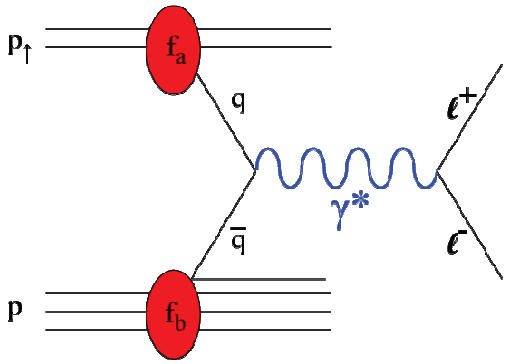
Measurement of Forward Jet Production in polarized pp collisions at √s=500 GeV

L. Nogach, IHEP (Protvino)
for A_NDY



The 20th International Symposium on Spin Physics, Dubna, Sep-17-2012

A_NDY: Measurement of the Analyzing Power for Large Rapidity Drell-Yan Production

S. Abrahamyan[1], A. Bazilevsky[2], L. C. Bland[2], E. J. Brash[4,3], E. Cisbani[5], H. J. Crawford[6], A. Derevshchikov[7], K. Drees[2], J. Engelage[6], K. O. Eyser[2], C. Folz[2], K. Gnanvo[8], G. Igo[9], E. G. Judd[6], X. Li[10], M. X. Liu[11], N. K. Liyanage[8], Y. Makdisi[2], N. Minaev[7], D. Morozov[7], L. Nogach[7], A. Ogawa[2], C. F. Perdrisat[12], C. Perkins[6,13], P. Pile[2], M. Planinic[14], V. Punjabi[15], G. Schnell[16], A. Shahinyan[1], T. G. Throwe[2], C.Van Hulse[16], and A. Vossen[17]

[1]Yerevan Physics Institute, Armenia
[2]Brookhaven National Laboratory
[3]Thomas Jefferson National Accelerator Facility
[4]Christopher Newport University
[5]INFN Roma, Italy
[6]University of California, Berkeley/Space Sciences Laboratory
[7]Institute for High Energy Physics, Protvino
[8]University of Virgina
[9]University of California, Los Angeles
[10]Shandong University, China
[11]Los Alamos National Laboratory
[12]College of William and Mary
[13]Stony Brook University
[14]University of Zagreb, Croatia
[15]Norfolk State University
[16]University of the Basque Country and IKERBASQUE, Spain
[17]Indiana University

February 28, 2012

Letter of Intent submitted 24 May 2010:

http://www.bnl.gov/npp/docs/pac0610/Crawford_LoI.100524.v1.pdf

PAC presentation:

http://www.bnl.gov/npp/docs/pac0610/aschenauer_DY-collider_june10.pdf

Proposal to 2011 PAC:

http://www.bnl.gov/npp/docs/pac0611/DY_pro_110516_final.2.pdf

2011 PAC recommendations:

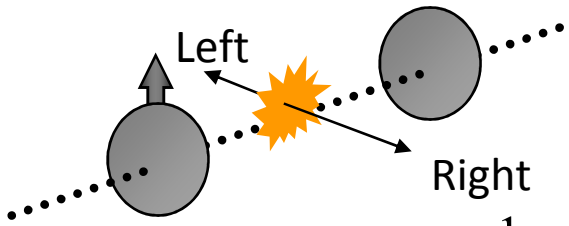
http://www.bnl.gov/npp/docs/pac0610/Final recommendations.pdf

Proposal for funding review 30 March 2012:

http://hena.lbl.gov/IP2/Business/review/0-proposal_120229.pdf

Review report 10 May 2012

Transverse Single Spin Asymmetries (for pions)



$$A_N = \frac{1}{P}\frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

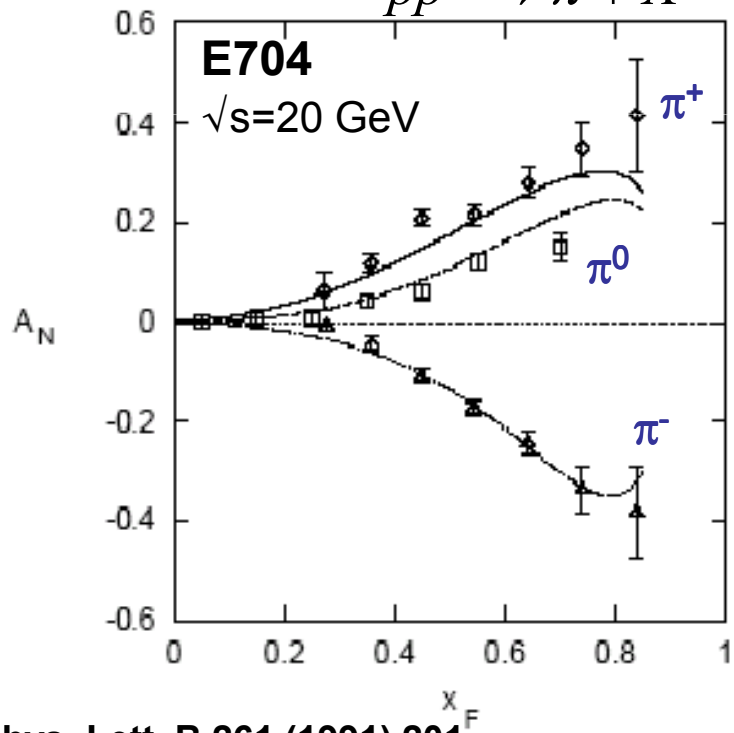
Theory expectation: small asymmetries at high energies (Kane, Pumplin, Repko, **PRL 41 (1978) 1689**)

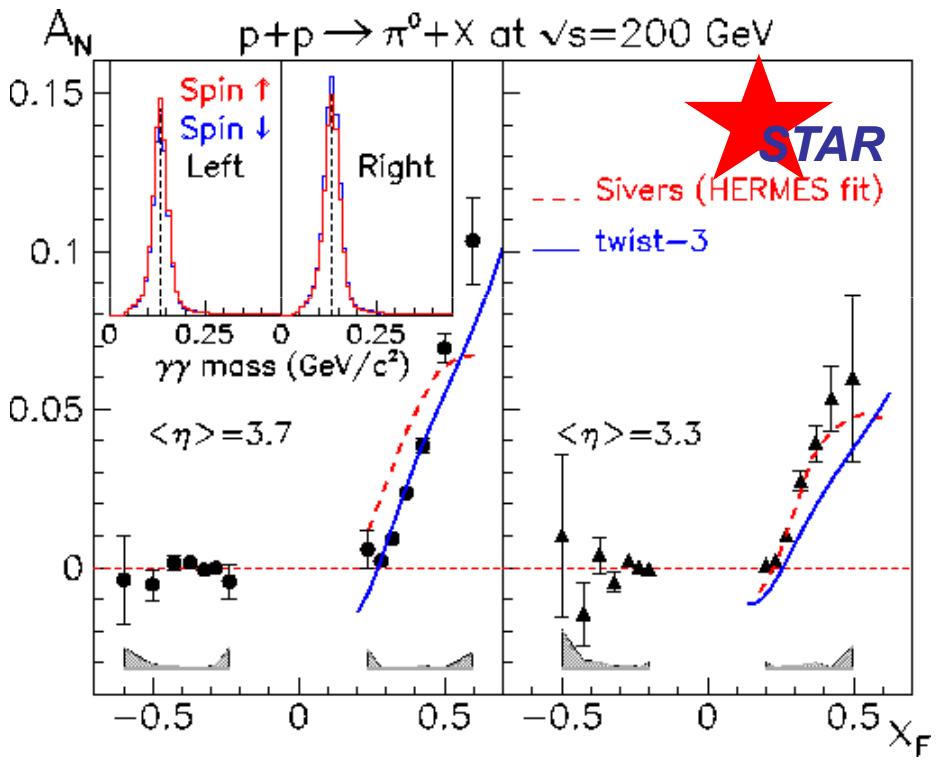
$$A_N \propto \frac{m_q}{p_T}$$

A_N O(10^{-4}) Theory

Experiment:

$$pp^{\uparrow} \rightarrow \pi + X$$





PRL 101 (2008) 222001

Jets integrate over π^+, π^- and π^0 ; "mirror" A_N for π^+ and π^- leads to the cancellations for jet A_N

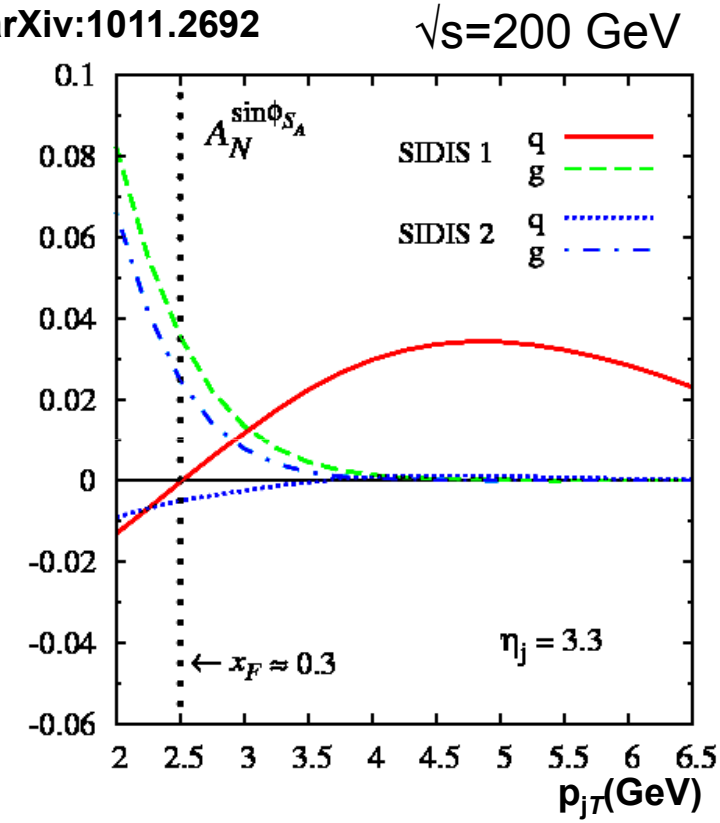
Phys. Lett. B 261 (1991) 201
Phys. Lett. B 264 (1991) 462

A_N O(10^{-1}) Measured

Motivation to measure jet A_N

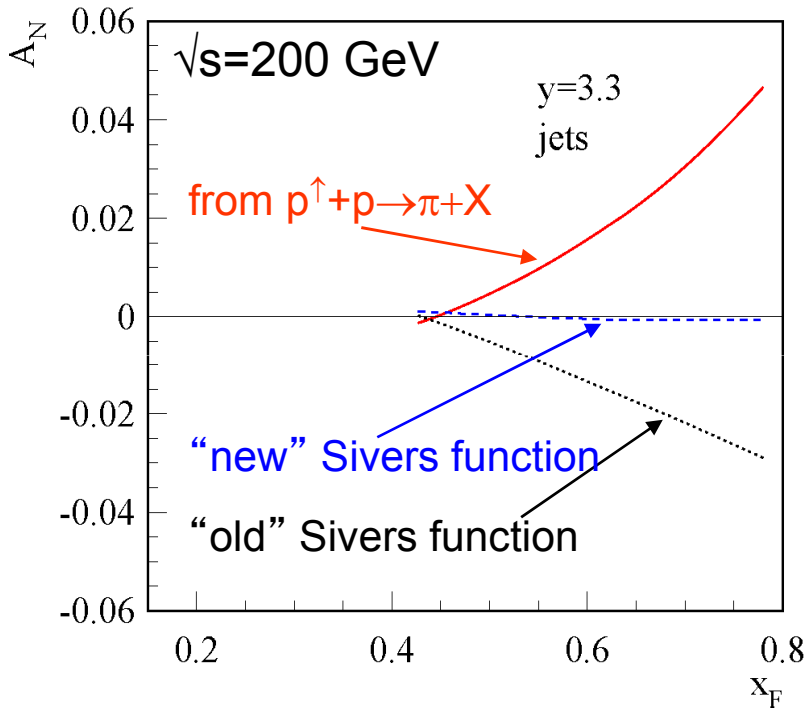
Sivers effect only (no Collins effect contribution)

arXiv:1011.2692



Estimated quark and gluon Sivers contributions to the jet A_N, using parametrizations from SIDIS

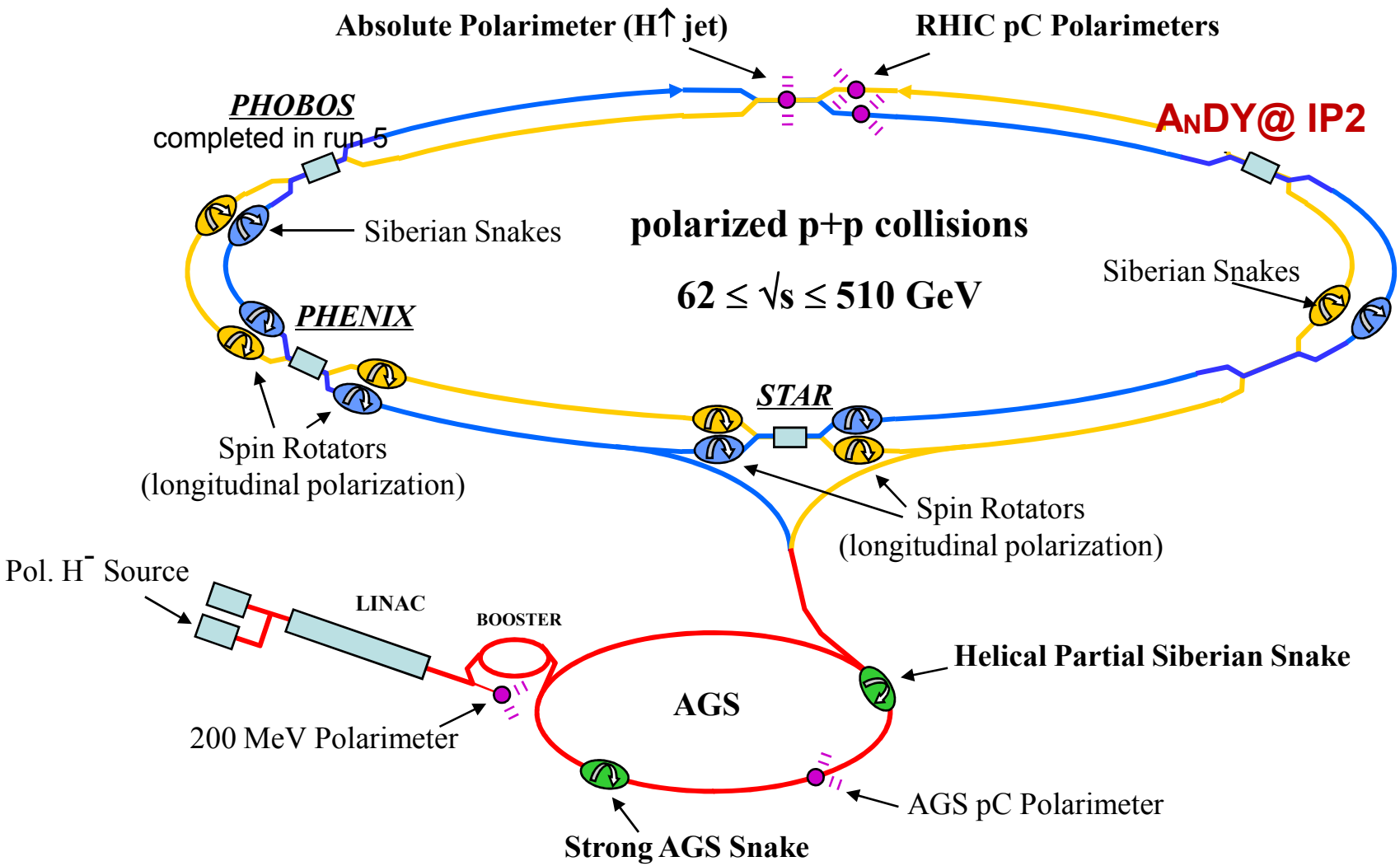
arXiv:1103.1591



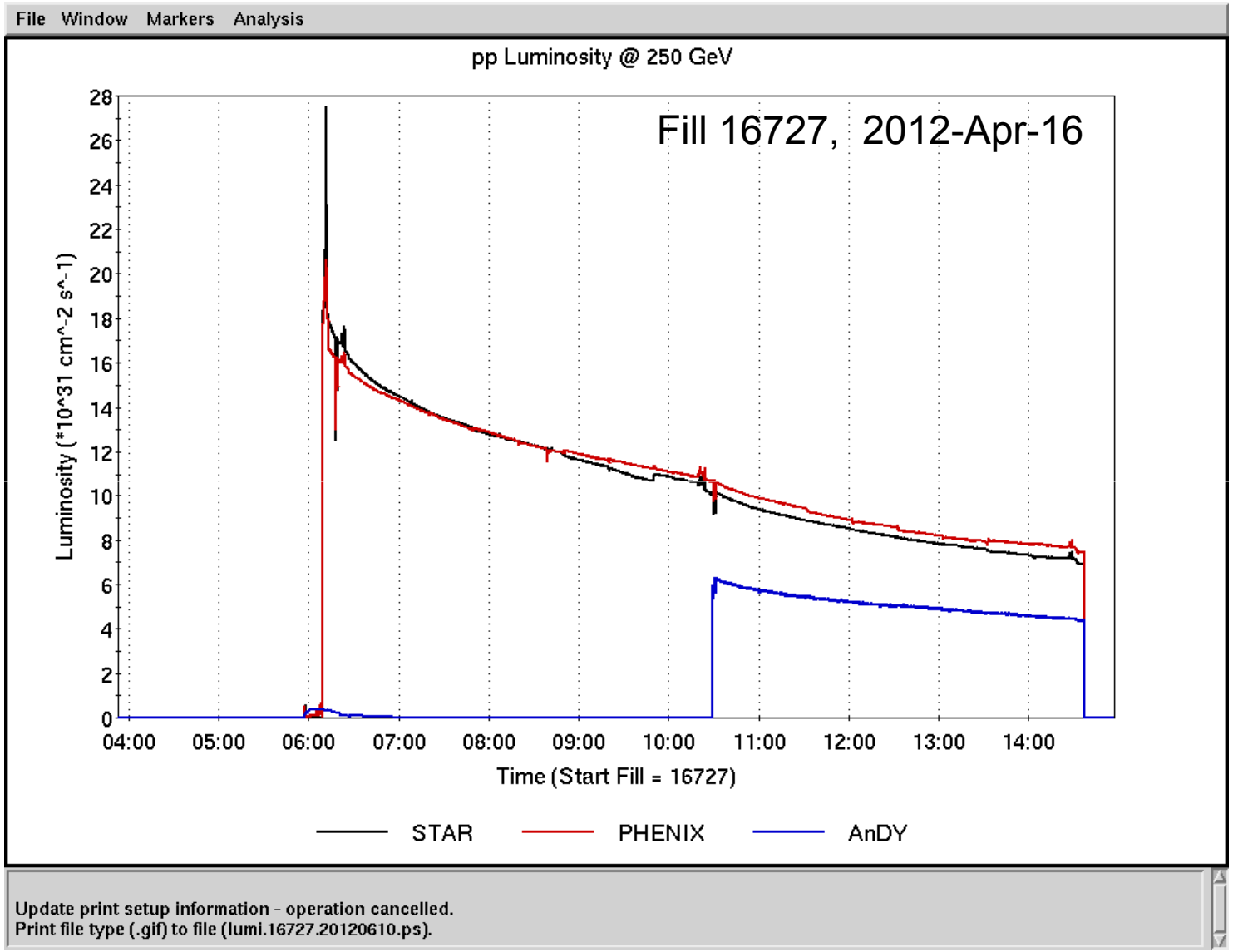
SSA for jets using different quark-gluon correlation functions

√s=500 GeV jets have 2.5x larger p_T at the same x_F, relative to these predictions

RHIC as a polarized proton collider

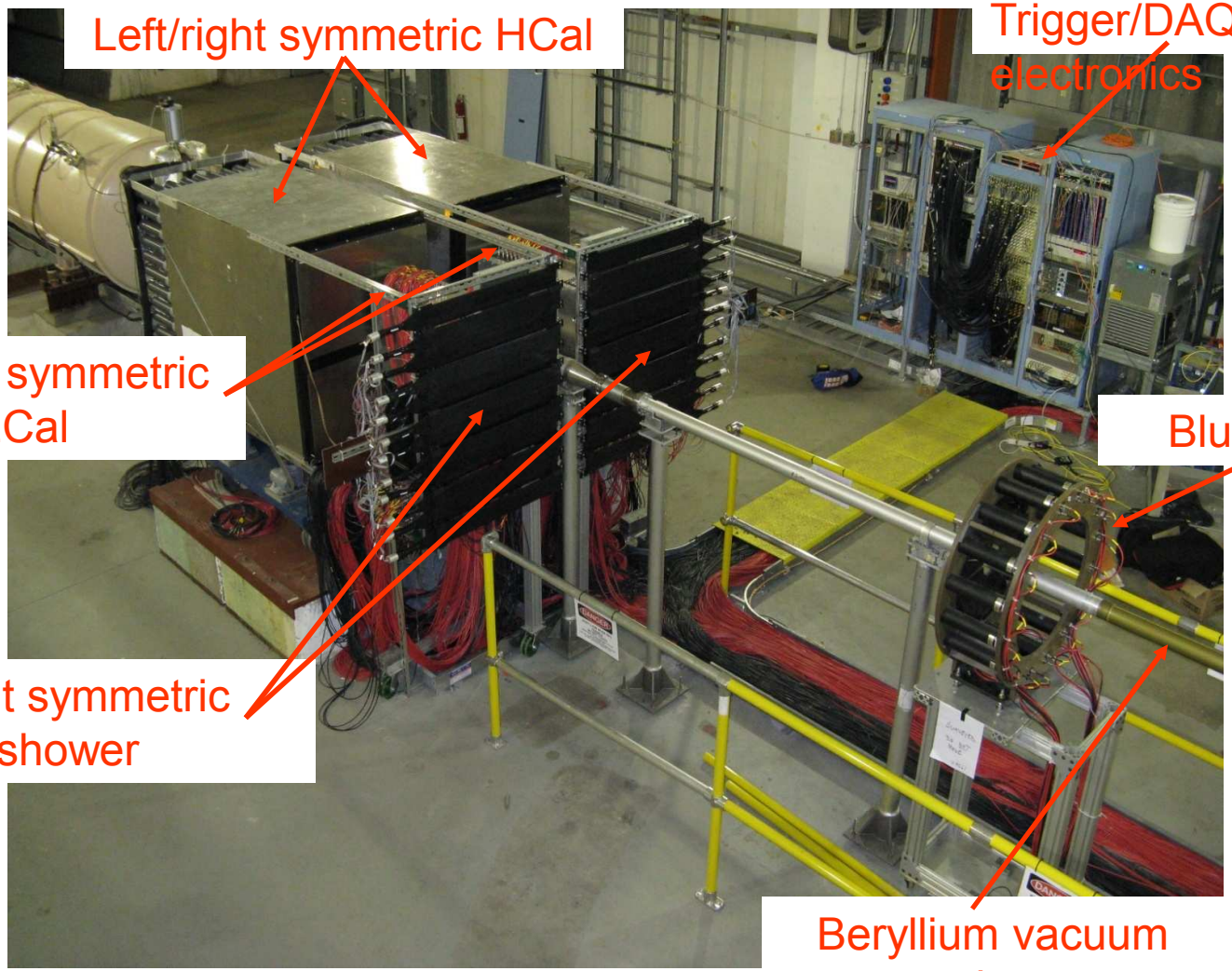


Two test runs for A_NDY



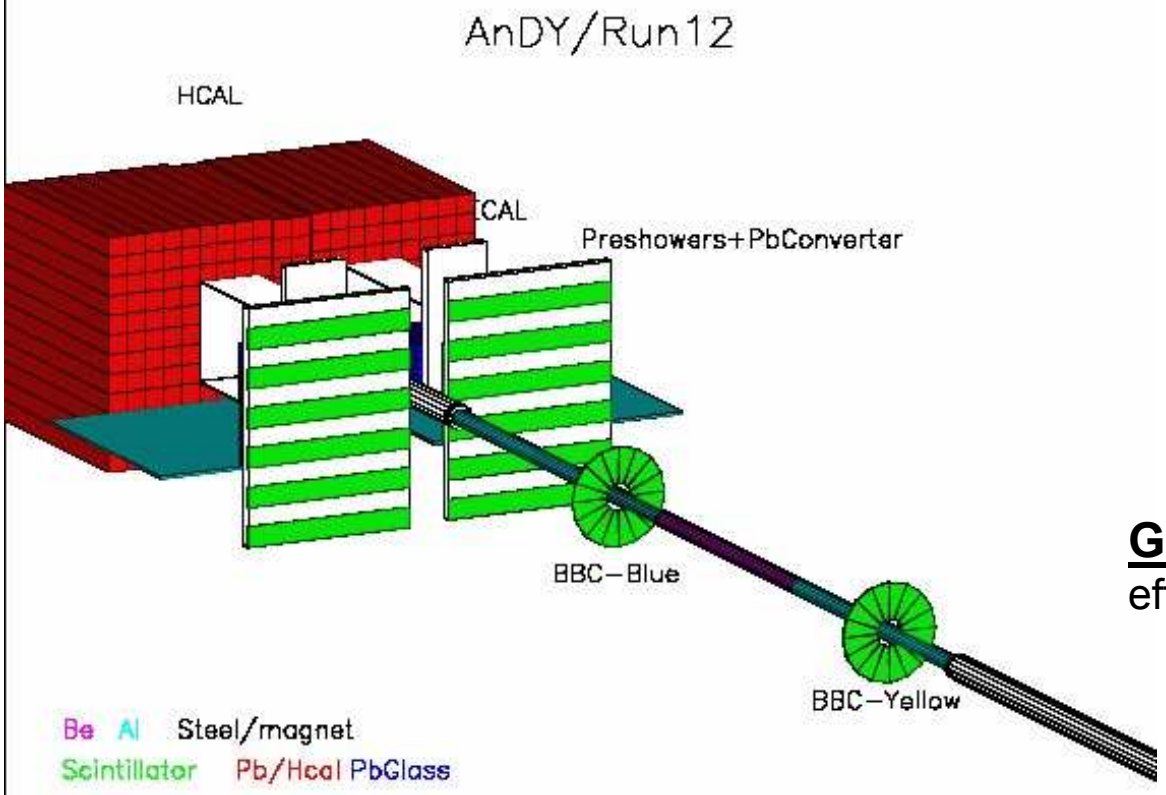
IP2 collisions began around mid-store with minimal impact on IP6 & IP8.
2x higher luminosity at IP2 compare to run-11 (decreased β*).

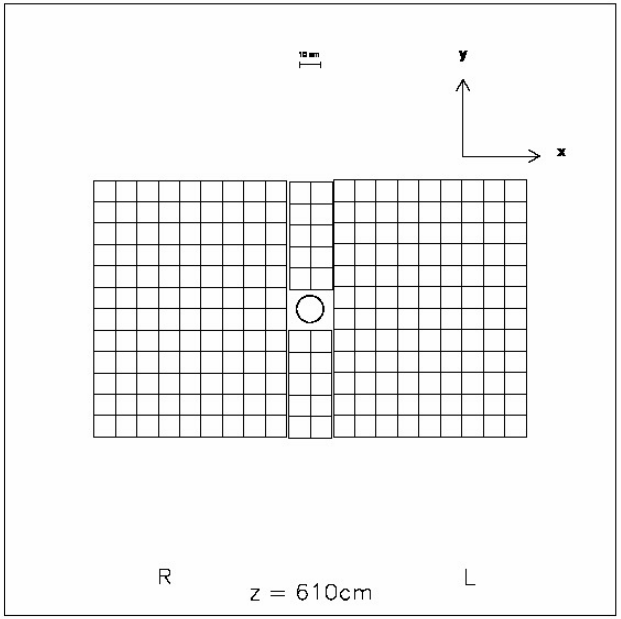
Run-11 setup


Left/right symmetric HCal
Trigger/DAQ electronics
Left/right symmetric ECal
Blue-facing BBC
Left/right symmetric preshower
Beryllium vacuum pipe

Run-12 setup

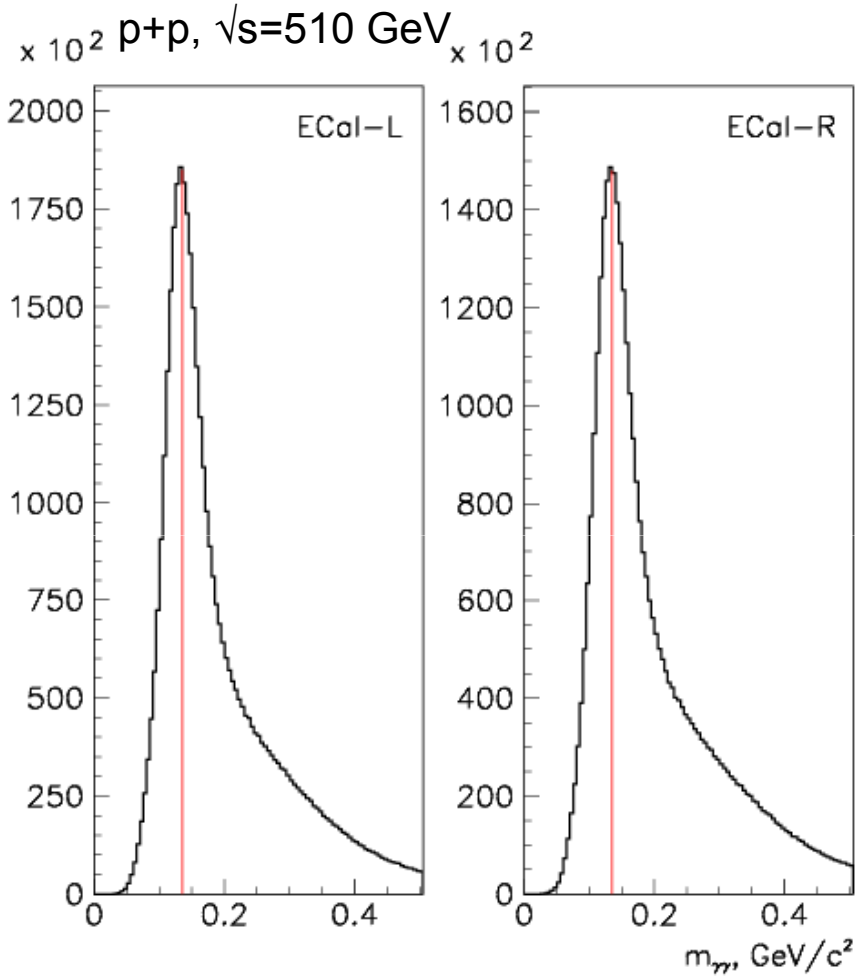
HCal Left/Right modules used in run-11 were modified into annular 20x12 detector with 2x2 hole for the beam pipe





Goal: to establish from measurement effects from trigger bias on run-11 jets

Calibration - ECal



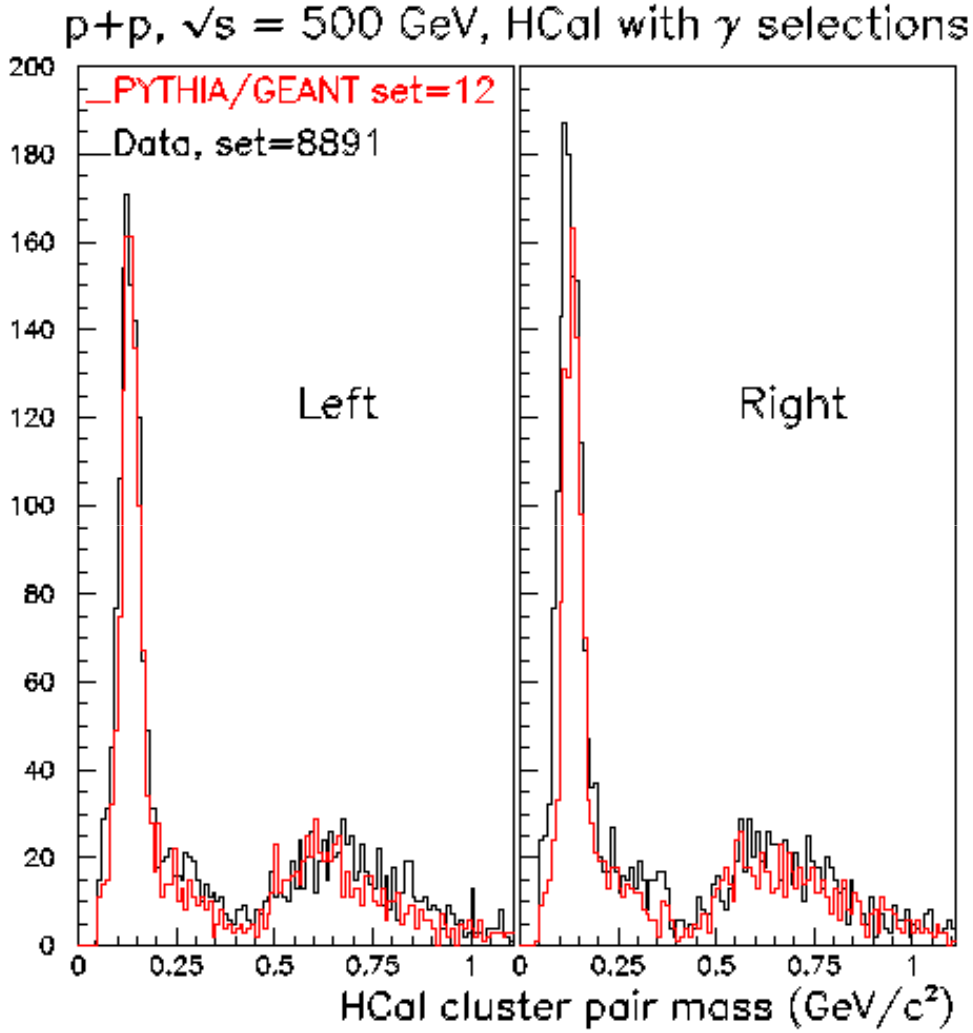
Di-photon invariant mass distribution in ECal modules

Calibration based on $\pi^0 \rightarrow \gamma\gamma$ reconstruction – iterative procedure to scale the gain to put the peak at the known π^0 mass

Event selection:
(1) $N_\gamma \geq 2$;
(2) 15 GeV < $E_{\gamma\gamma}$ < 40 GeV;
(3) $z_{\gamma\gamma}$ < 0.8;
(4) fiducial volume cut 1/2 cell.

Clear π^0 signal with the peak at the right place; cell-by-cell calibration of the matrices is known at the level of ~2%.

Calibration - HCal



Cluster pair mass distributions in HCal modules from minimum-bias run-11 data and simulations (absolute normalization)

- Relative calibration of HCal cells by cosmic ray muons
- Absolute energy scale is set by:

1) slope matching of energy distributions from minimum-bias data and simulation;
2) reconstruction of $\pi^0 \rightarrow \gamma\gamma$ from HCal clusters

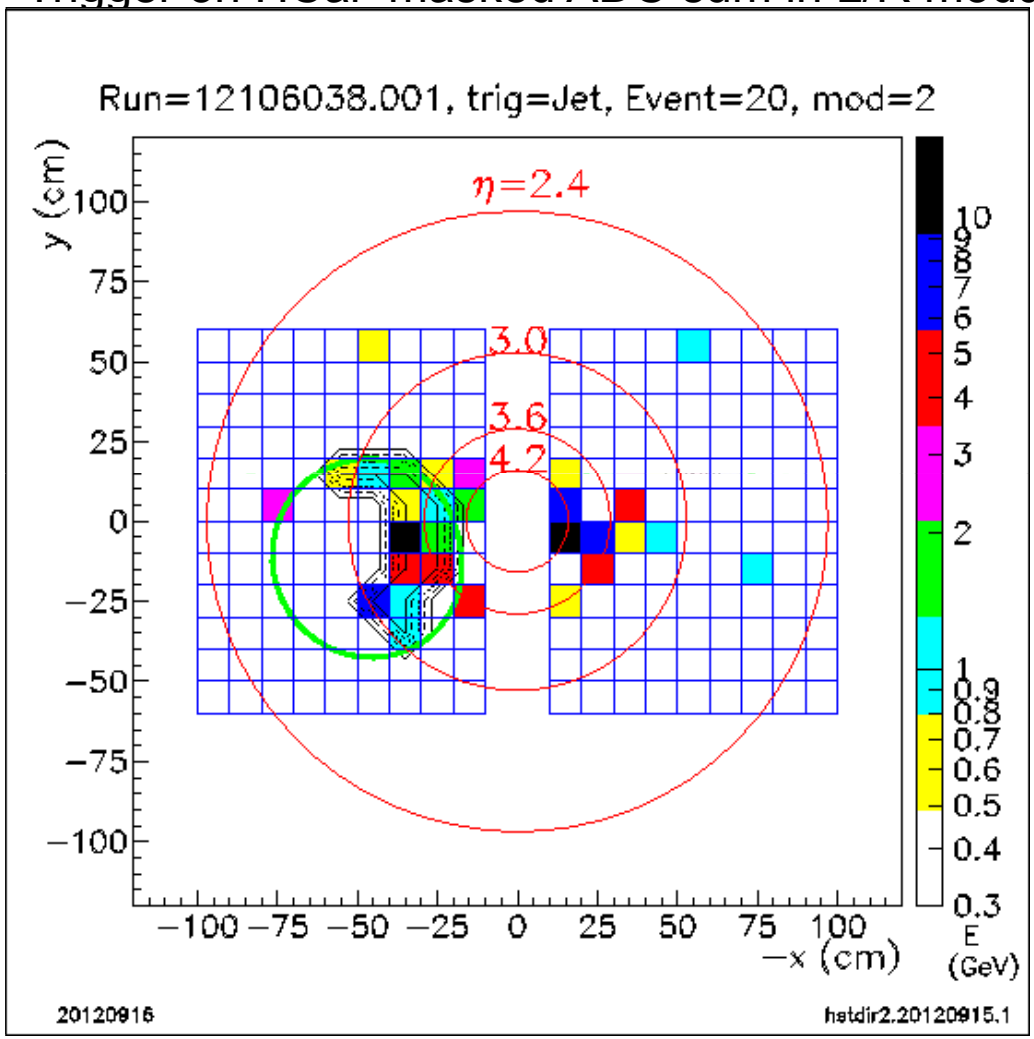
Cuts applied to select "electromagnetic" clusters:

(1) 1-tower clusters; (2) Ecl > 1.8 GeV;
(3) Epair > 5 GeV; (4) zpair < 0.5;
(5) |x|>50 cm to avoid ECal shadow

- Corrections to HCal calibration for hadron showers still need to be evaluated (expected ~20% from simulations)
- Neutral pions set the energy scale for the jets

Jet trigger events

Trigger on HCal masked ADC sum in L/R module

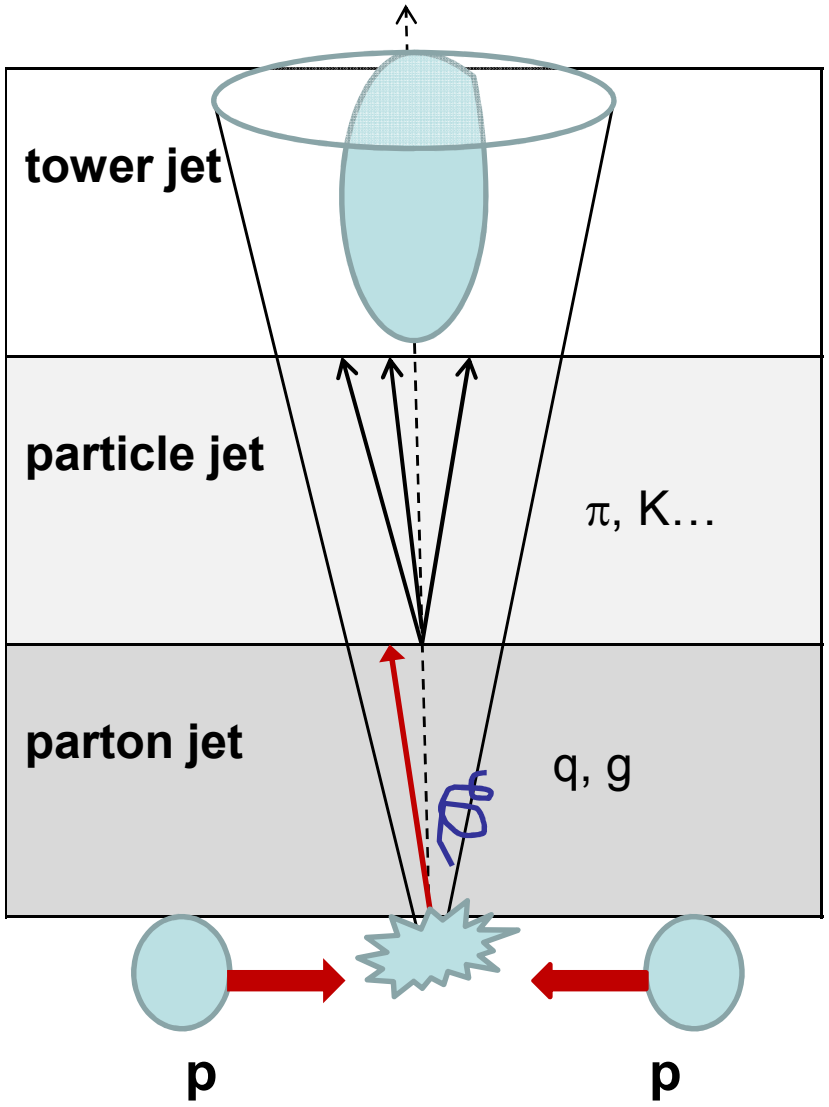


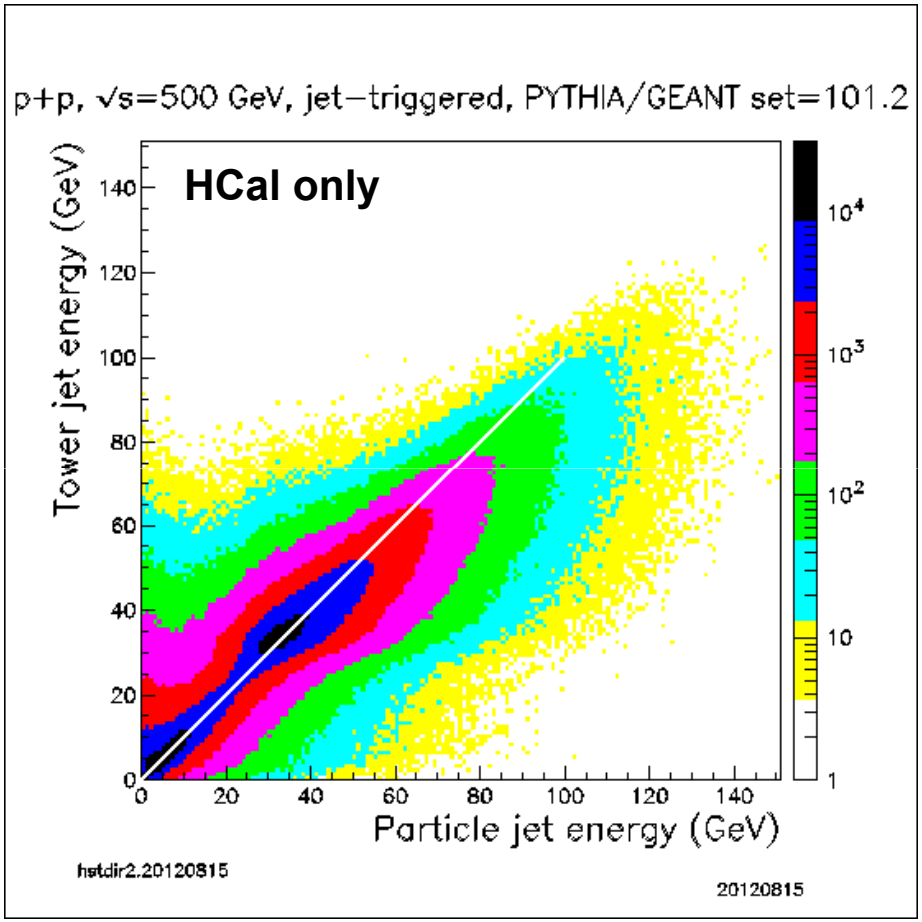
Events look "jetty", as expected (and cosmic ray muons show expected tracks)

Using cone jet finder:

1) High tower in HCal masked region is taken as a seed;
2) sum energy in cone of $R=\sqrt{\Delta\eta^2+\Delta\varphi^2}=0.7$ about high tower, with tower energy thresholds of 0.25 GeV
3) compute energy-weighted average $\langle\eta\rangle,\langle\varphi\rangle$
4) iterate until convergence...
   a) sum energy in cone of radius R about $\langle\eta_N\rangle,\langle\varphi_N\rangle$
   b) compute energy-weighted average $\langle\eta_{N+1}\rangle,\langle\varphi_{N+1}\rangle$
5) impose acceptance cuts to accept/reject jet: $|\eta_J - 3.25| < 0.25$, $|\varphi_J - \varphi^{off}| < 0.50$, where $\varphi^{off}=0$ for HCL and $\varphi^{off}=\pi$ for HCR

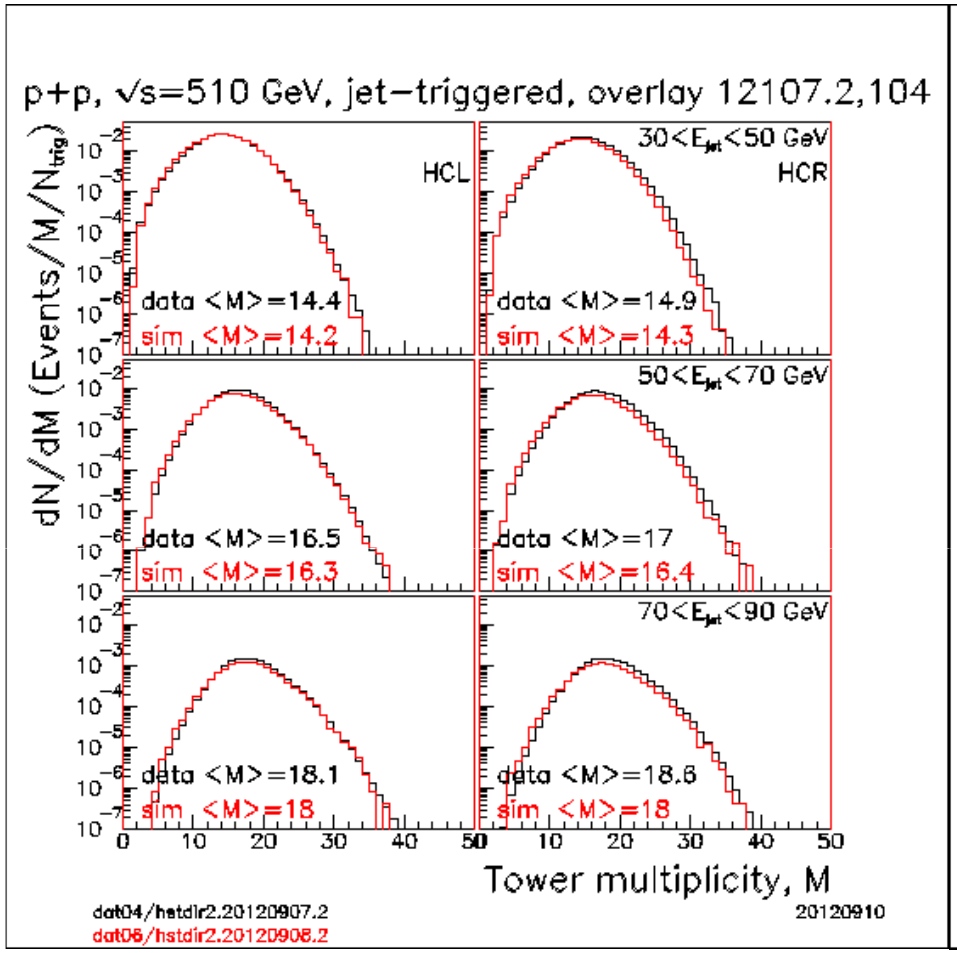
Jet definitions and correlations

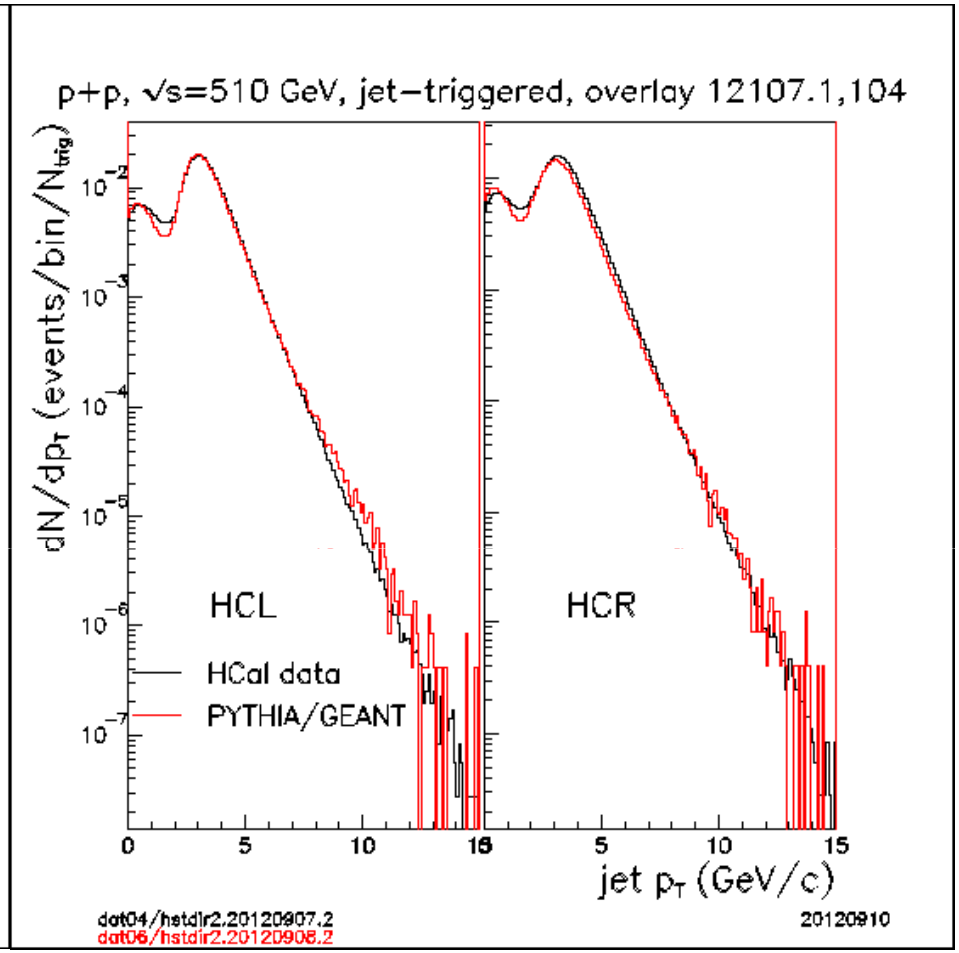




Correlation between particle jet energy and tower jet energy

Jet kinematics

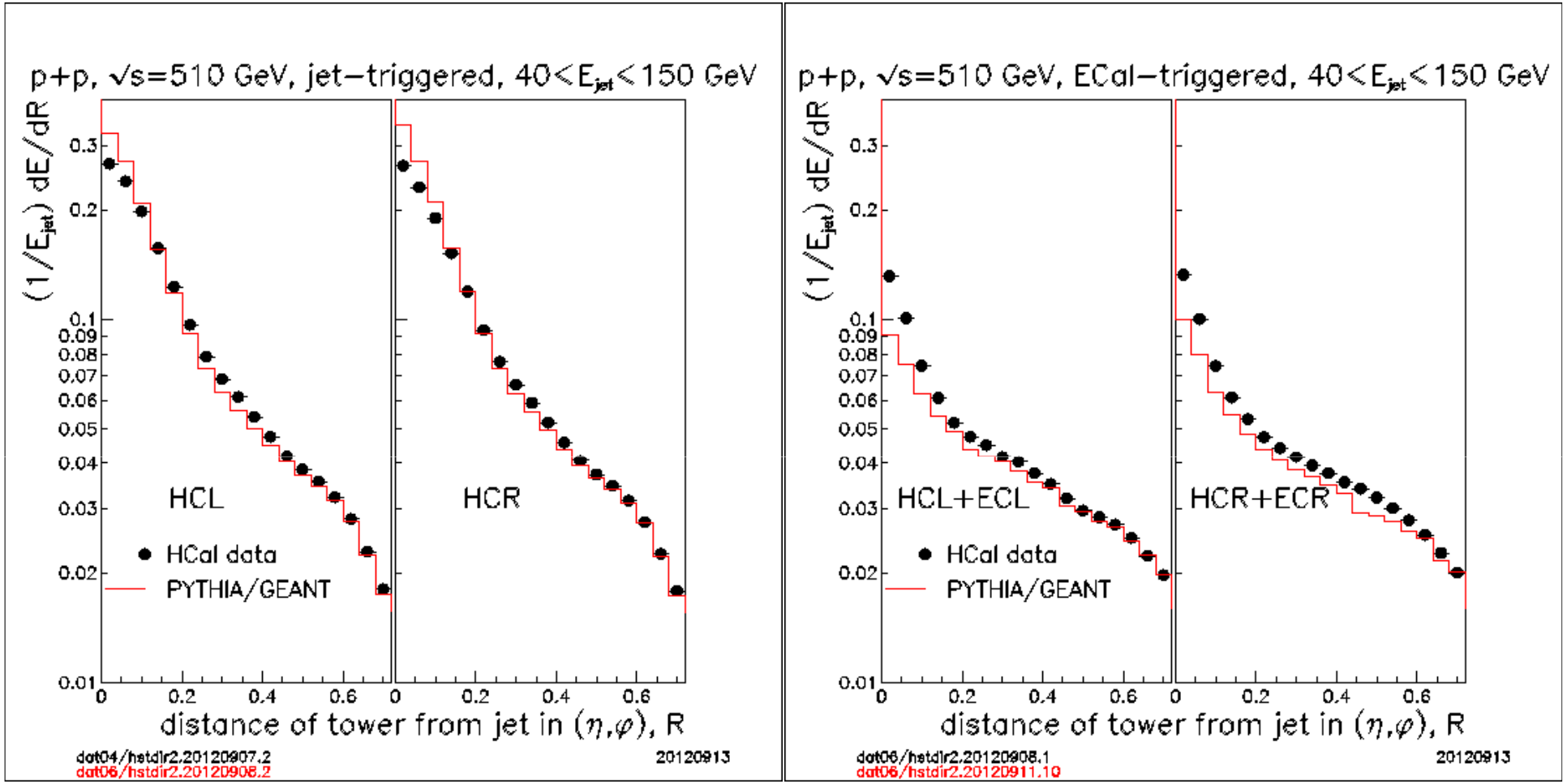




Multiplicity of towers in the jet cone as a function of jet energy from data and simulations

Jet p_T and x_F are calculated ignoring mass; good agreement between data and simulations above trigger threshold

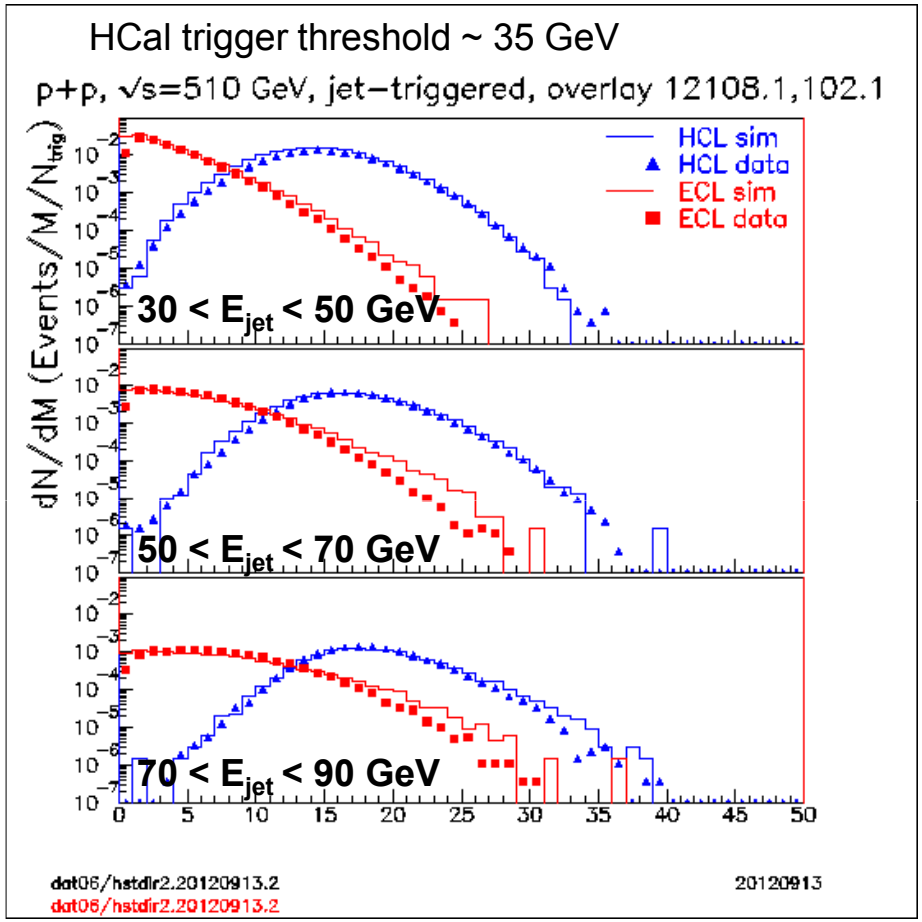
Jet shape

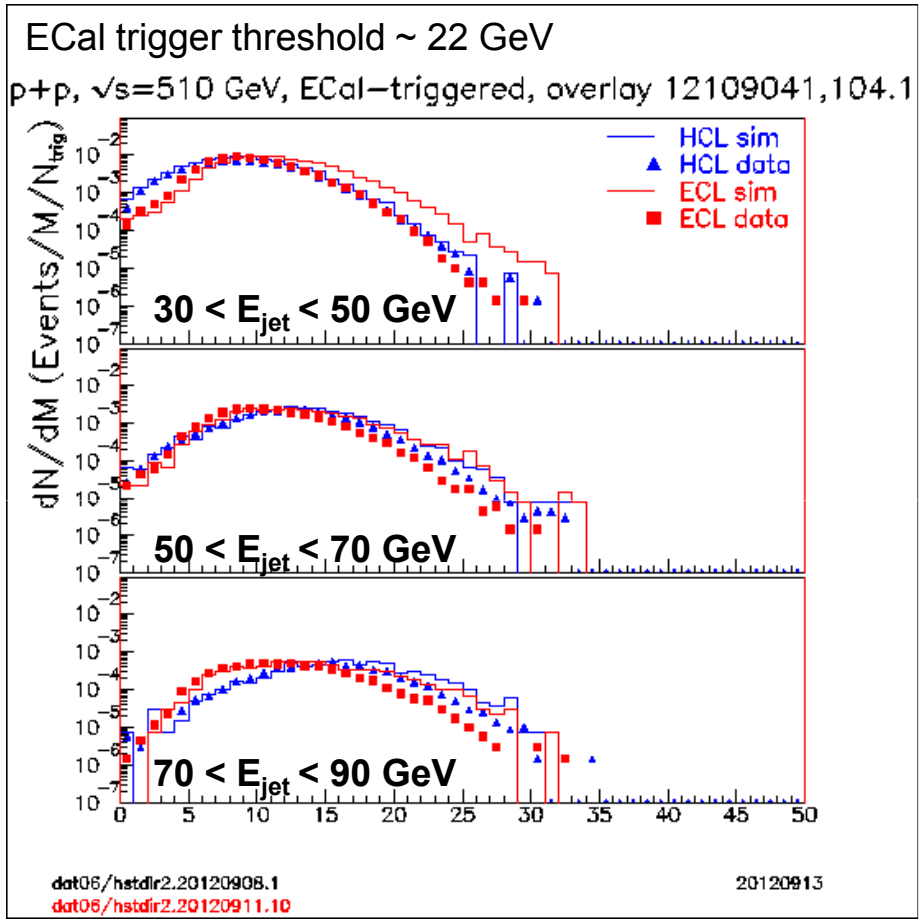


Distribution of fraction of energy in the jet as a function of distance in η-φ space from the jet center (jet shape)

Trigger bias for forward jets

Tower multiplicity for the jet trigger (left) and ECal sum trigger (right) events



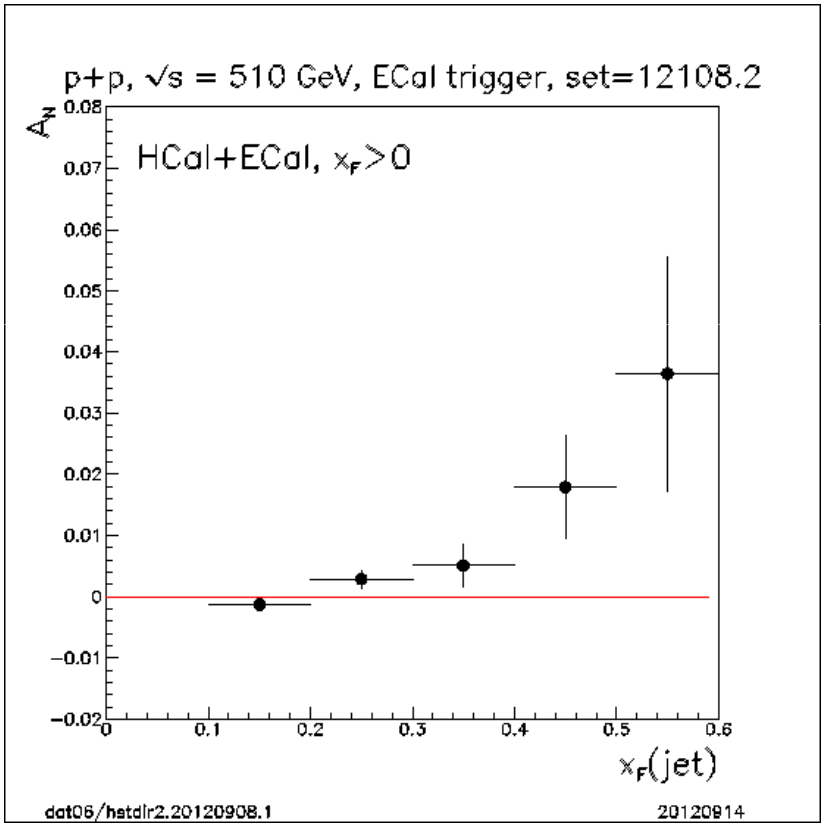


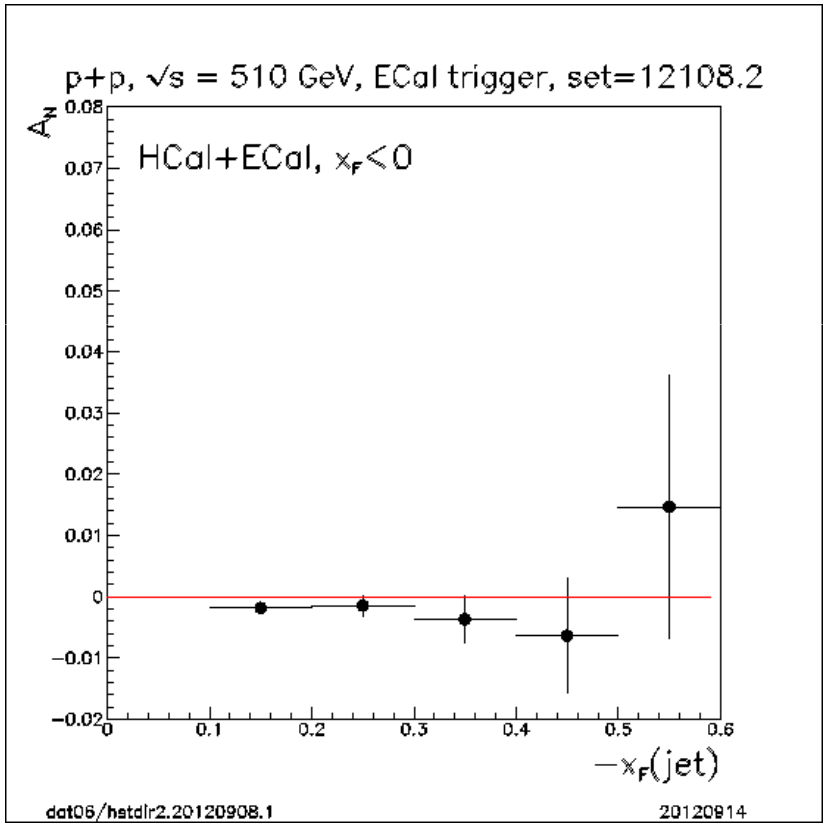
- ECal trigger biases jets, and the bias extends well beyond the trigger threshold
- The trigger bias imposed by ECal likely prefers jets that fragment to a hard neutral pion

A_N for ECal-triggered forward jets

Cross-ratio method to calculate the asymmetry:

$$A_N = \frac{1}{P_{Beam}} \times \frac{\sqrt{N_L^{\uparrow} \cdot N_R^{\downarrow}} - \sqrt{N_R^{\uparrow} \cdot N_L^{\downarrow}}}{\sqrt{N_L^{\uparrow} \cdot N_R^{\downarrow}} + \sqrt{N_R^{\uparrow} \cdot N_L^{\downarrow}}}$$

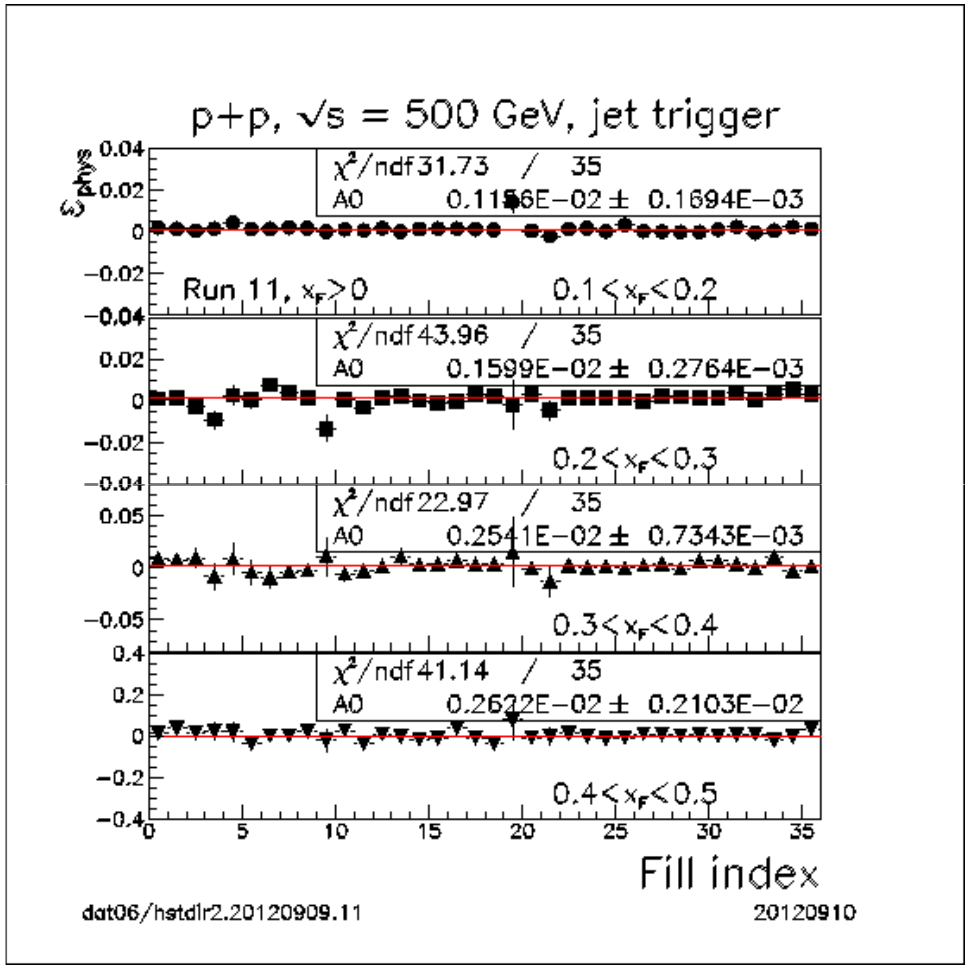


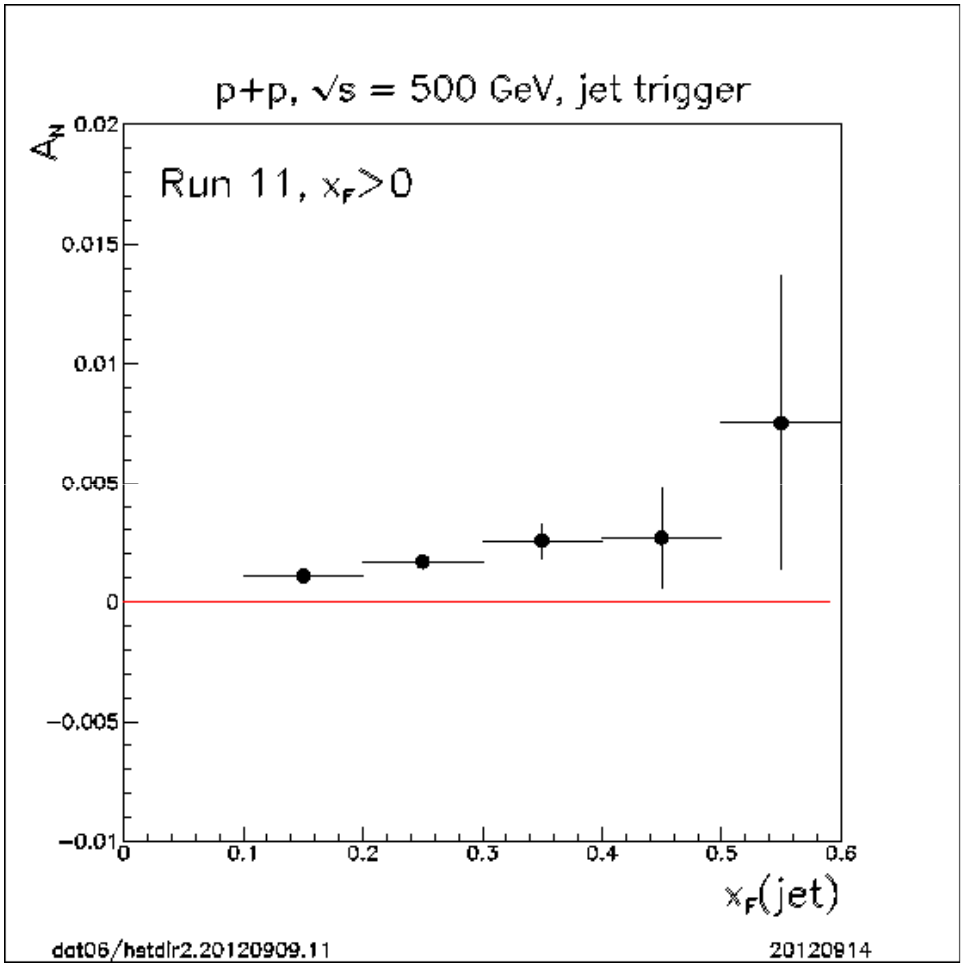


ECal-biased jet A_N at $x_F>0$ is positive, A_N at $x_F<0$ is generally consistent with zero

Forward jet A_N (x_F>0)

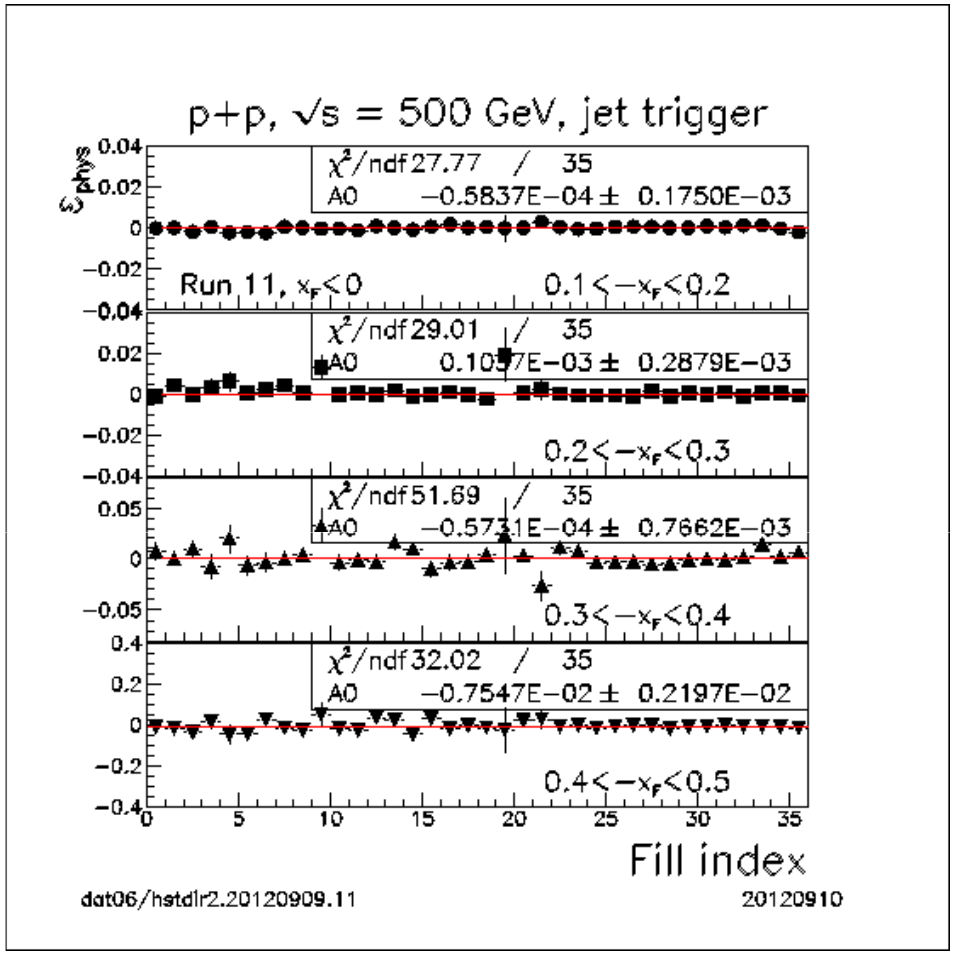
$$\varepsilon_{phys} = P_{Beam} \times A_N$$

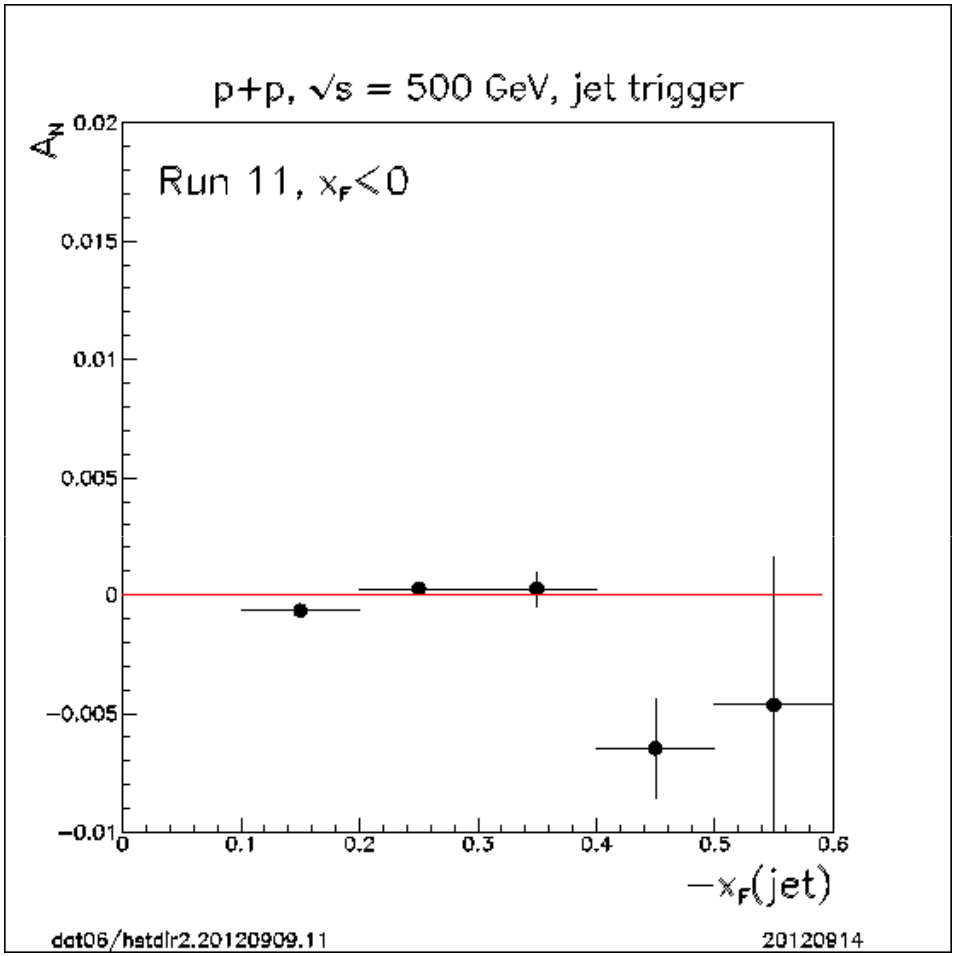




Jet A_N is small (~10^{-3}) and positive (up to ~6σ); fill dependence is consistent with statistics

Forward jet A_N (x_F<0)





Jet A_N at negative x_F (sorted by spin state of the (Yellow) beam heading away from the detector) is close to zero

Conclusions and outlook

- Improvements in the procedure of bringing IP2 into collisions and higher luminosity has been demonstrated in RHIC run-12.
- Measurements of ECal triggered and full jets have been made. Trigger on electromagnetic energy biases jets.
- First measurements of the jet analyzing power show that forward jets have a positive A_N that is small.

not unexpected, but…

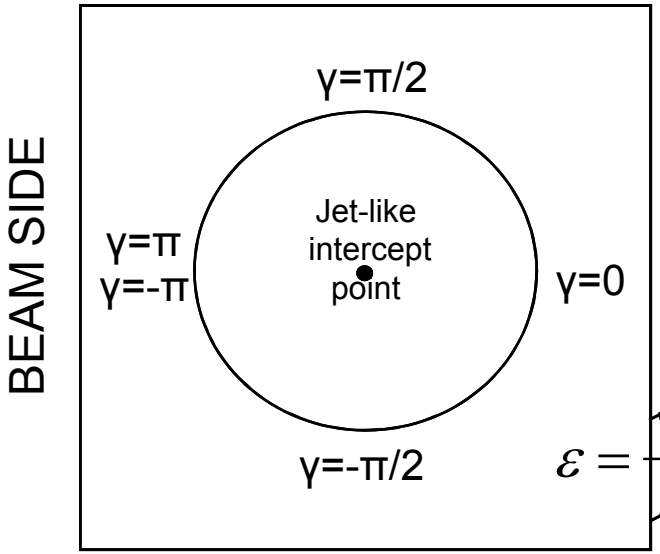
- Hadronic final states are complicated and hard to describe

- Drell-Yan production is believed to be best understood by theory for transverse momentum-dependent effects, and there is a fundamental prediction about sign change to test by experiment

Backup

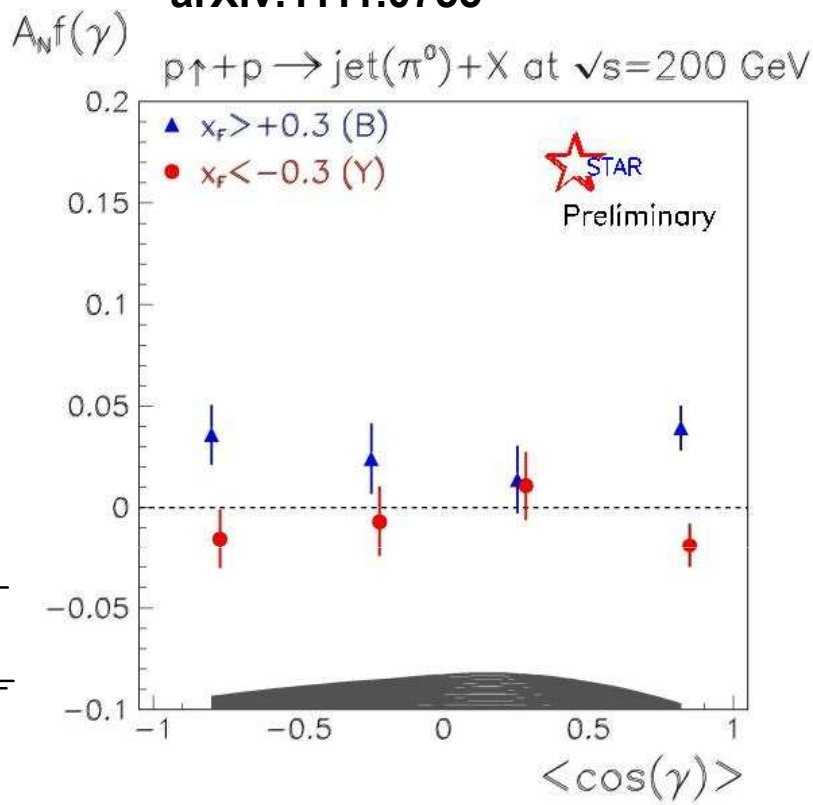
Asymmetry for “jet-like” events

The γ angle is the angle which jet-like event axis plane closes with the outgoing neutral pion. For a jet-like event hitting the center of a module, γ is defined as in the image, and mirror symmetrically (CW-CCW) for the other module.



$$\varepsilon = \frac{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} - \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}{\sqrt{N_L^{\uparrow} N_R^{\downarrow}} + \sqrt{N_L^{\downarrow} N_R^{\uparrow}}}$$

arXiv:1111.0755

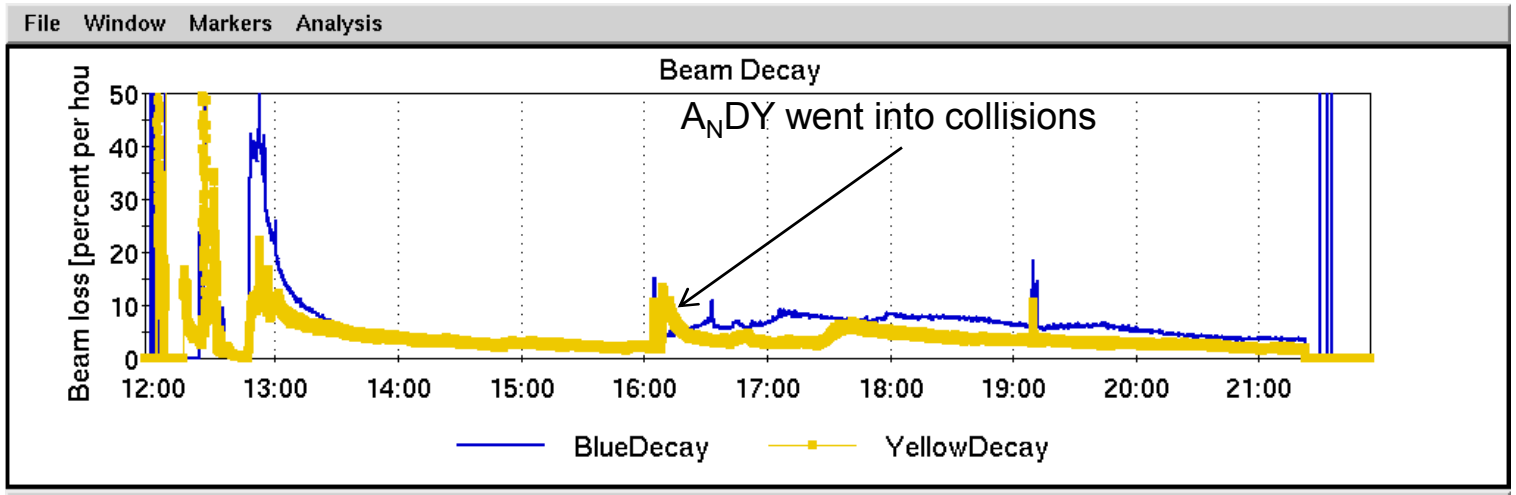


For the bin near γ=0:

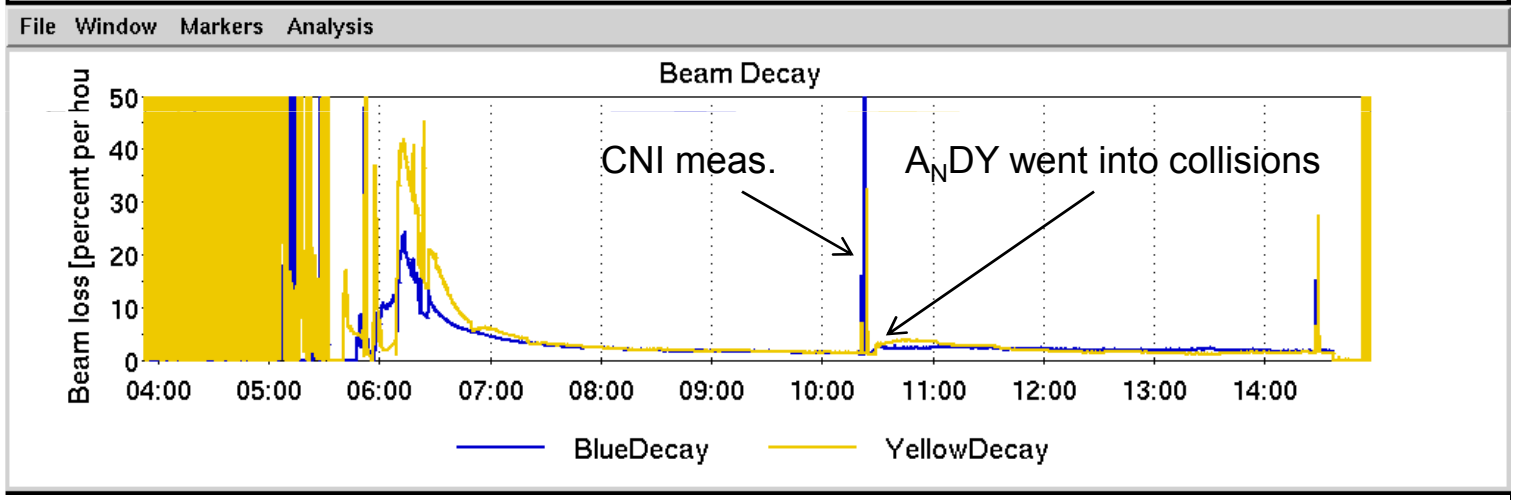
- $N_L^{\uparrow}$ stands for spin-up left-scattered jet and right scattered pion
- $N_R^{\downarrow}$ stands for spin-down right scattered jet and left scattered pion (related to $N_L^{\uparrow}$ by a 180^0 rotation around the beam axis)

The “jet-like” events x_F>0 asymmetry is positive (av. 0.031±0.014), but doesn’t show any Collins effect contributions.

Impact of IP2 collisions



Fill 15470
2011-Apr-17



Fill 16727
2012-Apr-16

Transient beam losses were essentially eliminated in run-12

Impact of IP2 collisions

Background in Phenix muon arms

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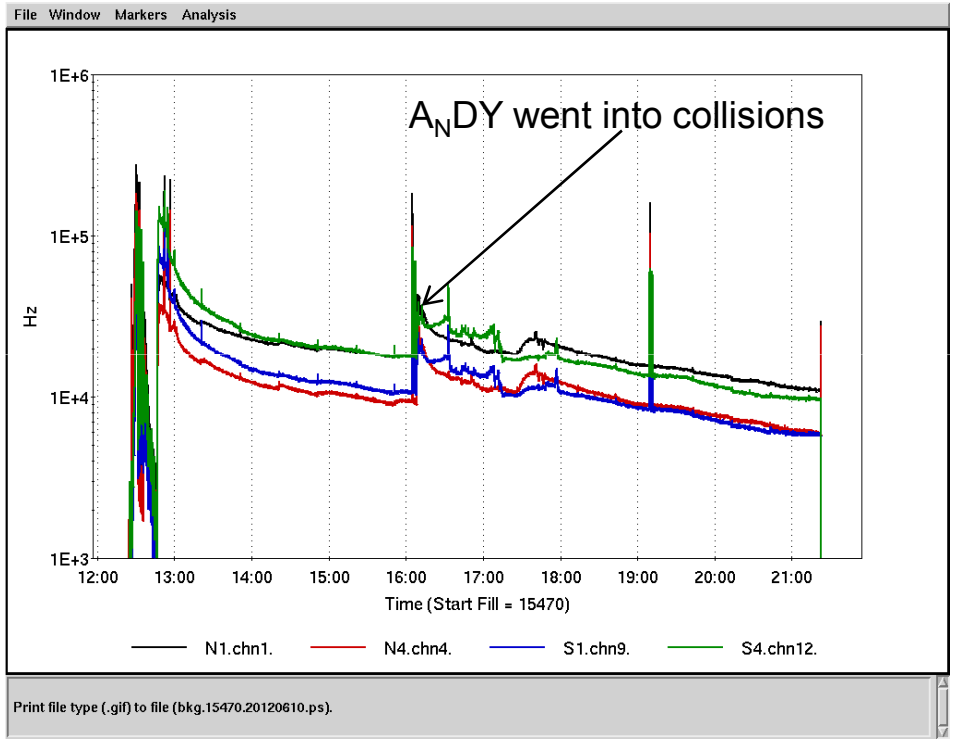
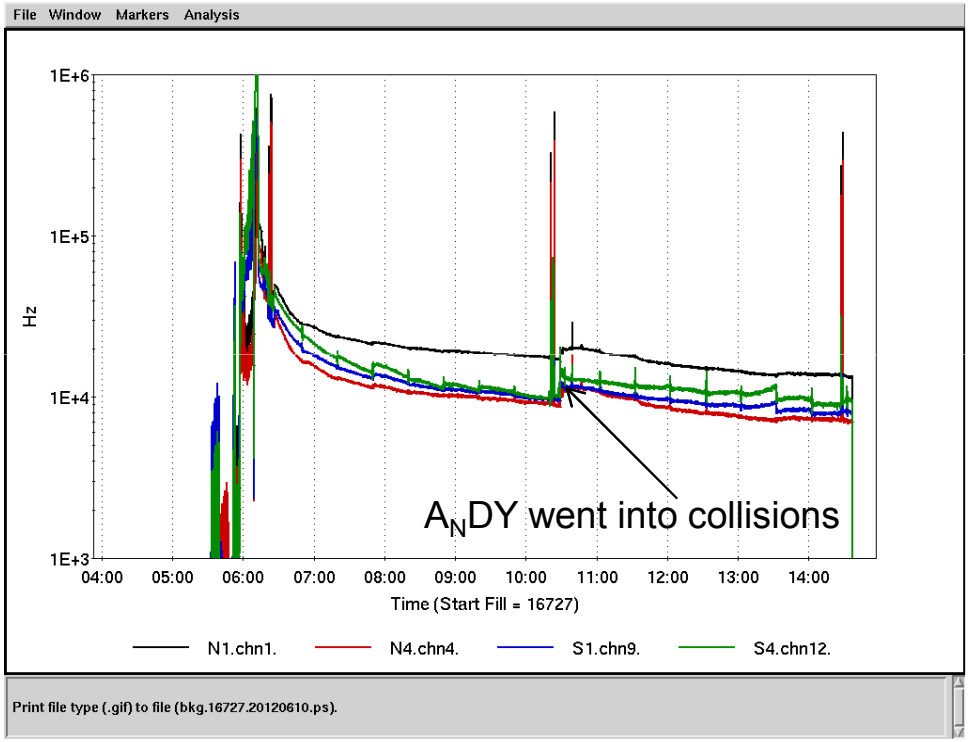
2011-Apr-17

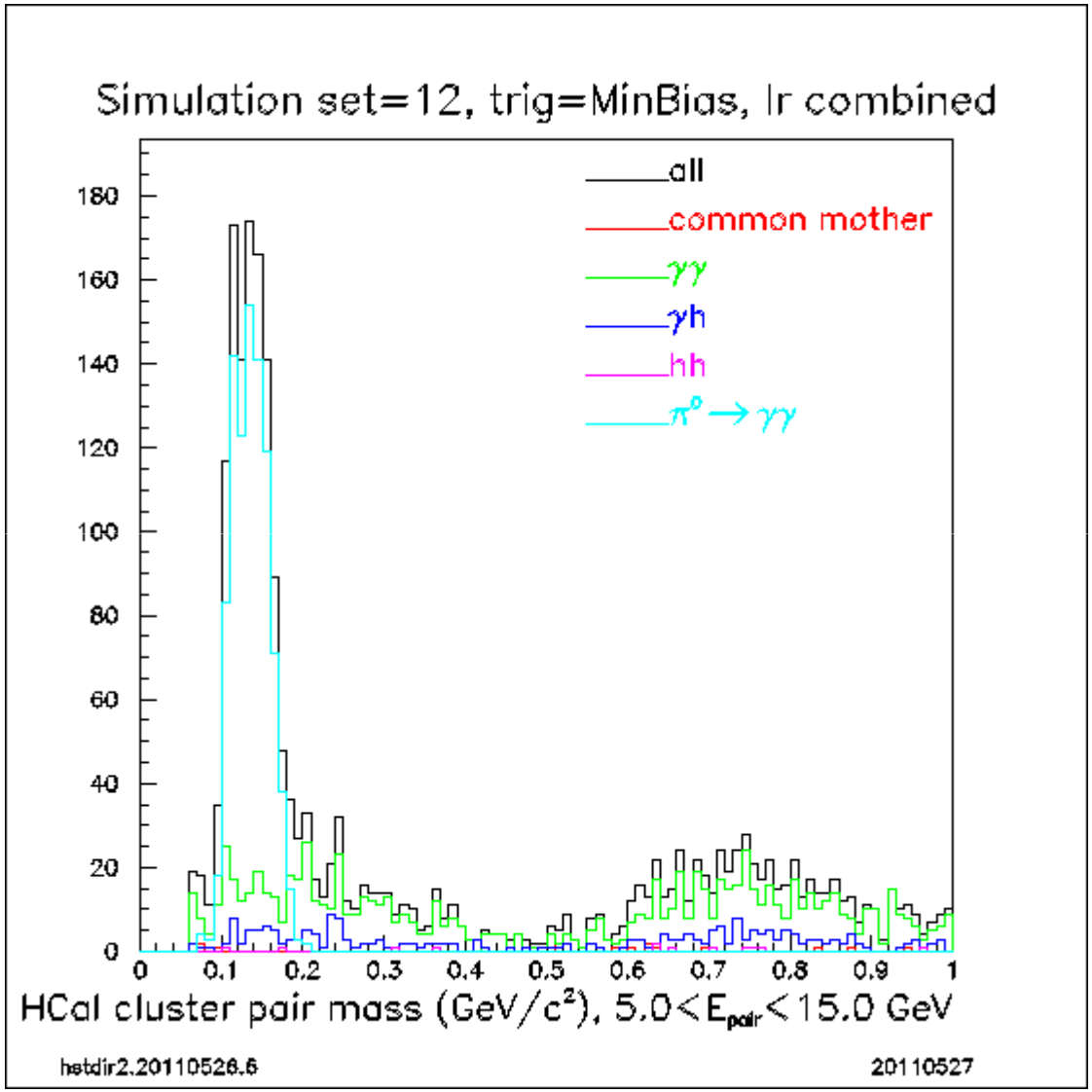


Fill 16727
2012-Apr-16



Background at IP8 from bringing into collisions IP2 is reduced

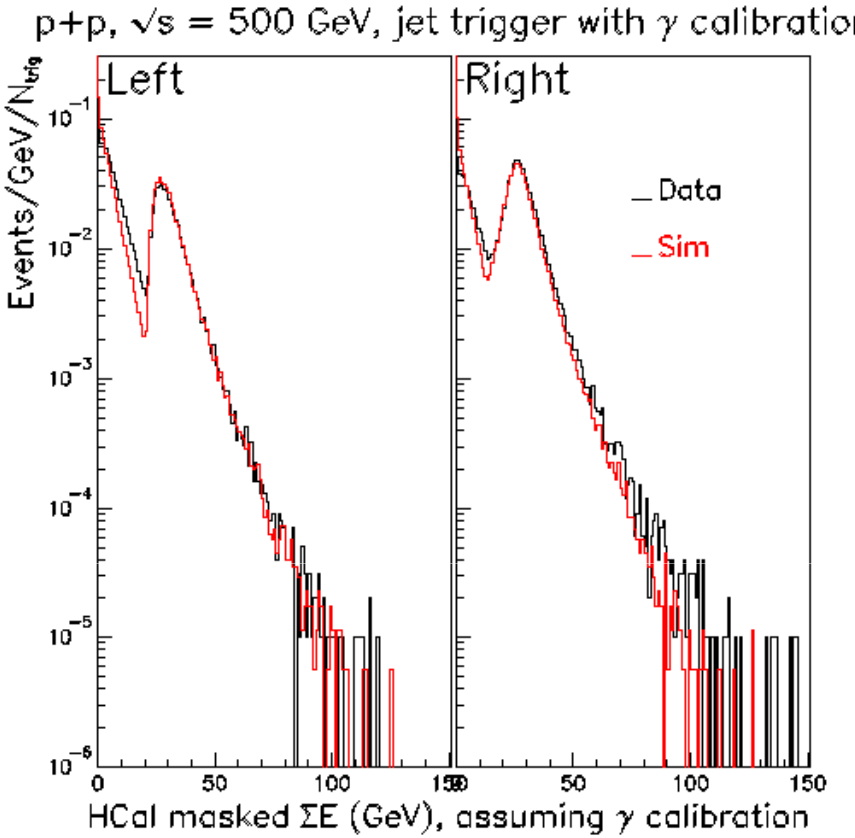
Pair mass from association

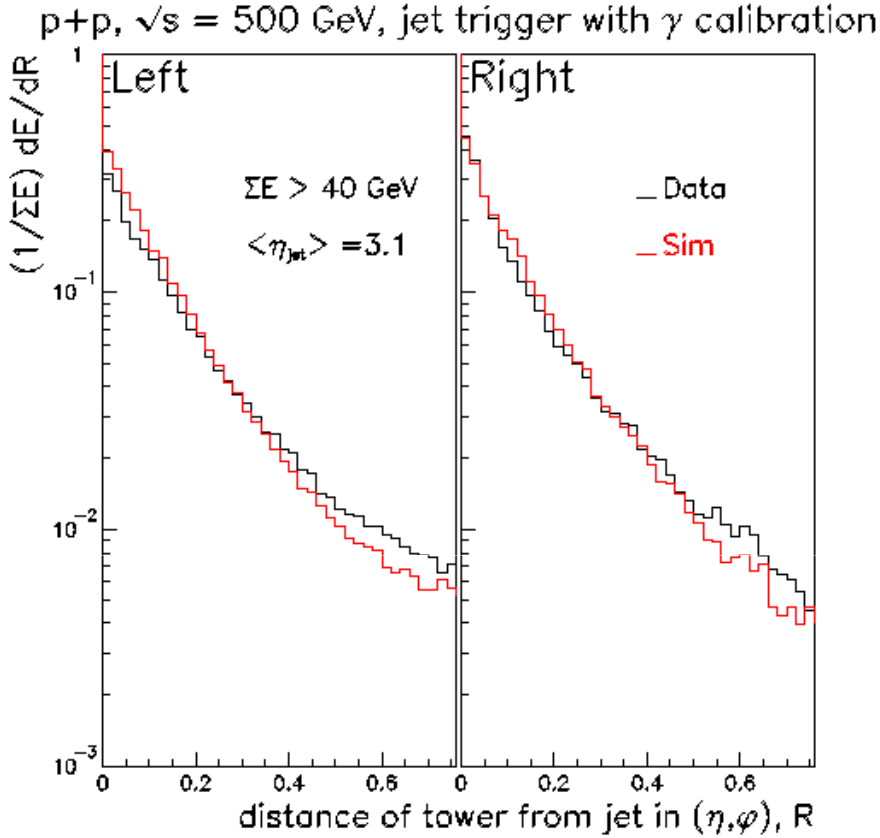


- Pair mass is computed subject to the requirements (1) 1-tower clusters; (2) E>1.8 GeV; (3) |x|>50 cm to avoid ECal shadow; (4) >1 clusters to form pairs; (5) E_{pair}>5 GeV; (6) M_{pair}<0.5 GeV; and (7) z_{pair}<0.4.
- The association analysis then allows identification of the origin of the clusters: i.e., $\pi^0 \rightarrow \gamma\gamma$ pairs; $\gamma_1\gamma_2$ combinatoric background; γh combinatoric background; etc.
- 916/1245 events with M_{pair}<0.22 GeV/c^2 are from $\pi^0 \rightarrow \gamma\gamma$ pairs

Towards Forward Jets

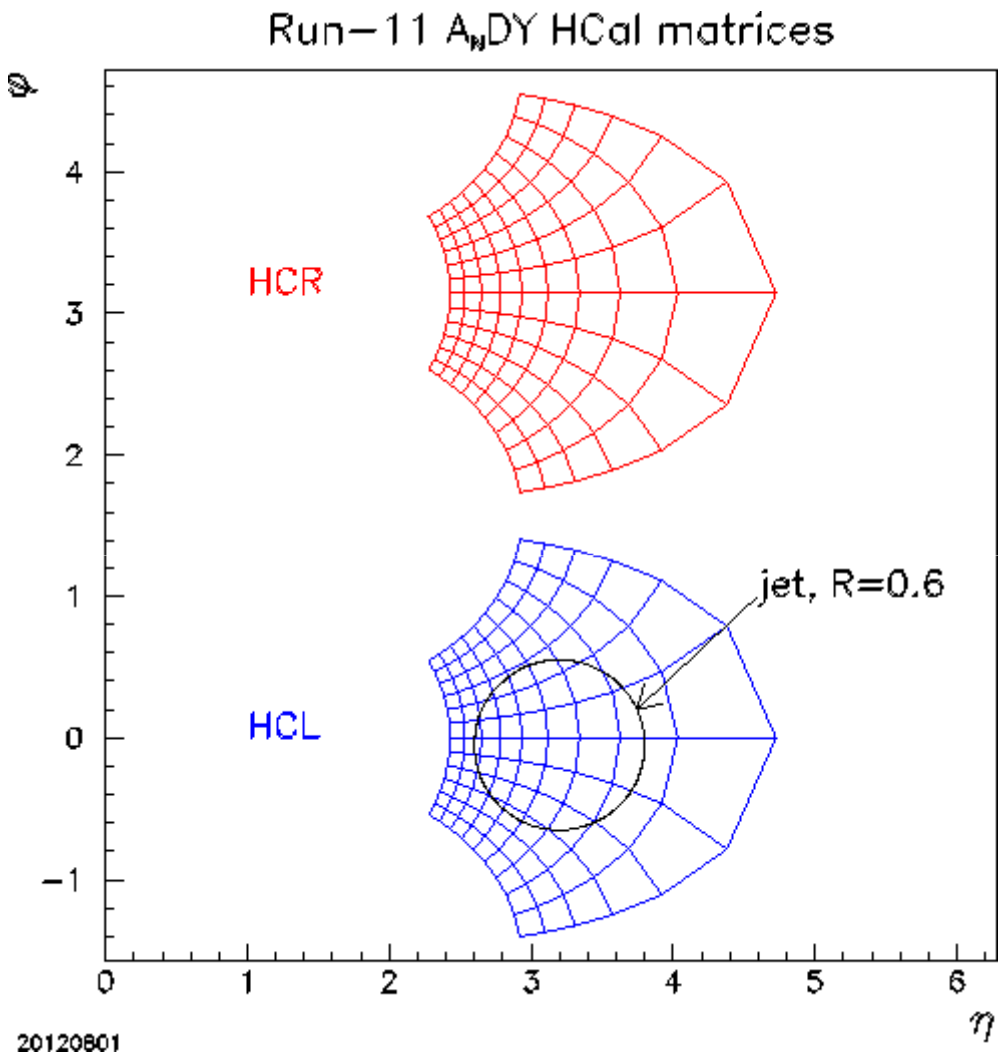
Run-11 A_NDY **arXiv:1112.1812**



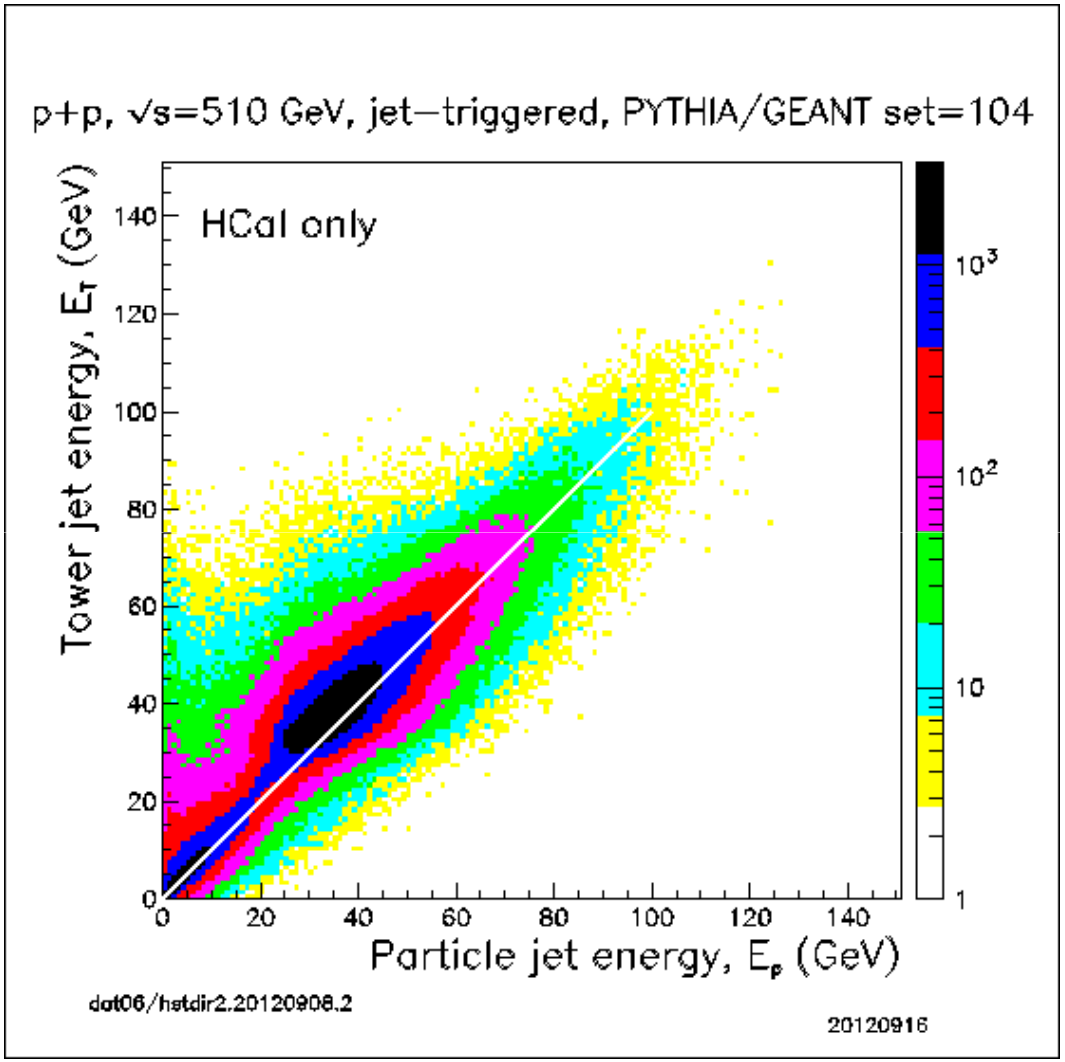


- Good agreement between data and PYTHIA/GEANT simulation for summed HCal response excluding outer two perimeters of cells ⇒ QCD backgrounds can be modeled
- Good agreement between data and simulation for jet shape
- Next up: forward jet analyzing power

HCal acceptance in (η,φ)–space



Jet energy



E = dE/0.48 - 0.1 GeV

dE – deposited energy in a tower
E – reconstructed tower energy