FUTURE HEAVY ION PHYSICS AT THE CMS

Michael Northup (On behalf of CMS)
Rice University
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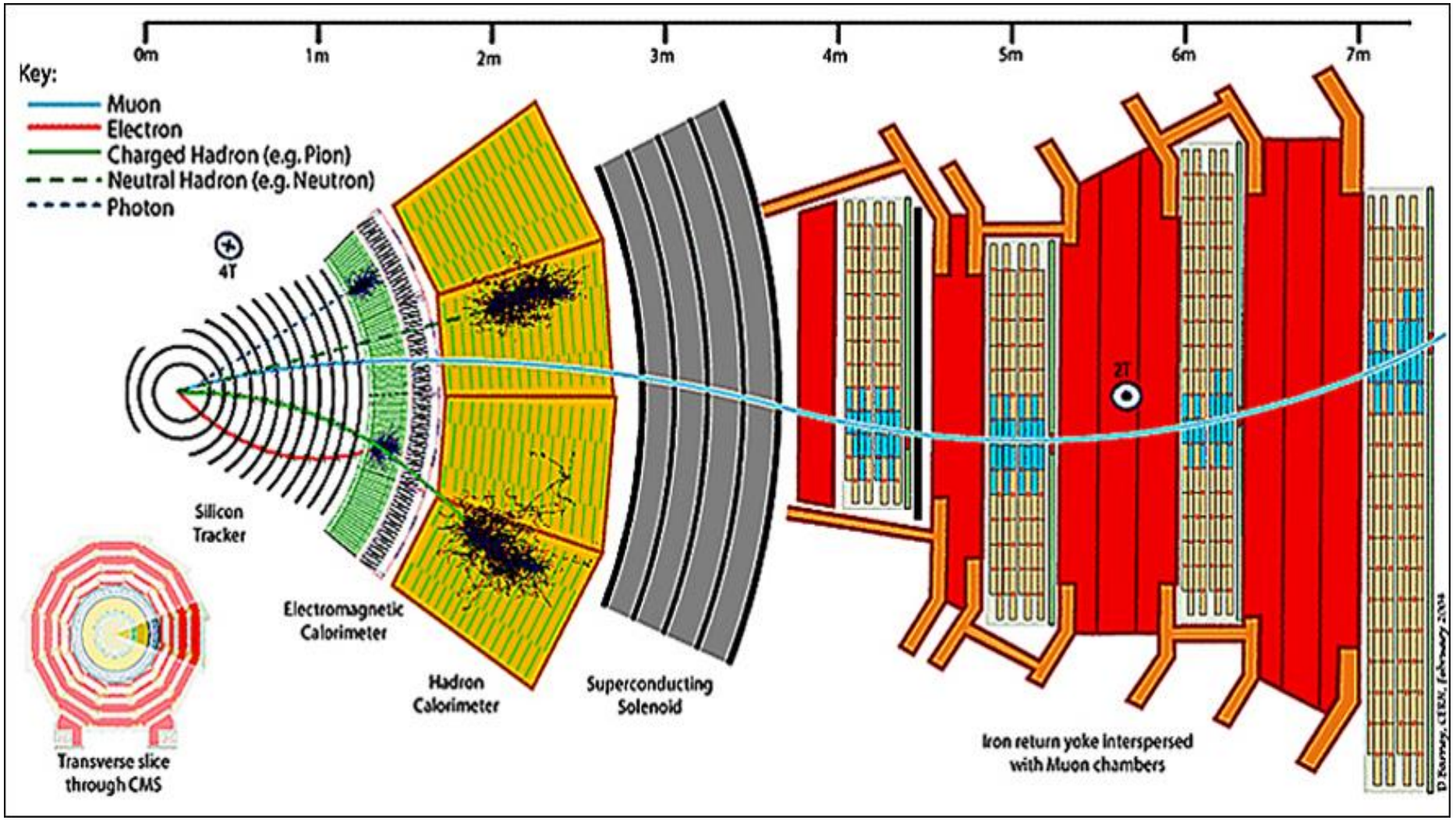
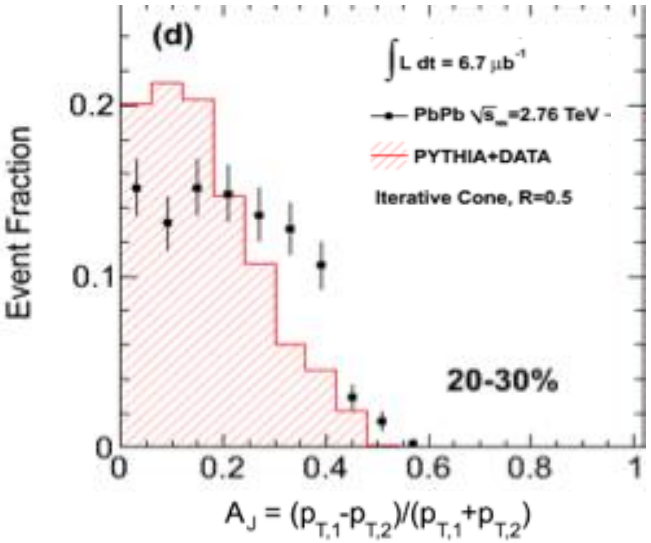
Basic CMS Anatomy



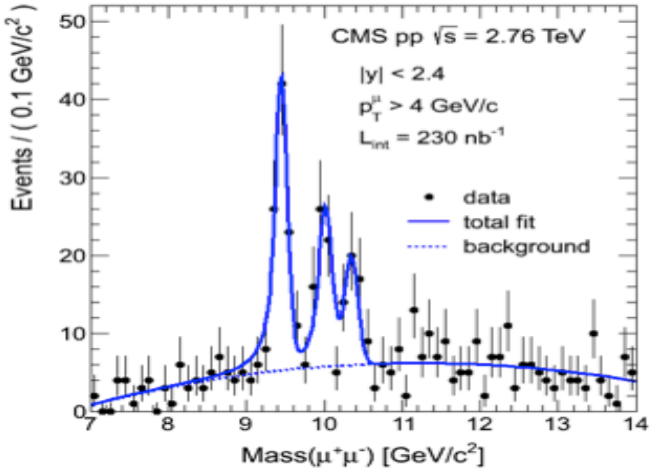
Run 1 Results

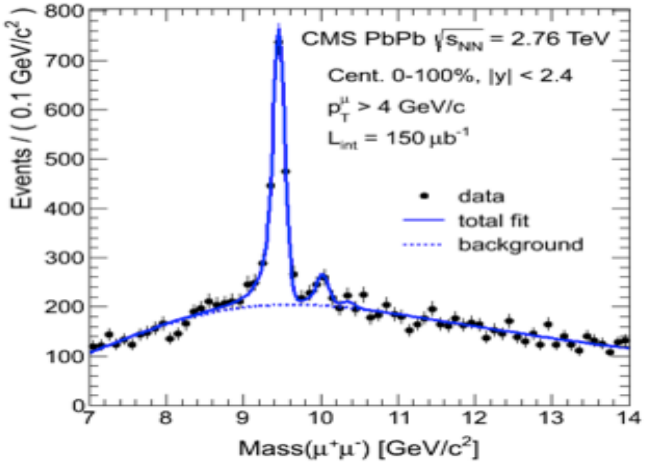
- Run 1 of the CMS was a resounding success for HI Physics with many exciting results reported.

Dijet Imbalance in PbPb



Y Supression in PbPb





PRC 84 (2011) 024906, PRL 109 (2012) 222301

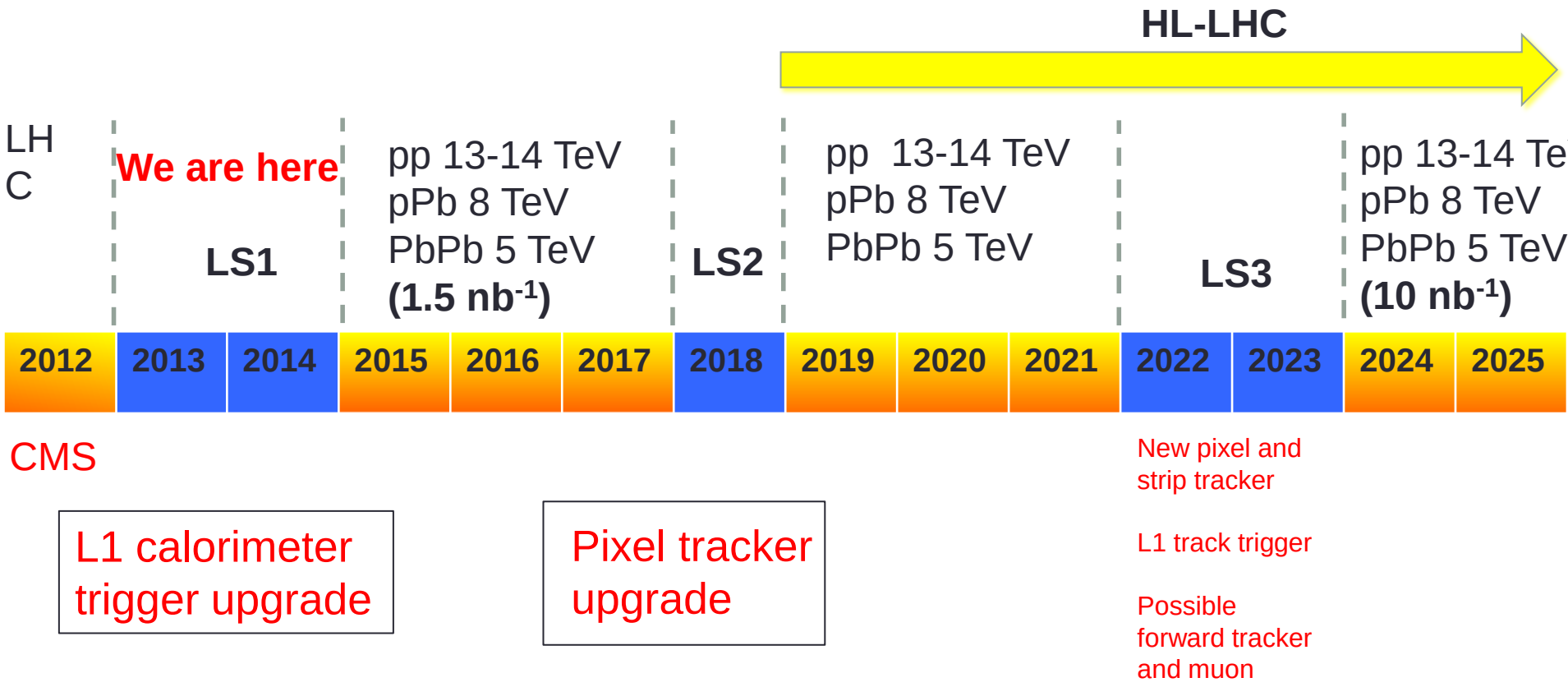
LHC Heavy Ion Run 1

- First very successful pPb run.
- Two very short pp reference runs at PbPb √s.

year	system	$\sqrt{s_{NN}}$ (TeV)	L_{int}	Sampled Events
2010	**Pb-Pb**	**2.76**	**~ 10 μb^{-1}**	
2011	pp	2.76	~ 250 nb^{-1}	
2011	**Pb-Pb**	**2.76**	**~ 150 μb^{-1}**	~1 Billion
2013	p-Pb	5.02	~ 30 nb^{-1}	
2013	pp	2.76	~ 5 pb^{-1}	

Schedule of LHC and CMS

- Upcoming runs will prove to be even more exciting with the CMS receiving much needed upgrades to the L1 trigger, pixel tracker, and other sub detectors.

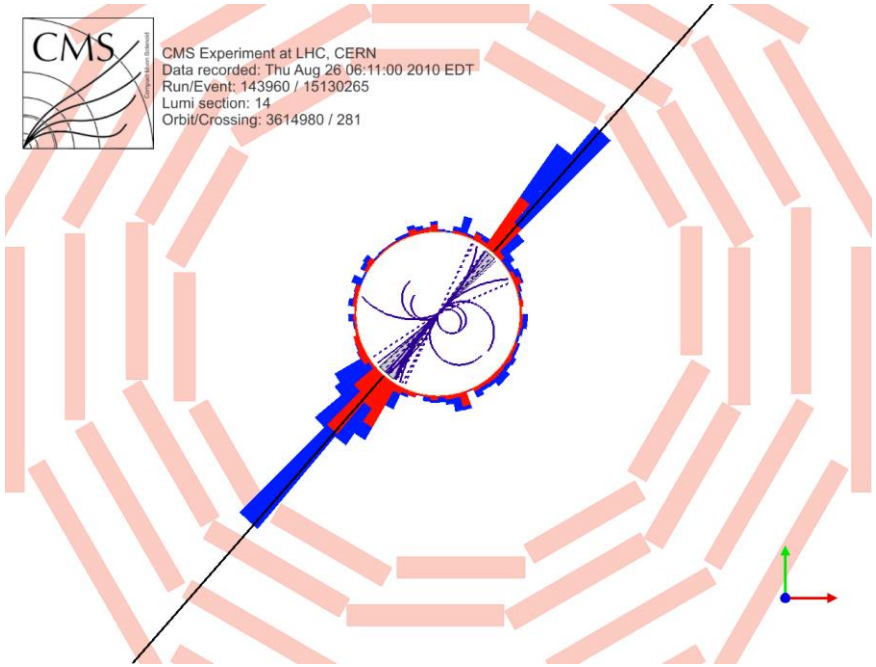


L1 Upgrade Motivation

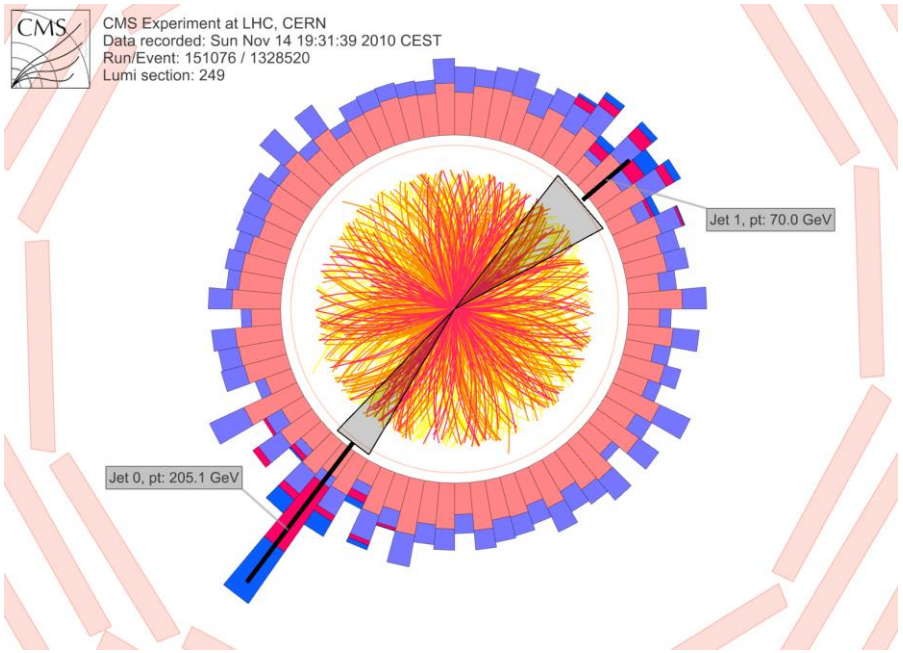
- CMS possesses a novel two level trigger design, the purely hardware based level 1 trigger (L1), and the purely processor based high level trigger (HLT).
- During LS1 the collision energy will increase to around $\sqrt{s_{NN}}$ = 5.0 TeV and the PbPb collision rate will increase to as high as 30 kHz, up from 3 kHz, which will increase the production rate of hard probes by more than a factor 10.
- Significant rejection factors will have to be reached at L1.
- This necessitates the use of background subtraction on single track and jet triggers.

PP-PbPb Background Comparison

pp

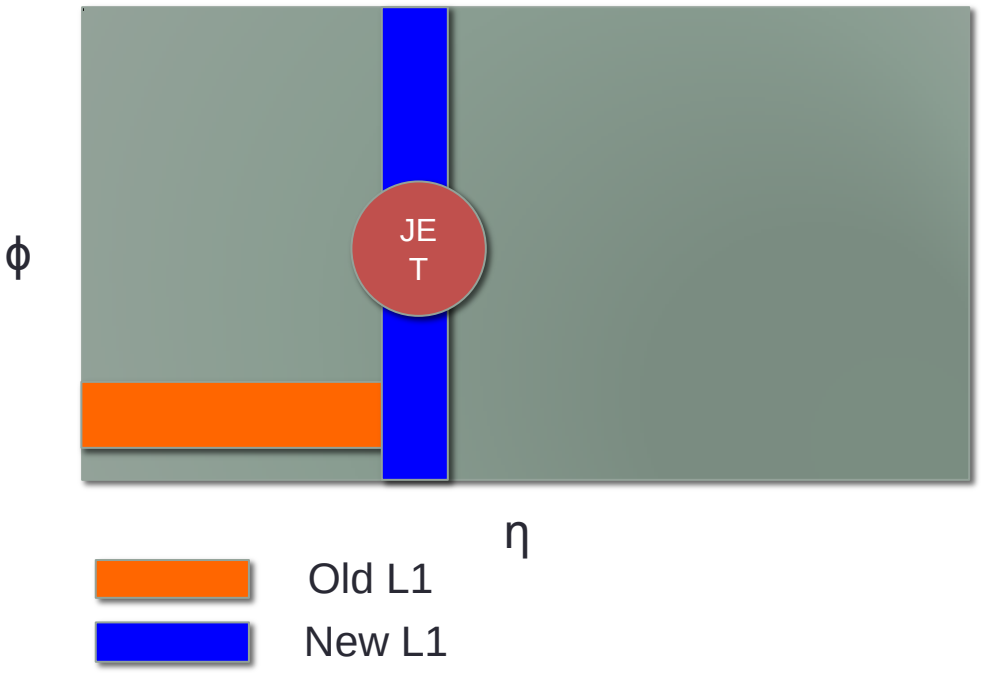


PbPb

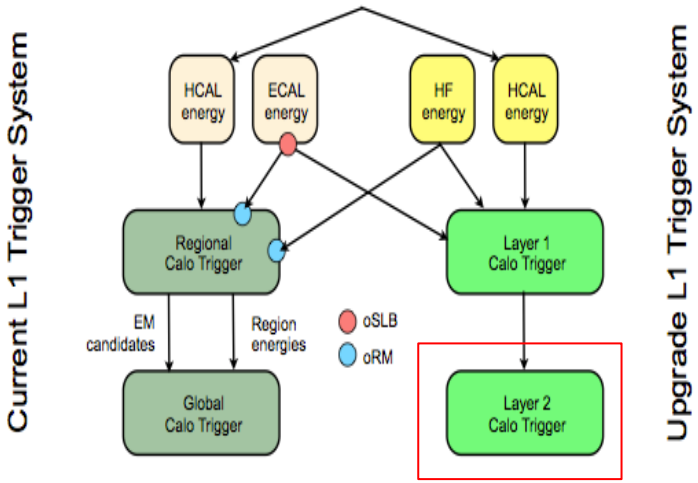


- Background in PbPb will push L1 trigger rate up to unacceptable levels.

L1 Background Subtraction



Schematic of L1 calorimeter trigger upgrade



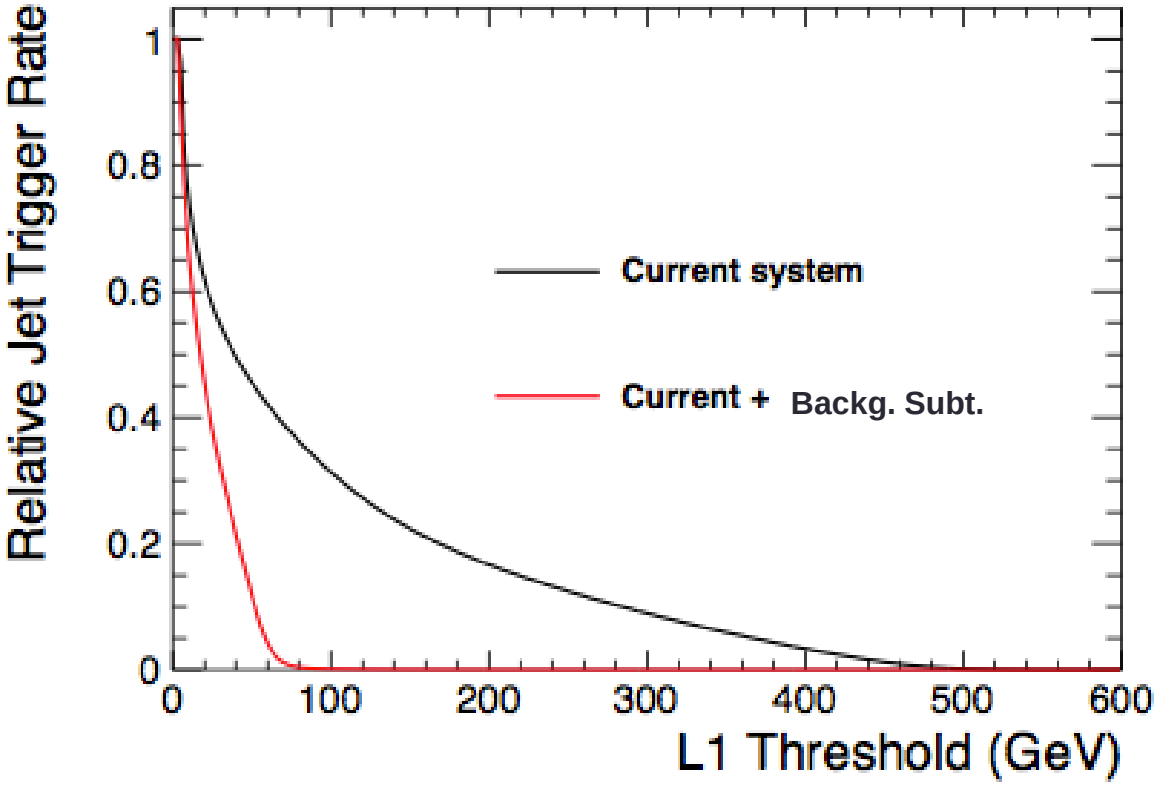
- New Layer 2 allows us to form Et sums over a ϕ-ring at constant η for the purpose of subtracting the background.

L1 Jet Rate Comparison

- Does the new background subtraction algorithm give a sufficiently reduced rate?

YES!

2011 PbPb minbias at $\sqrt{s_{NN}}$ = 2.76 TeV

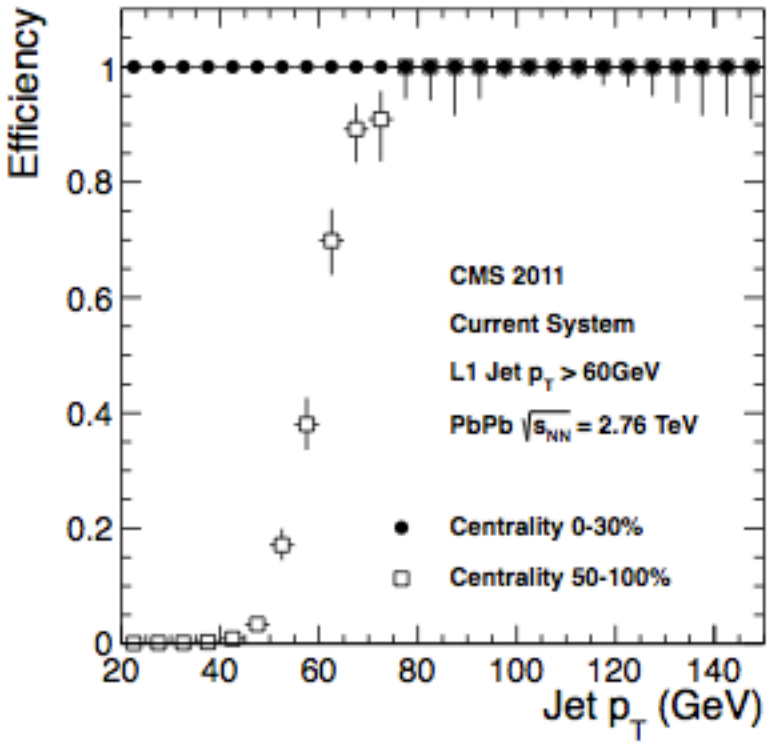


CMS-TDR-12

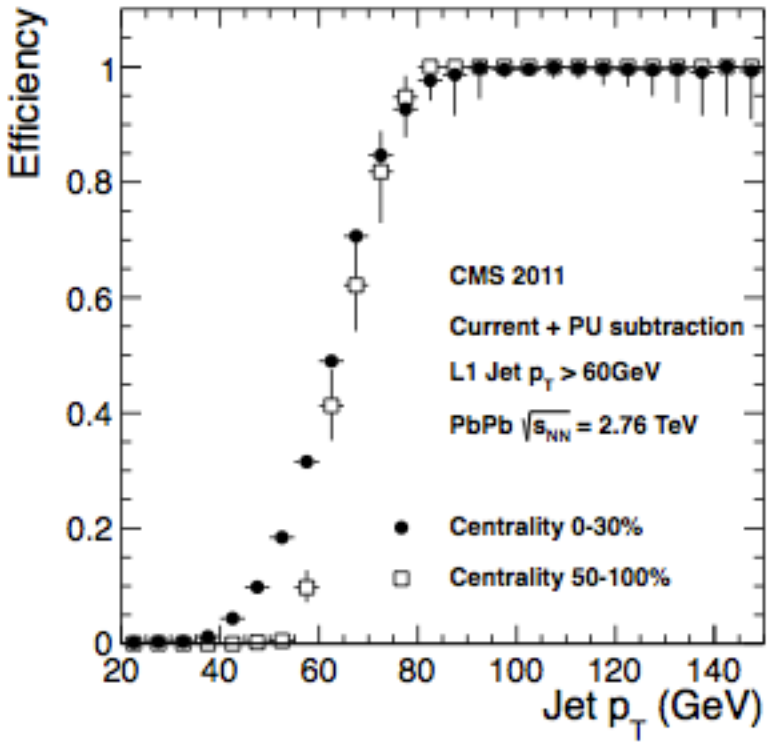
L1 Jet Efficiency Comparison

- We have shown low rate but what about efficiency?
- Trigger efficiency is less dependent on collision centrality.

Without Backg. Subt.



With Backg. Subt.



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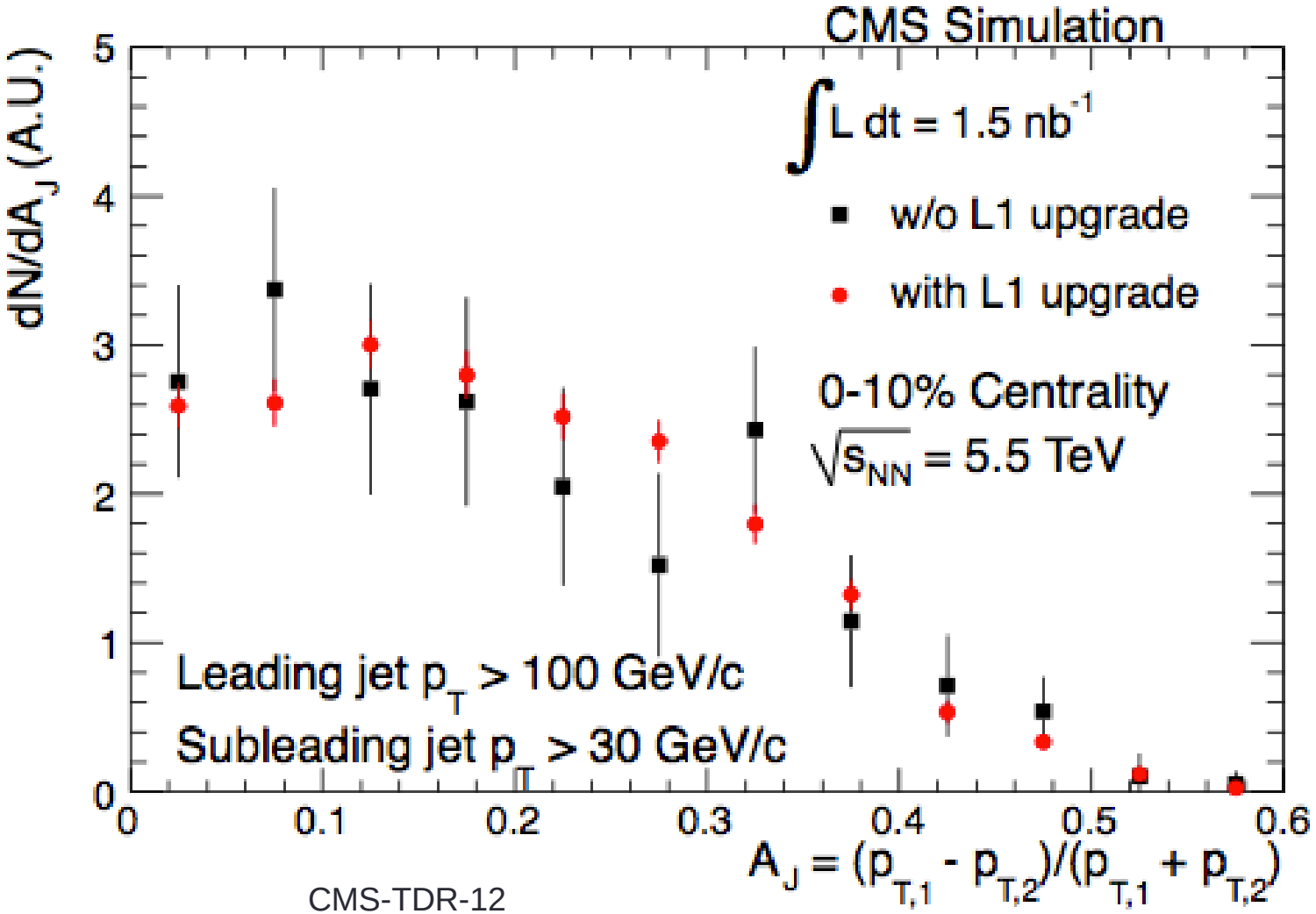
Dijet Imbalance Comparison

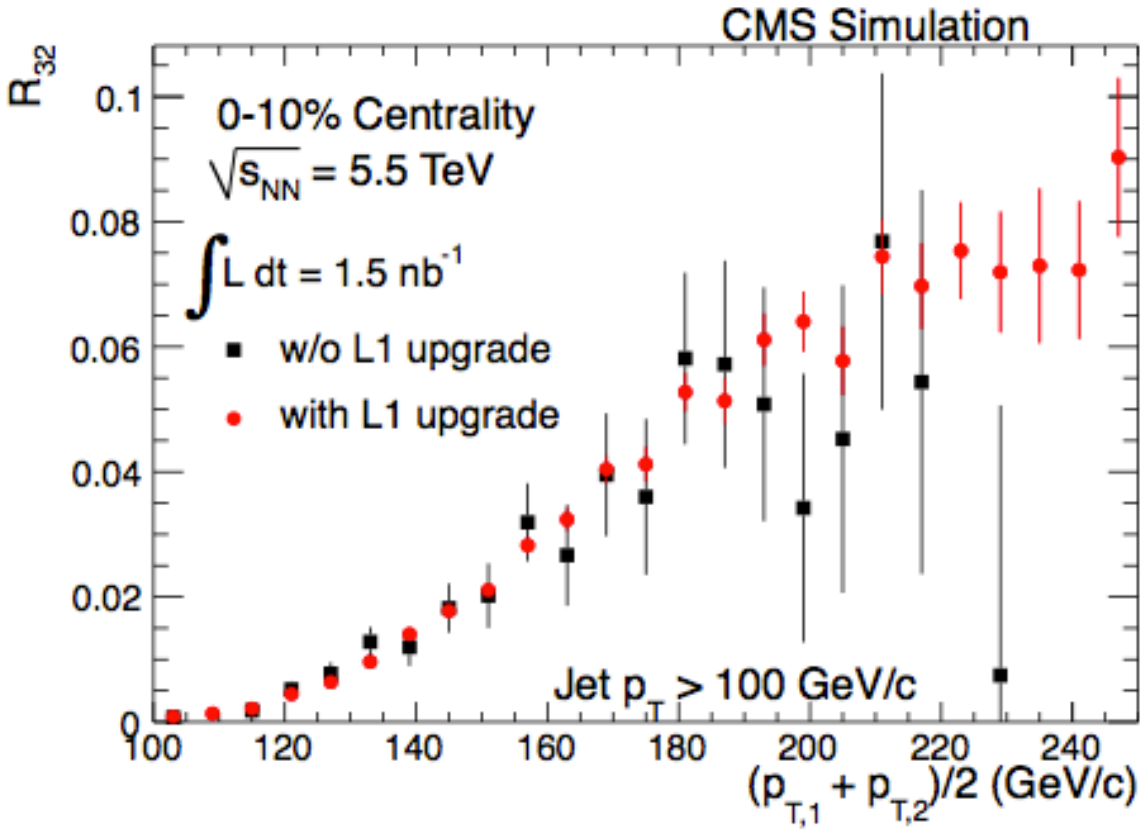
- We expect substantial improvement in measurement of A_J.



CMS-TDR-12

Inclusive 3-jet to 2-jet Cross Section Ratio

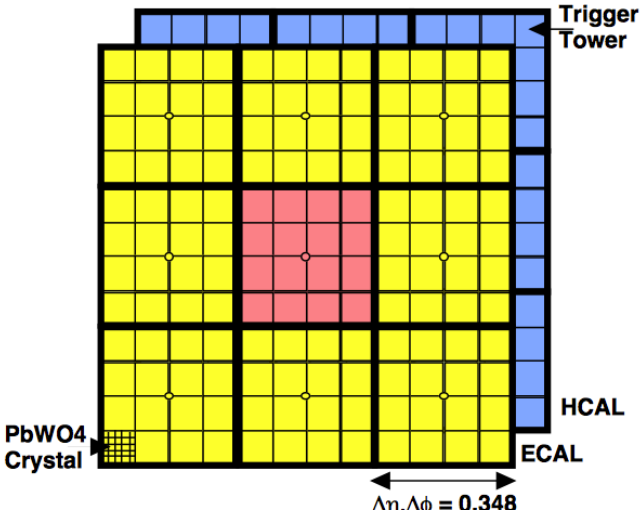
- Excellent testing ground for pQCD and possible modification of parton shower and gluon jet quenching in QGP.

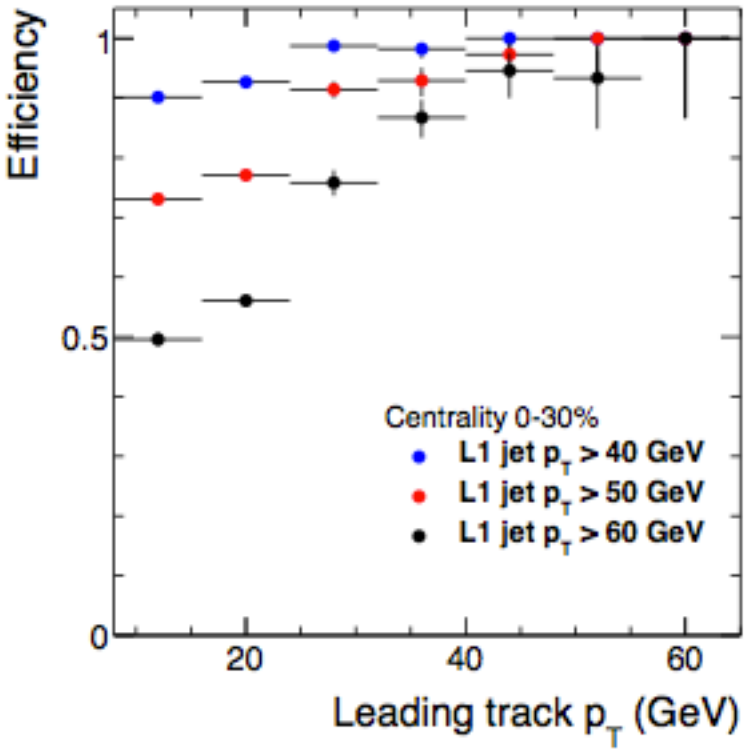


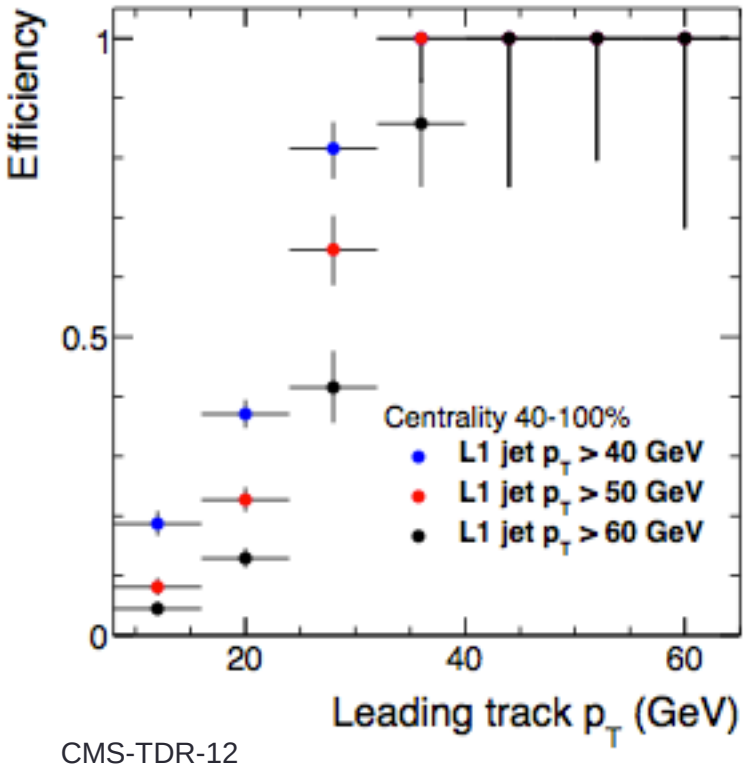
CMS-TDR-12

Single-Track Trigger

- Single track trigger can give CMS a tremendous advantage.
- Work underway to optimize region size.







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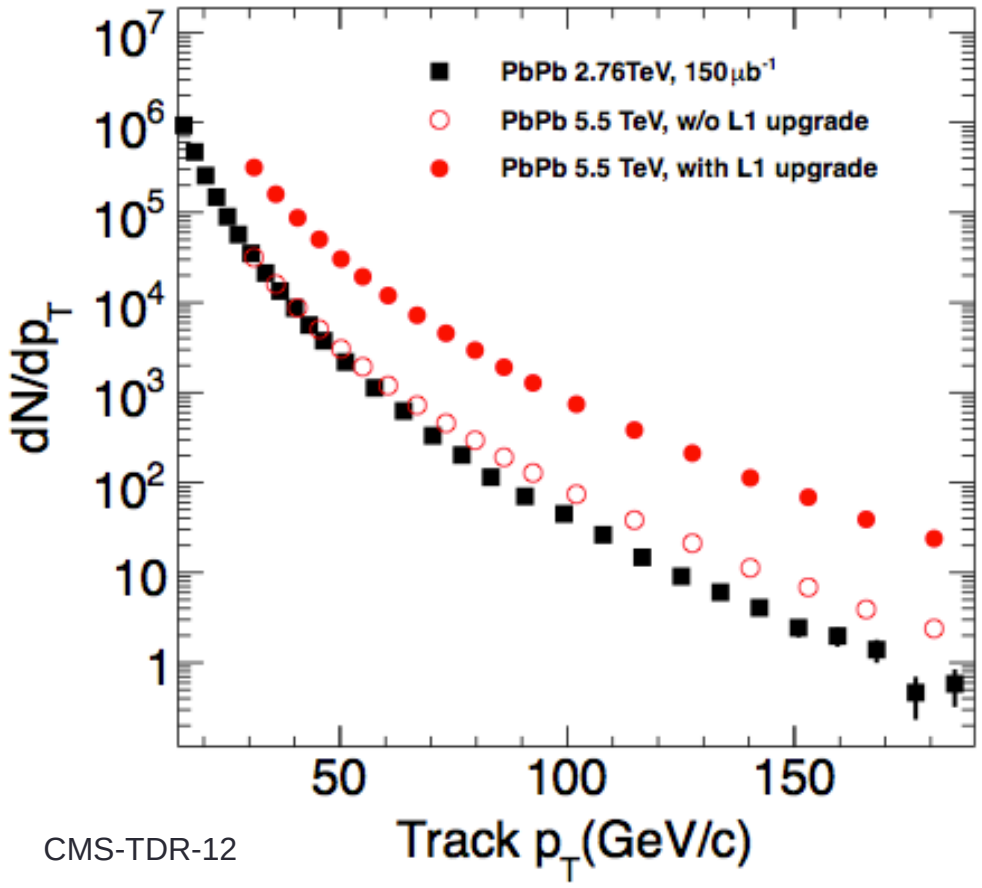
High-Pt Statistics Comparison

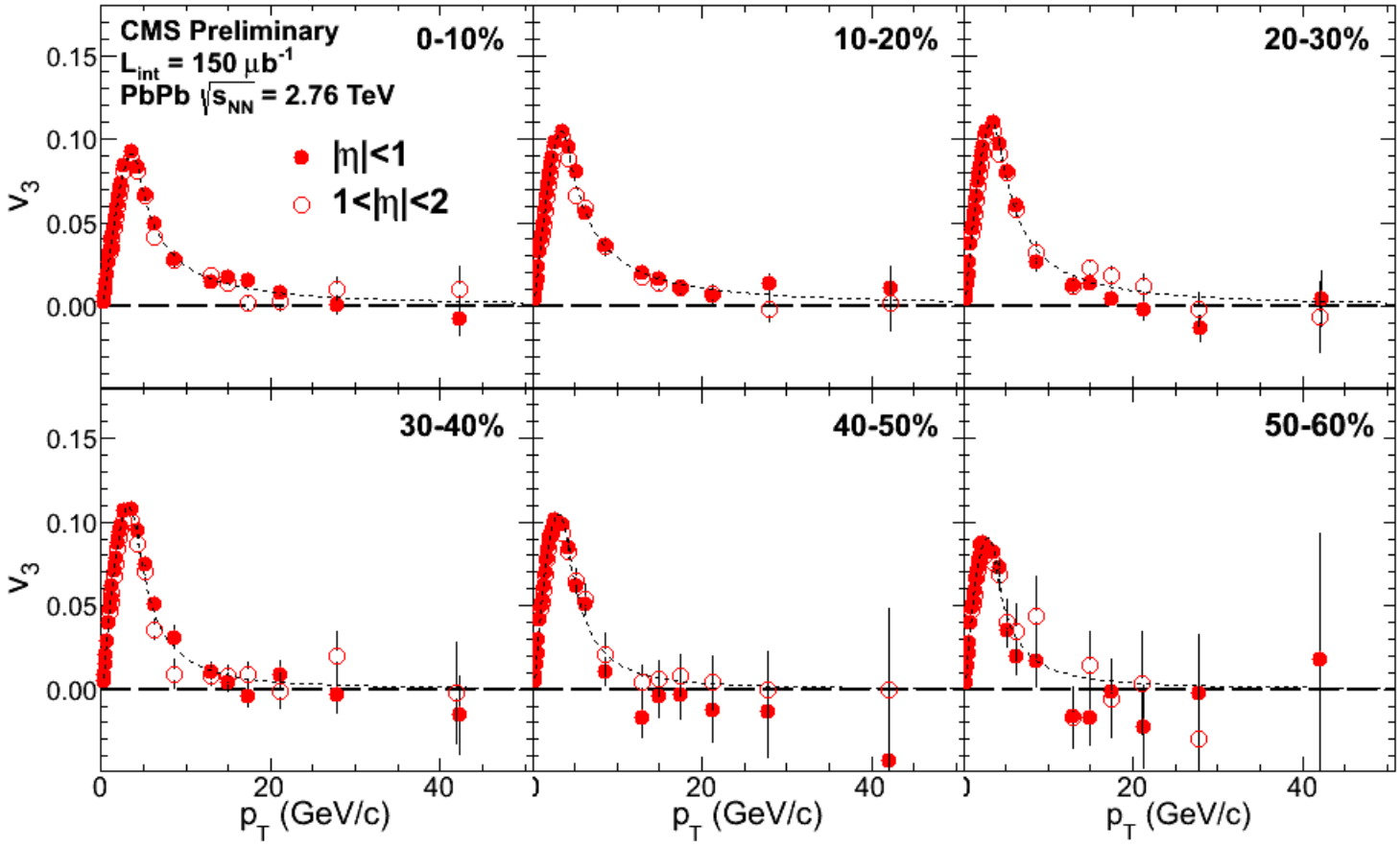


CMS-TDR-12

- At high pt, we experience at least a factor 10 increase in statistics.
- Must have high pt track trigger to exploit these new data.

Charged particle v3 at high Pt

- Can more precisely study path length dependence of jet quenching



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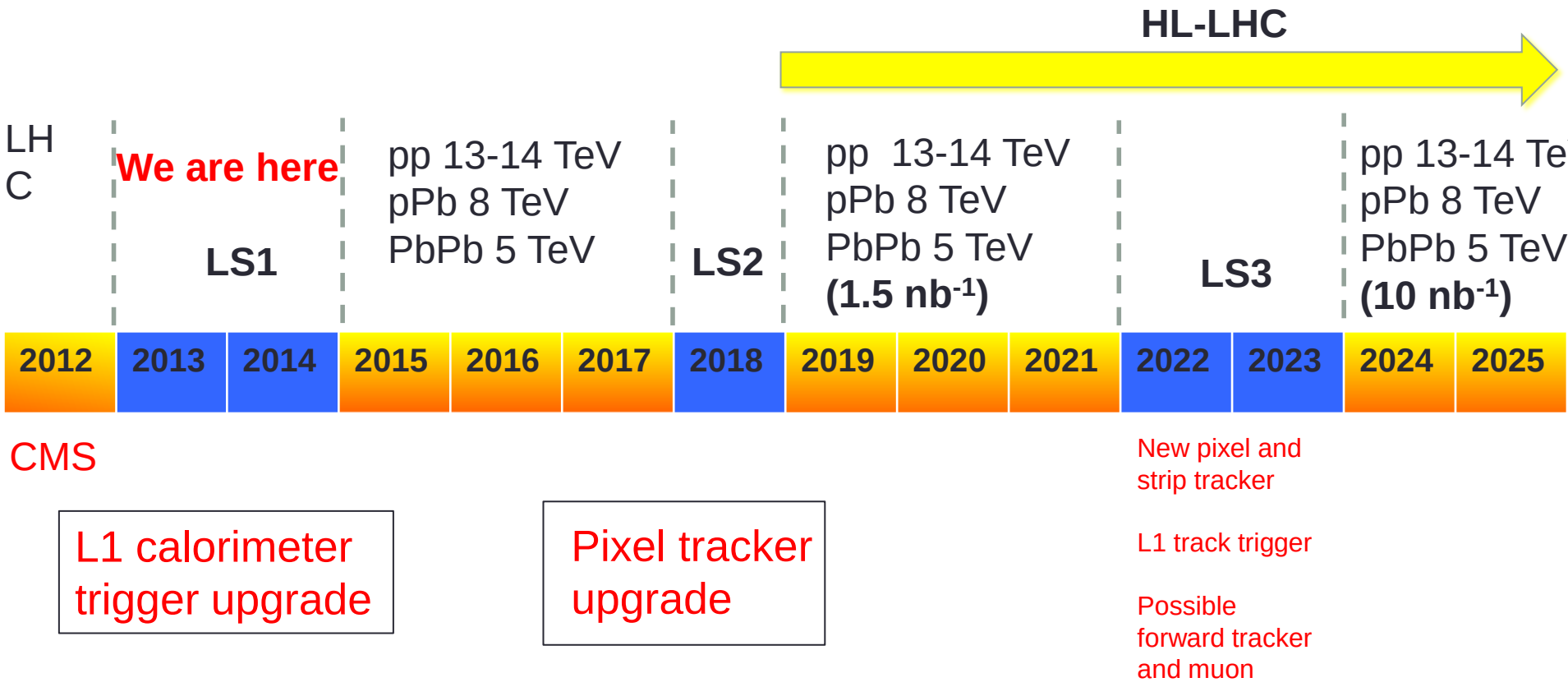
Schedule of LHC and CMS

- Upcoming runs will prove to be even more exciting with the CMS receiving much needed upgrades to the L1 trigger, pixel tracker, and other sub detectors.



HL-LHC Upgrade

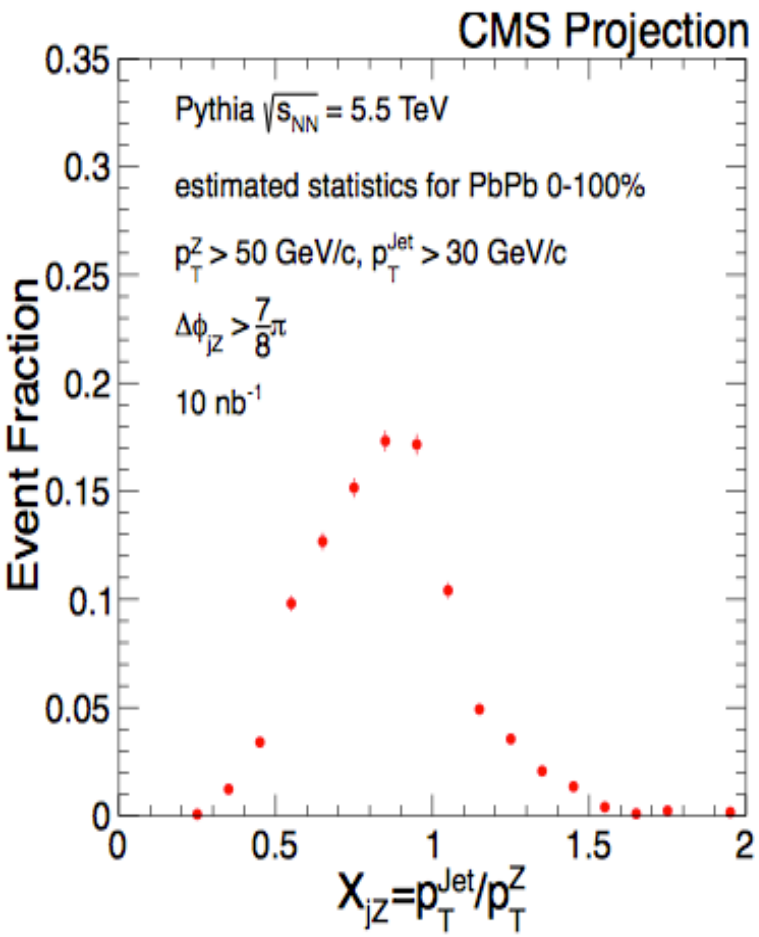
- Much greater statistics will be possible (factor of 20 increase in luminosity, > 10 nb^{-1}).
- Additional upgrades to cope with higher luminosity:
  - New Tracker
  - New L1 Tracking Trigger
  - ZDC upgrade
- Dramatic improvement in the measurement of parton energy loss, e.g.,:
  - Detailed studies of b-tagged jets
  - Measurements of *Z*+jet correlations

Hard Probe Event Rates

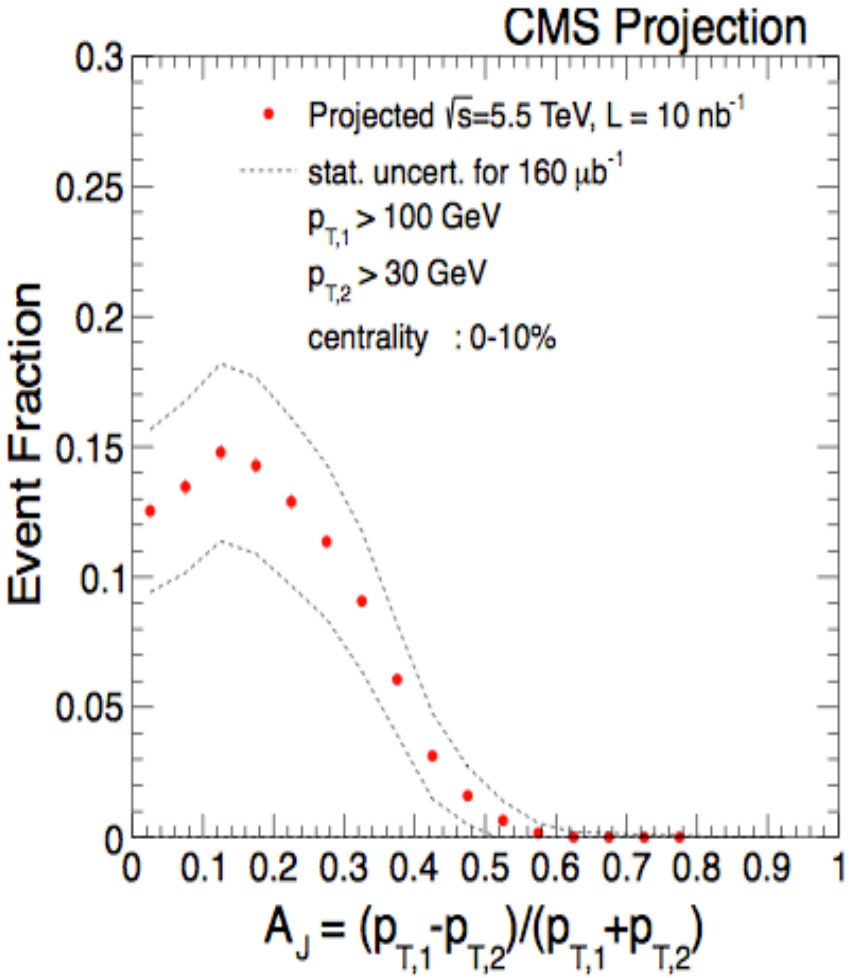
	2010–2011 2.76 TeV 160 μb^{-1}	HL-LHC 5.5 TeV 10 nb^{-1}
Jet p_T reach (GeV/c)	$\sim$ 300	$\sim$ 1000
Dijet ($p_{T,1} > 120$ GeV/c)	50k	$\sim$ 10M
b-jet ($p_T > 120$ GeV/c)	$\sim$ 500	$\sim$ 140k
Isolated γ ($p_T^{\gamma} > 60$ GeV/c)	$\sim$ 1.5k	$\sim$ 300k
Isolated γ ($p_T^{\gamma} > 120$ GeV/c)	–	$\sim$ 10k
W ($p_T^{W} > 50$ GeV/c)	$\sim$ 350	$\sim$ 70k
Z ($p_T^{Z} > 50$ GeV/c)	$\sim$ 35	$\sim$ 7k

Z + Jet and b-Tagged Dijet Projections

Z + Jet



b-tagged dijets



~ 7000 *Z* bosons with $p_T > 50$ GeV/*c*.

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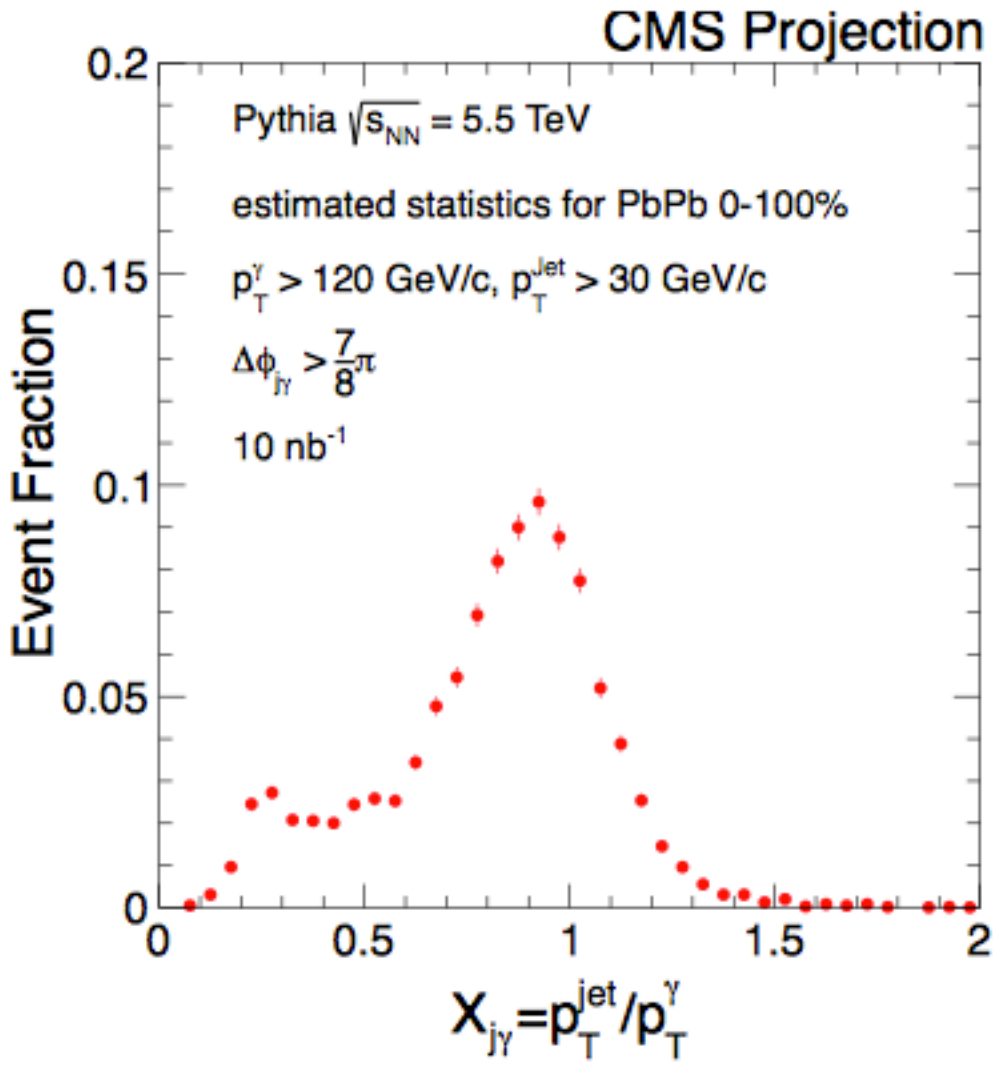
Gamma + Jet Projection



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Quarkonia Yield Estimates

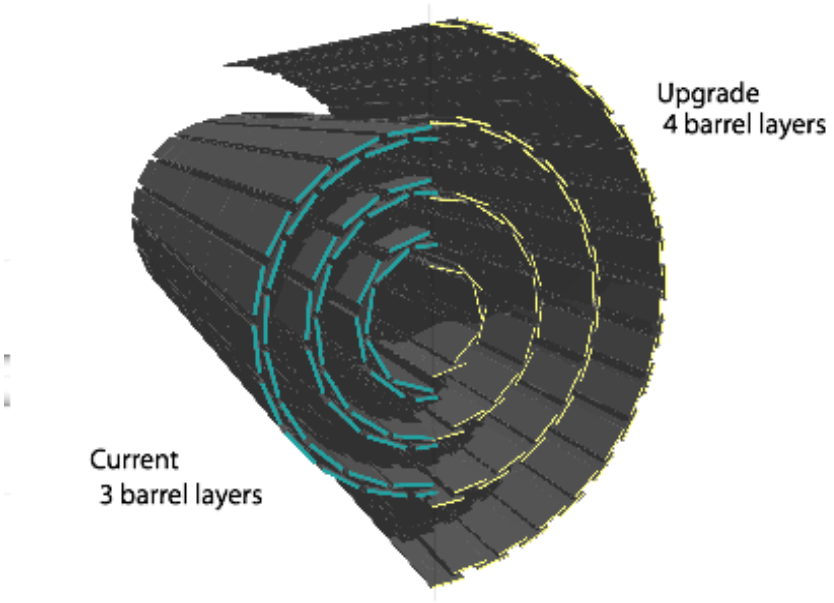
Table 3: Quarkonia yield estimates for $L_{\text{int}} = 10\ \text{nb}^{-1}$ at $\sqrt{s_{NN}} = 5.5$ TeV. Bottomonia are inclusive in p_{T}, charmonia have $p_{\text{T}} > 6.5$ GeV/c.

$\sqrt{s_{NN}}$	2.76 TeV		5.5 TeV					
L_{int}	150 μb^{-1}		$10\ \text{nb}^{-1}$					
Centrality(%)	0-100	0-100	50-100	60-100	70-100	80-100	90-100	0-100
Signal		p_{T}-inclusive raw yields						($p_{\text{T}} > 30$ GeV)
$B \to J/\psi$	2 250	300 000	12 400	6 150	2 350	810	215	5500
Prompt J/ψ	9 000	1 200 000	49 500	24 500	9 420	3 240	860	4400
$\psi(2S)$	200	26 600	1 100	547	210	70	20	100
$\Upsilon(1S)$	2 000	266 000	11 000	5 460	2 090	720	191	267
$\Upsilon(2S)$	300	40 000	1650	820	314	108	29	80
$\Upsilon(3S)$	50	6 700	275	137	52	18	5	20

CMS PAS FTR-13-025

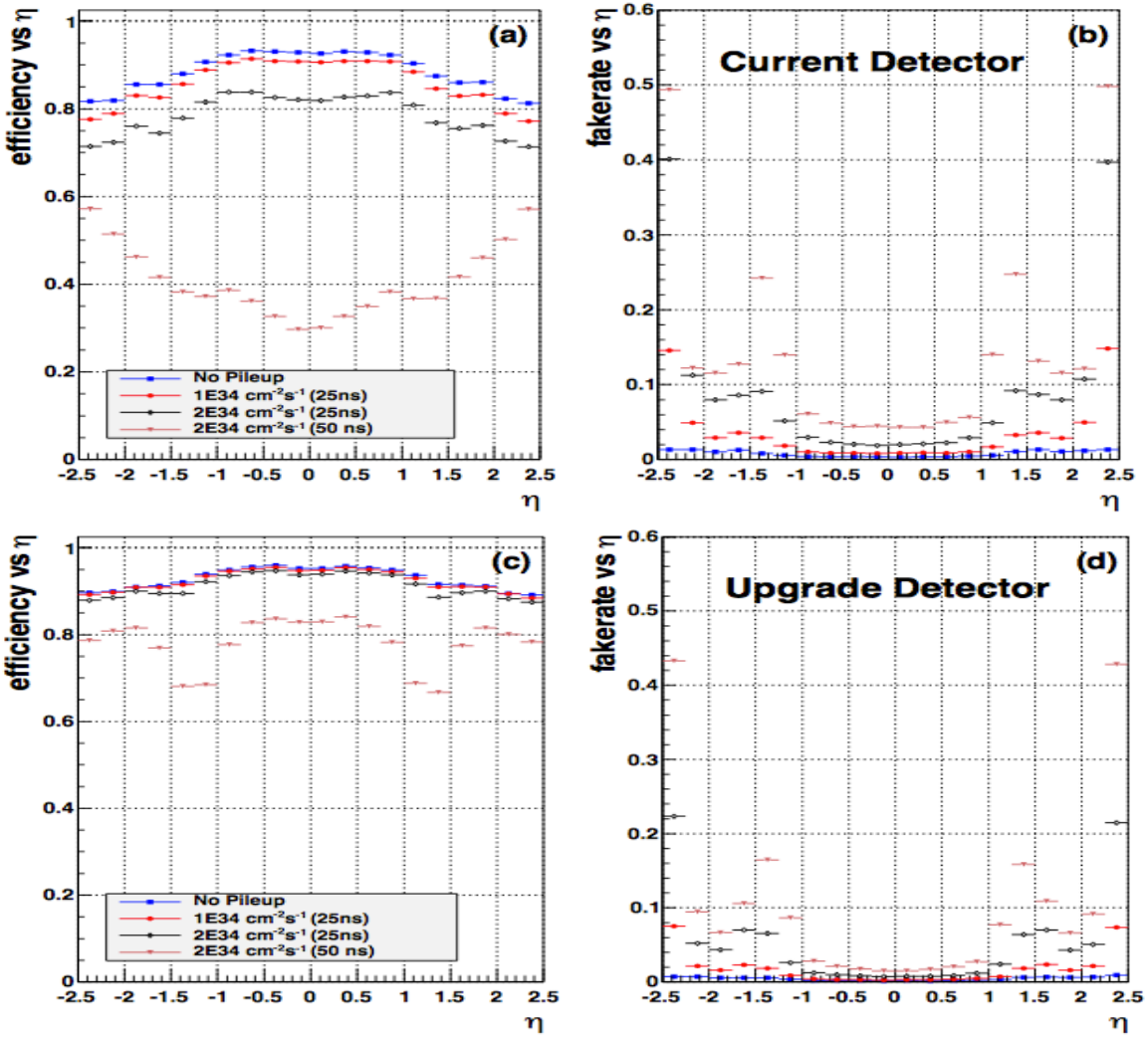
Pixel Detector Upgrade

- Up till the end of LS2, we expect luminosities for pp collisions to exceed 2 x 10^{34} cm^{-2} s^{-1} and average pileup to exceed 50.
- To cope with this new high luminosity, high pileup environment, a new pixel detector is needed.



Performance of New Pixel Detector

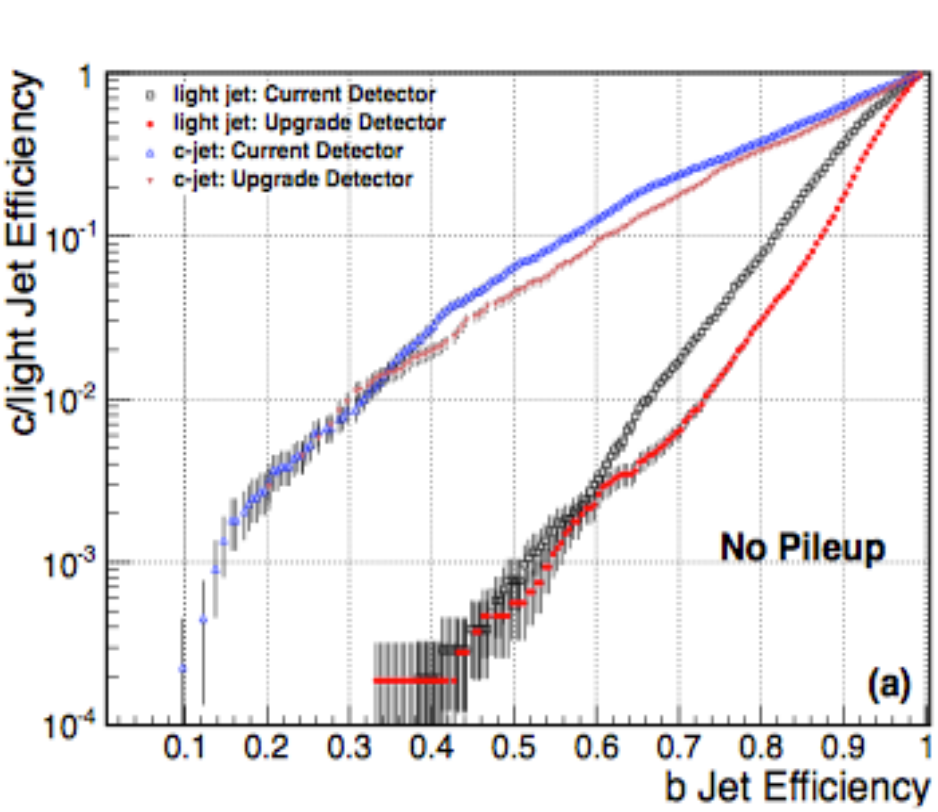
- The new pixel detector maintains high efficiency and low fake rate even in a high pileup (heavy ion like) environment.



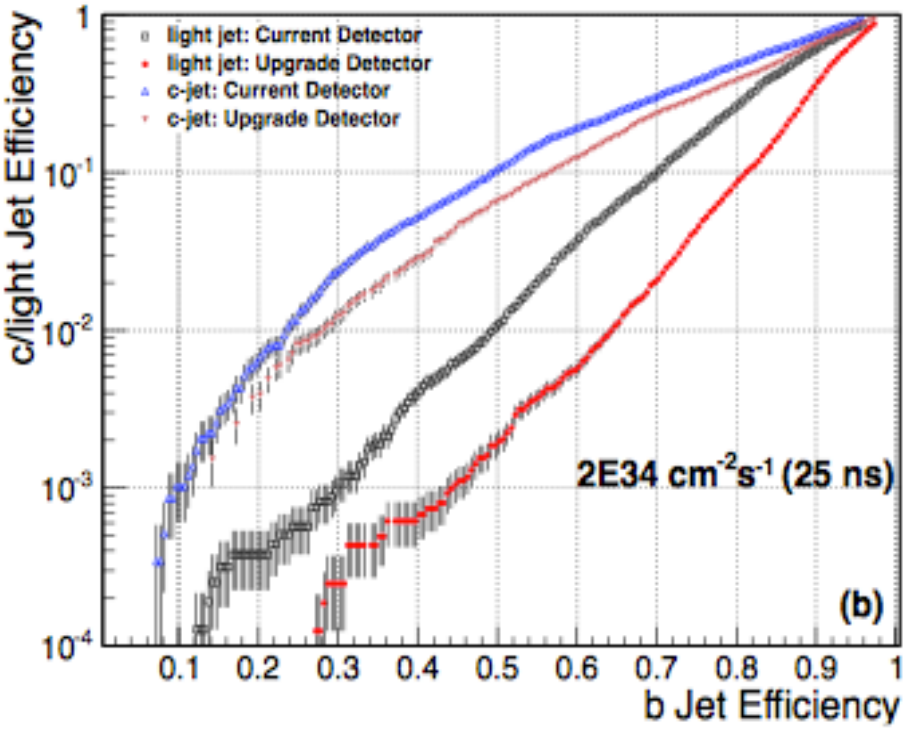
CMS-TDR-11

B-tagging Performance

- New pixel detector substantially outperforms the current detector even without pileup.



Average Pileup = 50



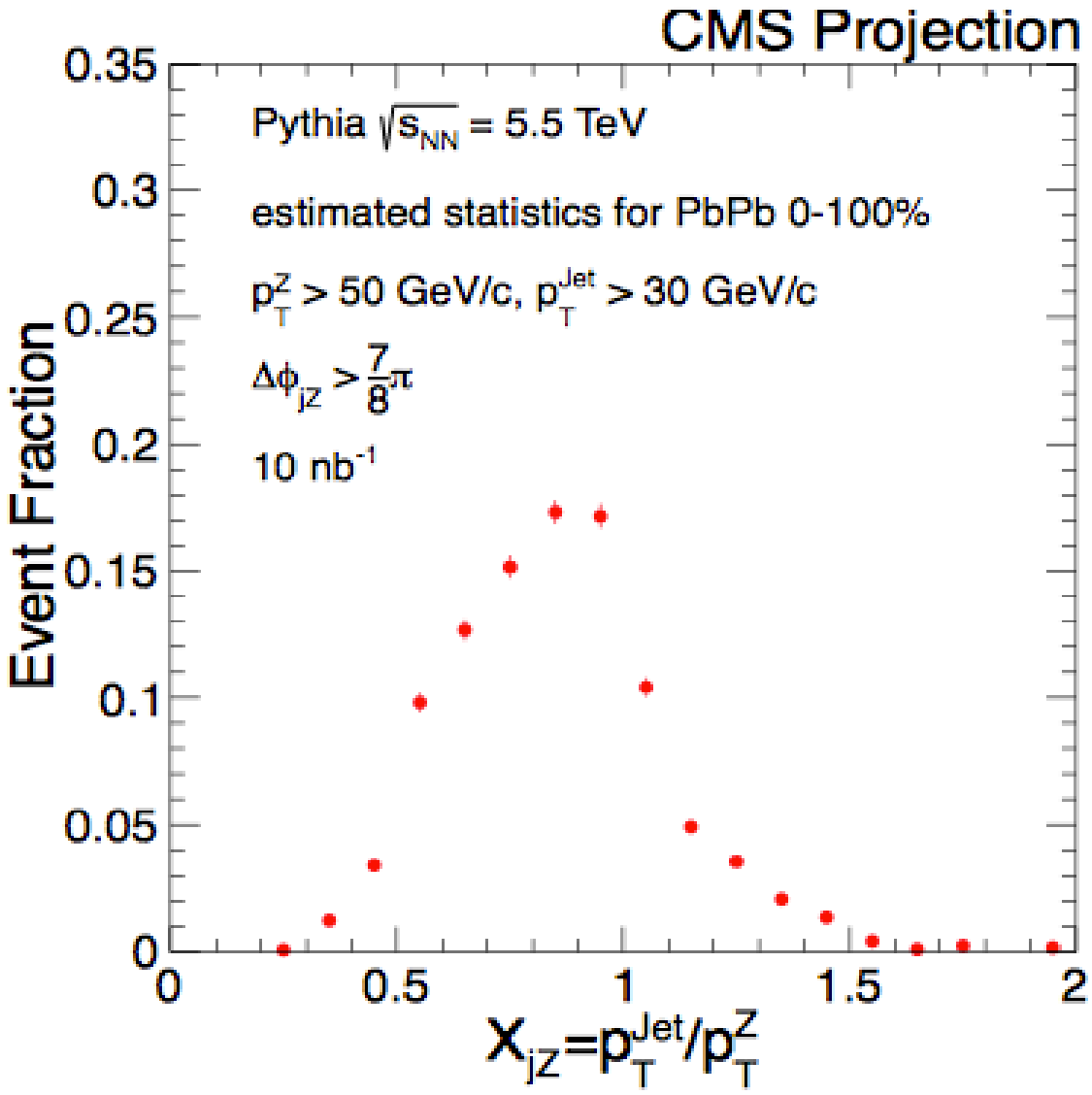
CMS-TDR-11

Closing Remarks

- Run 1 of the CMS yielded spectacular results for heavy ion physics.
- Future runs will require substantial upgrades to the L1 trigger, pixel tracker, and other sub detectors in order to exploit the full capabilities of the detector.
- With background subtraction, sufficient rate reduction can be achieved at L1.
- With the boost in statistics from the HL-LHC upgrade, we expect fantastic improvements to our ability to measure Z-jet, b-tagged dijets, and quarkonia.

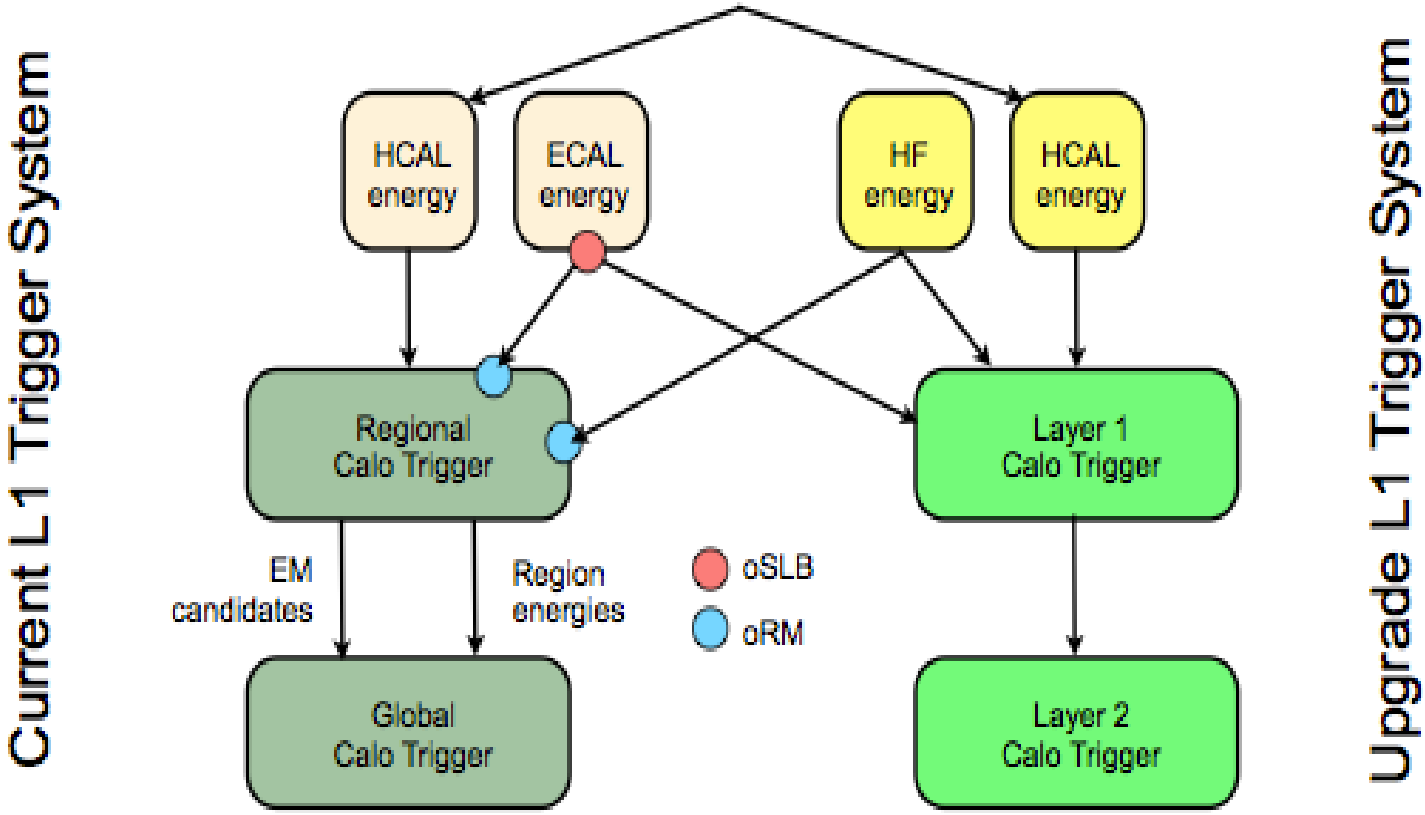
Backup

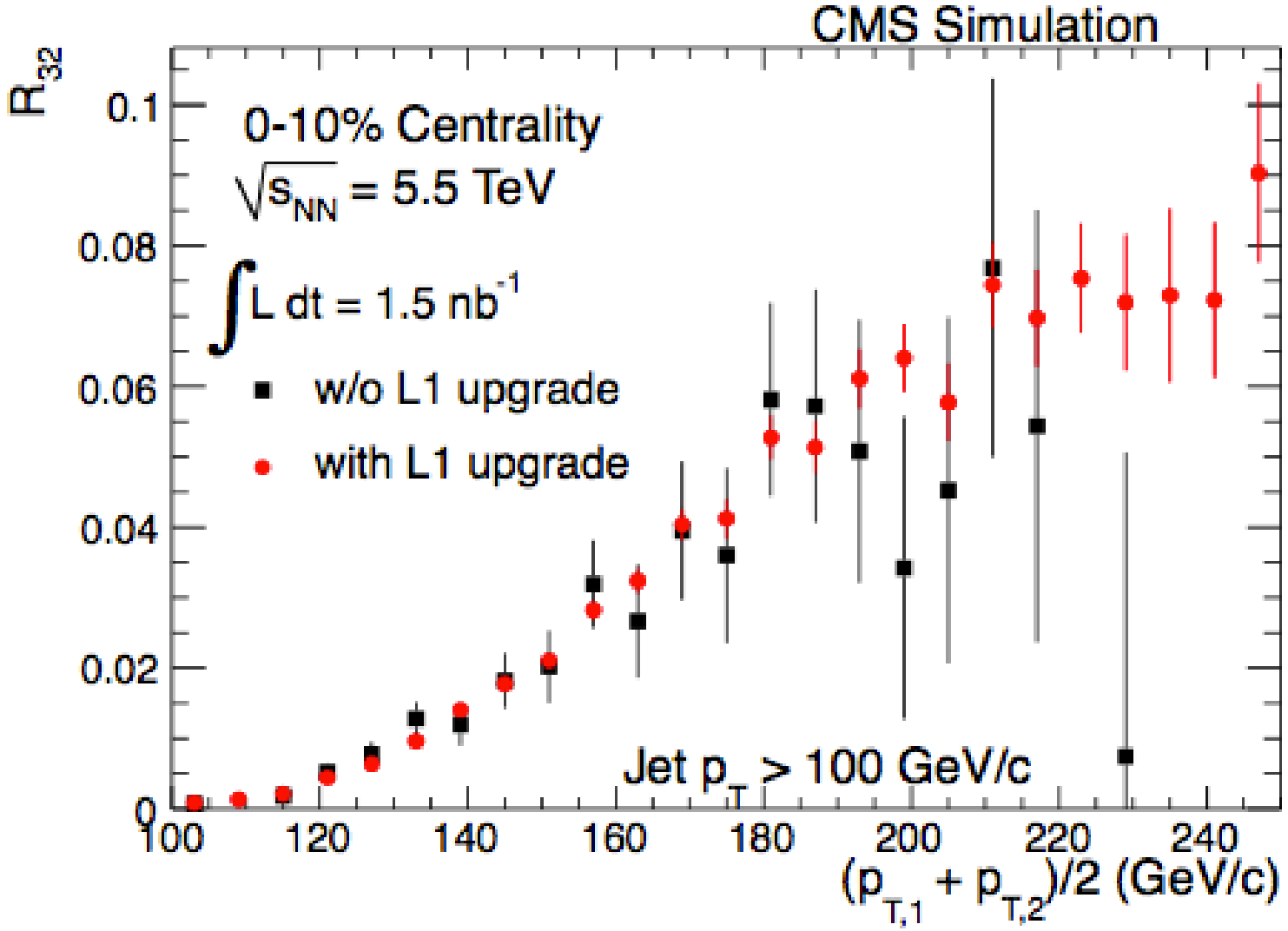
Z-jet


CMS Projection
Pythia $\sqrt{s_{NN}}$ = 5.5 TeV
estimated statistics for PbPb 0-100%
$p_T^Z > 50$ GeV/c, $p_T^{Jet} > 30$ GeV/c
$\Delta\phi_{jZ} > \frac{7}{8}\pi$
10 nb^{-1}
Event Fraction
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.5
1
1.5
2
$x_{jZ}=p_T^{Jet}/p_T^Z$

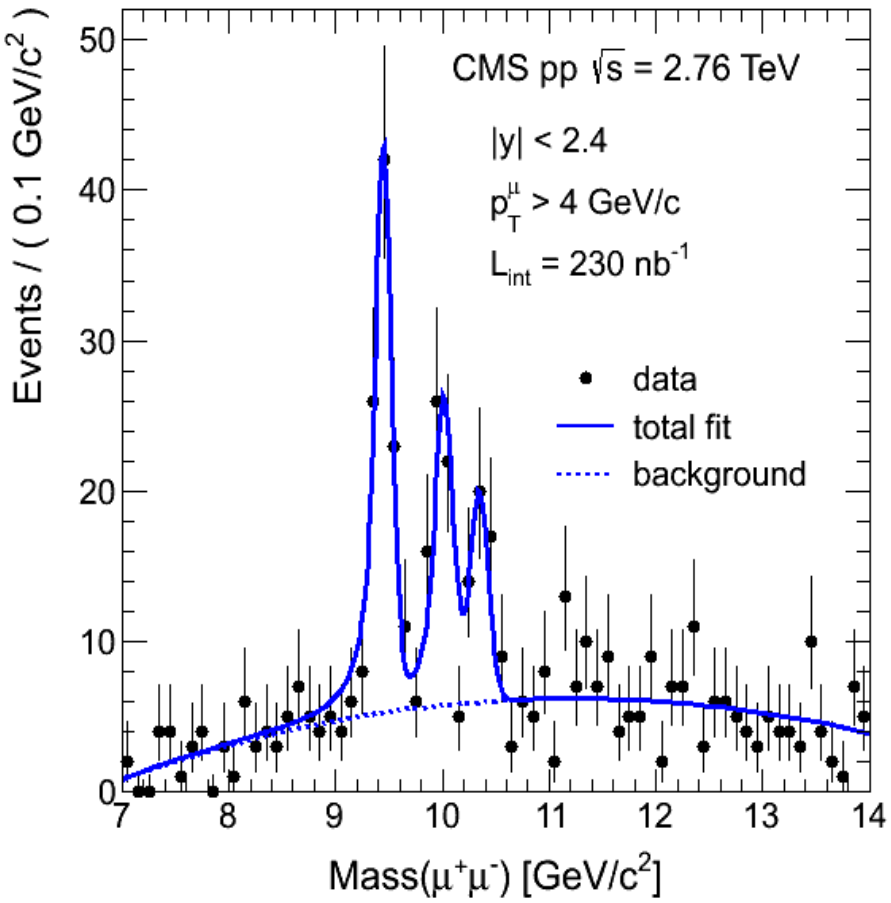
LS1 Upgrade to the L1 Cal Trig

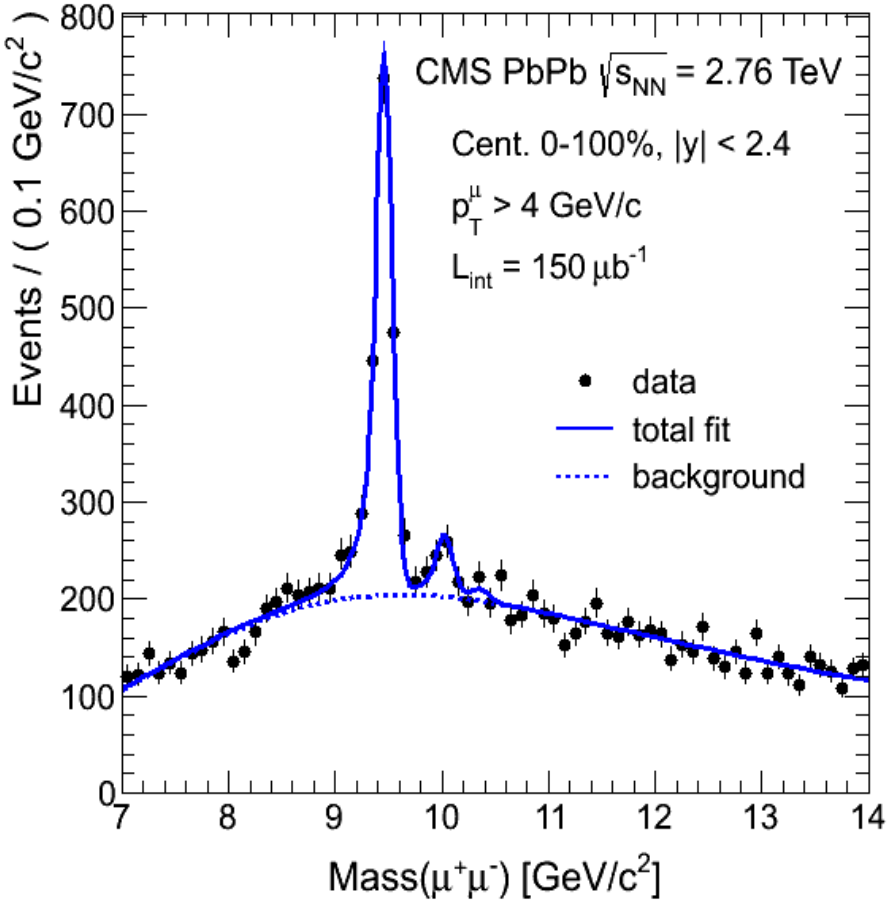
- Beam energy will increase by a factor 2 while luminosity will increase by a factor 10.
- Primary concern for HI is the L1 Calorimeter Trigger.



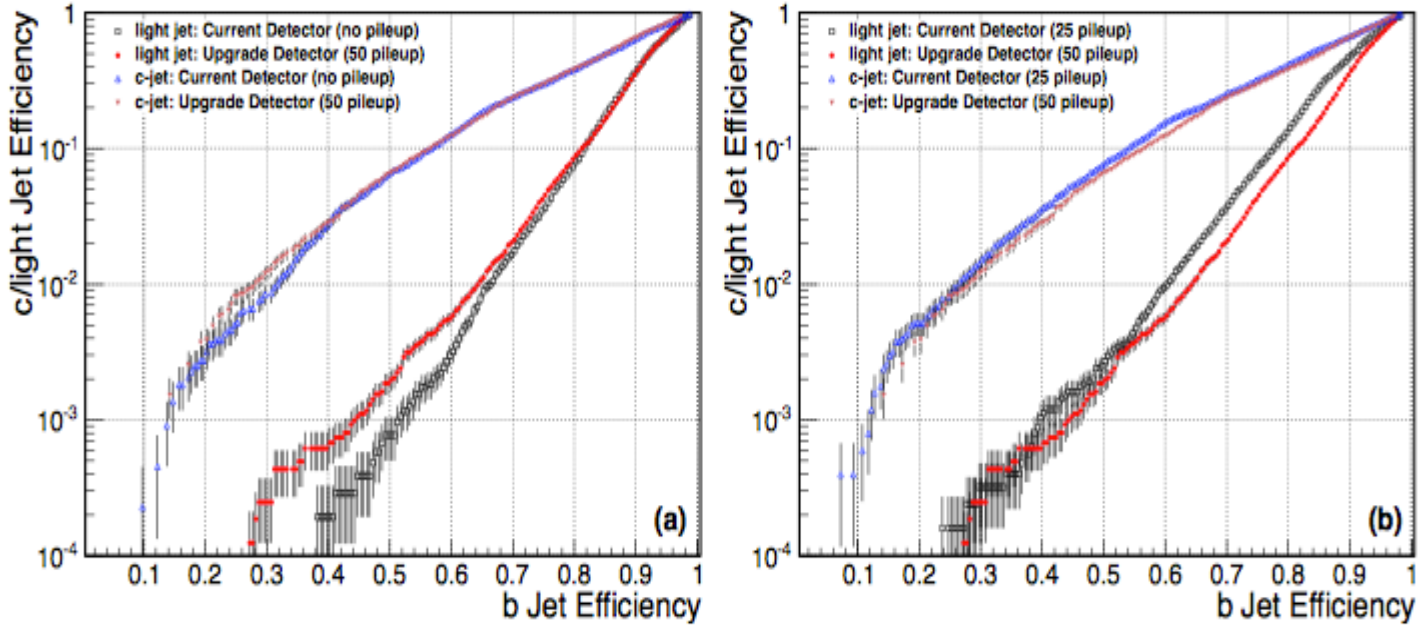

CMS Simulation
R_{32}
0-10% Centrality
$\sqrt{s_{NN}}$ = 5.5 TeV
$\int L\,dt$ = 1.5 nb^{-1}
w/o L1 upgrade
with L1 upgrade
Jet p_T > 100 GeV/c
$(p_{T,1} + p_{T,2})/2$ (GeV/c)
0
0.02
0.04
0.06
0.08
0.1
100
120
140
160
180
200
220
240

Y Excited State Suppression





B-tagging performance 2



Outline

- CMS 101
- Current Findings (CMS HI Current results)
  - Di jet
  - Quarkonium supression
- Schedule (Projections)
- L1 Upgrade plans and performance
  - Basic Goal for L1
  - Rate Plot
- Physics Performance (HL-LHC)
  - Jet Quenching
    - Di-Jets (b-Di Jets)
    - Z Jet
    - Gamma jet
  - Quarkonium Supression
    - Low pt charmonium
- Conclusions/Summary