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## Recent/Ongoing Research Highlights

July 2005

### CMS: Endcap Muon Chambers

I led the CMS Endcap Muon Chambers project from the earlier R&D stages starting in 1994 through the end of the construction in 2005. The CMS Muon System will play the key role in discovering the Higgs boson, should it exist, and in many other new physics searches at LHC (SUSY, Extended Gauge Group bosons, Extra Dimensions, etc). Nine research groups (~60 physicists) from 6 US universities (UF, UCLA, UCR, UCD, Wisconsin, and CMU), Fermilab, Petersburg Nuclear Physics Institute (Russia), and Institute of High Energy Physics (Beijing) collaborated on this project. The CMS Endcap Muon Detectors have the total sensitive area of 6,000 m<sup>2</sup> (approximately equal to the football field area) and will detect muons with the spatial precision of better than 100  $\mu\text{m}$ . The system is based on the technology of Multi-Wire Proportional Chambers (MWPC), or more specifically, Cathode Strip Chambers (CSC), both invented by G. Charpak many years ago.



The challenge of the R&D stage of the project was to further the CSC technology so that it could be realized at the scale and the level of complexity adequate for the CMS requirements, i.e. by far exceeding those of any of the past systems. In particular, the CMS Endcap Muon Chambers have about 2,000,000 sensitive wires (c.f. ~110,000 wires in the NA4 experiment, the largest MWPC system ever built before). There has not been an experiment where the CSC technology with the precision of <100  $\mu\text{m}$  was ever used at the scales exceeding a few square meters. Another novel feature of the CMS Endcap Muon chambers is their precision self-triggering capabilities, i.e. detection of muon track stubs (6-hit tracks, also known as Local Charged Tracks) with ~1 mm precision and ~4 ns time resolution at less than 500 ns latency.



In addition to the overall leading role in the chamber R&D effort, I can take personal credit for a number of design ideas that made construction of such a system possible. The most controversial among those was probably the choice of very wide strips, which I argued was possible while maintaining the required spatial precision of 100  $\mu\text{m}$ . This was adopted only after the beam tests with the first small scale chamber prototype in 1995 [1] validated the idea. To achieve the required 1 mm spatial resolution in detection of Local Charged Tracks at the pre-trigger level, I proposed what is now known as the cathode comparator readout. The beam tests of 1996 of the first prototype of such readout scheme proved the concept [2] and the comparator readout is now a part of the system. After building a number of full scale prototypes and carrying out a successful program of tests in cosmic rays at Fermilab in 1997, muon beam at CERN in 1998 and 1999 [3] and, also, in high rate environment in 1997-2001 [4, 5], the project moved in the construction stage in 2000. The chamber design is thoroughly documented in the CMS Muon Technical Design Report [6], of which I was one of the principal authors.



Mechanically, the detectors were assembled at Fermilab, PNPI (St. Petersburg), and IHEP (Beijing). Assembly of chambers with electronics and detector performance validation took place at UF, UCLA, PNPI, and IHEP—at so-called Final Assembly and System Tests sites, or FAST sites. In addition to coordinating the overall construction effort (with all the associated duties of keeping the project on schedule and at cost), I led the UF group effort on designing the program of performance validation tests and developing the FAST-DAQ and data analysis software for the FAST sites. This effort resulted in a suite of about 100 sub-tests. From the DAQ point of view, these tests were conveniently grouped in 20 distinct data taking runs, also known as FAST Site Tests [7]. UF and UCLA FAST sites started their production testing in 2002, PNPI and IHEP followed in 2003. Without exaggeration, the FAST site tests proved to be indispensable in identifying electronic board problems and providing quick feedback to the electronic board developers, which allowed them to take corrective actions at the earlier stages of electronics production. At CERN, we set up two sites for chamber pre-installation tests and post-installation commissioning, where exactly the same FAST-DAQ setups are now used.



As of July 2005, all 396 chambers (plus 22 spares) have been delivered to CERN, 234 of them are installed and fully commissioned. Notably, so far, not even a single wire out of 2,000,000 in the system has ever snapped. All Endcap Muon Chambers perform right on specs and have earned the reputation of a very reliable system. In fact, it was the cosmic ray muons detected by the Endcap Muon System (using the online FAST DAQ and Event Display) that was shown to the President of France Chirac on his visit to CERN in October of 2004 on the occasion of the laboratory's 50<sup>th</sup> anniversary.

## CMS: Endcap Muon System Data Quality Monitoring (DQM)

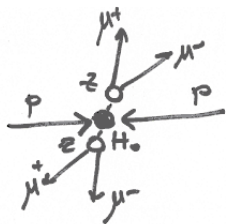


Setting up a coherent program (and all associated software tools) for online monitoring of detector performance is a very important task of the Maintenance and Operation program. Since 2003, I took charge for coordination of this task for the CMS Endcap Muon System [8]. The scope of the Endcap Muon System is about 600,000 readout channel of very diverse nature (digitized cathode strip signal waveform, anode wire hits, cathode comparators, pre-trigger anode and cathode Local Charged Tracks, or LCTs). In fact, if not for the LCT-driven readout, the endcap muon system events would be 7 times the size of what is allowed for the whole CMS. Upon commissioning the full Endcap Muon System, we expect to monitor about 200,000 histograms of about 100,000,000 bins. This can only be possible if the automated system of detecting and tracking problems is put in place. This effort is mostly concentrated at UF with some involvement of Caltech, Rice University, and Dubna.

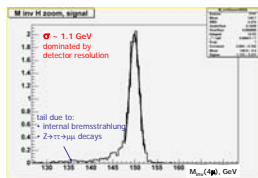


The first Endcap Muon System DQM prototype was released in time for the 2004 beam tests aiming to validate the final off-chamber electronic boards before launching their mass production. Although at that time the DQM prototype was lacking the automated problem detection capabilities, it nevertheless proved to be extremely useful in identifying a variety of readout problems. The next prototype of the Endcap Muon System DQM is ready for its field tests during the Slice Tests of 2005 and CMS Cosmic Challenge Tests in 2006. The range of tests now comes close to all we plan to implement in the final system and the first automated problem detection features are being added. Online DQM will play the key role in commissioning CMS as well as during many years of data taking.

## CMS: Search for Higgs boson via its 4-muon decay channel ( $H \rightarrow ZZ \rightarrow 4\mu$ )

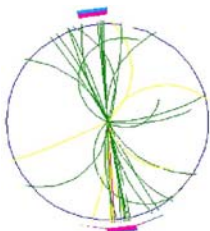


With the LHC start date approaching (2007), preparations for the data analysis become more and more important. I lead the UF group effort on preparations for data analysis “Search for the Higgs boson via its 4-muon decay channel” (also known as “golden channel”). We are working in close collaboration with our CMS colleagues from CIEMAT (Madrid) and Moscow State University. In 2006, CMS will publish the Physics Technical Design Report—the critical milestone intended to show the CMS readiness for physics analyses. The Physics TDR will review the CMS physics potential, given the performance of the final, as-built, hardware and the current state of the reconstruction and analyses software. The 4-muon Higgs boson decay channel is selected to be one of the 8 “full analysis” chapters in the Physics TDR.

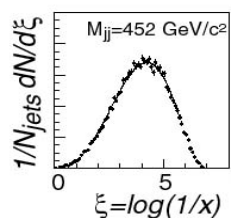


Now we are preparing 4 CMS Notes to be released this fall. The first note will review important background processes including some contributions that were overlooked in earlier studies. The second and third notes will address the theoretical uncertainties associated with PDFs and QCD energy scale variations as well as those arising from differences in NLO and LO kinematics (in all previous studies, NLO corrections have been taken into account only as simple K-factors to the LO cross section). The fourth note in preparation describes the scheme of evaluating the muon isolation cut efficiency from data and the associated experimental systematic errors (the isolation cut is the most critical in this analysis—it is used to suppress the otherwise overwhelming  $t\bar{t}$ ,  $Zb\bar{b}$  and other similar backgrounds). The results of these studies were regularly presented to the CMS collaboration at the internal meetings during the past year.

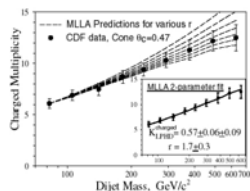
## CDF: Jet Fragmentation



I lead the program of jet fragmentation studies at CDF specifically aiming to advance our understanding of the relative roles of perturbative (calculable) and non-perturbative domains of QCD in shaping the main characteristics of quark and gluon jets. If the crisis of the Electro-Weak theory lies at the high energies and will find its resolution at LHC via observation of Higgs boson or some other more exotic phenomena, the predictive power of Quantum Chromodynamics gets stalled at the low energy limit where perturbative methods start failing due to the rising value of the strong coupling constant  $\alpha_s$ . Intra-jet structure, largely driven by very soft processes (transverse momenta of particles in jets with respect to the jet axis are typically of the order of 200 MeV) is the perfect testing ground for probing the limits of pQCD. In order to arrive to quantitative predictions at low momentum transfer scales, all terms of the perturbative expansion must be resumed in all orders. Such analytical resummations are available for many jet observables at the Next-to-Leading Log Approximation and a variety of its extensions.

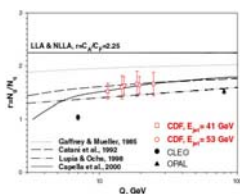


Momentum distributions of charged particles inside jets of 40-300 GeV were compared to those predicted for partons. Also, we analyzed how these distributions change as one selects particles at different angular distance from the jet axis. All data can be fitted surprisingly well with a single parameter available in theory  $Q_{\text{eff}}$  that plays simultaneously the role of  $\Lambda_{\text{QCD}}$  and the  $k_T$ -cutoff for the lowest allowed momentum transfer in calculations. The value of this parameter as it comes out from the fits is  $Q_{\text{eff}} = 230 \pm 40$  MeV [9].



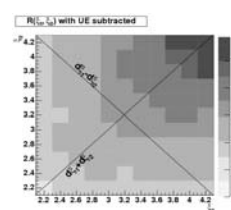
Overall multiplicity of charged particles in jets was compared to the predicted multiplicity of partons. Again, the analysis was done for jet energies of 40-300 GeV and for opening angles around jet axis of 0.3-0.5 rad. We find that there are  $0.57 \pm 0.11$  charged hadrons for each parton in the model [10]. Taking into account that charged hadrons comprise only about 60% of all hadrons produced, our result basically implies one-to-one match between the final pQCD cascade partons and the observable hadrons. The match of their momentum distributions also supports this conclusion. Thus, we strongly

confirm the hypothesis of the Local Parton-Hadron Duality.



The measurement of the ratio of charged particle multiplicities in gluon and quark jets  $r$  was the next natural step in this program of jet fragmentation studies. More than 15 papers on this subject were published by LEP experiments, starting from the first discouraging result  $r = 1.02 \pm 0.07$  published in 1991. The challenge of measuring this quantity at LEP stems from the necessity to use 3-jet events, while the theoretical calculations are available only for the back-to-back dijet configuration. By using an ingenious trick, only the most recent OPAL studies have overcome these problems and

resulted in the model-independent measurement of  $r = 1.51 \pm 0.04$ . This development at LEP has become a dramatic backdrop for our effort to pin down this quantity at Tevatron. By making use of the fact that back-to-back dijet and  $\gamma$ -jet events have very different quark-jet and gluon-jet fractions, we obtained a model-independent measurement of  $r = 1.64 \pm 0.17$  [11] in good agreement with the parton-level theory.



One of our ongoing studies is focused on answering the question of whether the long-range momentum correlations predicted for partons forming a jet survive the hadronization stage and can be observed at the charged particle level. Remarkably, we find that the answer is yes, both qualitatively and quantitatively! This further supports the thesis that the non-perturbative stage of hadronization is reduced to merely transforming final partons into observable hadrons, fully preserving their basic dynamic properties. The first results will be presented at the Particle and Nuclear Interaction Conference PANIC2005.

And finally, we just launched another study devoted to event shapes. Measurements of event shapes at LEP and HERA already provided us with a wealth of insights into the interplay between perturbative and non-perturbative QCD domains in jet fragmentation. However, both LEP and HERA observables are limited to only simple two-quark antennas at Leading Order. Proton-antiproton collisions, on the other hand, naturally result in a wide variety of underlying event color structures, including three-parton and four-parton color antennas with two incoming partons and one/two outgoing partons ( $\gamma$ -jet or dijet events), where partons can be either quarks or gluons. Note that the very same reach color structure has been a longstanding theoretical challenge—only recently calculations for event shape observables at Tevatron have become available and, hence, make these studies possible. The first public results are expected within a year.

## References appearing in this summary

1. TESTS OF CATHODE STRIP CHAMBER PROTOTYPES.  
M. Baarmand et al., Nuclear Instruments and Methods in Physics Research **A402** (1998) 36
2. SPATIAL RESOLUTION ATTAINABLE WITH CATHODE STRIP CHAMBERS AT THE TRIGGER LEVEL.  
M. Baarmand et al., Nuclear Instruments and Methods in Physics Research **A425** (1999) 92-105.
3. LARGE CMS CATHODE STRIP CHAMBERS: DESIGN AND PERFORMANCE.  
D. Acosta et al., Nuclear Instruments and Methods in Physics Research **A453** (2000) 182.
4. AGING STUDIES OF CMS MUON CHAMBER PROTOTYPES.  
T. Ferguson et al., Nuclear Instruments and Methods in Physics Research **A488** (2002) 240–257
5. AGING TESTS OF FULL SCALE CMS MUON CATHODE STRIP CHAMBERS.  
D. Acosta et al., Instruments and Methods in Physics Research **A515** (2003) 226-233
6. CMS MUON TECHNICAL DESIGN REPORT.  
CMS Muon Collaboration. CERN/LHC 97-32 (15 December 1997)
7. Final Assembly and System Test Sites Website: <http://www.phys.ufl.edu/cms/emu/fast/>
8. Endcap Muon System Data Quality Monitoring Website: <http://www.phys.ufl.edu/cms/emu/dqm/>
9. MOMENTUM DISTRIBUTION OF CHARGED PARTICLES IN JETS IN DIJET EVENTS IN P ANTI-P COLLISIONS AT  $S^{**}(1/2) = 1.8\text{-TEV}$  AND COMPARISONS TO PERTURBATIVE QCD PREDICTIONS.  
CDF Collaboration, Phys. Rev. **D68**, 012003 (2003)
10. CHARGED PARTICLE MULTIPLICITY IN JETS IN P ANTI-P COLLISIONS AT  $S^{**}(1/2) = 1.8\text{-TEV}$ .  
CDF Collaboration, Phys. Rev. Lett. **87**, 211804 (2001)
11. MEASUREMENT OF CHARGED PARTICLE MULTIPLICITIES IN GLUON AND QUARK JETS IN P ANTI-P COLLISIONS AT  $S^{**}(1/2) = 1.8\text{-TEV}$   
CDF Collaboration, Phys. Rev. Lett. **94**, 171802 (2005)