Experimental Summary

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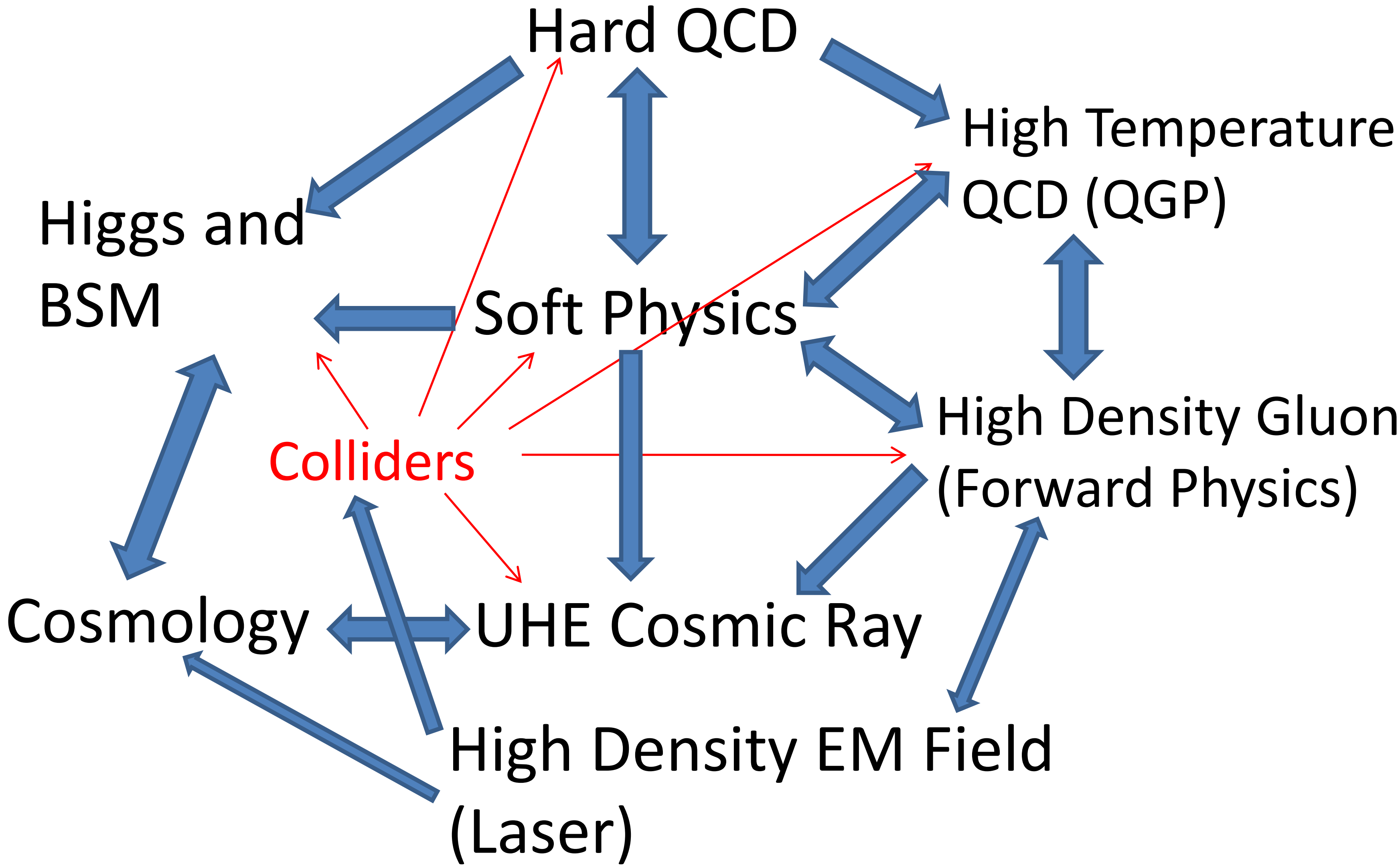
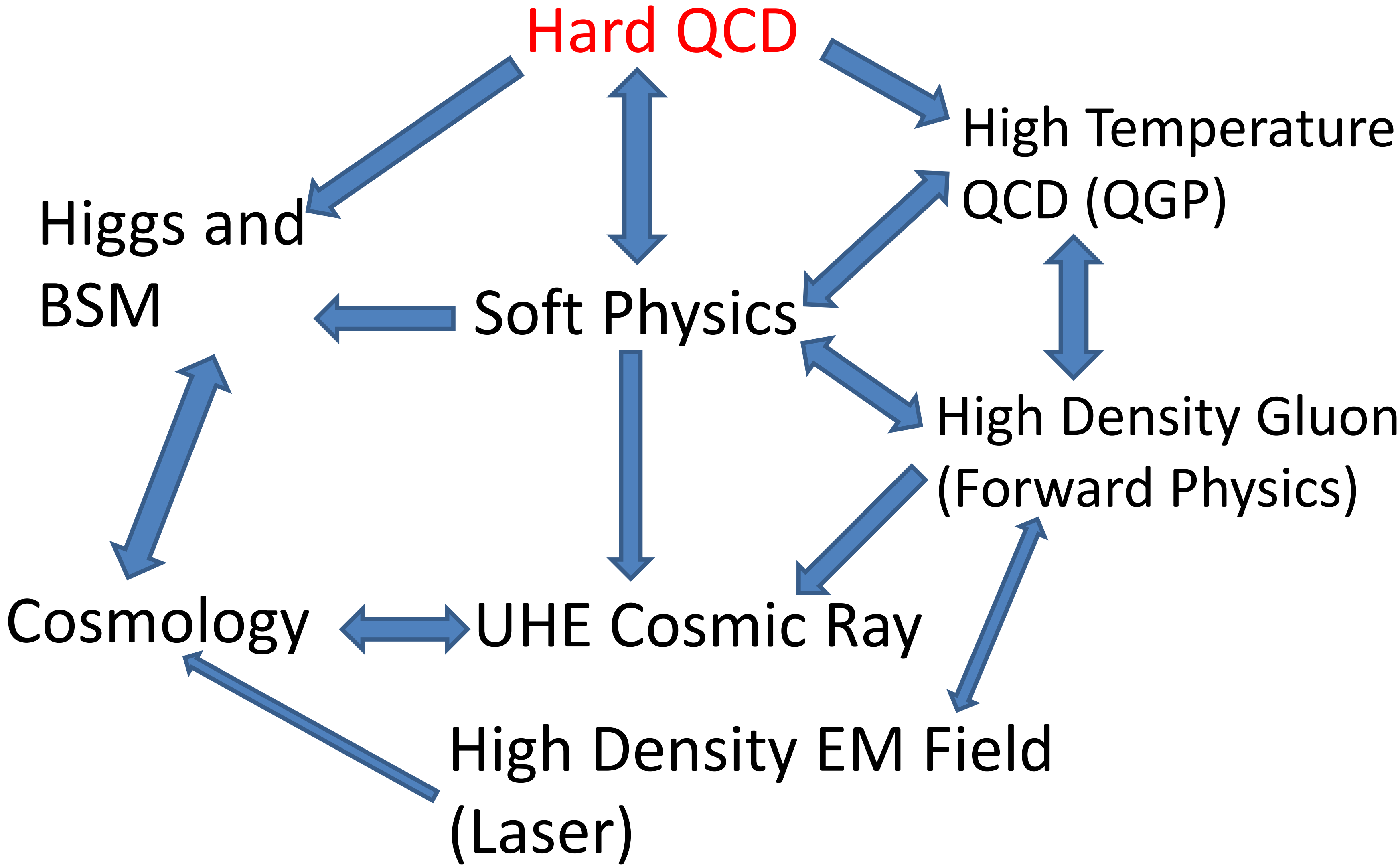
• Higgs and Standard model
• Hard QCD
• QCD phase diagram
• High Energy Density QCD
• Forward and Diffraction Physics and Cosmic Rays
• Soft Interaction and Multiparticle correlations
• High Field Science by High Intensity Lasers


Hard QCD
Higgs and
BSM
High Temperature
QCD (QGP)
Soft Physics
Colliders
High Density Gluon
(Forward Physics)
Cosmology
UHE Cosmic Ray
High Density EM Field
(Laser)



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Hard QCD

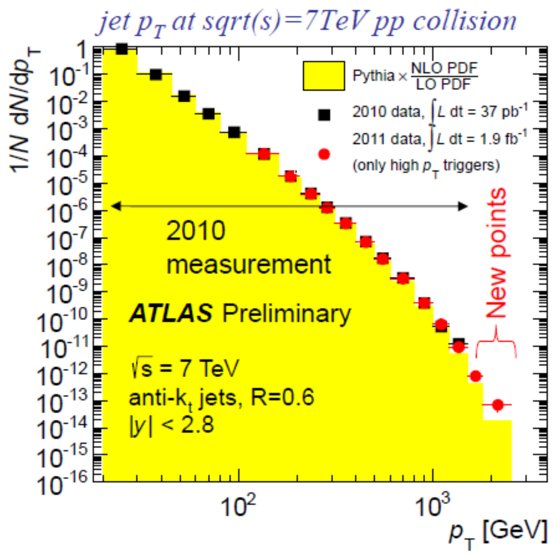
- pQCD is now very well established
- Both theory and experiment are now very accurate, and getting more and more accurate
- New LHC data, at higher energies and with excellent detectors, ATLAS and CMS, show impressive agreements between the data and theory, from a few GeV to a few TeV

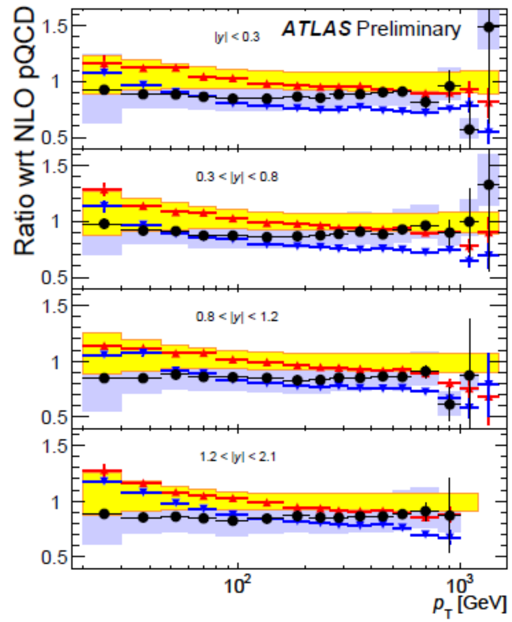
+) Basis for search of Higgs and Beyond Standard Model

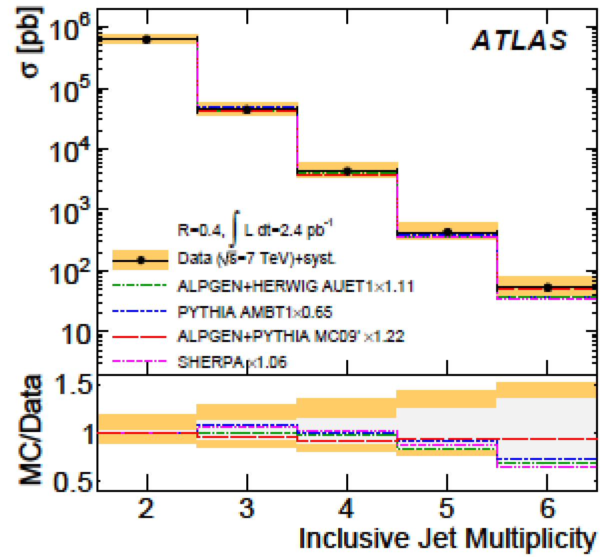
+) Well calibrated and accurate probe of QGP

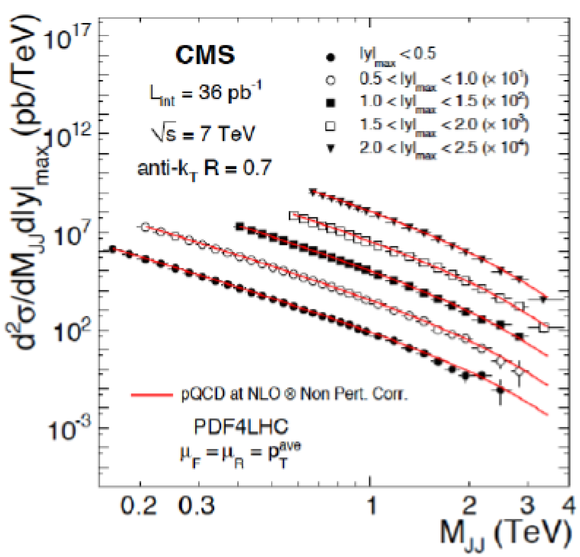
-) No “new Physics” seen in hard QCD sector so far

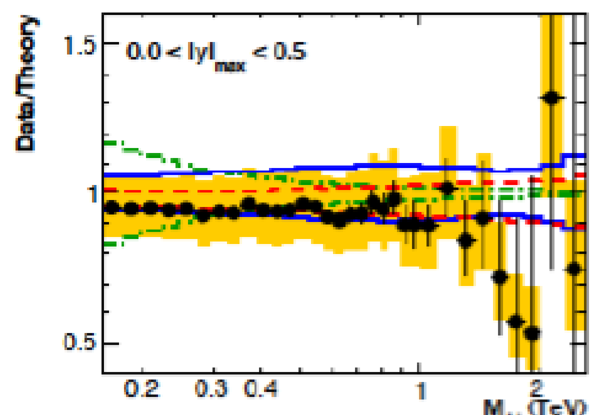
Jet results from LHC

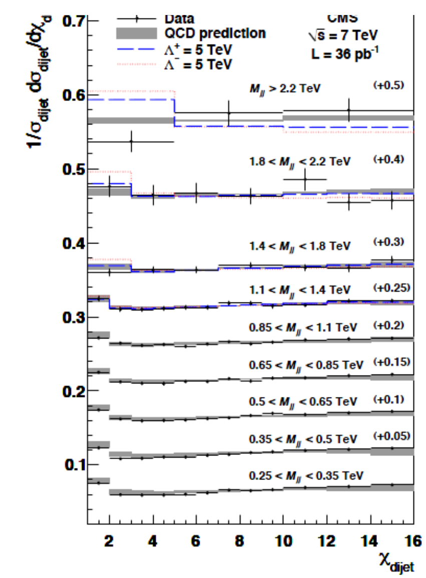






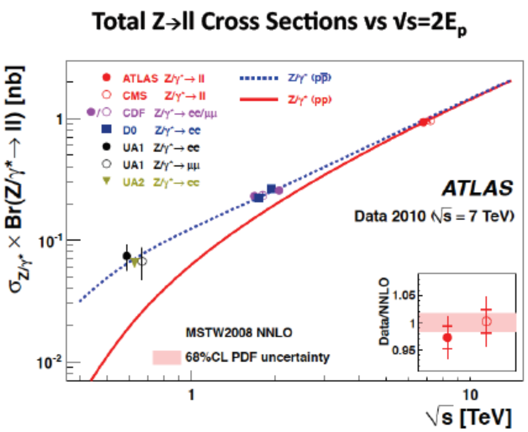


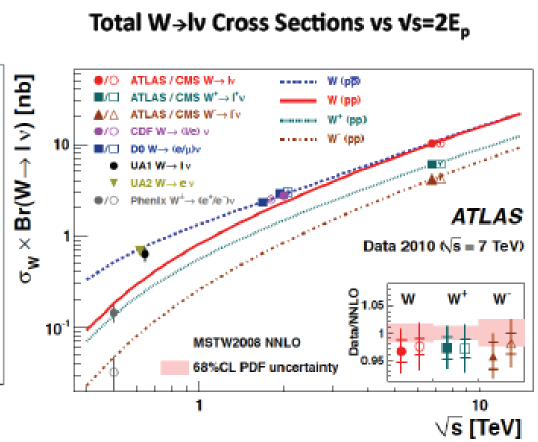


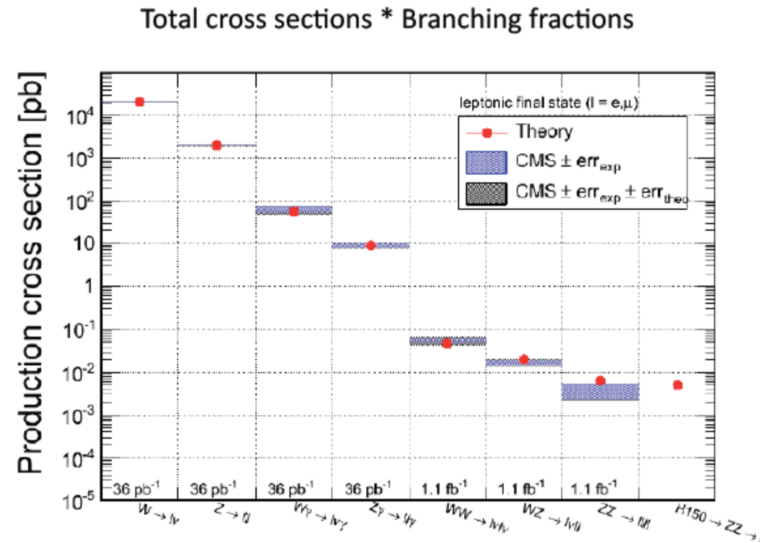


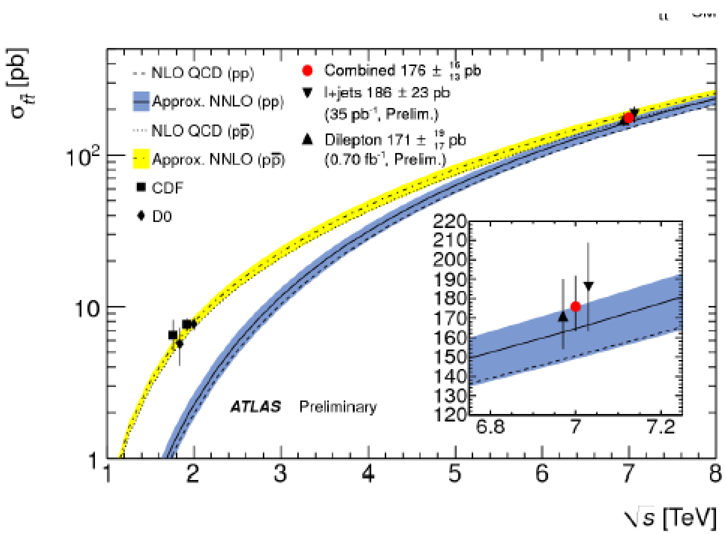
The data and theory agree very well for all distributions for wide kinematic range

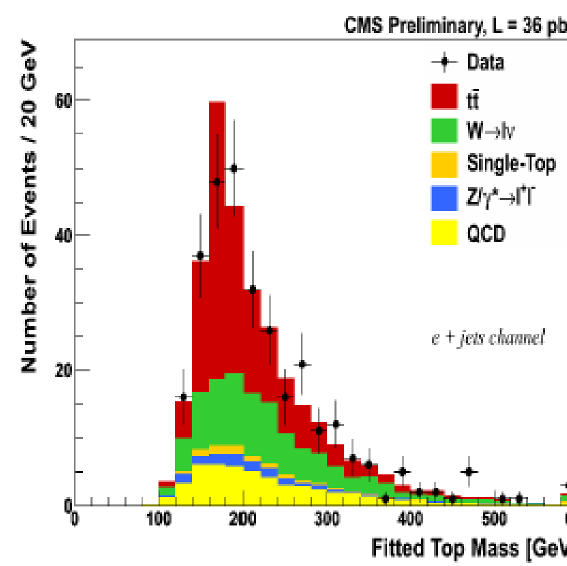
W, Z and top at LHC





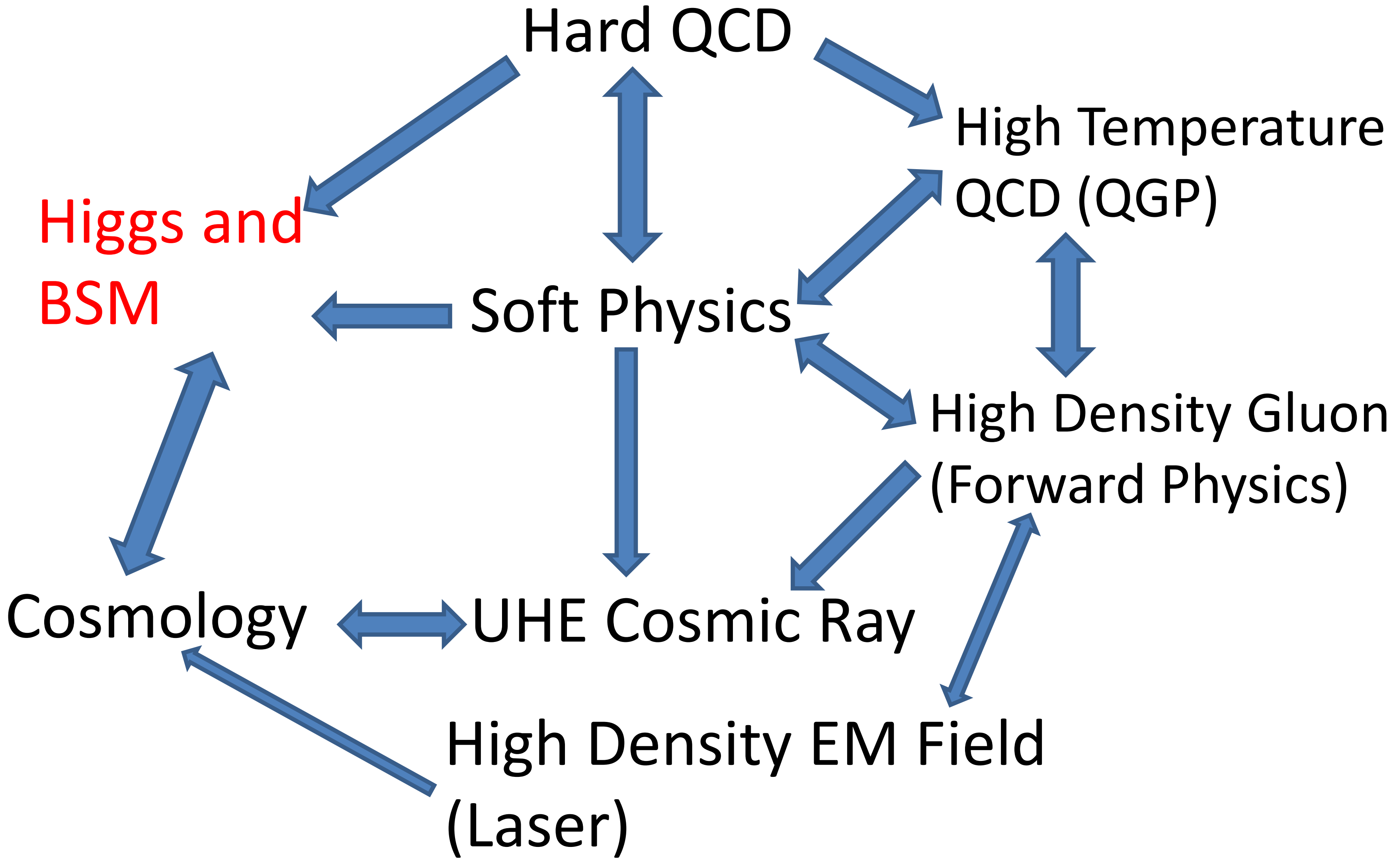






$$m_t = 173.1 \pm 2.1(\text{stat})^{+2.8}_{-2.5}(\text{syst})\ \text{GeV}.$$

- Many measurements on W, Z, and top
- Agree very well with theory
- QCD effects well understood (→ top mass)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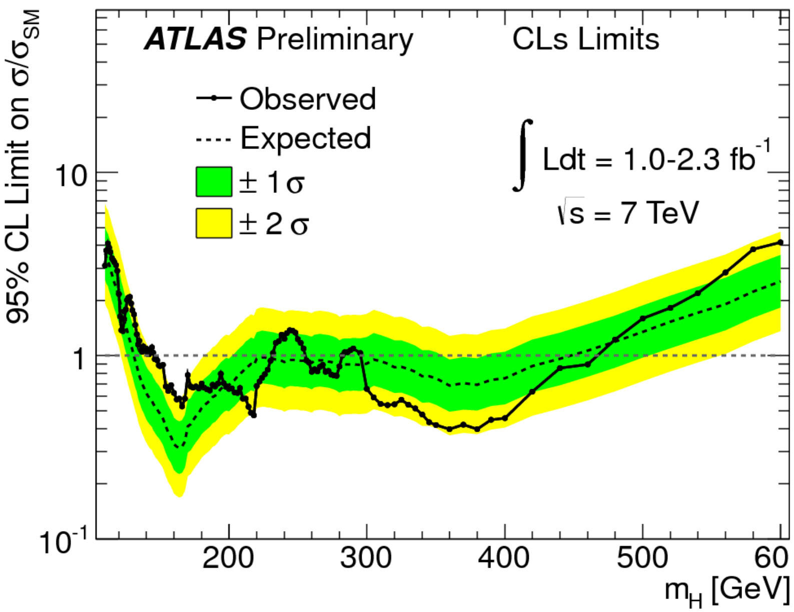
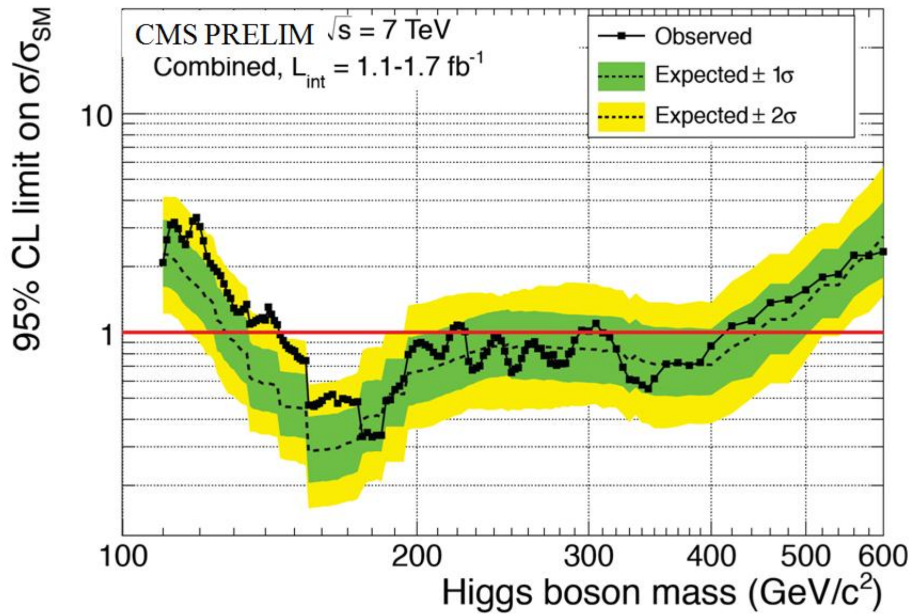
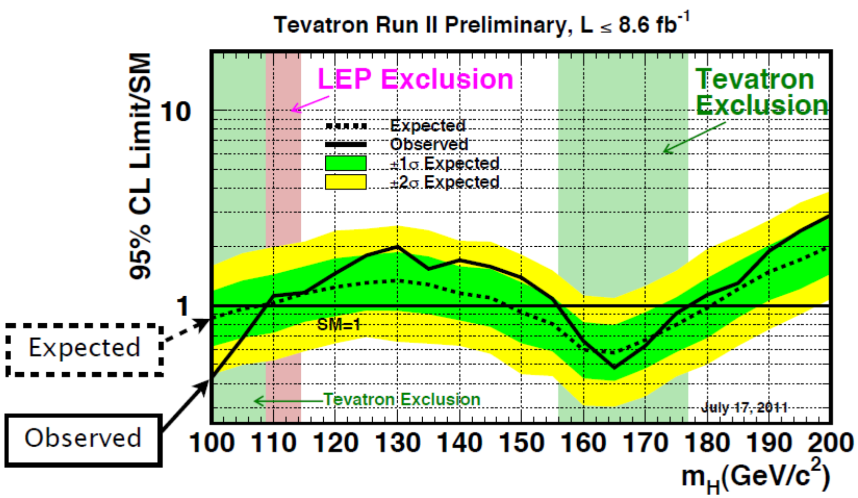
Higgs: still hiding but in limited space

146-232; 256-282; 296-466 GeV excluded



145-216; 226-286; 310-400 GeV excluded

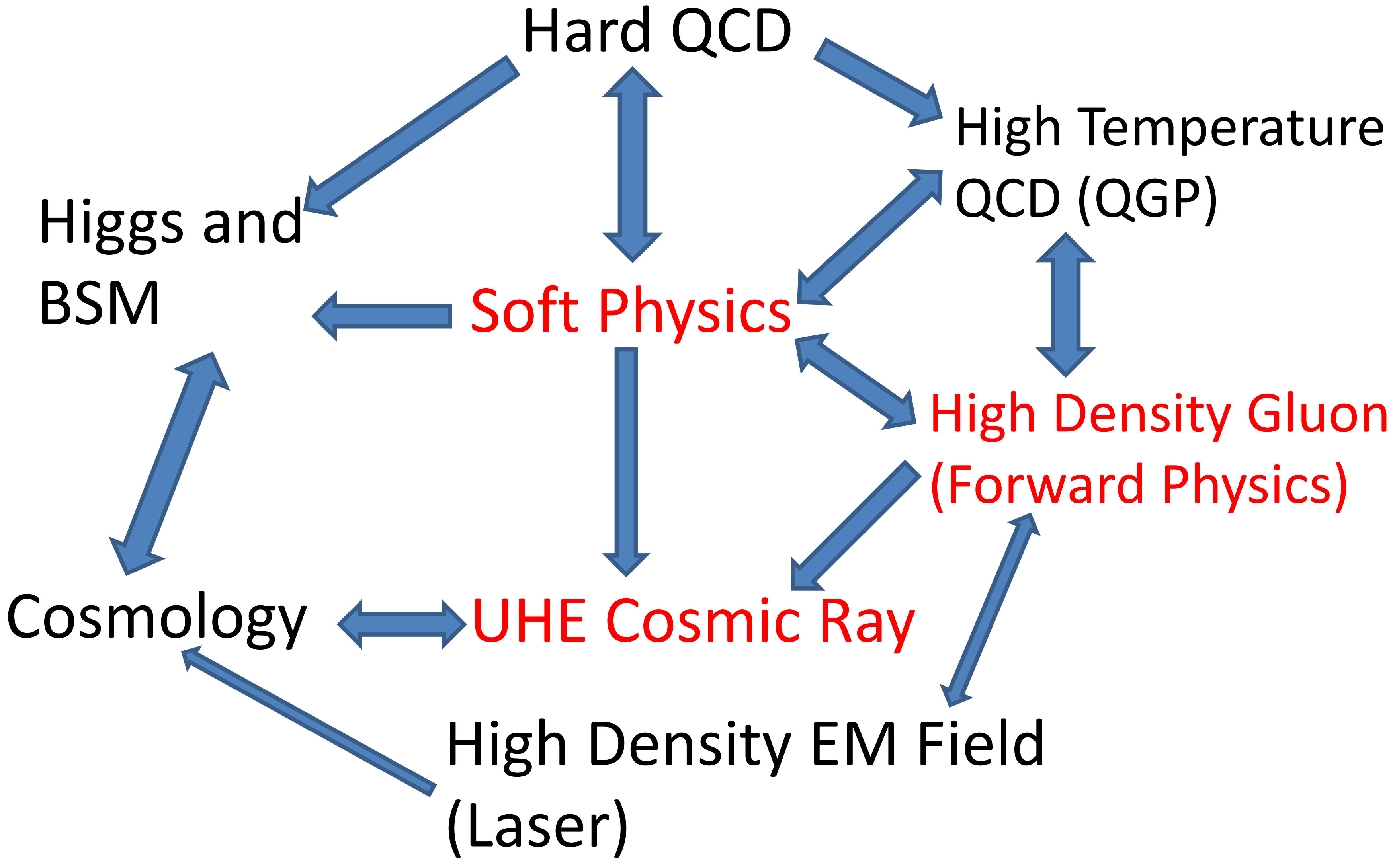




LEP exludes m<115 GeV

EW fits excludes m>161 GeV

- Place for SM Higgs is now limited to 115<m<145 GeV
- Impressive success of Hard QCD & experiments
- SM Higgs can be discovered soon
- Or is it excluded soon(???)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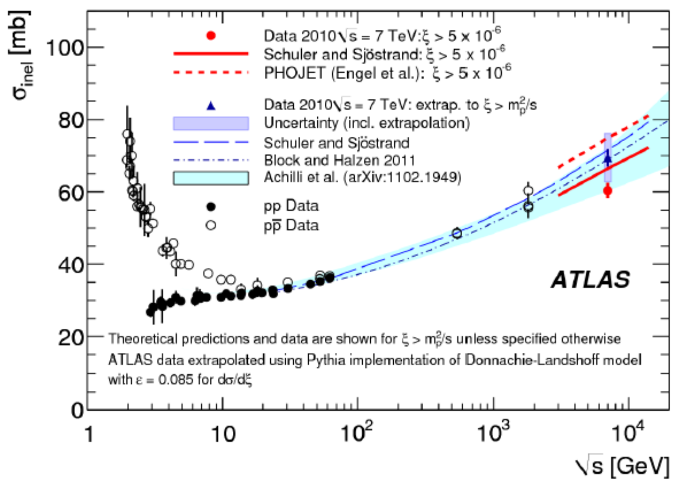
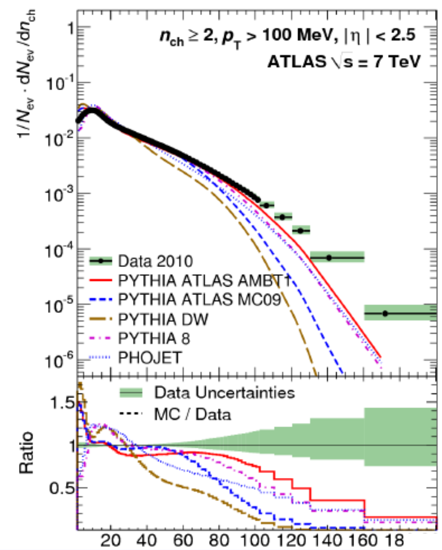
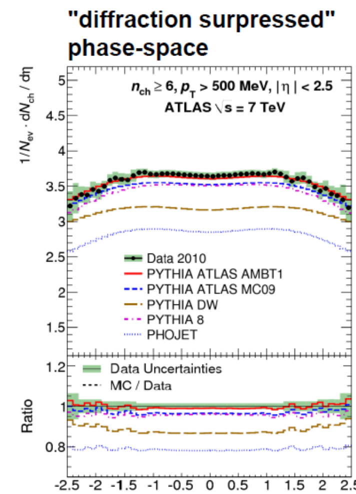
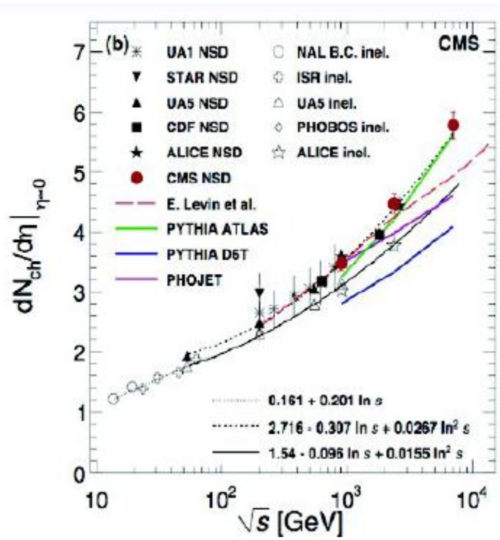
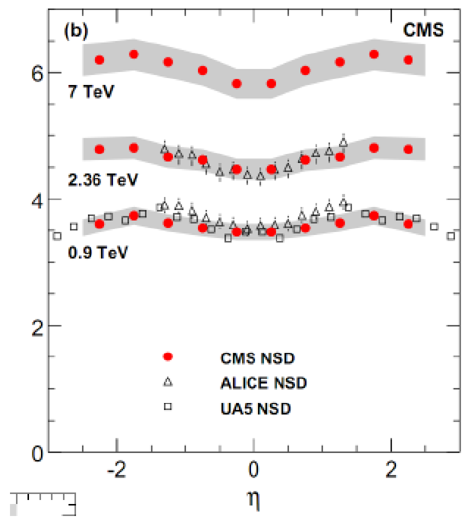
Soft physics data at LHC

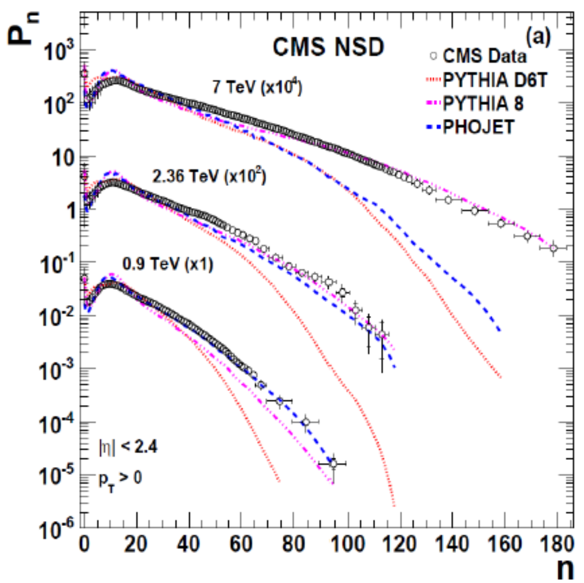








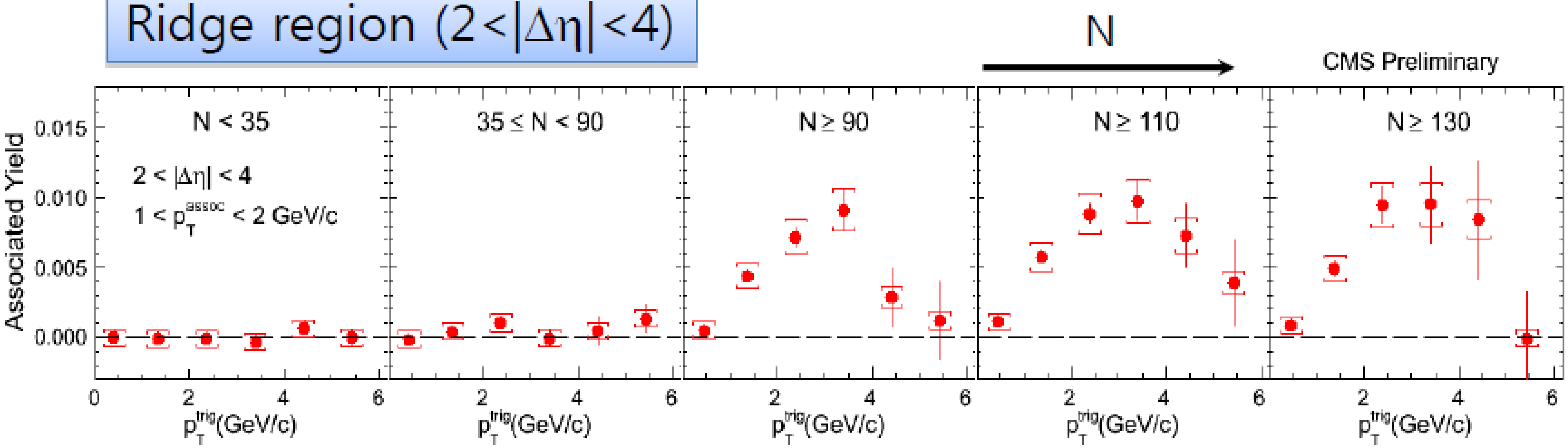


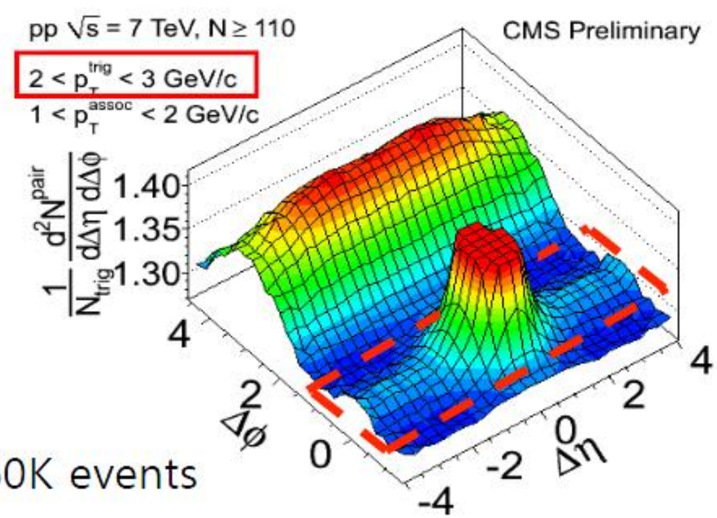


- Baseline for QGP physic
- New effects at high multiplicity events
- Basic data for UHE Cosmic rays

“Ridge” in p+p remains a mystery

Ridge region (2<|Δη|<4)

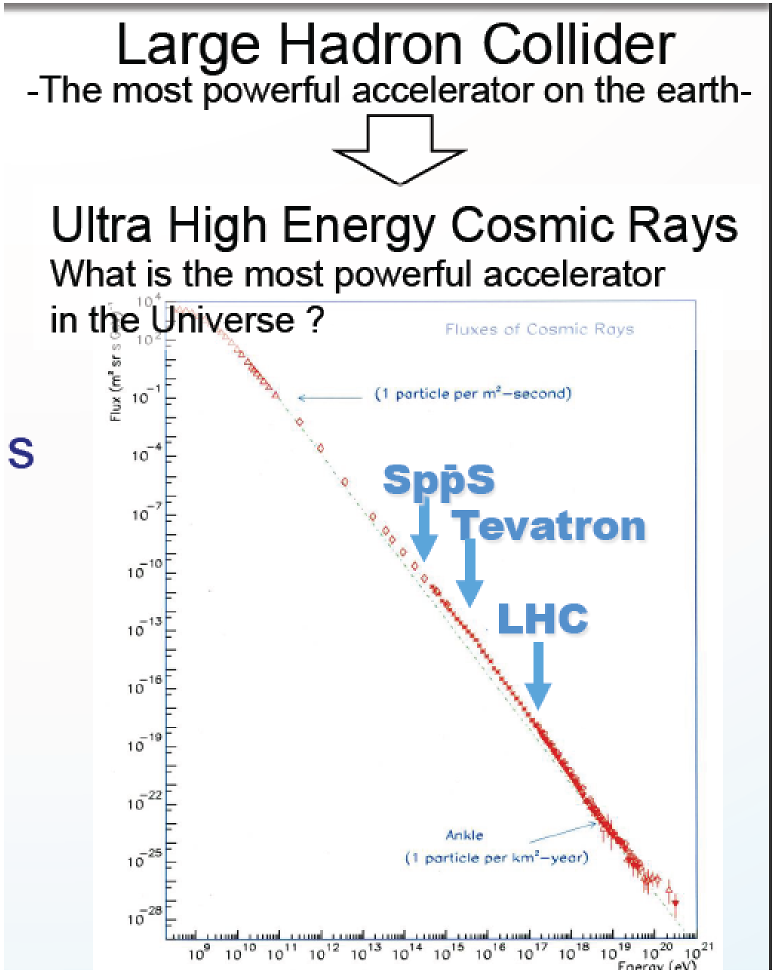


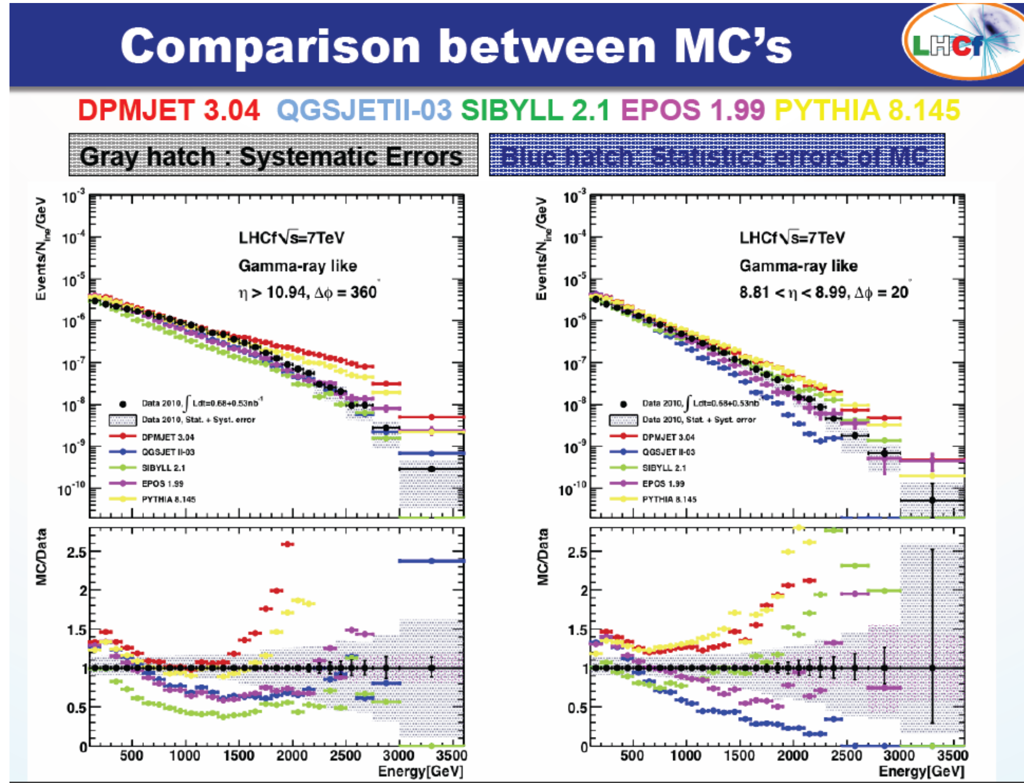


660K events

- Long range η correlation in p+p
- Unlike “ridge” in A+A, it is not v3
- Could be related to flux tube(?)
- Appears Nch > 90
- Dissapears for high pT(>6 GeV/c) trigger

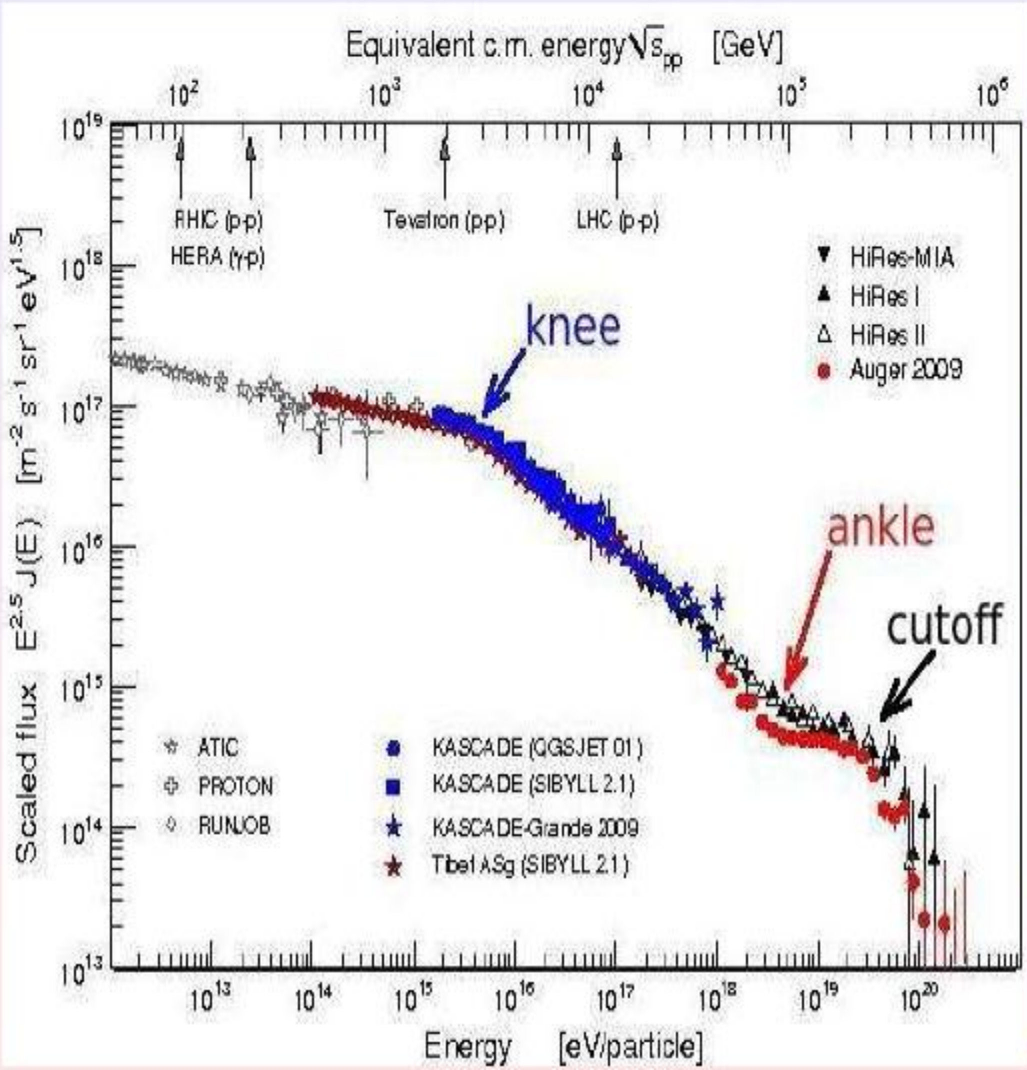
Forward Physics and Cosmic Rays





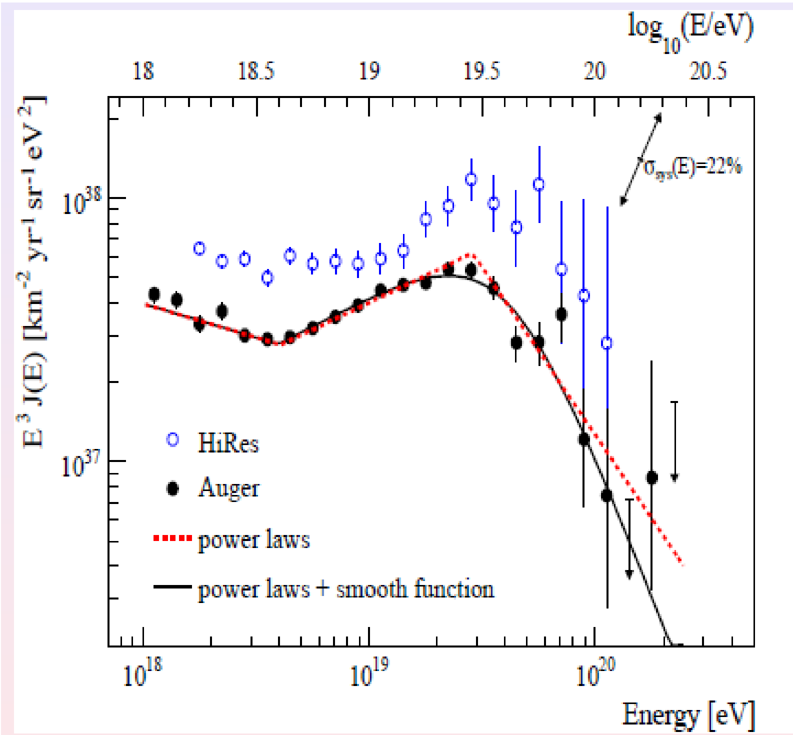
- LHCf measured photon production at very forward at LHC to study UHE Cosmic rays with Air shower technique
- LHC is at or beyond “Knee” of cosmic ray spectrum

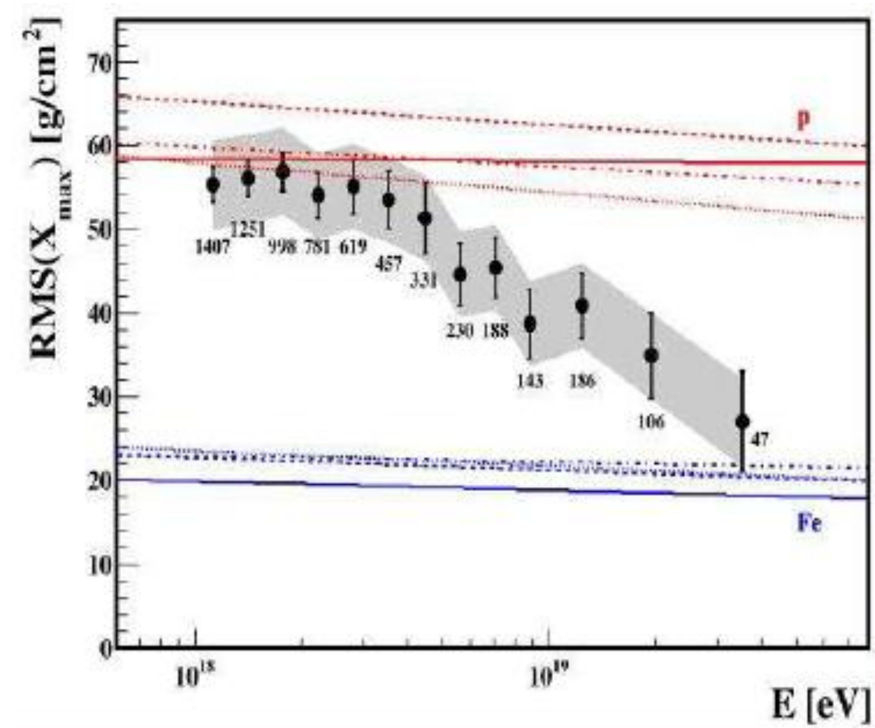
Cosmic Ray spectrum



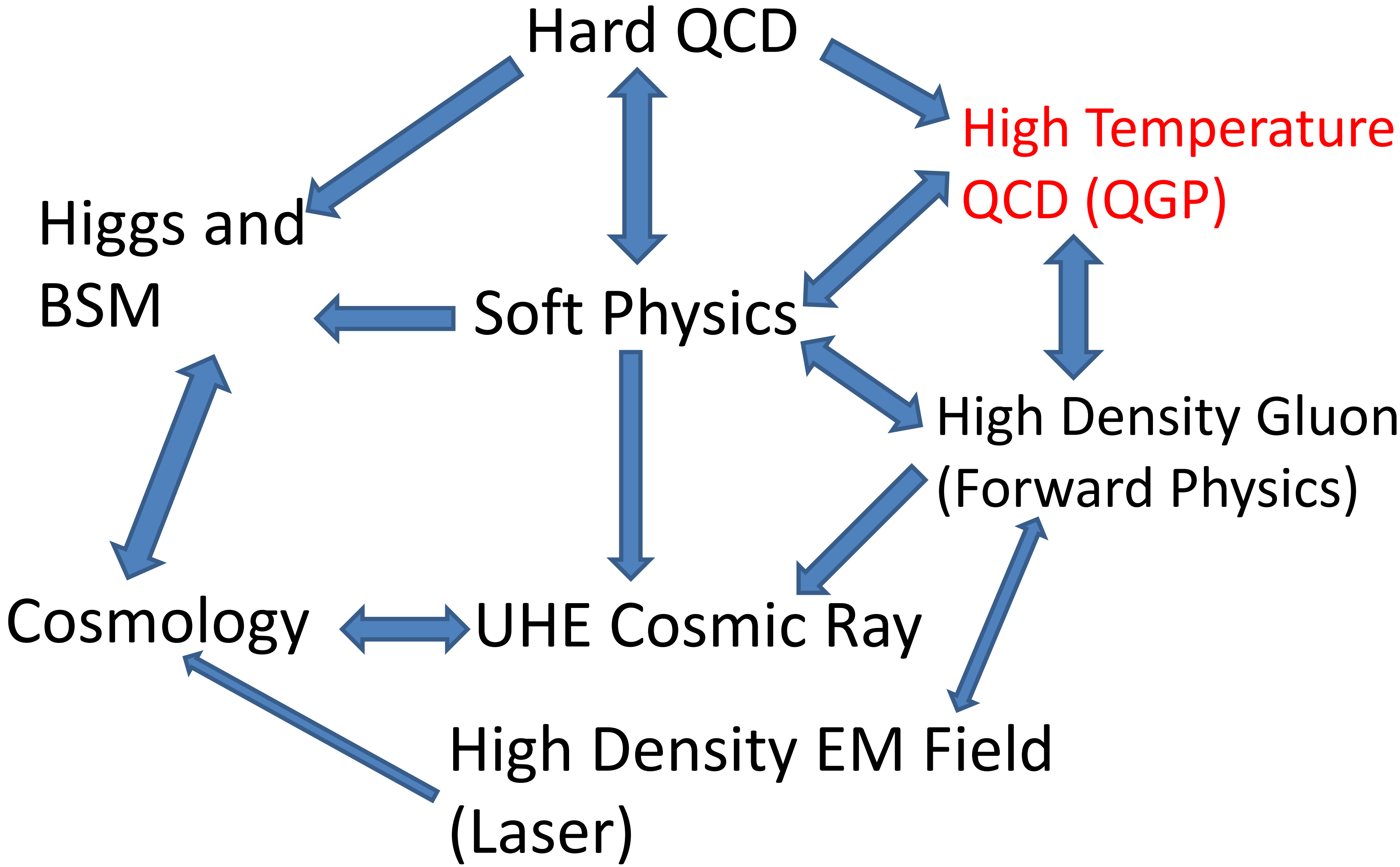
- flux $\times E^{2.5}$: 'leg'-like shape
- 'knee' around 3×10^{15} eV (effect of galactic acceleration / propagation)
- 'ankle' at few $\times 10^{18}$ eV (galactic / extragalactic transition?)
- cutoff at $\sim 10^{20}$ eV (interaction with background γs?)

Cosmic Ray Cut-off





- p + CMB γ interaction → cut off at 5×10^{20} (GZK cut off)
- The cut=off at $\sim 10^{20}$ eV observed by HiRes, Pierre Auger, and Telescope Array
- But most of UHE CR appears to be Fe, not proton (puzzle)
- MC tuning with LHC data doesn't solve the puzzle so far…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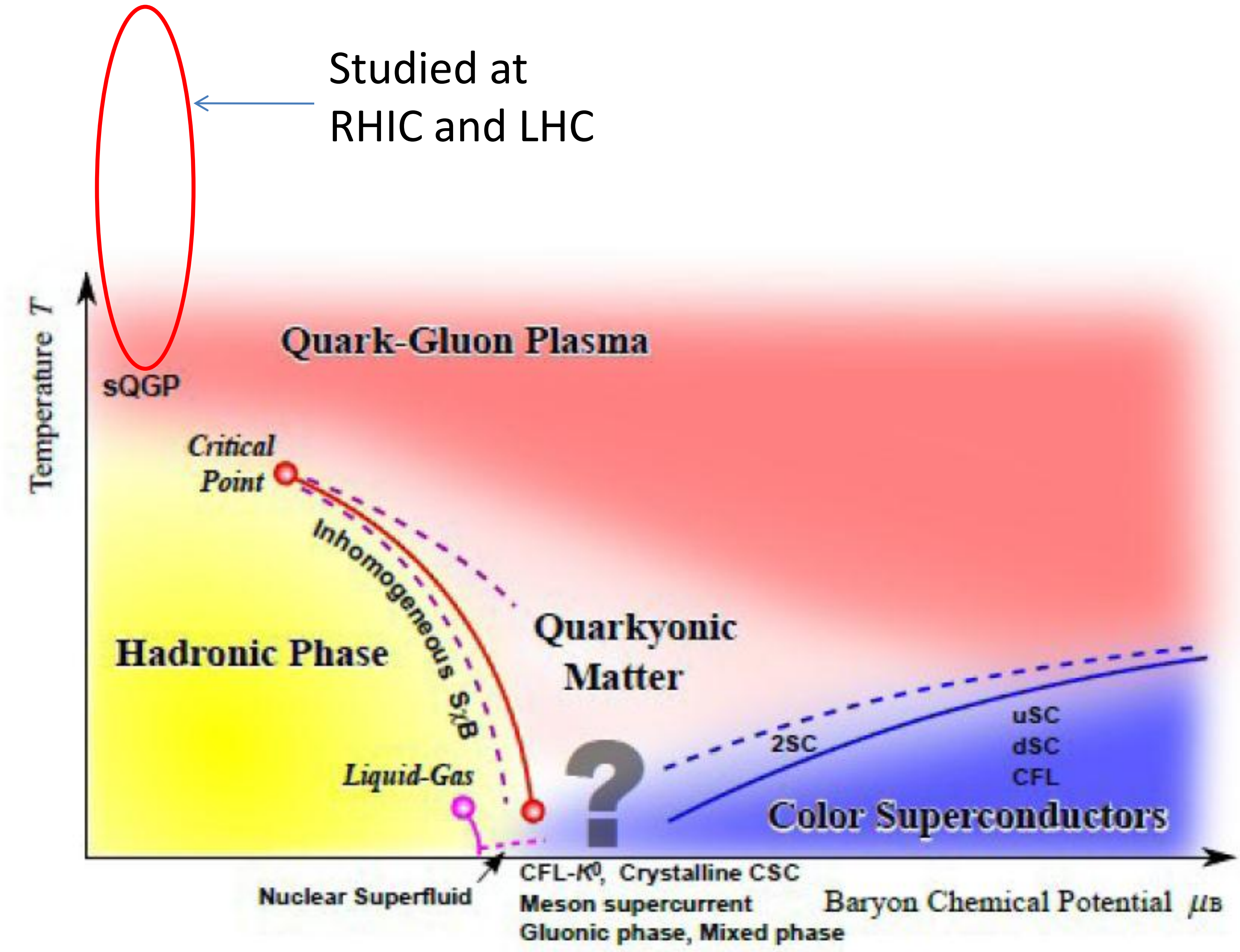
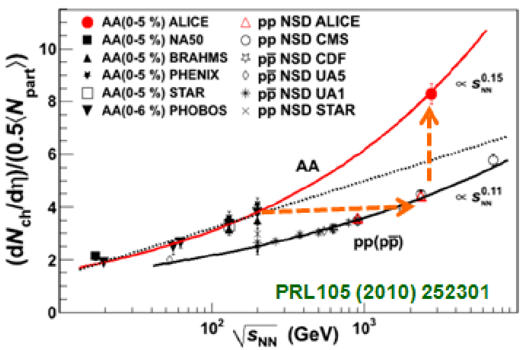
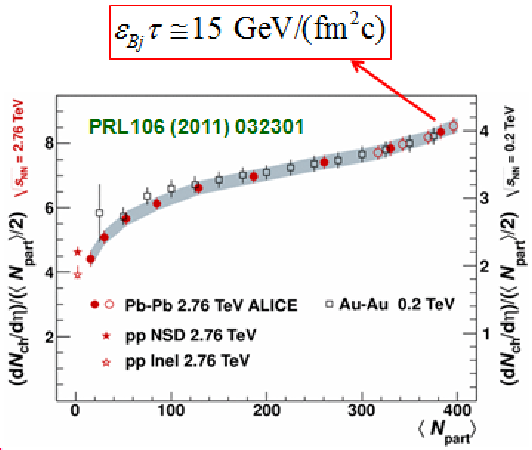
QCD phase diagmam



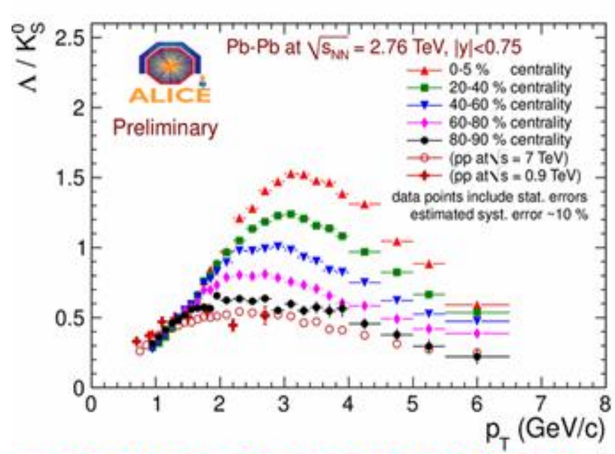
Soft Physics results at LHC



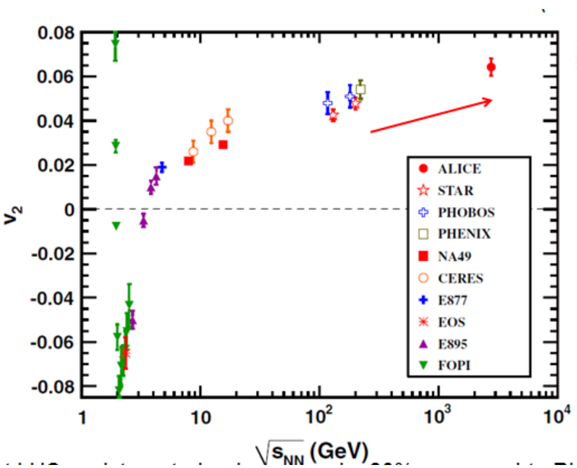
- $dN_{ch}/d\eta = 1584 \pm 76$
- $(dN_{ch}/d\eta)/(N_{part}/2) = 8.3 \pm 0.4$
  - ≈ 2.1 x central AuAu at $\sqrt{s_{NN}}$=0.2 TeV
  - ≈ 1.9 x pp (NSD) at $\sqrt{s}$=2.36 TeV



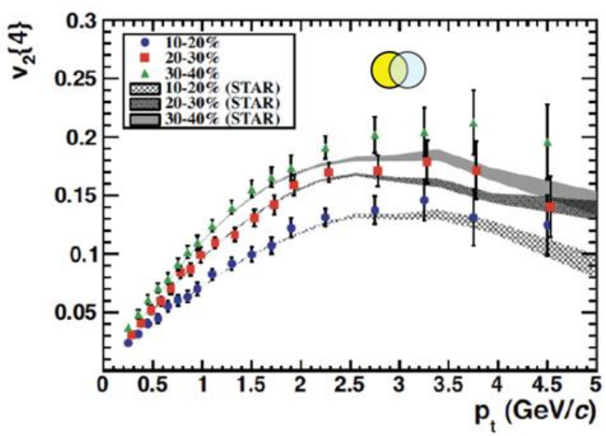
- Very similar centrality dependence at LHC & RHIC



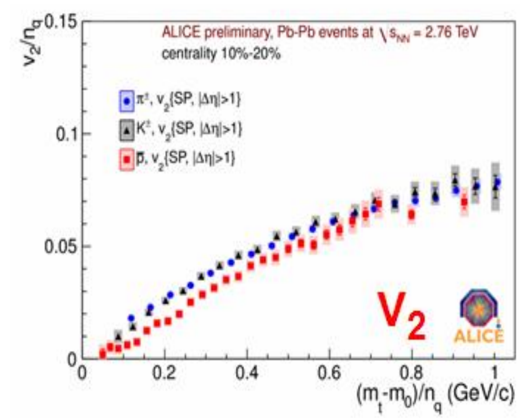
- Baryons more abundant at intermediate p_T



Integrated v2 is larger than RHIC



But v2(pT) is almost identical to RHIC



Quark number scaling is broken

QGP at LHC seen by soft probes

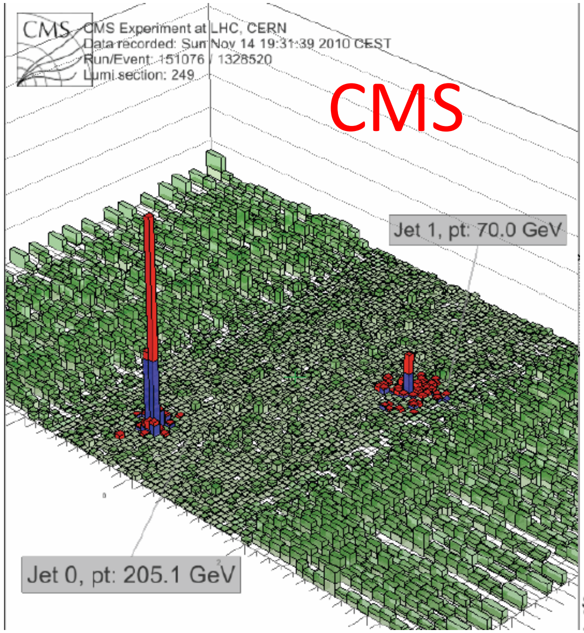
- $dN/d\eta$ vs Npart is very similar to RHIC
  - Strong gluon saturation effects?
- $dN/d\eta$ x2.1 of RHIC, larger than most predictions
  - But how much contribution from jets fragmentation?
- $\varepsilon\tau \sim 15$ GeV/fm^{2}c ~ 3 times of RHIC
- <pT>~30% higher than RHIC
  - stronger radial flow than RHIC
- Hadron abundance well described chemical model
- Baryon enhancement stronger than RHIC is observed
- V2(pT) is very similar to RHIC

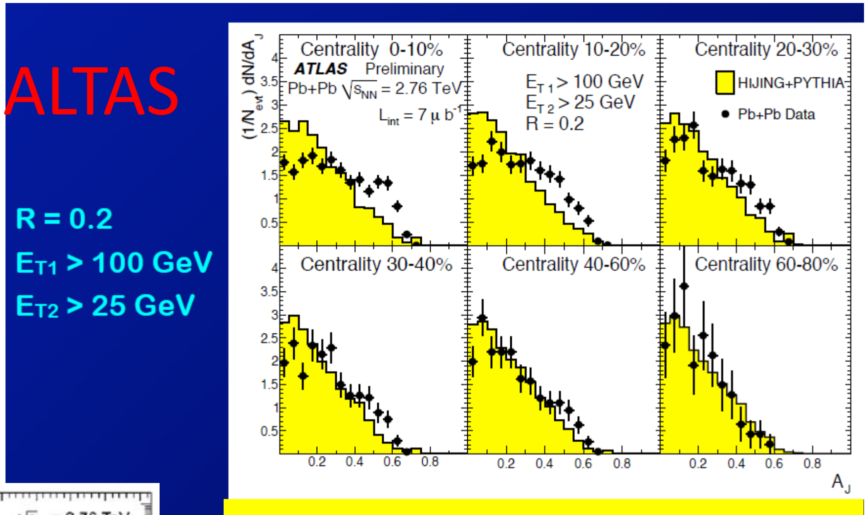
Larger, Hotter, and longer lived QGP than RHIC is formed

But QGP at LHC appears to be similar to that at RHIC

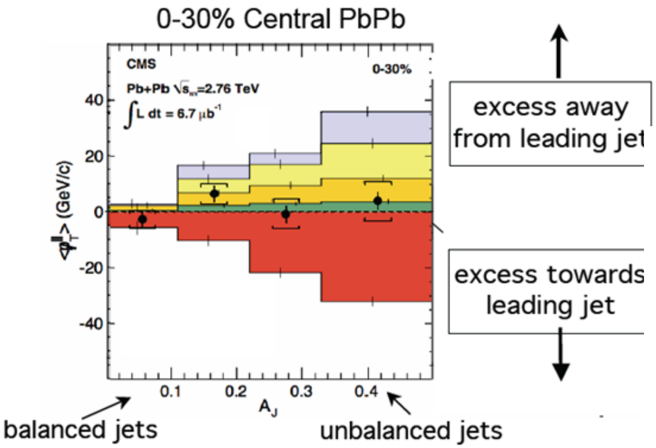
No big surprise

Jet measurements at LHC

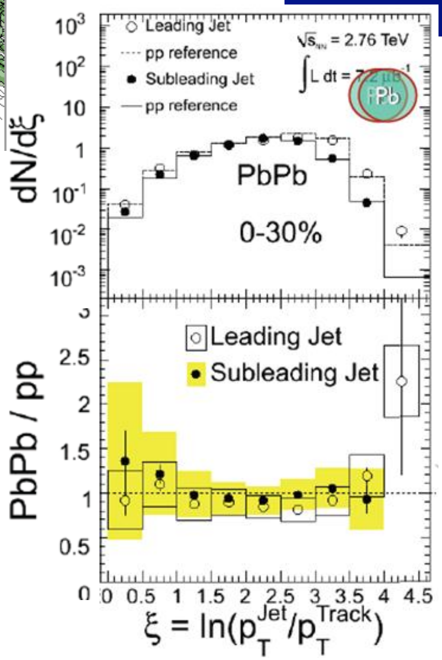




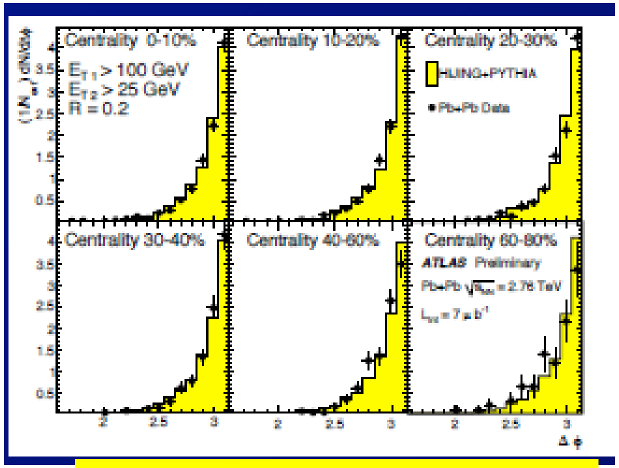
Large jet energy asymmetry



Lost energy goes to low pT particles



Jet shape is not modified



Little change in di-jet angle correlation $\Delta\phi$

LHC jets results

Very surprising

- R_{AA} ~ 0.5 and independent of p_T (for p_T>50 GeV)
- Large jet asymmetry A_J is seen

→ Large fluctuation of energy loss

→ Path length dependence of energy loss seems to be very steep

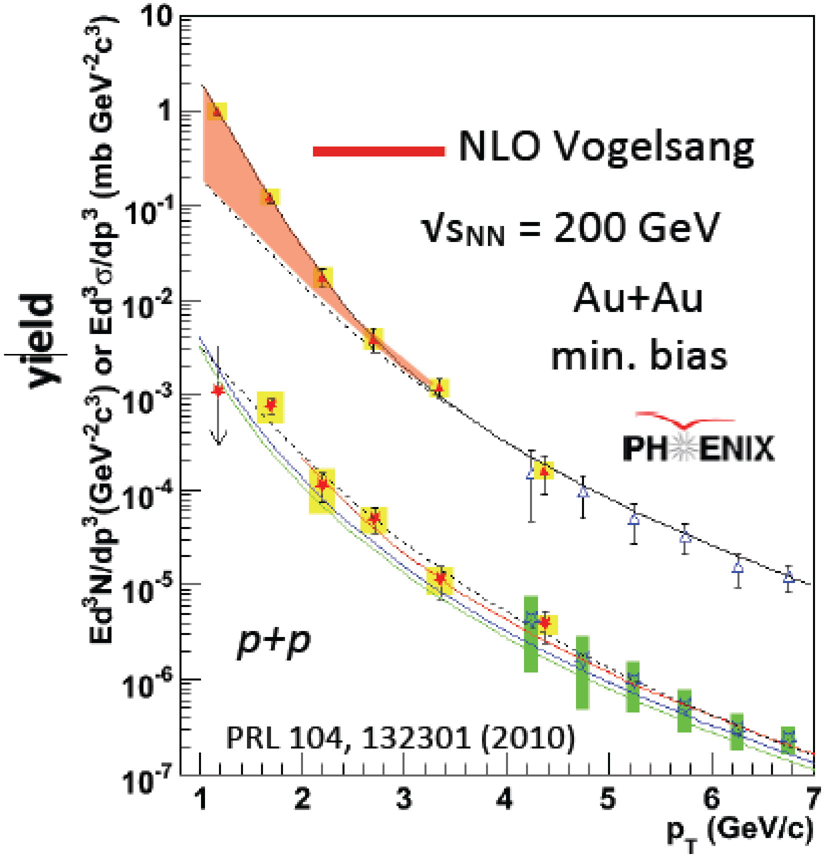
- *Little modification* of jet fragmentation
- *Little modification* of di-jet angular correlation
- Lost energy goes to low p_T particles at large angle (i.e. bulk matter)

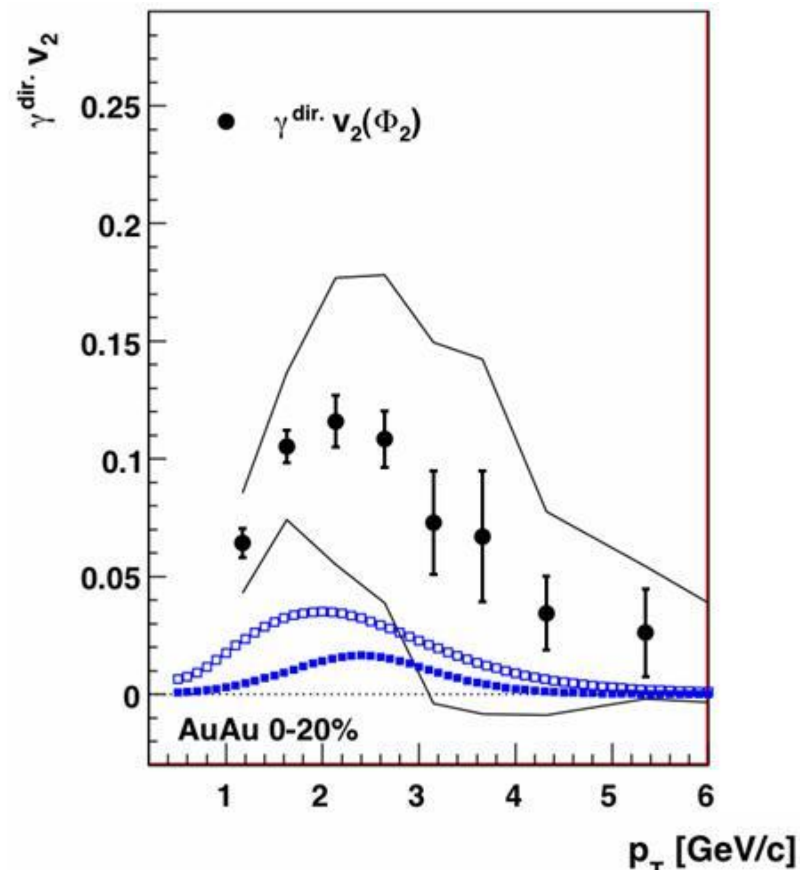
→ It is as if a parton only loses its energy in QGP and the lost energy is quickly dissipated in the medium. (heat up the medium)

→ Perturbative energy loss model is severely challenged (if not completely excluded)

Jet is a very powerful, direct probe of QGP

Thermal Photon at RHIC



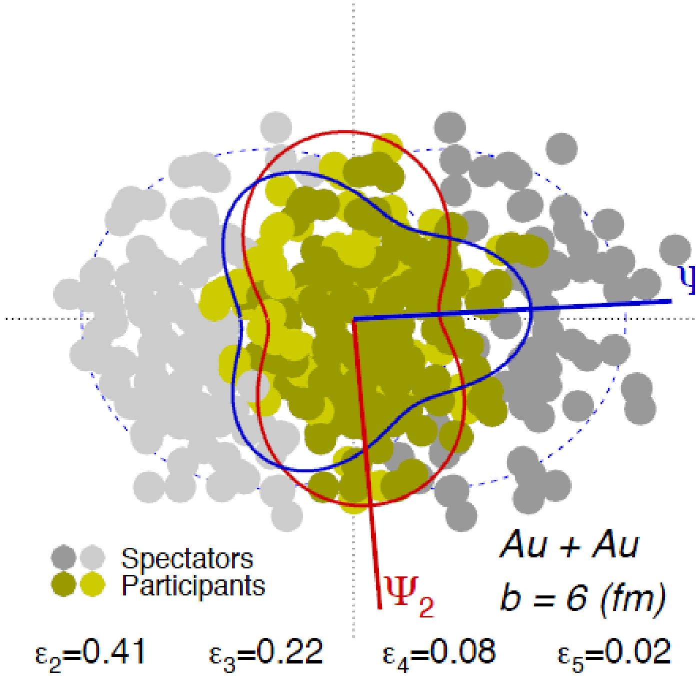


- Excess of low pT photon consistent with thermal photon

  T_{init} = 300 – 600 MeV

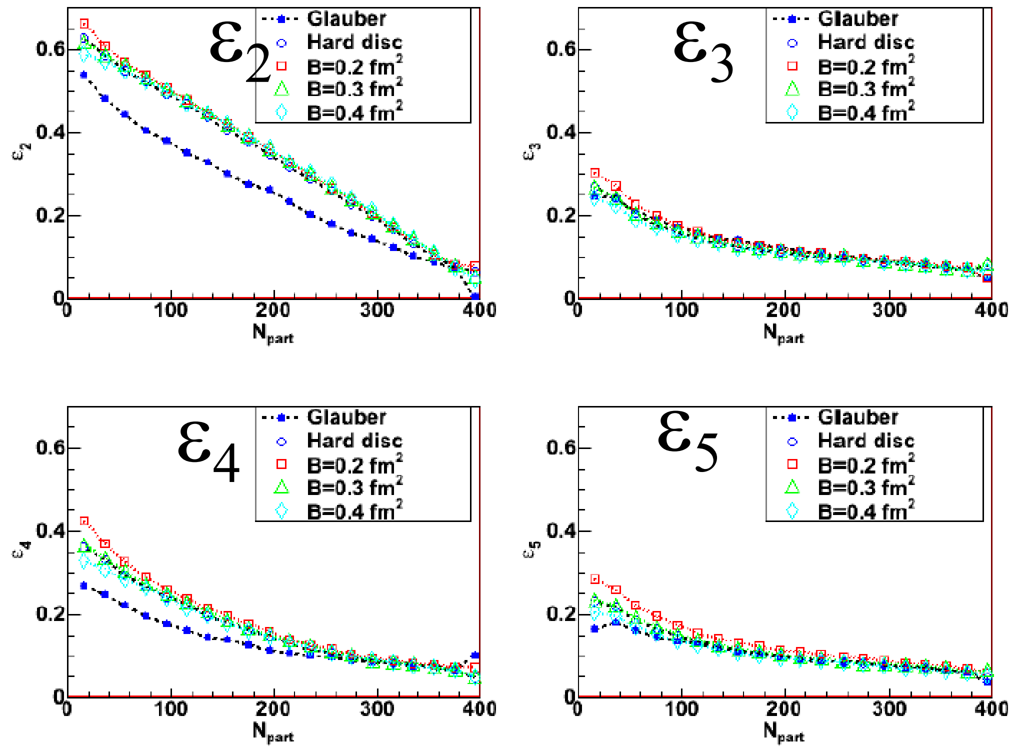
- Large v2 of direct photon at low pT
- Challenge to the theories

Initial state fluctuation and v3



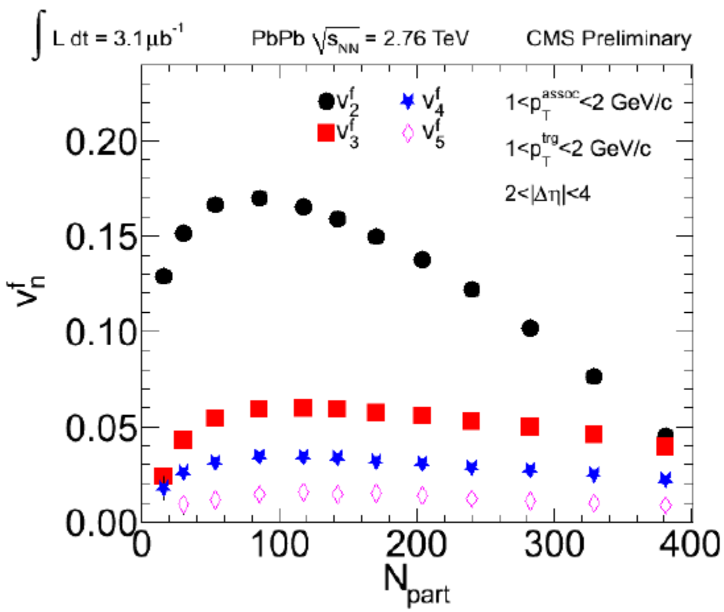
Eccentricity coefficients at RHIC

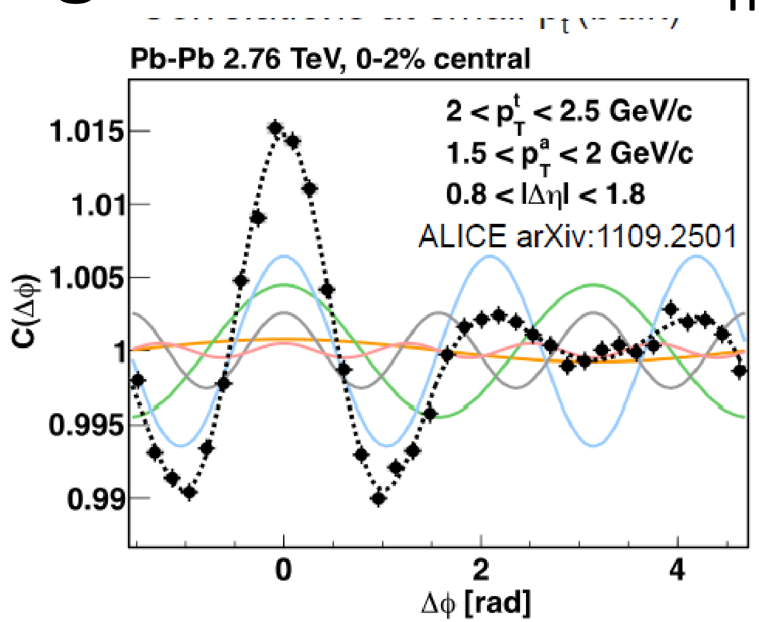
Curves: initial state models

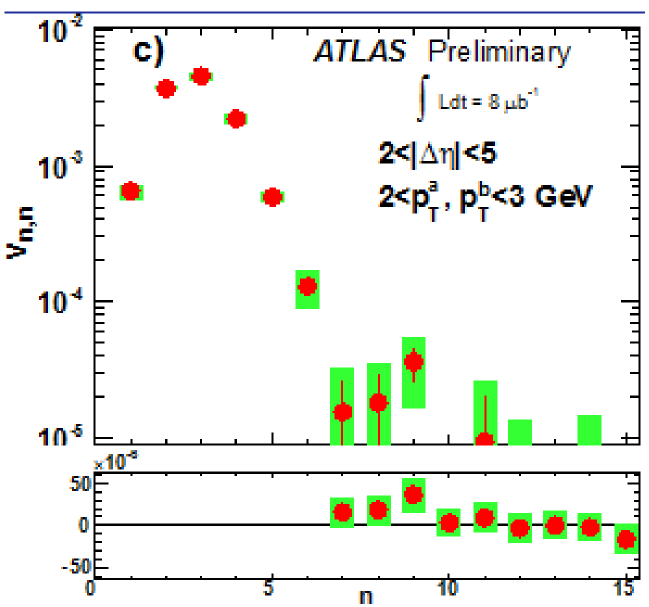


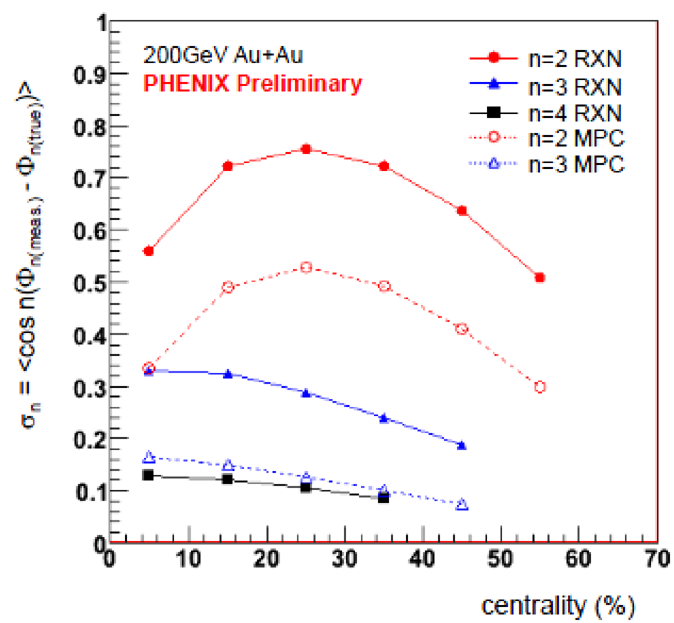
- Initial state fluctuation causes higer order eccentricity ε_n
- This is then converted to higher order harmonic flow v_n
- ε_2 : collision geometry
- ε_3 : Fluctuation

Measurements of higher harmonics v_n





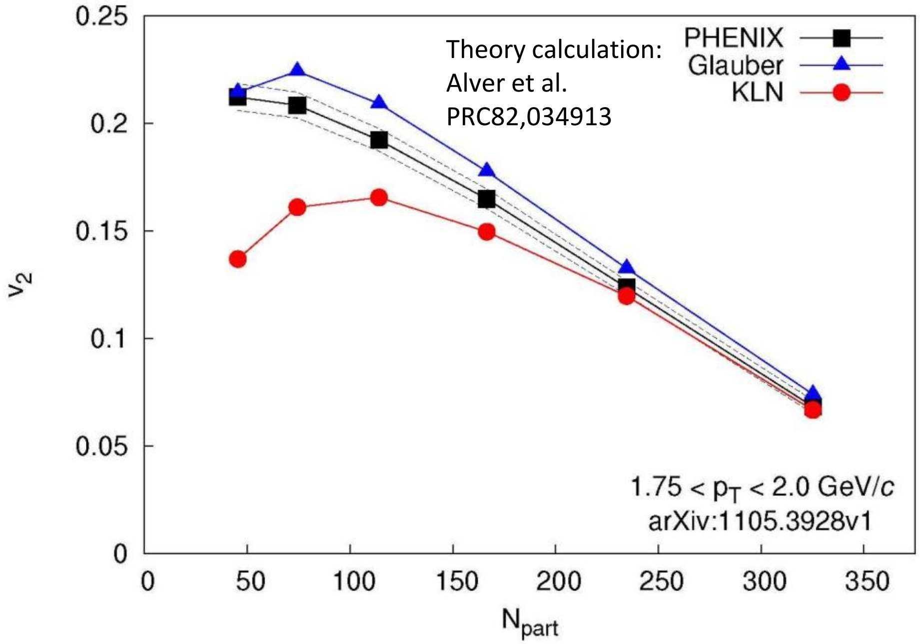




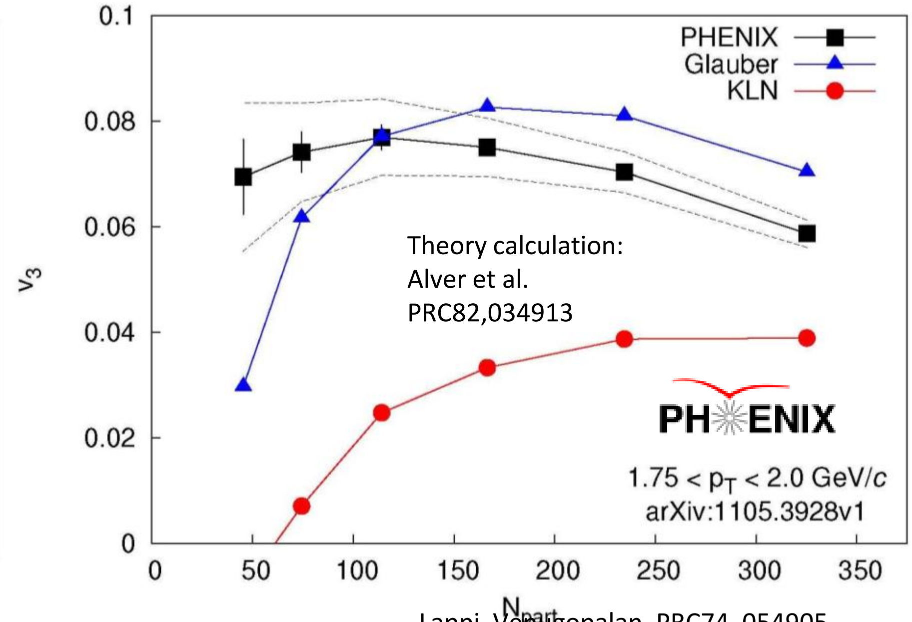
v_2 and v_3 to constrain η/s

PHENIX **arXiv:1105.3928**

v_2 described by Glauber and CGC



v_3 described only by Glauber



Lappi, Venugopalan, PRC74, 054905
Drescher, Nara, PRC76, 041903

- Glauber
  - Glauber initial state
  - $\eta/s = 1/4\pi$

Favored

← Two models →

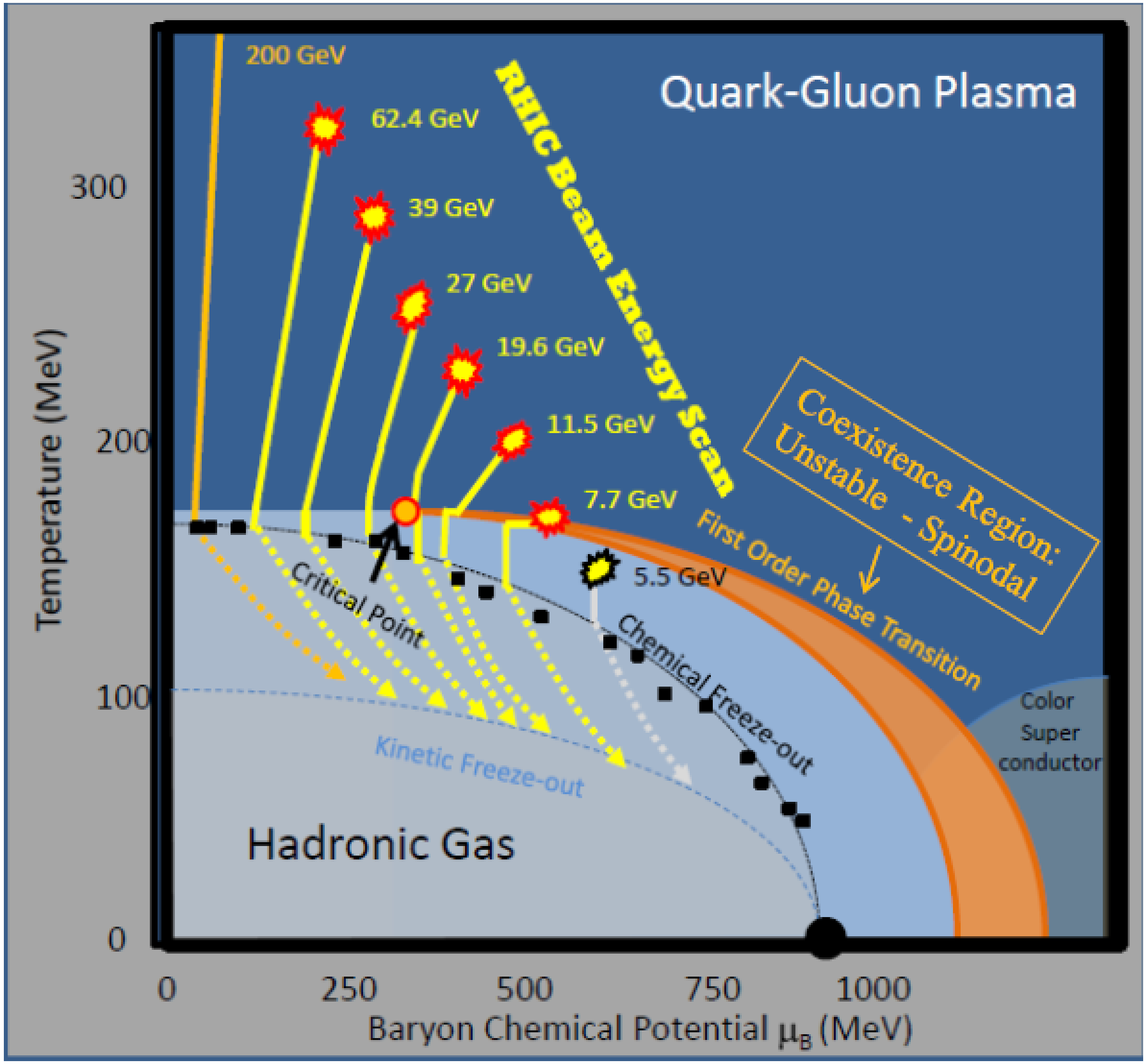
- MC-KLN
  - CGC initial state
  - $\eta/s = 2/4\pi$

Disfavored

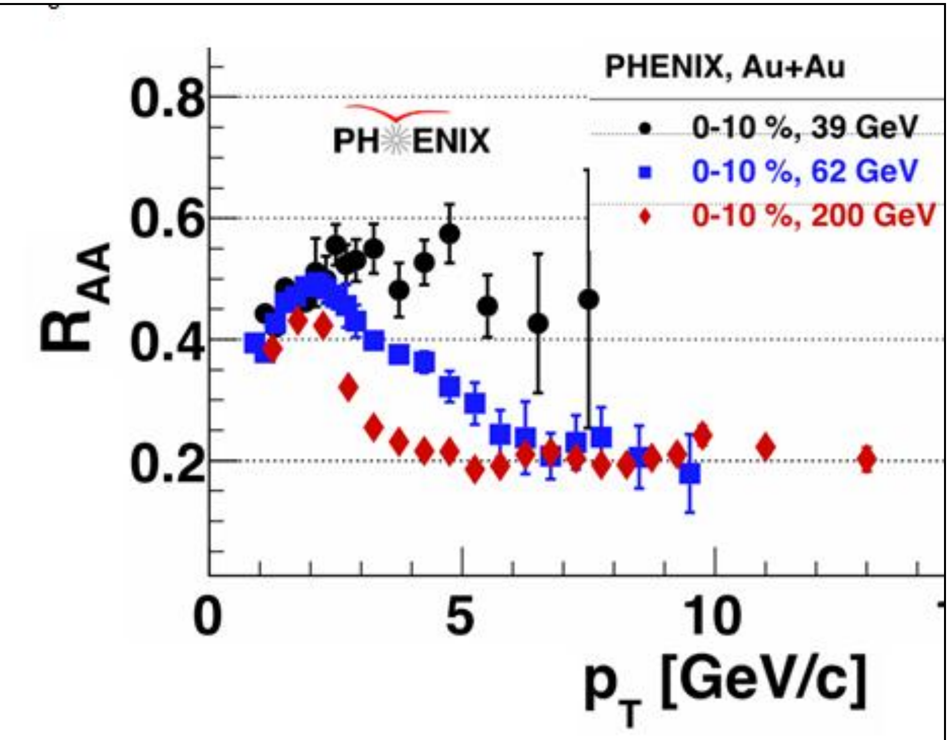
ε_2 (Glauber) $> \varepsilon_2$ (MC-KLN) while ε_3 (Glauber) $\approx \varepsilon_3$ (MC-KLN)

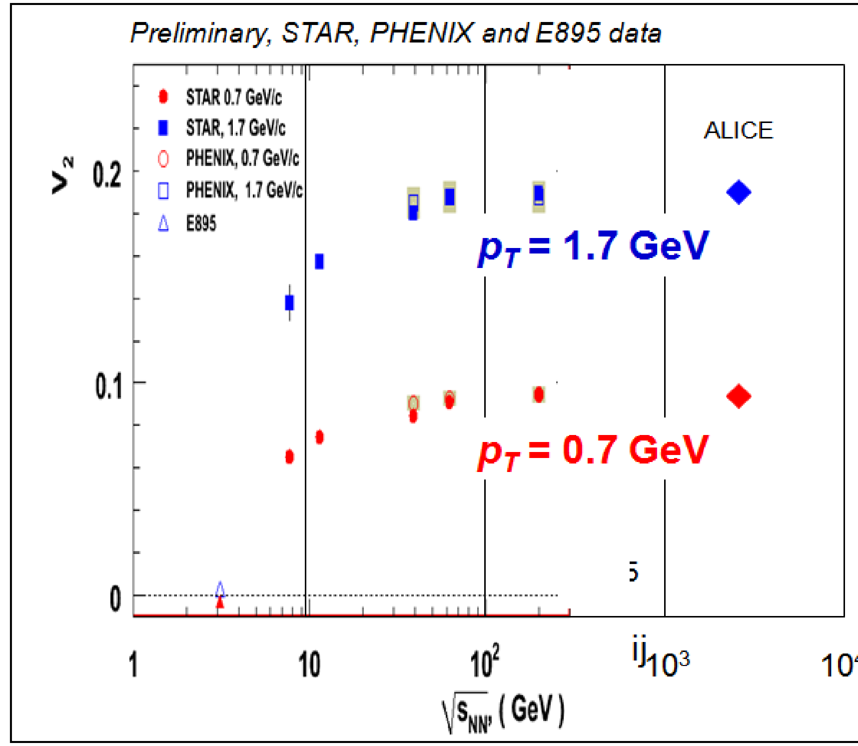
The difference of the two model is exaggerated due to the fact that ε_2 by MC-KLN is large. For more realistic CGC, the difference could be smaller.

Beam Energy Scan and search for Critical Point



Beam Energy Scan



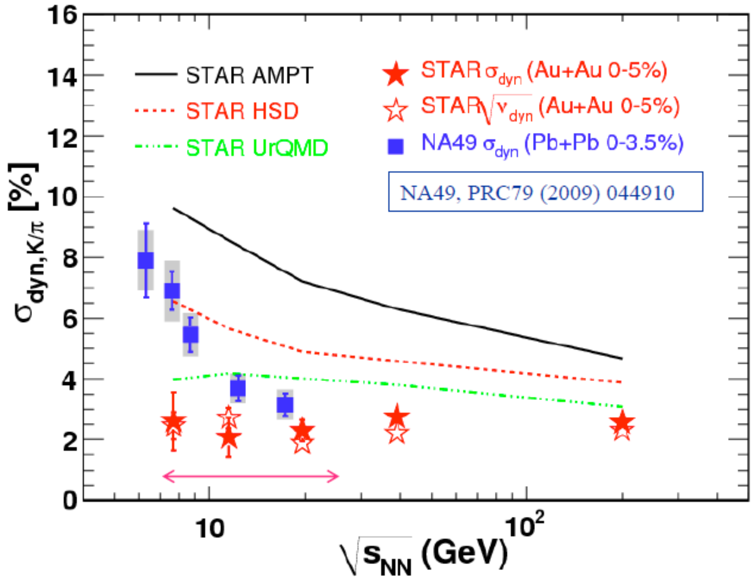


RAA < 1 above 39 GeV
Earlier data show RAA>1 at ~20 GeV

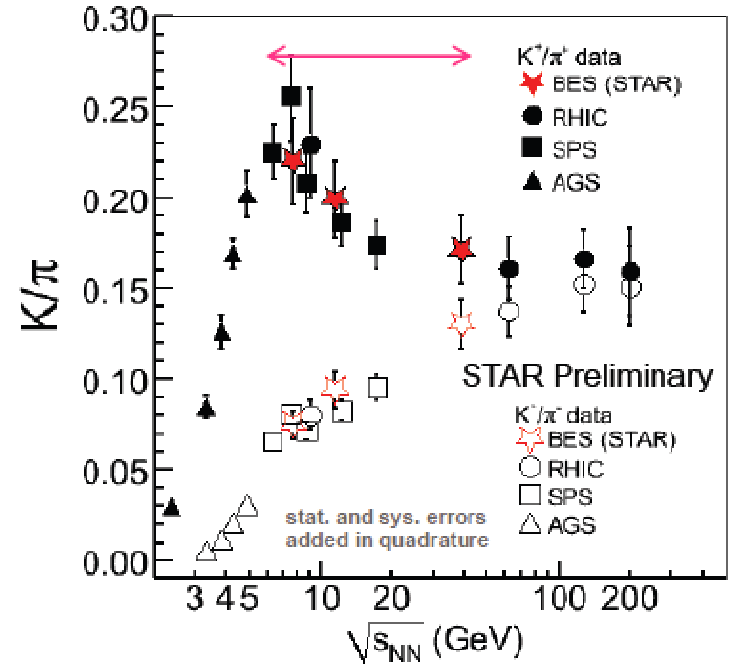
V2(pT) saturate above 39 GeV

- Onset of QGP formation between 20 and 39 GeV???

Beam Energy Scan



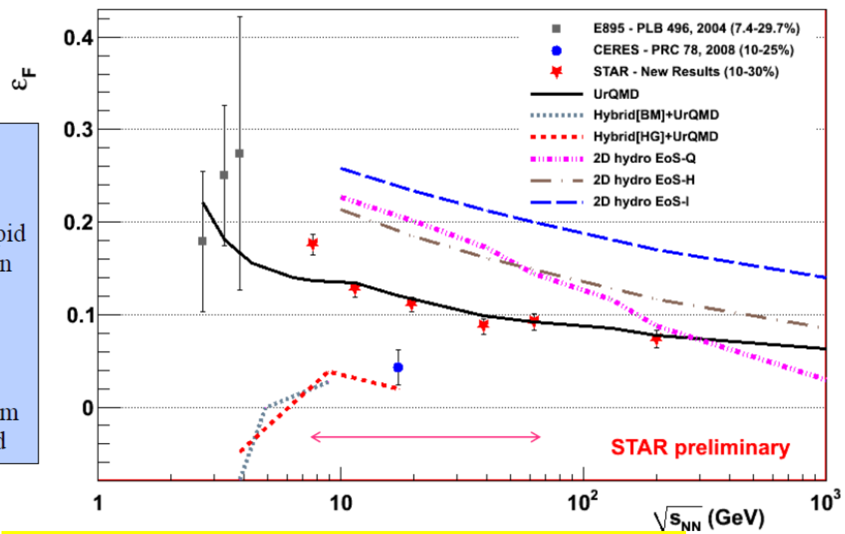
STAR data doesn't show critical behavior



K/π ratio shows a peak, but less sharp

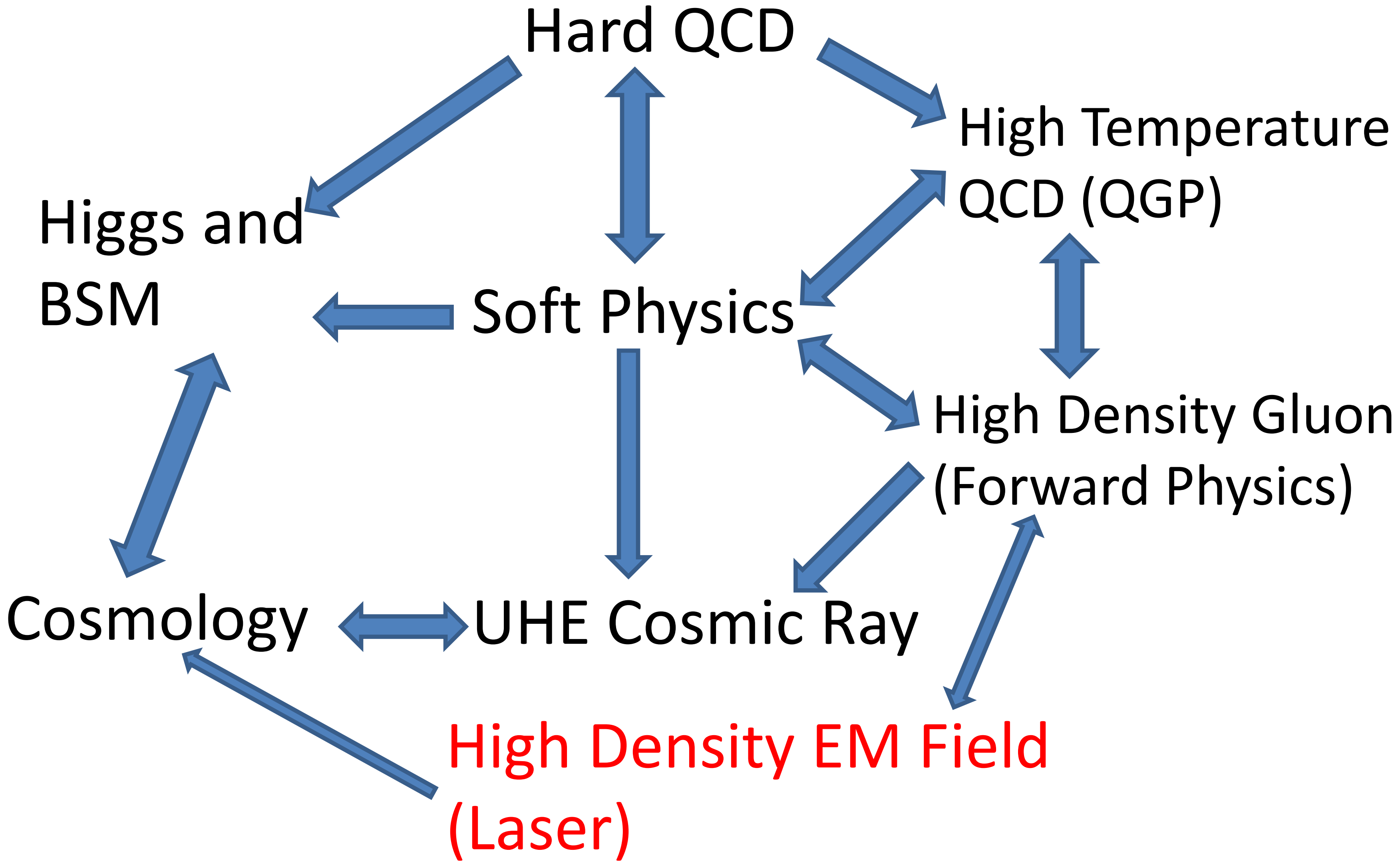
Softest Point should show rapid change in ε with energy

No mimimum observed

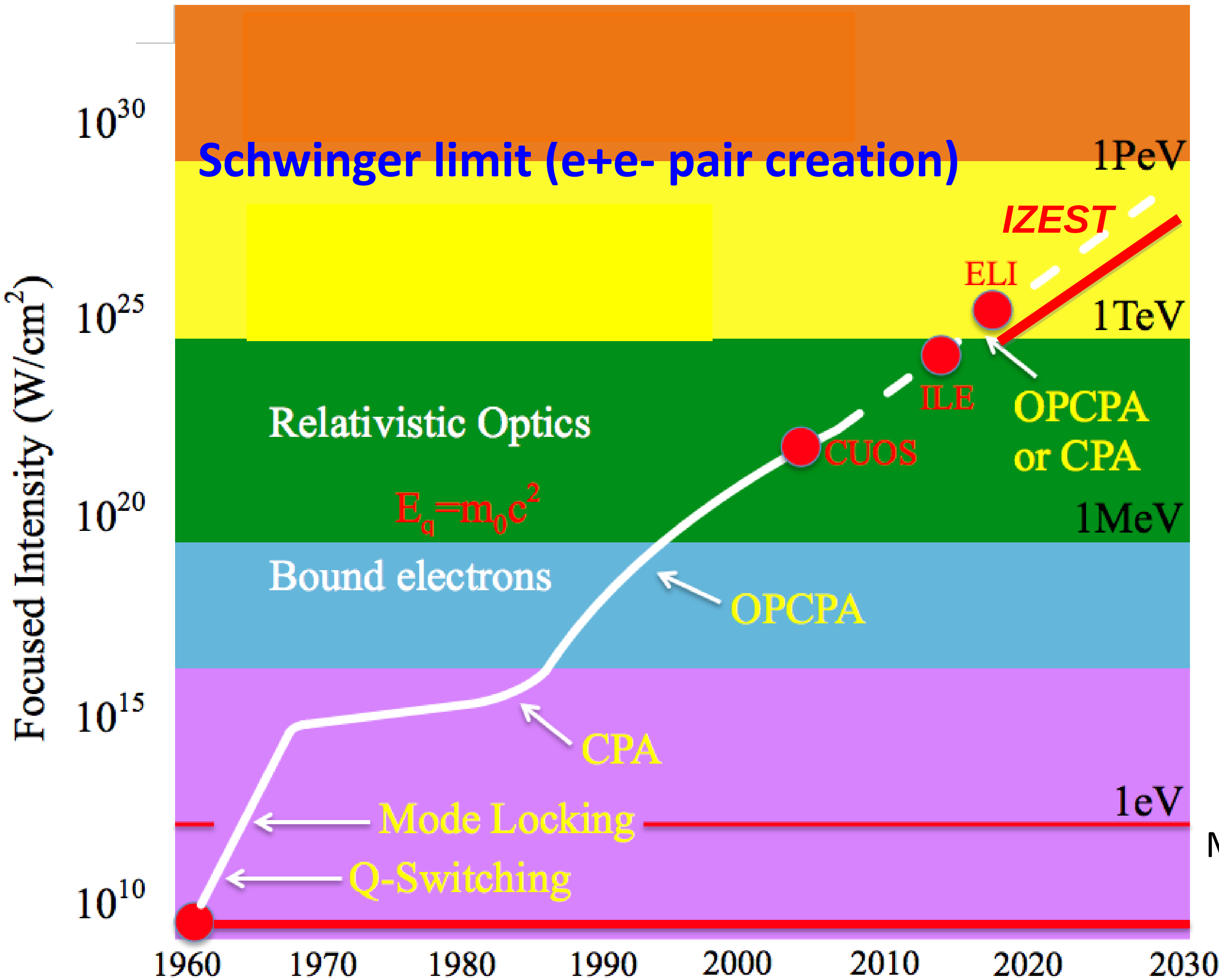


Rapid change of ε_F not observed

No clear indication of Critical Point


Hard QCD
Higgs and
BSM
Soft Physics
High Temperature
QCD (QGP)
High Density Gluon
(Forward Physics)
Cosmology
UHE Cosmic Ray
High Density EM Field
(Laser)

Leap of laser intensity



Mourou 2011

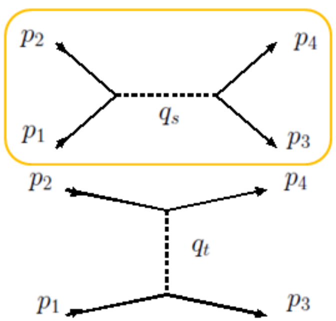
Probing Dark Energy particle in vaccuum

Scalar field production by photon-photon scattering with resonance enhancement

Building blocks

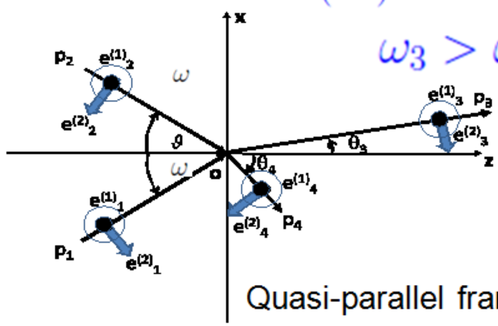
$$-L_{\mathrm{mx}\phi} = \frac{1}{4} B M_{\mathrm{P}}^{-1} F_{\mu\nu} F^{\mu\nu} \phi, \quad B = (2\alpha/3\pi)\mathcal{Z}\zeta$$

$$\vartheta \sim \frac{m_\phi}{2\omega} \sim \frac{10^{-9}\mathrm{eV}}{\mathcal{O}(\mathrm{eV})} \sim 10^{-9}$$



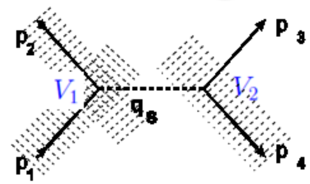
Resonance-dominated only in the s channel

$\omega_3 > \omega_4$

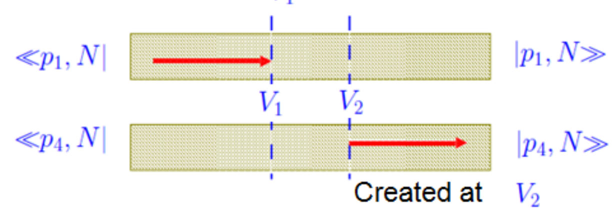


Quasi-parallel frame

Adding Inducing beam $|p_4, N\gg$



Creating p_4 at V_2 from sea of photons enhanced by $\sqrt{N}$

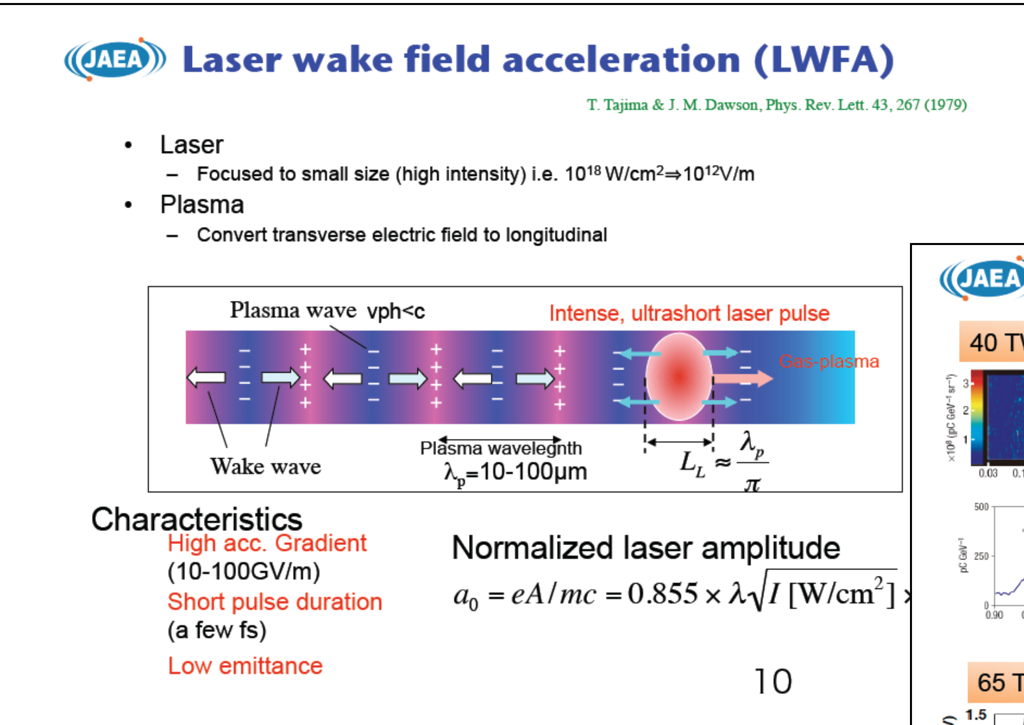


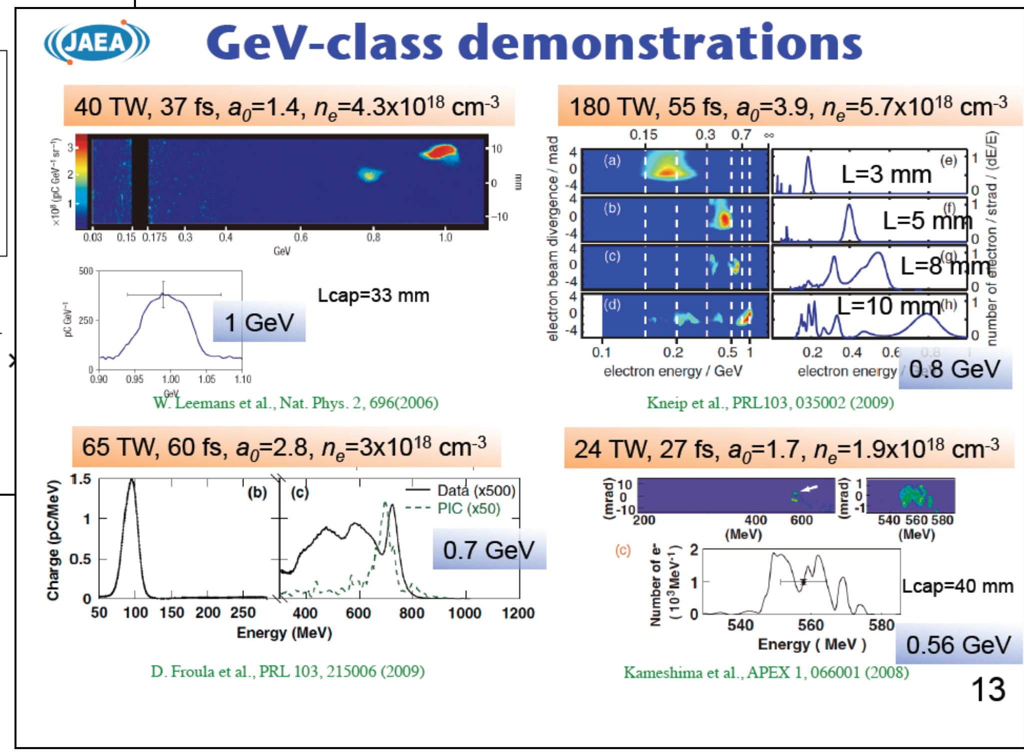
Rate of producing p_3 enhanced by N

$\overline{N} \sim (\cdots)^{1/3} \sim 10^{21} = 1\mathrm{kJ}$, detectable, fortunately

- *Potential* to probe new physics at *very high sensitivity*
- Enhancement by a factor of $N_\gamma^{\,3}$

New Accelerator technique





- Acceleration to ~1 GeV with LWFA demonstrated
- Many technical challenges for linear collider application

Harmony with different tunes

(If you have a big heart and broad curiosity)