Muon Bundles: Results From LEP, EMMA & the LHC

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MENU

Starter

Introduction – What is a muon bundle

Main Courses

1. *CosmoLEP Results*
   a. *ATLAS*
   b. *DELPHI*
   c. *L3+C*

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2. *EMMA*
3. *LHC*
   a. *ACORDE (ALICE)*
   b. *ACME (ATLAS)*
   c. *CMS*

Digestive

4. *Physics topics*
5. *Conclusion*

Muon Bundles

- *Showers of high multiplicity quasi-parallel penetrating particles were first observed about 50 years ago in shallow underground experiments (counter telescopes, multi-plate cloud chambers).*
- *They have been seen in many experiments: MACRO, ALEPH, L3+C, DELPHI, EMMA, DUMAND, ALICE, CMS & (ATLAS?), etc.*
- *They were dubbed "muon bundles" with surprisingly small distances between the particles (Abnormally low P_T?)*
- *The main sources of such events are decays of pions and kaons produced in numerous interactions of hadrons in EAS.*
- *In underground experiment muon P > ~50 GeV, thus muons are mostly generated in the top part of the shower*

Precursors: COSMOLEP & CORAL

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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CORAL
A Cosmic Ray experiment in and above the LHC tunnel

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CosmoLEP,
an underground cosmic ray muon experiment in the LEP ring

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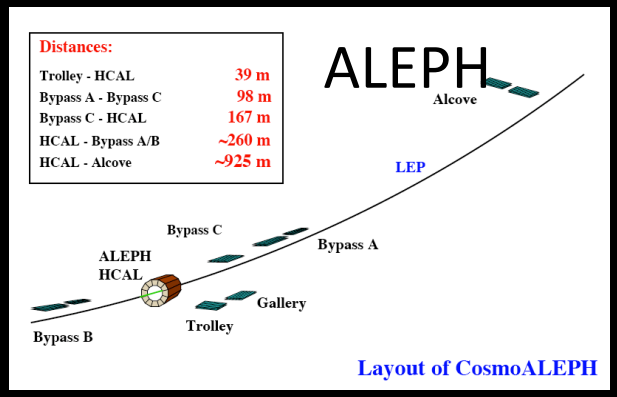
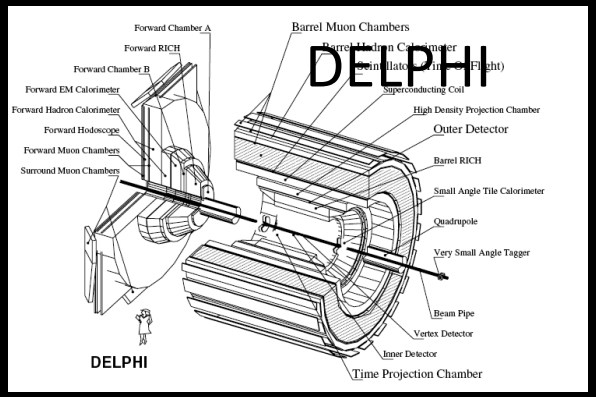
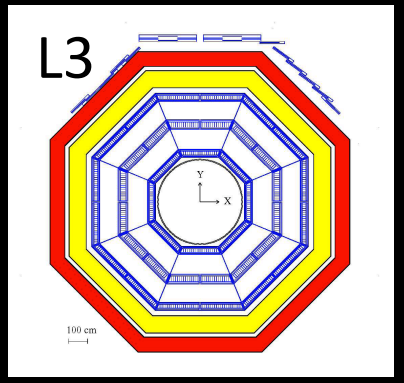
LEP Results

The "CosmoLep" Experiment

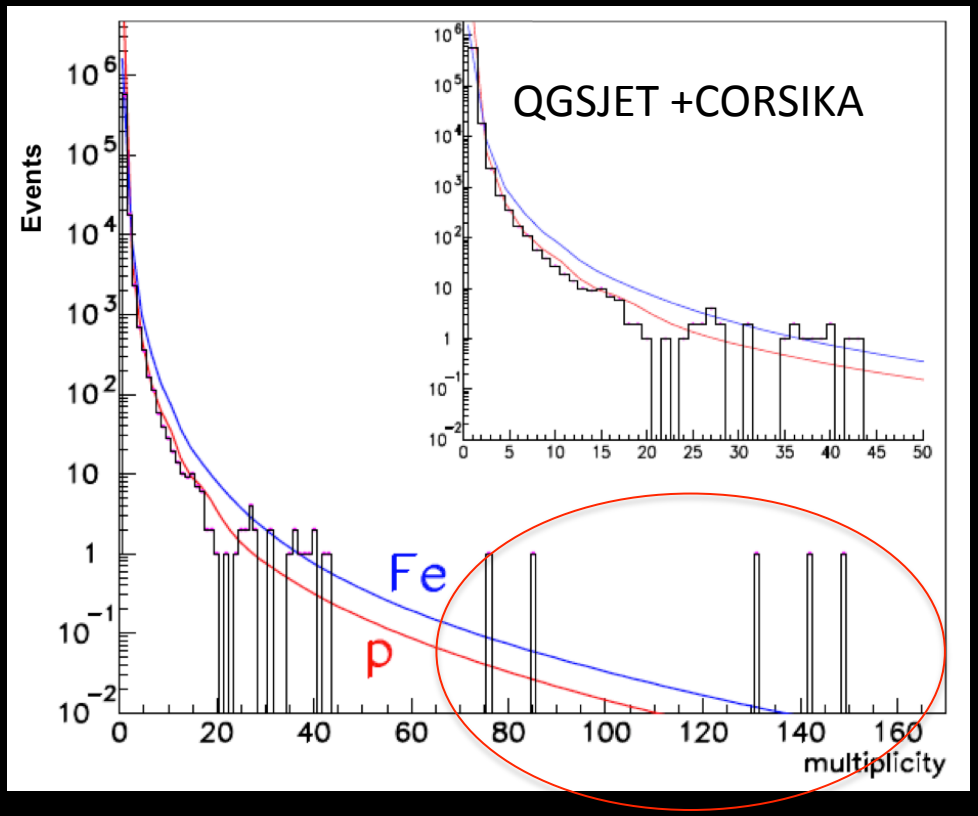


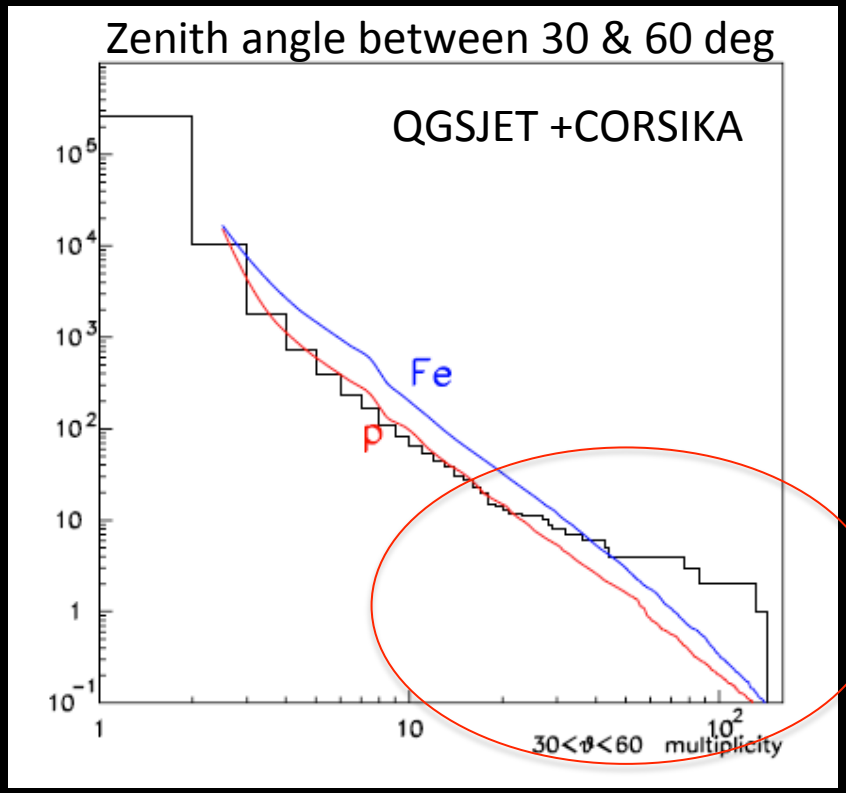




- *ALEPH: 140m rock - muon P > 70/cosθ GeV/c + UG array*
  - *HCAL (horizontal area ~50m^2), TPC (projected area ~16m^2), UG sci stations.*
- *DELPHI: 100m rock - muon P > 52/cosθ GeV/c*
  - *Hadron calorimeter (~75 m^2 horizontal area), Muon barrel, TPC, ToF detector, Outer Detector.*
- *L3+C: 30m rock - muon P > 20/cosθ GeV/c + surface array*
  - *Scintillator surface array (~200 m^2), trigger, muon barrel (100m^2 horizontal area), hadron calorimeter, etc.*
- *Cosmic ray energy coverage from 10^{14} →10^{18} eV*

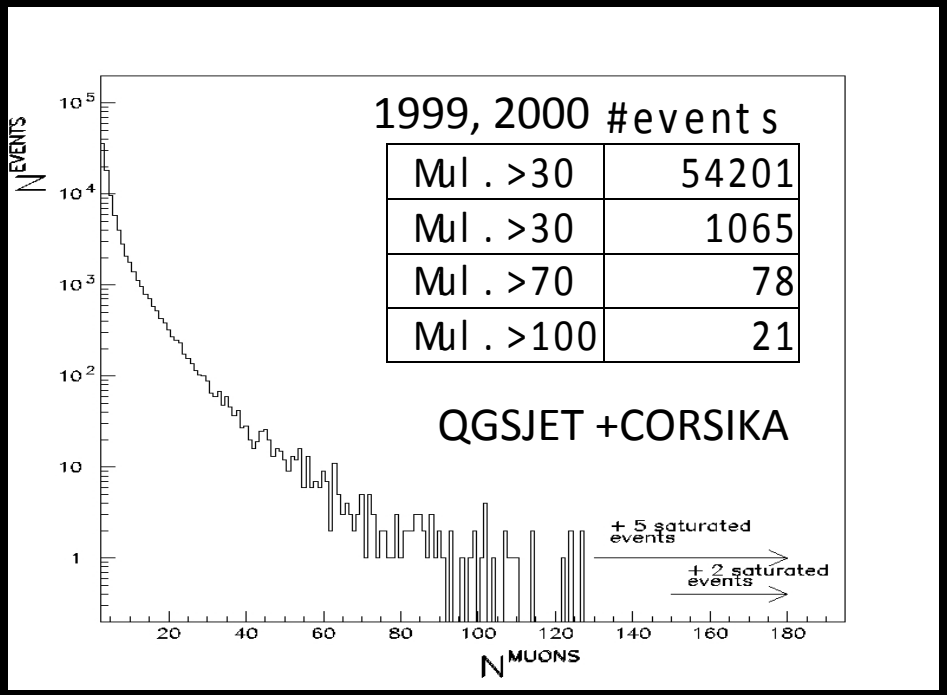
Aleph's Multi-muon Excess

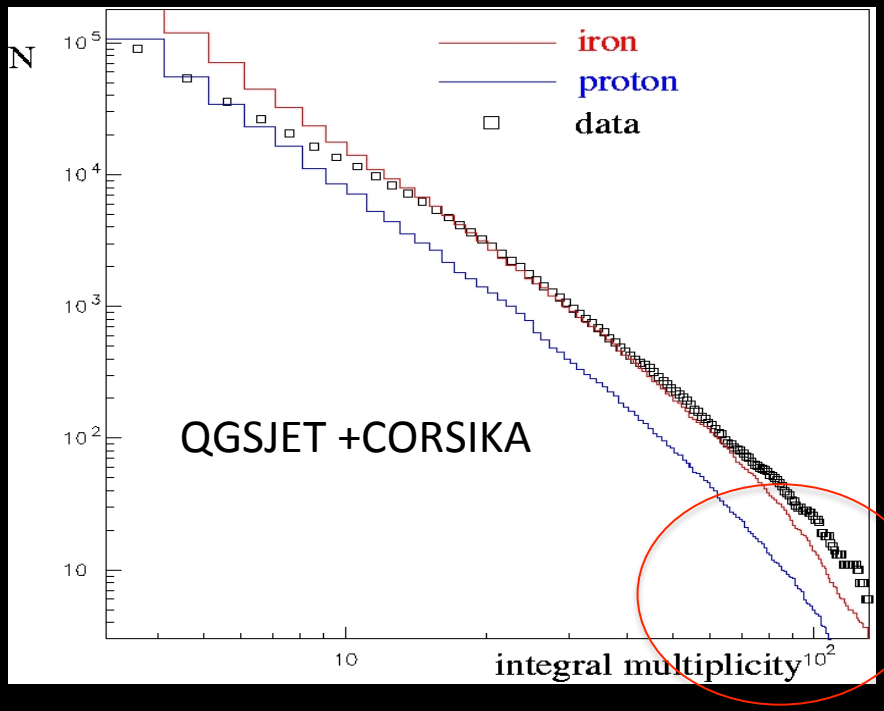




- *Data indicate that heavier component is needed to explain higher multiplicity muon bundles*
- *The very highest multiplicity muons bundles are not modelled*

Delphi's Multi-muon Excess

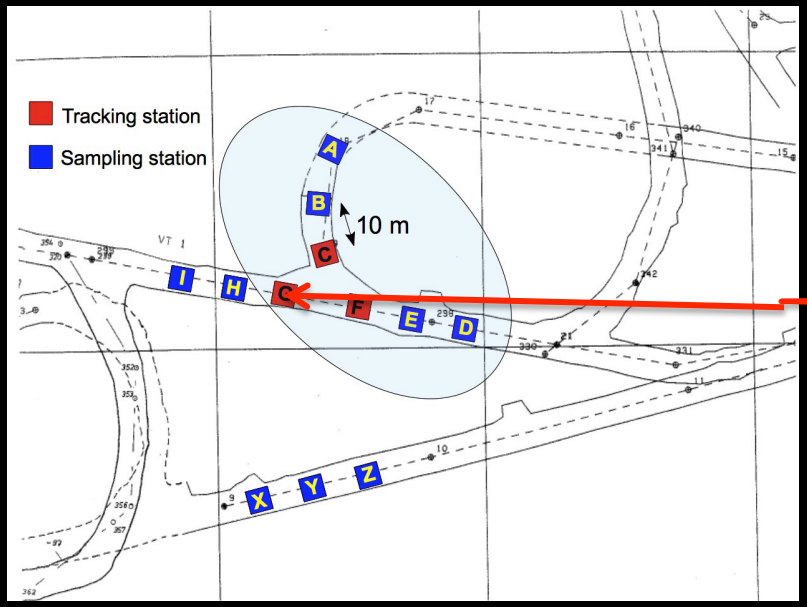




- *Delphi's data also indicated the need to have heavier primaries to explain the higher multiplicity data*
- *Again the very highest multiplicity events are not modeled.*

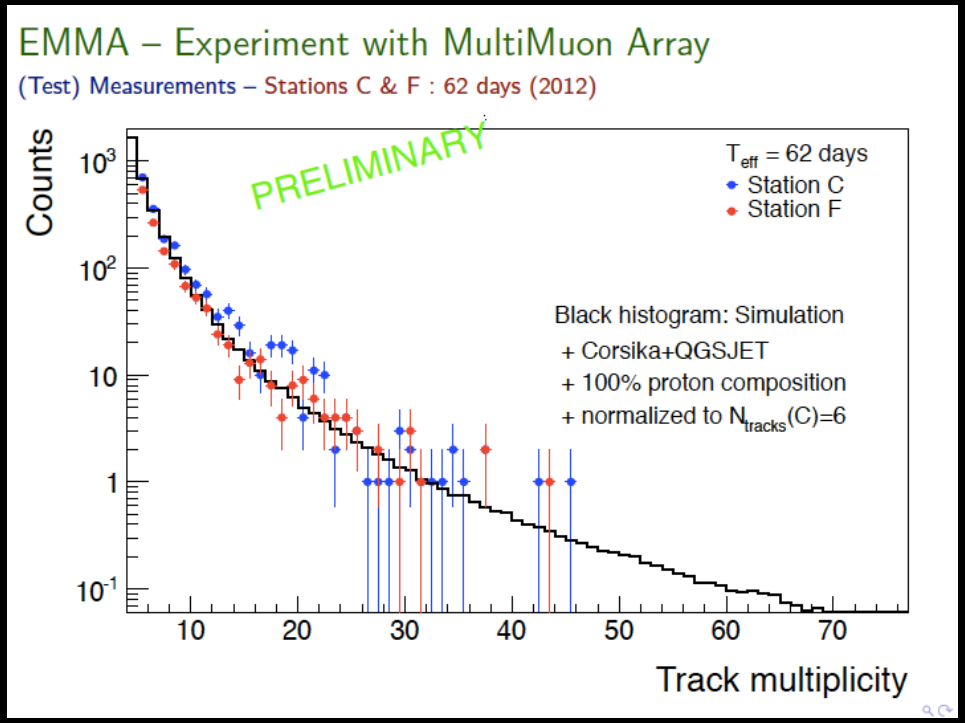

EMMA

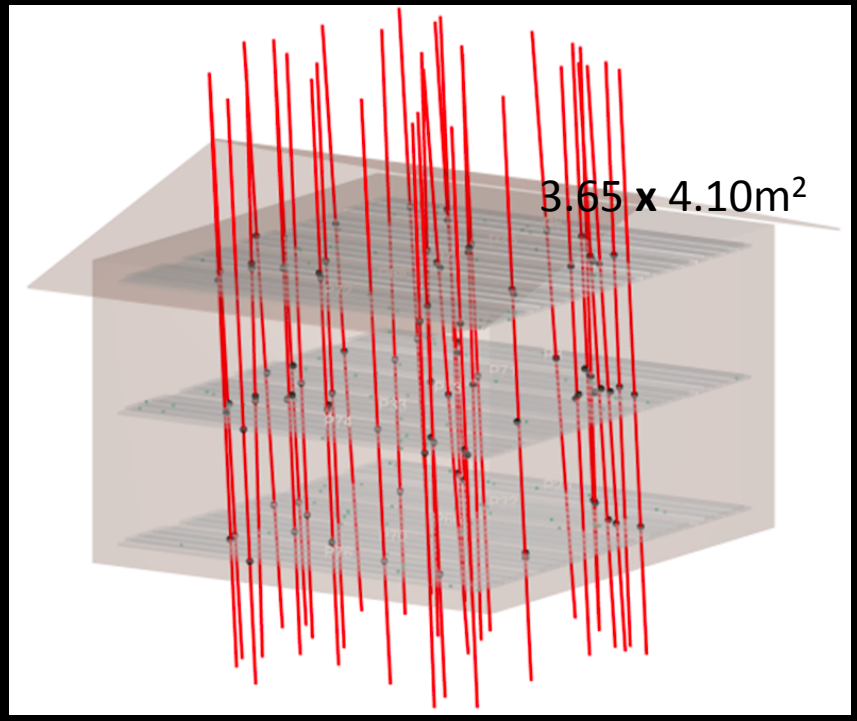
EMMA – Experiment with Multi-muon Array



- *EMMA is deployed at a depth of 75m (or 210 m.w.e) in the Pyhäsalmi mine, Finland – muon P > 50 GeV/c*
- *EMMA employs two types of detectors, plastic scintillation detectors and drift chambers.*
  - *Tracking detectors have 3 layers*

EMMA – Preliminary Result

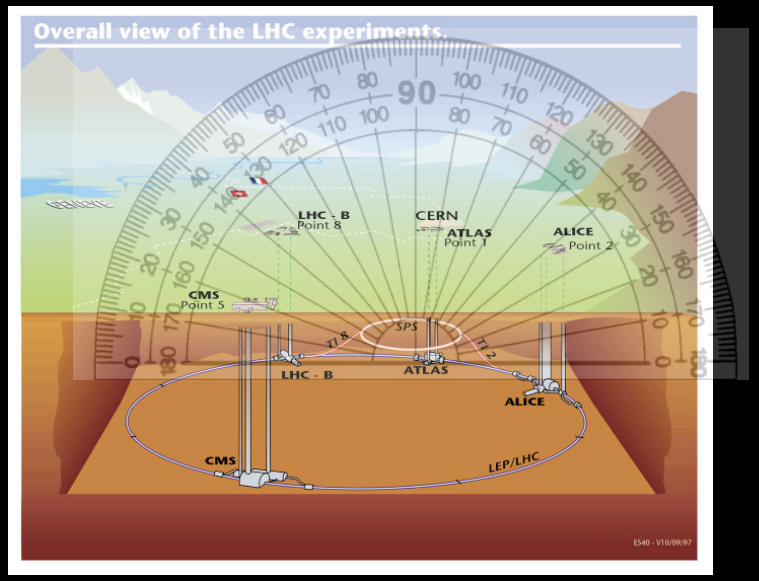




- *Early days yet but the data broadly confirms LEP observations*
  - *Heavier primaries needed to fit intermediate multiplicities*
  - *Evidence of a surfeit of high multiplicity muon bundles*

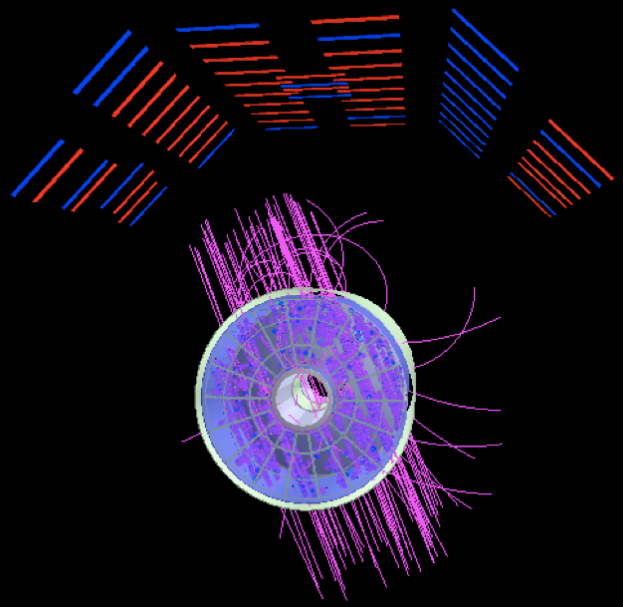
The LHC contribution

LHC Advantages



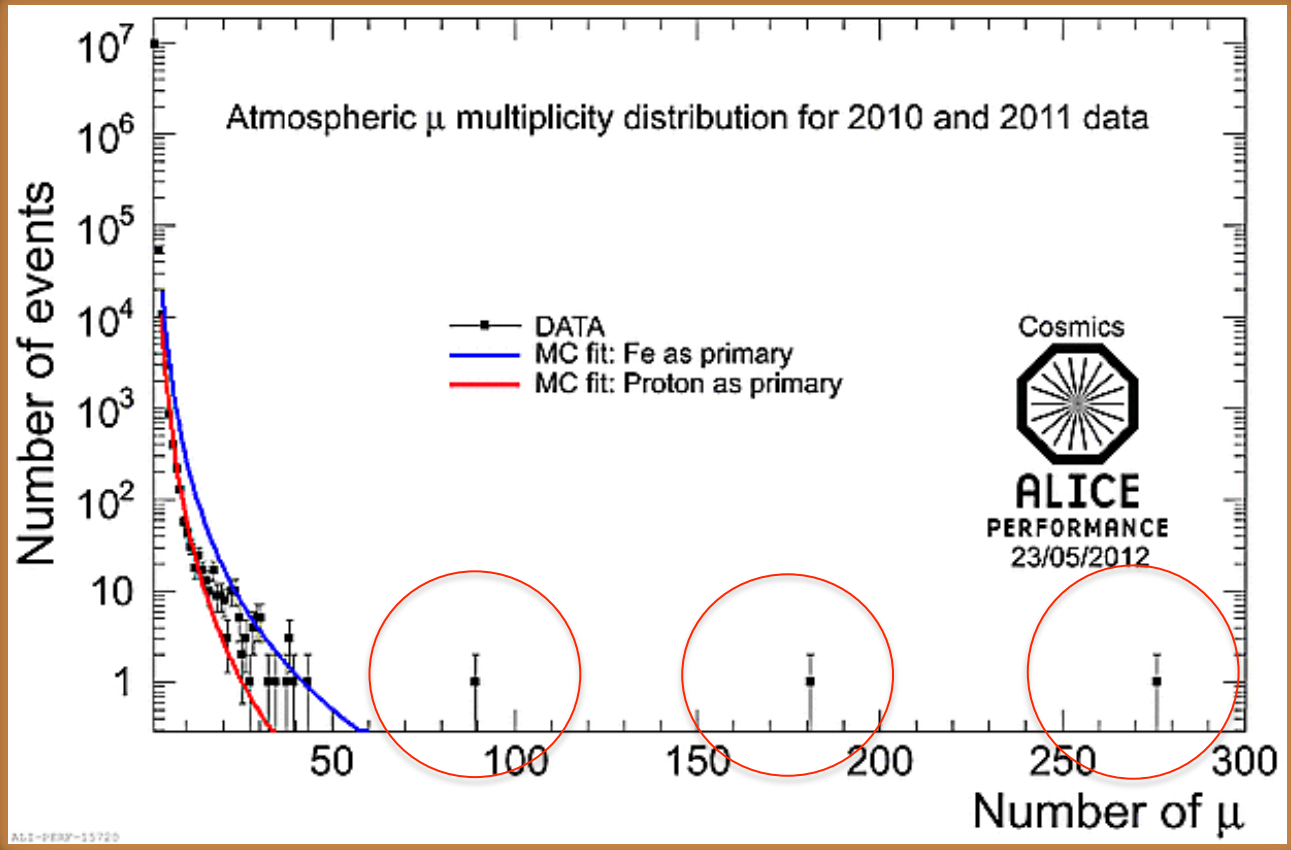
- *Unprecedented (horizontal) areas of precision muon chambers can be deployed ~ factor of ten greater than in the CosmoLEP with muon P thresholds ~50 GeV/c*
- *As with LEP we have the roughly flat overburden to enable us to study simply the effect of increasing zenith angles*
  - *Additionally the nearby Jura mountains; by choosing the Jura zenith angle (greater than 70^{o} etc) the overburden is increased to > 10 km w.e. permitting measurements with very different overburdens*

LHC CR Detector – ACORDE



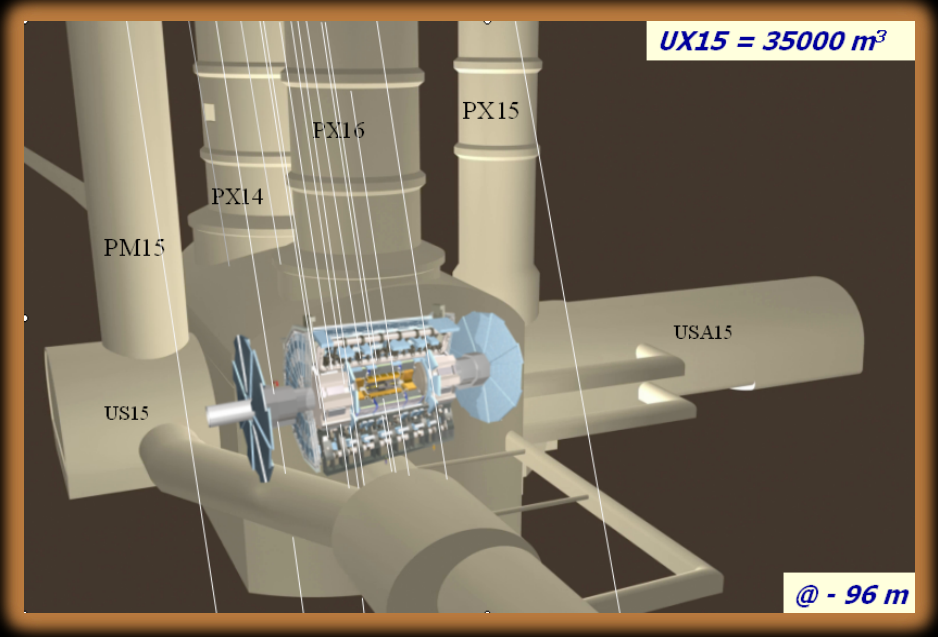
- *ALICE has deployed ACORDE to trigger on cosmic rays*
  - *ACORDE consists of an array of plastic scintillator counters placed on the 3 upper faces of the magnet*
  - *The Detector used in the analysis is the ALICE TPC*
  - *Horizontal area of TPC is ~14 m^2 (2.8m radius 5.2m long), depth=30m, muon P_T > ~20 GeV/c*

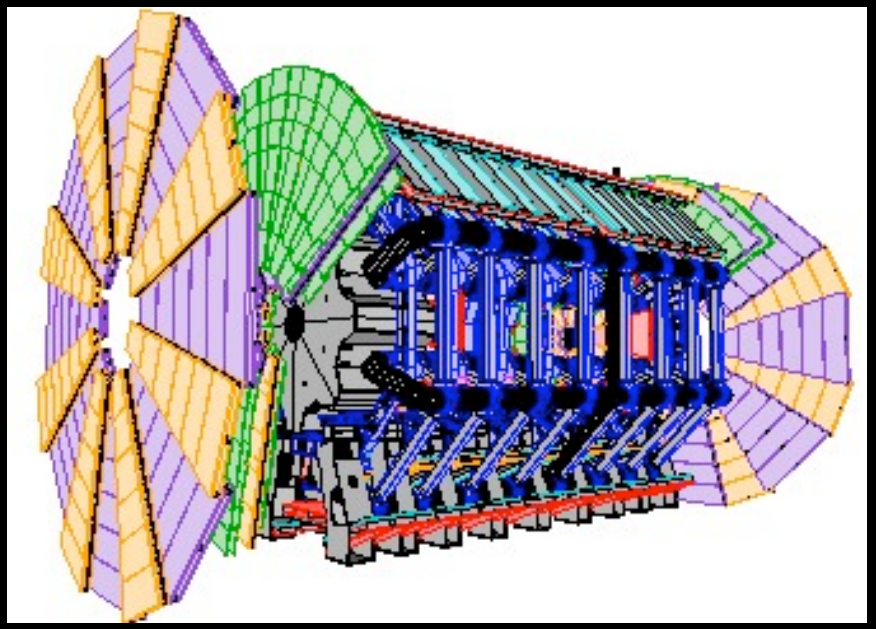
ACORDE – Muon Bundles



- *They see an excess of high multiplicity muon "bundles"*

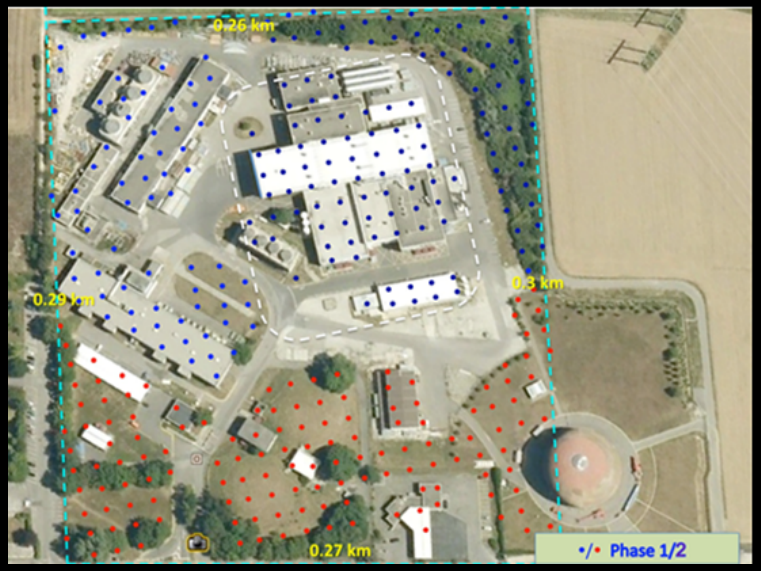
ACME – ATLAS Cosmic Muons & Exotics Detector (1)





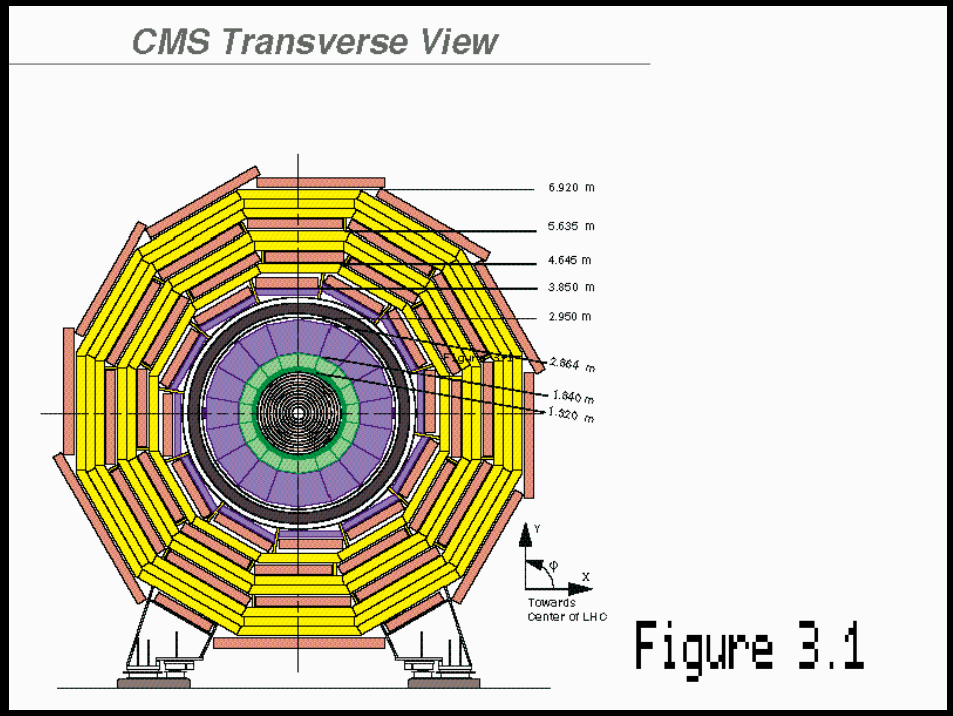
- *ATLAS would measure CR muons using unprecedented area of precision μ-tracking Muon system with horizontal area ~1000m² ~ 20 times that of the LEP detectors*
  - *Depth ~70m muon P > 40*
  - *Sensitive to cosmic rays with energy between 10^{14} and 10^{18} eV*

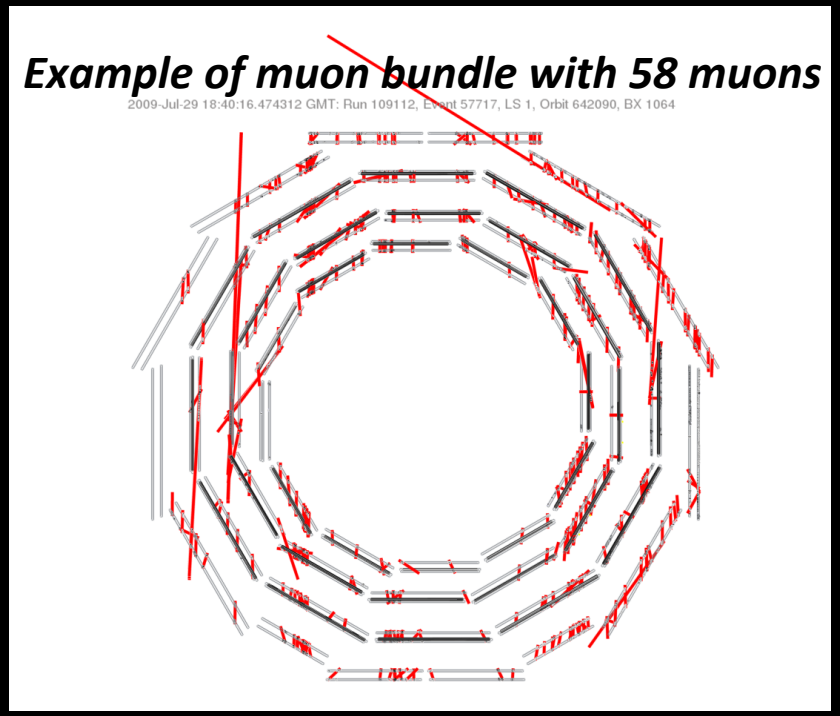
ACME – Surface Array



- *ATLAS - used to measure the muon content of the shower - will be combined with a surface array via the ATLAS trigger*
  - *The surface array used to measure the energy & shower direction*
- *ATLAS would use two triggers*
  - *The existing ATLAS cosmic ray trigger (that runs during data taking)*
  - *A trigger provided by the Surface or UG Array (~ 1/60 1 Hz)*

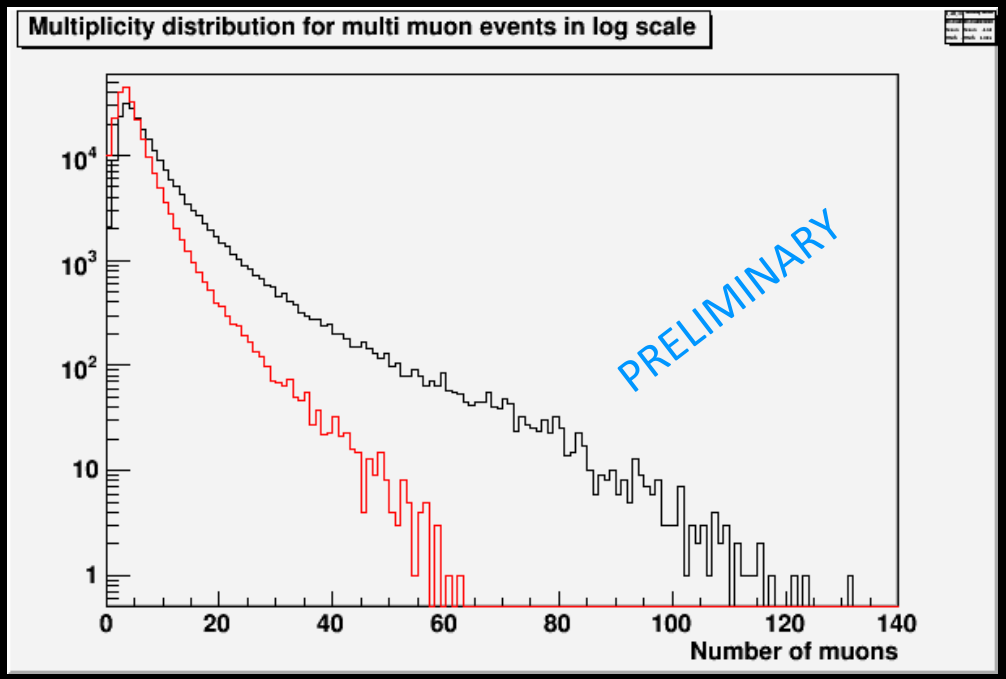
CMS – Preliminary Results



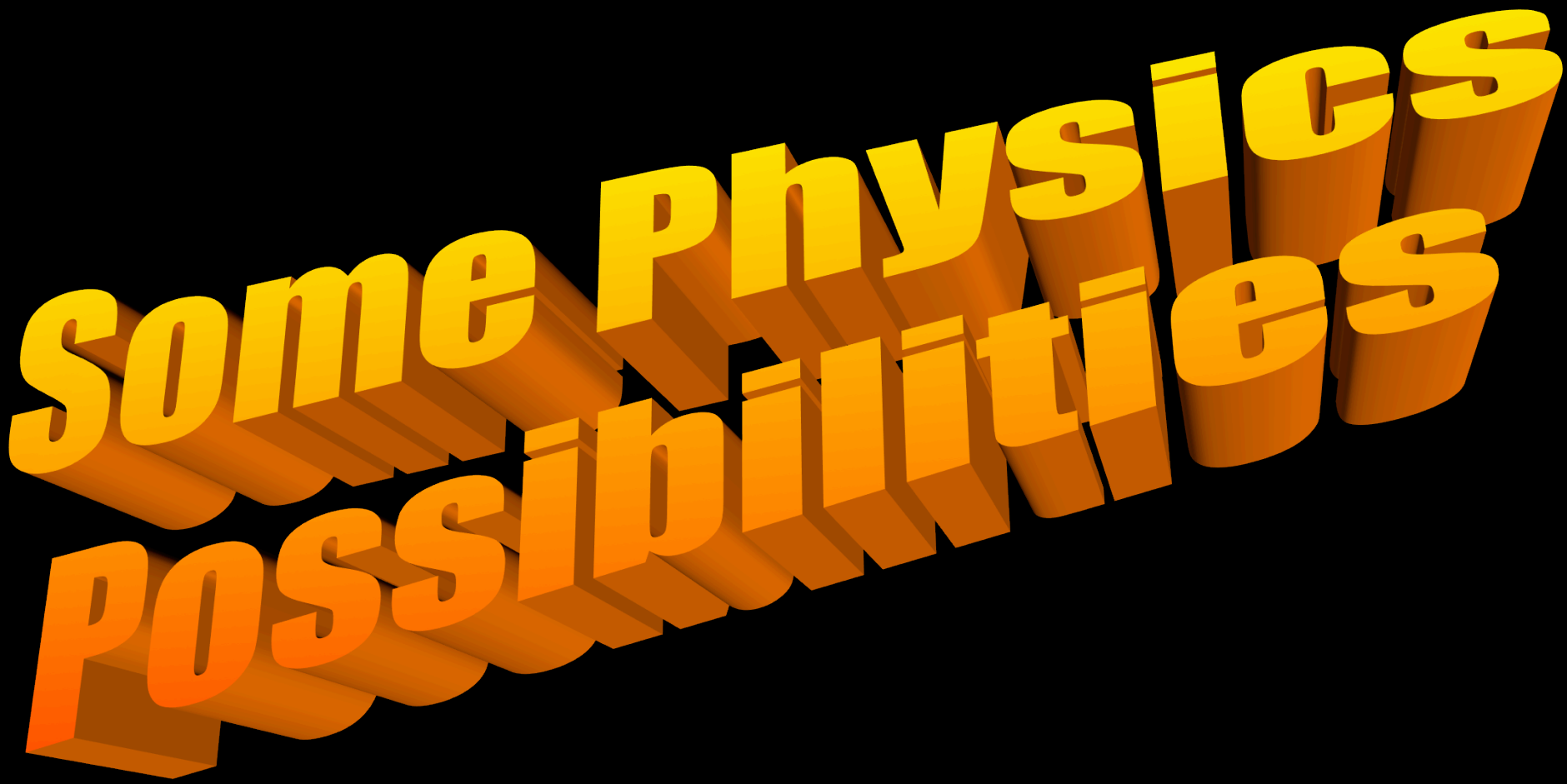


- *Depth of CMS ~100m, detectable muon P > ~ 50 GeV/c*
- *Projected area of muon chambers ~400 m^2 (as size of CMS is 15m x 25 m)*
- *Relied exclusively on muon chambers for analysis*

CMS – Prelim. Results on Muon Bundles



- *Analysis stated to be in very preliminary stage*
- *Many more muons being seen than in the ALEPH case which is not suprising since:*
  - *The area of the muons system is greater*
  - *The muon PT threshold of ALEPH was higher*

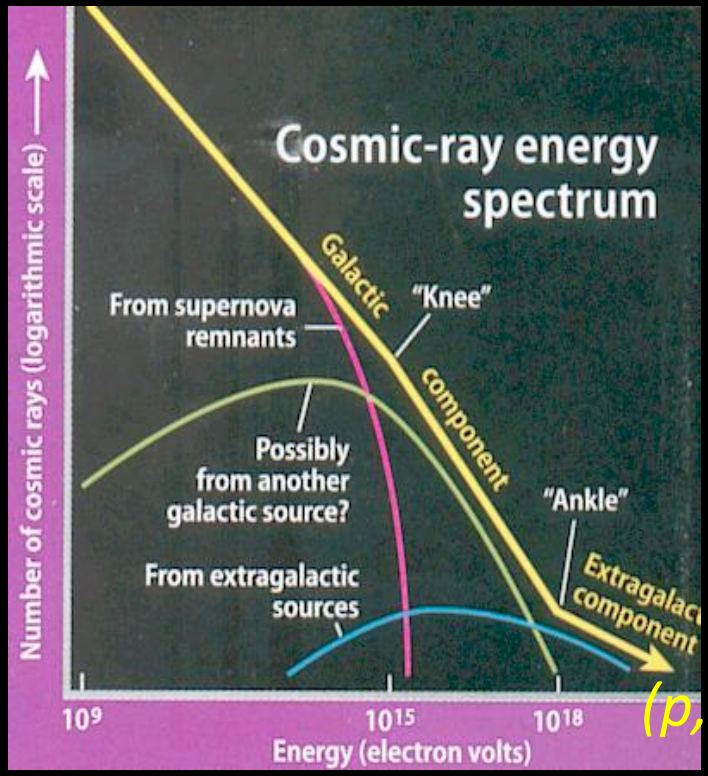

some Physics
possibilities

Physics – Muon Bundles

- *An indication of the energy and chemical composition of primary cosmic rays from core density and transveres extent of the muon bundles*
- *As a test of interaction models of different MC generators*
  - *Eg Look quantitatively into the μ- pair production by muons, a process of relevance to the MC generation of extensive air showers.*
- *Test for the formation of quark-gluon plasmas*
- *Muon Astronomy with neutral primaries e.g. γ's*
  - *Precise measurements of the μ direction ~10 mrad for collider detectors better for multi-μ's enable one to search for point sources*
  - *Search for Burst phenomena*
- *New Physics – LEP results indicate that the rate of high multiplicity muon bundles are not explained by current MCs*
  - *Strange quark matter, signal for a hidden sector, multi-W phenomena*

The Knee Region of the CR Spectrum

- *CR spectrum KNEE: 10^{15} → 10^{17} eV - Cosmic rays up to the KNEE are thought to be galactic*
- *The knee could represent cosmic acceleration mechanisms (Supernova shockwaves) reaching their maximum*
- *This is also the energy range → the limit of confinement of CRs within the galactic magnetic field*
- *The data indicate a knee-like structure in the E-spectra of light primaries He, C + an increasing dominance of heavy ones (A ≳ 20) TOWARDS higher energies.*
- *Maybe there is more composition dependent structure – a second and even a third knee.*



Conclusion

- *The study of muon bundles at shallow depths gives us the possibility to study unique data on multi-muon production in cosmic ray air showers in a particularly interesting energy regime ($10^{14} \rightarrow 10^{18}$ eV)*
- *The unprecedented areas of precision muon spectrometry provided by the main LHC detectors should allow us to reliable determine muon momentum and multiplicity*
- *We should remember that the only result out of LEP that did not agree "perfectly" with the Standard Model was the observation of too many high multiplicity muon bundles.*
- *Thus, with muon bundles studies we have the possibility to discover something new*