Heavy Ion Physics in ATLAS and CMS: Hard probes

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For

and

Collaborations

Overview

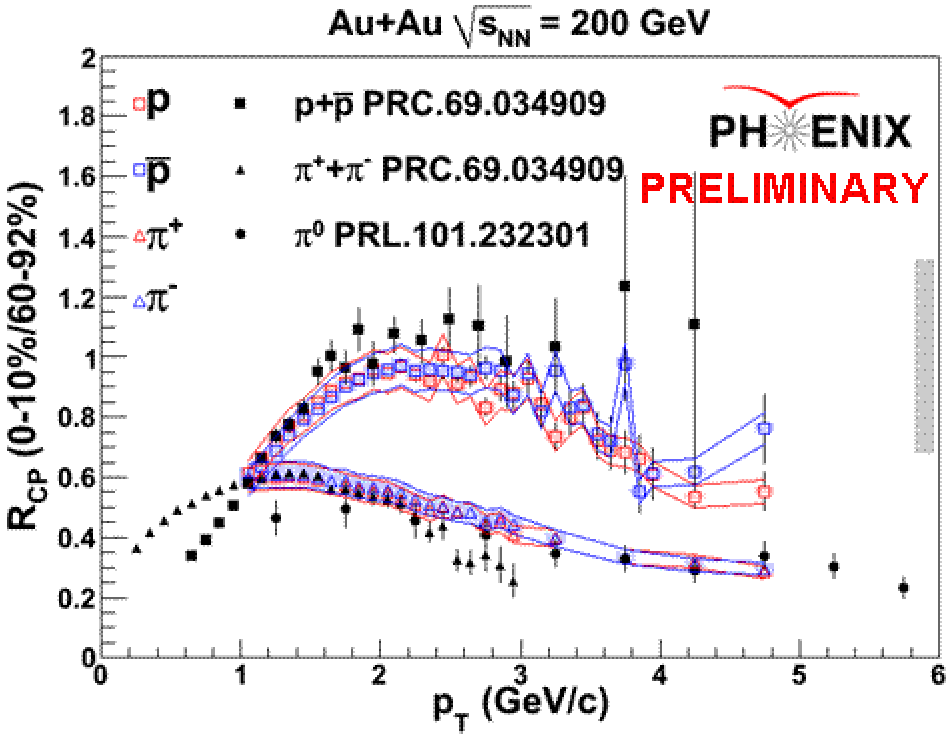
- From RHIC to LHC
- ATLAS and CMS detectors
- QCD matter in the hard sector

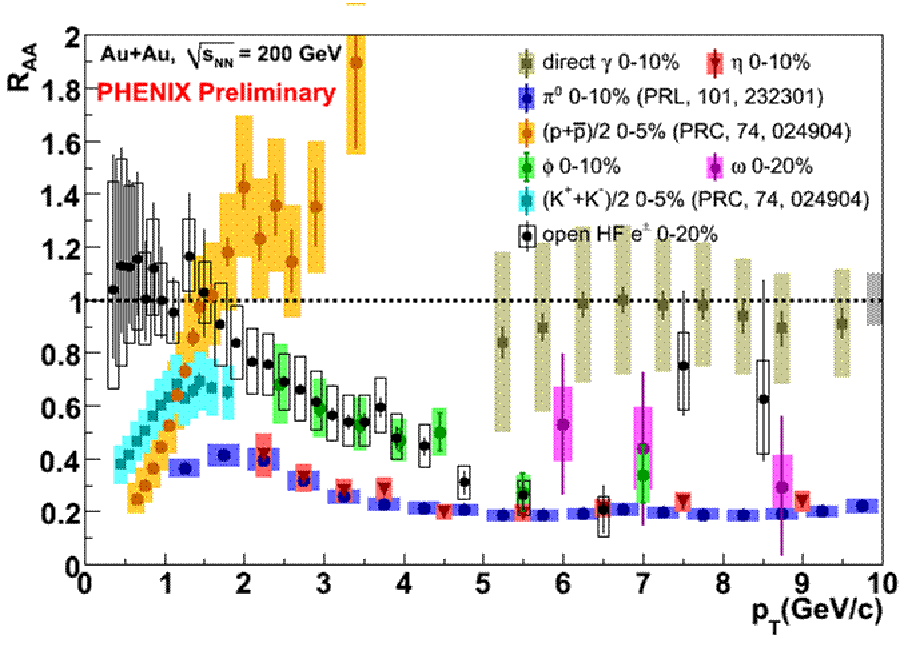
  high-p_T hadrons, jets, photon-jet

  qqbar suppression

- High and low p_T tracking
- Muon reconstruction
- Jet recontruction
- Photon reconstruction

Some evidences from RHIC





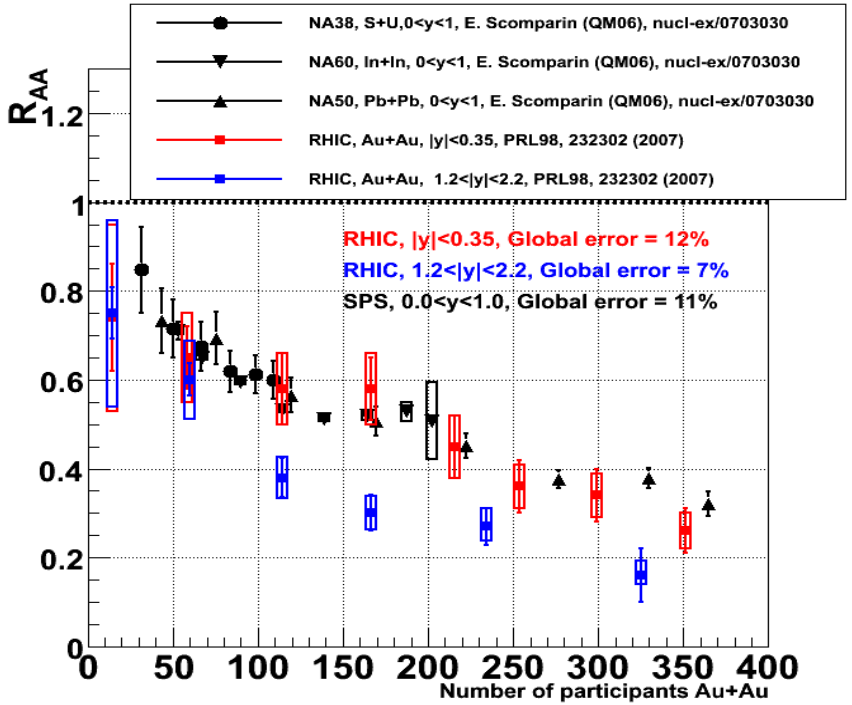
Pions are suppressed

Protons are not suppressed at intermediate p_T

J/ψ : recombination or suppression or ?

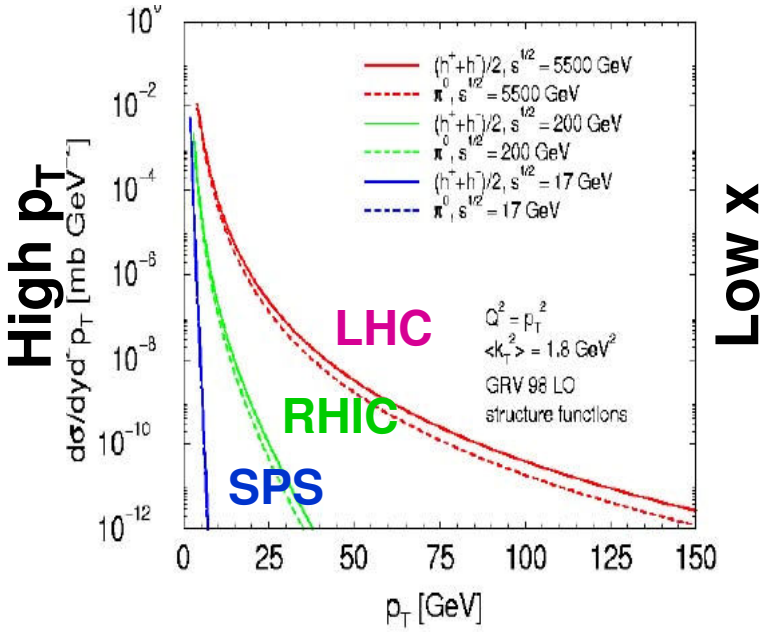
Y: High mass correlated di-electrons, seems, are suppressed (Y?)

First direct measurement of jets

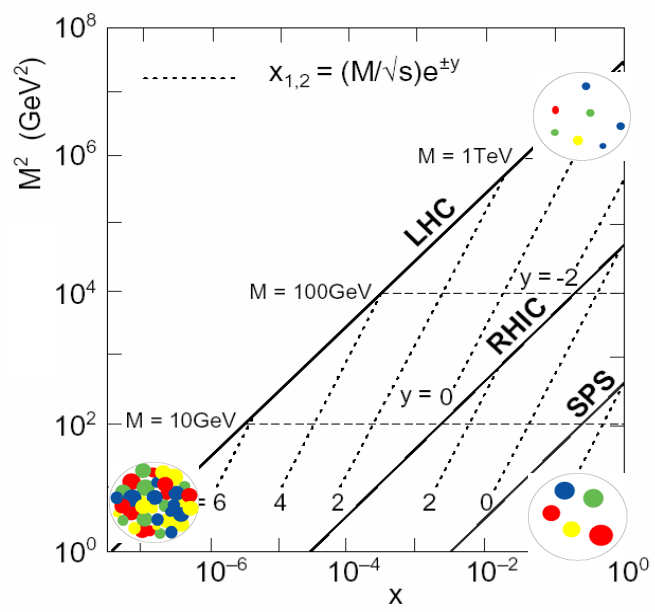


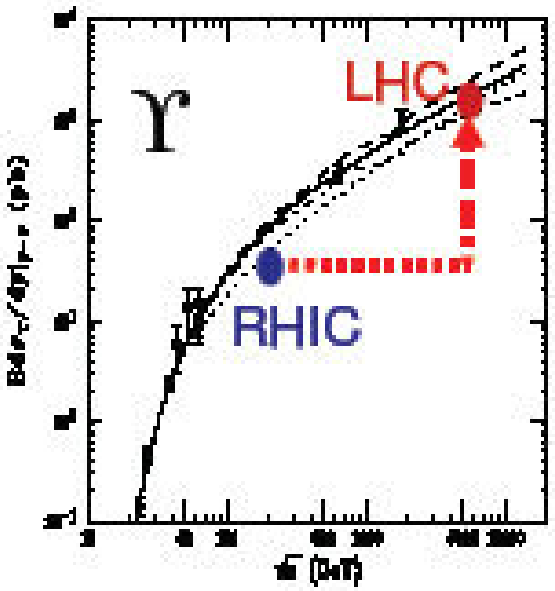
From RHIC (200 GeV/n-n) to LHC (5500 GeV/n-n)

- Initial state fully in the saturated CGC regime
- Initial energy density ~5 times higher
- Lifetime of a quark-gluon plasma much longer
- Large rates of hard probes over a broad kinematical range
- Plenty of heavy quarks (b,c)
- Weakly interacting probes become available (Z^0, $W^{\pm}$)

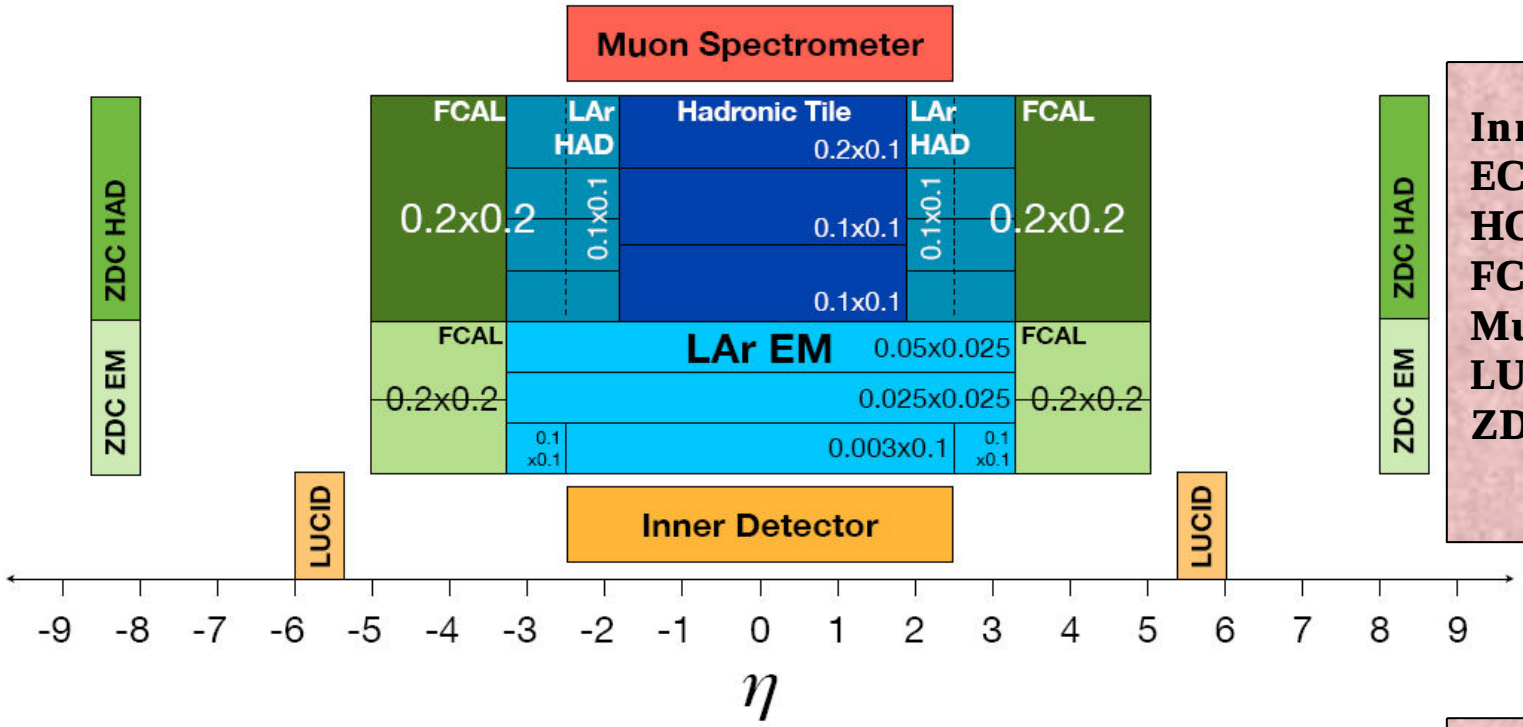


Low x



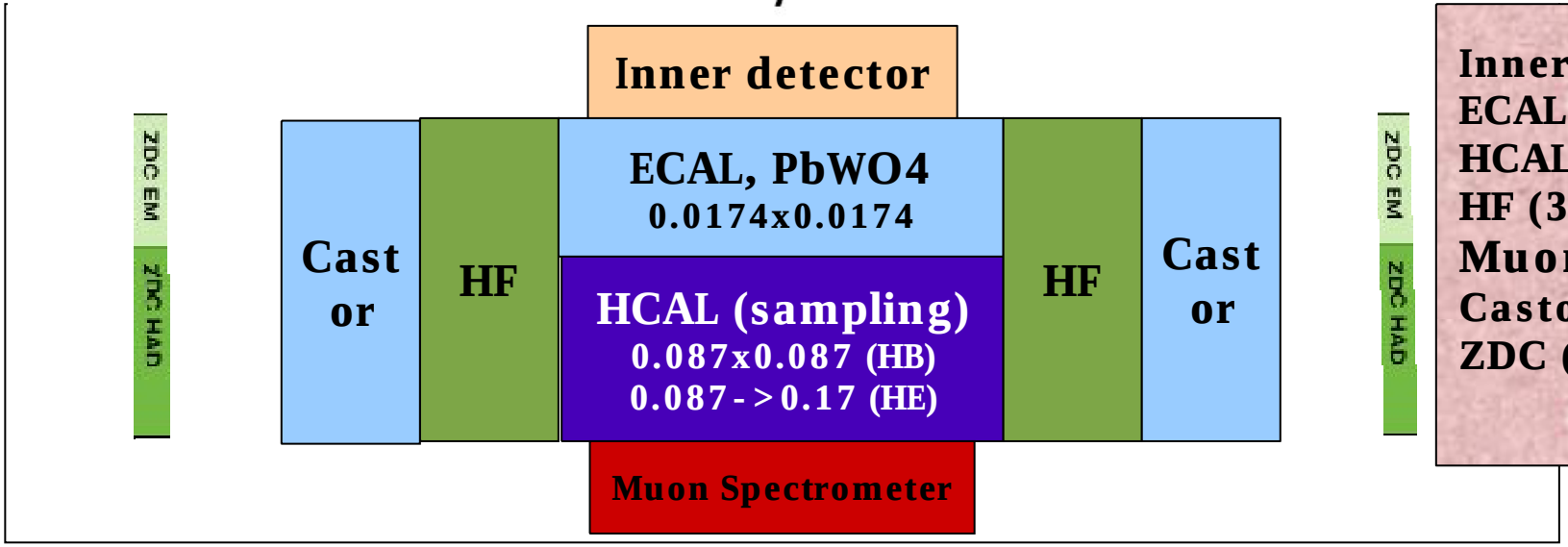


ATLAS and CMS acceptances



ATLAS:

Inner detector (|η|<2.5)
ECAL (|η|<3.2)
HCAL (|η|<3.2)
FCAL (3.2<|η|<5)
Muon (|η|<2.7)
LUCID (5.5<|η|<6)
ZDC (|η|>8)



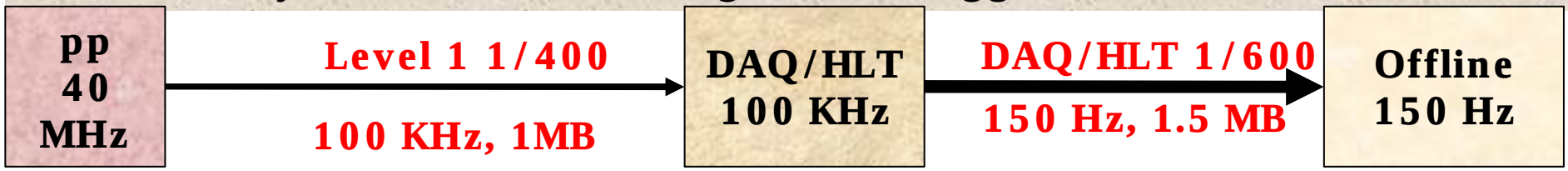
CMS:

Inner detector (|η|<2.5)
ECAL (|η|<3)
HCAL (|η|<3)
HF (3<|η|<5)
Muon (|η|<2.4)
Castor (5<|η|<6.7)
ZDC (|η|>8)

Different technologies but close acceptances – possibility to cross-check.

Hard probes triggering for HI in CMS

CMS trigger system is designed for luminosity 10^{34} (pp events) with 40 MHz bunch crossing frequency.
Two levels system: Level 1 and High Level Trigger

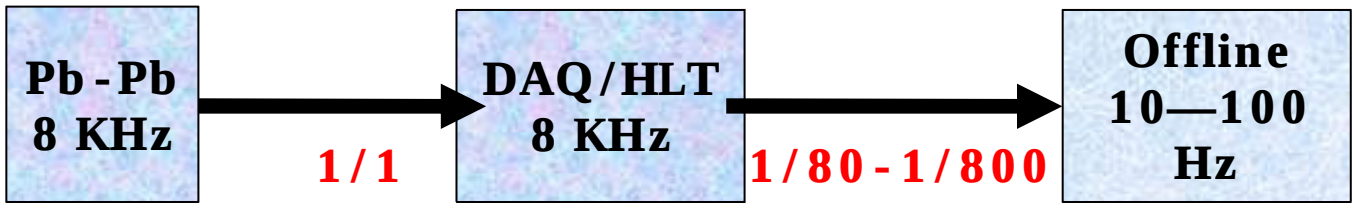


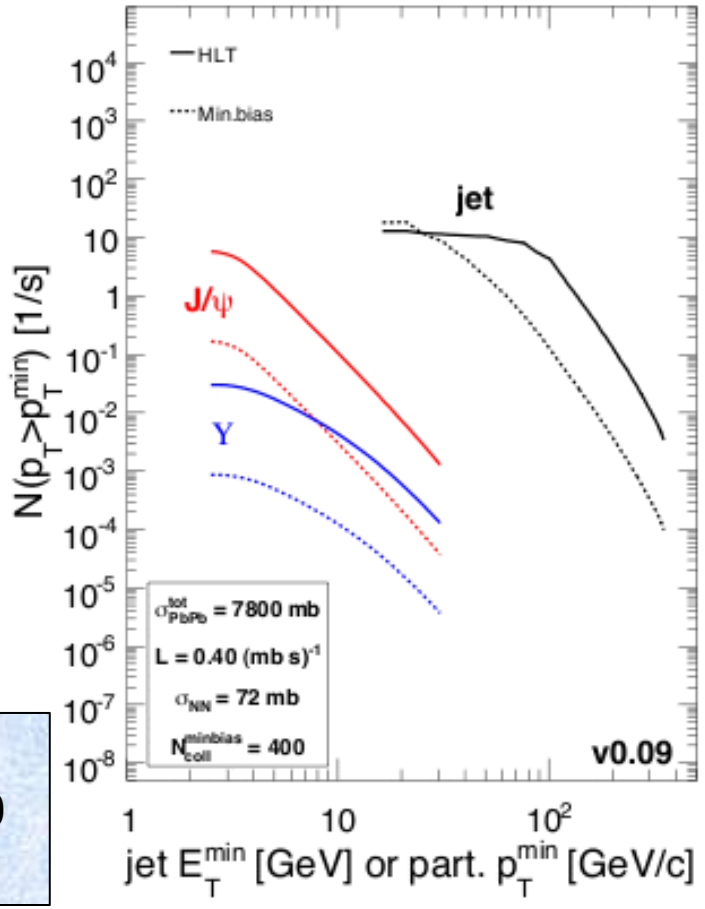
PbPb:

Luminosity($cm^{-2}s^{-1}$): 10^{27}
(factor 10^5-10^7 lower relative to pp)

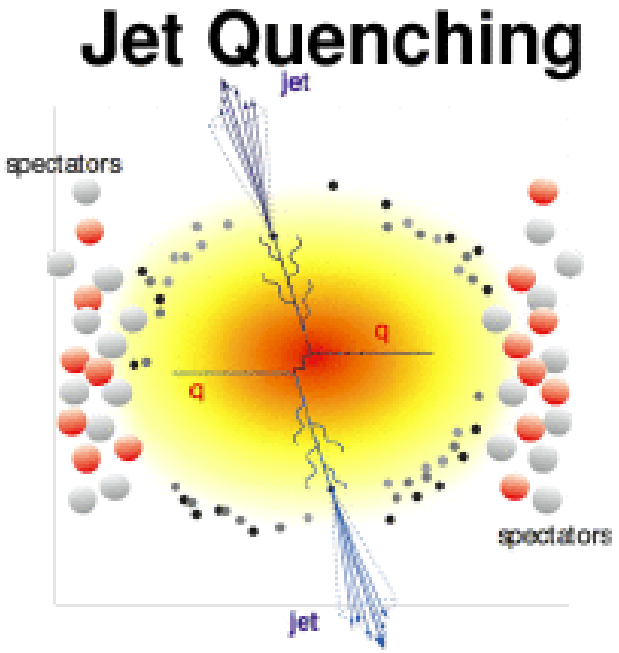
Bunch crossing rate (KHz): 8
(factor 12.5 relative to pp)

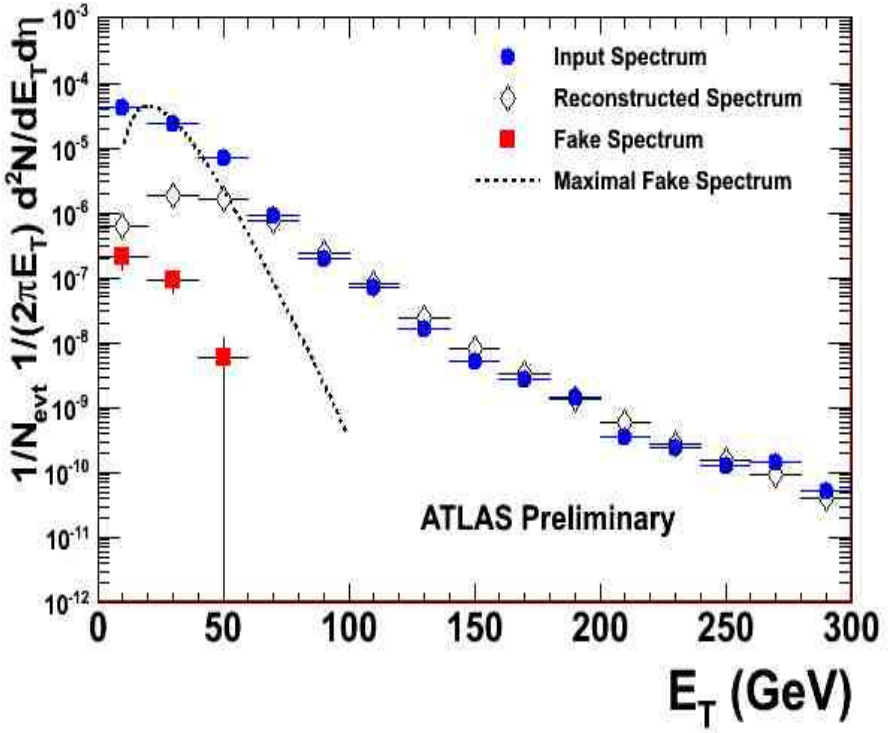
Event size after L1(MB):
2.5 (Minbias)
10 (Central)





Jet measurements

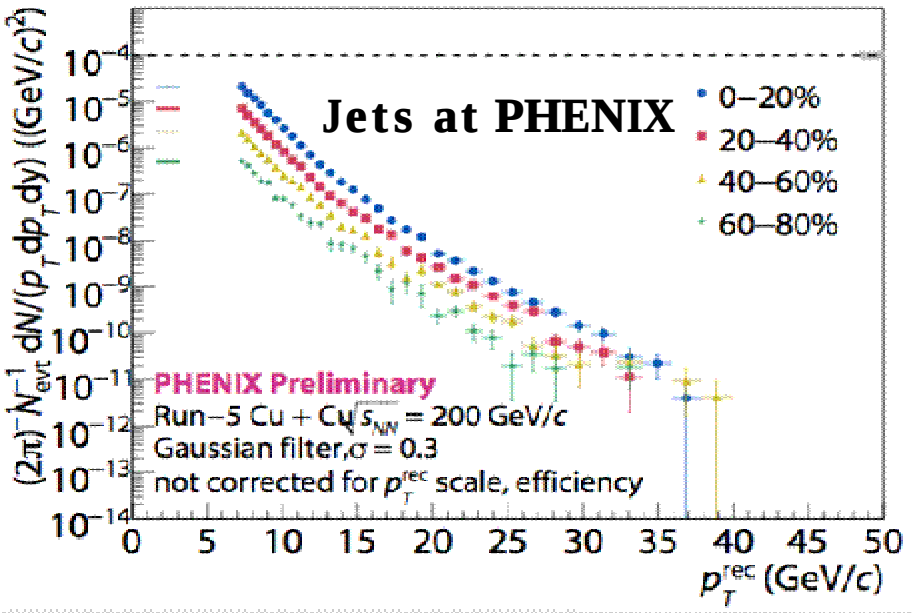




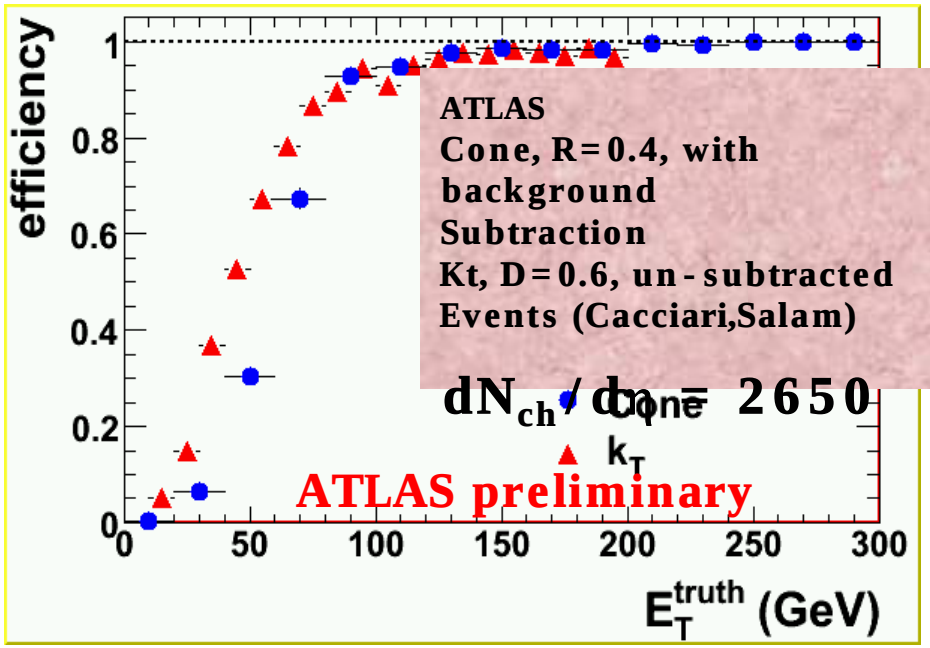
At RHIC mostly leading particle measurements

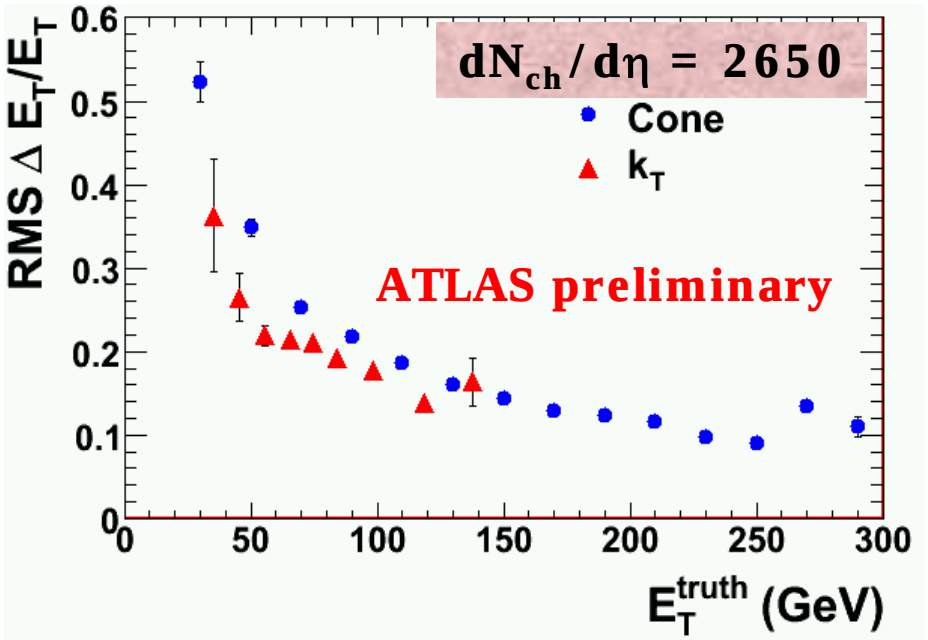
At LHC jets will be the ideal probe to study medium induced energy Loss effects in wide parton energy interval:

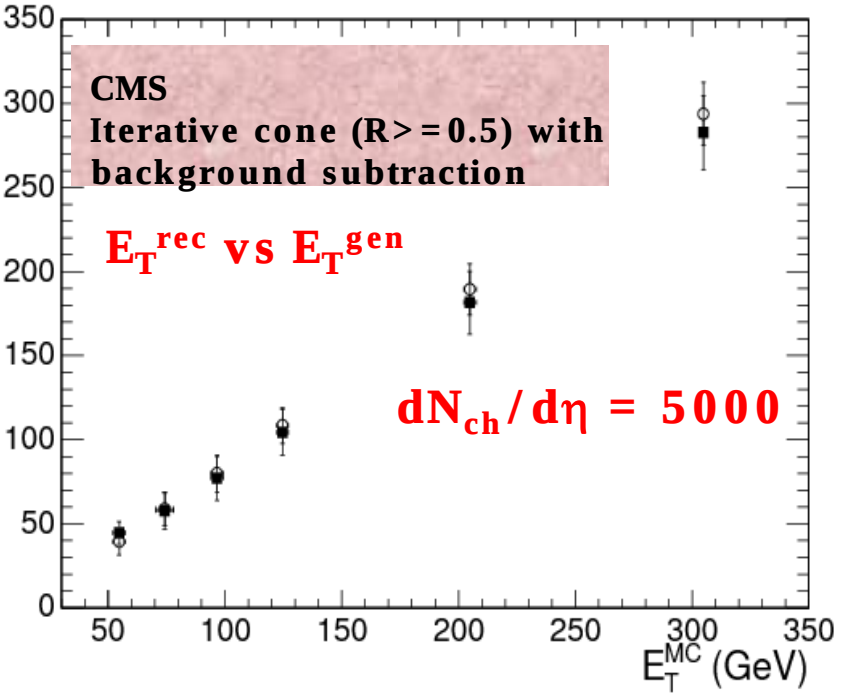
- **Dijets**
- **tagged jets**
- **jet shape**
- **….**

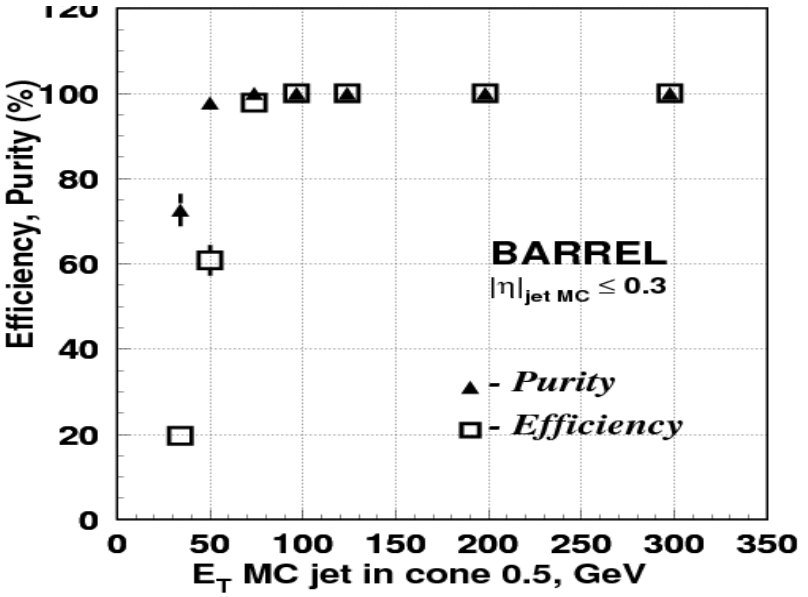


Jet finders in ATLAS and CMS for HI







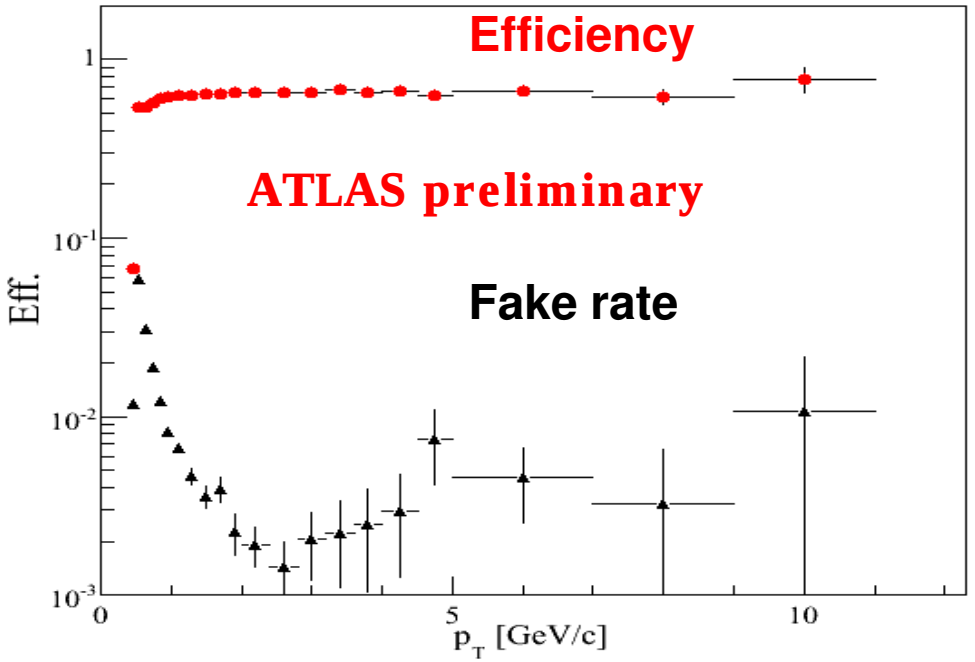


High-p_T tracking in ATLAS and CMS

ATLAS without TRT

3 pixel layers and 4 double-sided strip layers

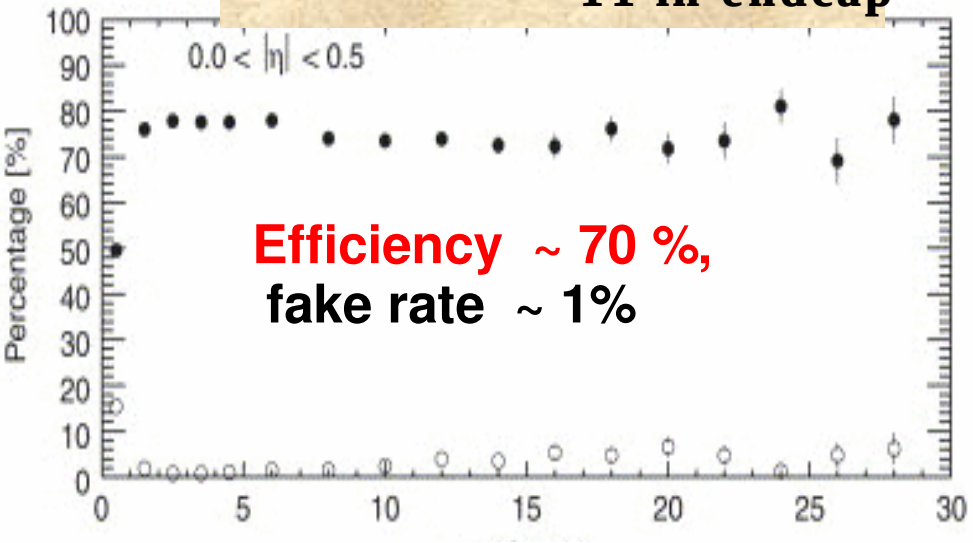
Pb+Pb 5500 GeV/A, b=2.3 fm, $|\eta|<1$

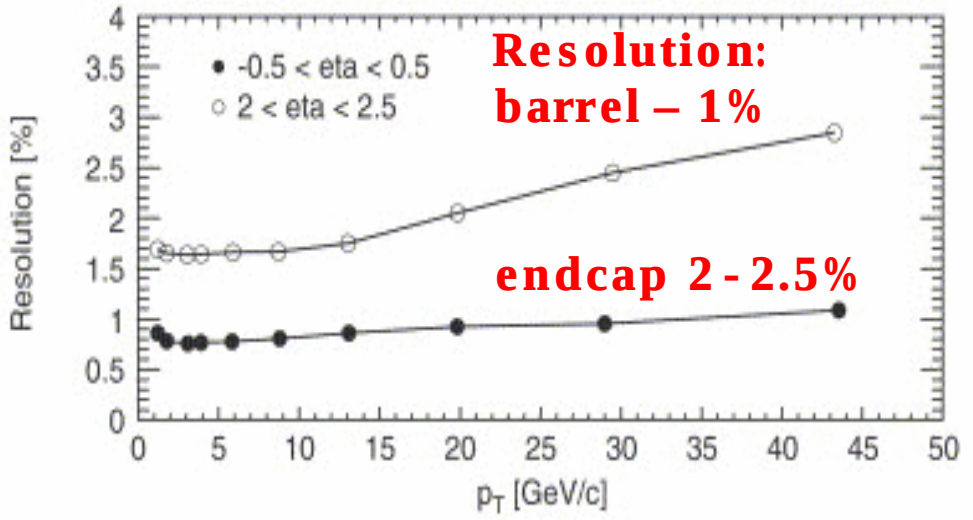


For p_T: 1 - 10 GeV/c:
efficiency ~ 70 %, fake rate < 1%
Momentum resolution ~ 3% (2% - barrel, 4-5% end-caps)

CMS full tracker

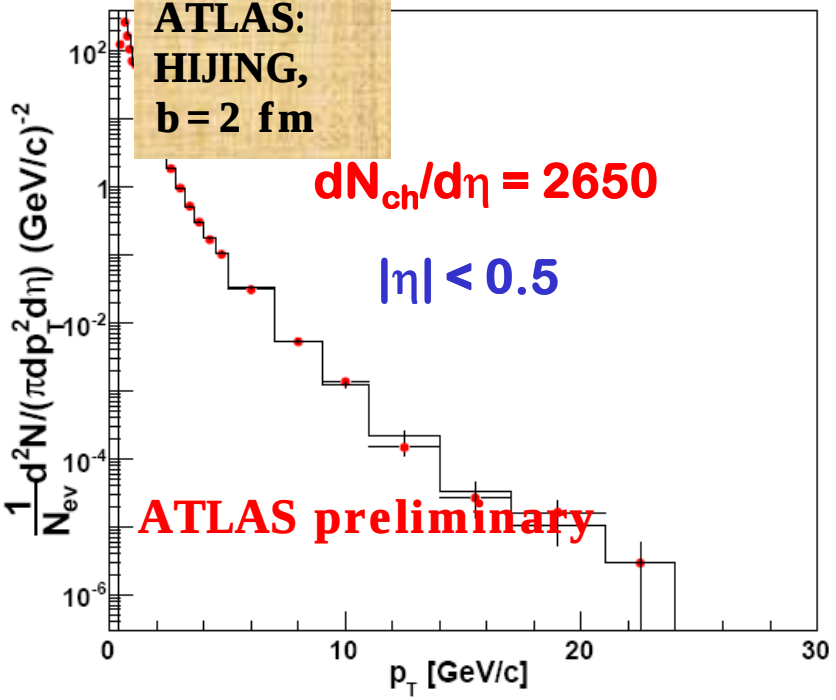
3 pixel layers in barrel, 2 pixel layers in endcap
Silicon layers: 10 in barrel, 11 in endcap



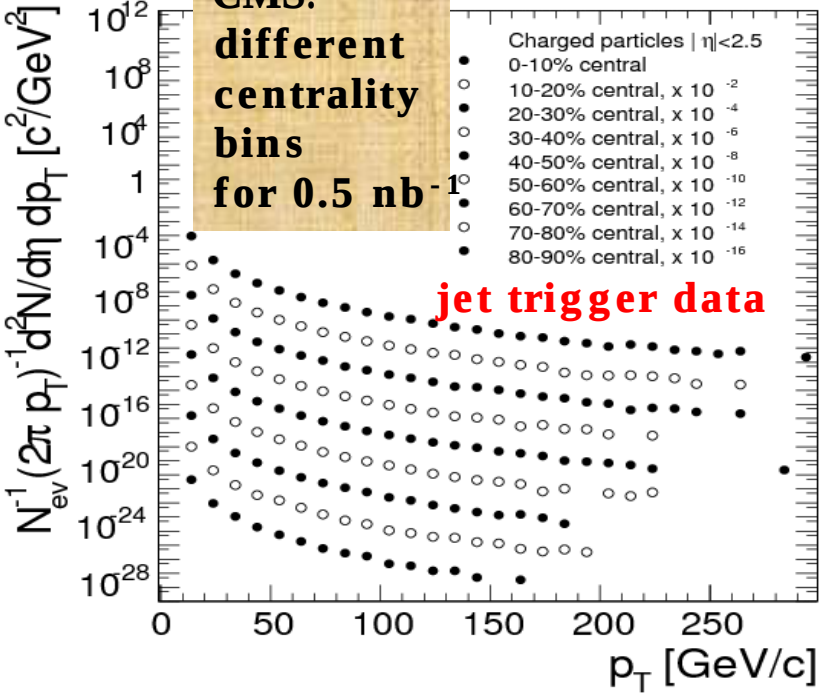


High-p_T hadron spectra (ATLAS and CMS)

ATLAS: HIJING, b = 2 fm

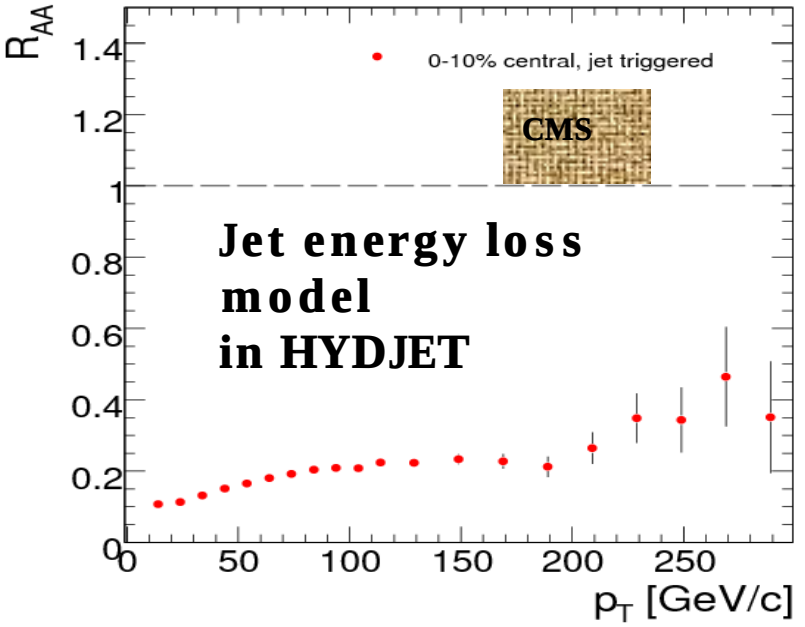


CMS: different centrality bins for 0.5 nb^{-1}

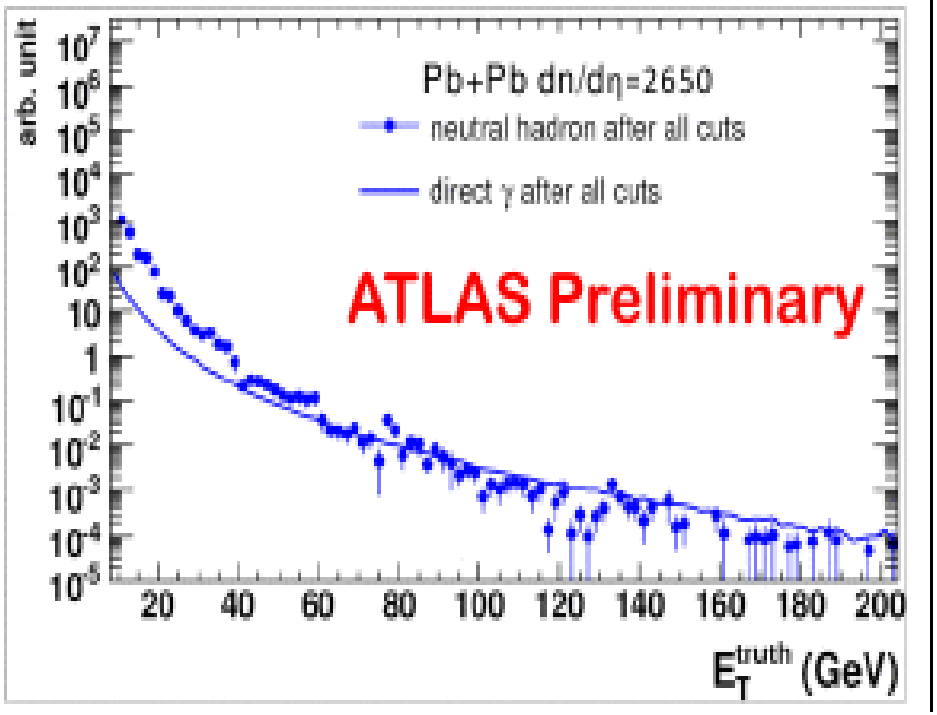


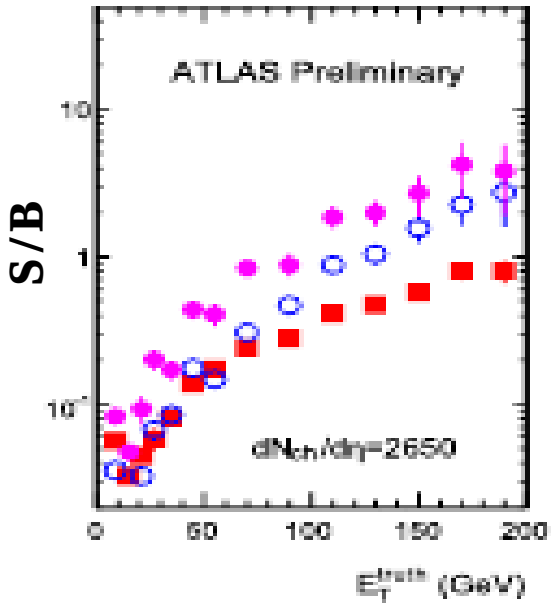
$$R_{AA} = \frac{\sigma_{pp}^{\text{inel}}}{\langle N_{\text{coll}} \rangle} \frac{d^2 N_{AA}/dp_T d\eta}{d^2 \sigma_{pp}/dp_T d\eta}$$

Nuclear modification function reach for 0.5 nb^{-1}



Photons (ATLAS)



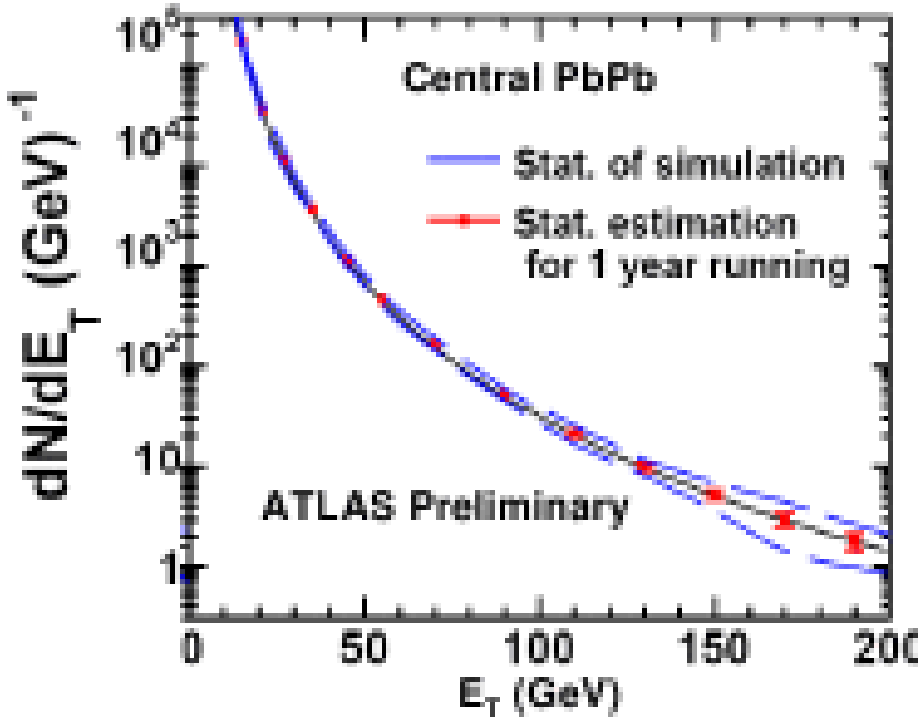


Combined cuts
Isolation cuts
Loose shower
Shape cuts

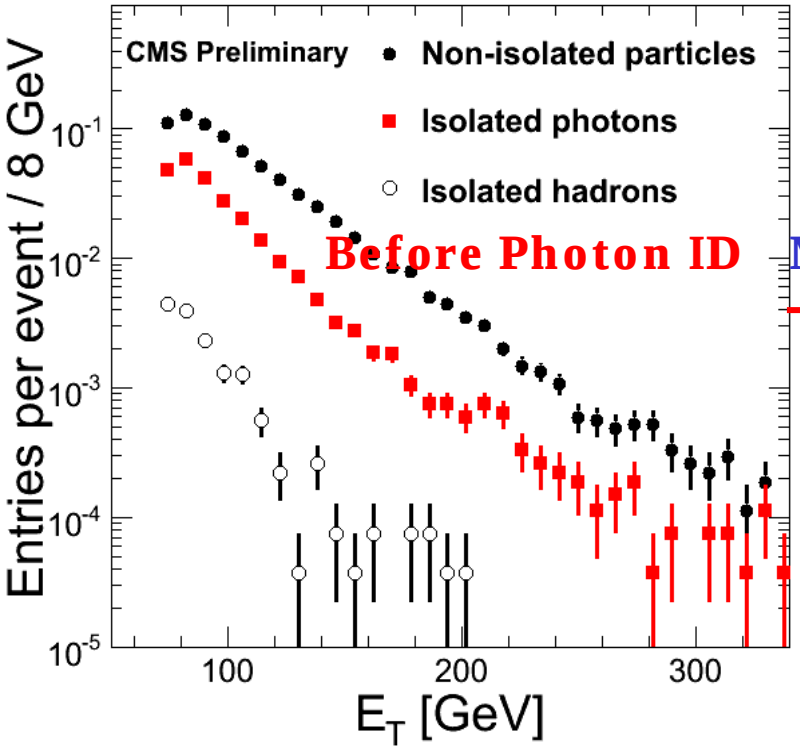
Background: neutral hadrons after cuts

Signal: direct γ after cuts

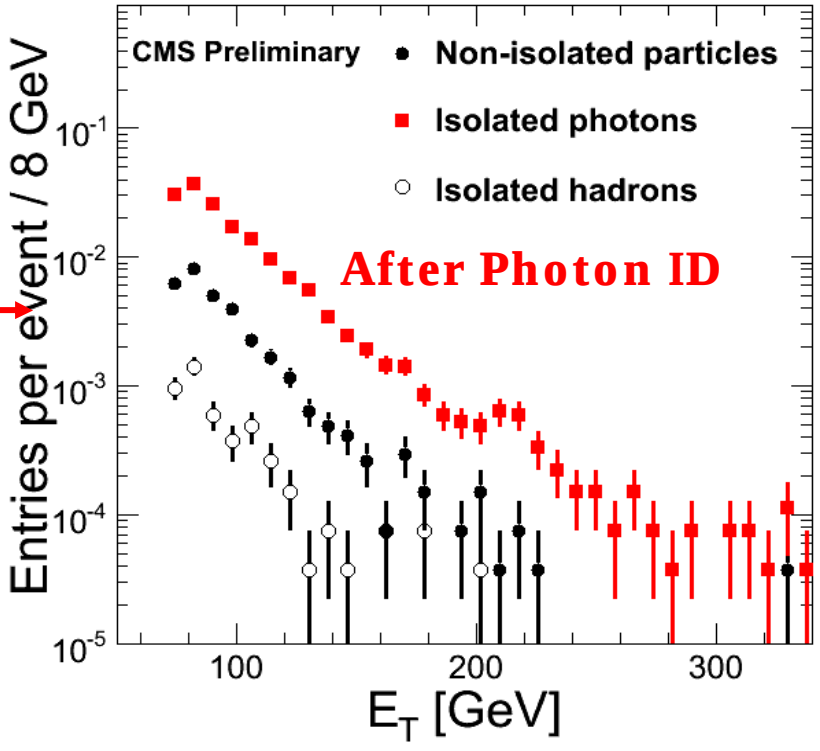
Background is suppressed with Isolation cuts



Photon reconstruction (CMS)



Multivariate analysis

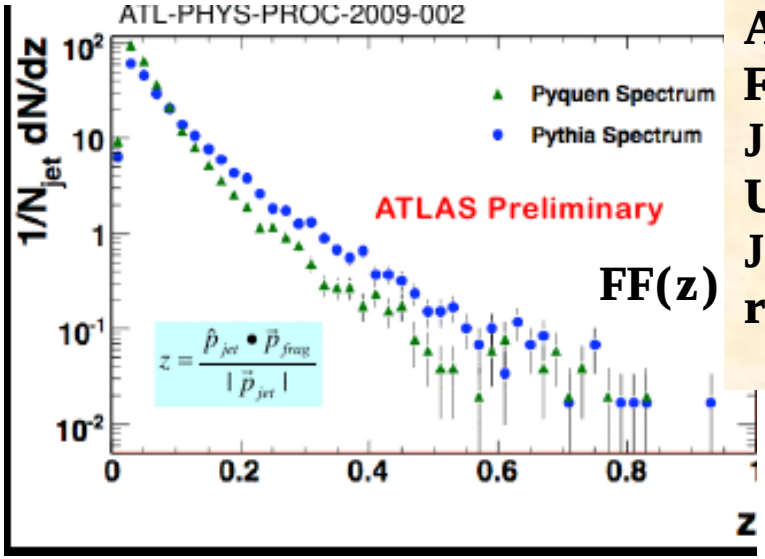


Photon reconstruction with Island Algorithm
Photon ID using Multi-Variate Analysis with 21 variables grouped into 3 sets:
ECAL cluster shape
and ECAL/HCAL/Tracker isolation cuts

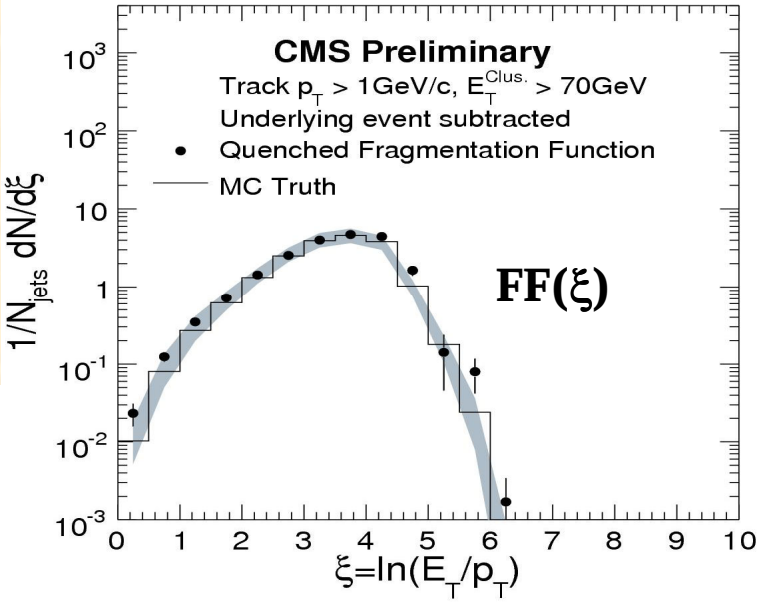
Performance:

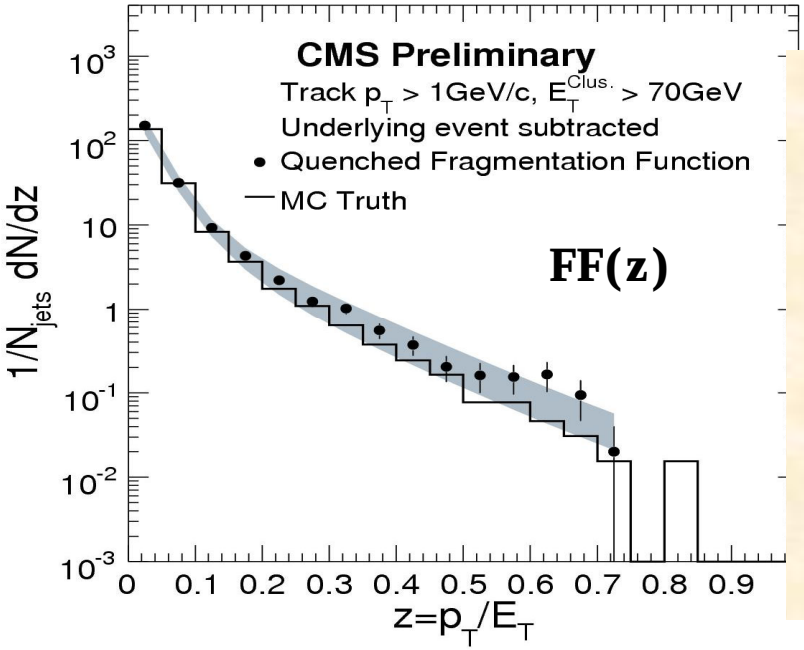
Efficiency = 60%
Fake = 3.5%
S/B=4.5

Fragmentation function measurements (ATLAS and CMS)

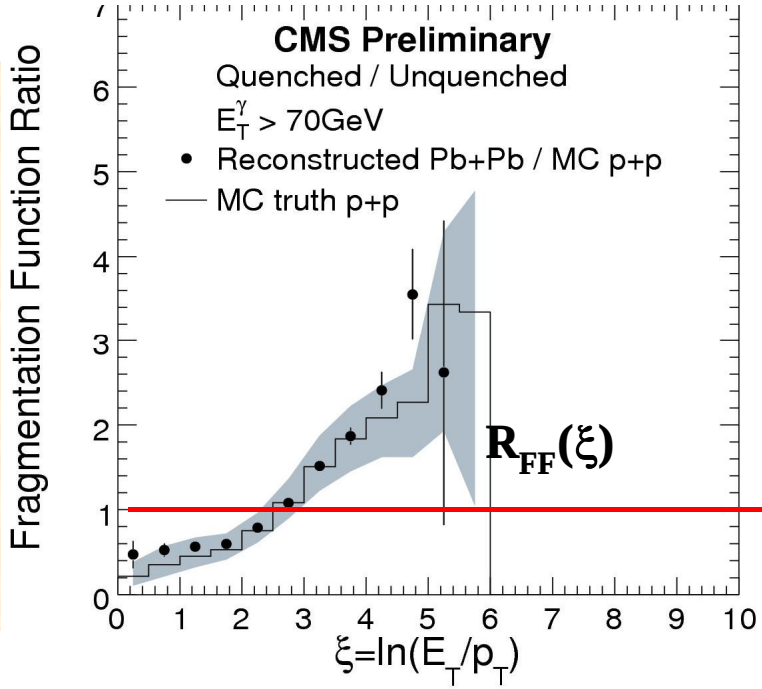


ATLAS:
Function relative to Jet parameters, Uncorrected for Jet position and resolution





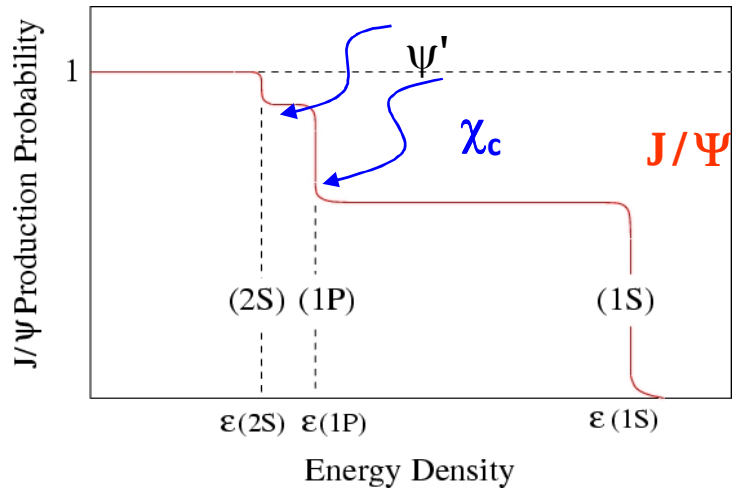
CMS:
γ+jet events are used
UE background subtracted using R=0.5 cone transverse to jet direction
Functions relative to photon energy



Dissociation of quarkonia: hot QCD thermometer

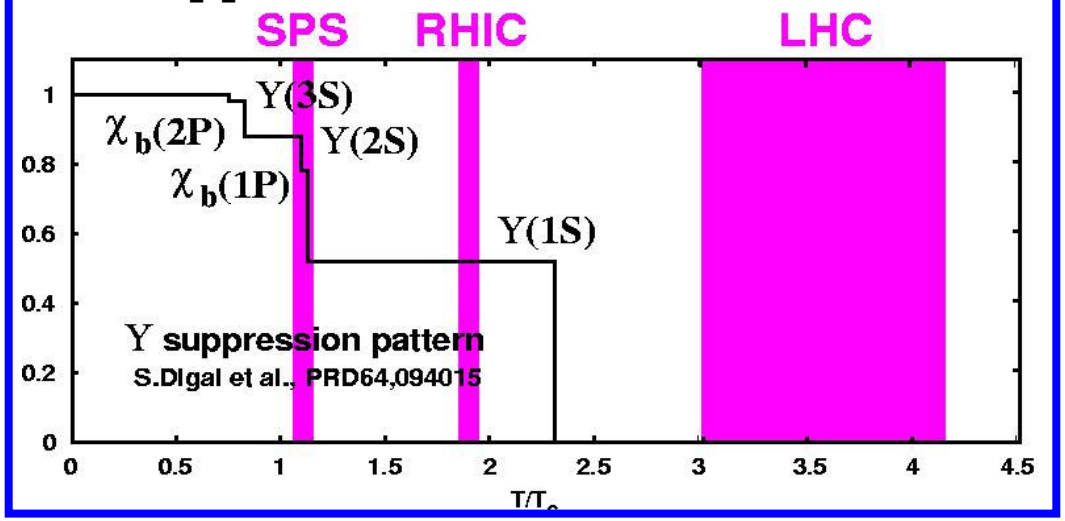
- Suppression: RHIC comparable to SPS
- Regeneration compensate screening
- J/Ψ not screened at RHIC ($T_D \sim 2T_c$)
- LHC: recombination or suppression

Suppression of C'onium states



- Υ Large Cross-section: 20 RHIC
- Υ melts only at LHC: $T_D \sim 4\ T_C$
- Less amount of bb(bar) pairs: less regeneration
- Much cleaner probe than J/Ψ

Suppression of B'onium states



- Quarkonia: J/ψ (BR:5.9%), Υ (BR:2.5%)
- Background: combinatorial due- to decays from π/K, b-,c-production

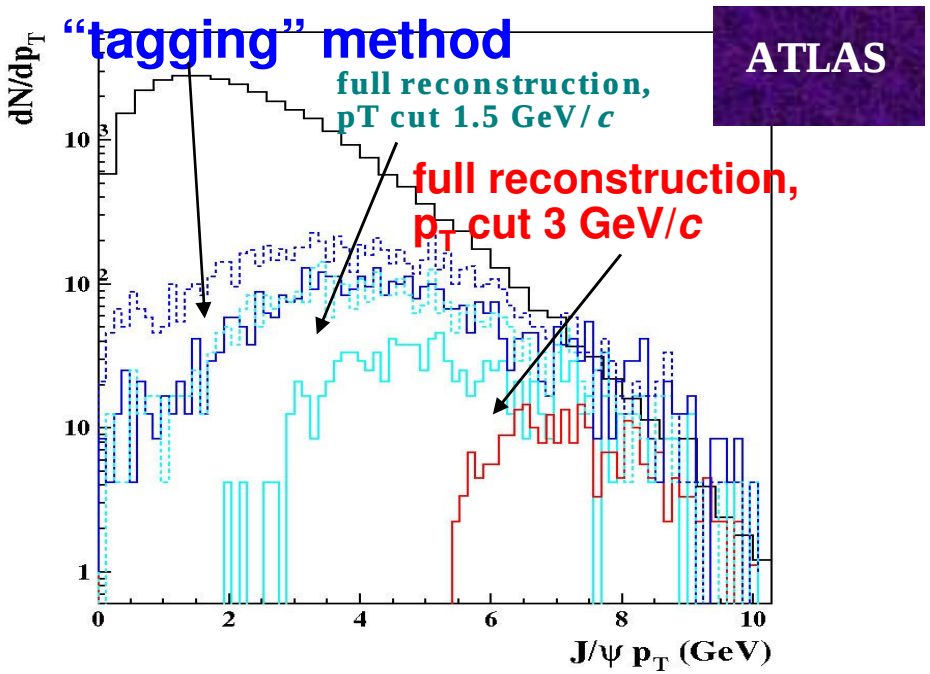
J/ψ measurements (ATLAS and CMS)

ATLAS

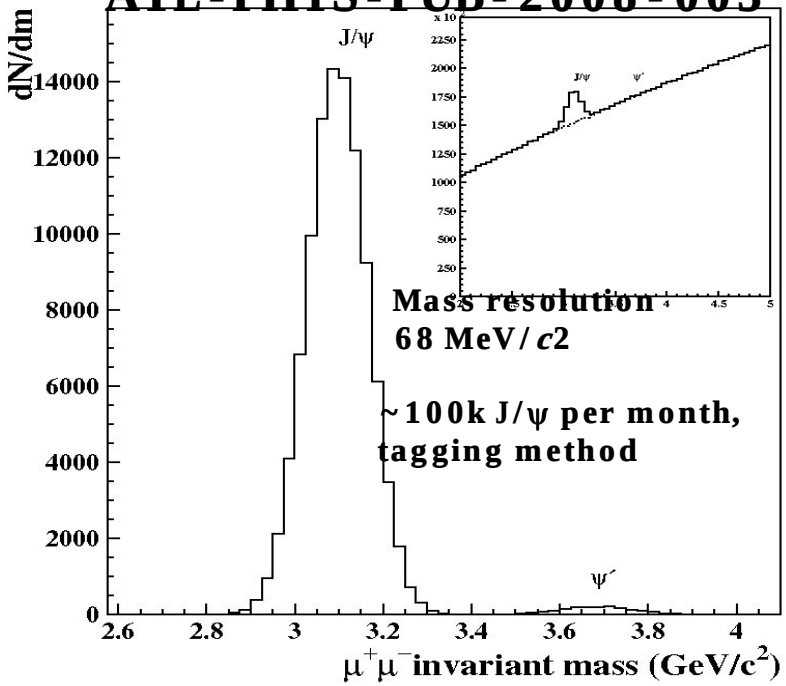
"tagging" method

full reconstruction, pT cut 1.5 GeV/*c*

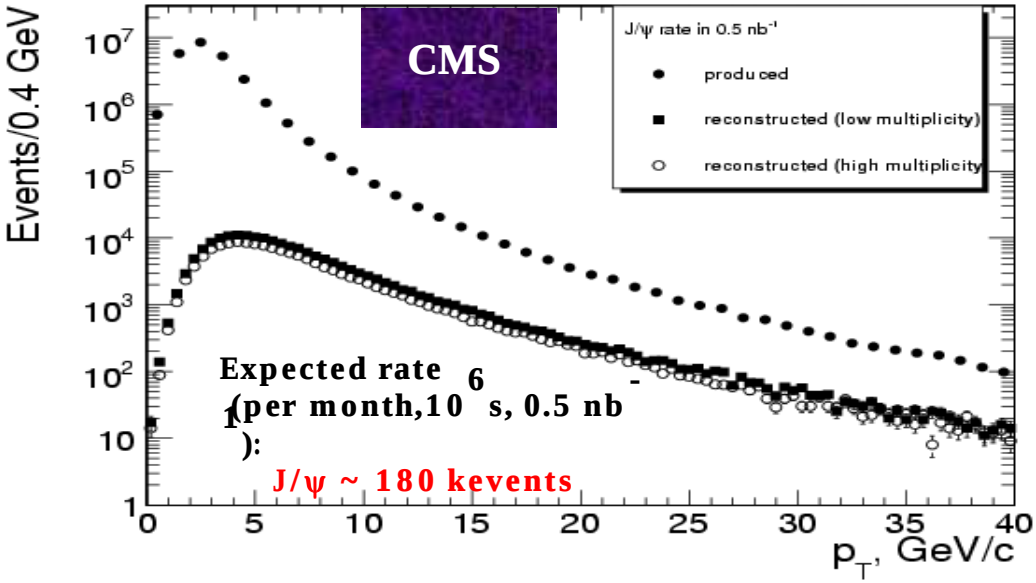
full reconstruction, p_T cut 3 GeV/*c*

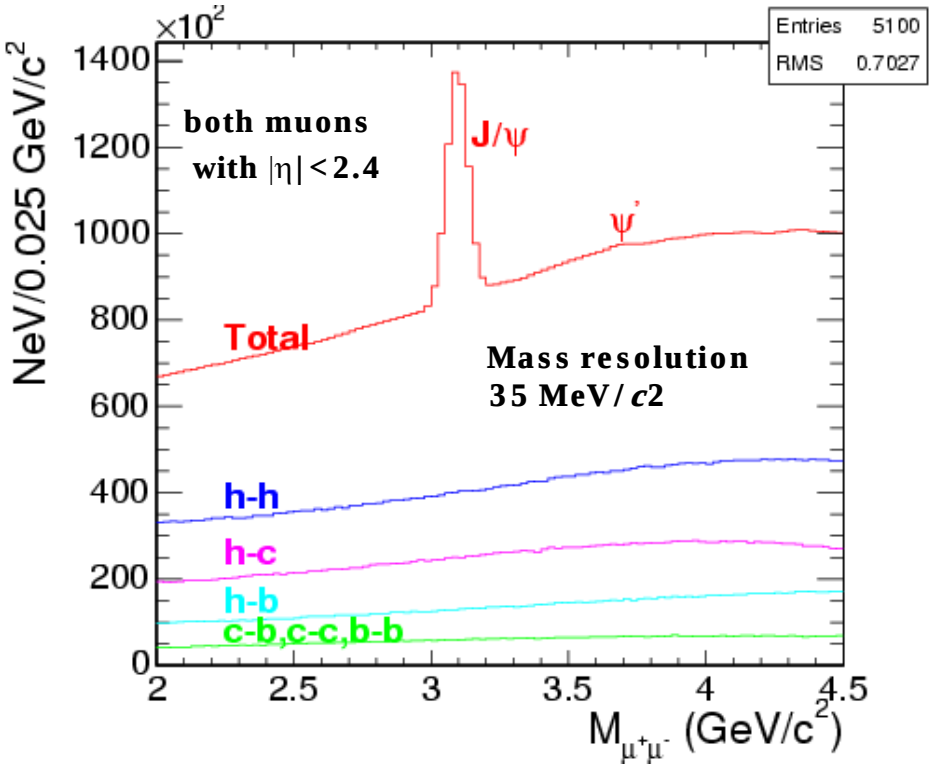


ATL-PHYS-PUB-2008-003

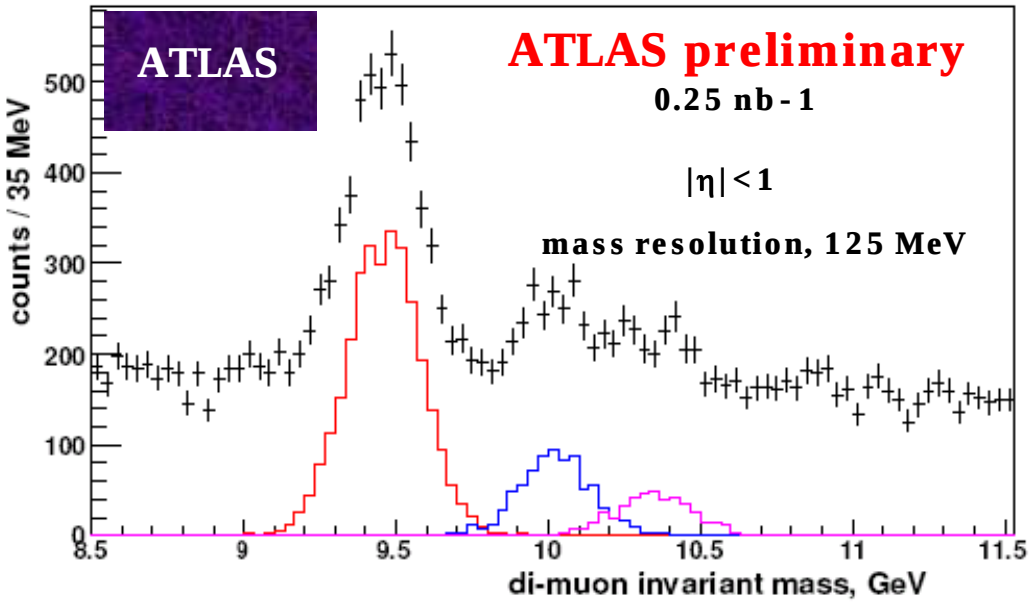


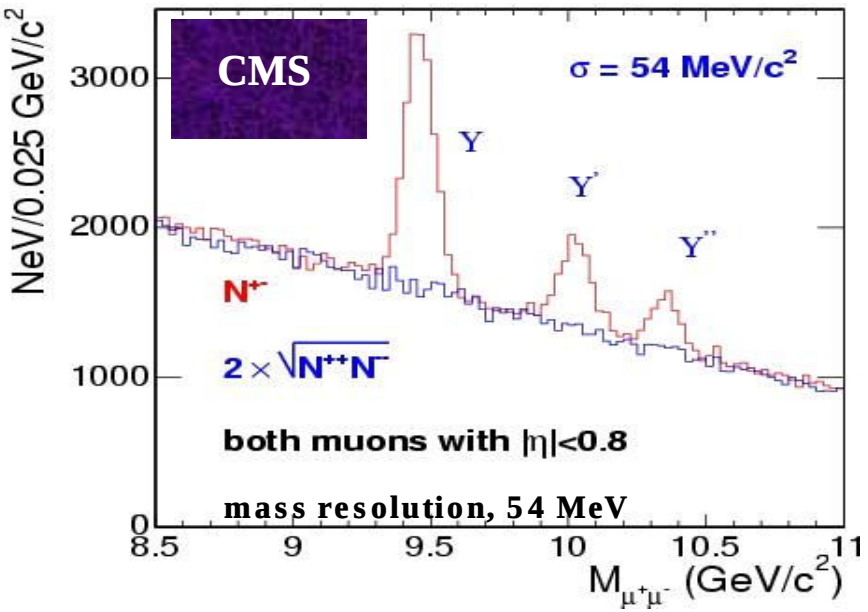
CMS

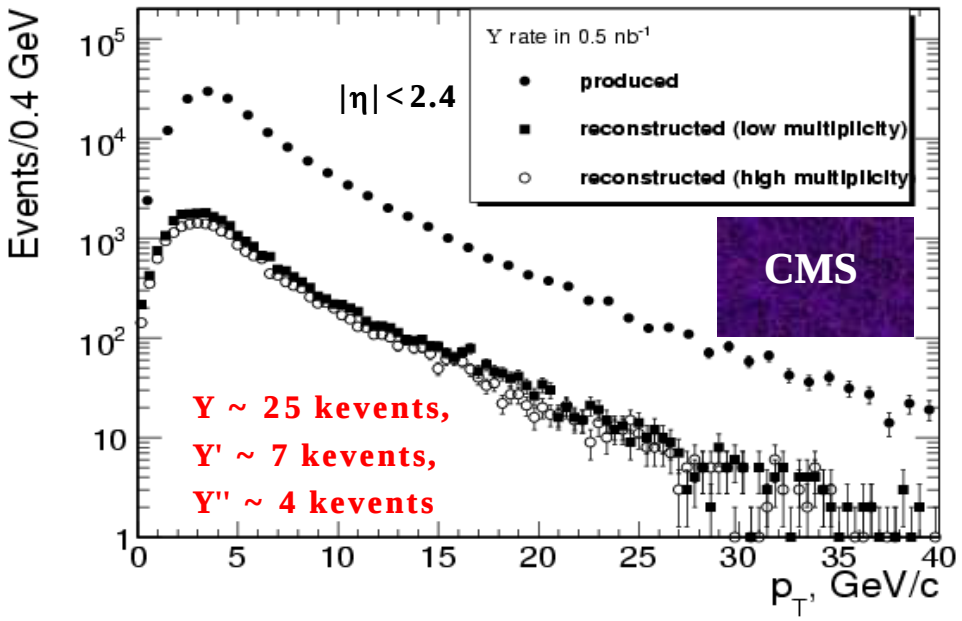


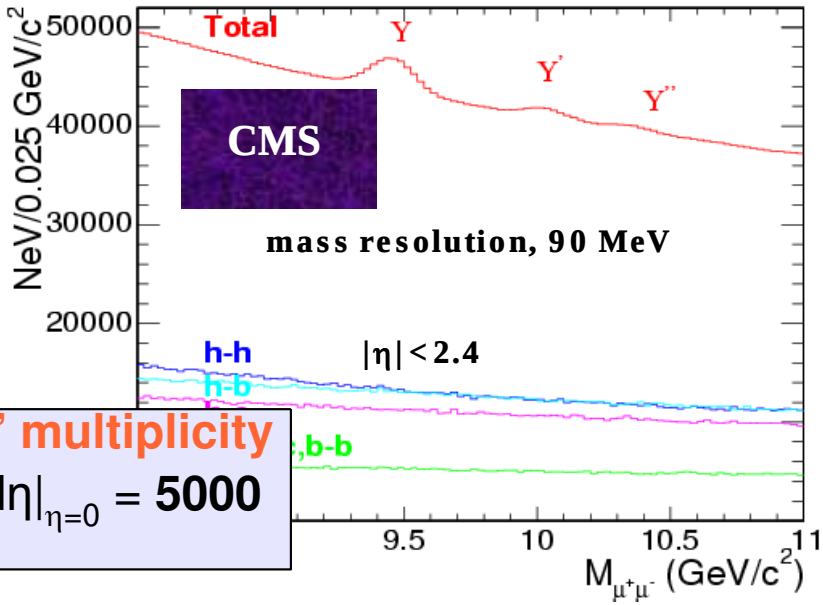


Upsilon measurements (ATLAS and CMS)









"high" multiplicity

$dN_{ch}/d\eta|_{\eta=0}$ = 5000

Summary

The excellent capabilities of ATLAS and CMS give the unique possibility of measuring hard probes of the dense medium state:

- **hard spectra of charged particles**
- **photons**
- **Jets**
- **Quarkonia**

The close p_T-eta acceptance of ATLAS and CMS detectors allows to cross-check measurements done with different technologies.

Heavy Ion Physics program at LHC starts with the FIRST pp data

Beam Parameters

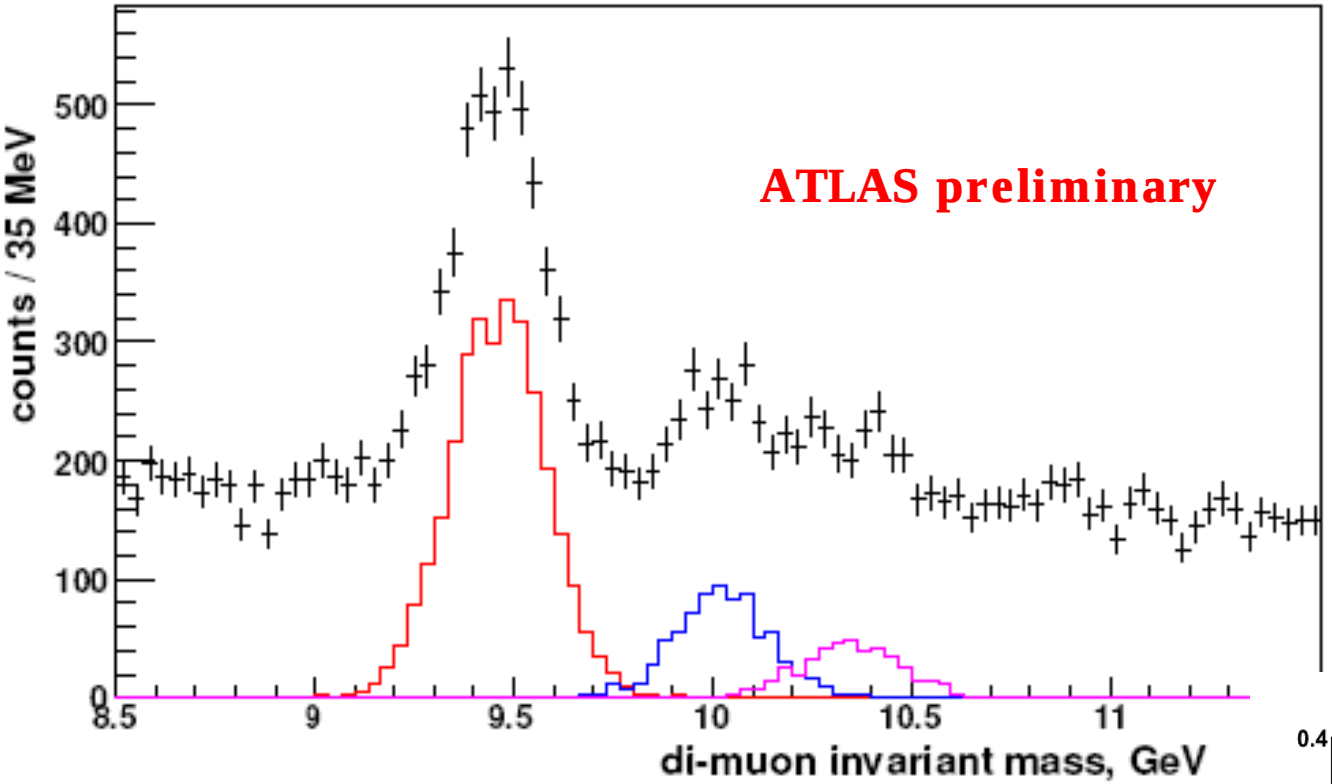
2010

Parameter	Units	Early Beam	Nominal
Energy per nucleon	TeV	2.0 ?	2.76
Initial ion-ion Luminosity L_0	$cm^{-2}\ s^{-1}$	$\sim 5 \times 10^{25}$	1×10^{27}
No. bunches, k_b		62	592
Minimum bunch spacing	ns	1350	99.8
β^*	m	1.0	0.5 /0.55
Number of Pb ions/bunch		**7×10^7**	**7×10^7**
Transv. norm. RMS emittance	μm	1.5	1.5
Longitudinal emittance	eV s/charge	2.5	2.5
Luminosity half-life (1,2,3 expts.)	h	14, 7.5, 5.5	8, 4.5, 3

- **Early beam: fewer bunches, lower energy, higher β***
- **Nominal beam: more bunches, higher energy, lower β***

Backup slides

Upsilon measurements (ATLAS)

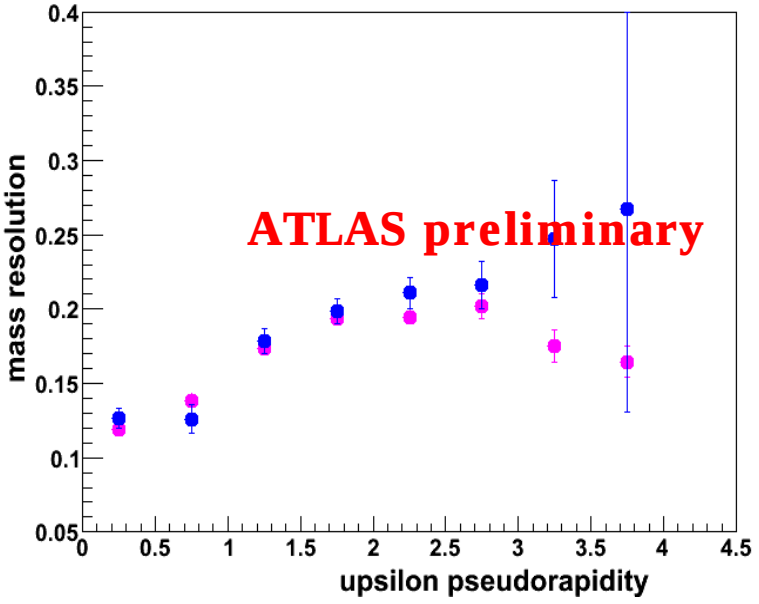


Υ, Υ', Υ'' in estimated background for 0.25 nb^{-1} integrated luminosity.

Barrel region only, $|\eta|<1$.

- Signal and background (without quenching!)
- For barrel muon spectrometers (e.g.)
  - Average mass resolution, 125 MeV

    15 k total Υ, Υ', Υ'' for 0.25 nb^{-1}.

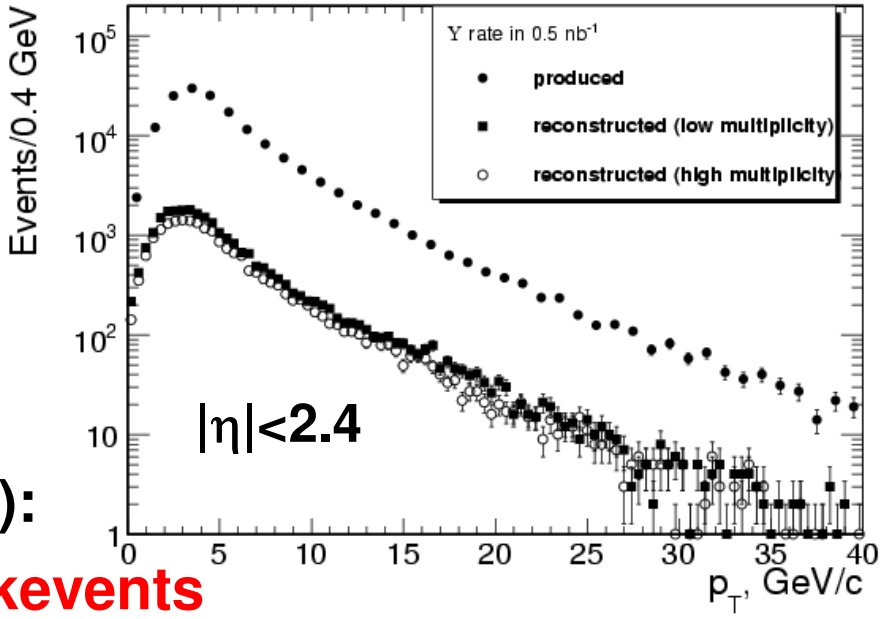


Upsilon measurements (CMS)

Excellent mass resolution:

σ_Υ = 54 MeV/c^2 $|\eta|<0.8$,

σ_Υ = 90 MeV/c^2 $|\eta|<2.4$

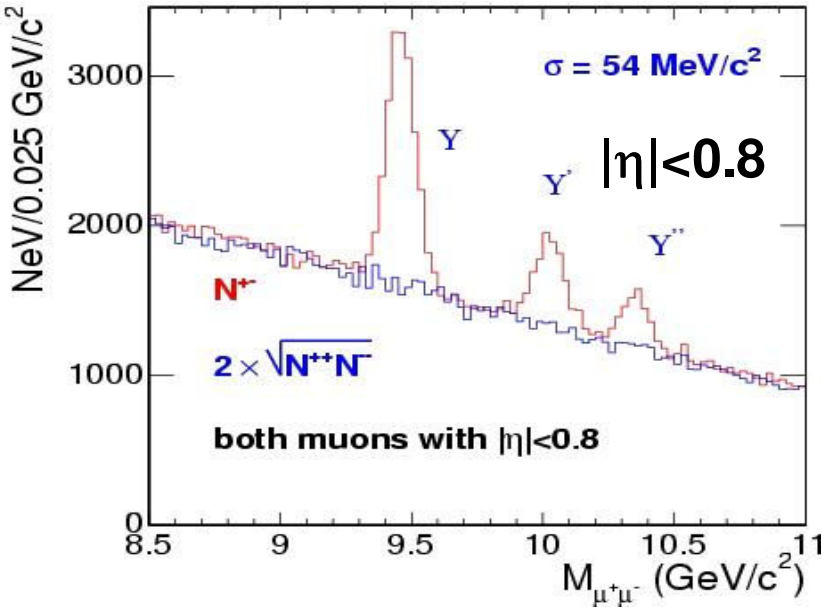


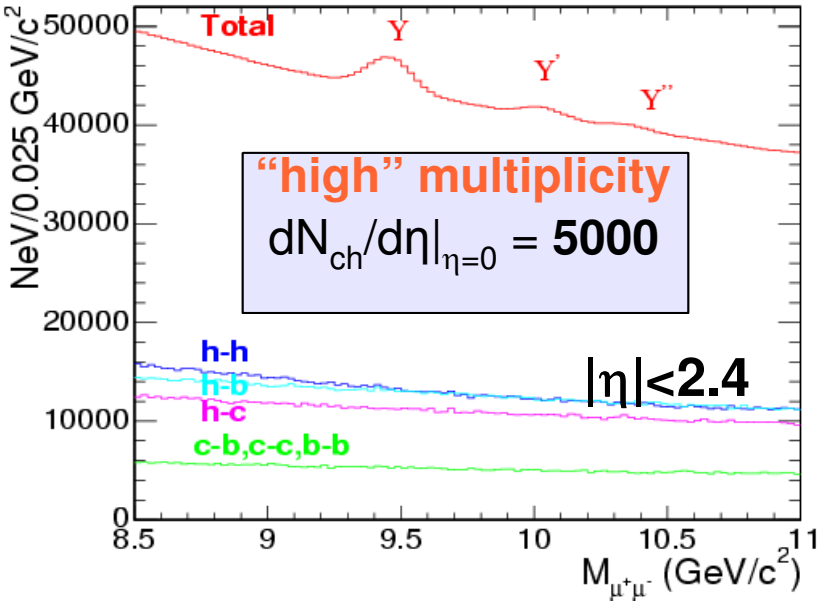
Signal/Background:

1 (0.1) for Υ in $|\eta|<0.8$ ($|\eta|<2.4$)

Expected rate (per month, 10^6s, 0.5 nb^{-1}):

Υ ~ 25 kevents, Υ' ~ 7 kevents, Υ'' ~ 4 kevents





J/ψ measurements (CMS)

Excellent mass resolution:

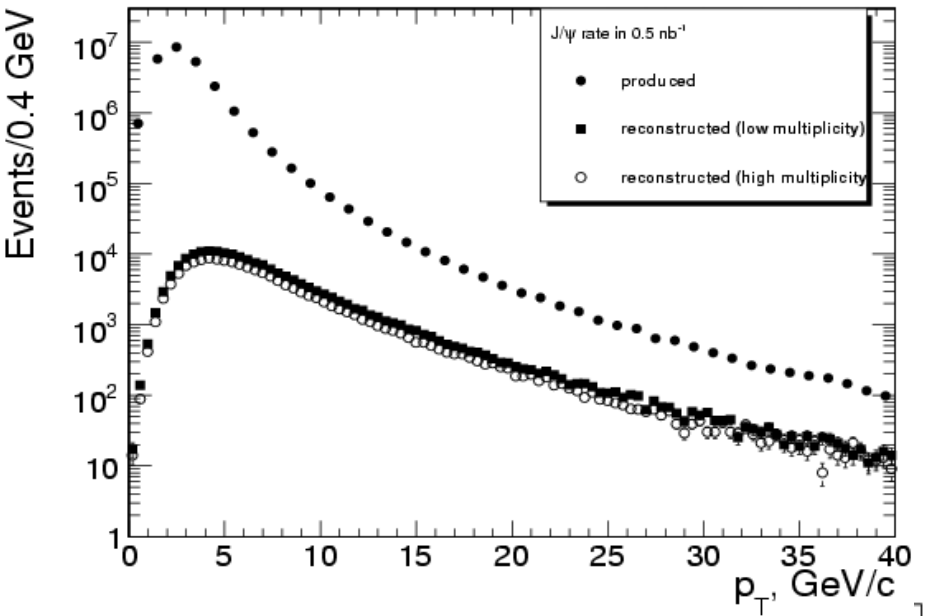
$\sigma_{J/\psi}$ = **35 MeV/c^2**, both muons with $|\eta|<2.4$

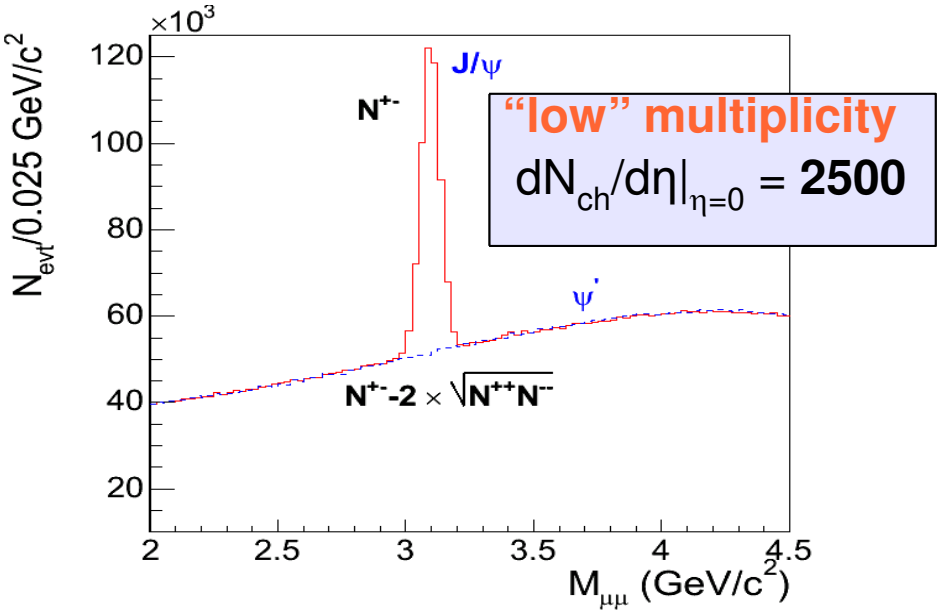
Signal/Background:

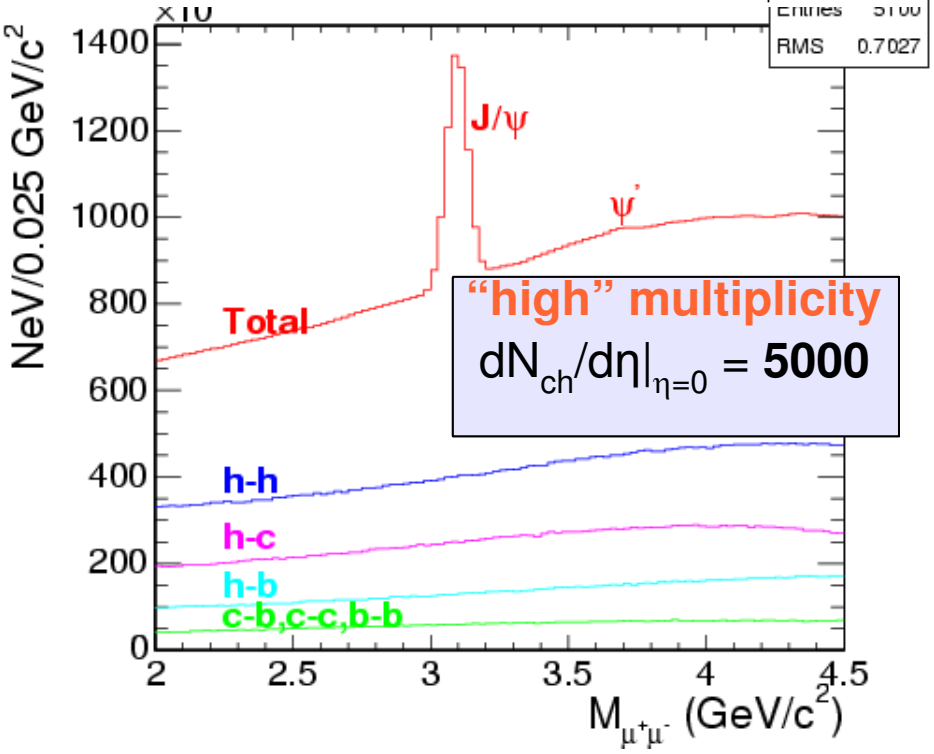
~5(1) for J/ψ in $|\eta|<0.8$ ($|\eta|<2.4$)

Expected rate (per month, 10^6s, 0.5 nb^{-1}):

J/ψ ~ 180 kevents



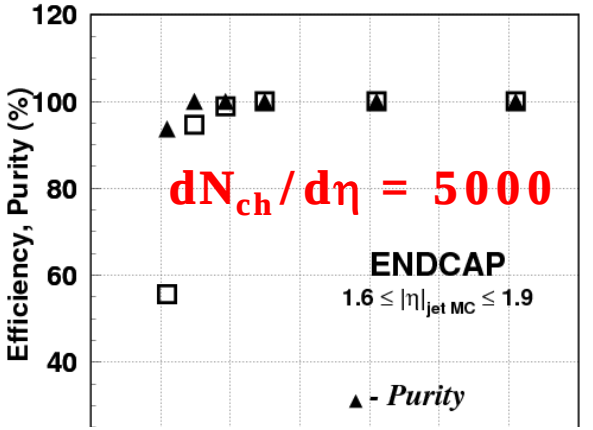


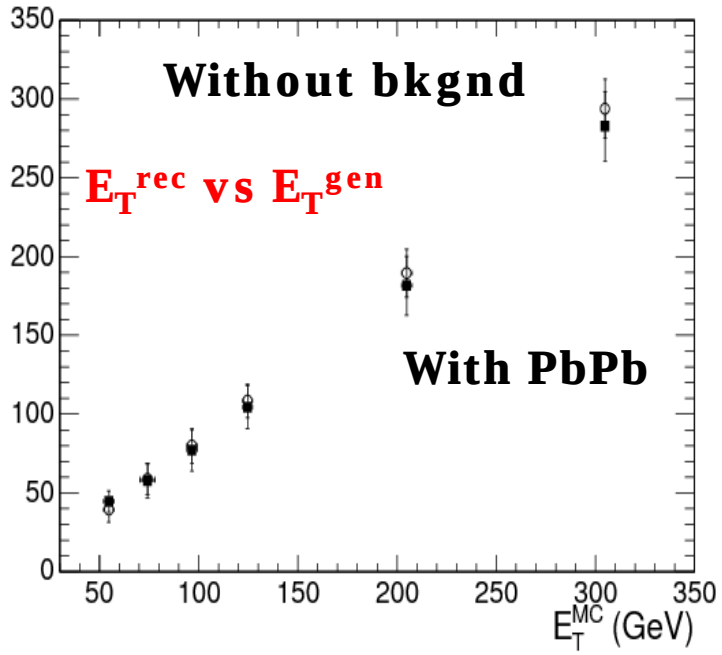


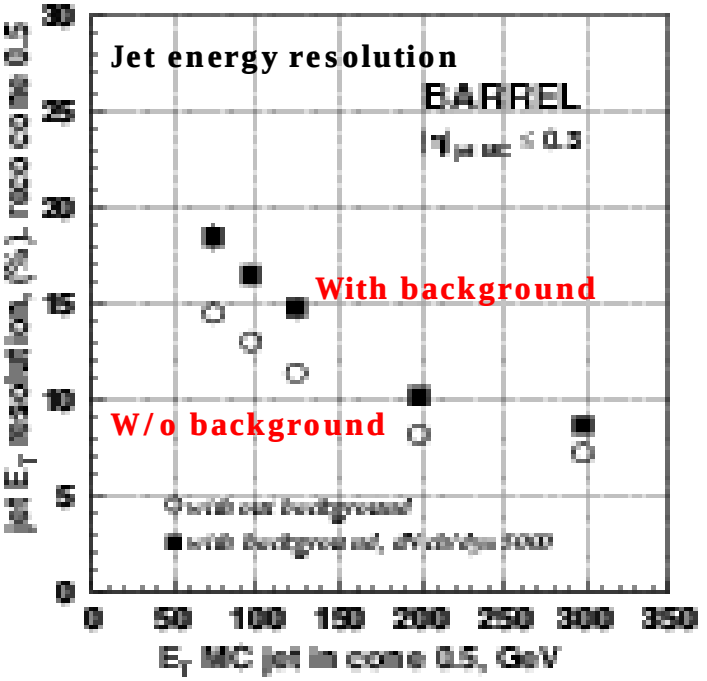
Jet finders in CMS for HI

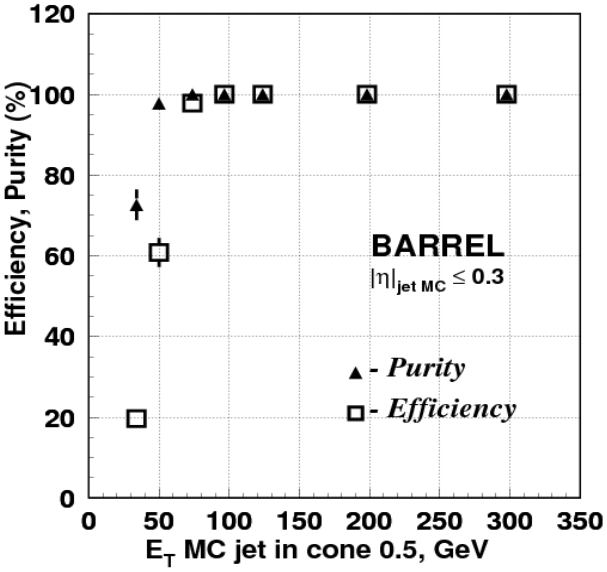
Iterative cone (R>=0.5) with background subtraction:

- **mean value is determined on an event-by-event basis: pile-up subtraction algorithm**
- **calculate average energy and dispersion in tower (in eta rings)**
- **for each event**
- **subtract average energy and dispersion from each tower**
- **find jets with a jet finder algorithm (any) using the new tower energies**
- **recalculate average energy and dispersion using towers**
- **free of jets recalculate jet energies**



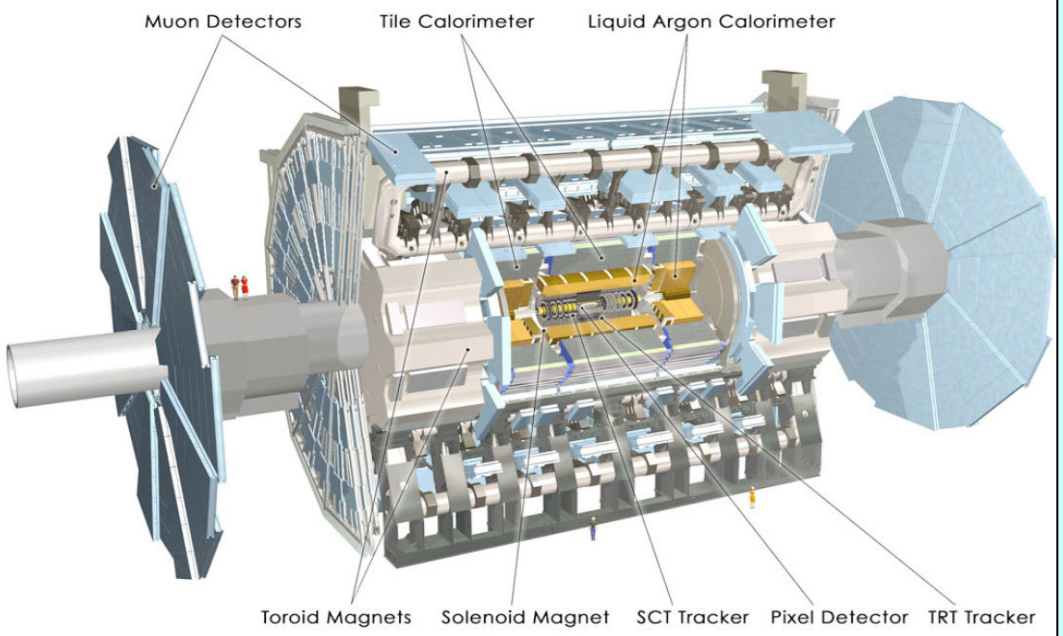






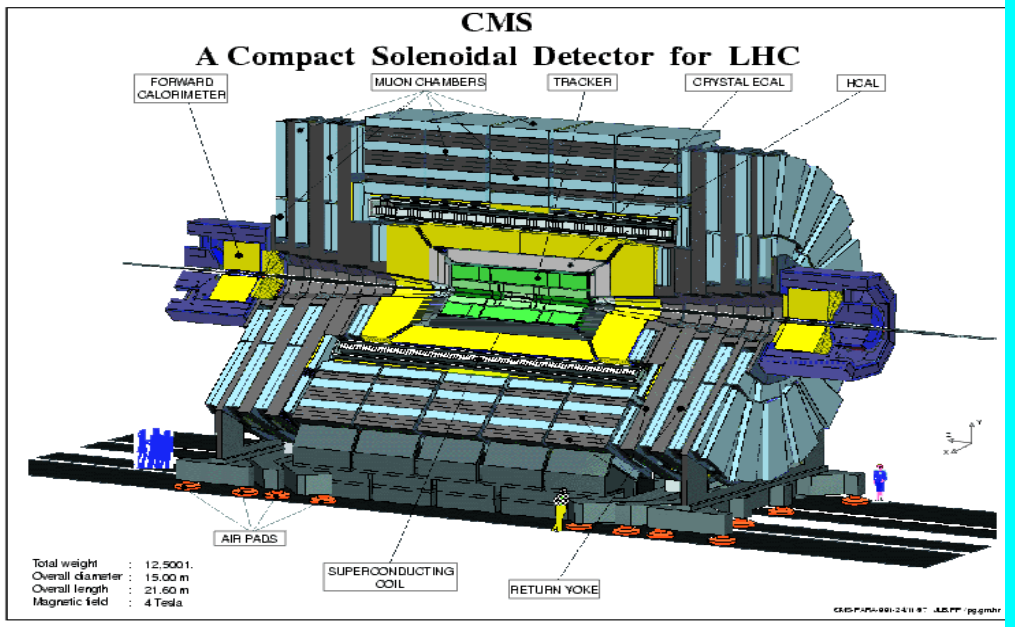
Space resolution is less then the size of calorimeter tower

ATLAS and CMS detectors for heavy ions



- Tracker: Silicon (Silicons: pixels+strips; TRT)
- Electromagnetic calorimeter (LAr+absorber)
- Central hadron calorimeter
  barrel (Lar+absorber),
  endcap (plastic+absorber)
- Forward calorimeter
  (Lar+absorber)
- Muon chambers
  Monitored Drift Tubes (MDT)+RPC (barrel),
  MDT + Cathod Strip Chambers
(CSC)+TGC(endcap)
- Zero-degree calorimeter

2 T magnetic field (solenoid + toroid)
momentum resolution 3% for pt<10 GeV/c with silicons only



- Silicon Tracker (Pixels and Strip)
- Electromagnetic Calorimeter (PbWO4)
- Central hadron Calorimeter
  (plastic + brass absorber)
- Forward calorimeter (Quartz-fiber and ferum)
- Muon Chambers (Drift tubes in barrel,
  Cathod strip chambers in endcap, RPC)
- CASTOR
- Zero-degree calorimeter

+ TOTEM

4 T magnetic field (solenoid), 2 T return yoke
momentum resolution < 2% for pT<100 GeV
Fast DAQ allows to take almost all events to HLT farm

Ultra-peripheral collisions

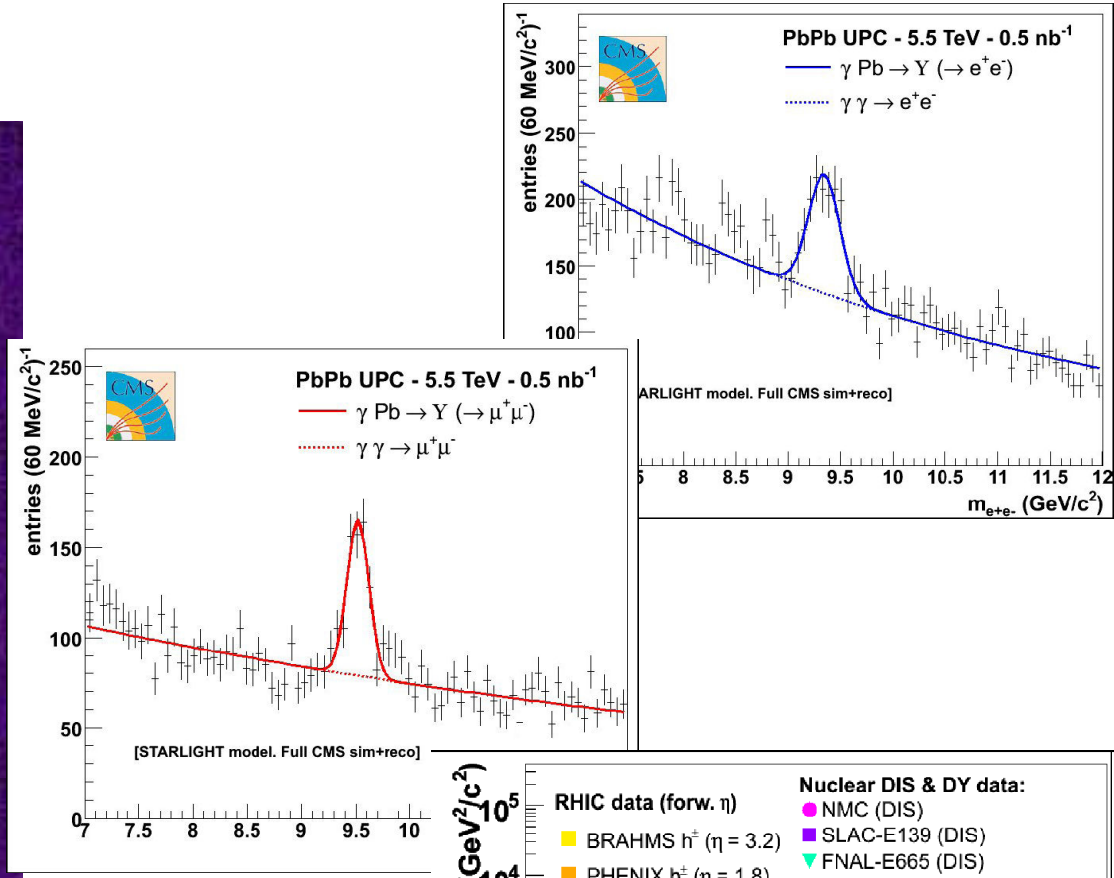
- At LHC the accelerated Pb nucleus can produce strong electromagnetic field
  - due to the coherent action of the $Z = 82$ proton charges

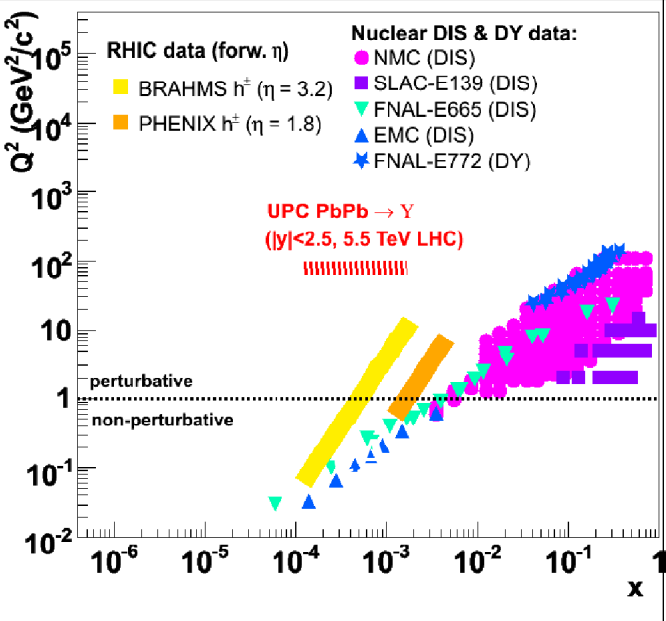
Equivalent photon flux $E\gamma_{max} \sim 80$ GeV

γ+Pb: cm $E_{max} \approx 1.$ TeV/n (~3×e+p HERA)

$\gamma+\gamma$: cm $E_{max} \approx 160$ GeV (~LEP)

- Measure the gluon distribution function in the nucleus (γPb)
  - low background
  - simpler initial state
- γPb→ϒ photo-production in CMS
  - Unexplored (x,Q^2) regime:
  - Pin down amount of low-x suppression in the Pb nuclear PDF (compared to the proton PDF)





J/ψ measurements (ATLAS)

Main problem: low acceptance due to minimum muon p_T ~ 1.5 GeV/*c*

Two methods considered:

- both muons fully reconstructed
- "tagging method" for one muon *(increase the statistics of J/ψ with low p_T)*

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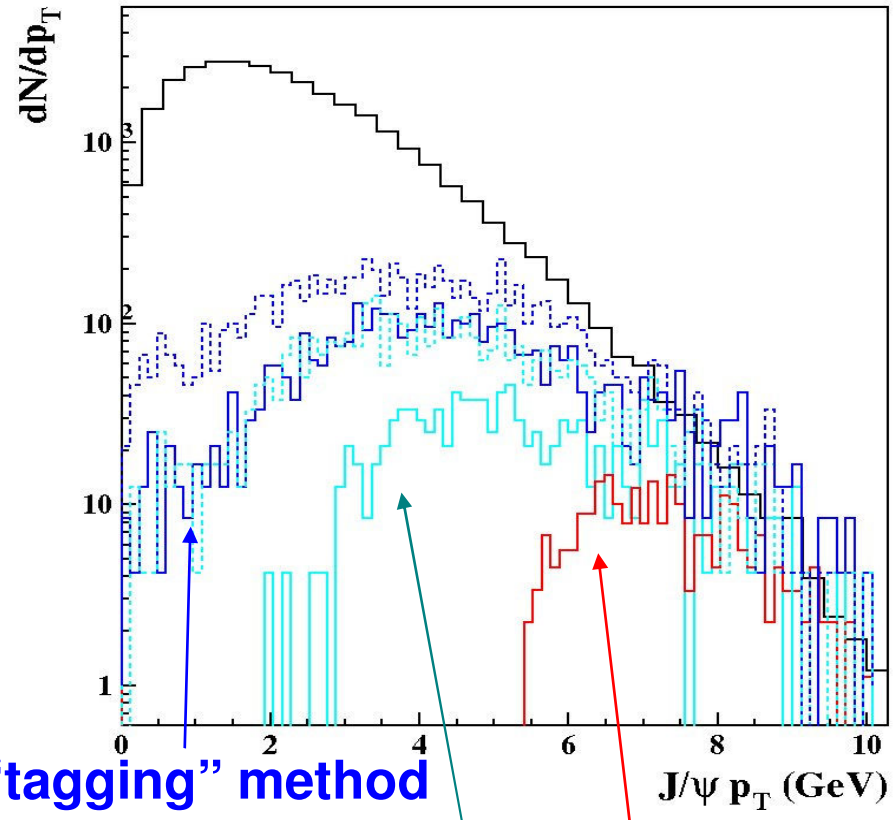
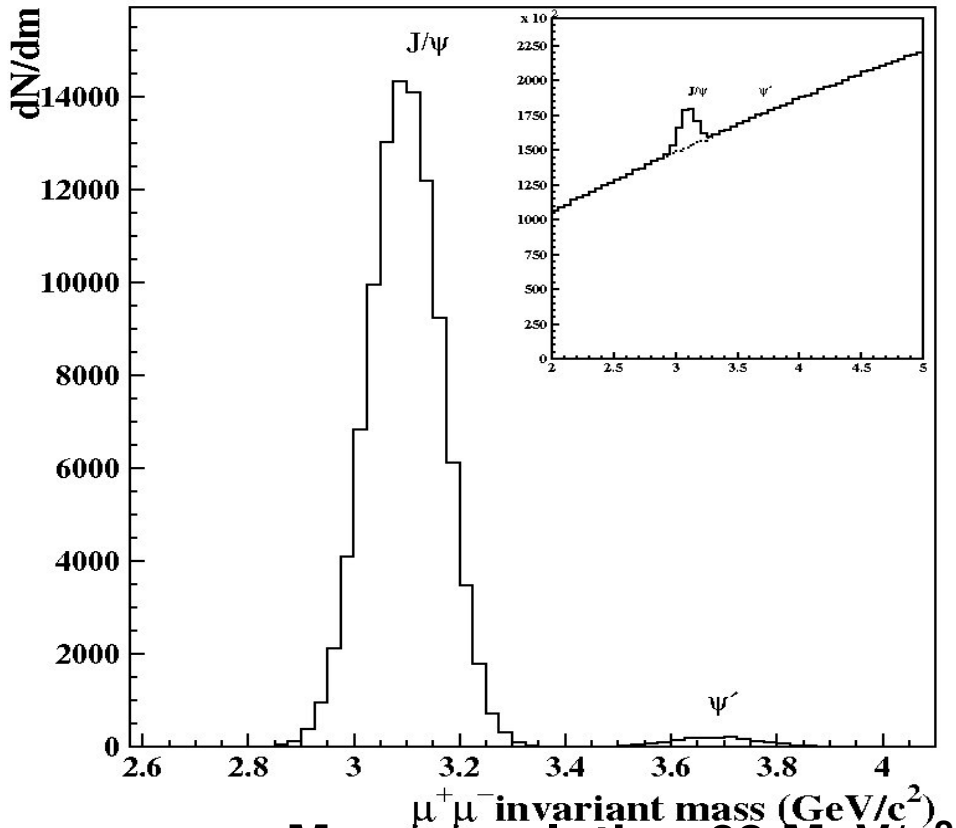


"tagging" method

full reconstruction, p_T cut 1.5 GeV/*c*

full reconstruction, p_T cut 3 GeV/*c*



Mass resolution 68 MeV/c^2

~100k J/ψ per month, tagging method

J/ψ and Upsilon rates (ATLAS)

Υ

Field	full	full	full	half	half	half
$\|\eta\|$ (max)	1	2	2.5	1	2	2.5
Acceptance x efficiency	4.7%	12.5%	17.5%	4.9%	13.8%	19.3%
	(2.6%)	(8.1%)	(12.0%)	(2.6%)	(8.9%)	(13.4%)
Mass resolution (MeV)	123	145	159	126	162	176
S/B	0.3	0.2	0.2	0.3	0.2	0.2
	(0.4)	(0.3)	(0.3)	(0.55)	(0.3)	(0.3)
$S/\sqrt{S+B}$	37	46	55	37	50	60
	(31)	(45)	(55)	(34)	(48)	(60)
Rate/month	5700	15000	21200	5900	16800	23400
	(3100)	(10000)	(14600)	(3100)	(10800)	(16300)

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J/ψ

Field	full	full	half
p_T (min) (GeV)	3	1.5	1.5
Acceptance x efficiency	0.055%	0.530%	1.100%
	(0.039%)	(0.151%)	(0.529%)
Mass resolution (MeV)	68	68	76
S/B	0.4	0.15	0.15
	(0.5)	(0.2)	(0.25)
$S/\sqrt{S+B}$	56	113	164
	(52)	(72)	(140)
Rate/month	11000	104000	216000
	(8000)	(30000)	(104000)

Fragmentation function measurements (ATLAS)

- "Raw" evaluation of
  - J_T distribution
  - Fragmentation func.
  - p_T > 2 GeV/c, |η| < 2.5
  - Jet E_T^{rec} > 70 GeV
- With constant (for simplicity) 70% correction for tracking efficiency
- Reproduce both shape and absolute yield, both J_T and D(Z)