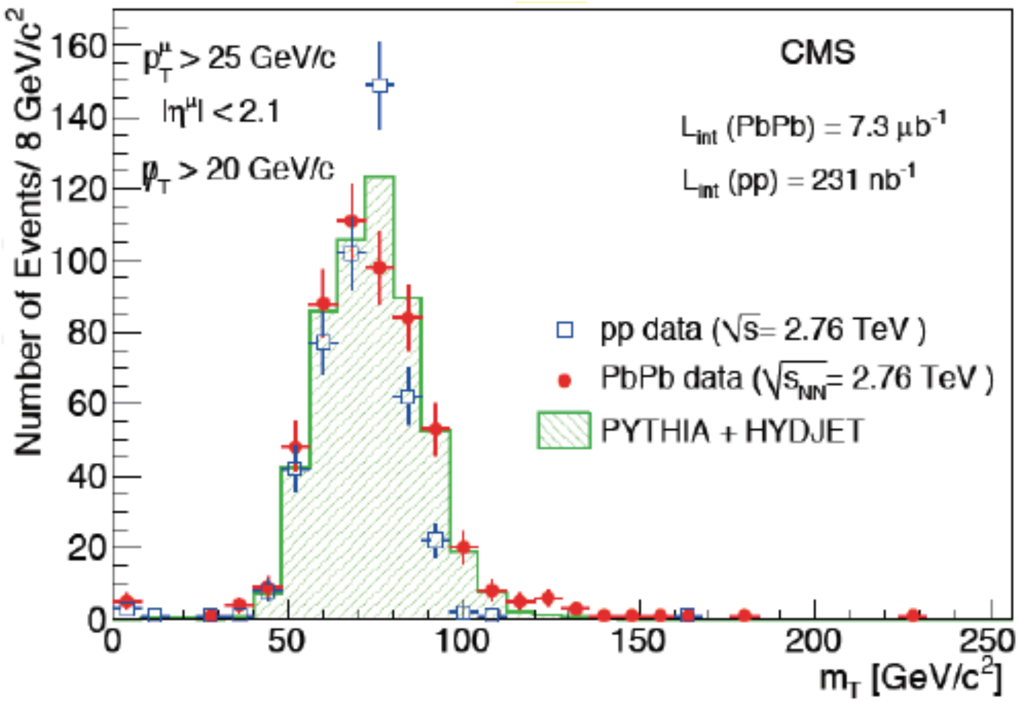
Simple missing p_T from tracks

Transverse mass



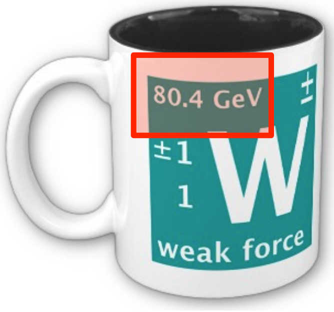
$$m_T = \sqrt{2 p_T^{\mu} \not{p}_T (1 - \cos\phi)}$$

PLB 715 (2012) 66

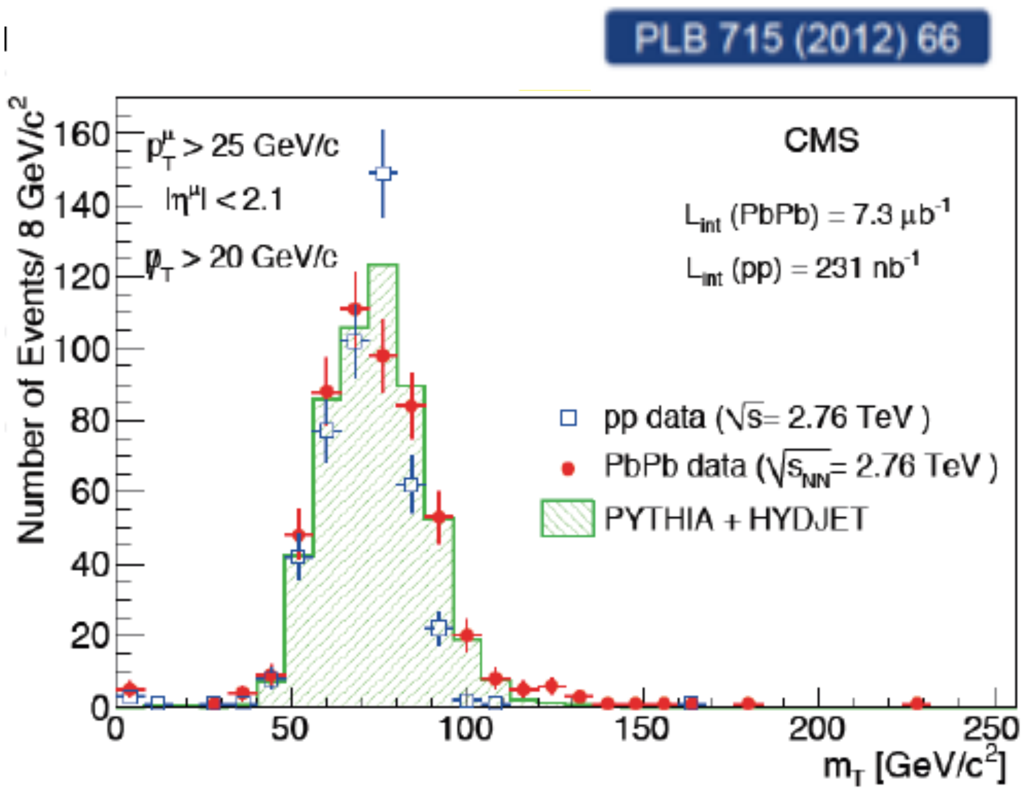


Compatible distribution W signals between PbPb, pp and MC

Transverse mass

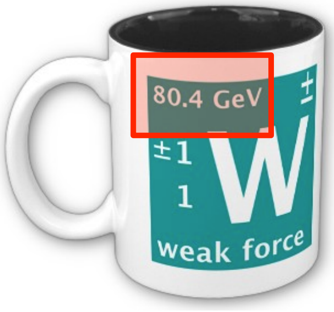


$$m_T = \sqrt{2 p_T{}^{\mu} \not{p}_T (1 - \cos\phi)}$$



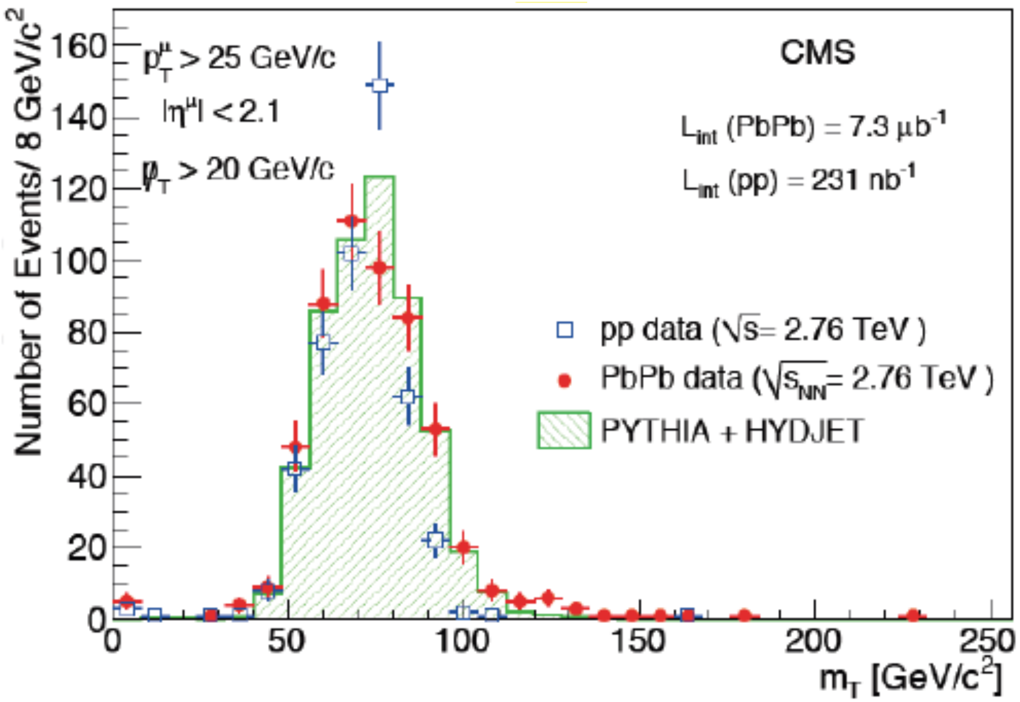
Compatible W signals in PbPb and pp

Transverse mass



$$m_T = \sqrt{2 p_T^{\mu} \not{p}_T (1 - \cos\phi)}$$

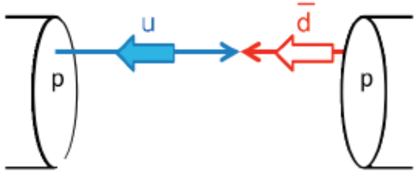
PLB 715 (2012) 66



	PbPb	pp
W^+	275	301
W^-	264	165

Compatible W signals in PbPb and pp

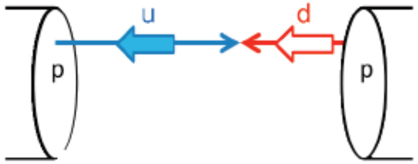
- **Why different yield for W^+ and W^- ?**



$u\bar{d} \rightarrow W^+$
$d\bar{u} \rightarrow W^-$

pp collisions = more W^+ than W^-
Pb+Pb collisions = more W^- than W^+

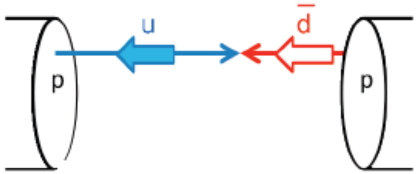
- **Why different yield for W⁺ and W⁻ ?**



$u\bar{d} \rightarrow W^+$
$d\bar{u} \rightarrow W^-$

pp collisions = more W^+ than W^-
Pb+Pb collisions = more W^- than W^+

- **Then why we have more W+ than W- in Pb-Pb?**

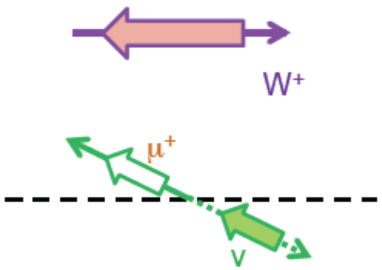


1. $W^{\pm}$ are boosted in the direction of valence quark

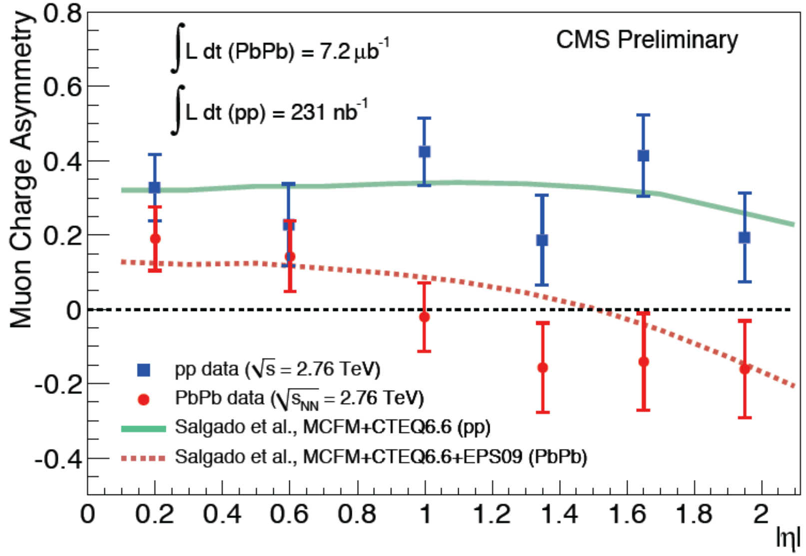
Spin conservation:

1. μ^+ boosted back to the W^+
2. μ^- boosted along with the W^-

➔ Muons charge asymmetry

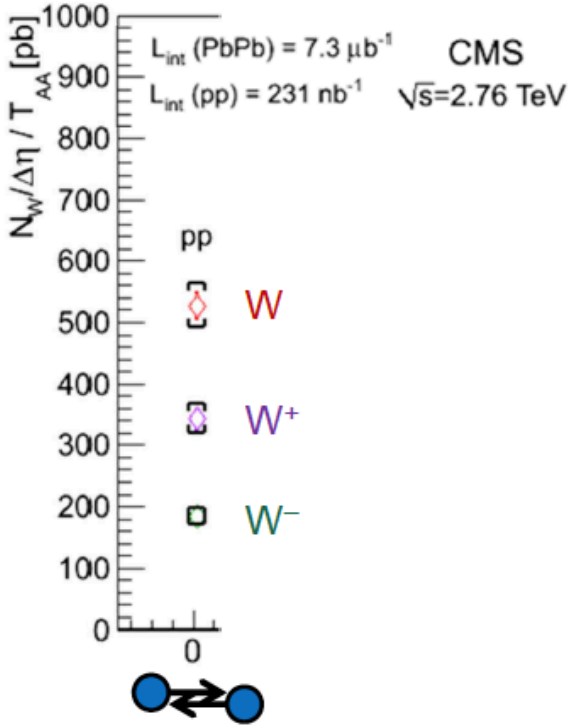


$$\frac{N(W^+)-N(W^-)}{N(W^+)+N(W^-)}$$



Centrality independence and R_{AA}

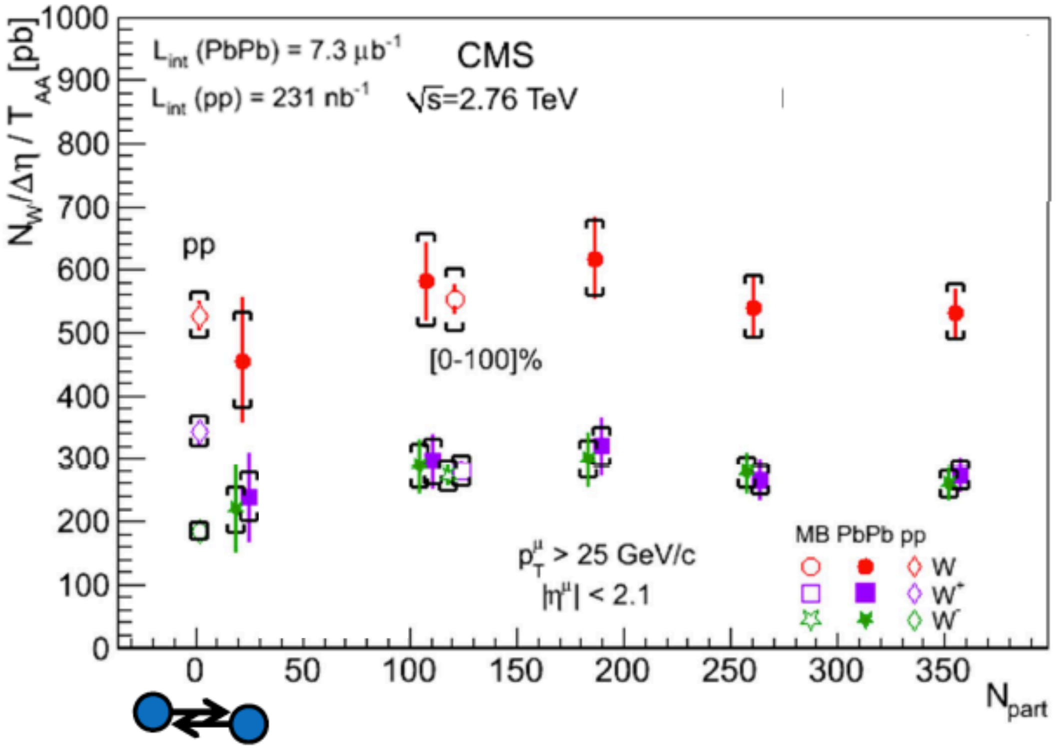
$d\sigma_{pp}$



Not from powheg but
data at 2.76 TeV

Centrality independence and R_{AA}

$$dN_{AA} / T_{AA} = d\sigma_{pp}$$



PLB 715 (2012) 66

Not from powheg but
data at 2.76 TeV

Centrality independence and R_{AA}

$$dN_{AA} / T_{AA} = d\sigma_{pp} \times R_{AA}$$

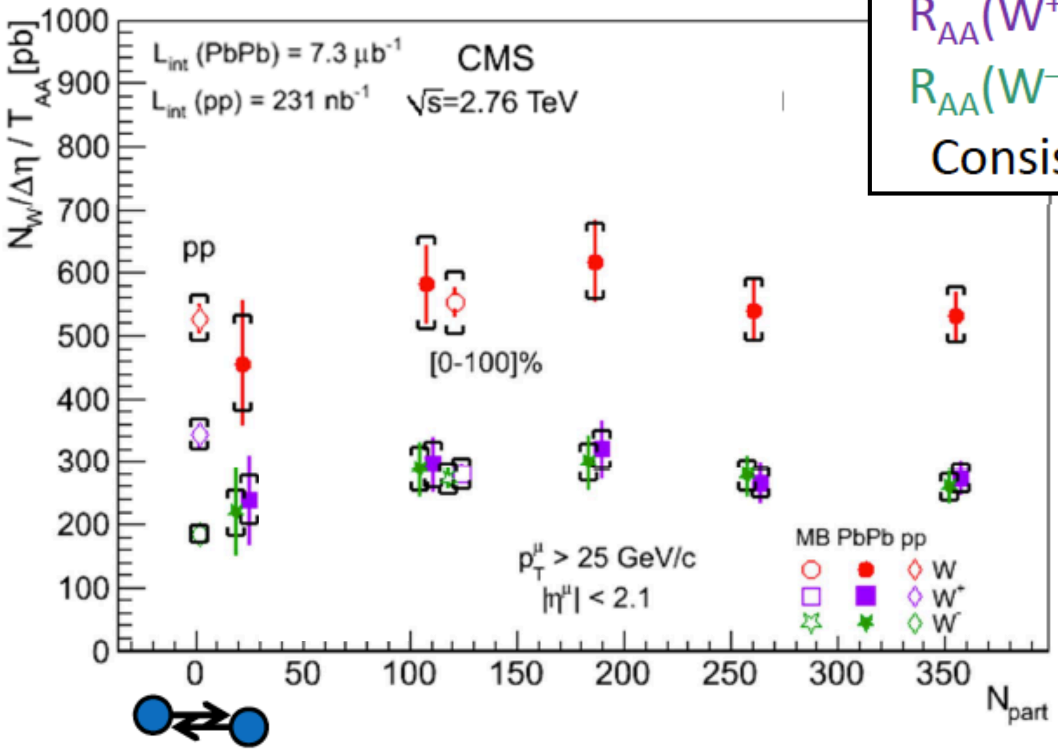
2010 PbPb ≈ pp data

$R_{AA}(W) = 1.04 \pm 0.07 \pm 0.12$

$R_{AA}(W^+) = 0.82 \pm 0.07 \pm 0.09$

$R_{AA}(W^-) = 1.46 \pm 0.14 \pm 0.16$

Consistent with pure isospin



PLB 715 (2012) 66

Not from powheg but
data at 2.76 TeV

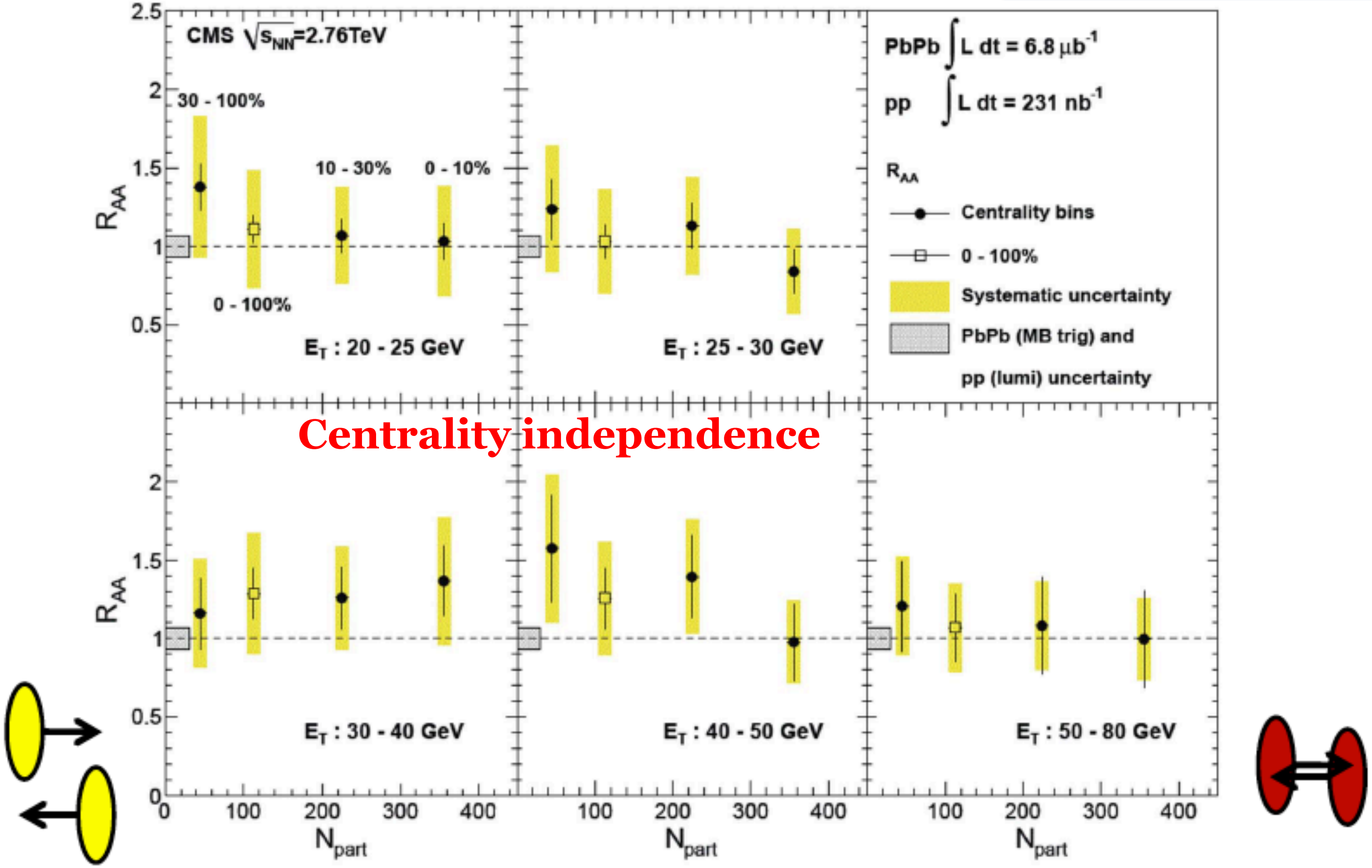
Conclusion (2/3)

1. $Z \rightarrow \mu^+ \mu^-$
   - Proportional to binary collisions
   - Independent of collision centrality
   - Could serve to estimate the initial energy of the away-side parton

2. $W^\pm \rightarrow \mu^\pm \nu$
   - Proportional to binary collisions
   - Independent of collision centrality
   - Strong isopsin effect (expected)

Last part: photons

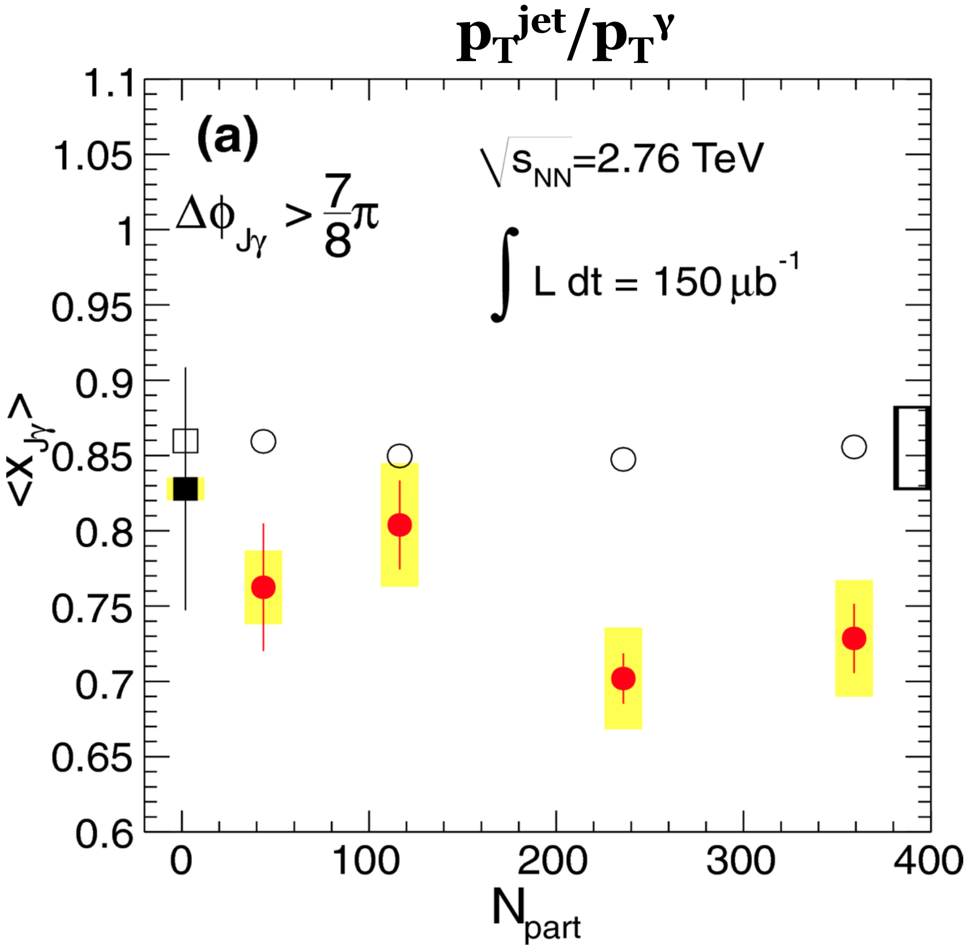
PLB 710 (2012) 256



photons-jet

PLB 718 (2013) 773

Look at a photon p_T > 60 and a jet p_T>30 GeV/c on the opposite side



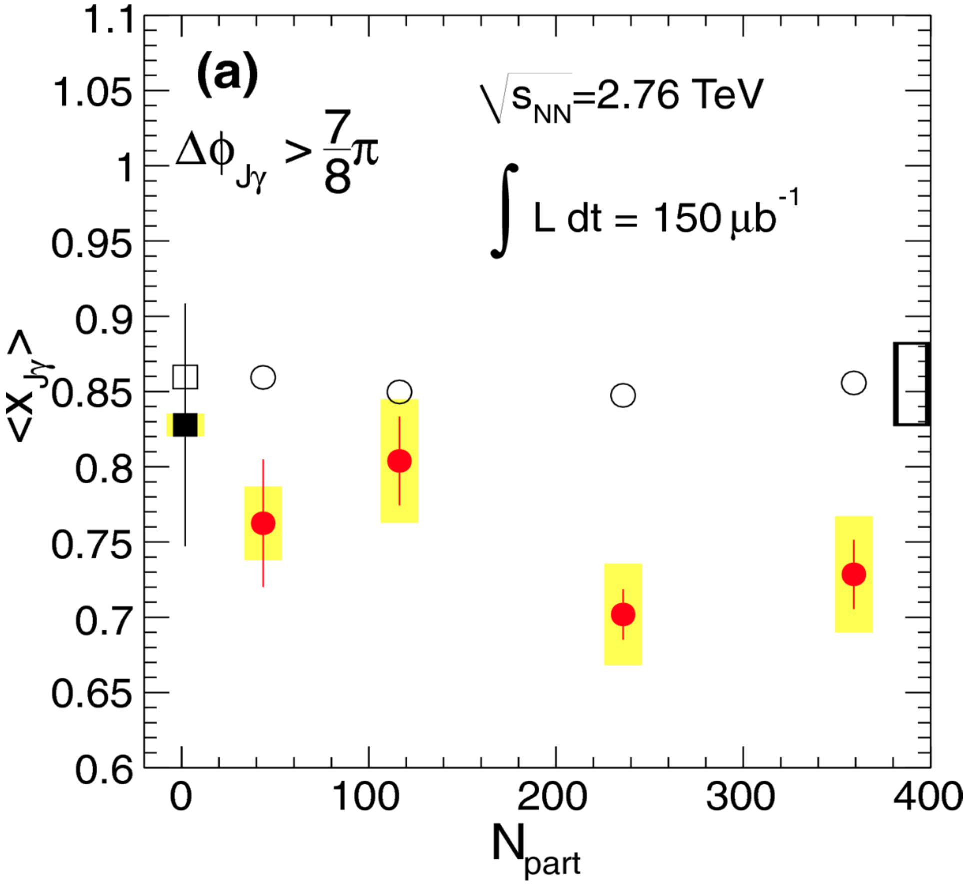
a) Opposite jets above threshold are 14% less energetic in PbPb than pp

photons-jet

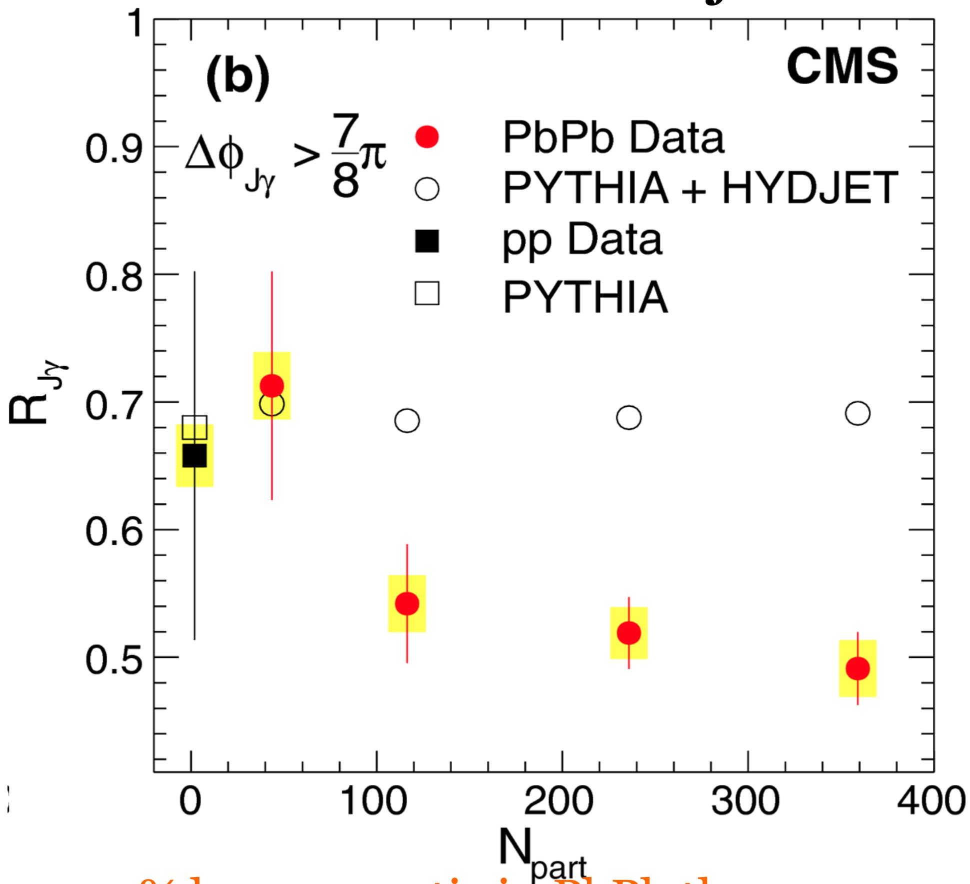
PLB 718 (2013) 773

Look at a photon p_T > 60 and a jet p_T>30 GeV/c on the opposite side

p_T^{jet}/p_T^{γ}



Fraction of photon associated to a jet



a) Opposite jets above threshold are 14% less energetic in PbPb than pp
b) 20% more are not associated to a reconstructed jet

Conclusion 3/3

1. $Z \rightarrow \mu^+ \mu^-$
- Proportional to binary collisions
- Independent of collision centrality
- Could serve to estimate the initial energy of the away-side parton

2. $W^{\pm} \rightarrow \mu^{\pm} \nu$
- Proportional to binary collisions
- Independent of collision centrality
- Strong isopsin effect (expected)

3. Isolated photon
- Proportional to binary collisions
- Independent of collision centrality
- Serves to estimate the initial energy of the away-side parton

Conclusion 3/3

1. Z ➔ μ⁺ μ⁻

- Proportional to binary collisions
- Independent of collision centrality
- Could serve to estimate the initial energy of the away-side parton

2. W± ➔ μ± ν

- Proportional to binary collisions
- Independent of collision centrality
- Strong isopsin effect (expected)

3. Isolated photon

- Proportional to binary collisions
- Independent of collision centrality
- Serves to estimate the initial energy of the away-side parton