I : Tachyons as Dark Energy Quanta?
II : Very Forward Hadron Spectrometer @ LHC & Cosmic Ray Showers

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2nd World Summit on Exploring the Dark Side of the Universe

I : Tachyons as Dark Energy Quanta?

Briefly:

A naïve experimental particle physicist’s perspective
Qualitative, no calculations

Dark energy considered as a scalar field – not “just” as a cosmological constant.

Associated quanta - like all other physical fields – i.e. particles

What properties?   Qualitatively different from all known particles

Proposal: Imaginary mass $M = i\,\Gamma$ (Γ real)

→ Speed always > speed of light (superluminal)

Tachyons T introduced in 1962 by Bilaniuk, Deshpande & Sudarshan in context of classical relativity (2 years before Higgs particle proposed)

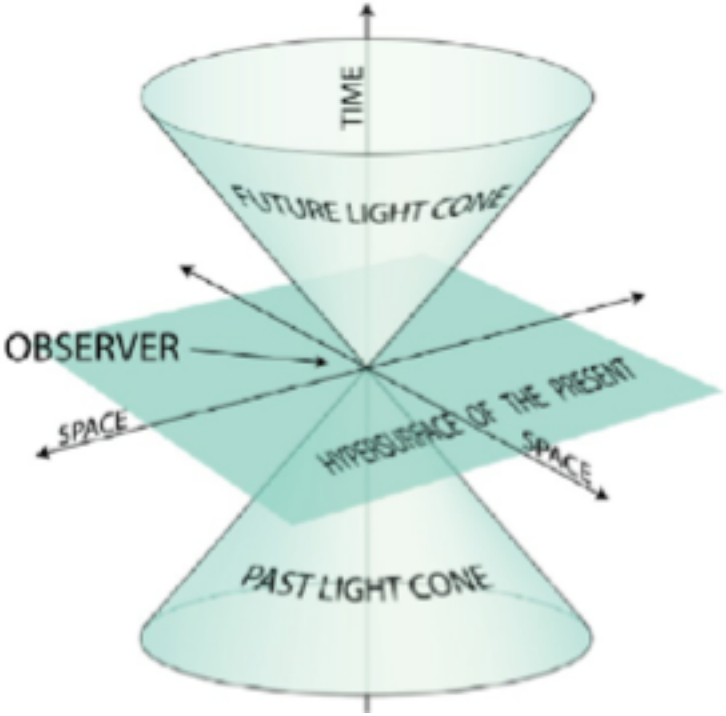
1. **Meta Relativity**
O.M.P. Bilaniuk, V.K. Deshpande, E.C.G. Sudarshan. Oct 1962. 6 pp.
Published in **Am.J.Phys. 30 (1962) 718-723**

From Wikipedia article:

In quantum mechanics, **Gell-Mann's totalitarian principle** states:
"Everything not forbidden is compulsory" Physicist Murray Gell-Mann borrowed this expression from T. H. White's *The Once and Future King*[2] to describe the state of particle physics around the time he was formulating the Eightfold Way, a precursor to the quark-model of hadrons.[3]
The statement is in reference to a surprising feature of particle interactions:

that **any interaction which is not forbidden by a small number of simple conservation laws is not only allowed, but *must* be included** in the sum over all "paths" which contribute to the outcome of the interaction.
Hence if it isn't forbidden, there is some probability amplitude for it to happen.

Are tachyons forbidden by some fundamental principle or conservation law?
Misconception: Tachyons can go backwards in time and violate causality.
NO: They cannot go into the absolute past (past light cone) of any observer



L.C. Different for every observer

$$\mathbf{E^2 = p^2c^2 + m^2c^4}$$

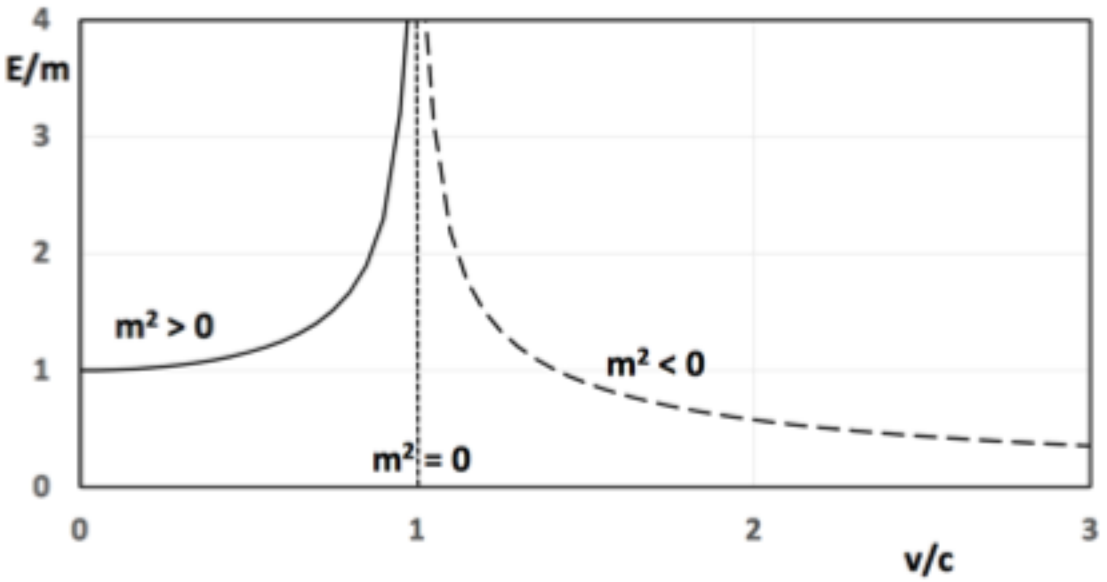
$\rightarrow E = mc^2$ iff $p = 0$

$\beta = p/E < 1$ if m^2 +ve   ($c = 1$)
$\beta = p/E > 1$ if m^2 –ve i.e. $\mathbf{m = i\Gamma}$ (Γ real)

Tachyons are hypothetical particles with "imaginary mass" & speed always > c

If E = 0 (in a particular Lorentz frame) $\beta = \infty$
In that limit line across universe
However E = 0 forbidden by Heisenberg (in finite time)
Quantum fluctuations flip direction ⟷

Special relativity only forbids superluminal speeds for particles with real mass (mass^2)

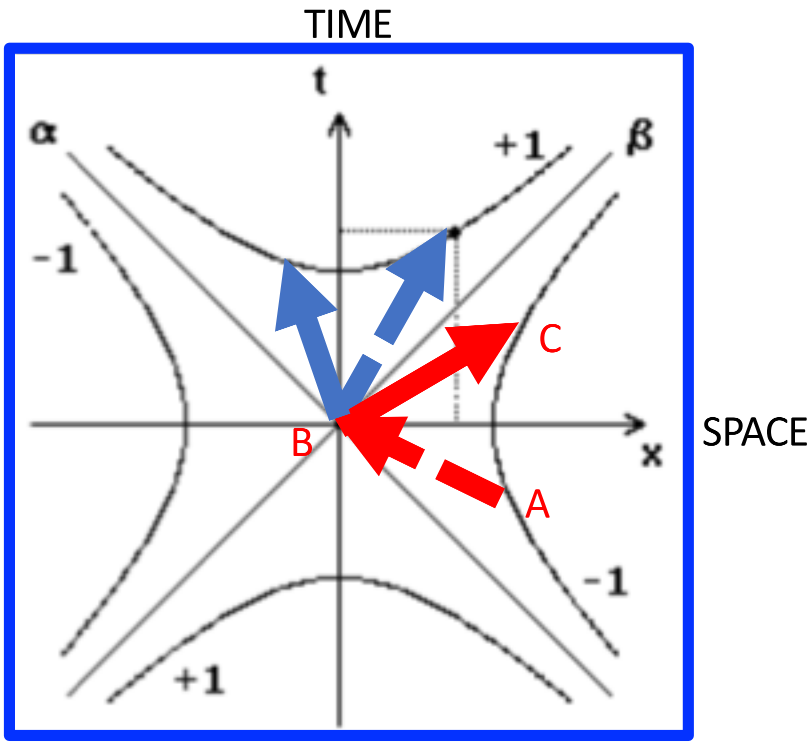


V → ∞ as E → 0

FIG. 1: $E/|m|$ versus v/c for three classes of particles.

Increase E speeds bradyon up towards speed of light from below
Increase E slows tachyon down towards speed of light from above

SYMMETRY



Origin: Here and Now (different for all of us)

Bradyon: Blue lines (different frames)
Boost can change direction in space

Tachyon: Red lines (different frames)
Boost can change direction in time
But not into B's absolute past!

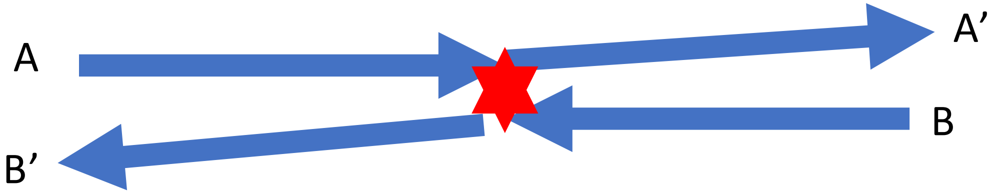
You cannot send a signal into your own past and "kill your grandmother" –
Tachyons do not necessarily violate causality.

A Lorentz boost can change "description" of process: **Emission at A - > absorption at B**
Emission at B - > absorption at C
A and C are the same tachyon at different spacetime locations.

No weirder than "instantaneous" quantum entanglement! Question: related physics??

We are used to this in particle collisions, on small spacetime intervals

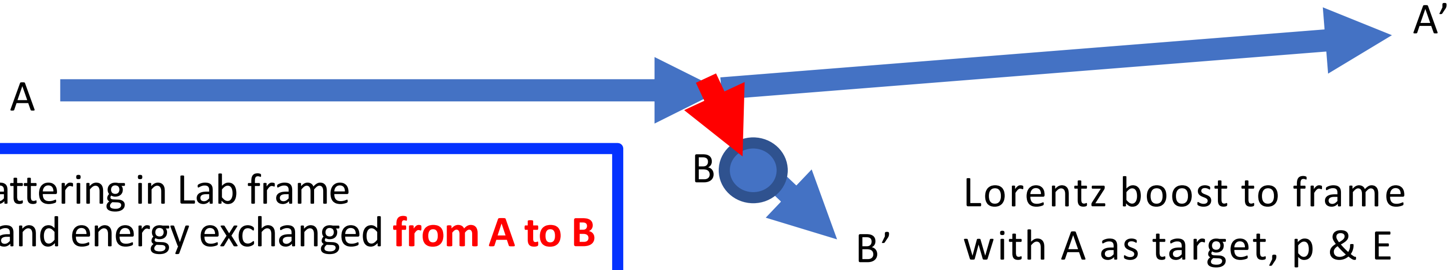
A Lorentz boost can change "description" of process: Emission at A - > absorption at B
Emission at B - > absorption at A



4-momentum transfer exchanged ⧗

Elastic AB scattering in CM frame
Momentum exchanged but no energy. p/E = ∞ ... direction meaningless
Invariant 4-momentum transfer^2 is negative (pomeron or photon)

p + p -> p + p + T?
(σ much too small!)



Elastic AB scattering in Lab frame
Momentum and energy exchanged **from A to B**
Invariant 4-momentum transfer^2 is negative

Lorentz boost to frame with A as target, p & E exchanged **from B to A**

Such local "superluminal" exchanges allowed by Heisenberg Uncertainty Principle

Allowed properties consistent with known physics : (i-)mass, spin, couplings, …

Interactions with matter:

Strong (QCD is underlying theory of strong interactions) ?
NO! E.g. would be strongly emitted in hadron collisions,
even p + p - > p + p + T giving lost energy (can be very small) & momentum (minimum)

Electromagnetic?
NO! Electric or magnetic charge. Emit Cherenkov radiation in vacuum, lose energy.

Weak (Electroweak)? **NO!** E.g. Z → TT does not happen – Z-width excludes (any Γ)

Superweak? Much weaker than known electroweak. Possibly.

Gravitational? **Yes**, of course. We believe in General Relativity!

Why consider tachyons as candidates for dark energy quanta?

Matter – Matter gravitational a la Newton $\boxed{F = G \,.\, M_1 M_2 / R^2}$

If M_1 and M_2 are imaginary, F is negative - > repulsion instead of attraction

Non-relativistic, but : Newton is limit of GR for speeds << c
Question/guess: Does it also apply for speeds >> c, limit for E --> 0 ?

Many papers on Tachyon Dark Energy : Scalar potential, unstable …
String theory - > rolling tachyon field (?) → vacuum unstable
Related to Brans-Dicke Scalar-Tensor theory of gravity
Chameleon: heavy in lab environment, light on a cosmological scale. Das & Banerjee 2008

Why are M and DE densities about the same today? – cosmological coincidence problem

Banijamali, Bellcci, Fazlpour, Solbi: arxiv:1803.02397 :
"The scenario of a tachyonic chameleon dark energy is compatible with observations (BAO & SN) for all examined scalar fields with non-minimal coupling functions to (dissipative) matter fields".

Etc… I will not review the literature!

Objections & (my) responses

Critique: As Universe expands : tachyon density decreases, inter-tachyon distance increases, acceleration will decrease.

Answer : New tachyons with E ~ 0 can be created out of expanding vacuum.
Scalars with no conserved quantum numbers.
Potentially can keep tachyon density constant (or increase or decrease?)

Critique: Tachyons would make the vacuum unstable.

Answer: The accelerated expansion is an explosion (time scale billions of years) – instability
Inflationary epoch another.
Two different tachyons with very different (imaginary) mass Γ

Critique: Such particles are too light and weakly interacting to be detected, therefore not relevant. Like 0-mass gravitons of general relativity. LIght axions?

Answer: Unified theory of all matter and interactions must include everything.
E.g. Einstein tried to unify EM & Gravity – ignored weak and strong interactions

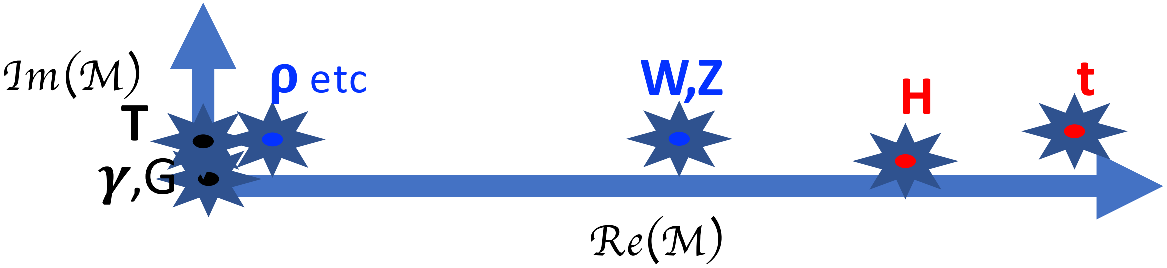
Other qualitative points:

If dark energy is a “tachyon gas” with mutual repulsion it will be **homogeneous and isotropic** , unlike attractive matter which clusters.

However it may not be uniform in presence of matter. Any possibility of testing that?

What is the mass Γ ? meV, μeV, neV, peV, feV? Could be more than one.

As identical bosons they can condense (Bose-Einstein condensate) – effects.



Schematic, not to scale!
Wave functions of unstable particles have $\mathcal{Im}$ part

Final remark for this first talk: Is this “not impossible - not even wrong”?
Is it useful, even if we can never detect individual tachyons?
Pauli’s: “terrible sin – invented a particle that can never be detected”

II : Very Forward Hadron Spectrometer @ LHC & Cosmic Ray Showers

VFHS or SAS@LHC: A Spectrometer for Multi-TeV Forward Particles at the LHC

An idea for a new LHC experiment or subdetector

Introduction: *Terra Incognita!* Strong interactions and cosmic ray showers

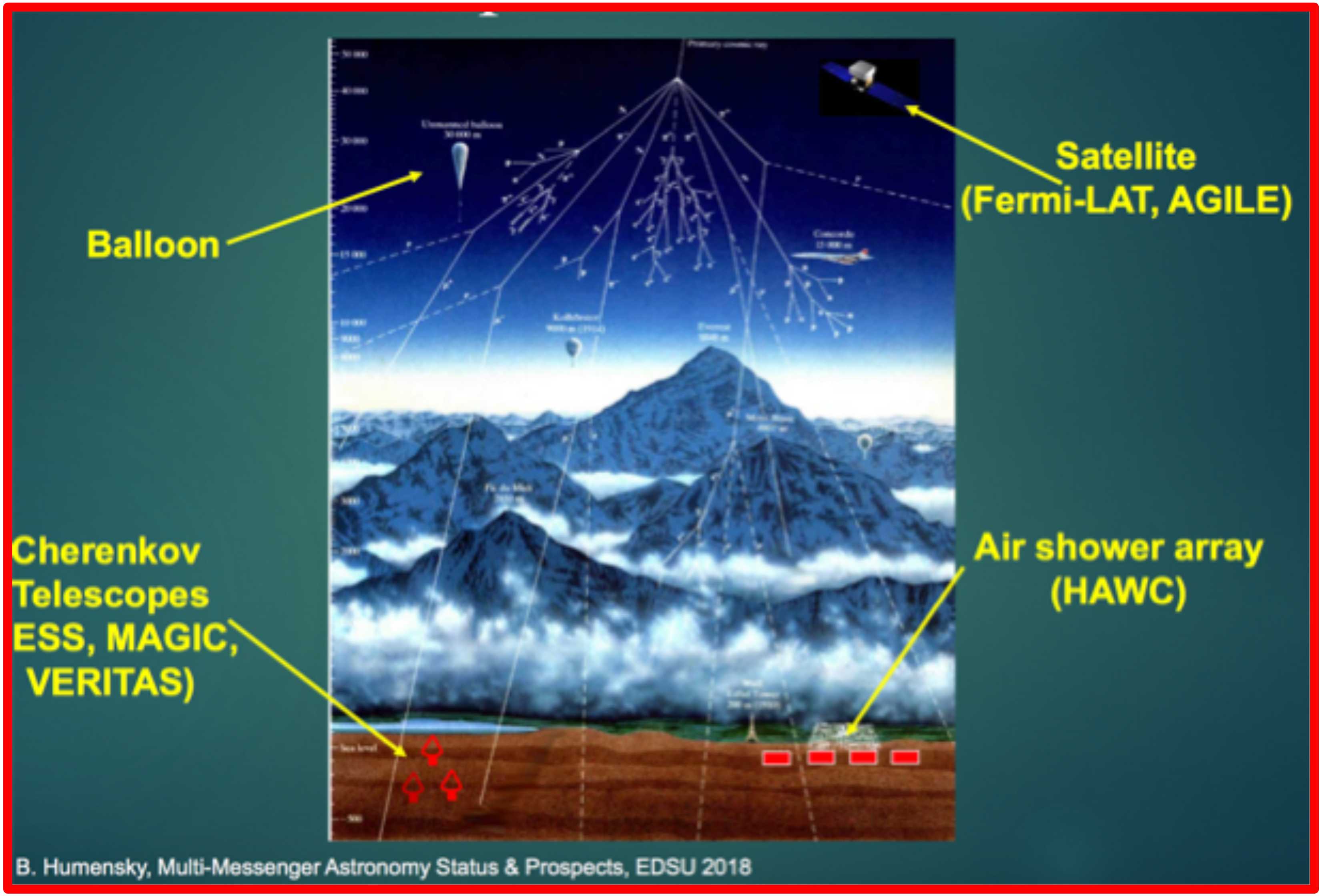
Some physics topics: single- and two- particle inclusive production (incl.charm)

TeV particles through 30 Tm spectrometer magnets, special vacuum chamber

Charged hadron identification : π, K, p with transition radiation detectors

What's next? A new collaboration or new subdetector for ALICE or LHCb?
(CMS or ATLAS are less favourable)

Nice slide taken from Bruce Humensky’s talk here



Balloon

Satellite
(Fermi-LAT, AGILE)

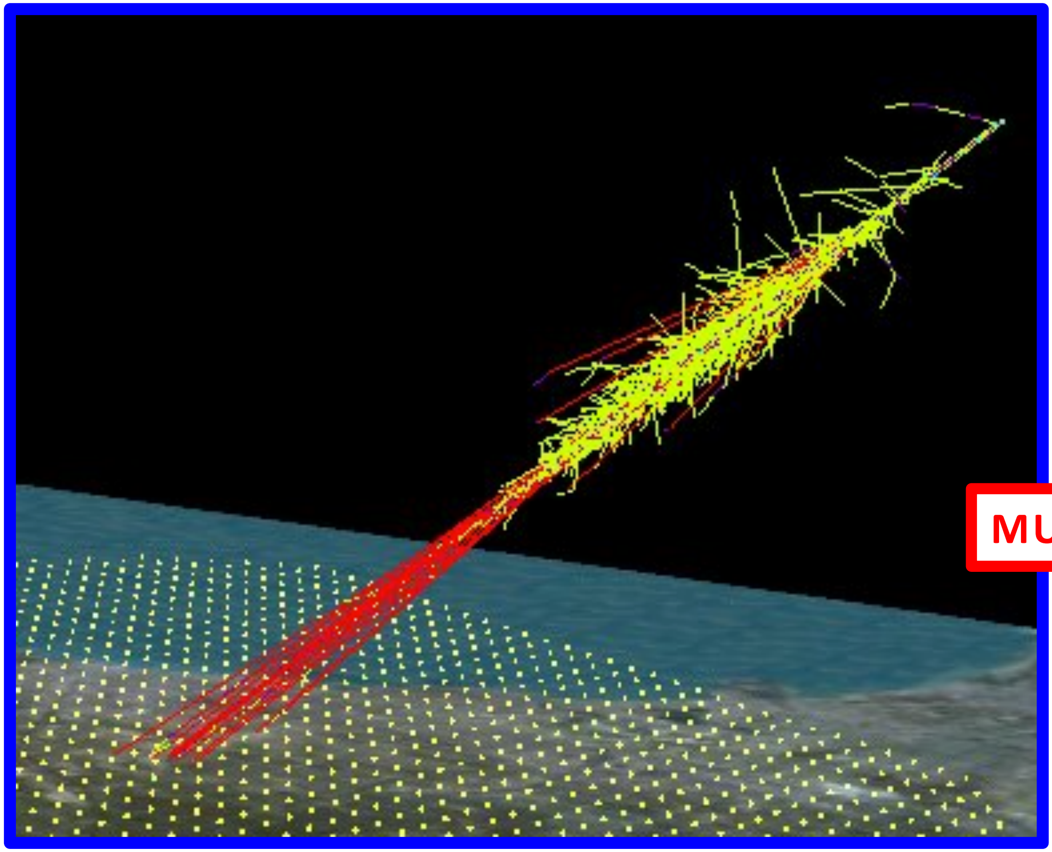
Cherenkov
Telescopes
ESS, MAGIC,
VERITAS)

Air shower array
(HAWC)

B. Humensky, Multi-Messenger Astronomy Status & Prospects, EDSU 2018

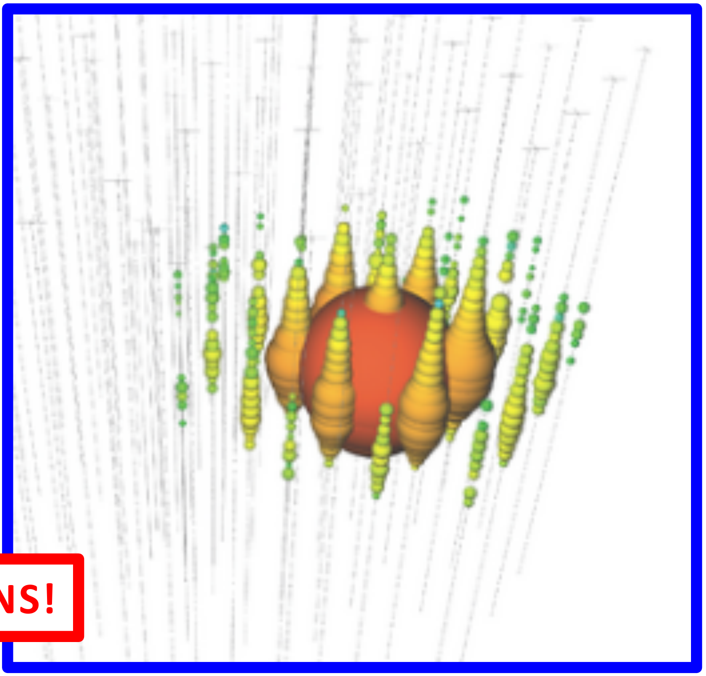
COSMIC RAY SHOWERs

Simulated UHE Cosmic ray shower over Auger observatory in Argentina



Water Cherenkov tanks ~ 1 km spacing

ICECUBE Event 20 : 1140 TeV ν



PMTs in Antarctic ice, 1 km^3

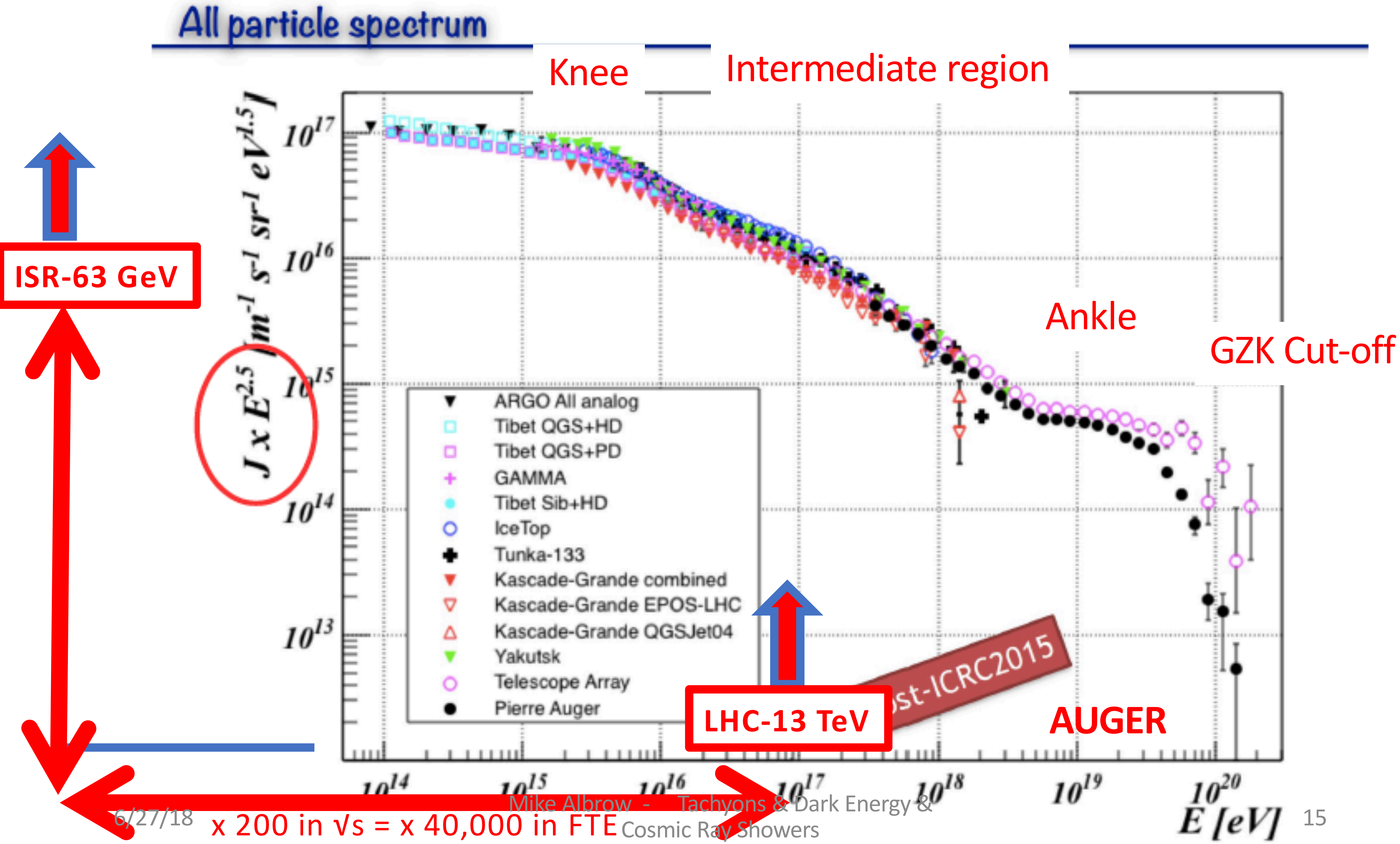
MUONS!

Simulating showers relies on particle production cross sections that are not well known

One day : p-N and N-N collisions at LHC?

COSMIC RAY SHOWERS: ASTROPHYSICS CONNECTION

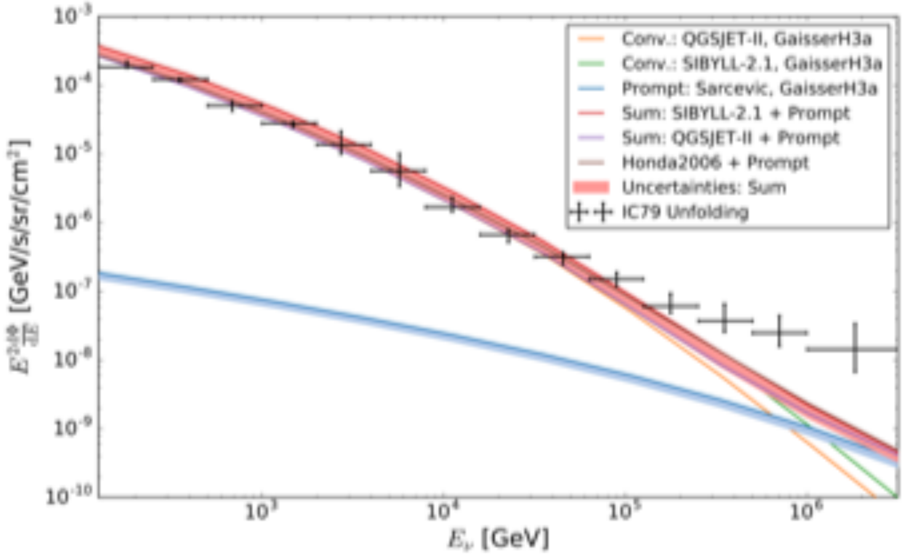
Spectrum of high energy Cosmic Rays $\phi(E) \times E^{2.5}$

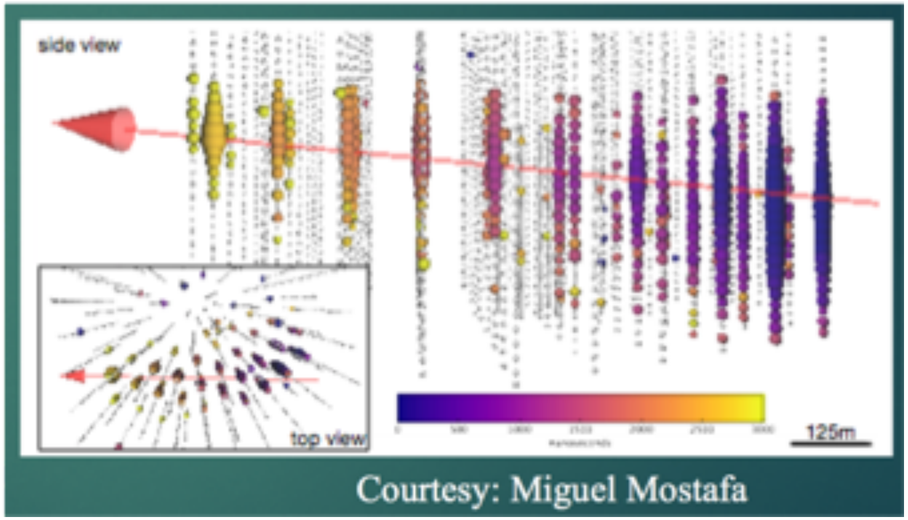


x 200 in √s = x 40,000 in FTE

ICE CUBE

Measurement of the ν_μ energy spectrum with IceCube-79





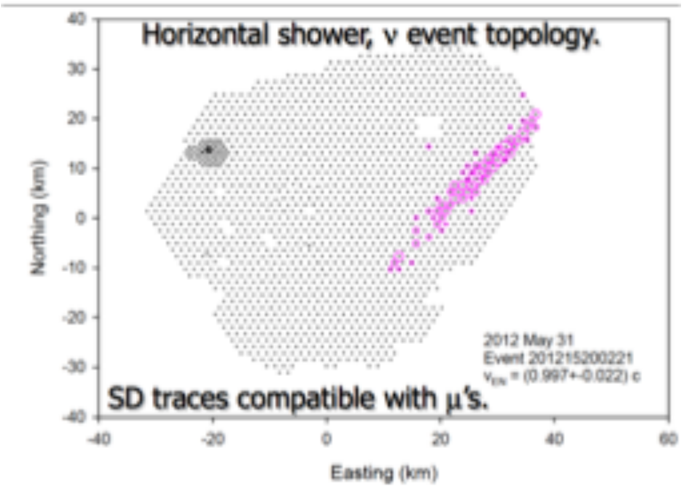
Courtesy: Miguel Mostafa

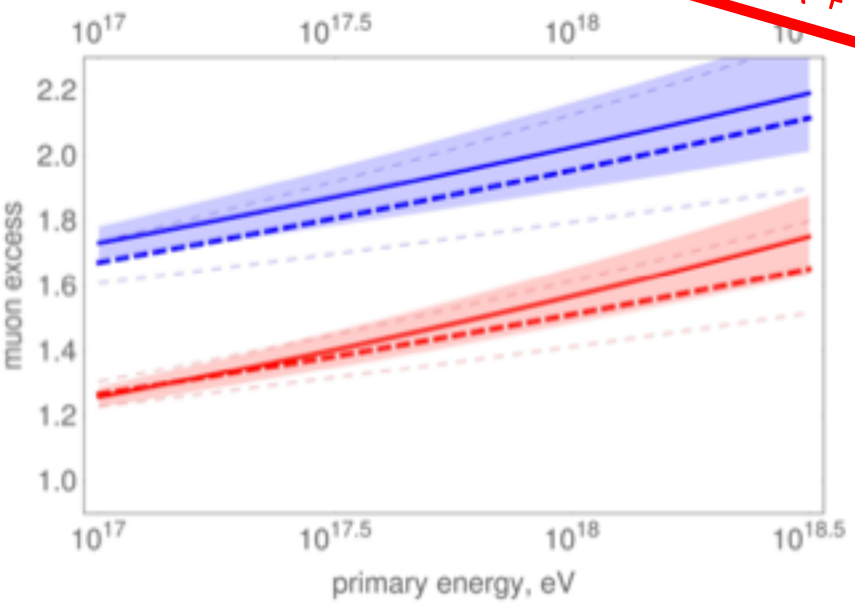
Composition of UHE cosmic rays (protons vs nuclei vs X):

Interpretation of data depends on models of
shower development. Vastly extrapolated and assuming no new physics.
Hadron collision models (e.g. PYTHIA) only tuned against central production and only up to LHC energies.

Muon content of extensive air showers: comparison of the energy spectra obtained by the Sydney University Giant Air-shower Recorder and by the Pierre Auger Observatory
arXiv: 1803.08662 [astro-ph.HE]

AUGER + SUGAR

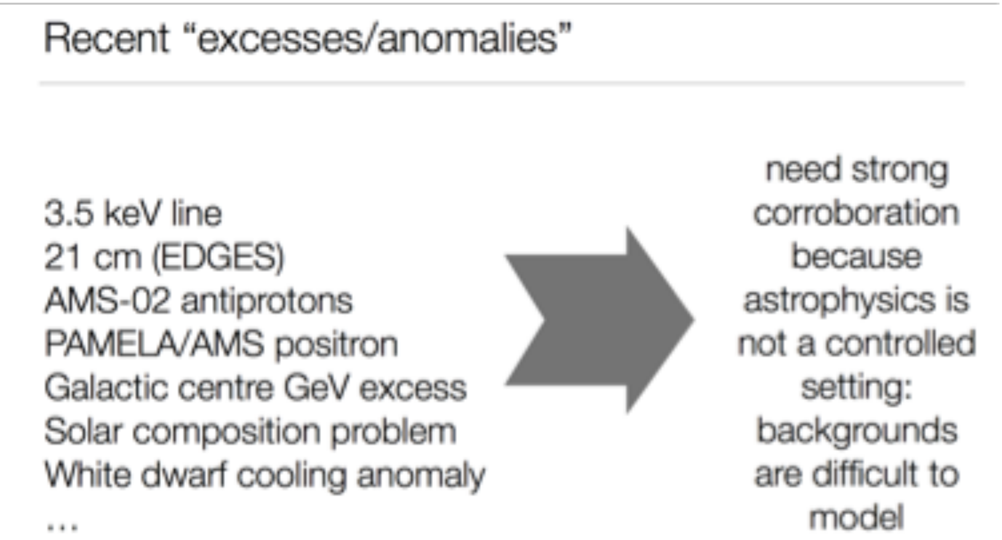




Tens of thousands of muons from h-A interaction!! ?? How?

AMIGA (Auger Muons and Infill for the Ground Array)
Buried under water tanks to measure muon content of showers .

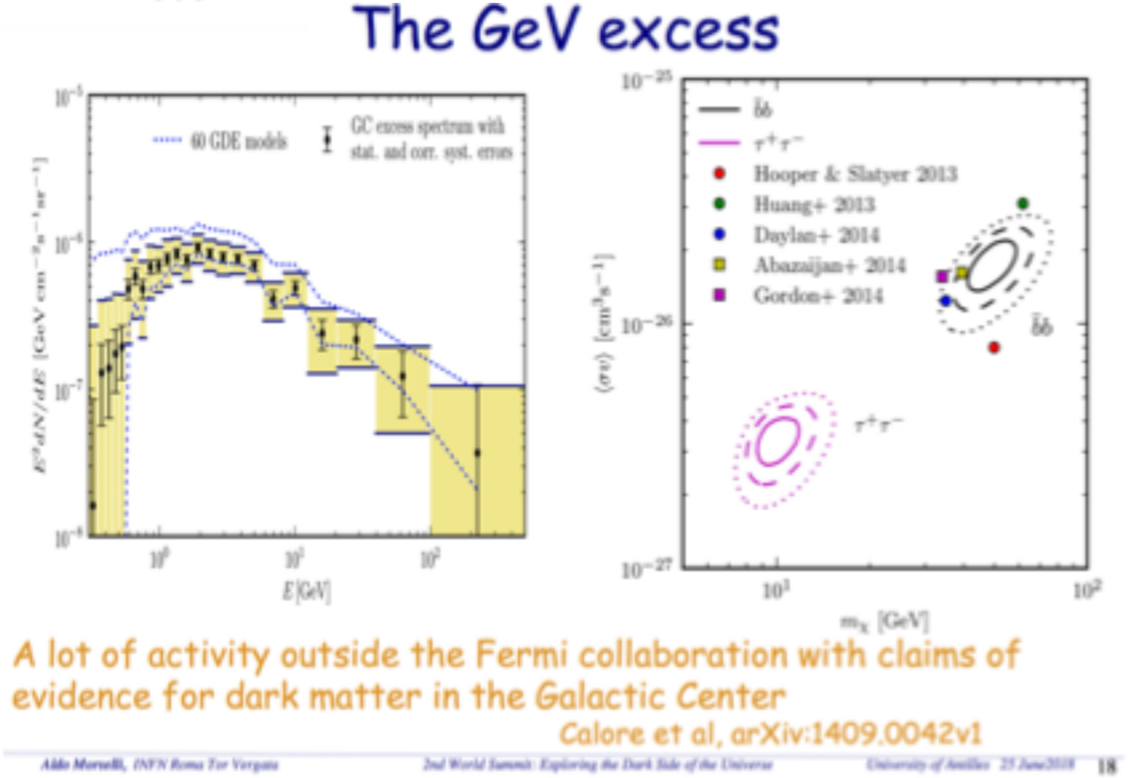
Taken from Aldo Morselli talk



Recent "excesses/anomalies"

3.5 keV line
21 cm (EDGES)
AMS-02 antiprotons
PAMELA/AMS positron
Galactic centre GeV excess
Solar composition problem
White dwarf cooling anomaly
…

need strong corroboration because astrophysics is not a controlled setting: backgrounds are difficult to model

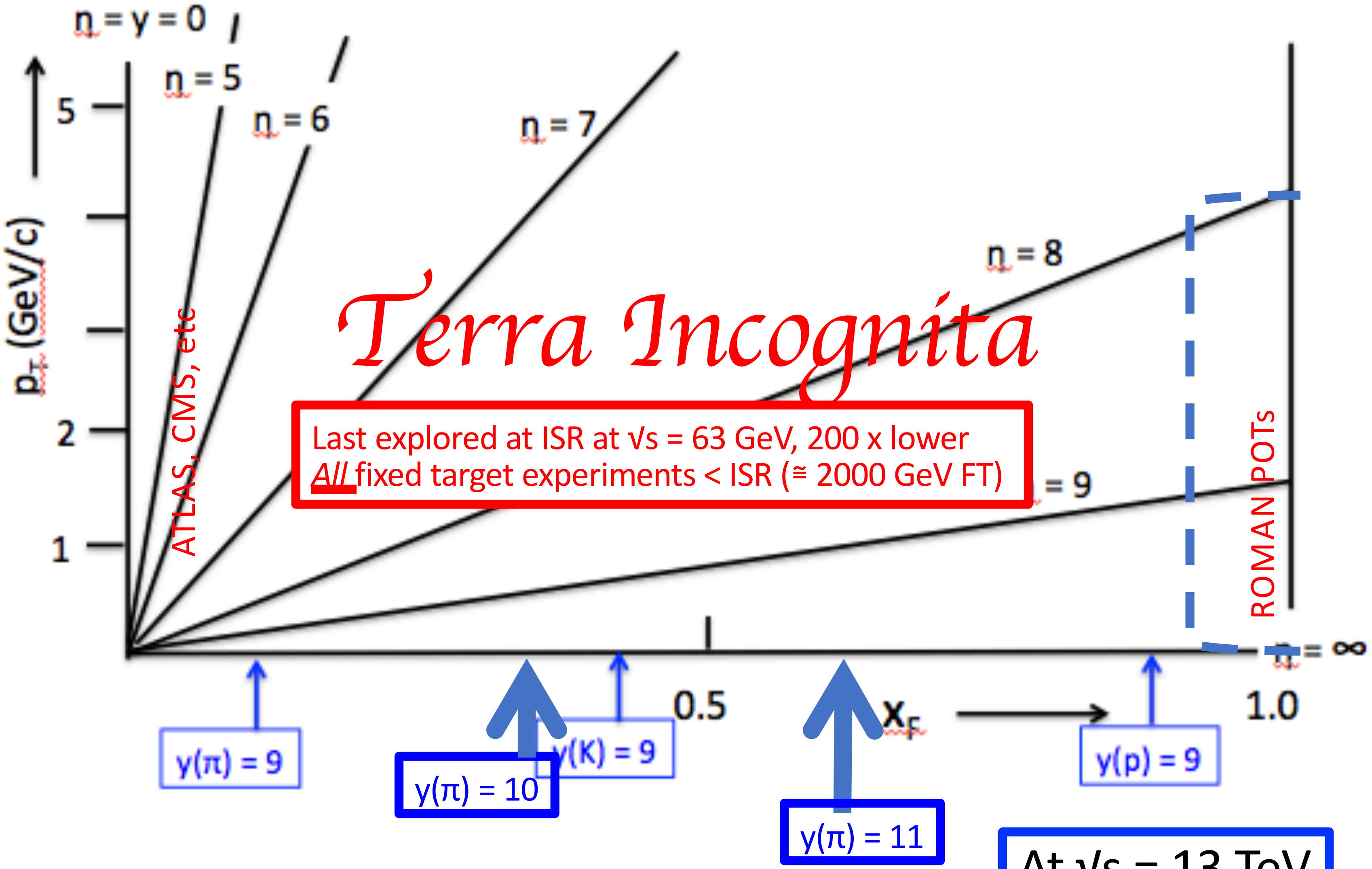


The GeV excess

A lot of activity outside the Fermi collaboration with claims of evidence for dark matter in the Galactic Center

Calore et al, arXiv:1409.0042v1

Aldo Morselli, INFN Roma Tor Vergata 2nd World Summit: Exploring the Dark Side of the Universe University of Antilles 25 June2018 18



Terra Incognita

Last explored at ISR at √s = 63 GeV, 200 x lower
All fixed target experiments < ISR (≅ 2000 GeV FT)

y(π) = 10

y(π) = 11

At √s = 13 TeV

ZDC & LHCf measure neutrals (n + K^0_L , $\pi^0 \rightarrow \gamma\gamma$) at θ ~ 0°.

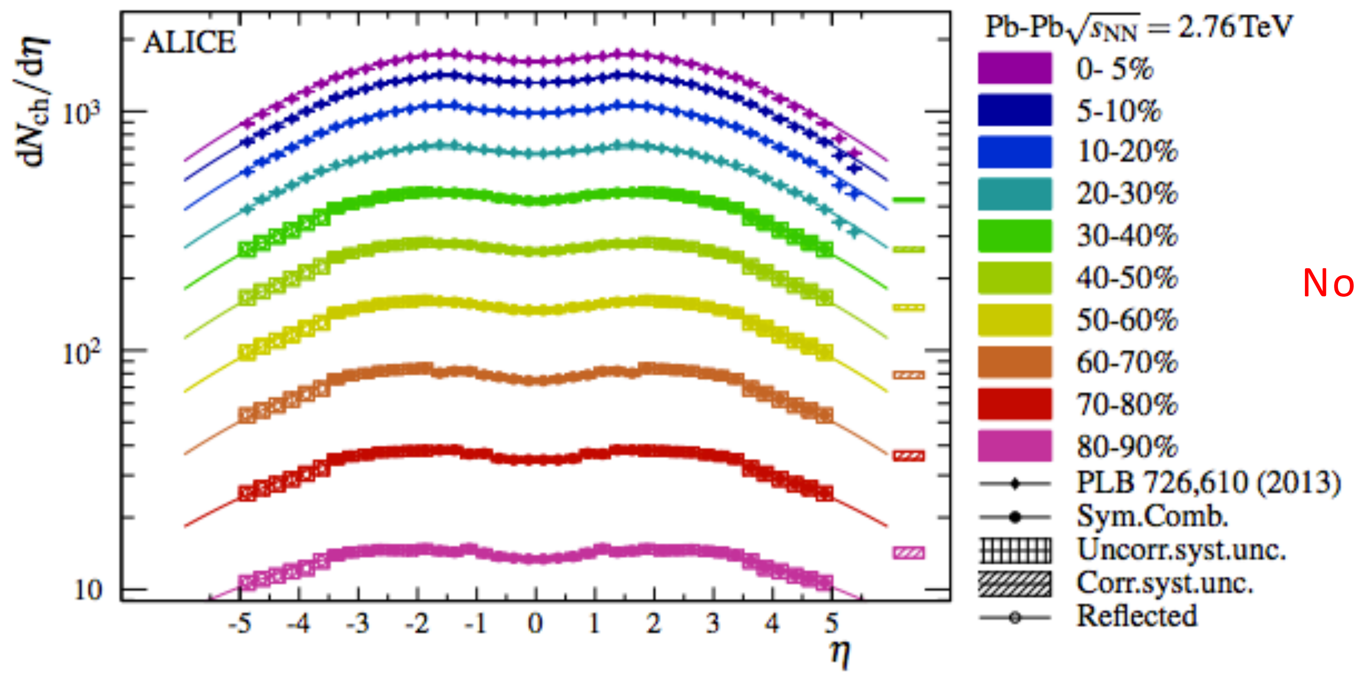
Broad rapidity coverage in ALICE (here Pb-Pb)

http://arxiv.org/pdf/1509.07299v1.pdf

CERN-PH-EP-2015-257
16 September 2015

Centrality evolution of the charged–particle pseudorapidity density over a broad pseudorapidity range in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

Centrality evolution of the charged-particle pseudorapidity density in Pb-Pb ALICE Collaboration



Note: This is "central"

Added value for HI collisions: measure nuclear fragments (d, t, He3, He4, …)
Better centrality measurements, forward flow, …

√s = 45 GeV,
CHLM (MGA inter alia) SAS @ ISR
Nucl Phys B 140 (1978) 189

40 years ago !

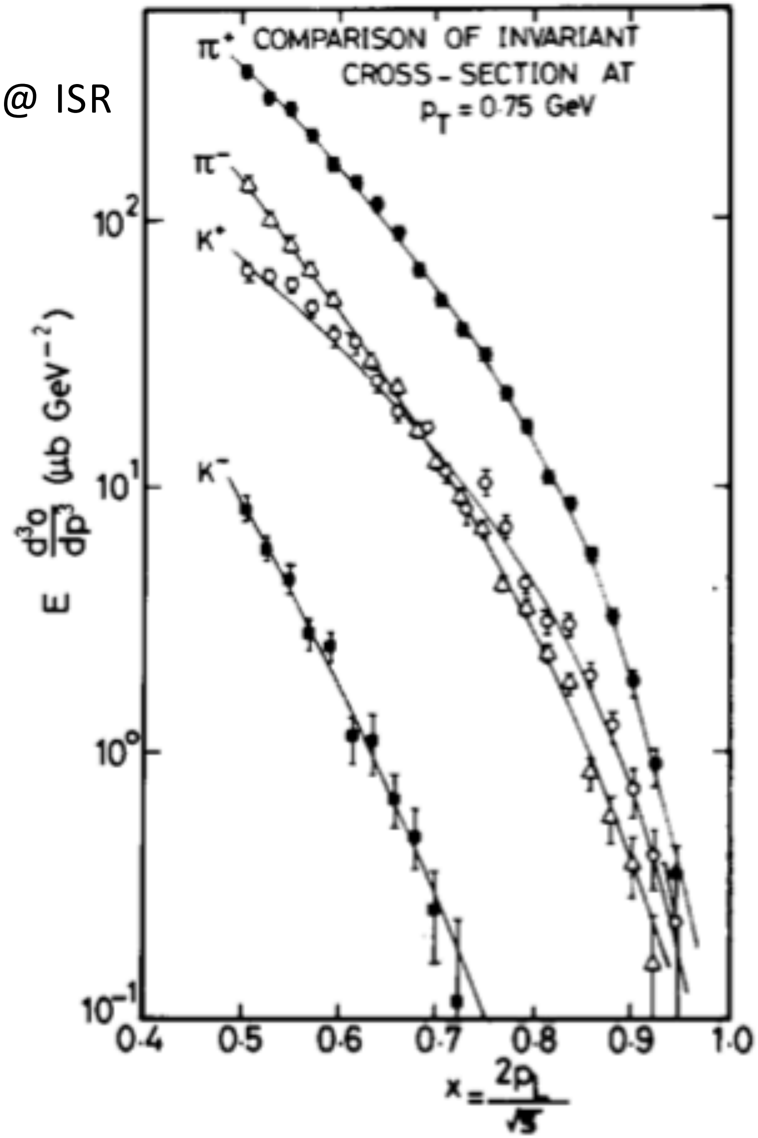
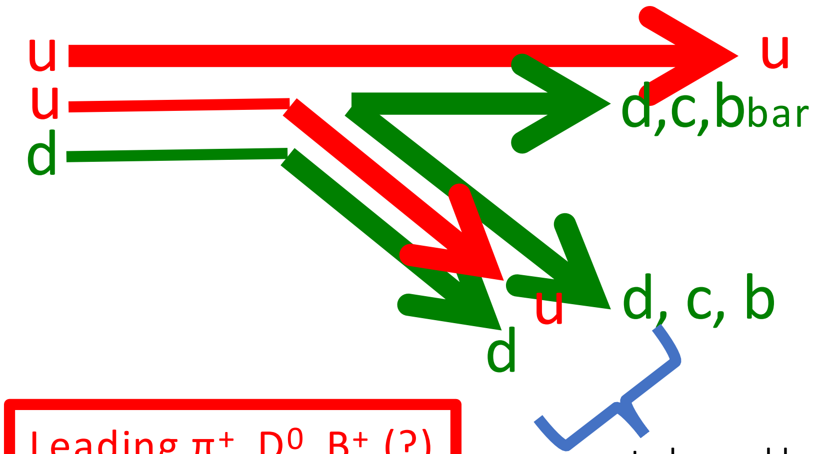


Fig. 2. Invariant cross sections for p + p → meson + X, for $p_T = 0.75$ GeV, a function of $x = 2p_L/\sqrt{s}$. The curves are empirical fits of the form $A \exp\{K(1-x)^C\}$ for $\pi^\pm$, K^+ described in the text. The curve for K^- is hand-drawn. The behaviour at other p_T values is similar.

$x_{Feynman} = x_F$ = p_z(hadron)/p(proton)

$x_F - x_{Bj}$ relationship, but less direct than in deep inelastic scattering.

E.g. p → π^+ is from leading u adding a dbar
p → π^- is from leading d adding a ubar
Ratio at high x reflects u:d in p

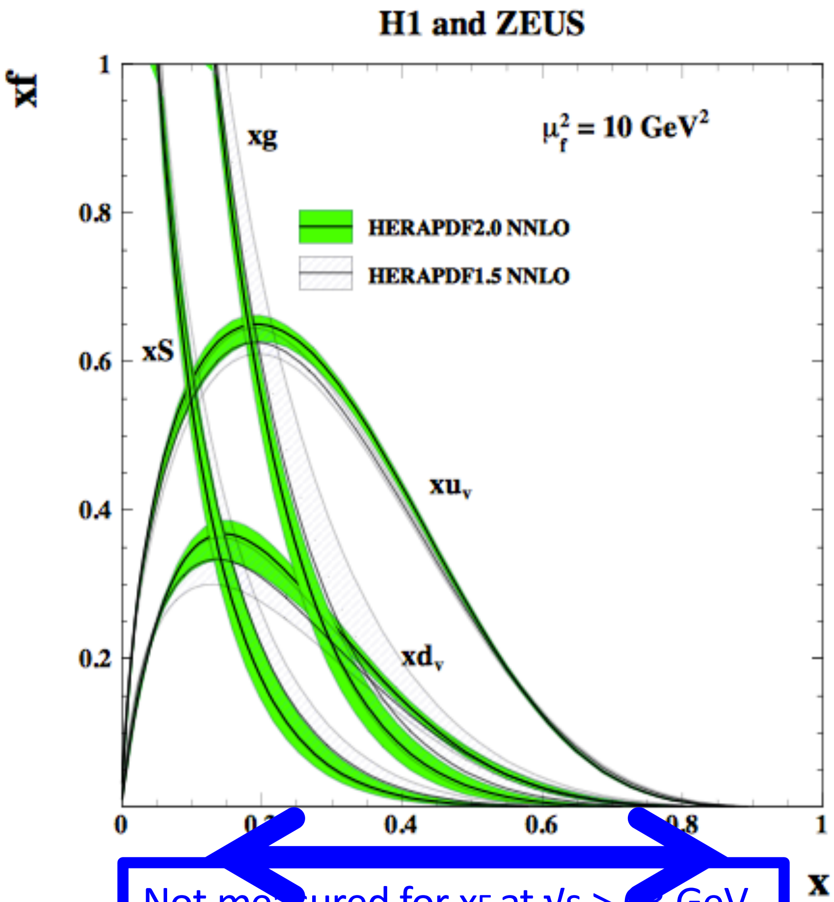


Leading π^+, D^0, B^+ (?)

t-channel baryon exchange (Reggeized)

$x_{Bjorken} = x_{Bj}$ = p(parton)/p(proton)

Major industry at HERA, and these PDFs needed for hard (partonic) interactions at LHC



Not measured for x_F at √s > 63 GeV

Figure 8: The parton distribution functions of HERAPDF2.0 NNLO, xu_v, xd_v, $xS = 2x(\bar{U}+\bar{D})$, xg, at $\mu_f^2 = 10\,\mathrm{GeV}^2$ compared to HERAPDF1.5 NNLO on log (top) and linear (bottom) scales.

DPMJET prediction

Very uncertain!

Spectra generated by /DPMJET-MARS
With 10^6 pp events, √s = 13 TeV
(N.Mokhov and O.Fornieri)

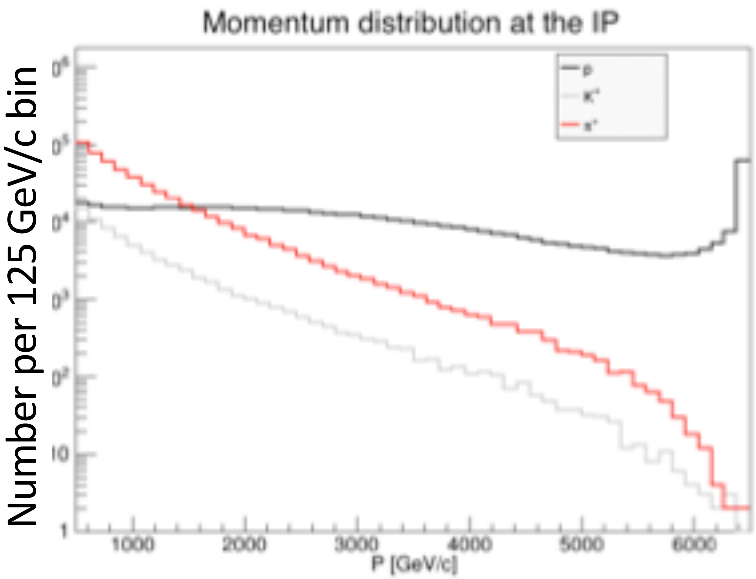
In 1 second, with 2808 bunches,
Have 30 x 10^6 bunch crossings and
30 x 10^6 x μ(= interactions/X) events.

Notes:
At 0.5 TeV (~ central)
$\pi^+ = \pi^-$ & $K^+ \cong K^-$ & K/π ~ 10%

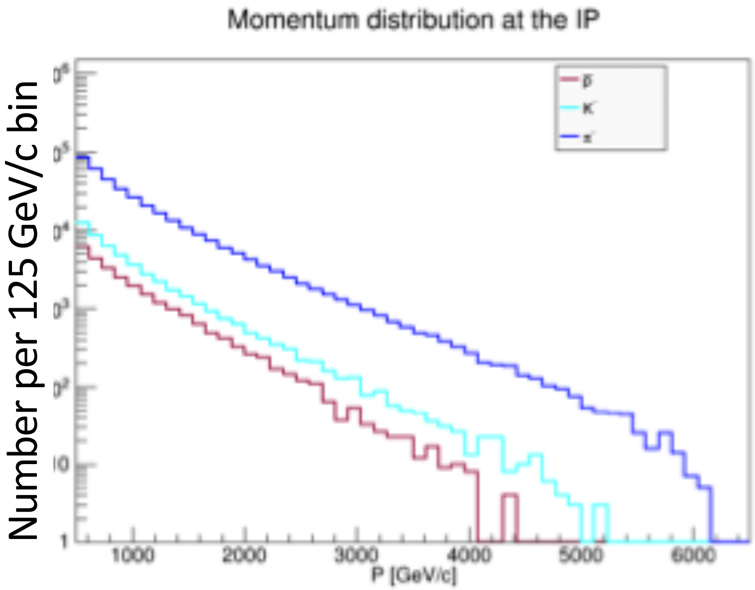
p's > π^+ above 1.5 TeV and flattish;
High x_F peak from diffraction

K^-(s-ubar) steeper than K^+ (u-sbar)
π^- (d-ubar) steeper than π^+ (u-dbar)

Antiprotons < K^- but only by a factor ~ 0.5



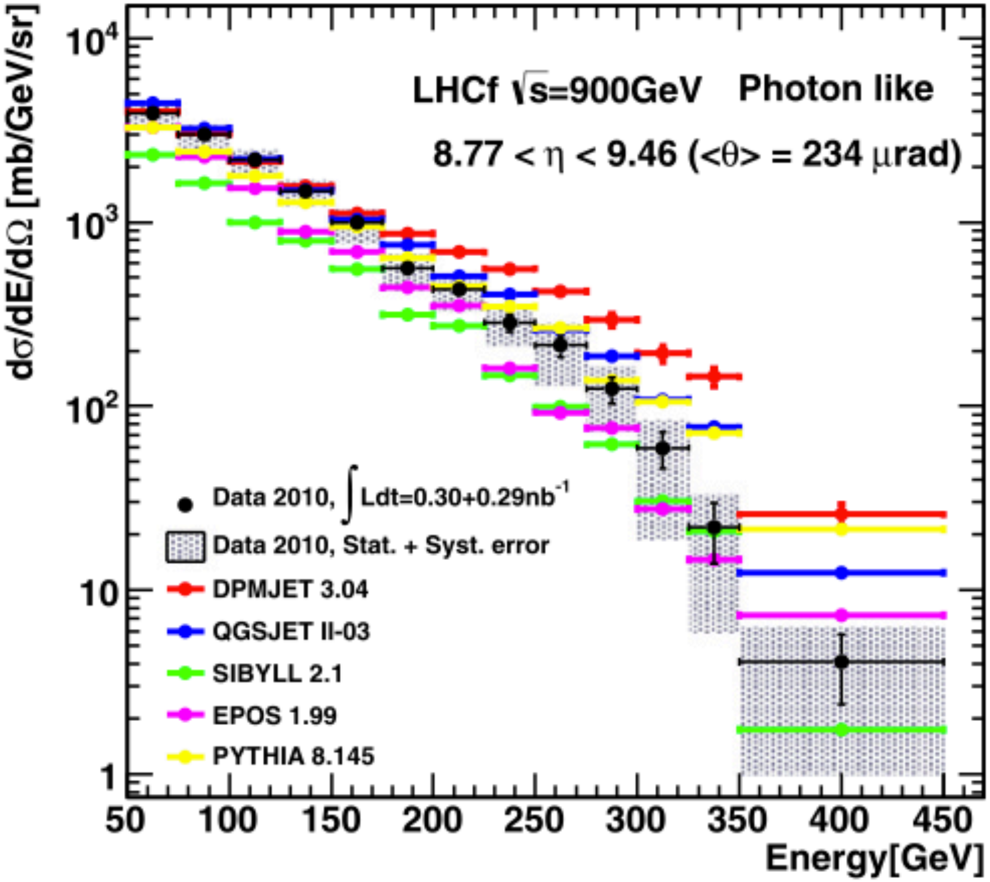
~ 100 x Acc/bin/sec if μ ~ 3



Neutrons not = protons, K^0 not = $K^{+/-}$

LHCf is a small 0º calorimeter measuring photon-like and n-like showers
Only 1.6 λ_I and 4 cm in size, σ(E)/E ~ 40% for neutrons.

To illustrate the large spread in predictions even at much lower √s (900).



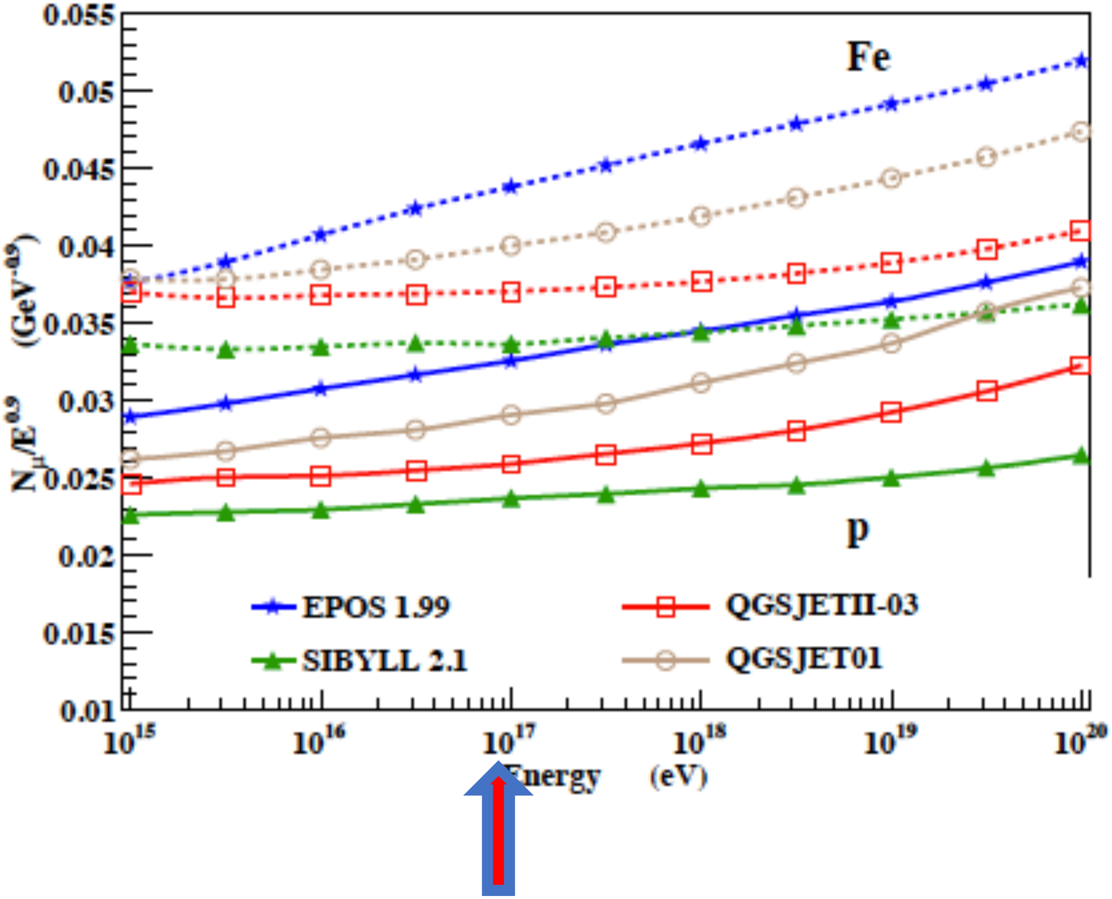
ZDC in CMS
7 λ_I and 8cm x 10 cm
Expect σ(E)/E ~ 15% at 3 TeV

A good 3D-imaging calorimeter for SAS : σ(E)/E < ~ 4%

Example of spread in Cosmic ray shower simulations
muons on ground / $E^{0.9}$ (to flatten curves) vs E.
p- Air (solid) and Fe- air (dashed)

Muon production

From FPWG_YELLOW_REPORT : CERN/LHCC 2013-021



These are on air not pp.

LHC has also run p-Pb and Pb-p and SAS could take data there. What about p-N and N-N?

Such special running may (should) be done in future.

Heavy ion groups (ALICE et al) would support this.

Big spread even assuming no surprises, e.g. high forward heavy flavor production

Equivalent FT energy of $\sqrt{s} = 13$ TeV
$E_{\cong} = s/2m_p$

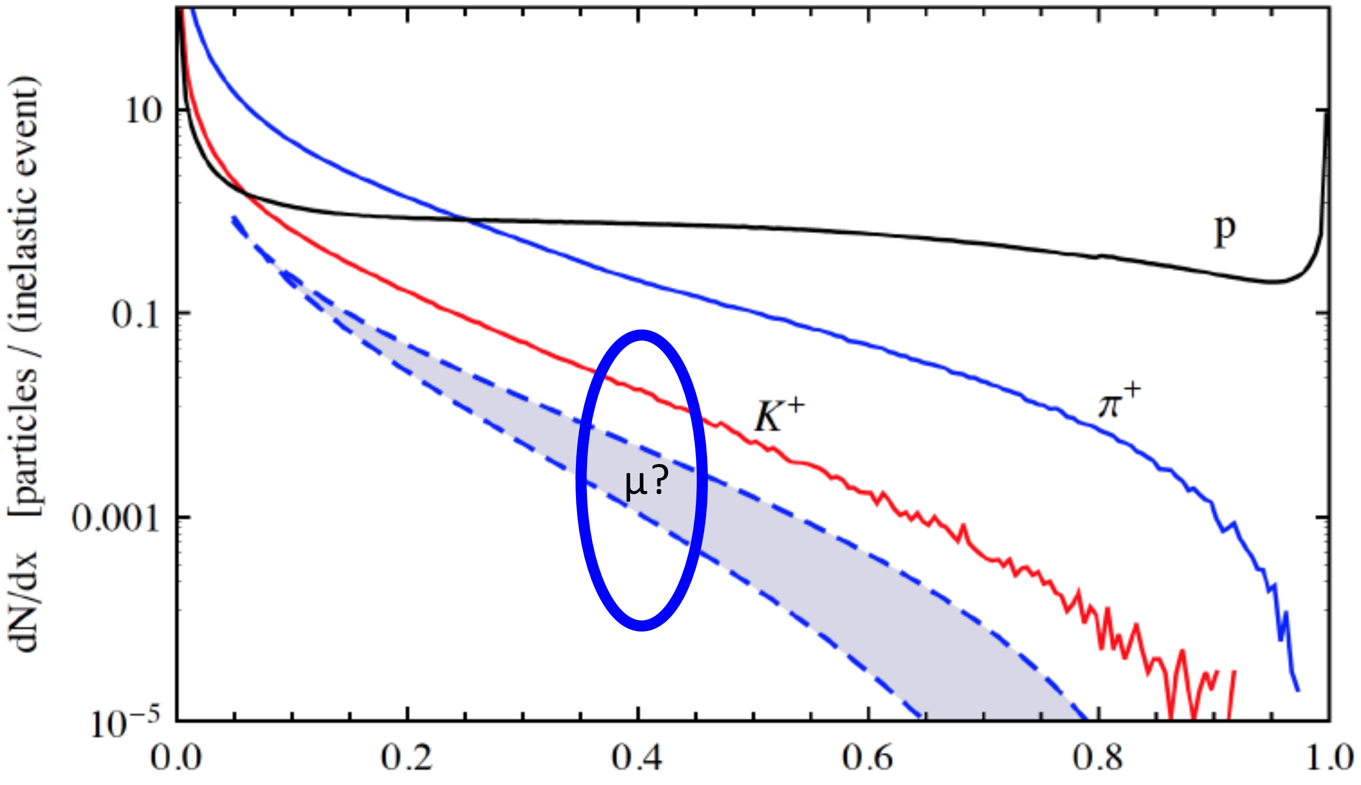
Charm and beauty hadrons only measured at LHC in central region.

Some models, e.g. Stan Brodsky “intrinsic heavy flavor” have enhanced forward Q production

-- Massive Quarks in sea carry high momentum for same rapidity (At $p_T = 0$ $x_F = m.e^y / \sqrt{s}$)

c, b → μ gives excess prompt muons at large xF.

In Δx = 0.1 at x = 0.4 about 10^{-3} per inelastic event. At PU = 1 have 30 million X/sec : ~ 10^4 μ/s !



Muons from charm decay
(from exotic model)

Idea, using 10 – 15 m of space in front of TAN:

Use **MBX dipoles** (Integral B.dL ~ 30 Tm) as **spectrometer magnets**.

Use straight section from ~ **85m to 140m** (TAN absorber) space.

Special vacuum chamber design for particles to emerge through minimal material

Precision tracking (silicon strips or pixels) over ~ 2 m (θx, θy to a few μrad)

Transition Radiation Detectors for $\gamma = E/m$ in $10^3 – 3.\ 10^4$ region

Hadron Calorimeter for energy measurement

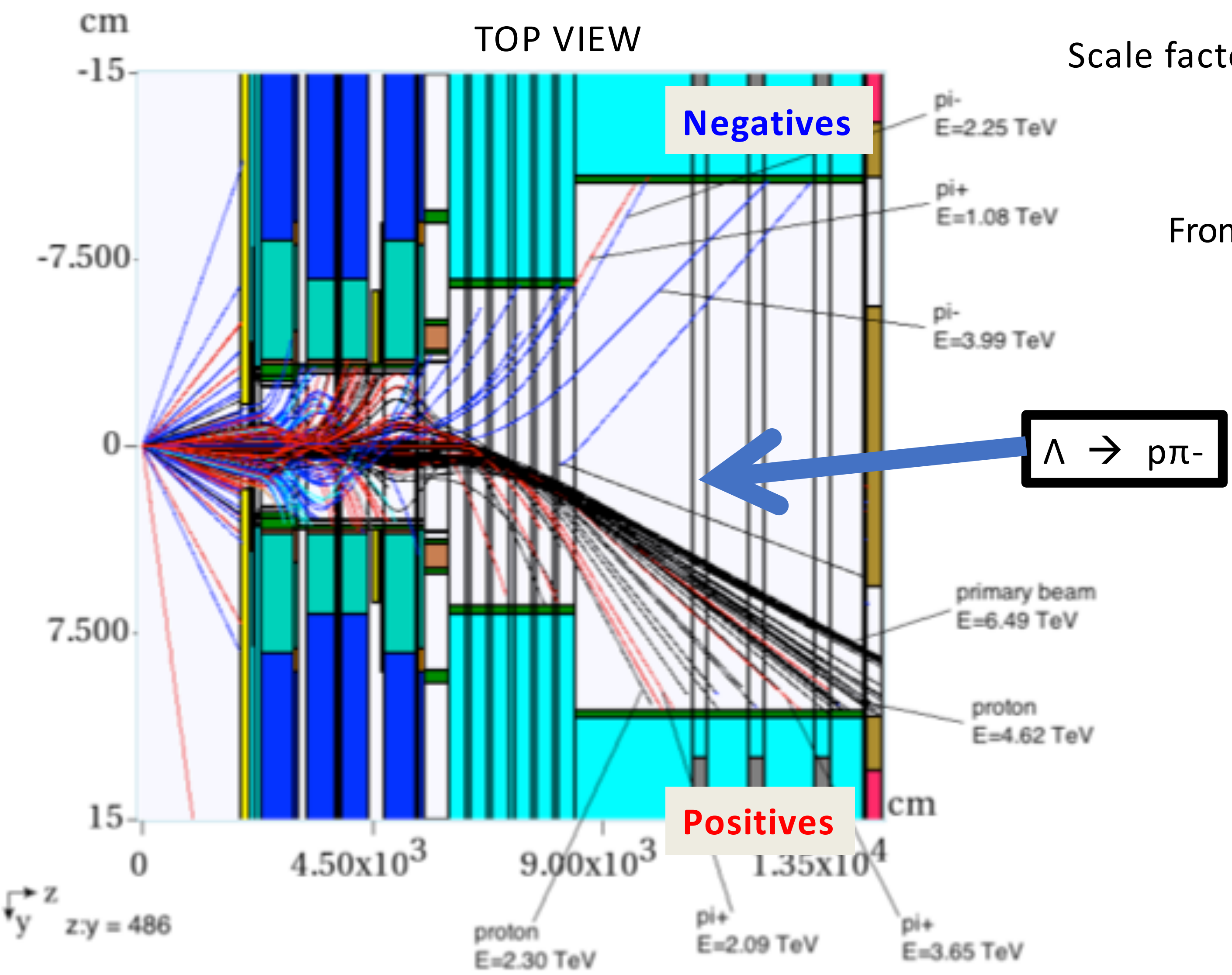
Muon tracking behind calorimeter

Possible addition (not discussed here):
Bent crystal to channel and so accept highest momenta (>~ 4.5 TeV, ~4 mrad bend)

200 inelastic collisions at Pt 5 (13 TeV, β* = 0.55 m): MARS

Nikolai Mokhov
Ottavio Fornieri

If μ = 1 this is 200 bunch crossings = 6 μs



Scale factor x:z = 486:1

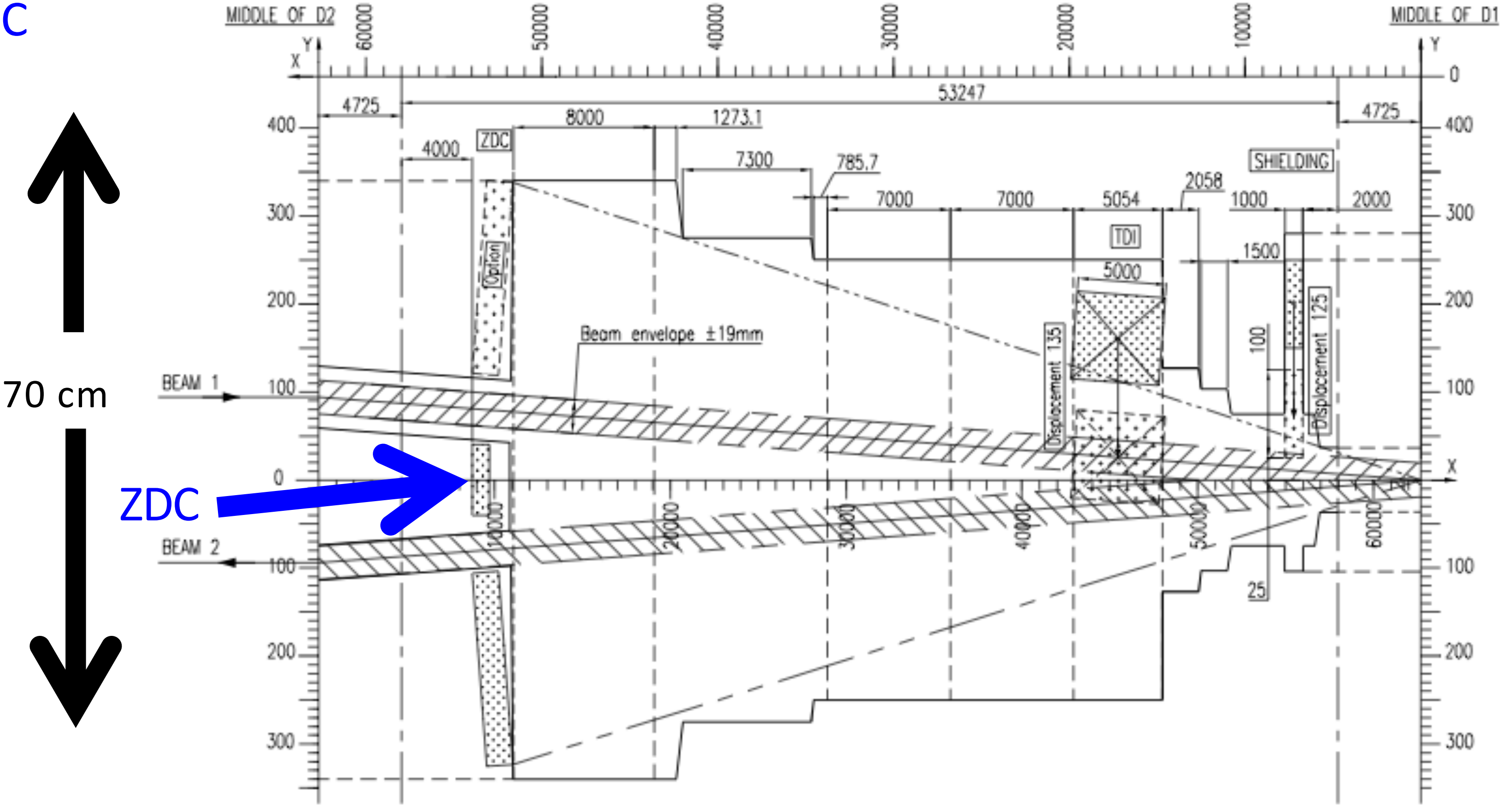
From interaction

Hitting pipe: 2 π- and 4π+ and about 8 protons / 200 collisions. Mostly near horizontal plane

CERN / LHCC 99–5
ALICE TDR 3
5 March 1999
ZDC

ALICE : Early design had a large conical beam pipe for ZDC
> Centrality etc measurements in Heavy Ion (Pb+Pb) collisions

TOP VIEW



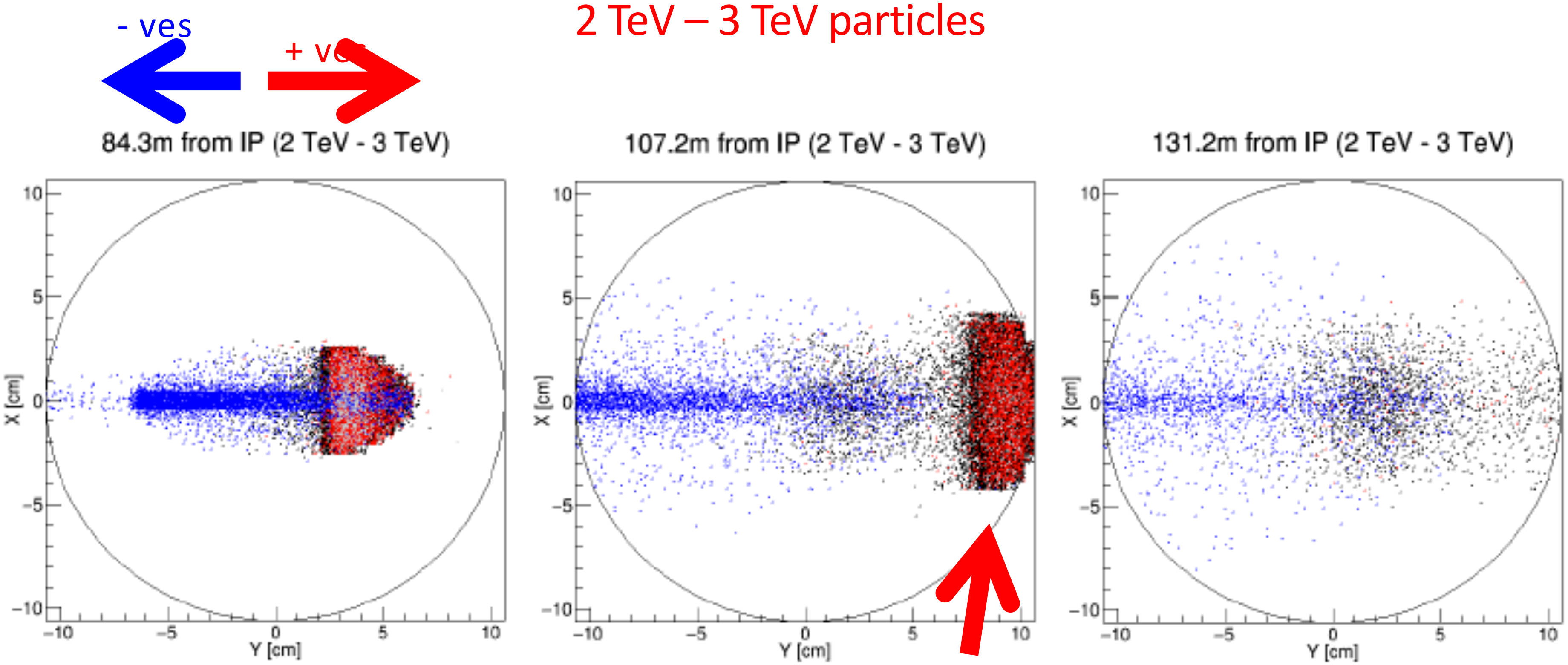
Make space in front of calorimeter (with “thin” window) for
tracking, TRDs, and behind calorimeter for muon measurement.

Muons	Calorimeter	-----------TRD-----------	Tracking	← particles
1m	2.5m	6 - 8m	2m	total = 12- 15m

MARS simulation (Nikolai Mokhov and Ottavio Fornieri

For Pt.5 (CMS) with $\beta^* = 0.55$m : need to do for $\beta^* = 5$m at at LHCb, ALICE
Looking along 20 cm diam beam pipe: only particles inside pipe shown, at 3 distances

2 TeV – 3 TeV particles



These all exit pipe between 107 and 131 m

Rectangular shapes are due to the F/D quad field for given energy slice.

>> Only need to cover ~ 10 cm in y on L and R sides, not all φ

SAS as a Multi-particle Spectrometer

Acceptance for 2 or more particles from same event.
Positive and negative particles on opposite sides of pipe, near horizontal plane.

Acceptances need to be calculated for realistic design.

Potentially:

J/ψ, $\psi(2S) \rightarrow \mu+\mu-$, $\chi_c \rightarrow J/\psi + \gamma$, Drell-Yan $\mu+\mu-$, $\gamma\gamma \rightarrow \mu+\mu-$
$K^0_S \rightarrow \pi^+\pi^-$, $\Lambda \rightarrow p\,\pi$
$D^0 \rightarrow K^+\pi^-$ … $\chi_c \rightarrow \pi^+\pi$, K^+K^-, etc.

Very forward charm and beauty also measured with single leading e and μ
Leptons can be identified.

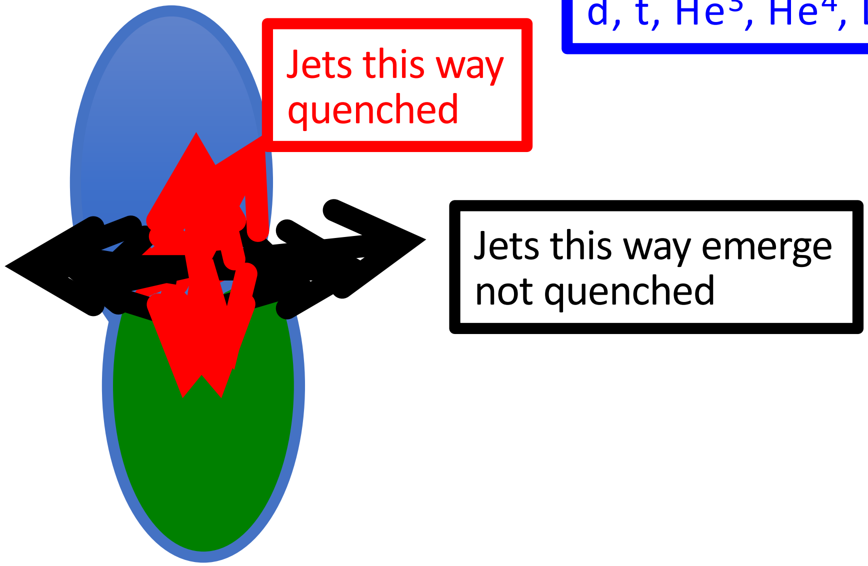
Leptons from π, K decay will be known, and their decay lengths are very long!

$\gamma c\tau\ (\pi) = 340$ km at 2.5 TeV !

Heavy – ion collisions (ALICE Specialty)

So far : p + Pb and Pb + Pb, with p + p in ALICE as “control” to study changes.
One day (feasible) : p + N and N + N as in atmosphere
Must be many interesting studies to do with SAS.

Head-on view

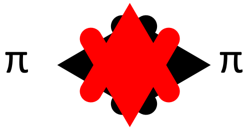


Jets this way quenched

Jets this way emerge not quenched

Nuclear fragments: d, t, He^3, He^4, Li…

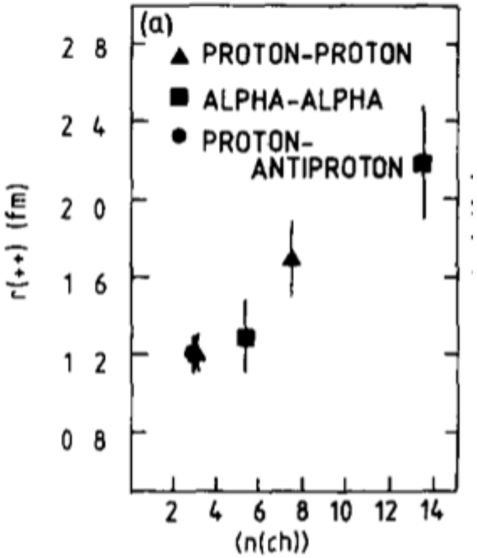
down beam pipe



Bose-Einstein correlations between π+π+ & π-π- close in momentum measure size of pion emission region.

Directional: correlate with ϕ(jets)

PL 129B (1983) 269 (R807, AFS)



Muon Measurement behind calorimeter

Muons : from primary collision:

Drell-Yan pairs, photo-produced J/ψ, ψ(2S), $Y_{1,2,3}$ and γγ → $\mu^+\mu^-$ (especially in AA)

Some acceptance for measuring both!

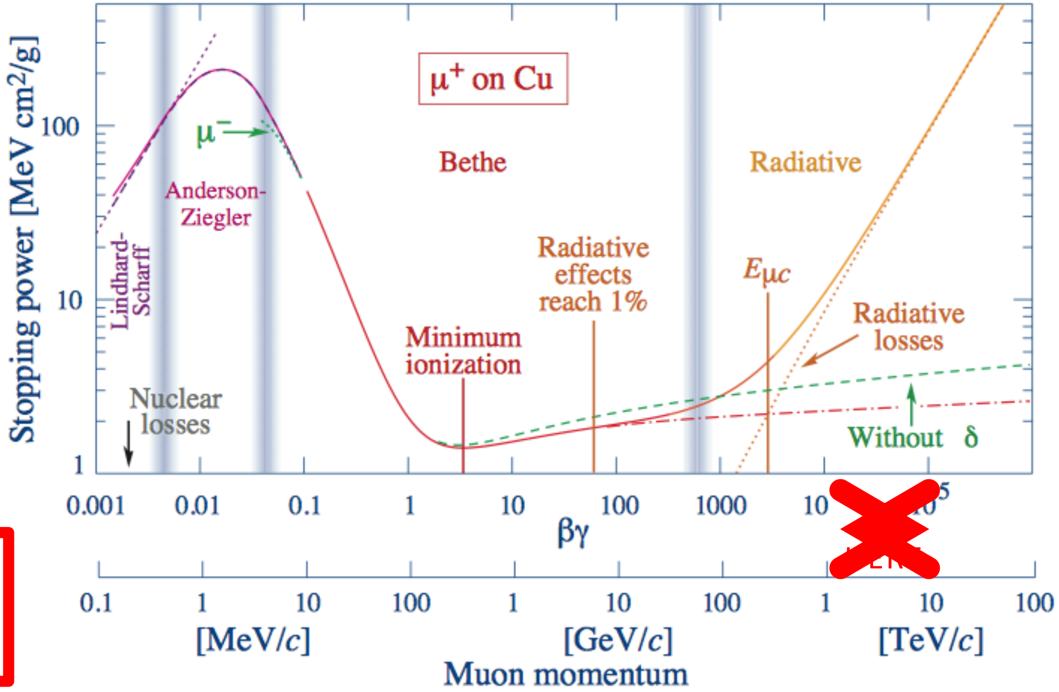
Almost prompt, from c, b decays. Note BR (D^0 → μ + X) = 6.7%

Background from π, K etc decays. γcτ(π) at 2.8 TeV = 150 km, . γcτ(K^+) = 70 km

Background from upstream interactions in pipes etc.

Momentum from upstream tracking, penetration and energy loss (fn(E)) through calorimeter

TRD signals consistent with m = p/γ = m(μ) (= m(π) , no separation.)



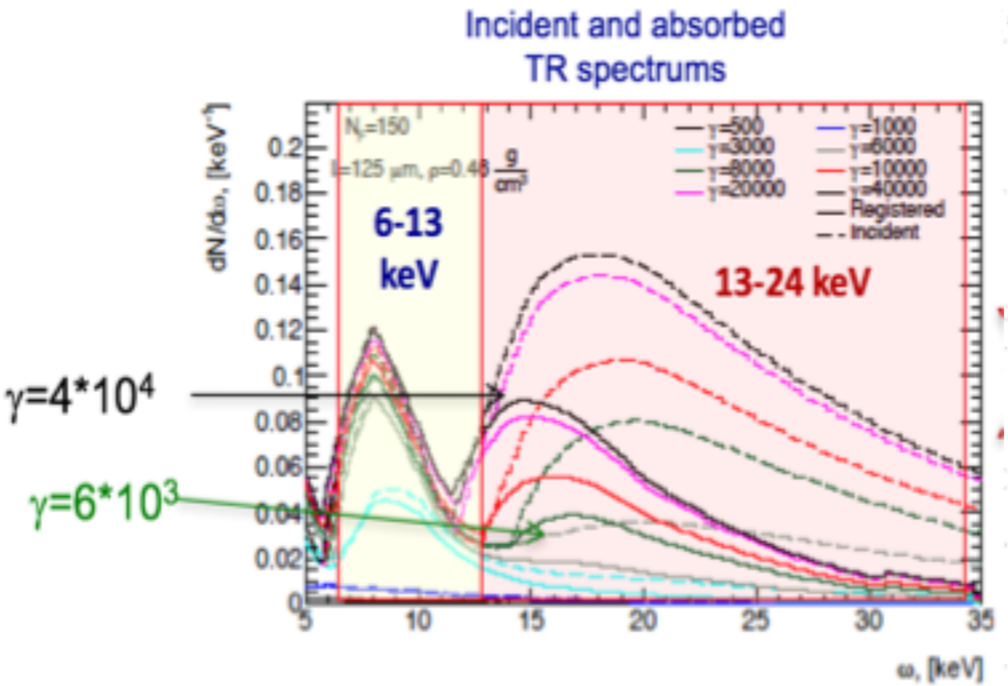
Many possible technologies
~ m^2 so high performance

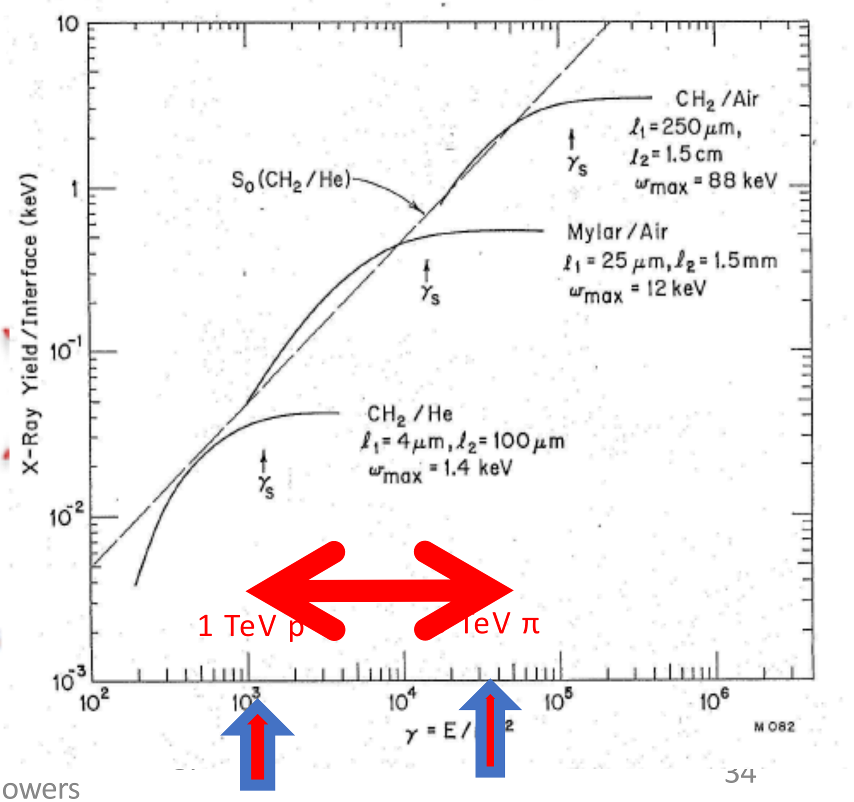
Transition Radiation Detectors - TRD

Anatoli Romaniouk, Mike Cherry et al.

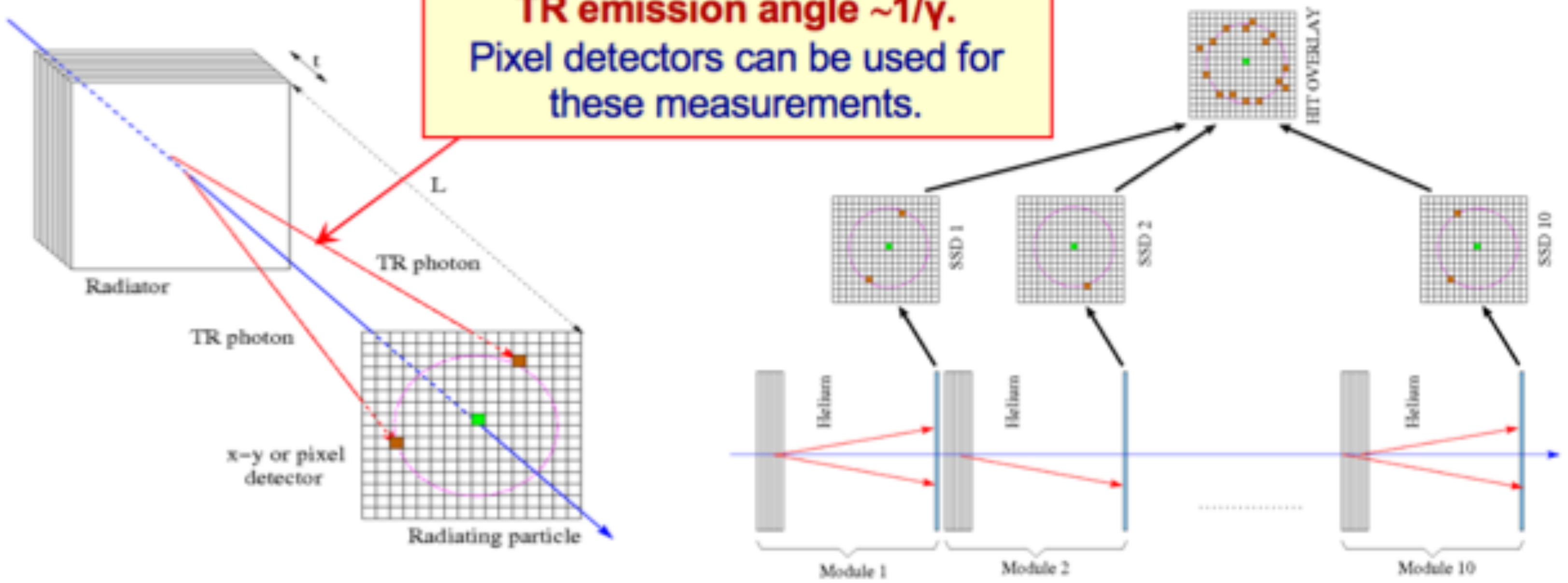
Probably only technique for distinguishing **π / Κ / p** at multi-TeV energies
Main technical challenge for SAS@LHC.
Interface between two materials different ε → X-ray emission ~ 1/137
Function of $\gamma = E/m$ Know E = p from tracking and calorimeter, hence m.
Fastest hadrons in SAS ~ 5 TeV π; $\gamma = 5000/0.14 \sim 3.6\ 10^4$
Slowest in SAS ~ 1 TeV p; $\gamma = 1000/0.94 \sim 1.1\ 10^3$

Can "tune" design
for γ – range : higher γ longer





Angle TRD: concept



Concept is based on the fact that **TR emission angle ~1/γ.** Pixel detectors can be used for these measurements.

Advantages:

- Combination angle and TR energy information would significantly improve identification power of such kind detectors.
- This approach would allow to minimize material budget
- It combines tracking and TRD functions in one detector

Summary

Terra Incognita : large phase space (in x_F, p_T) unexplored from √s = 63 – 13,000 GeV !
Justification in itself, but … may be new unexpected physics
Need to understand **Strong Interaction** in non-perturbative sector
Important to understand **UHE cosmic rays** : Sampled shower → primary, UHE collisions, muons

Spectrometer magnets and 85m vacuum chamber + 55m straight section

Need **special vacuum chamber** with thin exit windows. Feasible.
Technology for **tracking, calorimeter, muon** tracking exist
Particle ID with **transition radiation** possible (π,K,p) … interesting challenge to improve.
Open & accessible & small so evolution of techniques natural.

How and where?
Pt.8 (**ALICE**) has best conditions and better alignment with physics. (Pt.8 – LHCb also possible)
Both should find addition of SAS enhances their physics program, both pp and nuclei
Or : **Independent new** experiment (expect later merger)
TRD experts are developing suitable TR detectors (SAS-TRD proto-collaboration)

Crystal channeling experts are developing crystals – possible extension

It can be done and it should be done!

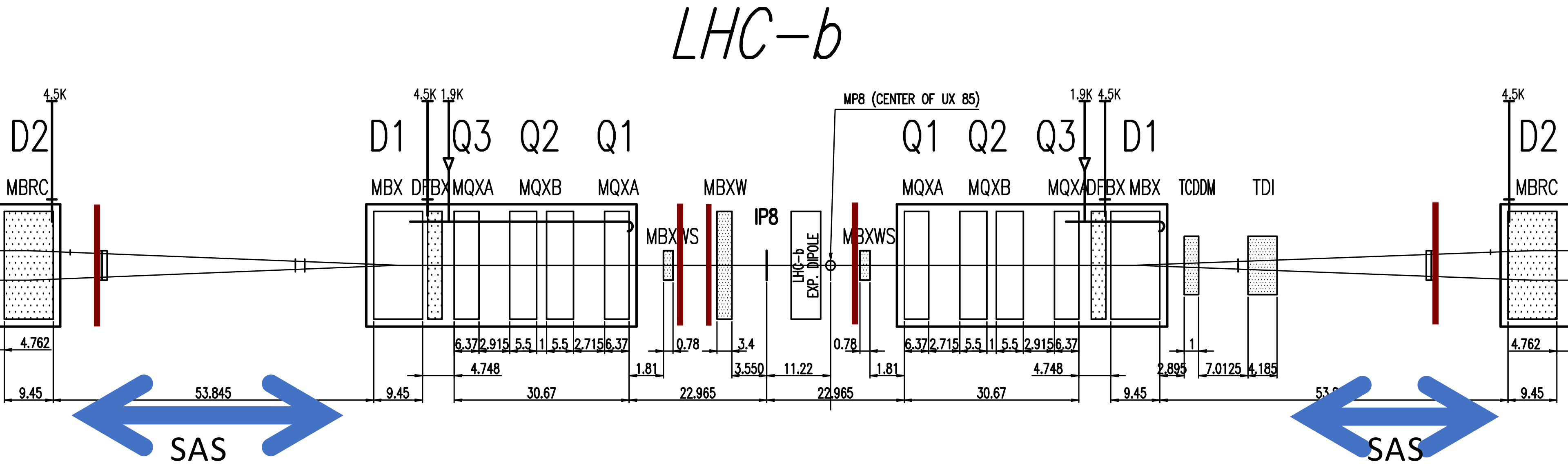
Thank You

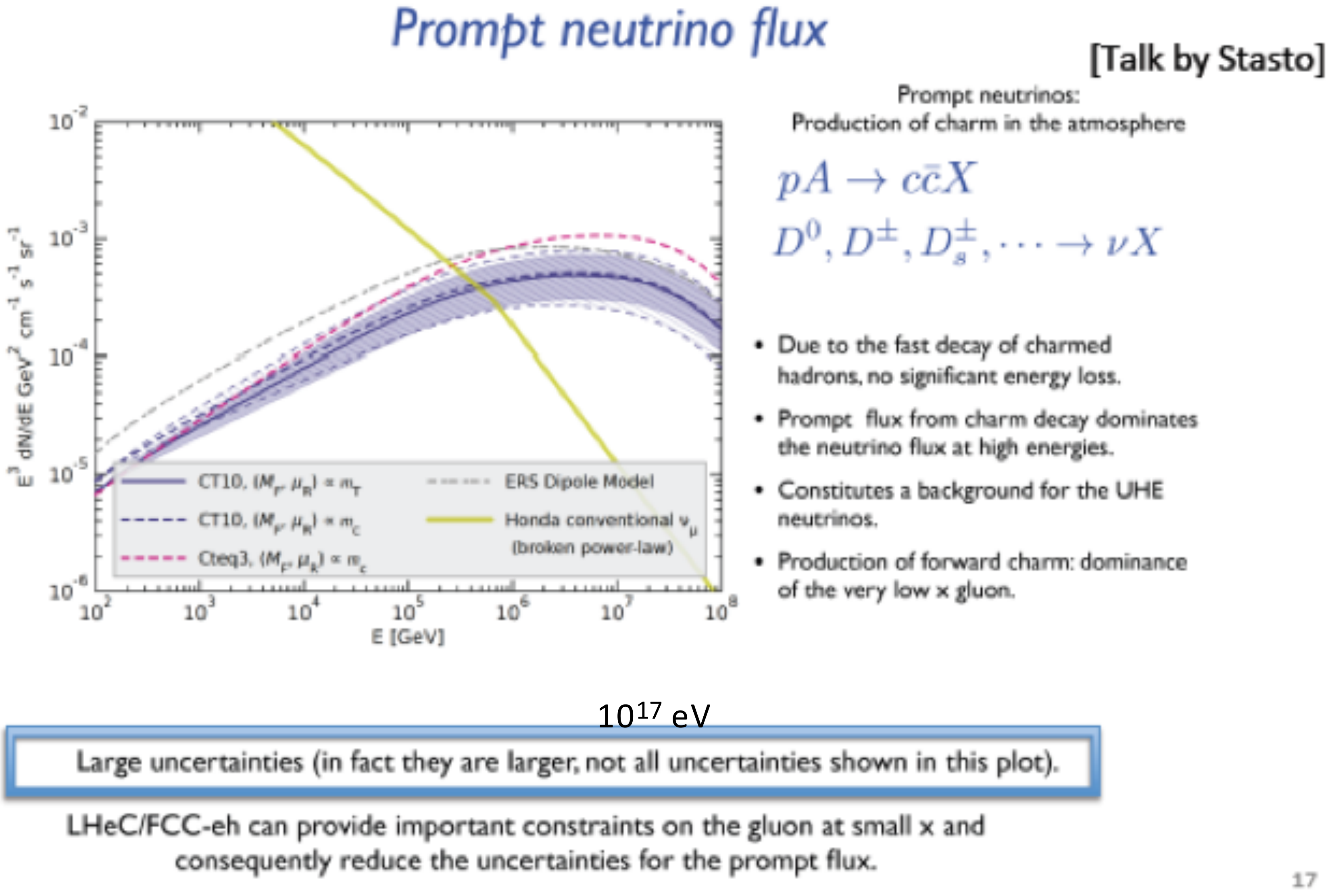
Back Ups →

ALICE has pp collisions for most of the LHC running
Cannot compete with ATLAS and CMS for high mass/high pT pp physics
Luminosity/pile-up much lower (good for SAS) and appropriate detectors.

Focus (pp) is on high multiplicity events, particle correlations, heavy flavor at low pT …
Can have unique strong interaction program with SAS

LHCb focus is on charm and beauty, forward (but not ***this*** forward)
SAS extends spectrometer to y ~ 8, 9
Acceptances not yet calculated.





Prompt neutrino flux

[Talk by Stasto]

Prompt neutrinos:
Production of charm in the atmosphere

$$pA \to c\bar{c}X$$

$$D^0, D^{\pm}, D_s^{\pm}, \cdots \to \nu X$$

- Due to the fast decay of charmed hadrons, no significant energy loss.
- Prompt flux from charm decay dominates the neutrino flux at high energies.
- Constitutes a background for the UHE neutrinos.
- Production of forward charm: dominance of the very low x gluon.

10^{17} eV

Large uncertainties (in fact they are larger, not all uncertainties shown in this plot).

LHeC/FCC-eh can provide important constraints on the gluon at small x and consequently reduce the uncertainties for the prompt flux.

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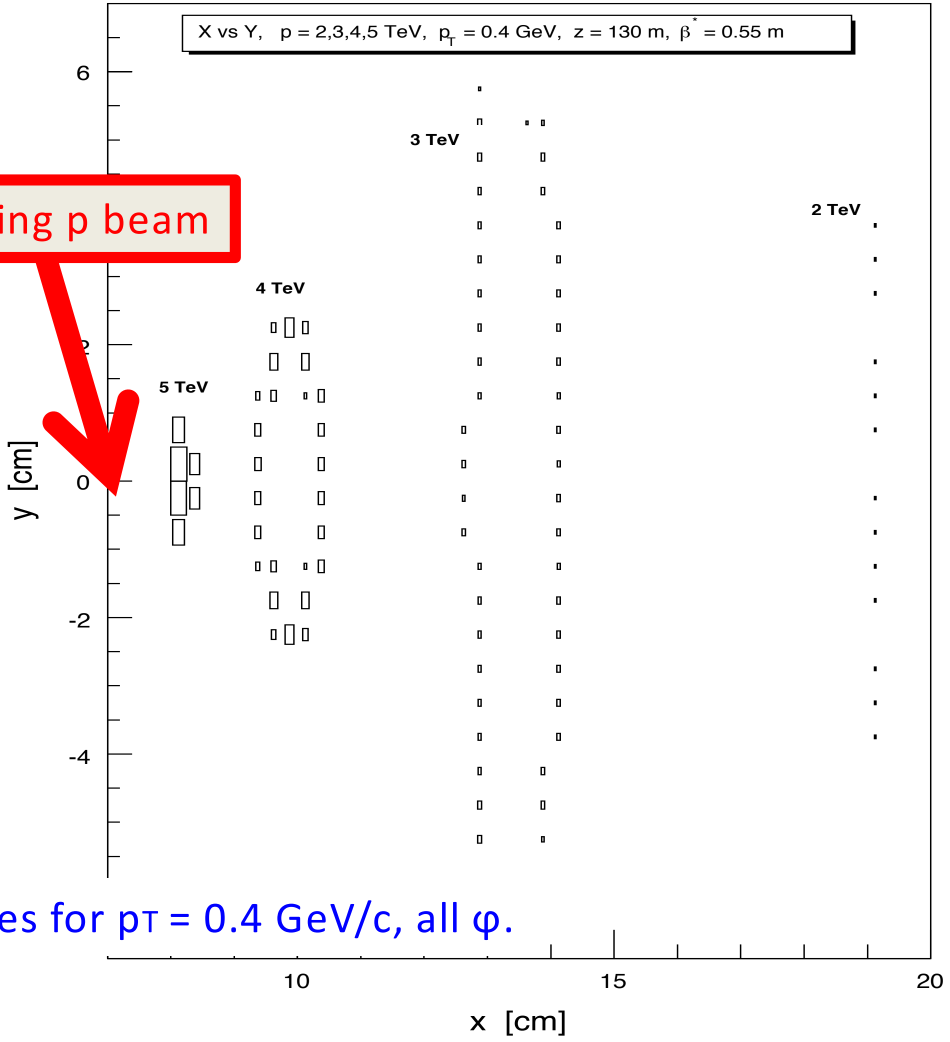
Forward charm can be measured more directly in SAS@LHC

Particle transport calculations (Pt.5, β* = 0.55m) using MAD files

Jerry Lamsa



Outgoing p beam

Ellipses for p_T = 0.4 GeV/c, all φ.

Positive particles contained in 40 cm diam pipe.
Only +/- 5 cm in y needed for $p_T <= 0.4$ GeV/c

Negatives on left side (not shown)

Less y coverage adequate (focusing)

x, y, θ_x and θ_y needed for p_T, p_z, φ

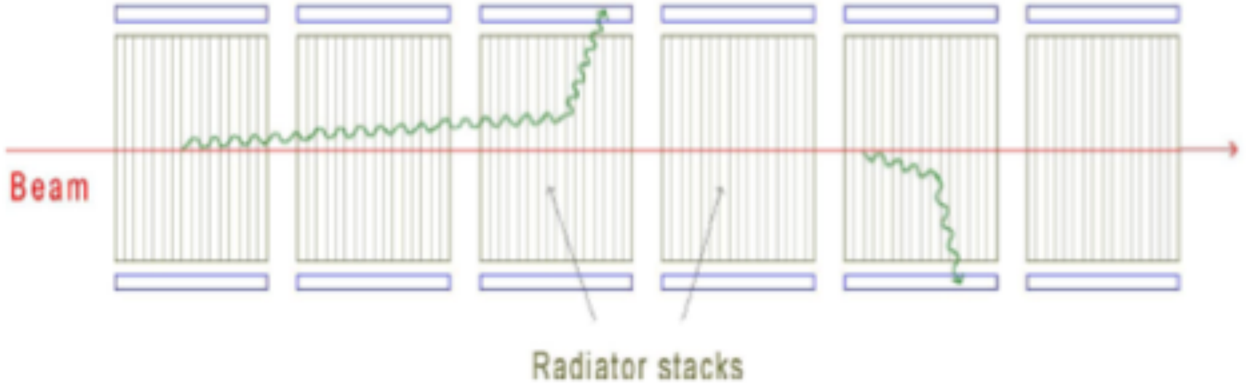
Calculations shown are for Pt.5 and specific optics.

At Pts 2 and 8, larger β* and different, need specific calculations.

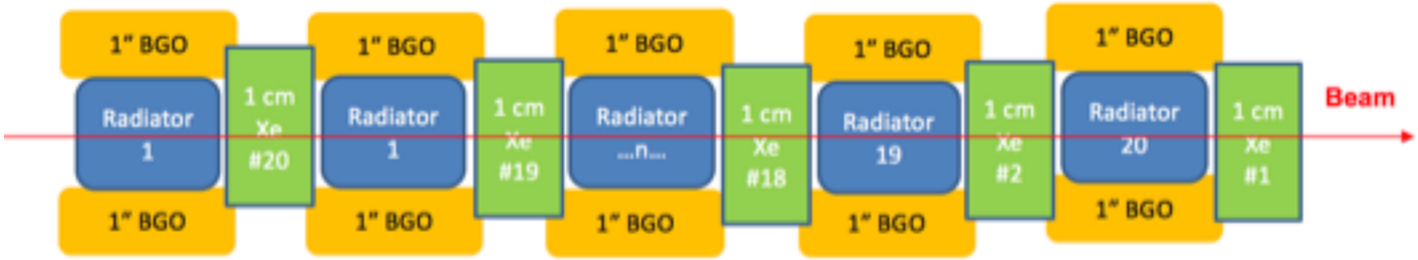
For single particle inclusive spectra do not need full φ – coverage, but valuable for correlations

SAS-TRD R&D Group formed : Test beams at CERN (2016, June 2017)
NRNU MEPhi (Russia), Louisiana Uni (USA), Bonn Uni. (Germany)
Bari Uni, (Italy), Lebedev Phys Inst. (Russia), CERN

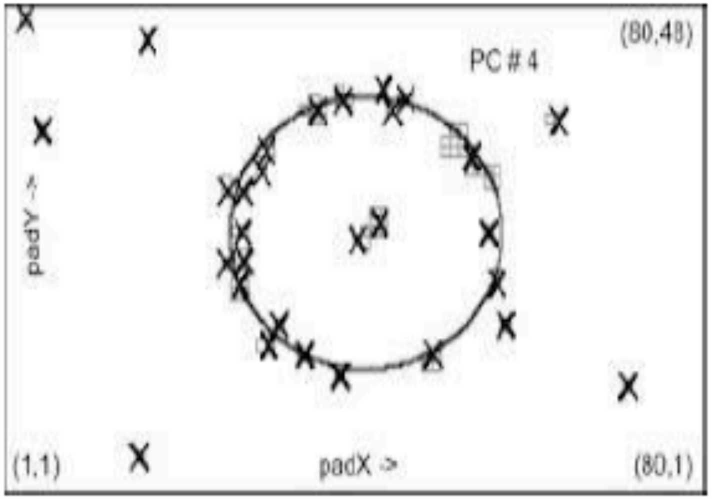
Compton TRD: concept.



20 modules (1-10 low γ_s configuration, 11-20 high γ_s configuration)
Radiator + Xe + Compton scintillators



Simulation work in progress



Can we envisage a "miniaturized"

ring imaging TRD = RITRD?

now we have more advanced pixel detectors ! (see next talk)

-we can collect with **10** sets radiator/pixel detector ≈ **20** TR photons (better than a conventional RICH) to **overlay** on a unique frame to reconstruct a ring

-conventional 15 μ foil radiators to let any hadron to radiate + 1 m *"espansion distance" in helium*→ L ≈ 10 m, still long, but X_0 and λ_I will be negligible!

-pixel size 50μ x 50 μ? (spatial resolution optimized by *centroid* calculation)

TRD also provides precision tracking information!

-the momenta , namely the rings radii per each kind of particle, are fixed by the calculator: at **1 m** of *espansion distance*→

R_p = 1mm @ γ= 1000 (1 TeV proton) or R_k = 0.5mm @ γ= 2000 (1 TeV kaon)

Mike Cherry, Louisiana State Univ., summary talk