Measurement of Jets in PbPb Collisions with CMS

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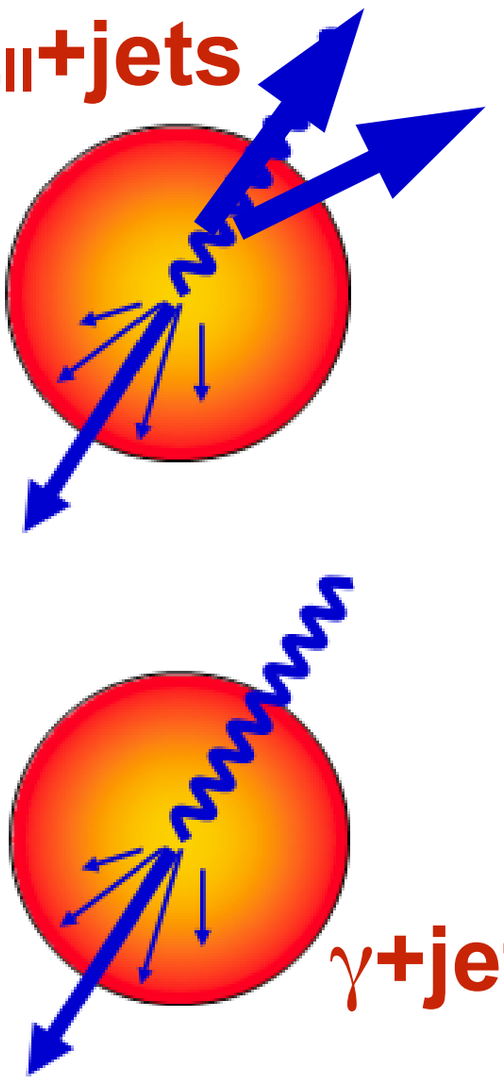
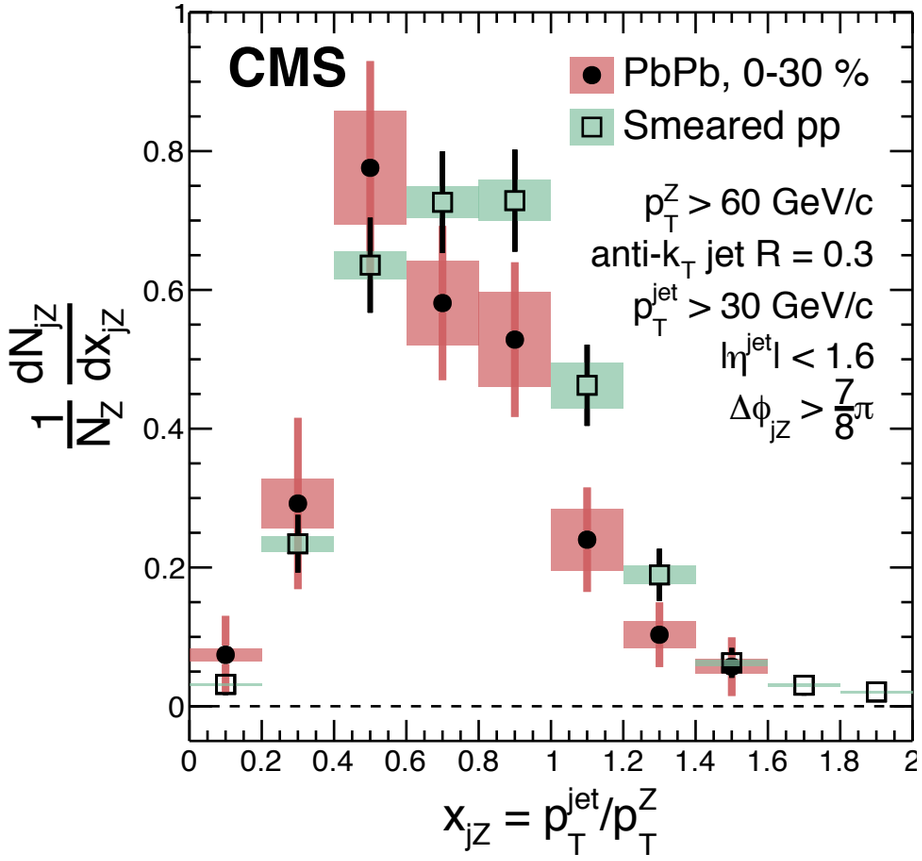
Quark Matter 2018 in Venezia, Italy
2018.05.16

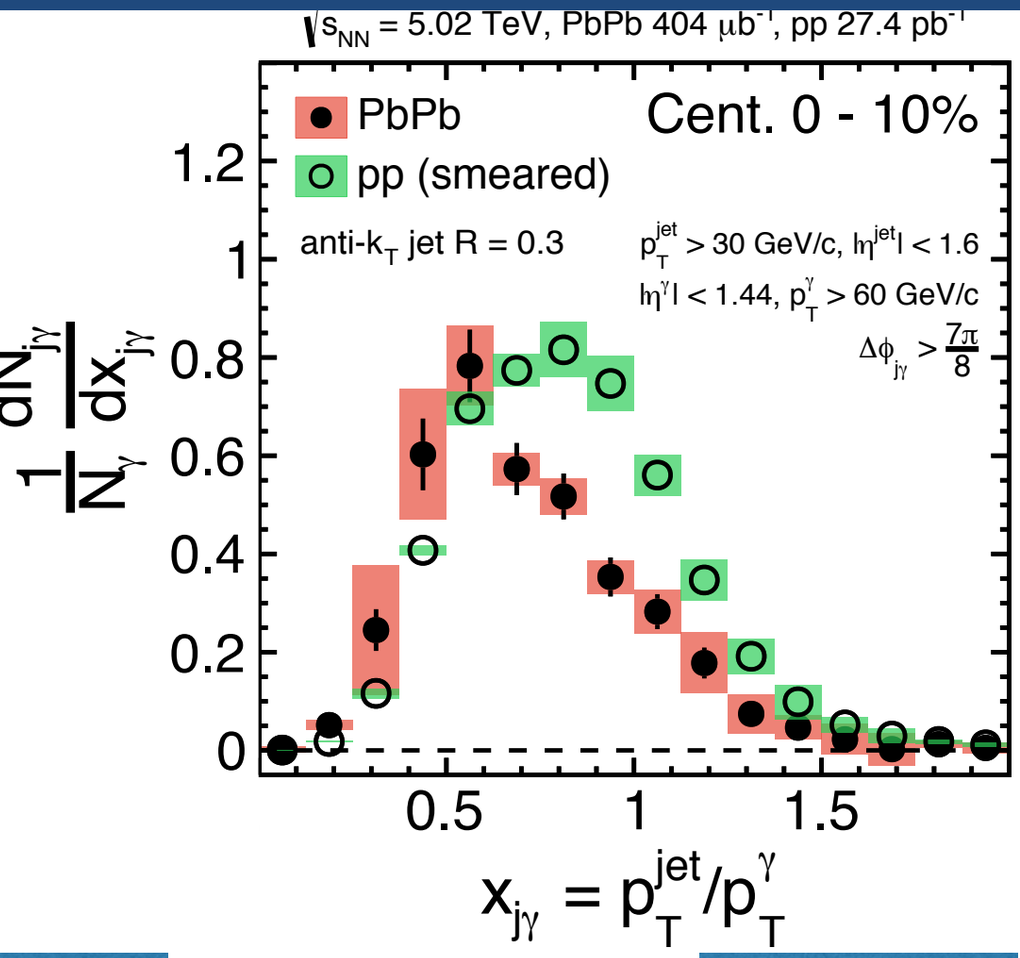
Latest Jet Results in PbPb w/ CMS

Z_{ll}+jets



γ+jets





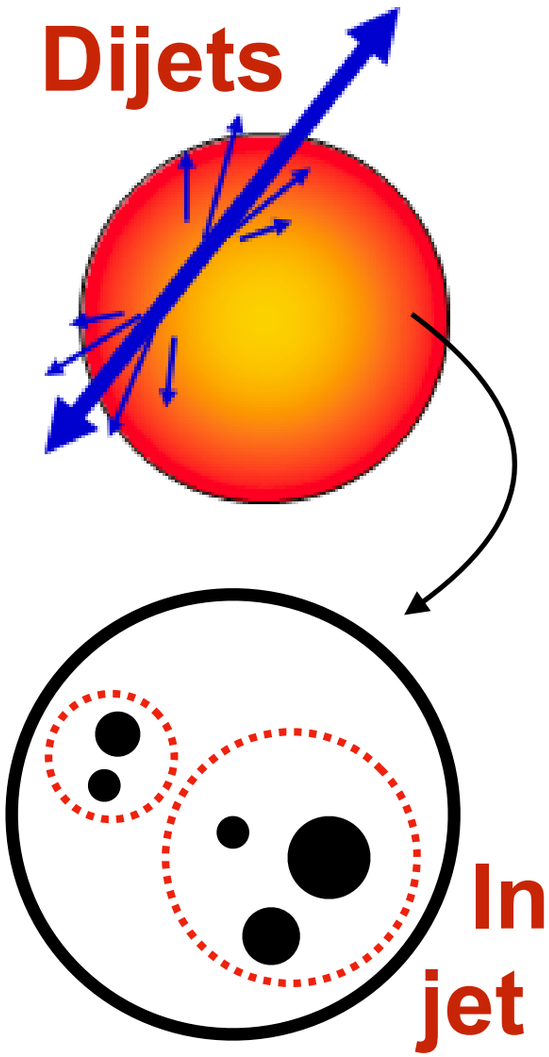
PRL 119 (2017) 082301

arxiv: 1711.09738

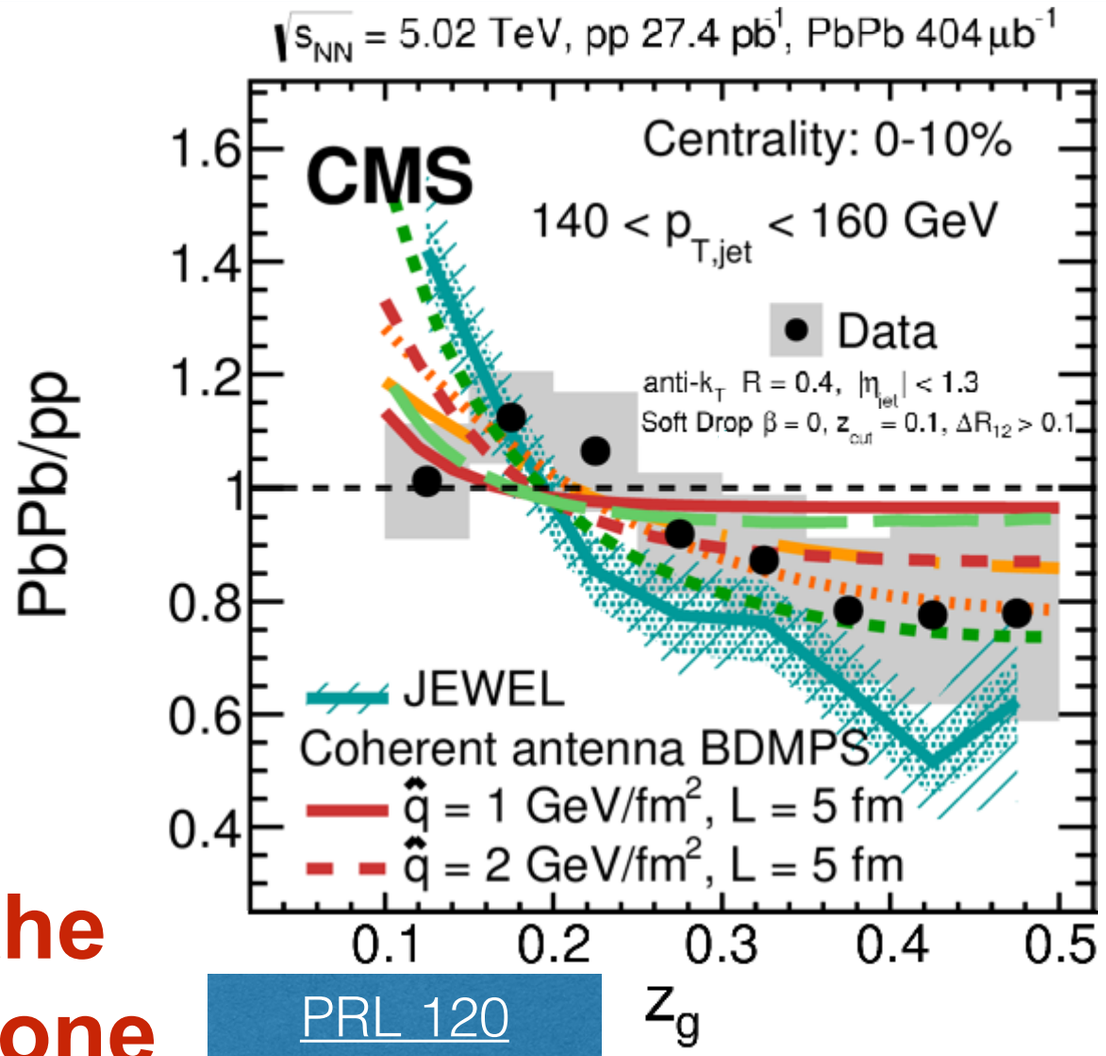
- Jets in heavy-ions require underlying-event (**UE**) subtractions
- In boson+jets results, CMS employs iterative pedestal (**PU)** subtraction
  - Zero-suppression algorithm, destroys constituent resolution
- All measurements employ R = 0.3 to minimize impact of UE

Latest Jet Results in PbPb w/ CMS

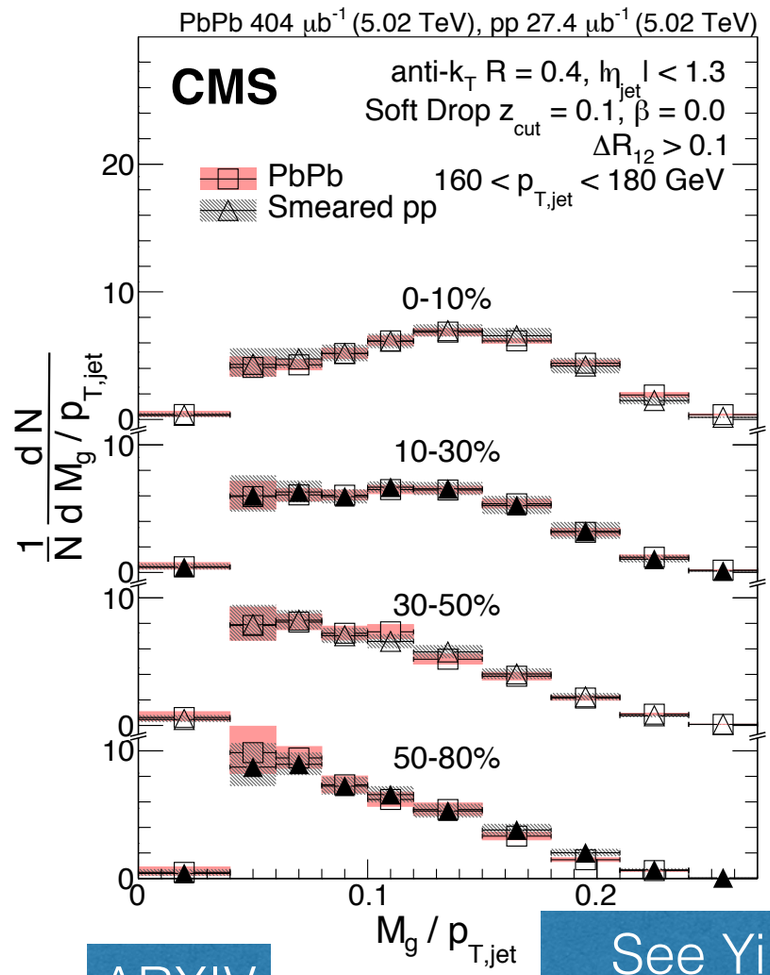
Dijets



In the jet cone



PRL 120 (2018) 142302

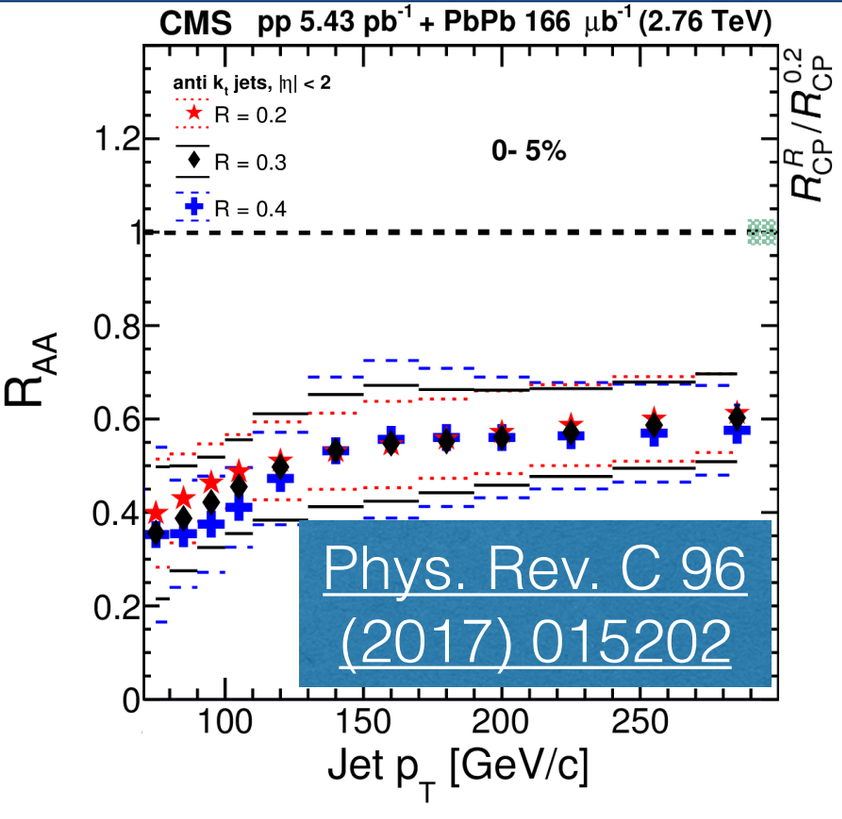


ARXIV NOW

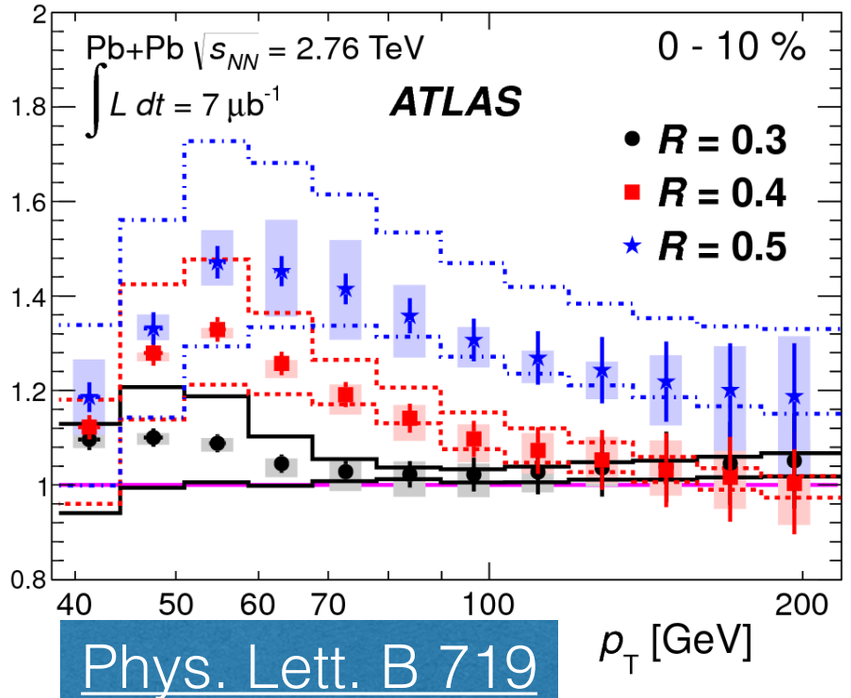
See Yi Chen this afternoon!

- In substructure results, CMS employs constituent subtraction (**CS**)
  - Preserves resolution of constituents (particle-like)
- All measurements employ R = 0.4
- No CMS measurement in PbPb currently goes beyond R = 0.5

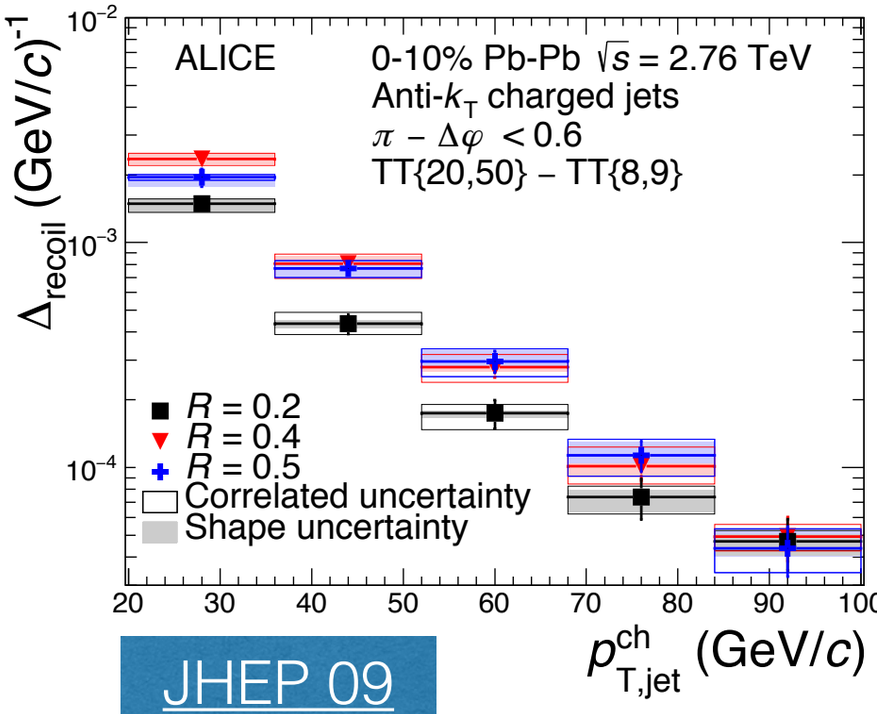
Scanning Jet Radius to Study Quenching



Phys. Rev. C 96 (2017) 015202



Phys. Lett. B 719 (2013) 220-241

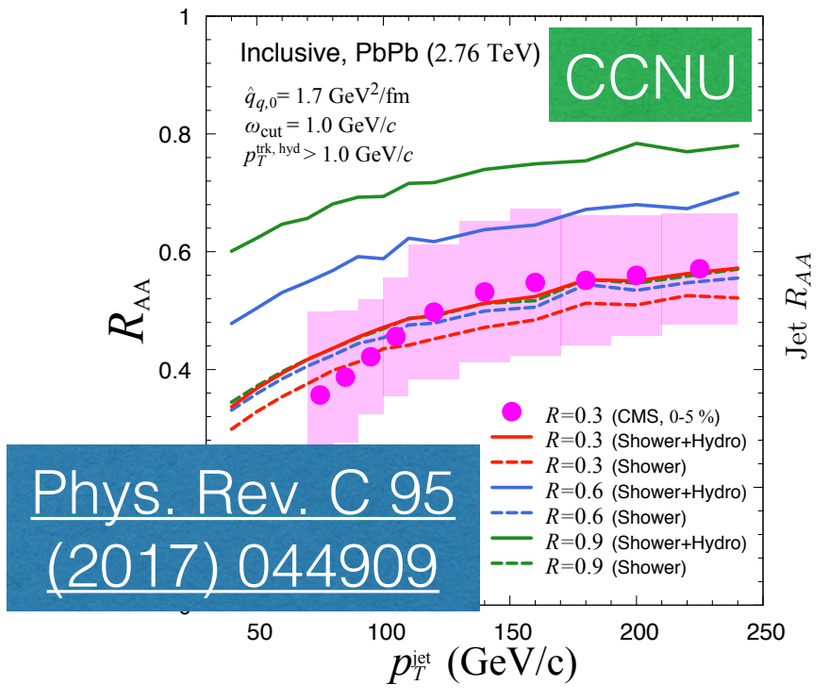


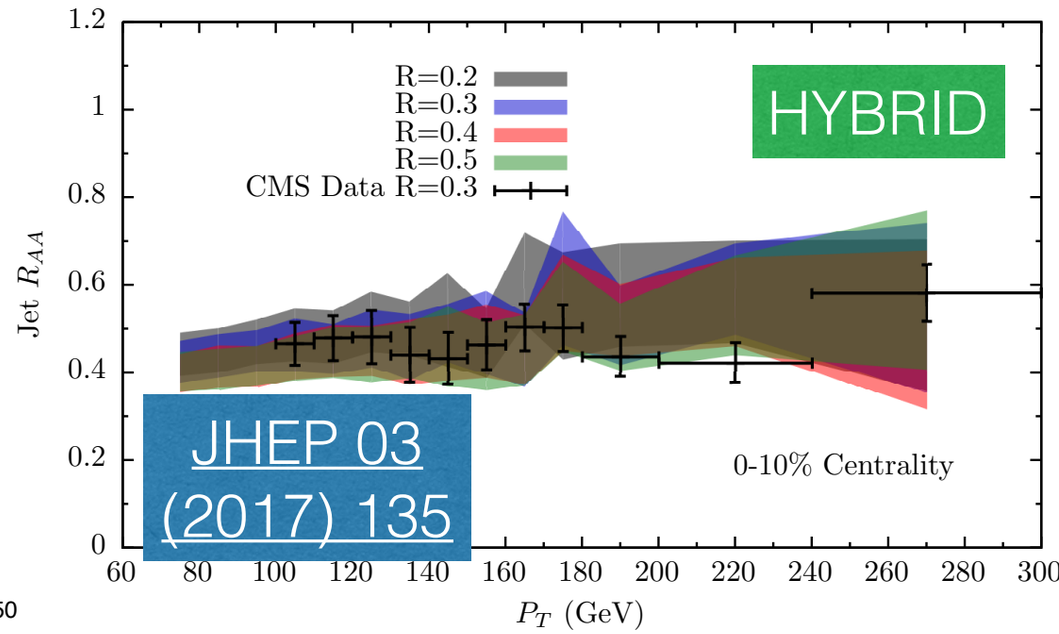
JHEP 09 (2015) 170

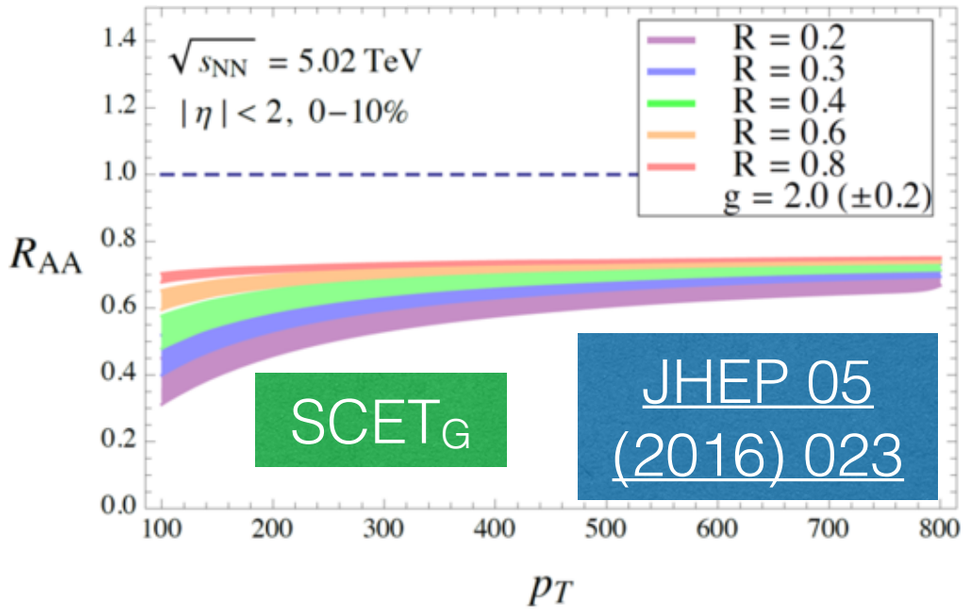
- **Experimental Results:** Measured jet production in R-scans
- Some effect at low-p_T, converges at high-p_T
- Restricted to low-p_T by sample size
- Limited systematically by pp reference being taken during different data-taking periods
- Limited in R by underlying-event (**UE**) at low-p_T

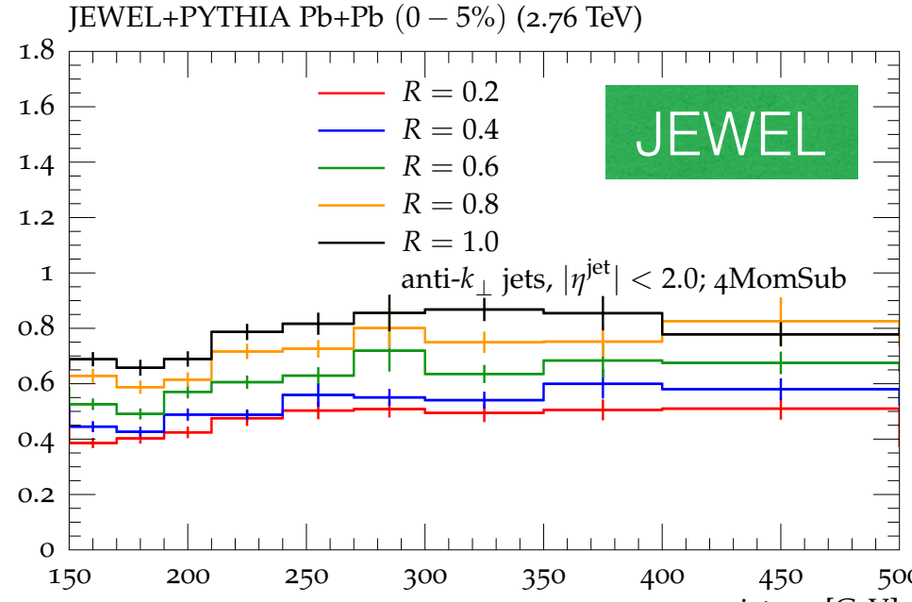
Scanning Jet Radius to Study Quenching

- **THEORY**
- More ambitious than experiments
- Scanning R=0.2 thru R=1.0
- Magnitude of R dependence varies with model
- Sensitive to:
  - Angular redistribution of energy
  - Medium Response

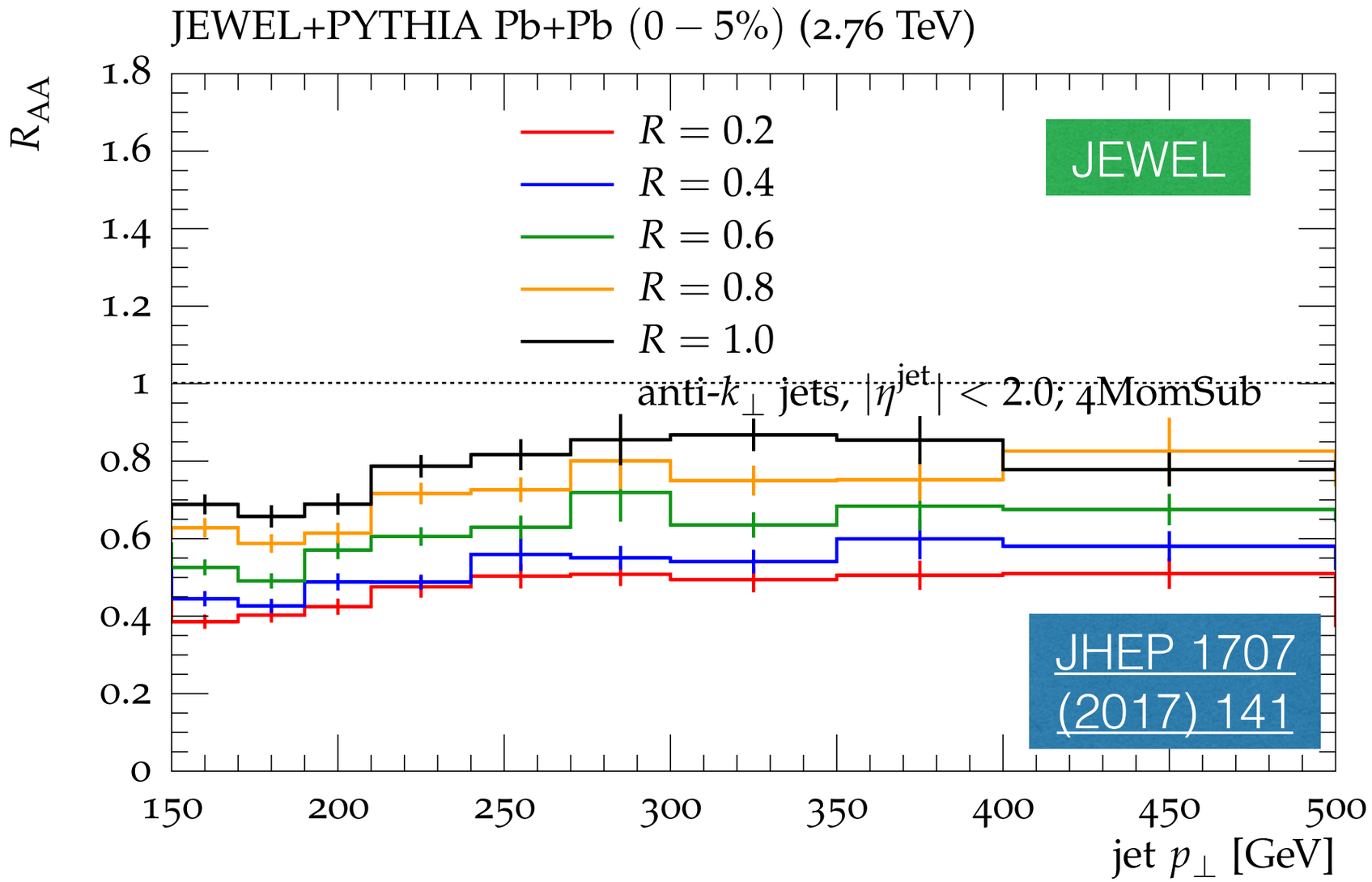








Highlighting One Prediction (JEWEL)



Roughly 25% difference between R=0.4 and R=0.8 (Standard CMS cones)

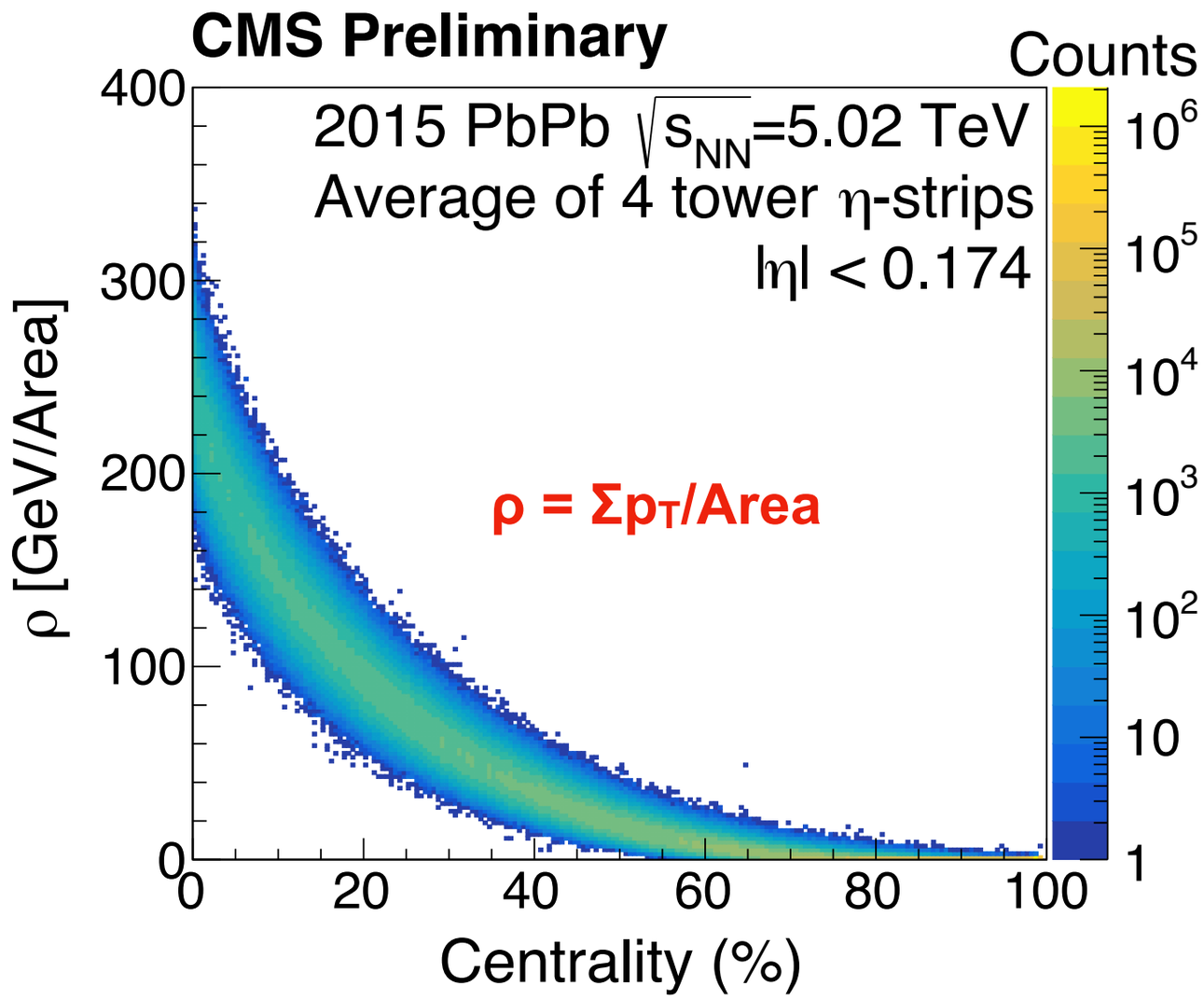
- Roughly flat, persistent suppression at high-p_T
  - Increasing with increasing jet cone radius
    - Changes if energy lost to medium is removed from event
  - A ratio of RAA will be sensitive with reduced systematics

Viability of Large Cone in Heavy-Ions

- Fluctuations in ρ contribute to jet resolution as N term:

$$\sigma\left(\frac{p_T^{RECO}}{p_T^{GEN}}\right)=\sqrt{C^2+\frac{S^2}{p_T^{GEN}}+\frac{N^2}{(p_T^{GEN})^2}}$$

- Typically HI chooses small cone
  - Limits **UE** contribution
  - (GeV/Area)
- Alternatively, scale away **UE** by p_T
  - N/p_T in quadratic sum
  - Possible with size of 2015 PbPb and pp samples

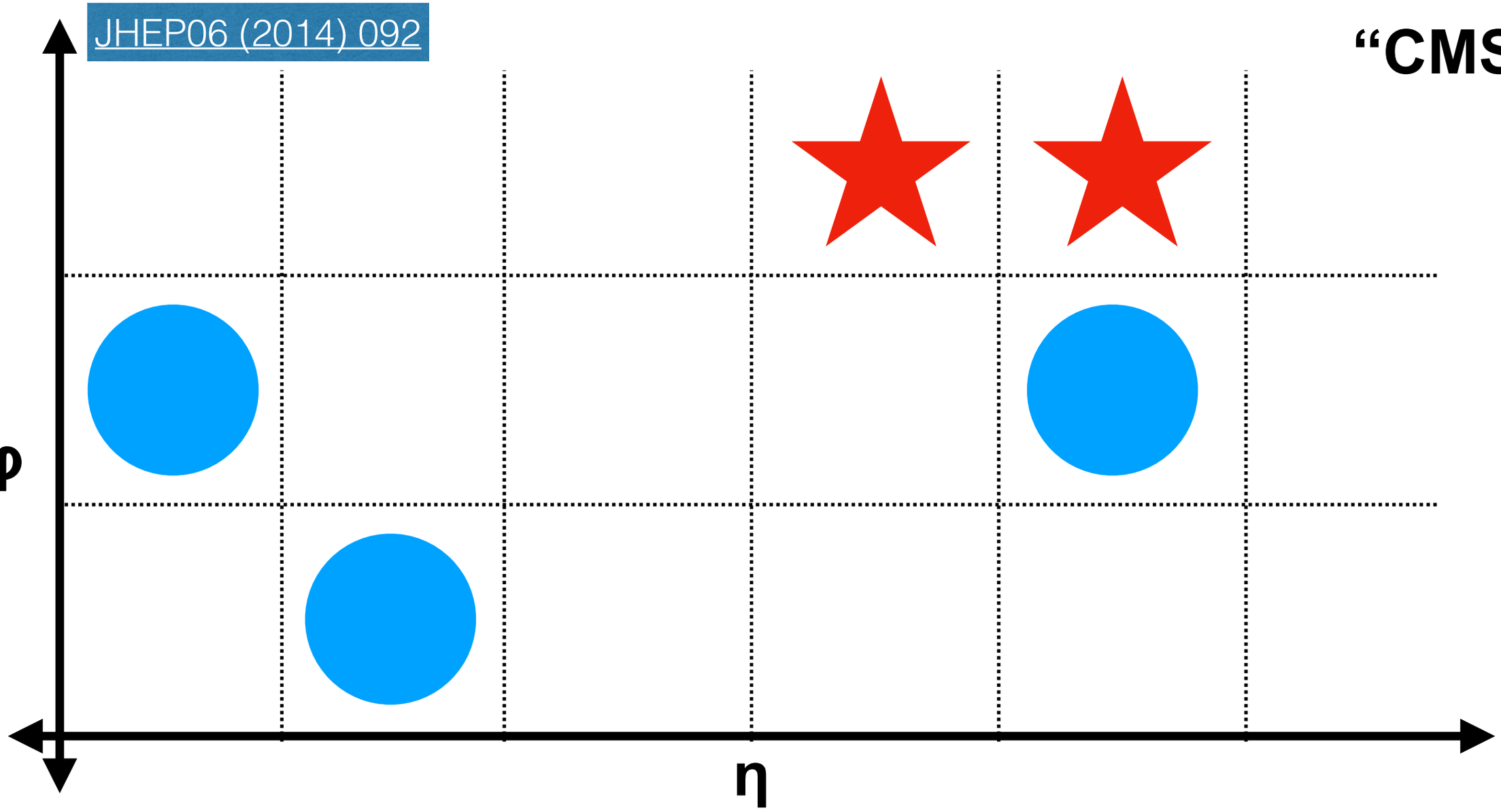


- pp: 27.4 pb^{-1} at 5.02 TeV
- PbPb: 404 μb^{-1} at 5.02 TeV

Constituent Subtraction

JHEP06 (2014) 092

“CMS”



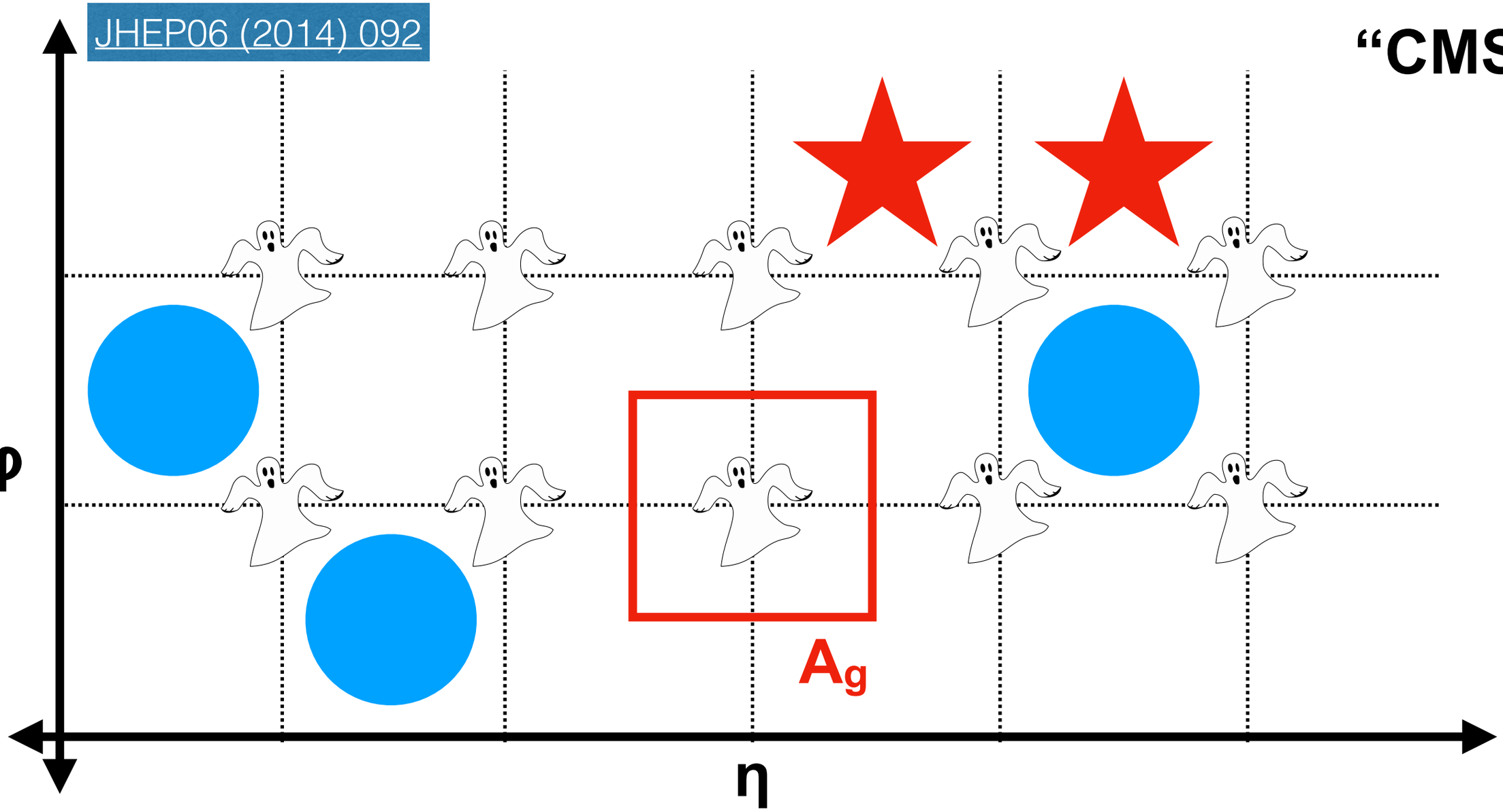
SIGNAL: Hard-scattering in PbPb collision producing jets

UNDERLYING EVENT: Uncorrelated particles from other nucleon-nucleon interactions

Constituent Subtraction

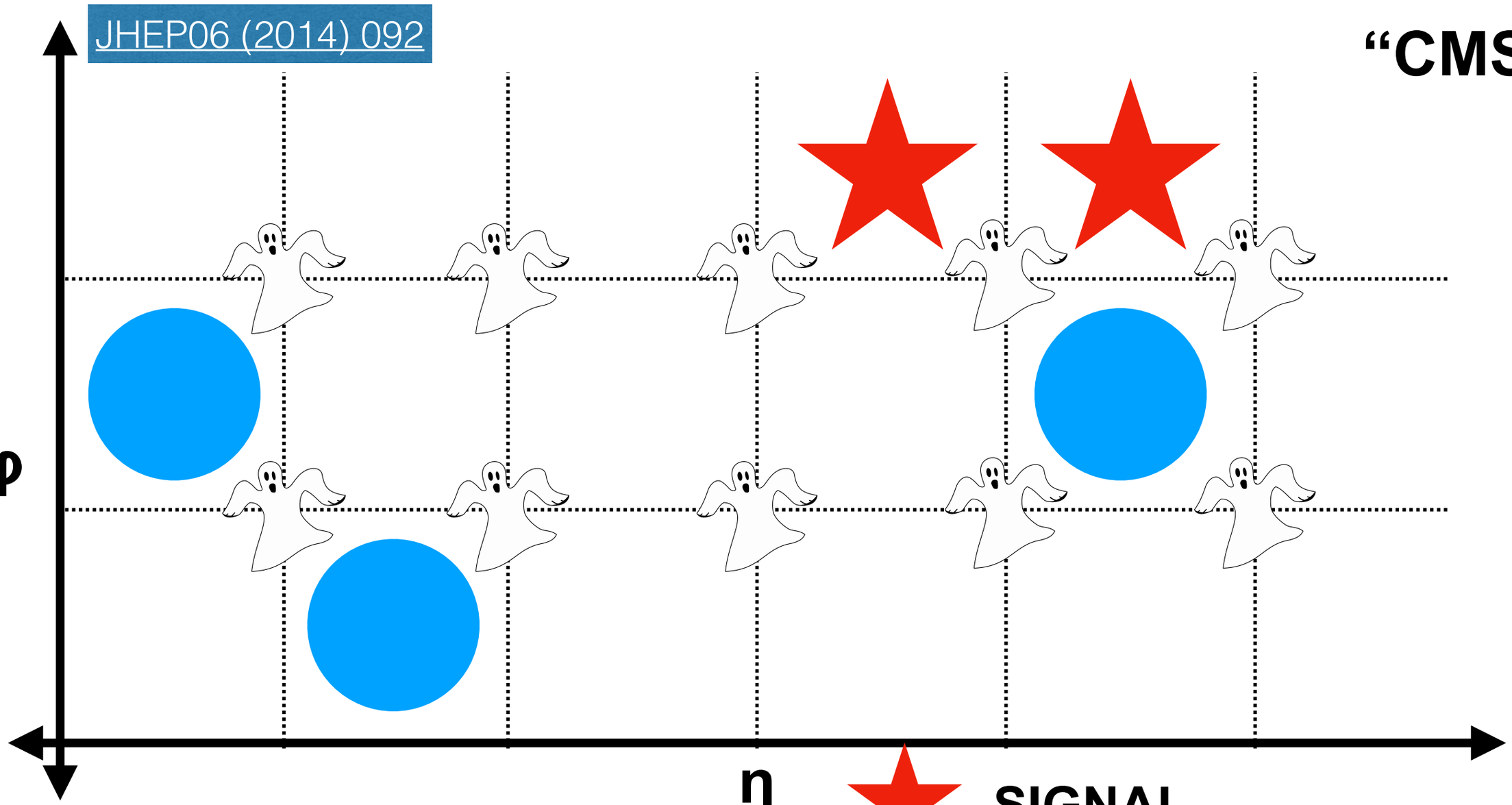
JHEP06 (2014) 092

“CMS”



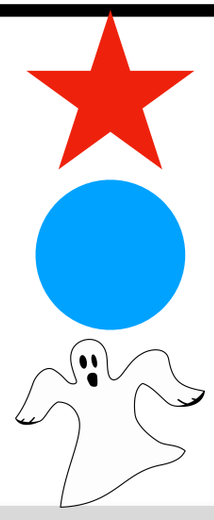
GHOST PARTICLES: Artificial particles added to the event on an η-φ grid. Ghosts are given a p_T according to ρ times the area the inhabit, A_g

Constituent Subtraction

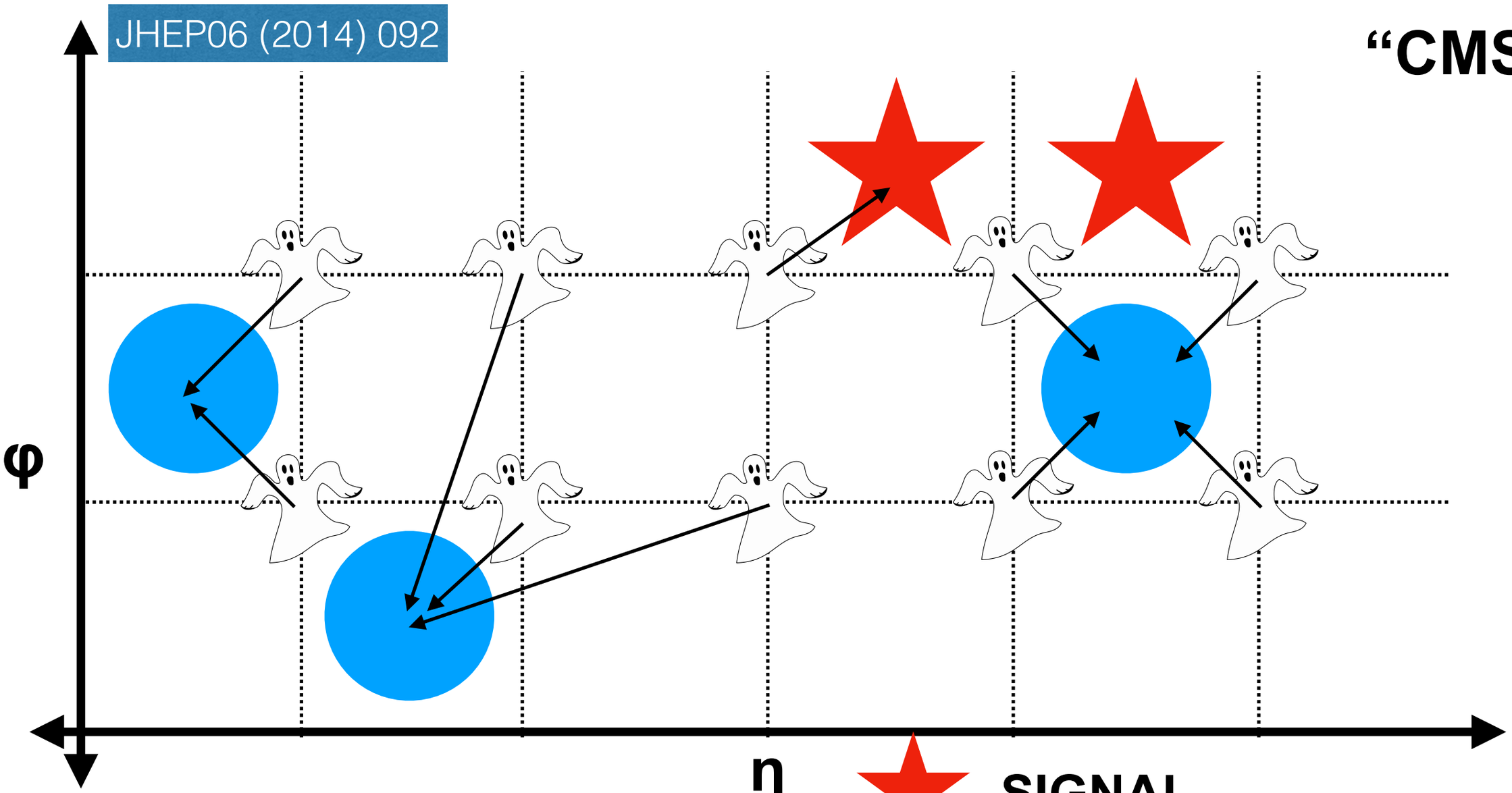


- Add "ghost" particles on η-φ grid according to: $p_{\mathrm{T}}^{g} = A_g \cdot \rho,$

$$m_{\delta}^{g} = A_g \cdot \rho_m.$$

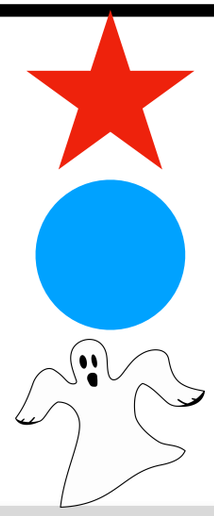


Constituent Subtraction



- Combine iteratively with real particles by minimizing metric:

$$\Delta R_{i,k} = p_{\mathrm{T}i}^{\alpha} \cdot \sqrt{\left(y_i - y_k^g\right)^2 + \left(\phi_i - \phi_k^g\right)^2}.$$

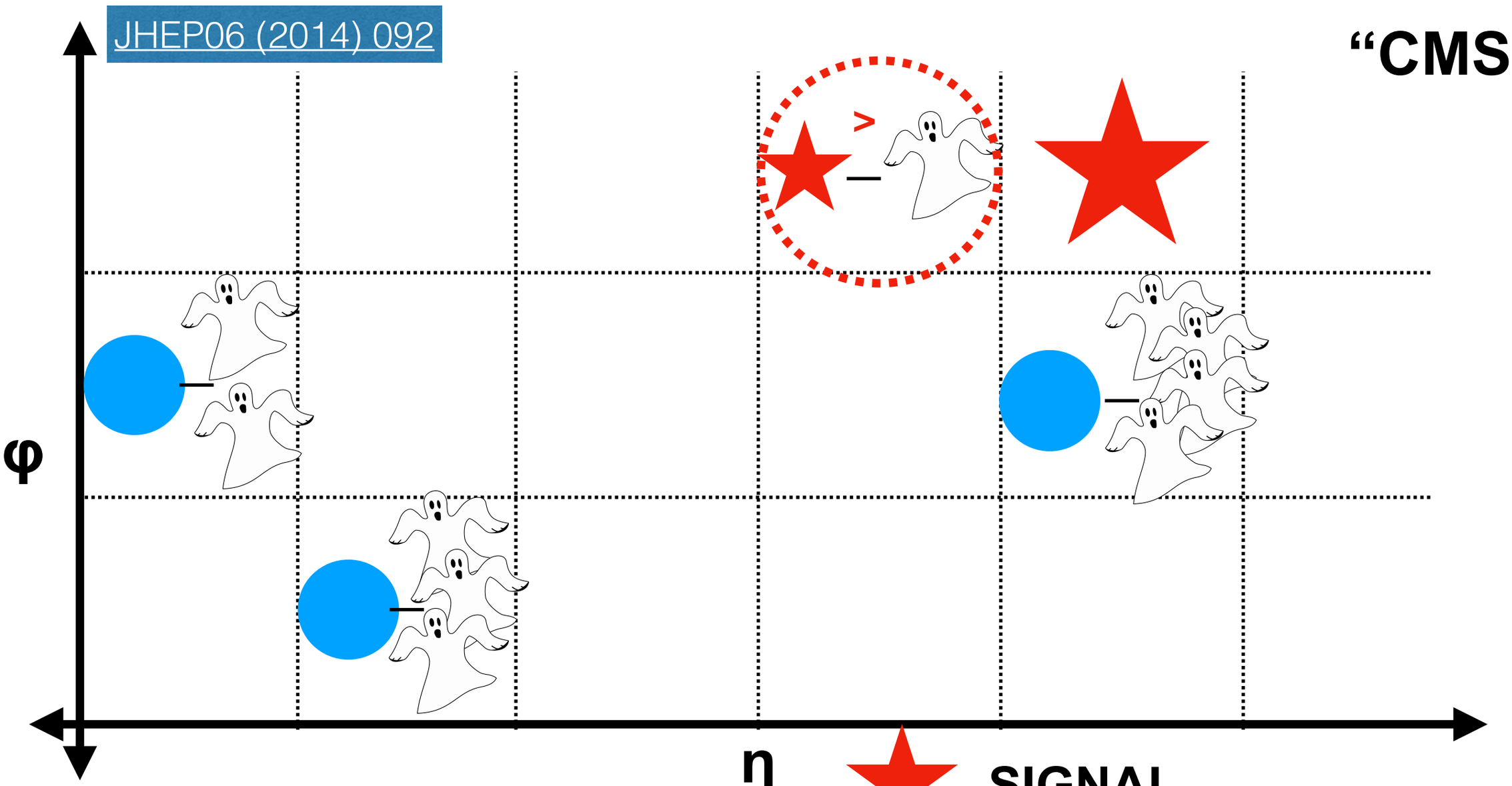


SIGNAL

UNDERLYING EVENT

GHOST PARTICLES

Constituent Subtraction

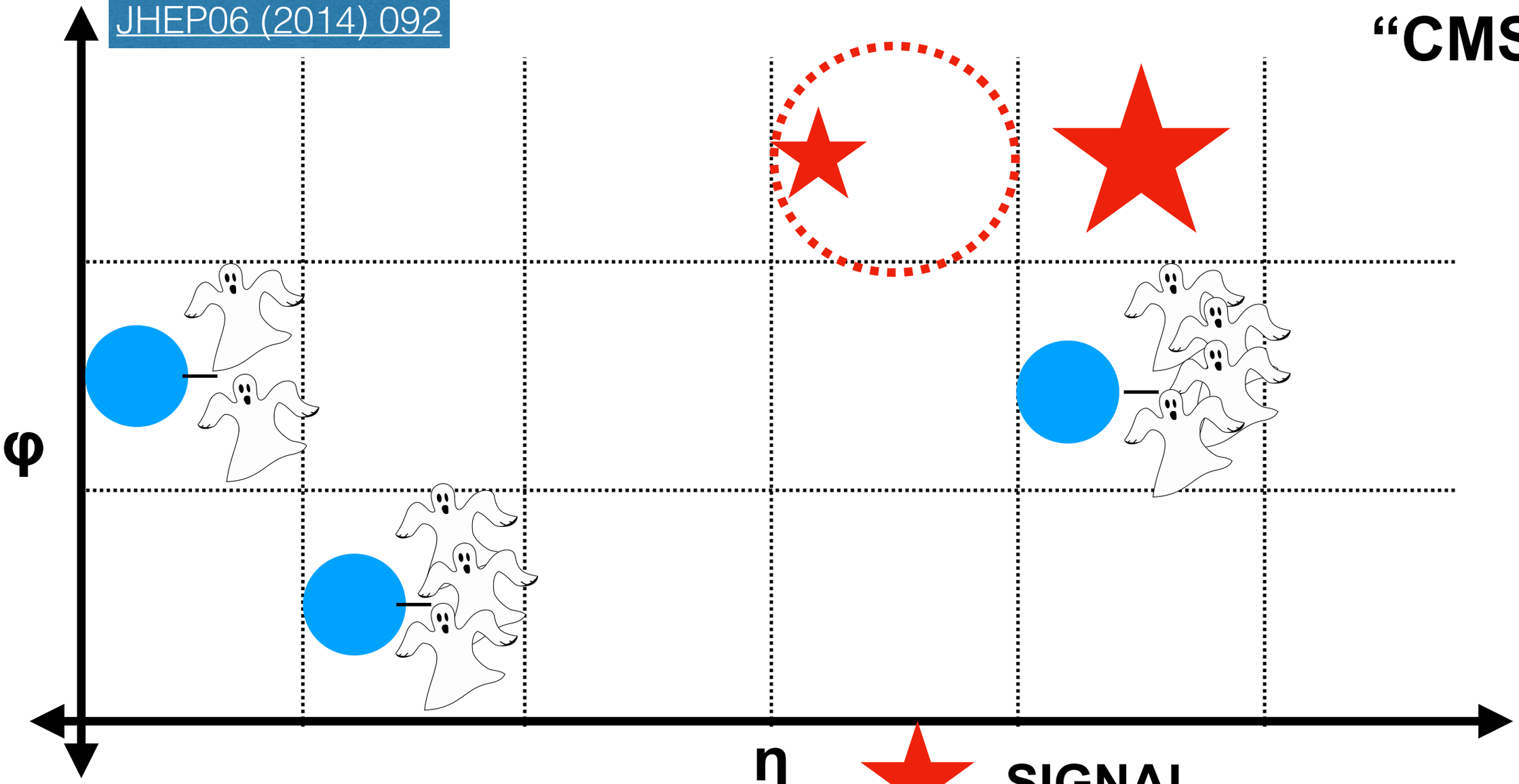


- Particle p_T > Ghost p_T
  - Ghost p_T = 0
  - Particle p_T -= Ghost p_T

Constituent Subtraction

JHEP06 (2014) 092

“CMS”



SIGNAL

UNDERLYING EVENT

GHOST PARTICLES

- Note: Some signal will occasionally be subtracted by probability. Relatedly, some UE will remain.

Constituent Subtraction

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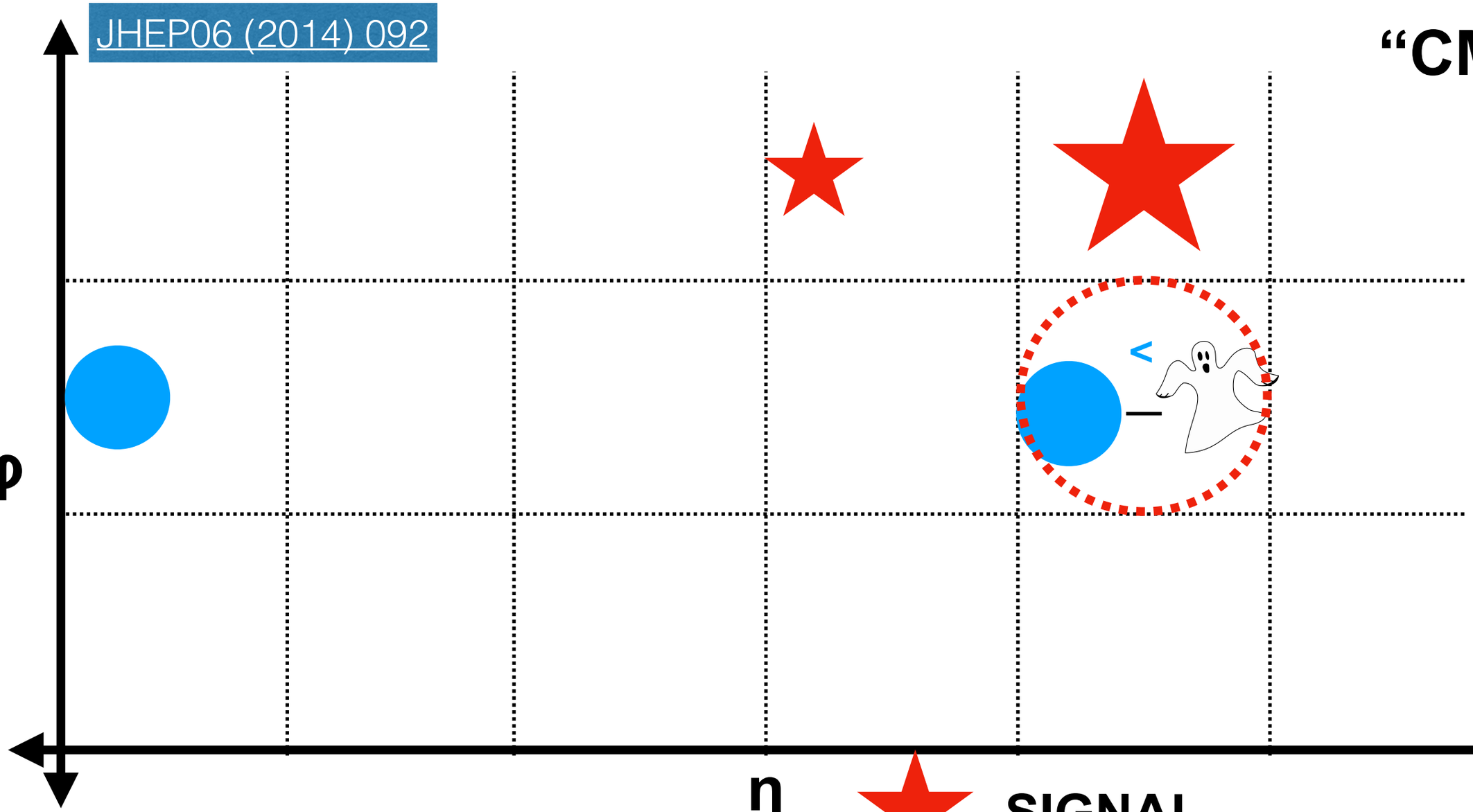
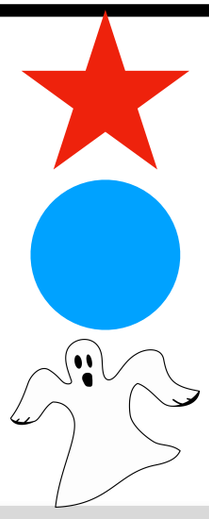
“CMS”



- Particle p_T < Ghost p_T
  - Ghost p_T -= Particle p_T
  - Particle p_T = 0



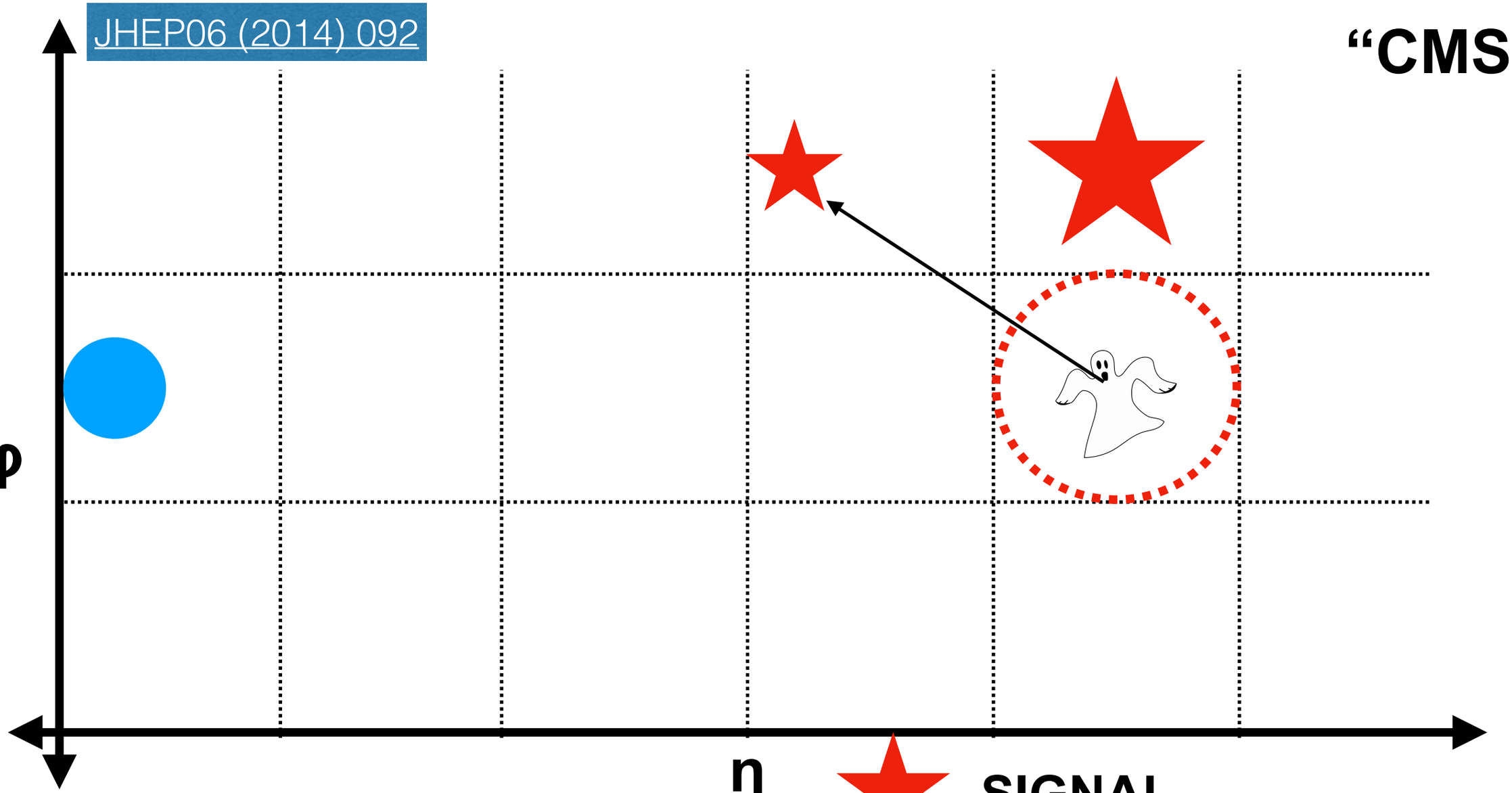
SIGNAL

UNDERLYING EVENT

GHOST PARTICLES

Constituent Subtraction

JHEP06 (2014) 092



- Particle p_T < Ghost p_T
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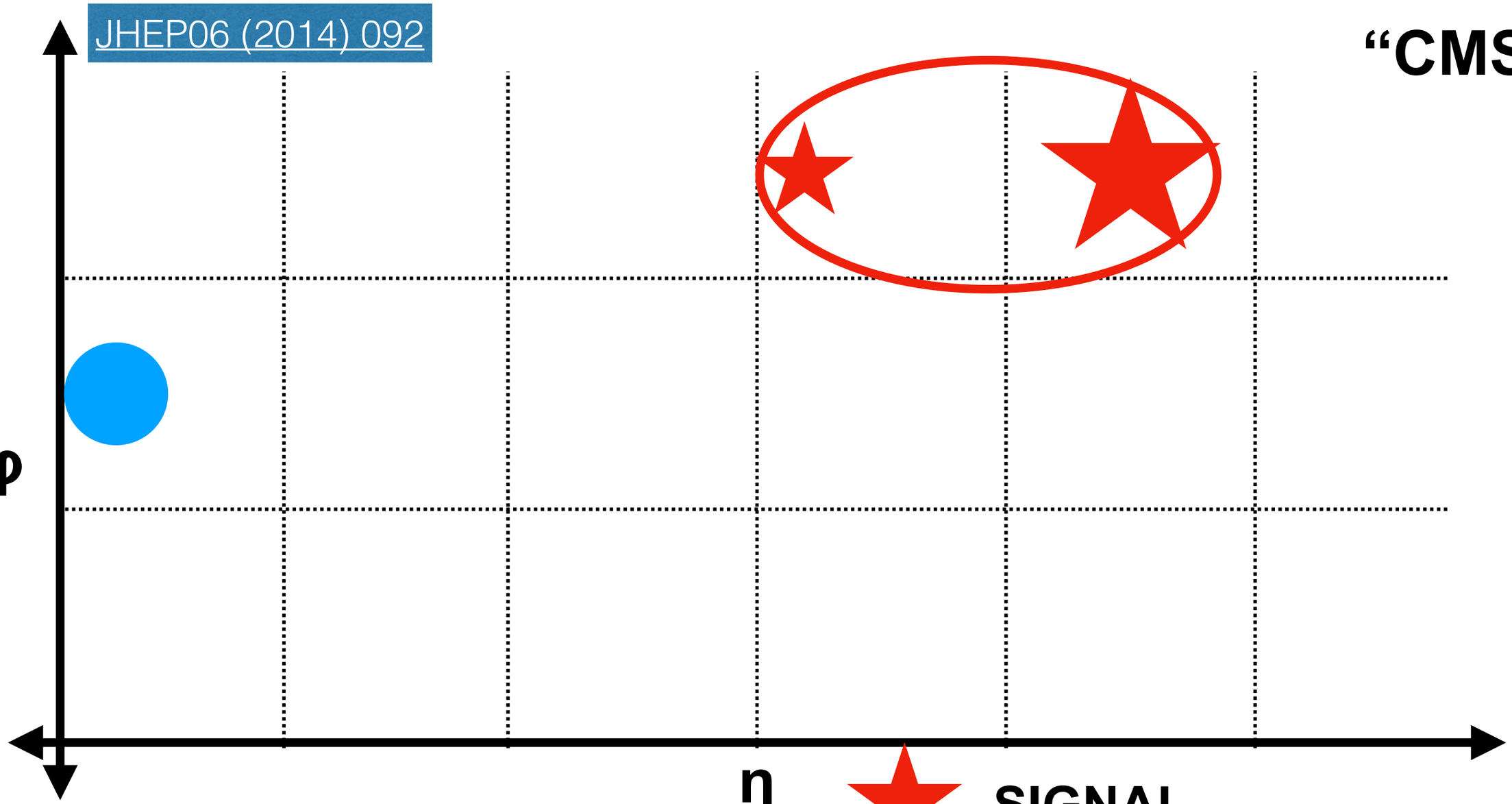
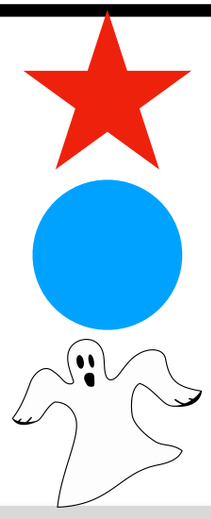
  - Particle p_T = 0

Constituent Subtraction



- Continue until ghost or real particles are exhausted
- Cluster remaining event into jets

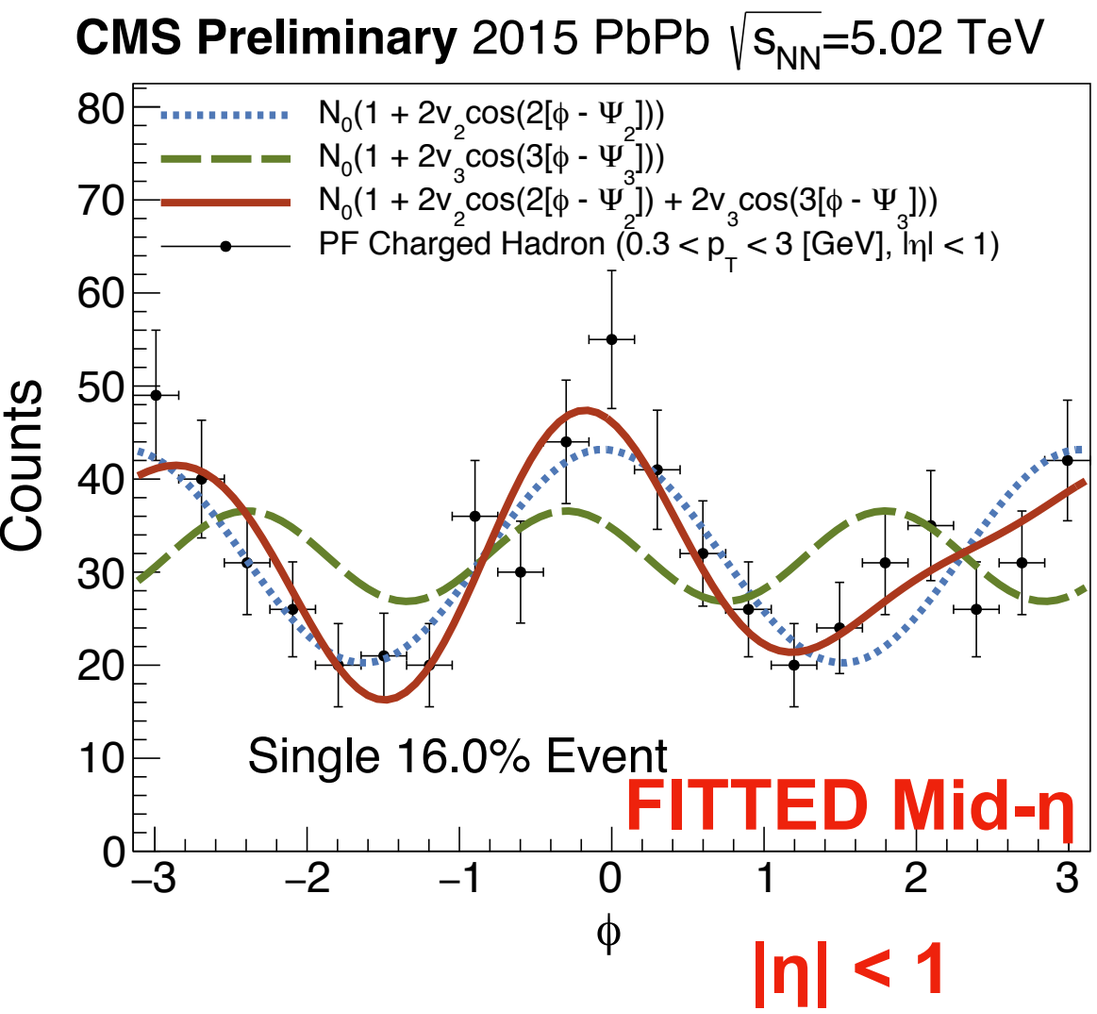


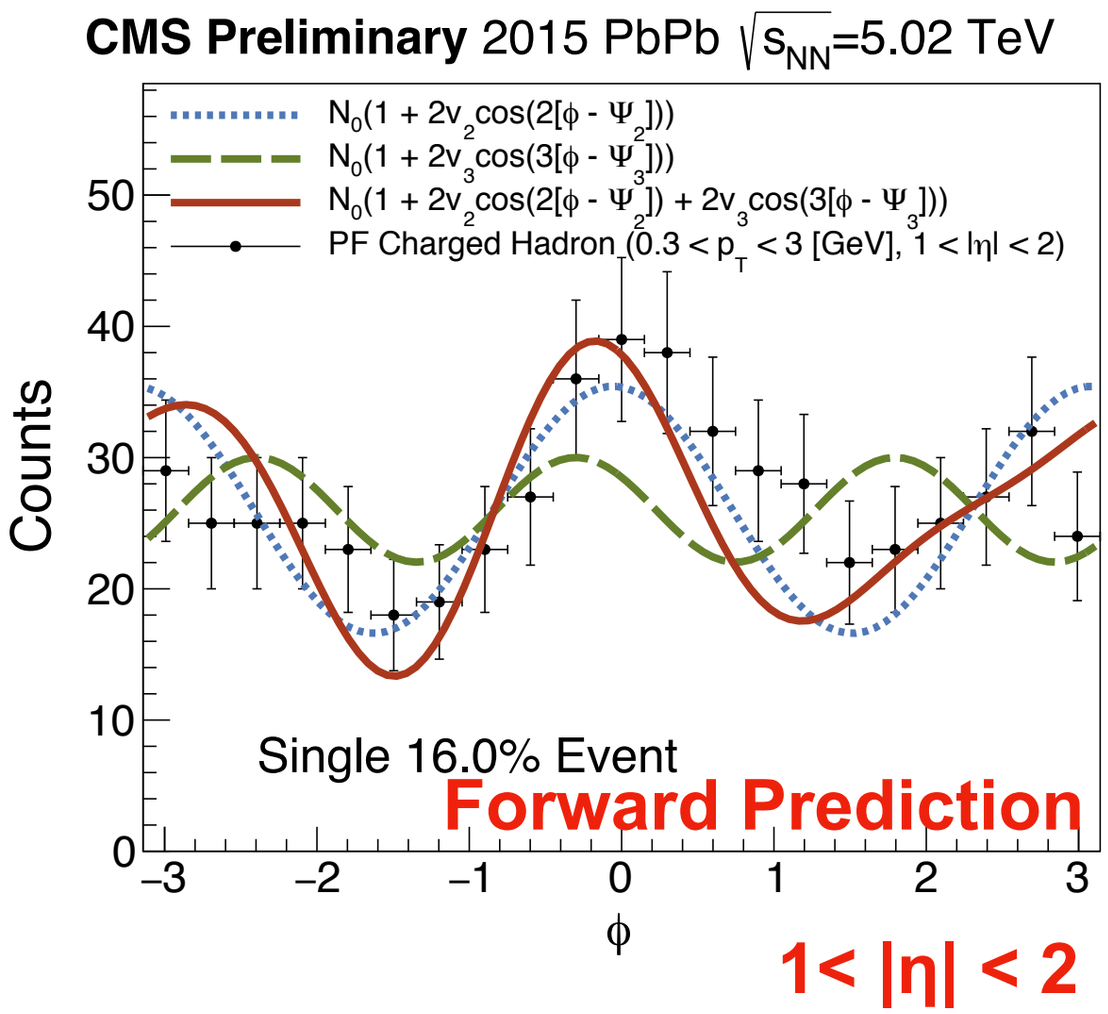
SIGNAL

UNDERLYING EVENT

GHOST PARTICLES

Estimating Flow Event-by-Event



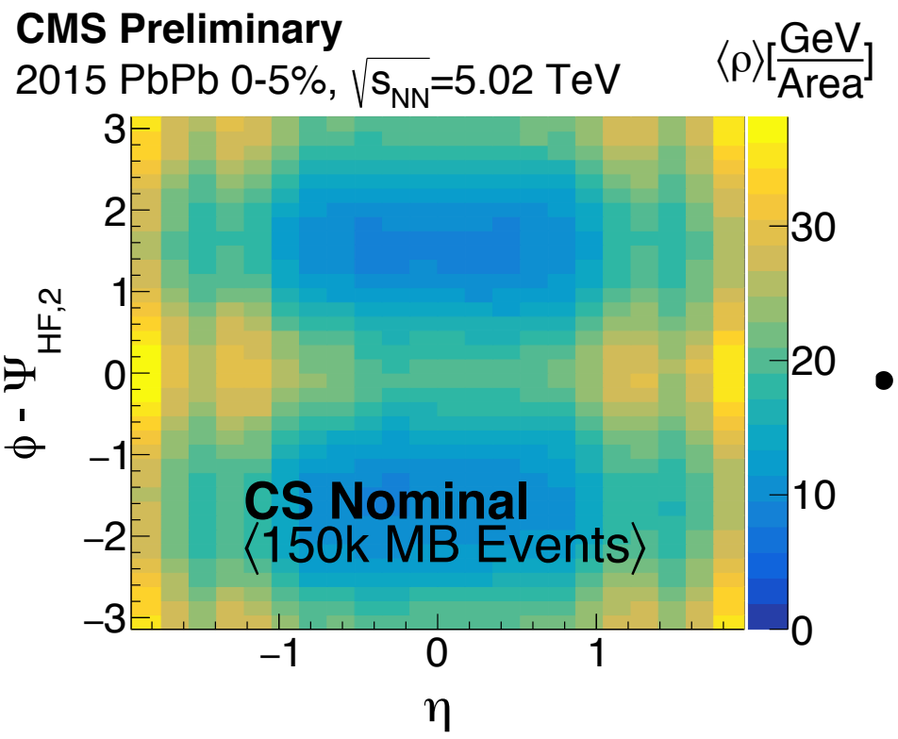


Following Example Of:

Phys.Lett. B 753 (2016) 511-525

- Extract an event-by-event v_2 and v_3 by fitting particle flow candidates
  - Charged Hadron candidates, $0.3 < p_T < 3$ and $|\eta| < 1$
  - Fit is employed over all η to model flow
- Extracted $v_2(v_3)$ are used to modulate CS ρ to add ghost particles

Incremental Improvements in CS at CMS



CS as employed in:

PRL 120 (2018) 142302

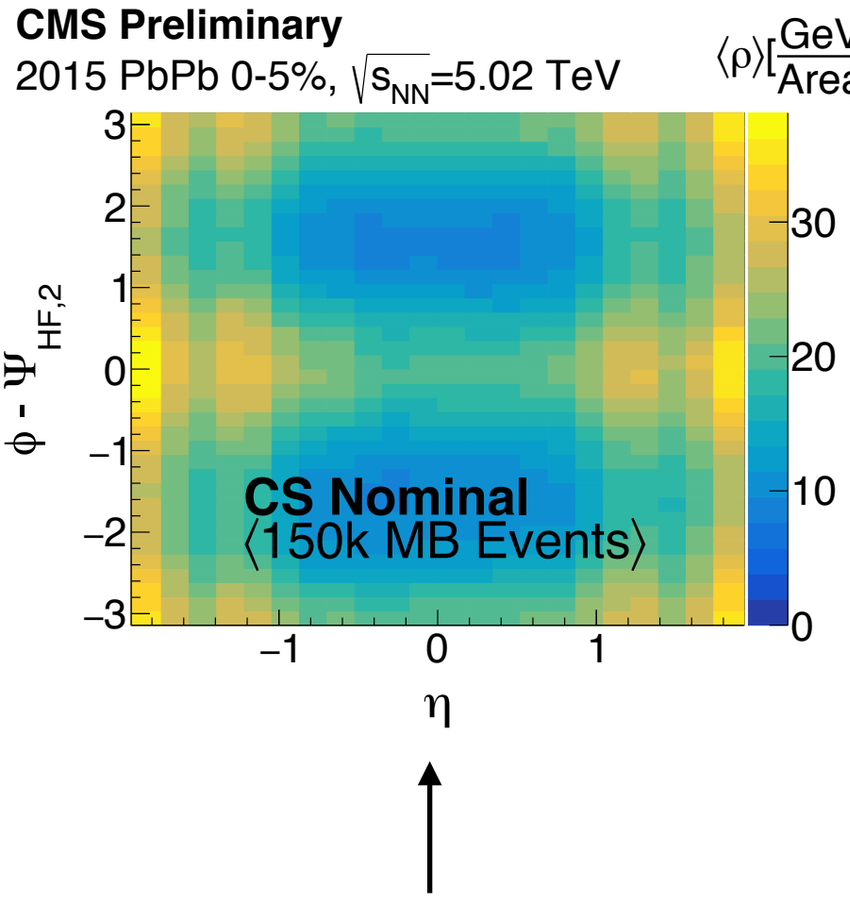
and:

Jet Mass (ARXIV NOW)

Using unsubtracted k_t clustered jets to extract ρ

- Unwrapped detector in coordinates **η-(φ-Ψ$_{HF,2}$)**
  - Average subtracted constituent sum
  - **φ-Ψ$_{HF,2}$** is azimuth relative the event plane
- Features:
  - Strong modulation in **φ** w.r.t **Ψ$_{HF,2}$**
  - Mid-rapidity ρ inconsistent with forward
    - Hence |η| restriction of measurements

Incremental Improvements in CS at CMS



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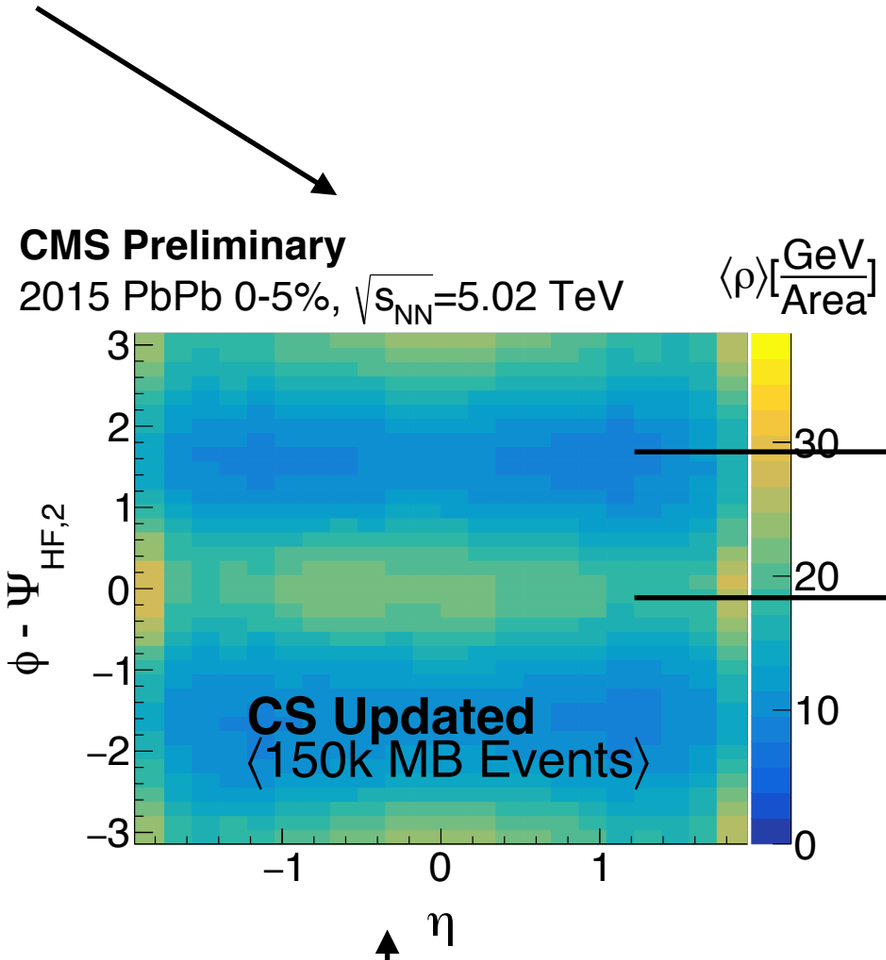
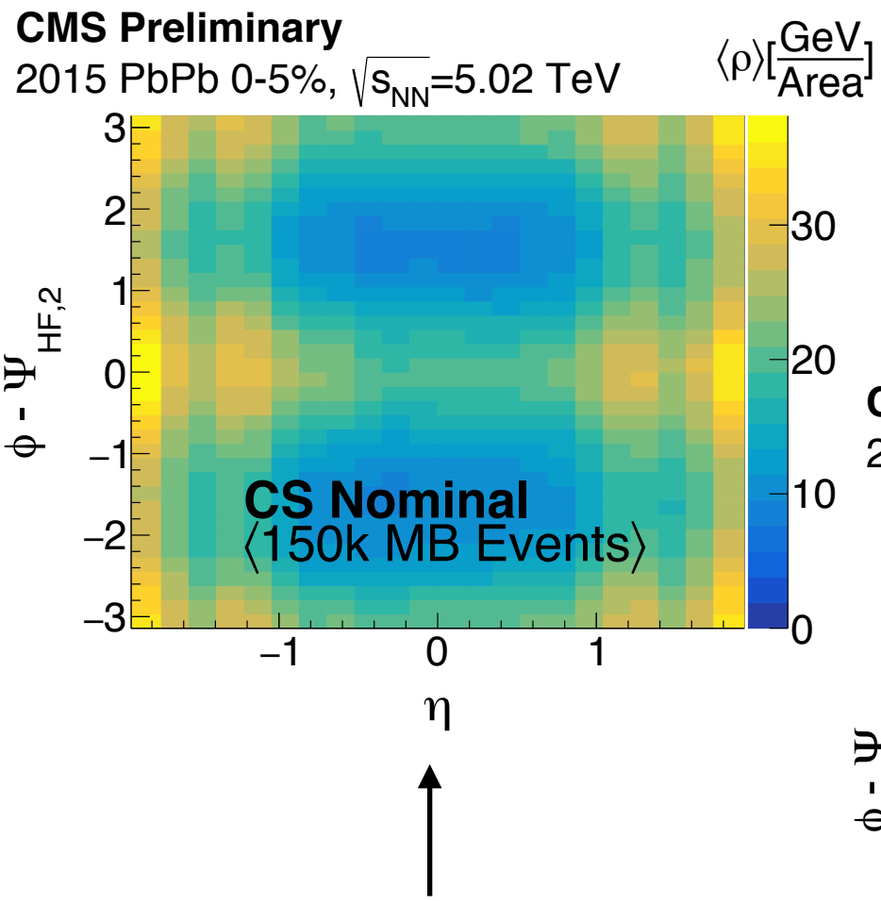


Switching to PU-style extraction of ρ

Reduces the forward ρ post-subtraction to levels consistent with mid-η

Comparing in and out-plane ρ, there remains significant modulation in φ relative $\Psi_{HF,2}$

Incremental Improvements in CS at CMS



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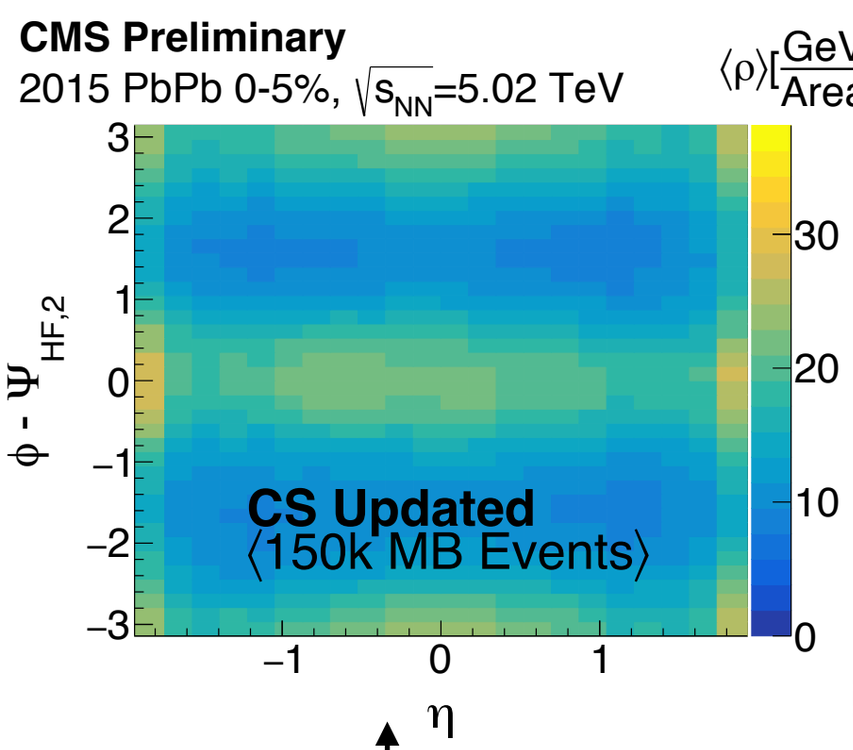
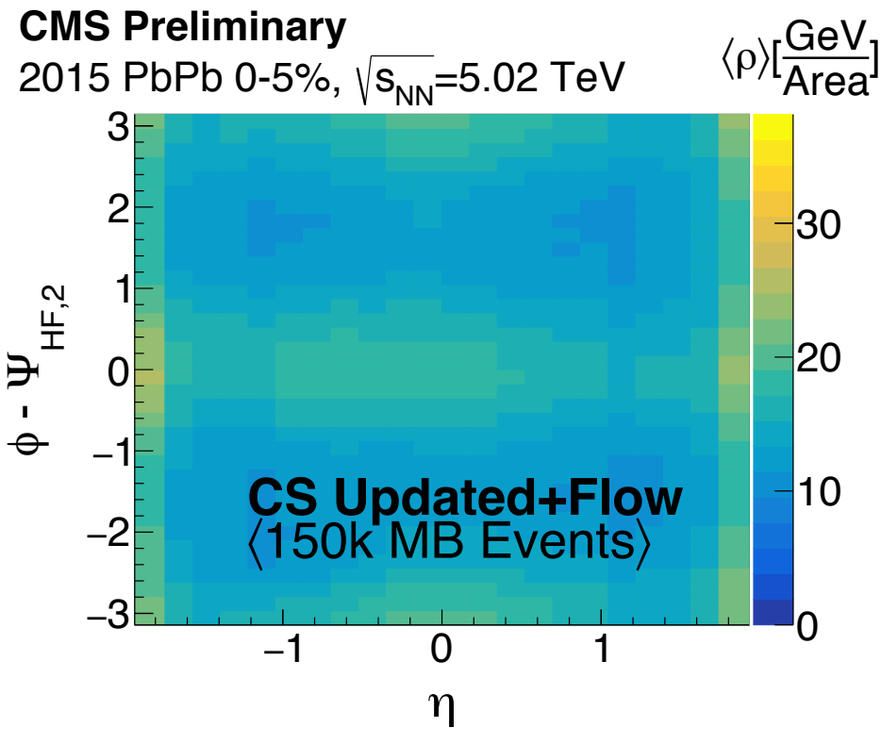


Switching to PU-style extraction of ρ

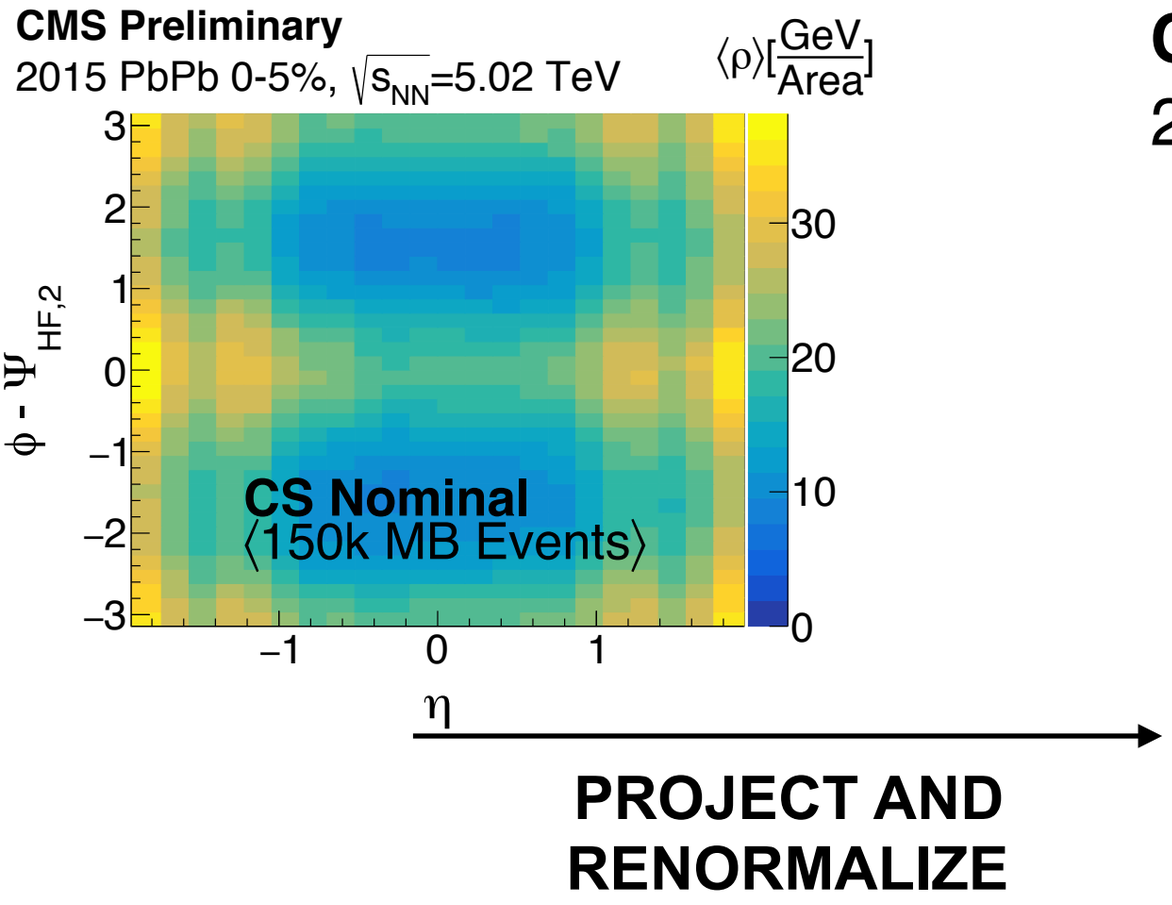
Reduces the forward ρ post-subtraction to levels consistent with mid-η

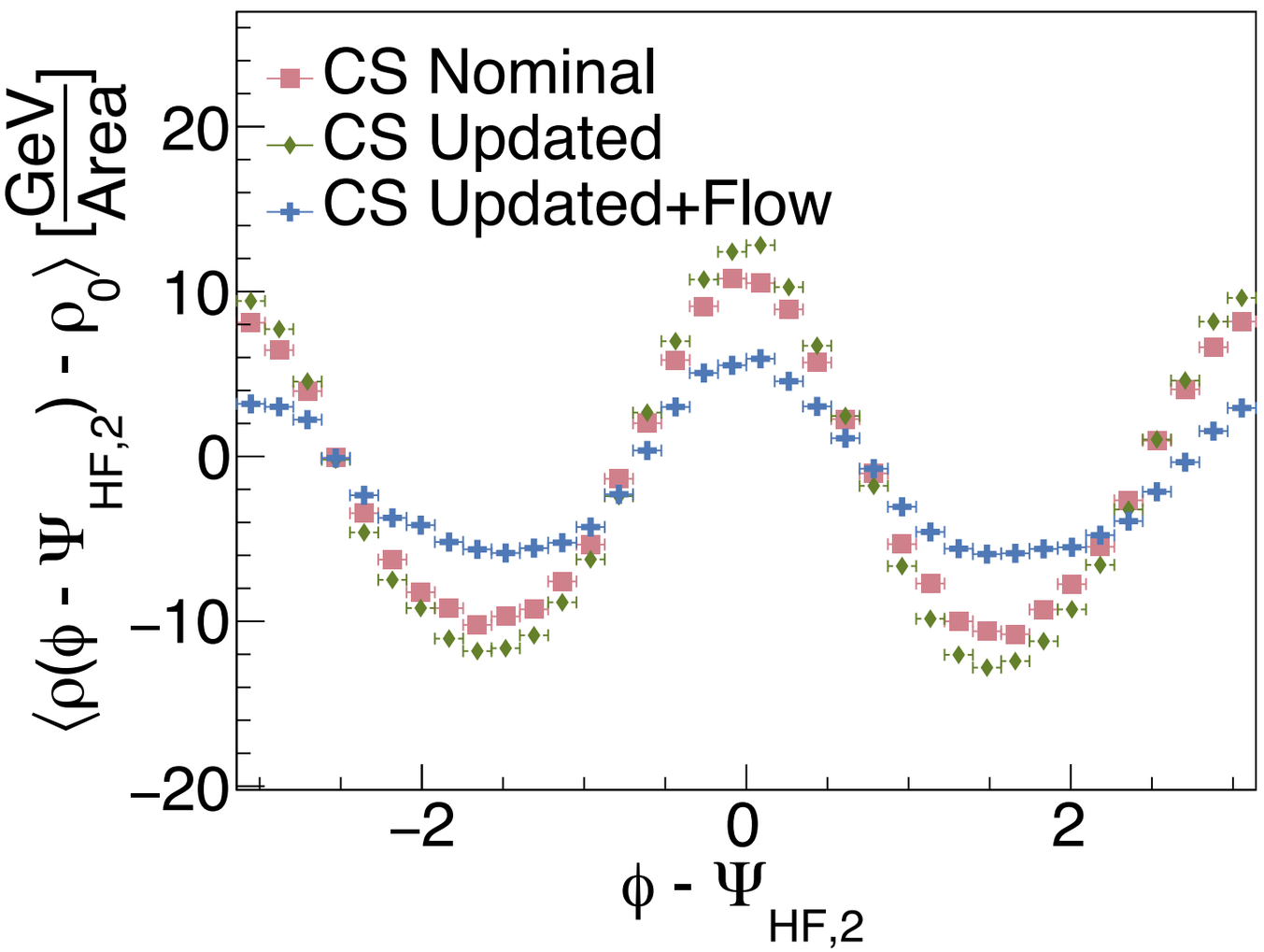
Add φ-modulated ρ using event-by-event flow fitting

Reduces deviations in ρ around $\Psi_{HF,2}$



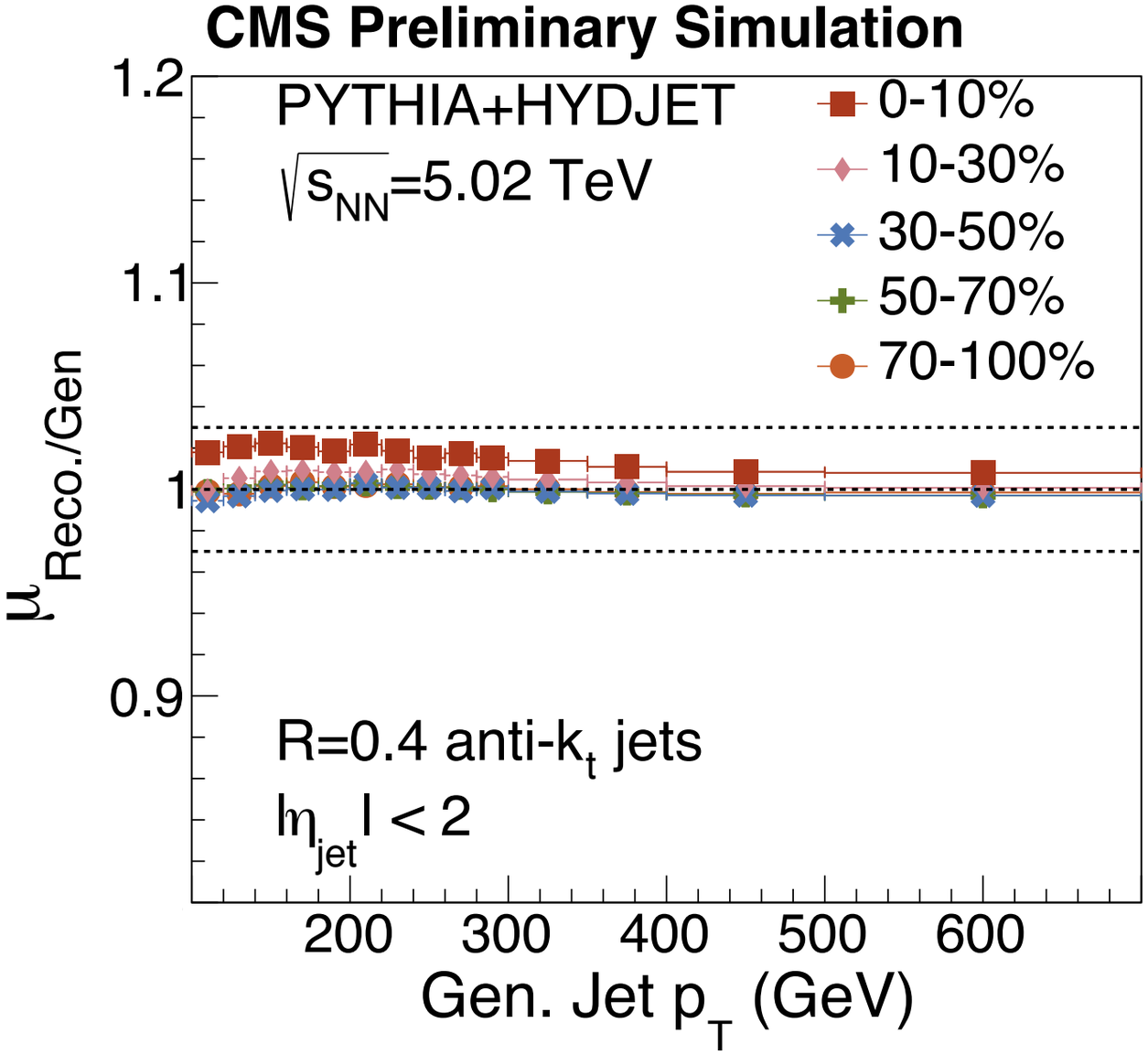
Projection of Detector on Azimuth

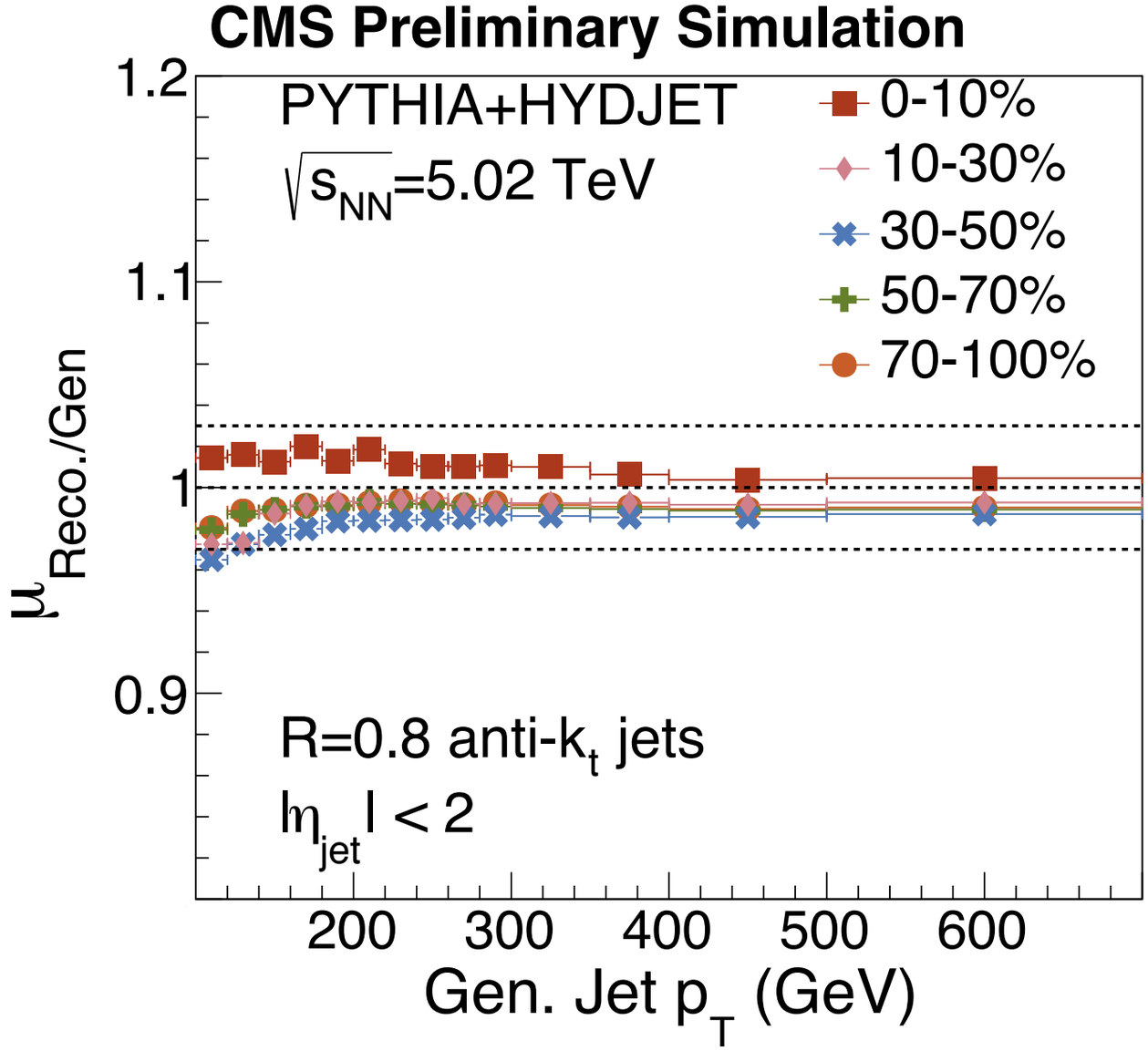




- CS Updated w/ Flow correction shows reduced modulations when projected onto azimuth compared to previous iterations
  - Reduction in jet energy scale dependence on event plane

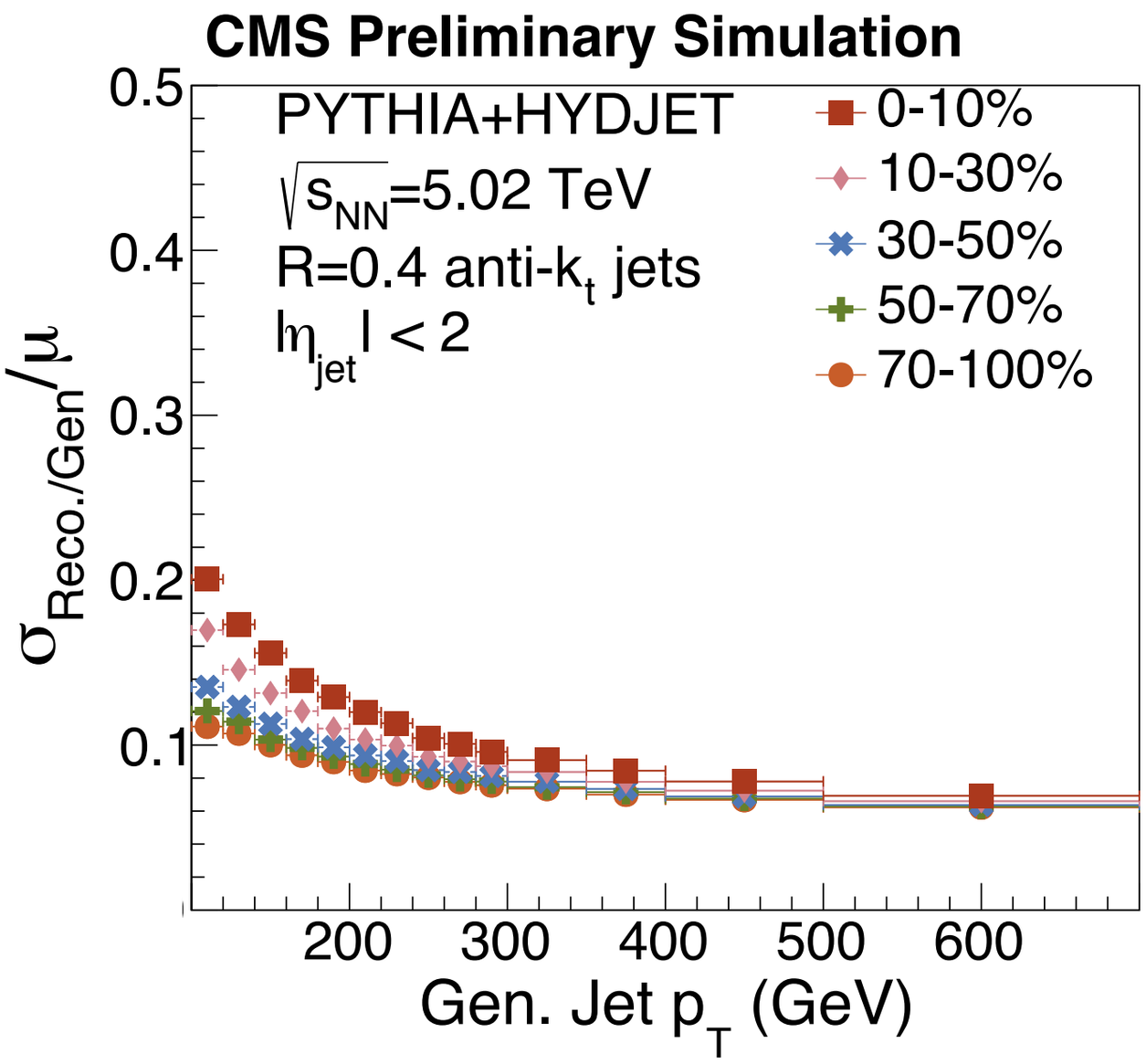
Jet Energy Scale at R=0.4 and R=0.8

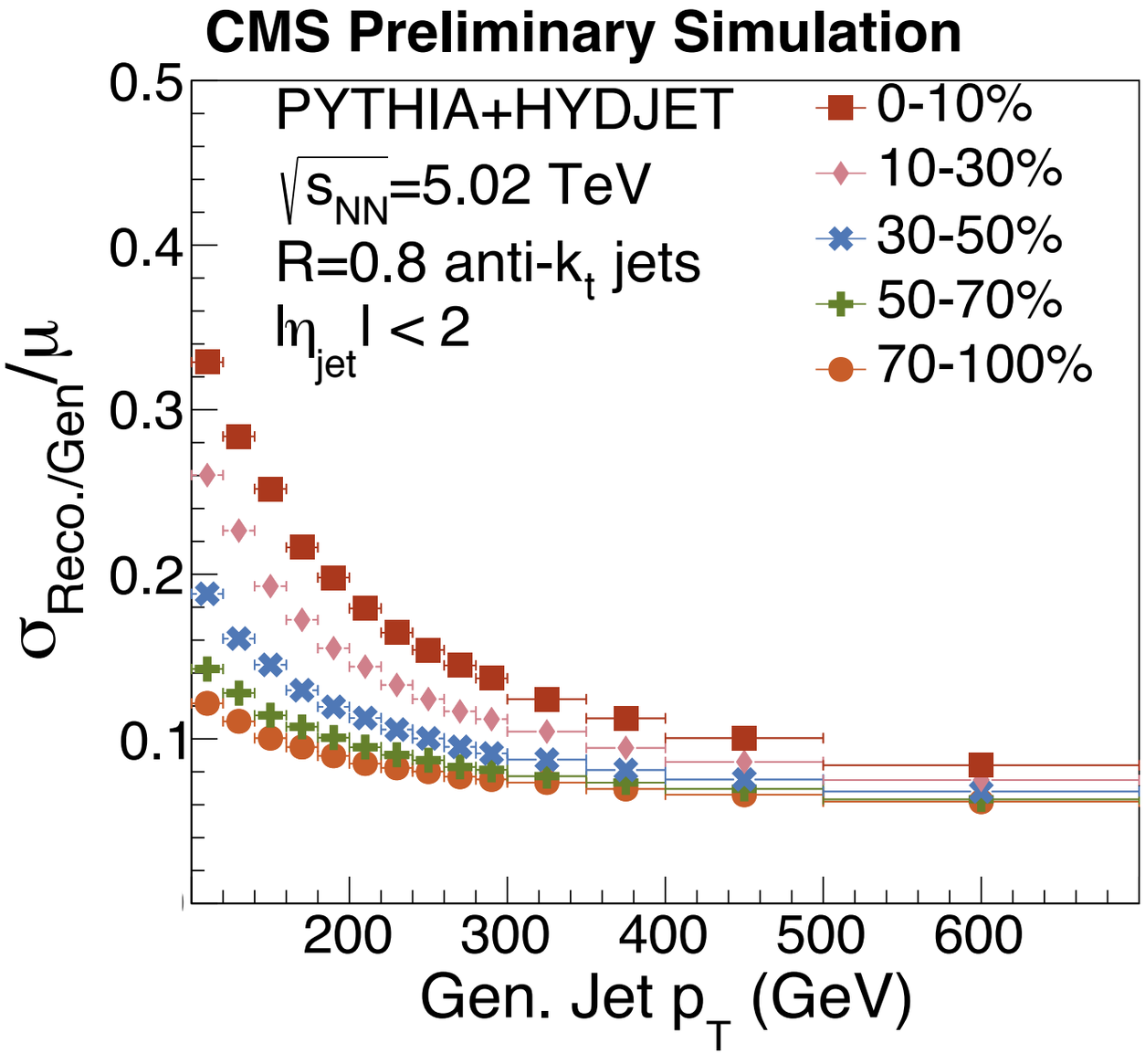




- Scale closure of R=0.4 (**Left**) and R=0.8 (**Right**) jets over all centrality
- In large cone, oversubtract at lower p_T in peripheral events
- Identical corrections applied to all centrality
  - Derived from unsubtracted jets in PYTHIA events

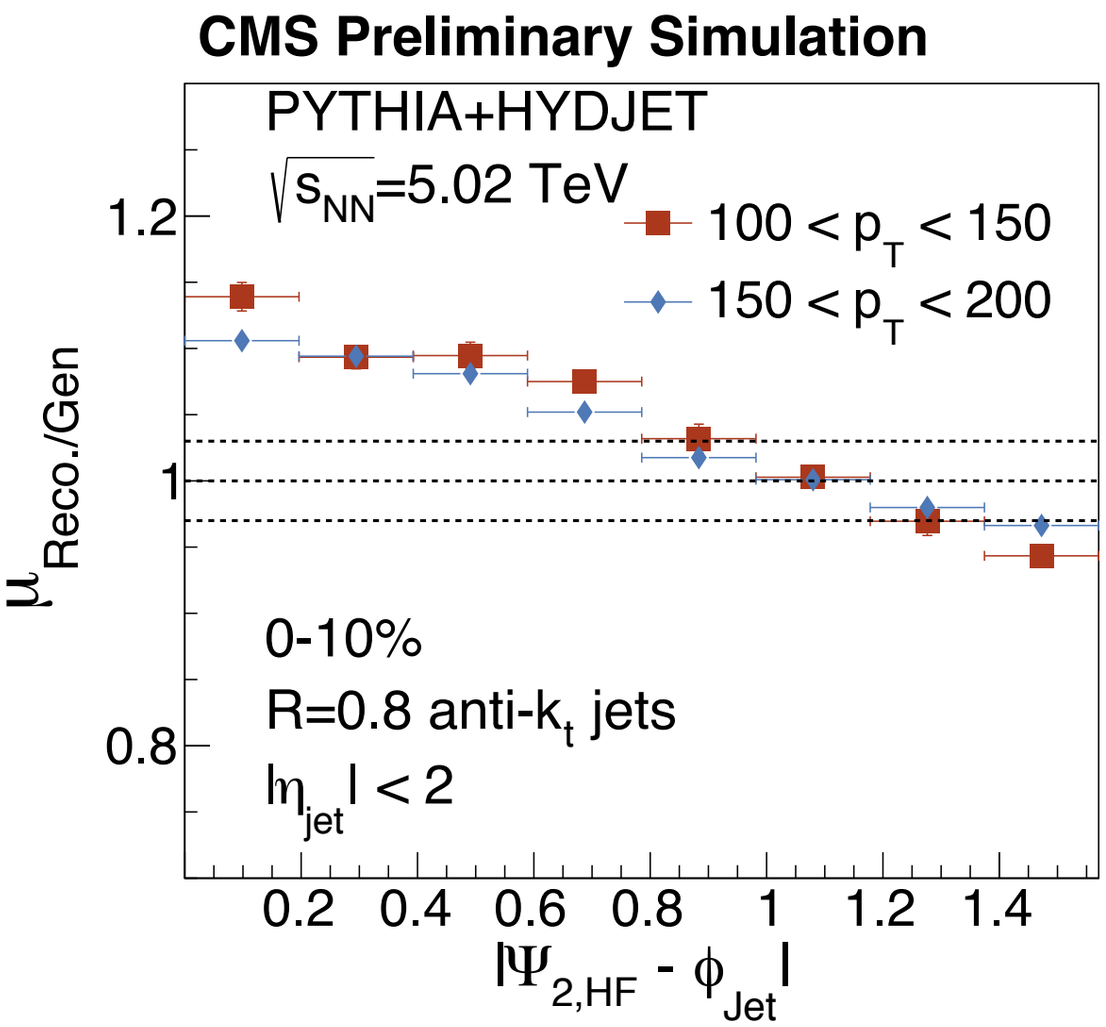
Jet Energy Resolution at R=0.4 and R=0.8



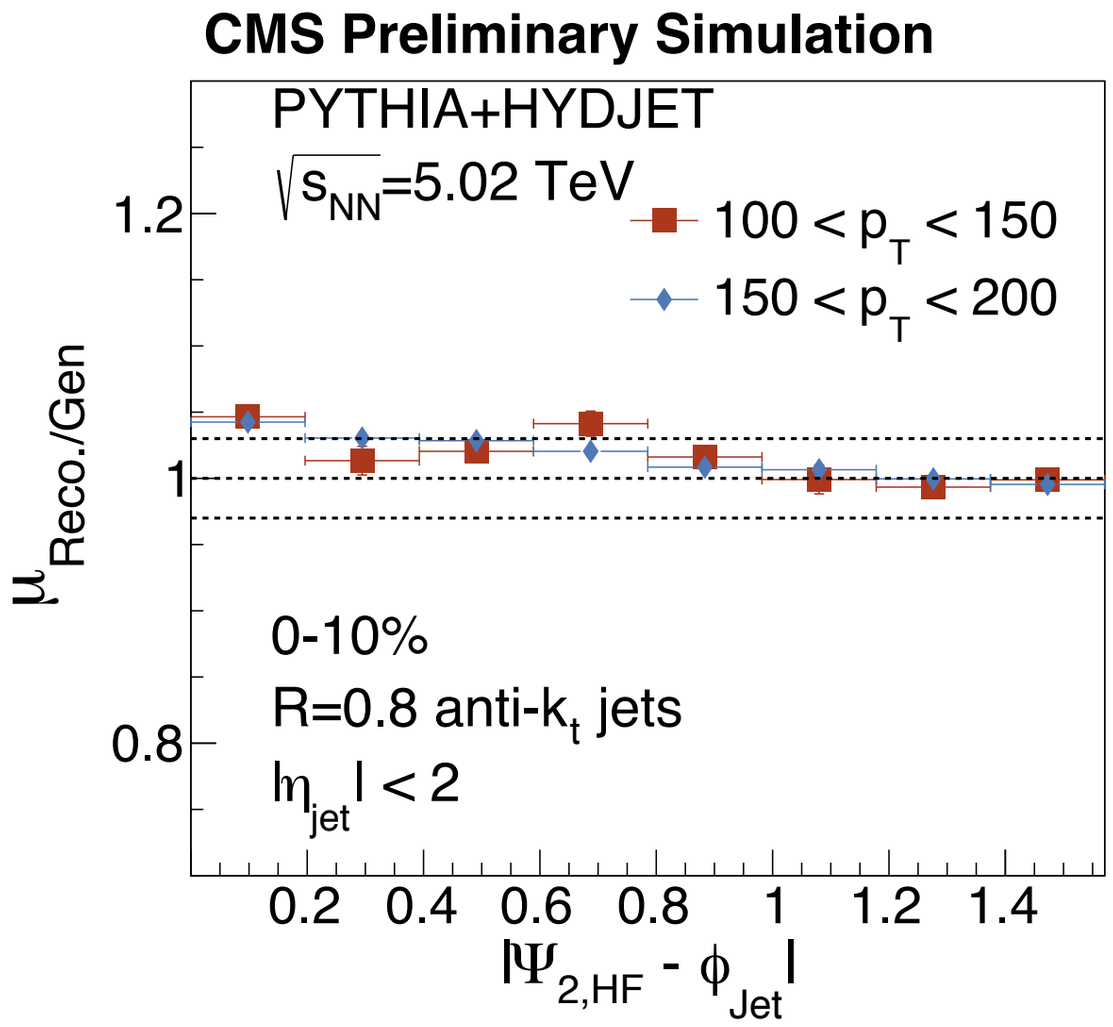


- Energy resolution of R=0.4 (**Left**) and R=0.8 (**Right**) jets over all centrality
- In large cone, UE drives high resolution at low-p_T
  - JER ~18% at 200 GeV (R=0.8)

Scale Closure vs. Event Plane (R=0.8)

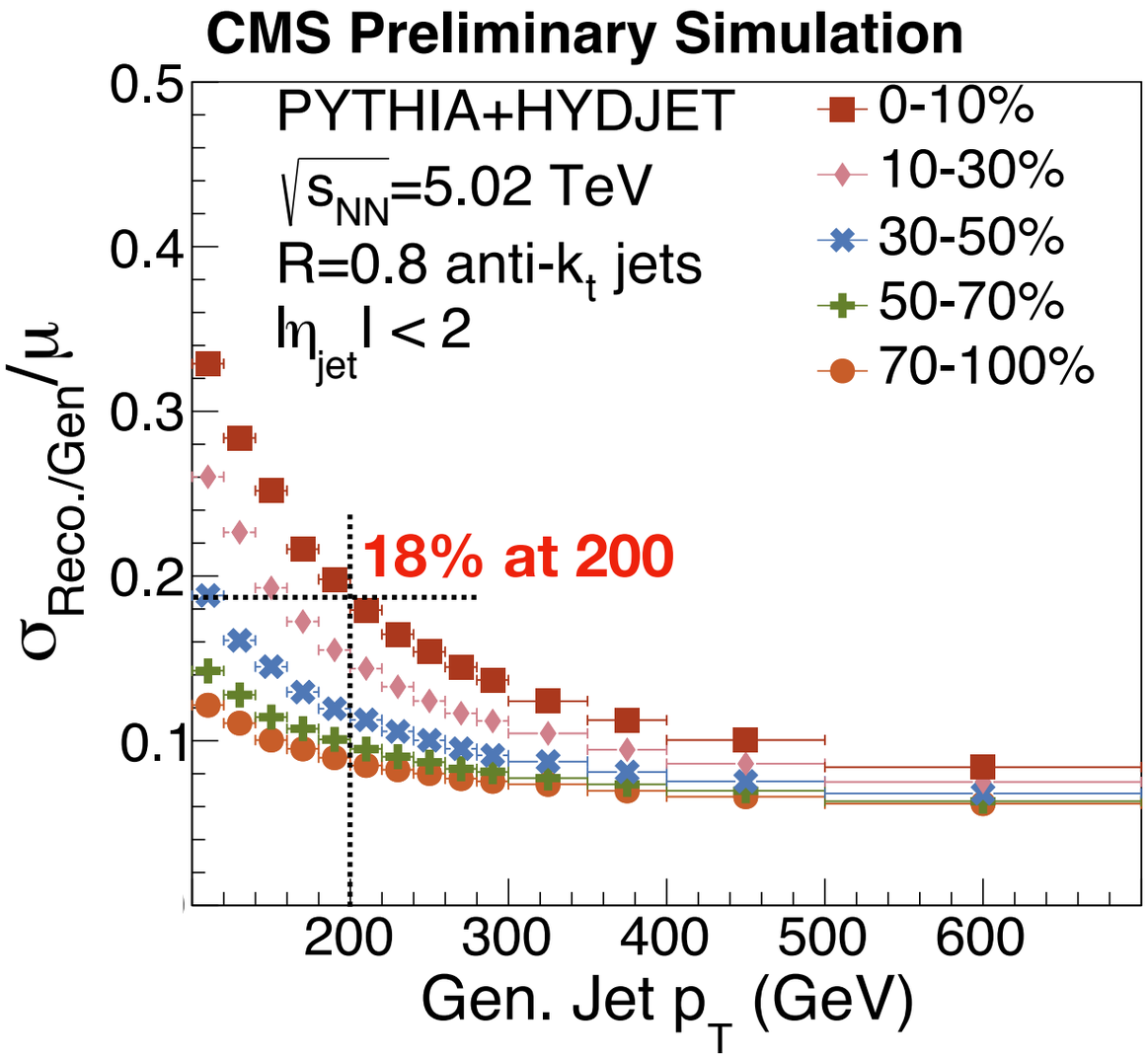


Add Flow Correction



- Jet energy scale closure as function of event plane for R=0.8 w/o flow correction (**Left**) and with flow correction (**Right**)
- Significant flattening of scale translates directly to resolution reduction
  - Compare to R=0.4 (backup)

Conclusions



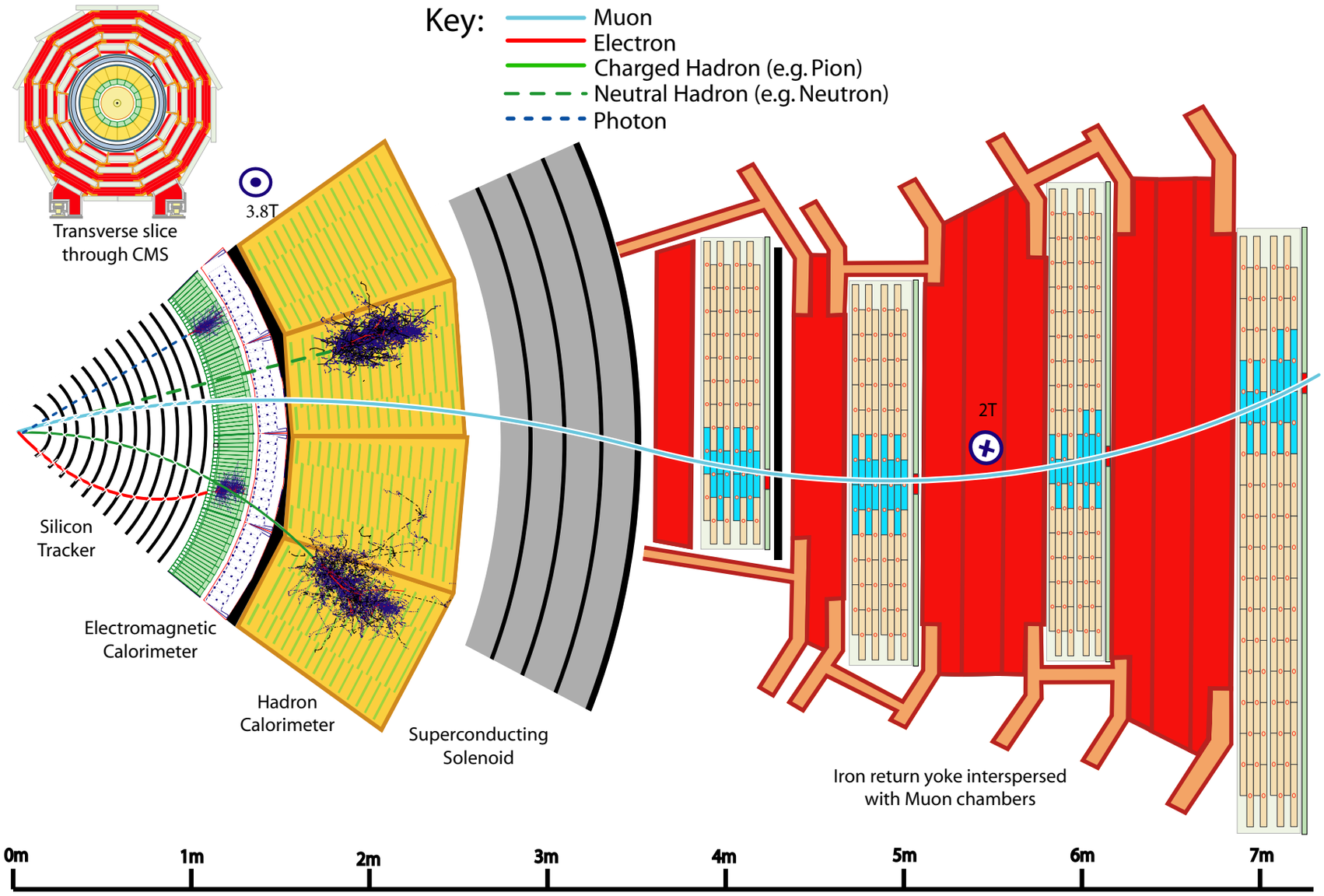
- An alternative view of how to handle UE subtraction in jets is presented
  - Instead of exploring tight cone R at low-p_T, consider large R at high-p_T
- Jet reconstruction is updated for forward-η and to account for flow modulations
  - **Perform Jet Nuclear Modification Factor Radius Scan up to R=1 for p_T > 200**
  - Extend CMS jet substructure measurements to large cone size

The MIT group's work was supported by US DOE-NP

Backup

The CMS Detector and Particle Flow

JINST 12 (2017) P10003



- CMS combines all subdetectors via the particle-flow algorithm
- Particle-flow objects serve as jet constituents

Jet Reconstruction with CMS in pp

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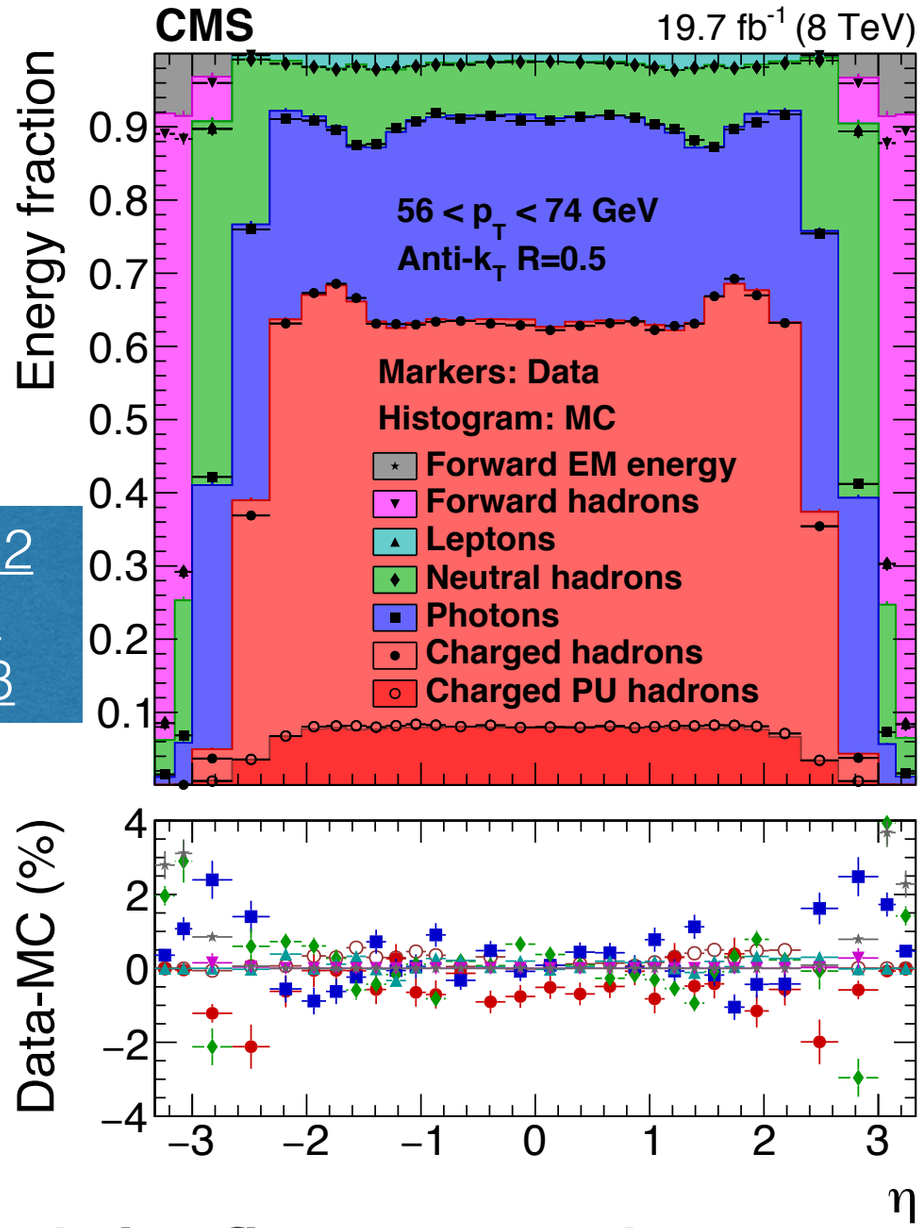
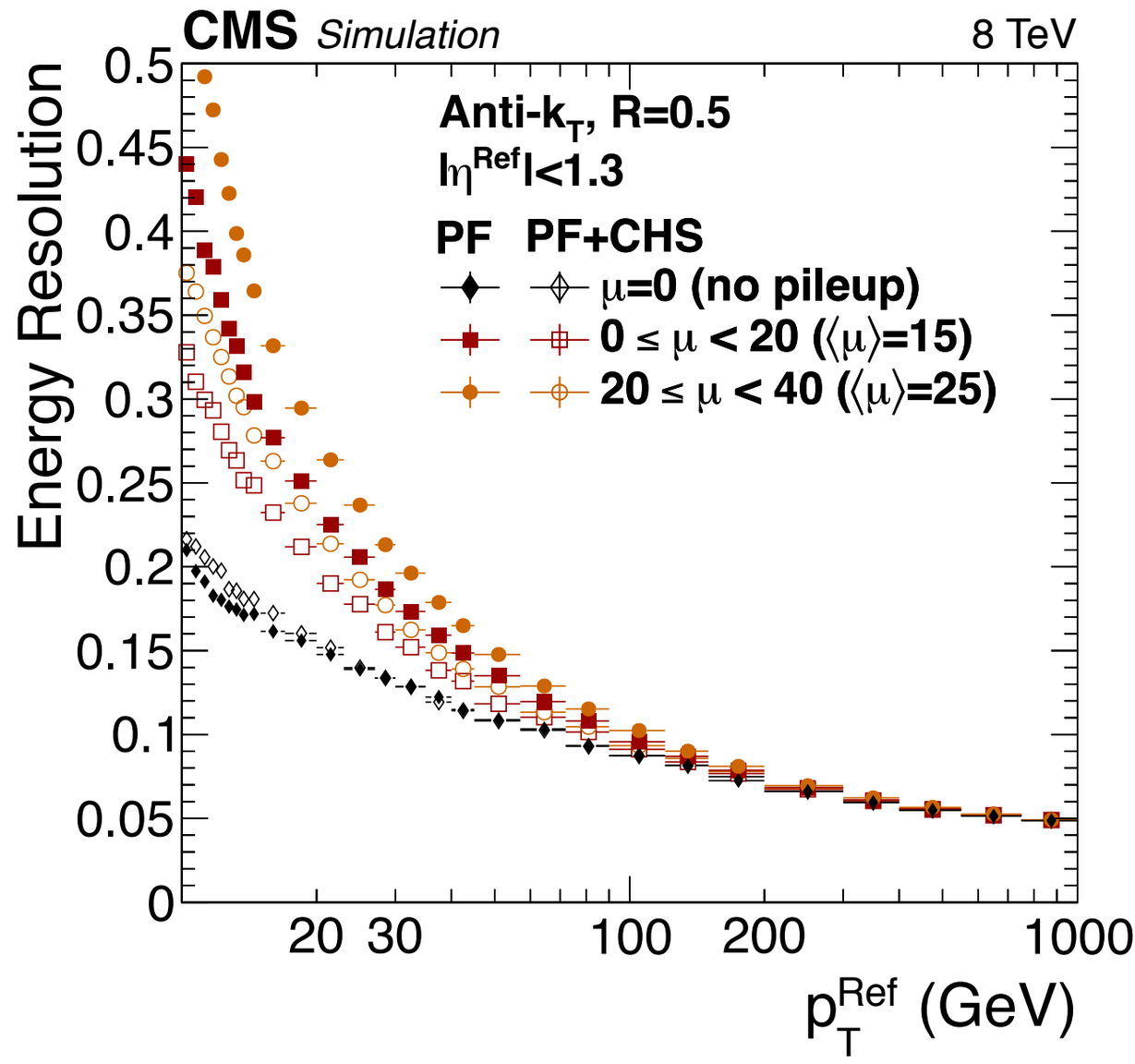
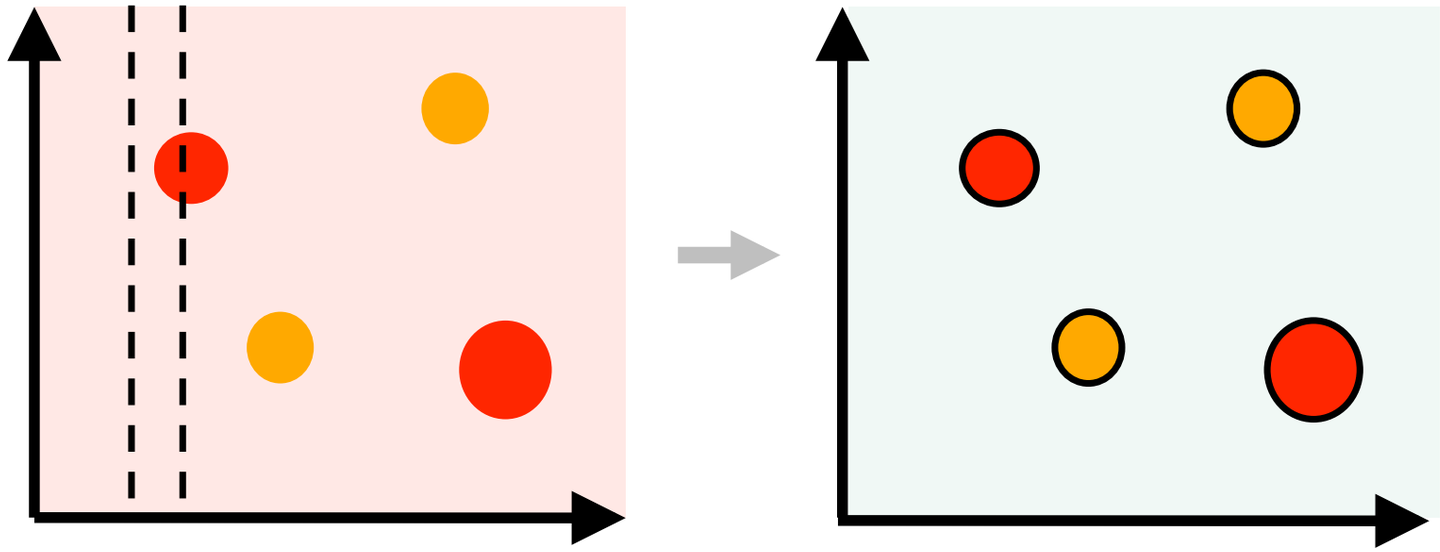




- Particle-flow constituents combine tracks, ECal and HCal
  - Strong improvement at low-p_T with addition of tracks

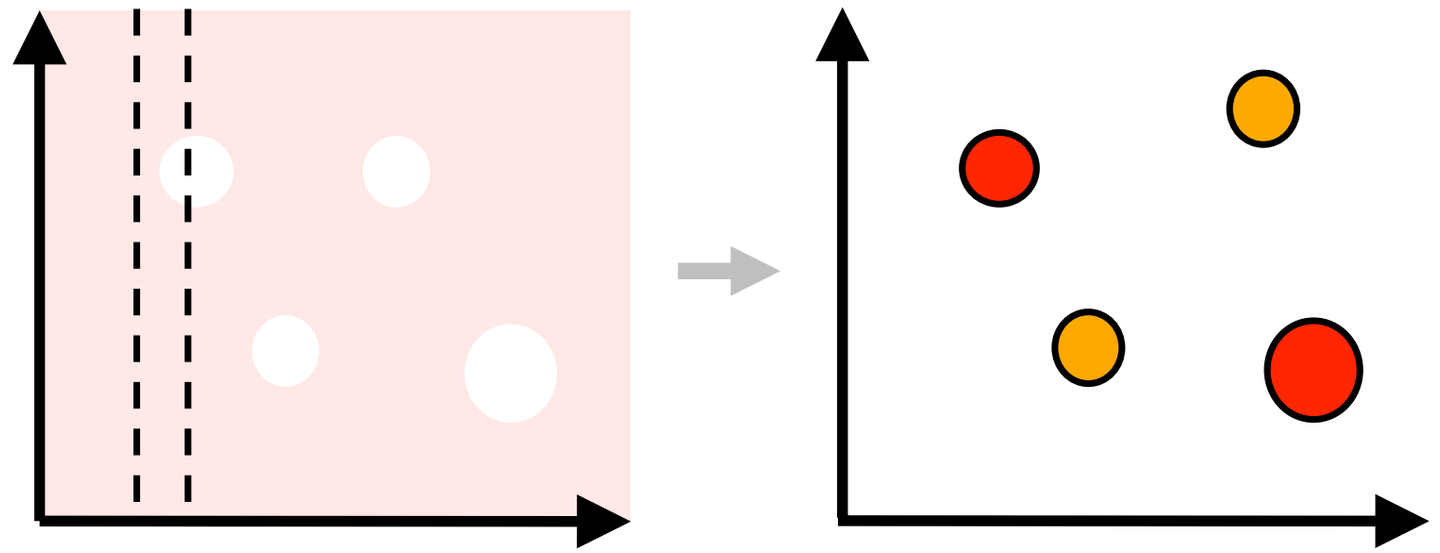
Iterative Pedestal Subtraction

- ρ or <E_T> is calculated in strips of rapidity
  - Follows HCal tower geometry
- A second iteration is run excluding "jetty" regions of the detector from each η-strip extraction
- **UE** estimation that naturally follows a changing detector geometry



1. <E_T> calculated in strips of η. Subtract <E_T> + σ

2. Run anti-k_T algorithm on background-subtracted towers



3. Exclude reconstructed jets and re-estimate background

4. Re-run anti-k_T algorithm to get final jets

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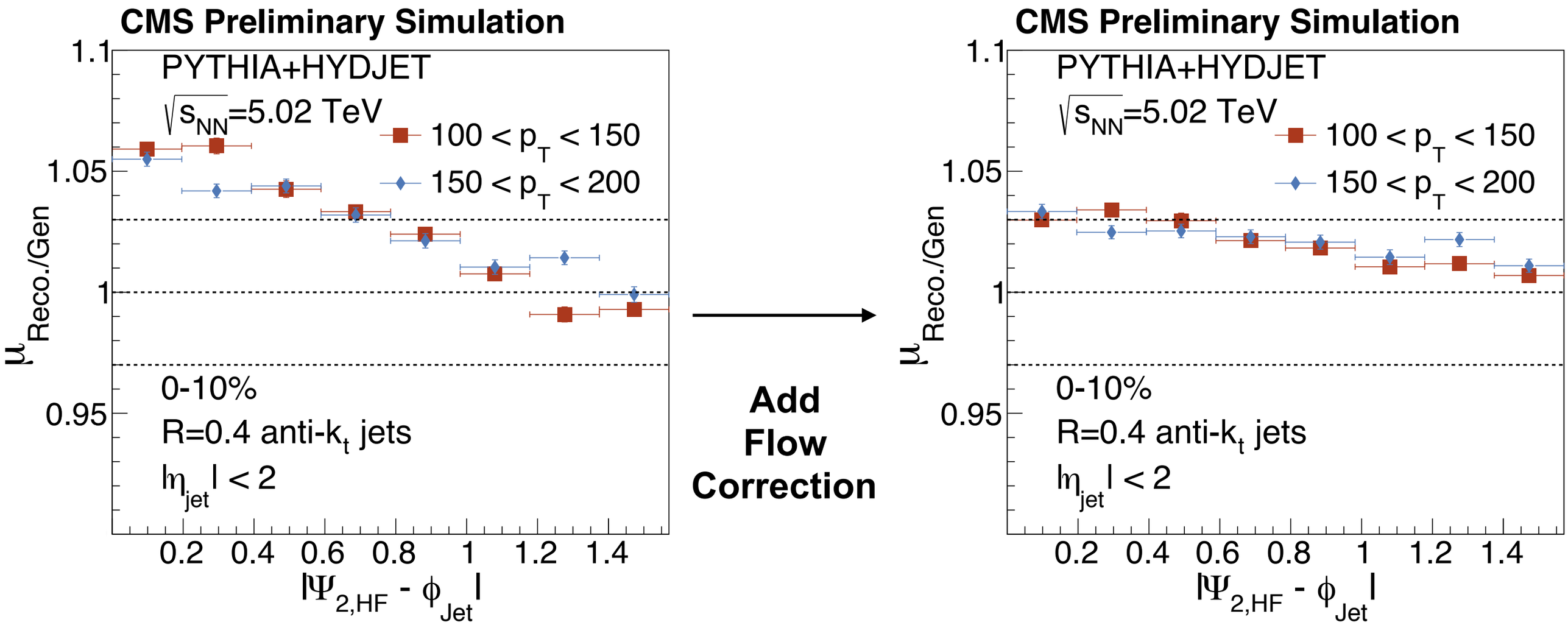
Scale Closure vs. Event Plane (R=0.4)



- Jet energy scale closure as function of event plane for R=0.4 w/o flow correction (**Left**) and with flow correction (**Right**)
- Some flattening of scale less than corresponding R=0.8 case