HEPHY
Institute of High Energy Physics

ÖAW
Österreichische Akademie der Wissenschaften

CMS

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RECFA Meeting
Vienna, 11 March 2011

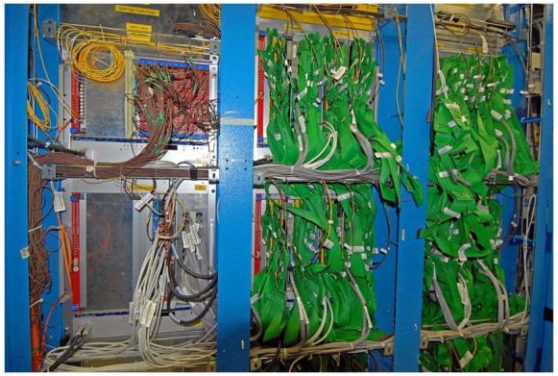
HEPHY's Role and History in CMS

- HEPHY has been a CMS contributor, and designer, right from the start at the end of the 1980's, together with a few UA1 colleagues.
- It officially became a founding member of CMS in 1993.
- It was a key initiator of the Trigger Project of CMS (first Trigger Coordinator, Trigger kick-off meeting in Austria 1994).
- It joined the Inner Tracker Project of CMS in 1994.
- It has participated in physics studies since the beginning, starting with B physics and Z', then taking on Supersymmetry, and more recently analyses of quarkonia.
- Counting authors, it is now the 10th biggest CMS institution out of 172.

CMS Hardware Contributions

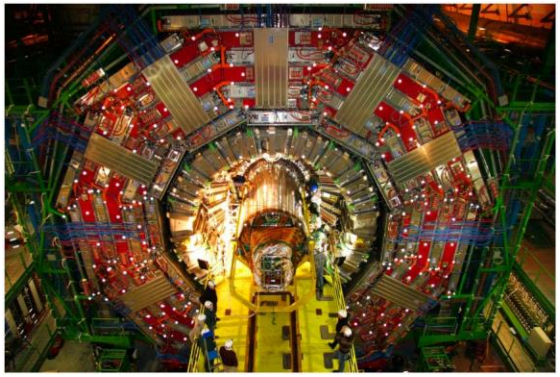
Trigger

- Global Trigger (selection stage of Level-1 Trigger)
- Central Trigger Control System
- Global Muon Trigger
- Muon Drift Tube Track Finder



Tracker

- Sensor design and qualification
- Module production for silicon strip tracker endcaps
- Pixel detector front-end drivers
- Development of opto-hybrids for strip tracker and pixel detector



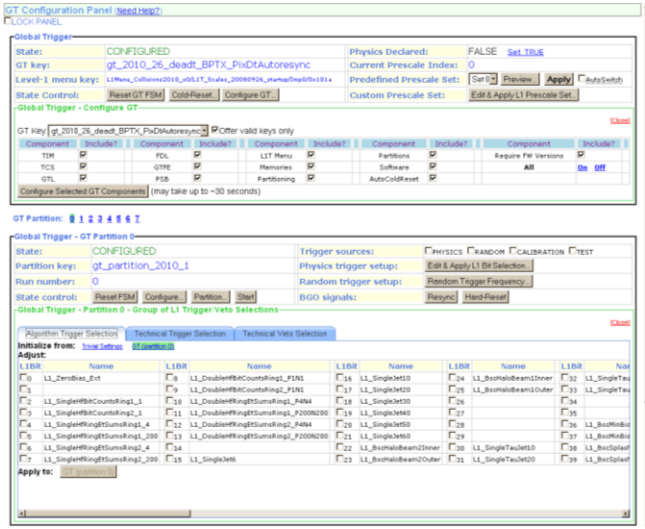
Upgrade

- Trigger: New trigger components in new technology (2017/2018)
- Tracker: Pixel FED upgrade (2017/2018), participation in conceptual and prototype work on high-luminosity tracker (2020 or later)

CMS Software Contributions and Operation

Trigger software

- Trigger Supervisor
- Level-1 online software
- Trigger menu development
- Coordination of Level-1 offline software
- Monitoring and validation



Tracking and vertexing software

- Algorithms for track and vertex reconstruction
- Electron reconstruction with Gaussian sum filter
- Tracker alignment with Kalman filter based algorithm

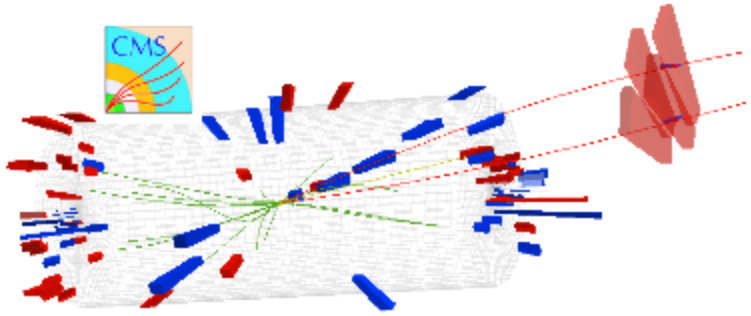
Operation

- Maintenance (hardware, firmware and software)
- Participation in shift and on-call duties
- Participation in run and technical coordination
- Participation in trigger and tracker performance studies
- Operation of Tier-2 centre (D. Liko's presentation)

CMS Physics Contributions

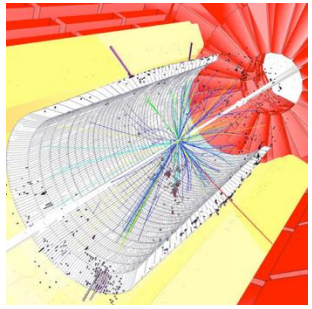
Standard Model Physics

- QCD (Quarkonia)



Beyond the Standard Model Physics

- Supersymmetry
- Searches with Simplified Models



Analysis services

- Contributions as experts in Analysis Review Committees

  W', W_R, N_R

  Top quark pair-production cross-section in lepton-jets channel with b-tagging

  Search for SUSY in b-tagged dijet and multijet events with E_T^{miss}

Recent important positions

Subsystem and Physics Coordination Positions:

Muon Physics Objects Group Convener (I. Mikulec)

b-tag/vertexing Convener (W. Adam till 2010)

Trigger Technical Coordinator (M. Jeitler, I. Mikulec till 2010)

Deputy Trigger Project Manager (deputy Management Board and Steering Committee member) (C.-E. Wulz)

Institution Board Chair for Trigger and Data Acquisition (C.-E. Wulz)

Level-1 Trigger Offline Software Coordinator (V. Ghete)

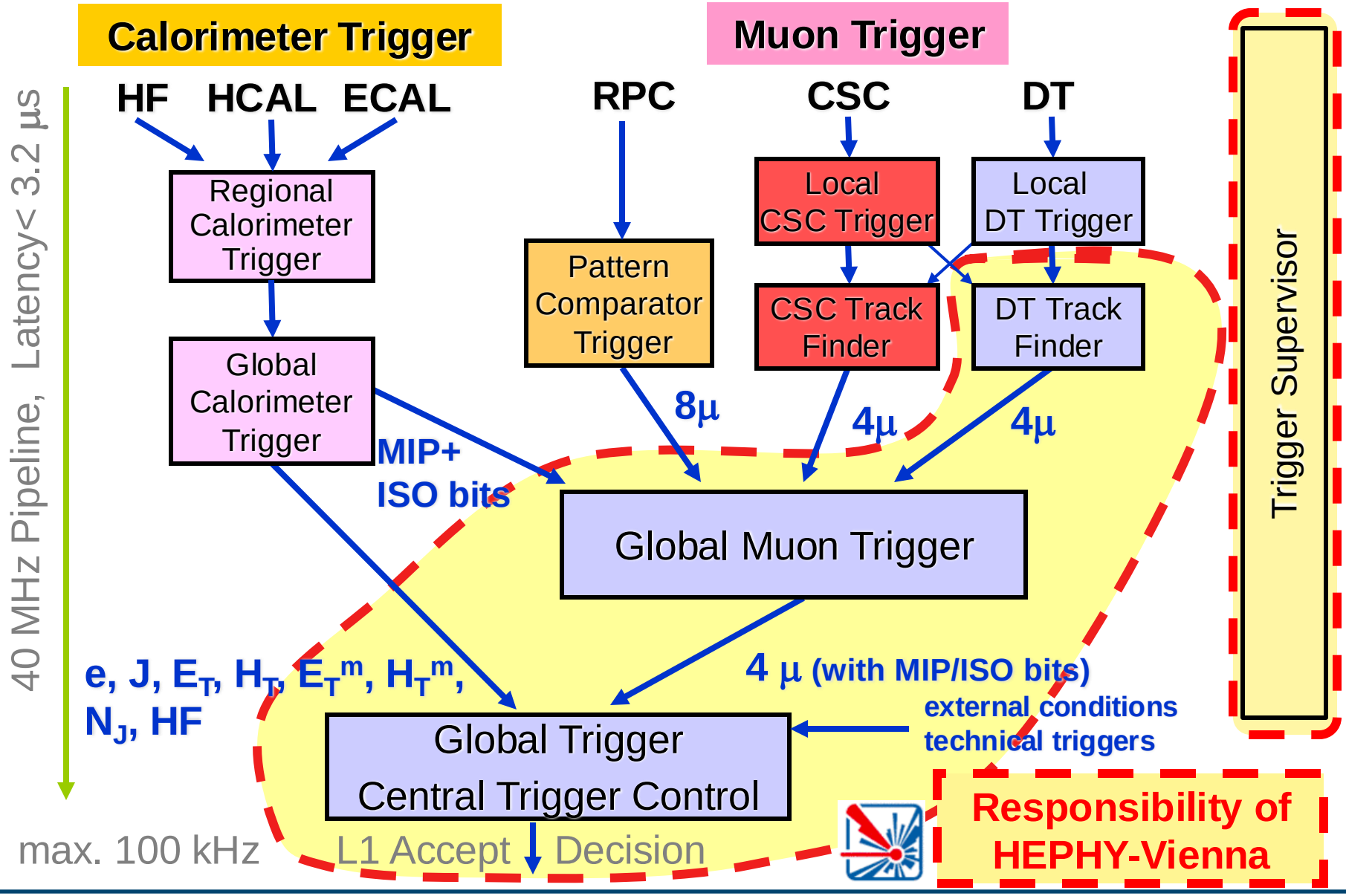
General CMS Positions:

Conference Committee Chair (Management Board member) (M. Krammer)

Member of Authorship Committee (C.-E. Wulz)

Member of Collaboration Board Advisory Committee (C-E. Wulz 2009-2010)

Member of Constitutional Committee (C-E. Wulz 2009-2010)

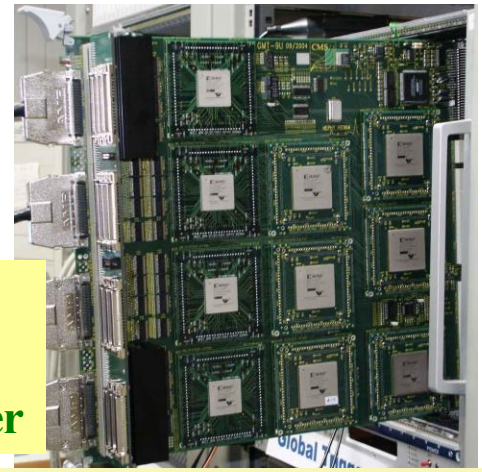

Calorimeter Trigger
Muon Trigger
HF
HCAL
ECAL
RPC
CSC
DT
Regional Calorimeter Trigger
Global Calorimeter Trigger
Pattern Comparator Trigger
Local CSC Trigger
Local DT Trigger
CSC Track Finder
DT Track Finder
Trigger Supervisor
40 MHz Pipeline, Latency< 3.2 µs
8µ
4µ
4µ
MIP+
ISO bits
Global Muon Trigger
e, J, E_T, H_T, E_T^m, H_T^m, N_J, HF
4 µ (with MIP/ISO bits)
external conditions
technical triggers
Global Trigger
Central Trigger Control
max. 100 kHz
L1 Accept
Decision
Responsibility of HEPHY-Vienna

Muon Drift Tube Track Finder

- **finds up to 144 muon candidates for each bunch crossing in the central region covered by drift tube chambers**
  - based on extrapolation and pattern matching techniques

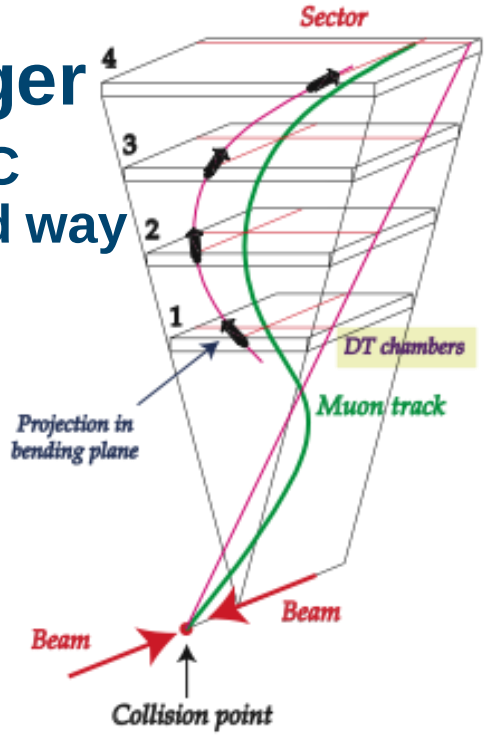
Global Muon Trigger

- **combines DT/CSC/RPC muons in a sophisticated way**



Global Muon Trigger

4 modules, 2 types (all by HEPHY)

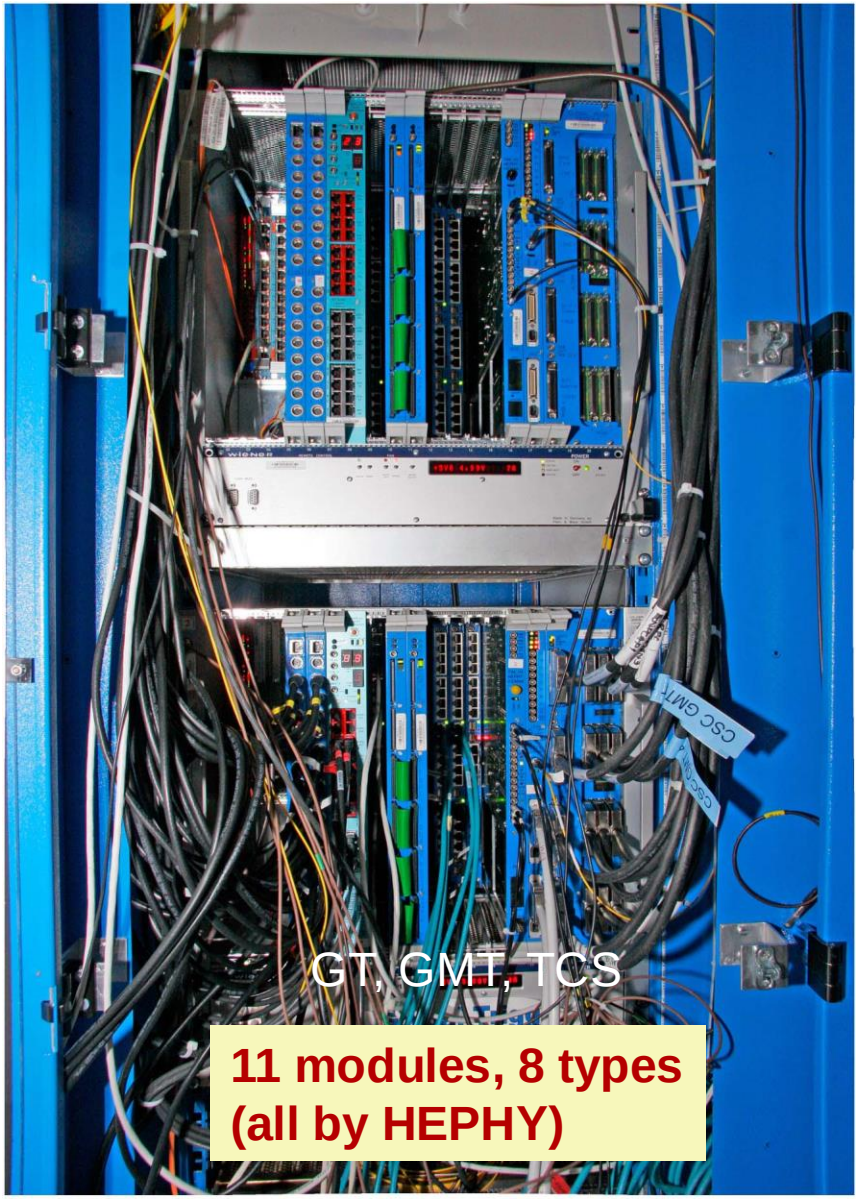


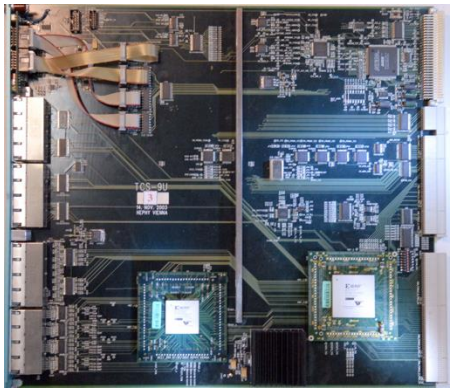
135 modules (122 by HEPHY), 8 types (6 by HEPHY)

Global Trigger

Main functionality

- Reception and Synchronisation of trigger objects
- Calculation of more than 100 Trigger algorithms (AND-OR-NOT) based on:
  - **transverse energy, transverse momentum, quality, location (η, φ), topology, (Δη, Δφ).**
  - **Up to 4 objects can be combined.**
- Final OR
- Distribution of Level-1 Accept decision





Trigger requests ("final OR")
from muon detectors, calorimeters and some other subdetectors

Status signals from subdetector partitions
(except tracker partitions; "ready", "busy", "error" etc.)

Central Trigger Control System

Status Emulator s

Status signals from tracker partitions
("ready", "busy", "error" etc.)

Timing information
from the LHC accelerator

4 modules, 2 types (all by HEPHY)

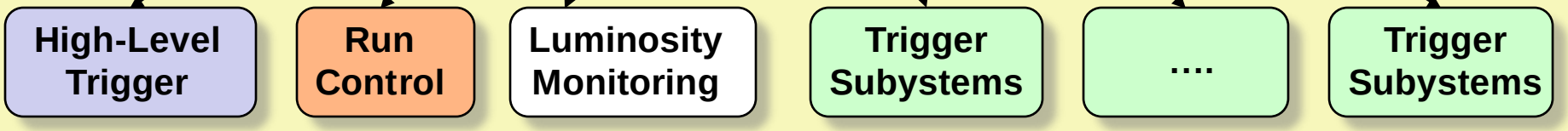
Trigger and control signals to subdetector partitions
(control signals: "start of orbit", "calibration trigger" etc.)

Trigger Control System

Trigger Supervisor

Trigger shifter using the Trigger Supervisor

Idea and basic version developed by HEPHY



- Access point for all trigger subsystems through web browser
- Configuration, tests, operation and monitoring of trigger components, interconnection tests between trigger subsystems
- Management of interplay with Run Control, the High-Level Trigger and the Luminosity Monitoring System

Tracker and Sensor Design, Qualification

- **Design of silicon detectors**
  - Sensor parameters, layout of test structures, readout electronics of APV25 readout chips

- **Definition of the layout for the Silicon Strip Tracker**

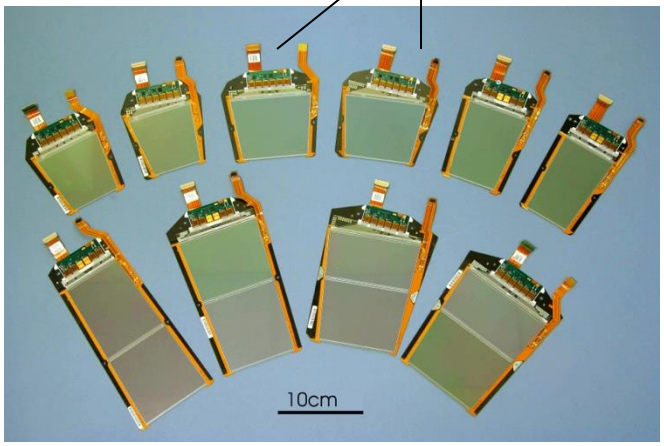
- **Quality assurance for silicon sensors of the SST**
  - **CMS Tracker sensor working group (HEPHY convener)**

    to define acceptance criteria, test procedures and stations, logistics for the production, interaction with companies
  - **test center for detectors and test structures:**

    one of four laboratories to test the 25000 silicon strip sensors

Tracker Construction

- **Module production for the Tracker End Caps (TEC)**
  - Coordination of the production of 7000 modules
  - Complicated logistics (about 20 laboratories involved)



- HEPHY as a module production center for all ring 2 modules:
  ~ 650 modules produced
  - Mechanical assembly
  - Thin wire bonding
  - Functionality tests
- HEPHY as a module repair center
  - Fault analysis, tests
  - Sensor recuperation

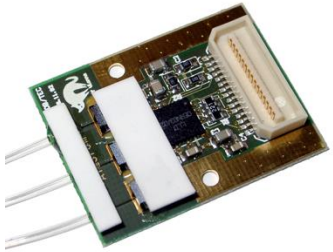
Tracker Electronics

- **Optical data transmission:**

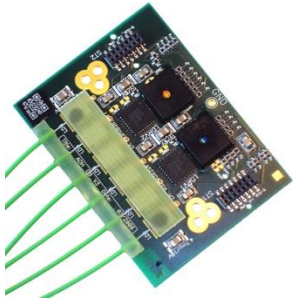
  Design and development of opto-hybrids
  - Production by **KAPSCH Components KG** (Vienna)

    14000 Analogue opto-hybrids for Tracker Outer Barrel, TEC and Pixel Detector
  - Test equipment
  - Technical responsibility production and quality assurance

TEC, TOB



Pixel Detector

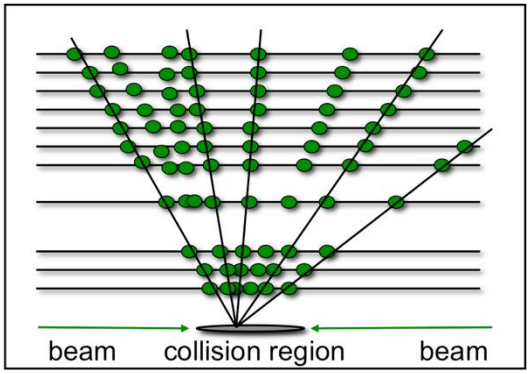


- **Pixel-FED: Front End Driver for the Pixel Detector**
  - Design and production of all Front End Drivers

    1.6 million pixels/module
  - Installed in the data acquisition of the Pixel Detector

Tracking and Vertexing Software

- **Algorithms for track and vertex reconstruction**
  (long tradition at HEPHY)
  - Kalman filter, adaptive filters, adaptive track smoothing etc.



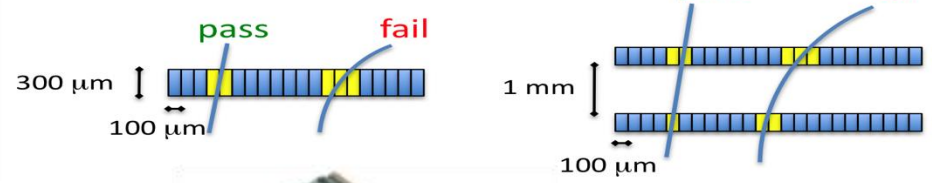
- **Several of HEPHY's developments are now standard methods** in the CMS reconstruction software:
  - **Vertex fitting** (linear and adaptive)
  - **Secondary vertex finding** (by iterated adaptive fitting)
  - **Electron reconstruction** (Gaussian-sum Filter)

- **Kalman Alignment Algorithm for the Tracker**
  - to evaluate the position of each module to a few µm (using tracks)
  - was applied for the Tracker alignment in tracker tests before installation
  - is one of the three presently adopted methods
  - competitive results compared to the HIP- and Millepede algorithms

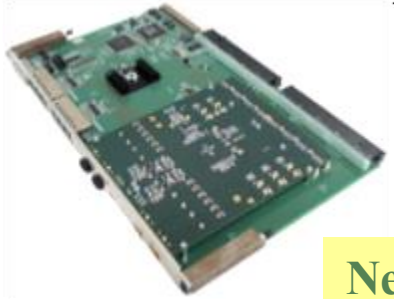
Upgrade Activities

- New technologies and architectures for triggering and sensor developments are under study.
- Trigger components, using μTCA technology, and upgraded Pixel FEDs should already be available by 2017, whereas the envisaged level-1 track trigger will only be necessary for the new high-luminosity Tracker (about 2020).
- Upgrade Technical Proposal has been written.

Track Trigger options



μTCA crate

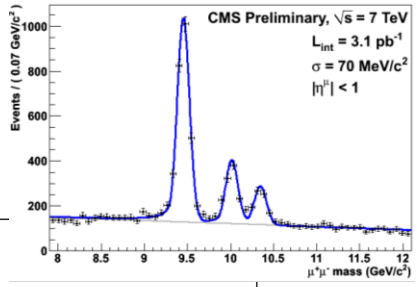


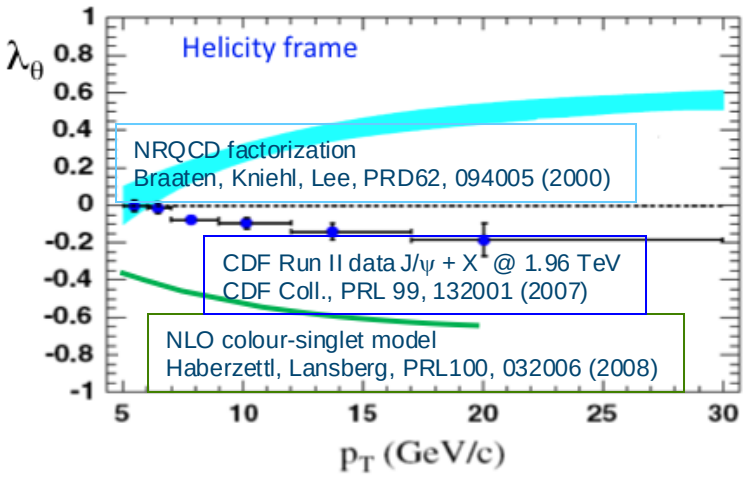
New trigger board

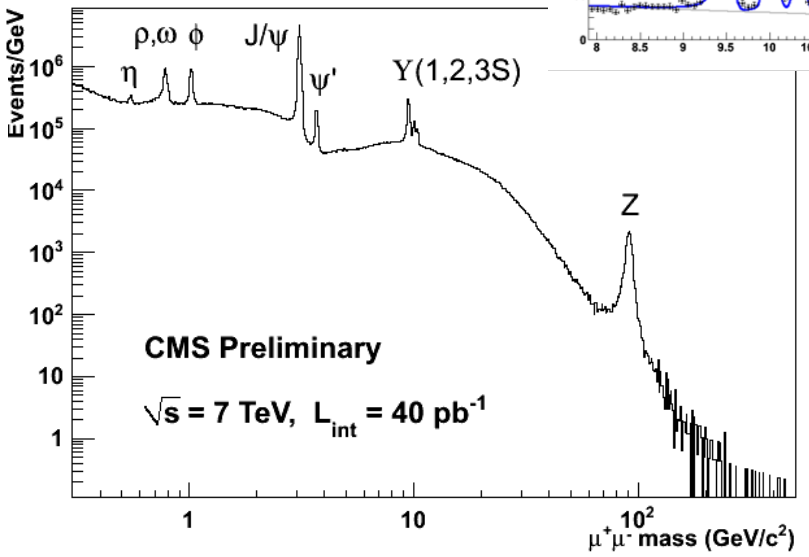
Standard Model Physics

Study of Quarkonia production as a probe of QCD

- **Polarization studies of J/ψ and Y**
  - Puzzles in J/ψ and Y polarization measurements
  - No satisfactory description by theory
  - No unambiguous answer from the Tevatron
- **Opportunity for competitive measurements at CMS**
  - Precise muon reconstruction
  - Flexible trigger

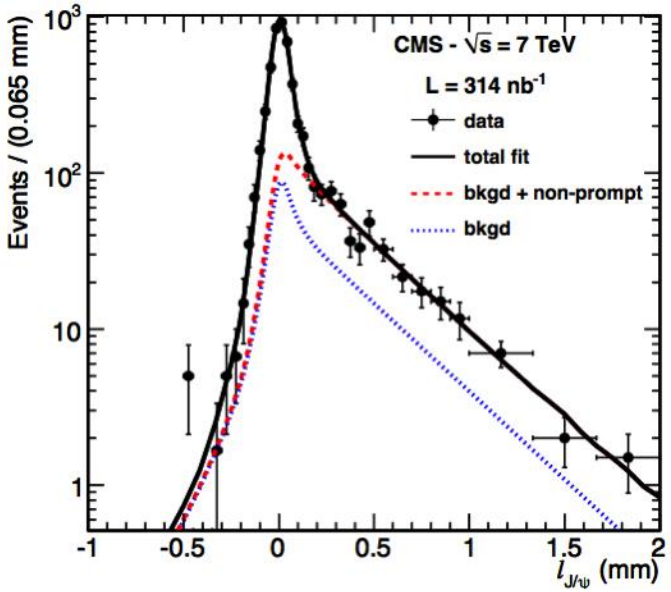






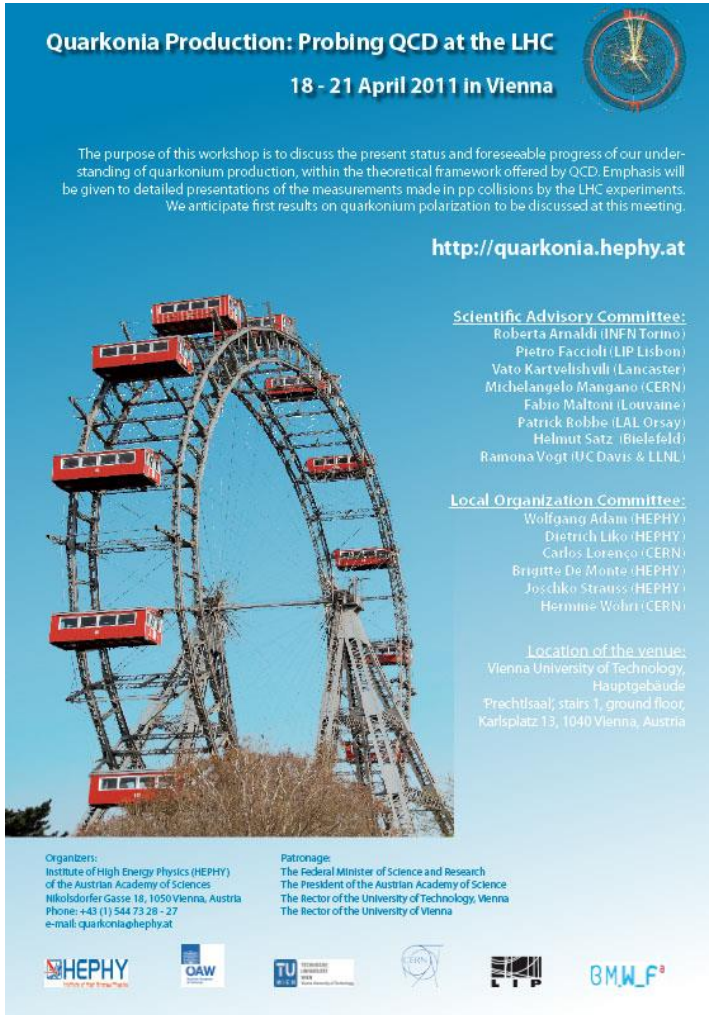
Quarkonia

- Our contributions to quarkonium physics in CMS
  - Development of a specific high-level (SW) trigger for selection of di-μ states using one triggered μ + a charged track
    - extends sensitivity in $p_T(J/\psi)$ well below the reach of "classical" 2μ triggers
    - essential for determination of trigger efficiency
    - example for the application of our tracking & trigger expertise



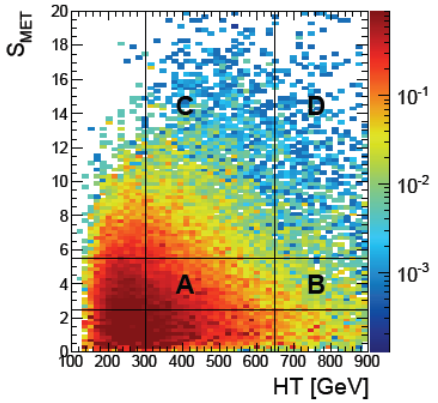
    - contributions to CMS J/ψ production paper arXiv:1011.4193, submitted to Eur. Phys. J. C

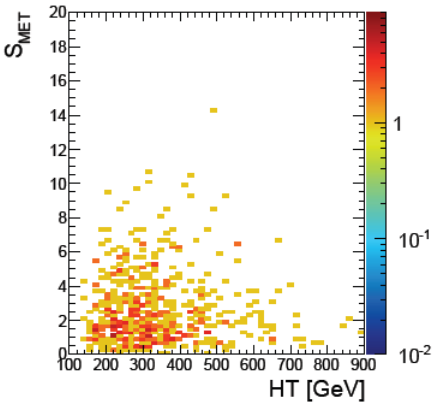
- **Quarkonia analysis at HEPHY**
  - Applying our expertise in the development of specialized triggers and fit procedures
  - in contact with QCD specialists at universities in Vienna and CERN, LIP, Wisconsin
  - in April 2011 HEPHY will organize a workshop dedicated to the review and interpretation of early quarkonium results: **"Quarkonium production: probing QCD at the LHC"**



Supersymmetry

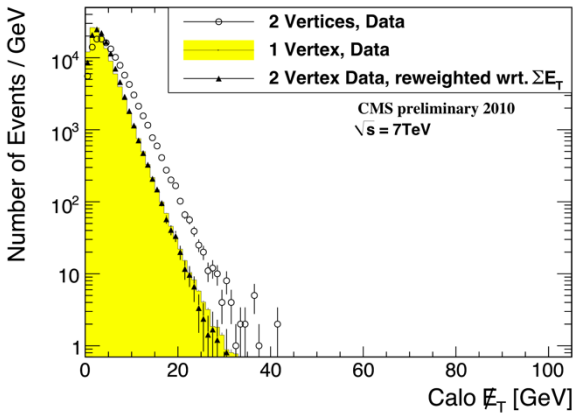
- HEPHY Vienna studies this central subject for the LHC both in theory and experiment (CMS)
  - We have been involved in this subject for a long time (including early trigger studies)
  - Current focus: search in leptonic topologies
    - events with a charged lepton, multi-jets and missing transverse energy
    - robust procedures for SM background estimation in early data
  - CMS SUSY results in the single-lepton channel with 2010 data have been approved just now
    - close collaboration with groups in UCSB and Cornell University



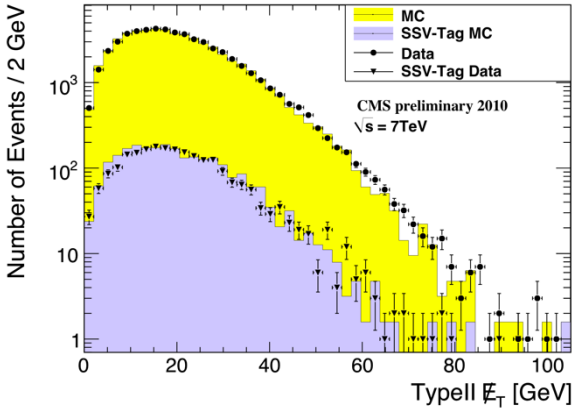


Supersymmetry

- Commissioning for SUSY searches in Vienna
  - During 2010: statistics too low for full analysis: we studied the essential element for SUSY searches: missing E_T



Missing E_T in bunch crossings with multiple interactions

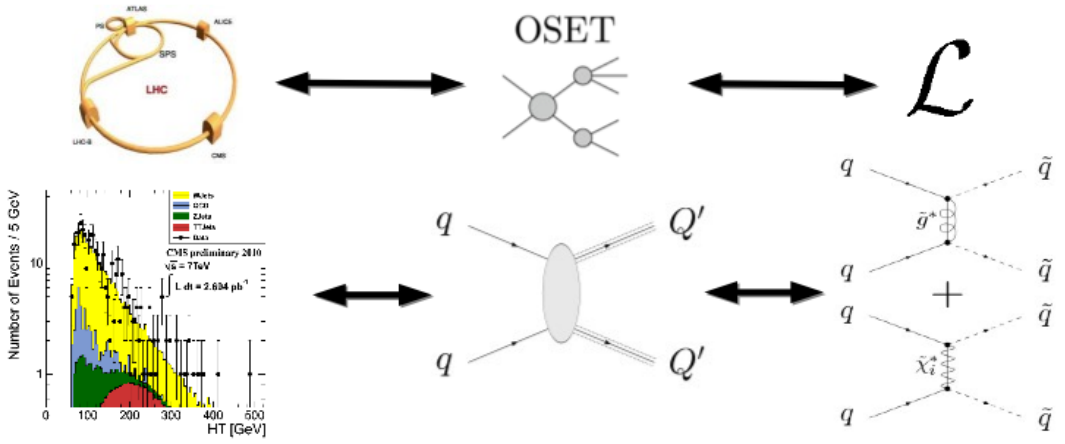


Missing E_T in heavy-flavour enriched events

- part of CMS contributions to ICHEP

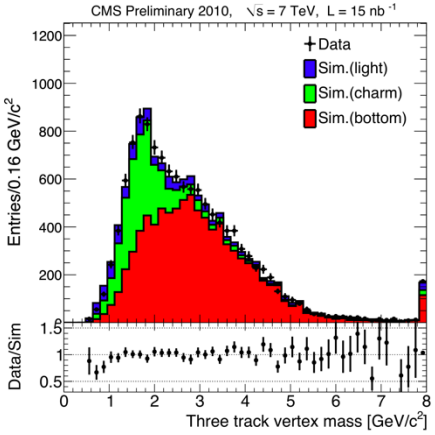
Simplified Models

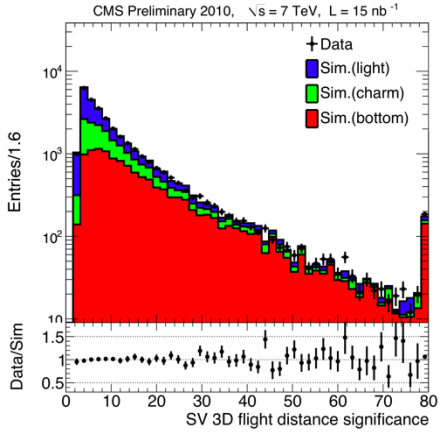
- … and On-Shell Effective Theories (OSETs)
  - Our second approach to searches for New Physics
  - BSM models based on a bottom-up approach
    - templates describing particle spectrum and decay chains
  - OSETs can be used to tune and interpret searches in a more model-independent way and to serve as interface between theory and experiment



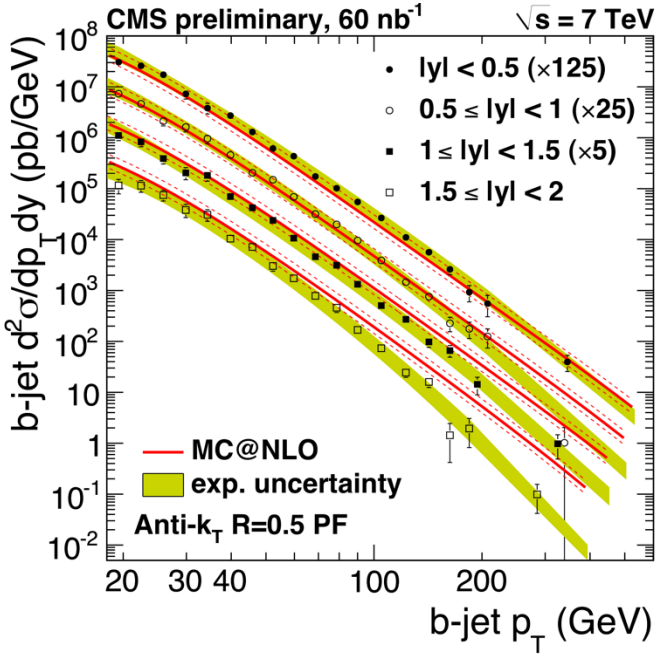
Other contributions to CMS physics

- Identification of b-jets
  - co-ordination of early CMS results on b-tagging





  - basis of early b cross-section measurement



Conclusions

- HEPHY is active in data analysis, in particular in the fields of Standard Model QCD and Supersymmetry.
- HEPHY has delivered important hardware and software contributions in the fields of tracking and triggering.
- HEPHY is deeply involved in the operation of CMS, in particular on a day-to-day basis in the trigger.
- HEPHY has started to work on upgrade activities.
- HEPHY's contributions have been essential for the success of CMS and will provide an excellent base for the exciting physics to come.