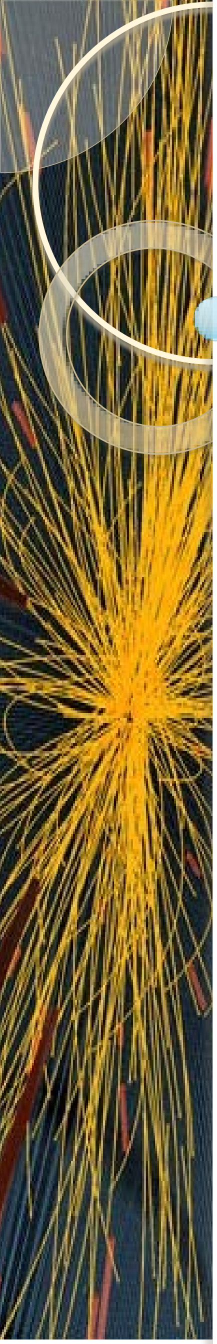
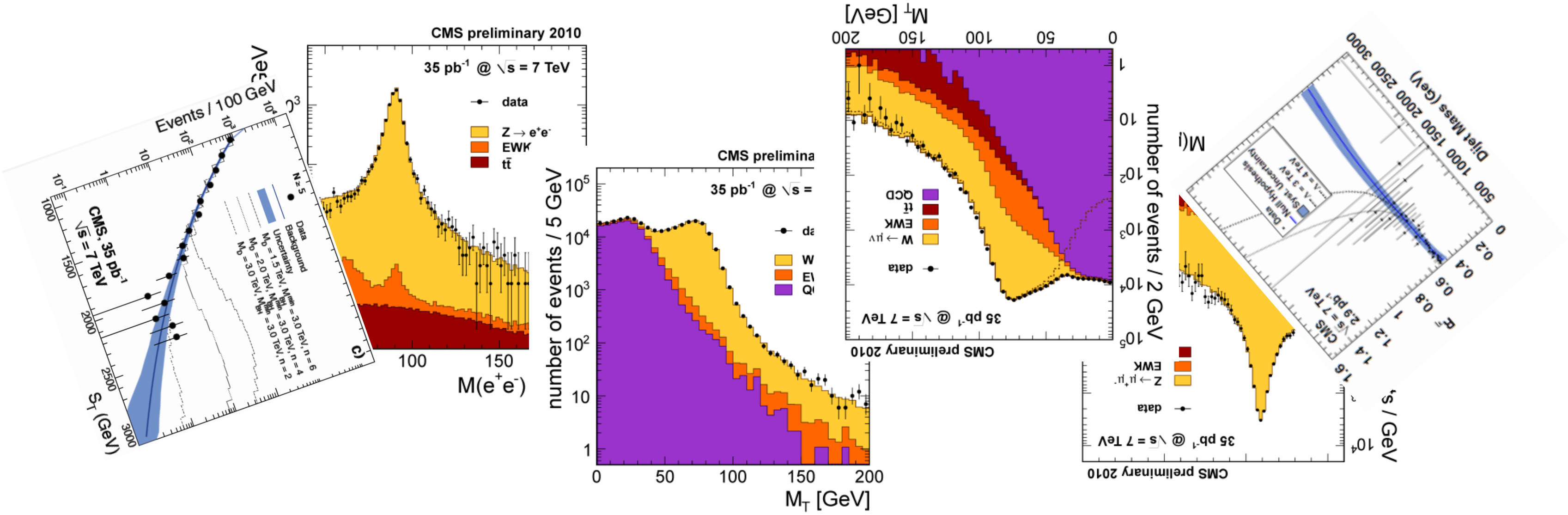


Maxime Gouzevitch

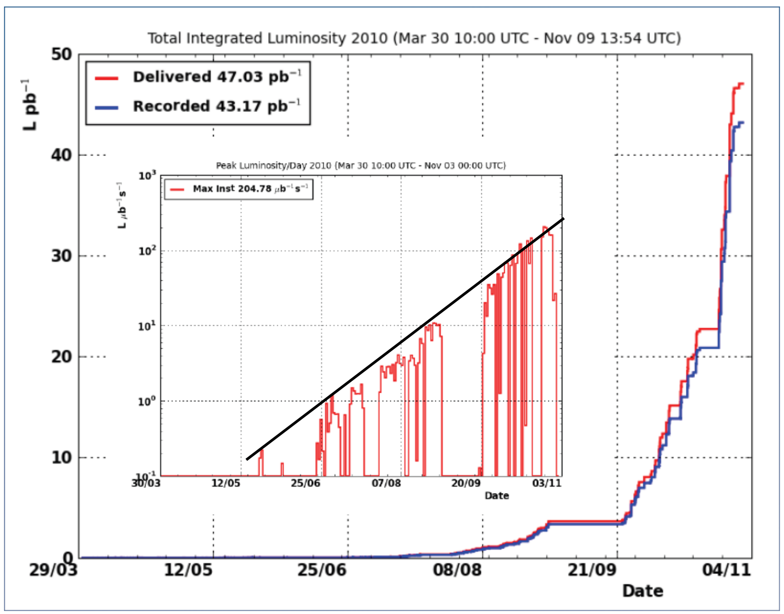
CMS results in 2010 and prospects for 2011-2012

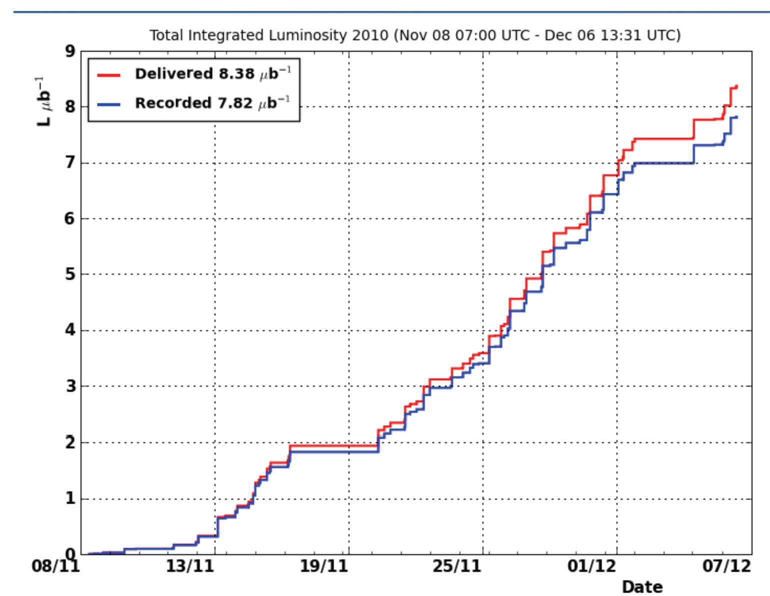
on behalf of the CMS collaboration



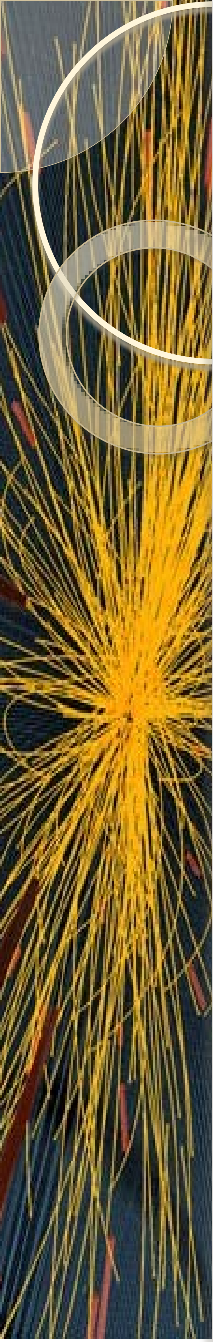
1) The power law of the Luminosity

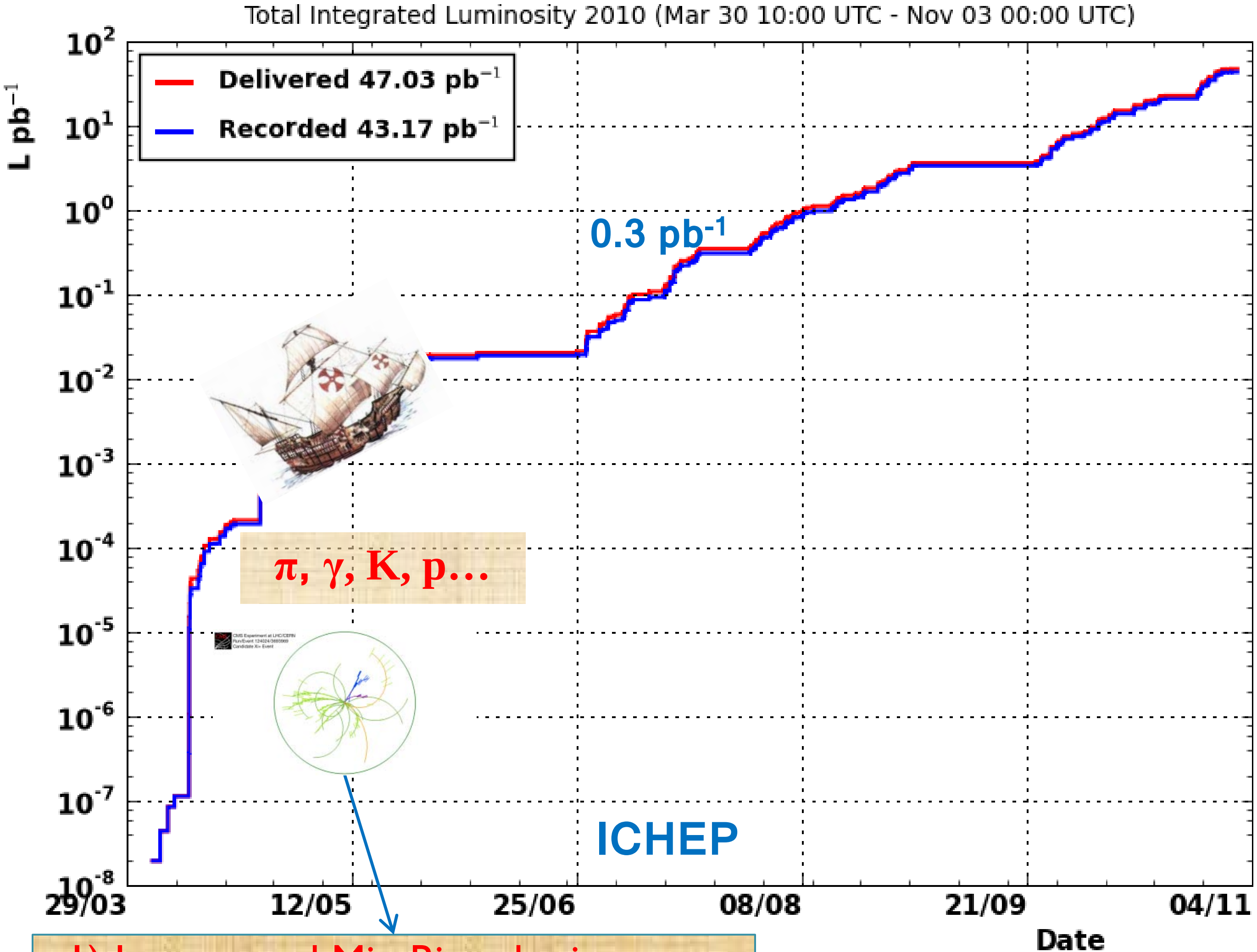
- 2010: luminosity x10 /month. Peak luminosity: $2 \cdot 10^{-32}$ $cm^{-2}s^{-1}$.
- “But trees don’t grow to the sky” in 2011-2012:
  - Increase ~3 times the instantaneous luminosity.
  - 1- 4 fb^{-1} of data to be collected in 2011 and 5-10 fb^{-1} in 2012 depending on the machine behavior.





2) The sailing way

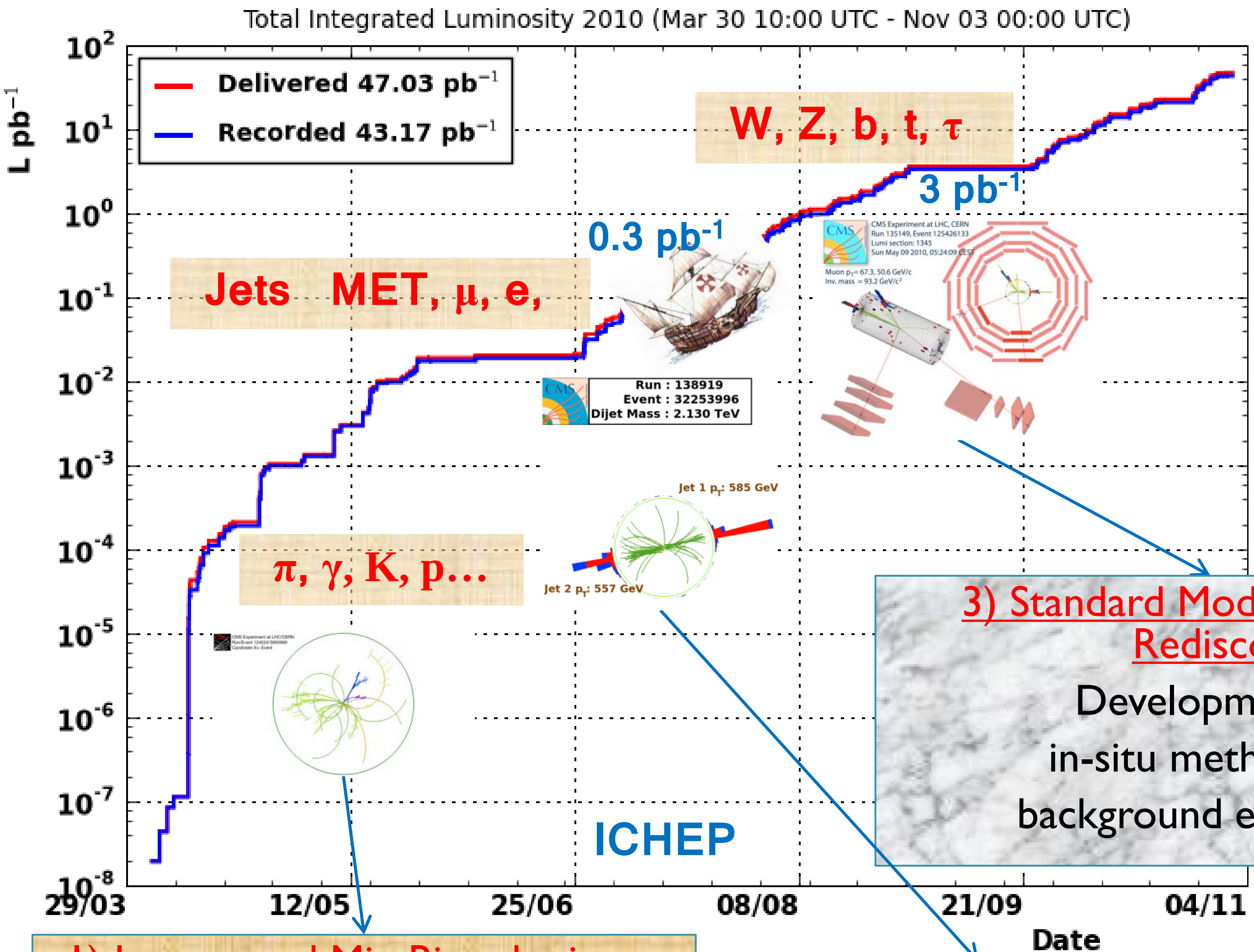




1) Low p_T and Min Bias physics:

Detector performance, systematic uncertainties and MC tuning.

2) The sailing way

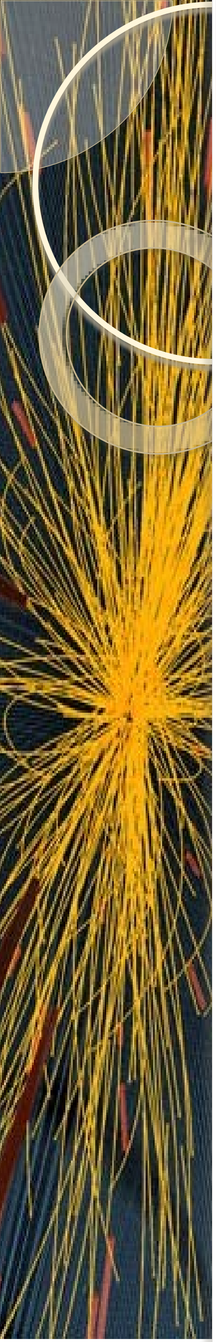


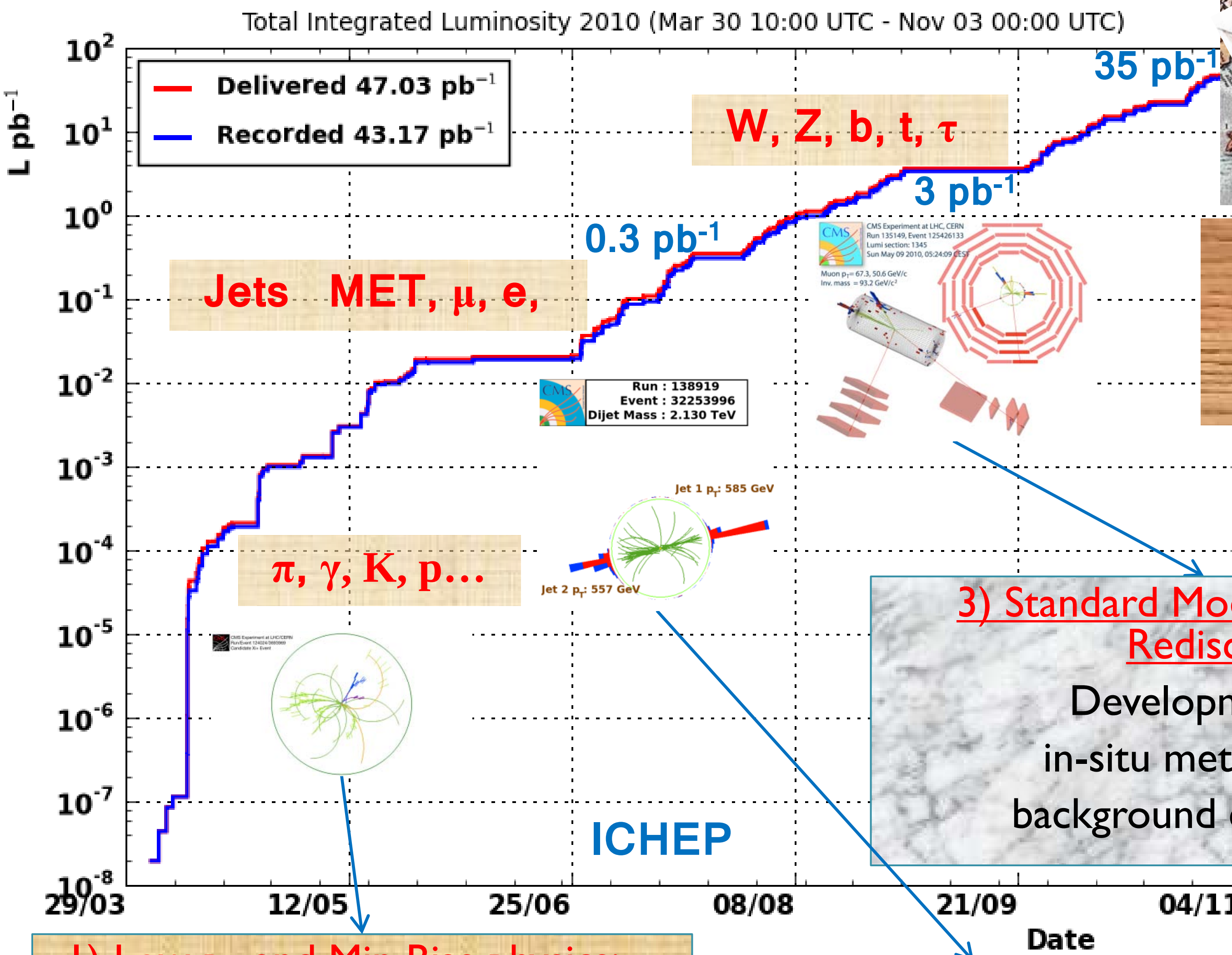
3) Standard Model and QCD Rediscovery:
Development of in-situ methods for background estimation

1) Low p_T and Min Bias physics:
Detector performance, systematic uncertainties and MC tuning.

2) Physics objects
Validation, calibration

2) The sailing way





4) TERRA INCOGNITA @TEV

3) Standard Model and QCD Rediscovery:

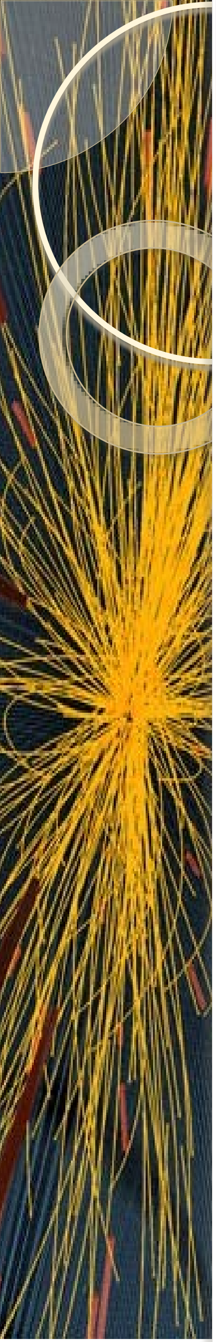
Development of in-situ methods for background estimation

1) Low p_T and Min Bias physics:

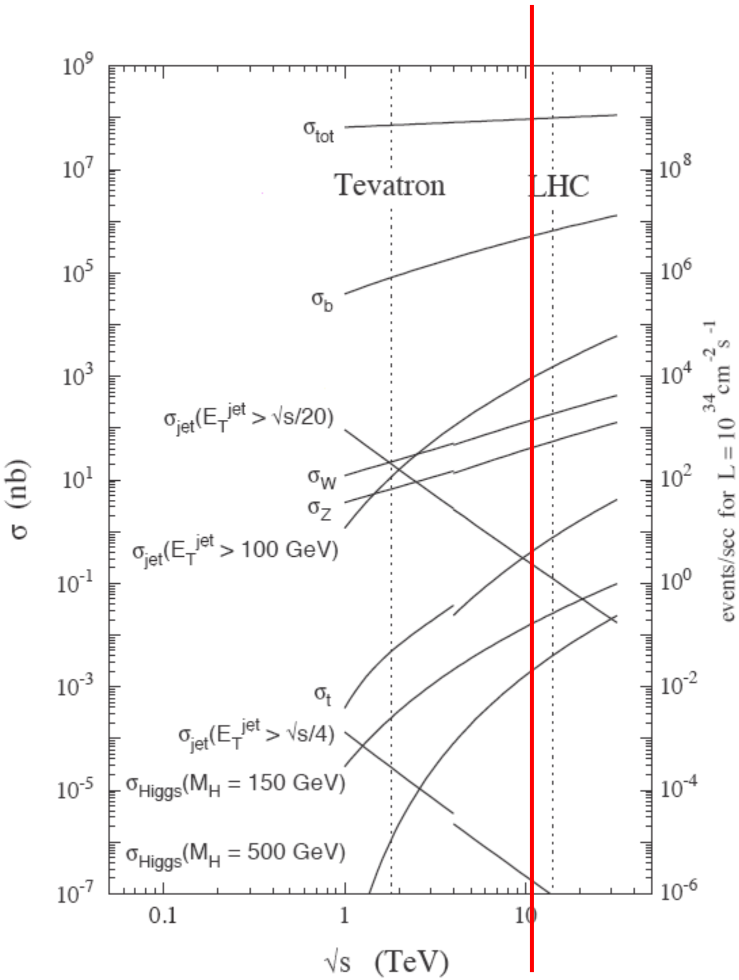
Detector performance, systematic uncertainties and MC tuning.

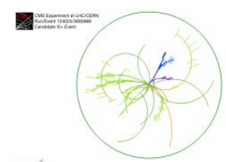
2) Physics objects

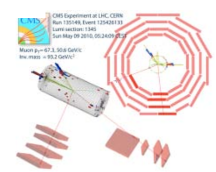
Validation, calibration



3) The sailing way

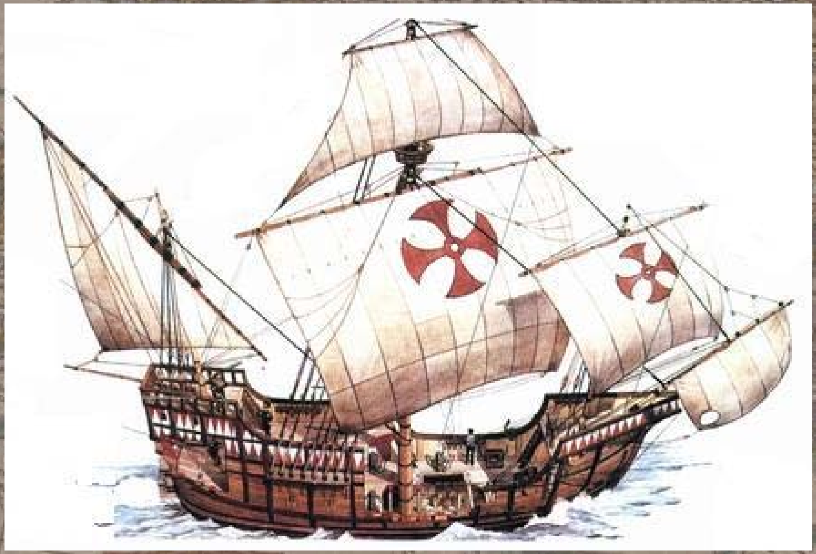




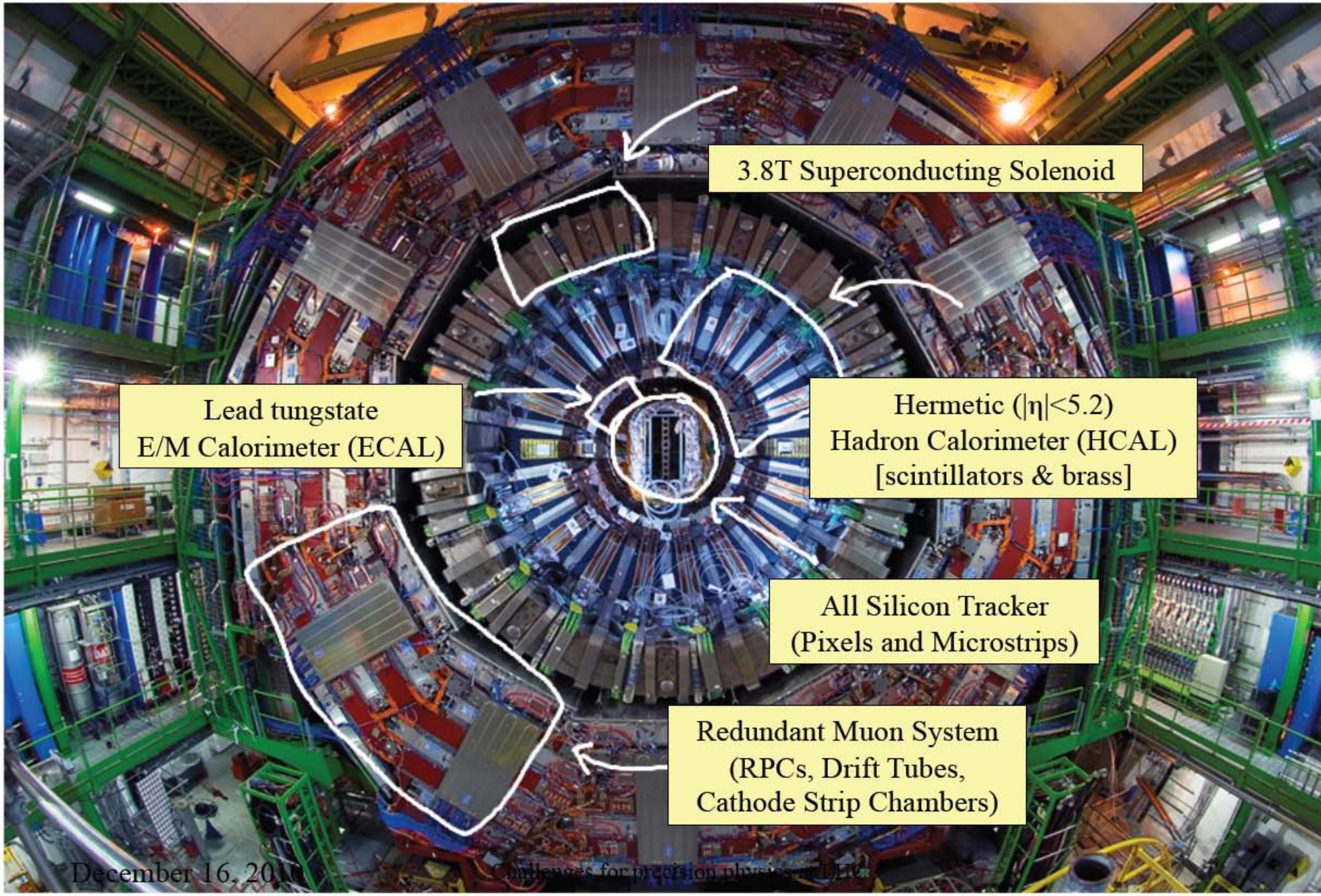


1. Detector performance
2. Standard model and QCD rediscovery
3. Terra Incognita

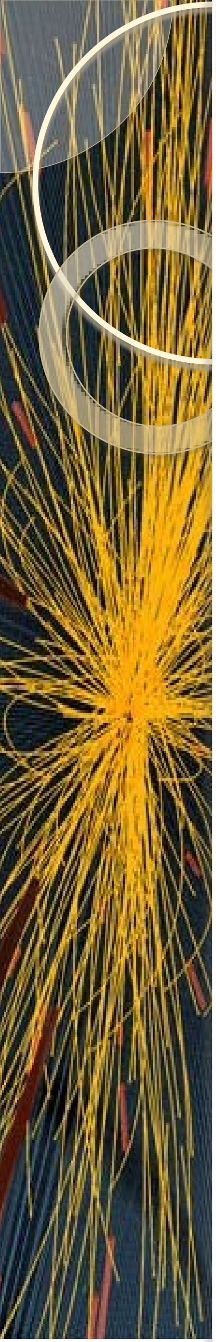
Detector performance



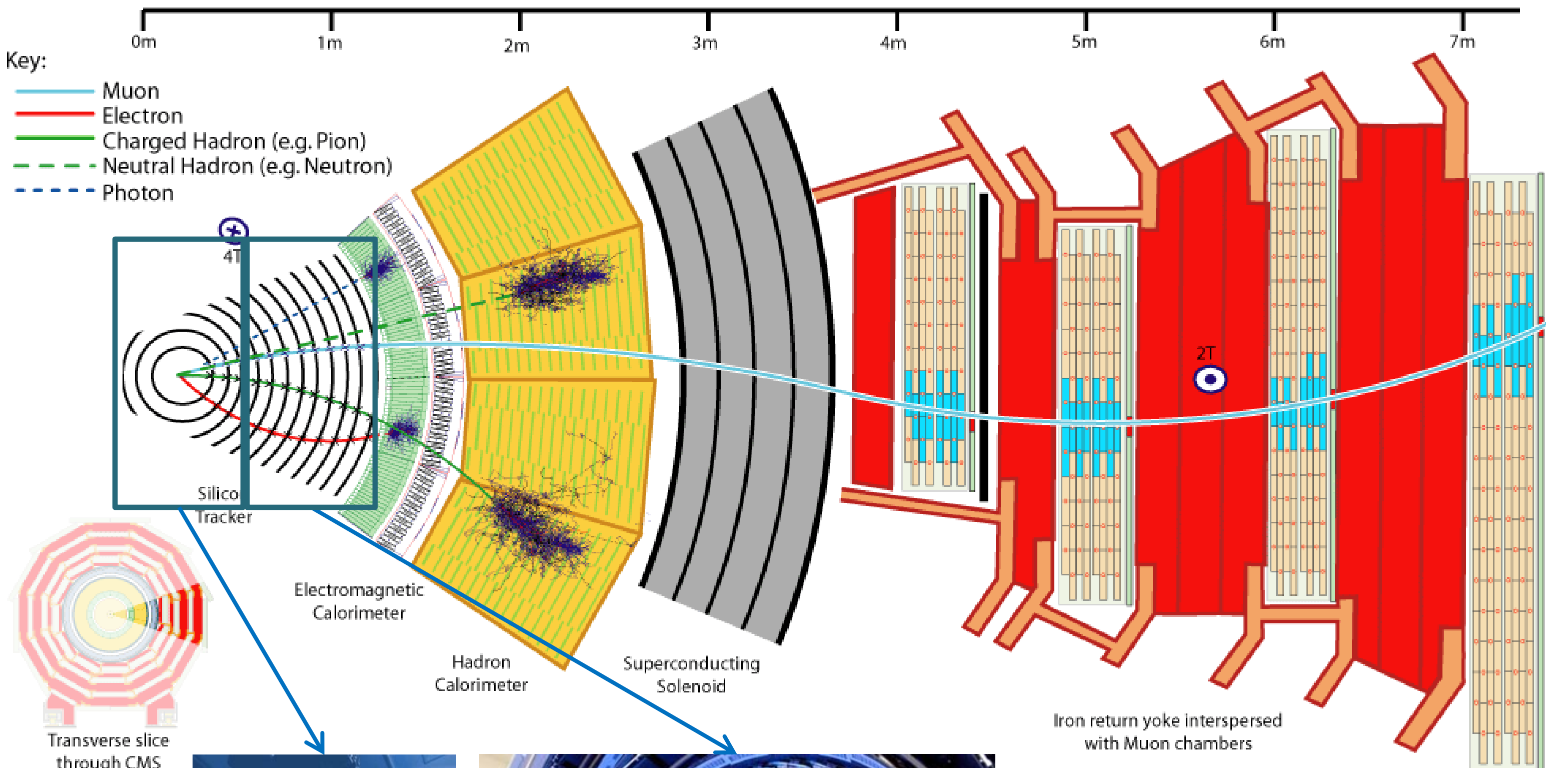
1) The CMS cabbage

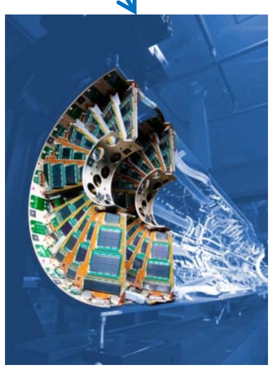


Detectors availability between 98-100%

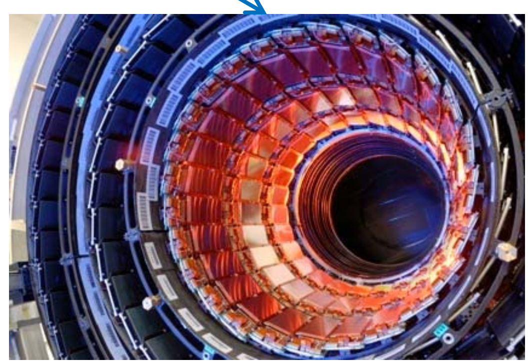


2) Tracker performance





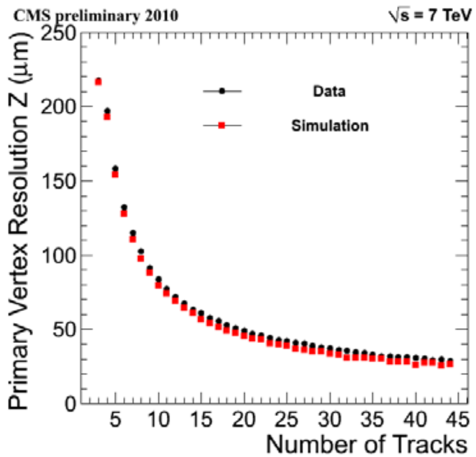
Pixel

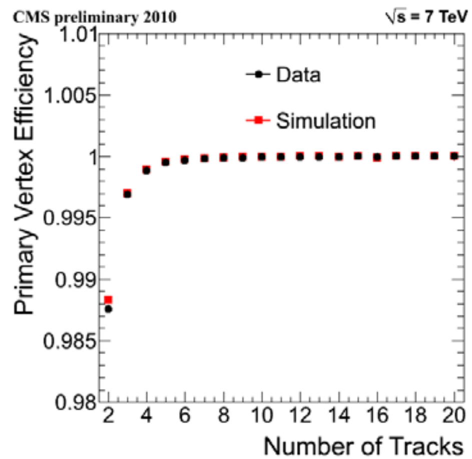


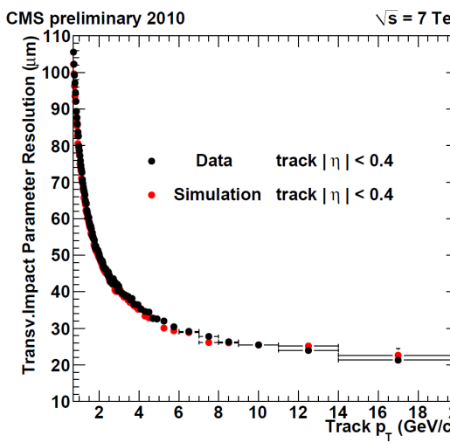
Strips

- Full silicium technology.
- ~75.000.000 channels.
Performance in collisions
arXiv:1007.1988

2.1) Tracker performances







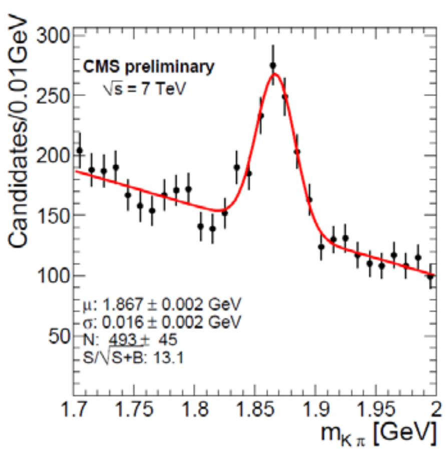
- Allow an efficient selection of Min Bias events.

PAS

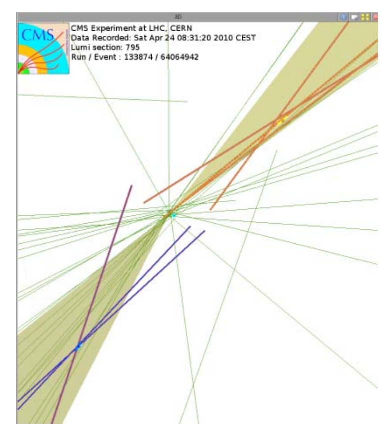
- Estimate event by event the number of pile-up (2.5 at the en of 2010).

D^0: cτ~100µm

Allow to separate short life time resonances with EW decay from the primary vertex.



B: cτ=500µm

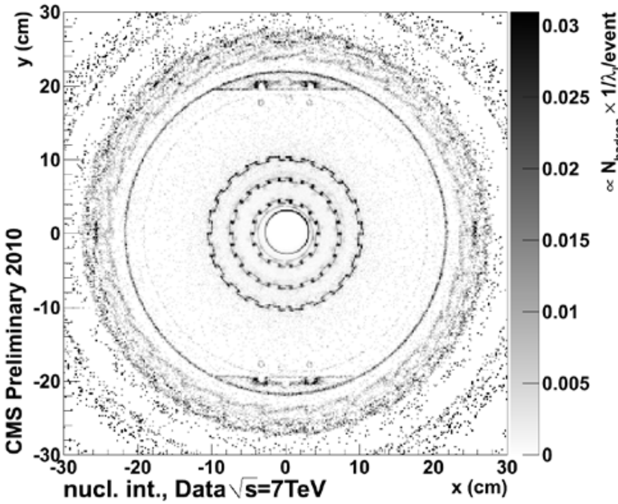


2.2) Material Effects and tracker radiography

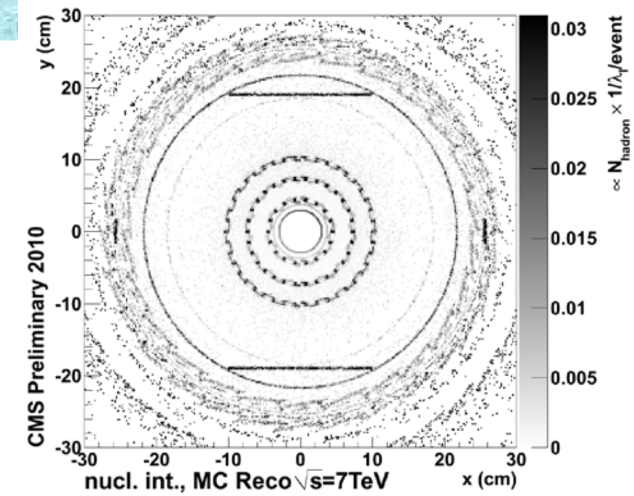
- The precise vertexing and dedicated tracking allow to reconstruct significantly (>2 cm) displaced vertices:
  - Material effects: Nuclear Interactions (0.1-0.5 λ) and conversions (0.5-2X_0). Nuisance for a clean particles reconstruction. But give access to the tracker material.

Nuclear Interactions

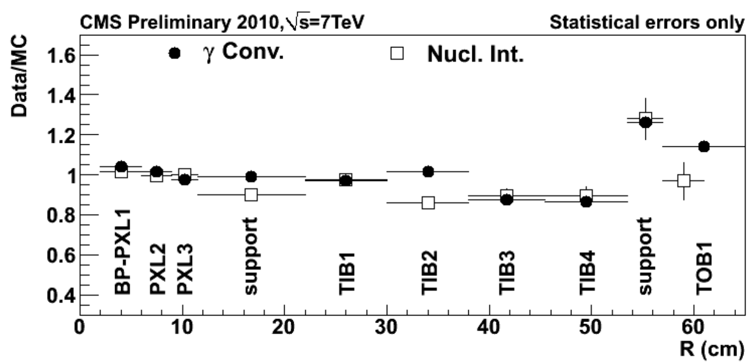
PAS-TRK-10-003



Data



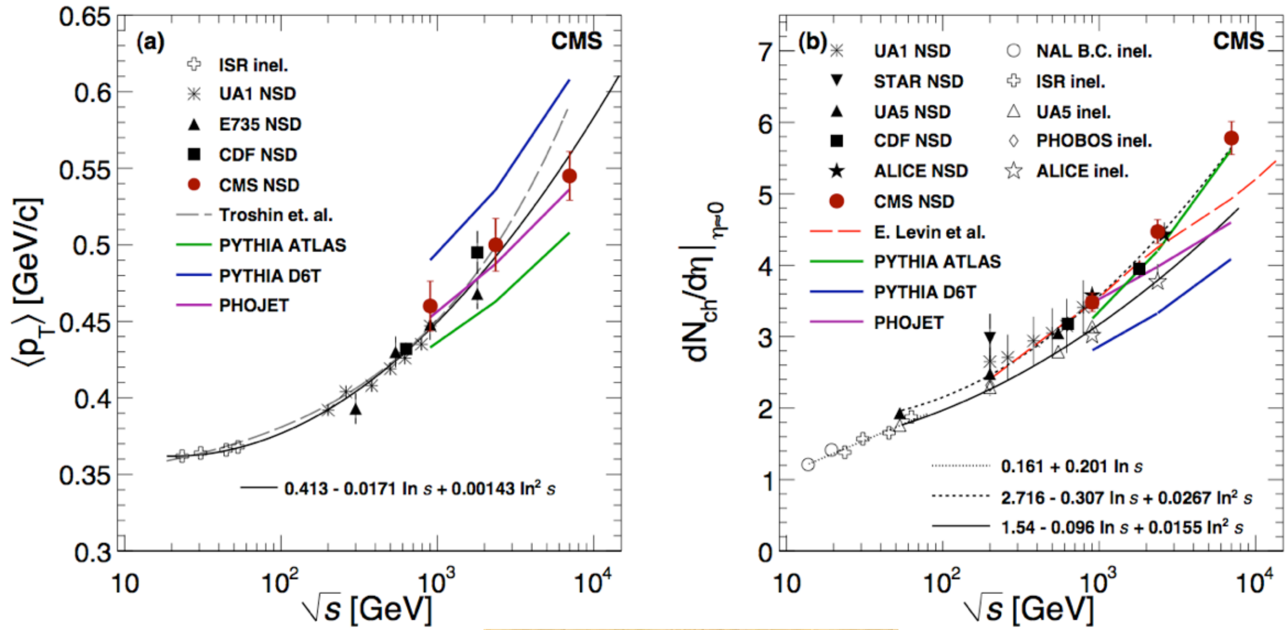
MC



(Data-MC)/MC<20%

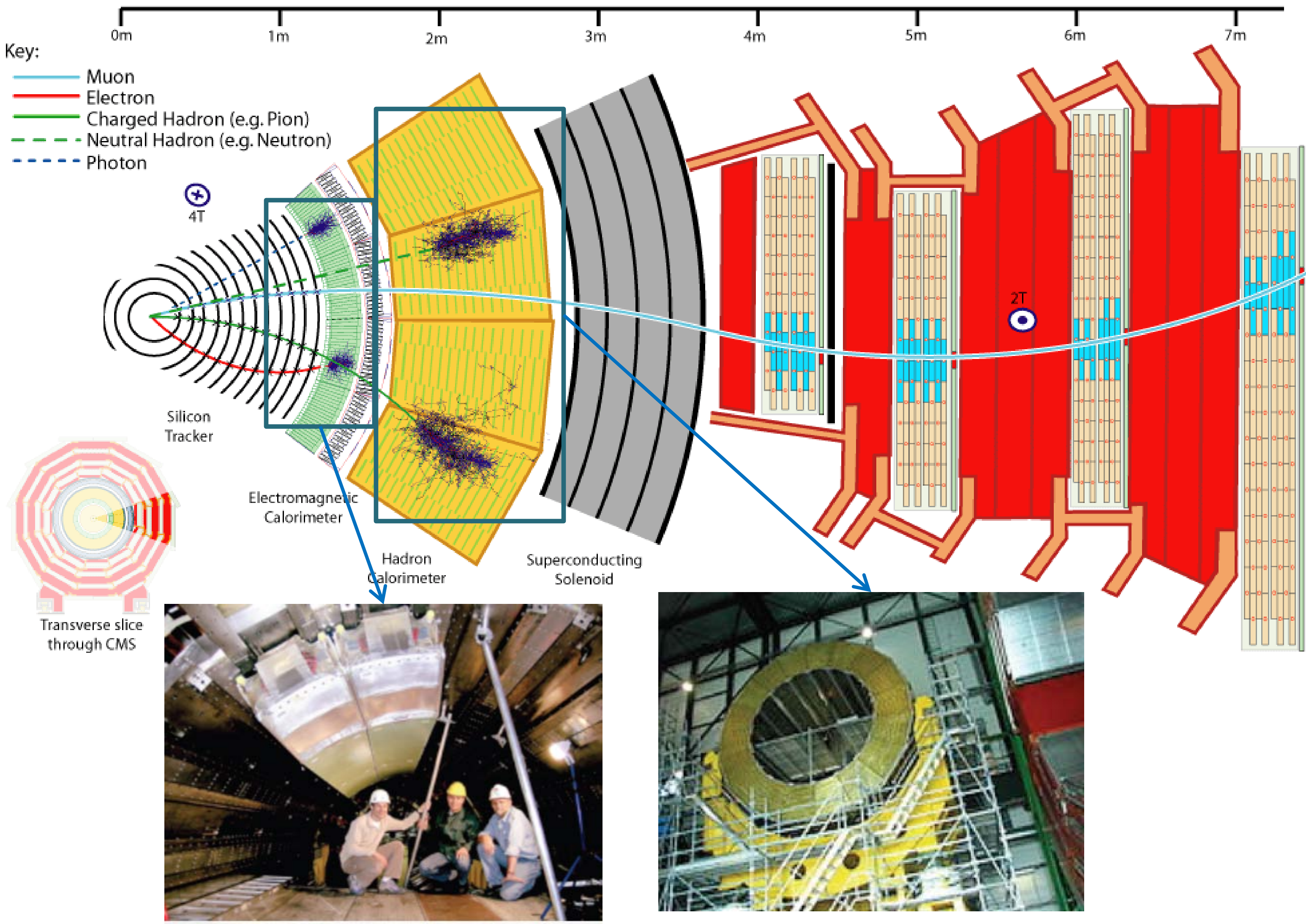
2.3) Low p_T physics with the tracker

- Events selected using Min-Bias triggers.
  No prescales at low luminosity ($10^{29} cm^{-2} s^{-1}$).
- Processes corresponding to Underlying Events (*PAS QCD-10-010*)
  → Jets correction, MC tuning.
- Measurement of charged hadrons density in η and p_T detector commissioning, MC tuning for LHC.



arXiv:1005.3299v2

3) Calorimeters: ECAL and HCAL

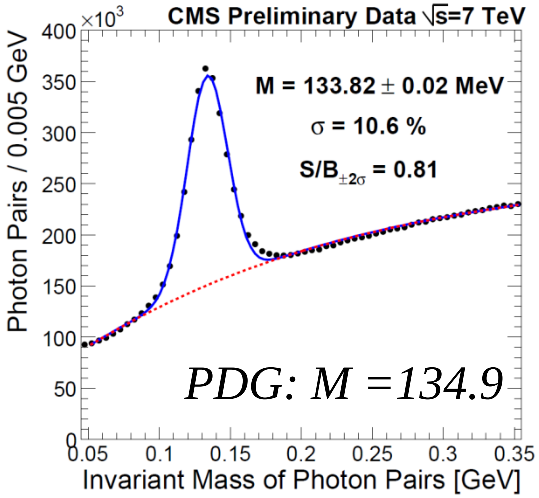


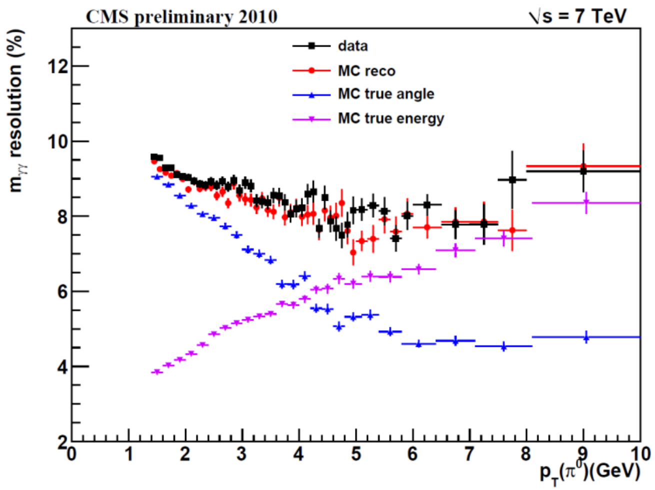
ECAL: PbWO4

HCAL: Scintillator+Brass, Quartz + Steel

3.1) Detector response

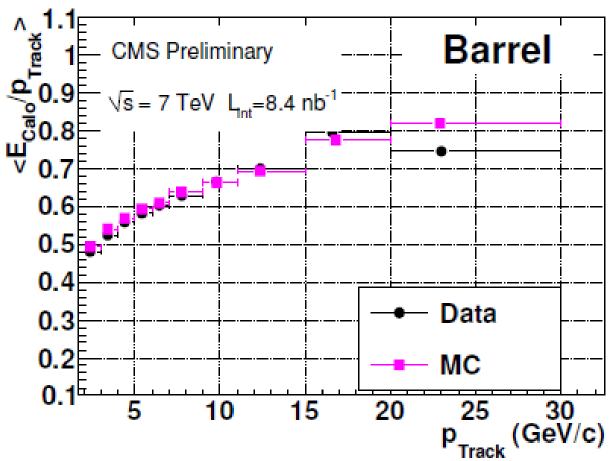
ECAL PAS-10-002



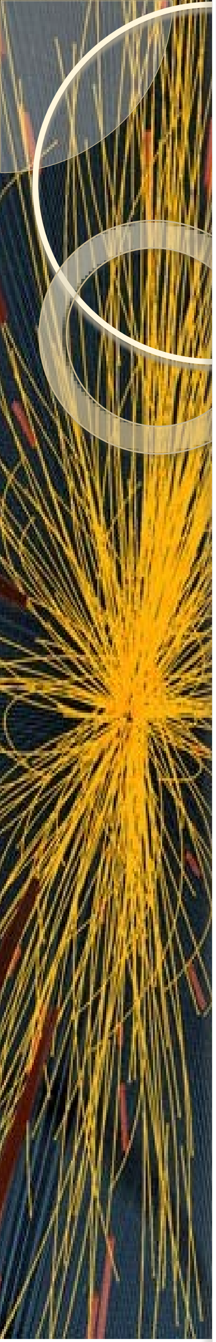


- π^0 benchmark shows a good control over calibration and alignment.
- Mass/Energy resolution well understood by MC.

HCAL JME-10-008

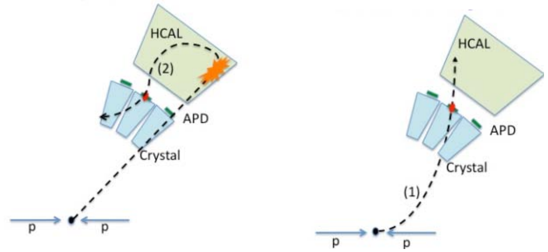


- Non linear response. Tested wrt to the tracker.
- Response calibrated to 1 at for p_π= 50 GeV.
- In data response well described by MC. Slightly lower in Data in barrel and larger in the Endcaps → Effect corrected for jets by calibration.

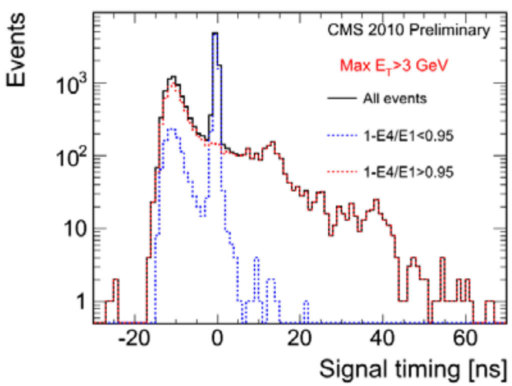


3.2) Calorimeter noise: clean the boat

ECAL spikes

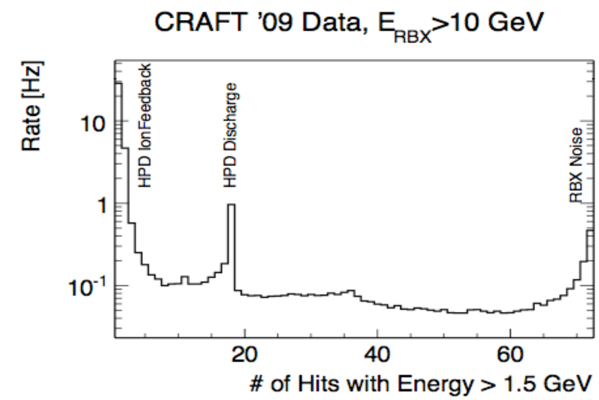


7 TeV Data

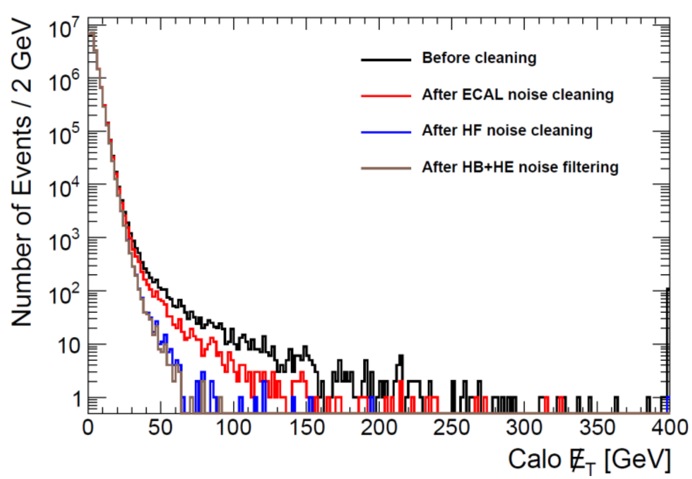


- Appears in the barrel where APD (Avalanche Photo-Diode) are used.
- 1 crystal, wide timing, abnormal pulse shape.

Coherent noises in HCAL

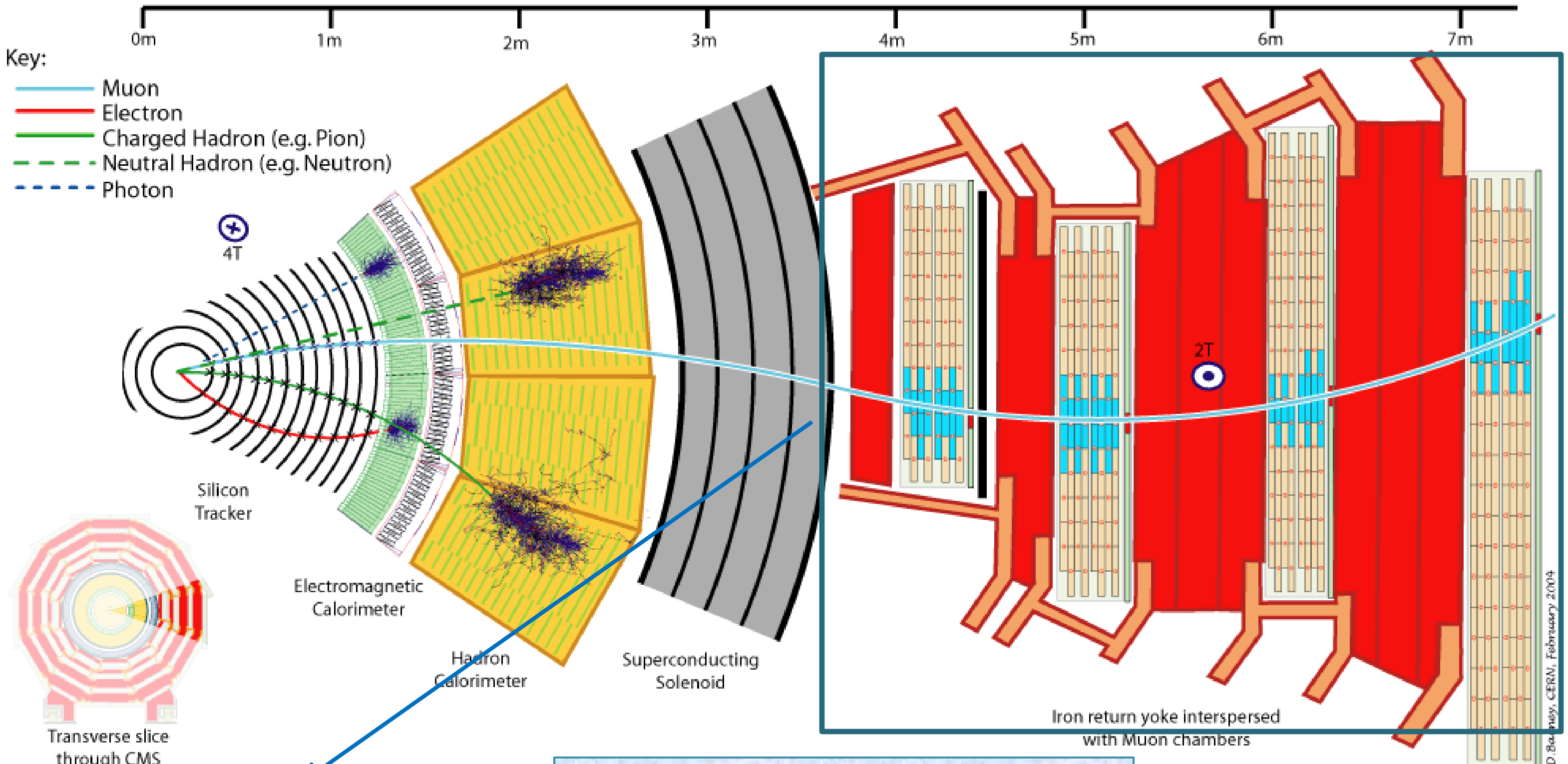


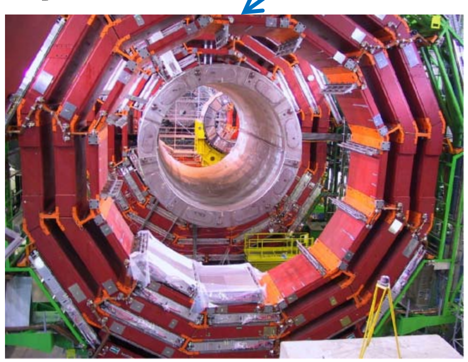
- Noise in readout detectors.
- Well defined patterns.



The calorimeter noise cleaning remove most of the tails in the missing E_T in MinBias events (no physical missing E_T expected).

4) Muon system is our Trade Mark



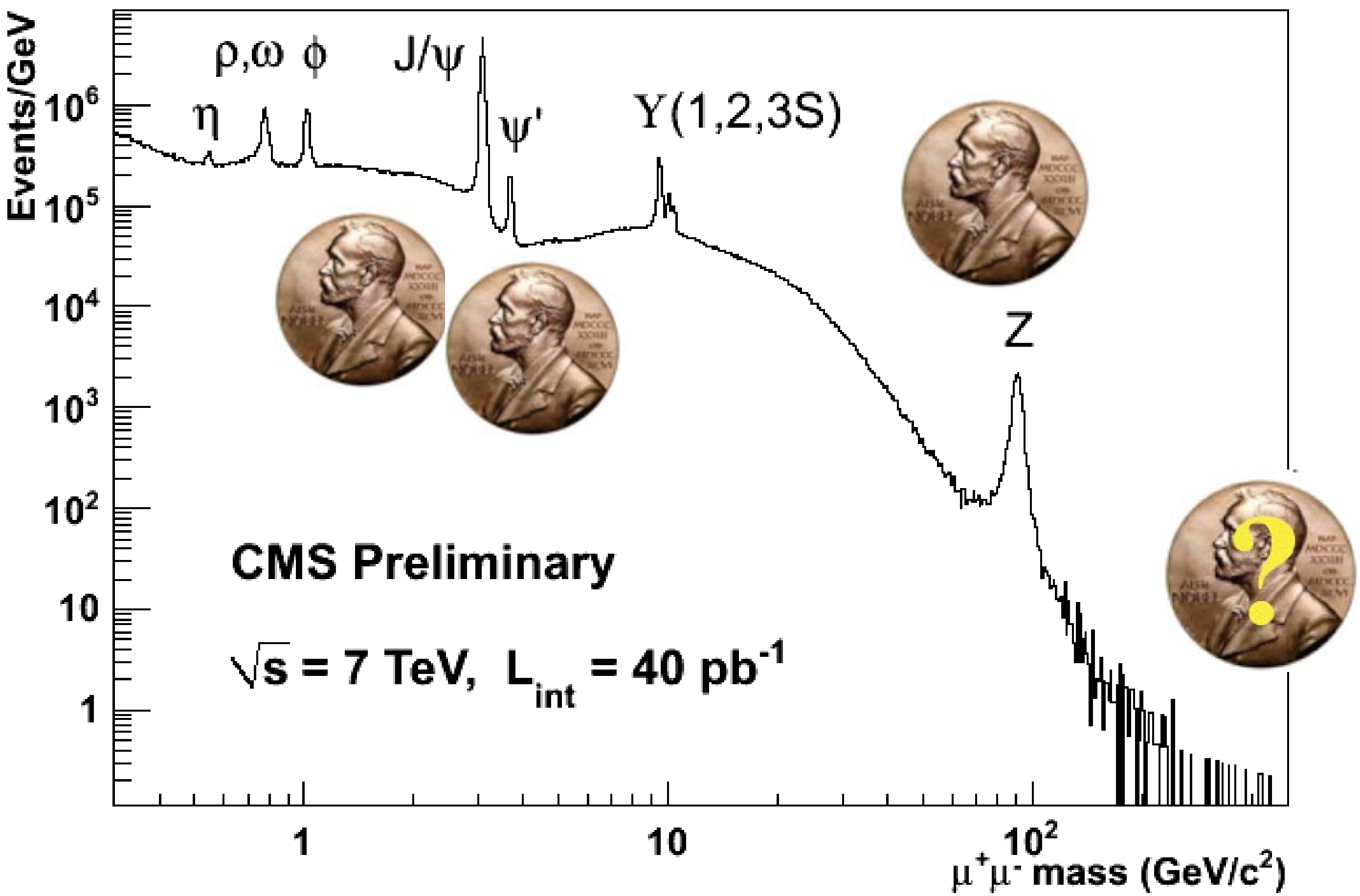


3+1 technologies:

- Drift Tubes (Barrel)
- Cathode Strip (Endcaps)
- Resistive Plate Chambers (Trigger)
- Central Silicon Tracker

Identification performance: PAS-MUO-10-002

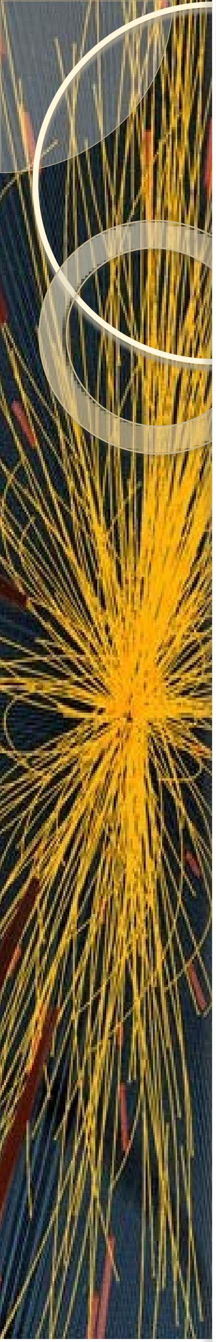
4.1) The di-muon resonance spectrum



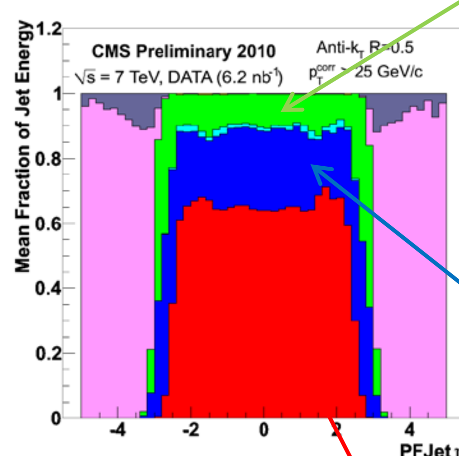
- CMS was designed to obtain the best μ momentum measurement from the tracker up to 200 GeV (4T field, 10 silicon layers in the barrel).
- The muon system (muon chambers + tracker) is the most powerful and well understood detector of CMS.

5.1) Particle Flow: global event reconstruction framework

- Using the combination of all available detectors to reconstruct and indentify particles (π, γ, K_0, μ, e)
- Low p_T π: precision dominated by the tracker.
- High p_T π: precision dominated by calorimeters.



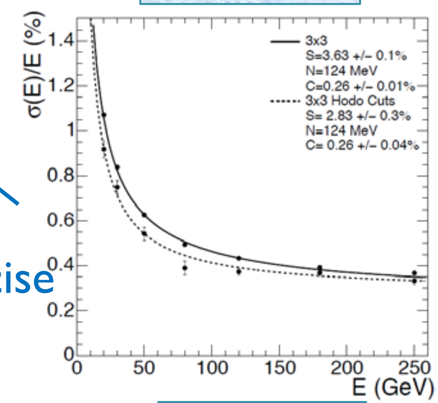
PAS-PFT-10-003



HCAL:

120%/ √E + 6.9%

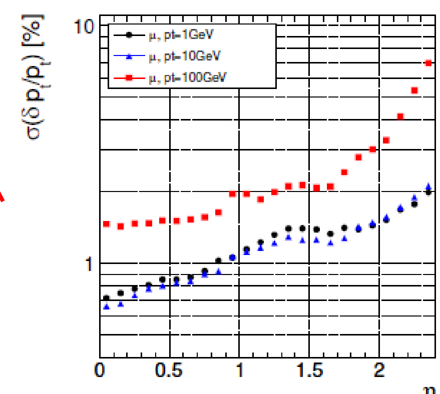
ECAL

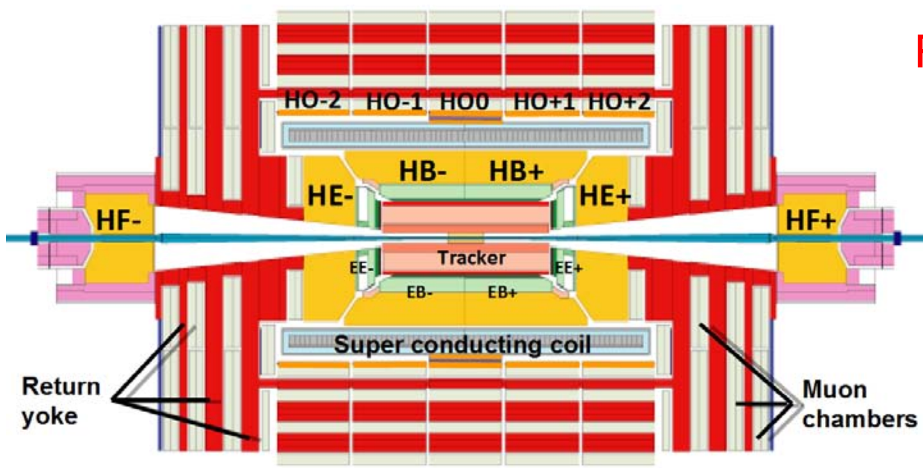


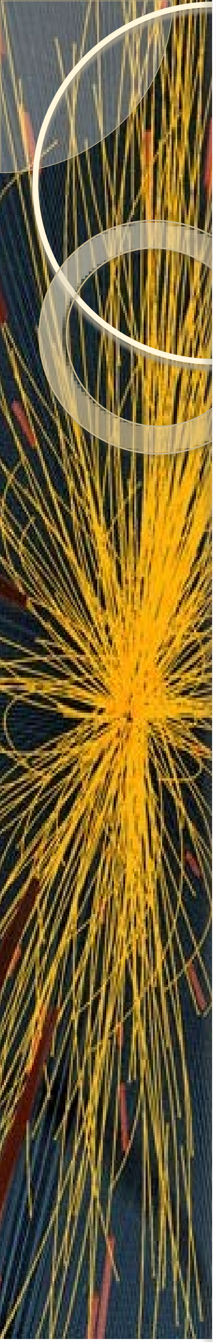
Precise

Precise

Tracker

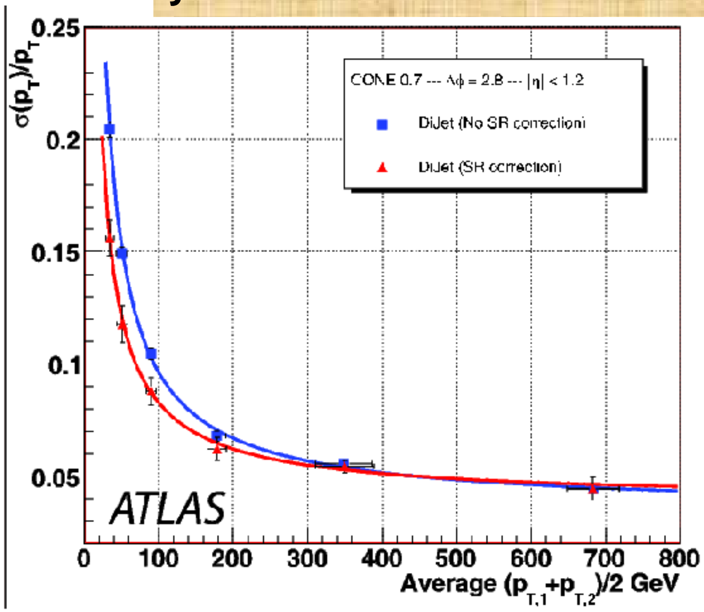




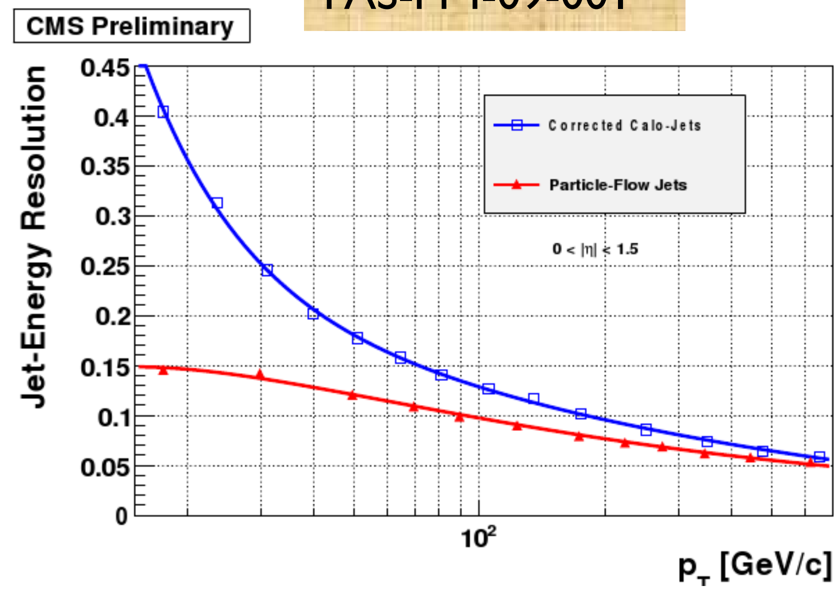


5.2) Particle Flow: global event reconstruction framework

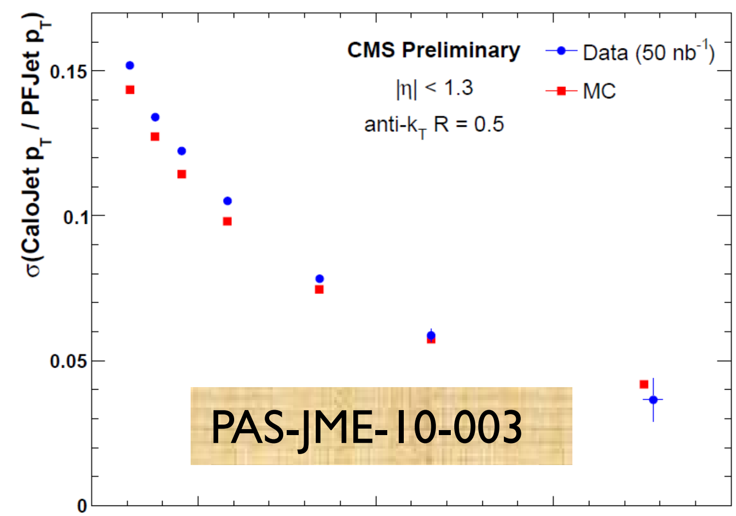
JetEtMissPublicResultsINSI



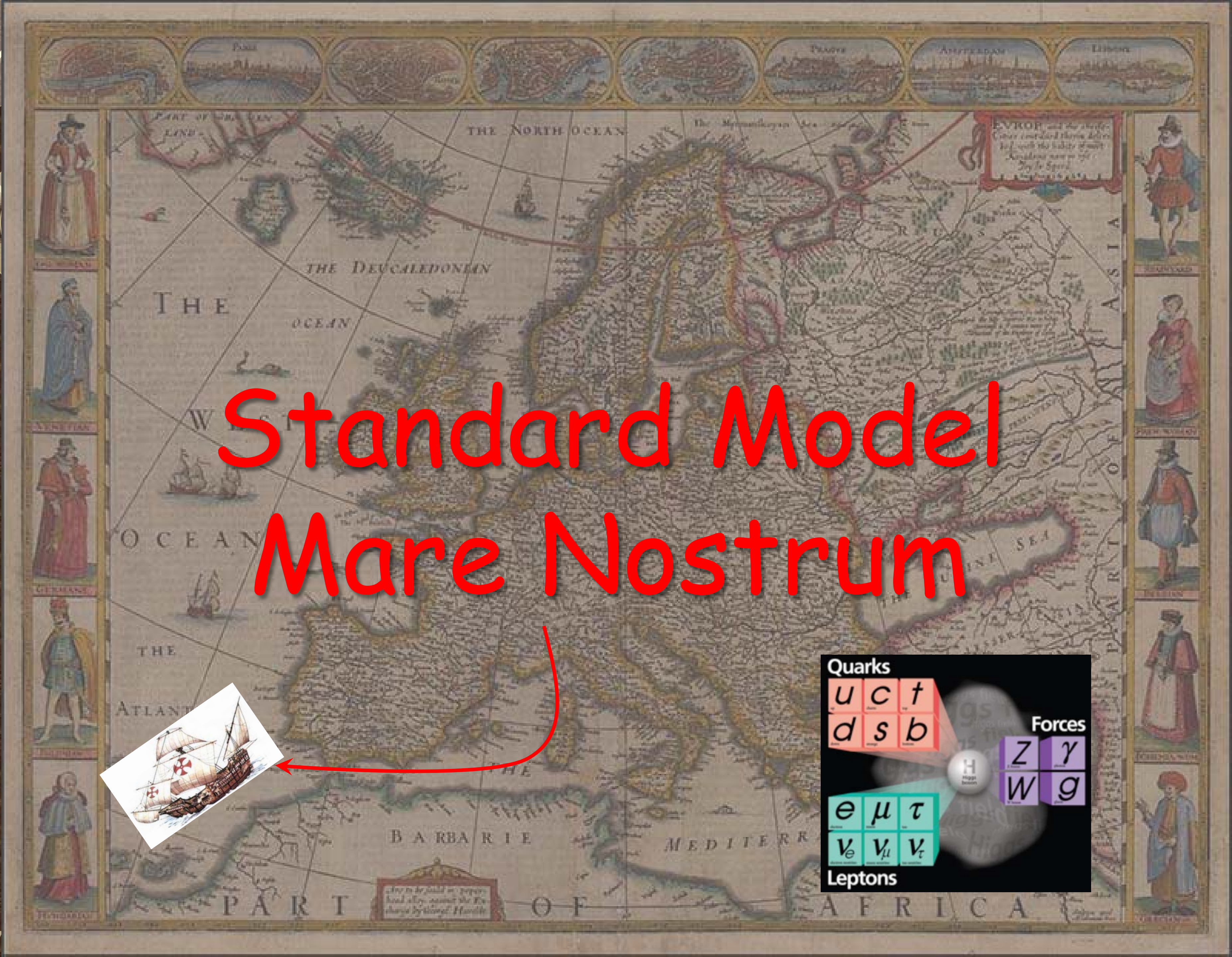
PAS-PFT-09-001



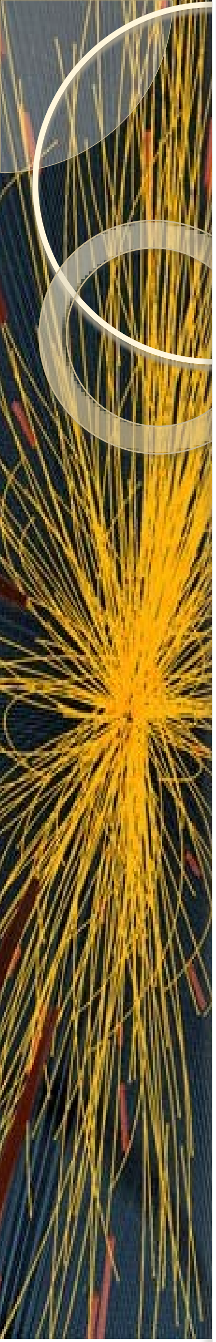
- Particle Flow particles are used to cluster jets or calculate MET.
- Jets response at 100 GeV:
  PF ~ 95%, Calorimeter ~ 70%.
- PF jets resolution is comparable to Atlas Calorimeter jets while CMS Calorimeter jets resolution is significantly worse.
- This expectation is confirmed in-situ with 7 TeV data.



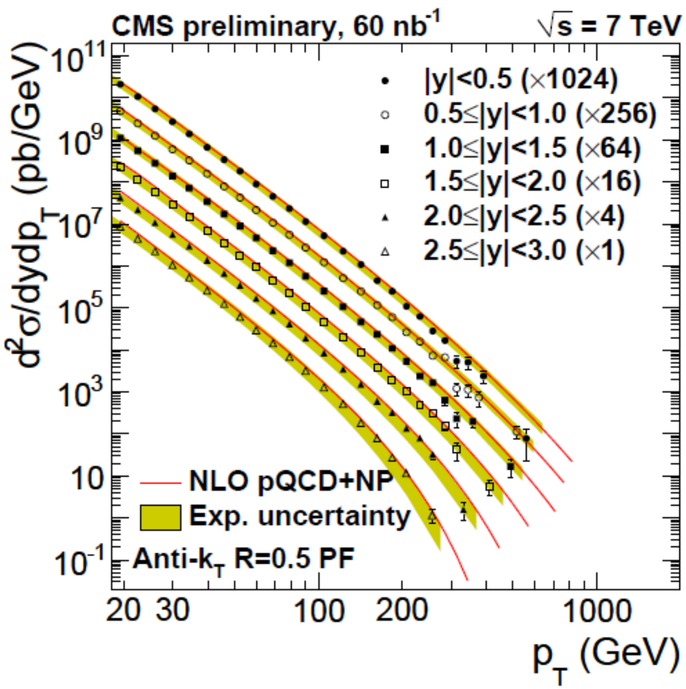
Standard Model Mare Nostrum



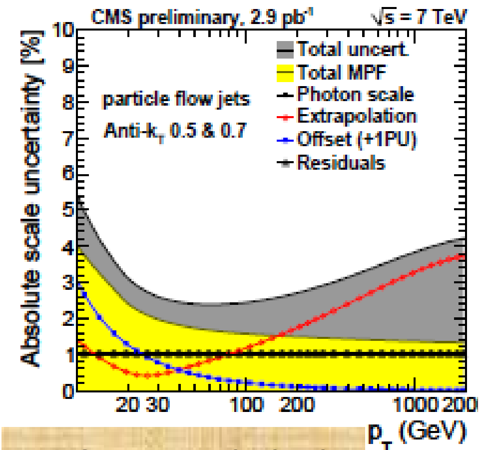
1.1) QCD sacred cows: cross sections

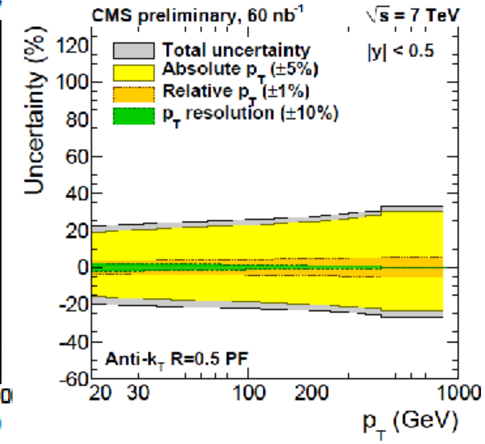


Inclusive jets spectrum:
PAS-QCD-10-001



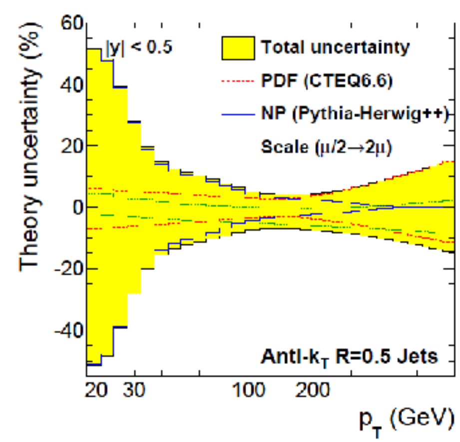
Excellent description by pQCD @ NLO.





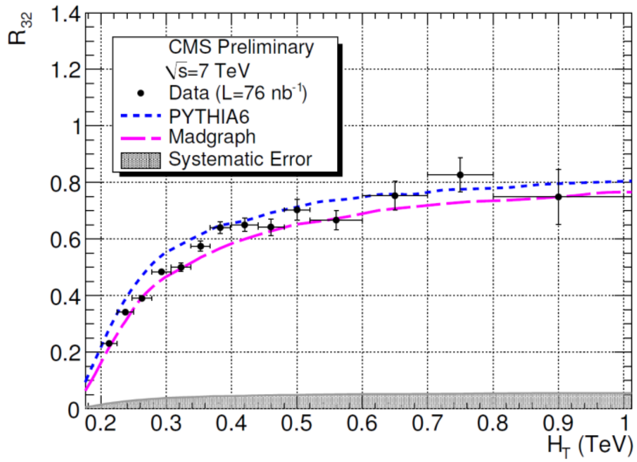
PAS-JME-10-010

Systematics dominated by the Uncertainty on the Jet Energy scale, estimated in-situ to 3-5% and dominated by neutral hadrons.



Sensitive to the proton PDF.

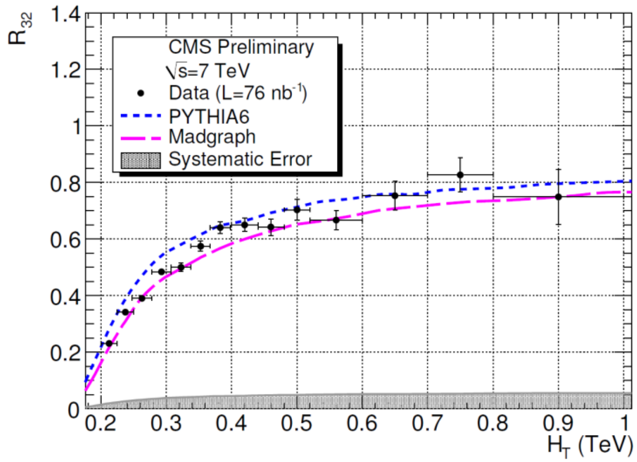
1.2) QCD sacred cows: normalized observables



R_{32} = 3-jet/2-jets : PAS-QCD-10-012

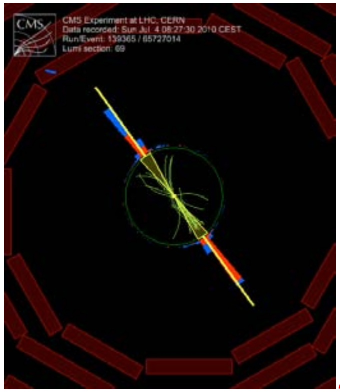
- HT total scalar transverse momentum of all jets with p_T>50 GeV.
- Reduced systematics due to the normalization.
- R32$\propto \alpha_S^3/\alpha_S^2 \propto \alpha_S$ and give a handle to LO MC parton showering.

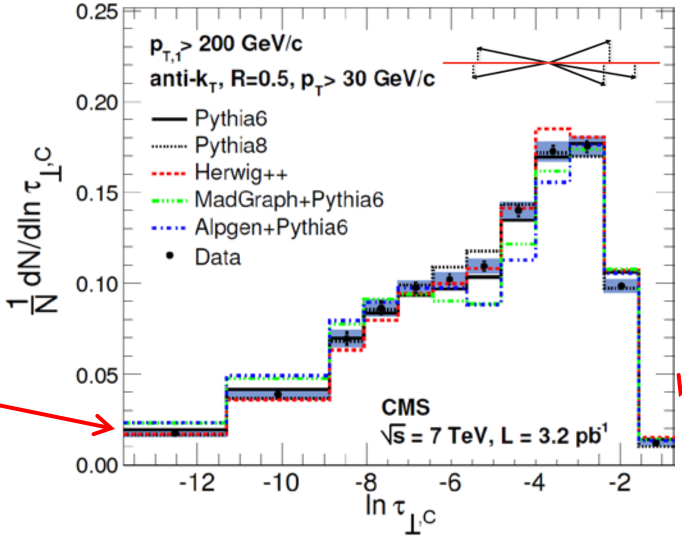
1.2) QCD sacred cows: normalised observables

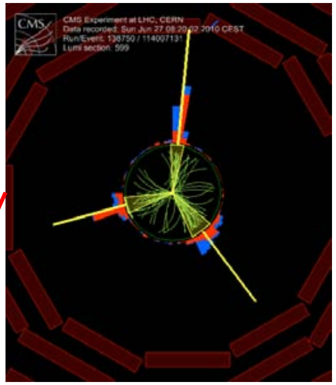


R_{32} = 3-jet/2-jets : PAS-QCD-10-012

- HT total scalar transverse momentum of all jets with p_T>50 GeV.
- Reduced systematics due to the normalization.
- R32∝ $\alpha_S^3/\alpha_S^2 \propto \alpha_S$ and give a handle to LO MC parton showering.







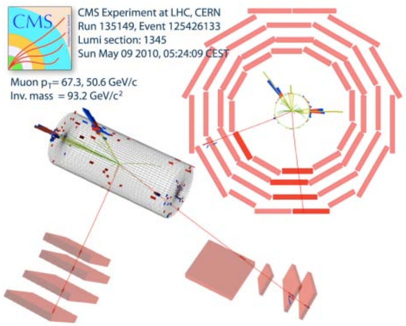
$\tau_{\perp,c} = 0$

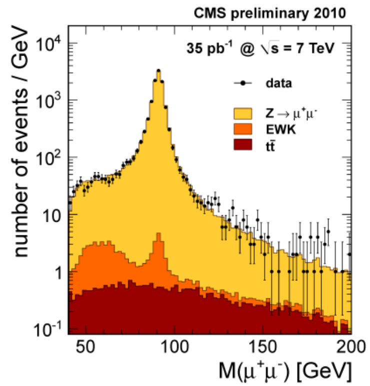
$\tau_{\perp,c} = 1/3$

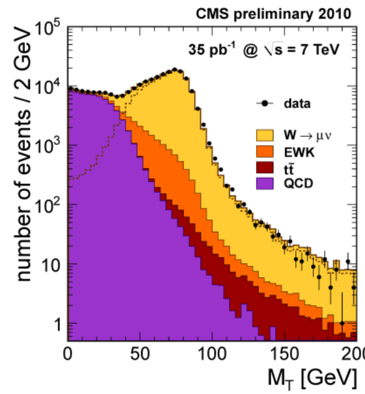
- Hadronic event shape sensitive to the parton showering in MC.
- Low sensitivity to the systematics.

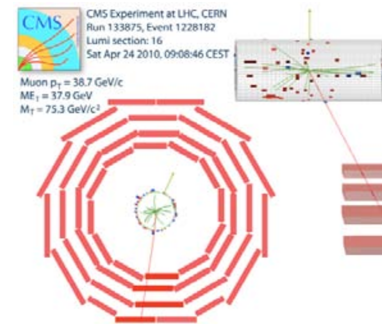
Hadronic event shapes: arXiv:1102.0068v1

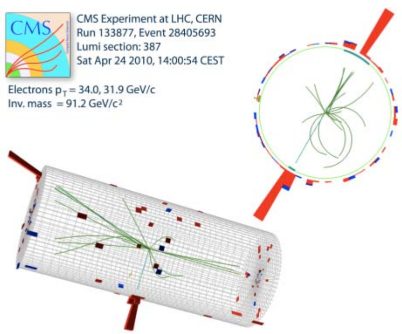
2) Captain, we just passer the EW cape!

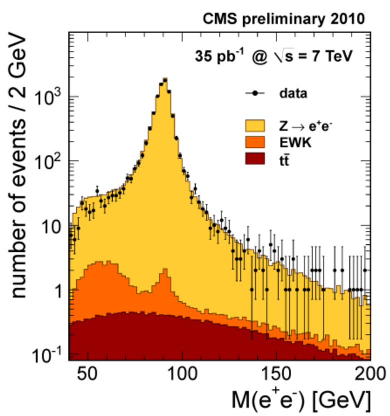


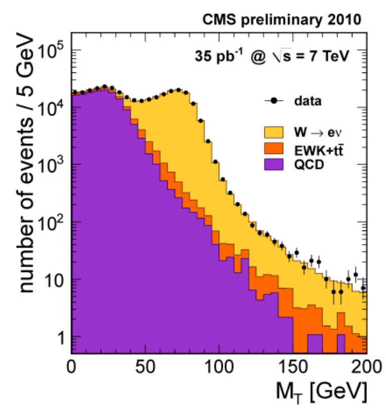


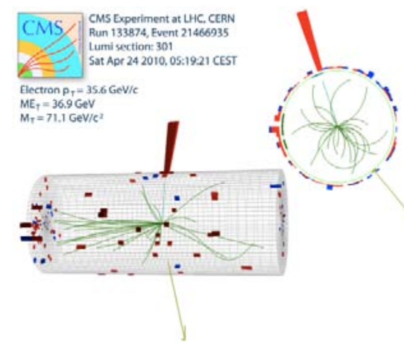






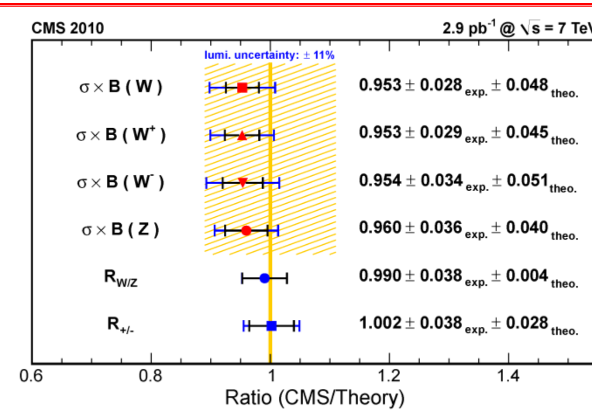






- The boson production at CMS is well understood → Background for Higgs searches.
- Backgrounds under control.
- Inclusive cross sections measured with 4%+10%(Lumi) precision and validate the theory, especially the quarks components in MSTW08.

arXiv:1012.2466v2 and PAS-EW-10-005

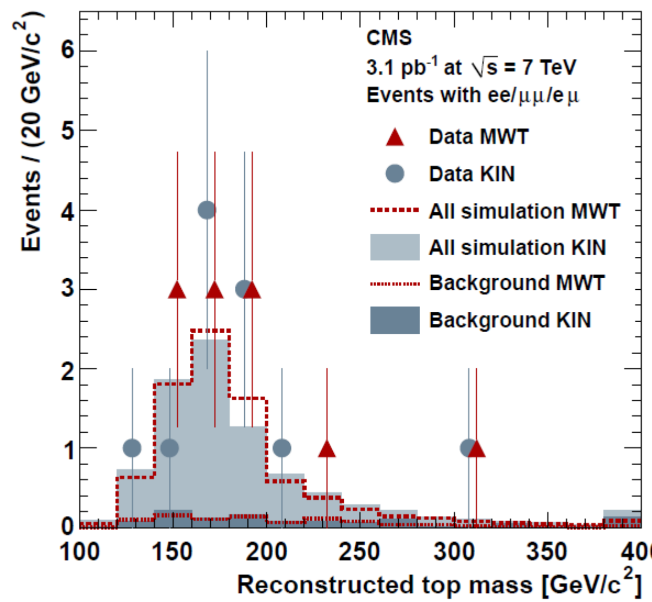


3) Top at the Horizon!

- Decay modes: 2 lepton + 2 b-jets + MET

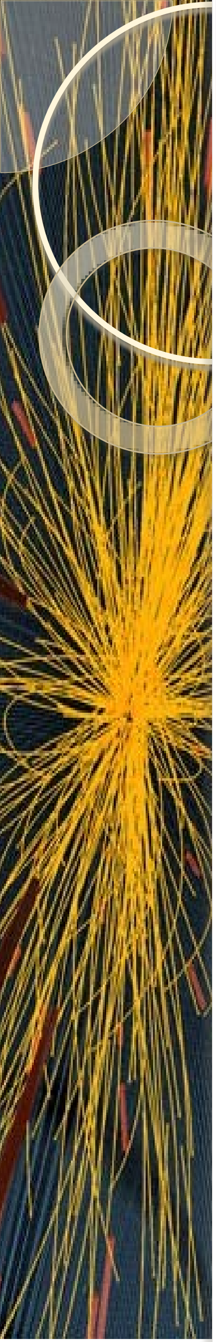
Full selection applied: Z-Veto, |M(ll)-M(Z)|>15 GeV
MET >30 (20) GeV in ee,$\mu\mu$, (eμ); N(jets)≥2

$\sigma(pp \rightarrow t\bar{t}) = 194 \pm 72(stat.) \pm 24(syst.) \pm 21(lumi.)$ pb



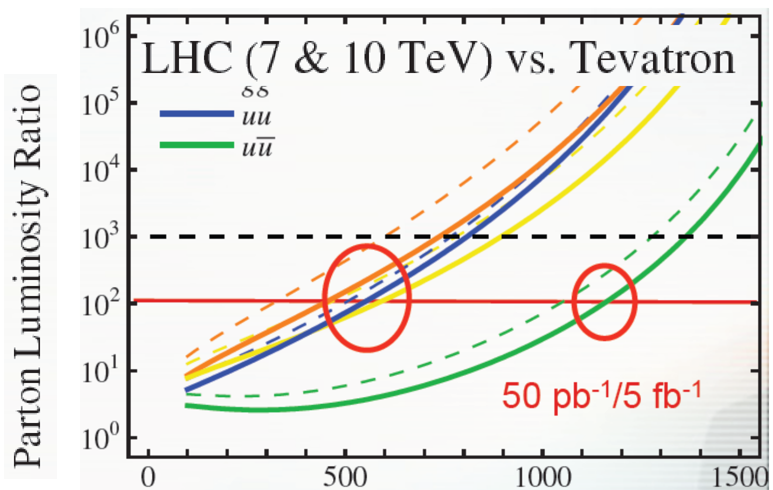
arXiv:1010.5994

Terra Incognita



0) Sail direction

- Counting experiments:
  - Raw Generic searches.
- Resonances search:
  - Few assumptions about mass shapes.
- Exclusive searches:
  - Rely on topological details.
- Try to use when possible the in-situ background measurement background. Otherwise rely on MC.



Bauer et al., Phys. Lett. B **690**, 280 (2010)

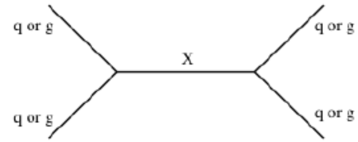
<u>LHC strategy in 2010:</u>

Parton Lumi > Lumi(Tvt)/Lumi(LHC)
- for all quark, gluon initial state @ 0.6 TeV.
- for quark – antiquark initial stat @ 1.2 TeV

1.1) Heavy resonance production: 2 particles final state

2 mandibula kraken

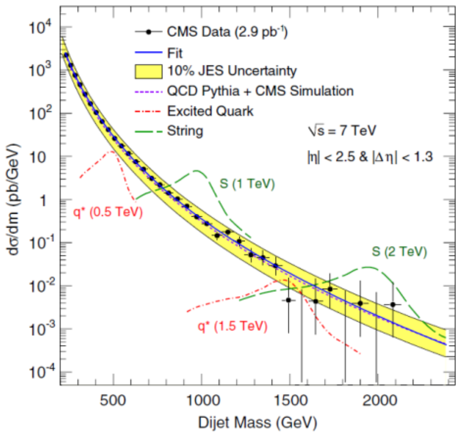
- Generic or half-generic search of narrow resonances (bumps)
- Generic search for excess in tails wrt to the Standard Model

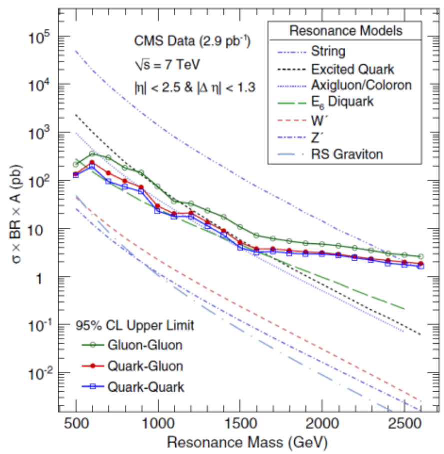


Signature	Model	Specificity	7 TeV Results
2 jets (qq, gg)	Z', RS Graviton, KK Graviton	Peak at large invariant mass	3 pb^{-1} Paper arXiv:1010.4439
2 μ, 2 e, 2 γ			Preliminary
t tbar (jets, μ+jets)	Z'	Boosted top	
2 jets (qg),	Excited fermions	Peak at large invariant mass	3 pb^{-1} Paper arXiv:1010.0203
eγ, μγ			
2 jets	Contact interactions KK extra dimensions	Excess at large mass wrt to SM	3 pb^{-1} Paper arXiv:1010.4439
2 γ			Preliminary
2 jets from displaced vertex	Heavy photons in little Higgs model	Originating from Sec. vertex	
eν	W*	Transverse mass of e + Missing E_T	35 pb^{-1} Paper arXiv:1012.4945

1.2) Example: 2-jets final state

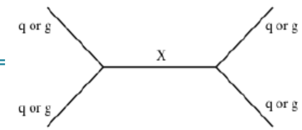
arXiv:1010.0203



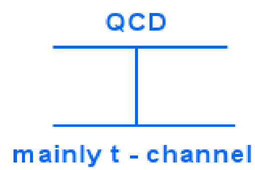


2-jets: $|\eta| < 2.5$, $|\Delta\eta| < 1.3$

$M_{12} \sim 2p_T\,(1+\Delta\eta^2/8)$



Central jets, large p_T
small $\Delta\eta$

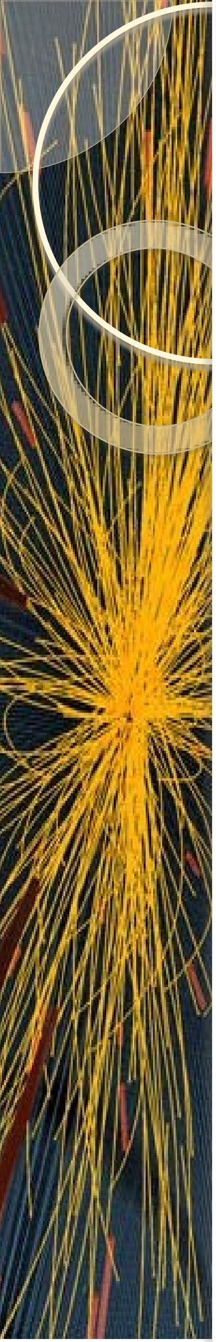


QCD large $\Delta\eta$

0) Take the shape from QCD.

1) Fit the shape to data. Look for excess.

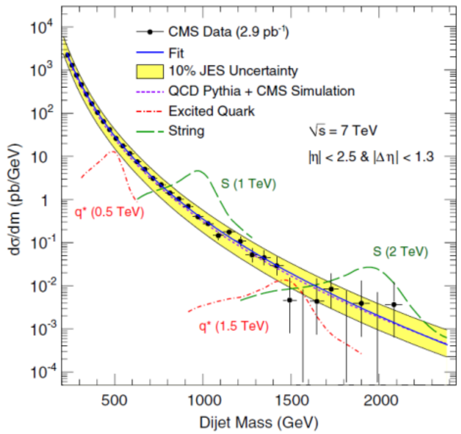
3) 2 approaches:
- Measure M in $\Delta\eta$ bins (papers shown here).
- Measure $\Delta\eta$ in M bins (χ distribution preliminary).

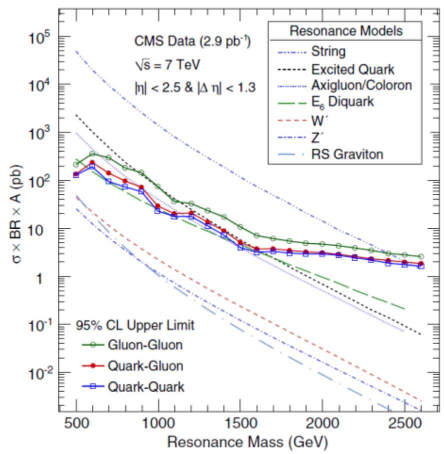


1.2) Example: 2-jets final state

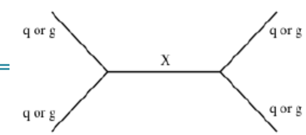
$M_{12} \sim 2p_T\,(1+\Delta\eta^2/8)$

arXiv:1010.0203





2-jets: $|\eta| < 2.5$, $|\Delta\eta| < 1.3$



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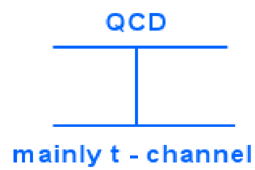

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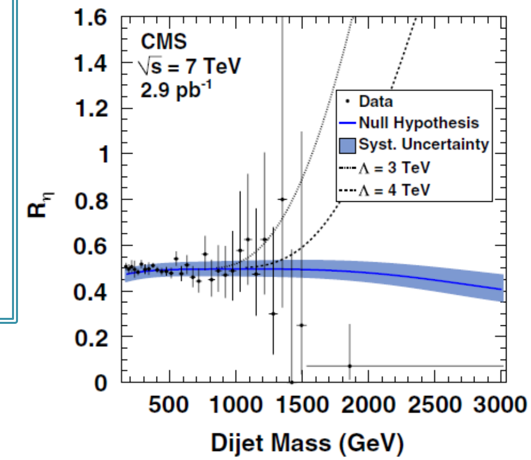

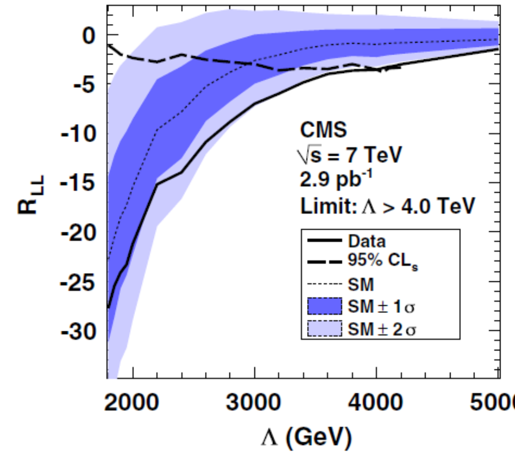

$$R = \frac{N_{evt}(\,|\eta jets| < 0.7)}{N_{evt}(0.7 < |\eta jets| < 1.3)}$$

2) Multi-particles final state: S_T blade

- S_T scalar sum over relevant objects of the final state.
  For black holes: all objects above p_T = 50 GeV.
- Kill the QCD (black holes) and DY + jets (Leptoquarks) background.
- Invariant under ISR, FSR splitting.

Signature	Model	Specificity	7 TeV Results
2 μ + 2 jets 2 e + 2 jets	Pair of Leptoquarks production (GUT)	Look on S_T tail and possibly check for transverse Mass.	arXiv:1012.4031 arXiv:1012.4033
3 l + ν, 2 l + 2ν	Pair of b’ (4^{th} gen.)		
Black Holes	Extra dimensions		arXiv:1012.3375

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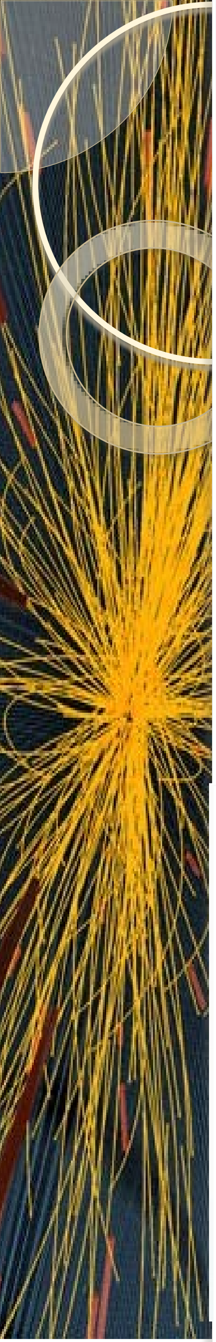

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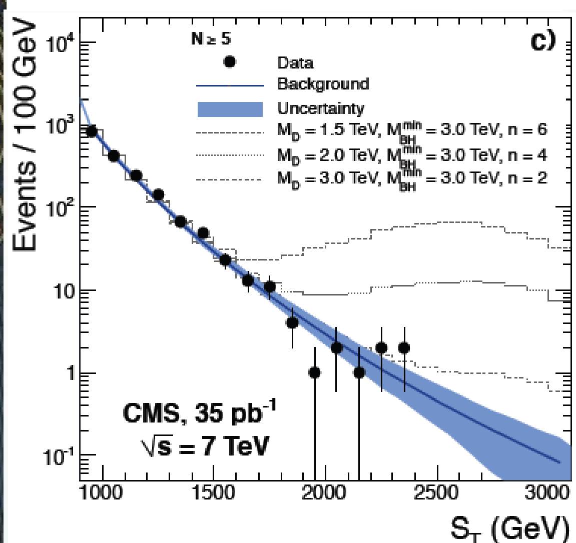
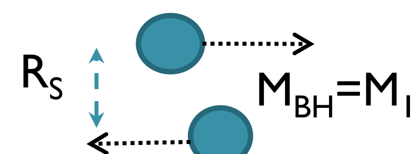
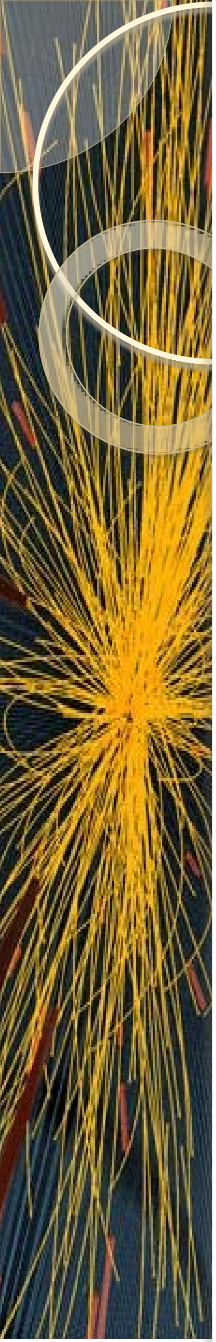


Black holes search

- First collider established limits.
- Large expected cross section (up to 100pb^{-1}).
- Isotropic Hawking evaporation.
- QCD background dominates. Shape taken from samples with 2 and 3 objects where no black holes expected.
- Limit on semi-classical BH: 3.5 – 4 TeV.

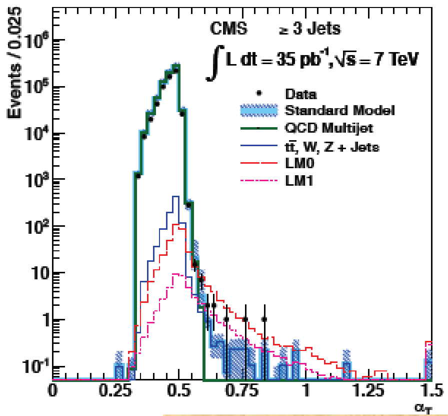


$\sigma = \pi R_S^2 \sim TeV^{-2}$



3) First SUSY results

- SUSY search look on complex final states with large variety of bkg.
- In 2010: mainly work on background determination (*PAS SUS-10-001*).
- Complexity of determination of benchmark models (LM0, LM1) which covers the interesting phase-space.



$$\alpha_T = \frac{1}{2}\frac{H_T - \Delta H_T}{\sqrt{H_T^2 - (MHT)^2}}.$$

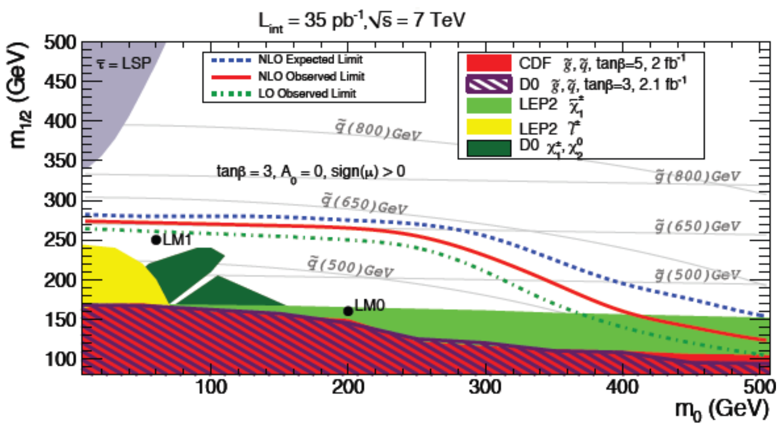
$$H_T = \sum_{\text{jets } j} p_{Tj}$$

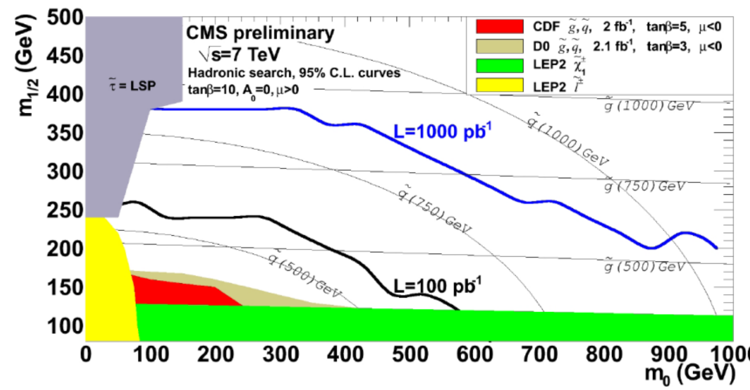
$$\Delta H_T = p_{T\text{pseudojet 1}} - p_{T\text{pseudojet 2}}$$

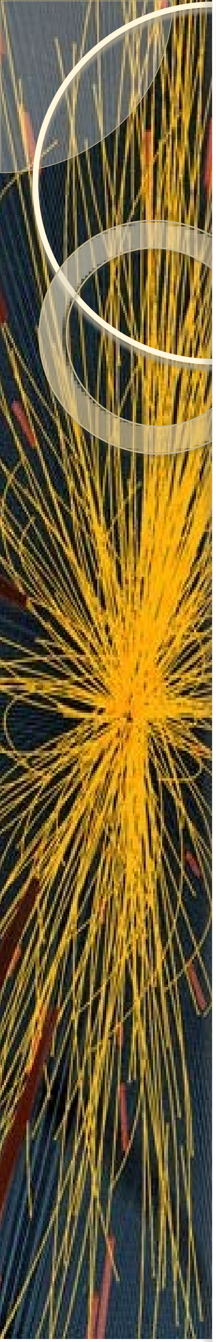
One of the most powerful: Hadronic only search based on α_T which fully suppress QCD and keep only EW bkg.

arXiv:1101.1628

Expectation: CMS-NOTE-2010/008





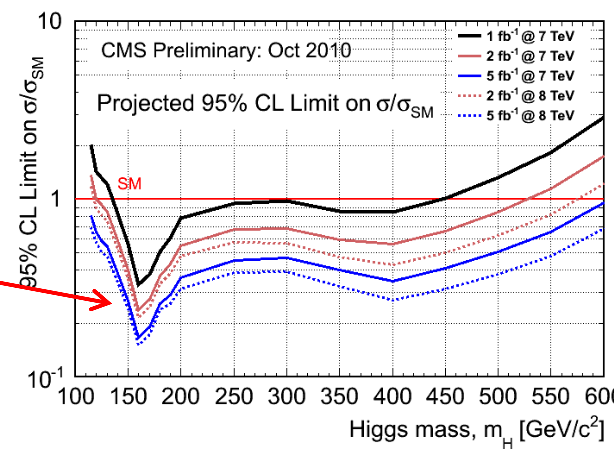


4.1) Prospects for Higgs searches

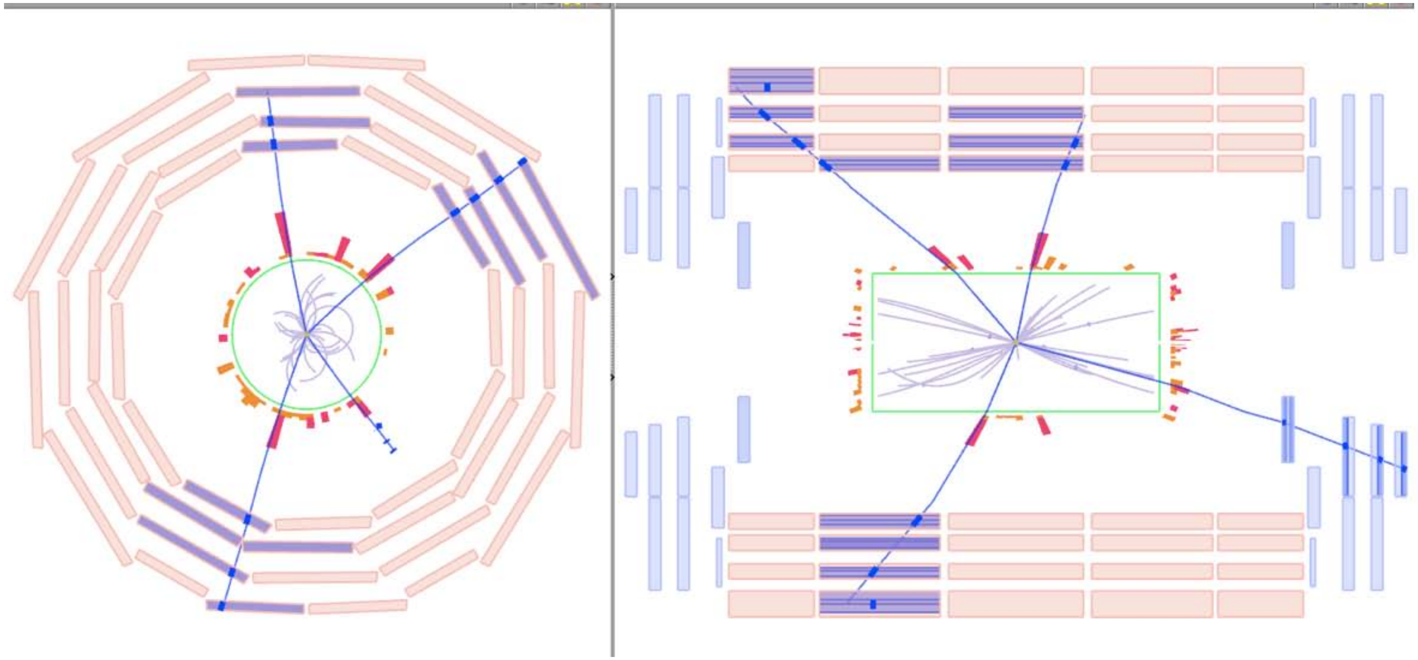
- Higgs search is the most challenging activity at the LHC today:
  - Relatively low energy (~ 0.2 TeV) and "useful" cross section (~0.1 pb).
  - Overwhelming QCD background at mb.
  - Variety of final states as function of Higgs mass.
  - Higgs cross section would have risen by a factor 2 at $\sqrt{s} = 8$ TeV ☹
- In 2010: Most efforts to work on in-situ background estimation:
  - $H \rightarrow \tau\tau$, $H \rightarrow WW$: VBF Production vs BFKL QCD dynamics.
  - All: lepton, γ isolation.
  - Etc…
- In 2011: Expect to reach/improve Tevatron limits or discover…

First exclusion limit or discovery expected in the well known $H \rightarrow WW^*$ channel.

Preliminary October 2010



4.2) Beautiful ZZ event



Invariant Masses

$\mu_0 + \mu_1$: 92.15 GeV (total(Z) p_T 26.5 GeV, ϕ -3.03),
$\mu_2 + \mu_3$: 92.24 GeV (total(Z) p_T 29.4 GeV, ϕ +.06),
$\mu_0 + \mu_2$: 70.12 GeV (total p_T 27 GeV),
$\mu_3 + \mu_1$: 83.1 GeV (total p_T 26.1 GeV).

Invariant Mass of 4μ: 201 GeV

Irreducible background for H→ZZ, or his Majesty King Higgs himself ☺

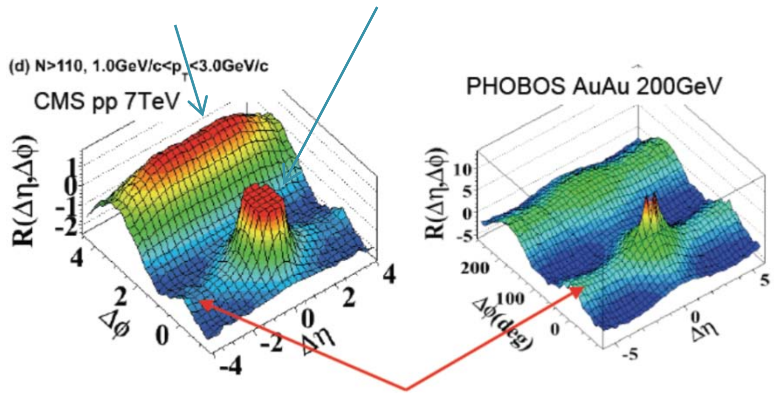
5) HI run

- The hot matter studies brought the most interesting results this year for CMS.

Long range, same side di-particles correlations in η in high multiplicity events in pp collisions.

Momentum conservation

Jets



Similar ridge observed in Phobos

arXiv: 1009.4122

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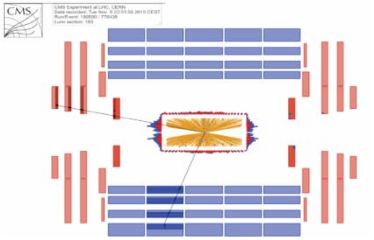
Z production: preliminary



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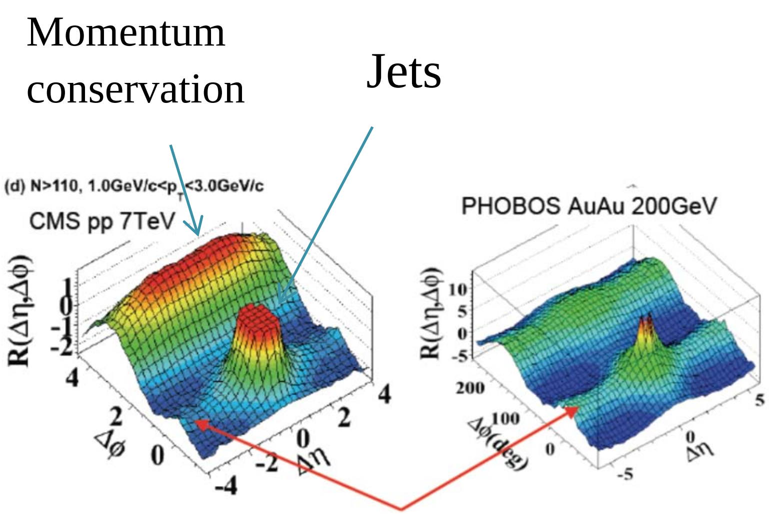

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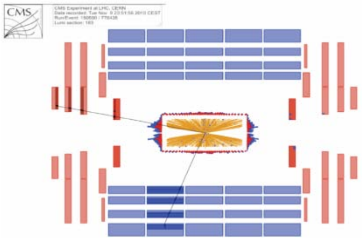

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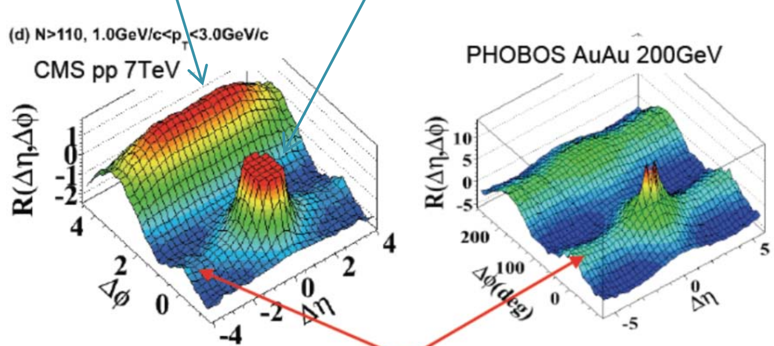

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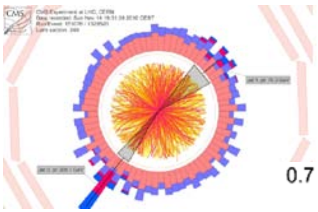
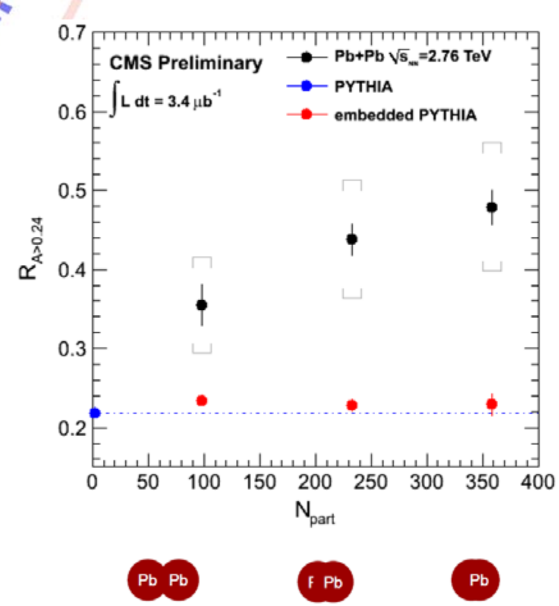
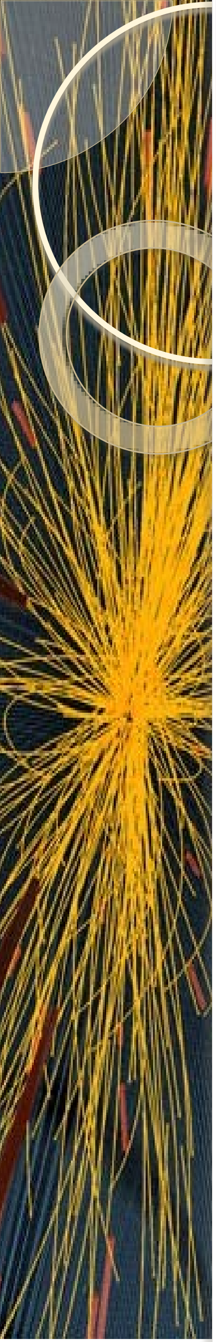


Jet quench: preliminary



Where is our caravella  ?

- Sailing in Mare Nostrum in 2010:
  - We are living the LHC era.
  - We trust our detector and you can trust also.
  - The detector is performing exceptionally well (we had sometime to prepare ourselves ☺).
  - The Standard Model works at those scales and we see it (sorry for quarkonia, b-jets and forward jets that I hadn't time to show, but the results are very promising).
  - We reach the Terra Incognita unexplored by our Tevatron colleagues. So no big surprise that no discovery yet.
  - Jets quench a significant step toward the QGP. Need LHC to produce punch-through jets in HI collisions.



Where do we sail  ?

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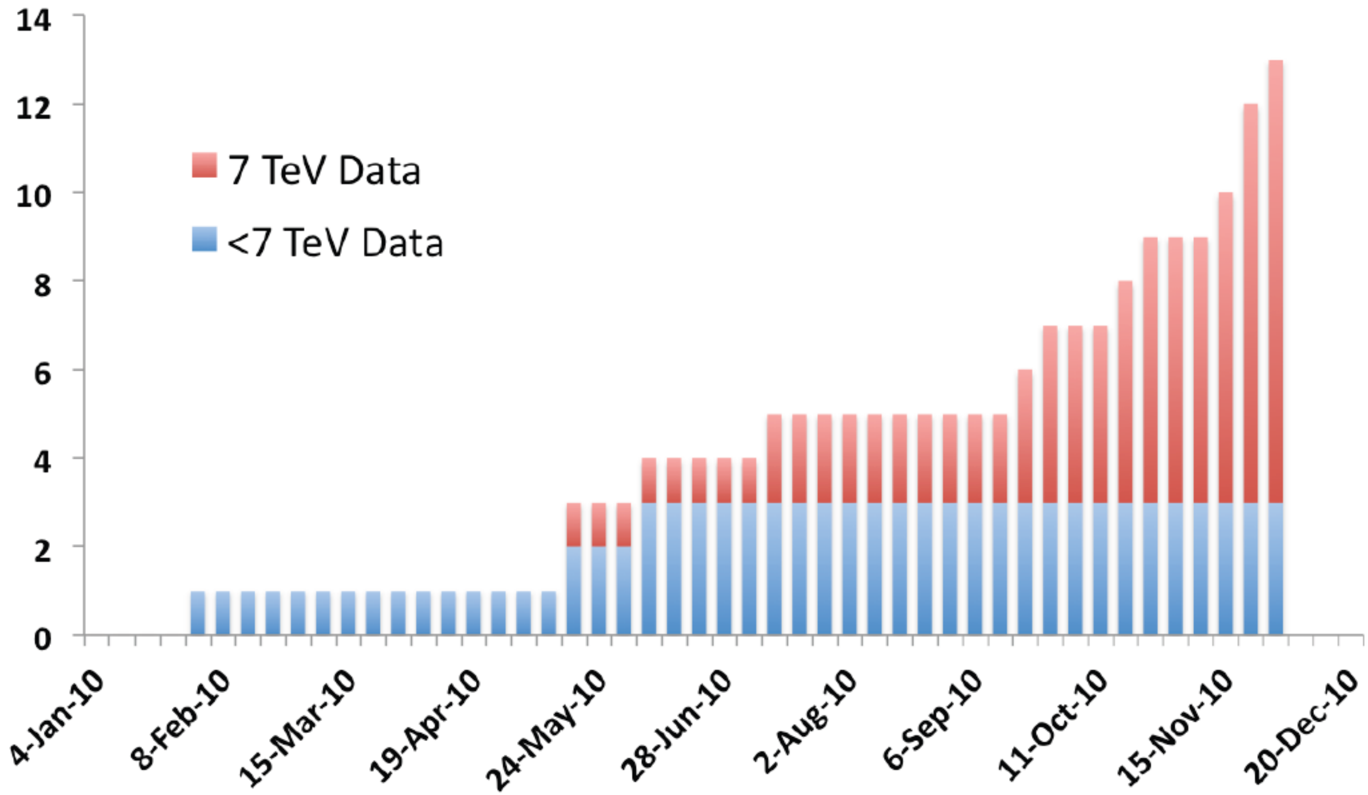
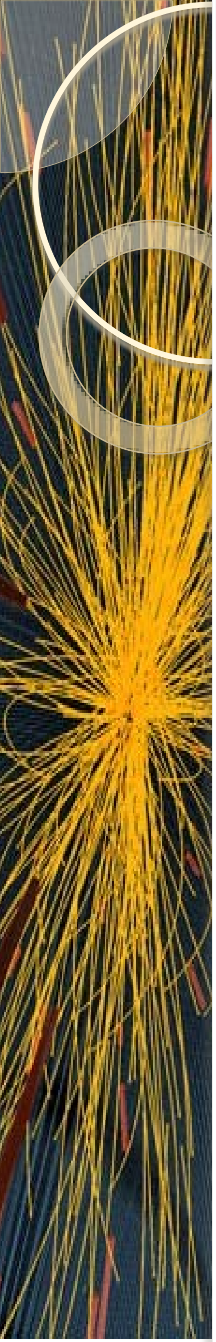
  - Jets quench a significant step toward the QGP. Need LHC to produce punch-through jets in HI collisions.

- Terra Incognita: In 2011 with 1-5 fb-1 of data
  - This shall be the year of discoveries if there is something to be discovered at TeV scale!
  - We would enter into the Higgs physics with LHC.

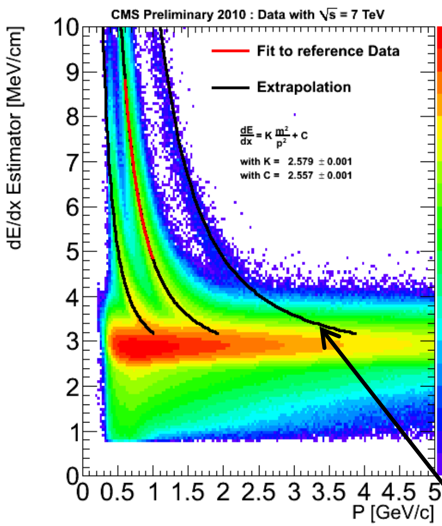
BACKUP


7 TeV Data
<7 TeV Data
14
12
10
8
6
4
2
0
4-Jan-10
8-Feb-10
15-Mar-10
19-Apr-10
24-May-10
28-Jun-10
2-Aug-10
6-Sep-10
11-Oct-10
15-Nov-10
20-Dec-10

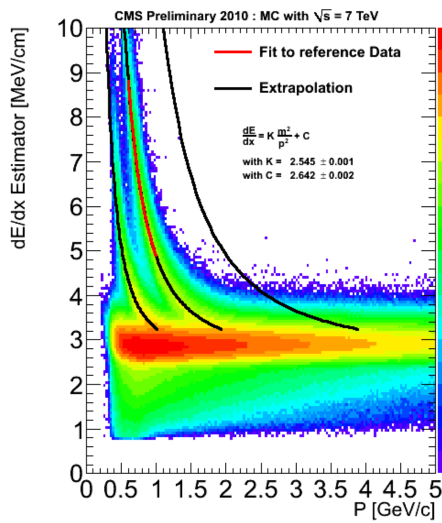


2.3) Low pT physics with the tracker (1)

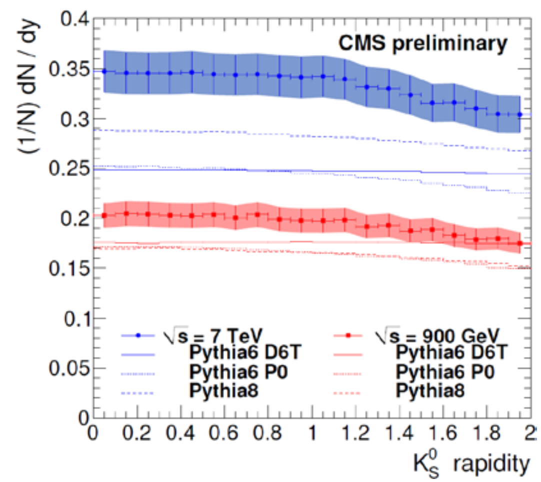
- Measurement of strangeness production using displaced vertices (*PAS QCD-100-007*) : hadronization.
- dE/dX used to distinguish π and p, important later for search of slow massive particles.
- 2 particles correlation (*PAS QCD-10-002*) : access to the fragmentation.



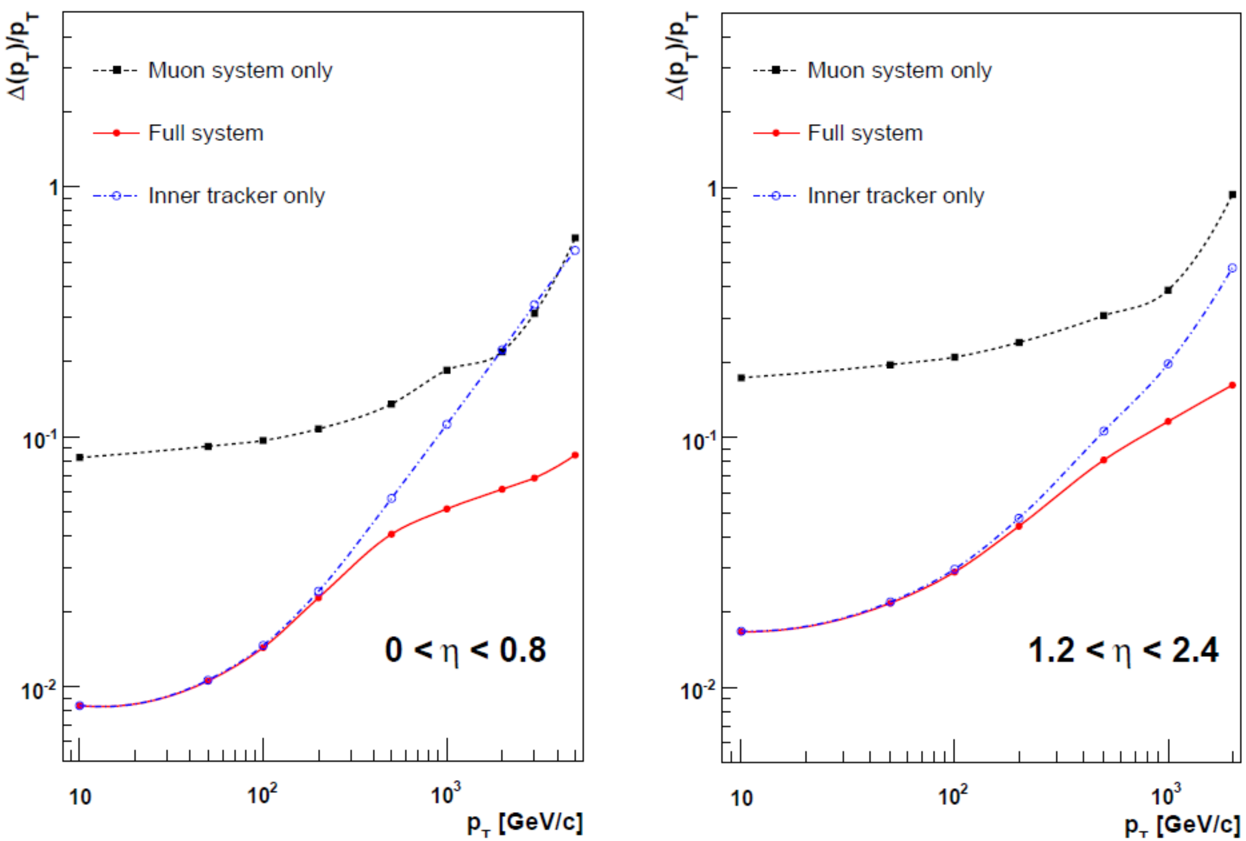
Data



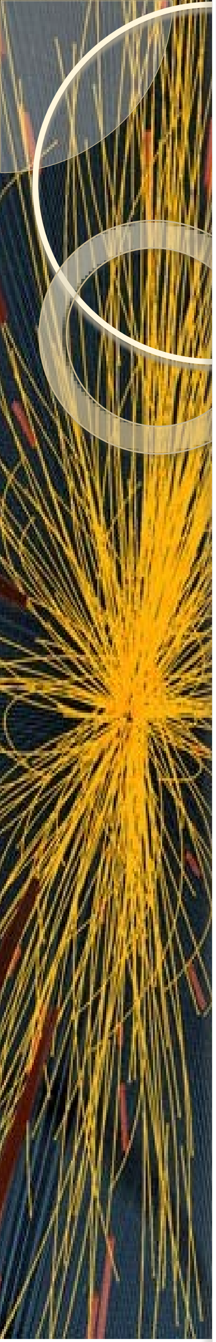
MC



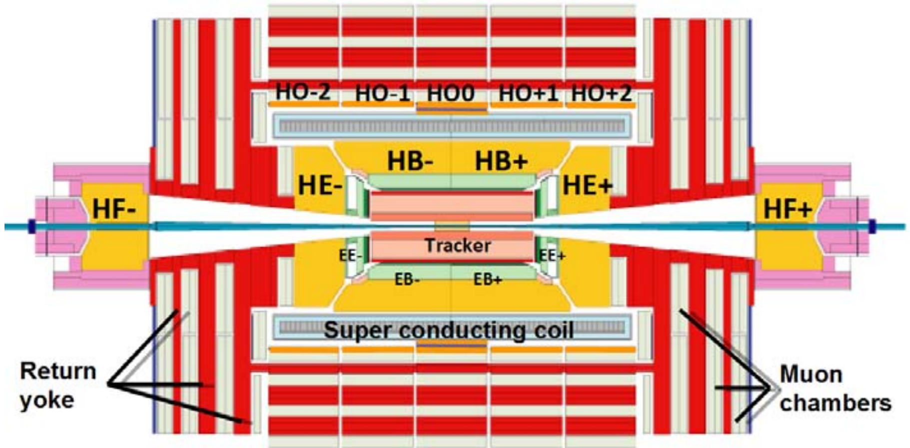
Deuteron



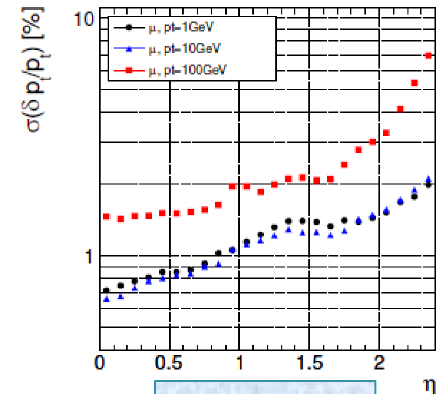
Δ(p_T)/p_T
Muon system only
Full system
Inner tracker only
1
10^-1
10^-2
10
10^2
10^3
p_T [GeV/c]
0 < η < 0.8
1.2 < η < 2.4



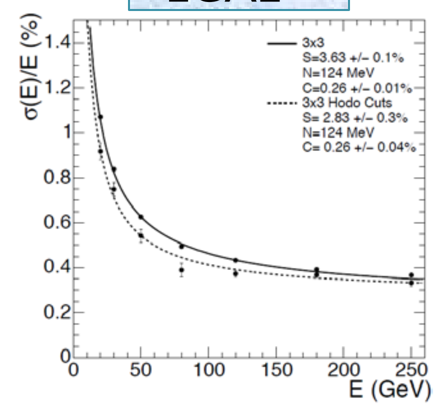
5.1) Particle Flow: global event reconstruction framework



Tracker



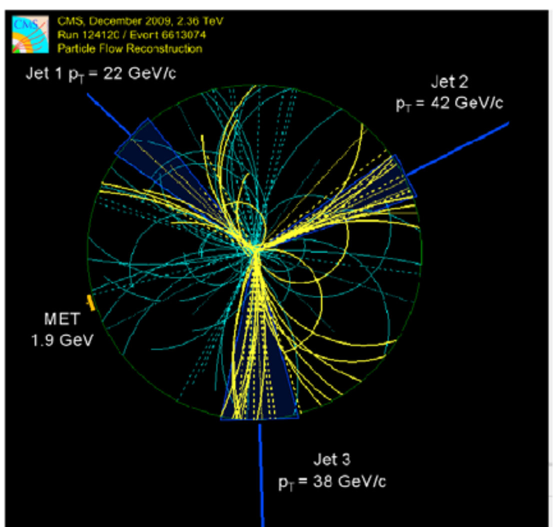
ECAL



- Using the combination of all available detectors to reconstruct and indentify particles (π, γ, K0, μ, e)
- Low pT π: precision dominated by the tracker.
- High pT π: precision dominated by calorimeters.

HCAL:

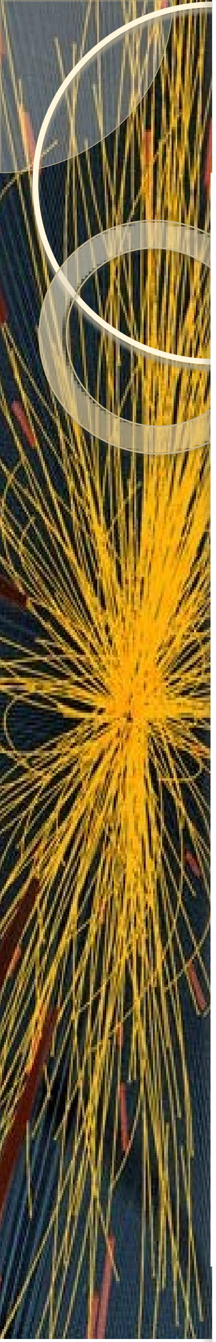
$120\%/\sqrt{E} + 6.9\%$



Transverse view of CMS Tracker (∅ = 2.5 m)

Particles in Jets
Particles out of Jets

— Charged hadrons
····· Photons
····· Neutral Hadrons

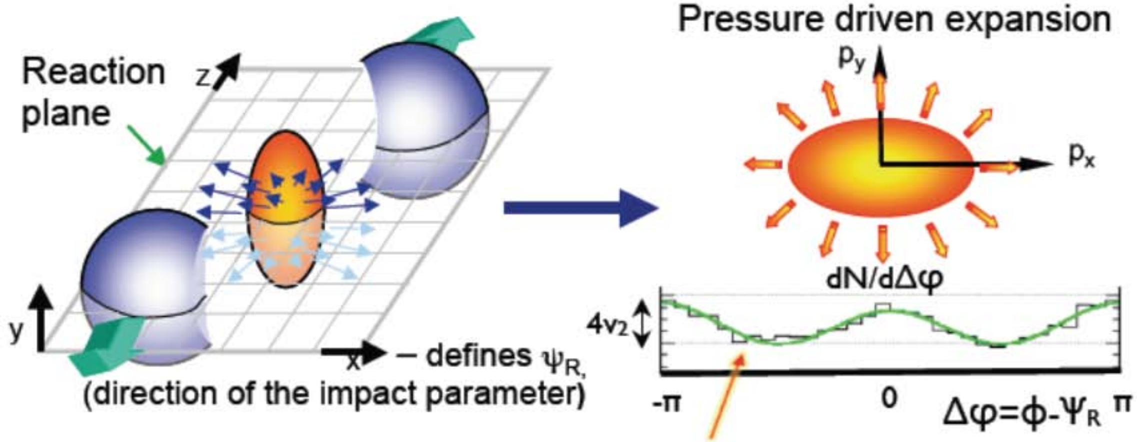


Mid Mass Regime, M_H~160: $N_{events} = \sigma \times BR \times L$

Experimental signature		Signal events: TeV Exp. 9 fb^{-1}	Signal events: LHC Exp 0.5 fb^{-1}	Comments
H→WW	H → (lν)(lν) **with n=0,1 jets**	222	236	**5 times better S/B**
	qqH → qq (lν)(lν)	15	20	**S/B ~same**
	qqH → qq (lν)(jj)	93	120	**S/B ~same**
	WH → (lν)(lν)(jj), same-sign dilepton	27	7	
	ZH → (ll)(lν)(jj)	5	1	

Correlation in Heavy Ions

Collective flow phenomena:



~ $\cos(2\Delta\varphi)$ (long-range in η)

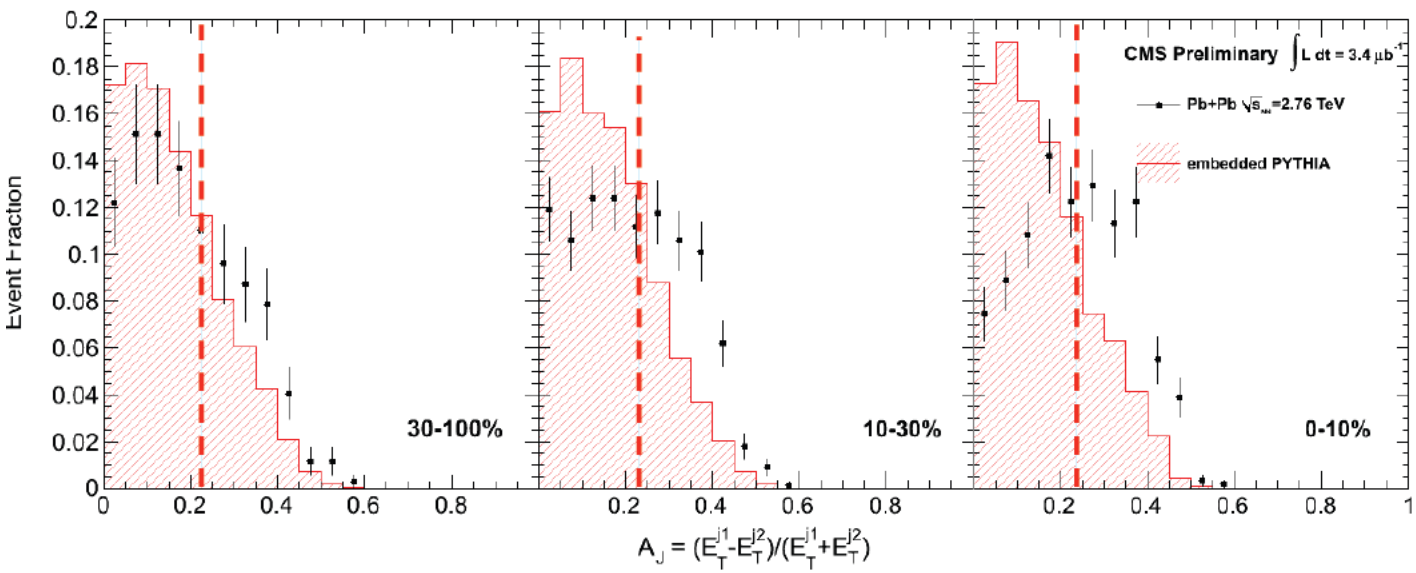
Extracted shear viscosity of the medium found to be close to theoretical lower bound $1/4\pi$

Dijet energy imbalance

Semi-Peripheral

Semi-Central

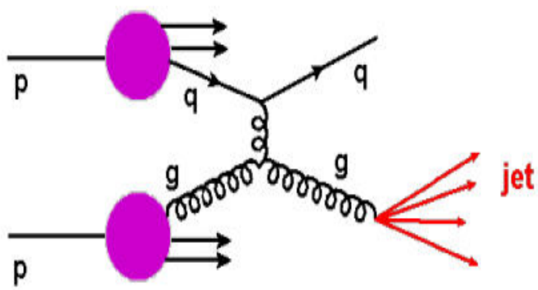
Central

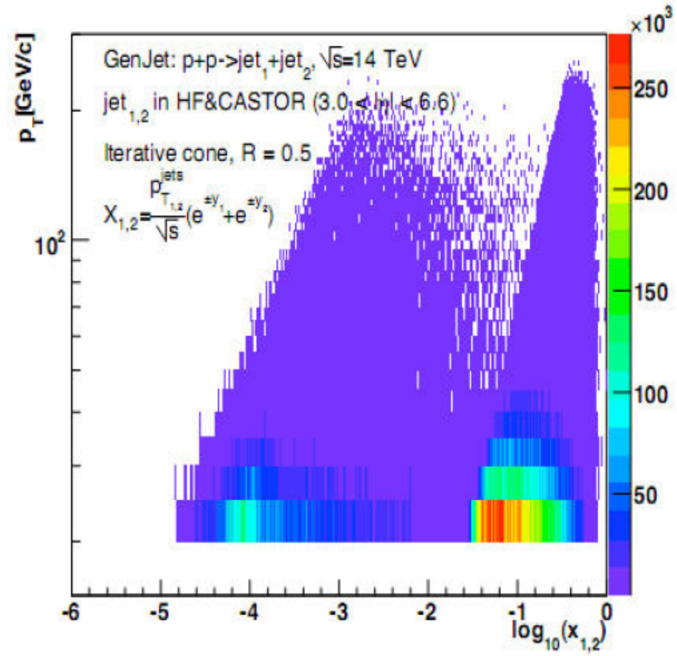


A significant dijet imbalance, well beyond that expected from unquenched MC, appears with increasing collision centrality

Forward jets: motivation

> Forward jets allow to probe Bjorken-x as low as 10^{-5}: region sensitive to non-linear QCD effects of parton recombination and saturation





[CMS PAS FWD-08-001 / FWD-10-003]

[CMS and TOTEM Collaborations, CERN/LHCC 2006-039/G-124]

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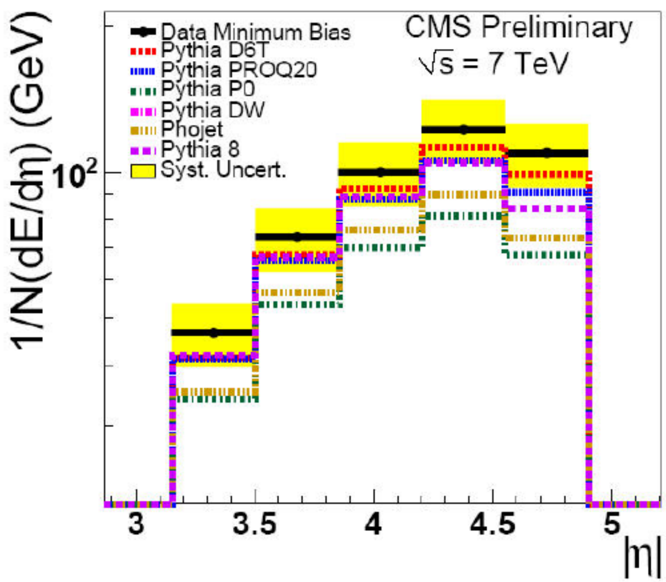
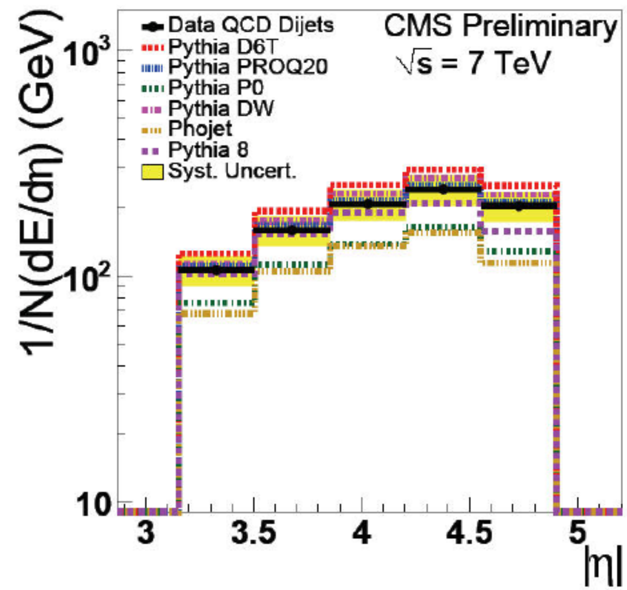
Forward energy flow: minbias and di-jet at 7000 GeV





- At 7 TeV, predicted energy flow in minimum bias events is below measurement for all tunes
- For di-jet sample D6T tune predicts too high energy flow, whereas the PROQ20 tune and PYTHIA8 are best and P0 tune and PHOJET are too low

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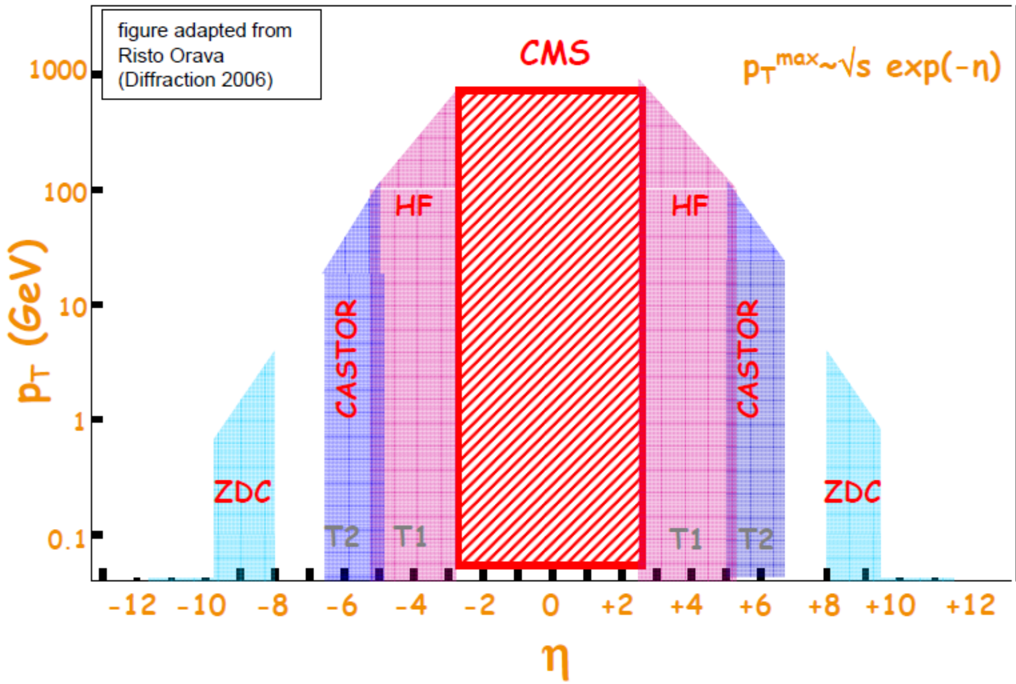
Fwd detectors phase space coverage in η and pt

[A. Panagiotou]



- HF, CASTOR, zero degree calorimeters + TOTEM detectors → unparalleled forward coverage

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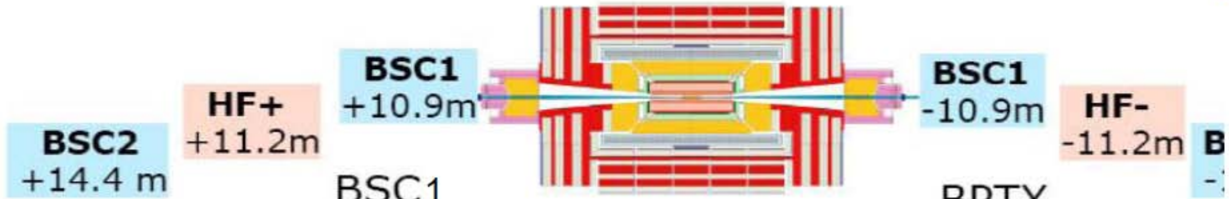
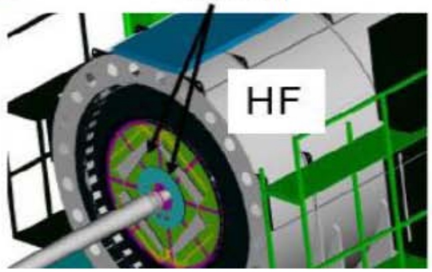
Trigger System

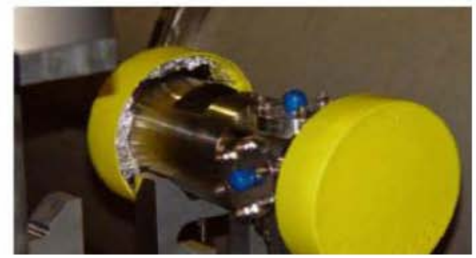


BPTX
+175m

BSC1

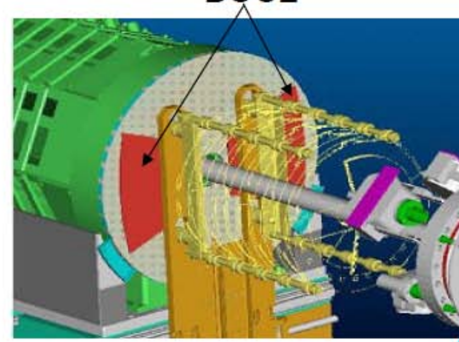


BPTX



- Beam scintillation counter: info on hits and coincidence signals
- Beam Pick-up Timing for eXperiments: precise info on structure and timing of LHC beams
- BSC + BPTX → minimum bias (beam halo/gas/splash, high multiplicity) triggering / monitoring for pp and HI

BSC2



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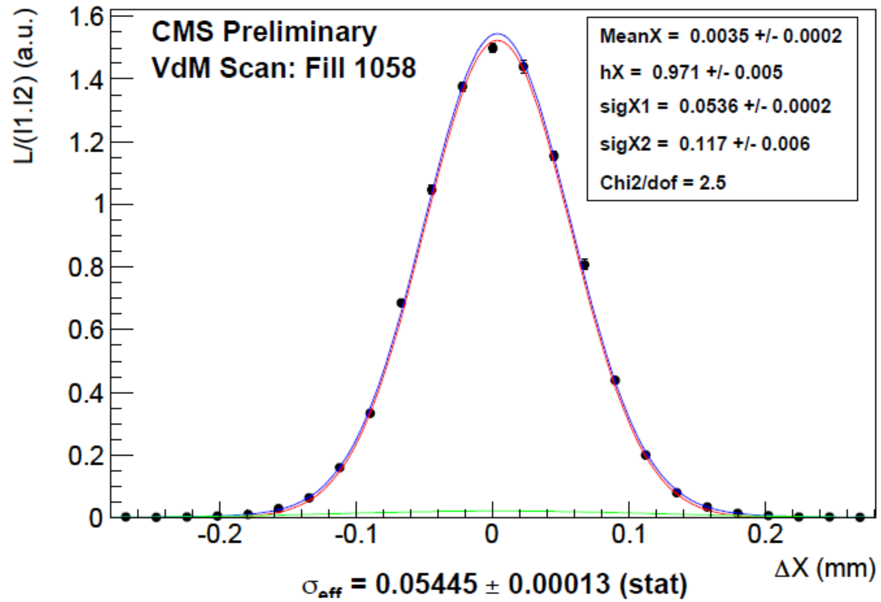
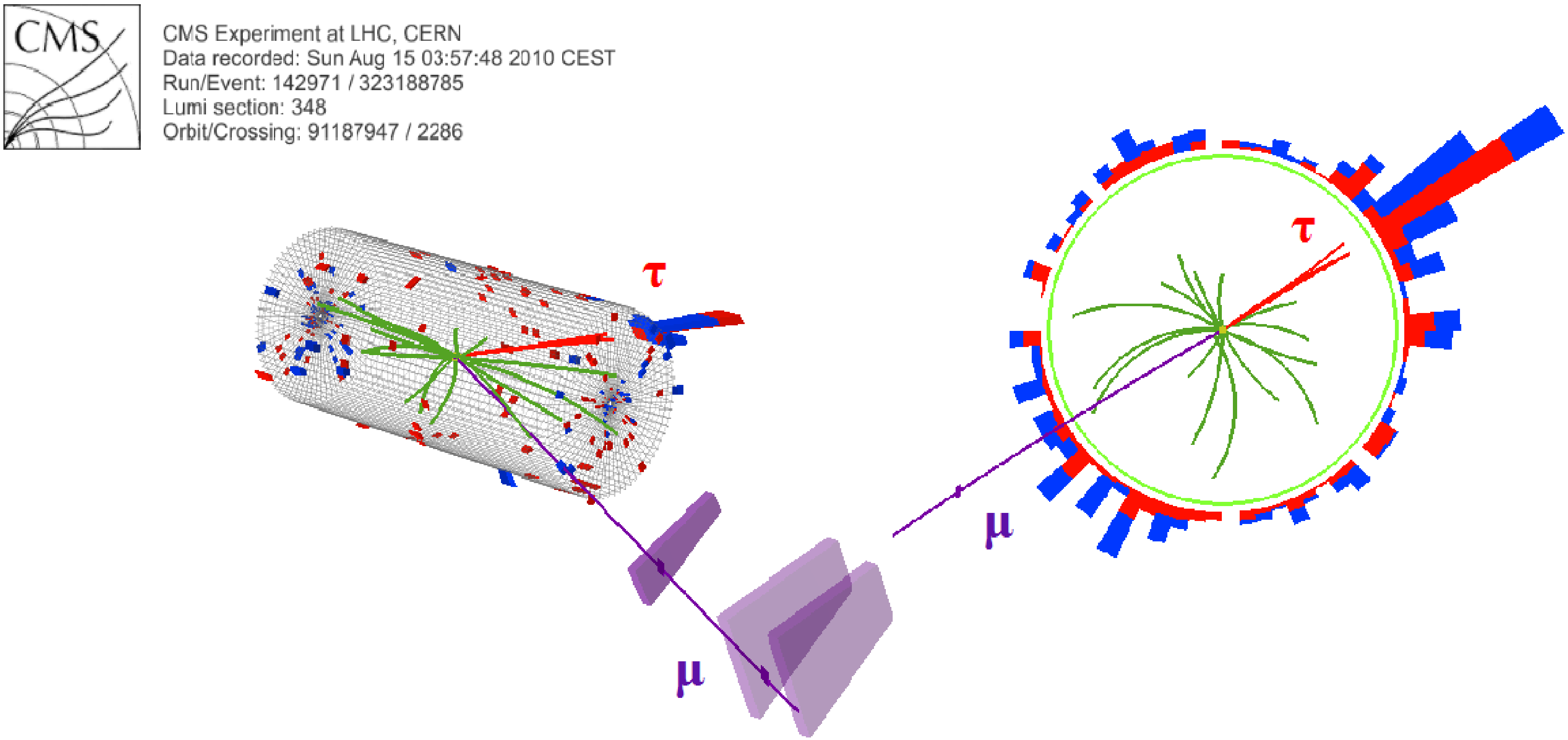
The beam intensities are measured using Fast Beam Current Transformers (FBCT), which measure the current in each 25-ns LHC bunch [6]. The FBCT measurements, which provide accurate bunch-to-bunch values, are normalized to a low-bandwidth measurement of the total circulating current, made by DC current transformers.



Error	Value (%)
Beam Background	0.1
Fit Systematics	1.0
Beam Shape	3.0
Scale Calibration	2.0
Zero Point Uncertainty	2.0
Beam Current Measurement	10.0
Total	11.0

CMS PAS EWK-10-004

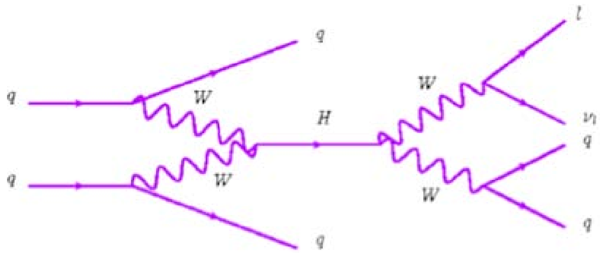
$Z \rightarrow$ tau tau $\rightarrow$ mu +tau_{had} (three prong tau)



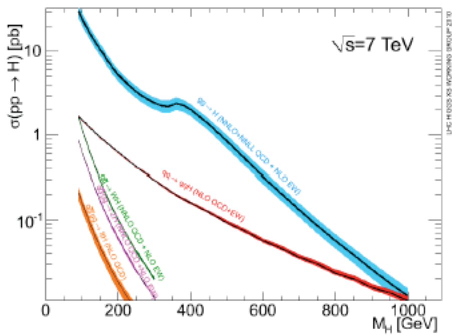
μ Pt = 32.4 GeV/c
η = 1.7

τ Pt = 37.4 GeV/c
η = 1.5
Mass = 1.2GeV/c^2

Vis. Mass= 70 GeV/c^2
M_T(μ,MET) =4.1 GeV



expectations



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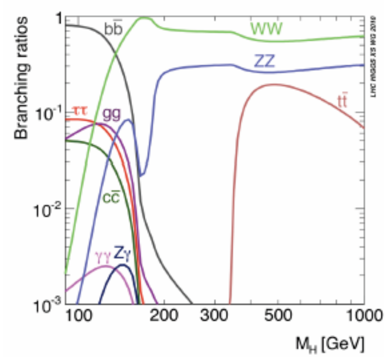

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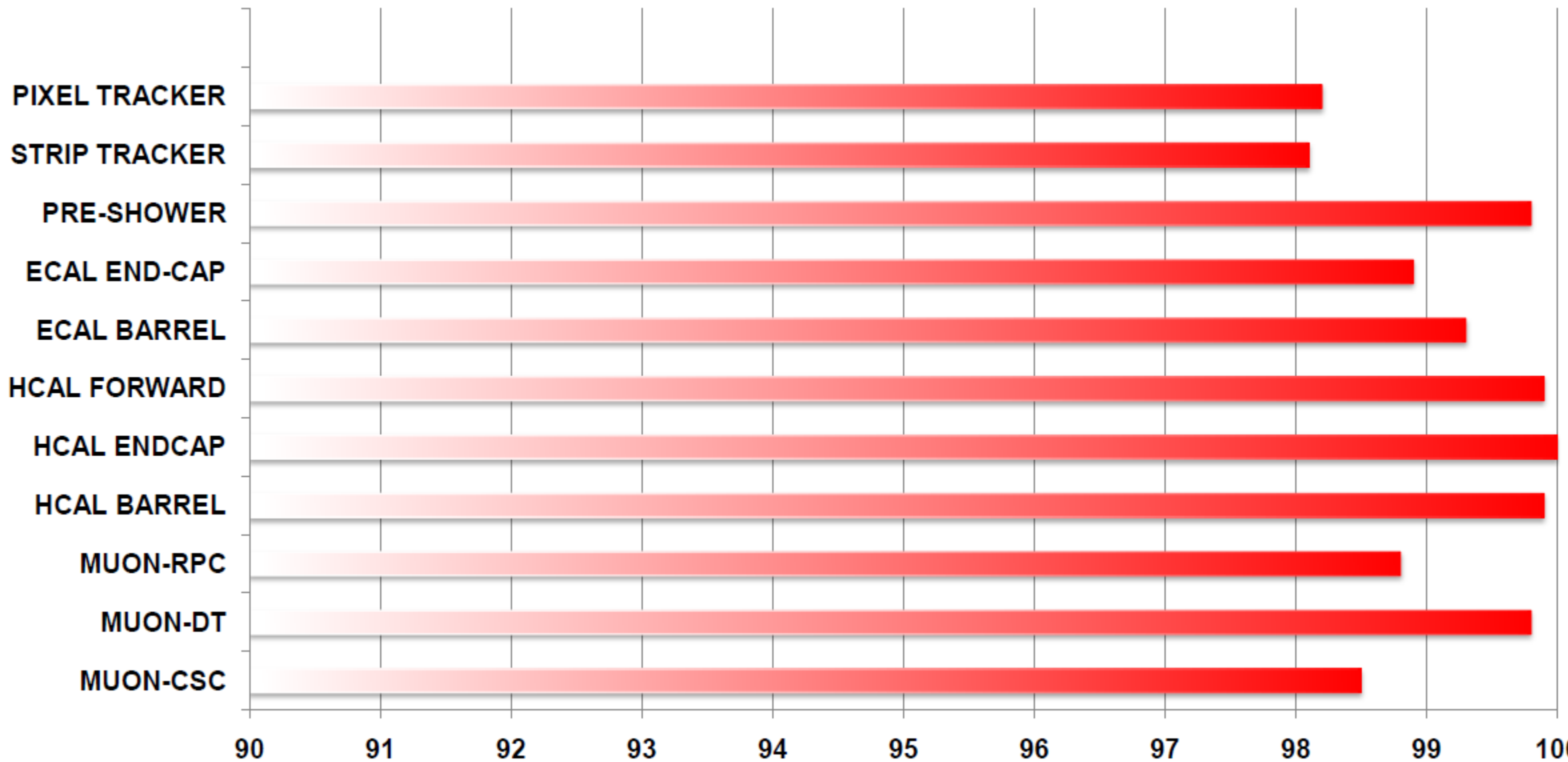
Sub-detectors operational status



	MUON-CSC	MUON-DT	MUON-RPC	HCAL BARREL	HCAL ENDCAP	HCAL FORWARD	ECAL BARREL	ECAL END-CAP	PRE-SHOWER	STRIP TRACKER	PIXEL TRACKER	
Series1	98.5	99.8	98.8	99.9	100	99.9	99.3	98.9	99.8	98.1	98.2	

G. Tonelli, CERN/INFN/UNIPI *ICHEP10 Paris* *July, 26 2010* 5