Status of CMS at DESY

Report to the 77th Physics Research Committee

24/25 April 2014 at DESY/Hamburg

Dirk Krücker

Status of CMS at DESY

Hamburg 24/25 April 2014

HELMHOLTZ ASSOCIATION

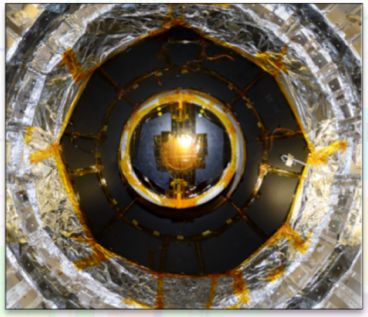
DESY

Overview

- CMS General Status
- DESY-CMS
  - Upgrades
  - Physics Analyses
  - Computing

CMS General Status – A Few Highlights

Master tracker cold test

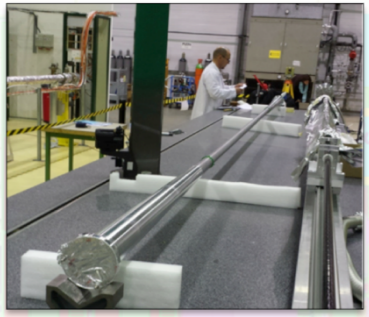


- Successfully operated
- Strip @ -20°C
- Pixel @ -25°C
- Necessary to reduce effects of radiation due to higher beam intensities in Run II

New Layer added to Muon

- 4th (RPC) Station (RE4) added in endcap region
- Completed on + side,
- - side by May

New beam pipe



- Needed for the coming pixel upgrade
- Ready for installation in June

New Management

- Spokesperson: Tiziano Camporesi
- Deputies
  - Paris Sphicas
  - Kerstin Borras (DESY)

All Installations on schedule

DESY-CMS Group

21 staff, 20 PostDocs, 25 PhDs, 1 PhD finished in last 6 months

Upgrades

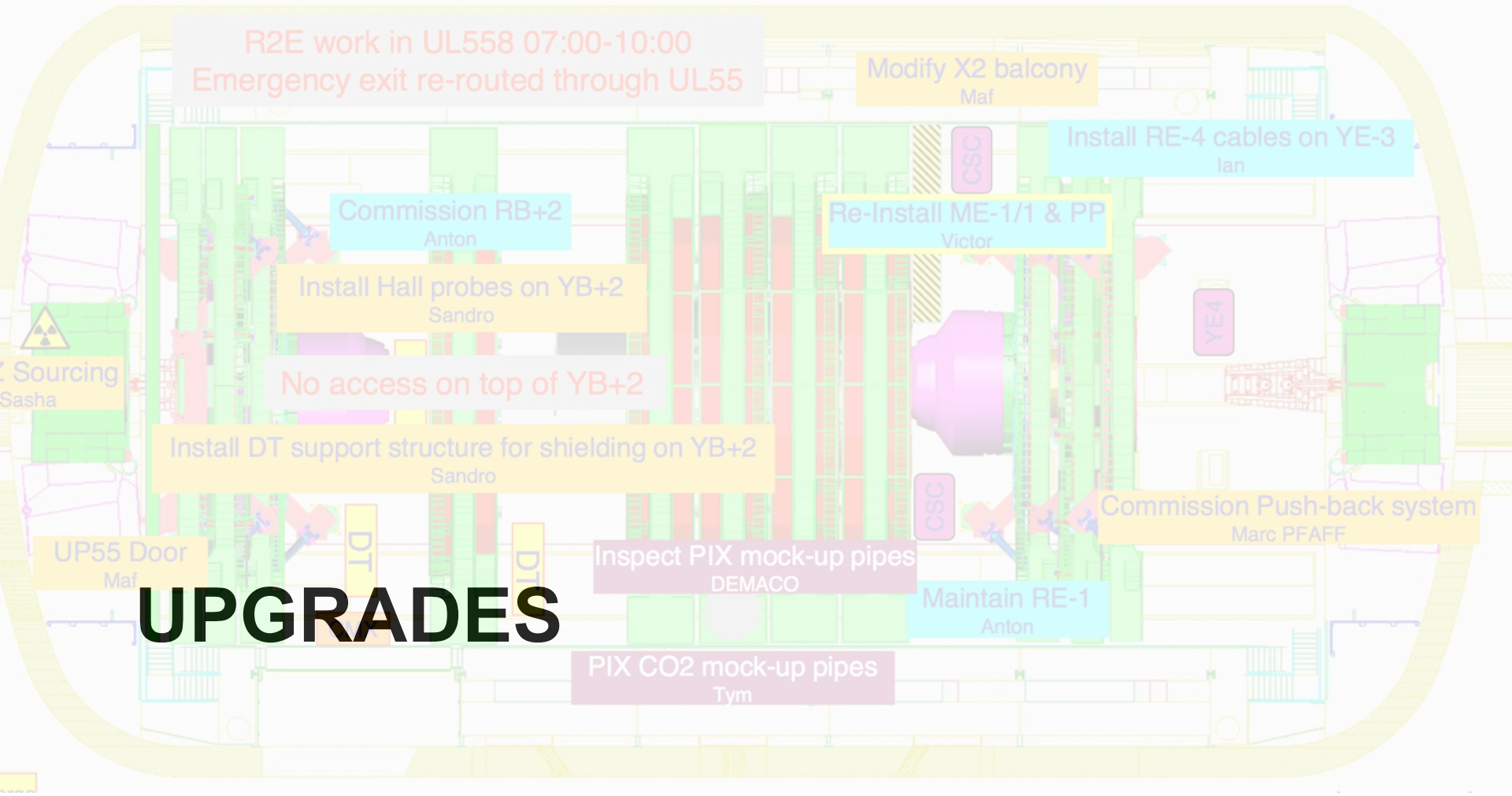
- BCM1F
- HCAL
- Pixels
- Sensors
- Tracker

Physics Analyses

- Higgs
- PDF
- QCD
- SUSY
- TOP

Operation and Components

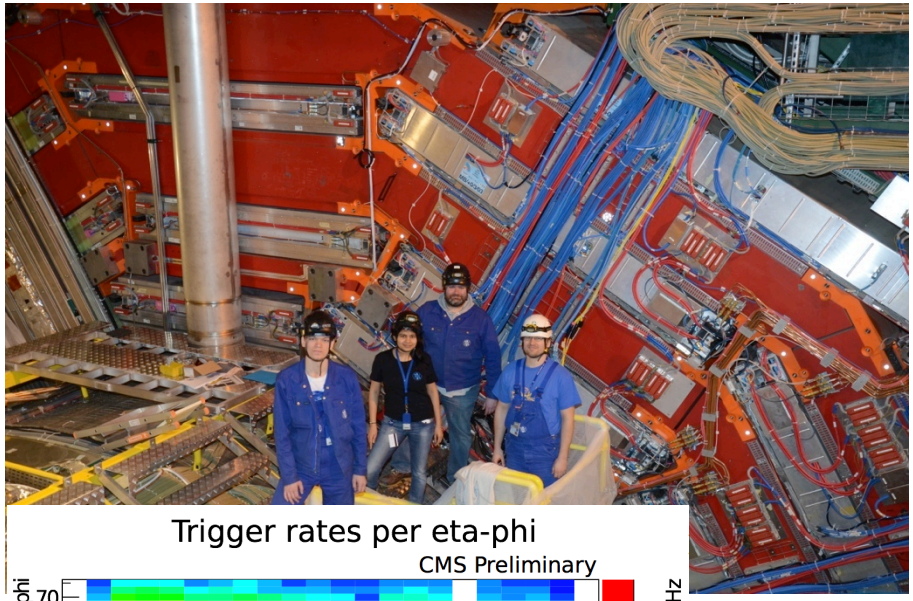
- Alignment
- BCM1F
- Castor
- Computing
- DQM

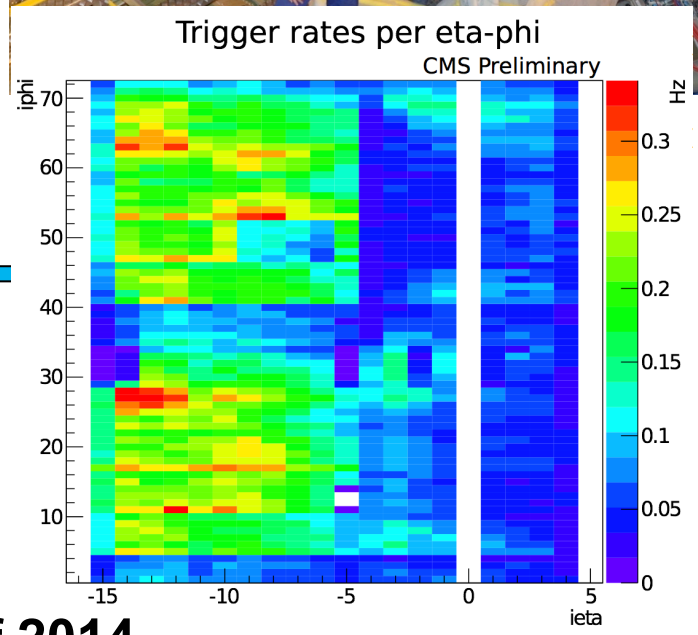

R2E work in UL558 07:00-10:00
Emergency exit re-routed through UL55
Modify X2 balcony
Maf
Install RE-4 cables on YE-3
Ian
CSC
Commission RB+2
Anton
Re-Install ME-1/1 & PP
Victor
Install Hall probes on YB+2
Sandro
YE4
Sourcing
Sasha
No access on top of YB+2
Install DT support structure for shielding on YB+2
Sandro
CSC
Commission Push-back system
Marc PFAFF
UP55 Door
Maf
DT
DT
Inspect PIX mock-up pipes
DEMACO
Maintain RE-1
Anton
PIX CO2 mock-up pipes
Tym

UPGRADES

LS1 (2013/14) - HO (Outer Hadron Calorimeter) Upgrade

- Replacing photo-sensors
- First use of SiPM in CMS
  - DESY is a key contributor
  - Leading QC, installation, and commissioning
  - 1/3 of installation man-power
- Installation complete
  - extraction completed
  - refurbishment completed
  - 100% installed
  - Slightly ahead of schedule
- Commissioning started in parallel
  - Initial calibration provided by DESY
- Talk at CALOR 2014





- Plot shows trigger rate for each individual channel
- Higher rates observed in the horizontal tiles under the shaft

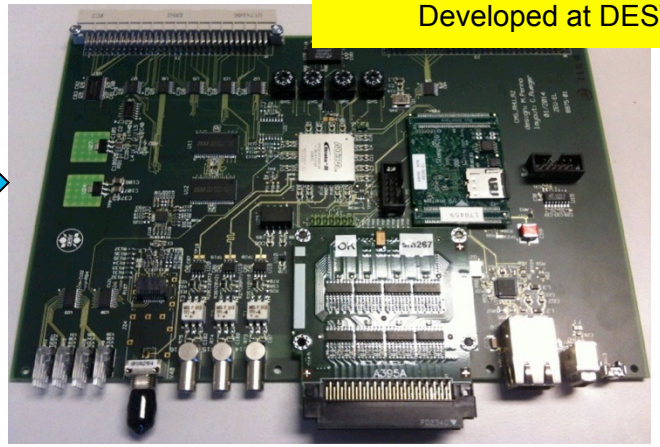
Well ready for beam by end of 2014

LS1 – BCM1F Beam Conditions Monitor & Luminometer

Enhanced Functionality: on-line Luminosity (part of the BRIL project), new geometry design, fast FE ASICs

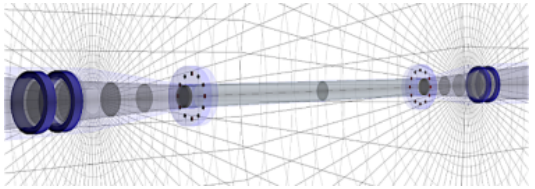
- RHU - Histogramming UNIT with TTC* decoding chip
  - Commissioning completed
  - In production
- C-shape PCB
  - Production (CERN)
  - Assembly and commissioning at DESY (ongoing)
- Diamond Sensors and FE ASICs
  - 24 sensors, two pads/sensor, sensors under test
  - Signal form and S/N in DESY test beam matches the expectations
- Installation starts in May 2014

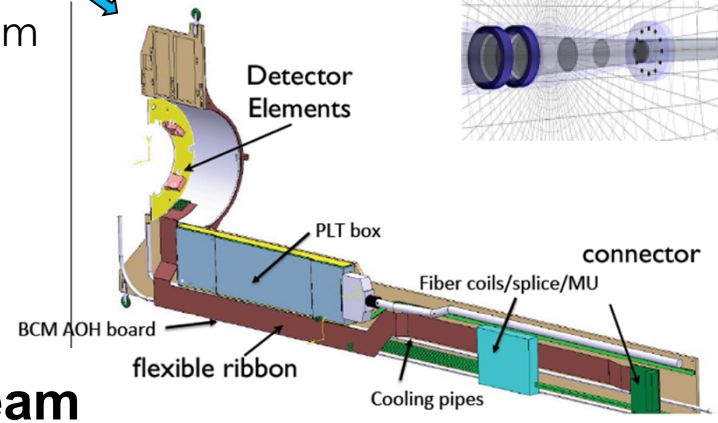
Real Time Histogramming Unit RHU, Developed at DESY (Z)



*LHC Timing, Trigger and Control

One piece semi-rigid PCB

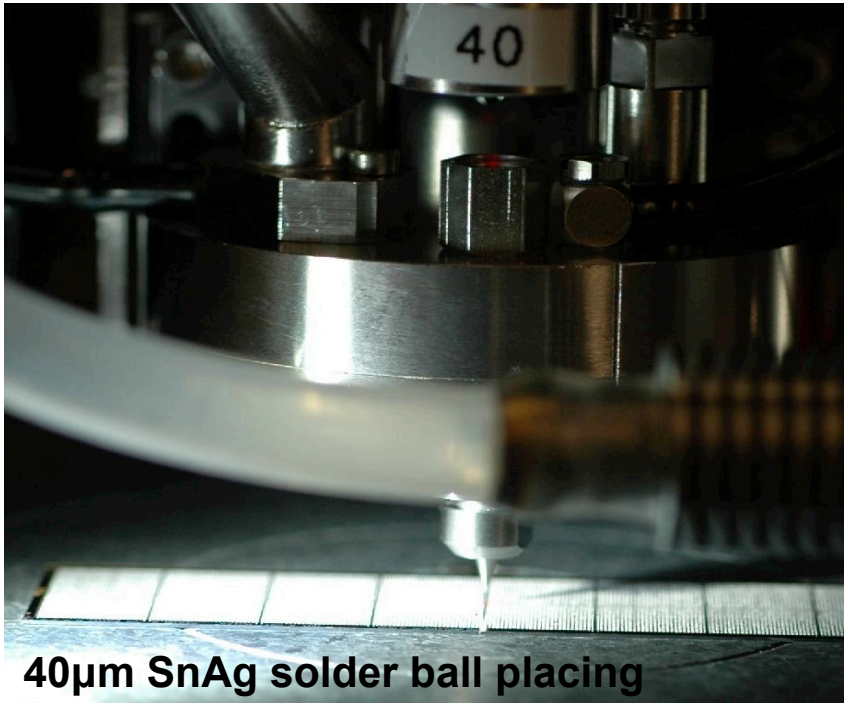




Sensors with whole readout chain successfully tested at DESY test beam

Phase I (2016/17) – Pixel Upgrade

- In house bump bonding
  - First full-size modules made with 66 560 solder balls (placed in 4 hours = 0.2 sec/ball)
  - **99.97% good** (well within specification)



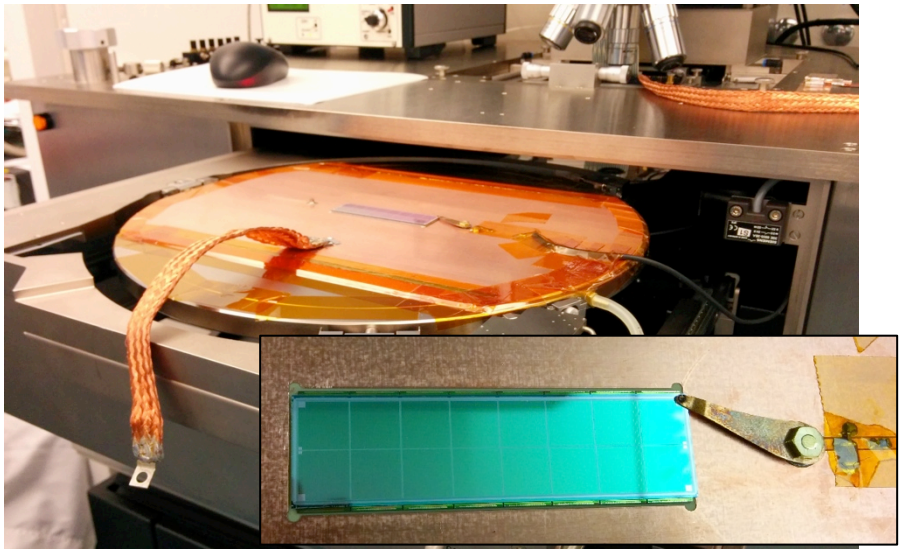
40µm SnAg solder ball placing

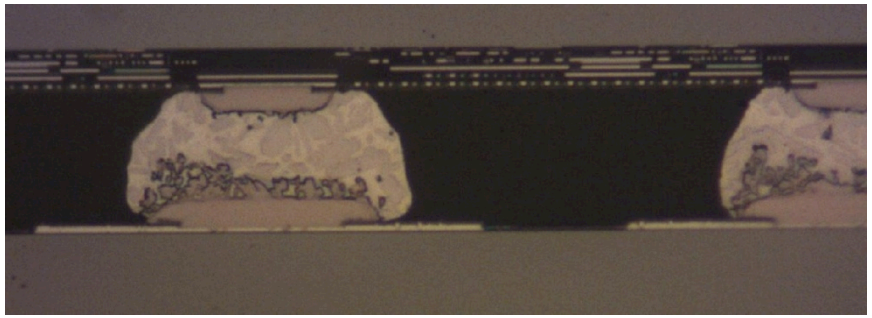
- **4th layer by DESY + German universities**
  - ~ 50% of modules & assembly in HH
- Module testing procedure established
  - Using an automated probe station
- DESY beam test of the readout chip
  - was essential to improve and test prototypes
  - Final production submission in 2 weeks
- Preparation of module production progressing well
  - Software for new test board developed
  - Gluing and testing tools in production at University of Hamburg
  - Production readiness review in June
  - Start of series production planned for 1st Sep. 2014
  - **In-time for delivery of ~300 modules early 2016**

In house bump bonding procedure established

Phase I – Pixel Upgrade – Bump Bonding Test

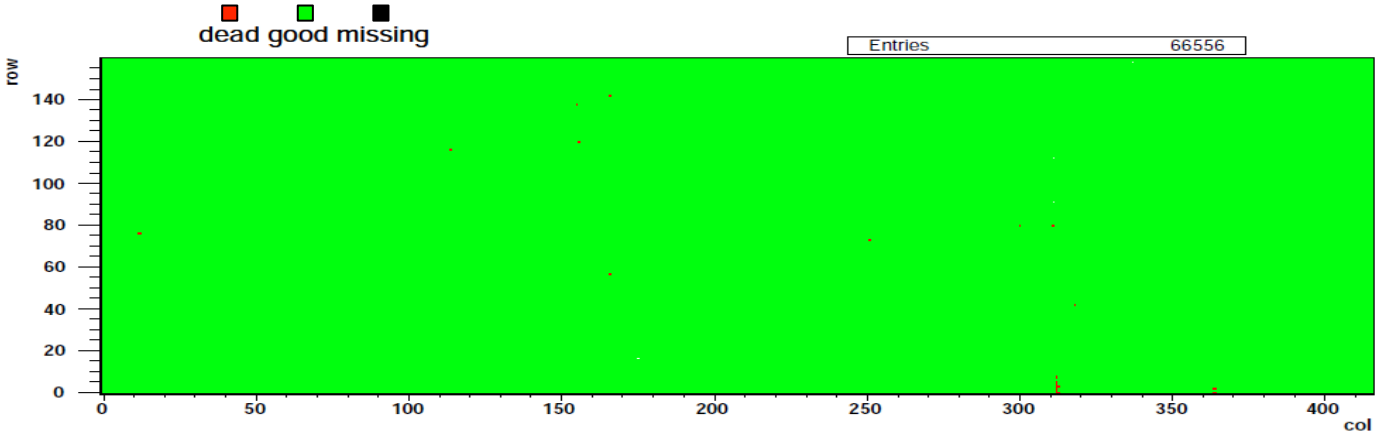
Module testing after bump bonding





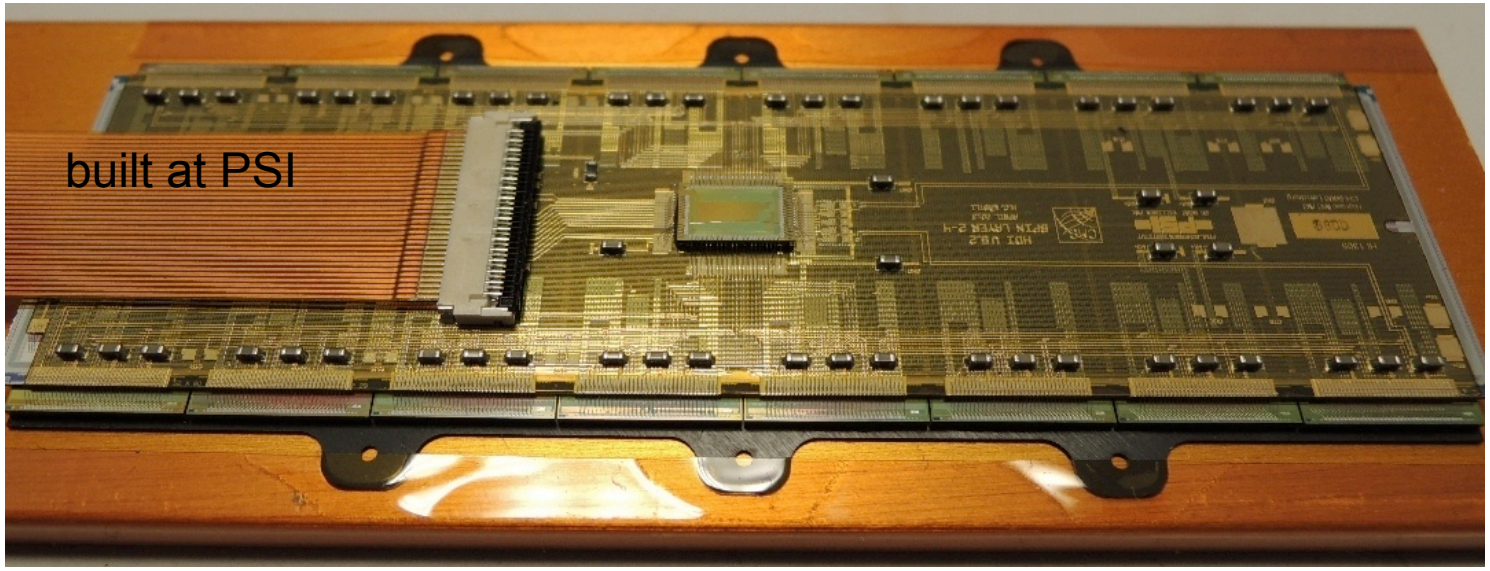
- Destructive test
  - Cutting and polishing & microsopic inspection
- Electrical test
  - Test pulse injection through sensor

4 dead
19 missing
66537 good!



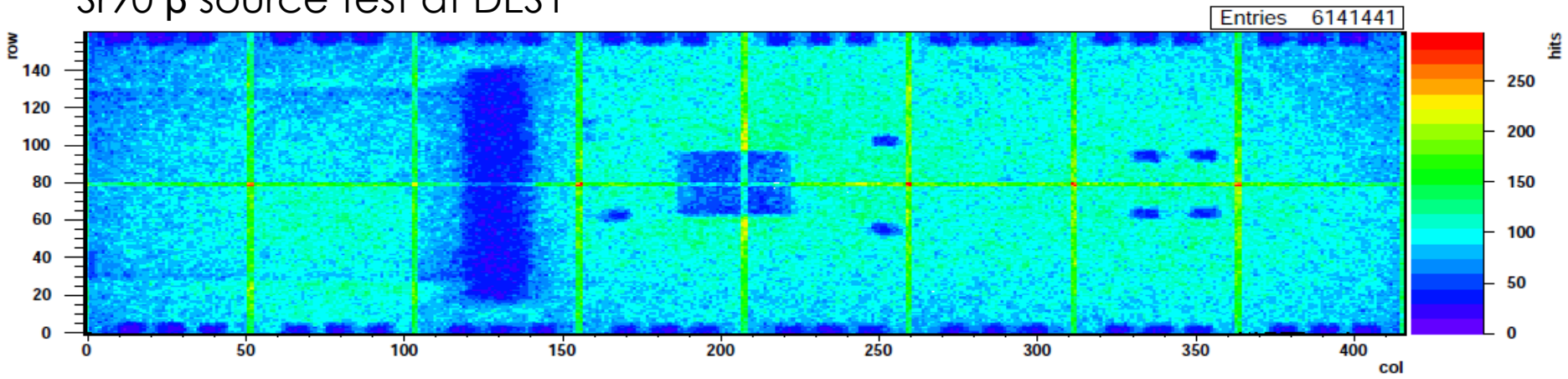
99.97% good bump connections

Phase I Pixel Upgrade – Module Testing



pre-series components

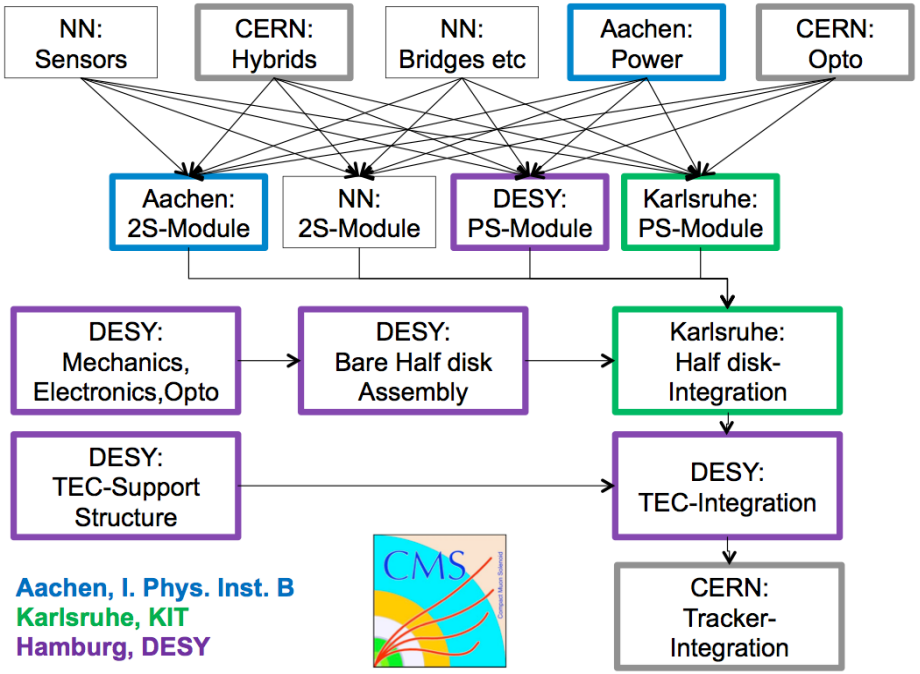
Sr90 β source test at DESY



Module testing procedure and software established at DESY

Phase II (2023) – Outer Tracker Endcap

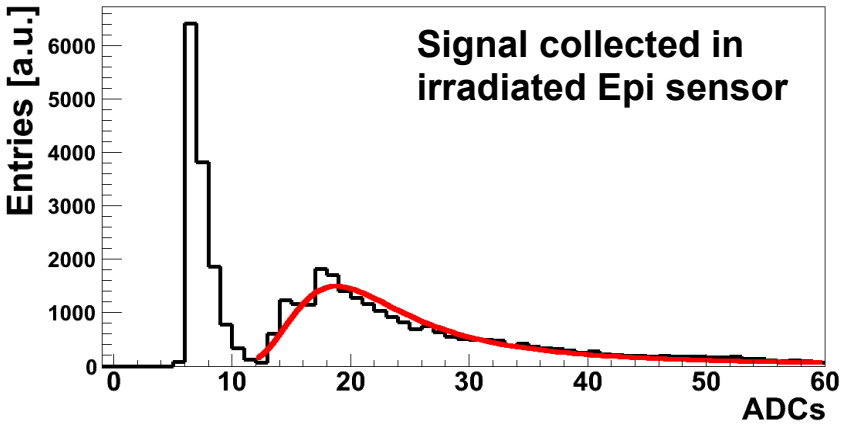
- DESY plans to build in cooperation with German universities one Outer Tracker endcap
  - Strongly encouraged by CMS tracker management
  - DESY plans to provide assembly and production infrastructure for ATLAS and CMS tracker end cap upgrade
- Funding discussion in Germany
  - Coordinated effort of all LHC experiments with BMBF and Helmholtz to secure funding of upgrade projects
  - Combined proposal for capital invest for ATLAS, ALICE and CMS planned to be submitted to Helmholtz this autumn



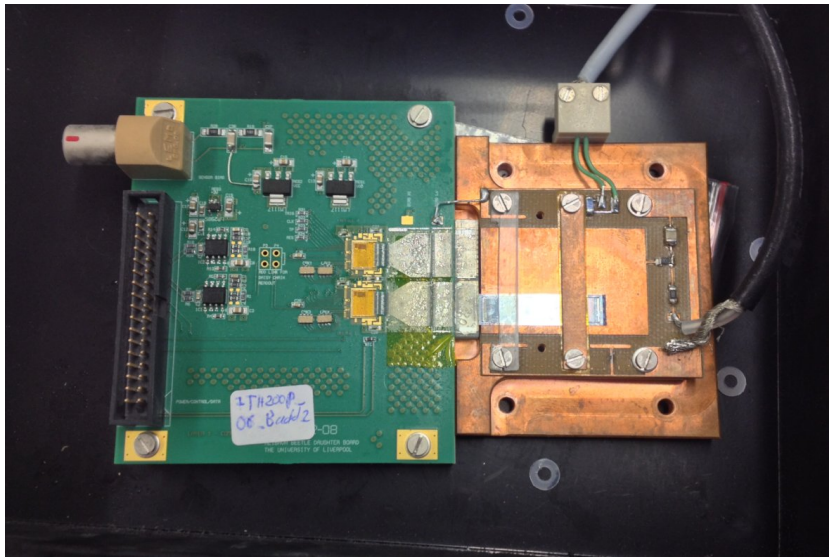
Coordinated effort to secure funding

Phase II - CMS Tracker Upgrade Sensors R&D

- CMS HPK campaign has led to choice of sensor polarity
  - **p-type sensors with 200µm thickness are baseline for Outer Tracker**
- Investigations now concentrate on
  - Sensor layout optimizations
  - Radiation-hard sensors for layers closer to interaction point
  - Vendor qualification
- DESY contributes with:
  - TCAD device simulations
  - Test beam studies of e.g. epitaxial sensors of 100µm thickness

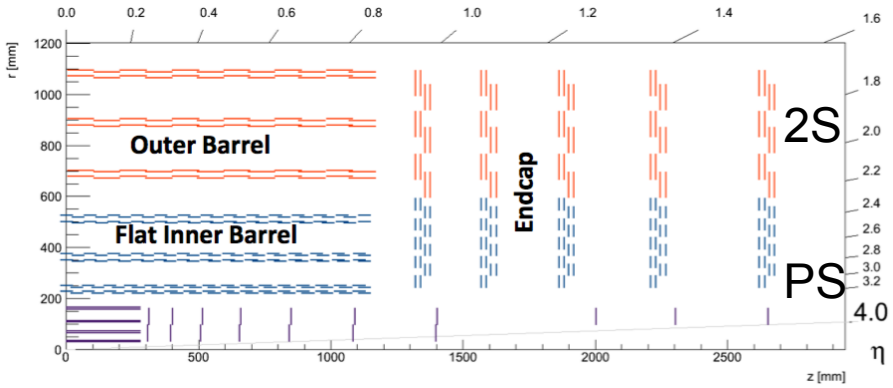


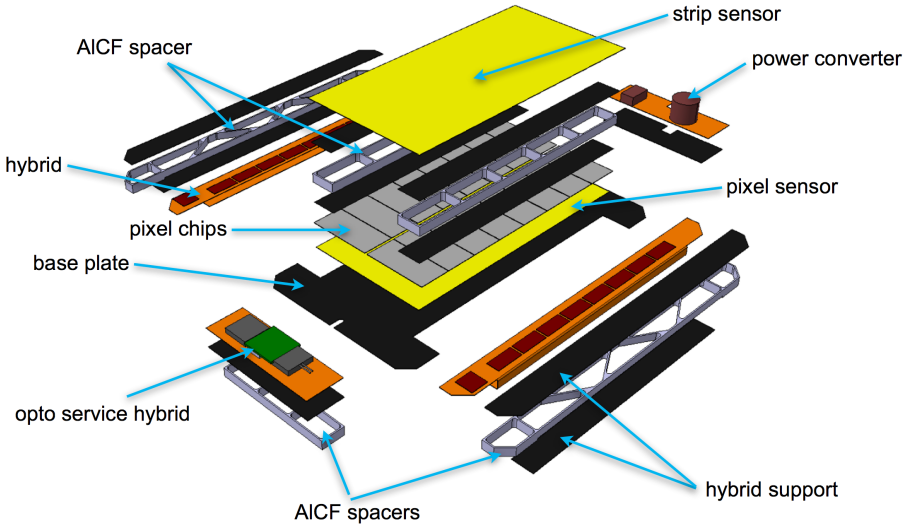
Strip sensor mounted on AliBaVa daughter board as used for testbeam



Phase II – Outer Tracker Modules and Mechanics

- 2S module (2 Strip Sensor)
  - Mass optimization of baseline design has started (simulation)
  - Most parts for a mechanical prototype (including flexible hybrid) are available
  - Thermal and mechanical prototype will be tested in infrastructure (FH-Elab)
- PS module (Pixel & Strip Sensor)
  - Significant progress in the design over the past half year
  - Very close to a baseline design
- Module support structures
  - Design of support structures is ongoing
    - Both module types
    - Barrel and end cap
  - A baseline design is expected within the next half year

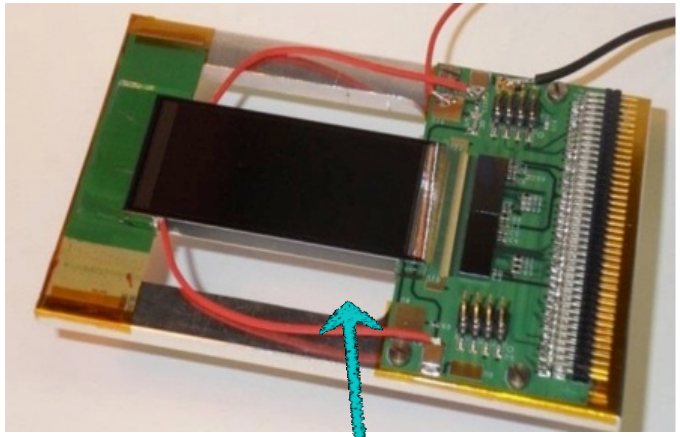


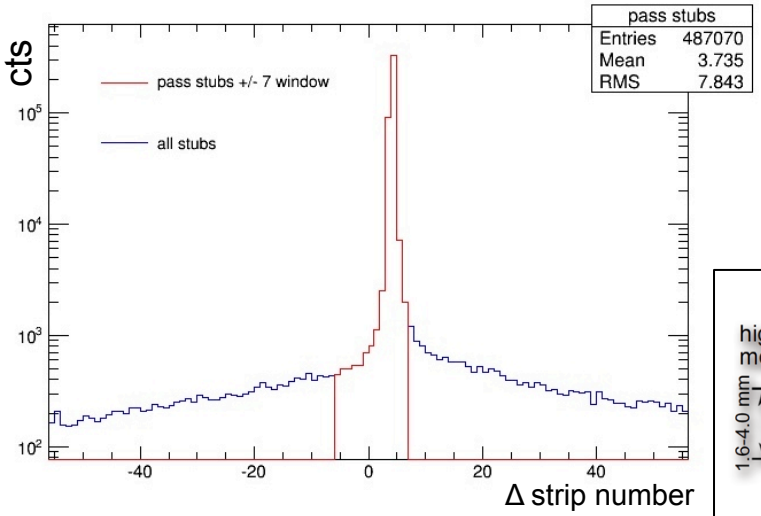


Approaching baseline design

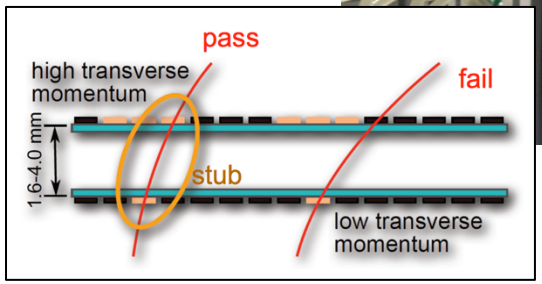
Phase II - Outer Tracker 2S Module

- Mini-2S module prototypes are available
  - Equipped with two CBC (**C**MS **B**inary **C**hip) front-end ASICs
  - 25 x 54 mm^2 active area
- **First successful test beam at DESY November 2013**
- Modules integrated into DESY test beam telescope
  - Successful commissioning of prototype DAQ

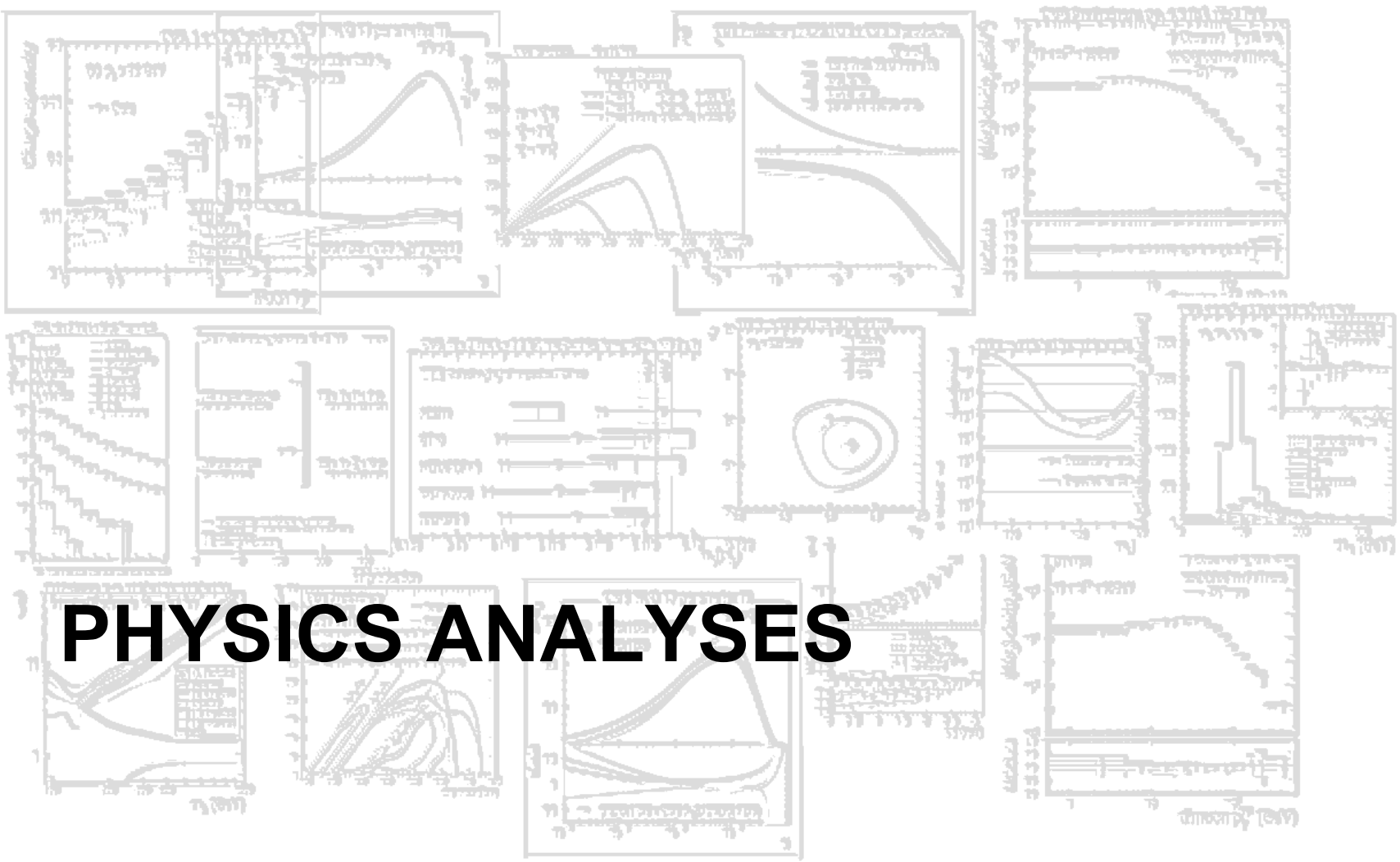




Test of CBC functionality and trigger capability



p_t discrimination

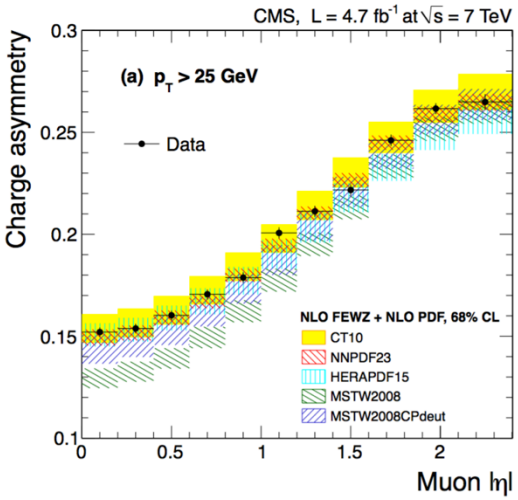


PHYSICS ANALYSES

PDF – W Production Constraining Light and Strange Quarks

- **CMS measurement of muon charge asymmetry in W production at 7 TeV (L=4.7 fb^{-1})**
- **arXiv:1312.6283 – subm. to PRD**

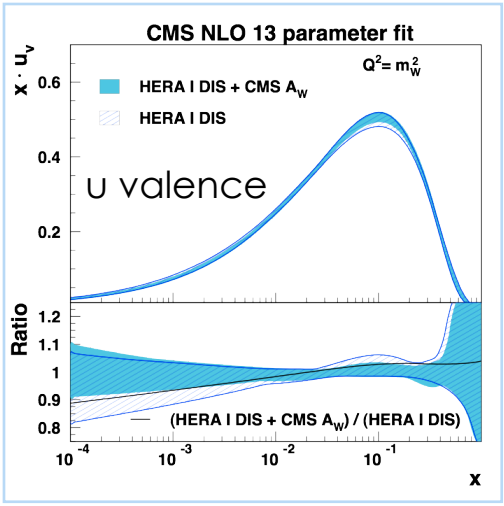
$$A_W = \frac{W^+ - W^-}{W^+ + W^-} \approx \frac{u_v - d_v}{u_v + d_v + 2u_{sea}}$$

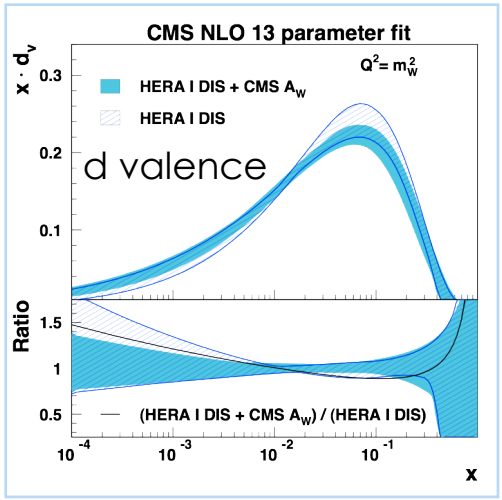


QCD fit at NLO with HERAFitter

HERAFitter

with combined **HERA I DIS data**

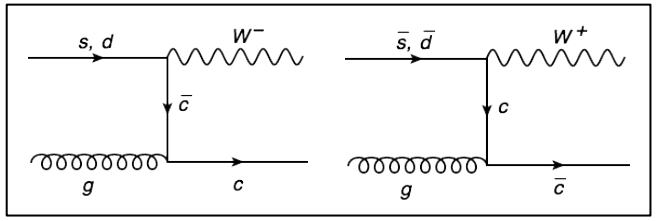




Significant improvement in uncertainty of the valence distributions

PDF – W Production Constraining Light and Strange Quarks

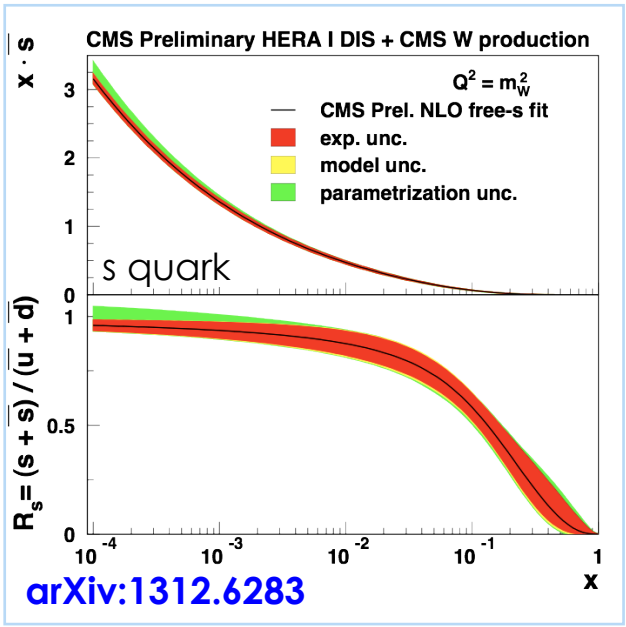
- In pp collisions, production process of W+charm probes strange quark directly at LO
  - **First time use of this directly sensitive process at a hadron collider**
- CMS associated W+charm production at 7 TeV
- CMS muon charge asymmetry in W production
- Instead of input from neutrino scattering experiments



QCD fit at NLO with HERAFitter
s quark fitted

HERAFitter

with combined
HERA I DIS data



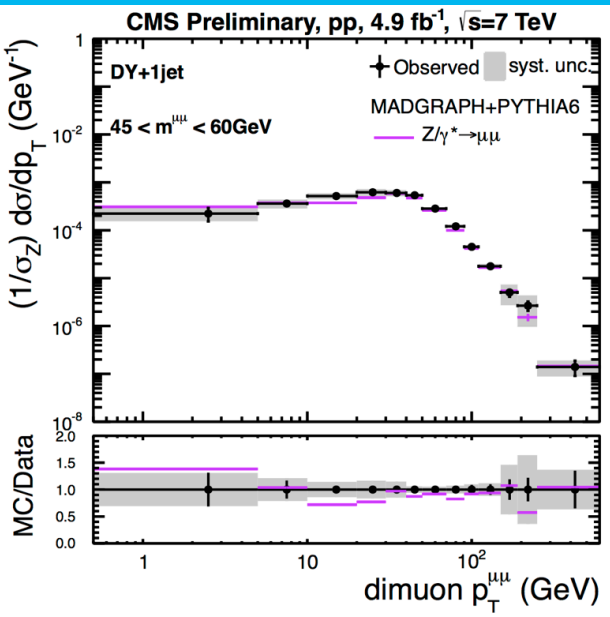
CMS strange quark distributions are in good agreement with PDFs with input from neutrino scattering experiments

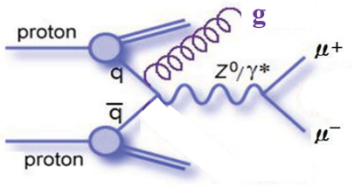
DESY

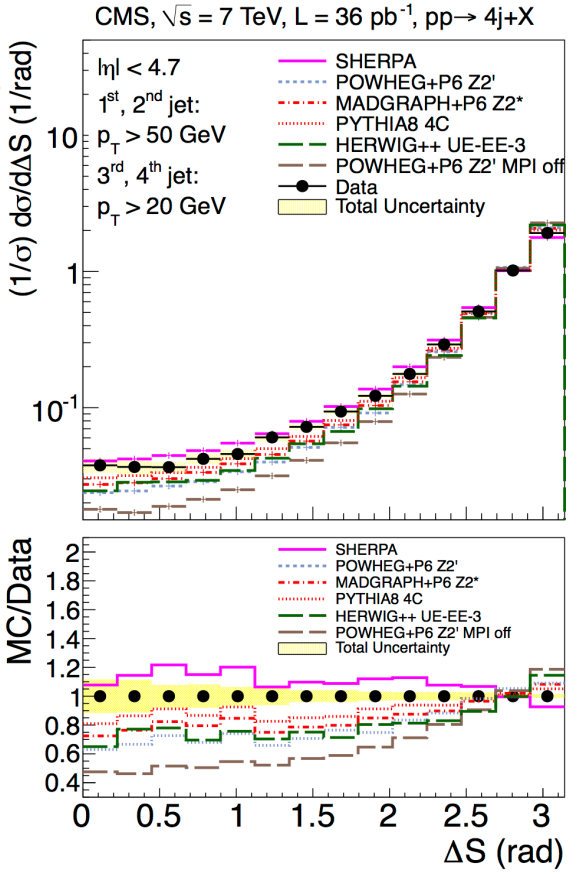
QCD

Drell-Yan as a QCD Lab
CMS-PAS-FSQ-13-003

- Drell-Yan is suitable to study initial-state radiation
- Sensitive to resummation effects in pQCD
- Peak position changes signficantly with additinal jet requirement.
  - Larger resummation region
  - Resummation of minijets
  - Well described by madgraph+pythia
- To be continued:
  High mass DY at 13 TeV







First CMS 4 Jet cross section measurement

- **arXiv:1312.6440 submitted to PRD**
- Important test for higher order QCD calculation
- Phi correlations are sensitive to production mechanism (**Multi Parton Interaction**)
  - Azimuthal angle between jet pairs

How good are our QCD modeling abilities?

TOP

Di-lepton channel

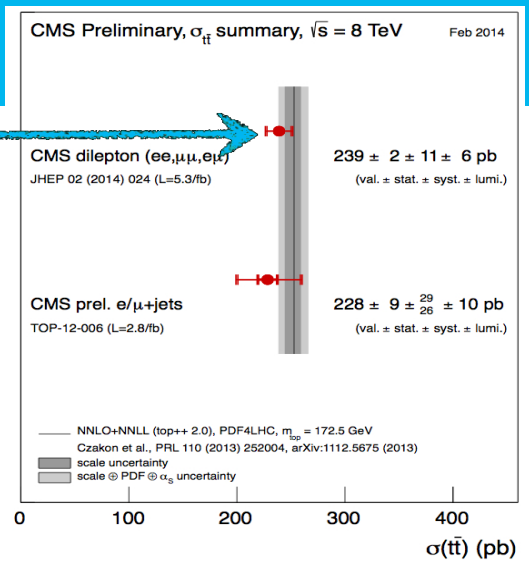
- Incl. and diff. cross section measurements e.g.:
  - Incl. cross section at 8 TeV

    Interpretation:
    - Top (pole) mass, α_S from tt cross sections with PDF dependence
  - tt+(H → bb, H → ττ starting) (with DESY Higgs group)
  - Several 8TeV papers in preparation
- Several starting analyses e.g.
  - 2D differential tt cross sec.
  - Simultaneous determination of gluon, m_{top}, α_S
- Targeted for 13 TeV
  - Inclusive & differential tt cross section "High Priority Analyses" (first few fb^{-1}) Contribution to Summer 2015 conferences

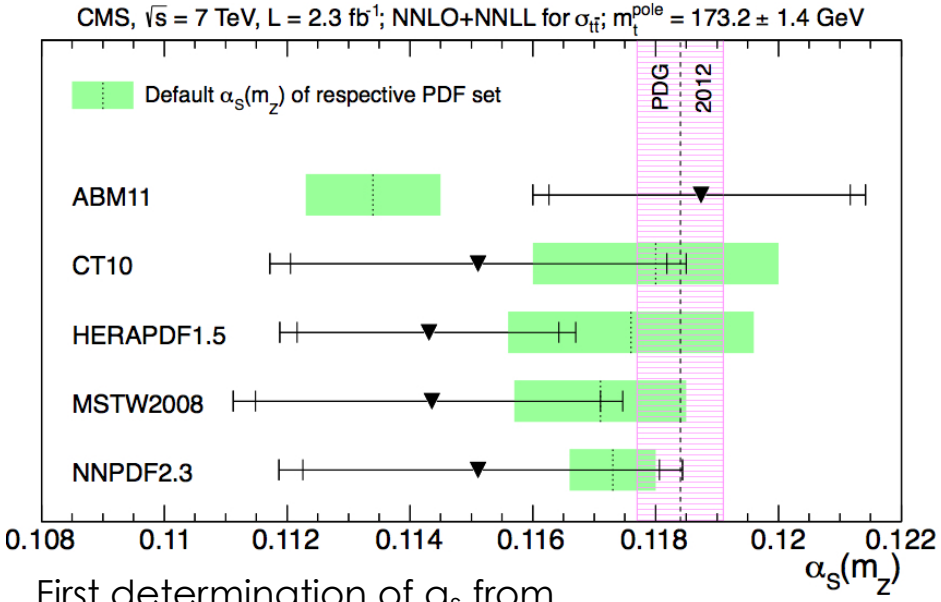
YIG (Maria Aldaya) since April 2014

Precise tt cross section in di-lep. channel challenging QCD precision at NNLO+NNLL

JHEP 02 (2014) 024



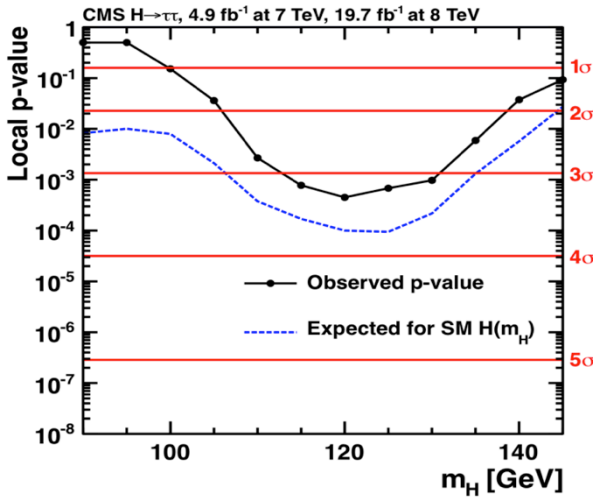
PLB 728 (2013) 496

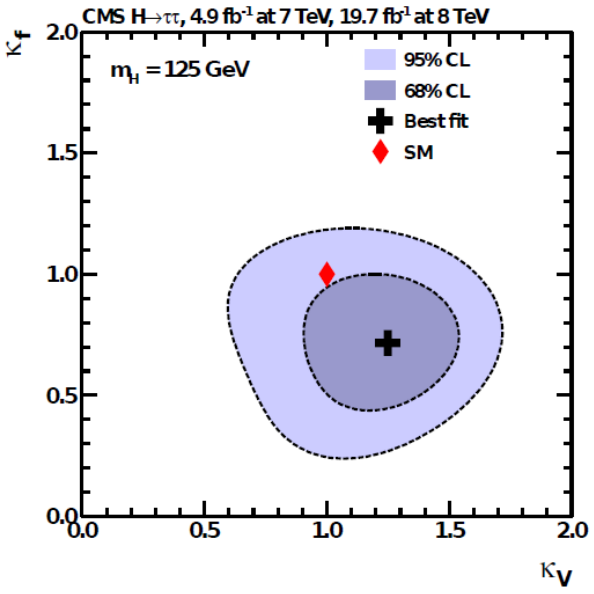


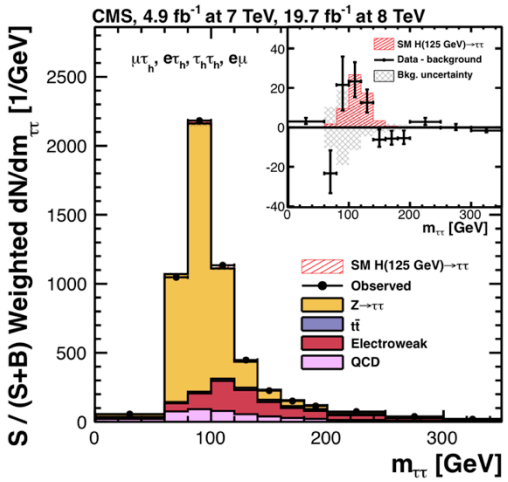
First determination of a_S from tt cross section at NNLO+NNLL QCD

Higgs - SM H→ττ

- CMS finds clear evidence for H→ ττ decays (3.2 σ observed, 3.8 σ expected)
  - DESY: strong contribution (four decay modes)
  - Combined with H→bb channel, 3.8 σ observed evidence for Higgs decays to fermions
- Hττ coupling >> Hμμ coupling → mass dependence (=non-universality) of coupling
  - Couplings agree with SM expectation
  - m_H = 122 ± 7 GeV





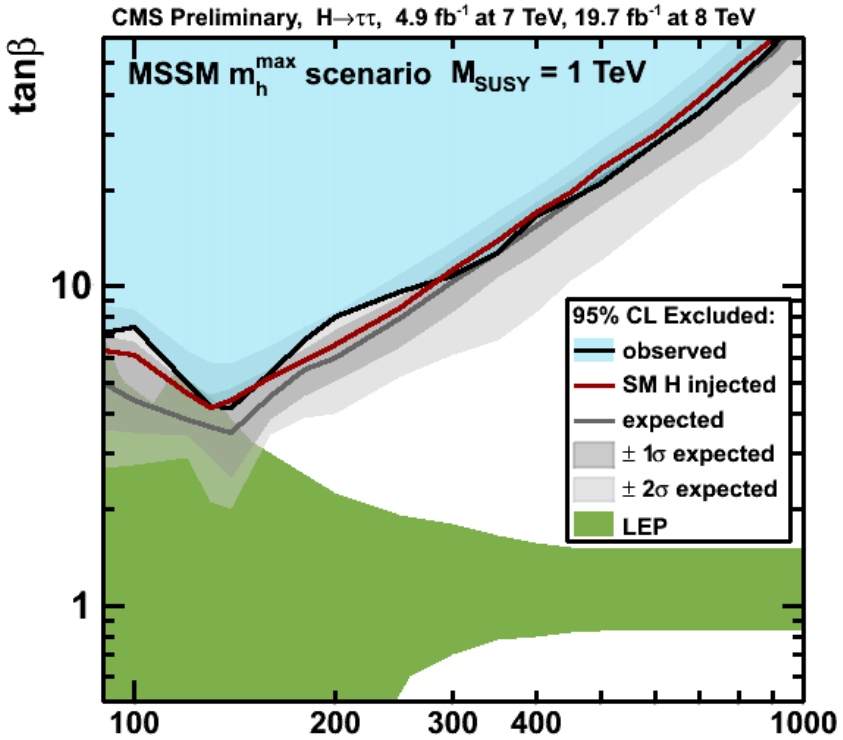


arXiv:1401.5041
Submitted to JHEP

CMS finds clear evidence for H → leptons in agreement with SM

Higgs - Final Run-I Results for MSSM H→ττ

- Search for additional neutral Higgs bosons, as predicted by minimal Supersymmetry (MSSM)
  - Fully compatible with observed H(125)
- Full 7 TeV + 8 TeV statistics & refined analysis techniques
  - Combination of five of six possible H→ττ decay modes
- Closing the LHC-LEP gap up to ~150 GeV
  - Mass range extended up to 1 TeV
- Observed H(125) starts to become relevant as "background" for BSM Higgs searches at low masses

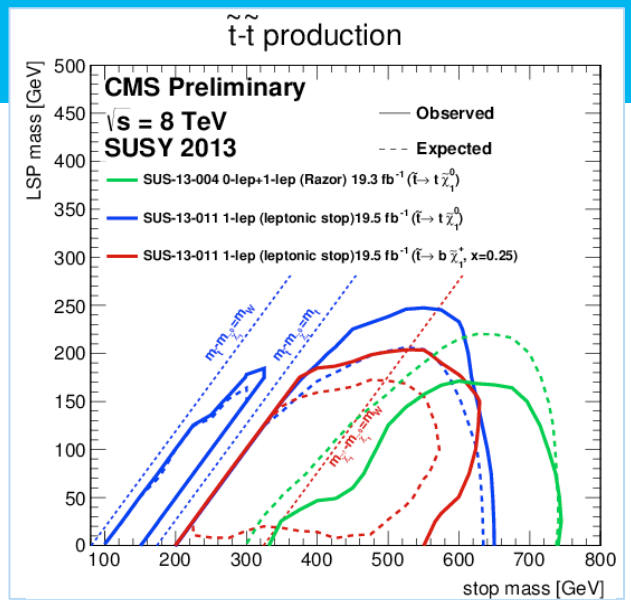


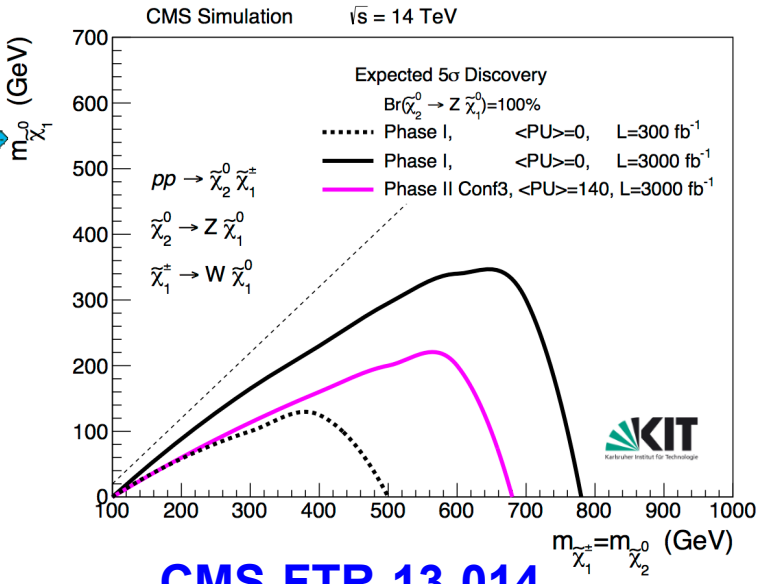
CMS-PAS-HIG-13-021
Publication in progress

Most stringent limits for neutral MSSM Higgs to date in this channel

SUSY

- Direct stop production in the single-lepton final state
  - Published **EPJC 73(2013) 2677**
  - Combined CMS paper for the 0/1/2 lepton channel
  - Preparation for 1-lepton direct stop search at 13 TeV
- **CMS SUSY Future Analyses Subgroup**
  - Projections of SUSY Searches for "*ECFA High Luminosity LHC Experiments Workshop*" (**ECFA/13/284**)
    - EWkino 3 lepton search at 300/3000fb^{-1}
  - Contribution to the Phase II Technical Proposal
    - Defining full SUSY model points for signal generation and analysis + MC production
    - Sensitivity study on direct stop production

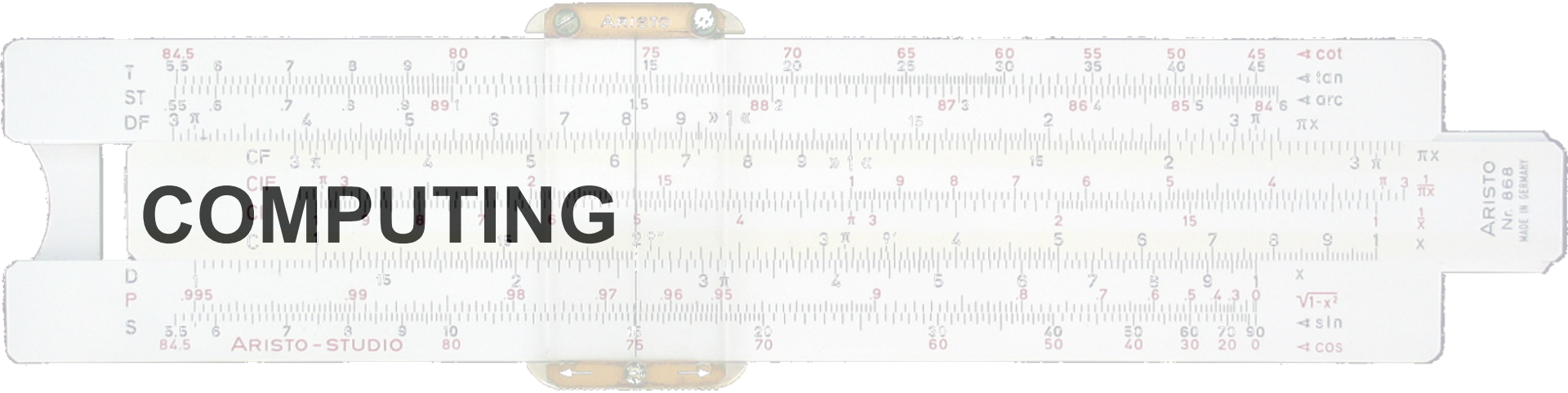




CMS-FTR-13-014

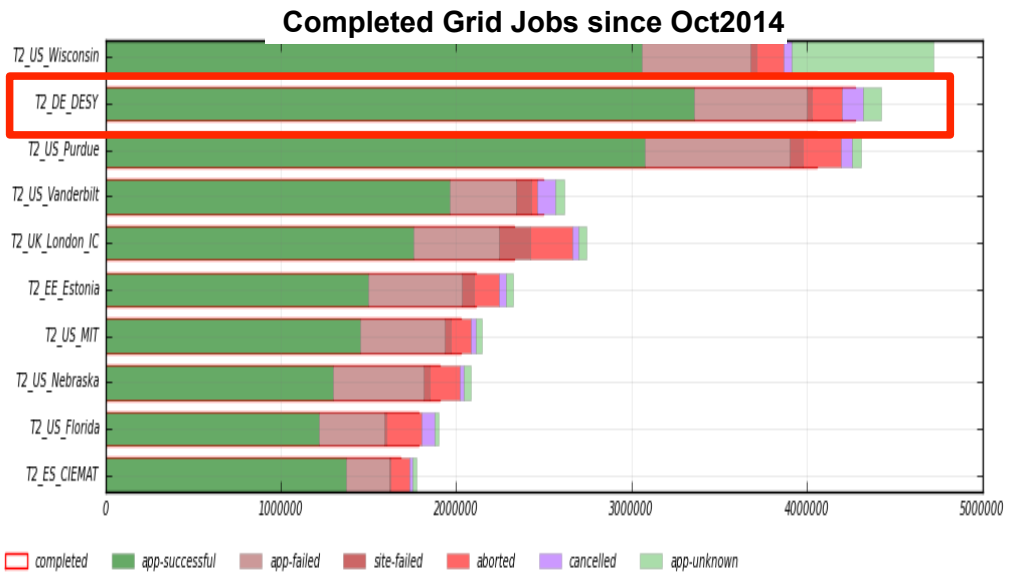
Studying the HL-LHC from a SUSY perspective

COMPUTING

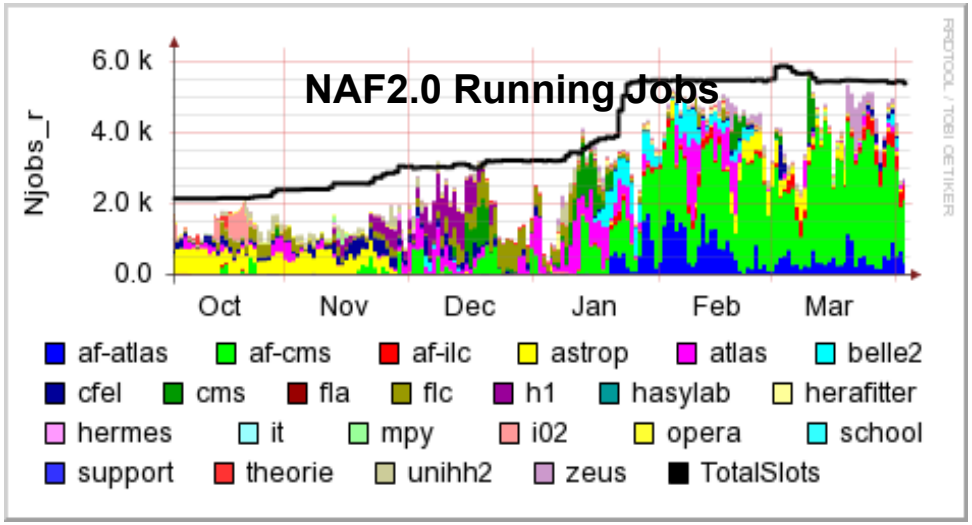


CMS Computing @ DESY

- CMS Tier2 T2_DE_DESY:
  - 2014 resource pledges in place
    - 19.0 kHS06* CPU
    - 1,400TB Disk
  - Very reliable and therefore actively used for analysis and MC production
  - Combined effort by (few persons in) DESY-IT, DESY-CMS and Uni. HH



- NAF2.0 Migration
  - All CMS users migrated
  - Resources well utilized from CMS
  - Migration Feedback meeting planned for May 14th
    - To discuss remaining issues
    - To agree on development priorities



* 1 Core ~ 10 HepSpec06

Summary

Upgrades

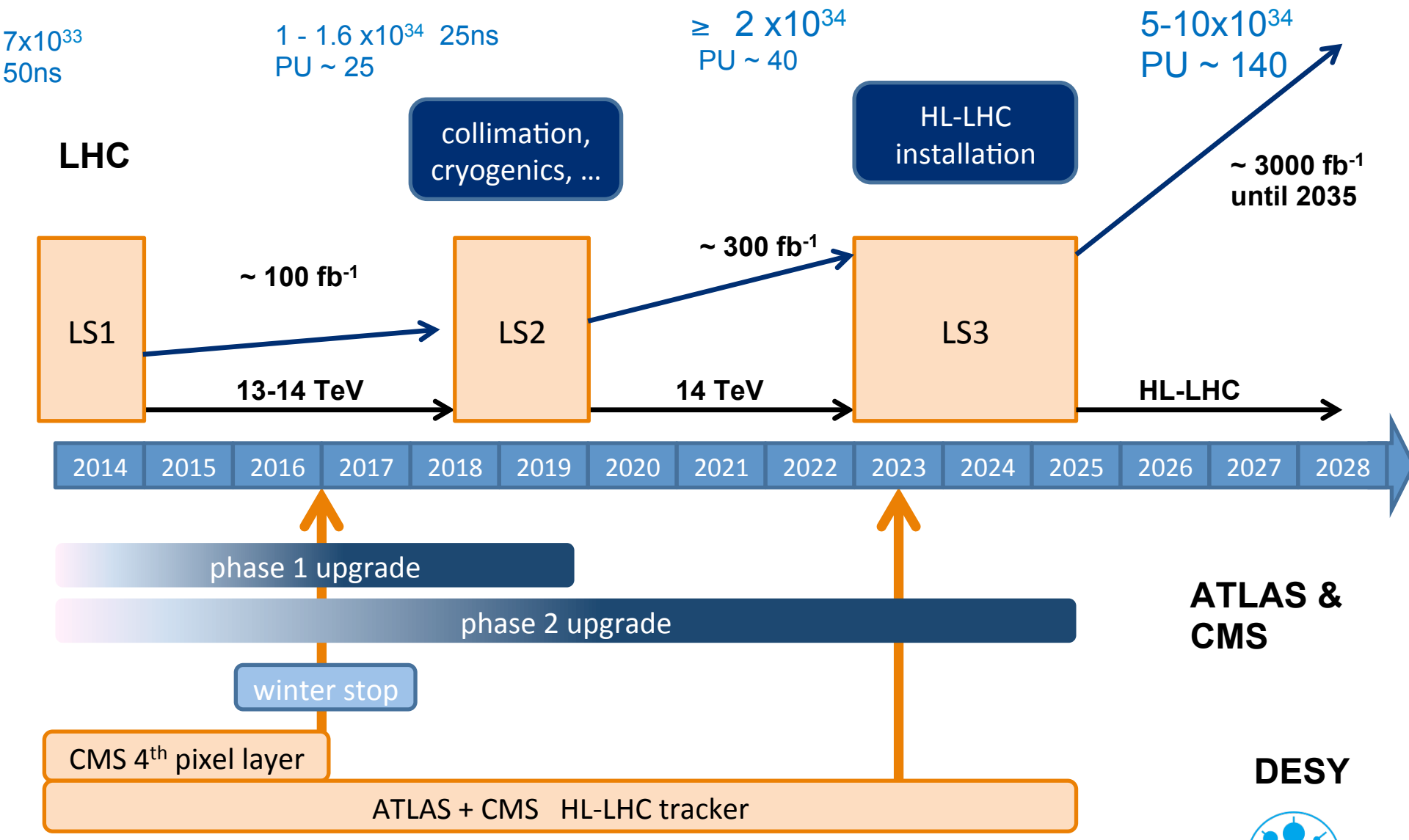
- Contributions to LS1
  - Proceeding well and are on schedule
- Phase I – Pixel detectors
  - Bump bounding established
  - First bare module produced
  - On schedule
- Phase II – Tracker endcap
  - Key activities in module and mechanical design
  - Preparing for endcap construction
  - Need to secure infrastructure and funding

Physics Analyses

- Many new results
  - W production constraint light and sea quark
  - QCD measurements test our modeling abilities
  - Top Quark precision measurements challenge the SM at NNLO+NNLL QCD
  - Clear evidence for Higgs to leptons, no hint for MSSM Higgs - Best limits for neutral MSSM Higgs bosons in H → $\tau\tau$
  - The SUSY group worked on the best limits for low stop masses and prepares for the future

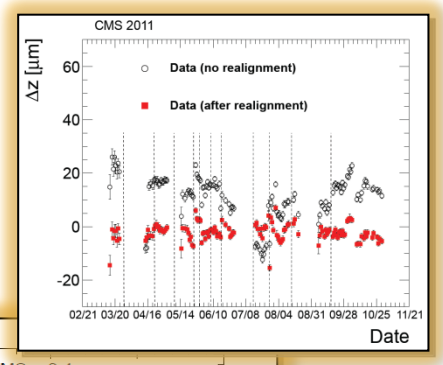
BACKUP

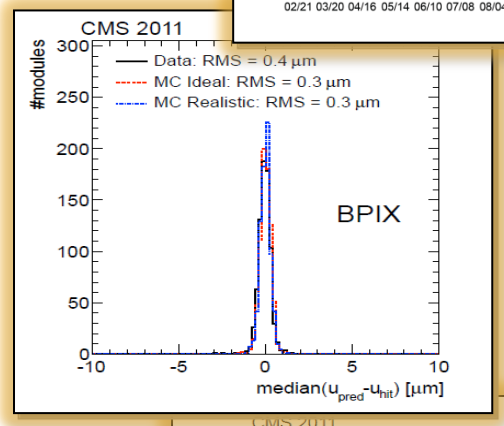
LHC and Experiments Schedule beyond LS1

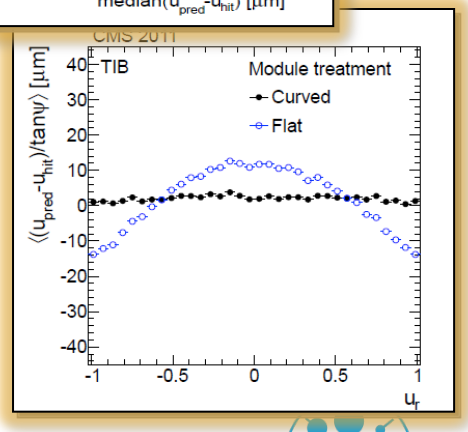


Alignment

- The comprehensive CMS tracker alignment paper passed the Final Reading and was released to the public
- Highlights: **arXiv:1403.2286, accepted by JINST**
  - Simultaneous fit of ~200,000 alignment parameters and ~20 million tracks (based on "Millepede-II" program)
  - Rigorous treatment of material effects ("General Broken Lines" fit)
  - Account for detailed time-dependence (movements)
  - Module-level determination of shape parameters (sensor curvatures & module kinks)
  - Weak mode stability
  - Multi-core parallel execution → high execution speed
  - Accuracy reaching ≤ 2 μm in the pixel tracker
- Managed to still include reference in H→ZZ→4l paper for which alignment is especially important
- Ongoing studies
  - weak mode resilience of 2012 legacy alignment
  - inclusion of $\Upsilon(1S)\rightarrow\mu\mu$ signature in the alignment procedure
  - preparation of 2015 alignment







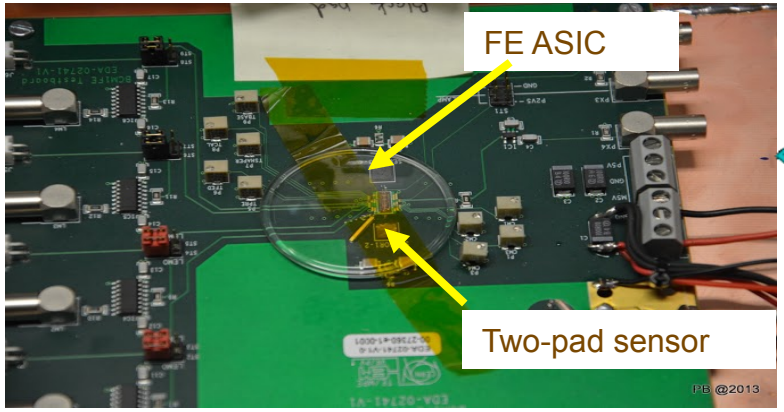
Data Quality Monitoring and Certification

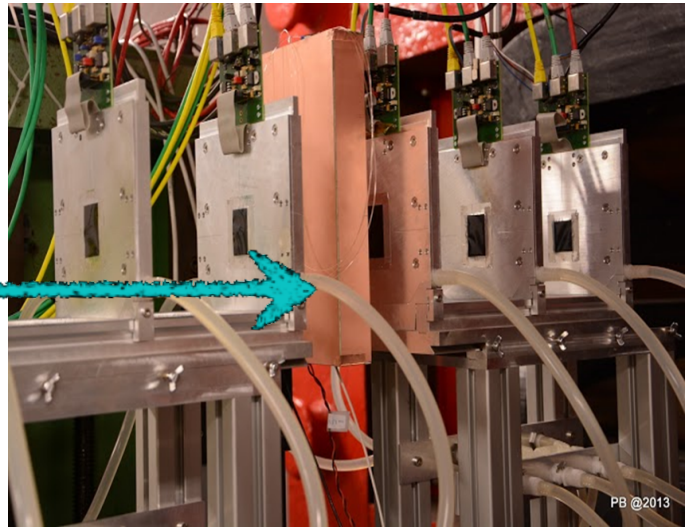
Activity and responsibility of the CMS DQM group

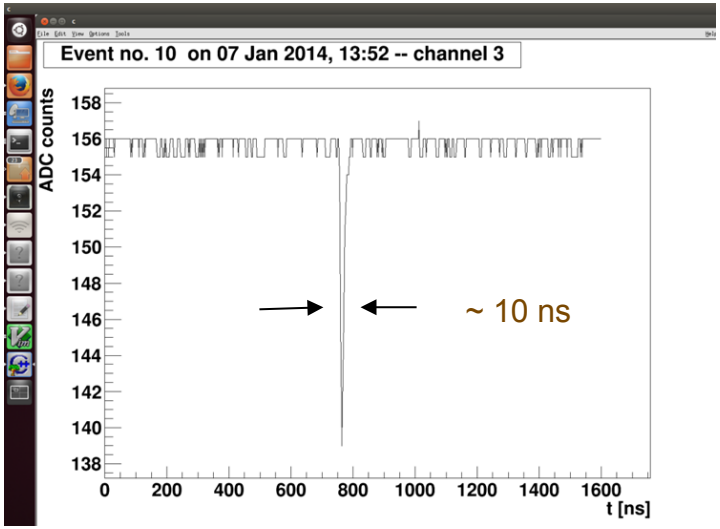
- CMS Remote Centre/Offline DQM
  - Preparing for shifts mid of 2014 in preparation for Run II
- Major activities in data certification during LS1
  - Defining and switching to new data certification procedure for Run II
  - Managing main certification tool –RunRegistry– for storing data quality flags (in close collaboration with IT responsible) and migrating other certification tools (scripts etc.)
  - Training detector/POG experts for new certification procedure
  - Testing the new procedure during global CMS runs
    - Succesfully during GRiN exercise (Global Run in November)
    - Implementing and testing of RunRegistry features during this month GR
  - Creation of the official files containing data quality used by all CMS data analyses (during data taking, file creation for specific studies during LS1)
- Harvesting
  - Collecting of DQM information from MC

LS1 - Beam Conditions Monitor & Luminometer

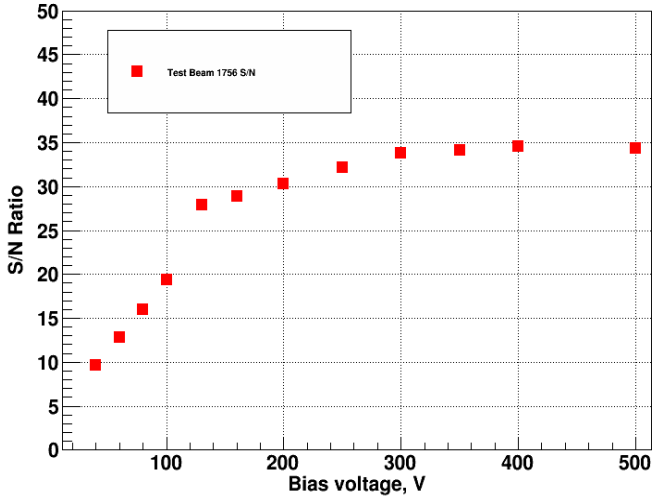
Testbeam at DESY : sensor+front-end
Whole readout chain tested







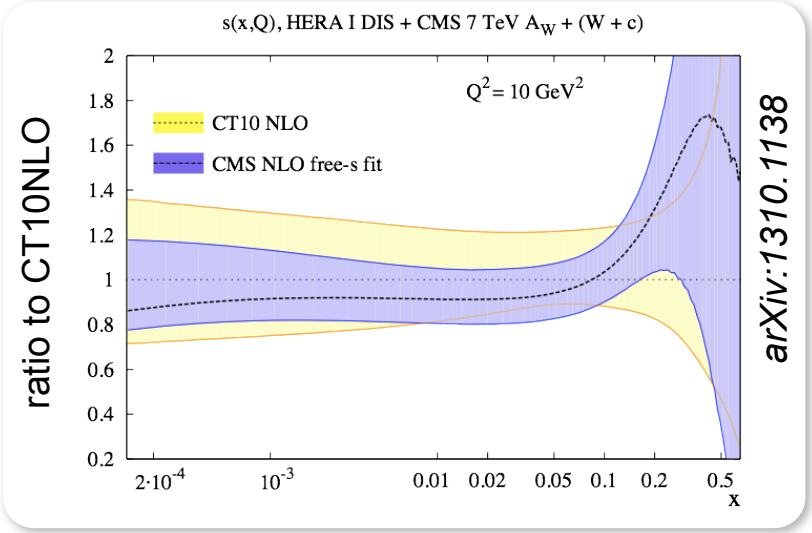
Signal form and S/N matches the expectations



PDF - Strange quark distribution using LHC data

Results agree with the global PDFs

where assumptions on s(x) are based on results of neutrino scattering experiments



Strangeness suppression factor :

$$\kappa_s(Q^2) = \frac{\int_0^1 (\bar{s}(x,Q^2) + s(x,Q^2))dx}{\int_0^1 (\bar{u}(x,Q^2) + \bar{d}(x,Q^2))dx}$$

Result of the CMS QCD analysis at NLO using W production:

$$\kappa_s = 0.52^{+0.12}_{-0.10}(exp.)^{+0.05}_{-0.06}(mod.)^{+0.13}_{-0.10}(par.)$$

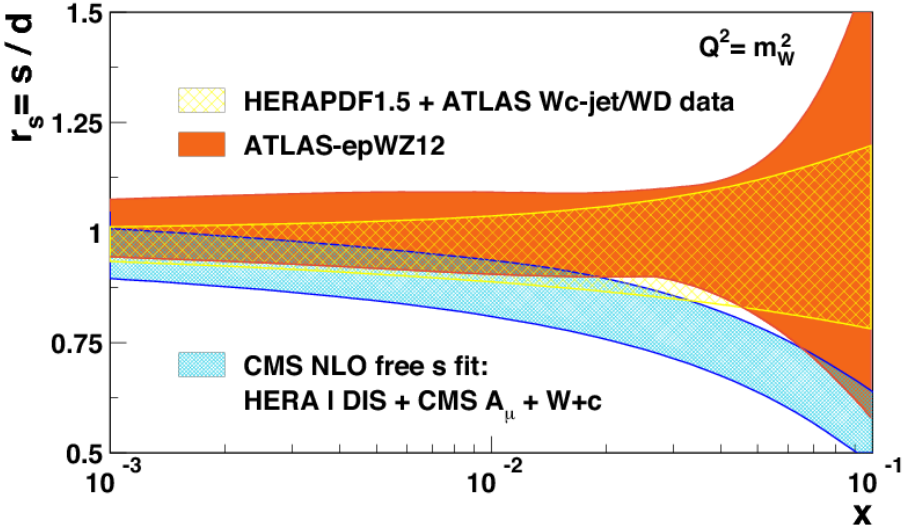
at Q^2=20 GeV^2

in good agreement with the NOMAD *[Nucl.Phys. B876 (2013) 339, κ_s =0.59 ± 0.019]*

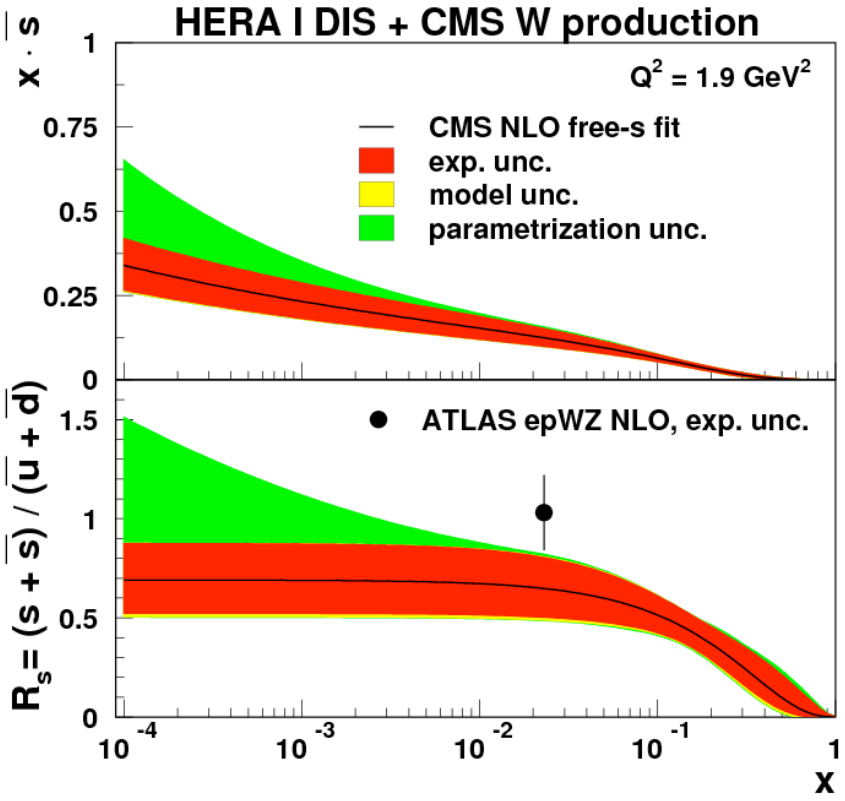
Direct constraints on the strange quark distribution by using collider data only in good agreement with results of neutrino scattering experiments

PDF

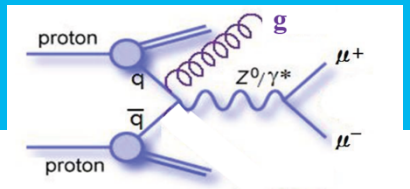
Comparison to ATLAS analysis of W+c production arXiv:1402.6263



https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP12021

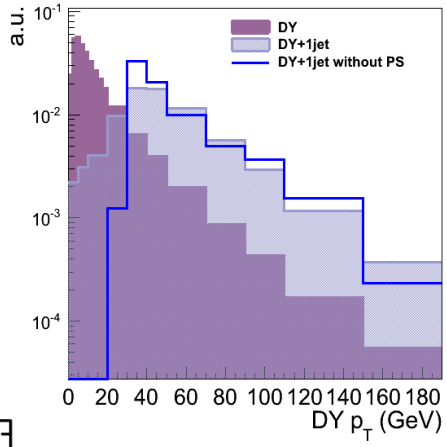


QCD at the Extremes – Drell Yan + Jets

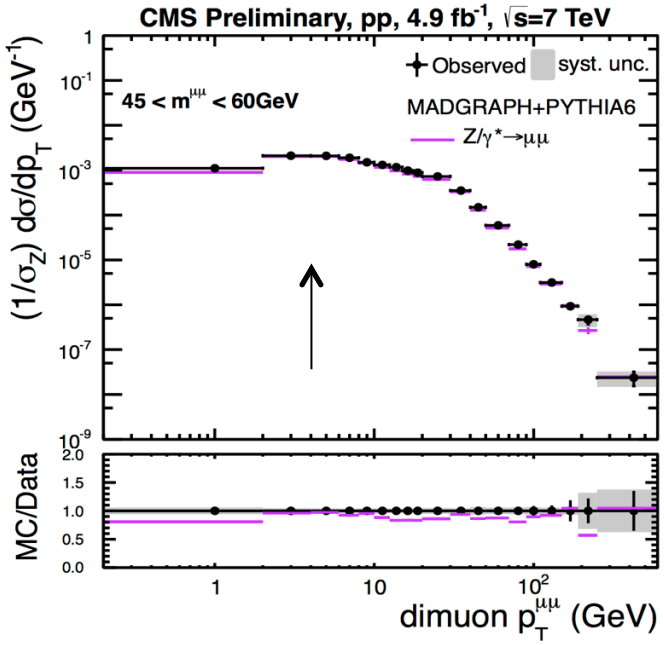


Drell-Yan as a QCD Lab

- Drell-Yan is suitable to study initial-state radiation not sensitive to QCD final-state radiation
- Sensitive to resummation effects in pQCD
- High mass DY at 13 TeV

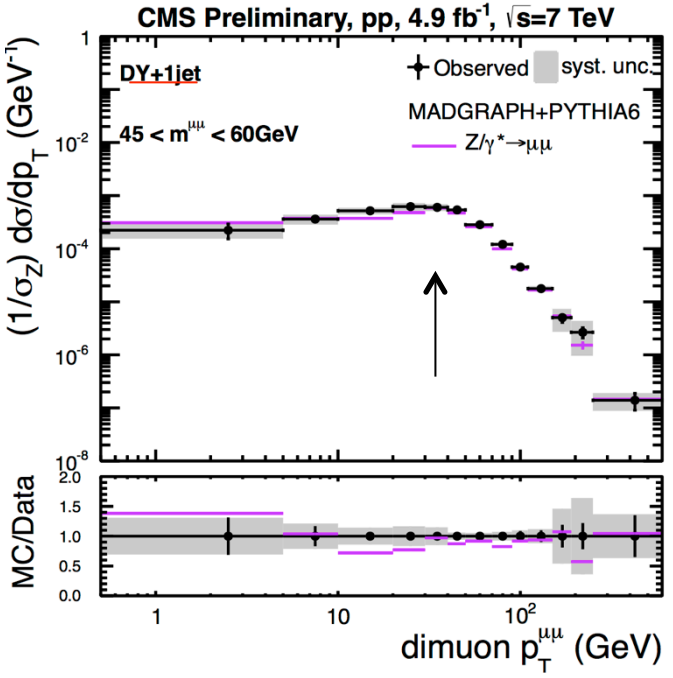


- Peak position changes signficantly with jet requirement. Larger resummation region
  - Resummation of minijets
- Overall well described by Madgraph+Pyhtia



additional jet
p_T > 30GeV

CMS-PAS-FSQ-13-003

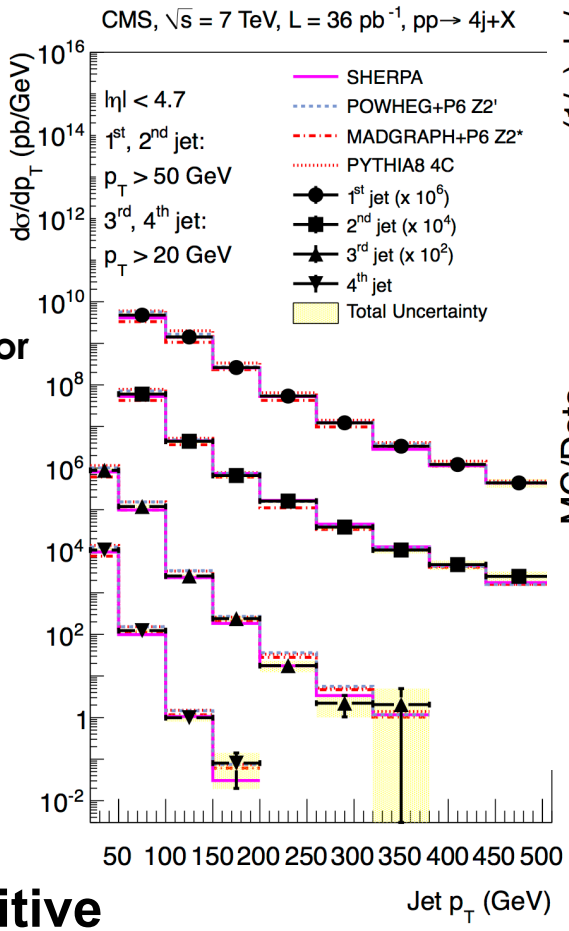


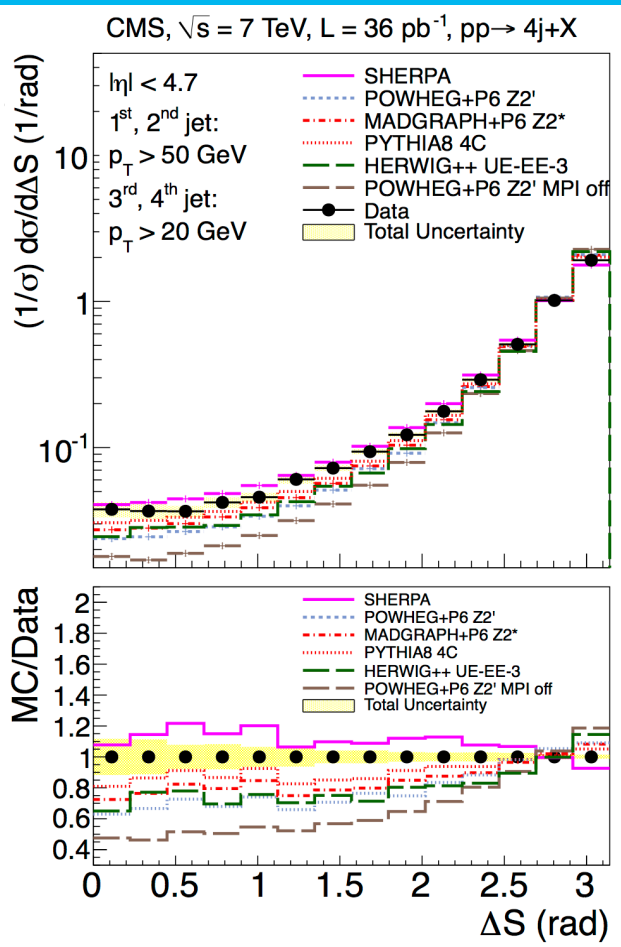
How well do we understand gluon resummation ?

QCD at the Extremes – 4 Jets

Testing our QCD modeling abilities in 4 Jets production

- First CMS 4 Jet cross section measurement public
  - Important test for higher order QCD calculation
  - Well described at high p_T
  - Phi correlations are sensitive to production mechanism (**single or double parton interaction**s)
- **arXiv:1312.6440 submitted to PRD**





Phi correlations are sensitive to production mechanism

DESY CMS public results since Summer 2013

- S. Chatrchyan et al. “Search for new physics in the multijet and missing transverse momentum final state in pp-collisions at √s=8TeV” arXiv:1402.4770.
- S. Chatrchyan et al. “Evidence for the direct decay of the 125 GeV Higgs boson to fermions” arXiv:1401.6527.
- S. Chatrchyan et al. “Evidence for the 125 GeV Higgs boson decaying to a pair of τ leptons” arXiv:1401.5041.
- S. Chatrchyan et al. “Measurement of the tt production cross section in the dilepton channel in pp collisions at √s=8TeV” JHEP 1402 (2014) 024, [arXiv:1312.7582].
- S. Chatrchyan et al. “Determination of the top-quark pole mass and strong coupling constant from the tt production cross section in pp collisions at √s=7TeV” Phys. Lett. B 728 (2014) 496, [arXiv:1307.1907].
- S. Chatrchyan et al. “Measurement of four-jet production in pp-collisions at √s=7TeV” arXiv:1312.6440.
- S. Chatrchyan et al. “Study of double parton scattering using W + 2-jet events in pp-collisions at √s=7TeV” JHEP 1403 (2014) 032, [arXiv:1312.5729].
- S. Chatrchyan et al. “Alignment of the CMS tracker with LHC and cosmic ray data” arXiv:1403.2286, submitted to JINST.
- S. Chatrchyan et al. “Measurement of jet multiplicity distributions in t t production in pp collisions at s √s =7TeV” CERN-PH-EP-2014-048.
- F. Hautmann and H. Jung “Transverse momentum dependent gluon density from DIS precision data” arXiv:1312.7875.
- P. Cipriano, S. Dooling, A. Grebenyuk, P. Gunnellini, F. Hautmann, H. Jung and P. Katsas “Higgs as a gluon trigger” Phys. Rev. D 88 (2013) 097501 [arXiv:1308.1655].
- CMS-PAS-HIG-13-021 “Higgs to tau tau (MSSM)” http://cds.cern.ch/record/1623367
- CMS-PAS-HIG-13-019 “Search for Higgs Boson Production in Association with a ttbar Pair in Decays to b-Quarks or Tau Leptons” http://cds.cern.ch/record/1564682
- CMS-PAS-TOP-13-007 “Study of the underlying event, b-quark fragmentation and hadronization properties in tt events” http://cds.cern.ch/record/1600599
- CMS-PAS-FSQ-12-008 “Measurement of azimuthal correlations between forward and central jets in pp-collisions at sqrt(s)=7TeV” http://cds.cern.ch/record/1643105
- CMS-PAS-SMP-12-028 “PDF constraints and extraction of the strong coupling constant from the inclusive jet cross section at 7TeV” http://cds.cern.ch/record/1632407
- CMS-PAS-BTV-13-001 “Performance of b tagging at sqrt(s)=8 TeV in multijet, ttbar and boosted topology events” http://cds.cern.ch/record/1581306
- DESY contributes to HCal and Physics Technical Design Reports (TDR) for the upgrade program in 2013.

Coordinating Roles within CMS

- **Level-1 Management**
  - M. Kasemann: Chair of the Authorship Board
  - K. Borras: Deputy Spokesperson (Jan. 2014 – Aug 2016); FB member
- **Physics**
  - H. Jung: FSQ-PRF Pub. Committee,
    Chair of Theorists in CMS committee
  - I. Melzer-Pellmann: Convener of SUSY Future subgroup (L3), Member of SUSY Pub. Committee
  - Andreas Meyer, Convener of top physics analysis working group (L2, 2014/15)
  - S. Naumann-Emme: Convener of top quark mass subgroup (L3, 2013/14)
  - K. Lipka, R. Placakyte: Coordinators of PDF@CMS Forum
  - I. Marfin: b-tag HLT subgroup convener
- **Computing**
  - C. Wissing: Operation (L2)
  - M. Kasemann: Chair of Computing Resource Board
- **Data Quality Monitoring**
  - D. Krücker: Organizer of remote DQM shifts (L3)
  - R. Placakyte: Data Certification (L3)
- **Tracker**
  - G. Eckerlin: Tracker Phase 1 Upgrade Management Board, Tracker Phase 2 Upgrade Management Board, Tracker Finance Board
  - D. Eckstein, W. Lange: CEC Sensor & Qualifying
  - A. Mussgiller: Convenor of Strip-Tracker Module-Design group
- **BRIL**
  - W. Lohmann: Chair of Institutional Board
  - R. Walsh: DPG convener
- **Hadron Outer Calorimeter**
  - B. Lutz: Coordinator for HO Upgrade at Point 5