Monte-Carlo tools for HIC simulations at CMS

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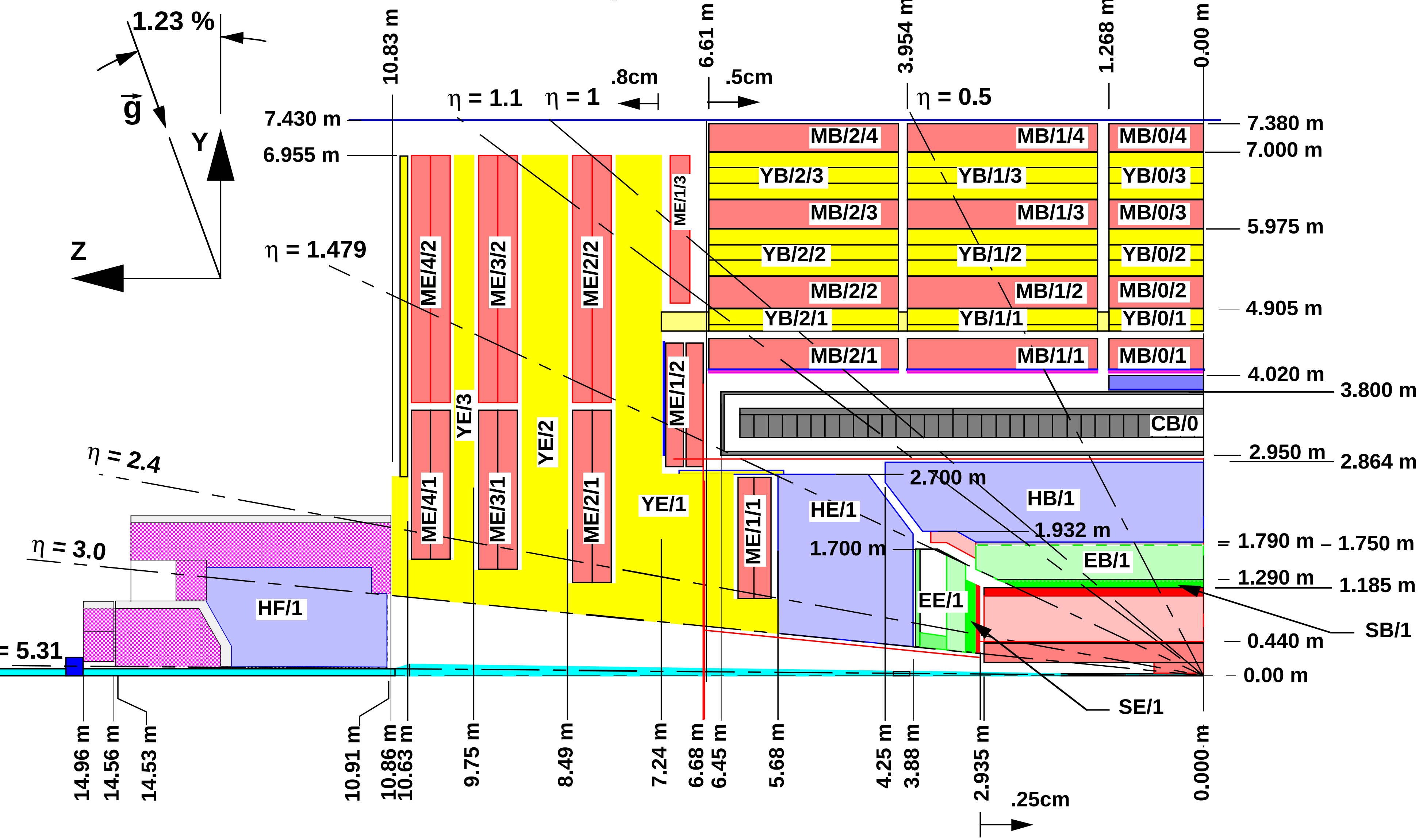
- **CMS detector and CMS specific for HI event simulations**
- **"Hard probes" simulation (example: jet reconstruction)**
- **"Global observables" simulation (example: azimuthal anisotropy and event plane reconstruction)**
- **Open problems and outlook**

C.M.S.

Compact Muon Solenoid



Longitudinal View

CMS - PARA- 003 - 29/09/97 PP

Physics data sheet for CMS sub-detectors

Energy resolution σ/E and granularity of CMS calorimeters in barrel (HB, EB), endcap (HE, EE) and very forward (HF) regions (ECAL – for e and γ total energy; HCAL, HF – for jet transverse energy).

Rapidity	$0 <\mid \eta \mid< 1.5$		$1.5 <\mid \eta \mid< 3.0$		$3.0 <\mid \eta \mid< 5.2$
Subdetector	**HCAL (HB)**	**ECAL (EB)**	**HCAL (HE)**	**ECAL (EE)**	**HF**
$\frac{\sigma}{E} = \frac{a}{\sqrt{E}} \oplus b$ **a:** **b:**	 **1.16** **0.05**	 **0.027** **0.0055**	 **0.91** **0.05**	 **0.057** **0.0055**	 **0.77** **0.05**
granularity $\Delta\eta \times \Delta\varphi$	**0.087×0.087**	**0.0174×0.0174**	**0.087×0.087**	**0.0174×0.0174** **to 0.05×0.05**	**0.175×0.175**

CASTOR project will allow extending calorimetry up to $|\eta| \sim 7$.

Tracker and muon chambers cover pseudorapidity $|\eta| < 2.4$.
Momentum resolution is $< 1\%$ at 1 GeV$< p_T < 100$ GeV.

Types of models for heavy ion collisions

1. Microscopic models:

Linear superposition of independent NN collisions + collective nuclear effects

Initial state nuclear effects:

- **"nuclear shadowing"**, $f_A(x, Q^2) \neq A f_p(x, Q^2)$
- **"Cronin effect", initial state scattering**

Final state nuclear effects:

- **string interactions (FRITIOF, QGSM, DPM, ...)**
- **hadron cascade (UrQMD, VENUS, ...)**
- **parton cascade (VNI, ...)**
- **medium-induced gluon radiation (HIJING, ...)**

2. Hydrodynamical (macroscopic) models:

Generation of event phase space according with hydrodynamical equations
+
set multiplicity and "freeze-out" parameters

Monte-Carlo tools for HI simulations at CMS

Simulation packages to get CMS responses:

- **CMSIM – GEANT-3 based Fortran simulation package adopted to heavy ion collisions, latest version CMSIM_127**
- **OSCAR – GEANT-4 based object-oriented simulation package, in progress**
- **ORCA – object-oriented package for signal digitization and reconstruction (does not need special adaptation for heavy ion collisions), latest version ORCA_7**

Event generators to get signals and backgrounds:

- **PYTHIA – to generate "hard probe" signals, e.g. jets, quarkonia, heavy quarks, etc.**
- **HIJING – to generate background for "hard probes" and global observables, e.g. energy flow vs. centrality, rapidity, etc. (but not azimuthal-sensitive observables!)**
- **HYDRO – simple hydro-type code to generate particle and energy elliptic flow**

Heavy Ion Event Generators: CMS specific I

Hard (high-p_T) probes of quark-gluon plasma:

- **Jets**
- **Heavy quarks in dimuons**
- **Quarkonia in dimuons**

An adequate analysis requests high statistics ($\sim 10^5 - 10^7$ events).
At the moment it is problematically to use HI generators for this.

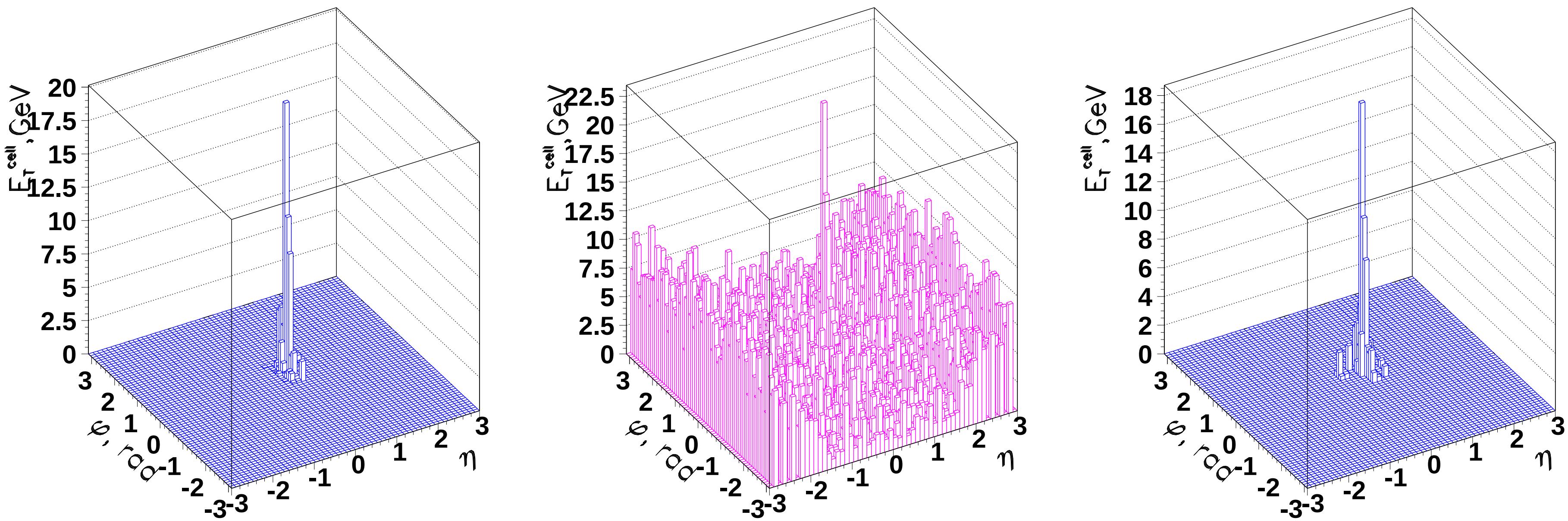
Example

1 central HIJING+CMSIM_125+ORCA_6.2 Pb+Pb event
(total multiplicity is ~ 100000)
takes ~ 150 MB of disk space and requests ~ 20 hours of running (Pentium 700MHz).

Rice HI database - 1000 central Pb+Pb HIJING events.
Moscow HI database - in progress.

Common practice: to generate signal events in pp (e.g. with PYTHIA) and superimpose it on the background (like HIJING event).

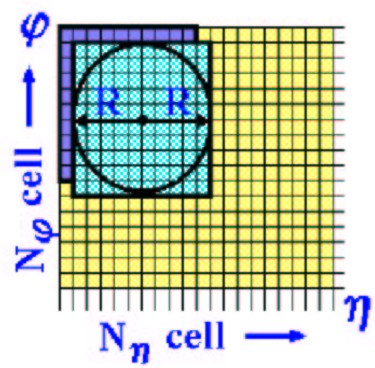
Jet reconstruction in HI collisions at CMS



PYTHIA (100 GeV jet)+HIJING (central Pb+Pb)+CMSIM_125+ORCA_6.2

Jet reconstruction in HI collisions at CMS

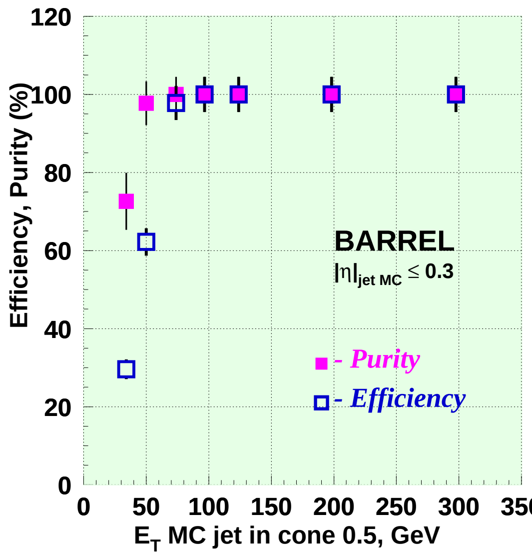
Pile up subtraction algorithm (Irina Vardanian)



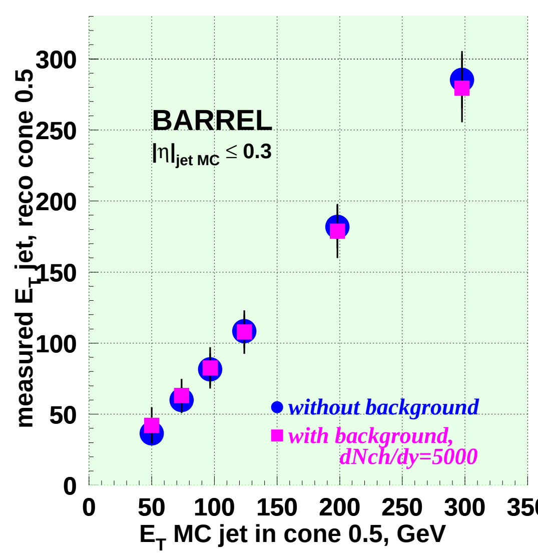
1. Subtract average pileup (background).
2. Find jets with iterative cone algorithm.
3. Recalculate background outside the cone.
4. Recalculate jet energy.

Full simulation: central Pb+Pb events, HIJING, $dN_{ch}/dy(y=0) = 5000$

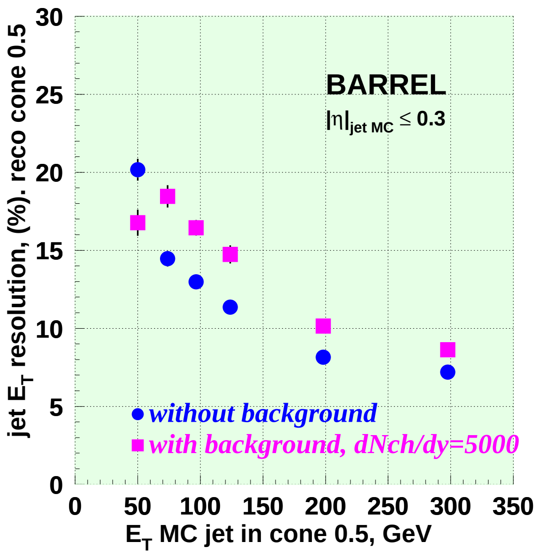
Efficiency, purity



Measured jet energy

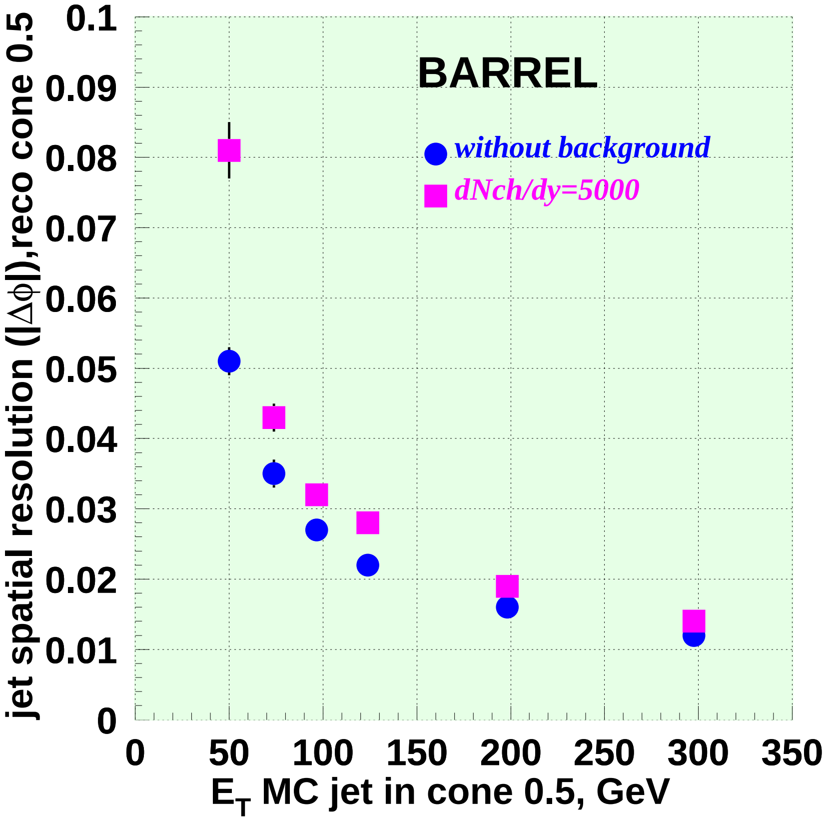


Jet energy resolution

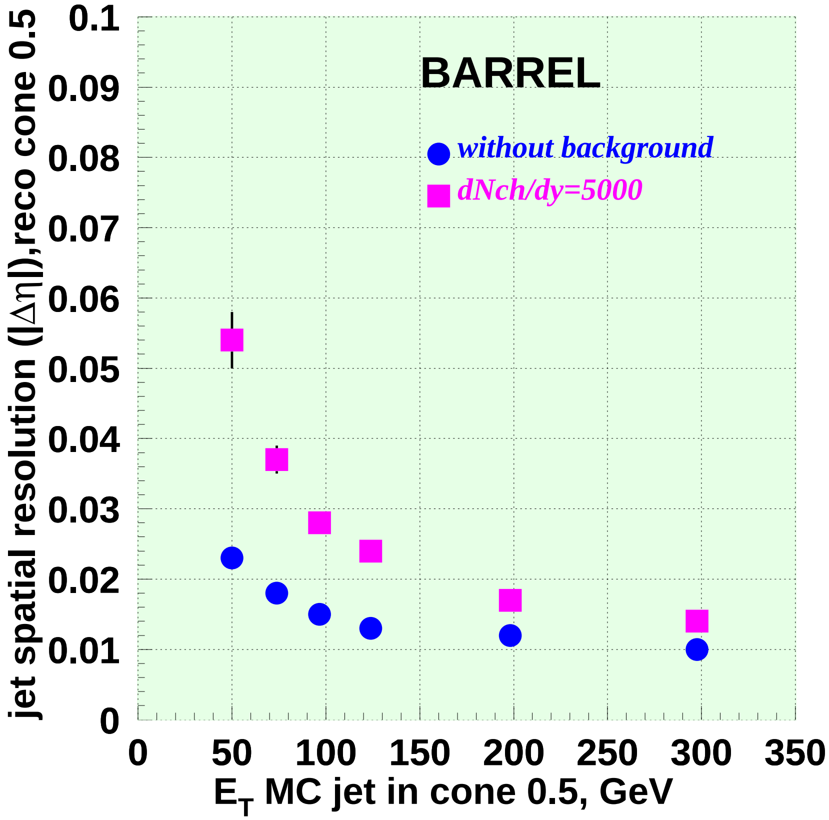


Jet reconstruction in HI collisions at CMS

Azimuthal angle resolution



Pseudorapidity resolution



Jet spatial resolution is better than $\eta \times \varphi$ size of HCAL tower 0.087×0.087.

Heavy Ion Event Generators: CMS specific II

Global observables in large acceptance:

- **Energy and particle flow**
- **Centrality and event plane measurements**

Sometimes $\sim 10^2 - 10^3$ events are enough for the analysis.

However: there is a problem of adequate description (especially at LHC energies).

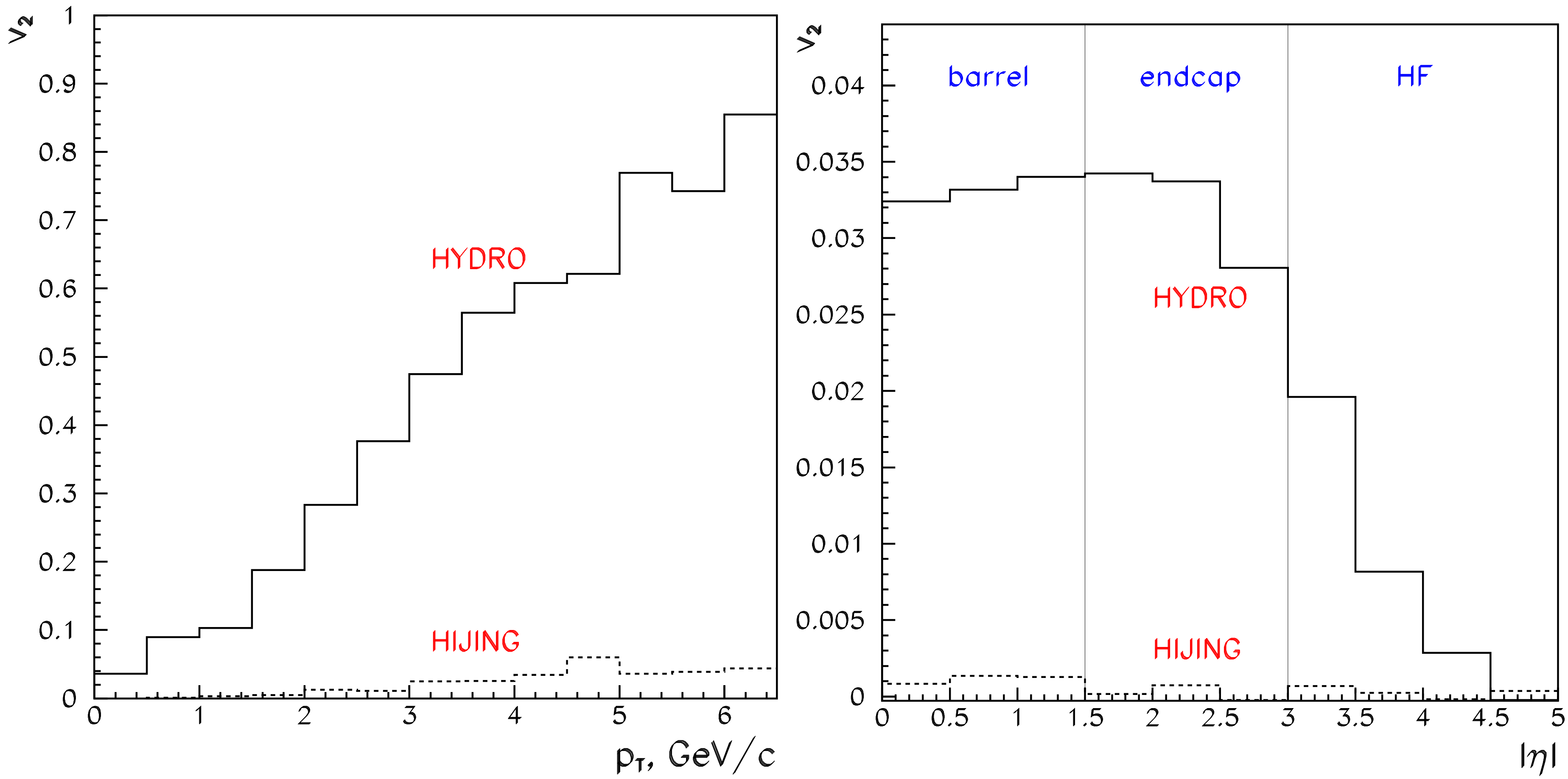
Examples

HIJING is adequate for centrality determination (reflects nuclear geometry), but practically does not yield elliptic flow (does not reproduce RHIC data). Thus HIJING cannot be applied for the analysis of azimuthal anisotropy and event plane determination.

HYDRO gives elliptic flow, but does not work in full kinematic range (restricted by mid-rapidity, not high p_T, non-peripheral collisions)

Elliptic flow in Pb+Pb events at LHC (b=6 fm)

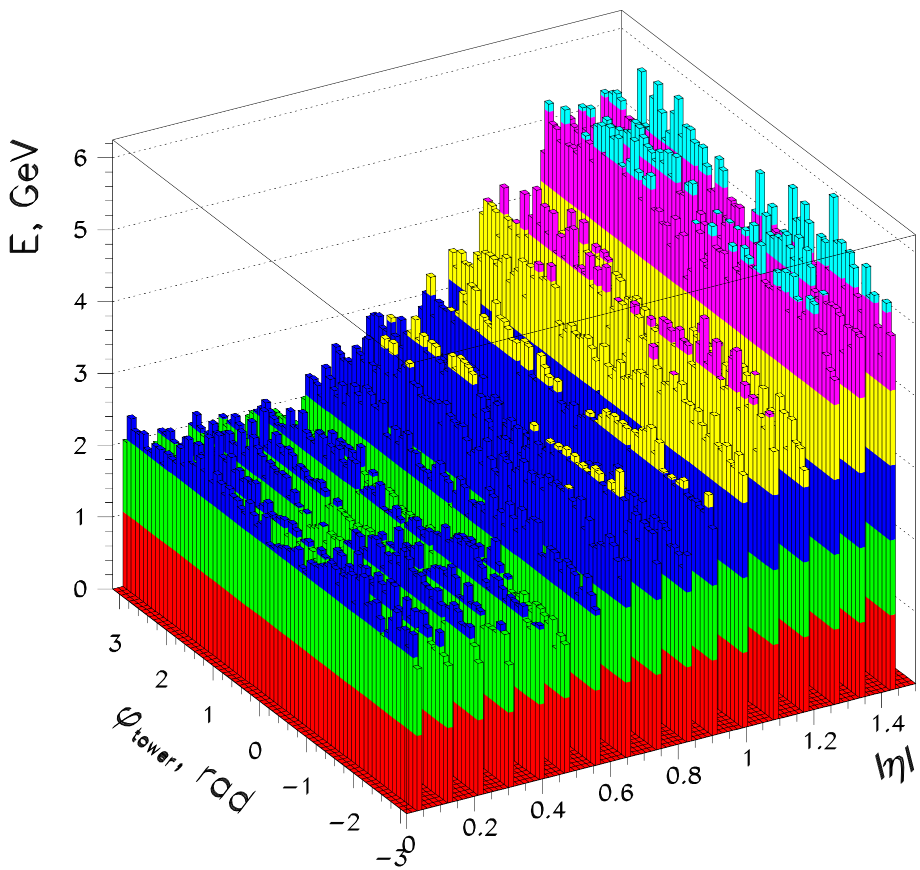
HYDRO vs. HIJING



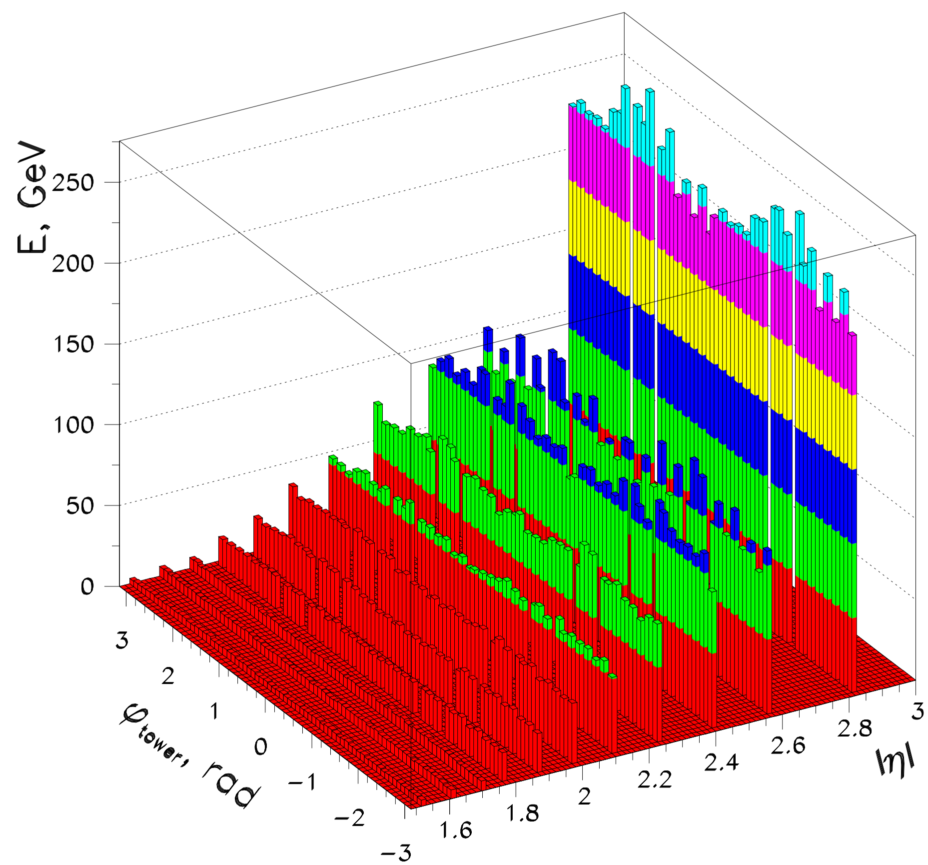
Coefficient of azimuthal anisotropy $v_2 \equiv \langle \cos 2\varphi \rangle$:
close to 0 for HIJING;
increases with p_T, depends slightly on $|\eta|$ in mid-rapidity for HYDRO.

Energy flow in Pb+Pb collisions at CMS

BARREL

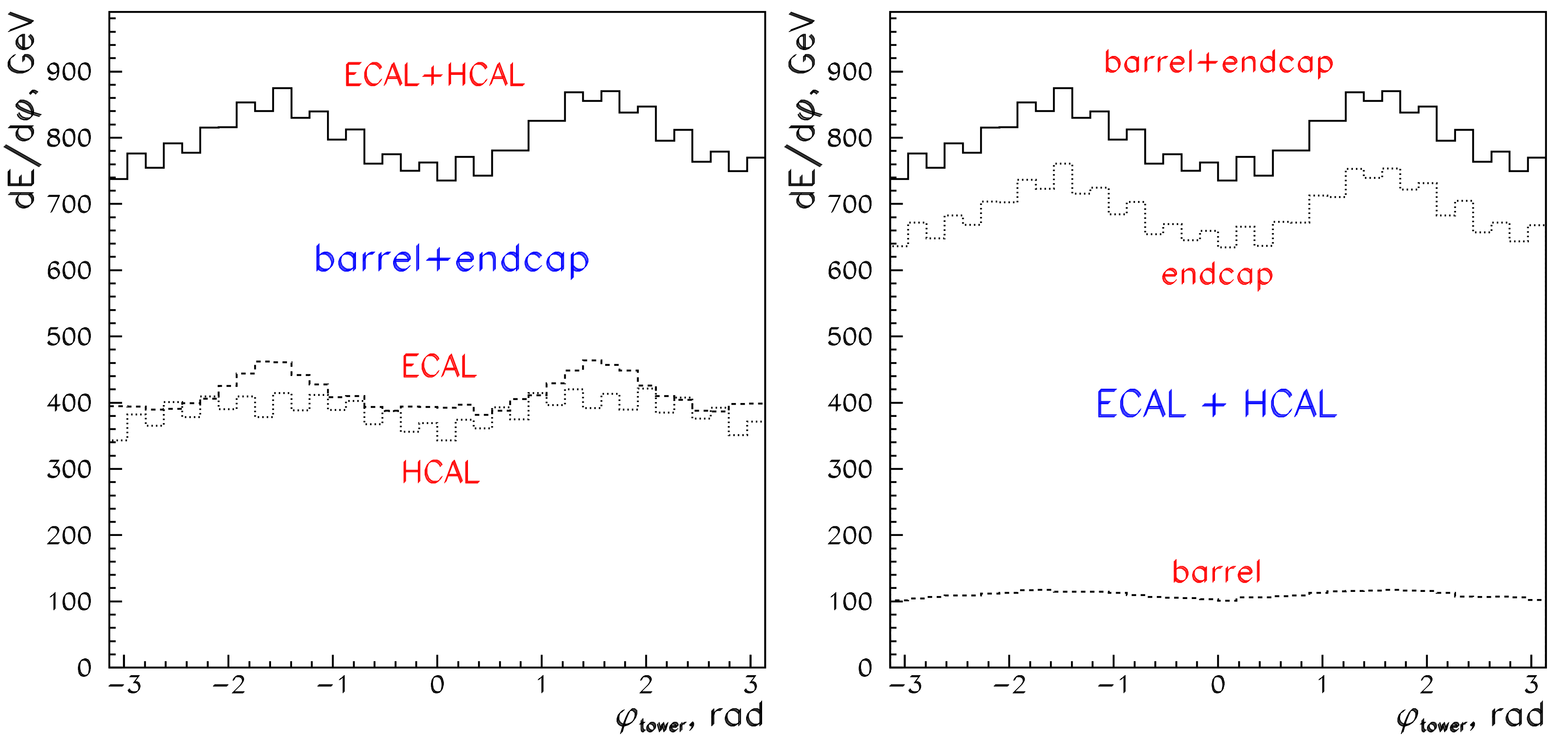


ENDCAP



HYDRO (b=6 fm)+CMSIM_125+ORCA_6.2 (*average over* 100 *events*)

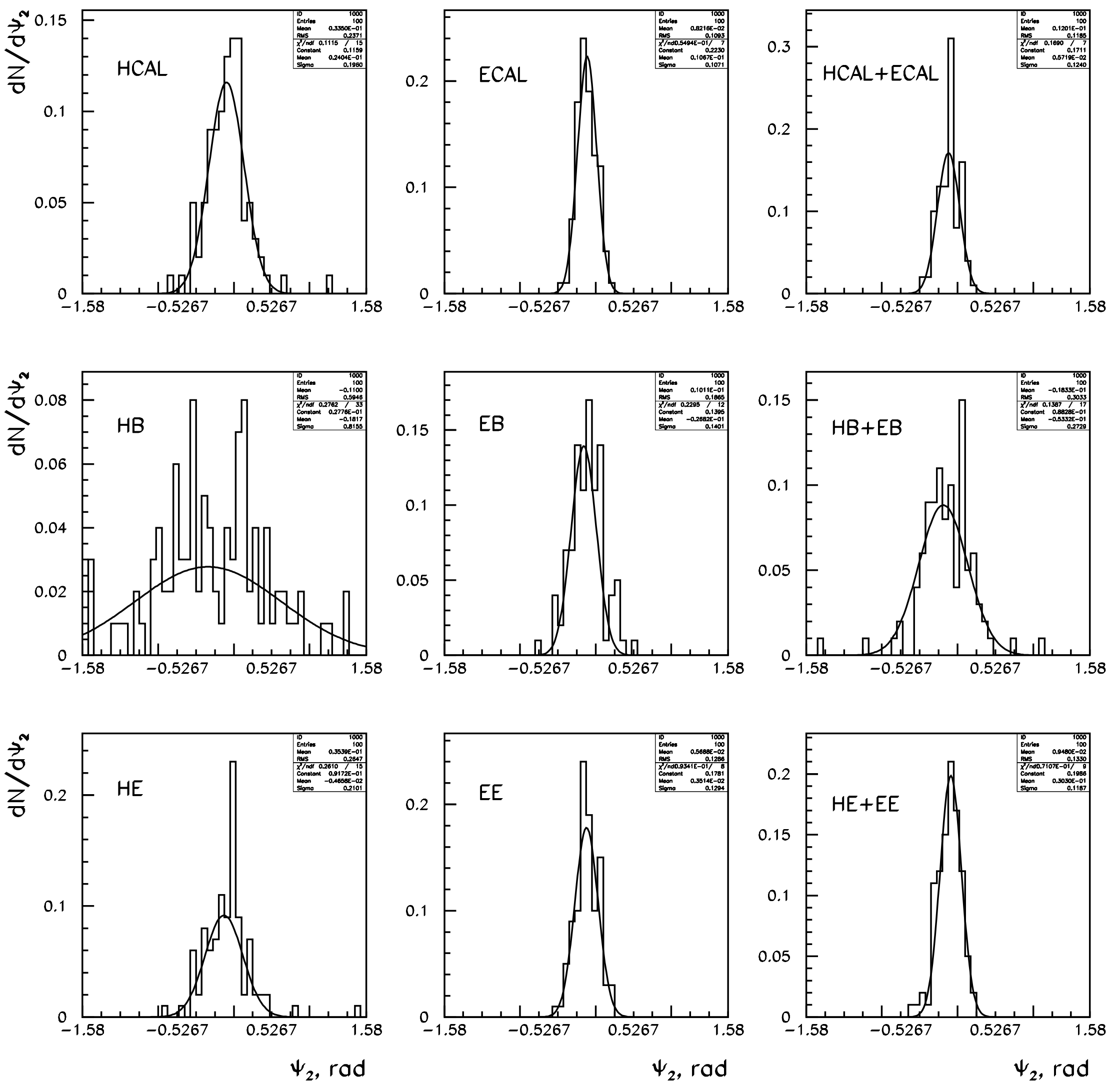
Energy flow in Pb+Pb collisions at CMS



HYDRO (b=6 fm)+CMSIM_125+ORCA_6.2 (*average over* 100 *events*)

Event plane reconstruction by CMS calorimetry

$$\tan 2\Psi_2 = \sum_i E(\varphi_i) \sin 2\varphi_i / \sum_i E(\varphi_i) \cos 2\varphi_i$$



The dominant role of endcaps for event plane determination is clearly recognized

Monte-Carlo tools for HIC at CMS: Outlook

Studies with available Monte-Carlo tools shows possibility to reconstruct various physics channels and HI event characteristics.

This is part of work on CMS Physics TDR by 4 analysis groups:

- **Heavy Ions**
- **Higgs**
- **Standard model**
- **SUSY/other Beyond the Standard model**

Global task for generator developers:

Development of Heavy Ion Event Generator (or significant modification of existing tools) for adequate description of particle spectra, correlations and anisotropic flow in full kinematical range for the LHC energies.
(combination of pQCD, nuclear geometry and hydro-type evolution?)

This Workshop is good place to discuss it!

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